

ALMA observations of $z > 6.5$ quasar hosts:
forming massive galaxies in the epoch of reionisation

Bram Venemans

Team Quasars @ MPIA

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+ Gijs Verdoes-Kleijn (Groningen), Laura Zschaechner (MPIA),
Xiaohui Fan (Arizona), ...

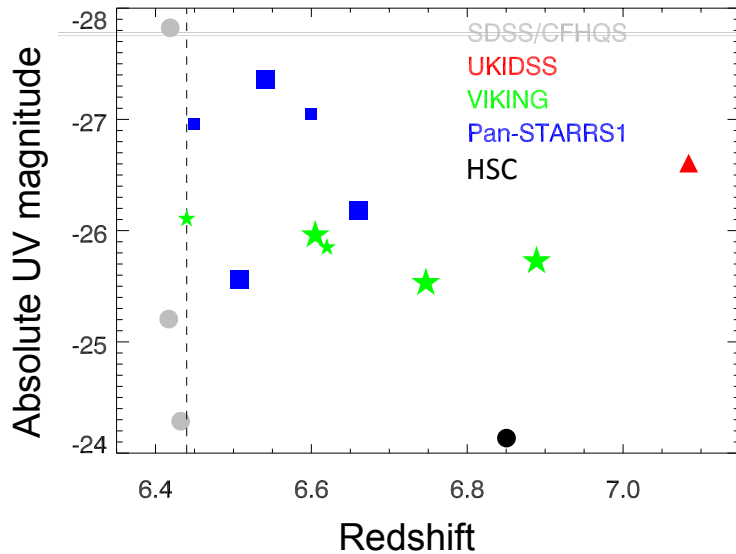
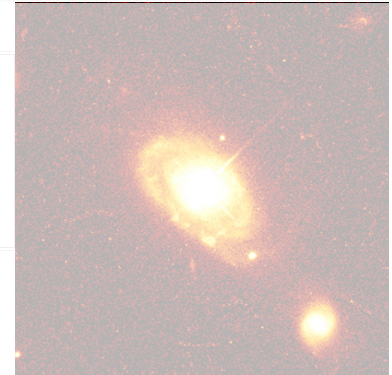
Quasars: accreting black holes

Quasars powered by accreting black holes



Quasars: accreting black holes

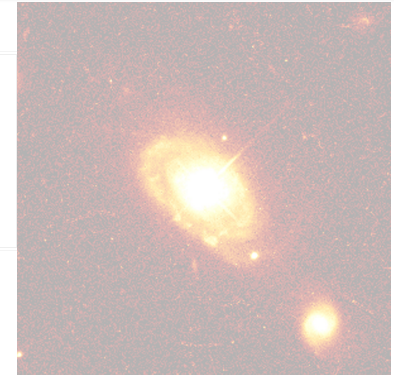
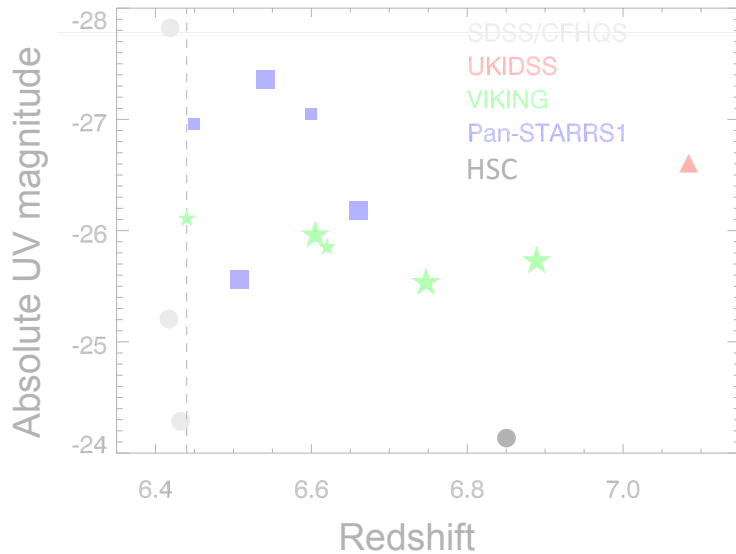
Quasars powered by accreting black holes



Discovered up to $z > 7$
(UKIDSS, VIKING, PS1, HSC, DES)

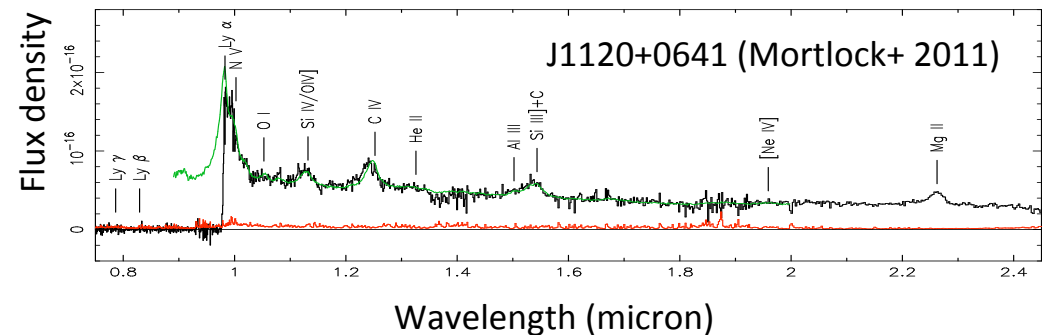
Quasars: accreting black holes

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Discovered up to $z > 7$
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Supermassive ($> 10^9 M_{\text{sun}}$)
black holes exist within
1 Gyr after the Big Bang



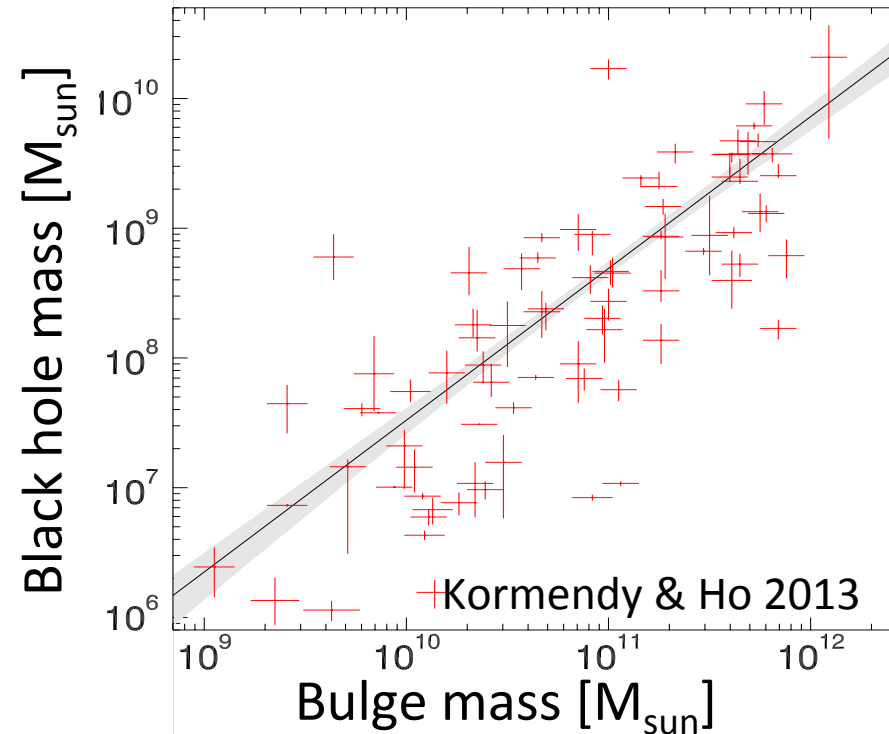
Distant quasars: key questions

- When were the first supermassive black holes formed?



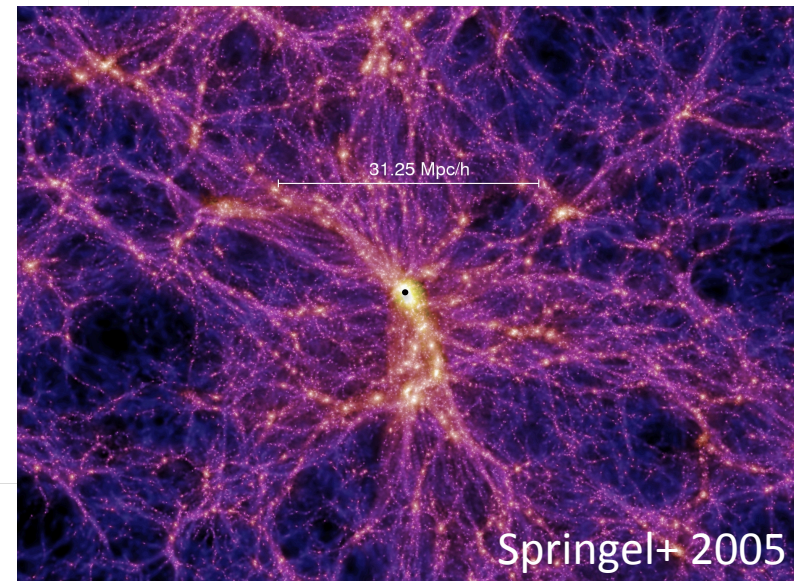
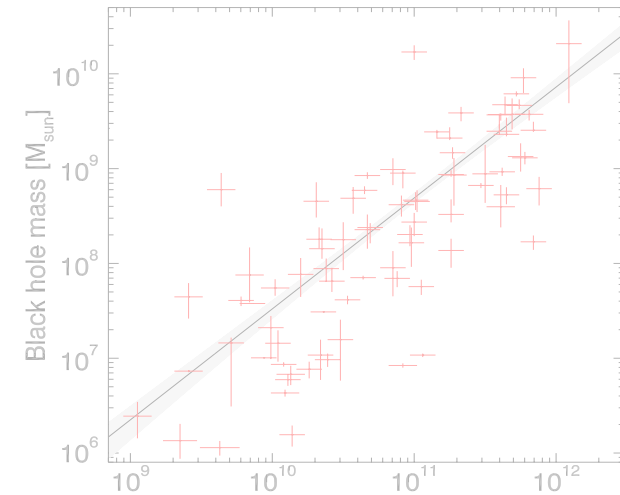
Distant quasars: key questions

- When were the first supermassive black holes formed?
- Properties of black hole hosts



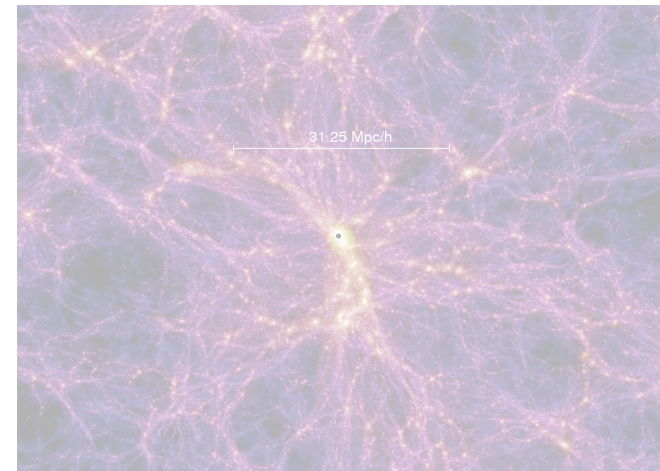
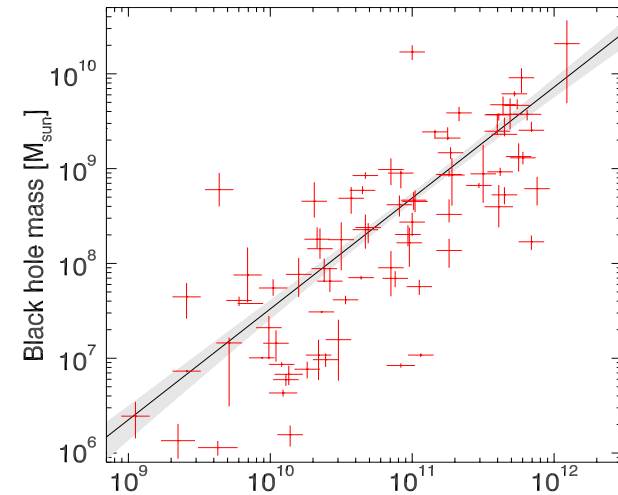
Distant quasars: key questions

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- Are distant quasars located in high density environments?



Distant quasars: key questions

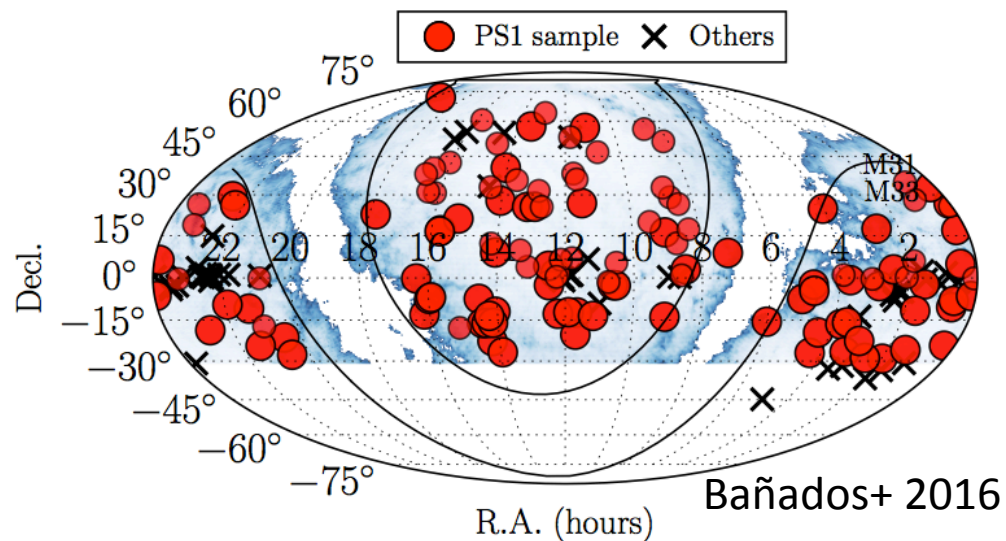
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Study of distant quasars

Enormous increase in
number of $z \gtrsim 6-7$ quasars

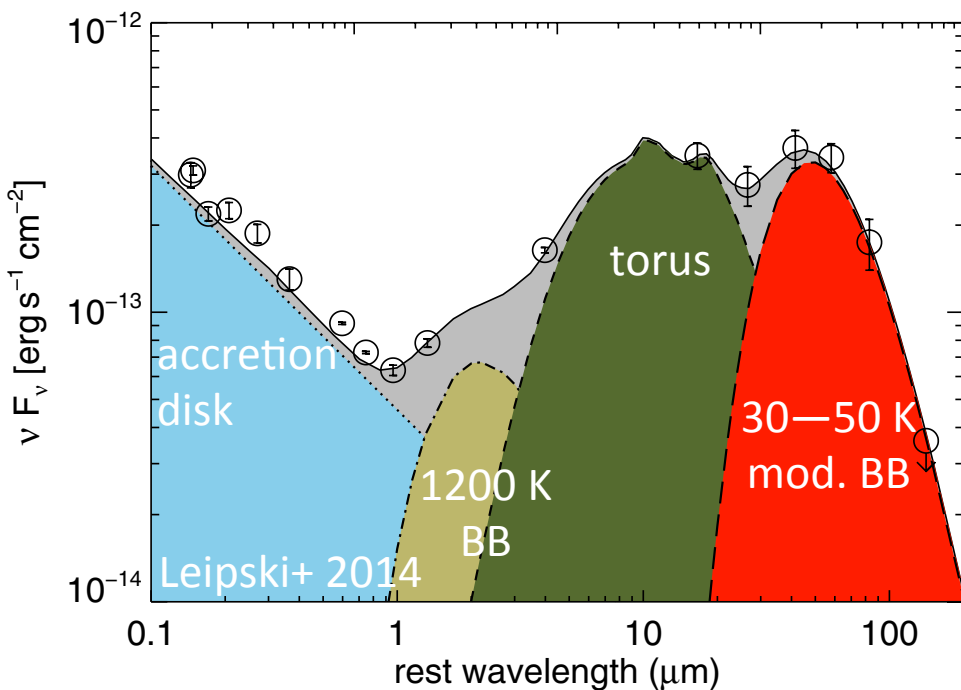
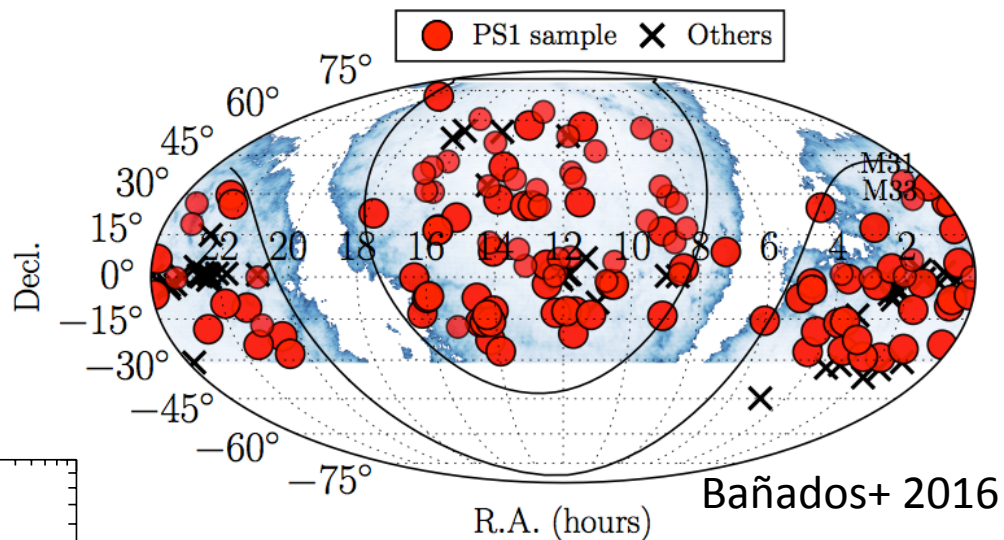
See Monday talks



Study of distant quasars

Enormous increase in number of $z \gtrsim 6-7$ quasars

See Monday talks



Spectral energy distribution

- **UV/optical**: accretion disk
- **mid-infrared**: hot dust and torus
- **far-infrared**: cold dust
→ host galaxy

(sub-)mm observations of quasars



Ground-based (sub-)mm observations (ALMA, NOEMA):

- **dust continuum**

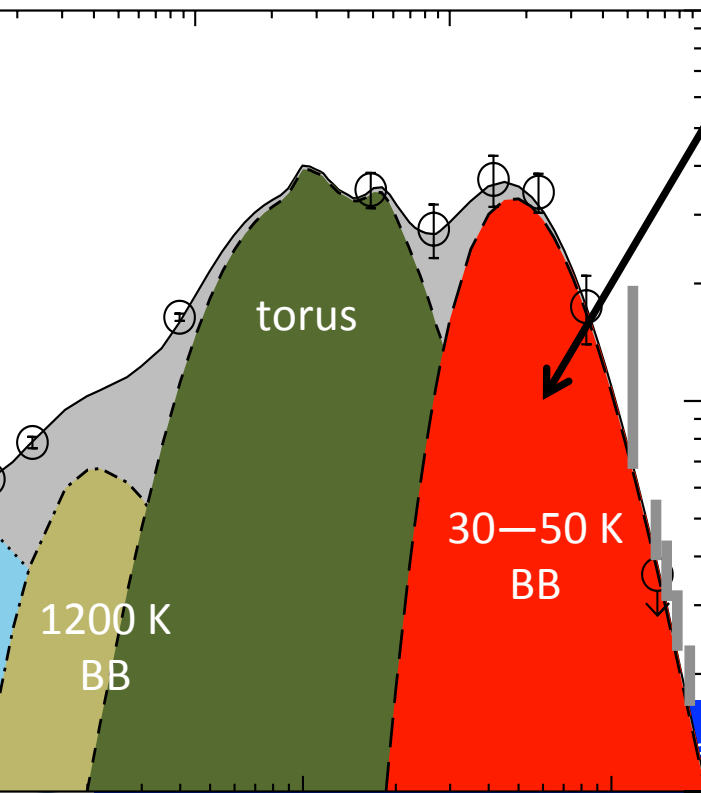
- star-formation (SF) tracer
- ISM mass

- **[C II] 158 μm line**

- main ISM coolant
- strongest line in FIR
- SF tracer

- **CO lines:**

- ISM tracer
- cold gas supply for SF



(sub-)mm observations of quasars



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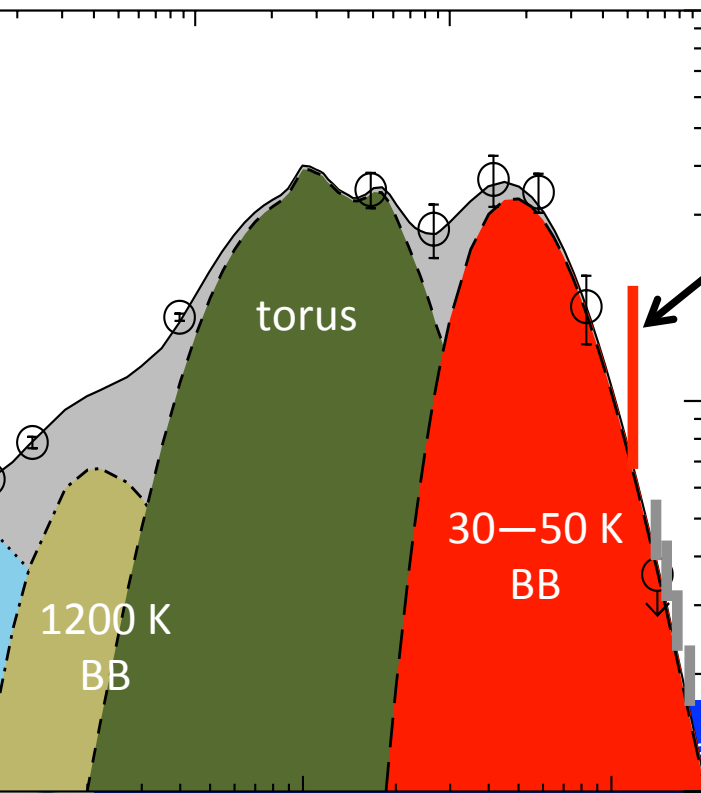
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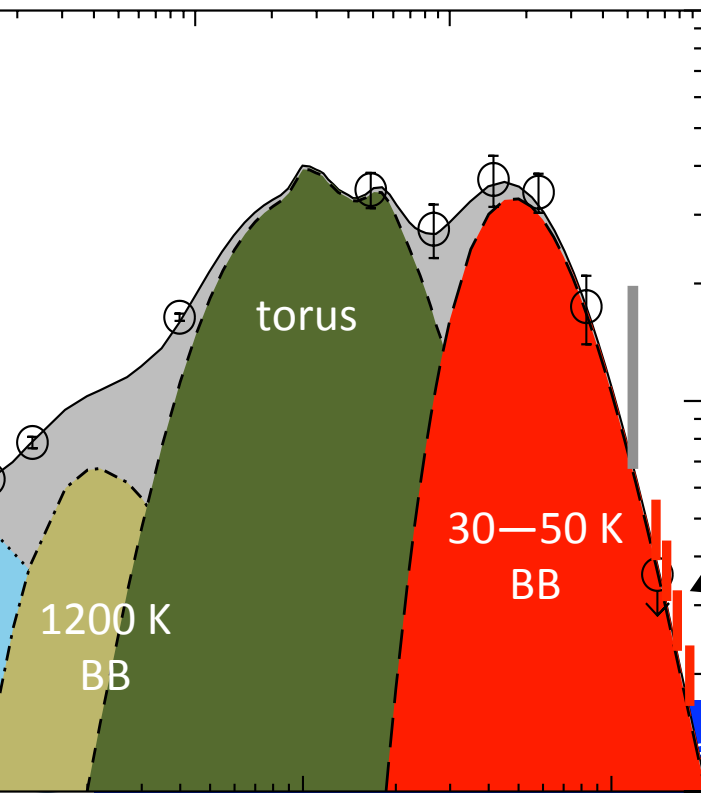
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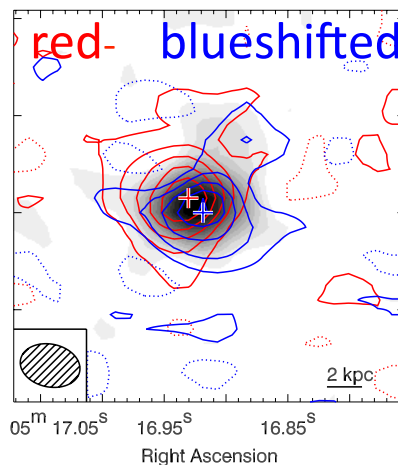
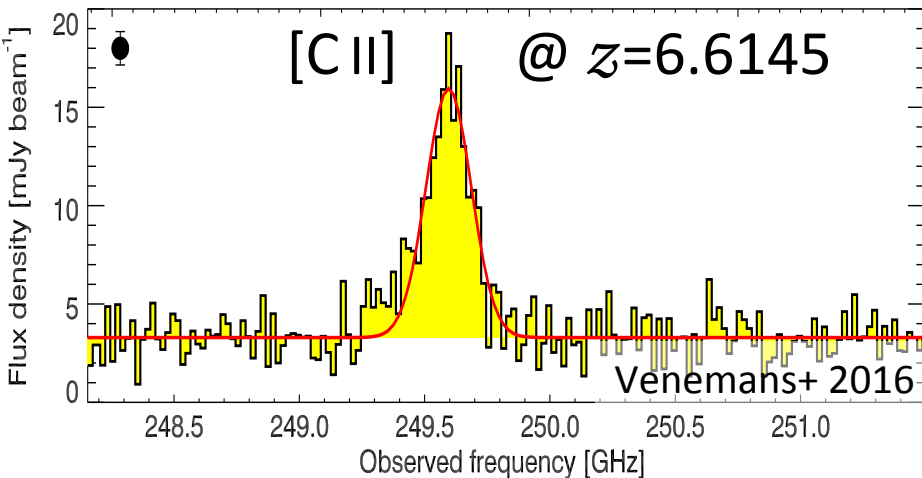
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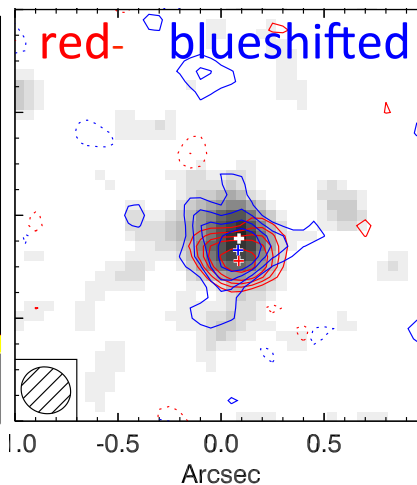
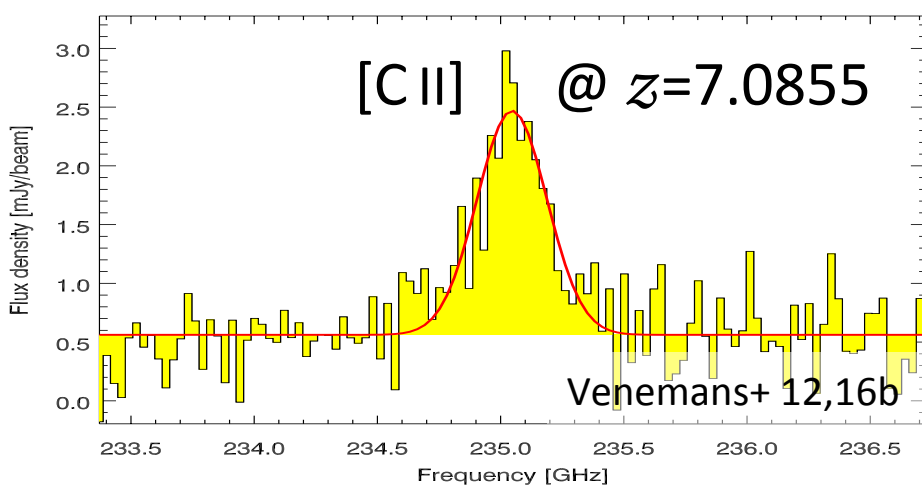
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ALMA observations of $z > 6.5$ quasars



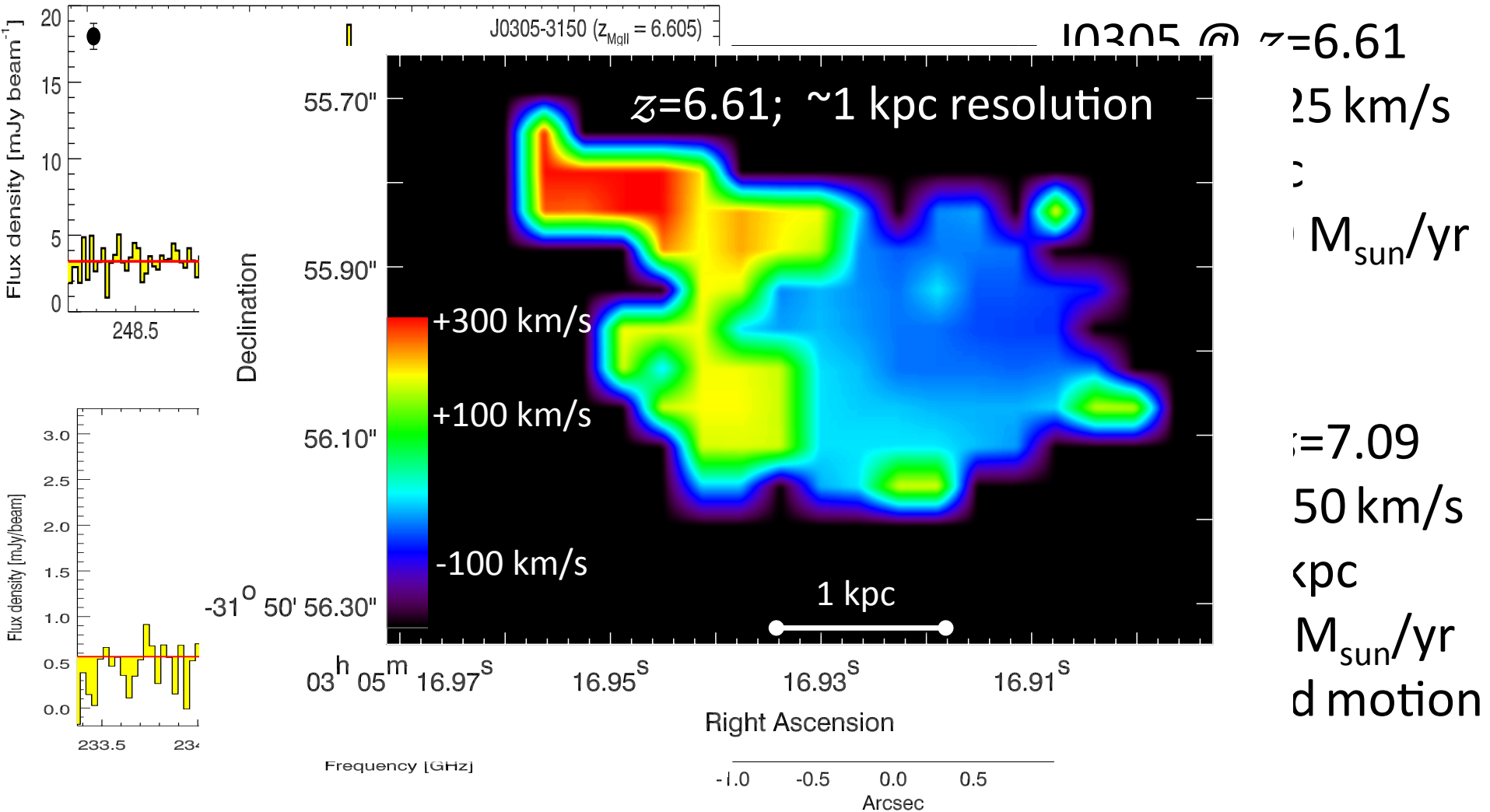
J0305 @ $z=6.61$
FWHM = 225 km/s
size \approx 3 kpc
SFR \approx 1000 M_{sun} /yr
rotation?



J1120 @ $z=7.09$
FWHM = 450 km/s
size \approx 1.5 kpc
SFR \approx 200 M_{sun} /yr
no ordered motion

10 $z > 6.5$ quasars observed: all hosts detected

ALMA observations of $z > 6.5$ quasars



Properties of $z > 6.5$ quasar host galaxies



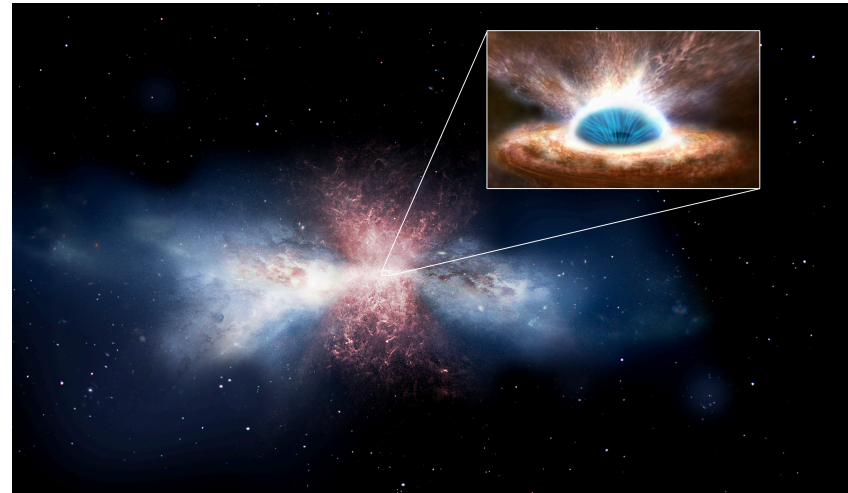
- Sizes from [C II]: 1 – 3 kpc
 - SFRs: 100 – 1500 M_{sun}/yr
 - SFRD: 50 – 400 $M_{\text{sun}}/\text{yr}/\text{kpc}^2$
- Orion-like SFRDs, over kpc scales

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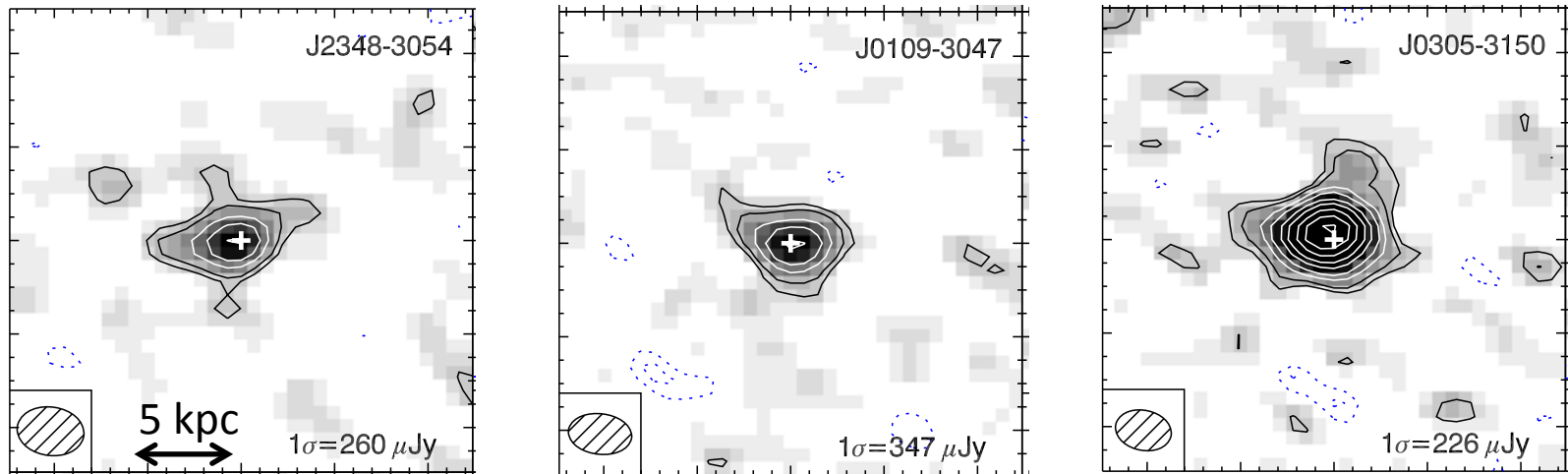


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- Any evidence for feedback?
- FIR continuum due to AGN heating?

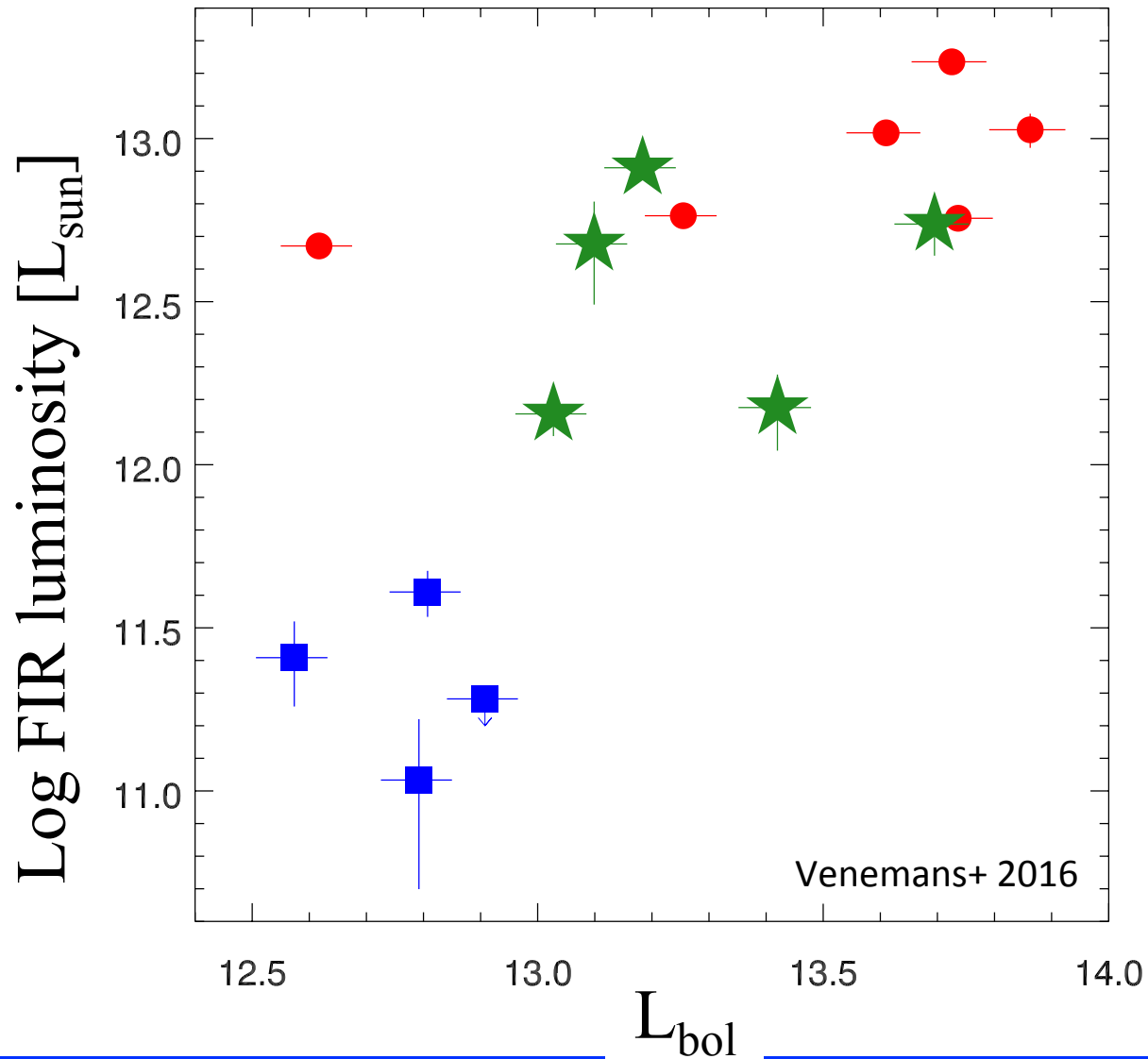


High S/N ALMA data of $z > 6.5$ quasars

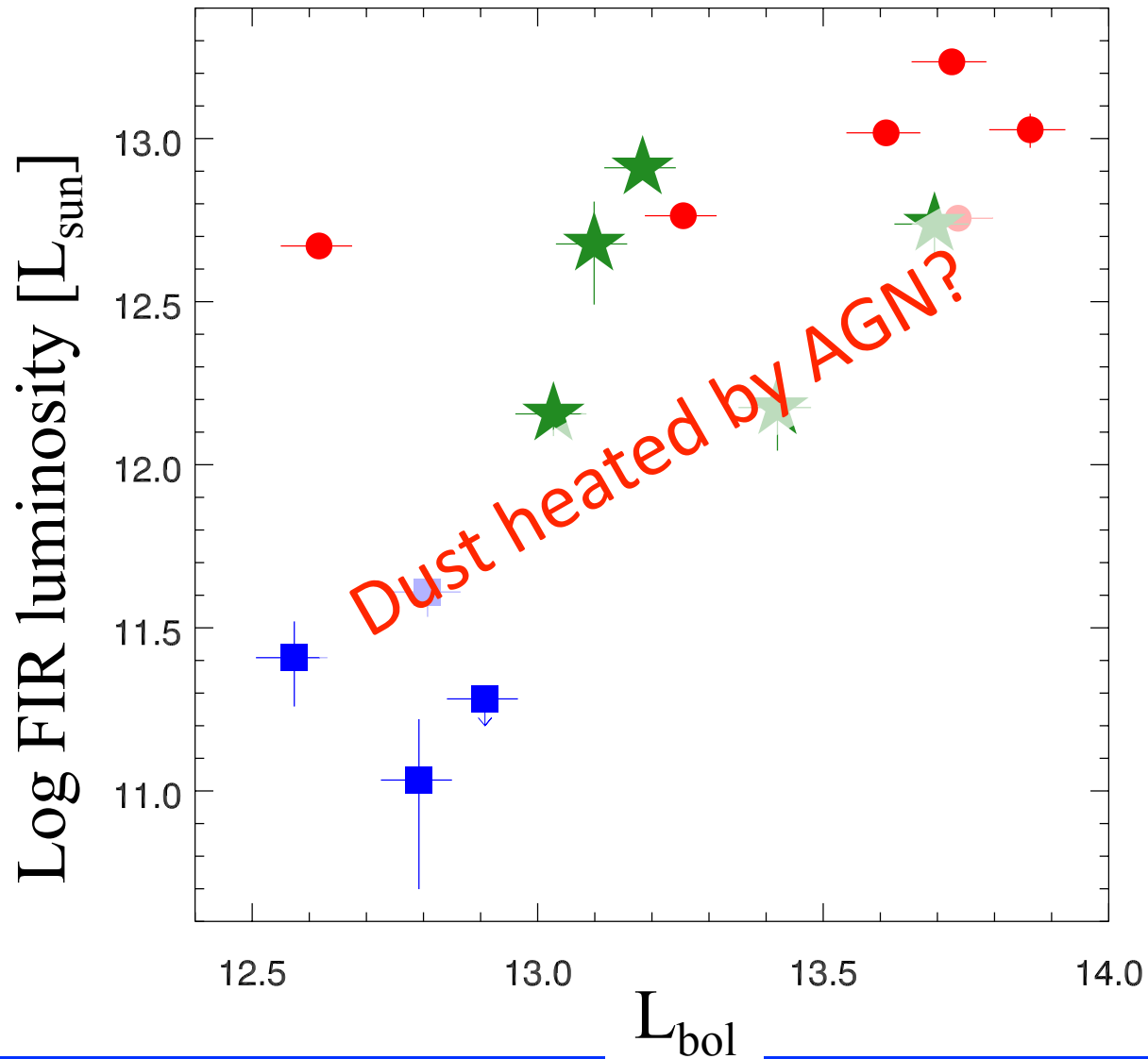


No evidence for $\gg 10$ kpc outflows

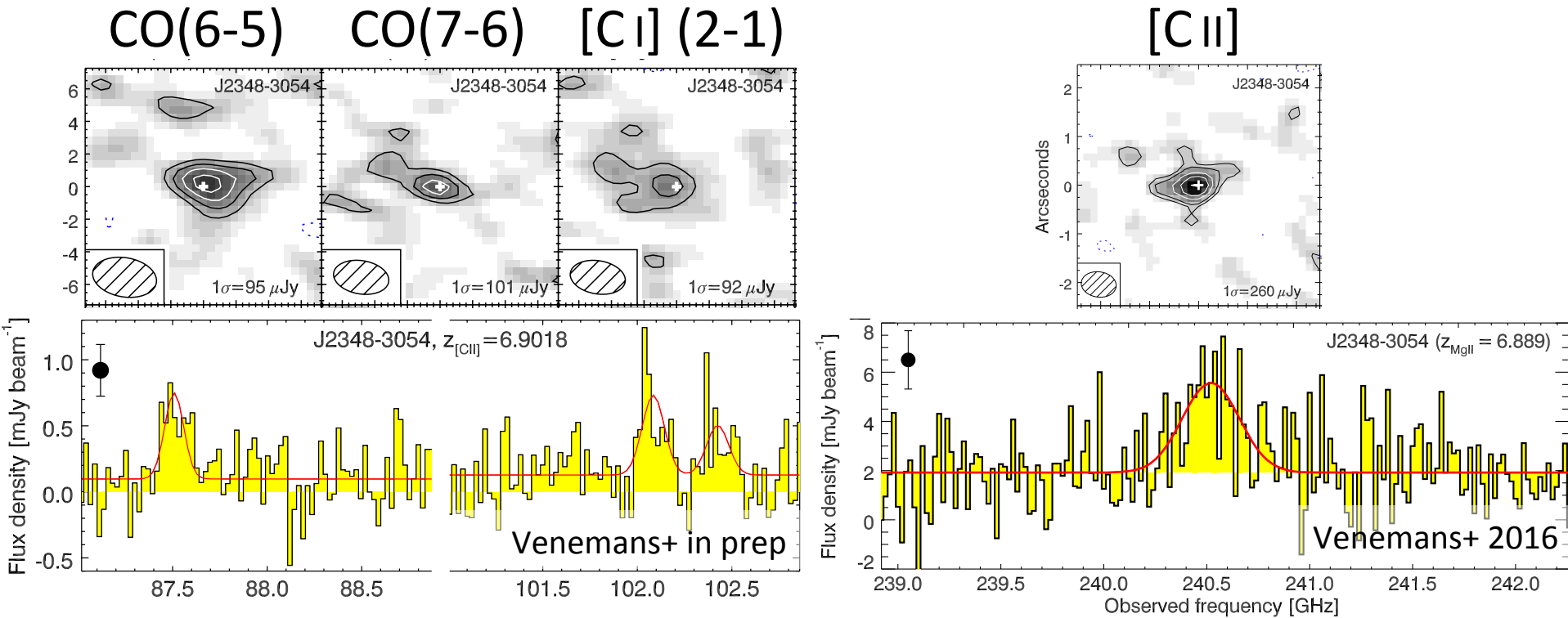
Correlation FIR and quasar luminosity



Correlation FIR and quasar luminosity



[C I], [C II], CO observations of $z = 6.9$ quasar



Detection of CO(6-5), CO(7-6), [C I] and [C II] with ALMA in a quasar host galaxy at $z = 6.9$

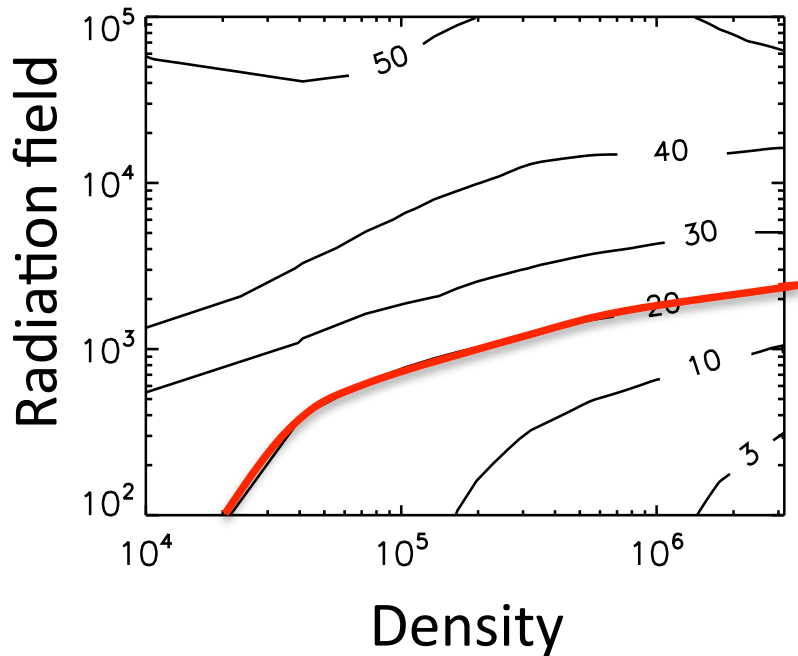
Line ratio [C II]/[C I] ≈ 20

Constraining the ISM at $z=6.9$

Radiation dominated
by star-formation



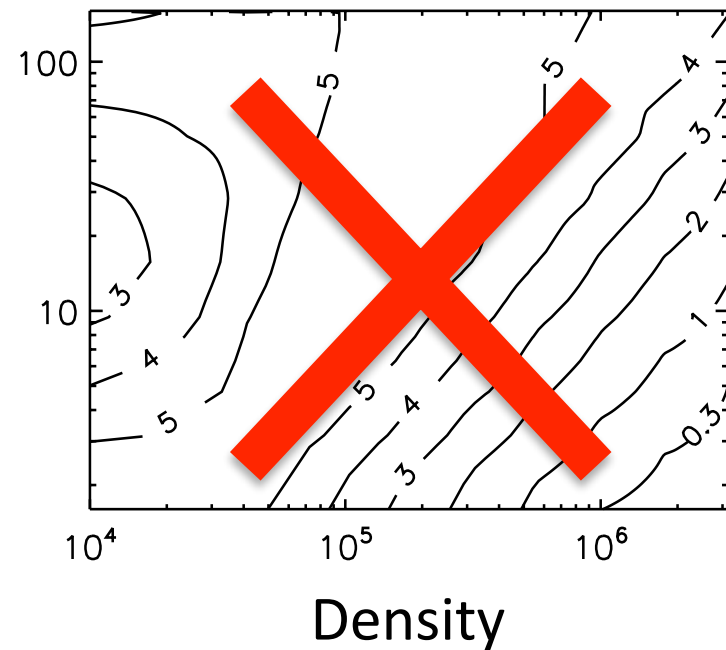
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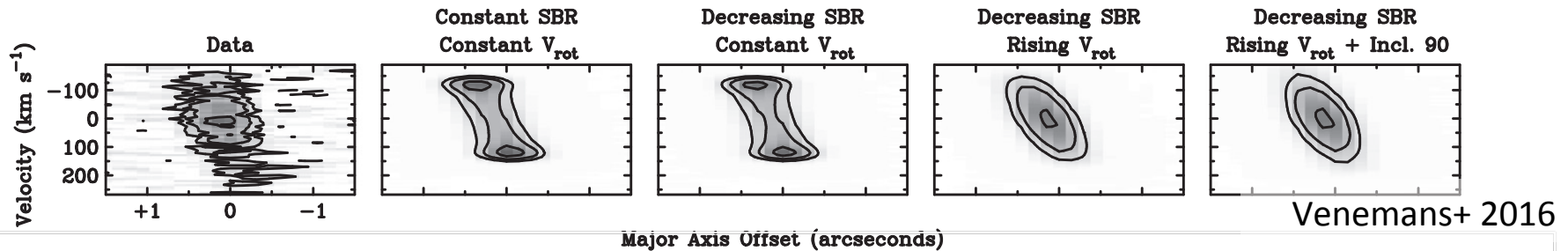
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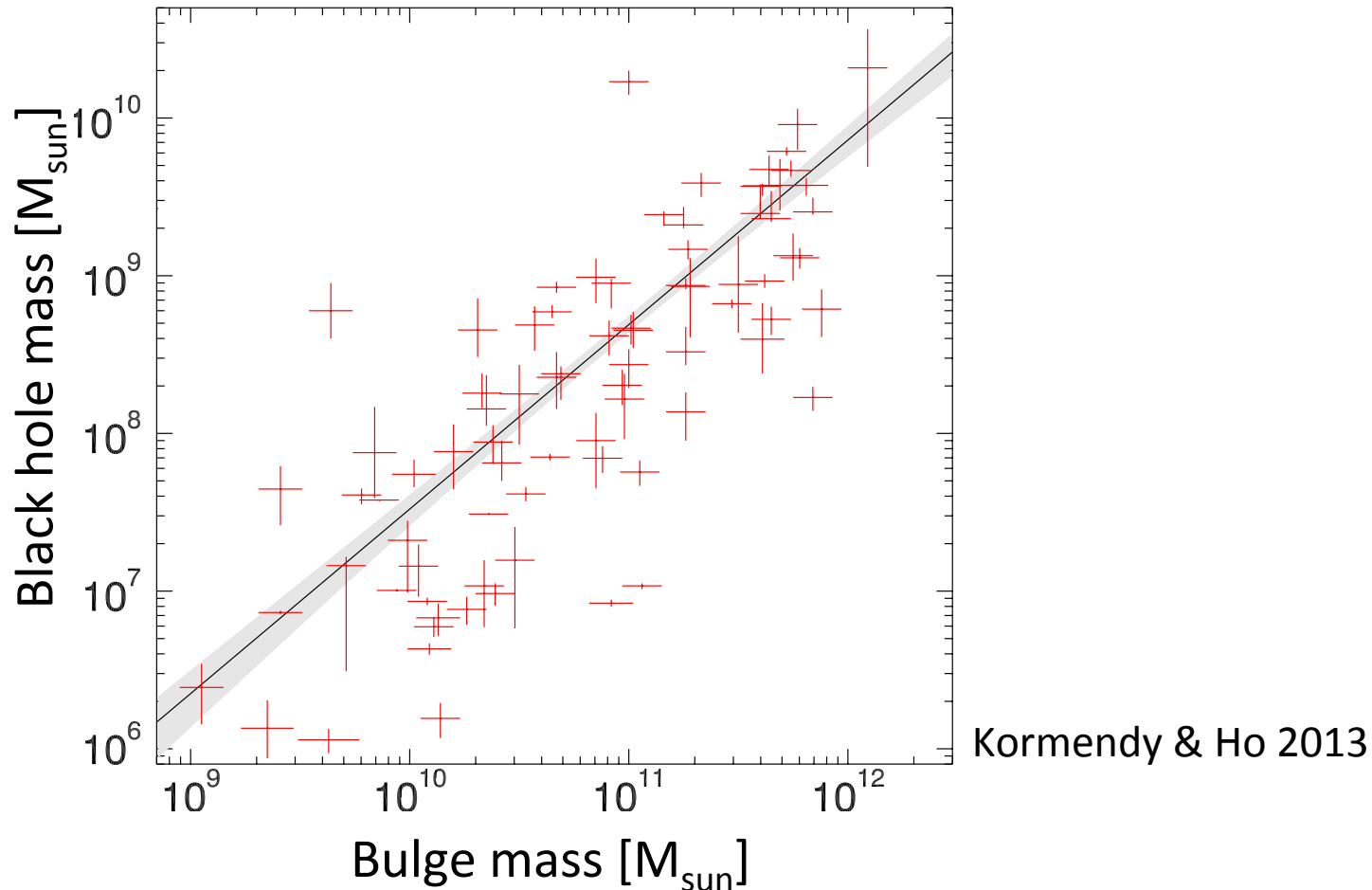
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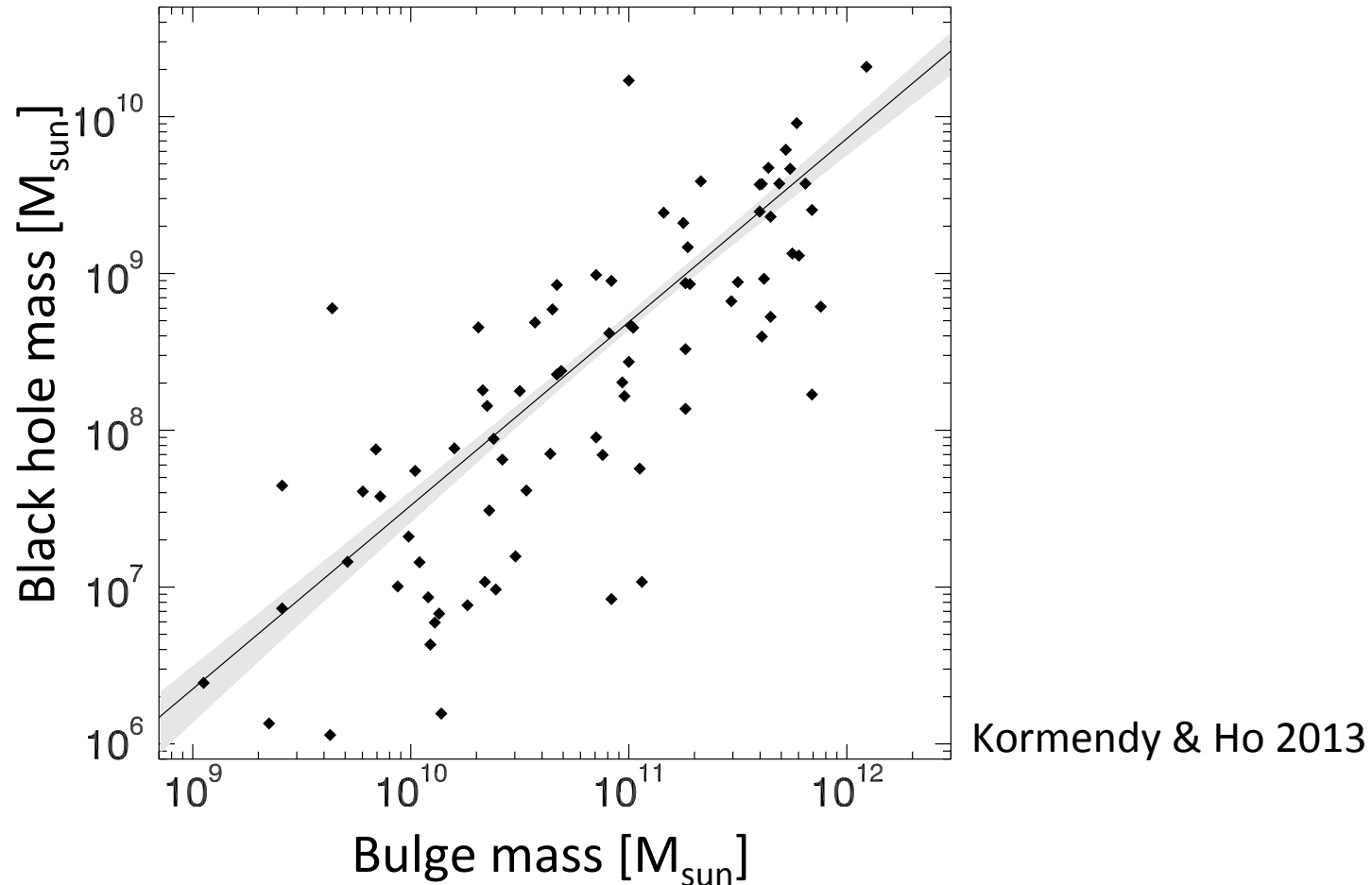
- Line width and size → dynamical mass
 - assume [C II] rotating disk
- Dynamical masses are in the range: $10^{10} - 10^{11} M_{\text{sun}}$

Properties of $z > 6.5$ quasar host galaxies

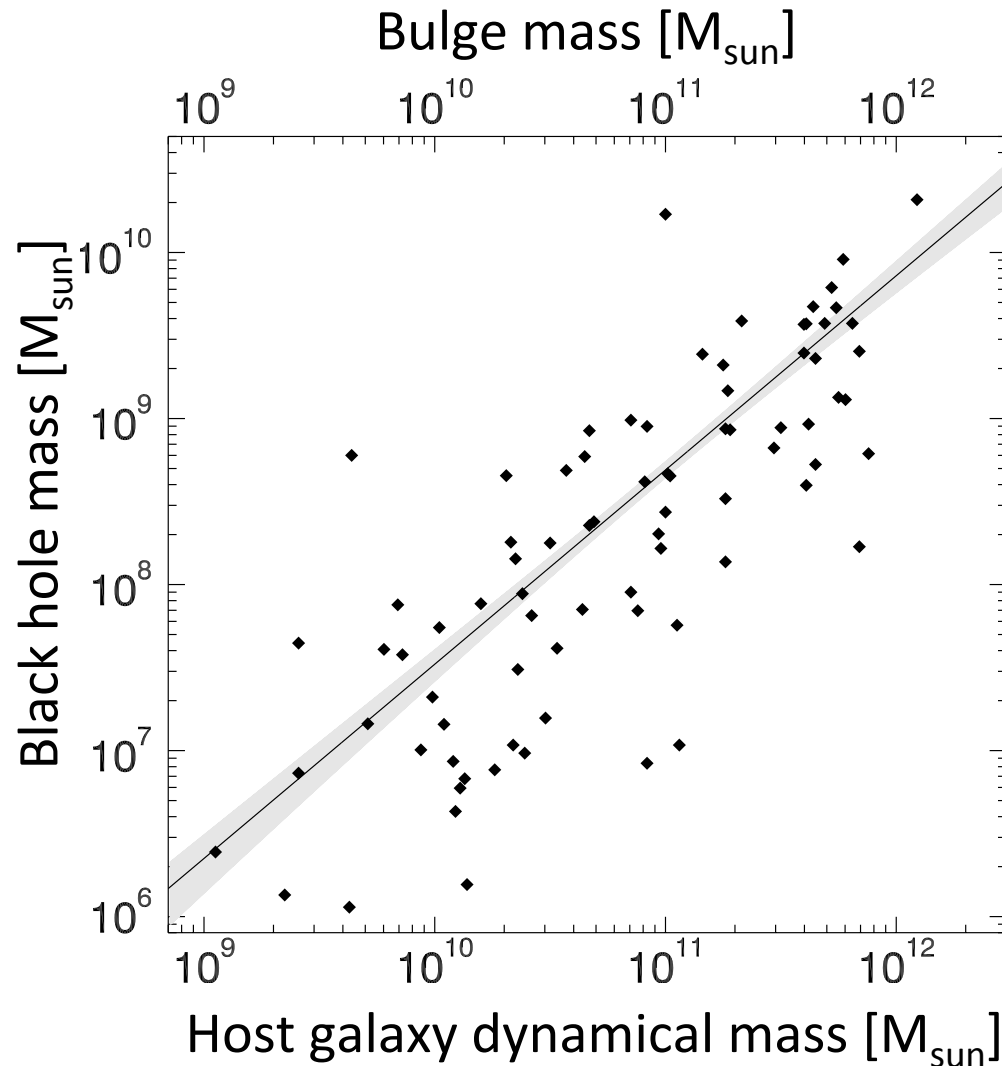
Local black hole–bulge mass relation



Properties of $z > 6.5$ quasar host galaxies

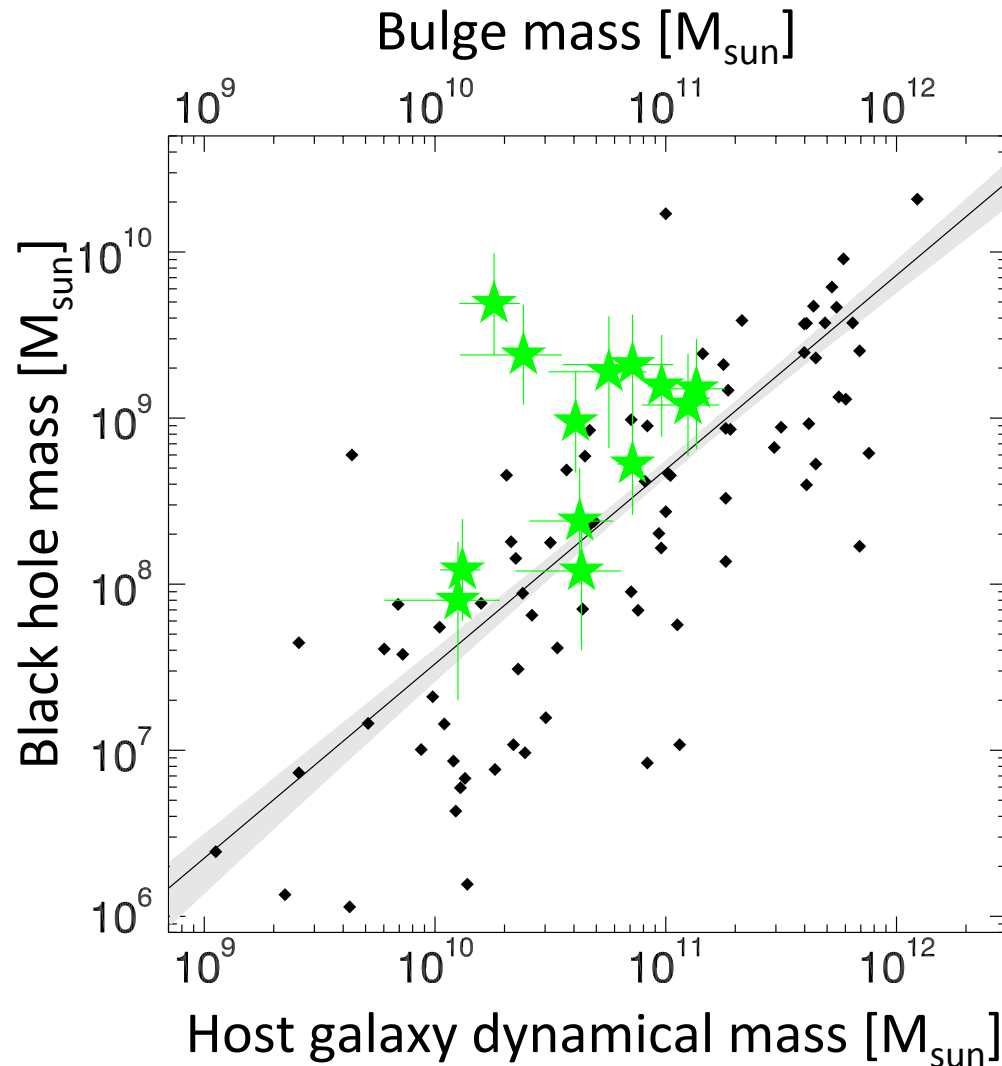


Properties of $z > 6.5$ quasar host galaxies



Our $z > 6.5$ quasar hosts
+ $z \sim 6$ quasar host
galaxies from literature

Properties of $z > 6.5$ quasar host galaxies



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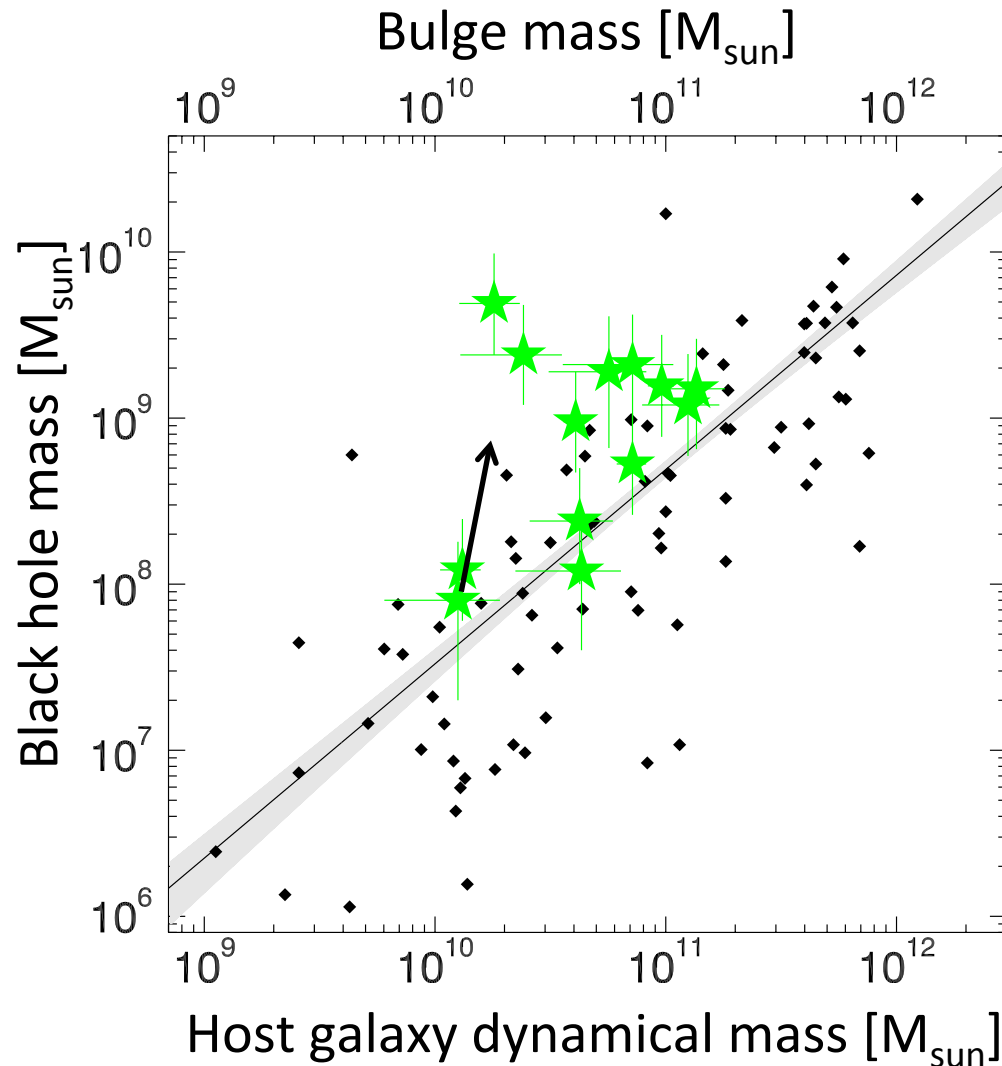
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Sample bias?

Venemans+ 2016



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Summary

- Many new quasars at $z > 6.5$, visible from ALMA
- Quasar hosts compact, intense starbursts
- Line ratios indicate FIR emission due to SF
- Black holes are “overmassive”

→ Sub-kpc ALMA imaging in queue

