

Microlensing variability in the gravitationally lensed quasar QSO 2237+0305 \equiv the Einstein Cross ^{*}

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We present the results of the first long-term (2.2 years) spectroscopic monitoring of a gravitationally lensed quasar, namely the Einstein Cross QSO 2237+0305.

We spatially deconvolve deep VLT/FORS1 spectra to accurately separate the spectrum of the lensing galaxy from the spectra of the quasar images. Accurate cross-calibration of the observations at 31 epochs from October 2004 to December 2006 is carried out using foreground stars observed simultaneously with the quasar. The quasar spectra are further decomposed into a continuum component and several broad emission lines.

We find prominent microlensing events in the quasar images A and B, while images C and D are almost quiescent on a timescale of a few months. The strongest variations are observed in the continuum, and their amplitude is larger in the blue than in the red, consistent with microlensing of an accretion disk. Variations in the intensity and profile of the broad emission lines are also reported, most prominently in the wings of the C III] and in the center of the C IV emission lines. During a strong microlensing episode observed in quasar image A, the broad component of the C III] is more magnified than the narrow component. In addition, the emission lines with higher ionization potentials are more magnified than the lines with lower ionization potentials, consistent with the stratification of the broad line region (BLR) inferred from reverberation mapping observations.

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1. Introduction

Most of the quasar microlensing studies so far are based exclusively on broad-band photometric monitoring (e.g. Colley & Schild 2003; Udalski et al. 2006). These observations are dominated by variations of the continuum, making it difficult to disentangle between variations of the continuum and of the broad emission lines (BELs). Both regions are affected by microlensing, but in different ways depending on their size.

Several theoretical studies show how multiwavelength lightcurves can constrain the energy profile of the quasar accretion disk and also the absolute sizes of the line-emitting regions (e.g., Schneider & Wambsganss 1990; Agol & Krolik 1999; Abajas et al. 1999; Kochanek 2004). In order to investigate the inner structure of quasars, we started the first long-term spectrophotometric monitoring of a lensed quasar. Our target is the Einstein Cross QSO 2237+0305, well known for its microlensing induced variability. The spectral variations of the four quasar images are followed with the Very Large Telescope (VLT) from October 2004 to December 2006. In this contribution we summarize the results presented in Eigenbrod et al. (2008). The full analysis of our monitoring data requires detailed microlensing simulations in order to constrain the quasar energy profile and BLR size. These simulations will be the subject of future papers.

2. Observations and data analysis

We acquired our 31-epoch observations with the FOcal Reducer and low dispersion Spectrograph (FORs1), mounted on the Unit Telescope # 2 of the ESO Very Large Telescope (VLT) located at Cerro Paranal (Chile). We performed our observations in the multi-object spectroscopy (MOS) mode. This strategy allowed us to get simultaneous observations of the main target and of four stars used as reference point-spread functions (PSFs). These stars were used to spatially deconvolve the spectra with the spectral version of the MCS deconvolution algorithm (Magain et al. 1998, Courbin et al. 2000), as well as to perform accurate flux calibration of the target spectra from one epoch to another. Technical details are described in Eigenbrod et al. (2008).

Different emission features are known to be produced in regions of different characteristic sizes. Emission features from smaller regions of the source are more highly variable due to microlensing than features emitted in more extended regions (e.g. Wambsganss et al. 1990). In order to study the variation of each spectral feature independently, we decompose the spectra into (1) a power law continuum $f_\nu \propto \nu^{\alpha_\nu}$, (2) a pseudo-continuum due to the merging of Fe II and Fe III emission blends, and (3) an emission spectrum due to the individual BELs.

3. Results

We observe chromatic variations induced by microlensing in the continuum of all images of QSO 2237+0305. The effect is most pronounced in image A during the last observing season (HJD \sim 2453900 days), and in image B at the beginning of our monitoring (HJD \sim 2453500 days). During these magnification events we notice a steepening of the continuum with the blue part of the spectra being more magnified than the red part (see Fig. 1). In quasar image A, all the emission lines are less magnified than the continuum, consistent with a scheme where the BLR is small

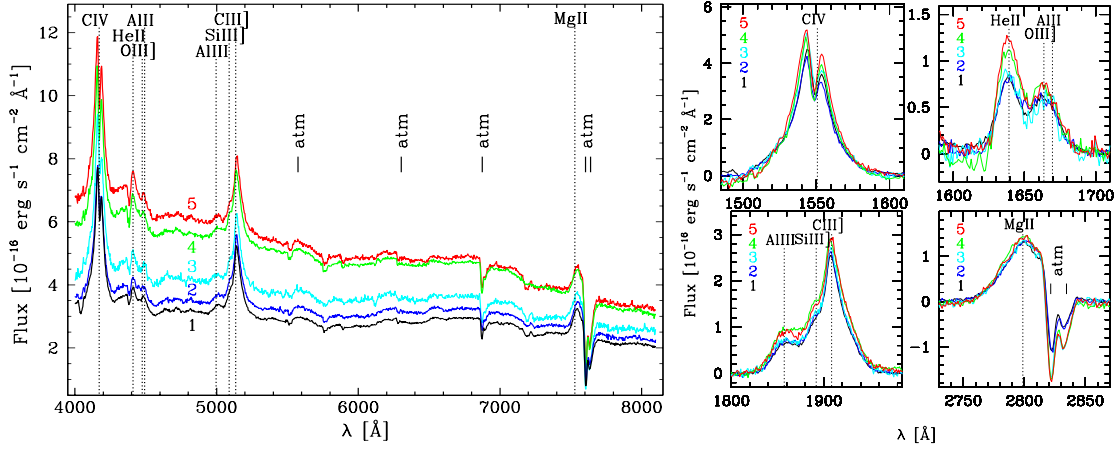


Figure 1: Spectra of image A at 5 different epochs during the magnification event that occurred during the summer 2006. The epochs are chronological with #1 = 25-08-2005, #2 = 21-10-2005, #3 = 06-12-2005, #4 = 27-07-2006, and #5 = 26-11-2006. *Left panel:* Chromatic variations of the continuum are conspicuous. The blue part of the spectra are more magnified than the red part. This is consistent with microlensing of an accretion disk. *Right panel:* We observe variations in the intensity and profile of the BELs, especially in the wings of the C III], center of the C IV, and intensity of the He II emission lines. In this last panel the continuum has been subtracted.

enough to be significantly microlensed, but less than the continuum, which is emitted in a more compact region. In addition, we find evidence the BLR is stratified, as lower ionization lines are less magnified and hence emitted in larger regions. The same global trend is observed in image B.

The behaviour of the Fe II+III emission is more difficult to interpret, as it is a blend of many lines. However, we note that the difference in magnification of the Fe II+III lines between a microlensing and a quiet phase is larger than for the other lines. This may suggest differential magnification of the emitting regions within the Fe II+III complex, i.e. that the Fe II+III is present both in compact and in more extended regions, a conclusion also reached by Sluse et al. (2007) with single-epoch spectra of the quadruply imaged quasar RXJ 1131–1231.

We also investigate the possibility of a change in the profile of the BELs. Such profile variations may be caused by differential magnification of regions with different velocities in the BLR (e.g. Lewis 1998). In image A, the broadest part of the C III] is more microlensed than the core, indicating that the broadest component of the C III] emission is emitted in a more compact region than the core of the emission line. Moreover, we observe nearly the same magnification ratio between the core and the broader component of the C III] emission line than is reported between the narrow [O III] and the broad H β emission lines (Metcalf et al. 2004). This gives a hint that the narrow component of the C III] emission line is, at least in part, physically connected with the narrow line region (NLR). In addition, we note evidence for variations in the central parts of the CIV emission lines in all images and at most epochs.

4. Conclusions

We present the first long-term spectrophotometric monitoring of a gravitationally lensed quasar;

the Einstein Cross QSO 2237+0305. The mean temporal sampling is of one observation every second week. The observations are carried out with the VLT in a novel way, using the spectra of PSF stars, both to deblend the quasar images from the lensing galaxy and to carry out a very accurate flux calibration.

We find that all images of QSO 2237+0305 are affected by microlensing. Image A shows an important brightening episode at the end of our monitoring campaign, and image B at the beginning. The continuum of these two images becomes bluer as they get brighter, as expected from microlensing magnification of an accretion disk. We also report microlensing-induced variations of the BELs, both in their integrated line intensities and in their profiles. In quasar image A, the broad component of the C III] line is more magnified than the narrow component. This might indicate that the core of this line is emitted in the NLR. Intensity variations in the BELs are detected mainly in images A and B. Our measurements suggest that higher ionization BELs like C IV, C III], are more magnified than lower ionization lines like Mg II. This is compatible with reverberation mapping studies and a stratified structure of the BLR. There is marginal evidence that regions of different sizes are responsible for the Fe II+III emission.

The very different behaviours of the BELs and the continuum with respect to microlensing offer considerable hope to reconstruct the two types of regions independently, using inverse ray-shooting simulations.

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