Mapping Multiscale AGN Outflows with JWST+Keck

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http://goals.ipac.caltech.edu

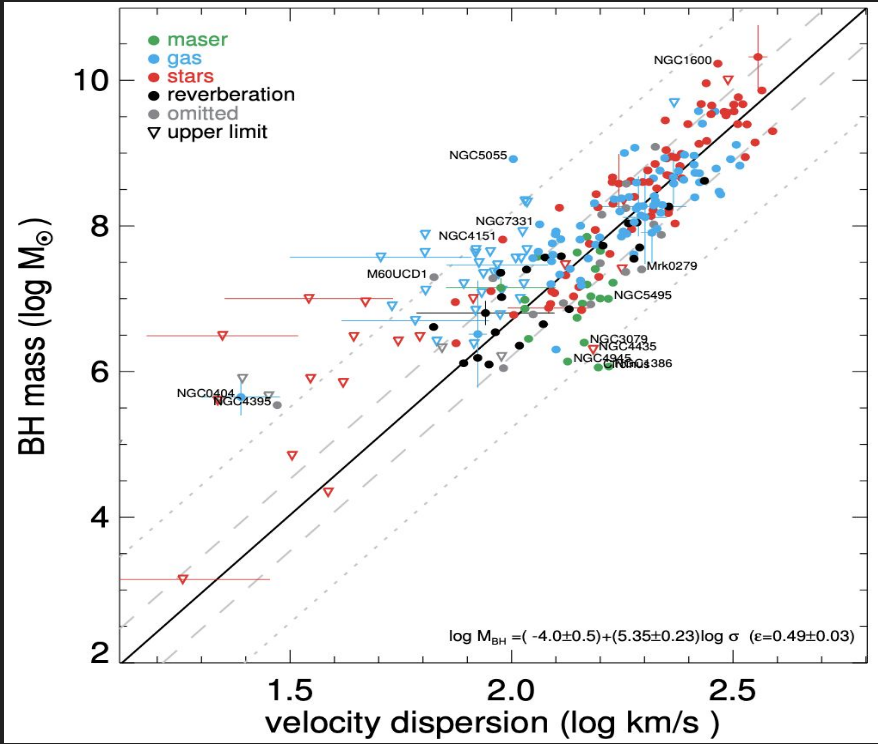
ELT Science in Light of JWST
UCLA, 13 Jan 2023

AGN Outflows and Galactic-Scale Feedback

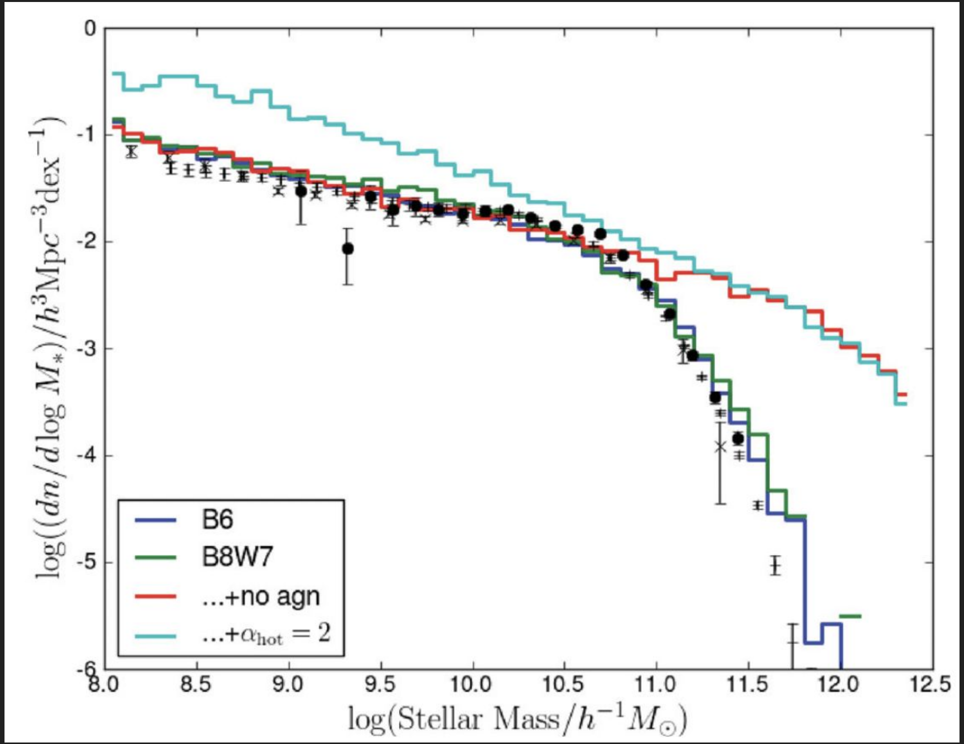
Credit: NASA; JPL-Caltech

- Overwhelming evidence that black holes are at the center of most galaxies.
- SMBHs grow by accretion gas that falls into their gravitational zone of influence.
- Accretion disks are the source of ample UV-optical ionizing radiation. AGNs can also launch jets.

AGN Outflows and Galactic-Scale Feedback



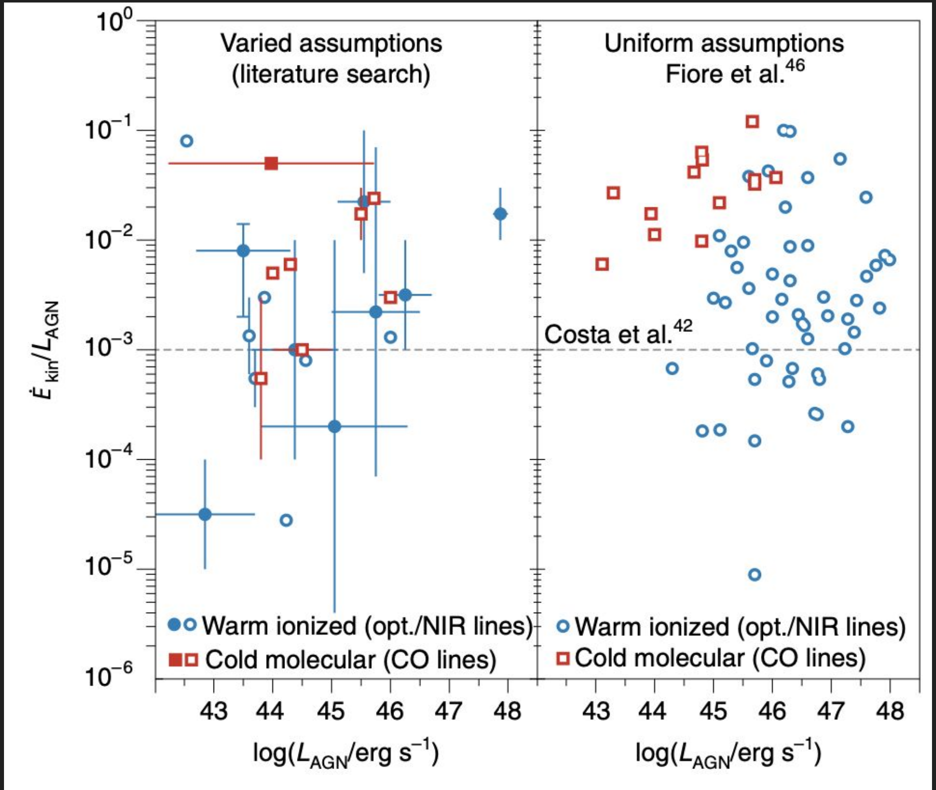
van den Bosch 2016



Bower et al. 2006

Observationally, when do AGN outflows provide significant feedback to the host galaxy?

- Detailed physics of outflows is elusive.
- Unclear what properties of the BH or host dictate feedback efficiency: ambiguous scaling relations.
- On the observational side, large uncertainties make comparison w/ models difficult.



Harrison et al. 2018

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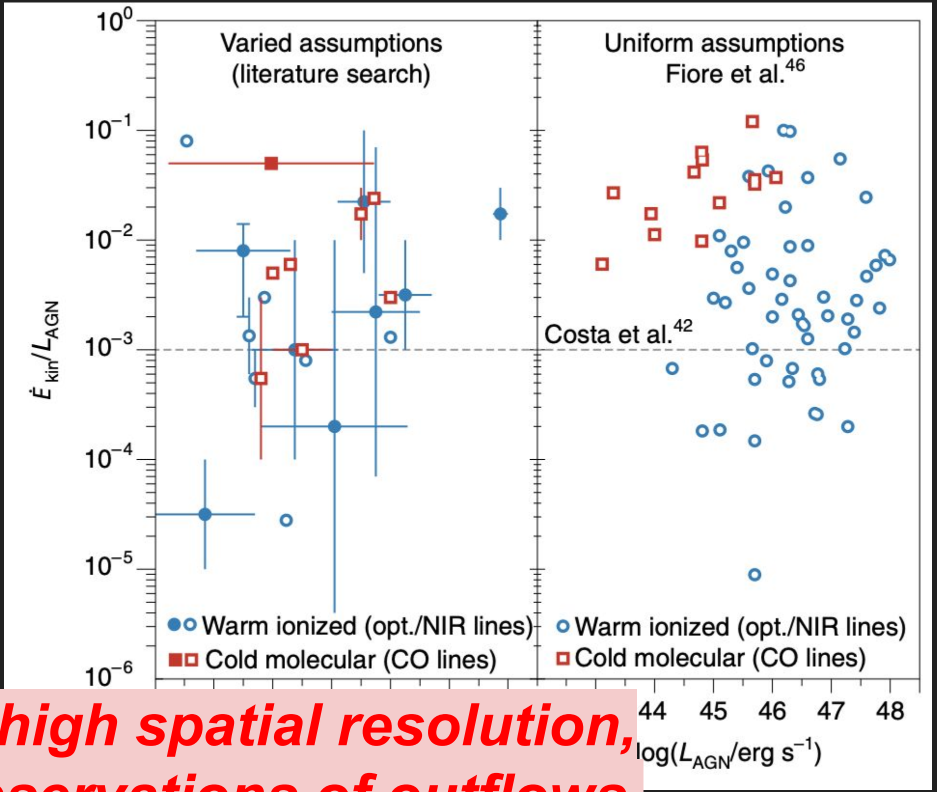
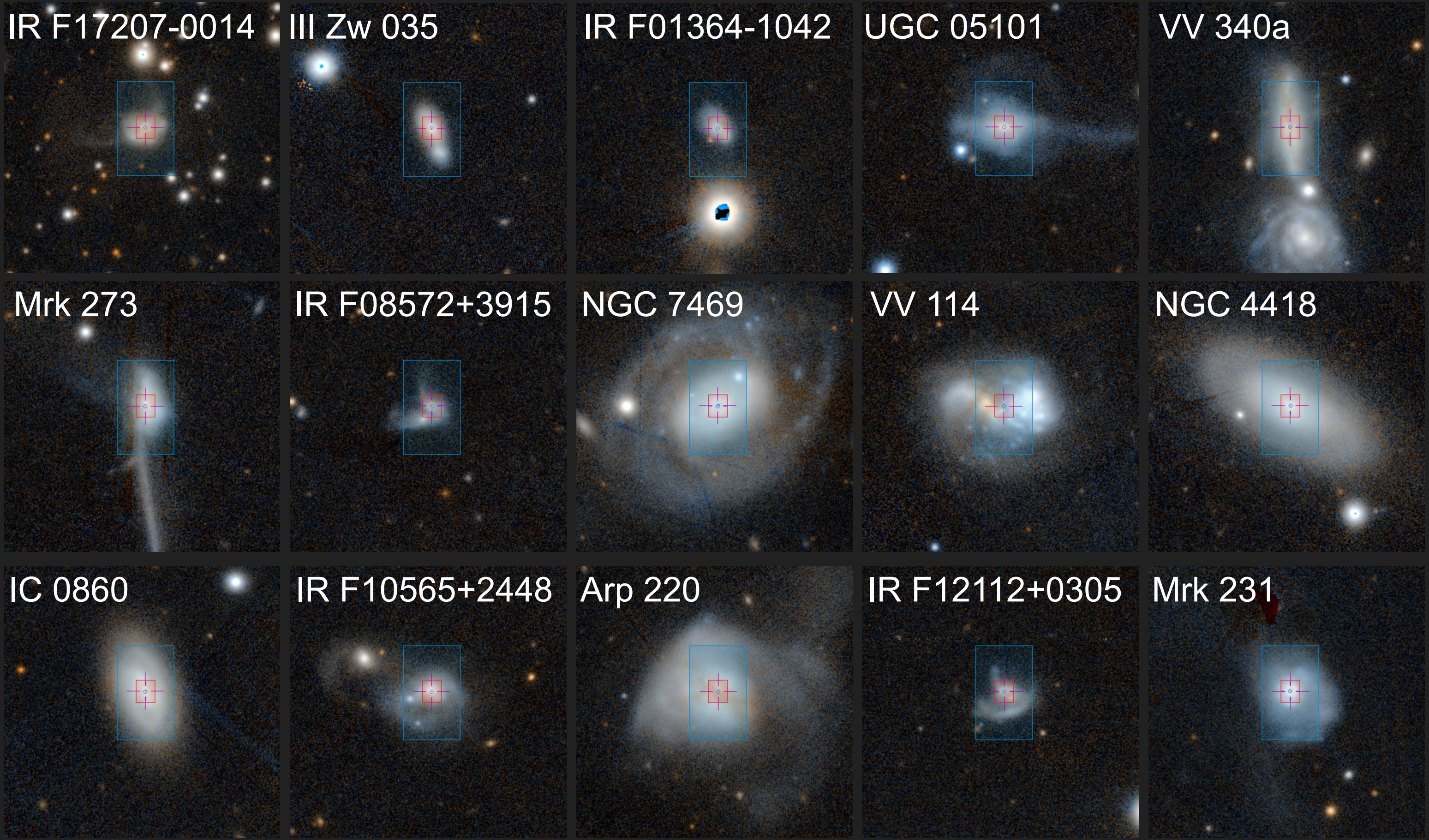


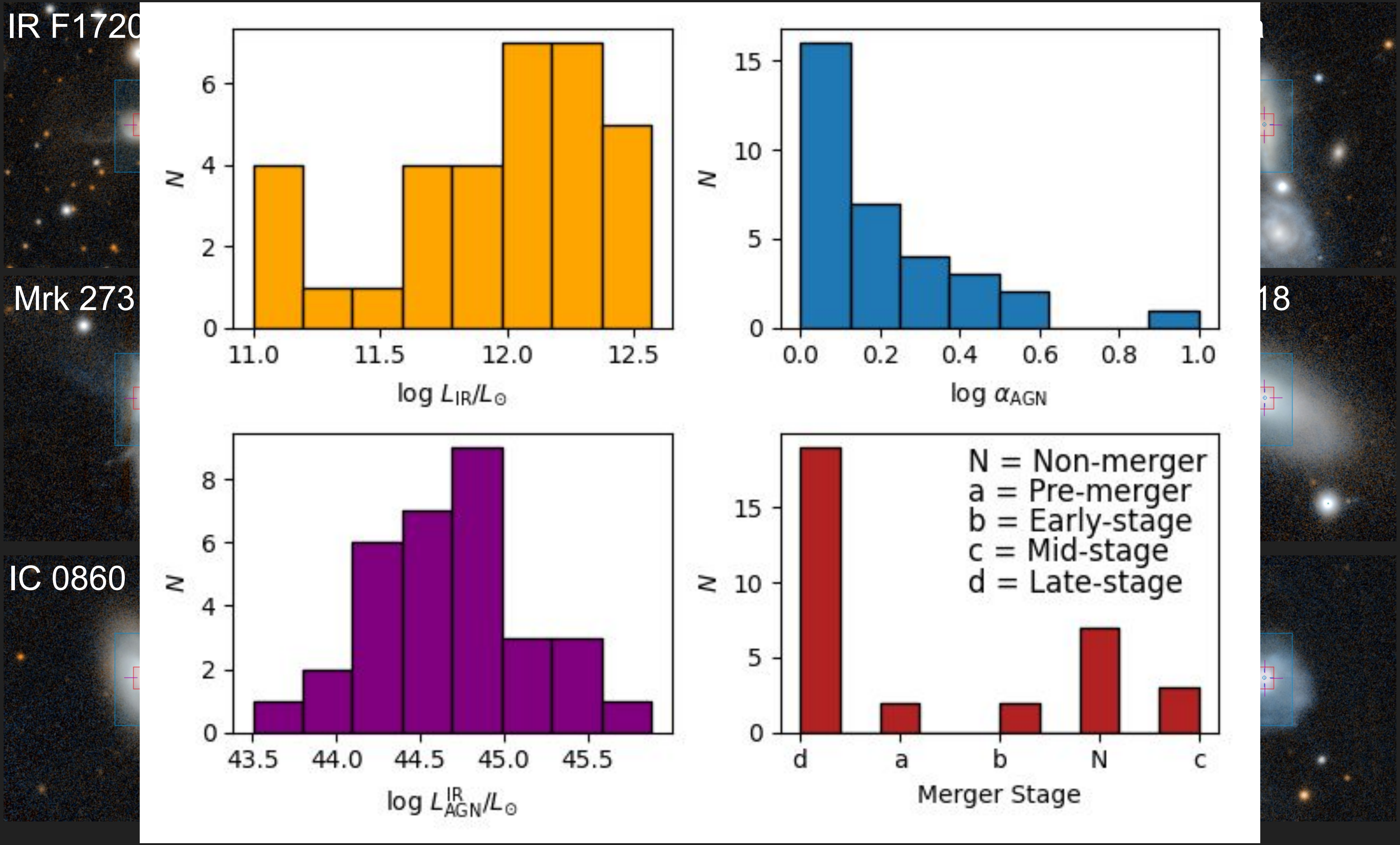
There is a need for high spatial resolution, multiwavelength observations of outflows.

Harrison et al. 2018

Keck+JWST Multiscale Feedback Study: **Sample**



Keck+JWST Multiscale Feedback Study: **Sample**

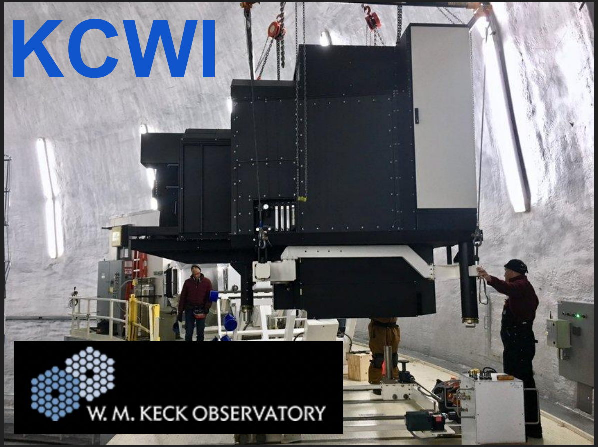


Keck+JWST Multiscale Feedback Study

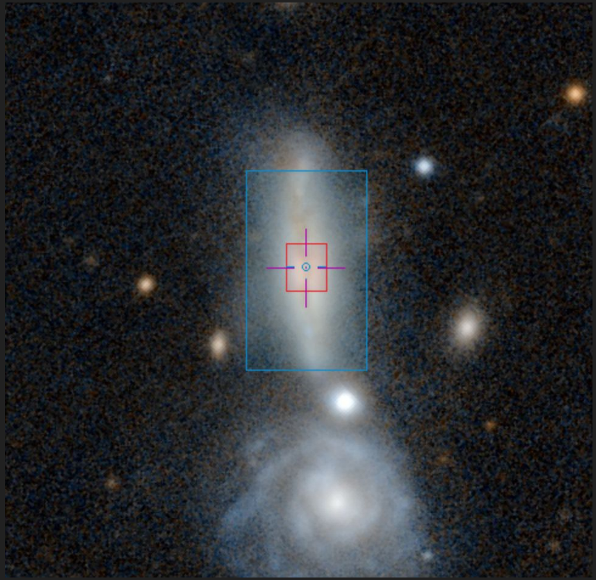
- While JWST targets dust-obscured emission from the inner kpc region of the host galaxies, Keck probes the galactic-scale optical emission.

- KCWI is a wide-field optical IFU optimized for low surface brightness emission.
  - FOV = 33” x 20” ~ 20 x 15 kpc
  - Δx ~ 1.4” x 0.3”
  - R ~ 2000-4500

- MIRI is a mid-infrared IFU ideal for observing optically obscured emission from buried AGN.
  - FOV < 8” x 7” ~ 5 x 5 kpc
  - Δx ~ 0.2” – 0.8”
  - R ~ 2000



JWST+Keck Multiscale Feedback: **Early Results (VV340)**



VV 340: Overview

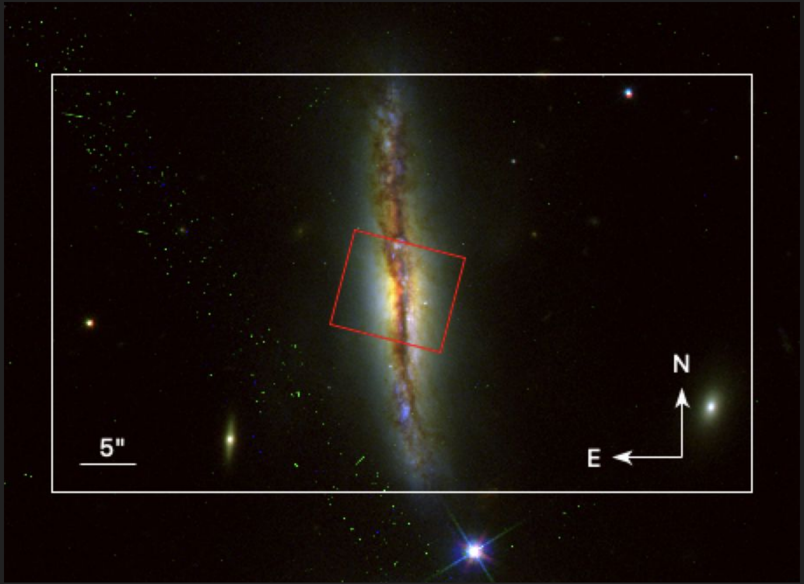
- Low redshift LIRG, consisting of a pair galaxies
    - z ~ 0.034 (157 Mpc)
    - $\log(L_{IR}/L_{Sun}) = 11.74$

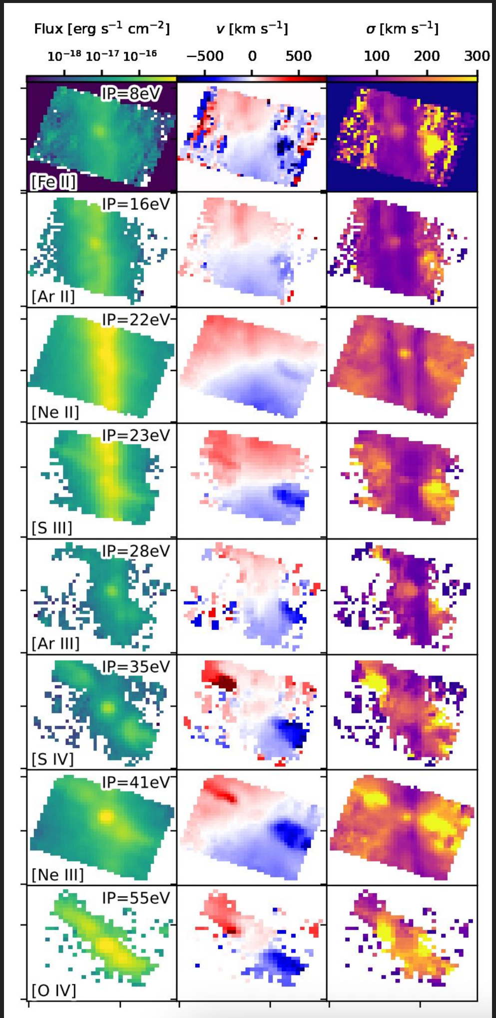
- Both are late-type disk galaxies, one edge-on (VV 340N) and one face-on (VV 340S).

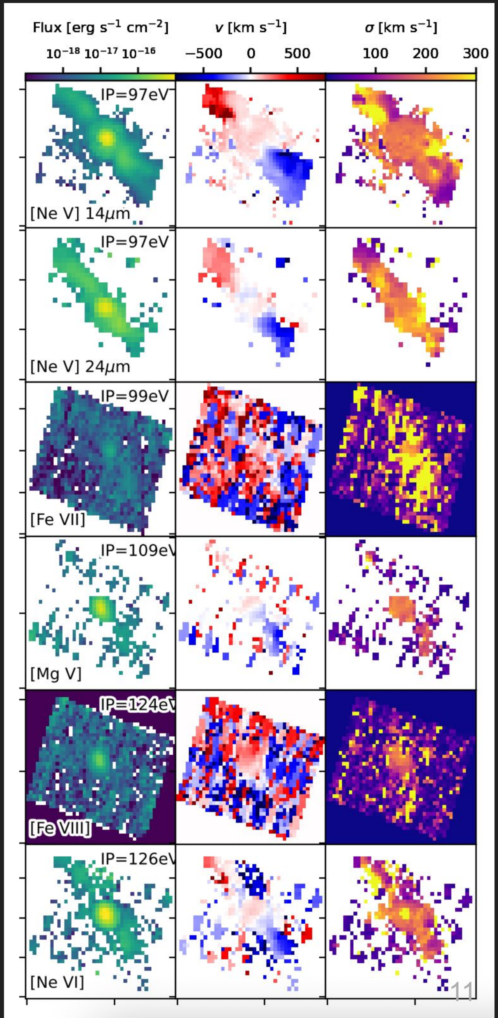
- The pair is separated by 40” = 27 kpc, at an early interaction stage.

- VV 340N is itself a LIRG, it emits 90% of the IR flux of the system.

VV 340: The MIRI Data

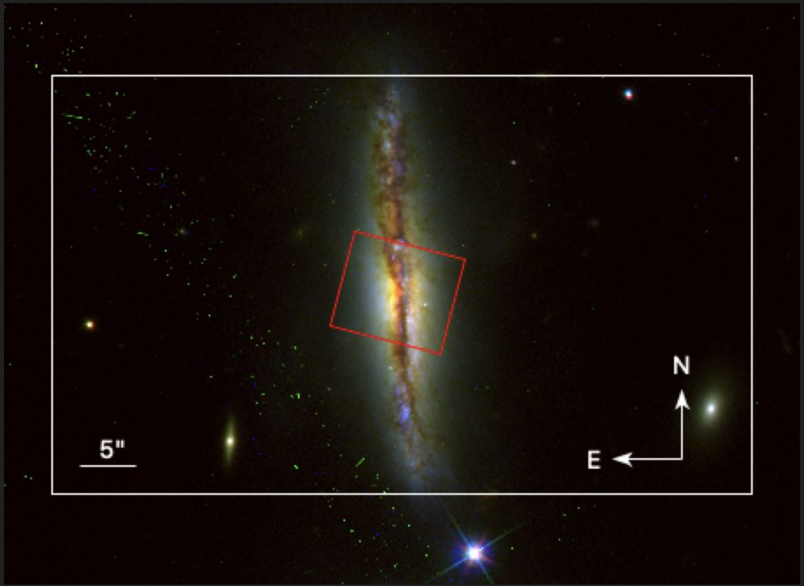


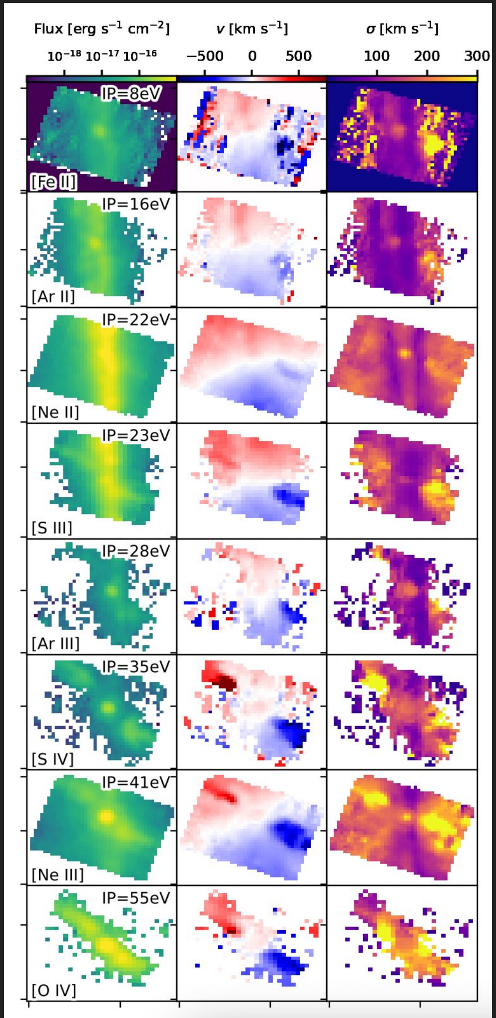


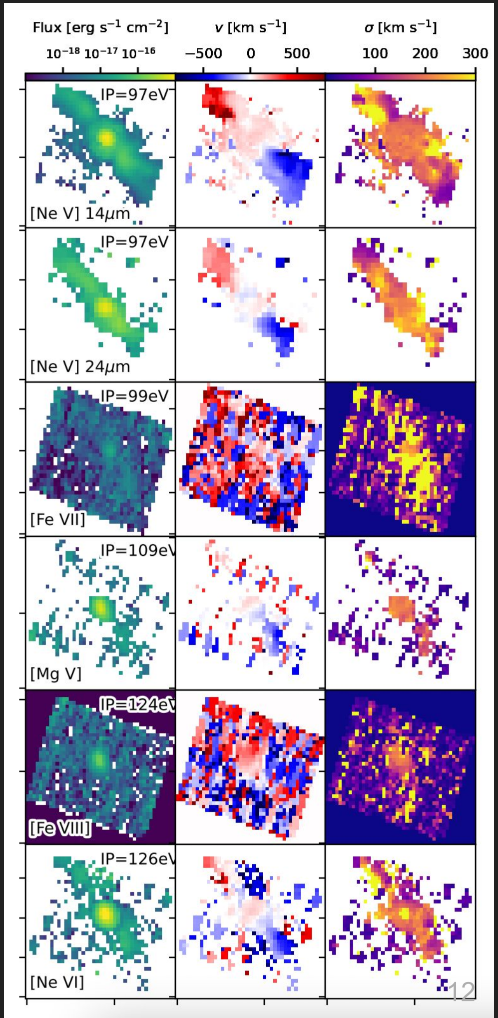


- We fit 14 bright MIR fine structure lines across the cube (within ~ 3 kpc of nucleus).

VV 340: The MIRI Data

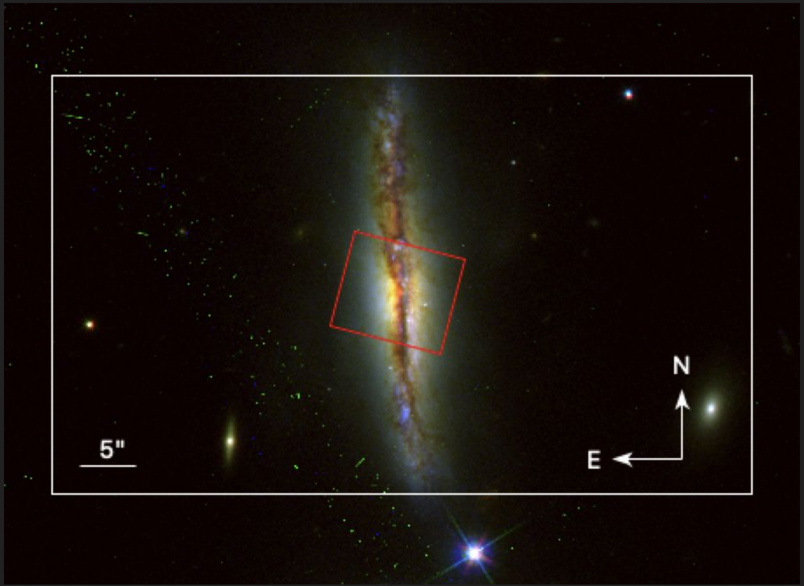


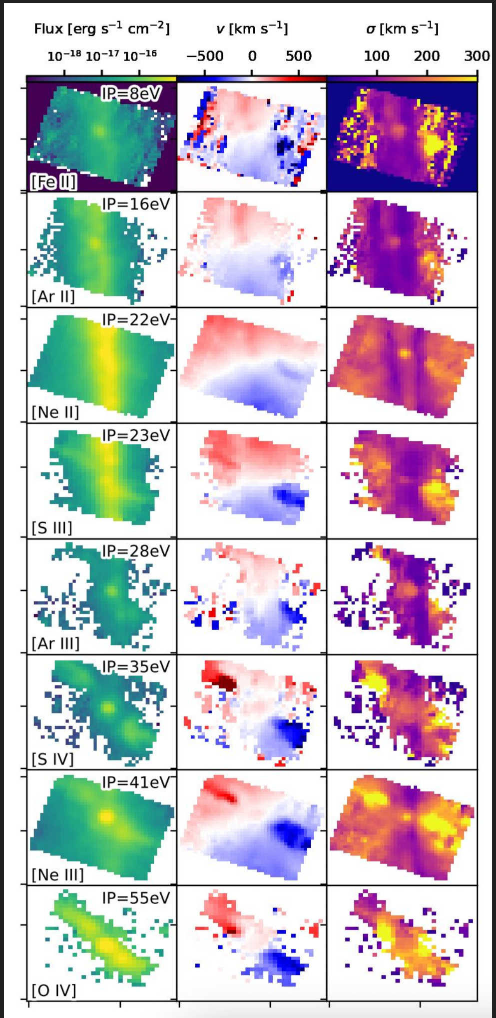


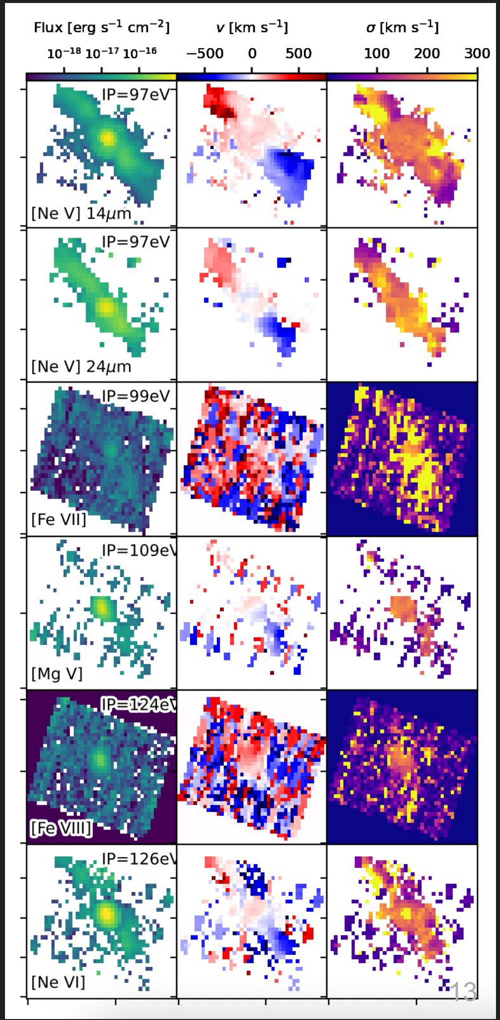


- In order of increasing IP, we see a transition from emission along the star-forming disk, to extraplanar emission at high velocity.

VV 340: The MIRI Data

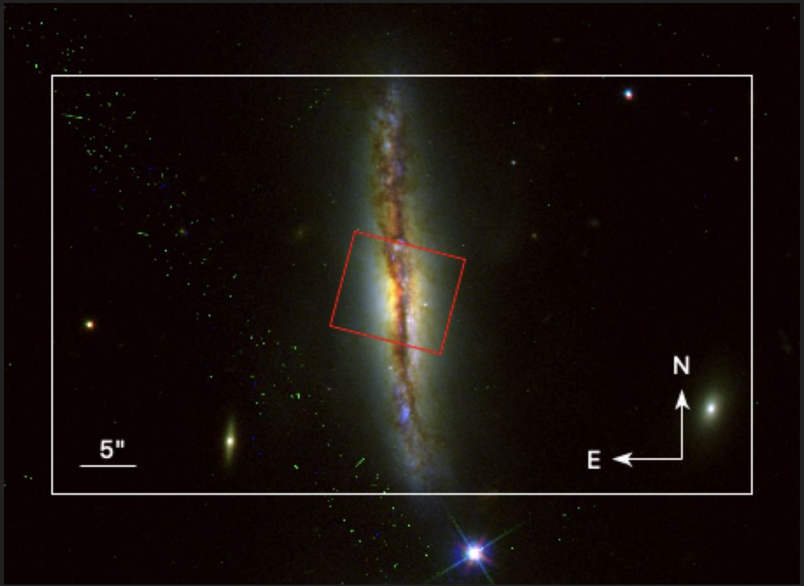


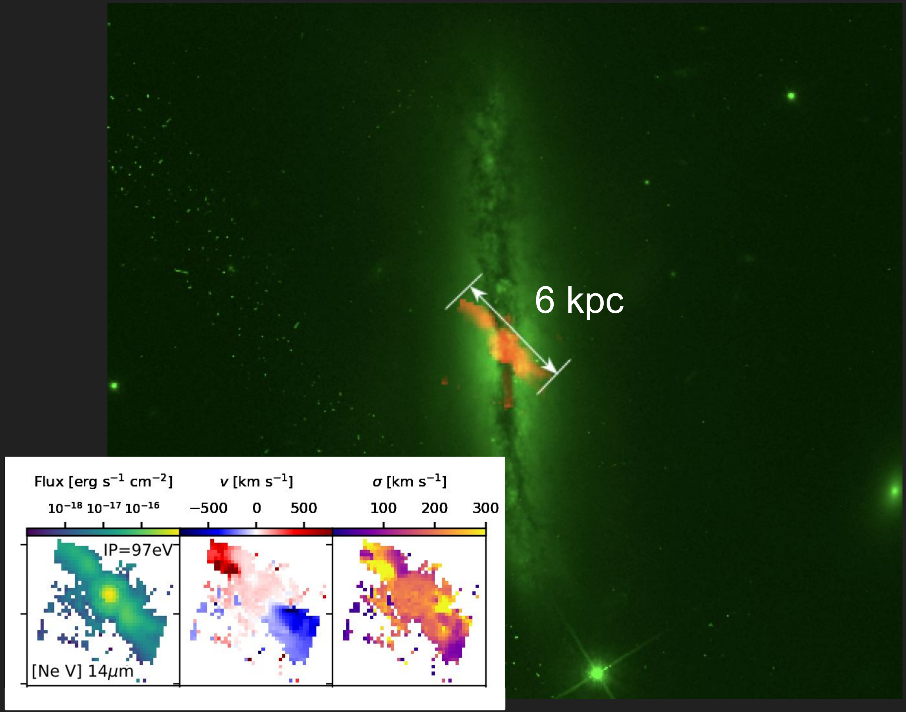




- The coronal lines (IP > 100 eV) are ionized by the AGN hard continuum.
- Indicate a high velocity collimated outflow extending to at least 3 kpc (!)

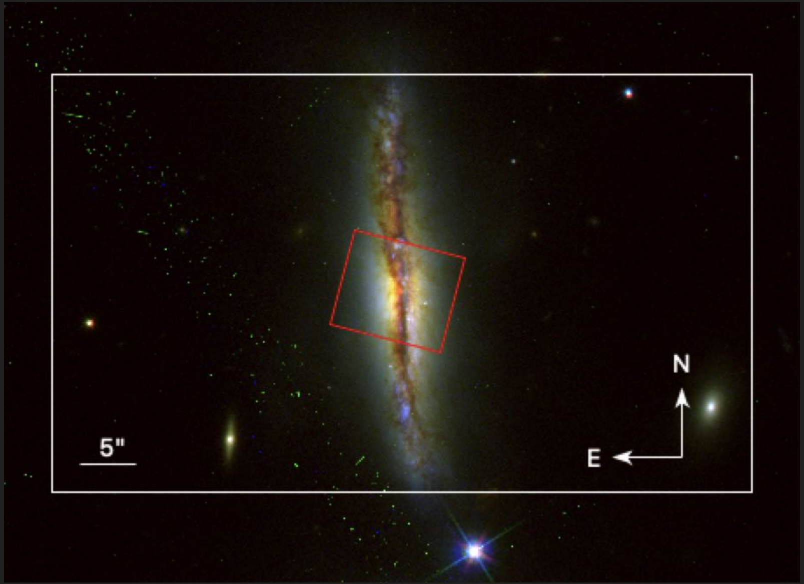
VV 340: The MIRI Data

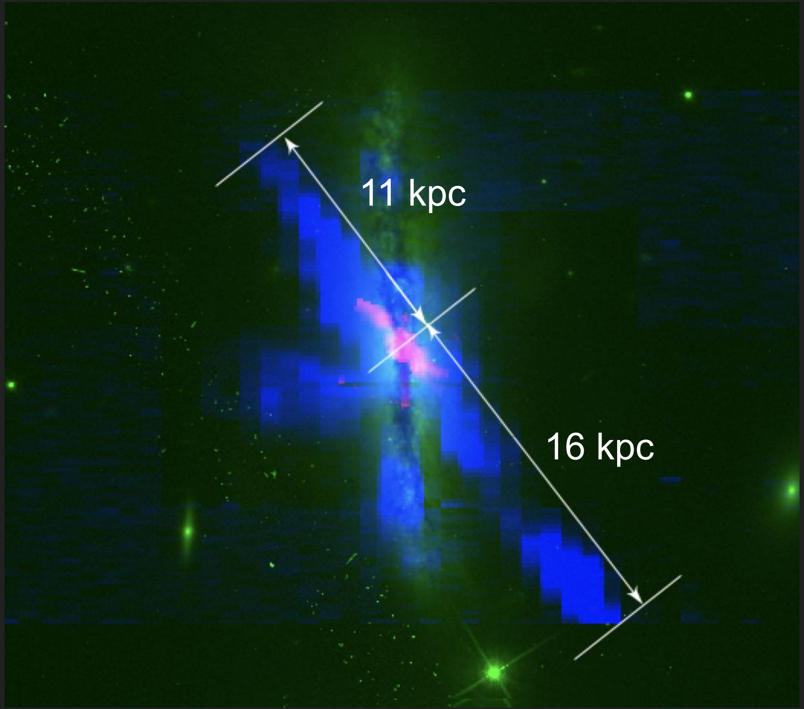




- We estimated the mass outflow rate assuming a biconical geometry and a volume filling factor of *f* = 0.001 for CLRs. An electron density is also needed, which we measured using the [Ne V]14,24 line ratio.
- The outflow rate is **dM/dt = 11.4 $M_\odot$ yr^{-1}**, with a kinetic power of **dE/dt = 1.3 x 10^{42} erg s^{-1}**.

VV 340: The KCWI Data



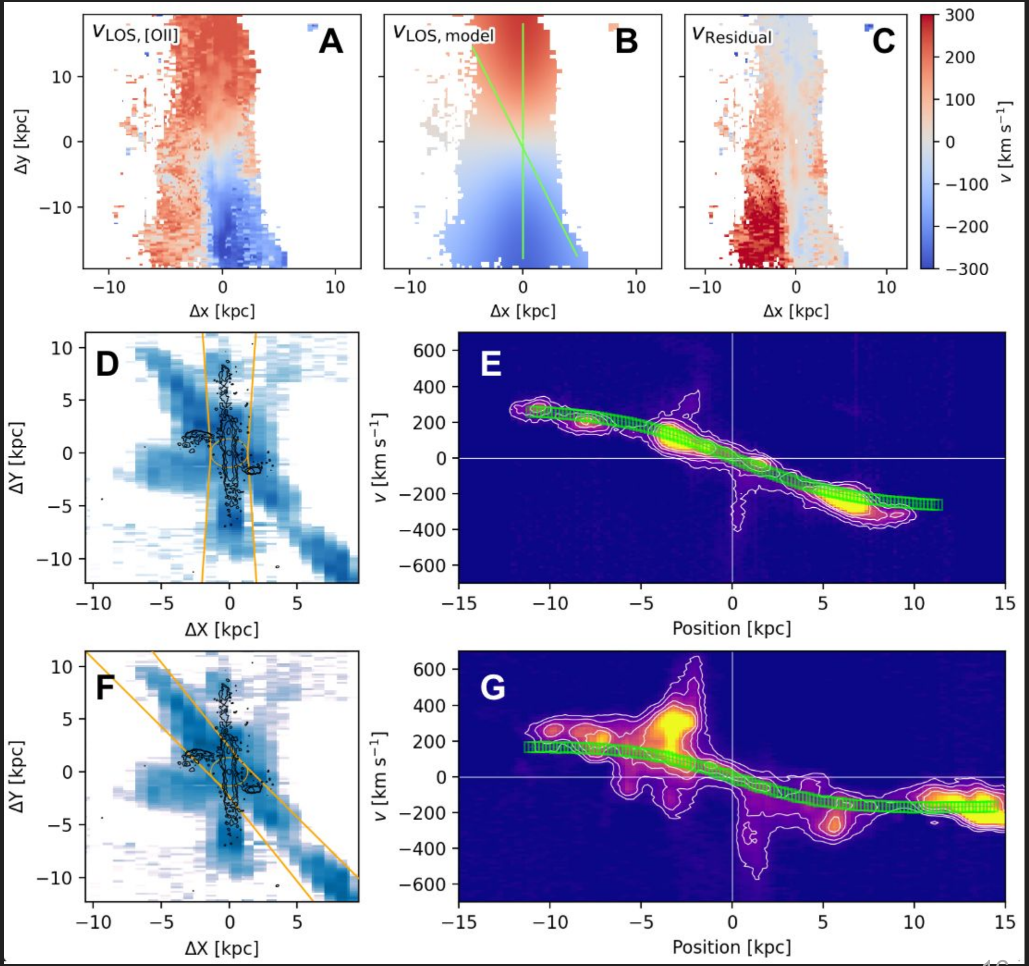


- KCWI observations were mosaicked to form a large 1’ x 0.6’ FOV (40x25 kpc).
- We detect bright [O II], [O III], Hβ, Hγ emission lines on the disk.

[Ne V] 14µm/F814W+F435W/[O III] 5007Å

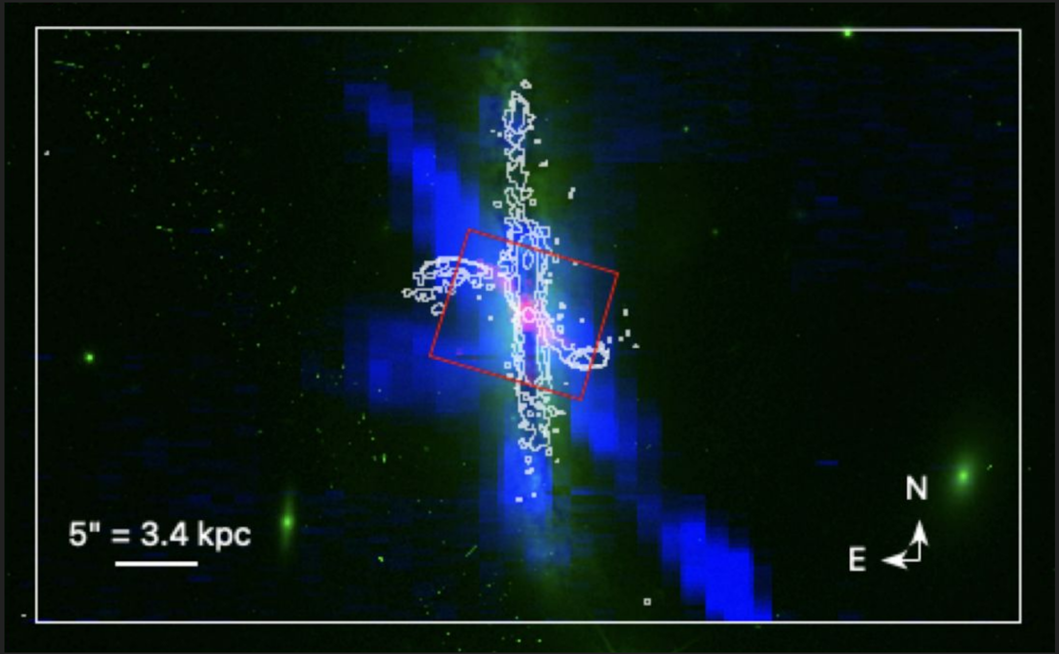
VV 340: The KCWI Data

- We fit the [O II] velocity field with a bulge+disk+halo dynamical model.
- We compared the gas velocities with the model using P–V diagrams.
- Along the star-forming disk, the gas appears to be following the expected rotation curve of the galaxy.
- Along the filaments, the gas shows non-circular motions, suggesting the large-scale nebulae are part of the outflow.



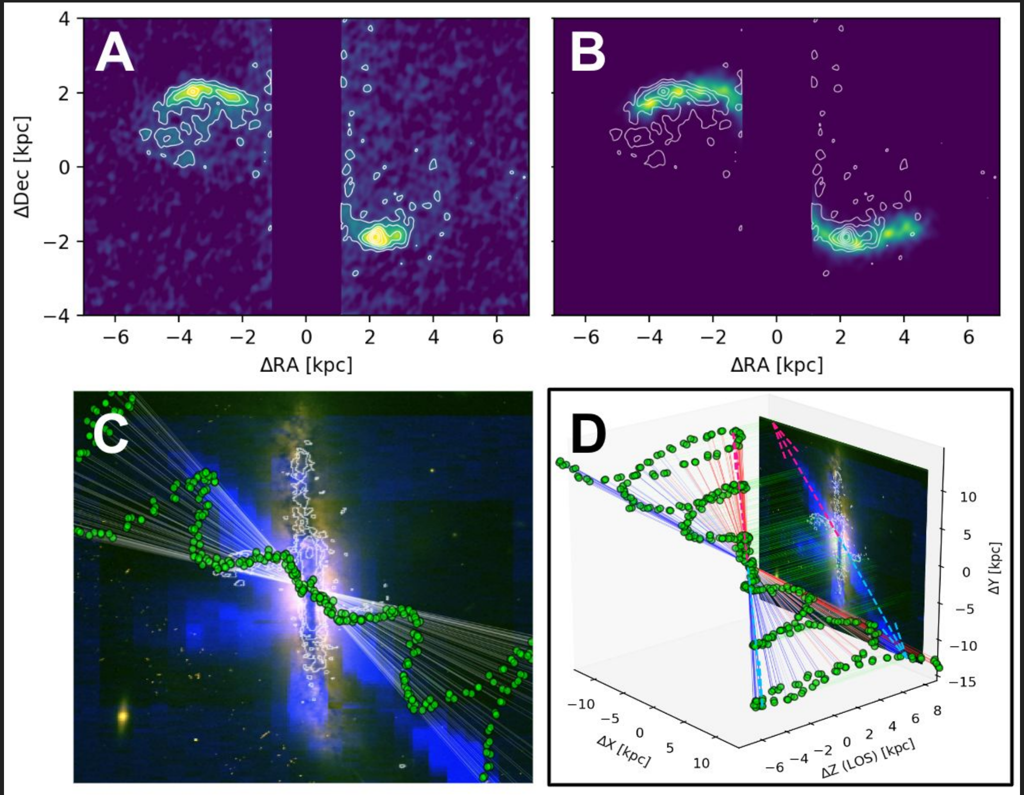
VV 340: The VLA Data

- High resolution A+B configuration VLA data reveal a remarkable structure in the 6 GHz continuum.
- A pair of narrow jets project outward ~4 kpc from the radio core in the direction of the ionized outflow.
- The jets bend symmetrically to align with the galaxy minor axis, forming an S-shape.
- The S-shape can form from precession of the jet.



VV 340: Discussion

- With a 6 GHz monochromatic luminosity of ~10^{23} W Hz^{-1}, VV 340N is radio quiet, but it's near the RQ-RL limit.
- The jet kinetic power is ~10^{43} erg s^{-1}, which is enough to power the outflow.
- The jet transfers kinetic energy and momentum into the ambient ISM, driving it outward.
- Coronal lines form in the outflowing gas from the AGN ionizing continuum.
- The extended filaments have [O III]/Hβ suggesting AGN photoionization or shocks.

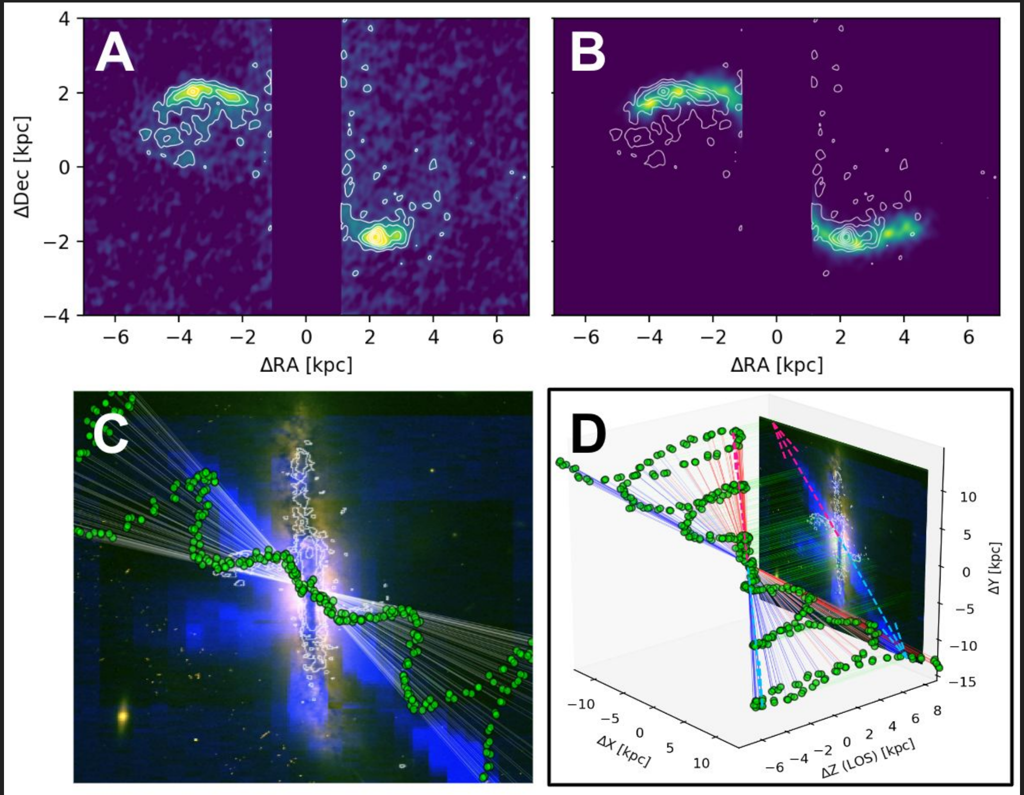


VV 340: Discussion

- The SFR in VV 340N is high, 40 M_{sun} yr^{-1}, or 4x the outflow rate, so the outflow is not quenching the galaxy via removal of gas.

- Precession provides a mechanism for the narrow collimated jet to prevent cooling of hot gas and suppress inflows over a wider area.

- The case of VV 340N demonstrates the importance of combining multiwavelength observations covering multiple spatial scales!



Outlook

- **This project:**
    - Nearly complete observations of sample.
    - Reduce uncertainties in outflow scaling relations.

- **ELTs:**
    - With massively improved angular resolution and sensitivity, ELTs will let us look beyond low redshift.
    - We can expect much larger, statistical samples of AGN outflows.

Summary

1. Early results for VV 340N, III Zw 035, etc. demonstrate KCWI is a machine to trace outflows to their full extent.

2. Multiwavelength observations are key for interpretation of outflows, their power sources and effect on host.

3. As we finish assembling the sample, we will be able to build reliable outflow scaling relations to answer when outflows truly impact their host galaxies.

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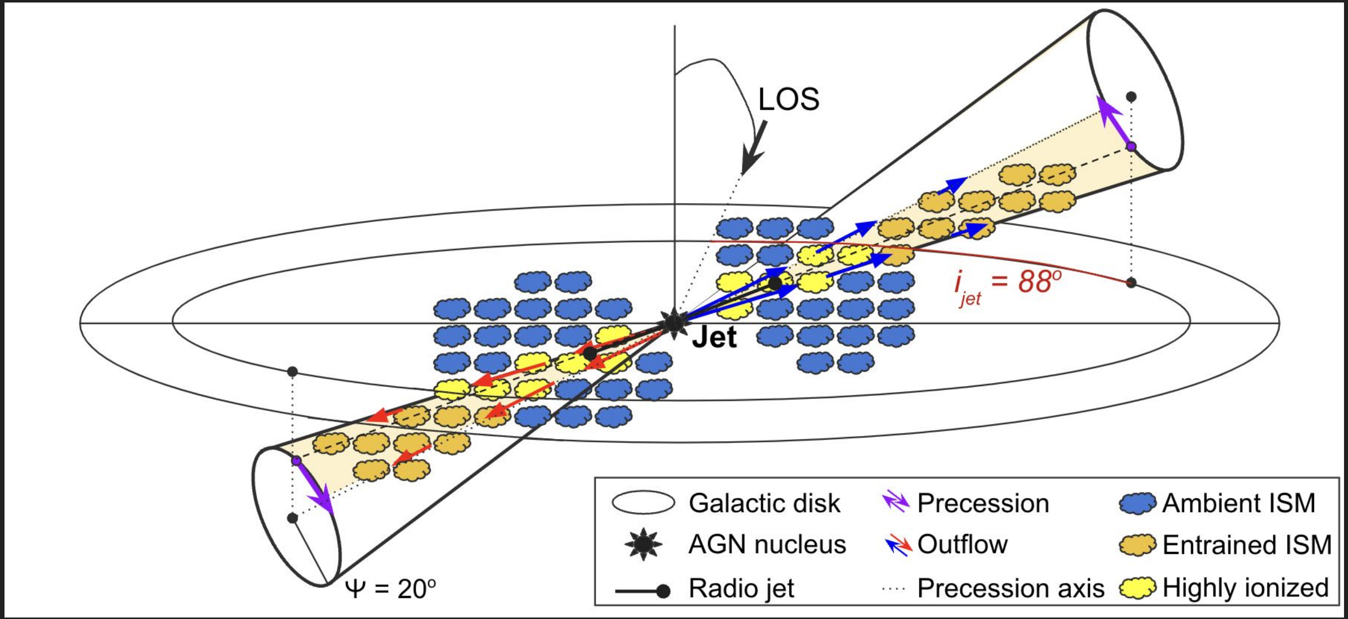
Acknowledgements:

Vivian U, Marina Bianchin, Loreto Barcos-Munoz, Yiqing Song, George Privon, Rosalie McGurk, Anne Medling, Aaron Evans, Lee Armus, Raymond Remigio, GOALS collaboration.

VV 340: Piecing it Together



- With a 6 GHz monochromatic luminosity of $\sim 10^{23}$ W Hz^{-1}, VV 340N is *nearly* bright enough to be radio loud. [Kellerman+16]
- The jet kinetic power is $\sim 10^{43}$ erg s^{-1}, which is enough to power the outflow.
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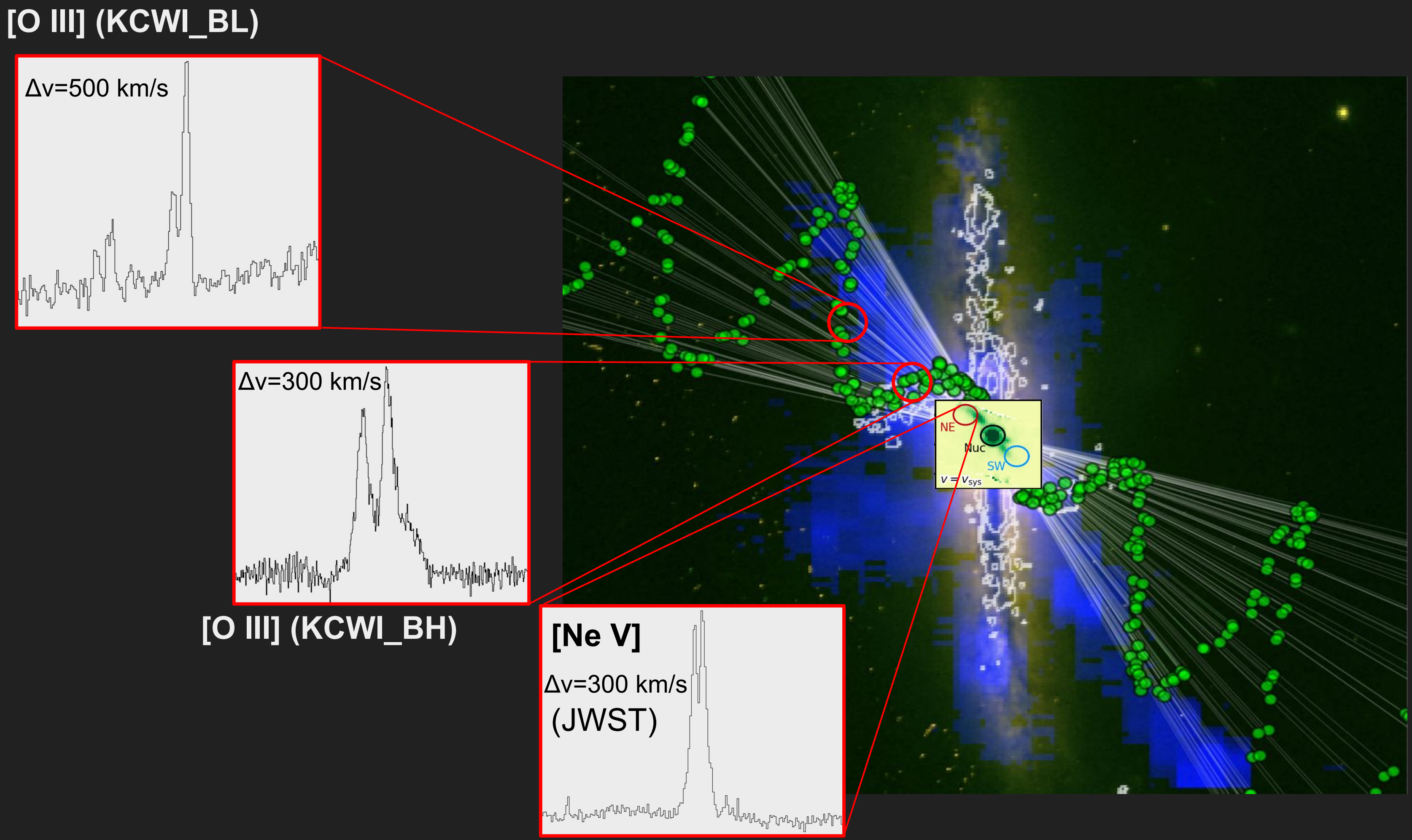
[O III] (KCWI_BL)
Δv=500 km/s
Δv=300 km/s
[O III] (KCWI_BH)
[Ne V]
Δv=300 km/s
(JWST)
NE
Nuc
SW
$v = v_{sys}$