High Resolution SMA Imaging of Gravitationally Lensed ULIRGs at $z > 2$ Discovered by *Herschel*

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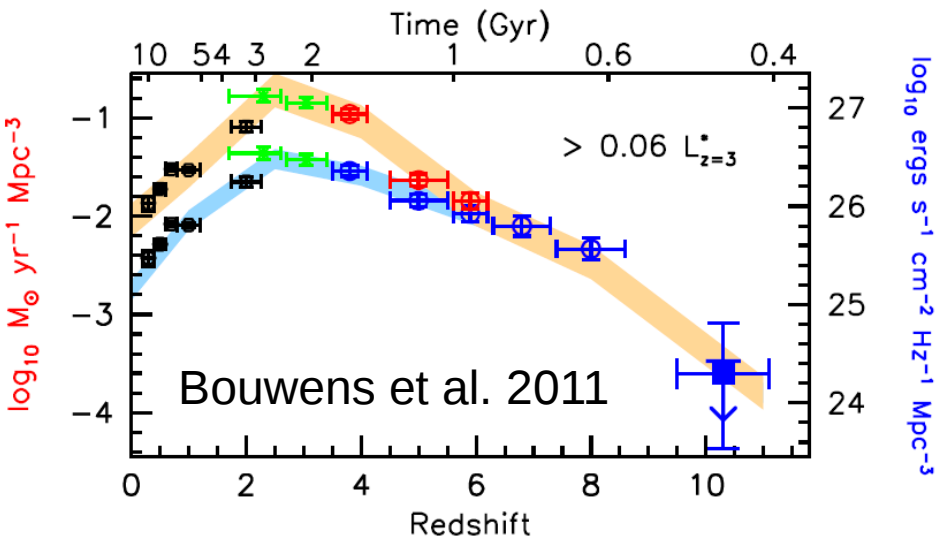
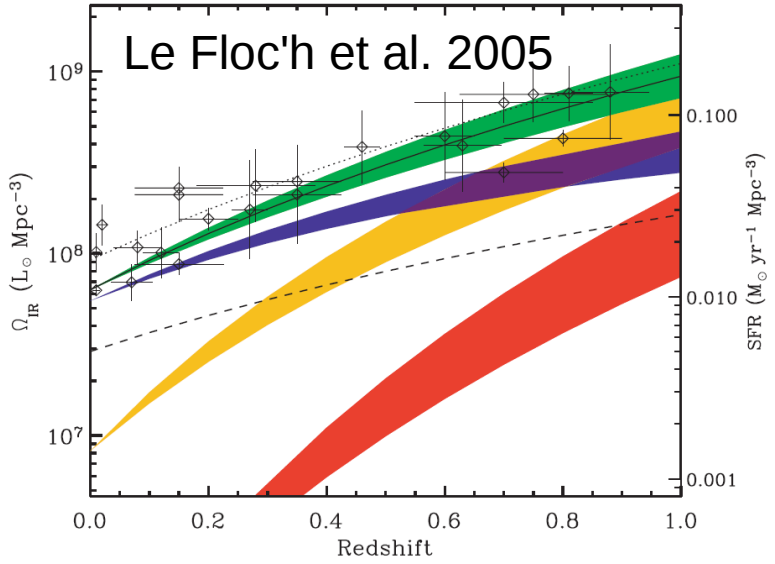
SMA Community Day – 7/11/2011

The Cosmic History of Star-Formation

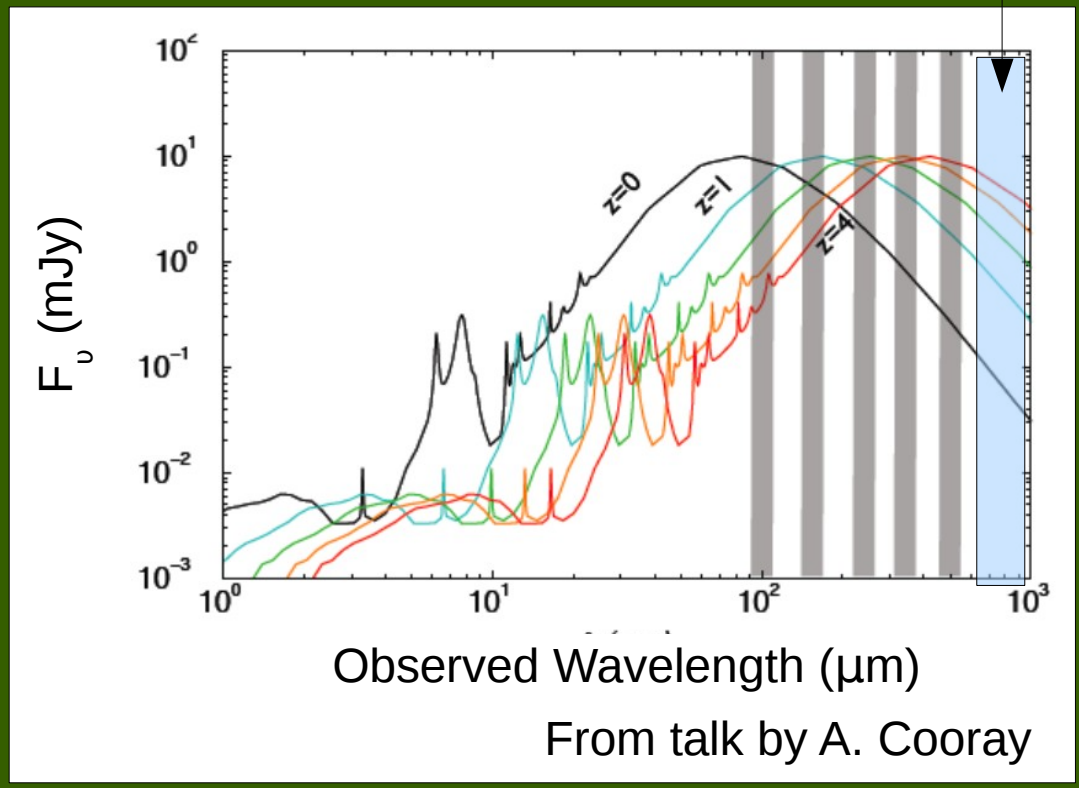
- SFR density peaks at z~2-4
- At z~2-4, obscured SF dominates un-obscured SF by 10x
- ULIRGs increasingly important at higher z





Finding Dusty Galaxies at z~2-4: Ground-based Sub-mm Surveys

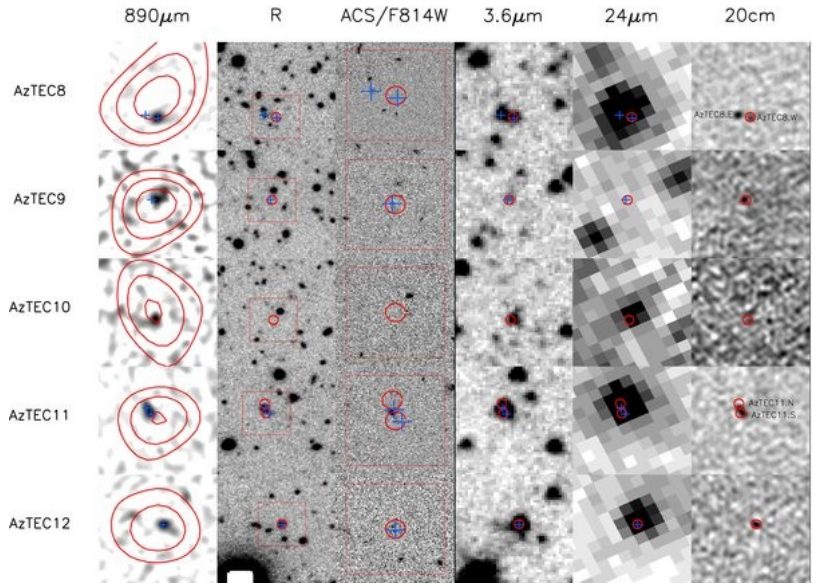
- Negative K-correction: At given L_{IR}, sub-mm flux independent of z
- Biased towards cold-dust objects
- Limited to small areas (~0.5 deg^2), sample sizes of hundreds, mostly “faint” sources ($F_{870\mu m}$ ~ 8 mJy)



From talk by A. Cooray

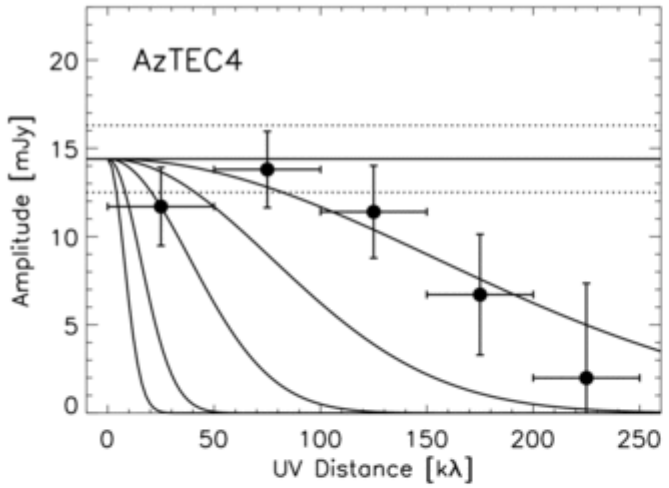
SMG: ULIRG at z>1 discovered in sub-mm surveys

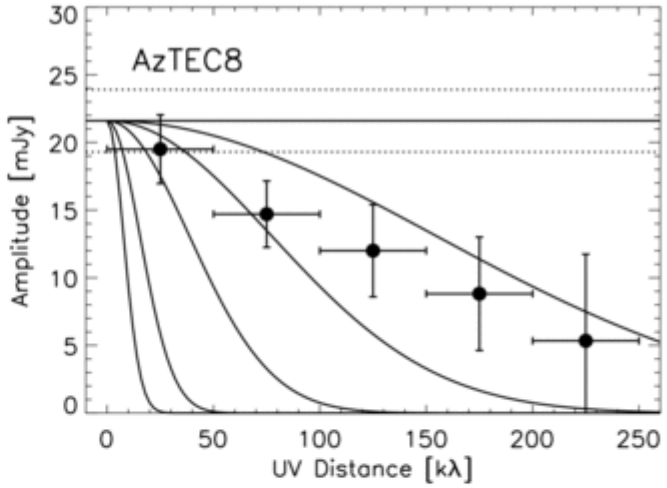
SMA Follow-up



- Accurate positions / component identification
- Resolving size-scale of FIR emission

  --> Eddington-limited starbursts!





Younger et al. 2007, 2008, 2009, 2010

Herschel: A Better Way

Wide-field surveys with Herschel (PACS+SPIRE)

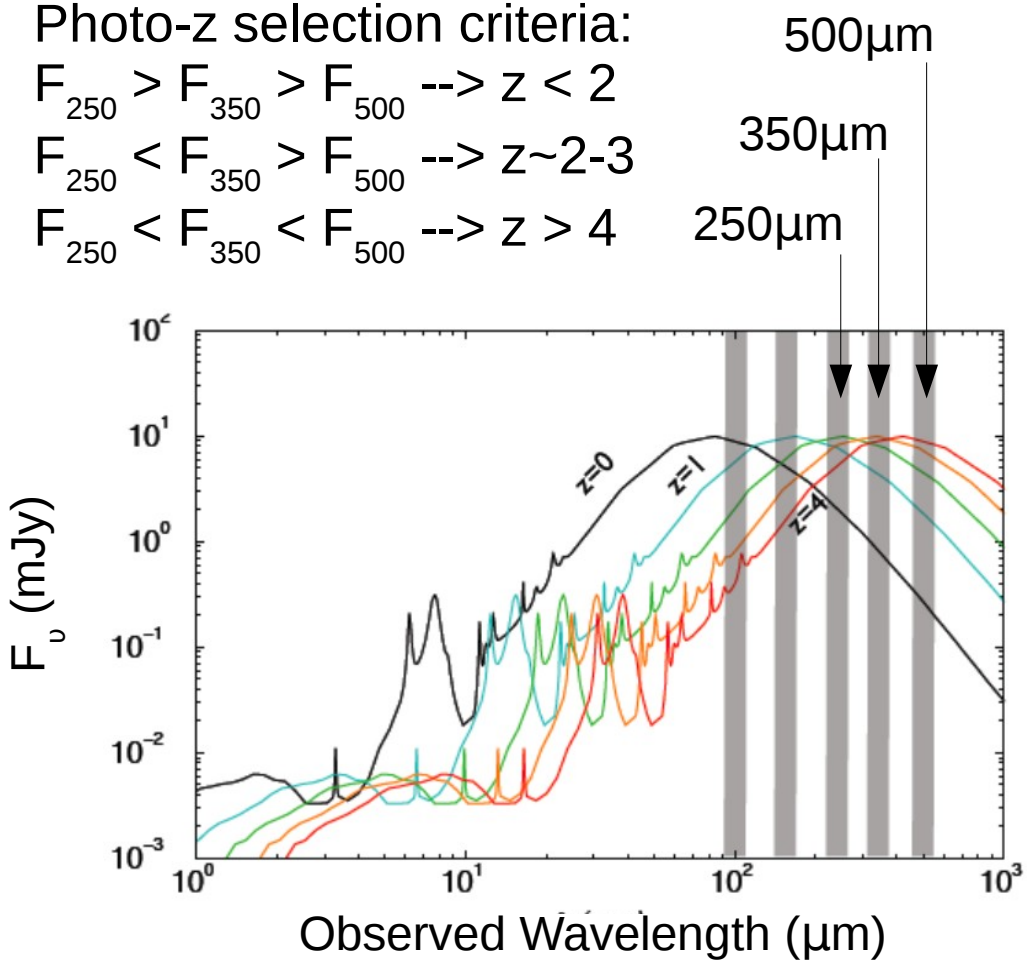
- HerMES: 70 deg^2, 850 hours (GTO)
- H-ATLAS: 550 deg^2, 600 hours (GO Key program)

Photo-z selection criteria:

$F_{250} > F_{350} > F_{500}$ --> z < 2

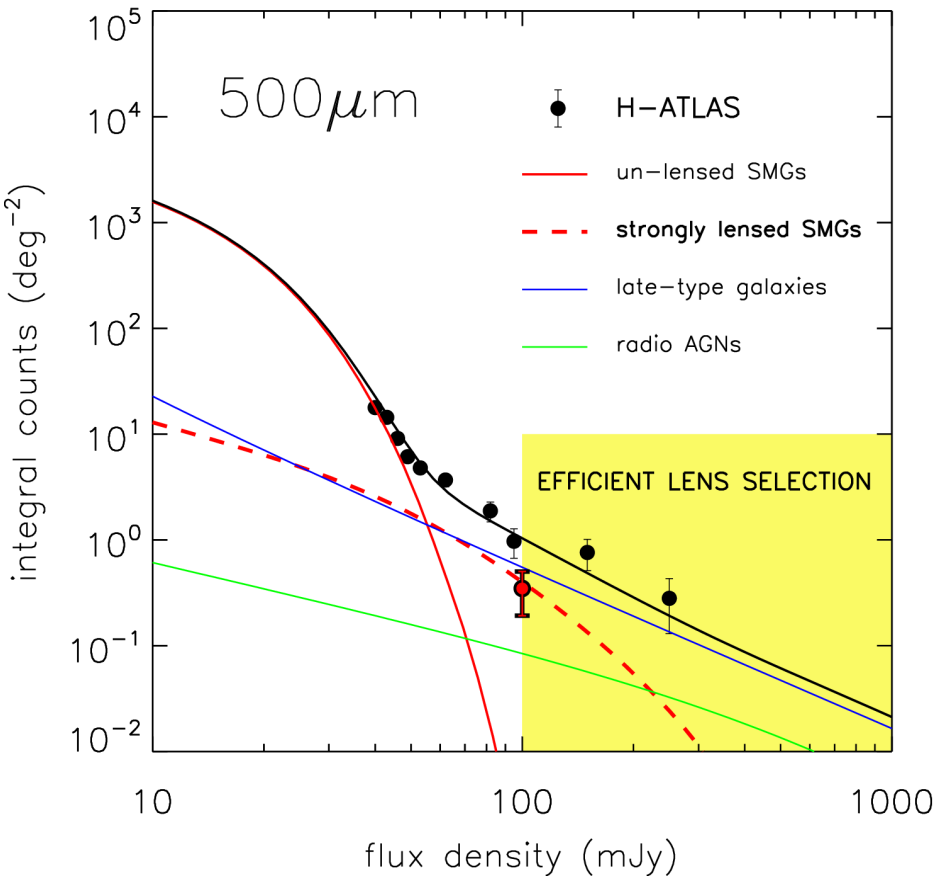
$F_{250} < F_{350} > F_{500}$ --> z~2-3

$F_{250} < F_{350} < F_{500}$ --> z > 4



From talk by A. Cooray

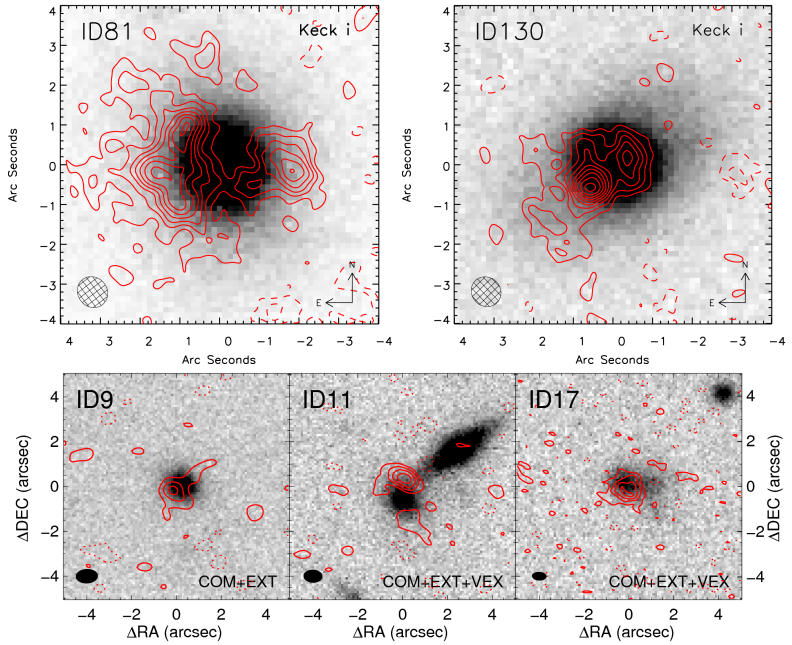
Discovery of Candidate Lensed SMGs



Negrello et al. 2010

- >100 candidate lenses in HerMES and H-ATLAS fields after removing low-z interlopers
- Surface density on sky ~0.5 deg^{-2}

SMA Imaging: The Importance of High Resolution



SMA 870μm contours overlaid on Keck i-band imaging. ID81 and ID130 from Negrello et al. 2010. ID9, ID11, and ID17 from Bussmann et al., in prep.

- Negrello et al. 2010: Initial sample of targets selected from Science Demonstration Phase: 2/5 show convincing evidence of lensing
- Bussmann et al. in prep: remaining 3/5 show strong evidence for lensing

Goals of Lensing Study

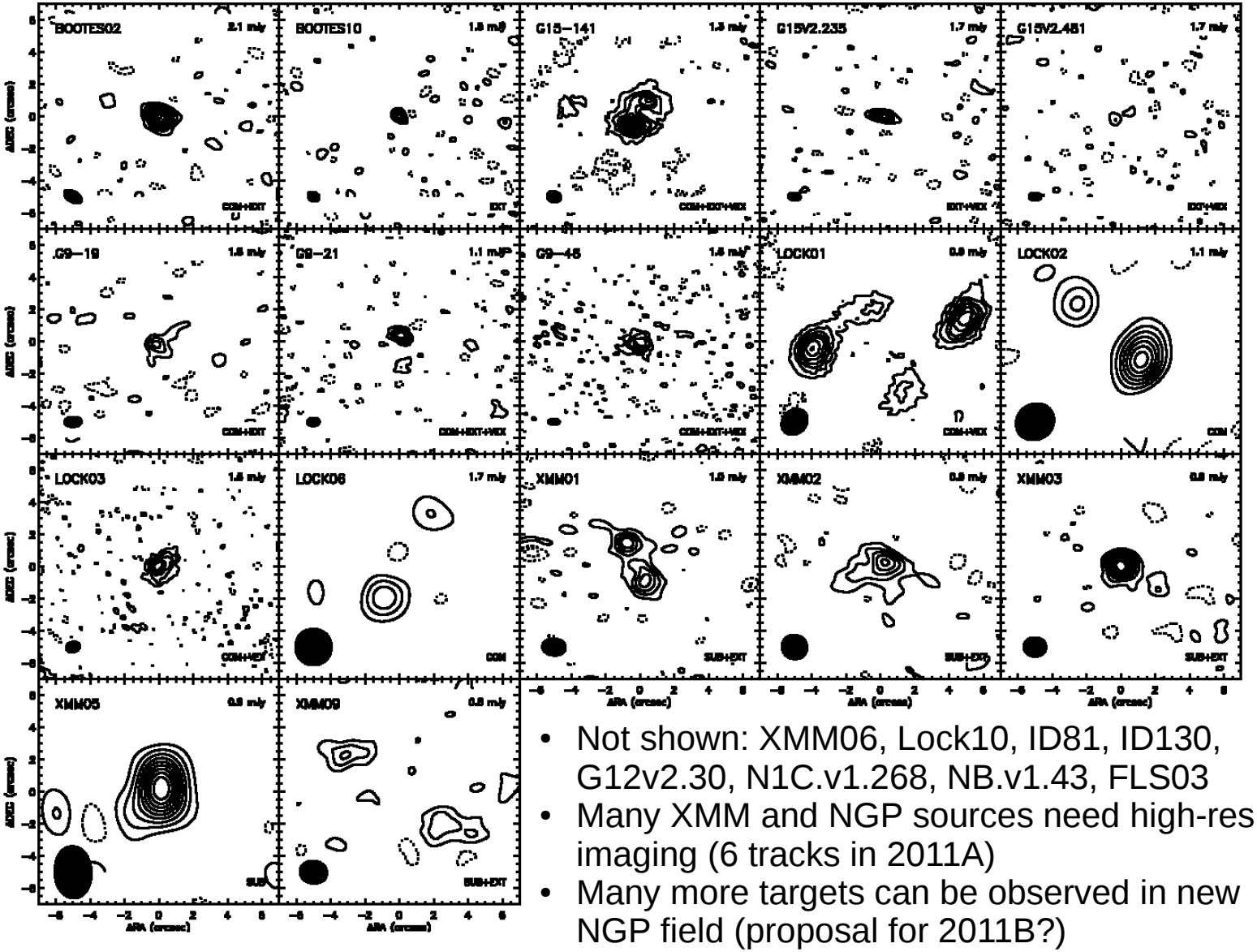
- Target sample size: ~20 (depends on remaining tracks in semester 2011A)
- Magnifications for ~20 ULIRGs at z~2-4
- Mass measurements for ~20 elliptical galaxies at z~0.2-1.0
- Compare SMA/HST imaging: dust/stars + improved constraints on M/L profile of lens
- Compare SMA/PdBI or SMA/CARMA imaging: dust/gas at ~0.3" res
- [CII] kinematics: cooling in z>4 ULIRGs

Current Status of SMA Imaging

Observing Semester	Tracks	Sources Detected	Papers
2009B	1	2	Conley+, Riechers+, Scott+, Gavazzi+, submitted
2010A	3	2	Negrello+ 2010, Hopwood+ 2011
	1	1	Cox+, submitted, Bussmann+, in prep.
	5	6	Wardlow+, in prep.
2010B	5	8	Bussmann+, Wardlow+, in prep.
2011A	2/6	3	Bussmann+, in prep.
Total	17/21	22	

Additional 4 tracks in queue for 2011A: Higher resolution imaging to improve lensing models!

Current Status of SMA Imaging



- Not shown: XMM06, Lock10, ID81, ID130, G12v2.30, N1C.v1.268, NB.v1.43, FLS03
- Many XMM and NGP sources need high-res imaging (6 tracks in 2011A)
- Many more targets can be observed in new NGP field (proposal for 2011B?)

G15-141: A Case Study

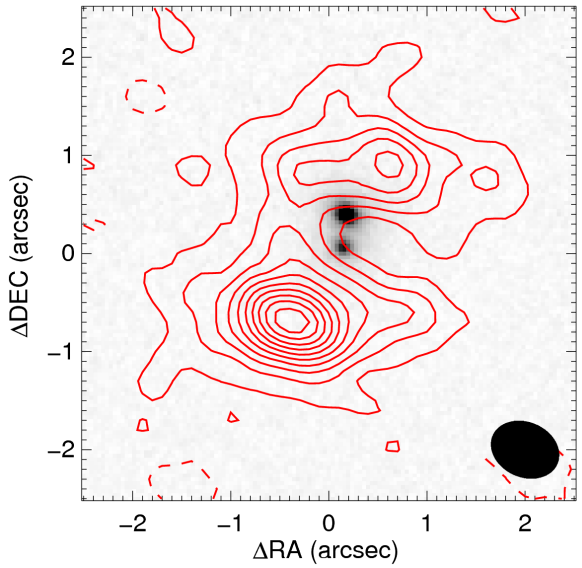
- Singular Isothermal Ellipsoid Lens Model
- z_{source} = 4.243 +/- 0.001
- z_{lens} = 0.7 +/- 0.2

- Constraints on magnification of background source and mass of foreground lens

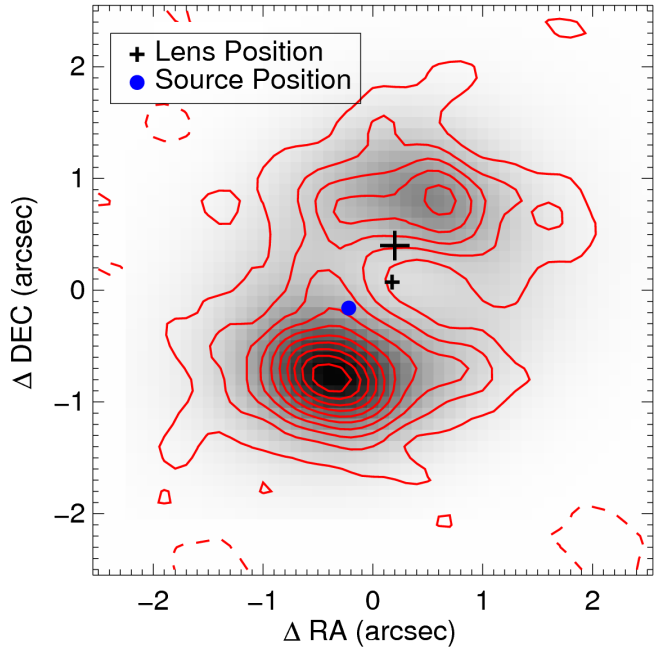
--> $\mu = 5.1^{+5.9}_{-1.8}$

--> $M_{lens} = 2.7 \times 10^{11} M_{sun}$

Keck AO K_s image + 870μm SMA contours



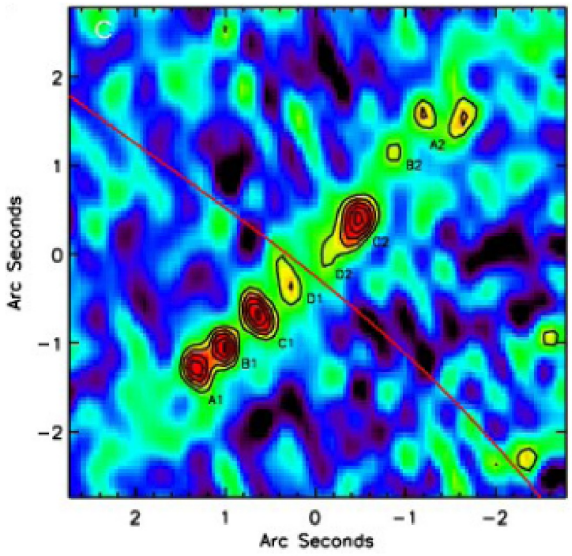
Simulated lensed image + 870μm SMA contours

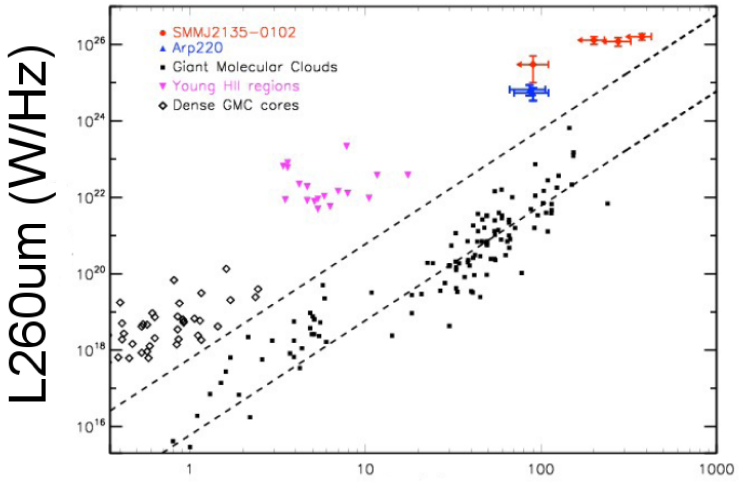


LENSMODEL: http://redfive.rutgers.edu/~keeton/gravlens

Probing GMCs at z>2

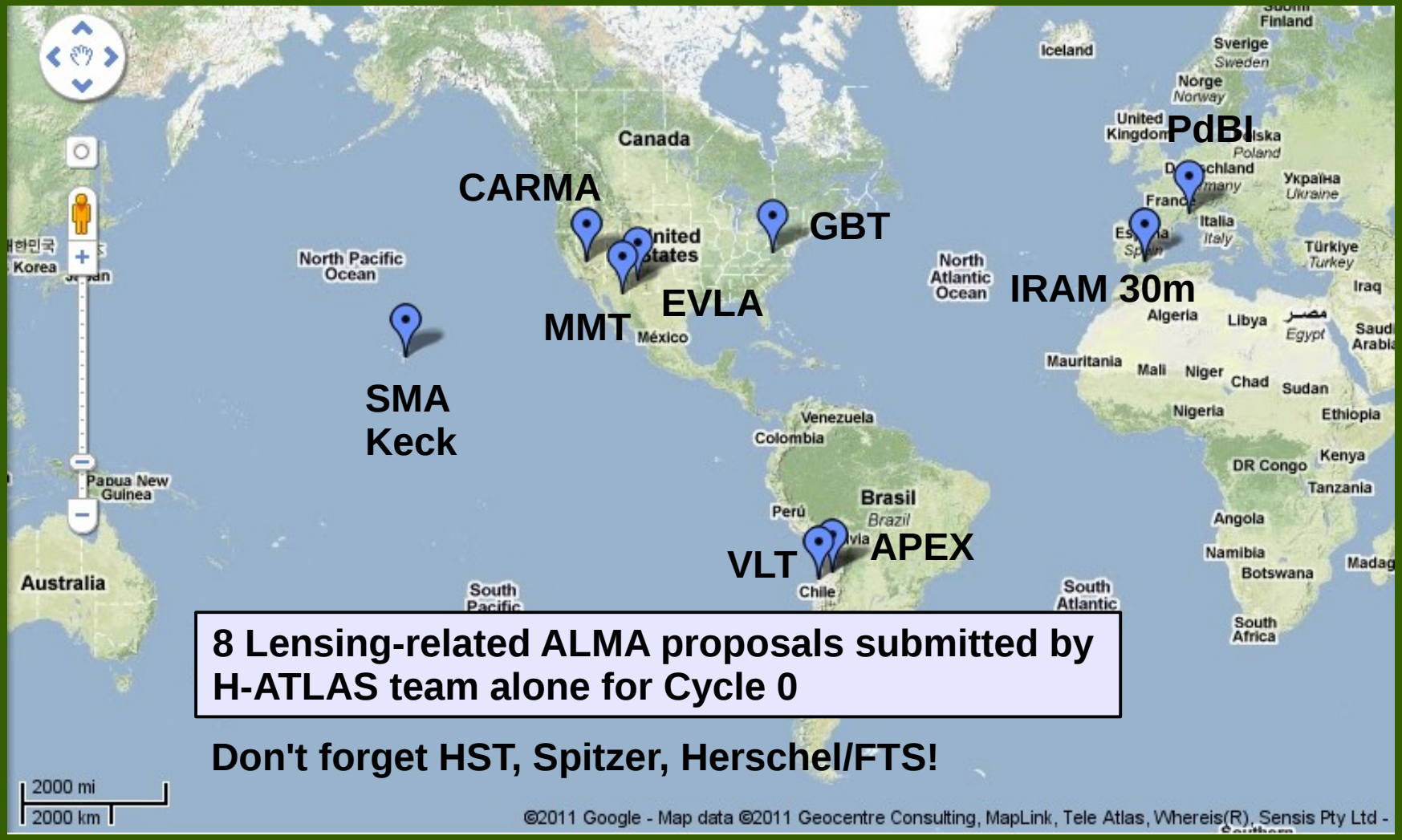
- High μ lensing can probe structure on ~100 pc scales
- Luminosity density in SMMJ2135-0132 comparable to the dense cores of GMCs in MWG, but on 100x larger scale → 10 million times more luminous!





Swinbank et al. 2010

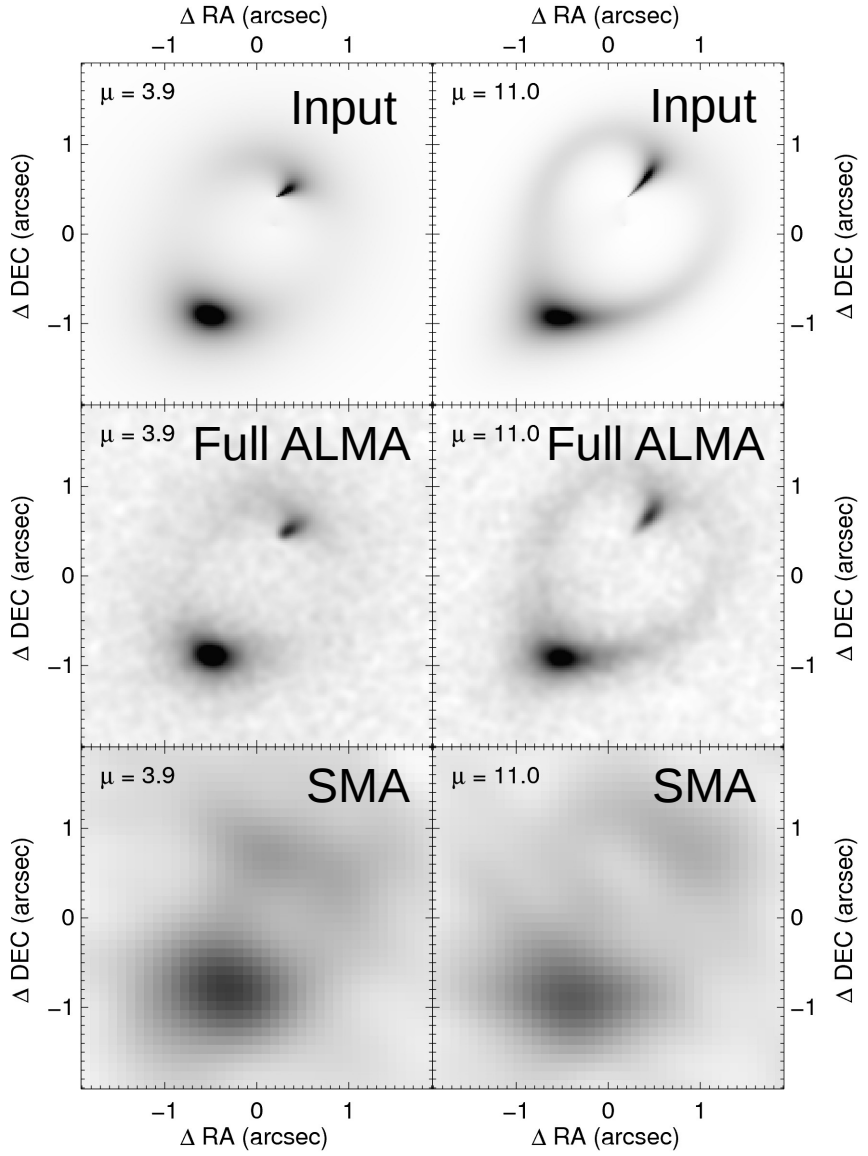
A Worldwide Follow-up Effort



8 Lensing-related ALMA proposals submitted by H-ATLAS team alone for Cycle 0

Don't forget HST, Spitzer, Herschel/FTS!

SMA and ALMA



SMA data can be used to motivate an ALMA proposal

- Example: SMA data constrain the magnification of a lensed ULIRG to be between 4 and 11
- ALMA Cycle 1 observations (full array of 50 antennas) can tighten constraints on the magnification

Conclusions

- >200 gravitational lens candidates discovered by Herschel
- The SMA is a leader in world-wide follow-up imaging of these objects
- Working towards measurements of lens masses and magnifications for ~20 ULIRGs at z>2

- Lens masses can be used to study dark matter in elliptical galaxies out to z~1
- Lensed ULIRGs offer potential to study obscured star-formation during the epoch of peak star-formation with unprecedented detail