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A powerful, ultra-steep spectrum radio galaxy having an extremely low-excitation emission line spectrum *

Gopal-Krishna [1], E. Giraud [2], J. Melnick [2], and H. Steppe [3]

[1] NCRA-TIFR, Poona University Campus, Pune 411007, India
[2] European Southern Observatory, Alonso de Cordoava 3107, Vitacura Casilla 19001, Santiago 19, Chile
[3] IRAM, Avd. Divina Pastora 7, (N-C), E-18012 Granada, Spain

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Abstract. In the course of our optical follow up of the Ooty sample of ultra-steep spectrum radio sources (USSRS), we have discovered an exceptionally interesting case of a classical double radio source of size $\sim 14''$ and spectral index $\alpha = -1.2$ associated with a red galaxy at a modest redshift of $z = 0.477$. The galaxy exhibits gaseous wisps broadly coincident with the radio lobes.

The optical spectrum is dominated by an emission line showing a very large rest-frame equivalent width of 350 Å, a spatial extent of $\sim 10''$ at the position angle of the radio structure, and a tilt with a maximum rest-frame velocity difference of ~ 760 km s^{-1}. These properties, as well as the presence of the optical wisps suggest that the system is a product of a merger involving a gas-rich disk and a massive elliptical.

Even though the object is relatively bright ($V = 21.3$), additional spectral lines could only be detected after a persistent, deep integration. These very faint features, identified with Hβ, [O III] λ5007, and H, K and G-band, have lead to an unambiguous interpretation of the dominant emission line as being [O II] λ3727. The detection of faint lines may have considerable relevance to some cases of radio galaxies for which extremely large redshifts ($z > 3$) have been inferred recently.

The red colour of the galaxy, and the equivalent widths of the stellar absorption features suggest that the continuum of 1411-192 is dominated by an old stellar population. The physical conditions of the gas are similar to those of LINERS, with shock-heating as a possible ionization mechanism. The association of an "ultra-soft" emission line spectrum with such a powerful radio galaxy is intriguing.

Key words: galaxies – galaxy mergers – galaxies: radio sources – galaxies: evolution – cosmology

1. Introduction

Unlike quasars, most galaxies with redshifts greater than 1 have been discovered in radio surveys. The farthest galaxy in the third Cambridge catalogue, 3CR 257 ($z = 2.474$), is actually more distant than 3CR 9 ($z = 2.012$), the remotest quasar in that catalogue (Spinrad, private communication). A majority of galaxies known to lie at $z > 2$ have been found by optical follow up of the 3C, 4C, Molenglo and 1-Jansky samples (e.g. Spinrad 1986; Mc Carthy et al. 1987a, 1990; Chambers et al. 1987a, b; Allington-Smith et al. 1988; Lilly 1989). However, since these and other radio samples contain thousands of radio sources, a selection criterion for maximizing the prospects of discovering high-redshift galaxies had to be found. Thus, using the 4C and Ooty lunar occultation samples of radio sources it was recognized about a decade ago that radio sources with steeper decimeter-wave spectrum are statistically more distant, as they tend to appear optically fainter and more compact in their radio extents (Blumenthal & Miley 1979; Tielens et al. 1979; Gopal-Krishna et al. 1980; Gopal-Krishna & Steppe 1981). The first major success using this clue came a few years ago from sensitive optical spectroscopy of a sample of 4C radio sources with ultra-steep radio spectra (Chambers et al. 1987b). Major observational programmes have since been initiated to exploit this method.

The detection of high-z galaxies has often been greatly facilitated by the presence of a very strong Lyman α emission ($\gtrsim 10^{44}$erg s^{-1}) which is sometimes very extended (≈ 100 kpc) and is usually elongated in the direction of the radio lobes (Spinrad 1989). A similarly striking alignment between radio and optical continuum emission is found for high-z galaxies (McCarthy et al. 1987b; Chambers et al. 1987a, b). Thus, extensive star formation appears to be triggered by the compression of a pre-existing circumgalactic medium by the expanding radio source (McCarthy et al. 1987a; Rees 1989; Begelman & Cioffi 1989; De Young 1989; Daly 1989; Eales & Rawlings 1990; Chambers & McCarthy 1990; see , however, Hammer et al. 1990, for an alternative viewpoint). Since the radio-loud phase is only expected to last for $\sim 10^8$ years (e.g. Gopal-Krishna & Wiita 1991), the postulated jet-induced stellar population should be fairly young, necessitating a star formation rate of the order of 100 $M_\odot$ yr^{-1} (Chambers & Charlot 1990). The optical light from some galaxies is significantly polarized at an angle perpendicular to the radio axis and this has led to the idea that part of the UV light from powerful radio galaxies may be beamed radiation scattered by dust (di Serego et al. 1989; Antonucci & Baravainis 1990; also Unger et al. 1987). In this case the star formation rates may be lower than the values predicted by the population synthesis models, but still radio galaxies must have experienced substantial cosmic evolution.

Send offprint requests to: J. Melnick

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Considerable uncertainty persists in the age estimation for the stellar population responsible for the near-infrared emission from high-z galaxies. While the tight Hubble diagram up to $z \sim 2$ (Lilly 1989) favour old stellar populations ($\geqq 10^9$ yr), the claimed extension of the K-band images along the radio axis (Chambers et al. 1988; Eisenhardt & Chokshi 1990; Eisenhardt et al. 1990; Eales & Rawlings 1990) would suggest much younger ages ($\sim 10^8$ yr, e.g., Bithell & Rees 1990; Chambers & Charlot 1990). Recently, however, Rocca-Volmerange & Guiderdoni (1990) have stressed that, compared to optical images, the near-infrared images are considerably more compact and the alignment effect is much less conspicuous (see also Eisenhardt et al. 1990). These authors prefer a model where a strong initial 0.1 Gyr starburst is invoked to produce the rest-frame visible emission, while a current burst is added to fit the observed far-UV spectrum and the strong Lyman α emission.

In spite of the dramatic developments in the field over the past few years, the number of galaxies known at very high redshifts ($z > 3$) remains very small and therefore our view of those early epochs may be severely biased by the few such galaxies known. It is hence crucial to substantially enlarge the sample of high redshift galaxies and also to search for objects with similar properties at lower redshifts. Toward this objective we have formed a sample of ultra-steep spectrum radio sources, selected primarily from the Ooty lunar occultation survey at 327 MHz, employing the criterion of a spectral index steeper than about -1.15, as defined between metre and centimeter wavelengths. This is a very stringent constraint since the distribution of spectral index α is known to fall very steeply beyond $\alpha = -1$ (e.g. Gopal-Krishna & Steppe 1982). Optical identification of the sample began about one year ago and we are now taking up the spectroscopic follow-up of the brightest objects. Up to now, the sample has yielded galaxy redshifts in the range $z = 0.7$ to $z = 2.7$. We report here the discovery of a relatively low redshift radio galaxy (1411-192, $z = 0.477$) whose radio-optical properties may have interesting implications for the search programs for high-z radio galaxies.

2. Observations

2.1. Radio observations

The source 1411-192 was first reported in the Molonglo catalogue MC 1 (Davies et al. 1973). During the 1970–71 series, seven lunar occultations of this source were observed at Ooty at 327 MHz. These observations showed the source to be a double with the two components separated by $\sim 14''$ along position angle PA $\approx 7°$, with the radio centroid located at

$$\mathrm{RA} = 14^h11^m36^s\!.39;\ \mathrm{Dec} = -19°14'00''\ (1950)$$

to an accuracy of 1″ (Subrahmanya & Gopal-Krishna 1979). Its flux densities of 1.33 ± 0.04 Jy, 158 ± 10 mJy and 68 ± 5 mJy at 408 MHz, 2695 MHz and 4750 MHz, respectively, imply spectral indices $\alpha_{408}^{2695} = -1.13$ and $\alpha_{408}^{4750} = -1.21$ (see Steppe & Gopal-Krishna 1984; Large et al. 1981). Subsequently we took a snapshot with the VLA at 5 GHz in the B-configuration. The derived map with a beam of $1''\!.9 \times 1''\!.5$ (PA $= -30°$), shown in Fig. 1 a, is consistent with the occultation results. The northern and southern components account for 34 and 26 mJy, respectively, at 5 GHz and imply an overall source size of $\sim 14''$. While no radio nucleus is obvious on the map, outer hot spots are seen within each radio lobe at the following coordinates:

$$\mathrm{RA} = 14^h11^m36^s\!.43;\ \mathrm{Dec.} = -19°13'52''\ (1950)$$

and

$$\mathrm{RA} = 14^h11^m36^s\!.31;\ \mathrm{Dec.} = -19°14'04''\ (1950).$$

2.2. Optical observations

The data were obtained with the ESO Faint Object Spectrograph and Camera (EFOSC1) at the 3.6 m telescope and EFOSC2 at the NTT on La Silla. The detectors were a double density RCA CCD with 1024 × 640 pixels and a pixel size of 15 µm corresponding to $0''\!.337$ at the 3.6 m, and a Thomson 1024 × 1024 with a pixel size of 19 µm ($0''\!.15$) at the NTT. The source was identified on a 5 min exposure obtained through a Bessel R filter on March 31, 1989 (EFOSC 1, seeing $1''\!.1$). A finding chart made from this exposure is shown in Fig. 2. The optical counterpart of the radio source is very close to a bright star at

$$\mathrm{RA} = 14^h11^m37^s\!.90;\ \mathrm{Dec.} = -19°13'55''\!.3\ (1950).$$

Astrometry was made from this star and stars marked B and D on Fig. 2 which were calibrated on the paper prints of the Palomar Sky Survey Atlas using 8 SAO stars around the optical object. The optical position of the image determined this way is

$$\mathrm{RA} = 14^h11^m36^s\!.3;\ \mathrm{Dec.} = -19°13'59''\ (1950).$$

Within an estimated uncertainty of 1″–2″, this position coincides with the midpoint between the two radio hotspots (Fig. 1 a).

The optical image shows a North-South structure seen most clearly on a 15 min V-band exposure taken with the NTT (seeing $0''\!.9$). Wisps are seen to emerge from the galaxy roughly in the north-south direction with an overall extent of $\sim 12''$ approximately (Fig. 1 b). The R image is much smoother and only slightly extended in the north-south. No extension is visible on the I image (seeing $0''\!.87$), which is however less exposed (8 min). The galaxy appears to be very red, but the photometry is uncertain due to the presence of the very bright star in the vicinity. Within a diameter of 9″, we estimate a magnitude of $V = 21.3$ and colour indices $V-R \approx 1.3$ and $V-I \approx 2.0$. As seen from Fig. 1, the wisps, which are reminiscent of the tidal tails observed in some interacting galaxies, are broadly coincident with the radio lobes.

To follow up these observations we took a low dispersion spectrum with EFOSC 1. We used a 2″-wide slit positioned north-south and the B1000 grism to cover the spectral range 3600–8000 Å at a resolution of 69 Å (FWHM). A single 7200 s exposure was recorded. The resulting spectrum showed a strong emission feature at ~ 5500 Å. This line has an equivalent width of ~ 450 Å and a spatial extent of $\sim 8''$ making Lyα at redshift of 3.52 a plausible identification. The expected C IV λ1549 line, however, was not detected. The other possible identification for the line is [O II] λ3727. We searched for other emission or absorption features but none were identified. We re-observed the object at higher resolution in the region of the strong line, and at the expected location of C IV for $z = 3.5$, and of Hβ–[O III] λ5007 for $z = 0.48$. A 7200 s integration was obtained on June 26, 1990 with the B 300 grism of EFOSC 1 and a slit of $1''\!.5$ in the North-South position. The reciprocal dispersion is 230 Å mm^{-1} for a spectral coverage of 3600 Å to 7000 Å. The spectrum (Fig. 3) confirmed the strong emission line and its large spatial extent, and showed a tilt of ~ 10 Å, but no other features, except perhaps for Hγ were found. On the following night the object was observed with a $1''\!.5$ slit at the same position angle using the R 300 grism which covers the 5600 Å–9900 Å spectral range at a reciprocal dispersion of 270 Å mm^{-1}. Two exposures of 7200 s were recorded. The resulting spectrum is shown in Fig. 4. A number of weak emission and

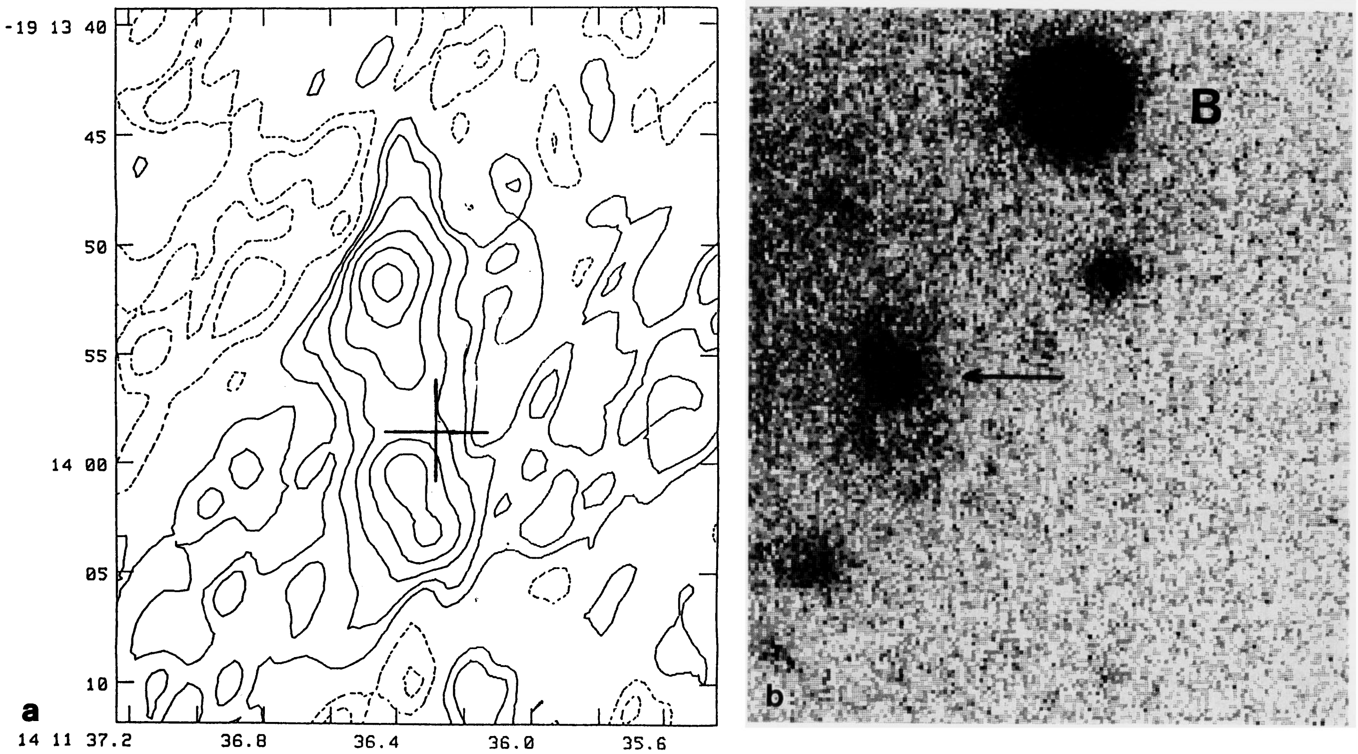


Fig. 1. **a** A VLA radio map of 1411-192 at 5 GHz with a beam of 1″.9 × 1″.5 (PA = −30°). The contour levels are −1, −0.5, 0.5, 1, 2, 4 and 8 mJy per beam, **b** a *V*-band CCD image of 1411-19 (indicated by an arrow) on the same scale as the radio map. North is up, east is to the left. The optical position of the galaxy is marked by a cross on the radio map. The optical image shows faint extensions in the direction of the two radio lobes

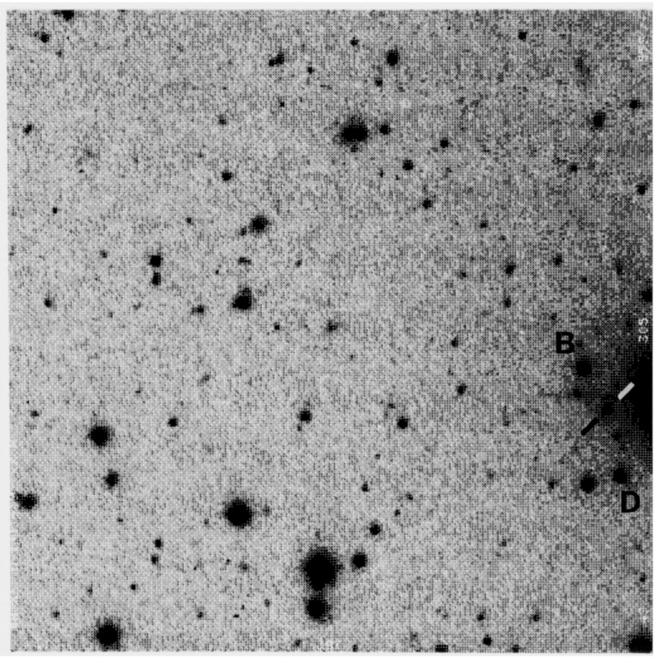


Fig. 2. A finding chart of 1411-192 made from a 5 min CCD exposure in the R band. Coordinates of the bright star on the edge of the image are RA = $14^h11^m37^s.9$; Dec. = −19°13′55″.3. North is up, east is to the right. The stars B and D were used as secondary astrometric standards

absorption features (Hβ, Hγ, [O III] λ5007, *H*, *K*, *G*-band) are clearly identified, establishing that the strong emission line is indeed [O II] λ3727 at $z = 0.477$ (throughout this paper [O III] λ5007 refers to the lines [O III] λ4959 and [O III] λ5007). There is a very large difference between the integrated equivalent width of [O II] (i.e. 350 Å) and other lines. For instance, the Hβ line has an equivalent width of 12 Å. The velocity structure of the [O II] line looks like a rotation curve (Fig. 5) and is clearly visible out to 4″.5 from the nucleus.

3. Results

3.1. Optical morphology and spectrum

Since both the *R* and *I* bands contain no strong emission lines, these images depict the morphology of the stellar component. These images are much smoother than the *V* image. The *V*− *R* and *V*− *I* colour indices are indicative of old stellar population or reddening (Sect. 3.4). We have measured the C55/C41 and C41/C35 ratios of the continuum flux densities at rest wavelengths 5530 Å, 4130 Å, and 3530 Å (the C41/C35 ratio being effectively a measure of the 4000 Å break amplitude). The bins are 200 Å wide. We find C41/C35 ≈ 2.2 and C55/C41 ≈ 1.2; both values indicate that 1411-192 is indeed a red galaxy. The equivalent widths of the most prominent absorption features ($W(K) = 12$ Å, $W(G) = 6$ Å, W(Mgb) ≈ 25 Å) are very similar to those of nearby elliptical galaxies (Hamilton 1985) and of red galaxies in the cluster Cl0500-24 at $z = 0.32$ (Giraud 1990).

Since the *V*-band is heavily contaminated by the [O II] λ3727 and the wisps are not clearly seen in the *R* and *I* bands, it is very

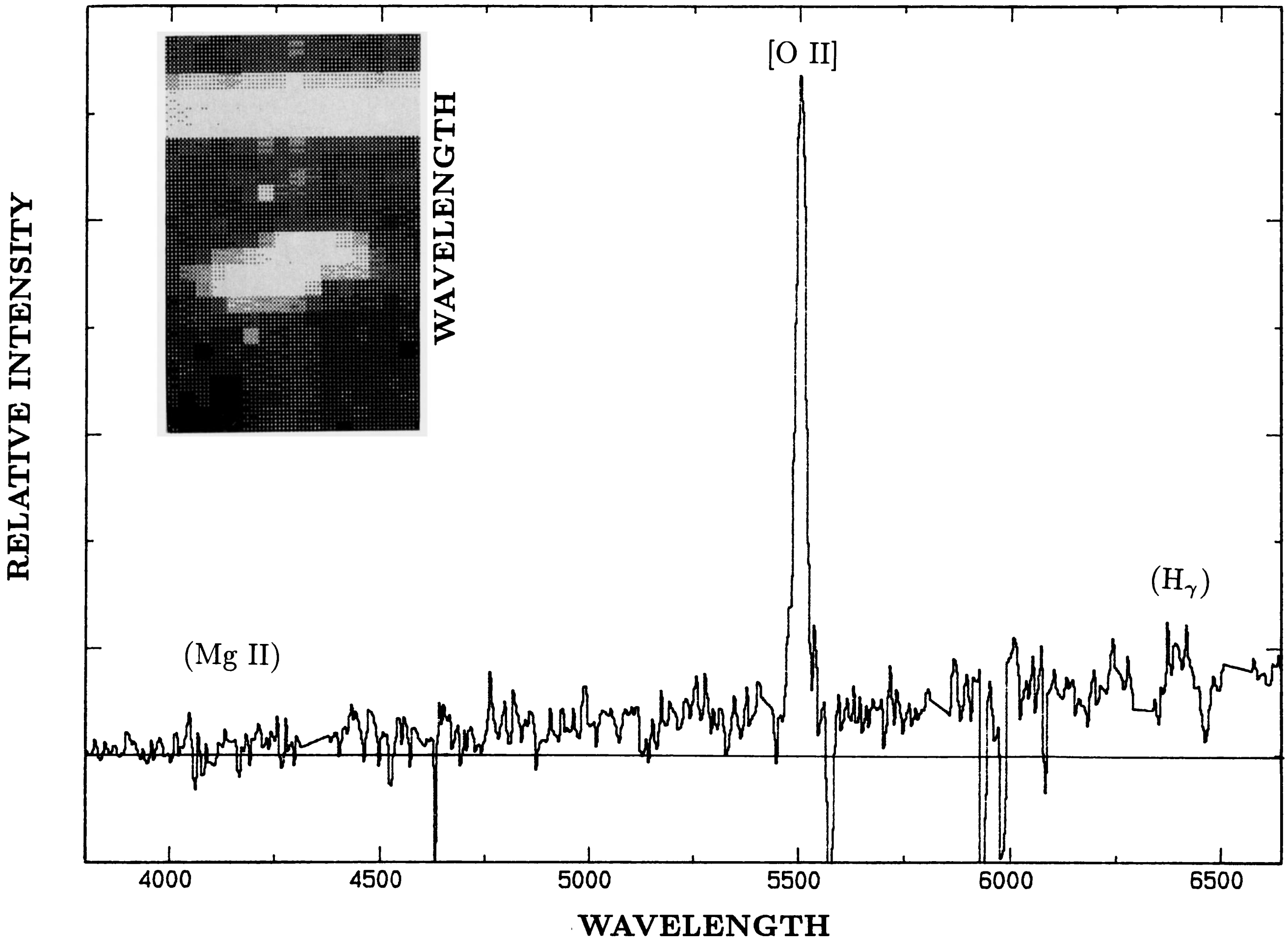
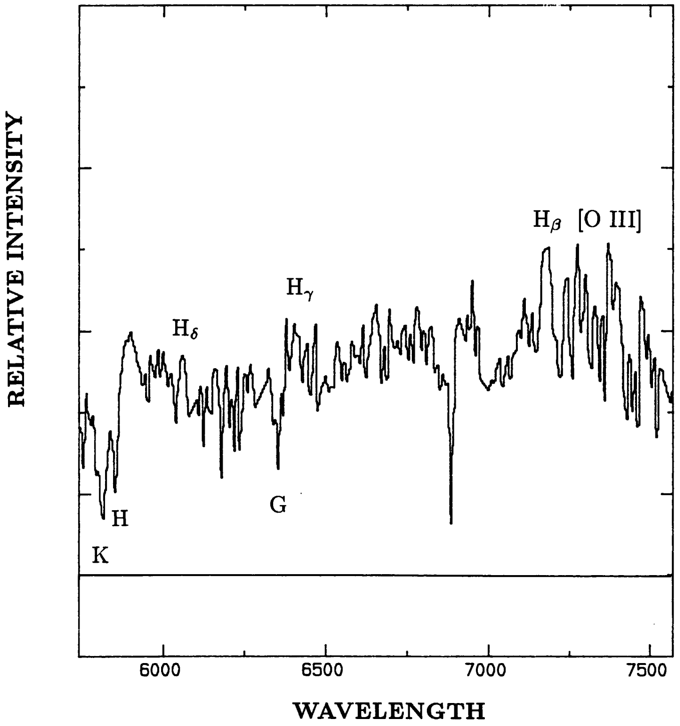


Fig. 3. A blue spectrum of 1411-192 showing the very strong [O II] λ3727 emission line. Upper left corner: a spectrogram in the region of the tilted [O II] line and the sky line at 5577 Å



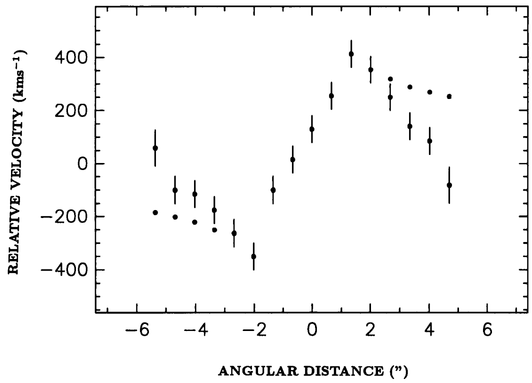


Fig. 5. Velocity curve of the ionized gas in 1411-192. A keplerian rotation curve corresponding to $V_M = 380\,\mathrm{km\,s^{-1}}$ is also indicated

Fig. 4. A red spectrum of 1411-192 showing the *G*, *H*, and *K* stellar absorption features and the Balmer lines. The [O III] λ5007 emission line is also detected

likely that the distorted V-band morphology reflects the structure of the gaseous component. The statistical trend for the very extended emission-line gas to align with the radio axis has earlier been noticed in many radio galaxies and quasars, situated at even moderately cosmological distances (e.g. van Breugel et al. 1985; van Breugel 1986; Fosbury 1989; Baum & Heckman 1989a, b; Tadhunter 1990; Hutchings et al. 1984; Stockton & McKenty 1987). Possible explanations advanced by these authors for this phenomenon include:

(1) ionization by the radio source: through shocks or photoionization by local UV synchrotron emission or direct heating by relativistic particles,

(2) photoionization of gaseous filaments piled up preferentially along the radio lobes, by an essentially isotropic nuclear radiation, and

(3) photoionization of the gaseous filaments by nuclear radiation emerging preferentially along the radio axis.

The wisps observed in the V image of the radio galaxy 1411-192 have a spatial extent corresponding to that of the [O II] λ3727 line. These gaseous extensions are strongly reminiscent of the tidal tails resulting in the process of merger of a gas-rich galaxy with a massive elliptical. Support for this interpretation comes also from the observed dynamical behaviour of the gaseous component, as discussed below. The alignment of the wisps with the nonthermal radio emission, however, indicates that the wisps are unlikely to be purely stellar features, as in the Toomre & Toomre (1972) models, but that there is a relation between the optical light in the tails and the radio plasma.

Table 1. Equivalent widths and line intensities $I/I(\mathrm{H}\beta)$. The columns indicate respectively: (1) the line identifications, (2) the equivalent widths measured in 1411-19, (3) the intensities of the lines relative to Hβ in 1411-19, (4) the line intensities relative to Hβ in the B52 model of Binette et al. (1985), (5) the line intensities relative to Hβ observed in the Cygnus Loop remnant (taken from Binette et al. 1982)

Line (1)	Equiv. width (2)	$I/I(\mathrm{H}\beta)$ (3)	$I/I(\mathrm{H}\beta)_{\mathrm{B52}}$ (4)	$I/I(\mathrm{H}\beta)_{\mathrm{CL}}$ (5)
Mg II λ2799	10:	0.3	–	–
[Ne V] λ3426	–	–	–	–
[O II] λ3727	235[a]–350[b]	10–12	15.8	12.1
[Ne III] λ3869	–	–	0.06	0.75
K	13	–	–	–
H+Hε	5.5	–	–	–
Hδ	3	0.23	0.24	–
G	6	–	–	–
Hγ	4.5	0.4	0.45	0.45
Hβ	9.5	1	1	1
[O III] λ4959	–	–	0.35	1.09
[O III] λ5007	12.5	1.1	1.02	3.35
Mgb λ5175	26	–	–	–

[a] Equivalent width of [O II] measured on 4″.
[b] Equivalent width of [O II] measured on 11″.

3.2. Dynamics of the gas

A velocity curve derived from the [O II] line is shown in Fig. 5. The rest-frame half-amplitude of the velocity gradient is $V \approx 380\,\mathrm{km\,s^{-1}}$. The velocity curve appears to be slightly off-centered from the continuum and there is a difference of $80\,\mathrm{km\,s^{-1}}$ between the central redshift of the [O II] line and the redshift from Balmer lines. Both differences, however, Δpos. = 1 pixel and $\Delta z = 0.0003$, are compatible with our error bars. In these respects, the dynamics of the gas in 1411-192 compares well with that of the radio galaxy 3C 324 ($z = 1.206$) where the [O II] λ3727 line is also found to be tilted, with a half-maximum amplitude of $650\,\mathrm{km\,s^{-1}}$ (Spinrad & Djorgovski 1984).

The spatially-resolved, tilted optical spectrum from the present galaxy could be interpreted in terms of a large disk of ionized gas rotating around a spheroidal galaxy, possibly fuelled by a tidal encounter and merger of a gas-rich galaxy. While an external source of gas in extended emission-line galaxies is also usually favoured by observations (e.g. Tadhunter et al. 1989) our observations of 1411-192 indicate a more complex dynamics. From Fig. 5, the velocity beyond $D_\mathrm{M} = 3\farcs35$ is found to decrease to subkeplerian values. Similar curves are encountered in some mergers (Schweizer 1982), as also in the nearby radio galaxy 0634-20 (see Tadhunter et al. 1989). They are characterized by fast keplerian rotation in the inner regions and counter rotation very far from the nucleus. The velocity structure of the ionized gas can be also described by two portions of expanding shells accelerated to a projected velocity of $380\,\mathrm{km\,s^{-1}}$. The rapid drop in velocity beyond D_M would suggest a velocity gradient in the outflow.

3.3. Physical conditions of the gas

Equivalent widths and intensity ratios of the detected lines, relative to H β, are given in Table 1. As evident from the spectrum, even without reddening corrections, 1411-192 shows an extremely low excitation emission line spectrum. According to standard diagnostic diagrams (Baldwin et al. 1981), the observed value of log ([O II] λ3727/Hβ) ≈ 1 is at the extreme edge of the domain for H II regions described by the models of McCall et al. (1985). The position of 1411-192 in the [O III] λ5007/Hβ *vs* [O II] λ3727/[O III] λ5007 plane is that of a LINER (Heckman 1980). The emission line spectrum of LINERs can be explained either as shock excitation, or photoionization by a dilute power-law spectrum (Ferland & Netzer 1983). In fact, the ionization parameter derived from the ([O II] λ3727/[O III] λ5007) ratio using the relations of Melnick & Terlevich (1987) or Penston et al. (1990), gives $u = \log U = -3.7$ to -4.5, an extremely low value indeed. A comparison of the line ratios of 1411-192 with the compilation of LINER spectra of Viegas-Aldrovandi & Gruenwald (1990) reveals that 1411-192 is among the lowest excitation emission line galaxies known. The lack of a significant decrease of the [O II]/[O III] ratio toward the center of the galaxy indicates that nuclear photons are not the dominant source of ionization.

The other known class of low excitation emission line objects are old supernova remnants. Table 1 lists emission line ratios for the Cygnus Loop taken from Binette et al. (1982). The similarity with 1411-192 is striking. Shock models are successful in describing the spectra of supernova remnants and, in fact, a comparison with models of Binette et al. (1985) shows that model B52, with a shock speed of $86\,\mathrm{km\,s^{-1}}$ and a postshock temperature of $10^{5.2}$K, broadly reproduces the intensities of the lines relative to Hβ (Table 1). This could mean that remnants play a significant role. The physical basis of this inference, however, is not clear. In the case of 1411-192 the rapidly expanding radio plasma may have caused a "superwind" into the ambient gas.

3.4. Reddening

In principle reddening corrections can be derived from the Hα/Hβ ratio. In the present case the redshifted Hα line occurs at 9689 Å which is in a region where sky lines and fringes are important, and the efficiency of the detector + grism is low. The Hα feature appears to be strong and the Hα/Hβ ratio is very likely larger than the intrinsic Balmer decrement of Hα/Hβ = 2.87. Thus reddening seems to be significant, but the data prohibit a reliable estimate.

4. Discussion

The optical spectrum of 1411-192 reveals a number of features that are atypical of distant powerful radio galaxies. In addition to the abnormally weak [Ne IV] λ2424 and Mg II λ2799 lines, the intensity ratio f = [O II] λ3727/[O III] λ5007 is close to 10, whereas the typical value for distant 3CR galaxies is only $\sim$0.3 (van Breugel & McCarthy 1990). Thus, guided by an *expectation* we could have easily discounted the [O II] λ3727 classification for the observed strong emission line in 1411-192 and instead, misclassified it as a Lyman α line, once a 2-hour integration had failed to reveal any additional features in the spectrum. A very high redshift of 3.5 could have thus been wrongly deduced, drawing additional 'support' from the observed ultra-steep radio spectrum and the radio-optical alignment. The present observations thus highlight the need for exercising caution in deducing redshifts from spectra showing just one clearly detected line.

The optical and radio observations of the ultra-steep spectrum radio source 1411-192 presented here may have important bearing on some basic issues such as ultra-steep radio spectrum, radio-optical alignment, and the excitation mechanism for the thermal gas. We briefly discuss these questions below.

As argued in Sect. 3.1, 1411-192 appears very likely to be a merger product. The role of mergers in triggering major bursts of star formation is well established (Lonsdale et al. 1984; Joseph et al. 1984; Cutry & McAlary 1985; Wright et al. 1988 and references therein). Terlevich & Melnick (1985) have shown that metal rich starbursts will produce LINER spectra if they are very small or very evolved. The large size of the emission line region in 1411-192 (100 kpc for H_0 = 75) indicates a rather powerful ionizing source such as a massive starburst or an active nucleus. In the latter case, however, one would expect a higher excitation in the central region of the galaxy, which is not observed (Sect. 3.3).

There is significant evidence that powerful radio galaxies could be fuelled via galaxy collisions involving at least one gas rich system (Heckman et al. 1986). Optical line emitting gas extended on scales of $\approx$ 10 kpc is indeed observed frequently around radio galaxies (Baum et al. 1988). In the case of 1411-192 we find that the ionized gas is unusually extended ($\sim$100 kpc) and, moreover, displays a spatial coincidence with the radio-emitting relativistic plasma. The kinematics of the gas is not that of quiescent material and seems to be influenced both by the postulated merging process and the radio source (Sect. 3.2). The optical lines emitted by the gas are likely to have been excited due to shocks (Sect. 3.3), and the required energy source could, conceivably, be the dissipation of the kinetic power associated with supernovae remnants and supersonic jets (as seen in the numerical simulations by Wiita et al. 1990; Clarke & Burns 1991). This is consistent with the positive correlation noted by Lilly (1989) between the steepness of the radio spectrum and the spatially extended star formation activity; a more vigorous interaction between the jet and the ambient medium would cause both an elongated ionized luminosity in the jet direction as well as a steepened radio spectrum.

In the case of 1411-192, while an extensive starburst/shock-excitation caused by the jet is energetically feasible for such a powerful radio source ($P_{\rm radio} > 10^{44}$erg s^{-1}), the "ultra-soft" emission-line spectrum of the galaxy is difficult to understand. Such a powerful source is expected to have a very bright blazar beam and hence the principal ionization mechanism for the extensive interstellar gas should have been photoionization by the active nucleus. This is believed to be generally the dominant ionization mechanism in case of powerful radio galaxies with ($P_{\rm radio} > 10^{42}$erg s^{-1}) (e.g. Baum & Heckman 1989a; Robinson 1989). In fact, for an unbiased sample of 15 powerful 3CR radio galaxies with $z < 0.2$, Saunders et al. (1989) found the median value of 0.3 for [O II] λ3727/[O III] λ5007. (as also given by Breugel & McCarthy for a sample of distant radio galaxies; Sect. 3.3) and in no case is the value found to be significantly above 1. This is in sharp contrast with [O II] λ3727/[O III] λ5007 $\sim$10 measured for 1411-192. It may be further noted that in a recent compilation of 183 extended ionized nebulosities detected around AGN at different activity levels, only 8 are classified as LINERS (Durret 1989). Of these 8, only 3C 84 (NGC 1275) and 3C 218 (Hydra A) are sufficiently radio loud to qualify as radio galaxies and 3C 218 alone approaches the level of 1411-192 in radio emission. Curiously, it too is an ultrasteep spectrum radio source with $\alpha = -1.1$ above 1 GHz (rest frame) (Kuhr et al. 1979).

5. Conclusions

The main results from the first detailed radio-optical study of 1411-192, which was selected from the Ooty sample of ultra-steep spectrum radio sources, are:

(i) This double radio source, with an edge-brightened morphology and an overall size of $\sim$14″ in the north-south direction, is identified with a galaxy at $z = 0.477$ that appears to be very red ($V - R \approx 1.3$).

(ii) The optical image is also extended north-south. The V-band image shows wisps stretching from the main body of the galaxy and spatially co-extensive with the radio-lobes. Since the wisps are clearly detected only in the V image which is strongly contaminated by the [O II] λ3727 line, they are most probably gaseous features. The morphology of the wisps is indicative of a recent merger of the massive elliptical with a gas-rich object. The [O II] λ3727 line shows a spatially-resolved velocity structure also consistent with the merger scenario (Sect. 3.2).

(iii) The measured line intensity ratios ([O II] λ3727/[O III] λ5007 $\sim$10 and [O II] λ3727/Hβ $\sim$10) for the main body of the galaxy indicate an extremely small ionization parameter, $U \sim 10^{-4}$, practically ruling out nuclear photons as the dominant source of ionization. The LINER type optical spectrum favours shock excitation by the expanding radio plasma. Such an emission-line spectrum is highly unusual for so luminous a radio galaxy ($P_{\rm radio} > 10^{44}$ erg s^{-1}).

(iv) Even after a 2-hour long integration with a 3.6 m telescope, the optical spectrum of 1411-192 continued to show the salient spectral features of the most distant galaxies ($z > 3$). Only a long integration (4 hours) facilitated by the relatively bright optical magnitude of this object (V = 21.3), could reveal the additional lines leading to an unambiguous identification of the main lines as [O II] λ3727. This underlines the relevance of very sensitive spectroscopy for some of the high-z galaxy candidates.

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