

Resolved Radio Emission from a Radio-loud, Super-Eddington Quasar at $z=3.4$

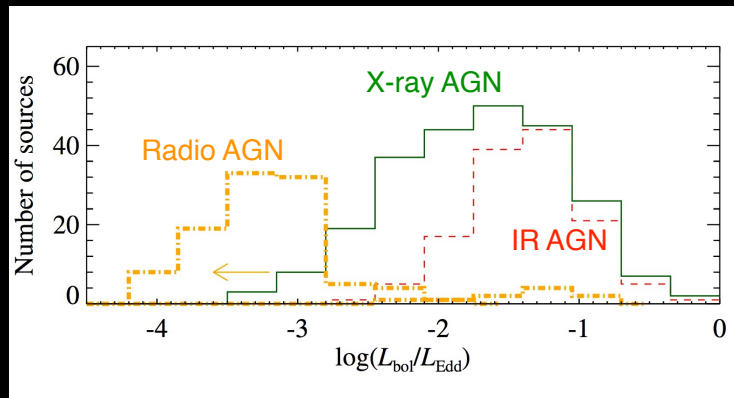
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Kohei Ichikawa (Tohoku University), Joseph Gelfand (NYUAD)

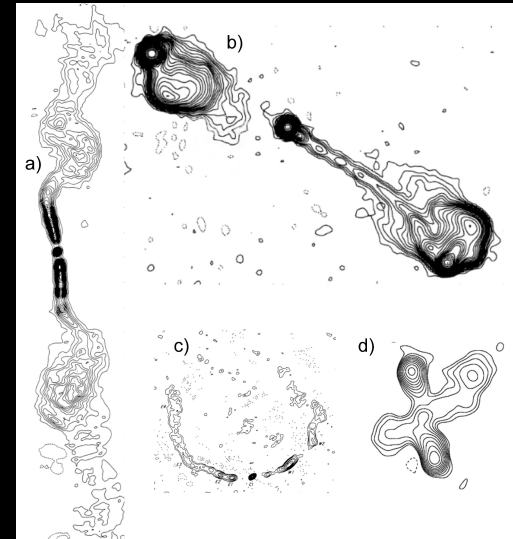
Illuminating the Active Universe:
Multi-wavelength and Multi-Messenger Insights into AGN
September 15, 2026



Radio Galaxies and Eddington Ratios



Padovani et al., 2017

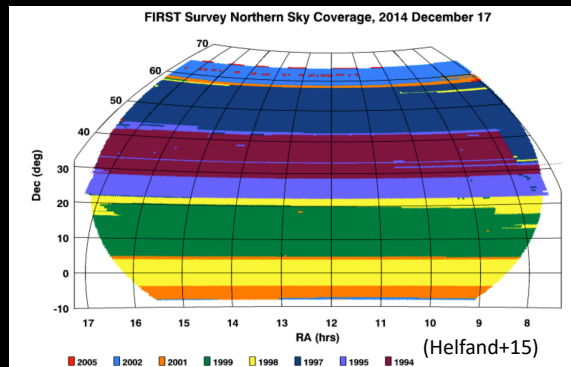


- Super-Eddington AGN are rare and not well understood
- Radio AGN typically have low Eddington ratios
- Radio loud implies jetted AGN
- Jets are hard to resolve at high z

The Galaxy

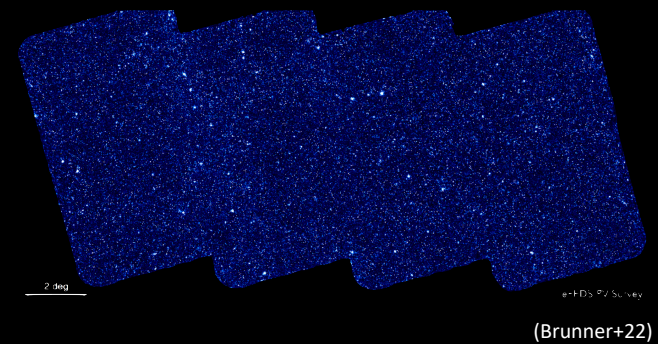
VLA/FIRST wide-area radio survey

($\nu=1.4$ GHz, $f_{\nu, \text{lim}}=1$ mJy, $>10^4$ deg²)



eROSITA eFEDS wide-area X-ray survey

(0.5-2 keV band, 140 deg²)

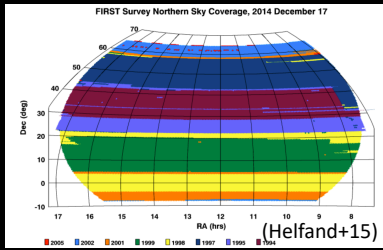


- eROSITA X-ray eFEDs survey x VLA/FIRST 1.4 GHz radio survey (Ichikawa et al. 2023)
- Identified X-ray luminous radio AGN
- Spectroscopic z's from SDSS spectra

The Galaxy (ID830)

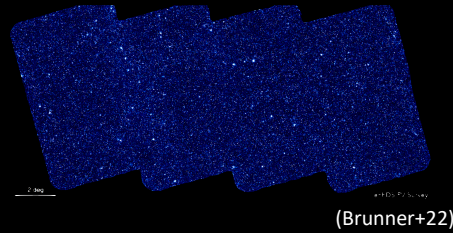
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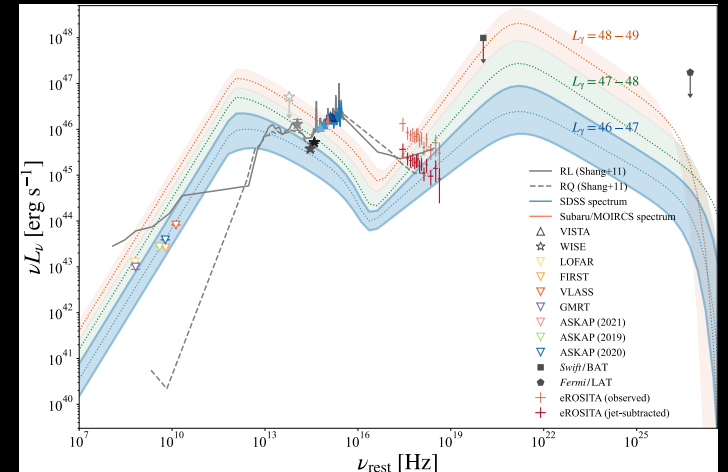
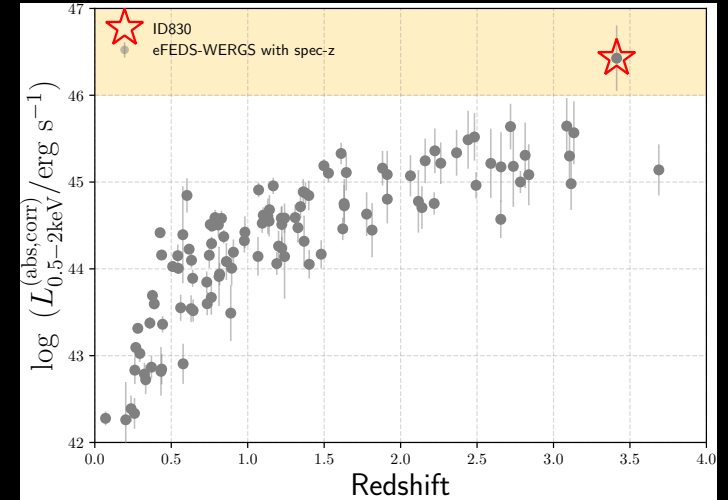


eROSITA eFEDS wide-area X-ray

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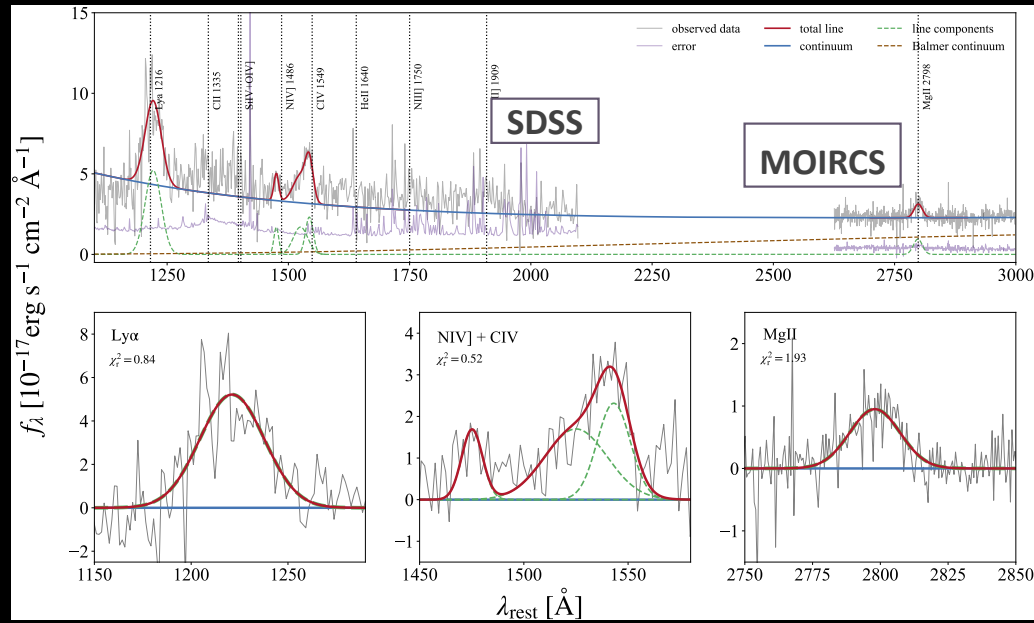


- eROSITA X-ray eFEDs survey x VLA/FIRST 1.4 GHz radio survey (Ichikawa et al. 2023)
- eFEDS J084222.9+001000, $z = 3.4351$ (ID830)
- Highly X-ray luminous: $\text{Log}(L_{0.5-2.0\text{keV}}) = 46.2$ erg/s, ($L_{\text{bol}} \sim \text{few} \times 10^{47}$ erg/s)
- Radio bright: $S_{1.4\text{GHz}} = 16.7$ mJy, $\text{Log}(R_{\text{obs}}) = 3.02$
- Previous CIV mass estimates suggest super-Eddington accretion



Obuchi et al., 2026a

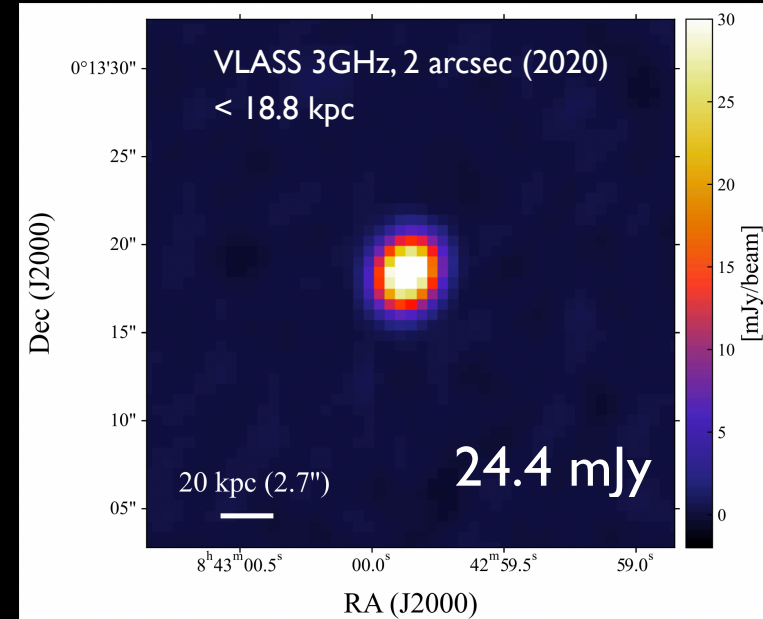
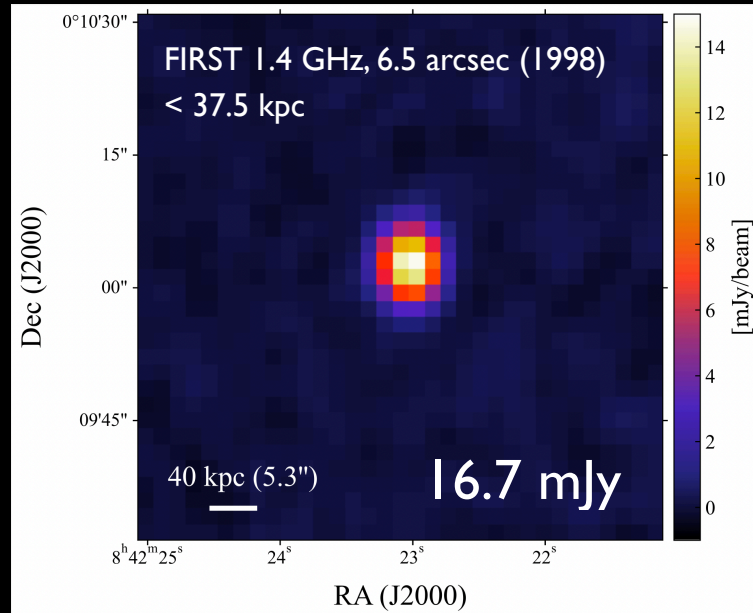
M_{BH} Measurement



- Subaru/MOIRCS J band spectrum
- $M_{\text{BH}} = (4.40 \pm 0.72) \times 10^8 M_{\odot}$
- $\lambda_{\text{Edd}} = 1.44 \pm 0.72$ (UV), 12.8 ± 3.9 (X-ray)

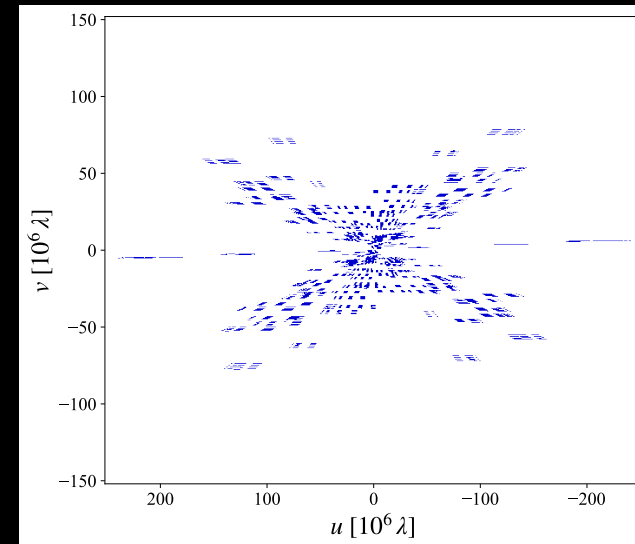
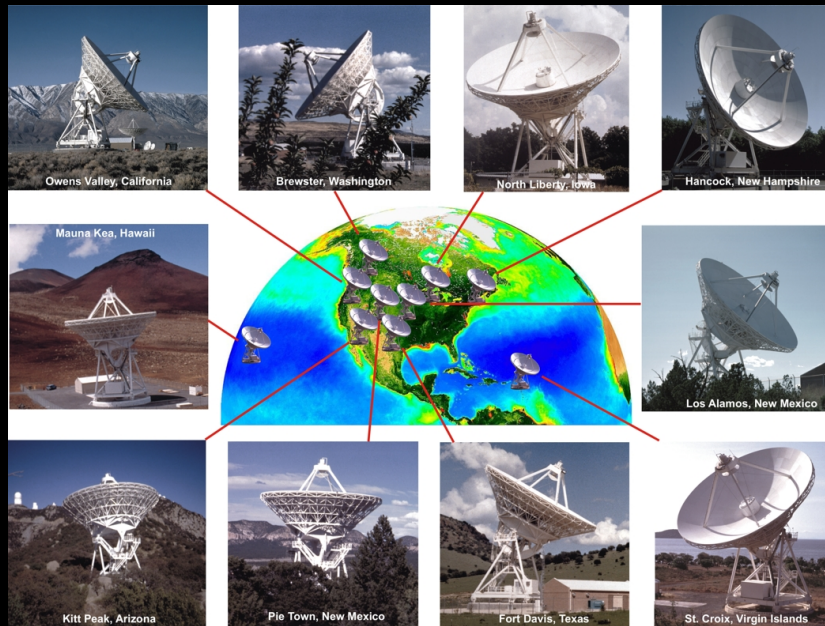
Obuchi et al., 2026a

Previous Radio Observations



- Need higher spatial resolution!

VLBA Observations



- L band (1.4 GHz): 15 mas (~ 112.5 pc)
- C band (5 GHz): 5 mas (~ 37.5 pc)
- X-band (8 GHz): 2.5 mas (20 pc)

- Sensitive to different size scales
- Accurate spectral index

Resolved Core-Jet Structure

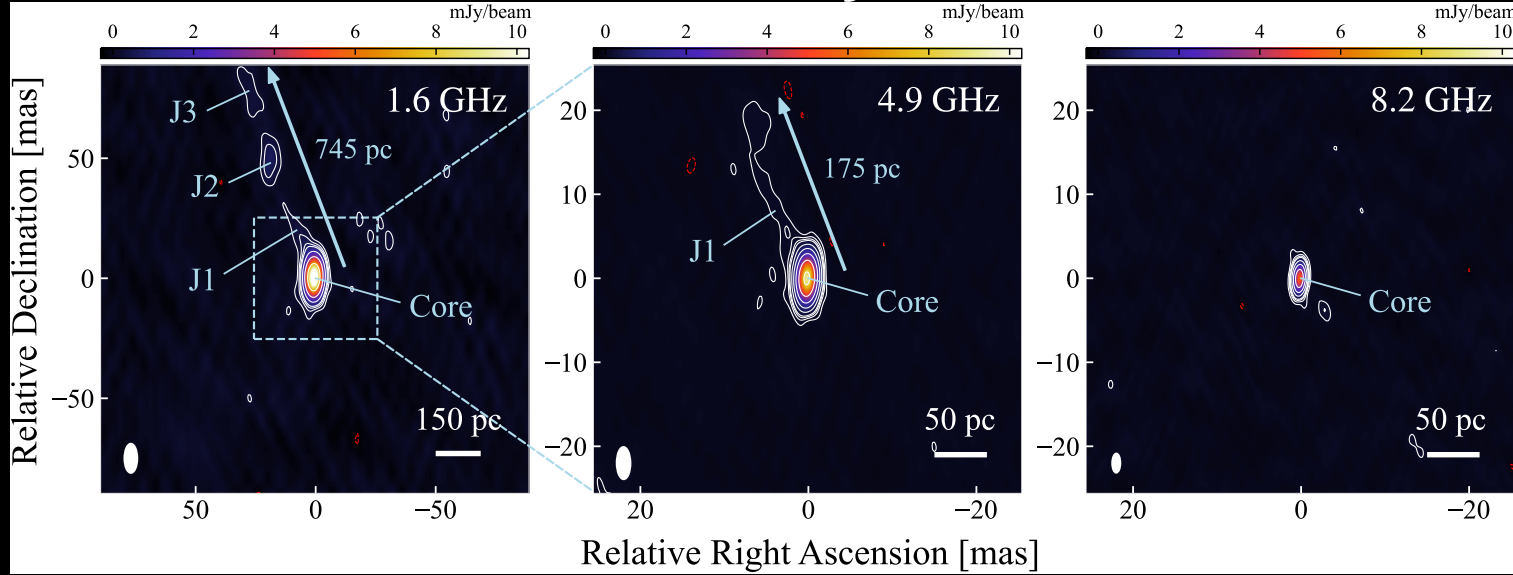


Table 2
Summary of Model-fit Parameters and Results

Freq. (GHz) (1)	θ_{maj} (mas) (2)	θ_{min} (mas) (3)	$\theta_{\text{p.a.}}$ (deg) (4)	$S_{\text{int,core}}$ (mJy) (5)	$S_{\text{int,jet}}$ (mJy) (6)	T_b (10^{10} K) (7)
1.63	3.27 ± 0.25	< 0.58	-23.0	13.42 ± 1.94	0.82 ± 0.08	> 1.44
4.88	1.26 ± 0.06	< 0.12	-27.1	10.23 ± 1.22	0.37 ± 0.04	> 1.60
8.17	1.12 ± 0.09	0.30 ± 0.02	-14.7	6.86 ± 0.98	< 0.40	0.17 ± 0.03

Note. Columns: (1) central frequencies; (2) major axis FWHM of the elliptical Gaussian model; (3) minor axis FWHM of the elliptical Gaussian model; (4) position angle of the major axis of the elliptical Gaussian model; (5) integrated flux density of the core; (6) integrated flux density of the jet (J1); (7) core brightness temperature at the rest-frame frequency.

Resolved Core-Jet Structure

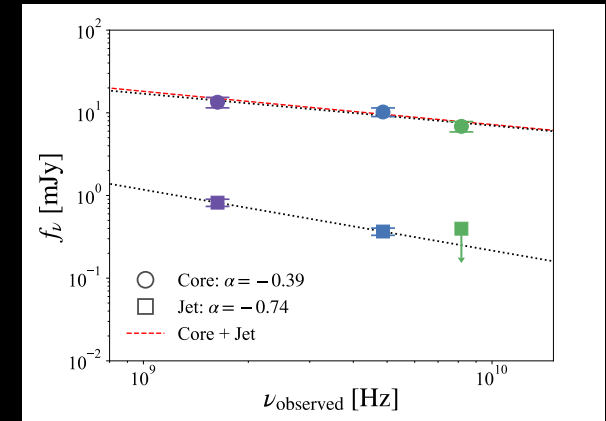
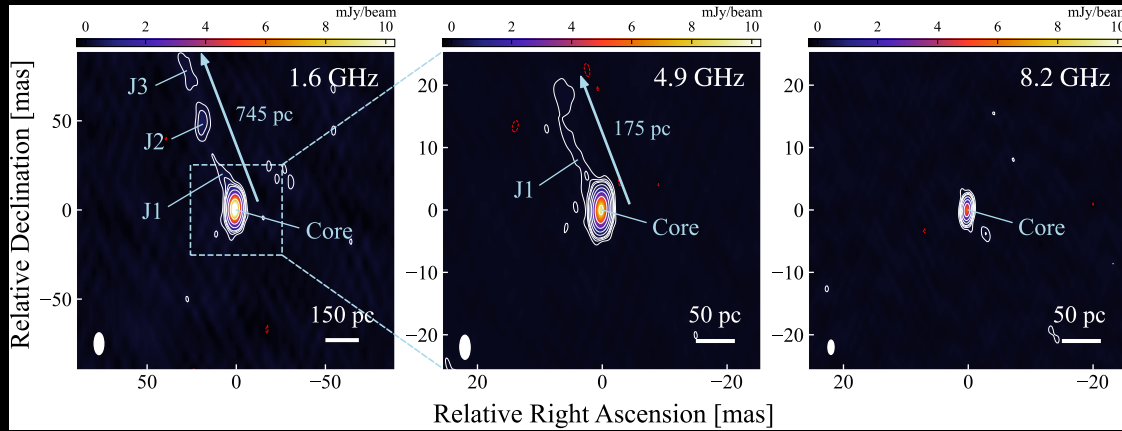


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- Clear one-sided kpc scale jet
- Core dominates over jet
- Not much emission beyond kpc scales

Jet Properties

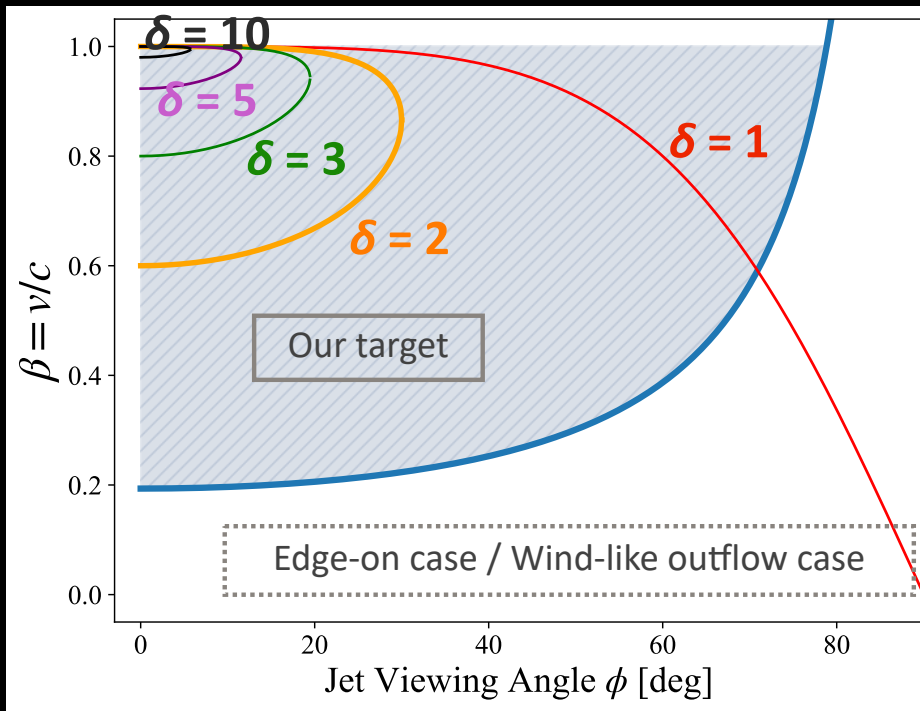
$$\delta = \frac{T_b}{T_{b,int}}$$

T_b : target brightness temperature

$T_{b,int}$: intrinsic brightness temperature (Kovalev+05, Homan+21)

$$T_b = 1.22 \times 10^{12} \frac{S_{int,core}(1+z)}{\theta_{maj}\theta_{min}\nu^2} \text{ [K]}$$

$$T_{b,int} \approx 4.1 \times 10^{10} \text{ K}$$



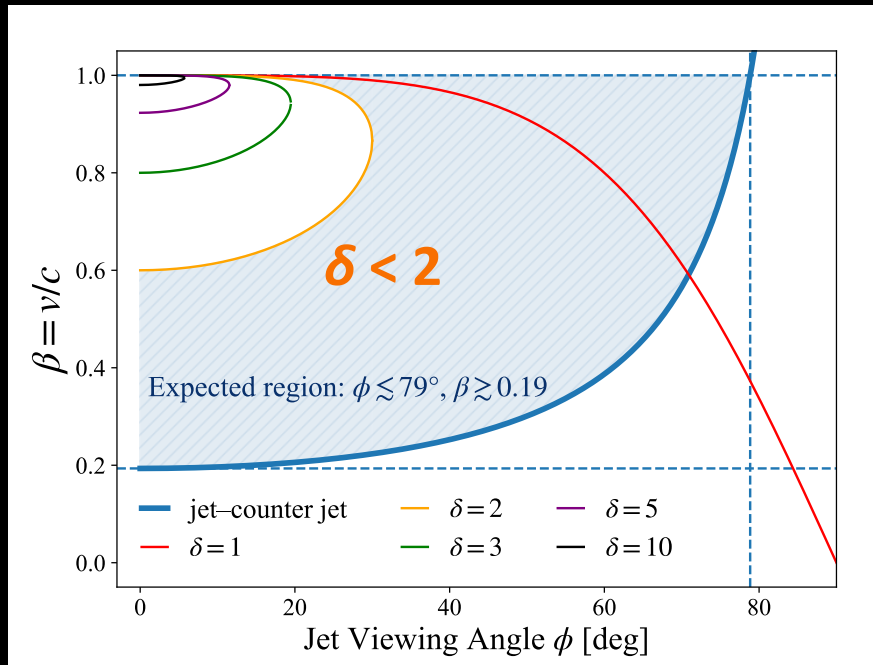
$$J = \frac{F_{jet}}{F_{counter\ jet}} = \left(\frac{1 + \beta \cos \phi}{1 - \beta \cos \phi} \right)^{2-\alpha}$$

J : jet-counter jet flux ratio
(Ghisellini+1993)

↓ Our target

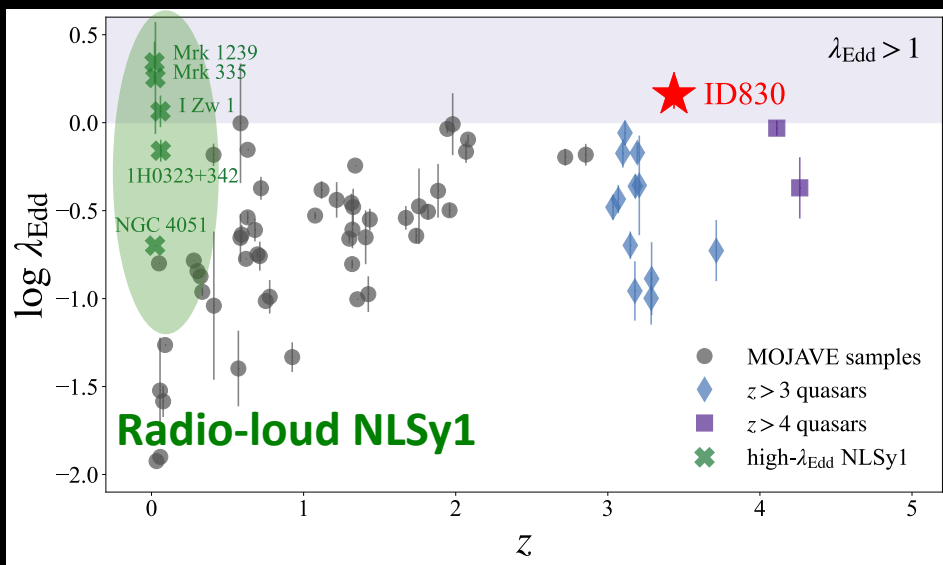
$J > 2.92$ (lower limit)

Jet Properties



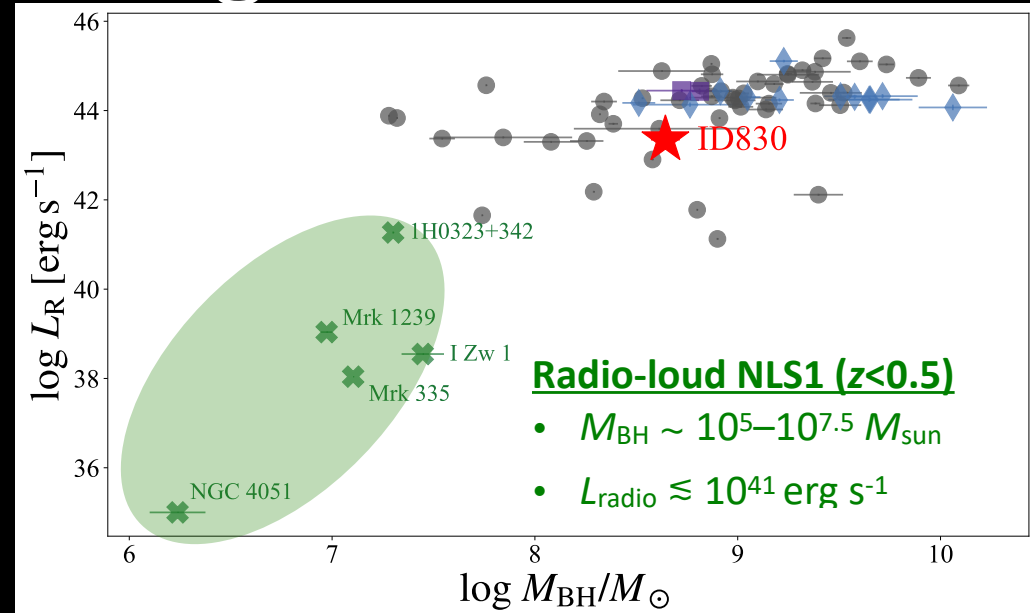
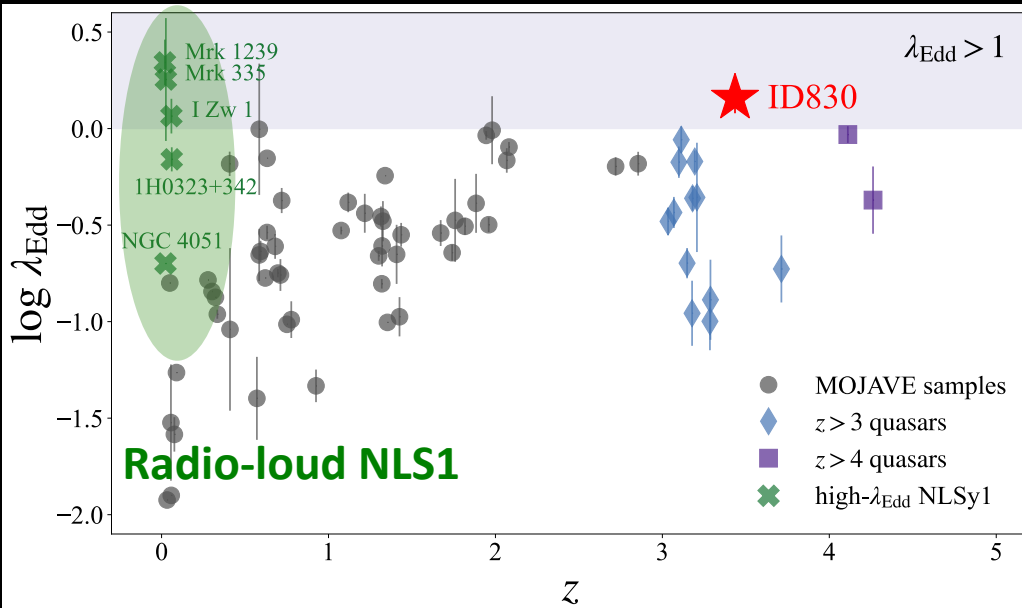
- Collimated, relativistic jet
- No significant Doppler boosting
- Jet: ~ 745 pc, $v > 0.19c$.
 - Implies 10^{3-4} yr super-Eddington phase

Low-z Analogs?



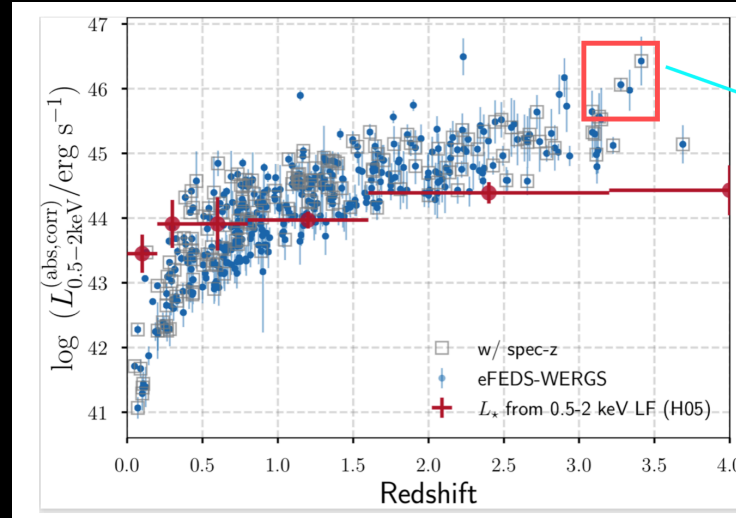
- ID830 unlike low- z radio galaxies: high λ_{Edd} , not jet dominated
- Maybe comparable to NLSy1's?

Low-z Analogs?



- ID830 unlike low- z radio galaxies: high λ_{Edd} , not jet dominated
- ID830 unlike low- z NLS1s: much higher SMBH mass, 5 GHz luminosity
- Need VLBI observations of more high- z , high-Eddington, high X-ray, high radio AGN

Additional Galaxies

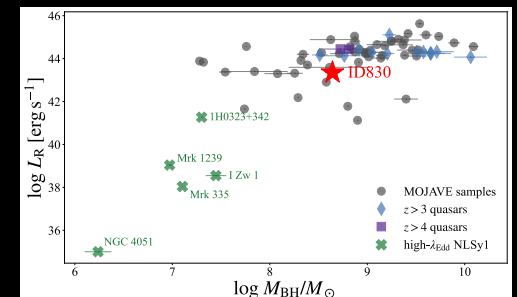
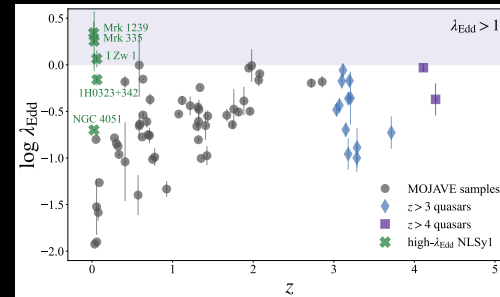
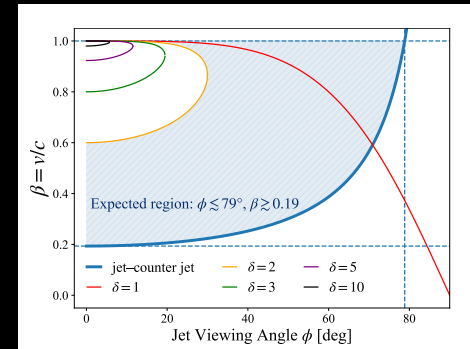
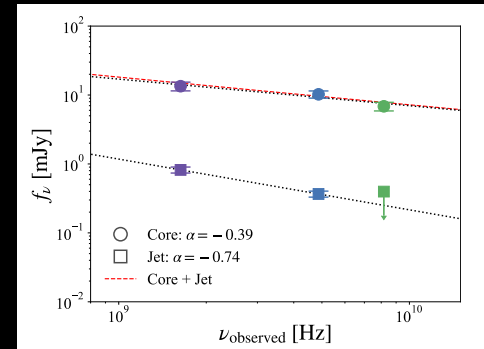
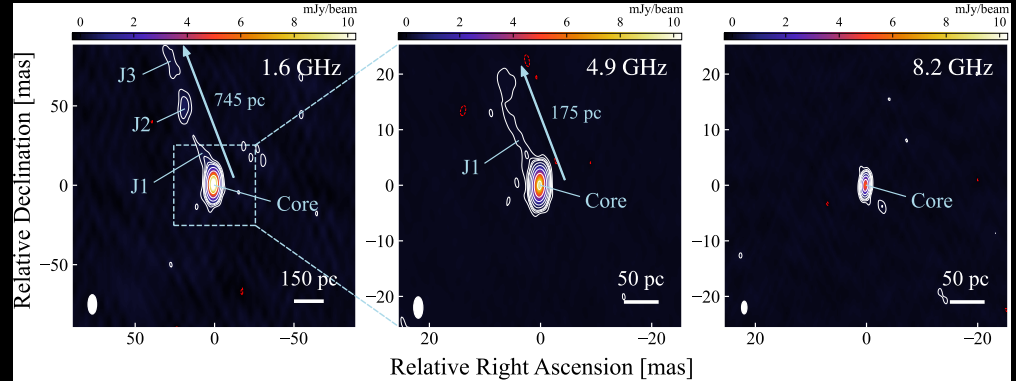


NAME	RA	Dec	z	$S_{1.4}$	α	$\log(L_{0.5-2\text{keV}})$
...	[J2000]	[J2000]	...	[mJy]	...	...
eFEDS-ID86	09 09 15.90	+03 54 43.5	3.28	134.5	~ -0.41	46.1
eFEDS-ID830	08 42 23.02	+00 10 02.6	3.40	16.0	~ -0.66	46.4
eFEDS-ID1032	08 42 59.89	+00 13 18.4	2.68	65.1	~ -0.06	45.6

From Ichikawa et al., 2023

Conclusions

- Resolved core-jet structure in radio loud, super-Eddington AGN at $z = 3.4$
- Core dominates over jet
- $\delta \sim 1, \phi < 79^\circ, v_{jet} > 0.19c$
- Unlike low z counterparts
- Need to build up a population study



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Thank you!

