1321+045: a CSS source in a cool-core galaxy cluster

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(see O’Sullivan et al. 2021, arXiv:2104.04548)
Introduction

• Cluster-dominant galaxies are a special location for AGN
  ▶ Host most massive black holes
  ▶ ~10x more likely to host radio AGN than non-central galaxies (Best et al. 2007)
  ▶ Cooling from ICM fuels repeated periods of jet activity

• Observations of surrounding ICM can help us study radio sources (fuelling, jet power, particle content, etc.)

• Identifying young radio sources could help us examine conditions that trigger feedback in clusters
Cluster-central CSS/GPS

- Relatively few have been studied:
- ~8.5% of BCGs in cool core clusters have GPS-like spectral features (Hogan et al. 2015)
- New cycle of activity in NGC 5044 is GPS-like: 4.5pc jets, self-absorbed spectrum peaking at 1GHz (Schellenberger et al. 2021)
- CSS sources in clusters:
  - 3C186: QSO in 8 keV cool-core cluster at z=1.06 (Siemiginowska et al. 2005, 2010, Migliori et al. 2012)
  - IRAS F15307+3252: QSO in 2 keV group at z=0.93 (Hlavacek-Larrondo et al. 2017)
  - 1321+045: in 4.4 keV cluster at z=0.263
1321+045: previous studies

- FR-I with ~16kpc lobes, spectral index $\alpha=-0.95$ (Kunert-Bajraszewska et al. 2010)
- *Chandra* 9ks snapshot shows 4.4 keV cluster with cool core (K-B et al. 2013)
- Lobes over-pressured by factor ~2 compared to ICM
- Relaxed cluster galaxy population (Wen & Han 2013)
- $L_{H\alpha}=4.5\times10^{41}$ erg/s (Liu et al. 2012) similar to cooling $H\alpha$ nebulae in low-z clusters
1321+045: new observations

- 80ks Chandra X-ray observation
- 2.5hr VLBA C-band (+1.5min archival VLA)
- 12hr IRAM 30m CO(1-0) & (3-2): non-detection, $M_{\text{H}_2} \approx 6 \times 10^9 \, M_\odot$
VLA and VLBA data

- Archival VLA 4.9 GHz confirms MERLIN 1.6 GHz morphology
- VLBA reveals 20pc jet in core, ~90º offset between jet axes
- Expansion timescale of 20pc jet = ~few hundred years
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Radio spectrum

• Continuous Injection model a good fit to 74 MHz - 4.9 GHz

• GLEAM survey points show break at 147 MHz
  => Lobe age ~2 Myr

• CI+off model: cutoff frequency poorly constrained, >290 GHz

• Lobes either still powered by jets, or only shut down <10^5 yr ago?

\[ \alpha_{\text{inj}} = 0.5 \text{ (fixed)} \]
\[ \nu_{\text{break}} = 147^{+39}_{-36} \text{ MHz} \]
\[ \chi^2_{\text{red}} = 1.1 \]
ICM: disturbed structures

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ICM: radial profiles

- ICM properties similar to other cool-clusters (e.g., ACCEPT sample, Cavagnolo et al. 2009)
- Thermal instability indicators ($t_{\text{cool}}/t_\text{ff}$, $t_{\text{cool}}/t_\text{eddy}$) suggest $\sim$45kpc cooling/condensation region
- $L_{\text{cool}}$ (within $t_{\text{cool}}<7.7\text{Gyr}$) $\sim$3.1x$10^{44}$ erg/s, Jet power $\sim$1.4x$10^{44}$ => close to thermal balance
Conclusions

• 1321+045 is hosted by a cluster with properties similar to strong cool-core systems at low redshift.
• Evidence of recent minor cluster merger - triggering event for AGN?
• Outer 16kpc lobes are ~2Myr old, probably capable of balancing ICM cooling if they are still powered by the jets.
• Inner 20pc VLBA jet few x100 yr old, ~90° offset from axis of older lobes.

Two possible scenarios:
1) Lobes and inner jet represent two outbursts, AGN jet axis has changed
   - reorientation timescale for the AGN is very short, ≲10^5 yr
2) Jets/lobes aligned close to line of sight, precession and bent jets explain apparent axis difference
   - inner jet is one-sided, W lobe significantly brighter than E
   - no detection of the AGN nucleus in X-ray, L_{2-10keV} < 1.5x10^{43} erg/s