A new determination of the time delay in 0218+357

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Abstract

Recent radio observations have been made of the lens 0218+357 with the VLA at 8.4Ghz and 15GHz. Observations were taken about every 2 days over a period of approximately three months. The 15GHz data has been fully calibrated and a time delay observed in total flux. Analysis of the results seem to confirm previous results which gave the time delay as 12 days. This result is preliminary and more work is needed to derive realistic error bars for the flux measurements and hence for the time delay. Time delays should eventually be available for percentage polarized flux and polarization position angle at both 8.4 and 15Ghz.

Introduction

The gravitational lens 0218+357 should eventually yield the most believable value of the Hubble constant yet known from a measurement of the time delay between the two point source imaged components. The two components have the smallest angular separation of any known lens (335 mas) resulting in a relatively small time delay, the redshifts of both the lensed source and the lensing galaxy

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are known and the mass model is well constrained due to the Einstein ring and extensive observations, including VLBI (Patnaik et al. 1995). Previous work (Corbett et al. 1996) derived a time delay of 12$\pm$3 days from VLA observations of the percentage polarized flux at 8.4 and 15GHz. This result leaves the time delay as the biggest source of error in the final determination of H_0 at this time. The aim of these new observations was to try and reduce the errors on the time delay to $\leq$10%.

Observations

0218+357 was observed with the VLA in A configuration from mid October 1996 to mid January 1997 resulting in 47 epochs of data, twice the amount used in the previous estimate of the time delay. As a further improvement on the 1992/93 data, extra care was taken in the pointing of the telescopes with observations to determine the pointing to a high degree of accuracy for each source. Observed at 8.4Ghz and 15Ghz (with resolutions of $0.2''$and $0.12''$respectively) the two components are easily separated and can be monitored for variations in total flux, percentage polarized flux and polarization position angle. Each observation consisted of scans of 3C84 for amplitude and phase calibrating purposes, and of 3C119 to check for variations in the flux of 3C84 over the course of the observations and to calibrate the position angle of 0218+357. The dwell time on 0218+357 was $\sim$20 minutes for the 15GHz observations.

At the same time as the VLA data was being collected, 0218+357 was being observed with MERLIN at a frequency of 5GHz (resolution $\sim$50 milliarcsec). A similar observing strategy to the VLA was adopted, but with a different point source calibrator (0234+285). As a check on the MERLIN total flux measurements, 0218+357 was also observed at 5GHz with the VLA.

Data Reduction and Analysis

The 15GHz VLA data has been fully calibrated using the NRAO *AIPS* package. Several epochs of 3C84 data were calibrated assuming a point source model (peak flux 26Jy) and then combined into one dataset. This was then mapped and the clean components used to self calibrate the original dataset which was itself mapped. This cycle was performed eight times in all until a satisfactory model of the source was obtained. This was deemed necessary as self calibrating 3C84 assuming a point source led to spurious spikes in the uv visibility plot. 0218+357 and 3C119 were then amplitude and phase calibrated using this model and any bad data flagged by telescope. Polarization calibration was applied assuming that 3C84 is unpolarized. During the calibration process, 6 days of data were discarded due to instrumental problems or because of bad weather at the VLA which particularly affects 15GHz data.

Calculating total intensity fluxes was done fitting directly to the uv visibilities using the Caltech *Difmap* package. The data was first split into its individual

IFs, self-calibrated, averaged into 30 second bins and then fitted to a simple model consisting of a gaussian for 3C119 and a point double for 0218+357. Also, in the case of 0218+357, as the data was read out of *AIPS*, only visibilities longward of 400 kilo-λ were passed so as to censure the ring emission.

Stokes Q and U fluxes were calculated using the *AIPS* equivalent of the *Difmap* modelfitter (*UVFIT*) due to doubts over *Difmap*'s robustness in handling polarization. The phase calibrated data produced by *Difmap* was read back into *AIPS* and fitted to the same model as for the total intensity measurements. *UVFIT*'s effectiveness was checked by fitting for total intensity with no discernable difference observed between it and *Difmap*. Percentage polarizations and position angles were then calculated using standard formulae.

The MERLIN data was calibrated in *AIPS* as above, but assuming a point source model for the amplitude and phase calibrator 0234+285. Modelfitting was also carried out in *Difmap* but with a slightly different model which gave each component a very small width.

Results

From the VLA 15GHz total intensity data it can be seen that 3C119 increased in flux by $\sim$2% over the observing period which is probably due to 3C84 decreasing in flux by a similar amount (see Figure 1). 0218+357 was calibrated under the assumption that 3C84's flux was constant, but a correction can be easily applied to compensate for this. The scatter around a straight line of best fit is 23mJy which corresponds to an error on the 3C119 fluxes of approximately 1%.

The light curves for the total flux of 0218+357 (averaged over both IFs) are shown in Figures 2 and 3. These show that the source has clearly varied significantly over the three months, brightening by $\sim$8%. What is also clear is that the curves are offset with component B lagging A. At this early stage of the analysis, no rigorous numerical method has been employed to calculate the time delay or the associated error. However, fitting a smooth third order polynomial to the data illustrates the delay quite nicely. (This does, however, sacrifice the information contained within the variations on time scales of a few days.) It should be noted that several of the lower points in both plots are correlated and that therefore these do not represent intrinsic variations in the source. Some of these points will probably be excluded from the final analysis. Sliding the two curves and aligning the peaks shows that the delay is of the order of 12 days. Analysis of the polarization plots are not so advanced yet, but appear to be consistent with the total flux results.

Analysis of the MERLIN data has yet to show a time delay. Comparison with the VLA 5GHz data shows that both arrays are seeing a very similar variation in component A flux i.e. a rise followed by a fairly steep decline. However, the percentage rise is different in each case, $\sim$10% for MERLIN and $\sim$5% for the VLA. Problems could be arising with the modelfitting due to the lack of MERLIN's uv coverage for a 15 minute observation and work is in progress to resolve these problems.

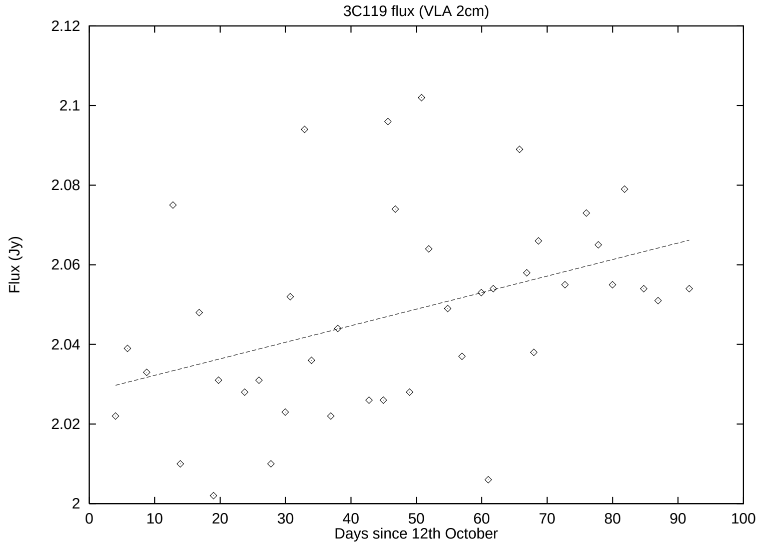

Figure 1: Flux of 3C119

Conclusions and Future Work

Results from the 15GHz VLA data have proved very promising so far. 0218+357 has co-operated and produced variations that can be seen in both components and it would appear that fluxes are being measured to a high degree of accuracy. A time delay will eventually be calculated from analysis of light curves formed from total flux, percentage polarized flux and polarization position angle at both 8.4 and 15GHz, with error bars derived from Monte–Carlo simulations. A time delay should also result from analysis of the MERLIN 5GHz data.

References

Corbett, E.A., Browne, I.W.A., Wilkinson, P.N. and Patnaik, A.R., 1996. In: Astrophysical Application of Gravitational Lensing, IAU Symposium No. 173

Patnaik, A.R., Porcas, R.W., Browne, I.W.A., 1995, MNRAS, 274, L5

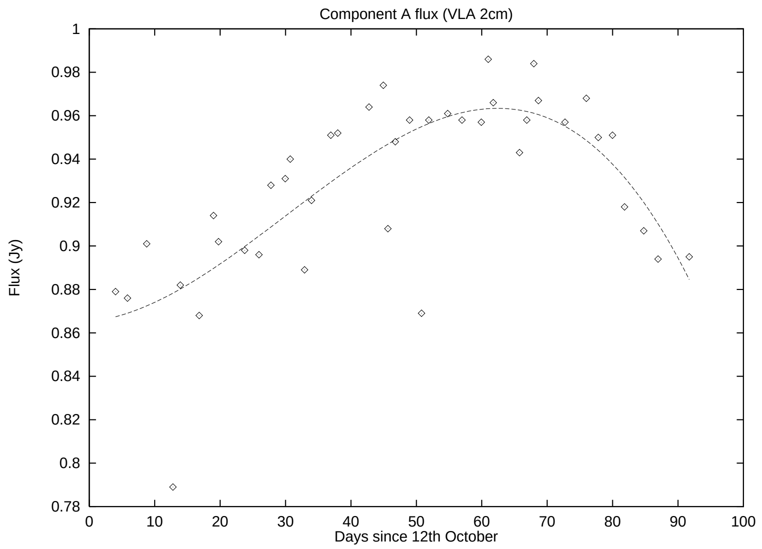

Figure 2: Flux of component A

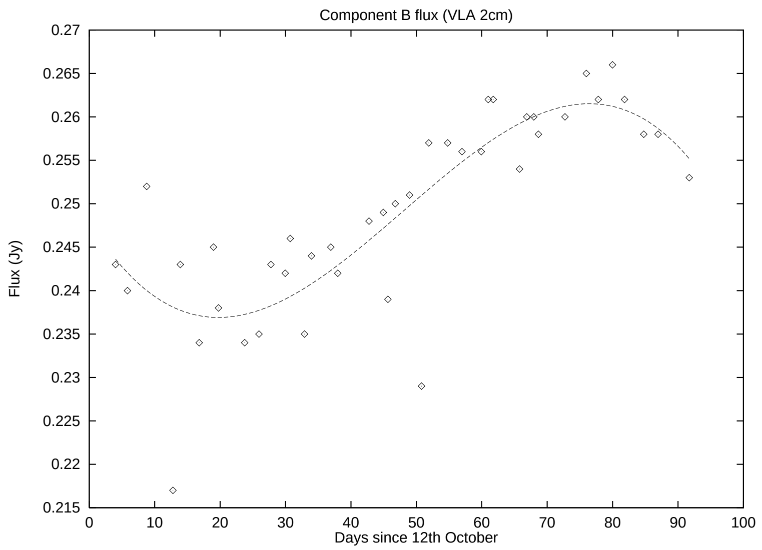

Figure 3: Flux of component B