

# Star-formation in quasar host galaxies revealed by strong gravitational lensing

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university of  
 groningen

faculty of science  
 and engineering

**ASTRON**

Netherlands Institute for Radio Astronomy

$z=4.00$

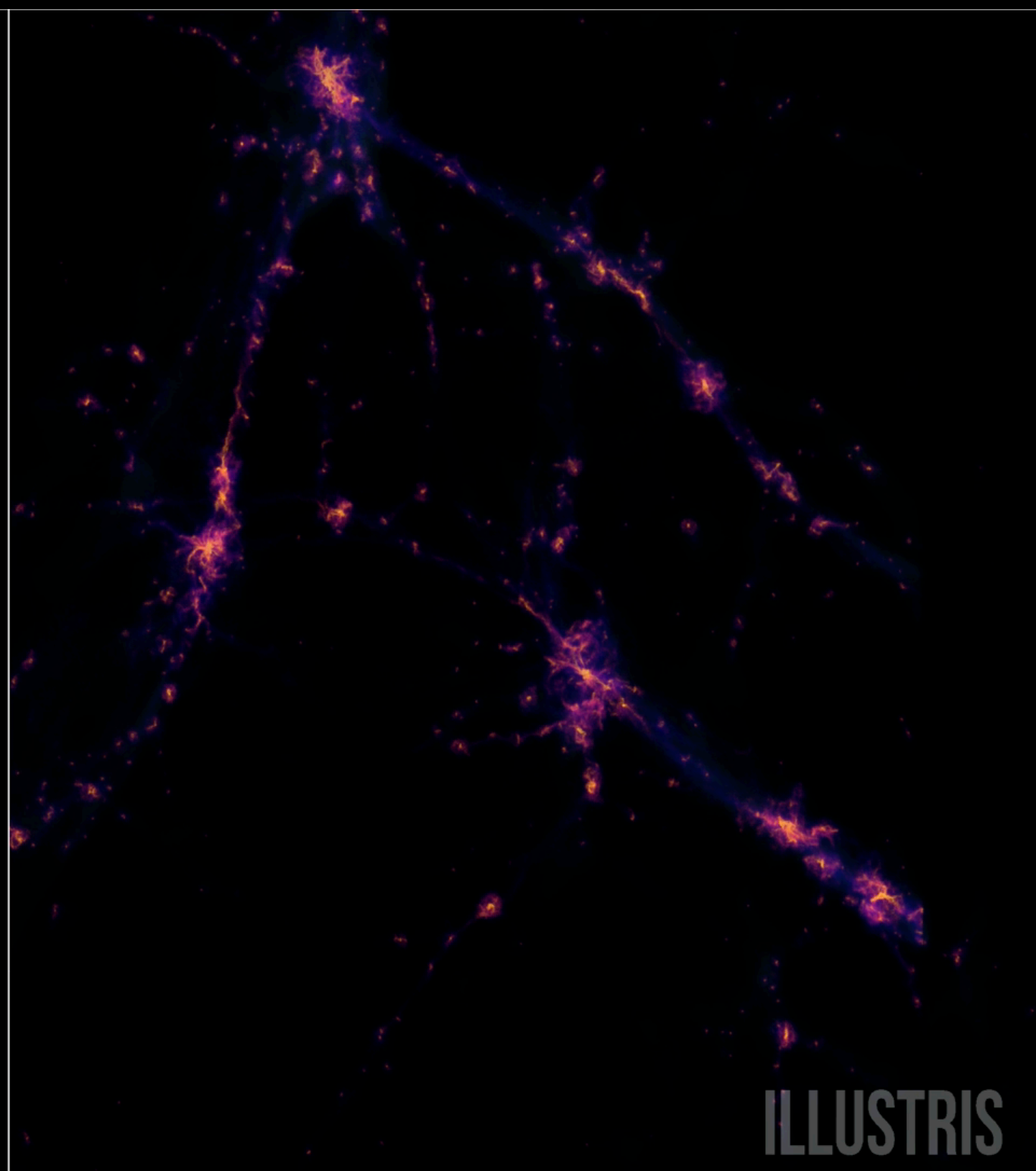
$\log_{10}(M_*)=10.4$

SFR=80.0

$s\text{SFR}=3.07\text{Gyr}^{-1}$



**Stellar light  
(optical)**



**Gas density  
(FIR—sub-mm)**

ILLUSTRIS

# Unanswered questions

## How are AGN triggered and fueled?

- SF feedback
- Mergers, interactions

## How is star formation regulated and suppressed?

- Mergers
- Stellar feedback
- **AGN feedback**
  - > radiative and mechanical (jets)

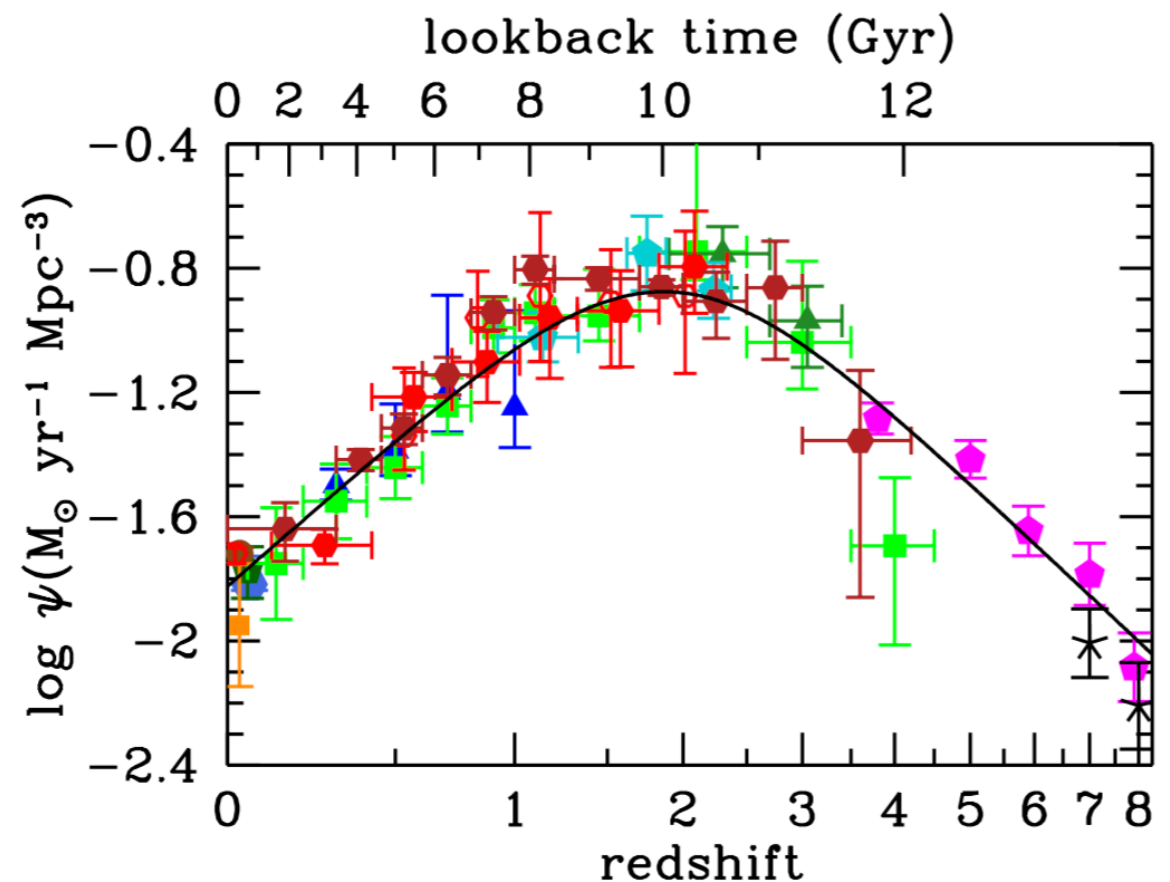
# Gravitational lenses as cosmic telescopes

## Increased apparent surface brightness

- x10 total magnification =>  $\div 100$  integration time
- Intrinsic luminosities below the confusion limit
- Fainter/more typical sources

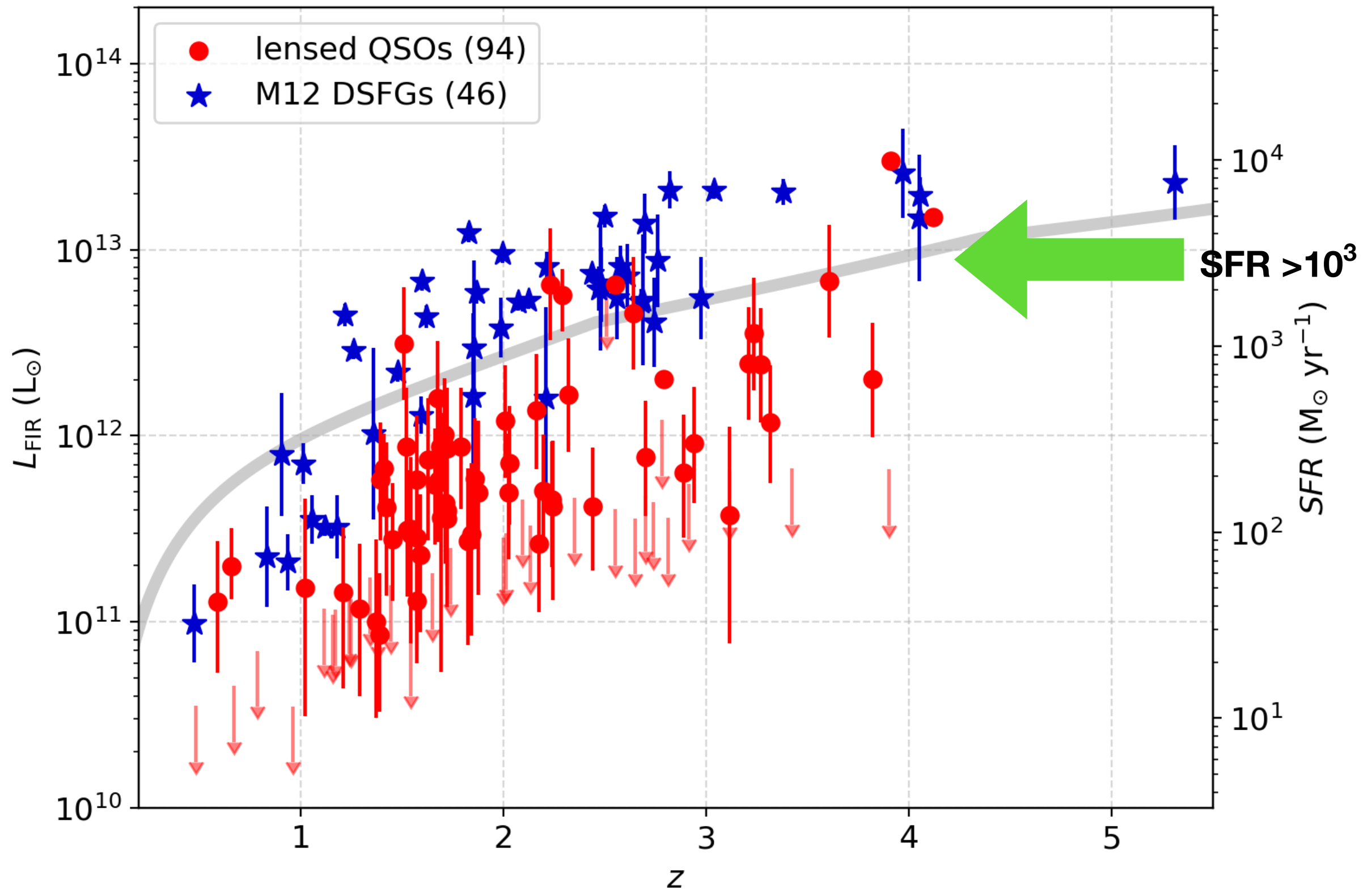
## Increased apparent surface area

- Higher resolution
- Resolving interactions, inflows, feedback effects at high redshift

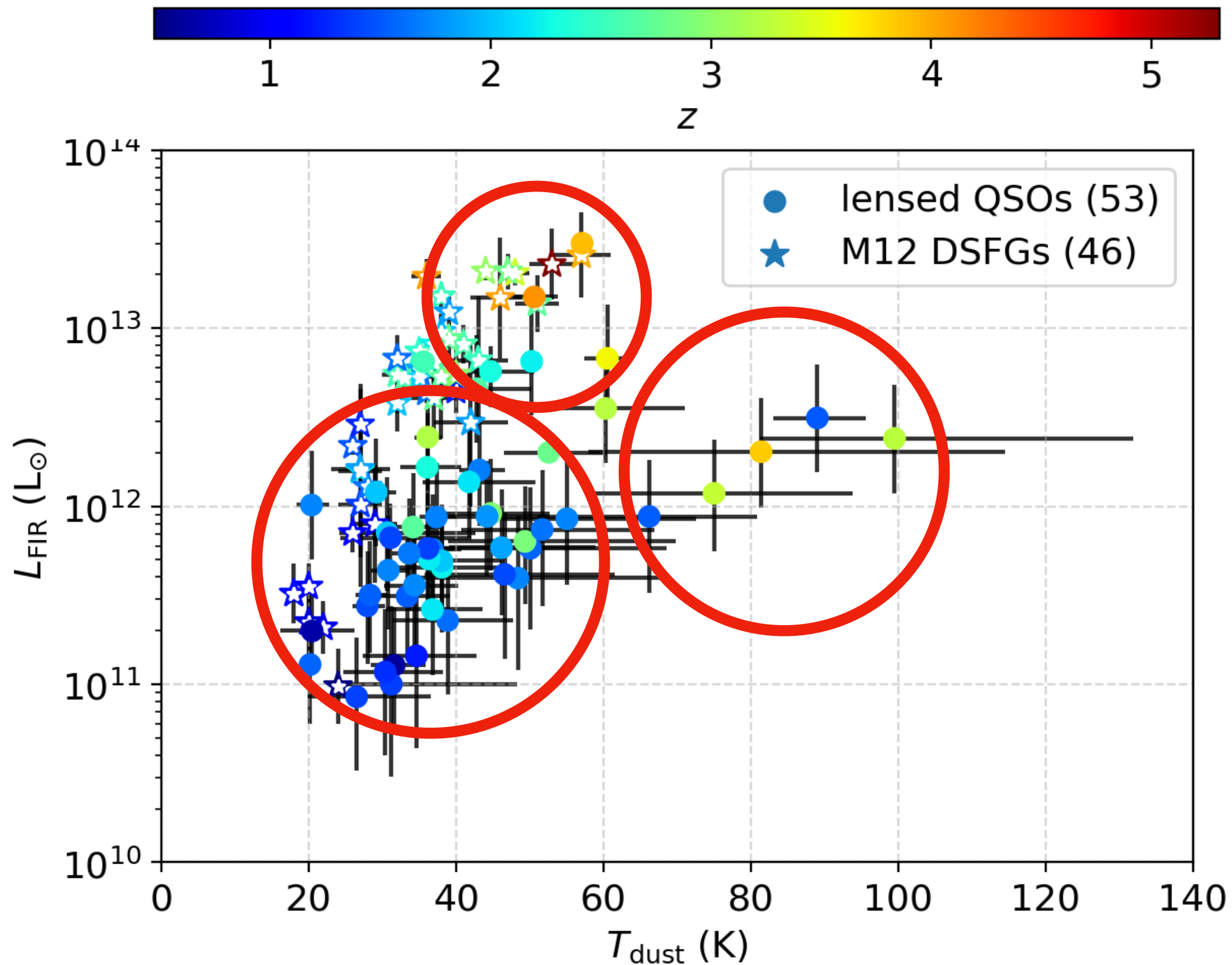




# Probing below the SPIRE detection limit

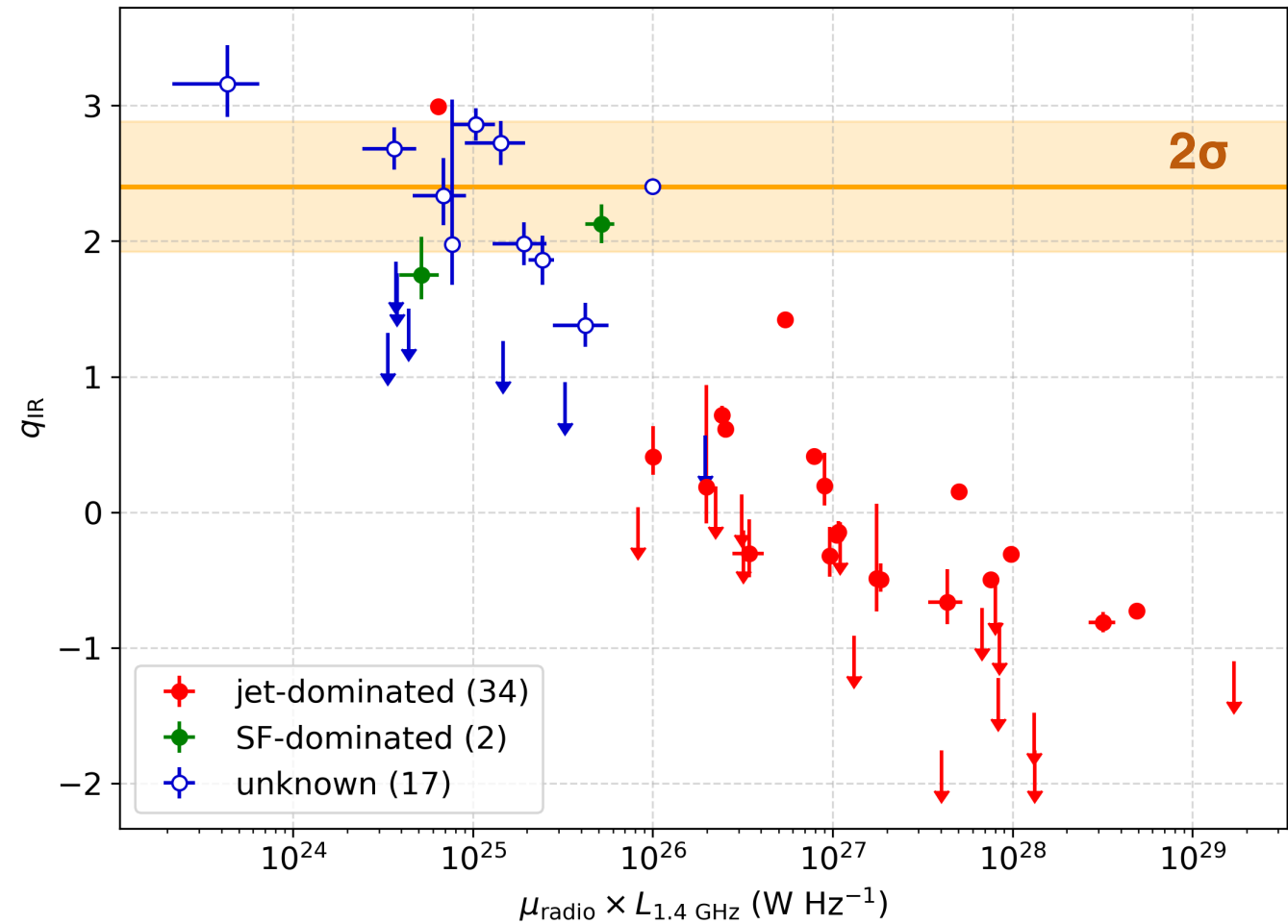
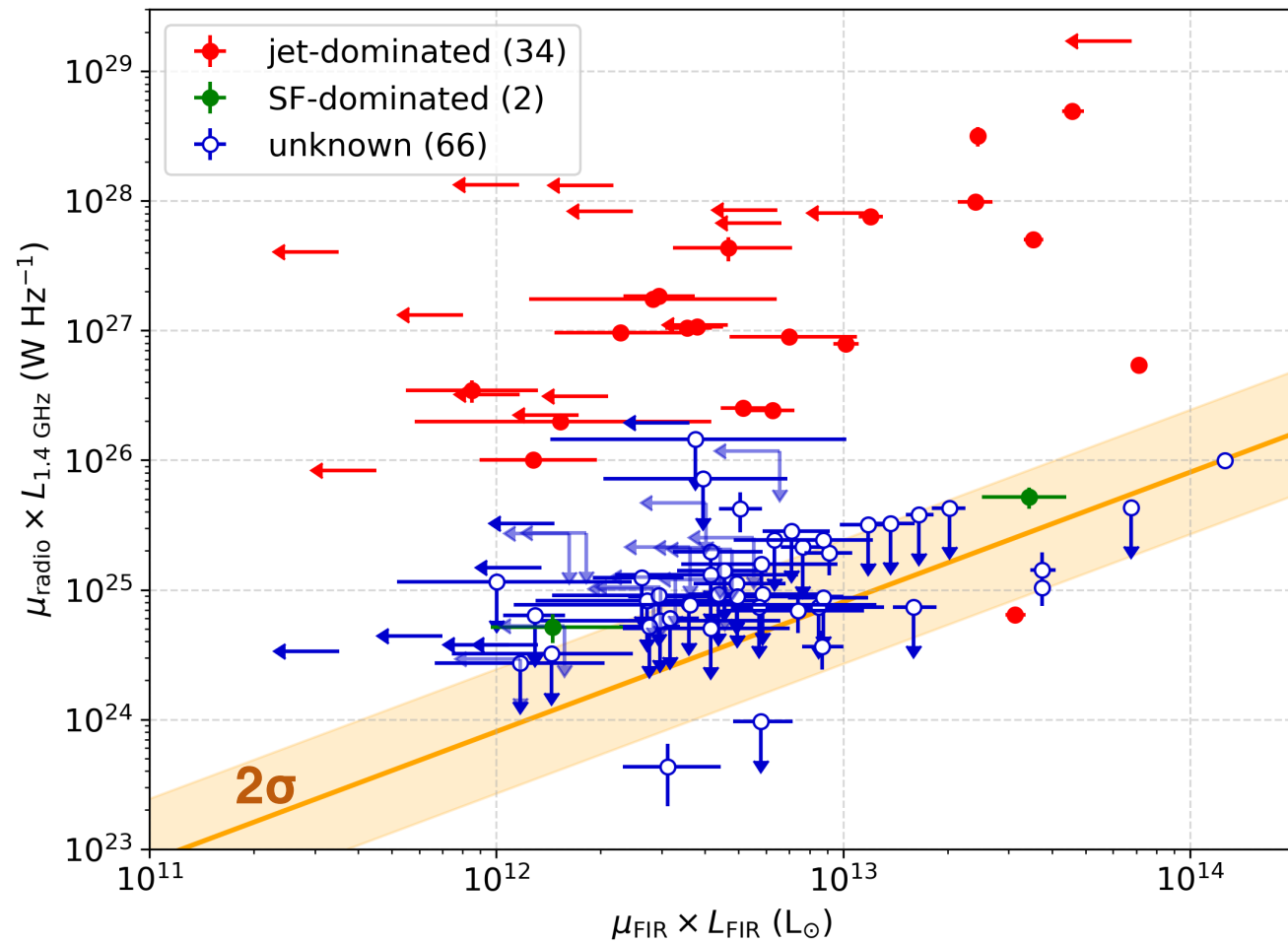


# Dust temperatures comparable to DSFGs



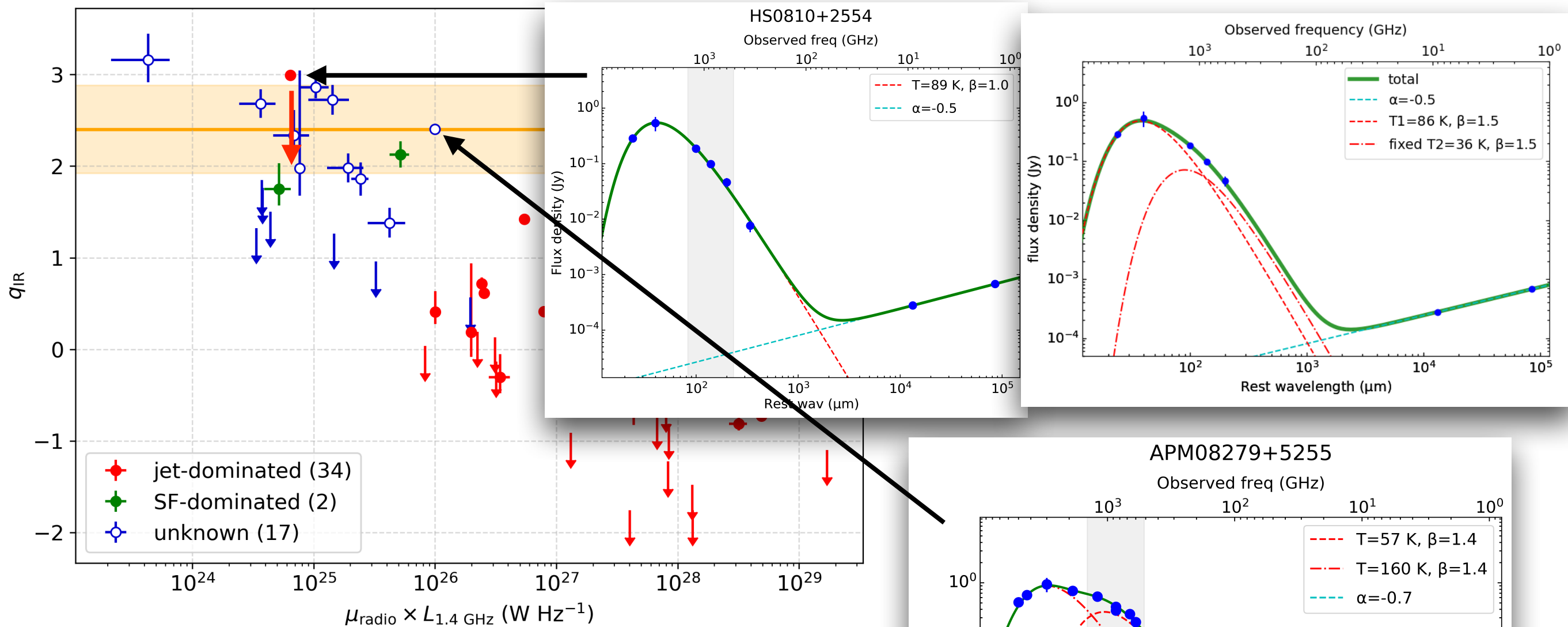
# Radio-infrared correlation

$$q_{IR} = \log_{10} \left( \frac{L_{IR}}{3.75 \times 10^{12} L_{1.4GHz}} \right)$$



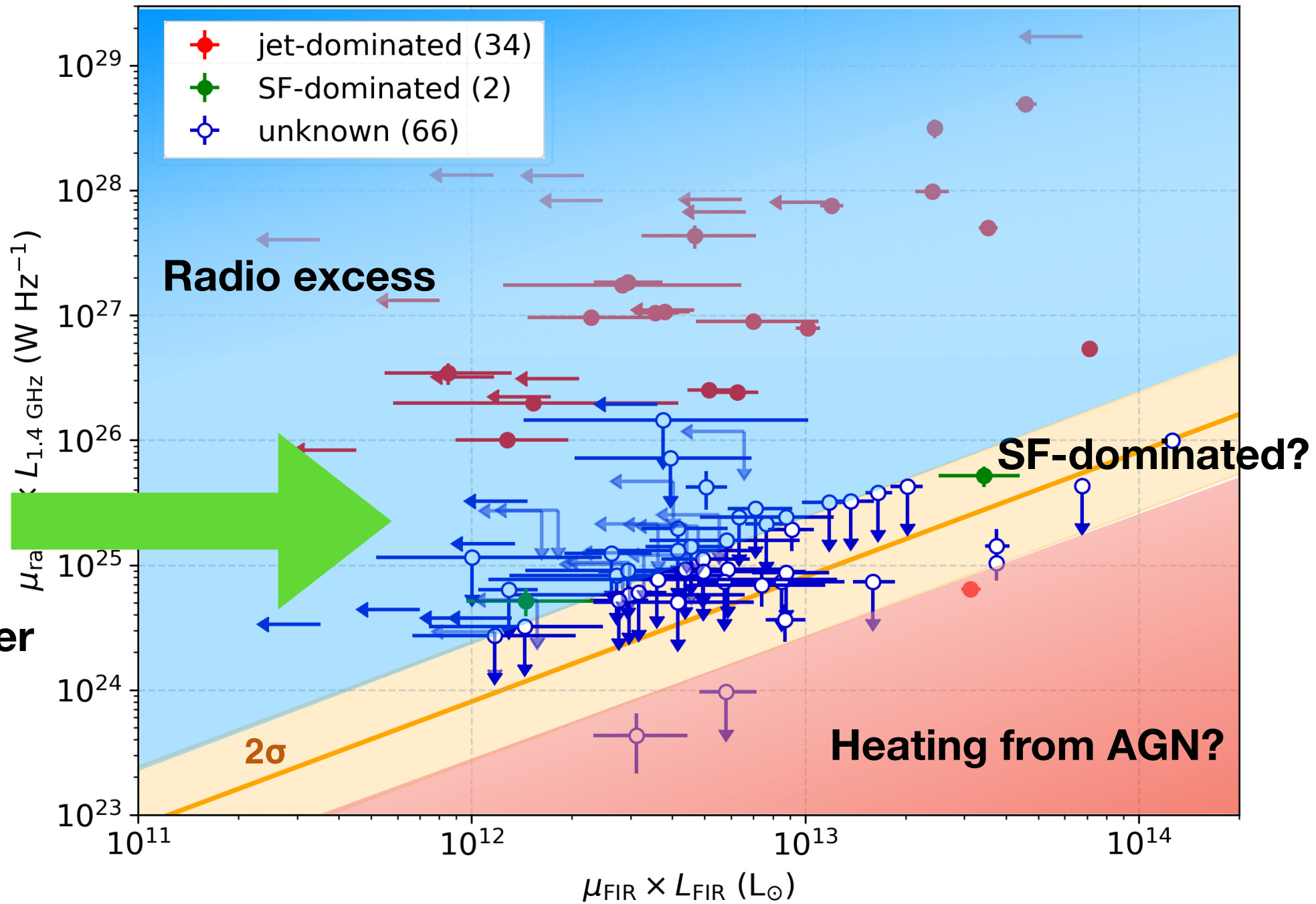
- Where do 'non-jetted' quasars fall relative to correlation for SF galaxies?
- Is there evidence of AGN contamination in FIR?
- Is there a difference in the FIR properties of jetted quasars?

# Radio-infrared correlation

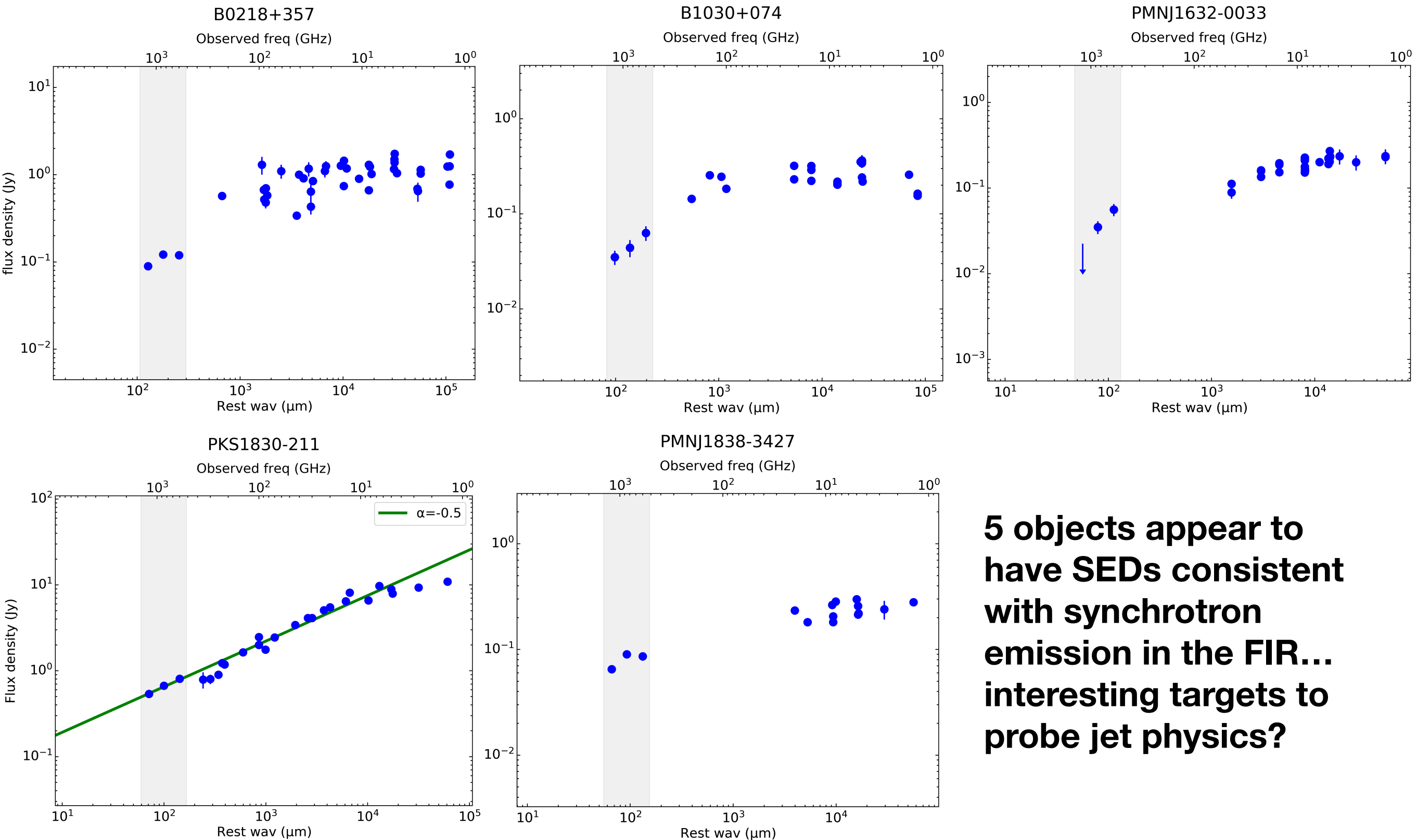


- APM08279 -> Can account for SF/AGN with enough data
- Radio-infrared correlation not good at identifying jetted quasars?

# Radio-infrared correlation



# Synchrotron-dominated subsample



**5 objects appear to have SEDs consistent with synchrotron emission in the FIR... interesting targets to probe jet physics?**

# Evidence for dust-obscured star-formation in quasar host galaxies

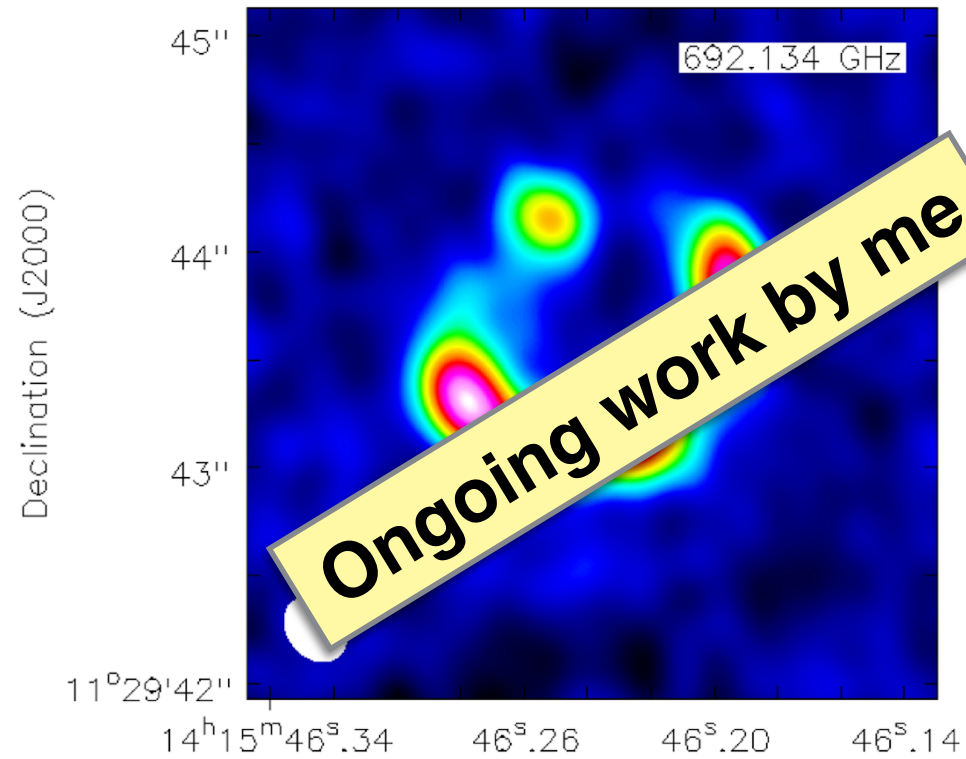
- **66%** quasar sample have evidence of star-formation, based on SEDs, dust temperatures and radio—IR, with median SFR  $120_{-80}^{+160} M_{\odot} \text{ yr}^{-1}$
- **~10%** of quasars have FIR properties similar to Herschel-selected DSFGs with SFR  $> 1000 M_{\odot} \text{ yr}^{-1}$
- **~15%** of radio-bright quasars synchrotron-dominated in FIR
- Results are consistent with quasar evolution scenarios
- No statistically-significant difference in FIR luminosities of jetted quasars
- Radio data required to understand AGN contribution to radio and FIR
- High-res data in FIR/sub-mm needed to investigate SF/AGN properties of individual objects in detail

**Stacey et al. (2018) in preprint arXiv:1705.10530**

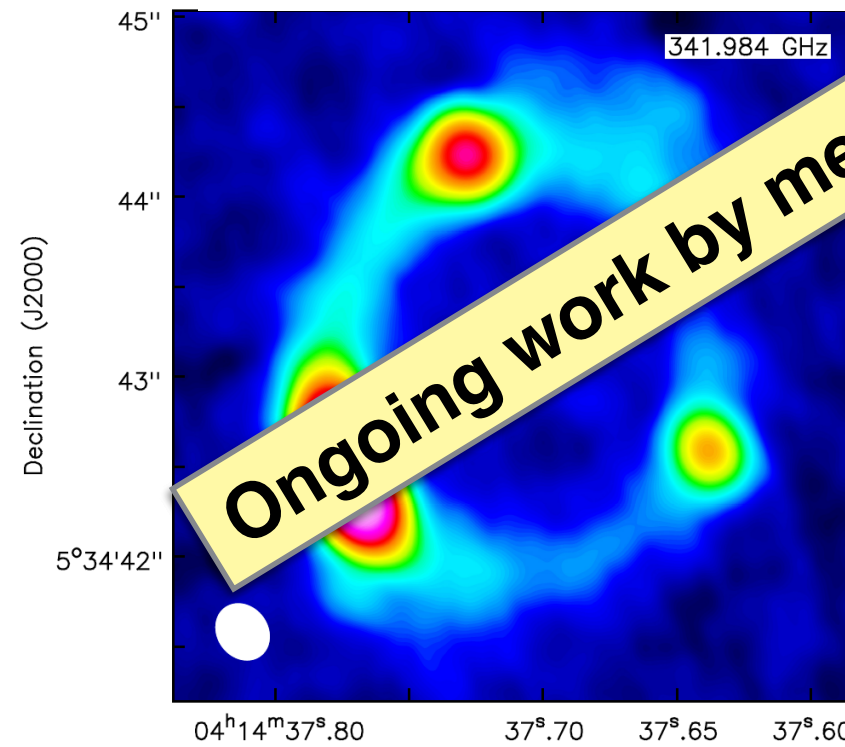


# Resolving dust and gas with ALMA

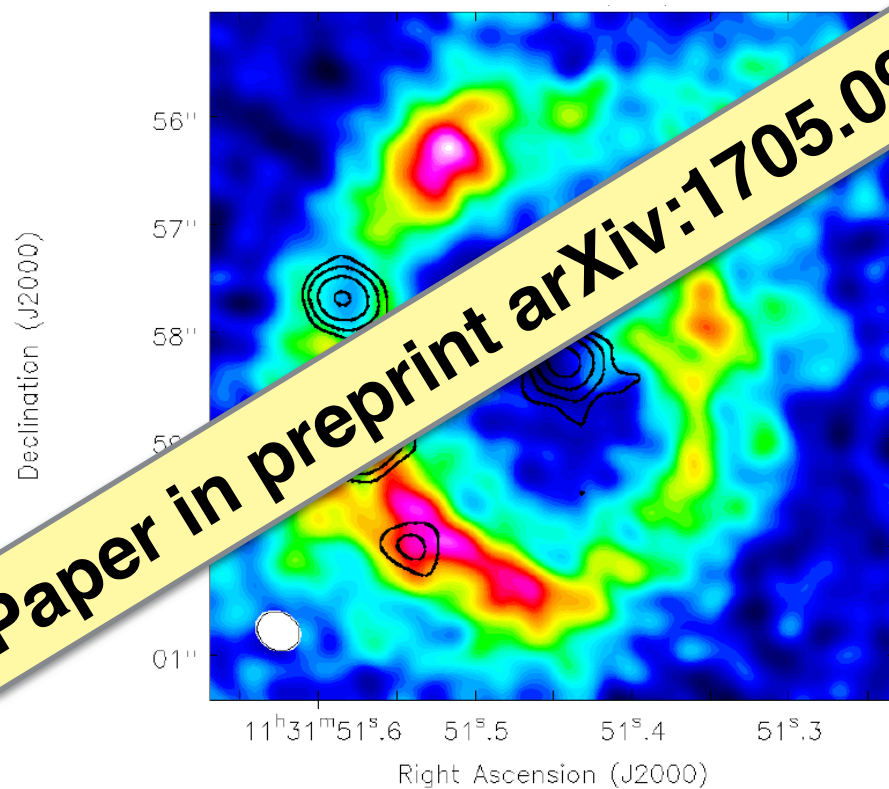
Cloverleaf



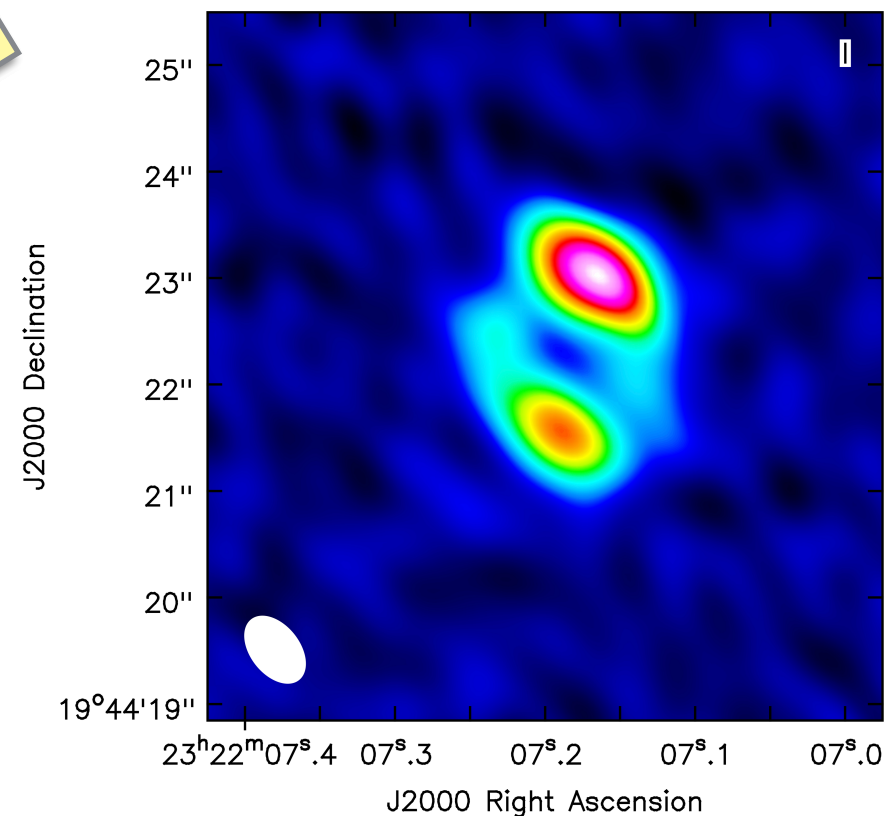
MGJ0414+0534



RXJ1131-1231 (CO 2-1)

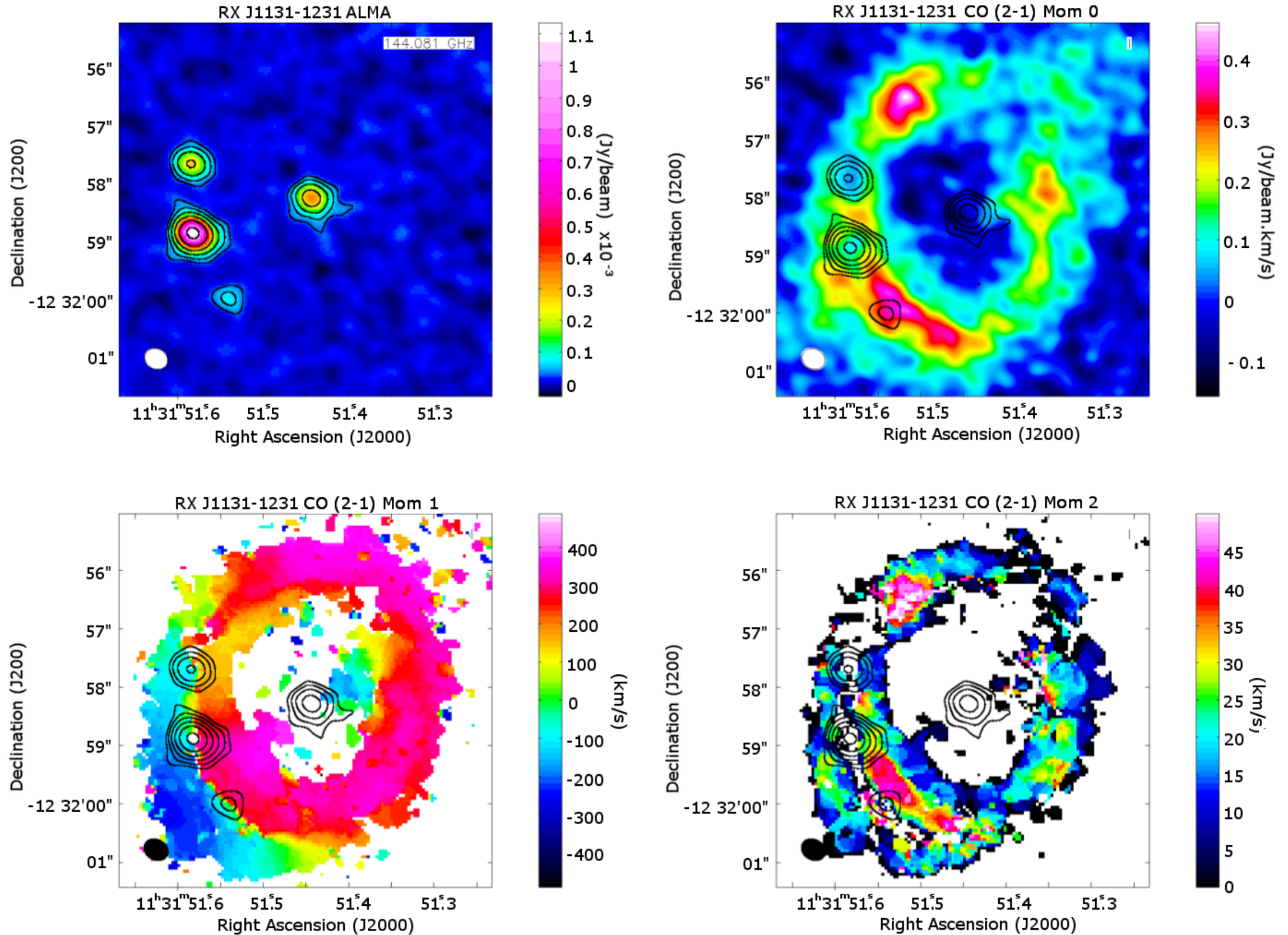


PSSJ2322+1944

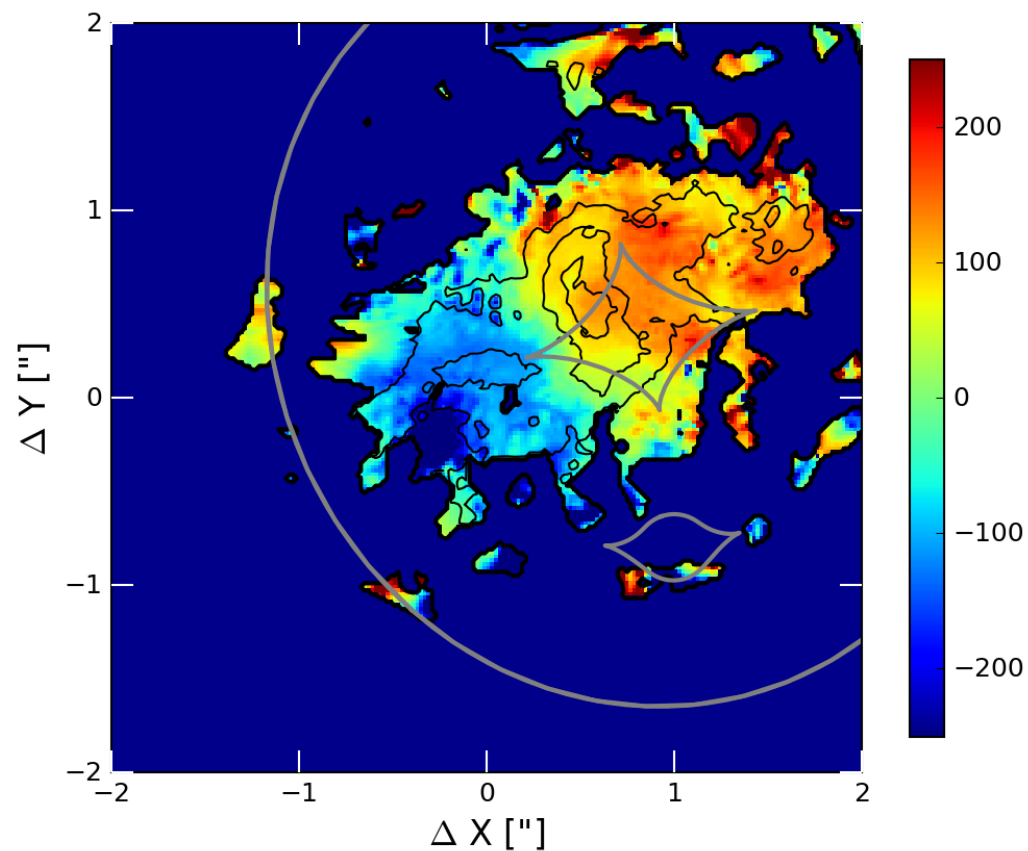
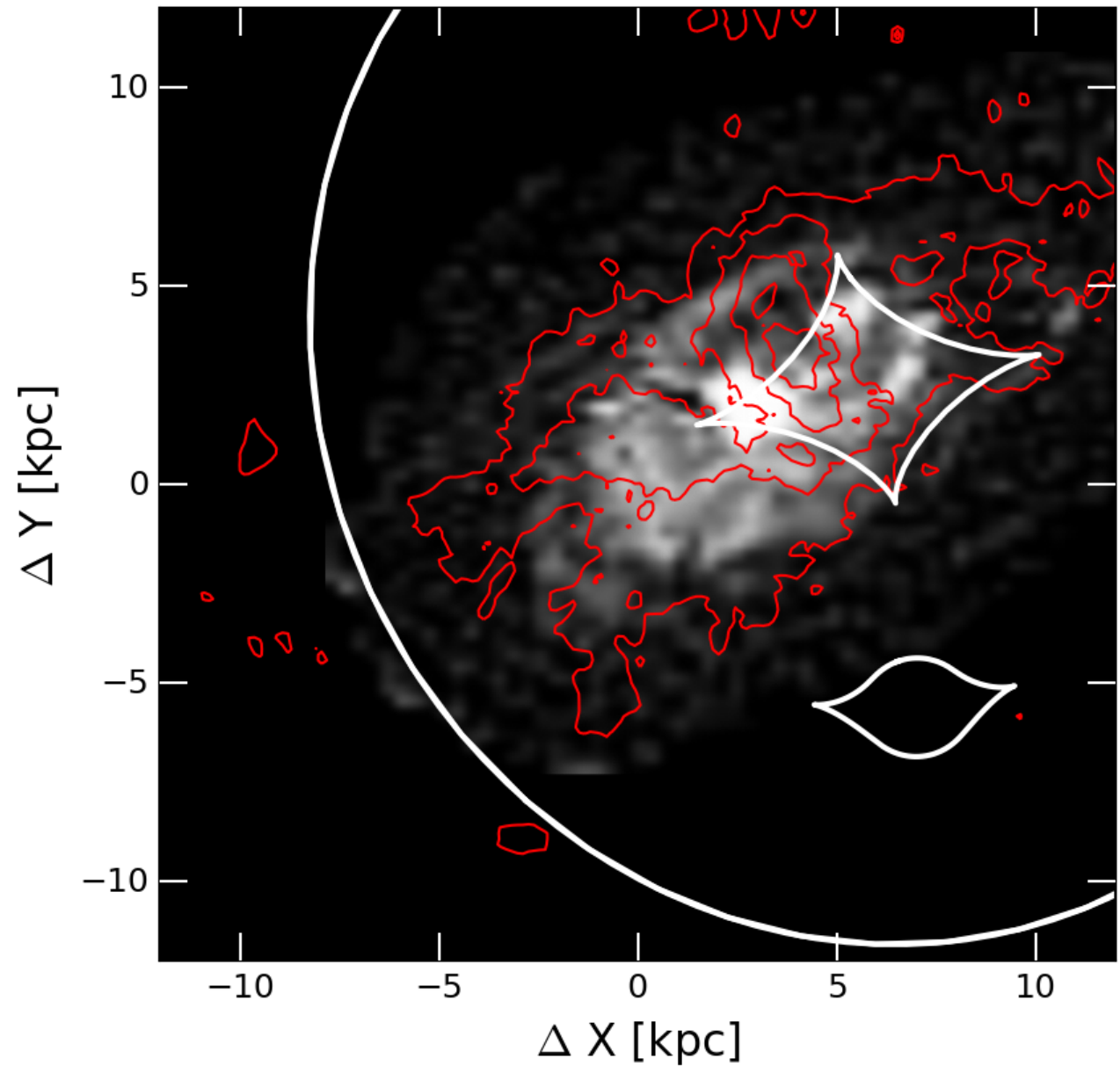
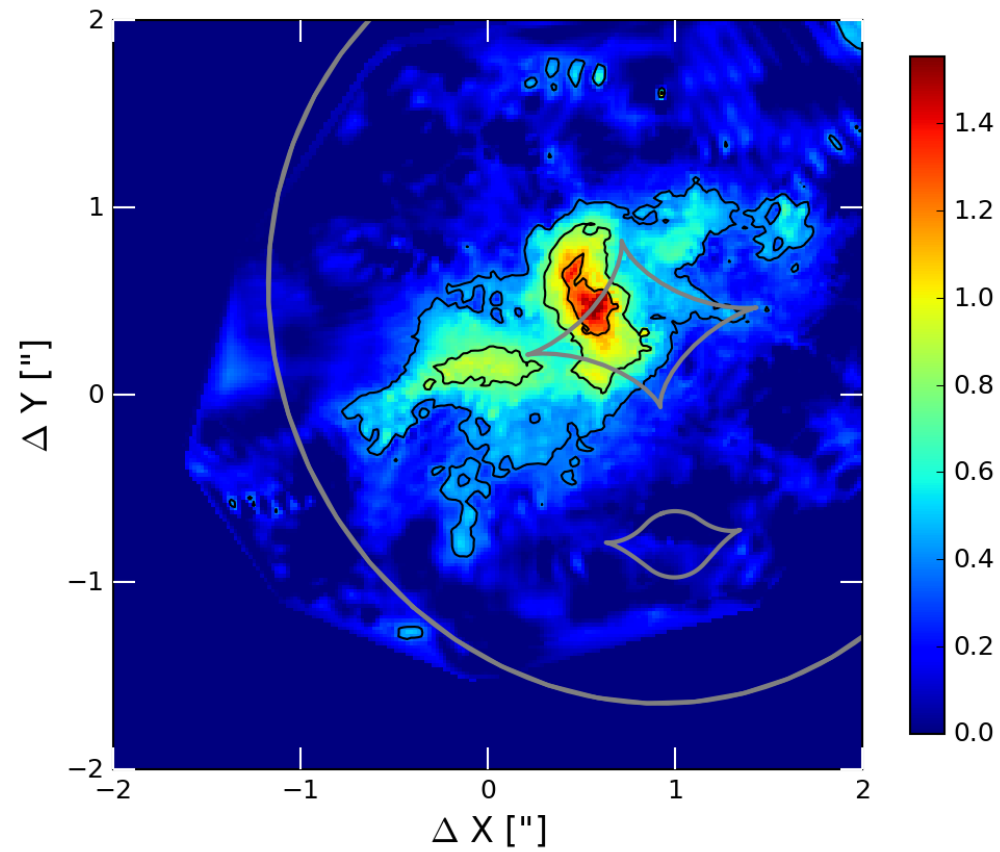




# RXJ1131-1231 ( $z=0.7$ ) - CO(2-1)



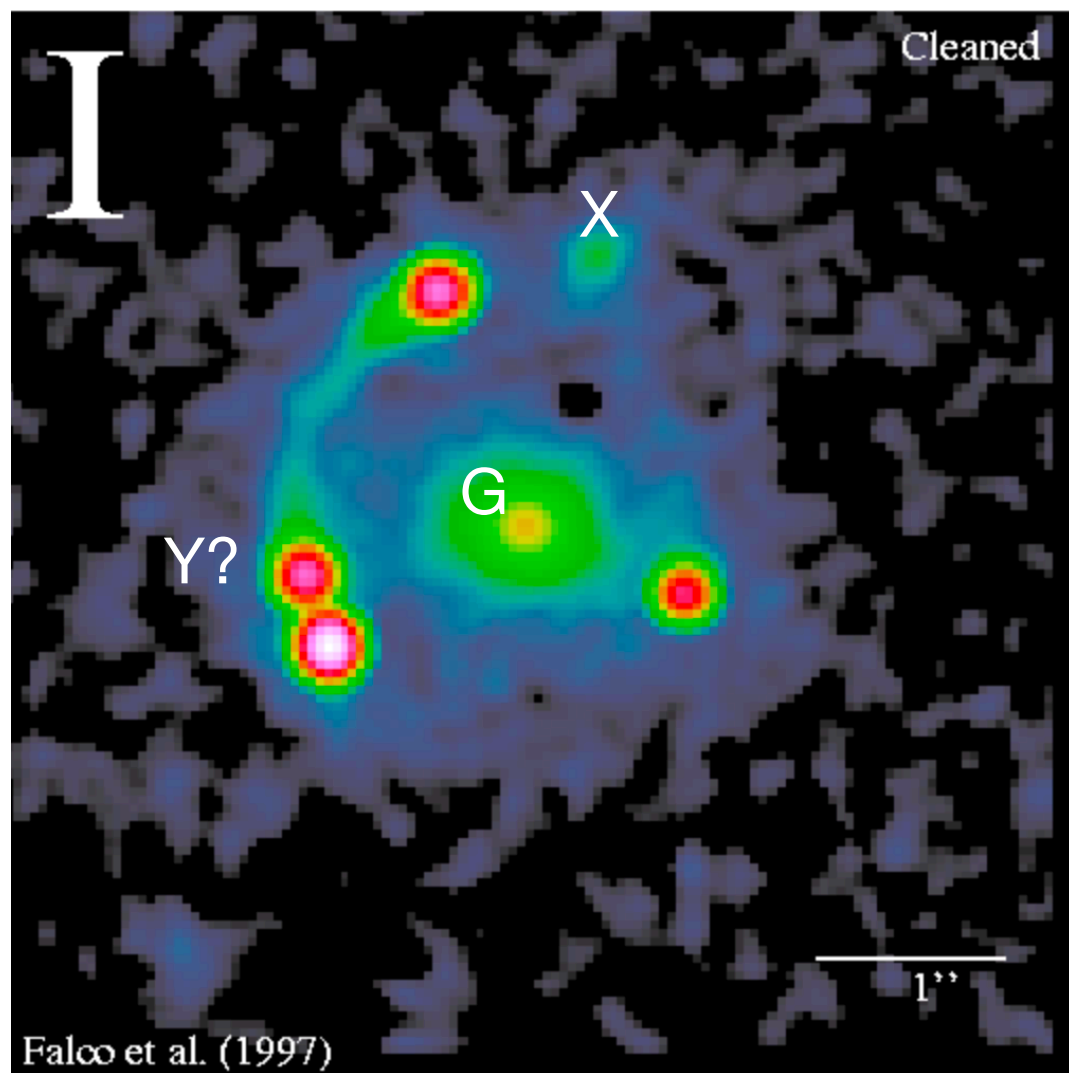
# RXJ1131-1231 ( $z=0.7$ ) - CO(2-1)



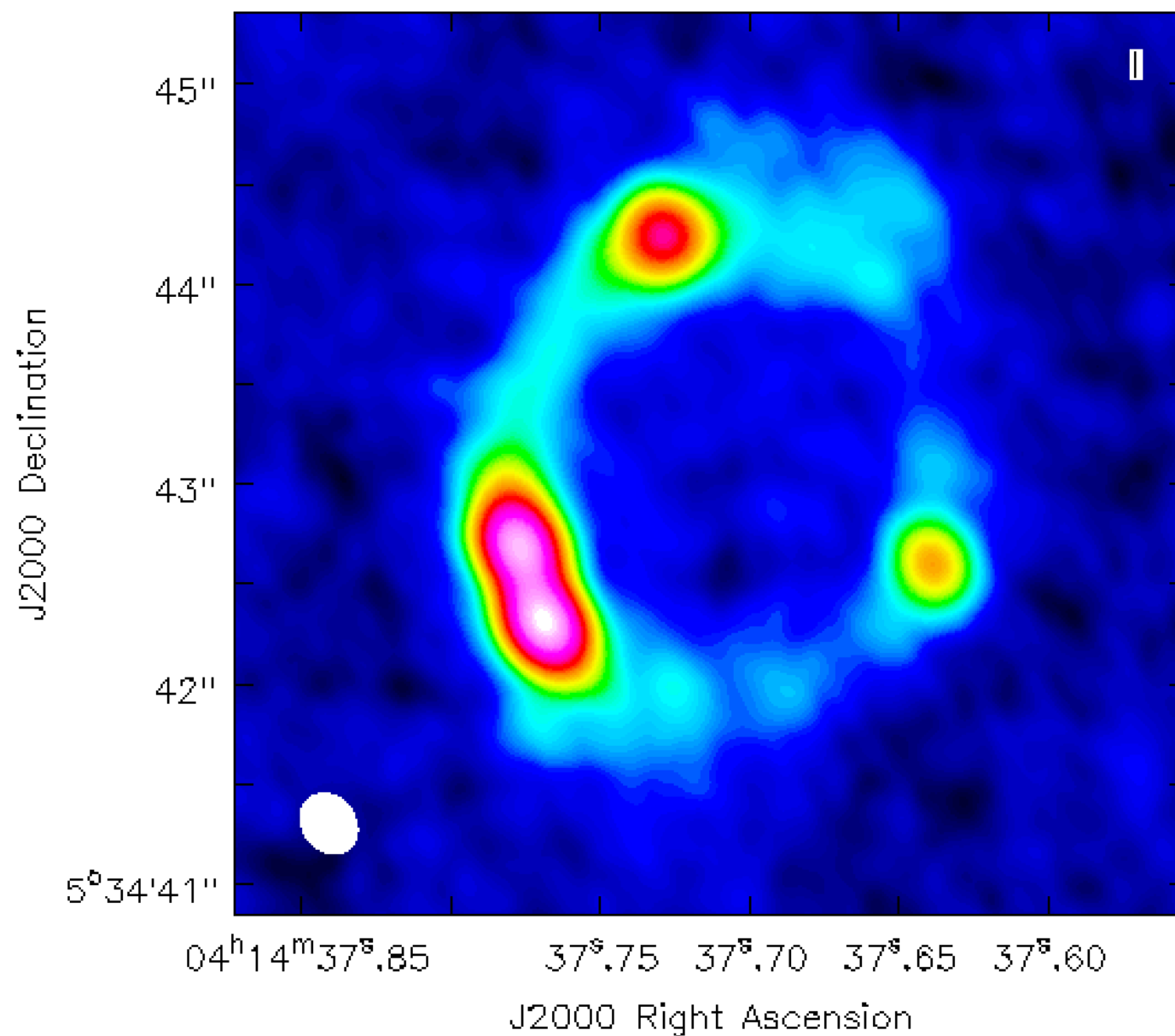
- Extended molecular gas disk (15 kpc) — size-redshift evolution?
- Molecular gas peak not coincident with the AGN.

# MGJ0414+0534 ( $z=2.6$ ) - preliminary work

HST



ALMA (340 GHz)

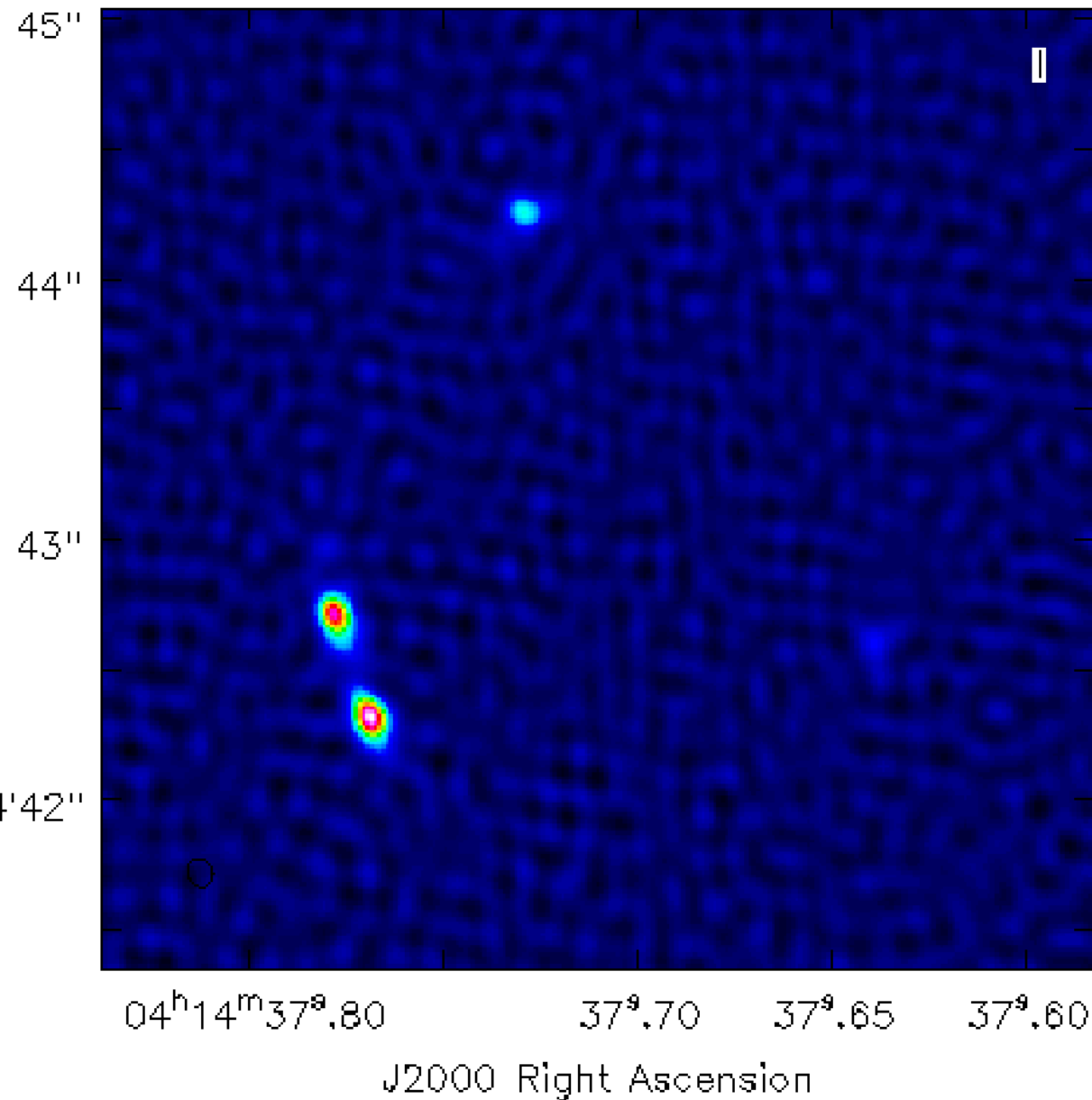


Composite synchrotron from the AGN and diffuse dust emission (SF?)

# MGJ0414+0534 ( $z=2.6$ ) - preliminary work

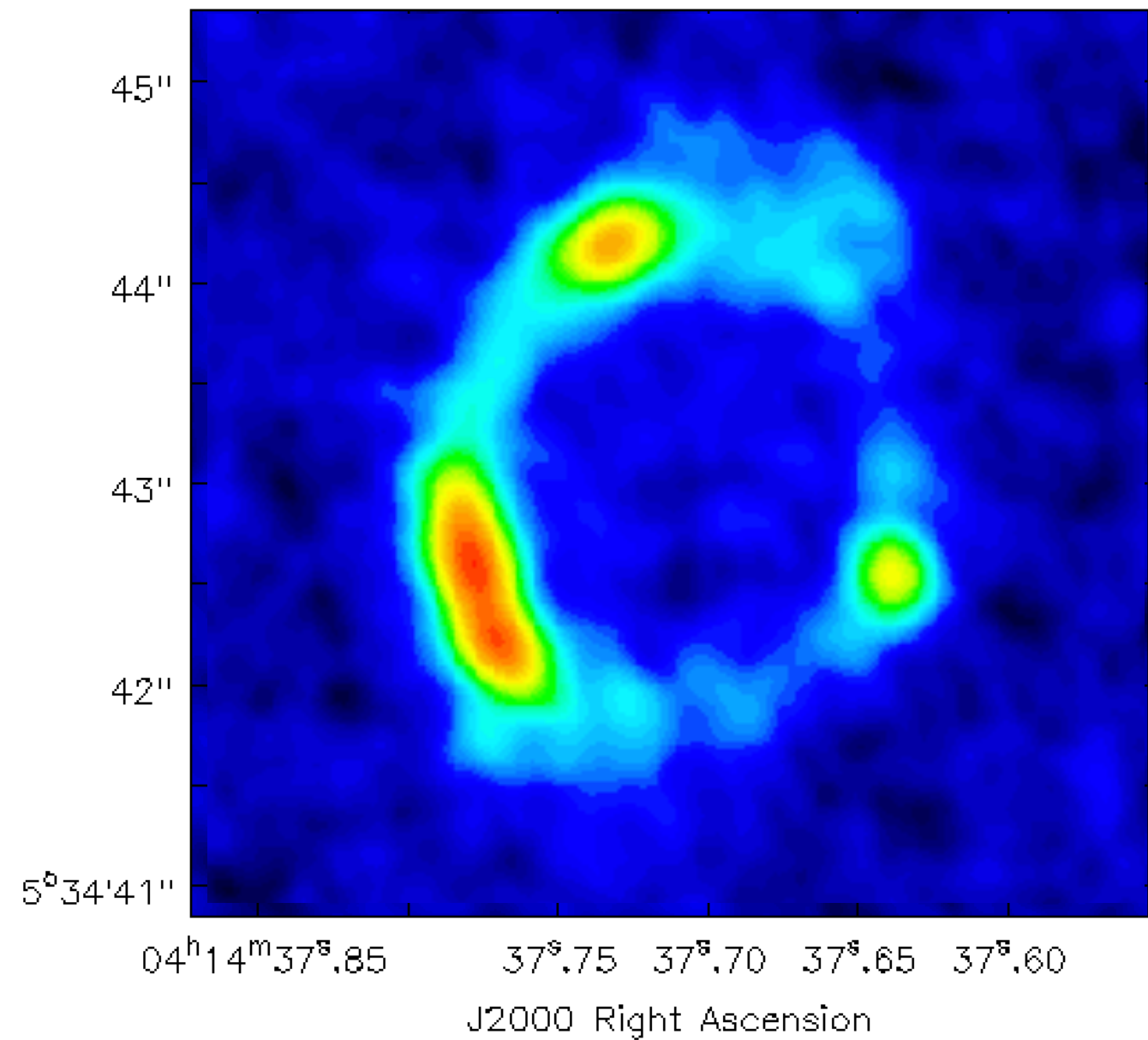
**Superuniform**

MGJ0414+0534



**Superuniform subtracted**

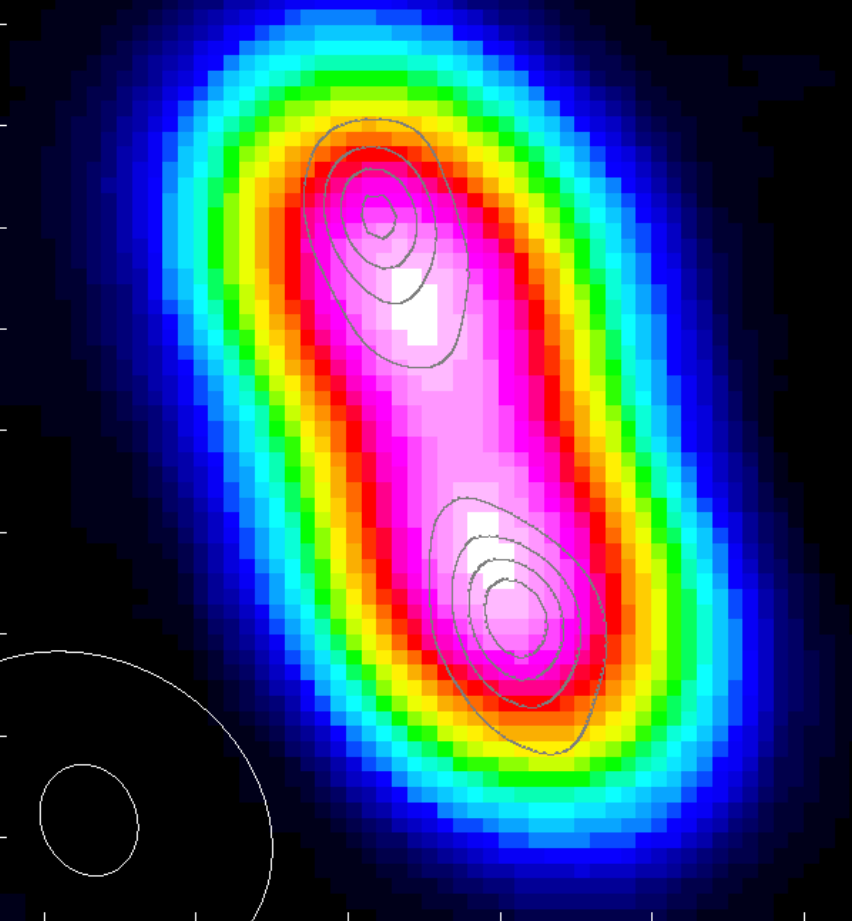
MGJ0414+0534



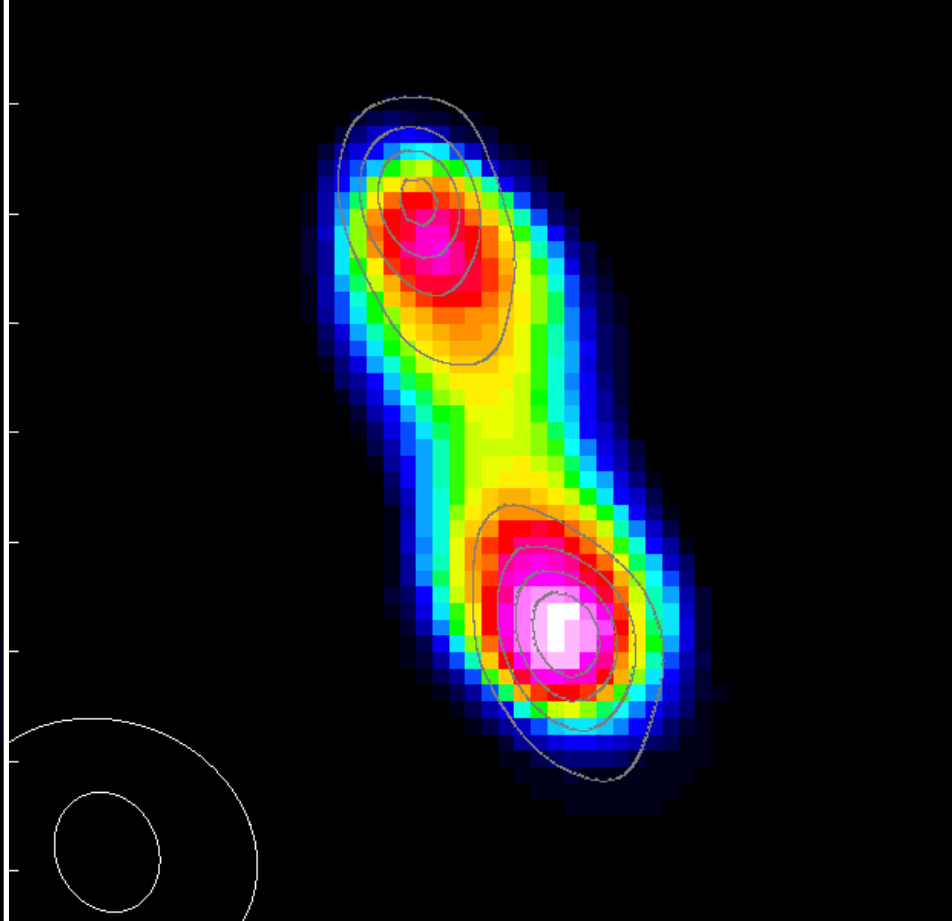
**Probing intrinsic scales of  $\sim 100$  pc**



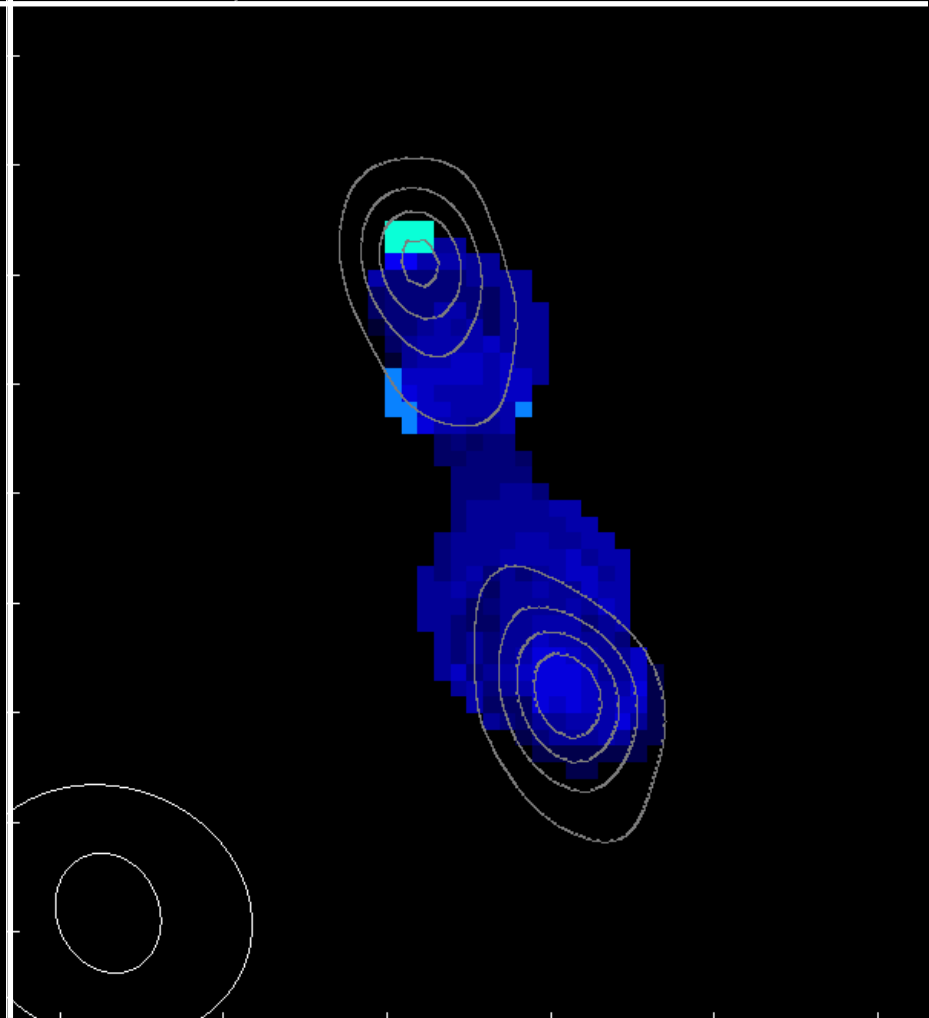
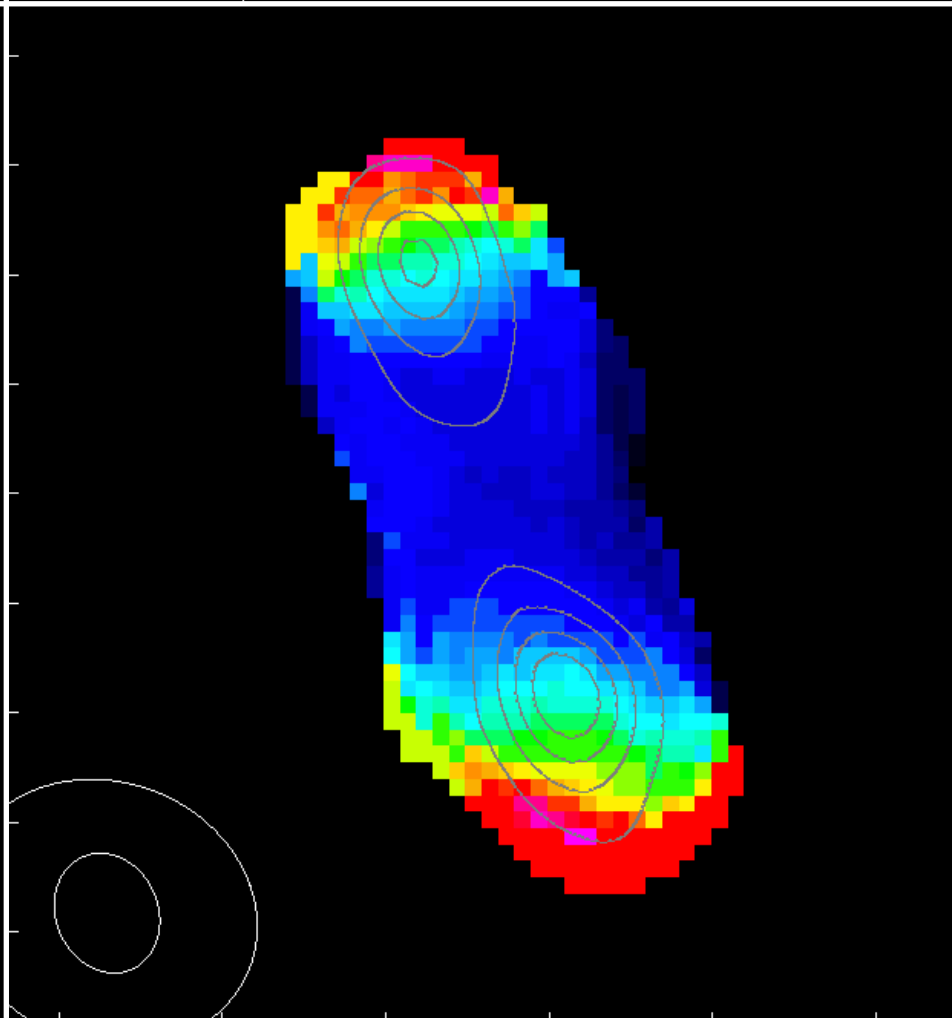
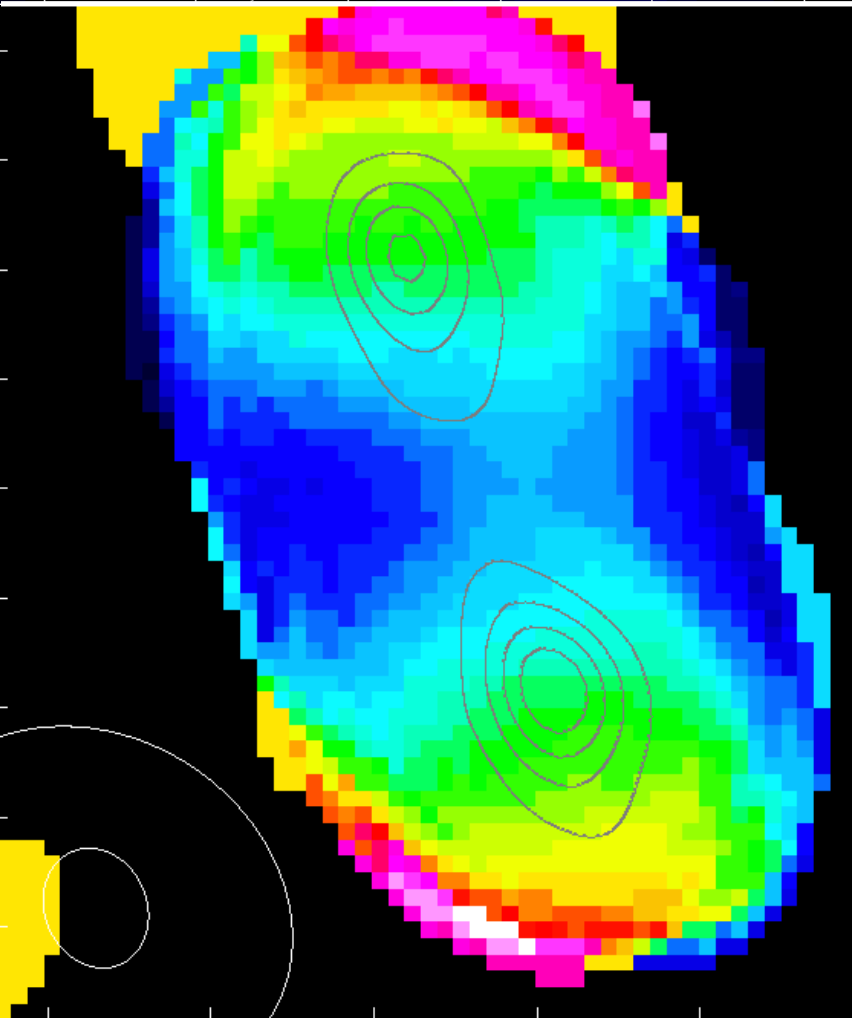
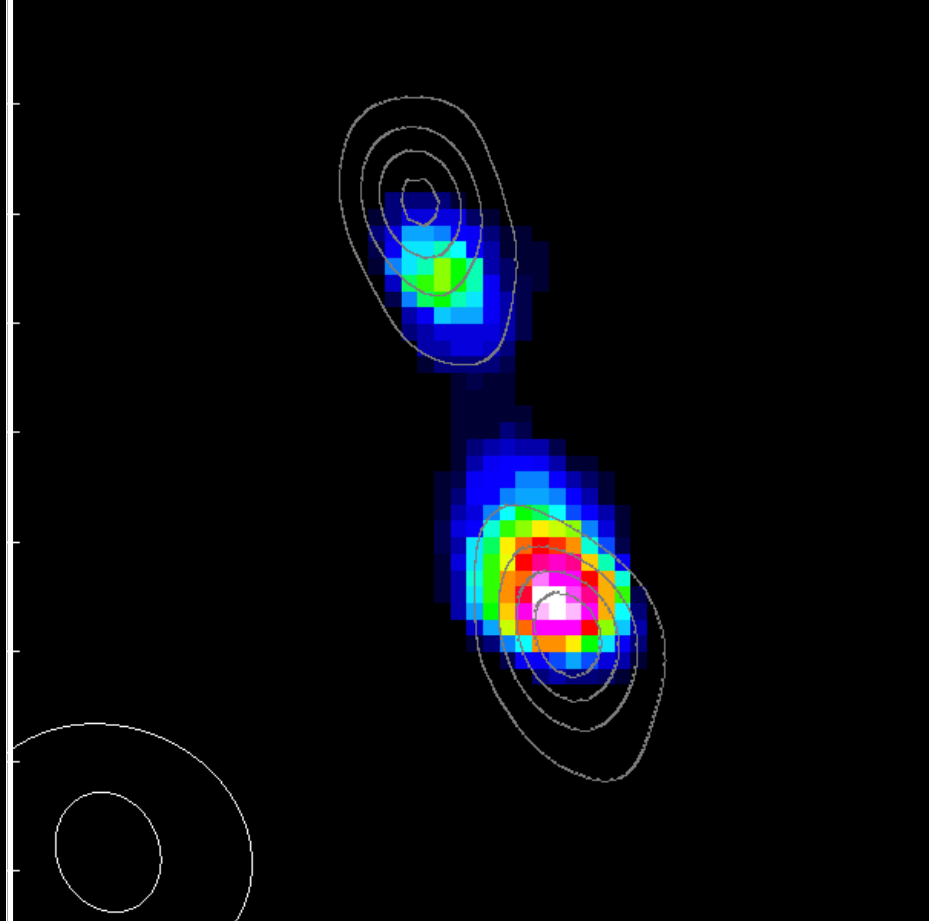
**Natural**



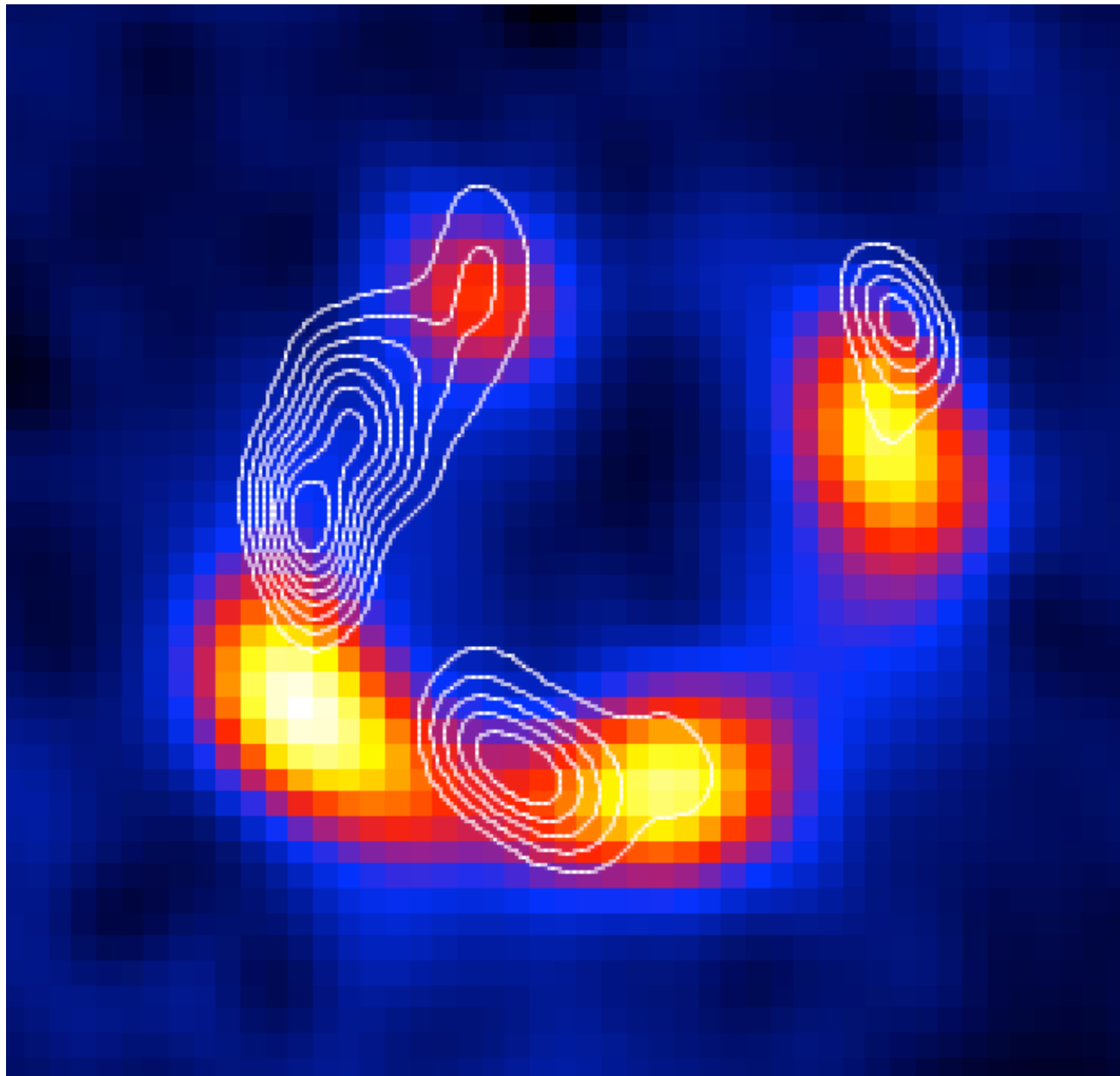
**Robust**



**Uniform**



# Cloverleaf (z=2.5) - preliminary work



ALMA band 9  
(colours)

e-MERLIN L-band  
(contours)

