Time Delays in Gravitationally Lensed Quasars

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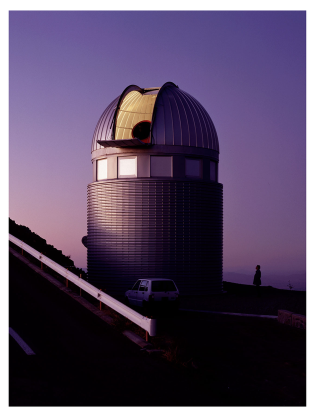
We present *R*-band light curves for doubly lensed quasars, and determine the time delay between the lensed images using 4 fundamentally different time delay estimation techniques in order to minimize the bias that might be introduced by the use of a single method. We are at present focusing on the optimization of the slow microlensing modelling and the error determination of one of these techniques, the Numerical Model Fit.


DATA

We joined data coming from 4 telescopes, taken within the framework of the COSMOGRAIL collaboration:

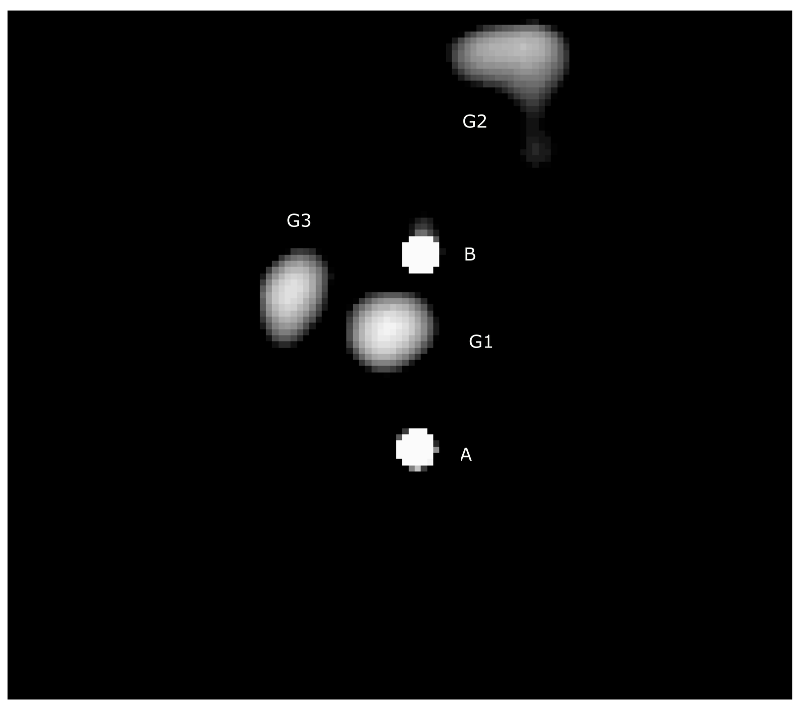
- ★ The 1.2-m Mercator telescope, La Palma, Canary Islands, Spain
- ★ The 1.5-m AZT-22 telescope, Maidanak, Uzbekistan
- ★ The 2-m Himalayan Chandra Telescope, Hanle, India
- ★ The 1.2-m Euler Telescope, La Silla, Chile

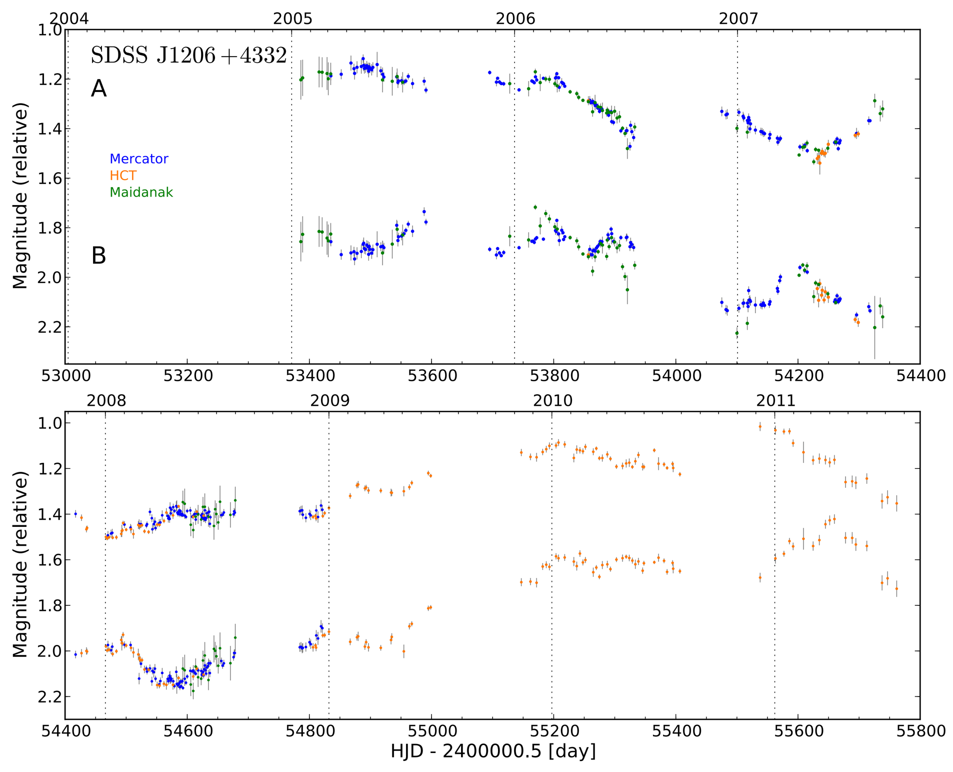



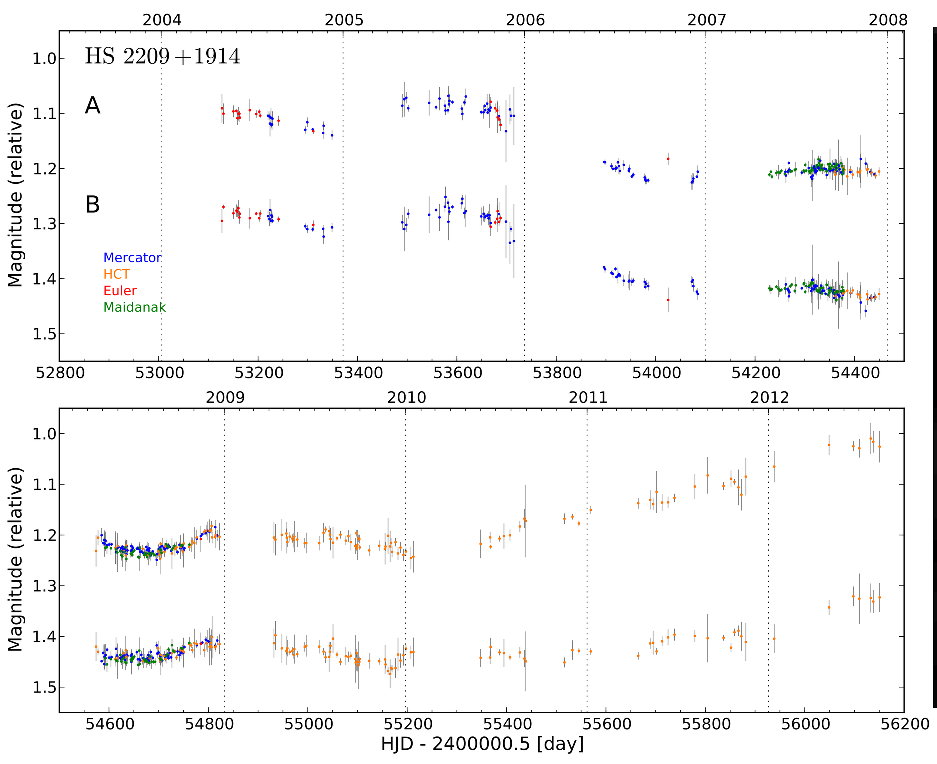
DATA REDUCTION AND TIME DELAY ANALYSIS

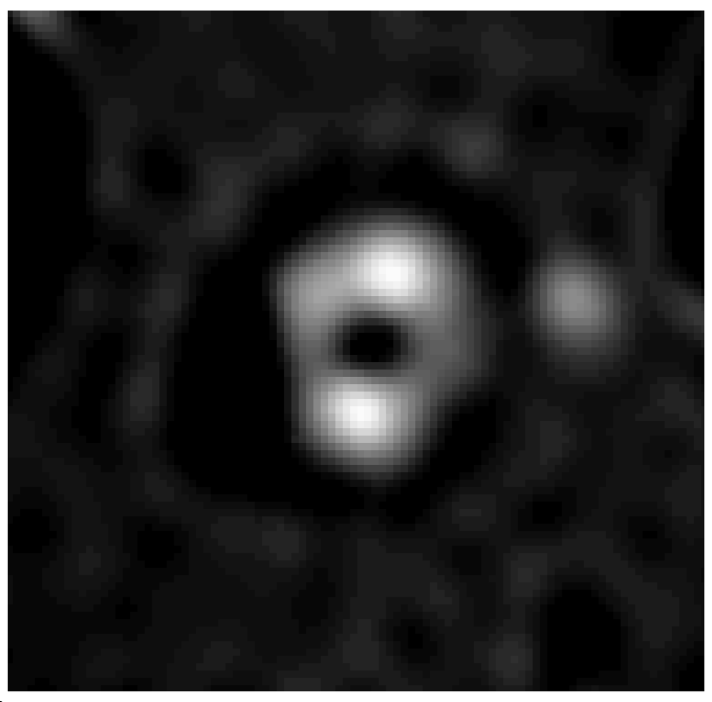
All data has been reduced in a homogeneous way as described in Tewes et al. (2013b). Photometry of the sources is obtained through simultaneous deconvolution using the MCS algorithm (Magain et al. 1998). Three of the time delay estimation methods are described in Tewes et al. (2013a). They include a dispersion-like technique, a regression difference technique, and a free knot spline technique. The fourth method is the Numerical Model Fit as explained and applied in Eulaers & Magain (2011).

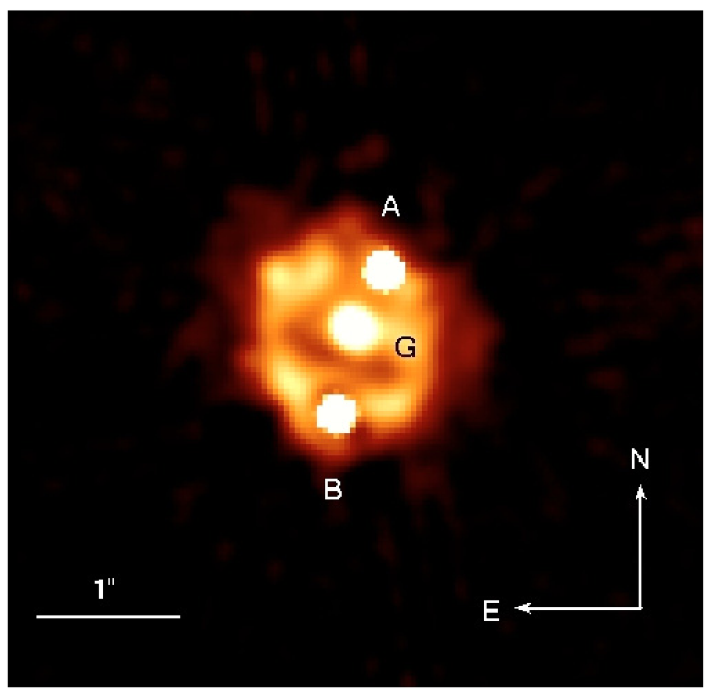
On the right, you see the result of the simultaneous deconvolution of 1109 *R*-band Mercator images of SDSS J1206+4332. We clearly identify the lensed images A and B separated by 2.98 arcseconds, the main lensing galaxy G1 and two more galaxies G2 and G3. From the light curves we derive a final time delay of Δt_{AB} = 111.3 ± 3 days.











The numerical background common to the simultaneous deconvolution of 2242 *R*-band images of HS 2209+1914 reveals a faint ring-like structure that is very similar to the deconvolved Hubble Space Telescope images shown in Chantry et al. (2010). However, the main lensing galaxy cannot be resolved on ground based images given the compactness of the system with an image separation of 1.02 arcseconds.

The time delay analysis of the light curves shown on the left converge towards an estimation of Δt_{BA} = 20 ± 5 days.

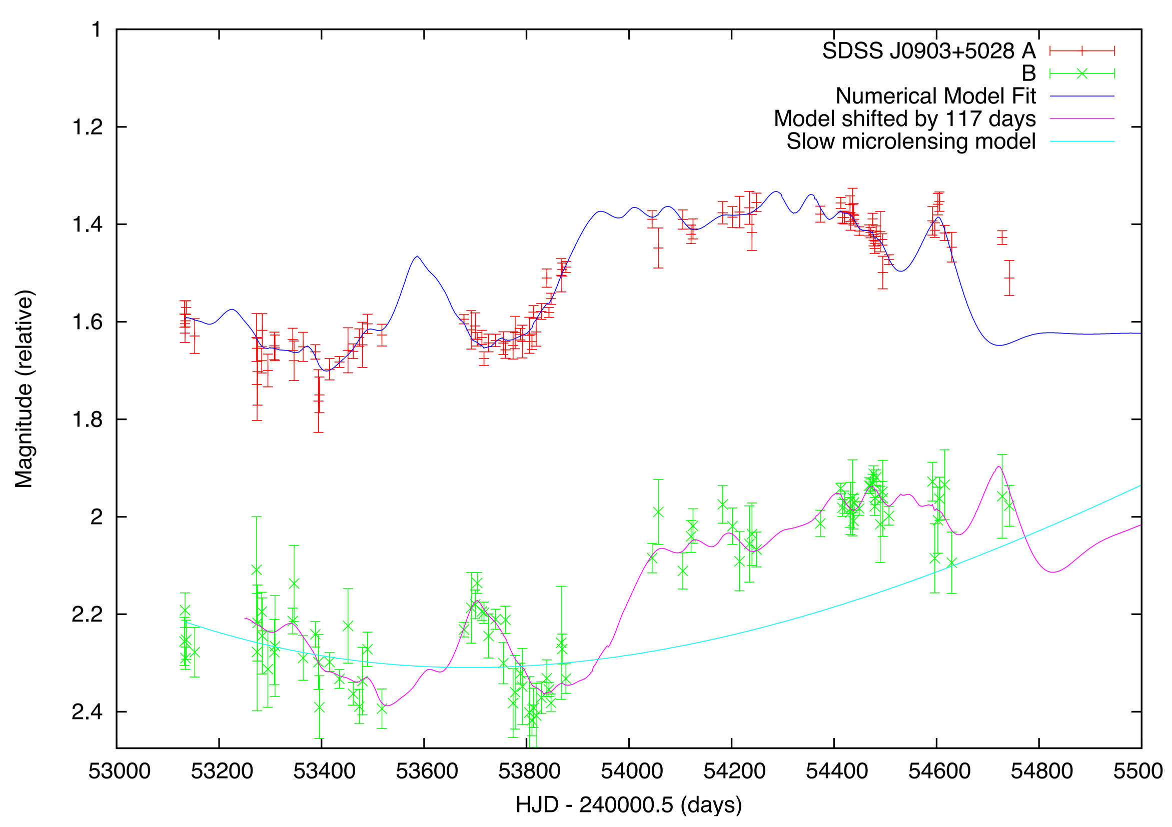
The Numerical Model Fit…

This method, as it was presented in Eulaers & Magain (2011) constructs a numerical model for the quasar variability, together with a linear microlensing trend, for a given time delay. The optimal time delay is the one that minimizes the difference between the data and this numerical model. To determine the error on the time delay, we first check that our residuals (data minus model) are compatible with a normalized Gaussian distribution. Then we add normally distributed random errors with the appropriate standard deviation to the numerical model light curve and redetermine the time delay. The mean value of the time delay distribution that we obtain after 1000 executions is considered to be the final time delay, and its dispersion represents the 1σ error bar.

… revisited

We are currently adapting some aspects of the NMF without touching the core of the method. Details and results of these improvements will be presented in Eulaers et al. (2013b), and include the following points:

- ★ The linear trend for slow microlensing has been replaced by a 4^{th} order polynomial: tests on 5 doubly lensed quasars (SDSS J1206+4332, HS 2209+1914, SDSS J1650+4251, SDSS J0903+5028, SDSS J1155+6346) have shown that :
  - ★ the microlensing model remains close to linear in spite of more freedom
  - ★ the time delay is not influenced by this higher order microlensing model
  - ★ only the results on SDSS J0903+5028 are dependent on the order for the microlensing model
- ★ Tests on systematic errors of the method on the time delay have shown that they remain marginal.
- ★ On top of the white noise added to the model light curve, we add red noise if statistic tests on the residuals show its necessity. This red noise is generated by a Markov chain, of which the parameters are iteratively adjusted. Tests on the above mentioned objects are ongoing.



SDSS J0903+5028

The time delay determination of this doubly lensed quasar is not straightforward in spite of clear photometric variability in the more than 4 years of Maidanak and Mercator data. The poor sampling during some of the seasons can partially be blamed for this difficulty, but microlensing probably complicates the case. The choice of a non-linear slow microlensing model in the NMF makes the time delay shift for 11 days. On top of that, the other three time delay estimation methods each yield a different result in a range from Δt_{AB} = 90 - 130 days.

=> *needs further investigation*

References

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