Powerful Quasars with Young Jets Revealed by Multi-Epoch Radio Surveys

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CSSGPS Workshop – May 10, 2021

Powerful Quasars with Young Jets

The Astrophysical Journal, 905:74 (22pp), 2020 December 10 https://doi.org/10.3847/1538-4357/abc341

Quasars That Have Transitioned from Radio-quiet to Radio-loud on Decadal Timescales Revealed by VLASS and FIRST

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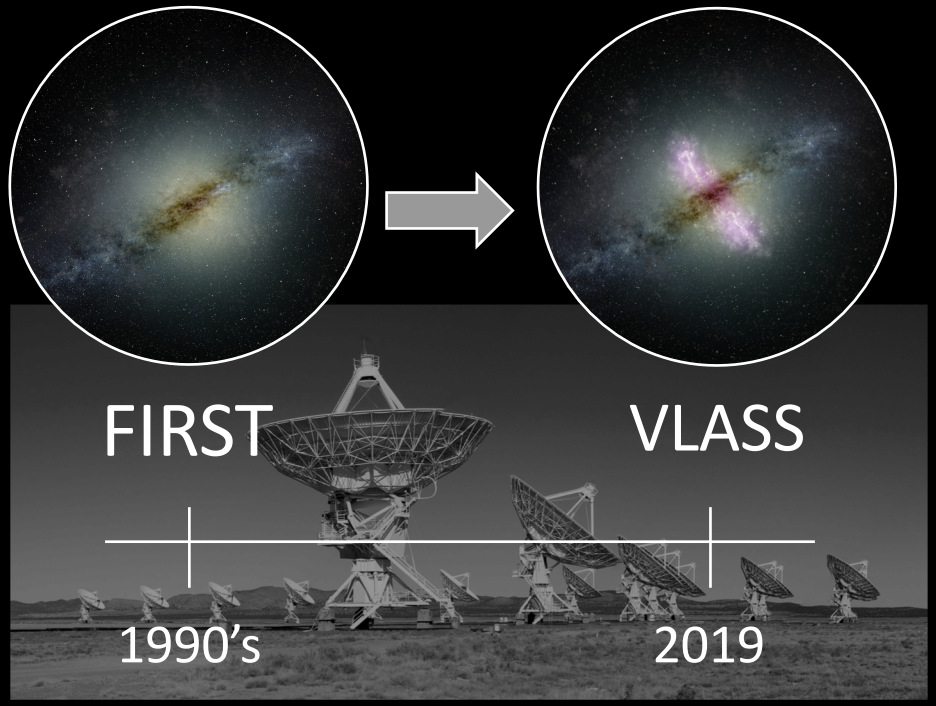
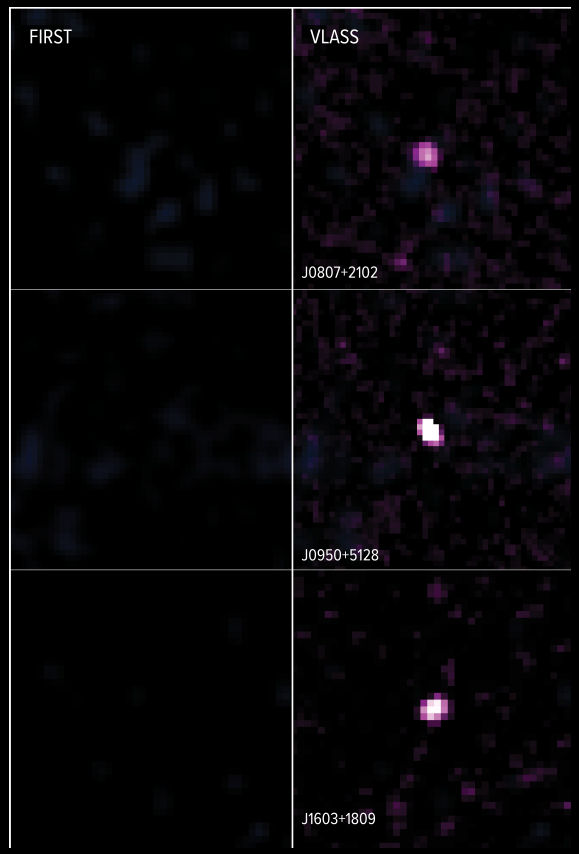
Newborn Radio Jets!

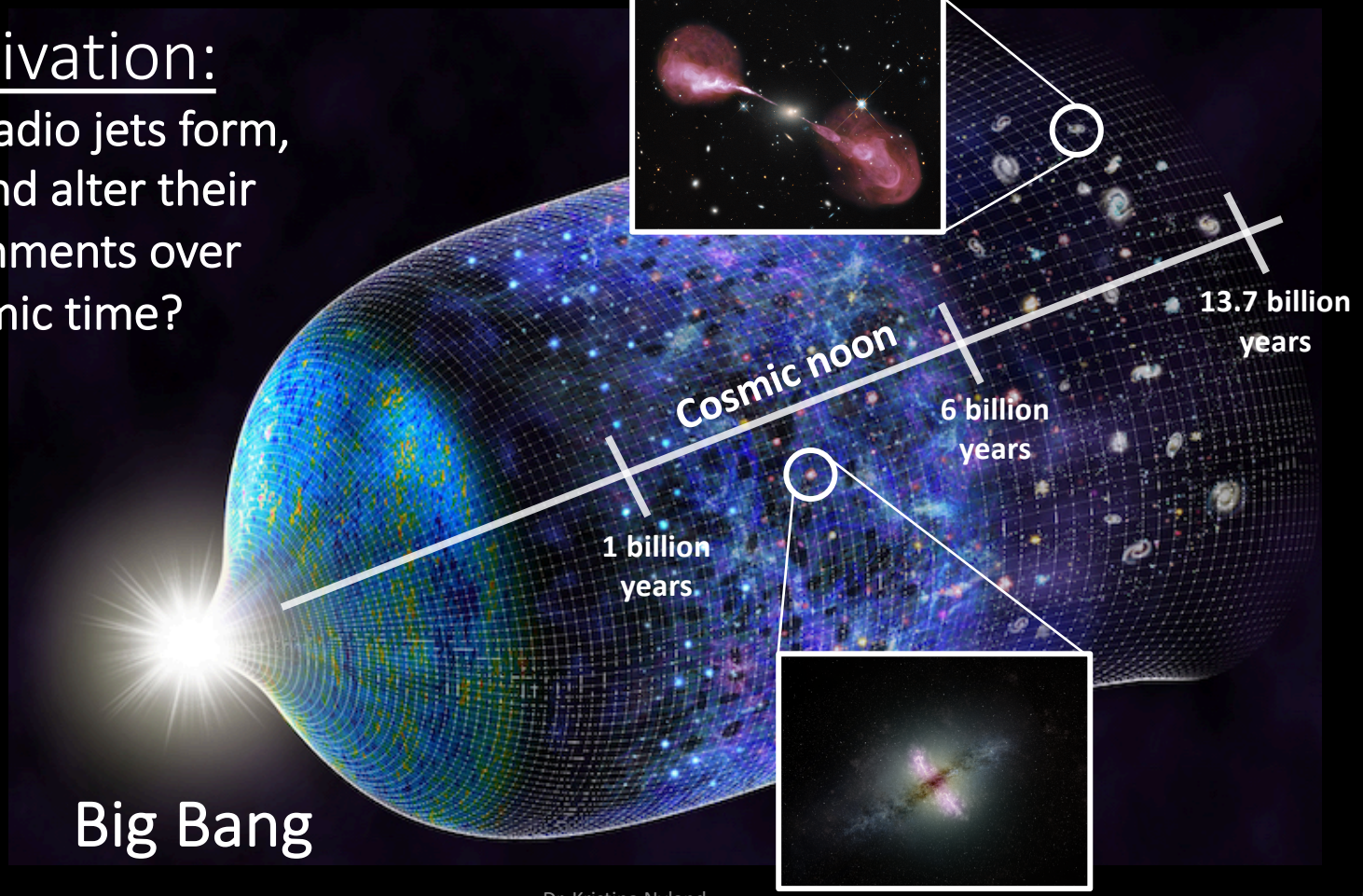




Credit: Sophia Dagnello; NRAO/AUI/NSF

Motivation:

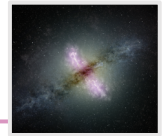
How do radio jets form, grow, and alter their environments over cosmic time?



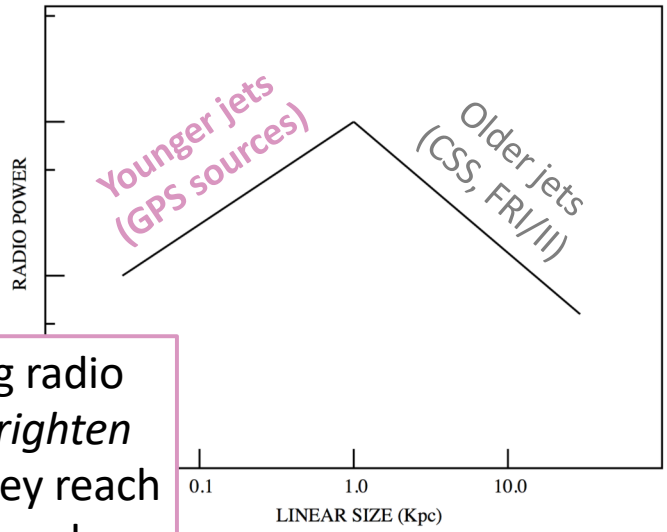
Identifying Young Radio Jets

	Key Radio Properties
1) Morphology	Kpc-scale or smaller
2) Spectral curvature	Peaked spectral shapes
3) Variability	Intrinsic/extrinsic variability

The Evolving Radio Properties of Young Jets

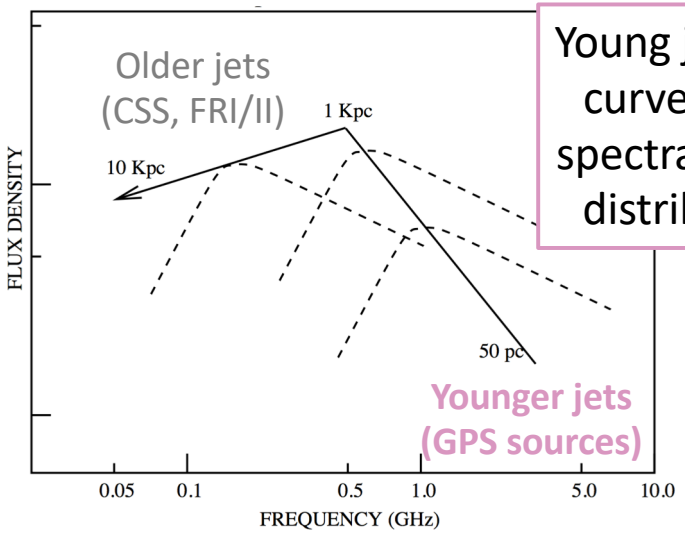


Size and Luminosity



Young radio jets *brighten* until they reach ~kpc scales

Spectral Shape and Flux



Young jets have curved radio spectral energy distributions

Adapted from Snellen et al. 2000

(Reviews on young jets: O'dea & Saikia 2020; O'dea 1998; Orienti 2016)

Identifying Young Radio Jets

	Observational Demands
1) Morphology	High-resolution imaging
2) Spectral curvature	Broadband radio spectra
3) Variability	Multi-epoch data

Identifying Young Radio Jets

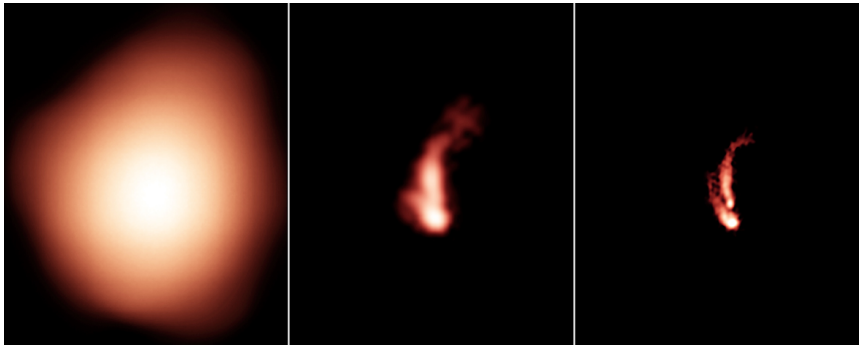
	Observational Demands
1) Morphology	High-resolution imaging
2) Spectral curvature	Broadband radio spectra
3) Variability	**Multi-epoch data**

See talks by: Aleksandra Wołowska (5/11), Monica Orienti (5/11), & Kathryn Ross (5/13)

VLA Sky Survey

Frequency	2-4 GHz
θ_{FWHM}	2.5”
Area	33,885 deg^2
Epochs	3

NVSS FIRST VLASS



Increasing angular resolution →

VLA SKY SURVEY

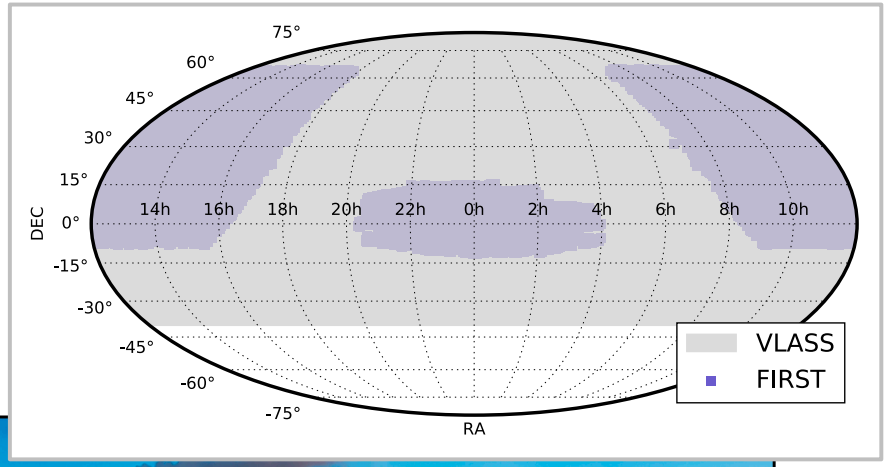
CIRADA
CANADIAN INITIATIVE FOR RADIO ASTRONOMY DATA ANALYSIS

Lacy et al. 2020 cirada.ca

Catching Young Jets with Multi-epoch Radio Data

	ν (GHz)	θ_{FWHM}	Dates	Epochs
FIRST	1.5	5"	1993-2011	1
VLASS	2-4	2.5”	2017-2019†	3

†*Epoch 1*



References:

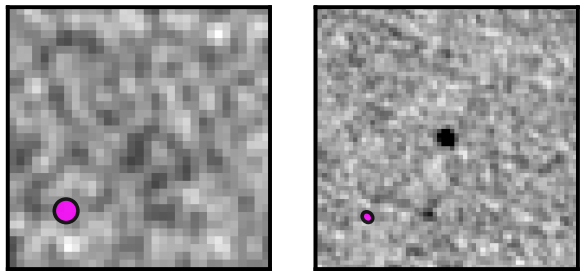
Becker et al. 1995
Helfand et al. 2015
Lacy et al. 2020

Selection Criteria

1

Initial Sample:
2000 variable sources over 3440 deg^2 of VLASS

FIRST VLASS

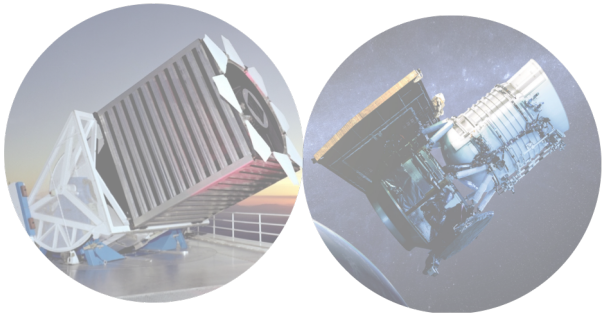


1999 2019

2

Quasar Cross-matching:

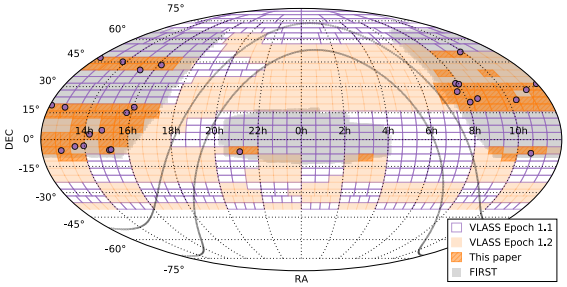
SDSS WISE

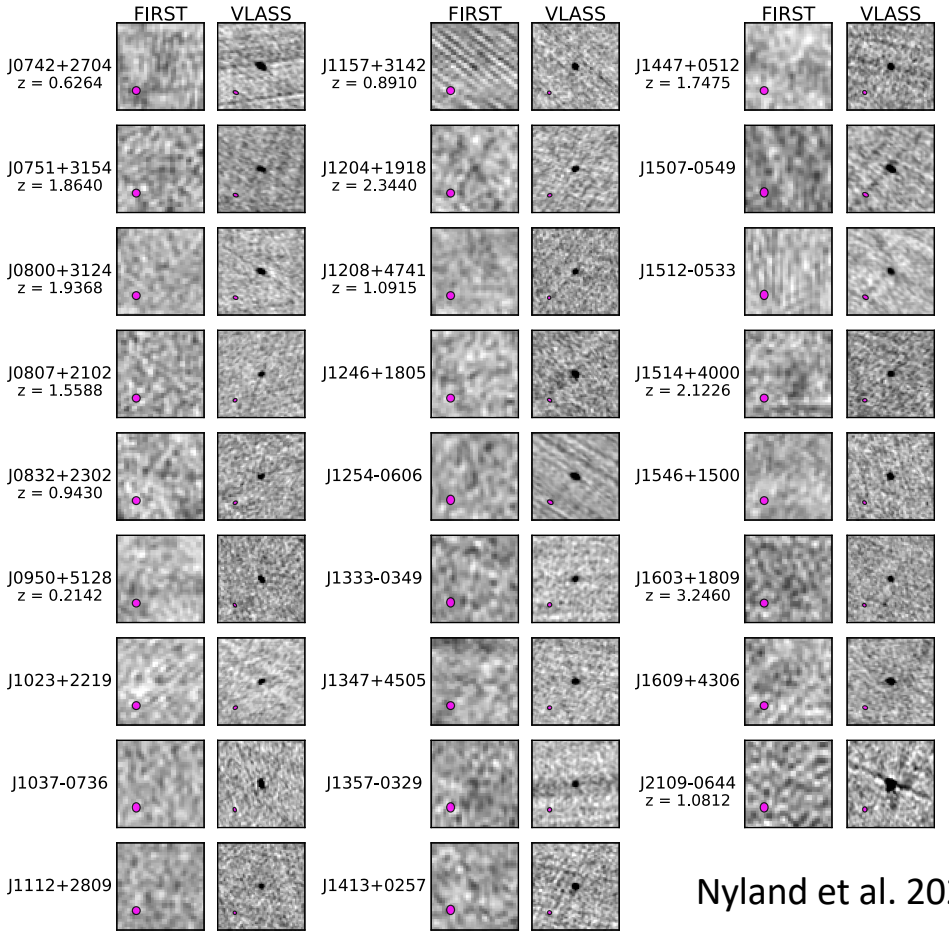


Nyland et al. 2020

3

Final sample:
26 newly radio-loud quasars (S_{VLASS} > 3 mJy)





Nyland et al. 2020

Sample Properties

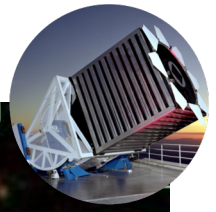
- Redshifts (13/26): $0.2 < z < 3.2$
- $\log(L_{VLASS}/\mathrm{erg\ s^{-1}}) \approx 40 - 42$
- $\log(L_{bol}/\mathrm{erg\ s^{-1}}) \approx 45.2 - 46.8$
- $\log(M_{SMBH}/M_{\odot}) \approx 8.0 - 9.7$

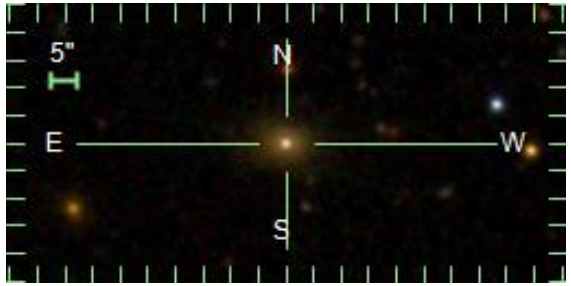
Example SDSS Images and Spectra

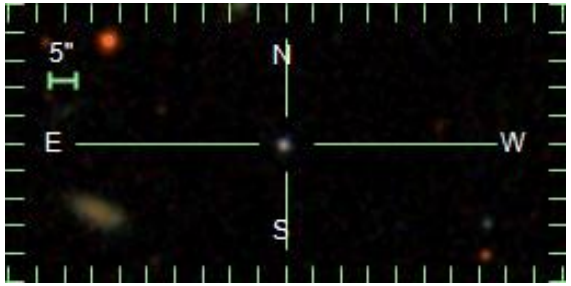
z = 0.2

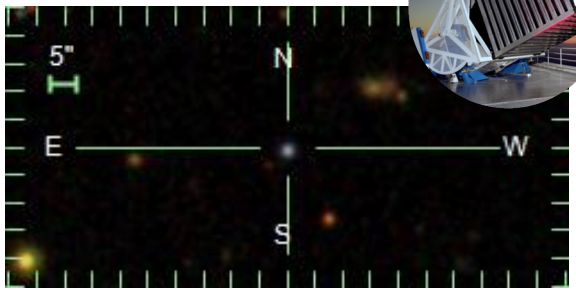
z = 1.6

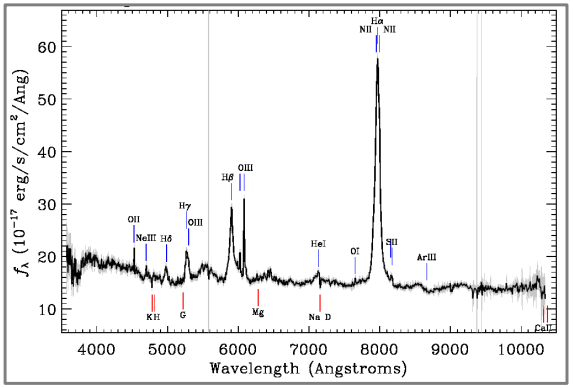
z = 3.2

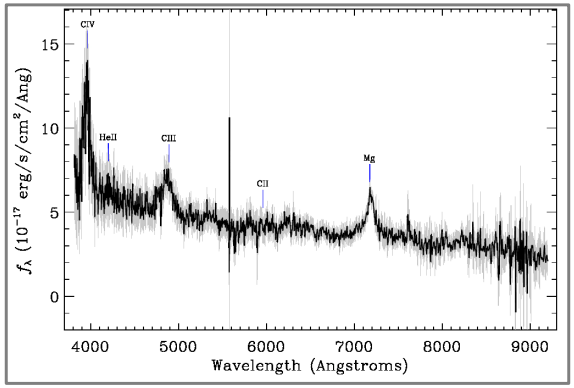


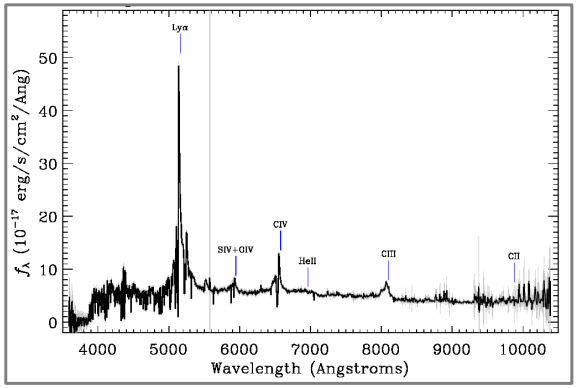










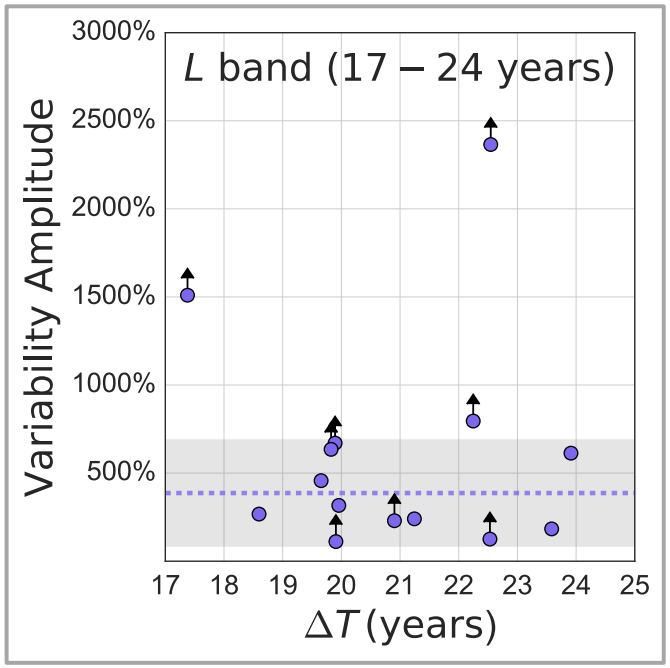


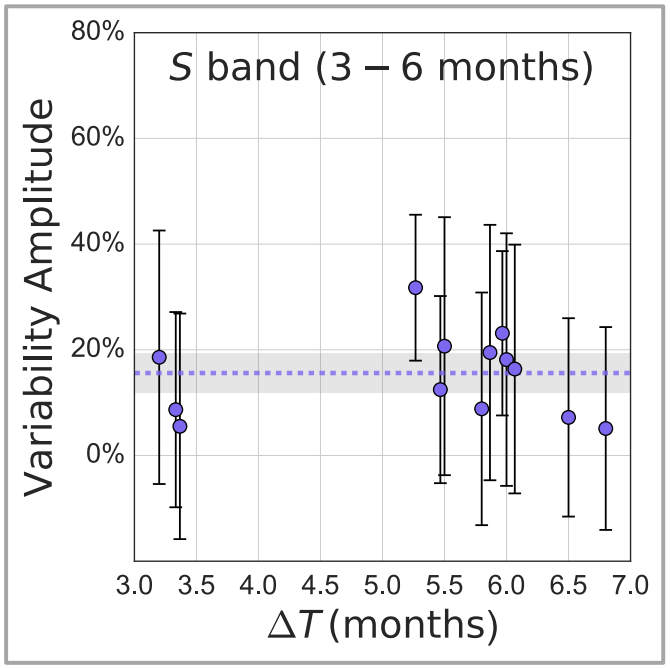
Simultaneous Multi-band VLA Follow-up

- **Verification** of VLASS quick look images
- Single-band **variability** measurements
- Radio **spectral curvature** (1-18 GHz)

Projects:
19A-422 (PI – Hallinan)
20B-329, 20B-459 (PI – Nyland)

Radio Variability Constraints

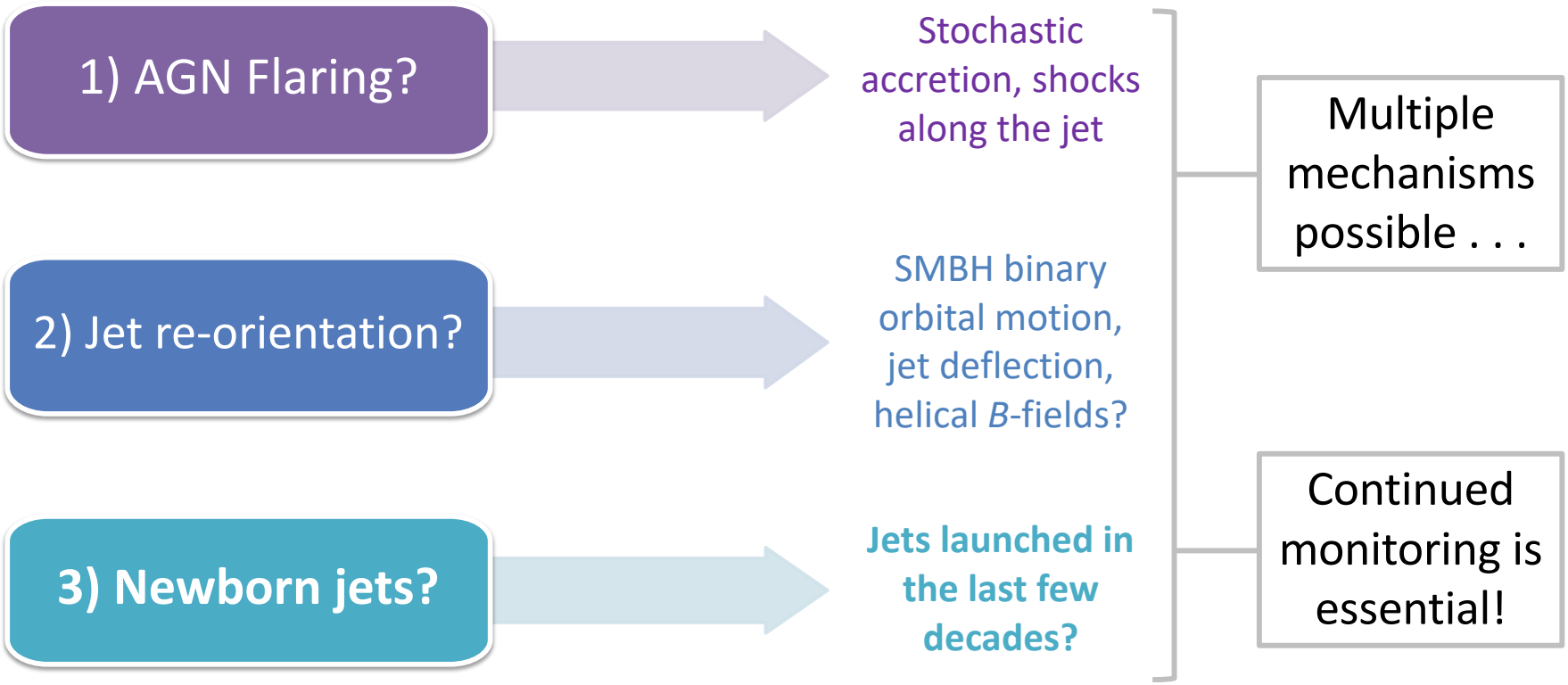




Variability amplitudes and timescales → intrinsic radio AGN variability

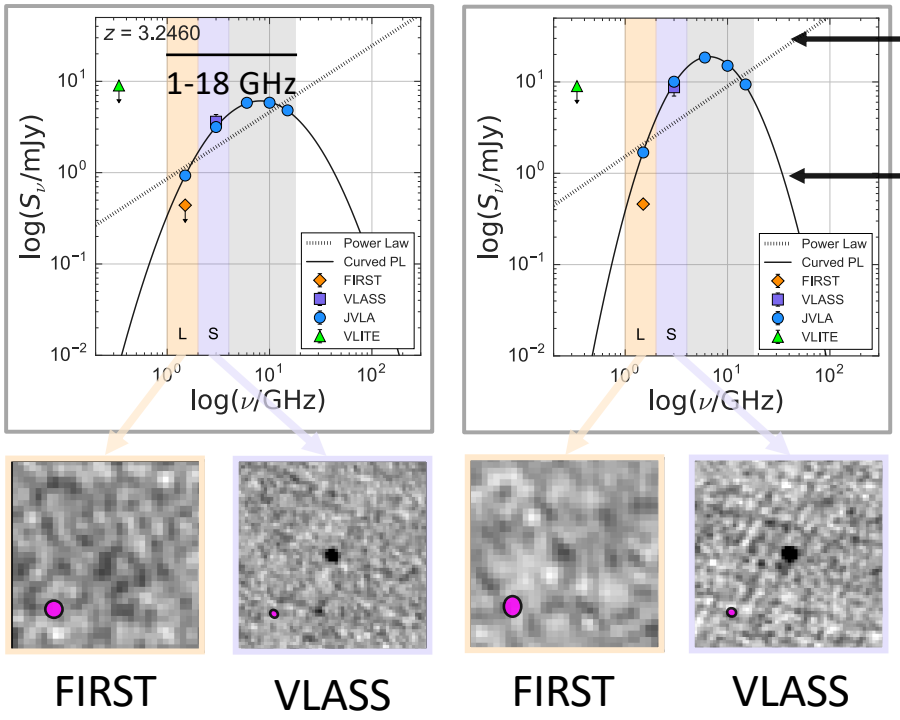
Nyland et al. 2020

Intrinsic Radio Variability Scenarios



Radio Spectral Shapes

Nyland et al. 2020



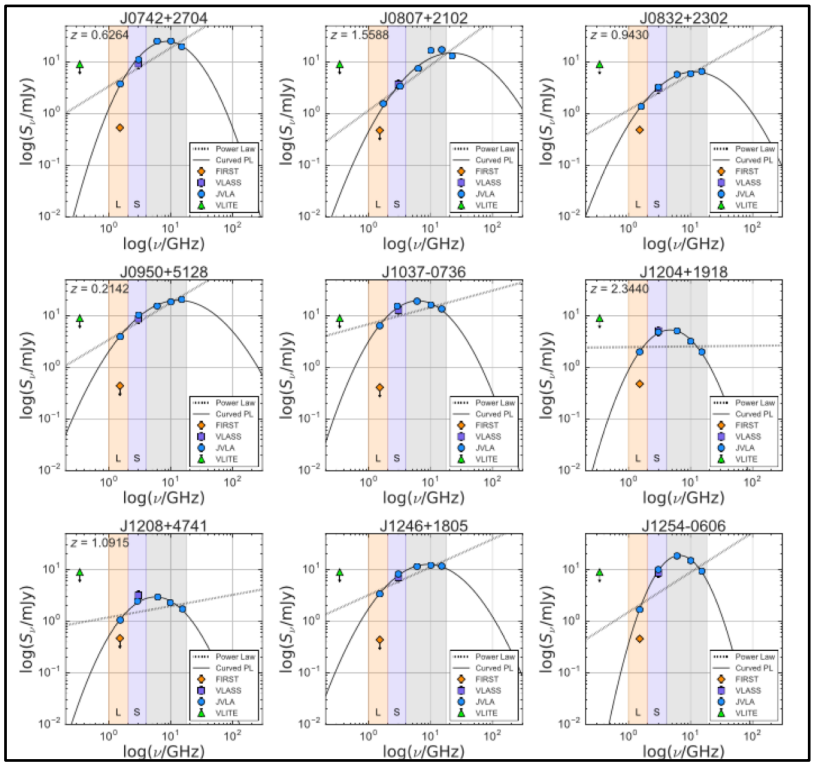
FIRST VLASS FIRST VLASS

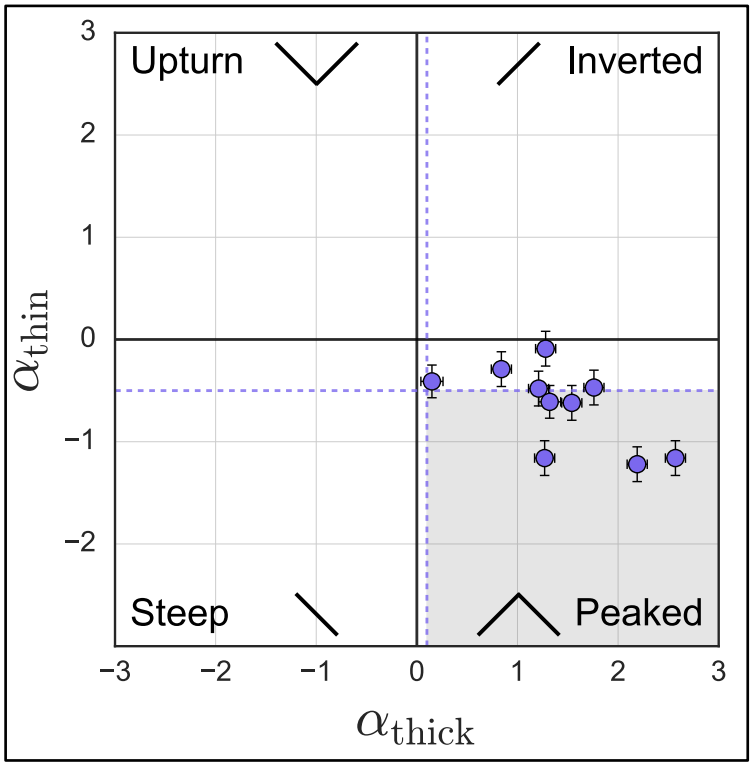
Power-law model doesn't fit

Curved power-law model fits!

Peaked spectra consistent with absorbed and compact jets

Radio Spectral Shapes





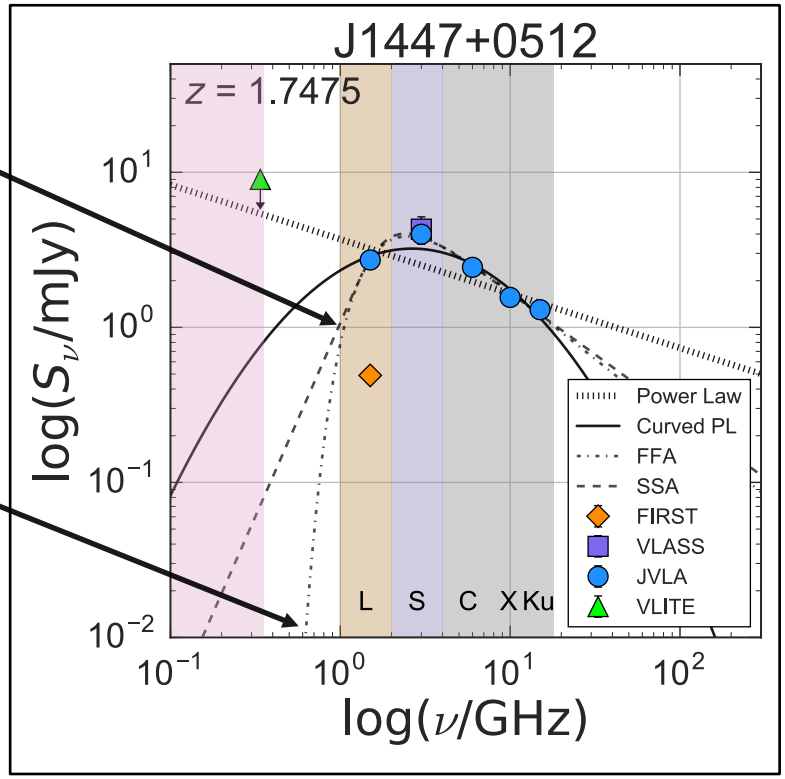
Nyland et al. 2020

Origin of the Absorption?

Synchrotron self absorption (SSA)

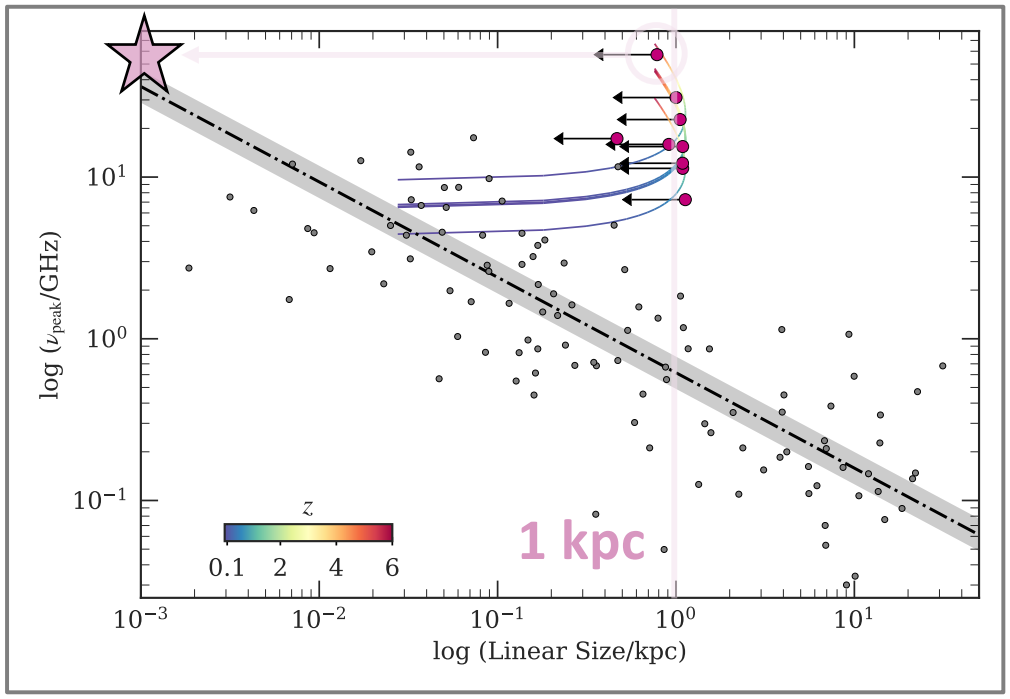
Free-free absorption† (FFA)

†Possible sign of jet-ISM interaction



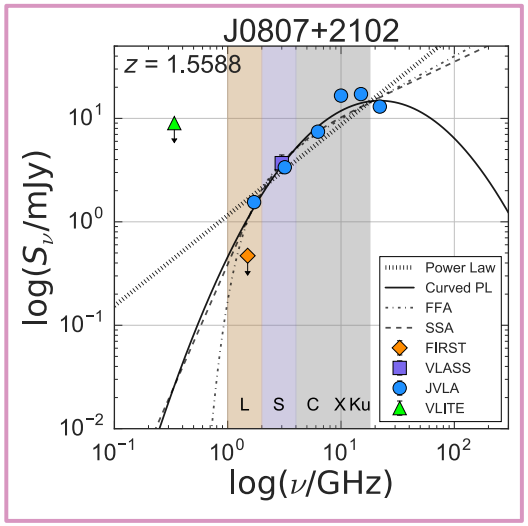
Deep sub-GHz data needed to separate SSA/FFA

Size Constraints from Turnover-size Relation

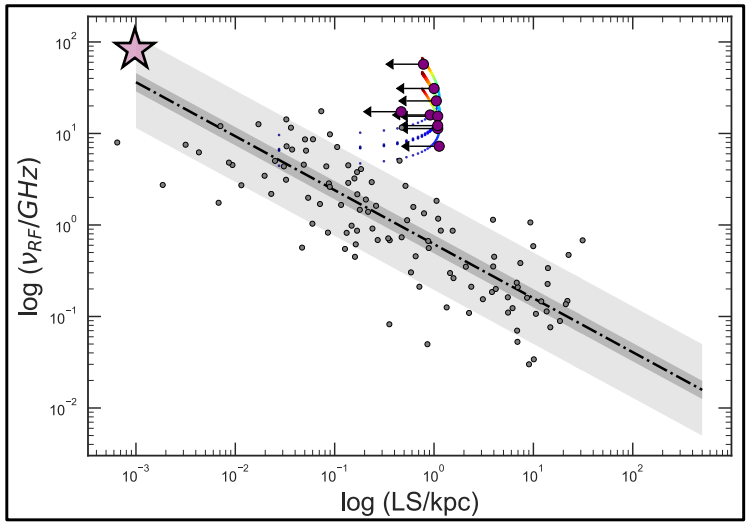


Consistent with sub-kpc jets launched decades ago

Turnover-Size Relation: Age Constraint Example



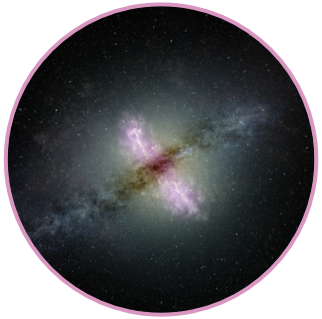
Spectral peak: 15 GHz
(= 40 GHz in restframe)



Size estimate: ~1-10 pc

Velocity: 0.1c (assumed)

Age: t=d/v ~30-300 yr



Young Jet!

Radio AGN Life Stages

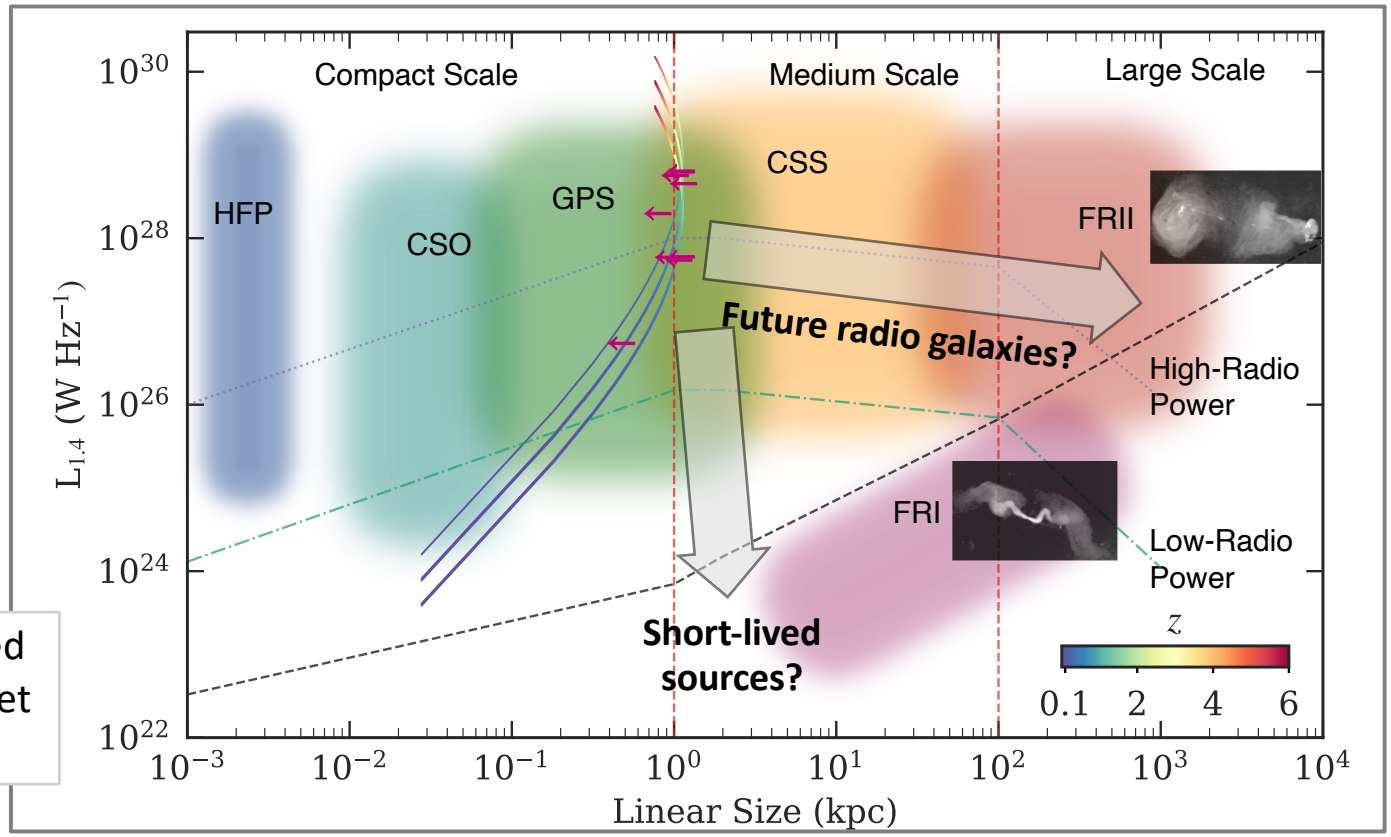
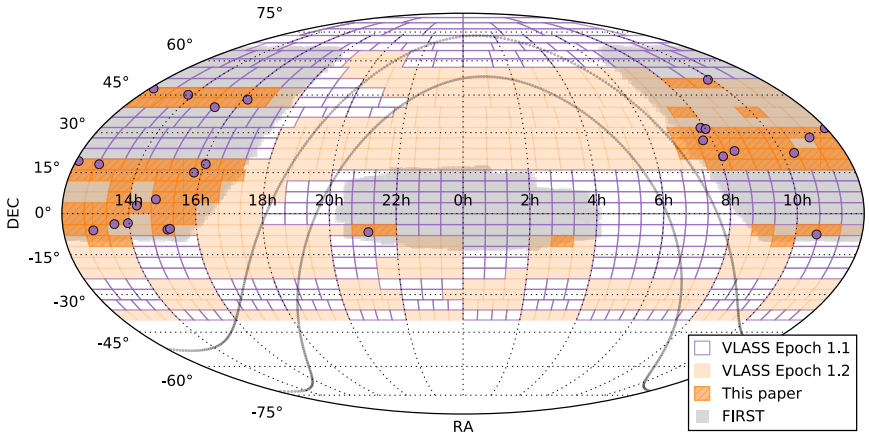


Fig adapted from Patil et al. 2020

Implications for Galaxy Evolution

Sky density:
4 x 10^{-3} deg^{-2} → period of occurrence = 10^5 yr



Nyland et al. 2020

Episodic, short-lived jets common at z = 1-3 →
Jet-ISM feedback?

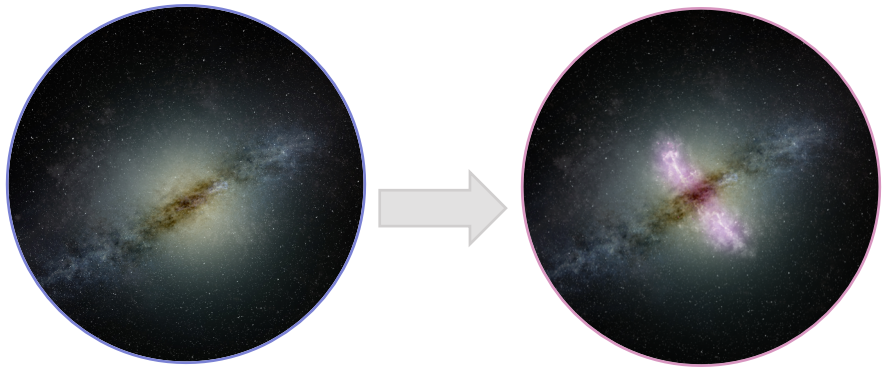
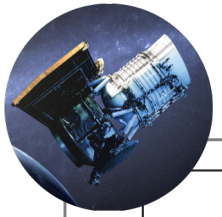
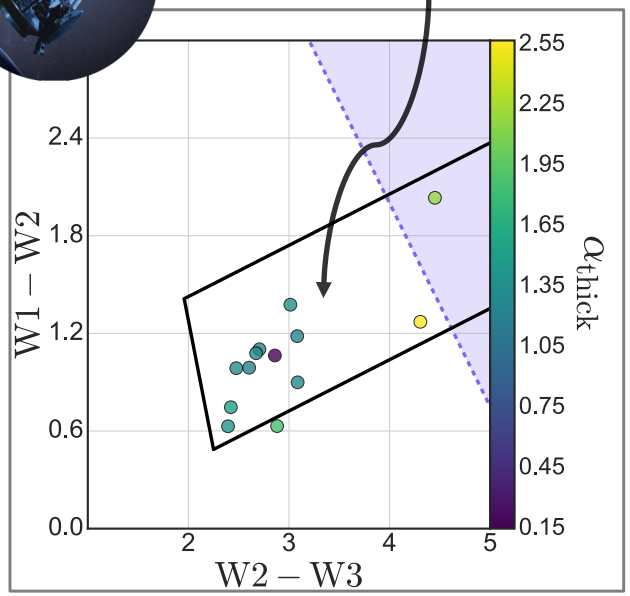


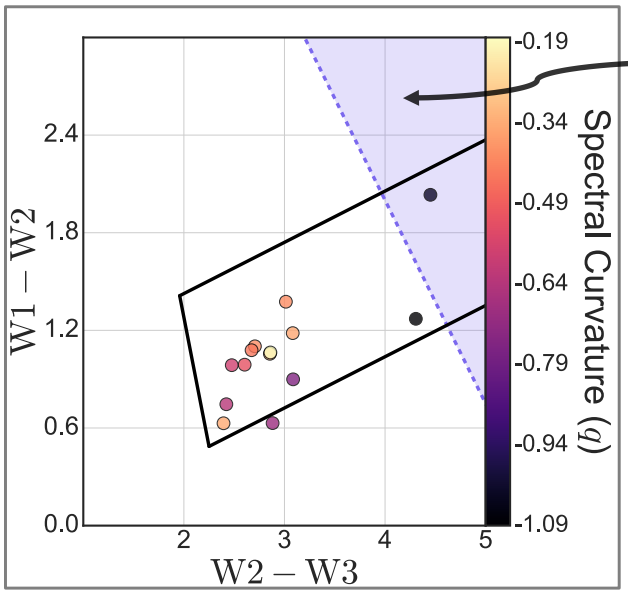
Image credit: Sophia Dagnello; NRAO/AUI/NSF

Connection with Quasar Reddening (and Mergers?)



Infrared AGN “wedge” (Matteos et al. 2012)





Heavily obscured, luminous AGN (Lonsdale et al. 2015)

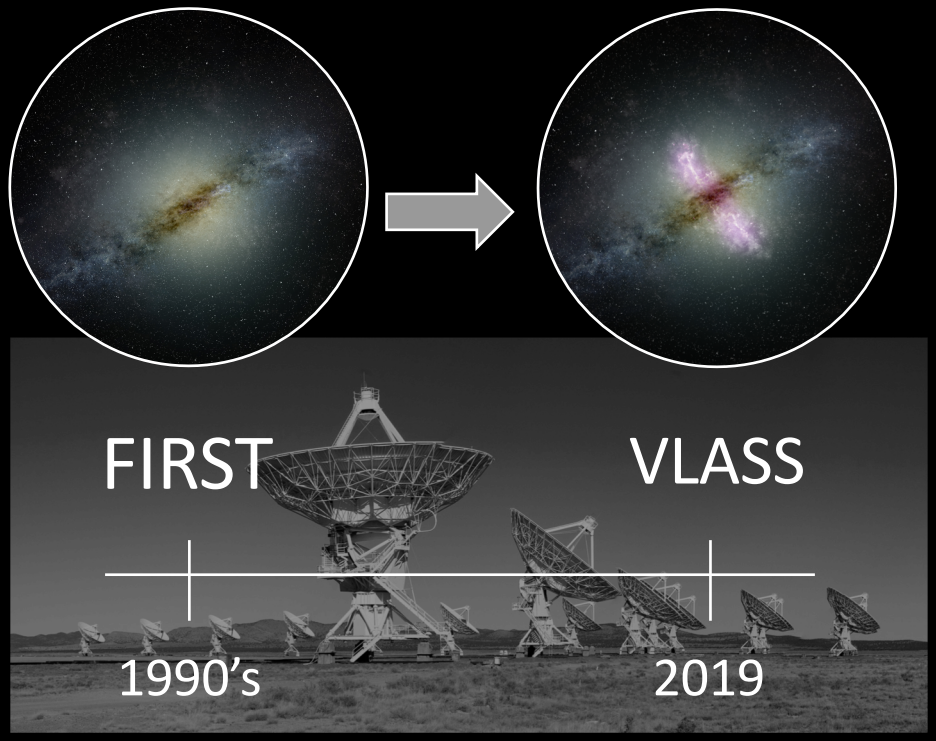
See talks by:
Carol Lonsdale (5/12)
Pallavi Patil (5/13)

Nyland et al. 2020

On-going and Future Work

- Continued radio SED monitoring (VLA)
- Milliarcsecond-scale imaging (VLBA)
- X-ray accretion state/morphology (new Cycle 22 *Chandra* data)
- Optical variability, host properties (new ground-based data, *HST*?)
- ISM content and conditions (ALMA?)

Summary



Nyland et al. 2020

Radio jets may "switch-on" over human timescales

Multi-epoch radio surveys catch newborn jets!

Short-lived jets common at z=1-3 → jet-ISM feedback?

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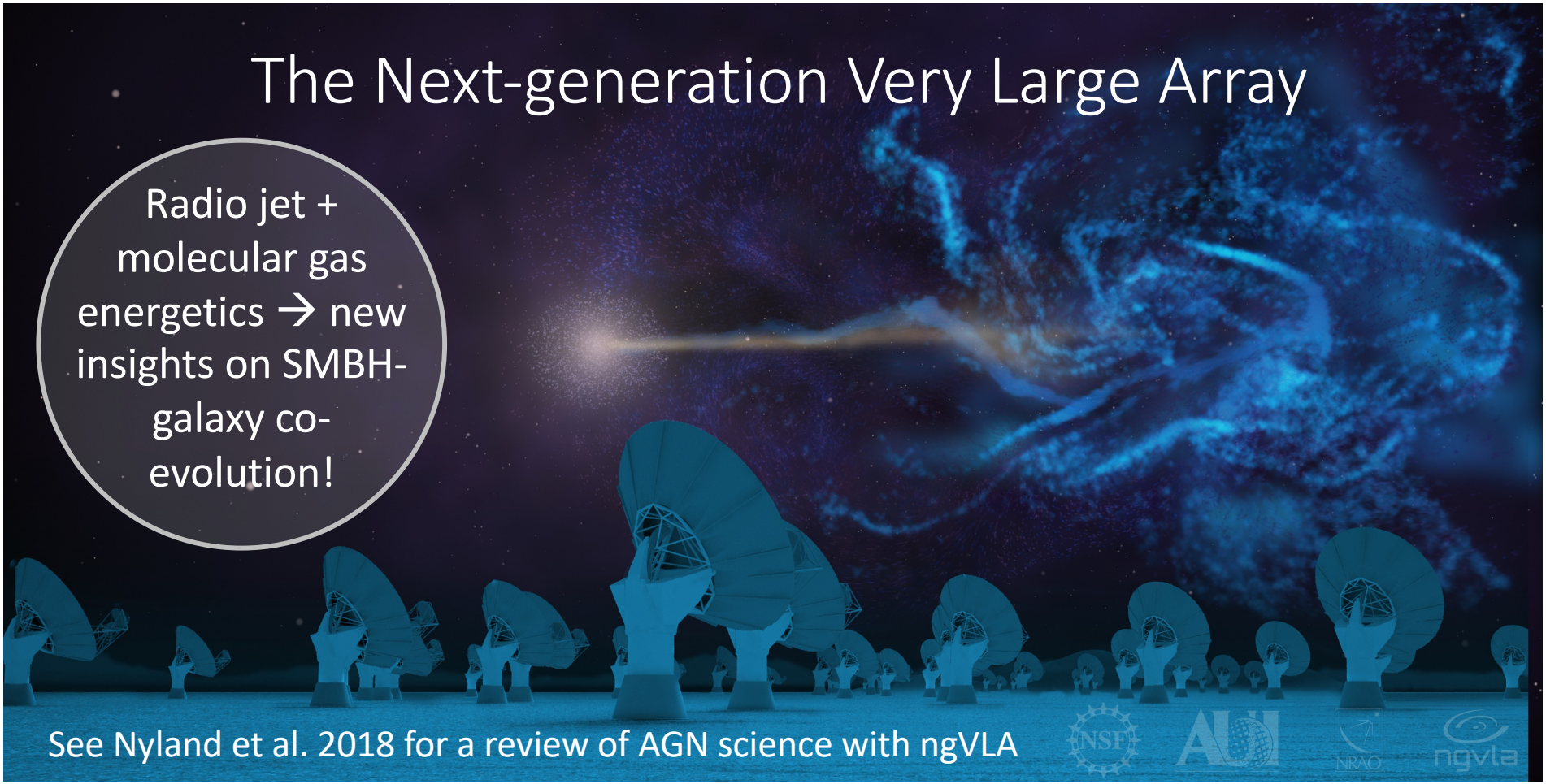
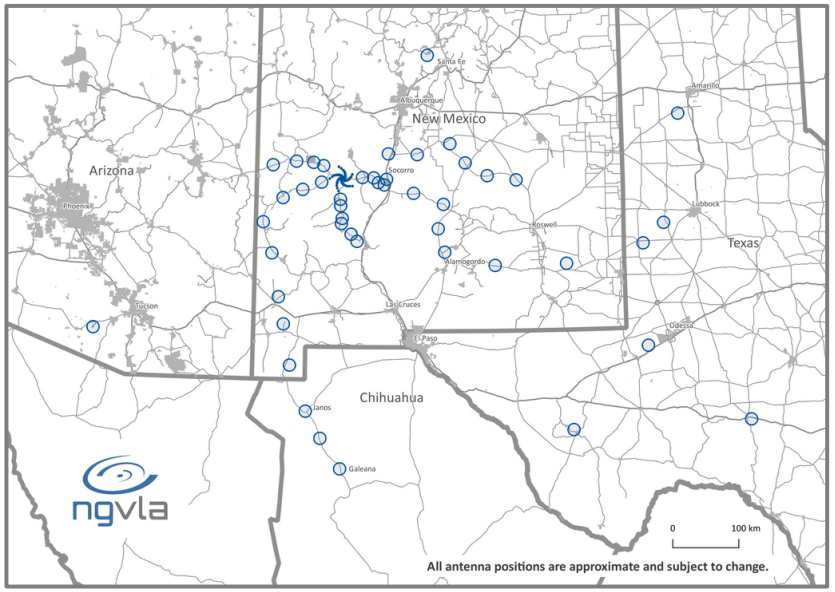
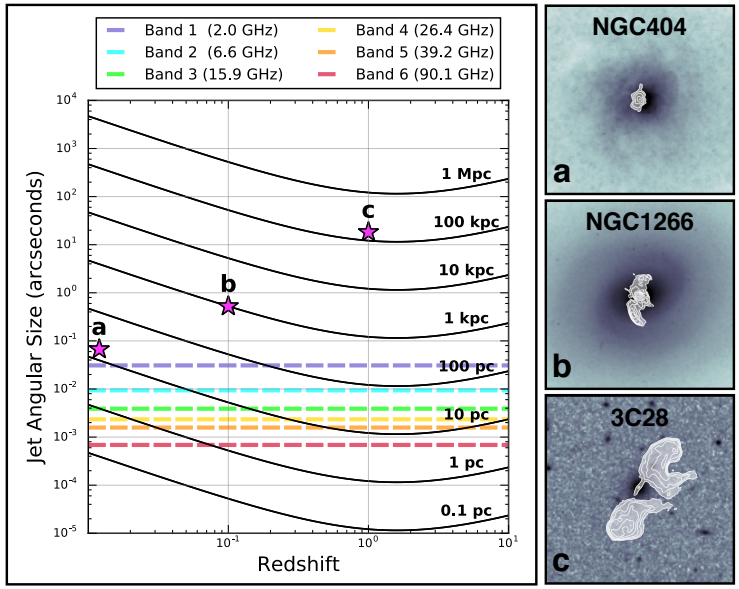
Extra Slides


The Next-generation Very Large Array
Radio jet + molecular gas energetics → new insights on SMBH-galaxy co-evolution!
See Nyland et al. 2018 for a review of AGN science with ngVLA
NSF
AUI
NRAO
ngvla

Imaging Compact Jets with the ngVLA



Nyland et al. 2018



Bmax = 1000 km

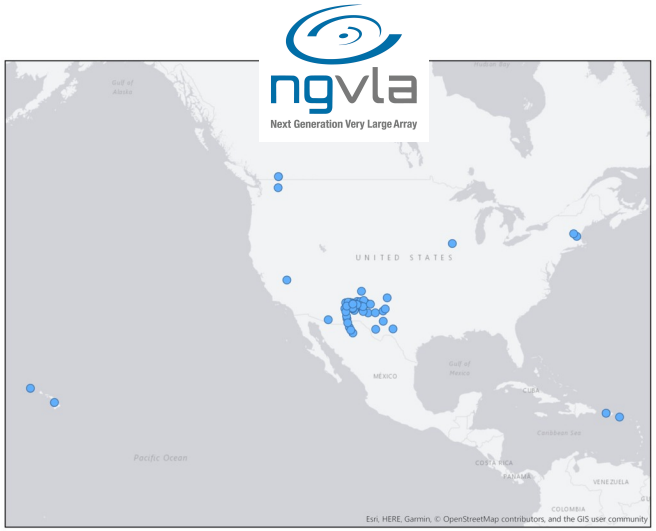
$\boldsymbol{\theta}_{max}$ = 0.5 to 44 mas

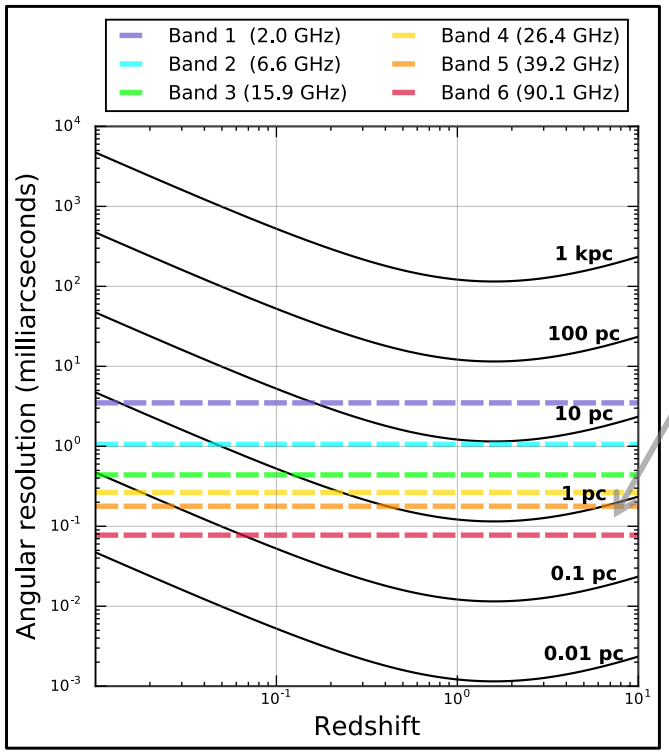
ngVLA will probe jet-ISM feedback on sub-galactic scales of 10 pc to 1 kpc

Imaging Compact Jets with the ngVLA

Bmax = 8,860 km

$\boldsymbol{\theta}_{max}$ = 0.06 to 5 mas

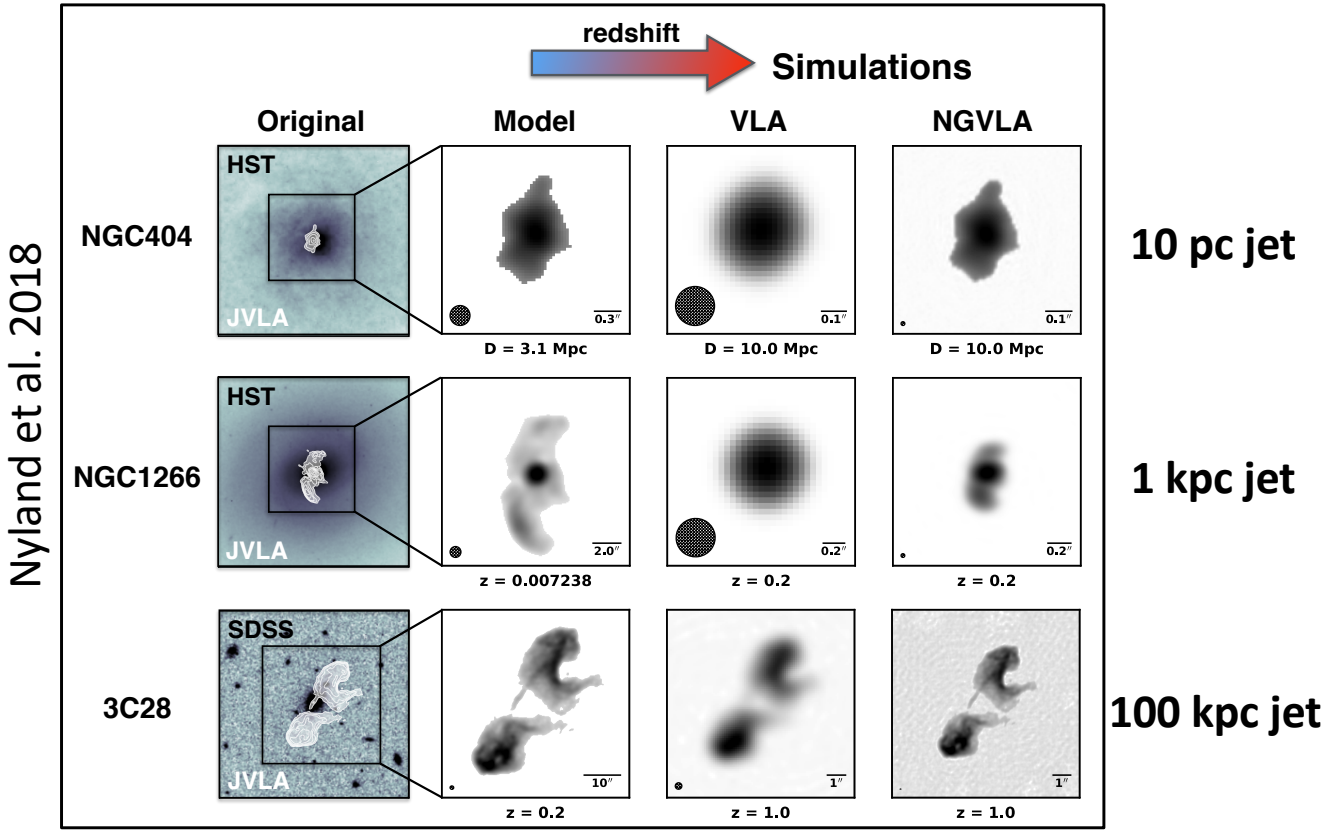




Nyland et al. 2018

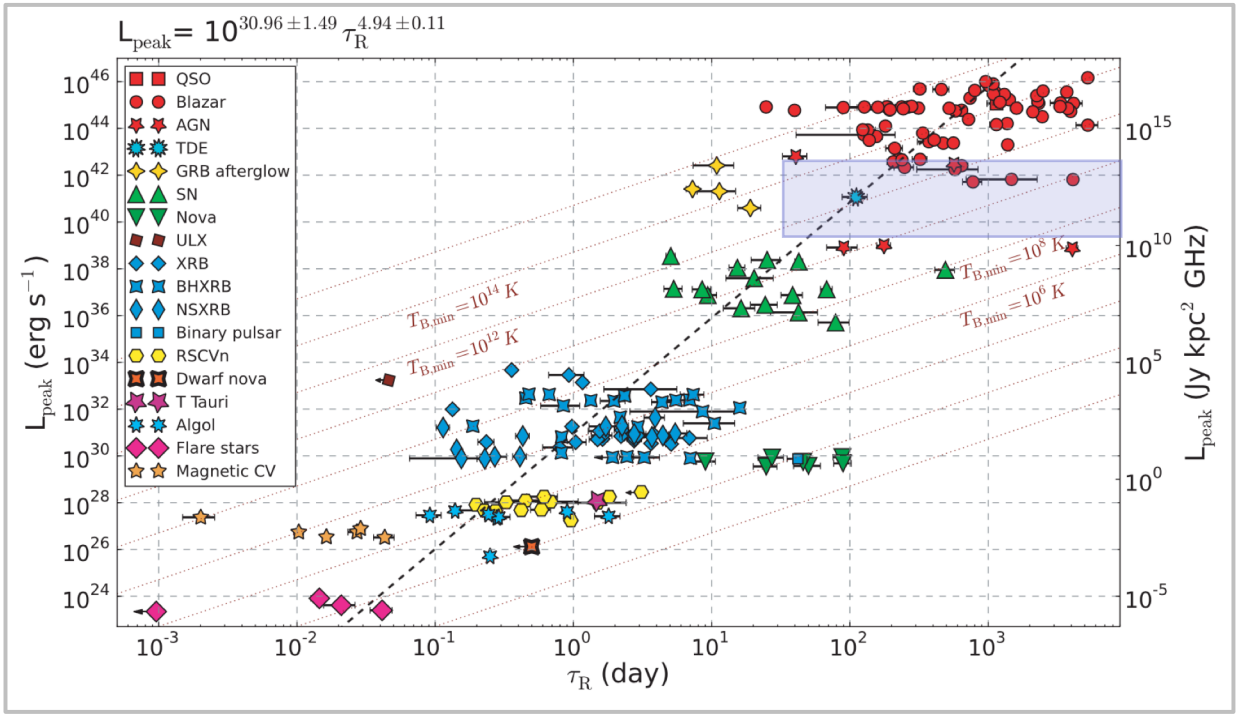
pc-scale resolution at *z* ~ 2 in highest-freq bands

Simulated ngVLA Images of Radio Jets



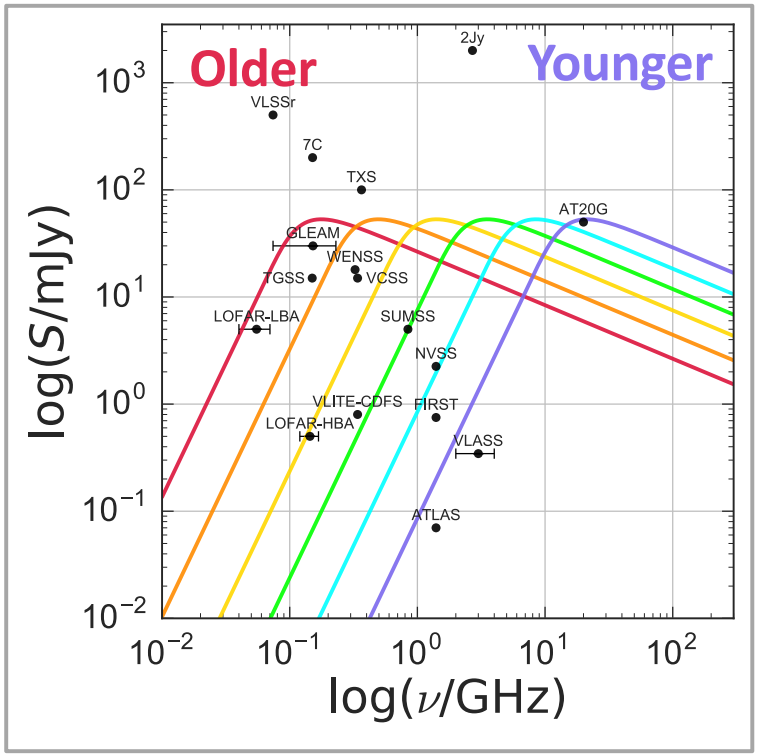
Origin of the Variability: Intrinsic Effects?

Pietka et al. 2015



Intrinsic AGN variability most consistent with luminosity and timescale constraints

Identifying Young Jets: Radio Surveys



Differences:

- Sensitivity
- Resolution
- Frequency
- Bandwidth
- Cadence

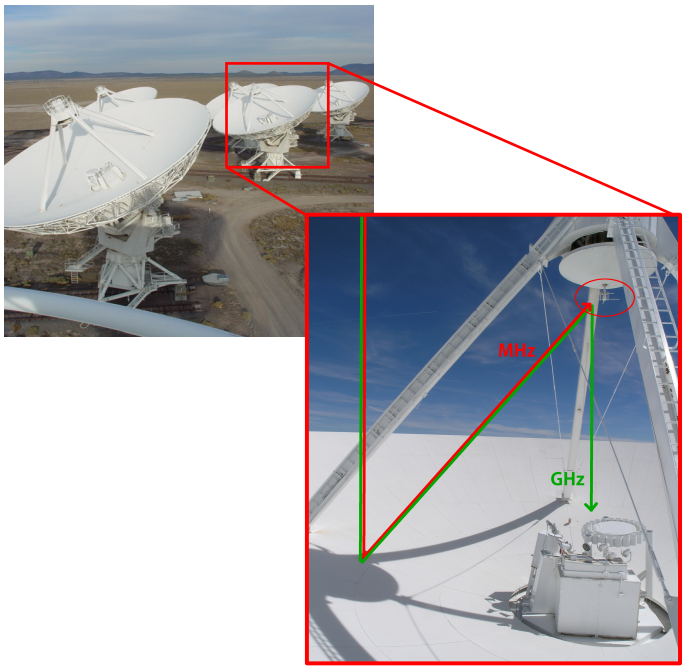
AGN jets in different life stages!

Figure based on Callingham et al. 2017

VLITE: The VLA Low-band Ionosphere & Transient Experiment

- **Commensal 340 MHz system** operating on 16 antennas of the Very Large Array
  - **RFI-free bandwidth: ~40 MHz**
  - **Resolution: up to ~5”**
- Data are recorded ***simultaneously*** during most regular VLA observations
  - **VLITE Commensal Sky Survey (VCSS) operates alongside VLA Sky Survey**

vlite.nrao.edu



VLITE 6 year benchmark: 37,589 hours of data!