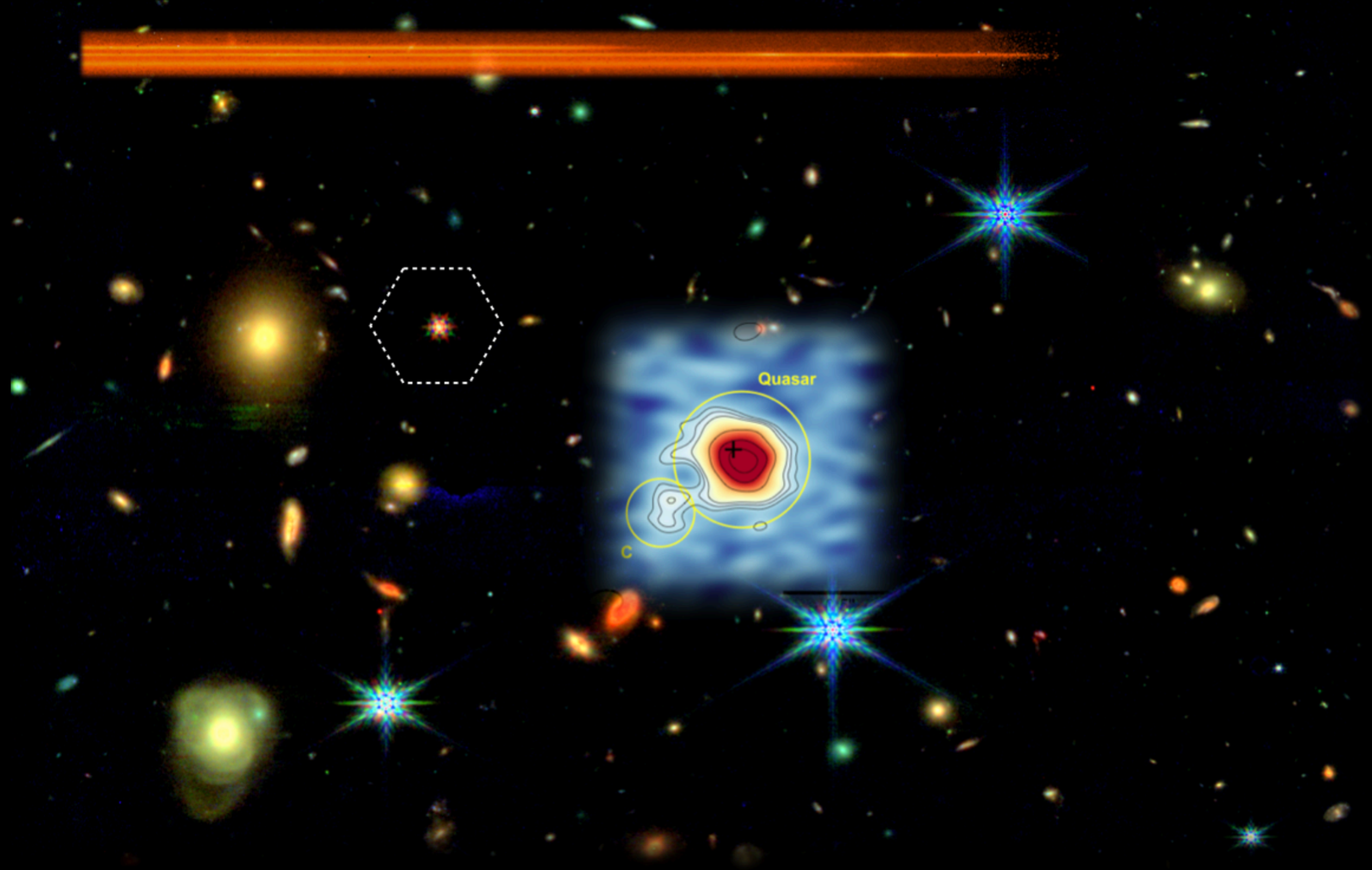
# Probing co-evolution between the earliest supermassive black holes and host galaxies using JWST and ALMA

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University of Arizona
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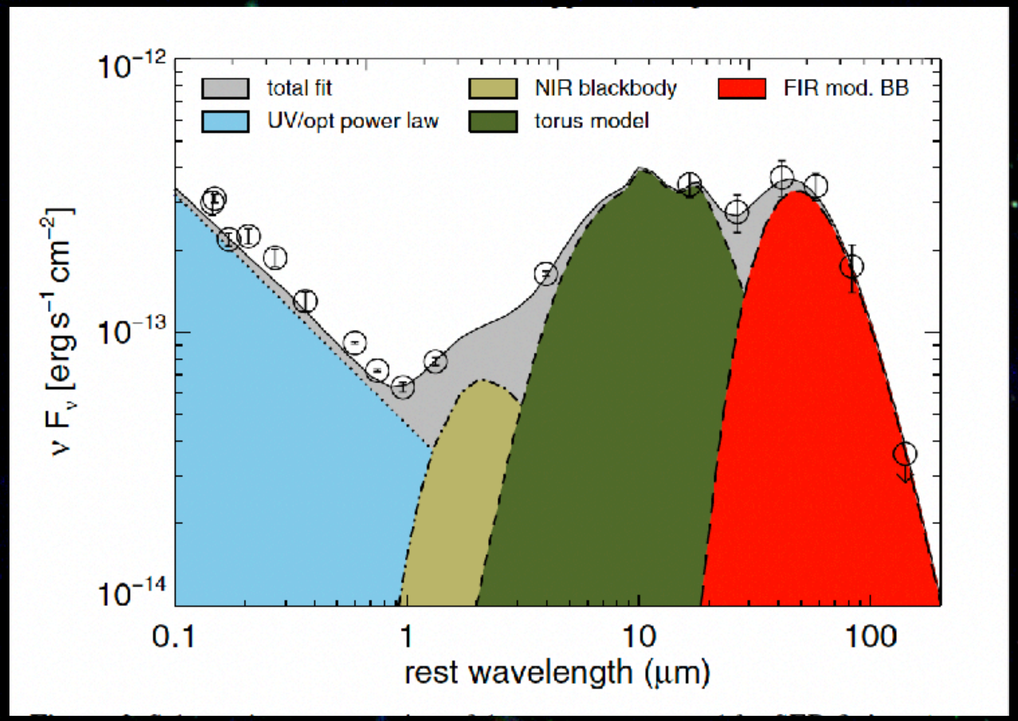
The EREBUS collaboration
(GO2078+GO1764)

Jan 08, 2024 @ AAS 243, New Orleans

# Quasars

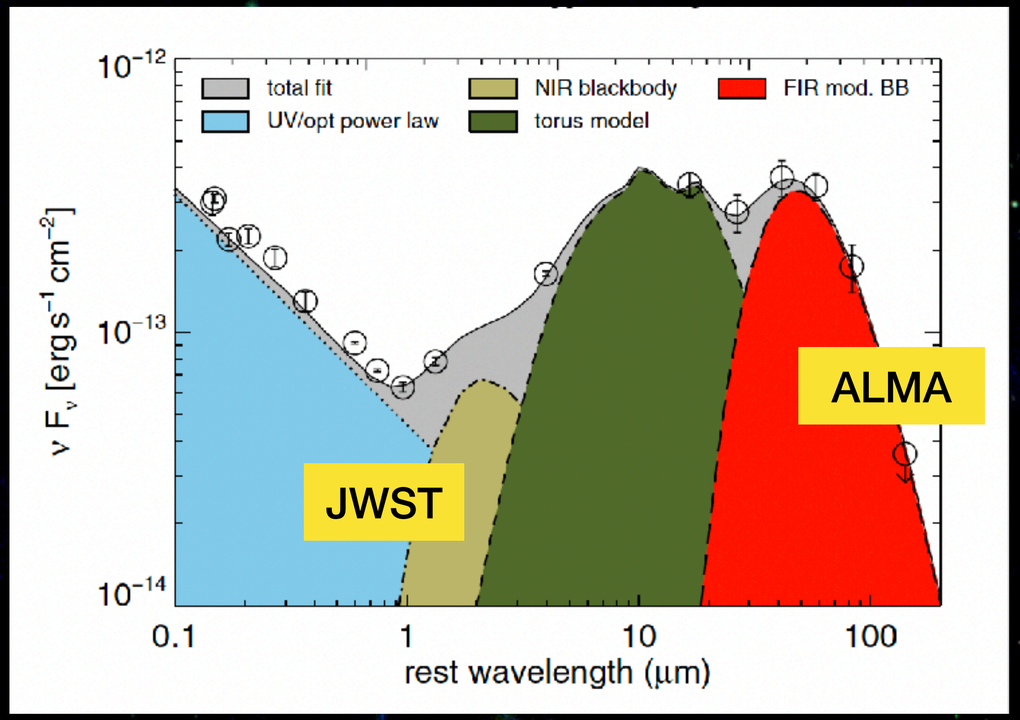



Leipski et al. 2014

- Compact, active nucleus
- Supermassive black holes (SMBHs)
- High luminosity
- Multi-wavelength emission from X-ray to radio

# Quasars at z ≳ 6

~ 920 Myr after the Big Bang




Leipski et al. 2014

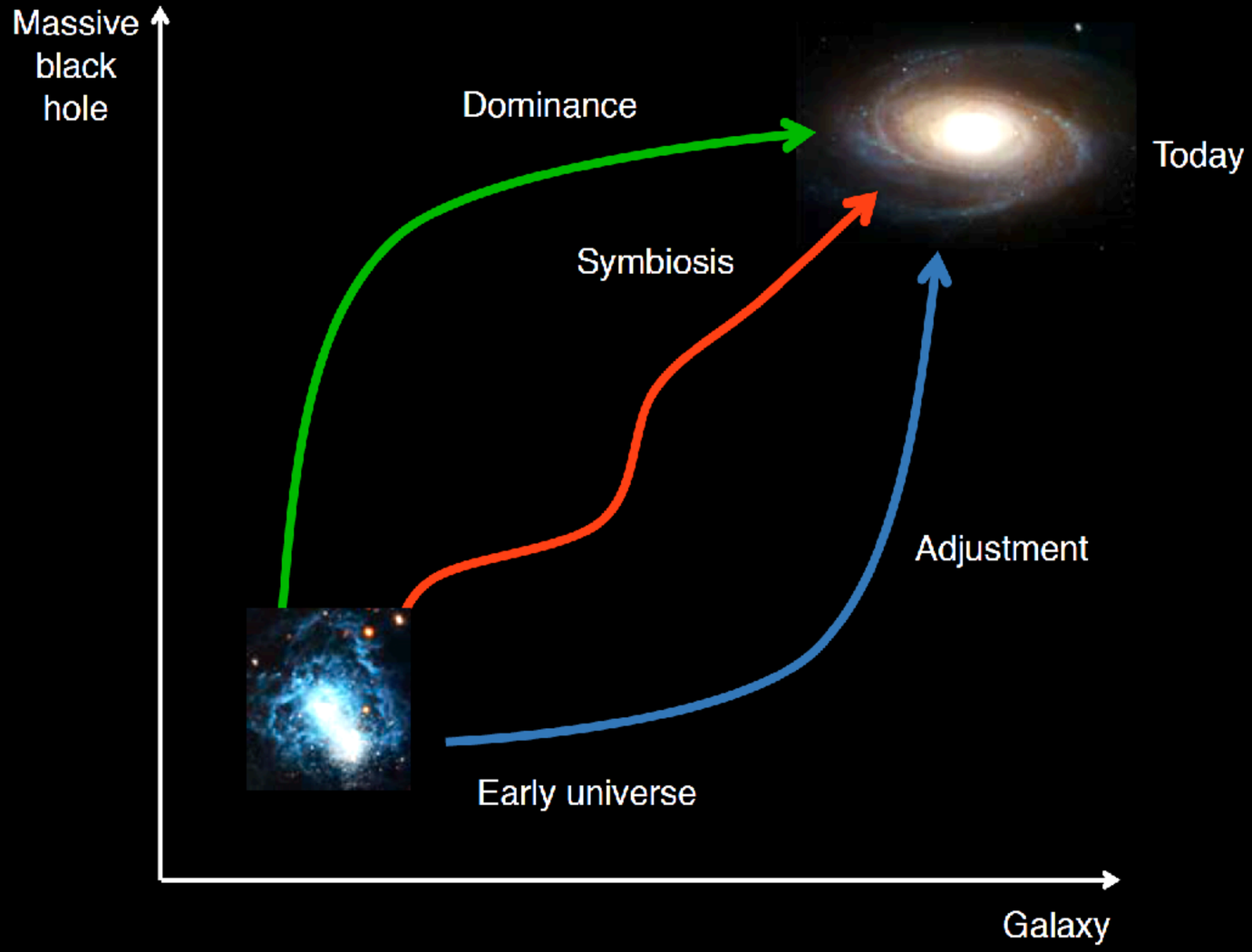
- ➡ Early SMBHs
- ➡ Early massive galaxies

- ➡ Intergalactic medium
- ➡ Intervening metal absorbers
- ➡ Metallicity evolution

- ➡ Overdense environments
- ➡ Early massive halos
- ➡ Large scale structure

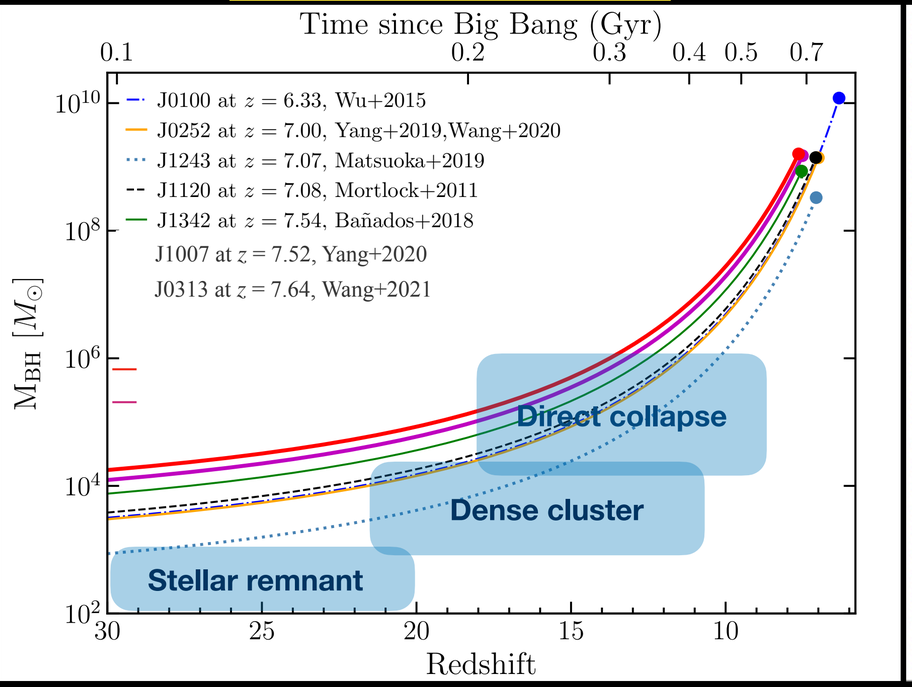
# SMBH - Host Galaxy of $z > 6$ Quasars

Volonteri 2012

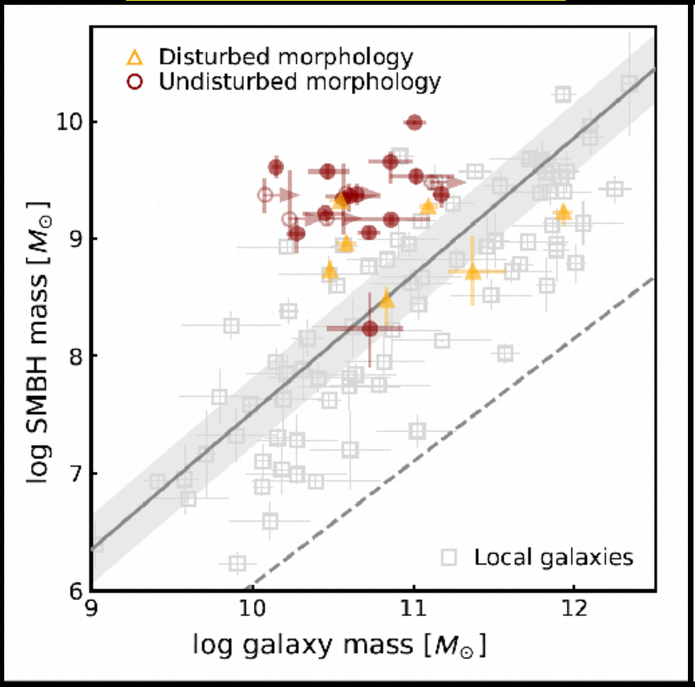


# SMBH - Host Galaxy of $z > 6$ Quasars

## Massive BH seeds

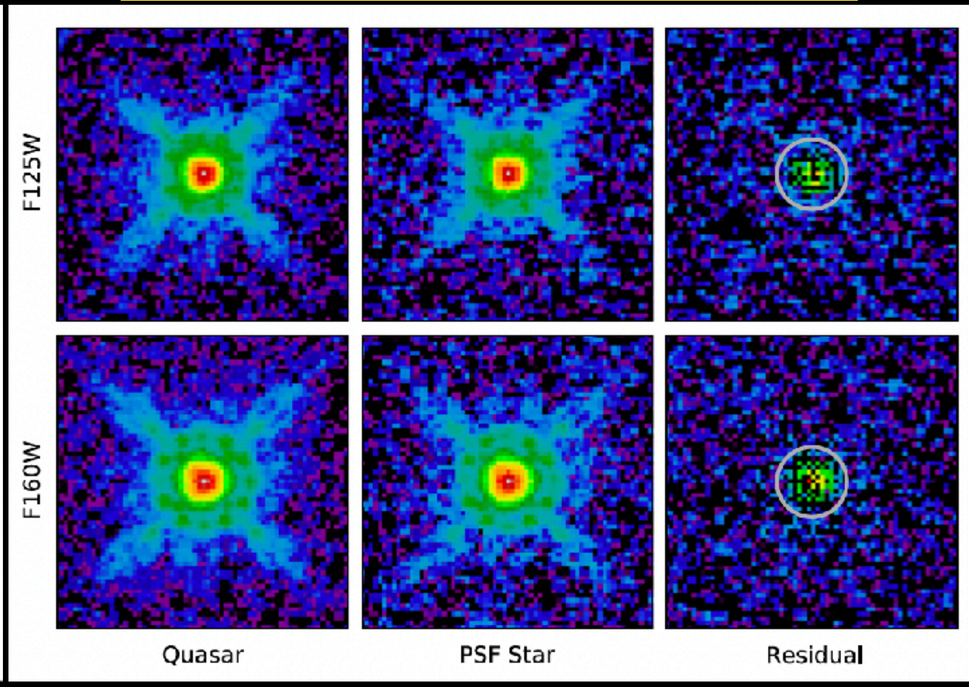



## Overmassive BHs




Neeleman+ 2021

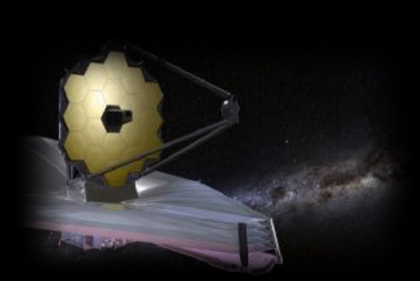
## No detection of host with HST




Mechtley+ 2012

Overmassive BHs in distant luminous quasars?

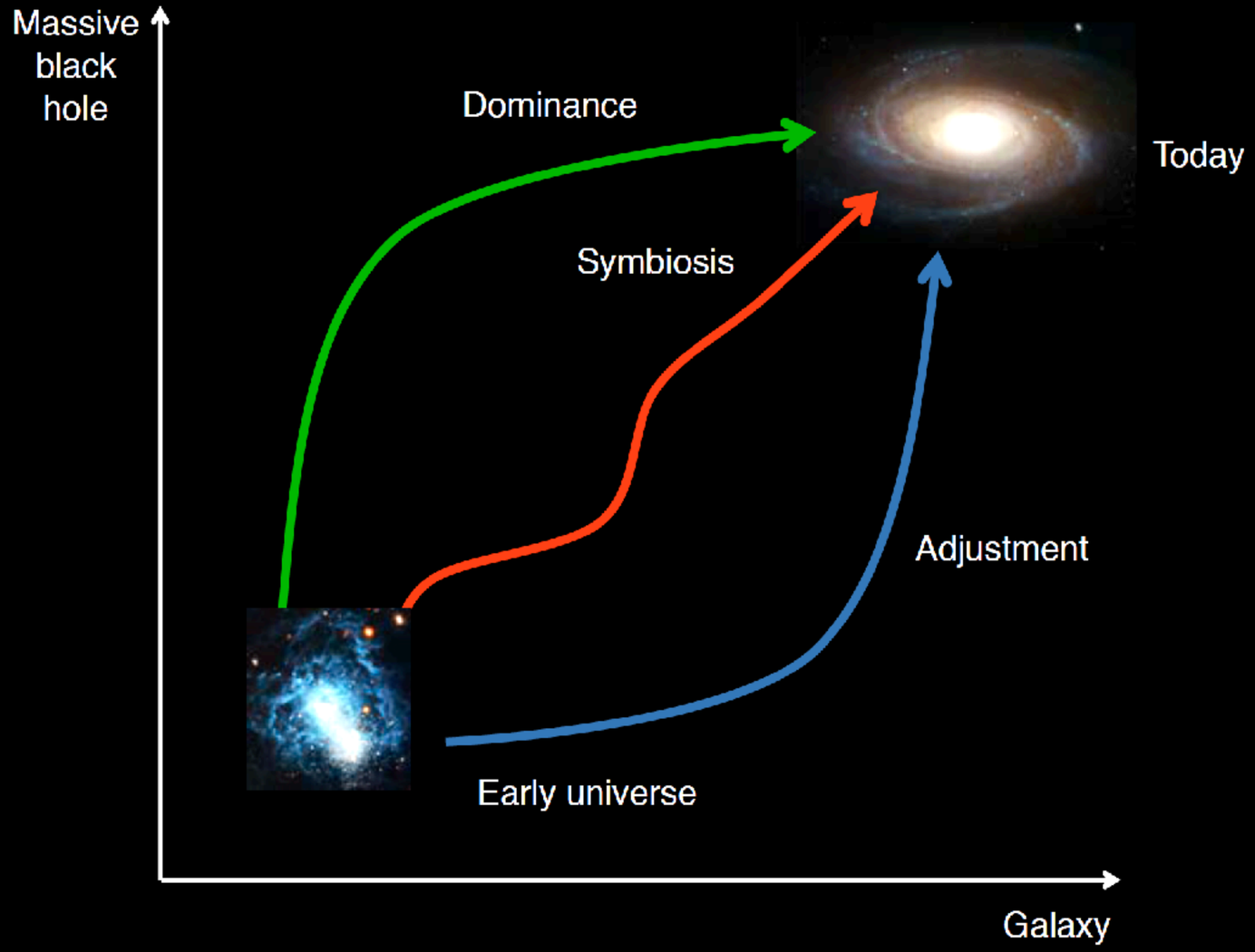
What kind of interactions between early SMBHs and their hosts?

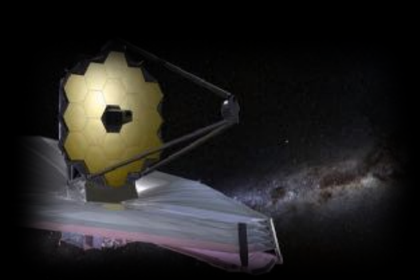


# The *JWST* - ALMA era

Credit: ESO/B. Tafreshi

Volonteri 2012





# The *JWST* - ALMA era

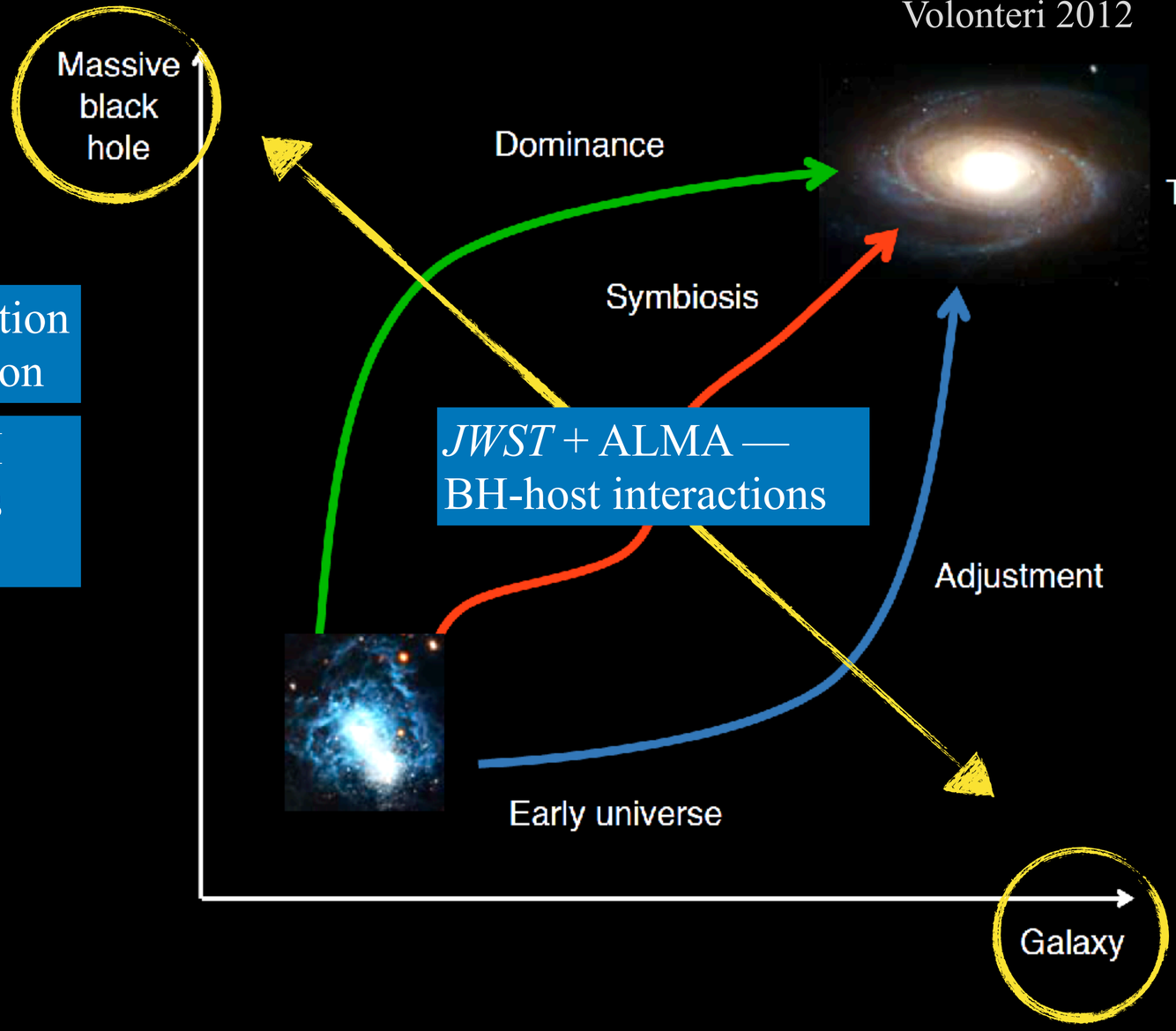
Credit: ESO/B. Tafreshi

Volonteri 2012

*JWST* — Hβ-based BH mass

BH mass function and its evolution

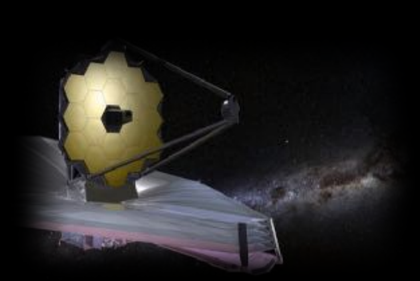
ALMA — BH mass from gas kinematics




*JWST* — UV SFR, stellar mass, star formation history

ALMA — morphology, gas kinematic, dynamical mass

*JWST*+ALMA — dust obscuration



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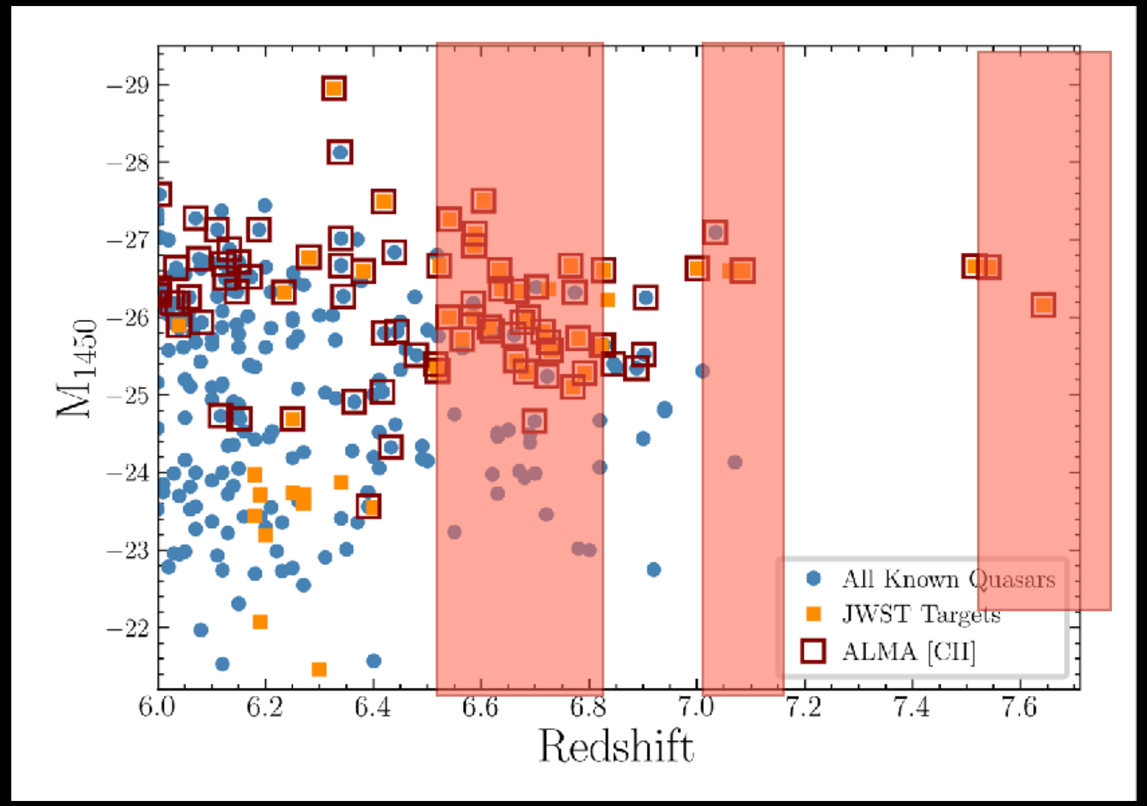



**A *JWST*-ALMA sample covering ~ 30 luminous quasars at z ~ 6.5 - 7.6**

## ✳ ASPIRE (GO 2078)

— "A SPectroscopic survey of Biased Halos In the Reionization Era: A Quasar Legacy Survey"

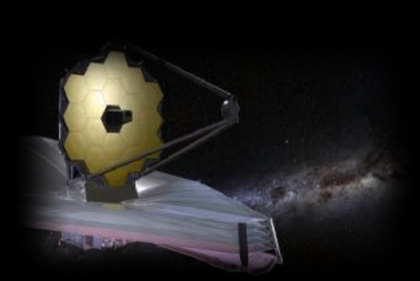
NIRCam slitless and imaging in 25 $z > 6.5$ quasar fields

**Feige Wang's talk in 317 AGN/Quasar V on Wed, 11:20 - 11:30**

## ✳ Quasar Frontier Program (GO 1764)

— "A Comprehensive JWST View of the Most Distant Quasars Deep Into the Epoch of Reionization"

NIRCam Imaging, NIRSpec FSS, NIRSpec IFU, MIRI Imaging, MIRI MRS for the three z~7.5 quasars



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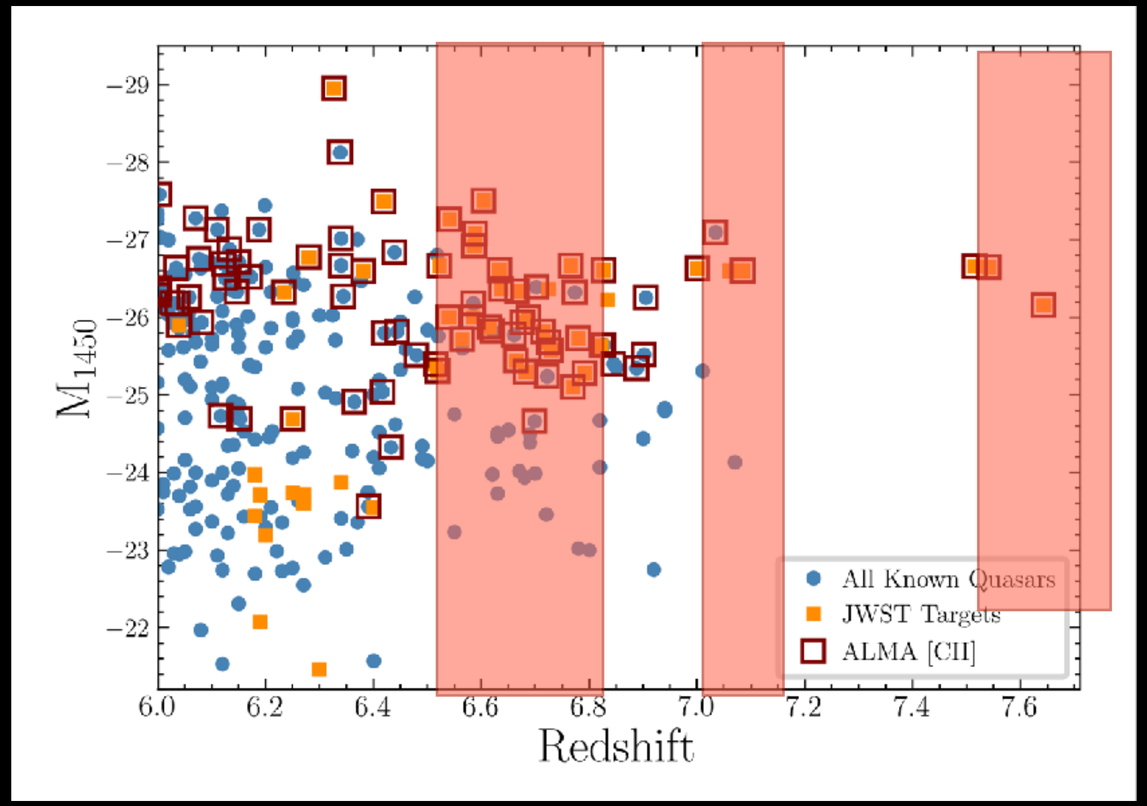
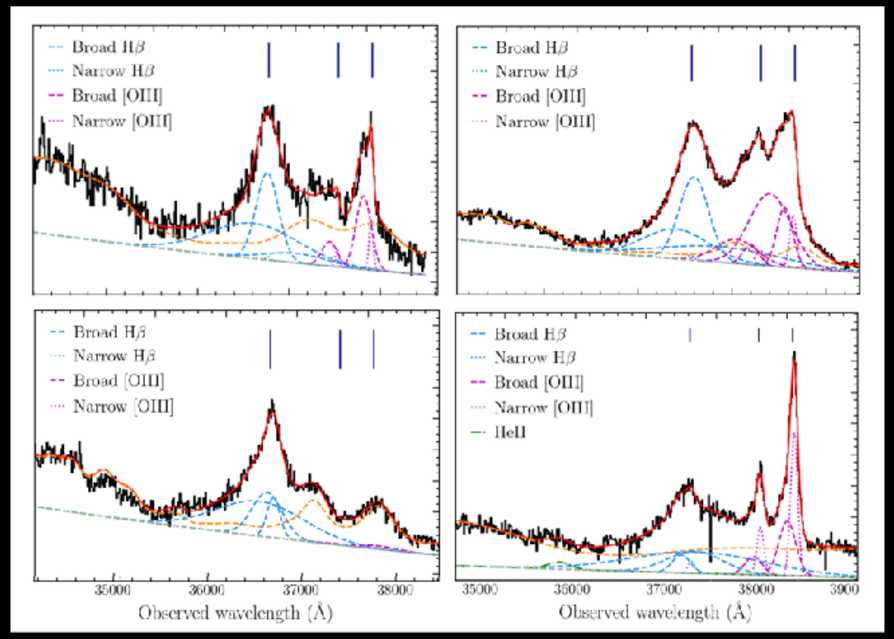
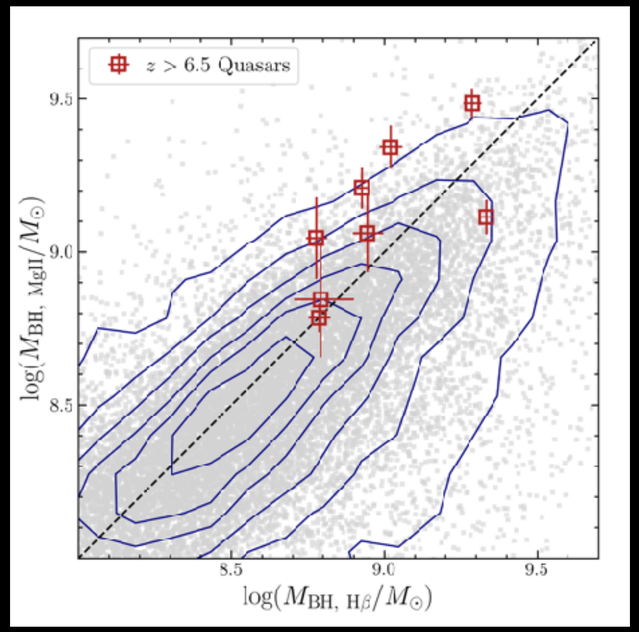



- ~120 hours JWST
- ~10 ALMA programs
- ~120 hours ALMA low-resolution (one large)
- ~70 hours ALMA high-resolution
- Multi-wavelength: from X-ray to radio

**A *JWST*-ALMA sample covering ~ 30 luminous quasars at z ~ 6.5 - 7.6**

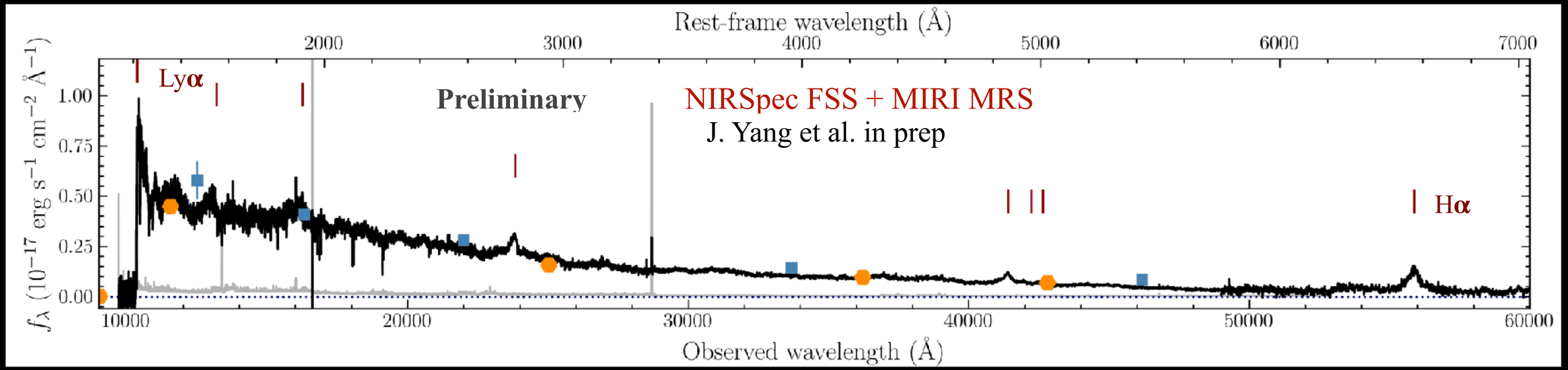
# **Quasar rest-frame optical emission and BH**, from NIRCam, NIRSpec, and MIRI




Yang et al. 2023

- Diverse H$\beta$ and [OIII] lines;
- Generally consistent MgII and H$\beta$ masses.
- Billion solar-mass BHs exist at z > 6.5.



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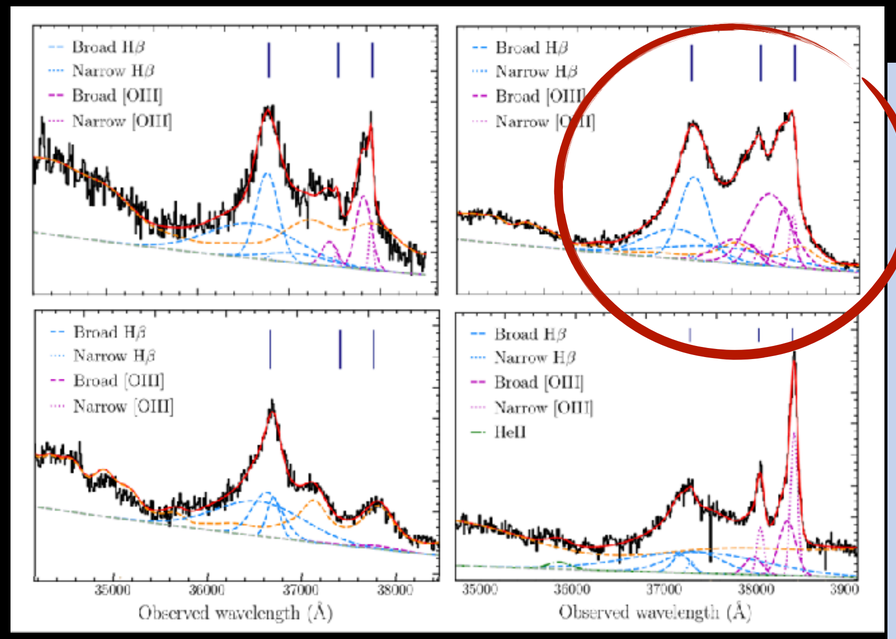
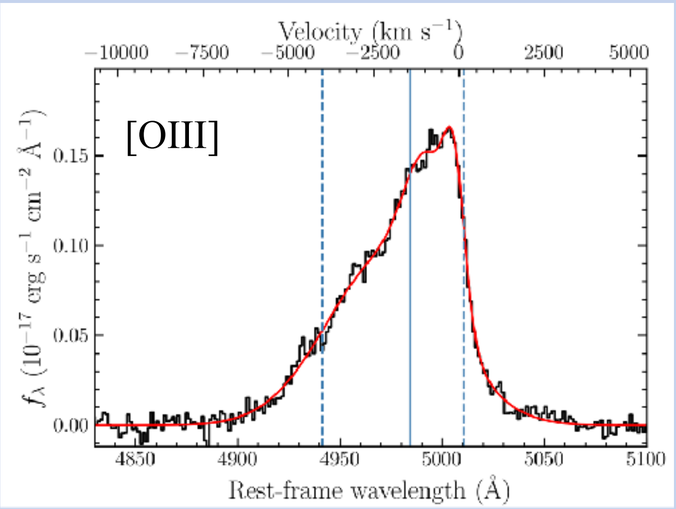



Yang et al. 2023

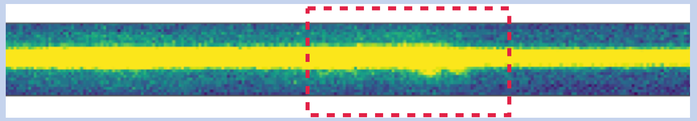
verse Hβ and [OIII] lines;

nerally consistent MgII and Hβ masses.

llion solar-mass BHs exist at z > 6.5.




Yang et al. 2023

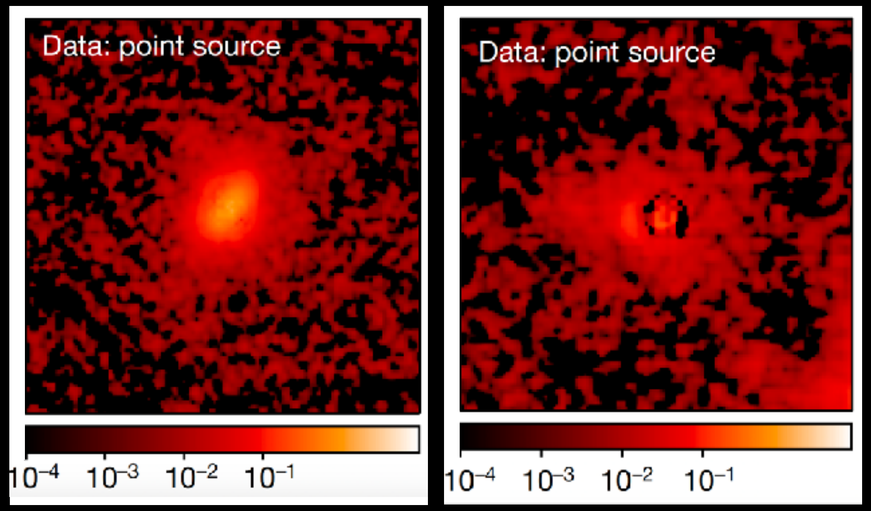


Extreme [OIII] outflow feature, with a $w_{80}$ of 4140 km s$^{-1}$

# Quasar host galaxies revealed by JWST

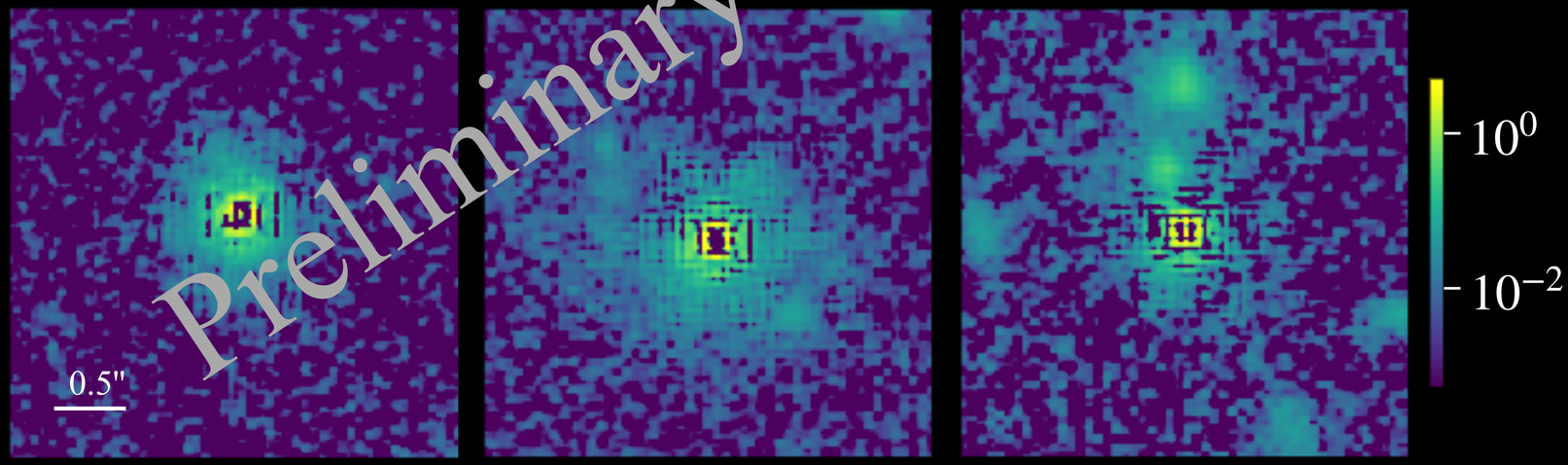
Please No Photos

Faint Quasars




Ding et al. 2023

Luminous Quasars

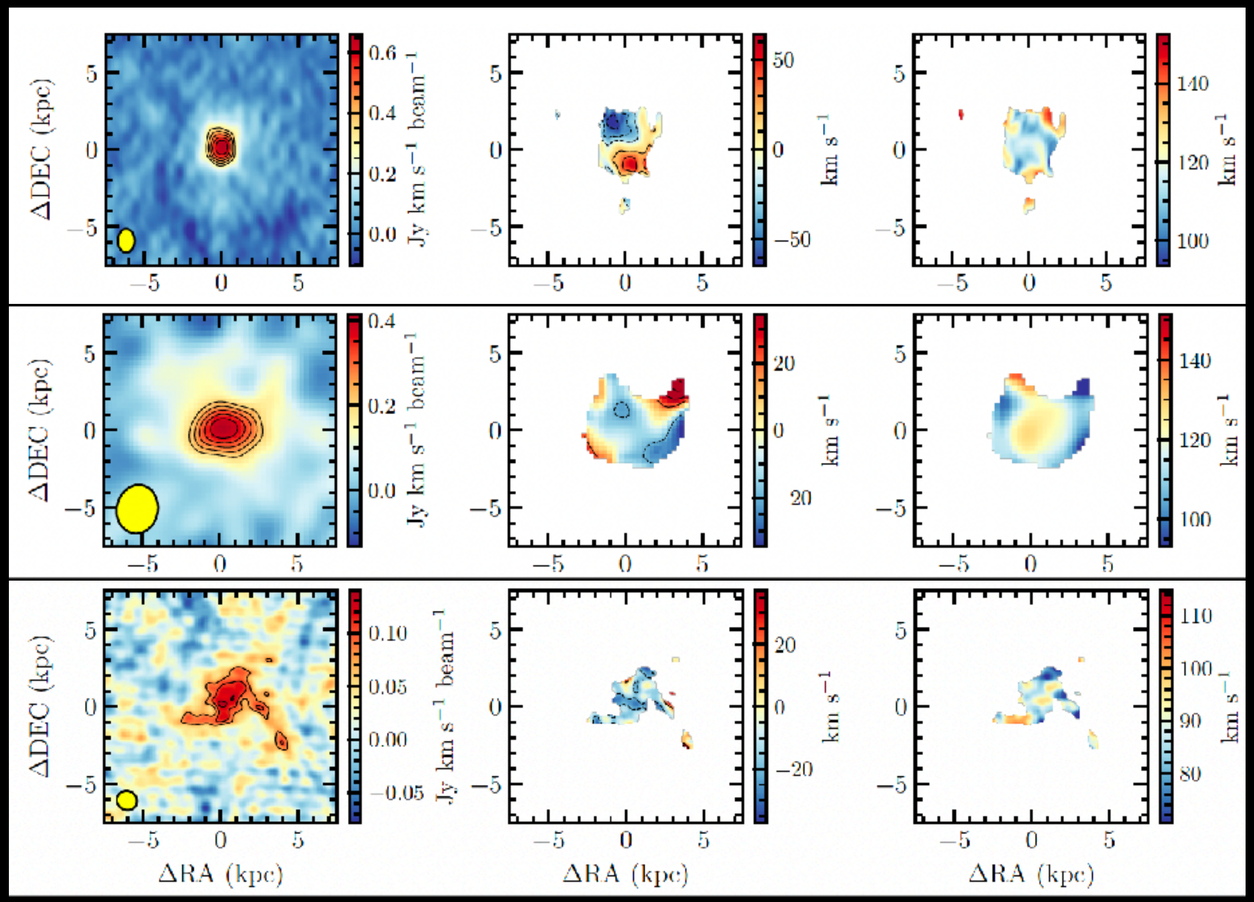



J. Yang et al. 2024 in prep

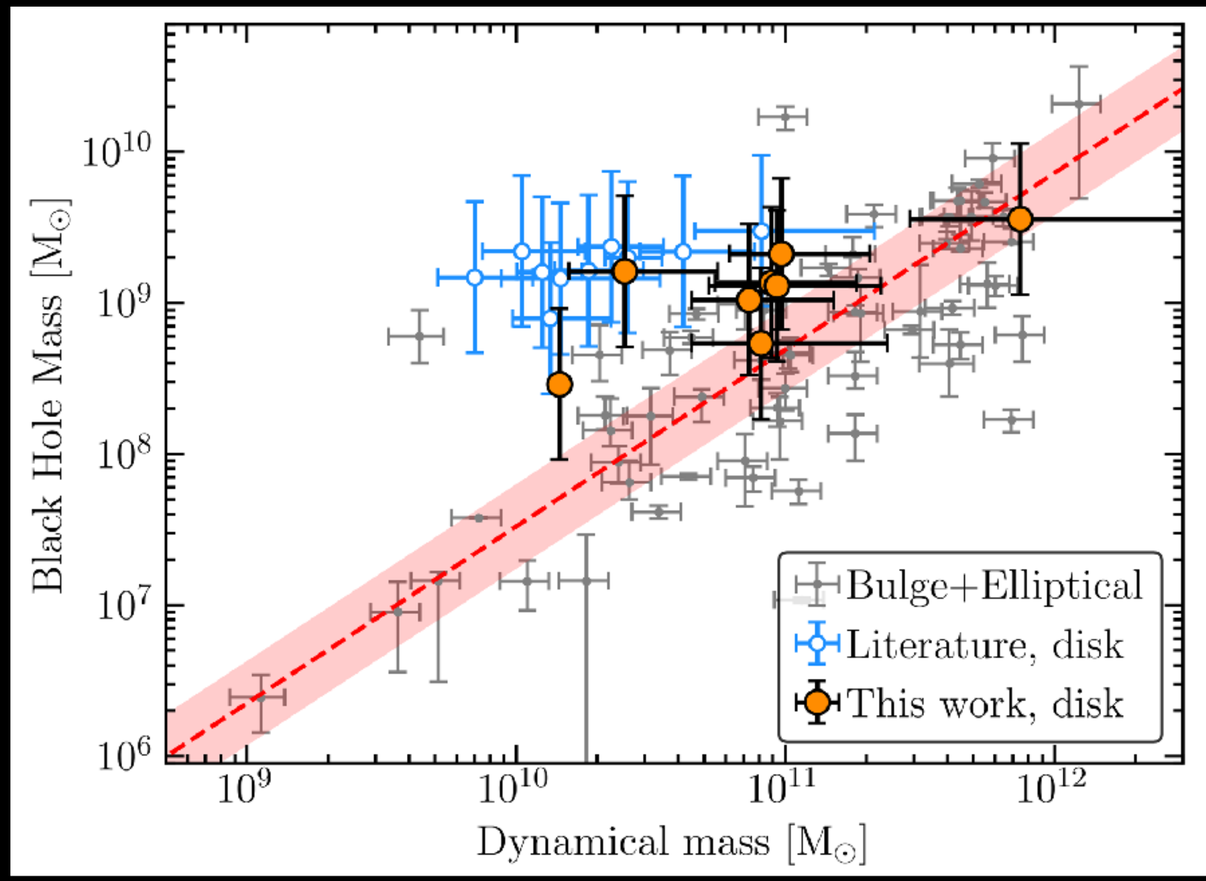
# ALMA — imaging the FIR emission of the host galaxy

Rest-frame FIR, tracing dust and cool gas ([CII]);
All have ALMA observations;
Half covered by high resolution ( $\sim 0.1'' - 0.15''$,  500 - 800 pc) data;

mom 0 mom 1 mom 2




Wang, **Yang** et al. 2024 submitted



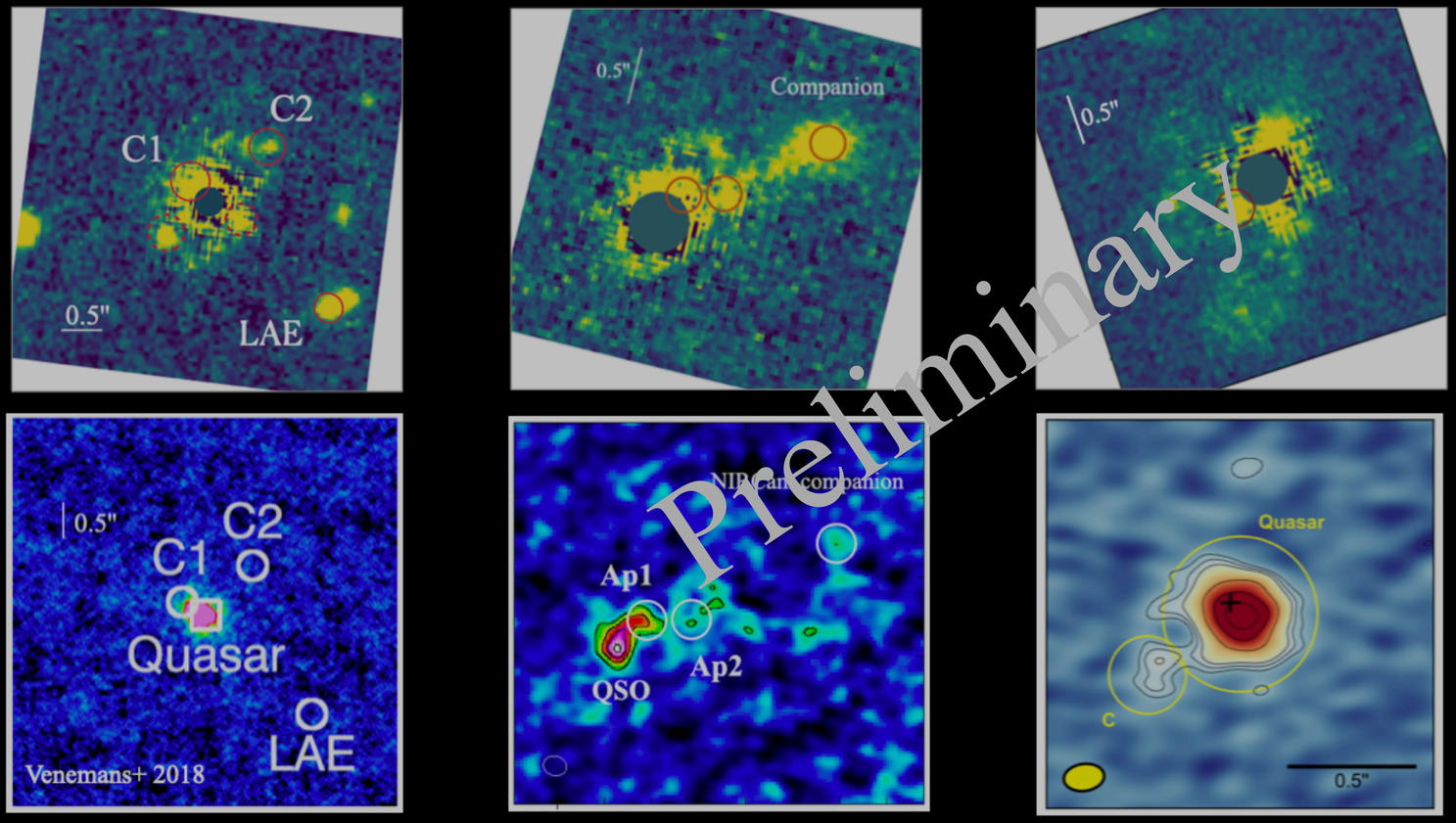
# JWST + ALMA: The assembly of early quasars

Please No Photos

Luminous quasars in busy systems

JWST

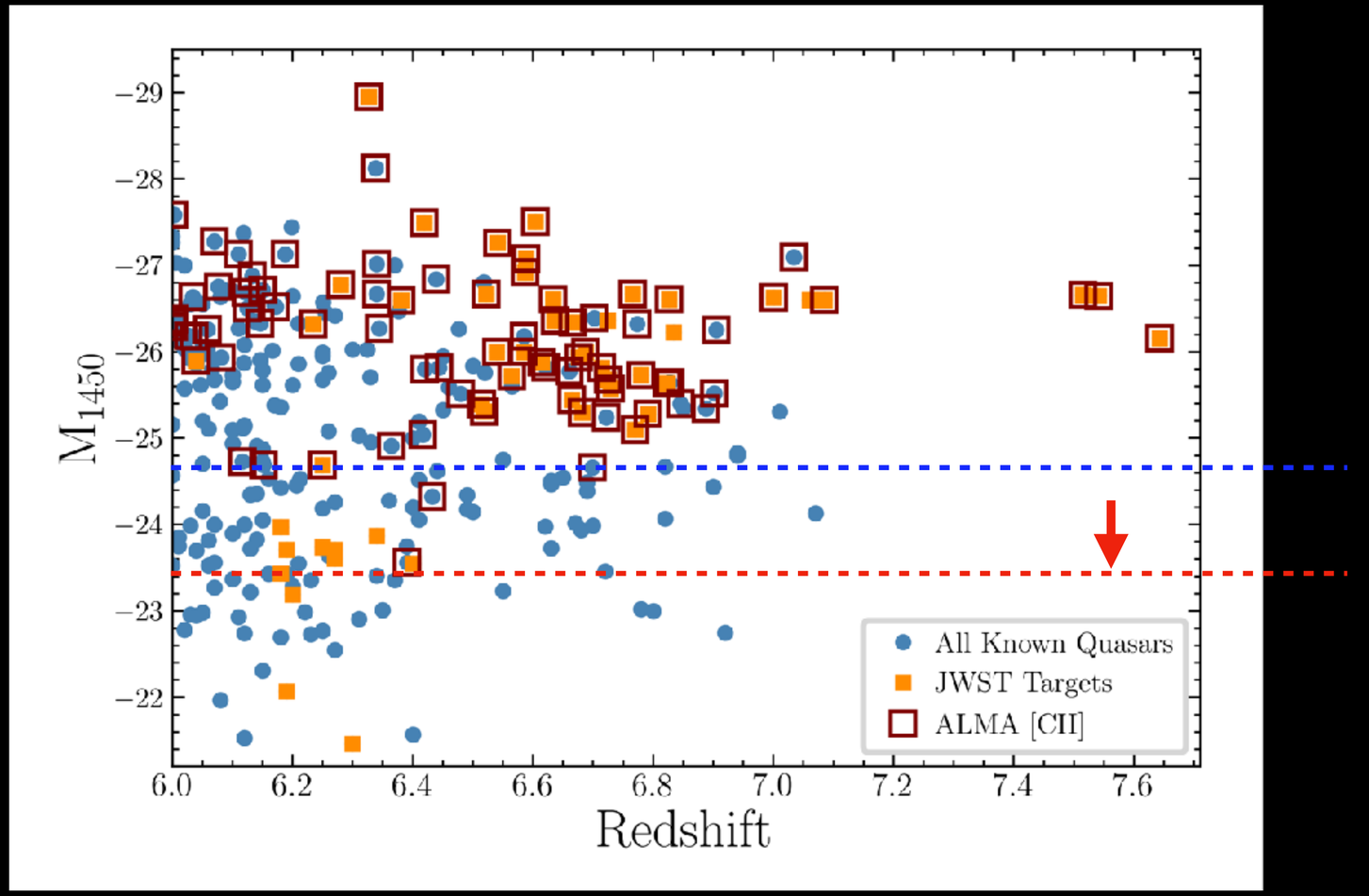
ALMA




J. Yang et al. 2024 in prep

**ALMA WSU:**

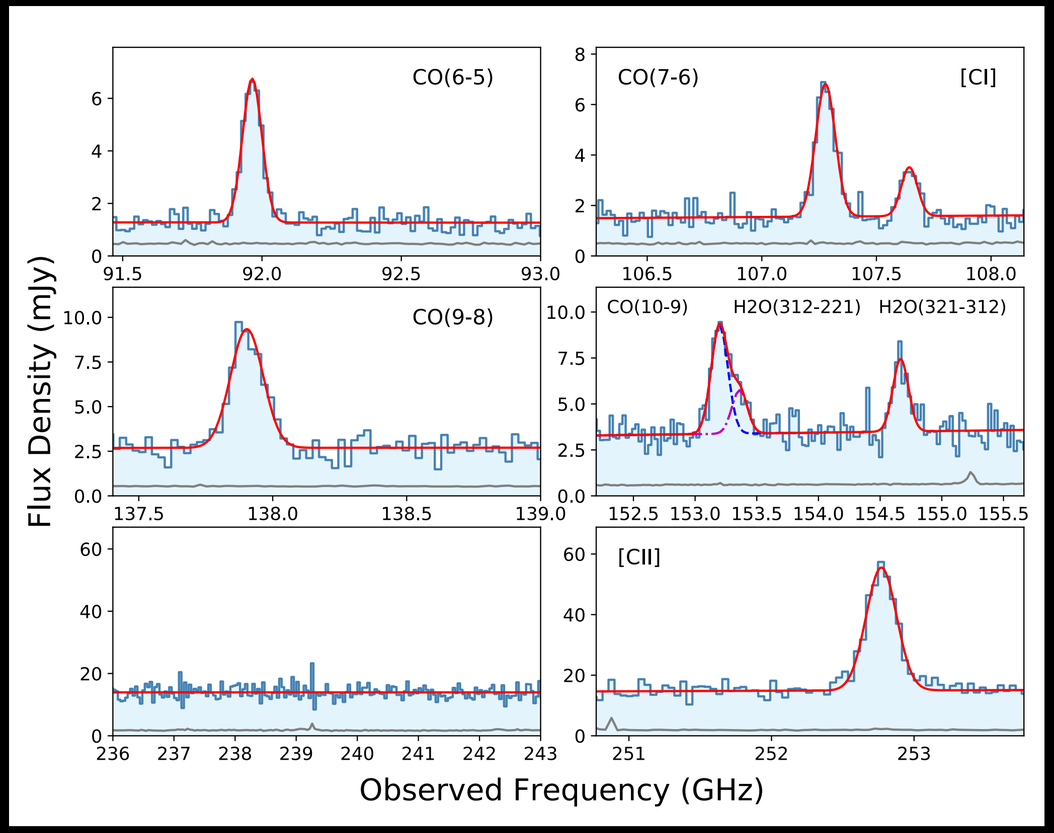
- Two times deeper [CII] survey of high-z objects



**ALMA WSU:**

- More than two times deeper [CII] survey of high-z objects
- Line surveys — molecular gas excitation, [CI] line, water vapor emission …

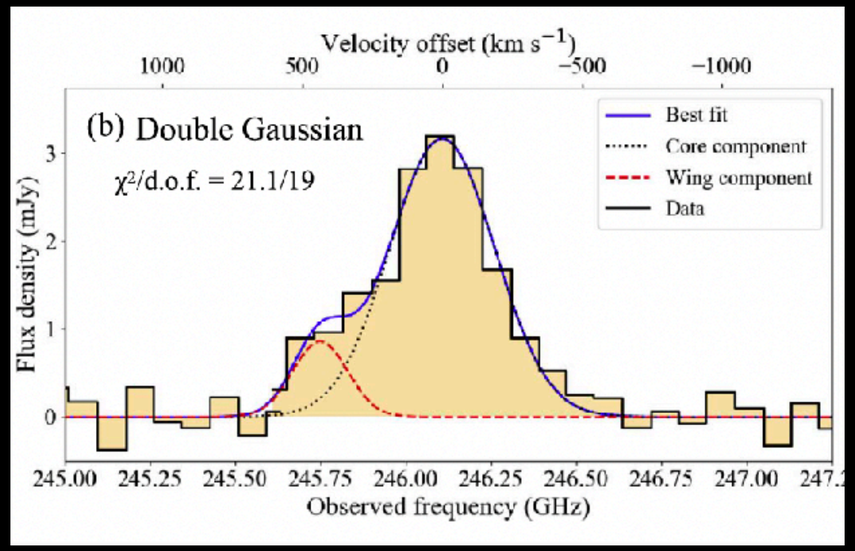
Currently only doable for a few extremely bright z > 6 quasars



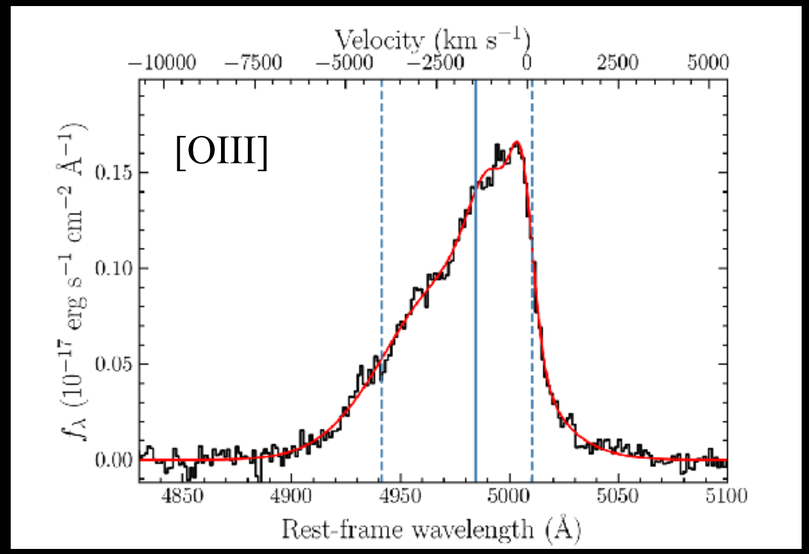

Yang et al. 2019

**ALMA WSU:**

- More than two times deeper [CII] survey of high-z objects
- Line surveys — molecular gas excitation, [CI] line, water vapor emission …
- High quality gas kinematics — host assembly and BH - host interaction




Izumi et al. 2021




Yang et al. 2023

**ALMA WSU:**

- More than two times deeper [CII] survey of high-z objects
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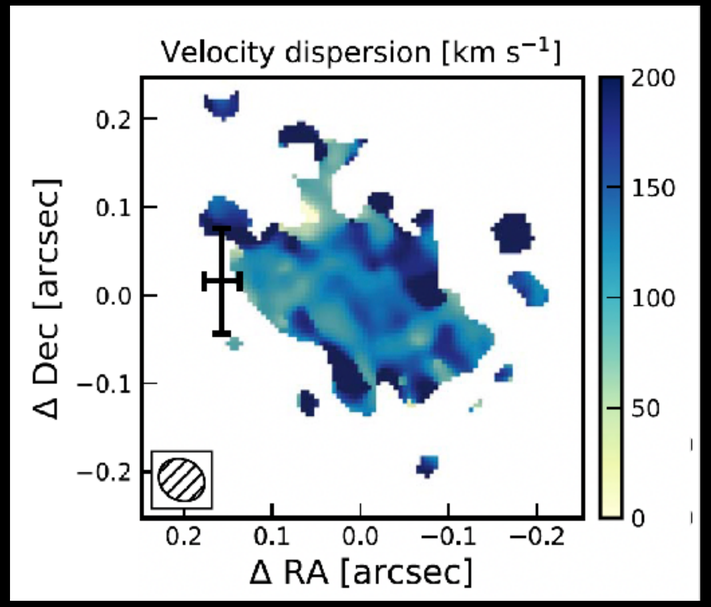
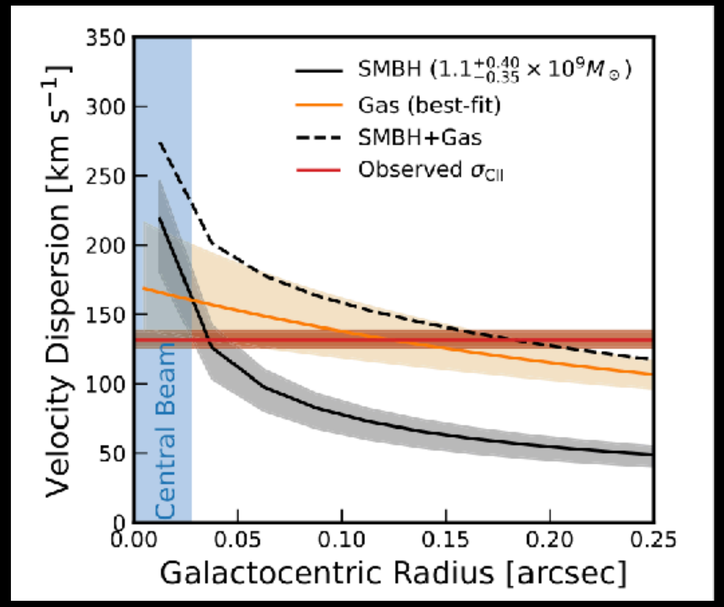
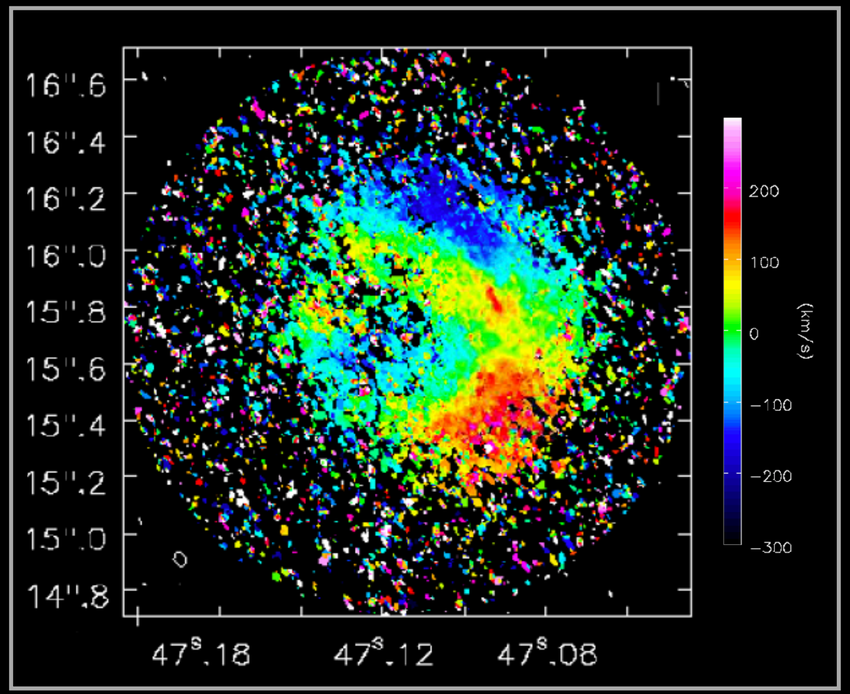
- High quality gas kinematics — host assembly and BH - host interaction
- High quality gas kinematics — independent BH mass

Preliminary — an extremely bright lensed quasar at z=6.5




Meyer et al. 2023



**ALMA WSU:**

- More than two times deeper [CII] survey of high-z objects
- Line surveys — molecular gas excitation, [CI] line, water vapor emission …
- High quality gas kinematics — host assembly and BH - host interaction
- High quality gas kinematics — independent BH mass
- Follow-ups of next generation quasar surveys (e.g., Euclid/LSST/Roman based quasars)

Quasar sample size will be expanded with more than one order of magnitude!

# Summary

JWST — So far, provides studies of quasars at z ~ 6 - 7.5 in unprecedented detail, changing our understanding of central SMBHs and host galaxies.

- ✓ A sample of 30 luminous quasars: rest-frame optical emission, H$\beta$ BH mass, and UV/optical host images for the first time

ALMA — Provides the high quality, high resolution images of dust and cool gas, revealing dynamical mass and gas kinematics in massive quasar hosts.

- ✓ Our JWST - ALMA dataset is revealing the assembly of a sample of early SMBH-host systems in great detail

ALMA WSU — **Give new insights into SMBH-host co-evolution;**
**Follow-ups of next generation quasar surveys**

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