# Spectral structure of X-shaped radio sources – A statistical view


Dharam Vir Lal
(Max-Planck-Institut für Radioastronomie, Bonn Germany)
M.J. Hardcastle (University of Hertfordshire, UK), R.P. Kraft (CfA, USA)
C.C. Cheung (NASA, GSFC, USA), S. Bhatnagar (NRAO, USA), A.P. Rao (NCRA, India)



## ABSTRACT

*Context.* The nature of X-shaped sources is a matter of considerable debate: it has even been proposed that they provide evidence for black hole mergers/spin reorientation, and therefore constrain the rate of strong gravitational wave events (Merritt &Ekers 2002).
*Aim.* To understand the nature of these unusual X-shaped radio galaxies.
*Our Approach.* We conducted a systematic study of a large sample of known X-shaped, comparison FR II, and newly discovered X-shaped candidate sources. We used Giant Metrewave Radio Telescope and Very Large Array at several radio frequencies.
*Current Understanding.* Based on morphological and spectral characteristics of these sources, currently a strong contender to explain the nature of these sources is the 'alternative' model of Lal & Rao (2007), in which these sources consist of two pairs of jets, which are associated with two unresolved AGNs.
*New Method.* Detailed morphological and spectral results of a large number of newly detected candidate X-shaped sources provide, in statistical sense, a crucial test to this model, and hence the new sample sources are excellent candidates for the spectral study; *i.e.*, to understand the "statistical" nature of $X$-shaped radio sources.
*Conclusion.* Currently, a possible model to explain the 'X' shape morphology and thus the formation scenario is the 'alternative' model, and hence, the statistical results are crucial to test this model. In addition, detailed morphological and spectral study would provide clues to merging of AGNs on mas. It is also possible that our current understanding of spectral ageing in radio lobes, particularly at low frequencies, is incorrect.


## X-shaped / Winged Radio Sources

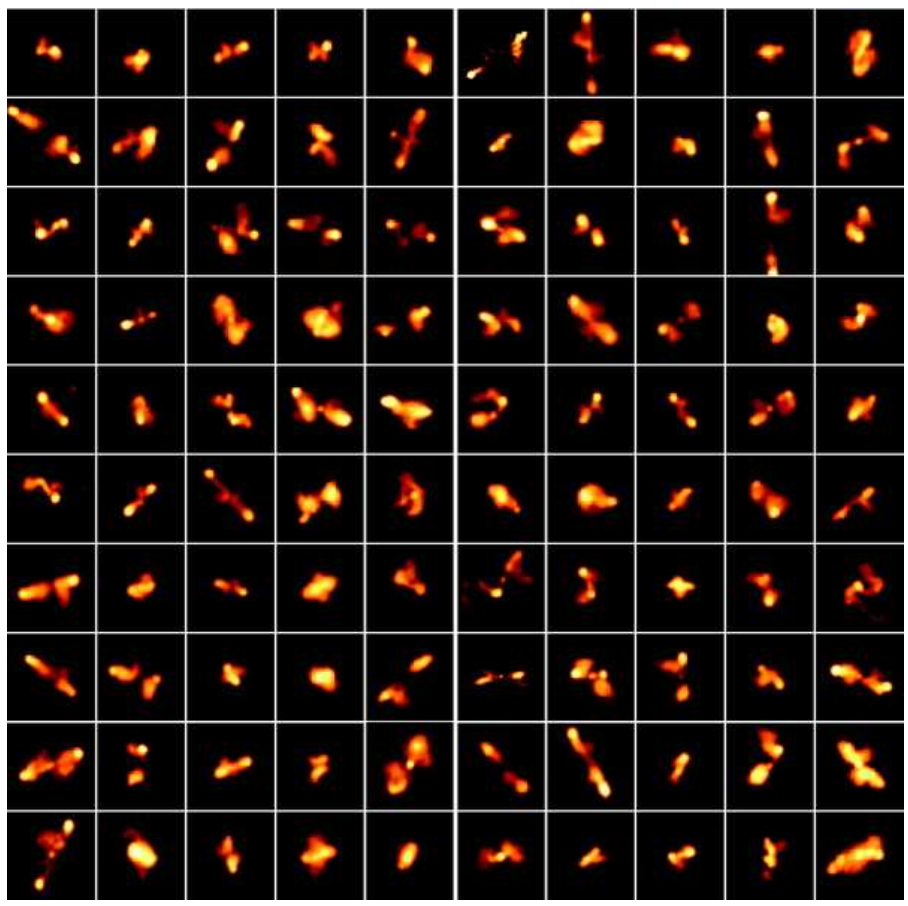
A peculiar and a small subclass of extragalactic radio sources branded the X-shaped, or 'winged' sources are characterised by two low-surface-brightness lobes ('wings') oriented at an angle to the 'active', or high surface brightness (active) radio lobes, giving the total source an 'X' shape. These two sets of lobes usually pass symmetrically through the centre of the associated host galaxy. Merritt & Ekers (2002) noted that majority of these sources are of Fanaroff-Riley type II (FR II) (Fanaroff & Riley 1974) and rest are either FR I or mixed.

## Suggested Formation Scenarios

Several authors have attempted to explain the unusual structure in X-shaped sources. These have been put forth as derivatives of central engines that have got reoriented, perhaps due to a minor merger (Merritt & Ekers 2002; Dennett-Thorpe et al. 2002; Gopal-Krishna et al. 2003). Alternatively, they may also result from two pairs of jets, which are associated with a pair of unresolved AGNs (Lal & Rao 2005, 2007). These, however, are not the only interpretations for the unusual morphologies; some authors suggest a hydrodynamic origin (Leahy & Williams 1984; Worrall et al. 1995; Capetti et al. 2002; Kraft et al. 2005) and some suggest a conical precession of the jet axis (Rees 1978; Parma et al. 1985; Mack et al. 1994).

## New Sample

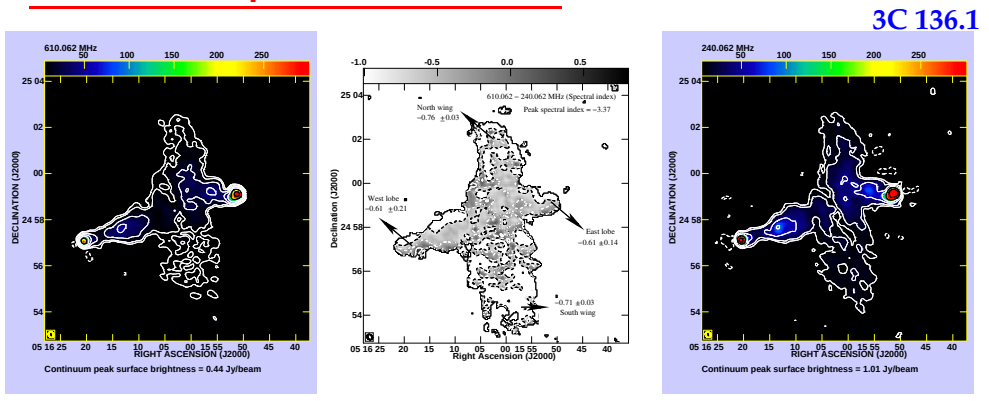
(Cheung 2007)



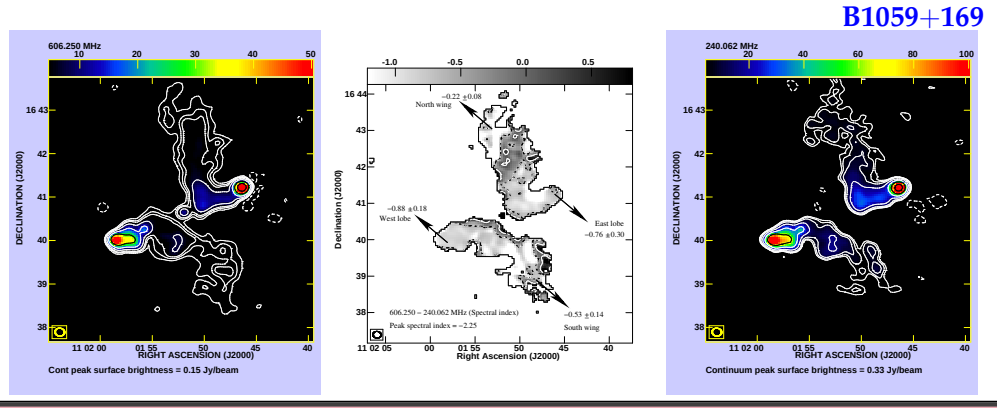

## Known X-shaped Radio Sources

(Lal & Rao 2005, 2007)

3C 136.1



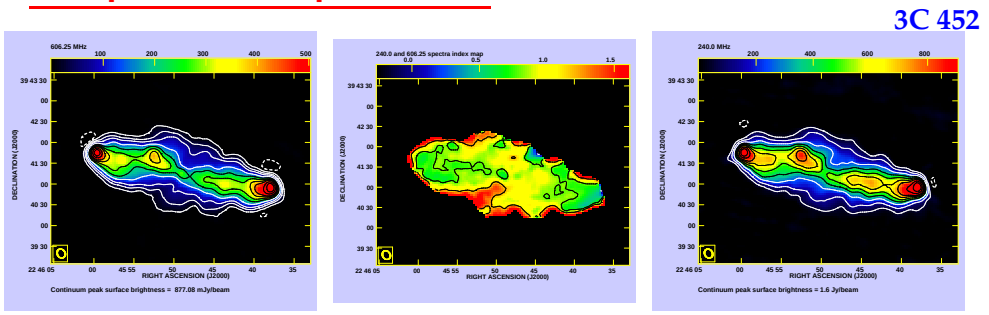

B1059+169




## Comparison Sample Source

(Lal, Hardcastle & Kraft (submitted))

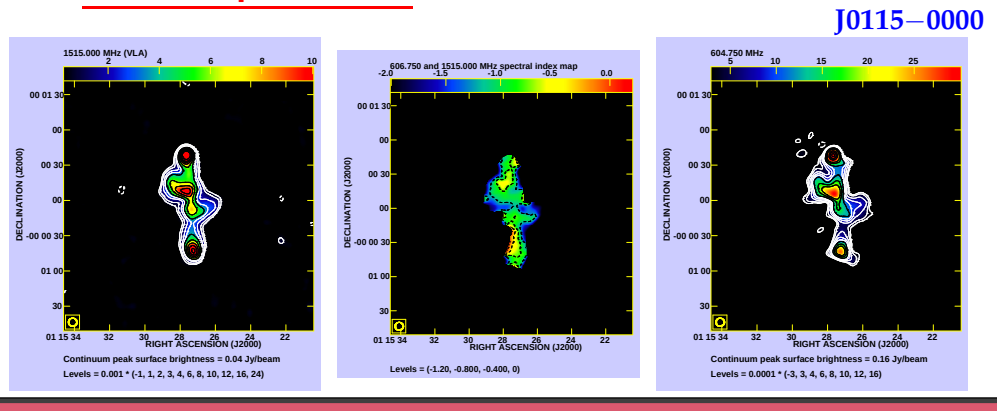
3C 452




## New Sample Source

(Lal, Cheung, Bhatnagar & Rao (in preparation))

J0115−0000




## Samples

**Known sample** The earlier sample of known X-shaped sources studied in detail was drawn from the list mentioned in Merritt & Ekers (2002) compiled by Leahy & Parma (1992). These source have been selected solely on the basis of their morphology, and the sample is inhomogeneous and in no sense a statistical complete sample.
**Comparison sample** The comparison sample consists of all nearby ($z < 0.1$) normal FR II sources from the 3CRR catalogue. These sources have radio luminosities and angular-sizes similar to that of the X-shaped sources, and we ensure that the sample sources are similar/matched to typical X-shaped sources. In addition, the sample sources have known weak transverse extensions (proto-wings?) and also have X-ray (*XMM/Chandra*) observations.
**New sample** The new sample is drawn from the compiled list of candidate X-shaped radio sources through a search of the FIRST survey database (Cheung 2007). The sample source have morphologies and angular-sizes (nearly) similar/matched to known X-shaped sources.

## Summary of Results

Almost all our 'comparison sample' sources show monotonic steepening of the radio spectrum from the hotspots to the low surface brightness features, a classical spectral signature seen in almost all normal FR II radio galaxies. Preliminary analysis of 'new sample' also shows similar result. Whereas, a significant fraction of a sample of 'known' X-shaped sources had wings with flatter, or at least comparable, spectral indices to those in the brighter active lobes. Therefore, there is something 'special' about the wings of X-shaped sources, in the sense that they do not simply behave like the low-surface-brightness regions of more typical FR II sources. The low surface brightness feature in 3C 321, a classical FR II radio source, also shows unusual spectral behaviour, similar to the spectral behaviour seen in wings in some of the X-shaped sources. This raises the possibility that 3C 321 consists of two pairs of jets, which are associated with two unresolved AGNs, a possible formation model for known X-shaped sources (Lal & Rao 2007). Another possibility is simply that our current understanding of spectral ageing in radio lobes, particularly at low frequencies, is incorrect.

## Important References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