Fast outflows in compact radio sources: evidence for AGN-induced feedback in the early stages of radio source evolution

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ABSTRACT

We present intermediate resolution, wide wavelength coverage spectra for a complete sample of 14 compact radio sources taken with the aim of investigating the impact of the nuclear activity on the circumnuclear interstellar medium (ISM) in the early stages of radio source evolution. We observe spatially extended line emission (up to \( \sim 20 \) kpc) in the majority of sources which is consistent with a quiescent halo. In the nuclear apertures we observe broad, highly complex emission line profiles. Multiple Gaussian modelling of the [O III]\( \lambda 5007 \) line reveals between 2 and 4 components which can have velocity widths (FWHM) and blueshifts relative to the halo of up to \( \sim 2000 \) km s\(^{-1} \). We interpret these broad, blueshifted components as material in outflow and discuss the kinematical evidence for jet-driven outflows as previously proposed for PKS 1549-79 and PKS 1345+12. Comparisons with samples in the literature show that compact radio sources harbour more extreme nuclear kinematics than their extended counterparts, a trend seen within our sample with larger velocities in the smaller sources. The observed velocities are also likely to be influenced by source orientation with respect to the observer’s line of sight. Nine sources have associated HI absorption. In common with the optical emission line gas, the HI profiles are often highly complex with the majority of the detected components significantly blueshifted, tracing outflows in the neutral gas. The sample has been tested for stratification in the ISM (FWHM/ionisation potential/critical density) as suggested by Holt et al. (2003) for PKS 1345+12 but we find no significant trends within the sample using a Spearman Rank analysis. This study supports the idea that compact radio sources are young radio loud AGN observed during the early stages of their evolution and currently shedding their natal cocoons through extreme circumnuclear outflows.

Key words: ISM: jets and outflows - ISM: kinematics and dynamics - galaxies: active - galaxies: ISM - galaxies: kinematics and dynamics

1 INTRODUCTION

We currently know little about the early evolution of powerful extragalactic radio sources, in particular, how the presence of a radio-loud AGN influences the evolution of the host galaxy, and how the ISM affects the expansion of the radio jets. Recent developments in both observation and theory have shown the importance of AGN feedback in galaxy evolution. For example, there exist close correlations between the mass of the central black hole and the properties of the galaxy bulge (e.g. Ferrarese & Merritt 2000, Gebhardt et al. 2000, Tremaine et al. 2002, Marconi & Hunt 2003). Theoretical analyses by, for example, Silk & Rees (1998) and Fabian (1999), and more recently, simulations by, for example, Di Matteo et al. 2005 and Hopkins et al. 2005, describe how, after relocating to the centre of the galaxy remnant after a merger (Heckman et al. 1986), the supermassive black hole grows through accretion, becomes active (a proto-quasar) and then sheds its enshrouding cocoon (deposited by the merger) through outflows driven by powerful quasar winds (Balsara & Krolik 1993). With time, the central regions will be cleared of fuel, starving both the central AGN and any star forming regions in the bulge and activity will cease.

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Clearly, understanding AGN-induced feedback is of vital importance for understanding the evolution of both AGN and their host galaxies. However, there remain many uncertainties in the models due to a lack of observational evidence, and feedback is often inserted as a ‘black box’. Whilst the models described above provide a good theoretical description of the shedding of the natal cocoon during the early evolutionary stages, these scenarios often assume that the feedback is dominated by quasar-induced winds. Whilst this may be true for radio-quiet AGN, in radio-loud AGN, the expanding radio jets may also provide a significant contribution to the overall feedback of the AGN through jet-induced outflows (e.g. Bicknell & Dopita 1997), particularly during the early stages of the radio source evolution when the radio jets are still on the same scales as the natal cocoon. Such a contribution on small scales should not be surprising given the increasing support for significant feedback from extended radio sources, for example, in the quenching of cooling flows in massive haloes (e.g. Best et al. 2006; Croton et al. 2006; Bower et al. 2006).

With this in mind, compact radio sources, comprising the Gigahertz-Peaked Spectrum radio sources (GPS: D < 1 kpc) and the larger Compact Steep Spectrum radio sources (CSS: D < 15 kpc), form a large proportion of the bright (centimetre-wavelength-selected) radio source population (∼40%; e.g. O’Dea 1998) particularly suited to studying AGN-induced feedback. First, GPS and CSS sources are currently believed to be compact due to evolutionary stage (Fanti et al. 1993) with estimates of dynamical and radio spectral ages of $t_{\text{dyn}} \sim 10^2 - 10^3$ yr (e.g. Owsianik et al. 1998; Tschager et al. 2000) and $t_{\text{sp}} < 10^4$ yr (e.g. Murgia et al. 1999) respectively. This is in preference to the frustration scenario in which the ISM is so dense that the radio jets cannot escape, and the radio source remains confined and frustrated for its entire lifetime (van Breugel 1984). Second, the small-scale radio jets will be on the same scales as the natal cocoon of gas and dust and so will readily interact with it. Finally, radio-loud sources contain all potential outflow driving mechanisms (quasar-induced winds, radio-jets and starburst-driven superwinds) and so are the only objects in which the relative importance of the different effects can be assessed in individual objects (e.g. Batcheldor et al. 2007).

The most direct way to probe the kinematics and physical conditions of the nuclear gas is through high quality optical spectroscopy. However, to date, much of the work on compact radio sources has either concentrated on the radio wavelength region or has relied on low signal to noise optical spectra. Despite this, an early optical spectroscopic study of a large sample of compact radio sources suggested evidence for non-gravitational motions (indicative of flows of gas) in the form of highly broadened emission line profiles which are often asymmetric with blue wings (Gelderman & Whittle 1994). However, the potential differences between the spectra of compact and extended sources were not quantified in this early study.

With new, deeper spectra, it becomes clear that the unusually broad nuclear emission lines are due to highly complex emission line profiles requiring multiple Gaussians to model them. The first concrete evidence for fast outflows in the optical emission line gas in a compact radio source was reported by Tadhunter et al. (2001) in the southern compact flat spectrum radio source PKS 1549-79. From their low resolution optical spectra, the high ionisation emission lines (e.g. [O III]) were both broader (FWHM $\sim 1350$ km s$^{-1}$ compared to $\sim 650$ km s$^{-1}$) and blueshifted by $\sim 600$ km s$^{-1}$ with respect to the low ionisation lines (e.g. [O II]). Recent higher resolution follow up on this source has shown that the outflowing component is present in all lines with a velocity of $679 \pm 20$ km s$^{-1}$ (Holt et al. 2006 [hereafter H06]). Similarly, Holt et al. (2003) (hereafter H03) reported a much more extreme outflow ($\sim 2000$ km s$^{-1}$) in the GPS source PKS 1345+12. In both sources, the outflows are believed to be driven by the small scale radio jets expanding through dense circumnuclear cocoons of gas and dust (see e.g. Figure 2 in Tadhunter et al. 2001 and Figure 4 in H03). A recent high-resolution optical and radio imaging study (HST and VLBI) was able to confidently rule out large-scale starbursts driven winds, but failed to distinguish between jet-driven outflows and AGN-induced winds (Batcheldor et al. 2007). However, previous HST imaging studies of compact radio sources have suggested evidence for an alignment effect on small scales in some CSS sources (de Vries et al. 1997; Axon et al. 2000) which would support the jet-driven outflows scenario. For PKS 1345+12, due to the differences in velocity width between the emission line components in different lines, H03 suggested a stratified ISM which may be the result of gradients in density and/or ionisation potential across the circumnuclear ISM.

Hence, we have obtained intermediate resolution (4-6 Å$^{-1}$) optical spectra with good signal-to-noise over a large spectral range, with the WHT, NTT and VLT, in order to search for such outflows in a complete sample of 14 compact radio sources. In this paper, the first of two, we present the kinematical data for the whole sample in order to search for the signatures of outflows in the nuclear emission line gas. In sections 2 and 3, we describe the sample selection, observations and data reduction procedure. In section 4, we model the emission lines, both in the extended halo (to determine the rest frame of each system) and in the nucleus (to search for outflows). Our data are of sufficient resolution to model the lines with multiple Gaussian components. In addition, in section 5 we have modelled the lines with single Gaussians to allow comparisons between the sample presented here and other samples (compact and extended) in the literature, and to investigate the possibility of density and/or ionisation gradients in the ISM in some sources. In this paper we concentrate on the emission line kinematics and the ionisation of the emission line gas will be discussed in a second paper.

Throughout this paper, we assume the following cosmology: $H_0 = 71$ km s$^{-1}$, $\Omega_0 = 0.27$ and $\Omega_\Lambda = 0.73$.

## 2 SAMPLE SELECTION

Our complete sample comprises 14 compact radio sources split across the northern and southern hemispheres. In the north, we have observed a complete sample of five sources (3 CSS, 2 GPS with $z < 0.4, 12^h < \text{RA} < 18^h$ 1$^1$). This corresponds to $\sim 200-300$ km s$^{-1}$, dependent on redshift, for [O III]5007Å for the objects in our sample.
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Table 1. Properties of the sample: (a) radio source; (b) optical ID where G = galaxy, Q = QSO; (c) radio source type where CSS = Compact Steep Spectrum, GPS = Gigahertz-Peaked Spectrum, CF = Compact Flat spectrum and CC = Compact Core; (d) redshift * redshifts from the literature, for the accurate redshifts derived in this study, see Table 3; (e) radio spectral index where $\alpha$ = 0.003 (Morganti 2004, private communication) where the central velocity is assumed to be the midpoint of the entire absorption profile. a taken from the literature and may be inconsistent with the sizes in column (j). b compact core component in 3C 213.1 and 3C 459, c extended radio source component in 3C 213.1 and 3C 459. For 3C 459 the different HI results are: 1) Morganti et al. 2001), v Vermeulen et al. (2003) and 8 Gupta et al. 2006.

| Object | ID       | Type | $z^*$ | $\alpha$ | Radio luminosity | HI 21cm absorption | Angular size | Linear size | Radio PA |
|--------|----------|------|-------|----------|------------------|---------------------|--------------|------------|----------|
|        | (a)      | (b)  | (c)   | (d)      | $P_{5GHz}$ (W Hz$^{-1}$) | $V_{helio}$ (km s$^{-1}$) | (g)          | (i)        | (j) |
| 3C 213.1 | G        | CC   | 0.195 | 0.30     | 26.41            | 0.19395             | 115          | 6.0         | 19.1     | -61 |
| 3C 268.3 | G        | CSS  | 0.371 | 0.88     | 27.04            | 0.37186             | 101          | 1.36        | 6.9      | -15 |
| 3C 277.1 | Q        | CSS  | 0.320 | 0.61     | 26.86            |                  |              | 1.67        | 7.7       | -49 |
| 3C 29.4 | G        | GPS  | 0.369 | 0.60     | 27.30            | 0.36843             | 229          | 0.06        | 0.31     | -50 |
| PKS 1345+12 | G        | CSS  | 0.122 | 0.44     | 26.69            | 0.12184             | 150          | 0.15        | 0.33     | 160 |
| 3C 303.1 | G        | CSS  | 0.267 | 1.08     | 26.43            |                  |              | 1.80        | 7.3       | -47 |
| PKS 0023-26 | G        | CSS  | 0.322 | 0.7      | 27.43            | 0.31890             | 126          | 0.68        | 3.2      | -34 |
| PKS 0252-71 | G        | CSS  | 0.566 | 1.14     | 27.55            |                  |              | 0.24        | 1.6       | 7      |
| PKS 1306-09 | G        | CSS  | 0.464 | 0.65     | 27.39            | 0.46921$^{\dagger}$ | 350$^{\dagger}$ | 0.46        | 15.7     | -41 |
| PKS 1549-79 | G        | CF   | 0.152 | 0.18     | 27.00            | 0.15224             |              | 0.12        | 0.3       | 90 |
| PKS 1814-63 | G        | CSS  | 0.063 | 0.91     | 26.54            | 0.06450             |              | 0.41        | 0.5       | -20 |
| PKS 1934-63 | G        | GPS  | 0.183 | 0.88     | 27.31            | 0.18282             | 18           | 0.70        | 2.1       | 89 |
| PKS 2335-20 | G        | CSS  | 0.635 | 0.82     | 27.58            |                  |              | 0.25        | 1.7       | 52 |
| PKS 2341+03 | G        | CC   | 0.220 | 0.97     | 27.65            | 0.21850$^{\dagger\dagger}$ | ~400 | 0.20$^{b}$ | 0.7$^{b}$ | 95 |

The whole sample has a radio power range of $26 < \log P_{5GHz}$ (W Hz$^{-1}$) < 28. Details of the sample are presented in Table 2. Hence, the total sample includes 8 CSS, 3 GPS, 1 compact flat-spectrum source and 2 compact core radio sources. The sample also includes both galaxy (13) and quasar (1) host morphologies.

The subsamples were chosen to fulfill the following criteria: i) redshifts low enough to include [O III]λ5007 in the spectra and similar for the subsamples; ii) RA and Dec ranges to be observed during the allocated runs and; iii) the samples were derived from well-studied samples (2Jy, 3C & 4C) to enable good comparisons between compact and extended sources.

3 OBSERVATIONS, DATA REDUCTION AND ANALYSIS TECHNIQUES

Long-slit optical spectroscopic observations of the full sample were obtained during two observing runs. The northern sample was observed on 12-14 May 2001 with ISIS, the dual arm spectrograph on the 4.2m William Herschel
Table 2. Log of observations. Column (c) denotes the arm/wavelength range of the spectrograph. (h) is the instrumental seeing († indicates seeing measured using the object continuum – for all other sources, a star on the chip was used). Note, the values quoted in column (h) represent upper limits on the true seeing as 1) where the seeing was measured using the target galaxy, these measurements may be affected by the extended galaxy haloes i.e. they are not stellar; and 2) the measurements based on the profiles of stars along the slit only provide a good seeing estimate if the slit passes through the centres of the stellar image, otherwise the FWHM (and therefore seeing) will be over-estimated. (i) gives the width of the extracted nuclear aperture in arcseconds, centred on the centroid of the nuclear continuum emission (quoted once per object in the table but the same aperture was used for both red and blue spectral ranges) and (j) denotes the photometric conditions (p = photometric, v = variable transparency). • denotes spectra taken aligned within 10 degrees of the radio source PA.

| Date       | Object | 'Arm' | Exposure | PA (°) | Slit width (arcsec) | λ range (Å) | Seeing (arcsec) | Nuclear aperture (arcsec) | Notes | Notes |
|------------|--------|-------|----------|--------|---------------------|-------------|----------------|--------------------------|-------|-------|
|            |        |       |          |        |                     |             |                |                          |       |       |
| WHT/ISIS observations |
| 14/05/2001 | 3C 213.1 | R     | 3*1200   | 80*    | 1.3                 | 7700-9200   | 1.5 ± 0.1†     | 2.5                       | v     |       |
| 13/05/2001 | 3C 268.3 | R     | 2*1200   | 155*   | 1.3                 | 7850-9350   | 1.4 ± 0.3      | 2.2                       | p     |       |
| 13/05/2001 | 3C 277.1 | R     | 3*1200   | 155*   | 1.3                 | 6200-7700   | 1.9 ± 0.2      | p                         |       |       |
| 14/05/2001 | 4C 32.44 | R     | 3*1200   | 129*   | 1.3                 | 7850-9350   | 0.9 ± 0.1†     | 1.8                       | p     |       |
| 14/05/2001 | 4C 32.44 | R     | 3*1200   | 105    | 1.3                 | 6200-7700   | 0.9 ± 0.1†     | p                         |       |       |
| 14/05/2001 |          | R     | 3*1200   | 105    | 1.3                 | 3300-6800   | 1.4 ± 0.1†     | p                         |       |       |
| 12/05/2001 | PKS 1345+12 (4C 12.50) | R     | 1*900    | 104    | 1.3                 | 6200-7700   | 1.3 ± 0.2      | 2.2                       | p     |       |
| 12/05/2001 | PKS 1345+12 (4C 12.50) | R     | 1*900    | 104    | 1.3                 | 3300-6800   | 1.3 ± 0.2      | p                         |       |       |
| 14/05/2001 | PKS 1345+12 (4C 12.50) | R     | 3*1200   | 110    | 1.3                 | 6200-7700   | 1.3 ± 0.2      | p                         |       |       |
| 12/07/2002 | PKS 1549-79 | R     | 3*1200   | 130    | 1.3                 | 7700-9200   | 1.8 ± 0.1†     | 2.5                       | p     |       |
| 12/07/2002 | PKS 1549-79 | R     | 3*1200   | 130    | 1.3                 | 3300-6800   | 1.8 ± 0.1†     | p                         |       |       |
| NTT/EMMI observations |
| 13/07/2002 | PKS 0023-26 | B     | 3*1200   | -105   | 1.5                 | 3700-7050   | 2.5 ± 0.2†     | 2.0                       | p     |       |
| 13/07/2002 | PKS 0252-71 | R     | 2*1200   | -105   | 1.5                 | 4000-11400  | 2.3 ± 0.2†     | p                         |       |       |
| 13/07/2002 | PKS 1306-09 | R     | 2*1200   | 135*   | 1.5                 | 5700-8700   | 1.6 ± 0.1      | 1.7                       | p     |       |
| 12/07/2002 | PKS 1549-79 | R     | 3*1200   | 135    | 1.0                 | 5700-8700   | 1.7 ± 0.2†     | 2.3                       | p     |       |
| 12/07/2002 | PKS 1549-79 | R     | 3*1200   | -5     | 1.0                 | 5700-8700   | 1.9 ± 0.1      | p                         |       |       |
| 12/07/2002 | PKS 1814-63 | R     | 1*1200   | -72    | 1.0                 | 5700-8700   | 1.1 ± 0.2†     | 1.0                       | p     |       |
| 12/07/2002 | PKS 1934-63 | R     | 3*1200   | -20    | 1.5                 | 5700-8700   | 1.2 ± 0.1      | p                         |       |       |
| 13/07/2002 | PKS 2135-20 | R     | 3*1200   | -115   | 1.5                 | 5700-8700   | 1.4 ± 0.2†     | 1.7                       | p     |       |
| 12/07/2002 | 3C 459 (PKS 2314+03) | R     | 3*1200   | -175   | 1.5                 | 5700-8700   | 1.5 ± 0.2†     | 1.7                       | p     |       |
| 12/07/2002 | 3C 459 (PKS 2314+03) | R     | 3*1200   | -175   | 1.5                 | 3700-7050   | 1.5 ± 0.2†     | p                         |       |       |
| 12/07/2002 | 3C 459 (PKS 2314+03) | R     | 1*1200   | 95*    | 1.5                 | 5700-8700   | 1.5 ± 0.2†     | p                         |       |       |
| VLT/FORS2 observations |
| 24/09/2003 | PKS 1549-79 | R     | 3*1200   | 75     | 1.3                 | 4950-8250   | 2.0 ± 0.1      | 1.5                       | p     |       |
| 24/09/2003 | PKS 1549-79 | B     | 3*600    | 75     | 1.3                 | 3050-6000   | 2.1 ± 0.1      | p                         |       |       |
Telescope on La Palma. In the red, the TEK4 CCD was used with the R316R grating with 1x1 binning and two central wavelengths (∼6950Å and ∼8450Å, dependent on object). The resulting wavelength calibration accuracies, calculated using the standard error on the mean deviation of the night sky emission line wavelengths from published values of Osterbrock et al. 1996, were 0.06-0.11Å (∼6950Å) and 0.10-0.53Å (∼8450Å). The spectral resolutions, calculated using the widths of the night sky emission lines, were 3.3-3.7 ± 0.1Å (∼6950Å) and 3.8-4.1 ± 0.1Å (∼8450Å). In the blue, the EEV12 CCD was used with the R300B grating with 2x2 binning. The wavelength calibration accuracy was 0.1-0.2Å with a spectral resolution of 4.3-4.8 ± 0.2Å. The spatial scale was 0.36 arcsec/pixel. Further details, including the instrumental setups and the useful wavelength ranges of the spectra are summarised in Table 2.

The southern sample was observed on 12-13 July 2002 using the EMMI spectrograph on the ESO New Technology Telescope (NTT) on La Silla, Chile in RILD mode. The M1/LL CCD was used with grisms #4, #5 and #6 to obtain spectra with central wavelengths 7095Å, 5385Å and 7223Å with 2x2 binning. The wavelength calibration accuracies were 0.24Å (7095Å), 0.06-0.15Å (5385Å) and 0.10–0.17Å (7223Å) with spectral resolutions of 14 ± 1Å (7095Å), 5.6 ± 0.1Å (5385Å) and 4.3-6.7 ± 0.1Å (7223Å). The spatial scale was 0.33 arcsec/pixel. Again, further details are presented in Table 2.

PKS 1549-79 was also observed with the FORS2 spectrograph on the ESO Very Large Telescope (VLT) on Cerro Paranal, Chile, in September 2003 to improve the S/N of the fainter features and resolve a seeing-slit width matching the nucleus. The spatial scale for the VLT observations was 0.25 arcsec/pixel.

The aim of this project is to search for outflows in the circumnuclear regions using optical spectroscopy with sufficient spectral resolution and signal to noise to accurately separate and model the different components of the highly broadened and complex emission lines. In order to include all of the outflowing regions in the slit, and to ensure the spectra were of sufficient resolution, all spectra were taken with a 1.0-1.5 arcsec slit. To reduce the effects of differential atmospheric refraction, all exposures were taken at low airmass (sec z < 1.1) and/or with the slit aligned along the parallactic angle. Due to various observational constraints, we have only aligned the slit along the radio axis for approximately half of the sources, and the PAs are listed in Table 2. However, as this study is concerned with compact rather than extended radio sources, the feedback effects we are interested in will be confined to the nuclear regions and the mis-alignment of the slit with the radio axis will not affect our results.

### 3.2 Continuum subtraction

Prior to emission line modelling of the nuclear apertures, the continuum was modelled and subtracted for most of the sources. Initially, a nebular continuum was generated and subtracted following Dickson et al. 1993 taking full account of reddening following H03. The remaining continuum was then modelled using a customised idl minimum χ² fitting programme (see e.g. Robinson 2001; Tadhunter et al. 2003; Holt et al. 2007 for details). The modelling program allows up to three separate continuum components – Old (OSP, here set to 12.5 Gyr with no reddening) and Young Stellar Populations (YSP, reddened with 0 < E(B-V) < 1.6 using Seaton 1970 with age 0.01-5.0 Gyr) taken from Bruzual & Charlot (1993) and an AGN-power-law component. We define the best fitting model as that with the least number of components required to adequately model both the overall SED and discrete stellar absorption features (e.g. Ca H+K, Balmer series).

Continuum modelling and subtraction was necessary for the detection and accurate modelling of the broader emission line components. For completeness, details of the continuum models used for subtraction prior to emission line modelling are given in Table 3. Note, the continua of several galaxies in this sample have been more recently accurately modelled and we refer readers to the corresponding papers: PKS 1345+12 (Tadhunter et al. 2003), Rodriguez Zaurin et al. 2007; PKS 1549-79 (H06); PKS 0023-26, PKS 1549-79 and PKS 2135-20 (Holt et al. 2007); 3C 213.1 and 3C 459 (Wills et al. 2007).

The continua of three sources were not modelled. 3C 277.1 has a pure quasar continuum (there is no evidence for an underlying stellar continuum), but it could not be reproduced by a simple power-law, and so we have not modelled or subtracted the continuum. However, when modelling the
emission lines, care was taken to remove the BLR contamination. The radio source PKS 1814-63 lies close to a bright foreground Galactic star and so the spectra are strongly contaminated by light from this star. Fortunately our observations were made during good seeing conditions and we clearly resolve PKS 1814-63 from the star. Whilst it was not possible to model the continuum, for accurate modelling of the broader emission line components, we have attempted to remove the stellar spectrum. Because the star is point-like, its spectrum will have no significant spatial variation and the star itself could be used for subtraction. Hence, each frame was copied, inverted and then shifted in the spatial direction, so the centroid of the continuum was aligned. The inverted spectrum was then subtracted from the original spectrum to remove the contamination from the continuum emission. Finally, no corrections were made for 3C 303.1 due to the mis-matching of the blue and red arm spectra.

3.3 Kinematic component definitions

The emission lines and their components vary significantly in width (FWHM). Hence, for our analysis, we define the following kinematical components for the Narrow Line Region (NLR) as used in H03:

- narrow: FWHM < 600 km s\(^{-1}\);
- intermediate: 600 < FWHM < 1400 km s\(^{-1}\);
- broad: 1400 < FWHM < 2000 km s\(^{-1}\);
- very broad: FWHM > 2000 km s\(^{-1}\).

4 RESULTS

In this section we discuss the kinematic results derived from two-dimensional optical spectra. Initially, the extended line emission is used to establish the systemic velocities followed by detailed modelling of the emission lines in the nuclear apertures.

4.1 Kinematics of the extended gaseous halo

In order to investigate the impact of the activity on the circumnuclear material, it is first necessary to establish the exact redshift of the galaxy rest frame. Many of the objects in the sample show clear evidence for extended emission lines, most notably the [O II]\(\lambda\lambda3727\) doublet and [O III]\(\lambda\lambda5007\), and in some cases H\(\alpha\) \(\lambda6562\) (see below). By modelling these, pixel by pixel, across the entire spatial extent, one can determine the radial velocity profile of the host galaxy (see also e.g. H03,H06). All such spatial fitting was done before modelling and subtracting the continuum and the emission lines were fitted using free fits. We define ‘free-fitting’ as when the only constraints used for the emission line modelling are those set by atomic physics (i.e. the separation, ratio of intensities and velocity widths of line components in a doublet emitted by a single ion). The radial velocity profiles for all

| Object      | Best fitting model | 12.5 Gyr    | YSP   | Model parameters | $\alpha$ | $\chi^2_{\text{min},\text{red.}}$ |
|-------------|--------------------|------------|-------|------------------|--------|---------------------|
|             | (a)                | (b)        | (c)   | (d)              | (e)    | (f)                 | (g)   |
| 3C 213.1    | 12.5 + 1.0         | 44 ± 2     | 61 ± 2| 0.0              | –      | –                   | 0.62  |
| PKS 1814-63 | 12.5 + 0.1 + $\alpha$ | 6 +14     | 37 +14| 0.0              | 84 +5  | 1.8 ± 0.2           | 1.22  |
| PKS 1934-63 | 12.5 + 0.1         | 48 +17     | 19 +17| 0.0              | 191 +22| 2.86 +1.06          | 1.07  |
| PKS 2135-20 | 12.5 + 0.5         | 95 ± 3     | 8 ± 2 | 0.0              | –      | –                   | 1.34  |
| PKS 0252-71 | 12.5 + 2.0 + $\alpha$ | 2 +35     | 57 +39| 0.1              | 39 +15 | 1.14 ±0.39          | 1.23  |
| PKS 1345+12 | 12.5 + 0.1 + $\alpha$ | 34 +18     | 39 +9 | 0.1              | 22 +18 | 2.98 ±1.42          | 0.49  |
| PKS 1814-63 | 12.5 + $\alpha$    | 85 ± 6     | –     | 16 ± 4            | –      | 1.56 ±0.28          | 0.59  |
| PKS 2135-20 | 12.5 + 0.1 + $\alpha$ | 16 +21     | 49 +11| 0.0              | 37 +15 | 0.66 ±1.20          | 0.59  |
| 3C 459      | 12.5 + 0.05        | 34 ± 1     | 67 ± 1| 0.0              | –      | –                   | 0.43  |
Outflows in compact radio sources

Figure 1. Rest frame velocity profiles for all sources in the sample. The numerous small points represent the pixel-by-pixel fitting where: triangles (△, ▽) are [O II]λλ3727 and squares/diamonds (□, ◆) are [O III]λλ4959,5007. In general, open symbols (△, ▽, □, ◆) are narrow components (where two narrow components are present, the second is traced by inverted triangles and diamonds), filled symbols represent the intermediate (▲, ■) and broad (▽, ◆) components. Exceptions are: 4C 32.44 (▲, ■: broad component; ▽, ◆: very broad component), PKS 1306-09 (open and filled points are narrow components), PKS 1814-63 ([O III] and Hα emission plotted where □: [O III] and ◆, ▲: Hα), PKS 1934-63 & 3C 459: (open: narrow, filled: broad), PKS 2135-20 (open: intermediate, filled: broad). Stars (where shown) mark the velocity of the detected HI absorption. Sources to note are: PKS 0023-26 (two components, small: narrow, large: broad), PKS 1306-09 (vertical dashed line marks the range of velocities over which HI absorption has been tentatively detected, Morganti, private communication), PKS 1814-63 (in addition to the deep HI absorption line (star), the range of velocities covered by the broad shallow absorption feature are marked by the vertical dashed line) and 3C 459 (large star: [O III] detection, large inverted star: [O III] detection, small stars: three components detected by Gupta et al. 2006). The large symbols (□, ◆, ■, ◆) represent the components of [O III]λλ4959,5007 detected in the nuclear aperture where the symbols (open/filled etc) are consistent with the smaller points in the same plot. The large symbols and their horizontal error bars show the position and size of the nuclear aperture. Finally, for 3C 459 (PA 95), two further points mark an extended region of line splitting ([O III]; ○: narrow, ●: broad) All extended apertures will be discussed in a future paper. The horizontal dashed line in each plot indicates the assumed systemic velocity (derived from [O III]). Note, for PKS 1345+12, this figure includes all three PAs observed and is taken directly from H03. For PKS 1549-79, we show the velocity profile along PA -5 only, again, taken directly from H06. For more details see H03, H06 and Rodriguez Zaurin et al. 2007. Note, where
We have determined the systemic velocities using a variety of techniques:

(i) **Sources with resolved extended emission.** Where the line emission line is clearly resolved we have assumed the extended narrow line emission traces the quiescent halo gas as in PKS 1345+12. For two sources (3C 277.1 and PKS 1934-63), the extended gas has settled into what appears to be a smooth rotation curve whilst for the remaining sources, the gas is more similar to that in PKS 1345+12 – consistent with gravitational motions in an elliptical galaxy (velocity amplitude ≤ 350 km s$^{-1}$; [Tadhunter et al. 1989]) but not yet completely settled. This technique is the most reliable for determining the systemic velocity and we have used this for most sources in the sample.

(ii) **Sources with two narrow components.** In four sources (3C 268.3, 4C 32.44, PKS 0252-71 and PKS 1306-09) we detect two narrow components in the nuclear aperture (for 3C 268.3, and marginally PKS 1306-09, these components are also extended and spatially resolved). Free fitting of the emission lines gives similar but slightly different FWHM. Forcing the two narrow narrow components to have the same FWHM also gives a good fit, and so we assume the two narrow components are emitted by the same mechanism/structure. Hence, the narrow line splitting we observe

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Note, for some objects, the velocity fields are only marginally resolved (see Section 3 and Table 2 for details of the spatial scale and the seeing) and this is why in some of the plots in Figure 1, the velocities do not appear to vary significantly.
could represent a rotation curve which is unresolved, or trace a bi-polar outflow in the gas. For these sources, we can therefore assume with reasonable confidence that the systemic velocity is located between the two narrow components.

(iii) Other methods. For two sources, we have little confidence in determining the systemic velocity. For PKS 1814-63, the foreground star obscures our view of the galaxy. Using the continuum subtraction technique described in Section 3.2, we have been able to model the extended line emission along two PAs. Along PA 65 the shape of the profile is unclear whilst along PA -72 a more defined shape is observed, which may be consistent with half of the rotation curve. For PKS 2135-20, we are the least certain and have made no attempt to estimate the systemic velocity – the source is unresolved and no narrow components are observed (the narrowest has FWHM $\sim 760$ km s$^{-1}$). In addition to the emission line measurements, we have attempted to measure the stellar absorption lines (e.g. Ca II K and some of the higher order Balmer lines) in a more recently obtained VLT spectrum (see Holt et al. [2007]) and estimate a redshift of $0.635 \pm 0.004$.

Using the above methods, we have confidently determined the systemic velocity in 12 of the 14 sources (3C 213.1, 3C 268.3, 3C 277.1, 4C 32.44, PKS 1345+12, PKS 1549-79, PKS 1934-63, 3C 459 and with some assumptions, 3C 303.1, PKS 0023-26, PKS 1306-09 and PKS 0252-71). Due to the issues discussed above, the velocities for PKS 1814-63 and PKS 2135-20 should be used with caution. Further, for all sources, the velocity amplitude of the narrow component is coinci-
dent with gravitational motions in an elliptical galaxy ($\leq 350$ km s$^{-1}$; Tadhunter et al. 1989).

The derived/assumed systemic velocities are marked on Figure 1 and it should be noted that zero on the y-axis of the velocity profile plots in Figure 1 does not mark the assumed systemic velocity, which is denoted by the horizontal dashed line. The results are summarised in Table 5. Note, whilst the extended gas was used to determine the location of the systemic velocity with respect to the various emission line components, the redshifts quoted as systemic in Table 5 were derived using measurements of several emission lines (narrow components) in the nuclear apertures (as part of the modelling in Section 4.2) rather than based on measurements of [O III] alone.

In addition to the velocities of the extended emission line components in Figure 1, the components of the nuclear [O III] lines are shown (see Section 4.2). In the majority of the radial velocity profiles, there is a clear offset in velocities of the broader components between the extended and nuclear apertures of order $\sim 100$ km s$^{-1}$. This is most likely due to continuum subtraction effects in the nuclear apertures and/or integrating over a larger aperture.

HI 21cm absorption is detected in 10 of the 14 sources (see Table 6) and the velocities of the detected components are plotted on Figure 1. In four sources (3C 213.1, 4C 32.44, PKS 1345+12 and PKS 1549-79) at least one component of HI is in agreement with the assumed systemic velocity. However, it is striking that the majority of detected HI components are significantly blueshifted with respect to the optically derived systemic velocities and, in the case of PKS 1345+12 at least, appear to trace the optical outflow. In only
two sources is the HI redshifted, consistent with infalling gas (PKS 0023-26 and PKS 1934-63).

4.2 Emission line modelling

As discussed in Section 1, the nuclear emission lines in compact radio sources are often broad with asymmetric profiles requiring multiple Gaussian components to model them. In Section 4.1 we identified the rest frame for each source. Here, after subtracting the continuum, we model all strong emission lines in the nucleus to search for outflows. In addition to multiple Gaussian fitting following H03, we present the results of single Gaussian fitting and asymmetry indices. These latter two steps will allow us to make comparisons between our data and previous work.

4.2.1 Multiple Gaussian modelling

The nuclear emission lines in compact radio sources are often broad with asymmetric profiles. Hence, single Gaussians are unable to adequately model the line profiles and multiple components are required. As an example, Figure 2 shows how fitting 1, 2 and 3 Gaussians to \([\text{O III}]\lambda\lambda 4959,5007\) in the nucleus of PKS 0252-71 affects the quality of the overall fit.

When modelling the emission line spectra of AGN, it is common to start with the brightest emission lines, e.g. the \([\text{O III}]\lambda\lambda 4959,5007\) doublet (e.g. Villar-Martín et al. 1999). The \([\text{O III}]\) lines were fitted using three constraints in accordance with atomic physics: the flux ratio between \([\text{O III}]\lambda 4959\) and \([\text{O III}]\lambda 5007\) was set at 2.99:1 (based on the transition probabilities; Osterbrock 1989); the widths of the corresponding components of each line were forced to be equal; and the shifts between the corresponding components of each line were fixed to be 48.0 Å. Note that the fitting program used can only work with a wavelength difference and not a ratio of wavelengths. However, we find the incurred error is smaller than our estimated uncertainty.

Following the technique of H03, we have modelled the \([\text{O III}]\) lines using the minimum number of Gaussians required to give a good fit. Hence, for all sources in the sample the fits to \([\text{O III}]\) required between 2 and 4 Gaussian components to model the doublet well. The best fitting models are presented in Figure 3 and the line data (velocity widths, relative shifts) are presented in Table 4. The errors quoted in Table 4 are a combination of the measurement errors (taken from DIPSO) and an estimation of the expected errors based on the spectral resolution of the spectra. Typically, for the weaker and/or broader components, the DIPSO error is representative of the true error on the result. For the stronger and/or narrower components, the DIPSO error is very small (<1 per cent) and is not a good indicator of the true errors. For these sources, we have estimated a percentage error based on the spectral resolution and signal-to-noise of the data. This is typically of order few-10 per cent. In addition,
the velocities of the nuclear [O III] lines are overplotted on the radial velocity profiles in Figure 1.

From Figure 3 it is clear that a number of sources show extreme line widths and shifts, particularly PKS 1345+12, 4C 32.44, PKS 1549-79 and 3C 459. It is interesting to note that these sources account for 4 out of the 5 smallest sources in the sample, each having a radio source with linear size <1 kpc. For the fifth source in this group, PKS 1814-63, non-detection of broader, more blueshifted components may be real although difficulties in subtracting the continuum due to the presence of a foreground star may also influence the result.

When modelling the emission lines in AGN, it is often assumed that one model will reproduce all emission lines. This technique has been particularly successful in studies of jet-cloud interactions in powerful radio galaxies (e.g. Villar-Martín et al. 1999; Taylor et al. 2003). Hence, after modelling [O III] in nuclear aperture of each source, we attempted to model the other nuclear emission lines with the same components and the same velocity widths and shifts as the corresponding [O III] model, hereafter the [O III] model.

As well as the constraints from the [O III] model, some emission line doublets required further constraints in accordance with atomic physics: the shift between the corresponding components of each line in all doublets (e.g. [Ne III]λλ3868,3968, [Ne V]λλ3346,3425, [N II]λλ6548,6583, [O I]λλ6300,6363 and [S II]λλ6716,6731) were set and for some doublets (e.g. [Ne III]λλ3868,3968, [Ne V]λλ3346,3425, [N II]λλ6548,6583, and [O I]λλ6300,6363) the flux ratios were set based on the transition probabilities. For [S II]λλ6716,6731, the flux ratio was required to be within the range 0.44 < |S II|/6716/6731 < 1.42, the ratios corresponding to the high and low density limits respectively.

With the exception of PKS 1345+12 and PKS 1934-63, one model (the [O III] model) fitted the other emission lines well. For PKS 1345+12, only the narrow component was consistently found in all lines whilst in PKS 1934-63, none of the emission line components was consistent in all lines. However, it should be noted that, due to the complexity of the emission line profiles in all sources, it was often necessary to force the position of the narrow component to be at the systemic redshift to obtain a good fit to the lines with the [O III] model. Further, in sources where two narrow components are detected, whilst free fitting gave different FWHM for the two components, it was also possible to obtain a good overall fit forcing the two narrow components to have equal FWHM (e.g. 3C 268.3, 4C 32.44, PKS 0252-71, PKS 1306-09, as discussed in Section 4.1). In these sources the derived systemic redshift was an average of the redshifts of the two components.

In addition to emission originating from the NLR, we have detected broad components to the permitted lines (due to the signal-to-noise of the data, often only detected in Hα), i.e. from the BLR, in three sources: 3C 268.3, 3C 277.1 and PKS 1549-79 (H06). 3C 277.1 is known to be a quasar and so the detection of a broad component to the permitted lines was not surprising. However, the detection of a broad component in Hα in 3C 268.3 has led to us re-classifying this radio source as a BLRG rather than an NLRG. The detection of broad Hα and Paα in PKS 1549-79 was reported in H06. The line data for the BLR components is presented in Table 4.

4.3 Single Gaussian Modelling

Whilst multiple Gaussian modelling has worked well for the majority of sources in the sample, two GPS sources (PKS 1345+12 and PKS 1934-46) were notable exceptions. In PKS 1345+12, a common narrow component was observed in all lines although different emission lines required different velocity widths and shifts for the broader components to provide good fits (H03). In PKS 1934-46, the situation is somewhat worse – it is less clear that a common narrow component exists for all lines when observed at this resolution/signal-to-noise.

For PKS 1345+12, H03 suggested a stratified ISM with three distinct regions, each responsible for the emission of one of the kinematic components. Hence, the different intermediate and broad components could be explained by gradients in ionisation potential and/or critical density across the regions emitting the intermediate and broad components. Stratification of the NLR was suggested as the reason for correlations between emission line FWHM (when fitting a single Gaussian) and ionisation potential or critical density in Seyfert galaxies (de Robertis & Osterbrock 1984, 1986). This is consistent with models in which there is a continuous variation of density, ionisation and velocity across a spatially unresolved inner narrow line region (INLR). This technique was applied to a sample of extended radio galaxies by Taylor (2004). In the latter work, no significant correlations were found in Cygnus A or in the sample of NLRGs, but 3/4 BLRGs studied did show significant correlations with ionisation potential and/or critical density, a feature expected for an INLR on a scale less than that of the central obscuring torus (r < 100 pc).

We have modelled all nuclear emission lines in all sources using single Gaussian free-fits. No clear correlations were observed for the majority of the sources, including the BLRGs, in contrast to the results of Taylor (2004). Figure 4 shows plots of the single Gaussian FWHM versus both critical density and ionisation potential for the smaller sources in the sample: PKS 1345+12, PKS 1549-79 and PKS 1934-63. Whilst visual inspection of the plots suggest trends, particularly in critical density, Spearman Rank analysis shows these visual trends to be insignificant.

The line widths (FWHM) derived from the single Gaussian modelling can also be used to compare this sample of compact radio sources to other samples of radio sources presented in the literature. The measured single Gaussian FWHM of the nuclear [O III] lines for this sample are presented in Table 5 and are compared to a sample of extended radio sources in Section 5.
5 DISCUSSION

5.1 Extreme emission line outflows

The nuclear emission lines in all of the compact radio sources in this sample are highly broadened, with complex emission line profiles, and require multiple Gaussian components to model them. These components are often shifted significantly with respect to one another and are therefore likely to trace flows in the nuclear emission line gas. However, in order to distinguish between inflows and outflows, it is necessary to accurately define the systemic velocity.

In Section 4.1, following a similar approach to that used for PKS 1345+12 (H03) and PKS 1549-79 (H06), we argued that the extended narrow component(s) represents the ambient, quiescent ISM in the galaxy halo. We are confident of this result in 12 of the 14 sources studied (see Section 4.1) – kinematically the narrow component is the least disturbed component and is typically the only extended component. In some of the sources in which HI absorption is detected,
Figure 3. continued. Models to the [O III]λλ4959,5007 emission line doublet.
Table 4. Rest frame emission line modelling results. Columns are: (a) object name; (b) component following the definitions above: n (narrow; rn and bn denote the ‘reddest’ and ‘bluest’ component where two narrow components are detected), i (intermediate), b (broad), vb (very broad) and BLR (broad line region component; i.e. a highly broadened component only observed in the permitted lines); (c) & (d) velocity width (FWHM) and error of each component; (e) & (f) velocity shift and error of the component from the systemic velocity. Note, the results for PKS 1345+12 and PKS 1934-63 are for [O III]. In sources for which free fitting gave two narrow components with different widths but the lines can also be modelled adequately by forcing the FWHM of the two narrow components to be equal, the FWHM of this alternative model for the narrow component is given and marked †.

| Object    | Velocity width | Δ | Velocity shift | Δ |
|-----------|----------------|---|----------------|---|
|           | (a)            | (b) | (c)            | (d) | (e)            | (f) |
| 3C 213.1  | n              | 523 | 44             | –   | –              | –   |
|           | i              | 1287 | 74             | -142 | 65             | –   |
| 3C 268.3  | rn             | 399 | 12             | –   | –              | –   |
|           | bn             | unres | –             | –   | –              | –   |
|           | i              | 1152 | 88             | -121 | 22             | –   |
|           | BLR            | 5664 | 525            | -760 | 122            | –   |
| 3C 277.1  | n              | 492 | 6              | +50  | –              | –   |
|           | i              | 1340 | 157            | -79  | 36             | –   |
|           | BLR            | 5177 | 185            | 335  | 31             | –   |
| 4C 32.44  | rn             | 316 | 6              | 176  | 8              | –   |
|           | bn             | 242 | 6              | -264 | 6              | –   |
|           | b              | 1831 | 73             | 360  | 22             | –   |
|           | vb             | 3548 | 380            | -852 | 442            | –   |
|           | n†             | 281 | 5              | –    | –              | –   |
| PKS 1345+12 | n            | 340 | 23             | –    | –              | –   |
|           | i              | 1255 | 12             | -402 | 9              | –   |
|           | b              | 1944 | 65             | -1980 | 36            | –   |
| 3C 303.1  | n              | 51  | 27             | –    | –              | –   |
|           | i              | 747  | 17             | -438 | 20             | –   |
| PKS 0023-26 | unres        | –    | –              | –    | –              | –   |
|           | i              | 1002 | 69             | 33   | 14             | –   |
| PKS 0252-71 | rn†           | 335 | 30             | –    | –              | –   |
|           | bn†           | 335 | 30             | –    | –              | –   |
|           | i              | 1236 | 68             | 65   | 24             | –   |
| PKS 1306-09 | rn           | 329 | 34             | 706  | 7              | –   |
|           | bn             | 425 | 20             | –    | –              | –   |
|           | n†             | 365 | 13             | –    | –              | –   |
| PKS 1549-79 | n            | 383 | 15             | –    | –              | –   |
|           | i              | 1282 | 25             | -679 | 20             | –   |
| PKS 1814-63 | unres        | –    | –              | –    | –              | –   |
|           | i              | 569  | 35             | -162 | 21             | –   |
| PKS 1943-63 | unres        | –    | –              | –    | –              | –   |
|           | b              | 1785 | 103            | -93  | 43             | –   |
| PKS 2135-20 | i            | 762  | 15             | –    | –              | –   |
|           | b              | 1686 | 84             | -157 | 29             | –   |
| 3C 459    | n              | 528 | 24             | –    | –              | –   |
|           | b              | 1647 | 48             | -497 | 49             | –   |

the velocity of the narrow component is also consistent with a deep, narrow component of HI which could be associated with a circumnuclear disk or torus (Morganti et al. 2001).

Previous studies have often struggled to determine the relationship between the HI, the optical kinematics and the systemic velocity (i.e. is the HI at rest, or tracing a flow of gas?) due to the inaccuracies in tying down the systemic velocities (see Morganti et al. 2001 for a discussion). In this paper, we have accurately established the systemic velocities in 12 out of 14 sources using detailed optical emission line modelling and have compared them to the HI data available in the literature in Figure 1 and Table 6.

HI absorption is detected in 10/14 sources. Comparing the optical and HI data, it is striking that the majority of absorption components are significantly blueshifted with respect to the optical systemic velocity, often by several hundreds of km s⁻¹, and represent outflows of neutral gas. Only three sources have HI components consistent with the optical systemic velocity (3C 213.1, 3C 268.3, and PKS 1345+12) which may be consistent with a circumnuclear disk or torus. However, in PKS 1345+12, the latest data show the
Table 5. Various emission line parameters used in the statistical analysis. Columns are: (a) object; (b) heliocentric redshift of the systemic velocity; (c) maximum shift velocity taken as the shift between the broadest NLR component and the systemic velocity (km s$^{-1}$); (d) FWHM of the [O III]$\lambda$5007 line when fitting a single Gaussian (km s$^{-1}$); (e) the asymmetry index, $A_{20}$ and (f) the kurtosis parameter, $R_{20/50}$. ⋆ indicates total range of HI absorption and the PKS 1306-09 data is from Raffaella Morganti (priv. comm.). † assumed optical z. * The shift between the two detected narrow components. * Redshift derived from the stellar absorption lines.

| Object     | z            | Max shift (km s$^{-1}$) | [O III] FWHM (km s$^{-1}$) | $A_{20}$ | $R_{20/50}$ |
|------------|--------------|-------------------------|-----------------------------|---------|-------------|
| 3C 213.1   | 0.19392 ± 0.00004 | -142                    | 687 ± 22                    | -0.015 ± 0.002 | 1.65 ± 0.17 |
| 3C 268.3   | 0.37171 ± 0.00006 | -760                    | 668 ± 15                    | -0.20 ± 0.02 | 1.53 ± 0.15 |
| 3C 277.1   | 0.31978 ± 0.00008 | -79                     | 483 ± 4                     | -0.10 ± 0.01 | 1.79 ± 0.18 |
| 4C 32.44   | 0.36801 ± 0.00004 | -852                    | 986 ± 28                    | -0.054 ± 0.005 | 2.16 ± 0.22 |
| PKS 1345+12| 0.12351 ± 0.00008 | -1980                   | 1547 ± 32                   | 0.55 ± 0.06 | 2.22 ± 0.22 |
| 3C 303.1   | 0.27040 ± 0.00006 | -438                    | 835 ± 8                     | -0.067 ± 0.007 | 1.45 ± 0.15 |
| PKS 0023-26| 0.32162 ± 0.00003 | +33                     | 262 ± 8                     | -0.046 ± 0.005 | 3.79 ± 0.38 |
| PKS 0252-71| 0.56288 ± 0.00009 | +65                     | 714 ± 9                     | -0.34 ± 0.03 | 1.68 ± 0.17 |
| PKS 1306-09| 0.46685 ± 0.00009 | 706$^a$                | 1009 ± 43                   | -0.46 ± 0.05 | 1.20 ± 0.12 |
| PKS 1549-79| 0.15220 ± 0.00003 | -679                    | 1372 ± 12                   | 0.24 ± 0.02 | 1.43 ± 0.14 |
| PKS 1814-63| 0.06466 ± 0.00007$^\dagger$ | -162               | 411 ± 17                    | 0.28 ± 0.03 | 2.55 ± 0.26 |
| PKS 1943-63| 0.18129 ± 0.00008$^\dagger$ | -93                 | 198 ± 6                     | -0.001 ± 0.0001 | 1.69 ± 0.17 |
| PKS 2135-20| 0.63634 ± 0.00003$^\dagger$ | -157               | 919 ± 7                     | 0.033 ± 0.003 | 1.84 ± 0.18 |
| PKS 0252-71| 0.635 ± 0.004$^*$ | -1009                  | 1009 ± 43                   | -0.46 ± 0.05 | 1.20 ± 0.12 |

Figure 4. Correlation plots for the nuclear apertures of PKS 1345+12, PKS 1549-79 and PKS 1934-63. For each source the plots are: top: rest frame FWHM (km s$^{-1}$) versus log(critical density cm$^{-3}$) and bottom: rest frame FWHM (km s$^{-1}$) versus ionisation potential (eV).
component of HI at the systemic velocity is actually most likely associated with an off-nucleus cloud (Morganti et al. 2004). Unlike the optical outflows, both the narrower and broader line components have significant blueshifts. Multiple HI components are observed in 5 sources. In PKS 1345+12, these are broadly consistent (velocity width and shift) with the optical components. Finally, two sources contain components consistent with infalling clouds (PKS 1934-63 and PKS 0023-26).

One of the key trends highlighted above (Section 4.2) is the detection of significantly shifted emission line components observed in the majority of sources in the sample. These are predominantly blueshifted, with the broader components blueshifted by the largest amounts. Figure 7 shows the distribution of shift for the sample. All sources except PKS 1306-09 – which has no ‘broad’ component, only two narrow components – are included in this plot and the shifts used are for the NLR components only.

For all but two sources (PKS 0023-26 and PKS 0252-71) the broad component is blueshifted with respect to the systemic velocity with velocities up to 2000 km s$^{-1}$ although most sources occupy the range -900 $< v_{\text{shift}} < 100$ km s$^{-1}$. Figure 7 further sub-divides the sample into the larger CSS sources and the smaller GPS sources. The effects of radio source size and orientation are discussed below.

The [O III] line emission is known to be resolved in three of the sources in this sample: 3C 268.3, 3C 277.1 and 3C 303.1. These have been imaged at high resolution with HST (de Vries et al. 1997, 1999; Axon et al. 2000) and O’Dea et al. (2002) have obtained corresponding HST/STIS spectroscopy of 3C 277.1 and 3C 303.1. For these sources, virtually all of the line emission detected by both de Vries et al. (1999) and Axon et al. (2000) lies within our slit. In our 2-D spectra, we observe clear extended line emission in 3C 268.3 and 3C 277.1 although the line emission imaged by HST lies within our defined nuclear aperture, within which no obvious spatial structure is resolved. The extended line emission that we detect will be presented in Holt et al. (2008, in prep.) along with a discussion of extended apertures. It is difficult for us to compare our kinematic results to those of O’Dea et al. (2002) as whilst their spectra are of significantly higher spatial and spectral resolution compared to ours, from the figures in their paper, the lines are at much lower signal to noise than our spectra and they have, for the main part, modelled the emission lines with single Gaussians. Depending on the dominance of different components, this can lead to erroneous line shifts (see e.g. H06). Comparing our single Gaussian modelling, we observe similar line widths (FWHM $\sim$500 km s$^{-1}$) in 3C 277.1 but significantly higher widths in 3C 303.1 (FWHM $\sim$800 km s$^{-1}$) compared to $\sim$500 km s$^{-1}$ in O’Dea et al. (2002). Further, the resolved [O III] emission may account for the narrow line splitting in 3C 268.3.

From the results presented here, it is clear that, with the exception of PKS 0023-26, PKS 0252-71 and PKS 1306-09, all sources in the sample have evidence for fast, blueshifted flows in the circumnuclear ISM. However, from the kinematical evidence alone it is impossible to distinguish between material in outflow on the side of the nucleus closest to the observer and material infalling on the far side of the nucleus. Holt et al. (2003) argued that, for PKS 1345+12, as the reddening increased significantly with FWHM, the blueshifted components were likely to be consistent with material being observed on the observer’s side of the nucleus and therefore tracing an outflow. We will discuss the issue of reddening in a future paper (Holt et al. 2008, in prep.).

5.2 The role of orientation

The original work on the compact flat-spectrum radio source PKS 1549-79 by Tadhunter et al. (2003) suggested that the direction of jet propagation was oriented close to the observer’s line of sight (LOS) as:

(i) PKS 1549-79 has a flat radio spectrum, often associated with radio loud quasars whose axes are close to the observer’s LOS;

(ii) PKS 1549-79 has core-jet radio morphology. As radio galaxies have two-sided radio jets, observing one-sided radio structure is usually interpreted as an orientation effect with the observer’s LOS aligned close to the direction of jet propagation (see H06, Figure 10).

Similarly, radio maps of PKS 1345+12 (e.g. Lister et al. 2003) show highly asymmetric radio jets, again suggesting the radio source is pointing close to the observer’s LOS. This argument is supported by the detection of a broad (FWHM $\sim$2600 km s$^{-1}$) component Pao (Veilleux et al. 1997) and the detection of a point source component in high-resolution near-IR images (Evans et al. 1999). However, this orientation is disputed by Lister et al. (2002, 2003) – see H03 for a discussion.

Interestingly, PKS 1345+12 and PKS 1549-79 contain two of the most extreme outflows in the sample discussed in this paper ($\sim$2000 km s$^{-1}$ and $\sim$680 km s$^{-1}$ respectively). Perhaps, then, the particular orientation of these objects with respect to our LOS is the reason why we observe such extreme kinematics in these sources. In contrast, for example, PKS 1934-63 has a weak core and is a symmetric double, as well as being one of the most compact sources in the sample, and has one of the smallest observed outflow velocities.

Due to the angular scales of the compact radio sources, compact flat-spectrum radio cores for the sources in this sample are not generally detected, even with VLBI (e.g. Tzioumis et al. 2002) – the core is only detected in 5/14 sources. It is therefore not possible to determine the radio source orientation accurately for most of the sample using the standard methods, for example, the $R$ (core-dominance) parameter (e.g. Orr & Brown 1982; Giovannini et al. 2001), radio flux density comparison of the jet and counter-jet (e.g. Giovannini et al. 2001), jet proper...
with caution. However, Best et al. (1995) studied the angular asymmetries in a sample of extended FR II 3CR sources and found the distribution of asymmetry angles to be consistent with the predictions of unified schemes. We have therefore classified the sources into three broad categories:

(i) Close to the LOS. All sources with an obvious core-jet and a large core/extended radio flux ratio e.g. PKS 1549-79, PKS 1345+12 and 3C 303.1.

(ii) Close to the plane of the sky. Symmetric radio morphology (e.g. similar jet extents and/or fluxes): e.g. PKS 1549-79, PKS 1345+12 and PKS 1934-63.

(iii) Intermediate. Sources not consistent with the other two categories.

Figure 5 shows the grouping with respect to the largest outflow velocity. Despite the crudeness of the method, the data suggest that the orientation of the radio source to the observer’s line of sight/the asymmetry of the radio morphology may be an important factor in determining the maximum outflow velocity observed. Sources with jets most likely pointing towards us contain the most extreme outflow velocities, and sources likely to be close the plane of the sky exhibit the least evidence for fast outflows in the NLR. Only two sources in the sample appear to be ‘mis-fits’ in this classification.

Table 6. Summary of the HI data for the sample compiled from the literature. Columns are: 1) object, 2) & 3) HI velocity shift and error with respect to the optical systemic velocity derived in this paper where negative velocities imply blueshifted HI; 4) & 5) HI full width at half maximum (FWHM) and estimated uncertainty (∗ full width at zero intensity (FWZI) of the broad, shallow absorption); 6) optical depth (∗ quoted fractional absorption); 7) HI column density derived assuming $T_{\text{rot}} = 100$ K and 8) references: v0: Veron-Cetty et al. (2003); m1: Morganti et al. (2001); m3: Morganti et al. (2003); v3: Vermeulen et al. (2003); g6: Gupta et al. (2006); H06: Holt et al. (2006); l6: Labiano et al. (2004); m: Morganti, private communication. ※ component of HI consistent with the optical systemic velocity.

| Object         | vel shift (km s$^{-1}$) | $\Delta$ (km s$^{-1}$) | FWHM (km s$^{-1}$) | $\Delta$ (km s$^{-1}$) | $\tau$ ($10^{-2}$) | N(HI) ($10^{20}$ cm$^{-2}$) | ref |
|----------------|-------------------------|-------------------------|--------------------|-------------------------|---------------------|-----------------------------|-----|
| 3C 213.1       | -9                       | 7                       | 115                | 0.05                    | 0.11                | v3                          |
| 3C 268.3       | -63                     | 4                       | 19                 | 0.3                      | 0.1                  | v3                          |
| -152          | 3                       | 101                     | 1.00               | 1.85                    | v3                  |
| -116          | 10                      | 101                     | 6                  | 2.5                     | 3.2                  | l6                          |
| 4C 32.44       | -128                    | 20                      | 229                | 0.17                    | 0.71                 | v3                          |
| PKS 1345+12    | -15$^b$                 | 180                     | 1                  | 2                      | m3                  |
| PKS 0023-26    | 40                      | 39                      | 0.20               | 0.14                   | v3                  |
| PKS 1306-09    | -250                    | 230$^b$                 | 0.3                | m                      |
| PKS 1549-79    | -74                     | 80                      | 2                  | 400                    | m1,H06              |
| PKS 1814-63    | -186                    | 50                      | 21.3               | 1700                   | m1                  |
| 0$^b$ – 258$^a$| ~280                     | 0.8                     | 2000               | m1                    |
| PKS 1934-63    | 389                     | 2                       | 0.22               | 0.06                   | v0                  |
| 3C 459         | -398                    | 9                       | 0.8                | 270                    | m1                 |
| -241          | 10                      | 130                     | 0.31               | 0.72                   | v3                  |
| -431          | 27                      | 71                      | 34                 | 0.0012                 | g6                  |
| -344          | 6                       | 121                     | 11                 | 0.0034                 | g6                  |
| -186          | 31                      | 164                     | 63                 | 0.0012                 | g6                  |

Despite the lack of radio information to accurately determine the radio source orientations, it is still interesting to make a rough estimate of the importance of orientation with respect to the observed outflow velocities. For the remainder of the sample, we have therefore adopted the rather crude approach of comparing the relative extents of the radio jets on either side of the nuclei in the radio maps. Assuming both jets are generated by the same central source, if they expand through empty space they should have similar intrinsic extents on either side of the core and any observed differences will be due to orientation effects. It should be noted that, should the jets expand through a dense ISM, interactions between the radio source and this ISM could significantly alter the path of at least one of the jets. Hence, a highly asymmetric ISM can alter the relative extents of the jets and mimic the effects of orientation with respect to the observer and these results should therefore be used
Figure 5. Histogram showing the putative orientation of the continuum, the radio emission is resolved into two distinct spectra (broad permitted lines and a strong blue power-law) serve strong optical signatures of the quasar in our optical core appears strong in the radio map of 3C 277.1 and we observe strong optical signatures of the quasar in our optical core.

| Table 7. Comparison of the maximum outflow velocity with the largest projected linear size of the sources in this sample. * compact core. |
| D < 1 kpc | D > 1 kpc |
| 4C 32.44 | (−852) | 3C 213.1 | (−142) |
| PKS 1345+12 | (−1980) | 3C 268.3 | (−760) |
| PKS 1549-79 | (−679) | 3C 277.1 | (−79) |
| PKS 1814-63 | (−162) | 3C 303.1 | (−438) |
| 3C 459* | (−497) | PKS 0023-26 | (+33) |
| PKS 0252-71 | (+65) | PKS 1306-09 | (0) |
| PKS 1934-63 | (−93) | PKS 2135-20 | (−157) |

Outflows in compact radio sources

5.3 Outflow driving mechanism

It is clear that extreme emission line kinematics exist in all of the compact radio sources in this sample. The emission line flows are likely to trace outflows in the emission line gas, similar to the results presented for PKS 1345+12 (reddening: H03) and PKS 1549-79 (source orientation: H06).

If compact radio sources are truly young AGN in which the outflows have not yet swept aside the natal cocoon, then because of the large gas and dust concentrations in the central regions, the effects of all types of outflow (quasar winds, jets, starburst superwinds) are likely to be more visible as there is more warm/cool gas around for the winds and/or jets to interact with. Whilst jet-cloud interactions are expected to produce extreme kinematics, all of these scenarios can potentially explain broad line widths and large velocity shifts and so, from the kinematical evidence alone, it is not possible to distinguish between the different outflow driving mechanisms.

Some of the best evidence for jet-driven outflows is provided by the co-alignment and similar scales of the radio source and the optical emission line structures. More than 30 CSS sources have been observed with HST in both broad and narrow bands (to isolate [O II] and/or [O III] emission) by de Vries et al. (1997, 1999) and Axon et al. (2000). The de Vries et al. samples include 3C 213.1, 3C 268.3, 3C 277.1 and 3C 303.1 and the Axon et al. sample includes 3C 268.3, 3C 277.1, 3C 303.1 and PKS 1345+12. These imaging studies reveal that the optical and radio emission is both:

(i) on similar scales (30-90%) of the optical line emission is concentrated within a few kpc and the radio sources are either completely embedded within this optical line emitting gas or extend just beyond it; Axon et al. (sample) and;

(ii) strongly aligned (typically < 10° in all sources, including the sources also found in our sample, in which the data could be accurately registered in the de Vries et al. sample, and in 6/11 sources in the Axon et al. sample, often elongated into jet-like structures).

The radio-optical alignment is also observed across the entire redshift range probed by these samples (0.1 < z < 1.5), rather than confined to higher redshifts as in more extended radio sources (z > 0.6; e.g. McCarthy et al. 1987; de Koff et al. 1996). Such close association between the optical emission line gas and the radio source suggest that the radio source is strongly interacting with the ambient medium as it expands through it (O’Dea et al. 2002). Follow-up HST/STIS spectroscopy of three CSS sources with resolved [O III] line emission (including 3C 277.1 and 3C 303.1) provides further evidence that the outflows are likely to be driven by the expanding radio jets; the emission lines have complex, broad profiles (FWHM ~ 500 km s⁻¹) which are offset with respect to the systemic velocity by 300-500 km s⁻¹ in the region(s) of the radio hotspots (O’Dea et al. 2002) and the line ratios are consistent with a mixture of quasars. Whilst the BAL outflows are on a different scale to those observed in compact radio sources (on the scale of the BLR rather than the NLR), it has been suggested that the extreme velocities observed may be partly due to an orientation effect (e.g. Weymann et al. 1991; Elvis 2000).
fast shocks (500-1000 km s$^{-1}$) and photoionisation/precursor (Labiano et al. 2005).

Finally, PKS 1345+12 and PKS 1549-79 were recently observed at higher resolution with HST/ACS (Batcheldor et al. 2007). In these sources, the optical line emission is clearly concentrated in the central regions, ruling out galaxy-wide starbursts as the dominant outflow driving mechanism. Further, the radio emission in both sources is on similar scales to the optical line emission. However, the region of line emitting gas is only marginally resolved and, whilst there is a suggestion that the isophotes may be elongated in the direction of the radio axis, this evidence is far from conclusive.

Despite the strong evidence for radio/optical alignments and the co-spatial scales of the optical and radio emission, we find no evidence for anti-correlations between the emission line widths and the ionisation potential (Figure 4) that are a clear signature of shocks in some extended radio sources. Hence, to confidently distinguish between the different ionisation mechanisms, it is necessary to combine the kinematical and imaging data with a detailed study of the line ratios (Holt et al., 2008, in prep.).

5.4 Are the kinematics in compact radio sources more extreme than in extended radio sources?

As discussed in Section 1, previous data have suggested that the kinematical properties of the nuclear emission line gas are different in compact radio sources compared to more extended radio sources. For example, comparison of the emission line profiles in samples of compact (e.g. Gelderman & Whittle 1994) and extended (e.g. Brotherton 1996) radio sources in the literature suggest that the line profiles of the compact radio sources are often broader and more asymmetric. However, to date, no attempt has been made to properly quantify the differences between the emission line profiles of compact and extended radio sources.

Many of the spectra in the literature are not of sufficient signal-to-noise and/or resolution to model the emission line profiles in detail and so we have used three line profile parameters on the strong [O III]λ5007 line to compare our sample to the data in the literature, for example, i) the line width (FWHM) derived from single Gaussian modelling; ii) the asymmetry index, $A_{20}$, and iii) the kurtosis parameter, $R_{20/50}$. The latter two are defined in Heckman et al. (1981). All the results for our sample are presented in Table 5. As our sample of compact radio sources is small, we have formed a larger sample including data from the literature (see Table 5). Our comparison sample of extended radio sources for these three parameters comprises all radio loud objects in the samples of Heckman et al. (1984) and Brotherton (1996) (see Table 5). The latter sample comprises solely quasars whereas the sample of Heckman et al. (1984) includes both radio galaxies and quasars.

Figure 6 shows that the distribution of FWHM of [O III]λ5007 is markedly different for the compact and extended radio source samples. For the extended sources, the distribution peaks at ~ 200-300 km s$^{-1}$ which is consistent with gravitational motions in an elliptical galaxy (Tadhunter et al. 1989). However, more extreme kinematics are observed in the sample of compact radio sources – the spread is larger and it peaks at FWHM ~1000 km s$^{-1}$ – ve-

Figure 6. Histograms showing the distribution in observed optical emission line FWHM of [O III] in samples of extended (D > 30 kpc; from Heckman et al. 1984 and Brotherton 1996) and compact (D < 30 kpc; this sample plus sources from Gelderman & Whittle 1994, four sources from the sample of Hirst et al. 2003 and PKS 1718-49 from Fosbury et al. 1977)). The shaded part of the bottom plot highlights the sources from this sample.

Figure 7. Histograms showing the maximum nuclear outflow velocity for this sample of compact radio sources (bottom) and a comparison sample of extended radio sources taken from Taylor 2004. Note, for the extended sources the shift plotted is broadest–narrowest component whilst for the compact sources, the shift between the broadest–systemic velocity is used as in a number of sources, two narrow components are observed (see Section 4.1). For the compact radio sources, the plot is further

Figure 7. Histograms showing the maximum nuclear outflow velocity for this sample of compact radio sources (bottom) and a comparison sample of extended radio sources taken from Taylor 2004. Note, for the extended sources the shift plotted is broadest–narrowest component whilst for the compact sources, the shift between the broadest–systemic velocity is used as in a number of sources, two narrow components are observed (see Section 4.1). For the compact radio sources, the plot is further
also remember that the various samples have different selection criteria which may affect the test to some degree.

Whilst the K-S test reveals a strong trend, the reader should note that more extreme velocities in smaller sources are also evident within the sample of compact radio sources, with the two most extreme velocities being detected in smaller GPS sources (PKS 1345+12 and 4C 32.44). Indeed, all but one of the most extreme velocities (v > 500 km s\(^{-1}\)) are detected in sources with projected linear size D < 1 kpc whilst the cluster of sources in the low outflow velocity region (100 < \(v_{\text{out}}\) < 1000 km s\(^{-1}\)) are predominantly the larger CSS sources (Figure 6 and Table 7). Such velocity evolution with source size is consistent with the idea that compact radio sources are young, starting as GPS sources and expanding to become CSS then extended radio sources.

Whilst the nuclear regions of extended radio sources appear to be less extreme than in more compact radio sources, extreme velocities (v \(\gtrsim\) 1000 km s\(^{-1}\); e.g. Solórzano-Iñarrea et al. 2001) are commonly observed in extended radio sources, but in the extended emission line regions (EELRs). EELRs are typically on similar scales as, and are aligned with, the radio axis and are therefore associated with jet-cloud interactions. Hence, in extended radio sources, the regions emitting the broader components are often significantly displaced from the nuclear aperture, coincident with the radio emission.

With this in mind, it is not surprising that extreme kinematics are observed in the nuclear apertures of compact radio sources. Compact radio sources are on the scale of the host galaxy (<15 kpc), often contained within the nuclear regions (<1 kpc), and so the signatures of interactions between the radio jets and the ISM will occur in the circumnuclear regions. Indeed, it is in the nuclear apertures of compact radio sources that we observe both broad, blueshifted components, which are generally spatially unresolved, as well as any quiescent components similar to those observed in the nuclear regions of extended radio sources.

The consistency between the spatial scales of the emission line regions and the radio emission has been confirmed in

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**Table 8.** Parameters for the comparison samples used in both this paper and in Paper II. Columns are: (a) sample name; (b) redshift range; (c) radio power range at 5 GHz except \(a\) at 178 MHz, \(b\) at 1.4 GHz and \(c\) no radio data was given for this sample; (d) number of sources used; (e) completeness of the sample. † see Section 2 for details. Note, for sources which are included in more than one sample, data are included only once and are taken from the sample with the highest quality data. * This comparison sample is only used in Holt et al., 2008, in prep.

| Sample | z   | Radio power \(\log P_{5\text{GHz}}\) (W Hz\(^{-1}\)) | N  | completeness |
|--------|-----|---------------------------------|----|-------------|
|        | (a) | (b)                             | (c) | (d)         | (e) |
| Compact radio sources | | | | |
| This paper | < 0.7 | 26-28 | 14 | complete† |
| Gelderman & Whittle (1994) | < 0.9 | 22-29 | 16 | not complete |
| Hirst et al. (2003) | 0.5-3.6 | > 26.5\(^a\) | 9 | complete |
| PKS 1151-34 | 0.258 | 26.8 | 26.8 |
| PKS 1718-643 | 0.014 | 24.3 | 24.3 |
| Extended radio sources | | | | |
| 2 Jy radio loud objects from Heckman et al. (1984) | < 0.7 | 25-29 | 36 | complete * |
| radio loud objects from Brotherton (1996) | < 0.7 | > 24.5\(^b\) | 45 | not complete |
| Taylor (2004) | < 0.95 | < 25 | 60 | not complete |
|        | < 0.2 | 26-29 | 12 | complete |

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9 Whilst the K-S test reveals a strong trend, the reader should also remember that the various samples have different selection criteria which may affect the test to some degree.
six sources in our sample (3C 213.1, 3C 268.3, 3C 277.1, 3C 303.1, PKS 1345+12 and PKS 1549-79) using HST broad- and narrow-band imaging (de Vries et al. 1997; Axon et al. 2001; Batcheldor et al. 2002). Hence, whilst the kinematics observed in the nuclear regions of compact radio sources are significantly different to those observed in the nuclei of more extended radio sources, they are entirely consistent with compact radio sources being a young, small scale version of the jet-cloud interactions observed in the extended sources with aligned radio and optical emission.

6 SUMMARY, CONCLUSIONS AND FUTURE WORK

It is clear that all compact radio sources show evidence for disturbed kinematics, with large line widths and shifts with respect to the galaxy rest frame in the optical emission lines. The main conclusions of this paper are:

- The extended emission line halo. For the majority of sources (12/14), we were able to determine the systemic velocity with confidence. For consistency, all techniques focused on the extended narrow component emission. In two sources, a smooth ‘rotation curve’ was observed, but in most sources, the extended narrow component emission was either not settled, as in PKS 1345+12, or split into two narrow components, assumed to represent a rotation curve in which the central regions were unresolved although this may also be a signature of bi-polar outflows.

- Extreme emission line outflows. All but three sources show evidence for outflows in the circumnuclear ISM. The most extreme outflow is in the GPS source PKS 1345+12 (∼2000 km s⁻¹). Interestingly, the second most extreme outflow was observed in another GPS source, 4C 32.44. As well as radio source size (CSS or GPS), the orientation of the radio source to the observer’s line of sight may also be important, with higher outflow velocities observed in sources pointing towards the observer.

- Blueshifted HI. HI absorption is detected in 10/14 sources, with multiple components observed in 5 sources. The majority of HI components (narrow and broad) are significantly blueshifted with respect to the systemic velocity and trace outflows in the neutral gas. In PKS 1345+12, (and others?) the outflowing HI components are broadly consistent with the emission line components. In only two sources (PKS 0023-26 and PKS 1934-63) is the HI redshifted, consistent with in-falling gas.

- Kinematical evidence for shocks. As well as the extreme line splitting/outflows, the emission line components are also highly broadened. Again, the two most extreme FWHM in the NLR gas are observed in GPS sources: PKS 1345+12 (∼2000 km s⁻¹) and 4C 32.44 (∼3500 km s⁻¹). Highly broadened components are almost exclusively confined to the nuclear apertures and therefore on the scale of the radio source. Higher resolution HST studies have resolved the [O III] emission line gas in several sources in this sample, revealing that the emission line gas is both on the same scale as, and is strongly aligned with, the radio source. This is consistent with observations of high redshift extended radio sources in which the broadband components are observed in regions coincident with the radio emission (e.g. Solórzano-İnarrea et al. 2001). The suggested importance of orientation on the observed outflow velocity also suggests the acceleration is confined to a spatially small region (i.e. coincident with radio jets) rather than occurring across the entire nuclear region (i.e. due to a quasar- or starburst wind).

- Smaller source – more extreme kinematics. These results provide further evidence that the radio source size is also important in determining the outflow velocity and the dominance of shocks. Shocks, and the kinematics associated with them, are predominantly confined to smaller extended sources (D ≤ 120 kpc: Best et al. 2000). The statistical tests presented in this paper show that the nuclear kinematics, in particular the emission line shifts, are more extreme in compact radio sources than in the nuclear regions of their extended counterparts at the 99.9% confidence level. Similarly, the most extreme outflows in the compact radio sources occur in sources with the smallest projected linear sizes, generally with D < 1 kpc, the GPS sources. Whilst this effect might be due, in part, to foreshortening, it has been argued that the majority of CSS sources cannot be larger radio sources foreshortened by projection effects (Fanti et al.).

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