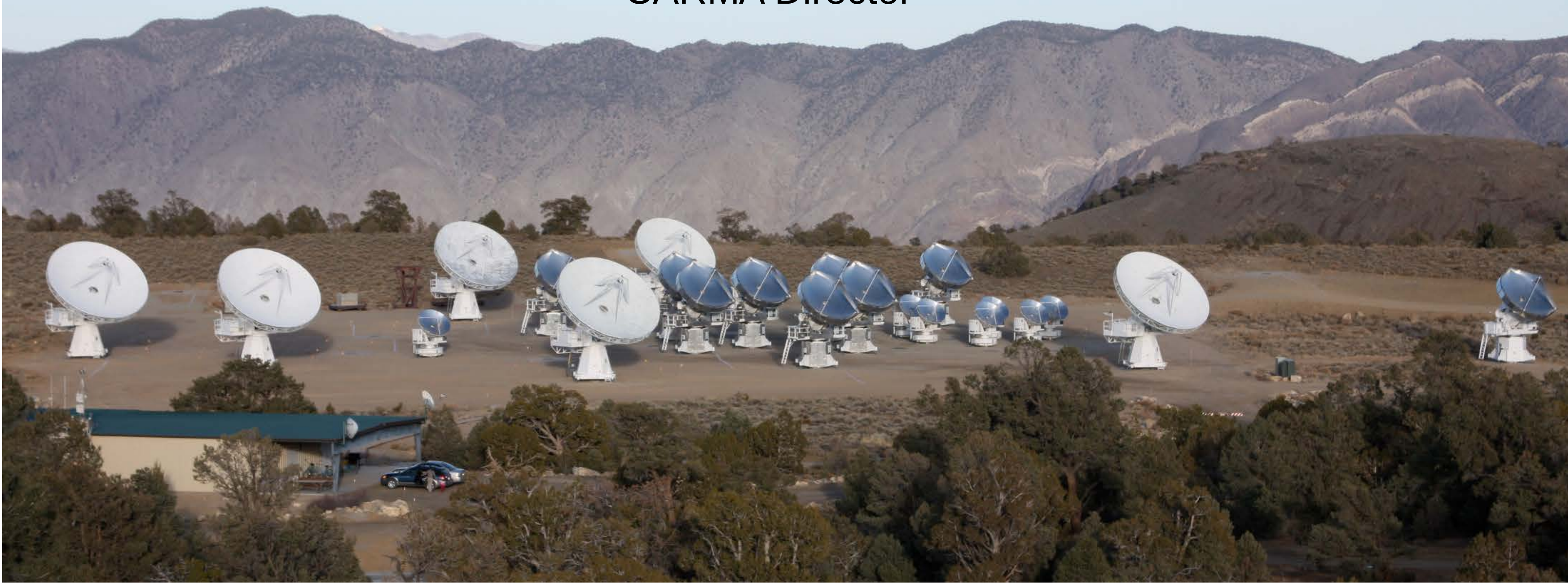
Combined Array for Research in Millimeter-Wave Astronomy

Lee Mundy
University of Maryland
CARMA Director

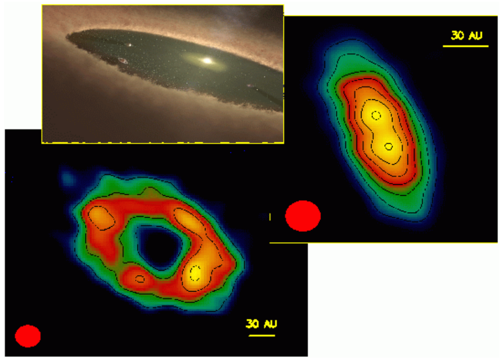


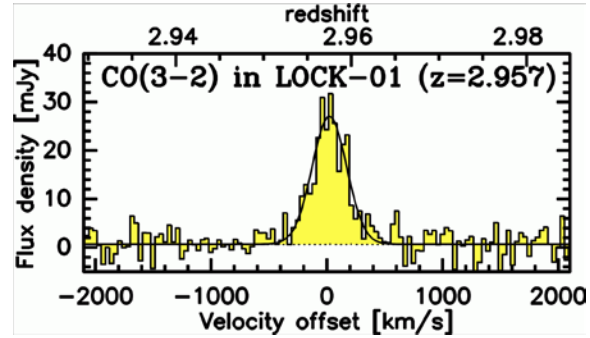
California Institute of Technology, University of California Berkeley, University of Illinois, University of Maryland and University of Chicago

and the National Science Foundation

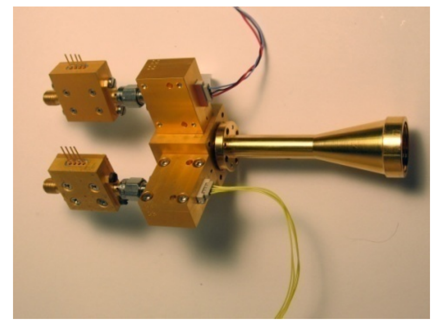
CARMA

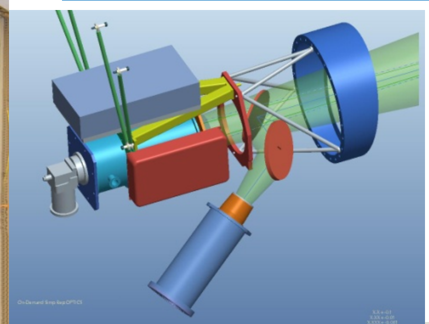
Science





Technical Development





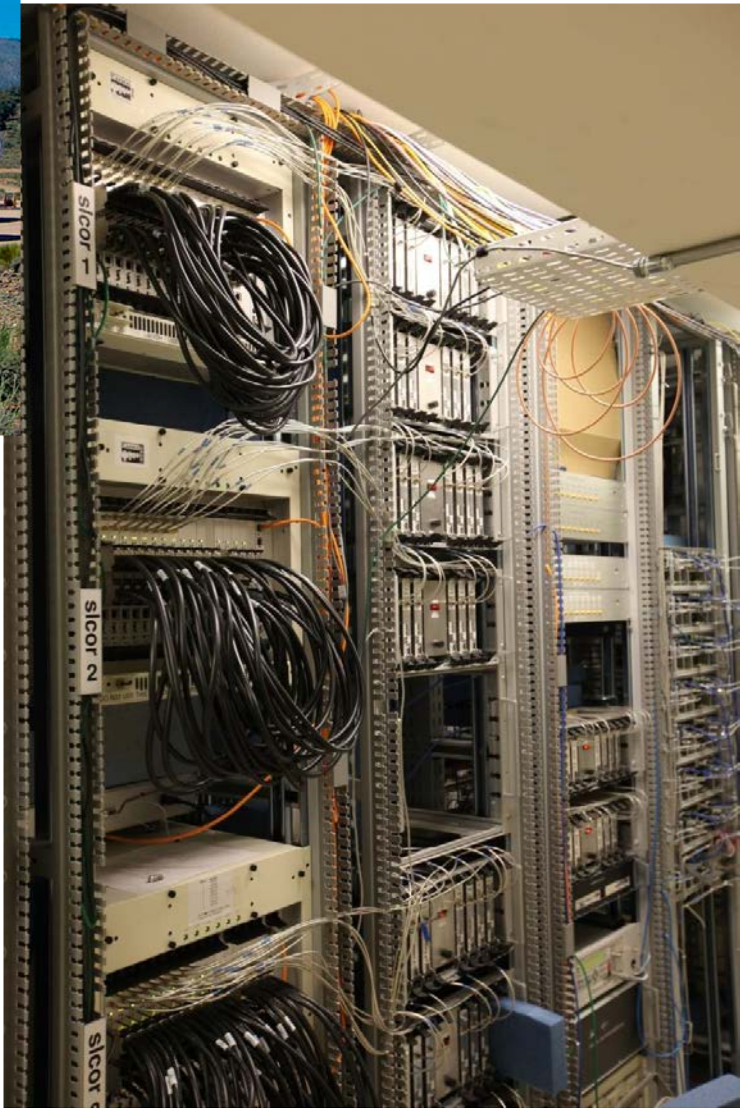
Training and Education

Complementing ALMA

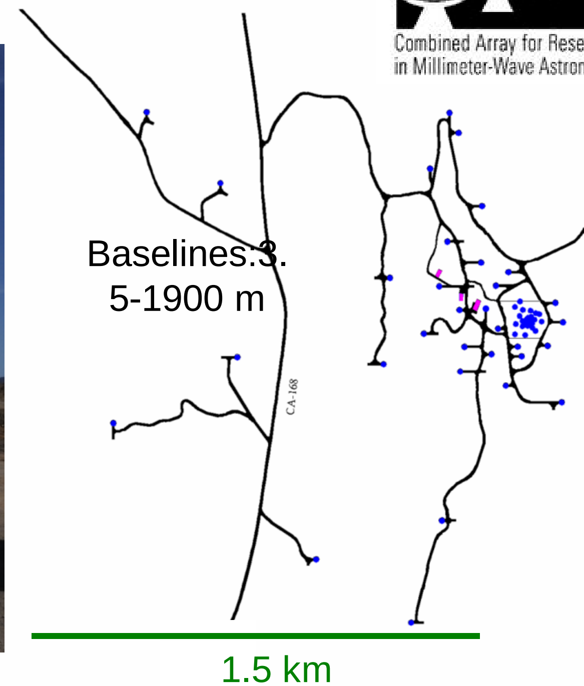
CARMA

CARMA

Combined Array for Research in Millimeter-Wave Astronomy



CARMA: Cedar Flat



Config	Max Baseline (m)	Resolution @ 230 GHz
A	1900	0.15”
B	950	0.35”
C	370	0.75”
D	150	1.7”
E	66	3.2”
Z	12	2’ (30 GHZ)

CARMA

Combined Array for Research in Millimeter-Wave Astronomy

Flexibility to have the array meet the needs of the science experiment:
23 antennas, 2 correlators = many options

3.5-m array:

Antennas:	8 x 3.5-m	
Collecting Area:	10 m^2	
Receivers:	26 – 36 GHz	25K (SSB)
	80 – 115 GHz	45K (SSB)
Correlator:	16 bands of 15 chans per band	
	8GHz total bandwidth	

10-m and 6-m Array:

Antennas:	15 (6 x 10.4-m and 9 x 6.1-m)	
Collecting Area:	722 m^2	
Receivers:	80 – 115 GHz	40K (DSB)
	215 – 270 GHz	70K (DSB)
	8 GHz bandwidth	
Correlator:	8 bands of 33 - 383 channels each, per sideband	
	4 GHz total bandwidth	
	bands tunable over 8 GHz	

CARMA-23 array:

Antennas:	10.4-m, 6.1-m, and 3.5-m	
Baselines:	253 baselines	
Receivers:	80 – 115 GHz	45K (SSB)
Correlator:	4 bands of 33-383 channels	
	2 GHz total bandwidth	

Designer arrays:

Antennas:	Combination of any types
Correlator:	15-element/8-element
Receivers:	1 cm, 3 mm, or 1.3 mm

Flexible 8-band spectral line correlator

CARMA
Combined Array for Research in Millimeter-Wave Astronomy

Continuum observations with up to 8 GHz bandwidth on the sky

Spectral line observations with velocity resolutions from 15 km/sec to 10 m/sec

Spectral observations can have up to 3000 channels on the sky

Nominal Bandwidth (MHz)	Channels per SB	Channel width (MHz)	∂V[3mm] (km/s)	V_{tot}[3mm] (km/s)	∂V[1mm] (km/s)	V_{tot}[1mm] (km/s)
500	96	5.21	15.6	1500	5.2	500
250	191	1.31	3.9	750	1.3	250
125	319	0.392	1.2	375	0.39	125
62	383	0.161	0.49	186	0.16	62
31	383	0.081	0.24	93	0.081	31
8	383	0.021	0.062	24	0.021	8
2	383	0.0052	0.016	6	0.005	2

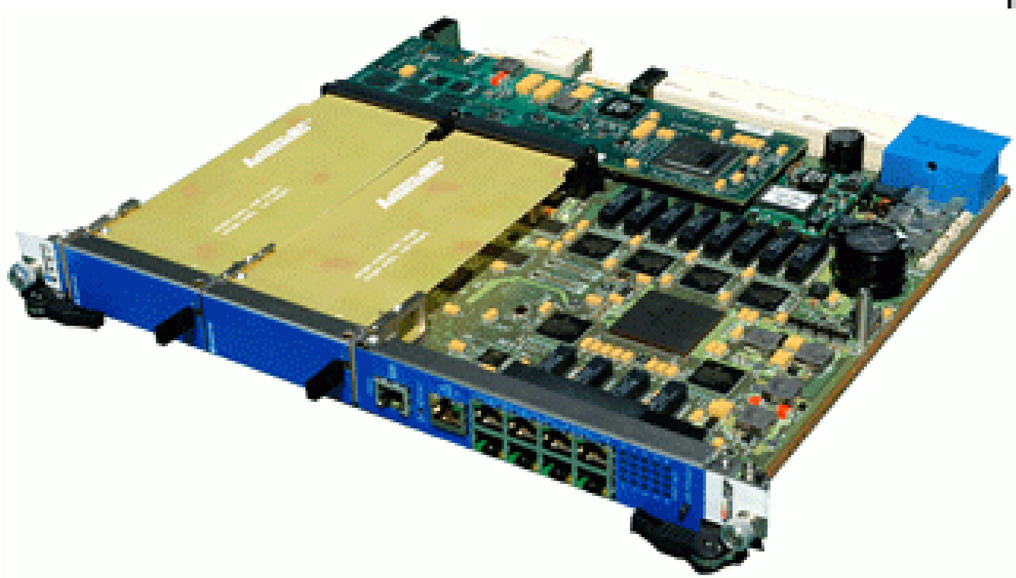
New 8GHz Correlator

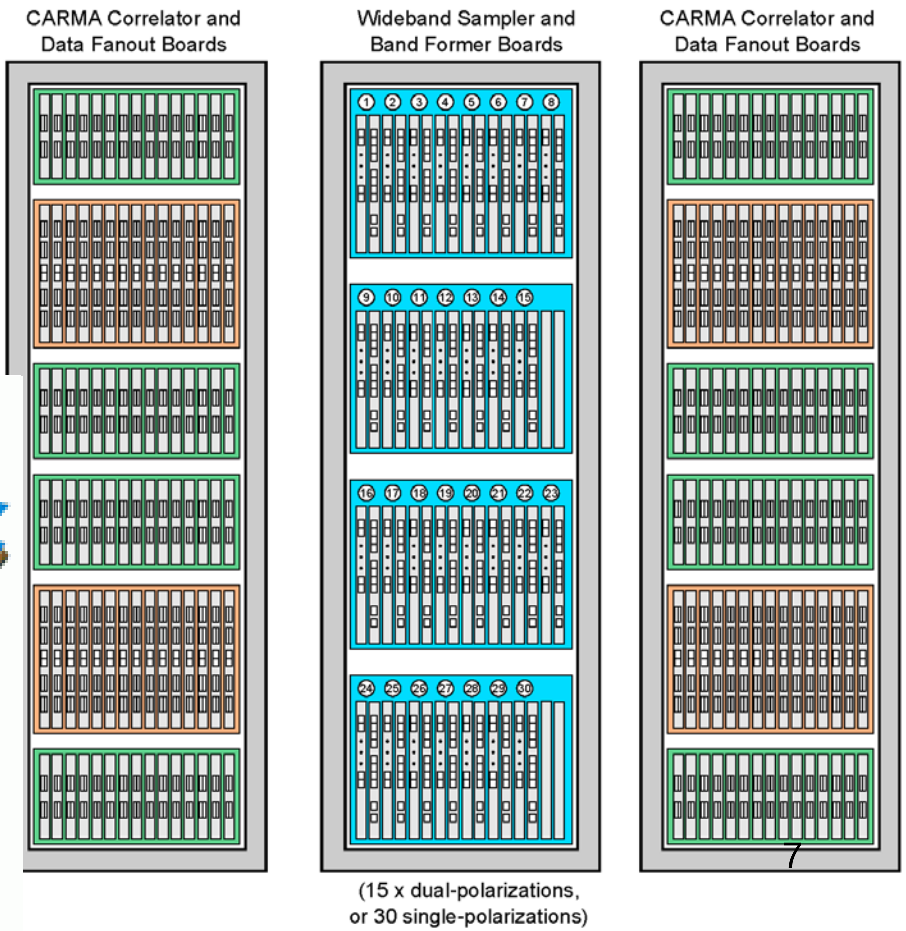
New correlator under development

Altera's latest FPGA chips: Stratix IV GT

High speed digital samplers

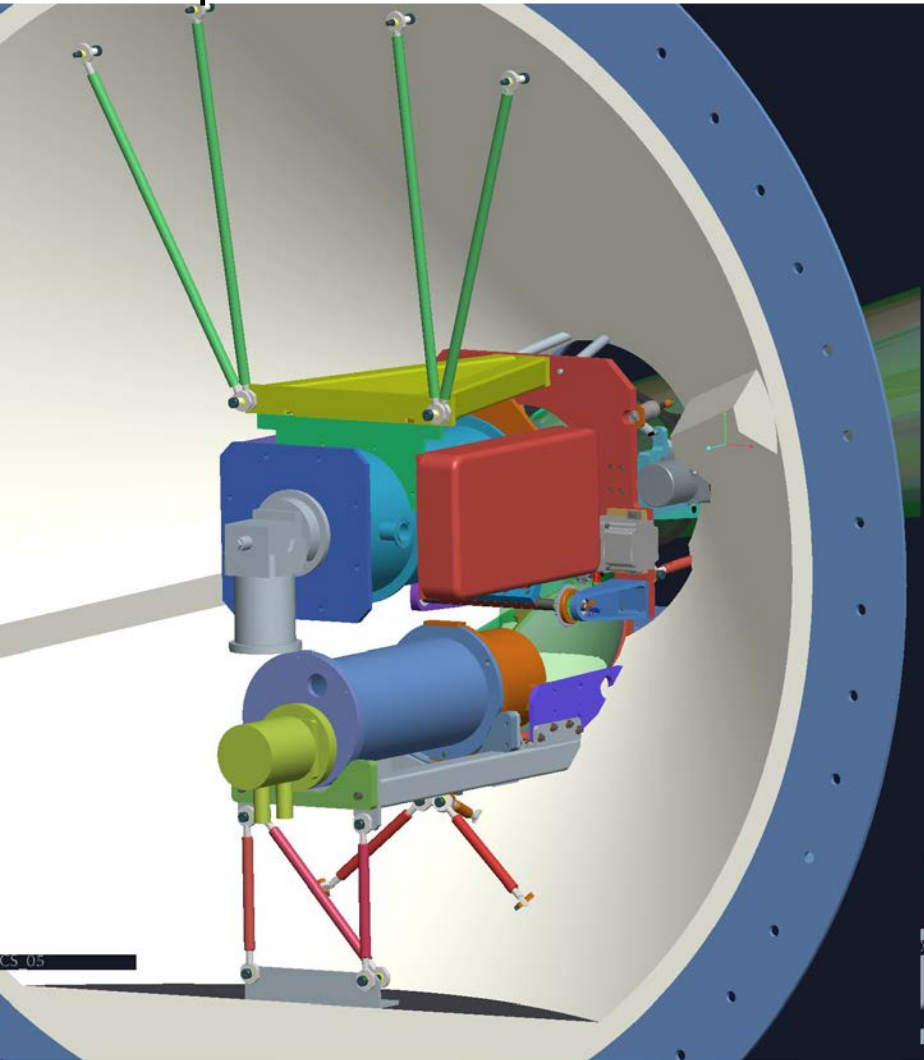
To be completed in Fall 2013

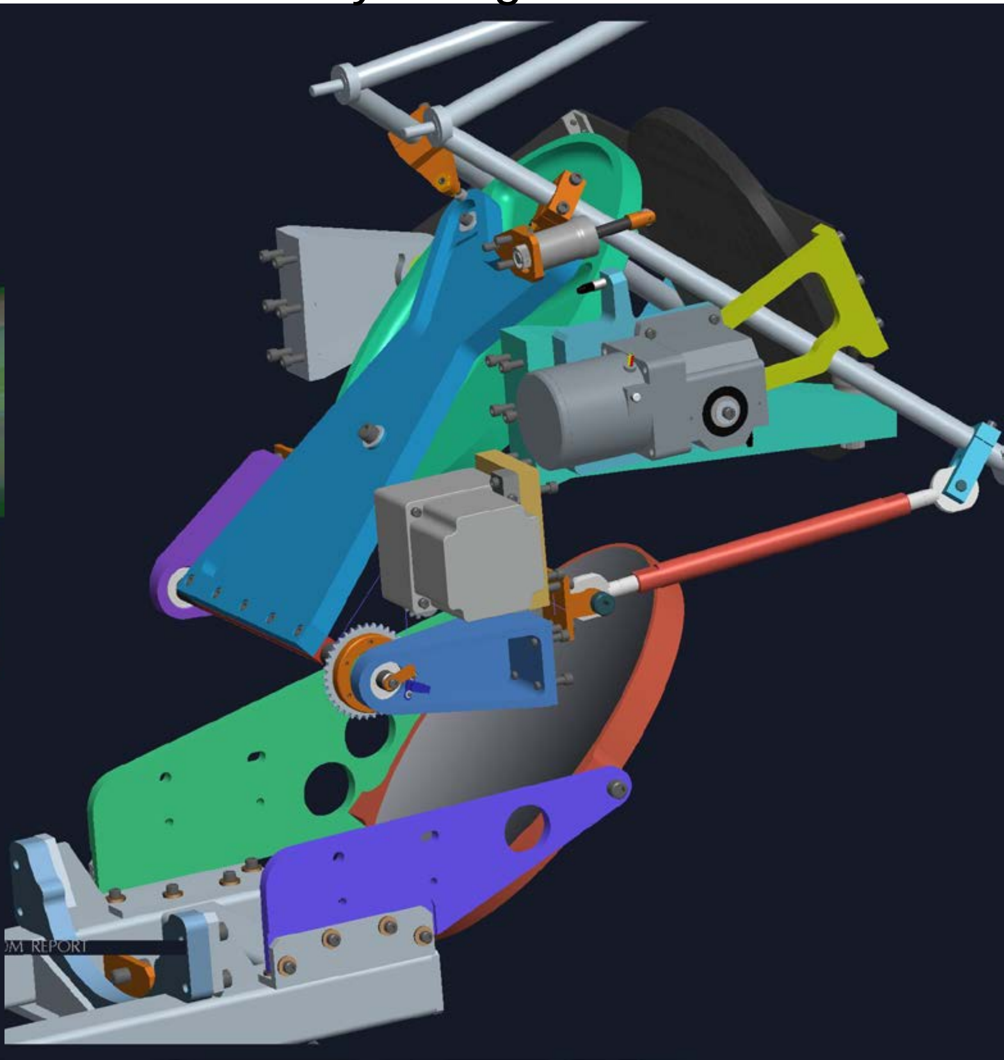




1 Cm receivers

- Originally on 3.5-m telescopes only
- Installing on 6 and 10-m so that have 23-elements
- Optics and receiver selection hardware currently being fabricated

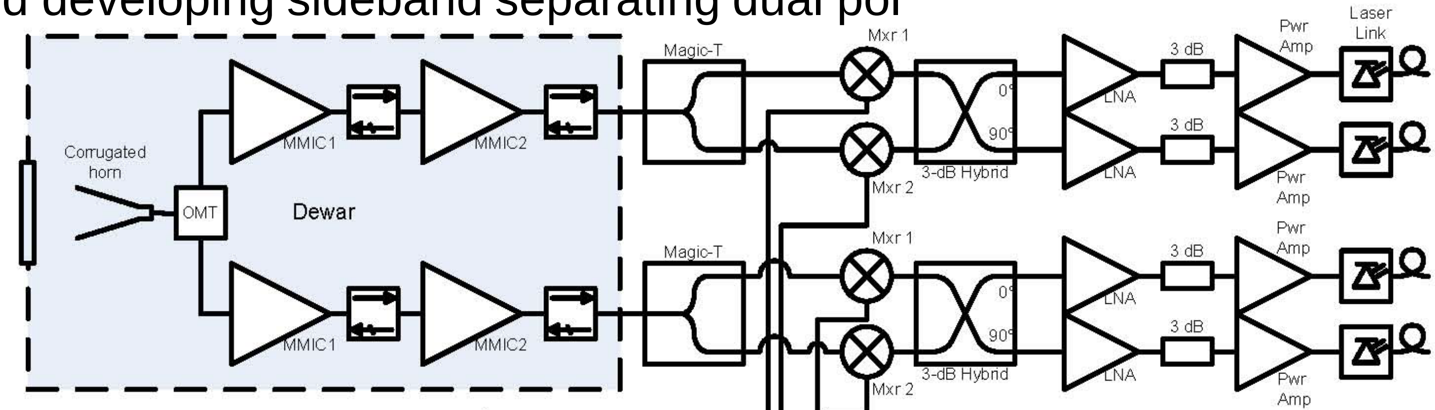


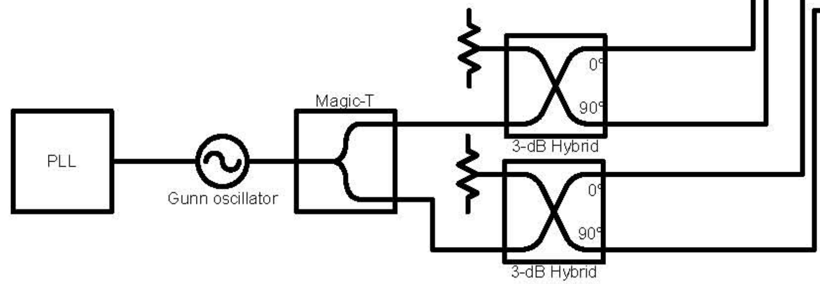


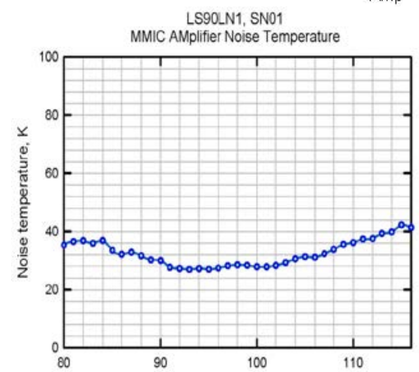
Dual polarization sideband separating 3mm MMIC receiver

Participating with Caltech Cahill Radio Astronomy Lab and JPL in MMIC chip development.

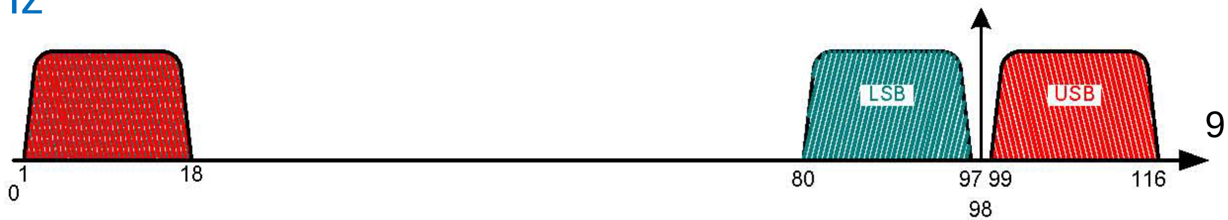
Designing and developing sideband separating dual pol







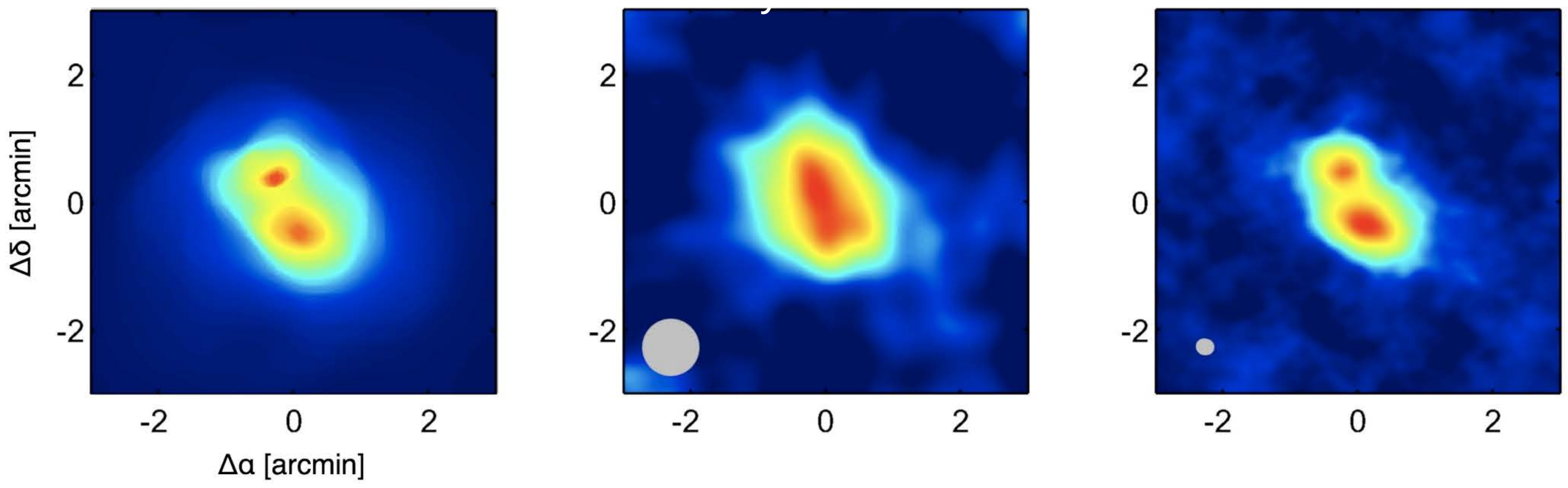
Aiming towards ultra-wideband system, 80-115 GHz



Science Drivers

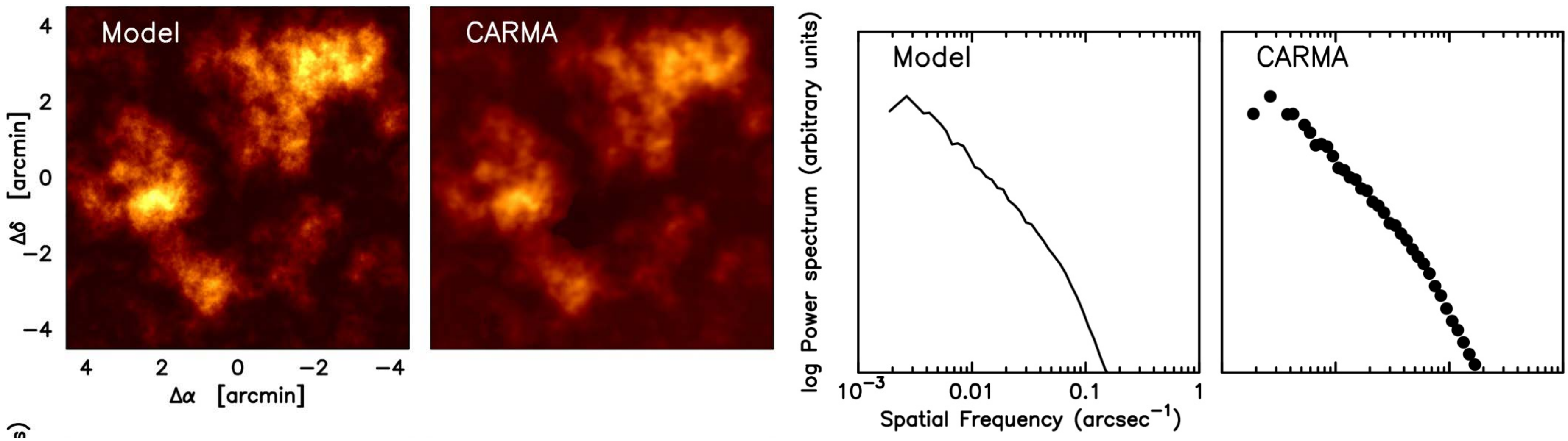
Combined Array for Research in Millimeter-Wave Astronomy

- Precision imaging of SZ effect in clusters at 1 cm and 3mm
  - SZE mapping to study the hot inter-cluster medium
  - Precision modeling of SZE to study cluster physics and evolution
  - Unique capability for cosmology community



Science Drivers

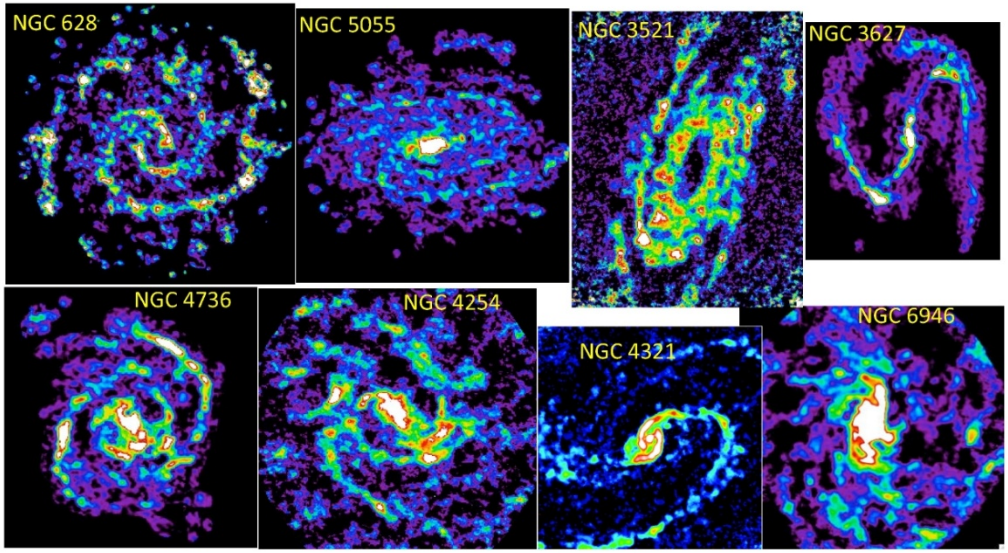
- Fast wide field mapping at 2-5” resolution:
  - ➢ The structure of molecular clouds and their evolution (map 1 square degree at 4” resolution & 0.2 km/s velocity channels with RMS of 0.1 K In 360 hours – 6-10 spectral lines simultaneously)
    - ❖ Systematic study of core mass function and its evolution
    - ❖ Chemical evolution of dense gas
  - ➢ Systematic surveys of ~100 nearby galaxies out to optical edge
    - ❖ Galactic scale formation and evolution of dense gas
    - ❖ detailed global dynamics of gas and galaxy

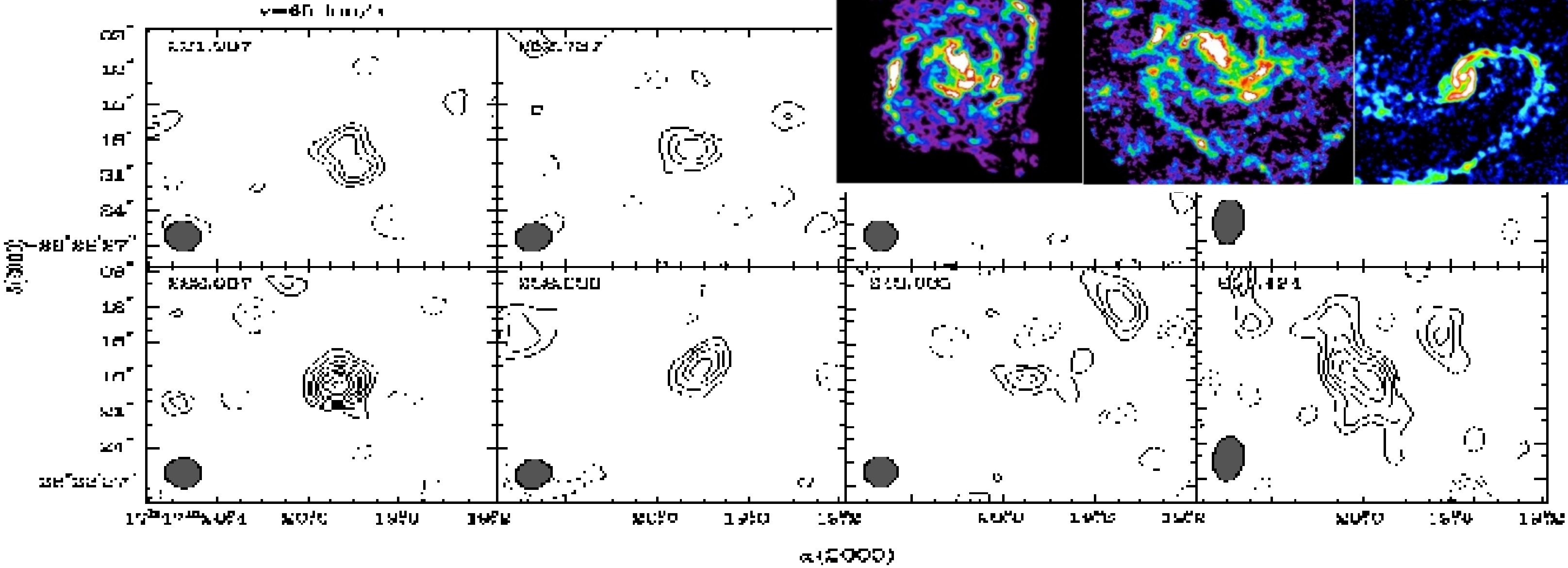


Science Drivers

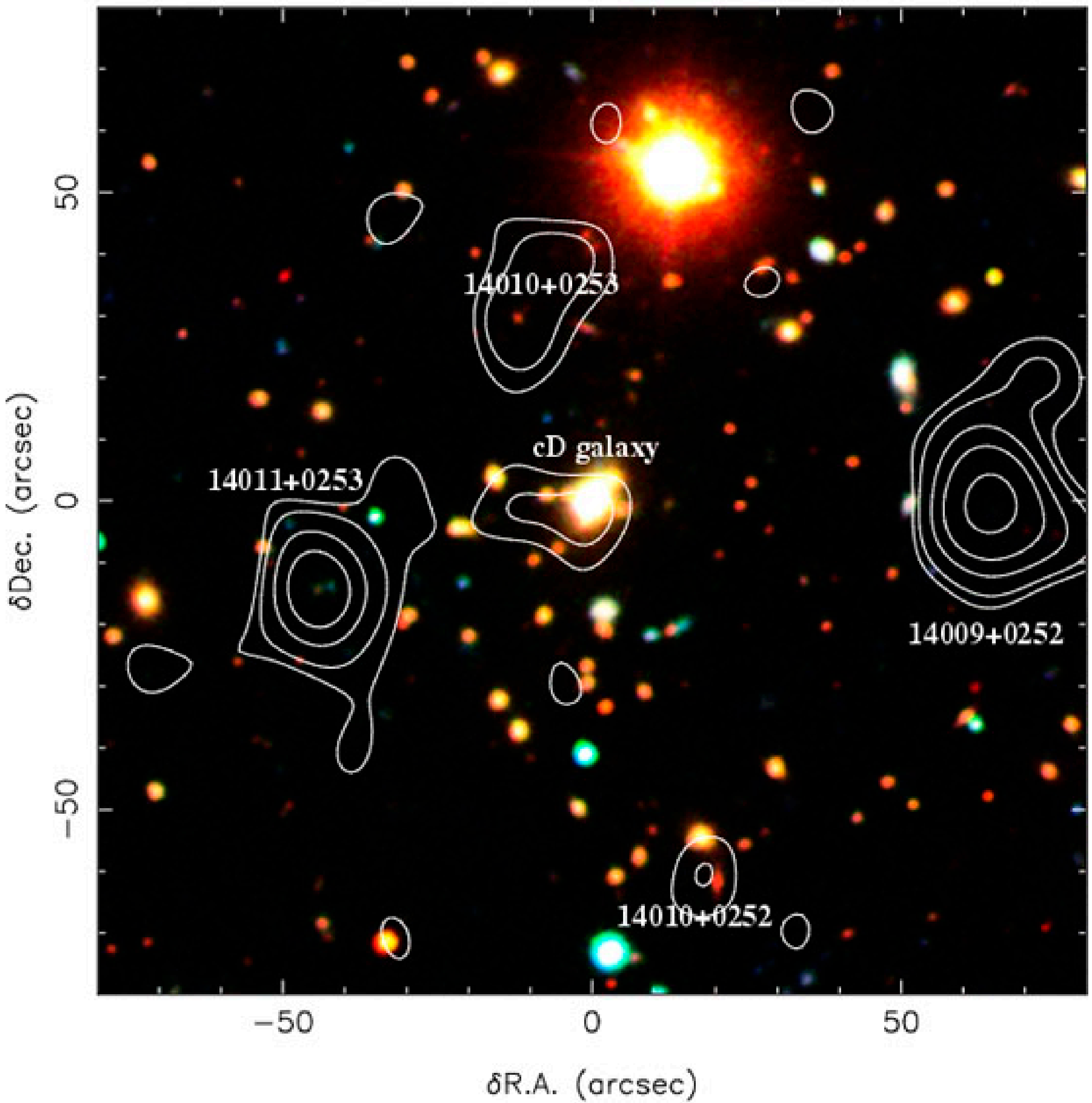
CARMA
Combined Array for Research in Millimeter-Wave Astronomy

- Wide bandwidth:
  - broad, modest depth surveys to identify primary chemistry
  - broad spectral surveys of nearby galaxies
  - spectral line studies of high-Z objects





Galaxies in the Early Universe



How early in the history of the Universe did galaxies form?

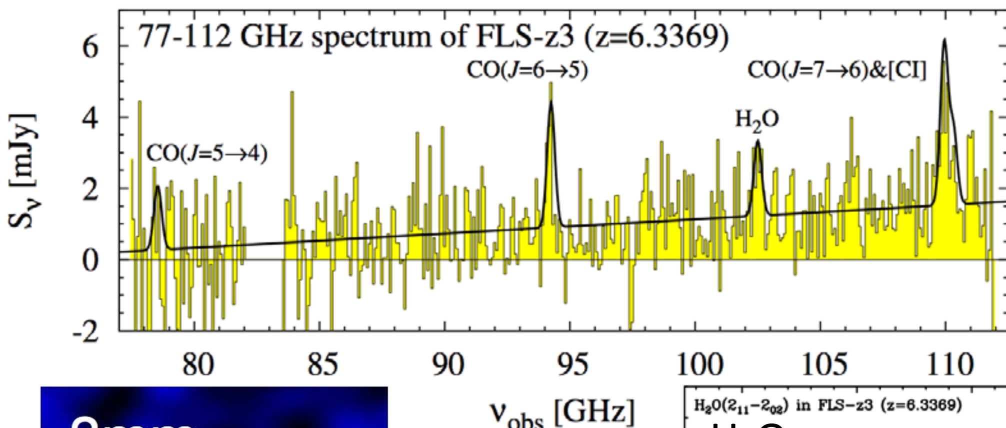
What did they look like?

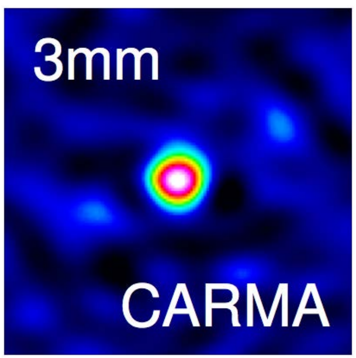
Young galaxies, rich in gas and dust, were first discovered at sub-millimeter wavelengths from their dust continuum emission

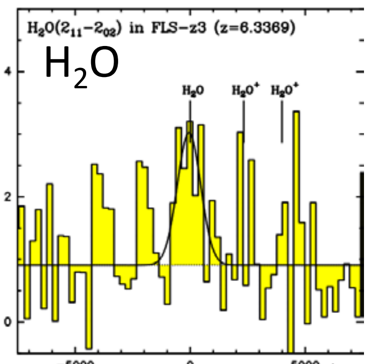
Ivison et al 2000 850 micron map in the contours overlaid on a deep 3-color optical image

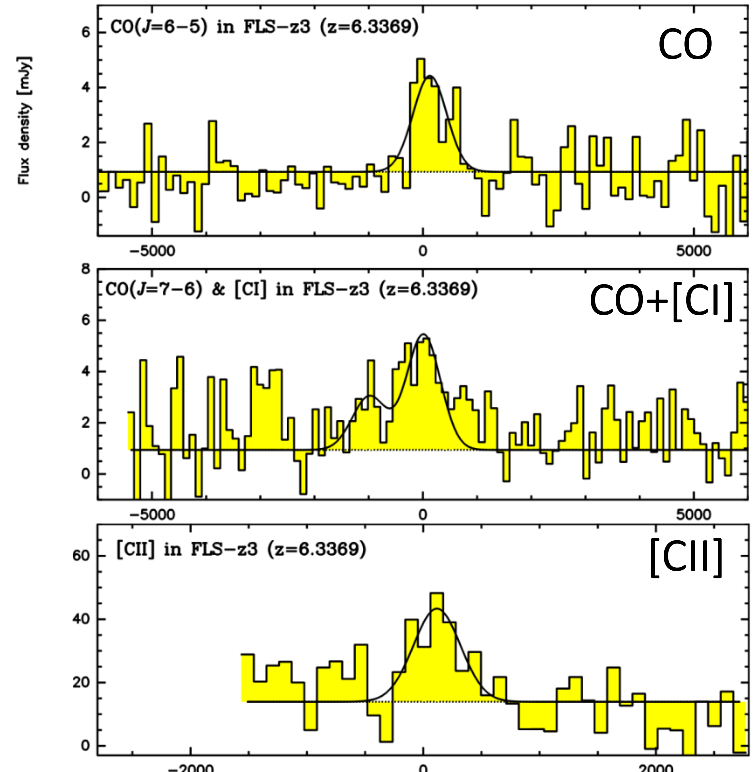
Water in the Early Universe

D. Riechers et al., Nature paper





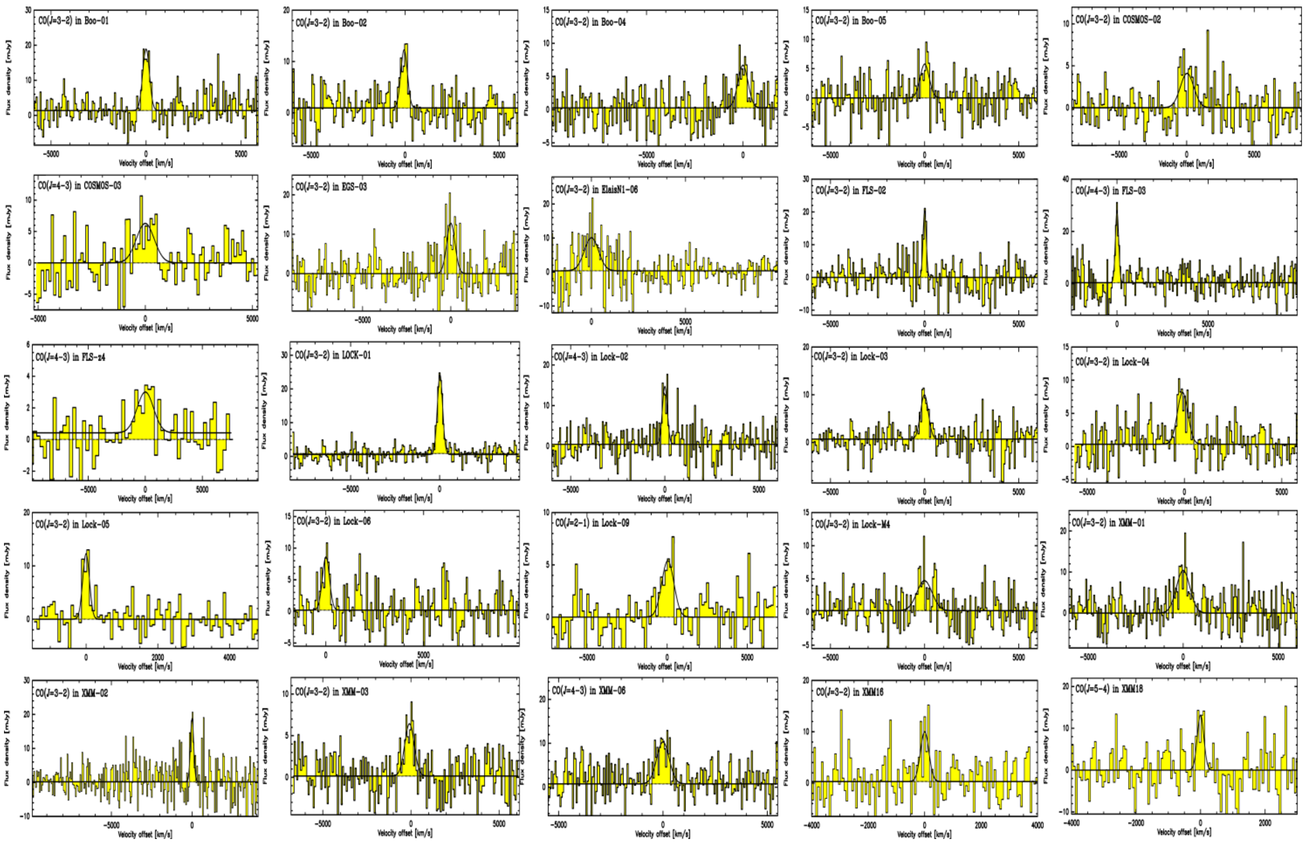




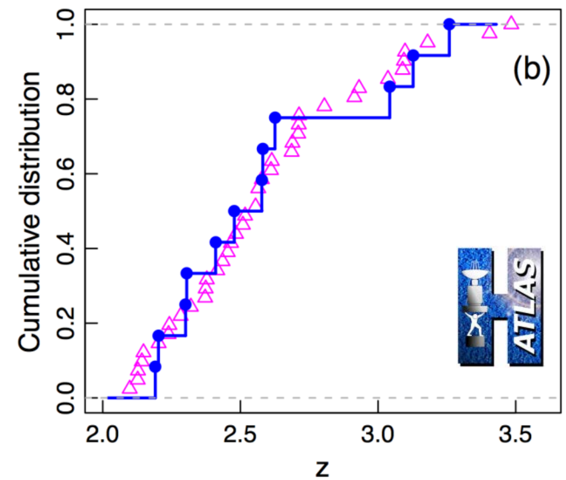
- "Blind" CO Search in the Reddest (optically invisible) Herschel/SPIRE Galaxy
  - strong continuum and CO, [CI], and H_2O line emission in 3mm band
  - very bright redshifted 1.9 THz/158µm [CII] fine structure line emission
- Redshift record for SMG (z=6.3369)
- Detection of water only 885 million years after the Big Bang

Redshifts of Herschel SMGs

D. Riechers et al. 2012.



Harris et al., in prep.
synergy with GBT



Redshift distribution identical to optical sample from Chapman et al. (2005)

1998-2009: ~20 SMGs detected in CO emission (all selected w/ optical spec-z)

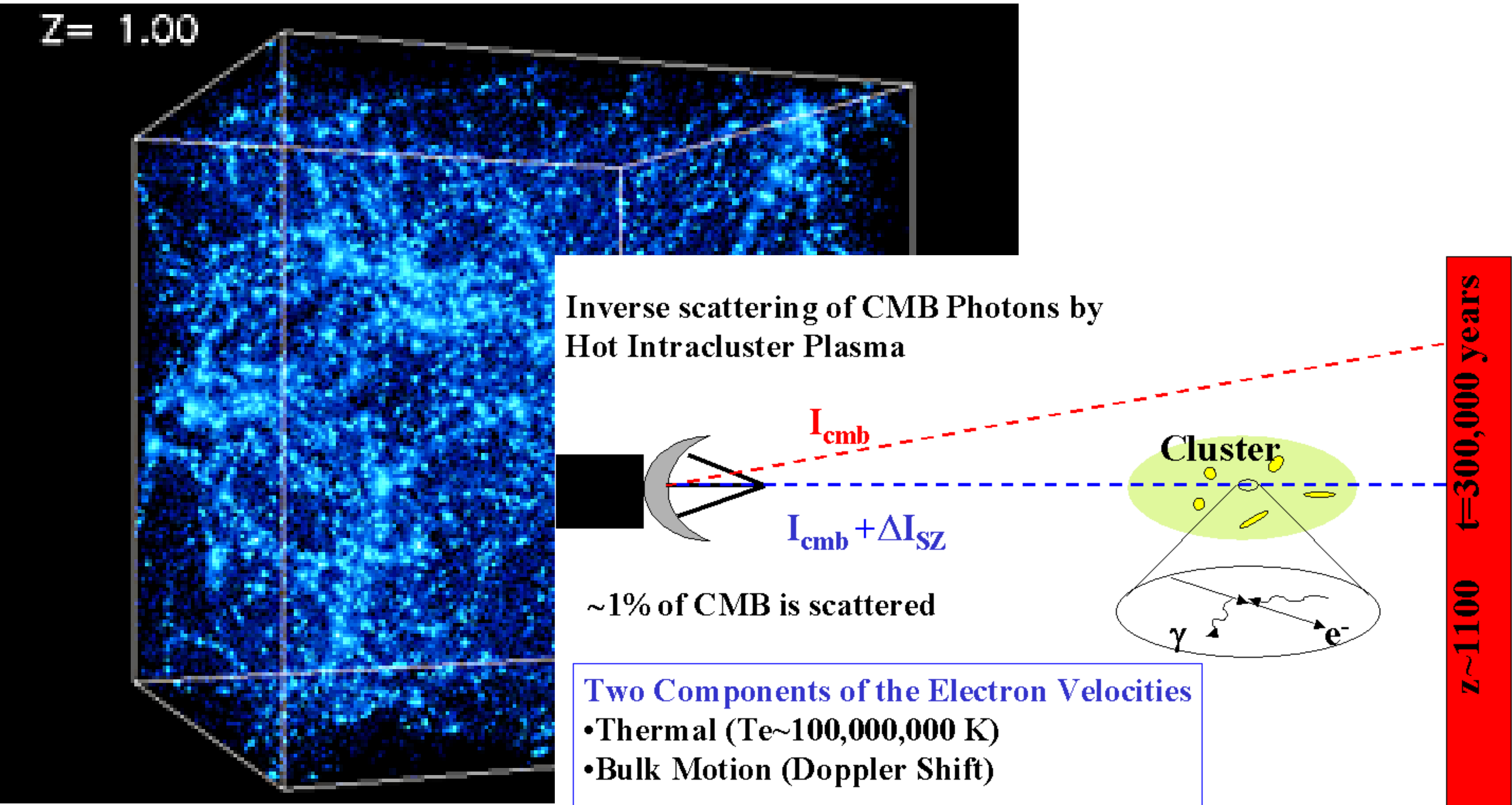
Since 9/2010: 42 new Herschel-selected SMGs det. w/ **CARMA** (27 ”blind” CO z) (z~1.0-4.4)

• More than tripled no. CO-detected SMGs

-Follow up high-resolution *ALMA* imaging, sample lensed by x5-10

The Formation and Evolution of Clusters

The cosmic background radiation gives rise to a unique probe of the mass and mass distribution of clusters of galaxies. This give insights into the formation and evolution of the largest structures in the Universe.

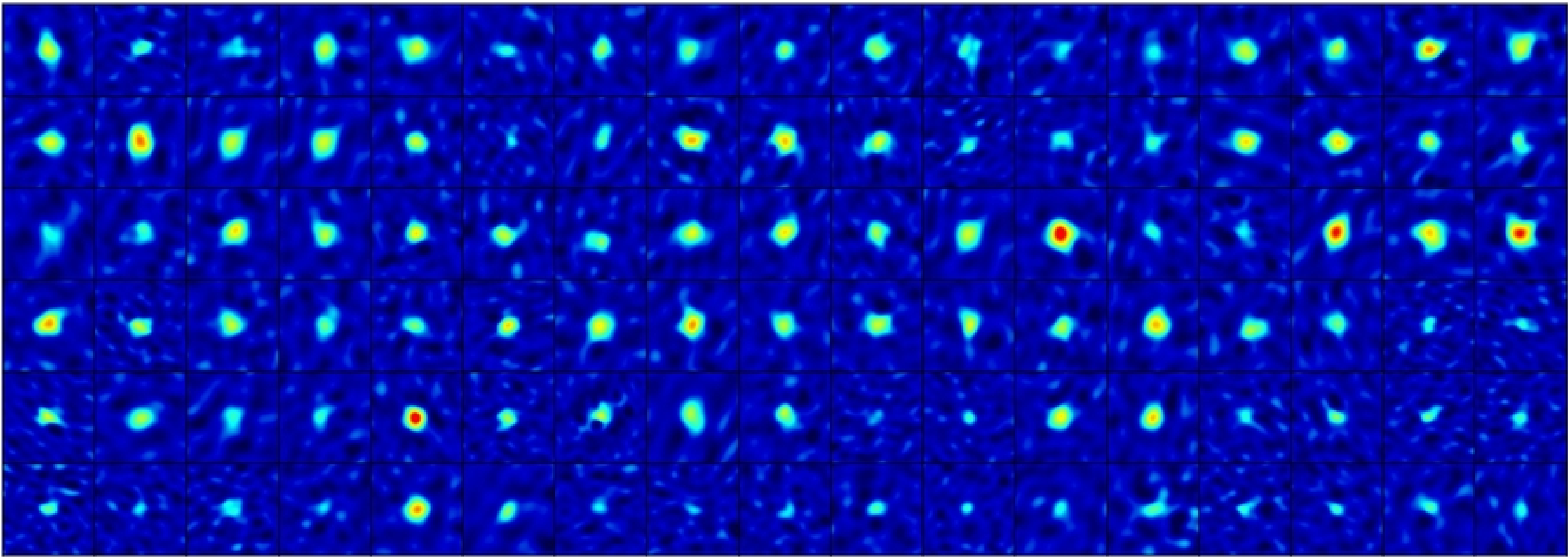


The Formation and Evolution of Clusters

CARMA has been extremely successful in detecting SZ effect in clusters.

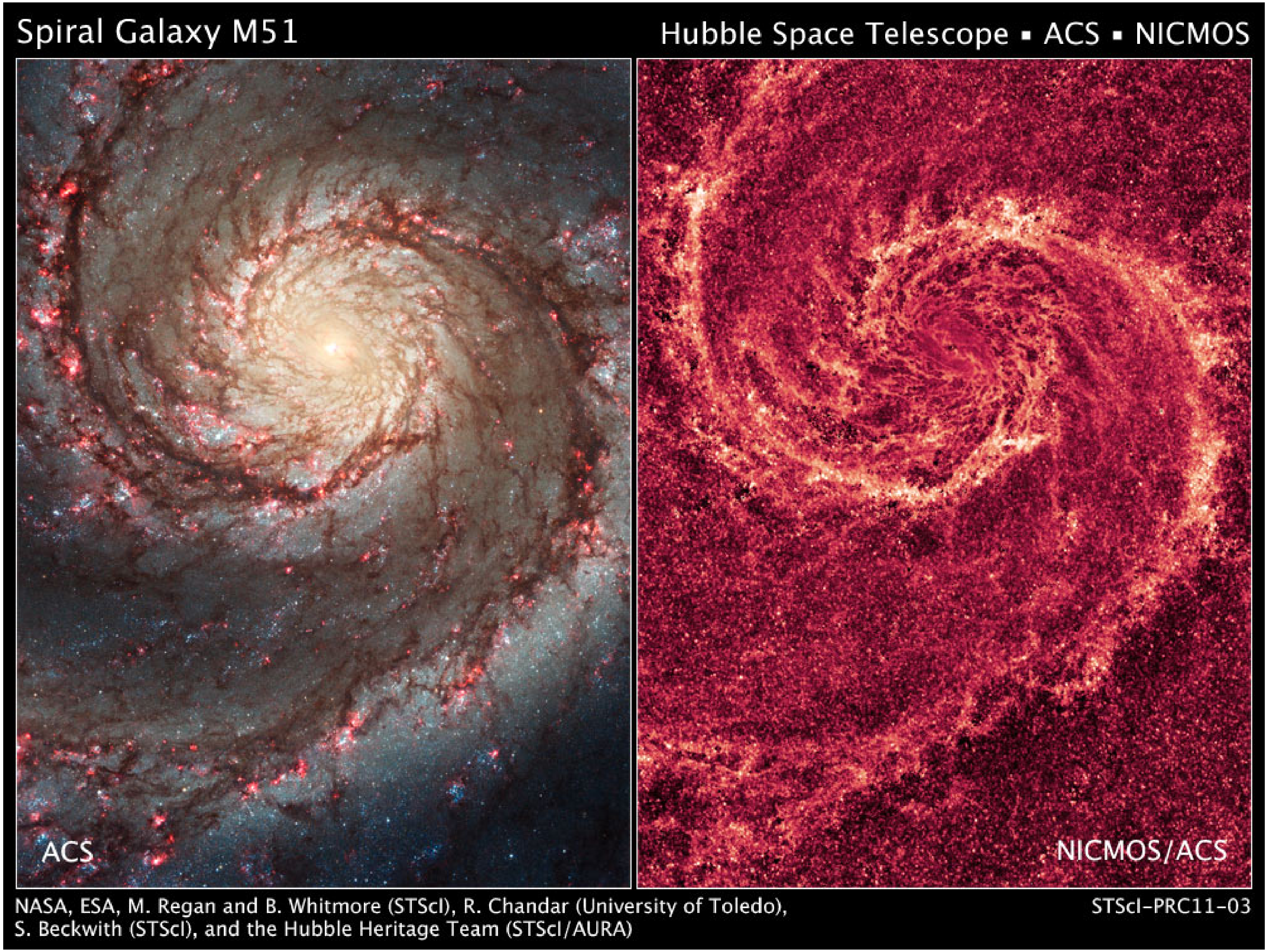
The current big interest is in finding the most distant, most massive clusters because their existence in the early the Universe challenges the standard model for the formation of structure in the Universe.

Look for a press release early next week.

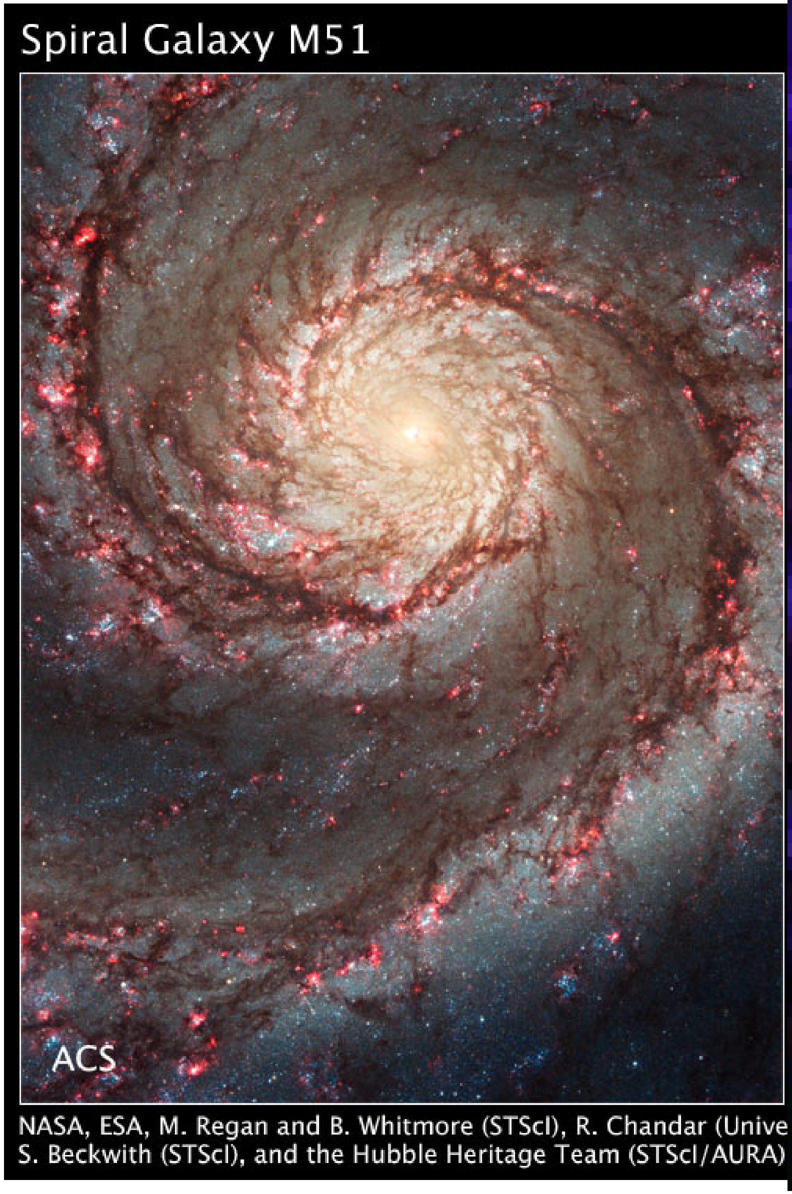


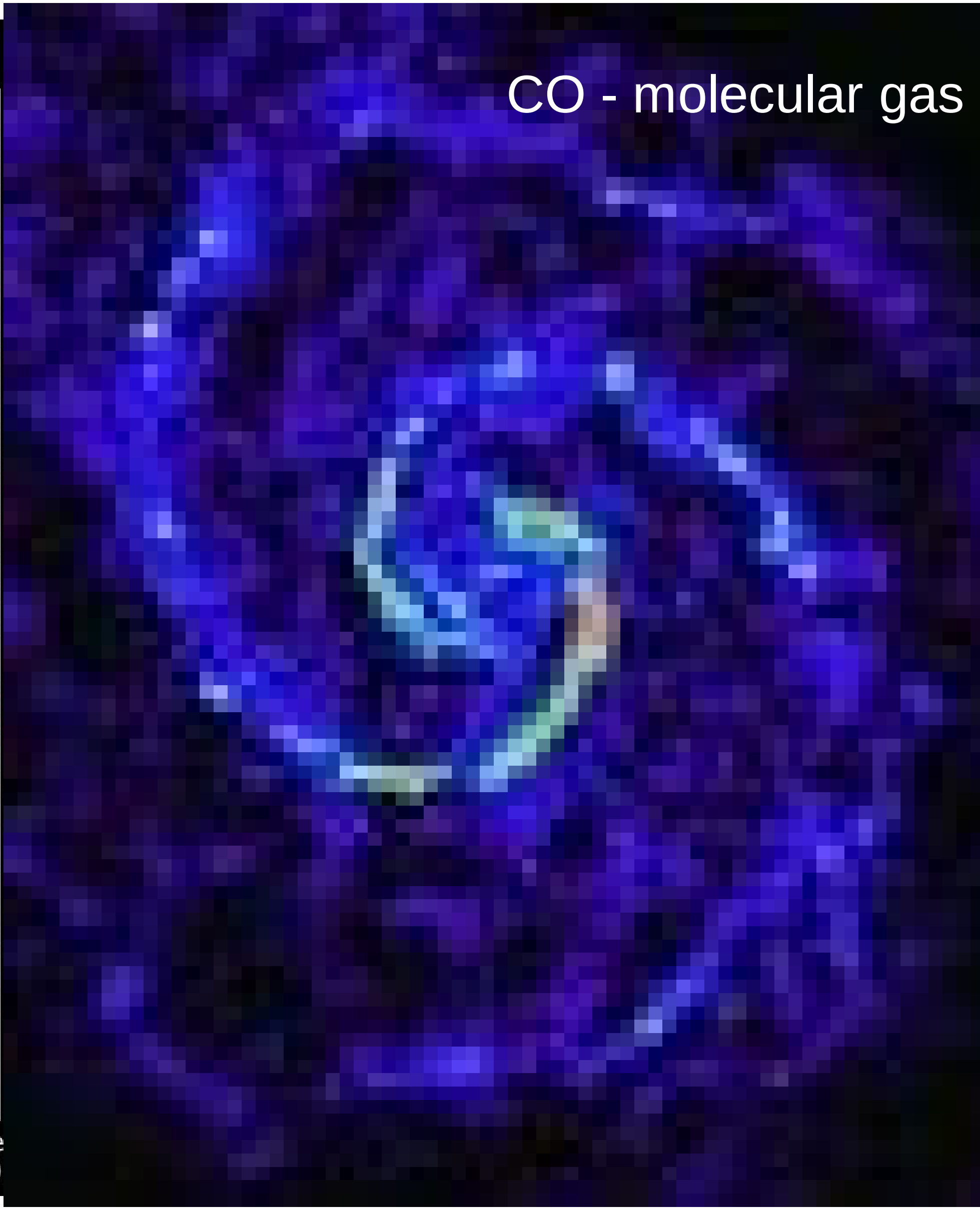
Sample of 102 SZA Sunyaev-Zel'dovich observations
(z up to 1.07; 2 x 10^{14} M_o to 2 x 10^{15} M_o)

Star formation in Galaxies

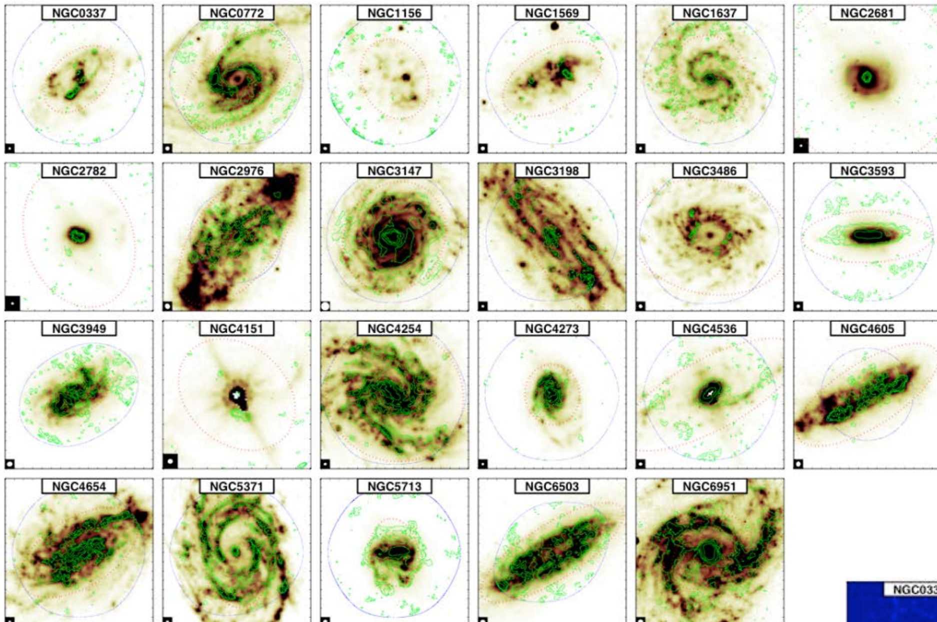


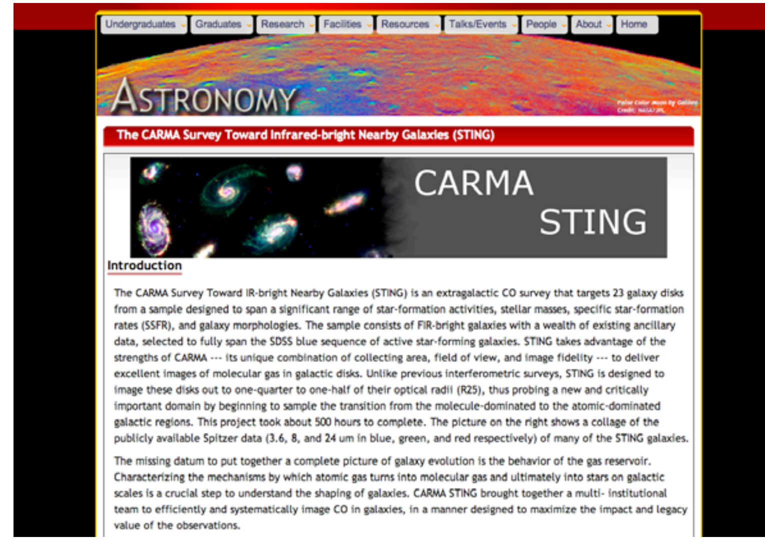
Star formation in Galaxies





CARMA STING





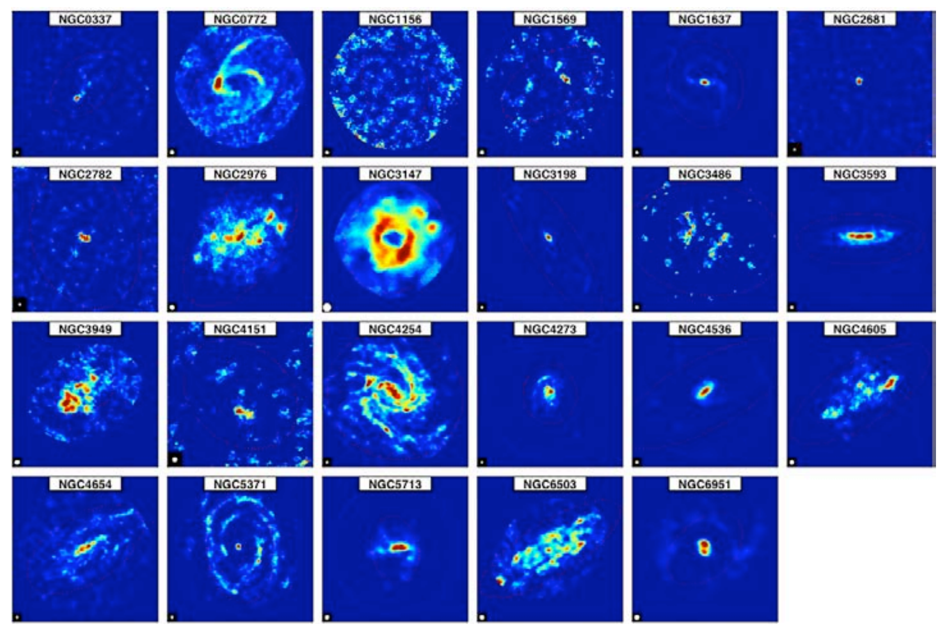
Introduction

The CARMA Survey Toward IR-bright Nearby Galaxies (STING) is an extragalactic CO survey that targets 23 galaxy disks from a sample designed to span a significant range of star-formation activities, stellar masses, specific star-formation rates (SSFR), and galaxy morphologies. The sample consists of FIR-bright galaxies with a wealth of existing ancillary data, selected to fully span the SDSS blue sequence of active star-forming galaxies. STING takes advantage of the strengths of CARMA --- its unique combination of collecting area, field of view, and image fidelity --- to deliver excellent images of molecular gas in galactic disks. Unlike previous interferometric surveys, STING is designed to image these disks out to one-quarter to one-half of their optical radii (R25), thus probing a new and critically important domain by beginning to sample the transition from the molecule-dominated to the atomic-dominated galactic regions. This project took about 500 hours to complete. The picture on the right shows a collage of the publicly available Spitzer data (3.6, 8, and 24 um in blue, green, and red respectively) of many of the STING galaxies.

The missing datum to put together a complete picture of galaxy evolution is the behavior of the gas reservoir. Characterizing the mechanisms by which atomic gas turns into molecular gas and ultimately into stars on galactic scales is a crucial step to understand the shaping of galaxies. CARMA STING brought together a multi- institutional team to efficiently and systematically image CO in galaxies, in a manner designed to maximize the impact and legacy value of the observations.

http://www.astro.umd.edu/STING

- Multi-institutional effort
- 500 hrs. of observations, 23 galaxies
- Data released to the community through website (it was used as one of the CASA tutorials by NRAO)
- Two ApJ papers out, 4 in preparation

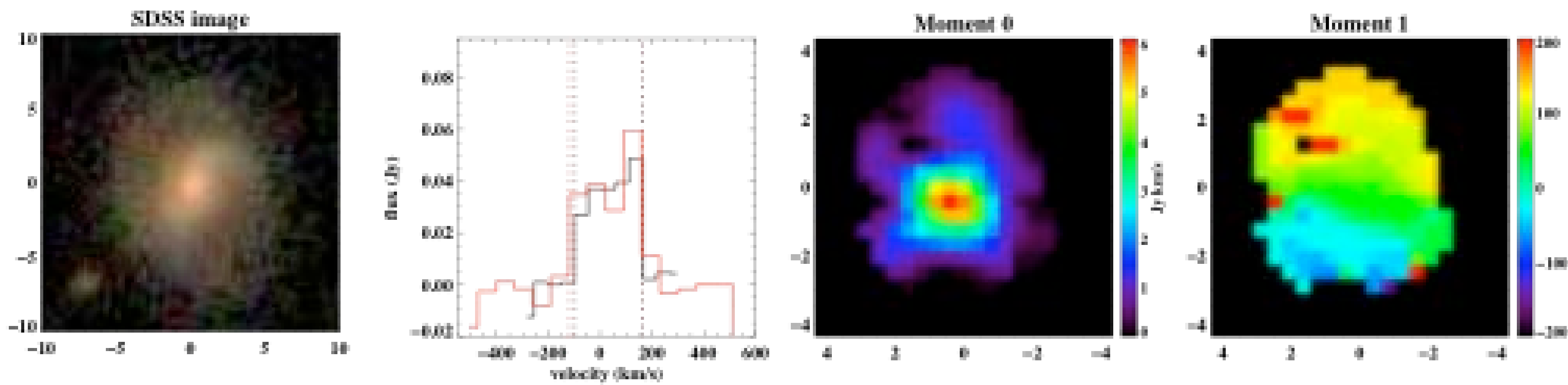


PI: A. Bolatto (UMd), T. Wong (UIUC), L. Blitz (UCB), A. Leroy (NRAO), F. Walter (MPIA), A. West (BU), D. Calzetti (UMASS), J. Ott (NRAO), E. Rosolowsky (UBC), S. Vogel (UMd), N. Rahman (UMd), F. Bigiel (Heidelberg), D. Fisher (UMd)

Evolution of molecular Gas in Normal Galaxies (EGNoG)

- CARMA "large project" proposal call from May (375 hours)
- Systematic survey of intermediate z molecular fractions at z~0.05-0.53
  - Complementary to existing z~1-2 surveys
  - Galaxies selected to be representative of the "main sequence" at those redshifts
- Nearly completed survey of 27 galaxies

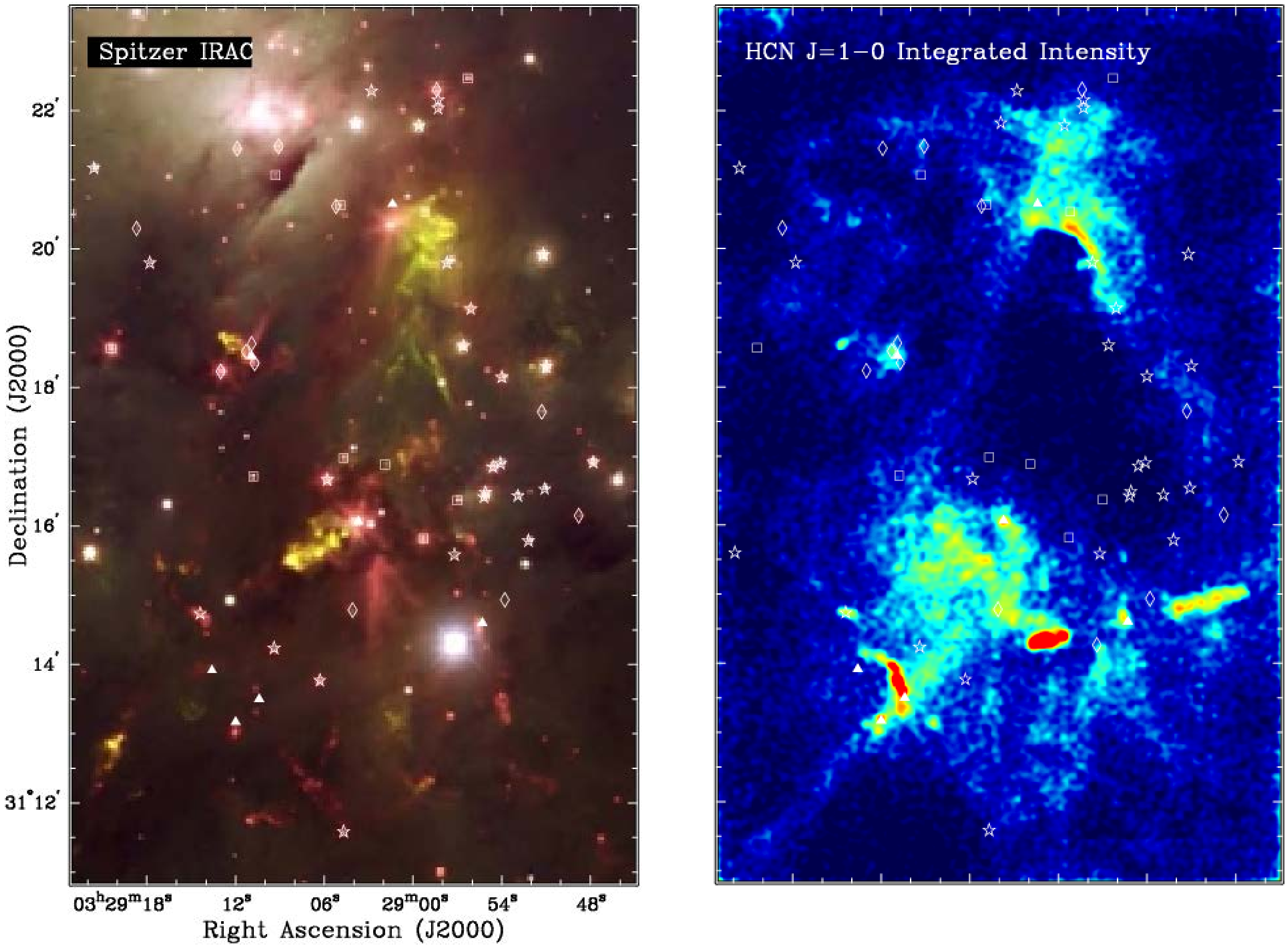
PI: A. Bauermeister (UCB), L. Blitz (UCB), A. Bolatto (UMd), M. Bureau (Oxford), T. Wong (UIUC), A. Leroy (NRAO), M. Wright (UCB), E. Ostriker (UMd), P. Teuben (UMd)



Physics of star formation

Combined Array for Research in Millimeter-Wave Astronomy

23-element CARMA – 527 pointings with 5” resolution of the NGC 1333 SVS 13 Region

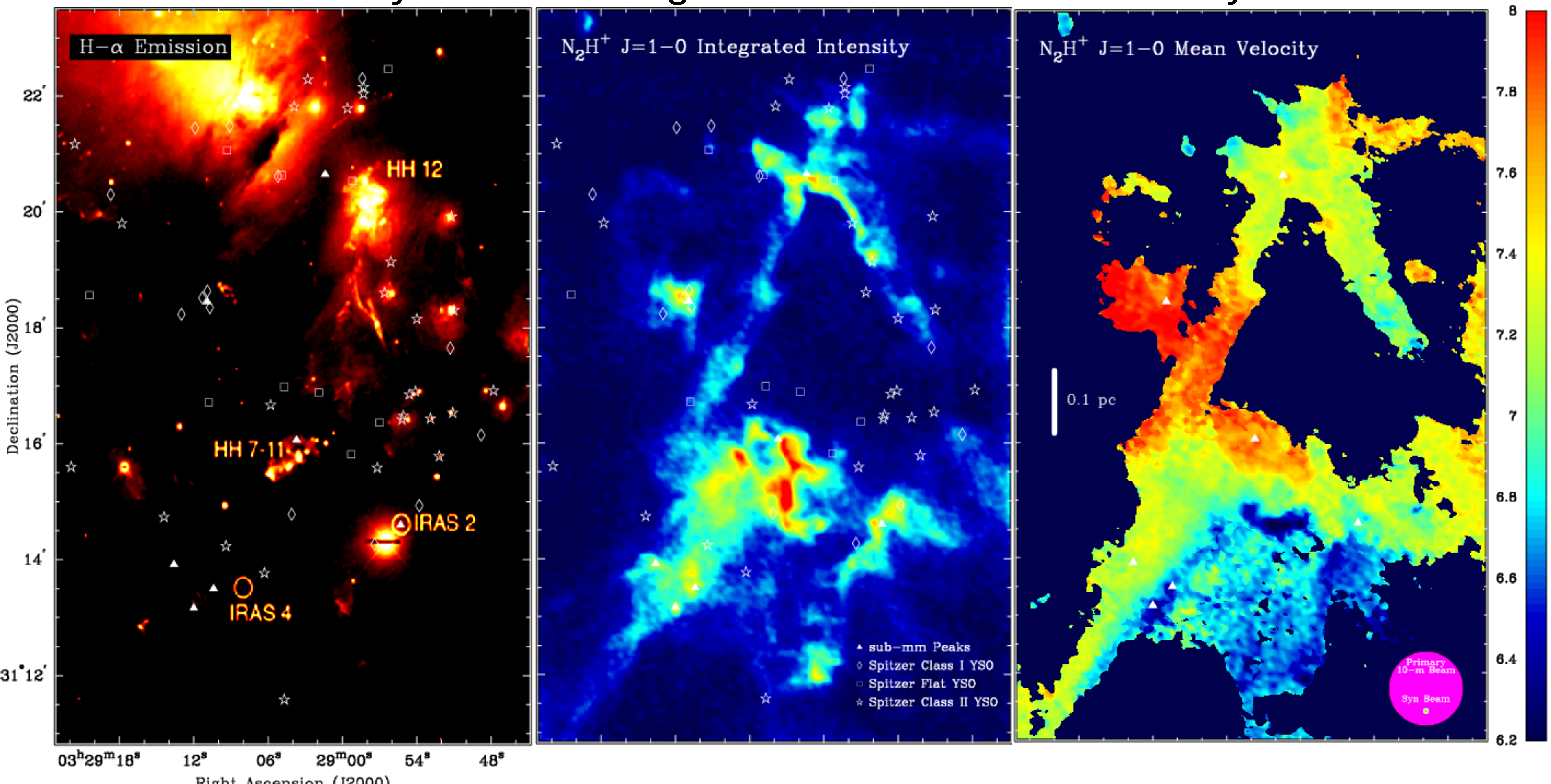


Physics of star formation

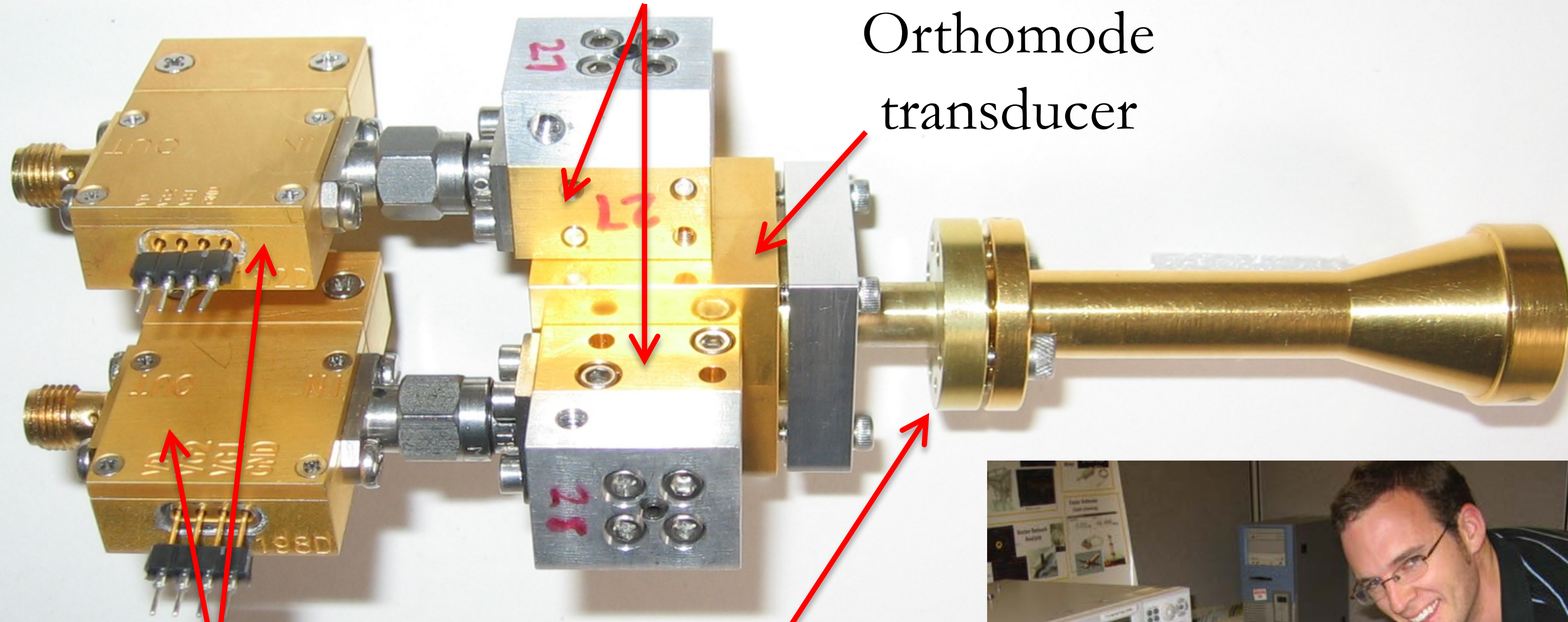
CARMA
Combined Array for Research in Millimeter-Wave Astronomy

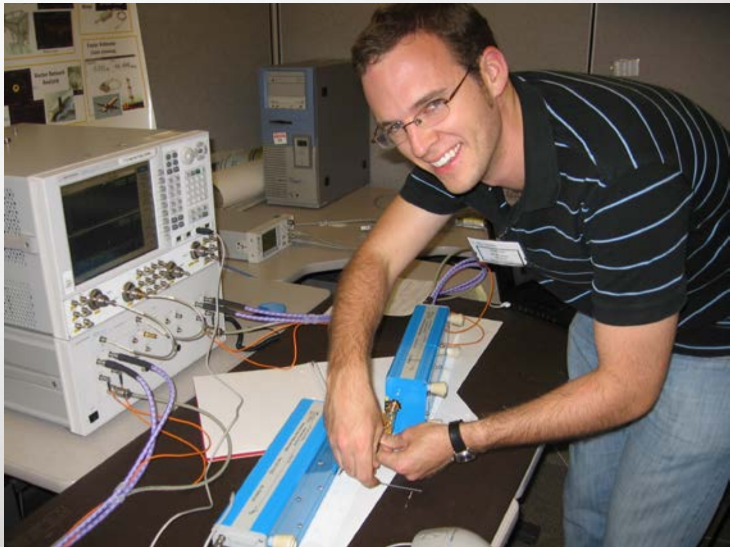
Large scale maps the molecular gas and kinematics, the YSO distribution and dust continuum emission

CLASSy: CARMA Large Area Star-formation Survey



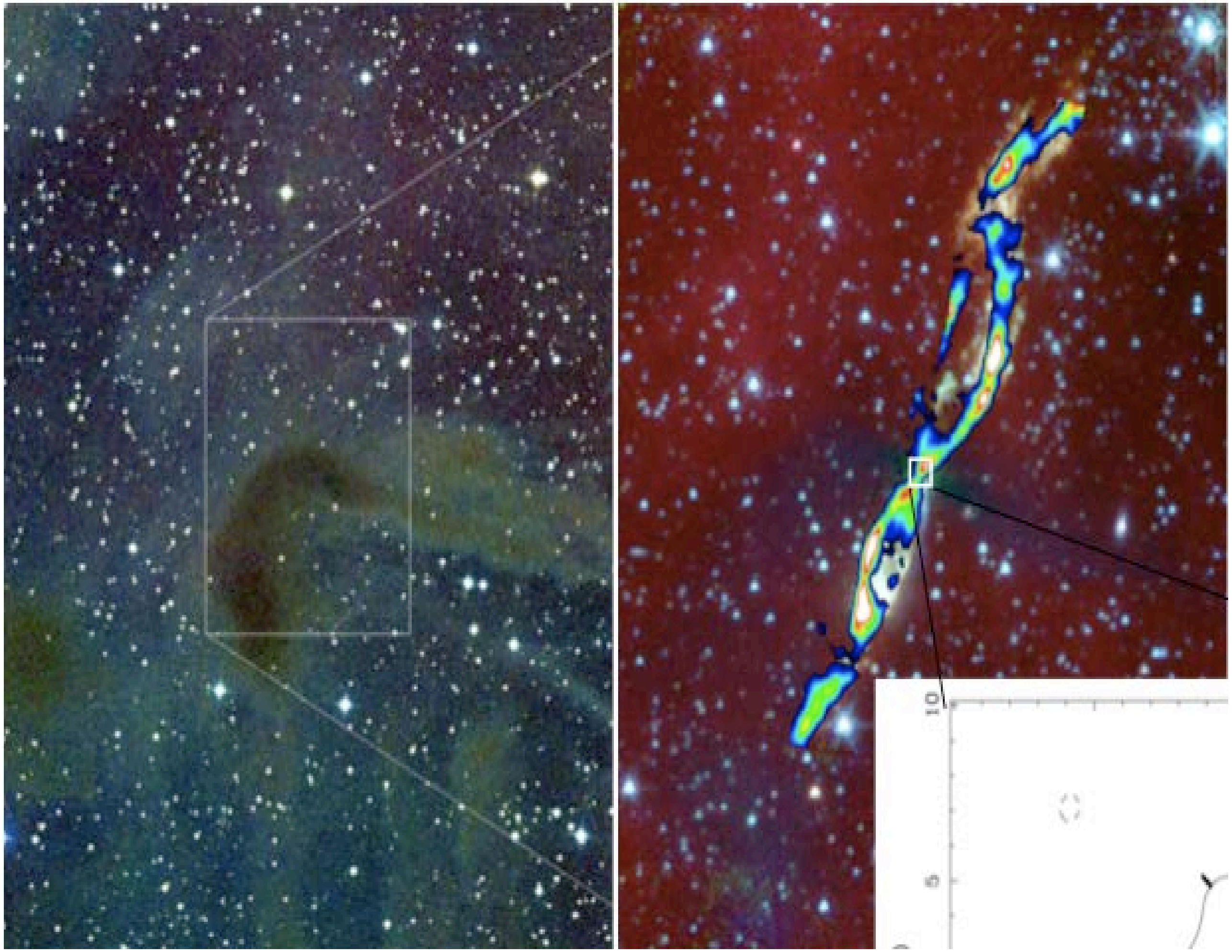
1 mm Dual-polarization Receivers





L1157: Magnetic fields and star formation

Stars form in molecular gas clouds in our galaxy. Their formation is a messy affair involving turbulent and magnetic fields, accretion of gas onto the forming star and ejection of gas at 10’s to 100’s of km/sec in polar jets.

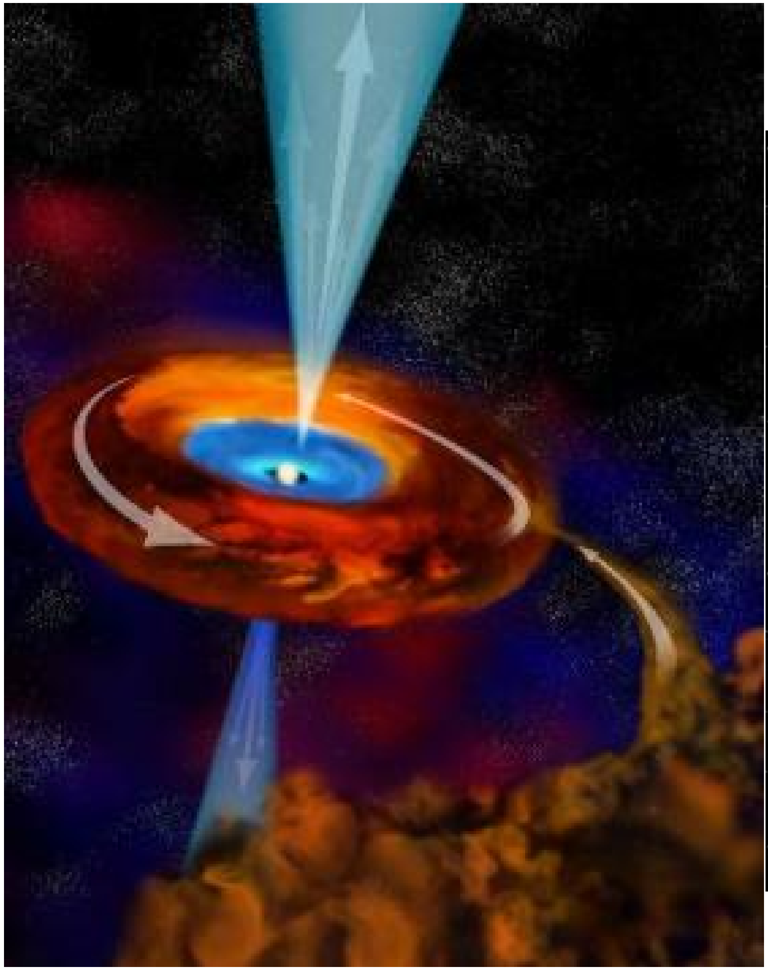


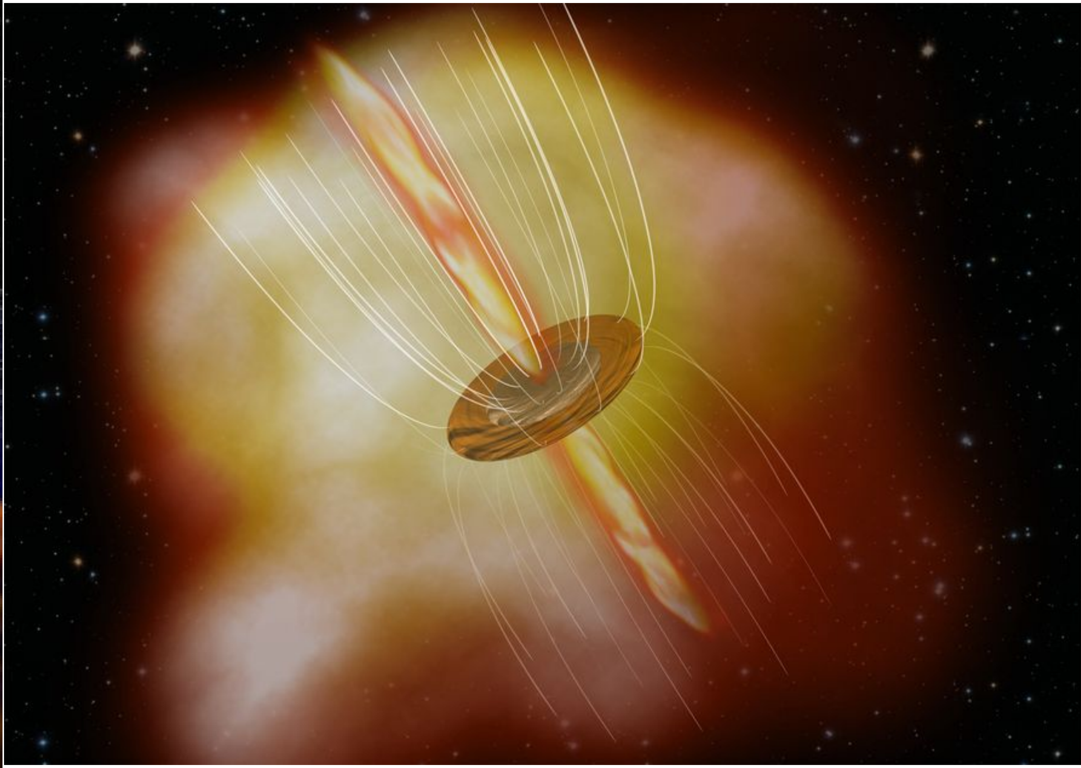
L1157: Magnetic fields and star formation

CARMA

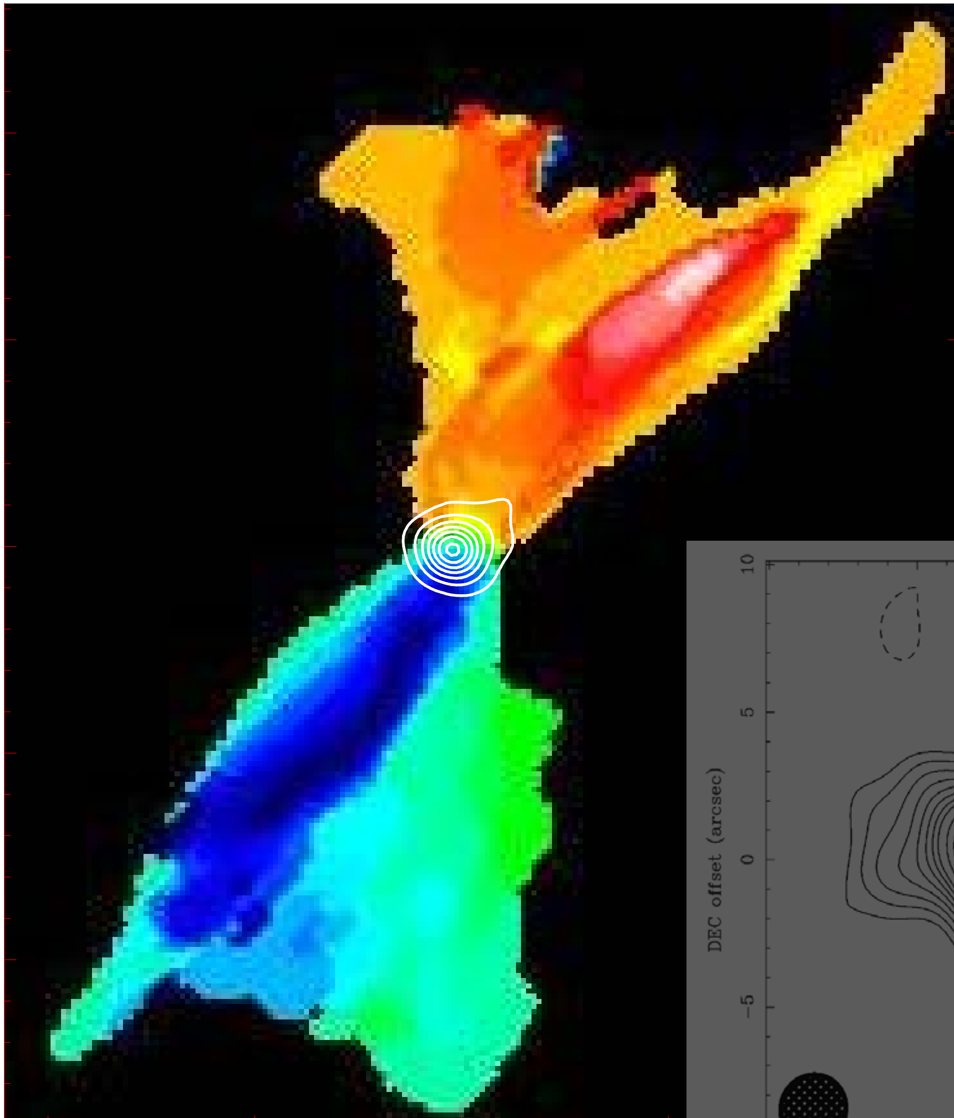
Combined Array for Research in Millimeter-Wave Astronomy

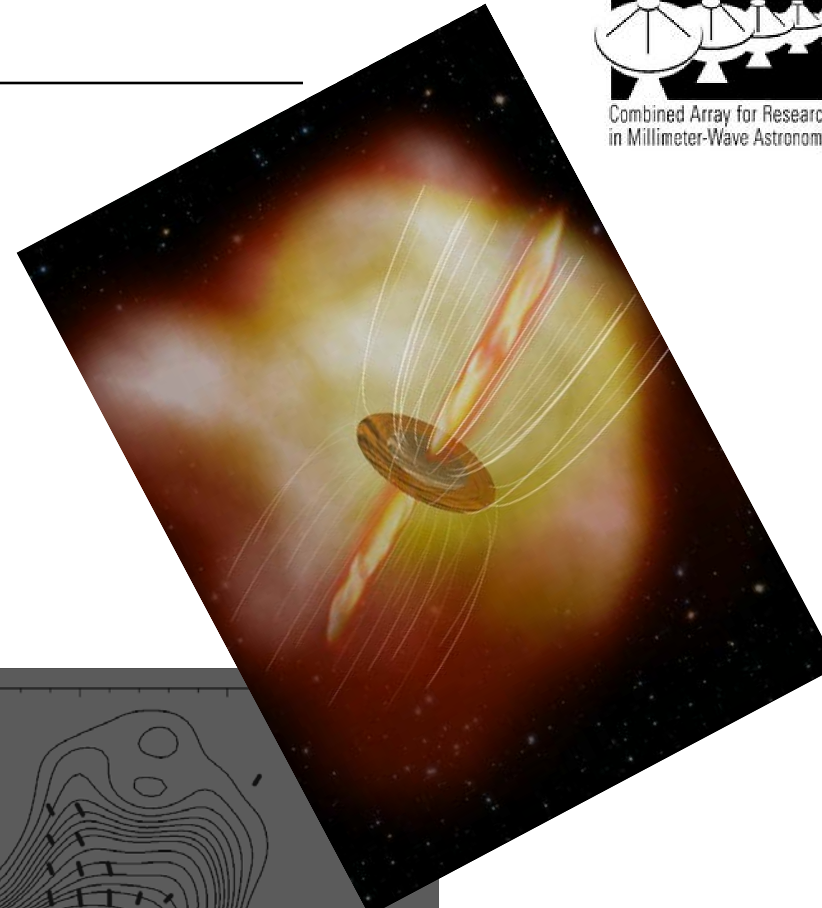
Stars form in molecular gas clouds in our galaxy. Their formation is a messy affair involving turbulent and magnetic fields, accretion of gas onto the forming star and ejection of gas at 10’s to 100’s of km/sec in polar jets.

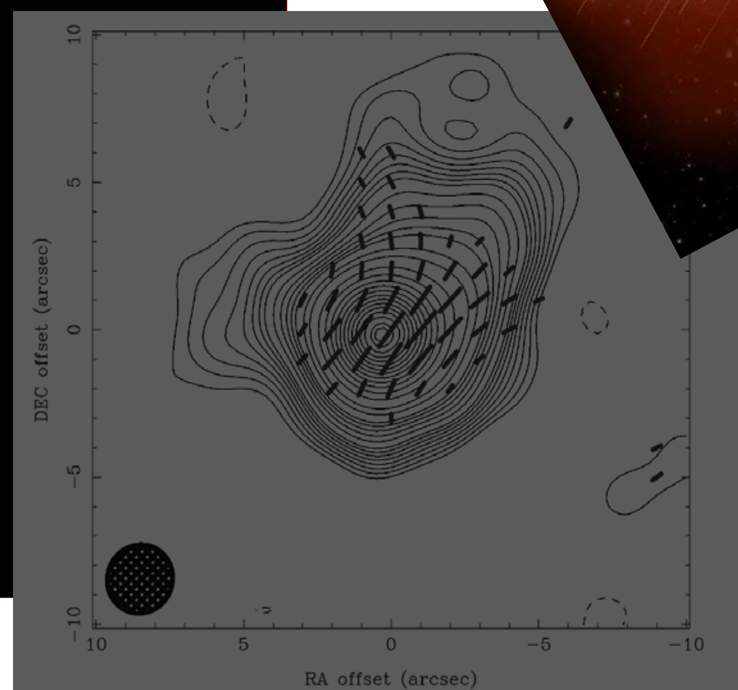




L1157

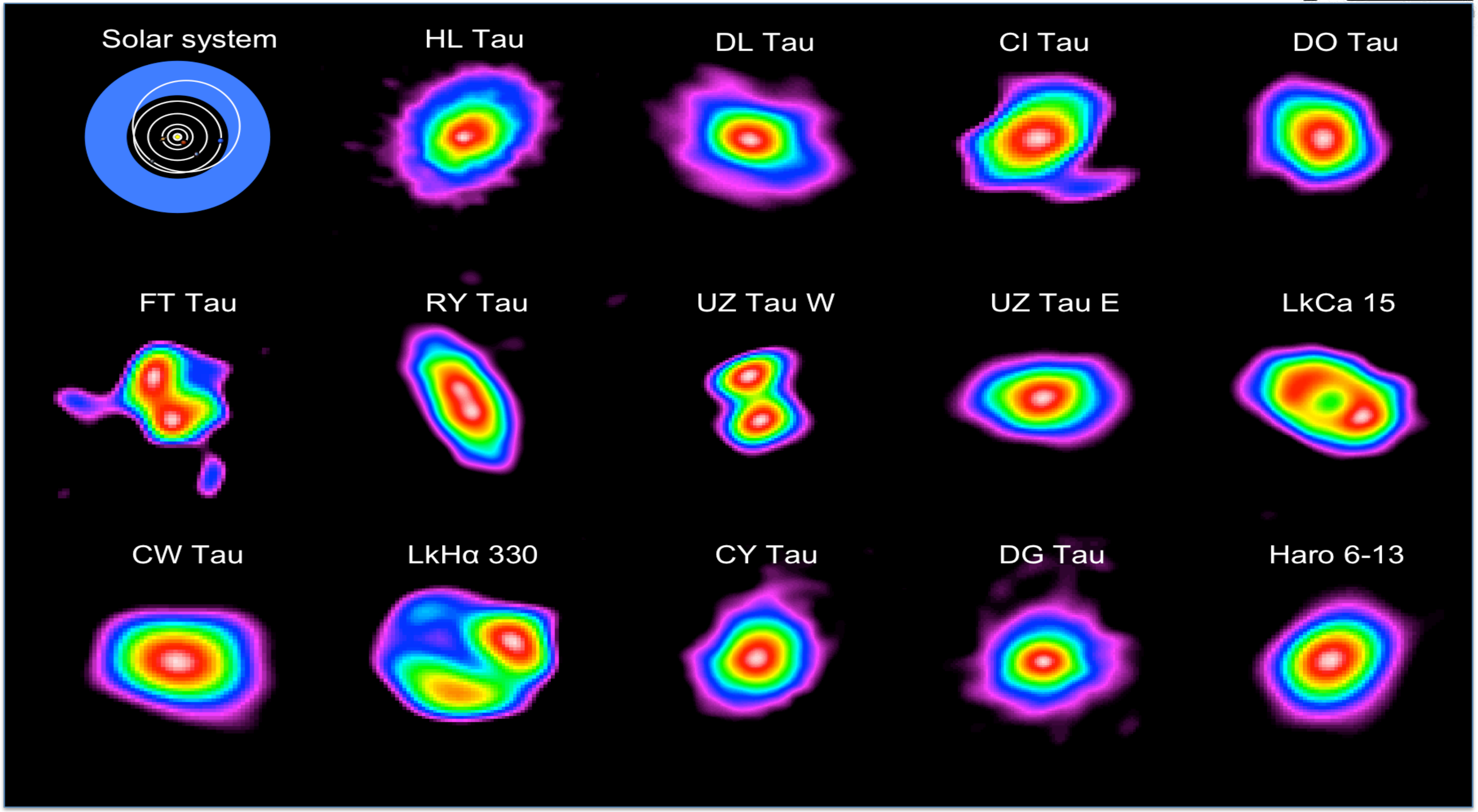






CARMA
Combined Array for Research in Millimeter-Wave Astronomy

Emission from Dust in Circumstellar Disks



Images courtesy of: Resolution = 0.15” to 0.35”

Andrea Isella, Laura Perez, John Carpenter, Woojin Kwon

The Uniqueness of CARMA

Cedar Flat: Array location and operations center

Owens Valley Radio Observatory: Technical development, fabrication and home base for CARMA Staff (labs, machine shop, offices, dorms)

Caltech: Receiver and technology development

Radio Astronomy Laboratory Berkeley: Technical development and fabrication

Laboratory for Astronomical Imaging Illinois: Proposal/Data handing, archiving, and pipeline analysis

Laboratory for Millimeter-Wave Astronomy Maryland: Realtime and correlator software, and data reduction software support

University of Chicago: Technical development and fabrication

Science groups at all five sites!

The Uniqueness of CARMA

Combined Array for Research in Millimeter-Wave Astronomy

A hands-on training/learning instrument:

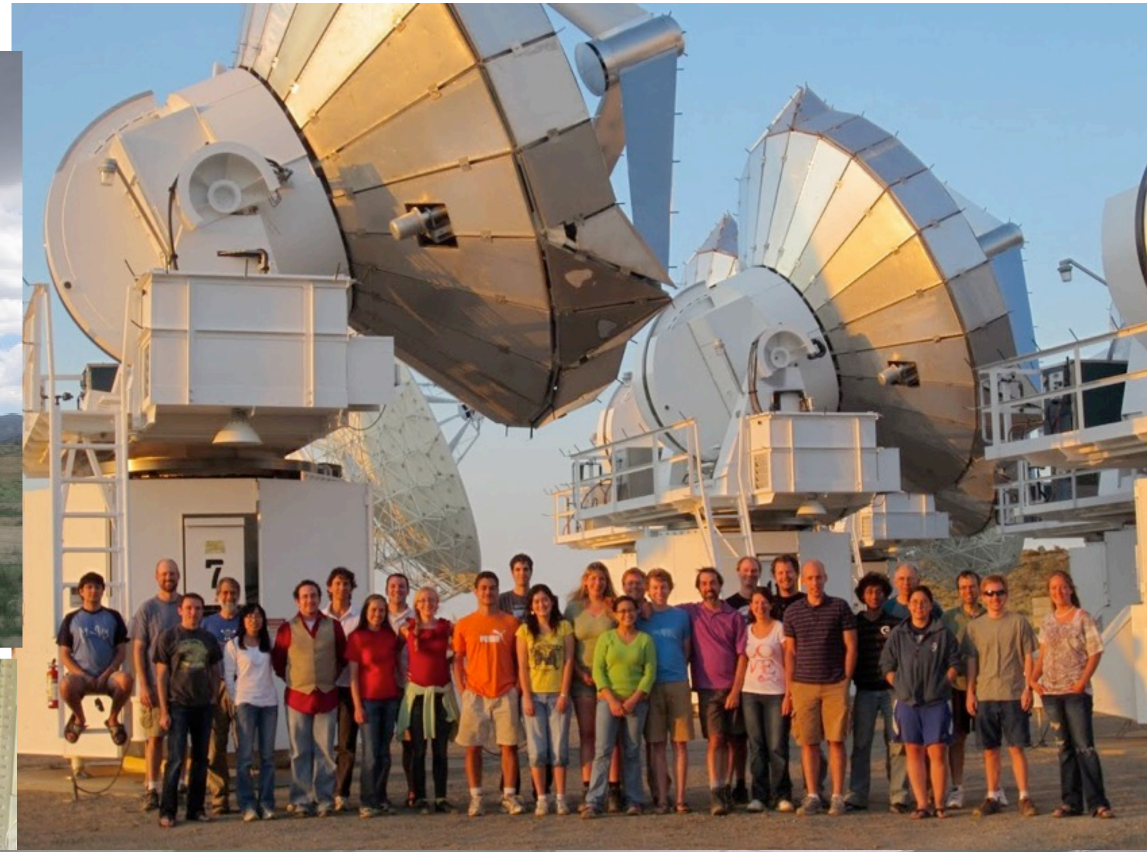
Students and postdocs operate the telescope and participate in realtime trouble shooting

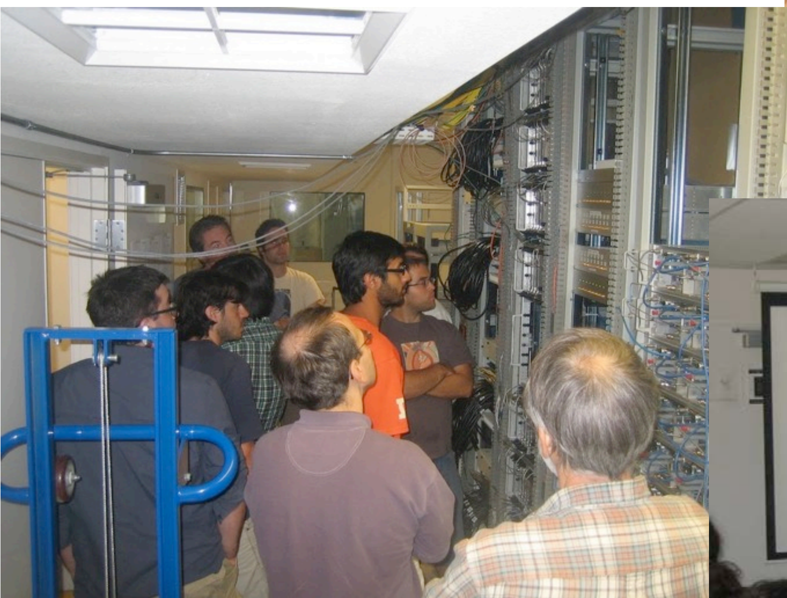
Student assigned array calibration tasks: baselines, pointing, correlator health, flux calibration

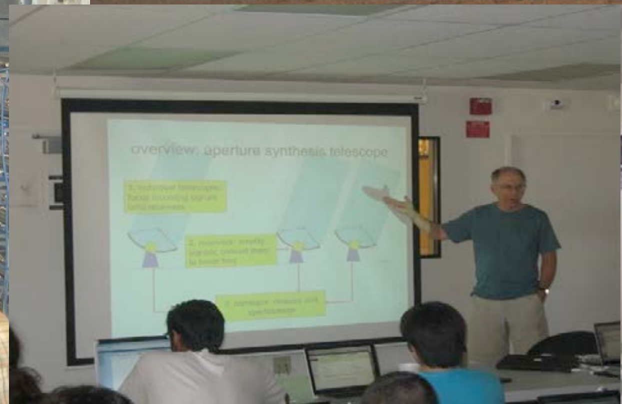
Student become involved in development projects:

C-PACS (Perez; Perez, Zauderer, Culverhouse)
full stokes (Hull)
1-cm receivers (Abdulla, Buckner, Morgan, Zablocki)
FPGA/correlator (Amit Bansod, Glenn Jones)
User software tools (Dalton Wu, Nick Hakobian)
Phasing for VLBI (Brinkerink)

CARMA Summer School







CARMA’s Role into the Future

Combined Array for Research in Millimeter-Wave Astronomy

Training of the next generation of radio expertise and instrumentalists

- there is no substitute for the inspiration of project ownership
- broad university base draws in students and resources
- ease of access and educational mindset of personnel enables participation

Test bed for innovative instrumentation, techniques, and science

- small size and flexibility of CARMA encourages innovation and experimentation
- ability to set aside array time for instrument development
- highly talented and motivated observatory personnel to support efforts

CARMA’s Role into the Future

Science:

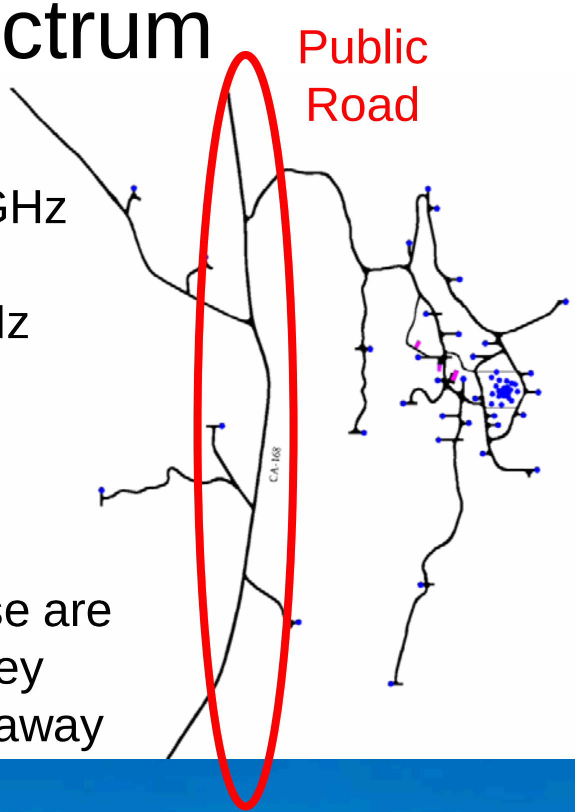
- ❖ Key Projects: large scale projects to create science and data products for the community. Feeds ALMA

- ❖ Exploratory science: new idea, new ways to use the array

- ❖ VLBI Projects with ALMA and SMA

- ❖ Enable the U.S. community to get the best from ALMA

CARMA and the Radio Spectrum



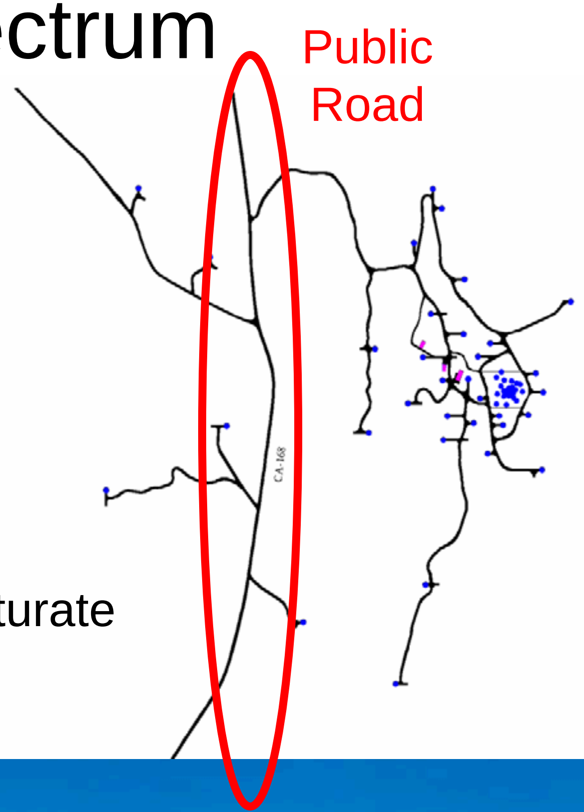
Operating frequencies: 28-34 GHz, 75-115 GHz, 210-270 GHz

10's of workhorse spectral lines at 75-115 and 210-270 GHz

100's of molecular lines of scientific interest spread through both bands

Half-dozen critical spectral lines to study the distant universe are red-shifted by the expansion of the Universe so they appear across the bands – depending on how far away the object is!

CARMA and the Radio Spectrum



Observatory is in Inyo National Forest – fairly isolated

Except for road which connects Owens Valley with Nevada

No cell phone reception

Worries: Car radar

Strong in-band satellite broadcasts that could saturate receivers

CARMA

Combined Array for Research in Millimeter-Wave Astronomy