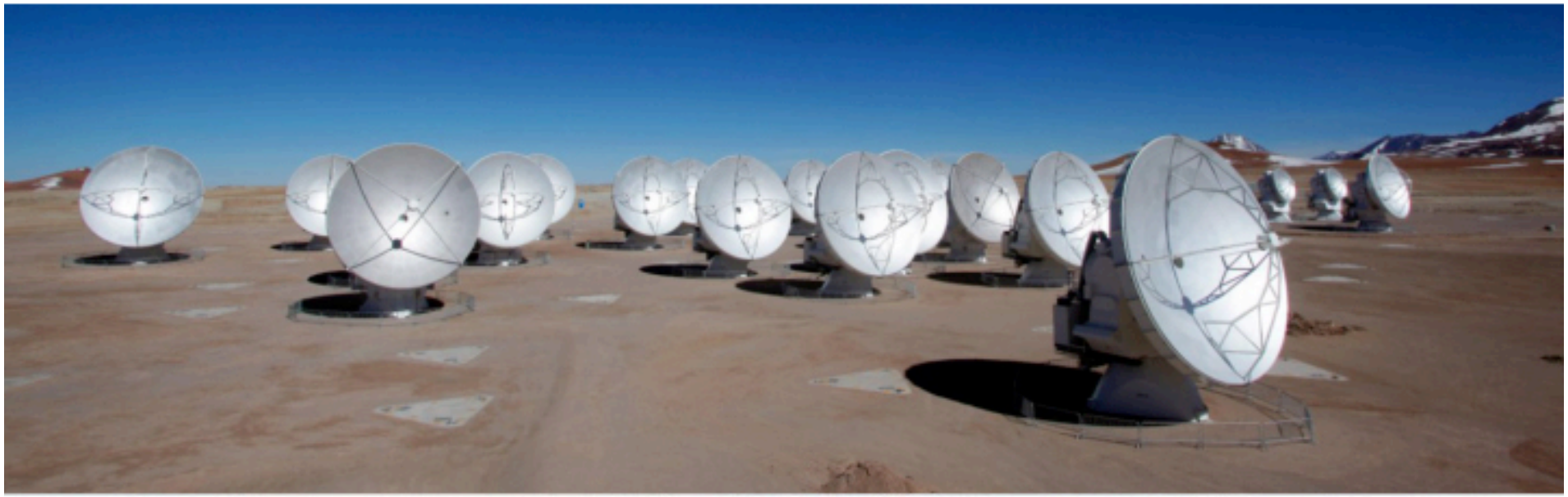
Galaxy Evolution Highlights

Recent results from the NRAO Telescopes



Adam Leroy

North American ALMA Science Center

Atacama Large Millimeter/submillimeter Array

Expanded Very Large Array

Robert C. Byrd Green Bank Telescope

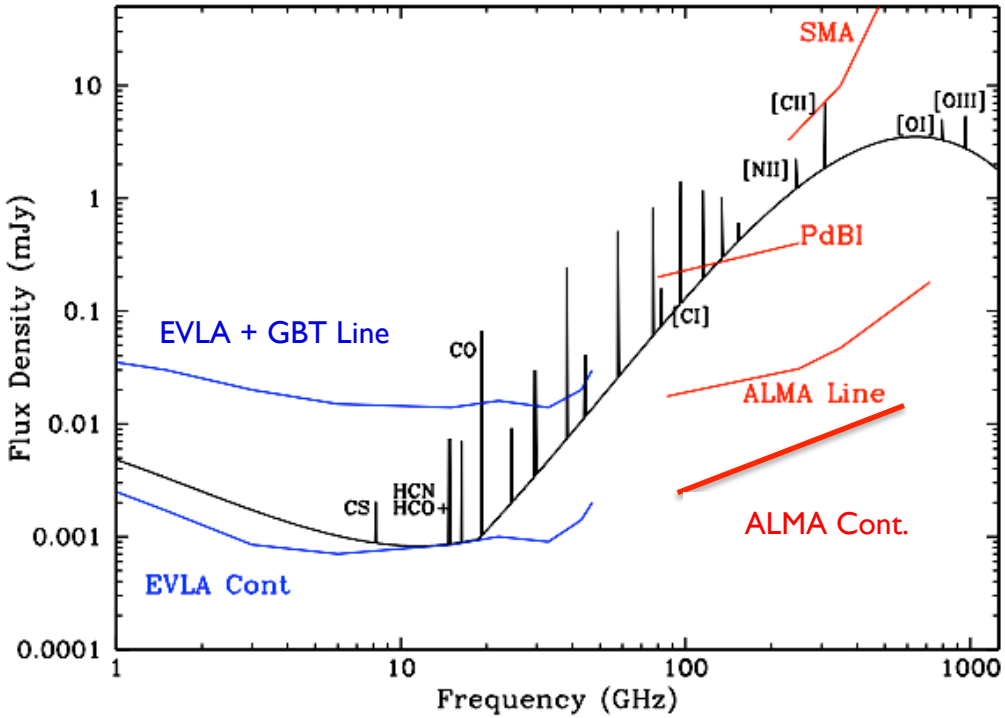
Very Long Baseline Array

NRAO

The "Radio Era" to Study Galaxy Evolution

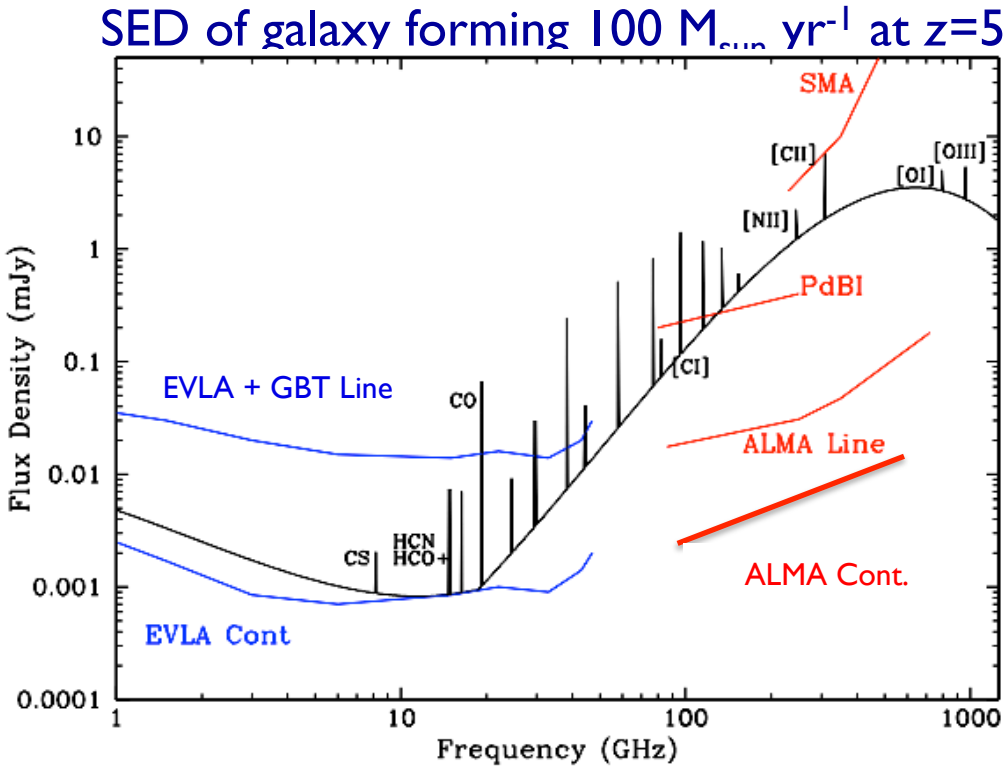
- Stars and star formation studied to z ~ 8, c. 500 Myr after Big Bang
- Major unknown is the distribution and evolution of the cold gas reservoir
- EVLA and ALMA are poised to unveil the fuel for galaxy assembly…

SED of galaxy forming 100 M_{sun} yr^{-1} at z=5

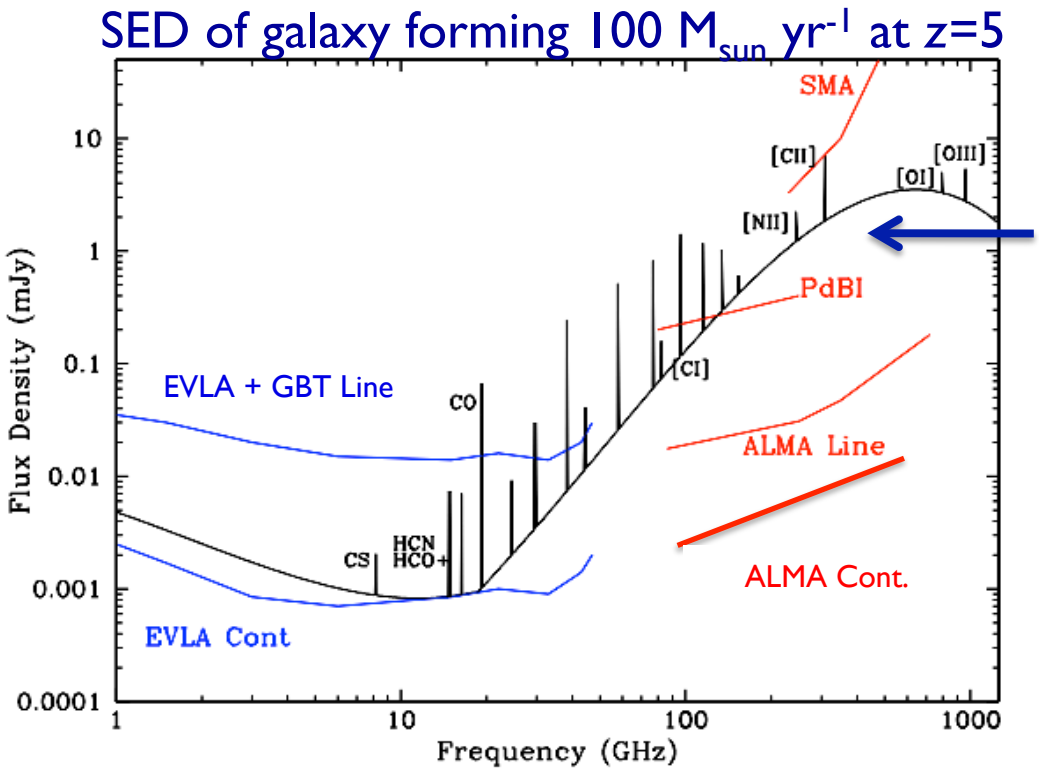


The "Radio Era" to Study Galaxy Evolution

Low-J molecular
- Total H2
- Dense gas
- Dynamics



The "Radio Era" to Study Galaxy Evolution

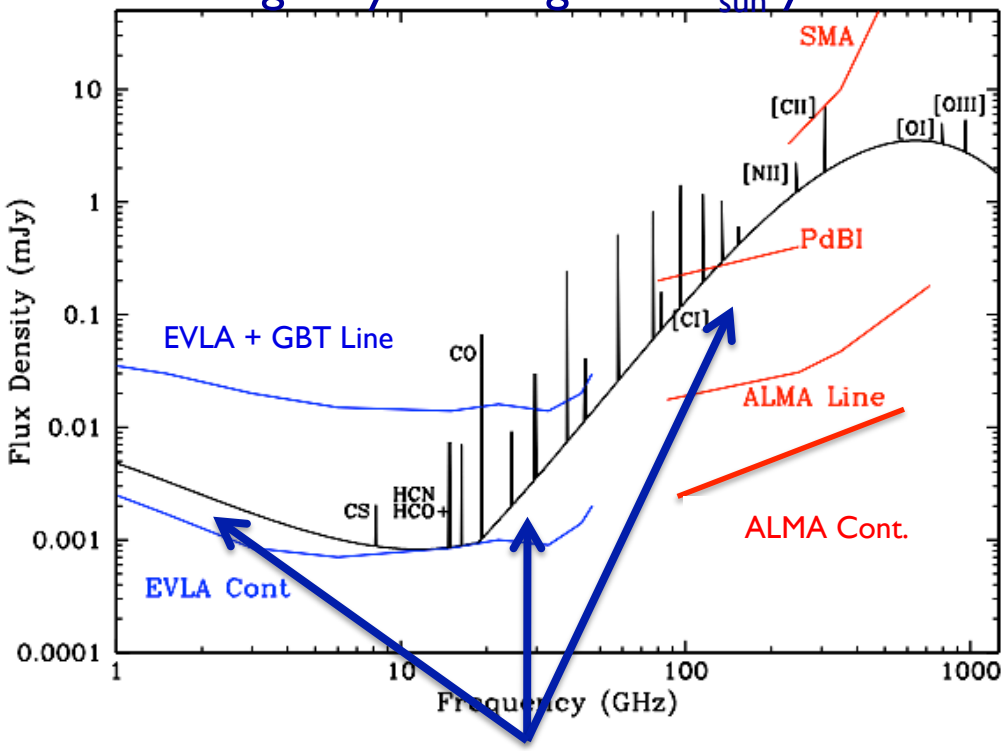


Atomic lines

- ISM coolants
- Distribution
- Conditions
- SFR

The "Radio Era" to Study Galaxy Evolution

SED of galaxy forming 100 M_{sun} yr^{-1} at z=5



Continuum (dust, free-free, synchrotron)

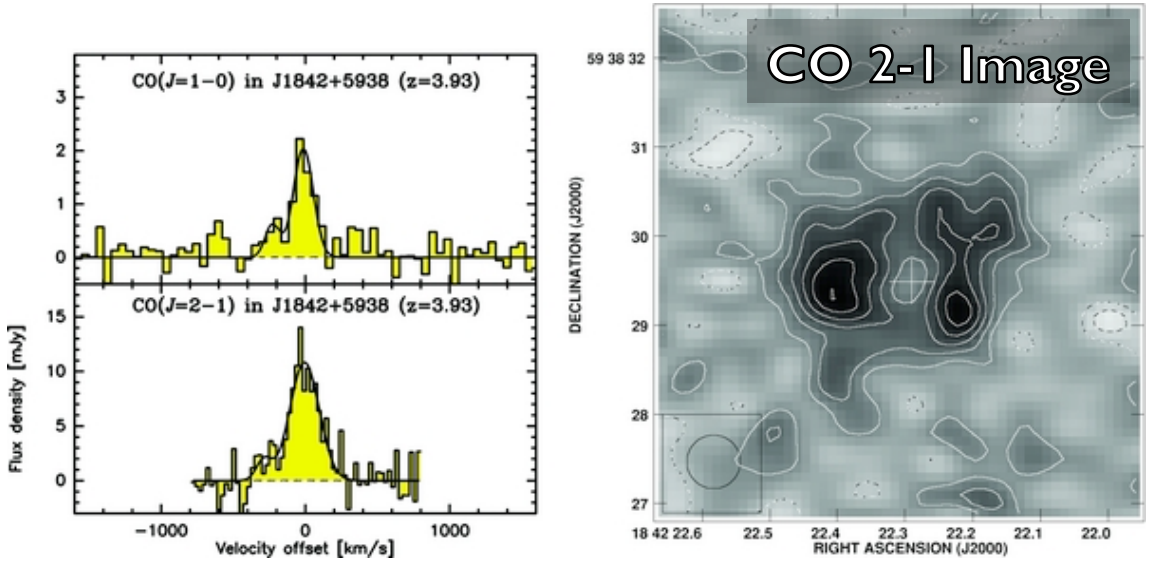
- SFR, ISM distribution, dust abundance

EVLA Images Molecular Gas at High-z

EVLA

- EVLA: a powerful tool to image low CO emission from galaxies at high z.

- Exploring the formation of massive galaxies, clusters, and the evolution of cold gas reservoirs and the molecular gas fraction.



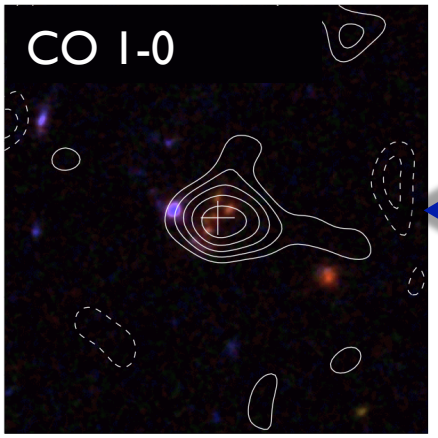
Molecular Einstein Ring Toward SMG MM18423+5938 (z=3.93)

LESTRADE ET AL. (2011)

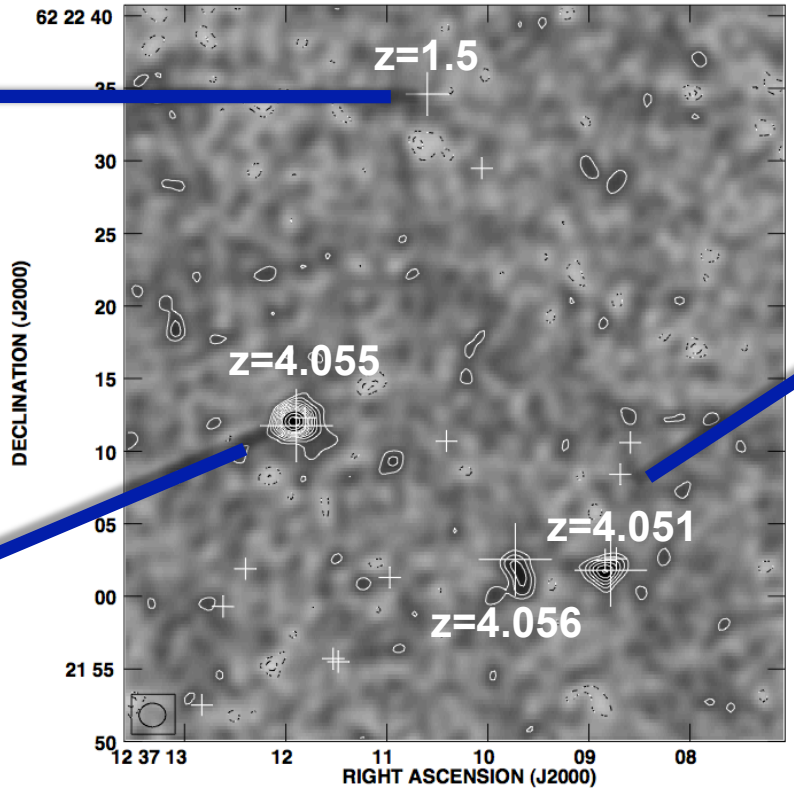
A Molecule-Rich Protocluster

EVLA

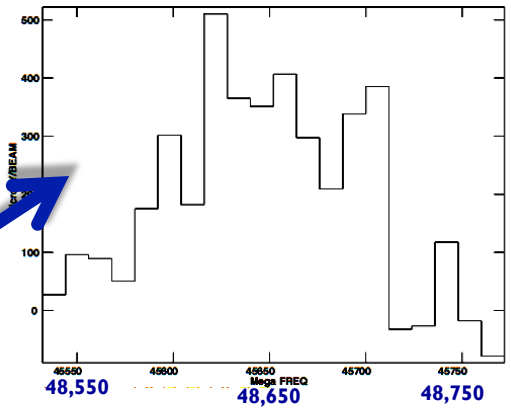
Foreground sBzK galaxy



46 GHz Observations of GN20

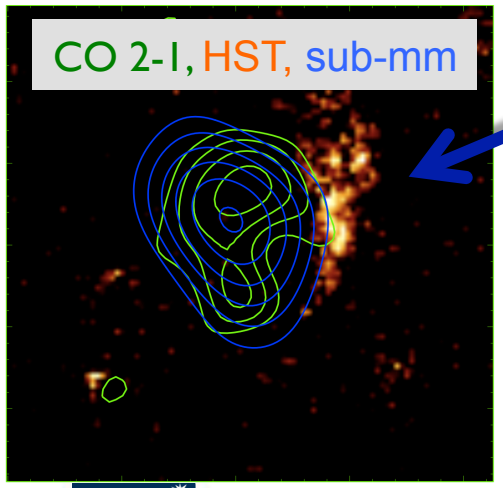


CO 2-1 Spectroscopy



Frequency [MHz]

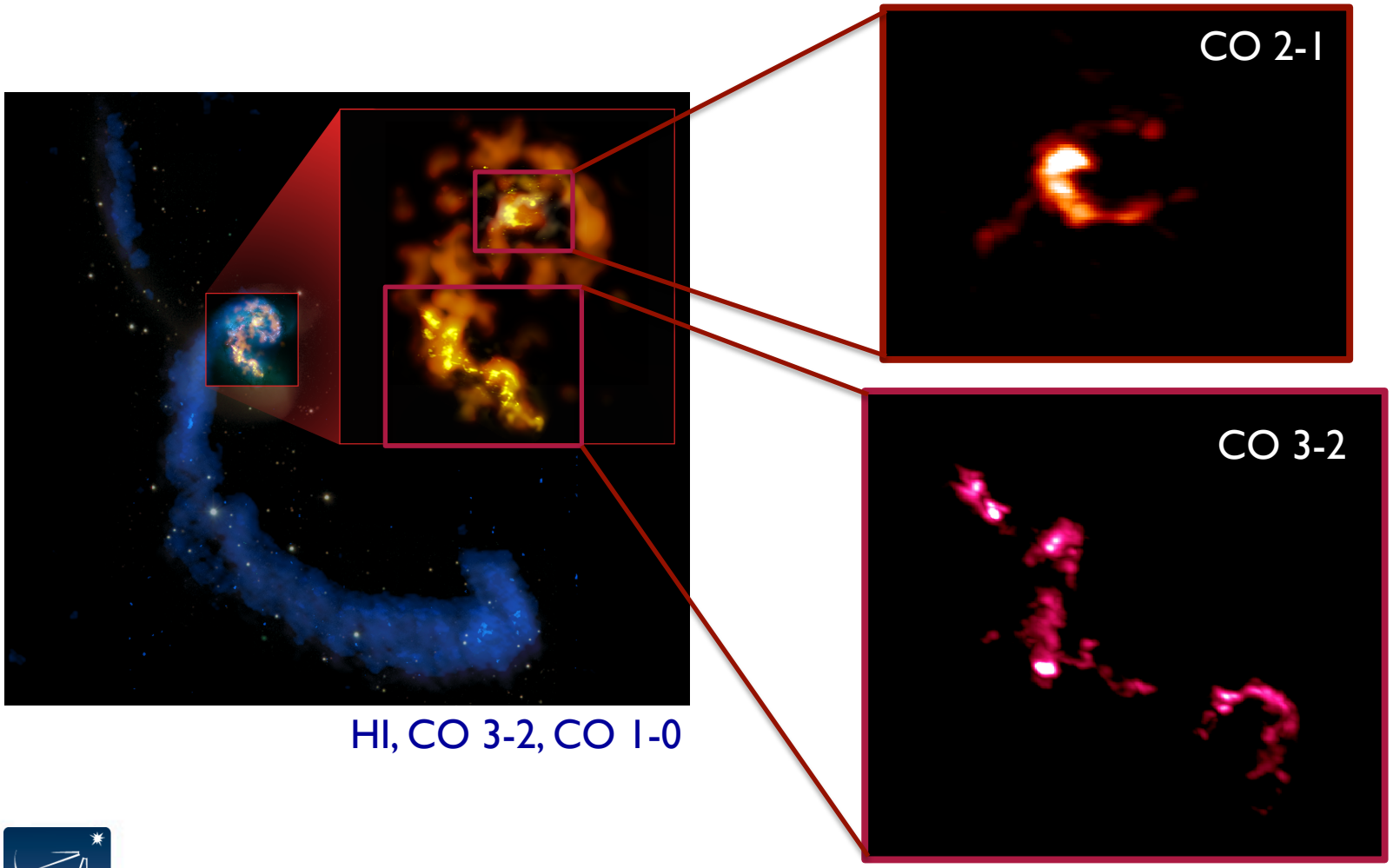
Imaging CO 2-1



CARILLI ET AL. (2011)

ALMA Images Nearby Galaxies

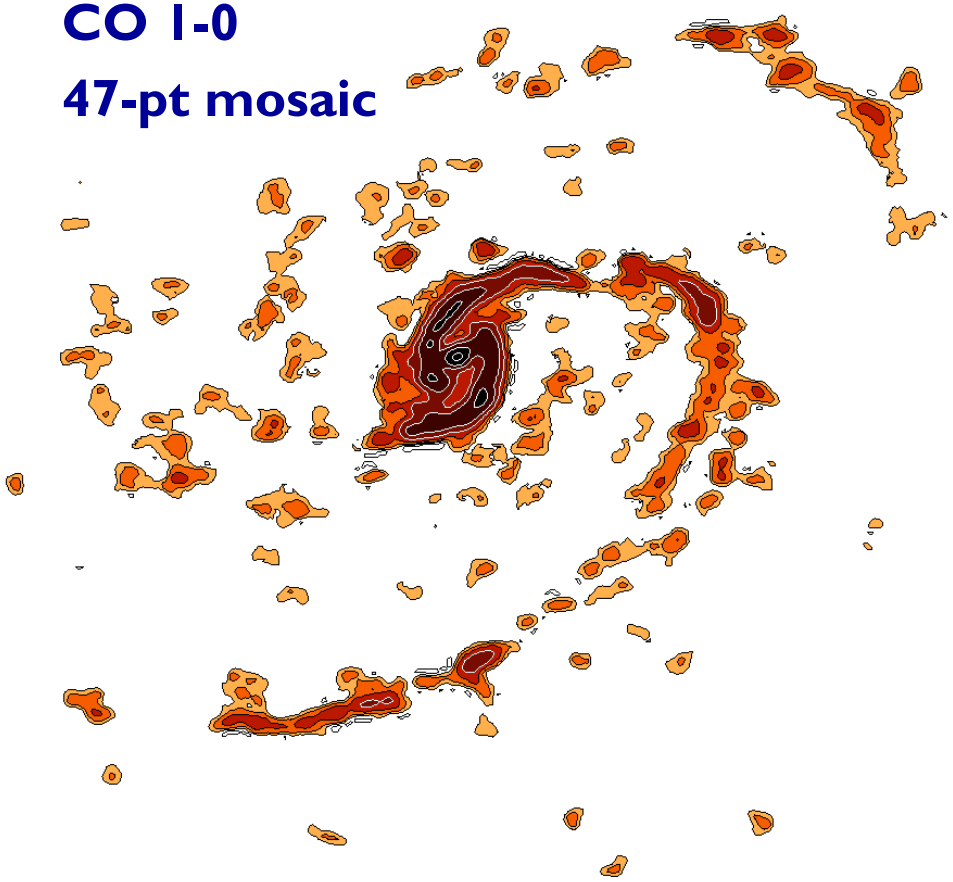
- Science verification imaging of the Antennae Galaxies

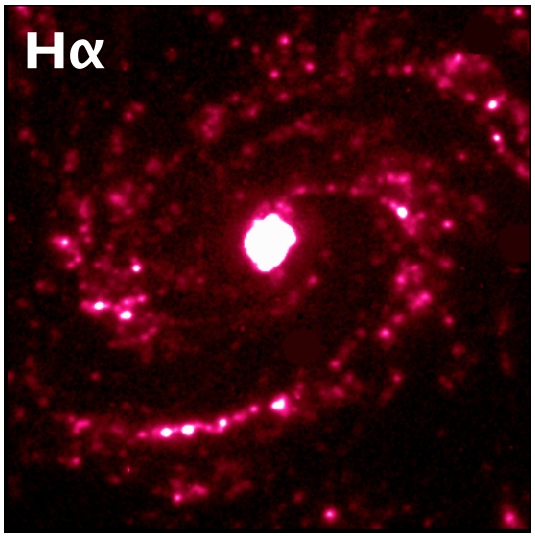


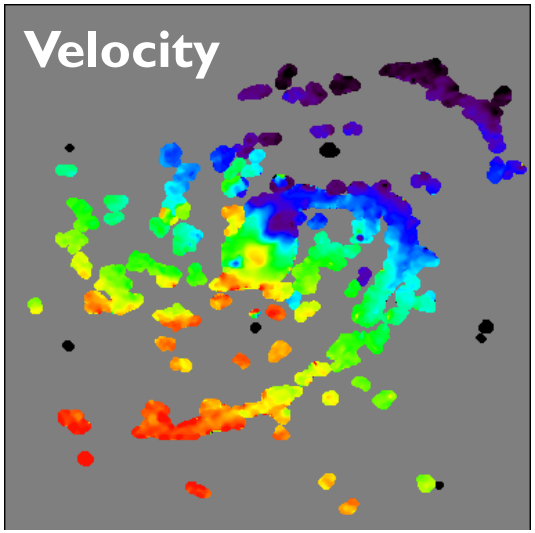
HI, CO 3-2, CO 1-0

ALMA Images Nearby Galaxies

- Science verification imaging of M100







ALMA Cycle 0 Underway

ALMA

- Observations of fine structure lines at high redshift.
  RESOLVE AND DETECT [CII] OUT TO z > 6, CONTRAST WITH [NII], REACH 300 PC RESOLUTION
- Detailed physical conditions at high resolution in local galaxies.
  PHYSICS OF STAR FORMATION, ACTIVE GALACTIC NUCLEI
- Exploring new populations.
  SPT SOURCES, WISE QSOS, BLIND SURVEY BEHIND A LENSED CLUSTER, LOCALIZING SMGS

Emphasis on physical conditions, extreme systems, and unknown populations.

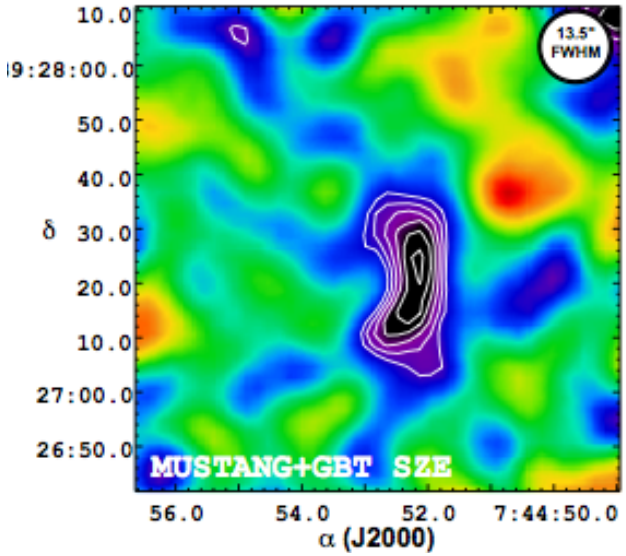
NRAO

SEE C. LONSDALE TALK + PRESS RELEASE AT ALMA SPECIAL SESSION

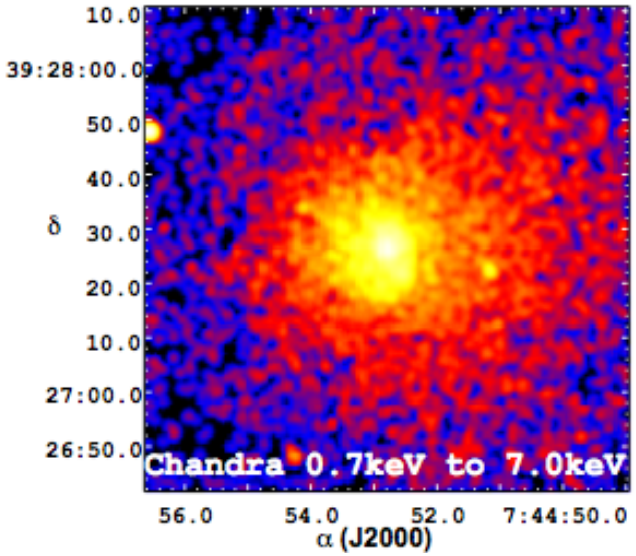
Imaging Massive Clusters via the SZE

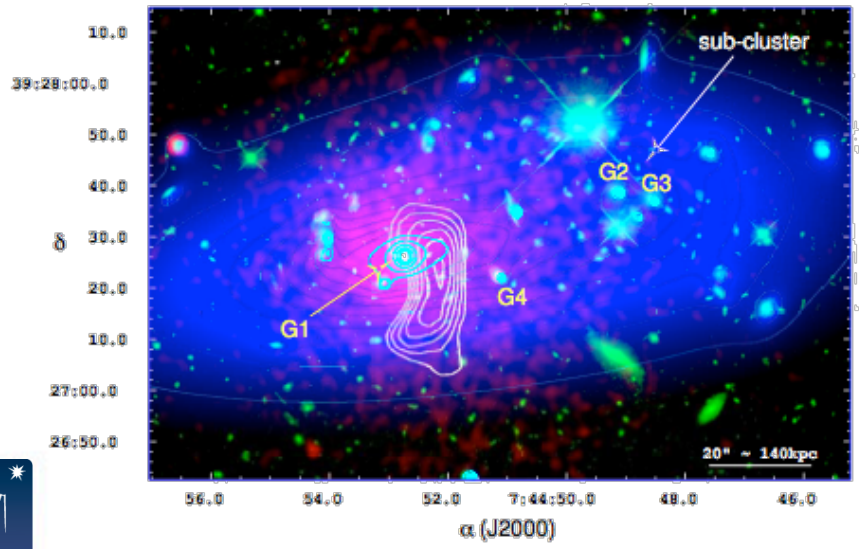
GBT

MUSTANG (GBT 4mm)



Chandra





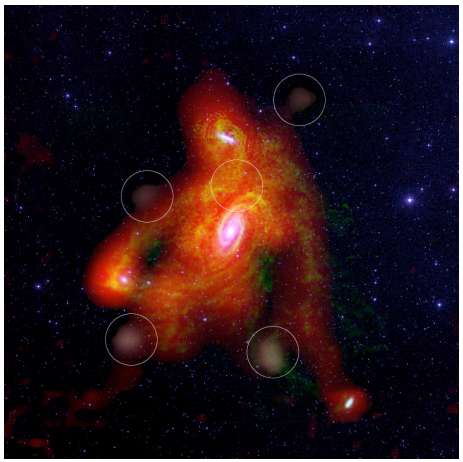
MUSTANG (contour)
Chandra
HST
Mass Model

Korngut et al. (2011)

HI Superstructure in Local Galaxies

GBT

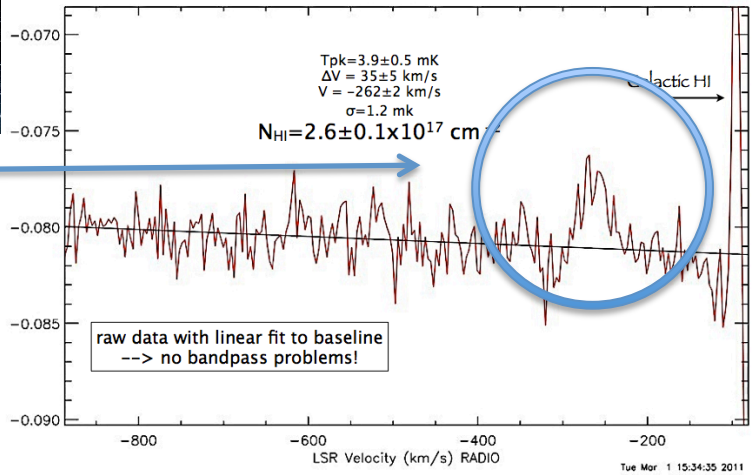
- Low column superstructure in nearby galaxy groups.



Chynoweth et al. (2008, 2011)

M31

M33



Not to scale!

Lockman et al. (Wed. poster) : GBT detects M31-M33 Stream

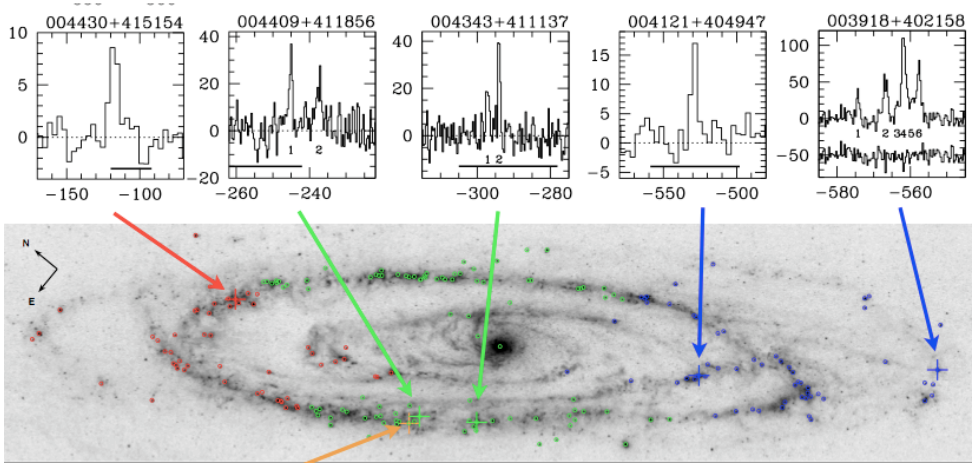
N(HI) ~ 2.6 ± **0.1** 10^{17} cm^{-2}

Pushing towards the cosmic web!

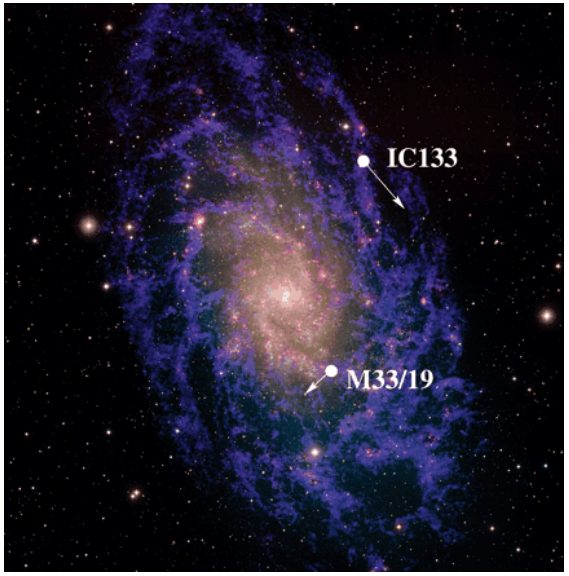
Local Group Dynamics & H_2O Masers

VLBA

- VBLA astrometry of masers in nearest galaxies yields 3-d proper motions
- Model the distribution of dark matter, boundedness
- Derive geometric distances from rotation
- 5 new H_2O masers in Andromeda, 6σ proper motion detection in ~3 yr?
- Builds on ongoing M33 work. Unique application of VLBA



Darling, 2011, ApJL, 732, 2



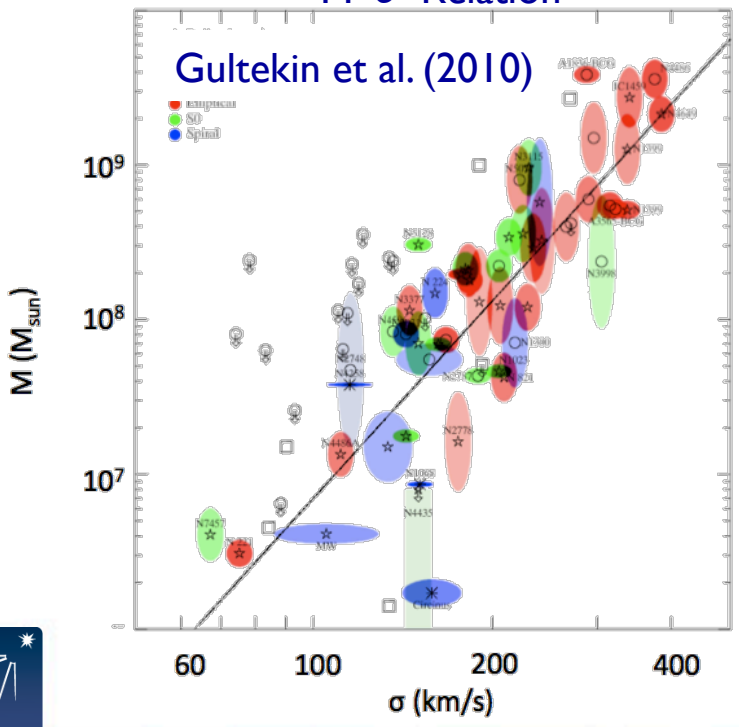
Brunthaler et al. 2005

H_2O Megamasers, H_0, and SMBHs

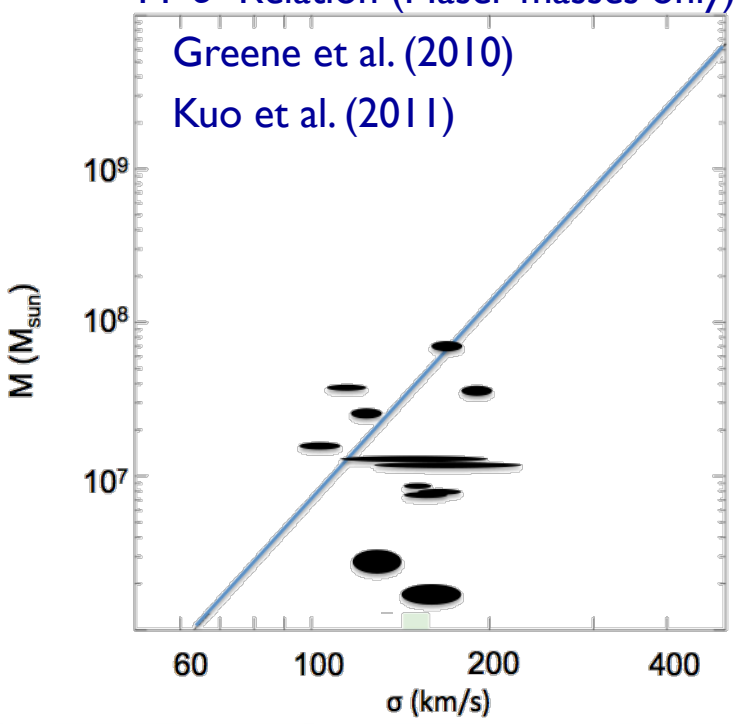
VLBA

- Key science project to find and monitor H_2O megamasers around SMBHs
- Megamasers trace rotation within sphere of influence of the SMBH
- So far 18 systems with directly measured masses (low mass ~ 10^7 M_{sun})
- These systems seem to deviate systematically below M-σ relation
- Current H_0 constraints 67 ± 6 km s^{-1} Mpc^{-1}

M-σ Relation



M-σ Relation (Maser masses only)



The "Radio Decade" for Galaxy Evolution

- EVLA, ALMA, GBT: Gas reservoirs of forming galaxies. $f(H_2)$, $\Omega(H_2)$ vs. z.

  How did the first stars and galaxies form?
  How do galaxies assemble and evolve with cosmic time?

- GBT, VLBA: Detailed dynamical models of the Local Group, SMBHs.

  The link between luminous and dark matter.
  Co-evolution of black holes and host galaxies.

- GBT: Superstructure of the Milky Way, Nearby Galaxies, Galaxy Clusters.

  How do cosmic structures form and evolve?

- EVLA, ALMA: Linking star formation and environment at low and high-z.

  How does star formation depend on external conditions?