

Letter to the Editor

A giant emission line arc in the intermediate redshift radio galaxy PKS 2250-41

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Abstract. We present observations of the southern radio galaxy PKS2250-41 ($z=0.310$) which show an emission line arc circumscribing the western radio lobe, and provide some of the clearest evidence yet for the strong influence of radio jets on the distribution and ionization of the warm gas in radio galaxies. The arc, situated some 36kpc from the nucleus of the host galaxy, has a relatively low ionization state and is associated with a blue, low polarization continuum source. We interpret these observations in terms of an interaction between the radio jet and a denser than average region of the ISM/IGM - perhaps associated with merging companion galaxies or intergalactic clouds.

Key words: galaxies: active - galaxies: jets - galaxies: individual (PKS2250-41)

1. Introduction

A striking feature of powerful radio galaxies at high redshifts ($z>0.5$) is the close alignment between the radio and optical emission structures (McCarthy et al. 1987, Chambers et al. 1987). One explanation for this “alignment effect” is that the jets compress the gas and promote star formation as they plough through the gaseous medium of the host galaxies or clusters (e.g. Rees 1987, de Young 1989, Begelman & Cioffe 1989). Alternatively, it has been proposed that the alignments are due to the illumination of the ISM by the anisotropic radiation fields of powerful hidden quasars, the aligned continuum structures representing light scattered out of the the radiation cones by dust or electrons in the haloes of the galaxies (Tadhunter et al. 1988, Fabian 1989).

Both models have received some observational support but neither appears entirely satisfactory. The strongest evidence in favour of the scattering model is provided by observations of large UV polarization in several high- z radio galaxies, with the polarization E-vector aligned perpendicular to the radio/optical structure axes (di Serego Alighieri et al. 1989, Scarrott et al. 1990, Tadhunter et al. 1992, Cimatti et al. 1993). However, it is not clear what proportion of the

UV continuum is scattered. Furthermore, the radio/optical alignments are closer than expected on the basis of the broad radiation cones predicted by the unified schemes for radio sources (Tadhunter 1994). There is also growing observational evidence for jet/cloud interactions, including detailed morphological associations between emission line and radio structures (e.g. van Breugel et al. 1985, Miley et al. 1992), extreme emission line kinematics (e.g. Chambers, Miley & van Breugel 1990, Tadhunter 1991), and correlated optical and radio structure asymmetries (McCarthy, van Breugel & Kapahi 1991). Thus, while scattered light clearly makes a significant contribution to the the UV continuum in several objects, jet/cloud interactions may also contribute to the alignment affect at some level. The relative importance of the two mechanisms remains to be determined.

In an attempt to gauge the rôle of jet/cloud interactions, we have begun an investigation of powerful radio galaxies at low/intermediate redshifts. These objects are close enough to study in depth, yet show the characteristic features of high redshift radio galaxies. Here we report observations of the intermediate redshift radio galaxy PKS2250-41 ($z=0.310$), which is one of the most spectacular objects discovered in our recent survey of southern radio sources (Morganti et al. 1993, Tadhunter et al. 1993).

On optical broad-band images PKS2250-41 has a clear double structure. One component of the double is associated with the western radio lobe. The other — which we identify with the nucleus of the host galaxy — lies between the two radio lobes. Both optical components emit strong emission line and continuum radiation (Tadhunter et al. 1993). PKS2250-41 is therefore similar to many high- z radio galaxies in showing closely aligned optical and radio structures.

2. Observations and Results

Alerted to the possible significance of PKS2250-41 to theories of jet/cloud interactions in radio galaxies, we obtained deep imaging, spectroscopy and polarimetry observations of the source using the ESO Faint Object Spectrograph and Camera (EFOSC) on the ESO 3.6m telescope at La Silla in July 1993. The observations were reduced and analysed following standard procedures using the Starlink KAPPA and the Caltech FIGARO packages. More detailed accounts of the reduction

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and analysis techniques will appear elsewhere (Clark et al. 1994, Shaw et al. 1994).

Our narrow-band $[\text{OIII}]\lambda 5007$ image resolves the western component of the optical double into a remarkable arc structure (Figures 1a, b), situated some 5.9 arcseconds (36kpc^1) from the nucleus of the host galaxy. This structure, which is reminiscent of a bow shock, is markedly different from the more centrally-concentrated extended feature visible in the continuum-dominated B-band image (Figure 1c). We also detect a double arc structure on the eastern side of the nucleus, but at a much lower surface brightness level. Positional comparisons show that, within the limiting accuracy defined by the offset between the radio and optical astrometric reference frames, the western emission line arc circumscribes the centroid on the western radio lobe, while the outer eastern arcs lies close to the centroid of the eastern radio lobe (Figure 1b).

Our long-slit observations show clear differences between the spectra of the western arc and the nuclear component (Figures 2a,b): while the nucleus has a high ionization spectrum and relatively red continuum colours, the western arc has a much lower ionization state and a notably bluer continuum. There is no obvious sign of kinematic disturbance in the extended gas — the radial velocity difference between the western arc and the nucleus is small ($\Delta V < 100\text{ km s}^{-1}$) — but the spectral resolution of our observations is low (20\AA FWHM), so we cannot rule out line broadening associated with the extended emission.

Further differences between the western arc and the nuclear region are revealed by our B-band polarization measurements, which consist of a total of 3hr integration with EFOSC in polarimetric mode. Following correction for emission line contamination, we obtain a 3σ upper limit of only 3.5% on the continuum polarization in a 3.7 arcsec diameter aperture centred on the western arc. In contrast, the nuclear region is significantly polarized at the $5.0 \pm 0.7\%$ level along $\text{PA}165 \pm 7^\circ$ — close to perpendicular to the inner isophotes of the B-band image. Thus, our observations suggest a mixture of emission mechanisms for the UV continuum: scattered AGN light in the near-nuclear regions, and locally generated continuum in the western arc.

3. Discussion

The close positional association between the arc and the western radio lobe provides strong evidence that the structure results from an interaction between the radio jet and material in the halo of the galaxy.

The jet/cloud interaction hypothesis is further supported by the emission line spectrum of the western arc, which is consistent either with shock ionization (Binette et al. 1985, Sutherland et al. 1993), or with photoionization by an AGN continuum at low ionization parameter (e.g. Robinson et al. 1987). The wide range of ionization present in the spectrum, with species as diverse as NeV, HeII and NI detected, rules out photoionization by normal OB stars.

To investigate the ionization of the extended gas in more detail we have measured the variation in the $[\text{OII}]\lambda 3727/[\text{OIII}]\lambda 5007$ diagnostic ratio along $\text{PA}270^\circ$ (approximately the radio axis). As Figure 3 illustrates, the ratio shows a definite peak close to the continuum centroid in the

¹ $H_0 = 50\text{ km s}^{-1} \text{ Mpc}^{-1}$, $q_0 = 0.0$ assumed throughout

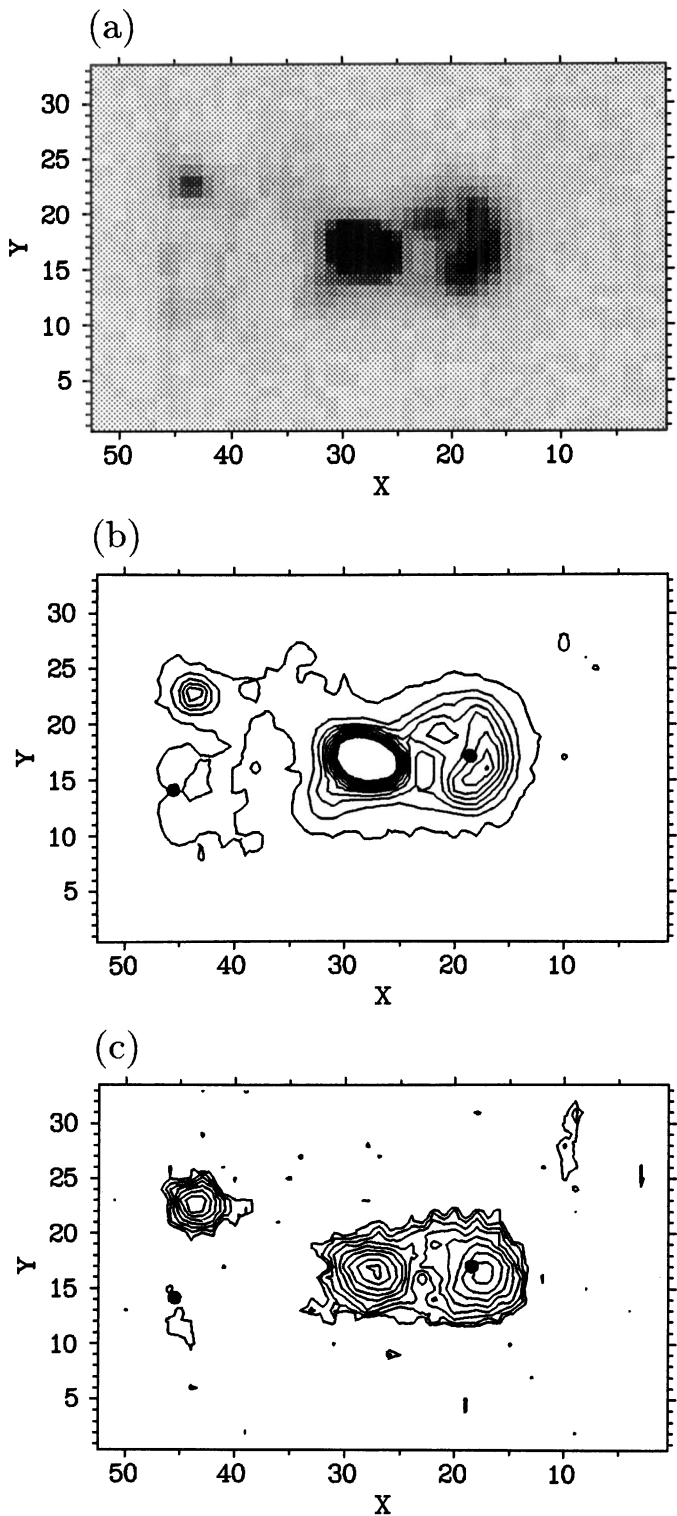


Fig. 1. Optical images of PKS2250-41: (a) grey scale representation of our narrow-band $[\text{OIII}]\lambda 5007$ image taken with an interference filter centred at 6562\AA with $\text{FWHM } 50\text{\AA}$; (b) contour representation of the narrow-band $[\text{OIII}]\lambda 5007$ image shown in (a); (c) contour representation of the broad B-band image. The centroid positions of the (unresolved) radio lobes derived from our 6cm Australia Telescope map (Morganti et al. 1993), are shown as dots on the contour plots. 1 pixel corresponds to 0.62 arcseconds and the seeing for the observations was 1.4 arcseconds (FWHM). North is to the top, and East is to the left.

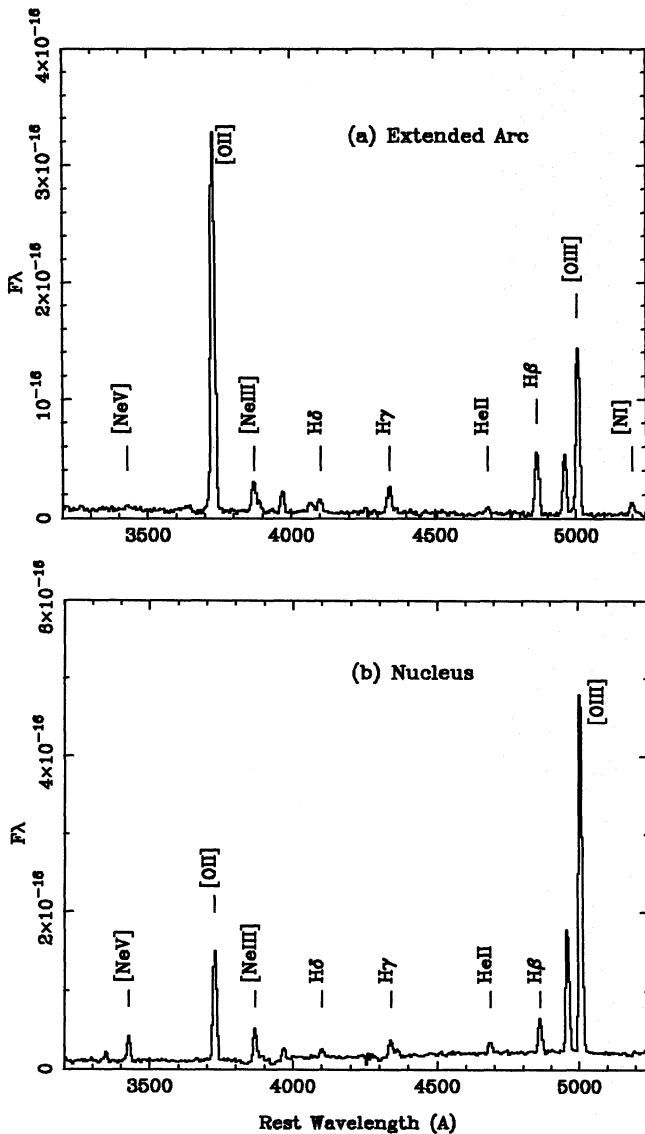


Fig. 2. Extracted spectra for (a) the western arc, and (b) the nuclear region (extraction apertures 2.0×3.7 arcseconds in each case). The spectral resolution of the spectra is 20 \AA (FWHM), and they have been shifted to the rest frame of the host galaxy. Note the marked differences in ionization and continuum colours between the two components.

western arc. Since the $[\text{OII}]\lambda 3727/[\text{OIII}]\lambda 5007$ ratio is proportional to the electron density for photoionized warm clouds (Penston et al. 1990), this peak can be interpreted as being due to a density enhancement in the arc. Assuming that the gas is photoionized by the host galaxy AGN, the variation of the ratio in the arc then implies a density enhancement by at least a factor of two compared with undisturbed gas at a similar radius. Such an enhancement is consistent with the idea that the clouds in the western arc have been compressed in a shock. Alternatively, the line ratio variation might indicate a change in the ionization mechanism, with shocks dominating over AGN photoionization at the location of the arc. In either case shocks are implicated.

We cannot identify the source of ionizing energy unam-

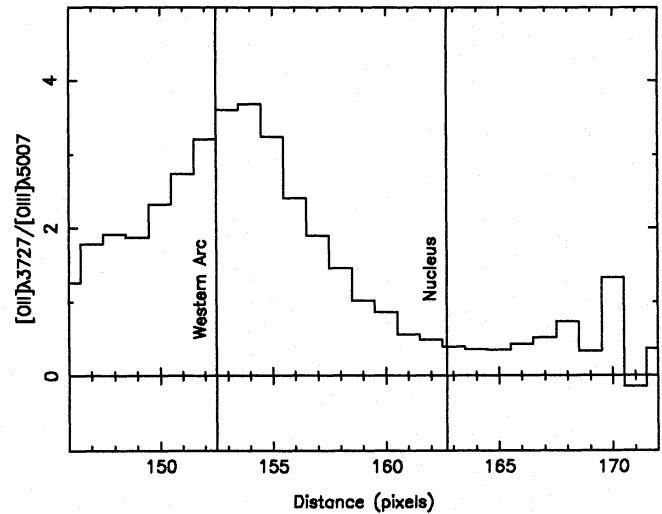


Fig. 3. The variation of the line ratio $[\text{OII}]\lambda 3727/[\text{OIII}]\lambda 5007$ with radius along PA270°. The positions of the centroids of the continuum emission in the nucleus and the western arc are marked. 1 pixel corresponds to 0.62 arcseconds.

biguously using our spectra, but we remark that if the radio jet energises the extended gas, the efficiency of conversion (η) of jet energy into the emission line+continuum radiation emitted by the warm clouds need only be modest. The estimated total radiative luminosity of the western arc ($\sim 20 \times L_{[\text{OIII}]} = 1.2 \times 10^{44} \text{ erg s}^{-1}$) is comparable with the radio luminosity on the western side of the nucleus. Since total jet powers are typically estimated to be a factor of 10 – 50 greater than the radio luminosities, conversion efficiencies of order $\eta \sim 0.02 - 0.1$ would be required for jet energisation.

Although an arc associated with a radio lobe has been seen before at low power in the nearby active galaxy M51 (Cecil 1988), to our knowledge this is the first time that such a feature have been seen with such clarity in a powerful radio galaxy. In most radio galaxies, the major emission line components are located behind the main lobe hot-spot emission of the radio source (McCarthy & van Breugel 1989). Indeed, models for shocks associated with the radio sources predict that the optical emission lines will occur downstream from the bow shock as the gas cools. The question then arises as to why we see the prominent arc structures in PKS2250-41. One possibility is that the structures represent a short-lived phase in the evolution of the radio source. However, the radio properties of the source do not appear unusual (Morganti et al. 1993), and we believe it more likely that the visibility of the structure is due to the jets encountering gaseous medium that has a higher density and/or volume filling factor than average — perhaps associated with intergalactic clouds, companion galaxies, or the debris of a tidal interaction with a companion galaxy.

Our observations also have a bearing on the controversy surrounding the origin of the extended UV continuum in powerful radio galaxies (e.g. McCarthy 1993). The failure to detect significant polarization in the western arc indicates that not all of the extended UV continuum is due to scattering in such objects. It also seems unlikely that jet-induced star formation mechanism would work in the “active” region at

the head of the jet in PKS2250-41. Alternative possibilities include emission from blue stars in the core of a merging companion galaxy, Bremsstrahlung emission associated with the hot gas in the shock, inverse compton scattering of the microwave background (Daley 1992), and nebular continuum from the warm emission line clouds. More extensive observations are required to distinguish between these possibilities.

4. Conclusions

These observations of PKS2250-41 demonstrate that the radio plasma has a strong influence on the distribution of the warm interstellar medium in radio galaxies. It now appears unlikely that the structures aligned with the radio axis in this and other powerful radio galaxies can result solely from the illumination of an isotropically distributed ISM by a cone of radiation from a hidden AGN.

As a nearby prototype of the high redshift radio galaxies, PKS2250-41 is clearly a key object. More detailed observations of this source in the future are certain to improve our general understanding of the way energetic plasma jets interact with the gaseous medium in the haloes of galaxies.

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