XMM-NEWTON OBSERVATIONS AND SIMULTANEOUS OPTICAL SPECTROSCOPY OF THE GRAVITATIONAL LENS SYSTEM SDSS J1004+4112

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ABSTRACT

We report on observations of the large separation gravitational quasar lens SDSS J1004+4112 obtained simultaneously with *XMM-Newton* and the integral field spectograph *PMAS* at Calar Alto observatory. The XMM X-ray and UV images show that the 4 lens images differ significantly in their spectral energy distributions. The optical spectra of the 2 brightest lens components show a reappearance of a previously observed excess in the blue wing of the C IV emission line. We discuss microlensing and intrinsic variability as causes for these unusual observations. The extended emission of the lensing cluster of galaxies is clearly detected in the *EPIC* images, providing an estimate of its X-ray luminosity and mass.

Key words: gravitational lensing; quasars; X-rays.

1. INTRODUCTION

The lensed quasar SDSS J1004+4112 (RBS 825, Schwope et al. 2000) has been found by Inada et al. (2004) in a survey of large separation lenses using the Sloan Digital Sky Survey (SDSS). Optical imaging revealed 4 images of the quasar, with a maximum separation of 14.6” it is the largest separation gravitational lens known so far. The lensing object is a cluster of galaxies at z=0.68, the quasar itself has a redshift of z=1.73. SDSS J1004+4112 is the first multiple quasar, where the lensing gravitational potential is dominated by a cluster of galaxies, and not a single galaxy. Modelling of the lensing potential gives only a rough estimate of the cluster mass ($M \geq 10^{14} h^{-1} M_{\odot}$, Oguri et al. 2004) . The predictions for the time delays between the images are similarly uncertain, the delay between the closest components A and B can be up to $37h^{-1}$ days, the largest delay C-D could be up to $3000h^{-1}$ days (Oguri et al. 2004). Optical spectroscopy of the individual components has revealed significant differences in the emission line profiles of the components (Richards et al. 2004), which have been attributed to microlensing of lens image A. Specifically, the blue wings of the emission lines are enhanced in the spectra of component A. This feature has been observed in May 2003 and then disappeared. The blue line wing excess has again been observed in our *PMAS* spectra of SDSS J1004+4112 which were taken simultaneously with the *XMM-Newton* data (Fig. 1).

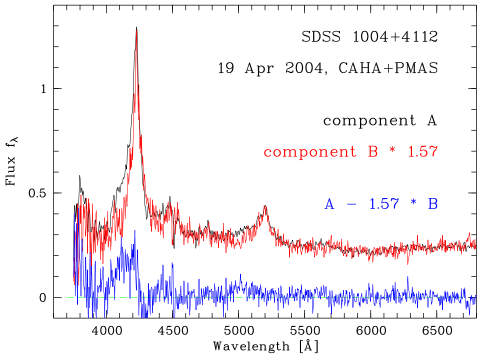

Figure 1. Optical spectra of SDSS J1004+4112 A and B taken almost simultaneously with the XMM data on 19/04/2004. The lower line is the difference spectrum (A - 1.57 · B) and shows that the blue wings of the emission lines are enhanced in component A.

2. XMM-NEWTON RESULTS

We observed SDSS J1004+4112 for 60 ksec with the XMM EPIC and OM instruments. Inspection of the EPIC images reveals that lens image A appears much fainter in X-rays than expected from its optical brightness (Figs. 2, 3). A deconvolution using PSF fitting with the SAS task *emldetect* results in a flux ratio B/A ~ 2, component A is more than 3 times weaker than expected from the optical/UV fluxes. The flux deficit of component A is constant over the XMM EPIC energy range, hence we can exclude that it is caused by photoelectric absorption. The simultaneous UV imaging of the XMM Optical Monitor (OM) shows that the UV continuum of the close components A and B is much brighter and harder than in images C and D (Fig. 4).

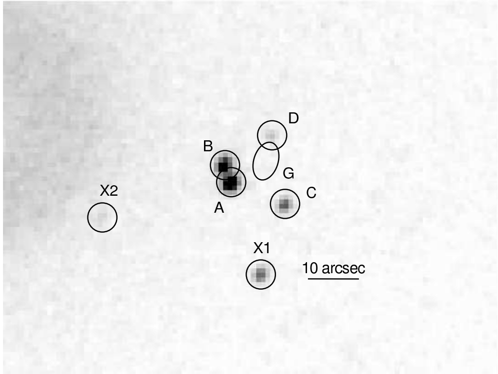

Figure 2. U-band image of SDSS J1004+4112 from the XMM optical monitor on 20/04/2004. Here the order of the components in brightness is the same as in previous optical observations.

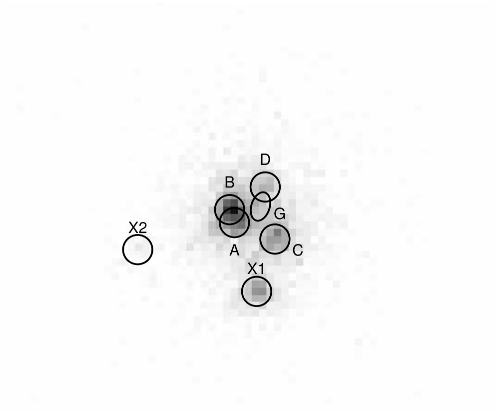

Figure 3. EPIC MOS image of SDSS J1004+4112 on 20/04/2004. It is obvious that the optically brightest component A is significantly fainter in X-rays than expected. Sources X1 and X2 are not related to the lensed quasar.

The following scenario could explain both the variable line profiles in image A and the unusual SEDs in the UV/X-ray wavebands: The UV and X-ray continuum of the lensed quasar is intrinsically very variable, during the time of the XMM observations the close images A and B were very bright. The variable continuum gives rise to variability of the optical lines, image A is probably affected by microlensing, which amplifies parts of the broad line region and causes the selective, repeated brightening of the blue line wing. The X-ray deficit of image A is still puzzling. Intrinsic variability is an unlikely cause, since the time lag to component B is relatively small. If caused by microlensing, this would be an extreme case of flux attenuation induced by microlensing. Repeated X-ray observations of SDSS J1004+4112 are needed to clarify this case.

Multiple PSF fitting with the XMM SAS *emldetect* task yielded a significant detection of the extended emission of the lensing cluster. We measure a 0.5-2.0 keV luminosity of $1.4 \cdot 10^{44} \mathrm{erg/s}$, and from the count rates in the 5 standard EPIC energy bands a gas temperature of $T = 4.3^{+2.1}_{-1.0}$ could be derived. With the scaling relations for clusters of this redshift (Kotov & Vikhlinin 2005) this puts the cluster in the mass range $3 - 6 \cdot 10^{14} \mathrm{M}_{\odot}$, consistent with, and improving the estimates from lensing models. Fig. 2b shows, that the extended cluster emission is asymmetric with respect to the brightest cluster galaxy and the lensing centre, tracing the distribution of cluster galaxies.

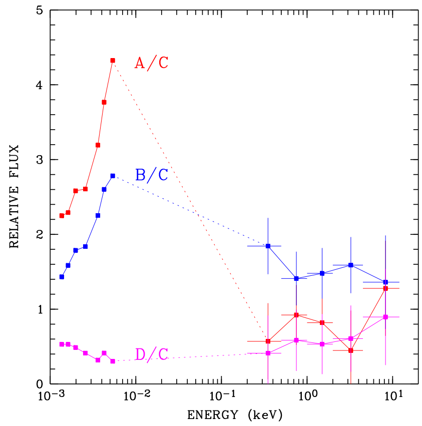

Figure 4. Relative spectral energy distributions of the lens components, normalized to image C. The SEDs include (non-simultaneous) optical Subaru data and XMM-OM and EPIC data.

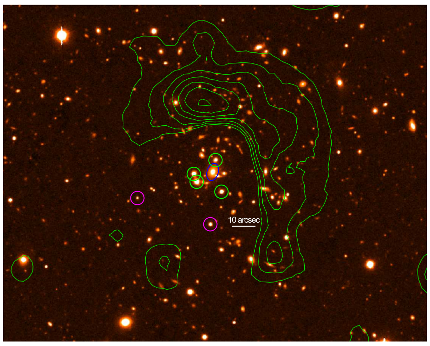

Figure 5. X-ray contours after subtraction of the point sources plotted over a Subaru I-band image. The extended emission of the cluster is clearly detected.

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