Study of the radio spectral properties of 4C 35.06

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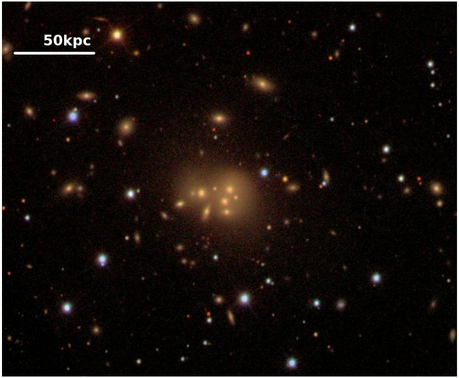
Outline of the talk

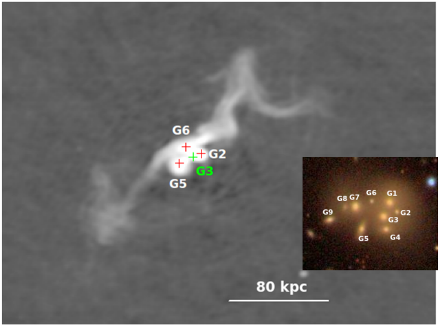
- Introduction.
- Optical and Radio observations
- Results
- Summary

- The radio source 4C 35.06 occurs at the central region of the rich cluster Abell 407.
- Central one-arcmin region shows an ensemble of nine galaxies, embeded within an extensive, diffuse stellar halo with redshifts ranging from 0.046 to 0.049.
- Seven galaxy pairs in this region are separated by less than 10 kpc in projection.
- This ensemble of galaxies is proposed as a cD galaxy under formation. **(Schneider & Gunn,1982).**
- This source is an ideal case for studying the growth and evolution of SMBH in cD galaxies and triggering of AGN.



Radio and optical observations

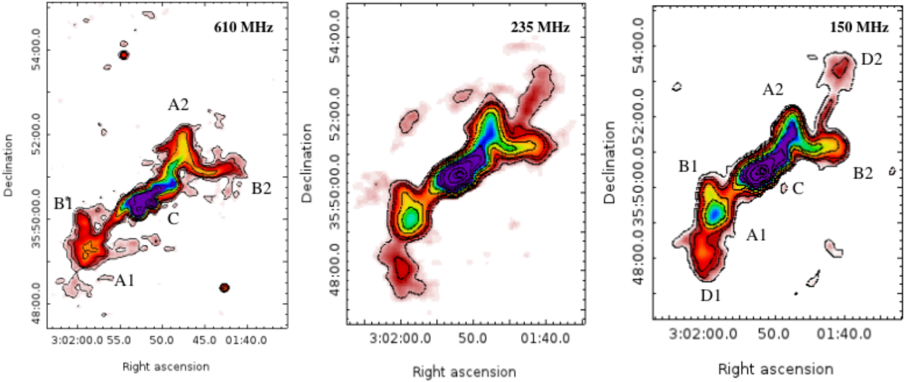
- The radio image exhibits a peculiar helical morphology .
- Three radio peaks at the center, only one (G6) aligned with the jet axis.
- The black hole mass of all the central galaxies of the order $10^8 M_\odot$



GMRT 610 MHz radio map with optical positions near radio peaks.

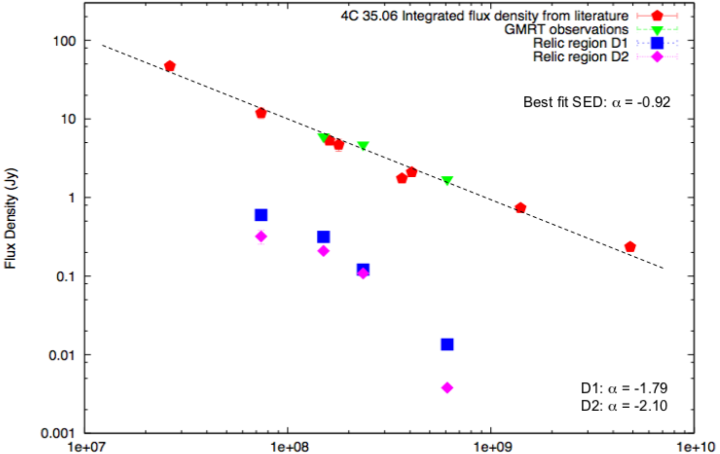
Results:GMRT radio maps

- The linear size varies from $\sim$ 230kpc at 610 MHz to ($\sim$ 400kpc) at 150 MHz, suggesting extended emissions at lower frequencies.
- The flux densities are 1.7Jy at 610MHz, 4.7Jy at 235MHz and 6.0Jy at 150MHz.



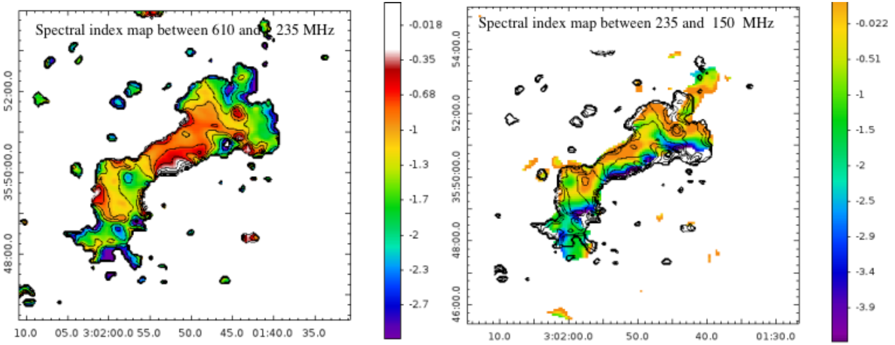
Results: Integrated spectra

- The integrated spectra shows a steep spectral index of -0.92 from 4.9 GHz down to 26 MHz. The spectral indices for the diffuse outer regions D1 is -1.79 and for D2 is -2.10 (ultra-steep).



Results:Spectral index map

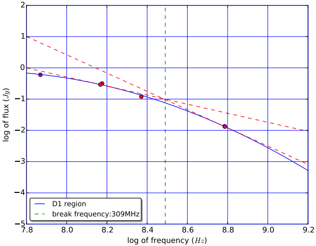
- Left panel: spectral index map between 610MHz and 235 MHz; Right panel: spectral index between 235MHz and 150 MHz.
- The outermost regions show very steep spectral index ($\sim\ -2.5$)

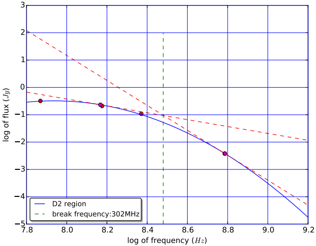


Results: Break frequency and spectral age

- We estimate the break frequency in the relic regions D1 and D2 to be $\sim$304MHz.
- The spectral age estimated as $(80 - 210) \times 10^{6} yrs$.
- $$t_{sp} = 1.59 \times 10^{9} \left[\frac{B^{1/2}}{\left[B^{2} + B_{IC}^{2}\right] [\nu_{c}(1+z)]^{1/2}} \right] \text{yrs} \qquad (1)$$

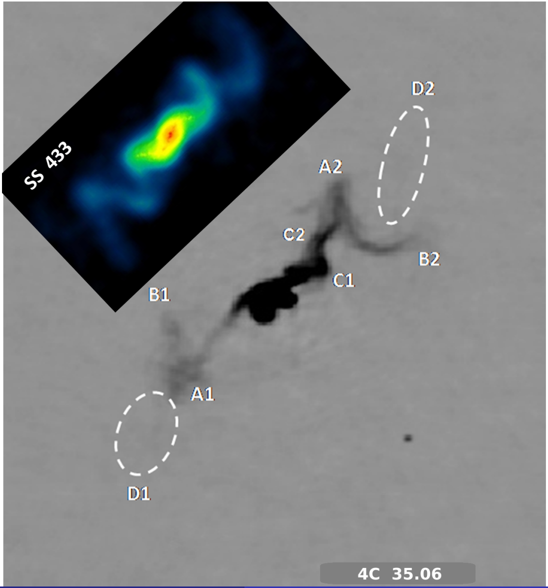
(Murgia et al. 2011). Here 'B' the magnetic field in μG, 'z'-redshift, B_{IC}=$3.25(1+z)^{2}$, ν_{c} - break frequency and B $= 1 - 10\ \mu G$





Results: Jet Precession

- The GMRT image at 610MHz in inverted grey colour, with extended emissions at lower frequencies marked on it.
- The image is showing loop like structure similar to galactic microquasar SS433 **(Blundell & Bowler., 2004)**.
- The relativistic jets behave in the same way ranging from stellar mass BH to SMBH.



Results:Jet Precession

- Two possible mechanisms for Jet precession (a) Binary black hole model (Begelman et al.1980,Tateyama & Kinham 2004), and (b) Lense- Thirring effect (Bardeen & Peterson, 1975;Liu & Melia,2002).
- In the binary black hole model, The accretion disk of the AGN can be precessed by the torque exerted by the companion black hole. This precession of the accretion disk will lead to jet precession .
- Here the closeness of the galactic members and the rotationally symmetric helically modulated large scale jet structure together suggests this site ideal for the search of a binary supermassive black hole system (Deane et al.2014; Begelman et al. 1980).

Results: Jet Precession

- The lense-Thirring effect comes in to play when the spin angular momentum of the blackhole is misaligned with the angular momentum of the accretion disk.
- We have estimated the precession time scale of the jet system **(Hongsu Kim & Yangwan.,2015)** for a black hole of mass $10^8 M_\odot$, with different values of specific angular momentum 'a' and Bardeen peterson radius r_{BP}.
- Bardeen peterson radius (r_{BP}) to be 10^2 *to* 10^3 (Mutiplication Factor 'F') times the schwarzschild radius R_s . **(Bardeen & peterson,1975,Scheuer & Feiler,1996;Shan-Jie Qian et al.,2014).**
- The precession time scales obtained are $\sim 10^5 years$ (with 'a'=0.1 and $F = 10^3$) and $\sim 10^8 years$ (with 'a'=0.1 and $F = 10^4$).
- The precession time scale matches with radiative age of the relic plasma ($\sim 10^8 years$) only at very low 'a' (~ 0.1) and high r_{BP} ($\sim 10^4 r_s$).

Summary

- The extremely steep spectrum at the ($\alpha =$ -1.7 to -2.1) relic radio plasma (spectral age of 80$-$210 My),suggests that these radio emissions are from older plasma, due to the previous epoch of AGN activity.
- Such AGNs in ultra steep spectrum relic systems are very rare and form an interesting population for understanding the life-cycle of releativistic jets.
- It is an ideal case for studying the formation and evolution of SMBHs in cD galaxies.
- The helical morphology is an indication of large scale precession which may be due to a binary black hole system or due to Lens-Thirring effect.

More slides-I

The precession time scale is given by **(Hongsu Kim & Yangwan.,2015)**

$$T_{LT} \sim \frac{2\pi}{\Omega_{GM}} \quad (2)$$

where

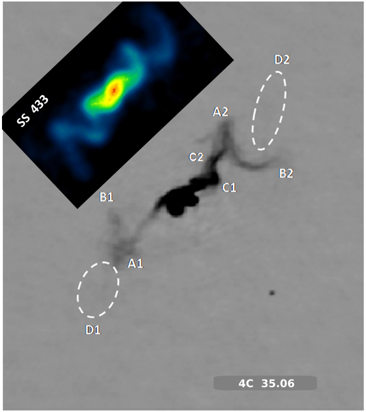
$$\Omega_{GM} = \frac{2GJ}{c^2 {r_{BP}}^3} \quad (3)$$

and

$$J = \frac{2GM^2 a}{c} \quad (4)$$

Here M is the black hole mass, r_{BP} the Bardeen- petterson radius and 'a' the specific angular mometum of the black hole.

More slides-II



The GMRT image of the source 4C35.06 at 610MHz in inverted grey colour showing the twisted helical jet structure. The extensions observed at lower frequen- cies 235MHz and 150MHz are marked with dotted lines.The inset image shows similar helical jets in galactic microquasar SS433, which is the total intensity image at 4.85 GHz observed with the VLA in A configuration **(Blundell & Bowler., 2004)**.The linear size of SS 433 jet system is only 0.26pc while that of 4C35.06 at 610 MHz is 230 kpc

More slides-III

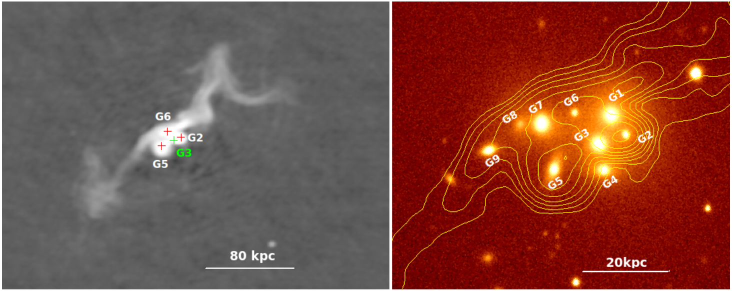
The equipartition magnetic field is given by

$$B(U_{min}) \;=\; (6\pi aAL/V)^{\frac{6}{7}}$$

where L= total radio luminosity from $\nu_1 = 10^7 Hz\ to\ \nu_2 = 10^{10} Hz$.
A = Parameter depending on spectral index.
V= total volume of the radio source.
a= Total particle to electron energy (Usually the values are assumed as a=1 to a=100.)

(Alann T. Moffet- Strong Non thermal radio emission from galaxies.)

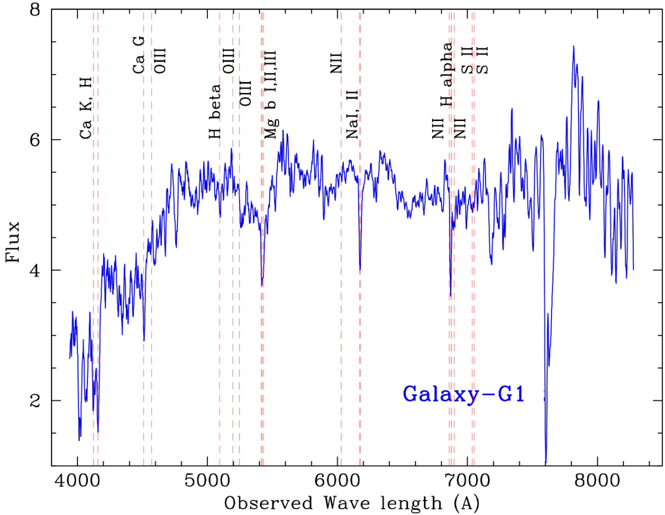
More slides-IV



Table

a	F	Precesssion time
0.1	1000	2.5×10^5yrs
0.2	1000	1.2×10^5yrs
0.4	1000	0.60×10^5yrs
0.6	1000	0.40×10^5yrs
0.8	1000	0.30×10^5yrs
0.1	10000	2.5×10^8yrs
0.2	10000	1.2×10^8yrs
0.4	10000	0.60×10^8 yrs
0.6	10000	0.40×10^8yrs
0.8	10000	0.30×10^8yrs

Table : Precession time scale for different values of 'a' and 'F'


Ca K, H
Ca G
OIII
H beta
OIII
OIII
Mg b I,II,III
NII
NaI, II
NII
H alpha
NII
S II
S II
Galaxy−G1
Flux
8
6
4
2
4000
5000
6000
7000
8000
Observed Wave length (A)

More slides-VI