A Joint GMRT/X-ray Study of Galaxy Groups

Interactions between AGN and the hot intergalactic medium

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With thanks to: T. Clarke, N. Jetha, M. Murgia, D.J. Saikia, S. Immler, T.J. Ponman, W. Forman, C. Jones

Introduction

Galaxy groups are a very diverse class of objects:

- Elliptical dominated systems - e.g. previous talk
  - Hot (10^6-10^7 K) X-ray emitting gas in diffuse halo.
  - Cool gas (HI) typically only in galaxies at large radii.
  - FR-I/FR-II Radio galaxies with variety of morphologies, powers, ages (and feedback mechanisms?) heating IGM.
- Spiral-rich groups
  - No large halo of hot, X-ray emitting gas.
  - Cool gas (HI) located in galaxies or tidal features.
  - Low power AGN (Seyferts).

To understand galaxy/group evolution, we need information on both classes.

Key Questions

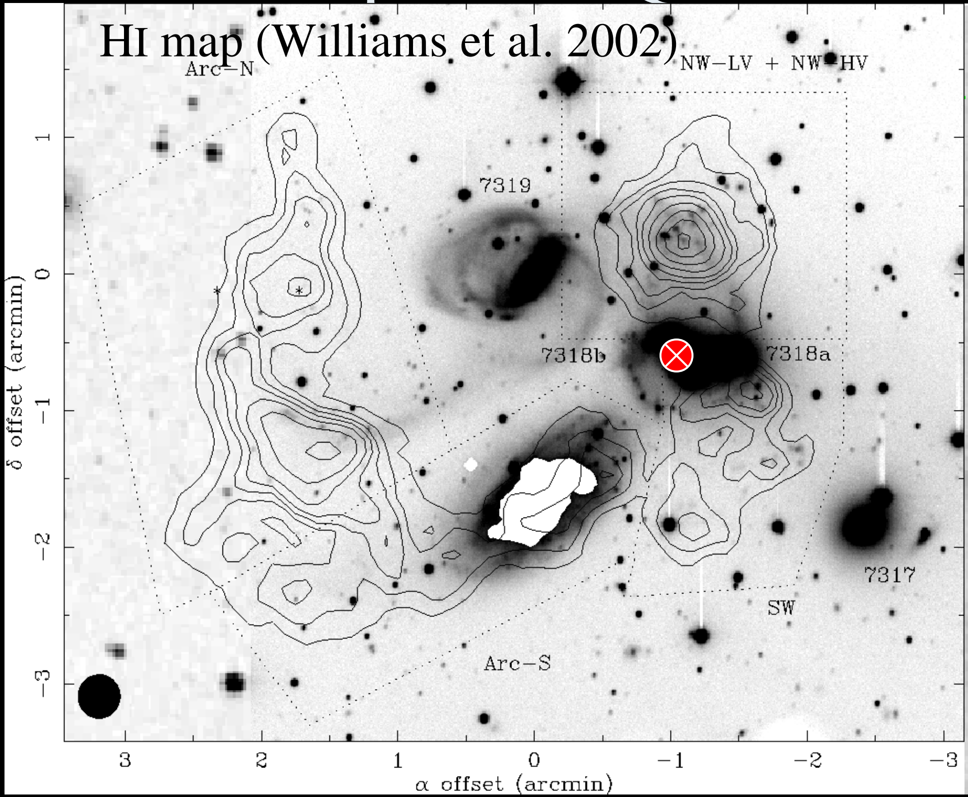
- Spiral-rich:
  - As groups evolve, what happens to the cool gas? How do we get from HI in galaxies to a diffuse hot halo?

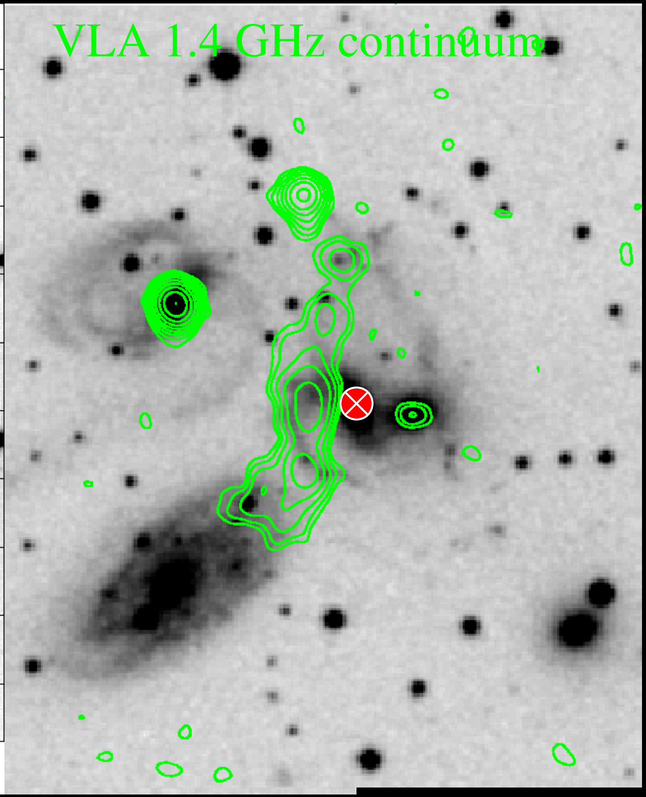
  ⇒Observe merging in groups - Stephan's Quintet

- Elliptical dominated:
  - How are observed radio and X-ray structures related?
  - What are the properties of the radio galaxies and what do they tell us about the age/duty cycles of AGN?
  - What are the mechanisms of energy injection?

  ⇒ Sample of 18 X-ray bright groups

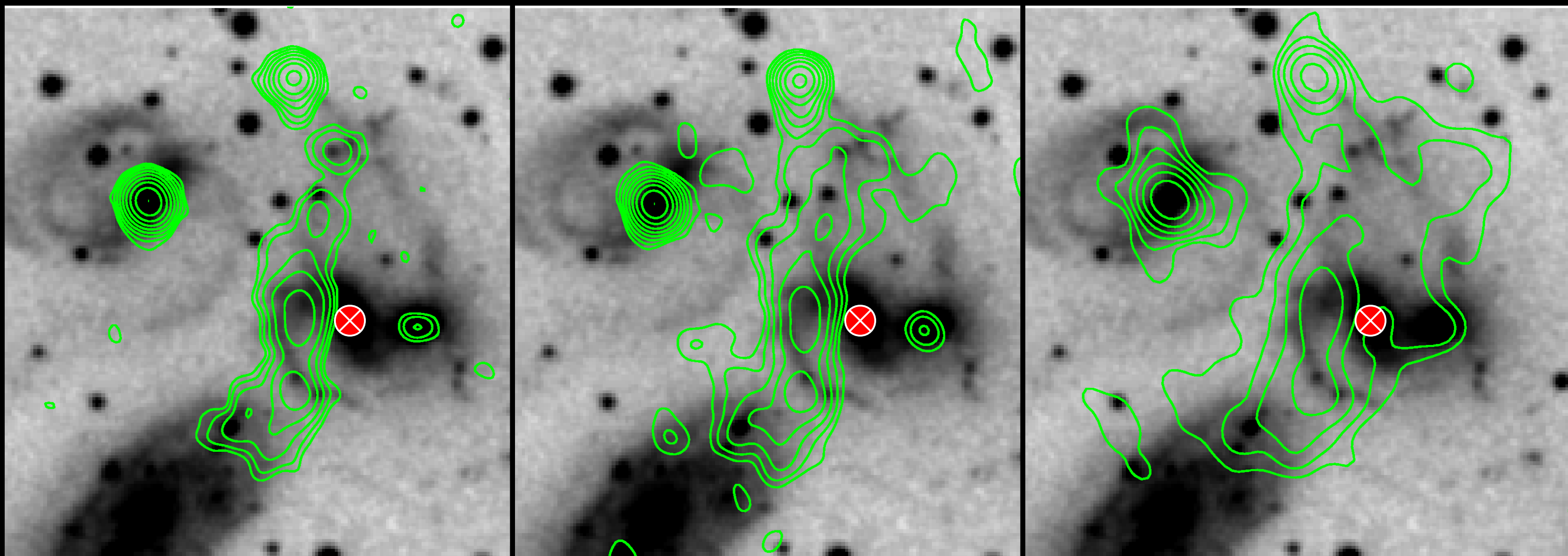
Stephan's Quintet - introduction





- 5 galaxies + 1 foreground (NGC 7320)
- NGC 7318b blue shifted - moving toward us at 900 km/s
- Optical and HI tails indicate past interaction(s) with NGC 7320c
- Radio continuum emission linking HI regions - shocked gas?

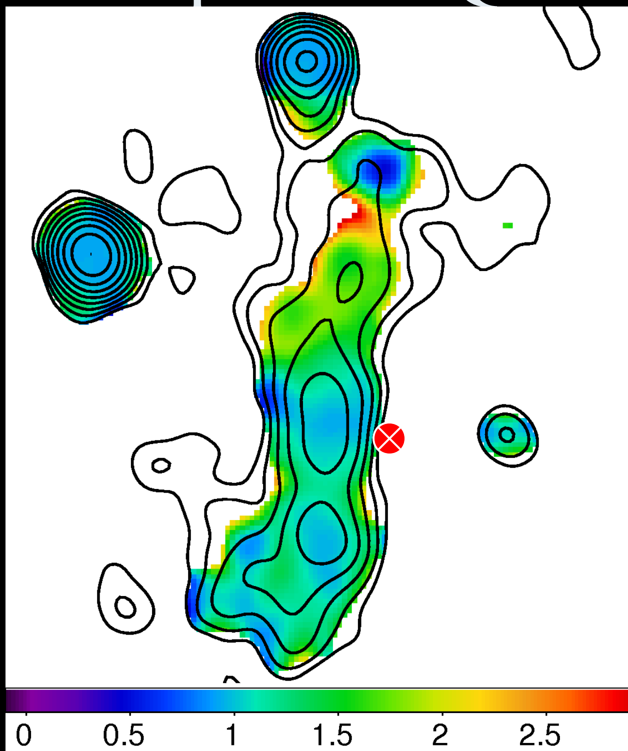
Stephan's Quintet - radio continuum imaging



VLA 1.4 GHz, res:8x8"   GMRT 610 MHz, res:6x5"   GMRT 325 MHz, res:12x10"

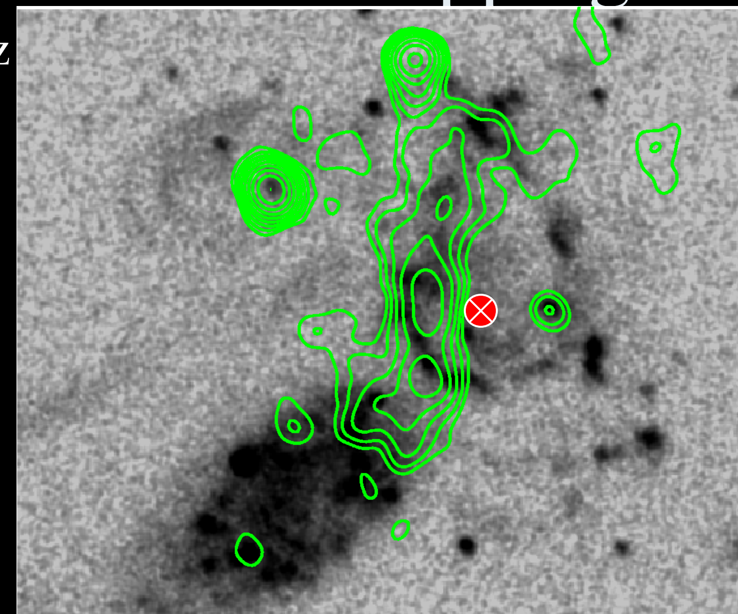
- Work in progress! GMRT data c/o D.J. Saikia & collaborators.
- High frequencies (VLA 1.4 & 5 GHz) highlight ridge.
- Ridge also detected in X-ray, Hα+NII, H_2.
- GMRT 610 & 327 MHz detect fainter emission to west.
- Brightest features in southern part of ridge, overlapping spiral arm.

Stephan's Quintet - spectral index mapping



1400-610 MHz
spectral index
res: 8"x8"

Contours:
610 MHz,
res: 6"x5"



610 MHz on Swift UVW2 (~200 nm)
c/o S. Immler

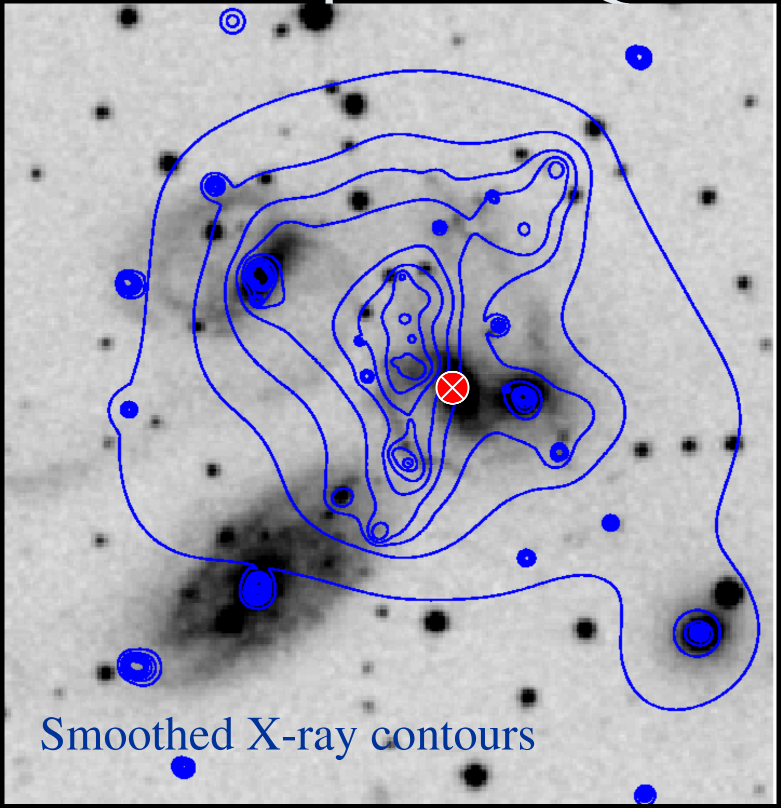
- Spectral index structure also differs between north and south of ridge
  ⇒ unlikely to be single source of emission

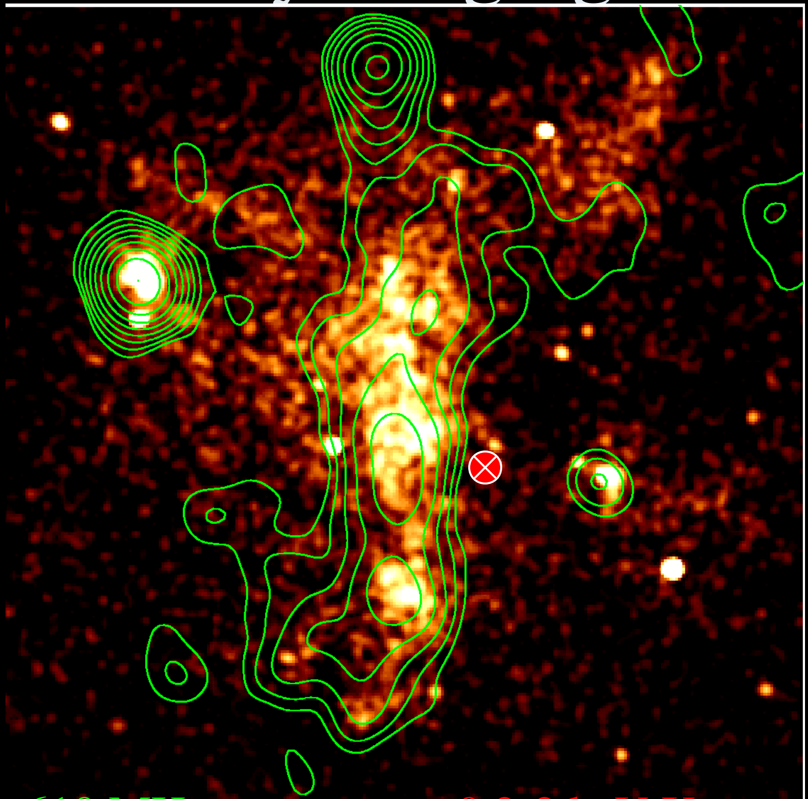
∀ α=0.7-0.8 consistent with star formation.

- Radio intensity peaks match UV bright knots ⇒ star formation.

⇒ Ridge is combination of star formation/SNae and shock emission.

Stephan’s Quintet - X-ray imaging

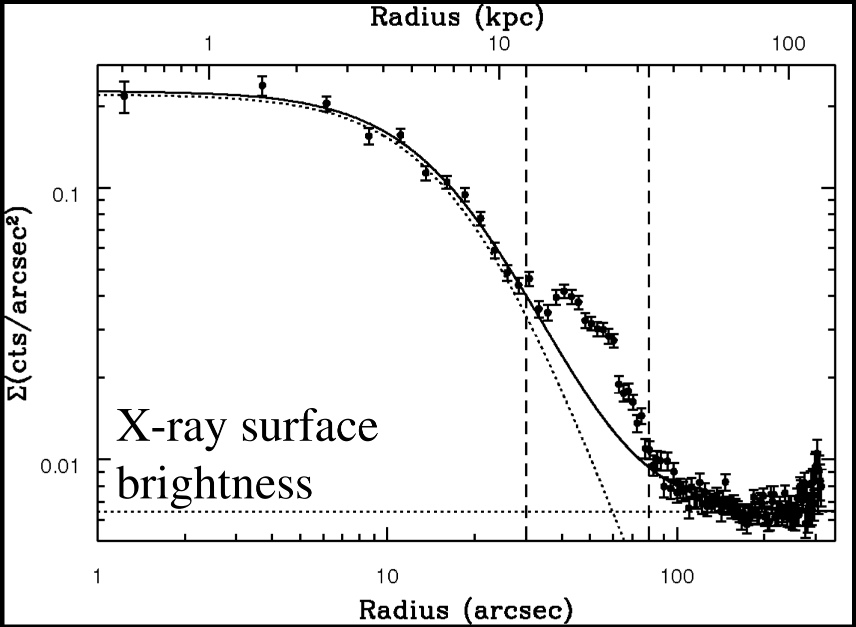


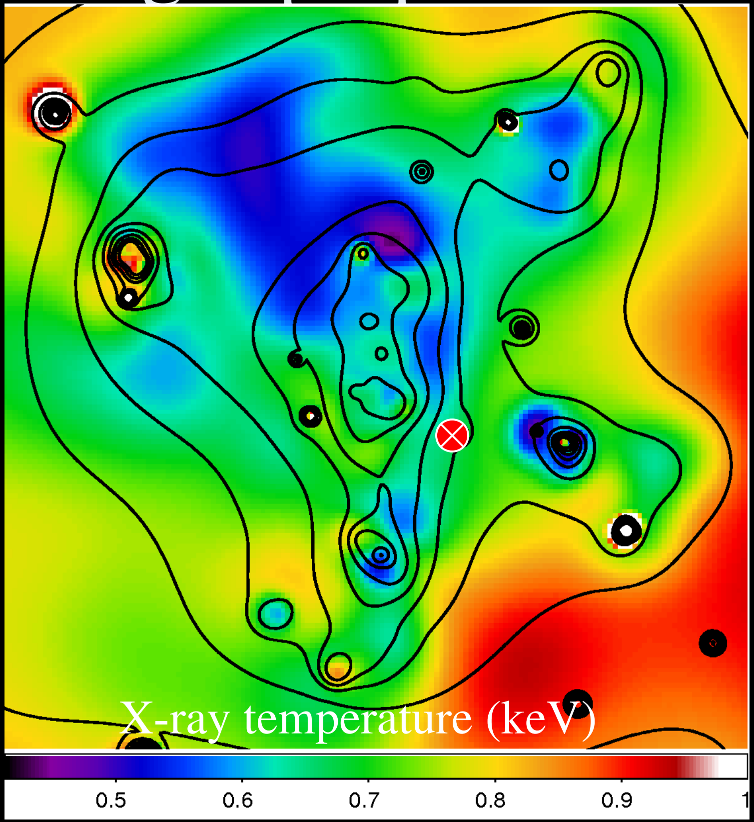


610 MHz contours on 0.3-2 keV X-ray

- Deep, 90 ksec Chandra pointing.
- AGN, X-ray binaries, bright ridge, other diffuse structures.
- X-ray brightest in north, radio brightest in south.

Stephan's Quintet - hot gas properties





- Gas extends 50+ kpc
- Mass ~2.8×10^{10} M_{sol}
- Group is HI deficient by ~2×10^{10} M_{sol} ⇒ shocked up to hot phase?
- Ridge is cool (0.6 keV) ⇒ oblique shock of HI filament?
- Expansion timescale (125 Myr to 50 kpc) longer than interaction timescale (20-80 Myr) ⇒ much of the hot gas predates collision.

Stephan's Quintet - Summary

- X-ray/Radio emission in ridge consistent with a combination of an obliquely shocked HI filament + star formation.
- Total mass of hot gas similar to HI deficit.
  $\Rightarrow$ HI may form core of hot gas halos of groups.
- Expansion timescale longer than interaction time.
  $\Rightarrow$ Previous interactions also caused shocks.

- Future plans: Radio analysis still underway - 4 frequencies between 325 MHz and 5 GHz will help constrain the interaction timeline and sources of emission in different regions.
- First X-ray results in O'Sullivan et al. (2008) arXiv:0812.0383

Key Questions

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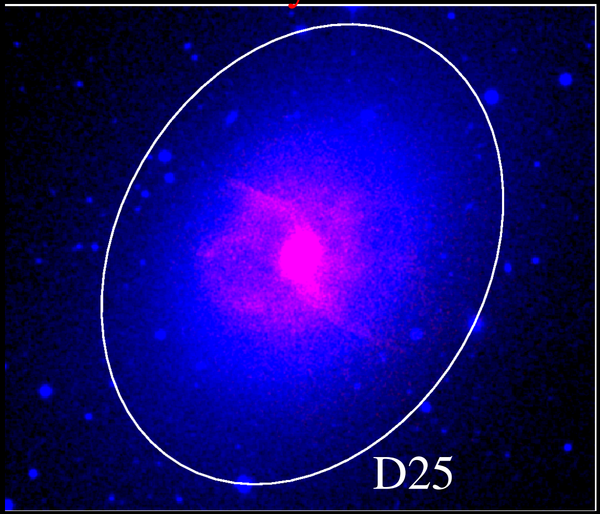
NGC 4636 - restarting jets

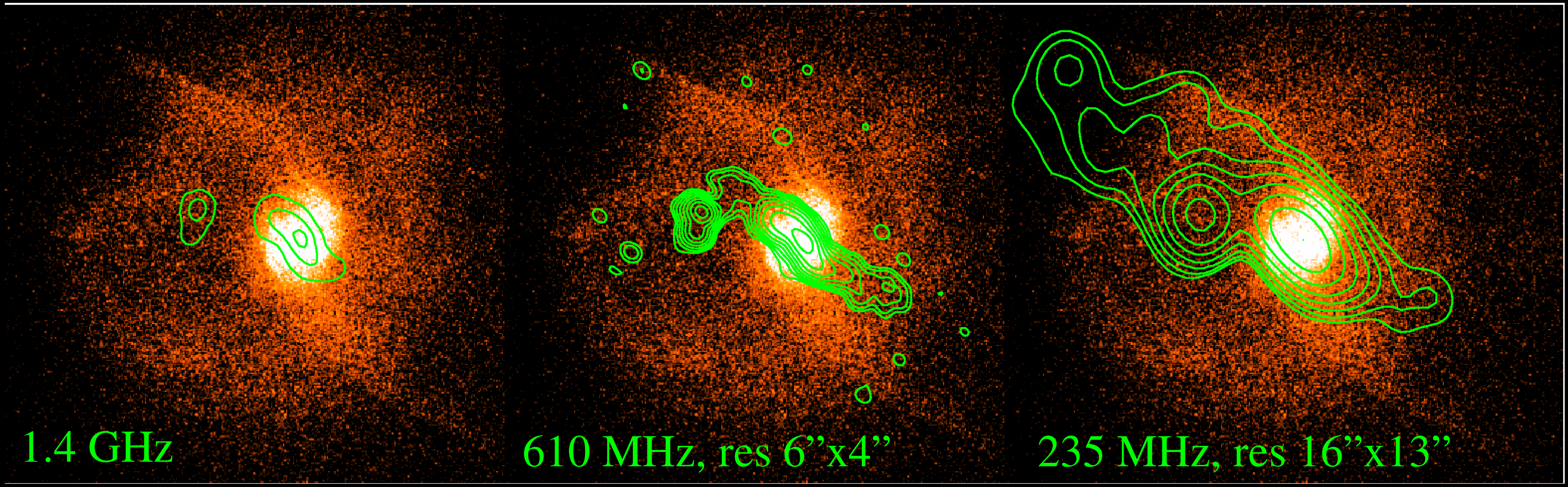
Chandra X-ray on DSS



- Cool core, cavities and shocks in X-ray gas.
- VLA 1.4 GHz shows small jets active now.
- GMRT 610 and 235 MHz reveal much more extended emission correlated with X-ray

⇒Young jets pushing out into old lobes/cavities

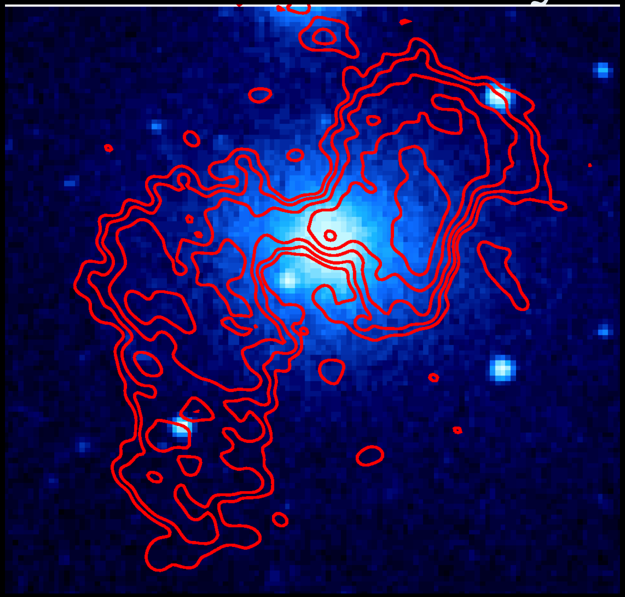
⇒ With 150 & 325 MHz data, we will be able to estimate age & duty cycle.



r.m.s=0.05 mJy/b

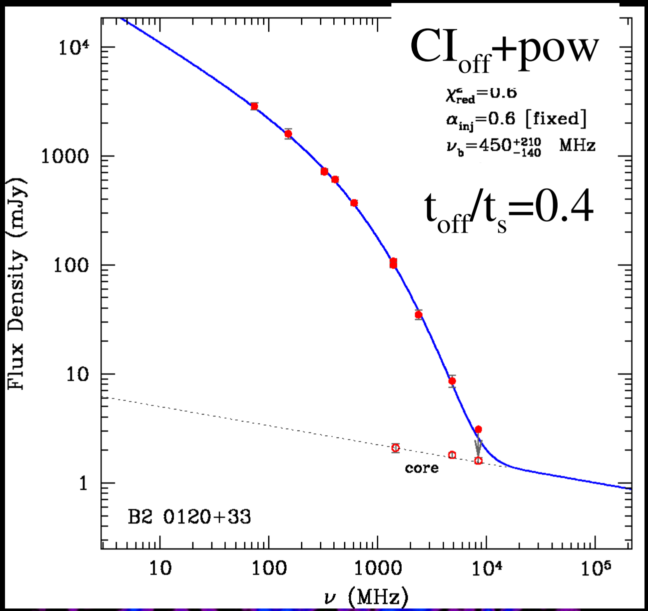
r.m.s=0.2 mJy/b

NGC 507 - a dying source



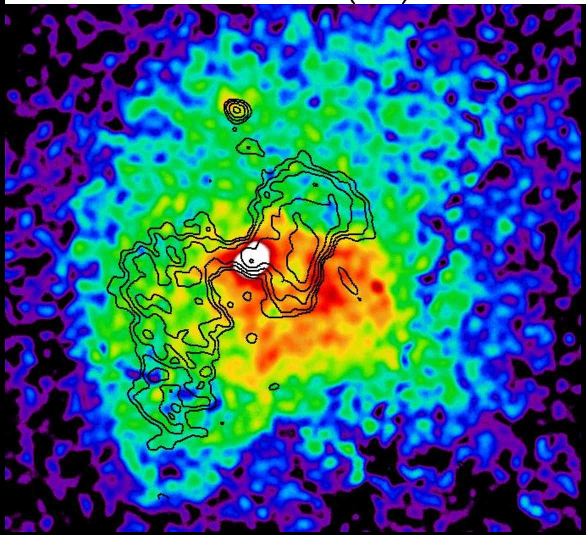
610 MHz on
DSS optical
(Res: 5x5”)

Murgia et al.
(submitted)



- No kpc-scale jets
- Multi-freq. data allows spectral index fit

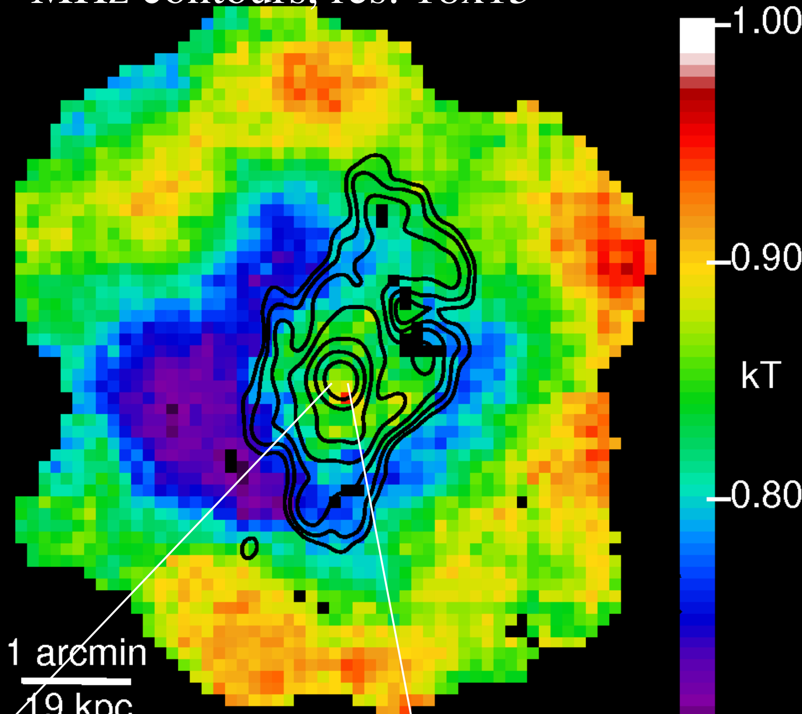
  estimate total age of source, dying phase ~30% of lifetime.
- Distorted lobes correlate with X-ray intensity, temperature, abundance
- Surrounding X-ray gas compresses radio lobes, extending visible lifetime?

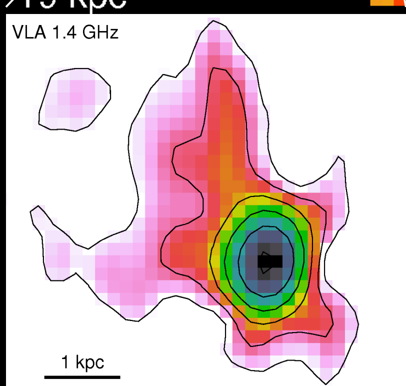


Chandra 0.3-2 keV X-ray image

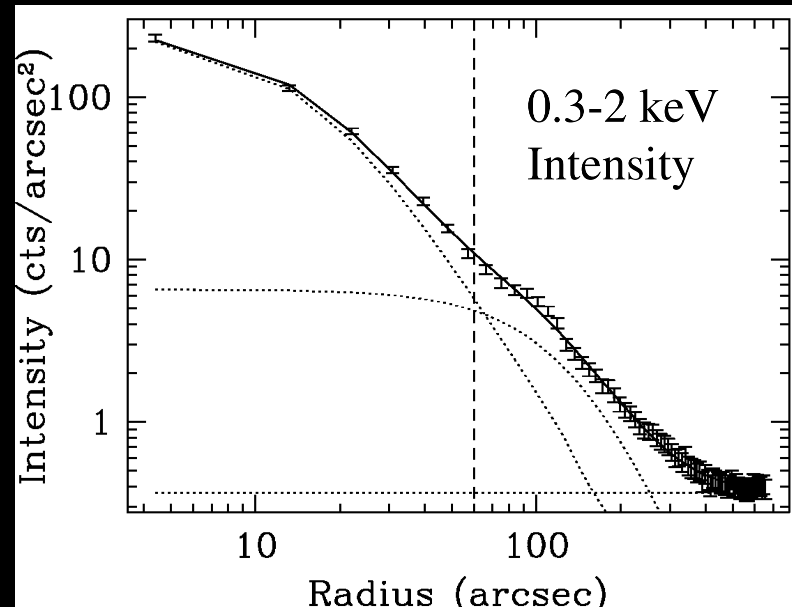
NGC 3411 - amorphous

X-ray temperature w. GMRT 610 MHz contours, res: 18x15”





VLA 1.4 GHz
res: 2.3x1.6”



- Unusual cool shell around hot core.
- 2×10^{57} erg required to heat cool core.
- 610 MHz diffuse emission agrees with temperature structure ⇒ AGN heating, but no jets seen.
- Either: cavities in line of sight (but no drop in surface brightness).
- Or: hot gas/radio plasma mixing?

Conclusions

- Low-frequency imaging reveals structures not previously seen, particularly in faint/old sources.
- Good frequency coverage allows modelling of the spectral index to determine ages and timescales of outbursts, complementing X-ray determination of energy output.
- Heating mechanisms other than the standard jet/cavity formation may be possible.
- Combination of multi-band, low-frequency radio data with deep X-ray observations key to understanding AGN/gas interactions, group/galaxy evolution.