Heavily Obscured and Luminous Quasars with Young Radio jets at z ~ 2

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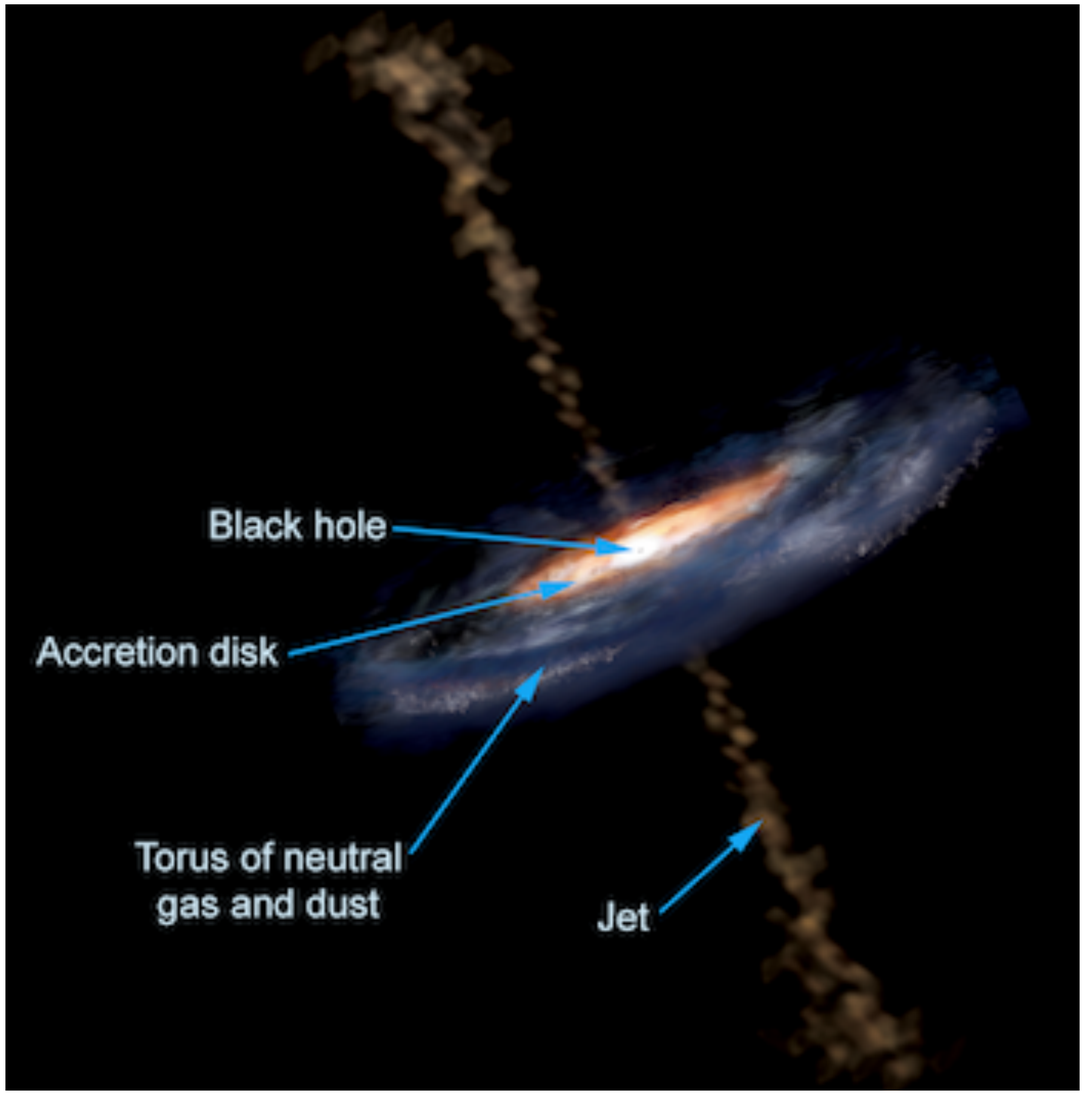
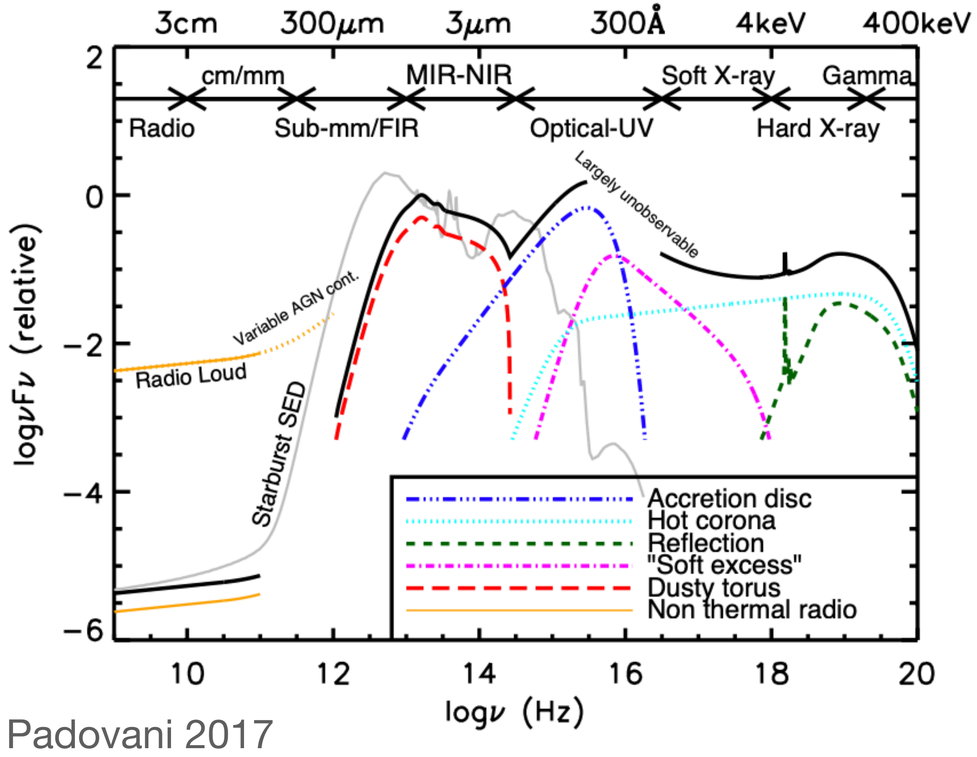
Active Galactic Nuclei (AGN)

- An actively accreting Supermassive black-hole (SMBH) is called AGN
- AGN are stronger emitters than nuclei of normal galaxies
- Very luminous objects, observable up-to high redshifts



Active Galactic Nuclei (AGN)

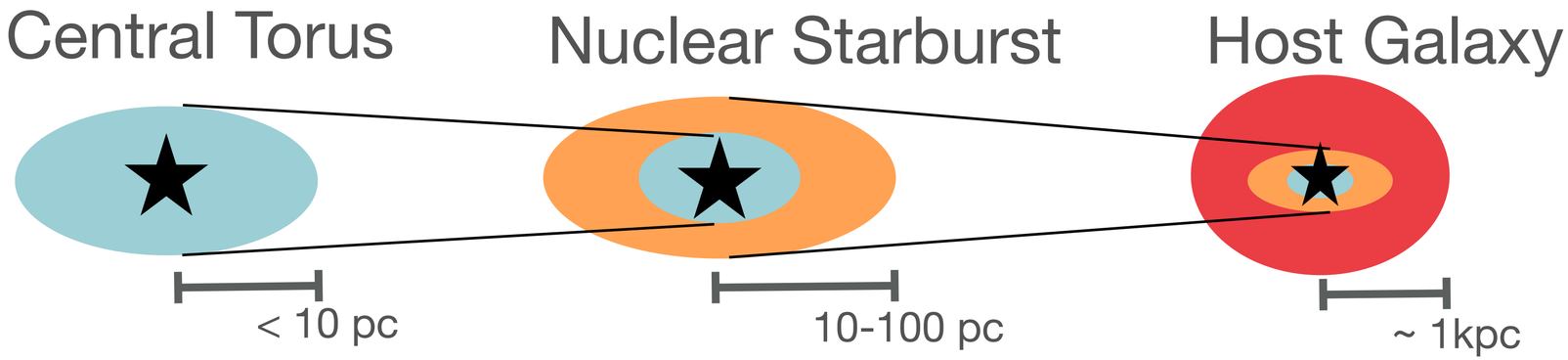
- Unique signatures across entire EM spectrum
- The view of accretion disk is obstructed in obscured AGN
- A significant AGN population is obscured
- Characterizing the complete census of AGN is essential to our understanding of the evolution of galaxies and growth of SMBHs



Padovani 2017

The Obscured Phase in AGN

Obscuration can occur on different spatial scales:

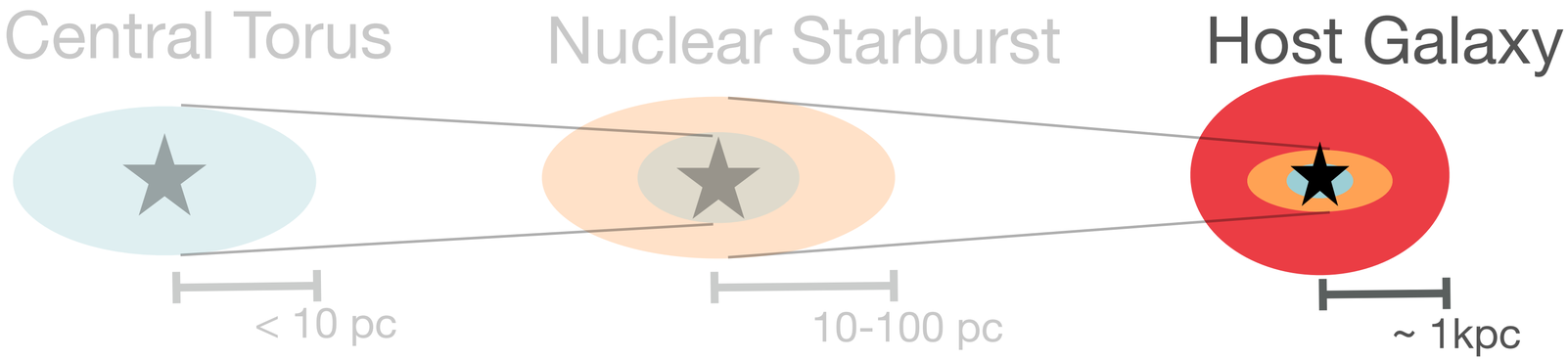


Type-2 AGN

Major-mergers

The Obscured Phase in AGN

Obscuration can occur on different spatial scales:

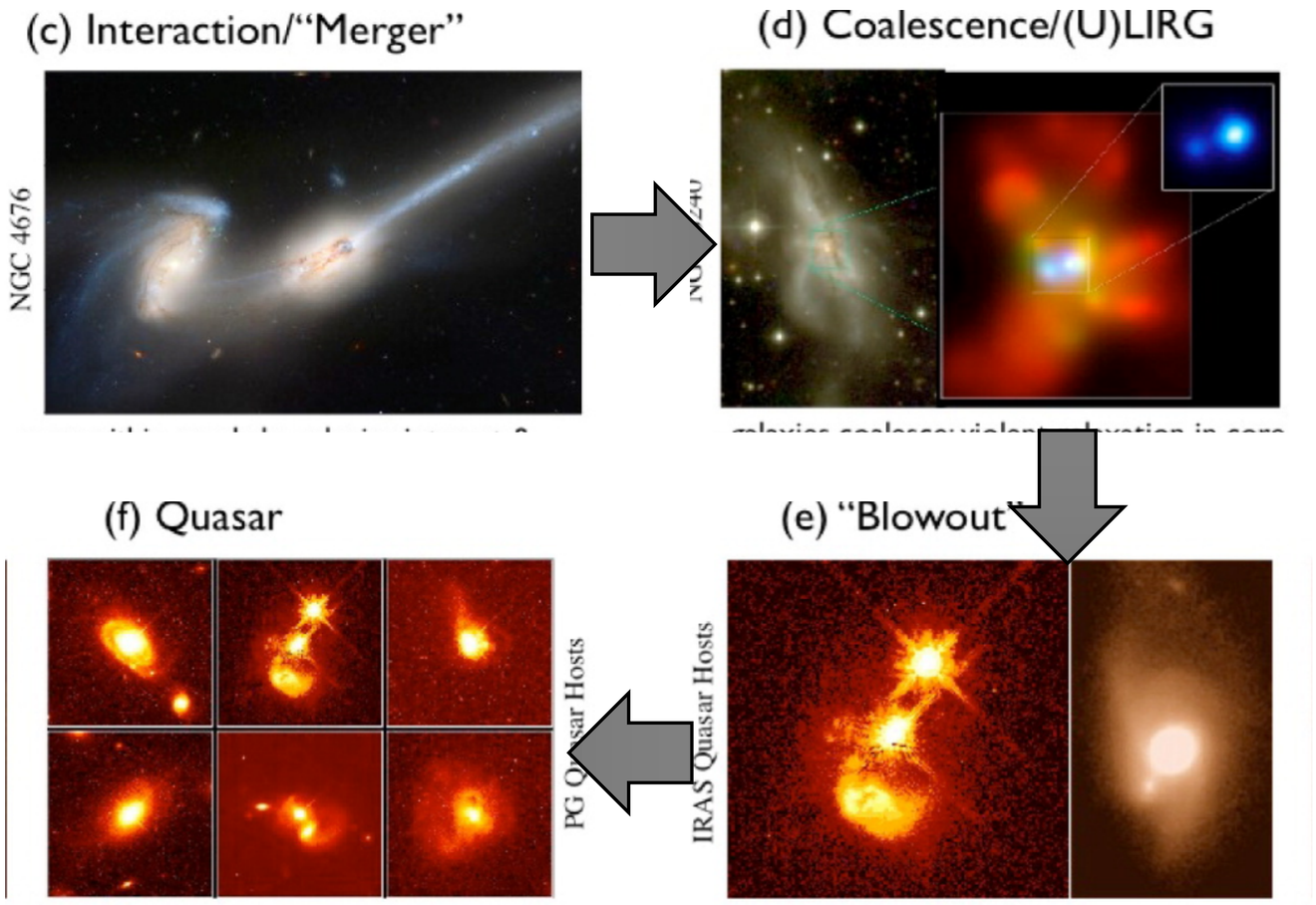


Type-2 AGN

Major-mergers

- Rapid SMBH and galaxy growth in a post-merger coalescence
- More likely seen in luminous galaxies

Catching Luminous Quasars Young



Hopkins et al. 2008

- Gas-rich major-mergers trigger star formation and AGN/Quasar
- SMBH is growing rapidly in the **Blowout** phase.
- Enshrouded by dust: Optically Faint, Heavily reddened, and MIR Bright
- More numerous at z ~ 2

Ideal systems to study AGN feedback and SMBH-galaxy co-evolution

Searching for Hidden AGN

Wide-Field Infrared Survey Explorer (WISE)

4 bands
3.6, 4.5, 12, 22 μm

NRAO VLA Sky Survey (NVSS)

L band- 21 cm

- Cross-match between very red WISE sources with bright, compact NVSS sources
- Study the earliest stages in the life-cycles of luminous AGN

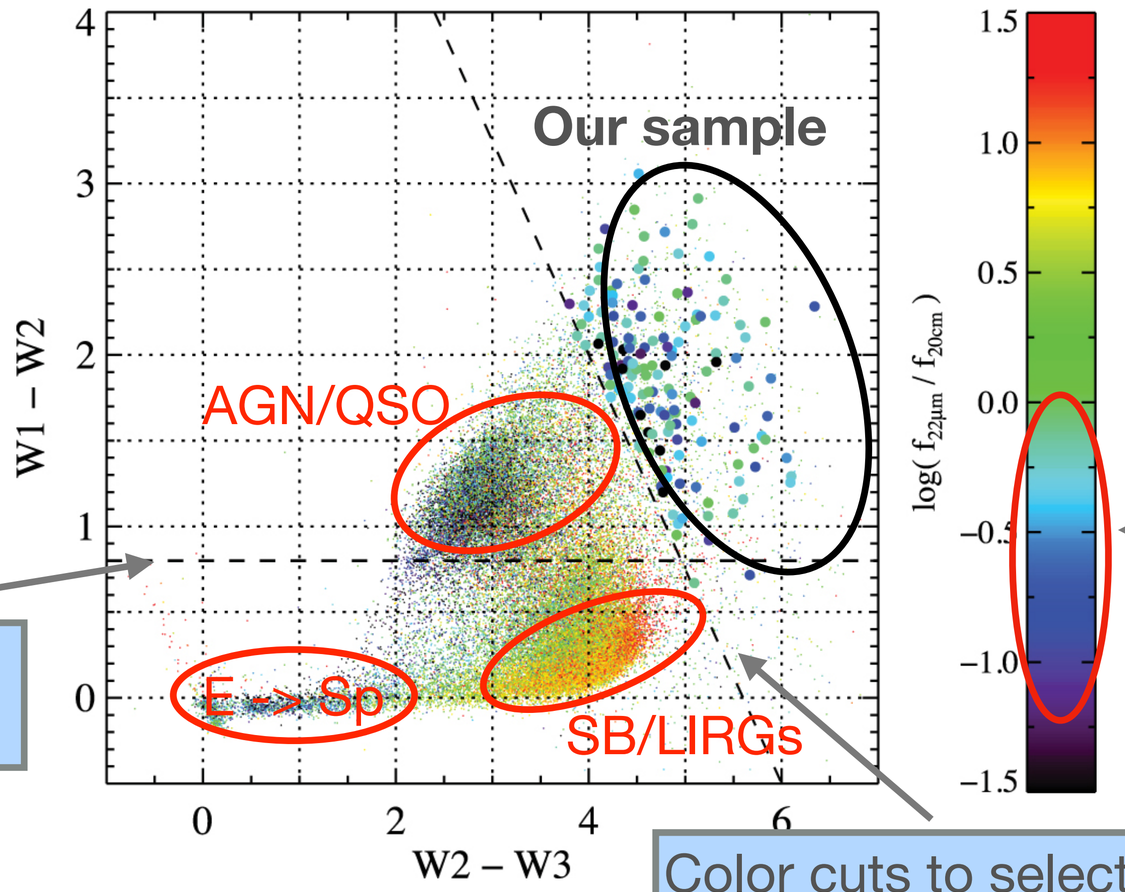
Searching for Hidden AGN Using mid-IR

Cross matching WISE extragalactic catalog with NVSS/FIRST

156 sources

$L_{IR} \sim 10^{12.5-13.5} L_{\odot}$

$z \sim 0.47 - 2.8$



$$q = Log \frac{f_{22\mu m}}{f_{21cm}}$$

Radio intermediate or powerful

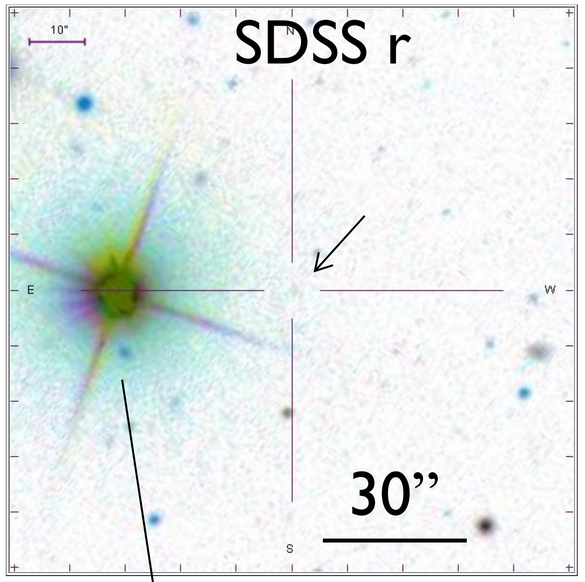
Also: Optically Faint → Distant

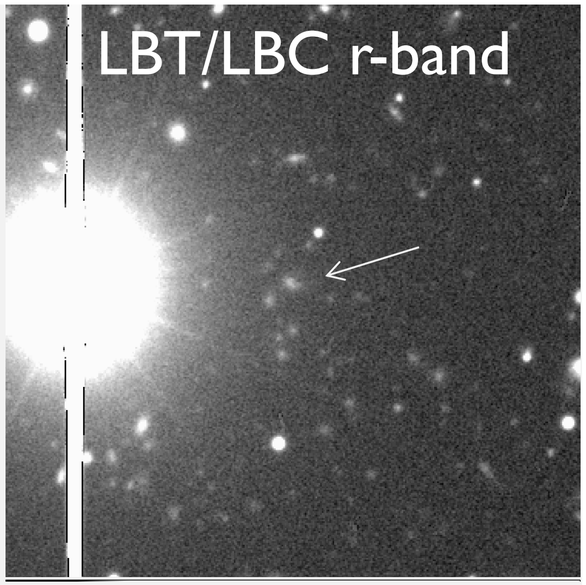
Stern et al. 2013 AGN selection

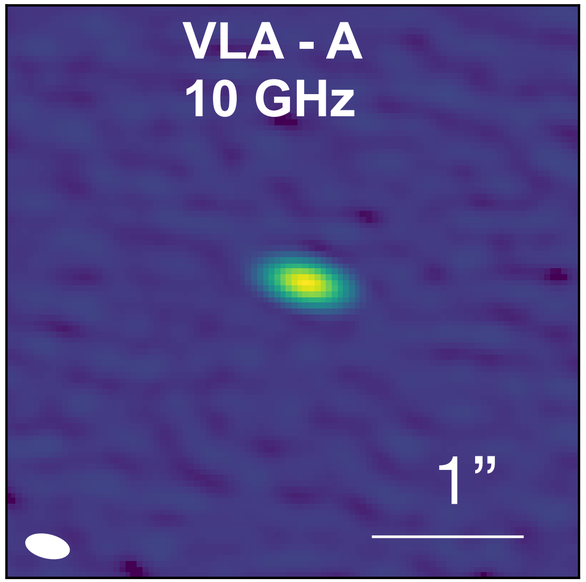
Color cuts to select reddest MIR colors

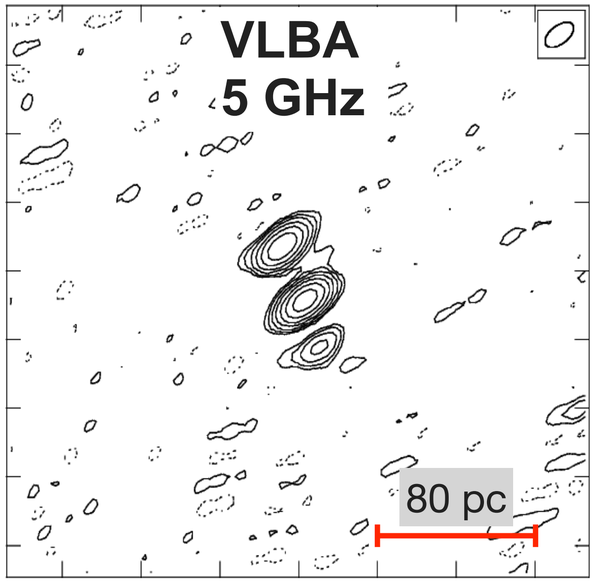
Lonsdale et al. 2015

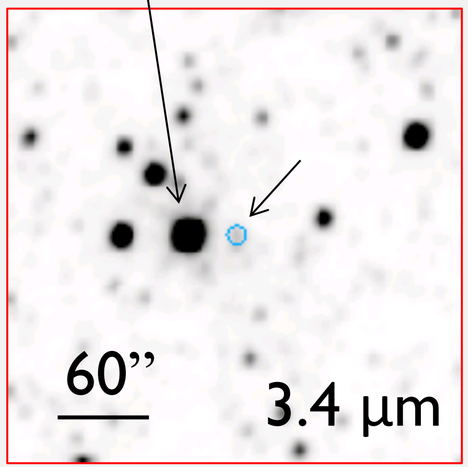
Our Multi-Wavelength Campaign

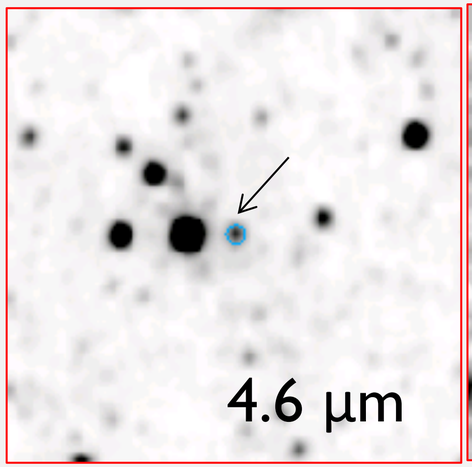


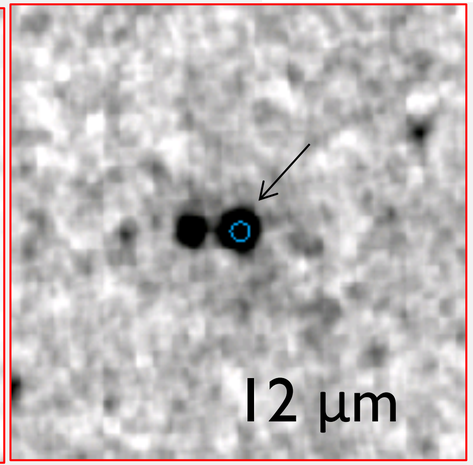


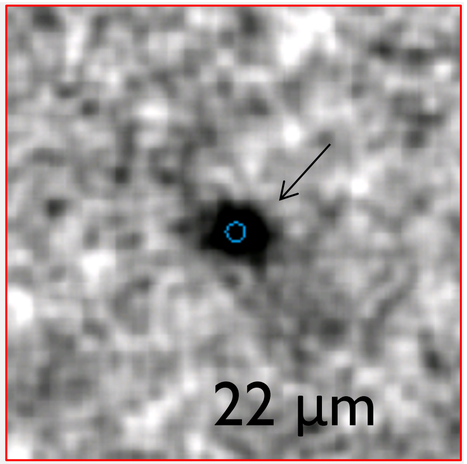


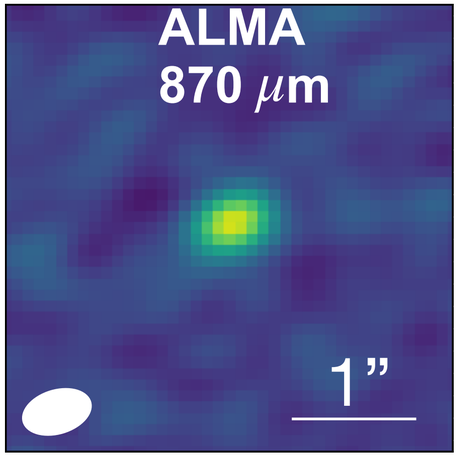








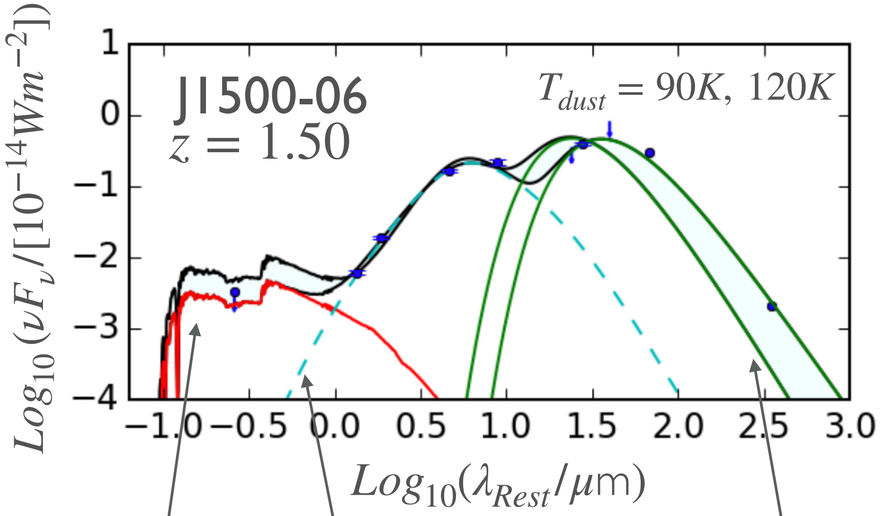




*Different Source

Results From IR SEDs

MIR & FIR SED Fitting

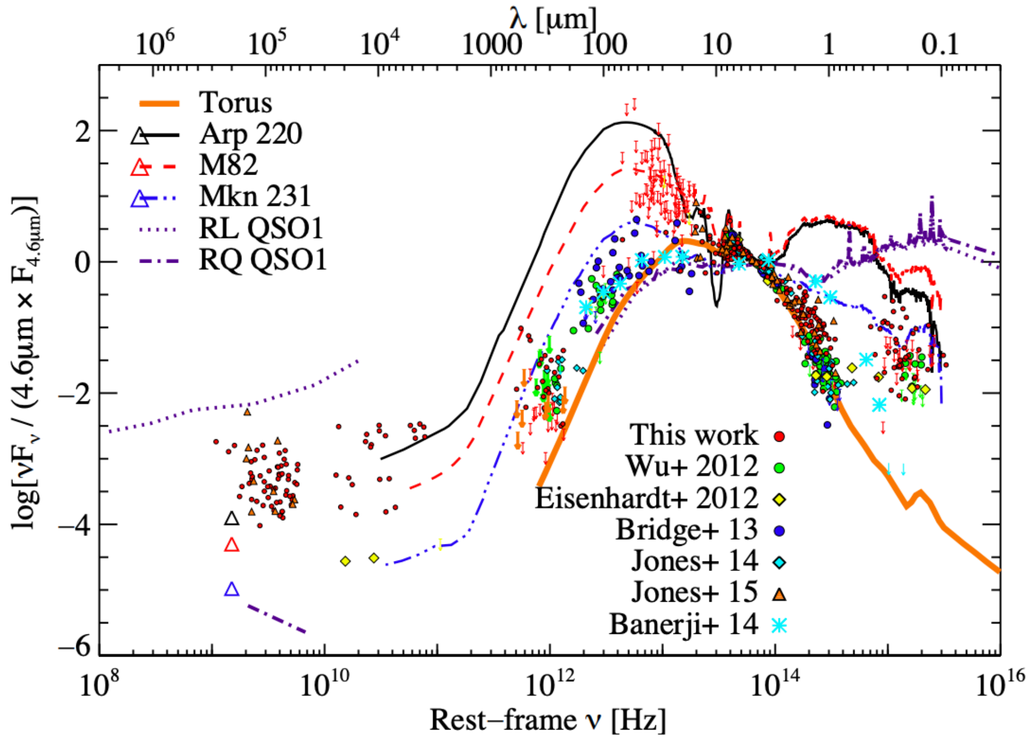


Obscured Stellar Component

AGN Heated Dust

Starburst

SED Ensemble



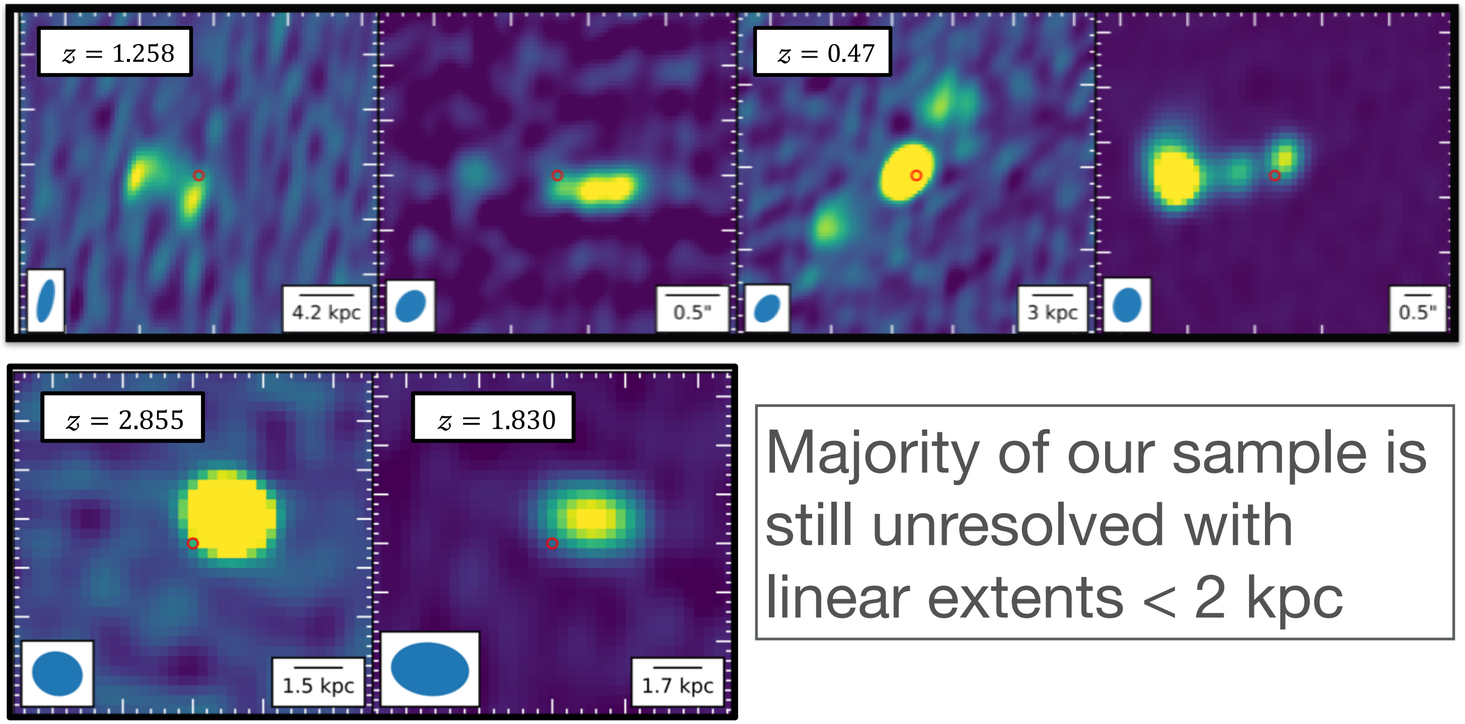
Lonsdale et al. 2015

SEDs suggest presence of a Luminous AGN ($L_{Bol} \sim 10^{12-14} L_\odot$) and possibly a starburst (SFR ~ $100 - 10000\, M_\odot yr^{-1}$)

High-Resolution JVLA Imaging

- X-band (8-12 GHz) multi-configuration snapshot survey (A & B) with 0.2” and 0.6” resolution
- Goal: to characterize morphologies and radio SEDs of our sample sources

28% of our sample have resolved 10 GHz morphologies with linear extents of ~ 4 - 50 kpc

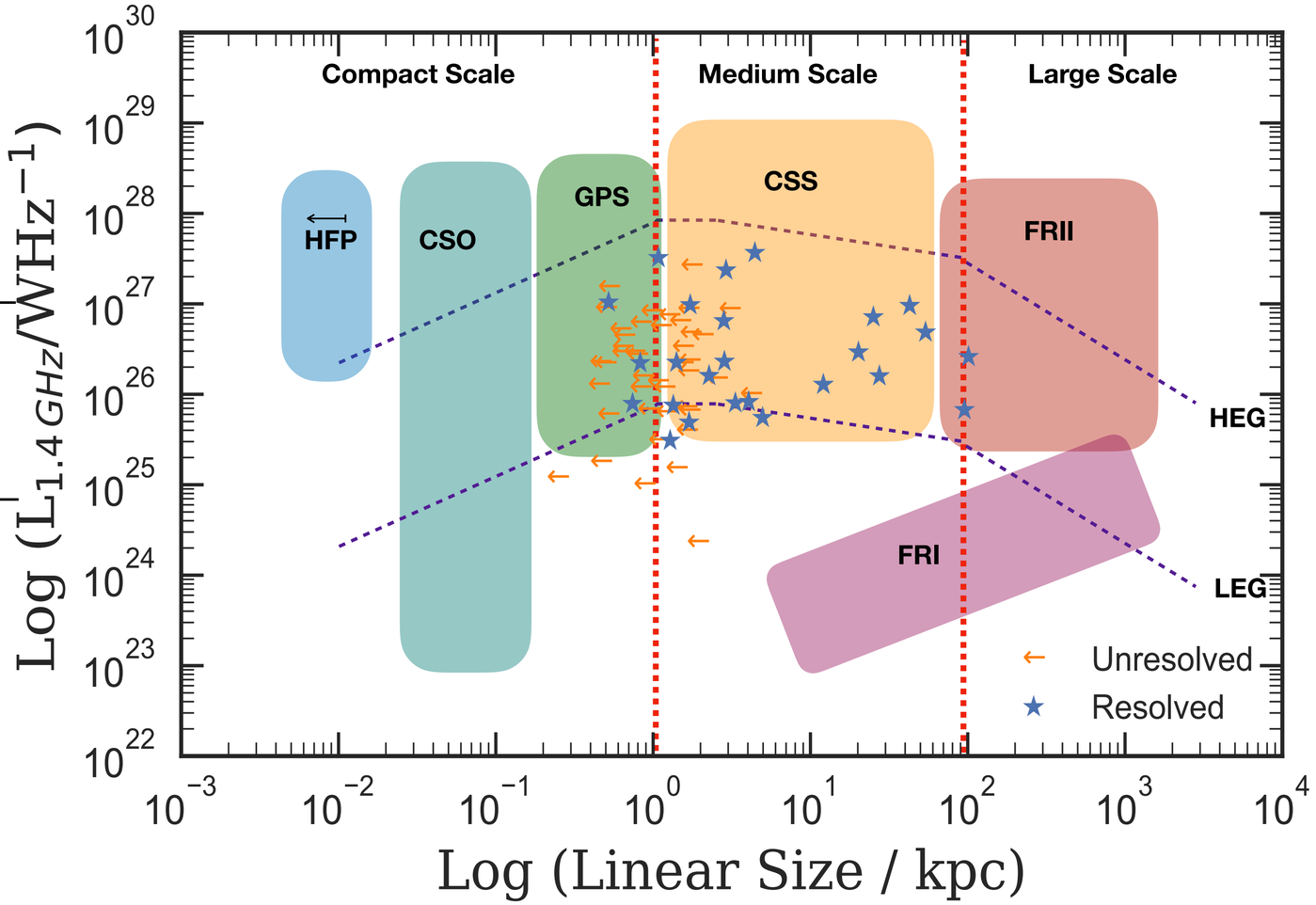


Majority of our sample is still unresolved with linear extents < 2 kpc

Patil et al. in Prep

Radio Luminosity vs Linear Size Relation

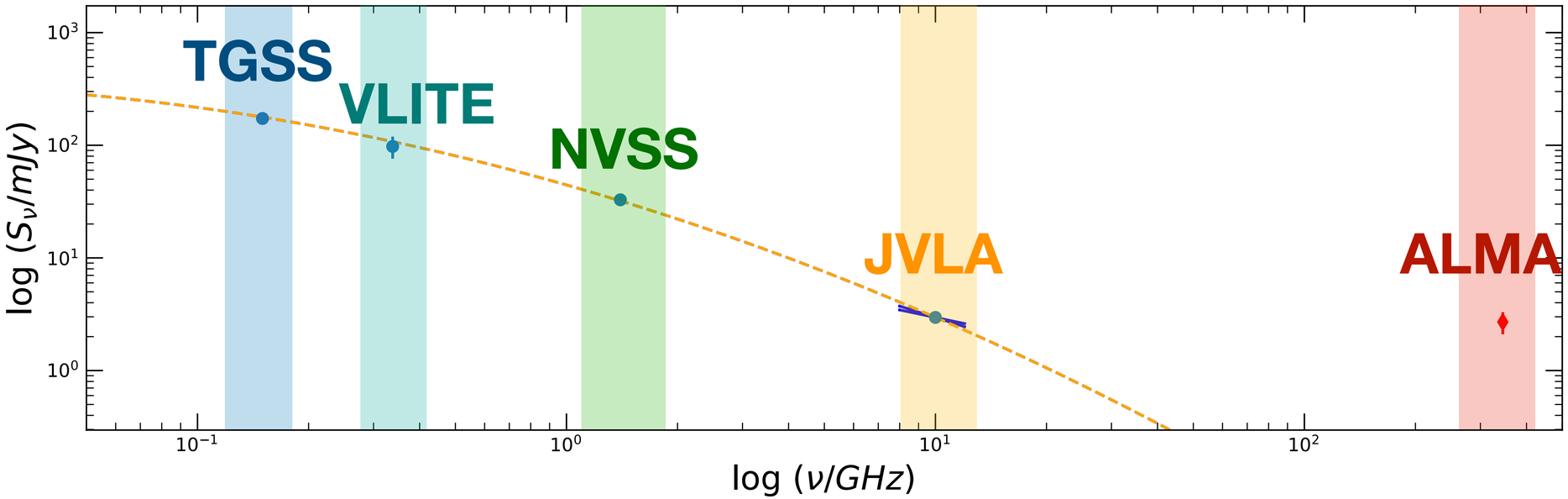
Luminosities:
Intermediate to
FRI and FRII

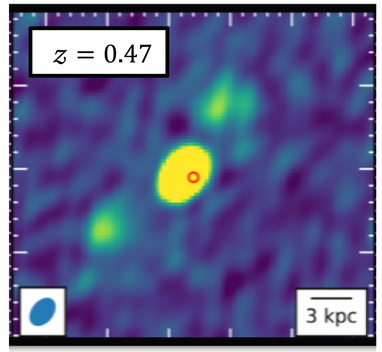


Derived from An & Baan 2012

Radio SED Analysis

Radio SED are crucial to study properties of jets and their impact on the environment

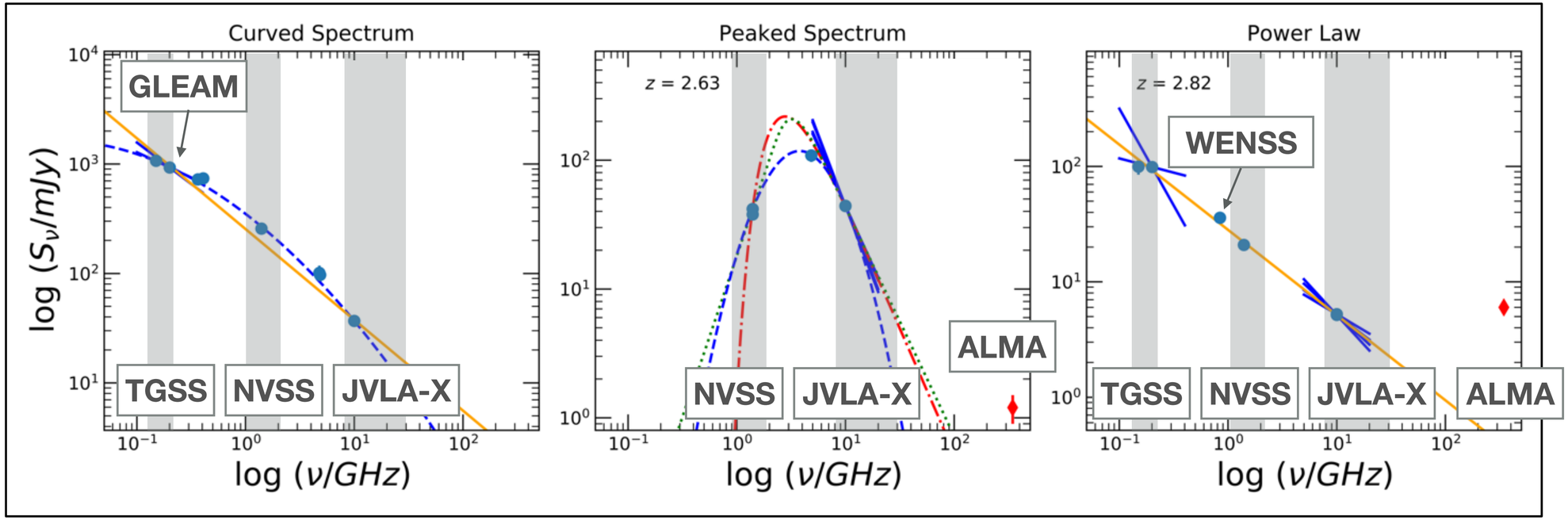




Other Surveys Used: GLEAM, WENSS, GB6, TEXAS, SUMSS, VLSSr

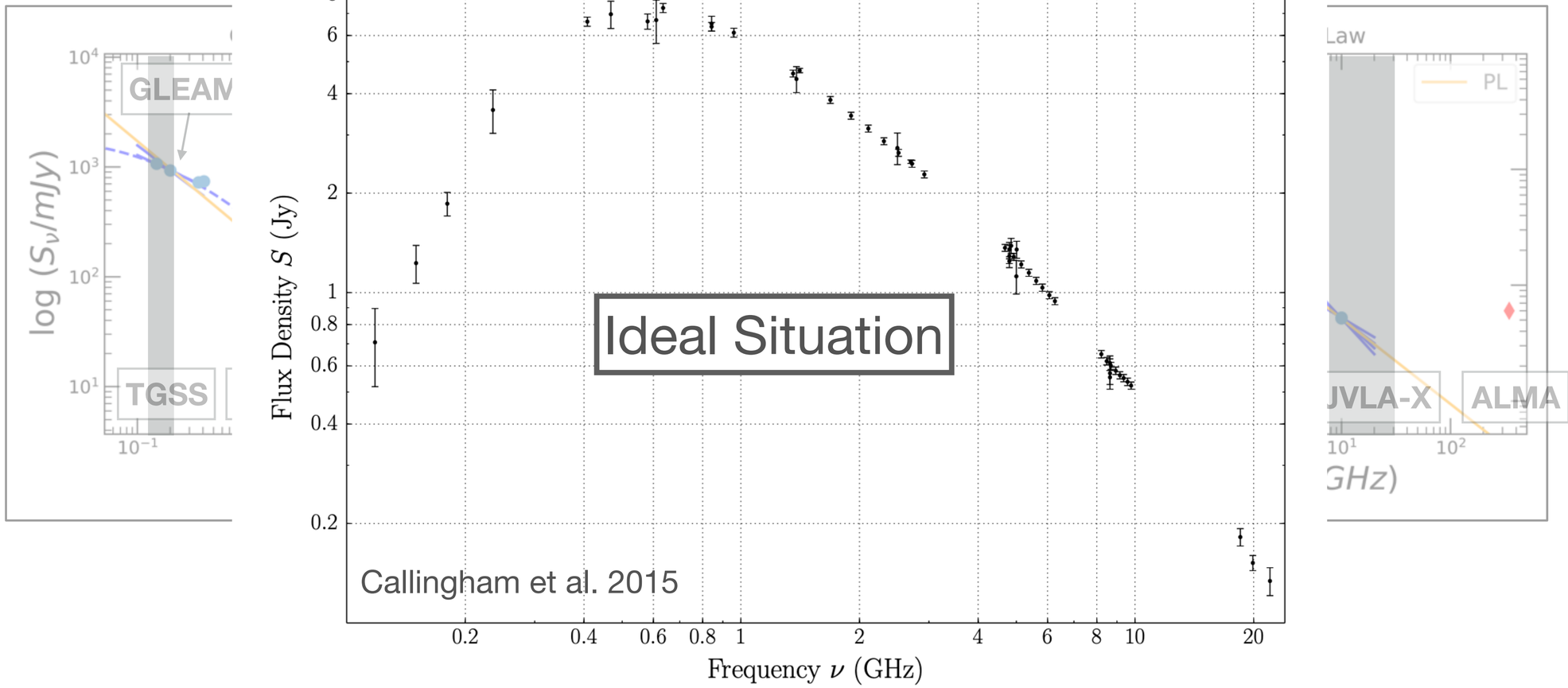
VLITE Data Courtesy: Tracy Clarke and Simona Giacintucci

Radio SED Reveals Young AGN



- 58% of the sample sources have curved radio SED with turnover frequencies from 150 MHz to 10 GHz
- A few meet the criteria for various young radio source classes (e.g. CSS, GPS and HFP)

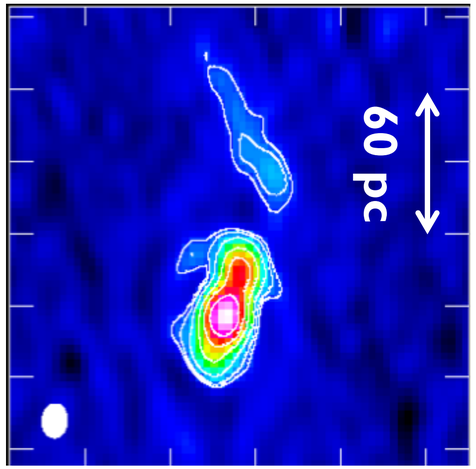
Radio SED Reveals Young AGN



Need sensitive low frequency observations with finer spectral resolution to better constrain the turnover.

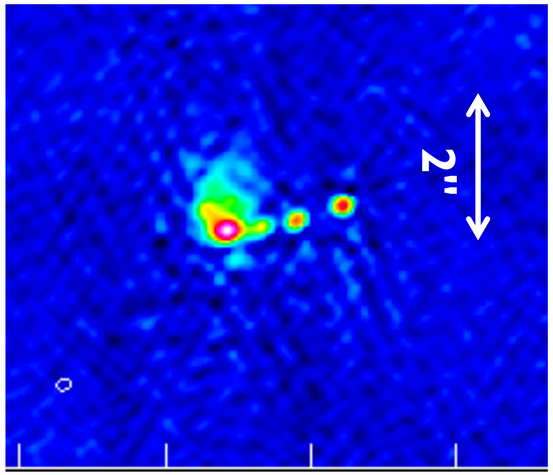
Follow-Up Programs

VLBA



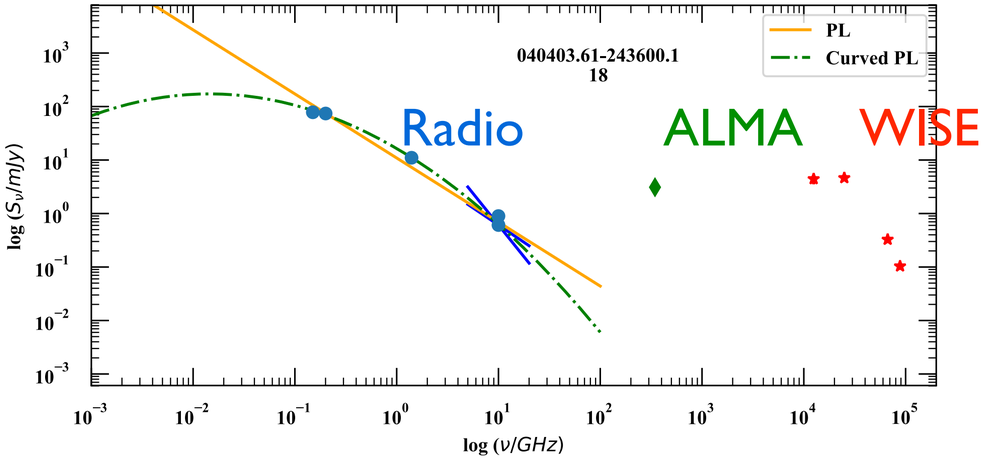
- $\theta_{FWHM} \approx 5 - 0.85$ mas
- Linear scales: 50 pc - 500 pc

e-Merlin



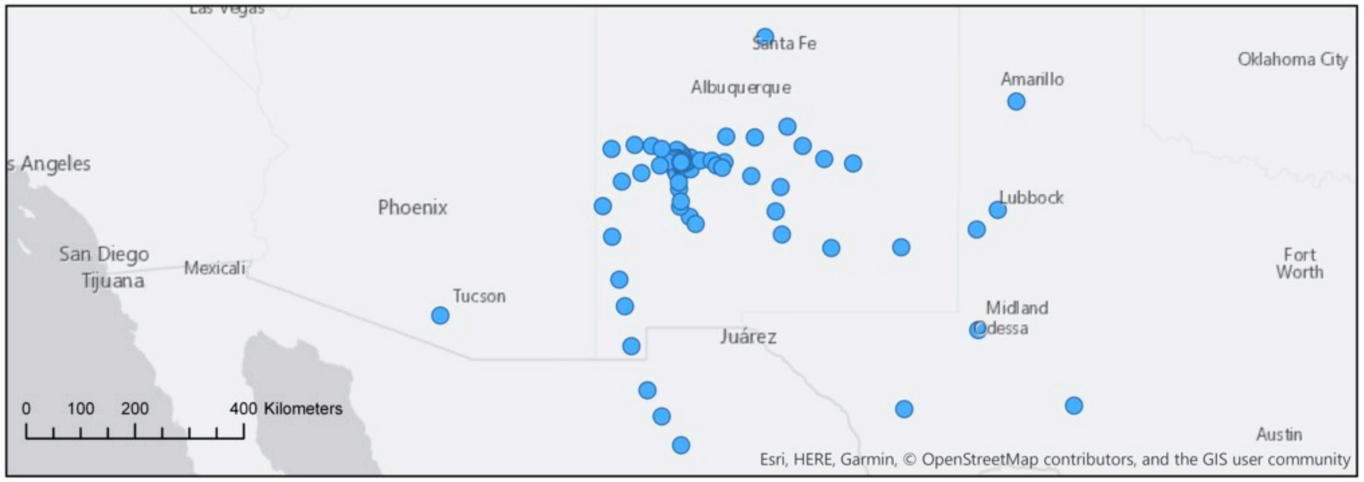
- $\theta_{FWHM} \approx 150 - 40$ mas
- Linear scales: 350 pc - 1 kpc

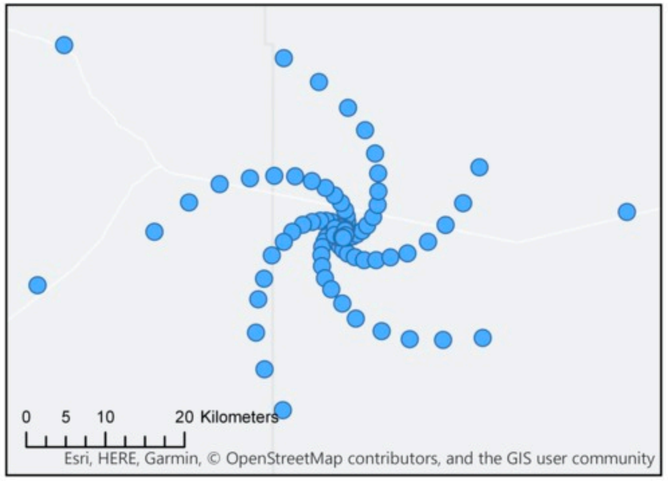
ALMA

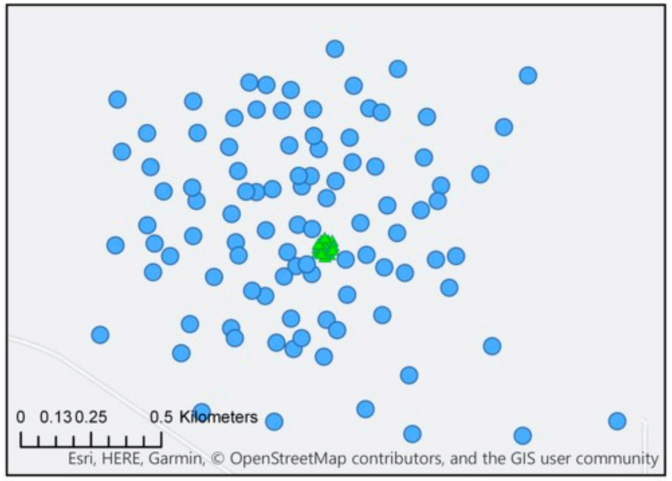


- Cycle-6: Spectral line (CO) imaging to constrain host galaxy ISM conditions and investigate feedback

Next-Generation Very Large Array



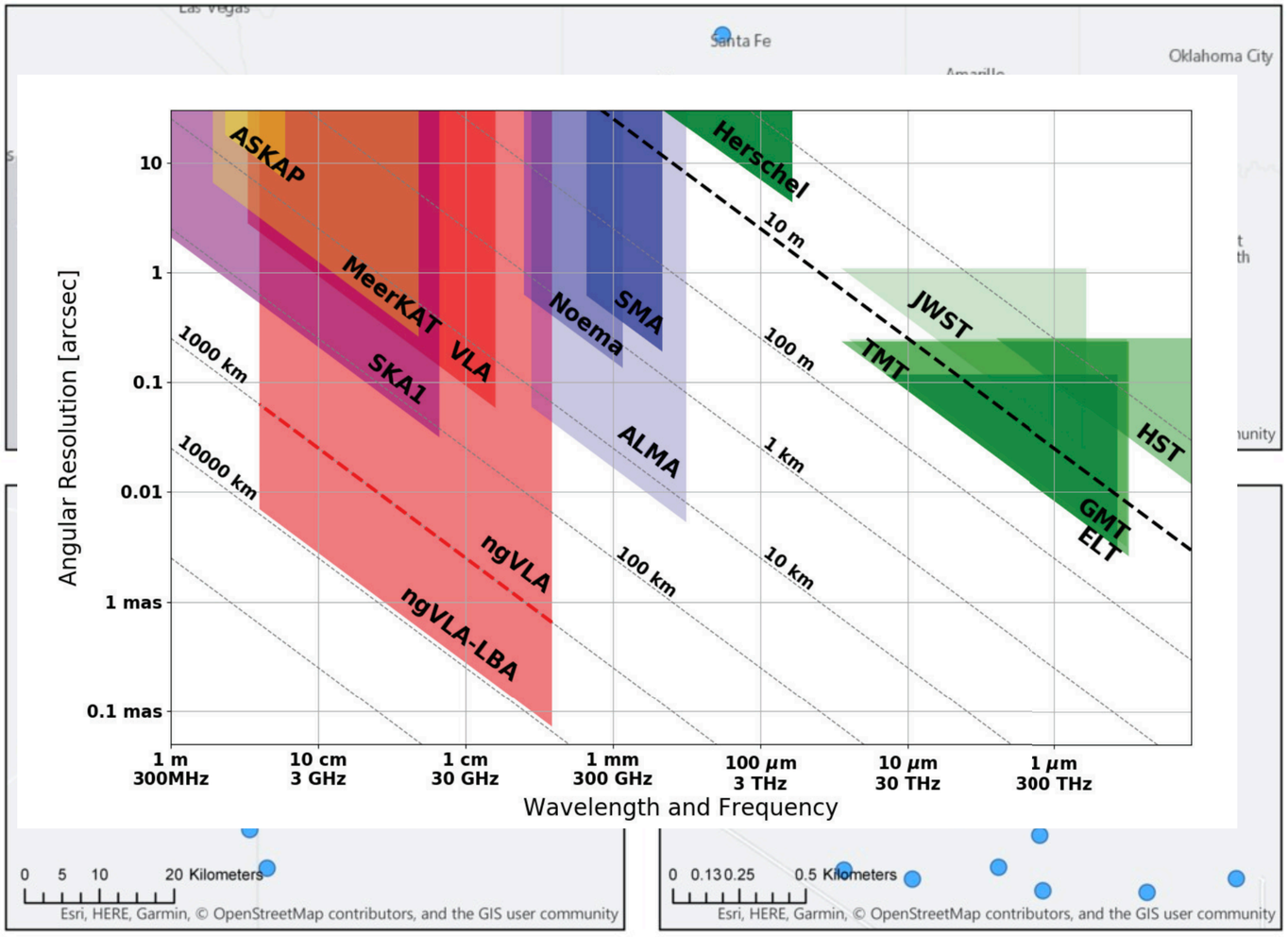




ngVLA capabilities

- 244 18-m dishes
- Frequency: 1-115 GHz
- $\theta_{FWHM} \approx 2 - 80\, mas$
- Linear scales: 10-700 pc for z ~ 1-6

Next-Generation Very Large Array



ngVLA capabilities

- 244 18-m dishes
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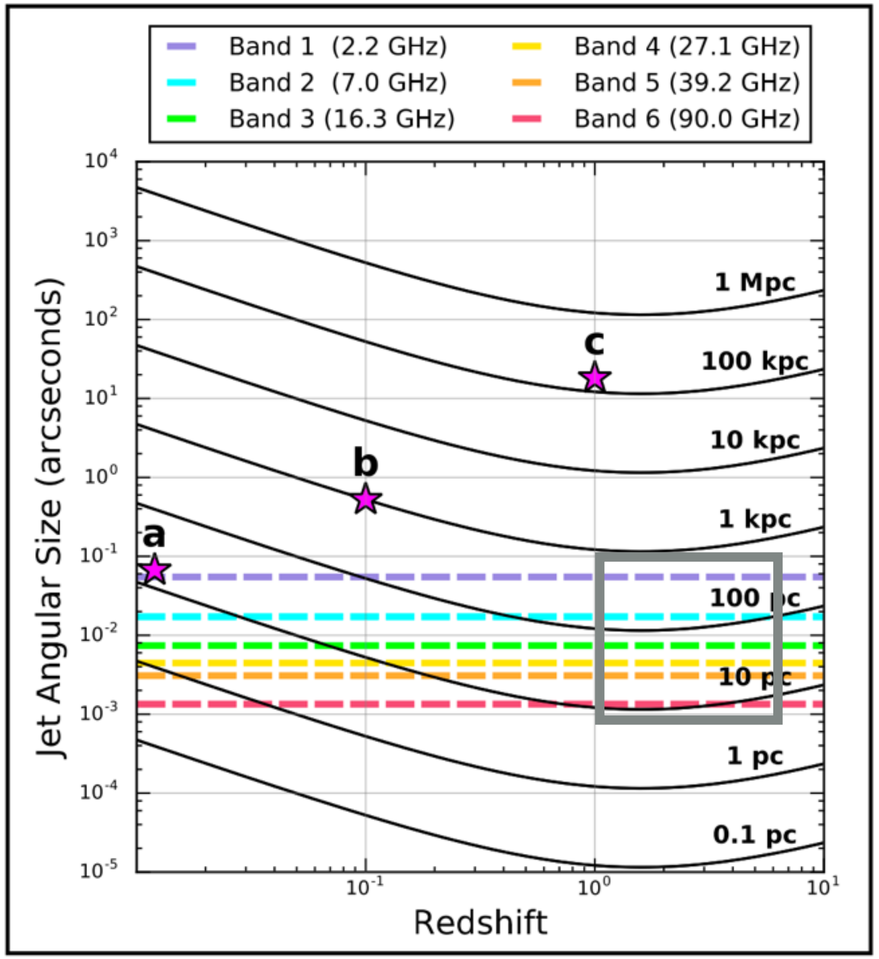
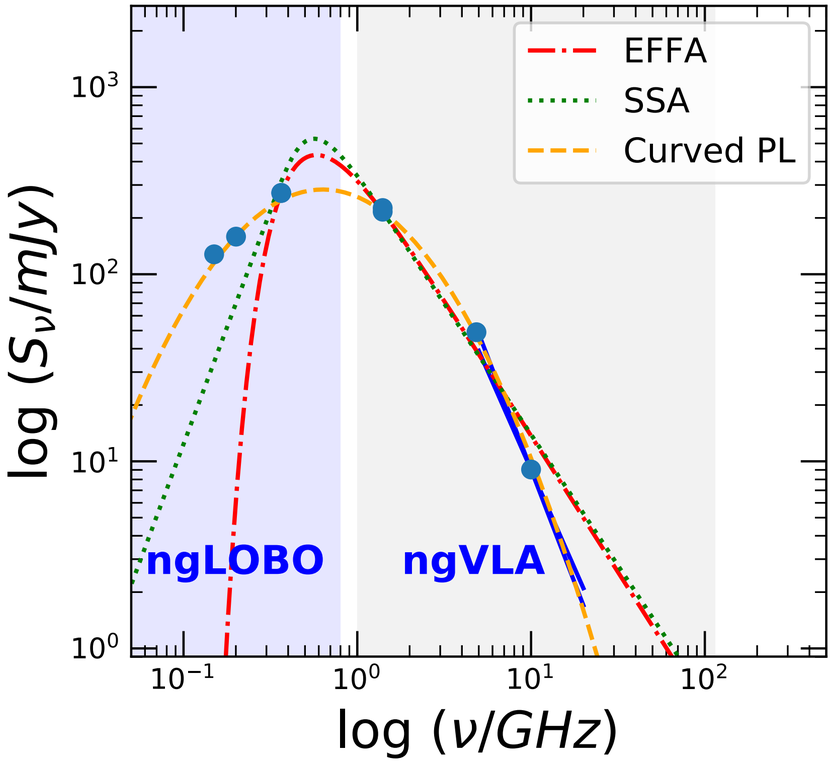
Young AGN in the ngVLA Era



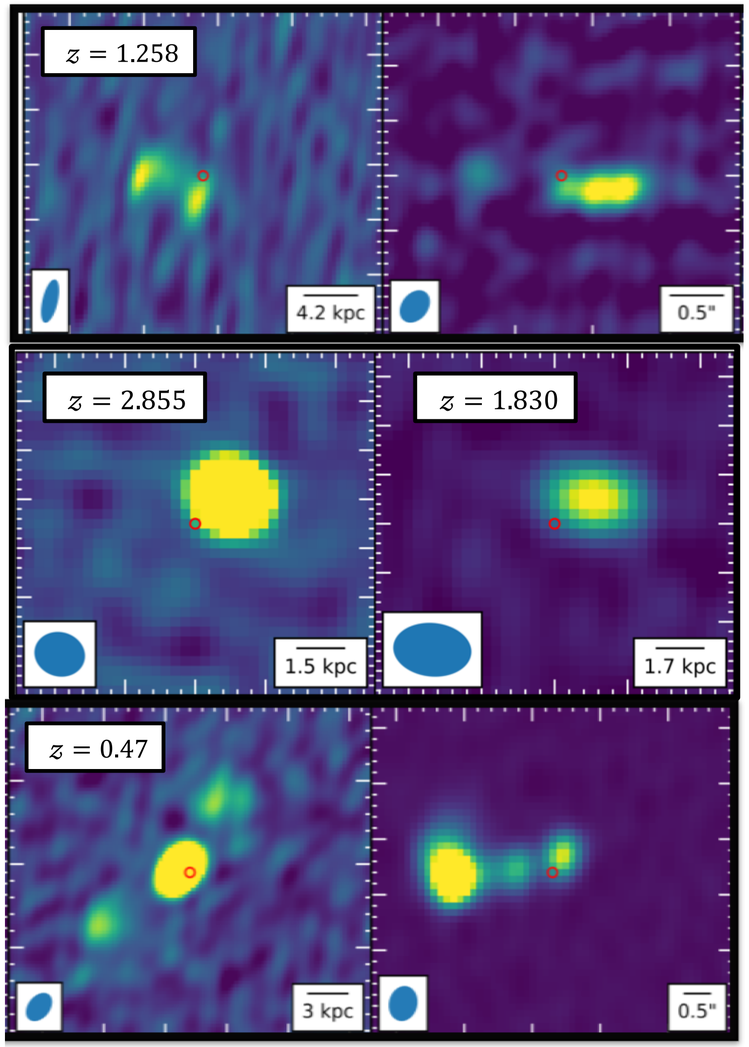
Nyland, Patil et al. 2018

- ngVLA is well-matched for mapping inner kpc scales at $z \sim$ 1-6
- ngVLA + ngLOBO can robustly characterize spectral turnover



ngVLA Science Book, p595-602

Summary



- Our Goal: Study the earliest stages in the life-cycles of luminous AGN
- High-resolution JVLA imaging of our sample of hyper luminous, obscured quasars has revealed compact (sub-kpc-scale) radio morphologies
- Preliminary radio SED analyses suggest that the radio jets in many of our sources are young
- Follow-up with the JVLA, VLBA/e-MERLIN, and ALMA to study jet properties and feedback is in progress!

Thank you

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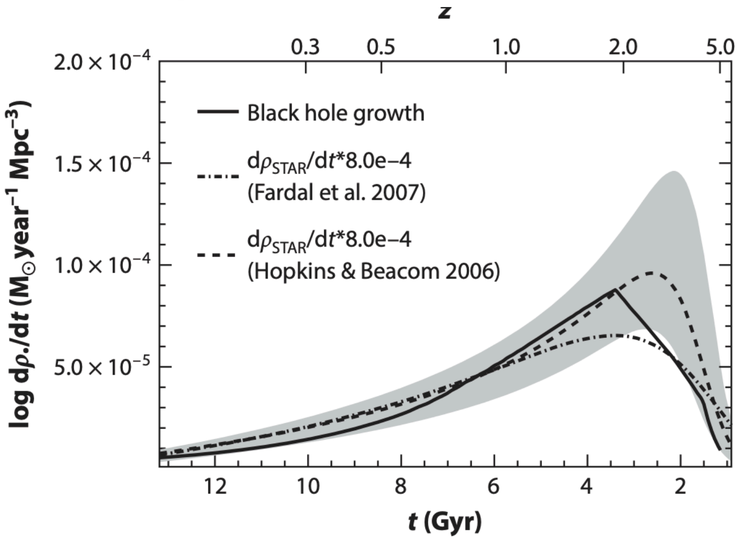
Additional Slides

AGN Play Key Role in Galaxy Mass Building

BH growth and SFR density peaks at z ~1-3

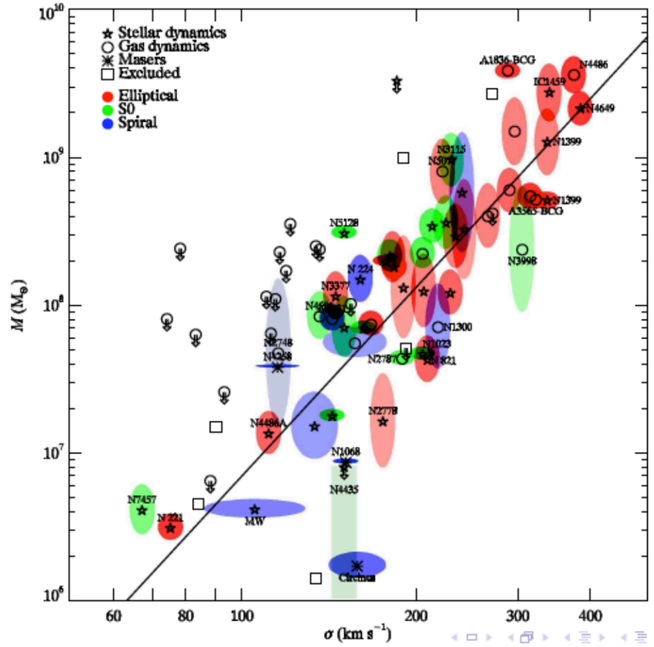


Heckman & Best 2014

AGN Feedback

SMBH-Host Galaxy co-evolution

$M_{BH} - \sigma$ Relation



Gültekin et al. (2009)

- Characterizing the onset of AGN activity is essential to our understanding of the evolution of galaxies and growth of SMBHs

Radio SED Fitting: Interactive Tool

Different Models

EFFA
IFFA
SSA
PL

Best-Fit Parameters

Fitted Parameters

EFFA:
S_0 = 64.80
α= -1.11
ν_p= 0.36 GHz

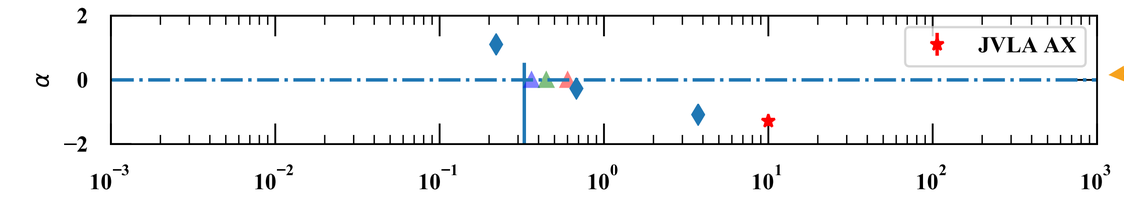
IFFA:
S_0 = 67.14
α= -1.13
ν_p= 0.60 GHz

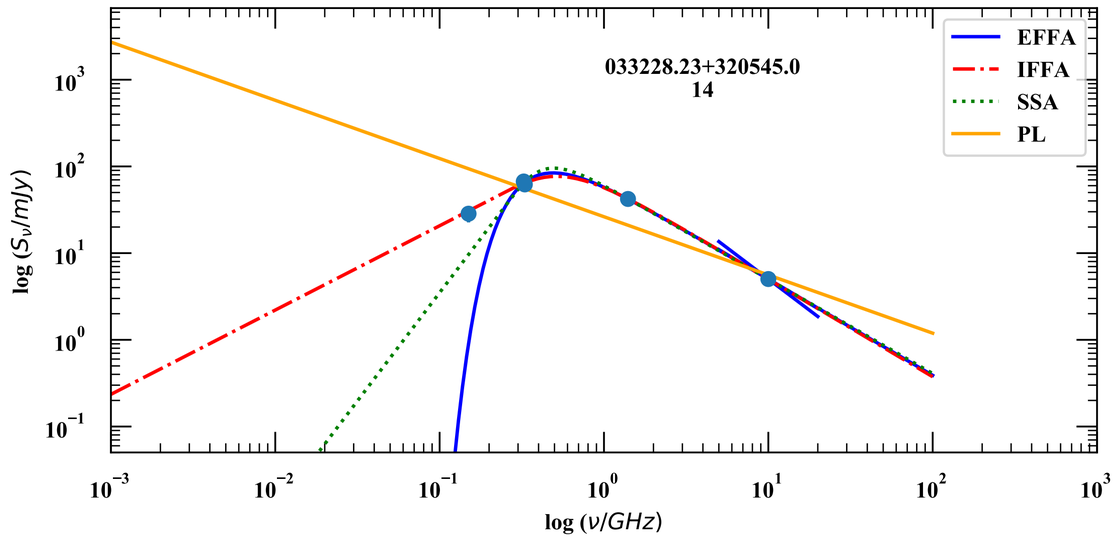
SSA:
S_0 = 148.01
α= -1.09
ν_p= 0.45 GHz

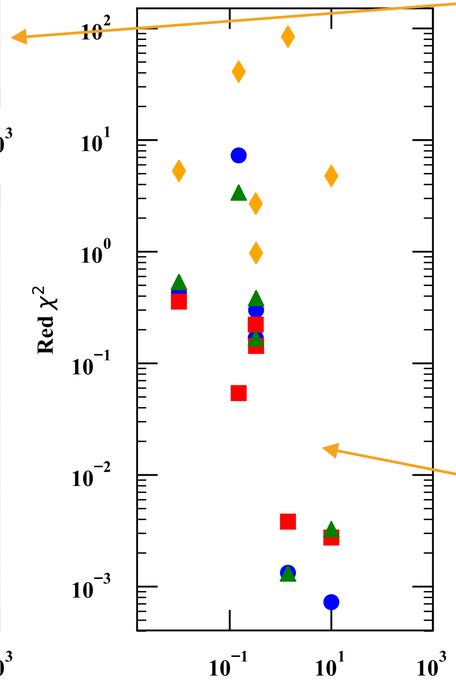
PL:
S_0 = 81.10
α= -0.67
ν_0= 0.19 GHz

Reduced $\chi 2$

$\Sigma\ \chi^2_{Red}$:
EFFA= 8.19
IFFA= 0.78
SSA= 4.46
PL= 139.23







Spectral Index between two nearest points

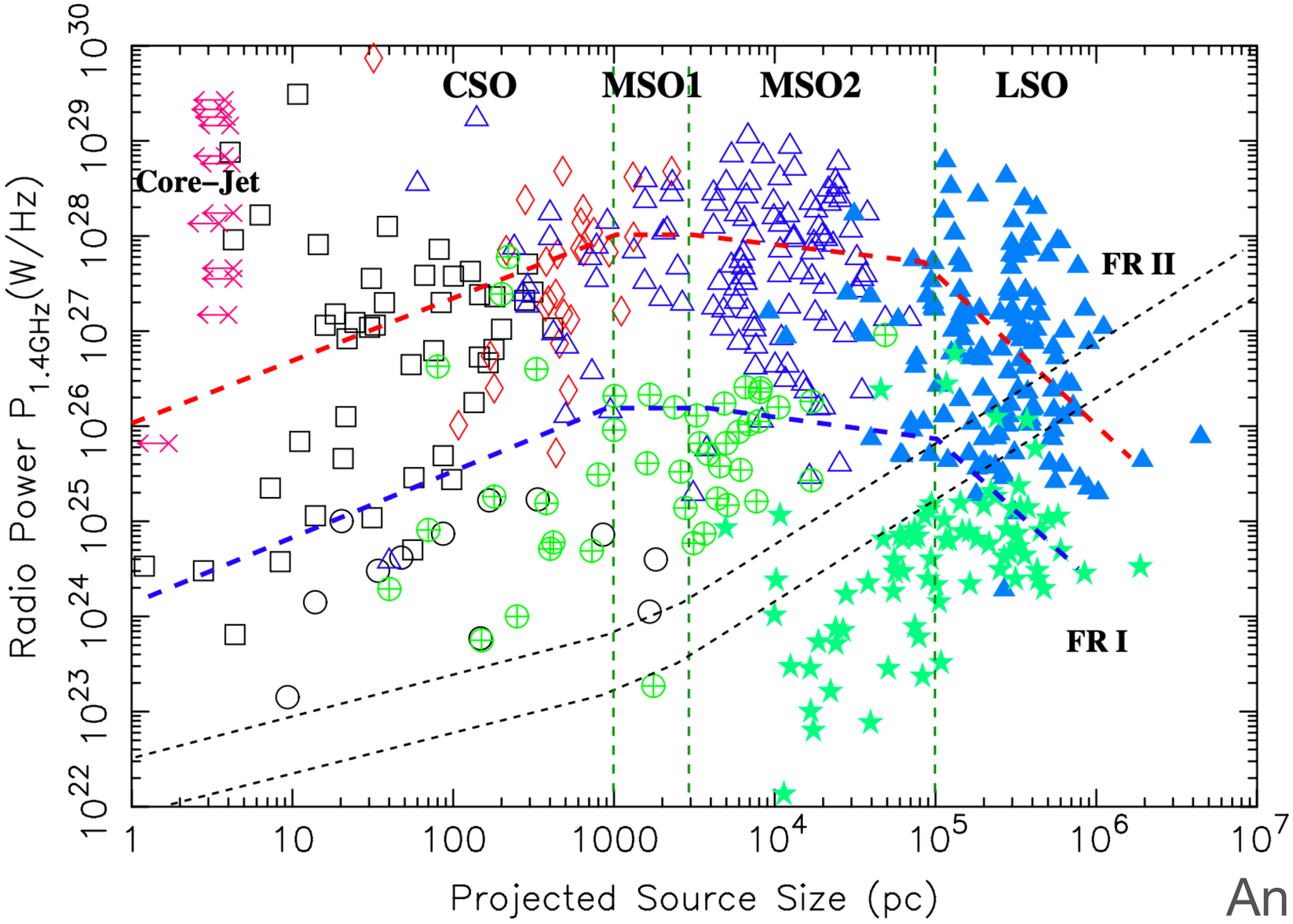
Residuals

log ν_{peak} -1.00
log S_0 0.00
α -1.00

Backward 10 | Forward 10 | Replot | Save | Next | Previous | Fit | Reset

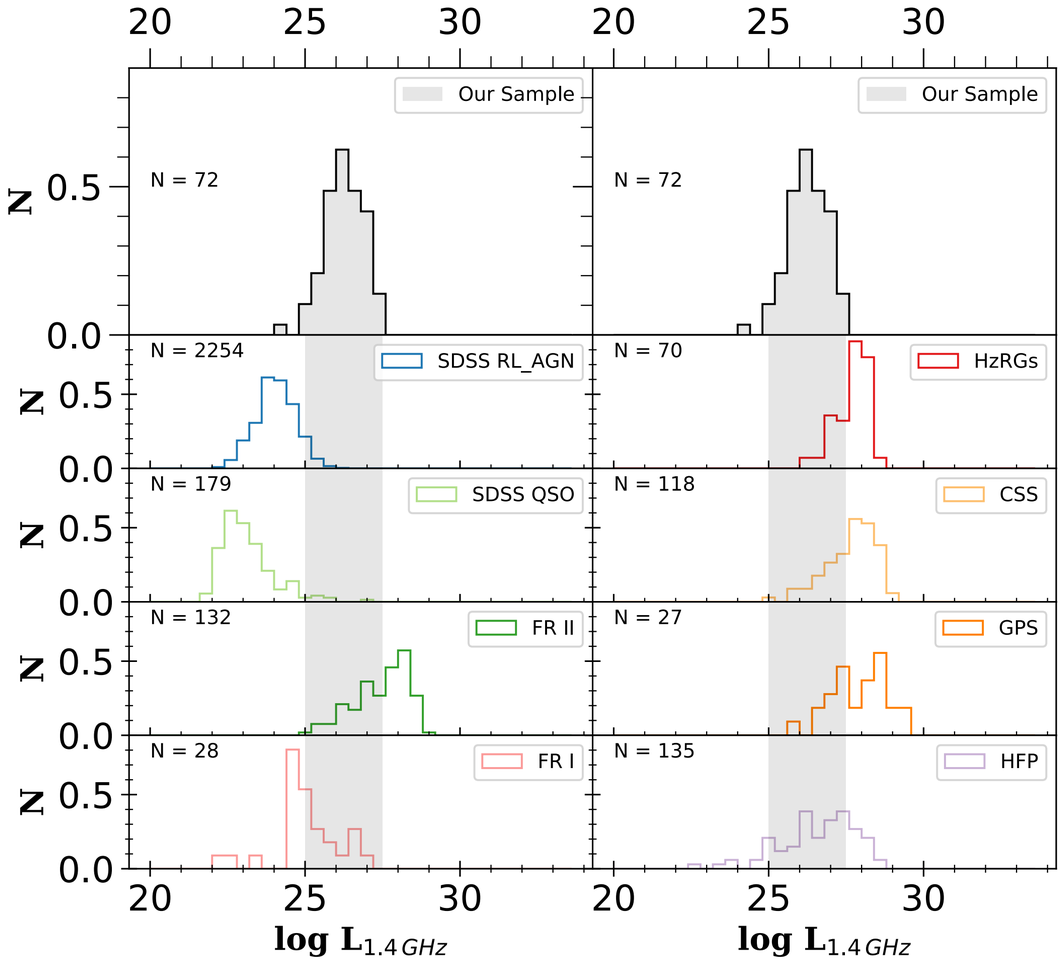
Sliders to change the Parameter Values

Luminosity vs Linear Size



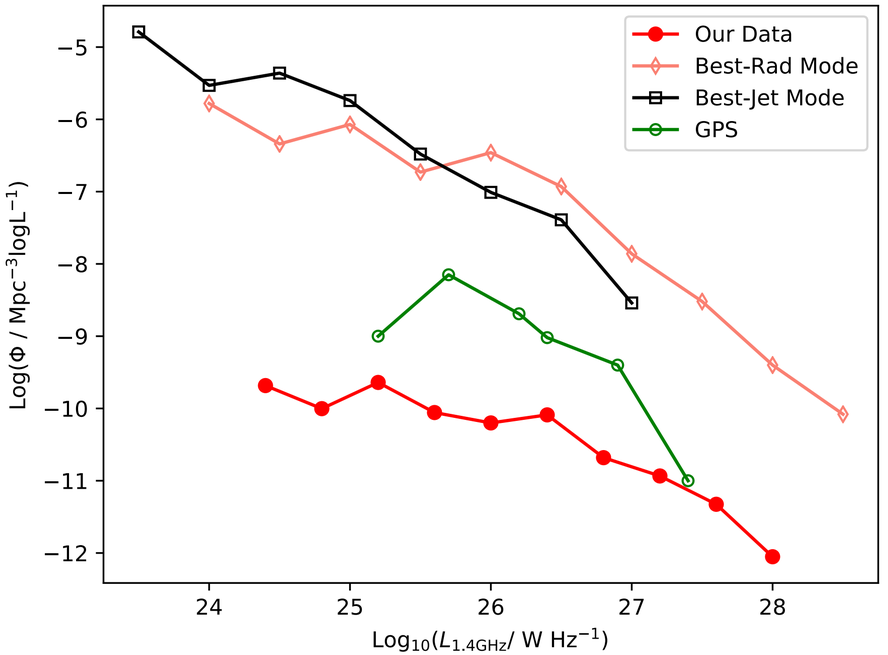
An & Baan 2012

Luminosity Distribution



Radio luminosities intermediate between FRI and FRII

Radio Luminosity Functions

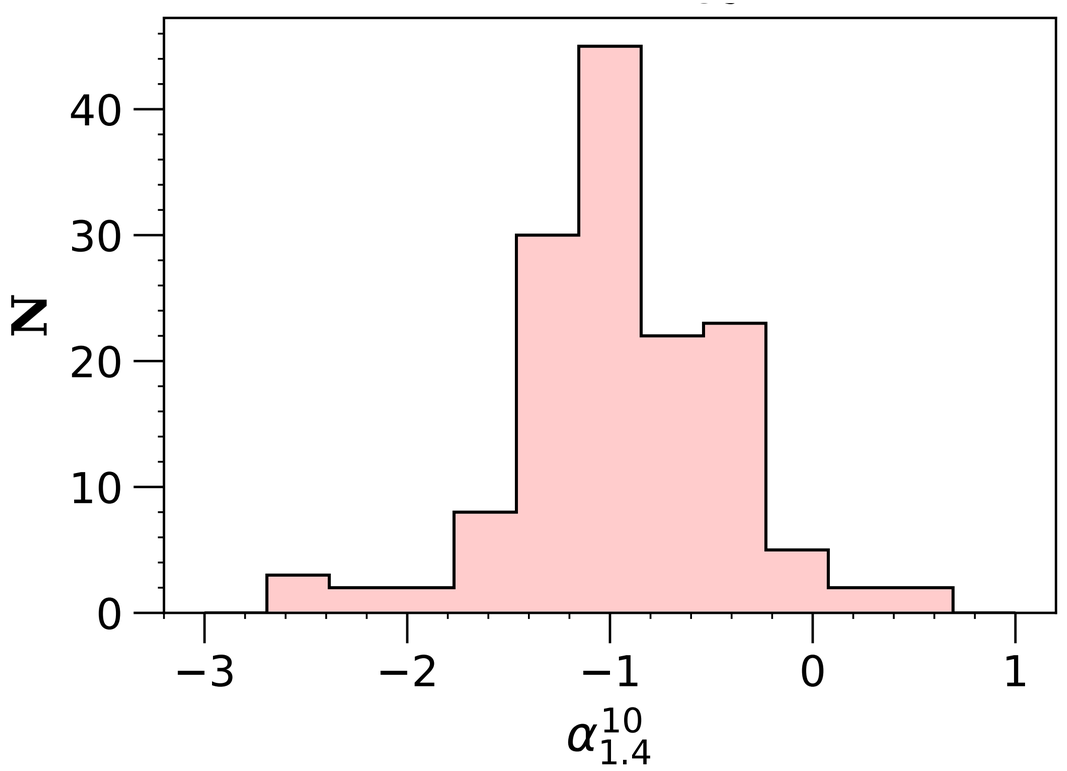


The space density of our sample sources is very low → Transient evolutionary phase?

Radio SEDs of the WISE-NVSS Sample

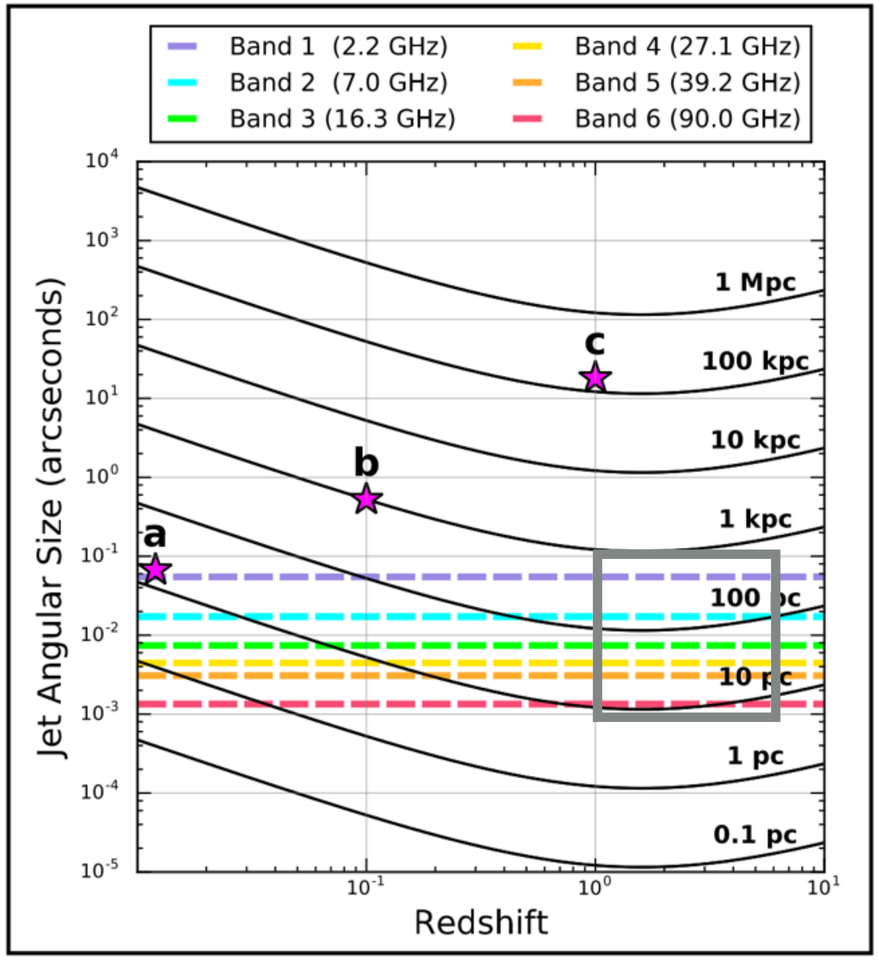
- Synchrotron emission from relativistic electrons in the jets
- SED Modeling: Properties of jets and their impact on the environment
- An interactive SED fitting tool using least square minimization

Spectral Index Between 1.4 GHz and 10 GHz



$$Median\ \alpha^{10}_{1.4} = -1.0$$

ngVLA Is Well-Matched for Mapping Inner Kpc Scales at $z \sim$ 1-6



Nyland, Patil et al. 2018

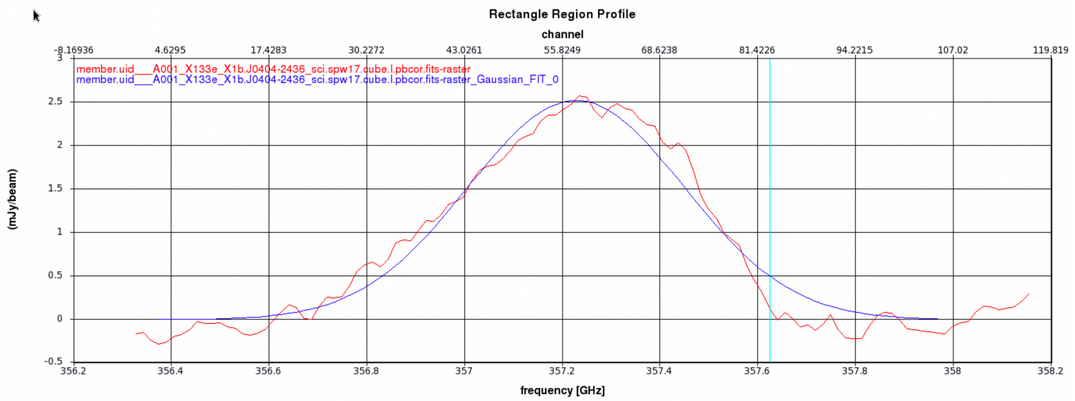
ngVLA capabilities

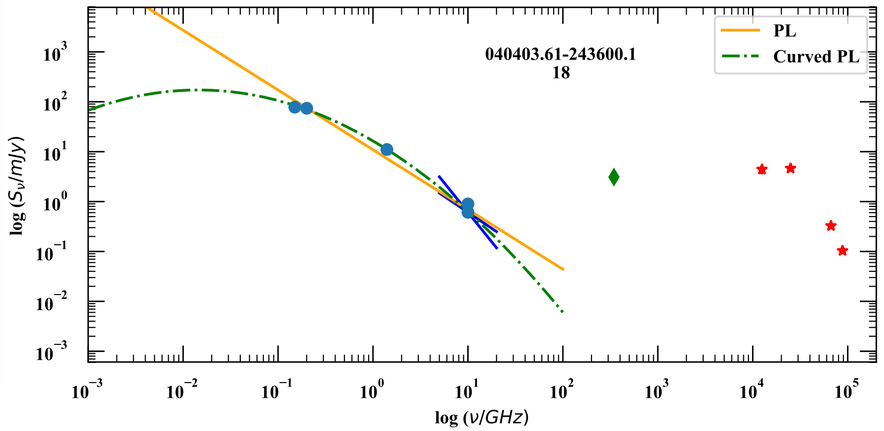
- $z \sim$ 1-6
- Frequency: 1-115 GHz
- $\theta_{FWHM} \approx 2 - 80\, mas$
- Linear scales: 10-700 pc

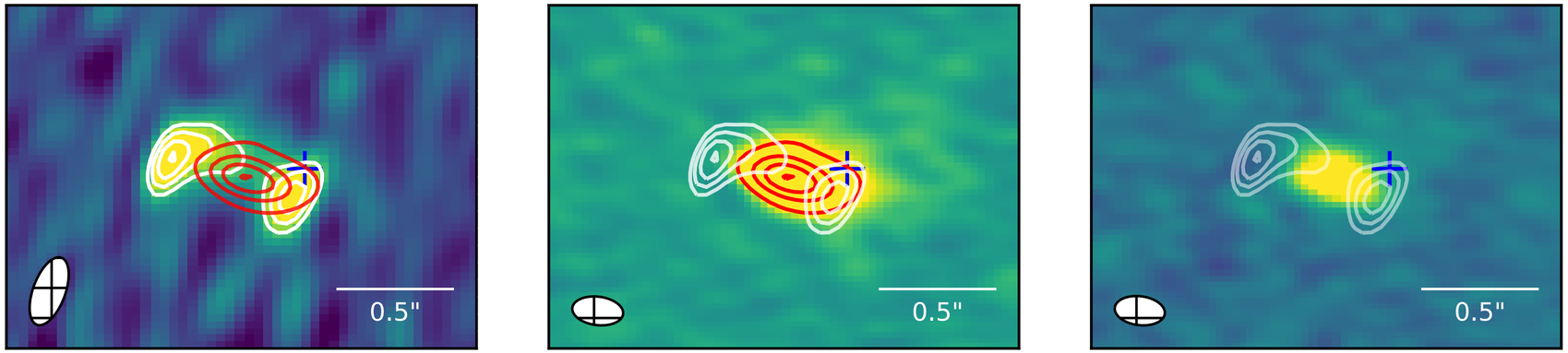
AGN science with ngVLA

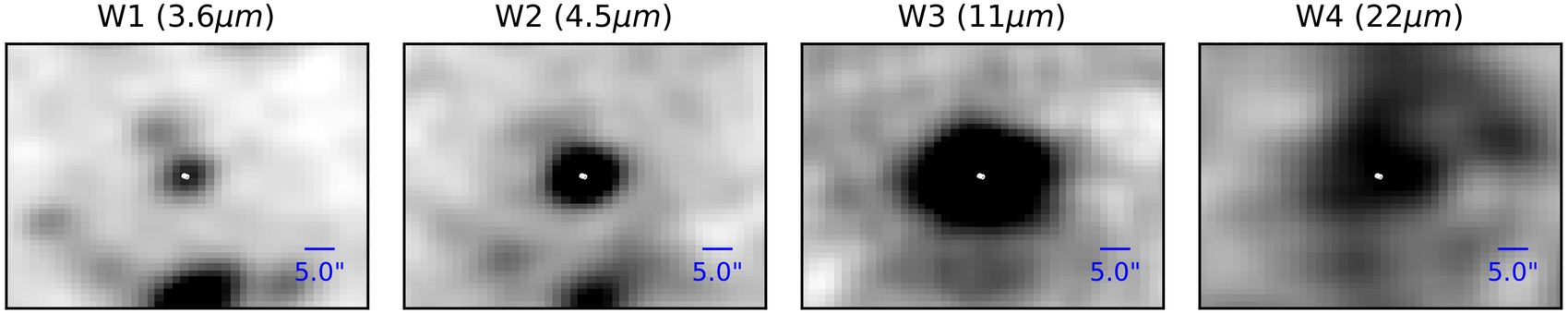
- Spectral ages
- Jet-driven feedback
- Characterizing spectral-turnover (ngVLA+ngLOBO)
- Probing Cold gas via low J CO lines and HI observations

ALMA Cycle-6 Preliminary Result









Dust Continuum and CO line Mapping

Pallavi Patil

NRL