Proceedings of the 6th European VLBI Network Symposium
Ros, E., Porcas R.W., & Zensus, J.A. (eds.)
June 25th-28th 2002, Bonn, Germany

III Zw 2: Evolution of a Radio Galaxy in a Nutshell

A. Brunthaler[1], H. Falcke[1], G.C. Bower[2], M.F. Aller[3], H.D. Aller[3], H. Teräsranta[4], and T.P. Krichbaum[1]

[1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany
[2] Radio Astronomy Laboratory, University of California at Berkeley, 601 Campbell Hall, CA 94720, USA
[3] University of Michigan, Astronomy Department, Ann Arbor, MI 48109-1090, USA
[4] Metsähovi Radio Observatory, Metsahovintie, 02540 Kylmälä, Finland

Abstract. III Zw 2 shows dramatic radio outbursts roughly every five years. Here we present the results of our VLA and VLBA monitoring of the latest flare with an excellent time and frequency sampling. We have discovered superluminal motion with a lower limit for the apparent expansion speed of 1.25 ± 0.09 c at 43 GHz. Spectral and spatial evolution are closely linked. Before and after this rapid expansion we have seen a period of virtually no expansion with an expansion speed of less than 0.04 c. However, at 15 GHz the picture is completely different from the behaviour at 43 GHz. III Zw 2 shows a constant slow expansion ($\sim$ 0.6 c). The difference between the two frequencies is qualitatively explained by optical depth effects in an 'inflating balloon-model', describing the evolution of radio lobes on an ultra-compact scale. The stop-and-go behavior could be explained by a jet interacting with a molecular cloud or the molecular torus.

1. Radio-Intermediate Quasars

If we plot the radio-to-optical flux ratio of quasars, we see two populations, the Radio Quiet and the Radio Loud Quasars with a few sources, Radio Intermediate Quasars (RIQs), between them. Whilst in total flux, RIQs appear to be part of the radio-loud distribution, their low extended flux indicates that they might rather be part of the radio-weak distribution. Falcke, Patnaik, & Sherwood (1996) and Miller, Rawlings, & Saunders (1993) proposed that RIQs might be relativistically boosted radio-weak quasars.

III Zw 2 (PG 0007+106, Mrk 1501, z=0.089) is one of the RIQs and also is one of the most extremely variable radio sources. It was initially classified as a Seyfert 1 galaxy (e.g., Arp 1968; Khachikian & Weedman 1974; Osterbrock 1977) but was later also included in the PG quasar sample (Schmidt & Green 1983). It is a core-dominated AGN with a highly inverted synchrotron spectrum with a spectral peak due to self-absorption around 43 GHz in outburst (Falcke et al. 1999) and faint extended structure typical for Seyfert galaxies (Unger et al. 1987). III Zw 2 is variable up to a factor of 30 within two years with major flares roughly every five years (Aller et al. 1985; Fig. 1). In 1997, III Zw 2 started a new outburst and we started to monitor this source with the VLA and VLBA. We observed III Zw 2 41 times from 1998 September until 2001 September with the VLA at six frequencies ranging from 1.4 to 43 GHz and 9 times over a period of 2.5 years with the VLBA at 15 and 43 GHz.

2. Results

The spectral peak – determined from fitting a broken power-law (e.g., Moffet 1975) to the spectra – stayed constant around 33 GHz during the slow and smooth rise

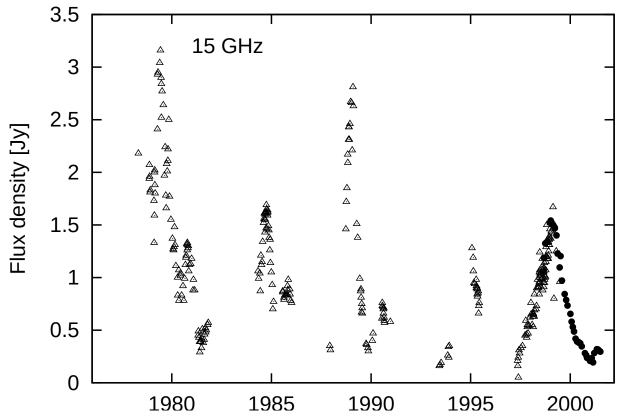

Fig. 1. Lightcurve of III Zw 2 at 15 GHz spanning 25 years. The triangles are from the Michigan monitoring program and the circles are from our VLA monitoring.

in flux density, and we detected no structural change on VLBI scale at 43 GHz during this time (see first three epochs of Fig. 3). In December 1998, the flux density started to drop rapidly. At the same time, the turnover frequency dropped quickly from ∼33 GHz to ∼10 GHz during a few months (see Fig. 2). Applying a simple equipartition jet model, we predicted a rapid expansion during this time.

Indeed the fifth epoch of VLBA observations showed a drastic structural change on milliarcsecond scales with an apparent expansion speed of $\sim$ 1.25 c (Brunthaler et al. 2000). After this phase of superluminal expansion and rapid spectral evolution, the expansion stopped and the spectral evolution slowed down. However, at 15 GHz the picture is completely different. III Zw 2 shows a slow but constant expansion ($\sim$ 0.6 c) during the whole time. This apparent contradiction can be explained by optical depth effects in an 'inflating-balloon model'.

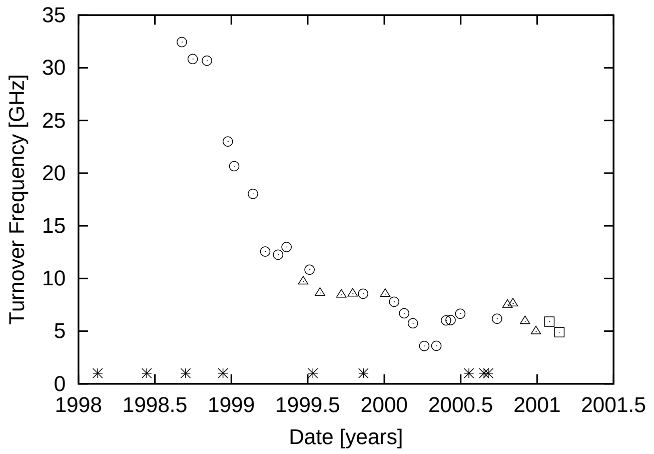

Fig. 2. Evolution of the turnover frequency. The circles mark epochs with 6 observed frequencies (1.4-43 GHz) and the triangles epochs with 5 observed frequencies (1.4-22 GHz). In the last two epochs only 4 frequencies (1.4-15 GHz) were used because of a new outburst at high frequencies. The stars mark the epochs of our VLBA observations.

3. 'Inflating-Balloon Model'

In this model, the initial phase of the flux density rise can be explained by a relativistic jet interacting with the interstellar medium or a torus that creates a shock. A relativistic shock was proposed earlier by Falcke et al. (1999) due to synchrotron cooling times of 14-50 days which is much shorter than the duration of the outburst. The ultracompact hotspots are pumped up and powered by the jet and are responsible for the flux-density increase. The post-shock material expands with the maximum sound speed of a magnetized relativistic plasma of $c_s \approx 0.6\,c$.

Since the source is optically thick at 15 GHz, one necessarily observes the outside of the source, i.e. the post-shock material expanding at the sound speed. At 43 GHz, the source is optically thin and one can look inside the source and see the stationary hotspots.

The rapid expansion at 43 GHz thereafter has marked the phase where the jet breaks free and starts to propagate relativistically into a lower-density medium until it is stopped again.

4. Conclusion

The unique and simple structure and timescales of such outbursts within 5 years makes III Zw 2 an ideal source to study radio-jet evolution relevant also to radio galaxies, especially those that appear as CSOs and GPSs.

III Zw 2 remains an extremely unusual object. The apparent superluminal motion confirms earlier predictions for this source, based on the argument that RIQs could be relativistically boosted jets in radio-weak quasars and Seyfert galaxies. The good agreement between structural and spectral evolution demonstrates that we are dealing with real physical expansion and not only a phase velocity.

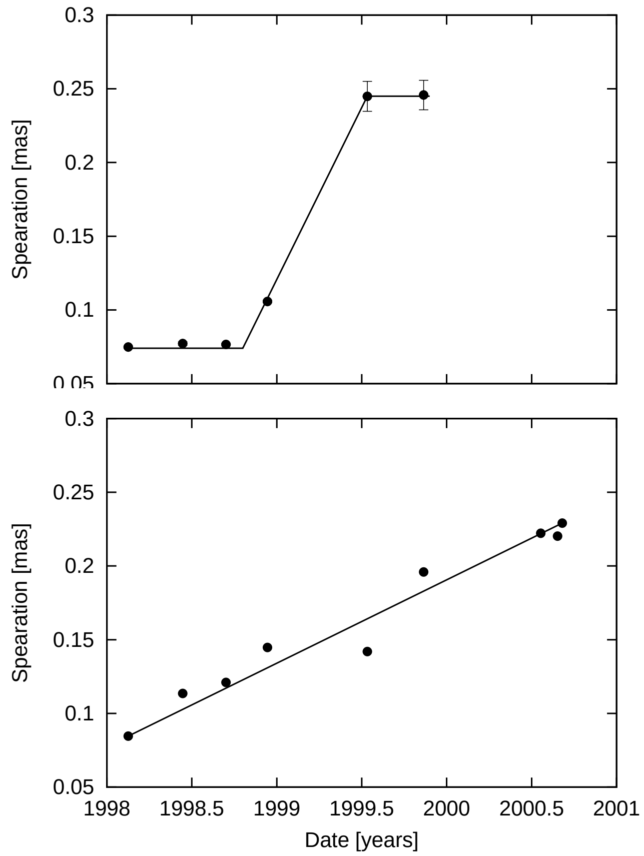

Fig. 3. Component separation at 43 (upper) and 15 (lower) GHz. The apparent expansion speed is 1.25 c at 43 GHz and 0.6 c at 15 GHz.

Since one has to look very carefully with frequent time sampling to detect this superluminal motion, it is possible that other Seyferts and radio quiet quasars also have relativistic jets in their nuclei. The fact that the sub-pc jet could be relativistic while appearing sub-relativistic at larger scales, raises the question: are Seyfert-jets decelerated on the pc-scale?

References

Aller H. D., Aller M. F., Latimer G. E., Hodge P. E., 1985, ApJS, 59, 513
Arp H., 1968, ApJ, 152, 1101
Brunthaler A., Falcke H., Bower G. C., et al., 2000, A&A, 357, L45
Falcke H., Bower G. C., Lobanov A. P., et al., 1999, ApJ, 514, L17
Falcke H., Patnaik A. R., Sherwood W., 1996, ApJ, 473, L13
Khachikian E. Y., Weedman D. W., 1974, ApJ, 192, 581
Miller P., Rawlings S., Saunders R., 1993, MNRAS, 263, 425
Moffet A. T., 1975, , in Sandage A., Sandage M., Kristian J. (eds.) Stars and Stellar Systems, Vol. IX, p. 211
Osterbrock D. E., 1977, ApJ, 215, 733
Schmidt M., Green R. F., 1983, ApJ, 269, 352
Unger S. W., Lawrence A., Wilson A. S., Elvis M., Wright A. E., 1987, MNRAS, 228, 521