

# **From Accretion to Feedback: AGN Science Priorities for Future NASA Missions**

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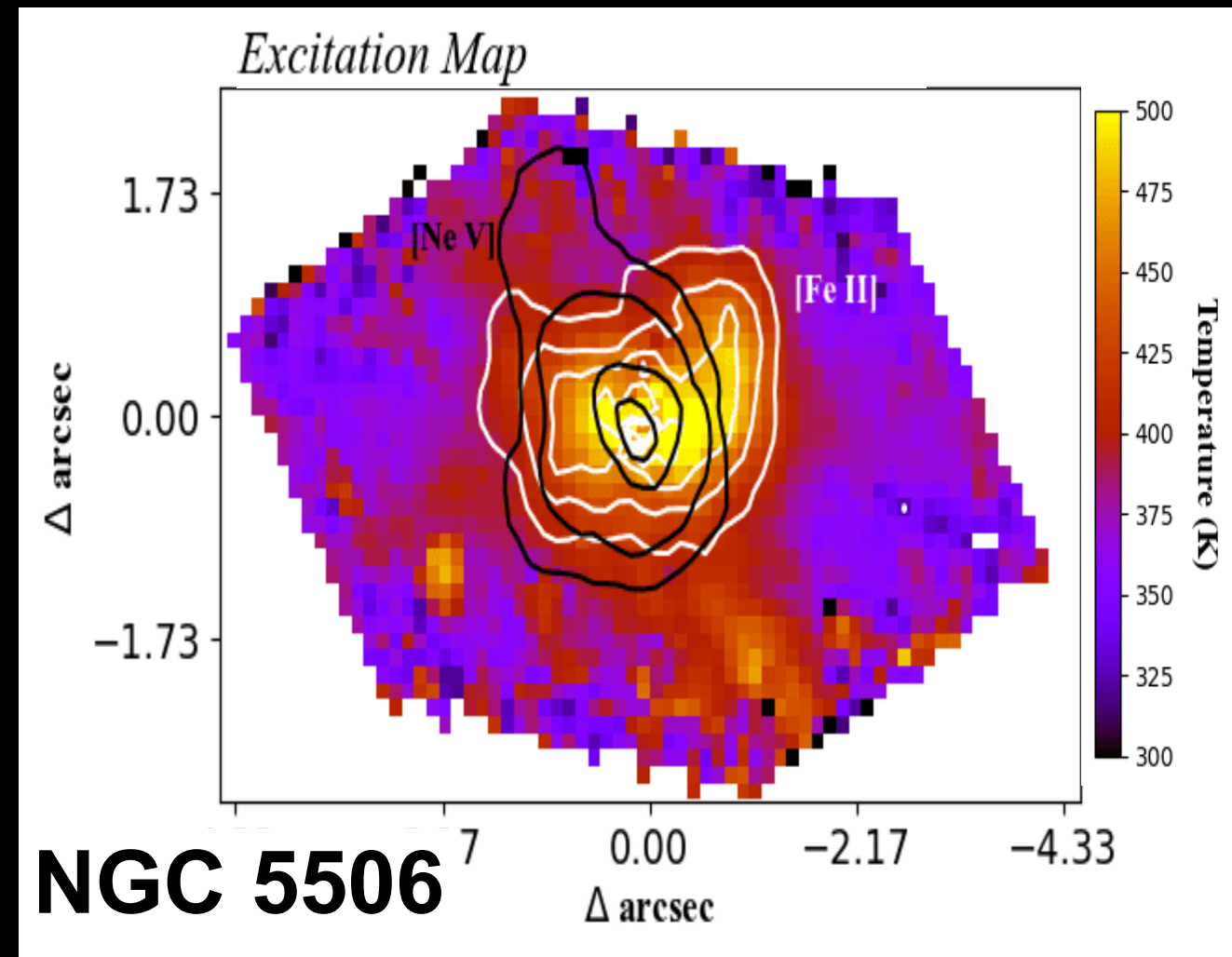
# Progress Since Astro2020

| Astro2020 theme         | Recent Progress                                                               | Future Science                          |
|-------------------------|-------------------------------------------------------------------------------|-----------------------------------------|
| Feedback physics        | JWST resolves PAHs, H <sub>2</sub> , [Fe II], shocks, dust, and host coupling | Energetics, timescales, causality       |
| Central engine physics  | NICER/XRISM probe variability, absorbers, Fe-K gas, winds                     | Spin, launch radii, wind power          |
| Early SMBH growth       | JWST finds LRDs and high-z AGN candidates                                     | True census needs deep X-ray surveys    |
| BH demographics / seeds | Better low-mass AGN searches and dynamical BH work                            | Relic seeds in dwarfs remain incomplete |

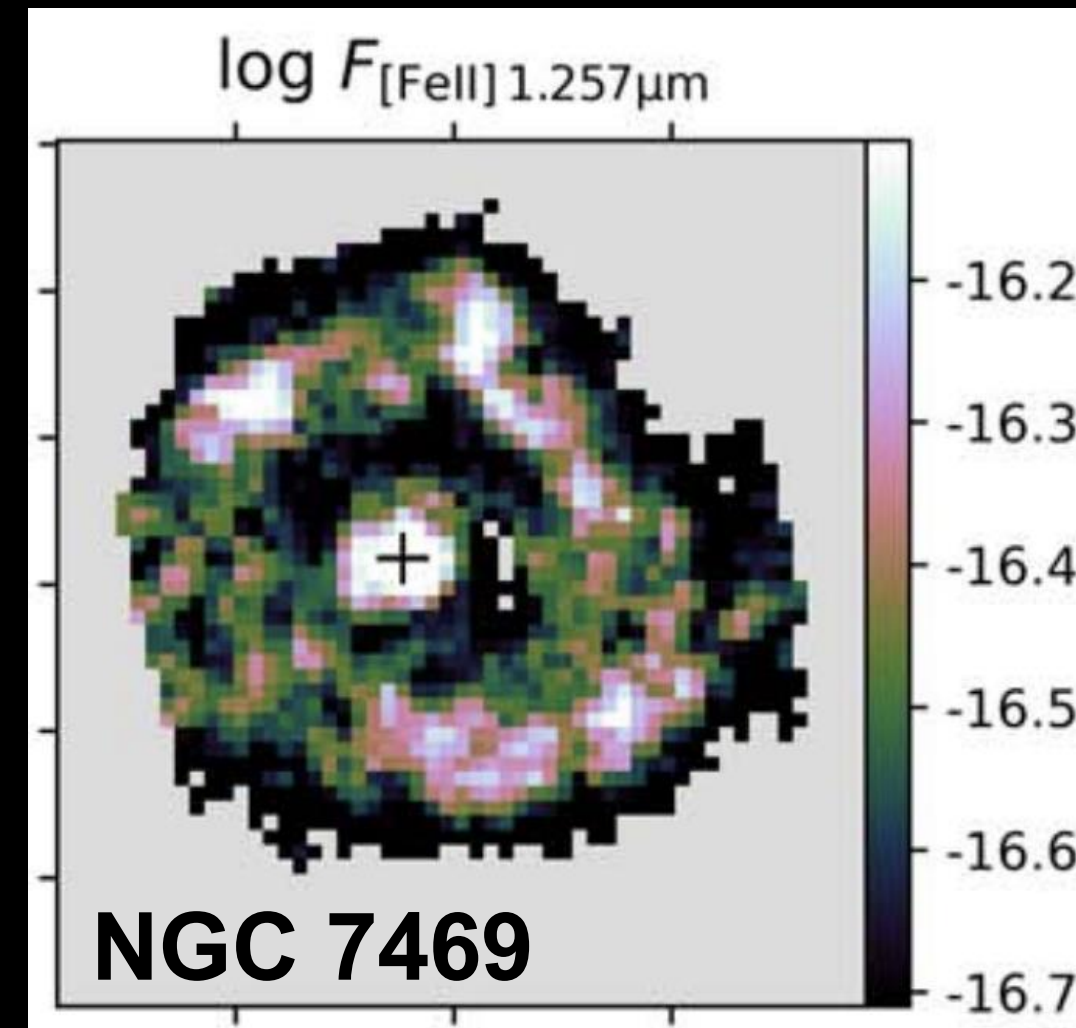
Progress has shifted the field from detecting AGN phenomena to measuring causal connections, energetics, and demographics.

# Toward Survey-Scale Diagnostics of AGN Feedback

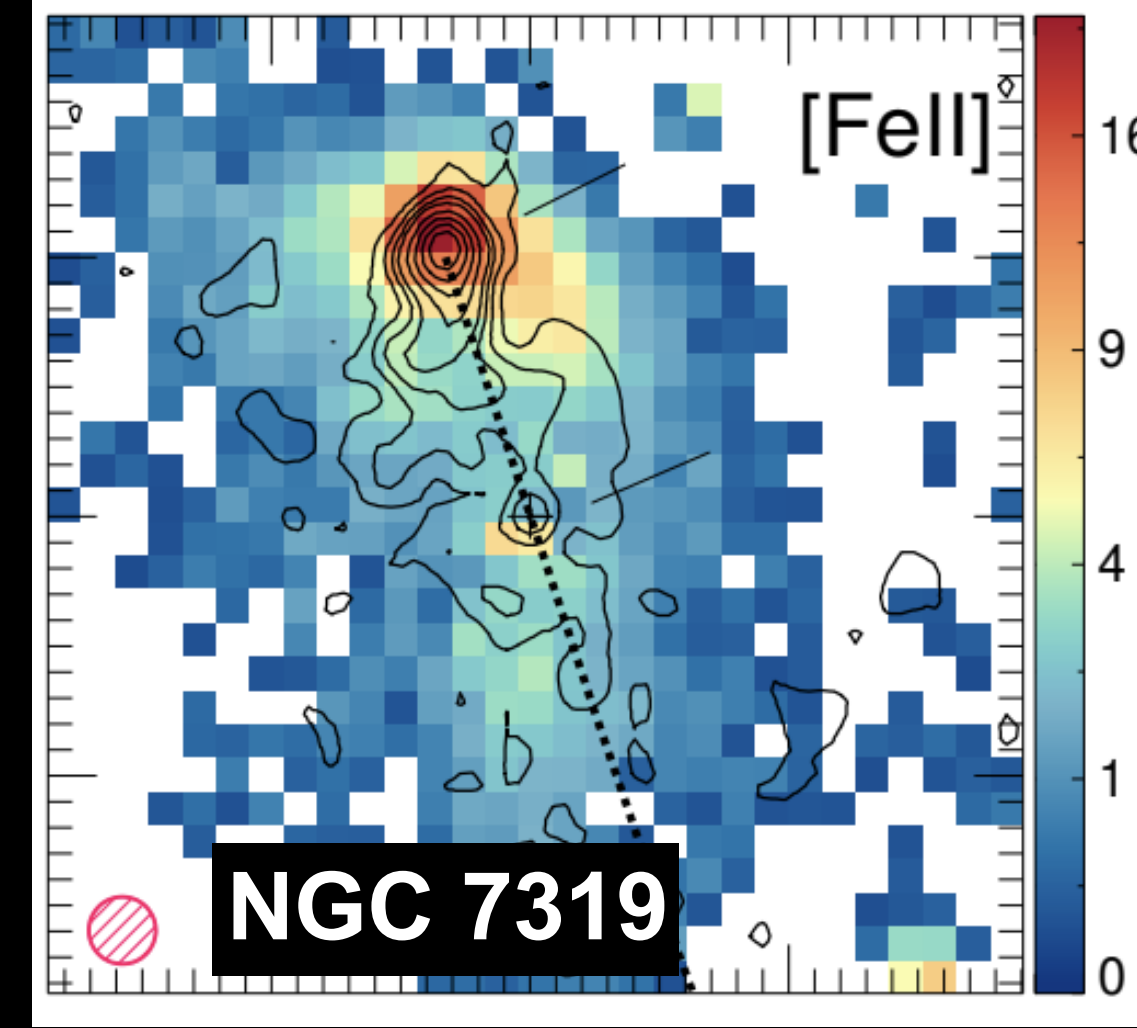
Delaney+ 2025



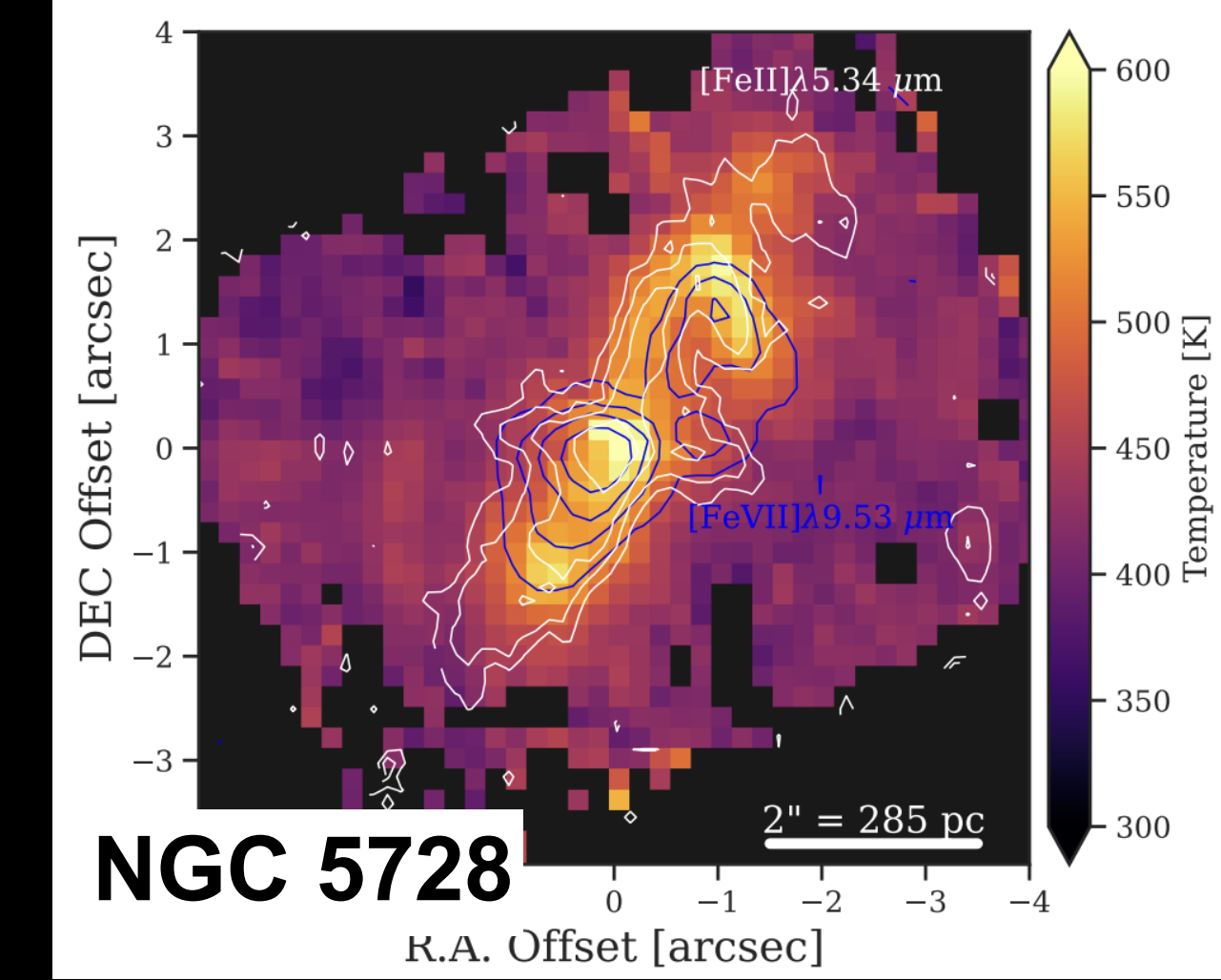
Bianchin+ 2024



Pereira-Santaella+ 2024



Davies+ 2024



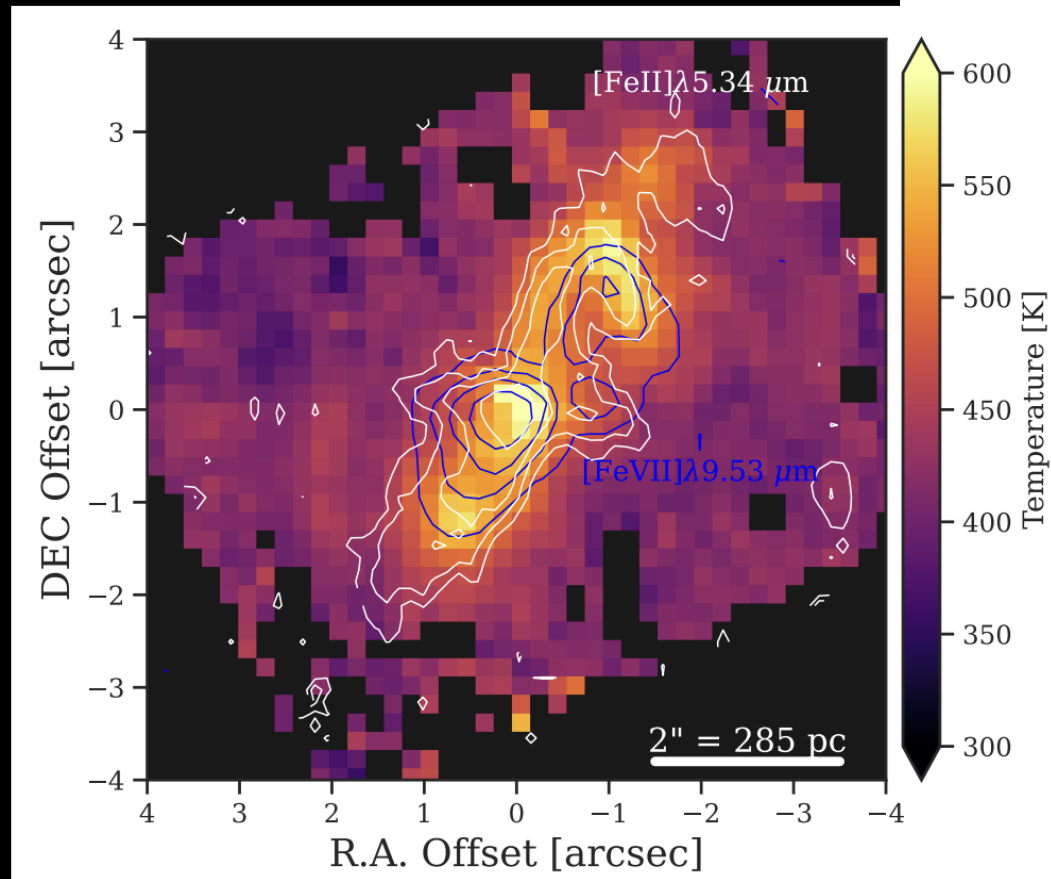
- We now have the tools to move from case studies to scalable diagnostics
- Shock tracers like  $[\text{Fe II}]$ ,  $\text{H}_2$ ,  $\text{Br}\alpha$ , and UV lines are already in wide use
- These lines reveal where feedback couples to host galaxy structures
- Multi-wavelength alignment is critical: radio, sub-mm, IR, optical, UV

We are ready to interpret feedback across full AGN populations

# Strong Coupling: Why Alignment Matters

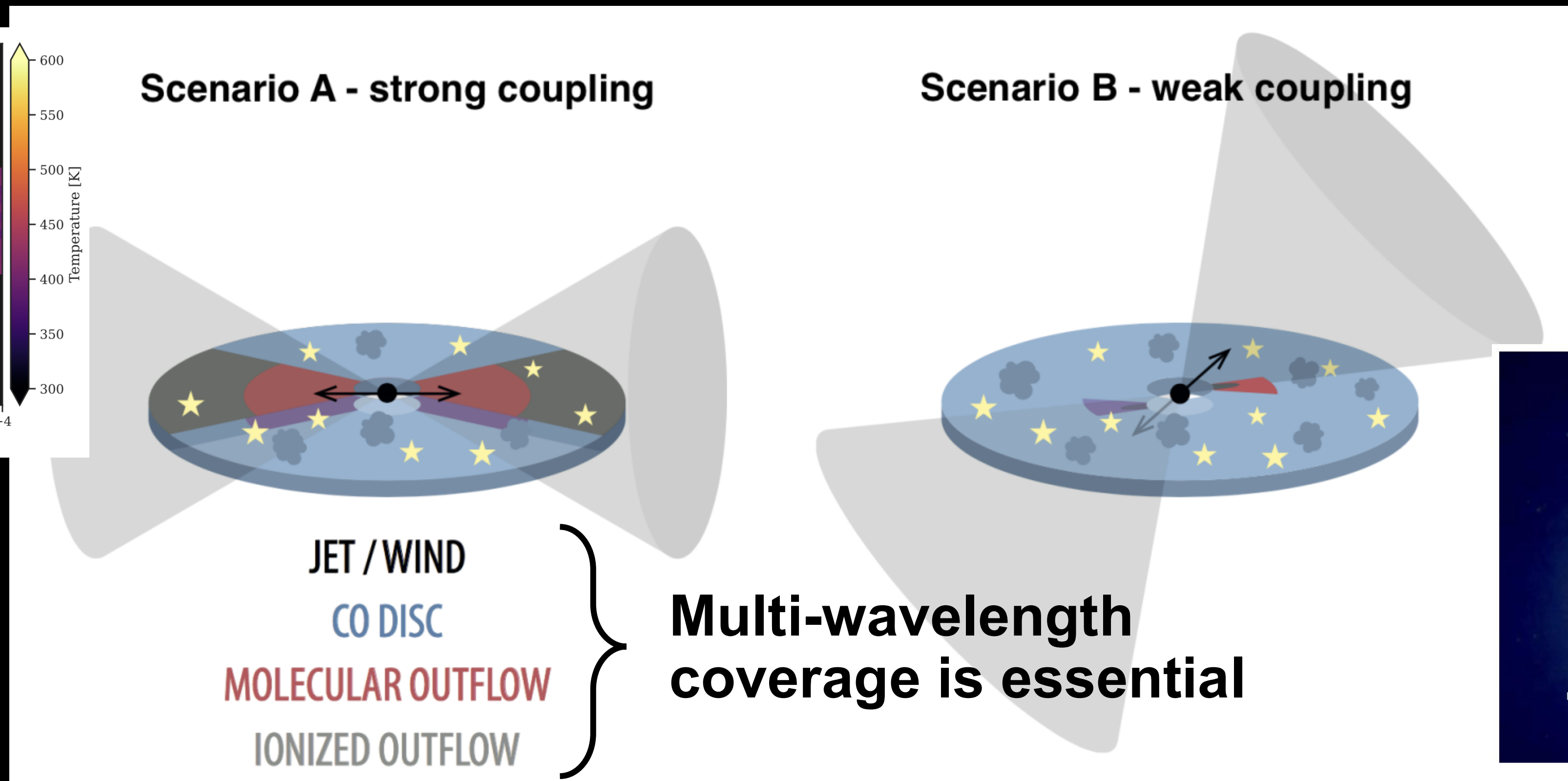
AGN feedback is only effective if it interacts with dense host material

Davies+ 2024

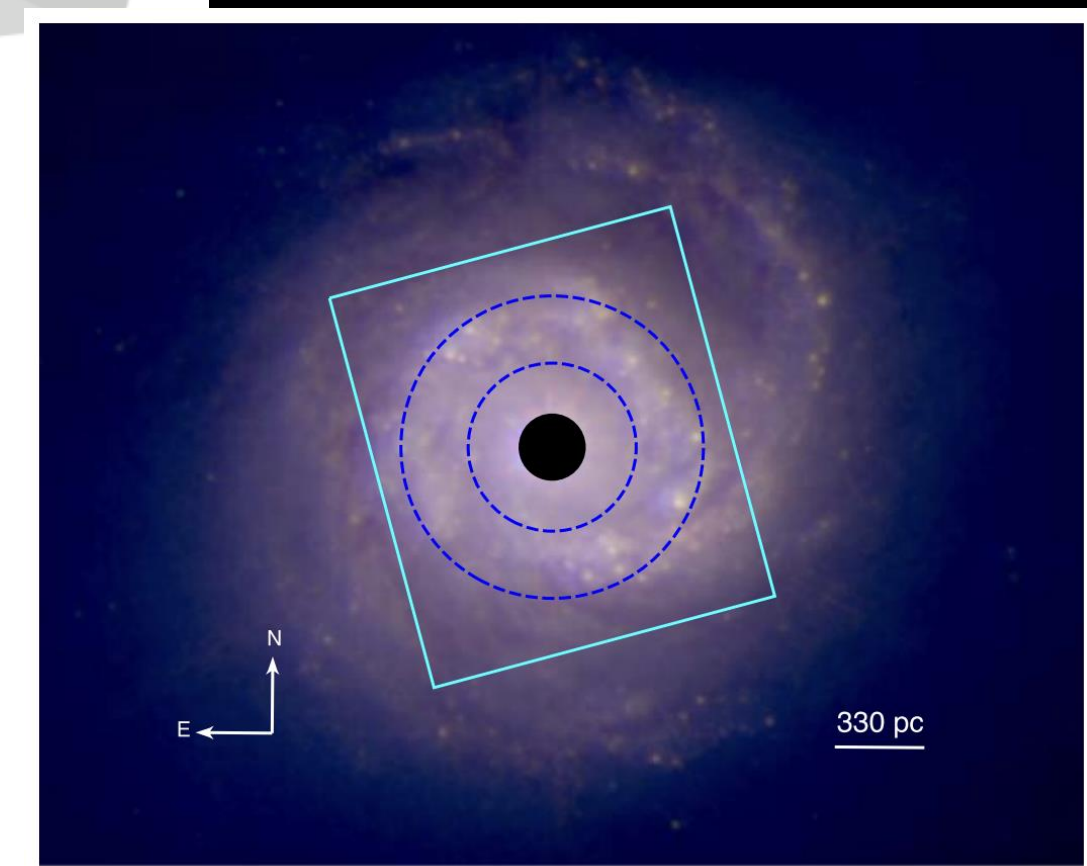


NGC 5728

Ramos-Almeida+ 2022



Bianchin+ 2024

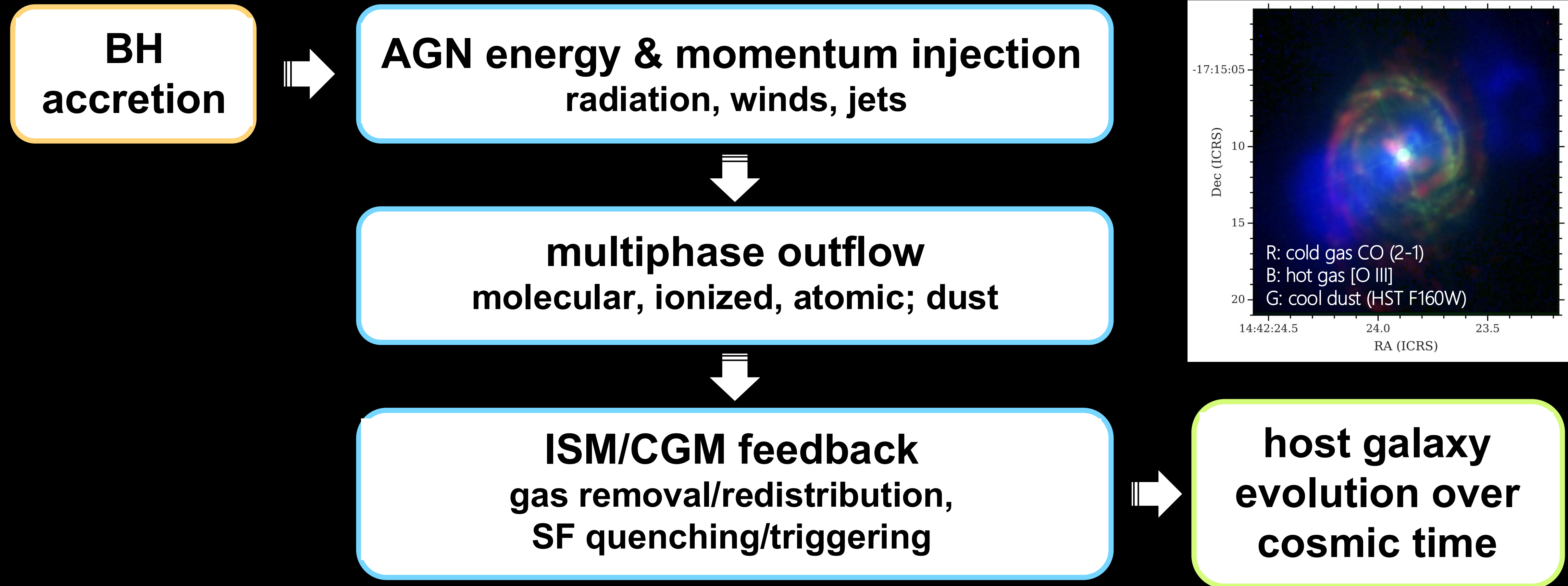


NGC 7469

Result: Strong coupling  $\rightarrow$  shocks, outflows, suppression / triggering of star formation

# Why Constrain AGN Feedback in the Local Universe?

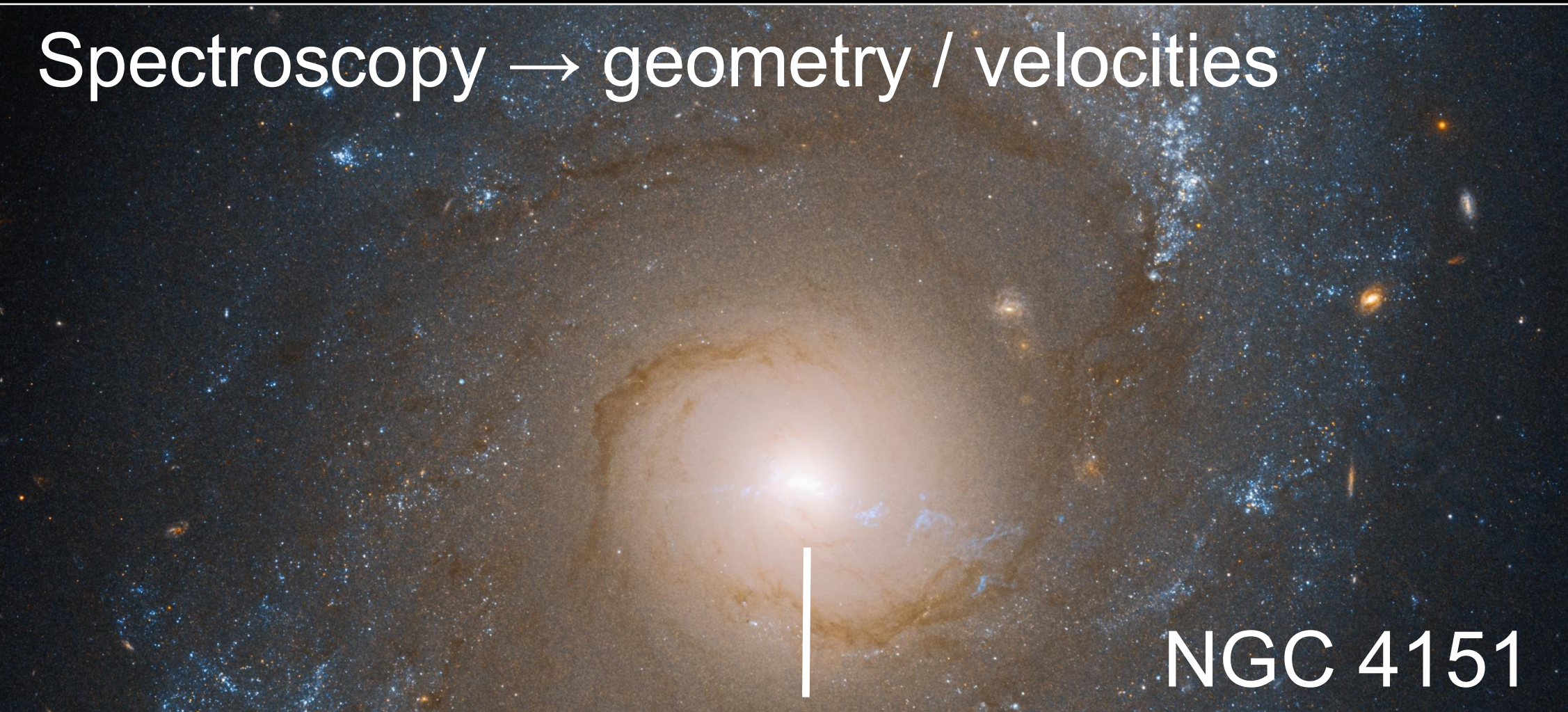
Nearby galaxies are our laboratories for measuring the feedback physics that simulations must assume across cosmic time.



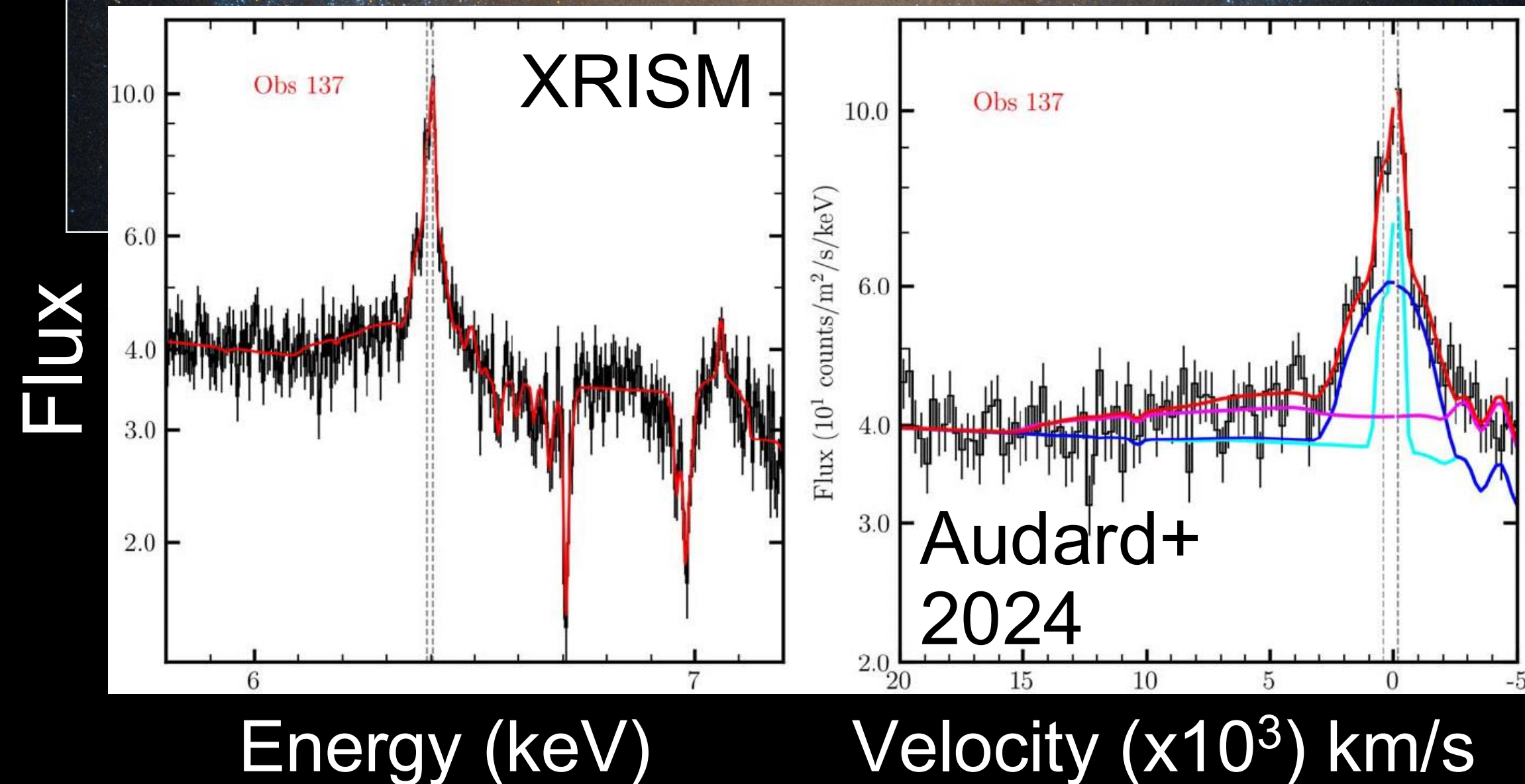
Future missions must resolve the spatial scales, gas phases, and kinematics needed to characterize AGN feedback from parsec to kiloparsec scales.

# X-rays Probe the Engine Behind the Feedback

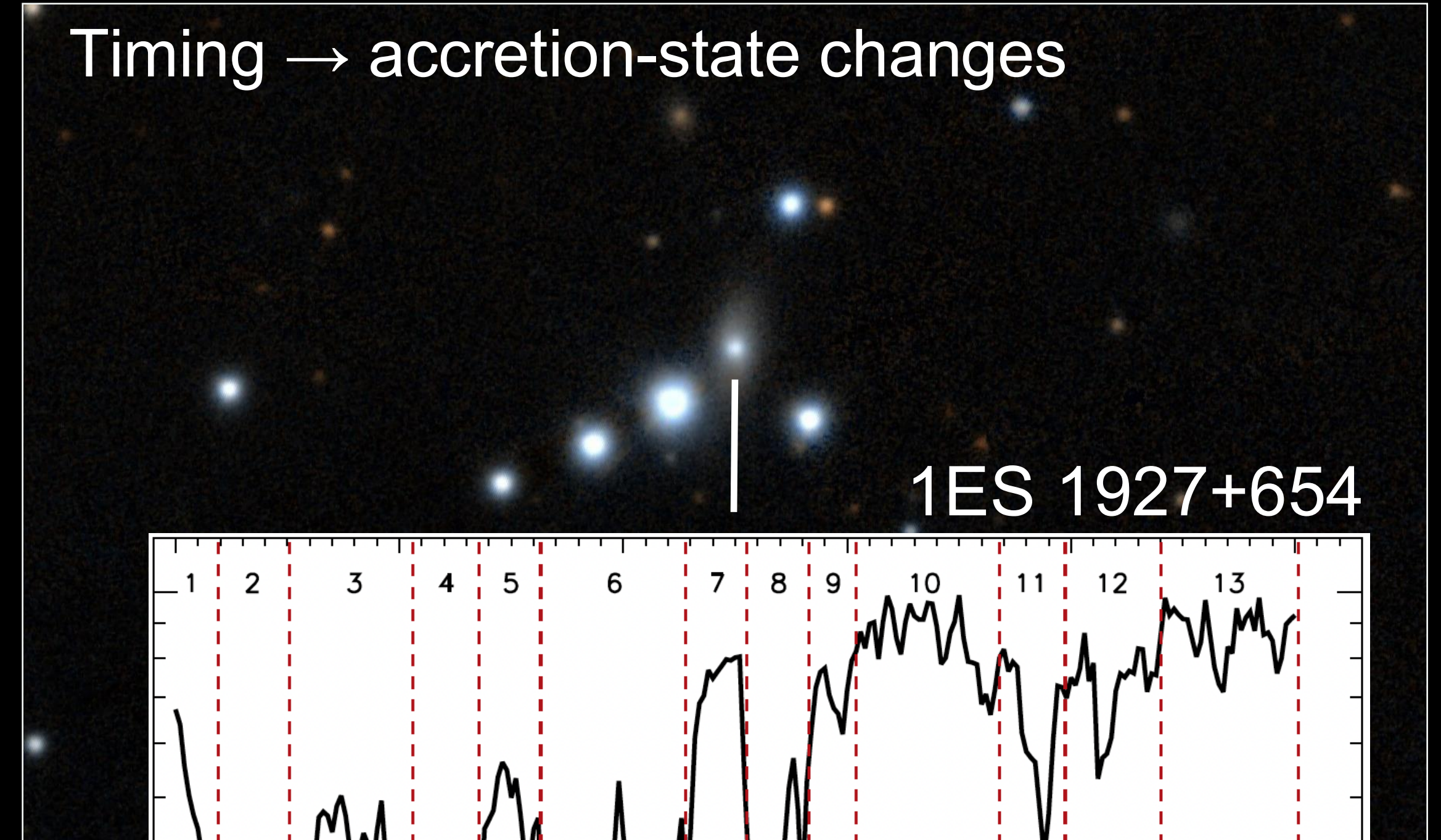
Spectroscopy → geometry / velocities



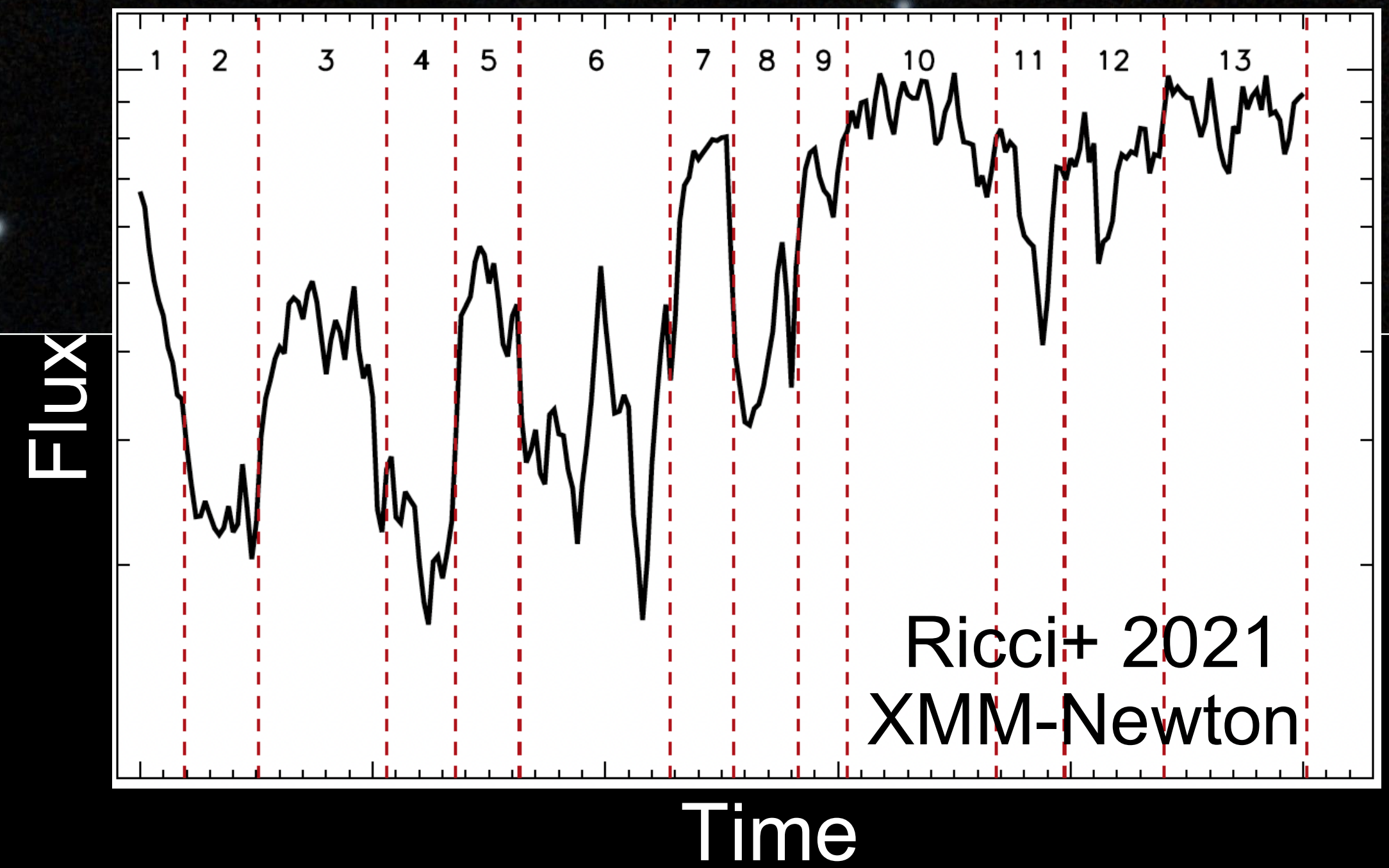
NGC 4151



Timing → accretion-state changes

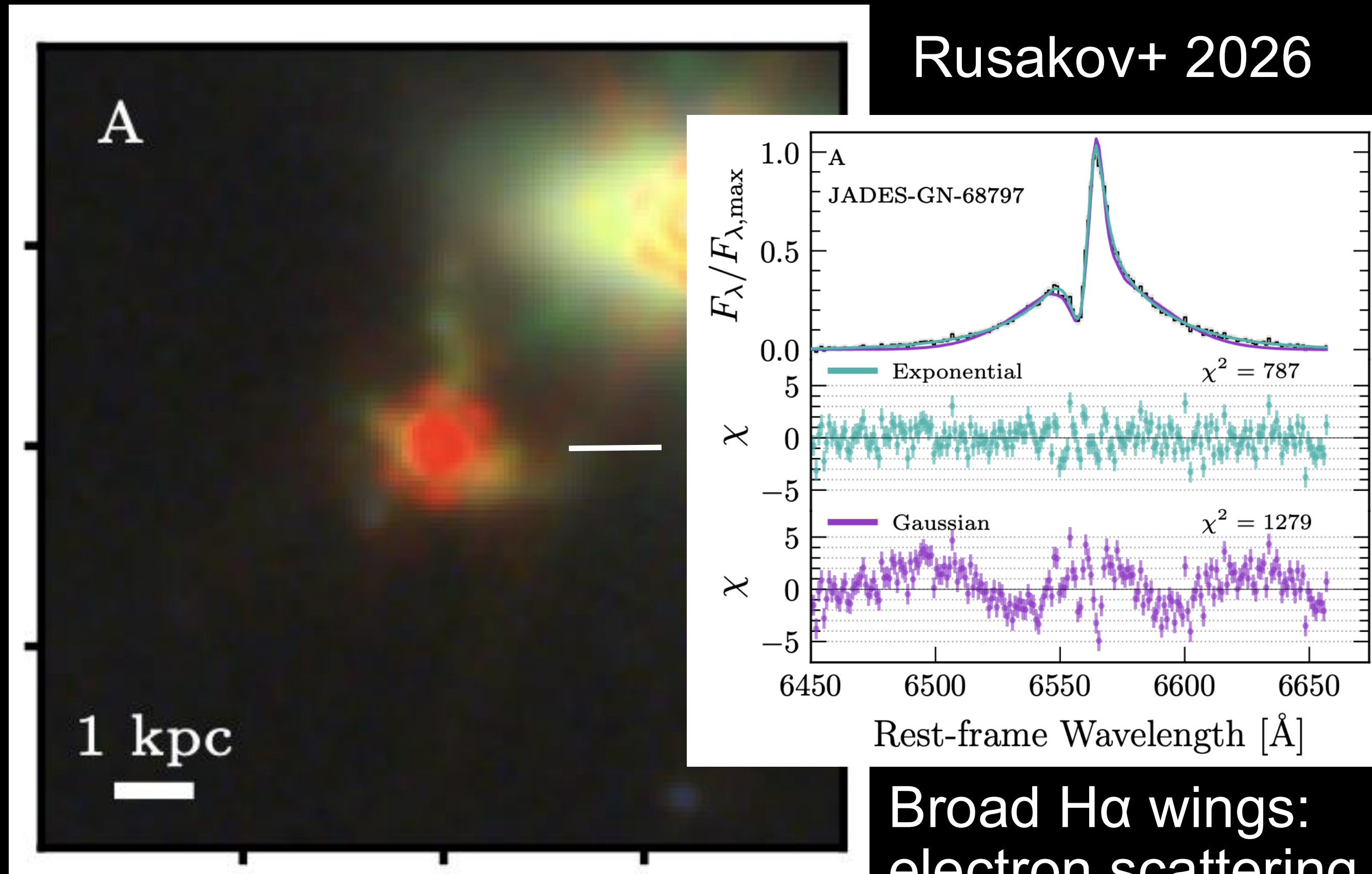


1ES 1927+654

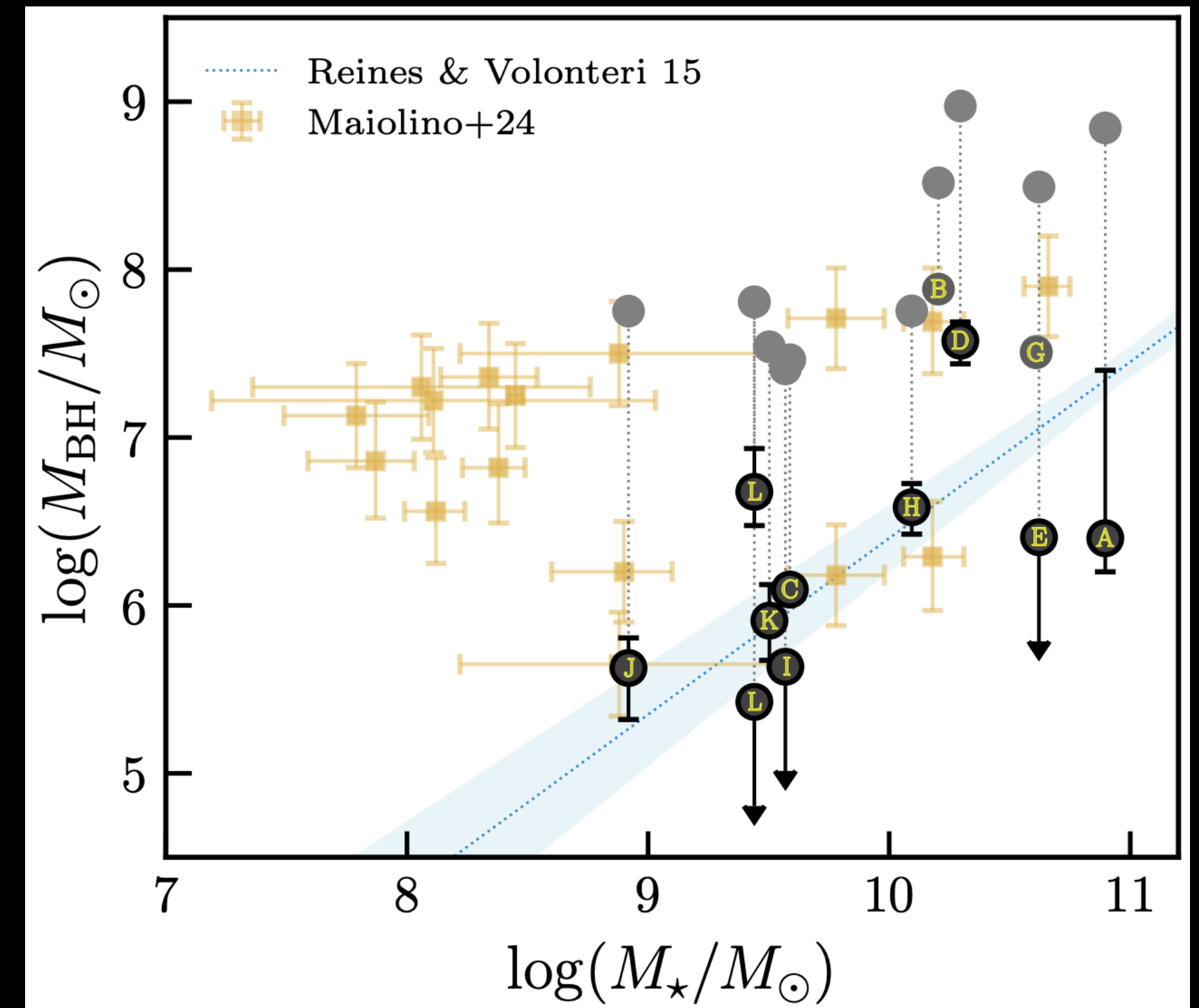


XRISM resolves inner gas structure; NICER-era monitoring reveals variability and accretion-state changes.

# Little Red Dots: Early SMBH Growth or a New Obscured Phase?



Broad H $\alpha$  wings:  
electron scattering,  
not just virial motion?



Revised masses ease  
“overmassive BH” tension

Dense gas cocoons may make young SMBHs appear over massive,  
X-ray weak, and spectroscopically strange.

# What This Means for Future Missions

AGN astronomy separates into three observational regimes, each requiring different future capabilities.

| AGN Science Regime                  | Science Question                                                                                          | What we need next                                                                                                                                                   |
|-------------------------------------|-----------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Nearby, unresolved nuclei           | What is happening in the central engine, accretion flow, corona, BLR/torus, and inner wind?               | <b>Sensitivity + variability:</b> high-throughput monitoring, high-resolution spectroscopy, rapid response, and multiwavelength timing.                             |
| Spatially resolved host interaction | How does AGN energy couple to the surrounding ISM, molecular gas, dust, PAHs, shocks, and star formation? | <b>Spatial resolution + waveband coverage:</b> resolved spectroscopy/imaging from UV/optical/IR/X-ray/radio to connect gas phases and feedback channels.            |
| High-redshift surveys               | When did black holes form, how fast did they grow, and how common are obscured or over massive early AGN? | <b>Sensitivity + survey speed + variability:</b> deep/wide surveys, time-domain identification, spectroscopy of faint compact sources, and obscuration diagnostics. |

# Future AGN Science: Capability Matrix

| Capability                    | Nearby Nuclei | Host Interaction | High-redshift Surveys |
|-------------------------------|---------------|------------------|-----------------------|
| Sensitivity                   | Essential     | Important        | Essential             |
| Variability/Cadence           | Essential     | Useful           | Essential             |
| Spatial Resolution            | Useful        | Essential        | Important             |
| Waveband Coverage             | Essential     | Essential        | Essential             |
| Spectroscopic Resolution      | Essential     | Important        | Important             |
| Survey Speed/<br>Multiplexing | Useful        | Useful           | Essential             |

# AGN Across ASTRA Landscape

AGN science naturally spans the full range of proposed future capabilities

| Wavelength Regime | AGN Science Enabled                                                                                     |
|-------------------|---------------------------------------------------------------------------------------------------------|
| Radio             | Jets, compact outflows, synchrotron shocks, feedback-driven radio structures, star formation separation |
| Far-IR            | Dust-obscured growth, cold molecular gas, buried star formation, feedback in dusty hosts                |
| Mid-IR            | PAHs, warm molecular gas, coronal lines, obscured nuclei, shocked gas, torus/host coupling              |
| Optical/Near-IR   | Host morphology, ionized gas kinematics, broad lines, high-z AGN surveys, little red dots               |
| Ultraviolet       | Accretion disk emission, broad absorption-line winds, CGM/IGM illumination, feedback tracers            |

# AGN Across ASTRA Landscape

AGN science naturally spans the full range of proposed future capabilities

| Wavelength Regime         | AGN Science Enabled                                                                   |
|---------------------------|---------------------------------------------------------------------------------------|
| Soft X-ray                | Disk winds, warm absorbers, coronae, obscuration, ionized outflows, AGN variability   |
| Hard X-ray                | Compton-thick AGN, intrinsic accretion power, buried SMBH growth                      |
| Gamma Ray                 | Blazars, relativistic jets, particle acceleration                                     |
| Neutrinos/<br>Cosmic Rays | Extreme AGN as possible sites of hadronic acceleration and multi-messenger emission   |
| Time Domain               | Changing-look AGN, TDEs, accretion-state changes, reverberation, variable obscuration |
| Gravitational Waves       | Merger rates, binary demographics, masses, spins, merger-driven accretion             |

# AGN science is positioned as a cross-cutting ASTRA science driver, not a single-wavelength niche case

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## What AGN needs from ASTRA

### 1. Sensitivity and cadence

for unresolved nuclei, variability, accretion-state changes, obscuration, and buried growth.

### 2. Spatial resolution and waveband coverage

for feedback coupling, shocks, PAHs, molecular gas, radio structures, and host-galaxy response.

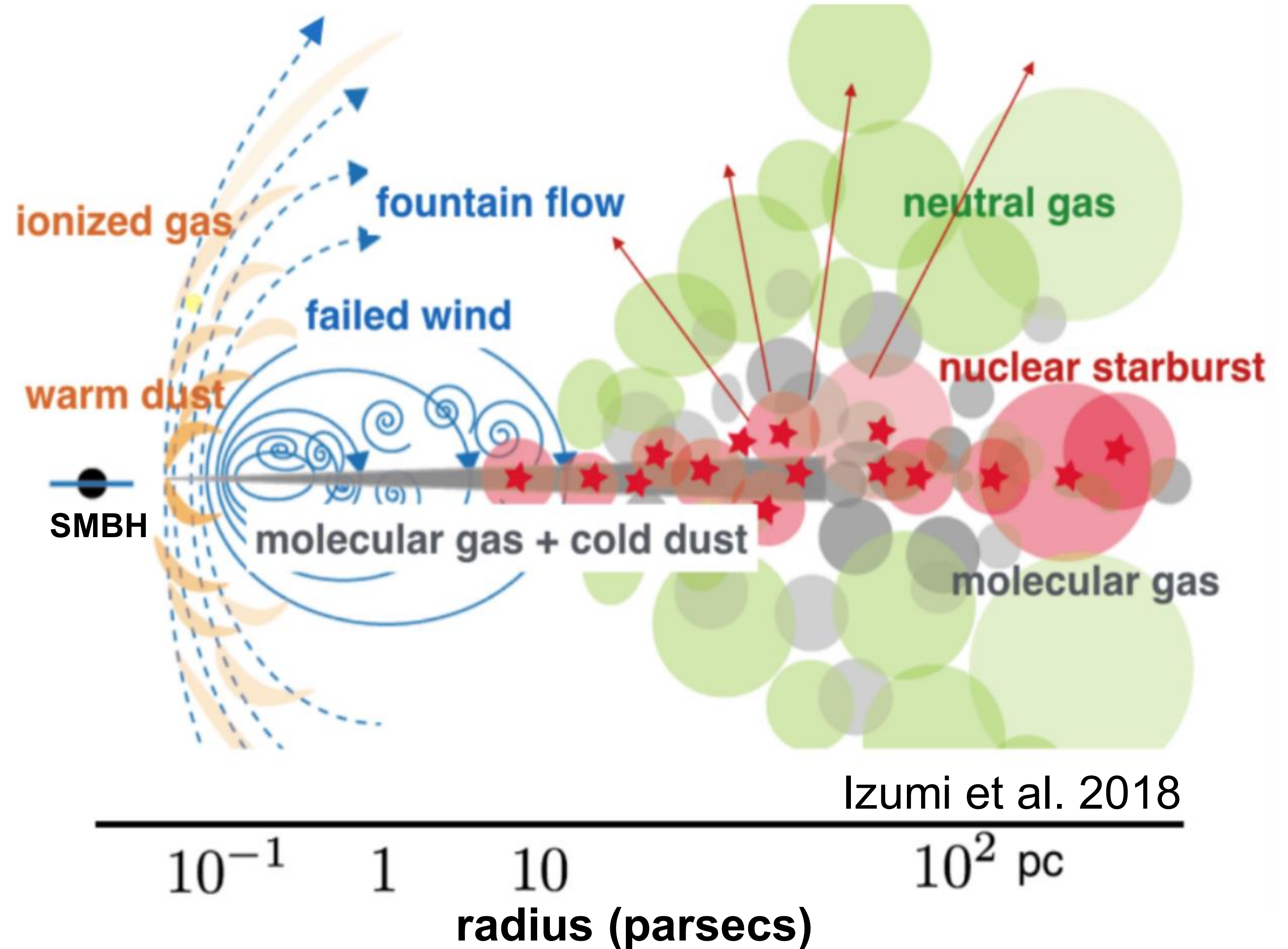
### 3. Deep, wide, multiwavelength surveys

for high-redshift AGN, Little Red Dots, obscured populations, demographics, and SMBH seeds.

From discoveries → causal tests, energetics, and demographics.

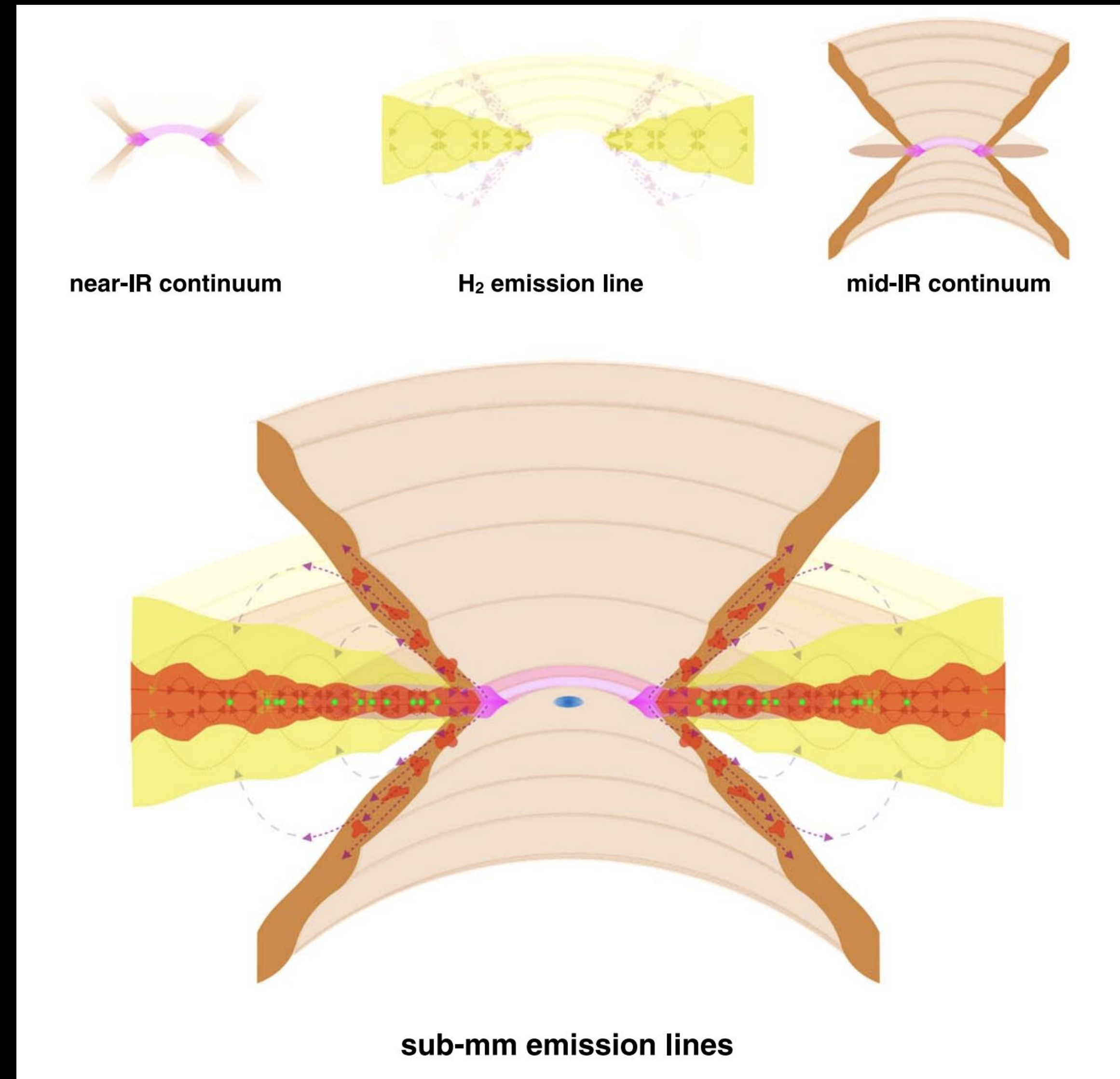
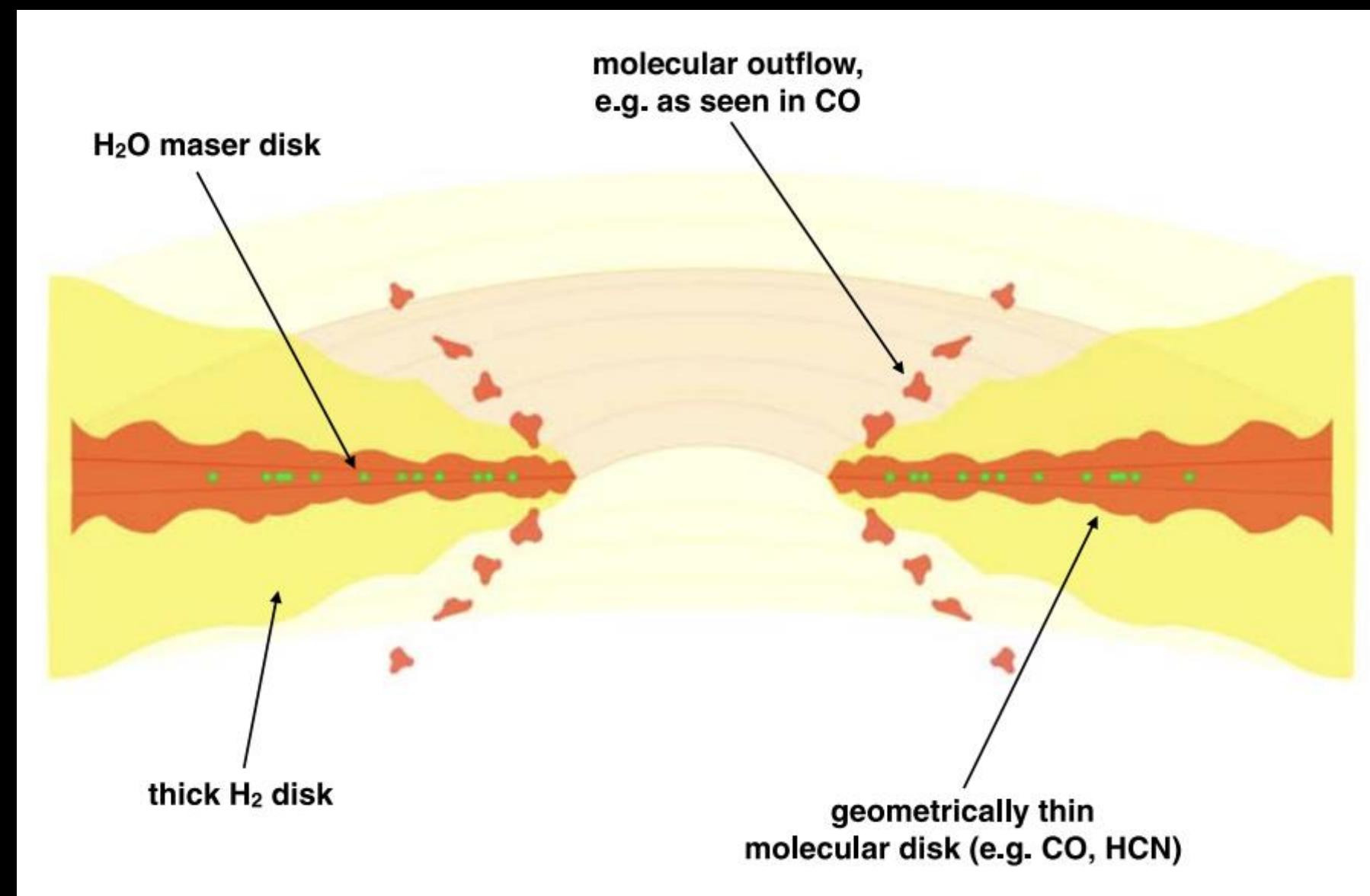


# Fountain model: Feeding & Feedback



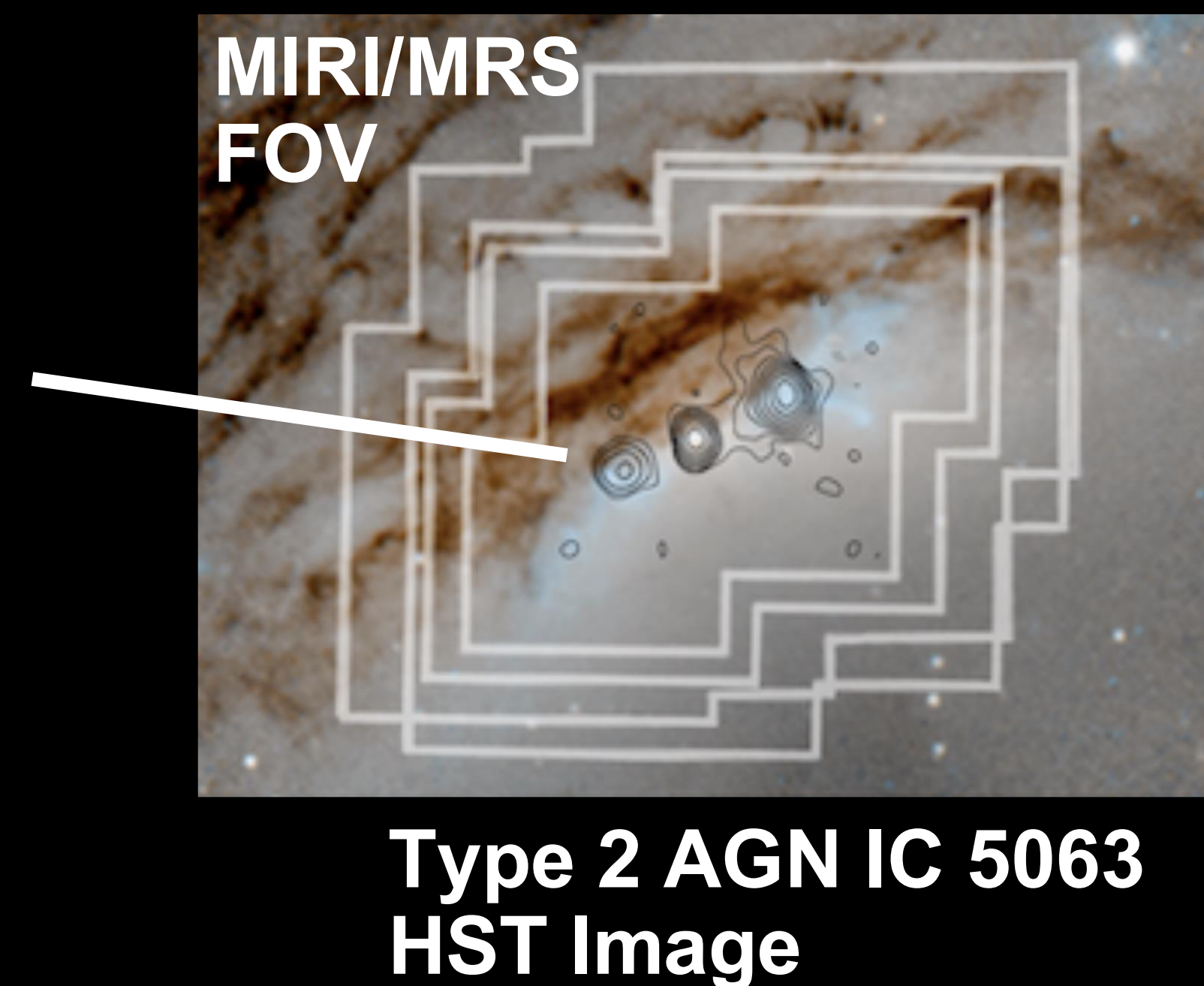
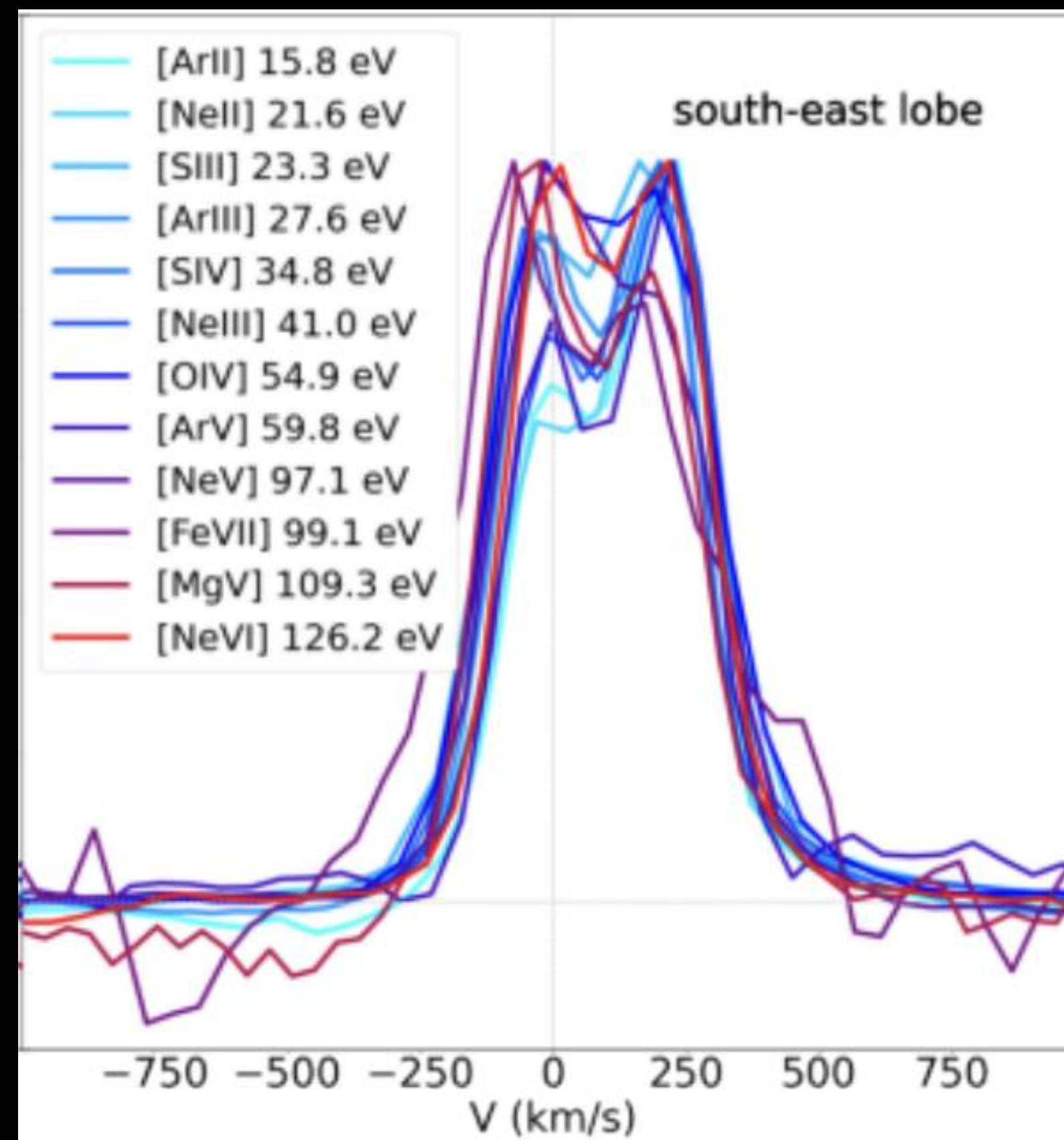
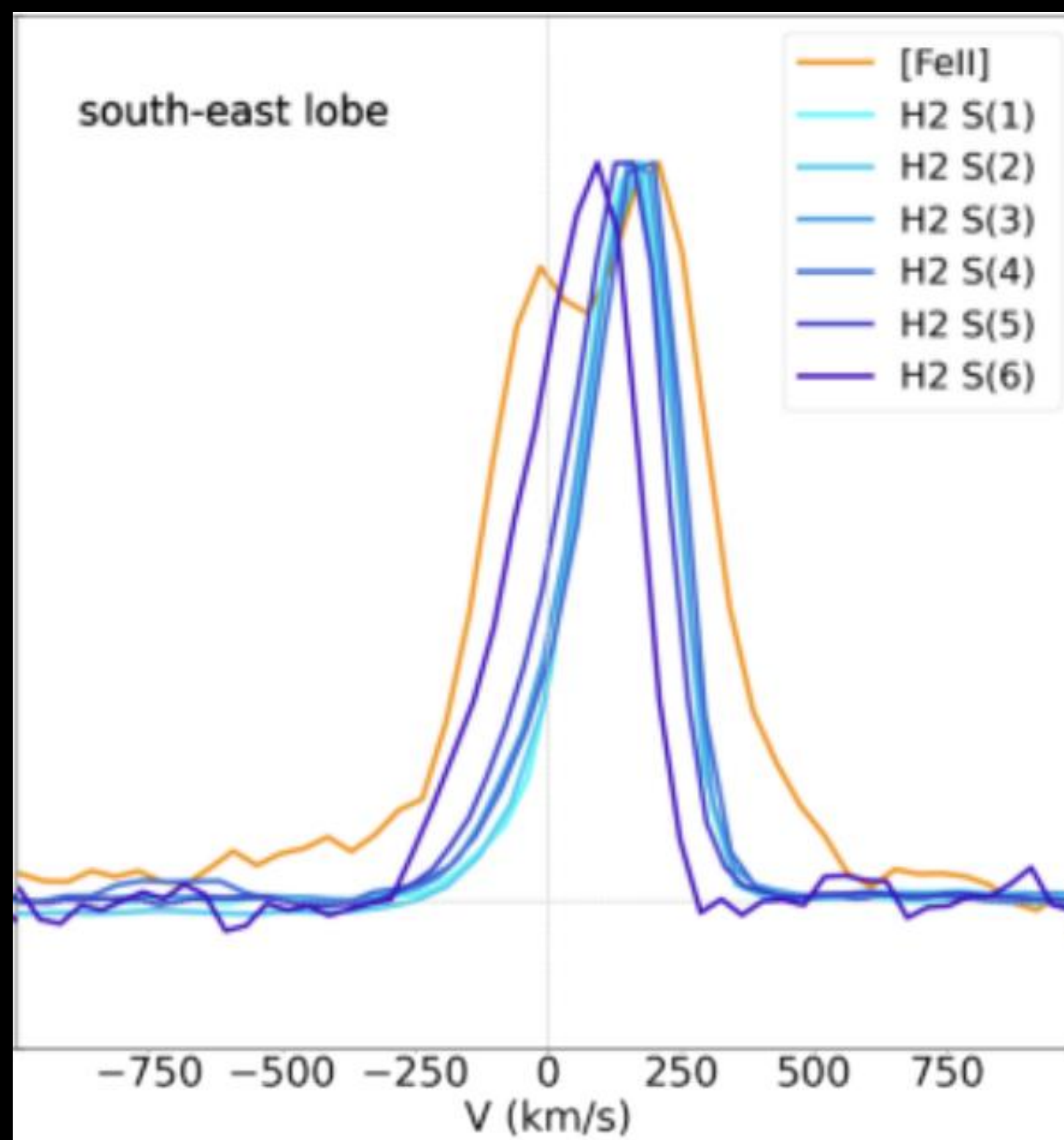
# Redefining the Torus: A multiphase structure

Honig et al. 2019



# Spatially Resolved Shock Diagnostics: A Shared Toolset

Dasyra+ 2024



Resolved spectra now provide laboratories for testing feedback energetics.