Low-Mass Star Formation with $w_{SMA}$

Chin-Fei Lee
Low-Mass Star Formation

a. dark cloud
b. gravitational collapse
c. protostar

d. T Tauri star

e. pre-main-sequence star

f. young stellar system

M. Liu (IfA/Hawaii)
Low-Mass Star Formation

Among the things that we have been doing, I think we can try more on:

1. Bigger field of View than ALMA ➔ Wide-field Imaging of filaments and cores (Combining with JCMT)
2. Better continuum sensitivity than before:
   ➔ Time monitoring of continuum emission in the inner envelopes and disks around Protostars and T-Tauri stars.
   ➔ Polarization measurement on envelope-core scale (Combining with JCMT & ALMA?)

3. Wider bandwidth than before and ALMA ➔ Molecular Line study for the chemistry in the inner envelopes and disks(?)
4. Lower oversubscription rate than ALMA ➔ Easier to get time ➔ Time monitoring of protostellar jets connecting to the time monitoring of continuum emission
85-pointing mosaic observations of Orion filament at 0.85mm continuum

wSMA can do this much faster, deeper, and wider

a semi-regular interval of 0.05 pc, roughly consistent with the local Jeans length, suggesting that observed star-forming cores may be formed via thermal fragmentation process within the filaments. The detected clumps are spatially resolved, and are likely to harbor protostars. (Takahashi et al 2013)
Cold filaments from JCMT SCOPE (PI Tie Liu)

They detected several tens of very cold (T~10 K) and quiescent (starless) filaments

(Henshaw et al. 2016)
brown-dwarf and very low-mass star formation (Liu+2016)

1.3 mm continuum in color image and black contours; CO outflows in red and blue contours

Extremely young Class 0: G192N: $M=0.43 \, M_{\odot}$ (JCMT); $M=0.38 \, M_{\odot}$ (SMA); $L_{\text{int}}=\sim 0.2 \, L_{\odot}$
Proto-brown dwarf: G192S: $M=0.23 \, M_{\odot}$ (JCMT); $M=0.02 \, M_{\odot}$ (SMA); $L_{\text{int}}=\sim 0.08 \, L_{\odot}$
Accretion is episodic!
Evidence of Episodicity: Episodic molecular outflow in the very young protostellar cluster Serpens South

Embedded Class 0 protostar

Estimated Episodic Period ~ 20-40 yrs <==> FUor bursts???

Plunkett et al. 2015
EXors and the magnetospheric instability

Mass accretes from outer disk to inner disk at some rate

Accretion onto the star may be less efficient than accretion within disk

D’Angelo & Spruit (2010, 2012) model (R-T instability):

1. Magnetic truncation radius > corotation (gas cannot accrete)
2. Matter piles up at truncation radius => truncation radius shrinks
3. Truncation radius < corotation => outburst

But EXors could also be due to inner disk instability (Zhang + 2015)
JCMT Transient Project Led by Gregory Herczeg, Doug Johnston

Program description

- First (?) dedicated sub-mm monitoring program
- 150 total hours spread over 8 fields of 30 arcmin
  - Perseus (2), Oph (1), Orion (3), Serpens (2)
  - Roughly monthly monitoring
  - Previous GBS epoch
- 182 Class 0/I protostars, 132 flat-spectrum srcs, 670 disks

Levels of accretion variability for MRI+GI instabilities (Bae+2014, green) and GI (Vorobyov & Basu 2010, red)
Recent NGC 2071 Results from Transient Project

Reduced 850 Micron Map  Location of Protostars  Location of Disk Sources

Doug Johnstone
With wSMA at higher resolution, we can zoom in to inner envelope/disk of 1000 AU in size, where the density is higher and thus the flux changes would be easier to detect (A week time delay, so monitoring every two days for 2 weeks, with a big mosaic e.g., 3′x3′?)

In some cases, we can resolve the disks at 0.2″, and thus more directly probing the origin of the burst, if we can make observations roughly monthly?
Hour-Glass Magnetic field Morphology in e.g., NGC 1333 IRAS4A envelope

Girart et al. 2006

Extended Infalling envelope + Flattened Envelope (Pseudodisk) + Hour-glass B-field morphology
Theoretical Model of Magnetized Core Collapse

Extended Infalling envelope + Flattened Envelope (Pseudodisk) + Hour-glass B-field morphology

Still Flattened envelope but no disk formed ➔ MBC!

Allen et al. 2003
Magnetic field Morphology in the Envelope

(CARMA @ 230 GHz dusty continuum, Hull et al. 2014)
Fig. 2. Physical and chemical structure of pre- and protostellar objects. (Left) Density (red), temperature (black), and typical abundance (green) profiles. (Right) Depletion signature for each class of object with the light blue indicating the region where the density is too low for significant freeze-out, the dark blue where the molecules are heavily frozen out, the yellow where CO ice has evaporated, and the red the "hot core" where the H$_2$O ice has evaporated (28).
ARO observations towards Splitzer Glimpse Extended Green Objects (EGOs), a sample of massive star formation regions.

Fig. courtesy of T. Bergin
SMA for this size scale

Bergin & Tafalla (2007)
Two mm sources in the B1-b molecular cloud core.
Ice lines in Class 0 protostars

The differences in the observed line maps are likely due to the CO and H2O ice lines

Anderl et al. (in prep)  Jørgensen et al. (2010)
L1157 : Class 0 Envelope and Outflow by IRAM 30m

(27” beam @ 90GHz, 10” beam @ 240 GHz)

Bachiller et al. 2001
We can do similar things with wSMA for the envelope and outflow near the source simultaneously.
HH 212 Protostellar system

We can observe
230 GHz and 345 GHz Continuum
CO J=2-1 & J=3-2,
SiO J=5-4 & J=8-7
HCO+ J=4-3 & J=3-2
HCN J=4-3 & J=3-2,
SO and CH3OH, N2H+, and other lines
and their isotologues all in 1 spectral setup
evelope, disk, outflow, jet simultaneously
SMA Multi-epoch SiO observations of HH 211 jet

@ 1” resolution Jhan & Lee 2016

~ 20 yrs of ejection period, FUors?

Jet velocity ~ 115 km/s or ~ 0.1” per yr

Observe once a yr @0.2” resolution, tracking the jet motion and intensity variation, comparing to internal shock model to retrieve the properties of the episodicity, e.g., variations in the mass-loss rate and velocity?
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