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LENSCLEANING B0218+357

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Abstract. Radio observations of gravitational lenses are an important case in which the data reduction and scientific analysis should and need not be separated. We present results of LensClean applied to a lensed BL Lac object B0218+357 showing the power of combining the two tasks. LensClean produces improved maps and constrains the lens model by minimizing the residuals between the best lensed source emission model and the observed data. One important result is an estimate of the Hubble constant from the time-delay in the lens B0218+357.

Key words: quasars: individual: JVAS B0218+357 – gravitational lensing – distance scale – techniques: interferometric

1. INTRODUCTION

Radio interferometric Clean maps are no direct reproduction of the brightness distribution of the sky but a convolution with the Clean beam. For simple sources, models can be fitted directly to the uv-visibilities and then used for scientific analysis. For more complicated sources it is usually more appropriate to use Clean maps. In the context of gravitational lensing, it is possible to combine the tasks of producing maps with the subsequent analysis directly. In this way the scientific model is fitted directly to the observational data, avoiding systematic errors and difficulties in error estimations caused by the splitting into mapping and analysis.

2. GRAVITATIONAL LENSES

In the analysis of gravitational lenses, the scientific models consist of the brightness distribution of the unlensed source and the mass model of the lens. The best modeling approach for extended sources is to fix the lens model in order to fit the best source brightness distribution and then minimize the remaining residuals in an outer loop in order to fit the mass model of the lens.

3. LENSCLEAN

The LensClean method (Kochanek & Narayan 1992; Ellithorpe, Kochanek & Hewitt 1996) fits the models of source and lens directly to the visibility data so that it can avoid the problems of the standard methods. The idea is simple: for a fixed lens model an emission model is fitted to the data as in standard

CLEAN, but taking into account the constraints imposed by the lens effect. For those parts of the source that are multiply imaged, all image plane components corresponding to the same source plane component have to be subtracted from the data simultaneously, with the amplifications given by the lens model. The CLEAN components are then subtracted from the visibilities and accumulated to form the CLEAN map after convolution with an appropriate CLEAN beam. But this map is not the primary product of LENSCLEAN. Instead the residuals are used to constrain the mass model of the lens. In the end a final map of the unlensed and lensed source can be produced using the best mass model of the lens.

4. B0218+357

The lens B0218+357 (Patnaik et al. 1993), see Figure 1, is close to a 'Golden Lens' which can be used to determine the Hubble constant reliably. It has a well-determined time-delay (Biggs et al. 1999), can be described by relatively simple mass distributions and provides a wealth of constraints for the models. The only disadvantage is the small image separation which makes direct measurements of the position of the lens galaxy very difficult.[1] This led us to apply LENSCLEAN to a 15 GHz VLA dataset of this system in order to determine the lens position and thus the Hubble constant. Details of this work and the improvements of the method that were necessary to obtain useful results are presented in Wucknitz et al. (2004) and Wucknitz, Biggs & Browne (2004).

Our final result for the lens position is shown in Figure 2. The resulting $H_0 = (78.5\pm5.8)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ $(2\,\sigma)$ is relatively large compared with other lenses but in good agreement with the HST key project value of 71 ± 6 $(1\,\sigma)$ (Mould 2000). Because VLBI data show that the assumption of isothermal models is a very good approximation for B0218+357, our value for H_0 is a very robust estimate. In contrast to other lenses, it does not give rise to a 'New dark matter problem' (Kochanek 2002).

As a secondary result, LENSCLEAN provides a model of the lens and source plane. The maps resulting from a newly developed method, based on the generalized concept of CLEAN beams in the source plane, are shown in Figure 1. There we also included VLBI maps and their backprojections into the source plane in order to collect information about the structure of B0218+357's source on scales from milli-arcseconds to arcseconds.

5. FUTURE WORK

We are currently analyzing a new long-track data set taken at 15 GHz with the VLA combined with the VLBA antenna at Pie Town, New Mexico. With the better resolution and S/N, the accuracy of the derived lens position will be improved significantly, as simulations predict. In addition we will apply LENSCLEAN to our deep global VLBI dataset (Biggs et al. 2003). This will lead to very tight constraints for the radial mass distribution of the lens and thus reduce this main systematic uncertainty of the H_0 result to an insignificant level.

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[1] Such a direct measurement was later successfully carried out by York et al. (2005), confirming our results within the error bars.

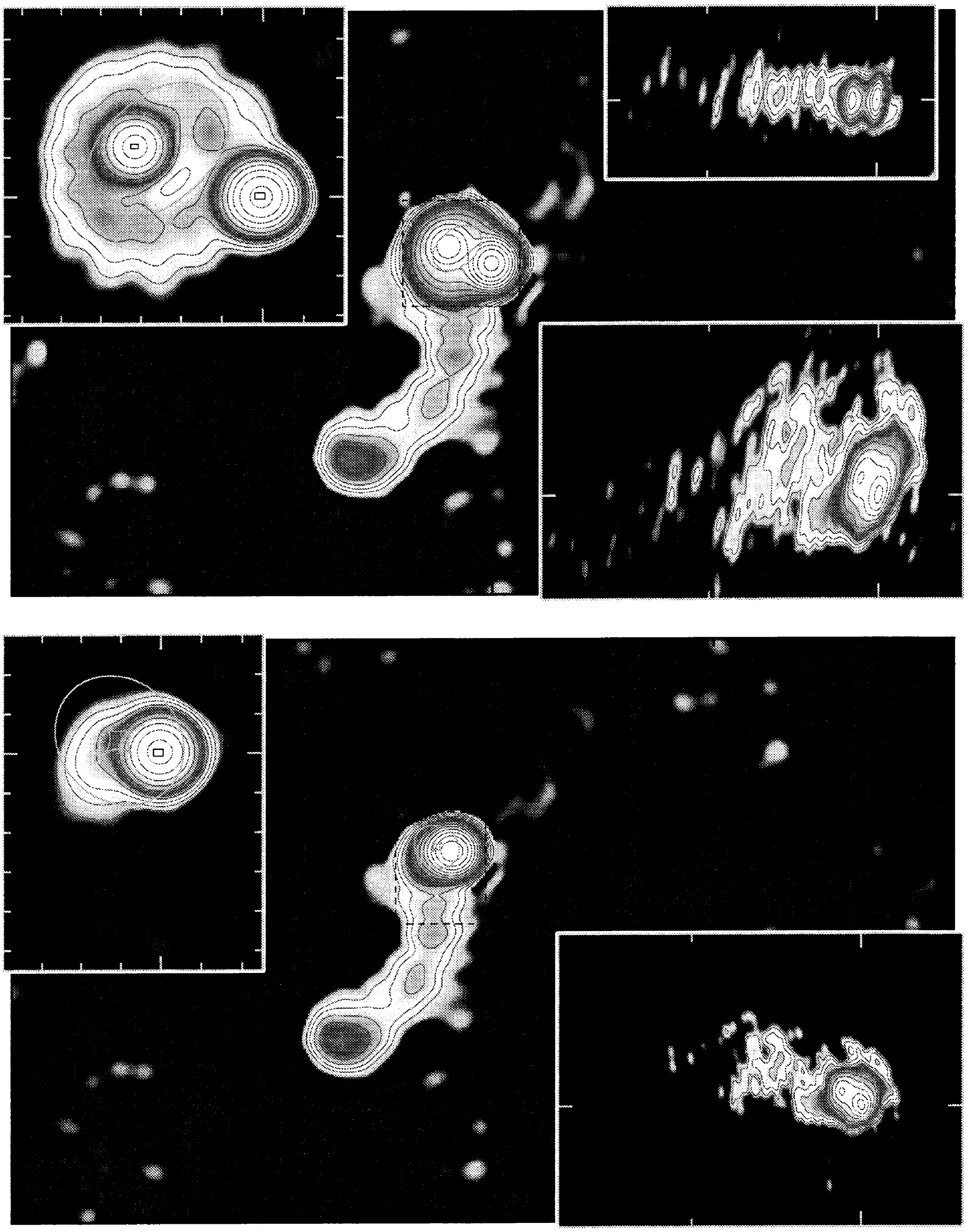

Fig. 1. Composite image of the lens plane (top) and source plane (bottom) of B0218+357. The main central images show 8.4 GHz data from the VLA (tick marks 1″). The insets on the left are from the 15 GHz VLA data set (tick marks 100 mas), the jets on the right are from 8.4 GHz global VLBI observations (tick marks 10 mas), see Biggs et al. (2003). A color version of this figure is published in Wucknitz et al. (2004).

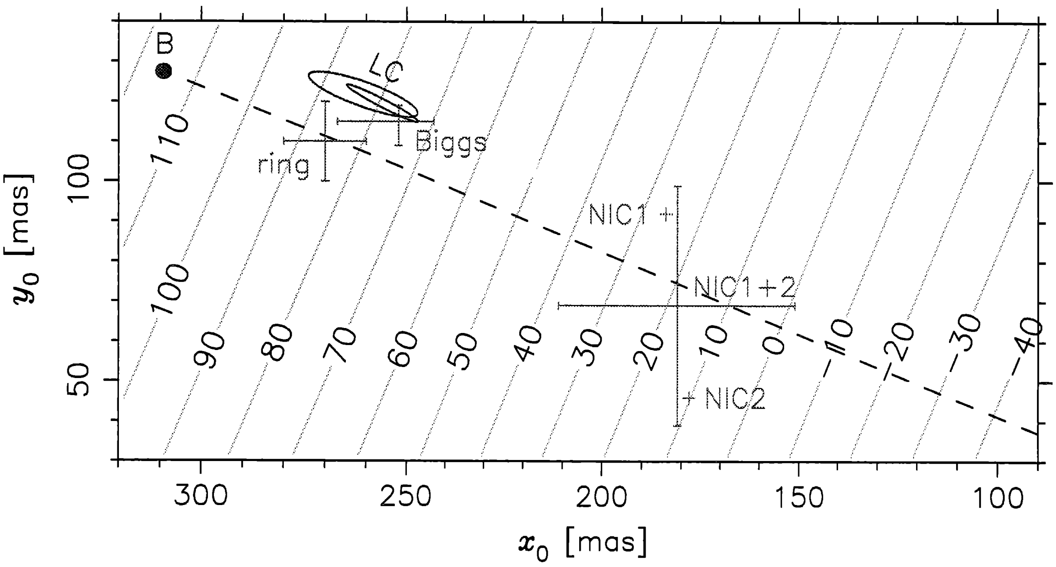

Fig. 2. H_0 [$\mathrm{km\,s^{-1}\,Mpc^{-1}}$] as a function of galaxy position for isothermal lens models ($\Omega = 0.3$, $\lambda = 0.3$). Optical measurements of the position ('NIC1' and 'NIC2' from Lehár et al. 2000) are unreliable. 'Biggs' is an estimate from Biggs et al. (1999), 'ring' is the center of the ring as given by Patnaik et al. (1993). Our LENSCLEAN results are shown by the 2σ ellipses ('LC').

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