



# The Properties and Morphology of Highly Ionized Coronal Line Outflows in Nearby Jetted AGN

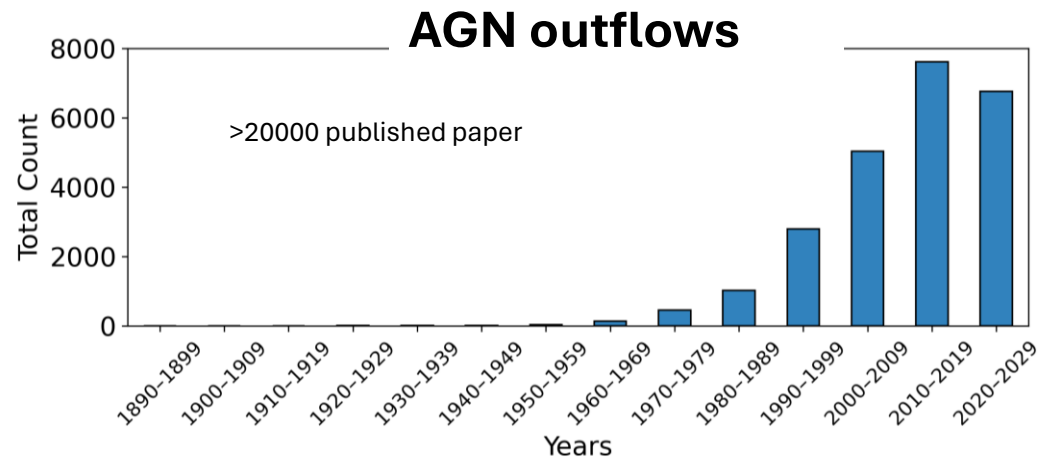
Payel Nandi

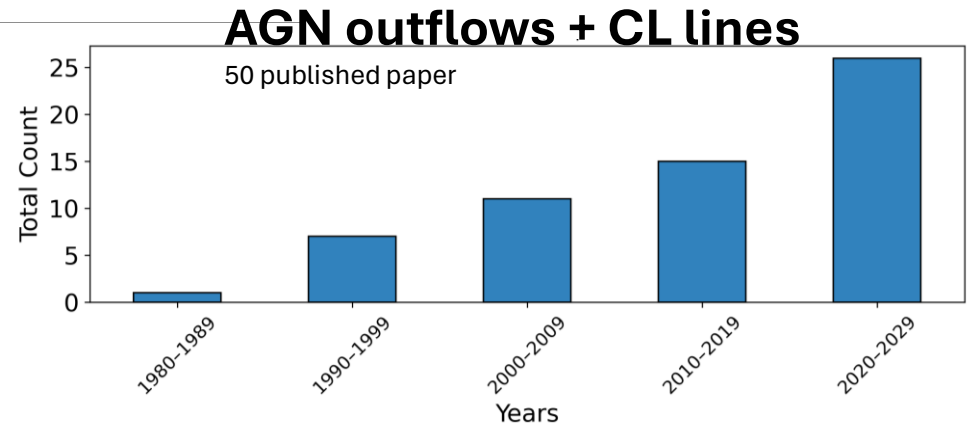
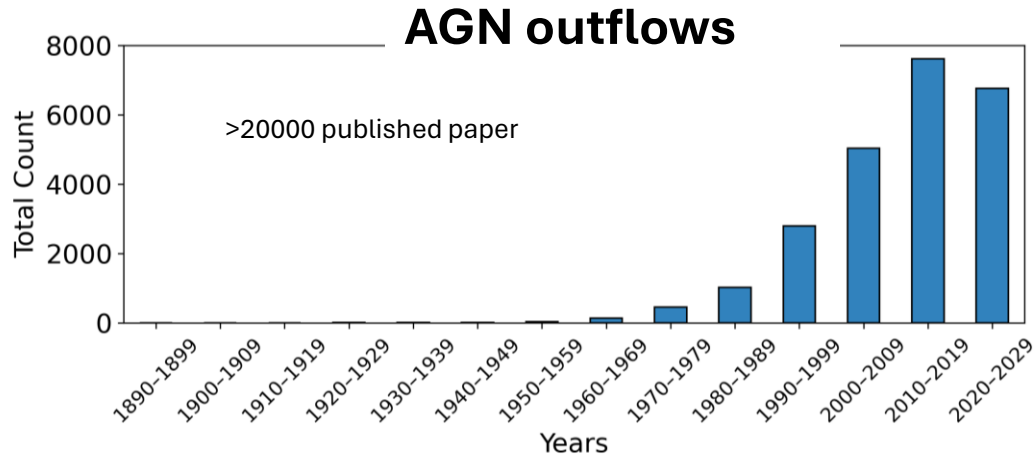
Humboldt Fellow

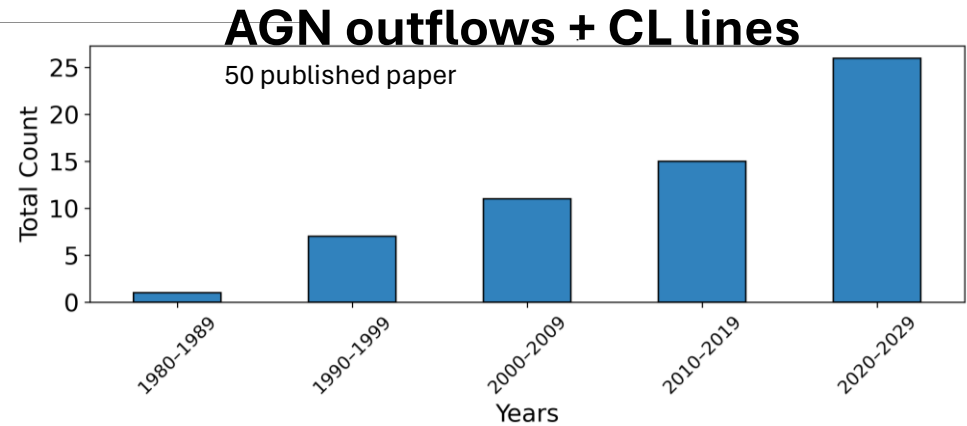
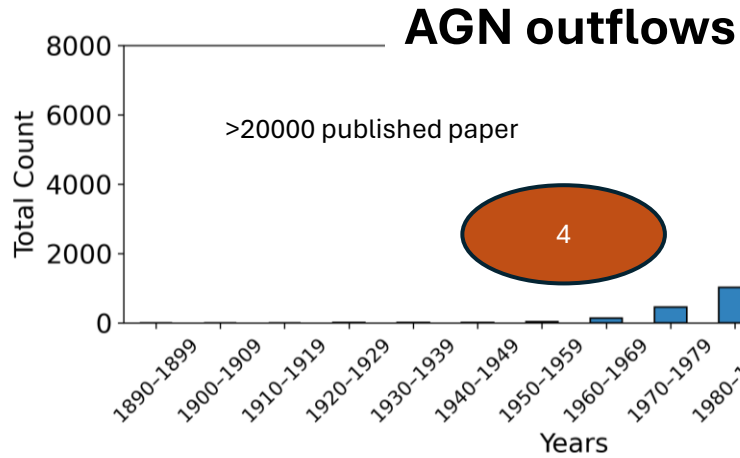
European Southern Observatory, Garching

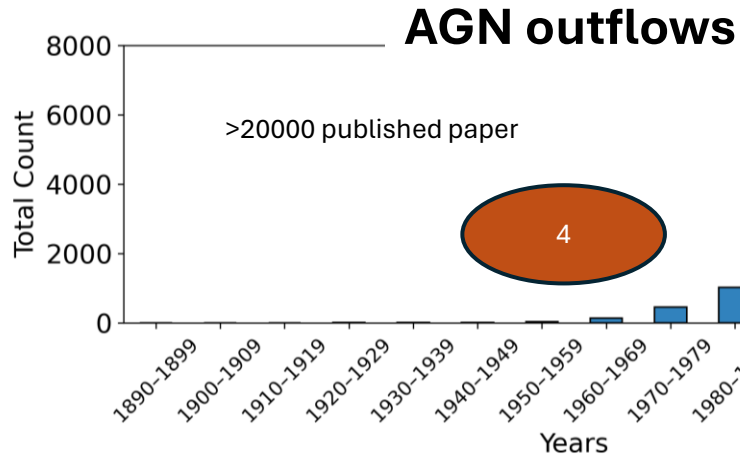
| Waveband    | Species            | Wavelength ( $\lambda$ ) | IP            | Critical Density ( $n_{\text{crit}}$ )    |
|-------------|--------------------|--------------------------|---------------|-------------------------------------------|
| Optical     | [Ne V]             | 3426 Å                   | 97.1 eV       | $\sim 1.6 \times 10^7 \text{ cm}^{-3}$    |
| Optical     | [Fe VII]           | 6087 Å                   | 99.1 eV       | $\sim 3.0 \times 10^7 \text{ cm}^{-3}$    |
| Optical     | [Fe X]             | 6374 Å                   | 233.6 eV      | $\sim 5.0 \times 10^9 \text{ cm}^{-3}$    |
| Optical     | [Fe XI]            | 7892 Å                   | 262.1 eV      | $\sim 1.1 \times 10^{10} \text{ cm}^{-3}$ |
| Optical     | [Fe XIV]           | 5303 Å                   | 361.0 eV      | $\sim 2.0 \times 10^{10} \text{ cm}^{-3}$ |
| Near-IR     | [Si X]             | 1.430 $\mu\text{m}$      | 351.1 eV      | $\sim 4.0 \times 10^8 \text{ cm}^{-3}$    |
| Near-IR     | [Si VI]            | 1.963 $\mu\text{m}$      | 166.8 eV      | $\sim 6.0 \times 10^8 \text{ cm}^{-3}$    |
| Near-IR     | [Fe XI]            | 1.987 $\mu\text{m}$      | 262.1 eV      | $\sim 2.0 \times 10^9 \text{ cm}^{-3}$    |
| Near-IR     | [Al IX]            | 2.040 $\mu\text{m}$      | 284.7 eV      | $\sim 1.5 \times 10^9 \text{ cm}^{-3}$    |
| Mid-IR      | [Mg VIII]          | 3.028 $\mu\text{m}$      | 224.9 eV      | $\sim 8.0 \times 10^7 \text{ cm}^{-3}$    |
| Mid-IR      | [Si IX]            | 3.935 $\mu\text{m}$      | 303.2 eV      | $\sim 2.0 \times 10^8 \text{ cm}^{-3}$    |
| Mid-IR      | [Ne VI]            | 7.652 $\mu\text{m}$      | 126.2 eV      | $\sim 3.5 \times 10^5 \text{ cm}^{-3}$    |
| X-ray / EUV | O VII Triplet      | 21.6 – 22.1 Å            | 138.1 eV      | --                                        |
| X-ray / EUV | Ne IX Triplet      | 13.4 – 13.7 Å            | 239.1 eV      | --                                        |
| X-ray       | Fe XVII            | 15.01 Å, 17.05 Å         | 489.1 eV      | --                                        |
| X-ray       | Fe XVIII – Fe XXIV | 10.0 – 14.0 Å            | 1.3 – 2.0 keV | --                                        |

[OIII]: 35 eV – mostly studied outflows

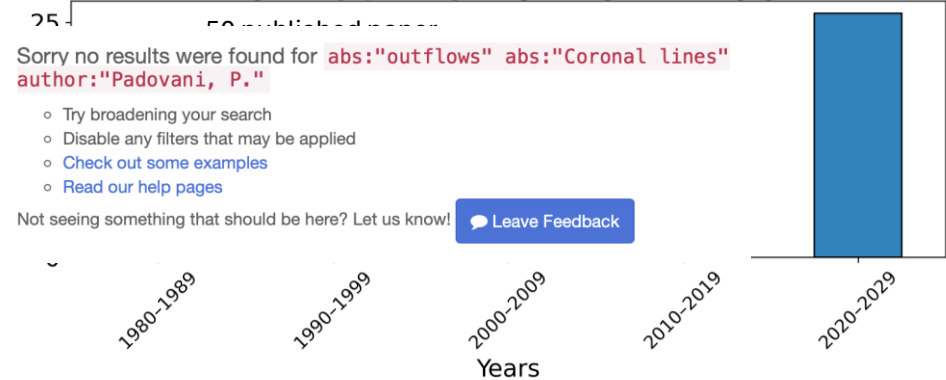




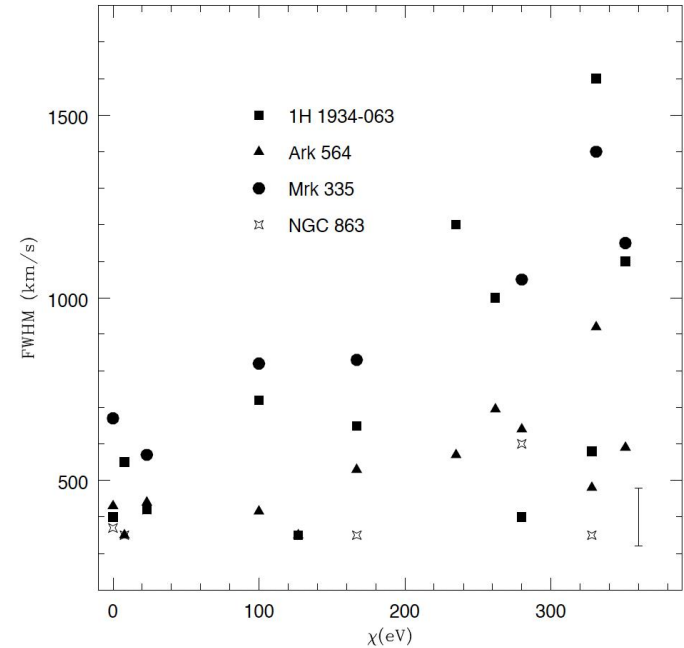




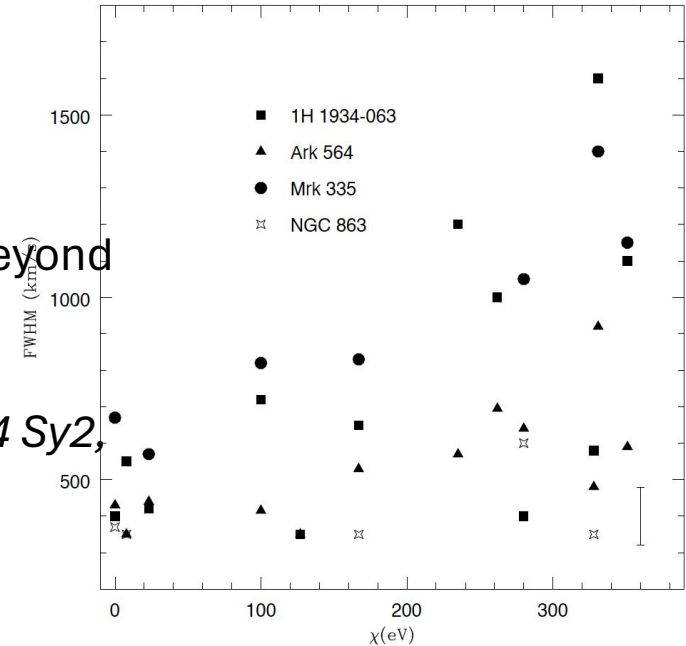
## AGN outflows + CL lines



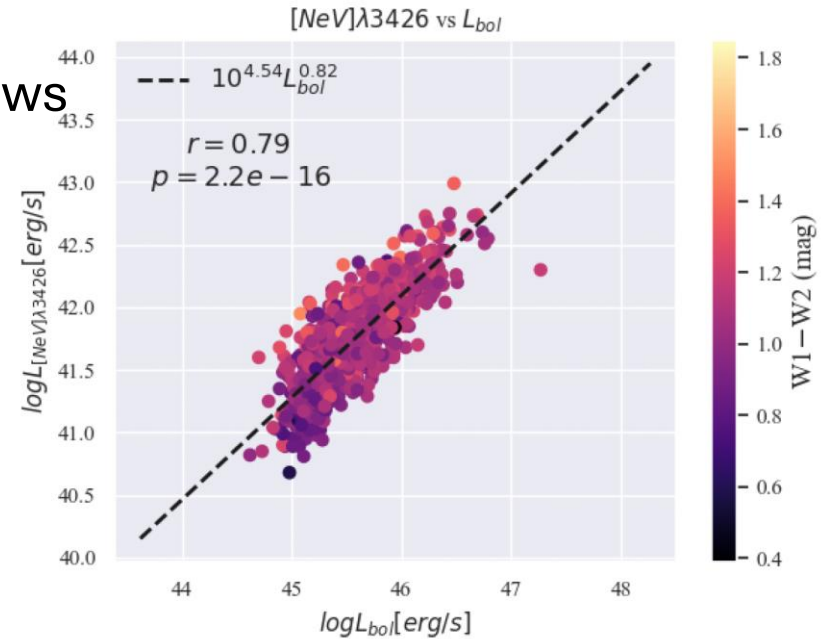
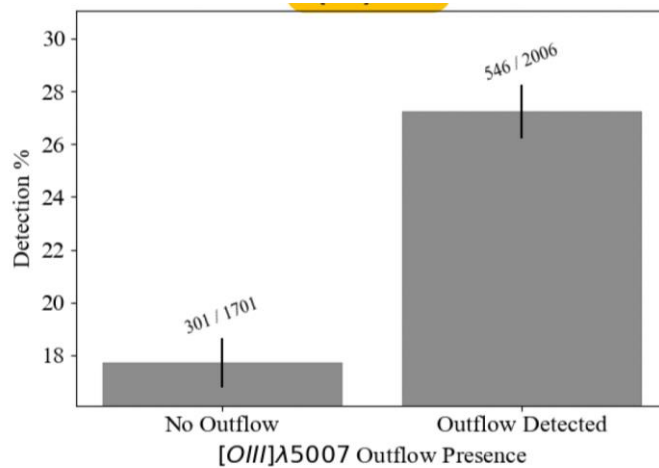
- **Rodríguez-Ardila et al. 2002 — 5 Sy1**
- systematic blueshifts
- prominent blue wings
- broader profiles than low-ionization lines,
- radially expanding, conical outflowing winds beyond the unresolved BLR–torus boundary.



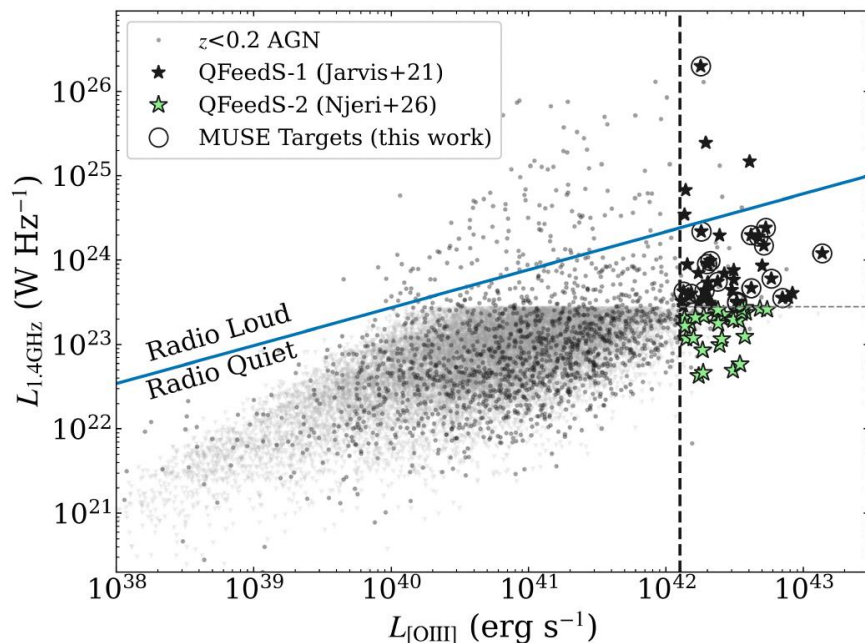
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- **Rodríguez-Ardila et al. 2006 — 6 AGN (2 Sy1, 4 Sy2, incl. NGC 1068 & Circinus)**
- 10s pc to 100s pc
- with double peaks and elevated  $\sigma$
- **AGN photoionization + fast radiative shocks**  
( $v_{\text{shock}} \geq 300 \text{ km s}^{-1}$ )



- The CLASS Quasar Catalog: Coronal Line Activity in **Type 1 SDSS Quasars**, Doan et al. 2025
- CL detection only 5%
- CL Quasars have more [OIII] outflows



# Qfeed survey : Jarvis et al 2021



PI: Chris Harrison

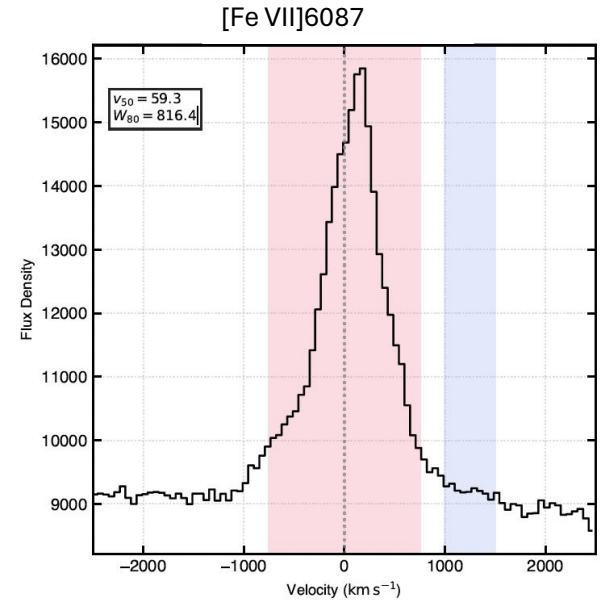
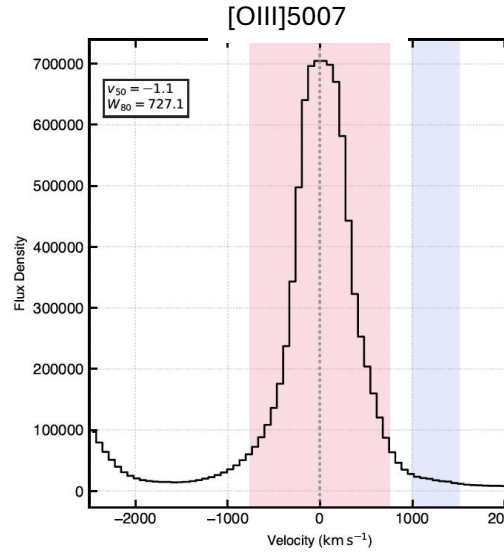
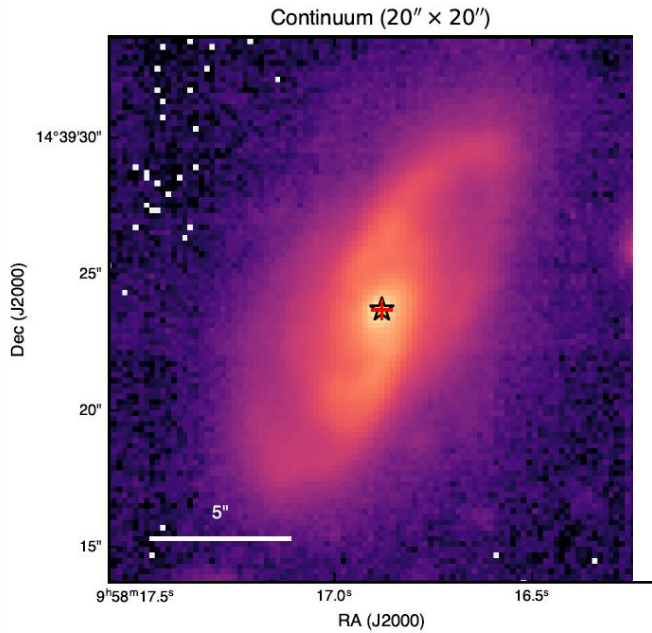
$z < 0.2$ , 25 type2, 17 type1

18 type 2 (Radio quiet) VLT/MUSE

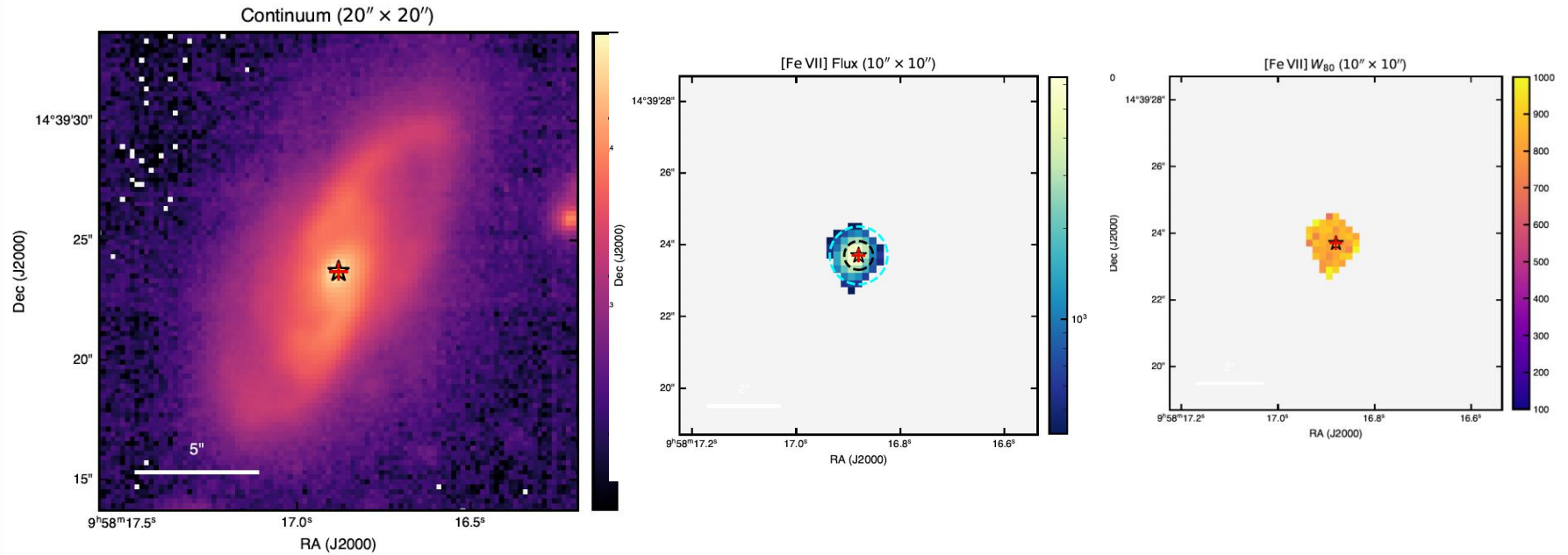
CL lines detection: 70-80% ( $>5\sigma$ )

[OIII] & [Fe VII]

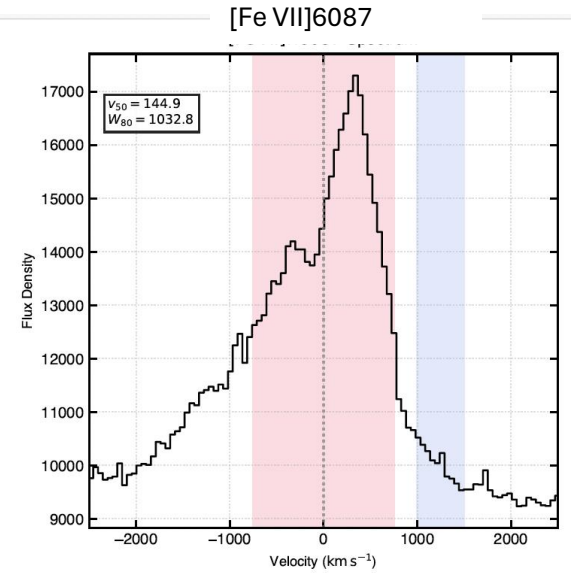
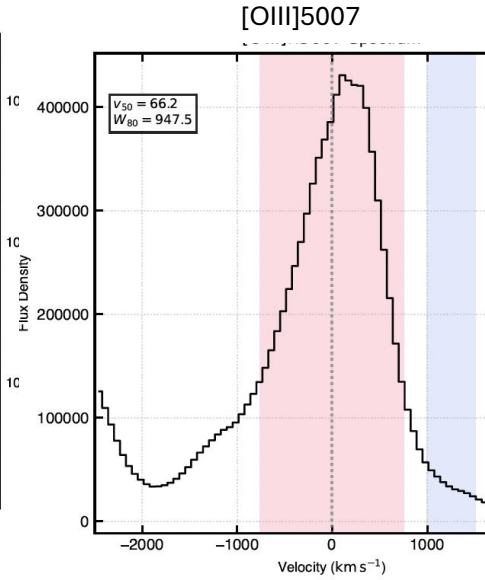
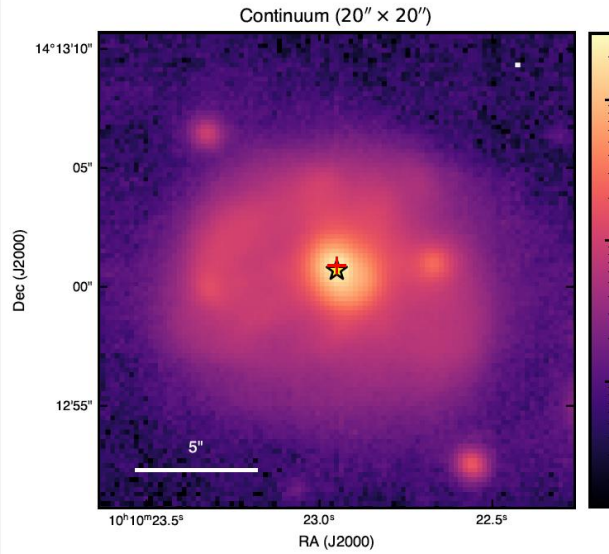
# Preliminary



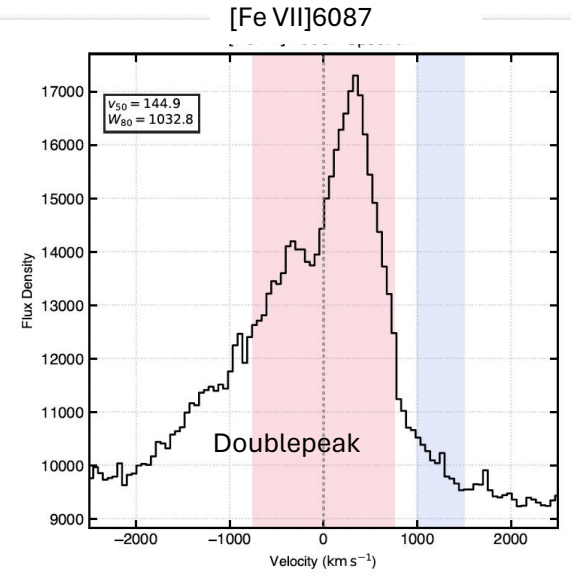
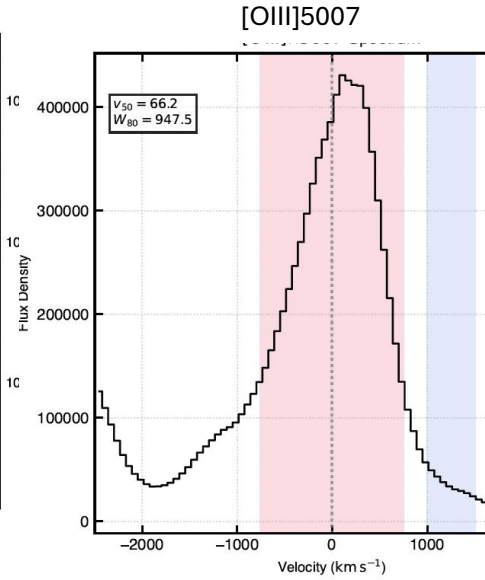
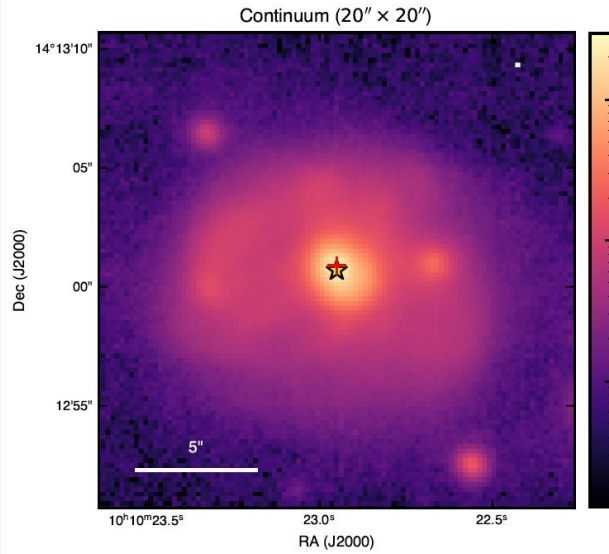
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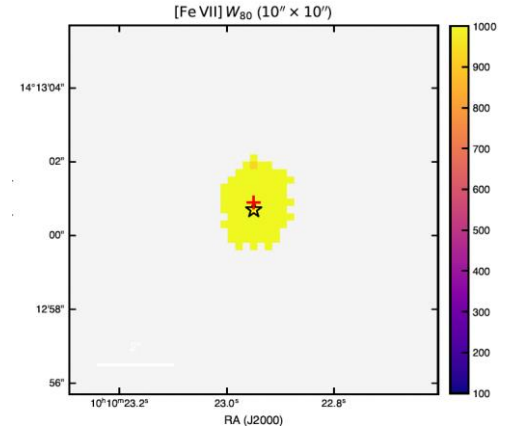
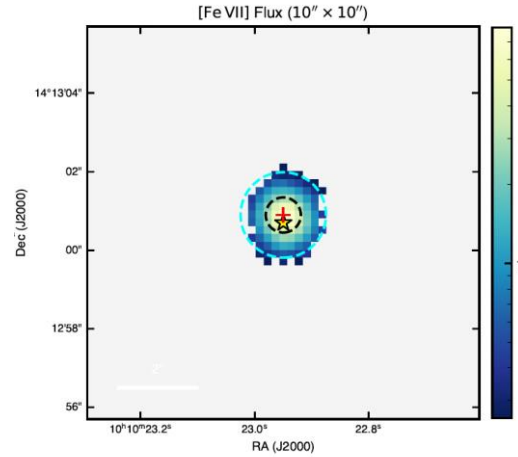
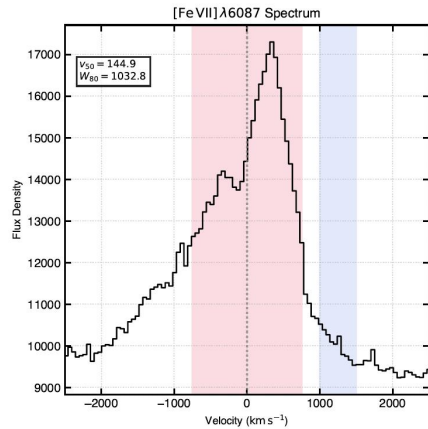
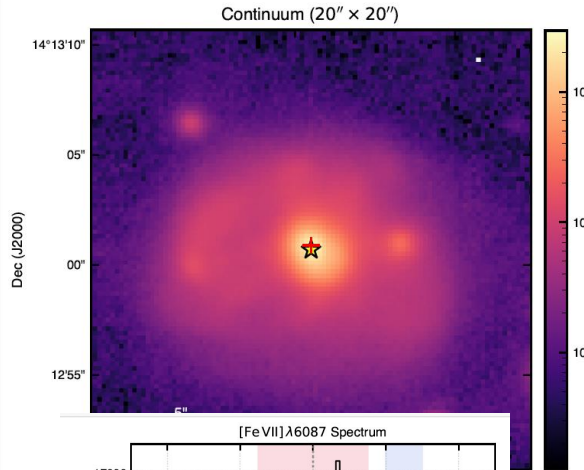
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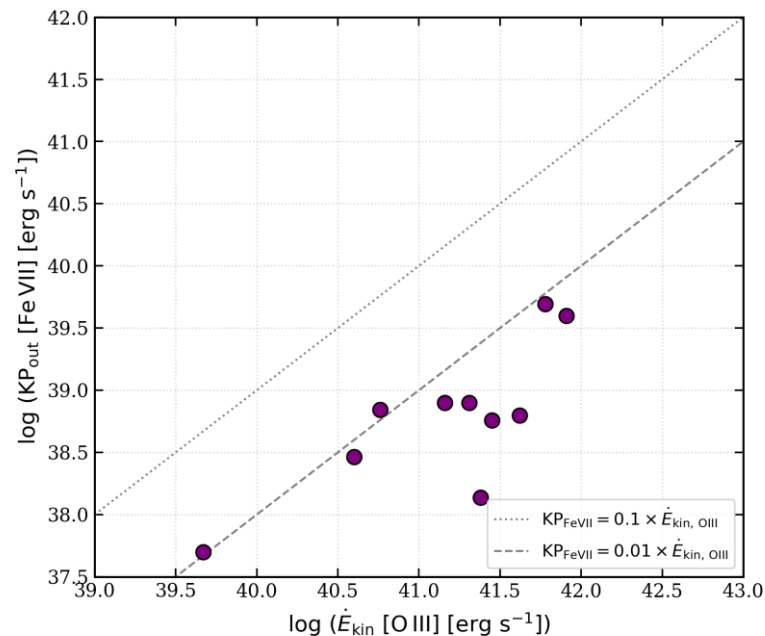
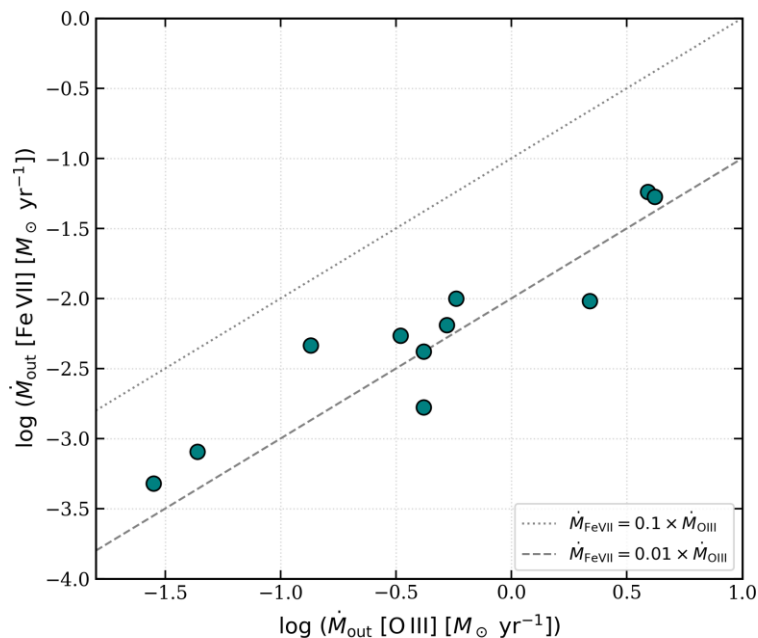
Preliminary



Whole CLR region is kinematically disturbed  
200 pc – 5kpc extended

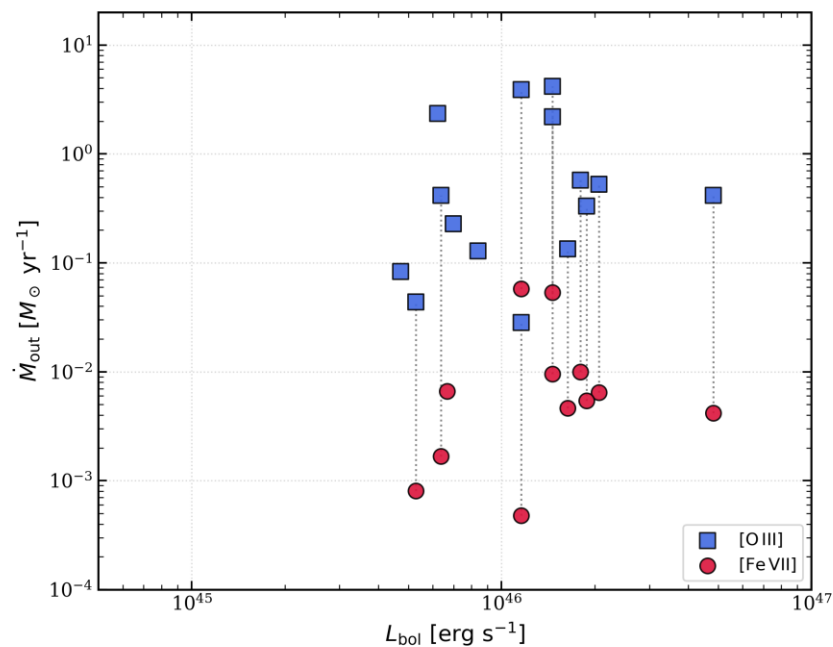
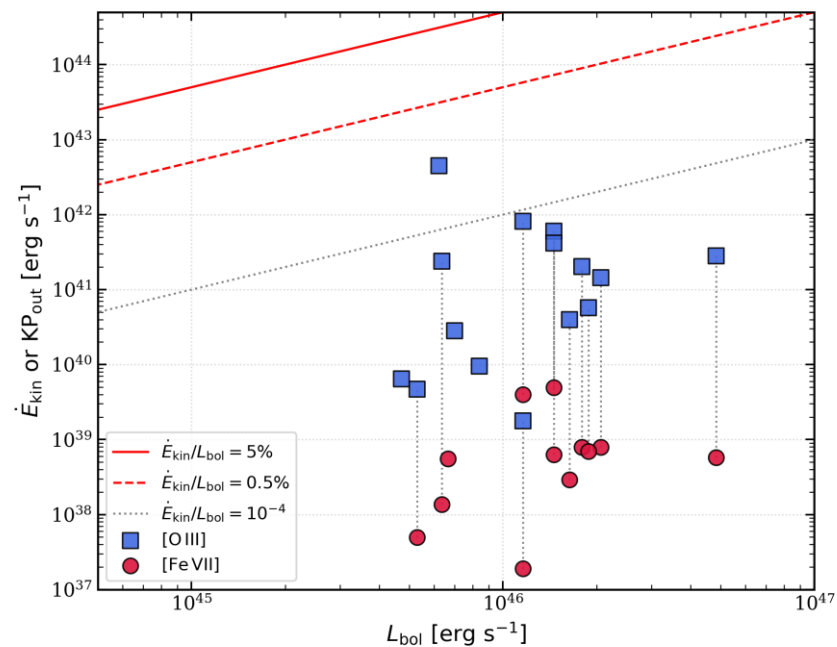
# CL outflows vs OIII based outflows

Preliminary



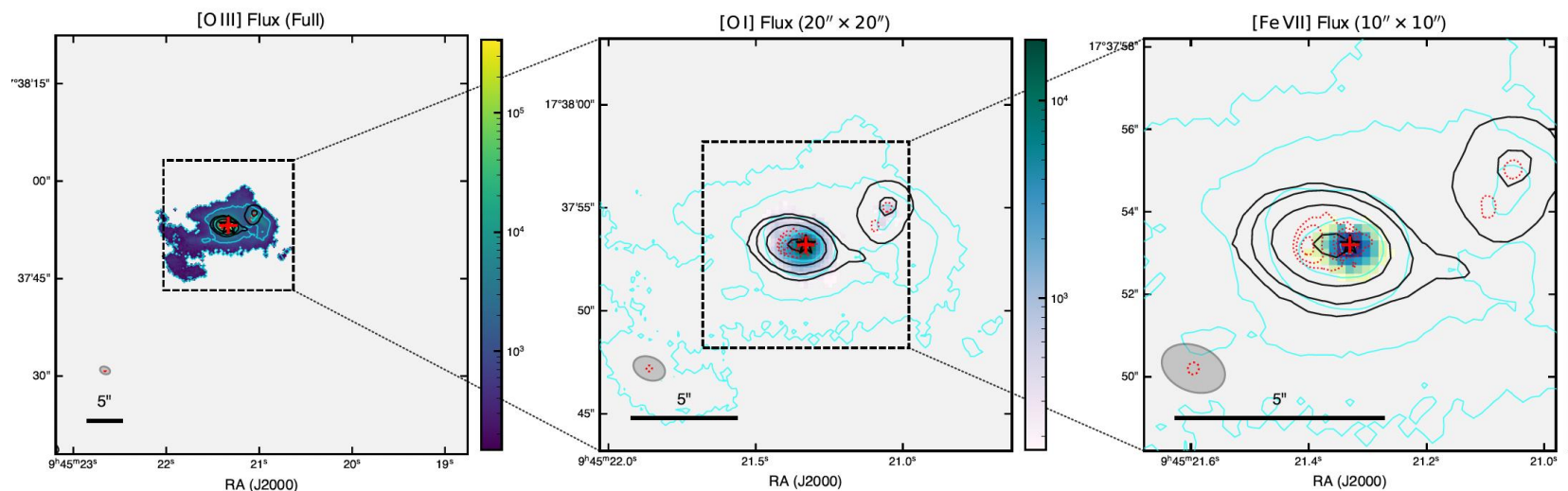
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Preliminary



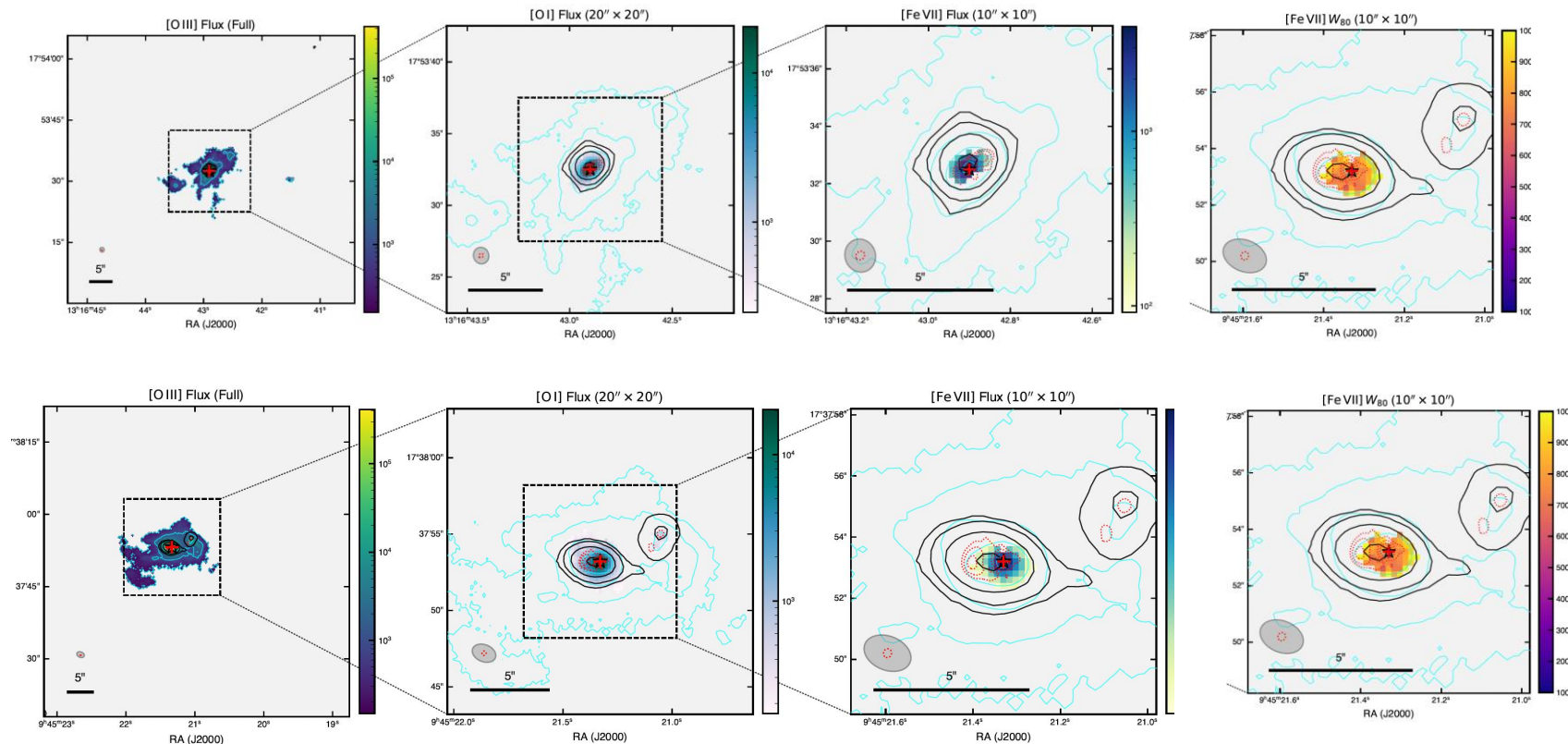
# Connection with radio jet

Preliminary



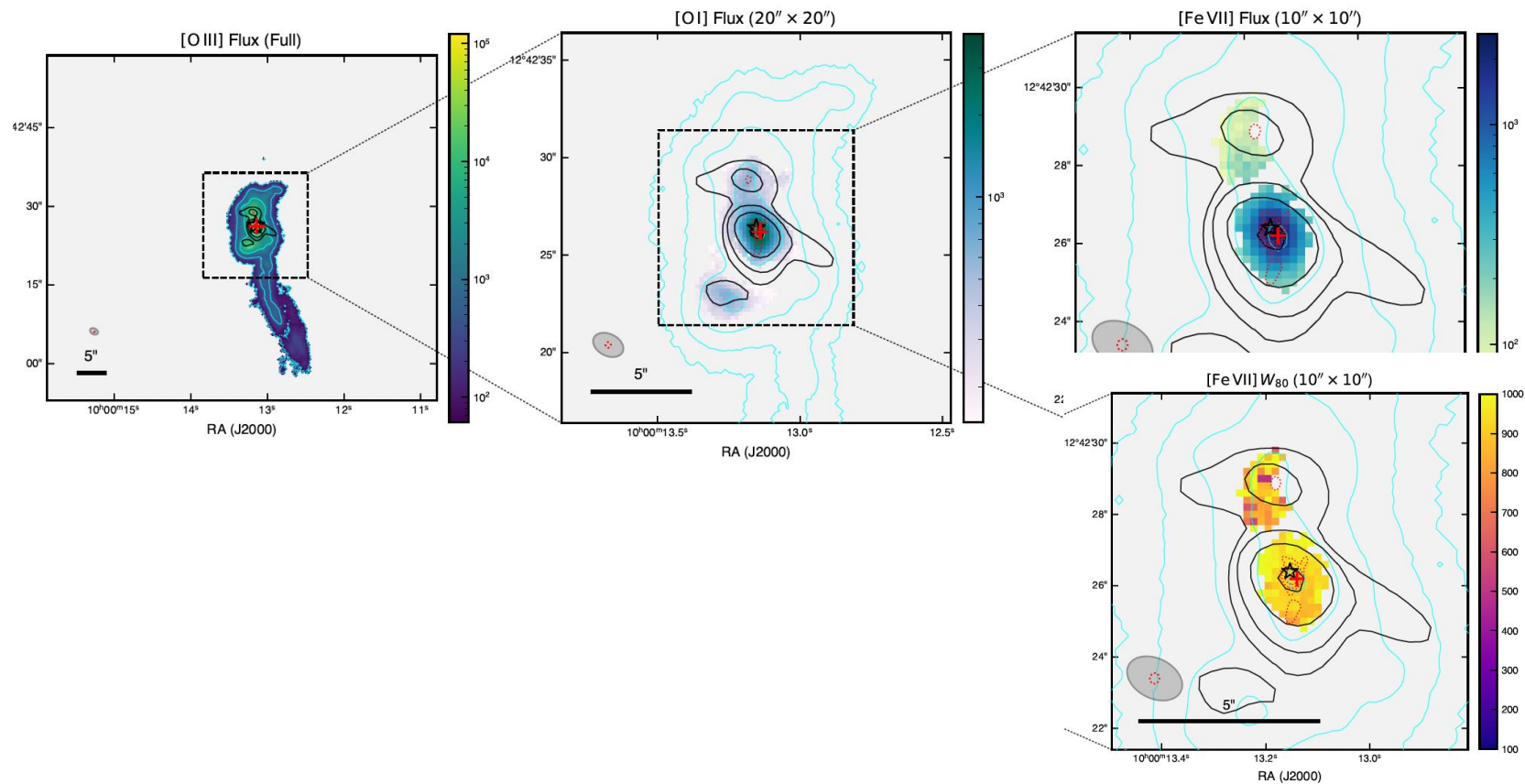
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Preliminary



# Connection with radio jet

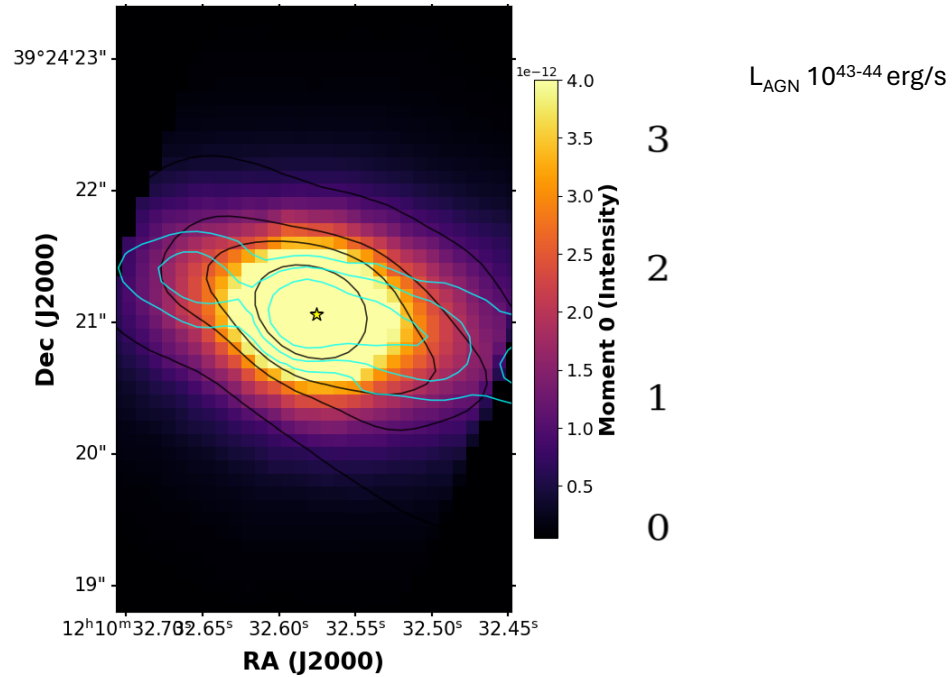
Preliminary



# Connection with radio jet

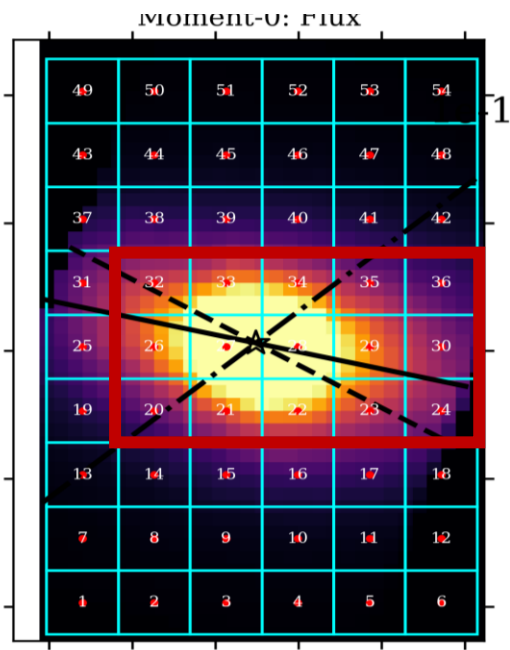
## NGC 4151 (Sy1)

Preliminary



# Connection with radio jet

Preliminary



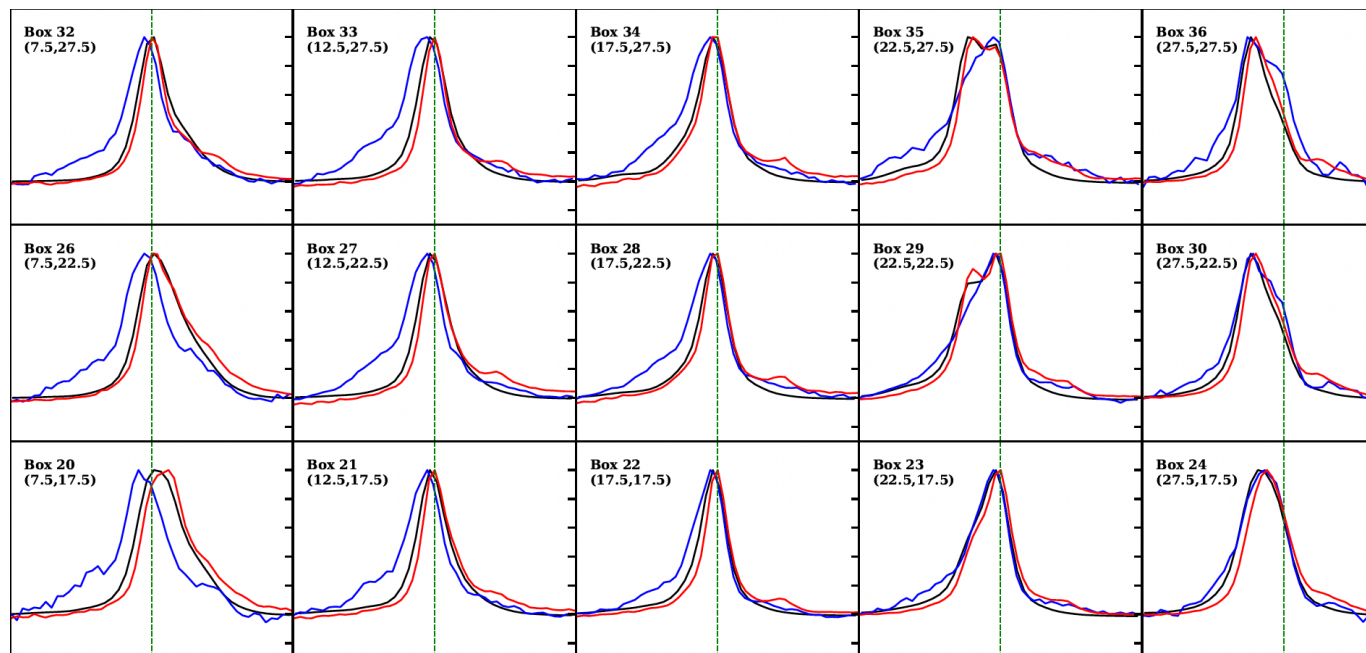
■ Jet (--)

■ NLR (-)

[Fe VII]- blue

[OIII] - black

[OI]- red

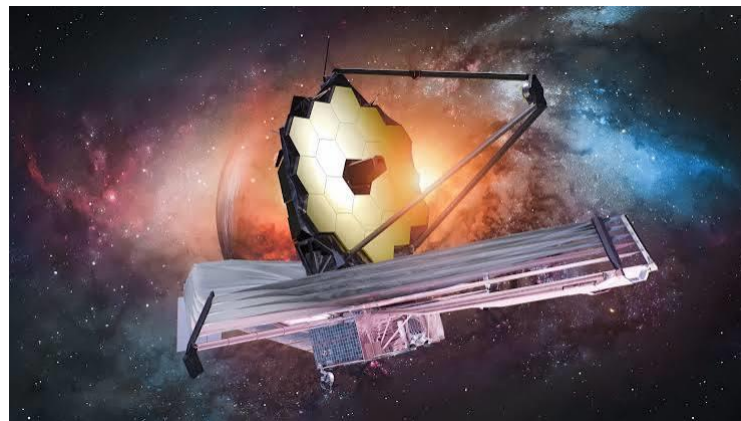


# Dwarf AGN

- Aravindan et al. 2026
- NIRSspec IFU

| Log( $M_{\text{BH}}/M_{\odot}$ )<br>(5) | Log[ $L(\text{AGN})$ ]<br>( $\text{erg s}^{-1}$ )<br>(6) |
|-----------------------------------------|----------------------------------------------------------|
| $5.8 \pm 0.5$ (i)                       | $43.1 \pm 0.4$                                           |
| $5.4 \pm 0.3$ (ii)                      | $43.7 \pm 0.8$                                           |
| $5.0 \pm 0.4$ (ii)                      | $43.9 \pm 1.1$                                           |
| $5.1 \pm 0.1$ (iii)                     | $43.0 \pm 1.0$                                           |

- 50-350 pc
- FWHM 100-500 km/s
- Mostly AGN photoionization



Nandi et al. 2026

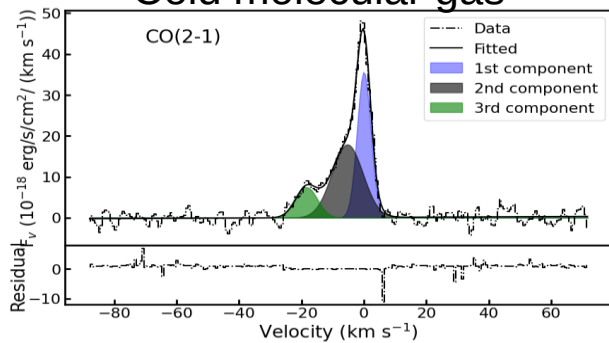
NGC 4395 (*Nandi et al. 2023a, 2023b*)

$L_{\text{AGN}} \sim 10^{41} \text{ erg s}^{-1}$

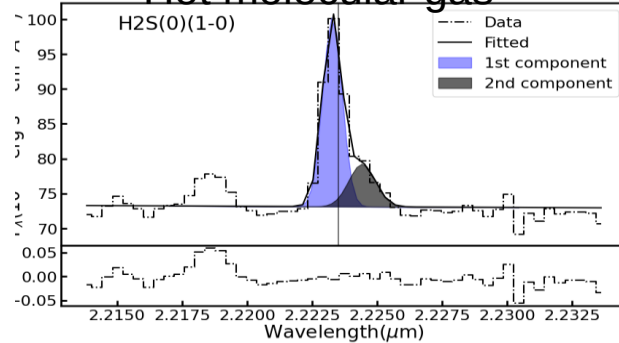
$M_{\text{BH}} \sim 10^4 M_{\odot}$

Radio jet  $\sim 10 \text{ pc}, 10^{40} \text{ erg s}^{-1}$

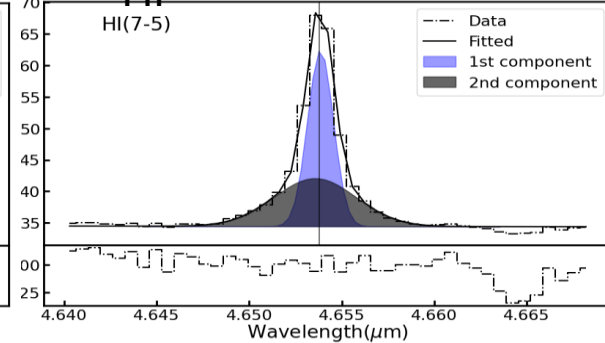
## Cold molecular gas



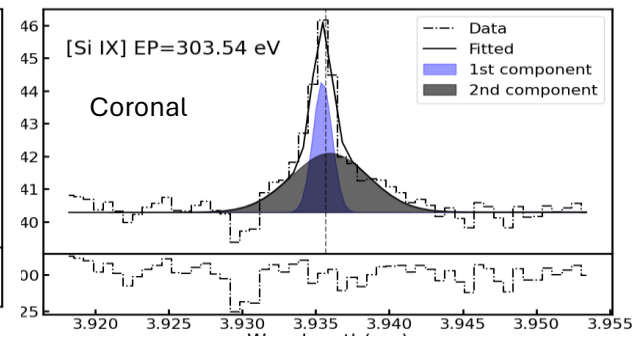
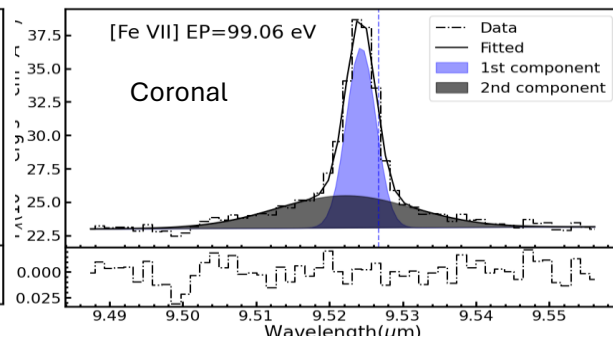
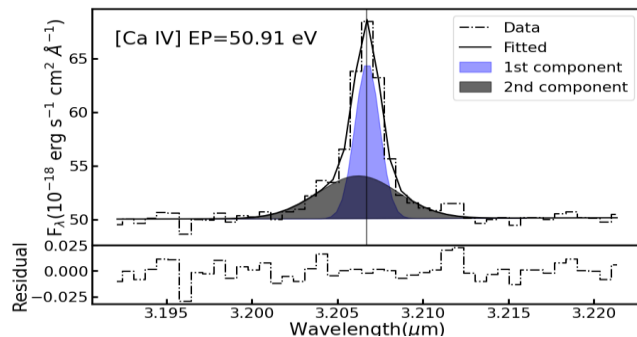
## Hot molecular gas



## HI



## Ionized gas (IP ----->>)



## Ionized outflows : 36 phases

Nandi et al. 2026, ApJ, 1001, 226

# Density

$n_e(15000\text{K}): 1800 \text{ cm}^{-3}$  [SII] ratio

| Lines                                         | $n_e$ (10000K)<br>( $10^4 \text{ cm}^{-3}$ ) | $n_e$ (20000 K)<br>( $10^4 \text{ cm}^{-3}$ ) | $n_e$ (30000 K)<br>( $10^4 \text{ cm}^{-3}$ ) | $n_e$ (50000 K)<br>( $10^4 \text{ cm}^{-3}$ ) |
|-----------------------------------------------|----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| [FeII]4.89/[FeII]5.34 (total)                 | $0.50 \pm 0.04$                              | $0.65 \pm 0.06$                               | $0.71 \pm 0.06$                               | $0.82 \pm 0.06$                               |
| [FeII]4.89/[FeII]5.34 (narrow)                | $0.27 \pm 0.02$                              | $0.34 \pm 0.03$                               | $0.37 \pm 0.04$                               | $0.43 \pm 0.04$                               |
| [FeII]4.89/[FeII]5.34 (outflow)               | $2.58 \pm 0.22$                              | $3.34 \pm 0.31$                               | $3.65 \pm 0.34$                               | $4.25 \pm 0.04$                               |
| [NeV]8.91/[NeV]24.3 (total)                   | $0.17 \pm 0.04$                              | $0.33 \pm 0.09$                               | $0.51 \pm 0.10$                               | $0.61 \pm 0.16$                               |
| [FeVII]7.81/[FeVII]9.53 (total)               | $5.20 \pm 2.25$                              | $6.36 \pm 3.04$                               | $7.39 \pm 3.74$                               | $7.88 \pm 4.87$                               |
| [FeVII]7.81/[FeVII]9.53 (narrow) <sup>a</sup> | —                                            | —                                             | —                                             | —                                             |
| [FeVII]7.81/[FeVII]9.53 (outflow)             | $12.19 \pm 3.05$                             | $15.65 \pm 4.11$                              | $18.61 \pm 5.17$                              | $23.64 \pm 6.76$                              |

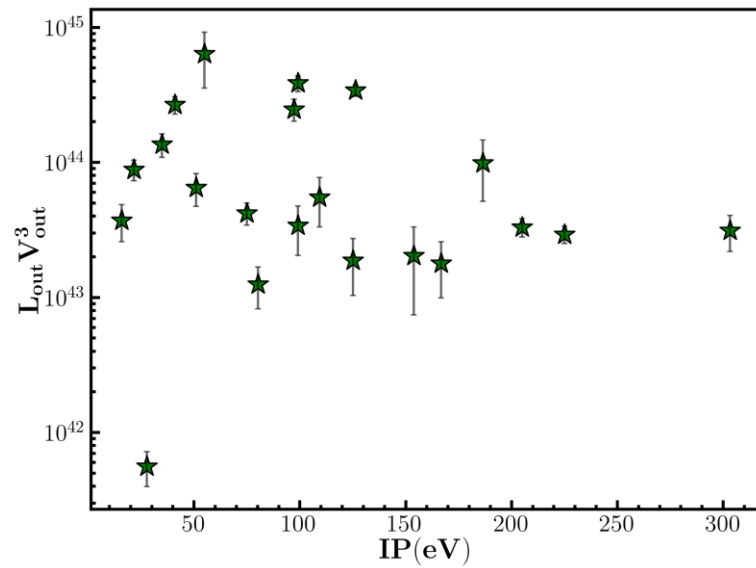
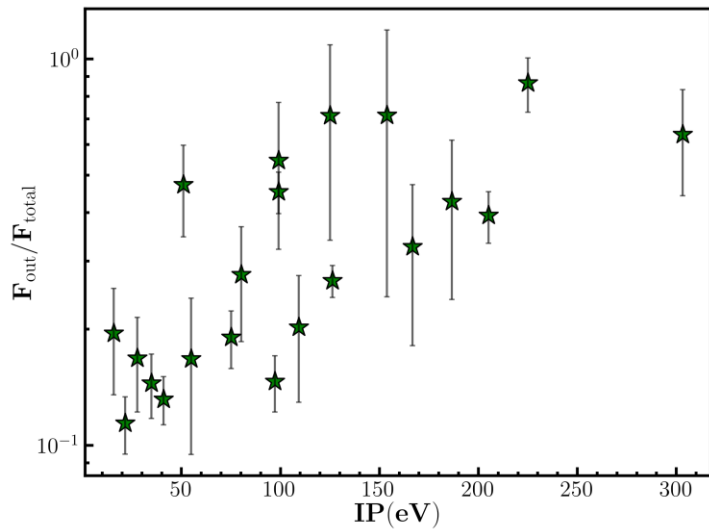
CL Size < 10 pc

FWHM: 100-708 km/s

Low ionized outflow power:  
 $(0.674-2.71) \times 10^{39} \text{ erg s}^{-1}$

**Coronal-line outflow power:**

- [Ne V]:  $(6.38 \pm 1.38) \times 10^{36} \text{ erg s}^{-1}$
- [Fe VII]:  $(1.90 \pm 0.78) \times 10^{38} \text{ erg s}^{-1}$
- [Mg VII]:  $(2.41 \pm 0.38) \times 10^{38} \text{ erg s}^{-1}$



- Coronal lines span from tens of pc out to kpc scales
- Systematically trace high velocities and turbulent gas
- It carries significant (more) outflow fraction
- Crucial probes connecting the inner BLR and torus to the extended NLR
  
- **Jet-driven or radiation-driven?** Is the coronal phase universally launched/shocked by radio jets, or can radiation pressure dominate?
- **Theory vs. Observation:** Dedicated shock and photoionization models tailored to these extended scales, alongside new high-resolution observations.

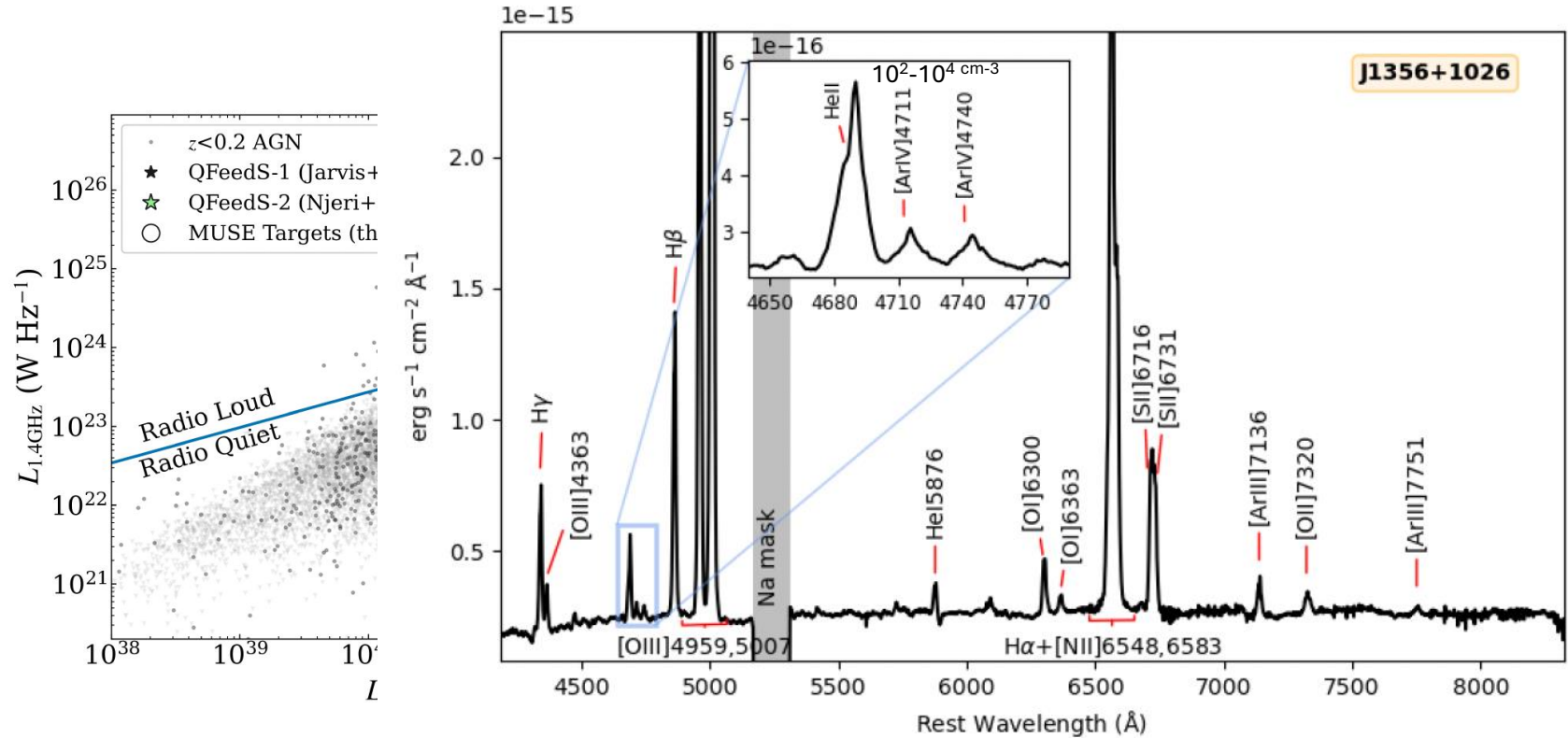
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0.5-5%

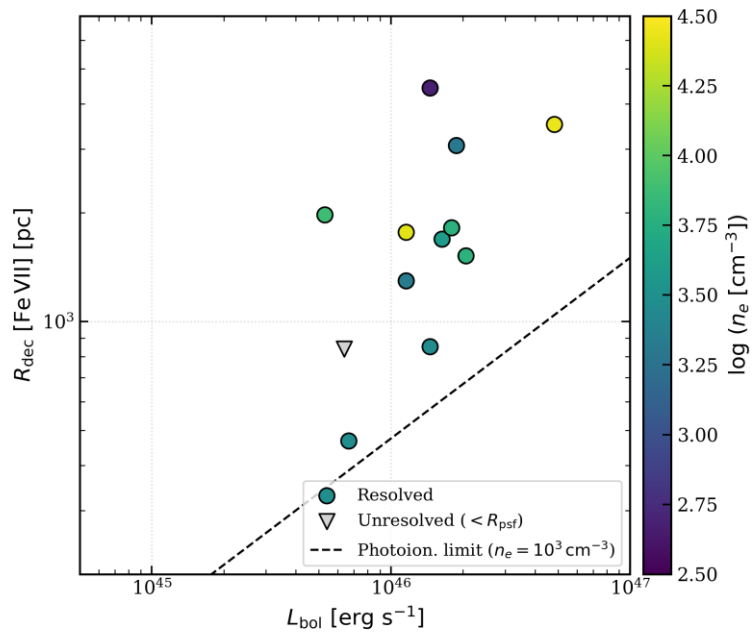


**Thanks for your attention**

# Qfeed survey : Jarvis et al 2021



Preliminary





# Coronal Lines and their outflows

| AGN Outflows                          | 23000 Journal articles |  |
|---------------------------------------|------------------------|--|
| AgN outflows+ CL lines                | 60                     |  |
| AgN outflows+ CL lines + Padovani, P. | 0                      |  |
| AGN outflows + Paola                  | 4 (2018-2024)          |  |

# Qfeed Survey