The Cloverleaf Quasar H1413+117: a Preliminary Lightcurve

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Abstract: The cloverleaf quasar H1413+117 was discovered to be a gravitational lens system in 1988. Since then, it has been photometrically monitored essentially as part of the ESO key-program *Gravitational Lensing*: we present here a first preliminary lightcurve for its four individual images.

1 Introduction

Since its discovery as a gravitational mirage in 1988 (Magain et al., 1988), the cloverleaf quasar H1413+117 has been observed in the direct imaging mode as regularly as possible. In particular, an extensive CCD photometric monitoring program was included in the ESO Key-Program "Gravitational Lensing" covering the period 1989-1993 (see Surdej et al., 1992, for a status report).

The individual brightnesses of the four components can in principle be derived from the different CCD frames. However, the problem is not easy to handle because of the very tight configuration of the gravitational lens system (see Fig. 1). In the present contribution, we detail the data reduction procedure and the measurement of the brightness of the four lensed images. We also present the first preliminary photometric lightcurves of the individual components of this interesting gravitational mirage.

2 Observations

The different CCD frames have been obtained at ESO (La Silla), essentially under average to good seeing conditions, either at the Cassegrain foci of the Danish 1.54m or of the ESO/MPI 2.2m telescopes, or at the Nasmyth focus of the 3.5m New Technology Telescope. Different CCD detectors have been used.

The observers were O. Hainaut, D. Hutsemékers, P. Magain, M. Remy, A. Smette and E. Van Drom. The systematic monitoring has been essentially performed through the Bessel

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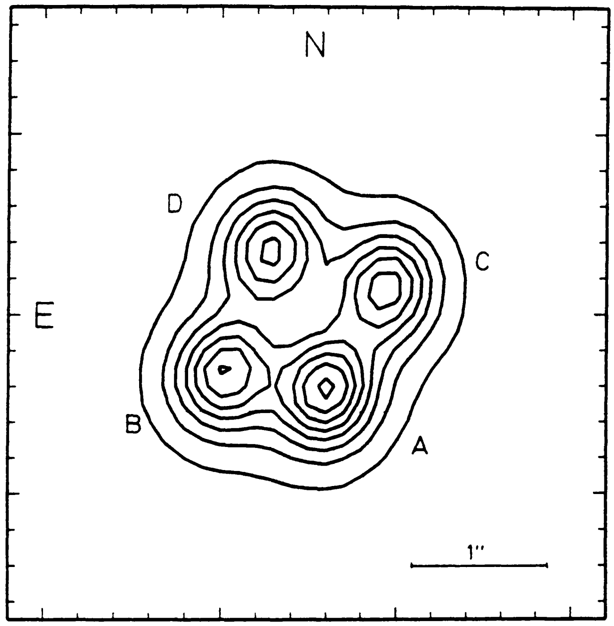

Figure 1: Isophotes of the V image of the cloverleaf quasar as observed with the instrument SUSI at the NTT on June 12^{th}, 1991 (FWHM $\sim$ 0.66 arcsecond)

V filter, although other filters have been occasionally used. The best CCD frame has been obtained by A. Smette with the NTT on June 12^{th}, 1991; it is presented in Fig. 1. The seeing was about 0.66 arcsec.

The reduction was performed using the ESO MIDAS package. Each frame was bias subtracted and flat fielded in the conventional way. However, a few problems appeared, therefore limiting the accuracy on the image brightness determinations: ESO CCD#5 was found to show a non-linear behaviour (Magain et al., 1992), and its bias to exhibit a marked gradient. Linearity problems with other CCDs were also detected.

3 Results

The aim of this work was to search for possible variations in the flux of the lensed images of H1413+117 with the hope of detecting photometric variability of the quasar (in order to put constraints on time delays between the four images) or micro-lensing effects. The brightness of each component of the multiply imaged QSO has been individually estimated thanks to a computer code developed by M. Remy. Several objects can be considered simultaneously. The programme fits a parametric function (the parameters being, for example, positions, brightnesses, shapes,...) to each observed profile by finding a local minimum of the global χ^2 using the method of Levenberg-Marquardt (Numerical Recipes). It is possible to put constraints on the different parameters. The search for the form of the function(s) representing at best the observed profile is performed by trials. Several functions were considered among which we essentially retained: the Gaussian and the Moffat profiles, as well as a numerical profile (the Point Spread Function or PSF) that is determined by using stars available in the field. This PSF was constructed via another routine written by P. Magain.

The brightness of each image has been derived by simultaneously fitting the four images. After a few attempts, it appeared that the best profiles were the numerical PSF's: after subtraction from the observed profiles, they turned out to give the smallest residuals compared to the other analytical functions.

Due to bad sampling, bad seeing or noisy numerical PSF's for some of the frames, the convergence of the fit to a global minimum of the χ^2 was not always guaranteed. Often, the fit had more than one set of solutions, and was highly dependent on the initial values of the parameters, particularly the positions. Therefore, further constraints were needed. Two frames acquired with the NTT, with a sufficiently good sampling and under very good seeing conditions, were analyzed in order to derive secure values for the relative positions of the four images with respect to a neighbouring star in the field. For all the frames, we therefore determined the angular scale by measuring the distance between two stars in the field, as well as the relative orientation of the CCD by looking at their position angle. Then, we performed a simultaneous fit of the neighbouring star and of the four components of the lensed quasar whose relative positions were fixed respectively to that of the star. The position of the whole quintuplet was left free as well as the individual brightnesses. The resulting best fit provided the brightness of each component.

Conditions were not always photometric and it was therefore not always possible to have a knowledge of the photometric zero point. We therefore computed differential magnitudes relative to the neighbouring star (the one that was fitted together with the quasar images). This star is referred to by number 40 according to the numbering in Kayser et al. (1990). In order to ascertain that possible variations were due to the quasar, a second star in the field (star number 47) has been used as a control star. The resulting lightcurves of the four images (in differential magnitudes) are given in Fig. 2. All the points have been plotted regardless of the quality of the fit. Variations of the lensed quasar are clearly detected.

4 Discussion

One can see from the curves of Fig. 2 that the time delay between the arrivals of light from the four components is small: the four curves seem to vary almost simultaneously. Based on these lightcurves, a rough estimate of an upper limit on the time delays is a few months; further work will allow us to further constrain this value. It is interesting to note that the magnitudes of the four images decrease by about 0.6 to 0.8 from 1987 to 1993. The observational error is of the order of two percent, i.e. markedly lower. The quasi simultaneous increase in luminosity probably represents an intrinsic variability of the quasar itself and constitutes a further proof of the lensed nature of H1413+117. Some points show an abnormal dispersion, which causes jumps in the curve. It seems that the fit did not correctly converge and that the program took a fraction of the brightness from images B, C and D and transferred it to image A. All the points have been plotted regardless of the quality of the fit; therefore, we still have to proceed to a critical analysis of the residuals in order to detect where these anomalies are coming from (convergence, noise in the PSF, sampling, ...).

5 Conclusion

In this contribution, we presented the preliminary lightcurves of the individual images of the cloverleaf quasar, observed since its discovery as a lensed system till the present days. The brightnesses of the four lensed images have been individually measured. The quasar did vary

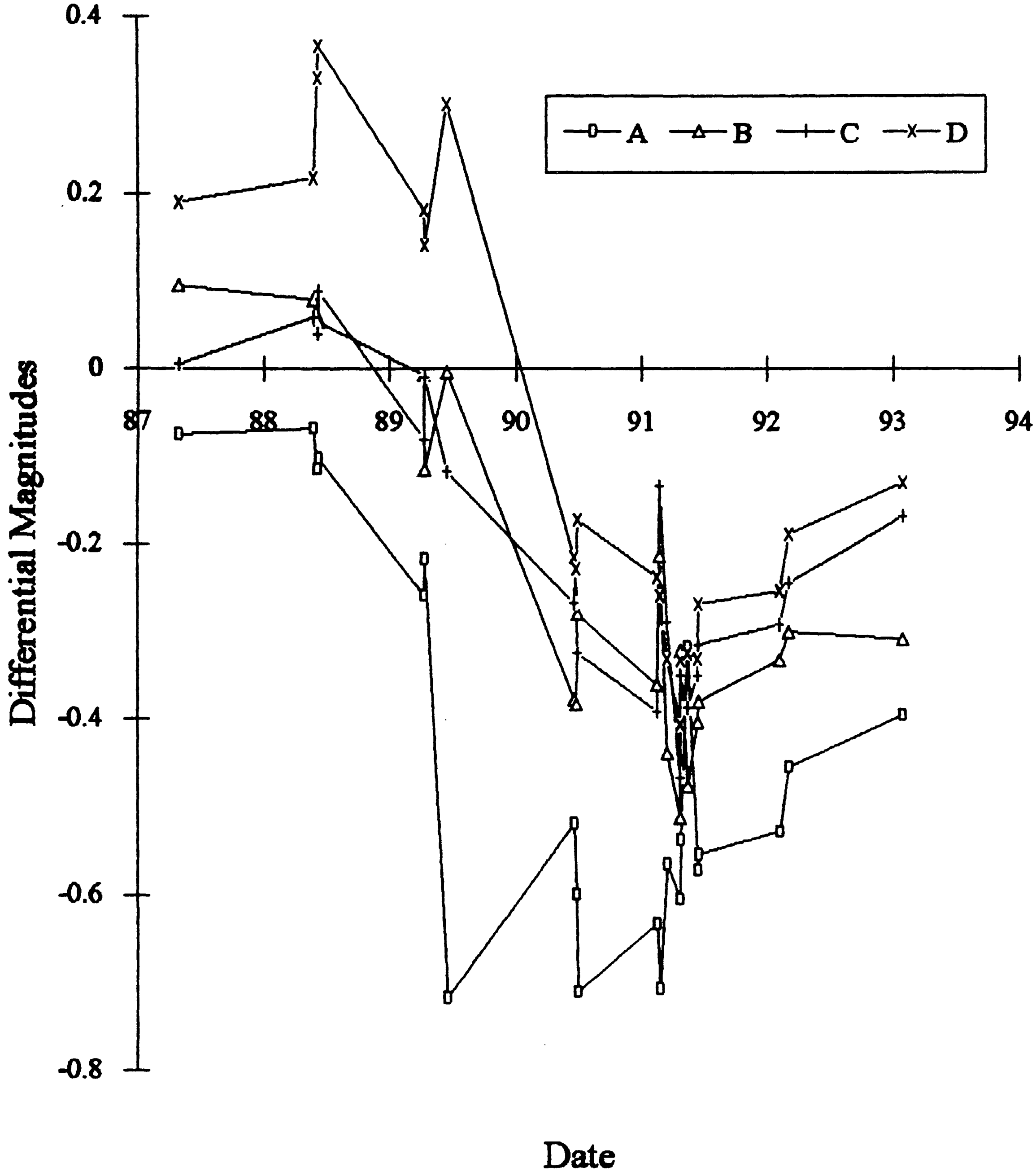

Figure 2: The lightcurve for the four components; the differential magnitudes are *quasar minus star*

and all the images exhibit similar brightness variations. An upper limit on the time delays of a few months is derived. We hope to further refine this value.

However, obtaining time delays with good precision implies to carry out further observations with a denser temporal sampling and on a longer time span. This again points out the interest of setting up a telescope fully dedicated to the photometric monitoring of gravitational lens systems.

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References

Kayser, R., Surdej, J., Condon, J.J., Kellerman, K.I., Magain, P., Remy, M., & Smette, A.: 1990, *Ap J* **364**, 15

Magain, P., Surdej, J., Swings, J.P., Borgeest, U., Kayser, R., Kühr, H., Refsdal, S., & Remy, M.: 1988, *Nature* **334**, 325

Magain, P., Surdej, J., Vanderriest, C., Pirenne, B., & Hutsemékers, D.: 1992, *The Messenger* **67**, 30

Surdej, J., Angonin, M.-C., Arnaud, J., Bauer, T., Borgeest, U., et al.: 1992, proc. 2nd DAEC Meeting, *The distribution of matter in the Universe*, eds. G.A. Mamon and D. Gerbal, 97