III Zw 2: Superluminal motion and compact lobe expansion in a Seyfert galaxy

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So far all relativistically boosted jets with superluminal motion have only been detected in typical radio galaxies with early type host galaxies. We have now discovered superluminal motion in the Seyfert I galaxy III Zw 2, classified as a spiral. The lower limit for the apparent expansion speed is 1.25 ± 0.09 c. Spectral and spatial evolution are closely linked. Before and after this rapid expansion at 43 GHz we have seen a period of virtually no expansion with an expansion speed less than 0.04 c. However, at 15 GHz the picture is completely different. III Zw 2 shows slow expansion ($\sim 0.6c$) during the time of no expansion at 43 GHz and no expansion during the rapid expansion at 43 GHz. 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 behaviour could be explained by a jet interacting with a molecular cloud or the molecular torus. Since III Zw 2 is also part of a sample of so called radio-intermediate quasars (RIQ), it confirms earlier predictions of superluminal motion for this source, based on the argument that RIQs could be relativistically boosted jets in radio-weak quasars and Seyfert galaxies.

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1. Radio-Intermediate Quasars

If we plot the radio-to-optical flux density 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. While in total flux density RIQs appear to be part of the radio loud distribution, their low extended flux density indicates that they might rather be part of the radio-weak distribution. Falcke et al. (1996) and Miller et al. (1993) proposed that the 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; Khachitikian & Weedman 1974; Osterbrock 1977) but was later also included in the PG quasar sample (Schmidt & Green 1983). III Zw 2 most likely has a spiral host galaxy (Hutchings & Campbell 1983; Taylor et al. 1996). It is a core dominated AGN with highly inverted synchrotron spectrum with a self-absorption frequency of 43 GHz (Falcke et al. 1999) during outbursts and faint extended structure typical for Seyfert galaxies.

III Zw 2 is variable up to a factor of 30 within two years with major flares roughly every five years (see Fig. 1). In 1997, III Zw 2 started a new outburst and we started to monitor this source with the VLA and the VLBA. We observed III Zw 2 in 27 epochs with the VLA in six frequencies ranging from 1.4 to 43 GHz and in 6 epochs with the VLBA at 15 and 43 GHz.

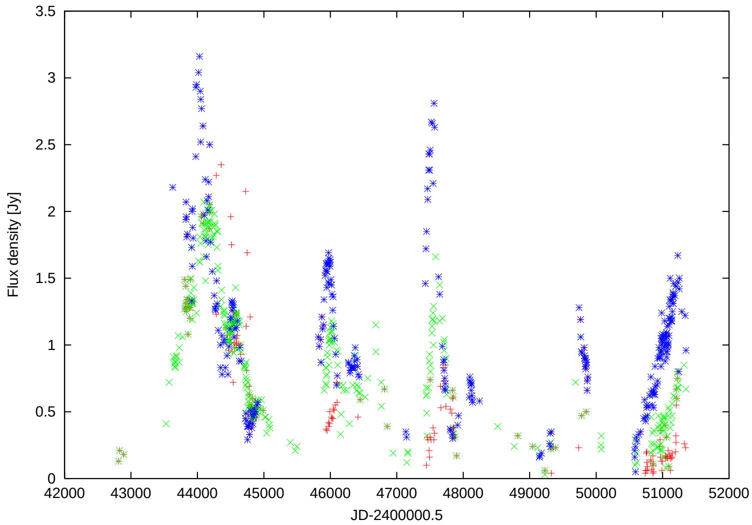

FIGURE 1. Lightcurve of III Zw 2 at 4.5 (+), 8.0 (x) and 14.5 (*) GHz from the Michigan monitoring program

2. Results

The spectral peak stayed constant at 43 GHz during the slow and smooth rise 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 98, the flux density started to drop rapidly – 2.5 times faster than it rose. At the same time the spectral peak dropped quickly from 43 GHz to 15 GHz during a few months (see Fig.2). Applying a simple equipartition jet model we predicted a very rapid expansion during this time.

Indeed the fifth epoch of VLBA observations showed a drastic structural change on milliarcsecond-scales with an apparent expansion velocity of $\sim 1.25c$ (Brunthaler et al. 2000). This expansion speed increases to $\sim 2.66c$ if one considers the time range during which the drop in peak frequency occurred. 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 expansion ($\sim 0.6c$) during the first four epochs, no expansion during the decrease in flux density and again slow expansion when the expansion at 43 GHz stopped again (see Fig. 3). This apparent 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 is much shorter than the duration of the outburst.

This ultra-compact hotspots are pumped up and powered by the jet and are responsible for the increase of flux density. 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

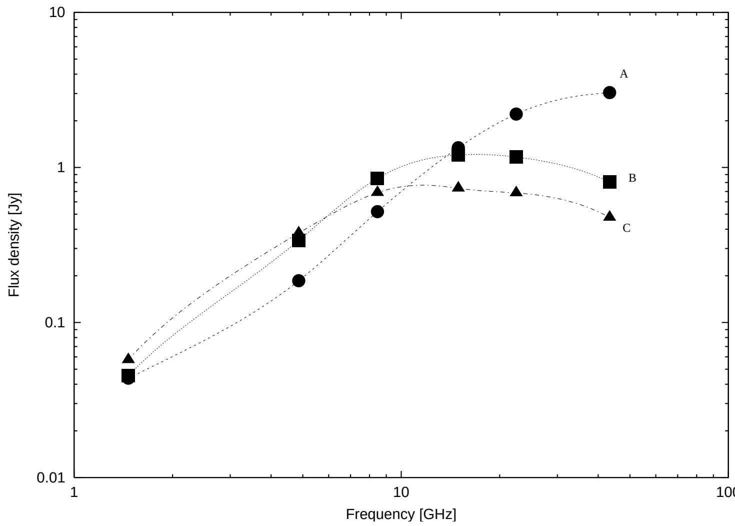

FIGURE 2. Spectra of III Zw 2 from 1998 November 04 (A), 1999 July 07 (B) and 1999 November 12 (C).

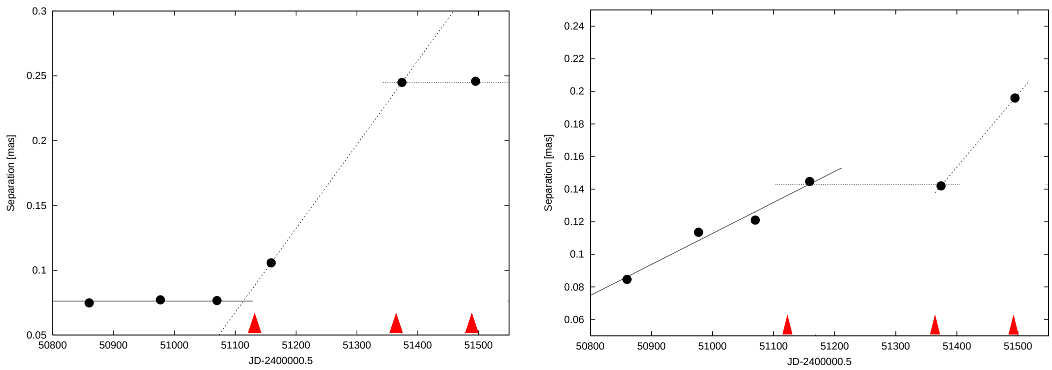

FIGURE 3. Component separation at 43 (left) and 15 (right) GHz. The marks indicate the times of the spectra shown in Fig. 2.

source, e.g the post-shock material expanding with 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 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. So far all relativistically boosted jets with superluminal motion and typical blazars have been detected in early type galaxies (e.g., Scarpa et al. 1999). We detected for the first time superluminal motion in a spiral

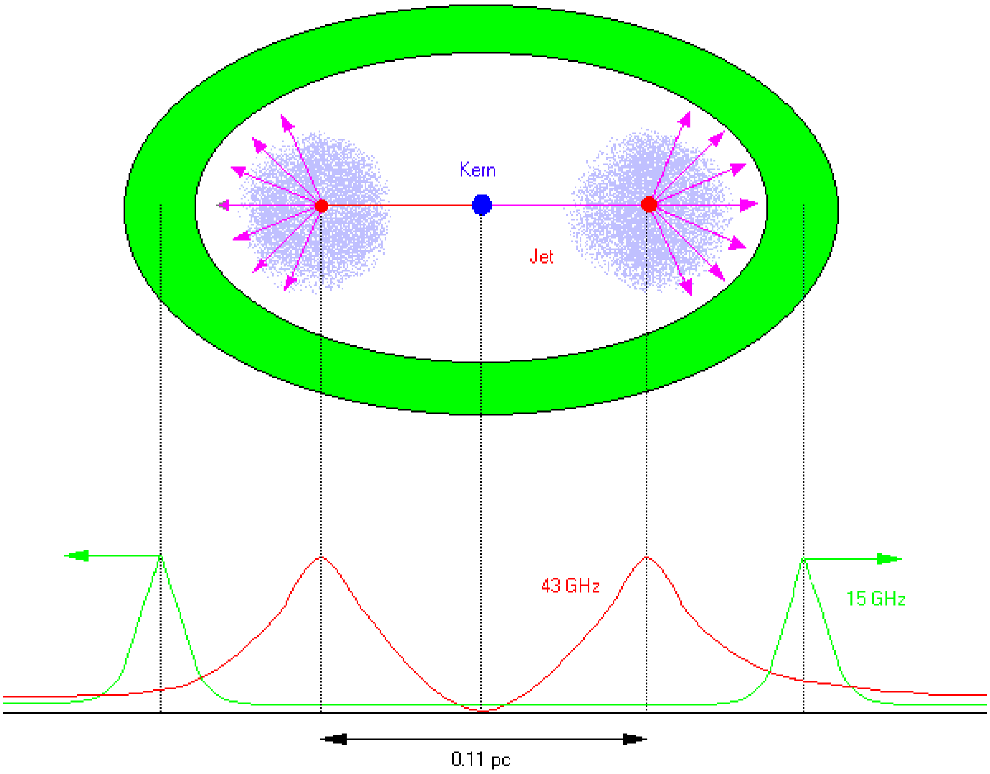

FIGURE 4. 'Inflating Balloon'-Model: At 15 GHz the source is optically thick and one sees the post-shock material expanding with sound speed (green). At 43 GHz one looks inside the source and sees the stationary shocks (red).

galaxy and the good agreement between structural and spectral evolution demonstrates that we are dealing with real physical expansion and not only a phase velocity.

Since one has to look very careful to detect this superluminal motion it is possible that other Seyfert/radio quiet quasars also have relativistic jets. The fact that the sub-pc jet is relativistic raises the question: are Seyfert-jets decelerated on the pc-scale?

REFERENCES

ARP, H. 1968 *ApJ* **152**, 1101.

BRUNTHALER, A., FALCKE, H., BOWER, G.C., ET AL. 2000, *A&A* **357**, L45.

FALCKE, H., PATNAIK, A., SHERWOOD, W. 1996 *ApJ* **473**, L13.

FALCKE ET AL. 1999 *ApJ* **514**, L17.

HUTCHINGS, J.B., CAMPBELL, B. 1983 *Nature* **303**, 584.

KHACHIKIAN, E. YE., & WEEDMAN, D. W. 1974 *ApJ* **192**, 581.

MILLER, P., RAWLINGS, S., SAUNDERS, R. 1993 *MNRAS* **263**, 425.

OSTERBROCK, D.E. 1977 *ApJ* **215**, 733.

SCARPA, R., URRY, C.M., FALOMO, R., PESCE, J.E., & TREVES, A. 2000 *ApJ* **532**, 740.

SCHMIDT, M., & GREEN, R. 1983 *ApJ* **269**, 352.

TAYLOR, G.L., DUNLOP, J.S., HUGHES, H., & ROBSON, E.I. 1996 *MNRAS* **283**, 930.