Non-stellar light from high-redshift radiogalaxies?

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Abstract

With the aid of a new IRCAM image of 3C356, we question the common assumption that radiosource-stimulated starbursts are responsible for the extended optical emission aligned with radio structures in high-redshift radiogalaxies. We propose an alternative model in which the radiation from a hidden luminous quasar is beamed along the radio axis and illuminates dense clumps of cool gas to produce both extended narrow emission line regions and, by Thomson scattering, extended optical continua. Simple observational tests of this model are possible and, in our view, necessary if we are to continue to accept that the colour, magnitude and shape evolution of radiogalaxies is controlled by the active evolution of stellar populations.

High-redshift ($z > 0.5$) radiogalaxies have different optical properties from their nearby counterparts: the rest-frame colours are far bluer [1,2] and their optical structures are extended along the radio axes [3,4]. These differences are commonly explained by models that invoke increased starburst activity at high z [1]; the alignment of optical and radio structures is then taken as evidence that the radiosource itself stimulates at least some of the star formation [3,5]. This interpretation is not, however, without its problems and we here use recent observational results to suggest that the extended optical continua has a non-stellar origin.

There is growing evidence that radiogalaxies, which by definition lack *obvious* central quasars, do possess such objects hidden from us by obscuration. It is now clear from the polarisation of optical-line and -continuum [6] and from the detection of both scattered and highly attenuated broad emission lines [7,8] that Seyfert II galaxies contain obscured broad-line (Seyfert I) nuclei. A similar unification of quasars and radiogalaxies is suggested, but not proved, by the available data [9,10] However, there is additional indirect support for this unification: quasars clearly radiate their optical emission anisotropically [11] and differences in the radio properties of quasars and radiogalaxies are most reasonably interpreted by differing average orientations [12,13,14]. Furthermore, there is a strong link between the bulk power developed in radio jets and the luminosity of the hidden quasar as inferred from the luminosities of the narrow emission lines [15]. This link leads us to suspect that known high-z radiogalaxies possess extremely luminous central quasars as, being drawn from bright flux-limited samples such as 3CR, they are of high radio luminosity.

Do we see any direct evidence for these hidden objects and can their presence explain any of the effects often attributed to starbursts? The answer is almost certainly yes: the extended emission line regions of high-z radiogalaxies have high effective ionisation parameters ($U_e \sim 10^{-2-3}$) and are most probably photoionized by the postulated hidden quasar [16]. How then might the associated extended optical continua produced? Although the 'standard' model of radiosource-stimulated starbursts is generally accepted, various alternatives have been proposed (although some perhaps rather more for their 'erotic fascination' [17] than for their scientific validity): gravitational lensing [18], the stimulation of radiosource activity by galaxy-galaxy interactions [19], inverse-Compton scattering of microwave background photons by the radio lobes [5], non-thermal emission associated with the radio jets, and finally scattering of either blazar or quasar light by either dust or thermal electrons [20,21,22].

For two high-z radiogalaxies, 3C356 and 3C368, images in the key infrared waveband have allowed us to compare the competing models [20]. The off-nuclear infrared components (knots) identified in the 3C356 [20] (Fig. 1) and 3C368 [5] have a number of common properties:

1. they are unresolved and on one side of the radio nucleus only (although aligned optical continua are seen on both sides of 3C368); there is no evidence for a smooth elongation in the infrared data.

2. they are red with spectral indices between B- and K-band of ~ 1.5 and ~ 2 respectively.
3. they are undetected in the radio at the 1 mJy level.
4. they are at similar distances from the radio core (≈ 50 and ≈ 30 kpc respectively) despite having radio structure differing in linear size by a factor of ~ 10.

These properties constrain the emission mechanism for the infrared knots as follows: (2) eliminates dust scattering as this would produce a spectrum biased strongly to the blue; (1), and other arguments [20], eliminate inverse-Compton scattering by a lobe of relativistic electrons; (3) eliminates non-thermal jet emission, gravitational lensing and the electron-scattering of blazar light as each predicts coincident radio components. The galaxy interaction model is both physically implausible [20] and cannot explain aligned optical structures on *both* sides of the radio-core. Thus, if the infrared emission is starlight it must be from a young ($< 10^8$ yr) starburst stimulated by the radiosource. To be consistent with such a model (2) indicates that the starburst must either be reddened by associated dust, which would be hard to produce in the short time available, or involve highly contrived stellar populations that seem, considering the differing ages of the proposed starbursts inferred from (4), unlikely to exist in both 3C356 and 3C368 [20].

We now focus on our preferred infrared emission mechanism, Thomson-scattering of hidden quasar light by thermal electrons associated with the extended narrow-line region. This mechanism will naturally produce a power-law spectra similar to that of the hidden quasar and furthermore highly ionized ($U_e \sim 10^{-2}$) emission line gas, coincident with the knot, provides evidence for both a highly efficient scattering medium and for a hidden luminous quasar. The small solid angle subtended by the knot (< 0.1 sr) and its total narrow line luminosity ($\sim 5 \times 10^{37}$ W [17]) indicate that the hidden quasar must beam at least $\nu L_\nu \sim 5 \times 10^{39}$ $\Omega_c / 4\pi$ W along cones of solid angle Ω_c. Although this inferred luminosity is higher than that of the brightest quasar in 3CR, this is not a serious cause for concern: *any* distribution in the values of Ω_c will cause a classification bias, those termed radiogalaxies will, on average, have narrower cones than those termed quasars making it misleading to compare *inferred* luminosities for these classes of object. We can use the [OII]3727 luminosity and size of the knot to put a lower limit to the electron number density n_e of $\sim 5 \times 10^6$ m $^{-3}$ although the high U_e suggests that n_e is unlikely to orders of magnitude higher. At such densities the gas will scatter incident light with an efficiency approaching unity and, given the high luminosity inferred for the quasar, it is entirely feasible, on energetic grounds, that the infrared knot (with $\nu L_\nu \sim 10^{38}$ W) results from Thomson scattering by thermal electrons associated with the narrow-line clouds.

Finally we mention another possible problem for the standard starburst model, namely that there are reported correlations between radio properties, the blueness of the galaxy and emission line luminosity [1,23]. At first sight these correlations appear to support our model because: (a) the bulk of the emission lines are photoionised directly by the active nucleus; and (b) radio luminosity is far more likely to be linked to non-stellar rather than stellar radiation [15]. However, using the available [OII] data at high z we find no more than marginal evidence for correlations between radio and optical properties (Fig. 2); moreover, using either the starburst or the scattering model, we have yet to find a convincing explanation for a link between optical properties and radio spectral index.

In conclusion, the Thomson scattering model discussed here provides an alternative, and in some ways more attractive, solution to the intriguing problem of why optical and radio structures are aligned in high-z radiogalaxies. The model can also be tested relatively simply by looking for polarisation and/or scattered broad lines in the extended optical continua.

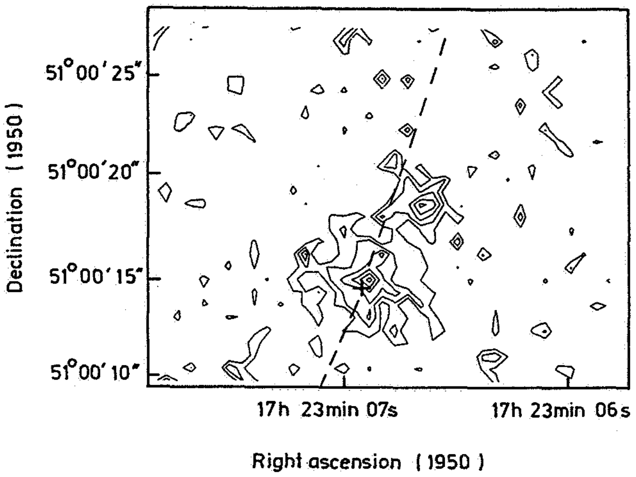

Fig. 1 K-band image of 3C356 [20]; the contour levels are $2 + n\sigma; n > 0$. The position of the radio-core and the direction of the radio structures (Laing,R.A., priv. comm.) are marked.

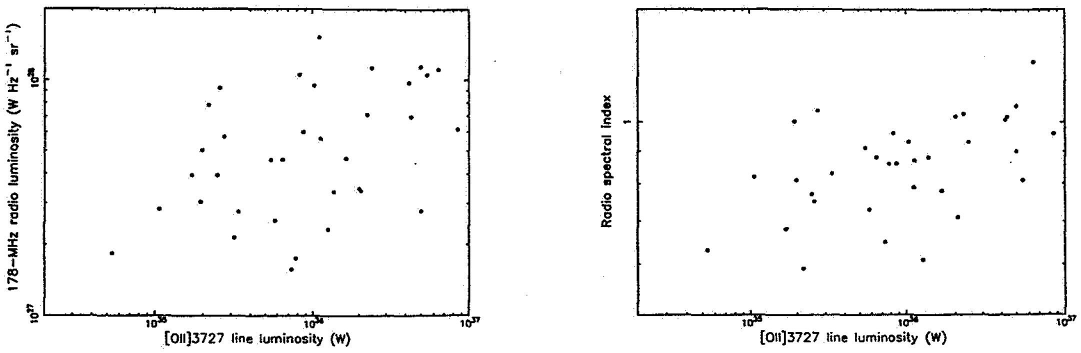

Fig. 2 The relations between [OII]3727 line luminosity, radio luminosity and radio spectral index. The objects plotted are those from the Laing *et al.* sample [24] with $z > 0.5$ and with [OII]3727 data [16] (i.e. the sample is not necessarily unbiased).

References

[1] Lilly S.J. & Longair M.S. MNRAS 211,833 (1984). [2] Spinrad H. PASP 98,269 (1986). [3] McCarthy P.J. *et al.* Ap.J. 321, L29 (1987). [4] Chambers K.C. *et al.* Nature 329,604 (1987). [5] Chambers K.C. *et al.* Ap.J., 329,L75 (1988). [6] Antonucci R.R.J. & Miller J.S. Ap.J. 297,621 (1985). [7] Miller J.S. & Goodrich R.F. BAAS 19, 695 (1987). [8] Ward M. *et al.*, in prep. [9] Antonucci R.R.J. Ap.J. 278, 499 (1984). [10] Fabbiano *et al.* Ap.J. 304, L37 (1986). [11] Jackson N. *et al.* Nature 338, 485 (1989). [12] Barthel P.D. Ap.J., 336,606 (1989). [13] Garrington S.T. *et al.* Nature 331, 147 (1988). [14] Pedelty J.A. *et al.*, preprint. [15] Rawlings S. & Saunders R. IAU 134, in press. [16] McCarthy P.J., PhD thesis, University of California at Berkeley(1989). [17] Thronson J.R. & Bally J. ApJ 319, L63 (1987). [18] Le Fèvre O. *et al.* Ap.J. 331,L73 (1988). [19] Djorgovski S. *et al.* AJ 93, 1307 (1987). [20] Eales S.A. & Rawlings, S., submitted. [21] Fabian A.C. MNRAS, in press. [22] Tadhunter C.N. *et al.*, preprint. [23] Lilly S.J., submitted. [24] Laing, R.A. *et al.* MNRAS 204, 151.