NRC·CNRC
HERZBERG INSTITUTE of ASTROPHYSICS

UNIVERSITY OF VICTORIA
ASTRONOMY
Department of Physics and Astronomy

Disentangling Star Formation with ALMA and ELTs

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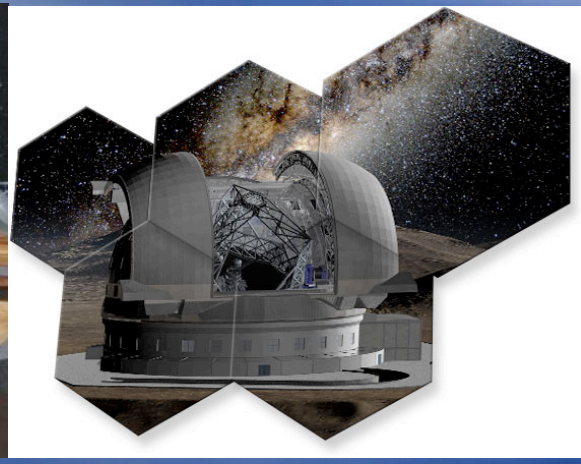
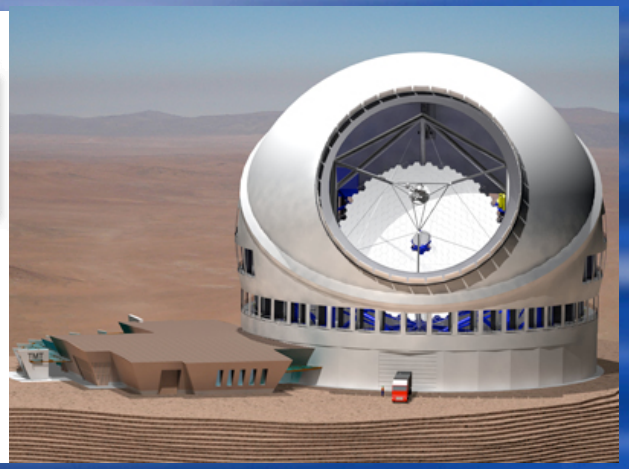
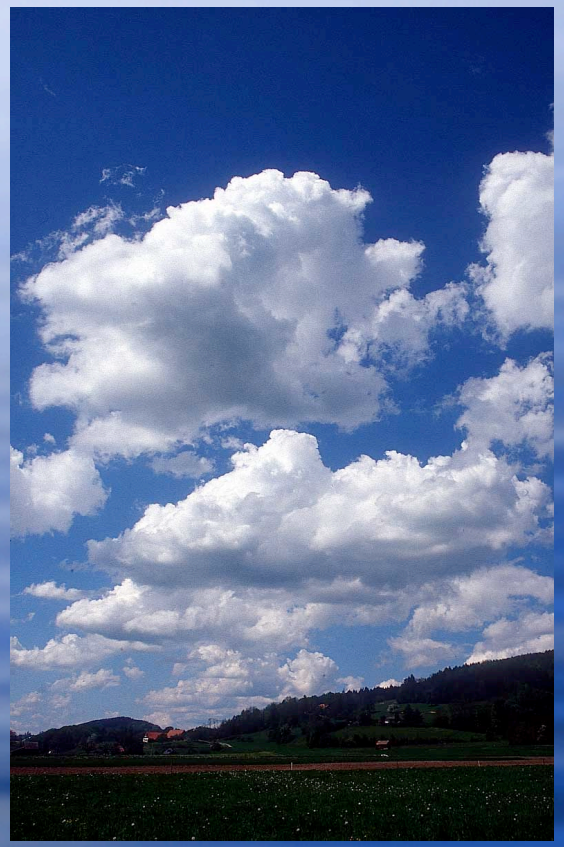
+ H. Kirk (Uvic) + J. Di Francesco (HIA)
+ J. Jorgensen (Bonn) + M. Tafalla (Madrid)
and many others …

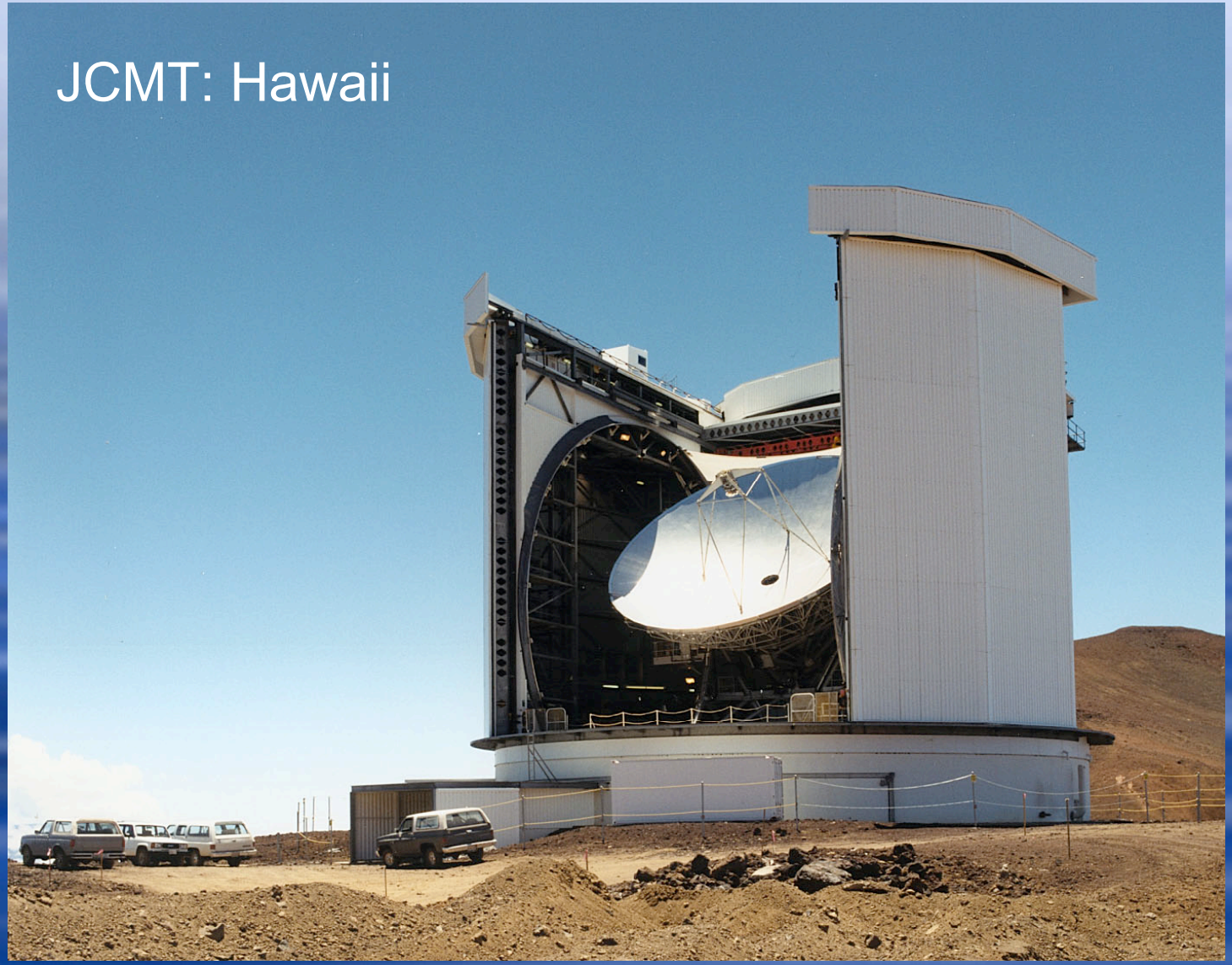
The Physical Route to Star Formation

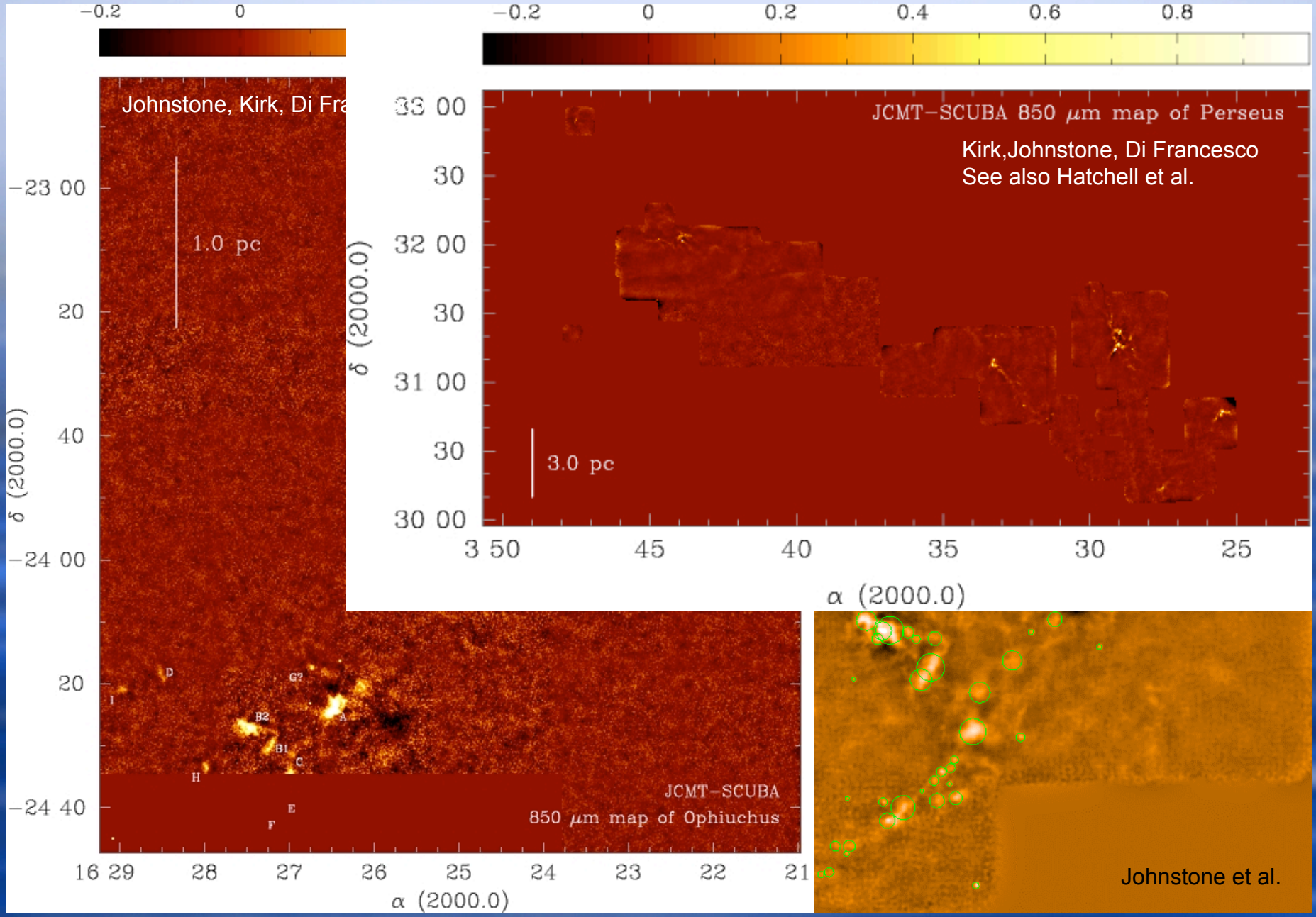
- Formation of molecular cloud
  - Properties: size, mass, energy
  - Where and how? Quasi-static or Dynamic?
- Formation of clumps and filaments
  - Properties: size, shape, mass, energy
  - Where and how? Quasi-static or Dynamic?
- Formation of cores
  - Properties: size, mass, energy
  - Where and how? Quasi-static or Dynamic?
- Formation of stars
  - Properties: size, mass, energy
  - Where and how? Inside-out?



Star formation is a by-product of cloud evolution.
Need to understand *all* physical processes at play in cloud.

Observing Molecular Clouds (dust emission)




−0.2
0
Johnstone, Kirk, Di Fra
1.0 pc
δ (2000.0)
−23 00
20
40
−24 00
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−24 40
p
I
G2
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α (2000.0)
JCMT−SCUBA
850 μm map of Ophiuchus
−0.2
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0.8
33 00
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32 00
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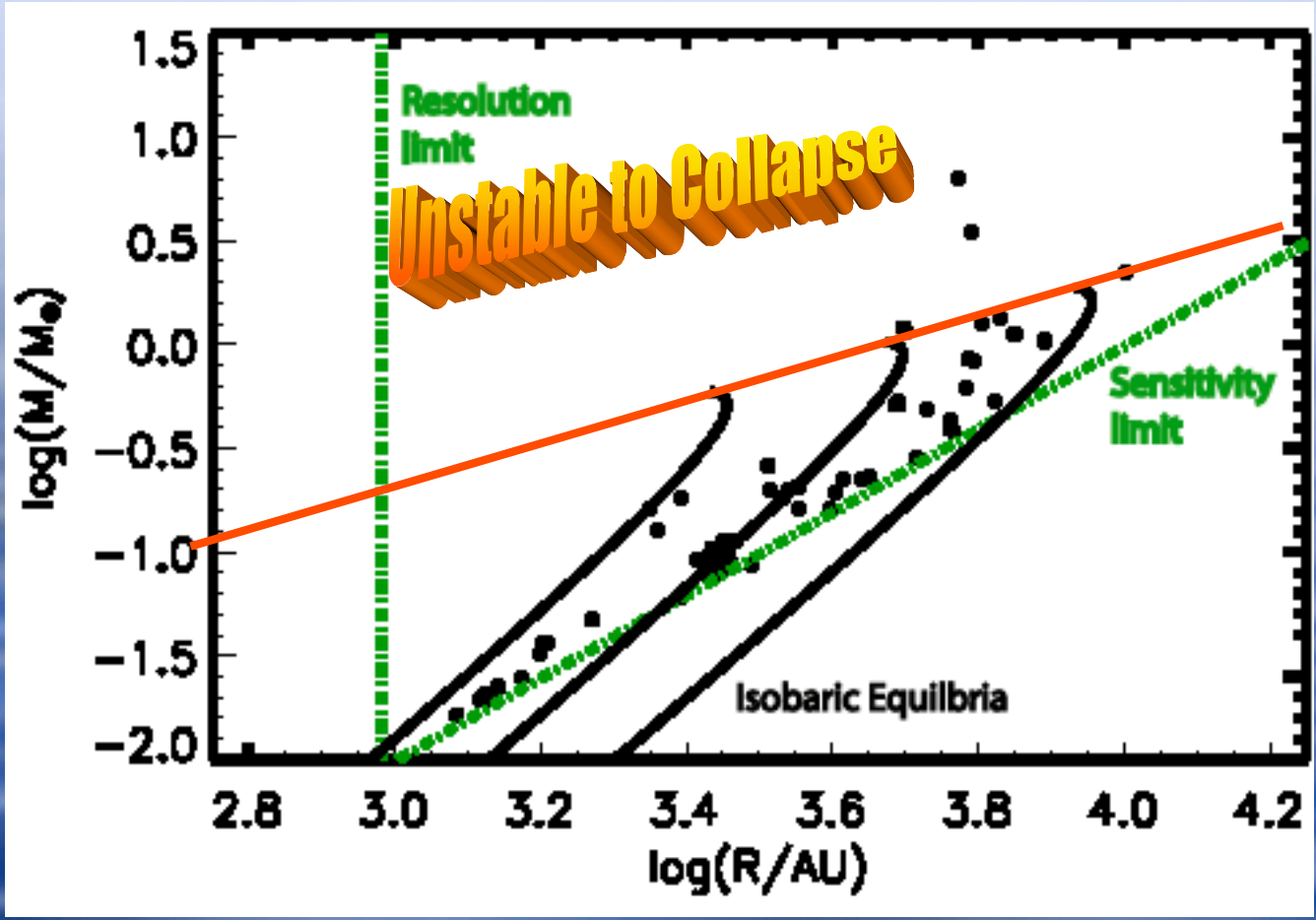
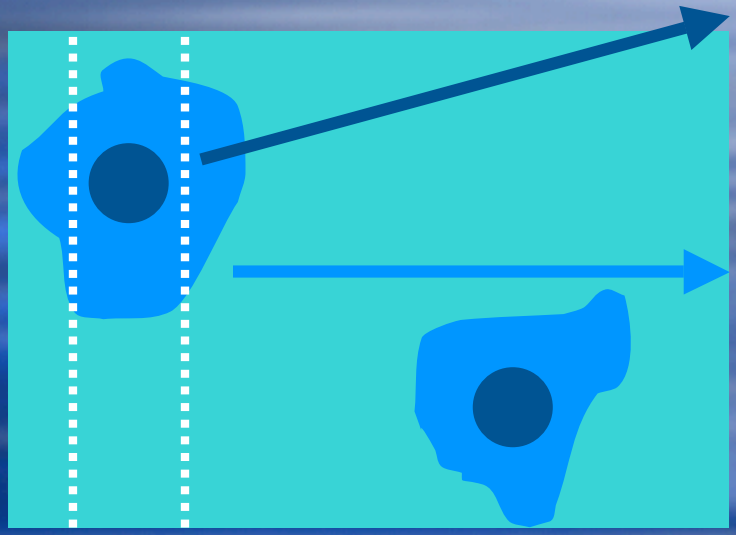
31 00
30
30 00
JCMT−SCUBA 850 μm map of Perseus
Kirk,Johnstone, Di Francesco
See also Hatchell et al.
3.0 pc
δ (2000.0)
3 50
45
40
35
30
25
α (2000.0)
Johnstone et al.

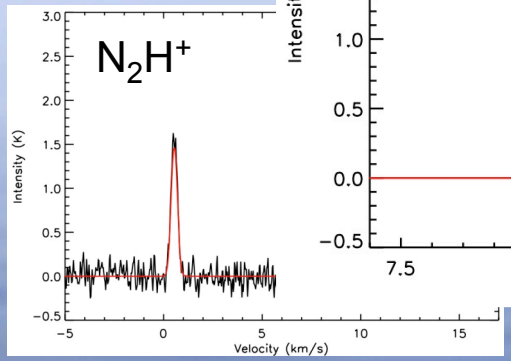


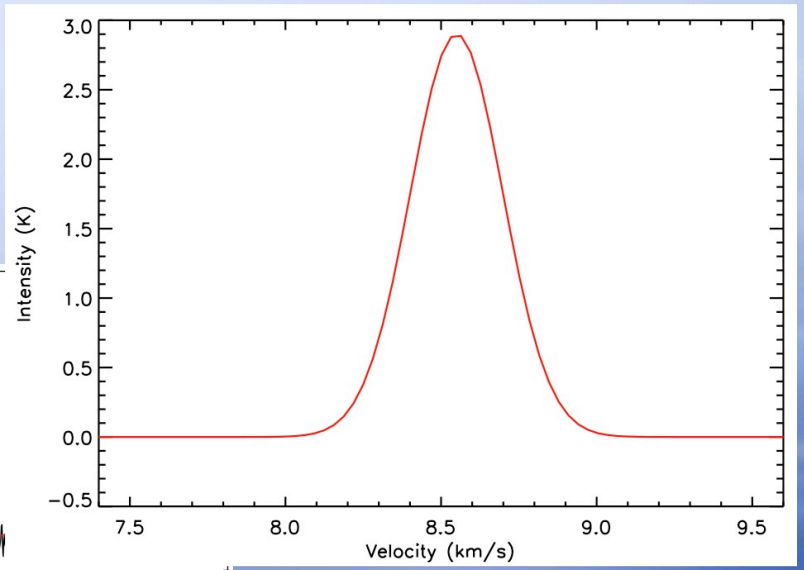
(green lines: resolution & sensitivity limits)

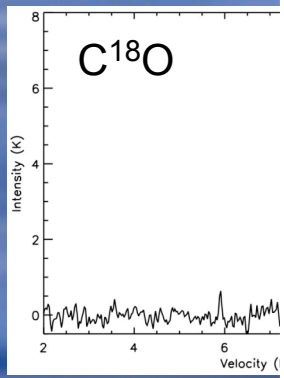
(black lines: isobaric equilibria - unstable only above turn-over)

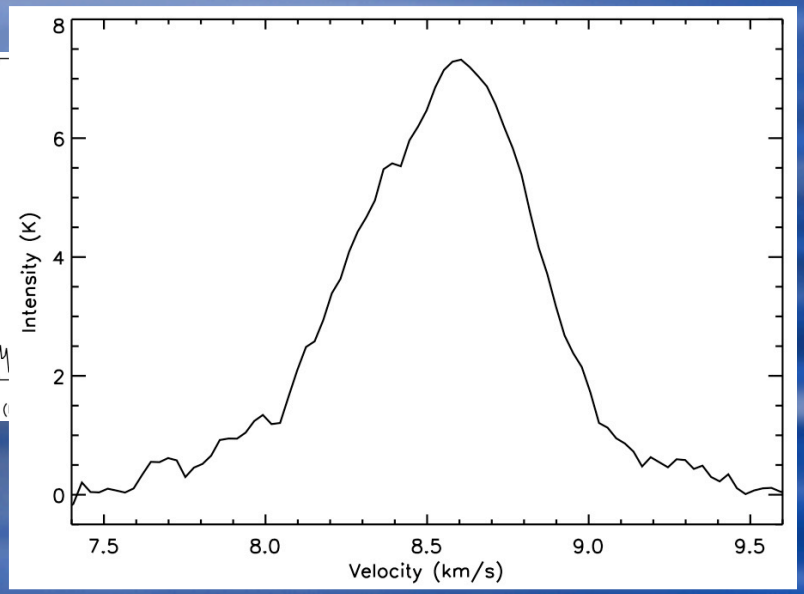
Kinematics from Lines:







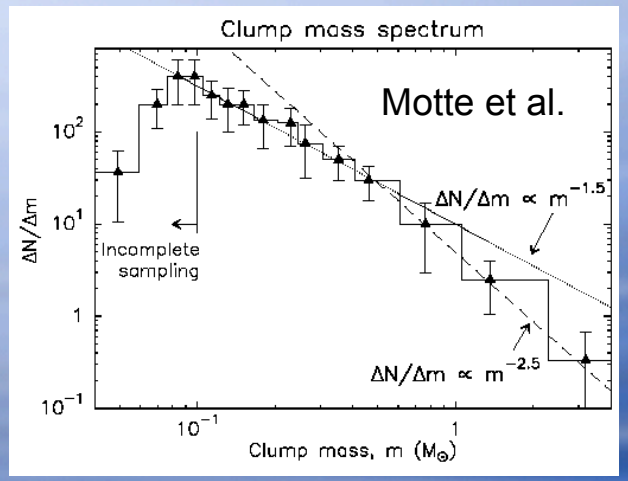


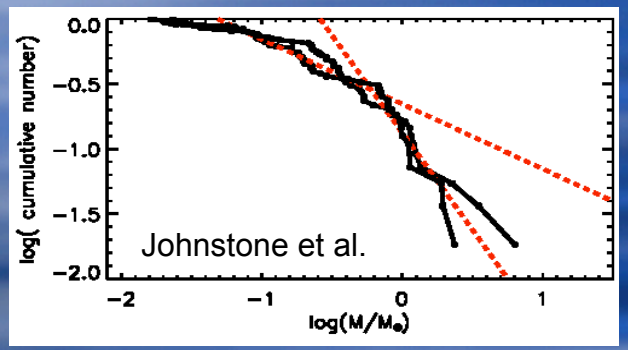


Kirk, Johnstone, Tafalla

Small Scale (Core) Structure in Clouds

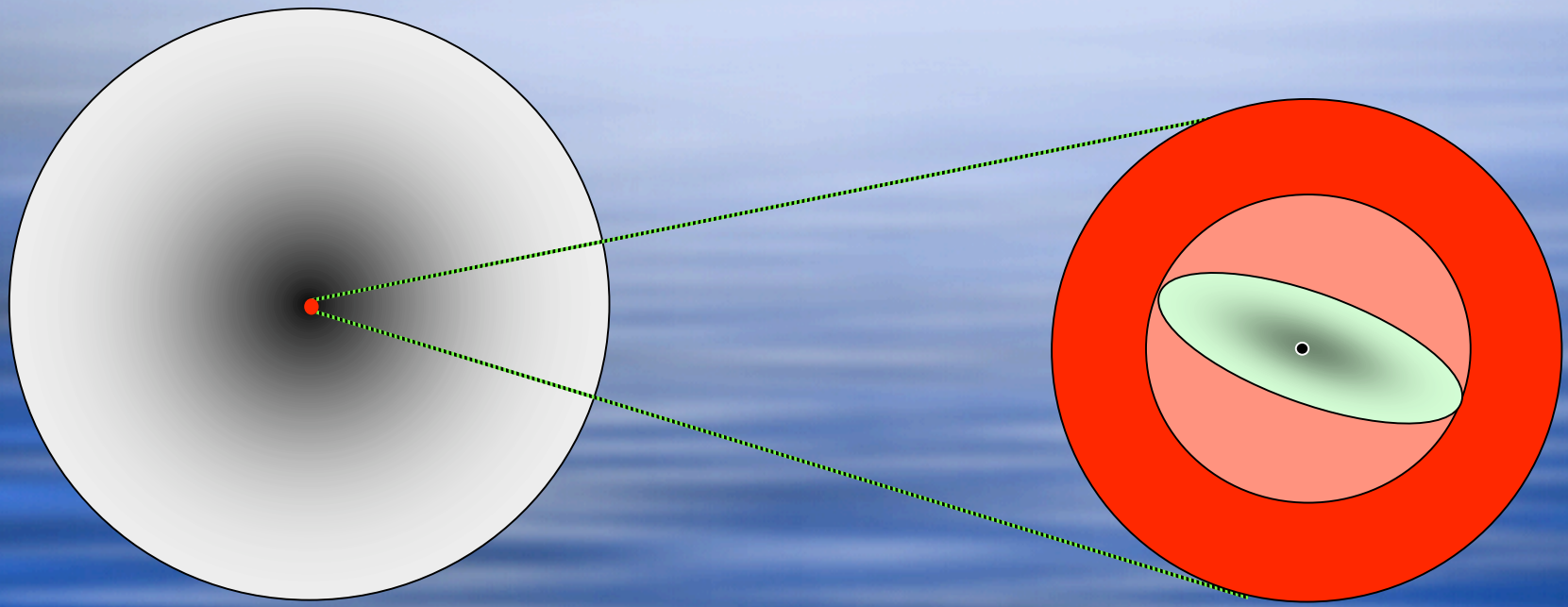
- Distribution of mass is steep
  - $N \propto M^{-3/2}$: mass resides in small objects
    - Similarity to IMF intriguing
    - Result indep. of structure analysis form
    - Totals to small fraction of the cloud
    - May be biased by resolution/sensitivity
- Thermal size vs. mass relation
  - Linewidths tend to be almost thermal
  - $M \propto R^3$ (Pressure-confined objects)
    - Largest objects are grav. unstable
- Found in localized regions of cloud
  - Highest A_v zones





Dense material has different properties than bulk cloud.
No requirement for non-thermal support.

ALMA: Leverage within Envelope



R_J~ 10,000 AU (50”)

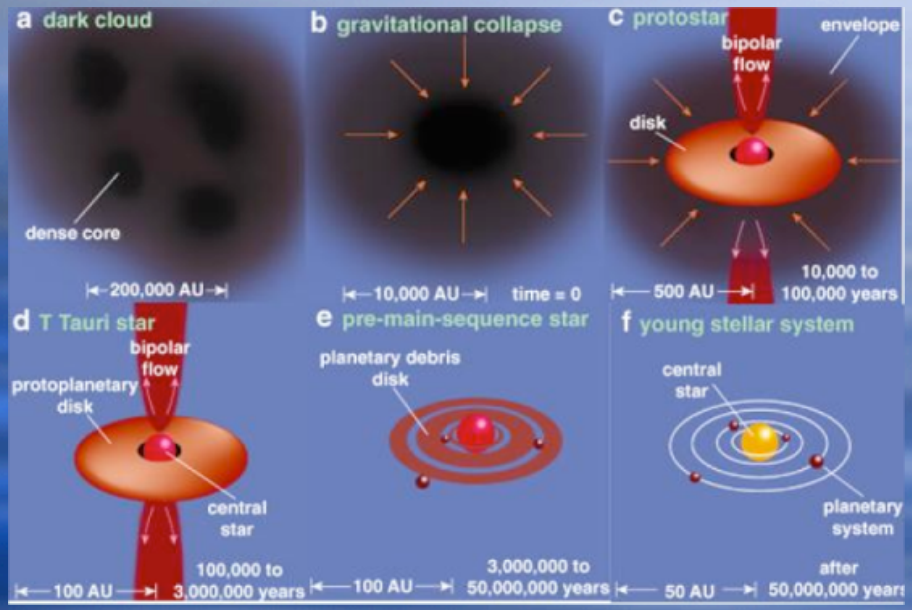
~ 200 AU (1”)

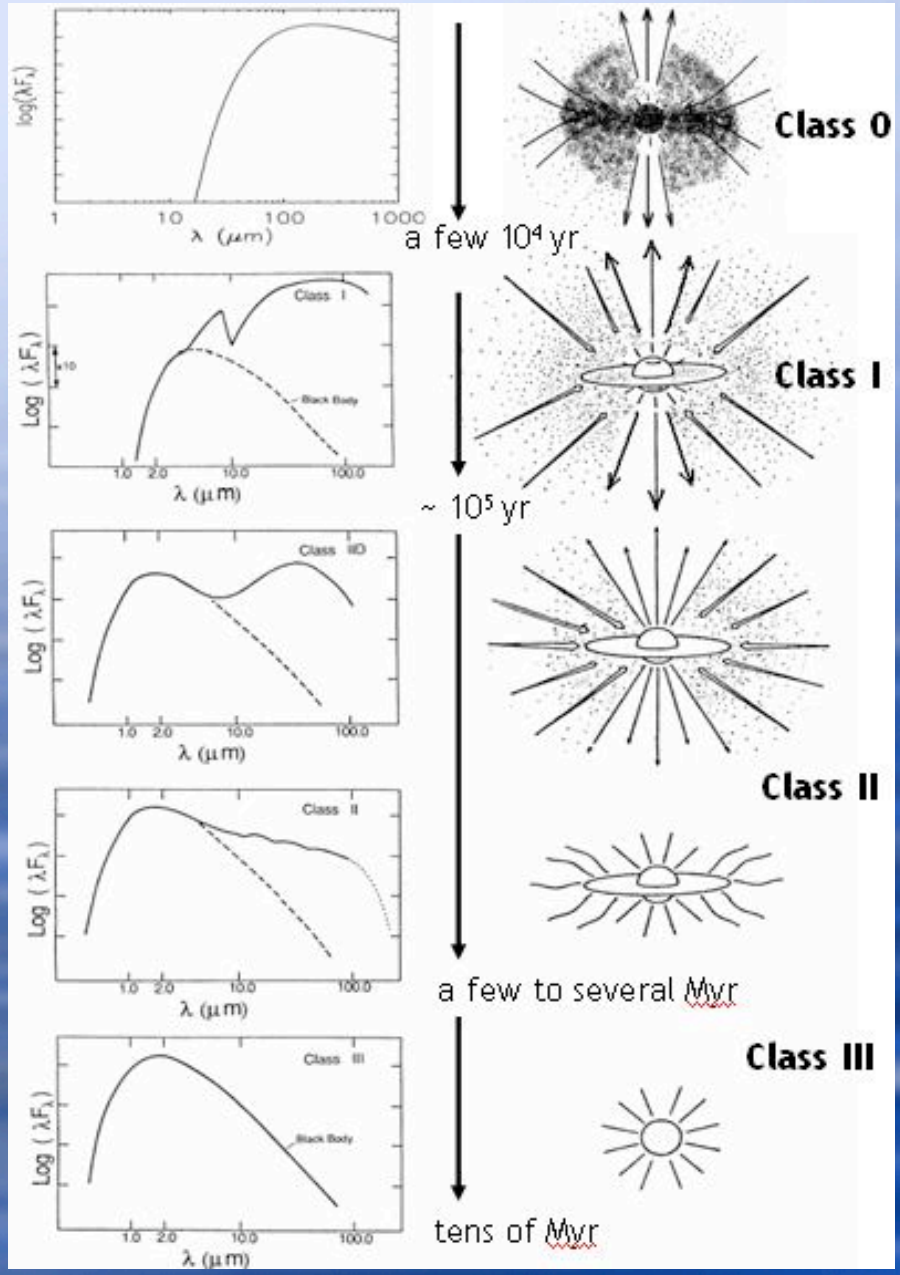
- Densities ranging from 10^4 cm^{-3} to 10^7-10^8 cm^{-3} (H_2)
- Temperatures ranging from ~10 K to a few hundred K.

The Angular Resolution Problem

Distance	200 pc (low mass)	500 pc (Orion)	2500 pc (high mass)
ALMA 1″	200 AU	500 AU	2500 AU
ALMA 0.1″	20 AU	50 AU	250 AU
Single Dish 10″	2000 AU	5000 AU	25000 AU

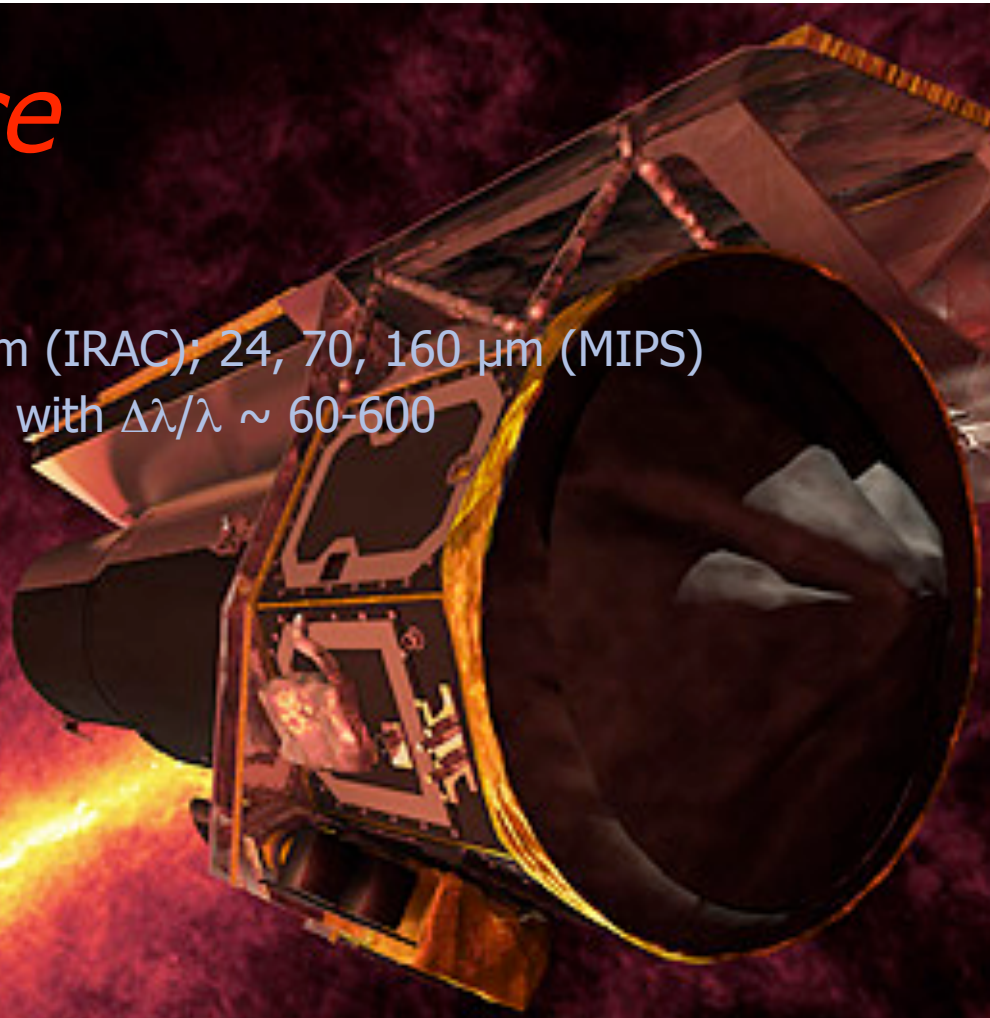
Protostellar Stages





The Spitzer Space Telescope

- Imaging at 3.6, 4.5, 5.6, 8.0 μm (IRAC); 24, 70, 160 μm (MIPS)
- Spectroscopy (IRS) at 5-37 μm with $\Delta\lambda/\lambda \sim 60\text{-}600$

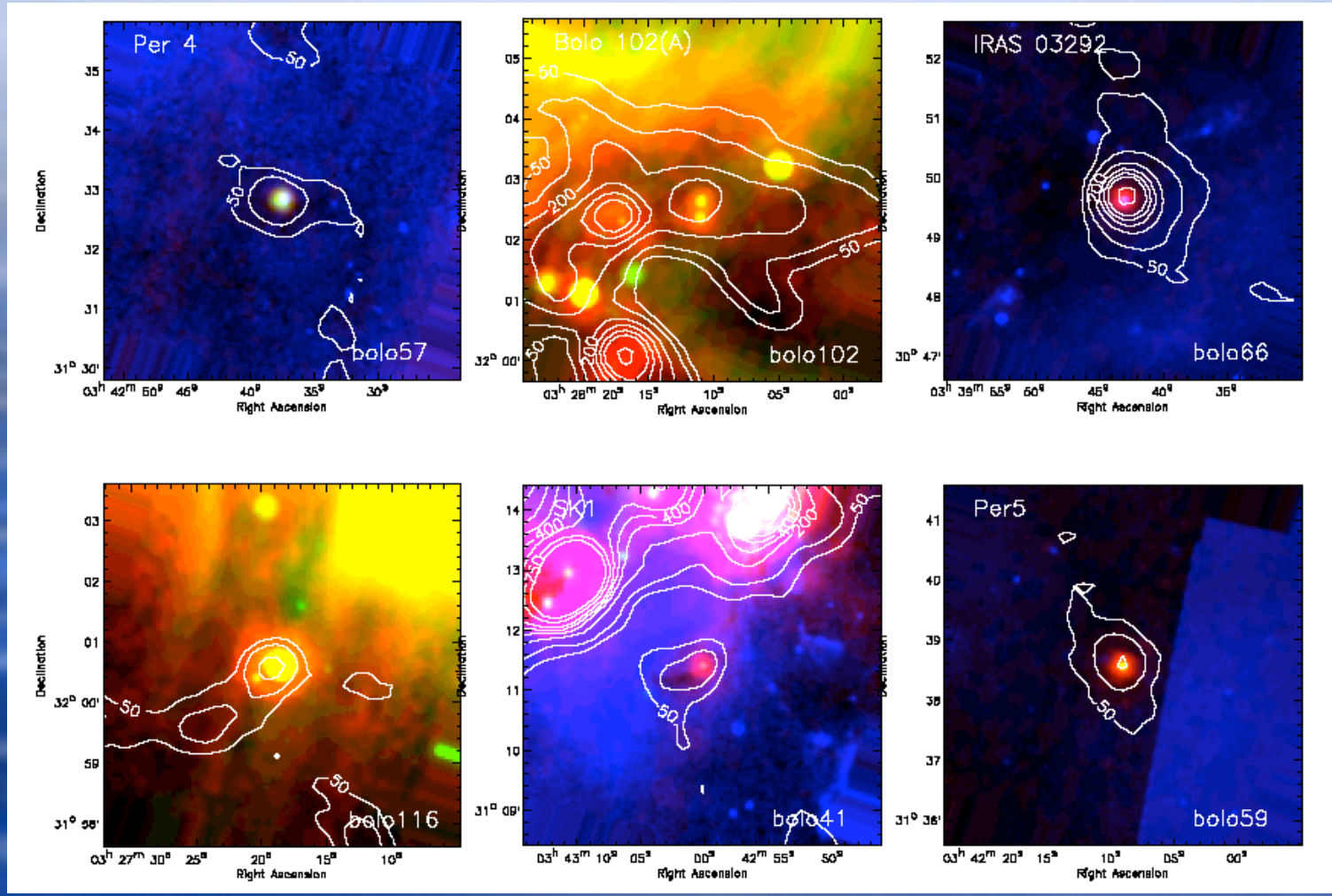


c2d legacy project

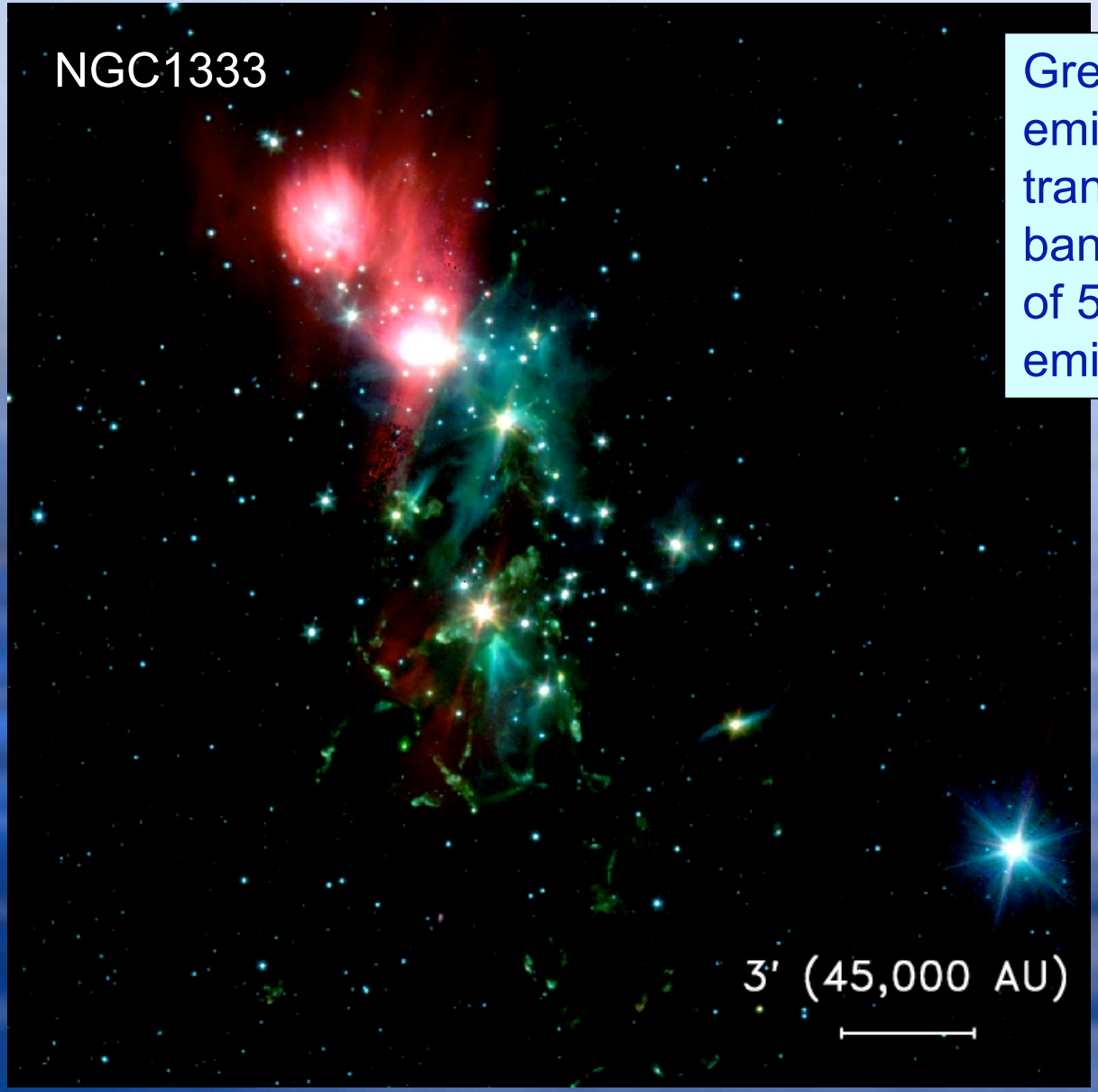
(Evans et al.)

...400 hours to image nearby star forming clouds and cores and perform spectroscopy of embedded objects and stars with disks...

Examples of Mid-IR Sources

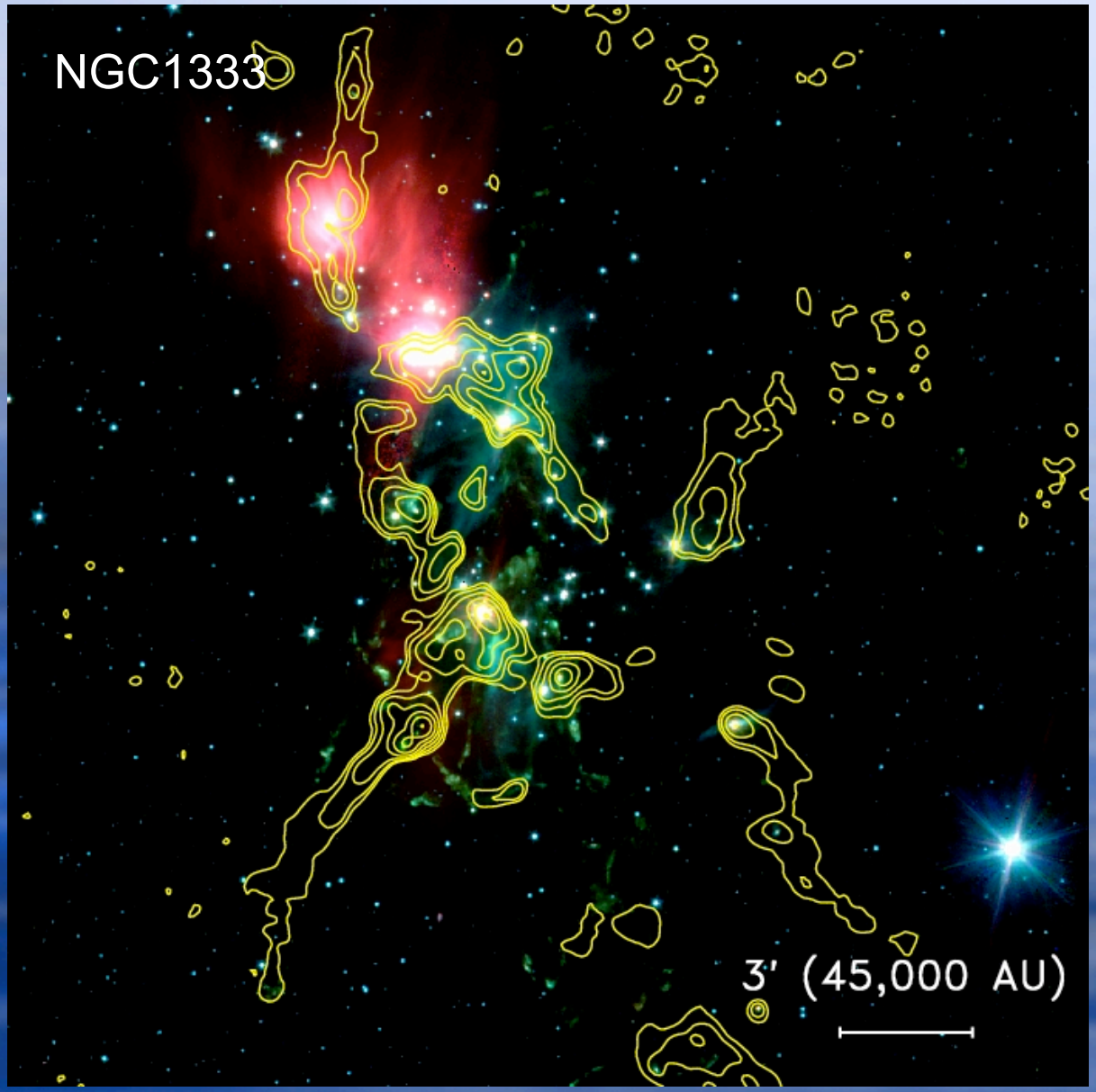


From M. Enoch



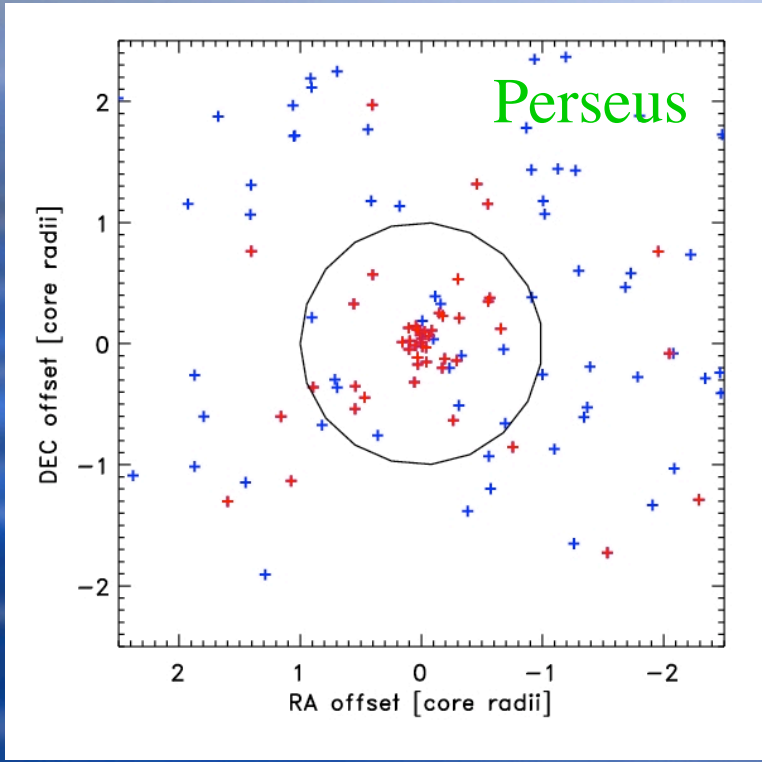
Green colors reflect emission from H_2 rotational transitions in the 4.5 μm band - probing shocked gas of 500-1000 K. Red is PAH emission in the 8 μm band.

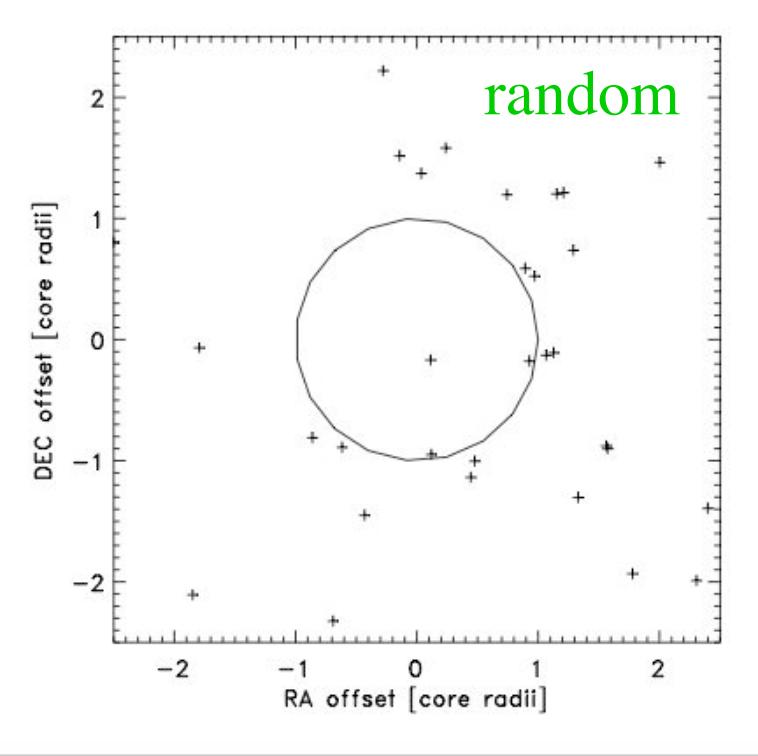
Spitzer/IRAC from c2d (*Jørgensen et al. 2006*)



Spitzer/IRAC from c2d (*Jørgensen et al. 2006*) with SCUBA map (yellow contours; *Kirk et al. 2006*)

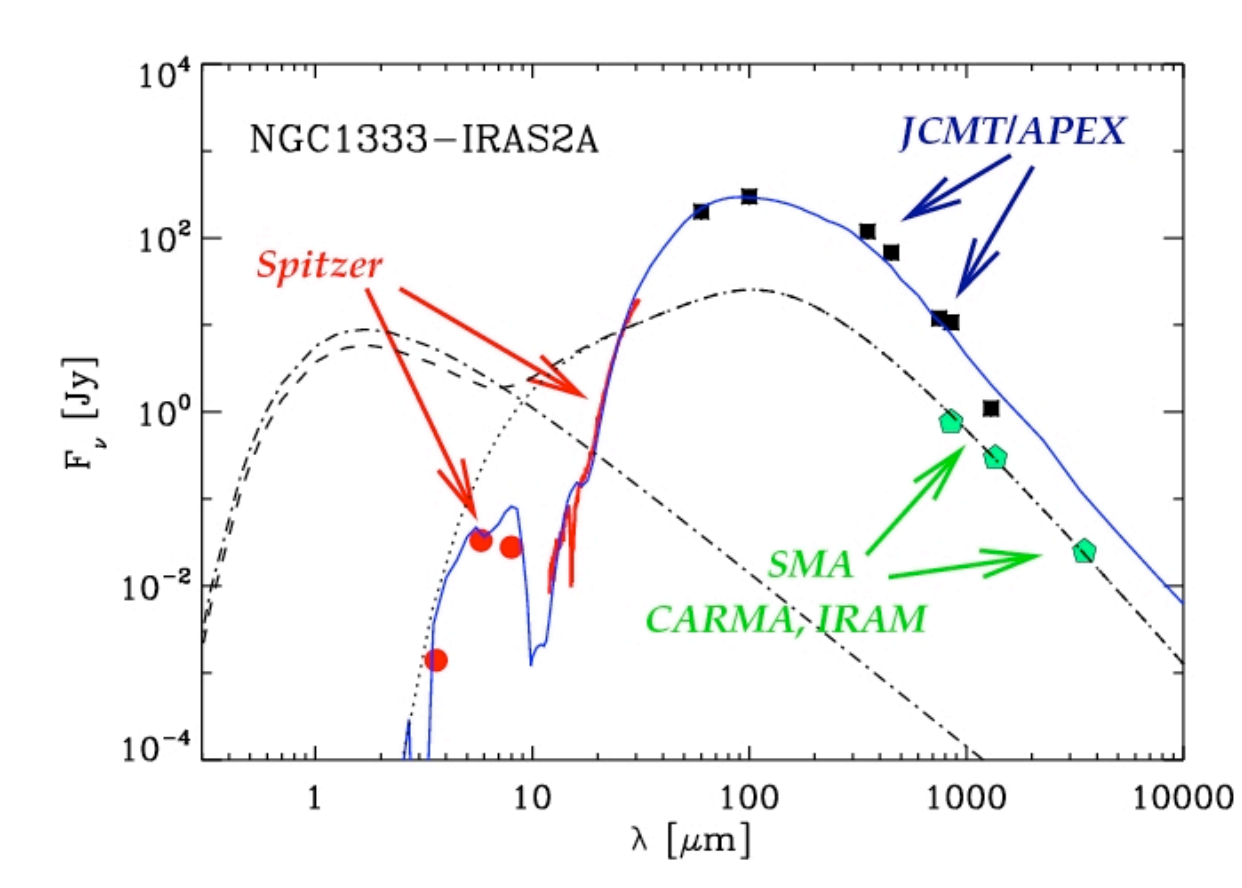
Correlation of Sub-mm and mid-IR





(Jørgensen, Johnsone et al. 2006)

Mid-IR SEDs - New Insights

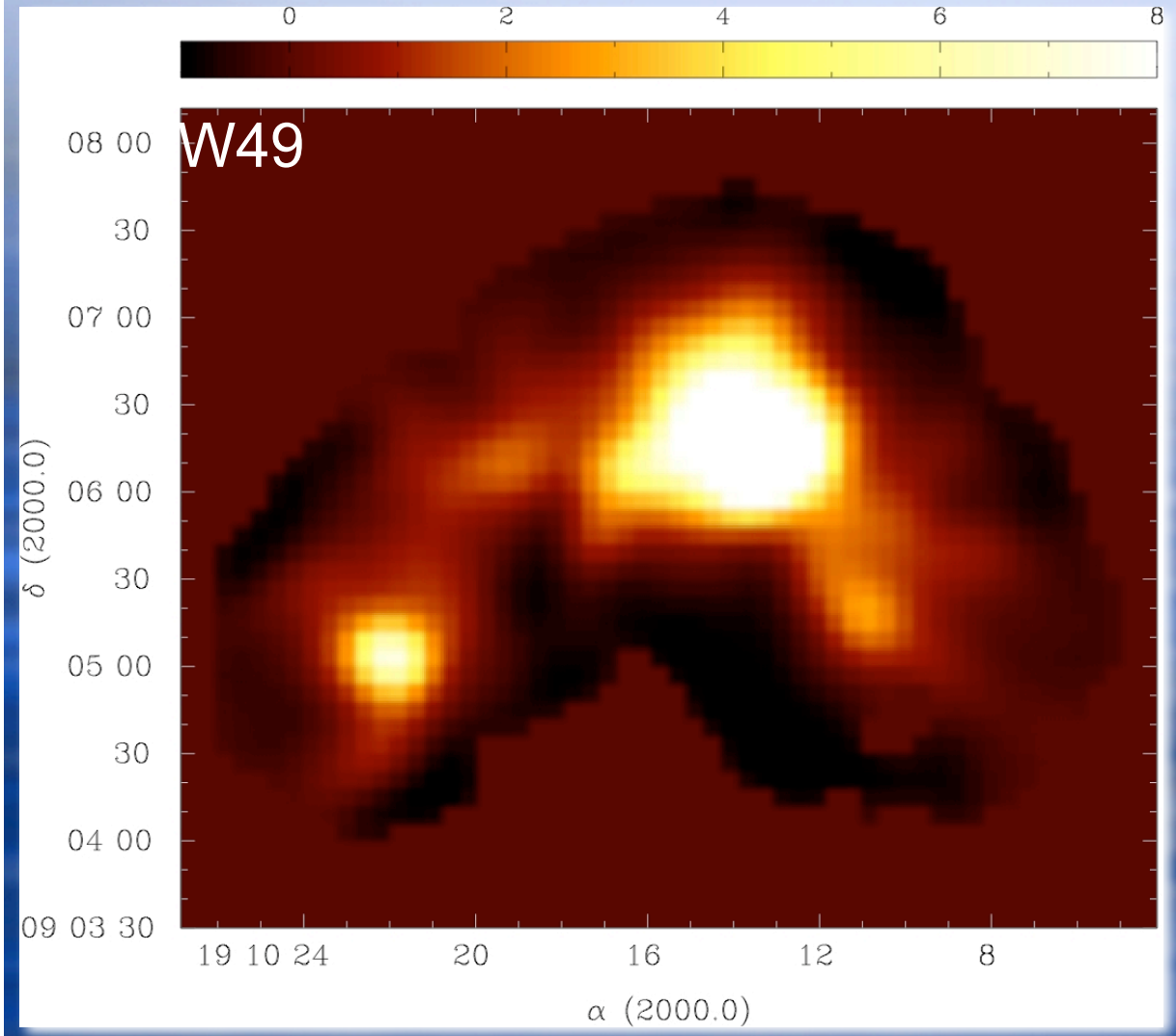


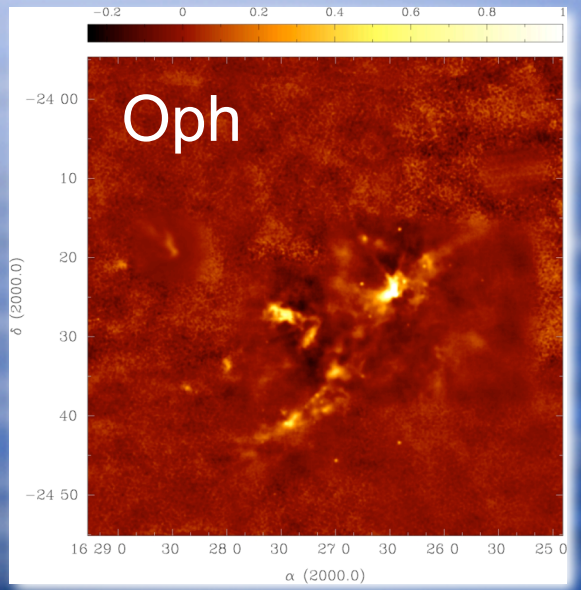
From Jørgensen

High Mass Star Formation: Resolution!

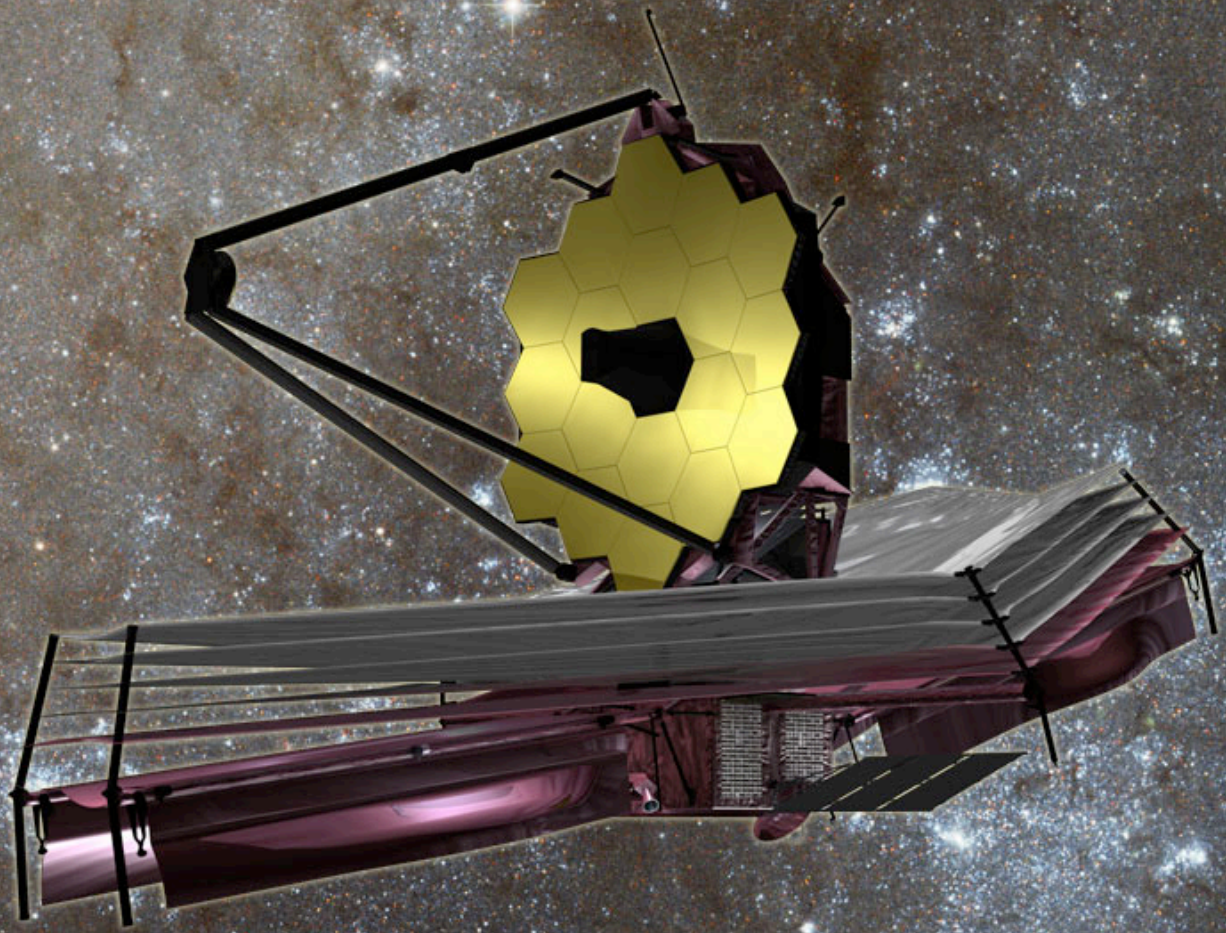
- Massive star formation is a significant problem
  - Distance makes resolution more important
    - If anything the relevant scale is smaller
      - Jeans mass argument
    - Time scale for evolution shorter (cloud and star)
  - Gregarious regions - much more complex
    - Many sources clustered together
    - Internal and external heating sources
    - Need resolution and image fidelity
  - ALMA will be well suited to this problem
    - High angular resolution
    - Excellent image fidelity
    - Large range of molecular tracers (warm and cold gas/dust)

High Mass Star Formation: Resolution!





The Not So Distant Future is Bright



Kicking the Darkness Till It Bleeds Starlight

- Need ALMA for angular resolution and sensitivity
  - Dust continuum
    - Structure in dense cores (nearby low-mass s.f.)
    - Structure within molecular clouds (distant high-mass s.f.)
  - Moleculuar lines
    - Kinematics of cores and their environment
    - Physical Conditions and Chemistry
- Need Mid-IR observations [JWST/ELTs(?)]
  - Imaging Observations (at high angular resolution)
    - Locations of protostars within cores
      - Fragmentation and clustering properties
    - Heating of core and local cloud environment (esp. high mass s.f.)
  - Spectroscopy (at high spectral resolution)
    - Physical Conditions and Chemistry