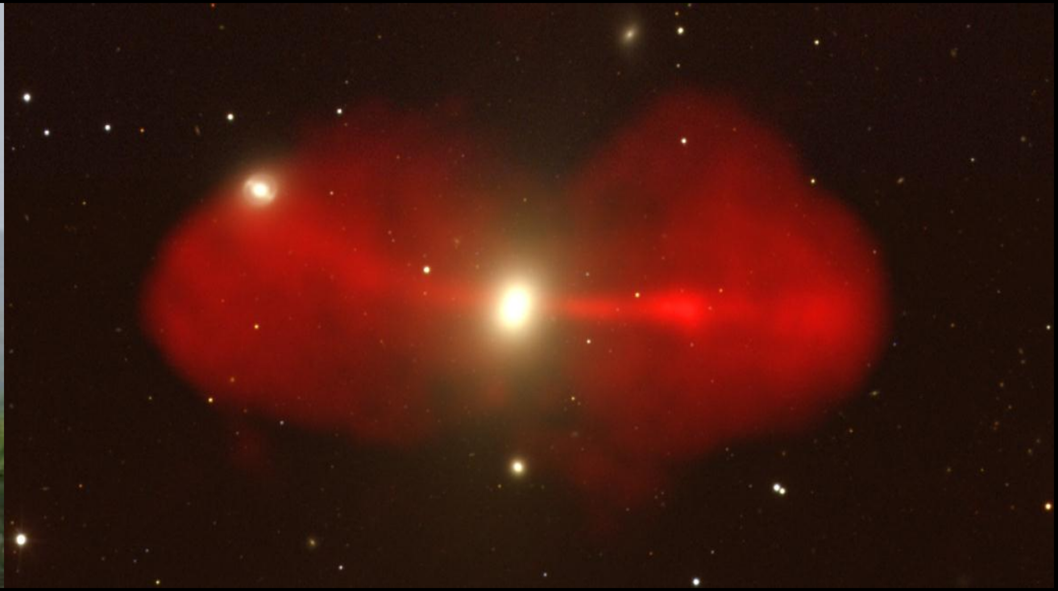
Radio Properties of nearby Groups of Galaxies



20-09-2012
Konstantinos Kolokythas

YERAC, PUSHCHINO 2012

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Outline

- Introduction on Active Galactic Nuclei (what are they?)
- Heating by Active Galactic Nuclei (AGN): Feedback (what is it?)
- Environment of research: Groups of Galaxies (why?)
- The CLoGS project (Complete Local-Volume Groups Sample)
- Results on NGC4261 and NGC5982 so far
- Conclusions

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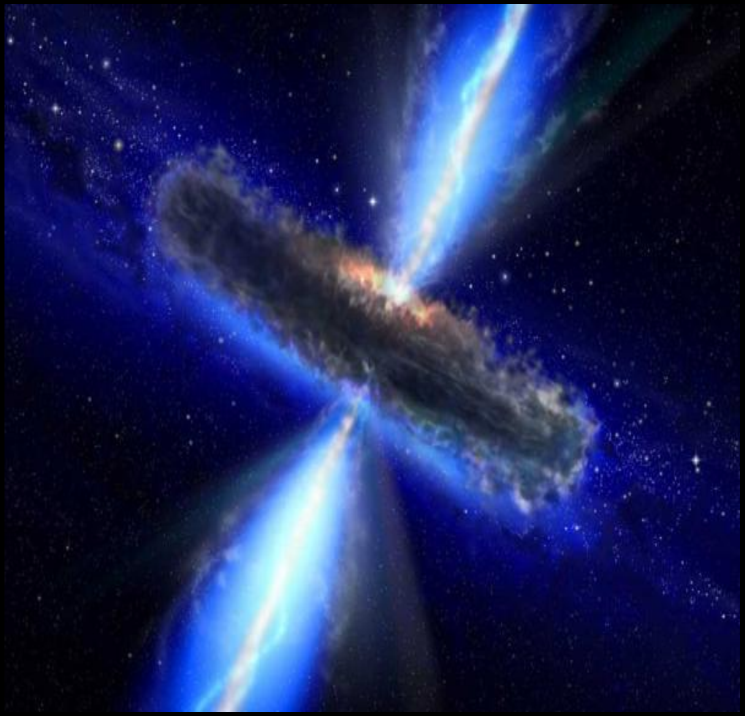
Active Galactic Nuclei (AGN)

- Extragalactic radio sources: Bipolar outflows of magnetic field and relativistic particles ejected from an AGN
- The central engine is the associated Quasar or AGN
- AGN is surrounded by an accretion disk and fuelled by the accretion of gas onto a SMBH
- Synchrotron radiation due to transportation of energy via an aligned beam in two oppositely directed beams (Jets)



Radiation from an active galaxy's central black hole
(Credit: ESA/NASA/AVO/Paolo Padovani)

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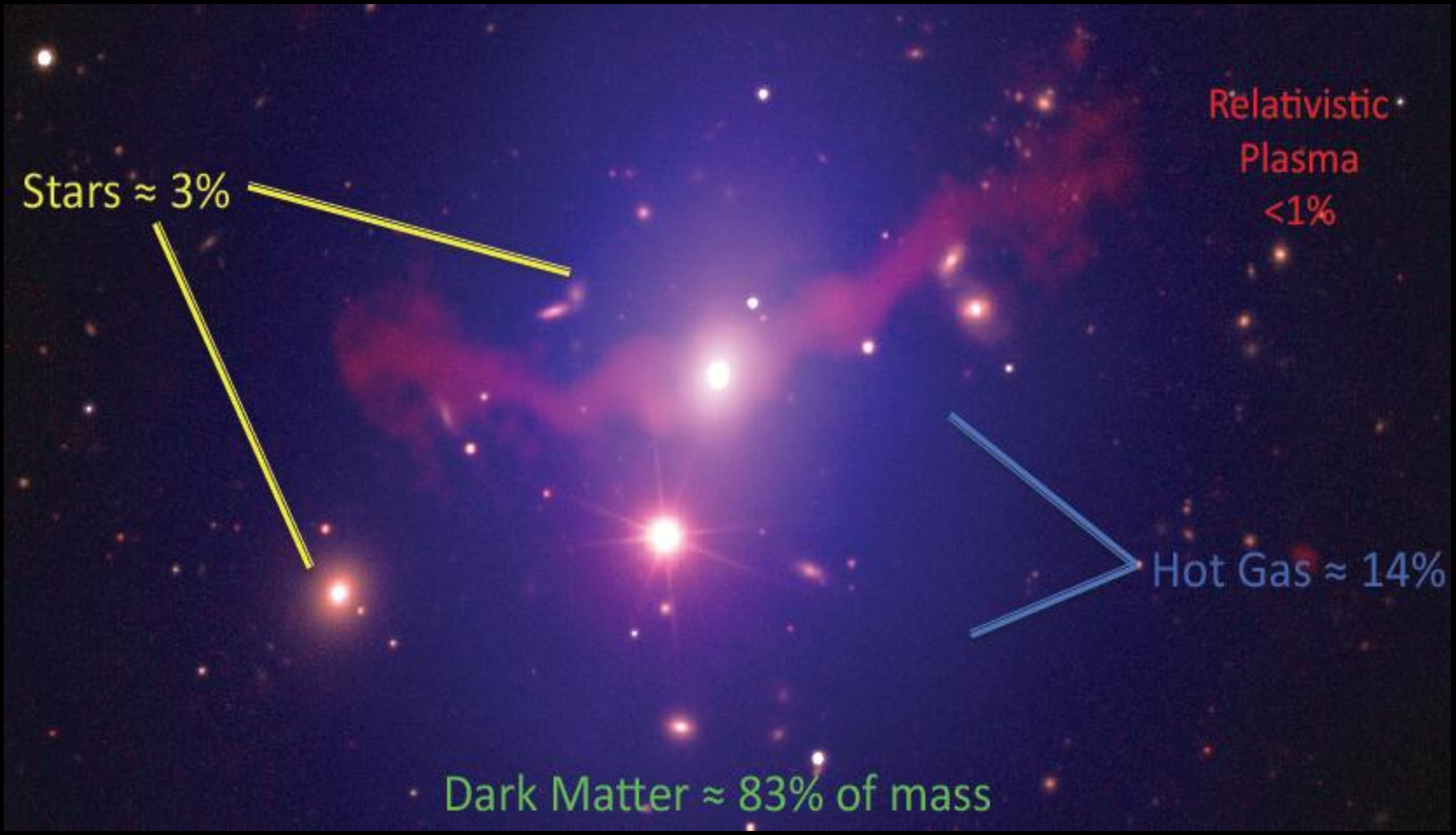
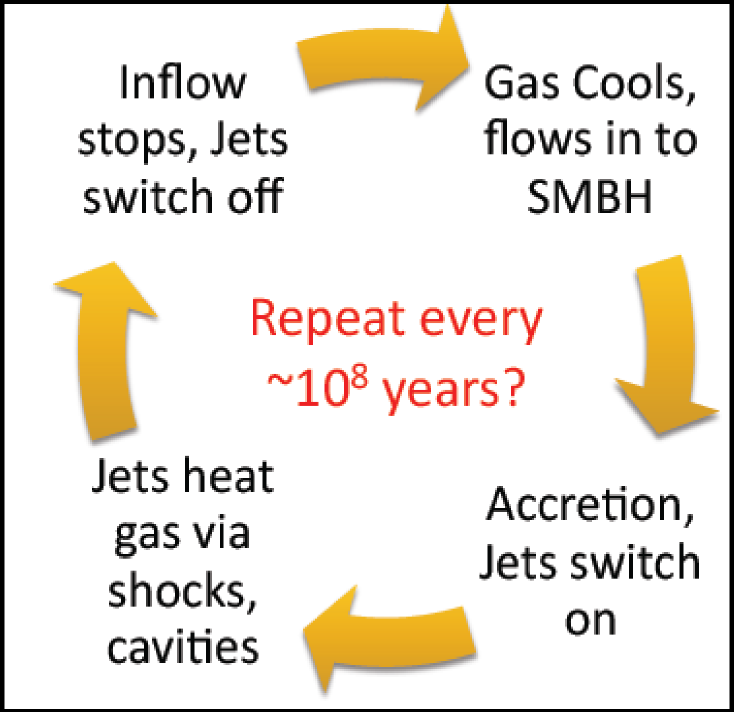
Heating by AGN: Feedback



Heating by AGN: Feedback

- Heating by AGN?
- Conversion of radio AGN outflow energy into heating of the circumgalactic medium is adequate to provide the heating needed
- *AGN feedback* is a loop process where energy in some form is produced from the central regions of the galaxy, which can heat up the inflowing gas, preventing it from cooling



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Galaxy Groups

- Groups of Galaxies contain >50% of the galaxies in the local Universe plus a similar fraction of the total baryonic mass

- Groups bring galaxies into close proximity at low relative velocities, promoting tidal interactions and mergers

- Therefore feedback in groups has the greatest impact on galaxy formation and galaxy evolution

- Obstacle: Lack of a statistically complete radio/X-ray sample of nearby groups

- CLoGS project sample consists of 53 optical & X-ray selected candidate groups in the local Universe (<80 Mpc)

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CLoGS project (Complete Local-Volume Group Sample)

- CLoGS project is a survey of galaxy groups observed in the
  - X-ray – hot gas
  - Optical - galaxies
  - Radio – AGN activity

- 235 and 610 MHz using GMRT
- GMRT sensitivity (for 2-3hr obs.):
  rms ≈ 50-100μJy/b @610MHz,
  rms ≈ 300-500μJy/b @235MHz
- Resolution: 5” @610 MHz to 12” @235 MHz (HPBW)

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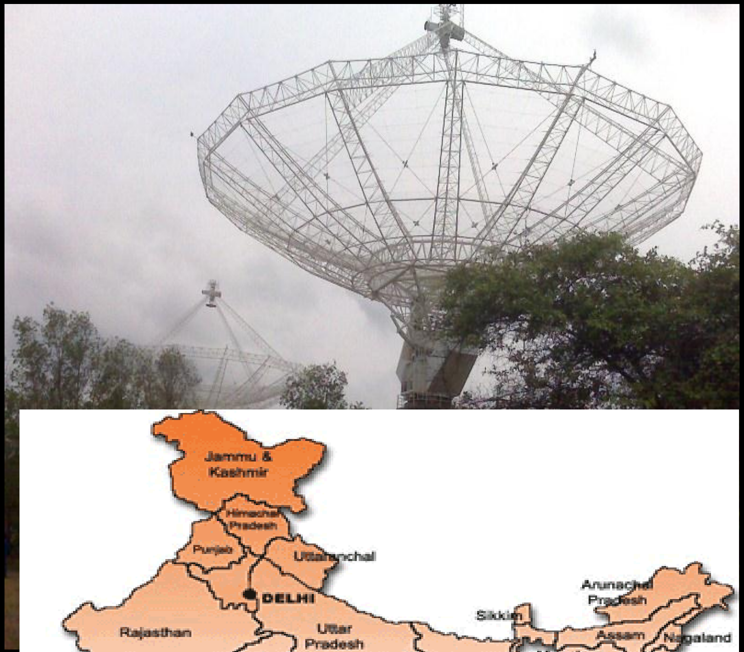
Giant Metrewave Radio Telescope (GMRT)

- Placed about 80 km north of Pune, in India
- 30 totally steerable huge parabolic antennas of 45m diameter each
- Maximum distance reaching up to 25 km at a range of frequencies from 50 MHz to 1450 MHz
- The dishes have been build of wire mesh in a parabolic configuration
- Due to design each antenna has minor wind loading - low total weight, hence GMRT low cost of construction.



Main science goals of CLoGS project

- Characterization of the AGN population in groups
- Properties of group central AGN (eg. power output, *study of spectral ageing of radio synchrotron emission*)
- Mechanisms of feedback heating (Are shocks / cavities dominant?)

CLoGS collaboration members

Principal Investigator	
Dr. Ewan O'Sullivan	Harvard-Smithsonian Center for Astrophysics University of Birmingham
Prof. Trevor Ponman	University of Birmingham
Dr. Somak Raychaudhury	University of Birmingham
Dr. Alastair Sanderson	University of Birmingham
Konstantinos Kolokythas	University of Birmingham
Dr. Jan Vrtilek	Harvard-Smithsonian Center for Astrophysics
Dr. Laurence P. David	Harvard-Smithsonian Center for Astrophysics
Dr. William Forman	Harvard-Smithsonian Center for Astrophysics
Dr. Christine Jones	Harvard-Smithsonian Center for Astrophysics
Dr. Chris Haines	University of Arizona
Dr. Simona Giacintucci	University of Maryland
Dr. Nazirah Jetha	University of Alabama, Huntsville
Dr. Myriam Gitti	INAF - Astronomical Observatory of Bologna/ Harvard-Smithsonian Center for Astrophysics
Prof. Stephen S. Murray	Johns-Hopkins University
Dr. Nimisha G. Kantharia	National Centre for Radio Astrophysics
Prof. Arif Babul	University of Victoria

More info:
http://www.sr.bham.ac.uk/~ejos/CLoGS.html

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LGG 278/NGC 4261

- LGG 278/NGC 4261 is a group on the outskirts of the Virgo cluster

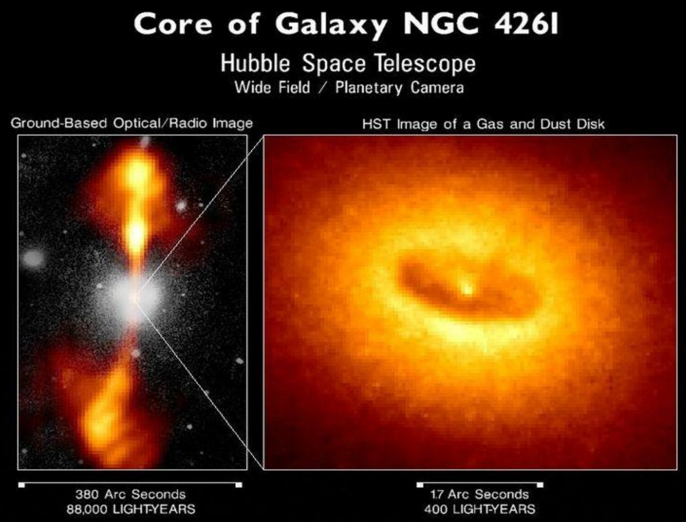
- Its dominant elliptical, NGC 4261, is a prolate, slowly rotating E2 galaxy (z~ 0.00745) whose primary axis of rotation is close to its major-axis

- Bright FR I radio source 3C 270 whose twin jets lie close to the plane of sky

- Radio analysis performed at 244 MHz, 610 MHz, 1.4 GHz and 4.8 GHz
  (Kolokythas K., O' Sullivan E., Raychaudhury S., Chandra I. paper in prep.)

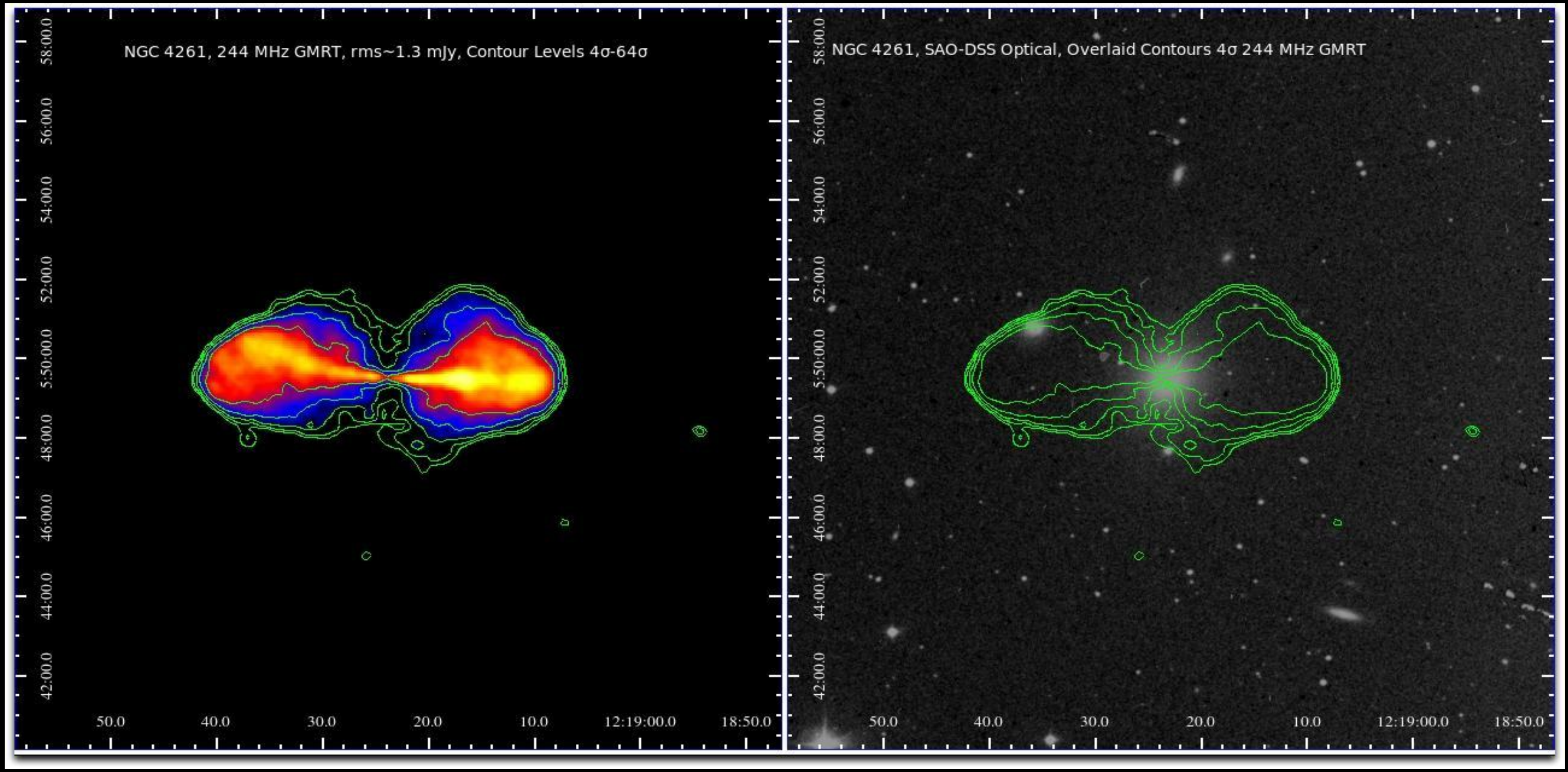
Observation date	Frequency (MHz)	Bandwidth (MHz)	Integration time (min)	HPBW, PA (full array, $'' \times ''$, $^\circ$)	rms mJyb^{-1}
2009 Feb 14	607	16	270	7.32×4.77, 76.62	1
2009 Feb 14	244	32	270	15.3×11, 67.17	1.3

Components	S_{244} MHz (Jy)	S_{607} MHz (Jy)	$S_{1.4}$ GHz (Jy)	$S_{4.8}$ GHz (Jy)	α^{244MHz}_{607MHz}
Total	39.70±3.20	26.30±1.30	18.30±0.90	7.30±0.40	0.45
Core	0.60±0.05	0.30±0.02	0.40±0.03	0.60±0.03	0.76
Right jet	21.00±1.70	13.30±0.70	9.60±0.50	3.80±0.20	0.50
Left jet .	18.32±1.47	12.30±0.60	8.60±0.40	2.90±0.15	0.44



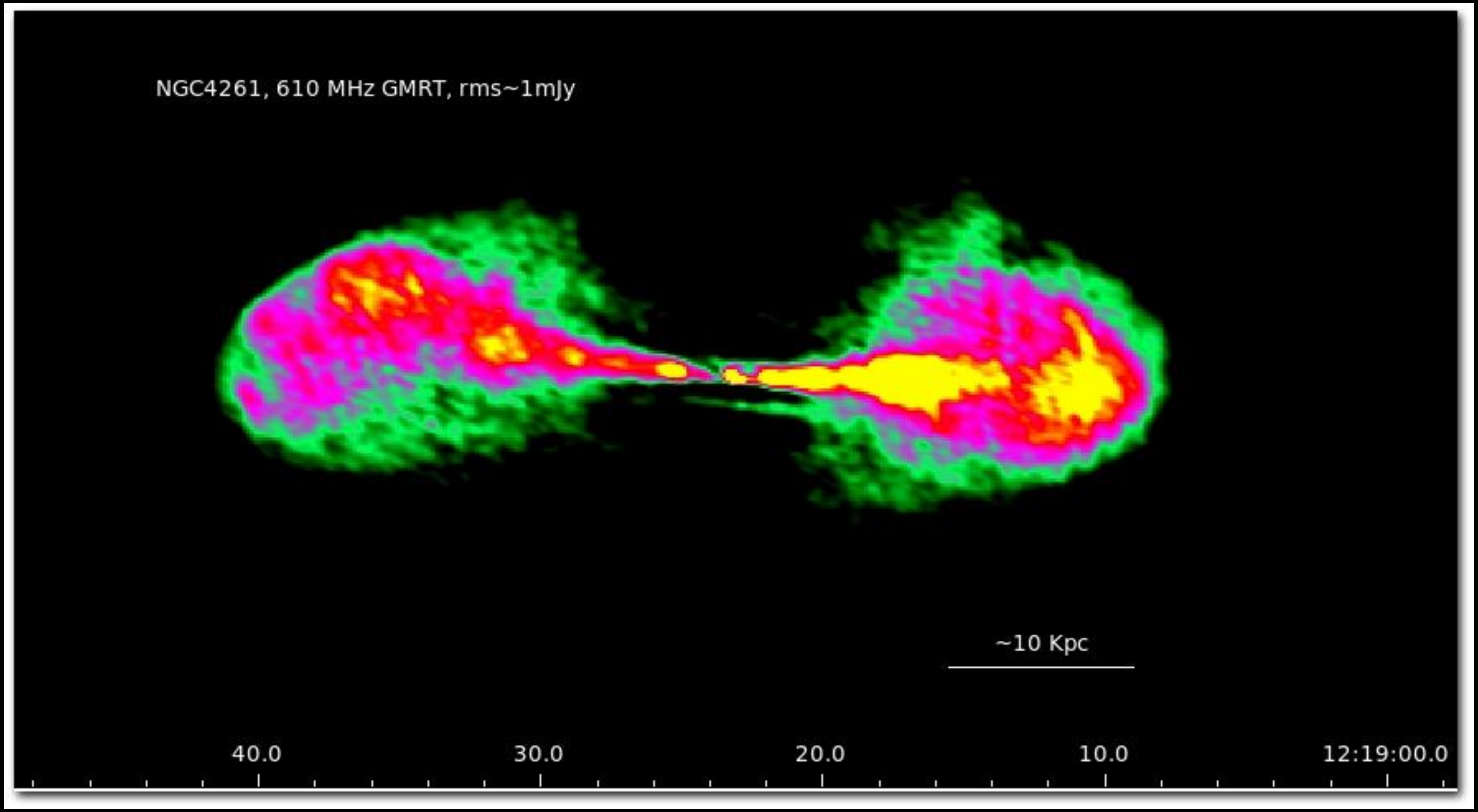
NGC 4261 (244MHz GMRT)

- On the left: Radio image of NGC 4261 at 244 MHz of rms ~1.3 mJy
- Contour levels start at 4σ and rise by factor of 2
- On the right: Optical image overlaid by 244MHz GMRT



NGC 4261 (610 MHz GMRT)

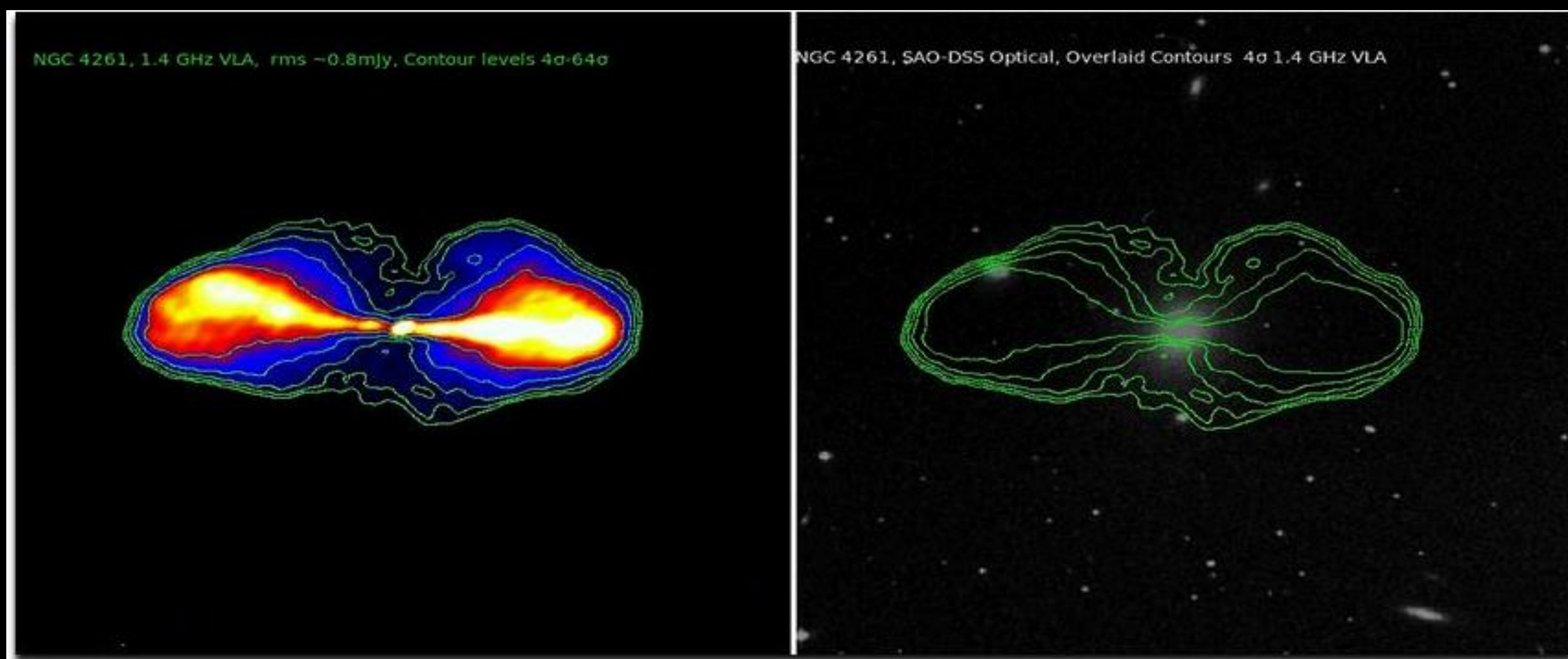
- Radio image of NGC 4261 at 610 MHz of rms ~1 mJy



NGC 4261 (1.4 GHz VLA)

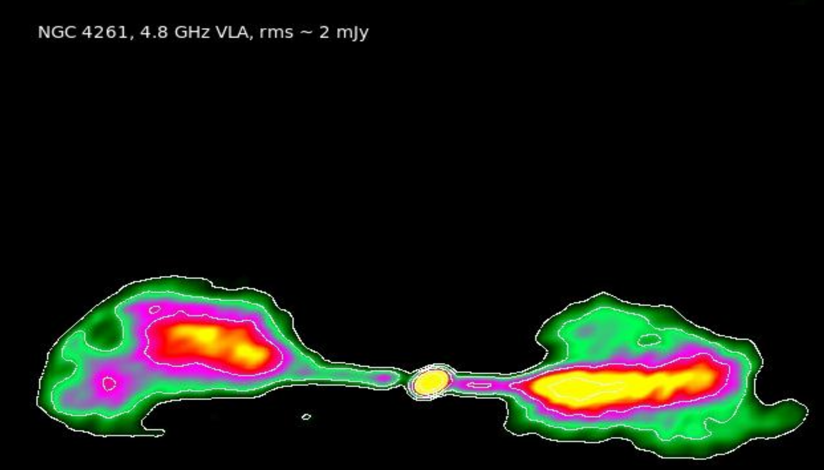
Project	Array	Frequency (GHz)	Integration time (min)	HPBW (Typical full array, $'' \times ''$)	rms mJy b^{-1}
DBCON 1	B&C	1.4	61	$\approx 19.01 \times 11.17$	0.8
DBCON 2	B&C&D	4.8	126	$\approx 18.6 \times 11.11$	2

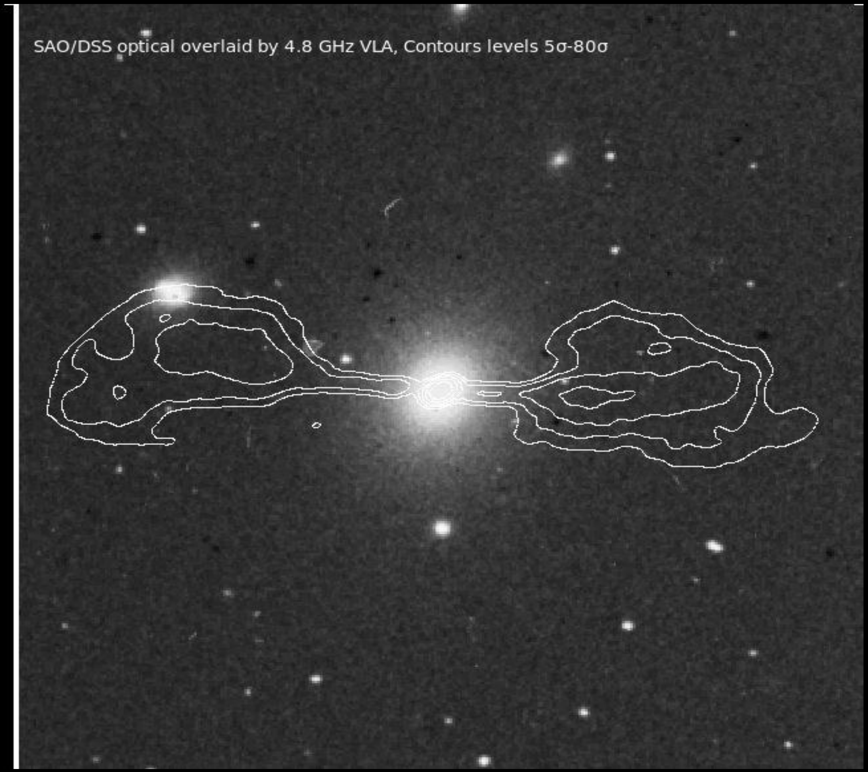
P						
A						
A'						
AH						
AH						
AH0303 A	1989 Mar 15	B	4.8	100	10	$\approx 1.5 \times 1.5$
AH0303 B	1989 Jul 28	BnC	4.8	100	10	$\approx 2.5 \times 2.5$
AP0077	1984 Apr 22	C	4.8	100	25	$\approx 4.0 \times 4.0$
AL0693 B	2007 Mar 18	D	4.8	50	81	$\approx 14 \times 14$



NGC 4261 (4.8 GHz VLA)

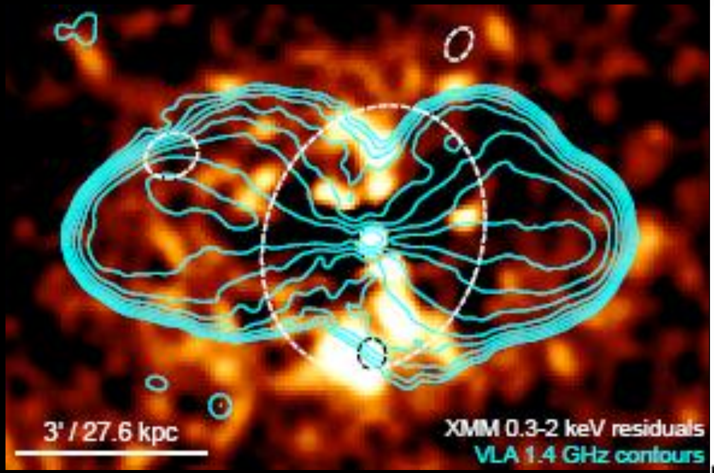
- On the left: Radio image of NGC 4261 at 4.8 GHz (VLA) of rms ~2 mJy
- Contour levels start at 5σ and rise by factor of 2
- On the right: Optical image overlaid by 4.8 GHz VLA radio contours starting at 5σ and rise by factor of 2

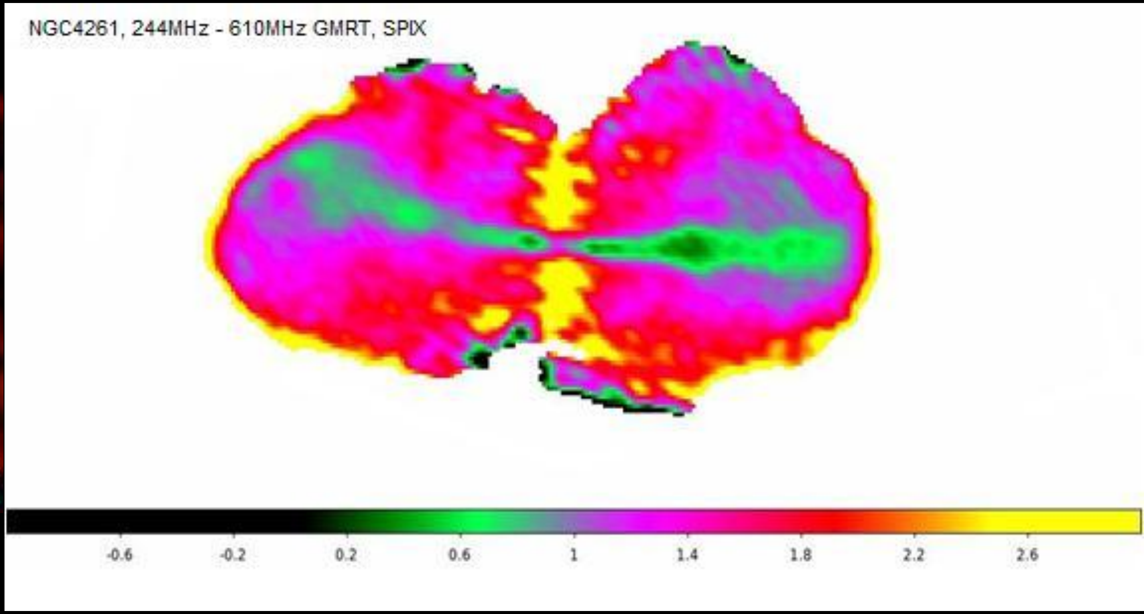




First results: NGC 4261 SPIX

- XMM residual map shows cavities corresponding to the lobes, & the N-S bar of X-ray emission (O'Sullivan et al 2011)
- Expansion of the lobes is probably responsible for the general north-south extension of the X-ray emission within the stellar body of NGC 4261
- Temperature map shows that the central gas is coolest → jets have pushed aside gas rather than heating it (O'Sullivan et al 2011)
- Steep spectral indices between the two lobes correlate with a bar-like X-ray structure and depolarization possibly indicating gas mixing

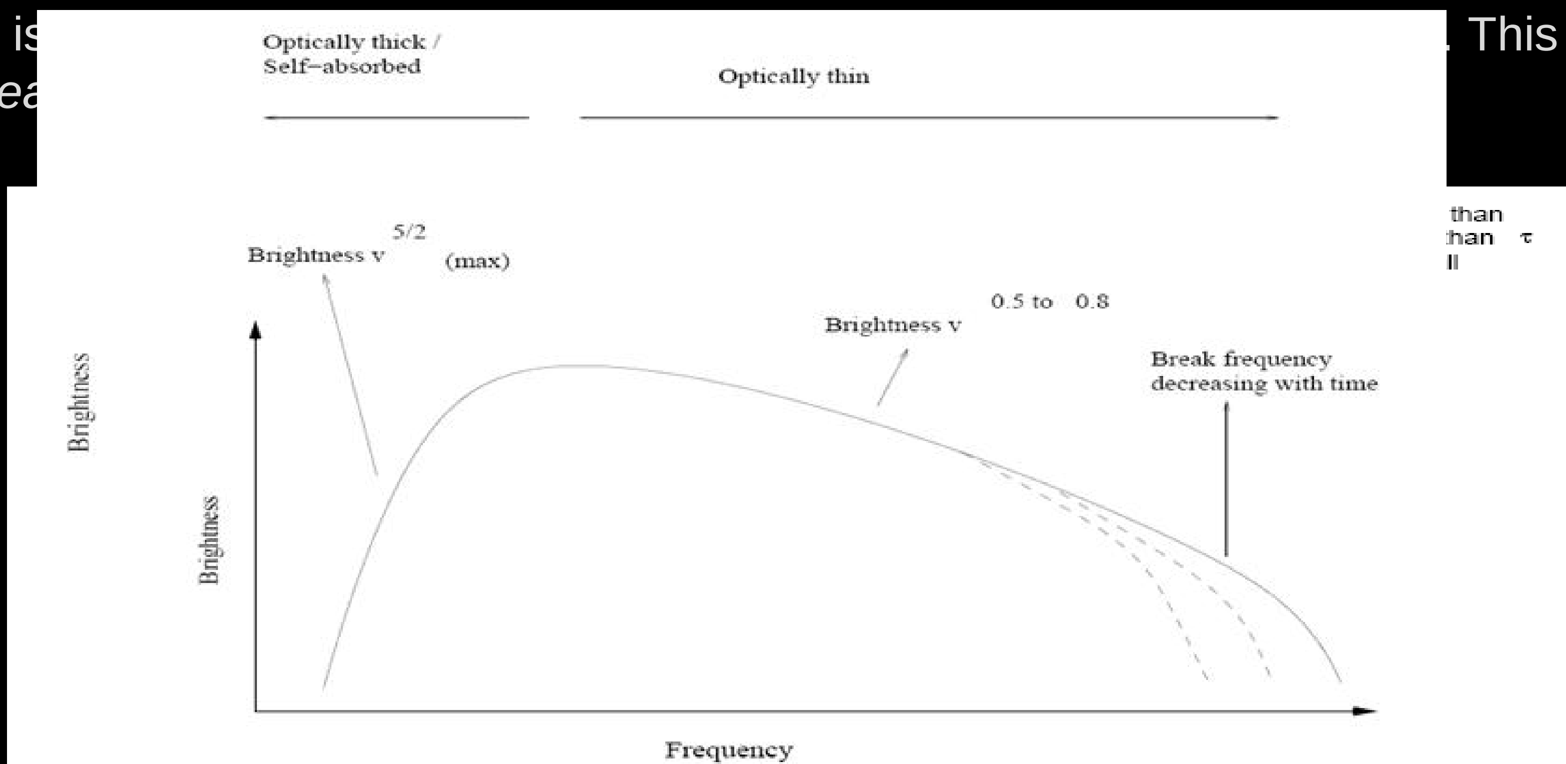




Synchrotron Spectral ageing

- <u>High-frequency cutoff:</u> Whatever the highest energies of the e^- in the initial synchrotron population if we return to a blob of synchrotron emitting plasma some time τ after it was accelerated, only e^- with lifetimes longer than τ will remain

- There is . This is the *brea*



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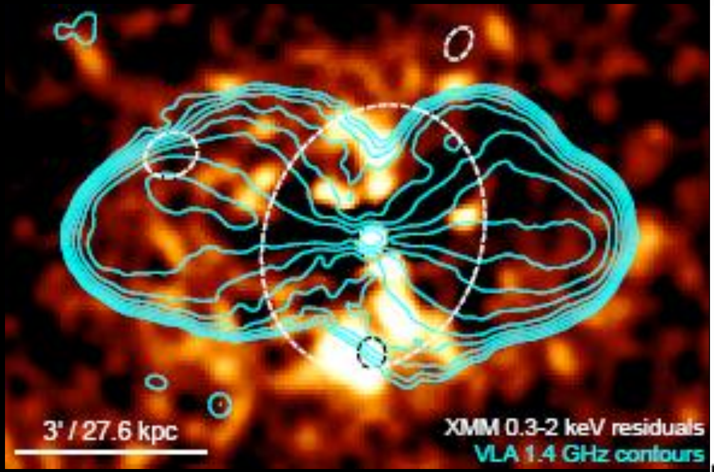
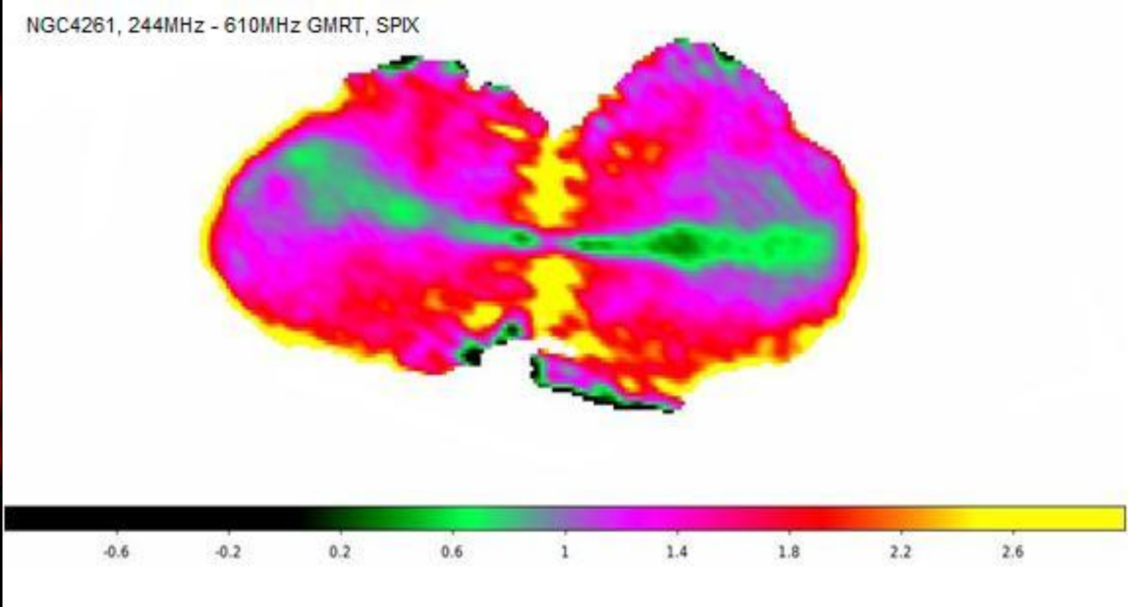
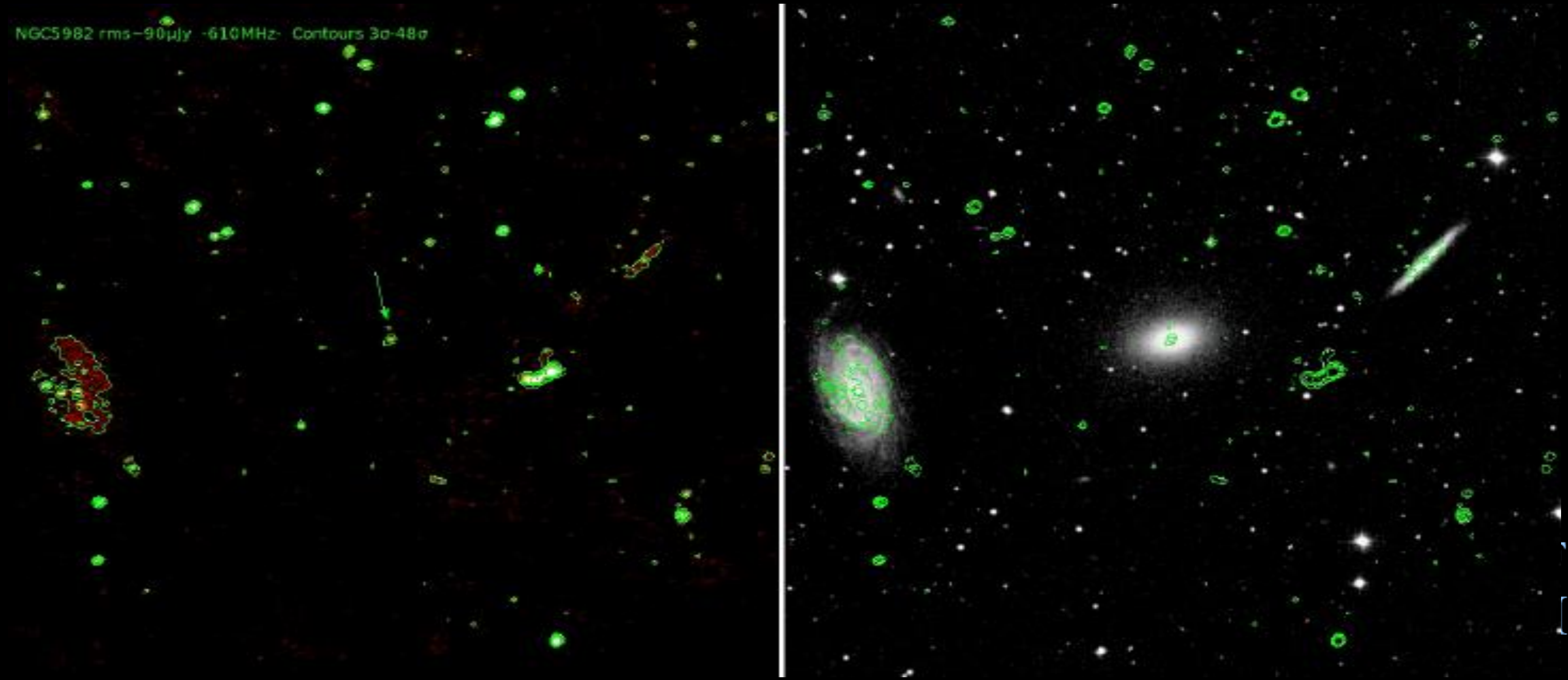




Results: NGC 5982 (610 MHz)

- NGC 5982: Face on elliptical galaxy (E3) placed in the NGC 5985 group, suggested to be a product of a minor merger (z~ 0.010064)
- Along with an edge-on barred spiral galaxy (NGC 5981) & a face-on barred spiral galaxy (NGC 5985) consist *Draco Trio*
- GMRT 610 MHz (~8.0” x 6.5”) reveal AGN in all, as well as star formation emission from the disk galaxies



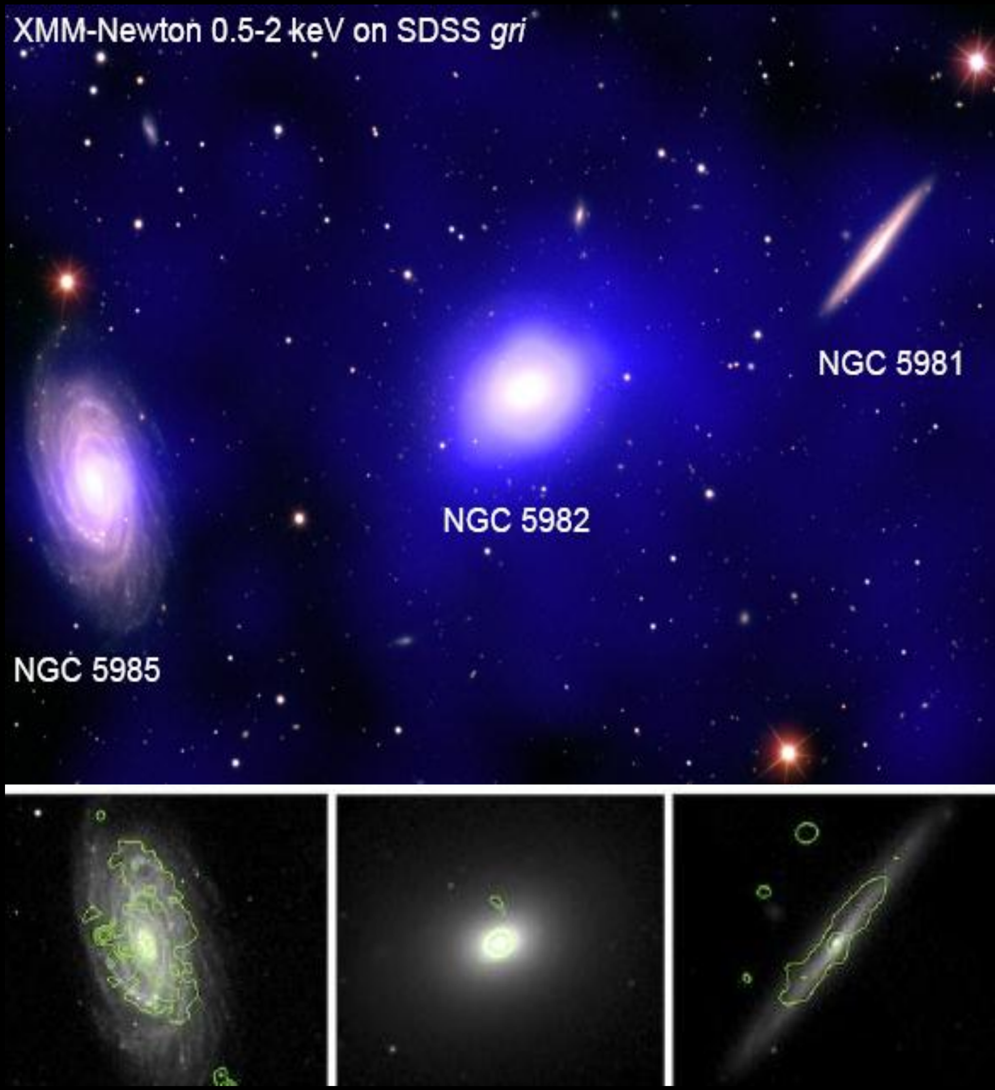
Results: NGC 5982 (Draco Trio)

- Radio fluxes:
- (left) NGC 5985 ~85 mJys
- (center) NGC 5981 ~2.5 mJys
- (right) NGC 5985 ~9 mJys

- ~12ksec XMM pointing detects ~0.5 keV group halo out to ~85 kpc

- Central AGN radio emission probably old & ceased (235 MHz analysis will show more)

- Central point sources co-existing with diffuse emission from the disks (AGN+SF). The AGN have not extinguished the SF



Conclusions (Take home points)

- The group environment is important to our understanding of galaxy evolution & role of AGN in governing star formation & IGM cooling

- Spectral index maps are used to investigate the interaction between radio source and surrounding environment (X-ray halo)

  - *X-ray provides*

    Location/properties of most baryons and an estimation of energy in cavities, shocks etc

  - *Radio provides*

    Timescales via synchrotron ageing, constraints on source geometry and direct view of AGN/gas interactions

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The end!

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CLoGS project (Complete Local-Volume Group Sample)

- CLoGS groups selected within this sample have:

- 4 or more member galaxies, excluding small associations which may lack a group-scale dark halo
- 1 or more early-type member galaxy
- optical luminosity L_B of at least $3x10^{10}L_{sol}$ for the brightest early-type galaxy, and
- Declination >-30°, to ensure visibility from the GMRT and VLA.

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Heating by AGN: Feedback

- **Evidence of AGN heating: Detection of X-ray structures (cavities, shocks etc) correlated with radio jets and lobes in numerous cool-core groups and clusters**
- **Combination of multi-frequency radio data and high-quality X-ray observations is required to provide insight into the processes involved**
- ***AGN feedback* is a loop process where energy in some form is produced from the central regions of the galaxy, which can heat up the inflowing gas**
- **If in sufficient quantity, provides enough energy to suppress star formation**
- **A basic requirement to this is that this heating occurs in a time comparable to the relevant cooling times**

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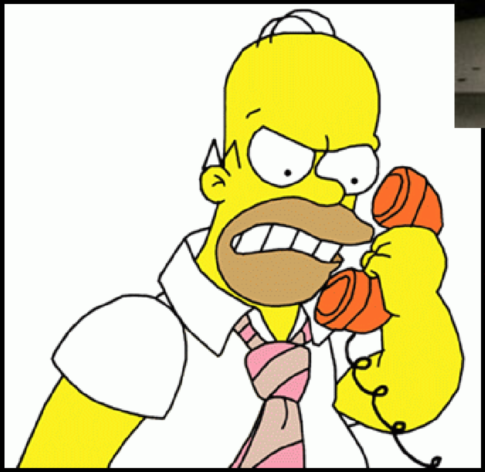
Radio Frequency Interference (RFI)



Data Analysis (AIPS)

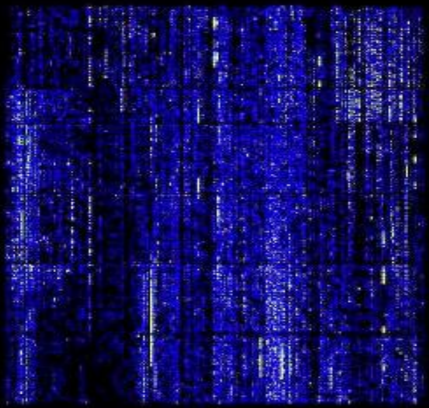
- Data analysis is done with Astronomical Imaging Processing System (AIPS)
- The observations at GMRT are done with a periodical switch between the source and the calibrators
- Phase difference between successive visibilities is used as task of goodness of our data

Source summary

Velocity type = 'TOPOCENT'   Definition = 'RADIO   '

ID	Source	Qual	Calcode	RA(2000.0)	Dec(2000.0)	No. vis
1	3C147	: 0000		05:42:36.1298	49:51:07.164	52200
2	1311-222	: 0000		13:11:39.3343	-22:16:41.725	69600
3	ESO507-25	: 0000		12:51:31.8042	-26:27:07.026	269700
4	NGC5153	: 0000		13:27:54.3044	-29:37:05.024	271440
5	3C286	: 0000		13:31:08.2443	30:30:32.530	16095
6	1449+632	: 0000		14:49:21.7252	63:16:14.440	46980
7	NGC5982	: 0000		15:38:39.8050	59:21:20.953	384540
8	3C48	: 0000		01:37:41.3139	33:09:35.174	42630

ID	Source	Freq(GHz)	Velocity(Km/s)	Rest freq (GHz)
1	3C147	0.6290	0.0000	0.0000
2	1311-222	0.6290	0.0000	0.0000
3	ESO507-25	0.6290	0.0000	0.0000
4	NGC5153	0.6290	0.0000	0.0000
5	3C286	0.6290	-62.0628	0.0000
6	1449+632	0.6290	0.0000	0.0000
7	NGC5982	0.6290	0.0000	0.0000
8	3C48	0.6290	-31.0330	0.0000



Synchrotron Spectral ageing

- Low-frequency cutoff : As a photon propagates through the plasma on its way out of the source, there is a chance that it will scatter off one of synchrotron e^- . This is *synchrotron self- absorption*
- If occurs many times before the photon can get out of the source, we 'see' emission from a thin layer near the surface of the source.