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Creative vs. Conventional Metaphors in Space Sciences

MA thesis

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Abstract

This paper aims to examine the distribution of creative and conventional metaphors across three genres: educational textbooks aimed at university students, popular science literature, and academic articles. The study also aims to identify which source domains are most frequently found in space sciences, comparing whether they appear across all three genres or dominate in particular ones. The theoretical framework is based on the Conceptual Metaphor Theory (Lakoff & Johnson 1980), emphasizing that the conceptualization of metaphors is a part of embodied cognition, alongside the Career of Metaphor Hypothesis (Bowdle & Gentner 2005), focusing on explaining how a metaphor shifts from being novel to conventional over repeated use. The distinction between creative and conventional metaphors, central to the work, was based on works by Phillip (2017) and Littlemore (2019). For this study, three genre-specific corpora (approx. 50,000 words each) were compiled from texts published between 2017 and 2024. A mixed-method approach was used, combining qualitative and quantitative analysis. To help identify and relate metaphorical expressions to their conceptual domains, the Metaphor Identification Procedure (MIP) (Pragglejaz 2007) is utilized. The results show that creative and conventional metaphors are present across all genres, with creative metaphors dominating in the popular science while conventional metaphors in the university-level textbook genre. Source domain analysis showed that the most frequently identified source domains were LIVING BEING, CONTAINER, and NATURAL PHENOMENON, with over 100 metaphorical expressions identified in each. The study results demonstrate that conventional metaphors rely on already established familiar mappings to ensure clarity and consistency, especially noticeable in the usage of conventionalized, well-established field-centered terminology. In contrast, creative metaphors tend to be mainly used to attract readers' attention and help to portray complex issues in more everyday terms, thus not requiring readers to have background knowledge in the field of space sciences.

Keywords: creative metaphors, conventional metaphors, space sciences, popular science literature, university-level textbooks, academic articles

Introduction

While metaphors have been widely studied in fields such as media (Wilson & Hay 2013;), advertising (Tuan 2010; Selmistraitis et al. 2024), legal (Johnson 2007; Lloyd 2016; Wang & Tu 2018; Šeškauskienė 2022; Kordić 2023), and many others, it was noticed that limited studies have been done when it comes to hard sciences which includes such disciplines as physics, chemistry, biology, geology, botany, and astronomy.

For many decades, two schools of scholars have "battled" either on the side of metaphors (Kuhn 1979; Maasen 1995; Palma 2018, etc.) or on the side against them. Some scientists tend to view metaphors as mere text decorations compatible with science in any way, shape, or form, as they may cause more harm than good while presenting scientific ideas in a deceiving way. For example, the well-known term *Big Bang* and its description are somewhat misleading despite being a now accepted scientific term. The reason behind it is relatively simple: "the Big Bang was neither Big […] nor a Bang" (Masting 2019: 25 as cited in Kramar & Ilchenko 2021: 95) as it did not involve an explosion but rather a rapid expansion of space itself. Moreover, when we hear or read the word *Bang* itself, we do not, on a firsthand basis, relate it to the creation of space, matter, or time, but simply, as mentioned before, an explosion (Kramar & Ilchenko 2021). Another reason against scientific metaphors is that not everyone may comprehend the metaphorical interpretations of specific ideas, which will most likely cause further confusion (Scharf 2013; Beger & Smith 2020) among members of both scientific and non-scientific communities.

Nevertheless, metaphors are impossible to avoid in such technical discourses, and in some cases, they are even more than necessary, especially when explaining phenomena beyond direct experience. They can help to explain scientific facts, explain newly formed ideas, and make complex topics more accessible to broader audiences (Veit & Ney 2021) while relating them to more familiar, relatable concepts (Scharf 2013). What is more, well-employed scientific metaphors can hold their epistemic value while contributing to science by being memorable and efficient (Veit & Ney 2021: 11) and be "accepted" by the scientific community as a possible explanation for new ideas, processes, phenomena, and others.

This is particularly relevant when looking at the domain of space sciences, which includes such branches as astronomy, astrophysics, cosmology, and others. As a part of hard sciences and especially technical fields, with abstract concepts and complex phenomena, it has scarcely been studied in connection with metaphors. The interest in the relationship between metaphors and space sciences has slowly grown over the past five years. For example, they have been studied concerning theory development (Grubic 2022), shaping of public understanding (Afonso & Afonso 2021), metaphor translation in popular science literature (Merakchi 2020; Caldarola 2023), and explanation of already conventionalized scientific terminology in astrophysics discourse (Kramar & Ilchenko 2021). However, no research has been identified that focuses explicitly on analyzing creative and conventional metaphors in space sciences has been identified. Therefore, this thesis seeks to fill that gap while answering the question regarding what metaphors prevail regarding their creativity and conventionality in popular science literature, university-level educational textbooks, and academic journal articles. These genres were chosen due to their differentiating audiences, ranging from field experts to the general public, as well as differences in language construction and complexity of the texts.

This research aims to investigate the usage of creative and conventional metaphors across three distinct genres of literature in the discourse of space sciences: popular science literature, university-level educational textbooks, and academic journal articles while hypothesizing that in both popular science as well as educational textbooks the ratio of creative metaphors will be more prevalent than in academic articles due to them serving both the intention of attracting reader's attentions while also simplifying complex issues presented in texts. To achieve the aim of the study, the following objectives were set:

1. To identify the prevailing source domains in the three genres (academic journals, university-level textbooks, and popular science literature) related to space sciences by identifying metaphorical expressions.
2. To analyze the development of source domains in terms of subdomains.
3. To analyze metaphorical expressions in terms of their creativity and conventionality and to discuss their distribution across the genres and the functions they perform.

The thesis is structured as follows: Chapter 1 focuses on the origins and the development of metaphor theory. In Chapter 2, attention falls on the theoretical analysis of the Conceptual Metaphor theory. Chapter 3 discusses the importance of metaphors in hard sciences, mentions previously conducted research regarding metaphors in space science discourse, and outlines differences between the three chosen genres. Chapter 4 presents background on creative and conventional metaphors. Chapter 5 provides data and procedures followed to conduct the analysis. In Chapter 6, the results and discussion of the conducted study are presented, including the analysis of the prevalence of source domains, identified metaphorical expressions in terms of their creativity and conventionality, and their performed functions. Lastly, the Conclusions section provides key findings of this research.

1. The Historical Development of Metaphor Theory

There is no distinguished date in the history of language regarding the appearance of metaphors, and it is unlikely that one will ever be established. In accordance with the contemporary metaphor theory, discussed later in this chapter, metaphors have existed as long as language. However, the earliest known attempt to analyze metaphors can be traced back to Aristotle (middle of the fourth century BCE) and his works *The Rhetoric* and *Poetics*. In *Poetics,* Aristotle defined metaphor as an "alien name" (Butcher 1902: 77), referring to the application of one concept in terms of another. Furthermore, Aristotle also argued that individuals are not born with an ability to control and use metaphors; it is a skill that requires mastering and whose incorrect usage can lead to confusion. His perspective on metaphors was limited to artistic elements used in literary writings, which opposes current theories that see metaphor as an essential part of language and thought.

After Aristotle's explanation and analysis of metaphors, they were not given much attention for centuries, and only in the 20th century did scholars like Richards (1936), Black (1955), Grice (1975), and Searle (1979) start to investigate them more thoroughly. Their theories, as described by Lakoff and Johnson (1980; 2003), collectively contributed to what is now referred to as the *traditional approach to metaphor*, which is grounded in several widely held ideas about metaphor. While each scholar offered unique perspectives, their work collectively converged on certain assumptions, which Lakoff (1993) named as "traditional false assumptions" (p. 204): (1) Language is literal, not metaphorical; (2) All subject matter can be understood in literal terms without the need of metaphor use; (3) Only literal language can be conditionally true or false; (4) Every definition in a lexicon of a language is literal rather than metaphorical.

To summarize, the study of metaphor has evolved significantly from Aristotle's early perspectives to more contemporary theories that recognize metaphor as fundamental to language and thought. While early scholars such as Richards, Black, Grice, and Searle contributed to the now so-called *traditional approach to metaphor*, Lakoff and Johnson's (1980; 2003) challenge of this approach highlighted its limitations in treating language primarily as literal. This shift from the traditional to the contemporary view of metaphor reflects a growing appreciation of it as an integral part of how humans process and make sense of their experiences.

2. Conceptual Metaphor Theory

The viewpoint of the *traditional metaphor approach* was challenged by Lakoff and Johnson (1980) in their groundbreaking work *Metaphors We Live By* (1980/2003) where they introduced a new one named the *Conceptual Metaphor Theory* (CMT), part of the broader field of cognitive linguistics, which redefined metaphor's role and nature in human cognition. Their work is suggested to have been based on Reddy's (1979) paper on conduit metaphor, which emphasizes that language is full of containers, i.e., sentences and words filled with meanings and delivered to people who unpack these containers to receive a desired message. Reddy's insight into how language conveys meaning laid the groundwork for Lakoff and Johnson's exploration of metaphor as a cognitive process. It is also thought that some ideas for the development of CMT were drawn from I. A. Richards' work *The Philosophy of* Rhetoric (1936), in which the author introduced the concept of metaphor as a means of language comprehension and cognition while also highlighting how metaphor influences our interactions and perceptions of the world. Another important figure that was of high influence on the development of the CMT was Black and his work on metaphor theory (1979), where he was interested in "cognitive aspects of certain metaphors" (p. 21) in varying fields outside of literary discourse. His theory, similarly to CMT, rejected the traditional view to some extent, stating that metaphors are not just creative figures of speech but are also highly cognitively integrated.

Lakoff and Johnson (1980) argued that metaphor cannot be considered as it has been thought to be before, i.e., poetic ornament. Instead, it needs to be looked at as a pervasive element of everyday language and thought. The need for the development of CMT originated from their shared interest in how people make sense of their language and experiences, with their central point being that our cognitive apparatus is "metaphorical in nature" (Lakoff & Johnson 2003: 4), meaning that we may unconsciously conceptualize everything and anything that our minds are capable of creating and comprehending, for example concepts such as time, quantity, state, change (Lakoff 1993: 11) through more concrete experiences. The conceptual metaphor itself was described as "experiencing one kind of thing in terms of another" (1980: 5) or as a structured network of "correspondences between two domains of experience" (Kövecses 2017: 14). This is what Lakoff and Johnson meant by stating understanding one domain in terms of another (Kövecses 2017). These systematic correspondences give rise to conceptual metaphors such as ARGUMENT IS WAR, LIFE IS A GAME, TIME IS MONEY, which means that we understand arguments in terms of war or conflict, life in terms of rules and strategies, etc. Conceptual metaphors are the underlying frameworks that shape our understanding of abstract concepts through more concrete experiences. Metaphorical expression itself is a linguistic phrase that reflects the underlying conceptual metaphor. For example, the conceptual metaphor LOVE IS A JOURNEY, provided by Lakoff and Johnson (1980), gives rise to such metaphorical expressions as *We're at a* ***crossroads***, *Look* ***how far we've come*** and others.

Another fundamental aspect of conceptual metaphor is its structure, which consists of two domains, the source domain and the target domain. Unlike the traditional metaphor, which follows the pattern of A is like B, thus providing comparison, the conceptual metaphor follows the pattern of A is B (Lakoff & Johnson 2003: 108). In the instance of a conceptual metaphor, A is what is referred to as the target domain, and B is the source domain. Both parts are important in mapping meaning from the source to the target domain, allowing us to understand abstract concepts through more concrete experiences. Here, the source domain provides the basis from which metaphorical expressions are derived, while the target domain represents the concept to which the metaphor is applied. The source and target domains interact through resemblance or similarity rather than physical association (Kövecses 2021). Lakoff and Johnson (2003) also imply that B is typically not A (a concrete concept cannot be abstract), or else the metaphorical meaning disappears, which is why we can have LOVE IS A JOURNEY but not JOURNEY IS LOVE. This is more commonly known as the principle of unidirectionality. For a conceptual metaphor to exist, both source and target domains must be present and reflect how we think and understand concepts. For example, in the conceptual metaphor TIME IS MONEY, we may see metaphorical expressions like *You're* ***wasting*** *my time, I don't have the time to* ***give*** *you,* or *This gadget will* ***save*** *you hours* (Lakoff & Johnson 1980). As illustrated in the examples, the words related to the target domain are not direct mentions of the time itself but refer to concepts associated with it.

Referring to Kövecses' (2017: 14) definition of conceptual metaphor as "a systematic set of correspondences between two domains of experience", it is important to note that the term *correspondences* is a synonym for mapping, a central component in understanding the basics of conceptual metaphor theory. His explanation of why these mappings can be used instead of correspondence is that specific elements and their relationships are thought to be transferred from the source domain to the target domain (Köveces, 2017). Conceptual metaphor mapping is initially a process during which the source domain projects onto and characterizes elements of a target domain and helps to "explain why the metaphorical expressions […] mean what they do" (Kövecses 2017: 15). Let's examine the conceptual metaphor LIFE IS MUSIC (Gadeikytė 2023). With this conceptual metaphor, life can be projected through music, which may be short, long, sad, harmonious, etc., e.g., *Lately my life feels* ***out of a rhythm****. It is sad that his life was so* ***short.*** *She's* ***composing*** *the next chapter of her life*. From here, the following mapping can be proposed:

Rhythm of music → Rhythm of life
Length of a song → Length of life
Composing music→ Planning future

However, Kövecses also raised the question of whether the target and source domains can fully align with one another, and the answer is relatively simple. It is not. Many things cannot be mapped out from the source to the target domain. An example given by Kövecses (2017) was THEORIES ARE BUILDINGS. In this case, specific details such as the number of rooms or the presence of a cellar cannot be mapped. He gives three possible explanations for this: 1) Lakoff's (1990) *invariance hypothesis* which states that only elements that match the target's structure can be mapped; 2) only parts of the source domain associated with primary metaphors (a basic metaphor that links an abstract concept to concrete one providing the basis for formation of more complex metaphors) can be transferable (Grady 1997: 3) mapping incorporates concepts that are directly related to the primary meaning of the source (Kövecses 2000). However, none of these three possible explanations fully addresses the mappings' complexity.

In summary, the *Conceptual Metaphor Theory* (CMT), introduced by Lakoff and Johnson (1980), inspired by Reddy, Richards, and Black, redefined our understanding of metaphor from a mere figure of speech to a complex cognitive process that highlights how abstract concepts are understood through more concrete ones with the help of metaphorical mappings. Further insights on CMT made by other scholars expanded the theory, while adding essential commentary that helped CMT move forward.

3. Metaphors Across Discourses

Considering the previous discussion, it is evident by now that "metaphor plays a significant role in cognitive processing, influencing our thinking, reasoning, […], actions" (Agnes 2009:21) and is used both consciously and unconsciously in various parts of our lives from trying to explain complex ideas to navigating everyday interactions. They appear in different discourses as politics (Cibulskienė 2005; Cienki 2008; Ahrens 2009; Chahbane & Zrizi 2023), media (Wilson & Hay 2013; Zhabotynska 2018; Akimtseva 2020), advertising (Smetonienė

2006; Tuan 2010; Selmistraitis et al. 2024), legal (Johnson 2007; Lloyd 2016; Wang & Tu 2018; Kordić 2023), health (Demjen & Semino 2016; Rossi 2021), science (Pulaczewska 2011; Duner 2015; Falkner 2016), and many others. As the focus of this thesis is on metaphors in space science discourse, the chapter will center on the metaphor research within this domain. Nevertheless, before delving deeper, it is also important to examine how metaphors are generally treated in hard sciences.

3.1. Metaphors and science

Historically, "scientists and philosophers alike have […] been reluctant to recognize the diversity of roles metaphors can play in science" (Veit & Ney 2021: 5). Metaphors were viewed as decorations or as elements that can induce inspiration, which is not compatible with science because metaphors may present the ideas in a deceiving way. Despite such negative predicaments, cognitive scholars claim that metaphors are common in scientific writing (Taylor & Dewsbury 2018; Veit & Ney 2021) because we think this way and they "make statements more concise and memorable" (Veit & Ney 2021: 5). An example provided by Veit and Ney (2021) is the term *Big Bang*. Instead of stating that it is the universe's expansion due to extreme density and hot state, the shorter phrase is more concise and easier to remember. When used for the first time, the term *Big Bang* carried a novel meaning. Still, over time, it lost its novelty due to its widespread use and acceptance as a scientific term to describe the theory mentioned above. Knudsen (2003: 1248) pointed out that metaphors are not uncommon in science, especially when, for example, new hypotheses, ideas, and theories are being formulated. However, these metaphorical expressions are not meant to survive long within any branch of science if they lack clarity. Thus, for a metaphor to be "accepted" by the scientific community as a possible explanation for something, it must be tested, questioned, or further clarified.

Moreover, metaphors in science, also referred to as *scientific metaphors* (Haack, 2019: 2049), are being used not only by scientists themselves but also by science journalists who make science accessible to a broader audience (Haack, 2019: 2049) and can serve multiple purposes. They can communicate basic factual knowledge, present information that meets the threshold in scientific contribution, it can promote a more comprehensive understanding of a topic, aid in prediction, or even inspire new research (Veit & Ney 2021: 7). Moreover, they are also beneficial for developing comprehension of problems while linking unfamiliar concepts to more familiar ones (Scharf 2013). For example, highly technical fields like physics, microbiology, mathematics, etc., rely heavily on precision and quantitative facts. Therefore, sometimes explanations of certain theoretical works and other concepts may become challenging without using metaphors to bridge the gap between complex ideas and general comprehension (Haack 2019). Educational textbooks in these and other technical disciplines frequently employ metaphors to make the content more approachable and less overwhelming for a reader while still capturing the essence of the described subjects (Scharf 2013).

Scientific metaphors clearly show a range of aesthetic qualities (Veit & Ney 2021: 11). The authors point out that they can be witty, funny, as well as graceful (Veit & Ney 2021: 11). A well-employed metaphor holds its epistemic value while contributing to science by being memorable and efficient (Veit & Ney 2021: 11). Creative metaphors (see Chapter 4) to that matter can be particularly important in science (Veit & Ney 2021: 16) as they shape scientific standards and indicate the metaphor's value in understanding.

Nevertheless, the use of metaphors in science is not without difficulties. Lancor (2014: 1246) highlights that even though "metaphors and analogies are inescapable" in science, their usage can become complicated. Especially in cases when different metaphors are being used to explain the same scientific concepts, such as energy (Lancor 2014: 1246), which can contradict each other (Lancor 2014: 1248) and confuse the reader. Another reason is that not everyone may grasp the metaphorical interpretation of an idea, which may induce problems (Scharf 2013; Beger & Smith 2020), such as misrepresenting scientific facts, most likely leading to misunderstandings within the scientific community (Taylor & Dewsbury 2018). As Scharf (2013) depicts, scientists, especially in the technical fields, are serious and are keener to misunderstand the metaphorical explanation or any comedic approach.

3.2. Space sciences and metaphors?

As we may have understood by now, metaphors are impossible to avoid and may be important in science communication. This does not leave out such branches of science as astronomy, cosmology, or astrophysics. For example, metaphors in astrophysics, as in any other branch of science, are essential for explaining phenomena beyond direct experience. However, the language of astrophysics, physics, cosmology, etc., is primarily mathematics, but as Pulaczewska (2011: 2) points out only using mathematical equations to explain concepts is incomplete as it lacks reference, therefore, language must be involved to connect these formulas to the real-world phenomena, this way making such technical branches of science deceptive to metaphor.

Despite metaphor's importance in science, research on metaphor in different fields of space sciences is relatively scarce compared to that made in other fields (see the beginning of Chapter 3). If we take into consideration astronomy, we can find some research done on its relation to conceptual metaphors, such as those by McCool (2008), Afonso & Afonso (2021), and Grubic (2022). In the case of Afonso and Afonso (2021), for example, they investigated how conceptual metaphors in interviews with astronomers in Portuguese newspapers shape public understanding of science. Further academic analysis revealed research done, as that by Merakchi (2020), Caldarola (2023), and Rad (2024), concerning the translation of identified metaphors from one language to another, mainly in popular science literature related to astronomy/astrophysics. Others (Kramar and Ilchenko 2021) solely focused on describing specific metaphorical terminology (now conventionalized) used in astrophysics while depicting what they have originally intended to mean and how they became staples in the scientific vocabulary of astrophysics and other space sciences. For example, the very well-known term *Big Bang*. The birth of this metaphorical expression, depicting the expansion of the universe from a single hot and dense point, came as a humorous interpretation by English cosmologist Fred Hoyle back in 1949 during an interview with BBC while referring to a theory to which he was opposing to (Mitton 2011) as he supported the *steady-state model* instead. Despite its metaphorical nature, the name *Big Bang* is somewhat misleading. As the short description of the *Big Bang* implies in the previous sentence, there was no explosion "the Big Bang was neither Big […] nor a Bang" (Masting 2019:25 as cited in Kramar & Ilchenko 2021: 95) as it did not involve an explosion but rather a rapid expansion of space itself. Kramar and Ilchenko (2021) further add that when we think of a *bang*, we associate it with an explosion and destruction rather than the creation of space, matter, and time. Another term is *Black Hole.* It refers to "objects for which the gravity is so strong that not even light itself can escape" (Owocki 2021: 138). Before the term was introduced, they were referred to as *gravitationally collapsed objects* but a physicist Robert Dicke (1960) linked it to the infamous prison Black Hole of Calcutta due to its inhumane conditions and even suffocation of inmates (Herdeiro & Lemos 2018 as cited in Kramar & Ilchenko 2021: 96). The name *Black Hole* in scientific discourse gained prominence during a 1967 conference after being suggested by a person from an audience. Since then, the metaphorical term quickly gained acceptance in academia, and to this day, no alternatives have been proposed for it, despite being, to some extent, misleading, as the *Black Hole* is not black and is not a hole (Kramar & Ilchenko 2021: 96).

As the above-provided research shows, the focus on space sciences is relatively new. Therefore, finding articles related to the analysis of metaphorical expressions identified in academic articles, books, and other types of literature produced by physicists or astronomers is a difficult challenge.

3.3. Exploring the genres of space science discourse

As space science delves into the mysteries of the universe, the research that has been done or what is generally known about concepts related to this discourse is being communicated through a diverse range of genres, which allows scientific discoveries to reach broader audiences. From complex and precise academic articles to popular science literature or textbooks made for those only starting their journey of becoming field specialists, they serve as windows in shaping our understanding of the cosmos by adapting complex ideas for different audiences.

3.3.1. Academic articles

Academic or scientific articles present "original research work with other scientists or for reviewing the research conducted by others" (Nature 2014). These articles are typically written for field specialists and are usually peer-reviewed to ensure quality and reliability. As will be seen later, in comparison to popular science literature or textbooks, academic articles use more formal and precise language. Moreover, scholars must also carefully employ technical terminology, correctly detailed equations, and the data itself, which requires a strong background in the field. While academic articles tend to keep their language as technical as possible, metaphors can still play a role, particularly when bridging unfamiliar ideas to familiar ones to aid understanding (Steele et al. 2022). However, as in any other case, if employed, they must be clear, accurate, and relevant to the explained concept.

3.3.2. University-level textbooks

University textbooks, as the name implies, are primarily used by students in higher education institutions and serve as essential learning tools, whether as supplementary or mandatory materials (Springer 2023). They provide foundational knowledge and well-structured information about a subject (Devetak & Vogrinc 2013). Unlike academic articles, textbooks are written to explain concepts, theories, and methods in a way that is easily understandable for their target audience, and, depending on the textbook, even for beginners. Textbooks tend to be broader in terms of topics (but not always). For example, textbooks written for undergraduate astrophysics/ astronomy students, such as those by Owocki (2021), Demtröder (2024), and Ferrari (2024) (also used in the empirical part of the thesis), will often include everything from the history of the field to explanations of the most complex concepts.

Additionally, textbooks tend to incorporate illustrations, examples, and sometimes even exercises at the end of each chapter (as seen in Owocki 2021) to help students built stronger foundation in the subject. Devetak and Vogrinc (2013: 9) also point out that "the text should be broken down to the topics, subtopics and notes in the margins so that transparency of the text can increase". Regarding language, despite being tailored for students who are already to a certain extent are familiarized with the concepts, it must be appropriate and with clear explanations (Devetak & Vogrinc 2013).

3.3.3. Popular science literature

Popular science literature is a type of writing that presents complex scientific ideas in a way that is easily understandable and interesting for the public and is typically prevalent in books and magazine articles. If taking into consideration books, they are usually written by scientists themselves as they "either link [the content of the book] to their research or explore big topics in their field" (Webb 2013: 177). In this genre, as the author tries to engage with the general audience, the writing style is more literary than technical, incorporating a more conversational tone, and could even feature humorous remarks and anecdotes (Webb 2013). Additionally, the structure of the text is also important, requiring "a clear beginning, middle and end" (Webb 2013) to maintain the reader's engagement. What is more, popular science literature tries not only to inform the reader but also to inspire their curiosity about the science. For instance, authors and renowned scientists like Neil deGrasse Tyson, Carl Sagan (1934-1996), and Katie Mack have made astrophysics and cosmology more accessible to a broader audience by breaking down complex topics like black holes, the Big Bang, and others into easily comprehensible concepts. While such literature avoids technicalities, its impact in sparking public interest in science is undeniable. Magazine articles, often referred to as science journalism, do not differ much from books, the main difference being that they are of a much shorter format, ranging from less than a page to several pages long. Similarly to books, science journalism's goal is to inform the reader and attract their curiosity. Nevertheless, science journalism has faced criticism from scholars regarding their non-critical reporting, inaccurate representation of expert opinions, and especially covering topics that have been surfacing in the scientific world for years (Secko et al. 2012).

Overall, metaphors are essential for communication, whether it is science or any other discourse, as they can simplify ideas, evoke emotions, or make portrayed information more memorable for the reader. However, they may also sometimes cause more confusion than clarity, as incorrectly portrayed processes, ideas, phenomena, or other concepts may induce false misinterpretations. Moreover, not everyone may grasp the metaphorical comparison in the same way. Thus, a metaphor used in any type of genre must ensure effectiveness and maintain clarity within the discourse.

4. Creative vs Conventional Metaphors

4.1. The Career of Metaphor

While building on the comprehension of metaphors, examining them from the perspective of creativity and conventionality is essential. This exploration naturally leads to the distinction between creative and conventional metaphors, the former inviting "sense creation" and the latter the "sense retrieval" (Bowdle & Gentner 2005: 199), both of which are crucial for further comprehension of metaphorical thought.

A significant part of understanding creative and conventional metaphors lies in the *Career of Metaphor* hypothesis proposed by Bowdle and Gentner in 2005. Despite being an old hypothesis, it is still important in contemporary metaphor research, as it provides a foundational framework for understanding the general aspects of creative (see 4.2) and conventional metaphors (see 4.3) and the convergence of metaphor from creative to conventional over time.

According to Bowdle and Gentner (2005), metaphors transition from novel to conventional via *conventionalization*. Initially, when a metaphor is used for the very first time, it is considered novel due to its creative approach to comparing two distinctively different concepts to create a new meaning. Over time, with repeated usage and exposure, the metaphor shifts from being understood as a comparison to being seen as a category. Once these metaphorical categories are established as secondary meanings of base terms, they begin to play a more significant role in how we understand them (Bowdle & Gentner 2005: 200). Thus, the base concept may evolve into a broader abstract category that can be applied to more targets. For example, *river* comes to represent something that can flow forward, such as *time,* from which we get the metaphor that *time is (like) a river* (Bowdle & Gentner 2005: 200).

More recent research has also been done concerning the neurological aspects of metaphor changes from novel to conventional. A study by Cardillo et al. (2012) explored how the brain processes metaphors as they become conventional over repeated exposure. Using brain imaging (fMRI), researchers observed that when a person encounters an unfamiliar metaphor, areas in the brain responsible for language, meaning, and visual processing become more active. Nonetheless, as we repeatedly get exposed to creative metaphors, the brain adapts, decreasing the mental load as they become more integrated into a person's mental lexicon.

4.2. Creative metaphor

Creative metaphors are linked to creativity, which is defined as the ability to reimagine existing or newly developed concepts in original and novel ways. There are various definitions of creative metaphor. According to the *Career of Metaphor* hypothesis, creative metaphors include base terms that relate to specific concepts within a particular domain but have not yet been linked to a broader, more generalized category (Bowdle & Gentner, 2005). Other scholars (Philip 2017; Littlemore 2019; etc.) commonly describe creative metaphors as comparisons between two previously unrelated ideas, often to express already existent or new concepts in innovative ways. They evoke a sense of creation (Boeynaems et al. 2017) from which these new, unheard variations are born. For a better understanding, we can investigate Bowdle and Gentner's (2005: 199) provided example of *science, which is a glacier*. The term *glacier* on its own refers to a slowly moving large mass of ice, but it does not carry additional metaphorical meaning such as "anything that progresses slowly but steadily" (Bowdle and Gentner 2005: 199).

As understood by now, the key feature in the creative metaphor is its novelty. However, we need to understand that novelty is a highly complex idea that involves not only introducing a new concept but also reinterpreting an already familiar one more creatively. It is, as such, "not a clear-cut category, but one which operates along a conventionality cline with the utterly predictable at one end, and the previously inconceivable at the other" (Philip 2017: 224). Novelty in metaphors can be understood in a spectrum ranging from entirely new, unique expressions (nonce-forms) to more familiar metaphors that may only be unknown to some individuals (Philip 2017). This makes the metaphorical novelty subjective, as it depends, according to Philip (2017: 226), on "personal experience of the language". The end of the spectrum is the absolute novelty, but according to Philip (2017: 226), "it is virtually impossible to prove. Essentially, what is considered novel depends on the context and familiarity of the metaphor for both the speaker and the listener. With the novelty aspect intact, they also must keep a certain level of coherence for a person to comprehend its meaning. If the metaphorical interpretation strays too far from the original idea, it will lose its intended meaning and fail to convey what was meant to be portrayed, as creative metaphors must be "comparisons, in which the target concept is structurally aligned with the literal base concept" (Bowdle & Gentner 2005: 199).

Moreover, creative metaphors often require more cognitive effort than conventional ones, as they evoke stronger emotional or sensory responses. Their usage also depends on the person who uses them. People who are generally more creative tend to exploit semantic relations between concepts more effectively, thus leveraging the imaginative potential of metaphors to create new representations of established concepts, words, and ideas (Kövecses 2005; Birdsell 2017; Philip 2017; Littlemore: 2019).

It has long been believed that creative metaphors appear more prominently in literary texts than in other types of discourse (Littlemore 2017). Consequently, they are sometimes referred to as *poetic, unconventional, novel, original,* or *literary metaphors*. Yet, scholars (Semino & Steen 2008; Littlemore 2017; Prandi & Rossi 2023) have emphasized that creative metaphors are not confined solely to literary texts but also occur in other diverse domains such as general conversations, political speeches, scientific writing, philosophy, and others. Subsequently, as definitions of *creative* and *creativity* do not delve into being somewhat related to literature, this may further support the idea that creative metaphors can be found in literary and non-literary discourses. This raises important questions about the characteristics and functions of metaphorical creativity across discourses outside of literature.

As Mueller (2010: 5) notes:

> If we understand conventionality in terms of expectations within a given discourse or genre, we can define 'creative metaphors' as expressions which draw attention to their metaphorization because they deviate creatively from conventional ways of expressing things and thoughts within a particular discourse or genre.

Thus, it highlights creative metaphor's ability to challenge the prevailing norms in within specific context. In scientific discourse, for example, creative metaphors may help to explain scientific ideas, processes, etc., in a clearer way for both the field and non-field specialists. They can be used in framing a variety of topics and once used for the framing of an issue (Boeynaems et al. 2017: 2861), can help to structure understanding. This framing function is especially valuable in contexts like political speeches or public health crises, where metaphors become central in shaping how the public perceives and understands issues. As a more recent and notable example, we can consider the Covid-19 pandemic. During this time, especially at the early stages of the pandemic, there was an urgent need to grasp and adapt to such an unexpected global crisis that disrupted the stability of society (Pérez-Sobrino et al. 2022). Therefore, various metaphors emerged which helped "to reason about different aspects of the pandemic as well as to heighten or mitigate its negative emotional impact" (Pérez-Sobrino et al. 2022: 128).

4.3. Conventional metaphors

In contrast, conventional metaphors, unlike novel, involve terms that refer to both literal and metaphorical categories. For instance, in the phrase *the heart of the matter* the word *Heart* in literal terms refers to the organ in one's chest but metaphorically it extends to symbolizing the center or something of utmost importance. Another example could be the *time is running out* (Lakoff and Johnson 1980: 66). It describes *time* as a limited resource which draws on the physical concept of something that runs out, such as liquid. As time passed, the phrase became more widely used among speakers, losing its original novel aspect, and now functions as a phrase to indicate urgency. Metaphors of this type may appear more frequently than novel ones in our everyday language (Lakoff & Johnson; Philip 2017; Littlemore & Turner; Littlemore 2019) and, unlike creative metaphors, conventional base terms may have multiple meanings, both literal and metaphorical, due to their shared similarities. As a result, conventional metaphors, according to Bowdle and Gentler (2005: 199) can be understood in two ways: (1) as comparisons, where the target concept is linked to the literal meaning of a base concept, or (2) classifications, where the target concept is seen as a part of the broader metaphorical category represented by the base term. Both conventional and novel metaphors can "coexist in poetic texts […], in philosophical and scientific terminologies and in the shared heritage of concepts we rely upon in everyday life" (Prandi & Rossi 2023: 14).

Another important factor in the processing of metaphors is the role of embodiment, which influences our physical and sensory experiences and shapes how we create and understand metaphors (Kövecses 2015; Littlemore 2019; Khatin-Zadeh et al. 2023). Regarding creative and conventional metaphors, scholars consider the former more prevalent in evoking embodied simulation (Littlemore 2019: 58) than the latter. This is due to their creative aspect, which corresponds to an ability to activate sensorimotor brain areas related to movement and sensation, making them feel more vivid and engaging (Littlemore 2019). For example, a metaphor such as *his thoughts were a tangled web of vines* reimagines vines as a physical sense of struggle and complexity, which adds a layer of novelty, allowing a deeper emotional and cognitive engagement instead of just simply stating that the person was confused.

Conventional language, according to Philip (2017) can be identified either through a lexicographic or psycholinguistic approach. The lexicographic approach is more prominent among linguists who analyze the frequency of occurrence of the phrase and its patterns while using corpora. If the identified phrase occurs frequently and in similar contexts, it then becomes a part of the conventional language system. In this way, it is *institutionalized* (Philip 2017: 222) or in other terms it is already considered a familiar phrase or an established common concept that can be found in dictionaries, thesauri, books, magazines, newspapers, etc, (Kövecses 2002: 240). In contrast, psycholinguistics centers on salience, which encompasses the speaker's familiarity of the expression, how often it is encountered, the appropriateness of the phrase in a particular situation and its cognitive prominence (Philip 2017). Although this approach offers a distinct and nonetheless important view of language, I will stand with the lexicographic perspective because it offers a more objective and data-driven analysis based on observable written patterns.

Despite theoretical advancements, according to Turner and Littlemore (2023: 43), creative metaphor identification remains challenging from the methodological point of view. Creative metaphors in comparison to conventional metaphors were not viewed as problematic or hard to comprehend because they were simply defined as those that connect two previously unrelated ideas (Turner & Littlemore 2023). However, more recent research done on creative metaphors, as mentioned by Turner and Littlemore (2023), distinguished two types of creative metaphors that are: (1) those establishing an entirely new mapping; and (2) those adding more details to an already existing mapping. Pérez-Sabrine et al. (2022) in their research acknowledge that the definition of boundaries between creative and conventional metaphors is challenging as even newly established metaphorical pairings are drawn on already existing mappings to some degree. Such implication suggests that no metaphor is completely independent of previously identified associations. Thus, as Turner and Littlemore suggest (2023) "it is therefore perhaps more appropriate to talk in terms of 'creative uses of metaphor' than 'creative metaphor' per se" (p. 43).

In conclusion, while creative metaphors involve more mental engagement, conventional metaphors provide familiarity, structure, and simplicity. Nonetheless, they are both significant contributors to comprehending complex ideas, whether in literary texts or other discourses, thus highlighting the dynamic nature of language.

5. Data and methods

5.1. Data

To construct the corpus for this study, data were/was systematically collected and processed from different genre sources. Due to the length of academic articles, each consisting of several thousand words, seven were selected and included in the analysis's corpus. The articles were chosen based on thematic relevance to the field of space sciences, which included topics of space formation and evolution of galaxies, black holes, planets, distant stars, and other cosmic structures, as well as other phenomena of the cosmos. This thematic focus ensured coverage of a higher density of topics and the ability to identify and analyze a broader range of metaphorical expressions relevant to the discourse of space sciences. Popular science literature texts were varying significantly in length, ranging from short articles less than a page long to those of several pages long, thus, a larger quantity of texts was taken for the analysis to balance the overall amount of data. In total, forty-four popular science texts were included in the corpus. In chosen university-level textbooks, it was indicated in the preface that the book is meant for undergraduate students. From this genre, a total of forty-seven texts made up the sub-corpus.

The table below presents a summarization of the name of the genre, word count in each genre, and sources from which the articles and texts were taken for the analysis:

Table 1. Summary of corpus composition

Corpus	***Word count***	***Sources***
Academic articles	50,054	Nature (2024), Astronomy & Astrophysics (2024), The Astrophysical Journal (2024)
Educational textbooks	50,669	Books: Attilo Ferrari *Fundamentals of Astrophysics: Astrophysical Methods* (2024); Bradley W. Carroll & Dale A. Ostlie *An Introduction to Modern Physics. Second Edition* (2017); Andreas Zezas *Star-Formation Rates of Galaxies* (2021)
Popular science literature	50,033	Science Illustrated (2022; 2023; 2024); Books: Neil deGrasse Tyson *Astrophysics for People in a Hurry* (2017), Katie Mack *The End of Everything* (2020)
Total:	159,756	

5.2.Procedure and methods

To achieve the objectives of the study, the following procedural steps were taken:

(1) **Corpus construction.** After the sub-corpora texts were selected (see p. 22), the texts from each genre were manually transferred into separate *Word* documents created specifically for each genre. During this step, non-linguistic items, such as page numbers, images, hyperlinks, author names, and other additional information included within the text, were manually removed to ensure the purity of the data. Additionally, formatting errors were discarded during the text transfer phase from the original file to the *Word* document. Following this process, the selected texts were formatted uniformly in all three sub-corpora and reviewed for thematic integrity, resulting in three polished and cohesive sub-corpora suitable for analysis.

(2) Each sub-corpus was subjected to manual close reading to identify metaphorical expressions. For this, Metaphor Identification Procedure (MIP) established by the Pragglejaz Group 2007: 3) was employed:

> 1. Read the entire text–discourse to establish a general understanding of the meaning.
> 2. Determine the lexical units in the text–discourse
> 3. (a) For each lexical unit in the text, establish its meaning in context, that is, how it applies to an entity, relation, or attribute in the situation evoked by the text (contextual meaning). Take into account what comes before and after the lexical unit.
> (b) For each lexical unit, determine if it has a more basic contemporary meaning in other contexts than the one in the given context. For our purposes, basic meanings tend to be
> —More concrete; what they evoke is easier to imagine, see, hear, feel, smell, and taste.
> —Related to bodily action.
> —More precise (as opposed to vague)
> —Historically older.
> Basic meanings are not necessarily the most frequent meanings of the lexical unit.
> (c) If the lexical unit has a more basic current–contemporary meaning in other contexts than the given context, decide whether the contextual meaning contrasts with the basic meaning but can be understood in comparison with it.
> 4. If yes, mark the lexical unit as metaphorical.

While following this method, a lexical unit was considered metaphorical if there was an identified contrast between its concrete meaning and the contextual meaning in the sentence and then if the lexical unit could be understood through a conceptual comparison. To help identify if the found lexical unit is metaphorical, *Oxford* and *Cambridge* dictionaries were used to look for the basic meanings of the lexical units. As an example, in the sentence *A recycling* ***universe*** *is more appealing than drawn-out decay, or a* ***last meal*** *before destruction.*, the lexical unit *last meal* was marked as a metaphorical expression. While following the above cited step of MIP, the basic meaning of *meal*, according to dictionaries, refers to food or the consumption of food. Despite that, in the sentence itself *last meal* does not refer literally to food or its consumption but is rather metaphorically used to describe the final stages of the universe. Therefore, the visible contrast between the concrete meaning and contextual meaning indicates metaphorical usage of the identified lexical unit.

(3) After identifying a metaphorical expression in the sentence, the corresponding sentence was copied and pasted into a dedicated *Excel* spreadsheet designed for each genre separately. The metaphorical expression was marked in bold for easier identification. Each of the three *Excel* spreadsheets contained the following categories: metaphorical expressions, commentary, tokens, target domain, source domain, subdomain, creative/conventional, title of the text, author, publication date. To categorize each metaphorical expression while interpreting its source and target domains, the qualitative approach was used.

(4) Each metaphorical expression was then analyzed to determine its source and target domain. The target domain was identified by considering the concrete object, phenomenon or process being described within the expression. In some instances, the target domain was not stated clearly within the expression as the target has been mentioned in a previous sentence. The source domain was determined by identifying the semantically related conceptual frameworks, for example LIVING BEING, NATURAL PHENOMENON, FOOD, etc., that was used to structure the understanding of the target.

(5) After categorizing each metaphorical expression according to its source and target domain, they were classified accordingly as creative or conventional, following Philip's (2017) framework. Conventional metaphors were identified as those that involve terms referring to both literal as well as metaphorical categories and which, through common usage, have become established in everyday language with entries typically found in standard dictionaries. In accordance with space sciences, it was taken into consideration that established conventionalized metaphorical terminology may not always appear in general dictionaries but are instead found in specialized dictionaries used by field specialists. Thus, Cambridge Illustrated Dictionary of Astronomy (Mitton 2008) and Oxford Dictionary of Astronomy 3rd edition (2018) were consulted. In contrast, creative metaphors were considered as those that compare two previously unrelated ideas, often used to express already existent or at times new concepts in novel ways (Philip 2017; Littlemore 2019) and which cannot be found in dictionaries as they are often seen to be used once o or do not repeat frequently enough to be acknowledged as of established expressions.

(6) Quantitative analysis was initiated during the research to examine the frequency and distribution of metaphorical expressions according to their source domains and

creativity/conventionality across the three sub-corpora. This step included counting the total number of identified metaphorical expressions in all three sub-corpora, then counting the number of metaphorical expressions accordingly in each source domain.

(7) Lastly, the ratio of identified source domains and their sub-domains, as well as creative and conventional metaphors, was compared across all three genres respectively.

6. Results and discussion: The distribution of creative and conventional metaphors across genres and source domains

This section provides quantitative results, a qualitative analysis discussion, and examples from each sub-corpus. It is divided into subsections that address the results of the most frequent source domains, discuss other less prominent source domains and metaphorical expressions identified, and discuss creative and conventional metaphors in academic articles, popular science literature, and educational textbooks.

After conducting the analysis of identified metaphorical expressions across the three sub-corpora, twenty-six source domains were identified across academic journal articles, popular science literature, and university-level textbooks. Table 2 below provides a breakdown of all identified source domains across the three genres, including the number of tokens found as well as their frequencies. The table also provides the distribution of creative and conventional metaphorical expressions identified within each source domain.

Before proceeding with the initial discussion, it should be noted that although the focus of the analysis is on the most prominent source domains and their predominant subdomains, the selection of source domains for the discussion also considered the type-to-token ratio since, in some instances, certain recurring scientific conventionalized terminology accounted for a larger or even dominating portion of all identified metaphorical expressions within the source domain or subdomain.

6.1. Quantitative distribution of source domains across different genres

An overview of the results (see Table 2) reveals that most identified source domains were found across all three or at least two genres. Specifically, half of the identified source domains (thirteen), such as AGRICULTURE, CONTAINER, JOURNEY, and others, have appeared in at least one metaphorical expression across all three sub-corpora. Additionally, six source domains, for instance, DIRTINESS/CLEANLINESS, ENTERTAINMENT, FIRE, and others, were identified in only two of the three genres. It is important to highlight that some source domains, such as FIRE, FOOD, LOCATION, and MOTION, were only present exclusively in popular science literature and educational textbooks with no instances identified in academic journal articles. In contrast, DIRTINESS/CLEANLINESS as well as ENTERTAINMENT were identified in both academic journals and popular science sub-corpora. Interestingly, seven source domains were unique to only one sub-corpora.

Table 2. The frequency of each source domain across all genres

Source domain	***Academic journals***			***Popular science***			***Educational textbooks***			***Total***
	Tokens/%	Creative	Conventional							
AGRICULTURE	**19**	-	19/100%	**1**	1/100%	-	**2**	-	2/100%	22
BUILDING	**2**	1/50%	1/50%	**4**	1/25%	3/75%	**5**	1/20%	4/60%	11
COMPETITION	**-**	-	-	**1**	-	1/100%	**-**	-	-	1
CONFLICT	**6**	-	6/100%	**20**	6/30%	14/70%	**4**	1/25%	3/75%	30
CONTAINER	**60**	1/1.6%	59/98.4%	**2**	-	2/100%	**139**	-	139/100%	201
DIRTINESS/ CLEANLINESS	**3**	-	3/100%	**3**	2/66.66%	1/33.33%	**-**	-	-	6
ENTERTAINMENT	**7**	-	7/100%	**19**	12/63.15%	7/36.8%	**-**	-	-	26
FACTORY	**-**	-	-	**2**	2/100%	-	**-**	-	-	2
FINANCES	**3**	1/33.3%	2/66.66%	**-**	-	-	**1**	-	1/100%	4
FIRE	**-**	-	-	**1**	-	1/100%	**2**	-	2/100%	3
FOOD	**-**	-	-	**40**	13/32.5%	27/67.5%	**1**	1/100%	-	41
FORCE	**4**	-	4/100%	**83**	-	83/100%	**3**	-	3/100%	90
GEOMETRY	**-**	-	-	**-**	-	-	**2**	-	2/100%	2
HISTORY	**-**	-	-	**-**	-	-	**1**	-	1/100%	1
HUNT	**4**	-	4/100%	**-**	-	-	**-**	-	-	4
JEWELRY	**1**	1/100%	-	**-**	-	-	**-**	-	-	1
JOURNEY	**13**	-	13/100%	**30**	18/60%	12/40%	**21**	3/14.28%	18/85.71%	65
LIGHT	**3**	-	3/100%	**4**	4/100%	-	**1**	1/100%	-	8
LIQUID	**8**	5/62.5%	3/37.5%	**7**	7/100%	-	**4**	-	4/100%	19
LIVING BEING	**50**	4/8%	46/92%	**175**	56/32%	119/68%	**108**	16/4.81%	92/85.18%	333
LOCATION	**-**	-	-	**5**	4/80%	1/20%	**7**	-	7/100%	12
MOTION	**-**	-	-	**10**	3/30%	7/70%	**2**	-	2/100%	12
NATURAL PHENOMENON	**45**	-	45/100%	**22**	3/13.63%	19/86.36%	**43**	-	43/100%	110
OBJECT	**6**	-	6/100%	**23**	7/30,43%	16/69.56%	**36**	19/52.77%	17/4722%	65
SPORT	**-**	-	-	**4**	3/75%	1/25%	**-**	-	-	4
SUPERNATURAL PHENOMENON	**4**	-	4/100%	**50**	1/2%	49/98%	**33**	-	33/100%	87
Total	**238**	13	225	**506**	143	363	**415**	43	372	1159

For example, FACTORY and SPORT only appeared exclusively while analyzing the sub-corpora for popular science literature, GEOMETRY and HISTORY being unique to educational textbooks, and HUNT as well as JEWELRY solely identified in the academic journals' genre. The main factor contributing to such "individualization" of certain source domains within a particular sub-corpus was the thematic focus of each text, for example, in cases where a particular cosmic phenomenon was briefly mentioned within one genre but not others. This resulted in metaphorical expressions repeatedly reappearing within a single sub-corpus, which led to the emergence of such unique source domains.

Furthermore, popular science literature, with twenty-one domains identified, proved to be the most extensive. Eighteen source domains were identified while analyzing metaphorical expressions in educational textbooks, and seventeen domains during the analysis of metaphorical expressions within the academic journal sub-corpora. What can be seen from the above-mentioned numbers, although the overall number of source domains varies slightly with a difference of one to four source domains in each genre, the number of metaphorical expressions identified varies substantially. In this case, popular science literature contained the highest number of metaphorical expressions identified, while academic articles contained the fewest.

While taking a closer look at the total numbers of metaphorical expressions identified in each source domain, we can see that in some instances the number of metaphorical expressions greatly exceeds compared of others. CONTAINER, LIVING BEING, and NATURAL PHENOMENON were particularly dominant, each associated with more than one hundred metaphorical expressions. Among these, the source domain LIVING BEING is the most prominent with three hundred and thirty-three metaphorical expressions. Other source domains such as FORCE and SUPERNATURAL PHENOMENON, JOURNEY, and OBJECT also had a relatively high number of tokens, although each having less than a hundred. Notably, these more frequent source domains were found across all three analyzed genres.

Furthermore, regarding the distribution of creative and conventional metaphors, both types were identified in all three sub-corpora. As hypothesized, creative metaphors were seen to prevail more in both popular science literature and university-level textbooks than in academic articles, with popular science showing several times higher numbers of identified creative metaphors than academic articles or even educational textbooks. In certain cases, creative metaphors were more dominant more than conventional ones within specific source domains and genres. For instance, the source domain ENTERTAINMENT was dominated by creative metaphors within popular science, LIQUID had more creative metaphors both in academic and popular science, and OBJECT showed a slightly higher number of creative metaphors in educational textbook sub-corpora. Nevertheless, conventional metaphors remained dominant overall across all three sub-corpora and majority of identified source domains, especially when considering the total number of identified metaphorical expressions.

6.2. The source domain of LIVING BEING

While conducting the analysis across all three corpora it was noticed that in space-related texts across all three of the chosen genres the most dominating and widely recurring metaphorical expressions were those that tended to describe the identified target domains such as space objects, forces, spacecrafts, cosmic events, particles and many others as entities with human- or animal-like qualities. The reason for categorizing these metaphorical expressions under a single source domain LIVING BEING was due to many identified metaphorical expressions and the actions portrayed by the targets not being clearly distinguishable as only representing humans or animals (see Appendix 1, Table 3). For example, categorizing such actions as *birth, hiding, digging, growth* either to humans or, on the contrary, to animals, is incorrect as these actions and behaviors can be attributed to both animals and humans. Thus, a more superordinate source domain was used as it is believed to dominate due to the tendency to personify or anthropomorphize abstract concepts and non-living objects, for easier visualization and relatedness.

Within the genre of academic articles, a total of fifty metaphorical expressions were identified, falling under the source domain of LIVING BEING. Despite this genre having the least number of metaphorical expressions identified compared to popular science literature and university textbooks, there was a total of twenty-one subdomains identified within the single source domain. In the popular science literature genre, the source domain LIVING BEING was the most prevalent not only by the number of metaphorical expressions identified but also by the number of subdomains related to it. In total, fifty-six subdomains were distinguished out of which twenty-two had been further divided into sub-subdomains according to the metaphorical expressions related to them. Generally, the university-level textbook genre is noticed to fall in between academic articles and popular science literature in terms of both the number of identified metaphorical expressions and the range of related subdomains as mentioned previously (see Table 2). Here, thirty-five subdomains were identified.

6.2.1. Subdomain: relationship

Within the broadest source domain of LIVING BEING, the most prevalent subdomain identified was *relationship,* with forty-four metaphorical expressions identified across all the genres. Notably, most metaphorical expressions appeared within the popular science sub-corpus. In this subdomain, all identified metaphorical expressions drew on human-like relationships rather than animal-like, with subdomains such as *family trees, family members, couples,* and *companions* describing the target domains. In academic journal articles, the metaphorical expression *High-mass stars play a crucial role in shaping not only their* ***parental clouds****, […]* uses "parental clouds" as a metaphorical image. Here, dense regions of gas and dust, that are scientifically more profoundly referred to as "molecular clouds", are metaphorically conceptualized as "parents", emphasizing their role as the birth givers (in this case, birthplace) of stars, this way assigning as if a family-based origin narrative to stellar formation. In popular science literature, *relationship* metaphors are seen to be much more diverse, naturally due to a higher number of metaphorical expressions found, and encompassing both family relations as well as romantic partnerships:

(1) *So how does the ancient giant fit into the Sun's* ***family tree****?*
(2) ***Red dot is the Sun's grandfather.***
(3) *If* ***the Sun had a twin****, there's also a possible explanation for the Solar System's most mysterious object: Planet 9.*
(4) ***Star couple*** *have a common field of gravity.*

The first example positions the target domain *ancient giant* within the generational framework, suggesting that stellar evolution can be understood through human family lineage. Similarly, the second and third examples evoke family relations describing the target domain as being a *grandfather* metaphorically portraying an older generation star (*red dot)* linked to the Sun's formation, while *twin* suggests the possibility of the Sun having originally formed with a binary star (two stars orbiting each other in a multiple star system). The fourth example shifts from family dynamics to romantic relationships, portraying, again, binary stars as a couple whose uniting "bond" is their shared gravitational field.

What has been noticed, in the educational textbook sub-corpus, all five identified metaphorical expressions shared a consistent pattern of companionship between space objects:

(5) *Moreover, when that* ***companion star*** *becomes a giant […].*
(6) *It is also possible that a neutron star in a close binary system may gravitationally strip enough mass from its* ***companion*** *[…].*

The terms *companion* and *companion star* both refer to the coexistence or partnership of two stars. Although metaphorical in nature, the term *companion star* itself has become a conventionalized scientific term, widely accepted in astrophysics to describe none other than binary stars as well!

6.2.2. Subdomain: birth

The basic meaning of *birth* is "the time when a baby or a young animal comes out of its mother's body", but it can also refer to the "beginning of something" (Cambridge dictionary 2025). The *birth* metaphor has been widely used by scientists and science journalists to describe the formation processes of galaxies, stars, other celestial bodies, and even the universe itself. However, although it is used within the scientific community, it is not considered part of the scientific terminology due to the existence of a technical term *formation,* which overruns the more general and metaphorical descriptor *birth.*

The analysis revealed that *birth* metaphors are relatively scarce in academic articles compared to popular science or educational textbooks.

In the academic corpus, the *birth* subdomain has been identified in only one instance:

(7) *Using the current observational techniques, resolving individual stars formed within their* ***birth environment*** *and their position within the large-scale galactic environments turns the Milky Way into a unique laboratory.*

This example shows the metaphorical expression *birth environment* used to describe regions within galaxies where stars form. Here, *birth* refers metaphorically to the beginning of stars, to the biological act of giving birth. The lexical unit *environment* reinforces the metaphor by suggesting a nurturing setting necessary for the development of stars, much like a mother's womb, which is essential for the development of a fetus.

Nonetheless, it is important to note that this case is somewhat ambiguous, as it is also possible to link the metaphorical expression *birth environment* to the source domain LOCATION, as it may evoke associations with places to give birth, such as hospitals or animal lairs, rather than the action birth or being born itself.

Further analysis of the *birth* subdomain showed that in both popular science literature and educational textbooks, it primarily served to describe the formation or beginning of space objects as well as space events represented through the concept of childbirth:

(8) **Stars are born** when dense clouds of molecular gas and dust collapse under the effects of gravity. (Popular science literature)
(9) According to the Big Bang theory, **the universe was born 13.8 billion years ago.** (Popular science literature)
(10) Today observations of collisions of galaxies seem to indicate that the evolution goes the other way: **galaxies are born** […]. (University-level textbooks)

Interestingly, in the educational textbooks, the *birth* metaphor tended to appear primarily at the beginning of chapters or in introductory sections, later transitioning to the more scientific term *formation*. Such a unique pattern could be explained in two ways: (1) the metaphor is used to attract the reader's attention; (2) it helps the reader familiarize themselves with the scientific phenomena in more familiar everyday language before introducing specialized terminology.

Continuing the analysis, it was also observed that in the popular science sub-corpus, the *birth* metaphor occasionally branched out to describe space objects, events or even conditions as the birth givers, this way anthropomorphizing them as living beings capable of producing offspring, thus reinforcing the connection between cosmic creation and familiar human and animal experiences of birth:

(11) *[…] after which a new Big Bang* ***gives birth to the next universe****.*
(12) *In the early universe,* ***burnt-out stars*** *in dwarf galaxies collapse,* ***'giving birth'*** *to small black holes that combine into medium-sized holes.*
(13) ***Inflation gives birth*** *to many universes.*

Moreover, despite the two main metaphorical extensions of *birth,* i.e. *formation* and *birth giver*, it was also found in the popular science sub-corpus that it may refer to starting anew after an end:

(14) *The universe shrinks but* ***may be reborn****.*
(15) *Even if the universe ends, it does not have to die forever: a* ***new universe might be born.***

In both examples, *reborn* and *might be born* metaphorically represent the cyclical process of the universe, suggesting that even though the universe may one day collapse, it could regenerate through a process known as cosmic recycling.

6.2.3. Subdomain: animal

Across all metaphorical expressions identified and categorized under the source domain LIVING BEING, more than ten cases were acknowledged where, distinctively, expressions did not primarily represent human-like behaviour but rather evoked animal-like behaviour and directly referenced specific animals or their body parts as sources for space objects and cosmic structures. As presented in the table (see Appendix 1, Table 3), this subdomain was only identified in metaphorical expressions extracted from educational textbooks and popular science genres.

A significant portion of identified metaphorical expressions within this subdomain referred to animals themselves:

(16) *In other words, a* ***wormhole*** *must be threaded by some sort of whose tension prevents the collapse of the wormhole.* (University-level textbooks)
(17) *As extremely distant sources of light, they make ideal* ***guinea pigs*** *for the detection of intervening junk.* (Popular science literature)
(18) *Its thousand galaxies orbit the cluster's center, moving in all directions like* ***bees*** *swarming a beehive.* (Popular science literature)

It is important to mention that out of all identified metaphorical expressions related directly to animals, the majority represented the same expression, *wormhole*. Thus, while looking into example (16) itself *wormhole* illustrates metaphorically a theoretical passageway through spacetime that creates shortcuts within the universe. The metaphorical imagery in this case emerges from the *wormhole's* comparison to an animal, specifically a worm flexible enough to adapt to various environments. Example (17) reinforces the guinea pig reference to experimentation/ testing on live subjects such as humans or animals. However, a non-living light source (quasar) can be used as a test subject to conduct experiments, much like rodents are used in laboratory settings. Lastly, example (18) shows galaxies being compared to bees. In this case, comparing galaxies to bees suggests a dynamic, coordinated motion of galaxies within clusters as if they are working together in a seemingly organized way, much like bees performing tasks within their colony.

What is more, in the educational textbooks sub-corpus, two expressions were derived that referred to cosmic structures named after animal body parts, which also can be categorized as a different sub-subdomain on its own:

(19) *Another example is* ***the horse head nebula*** *embedded in the vast and complex Orion nebula*. (University-level textbooks)
(20) *The first black hole to be tentatively identified in this way is Cygnus X-1, near the bright star Cygni in the middle of the* ***swan's neck***.

Both examples above metaphorically refer to a cosmic structure (Horsehead nebula and Swan nebula) named after animal body parts, drawing on their similarity to the structure's shape or silhouette, evoking familiar imagery.

What is more, both in popular science and educational textbook genres, several metaphorical expressions were identified that liken the filamentary structure of the universe to a spider's web or a web-like construction. For example:

(21) *In 2019, observations demonstrated that the fields also exist on the largest of scales – in the* ***cosmic cobweb****, where threads of thin gases link galaxy clusters*. (Popular science literature)
(22) *The result shows a remarkable* ***"cosmic web****" in the overall large-scale structure (LSS) of the universe*. (University-level textbooks)

The metaphor of *web* or *cobweb* in both provided examples highlights the intricate and interconnected nature of the cosmos, which visually resembles the structure of a spider's web to some extent. Thus, here, the *web* is not used literally but rather metaphorically as it conveys the idea of the delicate cosmic structures to a spider's web that connects various points in occupied space. What is more, *cosmic web*, despite not having a dictionary entry, is a widely recognized term in the scientific community.

Lastly, a couple of identified metaphorical expressions within the *animal* subdomain were noticed to represent their targets in relation to behaviour patterns or actions more commonly associated with animals:

(23) *A star comes too close to a* ***lurking black hole*** *[…].* (University-level textbooks)
(24) *The solar probe gained its amazing speed record by* ***harnessing*** *the Sun's gravitational field […].* (Popular science literature)

In example (23), the term *lurking* typically describes an animal, usually a predator, waiting to catch prey. Within this metaphorical expression, the target (black hole) is depicted as this predator, waiting for a star to pass close enough to be pulled in by its intense gravitational field. When looking into *harnessing* and *harness* in general (seen in the example (24)), its basic meaning refers to putting a harness on an animal, usually a horse, to use it or to control something to gain their power. Therefore, in this example, metaphorical expression *harnessing* implies the probe's usage of the Sun's gravitational field, much like a human would use an animal's strength for its gain, as in this case, to gain greater speed.

6.3. The source domain of JOURNEY

The domain of JOURNEY generally relates to the actions related to travel, exploration, moving from one point to another, and often evoking concepts of *movement,* destinations, as well as others.

Table 4. Frequency of subdomains identified across genres in the source domain JOURNEY

Subdomain	***Academic journals***	***Popular science***	***Educational textbooks***	***Total***
Completion	-	1	1	2
Crossing	1	-	-	1
Destination	-	1	1	2
Duration	1	-	-	1
Exploration	-	4	2	6
Gold rush	-	1	-	1
Harbor	-	-	1	1
Launch	-	1	-	1
Lead	-	-	1	1
Motion	-	1	-	1
Movement	1	5	2	8
Not coming back	-	1	-	1
Parachute	-	1	-	1
Passing by	-	1	-	1
Preparation	-	1	-	1
Ride	-	1	-	1
Return	-	-	1	1
Road	8	-	2	10
Separation	-	2	-	2
Transportation	1	-	-	1
Traveler	-	2	2	4
Tunnel	-	-	7	7
Vehicle	1	6	1	7
Quest	-	1	-	1

Similarly to other source domains, here as well, it can be observed that all three genres shared certain subdomains, for example, *movement* and *vehicle*, highlighting more common/ similar conceptualizations of various processes in space-related contexts. However, each genre also features unique subdomains that appeared only while analyzing found metaphorical expressions in a certain genre, often corresponding, as seen in the table, to a single metaphorical expression per subdomain.

6.3.1. Subdomain: movement

Movement was one of only two subdomains identified across all three genres. In these instances, metaphorical expressions were seen to describe the target as *travelling* in a specific direction, *moving further*, *speeding*, and *coursing*. Here are a few examples:

(25) *The lower stratospheric H2O in the abiotic scenarios that arises due to a lower CH4 surface flux is less efficient at trapping* ***the heat travelling upwards*** *[...].* (Academic articles)
(26) *The next big transition for the universe came when so much* ***starlight was coursing through space*** *[...].* (Popular science)
(27) *A* ***supermassive black hole is speeding out*** *of its home galaxy [...].* (Popular science)
(28) *[...] two arms are* ***going*** *one way and another arm is* ***winding*** *in the opposite direction [...]* (University-level textbooks)

In examples (25) and (26), we can notice that both metaphorical expressions, such as motion verbs *travelling upwards* and *coursing,* are used for intangible targets, thus metaphorically treating them as mobile agents. In example (27), the target is personified as an agent who can leave the home galaxy alone. However, in literal terms, the expression refers to the astrophysical phenomenon of a black hole's ejection from a galaxy due to galactic collisions or gravitational interactions. Lastly, example (28) includes a mixed metaphor where the target is described as both *going* and *winding*, thus blending directional travel with something that is coiling.

6.3.2. Subdomain: vehicle

While conducting the analysis, it was also noticed that in some instances metaphorical expressions under the source domain JOURNEY drew on the framework of vehicles or actions that are usually associated with them, such as *launching, parking, crashing,* or *transporting* this way describing complex, in this case usually astrophysical phenomena:

(29) ***The acceleration of the solar wind*** *[...).* (Academic articles)
(30) *[...] until it [solar wind] is finally* ***stopped by running into*** *the local interstellar medium.* (University-level textbooks)
(31) *[...]* ***each individual cell essentially a probe in itself****.* (Popular science)
(32) *Even in the midst of this great* ***galactic train wreck,*** *[...].* (Popular science)

Example (29) portrays a cosmic phenomenon and its propulsion as a vehicle gaining speed. Moreover, examples (30) and (32) both use metaphorical expressions to describe collisions: in example (30), *solar wind* (a stream of charged particles) is metaphorically likened to a fast-moving vehicle that comes to a halt as it interacts with a certain interstellar medium. Nonetheless, in scientific terms, the particles do not crash but rather slow down as they lose energy. In example (32), the metaphor represents simply the collision of galaxies, interpreted metaphorically while emphasizing its disastrous aftermath. What can be noticed in example (31), the metaphor shifts from describing a target portraying a vehicle-like action, to conceptualizing the target, a living organism, as a vehicle itself used for exoplanet exploration.

6.3.3. Subdomain: exploration

This subdomain was only identified in metaphorical expressions found in popular science and educational textbooks. When it comes to popular science literature, all the identified metaphorical expressions related to microorganisms as astronauts and earthlings that are described as future or possible future explorers of the cosmos:

(33) *George Church aims to equip his* ***tiny astronauts*** *with genes from the most robust of organisms here on Earth, so the* ***space travellers*** *can resist radiation, drought and heat, yet still reproduce extremely fast.*
(34) *If George Church's vision comes true, all the movies will have got it wrong – neither humans nor AI robots will be the* ***first earthlings to reach the stars****.*

Differently than in popular science literature, in educational textbooks, *exploration* is seen to be used more in relation to theoretical and scientific frameworks rather than literal space travel that we saw in the examples above:

(35) ***A Trip into a Black Hole.***
(36) *Since the round trip is symmetric, it is necessary only to find the time for either the* ***journey in or out*** *and then double the answer.*

Here, in the example (35), it refers not to a literal exploration of black holes but to a theoretical investigation, as implied, in this case, not only by the sentence itself but also while taking into consideration the context that follows. Example (36) the metaphorical usage of *round trip* in this context refers to the calculation of time necessary for conceptual exploration of black hole, further reinforcing the idea of scientific framework as a journey.

6.4. The source domain of OBJECT

Another metaphorically rich source domain identified across all three genres is OBJECT, encompassing a wide and colorful range of subdomains (see Appendix 1, Table 5). Upon analyzing metaphorical expressions, it was observed that targets such as *space objects,* the *universe, regions, energy, materials, light*, and many others were often metaphorically mapped onto other cosmos-unrelated everyday objects or described through actions, properties, and sounds that are usually associated with such items.

As shown in Table 5, we can see that, again, as seen in previously analyzed source domains, academic articles feature the least subdomains within this source domain. Notably, different from what is seen in other source domains, here educational textbooks contained the highest number of subdomains (nineteen) while popular science literature featured seventeen. Interestingly, not a single subdomain was shared across all three genres. Only five subdomains overlapped between educational textbooks and popular science literature genres. At the same time, academic articles were seen to have unique subdomains with only one to two metaphorical expressions related to each.

6.4.1. Subdomain: material

Identified metaphorical expressions under this subdomain were observed to typically refer to space phenomena and entities as forms of physical material that can be shaped, formed, or even acted upon. For example:

(37) *When galaxies do collide, their overall* ***pattern of stars*** *[…].* (Educational textbooks)
(38) *[…] we are actually viewing two colliding galaxies, with then their mutual tidal interaction* ***warping*** *and disrupting whatever symmetric forms may have existed in the source galaxies.*
(39) *The* ***universe will be torn to shreds****.* (Popular science)
(40) *Most computer models of their orbits show a slow decay that ultimately results in the hapless dwarfs* ***getting ripped apart****, and then eaten, by the main galaxy.*
(41) *[…]* ***the Sun was a burning lump of coal.***

What can be noticed in the examples presented above, (37) and (38), which were identified in educational textbooks, both metaphorically describe the collision of galaxies. Example (37) suggests that the collective structure of stars is visualized as a flexible material, such as fabric, that can be molded or reshaped. Although stars do not collide by themselves, the metaphor here represents the construction of stars as something pliable. Similarly, in (38), *warping* describes galaxies as pliable materials, usually wood, that can bend or twist due to heat or water damage. In this case, the metaphor draws from its literal sense and is used here to describe tidal gravitational forces that change the shapes of colliding galaxies. Examples (39) and (40) metaphorically illustrate the destruction or the end of the universe (39) and a galaxy (40) in terms of a fragile material, such as fabric, that can be easily pulled apart or torn by physical force. Example (41) evokes a vivid comparison of the target to an Earth material, *coal* that we burn and which, in exchange, radiates heat and light. The *burning lump of coal* in this metaphorical expression refers to the Sun's nuclear model while describing it in a familiar, conventional way.

6.4.2. Other subdomains

As seen in Table 5, no subdomains within the source domain OBJECT contained more than ten metaphorical expressions. Moreover, in cases such as *ball, burst,* or *motion,* where the number of expressions ranged from four to six, separate analysis of each is unnecessary, as in these and other cases, the metaphorical expressions tend to repeat. Thus, a general overview of several subdomains will be provided.

In both educational textbooks and popular science genres, it was observed that targets such as *space regions, energy, mass*, and *gravitational field* were metaphorically linked to a ball:

(42) *[...] when the universe was basically one* ***big all-encompassing fireball*** *[...].* (Popular science)
(43) *In terms of Einstein's General Theory of Relativity, mass acts to bend space and time, much the way* ***a bowling ball bends the surface of a trampoline.*** (Educational textbooks)

In the example (42), the *fireball* represents the early stage of the universe in the sense of a vivid object that projects intense heat and light, simplifying metaphorically the idea of a dense and hot early universe by likening it to a burning ball. In (43), the target domain *mass* is represented as a *bowling ball*, metaphorically conceptualizing the curvature of spacetime caused by *mass*.

Another interesting subdomain observed only within the genre of university textbooks is *telephone*. In this case, the target (abstract concept of scaling) was linked to the structured sequence of a phone number:

(44) *As a mneumonic, this is cast as a 10-digit* ***"telephone number,"*** *with the 3-digit "****area code****" representing the three steps of 10−5 from us down to the nucleus, and* ***7-digit main-number*** *representing seven key steps to the scale of the universe*.

In this single example (45), three metaphorical expressions are embedded in one sentence: *telephone number, area code*, and *main number,* all serving as metaphors to describe different levels of scaling in the universe.

6.5. The source domain of FOOD

Food and the cosmos may initially seem as two rather incompatible domains, unlikely to intersect when describing space-related targets. However, this source domain revealed forty-one metaphorical expressions, which, while not as prevalent as in other domains discussed earlier, present an interesting case due to their dominance within a single genre (popular science), while drawing on type-to-token ration, and still featuring more than ten subdomains with more than half of them having two and more expressions.

Table 6. Frequency of subdomains identified across genres in the source domain FOOD

Subdomain	*Popular science*	*Educational textbooks*	*Total*
Cake	1	-	1
Cannibalism	2	-	2
Consumption	3	-	3
Drinking	3	-	3
Grape/raisin	1	-	1
Last meal	1	-	1
Leftovers	1	-	1
Meal	5	-	5
Milk	1	-	1
Pastry	5	-	5
Pot	1	-	1
Recipe	2	1	3
Swallowing	14	-	14

6.5.1. General analysis

As we can see in Table 6, the most predominant metaphorical expressions were those under the subdomain of *swallowing*. While its basic meaning refers to the act of ingesting food through the mouth, in all identified metaphorical expressions it is figuratively applied to target domains: *space objects*, *forces, matter*, and *particles* to explain astronomical processes that involve one object obliterating the other. The expressions were categorized under the domain of food due to their focus on the act of food intake itself. For example:

(45) ***Dying star swallows** an entire planet.*
(46) *Atoms are pulverised: **protons swallow electrons** […].*

Nevertheless, all identified expressions (see Appendix 2) are ambiguous, as these metaphors could also alternatively be interpreted through the source domain of a LIVING BEING, with the target personified as the performer of the swallowing action.

Most metaphorical expressions within this domain, as the name itself implies, were mainly relating to different types of foods such as desserts, soups, berries, drinks, or even human meat:

(47) *No Big Crunch is required for a **doughnut universe**; we just ride back through the centre for another go around.*
(48) *The neutrons in the core might be pulverised and converted into **a soup of free quarks** with incredibly high density.*
(49) ***The Milky Way engaged in at least one act of cannibalism** in the last billion years, when it consumed a dwarf galaxy […]*

Example (47) compares the universe’s shape to a pastry. Across all cases, several such metaphorical expressions were identified throughout different articles. What is more interesting is that science communicators have widely used the doughnut comparison to describe the universe's shape in a vivid imaginary comparison. In example (48), *soup* metaphorically describes quark-gluon plasma (a dense and high-energy state of matter) by evoking the image of a fluid-like substance. Lastly, in example (49), we can see how the metaphor of *cannibalism*, which refers to the consumption of human flesh, depicts the event of galaxy merging.

6.6. Other source domains

Despite discussing only four source domains in the subchapters above, many others were identified (see Table 1). For instance, source domains such as CONTAINER, FORCE, SUPERNATURAL PHENOMENON, or NATURAL PHENOMENON were distinguished as the most prevalent domains in all three genres. However, they were not chosen for the analysis because the metaphorical expressions identified referred to already conventionalized scientific terminology. For example, in the source domain NATURAL PHENOMENON out of one hundred forty-five metaphorical expressions identified across all genres, 24.82% referred to *molecular clouds*, 21.37% to *solar wind*, corresponding to almost half of all cases. In the case of FORCE and CONTAINER, more than half of all identified cases in both source domains included a conventionalized term, *Big Bang* (FORCE) and *black hole* (CONTAINER), thus making it prevalent but repetitive. Therefore, due to these identified source domains relying heavily on a few frequently repetitive conventionalized metaphorical terminologies, results indicate a low type-to to-token ratio which affects both lexical variety and novelty of expressions within these domains despite the overall high number of tokens.

Furthermore, frequency-wise, other source domains had fewer than 40 metaphorical expressions each, the majority having fewer than twelve. What is more, in such cases, the source domain was usually identified between two or solely in a single sub-corpus. As these source domains were considered more precise and unique than others, more prevalent ones, they may also be seen to include more interesting and unique cases that make them unique both in relation to the analyzed domain of space science and in their prevalence of being creative or conventional.

6.7. Creative and conventional metaphors: meanings and ratio

Following the research objectives, one of the main aspects, in addition to discussing source domains, has been categorizing identified metaphorical expressions as either creative or conventional, based on their novelty and degree of familiarity in language. As mentioned before, metaphorical expressions were categorized as creative if they were seen to introduce unusual comparisons and mappings, usually single instances, with no dictionary entries found. On the other hand, expressions were marked as conventional if they were seen to reflect well-established metaphorical patterns and had entries either in general or space science-specialized dictionaries. The distinction between creative and conventional metaphors was important in this study as it helped to see how well-distributed they are across three genres, while looking at where they are most and where and least prevalent. Also, it deepened the understanding of their role in describing scientific phenomena or reshaping the existing structures and communicative functions.

As seen in Table 2 in Section 6 (see p. 27), both creative and conventional metaphors were identified across all three genres. Out of twenty-six identified source domains, eighteen contained at least one creative metaphorical expression, while twenty-four had one or more conventional metaphors in at least one genre. Overall, conventional metaphors were significantly more prevalent, with 960 (82.83%) tokens compared to creative metaphors that in total were identified in 199 (17.16%) instances. Moreover, while conducting the analysis, it was noticed that the distribution of creative metaphors is highly different across all genres. As seen in Figure 1, most identified creative expressions (71% of all instances) were found in the popular science genre, while the fewest tokens were found in academic journals.

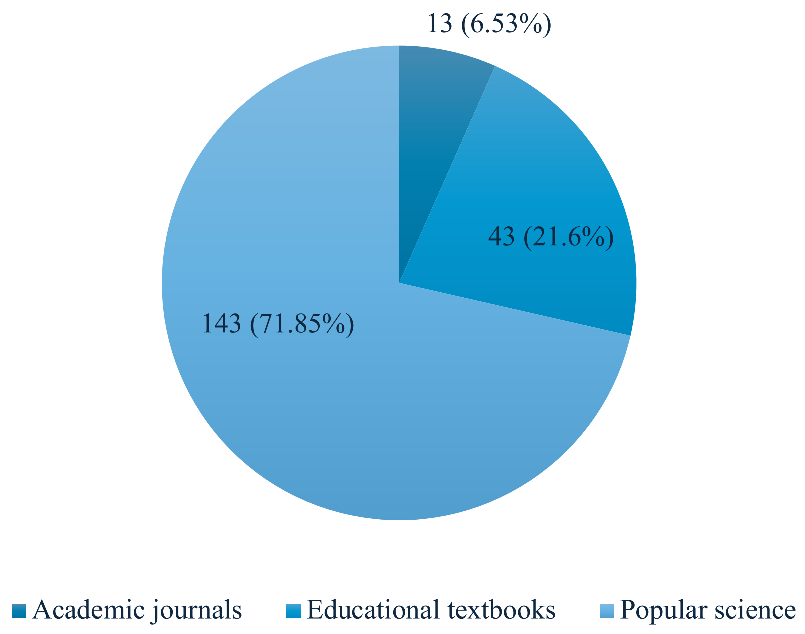

Figure 1. Distribution of creative metaphors across all genres

Such radical differences in ratios raise questions about the contributing factors for this type of distribution. Starting from the academic journal genre, the low number of creative metaphorical expressions can be explained while considering both the genre's technicality and the discourse of space sciences itself. The language used by scholars in academic journal articles is highly technical. It includes not only words but also many numbers, formulas, and symbols that may cover a large part of the whole article. Thus, using numbers alone can already be seen as a great contributor to the expulsion of creativity from the text. However, another disadvantage for the appearance of creative metaphors in such a genre is the use of technical, well-established, and genre-specific language, which usually does not require further explanations or interpretations, as the reader base consists primarily of field specialists. Regarding university-level textbooks, the number of creative expressions is also relatively scarce. However, while conducting the analysis, it was seen that in educational textbooks, creative metaphorical expressions usually appear when the discussed concept, process, or phenomenon is being mentioned for the very first time, thus trying to familiarize the reader before moving to more complex field-specific terminology. This shows that creative metaphors are used perform an explanatory function. Lastly, the popular science genre is primarily geared towards non-specialist audiences with no or minimal background knowledge in the scientific field they are reading about. Because of this reason, the usage of complex terminology will most likely cause confusion that can affect the reader's attention and desire to continue their engagement with the text. Therefore, creative metaphors play an important role as they are seen to be used in concept-explanatory contexts to create vivid comparisons of complex phenomena in everyday terms, this way, making the reader comprehend the provided information better and allowing them to stay engaged with the material, making it a fun way for science learning.

The following sections discuss creative and conventional metaphors separately, analyzing their function and meanings across all three genres.

6.7.1. Conventional metaphors

In the case of conventional metaphors, the university-level textbooks genre was found to be the most dominant. However, the difference in conventional metaphorical expressions identified between popular science and educational textbooks is only eleven tokens. Regarding conventional metaphors, the most prevalent source domains in the number of expressions were CONTAINER, NATURAL PHENOMENON, SUPERNATURAL PHENOMENON, previously discussed LIVING BEING, and FOOD.

One of the main reasons for the gap between the number of conventional and creative metaphorical expressions identified is the amount of conventionalized scientific terminology used by authors within the analyzed texts. Such metaphors typically go unnoticed by both field-specialists and non-specialist audiences as their metaphorical origin has been conventionalized over time. These include terms such as *spiral arms, black hole, solar wind, Big Bang, wormhole, molecular clouds, dwarfs, giants, switchback,* etc., that were noticed to reappear consistently across all genres.

In other instances, conventional metaphorical expressions, even if they did not describe scientific terminology, were categorized as conventional due to their frequent reoccurrence as they were noticed to appear in similar contexts, with consistent meanings across genres. Metaphorical expressions were categorized under the source domain LIQUID, if the target domain was represented in terms of liquids themselves, states, or processes related to liquids. Educational textbooks and popular science sub-corpora both had metaphorical expressions that related black holes' gradual loss of mass to the evaporation:

(50) *In one googol years (a one followed by a hundred zeros),* ***the last of the black holes will evaporate.*** (Popular science)
(51) *The final stage of a* ***black hole's evaporation*** *proceeds extremely rapidly [...].* (Educational textbooks)

These examples are considered conventional as they rely heavily on a familiar conceptual mapping between *evaporation* (the basic meaning describing the liquid turning to gas) and the loss of mass, which has become entrenched in scientific communication. What is more, the metaphorical expressions have been categorized as conventional as they were identified in two different genres, with articles written by different authors and published at different times.

Another instance identified in the source domain LIQUID is *stream*:

(52) *A* ***stream of fast wind*** *passes by both spacecraft during this conjunction.*
(53) *Traveling up to a thousand miles per second, these p****articles stream through space*** *and are deflected by planetary magnetic fields.*

While the basic meaning of *stream*, in dictionaries, refers to a flow of water and narrow rivers, it also has a well-established meaning that extends metaphorically to describe the flow of things (Cambridge Dictionary 2025). Thus, both instances are considered conventional as they draw from the widely recognized mapping of fluid motion onto abstract scientific phenomena.

Another rather interesting source domain where most metaphorical expressions were identified as conventional was CONFLICT. Here, it was noticed that many of the identified metaphorical expressions across genres corresponded to such actions as *hitting, capturing, resisting, shielding, taking over*, *protecting,* or items like weapons while describing target domains:

(54) *Indeed,* ***astronomers already have a target – the extremely remote object WHL0137-LS*** *[…].* (Popular science)
(55) *HATS-18, with its giant planet, is the most promising* ***target*** *among the remaining systems […].* (Academic articles)
(56) ***Jupiter acts as a gravitational shield*** *for Earth […].* (Popular science)

Examples (54) and (55) both present the *target*, basic meaning associating with aiming or shooting, is applied to cosmic objects that are under observation or a focus on. In example (56), the *shield*, basic dictionary meaning associated with military or police equipment, describes a space object acting as a shield itself. We cannot consider it creative, as *shield* is also described in dictionaries as something that can serve as a protective field.

The analysis of conventional metaphors across the space science discourse shows that they are the most predominant and are usually identified as conventionalized scientific terms that recur across articles, thus resulting in a high frequency of identified expressions. Such metaphorical expressions typically go unnoticed for readers due to their well-established usage and repetition across articles within the same or, in many cases, other genres as well. Thus, their usage can be considered to play an essential role in establishing stable scientific communication patterns.

6.7.2. Creative metaphors

Creative metaphors were seen to have dominated in the popular science genre, where a variety of complex terminology, processes, and other concepts were made more accessible to readers while interpreting them through more familiar concepts expressed in a metaphorical sense. Such metaphors often occurred once or were seen to be repeated sparingly by the same author, thus emphasizing their uniqueness. The analysis revealed a couple of source domains, such as FACTORY (popular science) and JEWELRY (academic articles), where only creative metaphors were identified. However, the prominence of creative metaphors was not seen to be more apparent within source domains that were genre-unique and scarce in the amount of identified metaphorical expressions, as initially thought, as the majority of creative metaphors were identified within source domains with forty or more expressions.

In many cases, it was noticed that creative metaphors served to dramatize or humanize space objects, cosmic events, and others. Such instances were noticed in the source domain

ENTERTAINMENT where target domains were represented in terms of gambling, music, dancing, art, and show:

(57) *These three, plus gravity, complete the* ***fab four forces of the universe*** *[…].*
(58) *[…] CMB looks ever so slightly blotchy, as if someone did an abstract* ***pointillism painting*** *on the sky with a brush […].*
(59) *[…] as the ageing star starting to expand until it reached an unfortunate planet that then became involved in a month-long* ***destructive dance*** *with the star.*
(60) *A long time ago in a dwarf galaxy far, far away,* ***a drama of cosmic dimensions is unfolding.***

Starting from example (57), here the fundamental forces of the universe are being described in accordance with the nickname *Fab Four* that was given to the band The Beatles, in this way comparing the importance of the forces to the pop culture icons. Example (56) illustrates cosmic background radiation as an art technique with images made of small dots, thus helping the reader to comprehend scientific data through another domain. However, when the author compares scientific phenomena to a term from another specific domain, it may cause further confusion rather than clarity, as it requires the reader to be acquainted with the art scene to depict the meaning of such metaphorical comparison. What can be seen in the example (59) is a personification of, in this case, the interaction between a star and a planet as a synchronized but somewhat chaotic and harmful event, while using *dance* to describe the movement of cosmic bodies. Example (60) can be seen to rise from the theatre subdomain to frame cosmic events as performances that unfold in front of an audience.

Other interesting cases of creative metaphors were noticed across the already analysed source domain of LIVING BEING across all three genres, where objects, events, processes, and others:

(61) *He also proposed an evolutionary interpretation that was going from ellipticals contracting and becoming spirals according to the* ***"ballerina" effects.*** (Educational textbooks)
(62) *If J should exceed this value, one would have a gravitational field with a "****naked****" singularity (i.e., a singularity not* ***"clothed" by an event horizon****).* (Educational textbooks)
(63) *In fact, observations of clusters detect just such a glow between the galaxies, suggesting that there may be as many* ***vagabond, homeless stars*** *as there are stars within the galaxies themselves.* (Popular science)
(64) *So* ***dark matter is our frenemy.*** *(Popular science)*

In example (61), we can see that a galaxy's movement is being anthropomorphized in the imagery of a graceful dancer who spins faster as her arms are drawn out. Furthermore, in examples (62) and (63), each sentence has two metaphorical expressions in it (categorized and analysed separately while conducting the initial analysis) and can be further seen to refer to humans. In the example. (62) *naked* and *clothed* refers metaphorically to singularity as an individual by suggesting both vulnerability and exposure as well as coverage. On the other hand, example (63) compares stars and homeless individuals, metaphorically referring to stars without permanent placement within a cluster or those that have drifted away. Example (64) is creative as it assigns human relationships to dark matter, emphasizing its double role as both a necessity and a mystery of the universe. What is also interesting is that in the examples. (61) and (62), taken from educational textbooks, metaphorical expressions are singled out by quotation marks, this way emphasizing their figurativeness and uniqueness within the space science discourse. Usage of quotation marks to single out a metaphorical expression has also been noticed in several other cases, both across academic journals and popular science genres.

Now, looking into extremely scarce source domains, let's investigate FACTORY and JEWELRY, which, as mentioned at the beginning of this subchapter, had only creative expressions identified, thus reflecting highly individual author choices:

(65) *Images of* ***dwarf galaxies that no longer manufacture stars*** *tend to look like tiny, boring smudges.*
(66) *It's hard to believe that* ***the universe would manufacture*** *six times as much mass in planets as in stars.*
(67) *HST images with equivalence to the R band [...] revealed a* ***necklace of such hot spots****, nearly filling a lighted ring.*

In examples (65) and (66), *manufacture*, which is generally associated with industrial production and human labour, is applied creatively to the formation of cosmic objects, as if framing the universe as a factory. It brings a sense of mechanical process and productivity to abstract cosmic events. Example (67), drawn from the JEWELRY domain, likens the circular arrangement of hot spots to a necklace.

Across all described and other identified cases, such figurative language does not derive from established scientific lexicon. Instead, it offers vivid imagery that helps readers to visualize or engage with various cosmic phenomena. This communicative strategy becomes particularly important in space sciences that rely heavily on highly technical and complex language, including specialized terminology, to describe a wide range of phenomena, calculations, or processes. As a result, general audiences and at times university students, who may still be developing their understanding in the field, can find it challenging to grasp the material thoroughly. Thus, creative metaphors can serve a crucial function of simplifying complex issues (Charteris-Black's 2014: 248) while using more familiar everyday language instead of complex terminology, thus allowing readers to comprehend difficult subjects and issues without extensive field knowledge. What is more, following Charteris-Black (2014: 248), they may help to grab the reader's attention, thus making the text not only easily understandable but also attractive.

Conclusions

This research examined the usage of creative and conventional metaphors across genres of academic journals, educational textbooks, and popular science. Following the objectives, the study identified the most frequent source domains across all three genres by identifying metaphorical expressions. Afterwards, the development of identified source domains was analyzed in connection with their subdomains. Lastly, identified metaphorical expressions were studied in terms of their creativity and conventionality as well as their functions within the expressions themselves. Therefore, in accordance with the aim and objectives of this research, and the conducted analysis, the following conclusions were drawn:

(1) After analyzing all three sub-corpora, twenty-six source domains were identified, with twenty-two identified in popular science literature, nineteen in university-level textbooks, and seventeen in academic journal genre. One of the most metaphor-rich source domains in all three genres was a LIVING BEING (333 tokens). Other prevailing source domains in the academic journals' genre were CONTAINER (60 tokens) and NATURAL PHENOMENON (45 tokens). Popular science literature was noticed to perceive more metaphorical expressions in such source domains as FORCE (83 tokens) and SUPERNATURAL PHENOMENON (50 tokens). Lastly, in the university-level textbooks genre, apart from LIVING BEING, another frequent source domain was CONTAINER (139 tokens). Overall, across all three genres, the most prevailing source domains in the number of identified metaphorical expressions (more than 100) were LIVING BEING (333 tokens), CONTAINER (201 tokens), and NATURAL PHENOMENON (110 tokens).

(2) It was noticed that each genre contained source domains unique only to one sub-corpus. Source domains COMPETITION, FACTORY, and SPORT were identified only in popular science, HUNT, and JEWELRY in academic journal articles, while GEOMETRY and HISTORY appeared in university-level textbooks. Each source domain had one to four metaphorical expressions identified, predominantly dominated by conventional rather than creative metaphorical expressions.

(3) In total, 1156 metaphorical expressions were identified across all three genres, with conventional metaphors identified in 83.04% of all cases, while creative metaphors appeared in 16.95% of all instances, with creative metaphors appearing the most in the popular science genre and conventional metaphors dominating in educational textbooks. These numbers indicate that the domain of space sciences, despite being metaphorical,

is predominantly dominated by conventional, rather than creative metaphors. However, it is essential to note that the number of conventional metaphors was highly influenced by conventionalized scientific terminology, such as *black hole, Big Bang, spiral arms, solar wind*, and many others that appeared across all three genres, thus adding to the total number of metaphorical expressions.

(4) The number of metaphorical expressions, both creative and conventional, can be concluded to depend on the genre, the type of text, and the author(s). Creative metaphors were scarcest in academic journals, concluding that academics tend to stay within the boundaries of technical language, as usually no explanations are needed, especially when discussing already familiar scientific phenomena, processes, or even space projects, as the reader base is typically expected to be skilled field professionals with enough field knowledge. What is interesting, despite educational textbooks also being scarce in the number of identified creative expressions, it was noticed, that usually such metaphorical expressions were identified at the beginnings of chapters or while explaining new concepts, this way familiarizing the reader with processes, phenomena, or a term before using concrete technical language afterwards such as moving from *birth* to *formation*. Popular science literature, as it focuses on non-specialist audiences, was seen to have used creative metaphors the most, both for concept-explanatory and innovative aspects, for example, comparing a bigger galaxy's mergence with a smaller one as *cannibalism.*

(5) The analysis revealed that creative metaphors perform several functions. Creative metaphors were used to simplify complex language in more familiar everyday terms, including descriptions of cosmic phenomena, objects, and processes. Moreover, it was noticed within the popular science genre that creative metaphors also help to gain the reader's attention while evoking vivid comparisons for abstract concepts, usually clearly distinguishable from the rest of the text.

Several limitations were identified while conducting this study. First of all, the size of each sub-corpus (including the number of texts collected across each genre) may not have fully captured the diversity of both creative and conventional metaphors and their source domains in space science discourse, thus only providing a general overview. Another limitation was noticed regarding the manual analysis of the sub-corpora. As each sub-corpus was read and manually analyzed only once, it is believed that some metaphorical expressions were not noticed, thus resulting in the current number of identified metaphorical expressions across each genre. Moreover, despite following a systematic procedure for metaphorical expression identification and categorization accordingly, as creative or conventional, the categorization had to involve interpretive judgment (for creative expressions) in some instances. Lastly, while conducting the analysis, ambiguous cases were identified where the same metaphorical expression presented properties applicable to several source domains (usually two), making it difficult in some instances to choose the most suitable domain. Nevertheless, as metaphorical expressions may be comprehended differently by each reader, such ambiguous cases were classified as accurately as possible based on basic dictionary meanings (if available) and personal judgment.

Future research regarding creative and conventional metaphors in space sciences could focus on further expanding the sub-corpus for each or a single genre to make a more contrastive analysis regarding the prevalence of source domains and diversity of both creative and conventional expressions. However, another possible approach could be an expanded analysis solely on creative metaphorical expressions across genres, or a genre, thus providing deeper insights regarding creativity. Moreover, a study regarding visual metaphors in space science discourse could be conducted. This is based on illustrative examples found in analyzed texts across all genres where the content of images was seen to merge with metaphorical language.

Kūrybinės ir konvencinės metaforos kosmoso srities moksluose

Santrauka

Summary in the Lithuanian language

Nesutarimai dėl metaforų naudojimo tiksliuosiuose moksluose daugelį metų skyrė mokslininkus į dvi stovyklas – vieni jas laikė būtinu elementu, kiti jas griežtai kritikavo, laikydami jas nenaudingomis ir neturinčiomis pagrindo tiksliųjų mokslų srityje. Nepaisant to, metaforos yra neatsiejama tiksliųjų mokslų, įskaitant ir kosmoso sritį, dalis, kadangi jos dažnai yra vartojamos atsitiktinai kaip mūsų kognityvinio mąstymo proceso rezultatas. Tinkamai perteiktos metaforinės raiškos gali padėti paaiškinti tiek naujas, tiek jau gerai išnagrinėtas idėjas naujai, tokiu būdu paverčiant, pavyzdžiui, skaitomą turinį artimesniu platesnei visuomenės daliai neturinčiai bazinių mokslinių žinių, šiuo atveju kosmoso srities moksluose.

Šio darbo tikslas - ištirti kūrybinių ir konvencinių metaforų paplitimą trijuose žanruose: moksliniuose straipsniuose, universitetiniuose mokomuosiuose vadovėliuose, bei populiariojoje mokslinėje literatūroje. Šiuo darbu taip pat yra siekiama nustatyti kurios šaltinio sritys (angl. *source domains*), yra dažniausiai identifikuojamos kosmoso srities moksliniuose leidiniuose, lyginant ar jos yra aptinkamos visuose ar būdingos tik konkrečiam žanrui. Tyrimui atilki buvo sudaryti trys tekstynai pagal žanrą, kiekvienas iš jų 50 000 iki 52 000 žodžių. Tyrimo metu buvo taikoma kiekybinė ir kokybinė analizės. Siekiant atpažinti metaforinius pasakymus ir susiejant juos su šaltinių sritimis, buvo naudotas MIP (angl. *Metaphor Indentification Procedure*) metodas.

Rezultatai rodo, jog tiek kūrybinės, tiek konvencinės metaforos yra aptinkamos visuose trijuose pasirinktuose žanruose. Kūrybinės metaforos vyravo populiariojoje mokslo literatūroje, o konvencinės dominavo universitetiniuose mokomuosiuose vadovėliuose. Detalesnė analizė parodė, kad dažniausiai pasitaikančios šaltinio sritys buvo LIVING BEING, CONTAINER ir NATURAL PHENOMENON, kiekvienoje iš jų fiksuojant daugiau nei po šimtą metaforinių pasakymų. Tyrimo eigoje kiekviename žanre buvo identifikuoti kiekvienam jų unikalios šaltinio srityse, nepasitaikiusios jokiame kitame žanre. Tyrimas parodė, jog konvencinės metaforos kosmoso srities moksliniuose tekstuose užtikrina aiškumą ir nuoseklumą, ir dažniausiai pasitaikė perteikiant jau įsigalėjusią mokslinę terminologiją. Kūrybinės metaforos buvo pastebėtos naudojamos norint patraukti skaitytojo dėmesį ir bandant perteikti sudėtingus terminus, idėjas ir, procesus labiau suprantama kalba.

Data sources

Bouchet, P. *et al.* 2024. JWST MIRI Imager Observations of Supernova SN 1987A. *The Astrophysical Journal*, 965(1), pp.51–51. doi:https://doi.org/10.3847/1538-4357/ad2770.

Carroll, B.W. and Ostlie, D.A. 2017. *An Introduction to Modern Astrophysics*. Cambridge University Press.

Dayal, P. 2024. Exploring a primordial solution for early black holes detected with JWST. *Astronomy and Astrophysics*, 690, pp.A182–A182. doi:https://doi.org/10.1051/0004-6361/202451481.

Ferrari, A. 2024. *Fundamentals of Astrophysics*. Springer Nature.

Maciejewski, G. *et al.* 2024. "Planet-star interactions with precise transit timing. IV. Probing the regime of dynamical tides for GK host stars". *Astronomy and Astrophysics*. doi:https://doi.org/10.1051/0004-6361/202452101.

Mack, K. (2020). *The end of everything : (astrophysically speaking)*. New York: Scribner.

Neil Degrasse, T. 2017. *Astrophysics for People in a Hurry*. New York: W.W. Norton & Company.

Owocki, S. 2021. *Fundamentals of Astrophysics*. Cambridge, United Kingdom; New York, Ny: Cambridge University Press.

Rezaei, K. *et al.* 2024. "3D structure of the Milky Way out to 10 kpc from the Sun". *Astronomy & Astrophysics*. https://doi.org/10.1051/0004-6361/202449255

Rivera, Y.J. *et al.* 2024. "In situ observations of large-amplitude Alfvén waves heating and accelerating the solar wind". *Science*, 385/6712: 962–966. doi: 10.1126/science.adk695

Taysum, B. *et al.* 2024. "Detectability of biosignatures in warm, water-rich atmospheres". *Astronomy and Astrophysics*. 692. https://doi.org/10.1051/0004-6361/202450549

Wells, A. *et al.* 2024. Dynamical accretion flows. ALMAGAL: Flows along filamentary structures in high-mass star-forming clusters. *Astronomy and Astrophysics*, 690, pp.A185–A185. doi:https://doi.org/10.1051/0004-6361/202449794.

Wolfgang, D. 2024. *Astrophysics*. Springer.

Zezas, A. & V., Buat. 2021. *Star-Formation Rates of Galaxies*. Cambridge University Press.

Science Illustrated. 2022. *Science Illustrated*, Issue 93, pp. 16, 18-19.

Science Illustrated. 2022. *Science Illustrated*, Issue 94, pp. 44-47.

Science Illustrated. 2022. *Science Illustrated*, Issue 95, pp. 48-53.

Science Illustrated. 2022. *Science Illustrated*, Issue 96, p. 34.

Science Illustrated. 2023. *Science Illustrated*, Issue 97, p. 12, 58

Science Illustrated. 2023. *Science Illustrated*, Issue 100, pp. 10-11, 28-35.

Science Illustrated. 2023. *Science Illustrated*, Issue 101, pp. 22-23, 26-31.

Science Illustrated. 2023. *Science Illustrated*, Issue 102, pp. 10-11, 66-69.

Science Illustrated. 2023. *Science Illustrated*, Issue 103, pp. 80-81.

Science Illustrated. 2024. *Science Illustrated*, Issue 104, pp. 30–39.

Science Illustrated. 2024. *Science Illustrated*, Issue 106, pp. 6-7, 10-12, 18-19, 36-41.

Science Illustrated. 2024. *Science Illustrated*, Issue 107, pp. 18, 54-59.

Science Illustrated. 2024. *Science Illustrated*, Issue 108, pp. 14, 17.

Science Illustrated. 2024. *Science Illustrated*, Issue 109, pp. 70-73.

Science Illustrated. 2024. *Science Illustrated*, Issue 110, pp. 6-7, 18, 26-33.

Science Illustrated. 2024. *Science Illustrated*, Issue 111, p. 12.

References

Afonso, A. S. & S. Afonso. 2021. “Conceptual Metaphors in Astronomers’ Discourses”, *Discourse and Argumentation in Science Education*, pp. 516-521.

Agnes, A. 2009. “The use of Metaphors in Advertising. A case study of Advertisements in Cosmopolitan”. *Argumentum* 5: 18-24.

Ahrens, K. 2009. Analysing Conceptual Metaphors in Political Language, in Ahrens, K. (eds.). *Politics, Gender and Conceptual Metaphors*. Palgrave Macmillan: London.

Akimtseva, Y. V. 2020. “Conceptual metaphor as a method of forming stereotypical images in English media discourse”, *Professional Discourse & Communication*, 2/3: 45-64.

Beger, A. and Smith, T.H. 2020. How metaphors guide, teach and popularize science. Amsterdam: John Benjamins Publishing Company.

Black, M. 1955. “Metaphor”. *Proceedings of the Aristotelian Society* 55: 273–294.

Bowdle, B. F. & D. Gentner. 2005. The Career of Metaphor, *Psychological Review* 112:1, 193-216. DOI: 10.1037/0033-295X.112.1.193

Butcher, S.H. 1902. *The Poetics of Aristotle.* London: Macmillan and Co.

Caldarola, P. 2023. *Translating Popular Astronomy and Astrophysics. A chapter from Astrophysics: A Very Short Introduction*. PhD dissertation. University of Padova.

Cardillo, E. R. *et al.* 2012. From Novel to Familiar: Tuning the Brain for Metaphors, *Neuro Image*, 59: 3212-3221. DOI: 10.1016/j.neuroimage.2011.11.079

Chahbane, K. & H. Zrizi. 2023. “Language and Politics: Framing the Use of Conceptual Metaphors in Political Discourse”, *International Journal of Linguistics, Literature and Translation,* 6/11: 114-119. doi:10.32996/ijllt.2023.6.11.15

Charteris-Black, J. 2018. *Analysing Political Speeches : Rhetoric, Discourse and Metaphor. 2nd ed.* London: Palgrave.

Cibulskienė, Jurga. 2005 "Konceptualioji Kelio Metafora Lietuvos Rinkimų Diskurse." *Kalbotyra: Mokslo Darbai*, 55: 51-64.

Cienki, A. 2008. The application of conceptual metaphor theory to political discourse: Methodological questions and some possible solutions, in Carver, T, & and J. Pikalo (eds.). *Political Language and Metaphor.* Routledge Taylor & Francis Group.

Demjen, Z., E. Semino & V. Koller. 2016. “Metaphors for ‘good’ and ‘bad’ deaths
A health professional view”. *Metaphor and the Social World*, 6/1: 1-19. doi: https://doi.org/10.1075/msw.6.1.01dem

Devetak, I. & Vogrinc, J. 2013. “The Criteria for Evaluating the Quality of the Science Textbooks”, in: Khine, M. (ed.) *Critical Analysis of Science Textbooks*. Dordrecht: Springer.

Dunér, D. 2015. Conceptual Metaphors of Science Prolegomena to a Cognitive History of Science. *Journal of Foreign Language Teaching and Applied Linguistics*, 2(2). https://doi.org/10.14706/jfltal15225.

Falkner, D. 2016. “Metaphors of Life: Reflections on Metaphors in the Debate on Synthetic Biology”, in: Hagen, K., Engelhard, M., Toepfer, G. (ed.) *Ambivalences of Creating Life. Ethics of Science and Technology Assessment*. Springer.

Gadeikytė, I. 2023. *Conceptual metaphors in English and Lithuanian hotel advertisements*. BA dissertation. Mykolas Romeris University.

Grice, H. P. 1975. Logic and Conversation, in: P. Cole & J. L. Morgan (ed.), *Syntax and Semantics, Volume 3: Speech Acts*. New York: Academic Press.

Grubic, T. 2022. “Metaphor and theory: a case study of astronomy”, *Prometheus*, 38/3: :310-334. doi: 10.13169/prometheus.38.3.0310

Haack, Susan. 2019. “The Art of Scientific Metaphors”, *Revista Portuguesa de Filosofia*, 75:4, 2049-2066. doi: 10.17990/RPF/2019_75_4_2049

Huguet Cabot, P. L. *et al.* 2020. “The Pragmatics behind Politics: Modelling Metaphor, Framing and Emotion in Political Discourse”, *Findings of the Association for Computational Linguistics.*

Johnson, M.L. 2007. Mind, Metaphor, Law. *Mercer law review*, 58(3), p.4.

Joseph Edward Grady 1997. *Foundations of meaning: primary metaphors and primary scenes*. Berkeley, Calif. University Of California At Berkeley.

Knudsen, S. 2003. “Scientific metaphors going public”, *Journal of Pragmatics*, 35: 1247-1263. doi: 10.1016/S0378-2166(02)00187-X.

Kramar, N. & O. Ilchenko. 2021. “From intriguing to misleading: The ambivalent role of metaphor in modern astrophysical and cosmological terminology”, *Amazonia Investiga*, 10/46: 92-100. doi: 10.34069/AI/2021.46.10.8

Kövecses, Z. 2002. *Metaphor: A Practical Introduction.* Oxford: Oxford University Press.

Kövecses, Z. 2017. Conceptual Metaphor Theory, in: E. Semino & Z. Demjen (ed.) *The Routledge Handbook of Metaphor and Language*. New York: Routledge.

Kuhn, T. S., 1979. Metaphor in Science, in: A. Ortony (ed.) *Metaphor and Thought*. Cambridge: Cambridge University Press.

Kövecses, Z. 2017. Standard and Extended Conceptual Metaphor Theory, in X. Wen & J. R. Taylor (ed.) *The Routledge Handbook of Cognitive Linguistics*. New York: Routledge.

Lakoff, G. 1993. The Contemporary Theory of Metaphor, in: A. Ortony (eds) *Metaphors and Thought*, 2nd ed. Cambridge: Cambridge University Press.

Lakoff, G. & M. Johnson. 1980/2003. *Metaphors We Live By.* Chicago: The University Chicago Press.

Lancor, R. 2014. “Using Metaphor Theory to Examine Conceptions of Energy in Biology, Chemistry, and Physics”, *Sci & Educ*, 23, 1245-1267. DOI 10.1007/s11191-012-9535-8

Littlemore, J. 2019. *Metaphors in the Mind: Sources of Variation in Embodied Metaphor*. Ch. 8. Cambridge: Cambridge University Press.

Lloyd, H.A. 2016. Law as Trope: Framing and Evaluating Conceptual Metaphors. *SSRN Electronic Journal*. doi:https://doi.org/10.2139/ssrn.2716683.

Ljubica, K. 2023. Metaphors Lawyers Live by. *International Journal for the Semiotics of Law - Revue internationale de Sémiotique juridique*, 36(4), pp.1639–1654. doi:https://doi.org/10.1007/s11196-023-09975-0.

Maasen, S. 1995. Who is Afraid of Metaphors? *Springer eBooks*, pp.11–35. https://doi.org/10.1007/978-94-011-0673-3_2.

McCool, M. 2008. “The universe in a single atom: communicating astronomy through metaphor”, *CAP Journal*, 4: 14-15.

Merakchi, K. 2020. *The translation of metaphors in popular science from English into Arabic in the domain of astronomy and astrophysics*. PhD thesis. University of Surrey.

Mitton, S. 2011. *Fred Hoyle: A life in science*. Cambridge University Press.

Mitton, J. 2007. *Cambridge Illustrated Dictionary of Astronomy*. Cambridge: Cambridge University Press.

Nature Education. 2014. *Scientific Papers | Learn Science at Scitable*. Nature.com Available at: https://www.nature.com/scitable/topicpage/scientific-papers-13815490/. [Accessed 15 January 2025].

Owocki, S. 2021. *Fundamentals of astrophysics*. Cambridge University Press.

Palma, H. A. 2018. "Metaphors in Science: A Change of Perspective" in: *Philosophical Perceptions on Logic and Order*. Hershey: IGI Global.

Pérez-Sobrino, P. *et al.* 2022. Acting Like a Hedgehog in Time of Pandemic: Metaphorical Creativity in the #reframecovid Collection, *Metaphor and Symbol*, 37:2, 127-139. DOI: https://doi.org/10.1080/10926488.2021.1949599

Philip, G. 2017. "Conventional and Novel Metaphors in Language" in: *The Routledge Book of Metaphor and Language*. New York: Routledge. 219-232.

Pragglejaz Group. 2007. "MIP: A Method for Identifying Metaphorically Used Words in Discourse". *Metaphor and Symbol*, 22/1: 1–39. https://doi.org/10.1080/10926480709336752.

Pulaczewska, H. 2011. *Aspects of Metaphor in Physics*. Max Niemeyer Verlag: Tübingen.

Reddy, M. J. 1979. "The conduit metaphor: A case of frame conflict in our language about language" in: A. Ortony (ed), *Metaphor and Thought. 1st ed*. Cambridge: Cambridge University Press.

Richards, I. A. 1936. *The Philosophy of Rhetoric*. New York and London: Oxford University Press.

Ridpath, I. (eds) 2018. *Oxford Dictionary of Astronomy. 3rd edition.* Oxford: Oxford University Press.

Rossi, M.G. 2021. "Metaphors and Persuasion in Healthcare Communication". *Langages*, 222/2: 59–76. doi:https://doi.org/10.3917/lang.222.0059.

Selmistraitis, L, I. Gadeikytė & M. Krawiec. 2024. "Conceptual Metaphors in Narrative Advertisements for Places: A Comparative Study Between English and Lithuanian", *Journal of Narrative and Language Studies*, 12/24: 85-102. doi: 10.59045/nalans.2024.44.

Searle, J. 1979. "Metaphor", in: A. Ortony (ed), *Metaphor and Thought. 1st ed*. Cambridge: Cambridge University Press.

Semino, E & G, Steen. 2008. "Metaphor in literature" in: *The Cambridge Handbook of Metaphor and Thought*. Cambridge: Cambridge University Press. 212-231

Smetonienė, I. 2006. "Konceptualiosios metaforos reklamoje", *Kalbos aktualijos*, 8: 33-42.

Springer.com. 2023. *Writing a Textbook | Springer | Springer — International Publisher*. [Available at: https://www.springer.com/gp/authors-editors/book-authors-editors/your-publication-journey/writing-a-textbook?srsltid=AfmBOoqolihcmB9YqiZJTWpP9pKTJLBKmdUgd9fkRn1cD9_ZF1xN_riy [Accessed 15 January 2025].

Stojan, N. & S. N. Mijič. 2019. "Conceptual Metaphors in Political Discourse in Croatian, American, and Italian Newspapers", *Academic Journal of Interdisciplinary Studies*. 8:1, 69-76. doi: 10.2478/ajis-2019-0007.

Scharf, C. A. 2013. *In defense of metaphors in science writing. Scientific American*. blogs.scientificamerican.com/life-unbounded/in-defense-of-metaphors-in-science-writing/.

Steele R, J. Baird & B. Davies. 2022. "Using Metaphors to Make Research Findings Meaningful", *Canadian Journal of Nursing Research*. 54/2:99-100. doi:10.1177/08445621221085555

Šeškauskienė, I. 2022. *Metaphor in Legal Discourse*. Cambridge Scholars Publishing.

Taylor, C. & B.M. Dewsbury. 2018. On the Problem and Promise of Metaphor Use in Science and Science Communication. *Journal of Microbiology & Biology Education*, 19(1). doi:https://doi.org/10.1128/jmbe.v19i1.1538.

Tuan, L.T. (2010). "Metaphors in Advertising Discourse". *Studies in literature and language*, 1/6, pp.75–81.

Turner, S. & L. Littlemore. 2023. "Literal or Metaphorical? Conventional or Creative? Contested metaphoricity in intense emotional experiences", *Metaphor and the Social World*, 13:1, 37-58. DOI: https://doi.org/10.1075/msw.00028.tur

Veit, W. & M. Ney. 2021. "Metaphors in Arts and Science", *European Journal for Philosophy of Science*. 11:44, 1-24. doi: 10.1007/s13194-021-00351-y

Wang, X. and Tu, Y. 2018. "The conceptual metaphors in law—a case analysis of PRC Company Law". *International Journal of Legal Discourse*, 3/2, pp.269–285. doi:https://doi.org/10.1515/ijld-2018-2011.

Webb, S. 2013. "Popular science: Get the word out", *Nature*, 504: 177-179.

Wilson, J., & Hay, M. 2013. "Internal media, conceptual metaphors and minority cultural identities", *Ethnicities*, 13/1: 49-67 doi:10.1177/1468796812450279

Zhabotynska, S. 2018. "Images of Ukraine—EU relations in conceptual metaphors of Ukrainian mass media. Cognition, communication, discourse", *Series: Philology*, 17: 118-140.

Appendix 1. Tables

Table 3. Frequency of subdomains identified across genres in the source domain LIVING BEING

Subdomain	*Academic journals*	*Popular science*	*Educational textbooks*	*Total*
Accessorizing	-	-	1	1
Action	6	2	3	11
Adapting	-	-	1	1
Animal	-	9	14	14
Animal/plants	-	-	1	1
Appearance	-	1	-	1
Assistance	-	2	-	2
Attempt	-	1	-	1
Authority	2	-	-	2
Baldness	-	-	3	3
Ballerina	-	-	1	1
Behavior	1	1	-	2
Birth	1	22	11	34
Blame	-	1	-	1
Body changes	5	5	1	11
Body part	13	2	22	37
Candidate	-	-	1	1
Capturing	-	-	1	1
Carry	-	1	-	1
Cleaning	-	2	-	2
Communication	1	13	5	19
Concealment	-	-	1	1
Contribution	1	-	-	1
Controlling	-	6	-	6
Creation	-	-	2	2
Crime	-	1	-	1
Dead body	-	1	-	1
Death	-	2	2	4
Desirability	1	-	-	1
Destruction	1	-	-	1
Detection	-	1	-	1
Development	-	-	1	1
Disruption	-	-	1	1
Emotions	-	2	-	2
Endurance	-	1	-	1
Erasing	-	1	-	1
Escape	-	1	2	3
Exposure	-	-	3	3
Falling	-	1	1	2
Feeding	-	-	1	1
Gravitational pull	-	1	2	3
Group of people	1	1	3	5
Heartbeat	-	1	-	1
Helping	-	2	-	2
Hiding	-	1	-	1

Homelessness	-	3	-	3
Host	1	-	-	1
Injury	-	1	-	1
Learning	-	1	-	1
Life	-	4	7	11
Light	-	2	-	2
Looking	-	1	-	1
Meeting	-	1	-	1
Mental activities	1	10	3	14
Midwife	-	1	-	1
Movement	1	4	-	4
Natural process	1	-	-	1
Obtain	-	1	-	1
Odd	-	1	1	2
Owner	-	1	-	1
Passerby	-	-	1	1
Population	1	-	2	3
Possession	-	1	-	1
Protection	1	-	-	1
Record holder	-	1	-	1
Relationship	1	38	5	44
Residing	-	-	1	1
Revealing	-	3	-	3
Running away	2	2	-	4
Setting time	-	-	1	1
Sitting	-	1	-	1
Species	3	-	-	3
Suffering	-	-	1	1
Suicide	-	1	-	1
Support	-	2	-	2
Survival	2	1	-	3
Undersize	-	1	-	1
Unsteady movement	-	3	-	3
Visitation	-	1	-	1
Winning	-	1	-	1
Working	-	1	-	1

Table 5. Frequency of subdomains identified across genres in the source domain OBJECT

Subdomain	***Academic journals***	***Popular science***	***Educational textbooks***	***Total***
Accessories	-	1	1	2
Ball	-	2	4	6
Balloon	-	-	1	1
Books	1	-	-	1
Burst	-	-	5	5
Candle	-	-	1	1
Clothing	2	-	-	2
Clean slate	-	1	-	1
Cookware	1	-	-	1
Confinement	-	1	-	1
Crackle	-	-	1	1
Crunch	-	1	-	1
Covers	2	-	-	2
Decay	-	2	-	2
Edges	-	1	-	1
Expiration	-	1	-	1
Form	-	1	2	2
Handing in	-	1	-	1
Hourglass	1	-	-	1
Instruments	2	-	-	2
Manufacture	-	-	2	2
Mark	-	-	1	1
Material	-	6	2	8
Motion	-	2	2	4
Pattern	-	2	-	2
Physical property	-	-	1	1
Pinwheel	-	-	1	1
Pop	-	-	1	1
Resources	-	1	-	1
Rope	-	-	1	1
Shell	-	-	3	3
Shield	-	1	-	1
Sink	1	1	-	2
Telephone	-	-	4	4
Touchable	-	-	1	1
Vacuum	-	1	-	1
Window	-	-	1	1

Appendix 2. Metaphorical Expressions

The source domain of LIVING BEING

(1) *Even **robots would need to endure** millennia of space travel.*
(2) *But **feather-light micro-organisms** could get there in just 20 years.*
(3) *In as little as an Earth week they spread across almost all the exoplanet's surface – and now the **microbes start sending light signals** back to their creators on Earth.*
(4) ***Microbes send back light signals.***
(5) *Their integrated **receptors can scan** the environment so they can send messages about conditions back to Earth*
(6) *Their integrated receptors can scan the environment so t**hey can send messages** about conditions back to Earth*
(7) ***Microbes** sent to exoplanets can be designed to do the same, **signalling information about the local conditions**.*
(8) ***Genes control the spread**.*
(9) *Once the **microbes** are down on the surface of Proxima Centauri b, **their first task will be to survive** in the alien environment and reproduce.*
(10) *But then how can the **microbes send information** communicating their discoveries back to researchers on Earth?*
(11) *Similarly, **microbes on an exoplanet could jointly create light signal**s that contain information about the conditions their receptors are detecting.*
(12) ***Receptors check out** the environment.*
(13) *Any one of these **distant worlds might answer a fundamental question** – are we alone in the universe?*
(14) *So the **star wobbles** a bit.*
(15) *Based on how much **it wobbles** and the pattern of the wobble, it is possible to determine if there is one or more exoplanets, and to estimate their distance from the star.*
(16) *But the **numbers do encourage hope.***
(17) *Astronomers estimate that around 1% of the **planets might provide** suitable conditions for life.*
(18) *Data from the retired **Kepler Space Telescope held a treasure**.*
(19) *Many discoveries are not made the moment data arrives from a craft or telescope but are **teased out** possibly years later by new analysis techniques or even just a very determined researcher.*
(20) ***Gravity takes control.***
(21) ***Gravity then takes over**, contracting the universe.*
(22) *This led to the conclusion that the universe is expanding, with the now-common model of **galaxies sitting on the surface of a balloon** that is being inflated, so that the distance between all points increases, and the greater the initial distance, the faster the movement apart.*
(23) *Then they **asked the model to predict** the future of the universe.*
(24) *The **model predicted** that expansion will soon come to an end.*
(25) *The **universe is born again**.*
(26) *That is hot enough for all matter to evaporate into its basic constituents, **erasing all details** of galaxies and black holes – and of course any life – before a clean-slate universe begins expanding again after about one billion years.*

(27) *A Bounce or a doughnut would allow our* ***universe another go*** *– and raises the probability that this may not be its first time around.*

(28) *A Bounce or a doughnut would allow our universe another go – and raises the probability that t****his may not be its first time around.***

(29) *The* ***universe will die*** *of cold*

(30) *But in a 'Big Bounce' variation,* ***a new universe could be born****.*

(31) *The huge and hot gas winds may have formed after a galaxy had undergone a period of intense star formation in which* ***stars are born and then die,*** *exploding into violent supernovas.*

(32) ***LIVING UNIVERSE***

(33) *And now researchers from the University of Texas at Austin have introduced a groundbreaking new theory: the* ***Big Bang had a dark twin***

(34) *And crucially, astronomers can search for* ***the Big Bang's dark twin*** *using new telescopes.*

(35) *However, we still have no observations from the* ***birth of the universe*** *– the earliest data is from 380,000 years after the Big Bang – and it has never been possible to detect dark matter or to determine from what particles it may be built.*

(36) *Those earliest moments involved* ***such a short time that they defy analysis****, and there is nothing to compare it against*

(37) *"They are part of our* ***cosmic family tree****," says MIT astrophysicist Anna Frebel.*

(38) ***Space overtakes*** *the spacecraft.*

(39) *Exactly what is driving the expansion of space remains a mystery to astrophysicists; they have found no proof of the best hypothesis, which is that an unknown force referred to as* ***'dark energy' works in opposition to gravity.***

(40) ***The universe outgrows us.***

(41) *So the researchers believe they have found solid proof that matter eventually* ***plunges straight into a black hole.***

(42) *Just because galaxies are in your face, and just because* ***they would have us believe that nothing else matters,*** *the universe may nonetheless contain hard-to-detect things between the galaxies.*

(43) *This spiral galaxy, historically dubbed the Great Nebula in Andromeda, is a* ***somewhat more massive and luminous twin of the Milky Way.***

(44) *Aided by modern detectors, and modern theories, we have probed our cosmic countryside and revealed all manner of hard-to-detect things: dwarf galaxies, runaway stars,* ***runaway stars*** *that explode, million-degree X-ray-emitting gas, dark matter, faint blue galaxies, ubiquitous gas clouds, super-duper high-energy charged particles, and the mysterious quantum vacuum energy.*

(45) *Aided by modern detectors, and modern theories, we have probed our cosmic countryside and revealed all manner of hard-to-detect things: dwarf galaxies,* ***runaway stars****, runaway stars that explode, million-degree X-ray-emitting gas, dark matter, faint blue galaxies, ubiquitous gas clouds, super-duper high-energy charged particles, and the mysterious quantum vacuum energy.*

(46) *Those dwarfs that do form stars are all irregularly shaped and, quite frankly, are a* ***sorry-looking lot.***

(47) *Dwarf galaxies have three things working against their detection: They are small, and so are easily passed over when* ***seductive spiral galaxies*** *vie for your attention.*

(48) *Dwarf galaxies have three things working against their detection: They are small, and so are easily passed over when seductive spiral galaxies* ***vie for your attention.***

(49) *You will find most (known)* ***dwarf galaxies hanging out near bigger galaxies****, in orbit around them like satellites.*

(50) *But the* ***lives of satellite galaxies*** *can be quite hazardous.*
(51) *Most computer models of their orbits show a slow decay that ultimately results in the* ***hapless dwarfs*** *getting ripped apart, and then eaten, by the main galaxy.*
(52) *The Milky Way engaged in at least one act of cannibalism in the last billion years, when it consumed a dwarf galaxy whose* ***flayed remains*** *can be seen as a stream of stars orbiting the galactic center, beyond the stars of the constellation Sagittarius.*
(53) *In the high-density environment of clusters, two or more large galaxies routinely collide and leave behind a titanic mess: spiral structures warped beyond all recognition, newly induced bursts of star-forming regions spawned from the violent collision of gas clouds, and hundreds of millions of stars strewn hither and yon having* ***freshly escaped the gravity of both galaxies****.*
(54) *In fact, observations of clusters detect just such a glow between the galaxies, suggesting that there may be as many* ***vagabond,*** *homeless stars as there are stars within the galaxies themselves.*
(55) *Supernovas are stars that have* ***blown themselves*** *to smithereens and, in the process, have temporarily (over several weeks) increased their luminosity a billion- fold, making them visible across the universe.*
(56) *While a dozen* ***homeless supernovas*** *is a relatively small number, many more may await discovery, since most supernova searches systematically monitor known galaxies and not empty space.*
(57) *Have they become* ***invisible corpses strewn throughout the universe****?*
(58) *We may henceforth need to rely upon these "intergalactic" telescopes to peer where (and when) ordinary telescopes cannot reach, and thus reveal the* ***future holders of the cosmic distance record.***
(59) *Remarkably, these single* ***subatomic particles carry enough energy to knock a golf ball from anywhere*** *on a putting green into the cup.*
(60) ***Gravity****, the most familiar of nature's forces,* ***offers us simultaneously the best and the least understood phenomena*** *in nature.*
(61) *It took the mind of the millennium's most brilliant and influential person, Isaac Newton, to realize that* ***gravity's mysterious "action-at-a-distance"*** *arises from the natural effects of every bit of matter, and that the attractive force between any two objects can be described by a simple algebraic equation.*
(62) *It took the mind of the last century's most brilliant and influential person, Albert Einstein, to show that we can more accurately describe* ***gravity's action-at-a-distance*** *as a warp in the fabric of space-time, produced by any combination of matter and energy.*
(63) *Its thousand galaxies orbit the cluster's center, moving in all directions like* ***bees swarming a beehive.***
(64) *The cluster should swiftly fly apart, leaving barely a trace of its* ***beehive existence*** *after just a few hundred million years had passed.*
(65) *Across the decades that followed Zwicky's work, other galaxy clusters revealed the same problem, so* ***Coma could not be blamed for being peculiar.***
(66) *First, we can eliminate with near-certainty all plausible familiar candidates, like the* ***suspects in a police lineup***
(67) *At odds in the universe were two competing effects:* ***gravity wants to make stuff coagulate****, but the expansion wants to dilute it.*
(68) *But* ***light turns out to be quite happy*** *traveling through the vacuum of space, devoid of any medium to carry it.*
(69) *Either* ***dark matter particles must wait for us*** *to discover and to control a new force or class of forces through which their particles interact, or else dark matter particles interact via normal forces, but with staggering weakness.*

(70) *You'd think that by now, after 4.6 billion trips around the Sun,* ***Earth would have "vacuumed" up all possible debris*** *in its orbital path.*

(71) *Not only is* ***the solar system scarred*** *by the flotsam of its formation, but nearby interplanetary space also contains rocks of all sizes that were jettisoned from Mars, the Moon, and Earth by the ground's recoil from high-speed impacts.*

(72) ***Pluto and its ensemble of siblings*** *called Plutinos cross Neptune's path around the Sun.*

(73) *Far beyond the Kuiper belt, extending halfway to the nearest stars,* ***lives a spherical reservoir of comets called the Oort cloud****, named for Jan Oort, the Dutch astrophysicist who first deduced its existence.*

(74) *Wherever and whenever this happens, the locked moon shows only one face to its* ***host planet.***

(75) *Wherever and whenever this happens, the locked* ***moon shows only one face to its host planet.***

(76) *While you can't breathe at those altitudes, some atmospheric molecules remain—enough to slowly drain orbital energy from* ***unsuspecting satellites.***

(77) *Jupiter's system of moons is* ***replete with oddballs.***

(78) *Jupiter acts as a gravitational shield for Earth, a* ***burly big brother****, allowing long (hundred- million-year) stretches of relative peace and quiet on Earth.*

(79) ***The Cassini probe,*** *for example, which* ***visited Saturn****, was gravitationally assisted twice by Venus, once by Earth (on a return flyby), and once by Jupiter.*

(80) *The Cassini probe, for example, which visited Saturn, was* ***gravitationally assisted*** *twice by Venus, once by Earth (on a return flyby), and once by Jupiter.*

(81) *Unfortunately for planet-hunting aliens,* ***Earth is puny****, so the Sun barely budges, which would further challenge alien engineers.*

(82) *While surveying the skies with a radio telescope for any source of strong radio waves, Antony Hewish and his team discovered something extremely odd:* ***an object pulsing at precise, repeating intervals*** *of slightly more than a second.*

(83) ***Black hole on the run.***

(84) *The astronomers hope to find other* ***supermassive black holes on the run****, to establish how common the phenomenon might be.*

(85) *But* ***the Sun's 'grandparents'*** *have never been observed directly.*

(86) ***The next generation of stars*** *originated from the remains of the first ones.*

(87) ***New stars are still being born***

(88) *Now an international team of scientists have used a different method to find the* ***Sun's grandparents.***

(89) *New stars still form from the gas and dust of previous* ***generations of stars****, particularly in the galaxy's spiral arms.*

(90) *New stars still form from the gas and dust of previous generations of stars, particularly in* ***the galaxy's spiral arms.***

(91) *So today, scientists* ***divide stars into three generations*** *that can be recognised by characteristic elements in their make-up.*

(92) ***The first generation was born*** *a few hundred million years after the Big Bang.*

(93) ***The first generation*** *was born a few hundred million years after the Big Bang.*

(94) ***The second generation*** *originated from the remains of the first stars, and the third generation stars are considered to have formed from some 2.8 billion years after the Big Bang up until today.*

(95) *The second generation originated from the remains of the first stars, and* ***the third generation stars*** *are considered to have formed from some 2.8 billion years after the Big Bang up until today.*

(96) ***Stars can be incredibly persistent,*** *in theory burning even for trillions of years, far longer than the accepted life of the universe so far.*

(97) ***Not all stars could grow so old****, and it's the larger stars that will die first.*

(98) *Not all stars could grow so old, and it's the* ***larger stars that will die first****.*

(99) *Those* ***first-gen stars*** *formed without any elements heavier than lithium. Second-generation stars include up to 0.1% heavy elements, and many of these are still burning today, including at the centre of the Milky Way.*

(100) ***Second-generation stars*** *include up to 0.1% heavy elements, and many of these are still burning today, including at the centre of the Milky Way.*

(101) ***Stars being born today*** *include still more heavy elements, up to around 4%.*

(102) *They were* ***assisted by a massive black hole****.*

(103) *But more observations are required before astronomers say with certainty that the tiny red dot is one of those first stars that lit up the universe, and so confirm that we are indeed looking at pictures of one of t****he Sun's grandparents.***

(104) ***Bright black hole reveals the ancient star.***

(105) ***The Sun is middle-aged.***

(106) *T****he biggest black holes have been gaining weight*** *since shortly after the Big Bang, allowing them to obtain a total mass of some 10 billion times that of the Sun.*

(107) ***Massive holes were born big.***

(108) ***While such a star is still alive****, radiation from the combustion processes in the core counteracts gravity's attempts to crush all the matter.*

(109) *While such a star is still alive, radiation from the combustion processes in the core counteracts g****ravity's attempts to crush all the matter****.*

(110) *But once the fuel has been consumed,* ***gravity gets the upper hand****, and the star's external layers of gas collide with the core from all sides, compressing the star to less than one millionth of its original volume.*

(111) *Inside other stars,* ***the strong nuclear force holds protons*** *and neutrons close together in the atomic nuclei.*

(112) ***Neutron stars are born in supernova explosions****, when the core of a huge star collapses, and we do not understand how the process can produce such a small neutron star.*

(113) ***They reveal themselves*** *only by the way in which their forces of gravity influence their surroundings.*

(114) ***Gravity reveals invisible planets.***

(115) *However, astronomers can spot them by means of the radial velocity method: exoplanets' masses pull slightly at their star, so if a* ***star seems to be 'staggering'****, it is probably orbited by one or more planets.*

(116) ***Gravity provides a boost.***

(117) ***Named GNz7q, the object was born 750 million years after the Big Bang*** *that took place 13.8 billion years ago, so in what astronomers know as the universe's cosmic dawn.*

(118) *So* ***the object was hiding right under the scientists' noses,*** *only retrieved by combining data of many different wavelengths*

(119) *Did* ***Big Bang magnetism light up the first stars?***

(120) *And if astronomers can show that it exists within the big voids, they could solve several mysteries – such as* ***how the very first stars of the universe were lit****.*

(121) *In the nebulas of galaxies,* ***magnetic fields help gravity to collect matter together****, so that stars can form.*

(122) ***New telescope settles the matter.***

(123) *It will take a number of years of data, but eventually **the SKA should prove or disprove** the existence of primordial magnetism*

(124) *At that time, we will finally know whether some of the magnetism that we experience everywhere around us actually dates all the way back to **the birth of the universe in the Big Bang.***

(125) ***The cosmic cobweb is magnetic***

(126) ***The matter of the universe is located in a 'cobweb'** where galaxy clusters form the junctions*

(127) *According to a new theory, **the Sun had a twin**, and the combined gravity of the two stars attracted billions of small heavenly bodies.*

(128) *DOES OUR **SUN HAVE A LOST TWIN**?*

(129) ***The Sun may have grown up with an identical twin**, according to a ground-breaking new theory that might finally explain the appearance of the outer Solar System – and perhaps the origin of Planet 9, which astronomers have been seeking for 100+ years.*

(130) ***The young Sun and its twin** would have had a powerful combined field of gravity that could have captured billions of asteroids and comets – and perhaps also the enigmatic Planet 9 – before the twin was torn away by a passing star.*

(131) ***Star couple** have a common field of gravity.*

(132) ***The Sun and its twin** are born in a densely packed star cluster.*

(133) ***Twins** attract ice cloud.*

(134) ***The star couple attracts asteroids**, comets and ice worlds from surrounding star systems.*

(135) ***The star couple** attracts asteroids, comets and ice worlds from surrounding star systems.*

(136) *Our Solar System formed after a cloud of dust and gas collapsed until the pressure at its centre became so intense that the hydrogen atoms began to merge into helium – **the birth of our Sun.***

(137) *Around **the new-born star**, the rest of the material began to flatten into a rotating disc.*

(138) ***The Oort cloud offers two mysteries of its own.***

(139) ***Such a star couple** would not be unusual.*

(140) ***The Orion Nebula is a massive cloud of dust and gases in which stars are born** – like the star cluster in which the Sun was born, but which scientists have not yet located.*

(141) *The Orion Nebula is a massive cloud of dust and gases in which stars are born – like **the star cluster in which the Sun was born**, but which scientists have not yet located.*

(142) *If **the Sun had a twin**, there's also a possible explanation for the Solar System's most mysterious object: Planet 9.*

(143) *In the new theory, however, **the Sun and its twin** orbited each other some 1000-1500 AU apart.*

(144) *But what about all the other stars from the cluster – our **Sun's lost siblings?***

(145) *Scientists have long tried to find out more about what happened to **the Sun and all its siblings** after they were born.*

(146) ***The Sun's twin** could be anywhere in that half circle, but at least 100 of the Sun's siblings remain relatively close, located within a few hundred light years.*

(147) *And they have probably found **two of the Sun's siblings**: the stars designated as HD 162826 and HD 186302.*

(148) *In both cases, the **two siblings are very similar to the Sun**.*

(149) *If we manage to find more of the **Sun's siblings** in the years to come, astronomers will gain increasing insight into the star cluster from which the Sun was born.*

(150) *We can, with careful calculations, work out how those tiny variations in density are destined to grow over time, starting from minuscule blips and, over the millennia,* ***growing up into*** *entire clusters of galaxies.*
(151) *The cosmos as we see it today is a vast, beautiful* ***web of galaxies*** *shining in the darkness.*
(152) *That blur is the Andromeda Galaxy, a great spiral disk of about a trillion stars and a supermassive black hole, all of which are* ***hurtling toward us*** *at 110 kilometers per second.*
(153) *Gas will ignite around the previously dormant central supermassive black holes, which will* ***meet in the middle of everything*** *and spiral into each other.*
(154) *By that time, the Sun will have already begun to swell to red-giant size, heating up the Earth enough to boil the oceans and completely* ***sterilize the surface of all possibility of life.***
(155) *Our immediate neighborhood collection of stellar systems, members of the blandly named* **Local Group, are a ragtag gang** *of small and irregular galaxies dominated by the two giant spirals, and we are all destined to get nice and cozy sooner or later.*
(156) ***If the cosmos were behaving itself,*** *the basic physics involved in the expansion of the universe should be about as simple as throwing a ball up into the air, as we discussed in the previous chapter.*
(157) *Throw it too slowly, it goes up for a bit, slows down, stops, and falls down again: that's like a universe where there's enough matter (or a weak enough initial Big Bang expansion) that* ***gravity wins and recollapses the universe.***
(158) ***A cosmological-constant-induced apocalypse is a slow and agonizing one,*** *marked by increasing isolation, inexorable decay, and an eons-long fade into darkness.*
(159) *In order for vacuum decay to occur, there has to be a trigger—something that will set the Higgs field wandering far enough to find the part of the potential corresponding to the "true" vacuum and* ***realize it would rather be there***
(160) ***The radial electron temperature profile exhibits similar behavior****, though varies less with the stream speed (6).*
(161) *The energy budget of the solar wind indicates that energy provided by* ***Alfvén waves makes a greater contribution*** *to stream acceleration at higher solar wind speeds (4).*
(162) *The acceleration of the solar wind streams with slower speeds can be explained without requiring a* **contribution** *from Alfvén waves (9).*
(163) *By contrast,* ***Alfvén waves do contribute*** *to the dynamics of fast solar wind (10, 11).*
(164) *Each U and W term includes* ***contributions from electrons, protons, and alpha particles.***
(165) *This formulation does not explicitly include the ambipolar electric potential induced by* ***hot electrons escaping the Sun's corona;*** *that energy is included in the electron thermal pressure or the enthalpy (UH).*
(166) *Under our assumed isothermal conditions in the corona, the* ***plasma still receives energy from the Alfvén waves****, but it exactly balances the cooling due to expansion.*
(167) *In the biotic scenarios, the* ***ozone layer survives*** *because hydrogen oxide reactions with nitrogen oxides prevent the net ozone chemical sink from increasing.*
(168) *Regarding Venus, O'Rourke et al. (2023) recently reviewed planetary evolution and note that* ***early climate runaway,*** *and hence the timing and extent of a potential giant steam atmosphere phase, is likely sensitive to the global coverage and refractive properties of its clouds, which are not well known.*
(169) ***HOX can in turn destroy*** *potential biosignatures such as ozone via catalytic cycles and methane via direct gas- phase reactions with the hydroxyl (OH) radical, which can also stabilise climate gases such as CO2 (Yung & DeMore 1998).*

(170) *The Chameides et al. (1977) lightning model was used to produce modern-Earth concentrations of NO and NO2 within the troposphere, and rainout rates of trace* ***gas species*** *were accounted for using the Giorgi & Chameides (1985) approach with effective Henry's law constants via temperature-dependent parameterisations from Sander (2015). 2.3. GARLIC spectral model.*

(171) *The presence of Earth's O3 layer centred at about 10 hPa (around 30km on modern Earth)* ***effectively shields the surface*** *from the incoming UV-B flux, resulting in the absorption 'shoulder' slope seen in Fig. 1d.*

(172) *This response in important* ***O3 sinks*** *is likely the main reason for the* ***survival of stratospheric ozone*** *across the IHZ (despite stronger photolytic UV-B sinks and more catalytic loss from HOX).*

(173) *the odd-nitrogen group (NOX = N + NO + NO2 + NO3; see also Fig. A.2), and nitric acid (HNO3), an important* ***reservoir species*** *for HOX and NOX.*

(174) *For atmospheric pressures between 10−1 and 102 hPa, OH becomes the* ***primary species*** *in the HOX family.*

(175) *A major result of our work is that* ***ozone could survive*** *warm, damp (hence high HOX) conditions towards the IHZ due to mutual destruction of its catalytic sinks (HOX by NOX).*

(176) *With its rest-frame optical sensitivity, the* ***James Webb Space Telescope (JWST) has unearthed black holes*** *as massive as 106.2−8.1 M⊙ at redshifts of z ∼ 8.5−10.6.*

(177) *This means that in some cases (of high supernova feedback), the* ***black hole grows*** *to be more massive than the stellar mass of its host halo.*

(178) *This is an* ***attractive alternative*** *to seeding these puzzling early systems.*

(179) *With its unparalleled sensitivity, the James Webb Space Tele- scope (JWST) has been crucial in shedding light on the* ***black hole population*** *in the first billion years of the Universe.*

(180) *and only over-massive black holes may be able to outshine their* ***hosts*** *and make them detectable by the JWST*

(181) *Observational issues notwithstanding, these puzzles have nat- urally prompted a flurry of research exploring the variety of* ***black hole*** *seeding and* ***growth*** *mechanisms allowed.*

(182) *We explored the* ***growth of black holes*** *assuming seeding at a redshift of zseed = 25 (corresponding to ∼134 Myr after the Big Bang) and seed masses ranging between 102−5 M⊙, and we allowed both Eddington-limited and super-Eddington accretion.*

(183) *Black holes* ***confirmed by the JWST***

(184) ***JWST-detected black holes contribute*** *very little to the dark matter content.*

(185) *We allowed the central* ***black hole to grow*** *by accreting a fraction of this gas*

(186) *The* ***black hole*** *can therefore grow by accreting the minimum between the Eddington mass and a fraction (fBH) of the available gas mass at the start of the redshift step (Mgi).*

(187) *As a result, the* ***black hole assembly*** *is the same in every model, even though we used different values that spanned the extrema of the parameter space.*

(188) *High-mass stars play a crucial role in shaping not only their* ***parental clouds****, but also the interstellar medium on kpc scales, enriching it with heavy elements and influencing the dynamics of their surround- ing environments via the energy they release through radiation and stellar winds*

(189) *Using the current observational techniques, resolving individual stars formed within their* ***birth environment*** *and their position within the large-scale galactic environments turns the Milky Way into a unique laboratory.*

(190) *The most prominent* ***dense clouds manifest*** *at galactocentric radii of around 3 and 4 kpc.*
(191) *Two dense regions around X = −3, one on the Y = 0 line and another slightly below it, correspond well with our* ***dominant clouds*** *in that region, although at slightly different distances*
(192) *Additionally, while there seems to be an offset between the masers and our clouds at the location of the Outer Arm in the outer Galaxy (red points), our* ***clouds seem to turn and follow*** *the potential spiral arm pattern.*
(193) ***Planet-star interactions*** *with precise transit timing IV.*
(194) *According to theoretical expectations, this process is* ***governed by the dissipation of tidal energy*** *in stellar interiors.*
(195) *One of them is equilibrium tides, quasi-hydrostatic ellipsoidal deformations induced by the gravity of a* ***planetary companion****.*
(196) *Their transit timing data reveal no sign of a long-term trend that could be attributed to* ***orbital decay.***
(197) *The presence of Earth's O3 layer centred at about 10 hPa (around 30km on modern Earth) effectively shields the surface from the incoming UV-B flux, resulting in the* ***absorption 'shoulder' slope*** *seen in Fig. 1d.*
(198) *However, our position within the dusty Milky Way disc has long limited our understanding of the location and substructures of* ***the Milky Way star-forming arms*** *to the 2D plane-of-the-sky views and uncertain kinematic distances.*
(199) *Since then, numerous works have focused on characterising the positions of* ***spiral arms*** *in the Milky Way via various approaches, from studying young stars (Russeil 2003; Cantat-Gaudin et al. 2018; Romero-Gómez et al. 2019) to atomic and molecular gas kinematics (Drimmel & Spergel 2001; Kalberla & Kerp 2009; Dame et al. 2001; Roman-Duval et al. 2010; Miville-Deschênes et al. 2017) and maser parallax measurements (Reid et al. 2019).*
(200) *The first evaluation of the map and the clouds within it does not show a clear indication of the* ***spiral arms in the Milky Way****.*
(201) ***The Local Arm*** *and segments of the Perseus Arm are the only clear arm features that could be extracted from the map.*
(202) *The Local Arm and segments of the* ***Perseus Arm*** *are the only clear arm features that could be extracted from the map.*
(203) *The Local Arm and segments of the* ***Perseus Arm*** *are the only* ***clear arm features*** *that could be extracted from the map.*
(204) *We deliver accurate distance estimates to the centre of each cloud, the uncertainty of the estimated distance, the extent of the cloud, its mean density and standard deviations, and its association with known star-forming regions and* ***spiral arms.***
(205) *The BESSEL survey uses a combination of maser parallaxes,* ***spiral arm*** *models based on masers, and kinematic distances to give all probable distance estimates for a given LOS and velocity*
(206) *In addition to the over-densities and* ***spiral arm segments****, one clear feature of the map is the presence of large cavities*
(207) *There are several clouds underneath masers belonging to Scutum–Centaurus–OSC, the* ***Norma arm****, and the spurs in the inner Galaxy; however, it is difficult to establish a one-to-one relation due to the crowding in both masers and cloud distributions.*
(208) *Additionally, while there seems to be an offset between the masers and our clouds at the location of the* ***Outer Arm*** *in the outer Galaxy (red points), our clouds seem to turn and follow the potential spiral arm pattern.*

(209) *Additionally, while there seems to be an offset between the masers and our clouds at the location of the Outer Arm in the outer Galaxy (red points), our clouds seem to turn and follow the potential* ***spiral arm*** *pattern.*

(210)

(211) ***The Hale telescope was the most powerful instrument to peer into*** *the deep universe beyond our Milky Way, until the end of the XX century with the advent of the new generation telescopes at Mauna Kea, Mount Graham, Las Campanas, La Silla, Paranal and the Hubble Space Telescope.*

(212) *The Hubble result on Andromeda resolved the question observationally:* ***the concept of the universe of galaxies was born,*** *extending the cosmic dimensions by 1,000 times or more.*

(213) *If J should exceed this value, one would have a gravitational field with a* ***"naked" singularity*** *(i.e., a singularity not "clothed" by an event horizon).*

(214) *An interesting unsolved problem in the theory of BH is Penrose's Cosmic Censorship Conjecture that no* ***naked singularity*** *exists, i.e. the central singularity is always clothed by a horizon.*

(215) *An interesting unsolved problem in the theory of BH is Penrose's Cosmic Censorship Conjecture that no naked singularity exists, i.e.* ***the central singularity is always clothed by a horizon.***

(216) *Signals sent from inside the horizon will be* ***captured by the black hole*** *and fall towards the singularity.*

(217) *Signals sent from inside the horizon will be captured by the black hole and f****all towards the singularity.***

(218) *This is in accord with the so-called* ***"no hair" ideas*** *about many different internal states of a black hole corresponding to the same external gravitational field, and that information is lost from the outside world once black holes are formed.*

(219) *Every time humans have looked at the universe with a* ***new set of 'eyes'*** *(for instance, using telescopes to look at visible light or radio waves, or gamma-ray detectors to view gamma rays) they have found things that were unexpected and revolutionized our understanding of the universe.*

(220) *Nowadays we know that stars are changing in time and also the* ***universe as a whole modifies****.*

(221) *It expands, galaxies are created and might collide with each other,* ***stars are born*** *by contraction of huge gas and dust clouds.*

(222) ***They pass through different development stages, like humans****, but on a very much longer time scale.*

(223) *In this sense one can speak of* ***birth, life and death of a star.***

(224) ***The Birth of Stars***

(225) *According to our present knowledge* ***stars ar created by the contraction*** *of huge clouds of gas and dust.*

(226) *In our galaxy which contains about 1011 stars,* ***new stars are mainly created in the spiral arms****.*

(227) *The mean* ***birth rate of stars*** *is about 3–5 stars per year.*

(228) ***The birth process lasts for 103–107 years****, strongly dependent on the mass of the new star*

(229) *One example of an interstellar gas and dust cloud, where the* ***birth of new stars*** *can be observed, is the Orion Nebula*

(230) *The Sun is expected to sustain its current energy output for about another 5 billion years, and so have a full* ***lifetime*** *of about 10 billion years.*

(231) ***Coronal holes*** *arise in open field regions between such closed loops,* ***allowing*** *the gas to escape into the outward solar wind expansion.*

(232) *Coronal holes arise in open field regions between such closed loops, allowing the g**as to escape** into the outward solar wind expansion.*

(233) *Though the dividing line is not exact, it is thought (see Figure 19.1) that all stars with initial masses* $M > 8M_\odot$ *will* ***end their lives*** *with such a core-collapse supernova, instead of following the track, AGB → PN → WD (white dwarf), for stars with initial mass* $M < 8M_\odot$. *Stars with initial masses* $8M_\odot < M \;\; 30M_\odot$ *are thought to leave behind a neutron-star remnant, as discussed in Section 20.3.*

(234) *Actually, in many simulations,this rebound stalls, and the material recollapses to directly form a black hole, without much of an external explosion; there is now some evidence from large-scale surveys that some uncertain* ***fraction of massive stars may indeed just end their lives*** *by such collapse into a black hole without a visible superova explosion.*

(235) *Since* ***not even light can ever escape*** *from this hole, it is completely black, absorbing any light or matter that falls in, but never emitting any light from the hole itself*

(236) *However, in a binary system, the presence of a black hole can be indirectly inferred by observing the orbital motion (visually or spectroscopically via the Doppler effect) of the luminous* ***companion star.***

(237) *Moreover, when that* ***companion star*** *becomes a giant, it can, if it is close enough, transfer mass onto the black hole, as illustrated in Figure 20.3.*

(238) *Rather than falling directly into the hole, the conservation of the angular momentum from the stellar orbit requires that the* ***matter must first feed an orbiting accretion disk.***

(239) *As the black holes spiraled ever closer toward merger, the waves steadily increased in frequency, which when translated into sound gave a characteristic* ***"chirp."***

(240) *When analyzed in comparison to computer simulations of such mergers,* ***the chirp*** *pattern indicated the black holes in this first-detected merger were quite massive, about* $29M_\odot$ *and* $36M_\odot$*, several times higher than the most-massive black holes inferred in the high-mass X-ray binaries discussed in Section 20.5.*

(241) *When galaxies do collide, their overall pattern of stars become strongly distorted by the mutual tidal interaction of the overall mass of the two galaxies; but the individual stars are too widely separate to collide, and so just* ***pass by each other.***

(242) *Much as stars within galaxies tend to form within stellar clusters, the* ***galaxies in the universe also tend to collect in groups,*** *clusters, or even in a greater hierarchy of clusters of clusters, known as "superclusters."*

(243) *Figure 29.4 schematically illustrates the overall evolution of the universe from our current modern era* ***populated by "normal" galaxies,*** *back in time.*

(244) *The time from this recombination to an age of about 100 Myr, when* ***the first stars were born****, is known as the "dark ages."*

(245) *These* ***oddball galaxies*** *chronicle a period when the universe was younger and more chaotic, when order and structure were just beginning to emerge.*

(246) ***An object as bizarre as a black hole deserves closer scrutiny.***

(247) *She is frozen in time, held for eternity* ***like a fly caught in amber.***

(248) *Our successors could watch for millennia while* ***stars were born, evolved, and died*** *without receiving a single photon from her.*

(249) *It is also possible that a neutron star in a close binary system may gravitationally strip enough mass from its* ***companion*** *that the neutron star's self-gravity exceeds the ability of the degeneracy pressure to support it, again resulting in a black hole.*

(250) ***Black Holes Have No Hair!***

(251) ***Black holes have no other attributes or adornments****, a condition commonly expressed by saying that "a black hole has no hair."*

(252) *Black holes have no other attributes or adornments, a condition commonly expressed by saying that "****a black hole has no hair."***

(253) *However, it appears that any attempt to send a tiny amount of matter or energy (even a stray photon)* ***through the throat*** *would cause it to collapse.*

(254) *We will briefly consider nonrotating, spherically symmetric* ***wormholes****.*

(255) *In other words, a wormhole must be threaded by some sort of whose tension prevents the collapse of the* ***wormhole.***

(256) *There is no known mechanism that would allow a* ***wormhole*** *to arise naturally; it would have to be constructed by an incredibly advanced civilization*

(257) *These solutions to Einstein's field equations have no event horizon (permitting two-way trips through the* ***wormhole****) and involve survivable tidal forces.*

(258) *Journey times from one end through to the other can be less than one year (traveler's proper time), although the ends of the* ***wormhole*** *may be separated by interstellar or intergalactic distances.*

(259) *The catch, of course, is the problematic existence of the exotic material needed to stabilize the* ***wormhole****.*

(260) *The unusual nature of the exotic material becomes apparent if we consider two light rays that converge on the* ***wormhole*** *and enter it, only to diverge when they exit the other end.*

(261) *We will leave* ***wormholes*** *as a fascinating possibility and abandon the discussion at this point, recalling Einstein's remark that "all our thinking is of the nature of a free play with concepts."*

(262) ***Stellar-Mass Black Hole Candidates****.*

(263) *If the black hole in such a system is able to* ***pull gas from the envelope of the normal companion*** *star, the angular momentum of their orbital motion would cause a disk of gas to form around the black hole*

(264) *If the black hole in such a system is able to pull gas from the envelope of the normal* ***companion star,*** *the angular momentum of their orbital motion would cause a disk of gas to form around the black hole*

(265) *Examination with ground-based optical telescopes revealed a* ***companion star*** *of type K0 IV with a radial velocity amplitude of 211 4 km s 1 and an orbital period of 6 473 0 001 d*

(266) *THE* ***MORPHOLOGY OF THE GALAXY****.*

(267) *However, as Shapley had suspected,* ***the Sun does not reside*** *near the center of the disk but is actually located roughly one-third of the way out from the middle.*

(268) *The interstellar* ***gas and dust clouds that plagued Kapteyn's attempts*** *at determining the overall structure of the Galaxy and that are clearly evident in Fig. 24.1 are primarily located near the midplane and found preferentially in the spiral arms.*

(269) *The unusual globular cluster Centauri also seems to be the remnant of* ***a dwarf galaxy that has been subsumed by the Milky Way.***

(270) *Some astronomers have suggested that those* ***six most distant clusters may have been captured by the Milky Way*** *or may be dwarf spheroidal galaxies, much as Cen and the Sagittarius dwarf galaxy may have been.*

(271) *Given that spiral galaxies are commonplace within the universe, it is natural to ask what causes spiral structure, and whether* ***spiral arms are long-lived*** *(with lifetimes comparable to the age of a galaxy) or transient.*

(272) ***INTERACTIONS OF GALAXIES****.*

(273) *The most massive stars evolve in* ***the blink of a cosmic eye*** *and distribute in their surroundings a variety of chemical elements (some synthesized in their core during their evolution) and a huge amount of energy that has the potential to remove material from galaxies, and prevent the formation of new stars or, on the contrary, promote it by inducing shocks or compression waves*

(274) *Other elements are made in intermediate- mass stars that release them at a later time after their* ***birth****.*

(275) *Each one of these* ***indicators suffers*** *from its own drawbacks and is sensitive to emission from stars with slightly different stellar masses.*

(276) *In nearby galaxies,* ***color-magnitude diagrams of individual stars or of galactic regions can give us clues*** *about their past.*

(277) *Clearly, it was very unlikely that the vast majority of galaxies had all been* ***caught in the middle of a transient event.***

(278) *The absolute value of the specific SFR (sSFR ≡ SFR/Mstar)* ***sets the clock of galaxy evolution*** *(Peng et al., 2010), determining the growth rate of individual galaxies, hence controlling their lifetime before they are quenched.*

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(282) *Different interpretations have been proposed to follow the* ***life of sources*** *assembling their stellar masses through different paths, with random episodes pushing them for short timescales above the main sequence, and eventually quenching the most massive sources to bury them in the graveyard of red and dead galaxies*

(283) *Understanding the physics of star formation, and the way to recover it for unbiased samples of galaxies at different redshifts, allows the reconstruction of the history of the stellar-mass* ***assembly of the universe.***

(284) *Another confusing factor is that* ***the Sun was not born where it is today*** *in the Galaxy and was much closer to the centre of the disc, as a result we might expect its composition to be higher*

(285) *These studies showed that every O star can expect* ***to be born in a binary system,*** *and that 70% of these O stars have evolution altered by a binary interaction.*

(286) *A unique phase of evolution that results from* ***binary interactions****, but is not possible from stellar rotation, is the creation of helium stars from stars with initial masses in the range from 10 to 20 M⨀.*

(287) *Stars with initial masses below the 10–20 M⨀ range tend to form white dwarfs and sdBO stars from* ***binary interactions.***

(288) *Since the* ***stars are short-lived****, they indicate the presence of recent star formation.*

(289) *As discussed in previous sections, however, these generalisations do not account for the uncertainties and spread in evolutionary pathways which arise from* ***binary interactions****: a concern for a massive star population which, typically, has a binary fraction approaching unity (Sana et al., 2012; Moe and Di Stefano, 2017).*

(290) *As discussed in previous sections, however, these generalisations do not account for the uncertainties and spread in evolutionary pathways which arise from binary*

*interactions: a concern for a **massive star population** which, typically, has a binary fraction approaching unity (Sana et al., 2012; Moe and Di Stefano, 2017).*

(291) ***Binary interactions** that lead to mass loss can also prevent supernovae and modify the distribution of remnant masses (and so accretion luminosities in the X-ray and elsewhere).*

(292) *It appears that within the disk, the field tends to follow the **Galaxy's spiral arms** and has a typical strength of 0 4 nT.*

(293) *Not only do bulge-to-disk ratios, the **tightness of the spiral arms**, and the ability to resolve the arms into stars and H II regions all correlate well with Hubble type, but so do a host of other physical parameters.*

(294) *The optical images of spiral galaxies are dominated by their **arms**.*

(295) *Trailing and Leading **Spiral Arms.***

(296) *Although the general appearance of spiral galaxies suggests that their **arms** are, meaning that the tips of the arms point in the opposite direction from the direction of rotation (see Fig. 25.20), verifying this is not always a simple matter.*

(297) *Although the general appearance of spiral galaxies suggests that their arms are, meaning that **the tips of the arms** point in the opposite direction from the direction of rotation (see Fig. 25.20), verifying this is not always a simple matter.*

(298) *Distinguishing between trailing and **spiral arms** requires a determination of the orientation of the plane of the galaxy relative to our line of sight so that radial-velocity measurements can be unambiguously interpreted in terms of the direction of galaxy rotation.*

(299) *In almost all cases where such a clear determination can be made, it does appear that **spiral arms** are trailing*

(300) *In almost all cases where such a clear determination can be made, it does appear that **spiral arms are trailing***

(301) *One problem immediately arises when the nature of spiral structure is considered; **material arms** composed of a fixed set of identifiable stars and gas clouds would necessarily "wind up" on a timescale that is short compared to the age of the galaxy.*

(302) *This effect will of course lead to a natural generation of trailing **spiral arms.***

(303) *However, after only a few orbits, **the spiral arms will become too tightly wound** to be observed; this situation is depicted in Figs. 25.21(b) and 25.21(c).*

(304) *However, after only a few orbits, the **spiral arms** will become too tightly wound to be observed; this situation is depicted in Figs. 25.21(b) and 25.21(c).*

(305) *Lenticular galaxies are a transitional form with a bright central bulge surrounded by a disk-like structure that lacks visible **spiral arms.***

(306) *In our galaxy which contains about 1011 stars, new stars are mainly created in the **spiral arms**.*

(307) *This shows that, like M51, our Galaxy also has distinct **spiral arms**, along which are concentrations of gas, dust, HII regions, GMCs, and active star formation.*

(308) *A spiral density wave in the disk forms the **spiral arms** that are the regions of active star formation out of the cold clouds of gas and dust*

(309) *The tightness of the winding of **the arms** can vary, and sometimes emanate from a central "bar."*

(310) *3-kpc **Expanding Arm***

(311) *A unique feature in the inner regions of the Galaxy that is most easily observed at the 21-cm wavelength of H I is the 3-kpc **expanding arm**, a gas cloud that is moving toward us at roughly 50kms.*

(312) *However, the spatial distribution of the total gas is not set in this model, and should result from many other physical effects (**spiral arms**, accretion) that could affect other star-formation laws (i.e. global or radial ones instead of the local ones).*

The source domain of CONTAINER

(313) ***Black holes are the gravitational sink-holes of the universe**.*
(314) *Every point in space is the center of its own sphere of ever deepening time, bounded by a **shell of fire.***
(315) *In the biotic scenarios, the ozone layer survives because hydrogen oxide reactions with nitrogen oxides prevent the net **ozone chemical sink** from increasing.*
(316) *Regarding volatile delivery, current theories suggest that rocky worlds forming in and around the IHZ of **Sun-like stars will likely accrete water inventories** that are broadly comparable with objects formed in the mid habitable zone*
(317) *The Cl atoms were released from their **reservoir** HCl, via reaction with OH (steam atmospheres featured high OH abundances) and increased UV-C photolysis of HCl.*
(318) *This additional **chemical sink** explains the change in tendency for N2O as the VMRs begin to fall below those calculated at S = 1.0 in the lower atmosphere, but initially increase when pressures are below 1 hPa. 3.2.*
(319) *Additionally, a decreasing HO2 abundance close to the surface at high S lowers the **chemical sink** strength for NO, which is the most abundant NOX family member in the lower atmosphere, and its increasing production and decreasing sink result in an increase in the NOX VMR profile.*
(320) *With increasing surface temperatures, the weathering rate of silicate rocks will increase (West et al. 2005) and draws more gaseous CO2 from the atmosphere effectively increasing the **CO2 surface sink** with increasing instellation.*
(321) *With its rest-frame optical sensitivity, the James Webb Space Telescope (JWST) has unearthed **black holes** as massive as 106.2−8.1 M⊙ at redshifts of z ∼ 8.5−10.6.*
(322) *In addition to these unexpectedly high masses, many systems show unexpectedly high ratios of the **black hole** to stellar mass of MBH/M∗ & 30% at these early epochs.*
(323) *We collated data for all of the **black holes** that were confirmed with the JWST (through spectroscopy, X-rays, or high-ionization emission lines).*
(324) *We then appeal to cosmological primordial **black hole** (PBH) seeds and show that these present an alternative path for the seeding of early structures and their baryonic contents*
(325) *The upper limit at which we assume a primordial origin for all of these **black holes** yields a continuous primordial black hole mass function (between 10−5.25 and 103.75 M⊙) and a fractional PBH value .10−12.*
(326) *The upper limit at which we assume a primordial origin for all of these black holes yields a continuous primordial **black hole** mass function (between 10−5.25 and 103.75 M⊙) and a fractional PBH value .10−12.*
(327) *We were able to reproduce the observed stellar and **black hole** masses for two of the highest-redshift black holes (UHZ1 and GHZ9 at z ∼ 10.3) with the same parameters as those that govern star formation, black hole accretion, and their feedbacks.*
(328) *We were able to reproduce the observed stellar and black hole masses for two of the highest-redshift **black holes** (UHZ1 and GHZ9 at z ∼ 10.3) with the same parameters as those that govern star formation, black hole accretion, and their feedbacks.*
(329) *Exploring a wide swathe of model parameter space for GHZ9, we find ratios of **black hole** to stellar mass between 0.1−1.86.*
(330) *This means that in some cases (of high supernova feedback), the **black hole** grows to be more massive than the stellar mass of its host halo.*

(331) *With its unparalleled sensitivity, the James Webb Space Tele- scope (JWST) has been crucial in shedding light on the **black hole** population in the first billion years of the Universe.*

(332) *These **black holes** comprise both intrinsically faint (Harikane et al. 2023; Maiolino et al. 2024a,b; Juodžbalis et al. 2024) and heavily reddened compact sources, the so-called little red dots*

(333) *Additionally, high-ionization lines (Maiolino et al. 2024b) and X-ray detections (Bogdán et al. 2024; Kovács et al. 2024) have been used to infer **black hole** masses as high as 106.2−7.9 M⊙ as early as z ∼ 10.3−10.6.*

(334) *Another issue is an over-abundance of **black holes** in the first billion years*

(335) *Interestingly, however, it has been shown that many of these **black holes** are compatible with local MBH-velocity dispersion or MBH-dynamical mass relations, sug- gesting that while baryons might exist in the correct number in the host haloes, they are inefficient at forming stars*

(336) *A number of works, however, have urged caution in taking **black hole** and stellar masses at face value.*

(337) *Eddington accretion is preferred over the standard Shakura & Sunyaev (Shakura & Sunyaev 1973) accretion disk, yielding **black hole** masses that are lower by an order of magnitude than those inferred by applying standard local relations to single-epoch broad lines*

(338) *and only over-massive **black holes** may be able to outshine their hosts and make them detectable by the JWST*

(339) *Observational issues notwithstanding, these puzzles have nat- urally prompted a flurry of research exploring the variety of **black hole** seeding and growth mechanisms allowed.*

(340) *In terms of astrophysical **black hole** seeds, low-mass seeds with a mass of ∼102 M⊙ can be created by the collapse of metal-free (Population III) stars in mini-haloes at high redshifts*

(341) *Theoretical works allow a range of solutions for the existence of such massive **black holes** at early epochs so far, including requiring high-mass seeding mechanisms*

(342) *We draw inspiration from a number of previous works that described that the Coulomb effect of a single **black hole** can generate an initial density fluctuation through the seed effect, which can grow through gravitational instability to bind (dark matter) mass around itself.*

(343) *These PBHs have already been used to provide solutions for dwarf galaxy anomalies (Silk 2017), act as the seeds of high- redshift massive structures and massive **black holes** (Mack et al. 2007; Carr & Silk 2018; Cappelluti et al. 2022; Liu & Bromm 2023), and to explain the excesses seen in the cosmic X-ray background (Ziparo et al. 2022) and radio wave background (Mittal & Kulkarni 2022)*

(344) *For **black holes** that cannot be explained by different seed masses and Eddington-limited growth mechanisms, we apply cosmol- ogy and infer the PBH masses at the epoch of matter-radiation equality (z = 3400), which are used to construct the PBH mass function.*

(345) *We explored the growth of **black holes** assuming seeding at a redshift of zseed = 25 (corresponding to ∼134 Myr after the Big Bang) and seed masses ranging between 102−5 M⊙, and we allowed both Eddington-limited and super-Eddington accretion.*

(346) *With continuous accretion onto the **black hole**, this formalism implicitly assumes a maximal duty cycle of 100%.*

(347) *We then collated data for all **black holes** confirmed by the JWST at z & 4.*

(348) *a total of 34 such **black holes** were identified through broad (∼1000−6000 km s−1) hydrogen balmer lines, which are assumed to trace the kinematics of gas in broad-line regions*
(349) ***Black holes** confirmed by the JWST*
(350) *Finally, we quote the primordial **black hole** seed mass for each object assuming continuous Eddington accretion onto this seed mass from a redshift of z = 3400. 2024a; Furtak et al. 2024; Greene et al. 2024), through high- ionization lines of nitrogen and neon (Maiolino et al. 2024b), or through X-ray counterparts in deep Chandra observations (Bogdán et al. 2024; Kovács et al. 2024).*
(351) *These were used to infer the existence of massive **black holes** as large as 107.5−108.1 M⊙ at z & 8.5, only 600 million years after the Big Bang.*
(352) *A key caveat, however, is that these observations apply locally calibrated single-epoch relations to infer **black hole** masses from observed spectra/X-ray luminosities.*
(353) *This is driven by two key reasons: The first reason is that this provides a redshift-independent estimate of the **black hole** mass.*
(354) *The second reason is that local relations between line broadening (or X- ray emission) and the **black hole** mass are associated with small- scale (<parsec scale) physics and dynamics that are not expected to show any significant dependence on the redshift*
(355) *These comprise 2 of the z ∼ 7 massive **black holes** (Harikane et al. 2023; Juodžbalis et al. 2024) and all objects observed at z & 8.5 (Kokorev et al. 2023; Bogdán et al. 2024; Kovács et al. 2024; Maiolino et al. 2024b).*
(356) *JWST-detected **black holes** contribute very little to the dark matter content.*
(357) *Primordial **black holes** as seeds of early galaxy assembly.*
(358) *the halo mass is higher by two orders of magnitude than the **black hole.***
(359) *We allowed the central **black hole** to grow by accreting a fraction of this gas*
(360) *The **black hole can therefore grow** by accreting the minimum between the Eddington mass and a fraction (fBH) of the available gas mass at the start of the redshift step (Mgi).*
(361) *The gas that was left over after **black hole** accretion was allowed to form stars with an efficiency that is limited by feedback from Type II supernova (SNII; exploding stars more massive than 8 M⊙), such that (see Dayal et al. 2014; Mauerhofer & Dayal 2023), ∆M =(Mi −∆M)feff, (7) ∗ g BH∗ where feff = min[fej, f] is the effective star formation efficiency.*
(362) *For each, we show the fraction of gas available for accretion onto the **black hole** (column 4), the maximum threshold efficiency for star formation (column 5), and the fractions of black hole and SNII feedback energies that can couple to gas (columns 6 and 7, respectively).*
(363) *Here, Eej = fw ε∆MBHc2 is the ejection energy provided by the accreting BH **black hole**, Ebin is the binding energy of gas in the halo (for details see Dayal et al. 2019), and f w is the fraction of black hole energy that couples to gas.*
(364) *Because we assumed **black hole** and SNII feedback to act instantaneously, the order of star formation or black hole accretion has no impact on the results.*
(365) *Because we assumed black hole and SNII feedback to act instantaneously, the order of star formation or **black hole** accretion has no impact on the results.*
(366) *Assembly of GHZ9 with primordial **black holes** acting as the seeds of structure formation.*
(367) *The bottom row (panels c and d) shows the ratios of **black hole** to stellar mass for each model.*

(368) *we explored a wide range of models, including extreme combinations of the gas-mass fractions available for* ***black hole*** *accretion/star formation and the fraction of black hole/SNII feedback coupling to the gas content.*

(369) *we explored a wide range of models, including extreme combinations of the gas-mass fractions available for black hole accretion/star formation and the fraction of* ***black hole****/SNII feedback coupling to the gas content.*

(370) *We start by noting that the exact order of black hole accretion or star formation has no bearing on our results, and* ***black holes*** *always accrete at the Eddington rate.*

(371) *As a result, the* ***black hole*** *assembly is the same in every model, even though we used different values that spanned the extrema of the parameter space.*

(372) *We start by discussing the set of models in which* ***black holes*** *are allowed to accrete the minimum between the Eddington mass and 90% of the available gas mass, with 10% of the gas forming stars at most, at any step.*

(373) *In classical relativity, if a black hole is placed in a* ***radiation bath****, it continually absorbs radiation without ever coming to equilibrium.*

(374) *But its relatively* ***weak gravity has allowed a lot of the light elements such as hydrogen and helium to escape into space,*** *leaving behind the heavier elements that make up our world, and us.*

(375) *It is tempting to imagine this as a tunnel, and writers of speculative fiction have dreamed of* ***white holes*** *pouring out mass or serving as passageways for starships. However, it appears that any attempt to send a tiny amount of matter or energy (even a stray photon) through the throat would cause it to collapse.*

(376) *This observation has been interpreted as implying that Sa's are somewhat more centrally condensed, containing correspondingly deeper* ***gravitational wells*** *in which gas can collect and combine to form molecules.*

(377) *All astrophysical objects possess angular momentum and stellar collapses producing* ***black holes*** *are likely not to take place in spherically symmetric conditions.*

(378) *As a first approximation [formula] where [formula] is the* ***black hole*** *angular velocity, so that this condition can also be read as [formula].*

(379) *Signals sent from inside the horizon will be captured by the* ***black hole*** *and fall towards the singularity.*

(380) *Since nothing can escape from* ***black holes,*** *this implies that in classical general relativity black holes last forever.*

(381) *Since nothing can escape from black holes, this implies that in classical general relativity* ***black holes*** *last forever.*

(382) *The theorem can be expressed saying that the surface area of the* ***black hole*** *(Eq. (3.140)) can never decrease*

(383) *He found that* ***black holes*** *can slowly evaporate.*

(384) *The basic idea is that the law of increase of* ***black hole's*** *surface area theorem looks very much like the second law of thermodynamics for the increase of entropy*

(385) *In this framework, the thermodynamics of a* ***black hole*** *can be studied defining a temperature.*

(386) *In classical relativity, if a* ***black hole*** *is placed in a radiation bath, it continually absorbs radiation without ever coming to equilibrium.*

(387) *However, in 1974 Hawking proved theoretically that, when quantum effects are taken into account,* ***black holes*** *radiate with a thermal spectrum.*

(388) *We can now compute the entropy of a Schwarzschild* ***black hole****.*

(389) *Since the area of a* ***black hole*** *is from Eq. (3.140) with J=0J=0: [formula] one derives the energy lost by the black hole through thermal radiation: [formula] and define the black hole entropy as: [formula].*

(390) *The ratio of a macroscopic quantity AA to a microscopic quantity ħħ ensures that* ***black holes*** *have large entropy.*
(391) *This is in accord with the so-called "no hair" ideas about many different internal states of a* ***black hole*** *corresponding to the same external gravitational field, and that information is lost from the outside world once black holes are formed.*
(392) *This is in accord with the so-called "no hair" ideas about many different internal states of a black hole corresponding to the same external gravitational field, and that information is lost from the outside world once* ***black holes*** *are formed.*
(393) *Note that during* ***black hole*** *emission of thermal quanta, MM decreases by energy conservation, and so does*
(394) *A phenomenological interpretation to the "evaporation" process is the creation of "virtual" particle-antiparticle pairs in the gravitational field of the* ***black hole*** *just outside the event horizon.*
(395) *The* ***black hole's*** *gravitational energy is used to create the "virtual" pair, and the lack of recombination yields that the escaping particle carries away some of the black hole's mass.*
(396) *The black hole's gravitational energy is used to create the "virtual" pair, and the lack of recombination yields that the escaping particle carries away some of the* ***black hole's*** *mass.*
(397) *The net effect as seen by an observer at a great distance is the emission of particles by the* ***black hole****, known as Hawking radiation, accompanied by a reduction in the black hole's mass.*
(398) *The net effect as seen by an observer at a great distance is the emission of particles by the black hole, known as Hawking radiation, accompanied by a reduction in the* ***black hole's*** *mass.*
(399) *The energy rate of the* ***black hole*** *evaporation can be calculated from the black-body formula: [formula] and the associated time scale [formula]: [formula].*
(400) *From these equations, it is clear that for stellar mass* ***black holes****, Hawking evaporation is totally unimportant: only for masses M≤1015 gM≤1015g is the timescale shorter than the age of the universe.*
(401) *Primordial* ***black holes*** *formed with M=1015 kgM=1015kg would evaporate at present time; the temperature of their thermal emission would be about 1011 K1011K, and their evaporation would produce gamma-ray pulses*
(402) *The galactic center is an intense radio source known as Sagittarius A*, likely a supermassive* ***black hole***
(403) *Observations of stellar and gas motions near the center of some spirals strongly suggest the presence of supermassive* ***black holes****.*
(404) *The presence of a* ***supermassive black hole*** *is even more evident in active galaxies: they show very luminous compact nuclei at radio and X and gamma ray frequencies, whose power cannot be interpreted in terms of stellar activity.*
(405) *But such neutron-star remnants have their own upper mass limit of Mns 2.1M⊙, beyond which the gravity becomes so strong that not even the combination of nuclear forces and degenerate pressure from neutrons can prevent a further collapse, this time forming a* ***black hole****.*
(406) *Actually, in many simulations, this rebound stalls, and the material recollapses to directly form a black hole, without much of an external explosion; there is now some evidence from large-scale surveys that some uncertain fraction of massive stars may indeed just end their lives by such collapse into a* ***black hole*** *without a visible supernova explosion.*

(407) *Neutron stars above this limiting mass will again collapse, this time forming a* ***black hole.***

(408) ***Black holes*** *are objects for which the gravity is so strong that not even light itself can escape.*

(409) *This the origin of the term "****black hole****."*

(410) *Stellar-mass black holes with M 2.1M⊙ form from the deaths of massive stars.*

(411) *However, in a binary system, the presence of a* ***black hole*** *can be indirectly inferred by observing the orbital motion (visually or spectroscopically via the Doppler effect) of the luminous companion star.*

(412) *Moreover, when that companion star becomes a giant, it can, if it is close enough, transfer mass onto the* ***black hole****, as illustrated in Figure 20.3.*

The luminosity of such black-hole accretion disks can be very large.

(413) *For a* ***black hole*** *of mass M accreting mass at a rate M˙ to a radius R that is near bh a a the Schwarzschild radius Rbh, the luminosity generated is GMM˙R*

(414) *By studying the resulting high-energy radiation, we can infer the presence and basic properties (mass, even rotation rate) of* ***black holes*** *in such binary systems, even though we cannot see the black hole itself.*

(415) *By studying the resulting high-energy radiation, we can infer the presence and basic properties (mass, even rotation rate) of black holes in such binary systems, even though we cannot see the* ***black hole*** *itself.*

(416) *As the* ***black holes*** *spiraled ever closer toward merger, the waves steadily increased in frequency, which when translated into sound gave a characteristic "chirp."*

(417) *When analyzed in comparison to computer simulations of such mergers, the chirp pattern indicated the black holes in this first-detected merger were quite massive, about 29M⊙ and 36M⊙, several times higher than the most-massive* ***black holes*** *inferred in the high-mass X-ray binaries discussed in Section 20.5.*

(418) *When analyzed in comparison to computer simulations of such mergers, the chirp pattern indicated the* ***black holes*** *in this first-detected merger were quite massive, about 29M⊙ and 36M⊙, several times higher than the most-massive black holes inferred in the high-mass X-ray binaries discussed in Section 20.5.*

(419) *The final, merged* ***black hole*** *was inferred to be about 62M⊙, with the extra 3M⊙ converted to energy in the emitted gravitational wave, which for a brief few milliseconds of the merger represented some 50 times the luminosity of all the stars in the observable universe!*

(420) *Unlike the merger of* ***black holes****, which owing to their restriction against any light emission had no detected electromagnetic (EM) signatures, this neutron-star merger was also detected in EM spectral bands ranging from gamma rays and X-rays, to ultraviolet and optical light, to infrared and even radio waves.*

(421) *26.4 Supermassive* ***Black Hole*** *at the Galactic Center*

(422) *Application of this and the semimajor axis into Kepler's third law then gives an extremely large mass, Mbh ≈ 4×106M⊙ for the central attracting object, which is inferred to be a supermassive black hole (SMBH). Exercise 1 illustrates the process for this mass determination.*

(423) *For this reason, a star that has collapsed down within the Schwarzschild radius is called a* ***black hole.***

(424) *Although the interior of a* ***black hole****, inside the event horizon, is a region that is forever hidden from us on the outside, its properties may still be calculated.*

(425) *A nonrotating* ***black hole*** *has a particularly simple structure.*

(426) *At the center is the, a point of zero volume and infinite density where all of the* ***black hole's*** *mass is located.*

(427) *A Trip into a **Black Hole**.*
(428) *An object as bizarre as a **black hole** deserves closer scrutiny.*
(429) *Imagine an attempt to investigate the **black hole** by starting at a safe distance and reflecting a radio wave from an object at the event horizon.*
(430) *Starting from rest at a great distance, she volunteers to fall freely toward a 10 M **black hole***
(431) *Furthermore, the coordinate speed of light becomes slower as she approaches the **black hole**, so the signals travel back to us more slowly.*
(432) *How does all of this appear to the brave astronomer, freely falling toward the **black hole**?*
(433) *Because gravity has been abolished in her local inertial frame, initially she does not notice her approach to the **black hole**.*
(434) *The gravitational pull on her feet (nearer the **black hole**) is stronger than on her head, and the variation in the direction of gravity from side to side produces a compression that is even more severe.*
(435) *Were she not indestructible, our astronomer would be torn apart by the tidal force while still several hundred kilometers from the **black hole**.*
(436) *It is also possible that a neutron star in a close binary system may gravitationally strip enough mass from its companion that the neutron star's self-gravity exceeds the ability of the degeneracy pressure to support it, again resulting in a **black hole.***
(437) *Intermediate-mass **black holes** (IMBHs) may exist that range in mass from roughly 100 M to in excess of 1000 M (or perhaps even greater than 104 M).*
(438) *It is not entirely clear how these objects might form, although the correlation of IMBHs with the cores of globular clusters and low-mass galaxies suggests that they may develop in these dense stellar environments either by the mergers of stars to form a supermassive star that then core-collapses, or by the merger of stellar-mass **black holes.***
(439) ***Supermassive black holes** (SMBH) are known to exist at the centers of many (and probably most) galaxies.*
(440) *Although a primordial **black hole** could be this size, it is almost impossible to imagine packing Earth's entire mass into so small a ball.*
(441) ***Black Holes** Have No Hair!*
(442) *Whatever the formation processes of **black holes**, they are certain to be very complicated.*
(443) *Another complication is the fact that all stars rotate, and therefore so will the resulting **black hole**.*
(444) *Remarkably, however, any black hole can be completely described by just three numbers: its mass, angular momentum, and electric charge*
(445) ***Black holes** have no other attributes or adornments, a condition commonly expressed by saying that "a black hole has no hair."*
(446) *Black holes have no other attributes or adornments, a condition commonly expressed by saying that "a **black hole** has no hair."*
(447) *There is a firm upper limit for a rotating **black hole's** angular momentum given by [formula].*
(448) *If the angular momentum of a rotating **black hole** were to exceed this limit, there would be no event horizon and a naked singularity would appear, in violation of the Law of Cosmic Censorship.*
(449) *The maximum angular momentum for a solar-mass **black hole** is [formula].*

(450) *We should expect that many stars will have angular momenta that are comparable to max, and so vigorous (if not maximal) rotation ought to be common for stellar-mass* ***black holes.***

(451) *The structure of a maximally rotating* ***black hole*** *is shown in Fig. 17.22.*

(452) *Near a rotating* ***black hole****, frame dragging is so severe that there is a nonspherical region outside the event horizon called the where any particle move in the same direction that the* ***black hole*** *rotates.*

(453) *Near a rotating* ***black hole****, frame dragging is so severe that there is a nonspherical region outside the event horizon called the where any particle move in the same direction that the black hole rotates.*

(454) *These solutions were obtained by ignoring the effects of the mass of the collapsing star, so the vacuum solutions do not describe the interior of a real* ***black hole.***

(455) *The possibility of using a* ***black hole*** *as a tunnel connecting one location in spacetime with another (perhaps in a different universe) has inspired both physicists and science fiction writers.*

(456) *Most conjectures of spacetime tunnels are based on vacuum solutions to Einstein's field equations and as such don't apply to the interiors of real* ***black holes****.*

(457) *For a real nonrotating* ***black hole****, all worldlines end at the inescapable singularity, where spacetime is infinitely curved.*

(458) *The story is somewhat different for a rotating* ***black hole***

(459) *In fact, it is difficult for an infalling object to hit the singularity in a rotating* ***black hole.***

(460) *But just as for nonrotating* ***black holes****, any attempt to pass the smallest amount of matter or energy along such a route would cause the passageway to collapse, thereby pinching it off.*

(461) *In summary, it seems extremely unlikely that* ***black holes*** *can provide a stable passageway for any matter or energy, even for idealized cases*

(462) *For more realistic situations, any voyager attempting a trip through a* ***black hole*** *would end up being torn apart by the singularity*

(463) *Stellar-Mass* ***Black Hole*** *Candidates.*

(464) *Extraordinary claims require extraordinary proof, and proof of the mere existence of* ***black holes*** *has been difficult to obtain.*

(465) *The best hope of astronomers has been to find a* ***black hole*** *in a close binary system.*

(466) *If the* ***black hole*** *in such a system is able to pull gas from the envelope of the normal companion star, the angular momentum of their orbital motion would cause a disk of gas to form around the black hole*

(467) *If the black hole in such a system is able to pull gas from the envelope of the normal companion star, the angular momentum of their orbital motion would cause a disk of gas to form around the* ***black hole***

(468) *Only the gravity of a neutron star or a* ***black hole*** *can produce X-rays in a close binary system, and in fact the compact object in most X-ray binaries is believed to be a neutron star.*

(469) *The first* ***black hole*** *to be tentatively identified in this way is Cygnus X-1, near the bright star Cygni in the middle of the swan's neck. Another promising candidate is LMC X-3, an X-ray binary in the Large Magellanic Cloud.*

(470) *As more evidence accumulates, it seems that astronomers have finally found the extraordinary proof required for the existence of a* ***black hole.***

(471) *The* ***black holes*** *of classical general relativity last forever.*

(472) *If a* ***black hole*** *coalesces with any other object, the result is an even larger black hole.*

(473) *If a **black hole** coalesces with any other object, the result is an even larger black hole.*
(474) *As the **black hole's** mass declines, however, the rate of emission increases.*
(475) *The final stage of a **black hole's** evaporation proceeds extremely rapidly, releasing a burst of all types of elementary particles.*
(476) *The lifetime of aprimordial **black hole** prior to its evaporation is quite long, [formula].*
(477) *Since the age of the universe is 13.7 billion years, this process is of no consequence for **black holes** formed by a collapsing star.*
(478) *However, a primordial **black hole** with a mass of roughly 1 7 1011 kg would evaporate in about 13 billion years.*
(479) *Thus primordial **black holes** with this mass should be in the final, explosive stage of evaporation right now and could possibly be detected.*
(480) *To date, measurements of the cosmic gamma-ray background at this energy have not detected anything that can be identified with the demise of a nearby primordial **black hole.***
(481) *Although there is as yet no positive evidence that primordial **black holes** exist, this negative result is still important.*
(482) *It implies that on average there cannot be more than 200 primordial **black holes** with this mass in every cubic light-year of space.*
(483) *Composition enrichment histories and gradients have significant implications for galaxy formation theories, as will be discussed in Section 26.2. Supermassive **Black Holes**.*
(484) *Observations of stellar and gas motions near the centers of some spirals strongly suggest the presence of supermassive **black holes.***
(485) *A precise determination based on kinematic studies of the triple nucleus of M31 (Fig. 25.13) gives a mass of 1 4 0 9 108 M for the central supermassive **black hole.***
(486) *Another (although less precise) method of determining the mass of a central **supermassive black hole** uses the velocity dispersion to obtain a mass estimate via the virial theorem.*
(487) *It is important to note that central **supermassive black holes** are not restricted to late-type galaxies.*
(488) *For example, based on observations made using the Hubble Space Telescope, it appears that the giant elliptical galaxy M87 (NGC 4476) also contains a 3 2 0 9 109 M **black hole.***
(489) *(M87 is also known to have a relativistic jet that is believed to be powered by the supermassive **black hole** at its center; see Fig. 28.10.)*
(490) *As the number of known central supermassive **black holes** has increased, it has become possible to look for relationships between the black holes and their host galaxies.*
(491) *As the number of known central supermassive black holes has increased, it has become possible to look for relationships between the **black holes** and their host galaxies.*
(492) *A very intriguing and useful correlation has been discovered between the mass of the **supermassive black hole** in a galaxy's center and the velocity dispersion of the stars within the galaxy.*
(493) *The velocity dispersion is measured for the stellar population near the **black hole.***
(494) *Correlations between the mass of **supermassive black holes** and other bulk galaxy parameters, such as the luminosity of the bulge, have also been uncovered.*

(495) *Apparently a fundamental link exists between the formation of the central **supermassive black hole** in a galaxy and the overall formation of the galaxy itself.*

(496) *Many neutron stars and some **black holes** may, how- ever, acquire extra momentum in the explosion.*

The source domain of NATURAL PHENOMENON

(497) *Up high in the thin atmosphere something appears – a space capsule is descending, then another, and finally an armada of space capsules, **raining down on the planet surface.***

(498) *The Parker Solar Probe will also gather new knowledge about the **solar wind**, the flow of electrically-charged particles emitted by the Sun at high speeds*

(499) *Whether they could support life is less certain; each is **showered by more radiation** from their host star than any in our own system*

(500) *Their analyses show that the giant cosmic rings may be formed by huge and **hot gas winds** blowing out from the centres of galaxies.*

(501) *Massive stars burn out quickly, and when they die they **expel their gas as outflowing winds.***

(502) *The huge and **hot gas winds** may have formed after a galaxy had undergone a period of intense star formation in which stars are born and then die, exploding into violent supernovas.*

(503) *Instead, **space is constantly 'budding' new independent universes into existence**, all the time.*

(504) *Dark matter does not yet exist, but a mysterious dark field, the **'seed' of dark matter**, forms to permeate the entire universe.*

(505) ***Galaxies extinguished one by one.***

(506) *For a half-billion years after the formation of the Sun and its planets, so much **junk rained down on Earth** that heat from the persistent energy of impacts rendered Earth's atmosphere hot and our crust molten.*

(507) *We call this the "**solar wind,**" which takes the form of high-energy charged particles.*

(508) *It's a speck no brighter than a dim star, all but lost in the **glare of the Sun**.*

(509) *The bubble is produced by **solar winds** constantly blowing particles out of the peripheral region, so protecting our Solar System from harmful radiation.*

(510) *Analysing the data from the three probes, the scientists spotted a sudden change in pressure from the **solar wind** in 2014, and this allowed them to take a closer look at the boundary and get a more detailed image of its shape.*

(511) ***Stars** can be incredibly persistent, in theory **burning even for trillions of years**, far longer than the accepted life of the universe so far.*

(512) *Second-generation stars include up to 0.1% heavy elements, and **many of these are still burning today**, including at the centre of the Milky Way.*

(513) *When a black hole exceeds the Eddington limit, **the radiation pressure from the incoming matter becomes so intense that it blows gas and dust away again.***

(514) *Twins attract **ice cloud***

(515) *If looking farther away means looking farther into the past, and if there was a time in the distant past when the universe was basically one big all-encompassing fireball, then it should be possible to look so far away that you see a **part of the universe that is still on fire.***

(516) *We're not looking at parts of space that are any different, but rather at a time when **ALL of space was on fire.***

(517) *But how do we know for sure that the background light we detect is actually from the **primordial fireball**, and not from, say, some collection of weird faraway stars or something?*

(518) *When the particle jets and s**upernova fires** have calmed, the resulting mass will become a giant ellipsoidal collection of old and dying stars.*

(519) *High-mass stars play a crucial role in shaping not only their parental clouds, but also the interstellar medium on kpc scales, enriching it with heavy elements and influencing the dynamics of their surround- ing environments via the energy they release through radiation and **stellar winds***

(520) *It was shown that most of the emission arising from the ER was thermal in origin from silicate dust, presumed to have condensed out in the red **supergiant wind** of the progenitor star.*

(521) *Giant exoplanets on 1-3 day orbits, known as ultra-hot Jupiters, induce detectable **tides** in their host stars.*

(522) *The energy of those **tides** dissipates at a rate related to the properties of the stellar interior.*

(523) *This finding is evidence of **tidal orbital decay** during the main-sequence lifetime.*

(524) *We calculate that the damping and mechanical work performed by the Alfvén waves are sufficient to power the heating and acceleration of the fast **solar wind** in the inner heliosphere.*

(525) *We calculate that the damping and mechanical work performed by the Alfvén waves are sufficient to power the heating and acceleration of the fast **solar wind** in the inner heliosphere.*

(526) *In situ measurements have shown that the **solar wind** does not cool adiabatically as it expands away from the Sun (1).*

(527) *The speed and temperature profiles of the fast **solar wind** (which has the highest speeds when measured far from the Sun) require mechanical forcing and direct heating of the plasma after it leaves the solar atmosphere (2–4).*

(528) *Protons in the slowest **solar wind** cool roughly adiabatically as they convect away from the corona, whereas protons in faster solar wind cool more slowly (5).*

(529) *Plasma that cools slower than adiabatically requires that additional heating occurs after the fast **solar wind** leaves the corona.*

(530) *Alfvén waves are transverse magneto-hydrodynamic waves that travel along the magnetic field and are thought to play a role in the processes that heat the **solar wind** (3, 7, 8).*

(531) *The energy budget of the **solar wind** indicates that energy provided by Alfvén waves makes a greater contribution to stream acceleration at higher solar wind speeds (4).*

(532) *The acceleration of the **solar wind** streams with slower speeds can be explained without requiring a contribution from Alfvén waves (9).*

(533) *By contrast, Alfvén waves do contribute to the dynamics of fast **solar wind** (10, 11).*

(534) *The substantial wave energy associated with these large Alfvénic fluctuations close to the Sun, and their gradual evolution with heliocentric distance, indicate that they could play a role in heating and acceleration of the **solar wind** (15, 16)*

(535) *Close to the Sun, spacecraft measurements show an overall decrease in speed of all **solar wind.***

(536) *Al- ternative approaches separate the **solar wind** into percentiles or by combining measurements taken at several heliocentric distances, but these cannot isolate the evolution of individual plasma streams over large distances.*

(537) *This requires identifying conjunctions when the spacecraft intersect the same **solar wind** stream*

(538) *Parker crossed the stream when it was at 13.3 solar radii from the Sun, around the outer edge of the Alfvén region, defined as the region where the* ***solar wind*** *is slower than the local Alfvén wave speed.*

(539) *The same plasma stream was subsequently crossed by Solar Orbiter at 127:7R⊙, where the* ***solar wind*** *is much faster than the Alfvén speed.*

(540) *The blue shaded region indicates the fast s****olar win****d stream that we study.*

(541) ***Solar wind*** *properties measured by Parker and Solar Orbiter across source surface longitude.*

(542) *They are consistent with other remote observations that showed that the sonic critical point, where the* ***solar wind*** *speed exceeds the local sound speed, is located at 1.9 R⊙ (32), near our modeled value of 2.2R⊙ (Fig. 4C).*

(543) *These Alfvénic structures can therefore provide the necessary additional heating and acceleration as the* ***solar wind*** *moves through the corona and inner heliosphere.*

(544) *The first evaluation of the map and* ***the clouds*** *within it does not show a clear indication of the spiral arms in the Milky Way.*

(545) *From our map of* ***clouds (****Fig. 3, right), we select regions with densities above 100 cm−3, corresponding to the molecular phase, and provide a catalogue of large* ***molecular clouds*** *in the Milky Way*

(546) *We deliver accurate distance estimates to the* ***centre of each cloud****, the uncertainty of the estimated distance, the extent of the cloud, its mean density and standard deviations, and its association with known star-forming regions and spiral arms.*

(547) *We deliver accurate distance estimates to the centre of each cloud, the uncertainty of the estimated distance, the extent of the* ***cloud****, its mean density and standard deviations, and its association with known star-forming regions and spiral arms.*

(548) *For each* ***cloud*** *from Dame et al. (1986) with a matching LOS to a cloud centre from our map, we use the BESSEL distance calculator to obtain all probable distance estimates for that*

(549) *For each cloud from Dame et al. (1986) with a matching LOS to a* ***cloud*** *centre from our map, we use the BESSEL distance calculator to obtain all probable distance estimates for that*

(550) *While we were able to extract a clear sample of* ***clouds*** *with reliable densities from the map, distinguishing real cavities from regions of underestimated densities due to missing data remains difficult.*

(551) *The most prominent* ***dense clouds*** *manifest at galactocentric radii of around 3 and 4 kpc.*

(552) *Two dense regions around X = −3, one on the Y = 0 line and another slightly below it, correspond well with our dominant* ***clouds*** *in that region, although at slightly different distances*

(553) *Additionally, some* ***clouds*** *identified in the first quadrant of our map align with those in Marshall et al*

(554) *There are several* ***clouds*** *underneath masers belonging to Scutum–Centaurus–OSC, the Norma arm, and the spurs in the inner Galaxy; however, it is difficult to establish a one-to-one relation due to the crowding in both masers and cloud distributions.*

(555) *Additionally, while there seems to be an offset between the masers and our* ***clouds*** *at the location of the Outer Arm in the outer Galaxy (red points), our clouds seem to turn and follow the potential spiral arm pattern.*

(556) *They provide physical properties of the* ***clouds*** *including, but not limited to, 3D positions, surface density, physical size, and mass*

(557) *We compare our results to their* ***cloud*** *distribution in Fig. 7.*

(558) *We first over-plot our* ***clouds*** *as contours on their molecular cloud distribution on the face-on view of the Galaxy.*
(559) *There is a wide circular void in the CO* ***clouds*** *of Miville-Deschênes et al. (2017), which are particularly noticeable around the Galactic centre, extending for about 4 kpc, which is due to limitations in the kinematic distance estimates at these regions.*
(560) *Ordinarily, the pair quickly recombines, but the* ***"tidal" gravitational force*** *across a Compton wavelength (GMmr3)λc(r3GMm)λc can work to separate the two particles; the work done is (GMmr3)λc2(r3GMm)λc2, and if it is larger than 2mc22mc2, annihilation does not take place.*
(561) *Finally, the bottom panel of Figure 1.2 gives a similar graphic for the range of speeds, from our own slow walk, through others (bicycles, cars, airplanes) we experience, then ranging to speeds of the Moon, Earth, and Sun in their orbits, to* ***stellar winds*** *and supernovae, and finally ending with the maximum possible speed, the speed of light, c = 3 × 108 m/s.*
(562) ***Coronal holes*** *arise in open field regions between such closed loops, allowing the gas to escape into the outward solar wind expansion.*
(563) *Coronal holes arise in open field regions between such closed loops, allowing the gas to escape into the outward* ***solar wind*** *expansion.*
(564) *The resulting* ***solar wind*** *expands outward, past the Earth and even all the other planets, extending to distances greater than 100 au, until it is finally stopped by running into the local interstellar medium.*
(565) *As illustrated in Figure 24.2, the magnetosphere formed by the Earth's own magnetic field shields our planet and its atmosphere from a direct hit by the solar wind, instead just channeling any* ***solar wind*** *plasma toward the magnetic poles, where interaction with Earth's atmosphere forms the aurorae, also known as the northern and southern lights.*
(566) *As illustrated in Figure 24.2, the magnetosphere formed by the Earth's own magnetic field shields our planet and its atmosphere from a direct hit by the* ***solar wind****, instead just channeling any solar wind plasma toward the magnetic poles, where interaction with Earth's atmosphere forms the aurorae, also known as the northern and southern lights.*
(567) *In contrast, the lack of a strong field on Mars has allowed the* ***solar wind*** *to gradually erode its now much thinner atmosphere.*
(568) *Owing to* ***tidal effects*** *from the galaxy, along with the shear from its differential rotation, the stars eventually disperse and mix with other stars (called "Population I") in the disk*
(569) *In many cases, it seems likely that the irregular form is because we are actually viewing two colliding galaxies, with then their mutual t****idal interaction*** *warping and disrupting whatever symmetric forms may have existed in the source galaxies.*
(570) *When galaxies do collide, their overall pattern of stars become strongly distorted by the mutual* ***tidal interaction*** *of the overall mass of the two galaxies; but the individual stars are too widely separate to collide, and so just pass by each other.*
(571) *This behavior is quite curious; does it imply that even* ***light is frozen in time?***
(572) ***Light is indeed frozen*** *in time at the Schwarzschild radius.*
(573) *She is* ***frozen in time,*** *held for eternity like a fly caught in amber.*
(574) *These differential* ***tidal forces*** *increase in strength as she falls.*
(575) *Were she not indestructible, our astronomer would be torn apart by the* ***tidal force*** *while still several hundred kilometers from the black hole.*
(576) *These solutions to Einstein's field equations have no event horizon (permitting two-way trips through the wormhole) and involve survivable* ***tidal forces.***

(577) ***Winds of hot stars*** *are radiation-driven, primarily due to the opacity of the many weak lines of iron.*
(578) *This process is feedback-controlled since the* ***strong winds*** *extract angular momentum and slow the star down but extra complication arises from how angular momen- tum is transported within the stellar interior*
(579) *Stars more massive than approximately 20 M⊙ have s****tellar winds*** *that are strong enough to to remove their hydrogen envelope and expose the helium core.*
(580) *They break down for Wolf-Rayet stars, which have high luminosities that drive optically* ***thick winds*** *(Hillier, 2011; Sander et al., 2015) and for red supergiants whose atmospheres are sufficiently extended that spherical geometry is essential (Gustafsson et al., 2008).*
(581) *At the higher end of this temperature range, however, models for optically* ***thick winds*** *may also be required.*
(582) *The simplest method is to pick the atmosphere with the closest surface gravity and temperature to that provided from the stellar model, although for stars with optically* ***thick winds*** *such as Wolf-Rayet stars a more complex match needs to be performed.*
(583) *It is most vital for the stars with optically thick winds because for these stars there is no hard boundary or edge to the star but a transition from the interior into the s****tellar wind*** *(e.g. Groh et al., 2014) making the definition of surface conditions difficult.*
(584) *Originally, the Hubble sequence was thought to represent an evolutionary path, where rotation progressively flattened galaxy-size* ***gas clouds*** *and caused the formation of spiral arms.*
(585) *It expands, galaxies are created and might collide with each other, stars are born by contraction of huge* ***gas and dust clouds.***
(586) *According to our present knowledge stars ar created by the contraction of huge* ***clouds of gas and dust.***
(587) *These* ***clouds*** *have been formed by interstellar matter.*
(588) *One example of an interstellar* ***gas and dust cloud,*** *where the birth of new stars can be observed, is the Orion Nebula*
(589) *The* ***gas clouds*** *consist mainly of atomic and molecular hydrogen gas.*
(590) *As we look along this disk plane of the MW, the background/foreground superposition of many stars and* ***giant molecular clouds*** *(GMCs) makes it very difficult to discern the overall structure, the way we readily can from the face-on view of M51 in Figure 21.5.*
(591) *Most of this broadening arises from cumulative Doppler shift along the line of sight from the motion associated with the orbit of distinct* ***gas clouds*** *about the galactic center; it thus provides a key diagnostic for determining the Galaxy's "rotation curve" as a function of galactic radius R with the Sun.*
(592) *Extension of this 21 cm method to longitudes 90 degree < l < 270 degree that point outward to larger galactic radii R > Ro is complicated by the need now to have an independent estimate of the distance to an observed* ***hydrogen cloud.***
(593) *When neutral* ***hydrogen clouds*** *or relatively young objects such as O and B stars, H II regions, and galactic (open) clusters are used as tracers of Galactic structure, a emerges, giving the disk the appearance of a pinwheel.*
(594) *The interstellar* ***gas and dust clouds*** *that plagued Kapteyn's attempts at determining the overall structure of the Galaxy and that are clearly evident in Fig. 24.1 are primarily located near the midplane and found preferentially in the spiral arms.*
(595) ***gas and dust clouds*** *exist in the Milky Way with a range of masses, temperatures, and densities.*
(596) *It is from these* ***clouds*** *that new stars are ultimately formed.*

(597) *A unique feature in the inner regions of the Galaxy that is most easily observed at the 21-cm wavelength of H I is the 3-kpc expanding arm, a* ***gas cloud*** *that is moving toward us at roughly 50kms.*

(598) *Rather than being driven away from the center in an explosive event that would require an unrealistic 1052 J of energy, the* ***gas cloud*** *is merely in a very elliptical orbit about the Galactic center resulting from gravitational perturbations from the bar.*

(599) *One problem immediately arises when the nature of spiral structure is considered; material arms composed of a fixed set of identifiable stars and* ***gas clouds*** *would necessarily "wind up" on a timescale that is short compared to the age of the galaxy.*

(600) *A spiral density wave in the disk forms the spiral arms that are the regions of active star formation out of the* ***cold clouds of gas and dust***

(601) *In contrast, any* ***gas clouds*** *in the ISM of each galaxy do collide, with the resulting compression increasing the density of gas and dust, and thus often triggering a strong burst of new star formation.*

(602) *In the disk of the Milky Way the typical rate of extinction in visible wavelengths is 1 magnitude kpc 1, although that value can vary dramatically if the line of sight includes distinct nebulae such as giant* ***molecular clouds.***

The source domain of FORCE

(603) ***Laser light photons push the probes*** *towards Proxima Centauri.*

(604) *These* ***particles produce auroras when they strike*** *Earth's atmosphere.*

(605) *This quintessence (blue arrows) has so far been* ***repulsive*** *and currently dominates over gravity (purple arrows), so expansion is accelerating.*

(606) *The* ***quintessence loses power****.*

(607) *Ever since the Big Bang, however, the* ***quintessence has remained consistently repulsive****, and in the past five billion years it has accelerated the expansion.*

(608) *Current universe contraction theories predict a 'Big Crunch' where* ***everything eventually shatters*** *in a sort of reverse Big Bang, taking a similar amount of time.*

(609) *The* ***universe will shatter****.*

(610) *"The key to the universe's fate may be* ***dark energy****, which is believed to* ***pull against gravity****."*

(611) *Dark matter is invisible, but it is widely assumed to exist, because we can see it* ***pulling at all visible matter.***

(612) *When a big star in the Cassiopeia constellation burned out, it released its outer layers of gas and* ***shattered in a violent explosion****.*

(613) *The* ***quasar*** *designated as J1342+0928* ***is powered by a massive black hole*** *with a mass corresponding to 800 million Suns.*

(614) ***The extreme pressure might shatter the neutrons****, turning them into a compact soup of their building blocks: up and down quarks.*

(615) ***Our planet pulls at the Sun****, and the two objects orbit a common centre of gravity.*

(616) *However, astronomers can spot them by means of the radial velocity method: e****xoplanets' masses pull slightly at their star,*** *so if a star seems to be 'staggering', it is probably orbited by one or more planets.*

(617) ***The Moon pulls at the ocean,*** *and tidal forces can be strong enough to shift rock in the ground.*

(618) *The cosmic cobweb is* ***magnetic***

(619) ***Twins attract ice cloud***

(620) *The universe is expanding again 4. In about 1 billion years, long before matter and energy might converge to one point as in the Big Bang theory, expansion will resume, and a new universe will emerge.*

(621) *Nearly all astronomers think that the universe unfolded from the Big Bang and has been expanding ever since.*
(622) *Take that theory, rewind it, and you have the basis of Big Bang theory, which tracks the growth of the universe back to its beginning, 13.8 billion years ago.*
(623) *Ever since the Big Bang, however, the quintessence has remained consistently repulsive, and in the past five billion years it has accelerated the expansion.*
(624) *Current universe contraction theories predict a 'Big Crunch' where everything eventually shatters in a sort of reverse Big Bang, taking a similar amount of time. Paul J. Steinhardt and his colleagues have their more imminent prediction: an expiration date of 165 million years.*
(625) *According to the Big Bounce theory, the contraction ends in a point of no extension, a singularity with all matter and energy, after which a new Big Bang gives birth to the next universe.*
(626) *The multiverse theory dates back to the 1980s, when theoretical physicists were trying to solve problems concerning the Big Bang theory, and came up with a brand new theory, the inflation theory.*
(627) *The Big Bang theory says that the early universe contained an extremely hot and dense soup of elementary particles and that the universe has since expanded and is still doing so.*
(628) *The inflation theory goes a little further back in time and tries to describe the universe that led to the Big Bang: a cold, empty universe that expanded extremely rapidly in a fraction of a second.*
(629) *Was there a dark Big Bang?*
(630) *That is the short and simple version of the beginning of everything, the theory of the Big Bang.*
(631) *And now researchers from the University of Texas at Austin have introduced a groundbreaking new theory: the Big Bang had a dark twin.*
(632) *And crucially, astronomers can search for the Big Bang's dark twin using new telescopes.*
(633) *Everything is from the Big Bang.*
(634) *However, we still have no observations from the birth of the universe – the earliest data is from 380,000 years after the Big Bang – and it has never been possible to detect dark matter or to determine from what particles it may be built.*
(635) *They believe that the answer to the dark matter conundrum is that the dark matter formed not in the Big Bang but some time afterwards.*
(636) *Twenty minutes after the Big Bang, the universe had expanded so much that temperatures had dropped dramatically – and the dark field changed phase.*
(637) *If successful, they will be able to see exactly how the narrative of the ordinary Big Bang needs to be expanded to include a later twin for dark matter.*
(638) *People always assume that everything formed simultaneously in one Big Bang, but who really knows*
(639) *Dark matter formed in the Big Bang*
(640) *The particles that make up dark matter formed in the Big Bang – we just haven't managed to detect them yet, because they are difficult to observe.*
(641) *The universe suddenly expand dramatically in the Big Bang.*
(642) *The common explanation is that dark matter formed along with everything else in the Big Bang.*
(643) *After inflation and up until about 20 minutes after the Big Bang, the first protons and neutrons and later the first large deuterium and helium atomic nuclei form.*

(644) *That realisation paved the way for the Big Bang model, according to which the universe originated 13.8 billion years ago and has expanded at different speeds during its existence.*

(645) *Our model of the Big Bang has been repeatedly confirmed by different observations, but it actually leaves some major questions unanswered.*

(646) *According to the Big Bang theory, the universe was born 13.8 billion years ago.*

(647) *To a close approximation, nuclear fusion during the first few minutes after the big bang left behind one helium nucleus for every ten hydrogen nuclei (which are, themselves, simply protons).*

(648) *During the first half million years after the big bang, a mere eyeblink in the fourteen-billion-year sweep of cosmic history, matter in the universe had already begun to coalesce into the blobs that would become clusters and superclusters of galaxies.*

(649) *The first stars that lit up after the Big Bang burned out long ago, but their remains are still alive.*

(650) *The first stars formed from the hydrogen and helium that originated in the Big Bang 13.8 billion years ago.*

(651) *The first stars originated a few hundred million years after the Big Bang, when big clouds of hydrogen and helium collapsed inward.*

(652) *The Big Bang produced a lot of hydrogen, a great deal of helium, and a little lithium – the three lightest elements.*

(653) *So back at the start, a first generation of stars must have consisted solely of the early universe's available hydrogen, hundred million years after the Big Bang, when big clouds of hydrogen and helium collapsed inward.*

(654) *The first generation was born a few hundred million years after the Big Bang.*

(655) *The second generation originated from the remains of the first stars, and the third generation stars are considered to have formed from some 2.8 billion years after the Big Bang up until today.*

(656) *Computer models of star formation in the early universe suggest that hydrogen and helium from the Big Bang probably collected into huge and dense gas clouds that created 'superstars' with masses of 100+ times that of the Sun.*

(657) *The biggest black holes have been gaining weight since shortly after the Big Bang, allowing them to obtain a total mass of some 10 billion times that of the Sun.*

(658) *The oldest supermassive black holes formed when matter collapsed shortly after the Big Bang.*

(659) *Scientists have discovered a new object in space that could help explain how quasars and supermassive black holes originated in the early years after the Big Bang.*

(660) *Named GNz7q, the object was born 750 million years after the Big Bang that took place 13.8 billion years ago, so in what astronomers know as the universe's cosmic dawn.*

(661) *THE UNIVERSE COULD BE FULL OF PRIMORDIAL MAGNETISM FROM THE BIG BANG*

(662) *Did Big Bang magnetism light up the first stars?*

(663) *If they exist, they must have originated during the Big Bang, and they may have caused the very first stars to light up.*

(664) *If so, that magnetism must have been in place immediately after the Big Bang – and could have played an important role in the universe's distribution of matter.*

(665) *Otherwise it may have been primordial magnetism from the Big Bang which is the answer.*

(666) *According to astronomers, this original magnetism could either have originated during the first microsecond after the Big Bang, or over the next 380,000 years, when all matter was a turbulent plasma of loose protons and electrons.*
(667) *They get one answer by using a snapshot of cosmic background radiation in the universe 380,000 years after the Big Bang and then calculating forwards to the modern universe.*
(668) *At that time, we will finally know whether some of the magnetism that we experience everywhere around us actually dates all the way back to the birth of the universe in the Big Bang.*
(669) *If so, the magnetism must have been generated during (or shortly after) the Big Bang.*
(670) *SEEING THE BIG BANG.*
(671) *There's a popular picture of the Big Bang as some kind of explosion—a sudden conflagration of light and matter from a single point that billowed out through the universe.*
(672) *The Big Bang wasn't an explosion within the universe, it was an expansion of the universe.*
(673) *The logic of the Big Bang theory is pretty simple.*
(674) *In any case, when we talk about the Big Bang theory, what we're really saying is: based on our observations of the present expansion and its history, we can conclude that there was a time when the universe was, everywhere, much hotter and denser than it is today.*
(675) *The story of how we went from thinking about the Big Bang to seeing it is a classic tale of serendipitous discovery in cosmology.*
(676) *In 1965, a physicist named Jim Peebles at Princeton University was doing the calculations, dialing back the cosmic expansion, and coming to the startling conclusion that radiation from the Big Bang should still be streaming through the universe today*
(677) *An attendee of Peebles's talk, Ken Turner, went to visit the Arecibo radio telescope, and on the flight back, had a chat with fellow astronomer Bernard Burke about how cool it would be to detect this Big Bang radiation.*
(678) *At which point, I can only assume Penzias had to have a bit of a sit-down, because now he knew that he and Wilson had just become the first human beings to see the actual Big Bang.*
(679) *A singularity is what most people think of when they think of the Big Bang: an infinitely dense point from which everything in the universe exploded outward.*
(680) *one that goes from Big Bang to Big Crunch and back again forever*
(681) *And though the standard Big Bang theory of steady expansion from a singularity has some major problems (which we'll get to imminently), we can still learn a lot about how physics works by thinking about what might have happened if the standard theory is right.*
(682) *Those bubbles expanding through the cosmos marked the Epoch of Reionization ("re-" because the gas had been ionized during the Big Bang at the beginning, and was now being ionized again by the stars).*
(683) *On each of those worlds, creatures like, or unlike, ourselves might be detecting the faint hum of the cosmic microwave background, deducing the existence of the Big Bang and the staggering knowledge that our shared cosmos does not go back forever in time, but had a first moment, a first particle, a first star.*
(684) *Throw it too slowly, it goes up for a bit, slows down, stops, and falls down again: that's like a universe where there's enough matter (or a weak enough initial Big Bang expansion) that gravity wins and recollapses the universe.*

(685) *This was 1917, half a century before widespread acceptance of the Big Bang theory, when the cosmos was still largely thought to be static and unchanging.*

(686) *Furthermore, recently adopted missions to Venus by ESA (EnVision,Ghail et al. (2016)) and NASA (Veritas and DAVINCI; Smrekar et al. (2020), Garvin et al. (2022)) will also have a* ***knock-on effect*** *on exo-Venus research.*

(687) *For scenarios S = 1.3 to S = 1.5, however, the radiation is more efficient at* ***penetrating down to the surface****.*

(688) *The atmospheric production of CO2 is dominated by the catalytic recycling of CO by the hydroxyl radical (OH; Yung & DeMore 1998), which* ***becomes more powerful*** *with the growing HOX abundances as solar constant values rise.*

(689) *These were used to infer the existence of massive black holes as large as 107.5−108.1 M⊙ at z & 8.5, only 600 million years after the* ***Big Bang.***

(690) *As discussed in Chapter 32, it is now thought that this initial seed of small-amplitude variations in density is provided by quantum fluctuations in the very early phases of the* ***Big Bang*** *itself!*

(691) *It is also possible that a neutron star in a close binary system may* ***gravitationally strip*** *enough mass from its companion that the neutron star's self-gravity exceeds the ability of the degeneracy pressure to support it, again resulting in a black hole.*

(692) *For many years it was believed that all* ***elliptical galaxies had been largely stripped of any dust or gas*** *that had not yet formed into stars or, alternatively, that star formation had proceeded very efficiently during the earliest history of these galaxies, depleting all available gas.*

(693)

The source domain SUPERNATURAL PHENOMENON

(694) *Most of the exoplanets astronomers have spotted are very different from Earth − some are huge gas planets, and* ***others are frozen ice giants****.*

(695) ***Gas planets are the universe's giants***

(696) *30% of* ***exoplanets are gas giants*** *like Saturn and Jupiter.*

(697) *Physicists have named these ultra-heavy dark matter particles '****darkzillas****' after the film monster Godzilla.*

(698) *We can even quantify what "hot and dense" means, and trace the history of the universe backward from the cool and pleasant cosmos we are enjoying now to a pressure-cooker* ***inferno*** *so extreme it shatters our understanding of the laws of physics.*

(699) *The first essay I ever wrote on the universe, in the early 1980s, was titled "****The Galaxy and the Seven Dwarfs****," referring to the Milky Way's diminutive nearby family.*

(700) *The star Proxima Centauri is a* ***red dwarf****, one of the smallest and coldest types of star.*

(701) *Aided by modern detectors, and modern theories, we have probed our cosmic countryside and revealed all manner of hard-to-detect things:* ***dwarf galaxies****, runaway stars, runaway stars that explode*

(702) *In any reliably surveyed volume of space,* ***dwarf galaxies*** *outnumber large galaxies by more than ten to one.*

(703) *Since then, the tally of local* ***dwarf galaxies*** *has been counted in the dozens*

(704) *While full-blooded galaxies contain hundreds of billions of stars,* ***dwarf galaxies*** *can have as few as a million, which renders them a hundred thousand times harder to detect*

(705) *Images of* ***dwarf galaxies*** *that no longer manufacture stars tend to look like tiny, boring smudges.*

(706) *Those* ***dwarfs*** *that do form stars are all irregularly shaped and, quite frankly, are a sorry-looking lot.*

(707) ***Dwarf galaxies*** *have three things working against their detection: They are small, and so are easily passed over when seductive spiral galaxies vie for your attention.*
(708) *But since* ***dwarfs*** *far outnumber "normal" galaxies, perhaps our definition of what is normal needs revision.*
(709) *You will find most (known)* ***dwarf galaxies*** *hanging out near bigger galaxies, in orbit around them like satellites.*
(710) *The two Magellanic Clouds are part of the Milky Way's* ***dwarf family****.*
(711) *Most computer models of their orbits show a slow decay that ultimately results in the hapless* ***dwarfs*** *getting ripped apart, and then eaten, by the main galaxy.*
(712) *The Milky Way engaged in at least one act of cannibalism in the last billion years, when it consumed a* ***dwarf galaxy*** *whose flayed remains can be seen as a stream of stars orbiting the galactic center, beyond the stars of the constellation Sagittarius.*
(713) *The system is called the* ***Sagittarius Dwarf****, but should probably have been named Lunch*
(714) *Some stars reassemble to form blobs that could be called* ***dwarf*** *galaxies.*
(715) *Did they evolve into the familiar* ***dwarf galaxies*** *of today?*
(716) *They were investigating the* ***dwarf galaxy*** *RCP 28, located some 7.5 billion light years from Earth.*
(717) *The oldest of these are* ***red dwarfs****, which still exist at the centre of the Milky Way and in star clusters orbiting our galaxy.*
(718) *But if some of the first stars were smaller than the Sun, a star type known as a* ***red dwarf****, then they could still exist somewhere in our galaxy.*
(719) *So astronomers have been searching – for four decades now – but have not yet managed to find a red dwarf star with the right composition – no heavy elements – to qualify as a first-gen star.*
(720) *TRILLIONS OF YEARS* ***RED DWARF****: The smallest live the longest*
(721) *A red dwarf is the smallest and most common of star types in the universe*
(722) *BILLIONS OF YEARS* ***YELLOW DWARF****: The Sun is middle-aged.*
(723) *Stars that are about the same size as the Sun are known as* ***yellow dwarfs.***
(724) *They are bigger than* ***red dwarfs****, but live much shorter lives – about 10 billion years.*
(725) *Stars of 1-8 solar masses normally swell into red giants before they shrink into* ***white dwarfs*** *and die.*
(726) *Initially the scientists believed that they were observing the explosion of a heavy and compact old star, a* ***white dwarf****, which sucks up gas and other material from a neighbouring star in a double star system.*
(727) *A long time ago in a* ***dwarf galaxy*** *far, far away, a drama of cosmic dimensions is unfolding.*
(728) *The black hole swallows the majority of the star, but flings the rest away in a giant arch of red-hot material which briefly flashes brightly enough to outshine all other light from the stars of the* ***dwarf galaxy.***
(729) *Eight hundred and fifty million years later, in June 2020, astronomers on Earth are searching the skies for signs of exploding supernovas, and almost by chance aim their telescopes at the* ***dwarf galaxy*** *where suddenly they see the flash of the star's death struggle.*
(730) *The new discovery of a medium-sized black hole in a* ***dwarf galaxy*** *was largely the result of happenstance.*
(731) *Astronomers were using two optical telescopes in Hawaii to search for supernovas – exploded stars – when they spotted an unexpected light flash from the* ***dwarf galaxy*** *850 million light years away.*

(732) *The intensity of the flash increased very rapidly, and during the following weeks the scientists were able to expand their view of the* ***dwarf galaxy*** *by inviting other telescopes to record the light burst, including the Hubble Space Telescope*

(733) *The fact that the medium-sized black hole was found in a dwarf galaxy makes it still more interesting, because it supports the theory that supermassive black holes form through dwarf galaxy fusion.*

(734) *The fact that the medium-sized black hole was found in a dwarf galaxy makes it still more interesting, because it supports the theory that supermassive black holes form through dwarf galaxy fusion.*

(735) *If each dwarf galaxy were to contribute a medium-sized black hole, the black holes might swallow each other to form even bigger black holes and so produce the result that we more commonly observe today: supermassive black holes at the centres of major galaxies.*

(736) *Scientists now know that they need to search dwarf galaxies for light flashes that characterise the encounters between stars and medium-sized black holes*

(737) *The Vera C. Rubin telescope will have a large mirror of 8.4 metres, so will be better equipped to study the light from these faint dwarf galaxies*

(738) *The new Vera C. Rcbin observatory in Chile is dce to be completed in 2024. gt shocld be able to captcre thocsands of light flashes from stars as they are swallowed by black holes in distant dwarf galaxies.*

(739) *In the earyw universe, burnt-out stars in dwarf galaxies collapse, 'giving birth' to small black holes that combine into medium-sized holes.*

(740) *But how did the first stars originate in the earliest dwarf galaxies?*

(741) *According to the theory, a swarm of dwarf planets are also captured.*

(742) *The common centre of gravity between them could have attracted Planet 9 and a swarm of smaller dwarf planets from other stars in the cluster from which the twins were born.*

(743) *At the same time, astronomers will be looking for dwarf planets in similar orbits, which the twin theory also predicts.*

(744) *In 2022-2032, the Vera C. Rubin telescope in Chile is to map out a series of heavenly bodies in the Solar System, such as dwarf planets.*

(745) *These PBHs have already been used to provide solutions for* ***dwarf galaxy*** *anomalies (Silk 2017), act as the seeds of high- redshift massive structures and massive black holes (Mack et al. 2007; Carr & Silk 2018; Cappelluti et al. 2022; Liu & Bromm 2023), and to explain the excesses seen in the cosmic X-ray background (Ziparo et al. 2022) and radio wave background (Mittal & Kulkarni 2022)*

(746) *APOGEE does not survey the sky uniformly, but rather it targets cool stars, particularly* ***red giants****, through multiple components of the Galaxy including thin and thick discs*

(747) *In this system, a 0.9 M⊙ G* ***dwarf*** *is orbited by a 1.1 MJup planet within 0.8 d*

(748) *The system is constituted by a solar analogue (G3, ~1 M⊙) and a massive (3.7 MJup)* ***gas giant*** *on a 1.4 d orbit*

(749) *Moreover, when that* ***companion star becomes a giant****, it can, if it is close enough, transfer mass onto the black hole, as illustrated in Figure 20.3.*

(750) *How these* ***behemoths*** *formed remains an open question.*

(751) *They break down for Wolf-Rayet stars, which have high luminosities that drive optically thick winds (Hillier, 2011; Sander et al., 2015) and for* ***red supergiants*** *whose atmospheres are sufficiently extended that spherical geometry is essential (Gustafsson et al., 2008).*

(752) *The most luminous cool stars, large **red giants**, and supergiants are also large in radius.*
(753) *These problems lead to difficulties in defining the effective temperature of **red supergiants**, which are still to some degree debated theoretically and observationally (Levesque et al., 2006; Davies et al., 2013).*
(754) *The number of stars varies from 108108 for **dwarf galaxies** to 10141014 for giant galaxies.*
(755) *The sizes of galaxies range from d**warf galaxies**, which have diameters between 0.1 and 1 kpc, to giant elliptical galaxies, which can reach diameters of up to 200 kpc.*
(756) *irregular galaxies are either **dwarfs** with 107÷8 MΘ or large galaxies up to 1010 MΘ.*
(757) *A supernova Ia occurs when a binary system of a **white dwarf** and another star (e.g. a red giant) comes so close together (below the Roche limit) that the white dwarf can attract matter from its companion.*
(758) *A supernova Ia occurs when a binary system of a white dwarf and another star (e.g. a red giant) comes so close together (below the Roche limit) that the **white dwarf** can attract matter from its companion.*
(759) *The energy released during these processes is about 1044 J, which is more than sufficient to let the **white dwarf** explode*
(760) *Since the mass of the **white dwarf** is known, the explosion energy can be calculated.*
(761) *Neutron stars are even more bizarrely extreme than **white dwarfs.***
(762) *With a mass typically about twice that of the Sun, they have a radius comparable to a small city, Rns ≈ 10 km, about a factor 600 smaller than even a **white dwarf,** implying a density that is about 108 times higher, and a surface gravity more than 105 times higher.*
(763) *But their overall properties can be well estimated by a procedure for treating neutron degeneracy in a way that is quite analogous to that used in Sections 19.4 and 19.5 for **white dwarfs** supported by electron degeneracy, just substituting now the electron mass with the neutron mass, me → mn ≈ mp, and setting Z/A = 1.*
(764) *Note again that, as in the case of an electron-degenerate **white dwarf,** this neutron-star radius also decreases with increasing mass.*
(765) *For analgous reasons that lead to the upper mass limit for **white dwarfs,** for sufficiently high mass the neutrons become relativistic, leading now to an upper mass limit for neutron stars (cf. Eq. (19.7)) that scales as [formula] where again the factor 1.1 comes from detailed calculations not covered here; apart from this and the factor (A/Z)2 = 4, this "Tolman–Oppenheimer–Volkoff" (TOV) limit is the same form as the Chandrasekhar limit for white dwarfs in Eq. (19.7).*
(766) *For analgous reasons that lead to the upper mass limit for white dwarfs, for sufficiently high mass the neutrons become relativistic, leading now to an upper mass limit for neutron stars (cf. Eq. (19.7)) that scales as [formula] where again the factor 1.1 comes from detailed calculations not covered here; apart from this and the factor (A/Z)2 = 4, this "Tolman–Oppenheimer–Volkoff" (TOV) limit is the same form as the Chandrasekhar limit for **white dwarfs** in Eq. (19.7).*
(767) *Our own Milky Way is part of a small cluster known as the "Local Group," which includes also the Andromeda galaxy, as well as several dozen smaller, "**dwarf" galaxies.***
(768) *At a distance of only 24 kpc from Earth and 16kpc from the center of the Milky Way, the **Sagittarius dwarf** spheroidal is the closest galaxy to Earth.*
(769) *The unusual globular cluster Centauri also seems to be the remnant of a **dwarf galaxy** that has been subsumed by the Milky Way.*

(770) *Some astronomers have suggested that those six most distant clusters may have been captured by the Milky Way or may be **dwarf spheroidal galaxies**, much as Cen and the Sagittarius dwarf galaxy may have been.*
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(772) *MACHOs that could supply the unseen mass may be in the form of **white dwarfs**, neutron stars, black holes, or less exotic red dwarfs or brown dwarfs.*
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(775) *That conclusion is also supported by searches for **white dwarfs** and small red dwarf stars, carried out using the Hubble Space Telescope.*
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(777) *Based on the faintest (deepest) searches yet conducted at the time of writing, **white dwarfs** can contribute no more than 10% of the dark matter halo's mass, and red dwarfs no more than 6% of it.*
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(779) *These can be enhanced by dust pro- duction (and hence increased opacity) in the cool atmospheres and remove the hydrogen envelopes of such stars, leaving the exposed cores that eventually cool to become **white dwarfs.***
(780) *Stars with initial masses below the 10–20 M⊙ range tend to form **white dwarfs** and sdBO stars from binary interactions.*
(781) *Broadly speaking, most stars can be divided into one of three groups which require different atmosphere model codes: hot stars, cool stars, and **white dwarfs***
(782) *At their simplest level, the atmospheres of **white dwarfs**, the stellar remnants that end the life of most main sequence stars, may be the simplest to model given that their high gravities lead to thin atmospheres.*

The source domain of JOURNEY

(783) *There are **passengers**, but not delicate humans, instead customised and hardy microbes.*
(784) ***Star travel is for microbes**, he says, because of key characteristics that robots never will have.*
(785) *George Church aims to equip his **tiny astronauts** with genes from the most robust of organisms here on Earth, so the space travellers can resist radiation, drought and heat, yet still reproduce extremely fast.*
(786) *Reduce the number of microbes and you can make each capsule even lighter. Church calculates that a billion **bioprobes** could be launched for the cost of one single Breakthrough Starshot mission – and they could reach far more exoplanets.*
(787) *The idea is to use the **solar sail as a parachute** and utilise the back pressure from light coming from the exoplanet's star, Proxima Centauri, reducing the probe's speed to land it gently enough on the planet's surface that the microbe payload is not destroyed.*
(788) ***Laser launches probes** towards stars.*
(789) *According to Church, we could **pre-equip the microbes** with genes that allow them a good chance both of surviving the long space journey and of thriving on the exoplanet.*

(790) *The **tiny astronauts** need to be prepared for anything, because the conditions on the exoplanet are unknown – that is precisely what they have been sent to investigate.*

(791) *Instead, the first stellar **astronauts will be microorganisms** – they're just genetically better equipped to take the lead.*

(792) *The **tiny space capsules release their cargo of microbes** that hopefully thrive on the exoplanet.*

(793) *Larger telescopes and those with a clear view from space can help with resolution, but other methods have yielded much of the **exoplanet gold rush.***

(794) *In the **Parker Solar Probe's quest** to venture ever closer to the Sun's atmosphere, the probe has reached incredible speeds – and will keep getting faster until Christmas*

(795) *The expansion of the universe means that **galaxies are all travelling away** from each other, like points on the surface of a balloon.*

(796) *No matter your position in the universe, other **galaxies will travel away**.*

(797) *The model predicted that e**xpansion will soon come to an end**.*

(798) *No Big Crunch is required for a doughnut universe; we just **ride back through the centre for another go around.***

(799) *According to most astrophysicists, **the way that galaxies and stars travel through the universe** cannot be explained solely by visible matter.*

(800) *In his honor, we call them the Large and Small Magellanic Clouds, and they are visible primarily from the Southern Hemisphere as a pair of cloudlike splotches on the sky, **parked beyond the stars.***

(801) *But **light turns out to be quite happy traveling through the vacuum of space**, devoid of any medium to carry it.*

(802) *The two brightest of the 1990s, comets Hale-Bopp and Hyakutake, were both from the Oort cloud and are **not coming back anytime soon.***

(803) *A **supermassive black hole is speeding out** of its home galaxy, leaving a star-strewn trail longer than the Milky Way is wide.*

(804) *The **quasar's light** t**ravelled for 13.1 billion years before arriving** at the big Gemini North telescope in Hawaii.*

(805) *After hundreds of millions of years, **a third star passes by, attracting away our twin,** while Planet 9 remains in our Solar System.*

(806) *Our own Milky Way shows evidence of having consumed dozens of smaller neighbors—we can still see trails of stars tracing giant arcs around our own galactic disk like **debris from an interstellar car crash.***

(807) *In order for vacuum decay to occur, there has to be a trigger—something that will **set the Higgs field wandering** far enough to find the part of the potential corresponding to the "true" vacuum and realize it would rather be there*

(808) *In situ measurements by spacecraft passing close to the Sun have found high-amplitude magnetic field rotations, termed **switchbacks** (12, 13).*

(809) *These **switchbacks** are characterized by a rapid change in the magnetic field direction, with near-constant magnetic field magnitude, accompanied by correlated velocity fluctuations.*

(810) ***Switchbacks** have been interpreted as large-amplitude Alfvén waves in the solar wind (12, 13); however, their definition and implied origin are debated.*

(811) *Although the **switchback** terminology suggests a change in polarity, the magnetic field does not always physically switch back to change its magnetic polarity.*

(812) *A test of that hypothesis would be to measure the energy contributions in a **switchback** patch at points near and far from the Sun.*

(813) *A suitable conjunction occurred in February 2022, when Parker and Solar Orbiter **crossed the same wind streamline** at the same solar latitude within 2 days of each other.*

(814) *The segment corresponds to source surface longitudes 120° to 125°, for which the Parker data show a patch of large-amplitude Alfvén waves, which we term a* ***switchback*** *patch.*

(815) *The* ***transit time for plasma*** *to travel from the location of Parker to Solar Orbiter during this period was 45 hours, estimated from the modeled velocity profile (27), which is similar to the measured delay between Parker exiting and Solar Orbiter entering the stream (~40 hours).*

(816) *The* ***switchback*** *patch corresponds to a local maximum in the solar wind speed and appears in both Parker and Solar Orbiter data taken over this longitude range.*

(817) *Equations 1 to 3 indicate that the* ***total energy transported through a cross-sectional area*** *Wr2 at center-of-mass velocity ucm is equal at both spacecraft.*

(818) *We conclude that the* ***switchback*** *wave energy at Parker is required to maintain energy conservation.*

(819) *In former times it was generally believed that stars and the whole universe were static objects which do not change in time but are constant forever* ***"from eternity to eternity".***

(820) *After traveling over a billion light years,* ***these waves arrived at Earth*** *and the LIGO detectors on September 17, 2015, one century after Einstein's publication of the General Relativity theory that predicted their existence.*

(821) *While distant galaxies show a redshift that implies they are* ***moving away*** *from us as part of the expansion of the universe, the mutual gravitational attraction between our Milky Way and the relatively nearby Andromeda galaxy is actually pulling them toward each other.*

(822) ***A Trip into a Black Hole.***

(823) *Since the* ***round trip*** *is symmetric, it is necessary only to find the time for either the journey in or out and then double the answer.*

(824) *Since the round trip is symmetric, it is necessary only to find the time for either the* ***journey in or out*** *and then double the answer.*

(825) *The possibility of* ***using a black hole as a tunnel connecting one location in spacetime with another*** *(perhaps in a different universe) has inspired both physicists and science fiction writers.*

(826) *Most conjectures of* ***spacetime tunnels*** *are based on vacuum solutions to Einstein's field equations and as such don't apply to the interiors of real black holes.*

(827) *Figure 17.23 depicts a* ***spacetime tunnel*** *called a (also known as an Einstein-Rosen bridge), f spacetime. The width of the throat is a minimum at the event horizon, and the "mouths" may be interpreted as opening onto two different locations in spacetime*

(828) *It is tempting to imagine this as* ***a tunnel****, and writers of speculative fiction have dreamed of white holes pouring out mass or serving as passageways for starships. However, it appears that any attempt to send a tiny amount of matter or energy (even a stray photon) through the throat would cause it to collapse.*

(829) *It is tempting to imagine this as a tunnel, and writers of speculative fiction have dreamed of white holes pouring out mass or* ***serving as passageways for starship****s.*

(830) *But just as for nonrotating black holes, any attempt to pass the smallest amount of matter or energy along such a route would cause the* ***passageway*** *to collapse, thereby pinching it off.*

(831) *In summary, it seems extremely unlikely that black holes can provide a stable* ***passageway*** *for any matter or energy, even for idealized cases*

(832) *However, in one case, NGC 4622, two arms are going one way and another arm is winding in the opposite direction; at least* ***one of these arms must be leading.***

(833) *It has also been suggested that M31 (Andromeda) has one tightly wound* ***leading arm.***

(834) *As discussed in previous sections, however, these generalisations do not account for the uncertainties and spread in* ***evolutionary pathways*** *which arise from binary interactions: a concern for a massive star population which, typically, has a binary fraction approaching unity (Sana et al., 2012; Moe and Di Stefano, 2017).*

(835) *This includes the various* ***evolution pathways*** *that are only possible as a result of binary inter- actions, the probability of supernovae disrupting multiple systems, and the relative flux of each source at relevant wavelengths.*

The source domain of OBJECT

(836) *Another third of the exoplanets are more like Neptune – freezing cold worlds on the* ***edge of their solar system****.*

(837) ***Kepler's trove of data*** *is still far from exhausted, and scientists continue to search for new discoveries.*

(838) *Nearly all astronomers think that* **the universe unfolded** *from the Big Bang and has been expanding ever since.*

(839) *Current universe contraction theories predict a '****Big Crunch****' where everything eventually shatters in a sort of reverse Big Bang, taking a similar amount of time.*

(840) *Paul J. Steinhardt and his colleagues have their more imminent prediction: an* ***expiration date of 165 million years***

(841) *That is hot enough for all matter to evaporate into its basic constituents, erasing all details of galaxies and black holes – and of course any life – before a* ***clean-slate universe*** *begins expanding again after about one billion years.*

(842) *A recycling universe is more appealing than* ***drawn-out decay****, or a last meal before destruction.*

(843) ***If it decayed****, it might change the laws of nature and possibly dissolve all matter.*

(844) *But all these features are typically not the case if you get* ***handed a random universe.***

(845) *The Kuiper belt is a* ***comet-strewn swath*** *of circular real estate that begins just beyond the orbit of Neptune, includes Pluto, and extends perhaps as far again from Neptune as Neptune is from the Sun.*

(846) *Wherever and whenever this happens,* **the locked moon** *shows only one face to its host planet.*

(847) ***The Sun's protective shield THE HELIOSPHERE*** *is the bubble of electrically-charged particles that are constantly flowing from the Sun through our Solar System.*

(848) *In 2019, observations demonstrated that the fields also exist on the largest of scales – in the cosmic cobweb, where* **threads of thin gases** *link galaxy clusters.*

(849) *A team of astronomers spotted magnetic field lines 50 million light years long along one of the* **gas threads.**

(850) *And this raised a fundamental question: are the universe's huge voids between the* ***gas threads*** *also full of magnetic fields?*

(851) ***Twins would have been a cosmic hoover.***

(852) *So the* ***Oort cloud*** *can be thought of as a* **vast hollow ball** *of objects engulfing the Solar System.*

(853) *So, for instance, light passing through a cloud of hydrogen will appear with a specific* **comblike pattern** *of dark lines when it's spread out across all the frequencies.*

(854) *If a star has a recognizable c***omblike pattern** *in its spectrum, but the lines appear at the "wrong" frequencies, that indicates the light from the star has been shifted by the star's motion.*

(855) *Rocky exoplanets in the inner habitable zone (IHZ) are at the c**utting edge** of exoplanetary research.*
(856) *For example, Salvador et al. (2023) reviewed water delivery and the **blanket effect i**nfluencing the giant steam atmosphere climate on early Venus.*
(857) *Due to UV shielding and **climate blanketing**, steam atmospheres shield UV and heat, which can directly affect photolysis and temperature-dependent gas-phase chemical reactions.*
(858) *The inversion serves as a barrier to upward mixing, which **acts as a 'lid'** on the troposphere, preventing mixing of water upwards into the stratosphere; this barrier effect is therefore weakened and results in greater H2O quantities reaching the stratosphere.*
(859) *However, the increased **HOX can act as a sink** for NOX and ClOX, and, importantly, this occurs in the regions where these species would otherwise strongly remove ozone catalytically, that is, in the lower stratosphere (NOX; Fig. 4. Vertical distribution profiles of the VMRs of O(1D) (a), HCl (b), the ClOX group (c; see also Fig. A.3), and CO (d) displayed in units of mol/mol for the biotic scenarios (see Fig. 1 for the colour legend).*
(860) *Since its explosion, SN 1987A has evolved from an SN dominated by the emission from the radioactive decay of 56Co, 57Co, and 44Ti in the ejecta to an SNR whose emission is dominated by the interaction of the SN blast wave with its surrounding medium (Larsson et al. 2011). The latter consists of an ER flanked by two outer rings (Burrows et al. 1995), possibly part of an **hourglass structure***
(861) *In Figure 3 we see a **red "skirt" growing with wavelength.***
(862) *For the F2550W filter, we find some structure in the **red skirt.***
(863) *From our map of **clouds (**Fig. 3, right), we select regions with densities above 100 cm−3, corresponding to the molecular phase, and provide a **catalogue of large molecular clouds** in the Milky Way*
(864) *Massive planets on extremely tight orbits, so-called ultra-hot Jupiters, are considered **unique tools** for probing some of the properties of stellar interiors via tidal interactions.*
(865) *At the beginning of the 20th century, the concept of the universe was essentially what William Herschel had proposed: **a flattened disk of stars and nebulae** with the Sun approximately at its center*
(866) *The signals these gravitational waves are expected to produce are **'pops'** and 'crackles' (it is difficult to say since very little can be assumed of their origin).*
(867) *The signals these gravitational waves are expected to produce are 'pops' and **'crackles'** (it is difficult to say since very little can be assumed of their origin).*
(868) *Since the total energy released in such a supernova Ia explosion is known from reliable model calculations, these supernovae can be used as good **standard candles** for distance determinations [8].*
(869) *It expands, **galaxies are created** and might collide with each other, stars are born by contraction of huge gas and dust clouds.*
(870) *Because we can resolve the Sun's surface and see that it is nearly round, it is perhaps not too hard to imagine that it is a real, physical object, albeit a very special one, **something we could, in principle, "reach out and touch."***
(871) ***Coronal** holes arise in open field regions between such closed loops, allowing the gas to escape into the outward solar wind expansion.*
(872) *The **"stiffness" of this neutron-degenerate core** leads to a "rebound" in the collapse, with gravitational release from the core contraction now powering an*

explosion that blows away the entire outer regions of the star, with the stellar ejecta reaching speeds of about 10 percent the speed of light!

(873) *The "stiffness" of this neutron-degenerate core leads to a* ***"rebound" in the collapse****, with gravitational release from the core contraction now powering an explosion that blows away the entire outer regions of the star, with the stellar ejecta reaching speeds of about 10 percent the speed of light!*

(874) *Actually, in many simulations,this* ***rebound stalls****, and the material recollapses to directly form a black hole, without much of an external explosion; there is now some evidence from large-scale surveys that some uncertain fraction of massive stars may indeed just end their lives by such collapse into a black hole without a visible superova explosion.*

(875) *And much as a sufficiently dense,* ***heavy ball could rip a hole in the trampoline,*** *for objects with mass concentrated within a radius Rbh, the bending becomes so extreme that it effectively punctures a hole in spacetime.*

(876) *This supported earlier suggestions that such high- mass elements, colloquially characterized as* ***"bling"*** *because of their prominent use as precious metals and in jewelry, are mostly produced in the "kilonovae" associated with such neutron-star mergers, rather than, e.g., in core-collapse supernovae of massive stars, as had been previously widely believed.*

(877) ***The tightness of the winding*** *of the arms can vary, and sometimes emanate from a central "bar."*

(878) *Such colliding systems are indeed often dubbed* ***"starburst galaxies."***

(879) *Although a primordial black hole could be this size, it is almost impossible to imagine* ***packing Earth's entire mass into so small a ball.***

(880) *If the black hole in such a system is able to pull gas from the envelope of the normal companion star, the angular momentum of their orbital motion would cause a* ***disk of gas*** *to form around the black hole*

(881) *When neutral hydrogen clouds or relatively young objects such as O and B stars, H II regions, and galactic (open) clusters are used as tracers of Galactic structure, a emerges, giving the disk the appearance of a* ***pinwheel****.*

(882) ***Baade's window*** *is 3 9 below the Galactic center, and the line of sight passes within 550 pc of the center.*

(883) *Because it is more difficult for light generated in the interior to escape from a star with a higher-opacity photosphere,* ***the star will tend to "puff up";*** *its radius will increase, with a corresponding decrease in effective temperature.*

(884) *Also, more than half of all elliptical galaxies harbor* ***discrete shells of stars.***

(885) *A single SFR measurement in an individual galaxy provides limited information on its past, and even less on the main history of the* ***stellar-mass assembly*** *in various galaxy populations.*

(886) *Such objects are caught in a transient,* ***starburst event,*** *likely driven by a merger having boosted both their SFR and their FIR luminosity.*

(887) *By analogy, similar high-redshift galaxies were first regarded as* ***starburst objects*** *until it became apparent that the data were suggesting a radically different picture.*

(888) *This effect is clearly seen in Herschel FIR-selected samples, where formally $\beta \sim -1$, but where only a tiny fraction of galaxies are detected at low stellar masses, i.e. those few really* ***starbursting ones*** *(Rodighiero et al., 2010, 2011).*

(889) *These i****nterrelationships are the imprints*** *of both internal and external physical processes such as gas consumption, feedback, winds/outflows, and gas accretion.*

(890) *The asymptotic giant branch (AGB) stars also have significant amounts of nucleosynthesis occurring in the* ***burning shells*** *surrounding the stellar core and are*

sites of significant production of carbon, nitrogen, and s-process elements (e.g. Herwig, 2005).

(891) *There is also strong evidence for self-regulation and quenching of* ***starbursts*** *due to star-formation powered galactic winds driving gas out of galaxies, which suggests that a high constant SFR cannot be sustained except in a very massive galaxy.*

The source domain of FOOD

(892) *The theory is known as the '**Big Slurp**', and involves the Higgs field and the Higgs boson, first discovered in 2012*

(893) *Or the **universe could be a doughnut**, as suggested by Prof. Dr. Thomas Buchert in Lyon, who also studies quintessence.*

(894) *No **Big Crunch** is required for a doughnut universe; we just ride back through the centre for another go around.*

(895) *A recycling universe is more appealing than drawn-out decay, or a **last meal before destruction.***

(896) *A Bounce or a **doughnut** would allow our universe another go – and raises the probability that this may not be its first time around.*

(897) *Eventually everything becomes one point, in a **'Big Crunch'**.*

(898) ***BIG SLURP:*** *The laws of nature suddenly change*

(899) *If the f**ormula for a habitable universe were like a recipe for a meal,** it would be the kind where the slightest deviation from the instructions will deliver a complete food failure.*

(900) *In a series of scientific articles jointly titled Multiverse Predictions for Habitability, the researchers have calculated what happens to the possibilities for life if you change the laws of nature a little, thereby **altering the recipe that can lead to life.***

(901) *The Big Bang theory says that the early universe contained an extremely **hot and dense soup of elementary particles** and that the universe has since expanded and is still doing so.*

(902) *And because the outer surface hardens, it cracks during the contraction, **a bit like a grape shrinking into a wrinkled raisin.***

(903) *They may have originated from other smaller galaxies, which the **Milky Way has swallowed.***

(904) *According to researchers, it is most likely that the universe is not twisted, with the 4D space forming t**he surface of a torus, (like a doughnut).***

(905) *An unknown extra dimension could also result in a closed universe with a finite extent, **like the surface of a doughnut.***

(906) *Our own spiral-shaped galaxy, the Milky Way, is named for its **spilled-milk appearance** to the unaided eye across Earth's nighttime sky.*

(907) *Most computer models of their orbits show a slow decay that ultimately results in the hapless dwarfs getting ripped apart, and then **eaten**, by the main galaxy.*

(908) ***The Milky Way engaged in at least one act of cannibalism*** *in the last billion years, when it consumed a dwarf galaxy whose flayed remains can be seen as a stream of stars orbiting the galactic center, beyond the stars of the constellation Sagittarius.*

(909) *The system is called the Sagittarius Dwarf, but **should probably have been named Lunch.***

(910) *What we know is that the matter we have come to love in the universe —t**he stuff of stars, planets, and life—is only a light frosting on the cosmic cake**, modest buoys afloat in a vast cosmic ocean of something that looks like nothing.*

(911) *The Dutch-born American astronomer Gerard Kuiper advanced the idea that in the cold depths of space, beyond the orbit of Neptune, there reside* ***frozen leftovers from the formation of the solar system.***

(912) *A****nything within that region is swallowed,*** *and cannot be seen.*

(913) *So the holes become supermassive from the start, efficiently* ***swallowing energy and matter*** *from their surroundings.*

(914) *The discovery suggests a new kind of ultracompact star that stretches physics to the limit,* ***squeezing matter into a quark soup****.*

(915) ***Quark soup fills the core***

(916) *The extreme pressure might shatter the neutrons, turning them into* ***a compact soup of their building blocks****: up and down quarks.*

(917) *The dying star expands massively, to perhaps a million times its original size, and* ***swallows any object in its vicinity*** *– including entire planets.*

(918) *Astronomers have previously observed evidence of dying stars either before or after they have* ***swallowed a planet*** *– but they have never captured the very moment in which an entire world is consumed.*

(919) *According to scientists, one particularly exciting aspect of the discovery is that they have to some extent been observing Earth's ultimate destiny, seeing what will happen when* ***the Sun burns out and starts to swallow the planets*** *of the inner Solar System – something which will occur in around five billion years.*

(920) ***The black hole swallows the majority of the star****, but flings the rest away in a giant arch of red-hot material which briefly flashes brightly enough to outshine all other light from the stars of the dwarf galaxy.*

(921) *After two years of detailed analyses, scientists now have no doubt what they were witnesseing –* ***a star being swallowed by a black hole.***

(922) *If each dwarf galaxy were to contribute a medium-sized black hole, t****he black holes might swallow each other*** *to form even bigger black holes and so produce the result that we more commonly observe today: supermassive black holes at the centres of major galaxies.*

(923) *Ordinary galaxies are full of gas, dust and stars, and at their centres, there is a* ***supermassive black hole that consumes the matter of the galaxy.***

(924) *At the centre of the observed galaxy there is already a black hole, and because it is in an early galaxy stage, where stars are formed at a very high speed, it will later become a supermassive black hole as* ***it swallows huge quantities of matter.***

(925) *When supermassive* ***black holes at the centres of galaxies swallow gas,*** *they emit luminous jet streams from their poles.*

(926) *We can even quantify what "hot and dense" means, and trace the history of the universe backward from the cool and pleasant cosmos we are enjoying now to a* ***pressure-cooker inferno*** *so extreme it shatters our understanding of the laws of physics.*

(927) ***Large galaxies tear apart and cannibalize smaller ones****; adjacent stellar systems combine with one another.*

(928) *Such laws are absolutely needed when we turn to simulations, to be* ***used as recipes.***

The source domain of CONFLICT

(929) *Up high in the thin atmosphere something appears – a space capsule is descending, then another, and finally* ***an armada of space capsules****, raining down on the planet surface.*

(930) *Such a* ***bioprobe invasion*** *sounds like science fiction: yet it could become reality within the foreseeable future, according to George Church, Professor of Genetics at Harvard University, the man behind the vision.*

(931) *The **laser cannons** used to propel the probes at launch do not need to be as powerful.*
(932) *The mission would be successful even if just a few of them **found their target**.*
(933) ***WRONG MASS DESTROYS** ATOMS*
(934) *In universes where the opposite is true, **electrons are captured by protons**, which then turn into neutrons.*
(935) *But scientists now have a theory for its origin, for which radio telescopes can try to find evidence: a **Dark Big Bang**.*
(936) *The new theory of a **Dark Big Bang** is particularly groundbreaking because dark matter develops in parallel with ordinary matter.*
(937) *For the **Dark Big Bang**, researchers will use the new Square Kilometre Array (SKA) radio telescope system which consists of thousands of antennas distributed across two sites, one in South Africa, the other in Australia, near Murchison some 800km north of Perth, WA.*
(938) *Physicists believe that they can use the SKA's measurements of gravitational waves to determine whether the **Dark Big Bang** really happened.*
(939) *Astrophysicists will use the Square Kilometre Array (SKA) to examine gravitational waves for evidence of the **Dark Big Bang**.*
(940) *Dark matter particles formed not along with all visible matter, but in a **Dark Big Bang**, and we should be able to detect its repercussions with new telescopes.*
(941) *If you do the math, you rapidly deduce that t**he gravity from ordinary matter could not win this battle by itself.***
(942) *To **combat this drag**, satellites in low orbit require intermittent boosts, lest they fall back to Earth and burn up in the atmosphere.*
(943) *Without **Jupiter's protection**, complex life would have a hard time becoming interestingly complex, always living at risk of extinction from a devastating impact.*
(944) *The most likely explanation is that it was **flung out of its galaxy like a slingshot**, which might happen if three massive black holes with the same gravity interact with each other.*
(945) *But as this **force is up against** the electrical repulsion between positively-charged protons in the atomic nucleus, there is a limit to how much matter can be compressed – even when subjected to the intense pressure at the centre of a star.*
(946) ***Planets have no defence** when a star runs out of fuel.*
(947) ***Warm rocky exoplanets within the habitable zone of Sun-like stars are favoured target**s for current and future missions.*
(948) *Due to UV shielding and climate blanketing, **steam atmospheres shield UV and heat**, which can directly affect photolysis and temperature-dependent gas-phase chemical reactions.*
(949) *With the increasing rate of HCl photolysis for S ≥ 1.3, the Cl abundances range from 1–100 pptv and **take over** as the primary atmospheric sink for N2O in the troposphere.*
(950) *During the first year of JWST operations, the iconic supernova SN 1987A, the closest optical SN in 400 yr (see McCray 1993; McCray & Fransson 2016 for reviews) was among **the first targets** selected for observation*
(951) *APOGEE does not survey the sky uniformly, but rather **it targets cool stars**, particularly red giants, through multiple components of the Galaxy including thin and thick discs*
(952) *As illustrated in Figure 24.2, the magnetosphere formed by the **Earth's own magnetic field shields our planet** and its atmosphere from a direct hit by the solar wind, instead just channeling any solar wind plasma toward the magnetic poles, where interaction with Earth's atmosphere forms the aurorae, also known as the northern and southern lights.*

(953) *As illustrated in Figure 24.2, the magnetosphere formed by the Earth's own magnetic field shields our planet and its atmosphere from a* ***direct hit by the solar wind****, instead just channeling any solar wind plasma toward the magnetic poles, where interaction with Earth's atmosphere forms the aurorae, also known as the northern and southern lights.*

(954) *During a* ***supernova detonation*** *(particularly of Type Ia), iron is ejected, enriching the interstellar medium.*

(955) *When neutral hydrogen clouds or relatively young objects such as O and B stars, H II regions, and galactic (open) clusters are used as* ***tracers of Galactic structure****, a emerges, giving the disk the appearance of a pinwheel.*

The source domain of ENTERTAINMENT

(956) *This is where Church's* ***decades of experience in gene technology enters the story****.*

(957) *In other words,* ***our universe seems to have been tuned for the very purpose of making our existence possible.***

(958) *We* ***won the cosmic lottery****.*

(959) *1* ***universe fine-tuned for life is an unlikely fluke***

(960) *In that case, our* ***universe is just one of those that happened to form with a lucky combination of laws of nature*** *that would make life possible.*

(961) *With a list like that, one could argue that* ***all the fun in the universe*** *happens between the galaxies rather than within them.*

(962) *Having resisted attempts to detect it directly on Earth for three-quarters of a century,* ***dark matter remains in play.***

(963) ***Like a multi-cushion billiard shot,*** *trajectories from one planet to another are common.*

(964) *When they crank up the contrast enough to get some color variation, astronomers can see that the CMB looks ever so slightly blotchy, as if someone did an abstract pointillism painting on the sky with a* ***brush as big around as the full Moon viewed from Earth.***

(965) *The few hundred thousand years before the end of the* ***fireball stage****, and the half million or so years right after, are extremely hard to observe.*

(966) *We nevitably reach a moment before which* ***all bets are off.***

(967) *During that time, the densities are high enough that* ***we expect extreme gravitational effects to be competing with the inherent fuzziness of quantum mechanics,*** *and we just don't know what to do in that scenario.*

(968) *In about four billion years,* ***Andromeda and our own Milky Way galaxy will collide, creating a brilliant light show.***

(969) *Stars could live and die, matter might slightly rearrange, but space was* ***space—it was just a background*** *on which other things happened.*

(970) *This became apparent to the astronomical community a few years later, when it turned out that f****uzzy smudges in the sky*** *previously called "spiral nebulae" were actually other galaxies*

(971) ***Alfvén waves are transverse magneto-hydrodynamic waves*** *that travel along the magnetic field and are thought to* ***play a role*** *in the processes that heat the solar wind (3, 7, 8).*

(972) *The substantial wave energy associated with these large Alfvénic fluctuations close to the Sun, and their gradual evolution with heliocentric distance, indicate that t****hey could play a role i****n heating and acceleration of the solar wind (15, 16)*

(973) *These* ***steam atmospheres are believed to play a crucial role i****n the early evolution of terrestrial planets and can eventually condense to form global oceans and hence lead to long-lived habitable conditions.*

(974) *Beyond 0.85 AU, the collapse of the* ***abiotic scenarios'*** *cold trap makes the abiotic and biotic thermal emission fluxes more difficult to distinguish*

(975) ***High-mass stars play a crucial role*** *in shaping not only their parental clouds, but also the interstellar medium on kpc scales, enriching it with heavy elements and influencing the dynamics of their surround- ing environments via the energy they release through radia- tion and stellar winds*

(976) *JWST images taken at day 12927 shows that the emission from the NE region of* ***the ring has fallen dramatically*** *and the strongest emission from the ring now arises from the SW region.*

(977) *However, the null detection of WNL dissipation in the WASP-19 and WASP-43 systems is meaningful, suggesting that the* ***theory might need some fine-tuning.***

The source domain of AGRICULTURE

(978) *Interplanetary space is so not-empty that* ***Earth****, during its 30 kilometer- per-second orbital journey,* ***plows through hundreds of tons of meteors per day****—most of them no larger than a grain of sand.*

(979) *Using analytic calculations, we explored the combination of* ***astrophysical seeding mechanisms*** *and Eddington accretion rates that can explain the observed objects.*

(980) *We then appeal to cosmological primordial* ***black hole (PBH) seeds*** *and show that these present an alternative path for the seeding of early structures and their baryonic contents*

(981) *We then appeal to cosmological primordial black hole (PBH) seeds and show that these present an alternative path for the* ***seeding*** *of early structures and their baryonic contents*

(982) *We then show that* ***PBHs can seed*** *a halo around themselves and assemble their baryonic (gas and stellar contents) starting at the redshift of matter-radiation equality ($z \sim 3400$).*

(983) *This is an* ***attractive alternative to seeding*** *these puzzling early systems.*

(984) *These high masses pose a crucial challenge for theoretical models of* ***black hole seeding*** *and growth due to the lack of cosmic time available for their assem- bly*

(985) *Observational issues notwithstanding, these puzzles have nat- urally prompted a flurry of research exploring the variety of* ***black hole seeding*** *and growth mechanisms allowed.*

(986) *In terms of astrophysical* ***black hole seeds****, low-mass seeds with a mass of ∼102 M⨀ can be created by the collapse of metal-free (Population III) stars in mini-haloes at high redshifts*

(987) *Finally,* ***high-mass seeds****, the so-called direct-collapse black holes (DCBHs; ∼105 M⨀), can form via supermassive star formation*

(988) *Theoretical works allow a range of solutions for the existence of such massive* ***black holes*** *at early epochs so far, including requiring high-mass* ***seeding mechanisms***

(989) *Theoretical anal- yses have also been used to demonstrate the need for both low- and high-mass* ***seeding mechanisms*** *(Fragione & Pacucci 2023), suggesting a continuum of seed masses rather than a bimodal distribution*

(990) *This means that individual* ***PBHs can essentially act as seeds*** *of structure formation*

(991) *Finally, starting at $z = 3400$, we present an illustrative formalism of how* ***these seeds might grow a halo*** *around themselves, in addition to building their gas content and stellar components yielding values of MBH/M$*$ $\sim 0.1-1.86$, in Sect. 3.1.*

(992) *We explored the growth of black holes assuming* ***seeding at a redshift*** *of zseed = 25 (corresponding to ∼134 Myr after the Big Bang) and seed masses ranging between 102−5 M⨀, and we allowed both Eddington-limited and super-Eddington accretion.*

(993) *Finally, we quote the primordial* ***black hole seed mass*** *for each object assuming continuous Eddington accretion onto this seed mass from a redshift of z = 3400. 2024a; Furtak et al. 2024; Greene et al. 2024), through high- ionization lines of nitrogen and neon (Maiolino et al. 2024b), or through X-ray counterparts in deep Chandra observations (Bogdán et al. 2024; Kovács et al. 2024).*

(994) *An explanation of these last 6 outliers with* ***low-mass seeds*** *requires invoking continuous super- Eddington accretion with fEdd = 2.1 that allows assembling MBH ∼108M⨀ asearlyasz∼10.3.*

(995) *Conversely, decreasing the* ***seeding*** *redshift would shift the mass function to higher masses.*

(996) *Primordial* ***black holes as seeds*** *of early galaxy assembly.*

(997) *Assembly of GHZ9 with primordial* ***black holes acting as the seeds of structure formation.***

(998) *As shown in the upper left panel for the earliest phase of the simulations at a redshift z = 27.30, one also* ***requires a small initial seed of density*** *fluctuations, which are then amplified by the gravitational attraction.*

(999) *As discussed in Chapter 32, it is now thought that this initial* ***seed of small-amplitude*** *variations in density is provided by quantum fluctuations in the very early phases of the Big Bang itself!*

The source domain of LIQUID

(1000) *The resulting heat will* ***dissolve all matter****, making galaxies and black holes disappear.*

(1001) *But if* ***the Higgs field were water in a glass****, its surface would be tilted*

(1002) *According to the Big Slurp theory, t****he universe is unstable, as if the water in a glass were tilted.***

(1003) *That is hot enough for all* ***matter to evaporate into its basic constituents,*** *erasing all details of galaxies and black holes – and of course any life – before a clean-slate universe begins expanding again after about one billion years.*

(1004) *This* ***phase transition can be compared to water boiling*** *and going from a liquid to a gaseous state*

(1005) *The University of Texas researchers believe that* ***bubbles similarly formed in the dark field.***

(1006) *Eventually,* ***the field 'boiled over' in an explosion of small and large bubbles*** *that make up the particles which we know today as dark matter.*

(1007) ***Dark field starts to bubble.***

(1008) *Gradually the phase 4 transition affects the dark field so strongly that it* ***boils over in an explosion of dark bubbles.***

(1009) *Astronomers now agree that when matter gets close enough to black holes, it no longer follows a straight line, but rather starts to circulate, l****ike water approaching the drain in your sink.***

(1010) *Perhaps the most exotic happenings between (and among) the galaxies in the vacuum of space and time is t****he seething ocean of virtual particles****— undetectable matter and antimatter pairs, popping in and out of existence.*

(1011) *Traveling up to a thousand miles per second, these p****articles stream through space*** *and are deflected by planetary magnetic fields.*

(1012) *While you can't breathe at those altitudes, some atmospheric molecules remain—enough to slowly **drain orbital energy** from unsuspecting satellites.*
(1013) *If magnetic field lines lead directly into a nebula, **the field can even generate rivers of gas** that are directed towards a specific region of the nebula.*
(1014) *We determined the source surface longitude separately for the plasmas observed at Parker and Solar Orbiter, by ballistically mapping the **stream trajectories** back to 2.5R⨀ above the Sun according to previous methods.*
(1015) *By examining how **mass flows onto a core**, the mechanisms driving their growth can be investigated.*
(1016) *Our MIRI images have not shown any evidence for such a point-like object. Cigan et al. (2019) detected with ALMA a **dust peak "blob"** that they attributed to either a pulsar wind nebula (PWN) or to a clump heated by 44Ti decay.*
(1017) *They argue that the most probable explanation is that the innermost region of dust and gas is heated by radiation from the NS, with early development of a PWN, and propose that the identified **central "blob"** is due to warm ejecta heated by the NS.*
(1018) *Figure 13 shows the ALMA images at 315 and 679 GHz with contours from the MIRI images and the position of the **warm "blob"** found by Cigan et al. (2019).*
(1019) *Figure 14 also includes contours from the ALMA 315 GHz image which probes cold dust, **the dust "blob"** at 679 GHz that Cigan et al. (2019) attribute to heating by the compact object, and the MRS [Ar II] 6.9853 μm line associated with the compact object*
(1020) *Note that the **dust "blob"** that Cigan et al. (2019) attribute to heating by the compact object can be seen in the third panel.*
(1021) *It is tempting to imagine this as a tunnel, and writers of speculative fiction have dreamed of **white holes pouring out mass** or serving as passageways for starships. However, it appears that any attempt to send a tiny amount of matter or energy (even a stray photon) through the throat would cause it to collapse.*
(1022) *However, a primordial **black hole with a mass of roughly 1 7 1011 kg would evaporate** in about 13 billion years.*
(1023) *Thus primordial black holes with this mass should be in the final, explosive stage of **evaporation** right now and could possibly be detected.*
(1024) *Some theories predict that matter and energy will continue to spread, eventually thinning out into a **barren icy darkness**.*
(1025) *Bright and beautiful and packed with stars, **galaxies decorate the dark voids of space like cities across a country at night.***
(1026) *Aided by modern detectors, and modern theories, we have probed our **cosmic countryside** and revealed all manner of hard-to-detect things: dwarf galaxies, runaway stars, runaway stars that explode, million-degree X-ray-emitting gas, dark matter, faint blue galaxies, ubiquitous gas clouds, super-duper high-energy charged particles, and the mysterious quantum vacuum energy.*
(1027) *Using these objects as tracers of the gravity field exterior to the most luminous parts of the galaxy, where no more visible matter adds to the total, Rubin discovered that their orbital speeds, which should now be falling with increasing distance out there in **Nowheresville**, in fact remained high.*
(1028) *The Kuiper belt is a **comet-strewn swath of circular real estate** that begins just beyond the orbit of Neptune, includes Pluto, and extends perhaps as far again from Neptune as Neptune is from the Sun.*
(1029) *That nebula had to be a stellar system separate from our galaxy, it had to be another "**island universe"**, another galaxy.*

(1030) *Observations using larger telescopes of a few nearby bright galaxies, like the Andromeda galaxy, began resolving them into huge conglomerations of stars, and distance measurements showed* ***they were "islands" separated from the Milky Way.***

(1031) ***The Stars in Our Neighbourhood***

(1032) *As we will learn, we live in a disk of stars, dust, and gas that severely impacts our ability to "see" beyond our* ***relative stellar neighborhood*** *when we look along the plane of the disk.*

(1033) *The slower rotation velocities of Im's imply that their values of the rotational angular momentum per unit mass are only about 10% of the value found for our Galaxy in the* ***solar neighborhood.***

(1034) *With the exquisite vision of the heavens provided by modern ground-based and space-based observatories, it has become increasingly apparent that galaxies are not* ***"island universes"****; they do not evolve in isolation.*

(1035) *If we calibrate our stellar models instead against* ***the Solar neighbourhood,*** *we should be using the recent cosmic abundance standard of Nieva and Przybilla (2012) derived from nearby B stars.*

The source domain of MOTION

(1036) *According to their '****Soft Bounce****' theory, a clean universe will emerge from the remains of the old.*

(1037) *Some theories predict that* ***matter and energy will continue to spread****, eventually thinning out into a barren icy darkness.*

(1038) *That would be the '****Big Bounce****'.*

(1039) *However, the scientists predicting the imminent contraction of the universe believe it will end in a different way, a* ***Soft Bounce****.*

(1040) *The* ***Soft Bounce*** *theory, which Paul J. Steinhardt presented with Anna Ijjas in 2019, predicts that the contraction will be slower, and would never reach a singularity.*

(1041) *But in a '****Big Bounce****' variation, a new universe could be born.*

(1042) ***Matter plunges straight into a black hole.***

(1043) *Until now, scientists have been unsure whether the matter would fall smoothly or* ***make a sudden plunge.***

(1044) *Thinking that this might prove Einstein's prediction, the Oxford team compared the collected data with computer simulations and models of l****ight falling into a black hole.***

(1045) ***Other Kuiper belt objects plunge all the way down to the inner solar system****, crossing planetary orbits with abandon.*

(1046) *One problem immediately arises when the nature of spiral structure is considered; material arms composed of a fixed set of identifiable stars and* ***gas clouds would necessarily "wind up"*** *on a timescale that is short compared to the age of the galaxy.*

(1047) *This process is feedback-controlled since the strong winds extract angular momentum and* ***slow the star down*** *but extra complication arises from how angular momentum is transported within the stellar interior*

The source domain of BUILDING

(1048) *It is like* ***getting a window into how stars formed*** *in the young universe.*

(1049) *The* ***Milky Way is our home***

(1050) *Researchers from the Massachusetts Institute of Technology (MIT) now believe to have discovered some of the oldest stars in the universe – in* ***the back yard of our own Milky Way.***

(1051) *The researchers believe that there may be many more ancient stars still to be discovered in the same* ***neighbourhood****.*

(1052) *Such regions often have unique filamen- tary structures, but in most cases, velocity gradients can be identified along these filamentary structures towards the c**entral hubs of clumps**.*

(1053) *Using the current observational techniques, resolving individual stars formed within their birth environment and their position within the large-scale galactic environments turns **the Milky Way into a unique laboratory.***

(1054) *The resulting **catastrophic "core collapse"** continues until the density becomes so high that the neutrons themselves become degenerate, at a core size of order a few tens of kilometers.*

(1055) *This has a concentration of galaxies along extended, **thin "walls,"** surrounding huge voids with few or no galaxies in the huge volume between the walls.*

(1056) *But there are particularly high concentrations at the intersections of the **walls.***

(1057) *For this reason, **a star that has collapsed down** within the Schwarzschild radius is called a black hole.*

(1058) *For this reason, lessons learnt from the great l**aboratories in nearby galaxies** should be kept in mind when extrapolating information to the whole galaxy scales.*

The source domain of LIGHT

(1059) *The light from the microbes causes other **microbes around them to switch on their biochemical light** as well, so a large part of the exoplanet's surface lights up.*

(1060) *The light from the microbes causes other microbes around them to switch on their biochemical light as well, so a large part of the **exoplanet's surface lights up.***

(1061) *We know that whatever it was that caused cosmic inflation eventually **turned off**, so perhaps a similar accelerated-expansion-causing field could have turned on since then, causing the acceleration we see today.*

(1062) *We know that whatever it was that caused cosmic inflation eventually turned off, so perhaps a similar accelerated-expansion-causing field could have **turned on** since then, causing the acceleration we see today.*

(1063) *With its unparalleled sensitivity, the **James Webb Space Tele- scope (JWST) has been crucial in shedding light on** the black hole population in the first billion years of the Universe.*

(1064) *and only over-massive **black holes may be able to outshine their hosts** and make them detectable by the JWST*

(1065) *New hot spots have continued to appear as the entire inner rim of the **ER has become lit up** by the interaction with the blast wave.*

(1066) *During these stages they emit radiation until they reach their final state, where they **go out**, either very fast after their explosion or as slowly cooling celestial objects.*

The source domain of CLEANLINESS/DIRTINESS

(1067) *According to their 'Soft Bounce' theory, a **clean universe** will emerge from the remains of the old.*

(1068) *A **recycling universe** is more appealing than drawn-out decay, or a last meal before destruction.*

(1069) *Whether or not that day arrives, I take comfort knowing that my chunk of cosmic debris is not alone as it **litters the space between the planets,** being joined by a long list of other chunks named for real and fictional people.*

(1070) *Note that the CLEAN algorithm does not enhance the resolution but replaces the **dirty beam** (with structure) with a "cleaned" beam fitted by a 2D Gaussian.*

(1071) *Note that the CLEAN algorithm does not enhance the resolution but replaces the dirty beam (with structure) with a* ***"cleaned" beam*** *fitted by a 2D Gaussian.*

(1072) *However, our position within the* ***dusty Milky Way*** *disc has long limited our understanding of the location and substructures of the Milky Way star-forming arms to the 2D plane-of-the-sky views and uncertain kinematic distances.*

The source domain of FINANCES

(1073) ***The energy budget of the solar wind*** *indicates that energy provided by Alfvén waves makes a greater contribution to stream acceleration at higher solar wind speeds (4)*.

(1074) *For the* ***energy flux budget*** *of the stream, we calculate that energy is conserved (within the measurement uncertainties), and that the dominant source of uncertainty is the variance of the stream over the source surface longitude.*

(1075) *The* ***chemical budget*** *of N2O in our model is dominated by (1) biological emission at the surface (held constant in all scenarios), (2) eddy mixing throughout the atmospheric column, which controls the rate of transport of (biomass) N2O from the lower levels up to the middle atmosphere, where it is destroyed in situ, (3) gas-phase removal via photolysis in the UV-B or/and reaction with electronically excited oxygen atoms mainly in the middle atmosphere and above, and (4) minor (<1%) in situ abiotic, gas-phase sources.*

(1076) *The result was what is called the* ***recession of galaxies****: galaxies have red shifted spectra, which means that they are moving away from our Galaxy.*

The source domain of HUNT

(1077) *This also suggests a weakening of the* ***cold trap*** *since it is less able to freeze out tropospheric water.*

(1078) *The lower stratospheric H2O in the abiotic scenarios that arises due to a lower* ***CH4 surface flux is less efficient at trapping the heat*** *travelling upwards, enabling the stratosphere to gradually heat.*

(1079) *Beyond 0.85 AU, the collapse of the abiotic scenarios'* ***cold trap*** *makes the abiotic and biotic thermal emission fluxes more difficult to distinguish*

(1080) *a total of 34 such black holes were identified through broad (∼1000−6000 km s−1) hydrogen balmer lines, which are assumed to* ***trace the kinematics*** *of gas in broad-line regions*

The source domain of SPORT

(1081) *And the closer it gets to the surface, the faster the probe will travel – so the* ***Parker Solar Probe is not done setting records*** *yet.*

(1082) *Remarkably, these single subatomic particles carry enough energy to* ***knock a golf ball f****rom anywhere on a putting green into the cup.*

(1083) *The planet* ***Jupiter****, with its mighty gravitational field,* ***bats out of harm's way*** *many comets that would otherwise wreak havoc on the inner solar system.*

(1084) ***THE INFINITE COSMIC TREADMILL.***

The source domain of FIRE

(1085) *Finally it gets so hot in the nebula that fusion processes begin, and* ***the stars are lit.***

(1086) *The absolute value of the specific SFR (sSFR ≡ SFR/Mstar) sets the clock of galaxy evolution (Peng et al., 2010), determining the growth rate of individual galaxies, hence controlling their lifetime* ***before they are quenched.***

(1087) *This complex story is also intimately linked to the presence of nuclear activity at the very center of massive galaxies: the accretion of gas onto SMBHs is indeed one of the potential* ***quenching*** *mechanisms that are invoked by models (Hopkins et al., 2008) and observations (detection of massive gas outflows in quasars at high-z Cicone et al., 2014).*

The source domain of GEOMETRY

(1088) *When we look up at the night sky,* ***stars are just little "points of light"****; but if we look carefully, we can tell that some appear brighter than others, and moreover that some have distinctly different hues or colors.*

(1089) *Indeed* ***they appear as mere "points"*** *because they are so far away that ordinary telescopes can almost never actually resolve a distinct visible surface, the way we can resolve, even with our naked eye, that the Sun has a finite angular size.*

The source domain of COMPETITION

(1090) ***Biology outcompetes technology.***

The source domain of HISTORY

(1091) *The time from this recombination to an age of about 100 Myr, when the first stars were born, is known as the* ***"dark ages."***

The source domain of JEWELRY

(1092) *HST images with equivalence to the R band (WFPC2/F675W, ACS/F625W, and WFC3/F675W; see Larsson et al. 2021) obtained between 1994 and 2009 revealed a* ***necklace of such hot spots****, nearly filling a lighted ring.*