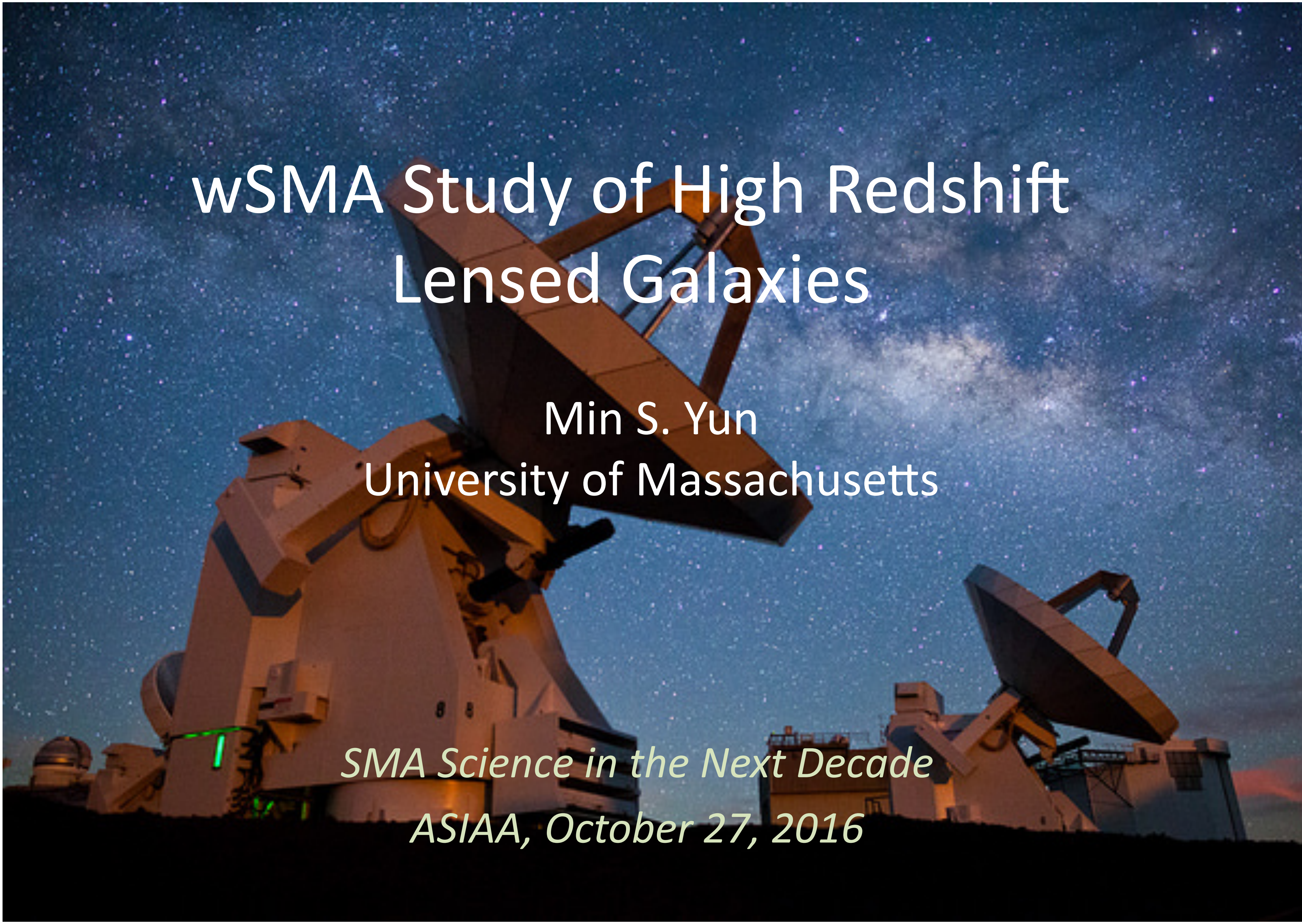


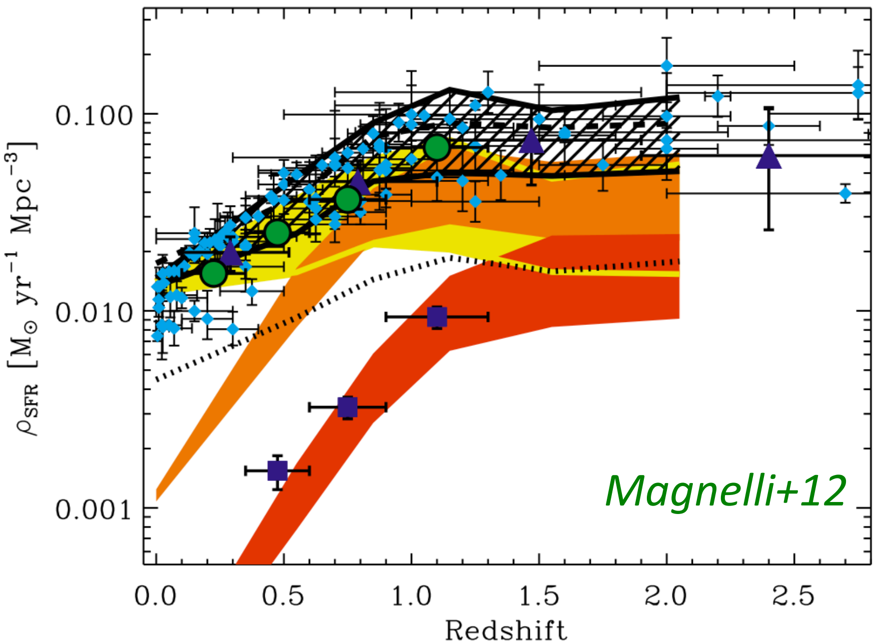
wSMA Study of High Redshift Lensed Galaxies

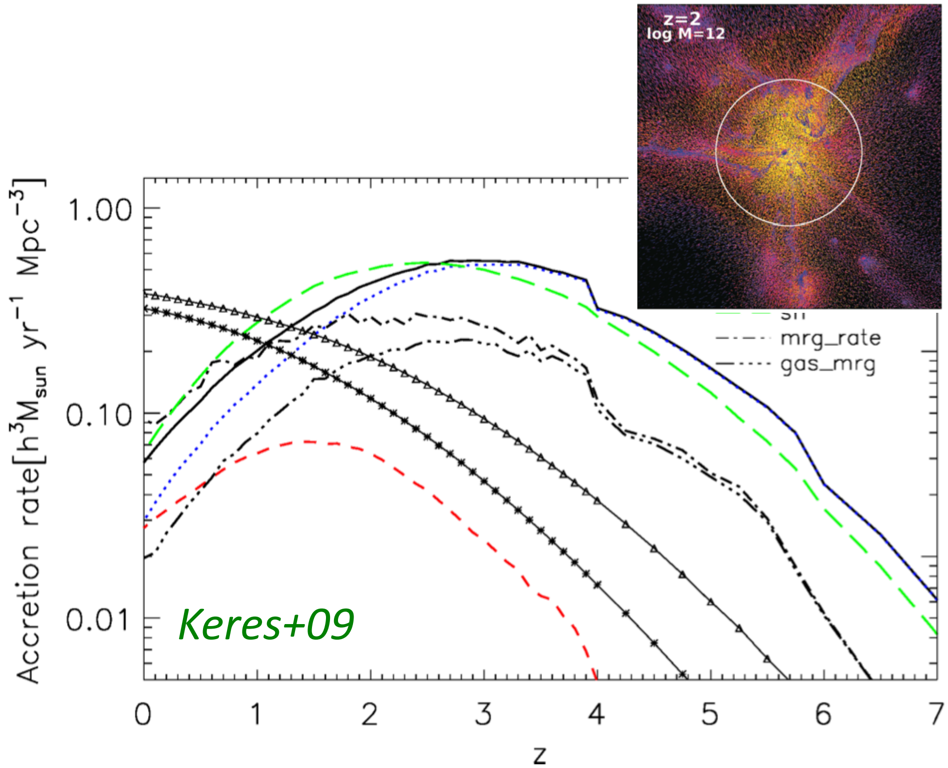
Min S. Yun
University of Massachusetts

SMA Science in the Next Decade

ASIAA, October 27, 2016

Star Formation Near and Far

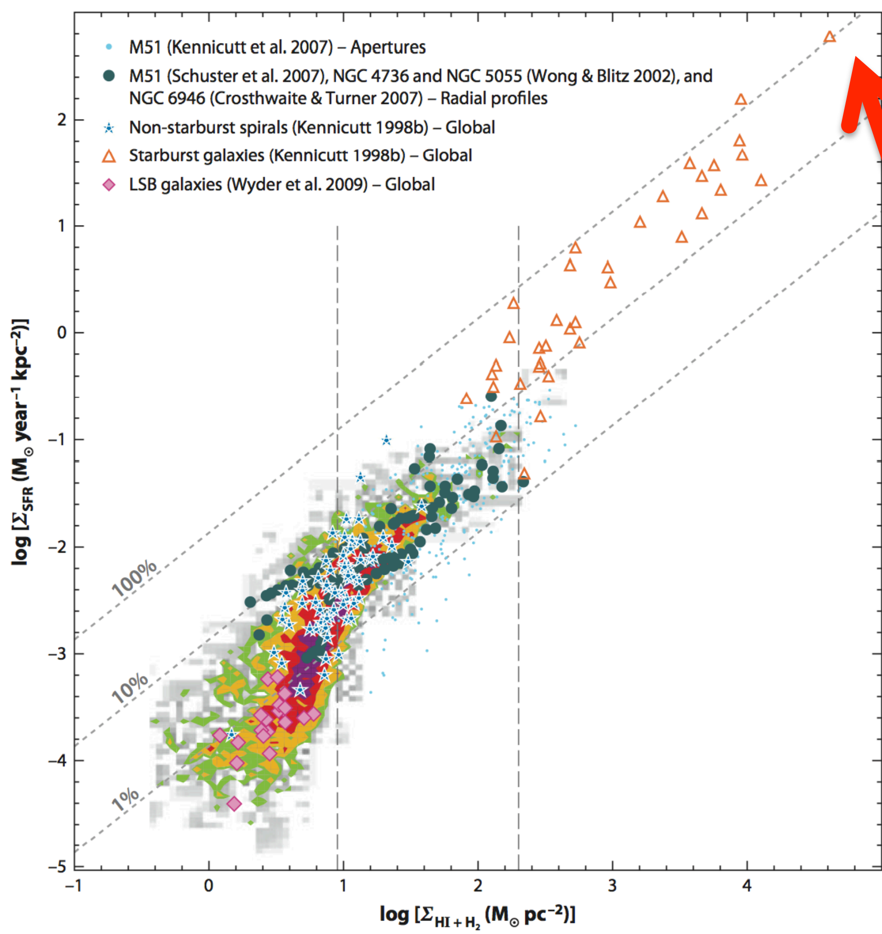




- Cosmic SFRD rises rapidly to z~1
- LIRGs/ULIRGs dominate cosmic SFH at z > 1

- Gas accretion rate mimic CSFH ("cold flow")
- Achieving high Σ_{SFR} only through gas-rich mergers?

Star Formation Near and Far



Kennicutt & Evans (2012)

- SF driven by (dense) gas density
- Gas depletion time (M_{gas}/SFR) ~ 0.1-1 Gyr
- Importance of feedback:
  - Eddington-limited SF? (Σ_{SFR}>10^3 $M_\odot$/yr/kpc^2; Thompson+05)
  - M(outflow) > SFR? (Chung +11;Cicone+12;Maiolino +12)

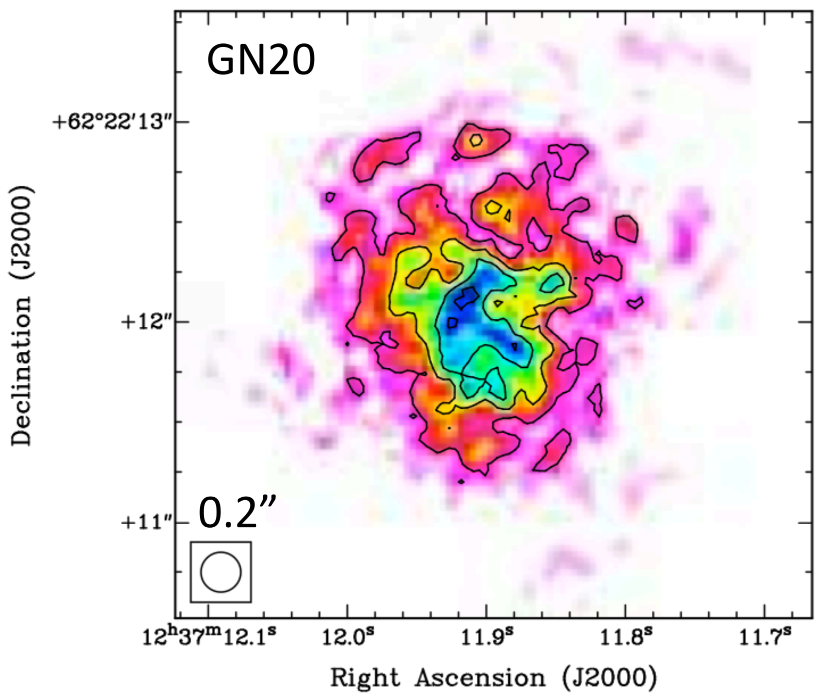
Outline/Summary

- wSMA moves the ball forward in two ways:
  - Improved continuum sensitivity
  - Wider spectral coverage for multi-transition studies (CO, C I, FIR lines)
- Strong lensing brings high-z SF and ISM physics to wSMA
  - Searches for “golden lenses” in the northern sky?
- A wish list:
  - Longest baselines
  - Flexible spectral windows

Probing the Physical Process Driving the Rapid Mass Build-up

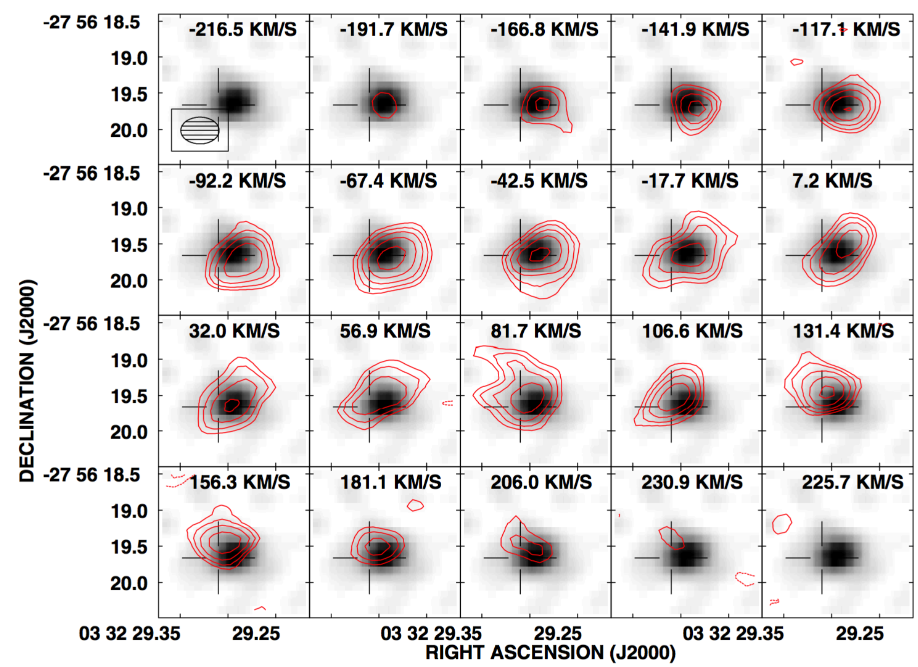
- Need to probe GAS structure and kinematics
- Need to probe 10-100 pc scales → $\theta \leq 0.01\text{-}0.1''$

Hodge et al. (2012)

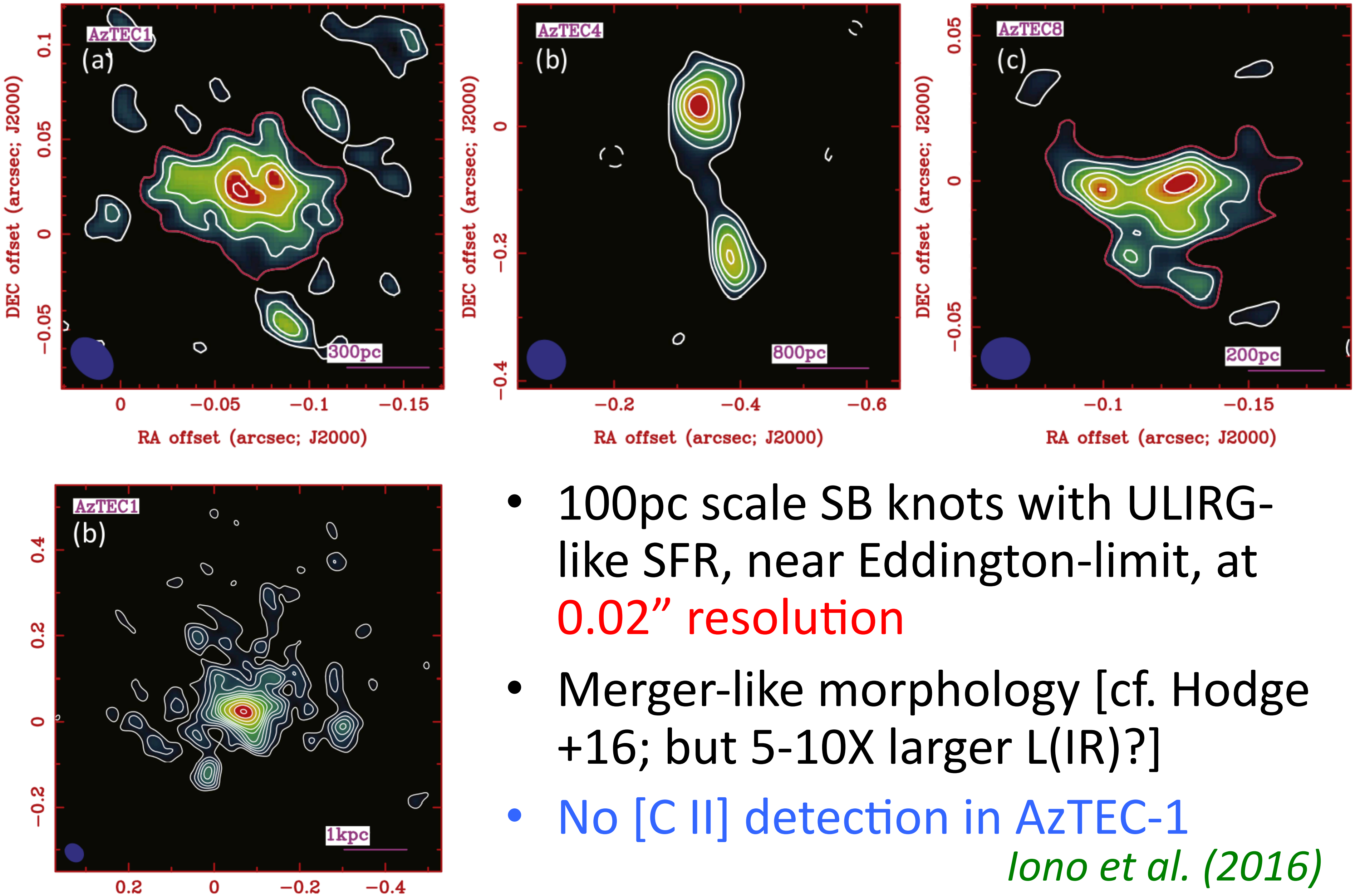


ALESS73.1

De Breuck et al. (2014)



High Resolution ALMA Continuum Study



- 100pc scale SB knots with ULIRG-like SFR, near Eddington-limit, at 0.02" resolution
- Merger-like morphology [cf. Hodge +16; but 5-10X larger L(IR)?]
- No [C II] detection in AzTEC-1

Iono et al. (2016)

AzTEC-1: SMA [C II] Observations

Yun et al. (2015)

- z_{CO} = 4.3420+/-0.0004 (LMT/RSR)
- M_{H2}:
  - $M_{H2}=(1\text{-}7)\times10^{11}M_\odot$
  - 1.1mm continuum →

  $M_{ISM}=4\times10^{11}M_\odot$ (Scoville+ 2014)
- $M_{dyn}=(1.1)(\sin i)^{-2}\ \times10^{10}M_\odot$
- $M_*=(2\text{-}4)\times10^{11}M_\odot$

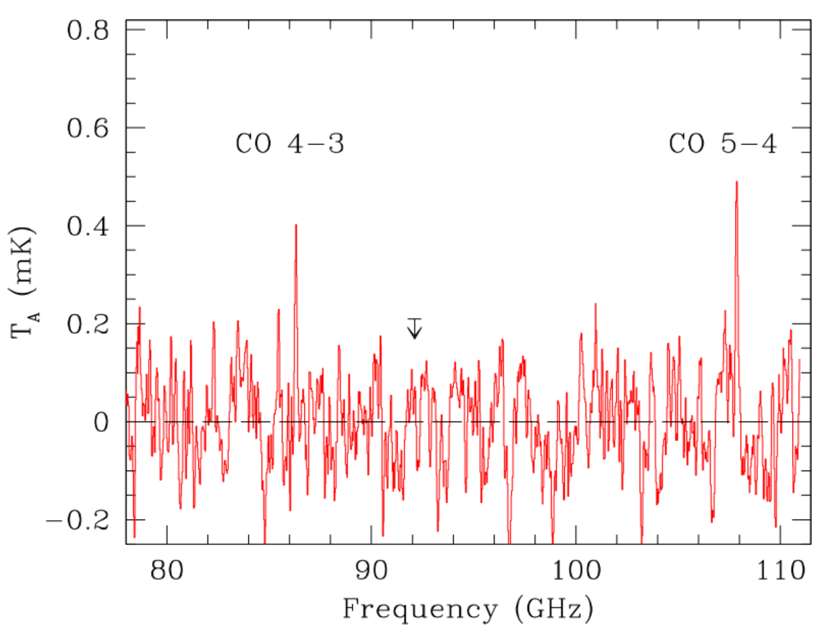
$z_{[C\ II]}$=4.3415+/-0.0003

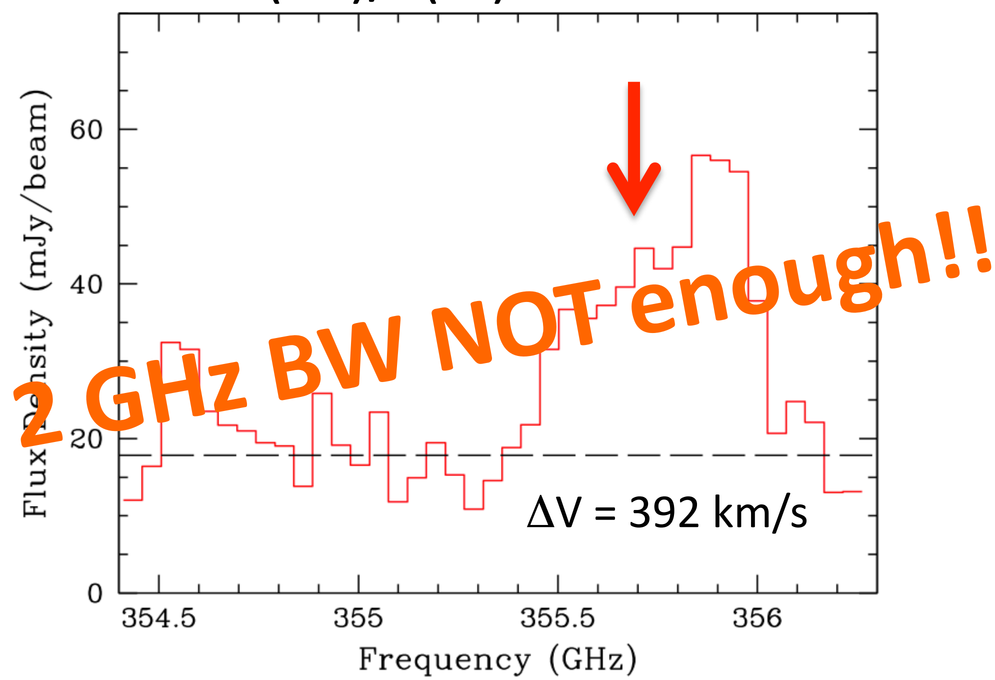
$S(CII)\Delta V$ = 13.1 +/- 0.9 Jy km/s

$L(CII) = 7.8 \times 10^9\ L_\odot$

$L(IR) = 1.7 \times 10^{13}\ L_\odot$

→ L(CII)/L(IR) = 0.00046





Can we do better?

RESOLUTION AND KINEMATICS OF MOLECULAR GAS SURROUNDING THE CLOVERLEAF QUASAR AT z = 2.6 USING THE GRAVITATIONAL LENS

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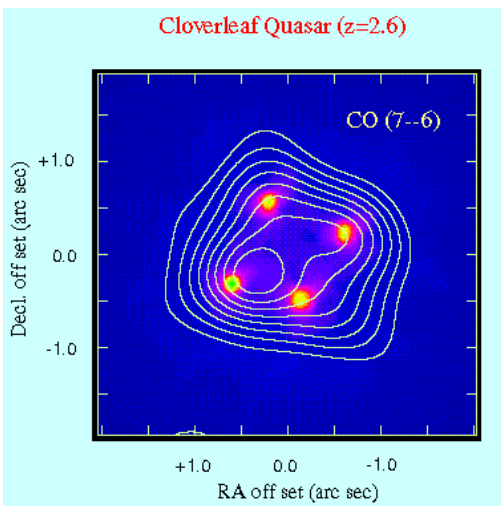
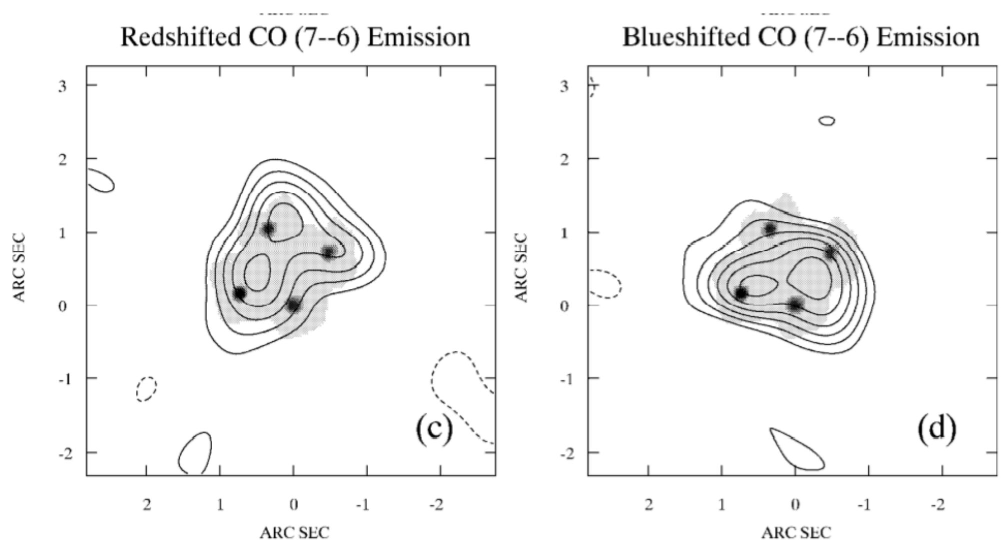
Received 1996 December 4; accepted 1997 January 23

ABSTRACT

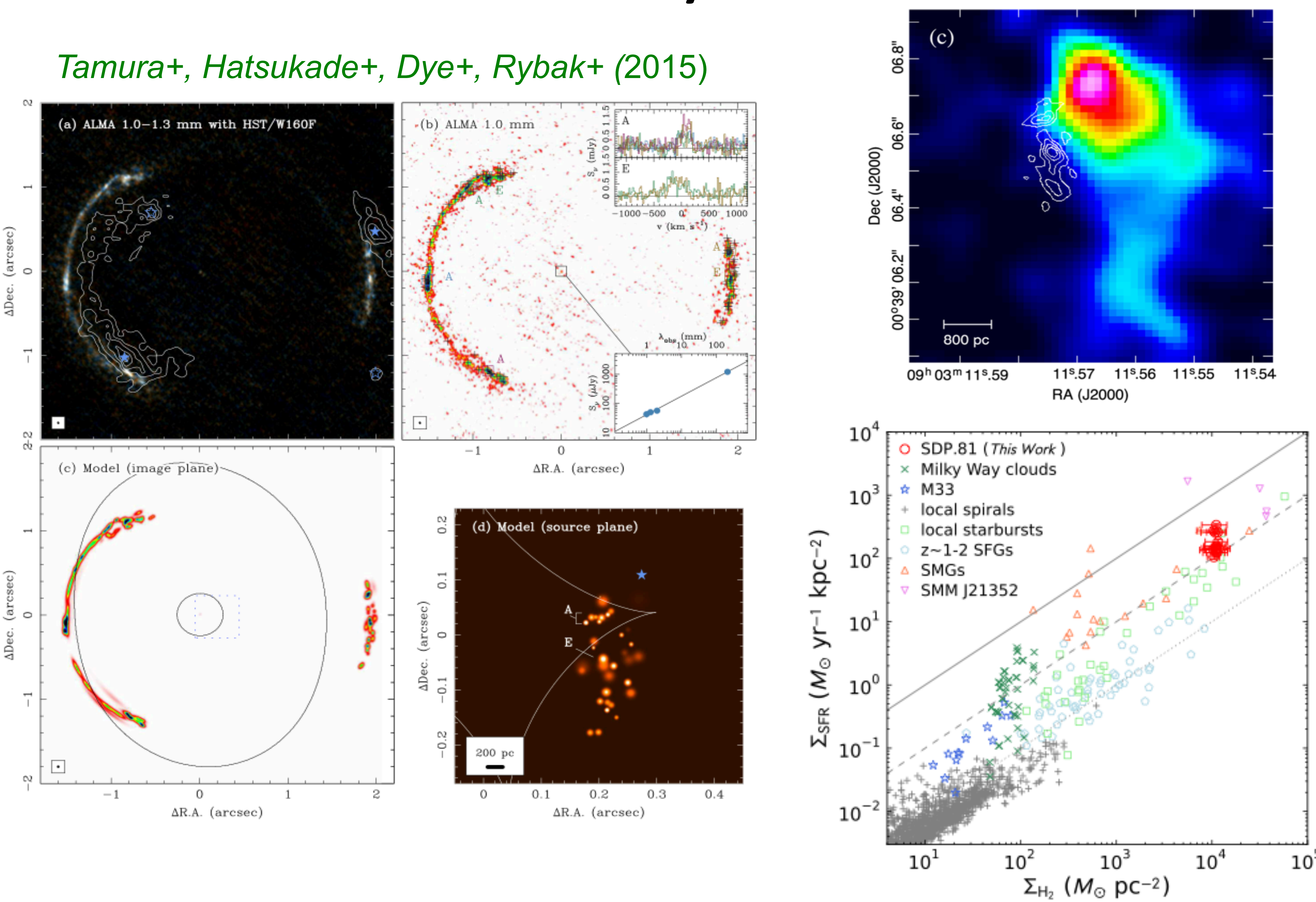
Gravitational lenses have long been advertised as primitive telescopes, capable of magnifying cosmologically distant sources. In this Letter we present new, 0.″9 resolution CO (7–6) observations of the z = 2.56 Cloverleaf quasar (H1413+117) and spatially resolved images. By modeling the gravitational lens, we infer a size scale of 0.″3 (~1 kpc) for the molecular gas structure surrounding the quasar, and the gas has a kinematic structure roughly consistent with a rotating disk. The observed properties of the CO-emitting gas are similar to the nuclear starburst complexes found in the infrared luminous galaxies in the local universe, and metal enrichment by vigorous star formation within this massive nuclear gas complex can explain the abundance of carbon and oxygen in the interstellar medium of this system observed when the universe was only a few billion years old. Obtaining corresponding details in an unlensed object at similar distances would be well beyond the reach of current instruments, and this study highlights the less exploited yet powerful use of a gravitational lens as a natural telescope.





SPD.81 by ALMA

Tamura+, Hatsukade+, Dye+, Rybak+ (2015)



Two ways to make a real progress:

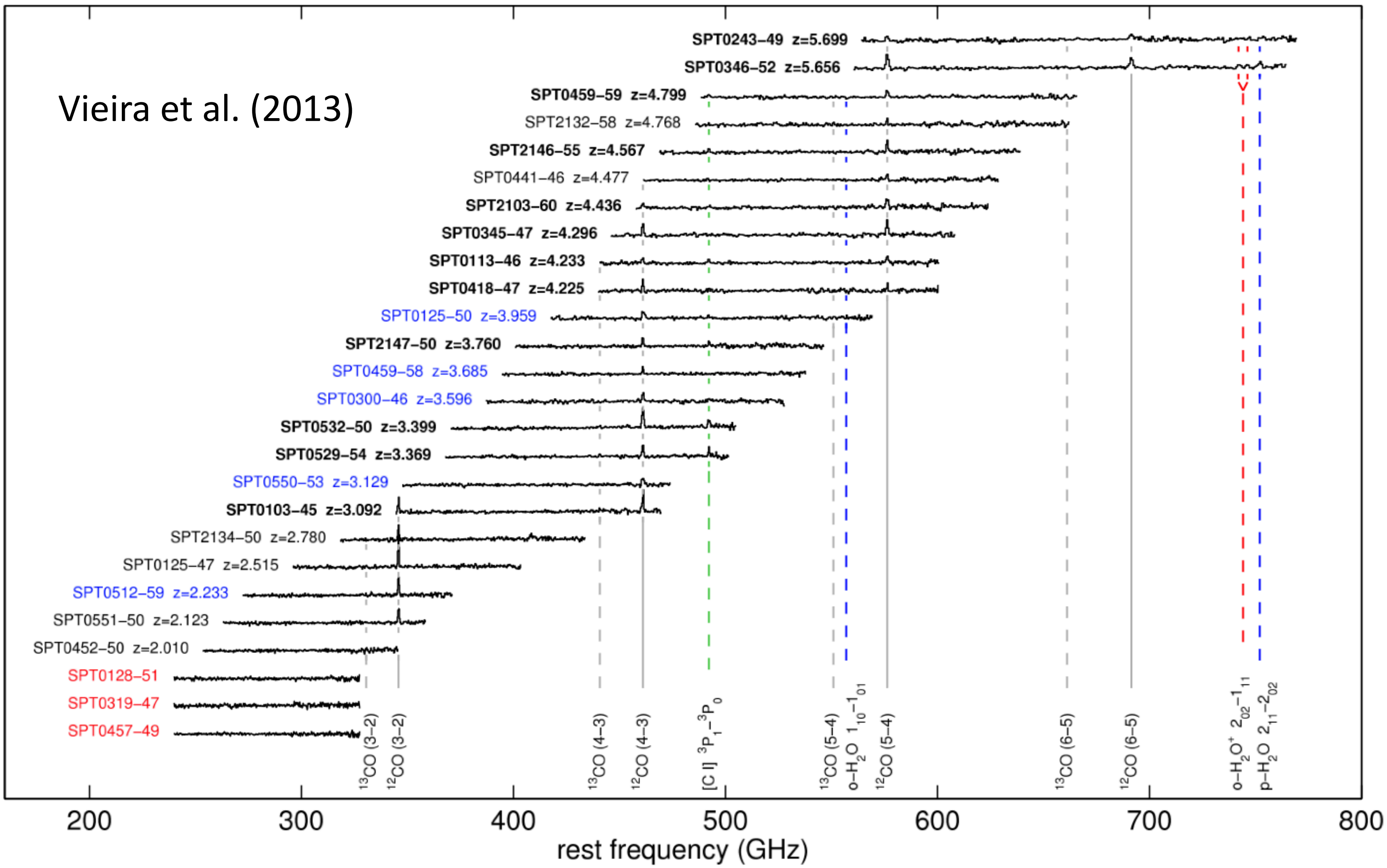
1. A detailed study of best examples (Orion, M82, Arp220, ….)
2. A statistical study of a large, well selected sample

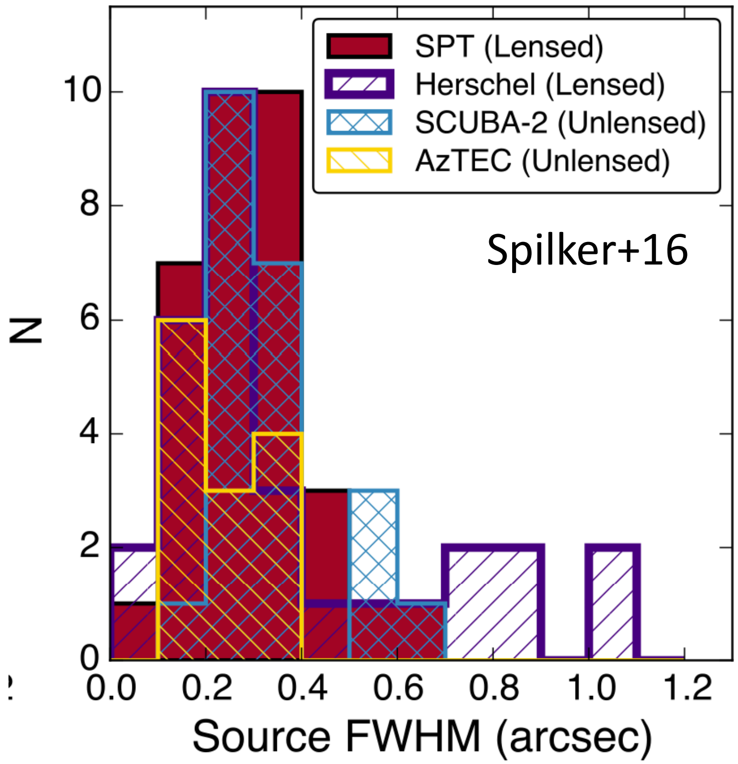
So, here is a candidate 1000 hr wSMA project!

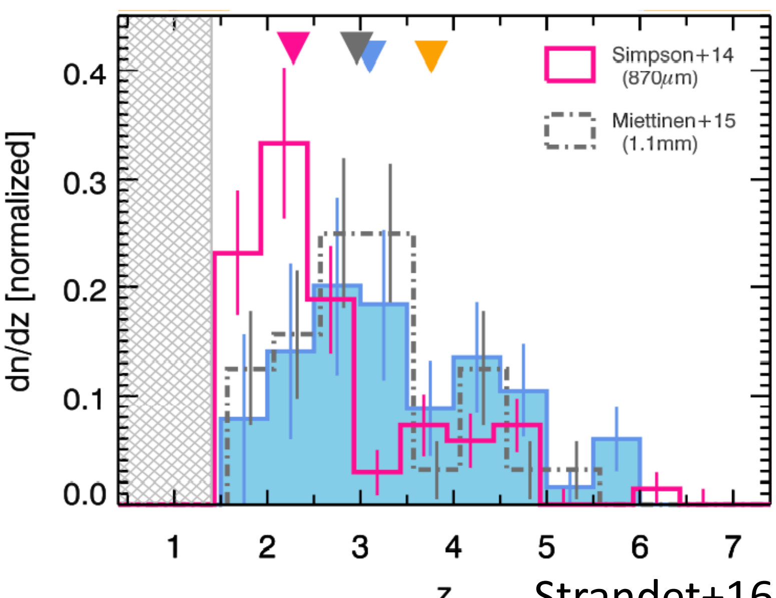
ALMA Study of SPT Sources

[Scott's colloquium talk yesterday]

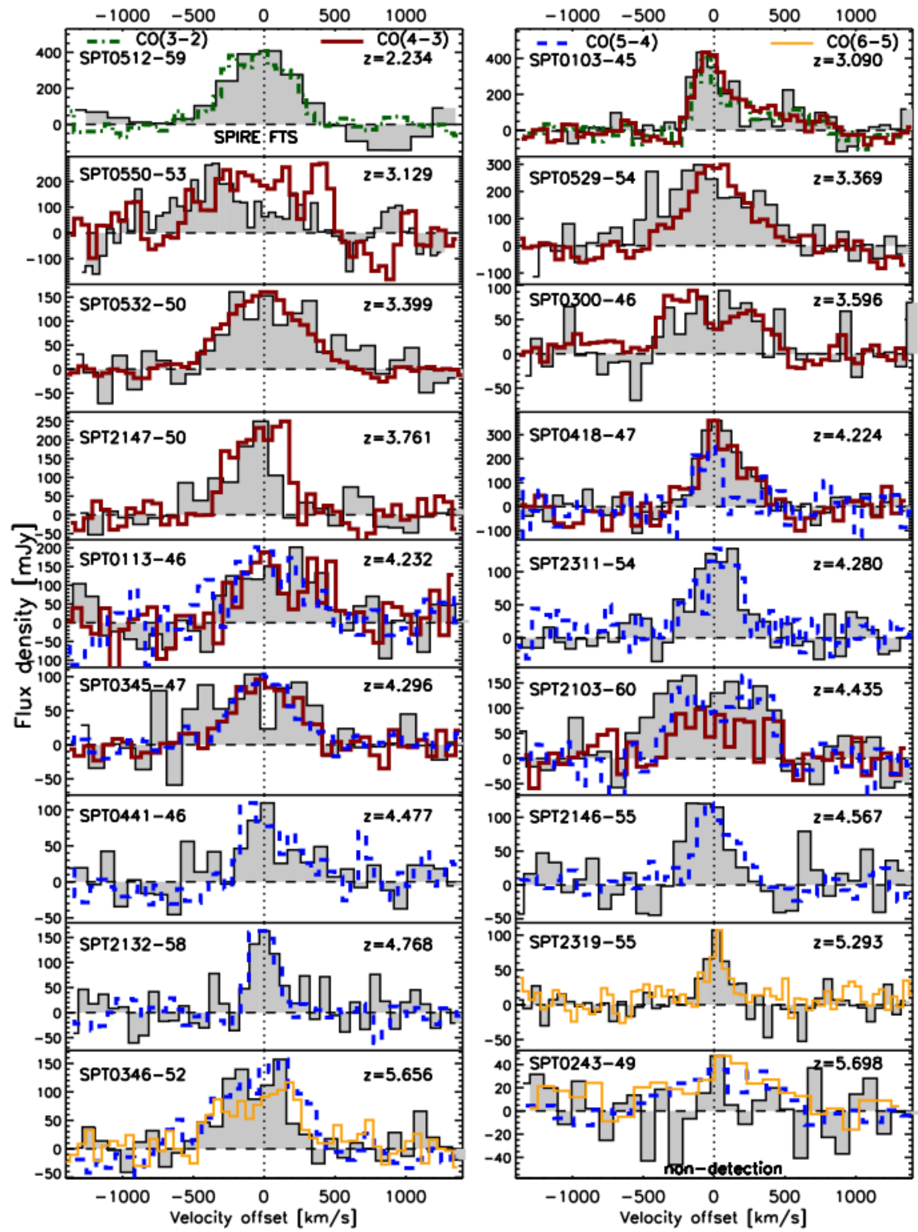
~60 sources studied over the last 4 ALMA Cycles; 10 min per band per source







Strandet+16



Gullberg+15; also a Cy4 [N II] program

What can wSMA do?

SMA:

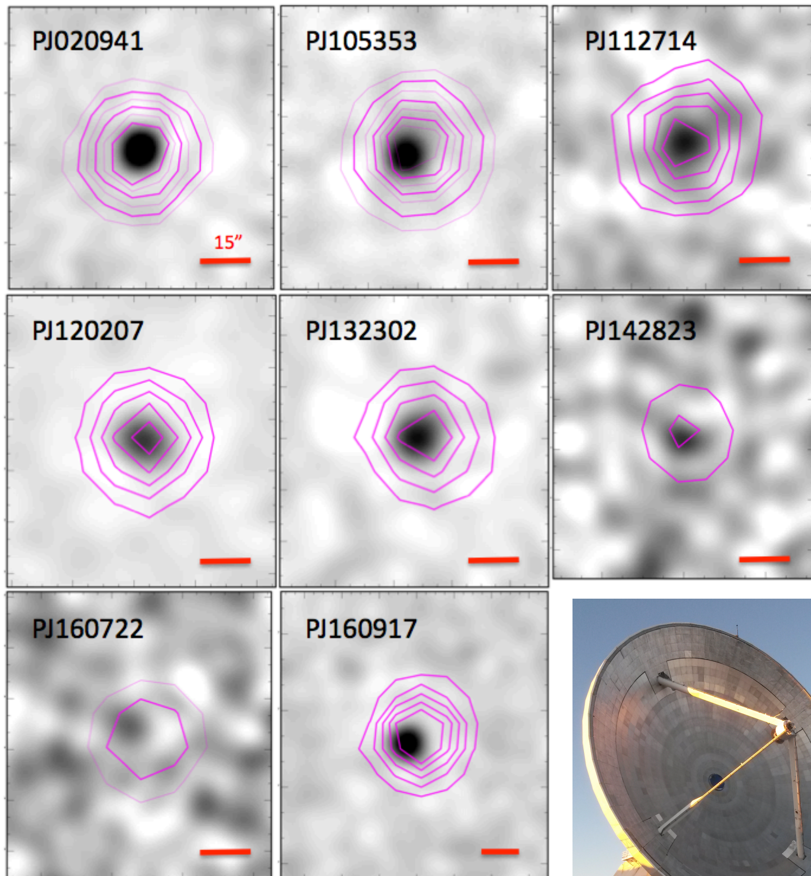
- 25 times smaller collecting area as ALMA
- Needs to integrate 3-6 hrs per source for good imaging

→ need to find sources 25/6=4.2 times brighter sources to do the same type of analysis (no need to spectral scan if redshift known, but needs spectral bandwidth and sub-bands)

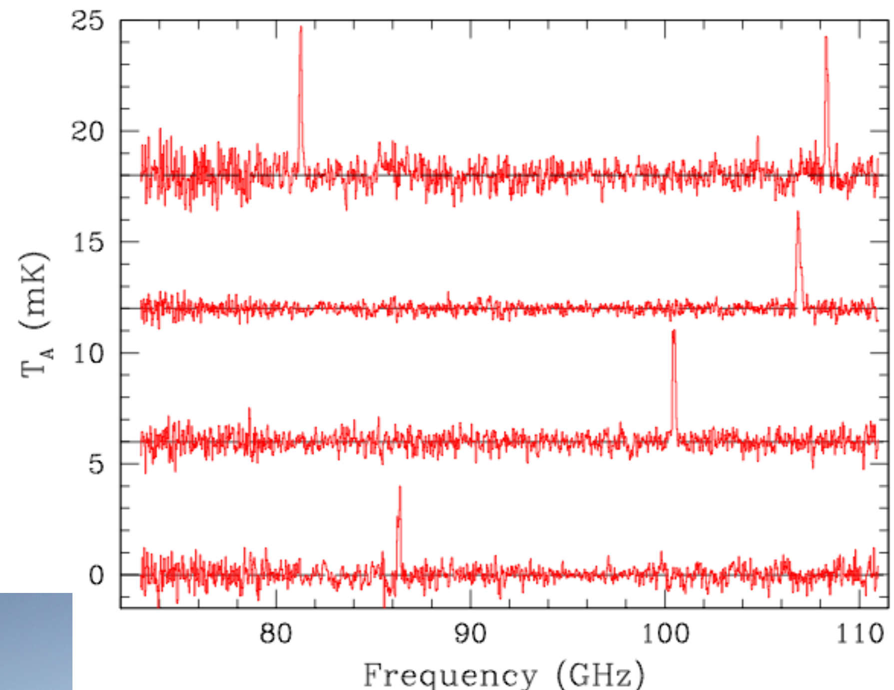
LMT Study of High-z Planck Sources

Harrington et al. (2016)

SPIRE 350um on AzTEC

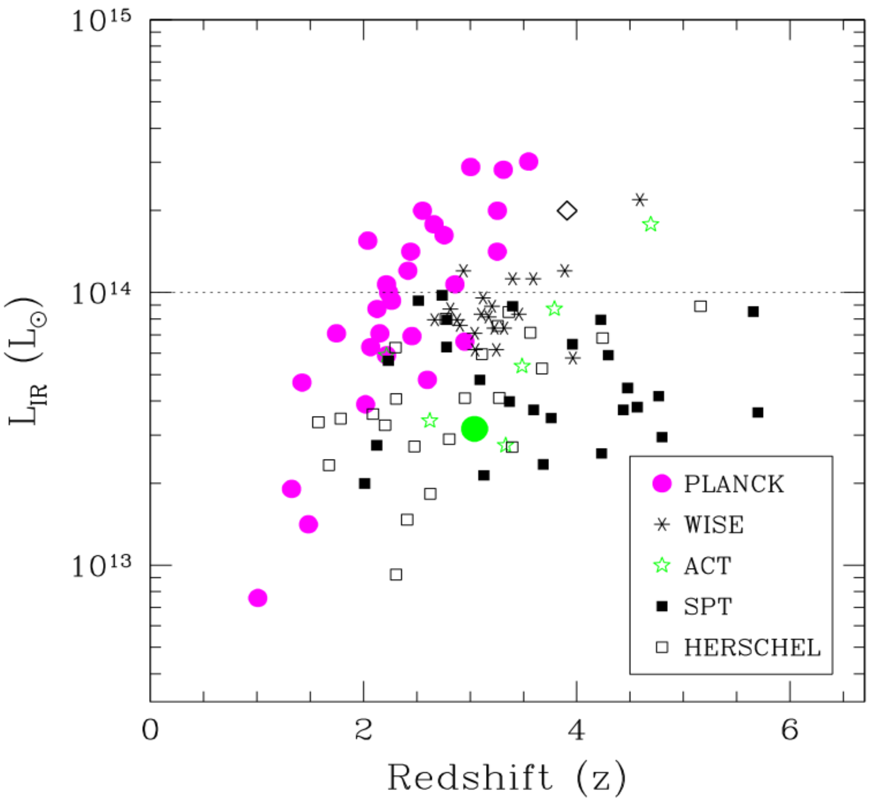


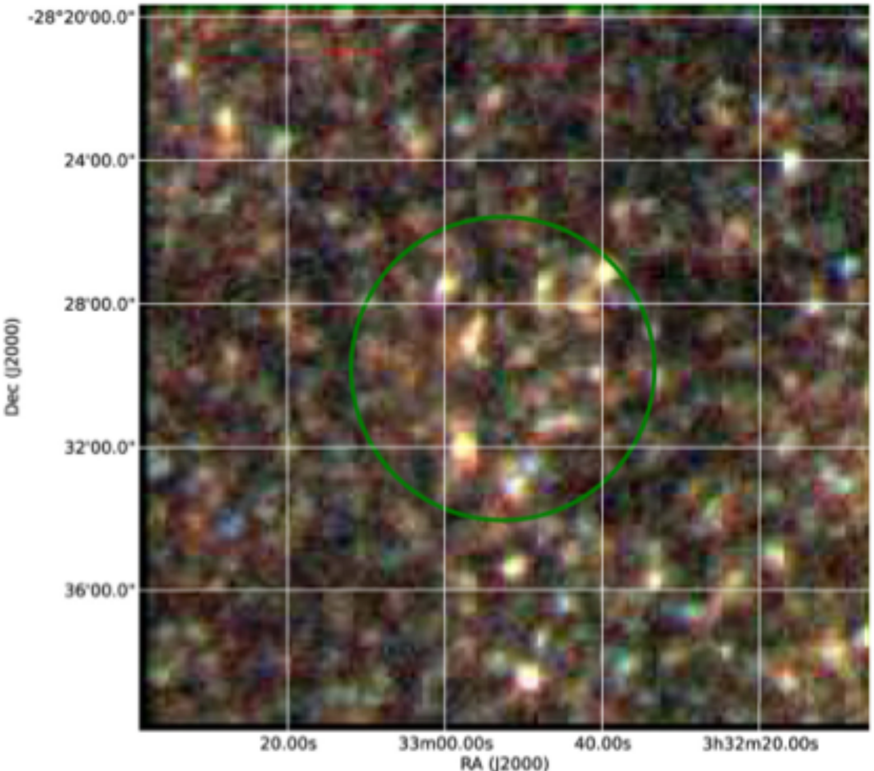
FWHM ~ 8" (3-20 minutes integration)



One or more CO line detected in 8/8 sources observed (15 to 30 minutes per source)

Planck-selected SMGs

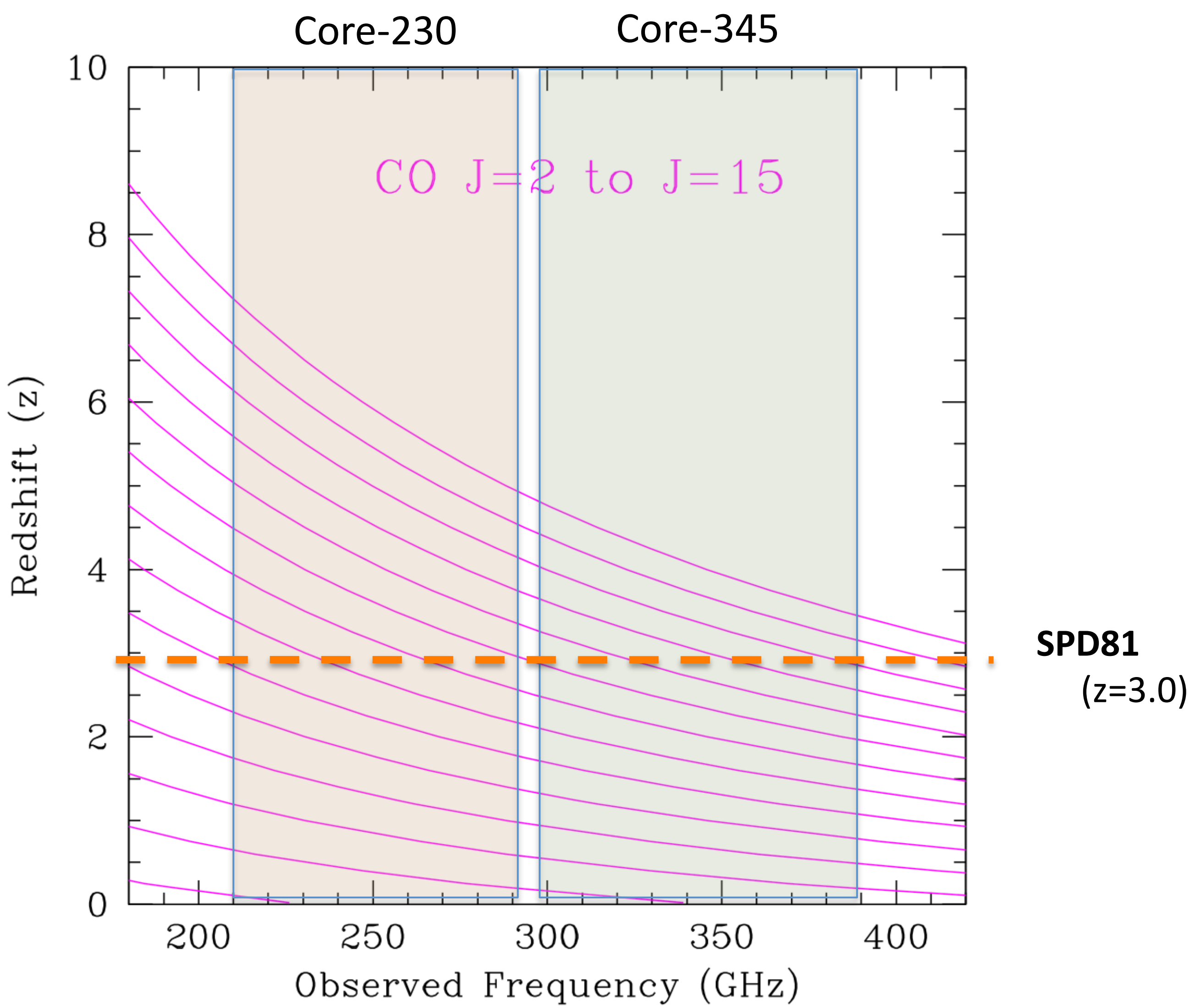




Clements+14

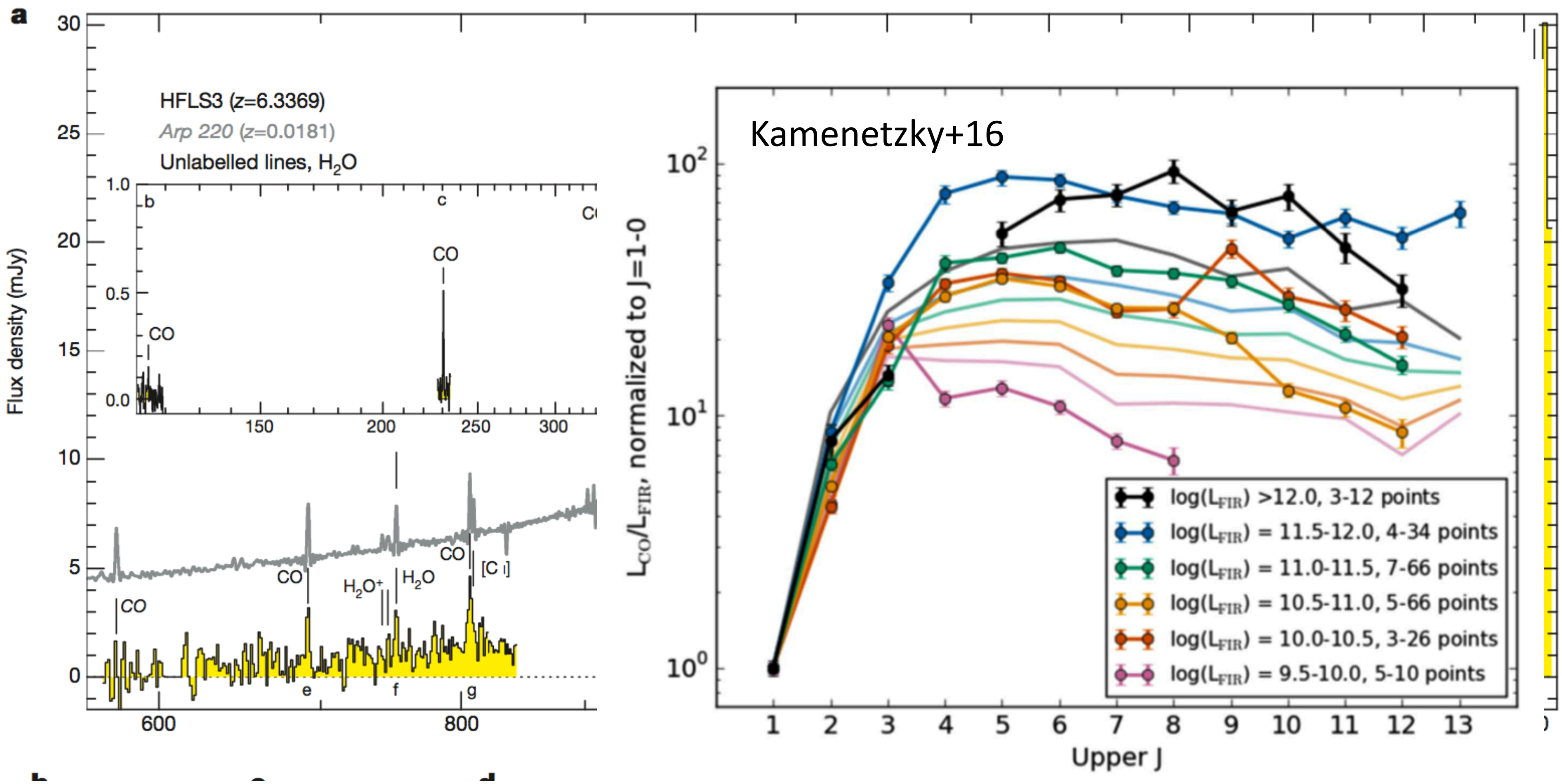
- Up to 31 high-z Planck sources identified using LMT so far
- Evidence for gravitational lensing, including by a cluster potential, in many cases
- Also some high-z protoclusters (e.g., Clements+14)?

CO Lines Accessible to the wSMA



CO Lines Accessible to the wSMA

Riechers+13

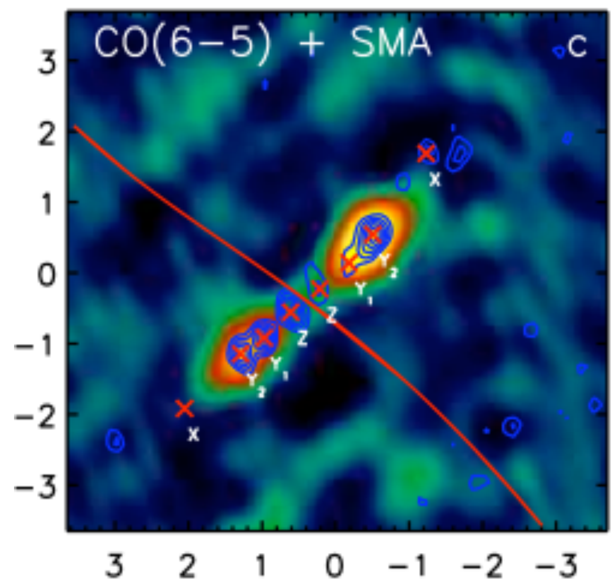


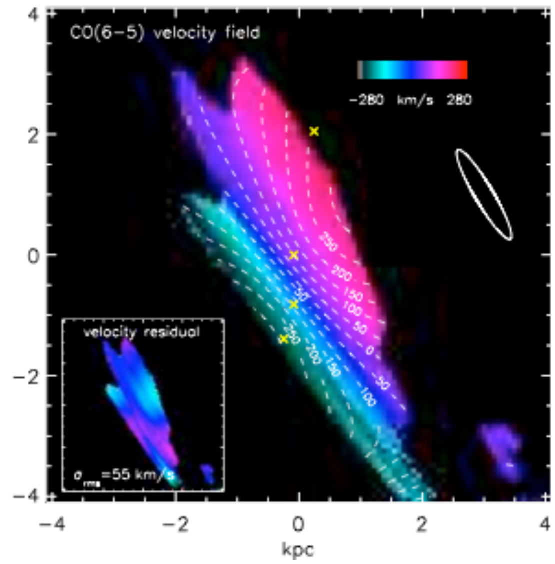
HFLS3 at z=6.3: CO ladders up to J=10-9 and multitudes of FIR lines

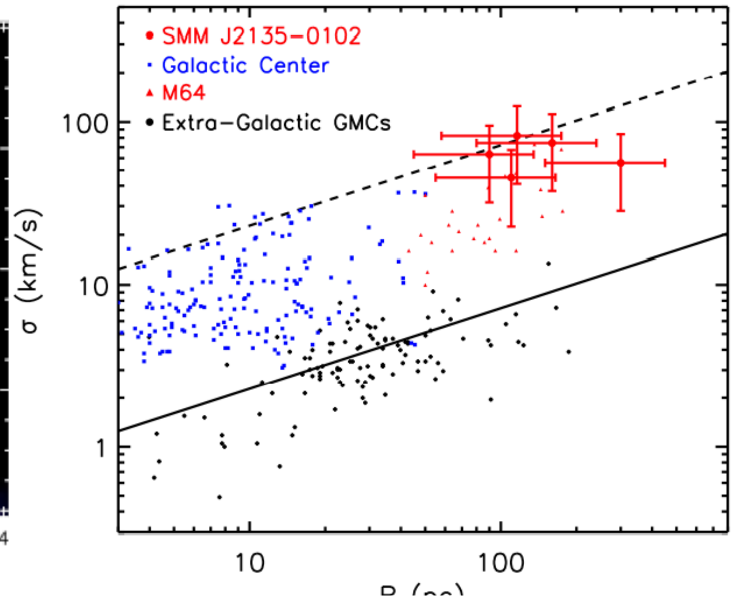
Herschel: CO SLED flat out to J=13 lines (Kamenetzky+16)

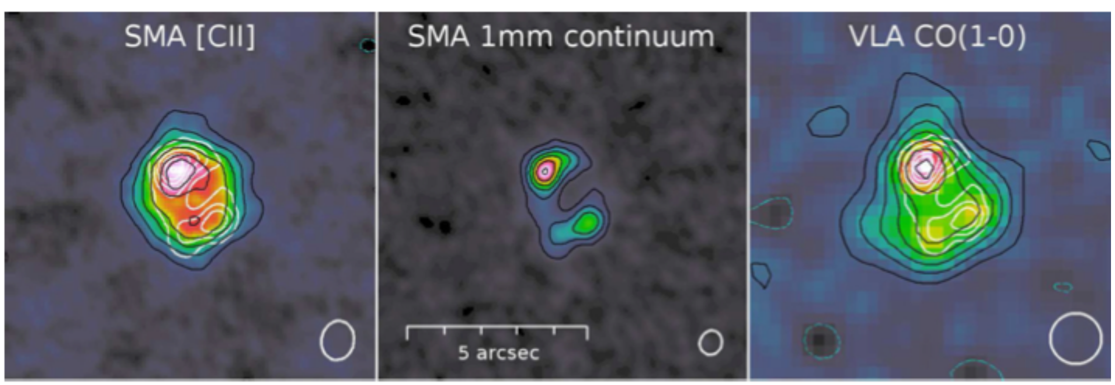
SMA Successes with Lensing

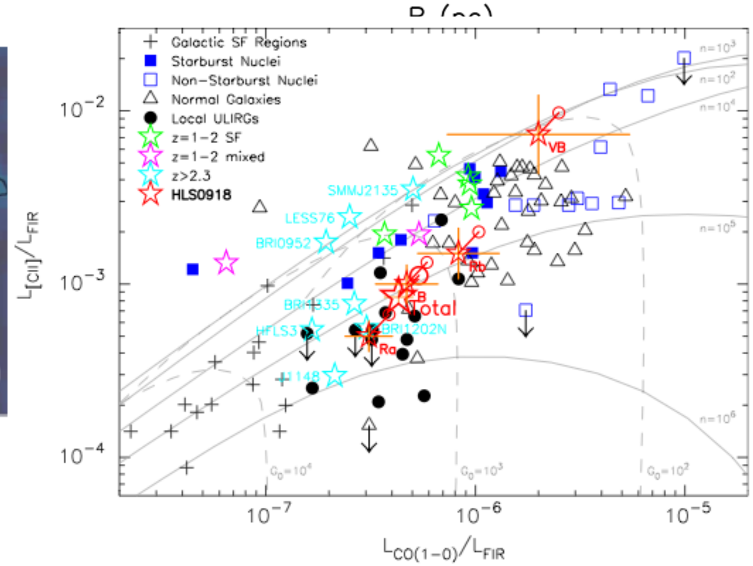
*Swinbank et al. (*2011)









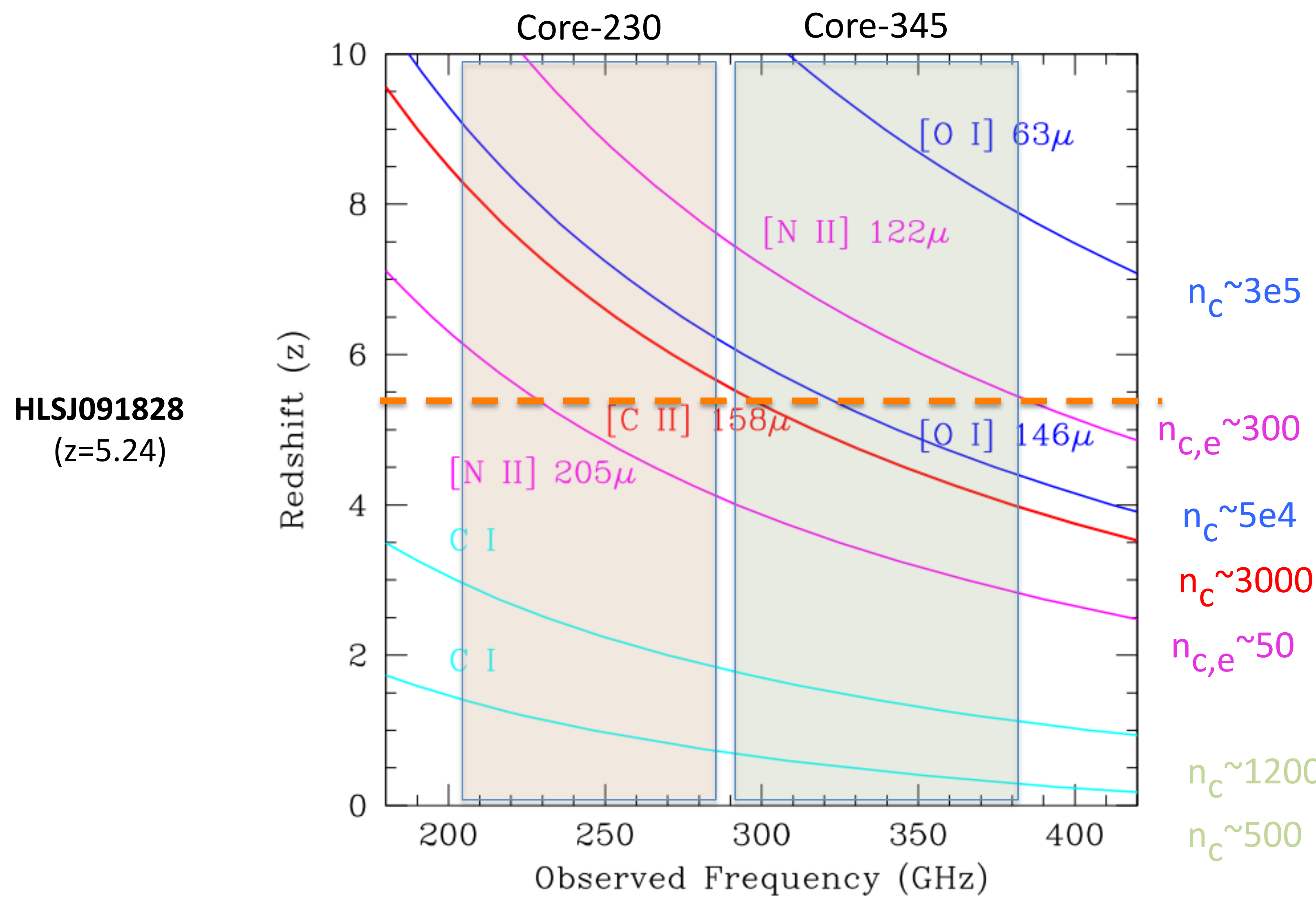


HLSJ091828

(z=5.24)

*Rawle et al. (*2014)

FIR Lines Accessible to the wSMA

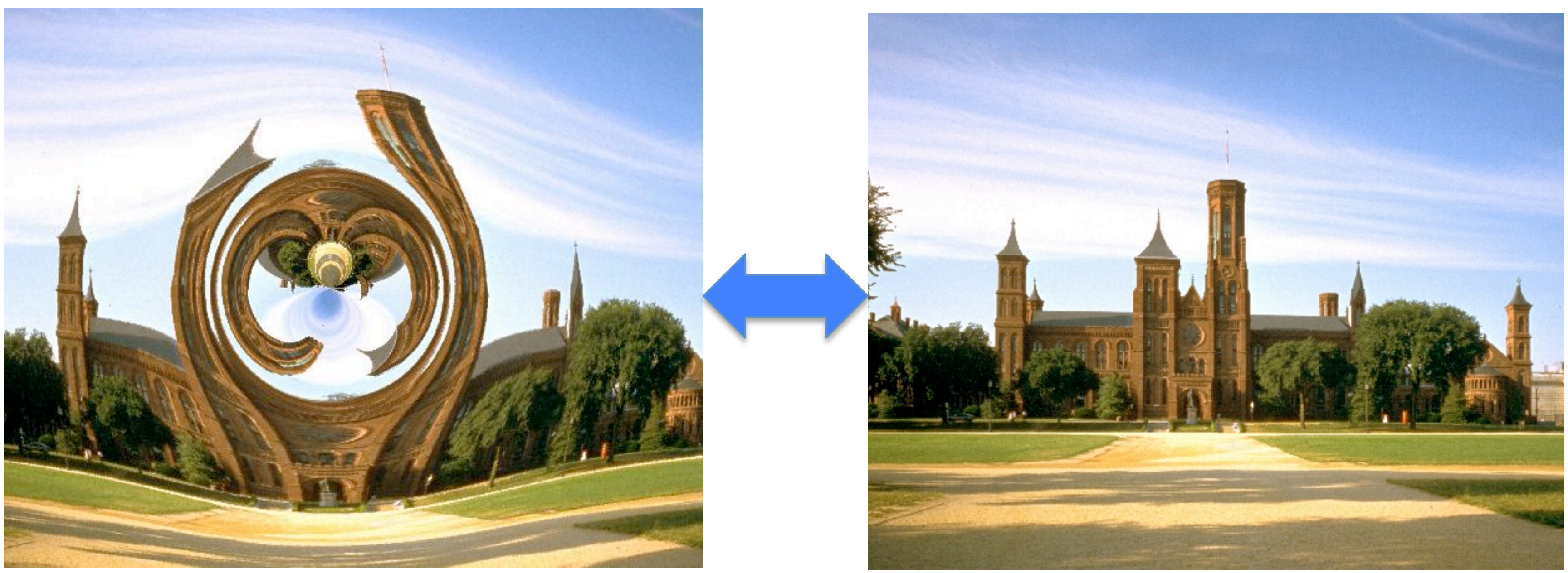


Search For "Golden Lenses"

NOT ALL LENSES ARE EQUAL ....

Lessons learned:

- need sufficient sensitivity (extremely bright sources)
- need a good lens model (e.g., Serjeant 2012)



What you could do with 1000 hrs of wSMA

1. Derive source sizes and geometry for 100+ strongly lensed SMGs and ULIRGs
2. Map gas excitation over 0.1-10kpc regions using CO SLED and FIR fine structure lines
3. Identify the best “golden lenses” for detailed investigations of gas distribution and kinematics, Kennicutt-Schmidt law, merger-origin, AGN activities, etc. down to 10’s of parsec scales

LMT-TolTEC Public Surveys

- Target field selection
  - Availability of deep multi-wavelength data
    - Counterpart identification (HST, JWST, radio, X-ray etc.)
    - Redshift information (photo-z and spec-z)
  - Size of each survey field
    - Cosmic variance
    - Large scale structure and clustering analysis
- Overlap with ALMA? Or unique Northern fields?

Community Workshops are coming.....

Sign-up: http://toltec.astro.umass.edu