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] T.P. Krichbaum [1]

[1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany
brunthal@mpifr-bonn.mpg.de

[2] RAL, 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 lightcurves and VLBA observations of the latest flare with an excellent time sampling. We have discovered superluminal motion with a lower limit for the apparent expansion speed of $1.25 \pm 0.09\,c$ at 43 GHz. Spectral and spatial evolution are closely linked and the evolution of III Zw 2 in a turnover frequency vs. linear size diagram is similar to the correlation for GPS and CSS sources . Before and after this rapid expansion we have seen a period of virtually no expansion. However, at 15 GHz III Zw 2 shows a constant slow expansion ($\sim 0.6\,c$). The difference 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.

Keywords: galaxies: active – galaxies: individual (III Zw 2) – galaxies: jets –

1 Introduction

In the currently favoured youth model for Compact Steep Spectrum (CSS) and GHz Peaked Spectrum (GPS) sources , the linear size of a source is related to the age of the source. The correlation between the turnover frequency and the projected linear size (e.g., O'Dea & Baum 1997) suggests that the turnover frequency decreases while the source ages and expands. Therefore the sources with the highest turnover frequencies represent the youngest objects. The origin of the turnover is probably caused by Synchrotron Self-Absorption (SSA), while Free-Free Absorption (FFA) could be also important in some objects such as NGC 1052 (Kadler et al. 2002; Kameno et al. 2001).

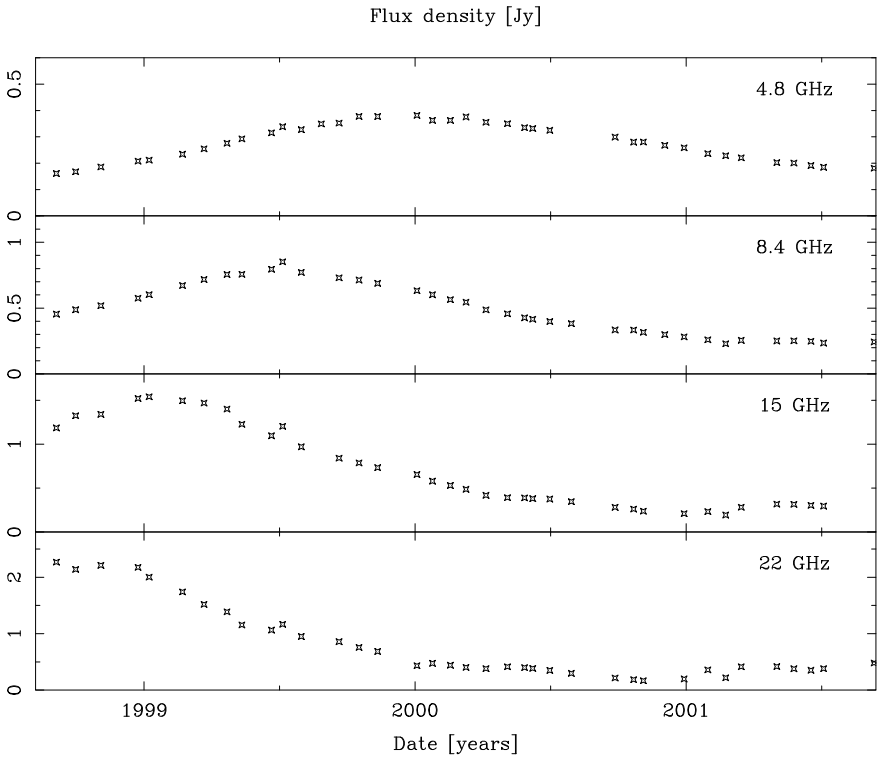

Figure 1: Lightcurves of III Zw 2 from 4.8 to 22 GHz from the VLA monitoring.

Some of the GPS/CSS have extended structure (e.g. 1245+676 Marecki et al. 2003). This indicates that they are in a phase of restarted activity and the extended structure is a product of a previous period of activity.

III Zw 2 (PG 0007+106, Mrk 1501, z=0.089) was initially classified as a Seyfert 1 galaxy (e.g., Arp 1968) 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 and it could be classified as a Millimeter Peaked Spectrum (MPS) source in analogy to GPS sources (Falcke et al. 1999). Its faint extended structure is typical for Seyfert galaxies (Unger et al. 1987). III Zw 2 is also part of a sample of Radio Intermediate Quasars (RIQ). 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 et al. (1996) and Miller et al. (1993) proposed that RIQs might be relativistically boosted radio-weak quasars. 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).

In 1997, III Zw 2 started a new outburst and we began 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 1.4, 4.8, 8.4, 15, 22 and 43 GHz and 9 times from 1998 February until 2000 September with the VLBA at 15 and 43 GHz.

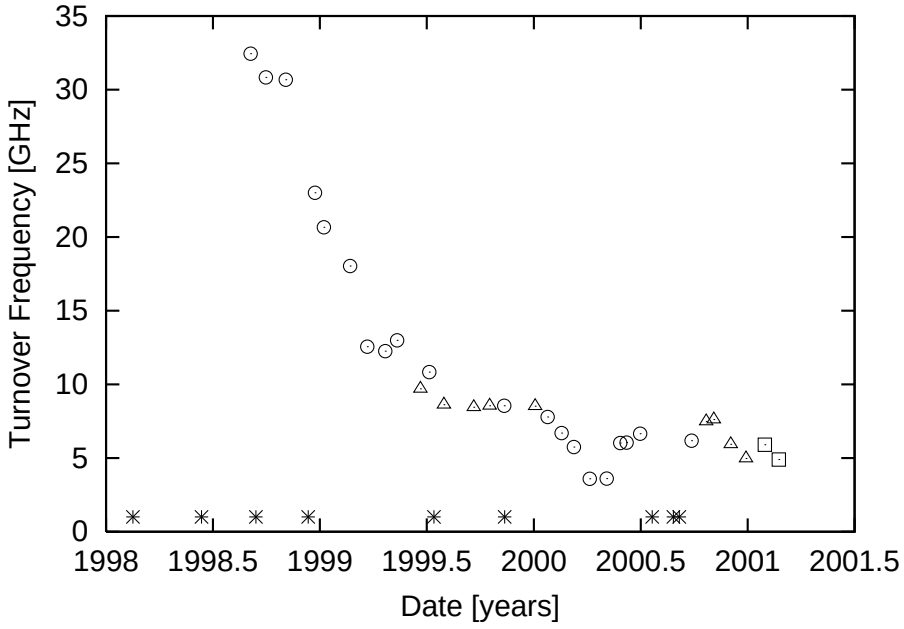

Figure 2: Evolution of the turnover frequency. The circles mark epochs with 6 observed frequencies (1.4-43 GHz) and the triangles epochs with 5 observed frequencies (1.4-22 GHz). In the last two epochs only 4 frequencies (1.4-15 GHz) were used because of a new outburst at high frequencies. The stars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

2 Results

The spectral peak – determined from fitting a broken power-law to the spectra – stayed constant around 33 GHz during the slow and smooth rise in flux density, and we detected no structural change on VLBI scales at 43 GHz during this time. The separation of model-fit components remained constant at 76 μas, corresponding to 0.11 pc ($H_0 = 75$ km/sec/Mpc; $q_0 = 0$). The statistical errors were estimated by dividing the original beam size by the post-modelfit signal to noise ratio. The typical beamsizes were 0.3×0.15 mas at 43 GHz and 0.8×0.35 mas at 15 GHz. In December 1998, the flux density started to drop rapidly. At the same time, the turnover frequency dropped quickly from $\sim$33 GHz to $\sim$10 GHz during a few months (see Fig. 2). Applying a simple equipartition jet model with a $R \propto \nu_{\rm ssa}^{-1}$ dependence, we predicted a rapid expansion during this time.

Indeed the fifth epoch of VLBA observations showed a dramatic structural change on milliarcsecond scales. The component separation increased to 245 μas or 0.36 pc. This yields 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. In the last three epochs, the source was too weak at 43 GHz to be detected.

At 15 GHz the picture is completely different. III Zw 2 shows a slow but constant expansion ($\sim 0.6\,c$) during the nine epochs of our monitoring program. This apparent

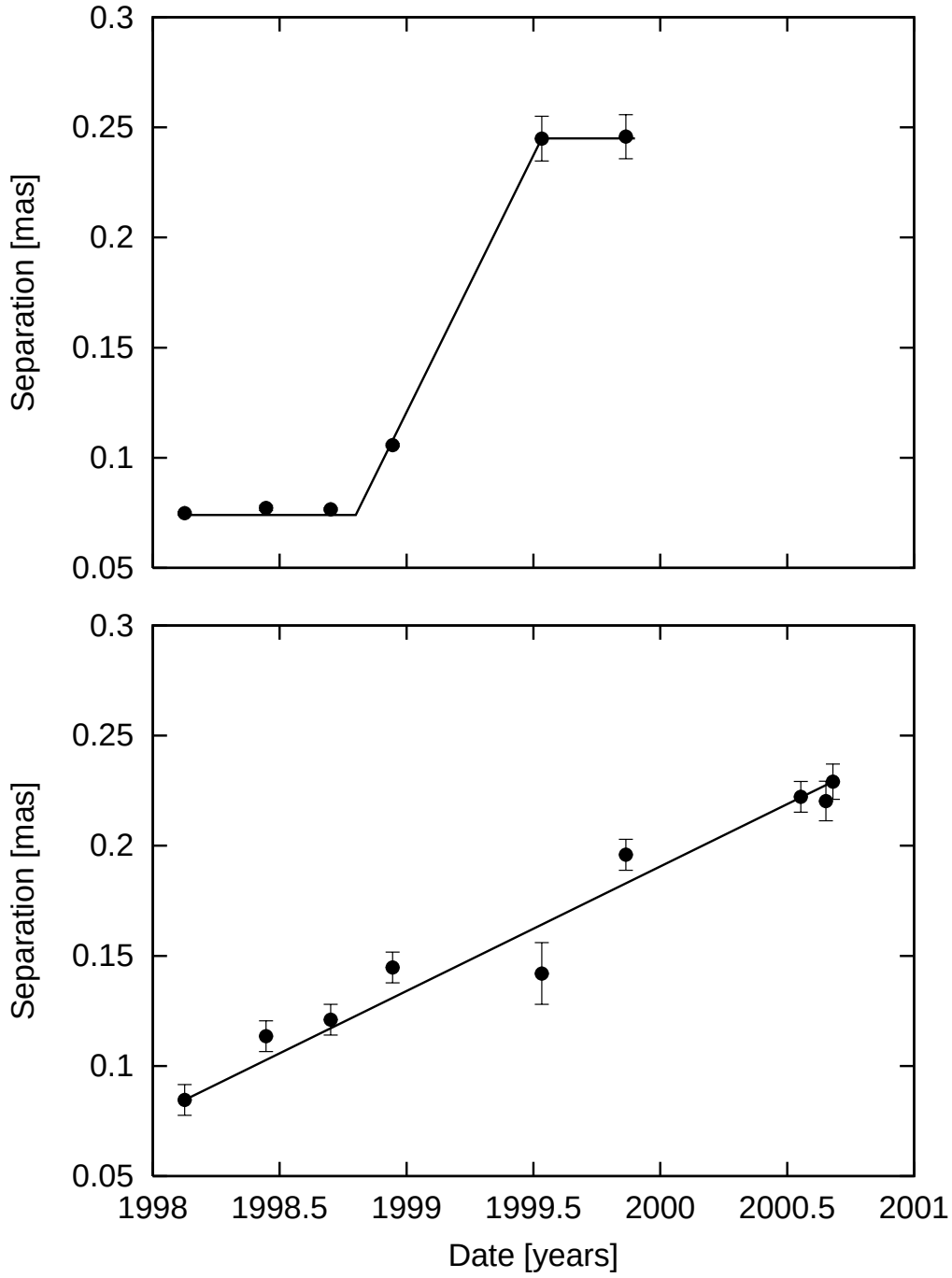

Figure 3: Component separation at 43 (upper) and 15 (lower) GHz. III Zw 2 shows no expansion during the first three epochs at 43 GHz, followed by a period of rapid expansion with an apparent expansion speed of $1.25\,c$ before the jet stops again. The errorbars of the first four epochs are smaller than the plotting symbol. At 15 GHz, the source shows a constant expansion with a speed of $0.6\,c$.

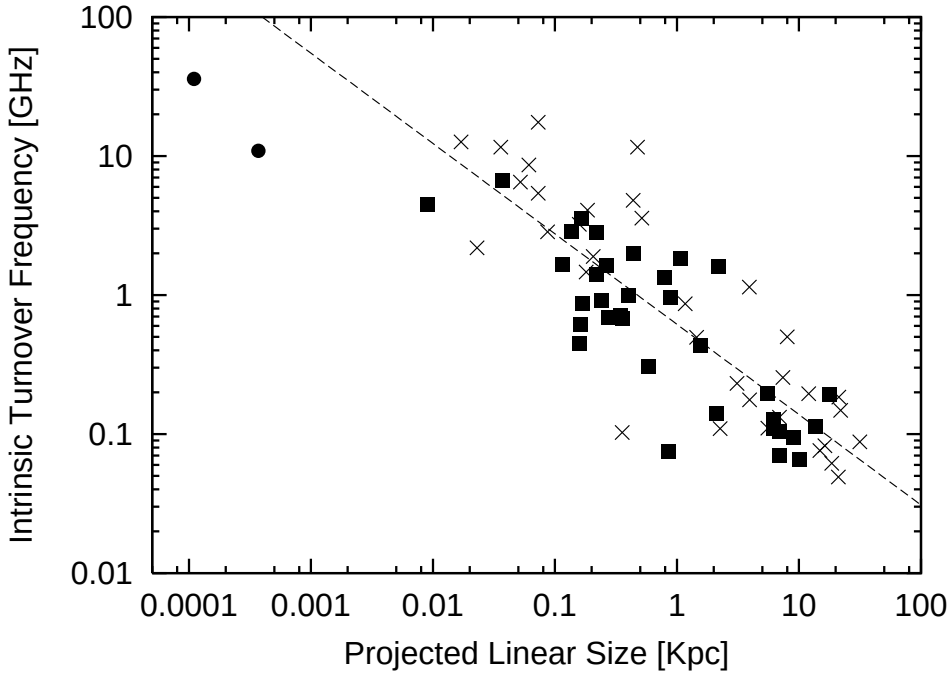

Figure 4: Intrinsic turnover frequency vs. linear size for GPS and CSS sources. The quasars are represented by crosses, and the galaxies by solid squares. Adapted from O'Dea & Baum (1997). The two circles mark the values for III Zw 2 before and after the expansion at 43 GHz.

contradiction can be explained by optical depth effects in an 'inflating-balloon model'.

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 are much shorter than the duration of the outburst. The ultra-compact hotspots are pumped up and powered by the jet and are responsible for the flux-density increase. The jet is frustrated and the hotspots are stationary. 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 sound speed. At 43 GHz, the source is optically thin and one can look into the source and see the stationary hotspots. This model is supported by the fact that the separation is larger at 15 GHz (post-shock material) than at 43 GHz (ultra-compact hotspots).

The rapid expansion at 43 GHz thereafter has marked the second phase where the jet breaks free and starts to propagate relativistically into a lower-density medium. This expansion is accompanied by the sharp drop of the turnover frequency. In the

third phase, the jet is stopped again while the spectral evolution slowed down.

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.

In Fig. 4 we plot linear size vs. turnover frequency for GPS and CSS sources. We include III Zw 2 before ($\nu_{ssa} \approx 33$ GHz; size ≈ 0.11 pc) and after ($\nu_{ssa} \approx 10$ GHz; size ≈ 0.36 pc) the expansion and the two points lie at the lower end of the scatter of the linear correlation for GPS/CSS sources. This could be explained by projection effects. Since III Zw 2 is a Seyfert 1 galaxy with superluminal motion, the jet is probably close to the line-of-sight. Hence the true size would be underestimated, and the points in the plot move to the right. However, the evolution of III Zw 2 during the expansion is almost parallel to the correlation. This implies that the same physical processes, i.e. Synchrotron Self-Absorption, are involved in III Zw 2 and in GPS/CSS sources.

III Zw 2 remains an extremely unusual object. With the extended structure, III Zw 2 is clearly not a young source but shows intermittent activity with outbursts roughly every five years. 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.

References

Aller, H. D., Aller, M. F., Latimer, G. E., & Hodge, R. E. 1985, ApJS, 59, 513

Arp, H. 1968, ApJ, 152 1101+

Brunthaler, A., et al. 2000, A&A, 357, L45

Falcke, H., et al. 1999, ApJ, 514, L17

Falcke, H., Patnaik, A. R., & Sherwood, W. 1996, ApJ, 473, L13

Kadler, M., Ros, E., Kerp, E., Lobanov, A. P., Falcke, H., & Zensus, J. A. 2002, in Proceedings of the 6th Eurpean VLBI Network Symposium, Ros, E., Porcas, R. W., Lobanov, A., Zensus, J. A. (eds.), (Bonn, Germany), 167-+

Kameno, S., Sawada-Satoh, S., Inoue, M., Shen, Z., & Wajima, K. 2001 PASJ, 53, 169

Marecki, A., Barthel, P. D., Polatidis, A., & Owsianik, I. 2003, PASA, 20, 16

Miller, P., Rawlings, S., & Saunders, R. 1993, MNRAS, 263, 425+

O'Dea, C. P. & Baum, S. A. 1997, AJ, 113, 148

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