VLBA Observations of Extremely Luminous, Young, and Highly Obscured Radio Quasars from the WISE-NVSS Sample

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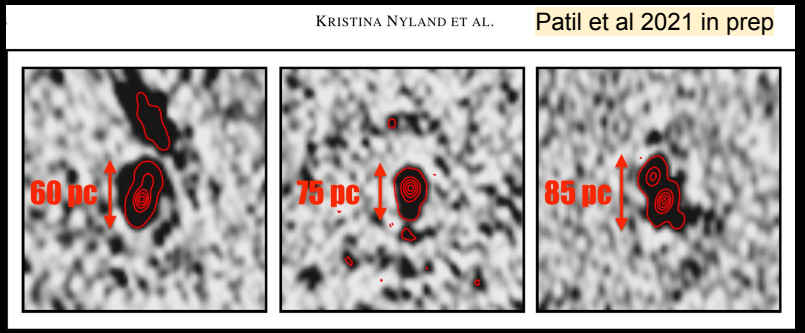
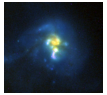


The WISE-Radio Young Obscured Quasar Sample

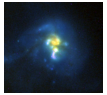


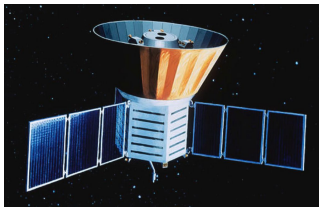
Lonsdale et al. 2015	Sample selection, redshifts, ALMA imaging
Patil et al. 2020	VLA imaging
Patil et al. 2021, in prep:	Multifrequency radio SEDs See Pallavi's talk on Thursday
Lonsdale et al 2021 in prep	VLBA snapshot survey of 90 sources at 5 GHz
Patil et al. 2022	VLBA & eMERLIN follow-up multi-frequency imaging

Core Team: Pallavi Patil, Mark Whittle, Kristina Nyland, Carol Lonsdale, Mark Lacy, Colin Lonsdale, Amy Kimball

Other contributors: Roberto Assef, Andrew Blain, Carrie Bridge, Jim Condon, Peter Eisenhardt, Andreas Efstathiou, Jeremy Harwood, Tom Jarrett, Kristen Jones, Suzy Jones, Minjin Kim, Amy Kimball, Lauranne Lanz, Dipanjan Murherjee, Robyn Smith, Dan Stern, Rachel Thorpe, Adam Trapp, Chao-Wei Tsai, Catherine Vlahakis, Belinda Wilkes, Jingwen Wu

Mergers, starbursts and obscured quasars



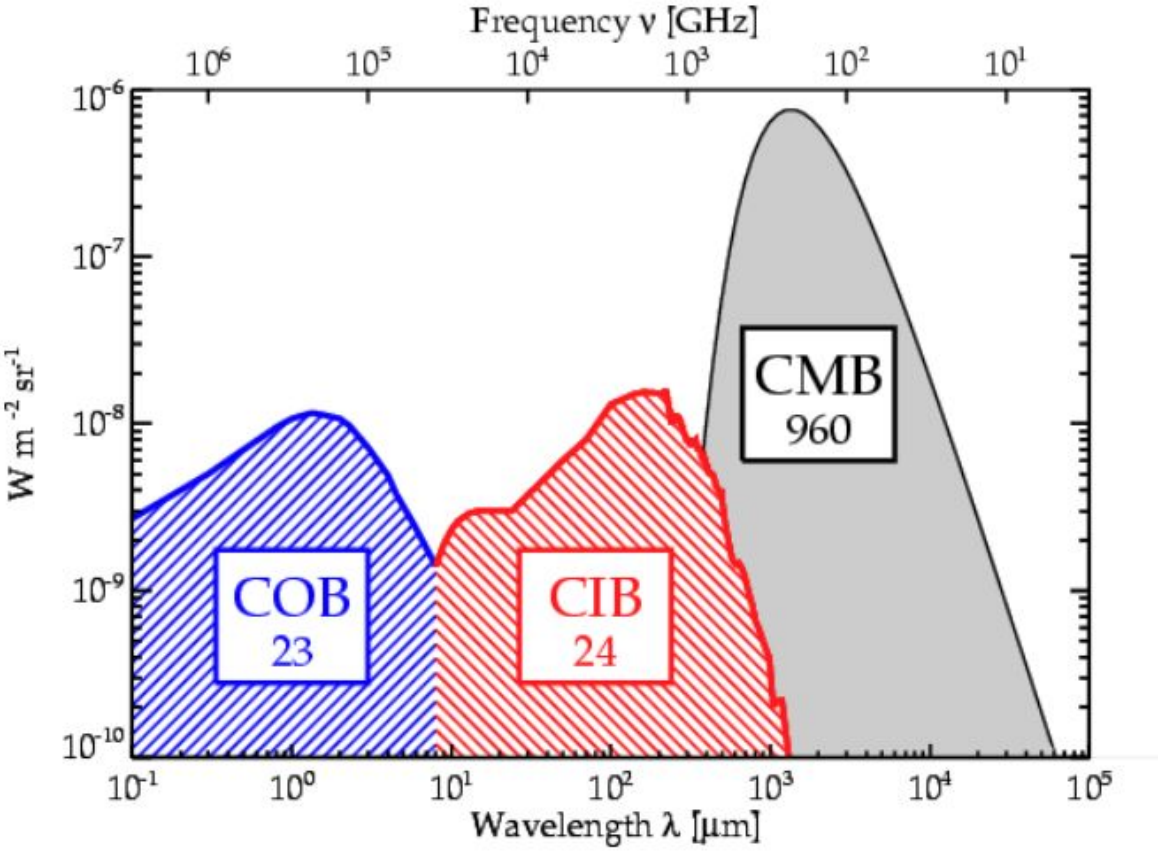


IRAS: ULIRGs dominate the local IR energy density

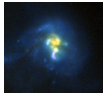
They are powered by heavily obscured starbursts and AGN

Their space density peaks at cosmic noon
Review: Lonsdale, Farrah and Smith 2006

COBE/DIRBE: the Cosmic Infrared Background is ~ equal in importance to the UV-optical background
Wright 2004



Mergers, starbursts and obscured quasars



Hopkins et al 2006 evolution model from merger to starburst to accreting BH and outflow

Short intense obscured QSO phase

How to test this scenario?

=> image with VLBI

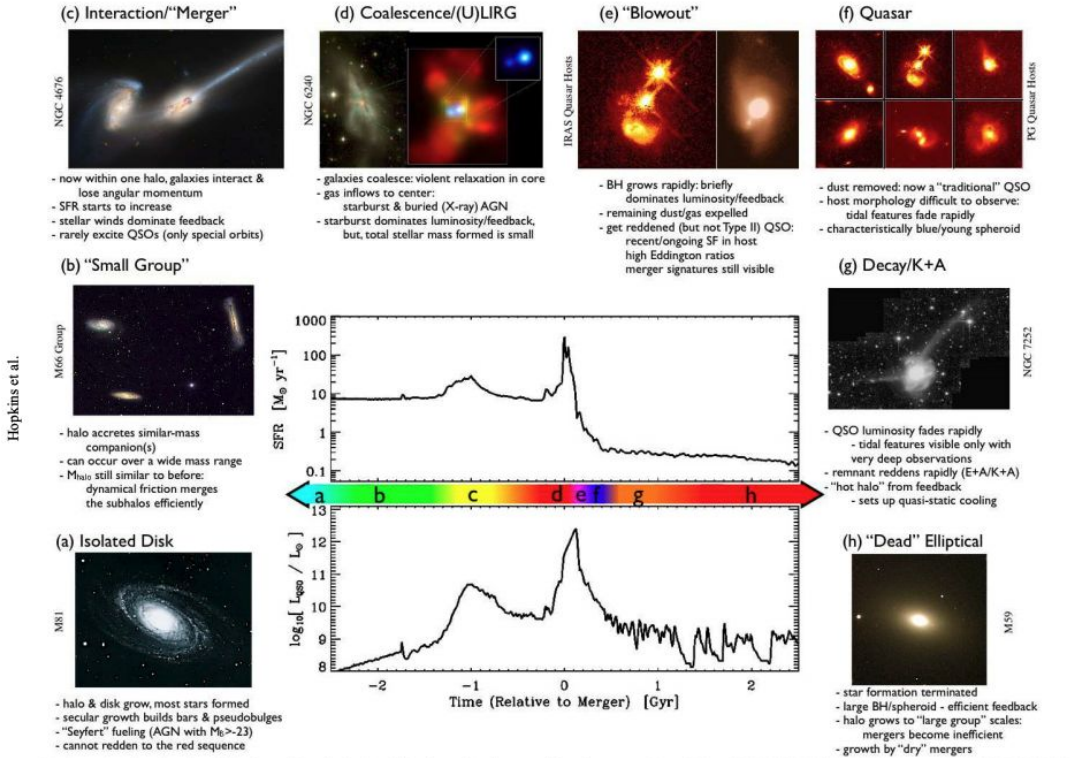
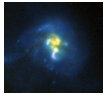


FIG. 1.— An schematic outline of the phases of growth in a "typical" galaxy undergoing a gas-rich major merger. *Image Credit:* (a) NOAO/AURA/NSF; (b) REU program/NOAO/AURA/NSF; (c) NASA/STScI/ACS Science Team; (d) Optical (left): NASA/STScI/R. P. van der Marel & J. Gerssen; X-ray (right): NASA/CXC/MPE/S. Komossa et al.; (e) Left: J. Bahcall/M. Disney/NASA; Right: Gemini Observatory/NSF/University of Hawaii Institute for Astronomy; (f) J. Bahcall/M. Disney/NASA; (g) F. Schweizer (CIW/DTM); (h) NOAO/AURA/NSF.

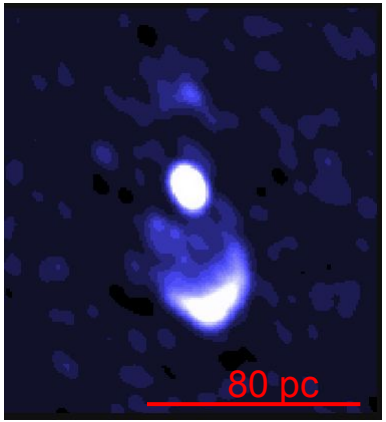
Mergers, starbursts and obscured quasars

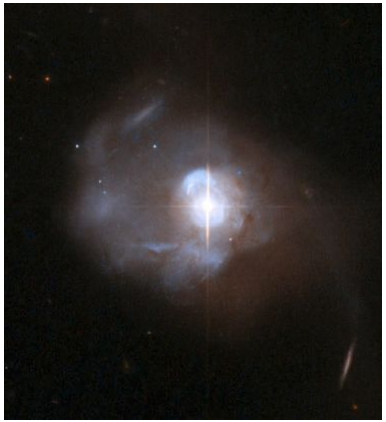


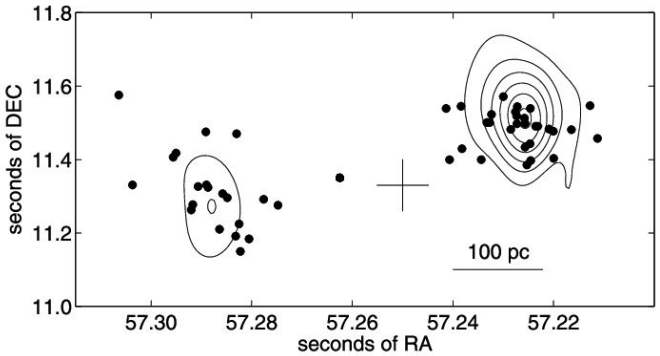
Our team has been imaging ULIRGs with VLBI to distinguish obscured AGN from starbursts

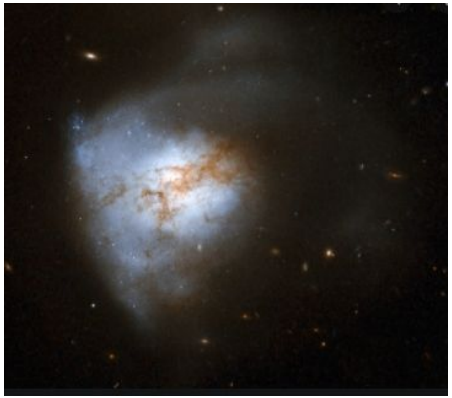
Mrk 231 Lonsdale et al 2003

Arp 220 Smith et al 1998

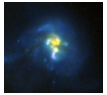






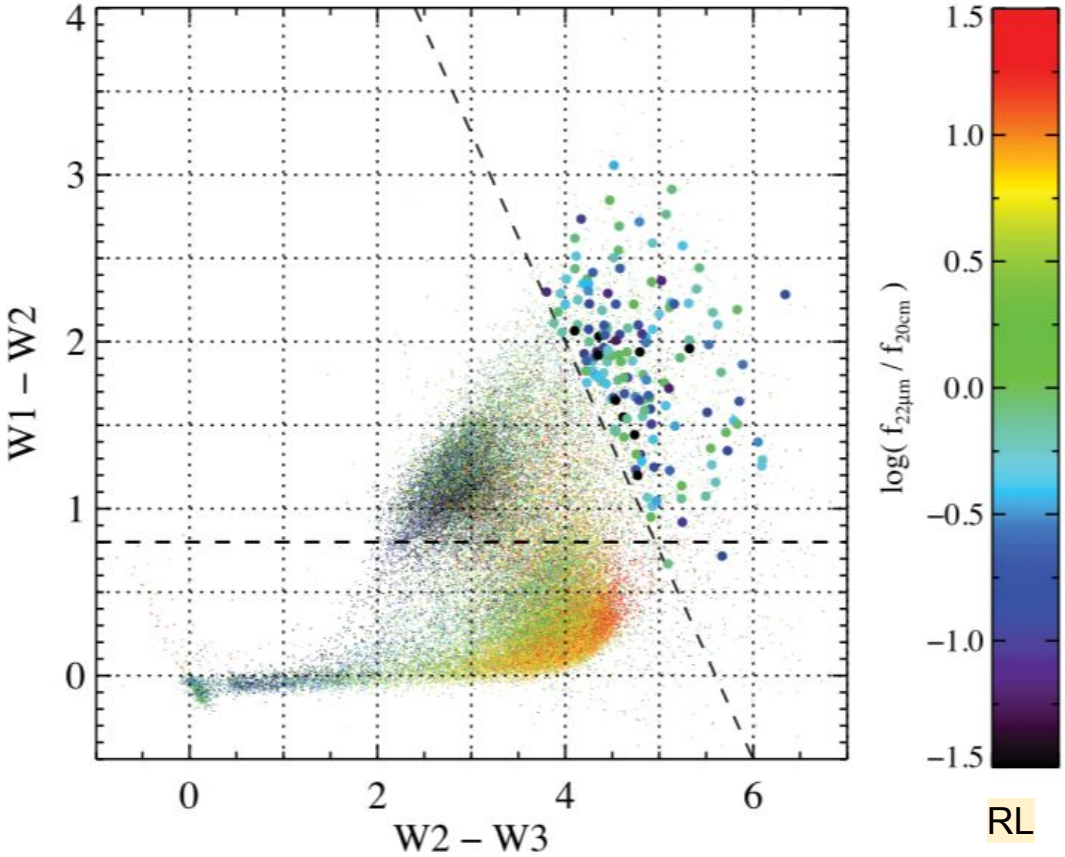


The WISE-Radio Young Obscured Quasar Sample

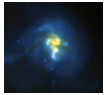


- WISE: select the most obscured objects in color space
- NVSS/FIRST: requiring a high radio/IR ratio guarantees an active radio AGN
- Redshift of interest: z=1-3, cosmic noon.
- These sources are therefore highly luminous by selection: quasars
- We found about 870 sources in the heavily obscured AGN/ULIRG region. The sample observed with VLA was 156.
- Redshift range is 0.3 to 2.8

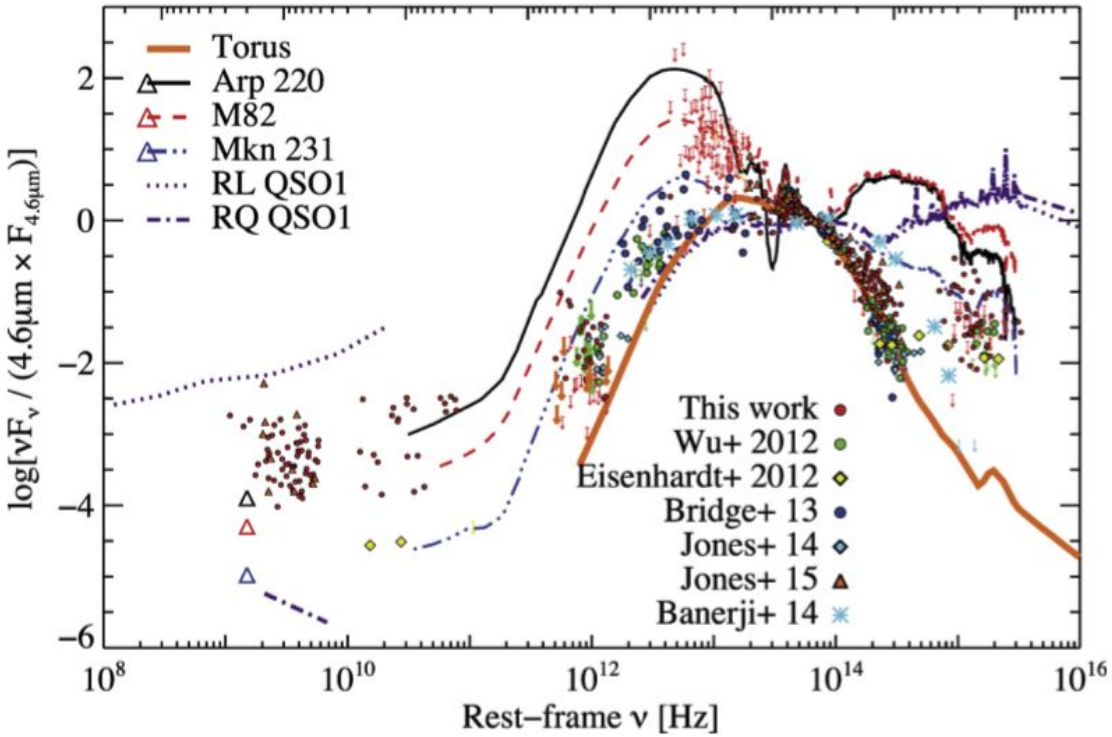
Lonsdale et al 2015



The WISE-Radio Young Obscured Quasar Sample

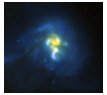


- Reddest objects known
- Moderately radio loud
- Extremely rare, consistent with a very short evolutionary phase
- New influx of large amounts of dense nuclear ISM?
- First new radio jet episode after a major merger?



Lonsdale et al 2015

Radio Campaign in Frequency-Resolution Space

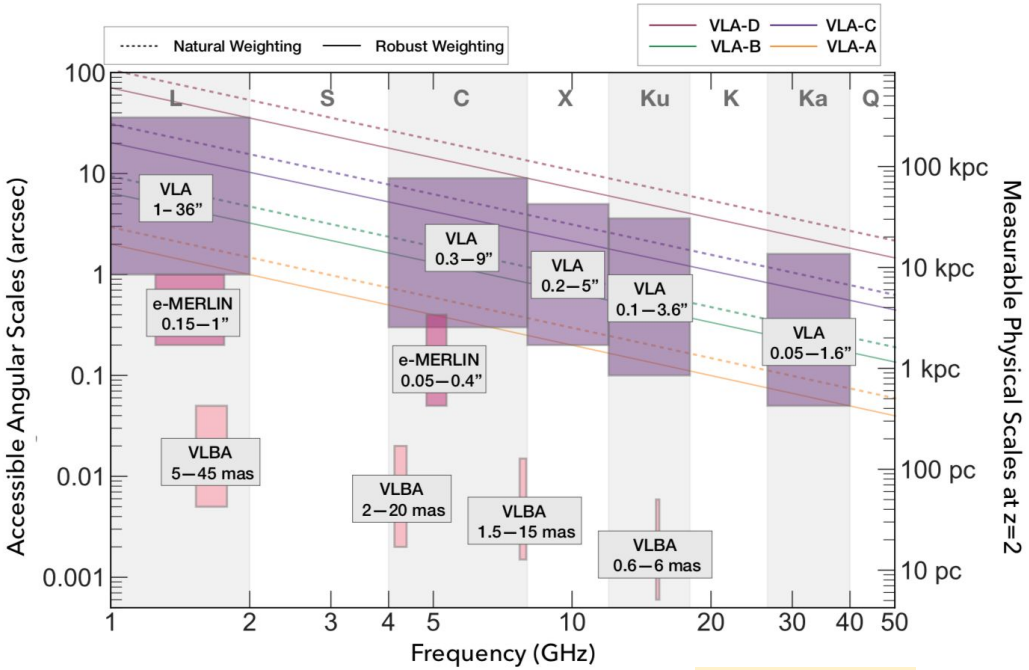


Pallavi Patil's talk

- Overall project goals and results
- VLA imaging and SEDs of 156 sources in X-band

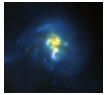
This talk

- VLBA snapshot imaging survey in C-band
- Deep imaging of 12 sources in L, C, X and Ku bands (Patil et al 2021)
- Early results for HFP and GPS sources



P. Patil's Thesis

Snapshot survey, VLBA C band



"Quick-look" imaging of 90 sources in C band, 5 GHz, 12m per source

1.4–2 mas resolution, ~ 10–20 pc at z ~ 2

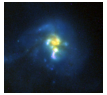
62 detections
- Unresolved singles
- Doubles
- Multiples
- Complex structures

Focus in this talk on HFP & GPS sample:

- 15 sources: 3 HFP and 12 GPS
- 8 have known redshift: 1.4 - 2.9

Will also present preview images from the deep LCXKu band survey of Patil et al, 2022

e-MERLIN L and C band imaging



15 targets with 4 hours per source

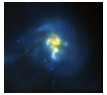
50-150 mas resolution, ~ 300–800 pc at z ~ 2

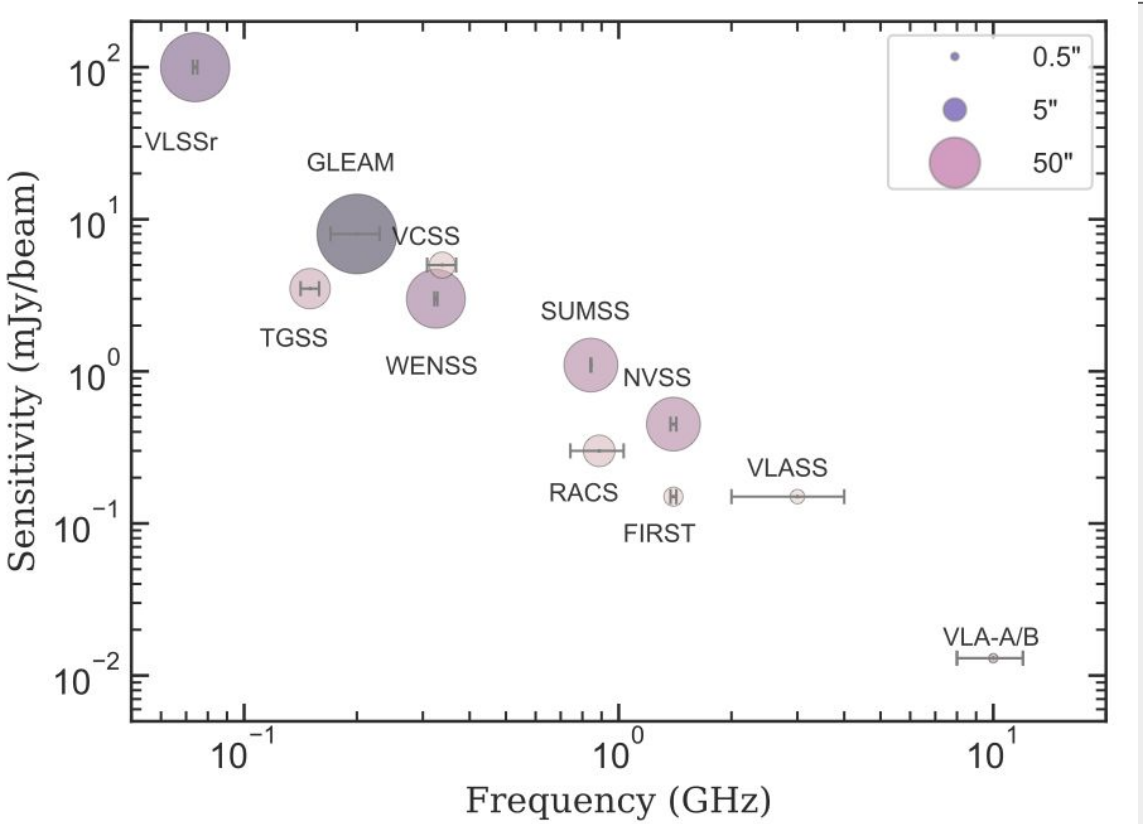
30-60 uJy/beam noise level

12 are part of VLBA snapshot imaging - All are compact < 150 mas

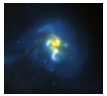
Will not be discussing these results today

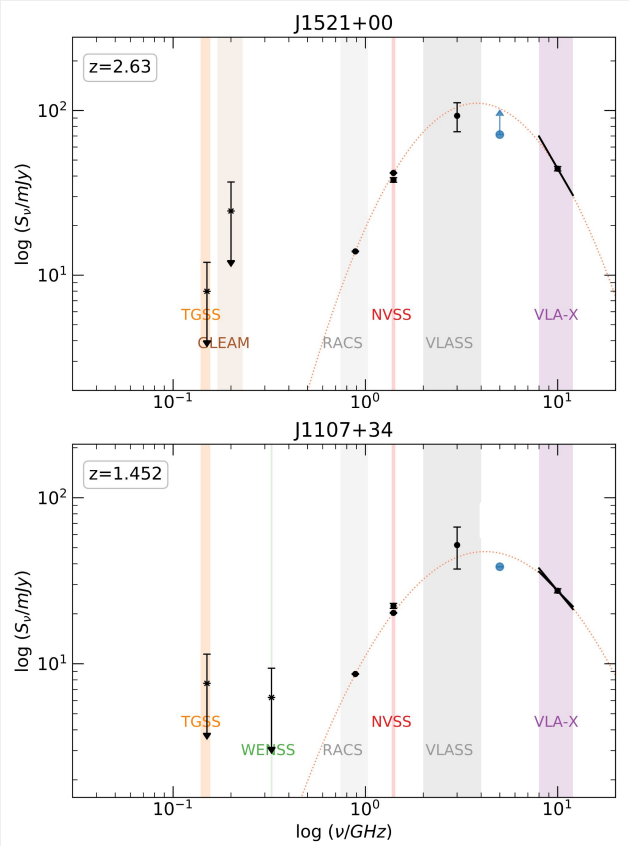
Archival radio surveys used in broadband radio spectra

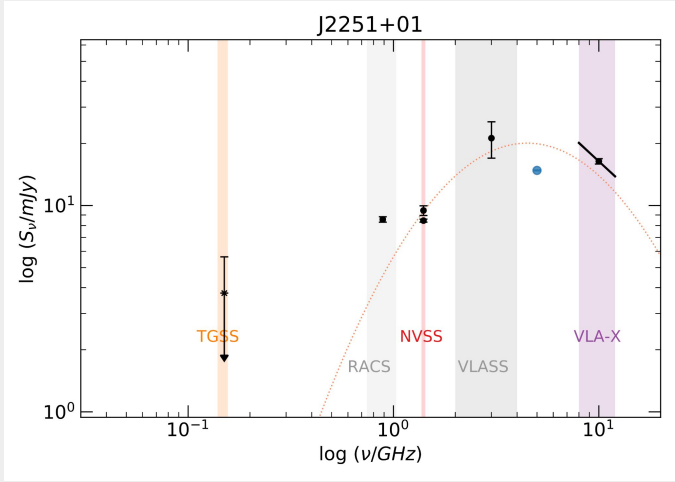




The 3 Highest Frequency Peakers in the Sample: HFPs







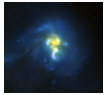
SED data and fits
Patil et al. in prep, 2021

VLBA C-band (blue)
Lonsdale et al. in prep, 2021

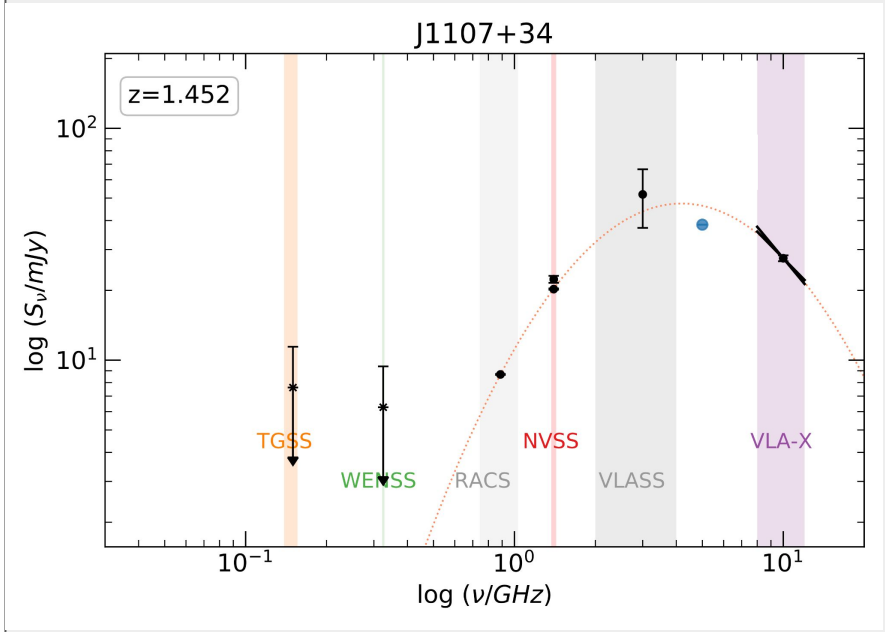
The VLBA-scale fluxes are approximately consistent with the SED fit made from the lower resolution data

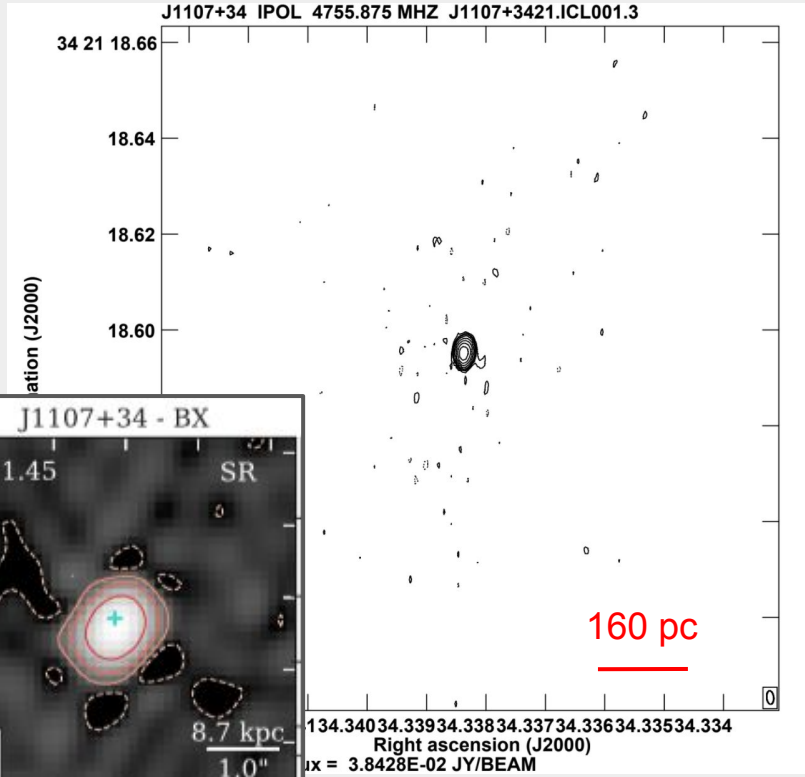
- All the flux could be arising from a single epoch source

J1107+34 VLA-X VLBA-C HFP with ν_{peak} ~10 GHz



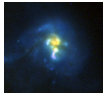
VLA: slightly resolved by B-array
VLBA: single compact source



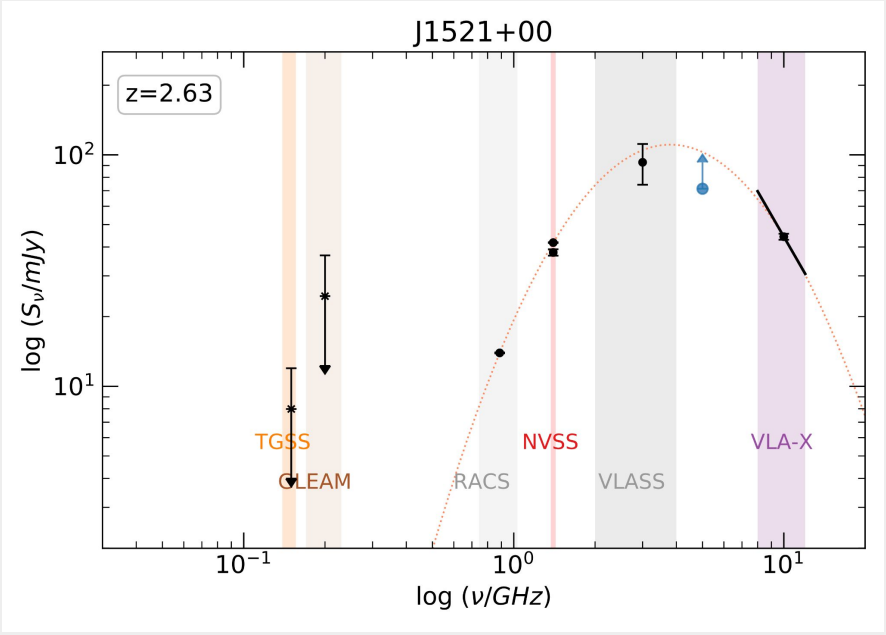


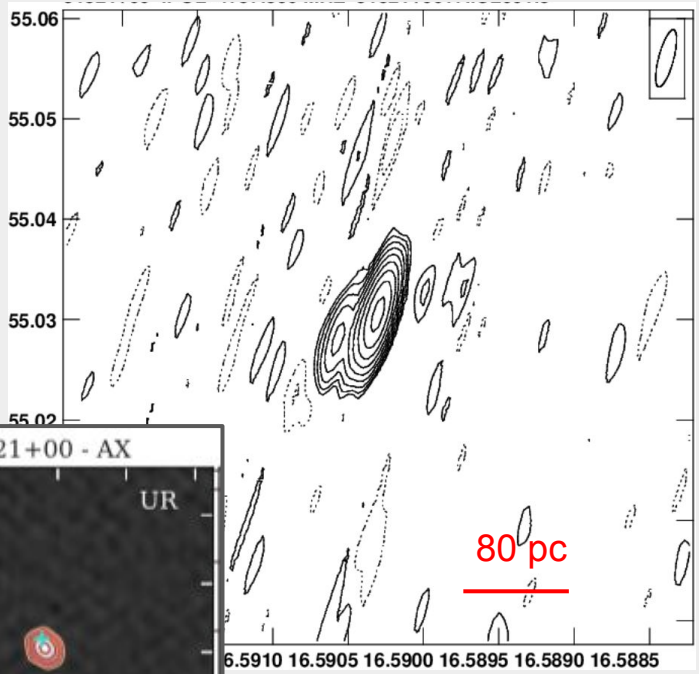
National Radio Astronomy Observatory

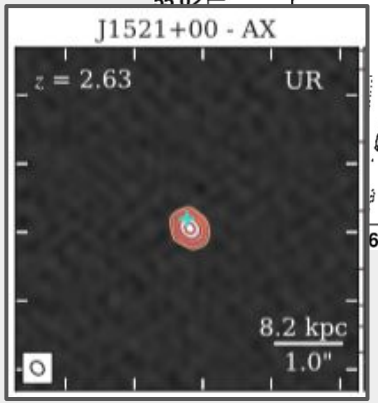
J1521+00 VLA-X VLBA-C HFP with ν_{peak} ~15 GHz



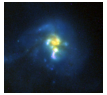
VLA: unresolved in A-array
VLBA: close double source



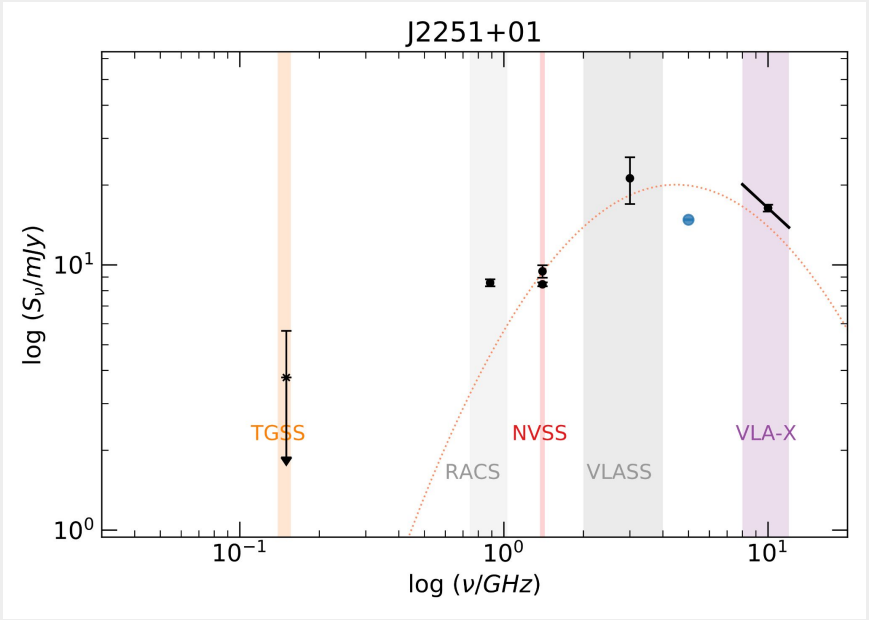


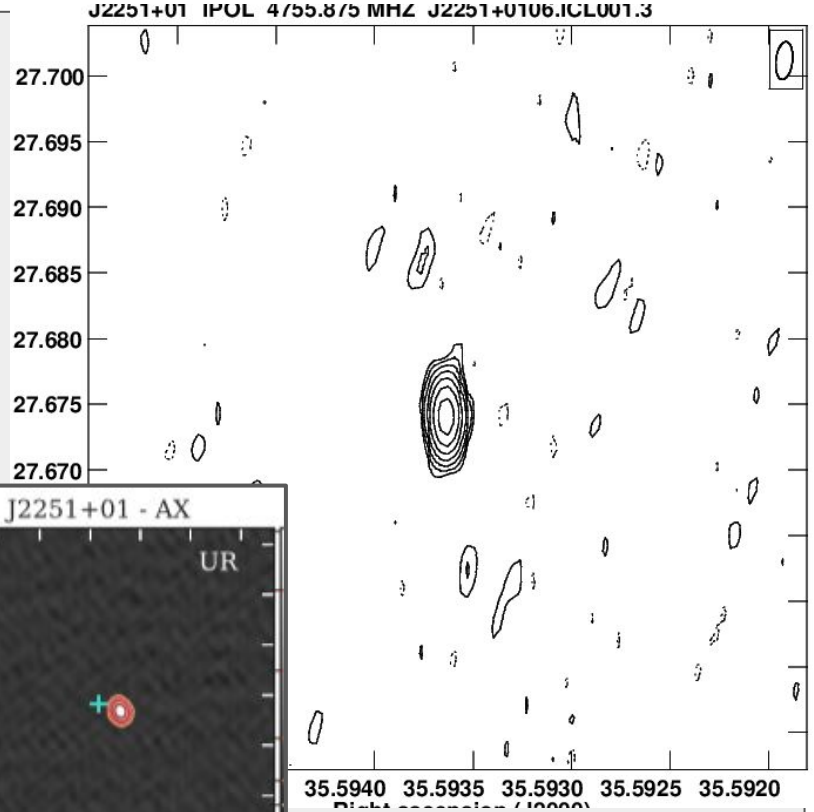


J2251+01 VLA-X VLBA-C HFP with ν_{peak}>~ 6 GHz

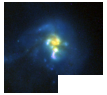


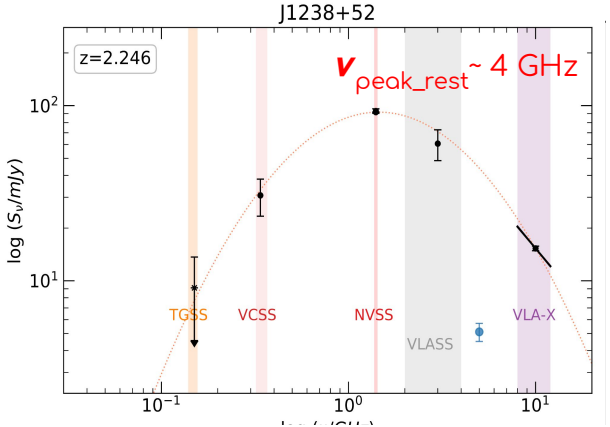
VLA: unresolved in A-array
VLBA: single compact source

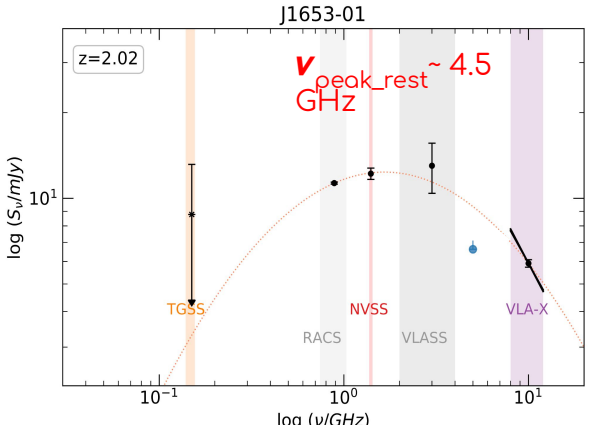


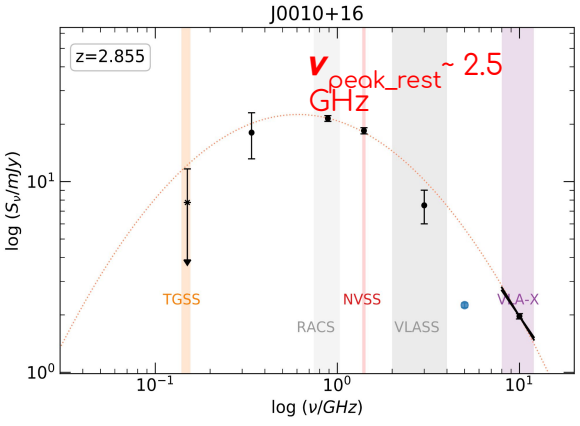


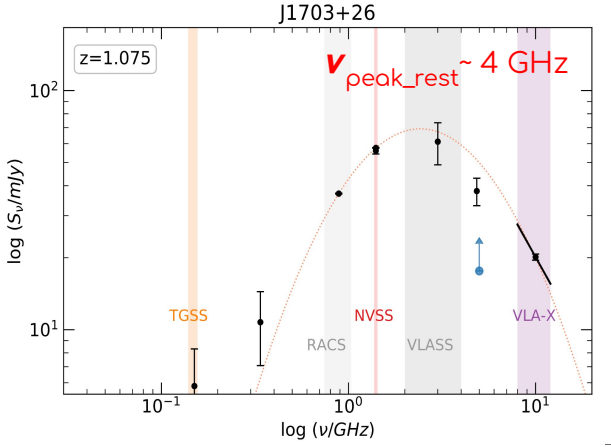
GPS sources with known redshift

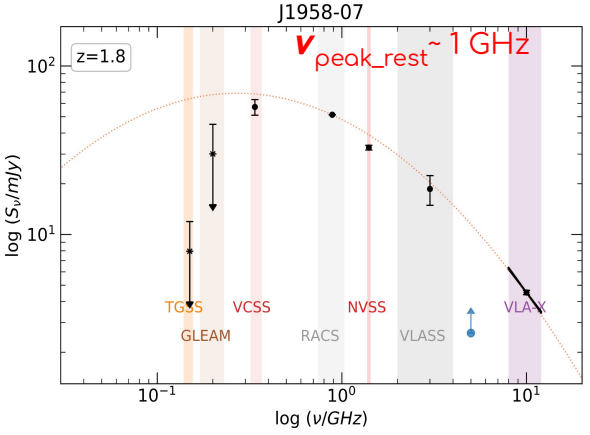








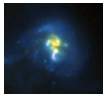


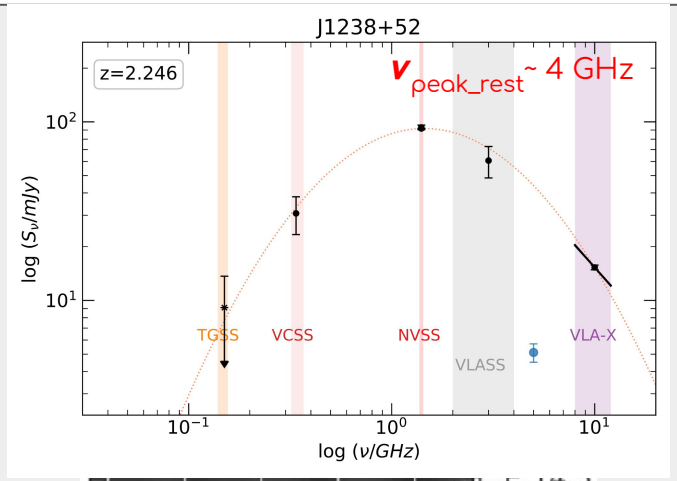


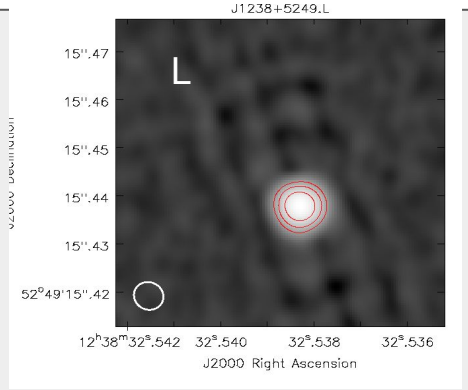
For the GPS sources, the VLBA-scale flux is often several times fainter than the SED fit to the lower resolution data

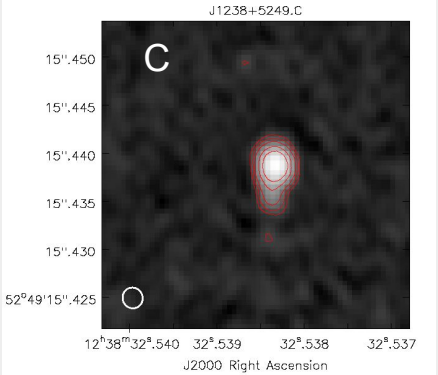
- VLBA is resolving out significant flux
- Presence of multiple epoch sources possible
- 1958-07 has a steep absorption spectrum

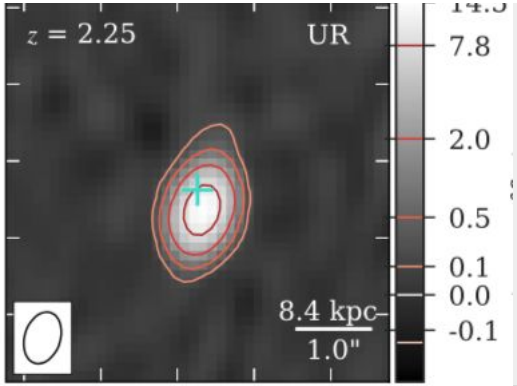
J1238+52 VLA-X VLBA-LCKu GPS VLBA: triple VLA: unresolved

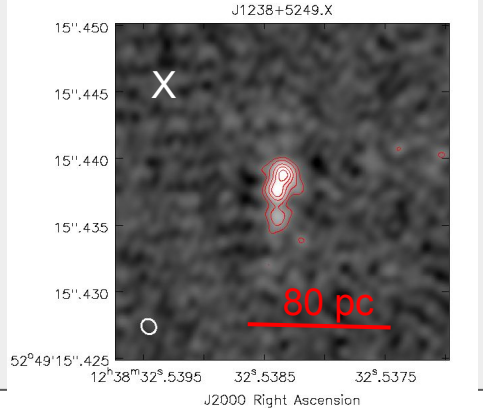


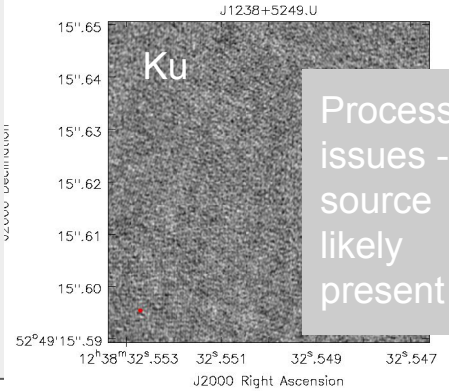






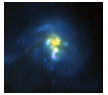




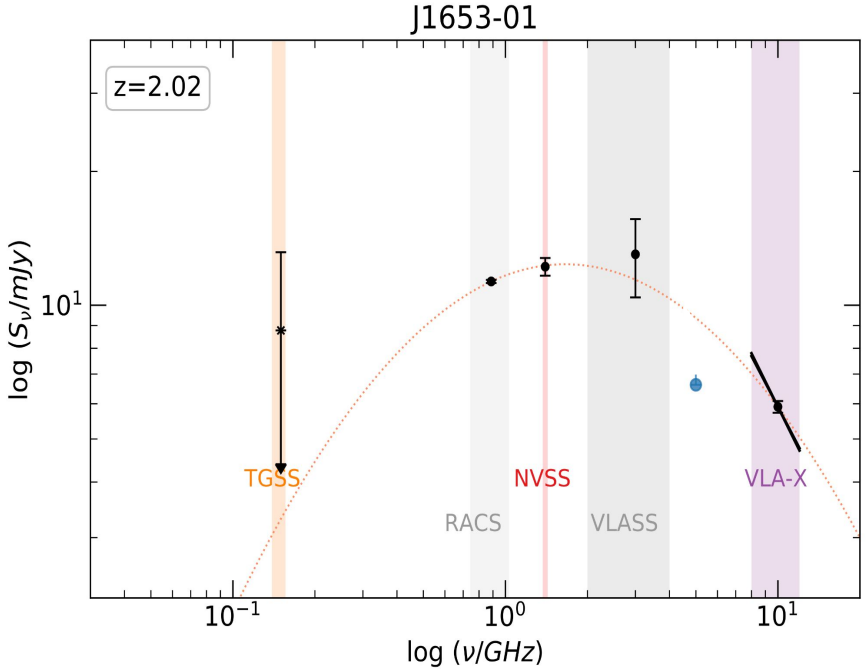


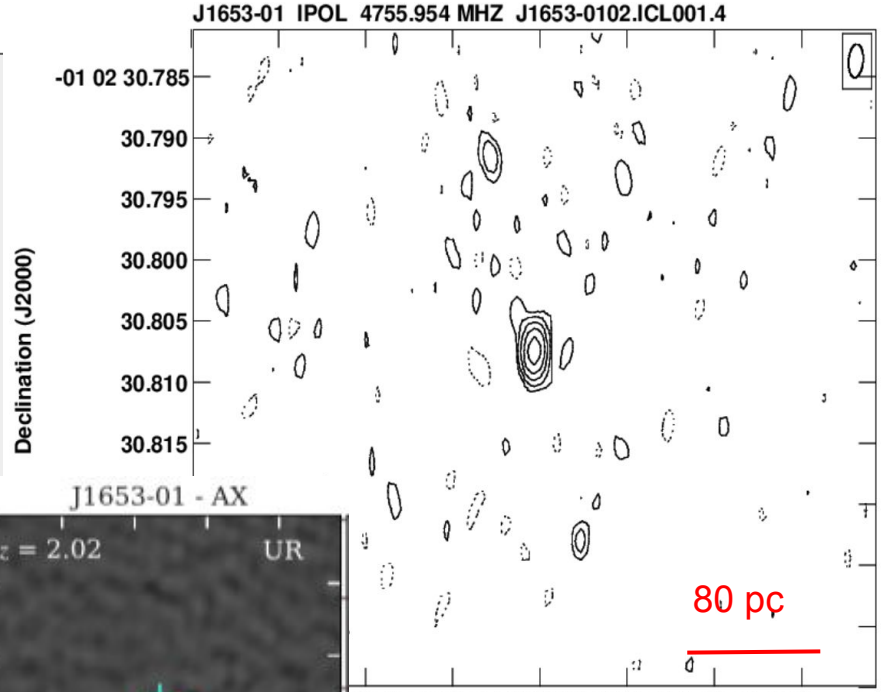
Processing issues - source likely present

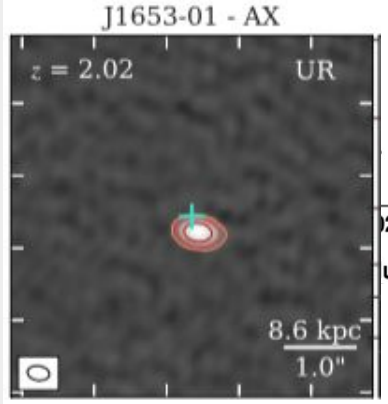
J1653-01 VLA-X VLBA-C GPS ν_{peak} ~ 4.5 GHz



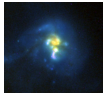
VLBA: compact core; possible triple
VLA: unresolved



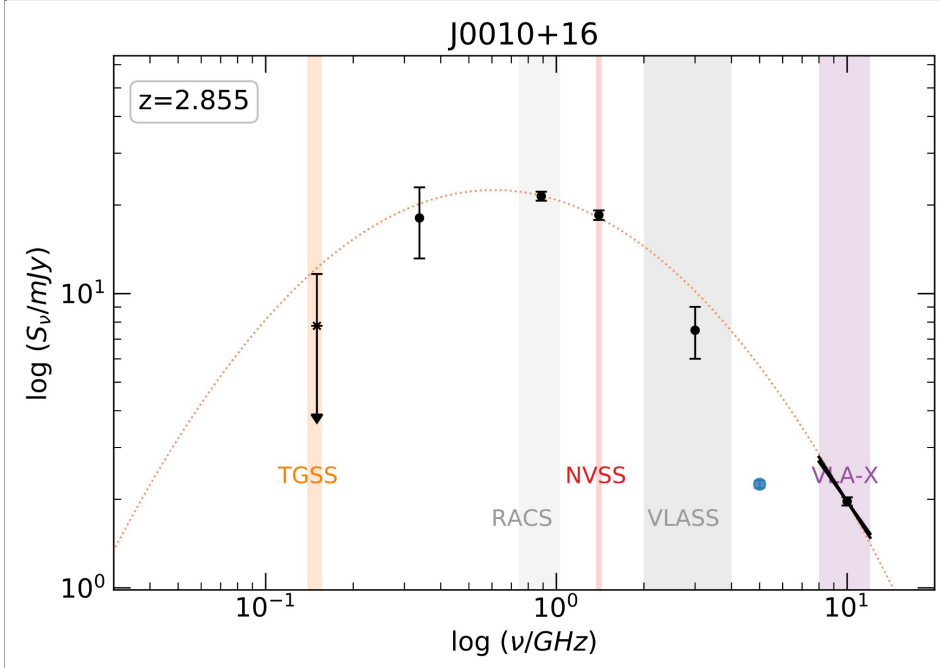


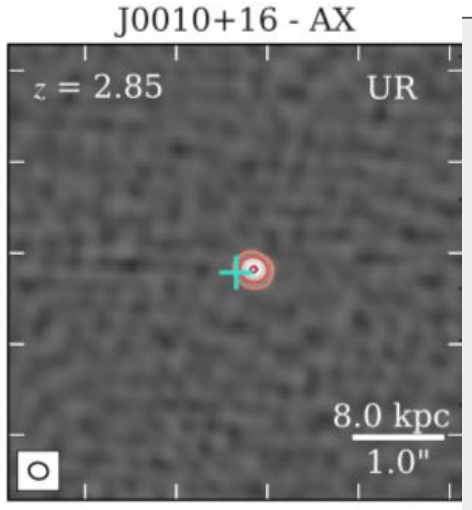


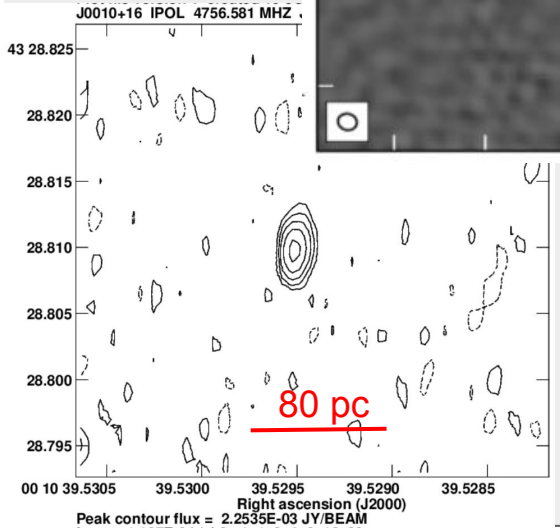
J0016+16: VLA-X VLBA-C GPS ν_{peak_rest} ~ 2.5 GHz



Both VLA and VLBA compact

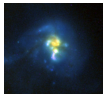


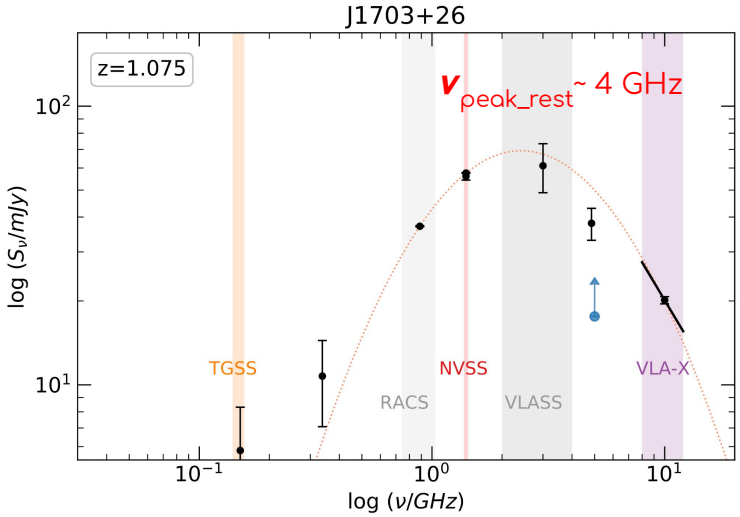


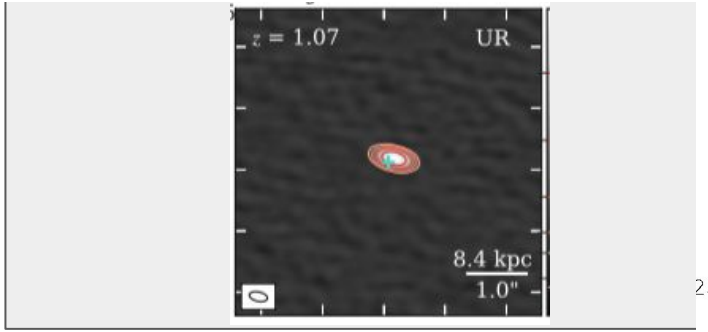


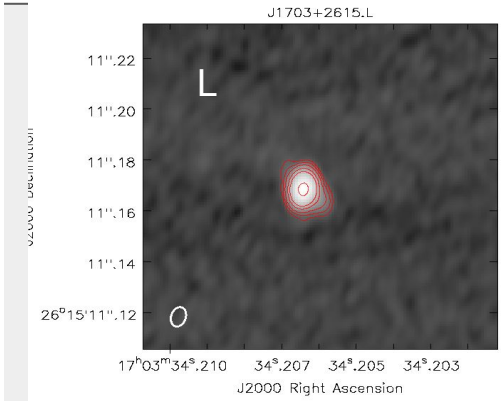
National Radio Astronomy Observatory

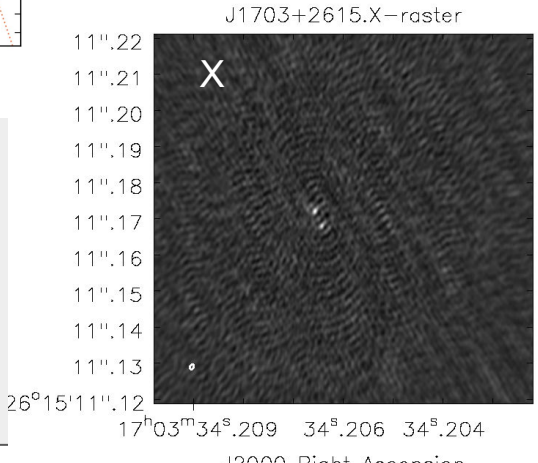
J1703+26 VLA-X VLBA-LCXKu GPS Unequal double with different SEDs

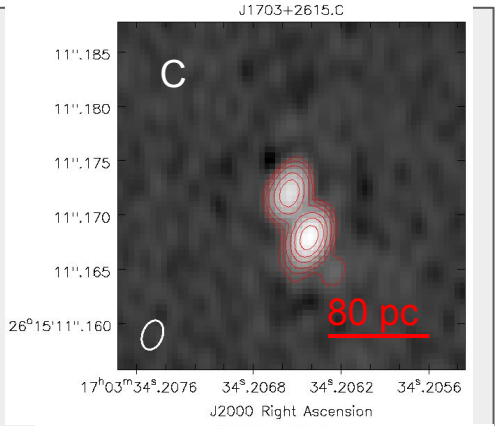


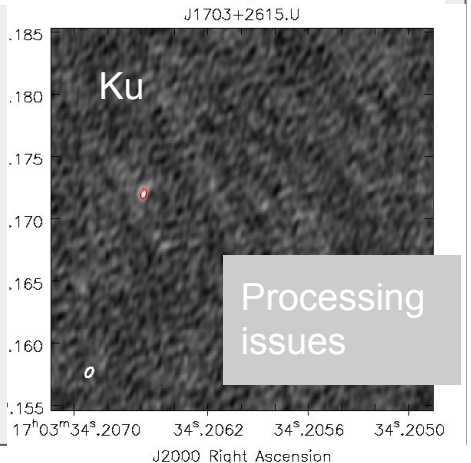




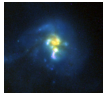




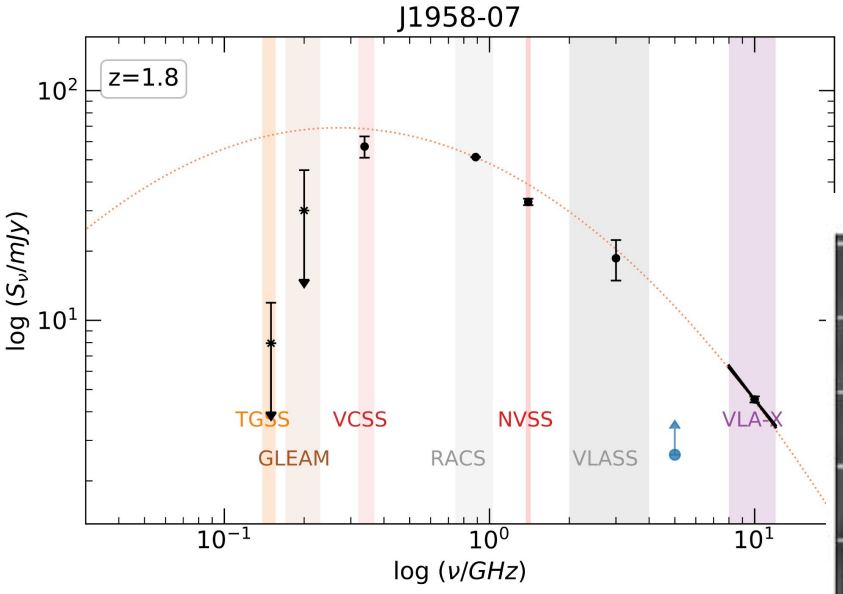


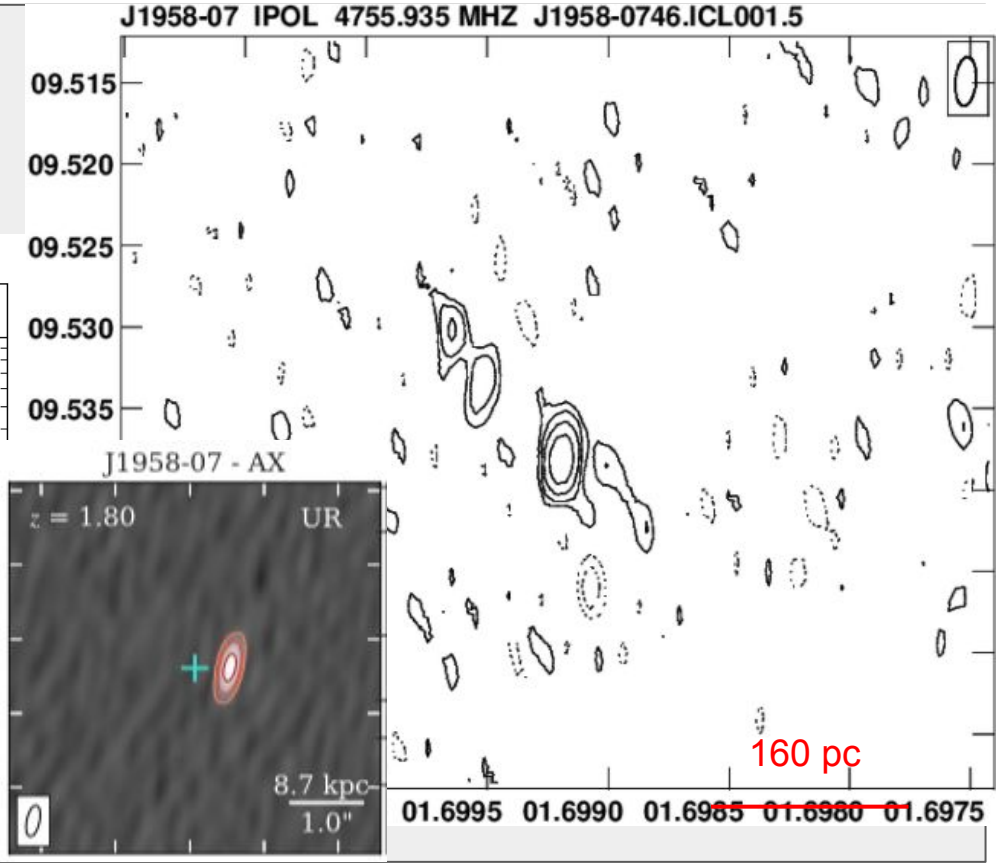


J1958-07 VLA-X VLBA-C GPS ν_{peak} ~ 1 GHz

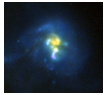


VLA unresolved
VLBA double, no core
Steep absorption SED

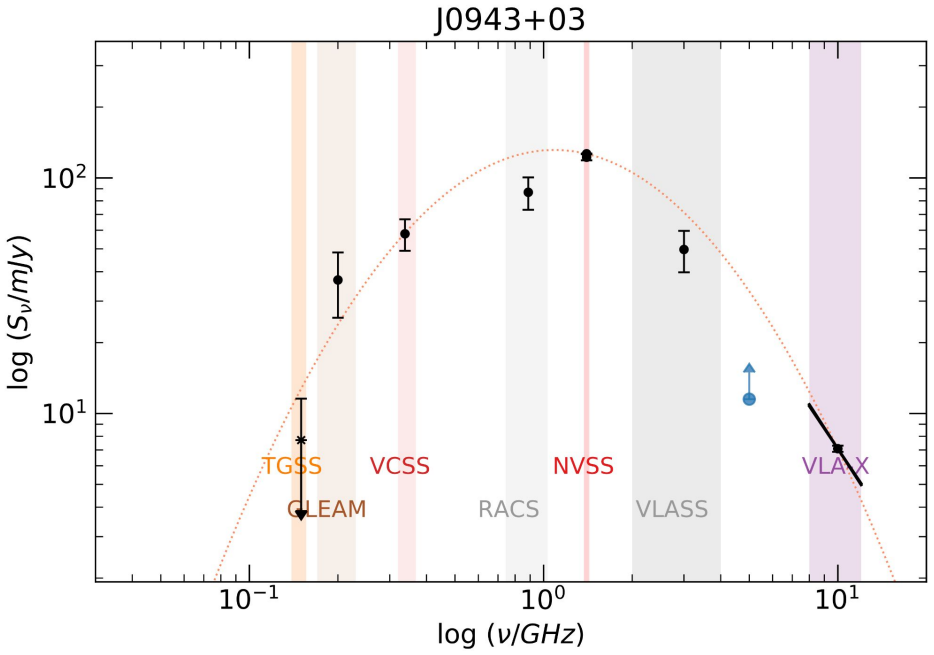


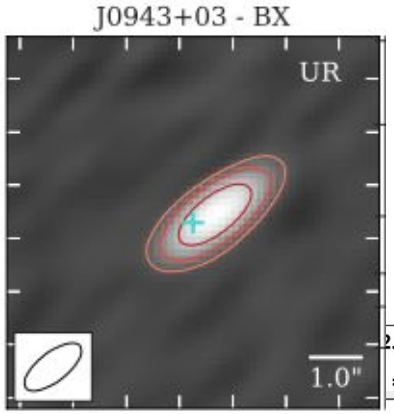


J0943+03 VLA-X VLBA-C GPS

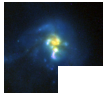


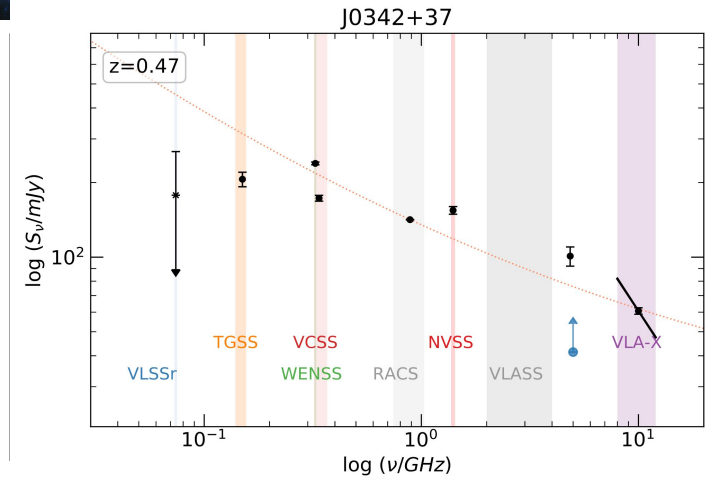
VLA: Unresolved single source
VLBA: Multiple, linear components

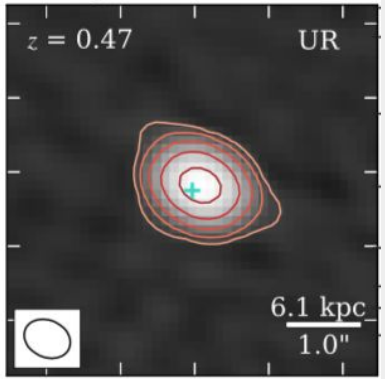




J0342+37 VLA-X VLBA-LCXKu No Peak Triple with companion

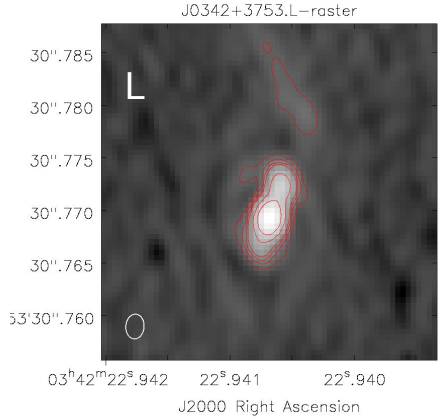


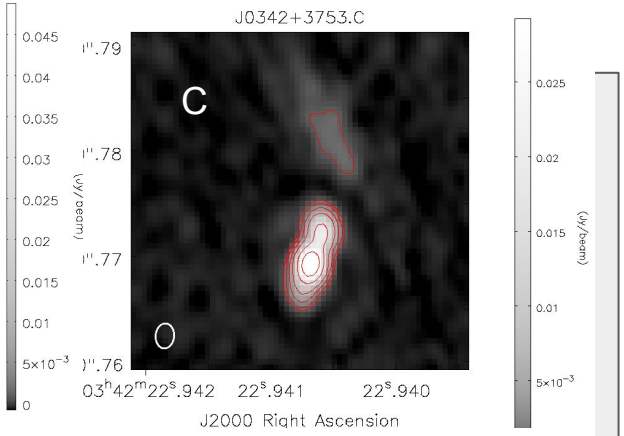


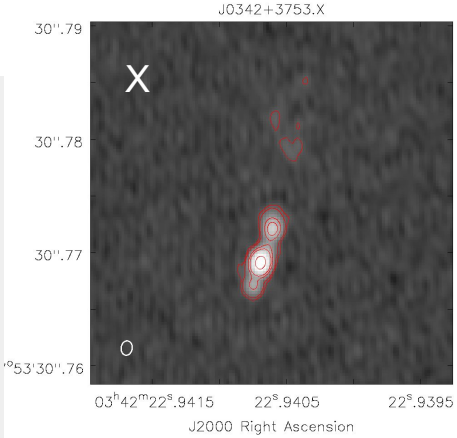


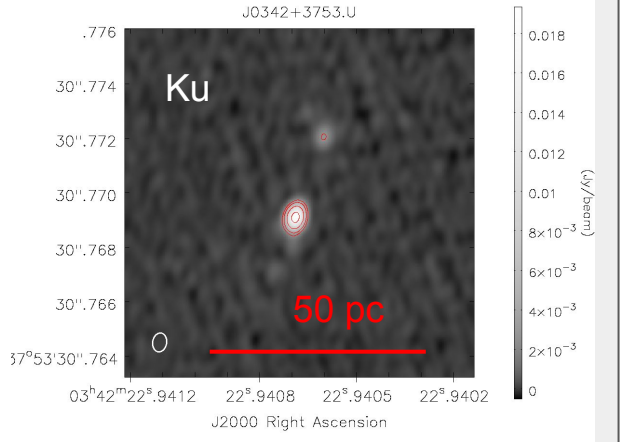
SED complex

Probably due to multiple components

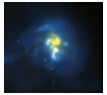


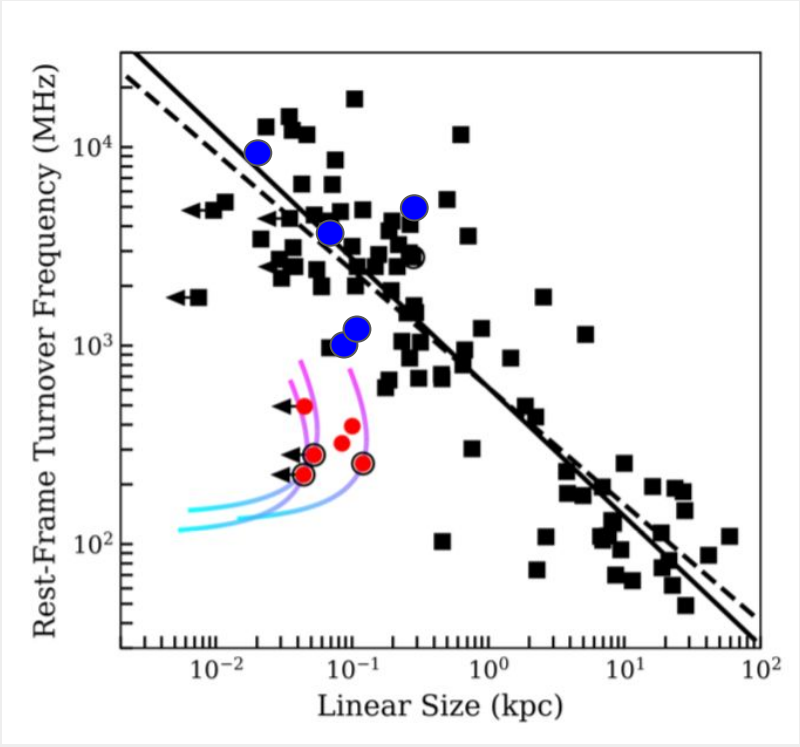






Linear size vs peak frequency

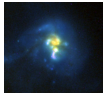




Our sources (blue) with are broadly consistent with the relation

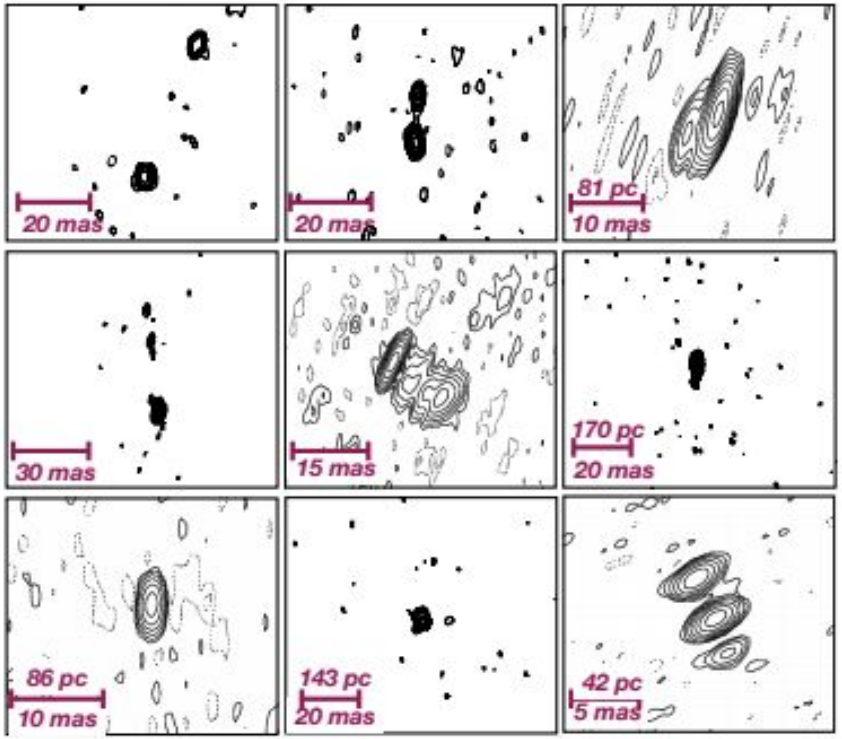
Plot from Kleim et al. 2019

Summary

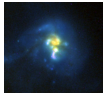


- 90 sources, C-band, 12m per source
- θ_{FWHM} ~ 1.4-2 mas
- 60% detections at SNR > 7σ

Patil et al in prep
Lonsdale et al in prep



Conclusions



Reddest AGN known in the near to mid-IR

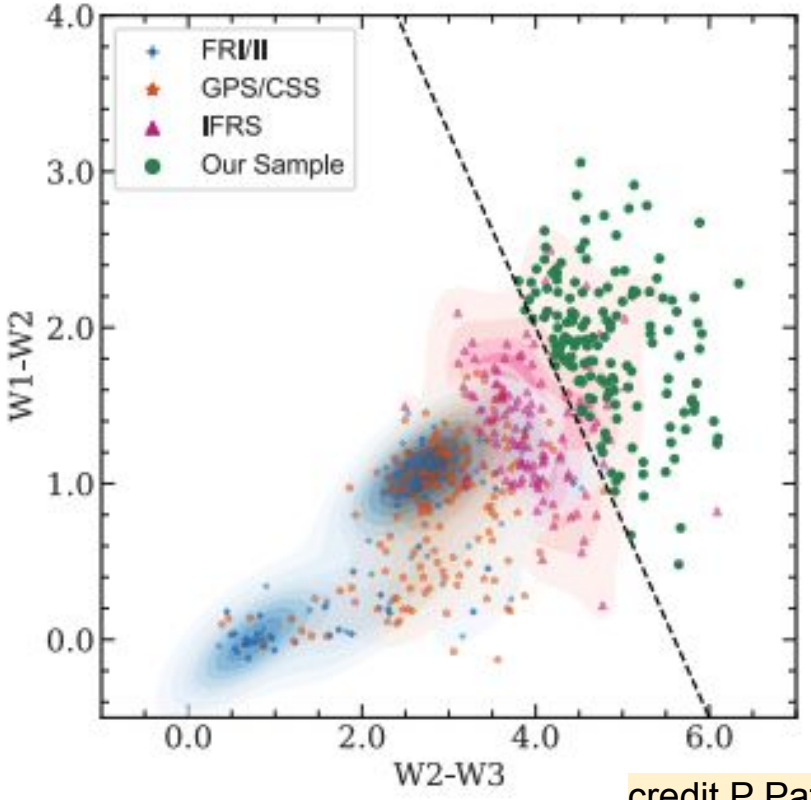
No overlap with CSS-GPS in WISE colors

Some overlap with high z radio IFRS population

General consistency with peak frequency - size relation

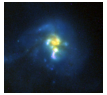
⇒ Unique highly obscured radio quasar sample at peak epoch of galaxy building

⇒ Some are potentially undergoing an initial episode of nuclear fueling after a major merger with high density cool ISM nuclear obscuration



credit P Patil

Conclusions



VLBA structures: compact cores, small doubles, triples on 100 pc scales and smaller

The 3 HFPs have VLBA fluxes most consistent with the overall SEDs, and could represent single epoch sources

Most of the GPS sources show a large loss of flux cf. the overall SED at 5 Ghz, indicating intermediate scale flux is resolved out

⇒ Source structures are complex with possible multi-epoch jet episodes

⇒ Modeling must involve multi-epoch multi-frequency detailed spectral mapping