ALMA Science Cases with our Galaxy

Town hall meeting for ALMA Cycle 4
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• 916 refereed articles (ADS) with “ALMA” in abstracts, as of 3/28/2016

• Array sciences: relatively compact structures!
• Cases in ALMA primer
  1. Protoplanetary disks
  2. Magnetic fields
  3. Evolved stars
  4. Asteroid 3 Juno

• Solar objects

• Evolved stars

• Young stellar objects
Science Cases in ALMA primer
1. Multi-wavelength Continuum Survey of Protostellar Disks in Ophiuchus

- Science goals: evolution of protostellar disks
- Method: dust properties based on SED
- Targets: 6 Class II YSOs in Ophiuchus MC (d~125 pc)
Observation design

• Receivers: Bands 3, 4, 6, 7, 8, 9, 10 (98, 145, 233, 344, 405, 679, 869 GHz)

• Angular resolution (LAS): 0.4” (2”)
e.g., 100 AU disks = 0.8” at 125 pc of Oph MC

• Sensitivity:
0.019, 0.043, 0.11, 0.24, 0.34, 0.94, 1.54 mJy/beam
e.g., 0.01 M☉, 20 K, typical opacity, 125 pc
detect 3 beam size disk, edges ~ 10% of the peak

• Target time (36 main array antennas)
26 min, 6.6 min, 1.2 min, 47 sec, 1.5 min, 3.3 min, 7.2 min
2. Dust Polarization and Magnetic Fields in Star Forming Clouds

- Science goals: **magnetic field effects at thermal Jeans-length scales**
- Method: dust polarization
- Targets: W51 e2 (d~7 kpc)

Ya-Wen Tang et al. 2009
Observation design

- Receivers: Band 7 (343 GHz) highest sensitivity to polarized dust emission

- Angular resolution (LAS): 0.2” (0.8”)
  thermal Jeans length scale 1400 AU at 7 kpc => 0.2”
  core size => 0.8”

- Sensitivity: 100 μJy/beam
  flux 9.3 Jy over 0.8”
  9.3 Jy / 16 beams = 0.6 Jy/beam
  1% polarization => ~6 mJy/beam, so 60σ detection

- Target time: 4.5 min but 3 hours requested for sufficient parallactic angle coverage
3. Observing Molecular Gas in a Planetary Nebula

- Science goals: physical processes that created the nebulae, origin of tiny clumps (windswept, photo-evaporating, or shadowing?)

- Method: map the structure of molecular gas in a Planetary Nebula

- Targets: Helix Nebula thousands of small (< 1''), dense ($n \sim 10^5$ cm$^{-3}$), quiescent ($\Delta V < 1$ km/s), and faint ($T_A < 5$ K) clumps slowly evaporating in the radiation field of the central white dwarf

Huggins et al. 2002
Observation design

• Receivers: CO 2-1 in Band 6 (230.538 GHz)

• Angular resolution (LAS): 0.3” (1’’)
  10x10 better than previous studies (~3’’) => 0.3”
  fragmentation scale => ~1”

• Mosaic required: Helix (diameter~25’)
  (primary beam~27” => roughly 7500 pointings)
  one pointing each SE and NW of the nebula

• Spectral resolution: 234 MHz bandwidth, 0.183 km/s resolution

• Sensitivity: 0.5 K, moderate sensitivity for bright Helix Nebula fragments

• Observation time: 3.4 hours to reach 0.5 K in 0.18 km/s, including overheads
  two positions => ~7 hours
4. Continuum High Resolution Imaging of the Asteroid 3 Juno

• Science goals: T distribution, regolith thickness and composition

• Method: observe at 1.3 mm continuum over time for rotational period and 3D shape as well

• Targets: Asteroid 3 Juno
Observation design

• Receivers: Band 6 (233 GHz)

• Angular resolution (LAS): 0.032” (0.17”)
  near-IR + modeling: Juno ~ 240 km
  5 beams => ~46 km resolution (32 mas at 1.97 AU)
  Max. Recoverable Scale 0.34” of the configuration > 0.17”

• Sensitivity: 0.1 mJy/beam
  flux 240 mJy at 250 GHz
  240 mJy/25 beams = 9.6 mJy/beam, 100σ detection

• Observation time:
  2 min for 0.1 mJy/beam (dual pol, 7.5 GHz bandwidth, 40 antennas)
  20 min including overheads
  more than 10 times observations (cf. Juno’s rotation P ~ 7.2 hours)
Science Cases using ALMA
Solar Objects: Asteroid 3 Juno

- One of the long-baseline campaign data sets
  ALMA partnership et al. 2015

- Angular resolution: 0.042"

- 1.3 mm continuum DAMIT models

- Results:
  - consistency between models and data
  - crater in images 6-7 subsolar points?
Evolved Stars: R Sculptors

- Unexpectedly large mass loss during the thermal pulse cycle of the red giant star R Sculptors
  Maercker et al. 2012 Nature

- Timescales and mass-loss properties during and after a thermal pulse determining lifetime of asymptotic giant branch and amount of elements returned

- ALMA cycle 0 observations:
  CO 3-2 (345 GHz)
  angular resolution of 1.3"

- Binary system <= spiral shell structure
  200 year lasting thermal pulse, 1800 years ago
  30 times higher mass-loss rate during the pulse
  (mass-loss ~ 3x10^{-3} M\odot, 3 times more mass than previously thought)
Circumstellar disks of Class 0 YSOs

- L1527
  Taurus MC (d~140 pc)
  CARMA (SMA): \(^{13}\text{CO}, 1.0''\)
  ALMA: \(^{18}\text{O}, 0.7'', 0.17\text{ km/s}\)

Tobin et al. 2012, Nature

Ohashi et al. 2014
Class 0 YSOs: Bipolar Outflow & Disk

- Episodic outflow events
  Plunkett et al. 2015, Nature

- CARMA-7 (Class 0 YSO) in Serpens South (415 pc)
  0.9″
  CO 2-1, \(^{13}\)CO, C\(^{18}\)O

- Clumpy CO emission => episodic ejection

- Slow-down jet-entrained material and/or intrinsically variable ejections

- “Keplerian rotating disk”?
Class 0 YSOs: Bipolar Outflow & Disk

- HH212 (Class 0 YSO, 400 pc) 
  Chin-Fei Lee et al. 2014

- angular resolution ~ 0.4”
  350 GHz continuum, HCO$^+$ 4-3

- Flattened envelope and compact disk in continuum
  Infalling envelope, rotating disk in HCO$^+$ (Keplerian?)
  $|V_{\text{off}}| < 1 \text{ km/s}, (1 \text{ km/s}, 2 \text{ km/s}), (2 \text{ km/s}, 3 \text{ km/s})$

> 120 k\lambda, clean comp.
Class I Binary System

- **L1551 NE**
  Takakuwa et al. 2014

- **Observations**
  - 0.9 mm continuum, $^{18}$O 3-2, $^{13}$CO
  - Angular resolution up to 0.36""
  - 1.6 times higher resolution, 6 times higher sensitivity than previous SMA data

- **Results:**
  - circumstellar disks, circumbinary disk
  - Keplerian rotation of circumbinary disk
  - infalling gas motion
Protoplanetary disks: HL Tau

- ALMA Partnership et al. 2015
- Bands 3, 6, 7 (102, 233, 344 GHz) continuum
- Angular resolution: up to 0.02"
- Flat disk, 7 bright and dark rings, grain properties, 1.3 M$\odot$ (HCO$^+$)
Protoplanetary disks

- A Major Asymmetric Dust Trap in a Transition Disk
  - Van der Marel et al. 2013, Science
    147 citations so far
  - Oph IRS 48 (d ~ 120 pc)
  - 0.44 mm (685 GHz, Band 9) continuum, CO 6-5
    0.32"x0.21"
    VLT 18.7 μm emission
Debris disks

- Dent et al. 2014, Science

- β Pictoris (d ~ 19.44 pc) edge-on debris disk, infalling comets at a few AU from the star, a massive planet at ~10 AU, atomic gas out to ~300 AU

- ALMA observations 870 µm continuum, CO 3-2 0.6'' (12 AU)

- CO photodissociation timescale in the unshielded outer disk (by UV photons of ISM) ~ 120 years << 600 year orbital period at 85 AU => CO must be continuously replenished at ~1.4x10^18 kg/yr

- Photodesorption can’t explain the amount. => planetesimal collisions trapped in resonances by an outward migrating planet or => a recent collision of ~Mars mass
Conclusions

• Unprecedented, highest angular resolution AND sensitivity at (sub)mm wavelengths

• Excellent image fidelity

• Want to study small structures (< 5") at (sub)mm => (sub)mm arrays (e.g., ALMA, ALMA ACA, SMA, NOEMA)
  And need a high sensitivity
  => **ALMA!!!