ALMA: Prospects and First Results

October 27, 2012
Frontiers in Star Formation:
A Conference in Honor of Richard Larson
Yale University

Dominik A. Riechers (Cornell)

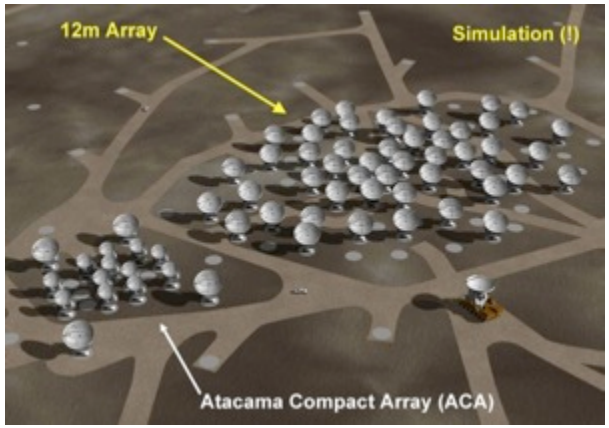
ALMA Basics

- Global partnership (shared cost ~$1.3 billion):
  - North America (US, Canada)
  - Europe (ESO)
  - East Asia (Japan, Taiwan)
  - In collaboration with Chile

- Unique high, dry site:
  5000m (16,500 ft) in Chilean Atacama desert

- At least 66 submillimeter/millimeter telescopes:
  - 12-m Array – 50 x 12-m
  - Atacama Compact Array (ACA) - 12x7-m, 4x12-m

- On budget and on time for completion in 2013

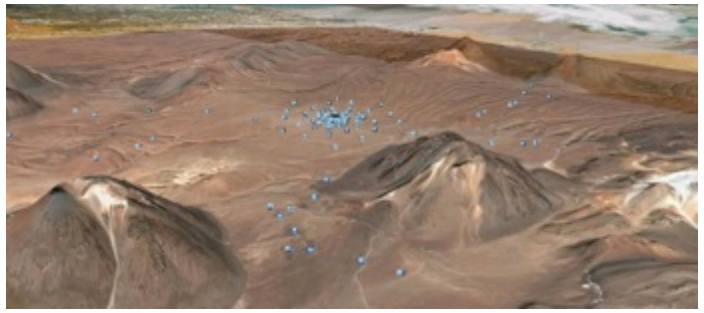


Full Science Capabilities

ALMA

10-100× better sensitivity and resolution than current mm arrays.

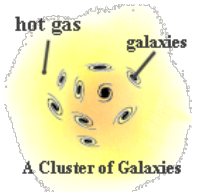
- Baselines to ~**15 km** (0.015" at 300 GHz) in "zoom lens" configurations
- Sensitive, precision imaging 84 to 950 GHz (3.6 mm to 315 μm)
- State-of-the-art low-noise, wide-band SIS receivers (8 GHz bandwidth per polarization)
- Flexible correlator with high spectral resolution at wide bandwidth
- Full polarization capabilities

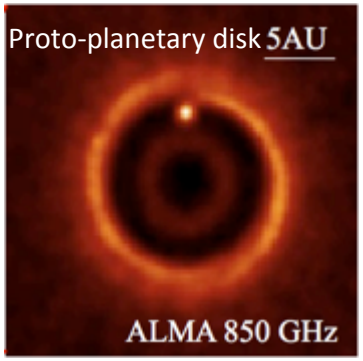


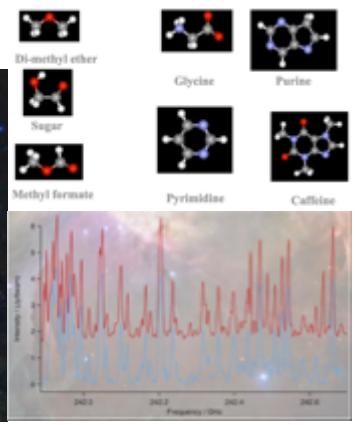
ALMA Science:

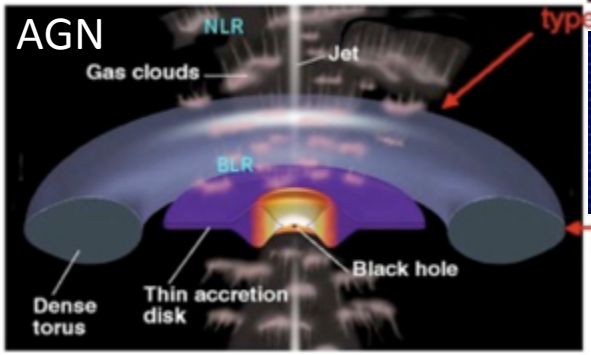
sharp, high fidelity (sub)mm imaging, dynamics & detailed spectroscopy

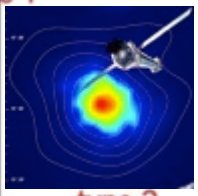
- Direct imaging, gas dynamics, dust grain growth in proto-planetary disks
- Detailed line spectroscopy of Galactic ISM: complex organic/pre-biotic molecules
- Imaging and gas dynamics of individual molecular clouds in nearby galaxies & AGN
- Imaging the star-forming material in distant galaxies out to z>6, 8, 10(?)
- Evolution of gas content of galaxies through cosmic time ("Deep Fields")
- Cosmology: Image Sunyaev-Zel'dovich (SZ) effect in galaxy clusters







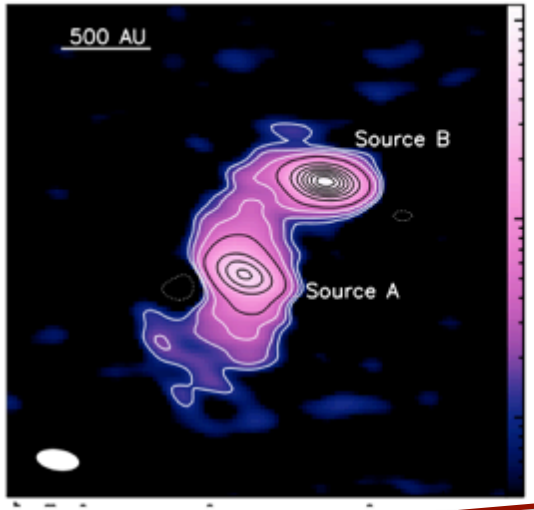


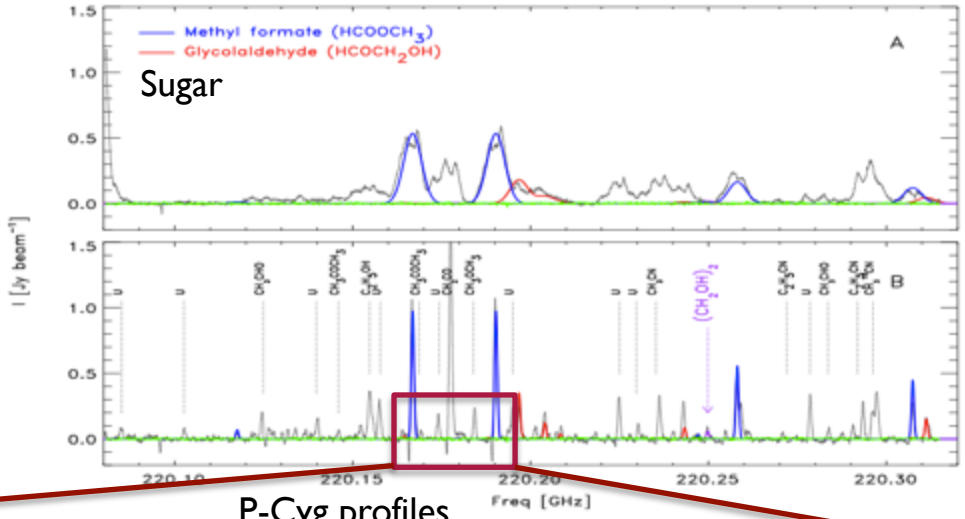


ALMA Images Proto-Binary: IRAS 16293-2422

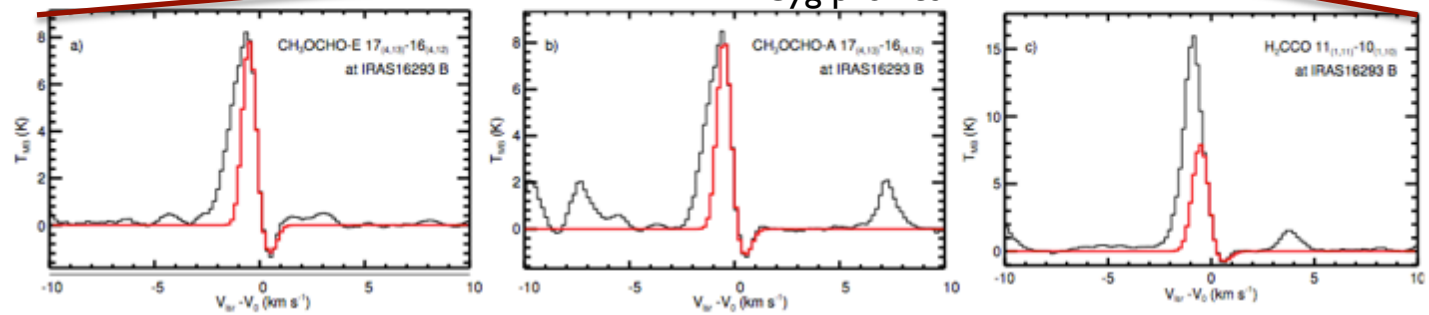
- 116293: hosts strong emission from complex organic molecules and other species associated with hot cores in massive SF regions
- Detect infall toward source B, detailed kinematics toward source A
- Detect simplest sugar Glycolaldehyde and its isomer

⇒ important pathway towards formation of complex bio-molecules





P-Cyg profiles



At 80 AU radius:

Supersonic infall velocity: 0.50±0.01km/s (c_s=0.32km/s @30K)

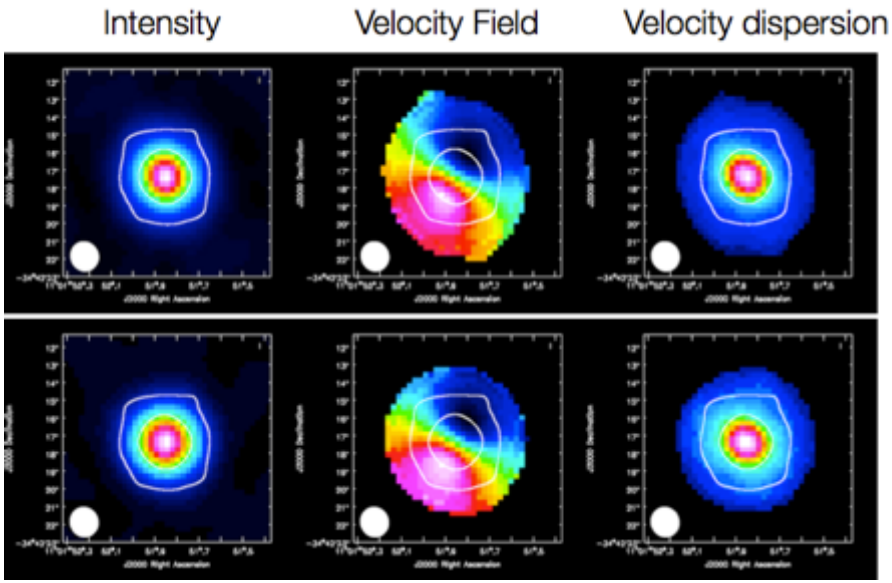
Infall rate: 4-5x10^{-5} $M_{sun}yr^{-1}$

Pineda ea. 2012
Jorgensen ea. 2012

ALMA Images Proto-Planetary Disks: TW Hya

- TW Hya: classical T Tauri star
  age: 10 Myr. distance: 51±4 pc. Actively accreting. opt. thick dust disk
- Deuterium fractionation: requires multiple pathways to deuterium enhancements in proto-planetary disks
- CO: high velocity wings (2.1 km/s projected, >20 km/s intrinsic), trace gas in to only ~2 AU from star

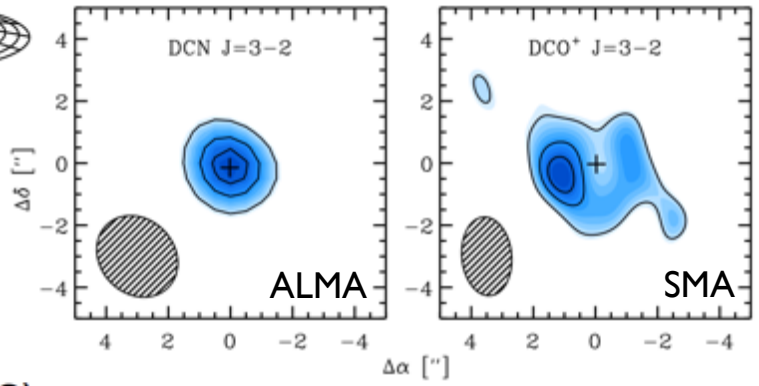
⇒ warped inner disk? in any case, significant amount of gas in inner region of disk with diminished dust optical depth



CO(3-2)

HCO+(4-3)

Deuterated HCN & HCO⁺



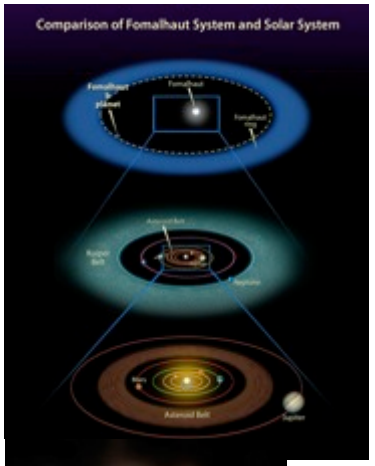
Oberg ea. 2012
Rosenfeld ea. 2012

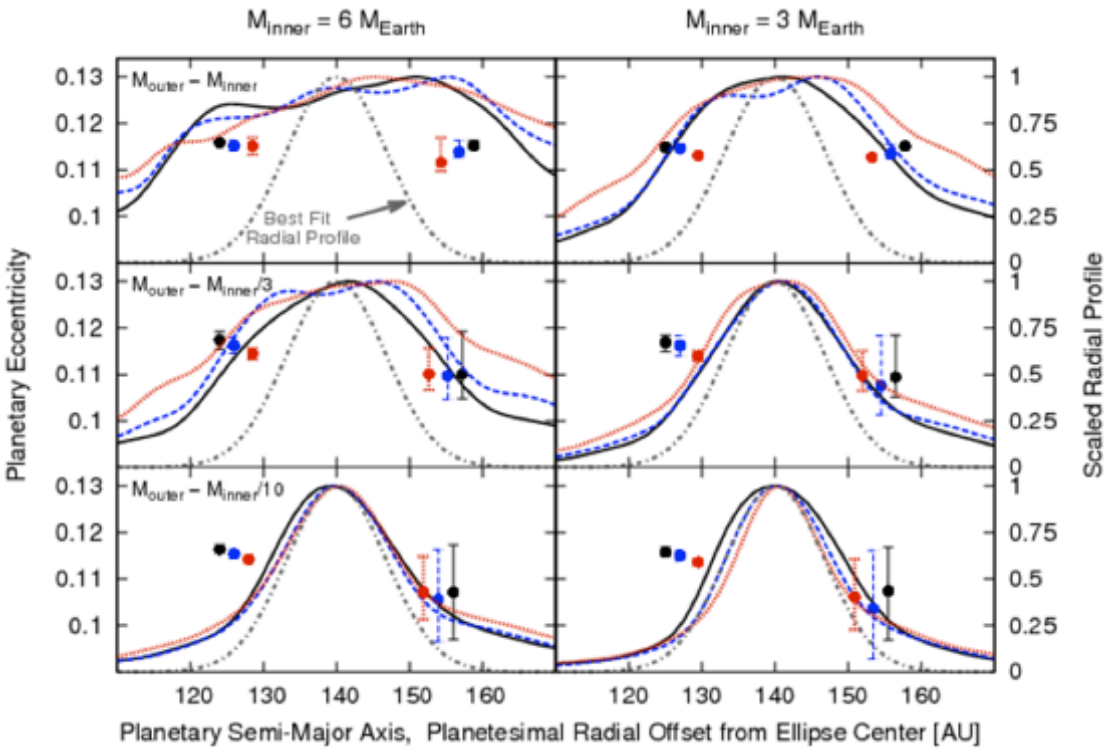
ALMA Images Debris Disks: Fomalhaut

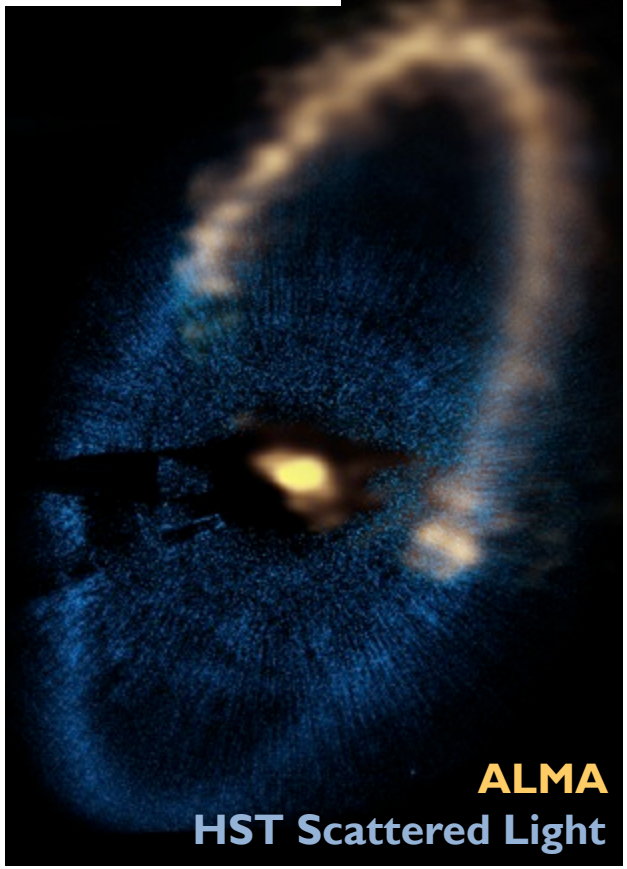
- mm-size grains trace parent body population

⇒ 13-19 AU wide, sharp boundaries

⇒ ring morphology consistent with confinement by two shepherd planets through angular momentum exchange



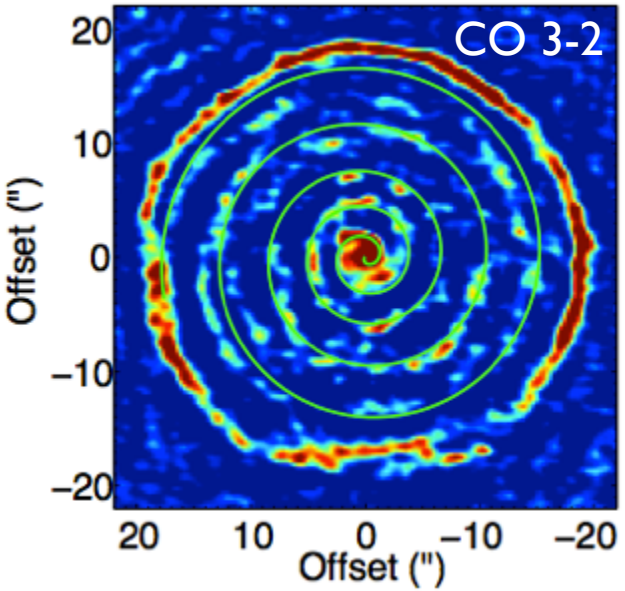


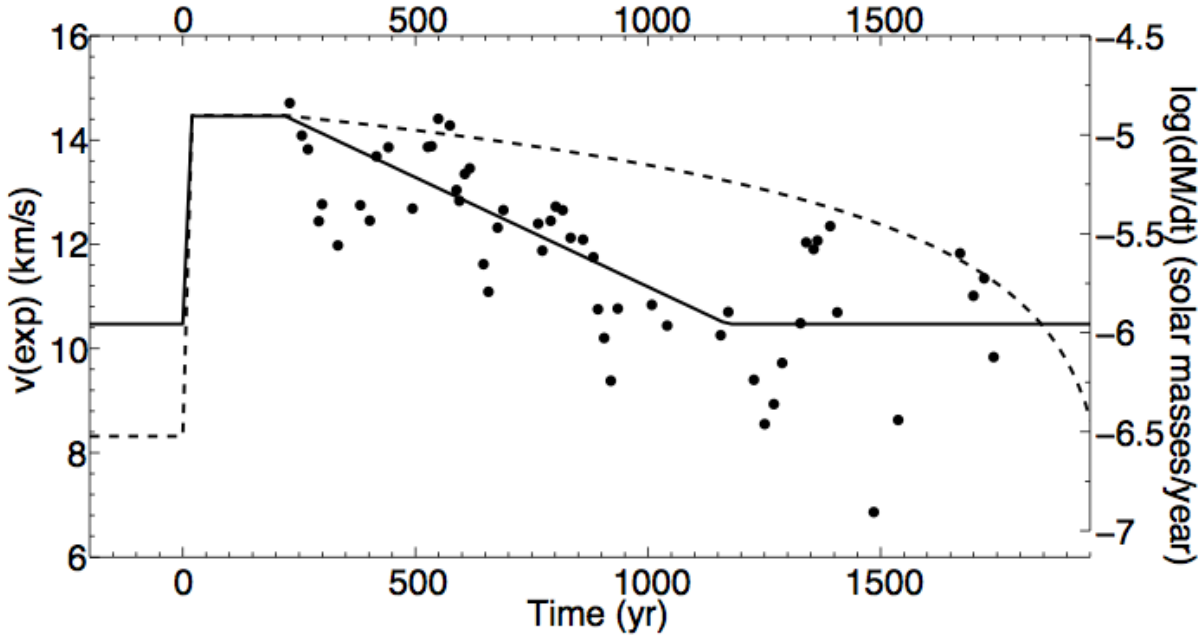


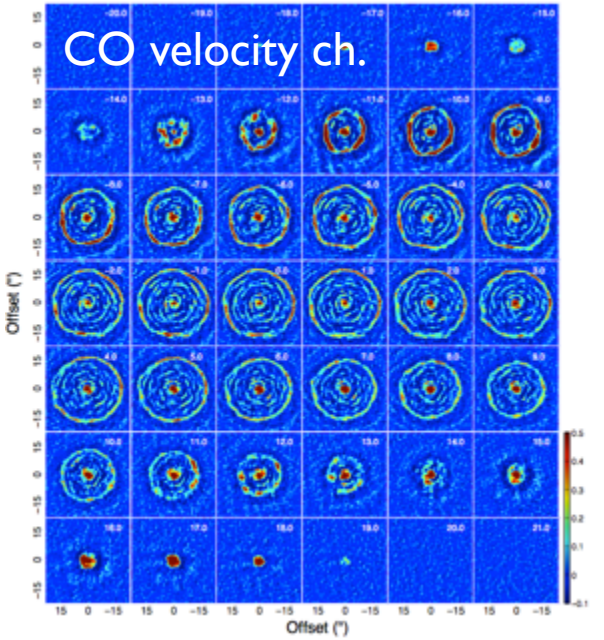
Boley ea. 2012

ALMA Images Evolved Stars: R Sculptoris

- AGB star with detached dust/gas shell
- Shell from thermal pulse 1800yr ago, lasted 200 yr, ejected $3 \times 10^{-3} M_{sun}$ @ v=14.3km/s, at 30x pre-pulse mass loss rate
- Shell has spiral structure, likely due to undetected binary companion



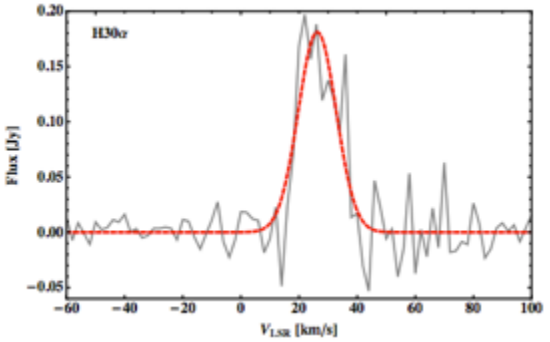




Maercker ea. 2012

ALMA Images Orion BN/KL

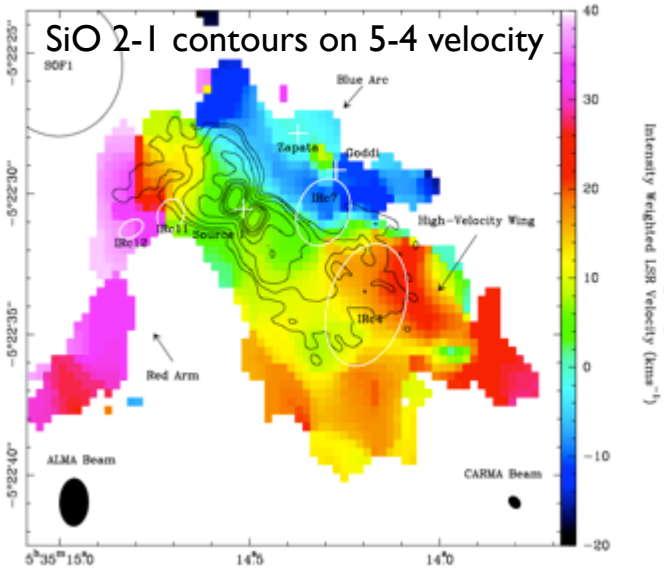
- analyzed so far: SiO, H_2O, Hα

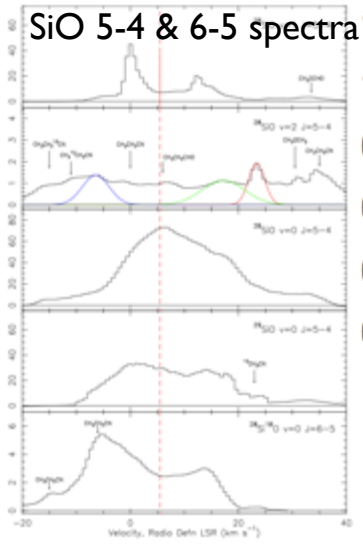


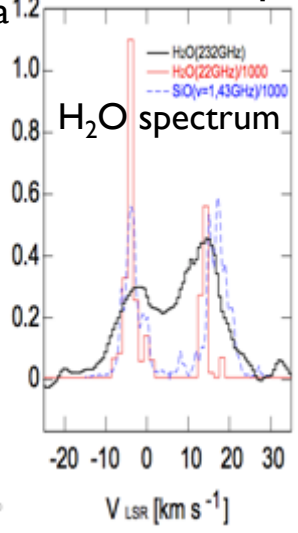
H30α recombination line Ori-BN
From dense, static base of ionized nebula around central massive star
⇒ Precise line-of-sight velocity of radio source BN (26.3±0.5km/s)

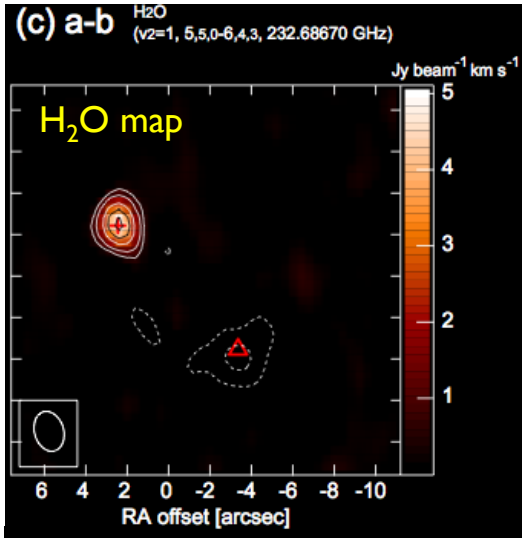
SiO, ^{29}SiO, Si^{18}O isotopologues, J=5-4 & 6-5 rotational, v_2=0,1,2 vibrational states; masers in bi-polar outflow from Ori-KL Source I (embedded high-mass YSO)
⇒ Extended structure has complex velocity structure due to interaction with Ori-BN/KL environment

Vibrationally excited 232.7 GHz H_2O (v_2=1) maser; only detected toward embedded protostar in Ori-KL Source I





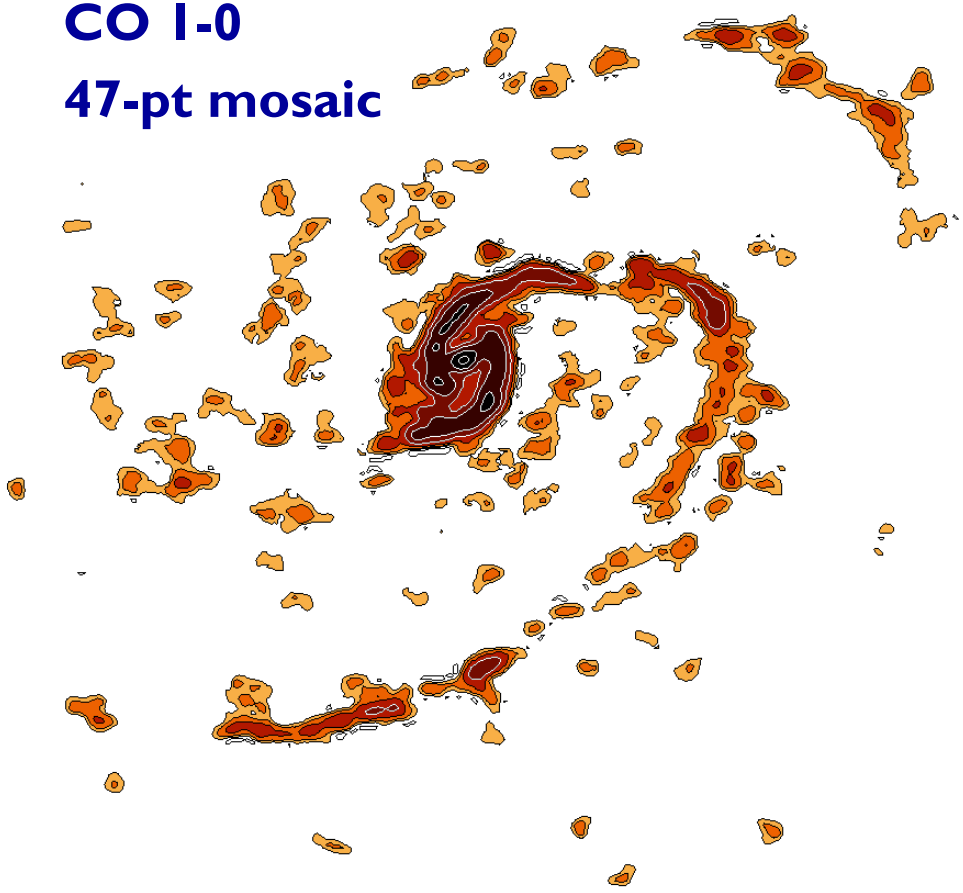




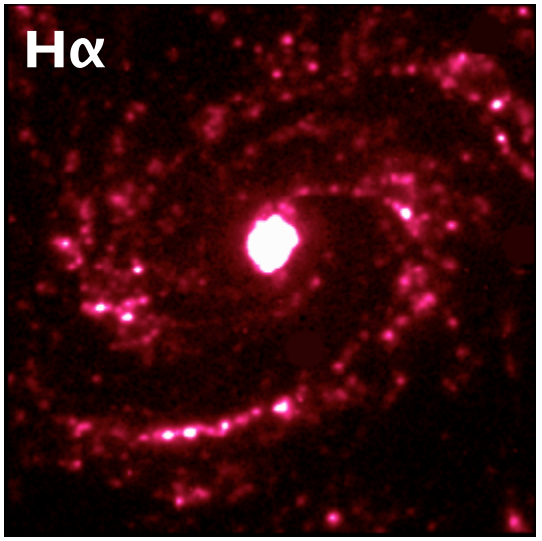
Zapata ea. 2012; Hirota ea. 2012; Galvan-Madrid ea. 2012; Niederhofer ea. 2012

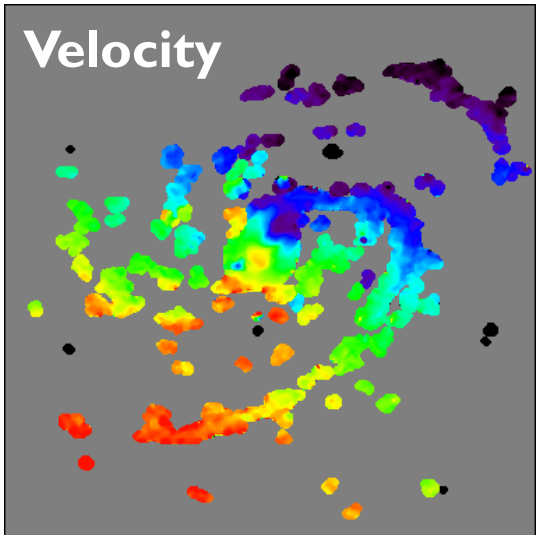
ALMA Images Nearby Galaxies

- Science verification imaging of M100



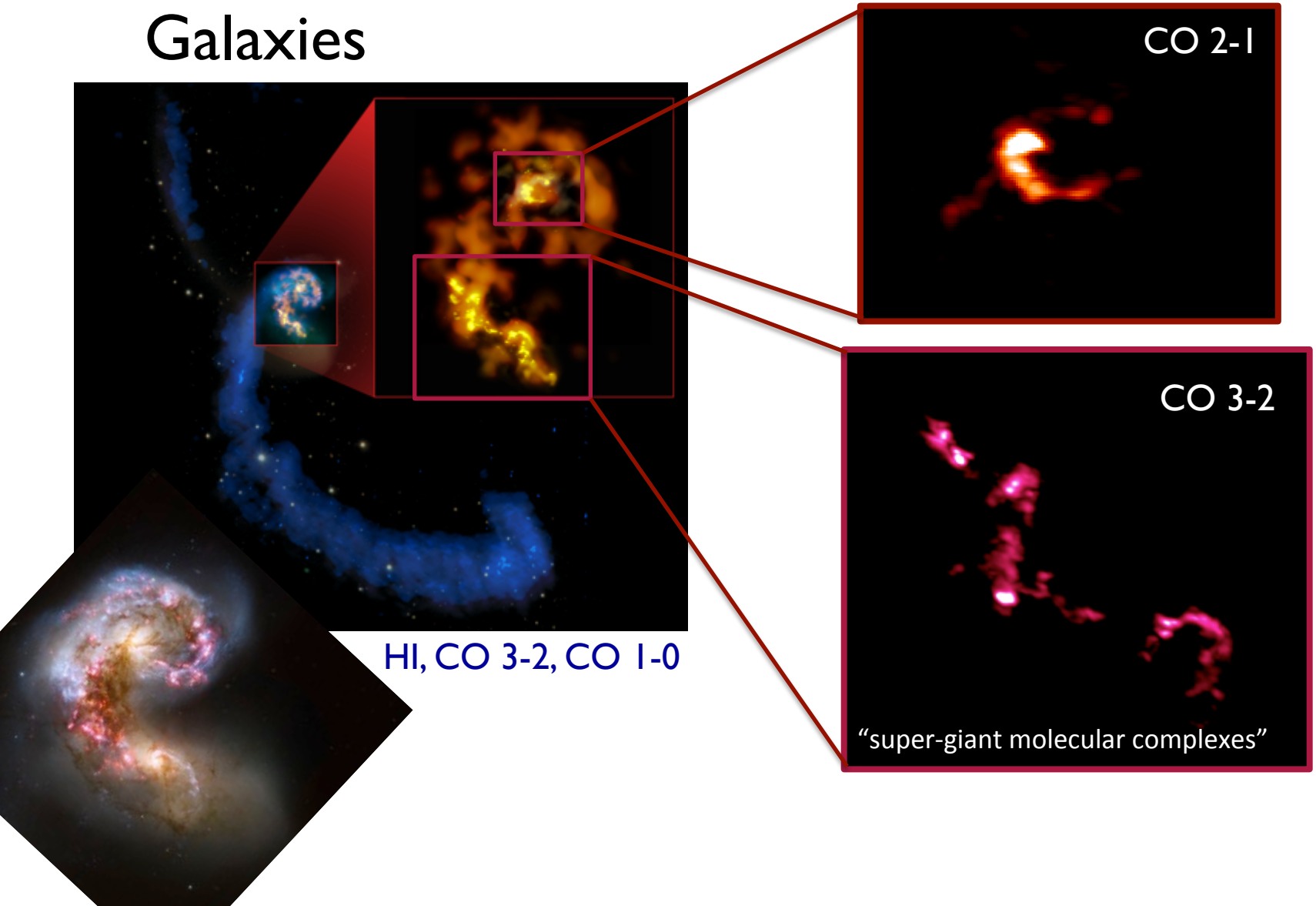
Grand design spiral galaxy in Virgo





ALMA Images Nearby Galaxies

- Science verification imaging of the Antennae Galaxies



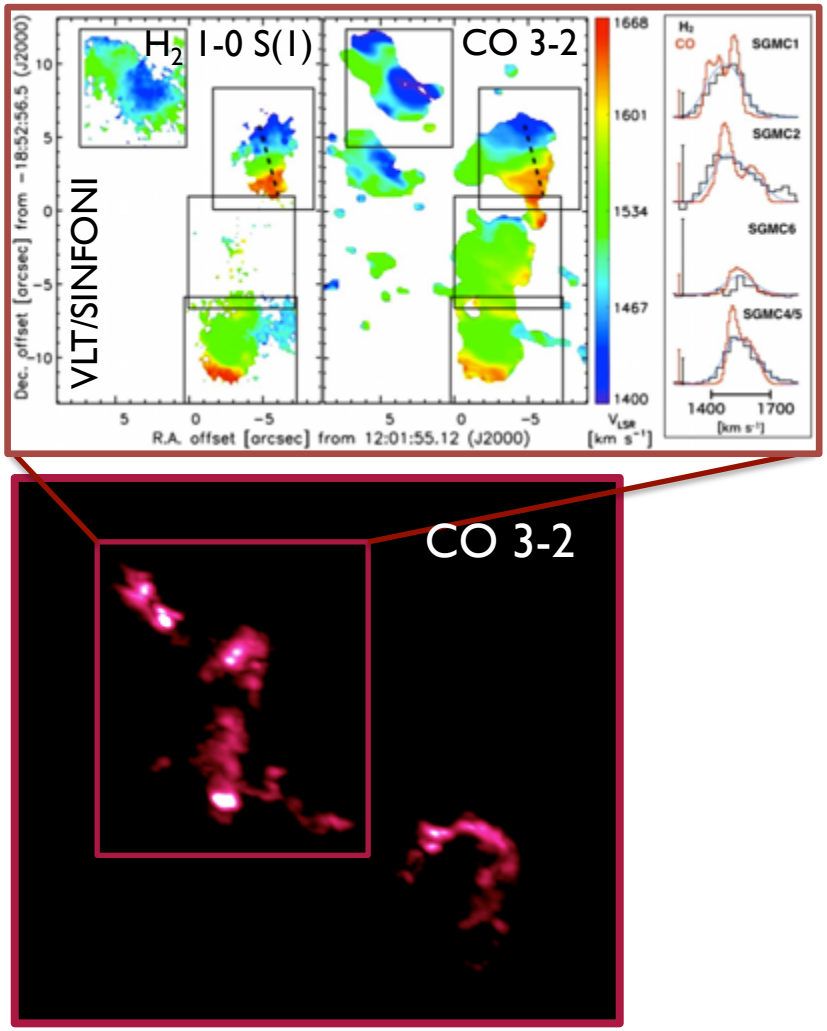
ALMA Images Nearby Galaxies

- Analysis: CO vs. H_2 1-0 S(1) dynamics in overlap region

- All except one "SGMC" have multiple velocity components

- CO & H_2 kinematics match but line ratios vary up to 10x

⇒ "SGMCs" dissipate turbulent energies at different rates?



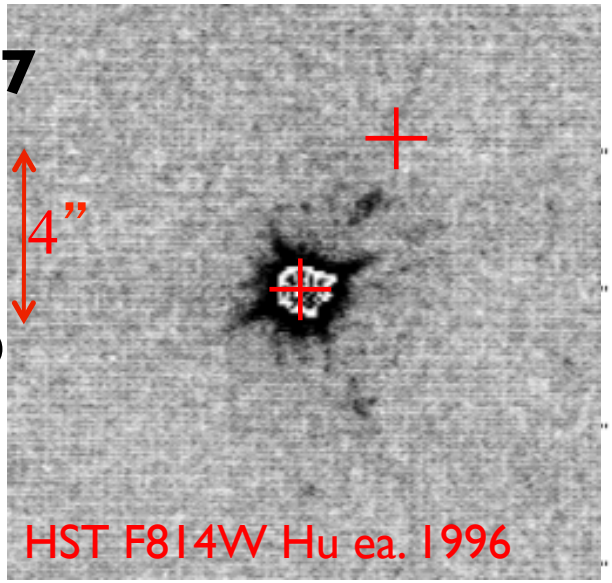
H_2: shocks, tracers energy dissipation

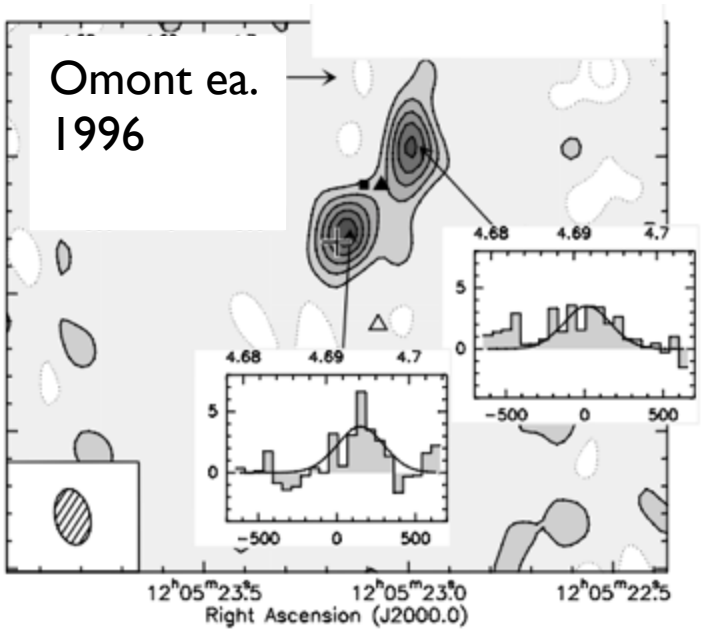
CO: traces gas mass

Herrera ea. 2012

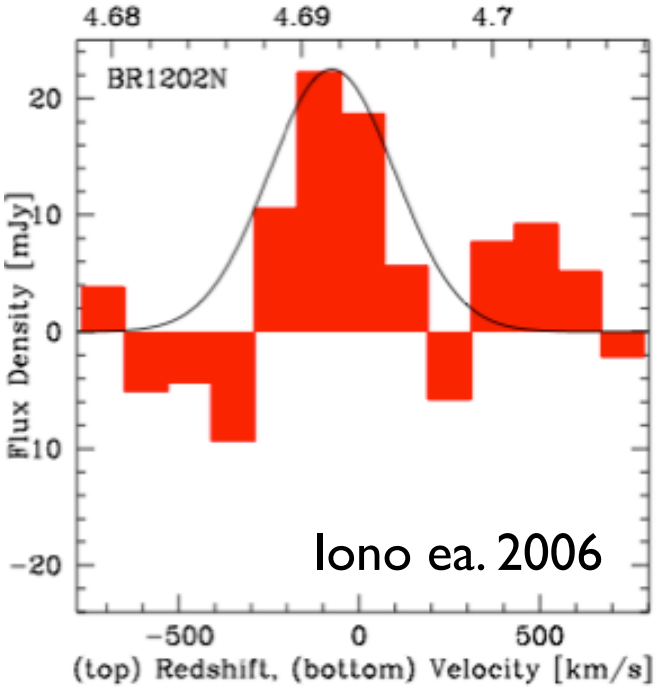
BR1202-0725 z=4.7

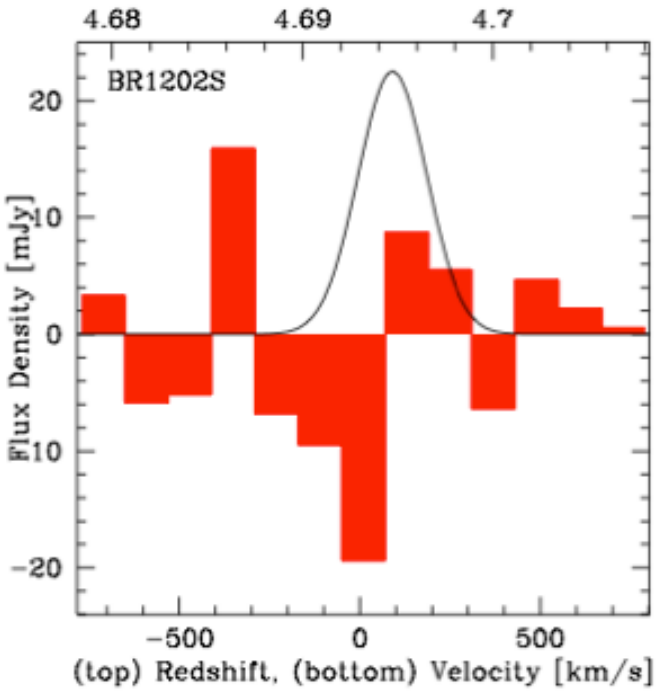
- Quasar-SMG pair
- Both HyLIRG
- Both detected in CO





SMA
[CII] 158μm
334GHz, 20hrs

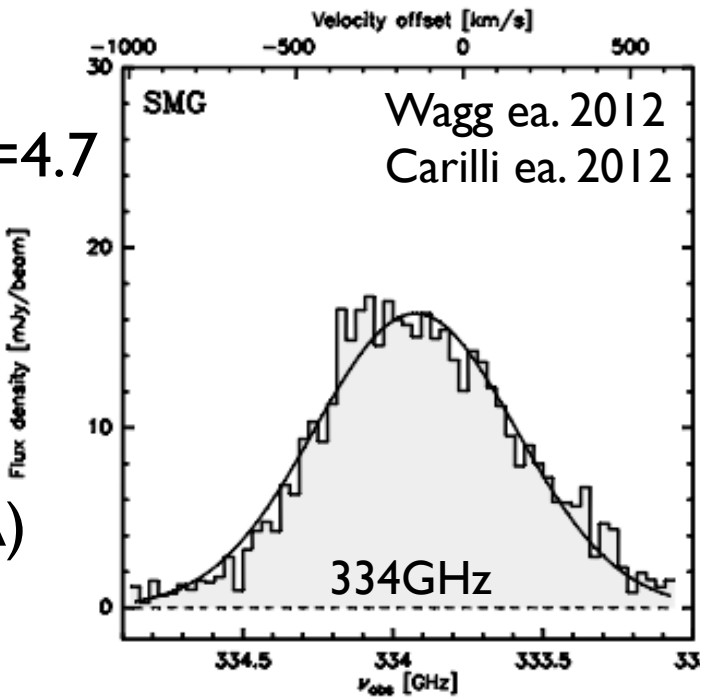


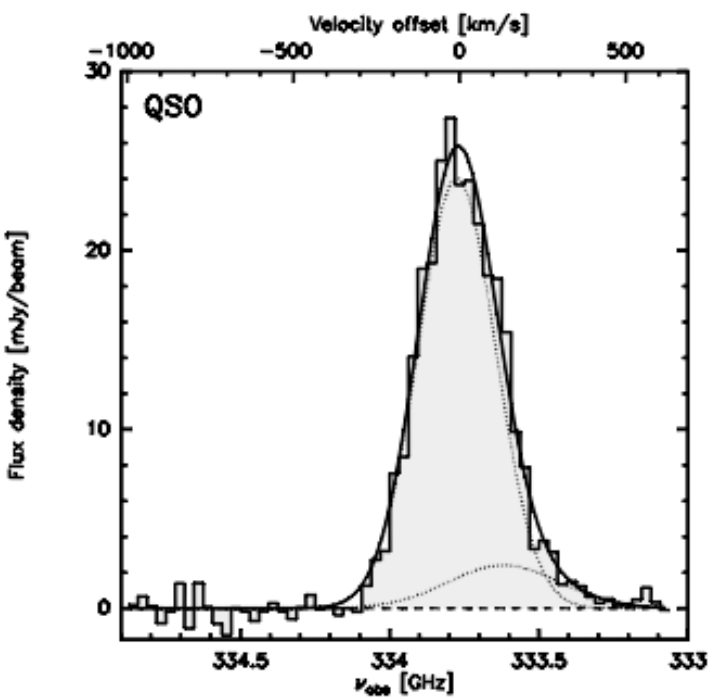


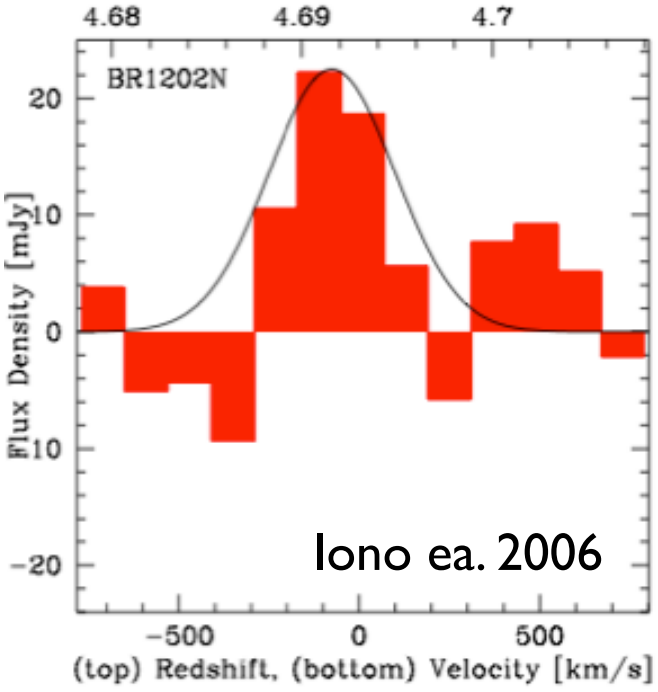
ALMA Images
[CII] in BR1202 z=4.7

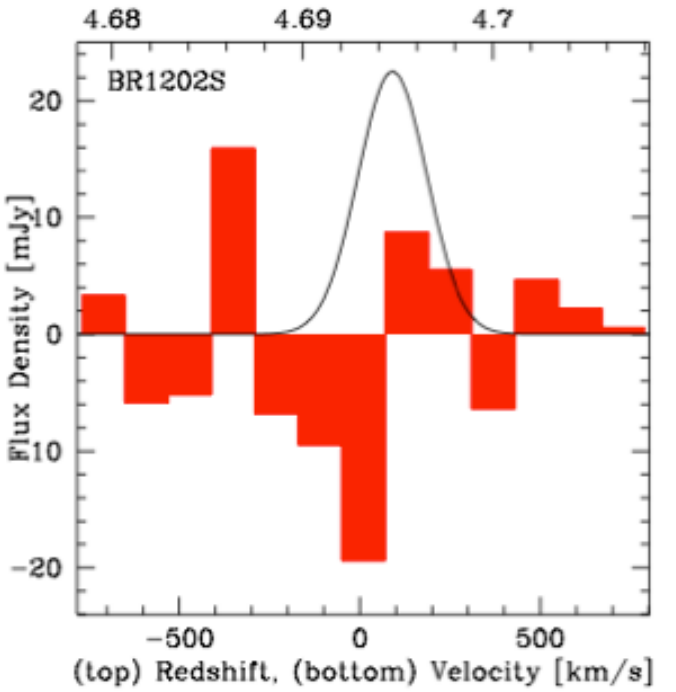
ALMA
20min, 16 ants
(~2min full ALMA)

SMA
20hrs





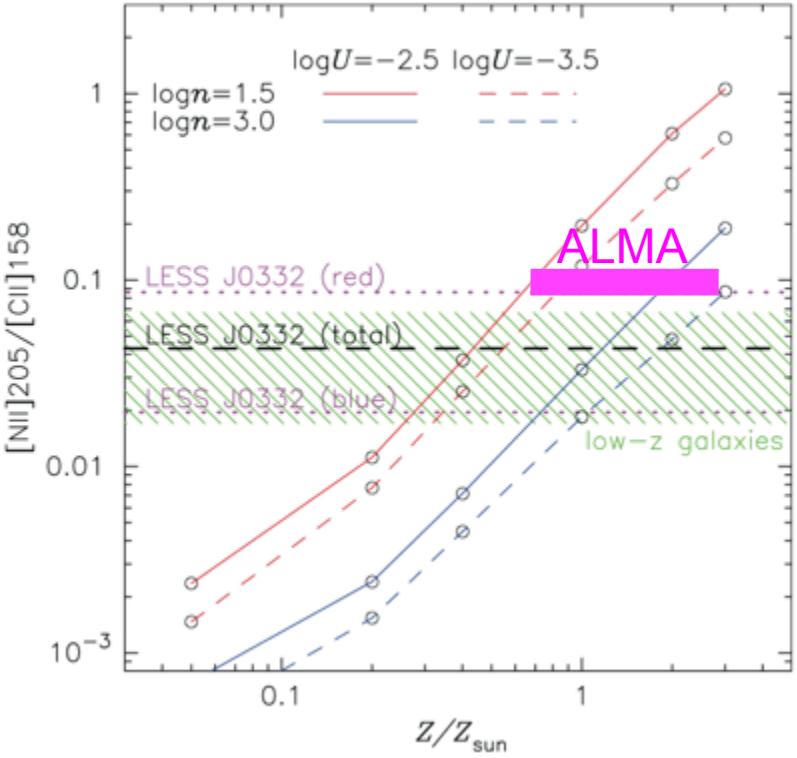


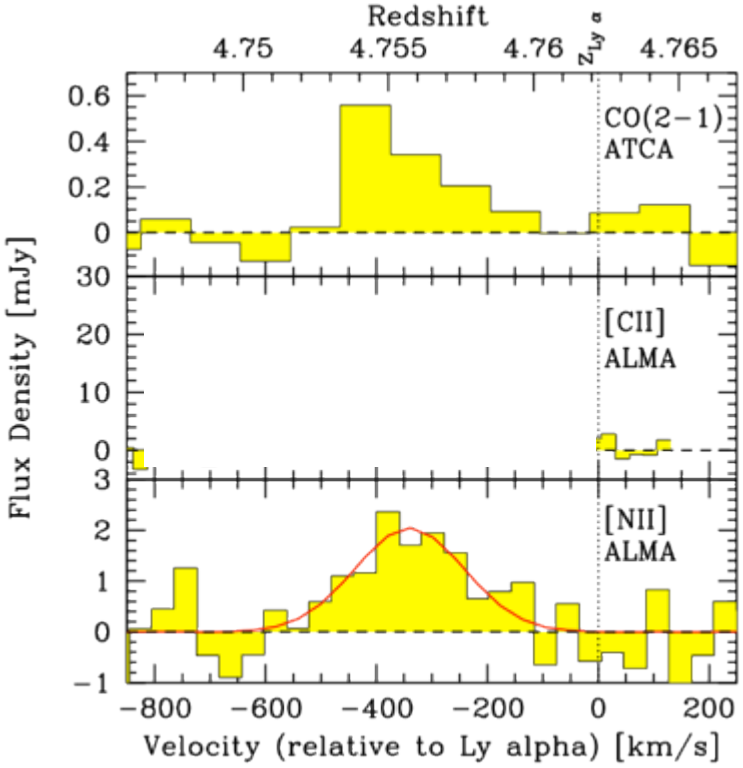


ALMA: [CII]/[NII]: tracing metallicity in z=4.76 AGN/starburst galaxy

- SMG w/ Compton-thick AGN at z=4.76

- [NII] 205μm arises in HII regions, while [CII] 158μm arises in both PDR and HII regions
- [NII]/[CII] depends mainly on N/C abundance ~ Z_{gas} => *good metallicity tracer*
- Small dependence on density n and ionization parameter U.





- [NII]/[CII] consistent with local $Z=Z_{solar}$ galaxies.

Nagao ea. 2012
De Breuck ea. in prep.

ALMA/LESS: 870μm submillimeter galaxy (SMG) source counts

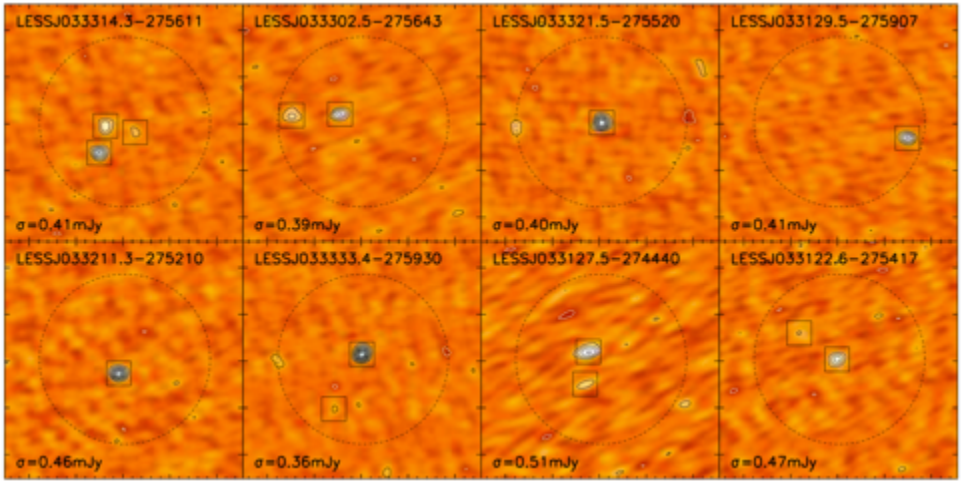
- imaged 122 SMGs in CDF-S (30'x30')

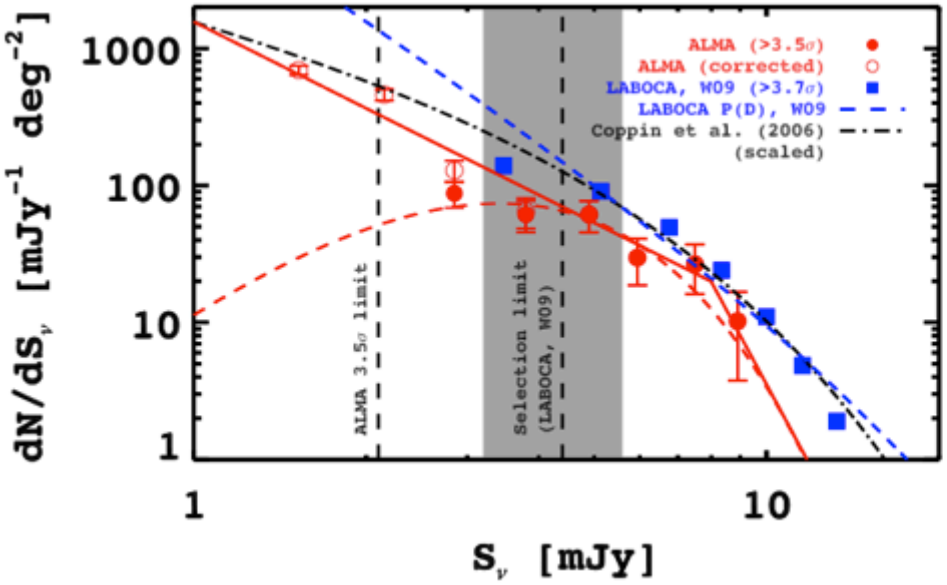
(original IDs: APEX/LABOCA, ~20" res)

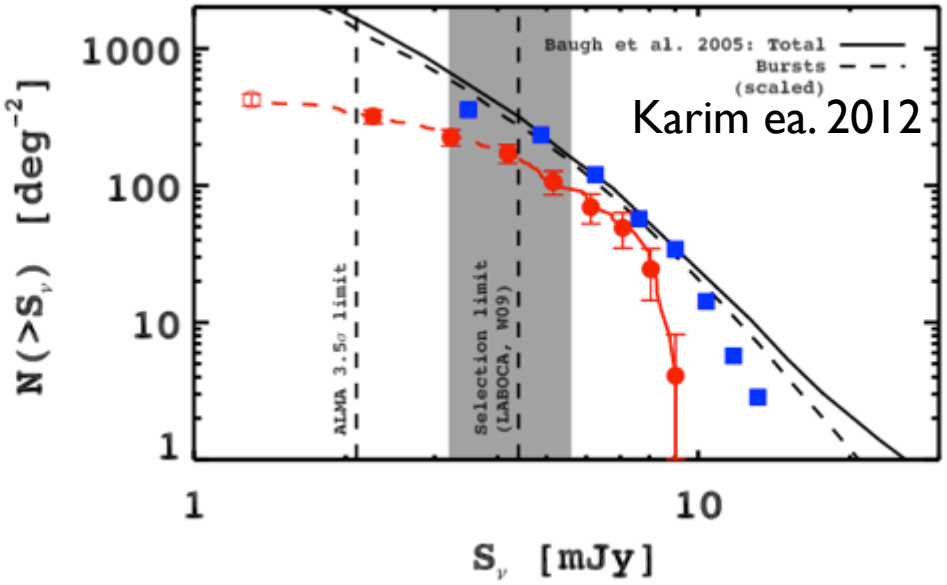
- 23 sources, incl. all the brightest, resolved into multiple SMGs
- 19 sources not detected

⇒ SMG counts have steep bright and shallow faint end

⇒ Systems with >1000 $M_{sun}yr^{-1}$ SFR very rare (<$10^{-8}Mpc^{-3}$)



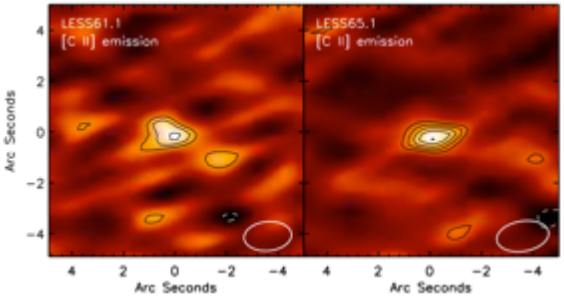


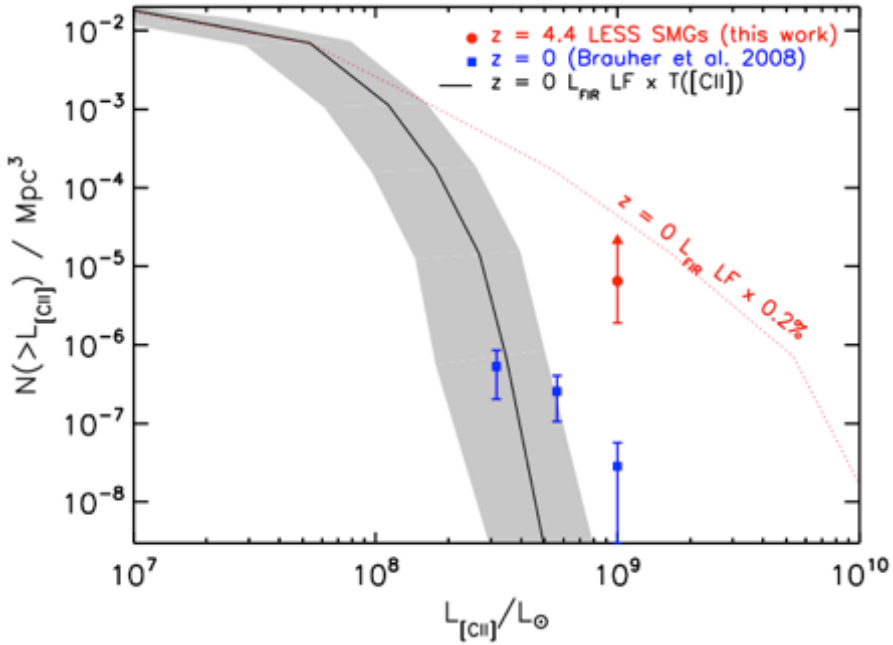


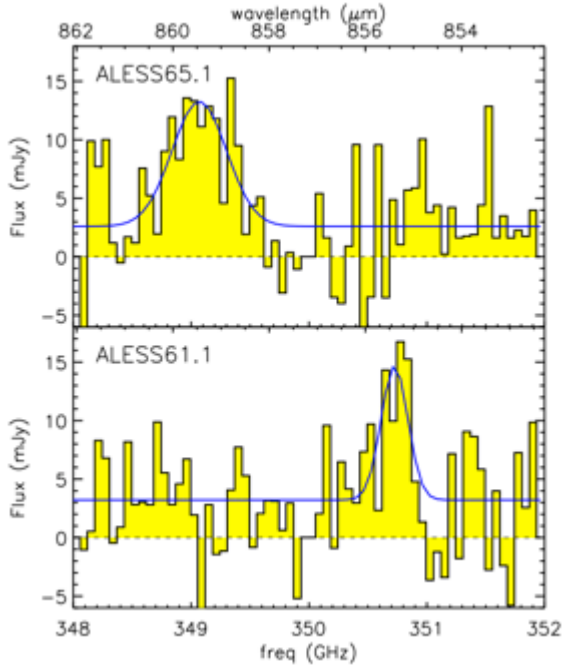
ALMA/LESS: serendipitous line detections

- 2/122 SMGs show evidence for lines
- interpretation: [CII] at z=4.4
- detection rate over 7.5 GHz bandpass consistent with SMG photo-z distribution in this field (<25% at z>4)
- ULIRG-like [CII]/FIR ratios
- lower limit on [CII] luminosity function at z=4.4

⇒ If correct, suggests strong evolution from z=0 to 4.4







Swinbank ea. 2012

Summary

- ALMA covers a unique wavelength regime offering >10-100x improvement in virtually all respects relative to previous (sub)millimeter observatories
- ALMA is currently doing early science observations, will be completed in 2013
- ALMA addresses a broad range in science goals, going from the solar neighborhood all the way back to a few 100Myr after the Big Bang
- First science verification/cycle-0 results show: even looking at well-studied objects with short integration times, ALMA enables ample new science (with some of the most stunning results still to be published)

$\Rightarrow$ Frontiers in Star Formation? About to be revised…