Radio Emission in Low Luminosity AGN: Magnetic Fields, Duty Cycles, Feedback, and SKA

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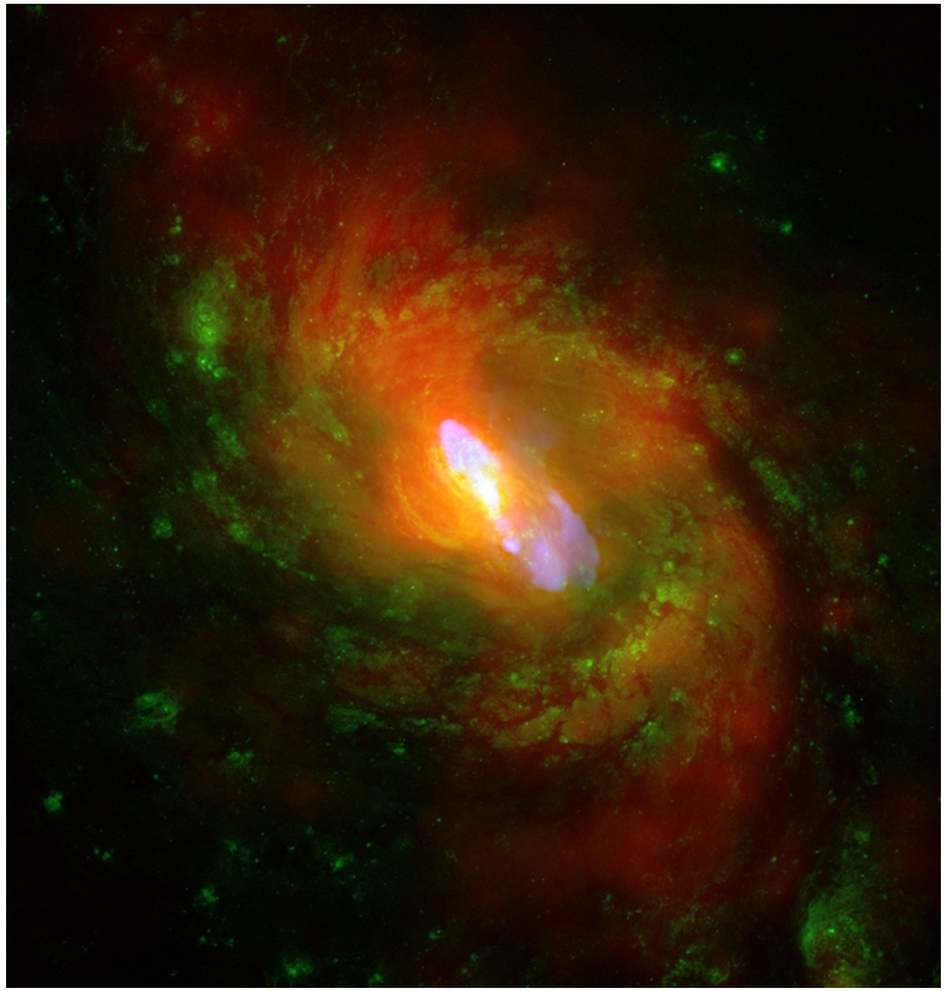
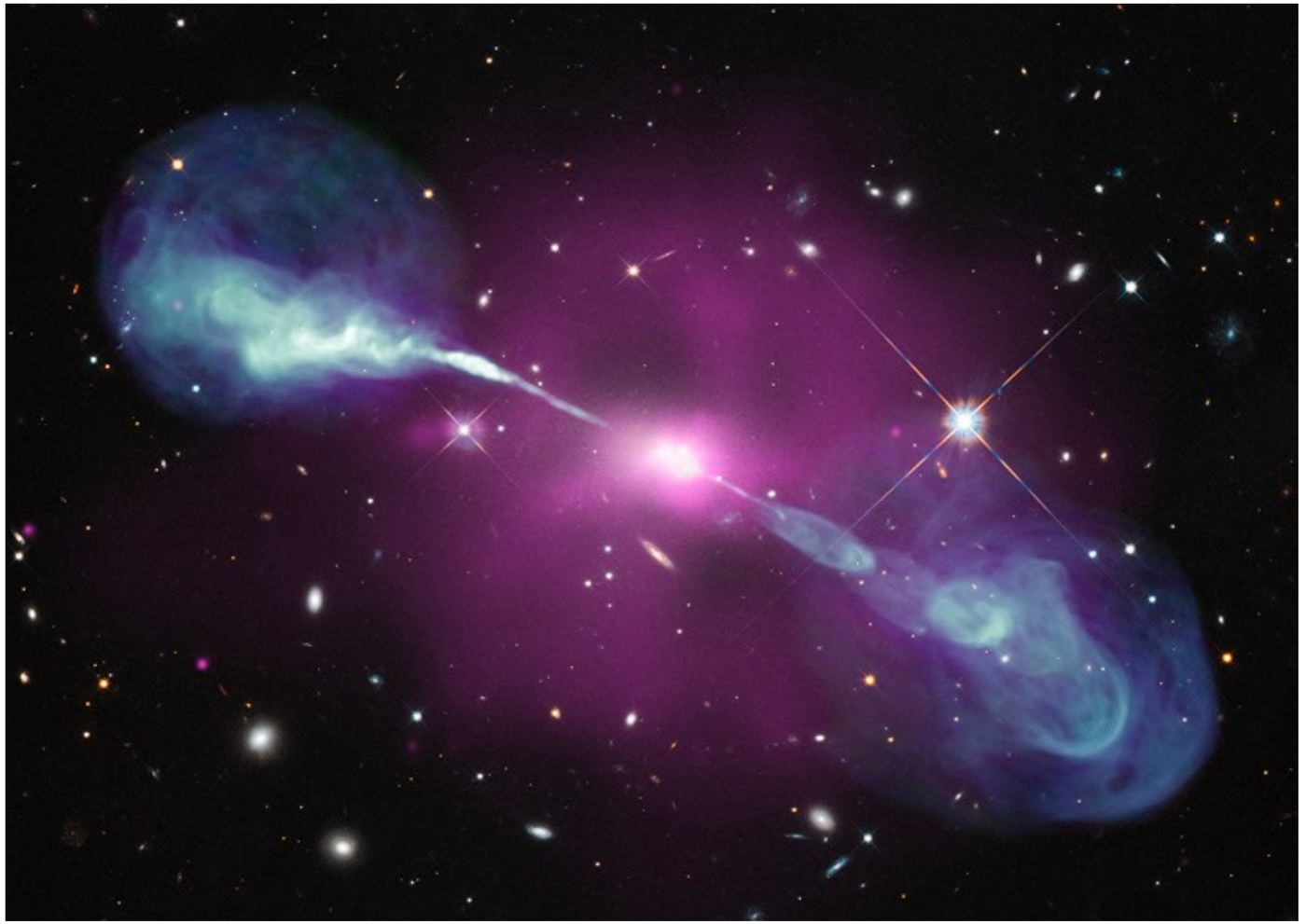
LLAGN: Seyfert galaxies & LINERs

- Seyfert galaxies: Star-like nuclei with emission-lines in their spectra (Carl Seyfert 1943).
- LINERs: Low ionisation nuclear emission line regions (Heckman 1980).
- Radio-to-optical flux density ratio, $R = S_{5\,GHz}/S_{B\text{-}band}$, shows bimodality at ~10 (Kellermann+ 1989). Seyferts & LINERs have $R \leq 10$.
- RQAGN make >80% of sources in complete samples.

Radio-quiet AGN



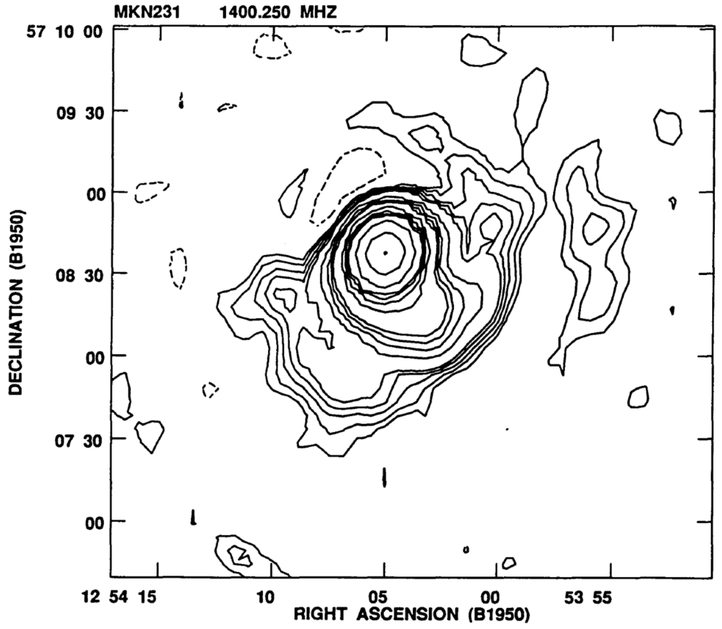
Radio-quiet AGN — NGC1068

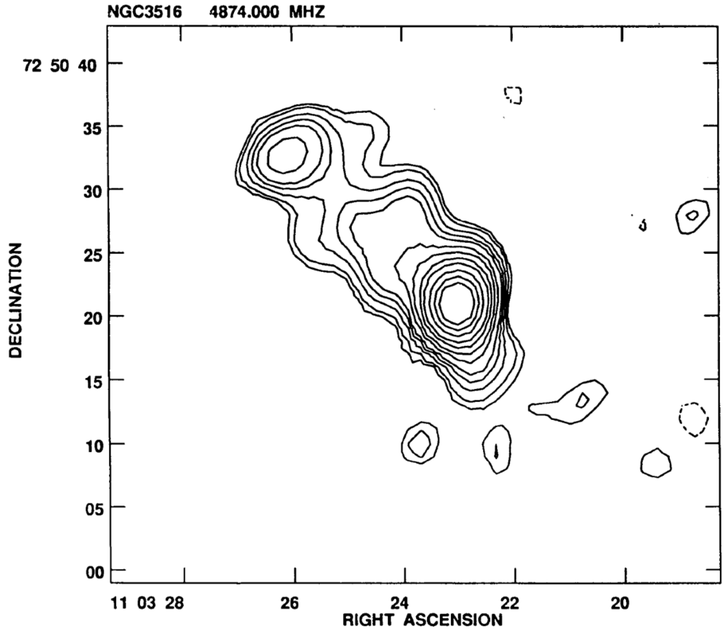


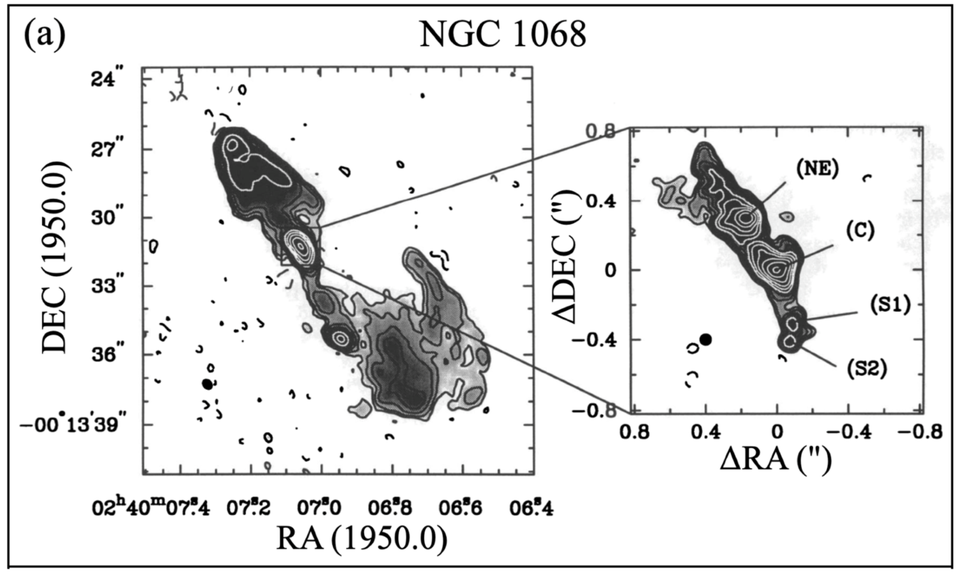
Radio-loud AGN — Hercules A

Improvement in Sensitivity: B-fields & multiple episodes

Radio emission from RQ AGN



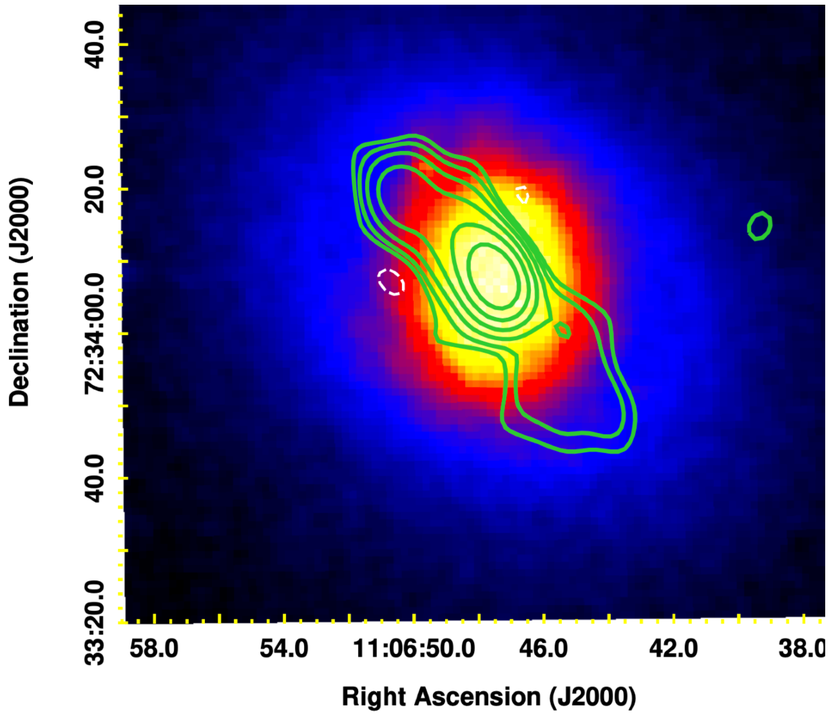


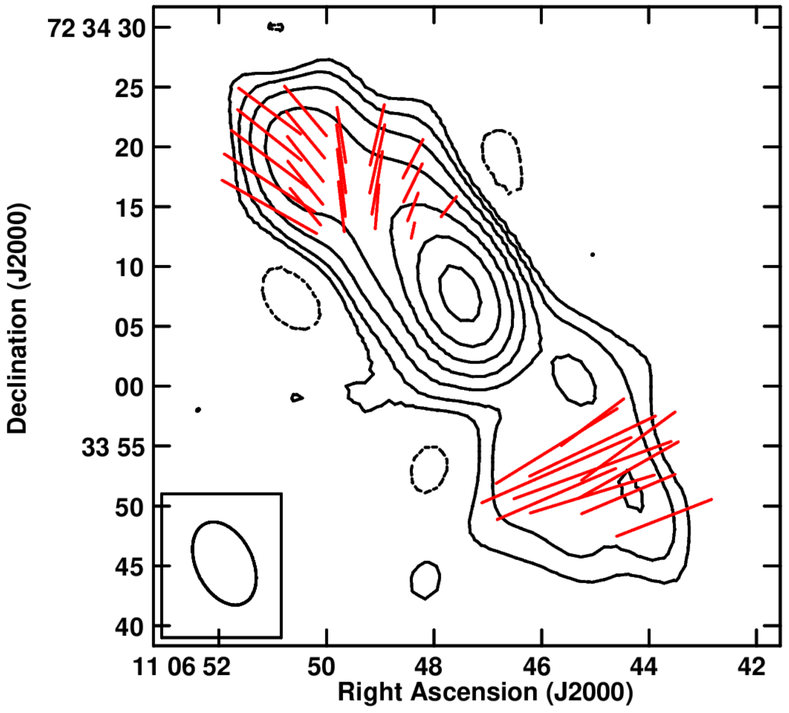


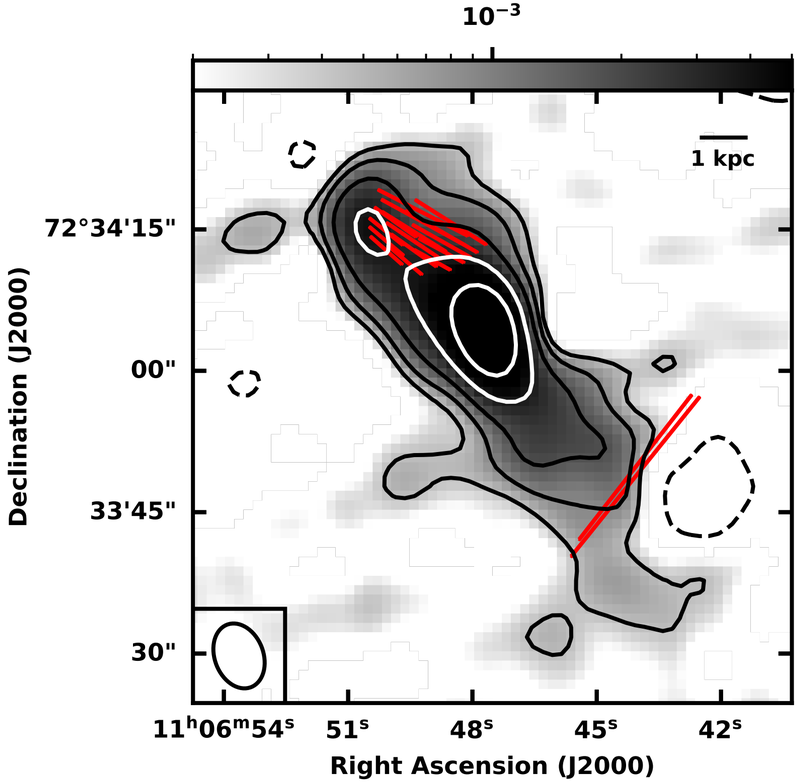
Seyfert galaxies with WSRT (Baum+ 1993) and VLA (Gallimore+ 1996)

AGN-driven radio outflows in RQ AGN (e.g., Gallimore+ 2006)

The Seyfert galaxy NGC3516

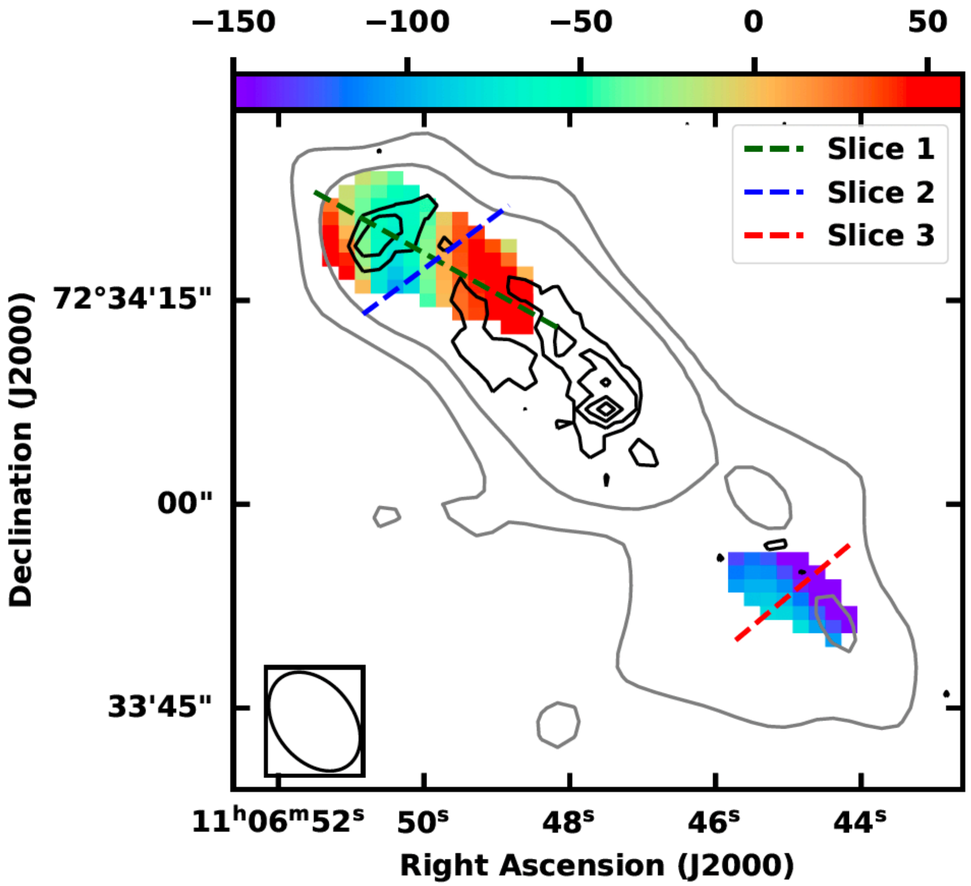


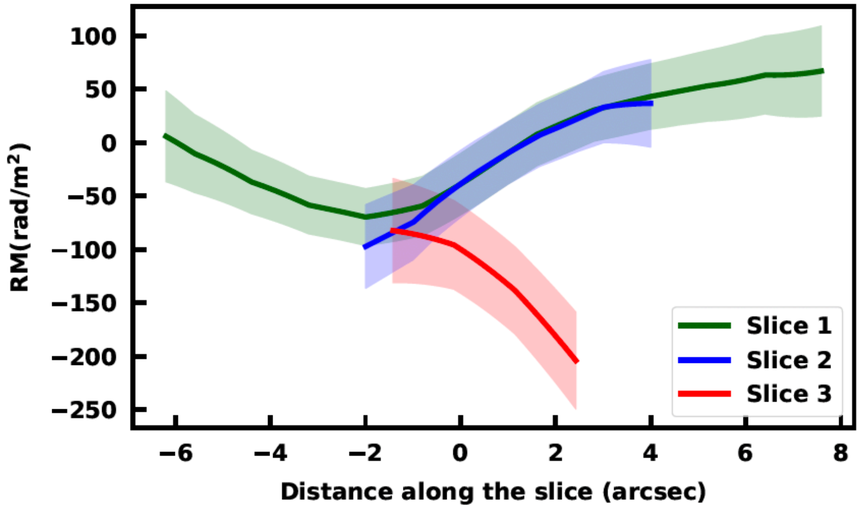




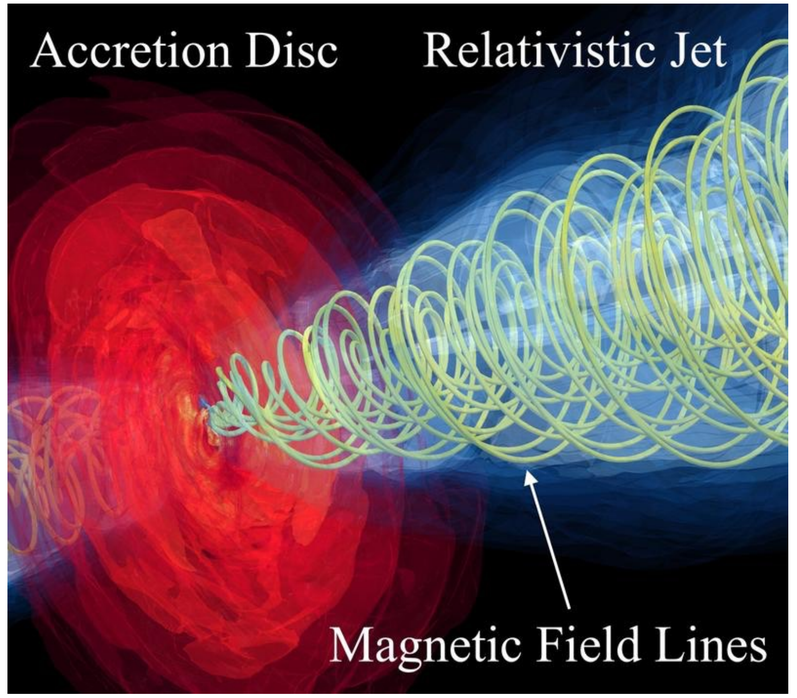
VLA 10 GHz image showing high degrees of linear polarisation, ~15-20% (Salmoli Ghosh+ 2025a). GMRT 650 MHz emission shows additional lobe emission (Salmoli Ghosh+ 2025b)

An RM Gradient in NGC3516



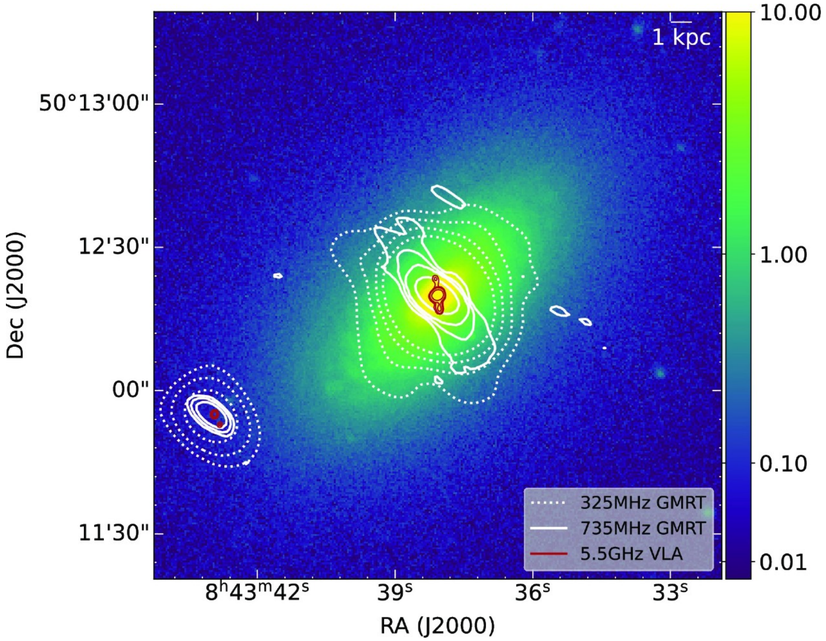


$$\mathrm{RM} = 0.812 \int n_e(l)\, B_{\parallel}(l)\, dl$$

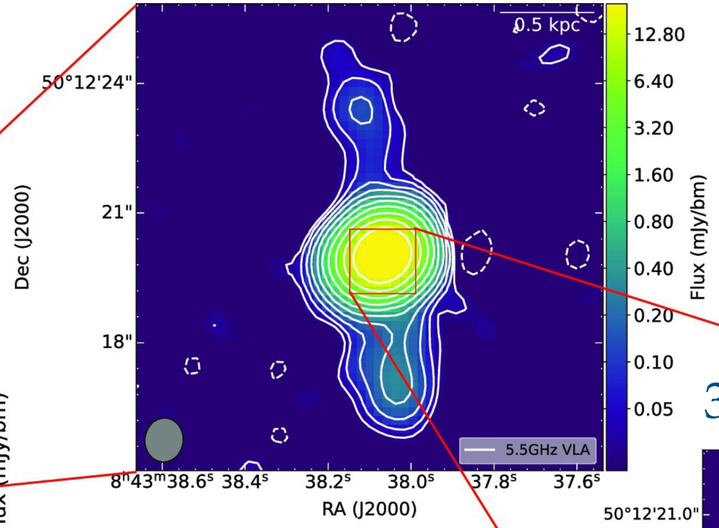


Helical B-fields? Magnetically launched jets in RQAGN? (Salmoli Ghosh+ 2025b)

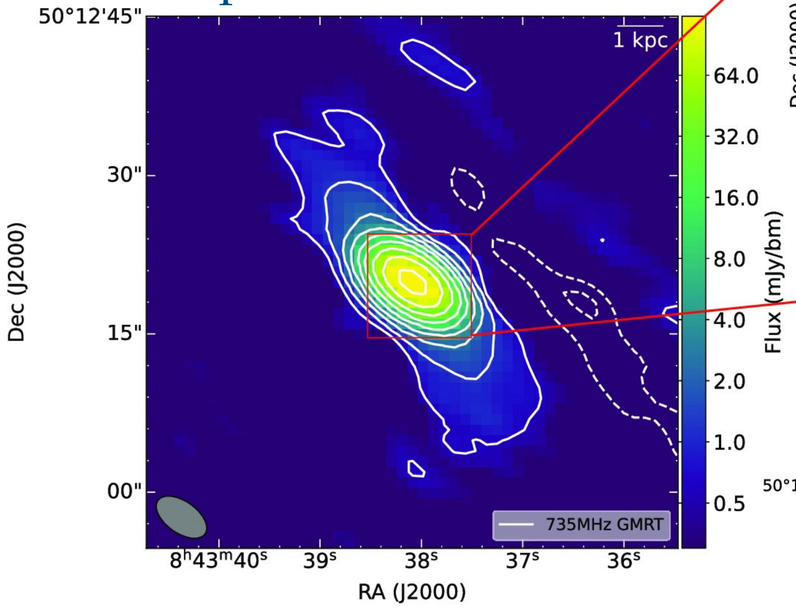
The multiple episodes of NGC2639



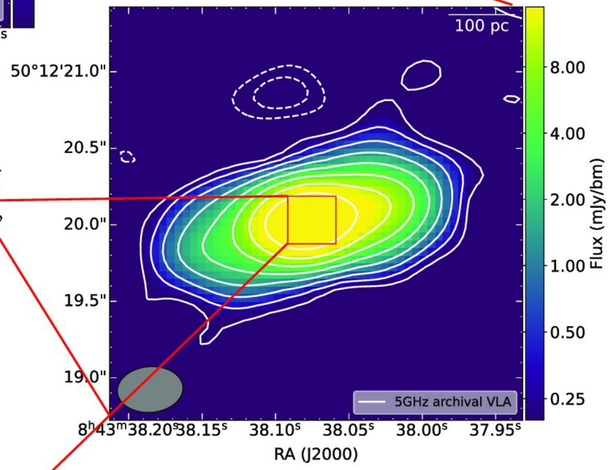
1.5 kpc VLA B @6 GHz



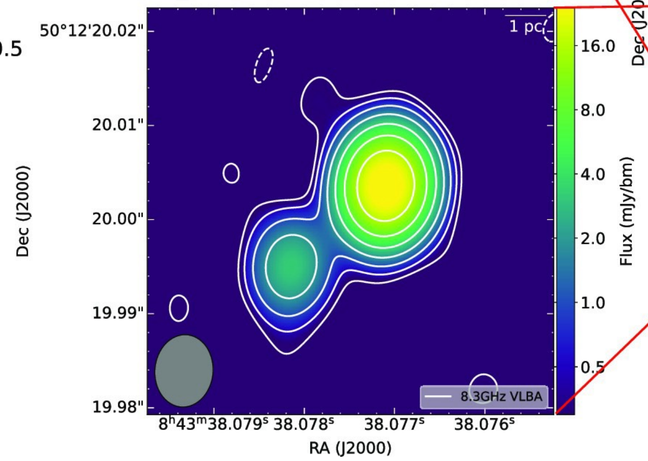
9 kpc GMRT @735 MHz



360 pc VLA A @5 GHz

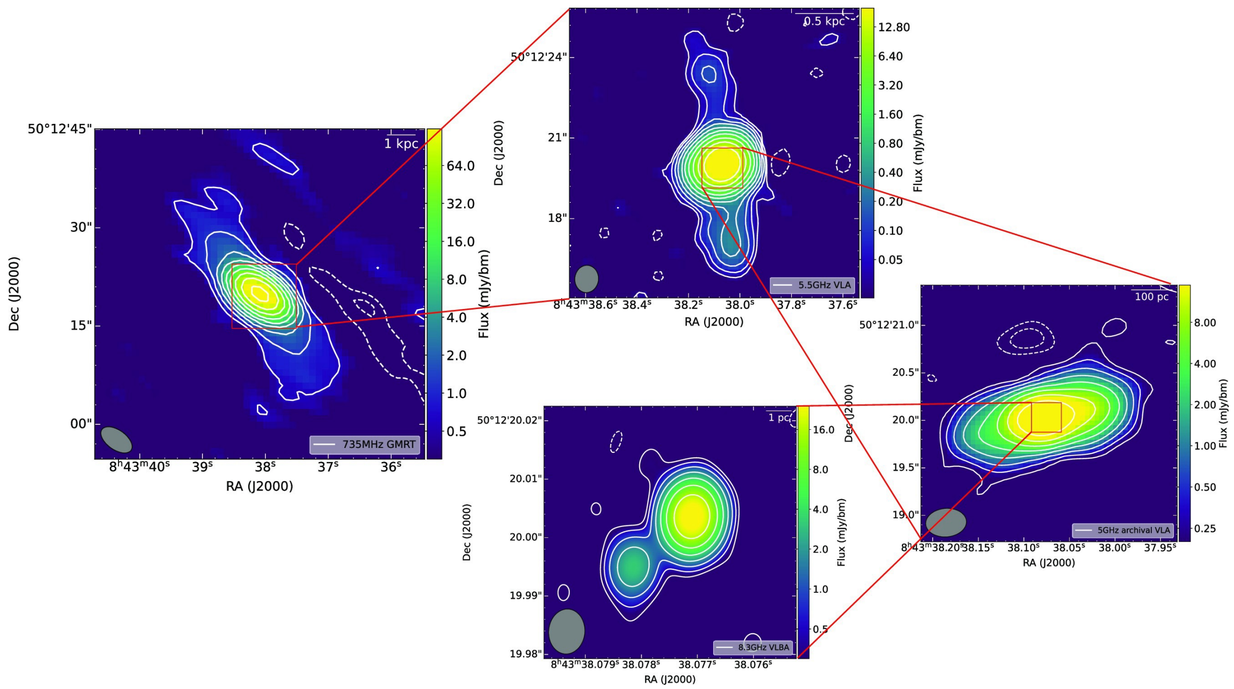


3 pc VLBA @8 GHz



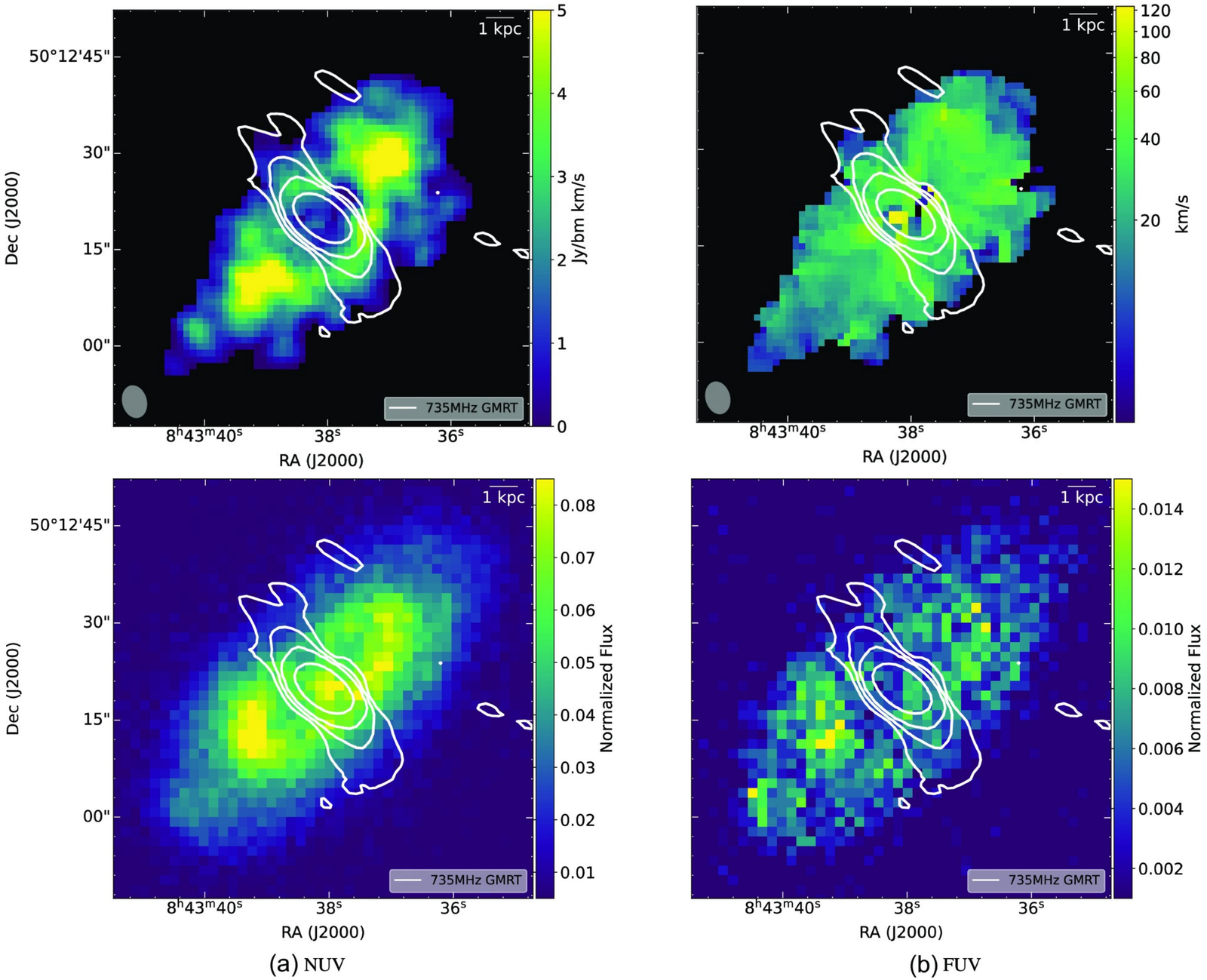
Vaishnav Rao+ 2023

The AGN Duty Cycle in NGC2639



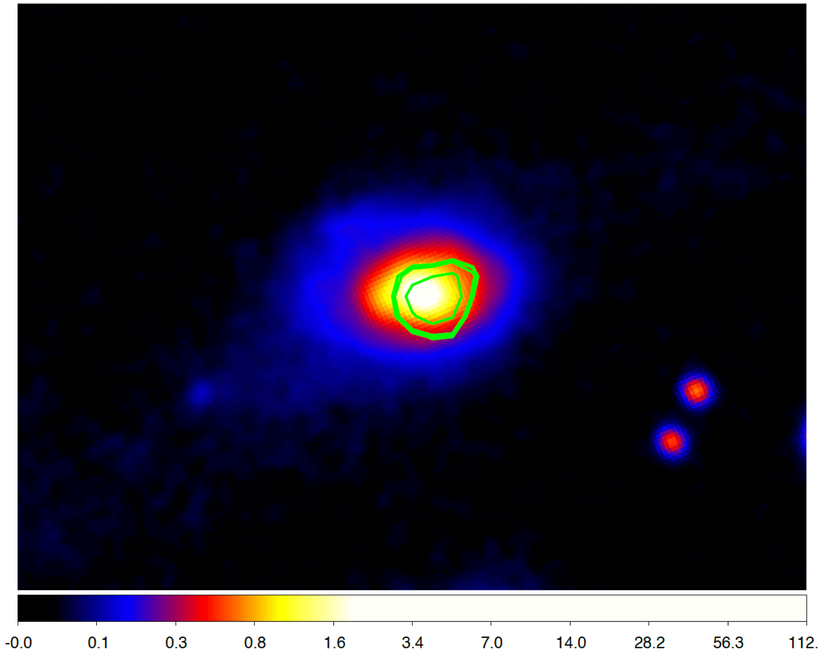
- Duty cycle = $t_{on}/(t_{on}+t_{off})$ (Clarke & Burns 1991)
- Broadband Radio Astronomy Tools (BRATS) — Harwood+ 2013
- Spectral ages: 34, 12, 3 Myr for the lobes.
- Duty cycle ~60% (Rao+ 2023)

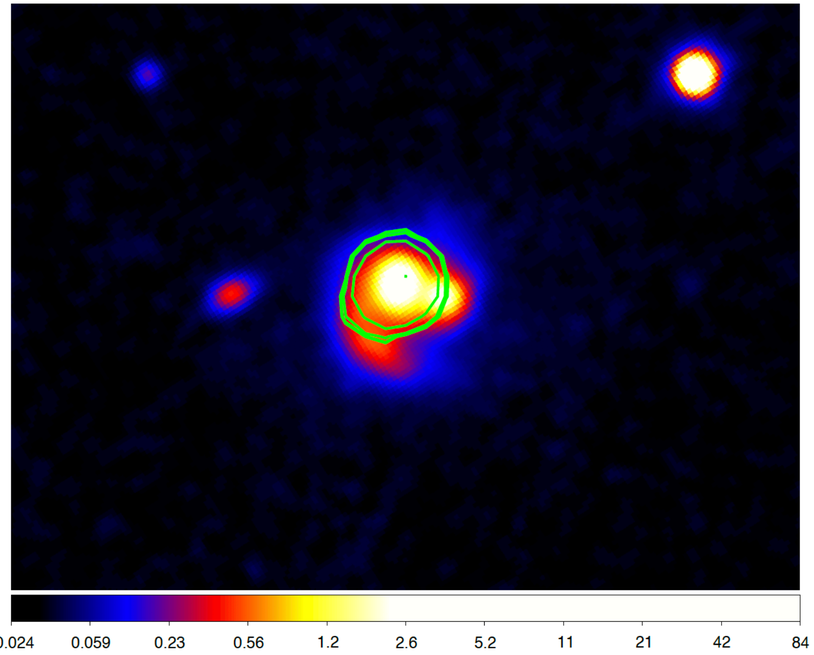
AGN "Feedback"



- CO(1-0) molecular gas (CARMA EDGE; Bolatto+ 2017) shows deficiency in a ~ 6 kpc region
- Higher velocity dispersion at jet edges.
- GALEX FUV & NUV images show similar deficiency → star-formation quenching.

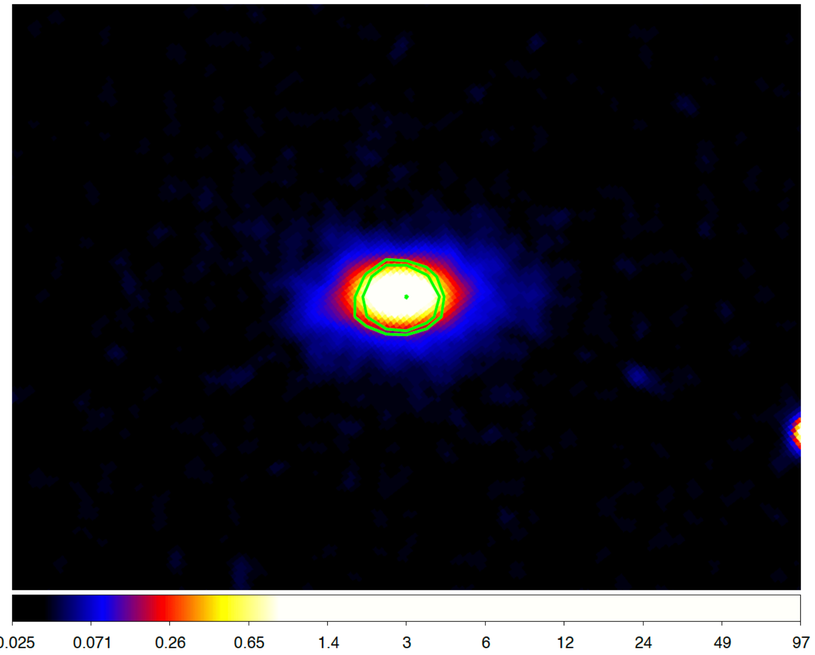
Improvement in Resolution & Sensitivity: RQAGN have jets

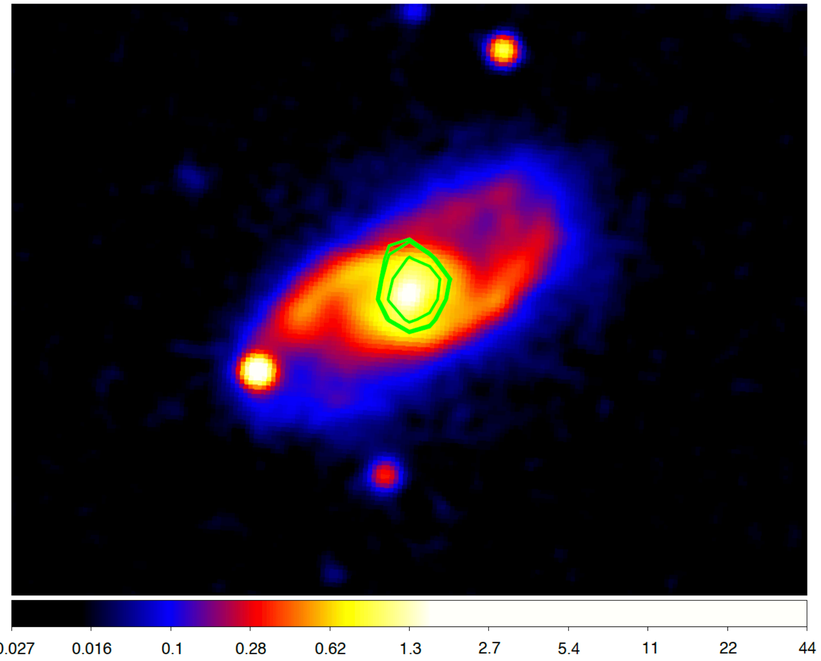


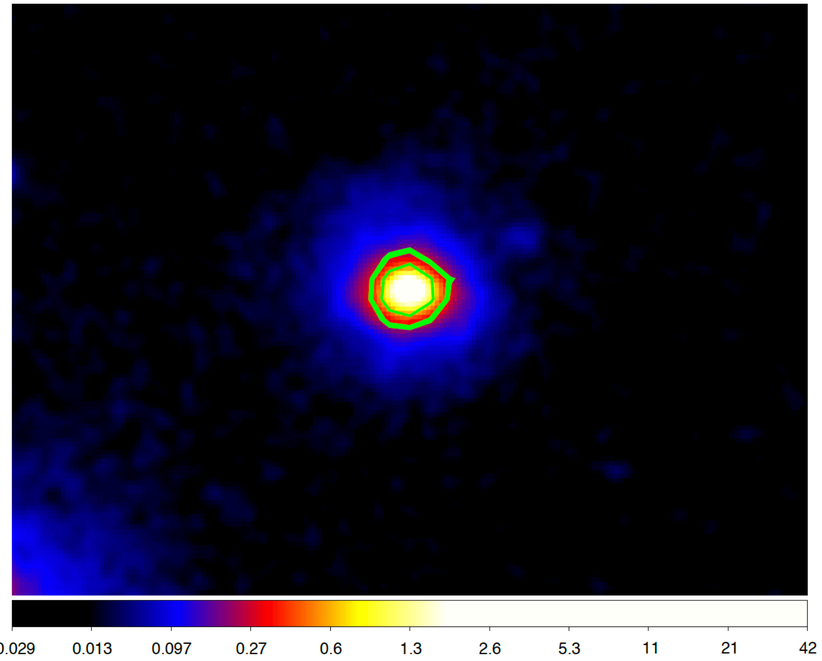


2 epoch VLBI study of KISSR galaxies

VLA FIRST+SDSS



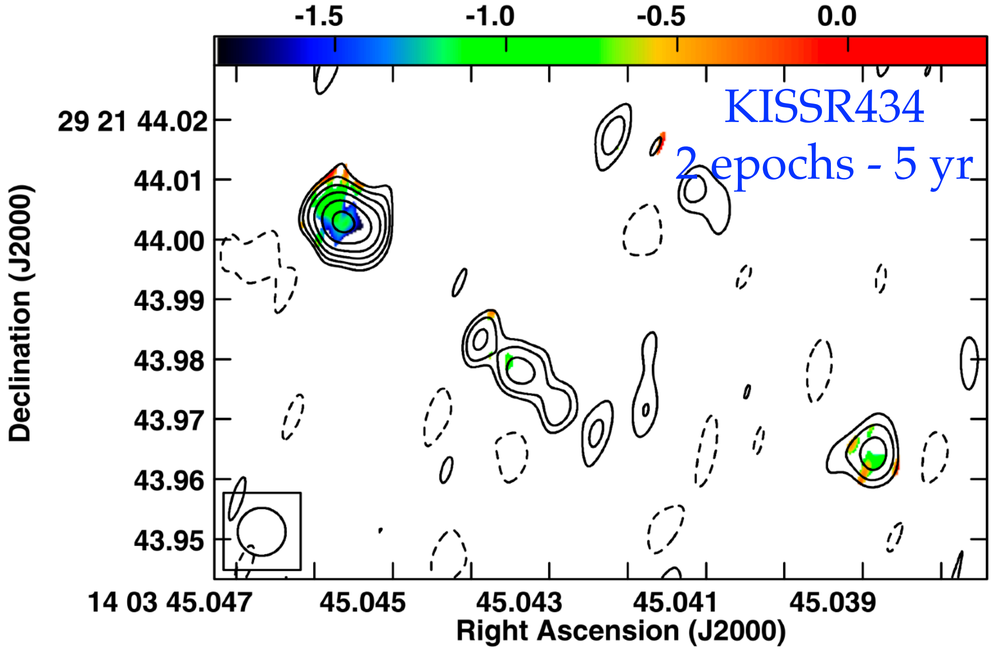


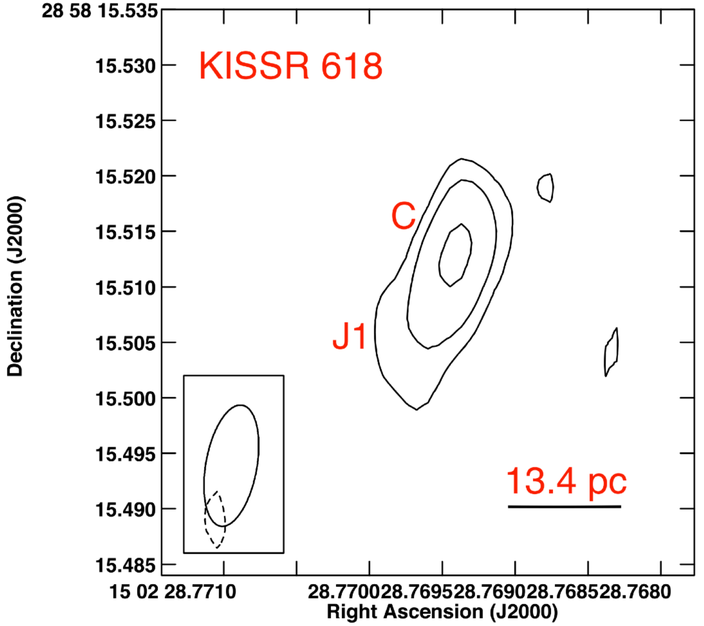


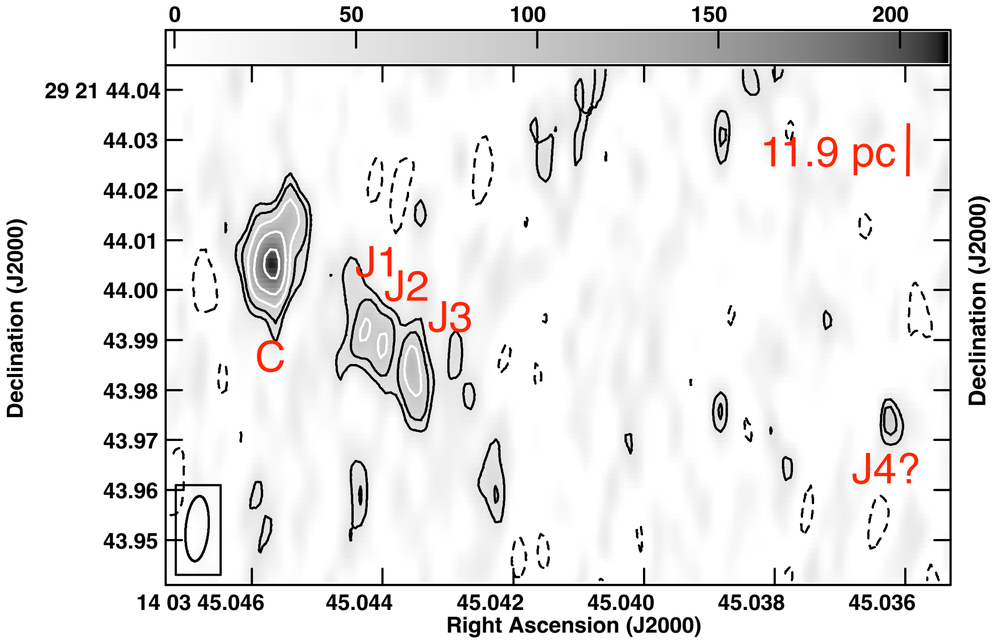
KPNO Internal Spectro-scopic (Red) Survey (Wegner+ 2003)

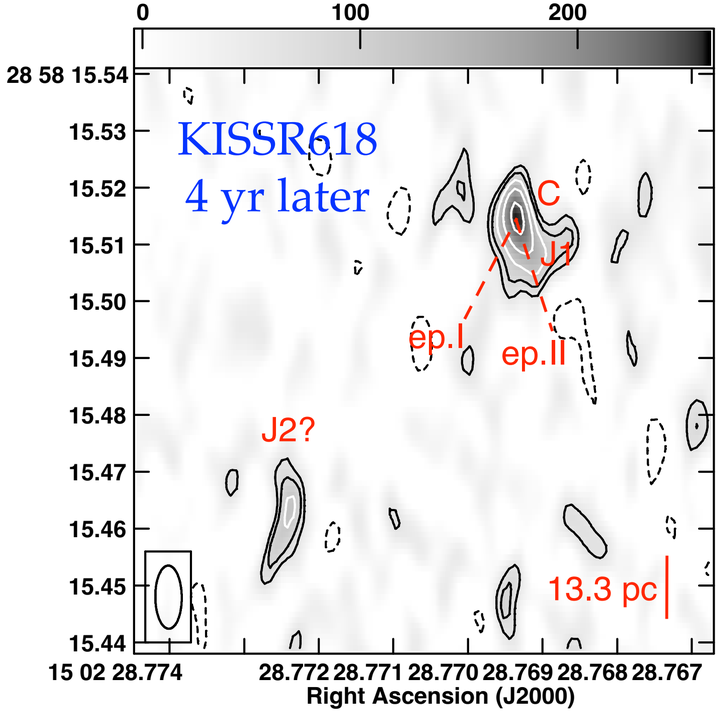
- Sample with double-peaked lines in SDSS

(Kharb+ 2021; Kharb+ 2025, in prep.)

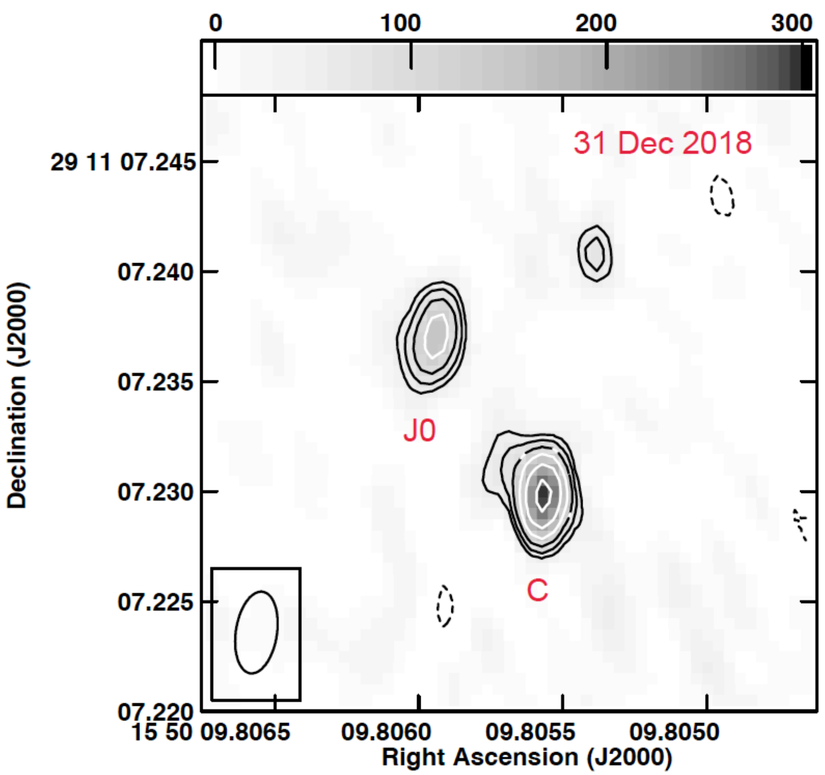




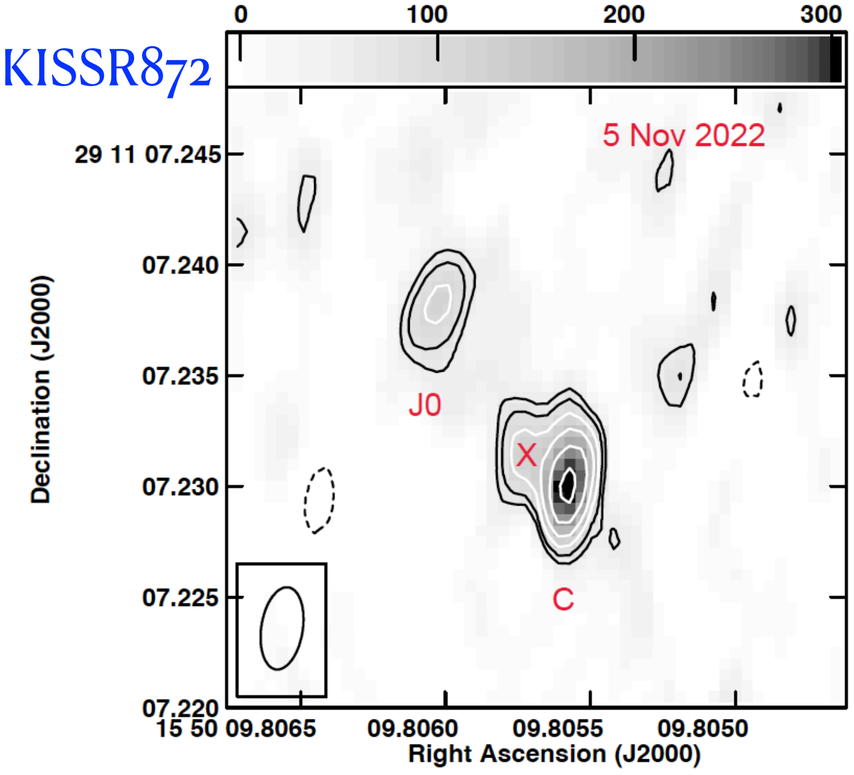


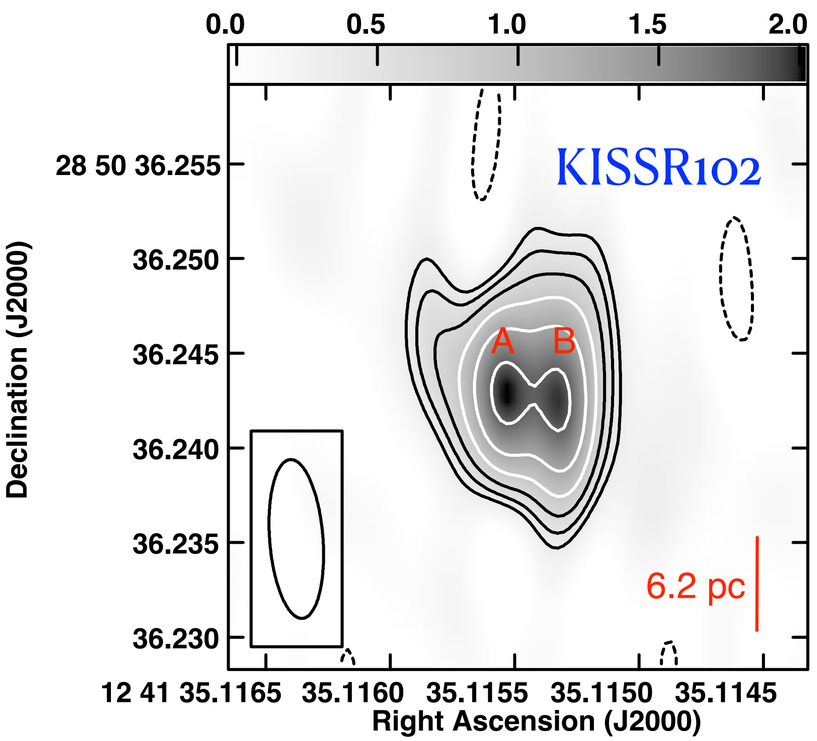


Fast jets in some RQ AGN



KISSR872





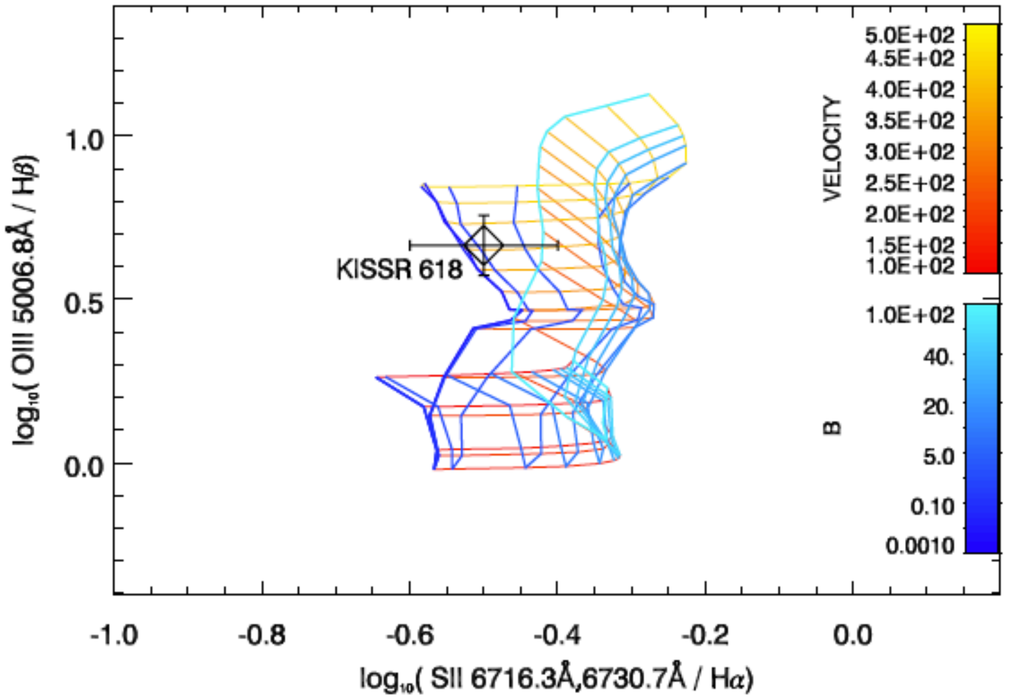
Apparent jet speed = 1.65 ± 0.57c in ~4 years in KISSR872 (Kharb+ 2024)

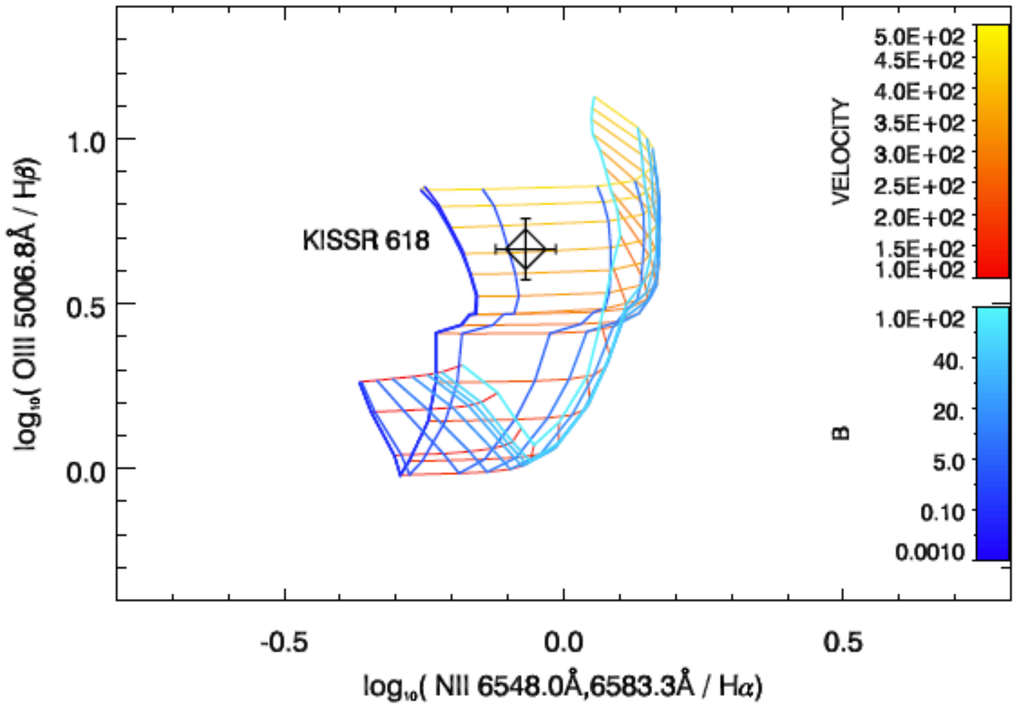
Apparent jet speed = 1.05 ± 0.45c in ~4 years in KISSR102 (Kharb+ 2025, in prep.).

Jet-Gas Interaction

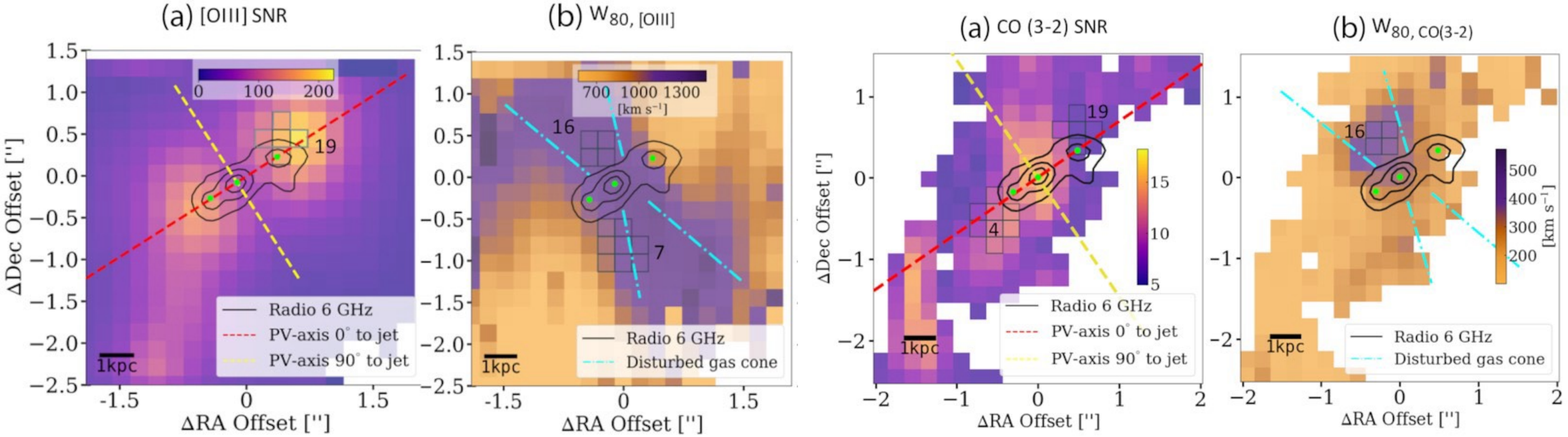
- SDSS spectra: plasma modelling code, MAPPINGS III (Sutherland & Dopita 1993).

- "Shock+precursor" model can explain line ratios like [OIII]/Hβ vs. [NII]/Hα or [OIII]/Hβ vs. [SII]/Hα in a majority of sources with jets.





Jet-mode AGN feedback in RQAGN



- VLT MUSE & ALMA CO observations of a RQAGN J1316+1753 (Girdhar+ 2022).
- TeaCup Quasar (Audibert+ 2023).
- Simultaneous “positive” & “negative” feedback effects observed in hydrodynamics simulations of jet-ISM interactions (Mukherjee+ 2018; Mandal+ 2021).

Summary

1. Radio-quiet AGN make up the vast majority of active galaxies.
2. RQAGN show episodic activity.
3. EHT + Fermi bubbles in MW — all galaxies may go through an active phase.
4. Magnetic fields could be instrumental in the production/collimation of radio outflows even in RQAGN. Implications for the RL/RQ AGN divide.
5. These outflows can impact their surroundings — AGN “feedback”.
6. SKA - high sensitivity at low radio frequencies will revolutionise our understanding of LLAGN.