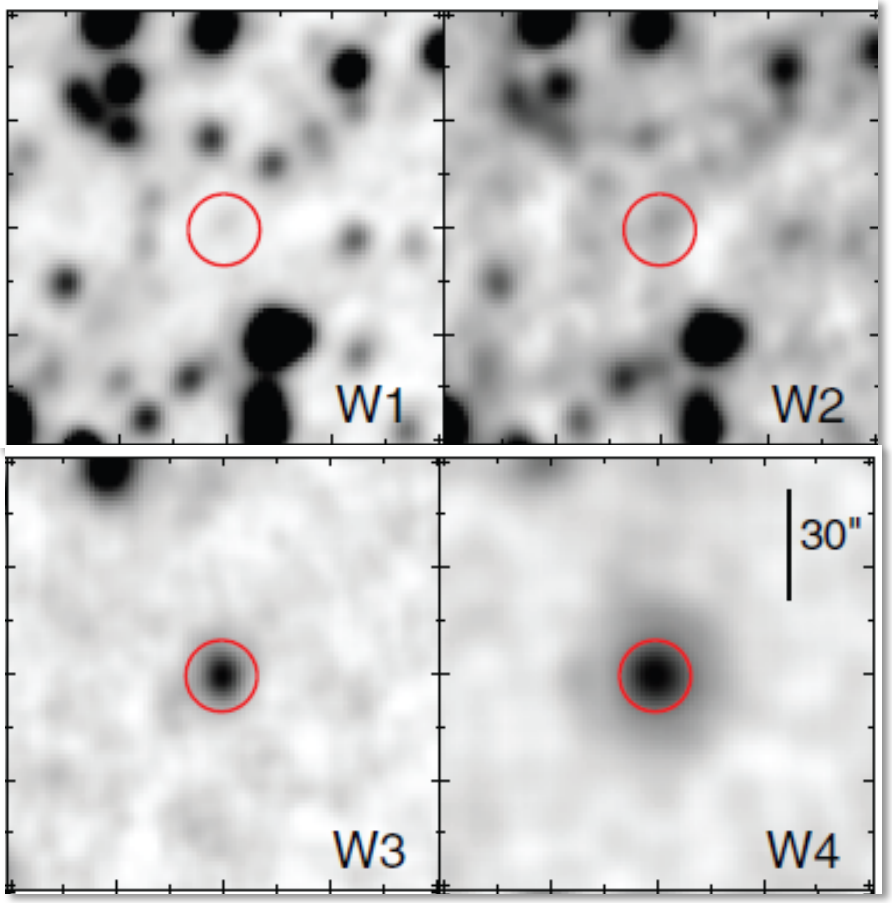
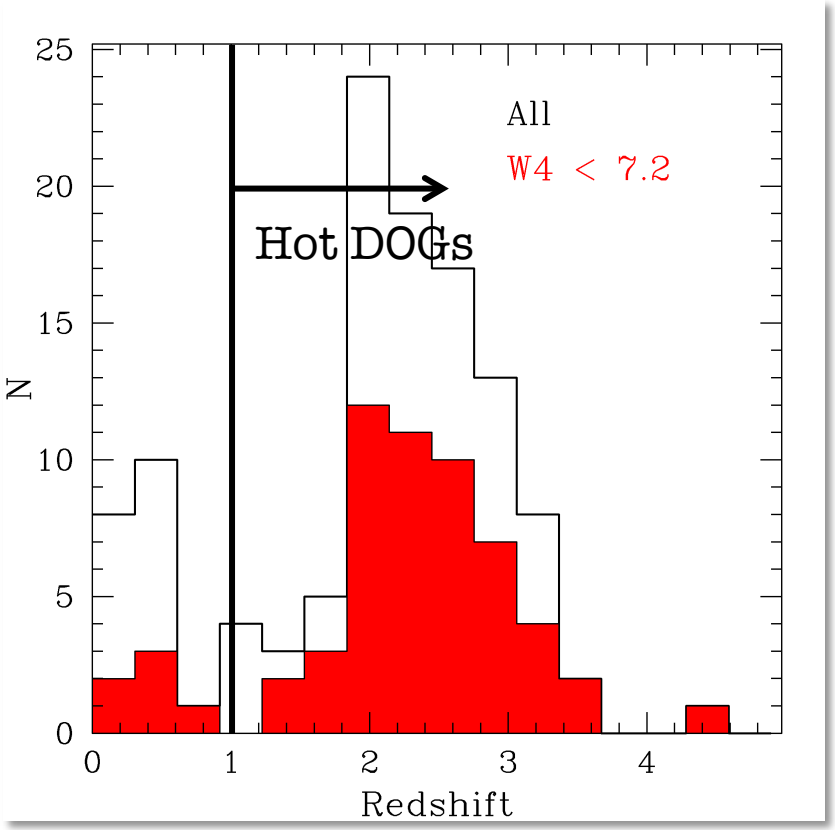
Hot Dust Obscured Galaxies: What are They?

- Hot DOGs are a newly discovered population of galaxies detected by WISE, selected to be strong W3 and W4 emitters, but undetected or very faint in W1 and W2.
- There are ~1000 such objects in the entire extragalactic sky, around z ~1 - 3.5



Eisenhardt+2012

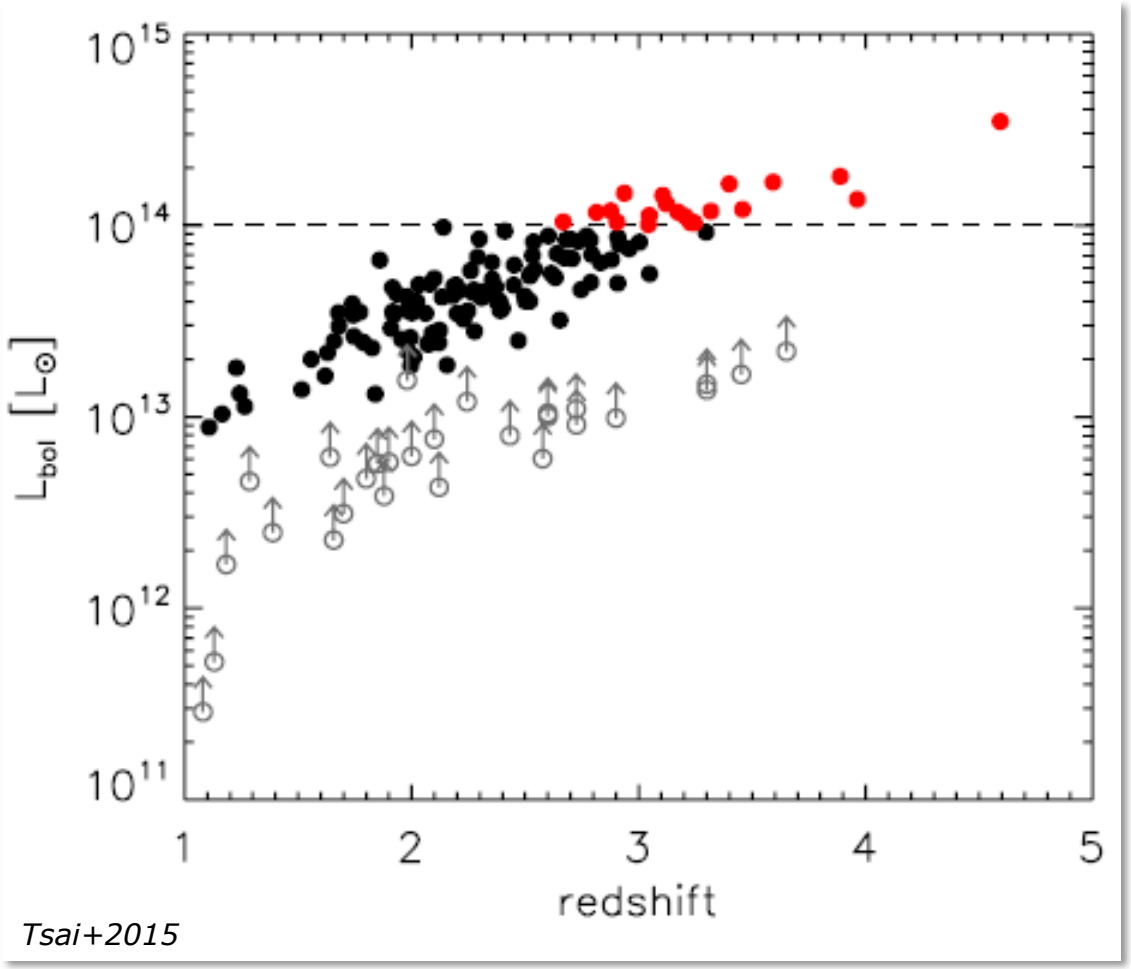


Assef+2015

Luminosity Distribution

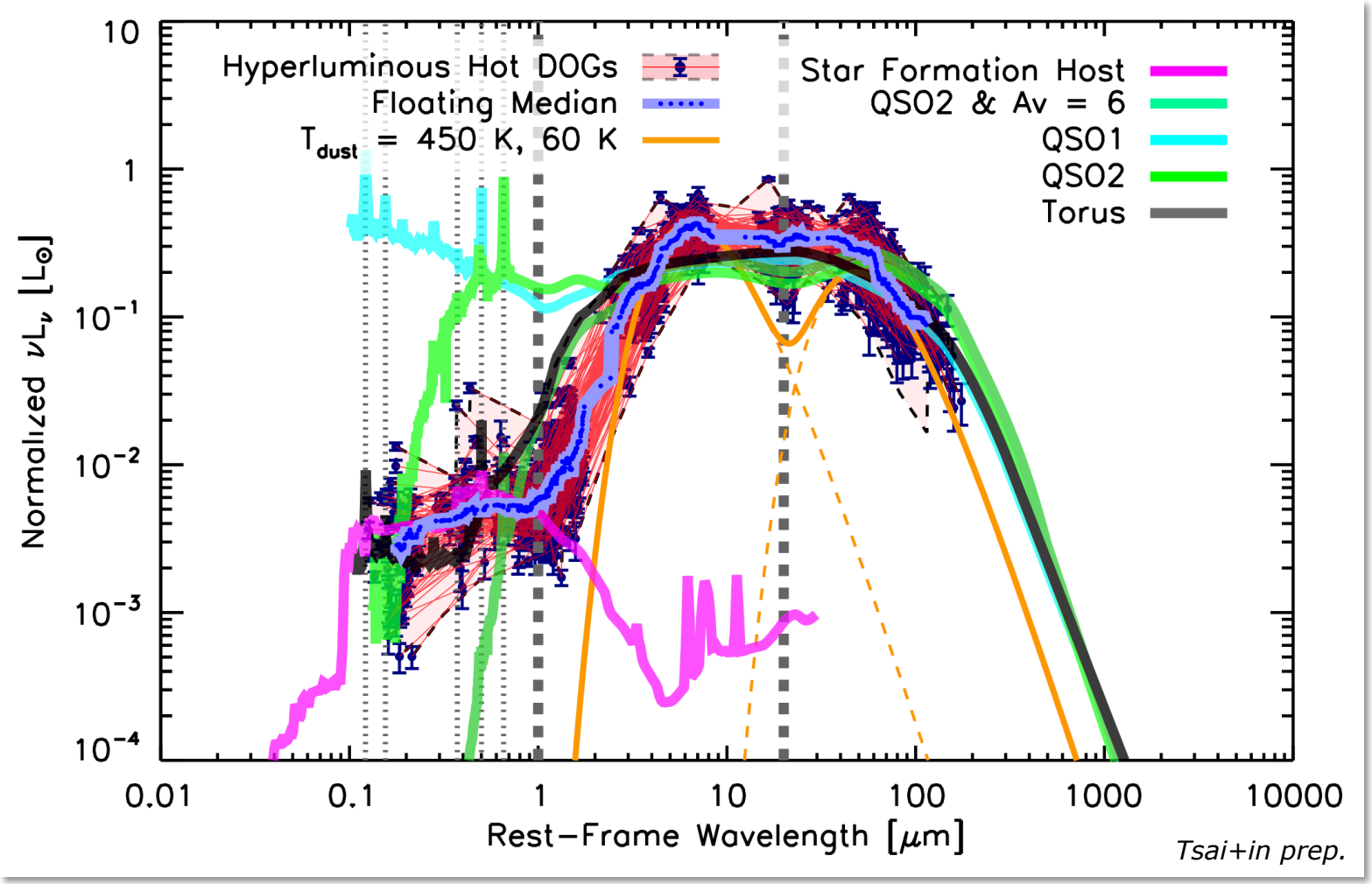
- Herschel photometry for ~ 200 Hot DOGs *(Tsai+in prep.).* Almost all have $L_{bol} > 10^{13}\ L_{\odot}$, and since IR dominates the power, almost all qualify as HyLIRGs.

- 10% have $L_{bol} > 10^{14}\ L_{\odot}$, mostly at z > 2.5



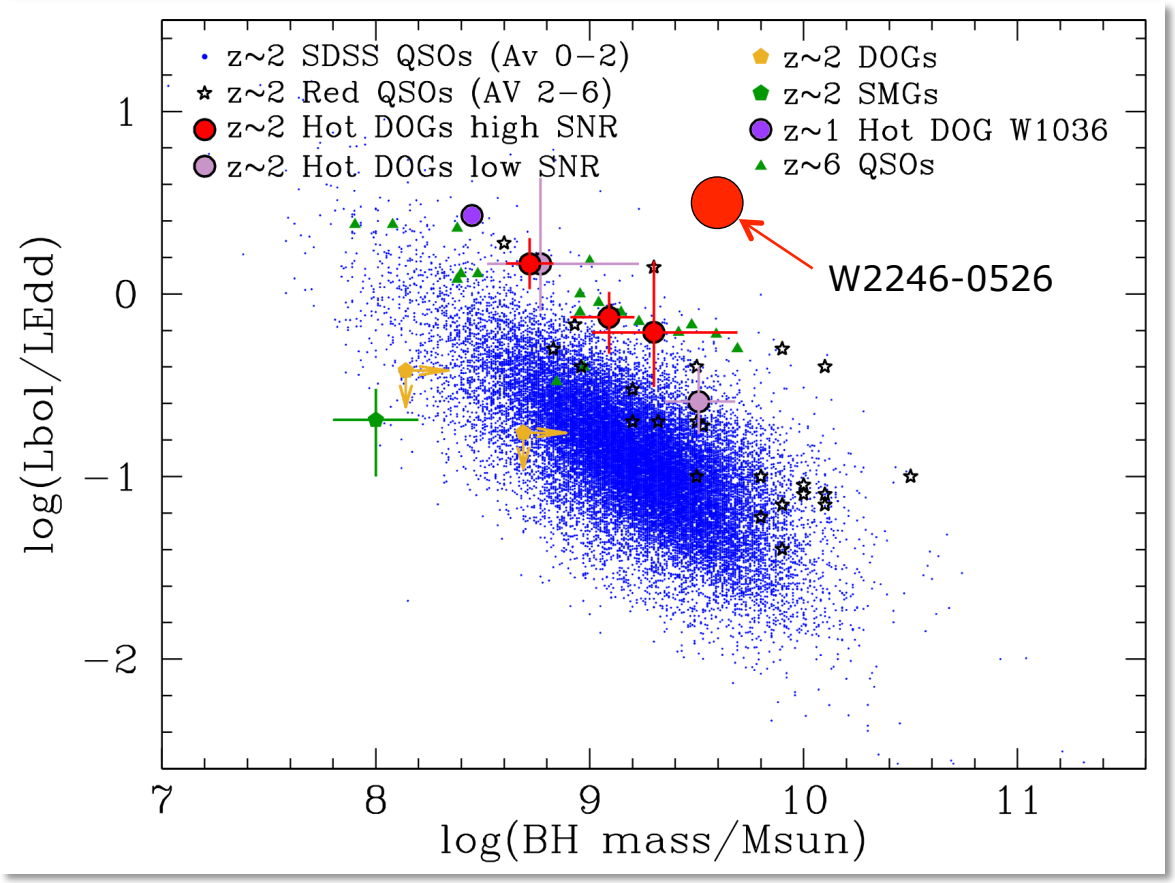
Typical Hot DOG Spectral Energy Distribution

- Dust temperatures as high as ~500 K
- All display a remarkably similar SED, dominated by AGN, even at λ > 100μm



Radiating at The Limit

- Pilot survey to measure the SMBH masses of five z ~ 2 Hot DOGs via broad Hα emission lines, using Keck/MOSFIRE and Gemini/FLAMINGOS-2.
- SMBH masses on the order of ~ $10^9 M_\odot$. Most luminous AGNs at given BH masses, suggesting they are accreting at the maximum rates for their BHs (Eddington ratios close to unity).
- W2246-0526: $\lambda_E \sim 3$, with $M_\bullet \sim 4 \times 10^9 M_\odot$



Wu+2018
Tsai+2018

Observations

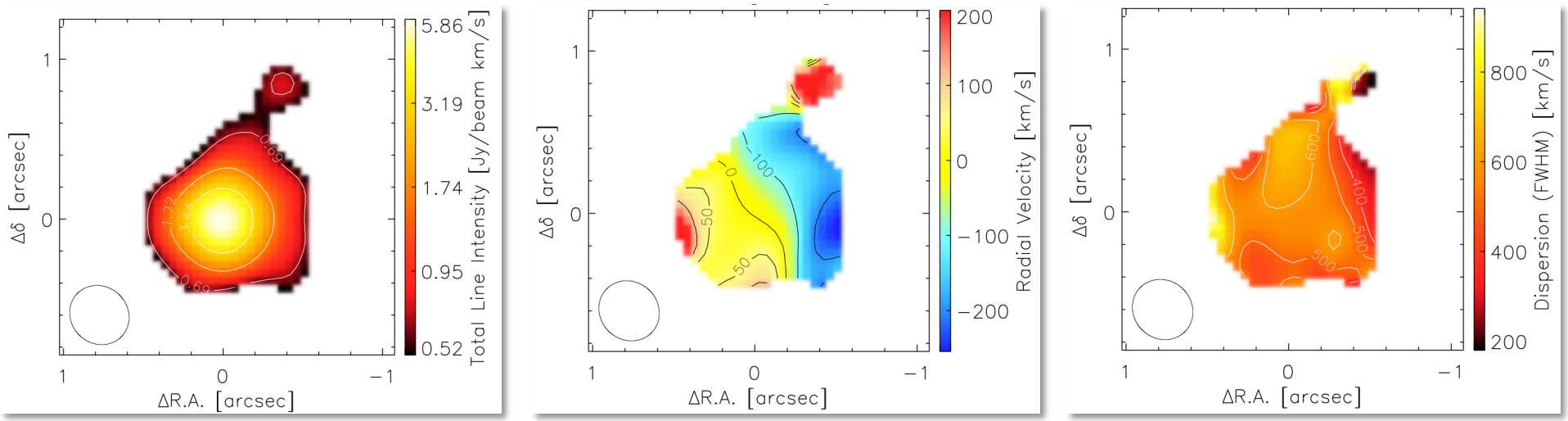
- ALMA cycles-2/3/4 campaign aimed at studying the ionized gas in the most luminous Hot DOGs at an angular resolution of 0.15” – 0.35” ~ 1 – 2.5 kpc.

- Shallow, bands 7 and 8 observations of [CII] and the underlying dust continuum emission at 158μm.

- Pilot sample of 7 Hot DOGs at z ~ 3 – 4.6 and L_{bol} ~ 1–3.5 x 10^{14} $L_{\odot}$, of which W2246-0526, the most luminous galaxy known, was the first to be observed.

The Most Luminous Galaxy Known: W2246-0526 (L_{BOL} = 3.5 x 10^{14} $L_\odot$; z=4.6)

Diaz-Santos+2016



- $L_{[CII]}$ ~ 6 x 10^9 $L_\odot$. Dust continuum size: 1.3 +/- 0.5 kpc < [CII] emission size: 2.5 +/- 0.3 kpc *(Kimball +2015, Venemans+2016,17).* Small velocity shear. Δv ≈ 200 km/s. Smooth rotation.

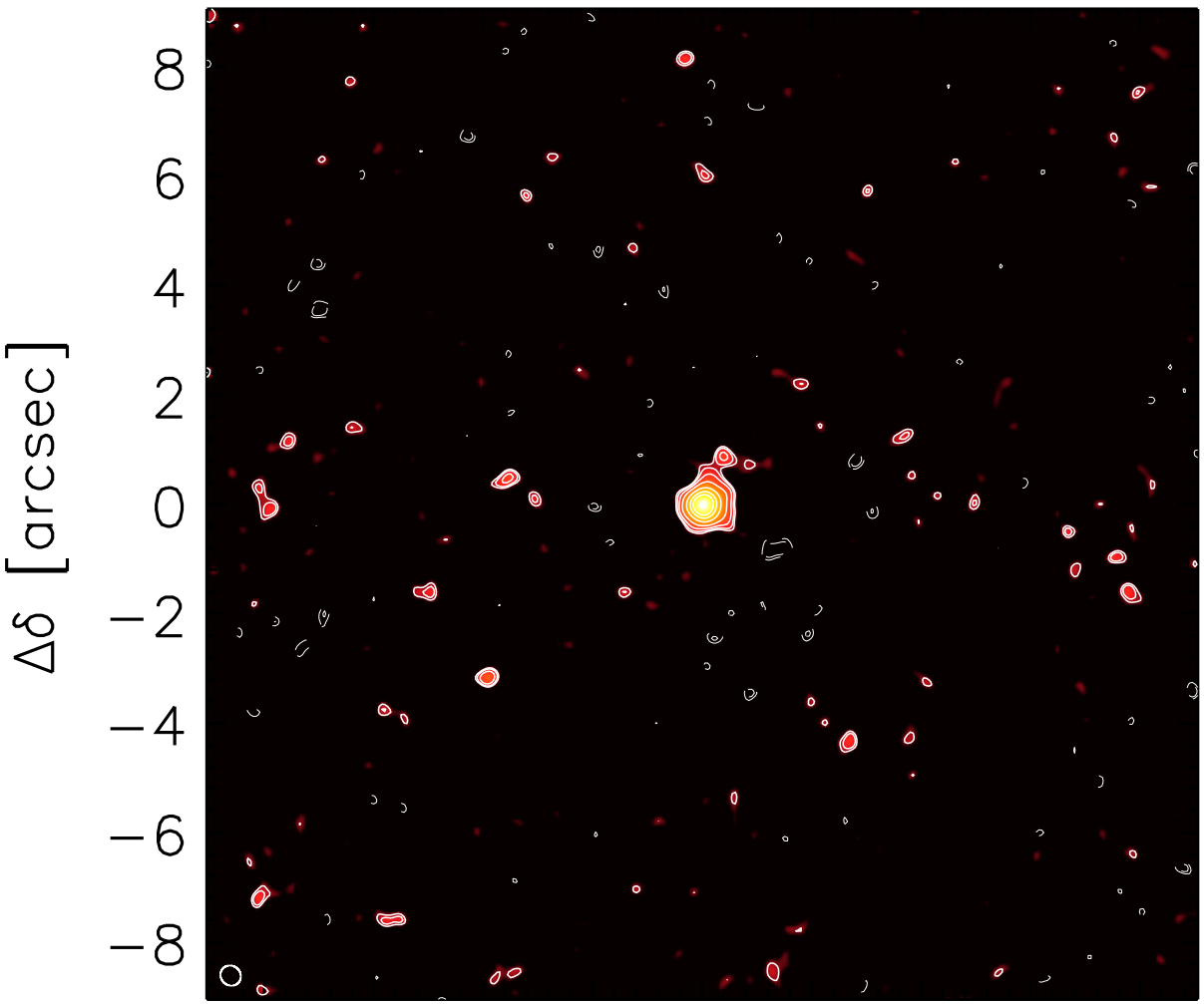
- Very uniform velocity dispersion. FWHM ~ 500-600 km/s across the entire galaxy. Highly turbulent ISM across the entire galaxy *(see also Falgarone+2017)*.

- W2246 is beyond stability thresholds that limit the energy deposition and radiation pressure the AGN can inject into the ISM before disrupting it. This requires an nearly ***isotropic***, yet probably slow expansion of the gas from the system.

- Feedback from the buried quasar likely causing uniform, several kpc-scale gas outflow. Critical evolutionary stage. Large-scale quenching of star formation in the host?

Environment: W2246-0526

- There is statistical evidence that Hot DOGs live in large over-densities *(Jones et al. 2014, Assef et al. 2015, Fan et al. 2017)*
- ALMA allows to search for other [CII] emitting objects at the same redshifts, and for continuum detections in the FOV



- W2246 has 3 galaxy companions detected in [CII] (1″ to NW, 5″ to SE, and 3″ NE)

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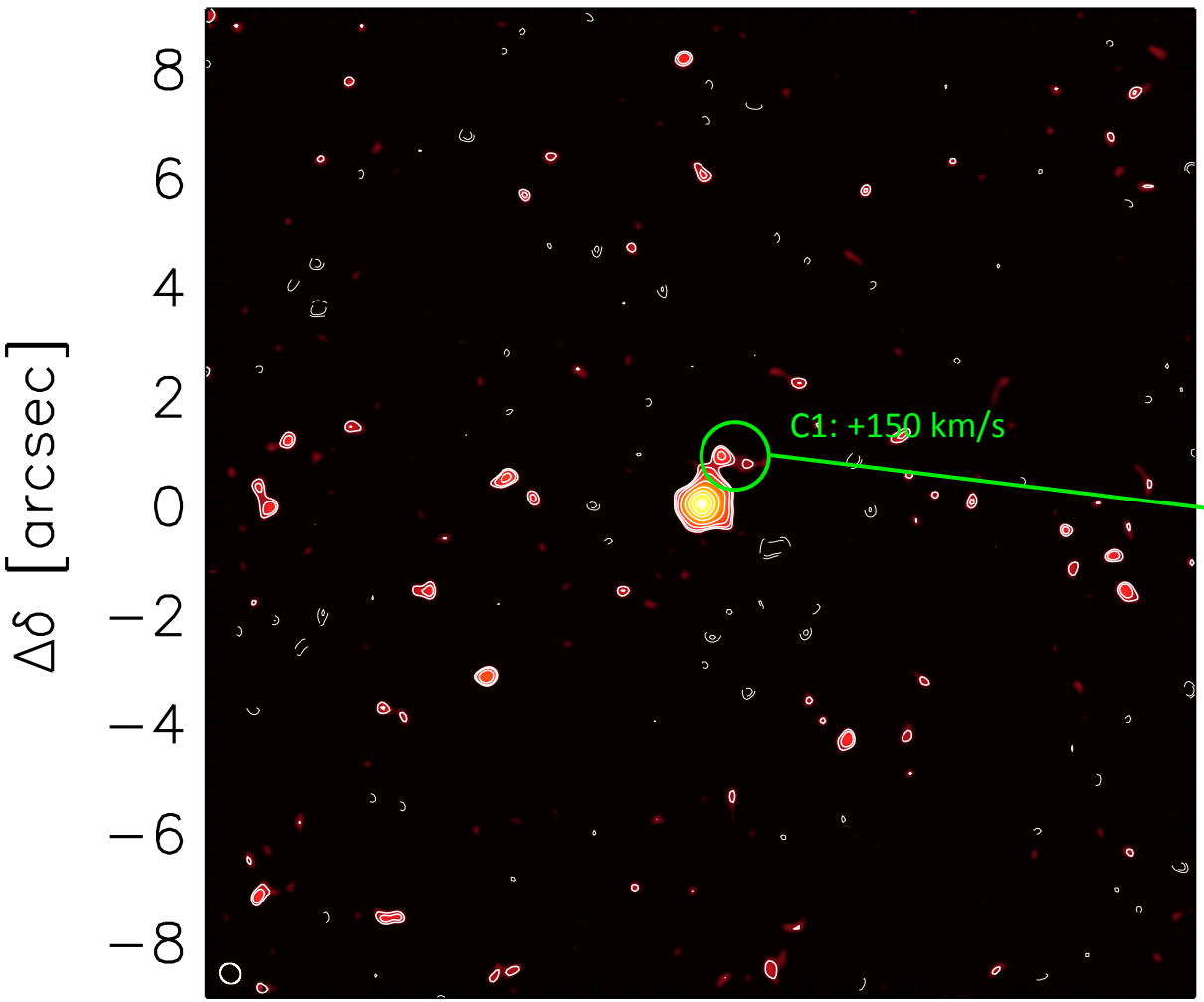

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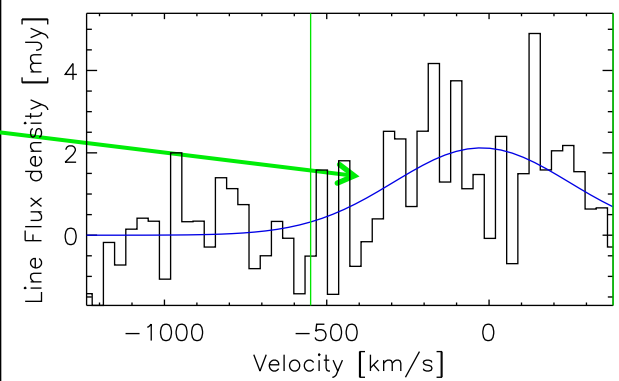

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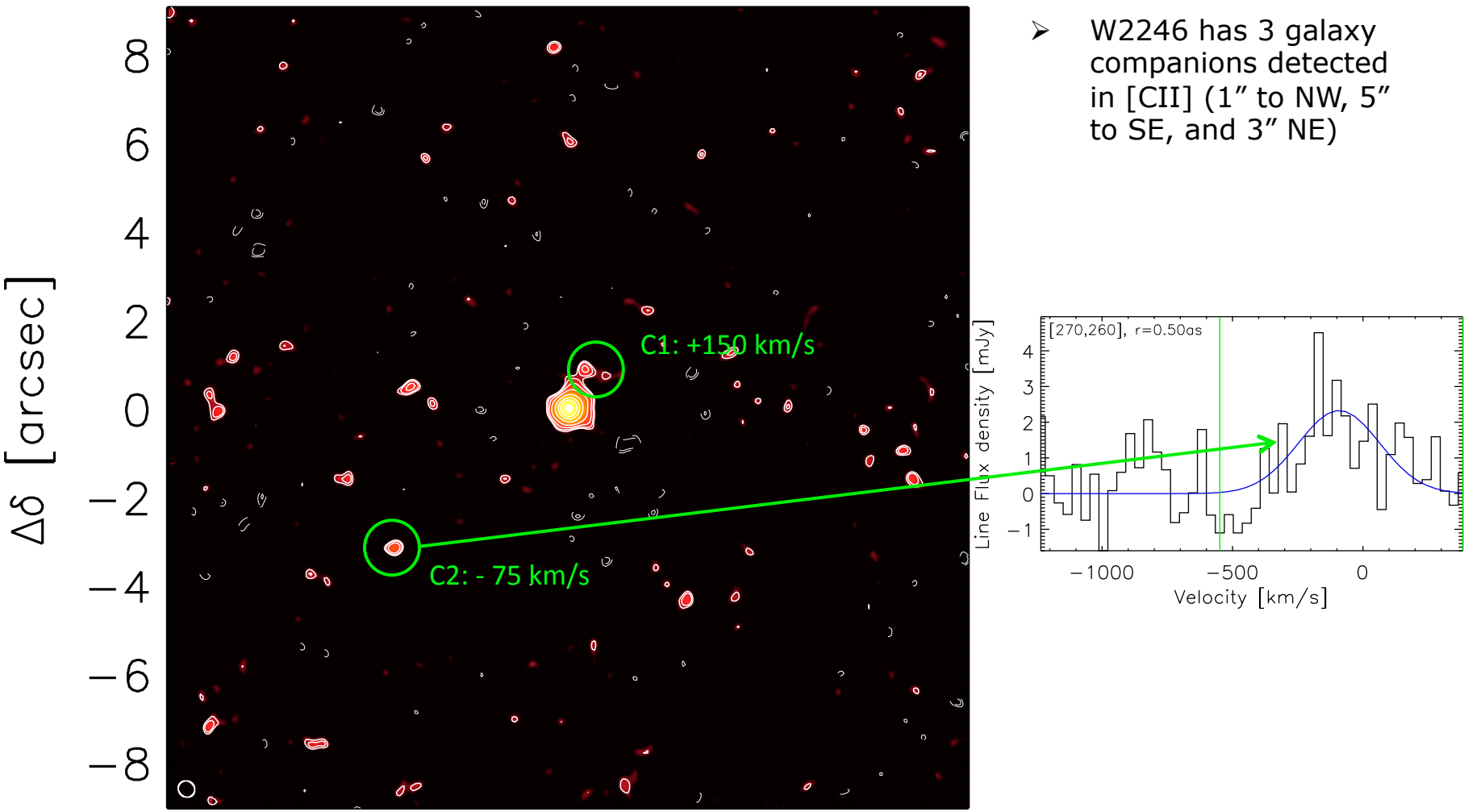

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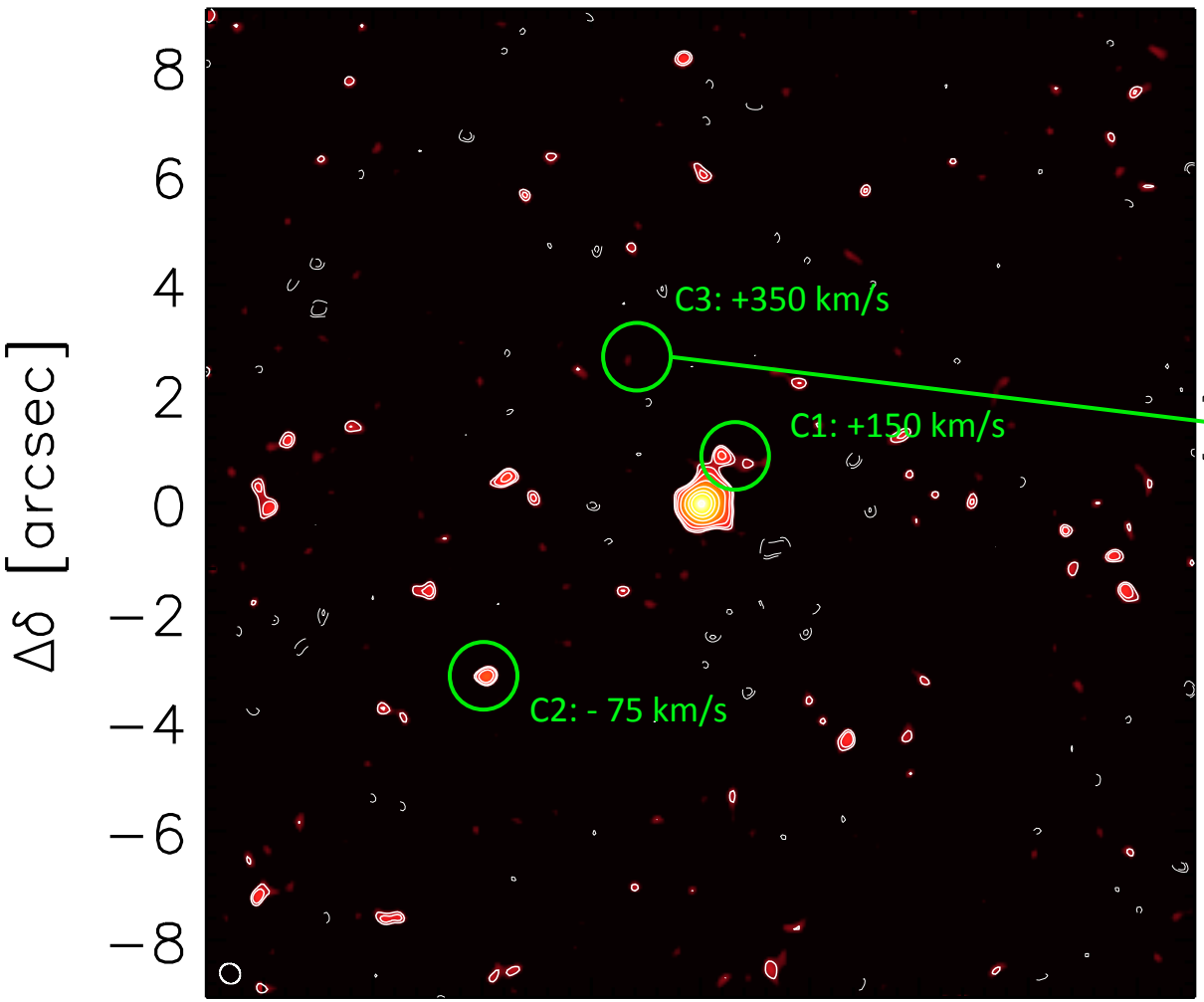

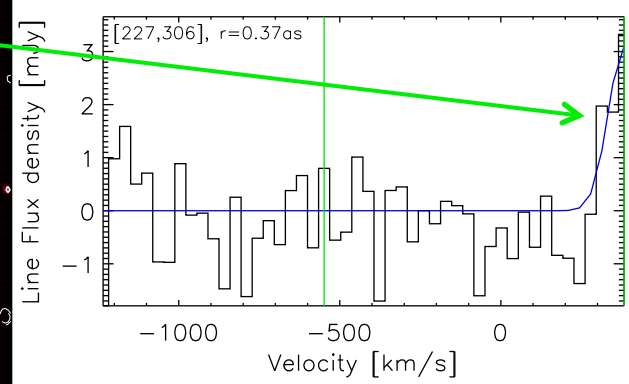

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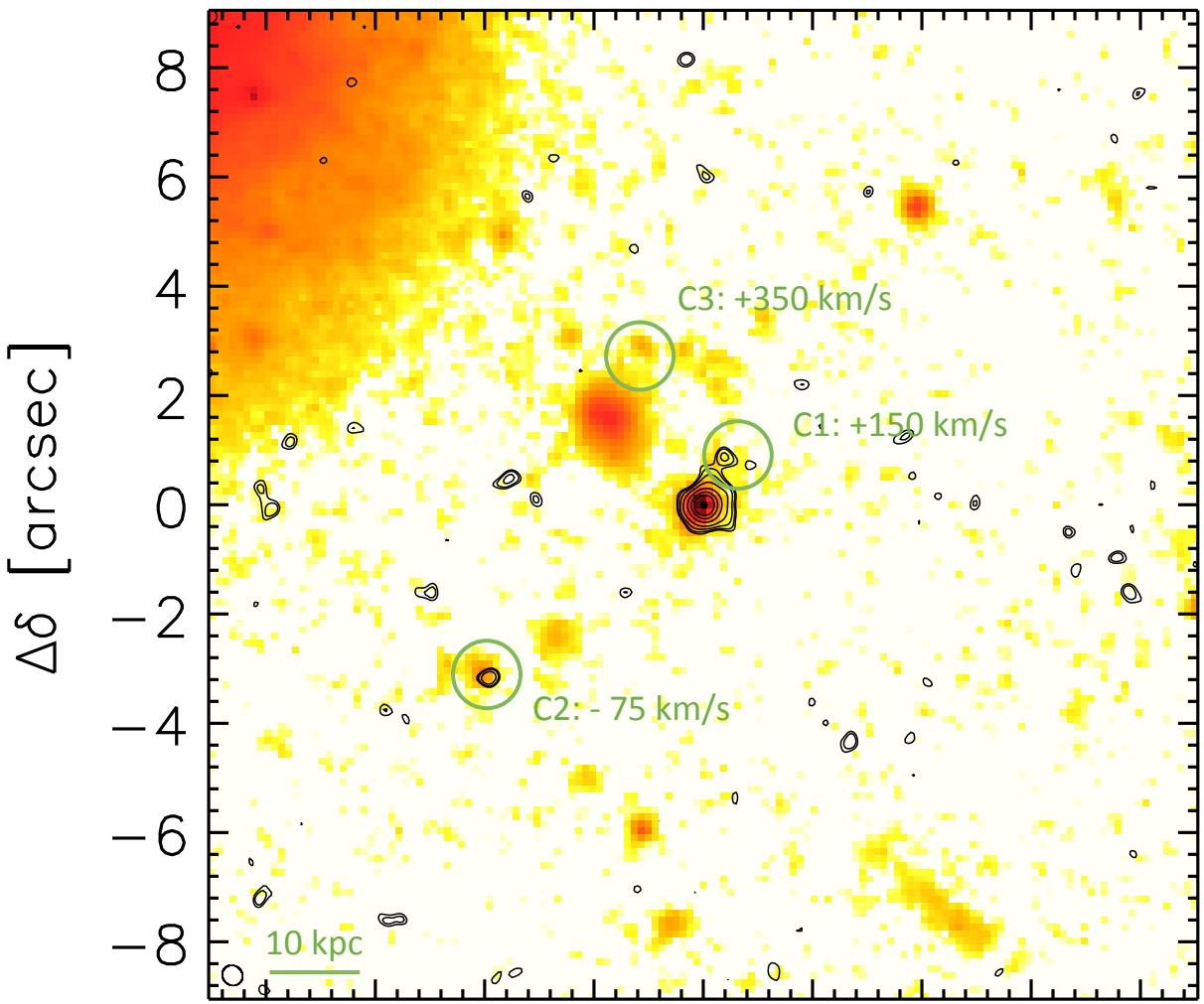

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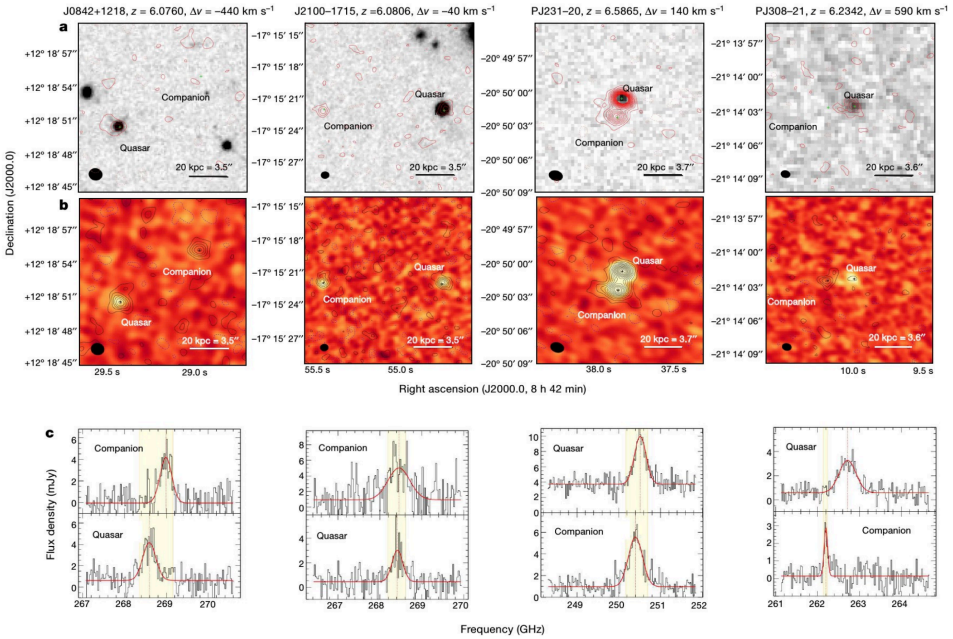
- Sources identified in HST rest-frame UV image.

Environment: Other High-z QSOs

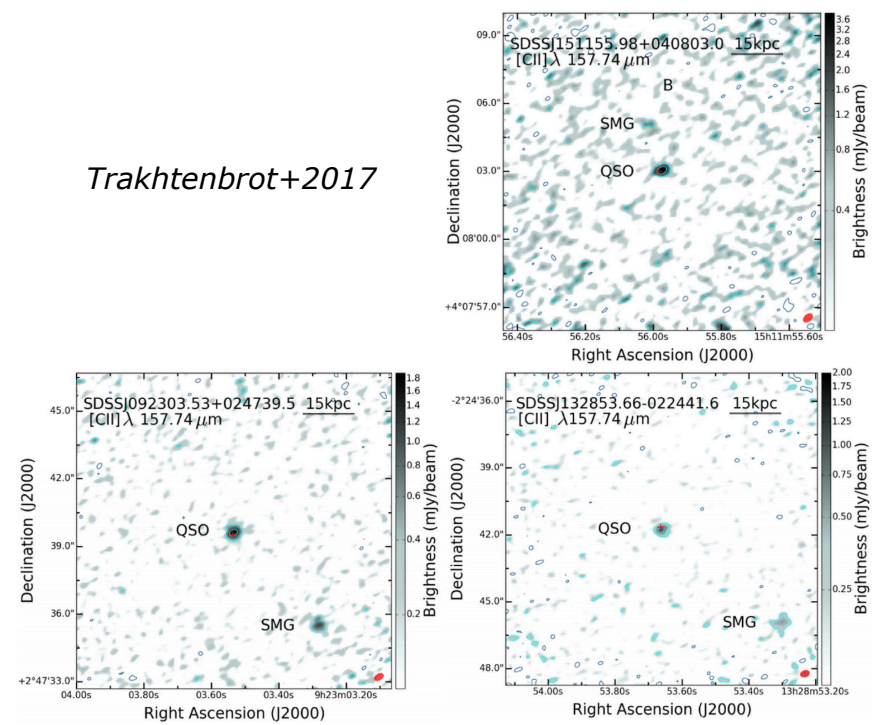
- 20+ QSOs at z~>6
- Companion galaxies detected in 4 sources, at distances < 600 kpc and velocity offsets < 600 km/s from the quasar.



Decarli+2017,2018

- Six z~4.8 luminous quasars powered by growing SMBHs
- Companion SMGs detected in 3 sources, separated 14-45 kpc from the quasar. SFR ~ 1/2 - 1/10 of the main host.

Trakhtenbrot+2017



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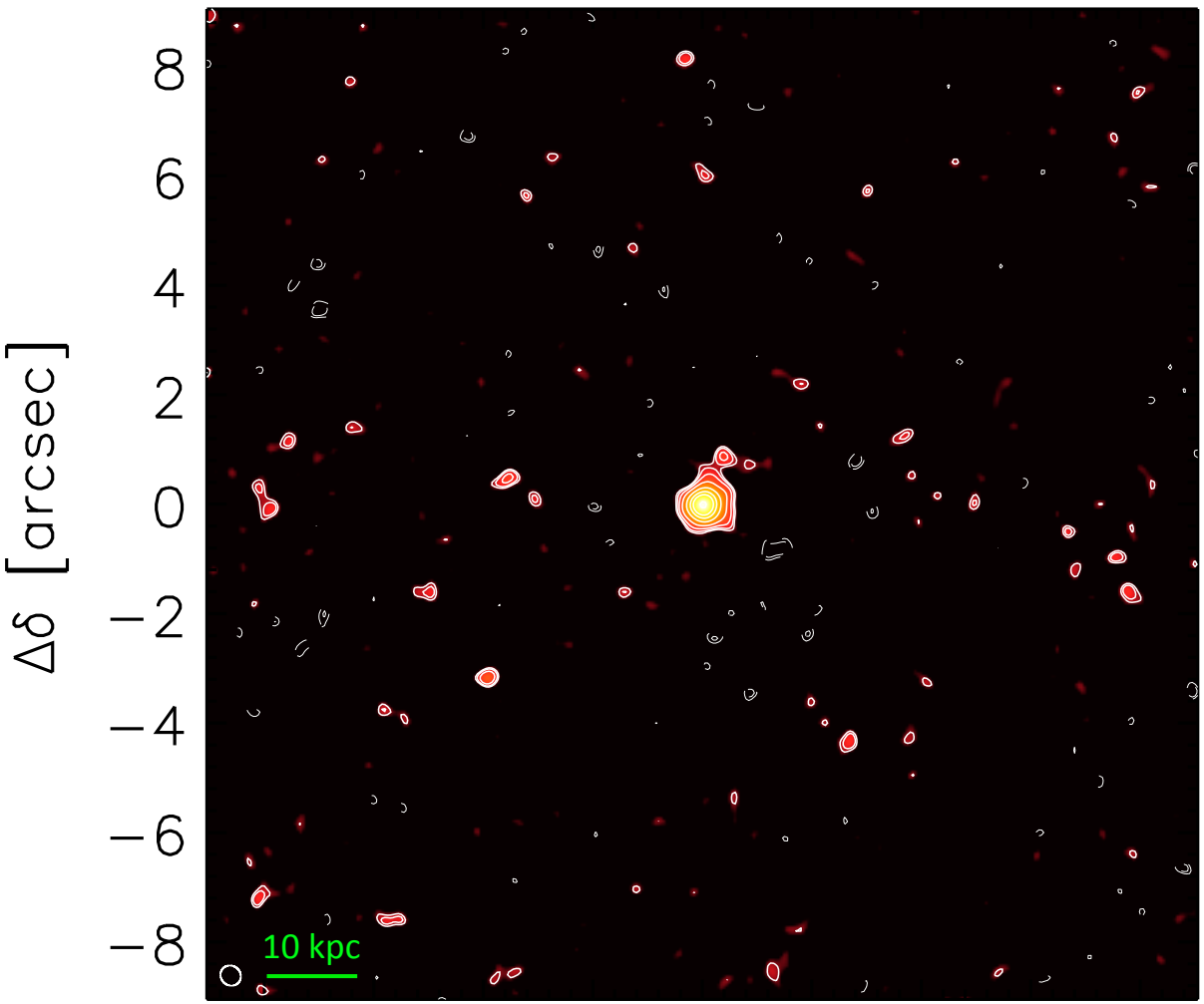

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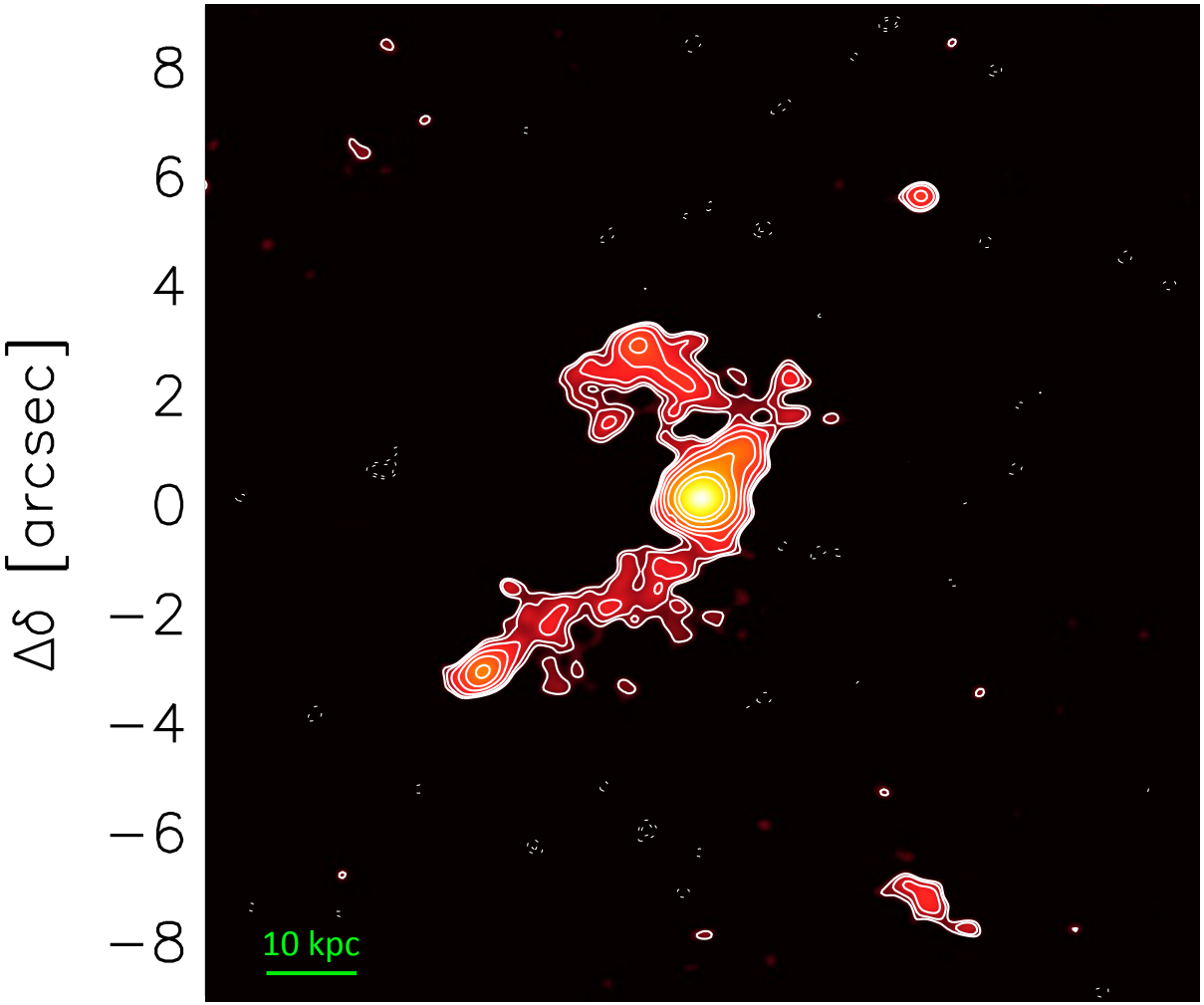

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Diaz-Santos+2018, Science

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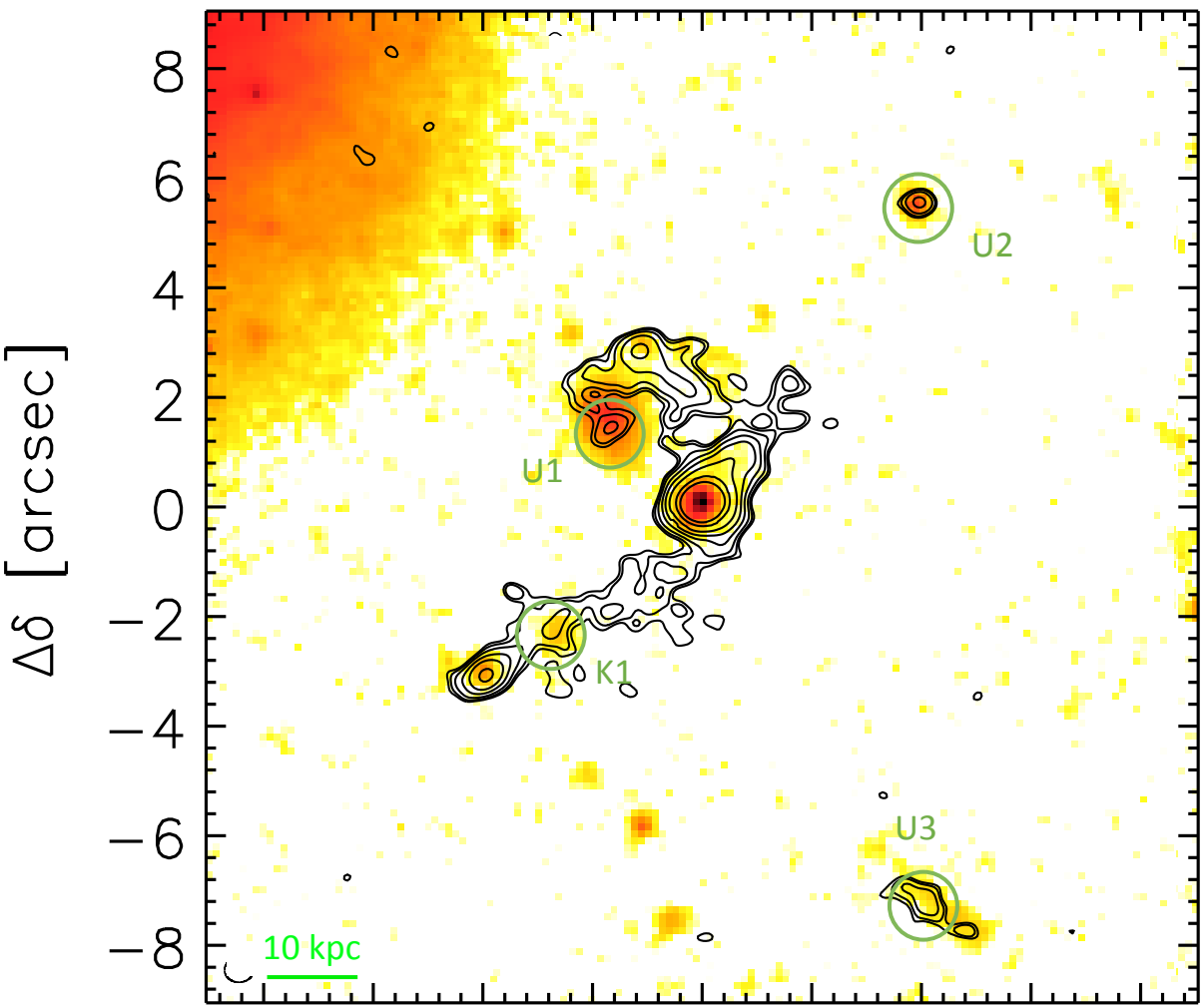

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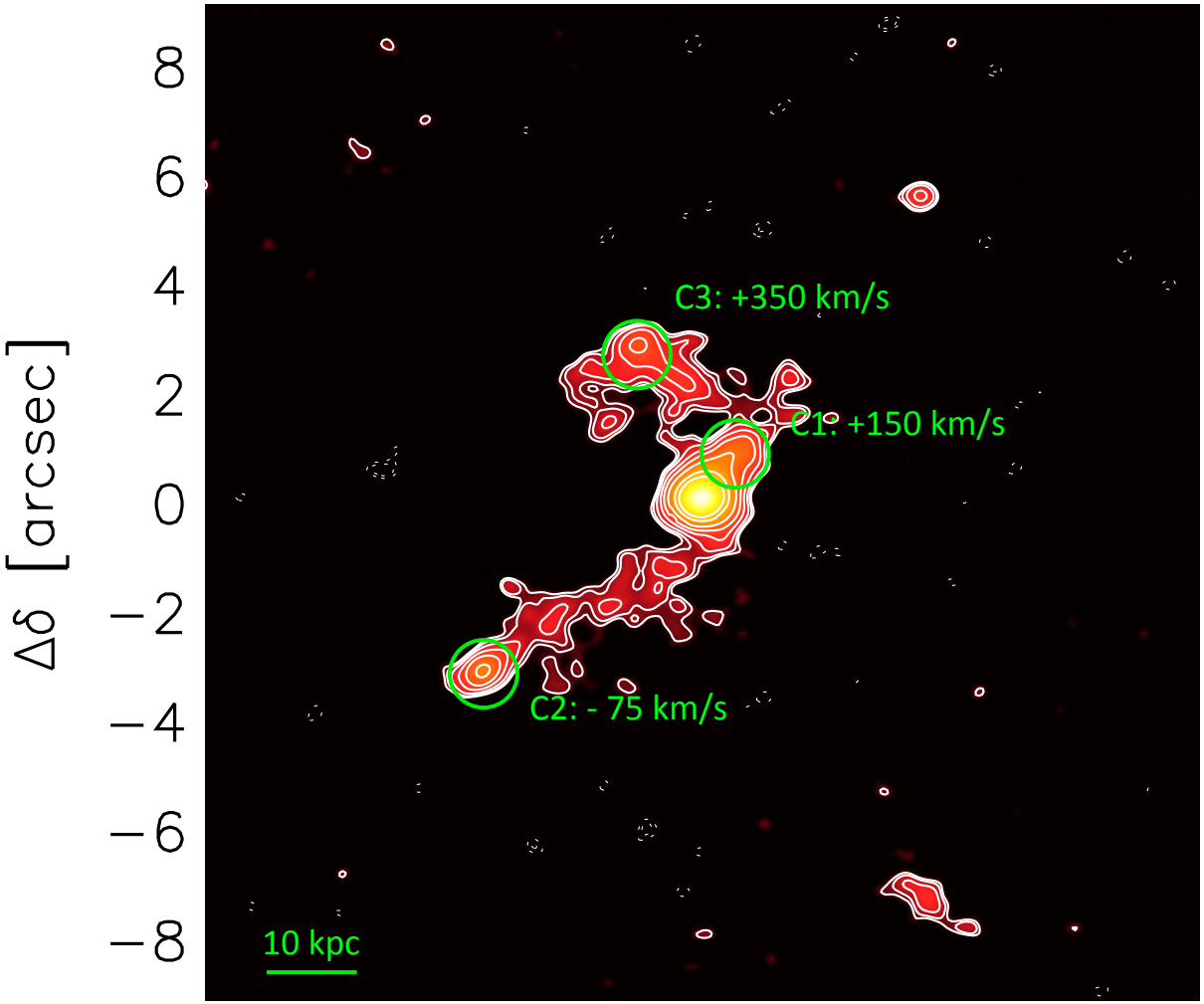

- M_{dust} (W2246-0526) ~ 5-15 x 10^8 $M_\odot$
- For a standard GDR of ~100, this implies at least 10^{11} $M_\odot$ in the entire merger system.
- M_{dust} outside is comparable to W2246-0526 itself.
- Companions account for ~14% of total M_{dust}.
- Streamer contains as much gas and dust as the companions themselves.

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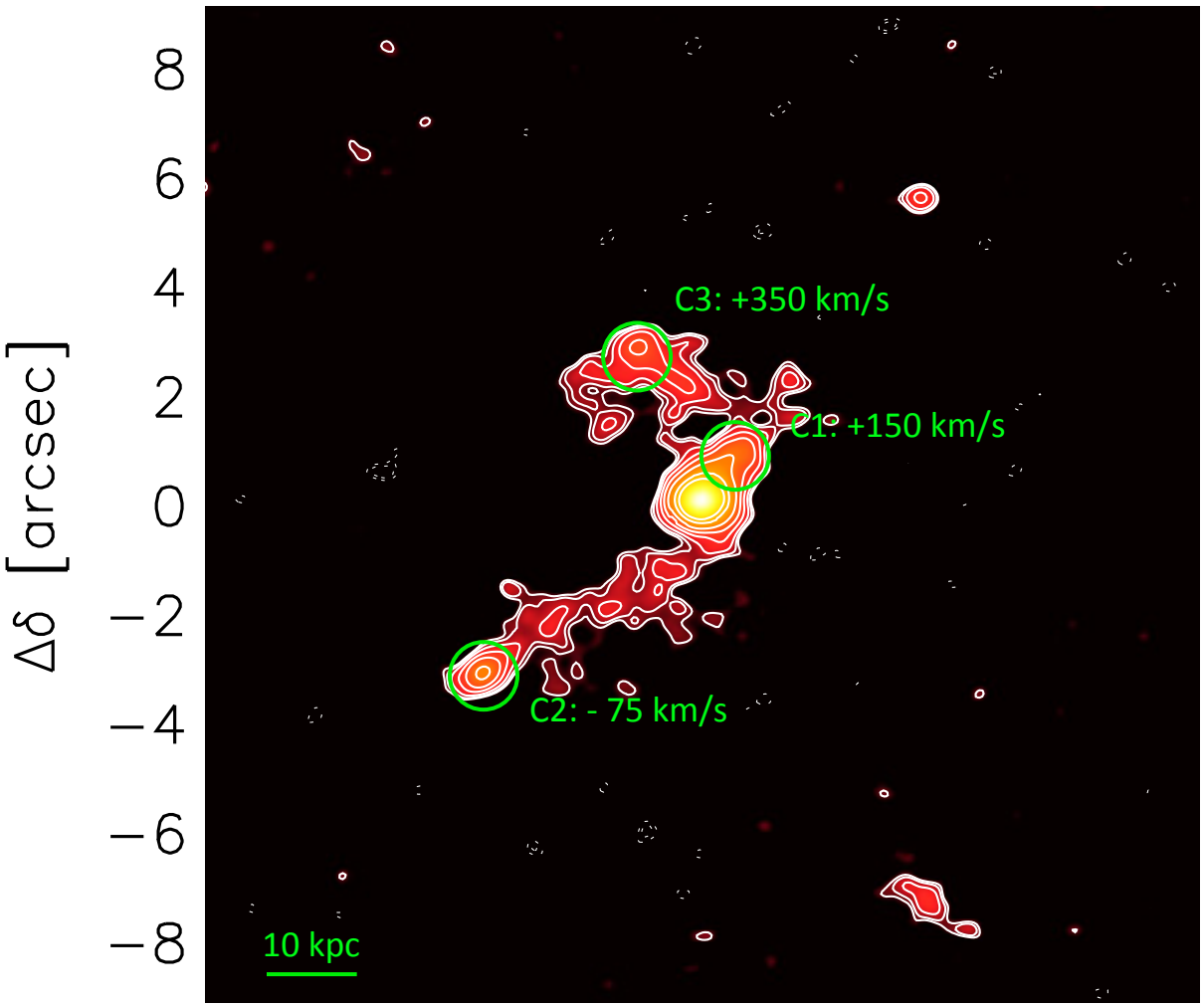

- SFR of the host ~550 $M_\odot$/yr (from SED fit)
- dM/dt ~ 500-1000 $M_\odot$/yr, >~ SFR and $Macc_{AGN}$

Enough to replenish the reservoir of gas to sustain the current star formation rate and BH activity for at least ~ 200 Myr, much longer than QSO active period.

Accretion of neighbor galaxies can provide the intermittent, large-scale influx of material needed to generate its extreme luminosity and build up the stellar and BH mass.

Conclusions

- Hot DOGs are powered by accretion onto a central SMBH, which generates luminosities in excess of 10^{13} $L_\odot$ -> hyper-luminous obscured quasars. The host galaxy is probably undergoing a critical, short-lived phase of its evolution.

- ALMA [CII] and 158μm continuum observations of a pilot sample of 7 Hot DOGs, including W2246, the most luminous galaxy known, to study their gas content and kinematics.

- Shallow [CII] observations of W2246 show a highly turbulent ISM. [CII] FWHM is ~ 500 km/s across the entire host galaxy, ~2.5 kpc. The ISM is probably being expelled in a slow isotropic outflow. Still, the SFR is ~500 $M_\odot$/yr, and $Macc_{AGN}$ at least 100 $M_\odot$/yr. A large influx of gas is needed to keep SF and accretion to the SMBH going.

- Deep ALMA 212μm dust continuum observations reveal dusty streamers connecting three companion galaxies to W2246, providing for the first time clear morphological evidence of a multiple-merger interaction at such high redshift.

- Merger-driven accretion of neighbor galaxies can be an important mechanism that simultaneously i) obscures the central SMBH in W2246−0526 under large columns of dust and gas, and ii) provides the intermittent, large-scale influx of material needed to generate its extreme luminosity, and maintain star formation in the host galaxy for at least a few hundred Myr, which would otherwise quickly deplete its gas reservoir.


Artist impression: NRAO/AUI/NSF, S. Dagnello