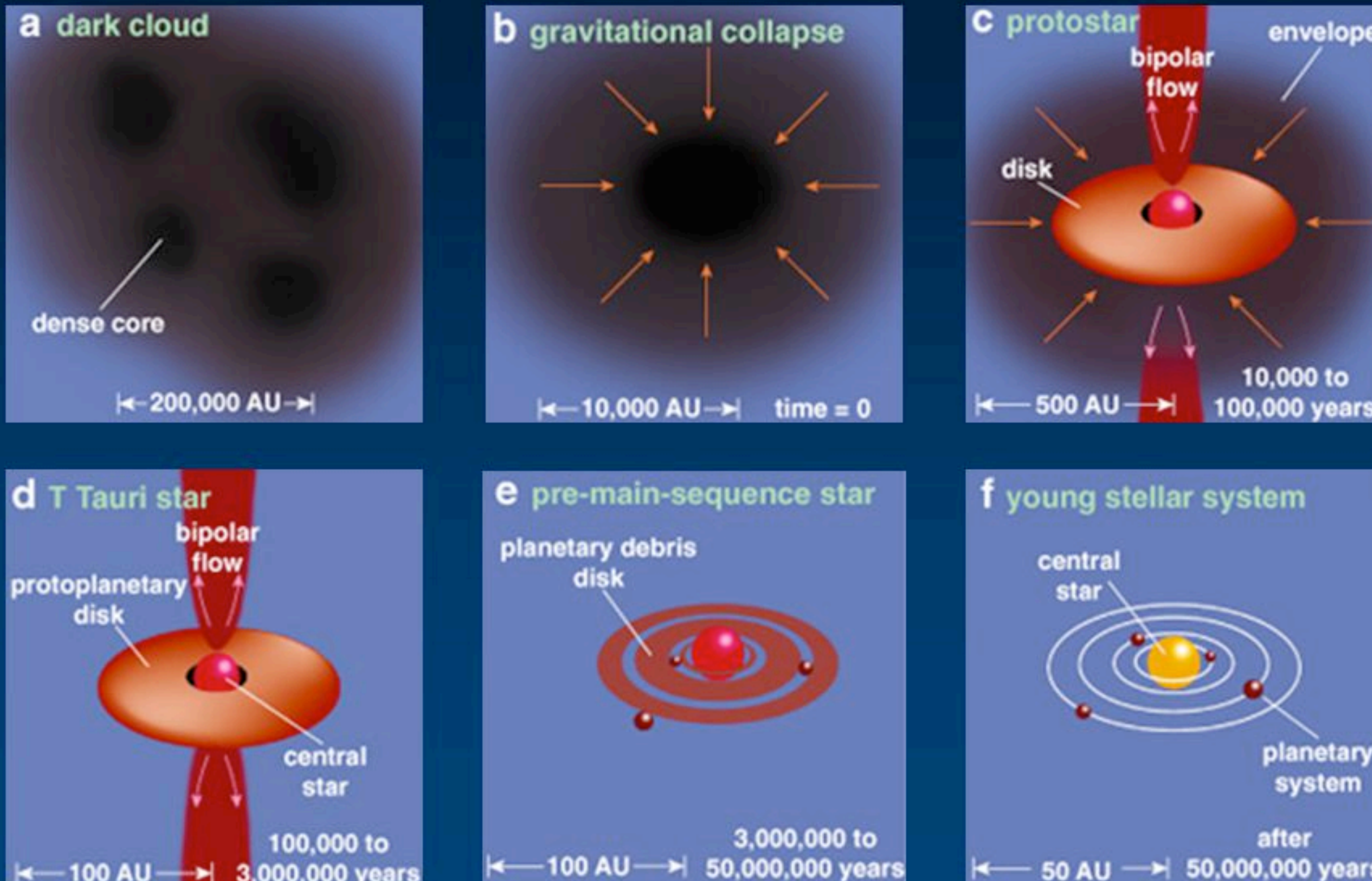
Low-Mass Star Formation with *w*SMA

Chin-Fei Lee

Low-Mass Star Formation



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.

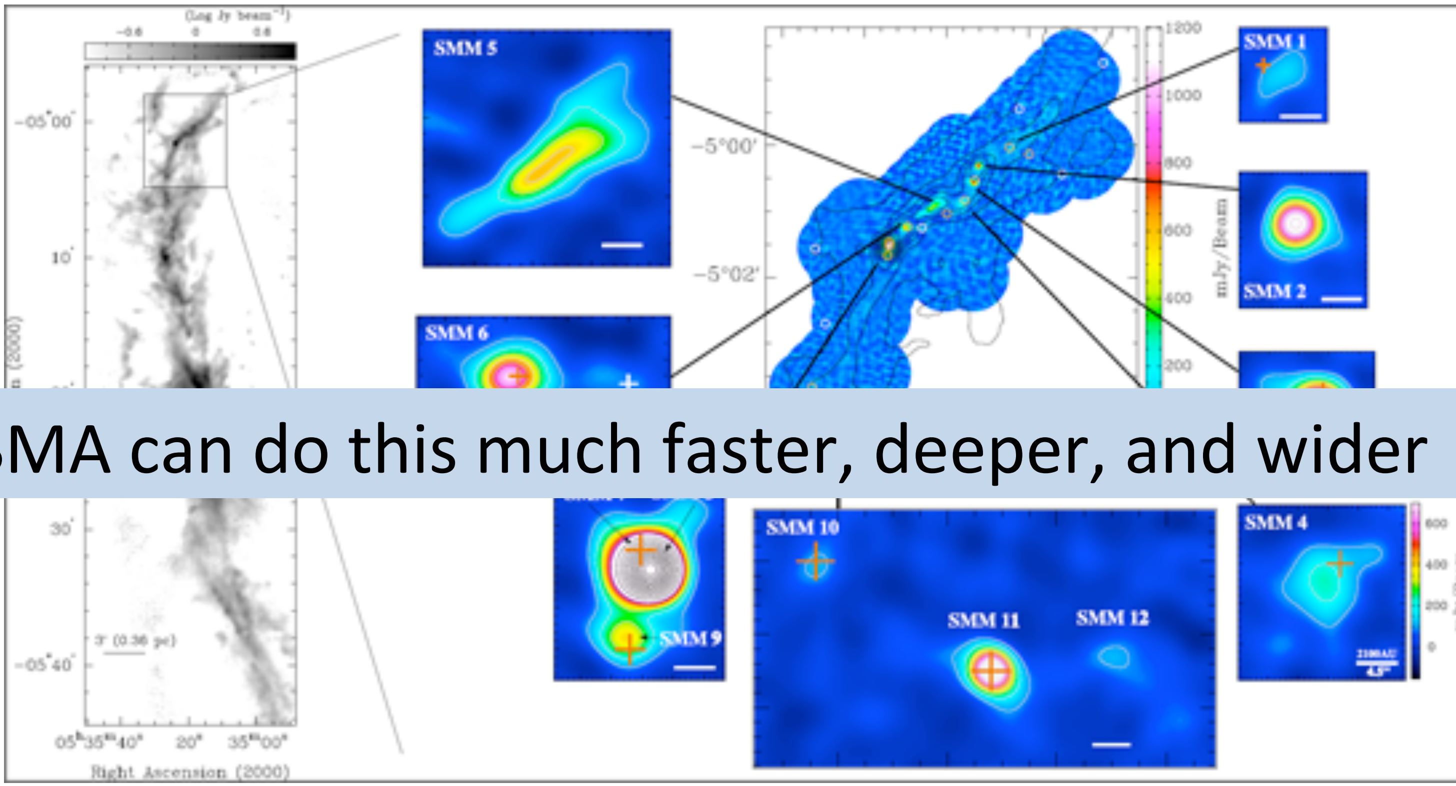
➔ Polarization measurement on envelope-core scale

(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

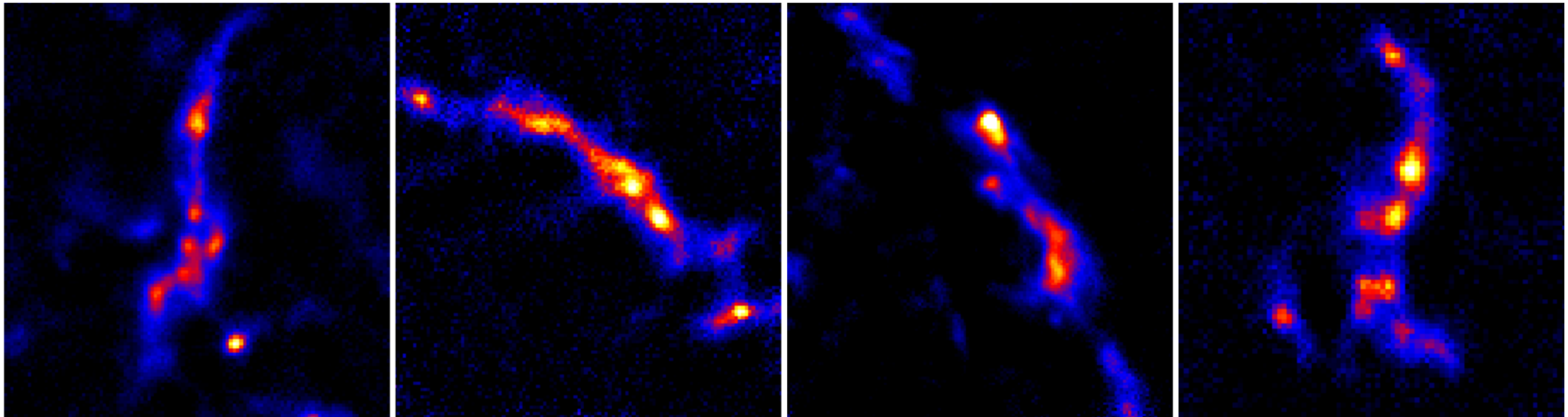


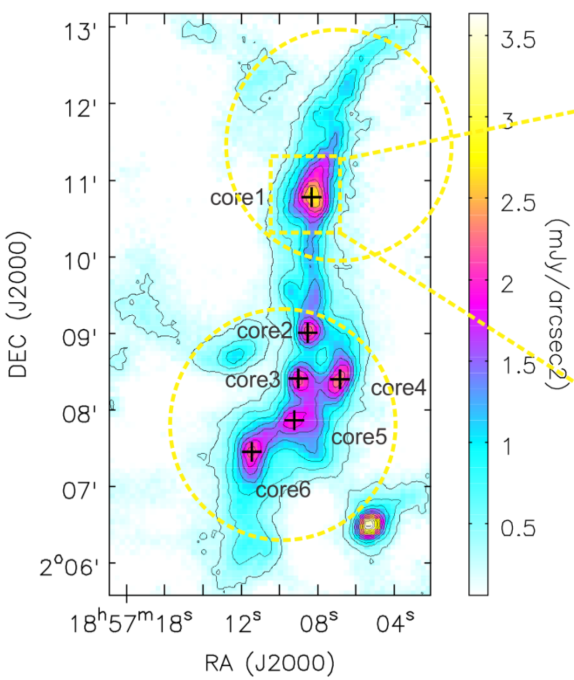
wSMA can do this much faster, deeper, and wider

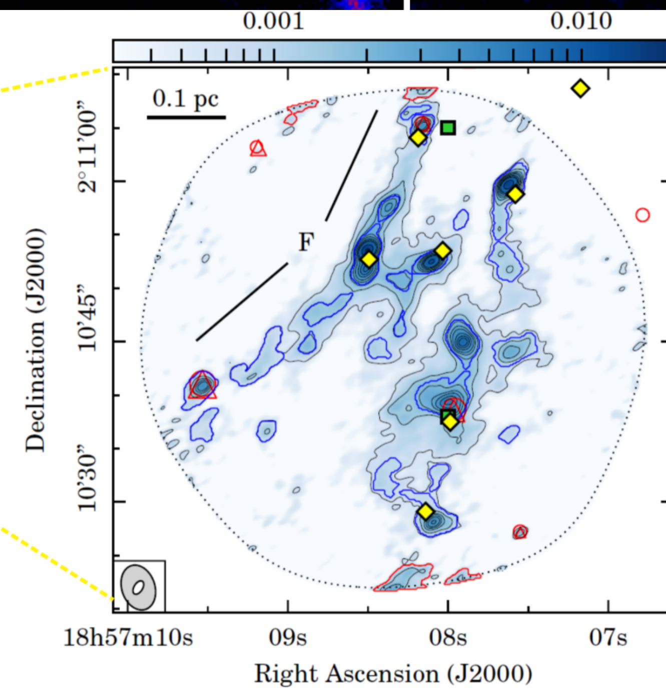
a semi-regular interval of 0.05 pc, roughly consistent with the local Jeans length, suggesting that observed star-forming cores may be formed via thermal fragmentation process within the filaments. The detected clumps are spatially resolved, and are likely to harbor protostars. (Takahashi et al 2013)

Cold filaments from JCMT SCOPE (PI Tie Liu)

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

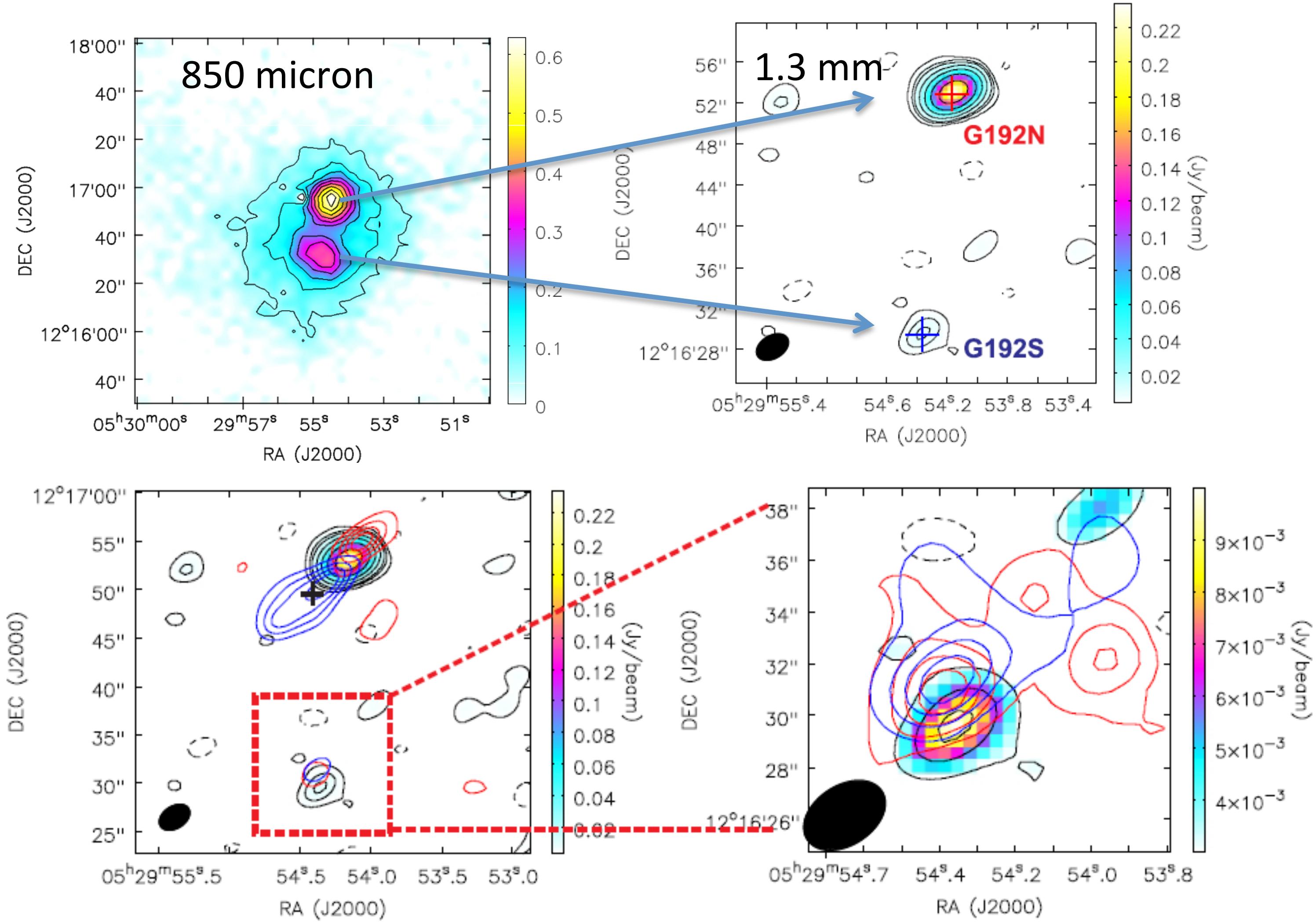






(Henshaw et al. 2016)

brown-dwarf and very low-mass star formation (Liu+2016)



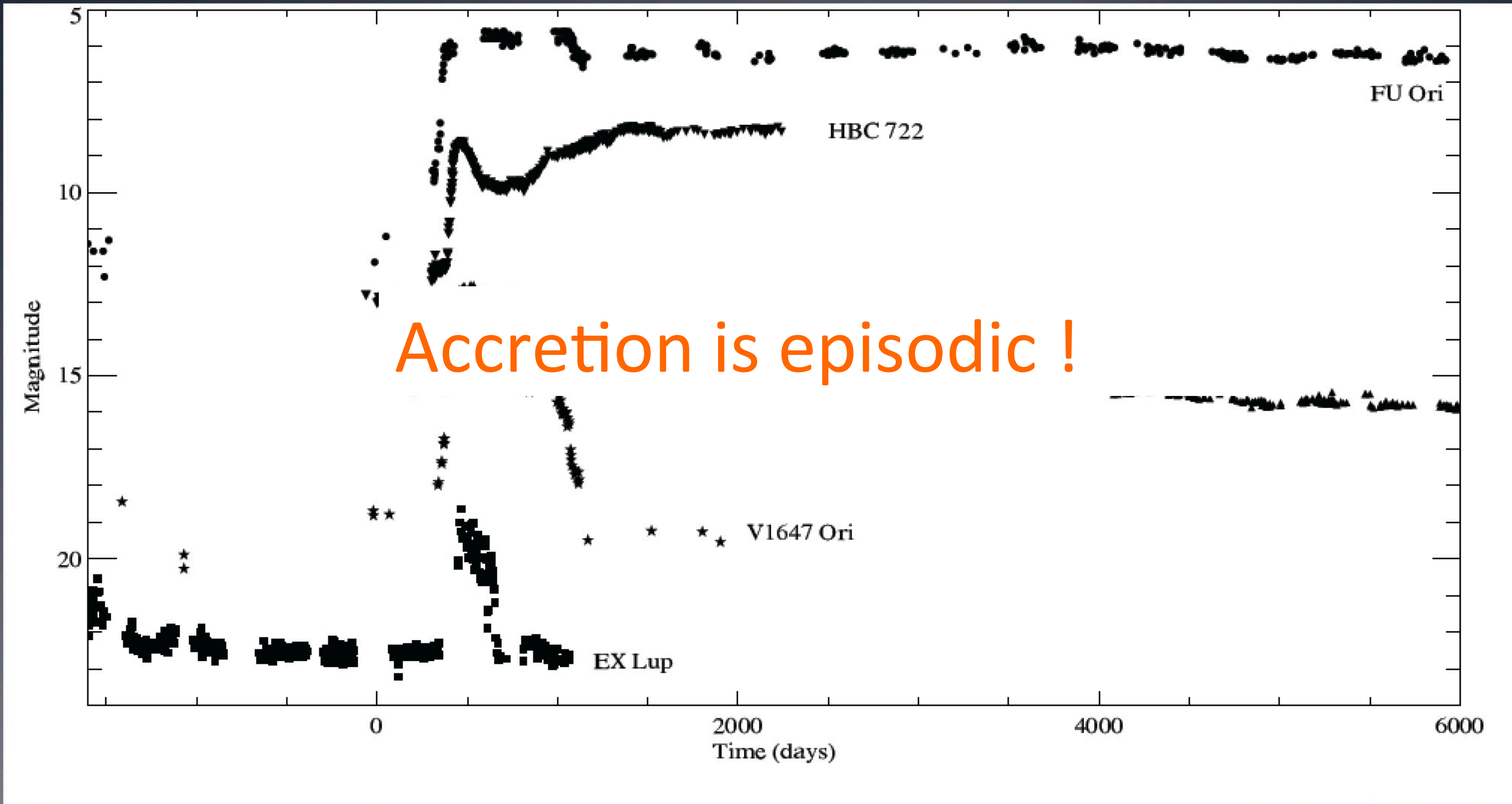
1.3 mm continuum in color image and black contours; CO outflows in red and blue contours

Extremely young Class 0: G192N: M=0.43 Msun (JCMT); M=0.38 Msun (SMA); Lint=~0.2 Lsun

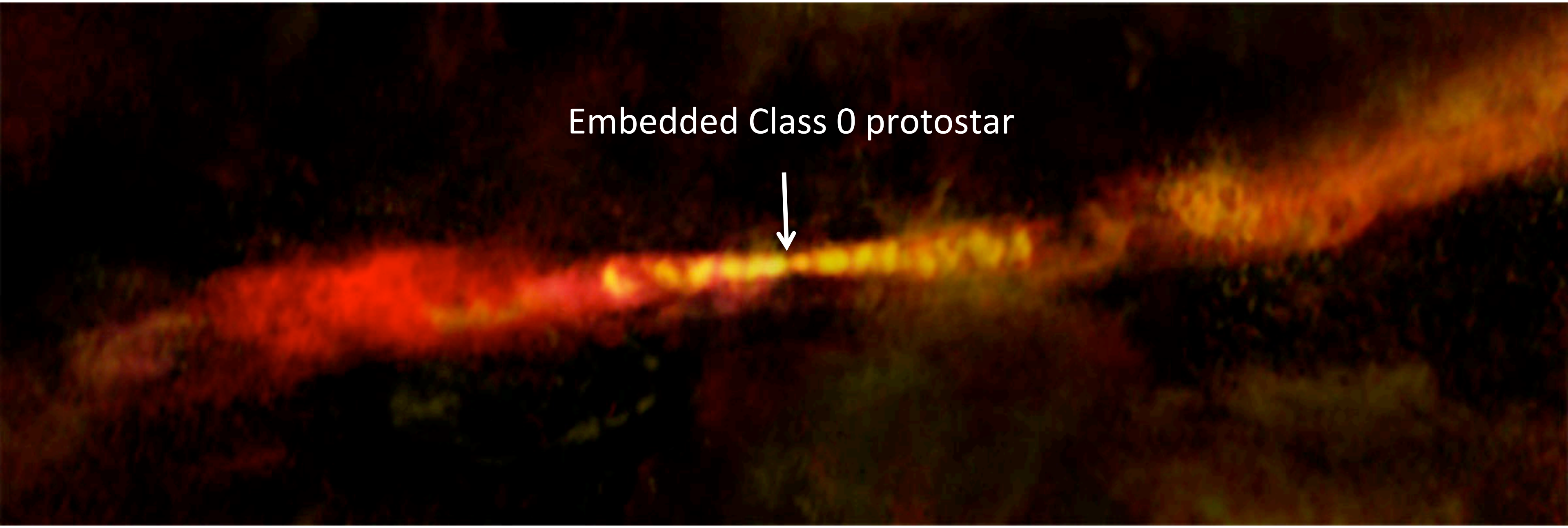
Proto-brown dwarf: G192S: M=0.23 Msun (JCMT); M=0.02 Msun (SMA); Lint=~0.08 Lsun

FUor and EXor outbursts

(adapted from Kospal+2011)



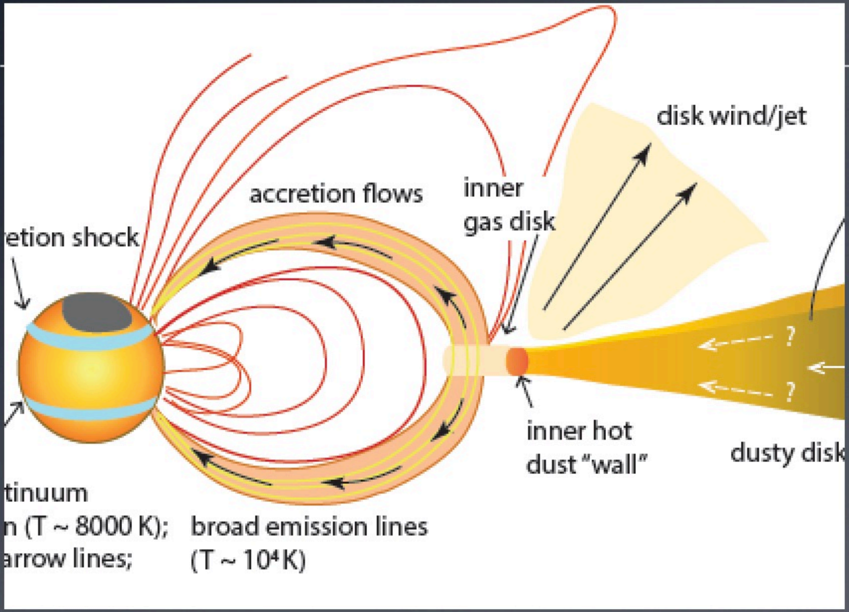
Evidence of Episodicity: Episodic molecular outflow in the very young protostellar cluster Serpens South



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):

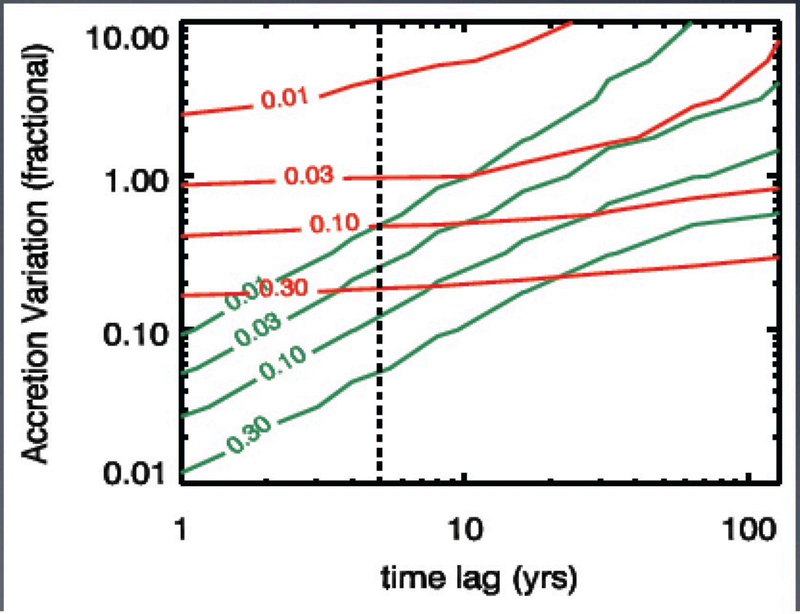
(1) Magnetic truncation radius > corotation (gas cannot accrete)
(2) Matter piles up at truncation radius => truncation radius shrinks
(3) Truncation radius < corotation => outburst

But EXors could also be due to inner disk instability (Zhang + 2015)

JCMT Transient Project Led by Gregory Herczeg, Doug Johnston

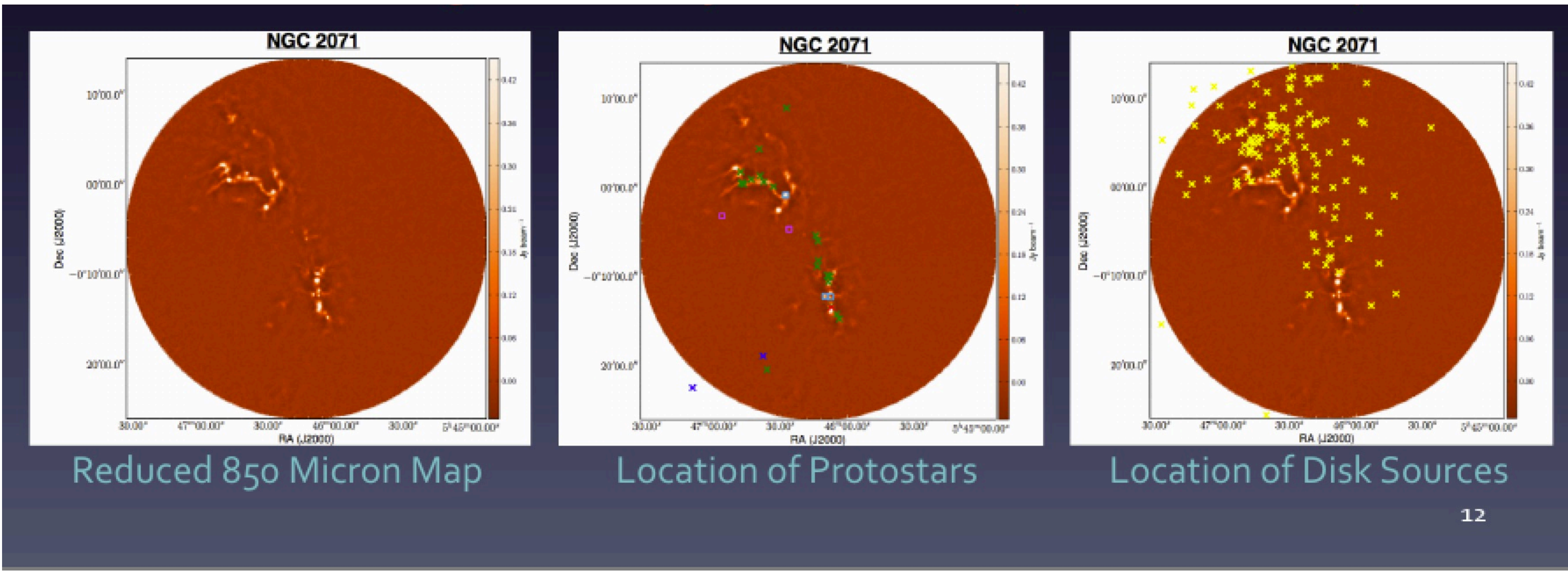
Program description

- 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)

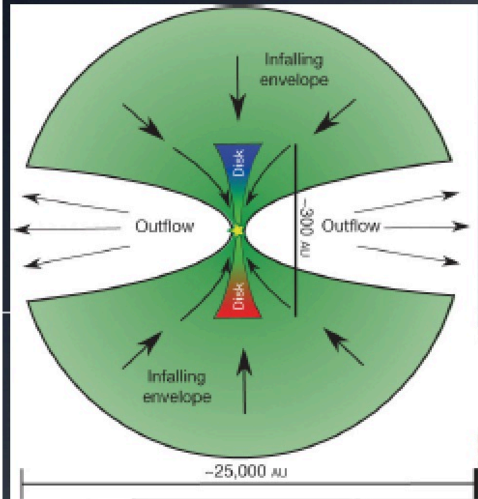
Recent NGC 2071 Results from Transient Project

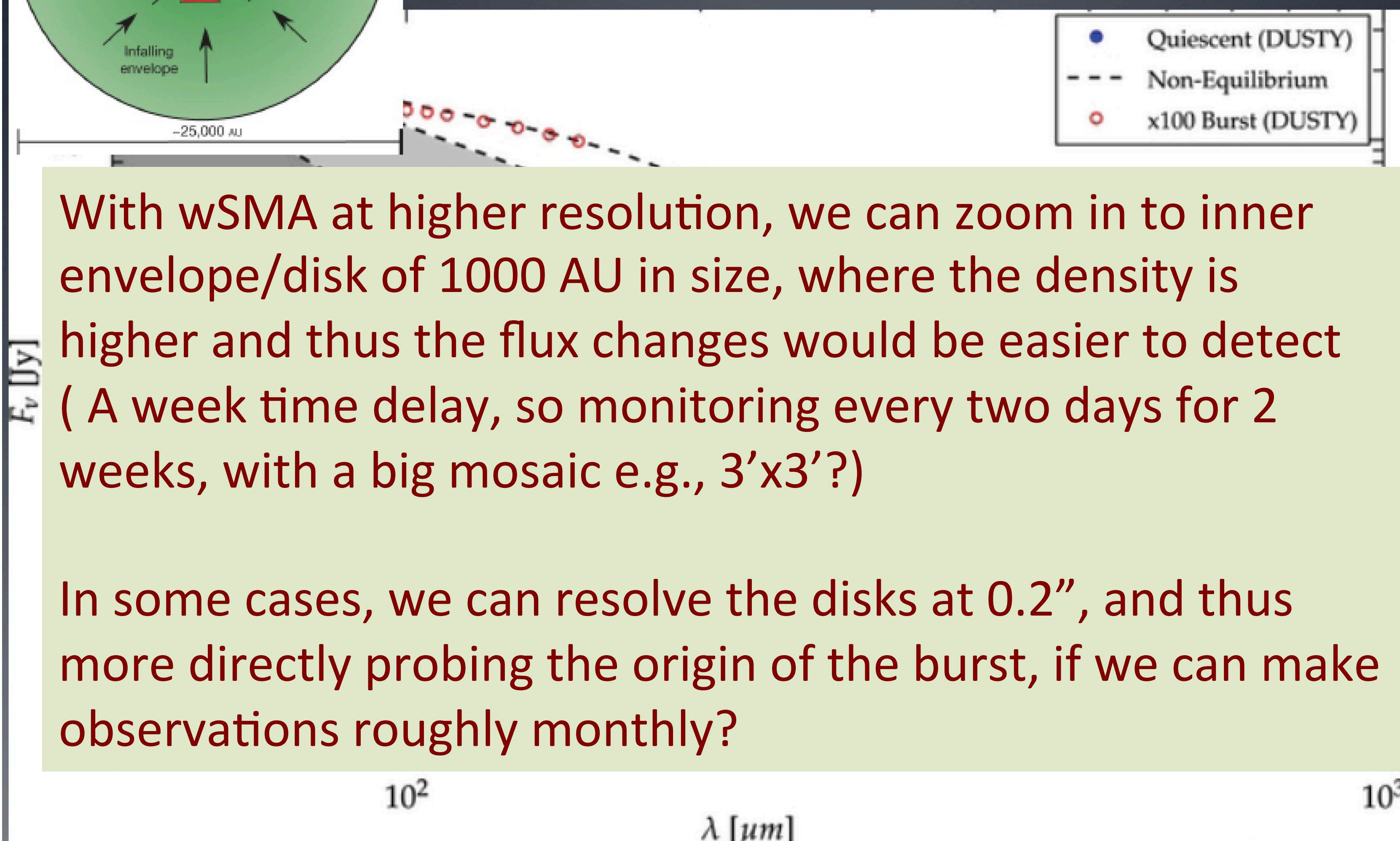


Doug Johnstone

Radiative transfer: a burst through an envelope

(Johnstone et al. 2013)



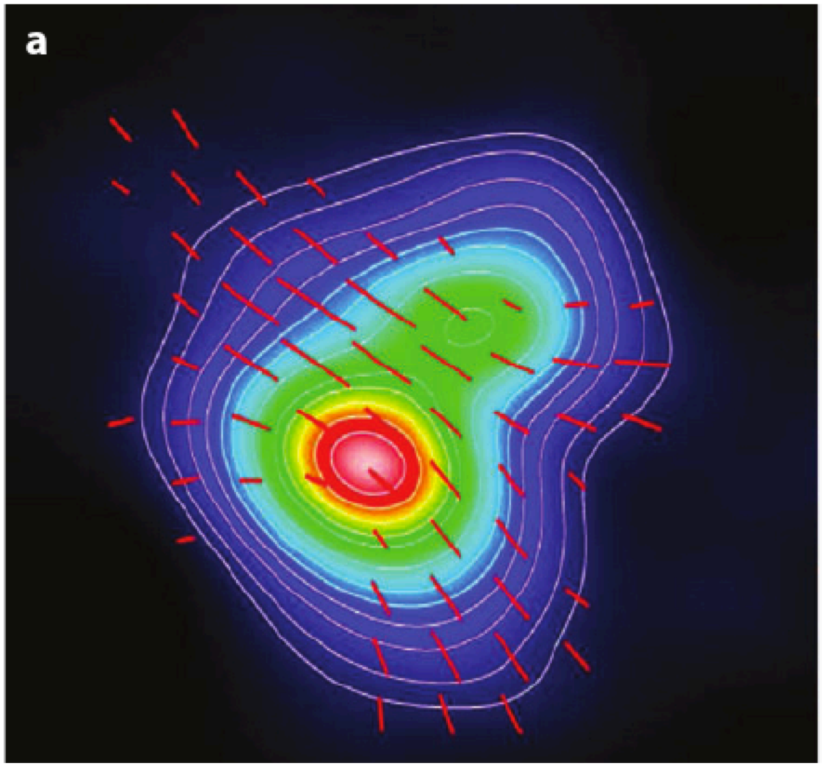


With wSMA at higher resolution, we can zoom in to inner envelope/disk of 1000 AU in size, where the density is higher and thus the flux changes would be easier to detect (A week time delay, so monitoring every two days for 2 weeks, with a big mosaic e.g., 3'x3'?)

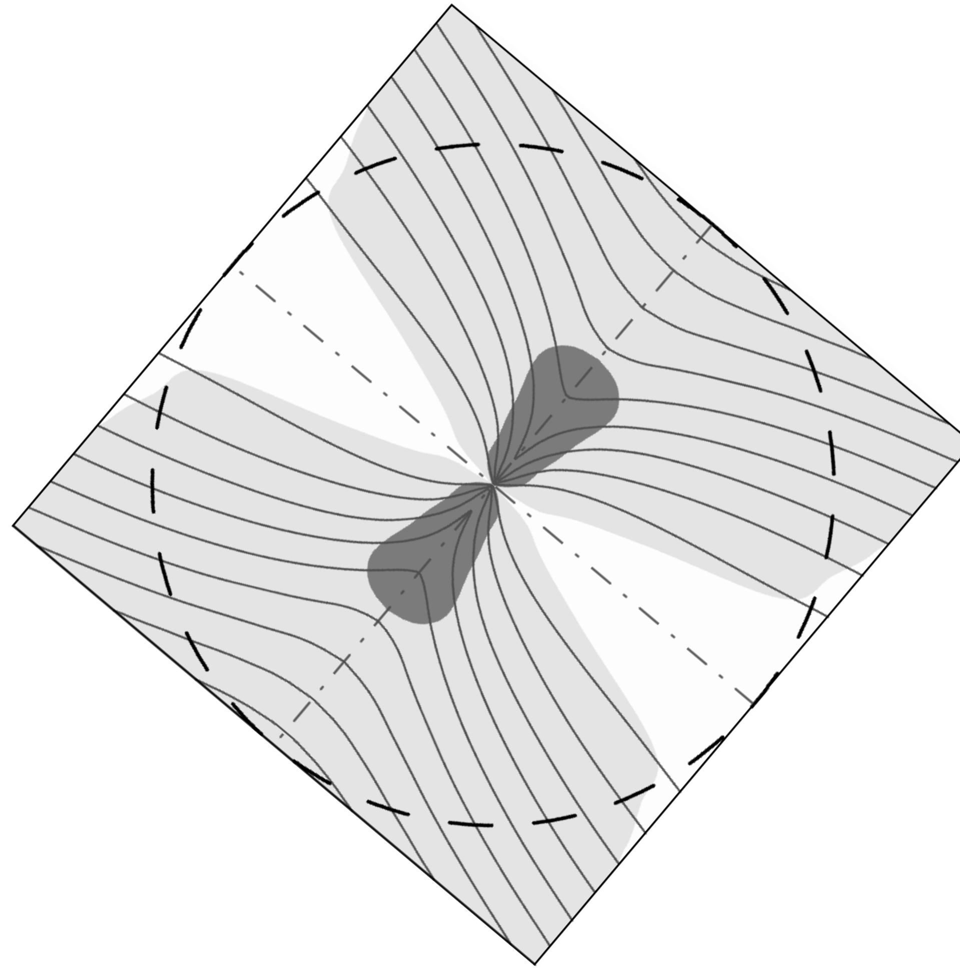
In some cases, we can resolve the disks at 0.2", and thus more directly probing the origin of the burst, if we can make observations roughly monthly?

Time delay: a few weeks (mostly light travel time)

Hour-Glass Magnetic field Morphology in e.g., NGC 1333 IRAS4A envelope

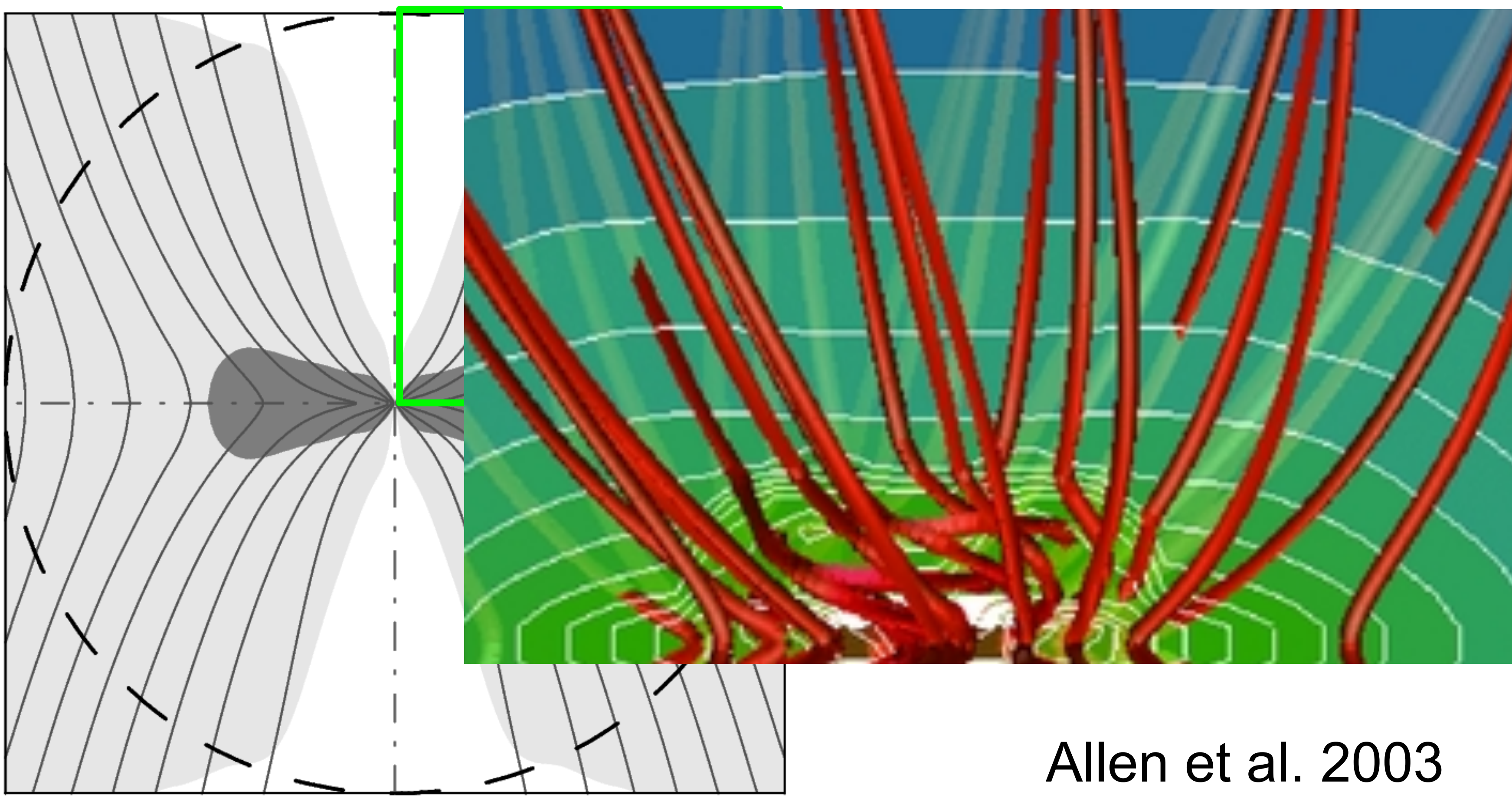


Girart et al. 2006



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

Theoretical Model of Magnetized Core Collapse



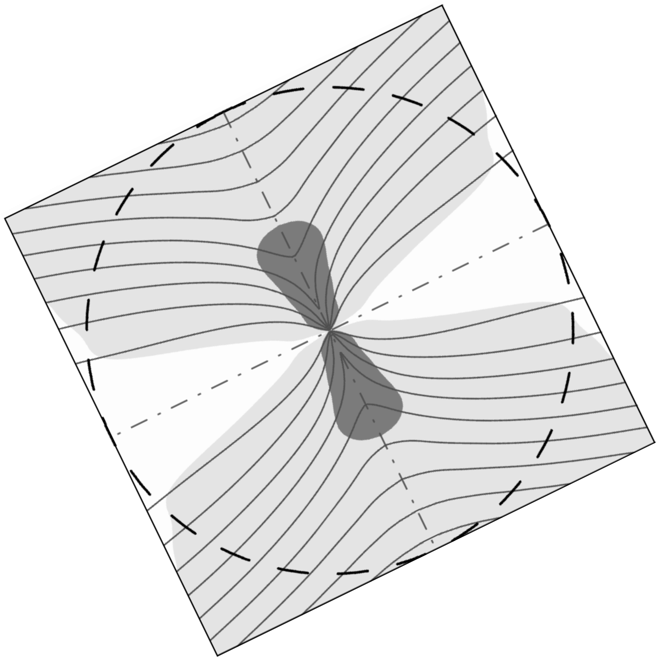
Extended Infalling envelope +
Flattened Envelope (Pseudodisk)
+ Hour-glass B-field morphology

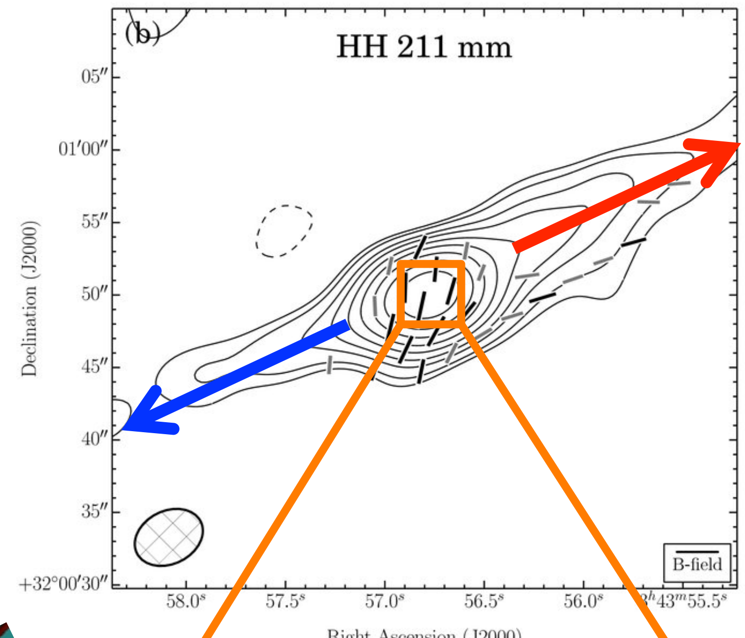
Allen et al. 2003

Still Flattened envelope but
no disk formed ➔MBC!

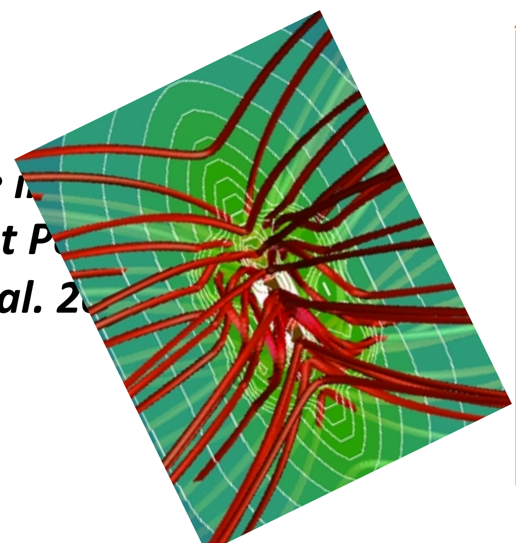
Magnetic field Morphology in the Envelope

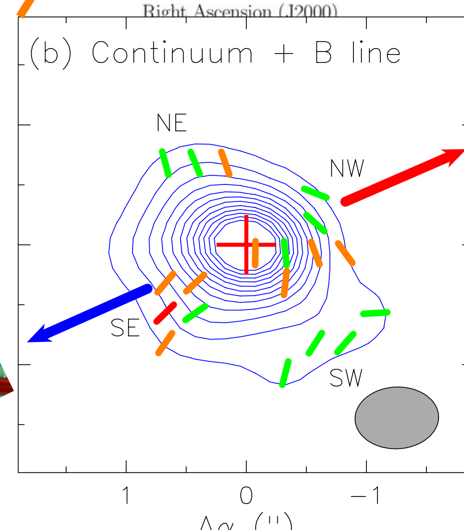
(CARMA @ 230 GHz dusty continuum, Hull et al. 2014)





Field morphology in the i
obtained with SMA Dust P
GHz Continuum (Lee et al. 2





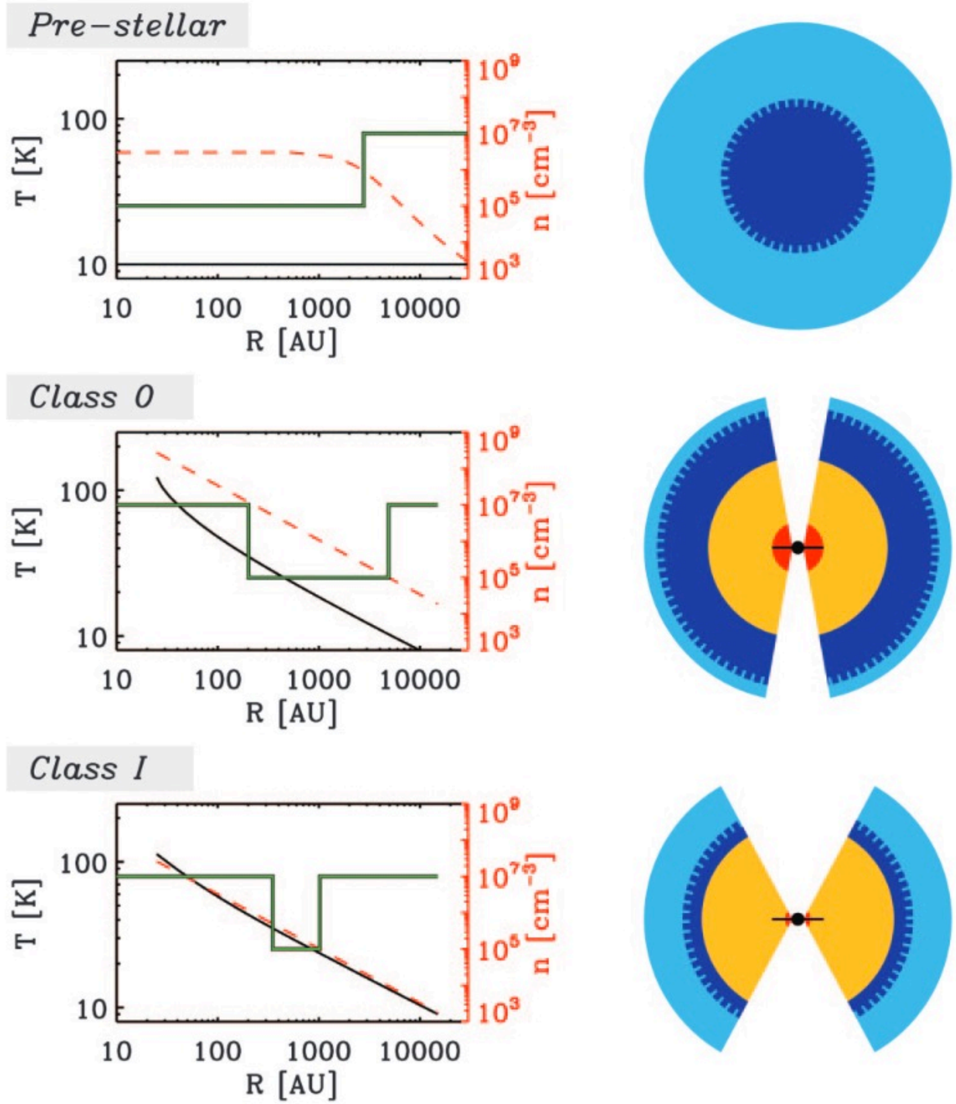


Fig. 2. Physical and chemical structure of pre- and protostellar objects. (*Left*) Density (red), temperature (black), and typical abundance (green) profiles. (*Right*) Depletion signature for each class of object with the light blue indicating the region where the density is too low for significant 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_2O ice has evaporated (28).

Van Dishoeck 2006

Pre-stellar phase

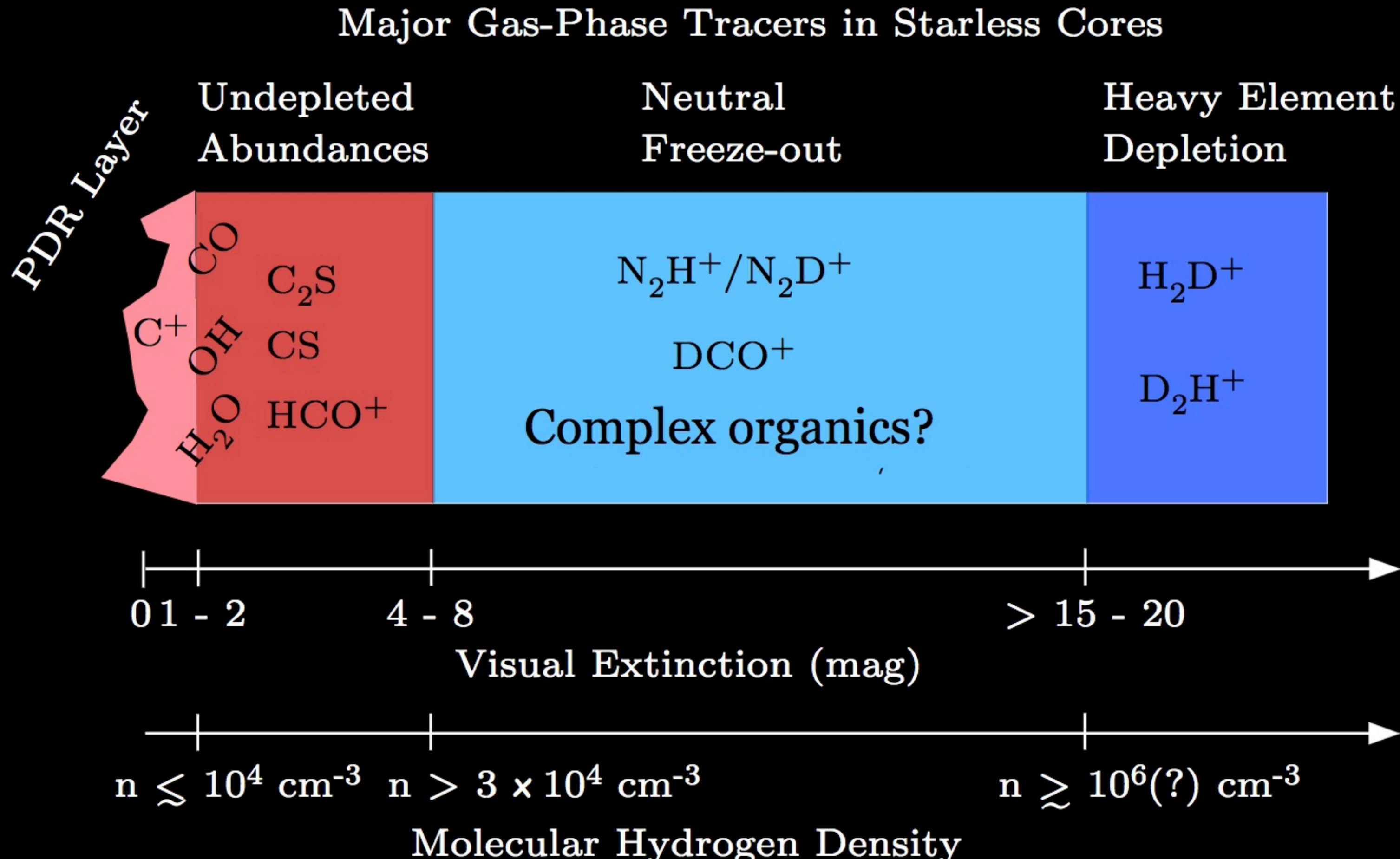
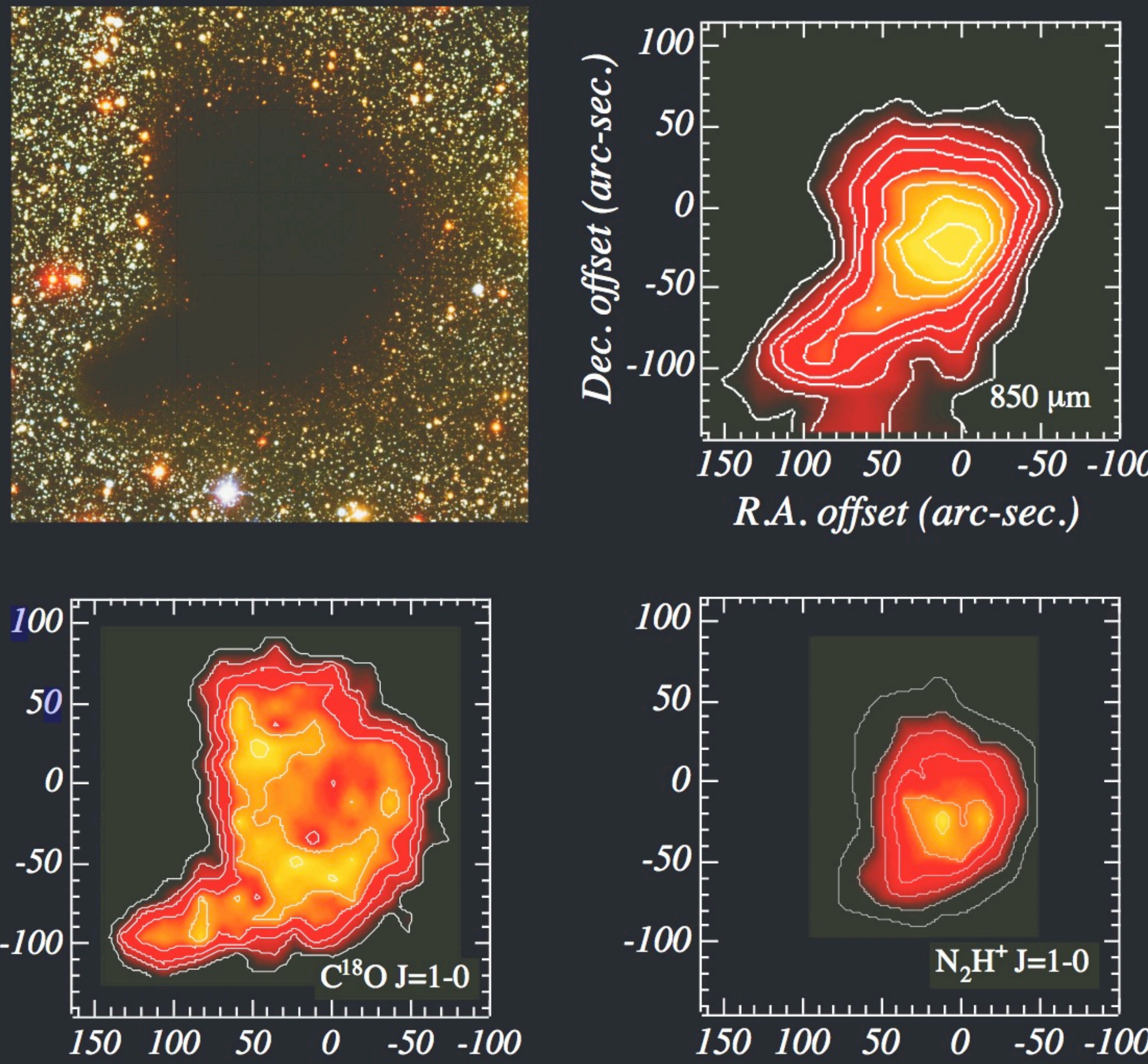


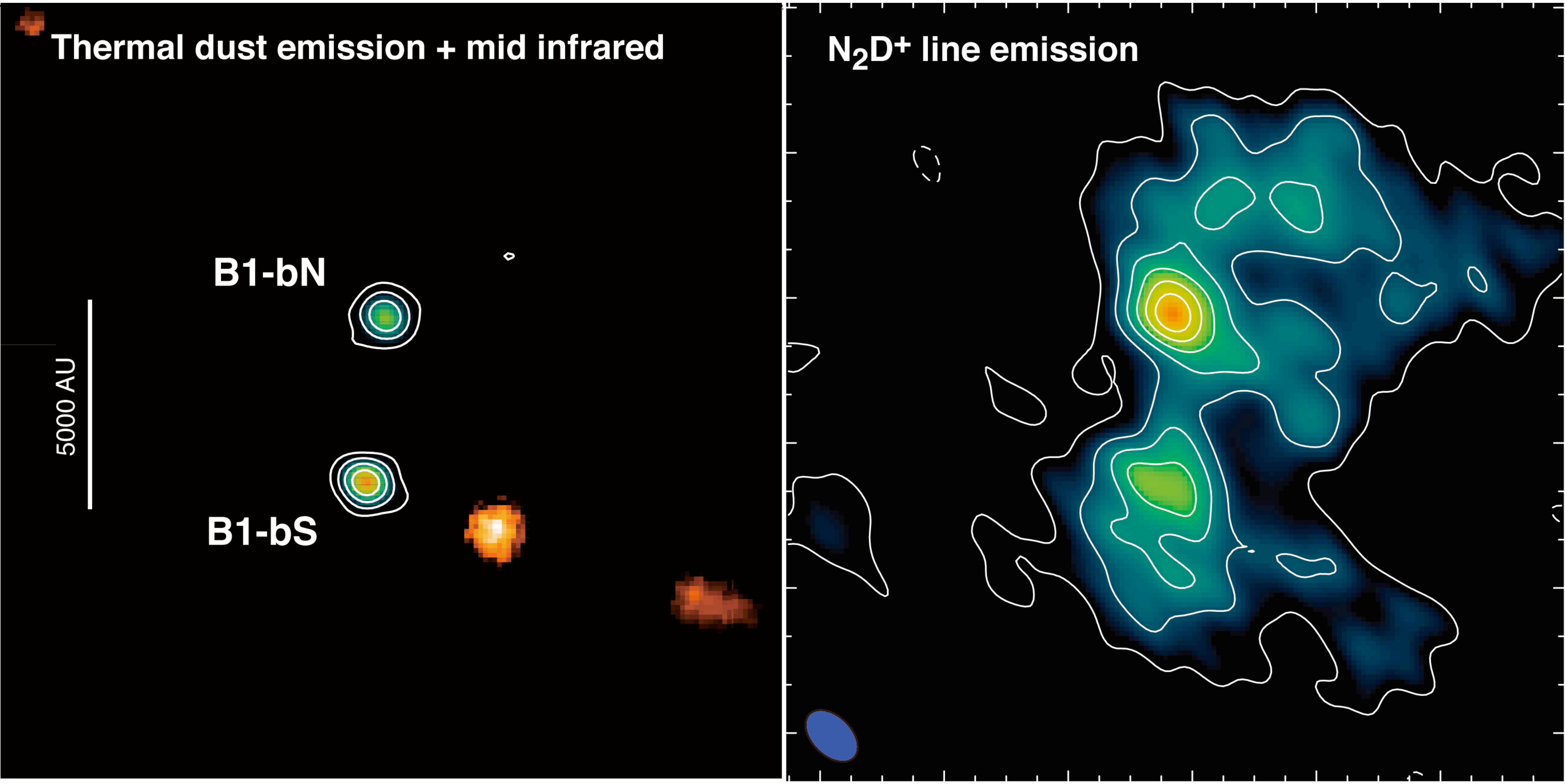
Fig. courtesy of T. Bergin



SMA for this size scale

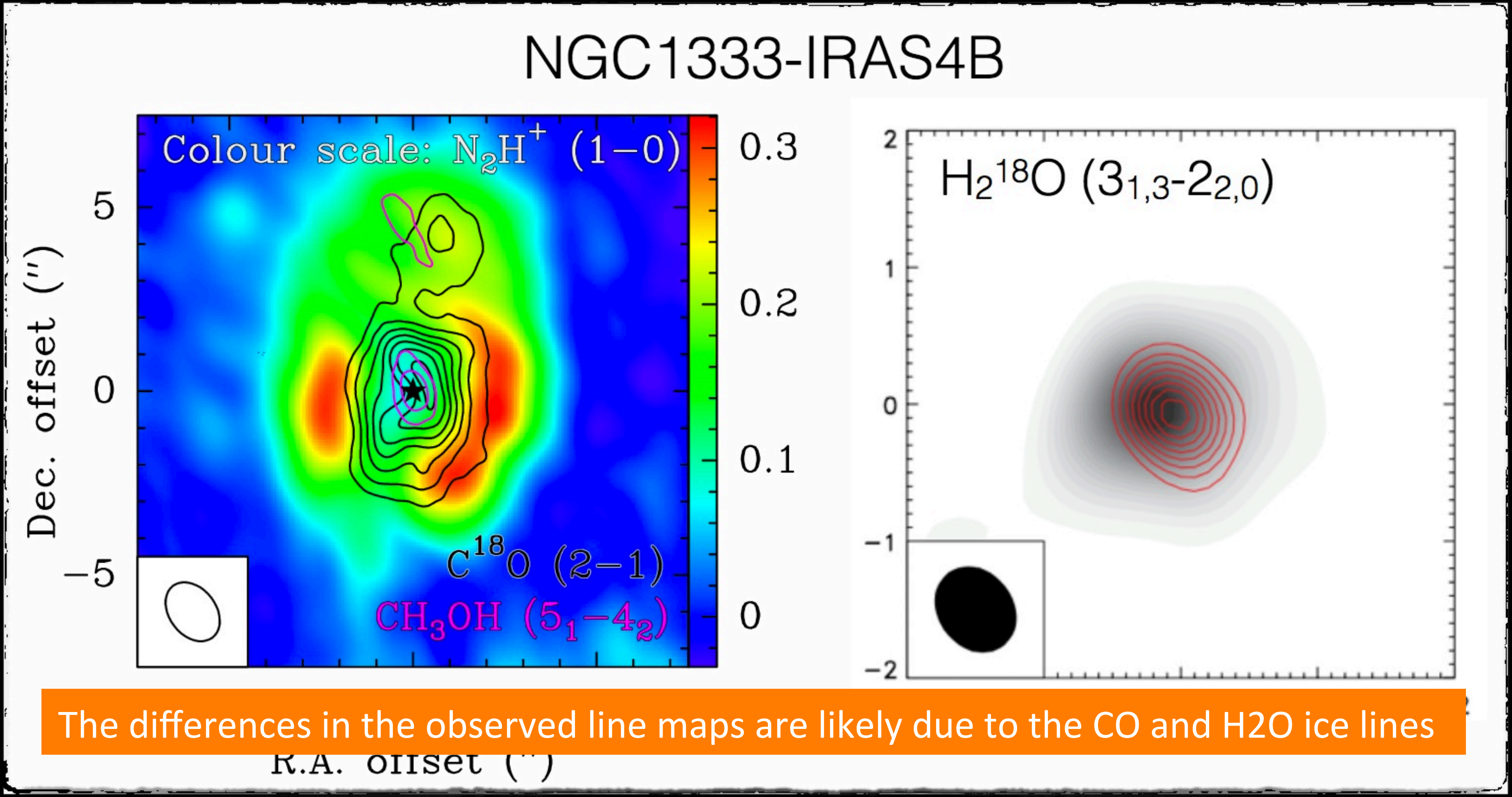
Bergin & Tafalla (2007)

Two mm sources in the B1-b molecular cloud core.



Huang & Hirano 2013

Ice lines in Class 0 protostars

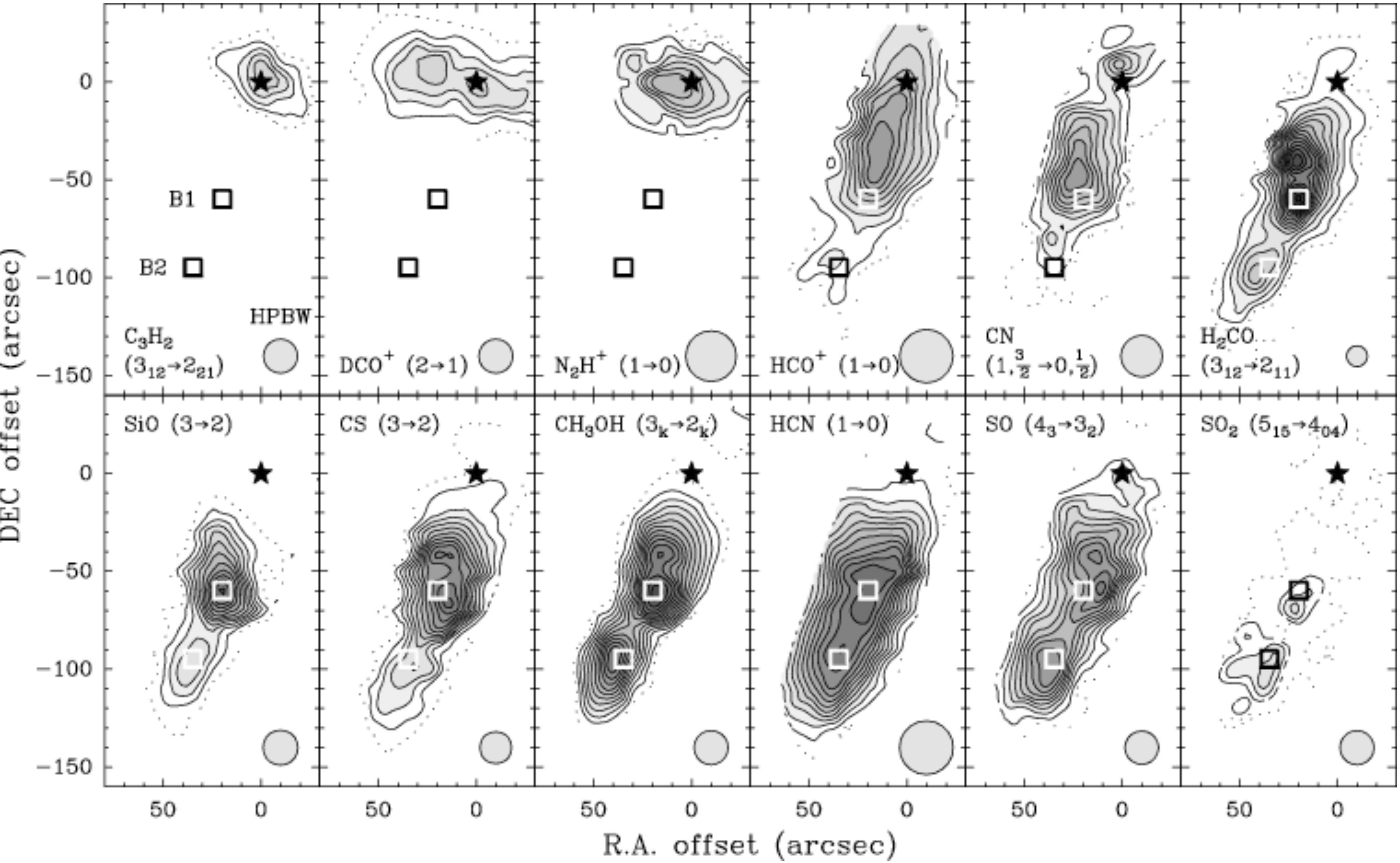


The differences in the observed line maps are likely due to the CO and H2O ice lines

Anderl et al. (in prep)

Jørgensen et al. (2010)

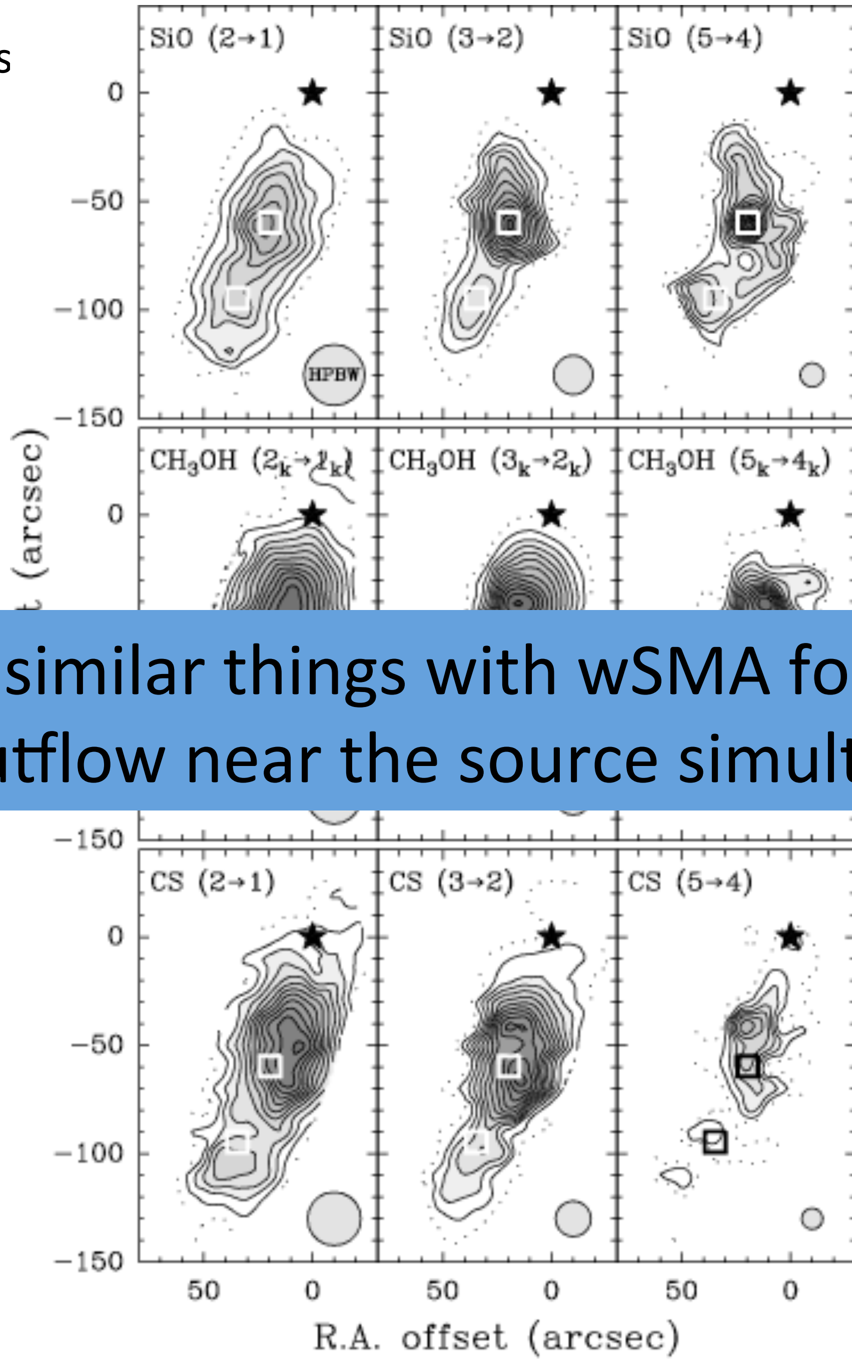
L1157 : Class 0 Envelope and Outflow by IRAM 30m



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

Bachiller et al. 2001

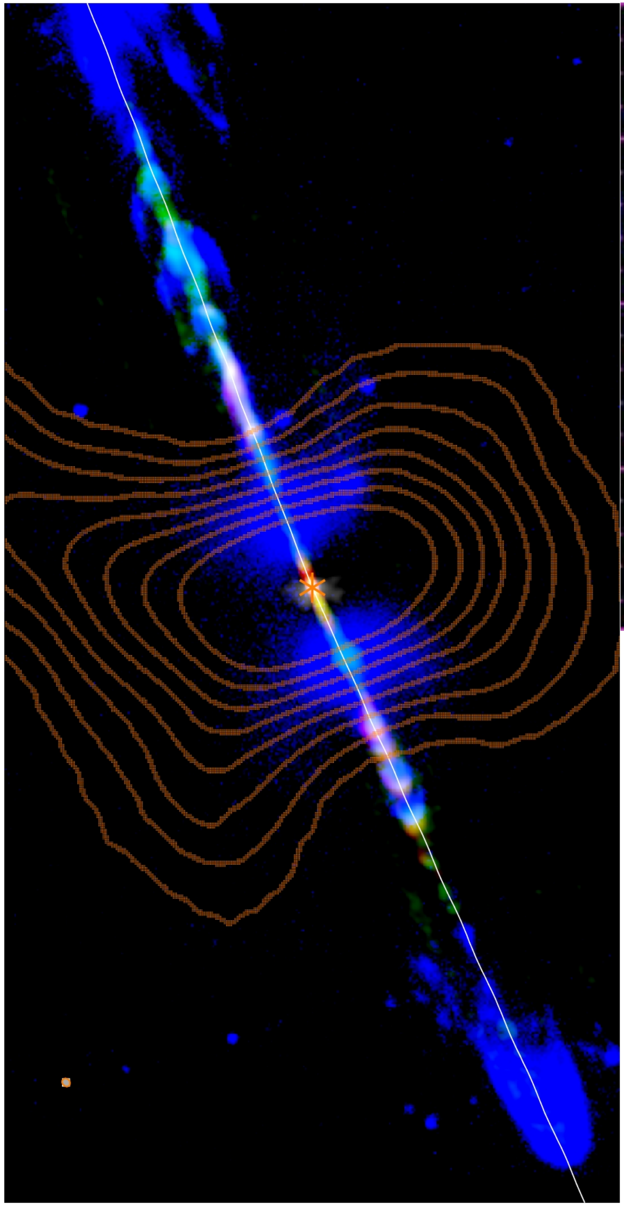
L1157 Observations

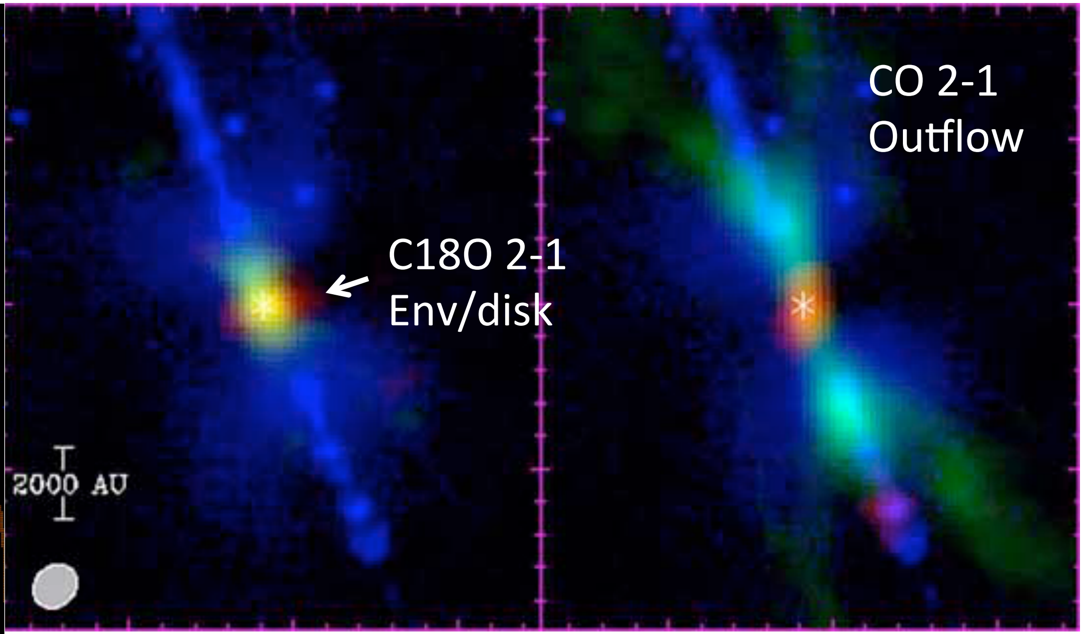


We can do similar things with wSMA for the envelope and outflow near the source simultaneously.

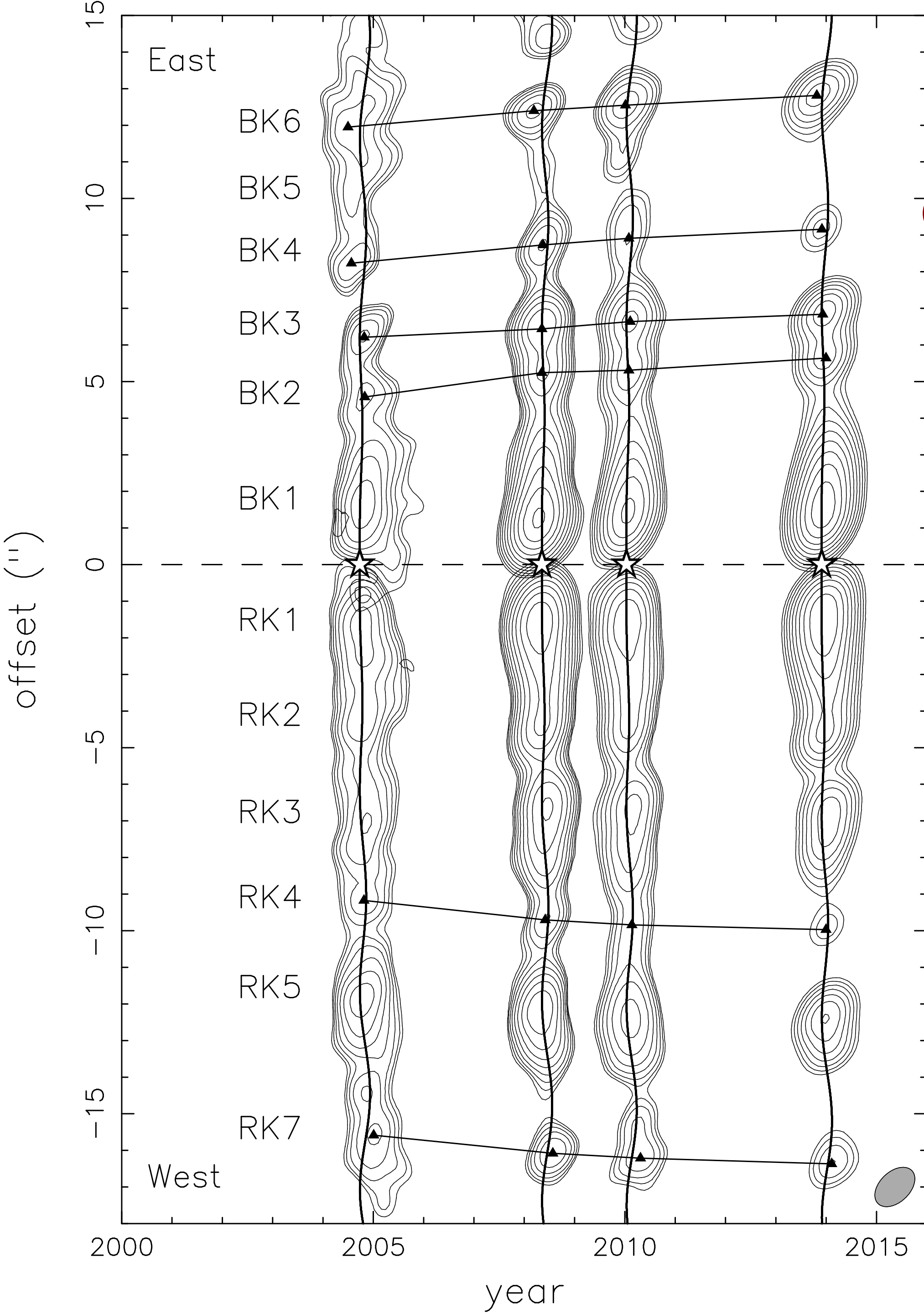
Bachiller et al. 2001

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
➔ envelope, 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?

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