BULK RELATIVISTIC MOTION IN A COMPLETE SAMPLE OF RADIO SELECTED AGN

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ABSTRACT. A complete sample of 13 flat spectrum radio sources is investigated over a wide range of frequencies and spatial resolutions. SSC-calculations lead to the prediction of bulk relativistic motion in all sources. So far 6 out of 7 sources observed with sufficient dynamic range by means of VLBI show evidence for apparent superluminal motion.

1. INTRODUCTION

Evidence for bulk relativistic motion in active galactic nuclei comes from (1) the apparent violation of the inverse compton limit as suggested by flux density variability, (2) the excess of expected over measured X-ray flux within the framework of SSC-models and (3) the direct measurement of apparent superluminal motion by VLBI.

We are carrying out a detailed investigation of radio sources selected from the MPIfR - NRAO strong source survey (s. Kühr et al. 1981) by the following three criteria:

1. $\alpha > -0.5$ $(S_\nu \sim \nu^{+\alpha})$
2. $S \geq 1$ Jy at the survey epoch
3. dec $\geq 70^o$, $|bII| \geq 10^o$.

The sources, 7 quasars and 6 BL Lac-type objects form a complete and homogeneous sample. In this paper we mainly deal with the investigation of the occurrence of bulk relativistic motion (b.r.m.).

2. OBSERVATIONAL STATUS

The sources have been observed over a wide range of frequencies - from radio to X-rays - and spatial resolutions - from arcseconds to 0.2 milli-

E. Ye. Khachikian et al. (eds.), Observational Evidence of Activity in Galaxies, 287–293.

https://doi.org/10.1017/S007418090015524X Published online by Cambridge University Press

arcseconds (mas). Table 1 lists the source names (col. 1), the optical identification (col. 2), the redshifts (col. 3) and the apparent visual magnitudes (col. 4). Radio spectra are available from 150 MHz to 22 GHz (Kühr et al. 1981), as well as measurements at 90 GHz and 250 GHz (Biermann et al. 1987 and Chini et al. 1987). X-ray observations were performed by the IPC aboard the EINSTEIN - and the ME- and LE-detectors on the EXOSAT observatory for the complete sample (Biermann et al. 1981, Biermann et al. 1987), except for 0153+74, 0836+71 and 1039+81. For these sources upper limits were derived from the HEAO-A1 survey (Wood et al. 1984) (s. col. 5 in Table 1). 8 of the 13 sources were detected with flux densities from 0.095 to 0.55 μJy at 1 keV. In Fig. 1 we present typical overall spectra of a QSO (1928+73) and a BL Lac-type object (1803+78). In order to obtain information about the subarcsecond structures we used the following interferometers: VLA (1.5 GHz), MERLIN (1.7 GHz) and telescopes of the European and U.S. VLBI networks at frequencies ranging from 608 MHz to 22.2 GHz. Multi-epoch VLBI observations were done at 5 GHz for the whole sample, and at 1.6 GHz for 3 sources. Detailes of these observations are given in Eckart et al. (1986a, b). One of the sources (1803+784) is listed in the IRAS point source catalogue (1985), BL Lac 0716+71 was detected with IUE (Schleicher et al. 1980).

TABLE 1
OBSERVATIONAL STATUS

Source	Id.	z	m	V L B I					X
				>50	18	6	2.8	1.3 cm	2 keV
(1)	(2)	(3)	(4)	(5)					(6)
0016+73	QSO	1.76	18.0		X	X		X	X
0153+74	QSO	2.34	16.0		M	M			U
0212+73	BL	2.67	19.0		X	M	X	X	X
0454+84	BL	-	16.5		X	X		X	X
0615+82	QSO	0.71	17.5		X	M	X		U
0716+71	BL	-	13.2	X	M	M		X	X
0836+71	QSO	2.16	16.5		X	M	X	X	U
1039+81	QSO	1.26	16.5		X	M		X	U
1150+81	QSO	1.25	18.5		X	M		X	U
1749+70	BL	-	16.5		X	M		?	X
1803+78	BL	-	16.4		X	M		X	X
1928+73	QSO	0.30[1)]	15.5	X	M	M		X	X
2007+77	BL	-	16.7		X	M		X	X

X: 1 epoch, M: multi-epoch observations (n ≥ 2), U: upper limit for the X-ray flux density
1)redshift taken from Lawrence et al. (1986).

3. RESULTS AND DISCUSSION

3.1 The radio structures

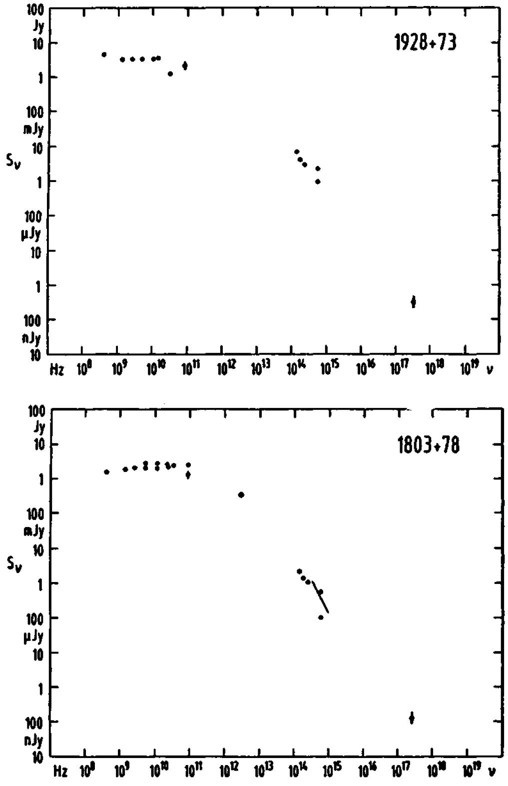

Fig. 1: Overall spectra of the QSO 1928+73 and the BL Lac-type object 1803+78

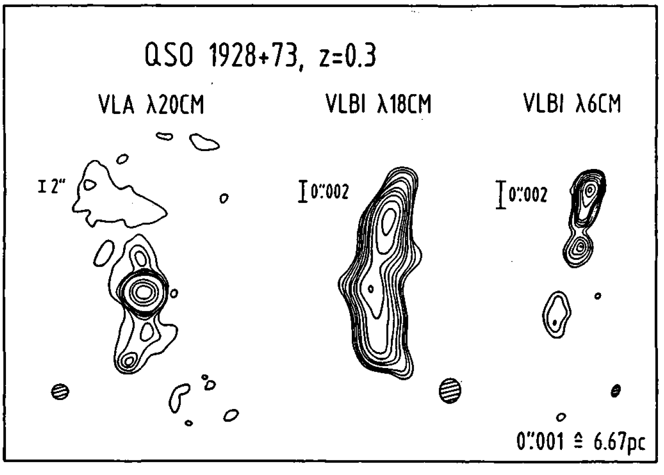

Fig. 2: Radio maps of 1928+73. Contours: 1, 2, 4, 6, 8, 10, 20, 50, 80% (λ6 cm, 1984.8); 3, 4, 5, 8, 10, 15, 20, 50, 80% (λ18 cm, 1984.9); -.1, .1, .2, .3, .4, .8, 1, 10, 25, 50% (λ20 cm, 1984)

The VLA and MERLIN data show that roughly 50% of the sources exhibit secondary structures with flux densities exceeding 10% of the flux densities of primary components (e.g. Perley et al. 1980, Ulvestad et al. 1981, Perley 1982, Antonucci et al. 1986). The mas structures obtained by VLBI measurements at different frequencies are summarized in Table 2. Dividing the general morphology in unresolved, slightly resolved (including halo-type sources) and core-jet, one can see, that at least at the higher frequencies all sources display structure. These structures are typically one-sided. The number of secondary components varies from one to at least 9. As an example in Fig. 2 we present the structures of the QSO 1928+73 at various frequencies and resolutions. The projected linear separations of components range from 2 pc to 165 pc (using redshifts or lower limits, $H_o = 50$, $q_o = 0.05$). There is no evidence for redshift dependent jet lengths (e.g. 100 pc for 1928+73, z = 0.3, 124 pc for 0153+74, z = 2.34, 108 pc for 0836+73, z = 2.16). In general the pc-scale structures are aligned with the kpc-scale emission, one exception being the BL Lac-type object 0716+71.

TABLE 2

VLBI structure	λ18	6	2.8	1.3 cm
unresolved	3	-	-	-
slightly resolved	2	3	2	-
core-jet	8	10	2	10

3.2 Spectral index distribution

Using well defined components in the 1.6 and 5 GHz VLBI maps, taking into account different epochs and dynamic ranges, we calculated spectral indices for primary and secondary components. The primary components have a median spectral index $\alpha = +0.4 \pm 0.2$, indicating that they are self-absorbed at 5 GHz. The secondary components have a median spectral index of $\alpha = -0.7 \pm 0.3$, indicating that they are optically thin at 1.6 GHz with a typical value for optically thin synchrotron sources (e.g. Moffet 1975).

3.3 Inverse Compton X-rays

Given the tight correlation between mm and X-ray flux densities (Owen et al. 1981), which is confirmed for this sample by recent observations at 1.2 mm wavelength (Chini et al. 1986), we can calculate the expected inverse Compton radiation S_{IC} of compact components and derive Doppler factors D: $S_{IC} \sim T_B^{3-2\alpha} \, S_\nu{}^{1-\alpha} \, E_x^{\alpha} \, (\frac{1+z}{D})^{2(2-\alpha)}$ μJy

with: S: radio flux density (Jy) at the observed frequency ν (GHz)
E_x: X-ray energy (keV)
T_B: brightness temperature (10^{12}K) of the compact component
(e.g. Eckart et al. 1986a, Marscher 1983). Using component sizes and flux densities from VLBI measurements we get an excess of calculated

https://doi.org/10.1017/S007418090015524X Published online by Cambridge University Press

over observed X-ray flux densities and thus a lower limit of the Doppler factor exceeding unity for 2 sources. Due to

1) the flat radio spectra up to at least 250 GHz
2) the frequency independence of brightness temperatures as evident from the VLBI data,

and the assumption, that a compact component exists with a synchrotron self-absorption frequency at or even beyond 250 GHz, we predict b.r.m. for all sources of the complete sample. (The redshifts for the BL Lac-type objects was assumed to be $z \geq 0.05$). Note that 1803+78 reaches its spectral luminosity maximum beyond the mm range. Furthermore the source was detected with intercontinental VLBI test measurements at 7 mm wavelength (Marcaide et al. 1985).

3.4 Apparent superluminal motion

In order to look for structural variations we are carrying out multi-epoch VLBI observations at 5 GHz, the time base varying from 2 to 6 years. So far 7 sources are observed with sufficient dynamic range, 3 clearly show apparent superluminal motion (1928+73: 15c, Eckart et al. 1985; 1150+81: 11c, 0212+73: 13c). For another 3 sources the data do not exclude apparent faster than light motion.:

0836+73: The source showed a separation rate of 0.2 mas in 6 years - a value which is 1/5 of the beam. Due to the high redshift of this object ($z = 2.16$) the present upper limit on v/c is 20.

1039+71: The measured separation within two years is 0.2 mas, corresponding to $v/c \leq 10$.

2007+77: The source showed a separation rate of 0.3 mas/yr between the first two epochs ($v/c = 5$). The third epoch VLBI map contains evidence for a more complex structure: fitting a 3-component model to the core-jet structure leads to consistent results.

As the core flux densities for the confirmed apparent superluminal sources vary up to 85% between subsequent epochs t1 and t2 (the variation defined as $dS/\langle S\rangle$, $dS=/S(t1)-S(t2)/$, $\langle S\rangle = 0.5/S(t1)+S(t2)/$), we can check on a violation of the inverse Compton limit at the same VLBI frequency and thus get an independent evidence for b.r.m. Between 1983.25 and 1985.41 the core flux density of the quasar 1150+81 increased by 70%. Applying light travel time arguments this translates into an observed source diameter of 3.9×10^{-2}mas and a corresponding brightness temperature of 2.2×10^{13}K. Assuming 10^{12}K as the maximum brightness temperature in the rest frame of the source, the Doppler factor is $D = (T_{obs}/10^{12}K)^{1/3} \cong 3$. The Doppler factors calculated for 0212+73 ($v/c = 13$, $dS/\langle S\rangle = 24\%$) and 1928+738 ($v/c = 15$, $dS/\langle S\rangle = 85\%$) exceed unity - 2 and 3 for 1928+73 and 0212+73 respectively. Applying the same argument to the 3 superluminal candidates 0836+73, 1039+81 and 2007+77 we find evidence for b.r.m. and conclude superluminal motion to be highly probable also in these sources.

4. CONCLUSION

At present our data are consistent with 6 out of 7 sources observed with adequate dynamic range to display apparent superluminal motion. Taking into account the independent evidence for b.r.m. in all sources of this complete sample via SSC-calculations, we conclude, that this sample of radio selected flat spectrum sources predominantly contains objects with their core radio emission being highly relativistic and pointing towards us under small angles. As the Doppler factors - always lower limits - lie in the range of 2 to 6 and v/c between 6 and 18 (present upper limit for 0836+71), the maximum angles to the line of sight can vary between 7 and 15 degrees with Lorentz factors γ between 7 and 100. As structural variations predominantly are detected near the 5 GHz cores, and all sources so far observed at higher frequencies (up to 22.2 GHz) show structures, multi -epoch VLBI observations at higher frequencies seem to be an important tool to directly study relativistic phenomena in AGN - in connection with variability investigations in the mm-range and simultaneous observations with mm-VLBI arrays and sensitive X-ray telescopes (e.g. ROSAT).

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