Studies of Molecular Clouds and Star Formation with the Large Millimeter Telescope

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New Worlds, New Horizons

- Questions related to *Star Formation* cross-cut the scientific themes of NWNH
- ALMA will make significant contributions to this work.
- How can we maximize the ALMA payoff?
  - NWNH recommends large single dish submm telescope.
  - UMass and Mexico have a large single dish mm-wave telescope which will make important contributions.

Outline

- “Fundamentals” in the case for large single dishes.
- Example “Star (and Planet) Formation” Projects for a Large Single Dish
- The Large Millimeter Telescope

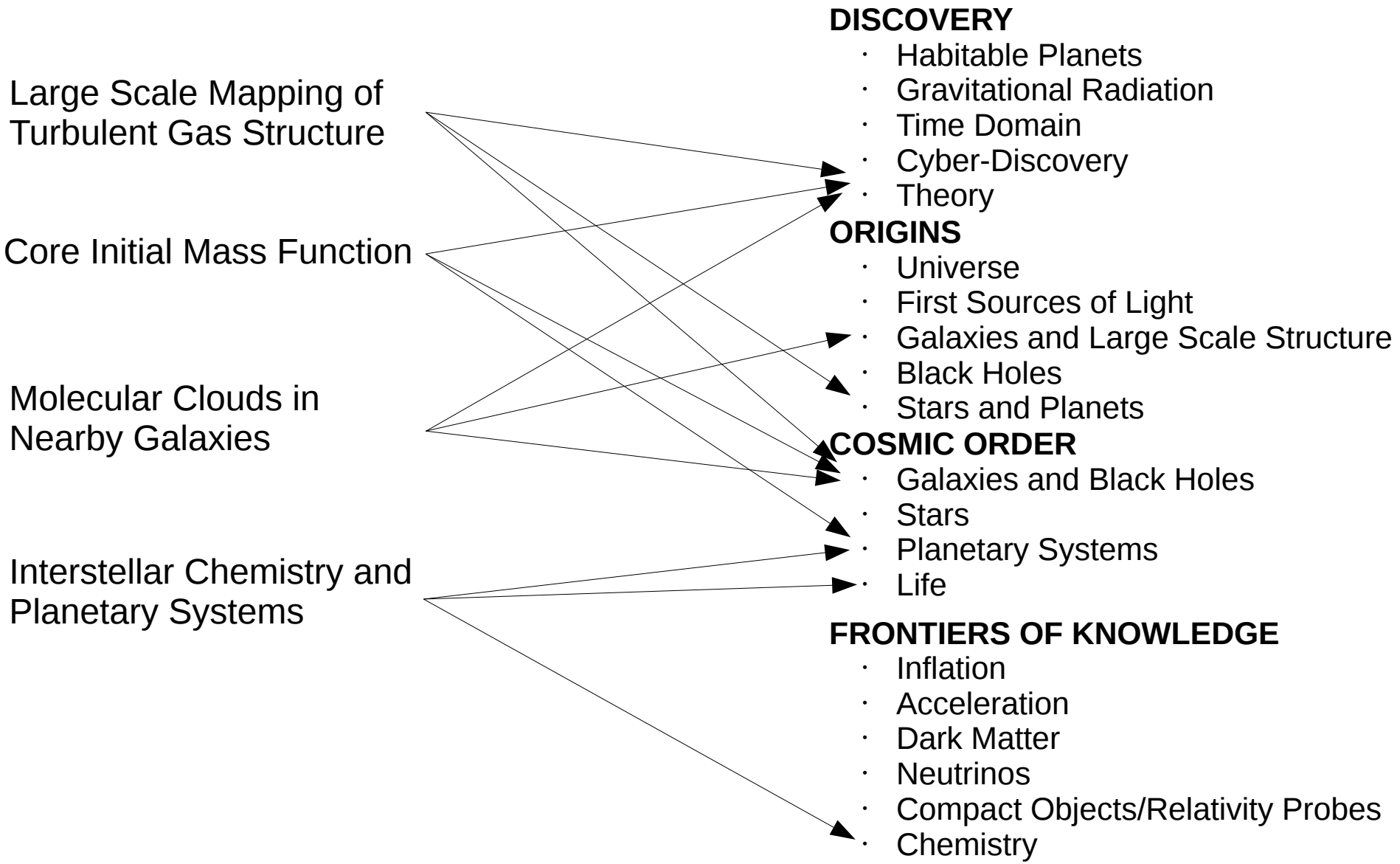
Star Formation Fundamentals

- Stars (and Planetary Systems) Form in Molecular Clouds.
  - If you want to understand star formation, you better understand molecular clouds.
- Molecular Clouds are Big; Stars are Small.
  - If you want to understand star formation, you better be able to study molecular clouds at all relevant scales.
- Millimeter waves are the best means to study the Molecular Gas.
  - MM-wave telescopes are essential tools for the study of Molecular Clouds and Star Formation.

Radio Telescope Fundamentals

- Interferometric Arrays and Single Dish Telescopes have different, and complementary, strengths.
  - A large single dish is the natural complement to ALMA for surveying the sky and studying extended, low surface brightness emissions.
- For a single dish to be a true complement to an interferometric array it must have enough collecting area, resolution and mapping speed.
  - A BIG single dish equipped with focal plane arrays is needed to complement ALMA.
- Receiver technology improves faster than our financial ability to instrument large interferometric arrays.
  - Single Dishes are natural platforms to bring up new capabilities and explore discovery space.

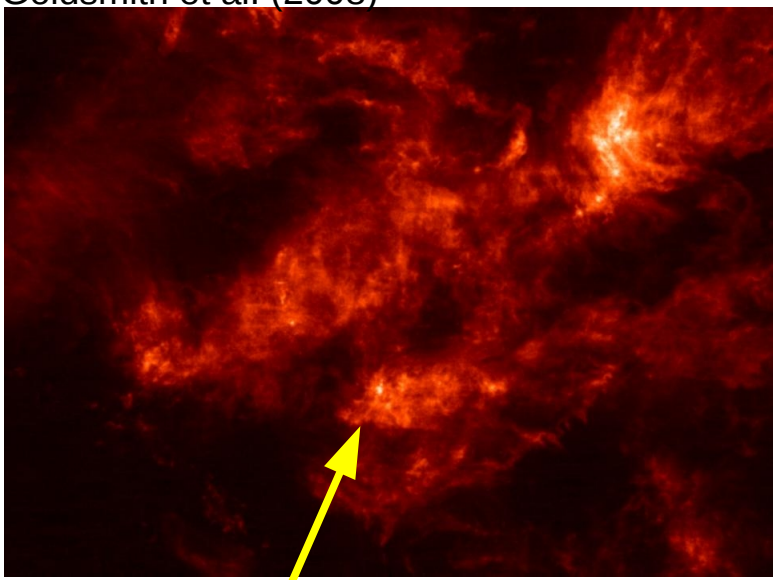
Example Projects for a Large Single Dish

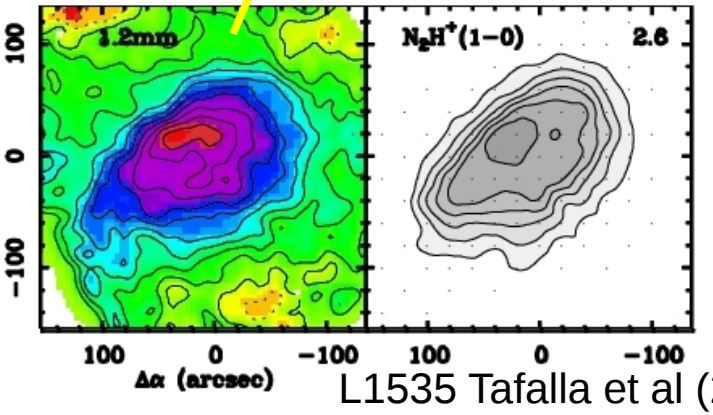


Example Projects: *Turbulent Gas Structure*

- Heterodyne focal plane arrays used to map clouds with high enough spatial dynamic range to identify critical scales.
- Address relative roles of:
  - Gravity
  - Magnetic Fields
  - Turbulence
  - Mechanical/Radiative Feedback
- Large Single Dish Advantage:
  - Large scale mapping capability.
  - Filled aperture for sensitivity t low surface brightness.
  - High spatial dynamic range.

FCRAO 14m Map of Taurus Complex
100 sq. deg. 3.2 MegaSpectra
Goldsmith et al. (2008)

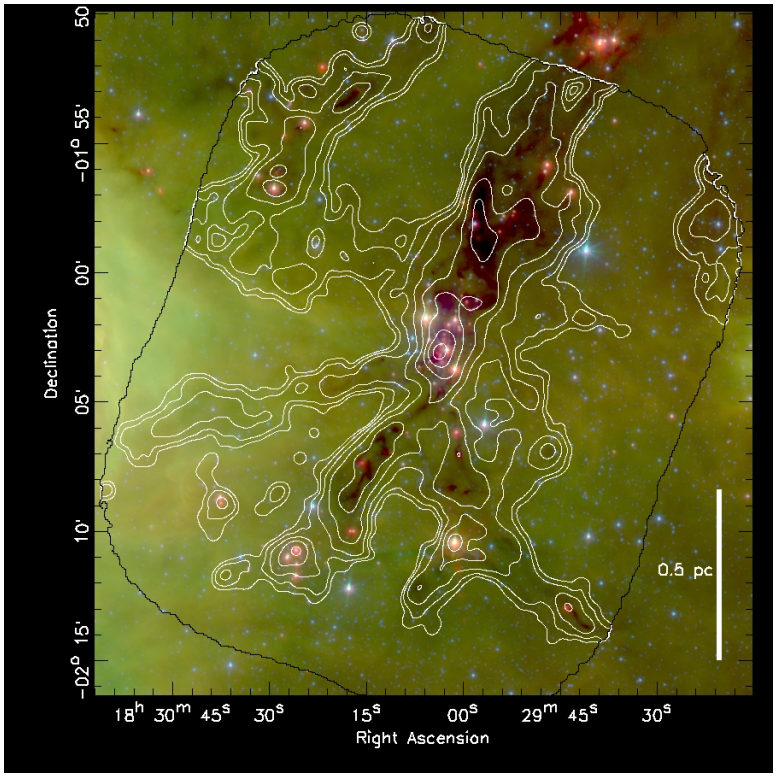




L1535 Tafalla et al (2002)

Example Project: *Core Mass Function*

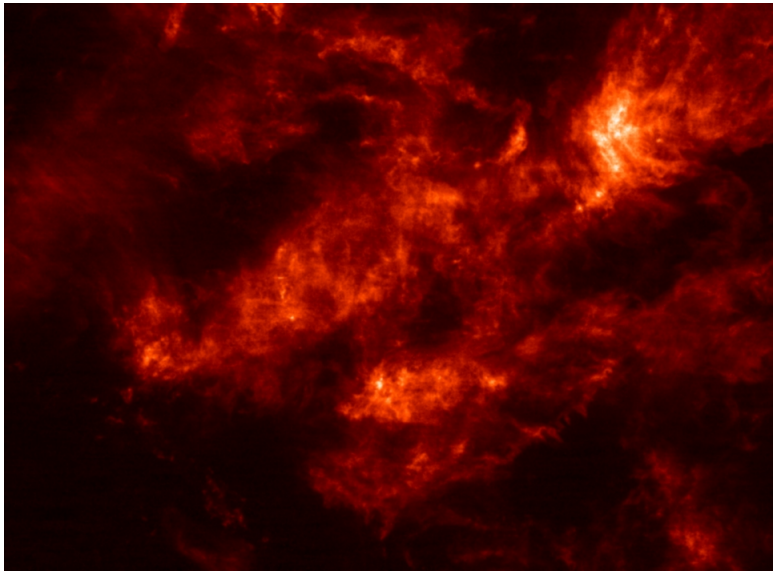
- Continuum Focal Plane Arrays used to map dust continuum in ~100 sq. deg. fields to brown dwarf limit.
- Identify molecular cloud cores
  - Establish Core Mass Function.
  - Relate CMF to IMF – does the IMF result from the CMF?
  - Relate CMF to cloud dynamics inferred from spectral line maps.
  - Identify millimeter-excesses in YSO's.
- Large Single Dish Advantage:
  - Continuum survey speed.
  - High Resolution with filled aperture for best surface brightness sensitivity.

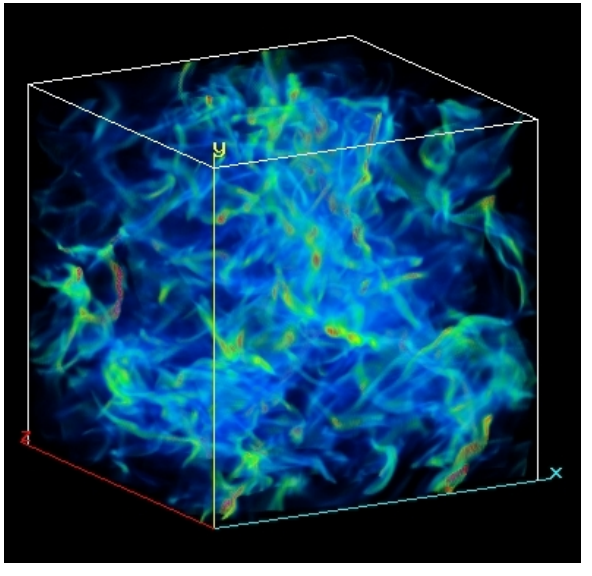


AzTEC/ASTE Map of Serpens South
Gutermuth et al. 2011

Theory Challenge: *Explain Observed Structures*

- Theoretical Requirements:
  - Simulations
  - Appropriate Data Sets for Comparison
- Large Single Dish Advantage:
  - Rapid mapping for creation of needed data cubes

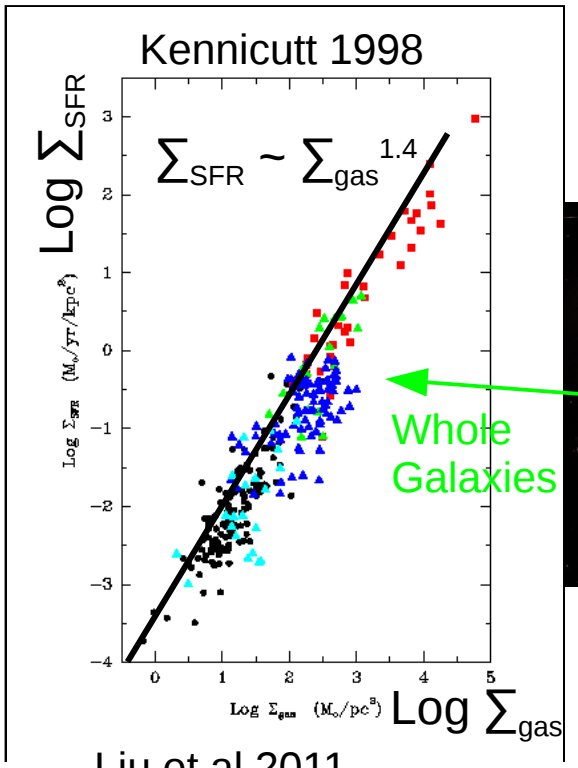


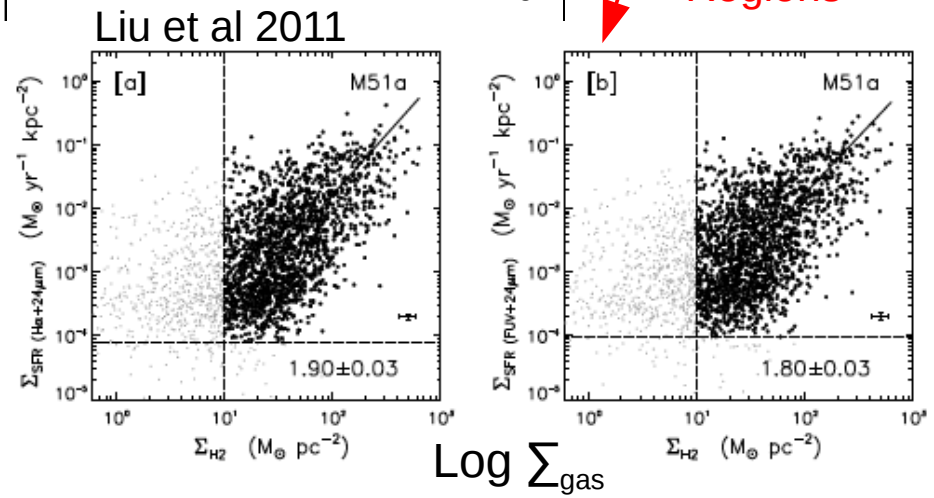


Ostriker, Stone, and Gammie 2001

Example Project: *Mapping Nearby Galaxies*

- Molecular line mapping of nearby galaxies with high sensitivity to a range of diagnostic tracers.
- Comparison with tracers of star formation allows tests of Kennicutt-Schmidt law.
- Large Single Dish advantage:
  - Probe star forming regions within galaxies.
  - Sensitivity to low surface brightness
    - Recovery of faint emission
    - Expands parameter space of galaxy properties.
  - High map speed enables large numbers of galaxies.

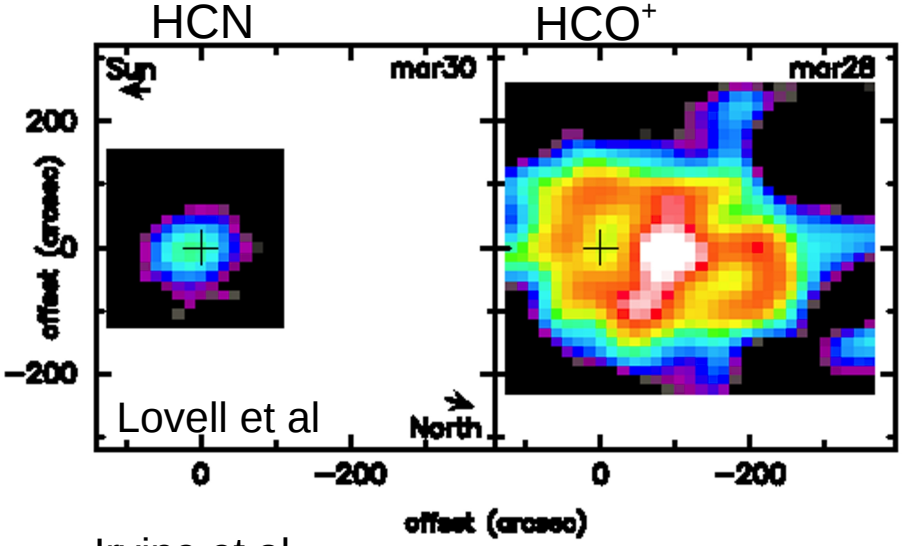




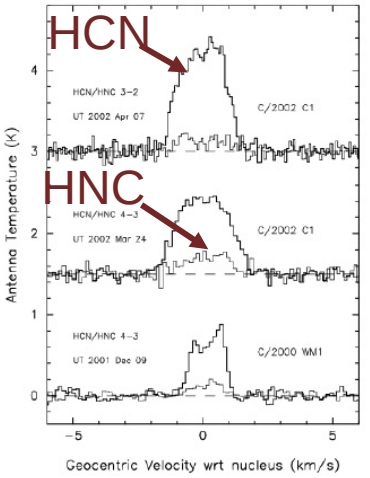
Example Project: *Interstellar Chemistry and Planetary Systems*

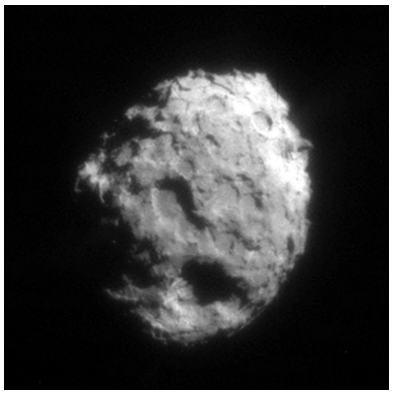
- Observations of molecular line emission from comets, circumstellar disks, molecular cloud cores.
- Molecular diagnostics:
  - Composition
  - Isotope Ratios
  - Ortho-Para Ratios
- Seek to establish relationships between regions:
  - Comets and ISM/Core/Disk?
  - Organics in comets and origin of life?
- Large Single Dish Advantage:
  - Expand census of comets
  - SB Sensitivity at high resoluti

Comet Hale-Bopp FCRAO 14m



Irvine et al





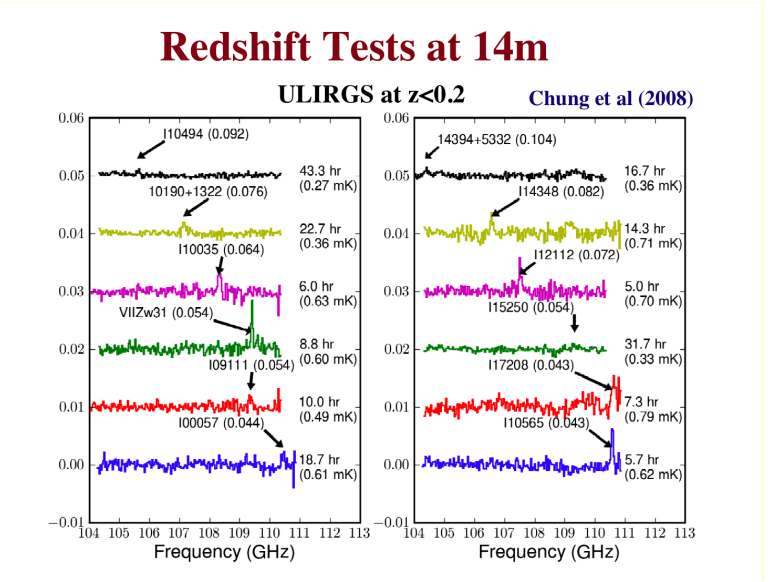
Comet Wild 2 (Stardust)

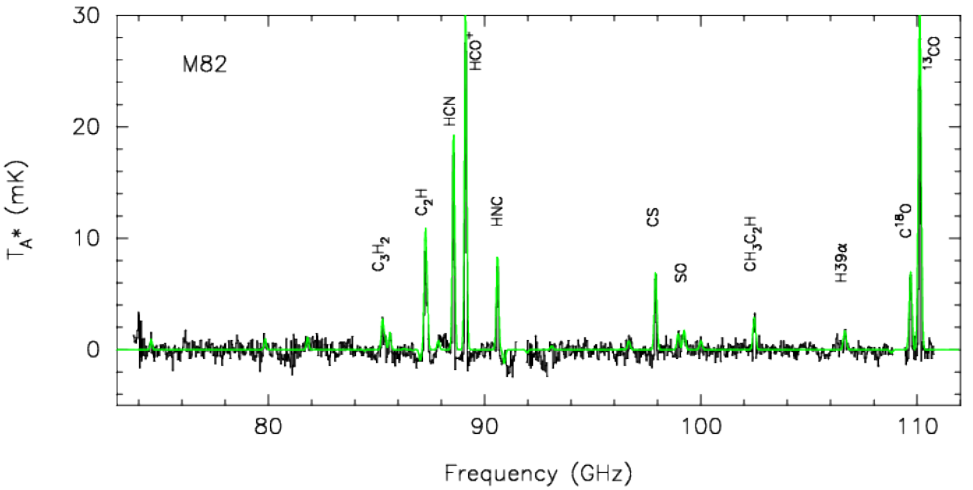
Status of the LMT

- Telescope Structure Complete
- Inner 32m-Diameter of Reflector Surface Complete
- Setting surface with holography: Expectation is 100 microns RMS in this initial attempt.
- Optical pointing tests underway: Expectation is 2” RMS absolute all-sky pointing with subarcsec tracking error.
- Secondary and Tertiary Optics complete.
- Installation of First light instruments is next.

First Light Instruments
Redshift Search Receiver

- Redshift Search Receiver
  - Ultra-wideband receiver/spectrometer for 3mm window.
  - Used on FCRAO 14m for initial scientific work.
    - Studies of molecular lines in nearby galaxies
    - Surveys of ULIRGs
  - LMT Expectation:
    - Measure redshifts of AzTEC sources.





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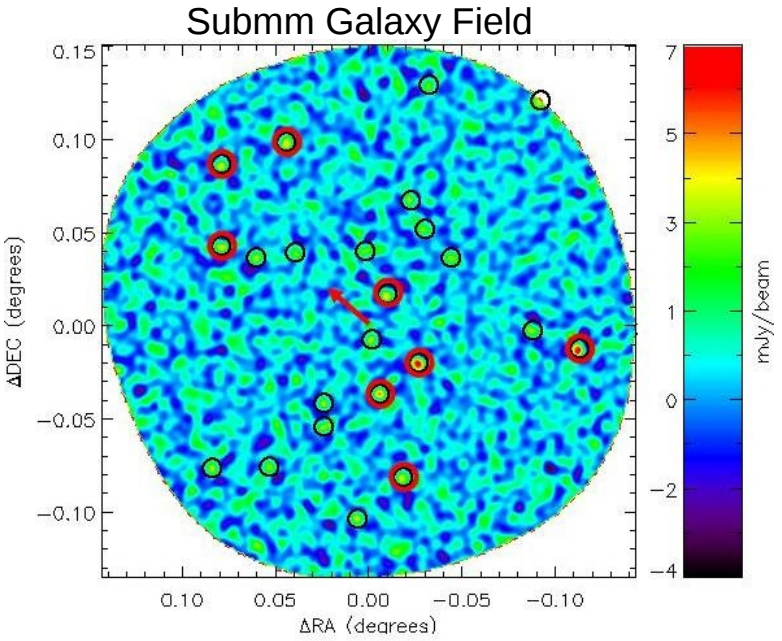
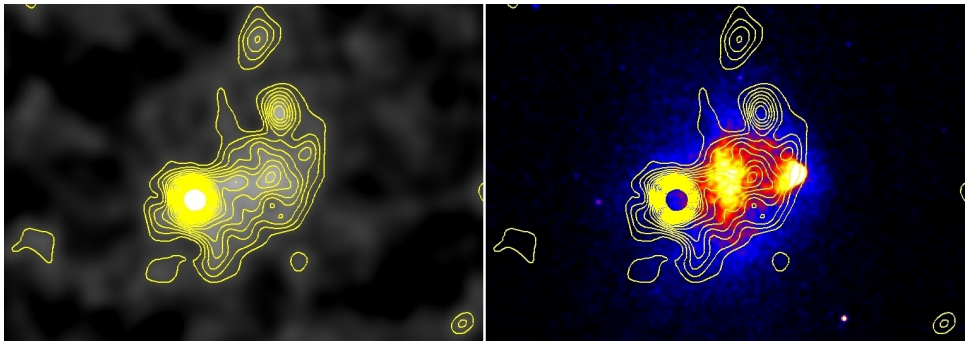
First Light Instruments
AzTEC

- 144-pixel bolometer array
- Used on JCMT and ASTE Telescopes
- Known for discovery of ~1000 submm galaxies – the AzTEC sources.
- LMT Expectation:
  - Improved mapping speed over AzTEC/ASTE (x20)
  - Improved source identifications with higher resolution.



1.1 mm Map

1.1 mm Map on Xray Image



SZ Effect and SMG Background in the Bullet Cluster
AzTEC/ASTE Wilson et al. 2008

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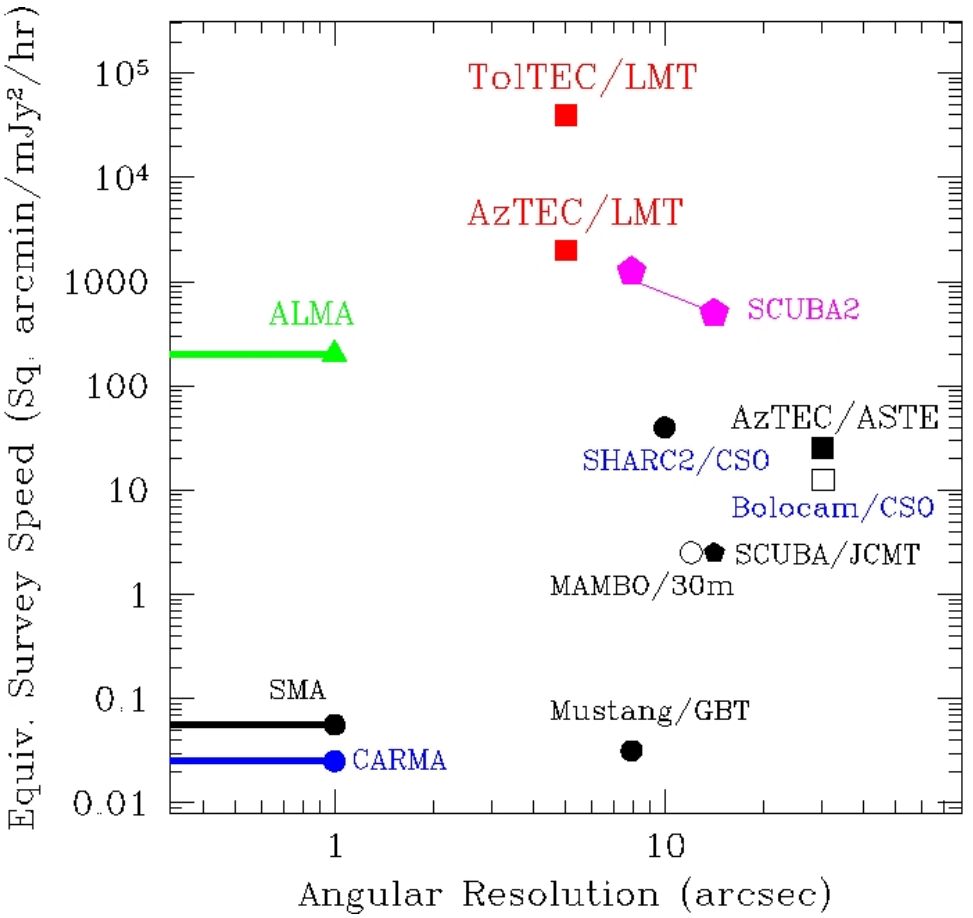
Next Generation Instruments

- First Light Instruments are only the beginning for LMT. Others completed and ready to follow:
  - SEQUOIA focal plane array for 3mm window
  - 1mm SIS receiver
- Next Generation Instrument planning underway
  - AzTEC successor TOLTEC:
    - LEKIDS
    - 10^4 pixels in 3-colors
    - 10 sq. deg./mJy/hr.



Conclusions

- A large single dish for millimeter-wave astronomy will provide a valuable complement to ALMA and will address the key scientific themes presented in New Worlds, New Horizons.
- ASTRO2010 recognized this fact with recommendation of CCAT as a new initiative for the next decade.
- LMT will address these objectives in this decade.