Astron. Astrophys. 204, 68–72 (1988)

ASTRONOMY AND ASTROPHYSICS

The quasar 0153+74

C.A. Hummel [1], C.J. Schalinski [1], T.P. Krichbaum [1], A. Witzel [1], and K.J. Johnston [2,]*

[1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-5300 Bonn 1, Federal Republic of Germany
[2] E.O. Hulburt Center for Space Research, Naval Research Laboratory, Washington, DC 20375, USA

Received January 28, accepted May 1, 1988

Summary. The radio emission at milliarcsecond scales from the quasar 0153+74 at centimeter wavelengths is dominated by two components, one of which is selfabsorbed and the other one optically thin between the wavelengths of 18 cm and 6 cm. Monitoring of the temporal variations of the positions of the two dominant components show their position to be stationary to 0.02 ± 0.04 milliarcseconds/yr. Weaker optically thin radio emission is found between the two components. This quasar together with 3C 395 may represent an early stage in the development of compact flat spectrum radio sources which display dominant one sided jet emission on parsec scales.

Key words: quasars – jets of quasars

1. Introduction

The study of the compact emission of core dominated extragalactic radio sources has shown them to display structure on size scales from parsecs to kiloparsecs. On parsec scales the emission appears to be dominated by one-sided emission from a compact inverted spectrum centimeter component that may be associated with a massive black hole. The remaining emission is usually in the form of a jet with steep spectrum components. On kiloparsec scales the emission is usually two-sided, typical of normal radio sources. An example of such a source is 1928+73 (Johnston et al., 1987). These sources all display a flat radio spectrum at cm wavelengths.

In contrast to these typical flat spectrum objects there is a class of compact objects which have peaking spectra at cm radio wavelengths. At milliarcsecond resolution, 90% of the flux density is found in two components with steep spectra at centimeter wavelengths which are resolved i.e. CTD 93 and 1518+047. These sources which are associated with galaxies or empty fields may represent the early evolutionary stage of typical two-sided radio sources in which the radio lobes have not moved out very far from the central compact nucleus of the galaxy.

In this paper we describe the source 0153+74 that may be intermediate between these two classes. It has a spectrum which is flat at cm radio wavelengths but becomes optically thin at mm wavelengths and is dominated at milliarcsecond resolution by two components which have an inverted and a steep spectrum respectively at cm radio wavelengths. We describe this source in detail which may be an evolutionary precursor of compact one-sided radio sources.

Send offprint requests to: C.A. Hummel

* Senior Humboldt Awardee at the MPIfR

2. Observations and results

The observations were obtained with the Mark II recording system. Measurements were made at 18 cm wavelength in 1981.79 and 1984.91 and at 6 cm wavelength in 1979.93, 1983.92 and 1986.44. These VLBI observations were obtained with telescopes in North America and Europe. The bandwidth was 1.8 MHz. Sources were observed over a large range of hour angles either switching between two sources or tracking a single source continuously. Some of the observations previous to 1982 were made over a small range of hour angles. Parameters of the observations obtained before 1984 are given in Eckart et al. (1986). Here we will give the parameters of the two observing epochs since then.

18 cm observations were made at epoch 1984.91. The stations were Effelsberg, Westerbork, Green Bank, GRAS, Owens Valley and a single VLA antenna. The duration of the observations was from 20 h UT Nov 28 to 9 h UT Nov 29, 1984. The observations were continuous.

6 cm observations were made with the stations Effelsberg, Medicina, Westerbork, Onsala, Owens Valley, a single VLA antenna, Haystack, Green Bank and NRL. The duration of the observations was from 01 h 30 m UT to 13 h UT June 11, 1986. The scans were of twenty minutes duration; 0153+74 was alternated with 0454+84.

The 6 cm data obtained at epoch 1986.44 along with the data from epoch 1983.92 were reduced as follows in order to bring out the weak features. After correlation with the Mark II processor at the MPIfR in Bonn, a global fringe fitting algorithm (Alef and Porcas, 1986) was applied to the data and hybrid maps were made. The visibility amplitudes were calibrated using a 15 min observation of the quasar 0615+82 (1 Jy flux at 6 cm) as a structural calibrator.

The station gain factors for the calibration were derived as follows: For simplicity all measured baseline-amplitudes of the calibrator 0615+82 were plotted against their projected baseline length neglecting the position angles. A gaussian curve was then fitted to the amplitudes. The structure of 0615+82 could be characterized by a single nearly circular gaussian component of diameter 0.8 mas. This model for the structure of 0615+82 was used to calculate a set of station gain factors. The calculated station gain factors are believed to be time-independent and so appropriate for the whole experiment assuming there were no pointing errors during the calibrator-scan. In principle the calibrator should be observed more than once during the experiment. The station gain factors were applied to the data.

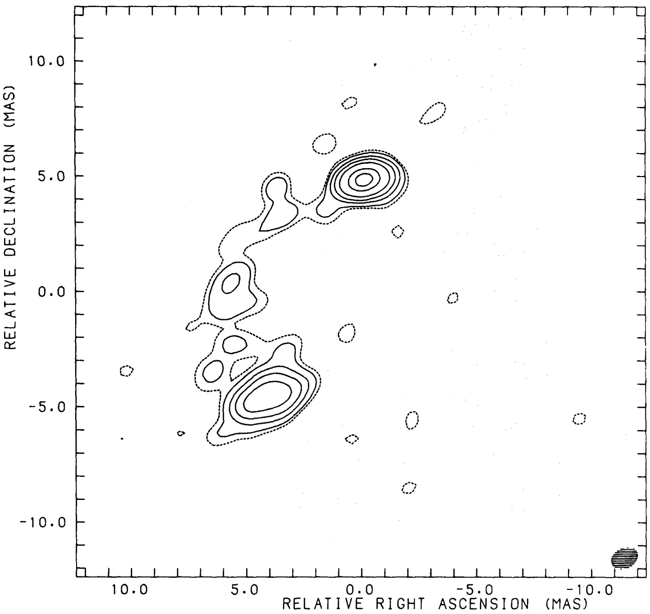

Fig. 1a. 6 cm map of 0153 + 74 at epoch 1983.92. The restoring beam is shown in the lower right corner. The contour levels are 1, 2, 5, 10, 20, 50, and 80 percent of the peak flux density which is 0.55 Jy/beam

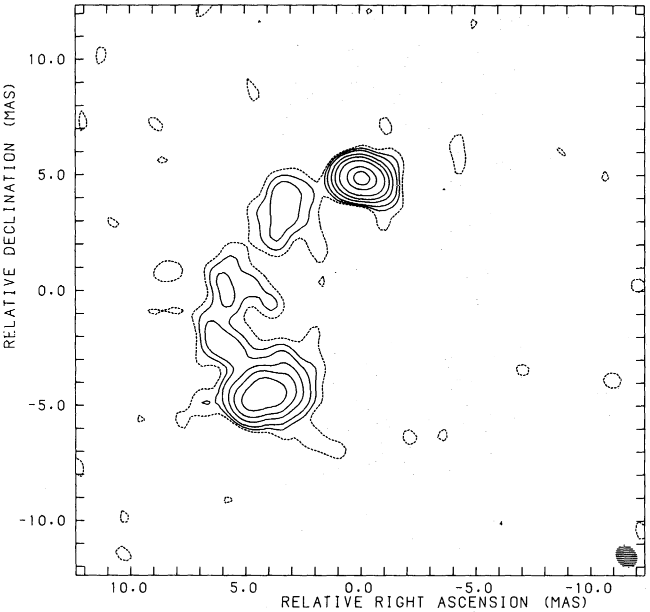

Fig. 1b. 6 cm map at epoch 1986.44. The contour levels are 0.4, 1, 2, 5, 10, 20, 50, and 80 percent of the peak flux density of 0.51 Jy/beam

The second-epoch data (1983.92, Eckart et al., 1986, 1987) have been reanalysed with special attention given to bring out the newly discovered structure found from the 1986.44 map.

Figure 1a shows the map of the quasar 0153 + 74 for epoch 1983.92; Fig. 1b gives the map from epoch 1986.44; the restoring beams are indicated at the lower right in the figures. The 6 cm structure is characterized by a northern nearly unresolved component (A; the core, see later) of 0.73 Jy, a secondary slightly resolved component (B) of 0.59 Jy and a "bridge" of more or less resolved weak components (C, D, E). The major axes of components A, C, D and E align with the bridge, which instead meets orthogonal with the secondary component with respect to its axis. The core component is strongly elongated in the east-west direction and the secondary component (B) seems to consist of two equally bright components. The VLBI-map contains all the 6 cm single dish flux density of 1.55 Jy. Component parameters derived by a modelfitting program are listed in Table 1.

From a comparison of the three existing VLBI-epochs at 6 cm wavelength the position of component B was constant with respect to A within the errors. A linear regression of the distances between components A and B yields a proper motion of 0.02 ± 0.04 mas/year. This source may exhibit superluminal motion due to its high redshift of $z = 2.34$; an upper limit can be taken from the error of the angular velocity, which corresponds to an apparent velocity of $\leqq 1.7$ c for $H_0 = 100$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$. No limits are given for the bridge components, since they are well defined only in epoch 1986.44.

The map at 18 cm wavelength at epoch 1984.91 is shown in Fig. 2. The quasar displays four components, which can be identified with the components A, B, C and D of the 6 cm map. The calculated spectral indices α ($S_\nu \propto \nu^\alpha$) between 18 cm and 6 cm wavelength are 0.9 (A), -0.5 (BE), -1.0 (D) and -1.4 (C).

3. Discussion

There are many properties of the quasar 0153 + 74 indicating that it is probably not dominated by effects resulting from bulk relativistic motion with high Lorentz factors γ along a small angle to the line of sight. The predicted X-ray flux by inverse Compton-scattering is of the order of the measured X-ray flux (1 μJy at 1 KeV), indicating that there is no significant Doppler boosting. The maximum brightness temperatures of the components (A: $0.2 \cdot 10^{12}$ K; B: $0.1 \cdot 10^{12}$ K) do not exceed the so called inverse-Compton-limit of 10^{12} K.

The flux density variability of the quasar 0153 + 74 is insignificant on timescales of years to months as well as on timescales of hours to days (Heeschen et al., 1987). These properties would appear to make 0153 + 74 resemble the compact double sources. However, there are important differences. The spectrum, which is shown in Fig. 3, is approximately flat up to 5 GHz and then steepens. Spectra of compact doubles, because of the similarity of the two components, resemble a single self-absorbed synchrotron component with a turnover frequency near 1 GHz. As the spectral decomposition in Fig. 3 shows, the turnover frequency of the core component (5400 MHz) is higher than that for a typical compact double component, although the ratio between the two turnover frequencies of the two components is not larger than that which can be found for compact doubles, e.g. 2050 + 364 (Mutel et al., 1985). There are the steep spectrum components between the two dominant components in 0153 + 74. These components are responsible for the overall flatness of the spectrum and the completely different appearance of the source at 18 cm in view of the 6 cm structure and the appearance of compact doubles at 18 cm.

The presence of the weak optically thin components between the two dominant sources, the fact that component A is self-absorbed and that 0153 + 74 is a quasar lead us to interpret the radio emission as that of a long jet emanating from component A. This resembles the emission from 3 C 395 (Simon et al., 1987). We identify the compact component A, which has an inverted spectrum, with the core. This core generates a jet, which we identify with the steep spectrum bidge-components. Component B

Table 1. Component parameters of 0153+74

λ [cm]	Epoch	S [Jy]	Comp.	f [Jy]	r [mas]	Pos. a.	a [mas]	b [mas]	pa
6	1979.93	1.66	A	0.64 ±0.06	0	0	0.7 ±0.5	<0.5	76±20
			B	0.38 ±0.04	10.2±0.2	156±20	1.9 ±0.5	<0.5	115±20
6	1983.92	1.50	A	0.71 ±0.03	0	0	0.83±0.05	<0.29	92± 5
			BE	0.58 ±0.03	10.3±0.2	156± 5	1.9 ±0.1	0.95±0.1	112± 5
			D	0.04 ±0.02	3.6±0.4	110±10	1.6 ±0.5	<0.5	156±30
			C	0.11 ±0.02	7.2±0.4	130±10	1.8 ±0.5	1.3 ±0.4	47±30
6	1986.44	1.56	A	0.73 ±0.02	0	0	0.88±0.05	<0.2	89± 5
			B1 B2	0.59 ±0.02	10.3±0.2	156± 5	1.9 ±0.1	0.86±0.1	111± 5
			D	0.075±0.007	3.3±0.4	110±10	3.4 ±0.5	1.1 ±0.3	106±10
			C	0.082±0.008	7.4±0.4	132±10	2.3 ±0.5	1.8 ±0.3	176±20
			E	0.068±0.007	9.5±0.4	142±10	2.1 ±0.5	0.65±0.2	49±10
			B1	0.30	10.0	158	1.8	1.0	92
			B2	0.30	10.6	155	1.5	0.7	120
18	1981.79	1.96	AD	0.41 ±0.04	0	0	2.7 ±1.5	<1.5	79±10
			BCE	1.49 ±0.15	8.6±1.3	156± 8	4.0 ±1.5	2.7 ±1.5	100±30
18	1984.91	1.9	A	0.27 ±0.03	0	0	1.9 ±0.9	<1.0	90±10
			BE	0.97 ±0.1	9.6±0.4	158±10	2.3 ±0.9	<1.7	125±10
			D	0.24 ±0.03	4.2±0.4	117±10	3.3 ±0.9	<1.0	150±10
			C	0.39 ±0.04	7.8±0.4	136±10	3.6 ±0.9	<1.4	17±10

S = total flux; f = component flux ± empirical errors; r = distance of component from component A; pos. a. = position angle of component with respect to A; a, b = major and minor axes of the elliptical gaussian component; pa = position angle of the major axis

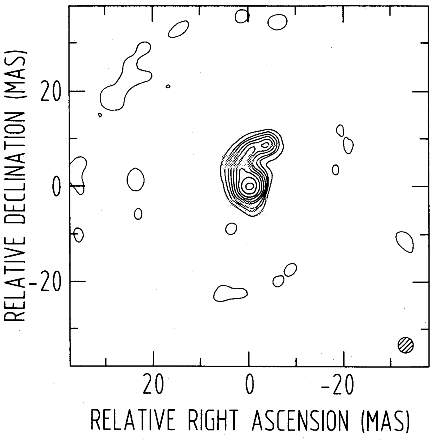

Fig. 2. 18 cm map of 0153 + 74 at epoch 1984.91. The restoring beam is shown in the lower right corner. The contour levels are 1, 2, 5, 10, 15, 20, 30, 50 and 80 percent of the peak flux density of 0.75 Jy/beam

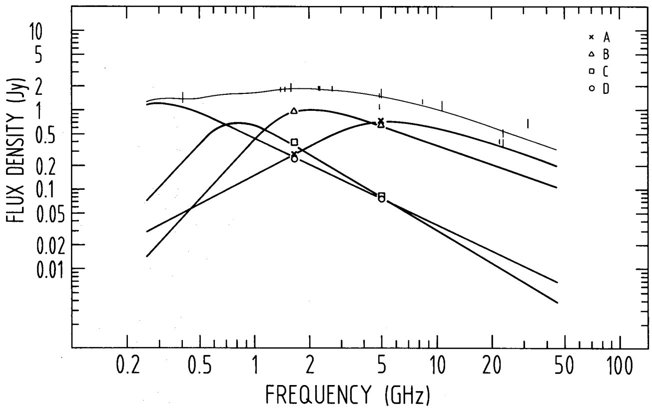

Fig. 3. Spectrum of 0153 + 74 with spectral decomposition

can be seen as a hot spot in the "working surface" of the jet at the location where it impinges on the interstellar medium of the host galaxy.

Physical parameters of the components such as brightness temperatures and magnetic field strengths can be derived from the measured diameters of the components and their spectral properties, which one can get from the spectral decomposition shown in Fig. 3. Using the synchrotron self-absorption formula (Kellermann and Pauliny-Toth, 1981) Table 2 lists these values. The secondary components have weaker magnetic fields than the more compact core. In Mutel et al. (1985) the unresolved components (at 5 GHz) of typical compact doubles have higher magnetic field strengths with respect to the resolved ones. The values for the latter ones are comparable with the resolved components in 0153+74. As already mentioned, the brightness temperatures of 0153+74 (and also 3C 395) are in the range from 10^{10} K to 10^{11} K. Therefore they are higher than typical values for compact doubles.

We will now present a model for the most interesting property of this source, the strongly bent jet. Apparent bending of jets can arise from deflection of the jet in the interstellar medium of the host galaxy or by variations of the ejection direction at the core. In

Table 2. Physical parameters for the quasar 0153+74 ($H_0 = 100\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, $q_0 = 0.5$)

$z = 2.34$, $D_L = 9.1\,h^{-1}$ Gpc, 1 mas $\hat{=}$ $3.9\,h^{-1}$ pc, 0.1 mas/year $\hat{=}$ $\beta_{\mathrm{app.}} = 4.3\,h^{-1}$
$\alpha_{11/6} = -0.26$, $\alpha_{11/3} - \alpha_{75/21} = -0.52$, $\alpha_{\mathrm{radio/optical}} \approx -0.8$, $B_R = 44 \cdot 10^{-6}$ G

Component	$\alpha_{18/6}$	θ[mas]	S_m[Jy]	ν_m[Ghz]	$B[10^{-3}\,\mathrm{G}]$
A	0.9	<0.42	0.7	5.4	<2.7
BE	−0.5	1.3	1.0	2.0	0.8
D	−1.0	2.0	1.2	0.3	0.0002
C	−1.4	2.1	0.7	0.8	0.1

Brightness temperatures at 6 cm and X-ray fluxes:

Componet	$T_B[10^{12}\,\mathrm{K}]$	S_{IC}[μJy]	S_X[μJy]
A	0.20	4.7 (0.2–20)	$\lesssim 1.0$
B	0.014		

D_L = Luminosity distance
B_R = $4(1+z)^2 \cdot 10^{-6}$ G = magnetic field of microwave background
θ = Component diameter at 6 cm wavelength
S_m = Maximum flux
ν_m = Frequency at flux maximum
T_B = Brightness temperature
S_{IC} = Inverse-Compton flux
S_X = Measured X-ray flux at 1 keV
h = Hubble constant in units of $100\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$

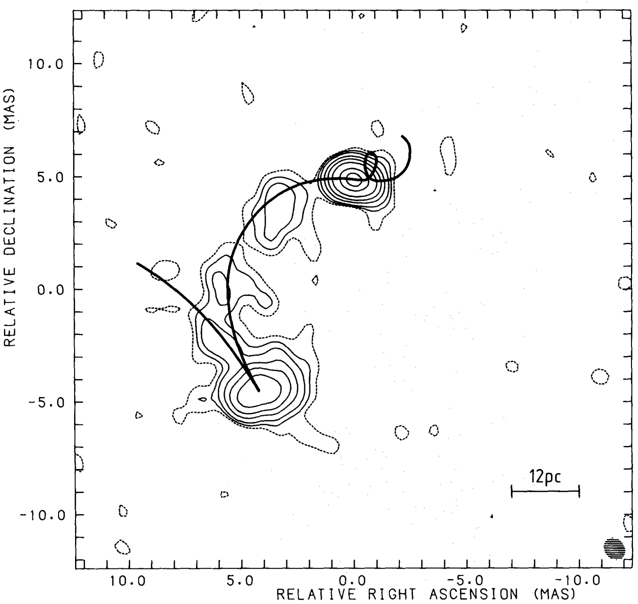

Fig. 4. Model of the precessing beam superposed upon the 6 cm map (1986.44). The parameters are: period 200 yr, inclination to the line of sight 23°, half cone angle 11°, azimuth 185° and velocity 0.87c

the first case components would move along the jet (as seems to be the case in 3C 345, Biretta et al., 1986), in the second case in straight lines away from the core. We examined the second possibility, because the jet resembles structures on the arcsecond scale, which have in some cases been adequately described by assuming that the jet is precessing with constant period P (Gower et al., 1982). Precessing beam models have already been used to describe the VLBI-structures of compact radio sources (Linfield, 1981). These precessing beam models require periods in the range of a few thousand to ten million years. Because of the strong curvature of the jet of 0153 + 74 periods of less than one thousand years have to be assumed, as will be shown in the following.

We developed an algorithm, which calculates iteratively a set of parameters of the precessing beam (half-cone angle ψ, inclination i, azimuth angle φ, velocity $\beta \cdot$ c and period P) only from a given (observed) geometry. There is no unique solution to the problem, so that one can approximate the geometry with different sets of parameters which again can be parameterised with the period P. For 0153 + 74, periods between 100 and 1000 years are derived and give models, in which ψ and i increase with increasing period P, while β decreases from highly relativistic values to about 0.6. The approximations are satisfactory, except that the position angle of the scondary component is not in agreement with the jet axis at this position.

The model can also account for the flux densities of the components as they are moving at different angles to the line of sight and are therefore Doppler-boosted differently. The angle to the line of sight is at a minimum at the core position and near the secondary component and largest somewhere in between them. Furthermore, the flux density of the secondary component can be enhanced by superposition of several components along the line of sight, which is very likely as the jet axis has a projected point of return there. Also one has to take into account the ageing of the components (synchrotron losses), which influences the overall extent over which the jet can be observed.

Figure 4 shows a plot of the model superposed on the 6 cm map of the quasar. It has the following parameters: $P = 200$ years, $i = 23°$, $\psi = 11°$, $\varphi = 185°$ and $\beta = 0.87$. From this figure it is evident, that the precessing beam model is in principle able to explain the structure of the quasar 0153+74. There is no doubt that the component flux densities can also be represented by components with different unbeamed flux densities and different degrees of superposition due to irregular ejection of components. If component B is indeed a hotspot in a working surface, the precessing beam model would still explain the jet curvature in between the main components.

A period of 1000 years is the maximum period which is consistent with the fact that no counterjet is seen in the map, although it leads to $\beta = 0.6$ and consequently is less able to explain component flux densities in the above manner. Therefore, the precessing periods invoked by the model are less than what is currently assumed to be theoretically possible. In a model, where significant precession of the black hole's axis (which defines the jet axis) is created by a second massive black hole orbiting around the other via the relativistic Lense-Thirring effect, the limitations to the observable precessing periods arise from the energy losses by emission of gravitational radiation, which causes very short lifetimes for the binary black hole systems (Begelman et al., 1980; Linfield, 1981).

In the model for compact double sources Carvahlo (1985) estimates their age to be 10^4 years from their expansion rates and sizes which are typically less than a kiloparsec. A further consequence of the short precessing period is that 0153+74 is much younger than typical compact double sources. The projected distance between core and secondary component is about $40\,h^{-1}$ pc. The de-projected size is therefore $100\,h^{-1}$ pc.

4. Conclusions

The radio emission at milliarcsecond scales from the quasar 0153+74 at centimeter wavelengths is dominated by two components, one of which is self-absorbed and the other one optically thin. Monitoring of the temporal variations of the positions of the two dominant components show their position to be stationary to 0.02 ± 0.04 milliarcseconds/yr. Weaker optically thin radio emission is found between the two components. The strong curvature of this jet is explained by a precessing beam model which leads to an age for 0153+74 well below 1000 years. This quasar together with 3C 395 may represent an early stage in the development of compact flat spectrum radio sources which display dominant one sided jet emission at parsec to kiloparsec scales.

Acknowledgements. We would like to thank A. Quirrenbach for critical discussions and Mr. U. Stursberg and Mr. H. Lüdeke for their patient work with the Mk II processor.

References

Alef, W., Porcas, R.W.: 1986, *Astron. Astrophys.* **168**, 365
Begelman, M.C., Blandford, R.D., Rees, M.J.: 1980, *Nature* **287**, 307
Biretta, J.A., Moore, R.L., Cohen, M.H.: 1986, *Astrophys. J.* **308**, 93
Carvahlo, J.C.: 1985, *Monthly Notices Roy. Astron. Soc.* **215**, 463
Eckart, A., Witzel, A., Biermann, P., Johnston, K.J., Simon, R., Schalinski, C., Kühr, H.: 1986, *Astron. Astrophys.* **168**, 17; 1987, *Astron. Astrophys. Suppl.* **67**, 121
Gower, A.C., Gregory, P.C., Hutchings, J.B., Unruh, W.G.: 1982, *Astrophys. J.* **262**, 478
Heeschen, D.S., Krichbaum, Th., Schalinski, C.J., Witzel, A.: 1987, *Astron. J.* **94**, 1493
Johnston, K.J., Simon, R.S., Eckart, A., Biermann, P., Schalinski, C., Witzel, A.: 1987, *Astrophys. J.* **313**, L 85
Kellermann, K.I., Pauliny-Toth, I.I.K.: 1981, *Ann. Rev. Astron. Astrophys.* **19**, 373
Linfield, R.: 1981, *Astrophys. J.* **250**, 464
Mutel, R.L., Hodges, M.W., Phillips, R.B.: 1985, *Astrophys. J.* **290**, 86
Simon, R.S., Johnston, K.J., Hall, J., Spencer, J.H., Waak, J.A.: 1987, in *Superluminal Radio Sources*, eds. J.A. Zensus, T.J. Pearson, Cambridge, Cambridge University Press, p. 72