Investigating quasar host galaxies with strong gravitational lensing

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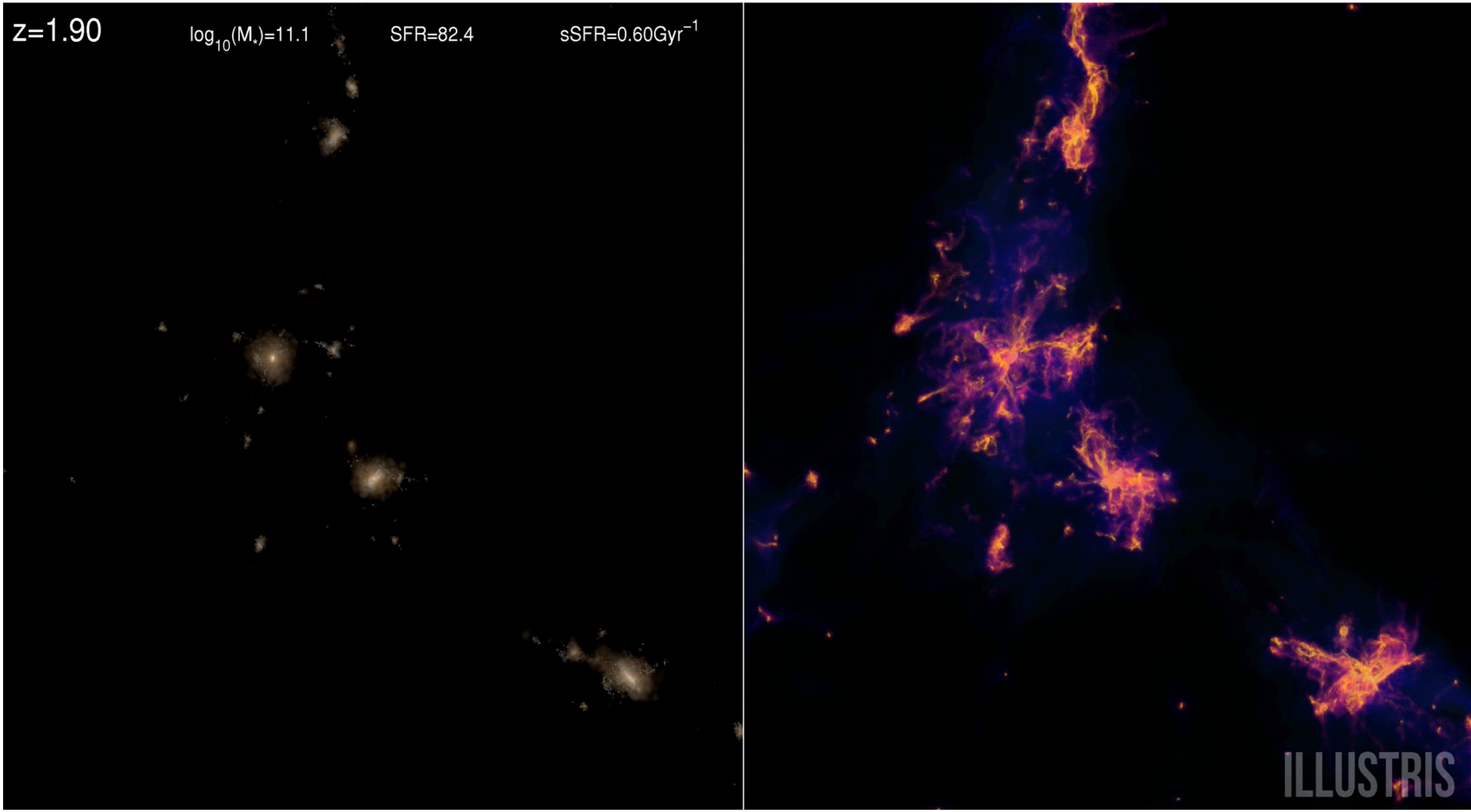
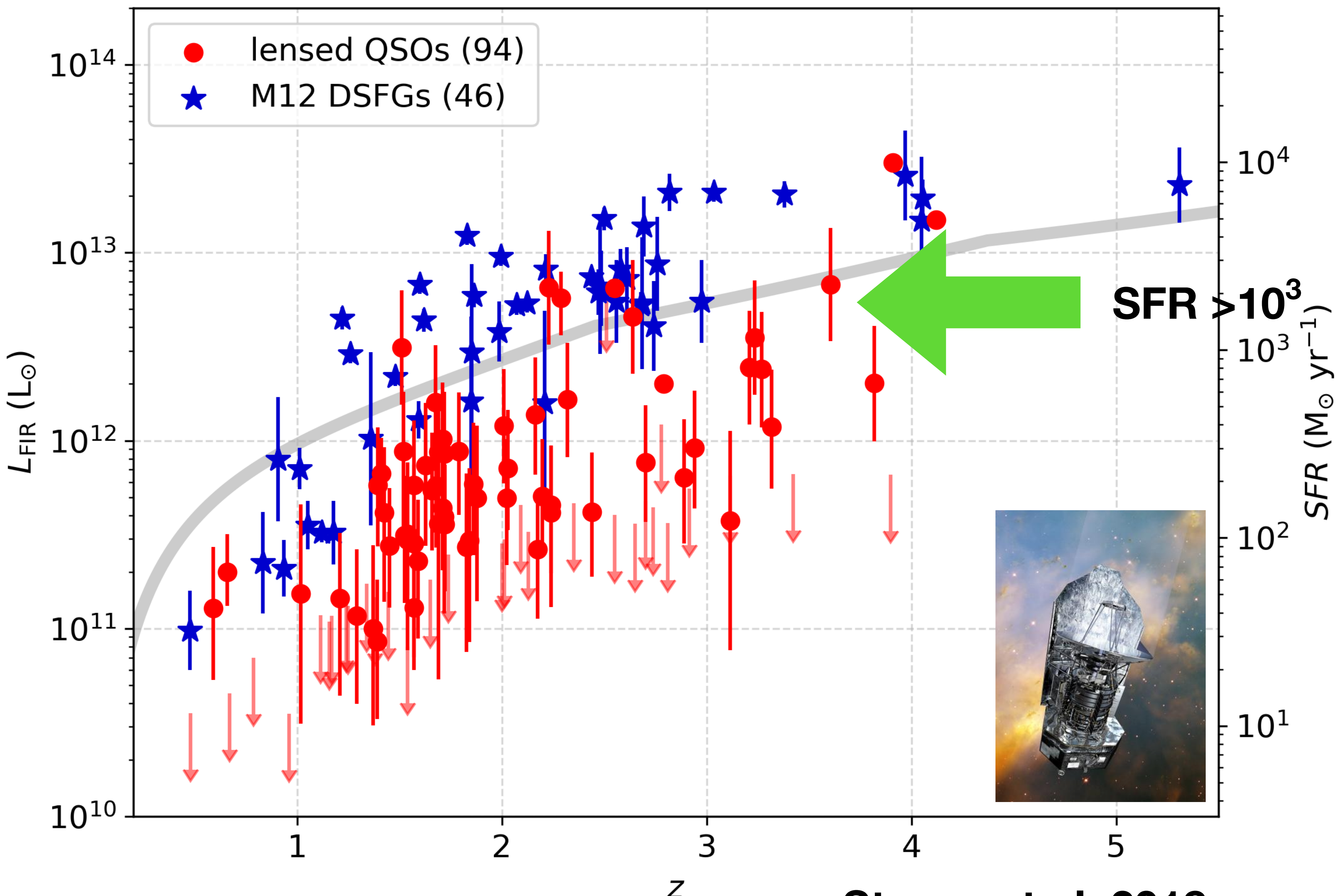
Formation of a massive elliptical galaxy



Stellar light (optical)

Gas density (FIR—sub-mm)

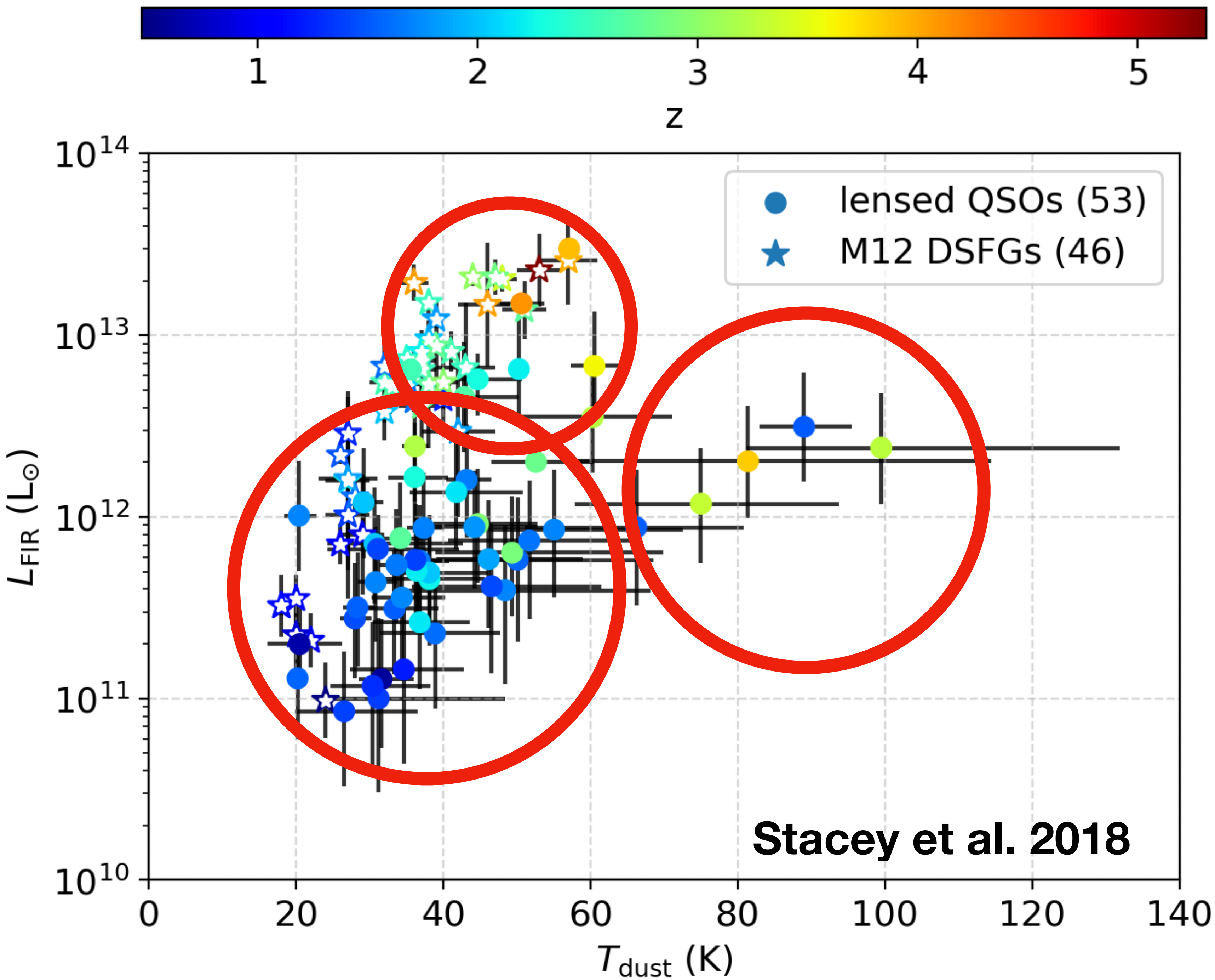
Probing below the confusion limit in the FIR



Stacey et al. 2018

- 70% of sample are detected
- ~**10%** of quasars have FIR properties similar to Herschel DSFGs with SFRs > 1000 $M_\odot$ yr^{-1}
- Generally consistent with quasar evolution scenarios, but extreme SFRs in tension with

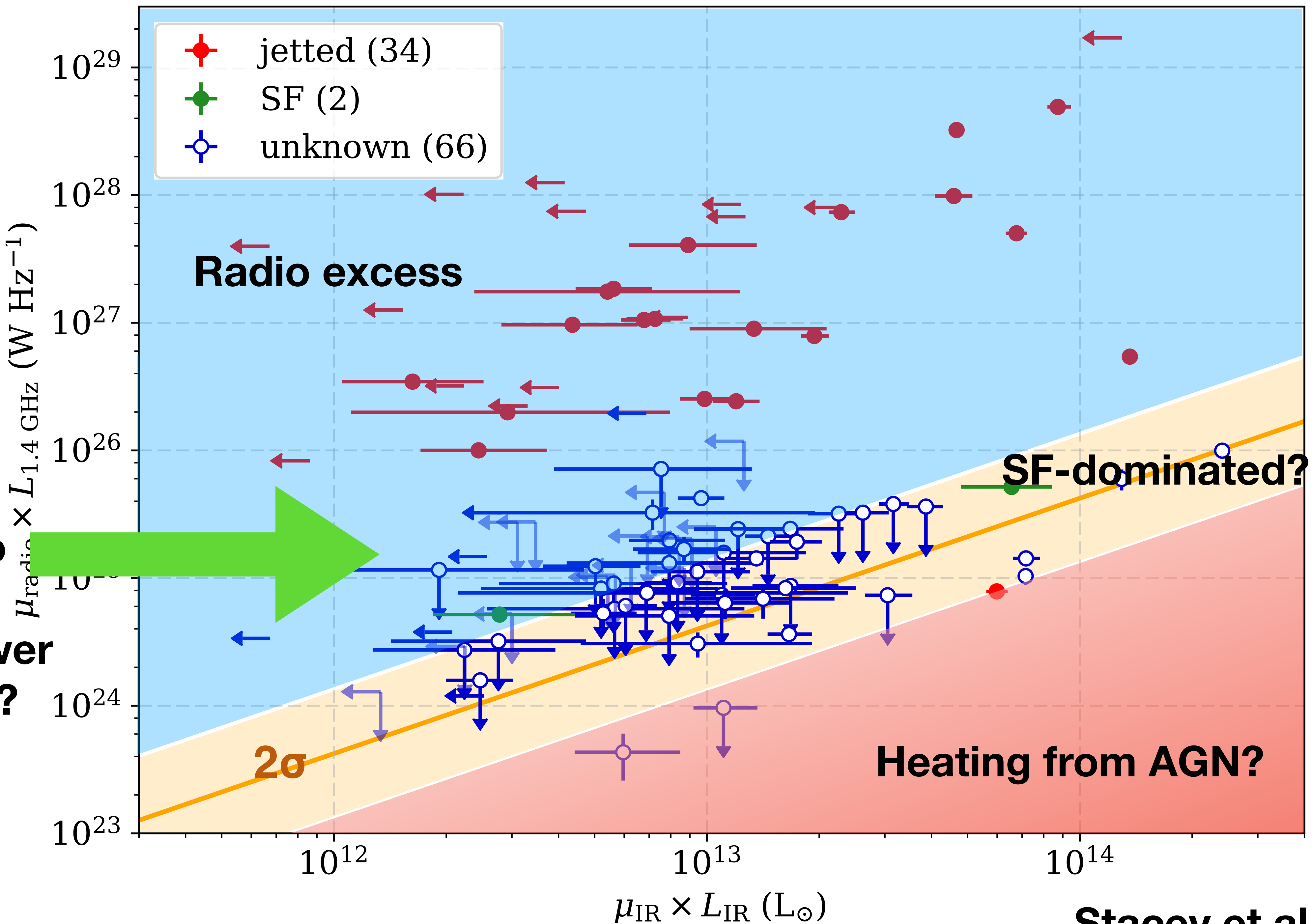
Dust temperatures comparable to DSFGs



- median lensing-corrected SFR of **120^{+160}_{-80} $M_\odot$ yr^{-1}** (assuming typical magnification of 10)
- Dust temperatures **38^{+12}_{-5} K**, consistent with star formation in most cases
- Some AGN contribution?

66% of lensed quasars have high levels of dust-obscured SF in host galaxy

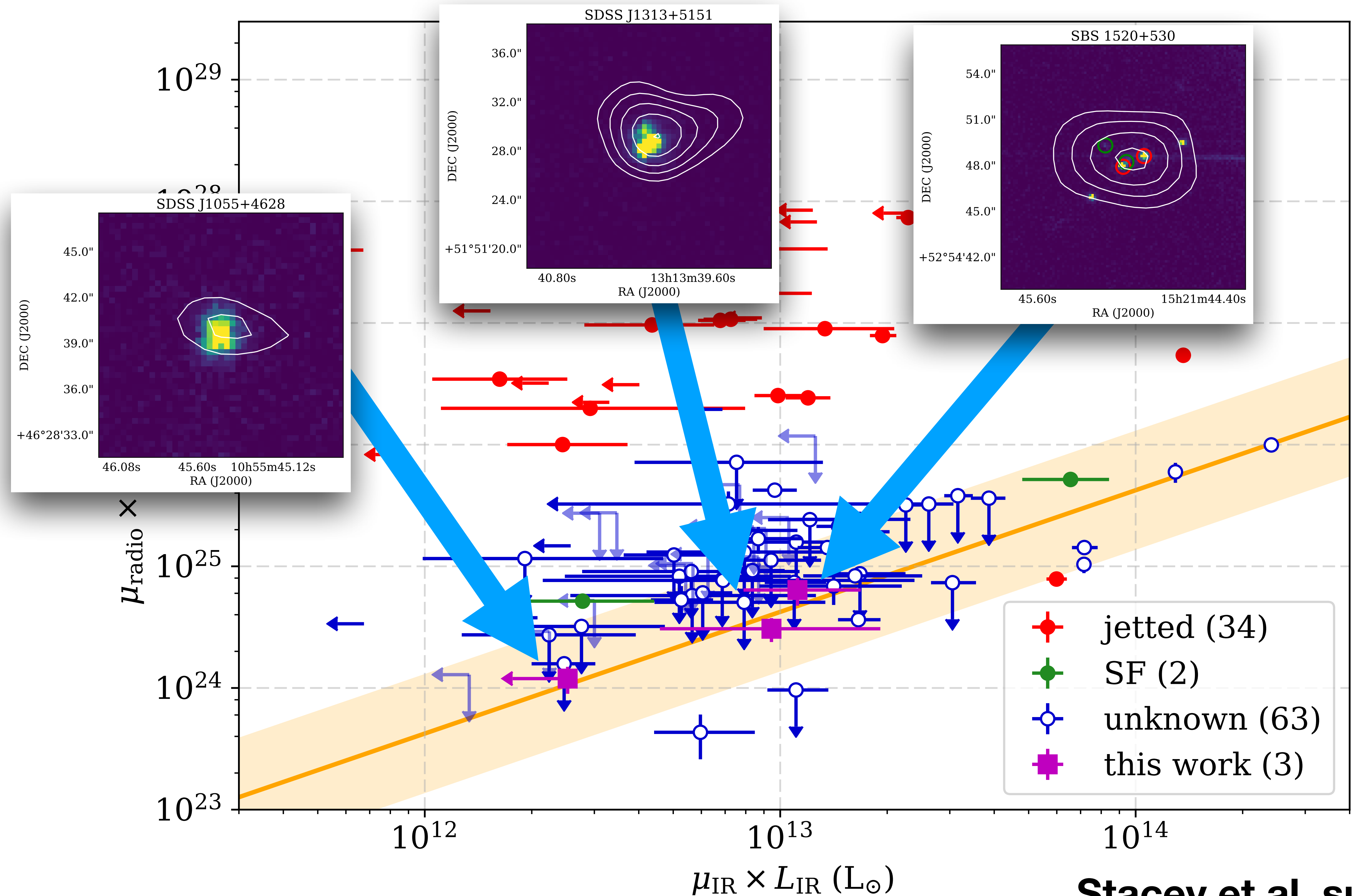
Radio-infrared correlation



Optically-selected, with radio excess = low power radio jets?

Stacey et al. 2018

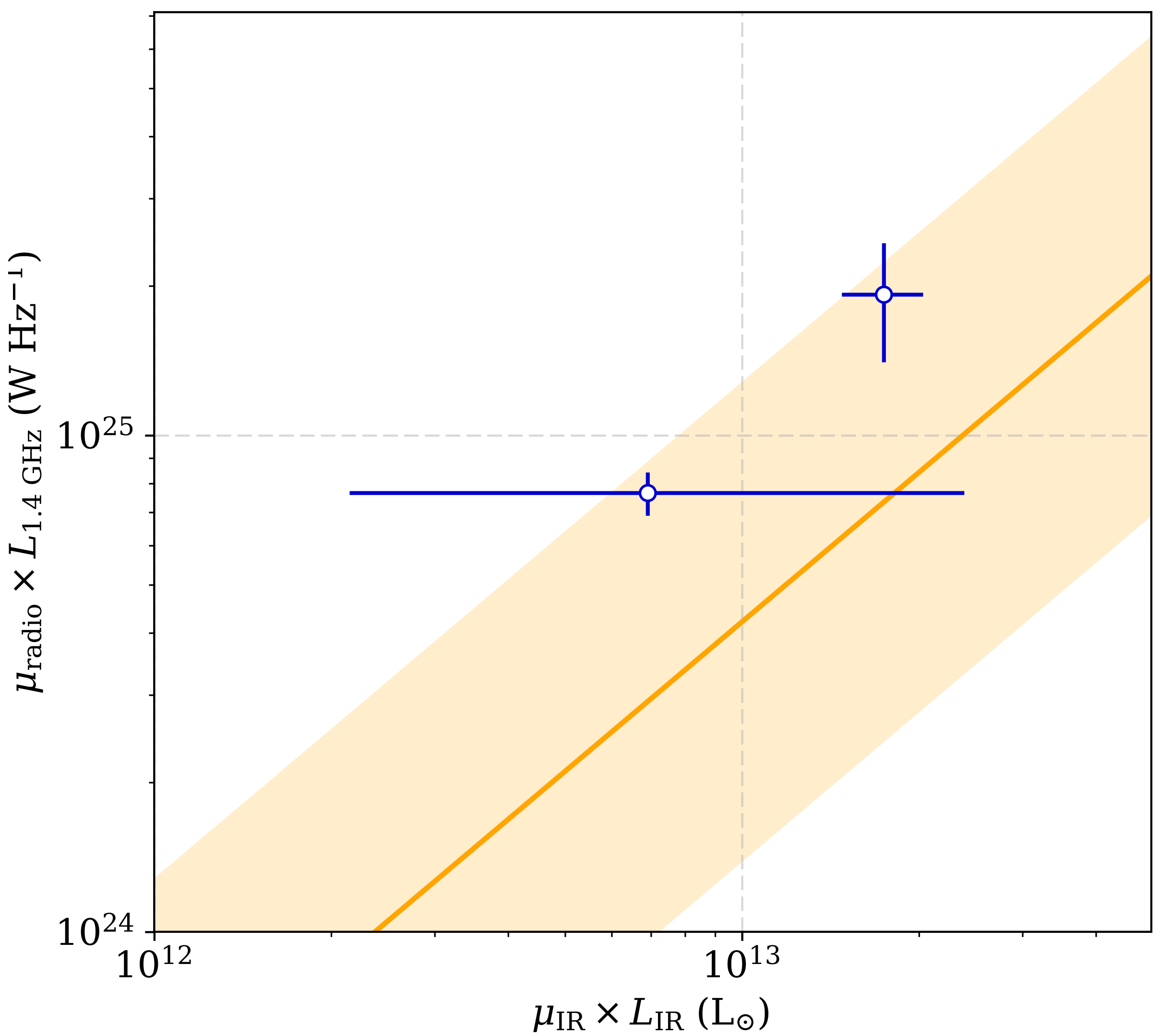
Radio-infrared correlation - LoTSS/HETDEX



Stacey et al. submitted

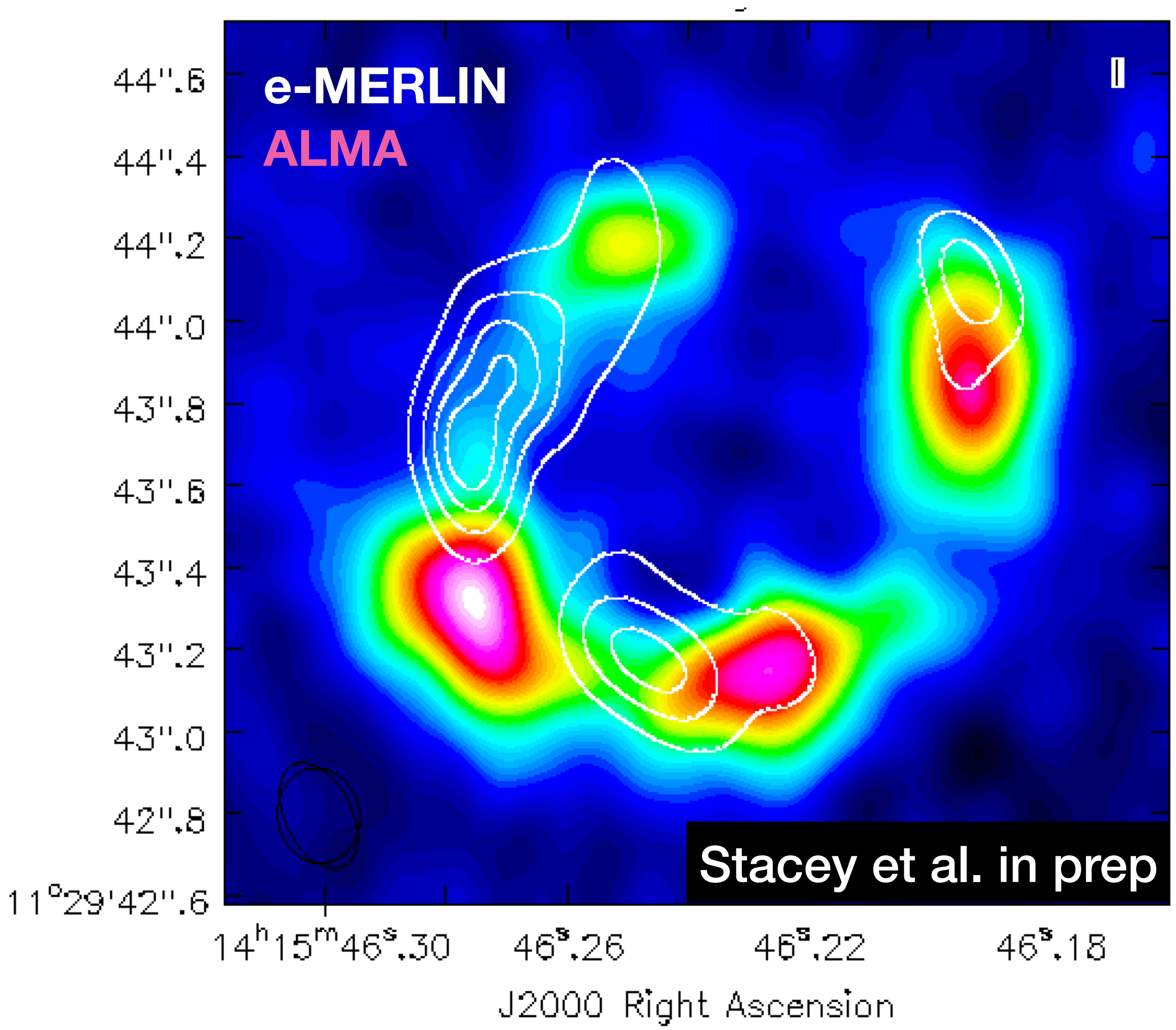
VLBI follow-up of optically-selected quasars

- We have begun follow-up of targets with FIRST radio detections - only two observed so far
- 2σ above radio-infrared correlation and **not detected on VLBI-scales**
- Suggests ~ 50% of FIRST radio emission is not in a compact component… or does it?



Disentangling AGN and SF in the Cloverleaf

- Cloverleaf has significant radio excess (x10), resolved radio jet (e-MERLIN), but is **not detected with EVN**
- Non-detection on VLBI-scales doesn't mean radio emission is not AGN
- How else to understand AGN contributions?

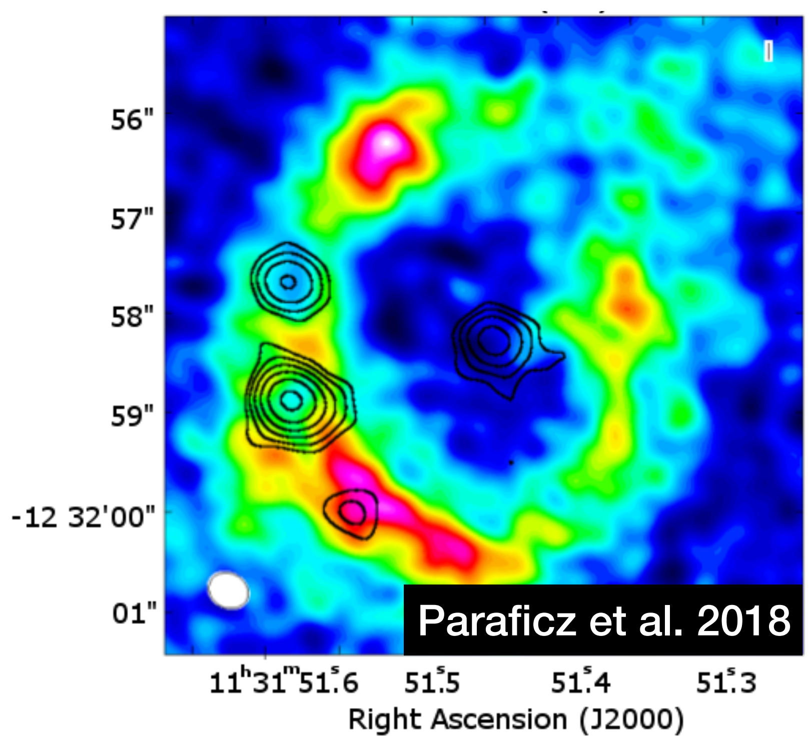


Even with VLBI, disentangling AGN contribution may be difficult

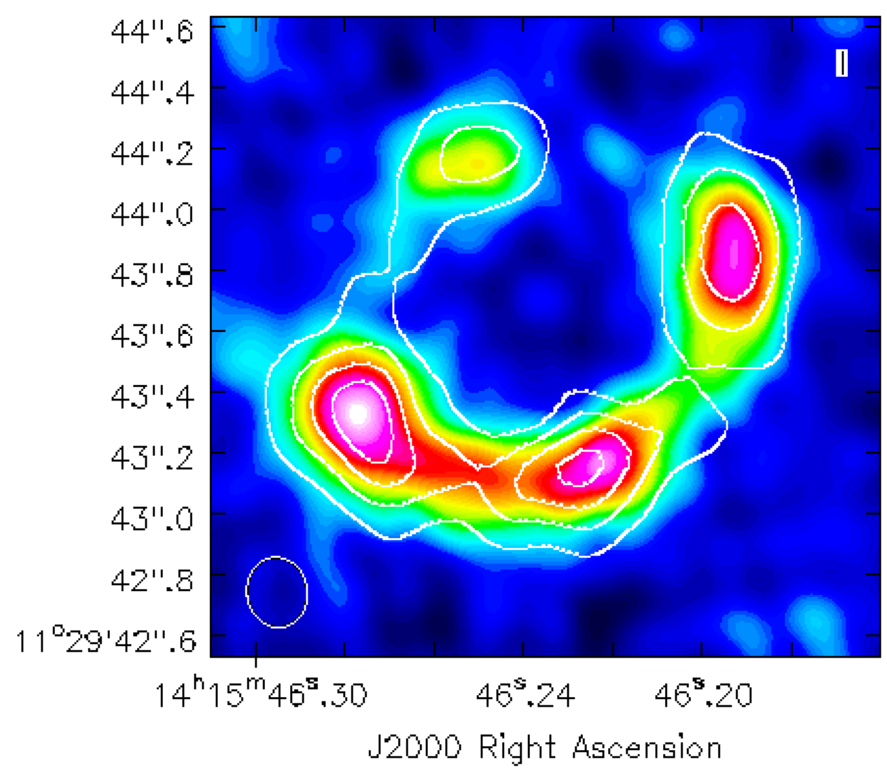
Resolving dust and gas on scales 80—300 pc

- Lensing magnification x10 increases effective resolution by similar factors, to resolve structure, kinematics at high-z
- Can test extreme SFRs we derive in FIR by comparison to dust and molecular gas content

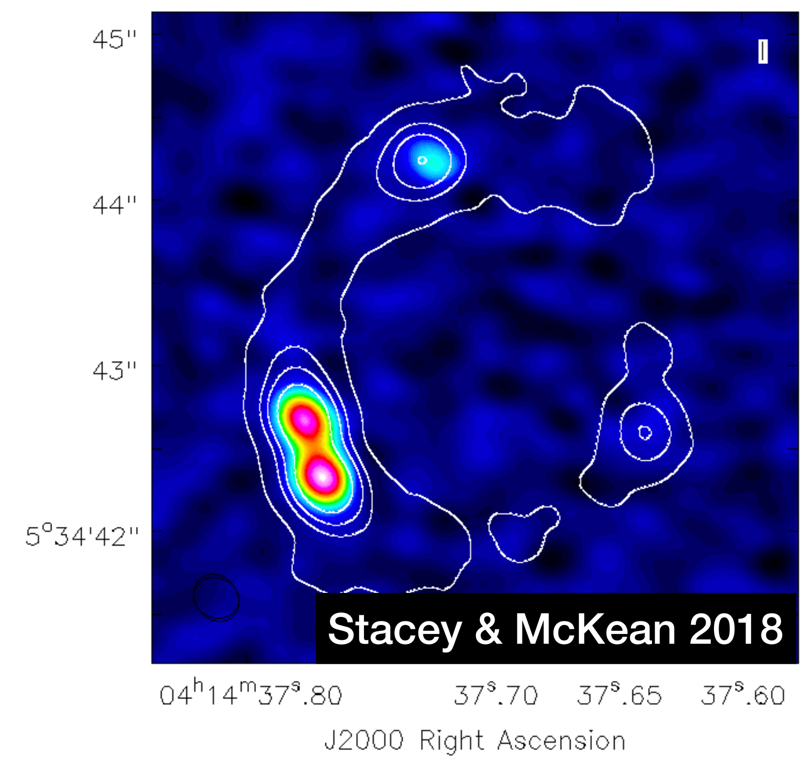
CO(2—1)
Bulk of cool gas



CO(9—8)
Star-forming gas

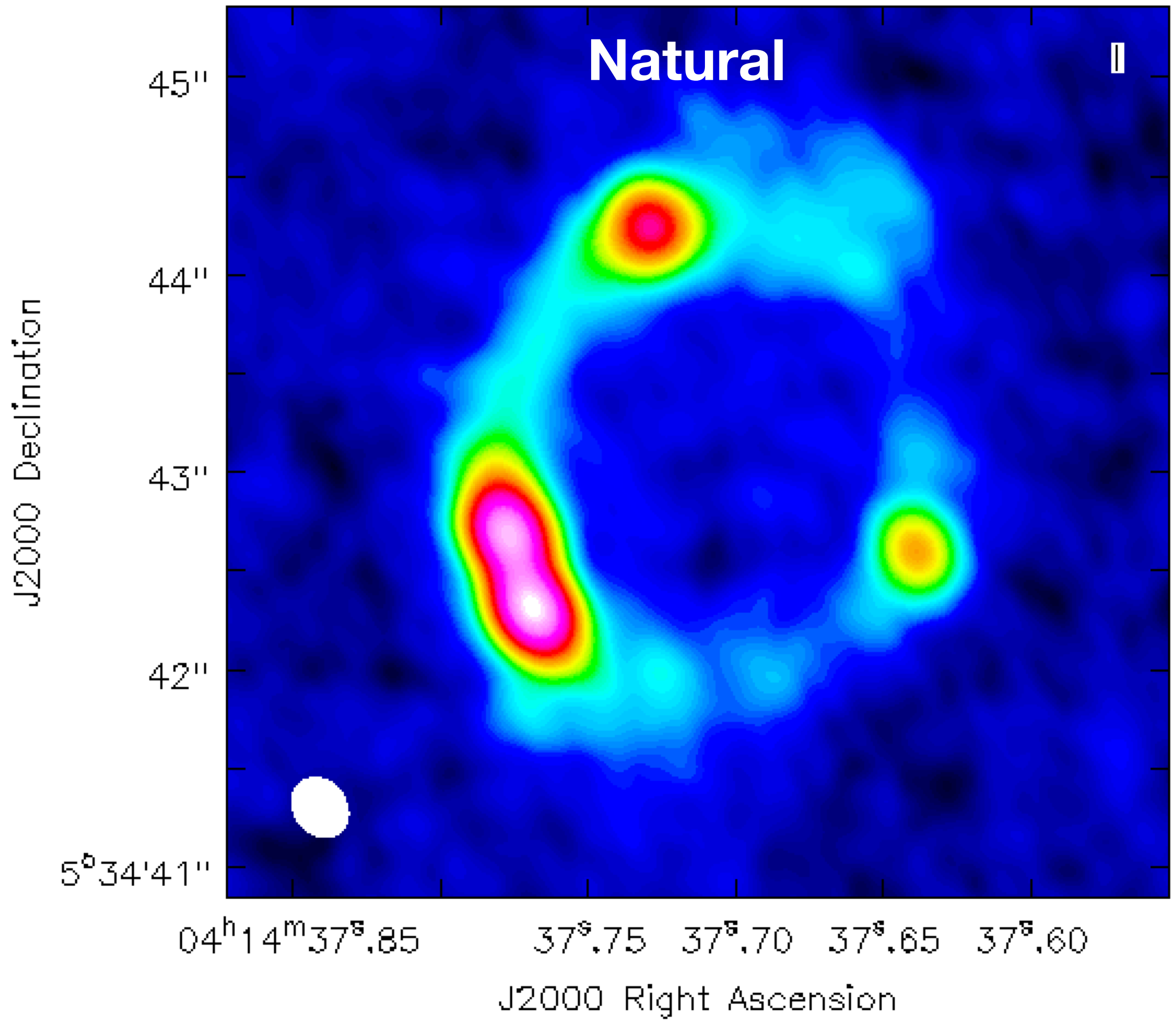


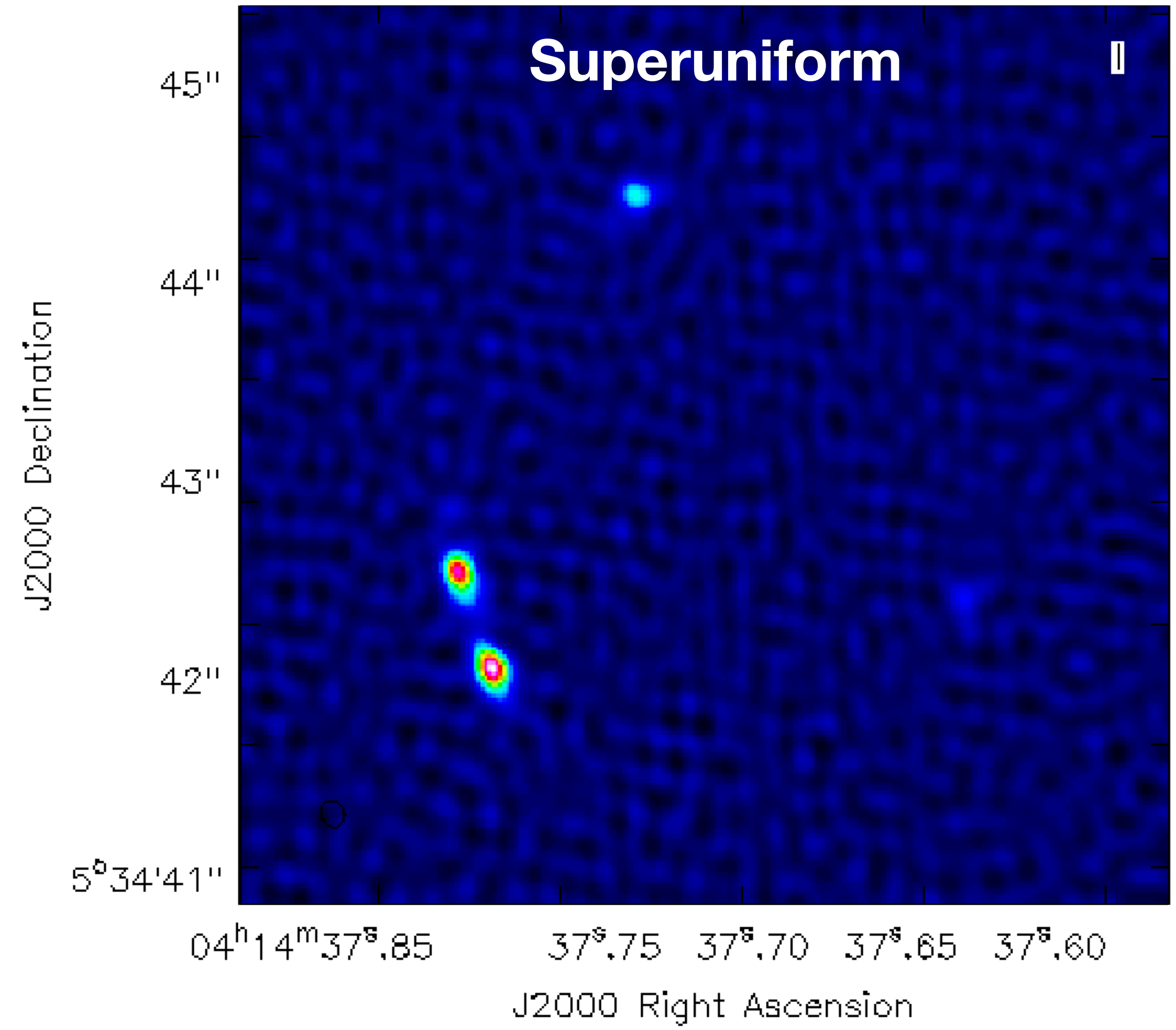
CO(11—10)
AGN-excited gas



- Magnification is not a number — need sophisticated source reconstruction techniques

MGJ0414+0534 (z=2.64)



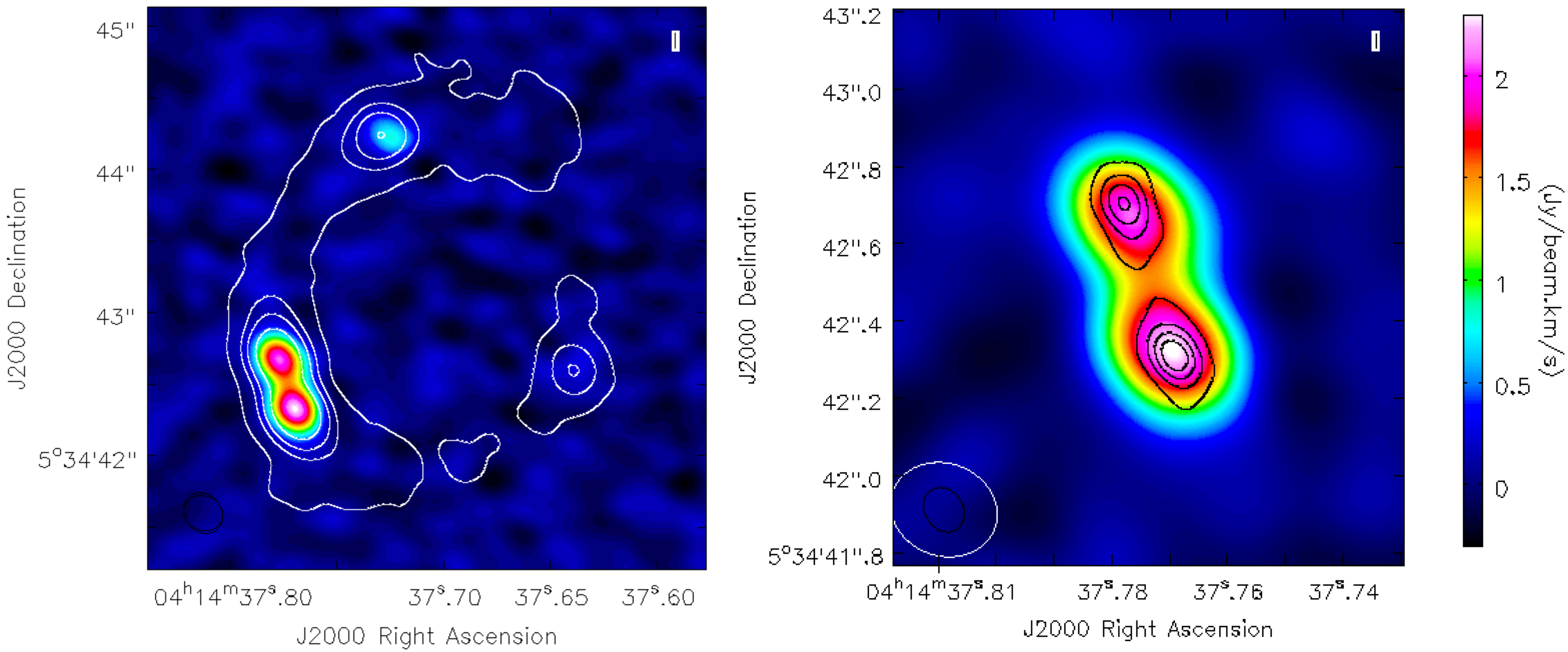


- ALMA 340 GHz continuum, resolution 0.1”—0.3”
- Composite AGN (synchrotron) and SF (dust)
- Resolving scales 100—400 pc at z=2.6

Stacey & McKean (2018)

MGJ0414+0534 - CO (11—10) line

- CO (11—10) high-excitation molecular gas, FWHM ~ 1200 km/s
- Flux ratio anomaly revealed on small spatial scales



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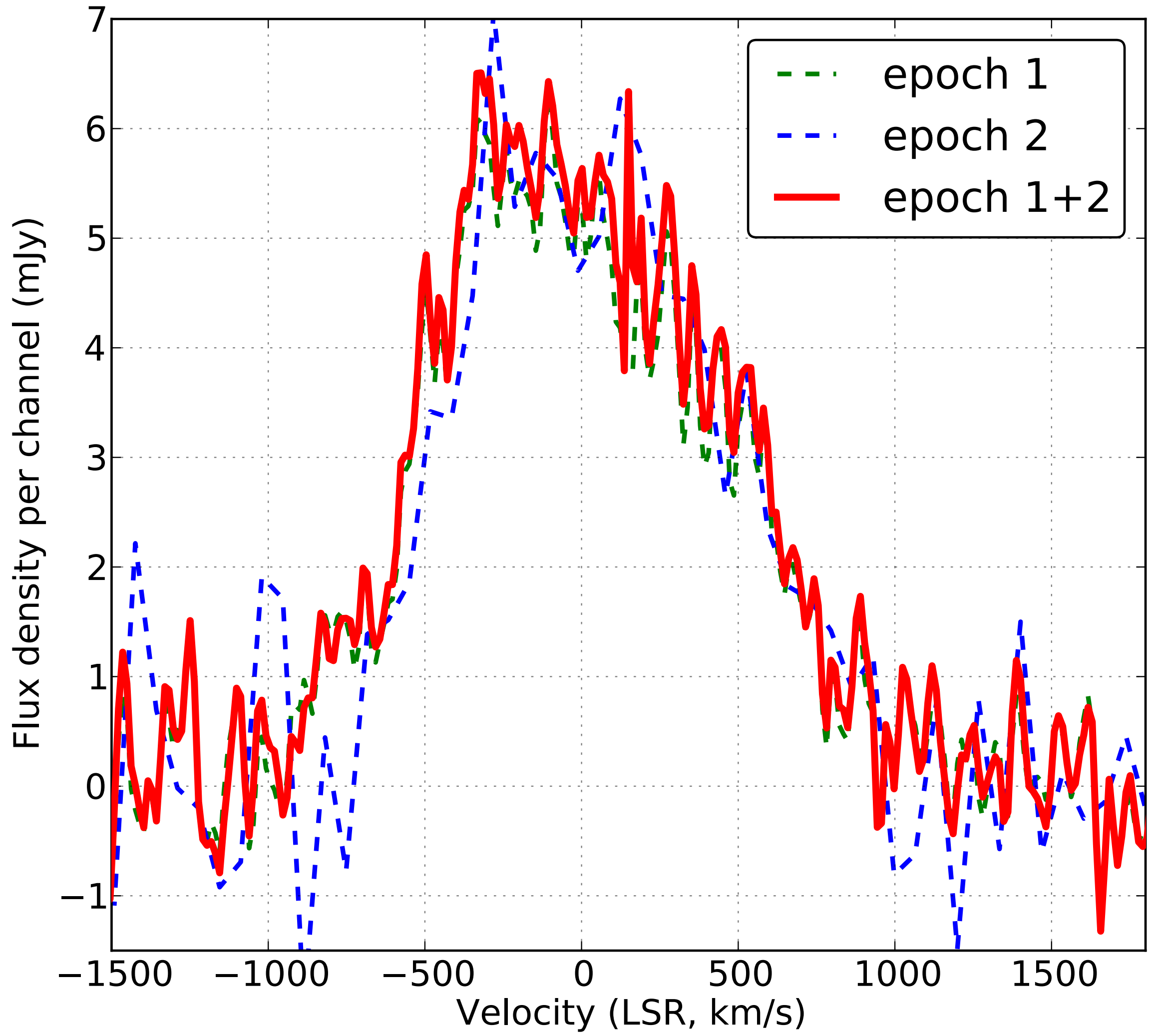
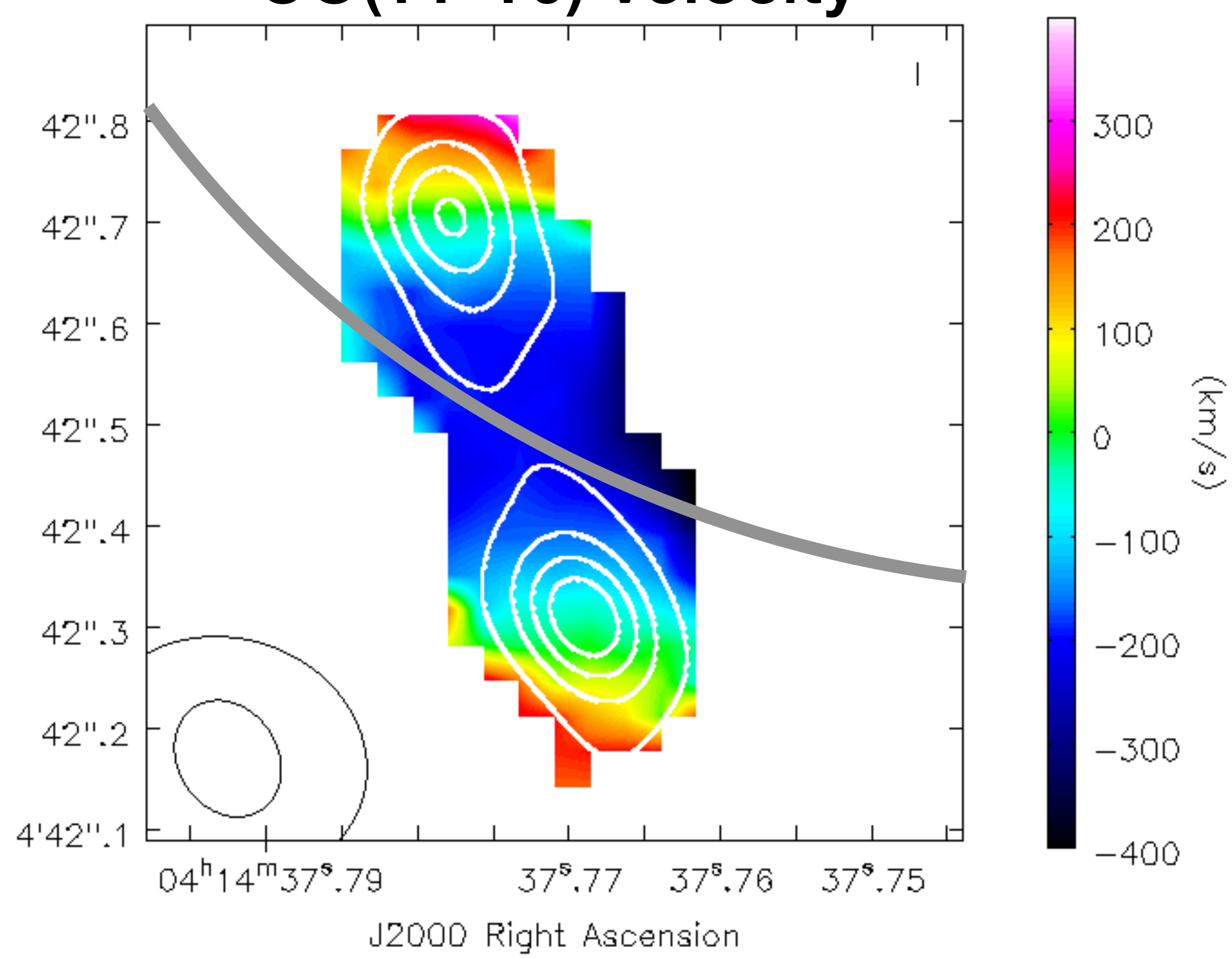


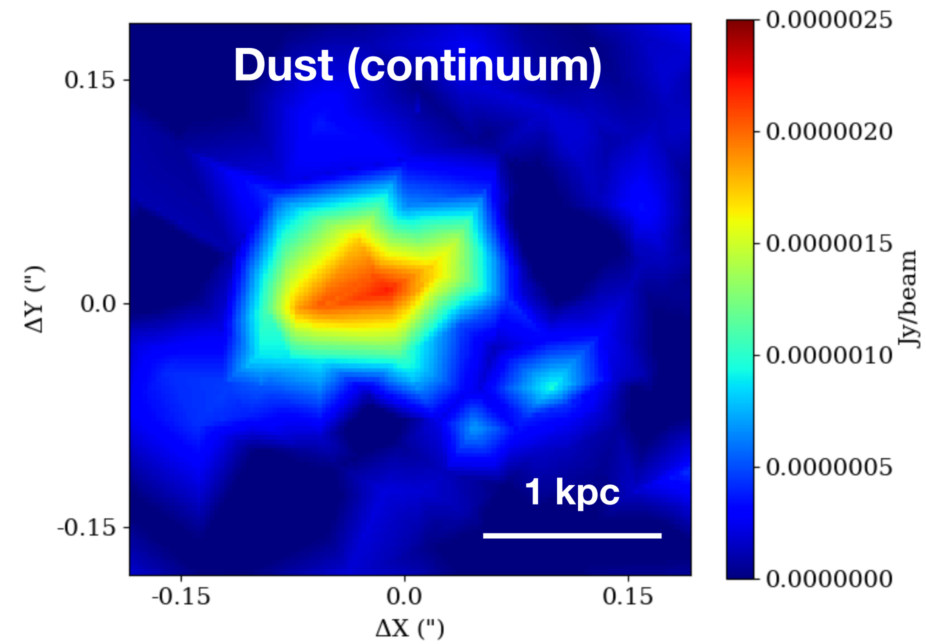
CO(11-10) velocity

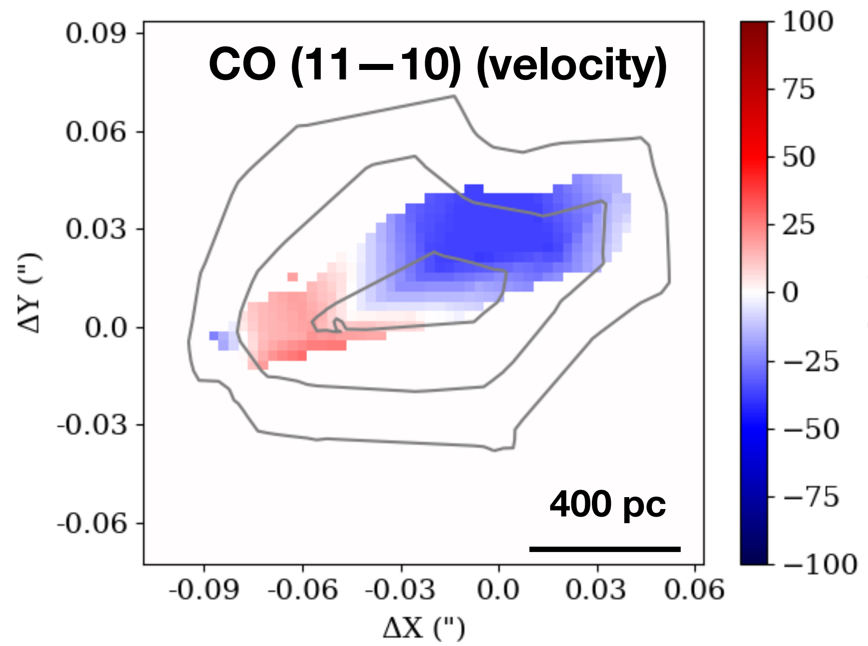


Stacey & McKean (2018)

MGJ0414+0534 - preliminary reconstruction of gas and dust

- Reconstructed dust emission
  - Compact size **~ 1 kpc** (magnified x18) similar to DSFGs
  - Implied SFR **880 $M_\odot$ yr^{-1}**
- Reconstructed CO (11—10)
  - Compact size of **~ 400 pc**
  - Enclosed dynamical mass **~ 10^{10} $M_\odot$**
  - Toomre parameter, **Q_g ~ 0.7** not a stable disk?





Gravitational lensing helps resolve compact dust and gas in host galaxy

Summary

- At least 66% of lensed quasars have high levels of dust-obscured SF in host galaxy, measured with Herschel/SPIRE (Stacey et al. 2018, arXiv:1705.10530)
- Lensed RQQs seem consistent with radio—infrared correlation (Stacey et al. submitted). But even with VLBI, disentangling SF from AGN may be difficult: need very sensitive, high-resolution data in in radio and FIR/sub-mm.
- Resolving dust and molecular gas on small scales with help of gravitational lensing (Stacey & McKean 2018, arXiv:1808.05571) could help test extreme SFRs derived from FIR/sub-mm and constrain energy injection into host galaxy from AGN

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