Astron. Astrophys. 322, 38–40 (1997)

ASTRONOMY AND ASTROPHYSICS

A distant elliptical galaxy seen through a foreground spiral*

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Received 21 October 1996 / Accepted 7 November 1996

Abstract. The radio source PKS 0400-181 is a classical edge-brightened radio double, which was tentatively identified with a faint red object thought to be a distant galaxy located behind a $z = 0.0367$ spiral galaxy. The properties of the red object were found to be consistent with a giant elliptical galaxy at a redshift of ~ 0.5. New spectroscopic observations confirm this interpretation; the measured redshift of the background elliptical is 0.341. This result provides further evidence that, contrary to some previous suggestions, spiral galaxies are not opaque.

Key words: galaxies: individual: PKS 0400-181 – galaxies: spiral – ISM: dust, extinction – galaxies: ISM

1. Introduction

The radio source PKS 0400-181 was originally identified with a 16th magnitude spiral galaxy (Savage & Wall, 1976). Subsequent VLA observations, however, revealed it to be an extreme Cygnus-A type edge-brightened, double-lobed radio source (Shaver et al., 1983). Such sources had in the past always been associated with elliptical galaxies, so this apparent identification of a classical radio double with a spiral galaxy generated considerable interest. There were two possible interpretations: either this was the first case of a classical radio double physically associated with a spiral galaxy, or it was a mis-identification with an undetected background elliptical galaxy. As no radio core was detected down to relatively low flux densities, a definitive identification based on astrometry was not possible, and a variety of other observations also failed to solve the puzzle.

CCD R and I-band images finally provided a tentative answer. They revealed the presence of a very red and slightly extended object superimposed on the image of the spiral, just 2.″4 from its centre and close to the radio centroid. It was concluded that this is probably a background elliptical, and that its properties (and those of the radio source) are consistent with a redshift of ~ 0.5 (Shaver et al., 1983).

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Some years later the radical suggestion was made that spiral galaxies may be completely opaque (Valentijn (1990) - although this has been the subject of considerable controversy; e.g. Huizinga & van Albada (1992); White & Keel (1992) - it has even been suggested that distant quasars may be totally obscured by intervening galaxies (Ostriker & Heisler, 1994)). If that were the case, the above interpretation of PKS 0400-181 would have to be completely re-considered. We have tested this interpretation by obtaining a spectrum of the red object, and here we present the results of these observations.

2. Observations and results

The observations were made in November 1991 using the ESO Faint Object Spectrograph and Camera (EFOSC) at the Cassegrain focus of the ESO 3.6 m telescope on La Silla. The Tektronix 512 x 512 chip used had a readout noise of 8.8 e^- and pixel size corresponding to 0.″61. The 2-minute Gunn-r image is shown in Fig. 1, and the red object is clearly visible superimposed on the image of the spiral galaxy, 2.″5 south-west of its optical centre.

Three spectra using the B300 grism (3600-7000Å) totaling 98 minutes were obtained. The slit width was 1.″5. The spectra were reduced and calibrated with MIDAS. Following the bias and flat field corrections we used the LONG context for the wavelength and flux calibrations. Cosmic hits were removed by applying a median filter in the spatial direction.

Fig. 2 shows two scans along the slit, at the blue and red ends of the two-dimensional B300 spectrum. These clearly reveal the position of the red object, and were used to select the scan lines extracted for the object and reference spectra. The western end of the spectrum is bluer than the eastern end (the two scans were scaled to have the same flux at R$\sim$ -8″). The S1 spectrum (c.f. Fig. 2) is quite flat redwards of the Balmer break and shows no emission. The S2 spectrum is bluer and shows [OII]λ3727 and Hα in emission. The Hα equivalent width is about 11 Å. Both spectra show Hβ in absorption with an equivalent width of $\sim$ 7 Å. Together with the spectral shape this indicate that the stellar population consists mainly of main sequence F and giant G type stars. On the whole the spectra are typical for Sb type galaxies (Kennicutt, 1992). The cause of the colour difference along the

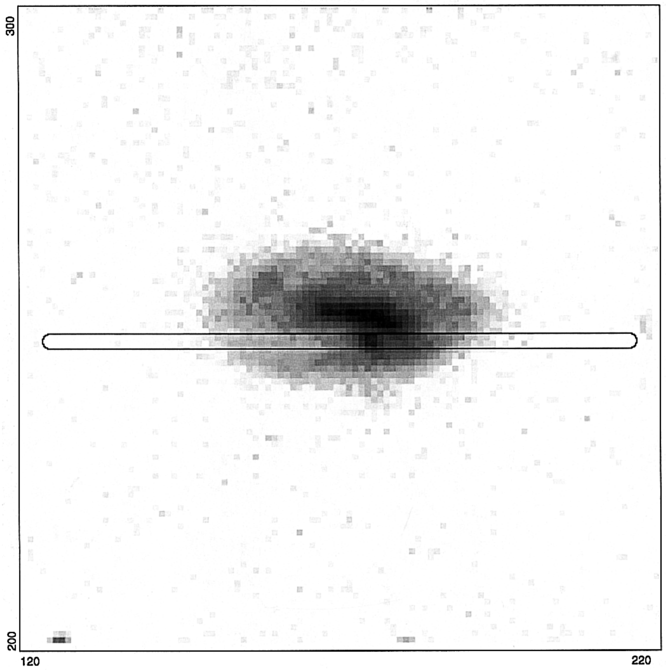

Fig. 1. Gunn-r of PKS 0400-181. The horizontal box indicate the position of the slit used for the spectroscopic observations. The frame size is 62 arcmin square. North is at the top, east to the left.

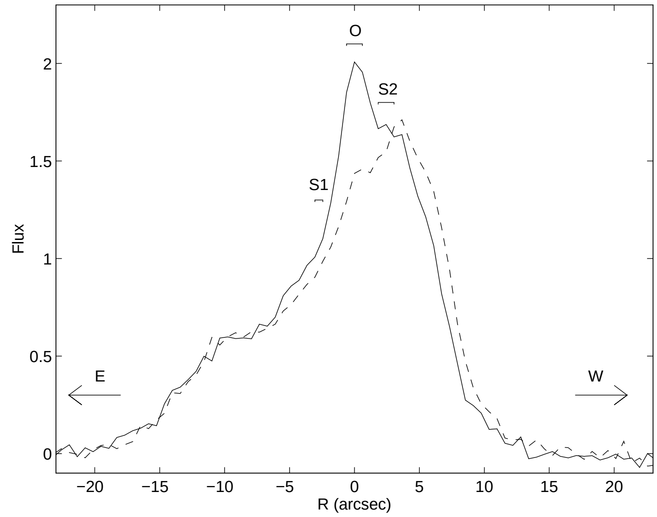

Fig. 2. Scans along the slit, obtained from the red (solid line) and blue (dashed line) ends of the two-dimensional spectrum. The ranges used for the red object (O) and reference spectra (S1 and S2) are indicated. R is the distance to the centre of the red object in arscec. The eastern (E) and western (W) directions are marked.

slit we attribute to the presence of HII regions in the western part of the foreground galaxy, although we cannot exclude some contribution from differential extinction.

We then subtracted S1 and S2 from the red object spectrum with weights based on the relative flux levels in the blue part of the spectra. As discussed above, the spectra corresponding to scans S1 and S2 have different shapes so we should actually use wavelength dependent weights. In fact the red object is located on the spot where the spiral galaxy show the strongest emission which probably make the final spectrum of the red object somewhat bluer that it actually is. However, as we are primarily interested in the absorption lines features and not the general spectral shape we use wavelength independent weights here. We also note that the sky subtraction was automatically taken care of in this procedure. A few of the stronger sky lines, e.g. [OI]λ 5577 Å and Na I at 5892 Å, are not perfectly subtracted as seen in Fig. 3. There are no strong sky lines at the positions of the absorption lines that we identify with the red object, however.

The final spectrum of the red object is shown in Fig. 3. The thin absorption feature seen in the spectrum redward of the H line as well as the dip just blueward of the K line we trace back to sharp noise features in the reference spectra used to subtract the spiral galaxy contribution (they are only present in individual integrations).

For comparison we also show in Fig. 3 the spectra of NGC 3379 (Kennicutt, 1992), which is a typical E galaxy, and a model spectrum of an old (12 Gyr) stellar population (K. Olofsson, private communication) derived from spectral evolutionary models. These spectra have been redshifted to z = 0.341. Comparing this with our data we note two features: 1) the general similarity of the spectral energy distributions and 2) the coincidence of some absorption lines: the Calcium H & K absorption and spectral break, the Mg G band and possibly a broad Hβ with some filled in emission. The redshift obtained from these features is z = 0.341 $\pm$ 0.003.

The redshift of the spiral galaxy obtained from the observed [OII]λ3727 and Hα emission lines lying closest to the centre was measured to be z = 0.037 $\pm$ 0.001, in agreement with that obtained by Shaver et al. (1983). Rotation is clearly seen, with a total velocity range of a few hundred km s^{-1}, consistent with the properties of this spiral.

3. Discussion

These observations confirm that the red object is indeed a background elliptical galaxy. The redshift of 0.341 is in good agreement with the value of $\sim$ 0.5 suggested by Shaver et al. (1983).

Clearly the foreground spiral galaxy is not opaque, even at a distance of half a disk scale length from its centre (5 kpc, assuming an exponential disk with inclination of 60°.) Although there are numerous studies of the opacity in the outer parts of disk galaxies with contradicting results, the central parts (radius $<$ one scale length) of bright spiral disks are generally assumed to be opaque (see e.g. Huizinga, 1994, for a review). A direct method to measure the extinction, free from confusing selection effects in statistical studies, is to observe individual galaxies that have partly overlapping images. Using this method, White & Keel (1992) and White et al. (1996) showed that the opacity varies considerably between arm and inter-arm regions. Spiral arms are mostly optically thick while in the inter-arm region

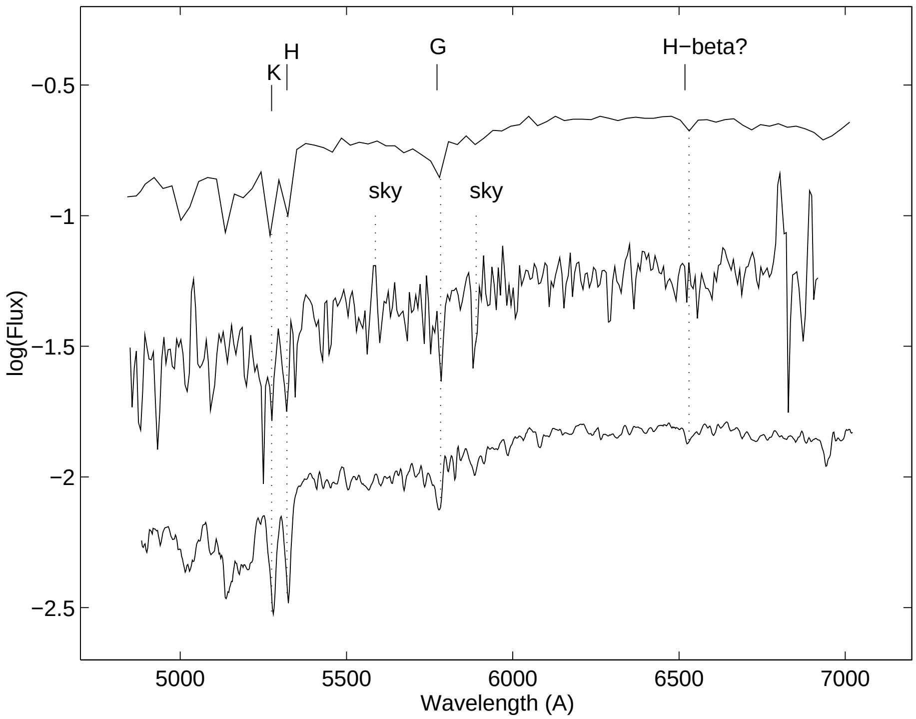

Fig. 3. Spectrum of the background elliptical galaxy (heavy middle line). The lower spectrum shows a redshifted (z = 0.341) template E galaxy spectrum (Kennicutt, 1992) and the upper spectrum shows a redshifted model E spectra (Olofsson, private communication). Some of the major identifying spectral features are marked.

there is a galactocentric radial dependence from $A_B \sim 1$ mag. in the central parts to zero in the outer parts.

The red object is located a few arcsec south of what appears to be a central bar in the foreground spiral galaxy. Assuming that it is located in an inter-arm region with $A_B \sim 1$ mag, its apparent I magnitude is $\sim$ 18.1. [Note that intrinsically I corresponds roughly to the V band. Note also that the visual absorption A_V=2.7 estimated by Shaver et al. (1983) from the Balmer decrement pertains to HII regions which are presumably located in spiral arms, and would therefore not be representative of the interarm regions (White et al. 1996)]. If H_0 = 75 km s^{-1} and q_0 = 0.5 then M_V = -22.7 at z = 0.341. This is typical for a giant elliptical galaxy. The radio power at 5.0 GHz is 2.7 10^{24} W Hz^{-1} sr^{-1}, and the linear size of the radio source is 270 kpc - typical of 3CR radio galaxies.

We conclude that the red background object is a typical FR II radio galaxy at z = 0.341 and $M_V \sim -23$. We see it through the central parts of a nearby barred Sb galaxy at z = 0.0361 and M_V = -19.5. This coincidence show that at least part of the central region of this spiral galaxy is not opaque.

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