Emission line studies of young radio sources

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Abstract

We demonstrate the efficiency of high quality optical spectroscopic observations of two compact radio sources, PKS 1549-79 and PKS 1345+12, as a probe of the kinematics and physical conditions in the circumnuclear gas in the early stages of radio source evolution. We outline a schematic model for PKS 1345+12 based on the model for PKS 1549-79 proposed by Tadhunter et al. (2001) in which the young radio source is expanding through a dense and dusty enshrouding cocoon, sweeping material out of the circumnuclear regions.

Key words: PKS 1345+12; PKS 1549-79; ISM kinematics & physical conditions.

1 Introduction

Gigahertz-Peaked Spectrum Radio Sources (GPS: D < 1 kpc) and the larger Compact Steep Spectrum Radio Sources (CSS: D < 15 kpc) account for a significant fraction of the radio source population (∼40%) though their nature is not fully understood (see O’Dea 1998 and references therein). Currently, we believe they are young radio sources (Fanti et al. 1995) supported by estimates of dynamical ages: \( t_{\text{dyn}} \sim 10^2 - 10^3 \) years (Owsianik et al. 1998); and radio spectral ages: \( t_{\text{sp}} < 10^4 \) years (Murgia et al. 1999). This is in preference to the frustration scenario where the ISM is so dense, the radio jets cannot escape and the radio source remains confined and frustrated for its entire lifetime (van Breugel 1984).

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If compact radio sources are young radio sources, we will observe them relatively recently after the event(s) which triggered the activity (e.g. a merger; Heckman et al. 1986). Indeed, many compact radio sources exhibit features attributed to mergers such as double nuclei, tidal tails, arcs of emission and distorted isophotes (e.g. Stanghellini et al. 1993). Hence, the host galaxy will still retain the dense ISM injected by the merger. The young radio jets will also be relatively small and so will readily interact with the dense ISM.

In these proceedings we demonstrate the efficiency of high quality optical spectroscopic observations as a probe of the kinematics and physical conditions of the ISM in the host galaxies of radio sources, particularly in the early stages of radio source evolution. We discuss observations of two compact radio sources, the flat spectrum radio source PKS 1549-79 and the GPS source PKS 1345+12, and outline a schematic model for PKS 1345+12. For detailed discussions see Tadhunter et al. (2001) and Holt et al. (2002, 2003).

2 PKS 1549-79

From low resolution spectra of the compact flat-spectrum radio source PKS 1549-79, Tadhunter et al. (2001) report:

- highly broadened forbidden emission lines (FWHM $\sim 1350 \text{ km s}^{-1}$).
- 2 distinct redshift systems: the high ionisation forbidden lines (e.g. [O III]) are blueshifted by $\sim 600 \text{ km s}^{-1}$ with respect to the low ionisation lines (e.g. [O II]) and HI 21 cm absorption.
Tadhunter et al. (2001) interpret the blueshifted emission lines as material in outflow. Due to the small scale radio source (\(\sim 300\) pc), the radio morphology (core-jet) and the flat radio spectrum, they proposed a schematic model in which the young radio source is enshrouded by a cocoon of dense gas and dust completely obscuring the central QSO nucleus. The young radio jets are expanding and sweeping material out of the nuclear regions with the direction of propagation close to the observer’s line-of-sight (see Fig 1).

3 PKS 1345+12

We present here a summary of results from intermediate resolution (\(\sim 4\text{Å}\)) spectra over a wide spectral range (\(\sim 4500\text{Å}\)) from ISIS on the 4.2m WHT on La Palma. For a detailed discussion see Holt et al. (2003).

From modelling of the highly extended [O II]\(\lambda\lambda 3726,3729\) emission line (\(\sim 20\) kpc) using between 1 and 3 Gaussian components, we believe that the narrowest of these represents the galaxy rest frame:

- It is the only component observed across the entire spatial range;
- It is consistent with the deep HI absorption (Mirabel 1989; Morganti et al. 2002) (see Fig 2) and the stellar absorption lines (Grandi 1977);
- It is the least kinematically disturbed component (FWHM \(\sim 340\) km s\(^{-1}\));
• It has a small velocity amplitude ($\Delta_{vel} < 250 \text{ km s}^{-1}$; see Fig 2) consistent with gravitational motions (Tadhunter et al. 1989);
• It is the only component consistently observed in all emission lines, irrespective of the model required to reproduce the emission line profile.

In the nuclear aperture, the emission lines are broad with strong blue asymmetries. It is essential to model all emission lines with 3 Gaussian components (see Fig 2, also Holt et al. 2003). The narrowest of these is consistent with the narrow component of [O II] and the rest frame of the galaxy. The intermediate and broad components are blueshifted by up to $\sim 2000 \text{ km s}^{-1}$ with respect to this narrow component. Due to large reddening in the nucleus (see below), we interpret this as material in outflow. However, one model does not reproduce all emission lines – different velocity widths and shifts for the broad and intermediate components are required for [O I] $\lambda\lambda 6300,6363$ and [S II] $\lambda\lambda 6716,6731$ (see Holt et al. 2003).

We estimated the density in the nucleus using the density diagnostic, the [S II] $\lambda\lambda 6716,6731$ doublet. The intermediate and broad components have densities consistent with the high density limit. By varying the fit parameters, we obtained lower limits on the density of $n_e > 5300 \text{ cm}^{-3}$ and $n_e > 4200 \text{ cm}^{-3}$ for the intermediate and broad components respectively. The narrow component is consistent with the low density limit ($n_e < 150 \text{ cm}^{-3}$).

We have investigated reddening in the nucleus of PKS 1345+12 using three independent techniques, each assuming a simple foreground screen for interstellar extinction and the Seaton (1979) extinction law.

• **Balmer line ratios.** The H$\alpha$/[N II] blend is highly complex. We measure H$\alpha$/H$\beta$ ratios of $3.32 \pm 0.33$, $5.25 \pm 0.28$ and $18.81 \pm 4.74$ corresponding to E(B-V) values of $0.06 \pm 0.05$, $0.42 \pm 0.10$ and $1.44 \pm 0.50$ for the narrow, intermediate and broad components respectively. By varying the model fitting parameters, we estimate a lower limit on the reddening in the broadest component of E(B-V) $> 0.92$.

• **Comparison with the infra-red.** Veilleux et al. (1997) present measurements of Pa$\alpha$. The broadest component is consistent in velocity width and shift with the broadest component in [O III]. By varying the quoted flux of Pa$\alpha$ by a factor of 2, to account for possible slit loss differences between the observations, Pa$\alpha$/H$\beta$ gives a range of E(B-V) values: $1.60 < E(B-V) < 2.00$. This is consistent, within the errors, with the measured value for H$\alpha$/H$\beta$.

• **The nebular continuum.** Before modelling the faint lines in the nucleus, we subtracted both the nebular (see Dickson et al. 1995) and stellar continuum. If zero reddening is assumed for all components, a large discontinuity, corresponding to the Balmer edge at $\sim 3645$ Å, remains when subtracting the nebular continuum from the spectrum (see Fig 7 in Holt et al. 2003). However, if the measured E(B-V) values are assumed, the discontinuity dis-
Fig. 3. Schematic model for PKS 1345+12.

appears. The strength of this discontinuity is particularly sensitive to the amount of flux in the intermediate component and we estimate a lower limit of $E(B-V) > 0.3$ for the intermediate component.

The nucleus of PKS 1345+12 is highly reddened, with reddening increasing with broadness of component.

We estimate an upper limit on the mass of line emitting gas of $< 10^6 \, M_\odot$ (from the density and reddening-corrected $H\beta$ luminosity) which is consistent with the radio source being young.

4 The model

Combining these results, we have developed the model from Tadhunter et al. (2001). Fig 3 shows the schematic model which retains the small scale radio jets expanding out through an enshrouding cocoon giving rise to emission line outflows. New features include stratification of the ISM - all emission lines in the nucleus require 3 Gaussian components though the velocity width and shift of the intermediate and broad components varies between emission lines. However, gradients (e.g. density, velocity, ionisation potential) must exist across the regions emitting the intermediate and broad components. The
narrow component remains consistent in all emission lines and represents the relatively quiescent halo. ‘Strata’ positioning is determined by the reddening - the reddening increases with broadness of component and so the broadest component must originate from the region closest to the nucleus.

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