SDSS J120923.7+264047: a new massive galaxy cluster with a bright giant arc

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ABSTRACT

Highly magnified lensed galaxies allow us to probe the morphological and spectroscopic properties of high-redshift stellar systems in great detail. However, such objects are rare, and there are only a handful of lensed galaxies that are bright enough for a high-resolution spectroscopic study with current instrumentation. We report the discovery of a new massive lensing cluster, SDSS J120923.7+264047, at z = 0.558. Present around the cluster core, at angular distances of up to ~40 arcsec, are many arcs and arc candidates, presumably due to lensing of background galaxies by the cluster gravitational potential. One of the arcs, 21 arcsec long, has an r-band magnitude of 20, making it one of the brightest known lensed galaxies. We obtained a low-resolution spectrum of this galaxy, using the Keck-I telescope, and found it is at redshift of z = 1.018.

Key words: gravitational lensing – galaxies: clusters: individual: SDSS J120923.7+264047 – galaxies: high-redshift.

1 INTRODUCTION

High-redshift galaxies (z > 1) are out of reach for current high-resolution spectrographs. Fortunately, such galaxies may be highly magnified, when lensed by galaxies or cluster of galaxies, making them bright enough for high-resolution spectroscopic studies. However, high-magnification lensed galaxies are rare, and only a small number of targets suitable for high-resolution spectroscopic studies are known. Among these are MS1512−cB58 (Yee et al. 1996), with r = 20.4 mag at z = 2.72; an r = 20.3 mag Lyman break galaxy at z = 3.07 (Smail et al. 2007) and, finally, a highly magnified galaxy, at z = 2.73, with r = 19.2 mag (Allam et al. 2007). Studies of these objects (e.g. Pettini et al. 2000, 2002; Teplitz et al. 2000; Baker et al. 2004; Schaerer & Verhamme 2008) provided valuable information on their metallicity and interstellar medium.

In this paper, we report on the discovery of a previously unknown rich cluster of galaxies at z = 0.558. The cluster containing a bright ‘giant arc’, which is an appropriate target for high-resolution spectroscopic studies. In addition, the cluster, which has a considerable Einstein radius of probably ~20–40 arcsec, contains a large number of additional arcs and lensed galaxies. This cluster is probably as rich as the Abell 1689 lensing cluster (Broadhurst et al. 2005), and therefore it is an excellent target for detailed strong and weak lensing modelling (e.g. Bradač et al. 2006; Halkola, Seitz & Pannella 2006).

The outline of this paper is as follows. We describe the observations in Section 2, and in Section 3 we discuss the cluster and arcs along with their measured properties. Finally, we briefly discuss the results in Section 4.

2 OBSERVATIONS

The discovery of the cluster and arcs described in this paper was made as part of a survey for large separation lensed quasars (e.g. Maoz et al. 1997; Ofek et al. 2001; Phillips et al. 2001; Inada et al. 2003, 2006; Oguri et al. 2004, 2008), among Sloan Digital Sky Survey (SDSS; York et al. 2000) photometrically selected quasars. This search will be described elsewhere. Our search uncovered a previously unknown cluster of galaxies in a SDSS image. In addition to the cluster, a giant arc was clearly visible near the cluster, in the relatively shallow SDSS images.

On UTC 2008 January 04, we obtained 5 × 220 s g-band and 5 × 180 s R-band images of the cluster environment using the Low Resolution Imaging Spectrograph (LRIS; Oke et al. 1995) on the Keck-I telescope, under seeing of 0.6 arcsec. The combined Keck R-band image is presented in Fig. 1, and the combined g-band image is presented in Fig. 2. The images were calibrated astrometrically using six objects appearing in both the Keck and the SDSS images. The solution rms is better than 0.1 arcsec in both axes and both images. In Table 1, we give the positions and photometry of the main arcs detected in the images. We have measured the magnitude of each arc, by combining all the light within a polygon defined by the SExtractor segmentation (Bertin & Arnouts 1996). In case SExtractor broke an arc to several segments, we combined the light within these segments. The SExtractor detection threshold was set to about 2σ above background.
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Figure 1. R-band image of SDSS J120923.7+264047, obtained with LRIS mounted on the Keck-I 10 m telescope. Objects labelled by A1...K are candidate arcs. The properties of the labelled arc candidates are listed in Table 1. Also labelled are the cluster bright galaxy (cg1; SDSS J120924.41+264057.8) at $z = 0.542$; (cg3; SDSS J120923.60+264059.9) at $z = 0.542$ and a bright SDSS quasar (cq1; SDSS J120920.61+264041.2), at $z = 1.555$. The quasar, cq1, which has an $r$-band magnitude of 20.3, is found 41 arcsec from the bright cluster galaxy, so most probably it is not strongly lensed by the cluster. Also marked is the position (and actual width) of the slit we used to obtain the spectrum of the arc.

Figure 2. g-band image of SDSS J120923.7+264047, obtained with LRIS mounted on the Keck-I 10 m telescope (see Fig. 1 for details).

On the same night, using LRIS-Atmospheric Dispersion Compensator, we also obtained a 1300 s spectrum of the bright giant arc, labelled A1...A4 in Fig. 1. We used a 0.7 arcsec slit with the 5600 Å dichroic; the 400/3400 grism on the blue side and the 400/8500 grating, centred on 7693 Å, on the red arm. The slit position angle was set to 180°, in order to also include the blue (SDSS $g - r \approx 0.6$) galaxy labelled cg2 in Fig. 1. The spectrum was flux calibrated using observations, obtained on the same night, of the spectrophotometric standard Hz2 (Turnshek et al. 1990). The

| Name | RA J2000 | Dec. J2000 | $g$ (mag) | $r$ (mag) |
|------|---------|-----------|----------|----------|
| A1   | 12:09:24.19 | +26:40:54.7 |          |          |
| A2   | 12:09:24.38 | +26:40:51.9 |          |          |
| A3   | 12:09:24.46 | +26:40:49.1 |          |          |
| A4   | 12:09:24.48 | +26:40:47.0 |          |          |
| A    |          |           | 20.3     | 20.0     |
| B    | 12:09:24.00 | +26:40:49.9 |          |          |
| C1   | 12:09:21.91 | +26:40:56.9 |          |          |
| C2   | 12:09:22.31 | +26:41:05.9 |          |          |
| D    | 12:09:22.04 | +26:40:46.5 |          |          |
| E    | 12:09:21.22 | +26:40:45.8 |          |          |
| F1   | 12:09:24.94 | +26:40:53.5 |          |          |
| F2   | 12:09:24.96 | +26:40:51.6 |          |          |
| G    | 12:09:25.06 | +26:40:54.5 |          |          |
| H1   | 12:09:23.65 | +26:40:20.2 |          |          |
| H2   | 12:09:22.82 | +26:40:23.5 |          |          |
| I    | 12:09:23.38 | +26:40:13.2 |          |          |
| J    | 12:09:24.17 | +26:40:12.6 |          |          |
| K    | 12:09:24.10 | +26:40:03.6 |          |          |
same setup, on UTC 2007 December 15, a 1500 s exposure spectra of arc A is shown in Fig. 3. We also obtained using the webtool, we converted the ROSAT/PSPC count rate to an absorbed flux of $6.9 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$, assuming a Galactic neutral hydrogen column density of $1.8 \times 10^{20}$ cm$^{-2}$ (Dickey & Lockman 1990; Kalberla et al. 2005) and a power-law spectrum with a photon index of $\Gamma = 1$ (assuming thermal optically thin bremsstrahlung). Given the luminosity distance to the cluster, this flux implies a luminosity of $\sim 8 \times 10^{44}$ erg s$^{-1}$ in the 0.1–2.4 keV band. Using the X-ray luminosity–mass relation given by Reiprich & Böhringer (2002), we estimate that the $M_{200}$ mass of the cluster is approximately $10^{15} M_\odot$.

1 Assuming third year Wilkinson Microwave Anisotropy Probe (WMAP) cosmological parameters: $\Omega_m = 0.716$, $\Omega_b = 0.268$, $H_0 = 70.4 \text{ km s}^{-1} \text{ Mpc}^{-1}$; Spergel et al. 2007.

2 http://cxc.harvard.edu/toolkit/pimms.jsp

3 $M_{200}$ is the mass enclosed within $r_{200}$, which is the radius in which the mean density equals 200 times the mean density of the Universe (e.g. Navarro, Frenk & White 1997).

4 DISCUSSION

Strong and weak lensing are being used to trace the mass distribution of galaxy clusters. However, detailed modelling of the mass distribution of the cores of galaxy clusters requires the identification of multiple images of lensed sources. Such an identification needs good multi-band colour information, or/and good spatial resolution (e.g. Broadhurst et al. 2005; Sharon et al. 2006). Indeed, we are planning additional multi-band observations of this cluster, which will enable a detailed modelling of the cluster gravitational potential.

To confirm the presence of the cluster, in Fig. 5 we show the colour–magnitude diagram for SDSS galaxies found with 2 arcmin from the cluster bright galaxy (black circles). For comparison, we also show all the SDSS galaxies found within 5 arcmin and 1° from the cluster bright galaxy (grey dots). The solid (dashed) red lines display the locus of Elliptical (Sb) galaxies as a function of redshift. These lines take into account the Galactic extinction ($E_{B-V} = 0.019$ mag) in the direction of the cluster (Schlegel, Finkbeiner & Davis 1998; Cardelli, Clayton & Mathis 1989). It is evident that in the cluster direction there is an excess of high-redshift galaxies, relative to the field.

At the approximate position of the bright cluster galaxy, we find a known ROSAT source (Voges et al. 2000). Using the PIMMS webtool, we converted the ROSAT/PSPC count rate to an absorbed flux of $6.9 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$, assuming a Galactic neutral hydrogen column density of $1.8 \times 10^{20}$ cm$^{-2}$ (Dickey & Lockman 1990; Kalberla et al. 2005) and a power-law spectrum with a photon index of $\Gamma = 1$ (assuming thermal optically thin bremsstrahlung). Given the luminosity distance to the cluster, this flux implies a luminosity of $\sim 8 \times 10^{44}$ erg s$^{-1}$ in the 0.1–2.4 keV band. Using the X-ray luminosity–mass relation given by Reiprich & Böhringer (2002), we estimate that the $M_{200}$ mass of the cluster is approximately $10^{15} M_\odot$.

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