Abstract. The four-component gravitational lens CLASS B1608+656 has been monitored with the VLA for two seasons in order to search for time delays between the components. These time delays can be combined with mass models of the lens system to yield a measurement of $H_0$. The component light curves show significantly different behavior in the two observing seasons. In the first season the light curves have maximum variations of $\sim 5\%$, while in the second season the components experienced a nearly monotonic $\sim 40\%$ decrease in flux. We present the time delays derived from a joint analysis of the light curves from the two seasons.

1. Introduction

The four-image gravitational lens CLASS B1608+656 was one of the first lenses discovered in CLASS (Myers et al. 1995). Follow-up radio and optical imaging showed the four-component morphology at all wavelengths. In addition, HST multicolor imaging showed the presence of two lensing galaxies as well as lensed arcs and a faint Einstein ring (see images in Jackson et al. 1997 and on the CASTLeS web page at \url{http://cfa-www.harvard.edu/glensdata/}). Spectroscopic observations have given the redshifts of the lensing galaxies and the lensed background source, which is a post-starburst radio galaxy (Myers et al. 1995; Fassnacht et al. 1996). With the numerous observational constraints from the HST imaging and evidence of radio variability from early VLA observations, this
system presented an excellent possibility to be used for a determination of $H_0$. Thus, a program of VLA monitoring was started in late 1996.

The results of the first season of VLA monitoring, between 1996 October and 1997 May, are presented in Fassnacht et al. (1999). We measured the three independent time delays in the system from the monitoring data, yielding $(\Delta t_{BA}, \Delta t_{BC}, \Delta t_{BD}) = (31\pm7, 36\pm7, 76^{+9}_{-10})$ at 95% confidence. The time delays were combined with the model presented in Koopmans & Fassnacht (1999) to yield $H_0 = 59^{+8}_{-7}$ km s$^{-1}$ Mpc$^{-1}$ (95% confidence) with an additional uncertainty of $\pm 15$ km s$^{-1}$ Mpc$^{-1}$ from the modeling. The uncertainties on the measured time delays, and hence on the resulting determination of $H_0$ are rather large because the background source flux density varied by only $\sim 5\%$ during the first season of monitoring. In principle, stronger variations should allow the alignment of the light curves more accurately, thus leading to smaller uncertainties in the measured time delays. For this reason, a second season of monitoring was begun. These proceedings present initial results from the second season of monitoring.

2. Observations and Data Reduction

We observed the B1608+656 system at 8 GHz with the VLA between February and October 1998. The system was observed 80 times during this period, with observations made, on average, every 3.1 d. With the exception of using the source 1634+627 as the primary flux calibrator instead of 3C 286, the data reduction procedure was the same as described in Fassnacht et al. (1999).

3. Results and Discussion

The final light curves for the four B1608+656 components show large variations in flux density, on the order of 40% (Fig. 1a). These variations are quite a contrast to the variations of only $\sim 5\%$ seen in the light curves from the first season of monitoring. However, the nature of the variations, a nearly monotonic decline, introduces a degeneracy in magnification-delay space, making it difficult to align the curves accurately. In order to break this degeneracy, we have conducted a joint analysis of the data from the first two seasons. This approach is useful because the nearly constant light curves from the first season limit the allowed range in magnification while the steeply declining second season curves limit the allowed range of delays. An initial $\chi^2$ minimization analysis (see Fassnacht et al. 1999 for a description of the details) produces much clearer minima than those produced from the first-season data alone (Fig. 1b). We also conducted Monte Carlo simulations to estimate the uncertainties on the delays. As hoped, the uncertainties decreased by 30 – 50%. The delays produced by this initial analysis are thus $(\Delta t_{BA}, \Delta t_{BC}, \Delta t_{BD}) = (26 \pm 5, 34 \pm 5, 73 \pm 5)$ at 95% confidence. The delays derived from the joint analysis are consistent within the errors with those produced from the first season. However, there is a systematic shift to lower delays, which is especially noticeable for the shortest delay. This change may be due to small errors in matching the absolute flux densities of the curves between the two seasons, an effect that is being investigated further.
Component light curves for B1608+656 system from second season of monitoring. Each light curve has been normalized by its mean value (22, 11, 11, and 4 mJy for components A, B, C, and D, respectively).

χ²-minimization curves from the joint analysis of the first and second seasons’ monitoring data. The minimum reduced χ² values for this choice of smoothing and interpolation occur at delays of 28, 35, and 72 d.

Composite curves created by shifting the component light curves by these delays are presented in Fig. 2.

4. Future Prospects

The B1608+656 system has produced a measurement of $H_0$ through a combination of the measured time delays with a mass model for the lensing galaxies. However, the uncertainties in both the lens model and the measured delays are still larger than desired. Future work on this system could reduce the uncertainties in both of these areas. On the modeling side, Blandford and Surpi are developing a new lens model using the full information in the HST images of the system. The time delay uncertainties also can be reduced if the source varies in a strong, but non-monotonic, manner. It should be noted that just such a variation occurred during the gap between the first two seasons when the source began its change from its previous, nearly constant, flux density. This change in behavior was missed because the VLA was in its compact configurations and could not resolve the individual source components. We are currently conducting a third season of monitoring with the VLA to search for more variability in the background source.

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Figure 2. Composite curves created by shifting the component light curves by the measured time delays and overlaying them. Symbols as in Fig. 1a. a) (left) Season 2 only. b) (right) Season 1 and season 2.

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