SMA Science Highlights

- Solar system objects
- Protoplanetary disks
- Star formation
- Polarization and Magnetic fields
- Evolved star envelope
- Galactic Center/AGN
- Time domain astronomy
- Nearby and distant galaxies

- Remarks

Qizhou Zhang

Input from Sean Andrews, Shane Bussmann, Mark Gurwell, Jim Moran, Nimesh Patel, and David Wilner
Outline

- Solar system objects
- Protoplanetary disks
- Star formation
- Polarization and Magnetic fields
- Evolved star envelope
- Galactic Center/AGN
- Time domain astronomy
- Nearby and distant galaxies

- Remarks
2007: Remnant Stratospheric HCN on Jupiter from Comet P/Shoemaker-Levy 9

HCN, CO, and CS were seen in Jupiter’s stratosphere only after the impacts of Comet P/Shoemaker-Levy 9 in July 1994. Since then, their abundances have decreased faster than expected. SMA imaging of Jupiter in April 2007 at 265.9 GHz show HCN(3-2) emission on the limbs (where path lengths are maximized). HCN is not seen at polar latitudes, suggesting that as it diffuses poleward, it is entrained in polar vortices and transported to lower altitudes where it is destroyed (Moreno et al 2007)
SMA imaging reveals detailed structure of gas/dust in disks around nearby young stars.

Evidence for *planet formation in action*.

Many (most?) massive disks have dust-depleted cavities with radii of ~20-70 AU cleared by tidal interactions with young (1 Myr) planetary systems.
Polarized Dust Emission

Red bars -- magnetic field direction. Contours: 0.8mm dust continuum

Both objects show ordered magnetic field and a pinched hour glass morphology, indicating an important role of magnetic field in star formation.
SMA Polarization Legacy Survey
Collaborative effort between SAO/ASIAA

21 massive molecular clumps, largest by (sub)mm interferometer
25 nights from 2011-2013 (enabled by x2 bandwidth c.a. 2009)


Publications:

- Li, H. et al. 2015, Nature, 520, 518
Magnetic Fields and Star Formation

Magnetic fields in dense cores align with or orthogonal to B in parental clump

**Simulation:** B-fields aligned within a 35° cone

**Simulation:** B-fields aligned within a 80-90°

Qiu et al. 2014; Zhang et al. 2014
HH211: Higher excitation gas in SiO 8-7 and CO 3-2 closer to central star and jet axis, and trace a high density \( n_{H_2} \sim 10^6 \text{ cm}^{-3} \) primary jet.

Palau et al. 2005; Hirano et al. 2005; Lee et al. 2007
Survey 9 Class 0 protostars in many lines and continuum (230/345 GHz)

Jørgensen et al. 2007 ApJ, 659, 479 (Basic Results)
Dynamical interactions

Proper motion of three massive stars at center of outflow suggest common spatial location ~500 years ago

L_{bol} \sim 10^5 L_{\text{sun}} (Orion BN/KL)
M \sim 10 M_{\text{sun}}
E \sim 10^{47} \text{Erg}
High vel. >100 km s^{-1}
Very poor collimated (degree of collimation 200° – 300°)
Bright in optical and infrared bands

(Discovered by Allen & Burton in 1993)

Zapata et al 2009

H_2 Bullets: Grey scale
Explosive outflow in CO 2-1

Orion BN/KL
Trapezium

Orion Nebula
CISCO (J, K' & H\alpha (\nu=1-0 S(1)))
Subaru Telescope, National Astronomical Observatory of Japan
January 28, 1999
Infrared Dark Cloud G11.11: Fragmentation

**P1:**
- \( M(\text{clump}) \approx 10^3 \) Msun
- \( L = 1.3 \times 10^4 \) Lsun
- SMA detects 6 cores
- 5-23 Msun

**P6:**
- \( M(\text{clump}) \approx 10^3 \) Msun
- \( L = 1.4 \times 10^4 \) Lsun
- SMA detects 17 cores
- 3-28 Msun

- \( T = 11-20 \) K
- \( V = 1.5 \) kms\(^{-1}\)
- \( M_{\text{Jeans}}(\text{thermal}) = 1 \) Msun
- \( M_{\text{vir}} < M(\text{cores}) \)

Wang et al. 2014
Infrared Dark Cloud G11.11: Fragmentation

P1:
- $M(\text{clump}) \sim 10^3 \text{ Msun}$
- $L = 1300 \text{ Lsun}$
- SMA detects 6 cores
- 5-23 Msun

P6:
- $M(\text{clump}) \sim 10^3 \text{ Msun}$
- $L = 140 \text{ Lsun}$
- SMA detects 17 cores
- 3-28 Msun

$T = 11-20 \text{ K}$
$V = 1.5 \text{ kms}^{-1}$
$M_{\text{ Jeans(thermal)}} = 1 \text{ Msun}$
$M_{\text{ vir}} < M(\text{cores})$

Wang et al. 2014
Increase of chemical complexity → Stellar heating evaporates complex organic molecules CH$_3$OH, CH$_3$CN, which then continue to evolve in gas phase reaction.
IRC+10216 spectral line survey

SMA SINGLE DISH


Distribution of line widths

SMA Single dish

Faraday Rotation in Sgr A*  
(Marrone et al. 2006)

\[ \chi = \chi_0 + \lambda^2 \cdot RM \]
\[ RM = 8.1 \times 10^6 \int n_e B \cdot dl \]
\[ = -5.1 \times 10^5 \text{ rad/m}^2 \]
Accretion rate \( \sim 10^{-8} M_{\text{Sun}}/\text{yr} \)

See also Kuo et al. 2014 on M87
Closest known black hole X-ray binary at 2.39 kpc, 10 Msun, 6.5d orbital period

Being quiescent for 26 yrs, first time detection in mm/submm wavelengths

Time variability in mins to days, largest flare rose 75 mJy to 6 Jy in 25 mins

Mm/submm emission shows higher variability and lead cm emission, consistent with optically thin plasma ejecta in the jet.

GRB: time coverage before the peak of the light curve is critical
AGN: time monitoring
1.3mmλ VLBI Observations of SgrA*

Doeleman et al. 2008, also Johnson+ 2015
See also Doeleman et al. 2012 on M87

Simulation of orbiting “blob” close to inner-most stable circular orbit (Broderick & Loeb)
SMA observations reveal molecular gas in a circumnuclear ring and in the nucleus of the galaxy that fuels the starburst.
[CII] from an SMG at z=5.2

- $z_{\text{source}} = 5.243$
- $z_{\text{lens}} = 0.6$

SMA + Subaru i-band

Kawle et al., 2014.
High-res SMA Imaging of 30 Lensed SMGs

Bussmann et al., 2013
Extragalactic projects tend to require more observing time as compared to star formation projects.

**No. of tracks observed**
- Extragalactic: 42%
- Galactic Star Formation: 47%
- Planetary: 1%
- Other: 4%

**No. of Publications**
- Extragalactic: 27%
- Galactic Star Formation: 61%
- Galactic Center: 3%
- Other: 1%
- Planetary: 1%
Time Oversubscription

- Majority of time requests come at PWV < 2.5mm, normally reserved for 345 GHz

Oversubscription by Weather

Time Request by Weather

- <1mm: 12%
- <2.5mm: 56%
- <4mm: 32%
Summary

- SMA is a highly sought instrument among the mm/submm community.
- Science output from the SMA remains steady, and compares favorably to other similar facilities.
- The main science output of the SMA is galactic star formation (61% publications) and extragalactic science (27% publications).