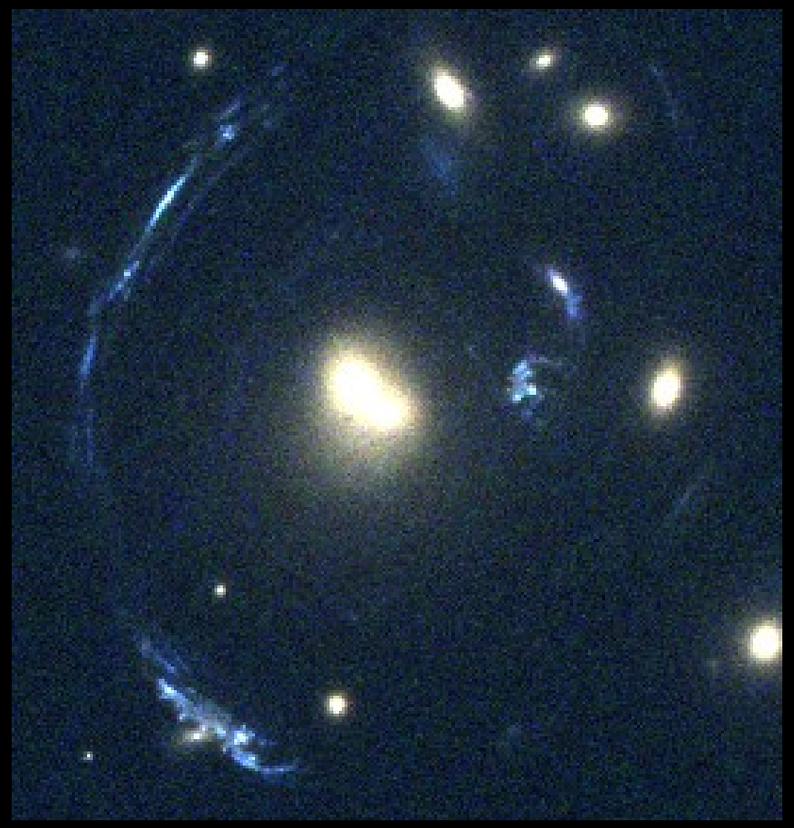
Dissecting Molecular Gas and Star Formation in the Strongly Lensed z~2 Galaxy SDSS J0901+1814



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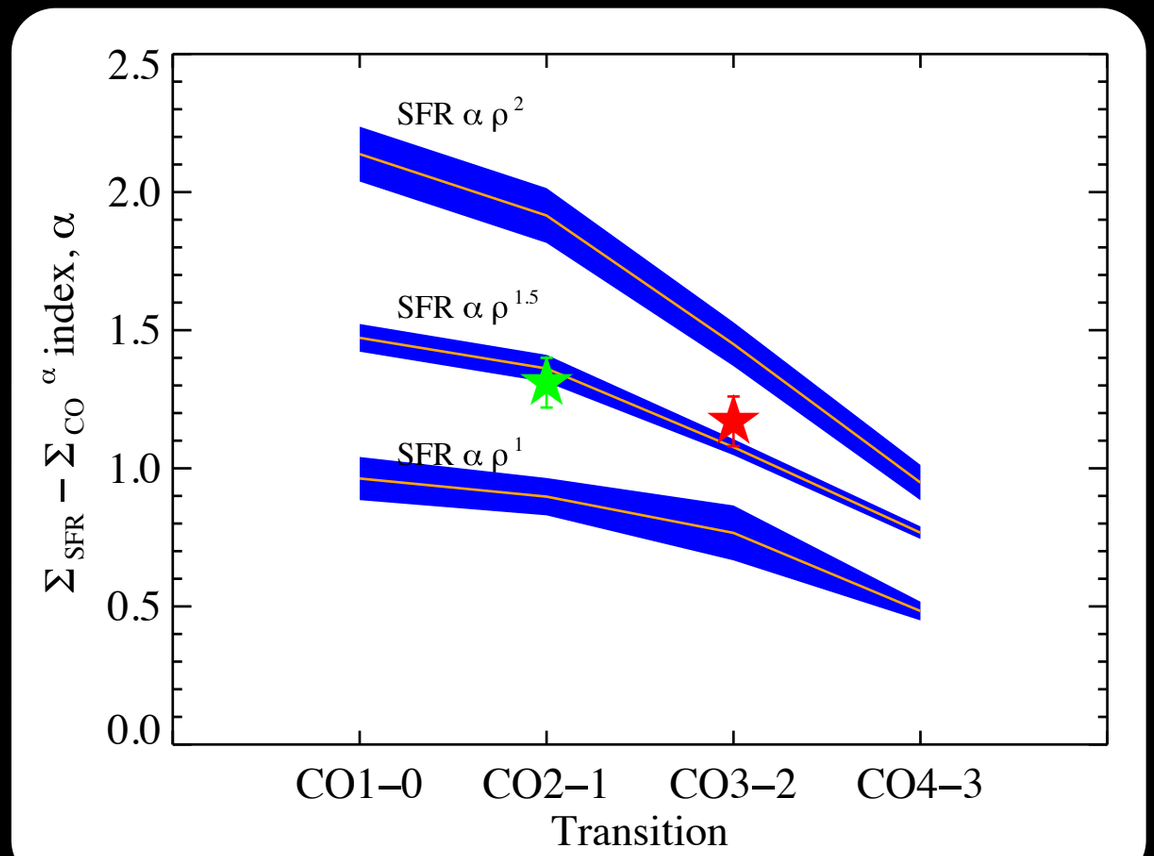
Rutgers: Andrew Baker, Jesus Rivera, Charles R. Keeton,
Manchester: Amitpal Tagore

Motivation:

- Where do high-z starbursts fall on the Schmidt-Kenicutt relation?
- In what ways does differential lensing affect unresolved characterizations of strongly lensed galaxies?
- How well do global line ratios capture gas physical conditions within high-z galaxies?

CO Excitation and the Schmidt-Kennicutt Relation

- Choice in molecular gas tracer affects the Schmidt-Kenicutt relation in two ways: the index and the normalization
- **Index:** Different excitation tracers are sensitive to different densities, making observed index dependent on gas conditions
- **Normalization:** Many high-z observations are of mid-*J* CO lines; must assume excitation to get total molecular gas mass

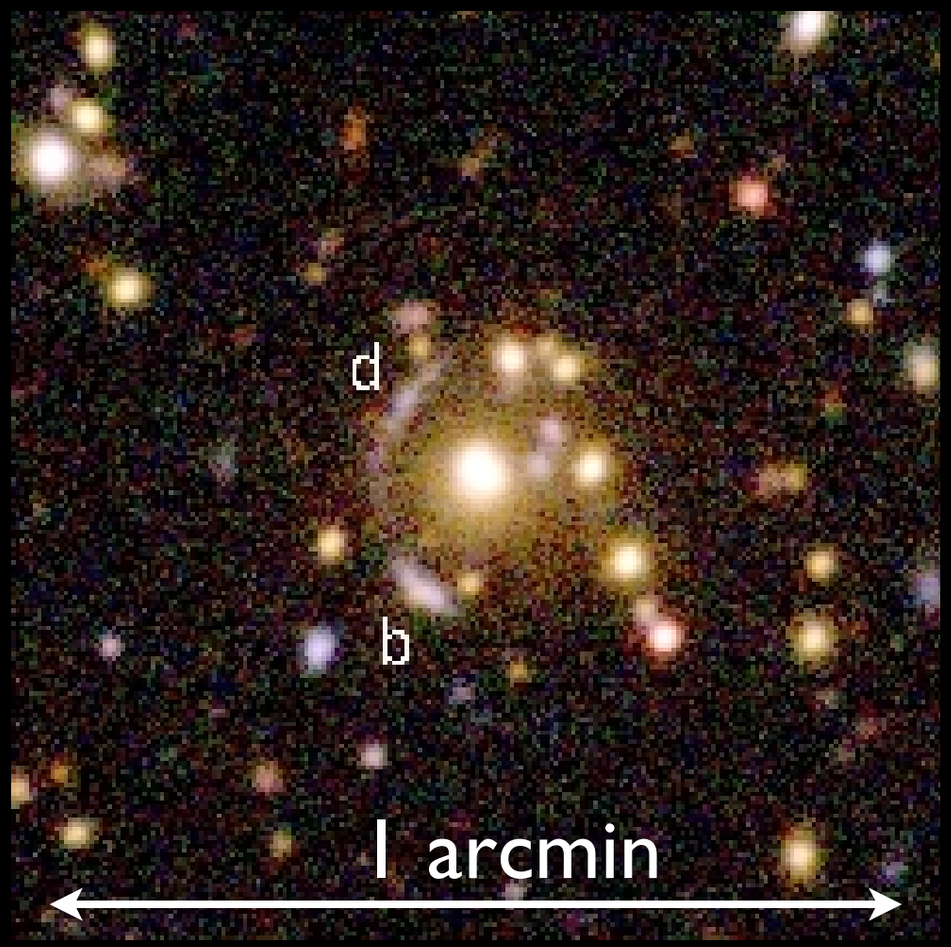


Narayanan et al. 2011

SDSS J0901+1814

- Discovered in a systematic search for strongly-lensed star-forming galaxies in SDSS (Diehl et al. 2009)
- Bright in both rest-UV and dust emission
- Magnification ~ 12
- z=2.26 main sequence galaxy based on SFR_{FIR} vs. $M_{\star}$

  (Saintonge et al. 2013)
- Contains an AGN, but it is not significant at long wavelengths (Fadely et al. 2010)



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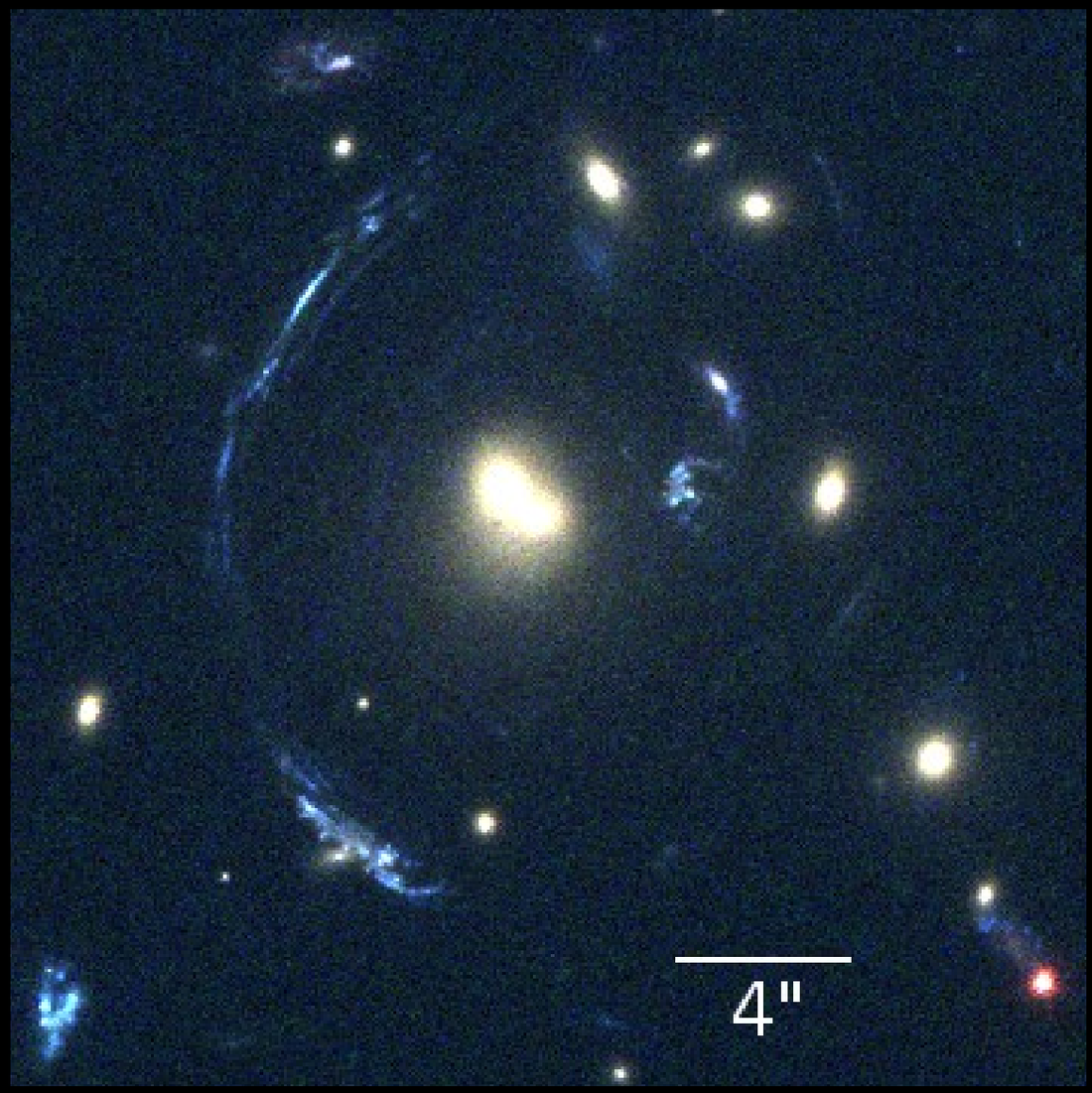
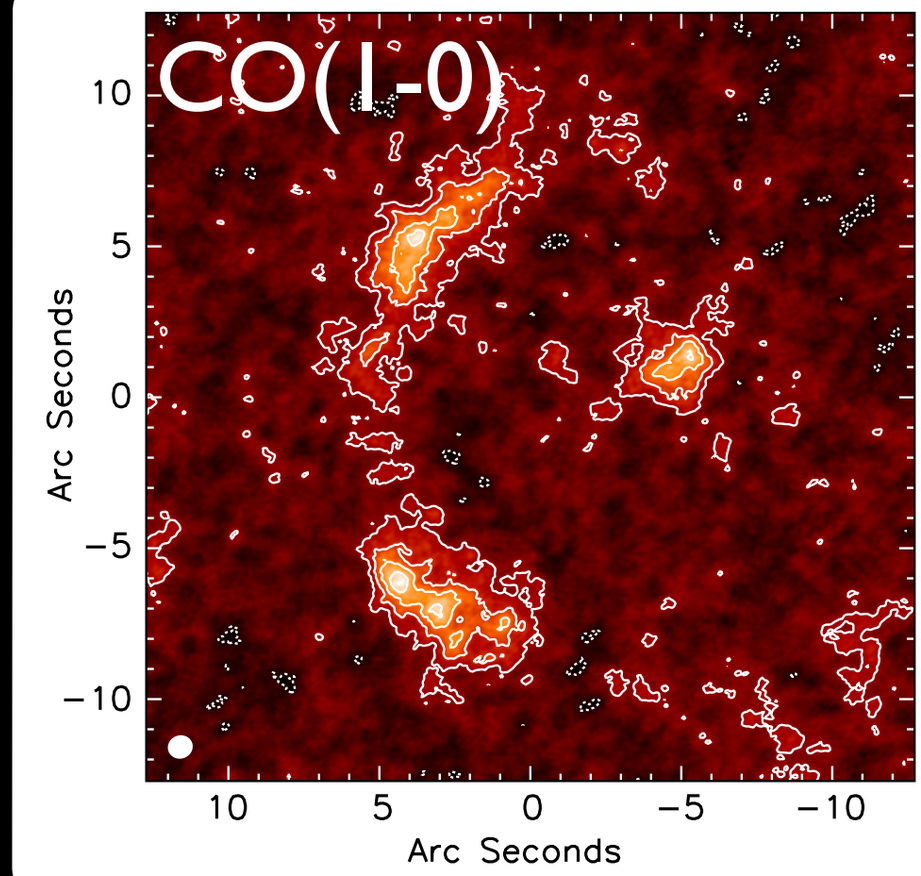
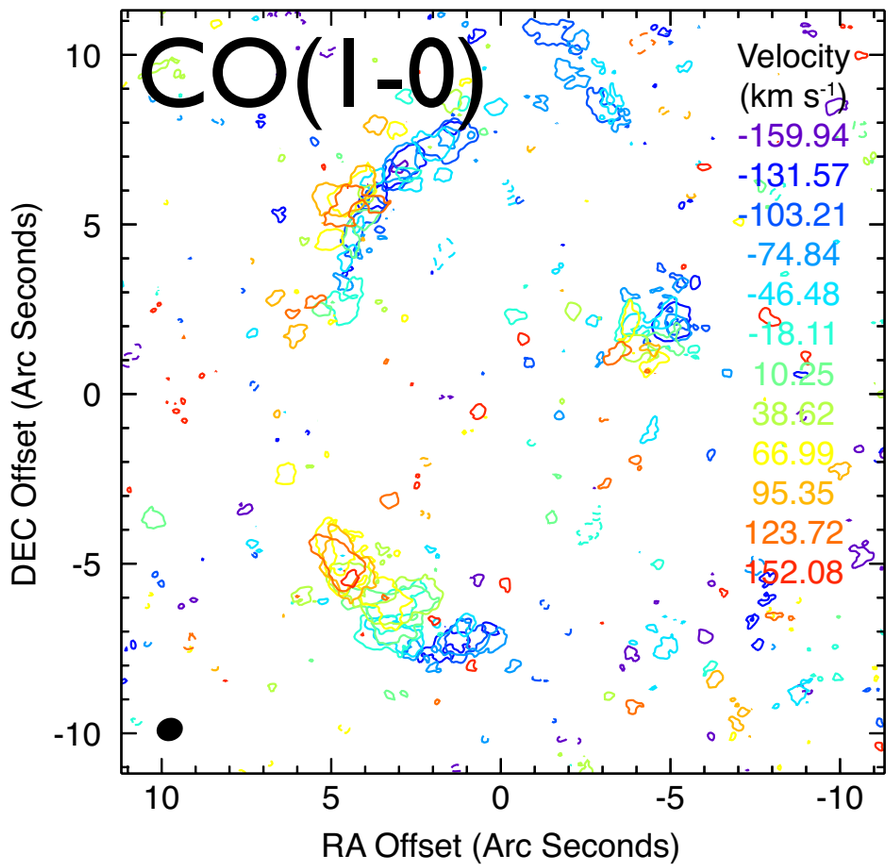


SDSS J0901+1814 cont.

Observations





- VLA observations of CO(1-0)
- VLT/SINFONI observations including Hα and NII
- PdBI observations of CO(3-2)

- ALMA observations (~~just ACA so far~~ 12m array Monday!) of CO(7-6), CI($^3P_2$-$^3P_1$), and 1.3mm continuum
- Photometry from optical through infrared

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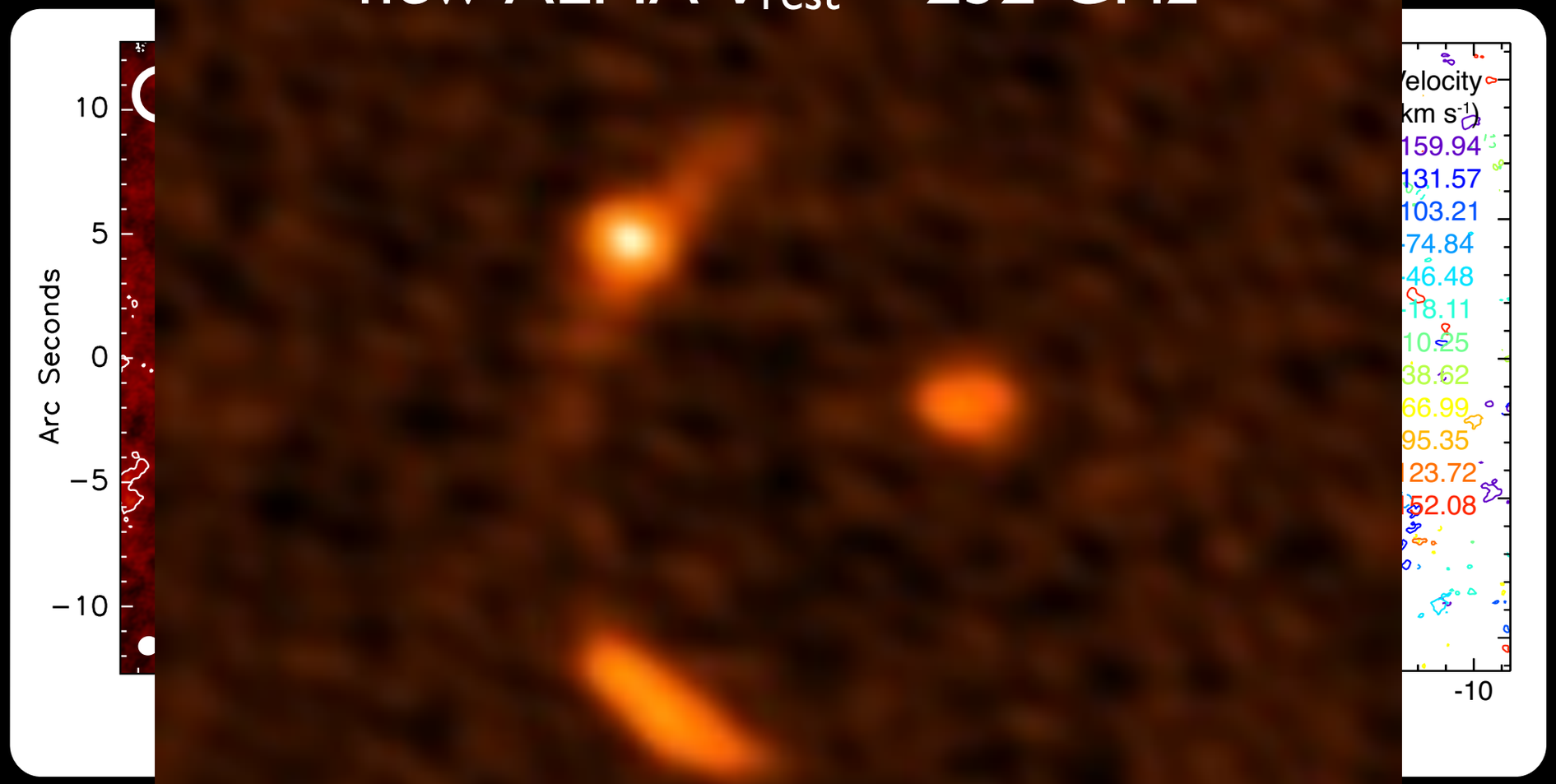

new ALMA ν_{rest} = 232 GHz

- VLA c
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SDSS J0901+1814 cont.

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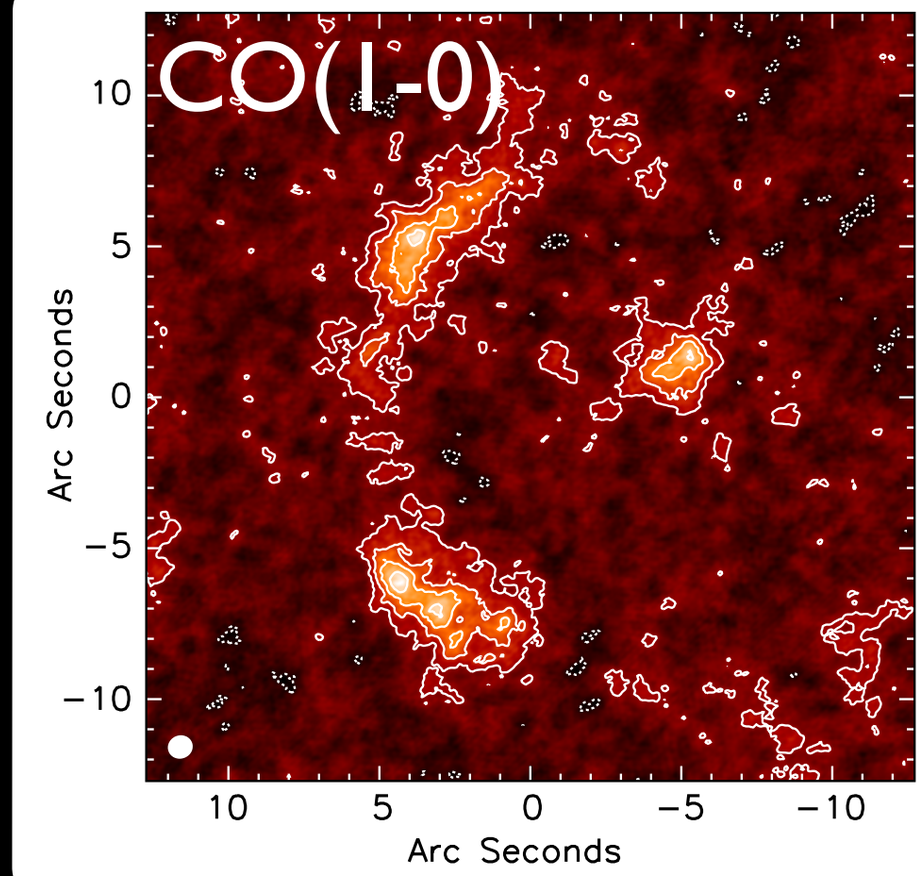

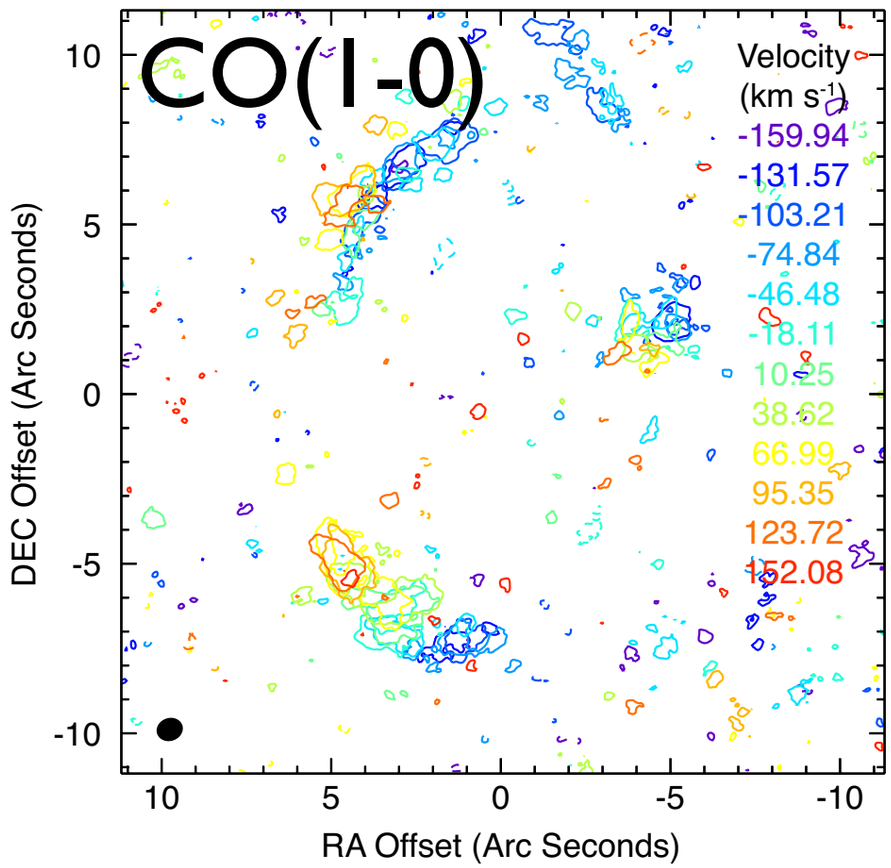

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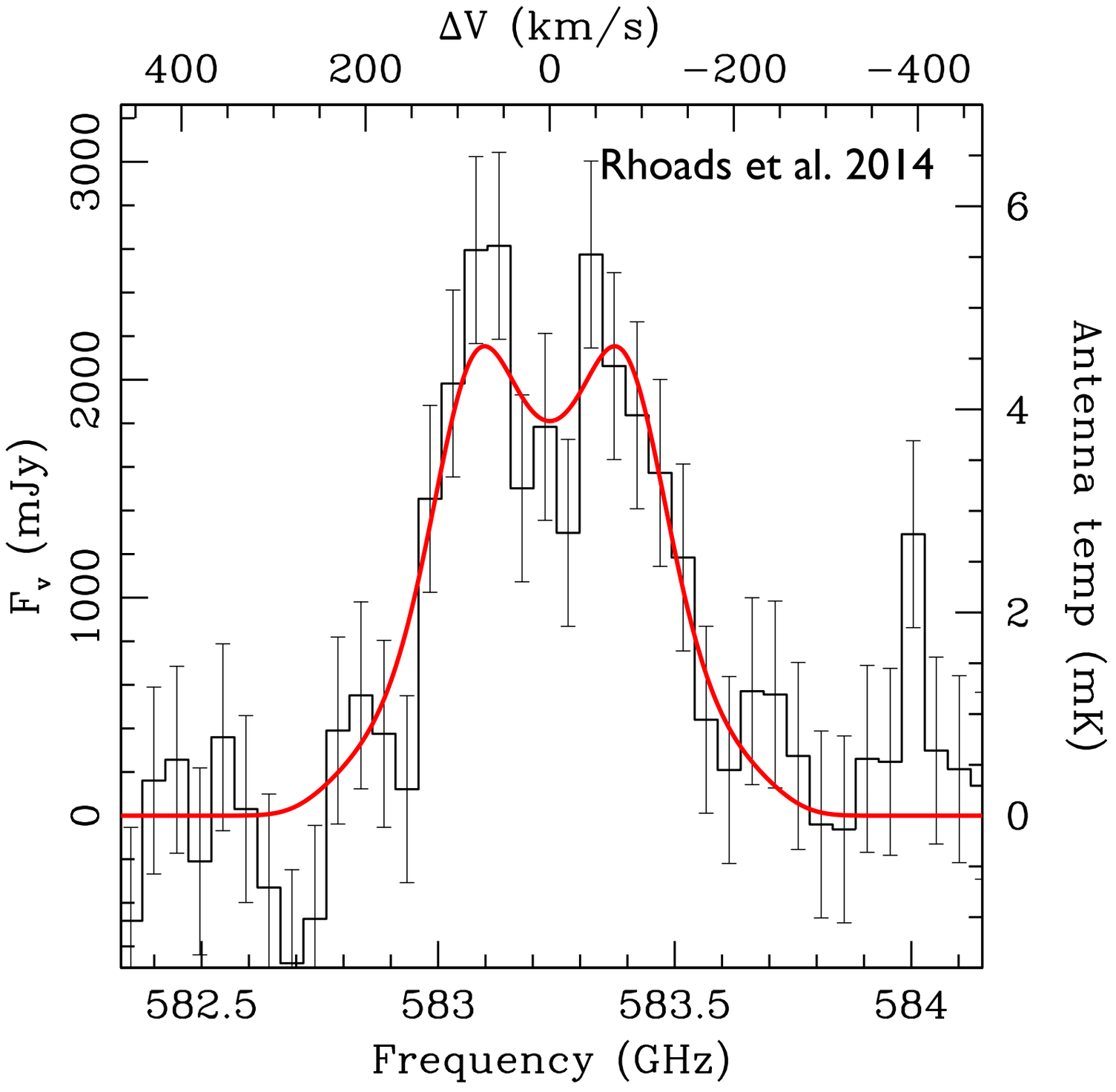
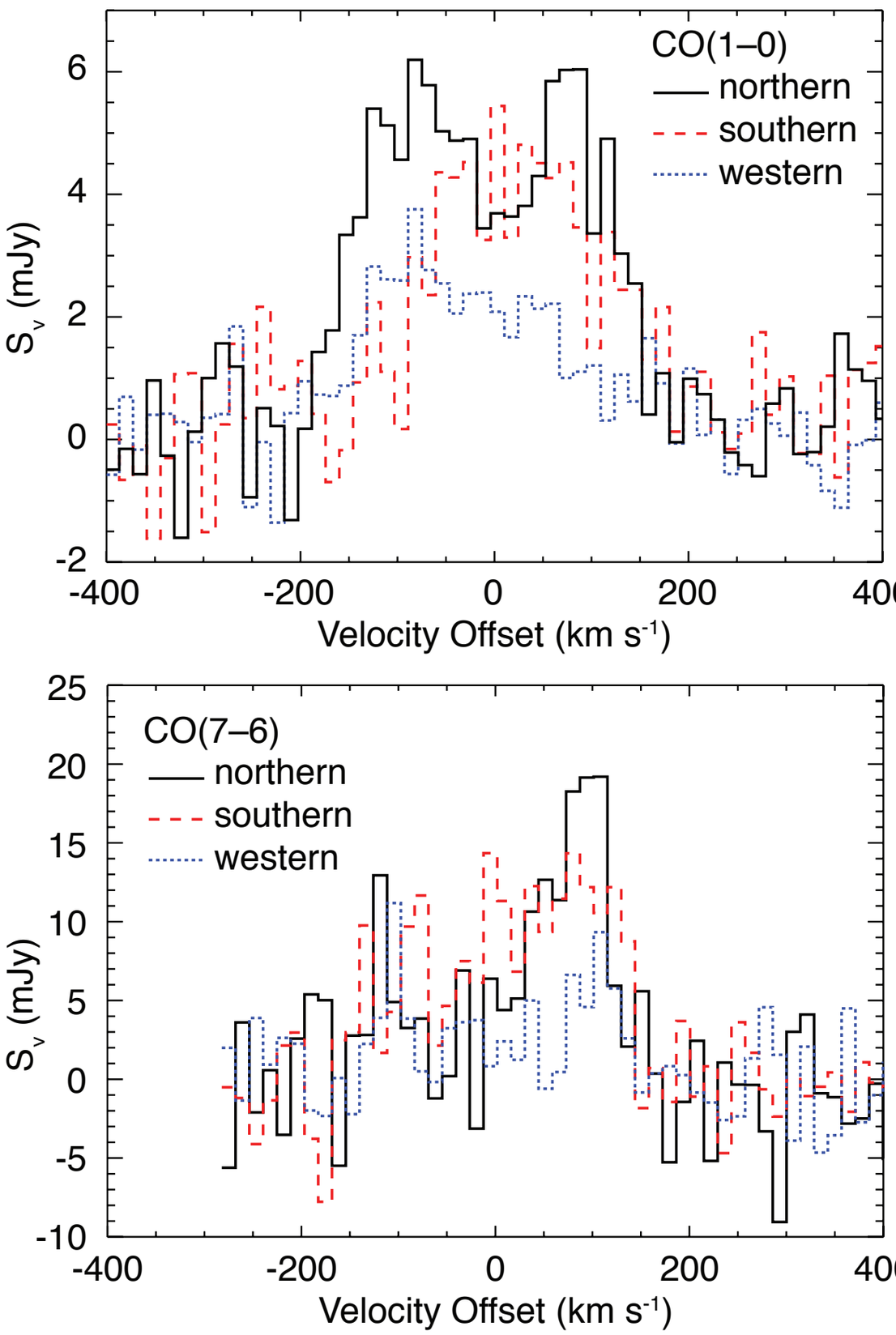
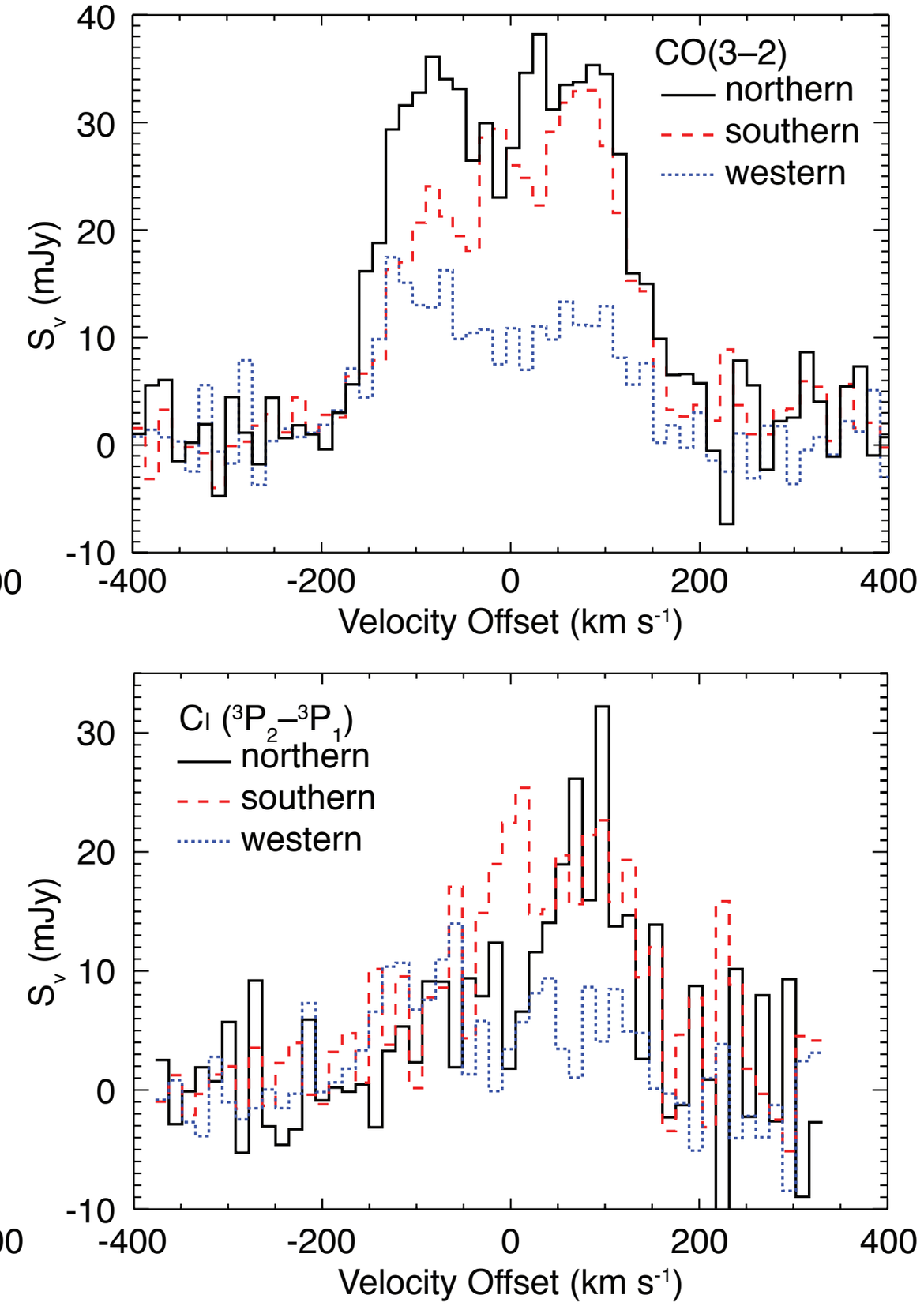
Strong Lensing and Line Profiles



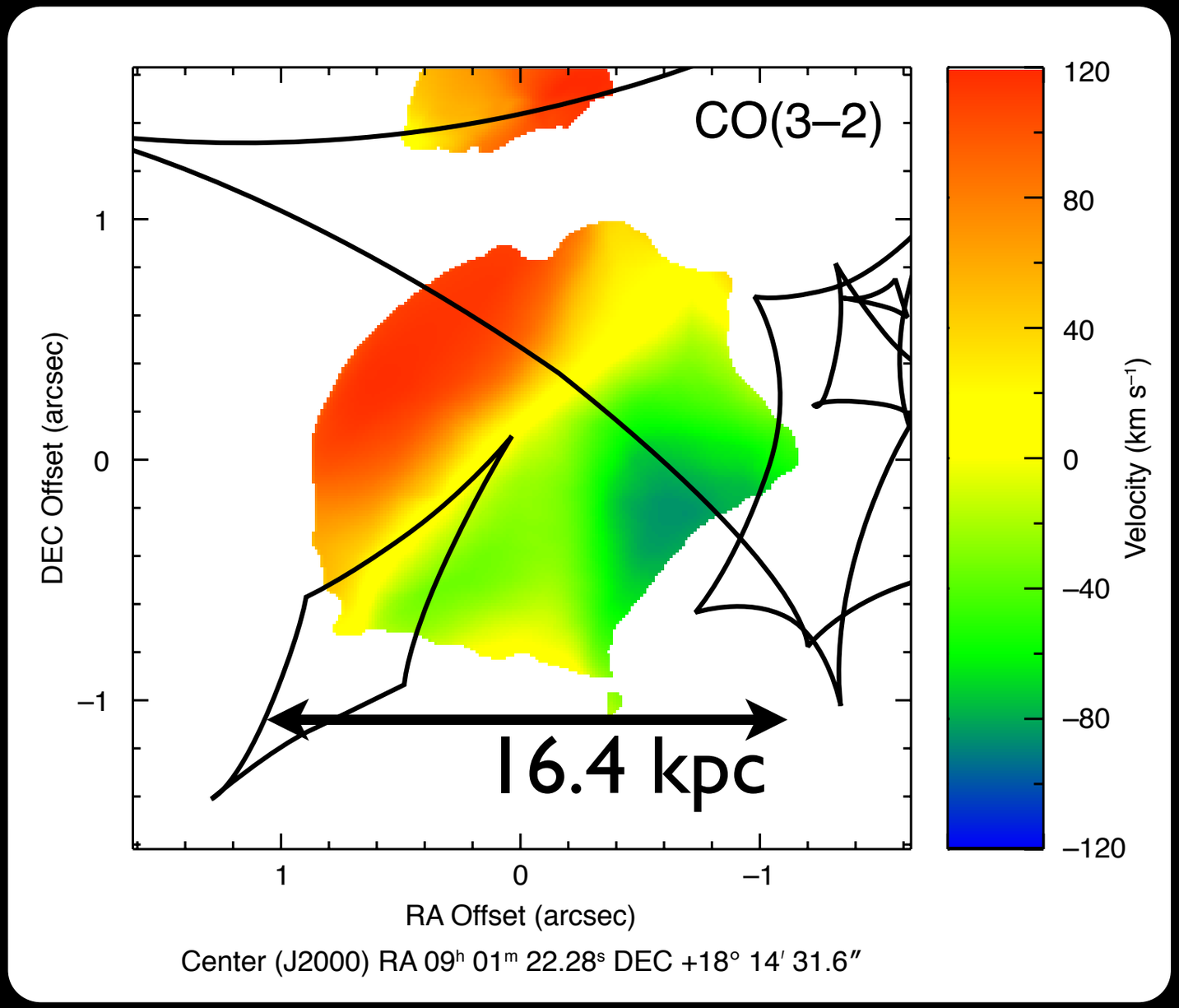
Herschel/HIFI spectra of CII

Differences in the relative line profiles of the two transitions for each image imply differential lensing



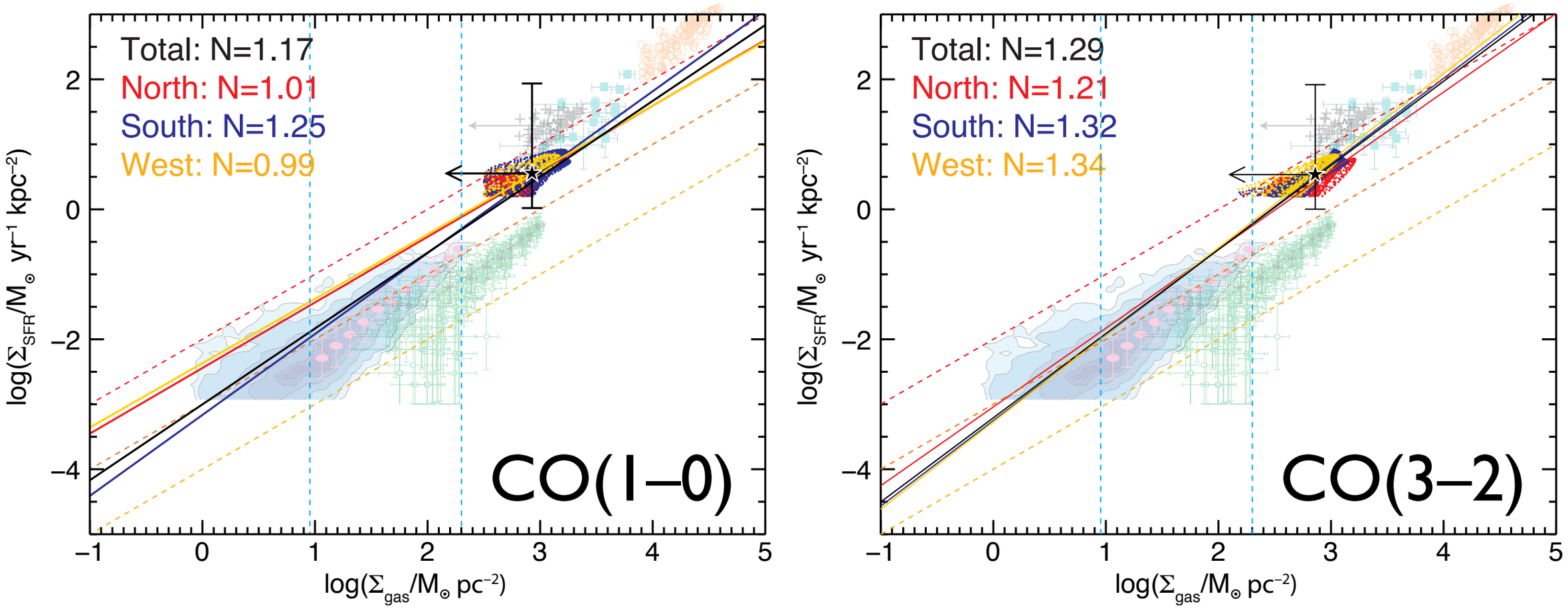


Strong Lensing and Line Profiles cont'd



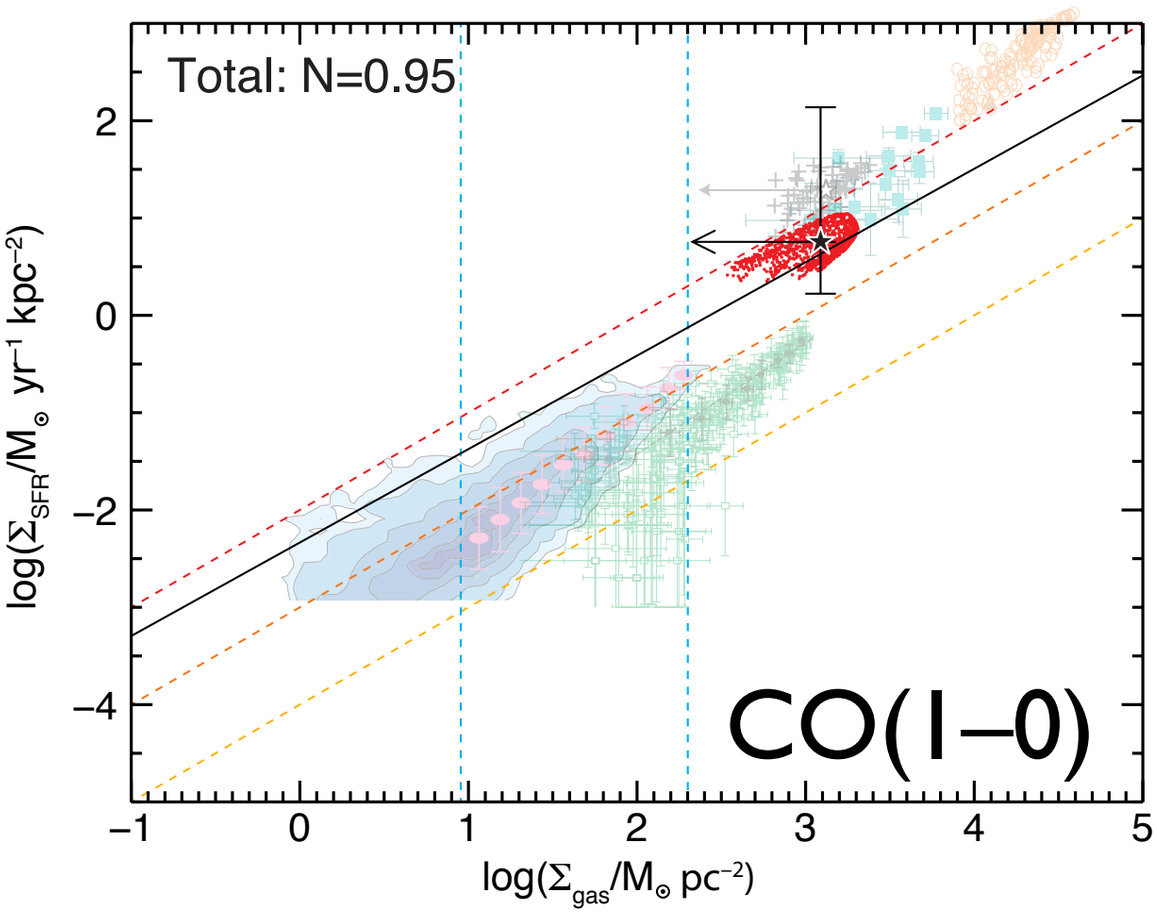
- J0901 crosses caustic → all of J0901 is doubly imaged (southern and western images), part of J0901 is quadruply imaged (northern image)
- Southern image has additional perturber → Western spectra likely most representative of true line profile

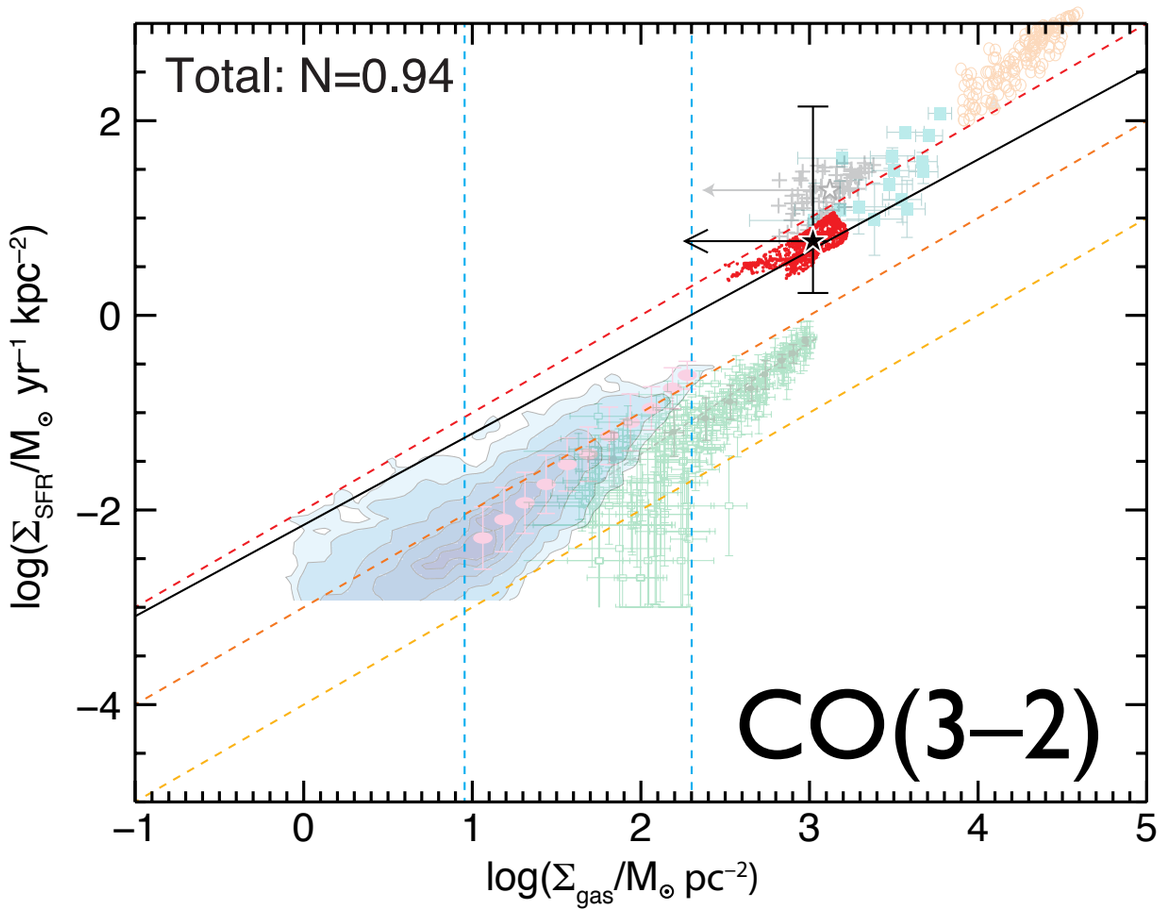
Resolved Schmidt-Kennicutt Relation



- Index measured using a Monte Carlo technique (Blanc et al. 2009; Leroy et al. 2013) that avoids biases due to surface brightness cuts (2σ shown)
- CO(1-0) and CO(3-2) indices are borderline inconsistent

Lensing-corrected

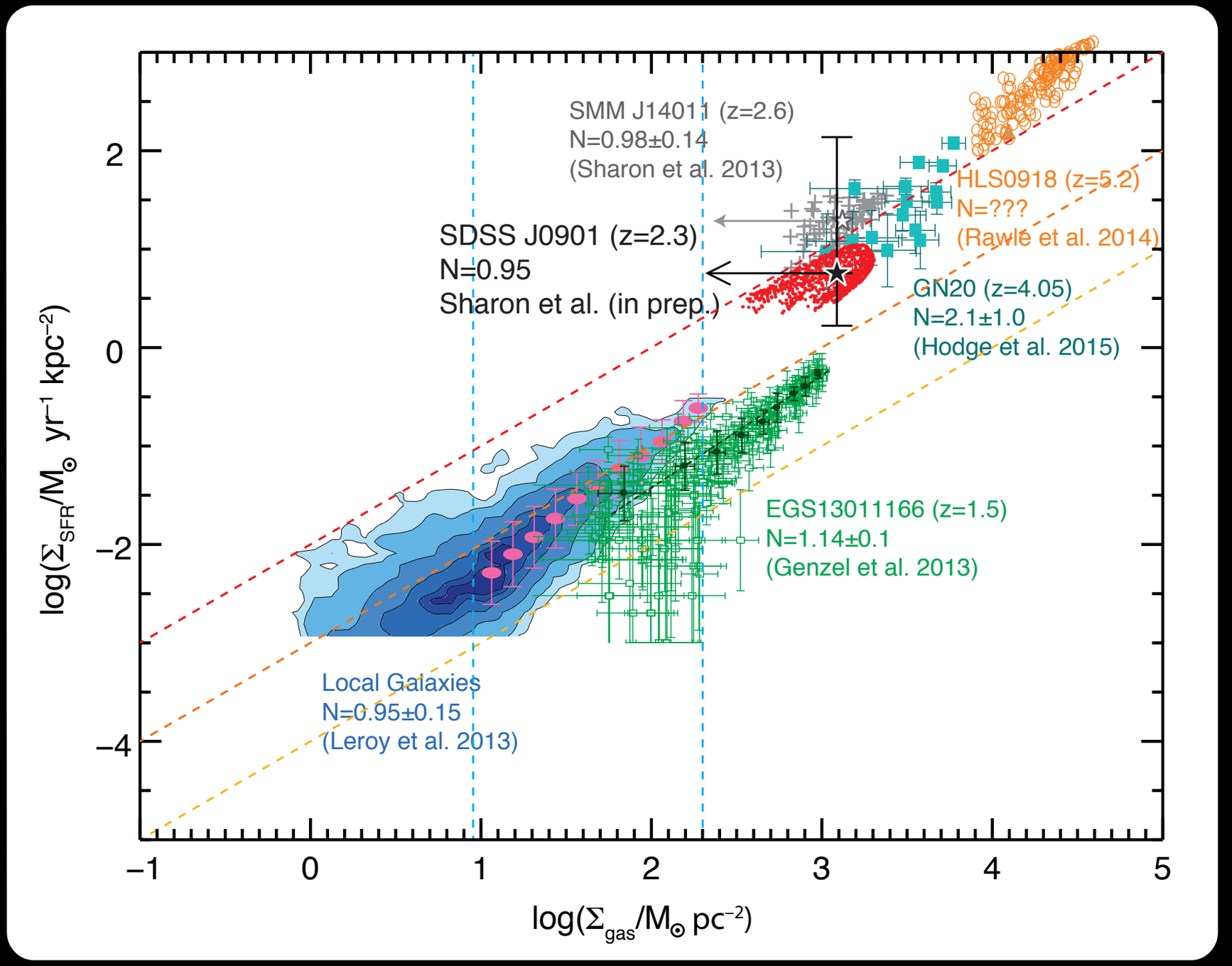




- CO(1–0) index consistent with before; CO(3–2) is a poor fit
- Offset consistent with global (uv-matched) excitation of $r_{3,1}$=0.71±0.11

Comparisons to Other Galaxies

- All indices are ~consistent with N=1
- Accounting for both obscured and unobscured star formation is critical! (see also Genzel et al. 2013)



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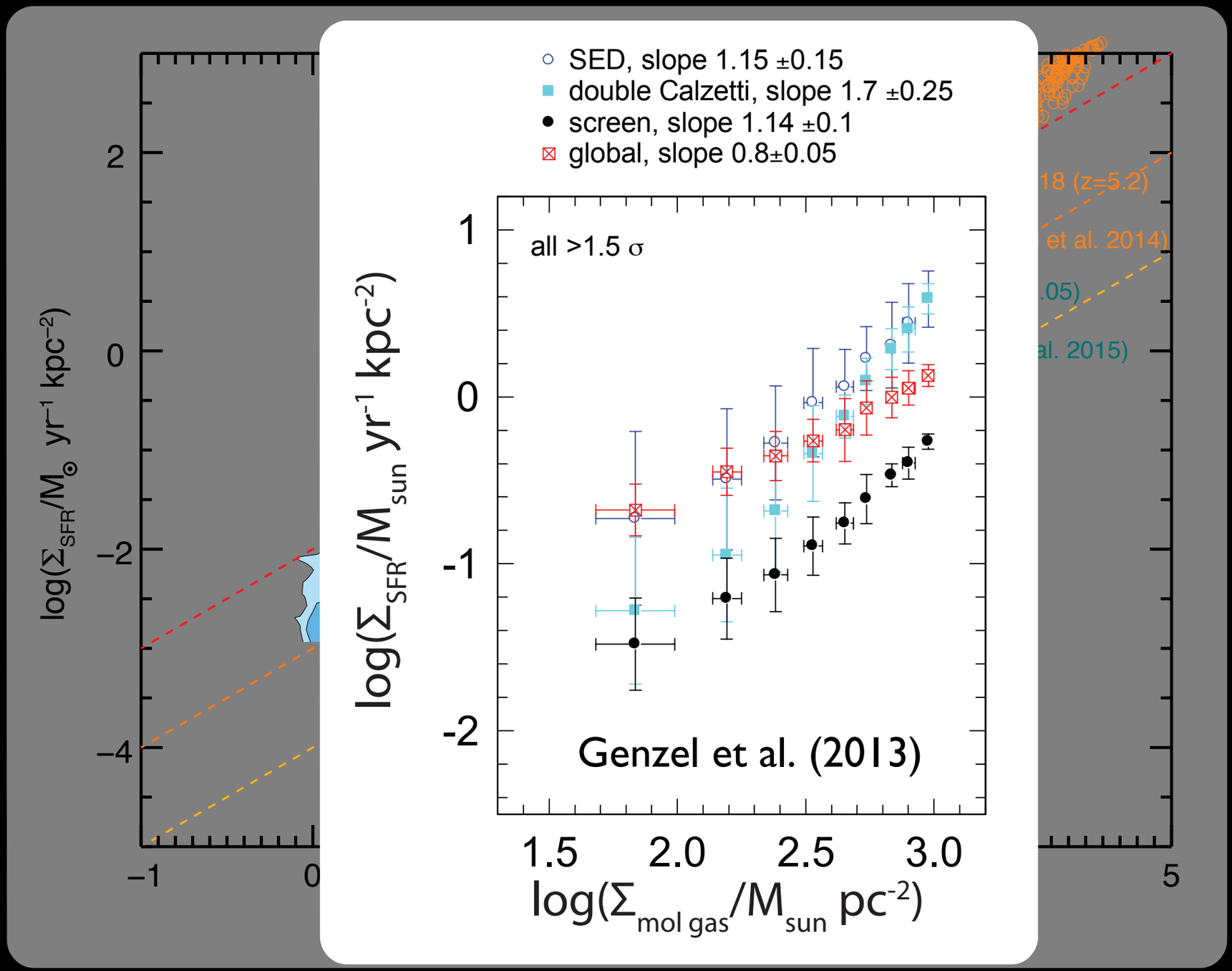

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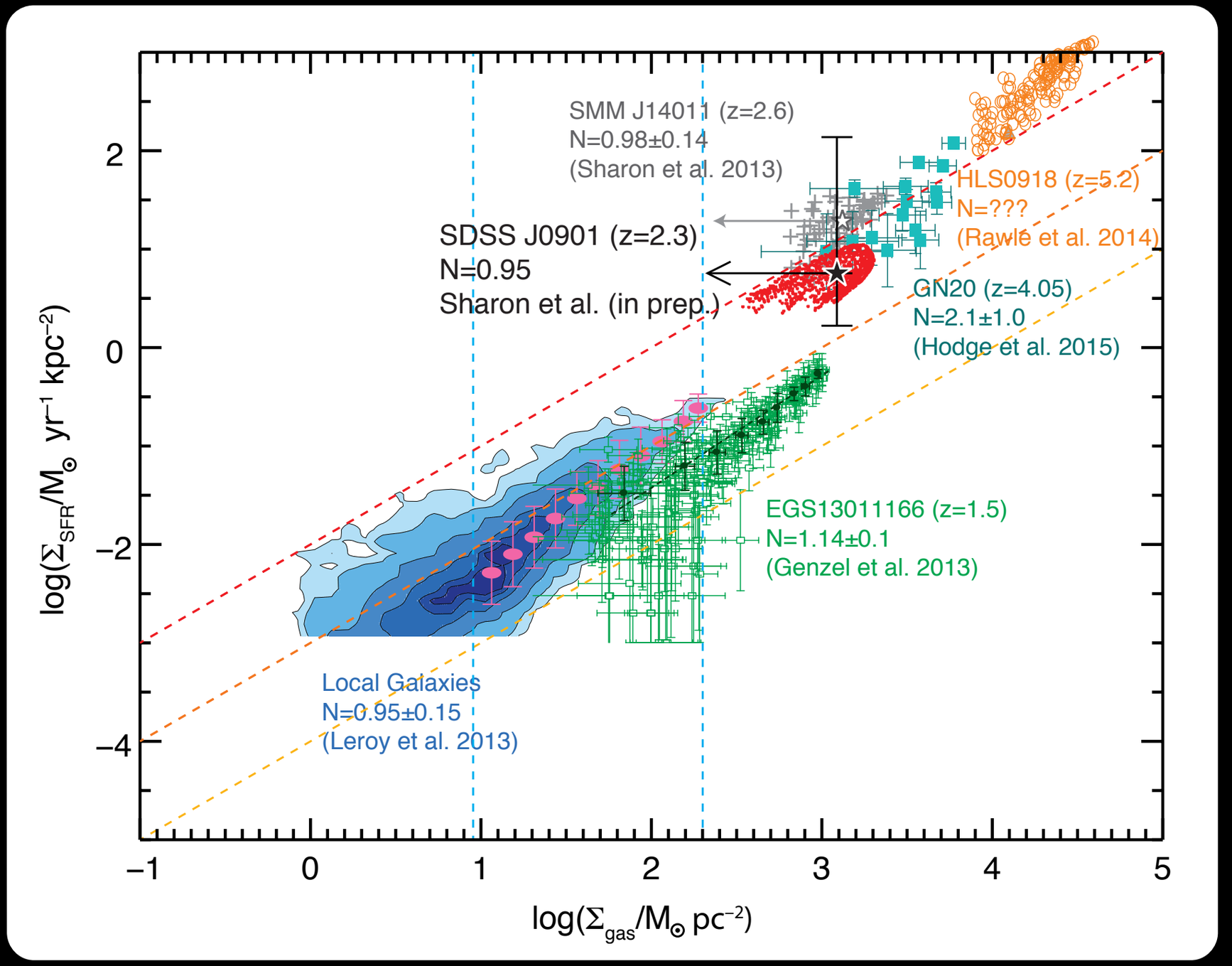
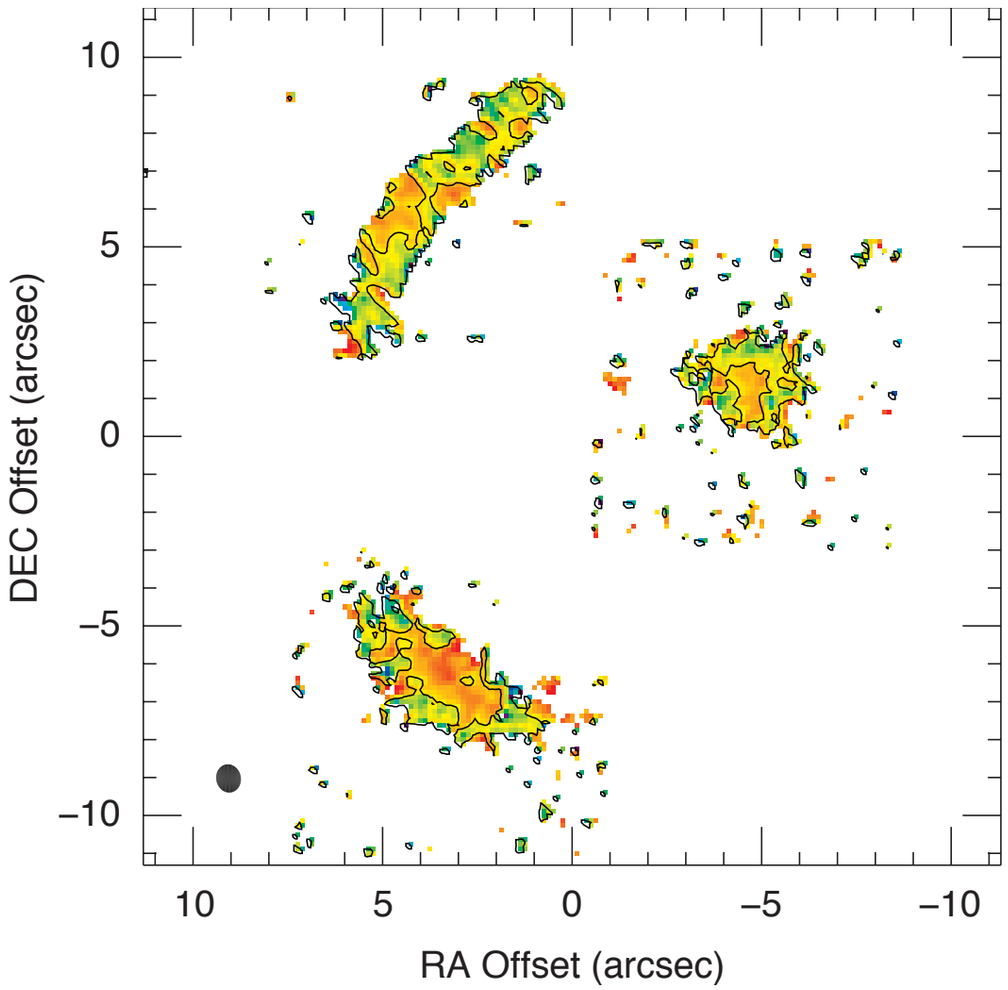
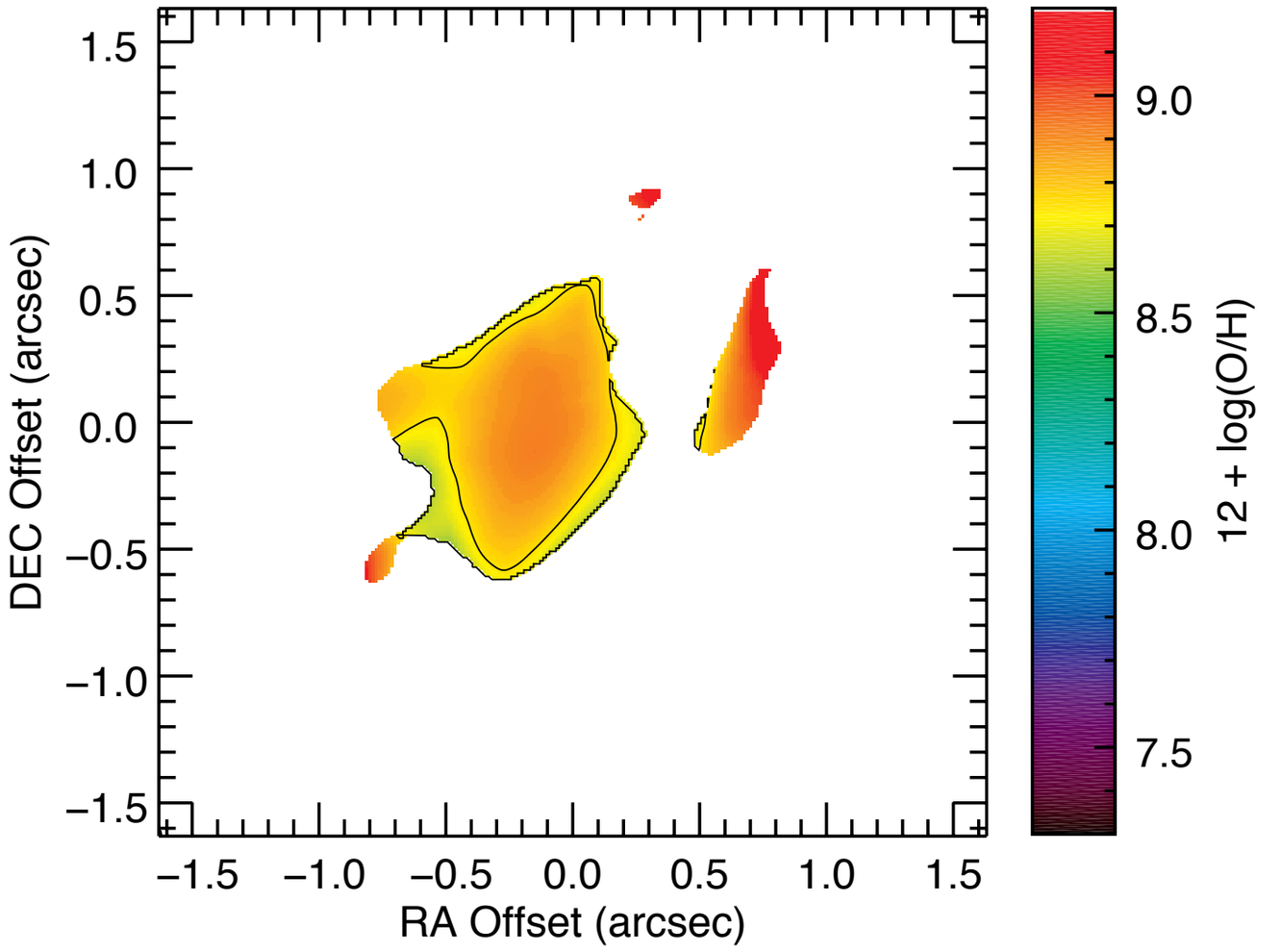


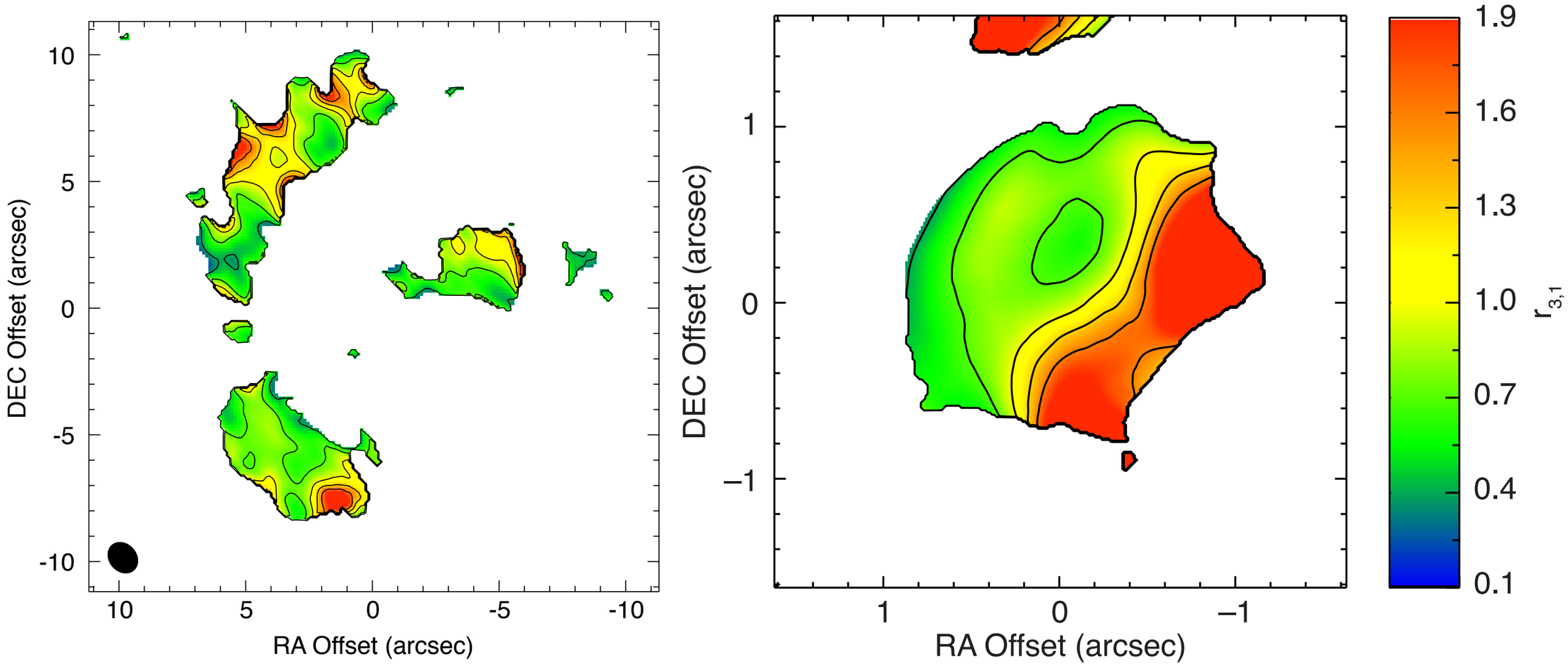
Spatially Resolved Metallicity Maps





- Image plane: clipped at 2σ in Hα, De-lensed: clipped at 2σ in NII
- Clear metallicity gradient
- Central region affected by AGN (too high NII/Hα)

Spatially Resolved CO Excitation Maps



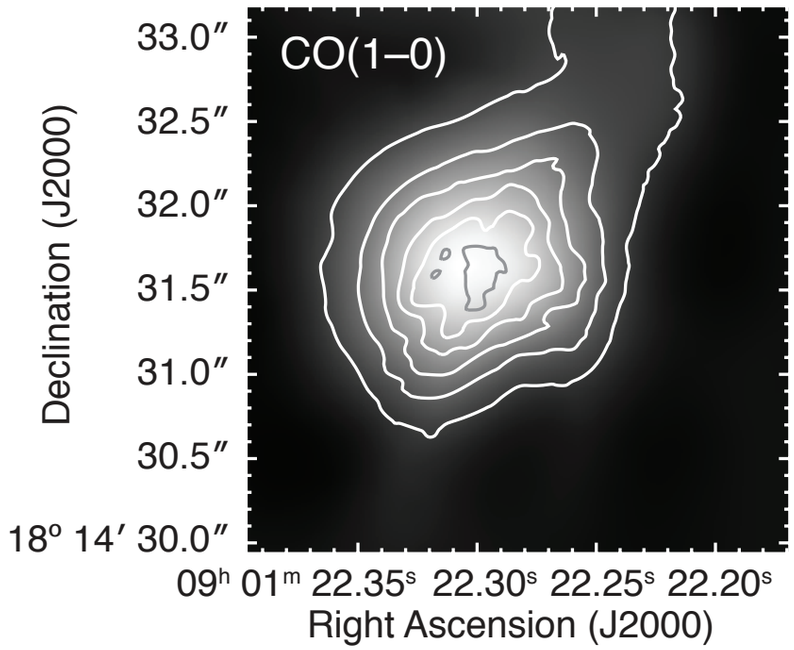
- Evidence for an excitation gradient (but not near the central AGN?)
- De-lensed image looks most similar to least-disturbed western image

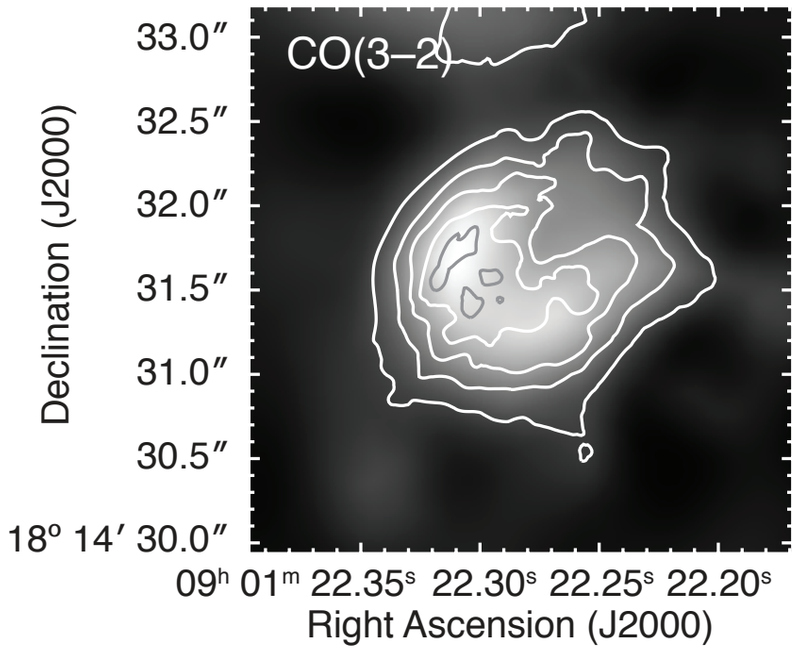
Summary

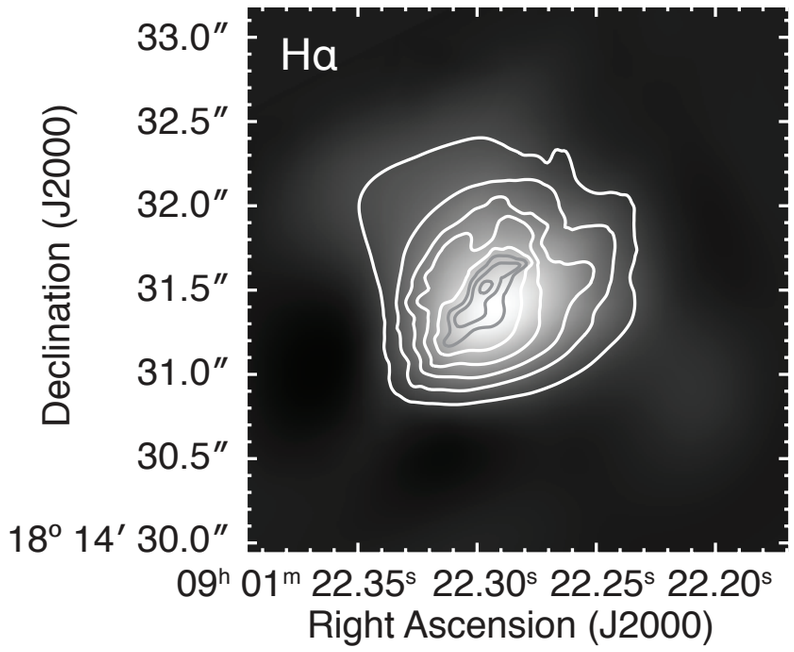
- For Schmidt-Kennicutt at high-z, beware conversion factors and extinction corrections
- Star formation efficiency does appear higher for at least some high-z galaxies
- Beware interpreting integrated properties of strongly lensed galaxies
- Tentative confirmation of spatially varying CO excitation

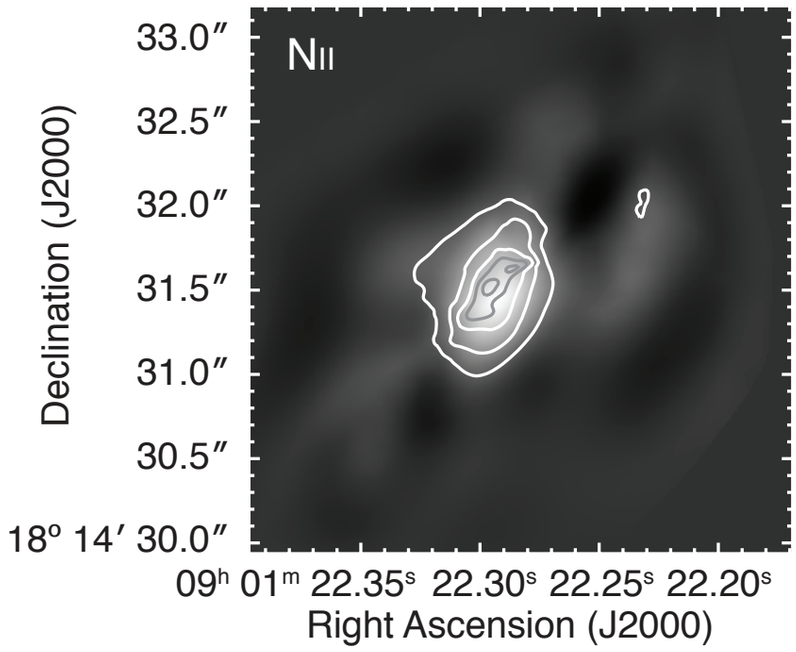
Bonus material!

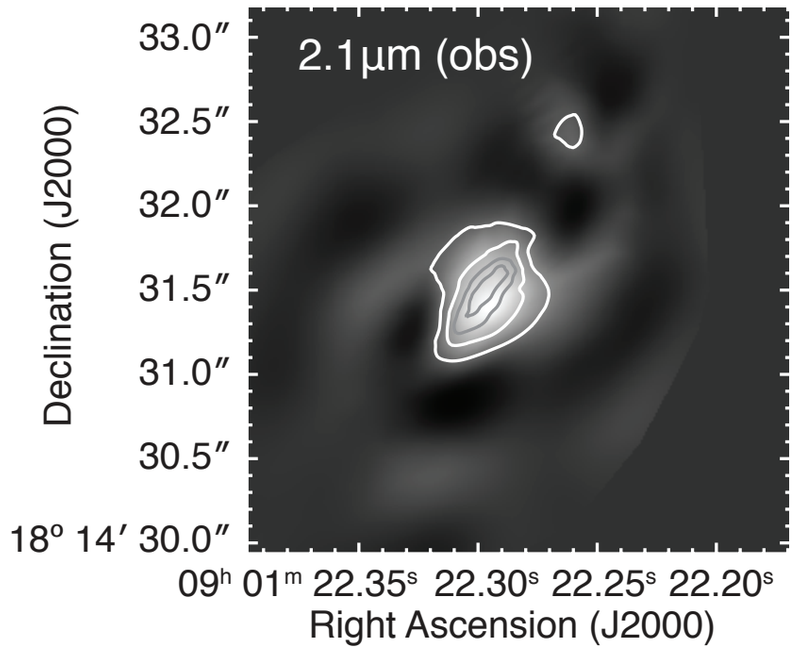
Reconstructed Maps











ALMA Observations