



# VaDAR: Varstrometry for Dual AGN using Radio interferometry

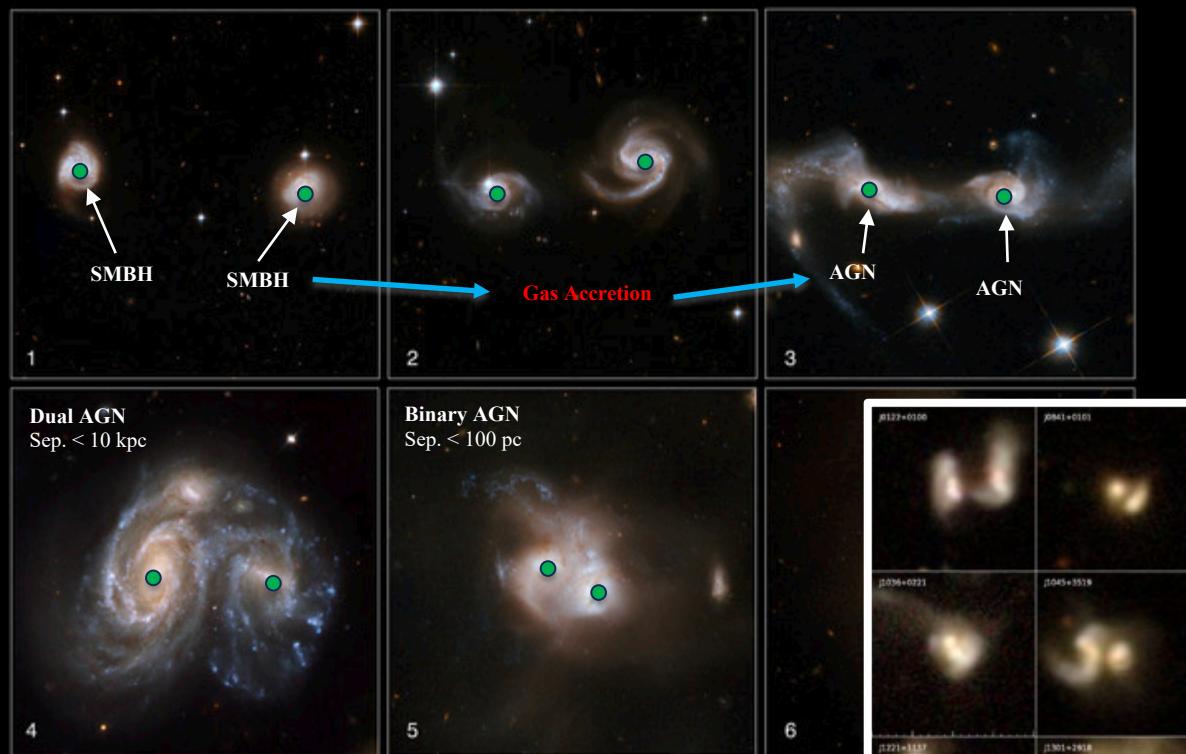
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George Mason University, US Naval Research Lab

Collaborators: Tracy Clarke, Kristina Nyland, Nathan Secrest, Ryan Pfeifle, Henrique Schmitt, Shobita Satyapal, Barry Rothberg, Paula Fudolig

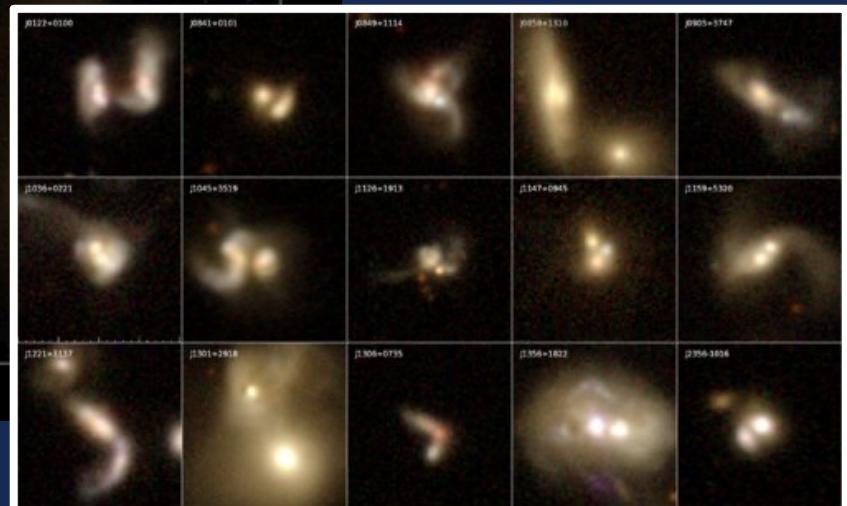


## Evolution of a Galaxy Merger



ESA

Galaxy mergers can result in pairs of gravitationally-bound supermassive black holes.

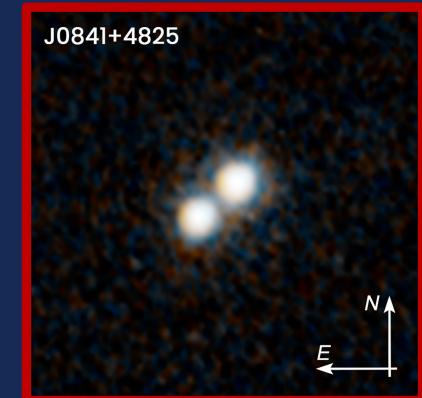
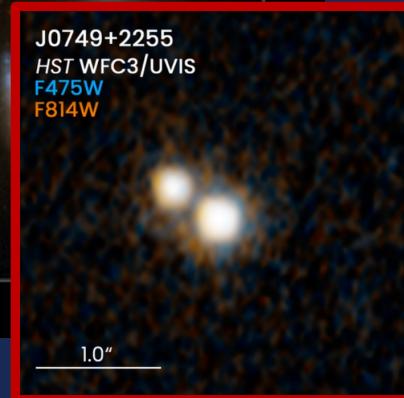
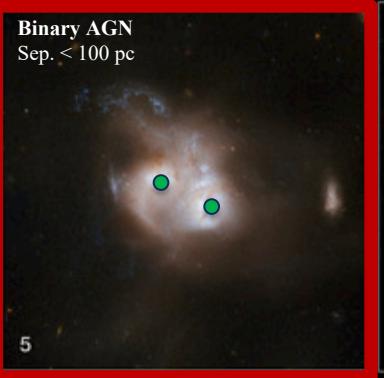
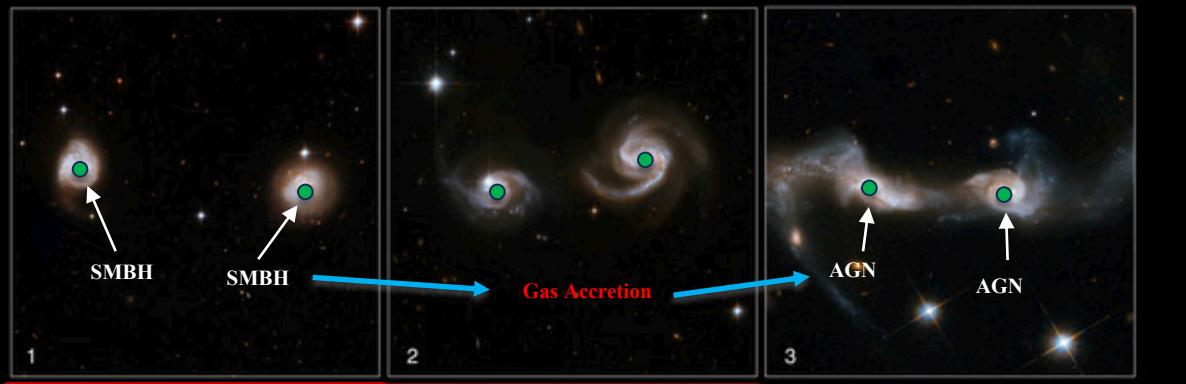


Pfeifle et al. 2019

VaDAR

AAS 2024

## Evolution of a Galaxy Merger



**AGN Pair Systems:**

Only 40-50 confirmed...

**Dual AGN:** Sep. < 10 kpc  
**Binary AGN:** Sep. < 100 pc

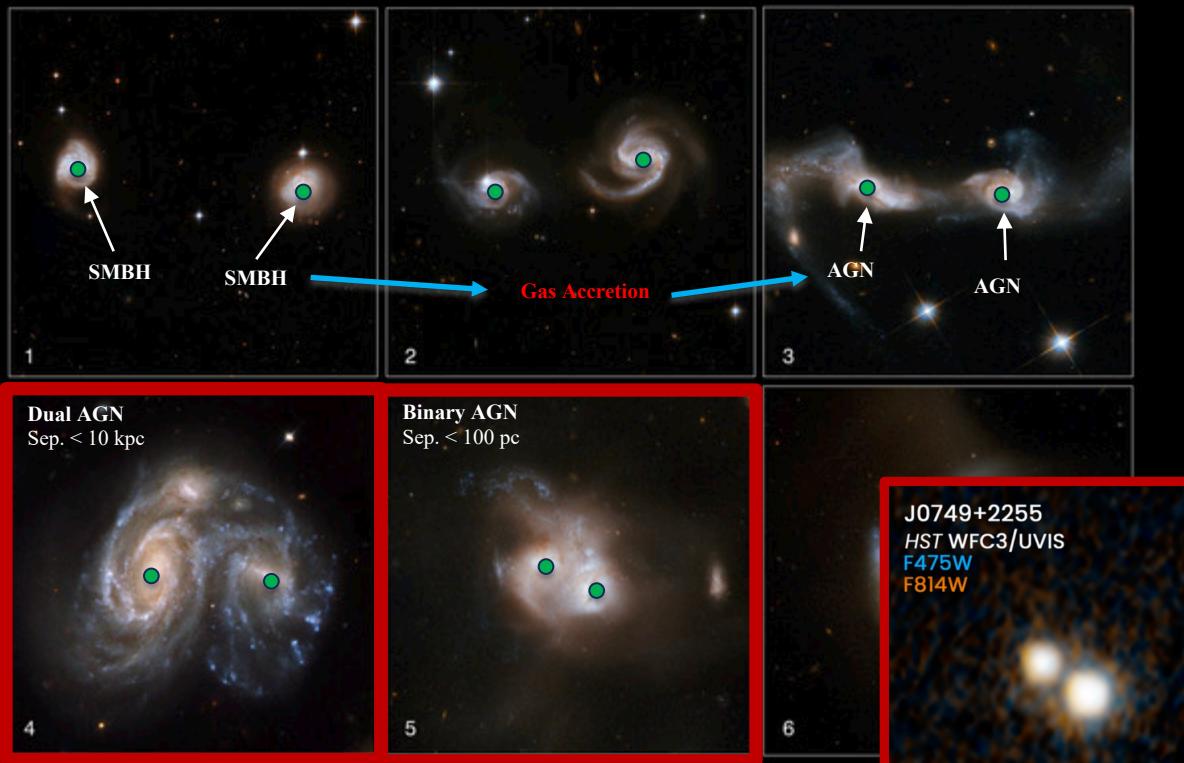
ESA

Hwang et al. ApJ. 2020.

VaDAR

AAS 2024

## Evolution of a Galaxy Merger



## AGN Pair Systems:

Only 40-50 confirmed...

Dual AGN: Sep. < 10 kpc  
Binary AGN: Sep. < 100 pc

What systematic methods exist for the detection of AGN pairs?

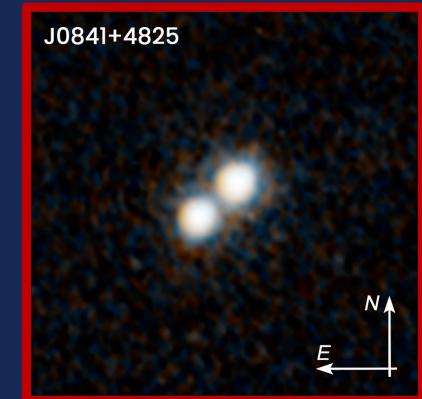
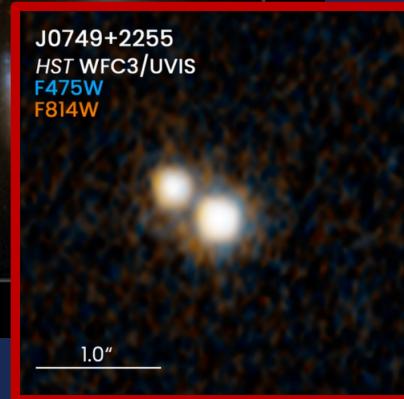
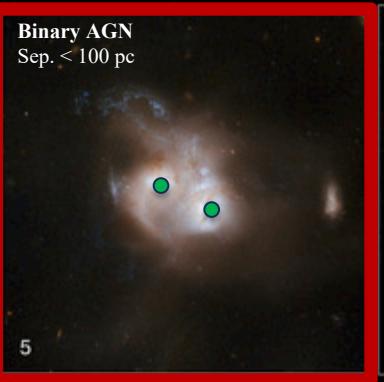
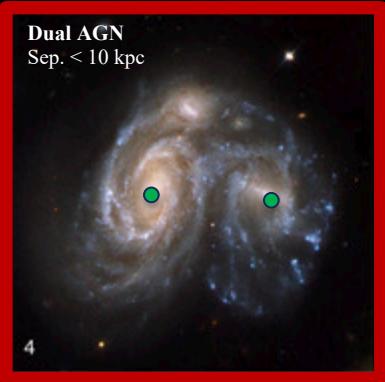
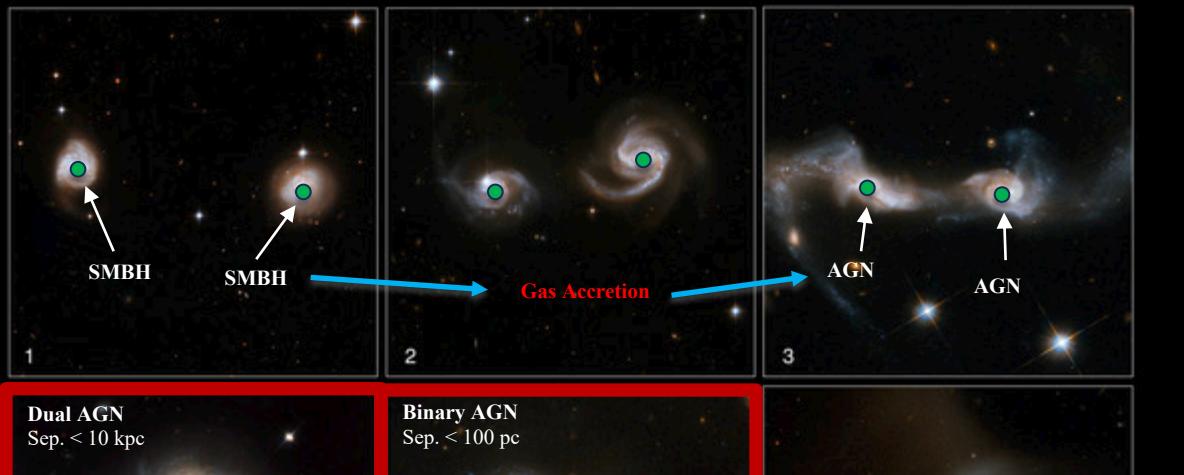
J0749+2255  
HST WFC3/UVIS  
F475W  
F814W

1.0''

N  
E

Hwang et al. ApJ. 2020.

## Evolution of a Galaxy Merger

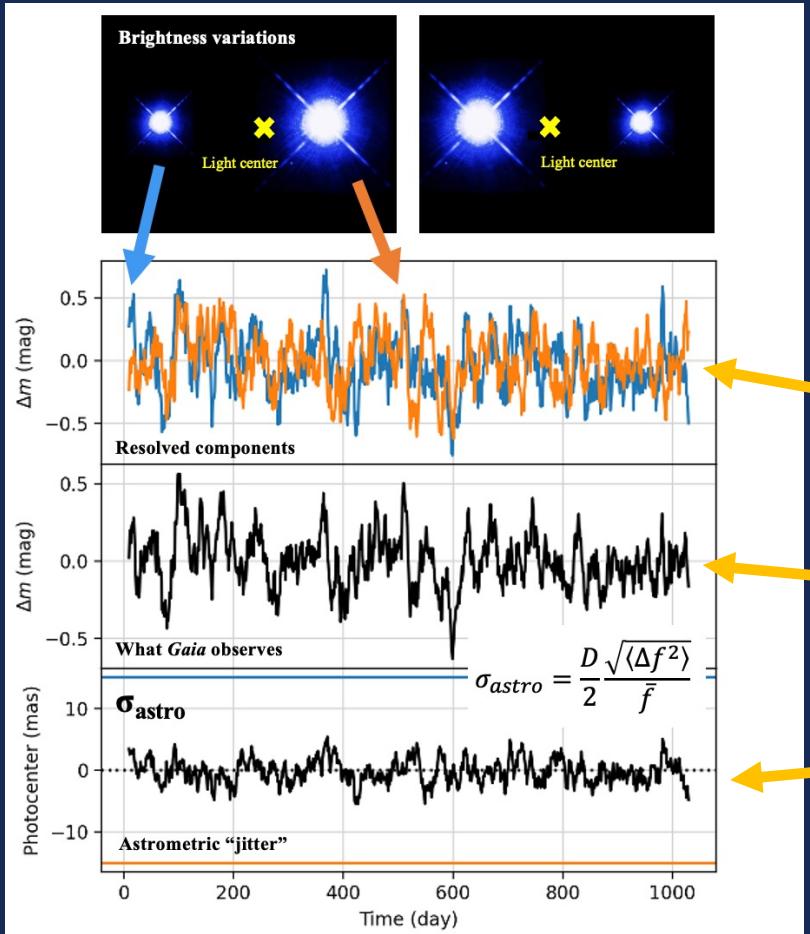


**AGN Pair Systems:**

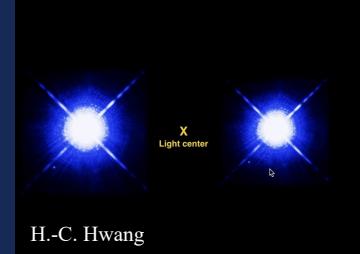
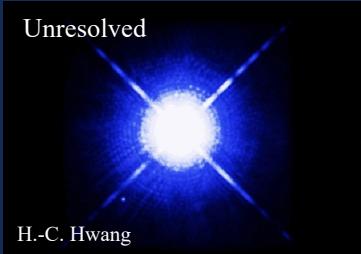
Only 40-50 confirmed...

Is there a systematic method that can be used for their detection?

**A new method pairs precise astrometric measurements with high-resolution radio observations.**



AGN pair, unresolvable with *Gaia*, light center appears to shift



If it was resolvable with *Gaia*, we might observe  
a lightcurve for both AGN

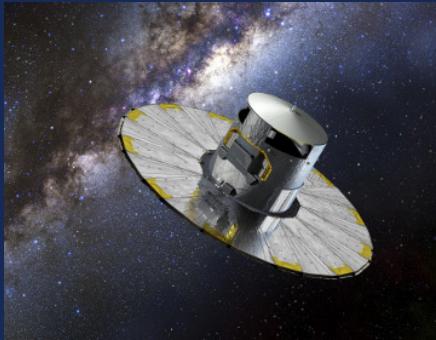
Instead, we see a joint-variability lightcurve,  
indistinguishable from a slightly variable single  
AGN

Shifting light center manifests in photometric  
data – excess “jitter” in astrometry

Variability + astrometry = varstrometry!

Hwang et al. 2019

# Radio Varstrometry



ESO/Gaia

+



NRAO/VLA

**VaDAR: Varstrometry for Dual AGN using Radio interferometry**

Combining high-resolution radio interferometry with high-precision astrometric variability measurements

**Is the VaDAR method a possible systematic method for future searches for multi-AGN?**

**Can this method produce a population of multi-AGN in a new redshift/separation regime?**

**What are the properties of the sample selected by VaDAR?**

# VLA Observations

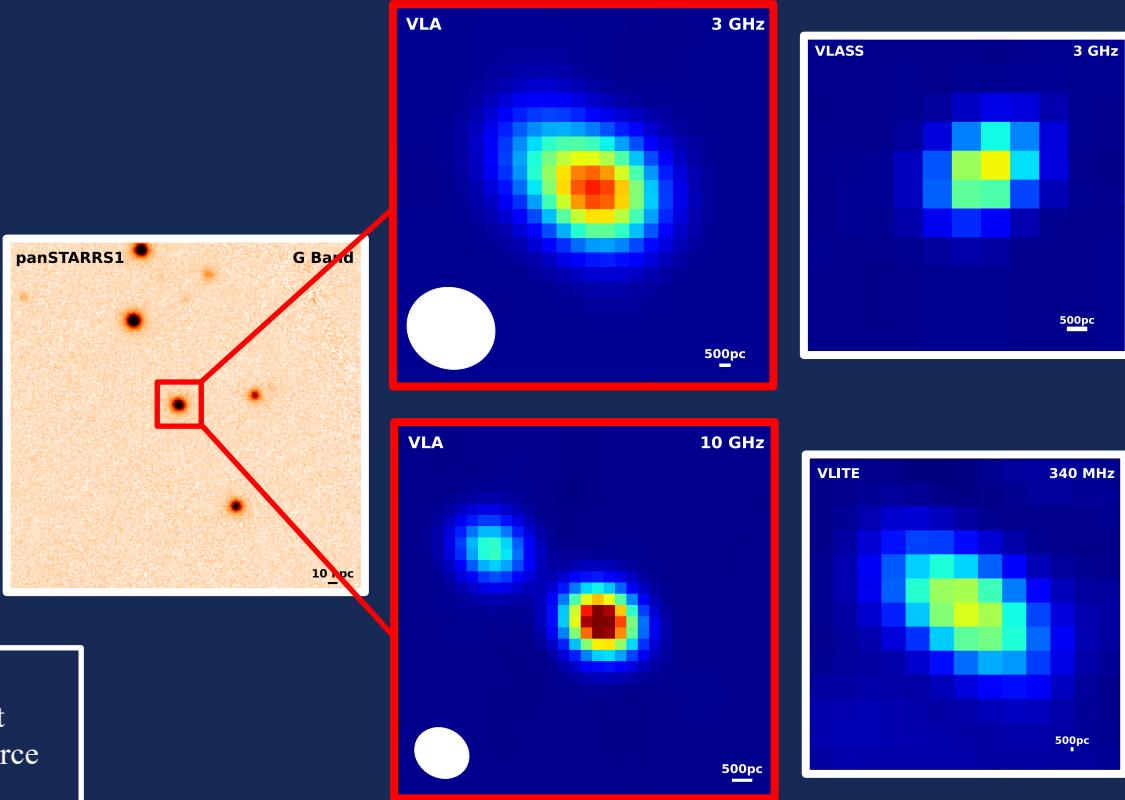
## Sample:

18 quasars (SDSS DRQ16), cross-matched  
with *Gaia* EDR3 (within 1.5'')  

- *astrometric\_excess\_noise\_sig* > 5
- $z > 0.5$
- *Gaia G* magnitude < 20  
= 148 QSO
- radio survey catalog fluxes  
- VLASS, VLITE, etc.  
= 18 QSO

## Observations:

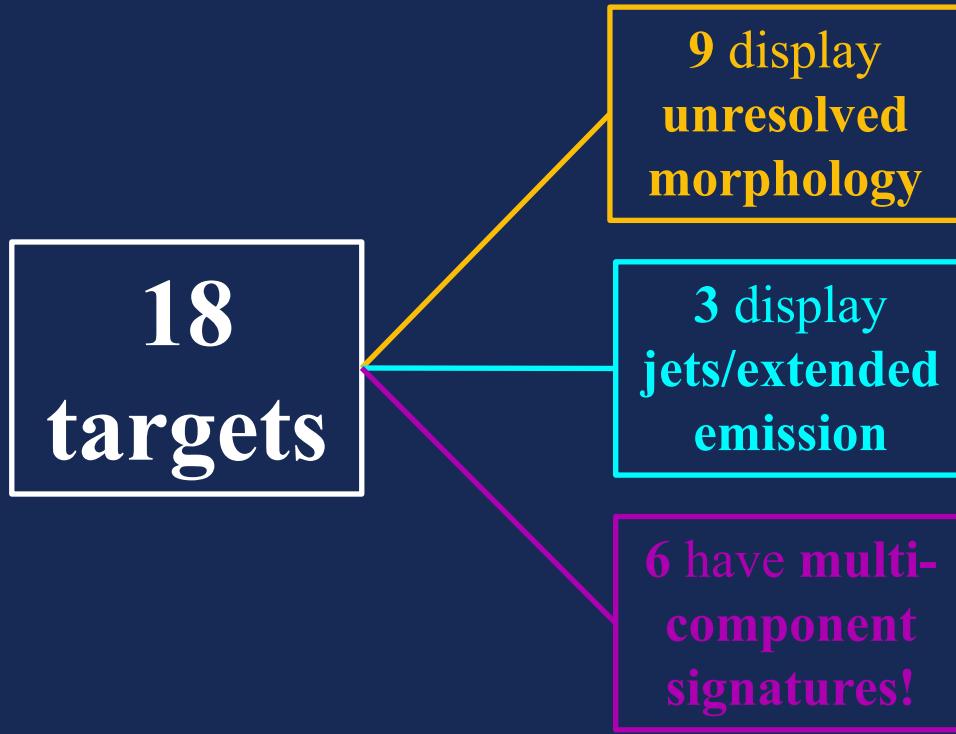
VLA – A configuration  
S-band (2-4 GHz, 0.65'', LAS 18'')  
X-band (8-12 GHz, 0.2'', LAS 5'')

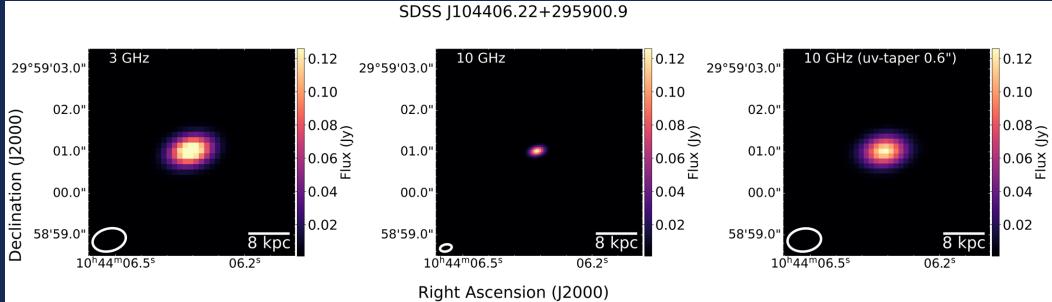


Schwartzman et al. in prep

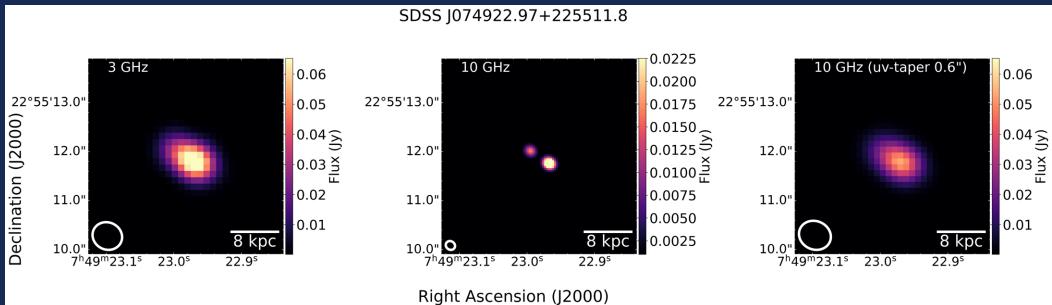
**Astrometric excess noise:** amount of statistical dispersion required such that *Gaia*'s astrometric solution for the source leaves no unexplained variance.

# Morphology Results:

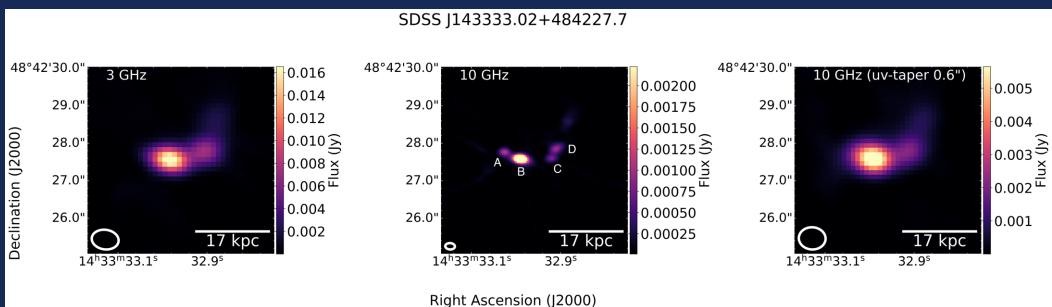




**9 display unresolved morphology**



**6 have multi-component signatures!**



**3 display jets/extended emission**

# Contaminant Results:

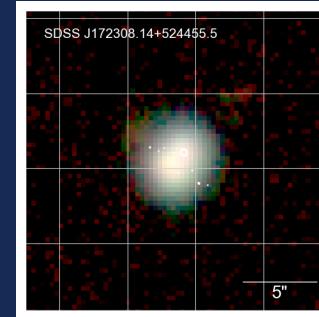
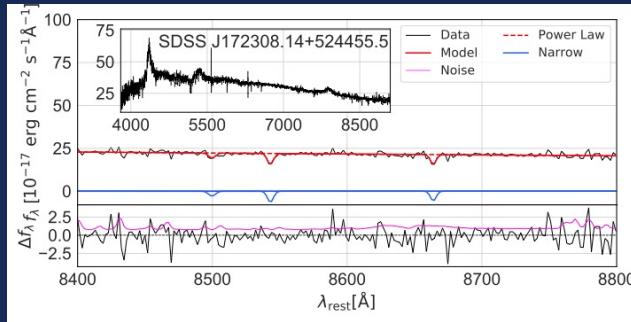
Contaminants?

18  
targets

9 display  
unresolved  
morphology

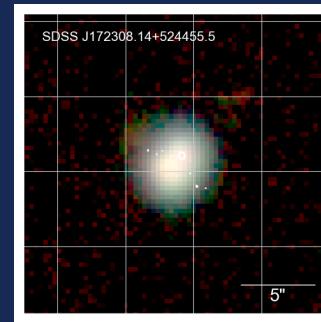
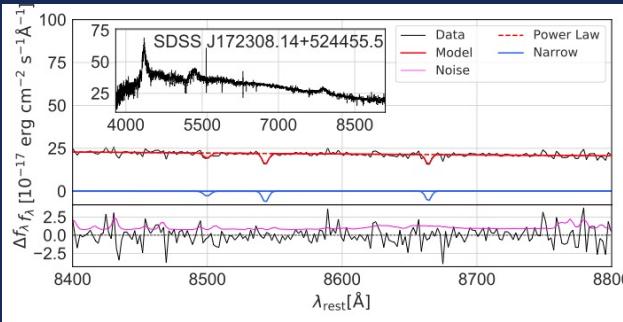
3 display  
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6 have multi-  
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# Contaminants:

## 4 Star+quasar superposition

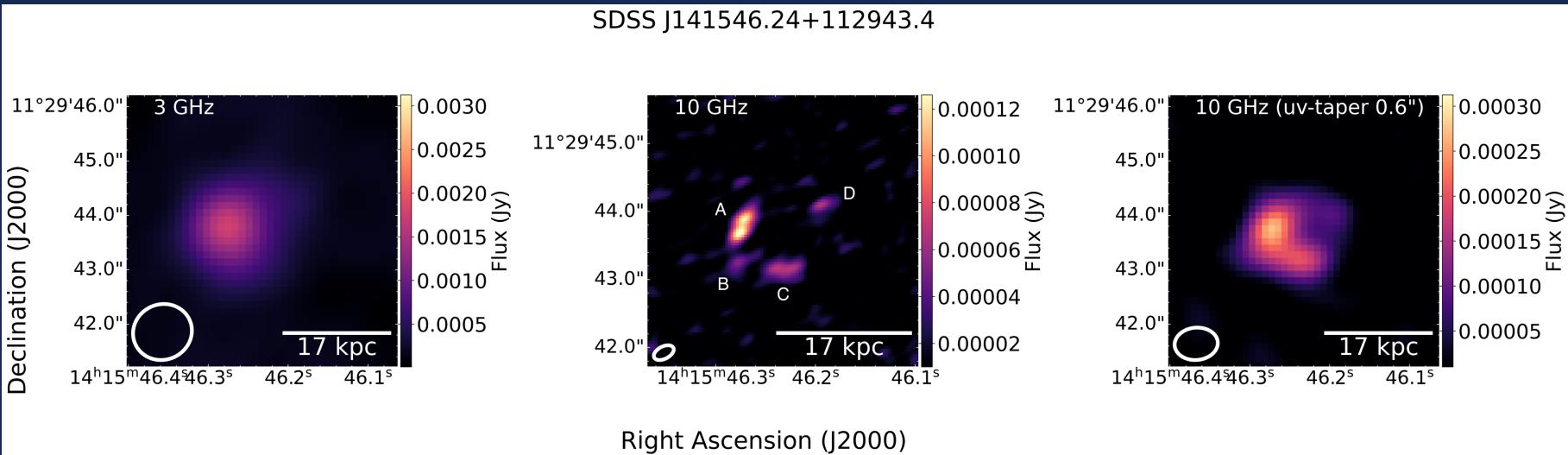


# Contaminants:

4 Star+quasar superposition

4 Gravitational lenses

SDSS J141546.24+112943.4



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# Contaminant Results:

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4 likely  
star+quasar  
superposition

4 identified as  
grav lenses

# Radio Spectra Results:

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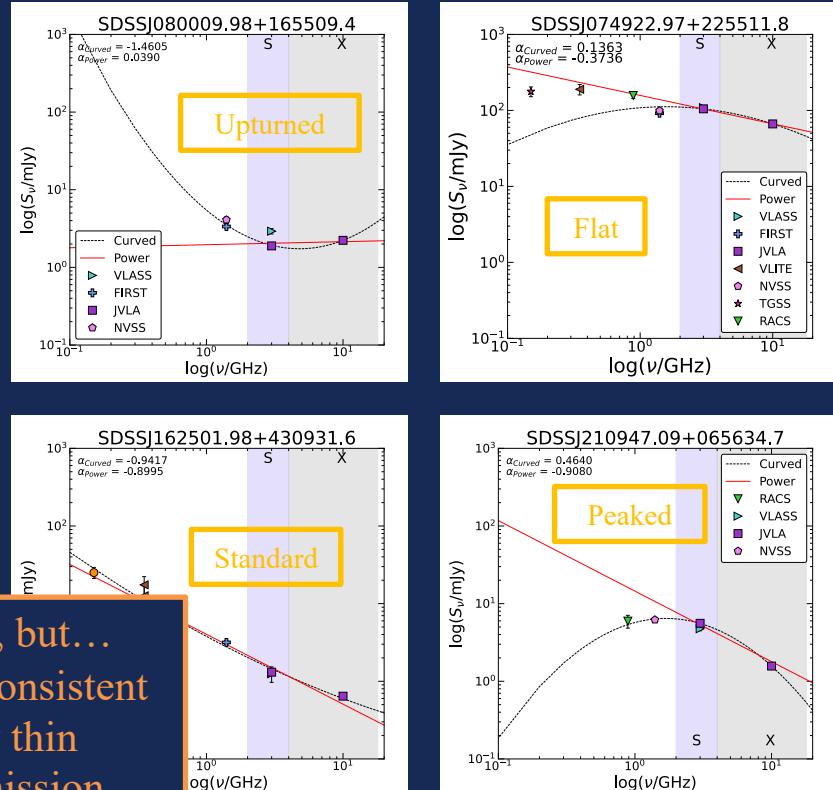
4 identified as  
grav lenses

Radio Spectral Fitting?

# Radio Spectra

- Considerable existing survey data:
  - VLASS, RACS, LOTSS, NVSS, FIRST, TGSS, VLITE, etc.
- Spectra fitted with standard and curved power laws
  - Pallavi Patil's *radio\_spectral\_fitting* code (Patil+22)
- Spectral shapes classified:
  - Standard Power Law: 4
  - Curved Power Law: 5
  - Peaked: 2
  - Flat: 3
  - Upturned: 4
  - Inverted: 0

Diverse sample, but...  
Spectral indices consistent  
with optically thin  
synchrotron emission



# Radio Spectra Results:

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# Overall Sample Results:

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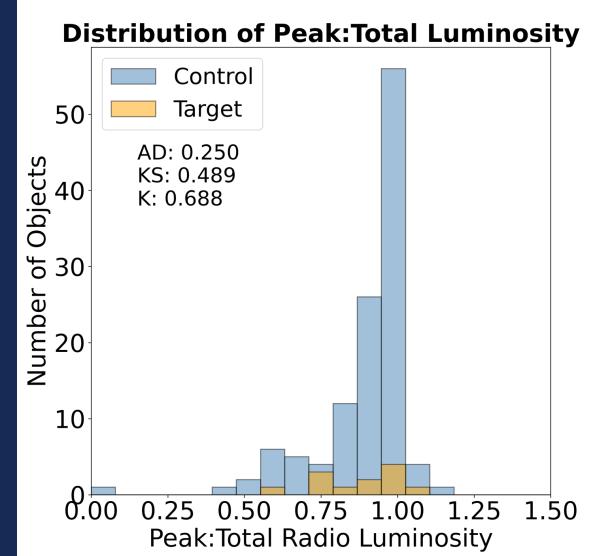
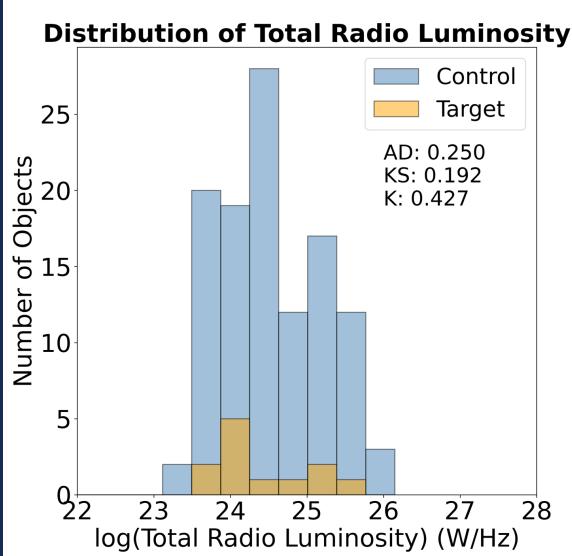
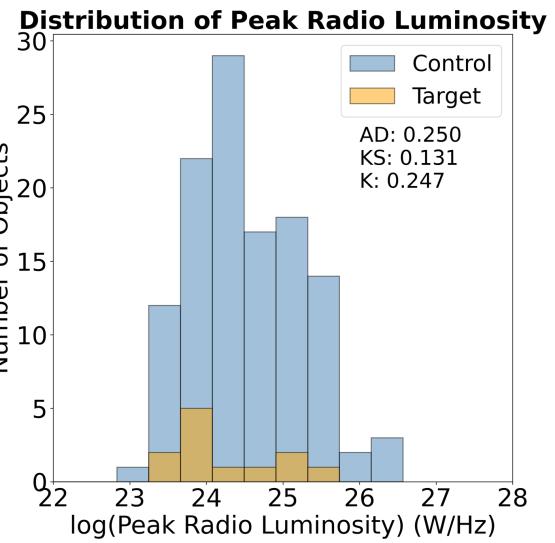
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Overall Sample?



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Targets: 12 objects with **AENS > 5**, G mag < 20, z > 0.5

Controls: 120 objects with **AENS < 4**, G mag < 20, z > 0.5

i.e., no significant astrometric variability

Matched to targets based on sky coverage

Overall target sample is not significantly radio loud, in comparison to matched controls

# Overall Sample Results:

18  
targets

9 display  
**unresolved  
morphology**

3 display  
**jets/extended  
emission**

6 have **multi-  
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signatures!**

- 4 likely star+quasar superposition
- 4 identified as grav lenses
- Spectral indices consistent with optically thin synchrotron emission
- Overall target sample is not significantly radio loud, in comparison to matched controls

# Overall Sample Results:

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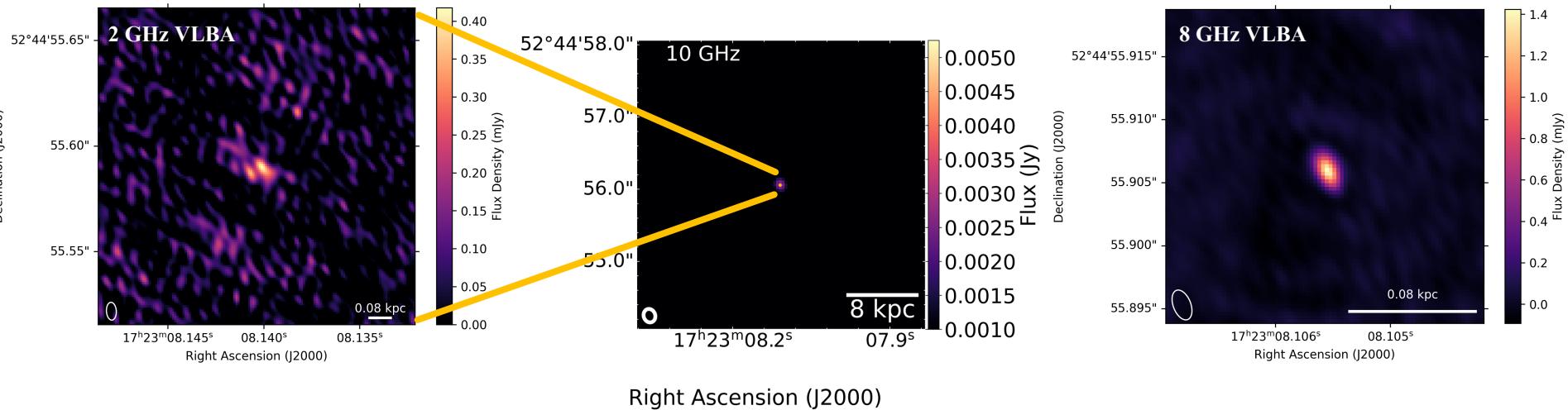
Spectral indices consistent  
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synchrotron emission

Overall target sample is not  
significantly radio loud, in  
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7 selected for  
VLBA follow-up

Preliminary results: calibration and imaging in progress, work done by **Paula Fudolig**, a first-year graduate student at GMU

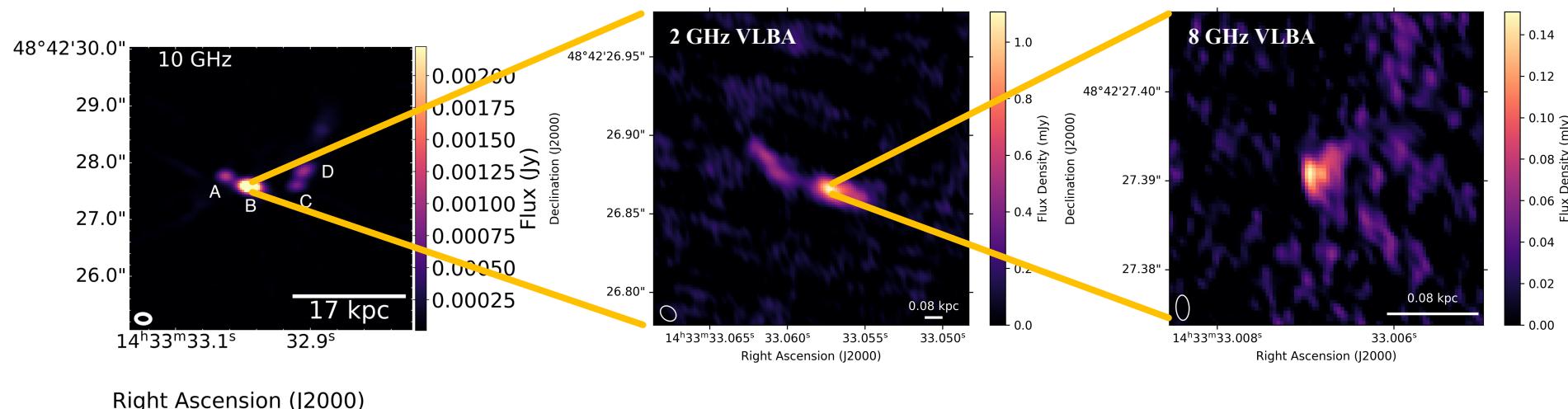
SDSS J172308.14+524455.5



Schwartzman et al. 2024

Preliminary results: calibration and imaging in progress, work done by **Paula Fudolig**, a first-year graduate student at GMU

SDSS J143333.02+484227.7



Right Ascension (J2000)

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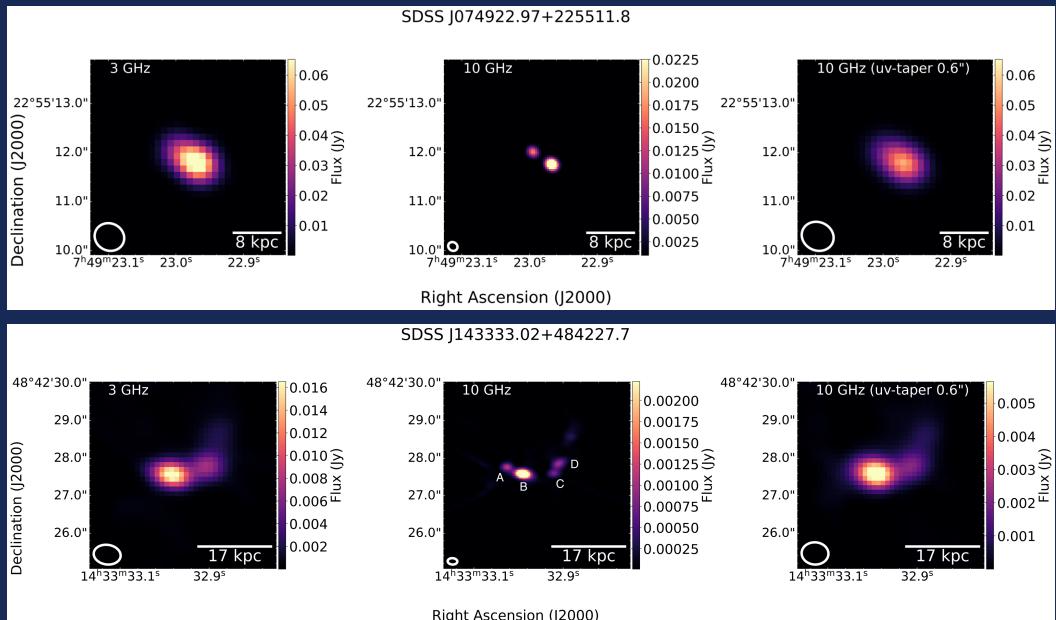
# Conclusions

## - VLA:

- Diverse sample, ~40% identified as dual or lensed quasars
- Optical/more radio follow-up proposals planned
- Sample still yet to be fully constrained

## - VLBA:

- Calibration and imaging still in progress
- Interesting early results!
- Look for paper in 2024



Questions?