Searching for dual AGN in galaxies using multi-wavelength observations

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SKA Science day, Sweden

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How do AGN pairs form in the centers of galaxies?

i) During mergers, the SMBHs sink to the centre of the merger remnant

ii) They result in gravitationally bound SMBH dual/binary systems.

iii) Simulations show that mergers cause gas accretion onto the SMBHs which can ignite AGN activity in the BH pair.
So they form **dual/binary AGN.**

iv) Finally they coalesce emitting huge amount of gravitational wave energy.

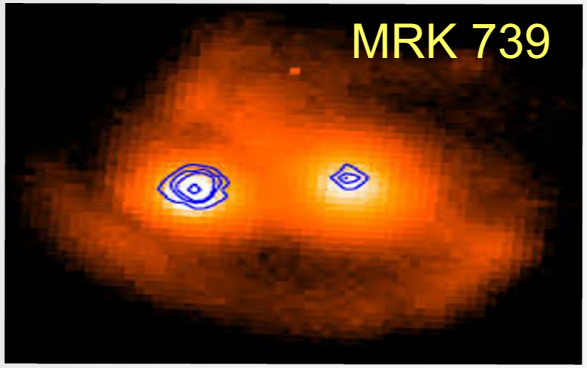
Begelman et al. (1980)

Lotz et al. (2011) hipacc.ucsc.edu

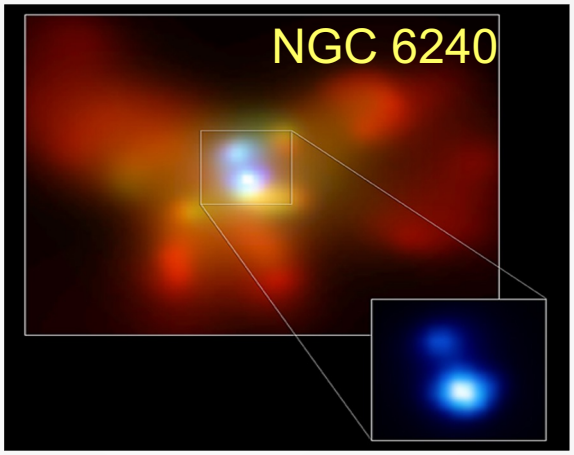
Dual/Binary AGN can help us understand the end stage of mergers and their effect on the nuclear regions of galaxies.

Dual/binary AGN : Direct detections

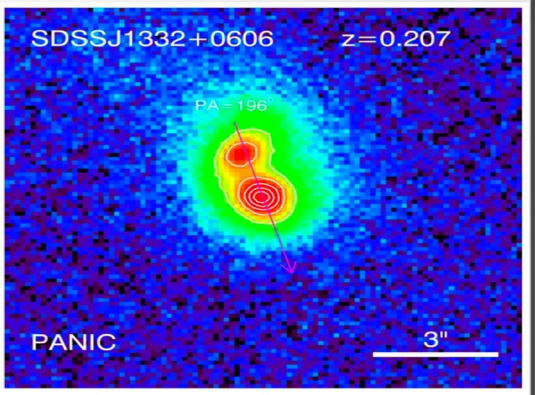
Using high-resolution X-ray, Optical/UV, radio imaging



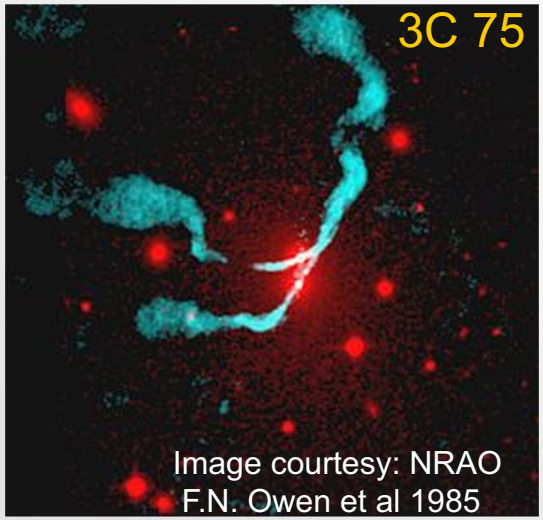
Koss et al. (2011)

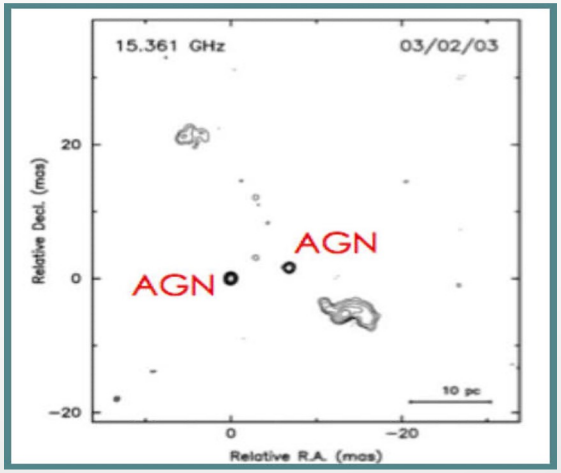


Komossa et al. (2002)

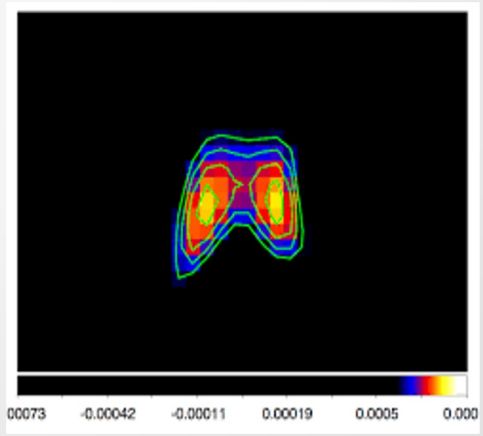


Liu et al. (2013)





Rodriguez et al (2006)

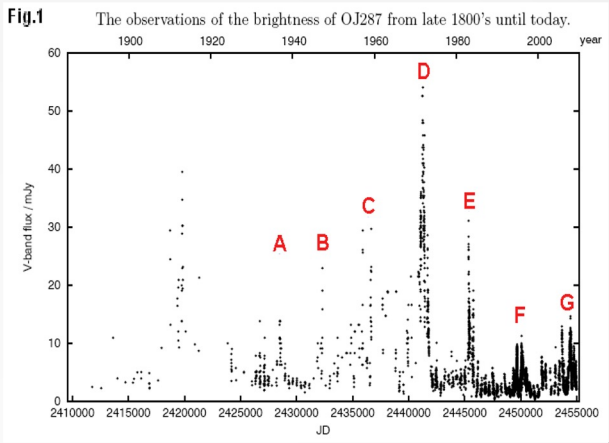


Kharb et al (2017)

Indirect Signatures: Binary/dual AGN

1. Periodicity in flux variability:

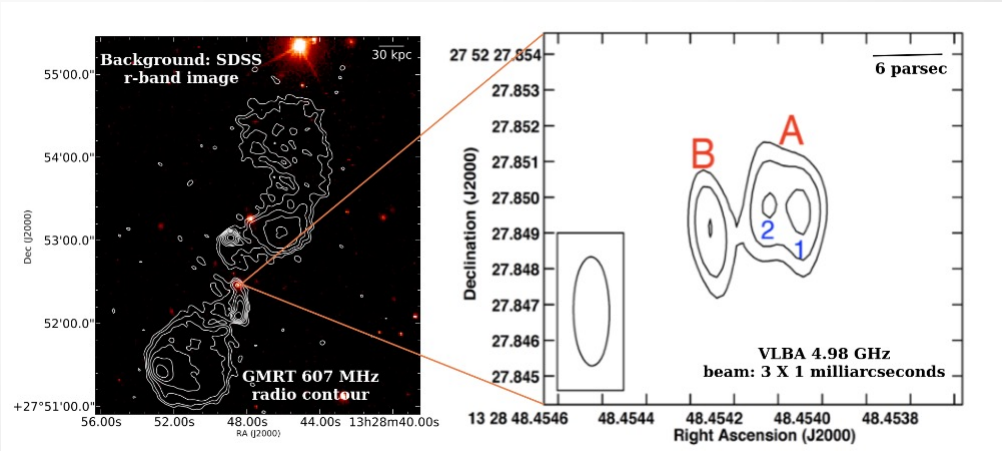
- Periodicity in optical variability can be explained by dual/ binary AGN.
- OJ287, BL-Lac object has 100 yrs of optical data which shows a period of 12yrs.



Sillanpaa et al. (1988), M Valtonen et al. (2011), Dey et al. (2018), Komossa, S et al. (2020)

2. X- or S-shaped radio galaxies:

- The jet of the AGN shows S-, Z- or X -shaped structure.
- These can be explained by the jet precession which can be due to dual AGN

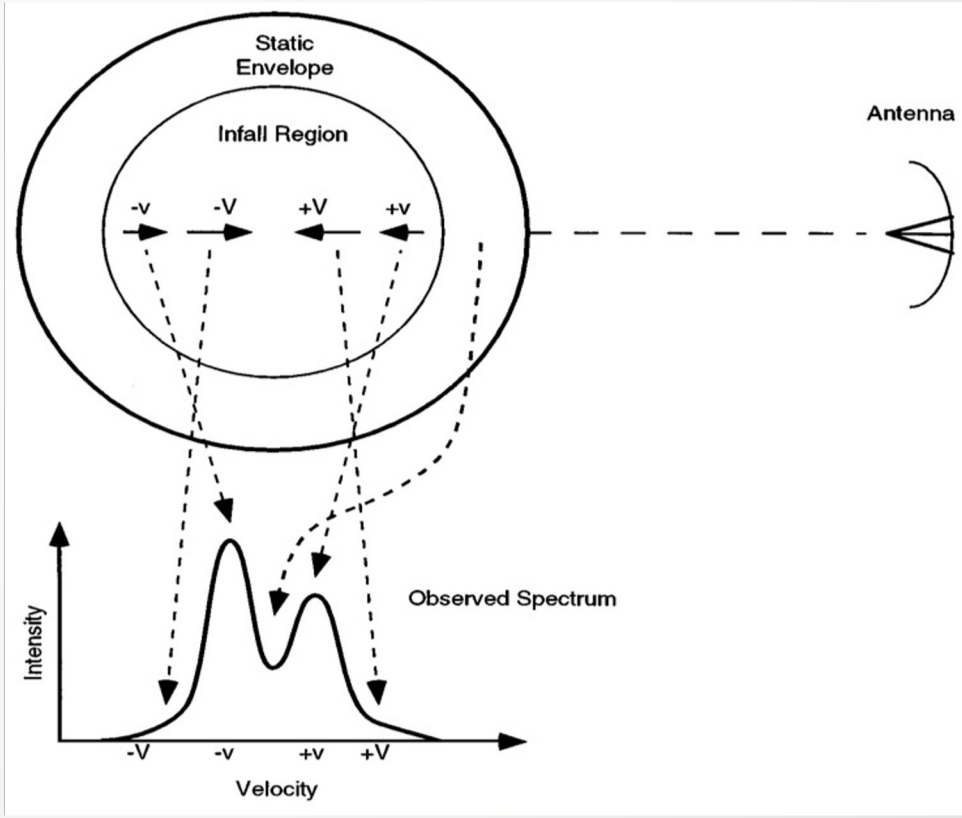


Nandi et al. (2021)

Indirect Signatures: Binary/dual AGN

3. Double-peaked emission lines ([OIII]) in optical spectra (DPAGN)

- Emission lines show double peaks. This can be due to redshift and blueshift of two NLR regions.
- These DPAGNs can be due to DAGN, jet-ISM interaction, or rotating nuclear disks.
- One needs to do high-resolution multi-wavelength imaging to confirm the presence of DAGN or binary AGN.

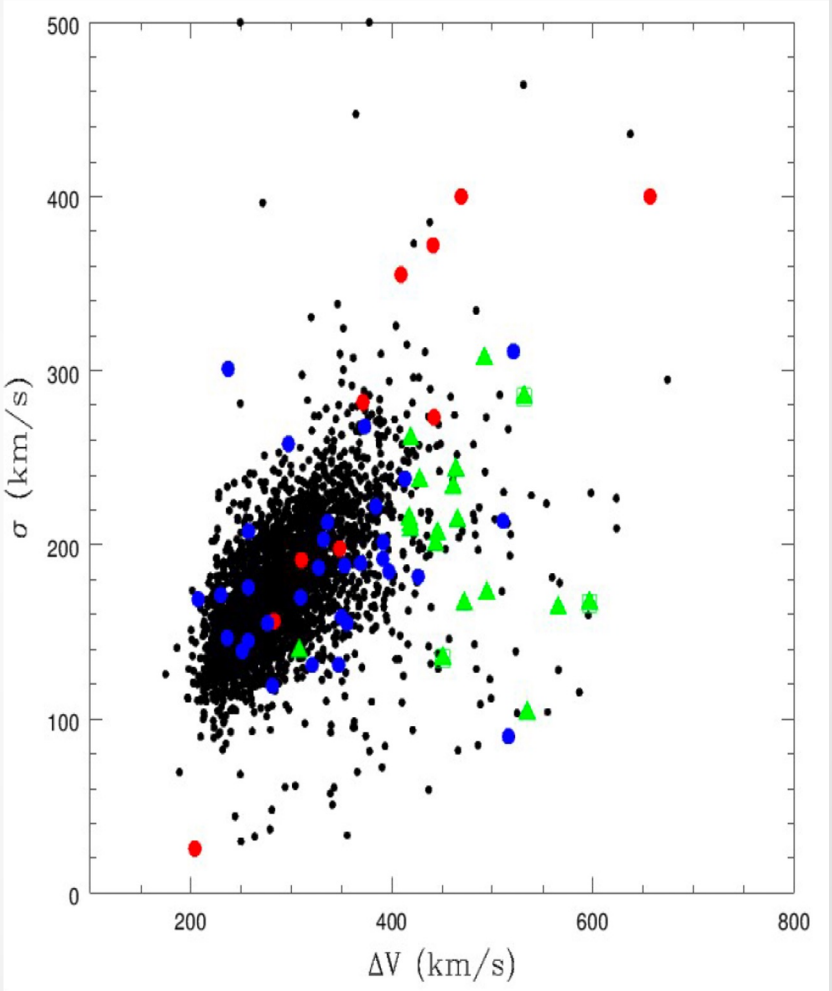


Astrobites

Zhou et al. (2004), Greene & Ho (2005), Kharb et al. (2015), Comerford et al. (2012)

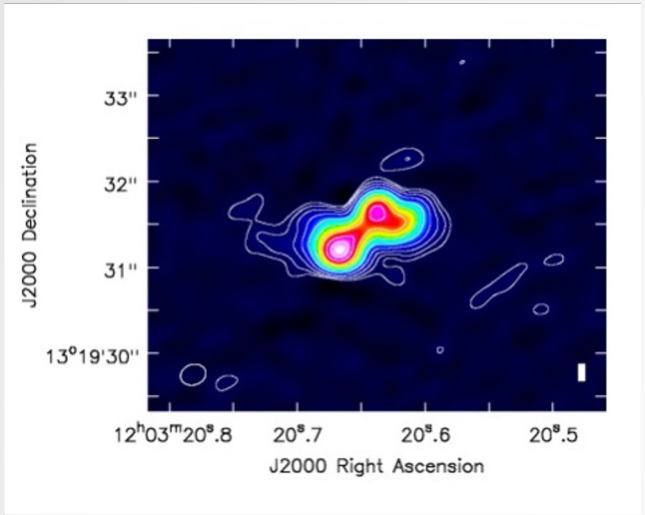
Sample selection for VLA observations

- Δv vs σ plot where Δv is the Doppler separation of the [OIII] emission line and σ is the stellar velocity dispersion of the bulge.
- Selected outliers with $\Delta v > 400$ km/s.
- Have radio detection in NVSS or FIRST survey.
- Sample 1 consists of 20 galaxies ($0.1 < z < 0.5$).
- Observed with VLA at C-, X- bands.

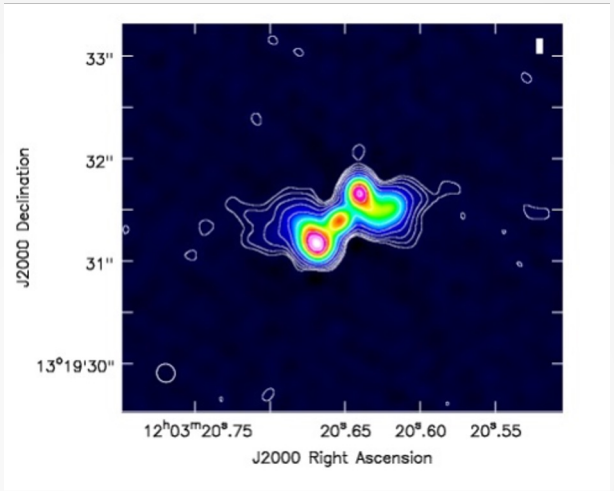


2MASXJ12032061+1319316: S-shaped radio jets

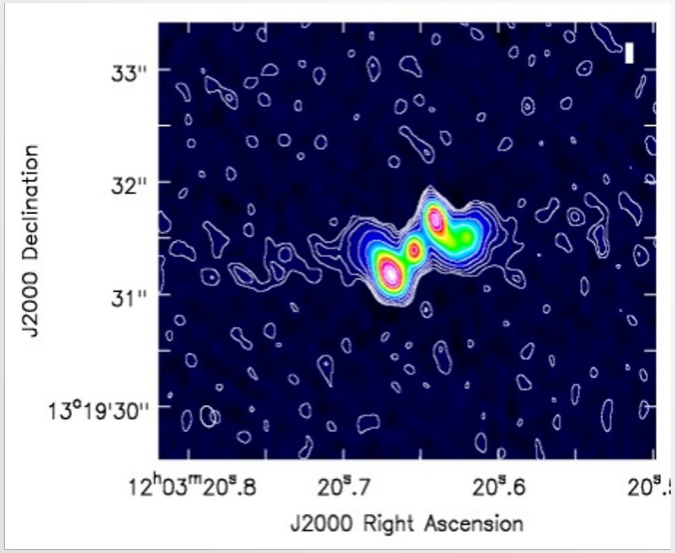
6 GHz image



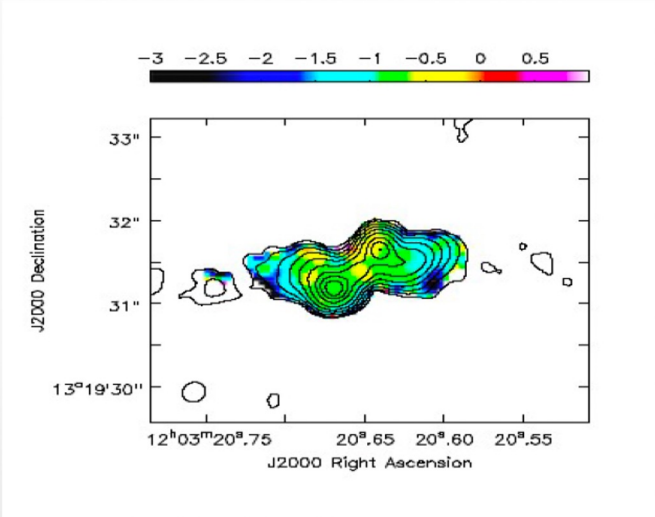
8.5 GHz image



11.5 GHz image



Spectral index map

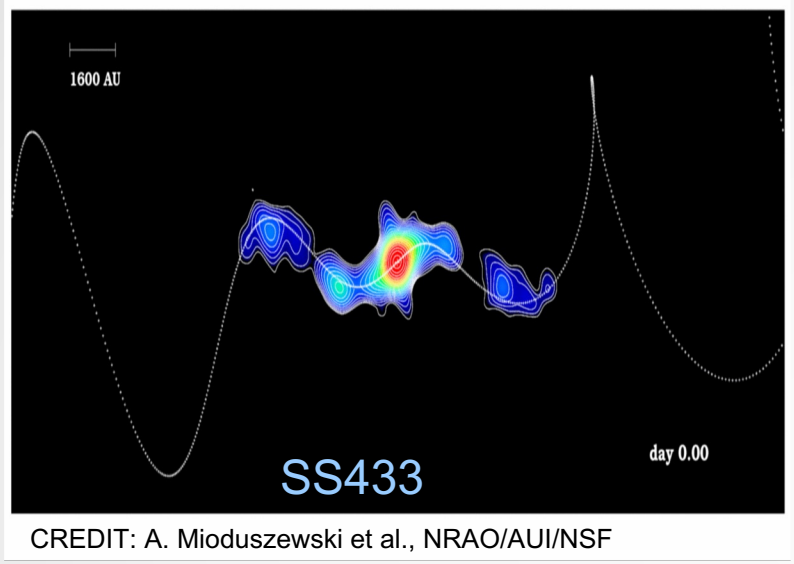


Total size of ~3kpc.

Core has flat spectral index (α)

Jets have steeper α.

Modeling the S-shaped structure: jet precession

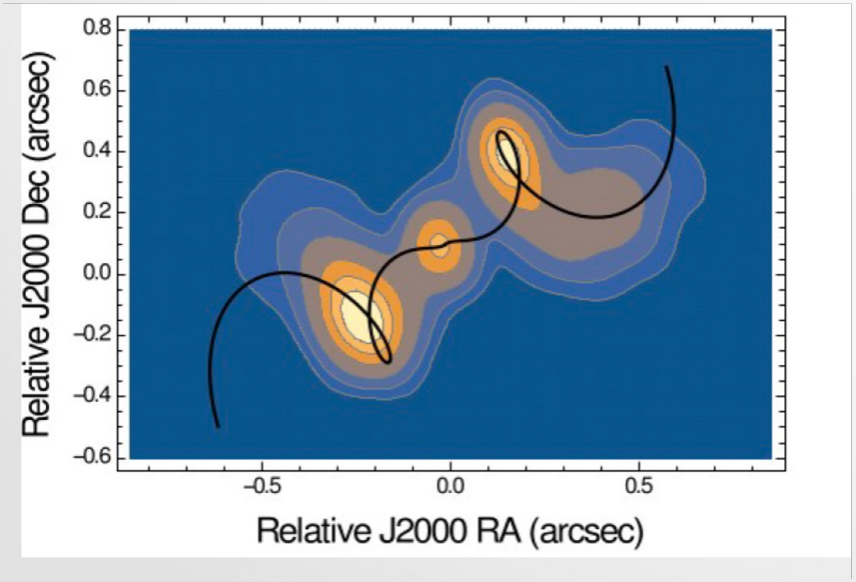


CREDIT: A. Mioduszewski et al., NRAO/AUI/NSF

The fitted Hjellming & Johnston (1981) jet precession model (black curve) provides a Period ~10^5 yrs.

The calculated separation of binary SMBH (if present) to be ~0.02 pc.

Rubinur et al. (2017)

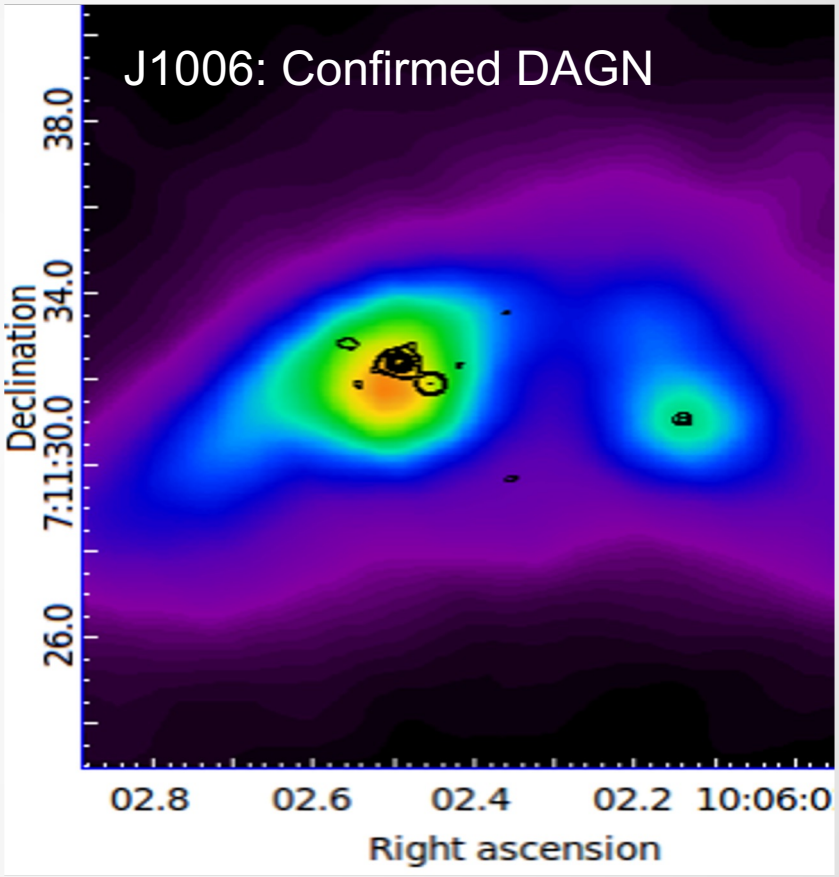


Dynamical modeling has been done using 3D MHD simulations to reproduce the emission where the best fit is found with a dynamical age of 2.23 Myr.

Giri G, Dubey R, Rubinur et al. (2022)

Results: A confirmed DAGN, S-shape source and more

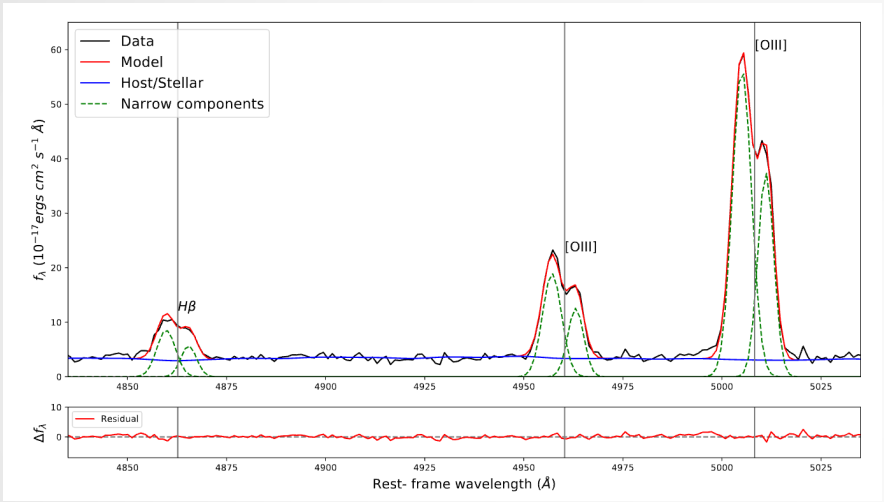
- Spectral index map and optical spectra confirmed dual AGN in one dual - core galaxy
- While the other two can be dual AGN or AGN+SF nuclei pairs.
- For our dual AGN detection, the DPAGN emission lines do not originate from the dual/binary AGN.
- Hence, these are not good indicators of dual/binary AGN. Instead, closely interacting galaxies or merger remnants are better candidates for detecting dual AGN.

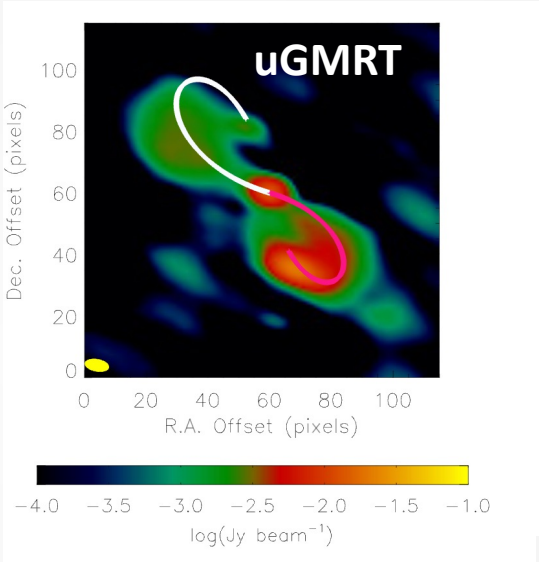


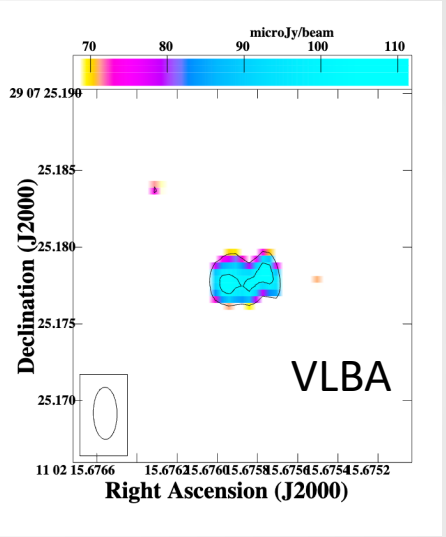
Rubinur et al. (2018, 2019)

A VLBA-uGMRT search for candidate binary black holes:

Study of six X-shaped radio galaxies with double-peaked emission lines:







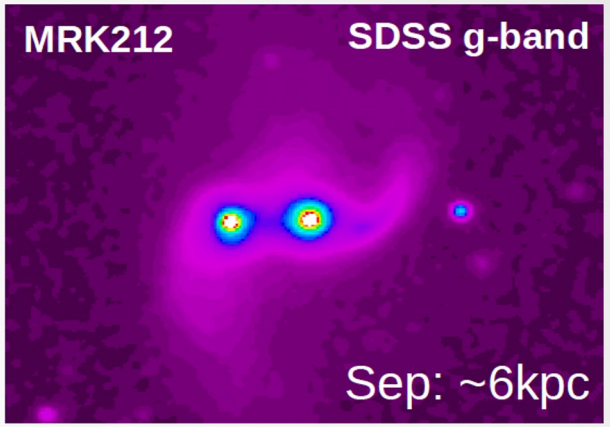
- Three out of the six sources show dual VLBA compact components.
- The black hole separations estimated from the double-peaked emission lines agree well with the VLBA compact component separations.
- The precession induced by a noncoplanar secondary black hole is a feasible mechanism for explaining the observed X-shaped radio morphologies and the black hole separations estimated from other methods.

Sebastian et al. + Rubinur (2024)

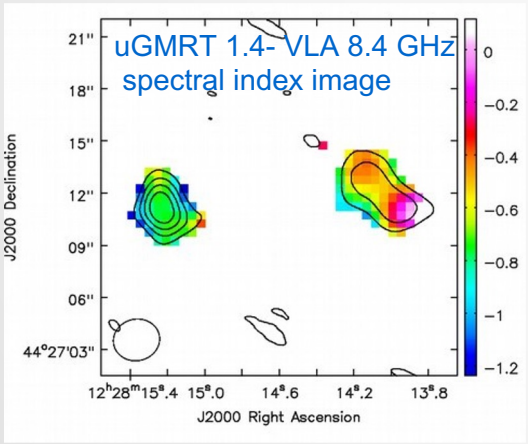
Results: UVIT sample galaxy- MRK 212

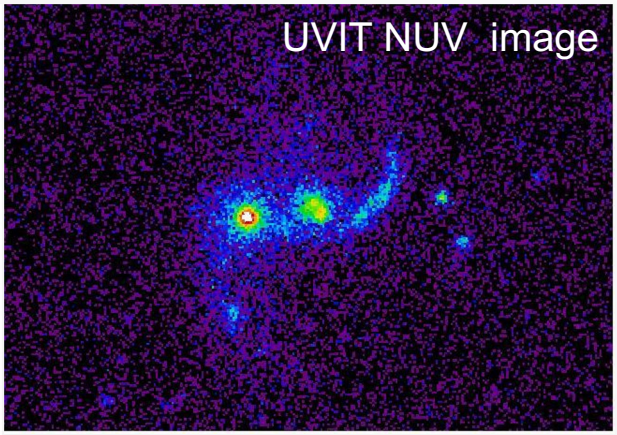
Motivation: i) Dual AGN? ii) Star-formation, AGN feedba

Data: UVIT deep observations, radio continuum data from EVLA, uGMRT; optical spectra from HCT.



Results:





The UV SF knots around the right nuclei coincide with the extended radio structure

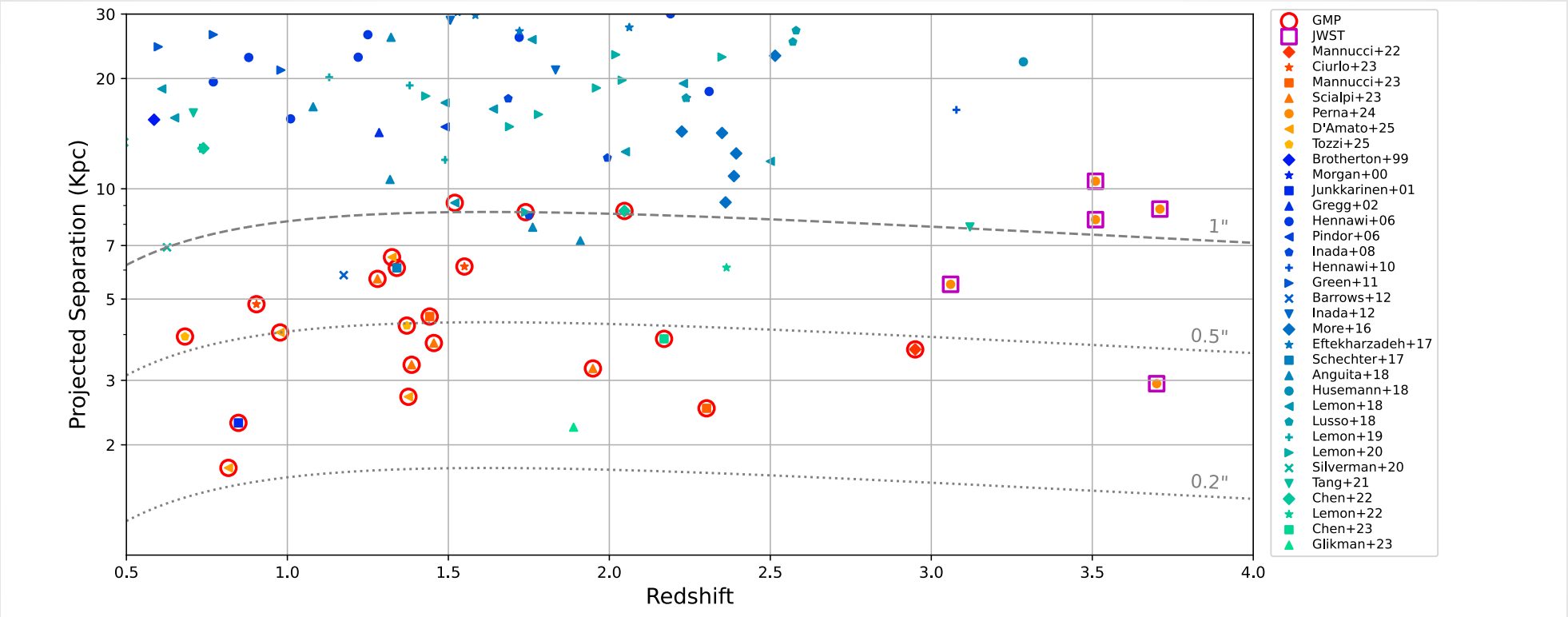
The radio spectral indices are consistent with SF.

- Radio morphology, spectral index, optical spectra supported dual AGN.

(**Rubinur et al. 2021**)

GMP-selected dual AGNs:

P.I : Filippo Mannucci, INAF - Osservatorio Astrofisico di Arcetri



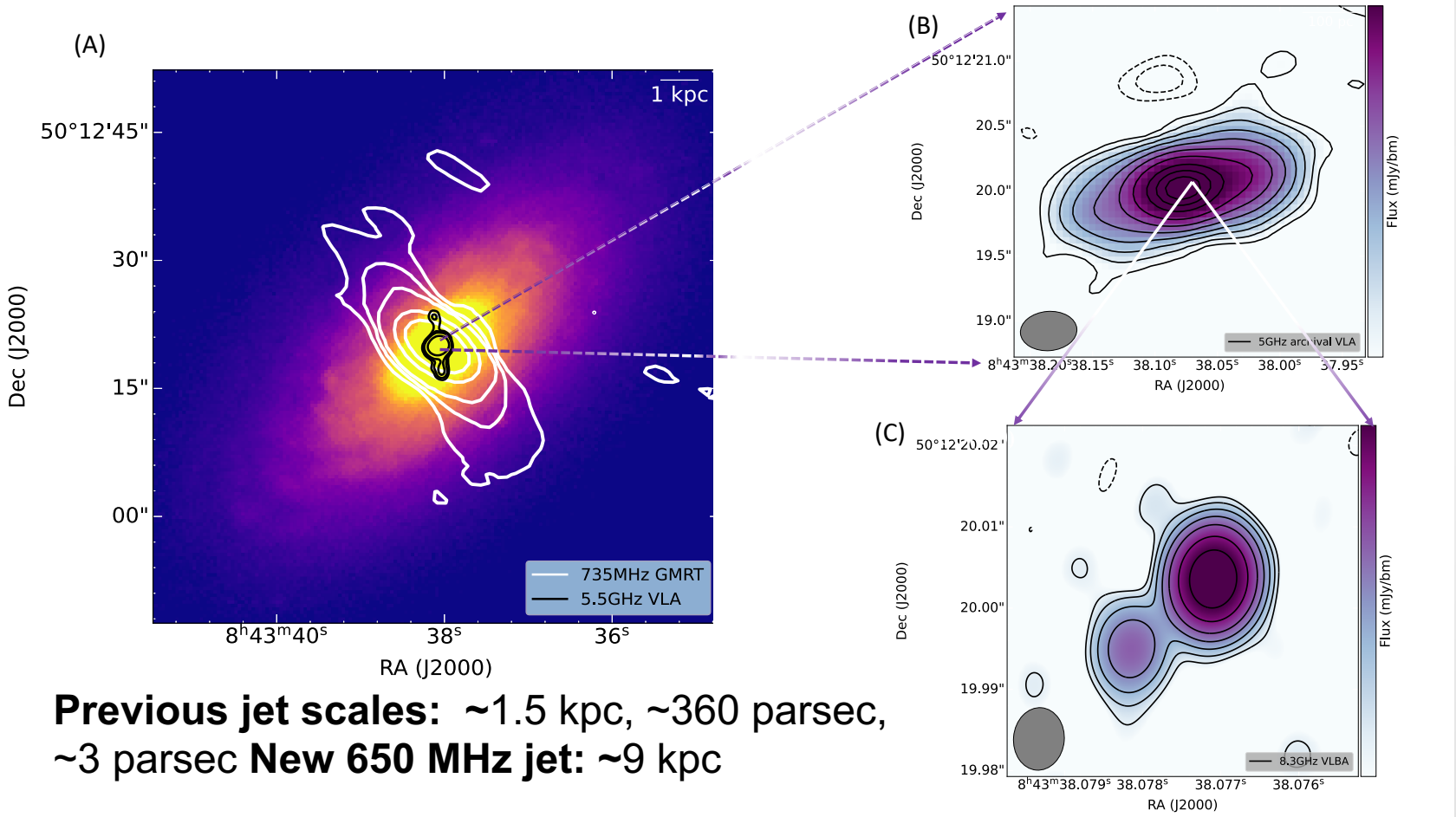
The Gaia Multipeak (GMP) technique is used to identify large numbers of dual or lensed active galactic nucleus (AGN). High-resolution spectroscopy with VLT/ERIS and Keck/OSIRIS → compare them with the classifications obtained from the near-IR color of seven systems obtained with LBT/LUCI → Confirmation of DAGN.

Mannucci, F et al. + Rubinur (2023), Curilo et al. + Rubinur (2023), Scalpi et al. + Rubinur 2024 arXiv230511850S

Understanding kilo-parsec scale radio structures in Seyfert galaxies with uGMRT

The fourth episode of jet activity?

NGC 2639

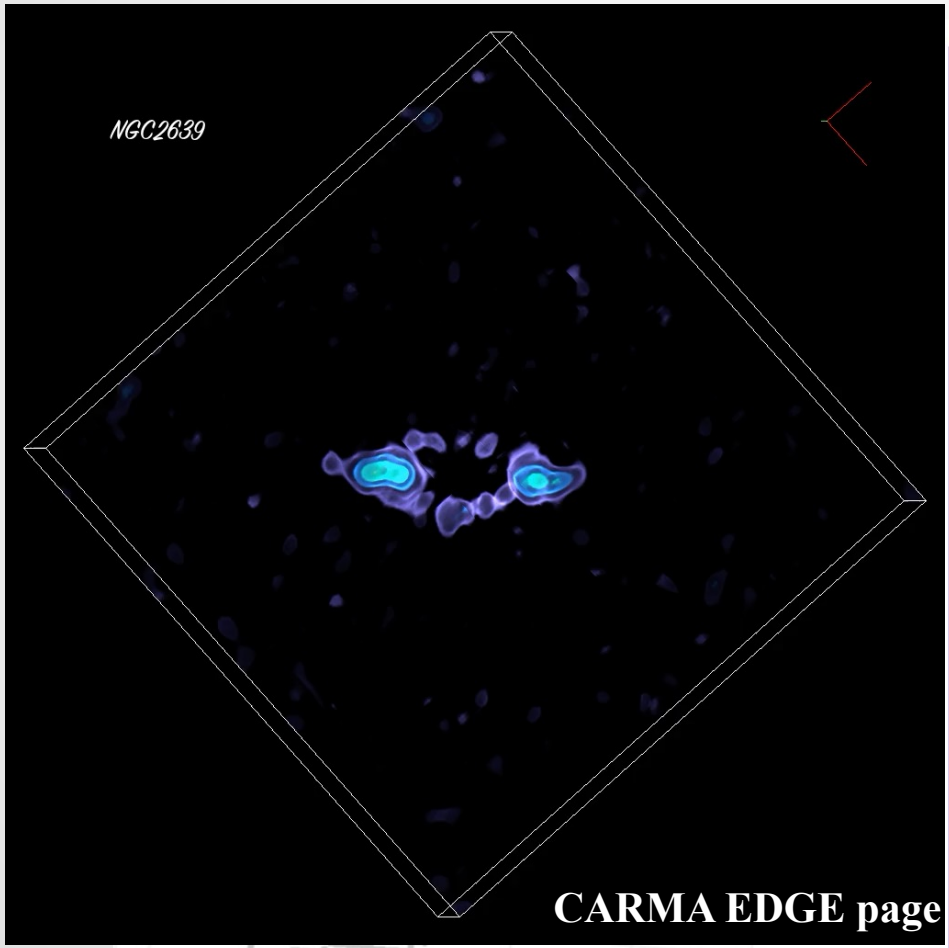


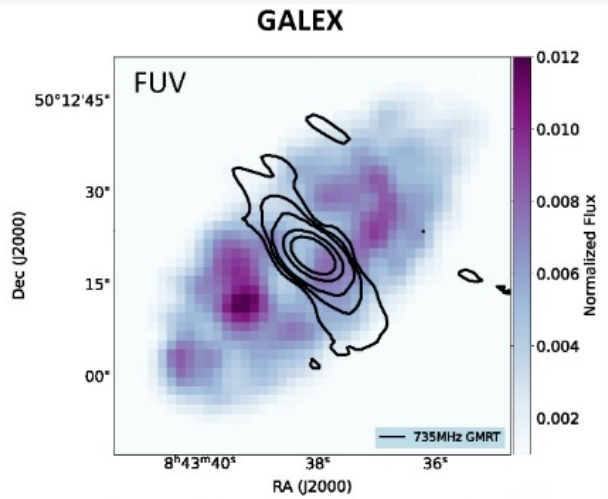
Previous jet scales: ~1.5 kpc, ~360 parsec, ~3 parsec **New 650 MHz jet:** ~9 kpc

Rao, Kharb, Rubinur et al. (2023), Rubinur et al. (2024b)

Understanding kilo-parsec scale radio structures in Seyfert galaxies with GMRT

AGN Feedback Signatures?



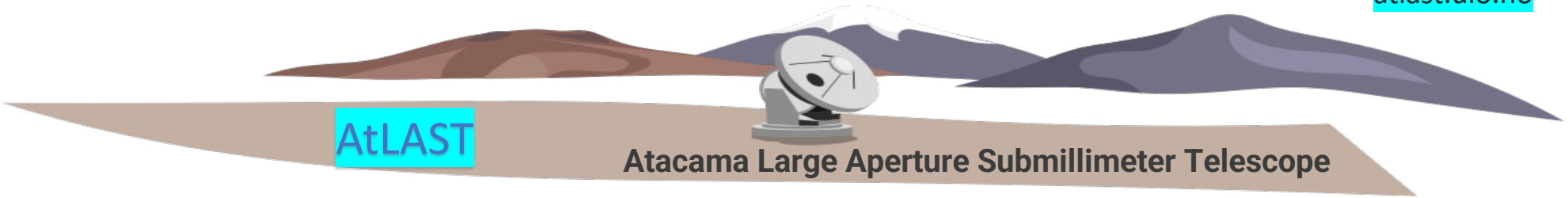


For the molecular gas ring radius of 3 kpc, the PV work required is >3.44 × 10^{54} erg.

Only ~0.5% of the east–west jet; ~0.7% for the north–south jets and ~0.06% for the north-east–south-west jets power is sufficient to push aside the molecular gas in NGC 2639.

Rao, Kharb, Rubinur et al. (2023), Rubinur et al. (2024b)

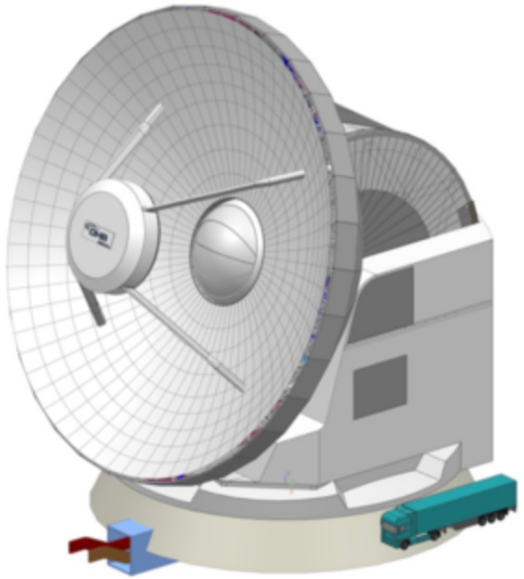
atlast.uio.no



AtLAST

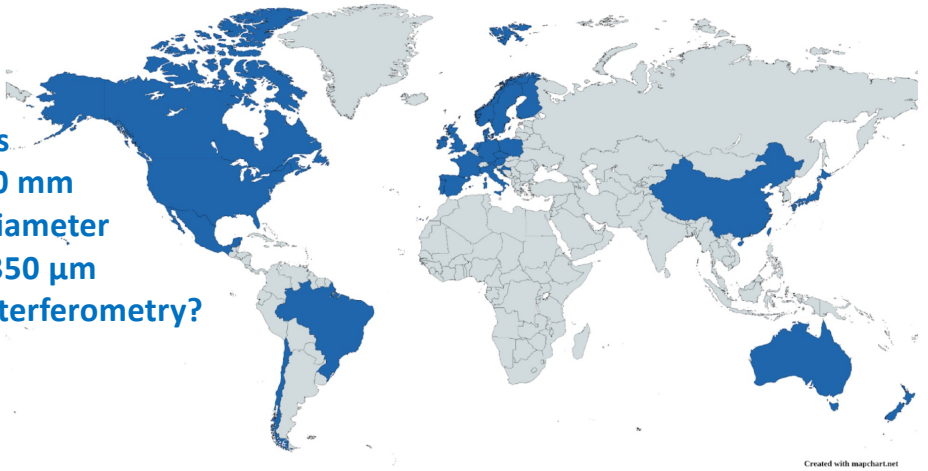
Atacama Large Aperture Submillimeter Telescope

P.I – Claudia Cicone (UIO)



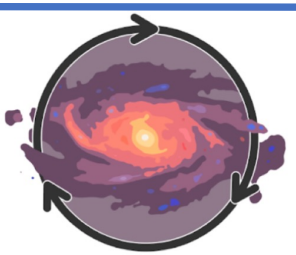
A next-generation 50-meter class single-dish astronomical observatory operating at sub-mm and mm wavelengths.

- At least six large instruments
- Wavelength (λ) range: 0.3-10 mm
- Field of view: 1- 2 degrees diameter
- Spatial resolution: ~1.5” at 350 μm
- Part of Very long baseline interferometry?

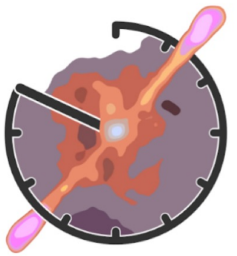


Global distribution of researchers that contributed to maturing AtLAST's science case.

Where are all the baryons?



How do structures interact with their environments?



What does the time-varying (sub-)mm sky look like?

Booth et al. (2024)

- The new EU project AtLAST2, will start in 2025. Consolidate the plans for the new observatory.
- This will be done by a significantly expanded consortium of partners including the Chalmers group.

Stay tuned!

Summary

- Detected three dual core, two S-shaped* core-jet, one extended source, and 13 compact single cores, and one is not detected.
- S-shaped radio jets: Binary AGN candidates.
- The present data support low-luminosity dual AGN in MRK 212.
- GMP selected sample has increased the number of DAGN in high-redshift.
- NGC 2639: Fourth episode of radio jet. AGN feedback signature?