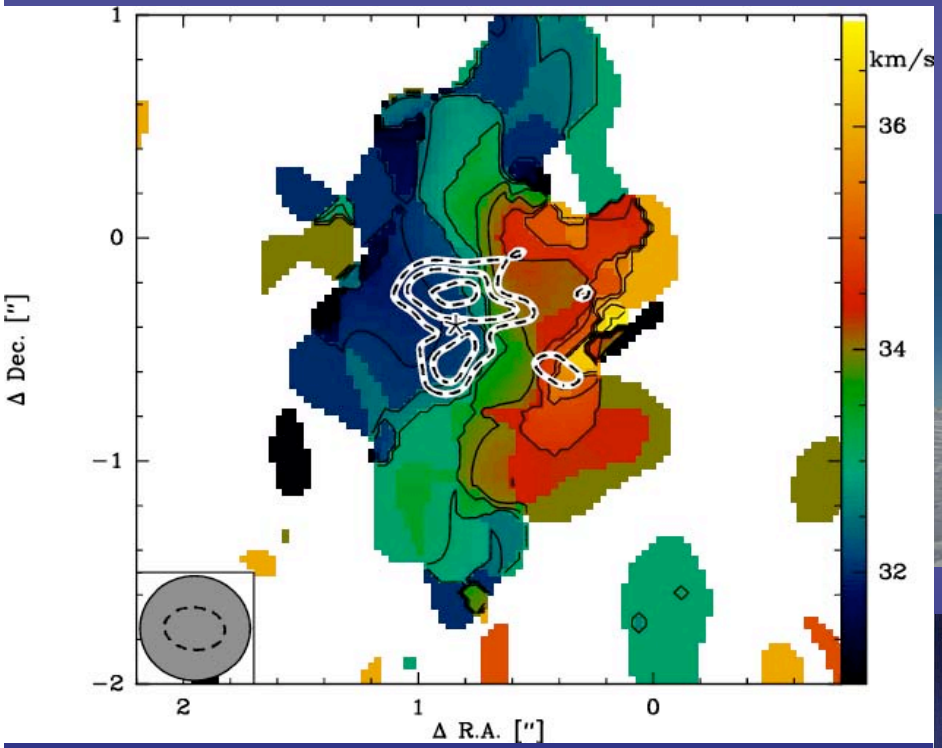
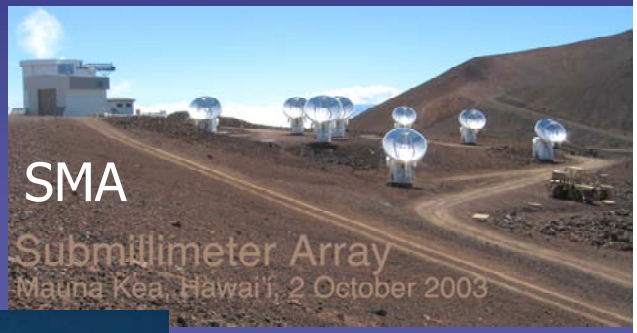
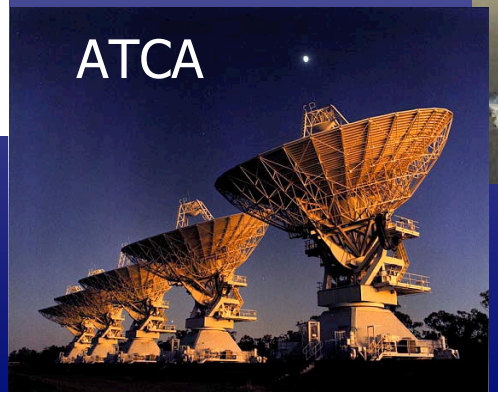
Constraining massive star formation with interferometry observations

Henrik Beuther







Overview

- What are the physical conditions at the onset of massive star formation?
- How do rotation, infall and disks behave in massive star formation?
- How do massive clumps fragment, and what are their density distributions?
- Summary
- HERCOOLES: The Herschel Cooling Program for Early Stages of Massive Star Formation (An Open Time Key Proposal)
- What do imaging spectral line surveys tell about physics, chemistry and on the long run biology?

Suggested evolutionary Sequence

High-mass starless cores

$M_{star} = 0\ M_{sun}$

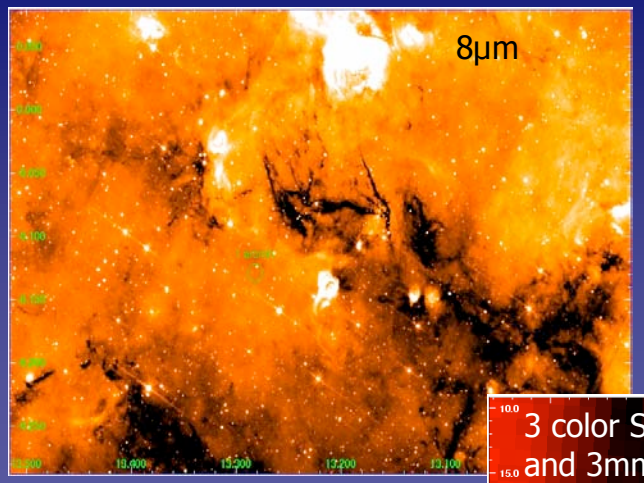
High-mass cores with accreting protostars destined to become high-mass stars

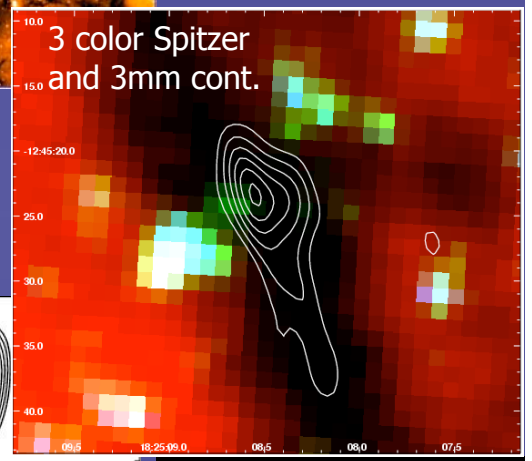
$M_{star} < 8\ M_{sun}$

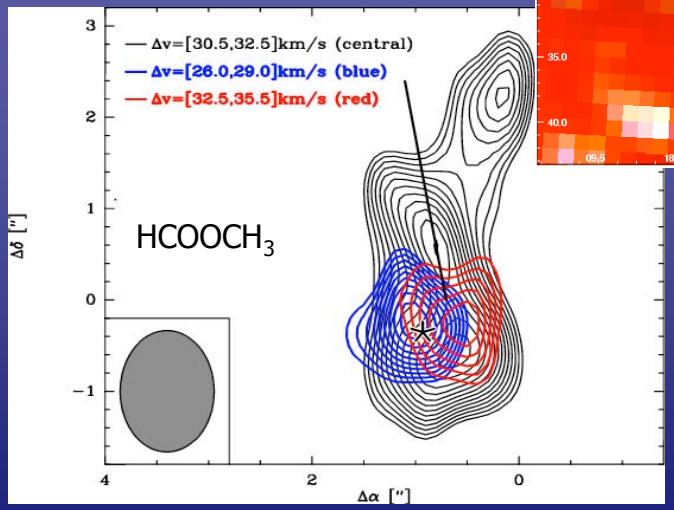
High-Mass Protostellar Objects (HMPOs, including Hot Cores)

$M_{star} > 8\ M_{sun}$

Main-sequence stars

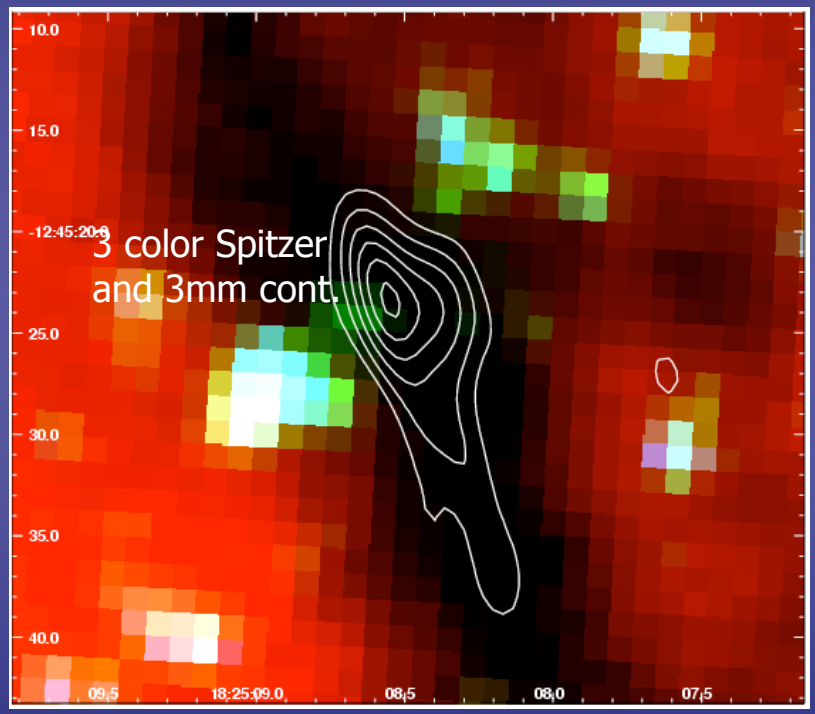






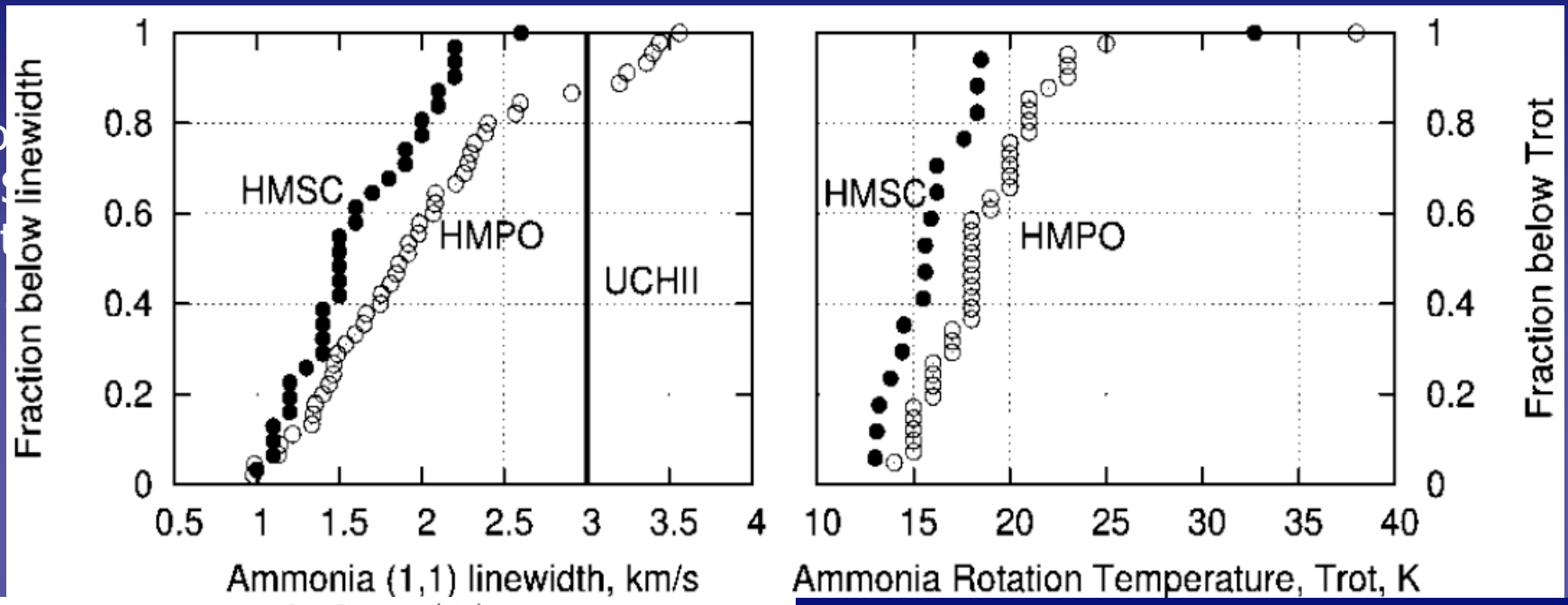
Beuther et al. 2007
(Protostars & Planets V)

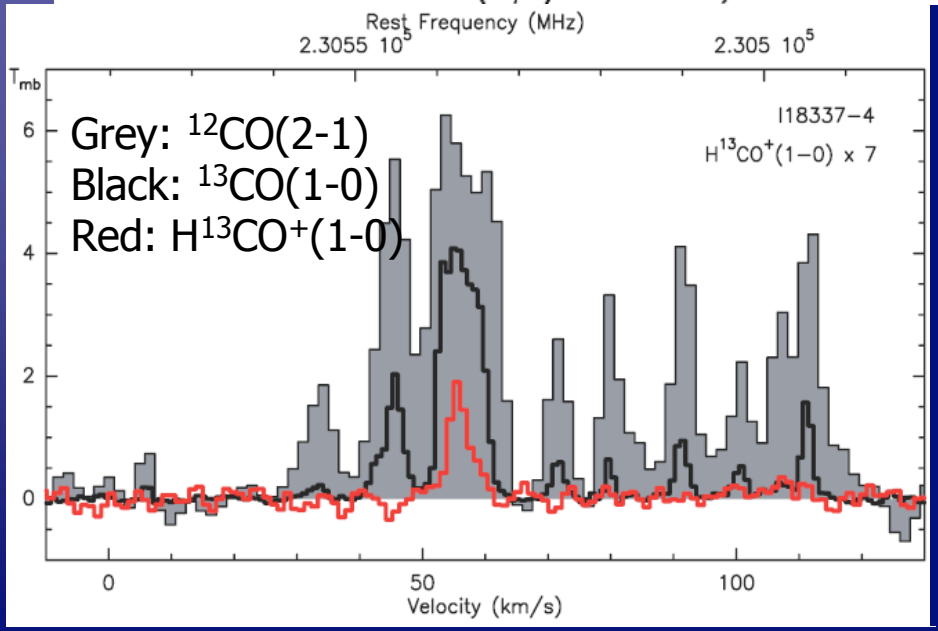
- **What are the physical conditions at the onset of massive star formation?**
  - Rotation, infall and disks in MSF?
  - Fragmentation and density distributions?
  - Summary
  - HERCOOLES: A Herschel OT Key Project.
  - Imaging spectral line surveys revealing physics/chemistry and potentially biology?



A sample of IRDCs: Potential HMSCs?

Colo
MS
Cont
1.





-Sample of 43 IRDCs.

- High-density tracer important to get $v_{lsr.}$

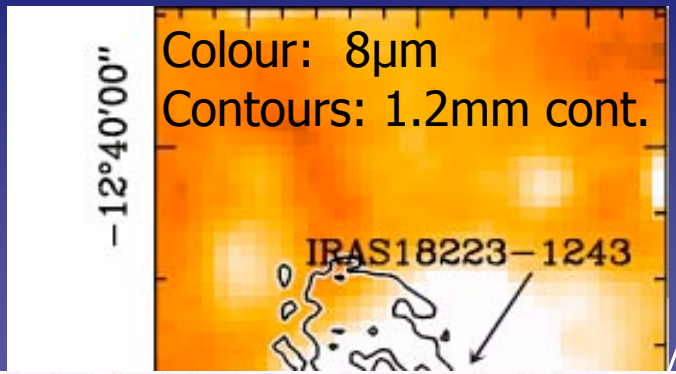
- 18 SiO detections
  --> > 40% star formation activity.

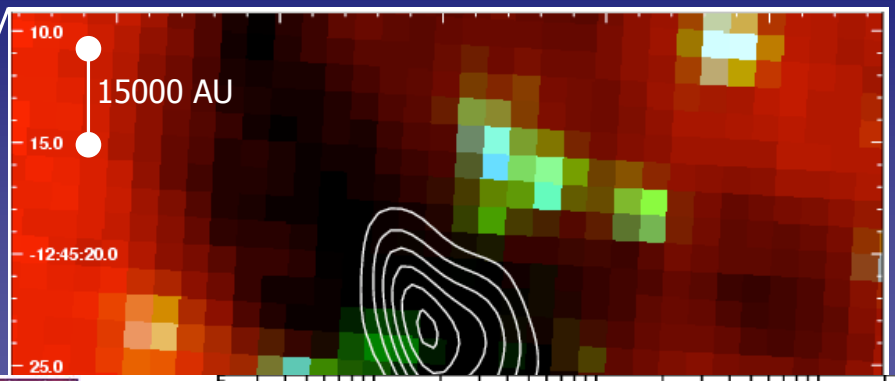
- CH_3OH/CH_3CN abund. low ($10^{-10}cm^{-3}$), similar to low-mass starless cores.

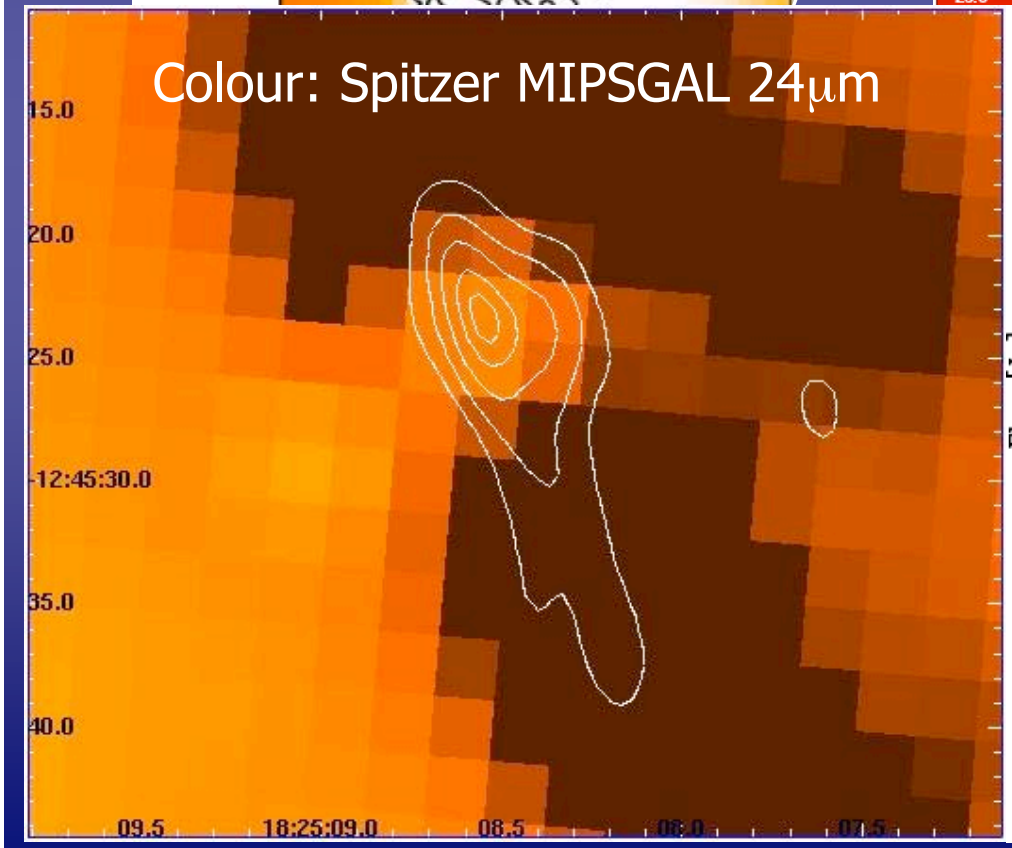
Beuther & Sridharan 2007

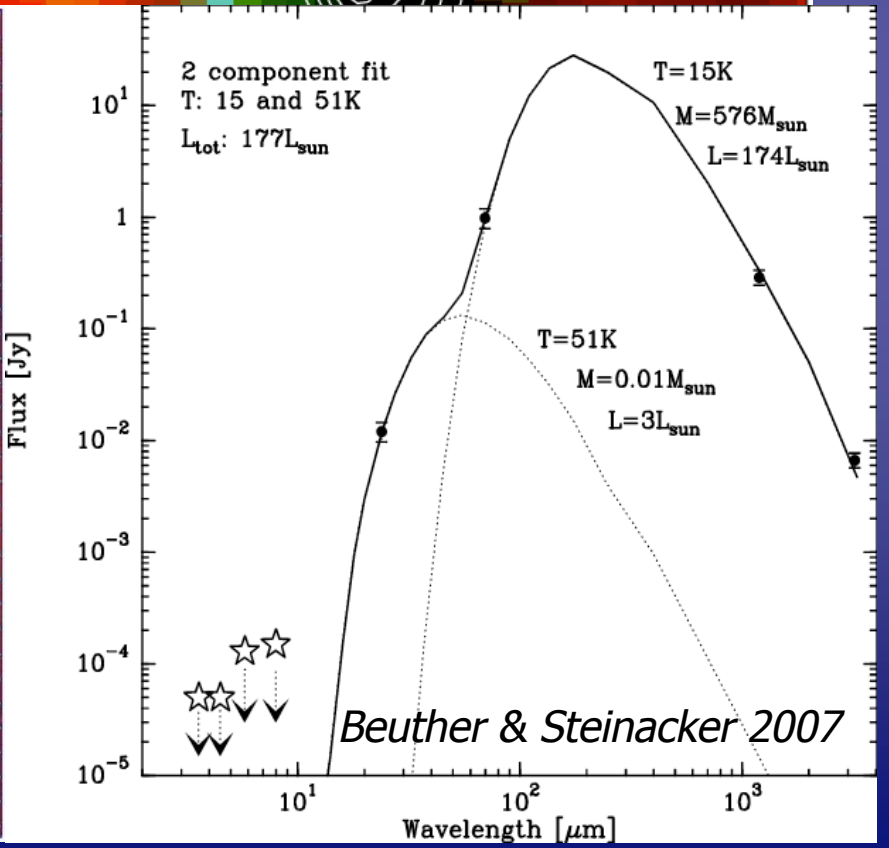
Are high-mass starless cores existing?

The case of IRDC 18223-3









Conditions at the onset of massive star formation?

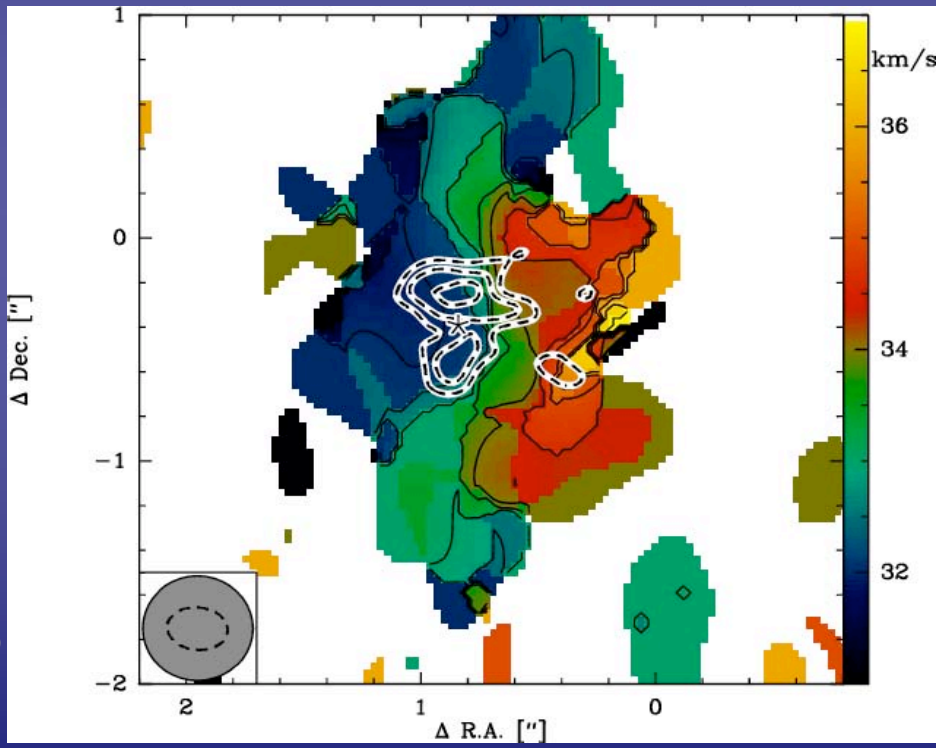
Rotation, infall and disks in MSF?

- Fragmentation and density distributions?

Summary

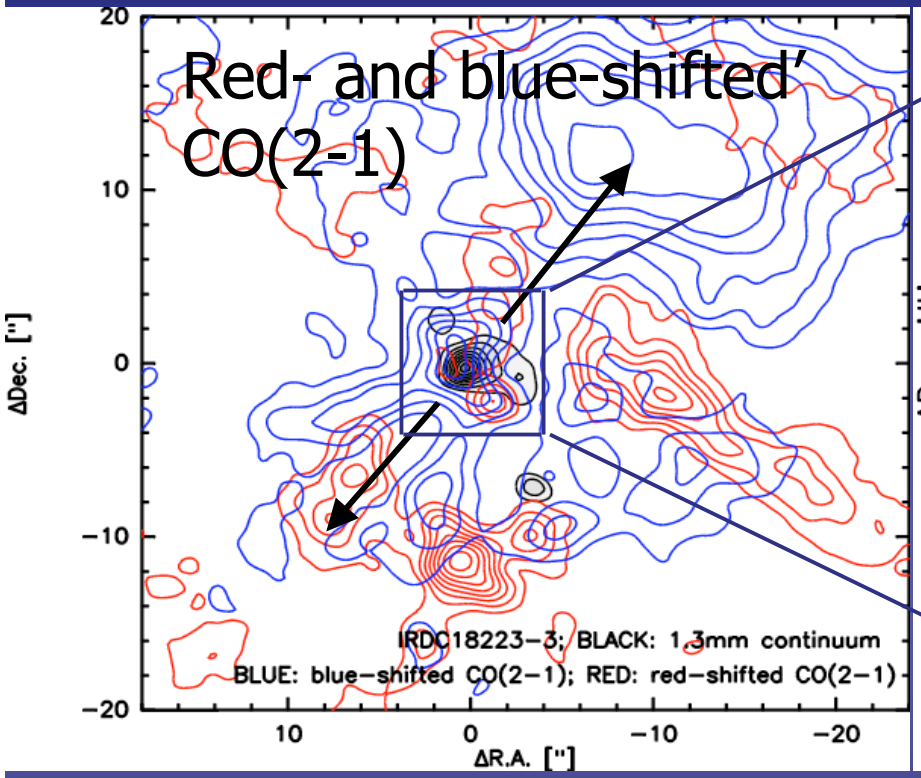
HERCOOLES: A Herschel OT Key Project.

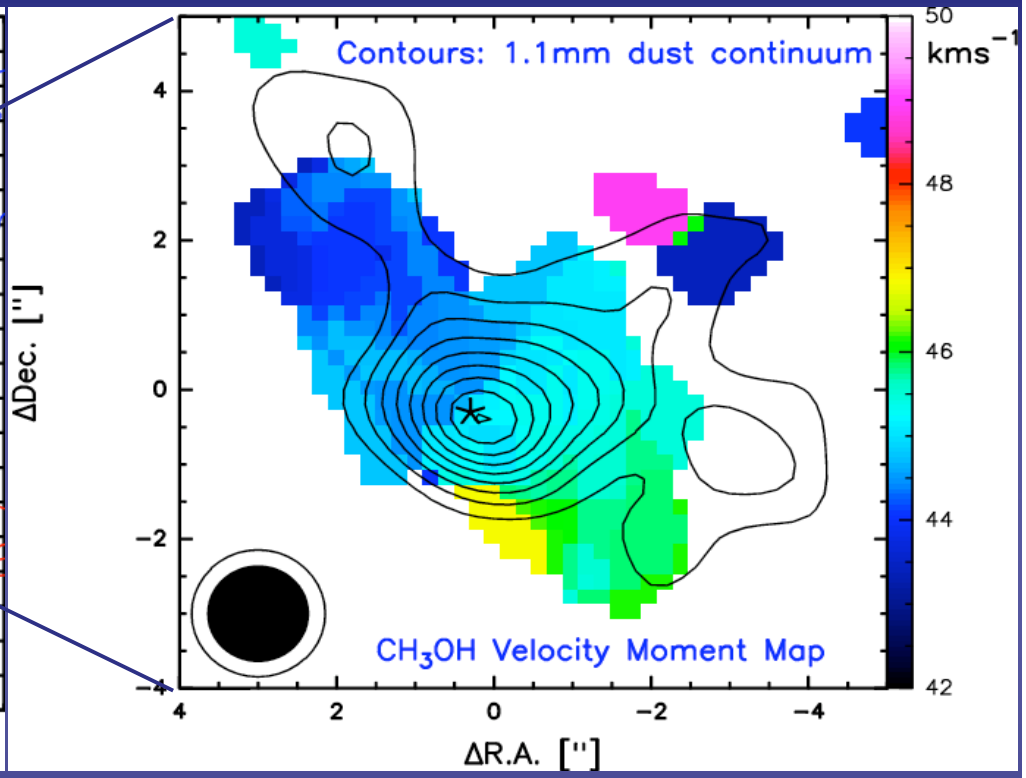
- Imaging spectral line surveys revealing physics/chemistry and potentially biology?



Rotation and outflow at the onset of MSF

IRDC 18223-3, distance ~ 3.7kpc



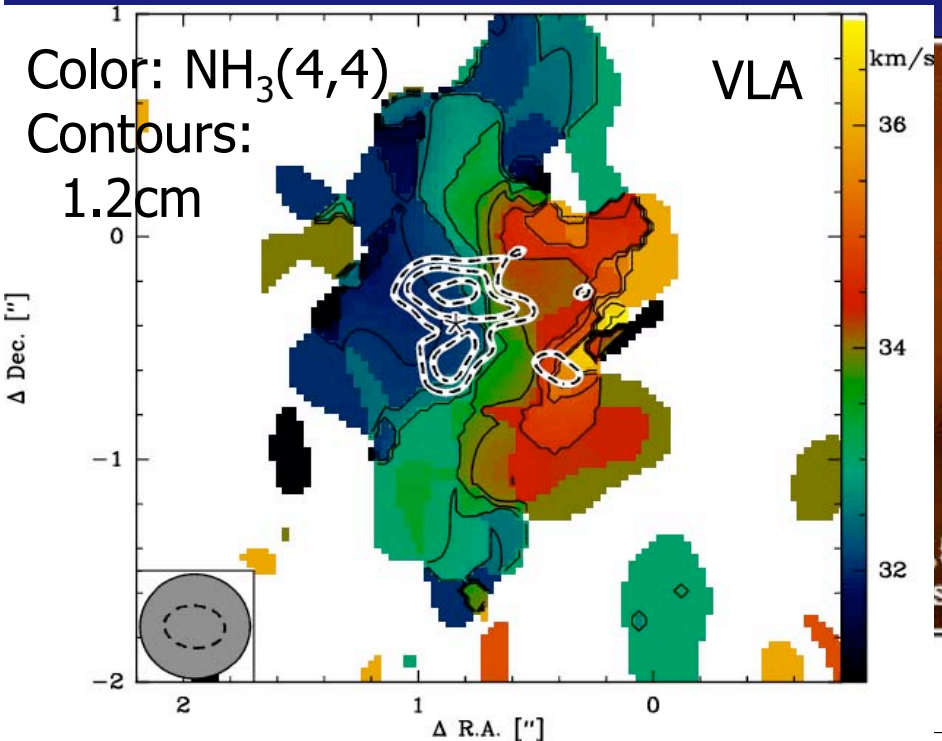


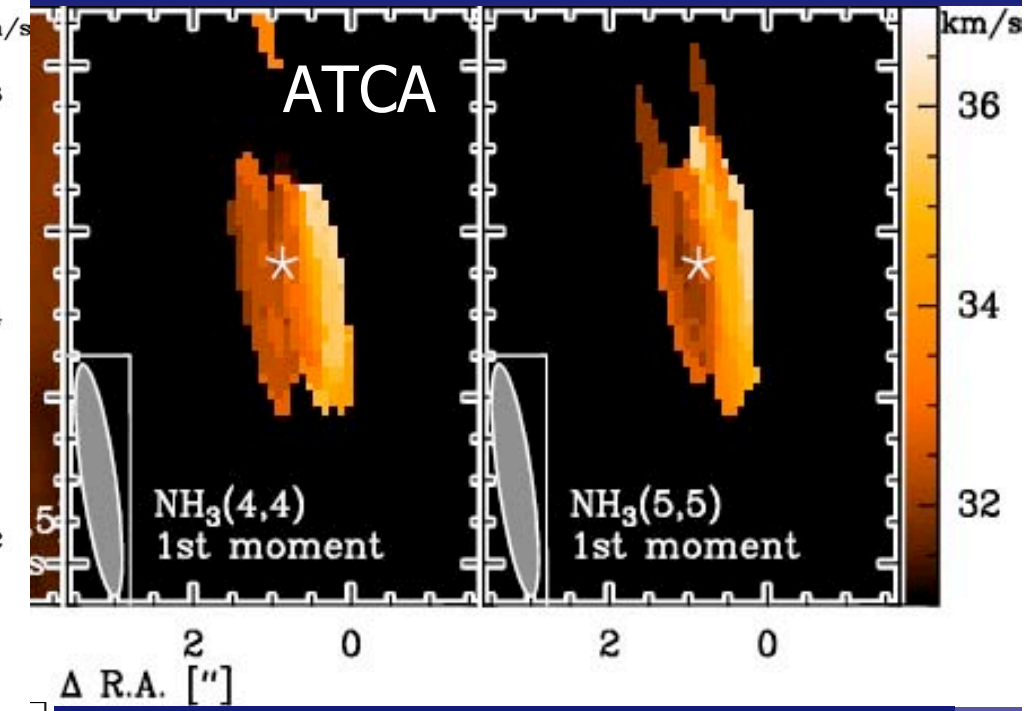
- Outflow wings +-15 km/s
- Outflow mass 13.2 M_{sun}
- Outflow rate 3.5×10^{-4} M_{sun}/yr
- Dynamical age ~3.7×10^{4} yrs

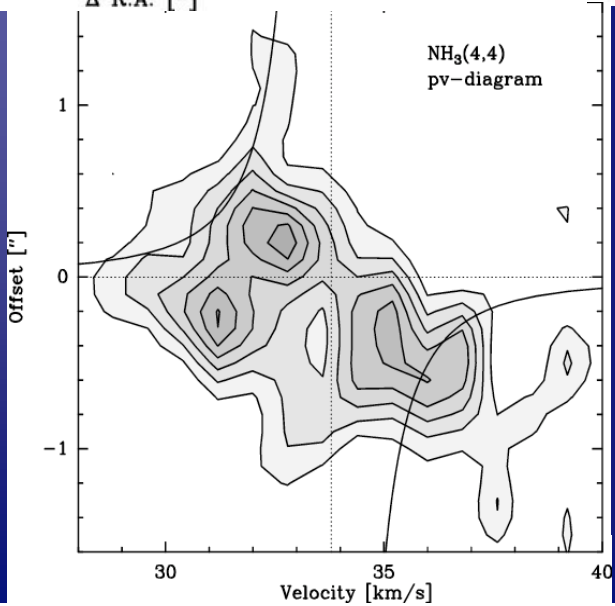
- Δv ~ 2.1 km/s
- Velocity spread ~ 2.5 km/s
- Structure size ~ 25000 AU
- Likely optically thick line?

Fallscheer et al., in prep.

The Disk candidate in IRAS 18089-1732





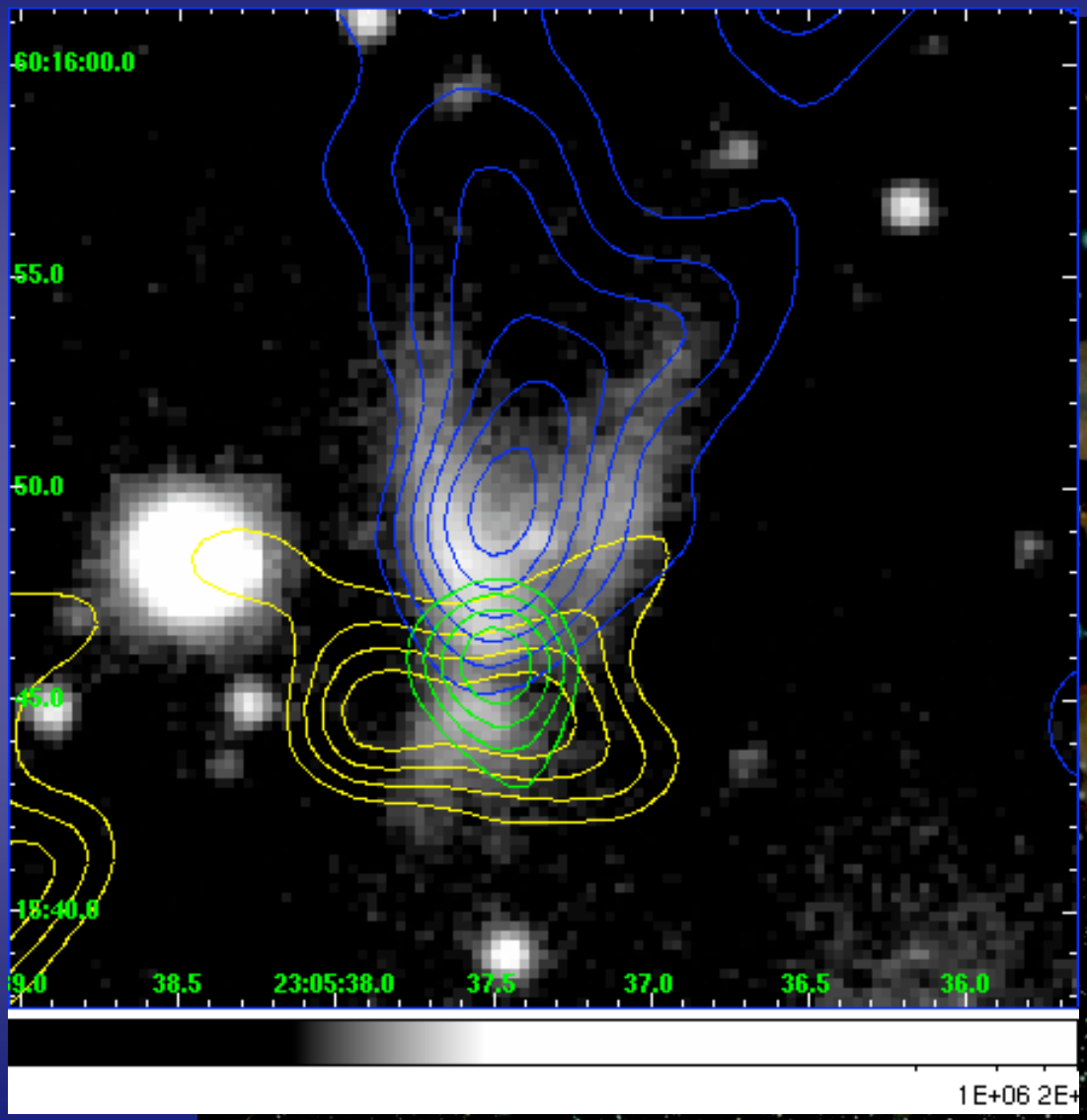


New high-excitation ammonia $NH_3(4,4)/(5,5)$ data

- Clear east-west velocity gradient.
- Non-Keplerian motions.
- T > 100K in rotating structure.
- $\Delta v(NH_3(5,5)) \sim 4.7$ km/s

Beuther & Walsh, subm.

A more evolved disk in MSF?



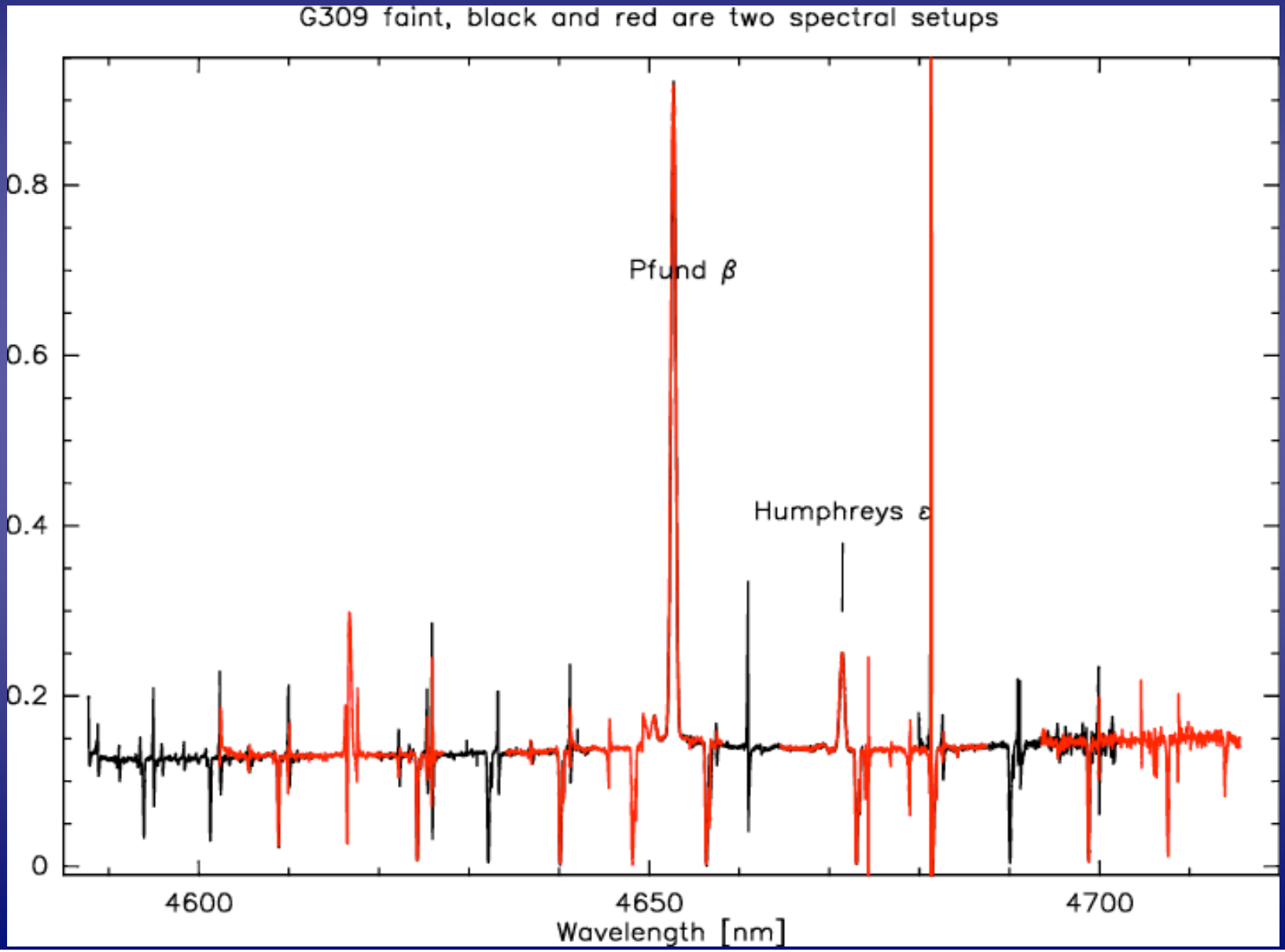
SMA @ 1.3mm and about 5.6kpc

- Blue: CO(2-1)
- Green: 1.3mm continuum
- Yellow: $C^{18}O$(2-1)

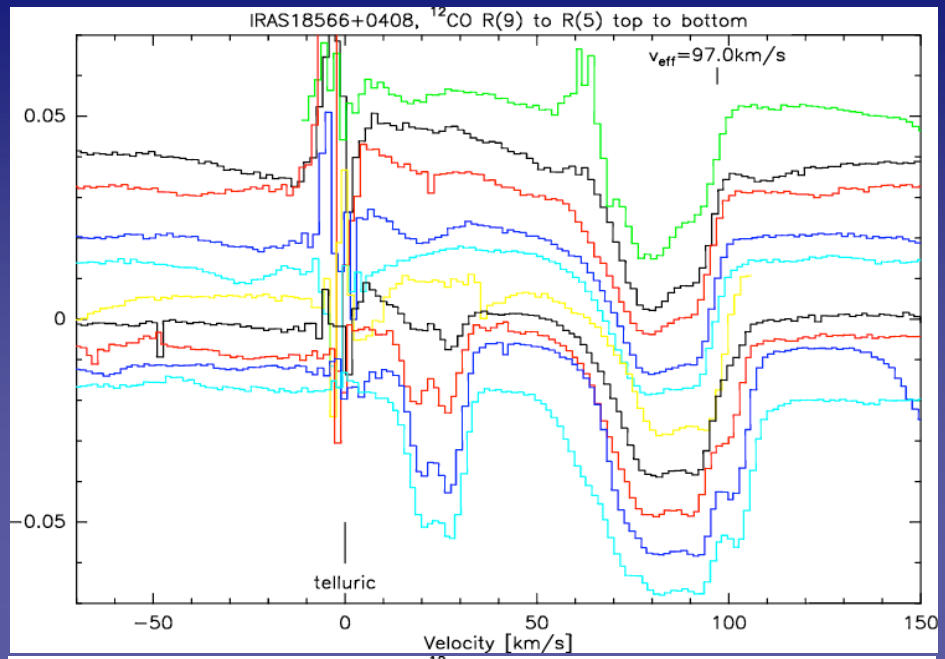
- No dust emission on large scales
- Gas mass ~ $5M_{sun}$
- $\Delta v(C^{18}O) \sim 0.8$km/s
- Size ~ 20000 AU

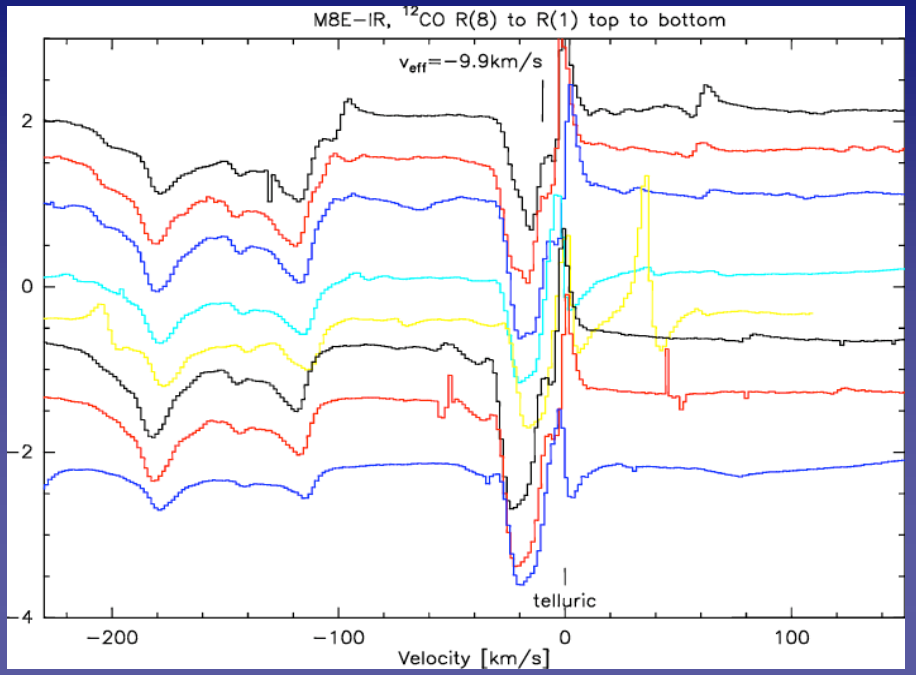
Quanz et al. in prep.

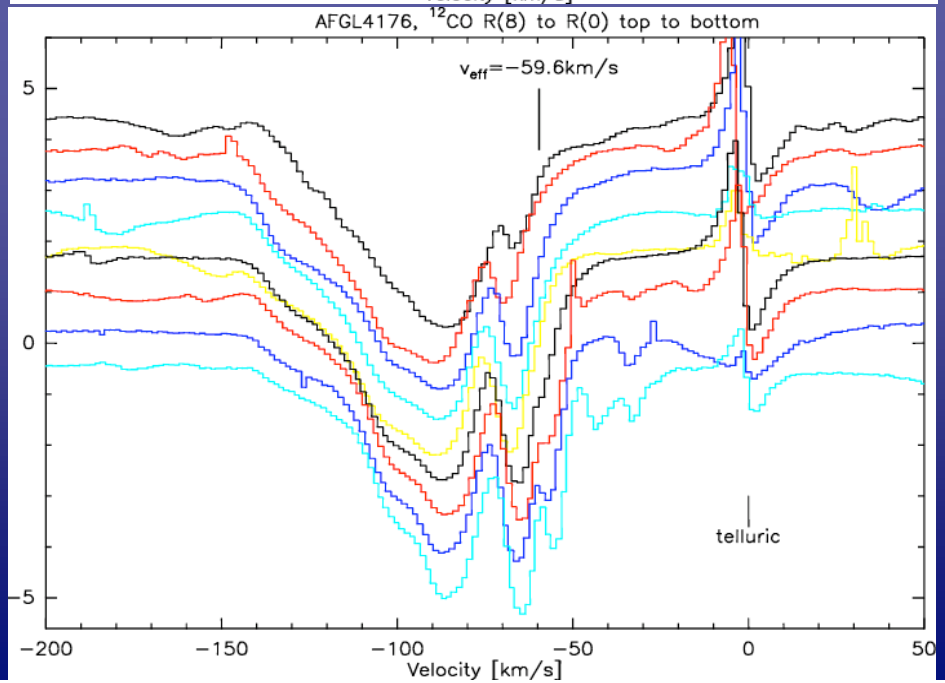
Massive disk candidates at mid-infrared Wavelength: CRIRES observations at VLT

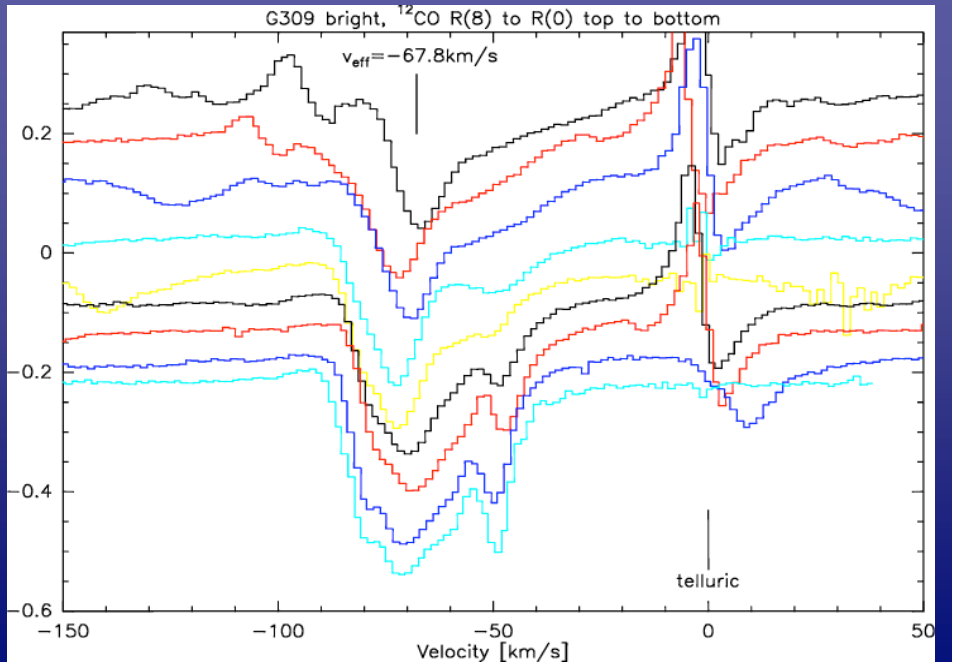


CRIRES observations of massive disk candidates II

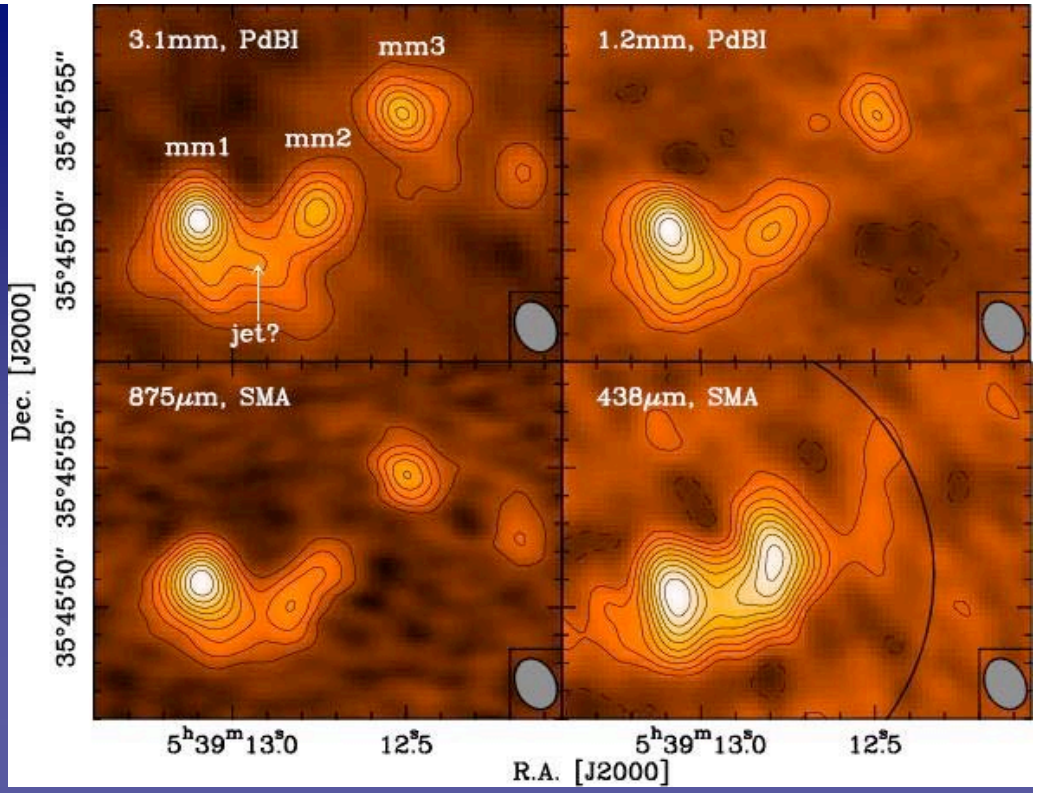








- *Conditions at the onset of massive star formation?*
  - *Rotation, infall and disks?*



- **How do massive clumps fragment, and what are their density distributions?**

- Summary

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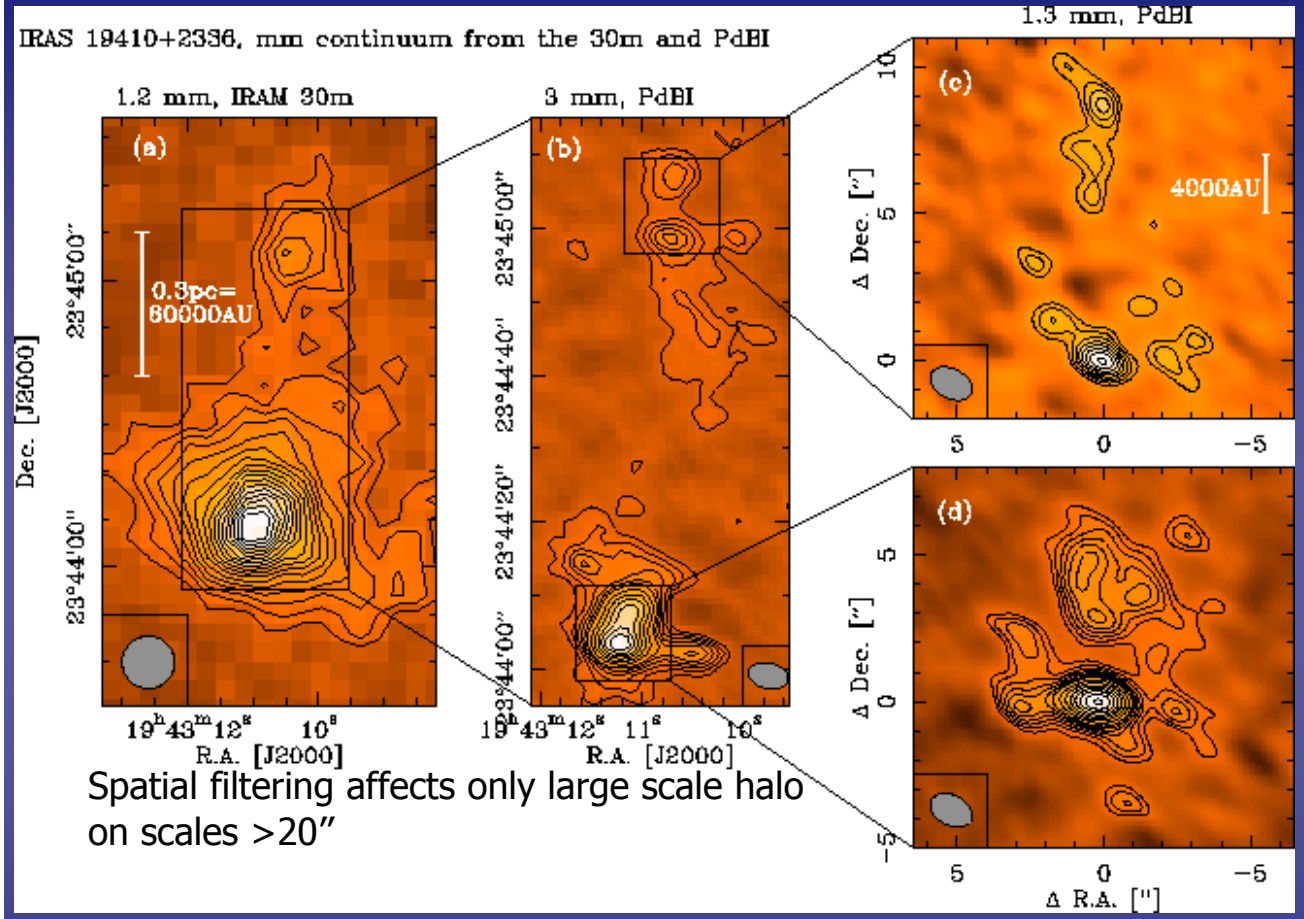
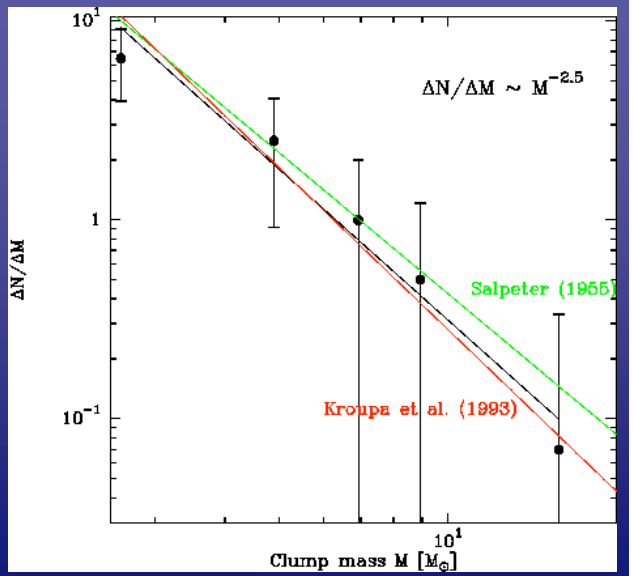
  - Imaging spectral line surveys revealing physics/chemistry and potentially biology?

Fragmentation of a massive protocluster



Spatial filtering affects only large scale halo on scales >20"

- 12 clumps within each core.
- Integrated masses
  $98M_{sun}$ (south)
  $42M_{sun}$ (north)
  --> 80 to 90% of the gas in halo
- Core masses
  $1.7M_{sun}$ to $25M_{sun}$
- Column densities
  $10^{24}cm^{-2}$ -->A_v~1000

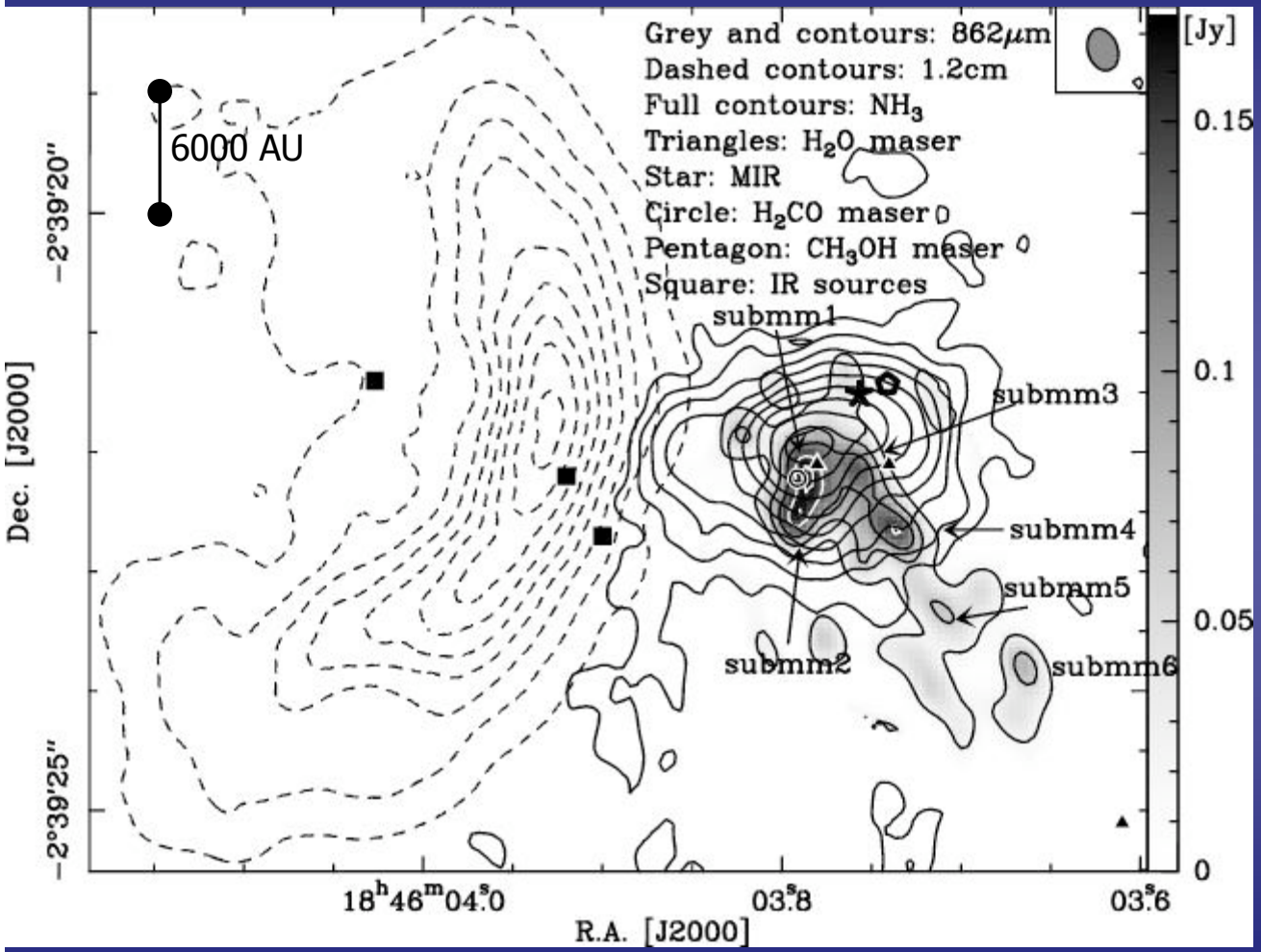


Assumptions: - All emission peaks of protostellar nature
- Same temperature for all clumps (46K, IRAS)

Caveats: - Temperature structure
- Peaks due to different emission processes, e.g., outflows?
- Are these cores bound or unbound?

Beuther & Schilke 2004, Science 303, 1167

Dissecting the Hot Core G29.96

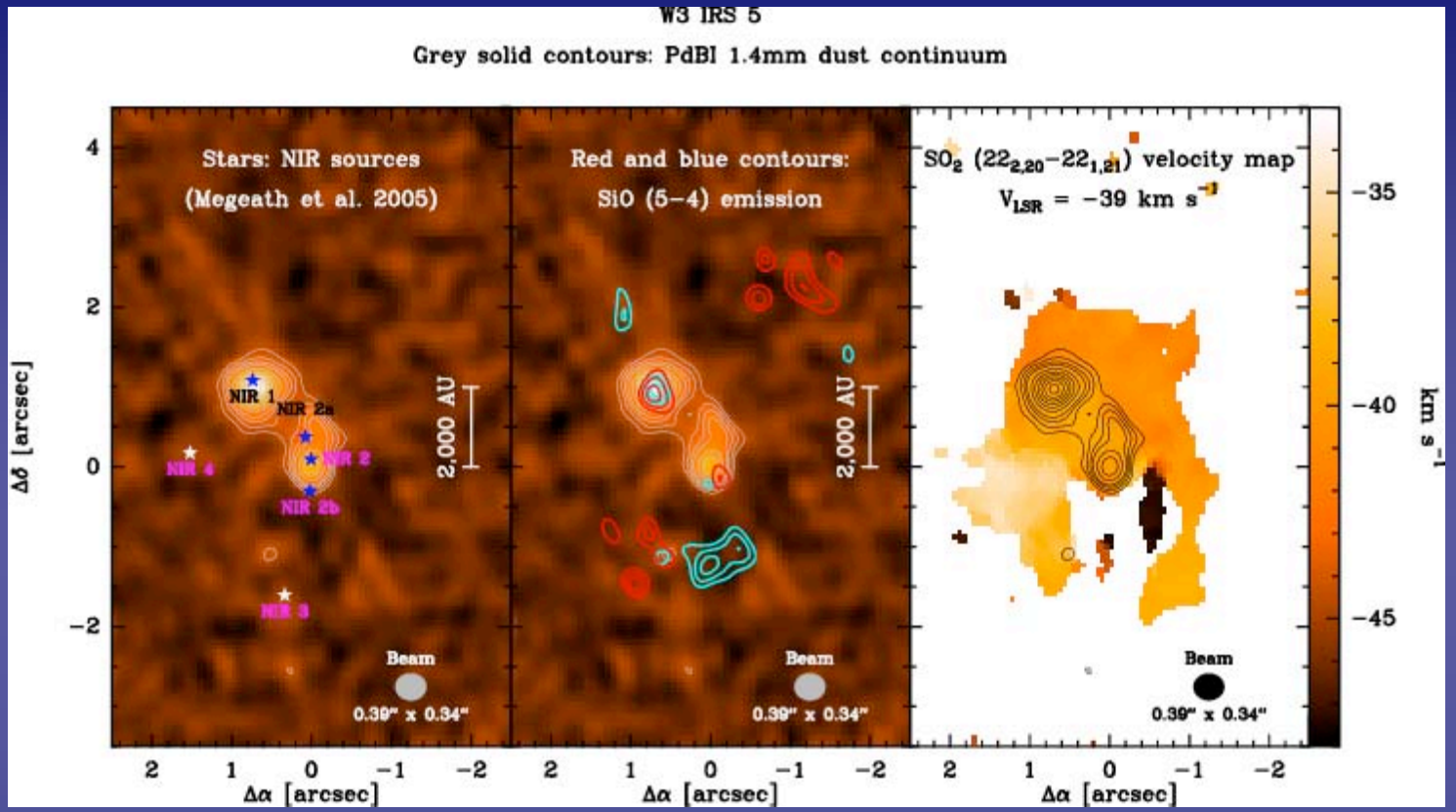


- 0.36"x0.25" resolution
- 4 sources within 6900(AU)^2 proto-Trapezium with protostellar density of ~ 2x10^5 protostars/pc^3
- Three different sites of massive star formation in very close proximity (UCHII, submm, MIR)

Grey: 862μm continuum
Full contours: NH_3
Dashed contours: cm continuum

Beuther et al. 2007

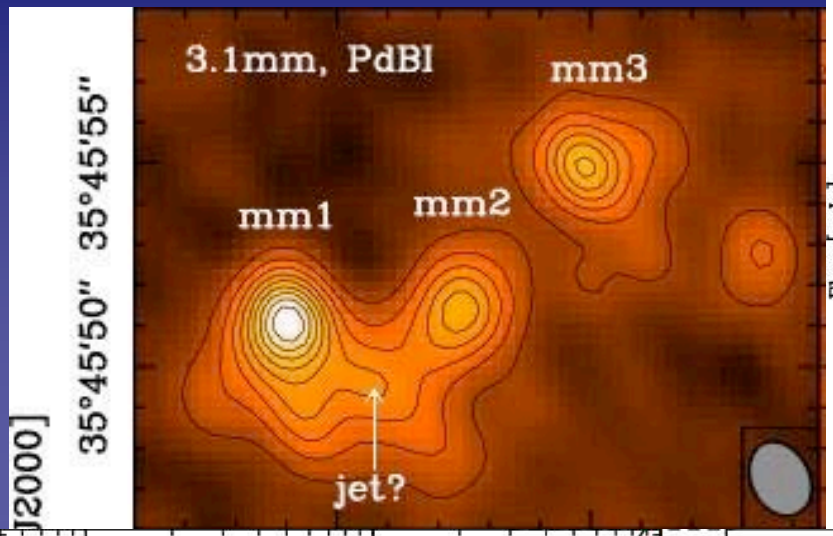
Fragmentation in W3

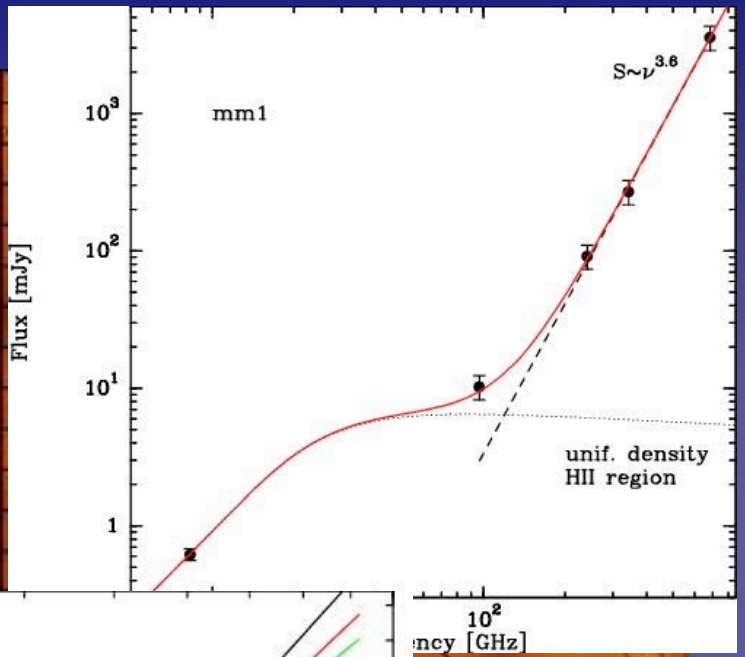


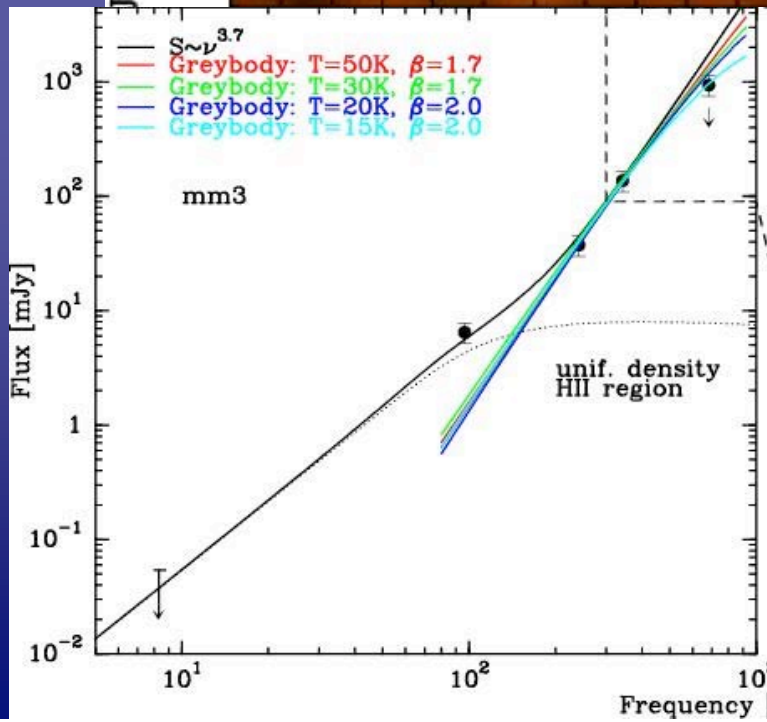
- At 0.35” resolution we resolve three sources with 1” (=2000AU), coincident with previous cm and NIR source --> proto trapezium. $5000 < A_v < 10000$.
- Outflows emanate close to the line of sight. That only allows detection in NIR.
- SO_2 gradient across sources. Probably a rotating (infalling?) envelope around sources. SO_2 line-width toward mm peaks ~ 6.2 and 7 km/s. What about disk(s)?
- SO_2 velocity discontinuity south-east of cores.

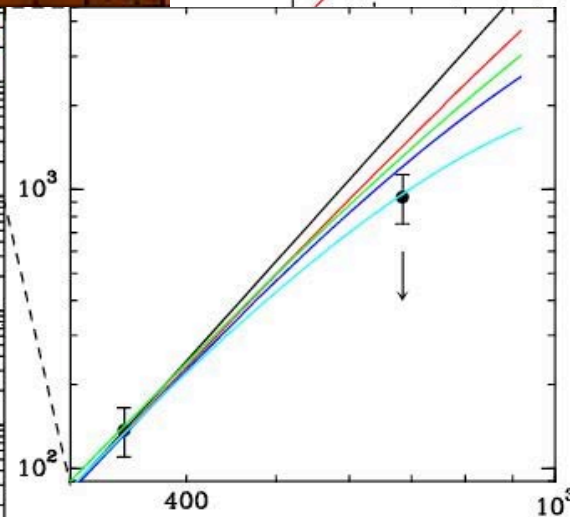
Rodon et al. in prep.

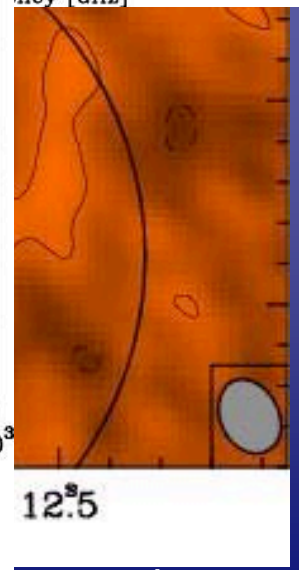
Multi-wavelength observations of the HMPO IRAS 05358





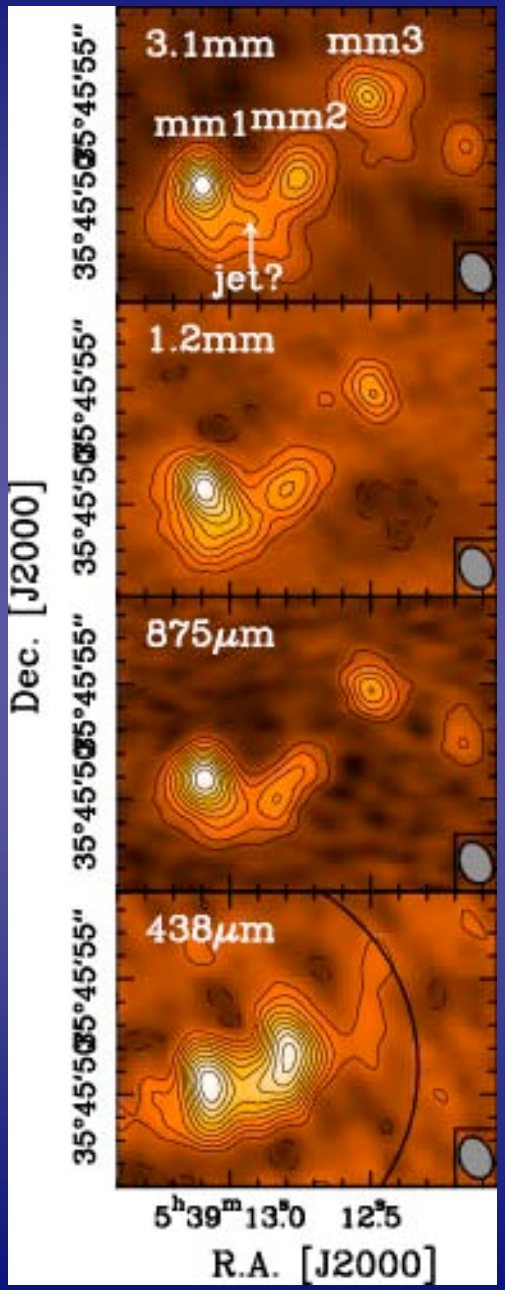


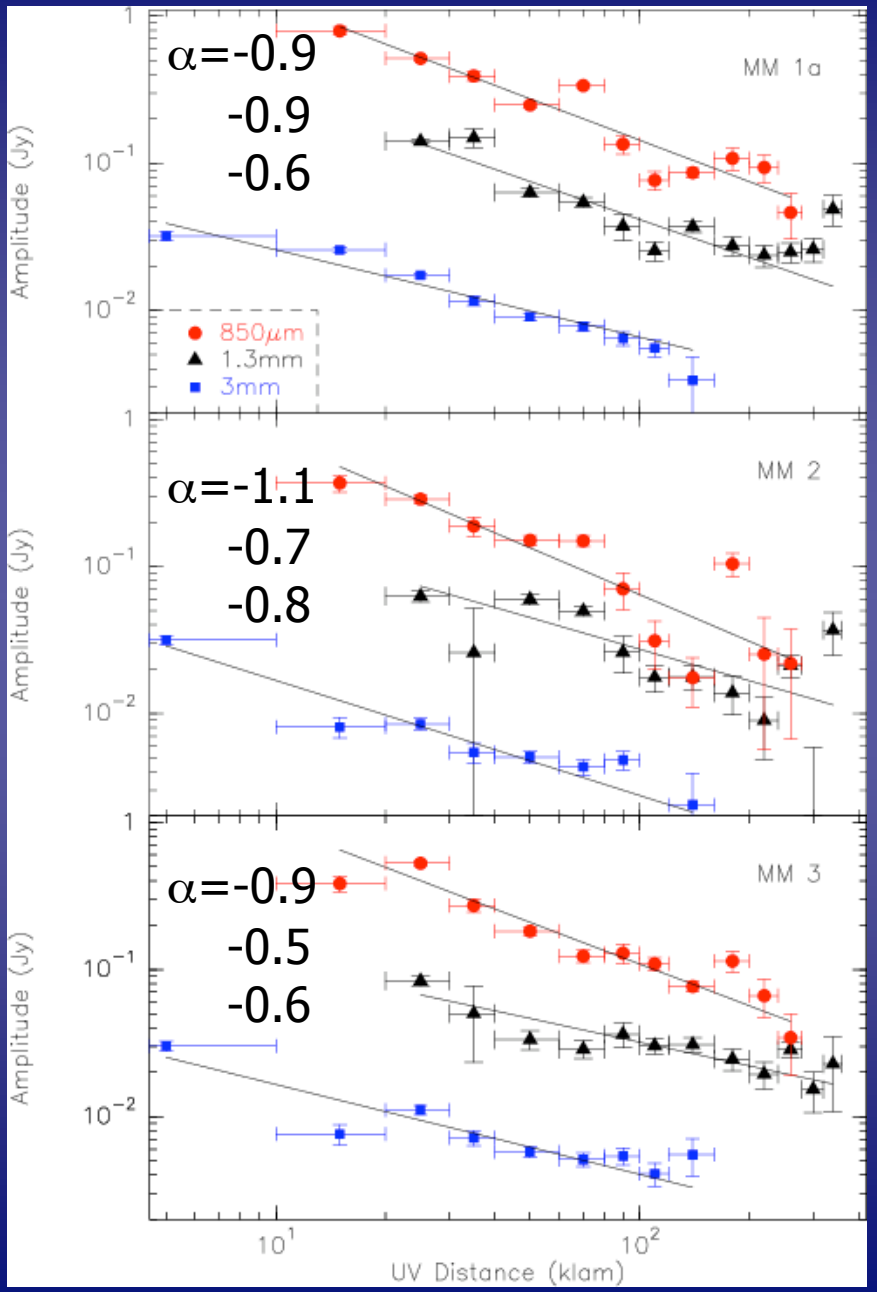




Beuther et al. 2007

Density distribution of sub-sources





$V(s) \sim s^{\alpha}$
with $\alpha=p+q-3$
and $T \sim r^{-q}$
$(q\sim0.4)$
$n \sim r^{-p}$
$p=1.5 \rightarrow \alpha=-1.1$
$p=2.0 \rightarrow \alpha=-0.6$

Beuther et al. 2007

Summary

- Exploring the onset of massive star formation (IRDCs).
- Massive accretion disk studies are still in its infancy. Toroids or disks?
- Some fragmentation studies support early gravo-turbulent fragmentation, however, extreme cases?
- Density distributions of young massive cores $\rho \sim r^{-p}$ with $1.5 < p < 2$.

--> Massive star formation up to 30 M_{sun} consistent with accretion scenario. Coalescence may exist in some extreme cases.

--> Interferometry is powerful tool to investigate the physics and chemistry of many astrophysical phenomena.