

## Deep *I*-band imaging of $z = 5.99$ quasar

V. D. Ivanov\*

European Southern Observatory, Ave. Alonso de Cordova 3107, Casilla 19, Santiago 19001, Chile

Received 2 May 2002 / Accepted 14 May 2002

**Abstract.** Deep *I*-band imaging was carried out to search for the optical counterpart of the X-ray jet candidate near SDSS 1306+0356, reported by Schwartz (2002 [astro-ph/0202190]). The data suggest that the extended X-ray source may be a jet, related to a galaxy rather than to the quasar itself.

**Key words.** quasars: general – galaxies: jets – galaxies: high redshift

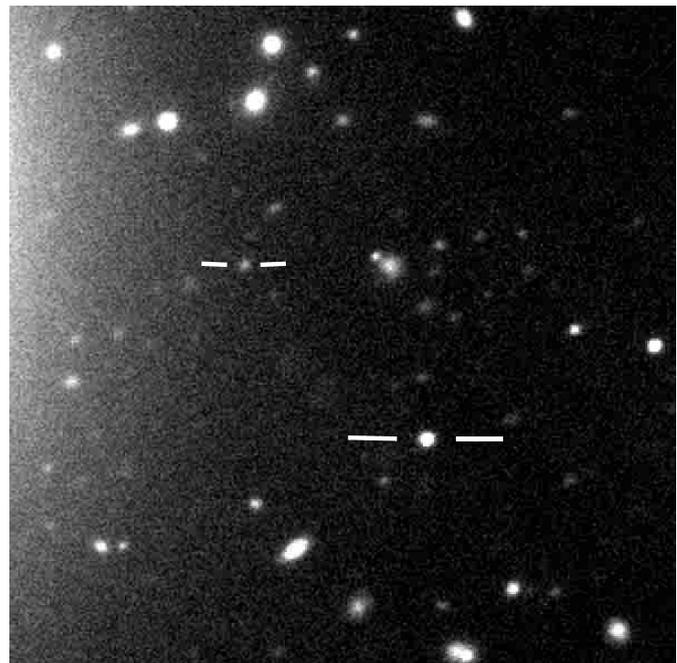
### 1. Introduction

Synchrotron jets are observed in many quasars and nearby radio galaxies. They have been detected in a broad range of wavelengths, from radio to hard X-ray (Scarpa et al. 1999; Schwartz et al. 2000; Sambruna et al. 2002; Harris & Krawczynski 2002). The highest redshift quasars are among the earliest objects in the Universe. The X-ray emission produced close to the central black hole is related intimately to the processes in the central engine and therefore offers the possibility to probe directly the processes occurring in the quasar nuclei.

Recently, Brandt et al. (2002) carried out a *Chandra* survey of the quasars with highest known redshifts up to date, spanning the range from  $z = 5.8$  to 6.3. All three objects targeted by this program were detected. Schwartz (2002) found a serendipitous source 23.3 arcsec to the North-East of the quasar SDSS J130608.26+035626.3 (SDSS 1306+0356 hereafter;  $z = 5.99$ , Fan et al. 2001). The source was extended over  $5 \times 2$  arcsec box, aligned with the quasar. Schwartz suggested that it can be a jet, associated with the quasar. The goal of this project is to find an optical counterpart of the X-ray source, and to explore its nature.

### 2. Observations and data reduction

Deep Bessel *I*-band imaging was carried out at the VLT with FORS1. A series of four 787 sec images was obtained on Mar 18, 2002. The standard data reduction was applied, and the four images were combined. The seeing measured on multiple unresolved sources is 0.56 arcsec, with a scale of 0.2 arcsec  $\text{px}^{-1}$ . The outer parts of the images were affected by reflection from a bright nearby star but the quasar itself was not contaminated. Gray scale reproduction of the final image is shown in Fig. 1.

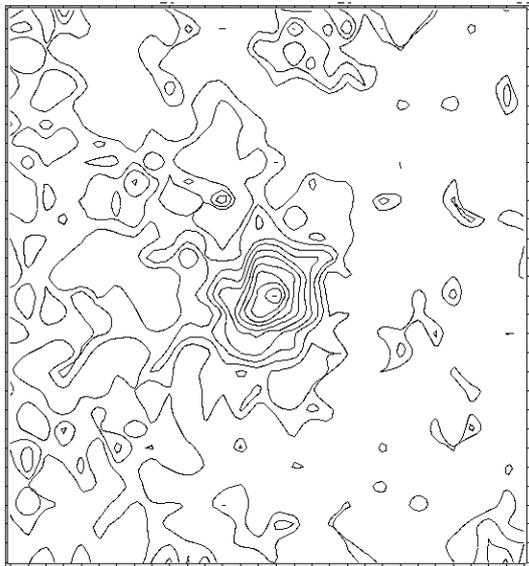


**Fig. 1.** The field of SDSS 1306+0356. The quasar, and the optical counterpart of the extended *Chandra* source are indicated, respectively with long and short dashes. The field is  $1 \times 1$  arcmin. North is up and East is to the left. The higher background level to the East is caused by a bright nearby star.

### 3. Results

Two candidates for an optical counterpart were discovered near the location of the X-ray source. The first one is at RA = 13:06:09.34 Dec = +03:56:42.1 (J2000), 22.7 arcsec to the North-East from the quasar. It is extended in NW-SE direction (Fig. 2). The source spans at least 1.5 arcsec along the major axis, corresponding to a projected diameter of at least 9 kpc at the redshift of the quasar.

\* e-mail: vivanov@eso.org



**Fig. 2.** Contour plot of the best candidate for an optical counterpart to the X-ray source. The field of view is  $6 \times 6$  arcsec, tic marks equal 0.2 arcsec (1 pixel). North is up and East is to the left. The contours span a range from 23.06 to 26.77 mag arcsec $^{-1}$ , and are equally spaced in flux.

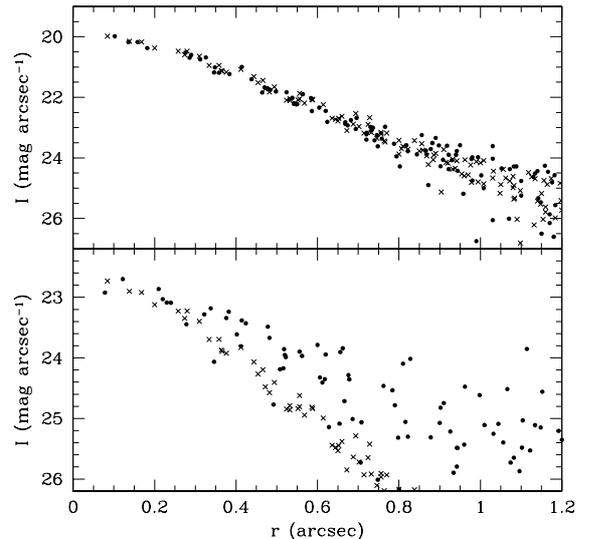
We assumed  $H_0 = 65$  km s $^{-1}$  Mpc $^{-1}$ ,  $\Omega_0 = 0.3$ ,  $\Omega_\Lambda = 0.7$ , and  $q_0 = -0.55$ , same as in Schwartz (2002). The radial profiles of the quasar and the source are plotted in Fig. 3. A bright star is shown for comparison. Clearly, the source is well resolved, while the quasar is not. The total apparent *I*-band magnitudes of the source is  $23.01 \pm 0.11$  mag.

The second candidate is located at RA = 13:06:09.19 Dec = +03:56:39.3 (J2000). It is unresolved and has *I*-band brightness of  $24.81 \pm 0.20$  mag. It was discarded from further considerations because its position differs from the location of the X-ray source by more than 4 arcsec, which exceeds the accuracy of our coordinates ( $\sim 0.5$  arcsec, as estimated from the quasar coordinates). The apparent *I*-band magnitudes of the quasar was measured as well:  $20.65 \pm 0.05$  mag.

The transverse elongation of the optical source with respect to the elongation of the X-ray source casts a strong doubt on the interpretation offered by Schwartz (2002). The data indicates a foreground galaxy, rather than UV/optical emission from a jet associated with SDSS 1306+0356.

However, Schwartz (2002) demonstrated that the extended X-ray source is statistically significant. It is comprised of 7 counts, which exceeds by far the expected background flux of 0.13 counts. He estimated that the probability of observing 7 photons in a 10 arcsec $^2$  box is  $5.8 \times 10^{-9}$ .

What are the chances of observing a galaxy with the given magnitude in such a close proximity ( $\sim 0.6$  arcsec) from the X-ray source? An integration of the *I*-band number counts provided by Yasuda et al. (2001) suggests that  $3.8 \times 10^5$  galaxies brighter than  $I \sim 23$  mag can be found per square degree. Therefore, the probability of random coincidence of the X-ray source and a galaxy is  $\sim 0.01$ .



**Fig. 3.** Radial profiles of SDSS 1306+0356 (top, solid dots), and the best candidate for an optical counterpart to the X-ray source (bottom, solid dots), in arbitrary units. The radial profiles of a foreground star are shown for comparison (crosses). The sky background was subtracted locally for each object.

An alternative estimate can be obtained by using the surface density of optically detected objects near the X-ray source. There are 6 such objects within  $10 \times 10$  arcsec area. Thus, the probability is  $6 \times (0.6/10)^2 \sim 0.02$ .

In the light of the new data, the most likely explanation is that the X-ray source, if it is a jet, is associated with the galaxy, rather than the quasar. Multiband observations are needed to determine the redshift of the host. The bright nearby star (SAO 119762, K0,  $V = 8.32$  mag) affects the sky background preventing meaningful galaxy number counts in the vicinity of the quasar.

*Acknowledgements.* The author is grateful to members of Paranal Science Operations team for carrying out the observations in service mode, and to the referee Dan Schwartz for the useful comments that helped to improve this letter.

## References

- Brandt, W. N., Schneider, D. P., Fan, X., et al. 2002, ApJ, 569, L5
- Fan, X., Narayanan, V. K., Lupton, R. H., et al. 2001, AJ, 122, 2833
- Harris, D. E., & Krawczynski, H. 2002, ApJ, 565, 244
- Sambruna, R. M., Maraschi, L., Tavecchio, F., et al. 2002, ApJ, in press [astro-ph/0202412]
- Scarpa, R., Urry, C. M., Falomo, R., & Treves, A. 1999, ApJ, 526, 643
- Schwartz, D. A., Marshall, H. L., Lovell, J. E. J., et al. 2000, ApJ, 540, L69
- Schwartz, D. A. 2002, ApJ, 571, in press [astro-ph/0202190]
- Yasuda, N., Fukugita, M., Narayanan, V. K., et al. 2001, AJ, 122, 1104