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

F. Peter Schloerb
University of Massachusetts at Amherst
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

  - 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

**Large Scale Mapping of Turbulent Gas Structure**

**Core Initial Mass Function**

**Molecular Clouds in Nearby Galaxies**

**Interstellar Chemistry and Planetary Systems**

**DISCOVERY**
- Habitable Planets
- Gravitational Radiation
- Time Domain
- Cyber-Discovery
- Theory

**ORIGINS**
- Universe
- First Sources of Light
- Galaxies and Large Scale Structure
- Black Holes
- Stars and Planets

**COSMIC ORDER**
- Galaxies and Black Holes
- Stars
- Planetary Systems
- Life

**FRONTIERS OF KNOWLEDGE**
- Inflation
- Acceleration
- Dark Matter
- Neutrinos
- Compact Objects/Relativity Probes
- Chemistry
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 to low surface brightness.
  - High spatial dynamic range.

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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.

\[
\sum_{\text{SFR}} \propto \sum_{\text{gas}}^{1.4}
\]

Kennicutt 1998

\[
\begin{align*}
\log \sum_{\text{SFR}} & \sim \log \sum_{\text{gas}} \\
\log \sum_{\text{gas}} & \sim \log \sum_{\text{SFR}}^{1.4}
\end{align*}
\]

Liu et al. 2011

- Whole Galaxies
- Star Forming Regions
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 resolution
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.

SEE MIN'S POSTER!
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.

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

SEE MIN’S POSTER!
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.