RECURRENT ACTIVITY IN RADIO GALAXIES

M. Jamrozy (1), D. J. Saikia (2), C. Konar (3), J. Machalski (1), Ł. Stawarz (4,1)
K.-H. Mack (5), A. Siemiginowska (6)

(1) Uniwersytet Jagielloński, Kraków, Poland (2) National Centre for Radio Astrophysics, TIFR, Pune, India
(3) ASIAA, Taipei, Taiwan (4) Institute of Space and Astronautical Science, JAXA, Kanagawa, Japan
(5) INAF-Istituto di Radioastronomia, Bologna, Italy (6) Harvard-Smithsonian Center for Astrophysics, Cambridge, USA

One of the most interesting issues in our understanding of active galactic nuclei (AGNs) is the duration of their active phase and whether such activity is episodic. The morphology and spectra of radio emission from radio galaxies contain information on the history of their central AGN. They thus provide a unique opportunity to study the time scales of the AGN's duty cycles. In this poster we show some of the most striking examples and summarize our recent results on recurrent activity in radio galaxies.

Classical powerful radio galaxies (RGs) are characterised by extended radio lobes with leading compact and bright hot spots, and often a compact central radio core. The lobes are powered by two relativistic jets emerging from a supermassive black hole at the centre of a galaxy. However, a small fraction of RGs show structures which can by explained as a product of repeated activity of the central AGN. A striking example of episodic nuclear activity is when a new pair of radio lobes is seen closer to the nucleus before the 'old' and more distant radio lobes have faded. Such sources have been christened as 'double–double' radio galaxies (DDRGs) by Schoenmakers et al. (2000). Approximately twenty of such DDRGs are known in the literature (see Table 1, and for a review see Saikia & Jamrozy 2009).

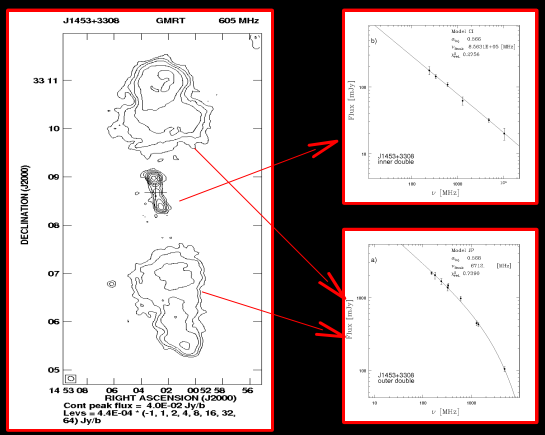

Figure 1. (left) A low-frequency GMRT image of J1453+3308. **(right)** Synchrotron spectra of the inner and outer lobes. The maximum spectral ages for the northern and southern lobes of the outer double have been estimated to be ~47 and 58 Myr, respectively, while the spectrum of the inner double is practically straight with an age less than about 2 Myr (Konar et al. 2006).

In addition, diffuse relic radio emission due to an earlier cycle of activity may also be visible around radio sources which are not characterized by a 'classical double' structure with hotspots at the outer edges. The relic radio emission is expected to remain visible for $\sim 10^8$ yr or so, and have a steep radio spectrum due to radiative losses. Such a radio emission possibly due to an earlier cycle of activity has been suggested for a number of sources from both structural and spectral information. These include, e.g. 3C388, HerA, 3C310 and CenA.

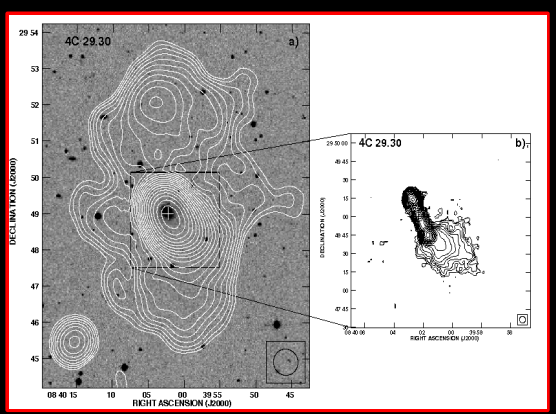

Figure 2. 1400 MHz VLA images of 4C29.30 (J0840+2949). **(a)** D-array contour map of the entire source overlayed on the optical field from the Digital Sky Survey. **(b)** B-array contour map of the central part of the source from FIRST. Jamrozy et al. (2007) determine the spectrum of the inner double from 240 to 8460 MHz and show that it has a single power-law spectrum with a spectral index of ~0.8. Its spectral age is estimated to be less than 33 Myr. The extended diffuse emission has a steep spectrum with a spectral index of ~1.3 and a break frequency ≤240 MHz. The spectral age is larger than 200 Myr, suggesting that the extended diffuse emission is due to an earlier cycle of activity.

Table 1. Radio sources with evidence of recurrent activity.

Source	Alt. name	Opt. Id.	Red-shift	l_a kpc	l_o kpc	Notes
J0041+3224	B2 0039+32	G	(0.45)	171	969	DDRG
J0116-4722	PKS 0114-47	G	0.1461	460	1447	DDRG
J0821+2117	TXS 0818+214	G	(1.0)	5.4	547	DDRG
J0840+2949	4C29.30	G	0.0647	36	639	DDRG
J0921+4538	3C219	G	0.1744	69	433	DDRG
J0929+4146		G	0.3650	~30, 652	1875	TDRG*
J0935+0204	4C02.27	Q	0.6491	70	470	DDRQ
J1006+3454	3C236	G	0.1005	1.7	4249	DDRG
J1158+2621	4C26.35	G	0.1121	138	483	DDRG
J1242+3838		G	0.3000	251	602	DDRG
J1247+6723	VII Zw 485	G	0.1073	0.014	1195	DDRG
J1325-4301	Cen A	G	0.0018	~12	~600	DDRG
J1352+3126	3C293	G	0.0450	1.6	190	misaligned DDRG
J1406+3411	3C294	G	1.7790		126	relic X-ray
J1453+3308	4C33.33	G	0.2481	159	1297	DDRG
J1504+2600	3C310	G	0.0538	~90	320	Flatter-α bubbles
J1548-3216	PKS 1545-321	G	0.1082	313	961	DDRG
J1651+0459	Her A	G	0.1540		513	Steep-α relic
J1835+6204	8C 1834+620	G	0.5194	369	1379	DDRG
J1844+4533	3C388	G	0.0917		~70	Steep-α relic
J1959+4044	Cyg A	G	0.0561		136	relic X-ray jet
J2223-0206	3C445	G	0.0562	130	612	DDRG

* this is the only known 'triple-double' radio galaxy (TDRG)

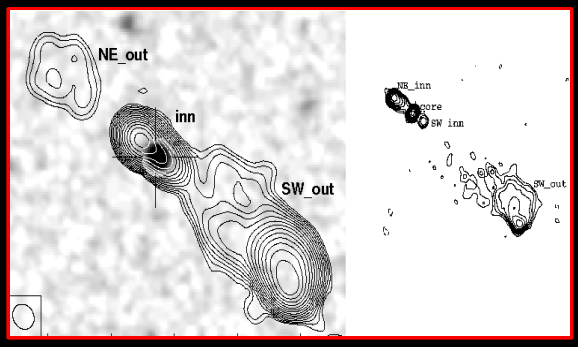

Figure 3. J0935+0204 is the only quasar so far with indications of a double-double structure (Jamrozy, Saikia & Konar 2009). The lobes of both the inner and outer doubles are highly asymmetric, especially in flux density, and it is possible that the jets may also be intrinsically asymmetric. The existence of a hot-spot in one of the lobes of the outer double indicates that the time scale of episodic activity is less than a few Myr.

Deep low-frequency radio and X-ray studies have proved to be useful to probe episodic or recurrent AGN activity in radio galaxies. The existing observations have, however, possibly revealed only the tip of the proverbial iceberg. One should realise that from the technical point of view it may be hard to detect diffuse large-scale radio emission from an old period of activity in the vicinity of young structures which are usually much brighter than the preceeding ones. It is clear however, that the phenomenon of recurrent activity in RGs is still open for further research. Detailed studies of the DDRGs are of key importance to learn more about duty cycles of AGNs and how this affects the evolution of extragalactic radio sources in general. With the advent of new low-frequency radio telescopes we are in an exciting phase of studying episodic activity in AGNs.

We invite you to see also the poster entitled *'Optical, radio and X-ray properties of J1159+5820'* by D. Kozieł-Wierzbowska et al.

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