The cold environments of FU Orionis-type eruptive stars

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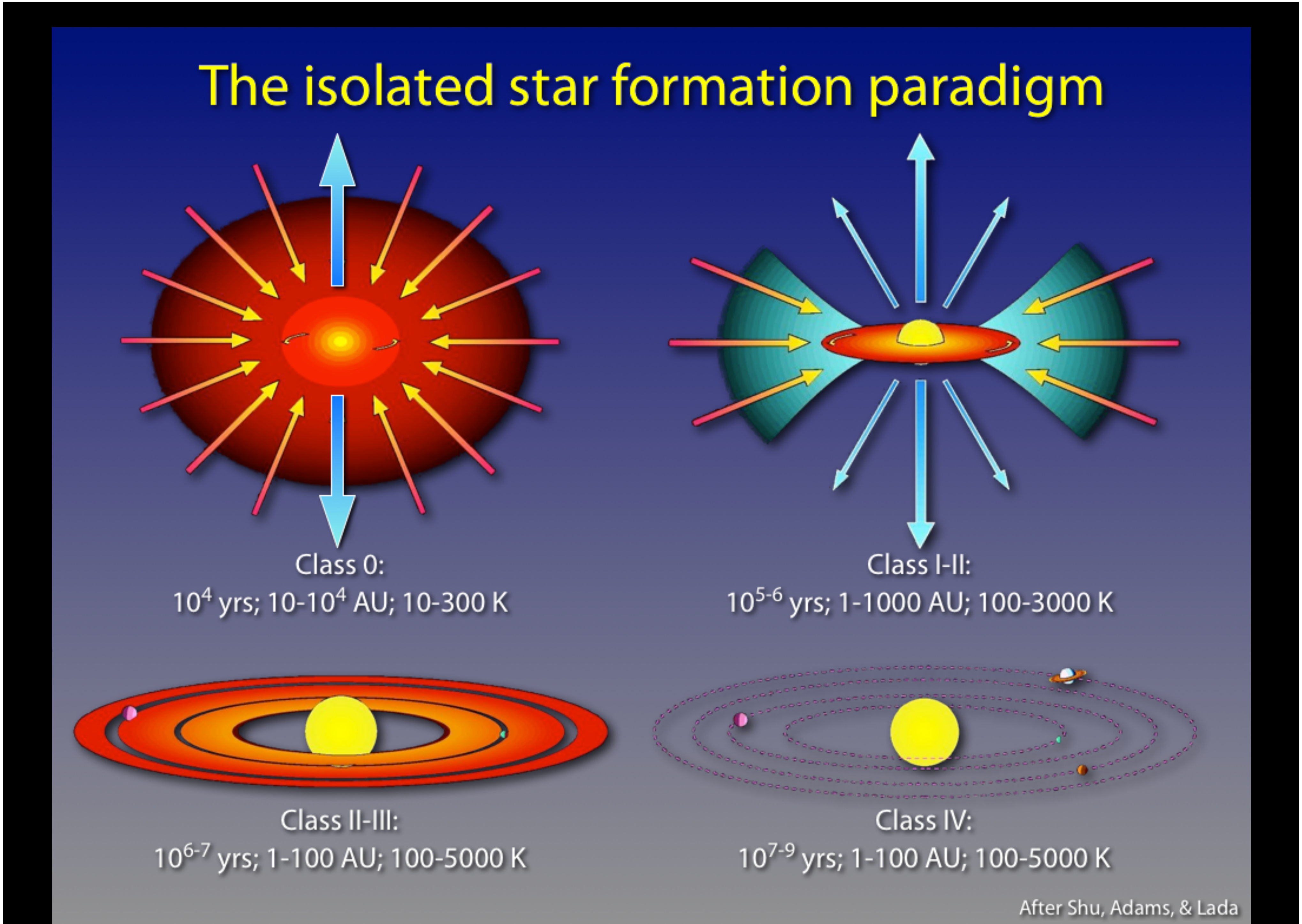
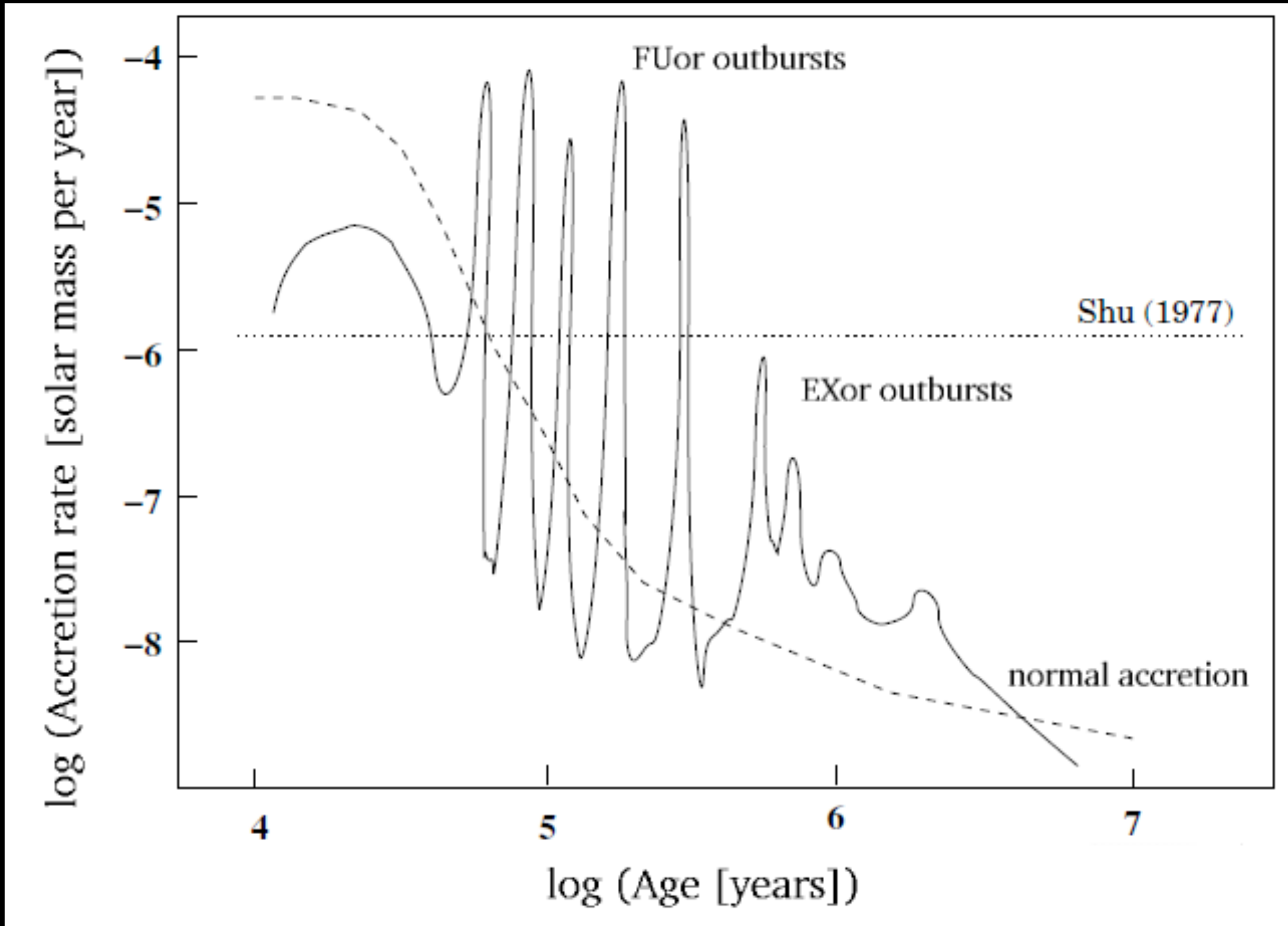


Figure courtesy of Mark McCaughrean

Episodic accretion

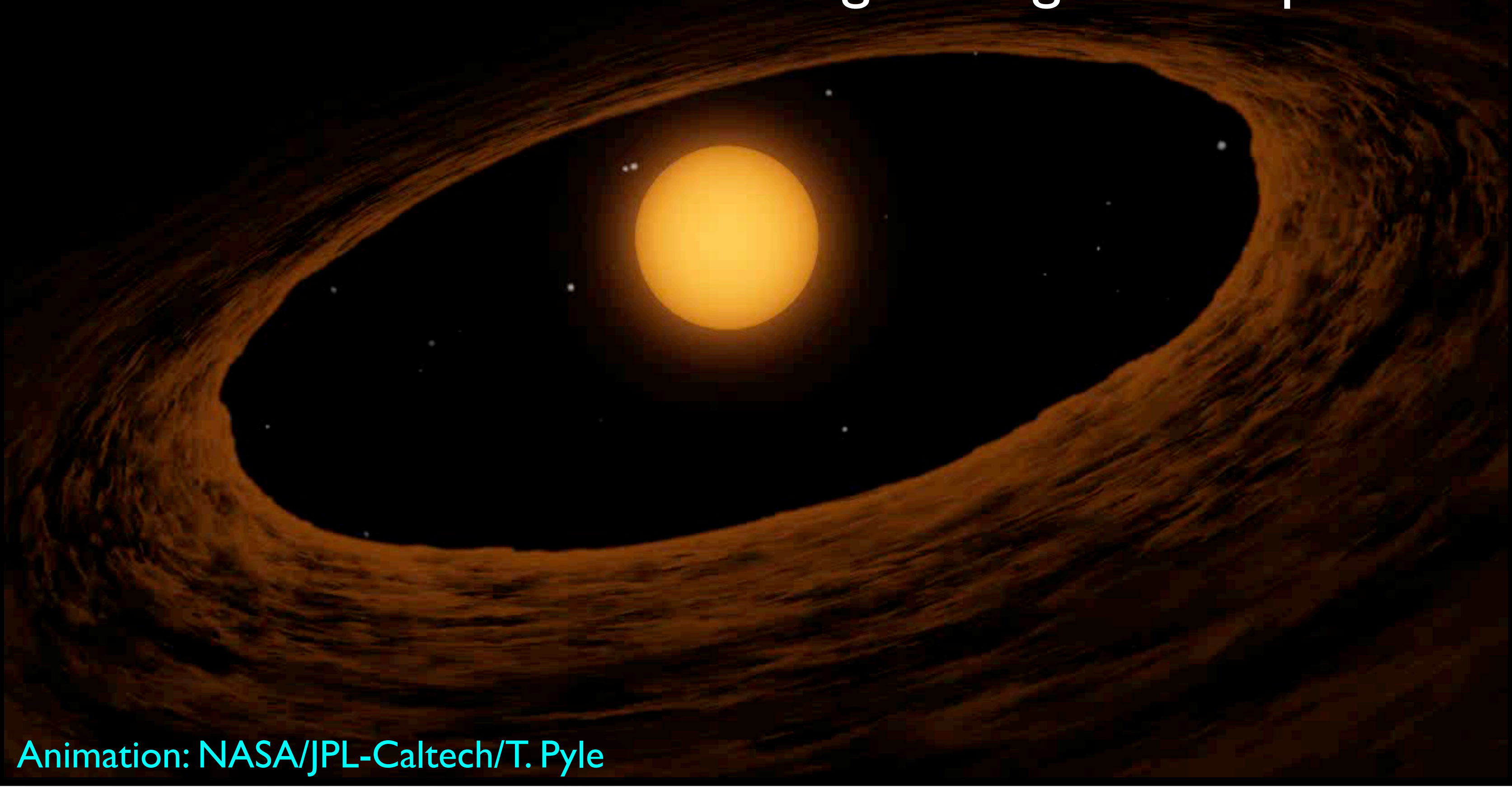


Schulz et al. (1995)

Episodic accretion

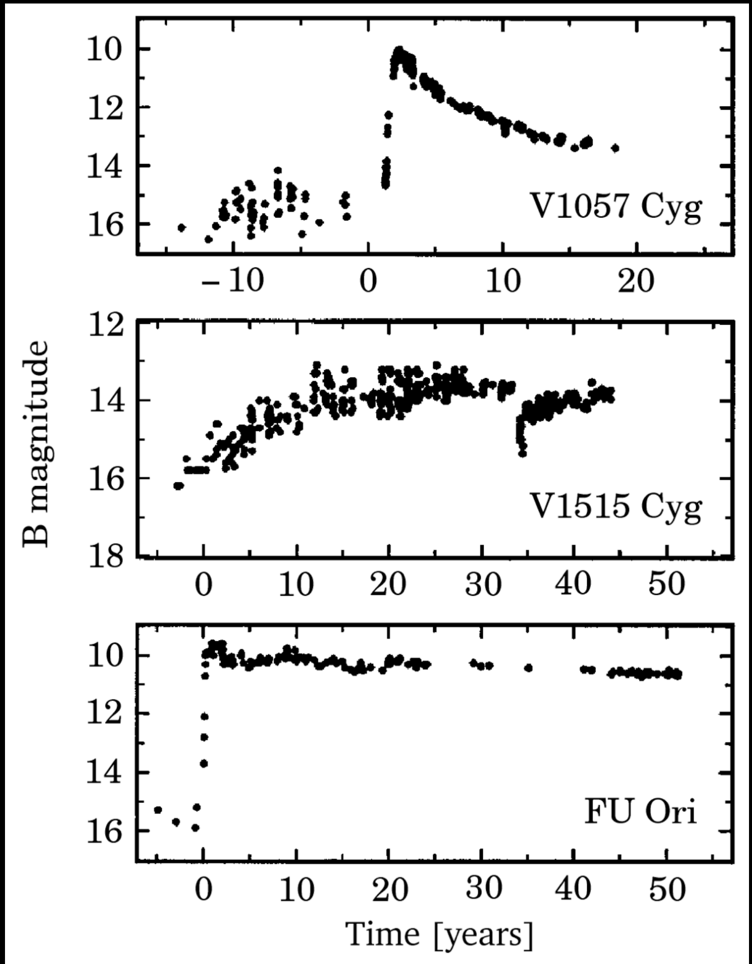
Thermal instability model (Bell et al. 1994):

- Envelope feeds material to the outer disk at a high rate
- Inner disk: low temperature → low sound speed → low viscosity
- Material accumulates → warms up → ionization front
- Material flows onto the star → brightening in the optical/IR



Animation: NASA/JPL-Caltech/T. Pyle

FU Orionis-type objects (FUors)



Hartmann & Kenyon (1996)

FUor outbursts are important because:

- They help building up the final stellar mass (10^{-2} $M_\odot$ accreted in one outburst)
- They affect disk properties (temperature, density, chemical structure) → conditions for planet formation
- Possibly all low-mass young stars go through FUor phases

Circumstellar structure

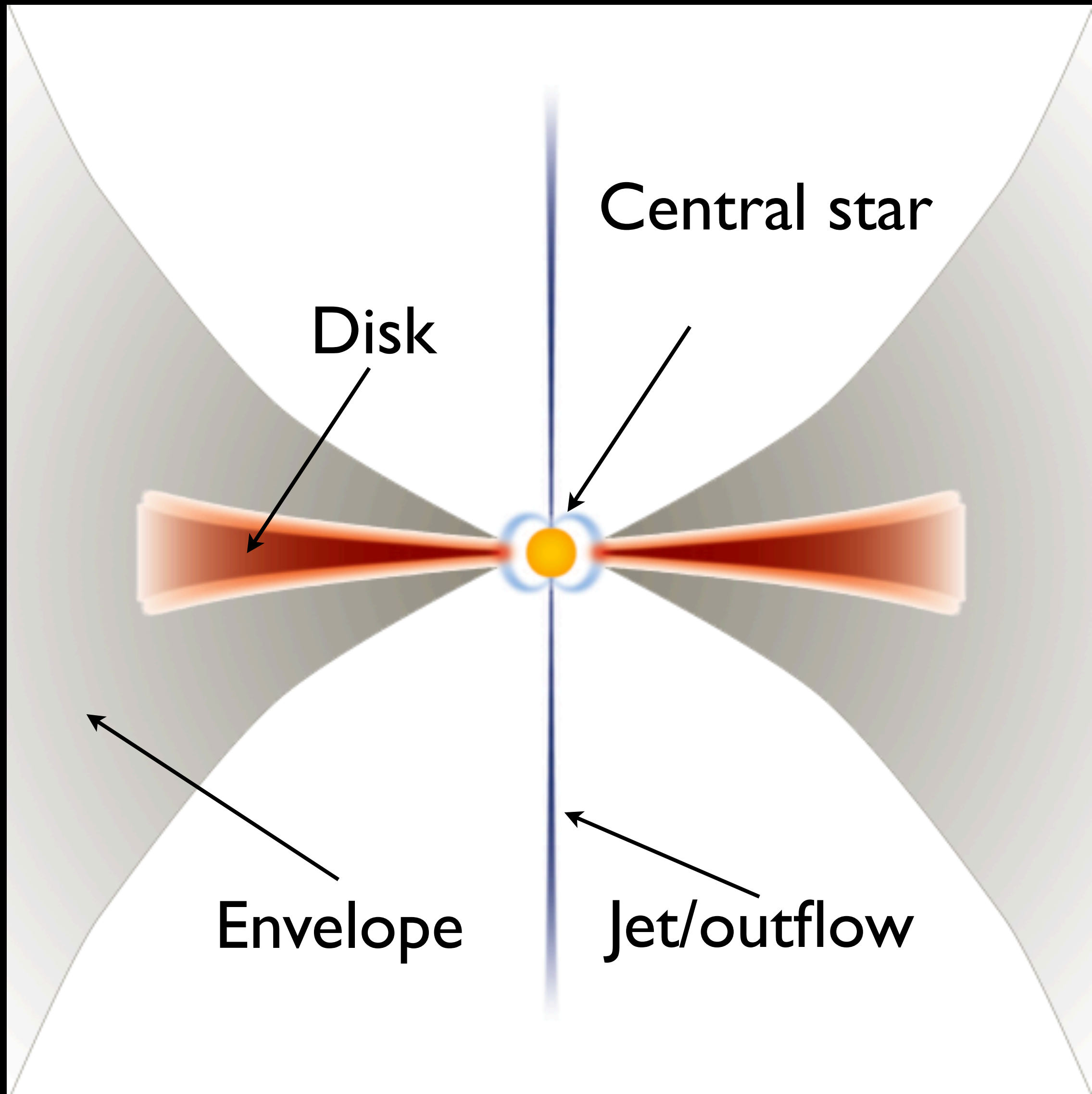


Figure courtesy of Örs Detre

What causes the outburst?

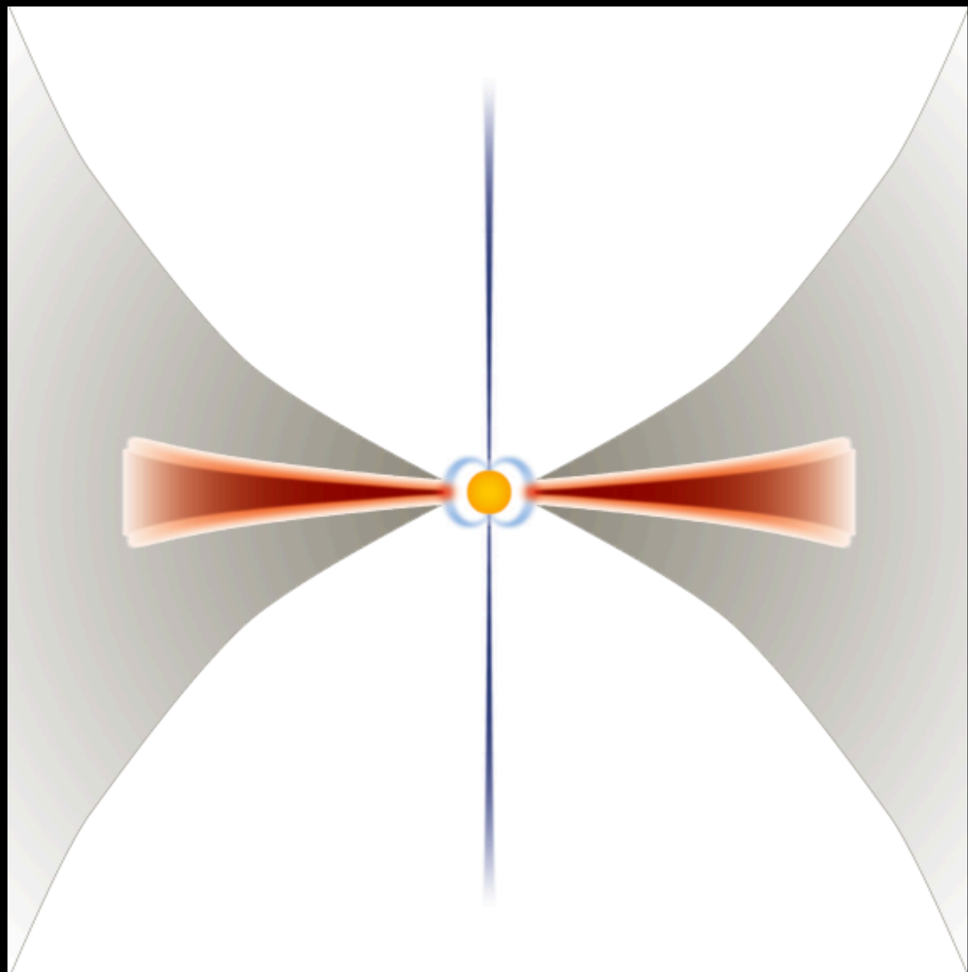
Thermal instability model (Bell et al. 1994):

- Accretion from an envelope onto the disk with an unusually high rate ($\dot{M} > 10^{-6}\ M_\odot$/yr)
- Details of the outburst strongly depend on the mass fall from the envelope: velocity structure, accretion rate, affected disk area
- Prediction: below the critical value for $\dot{M}$, there is no eruption at all

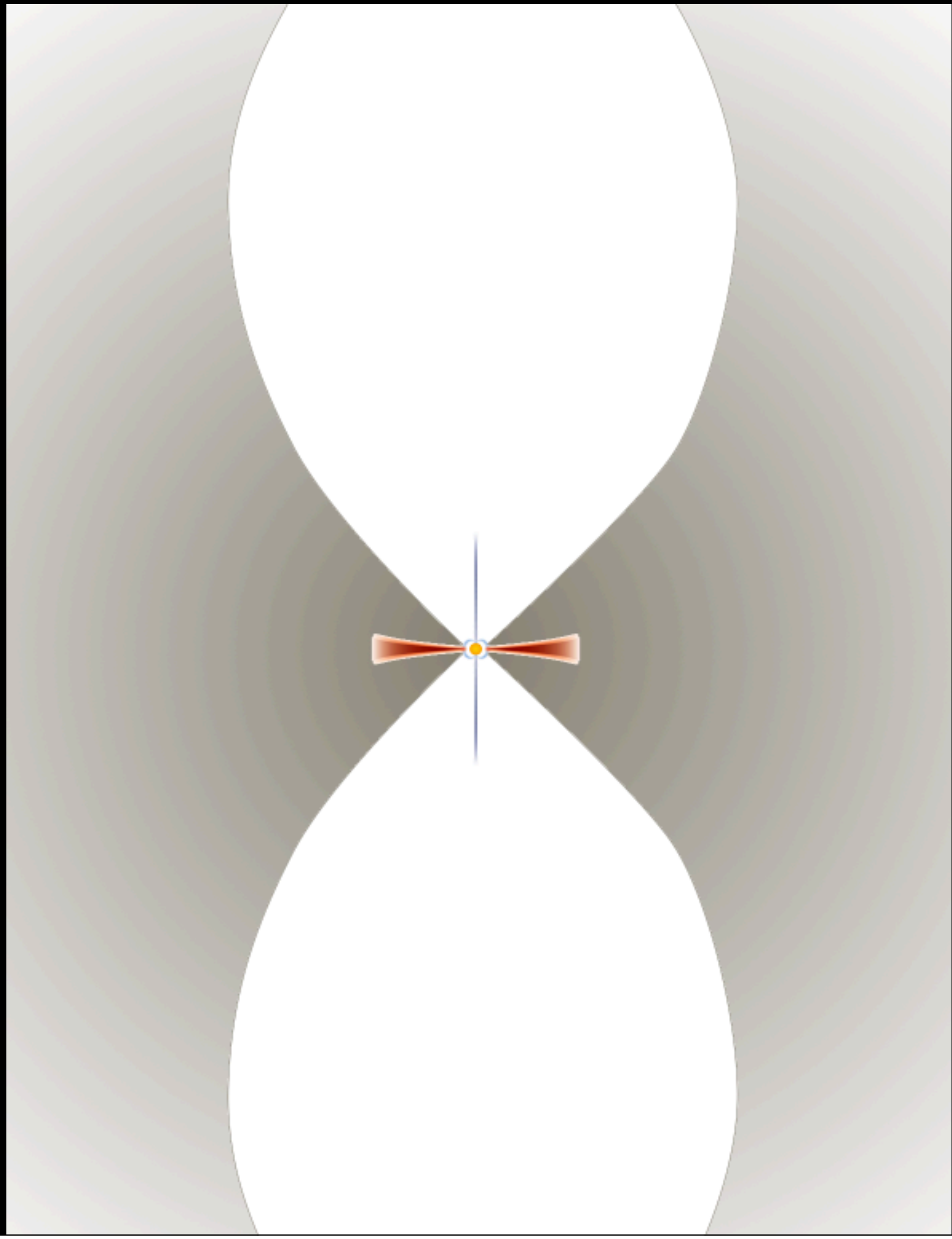
Open questions

- Do all FUors have envelopes?
- How similar are the envelopes of different FUors (size, mass)?
- What is the velocity structure of the envelope (infall/rotation)?

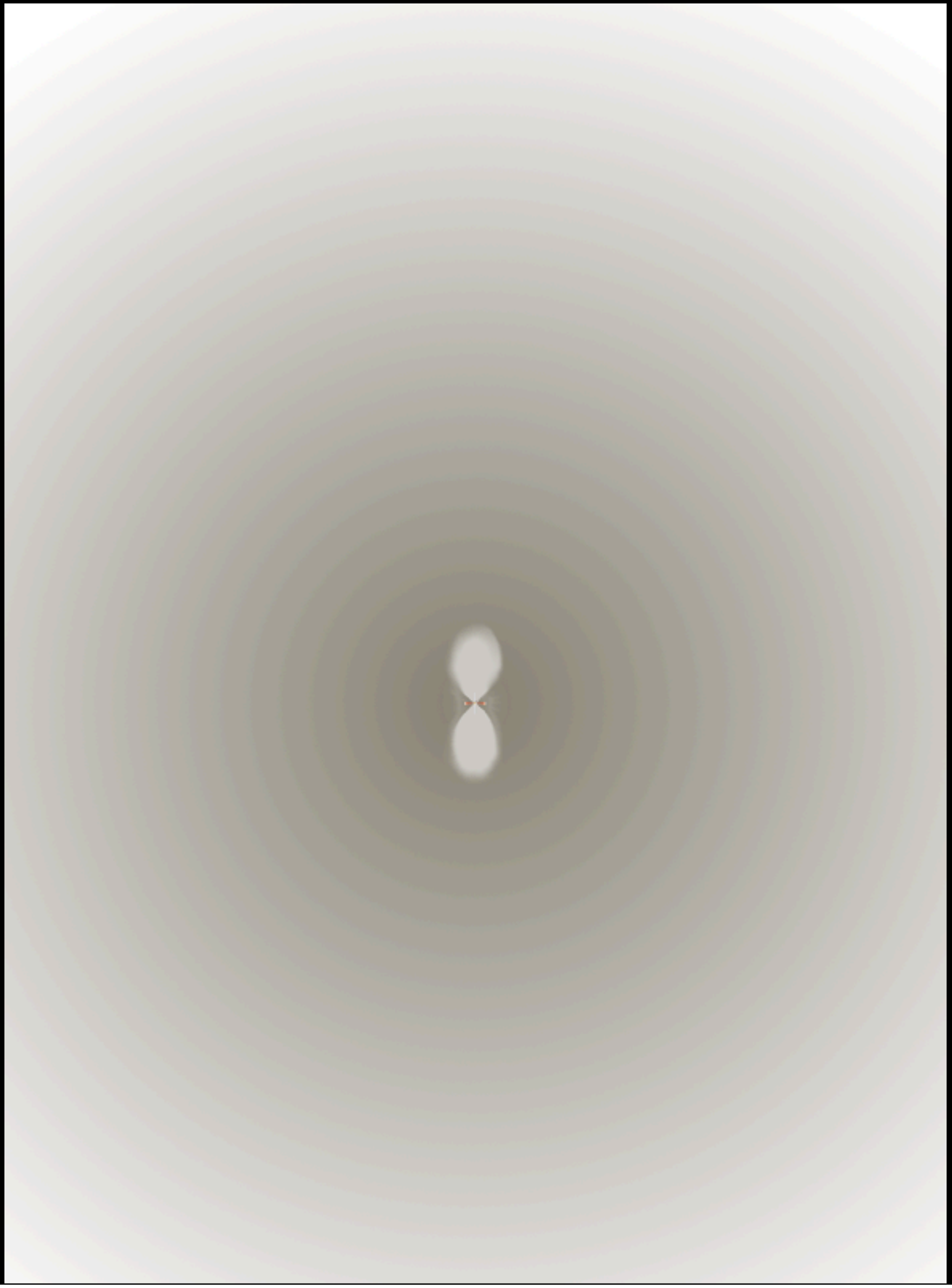
Circumstellar structure



Circumstellar structure



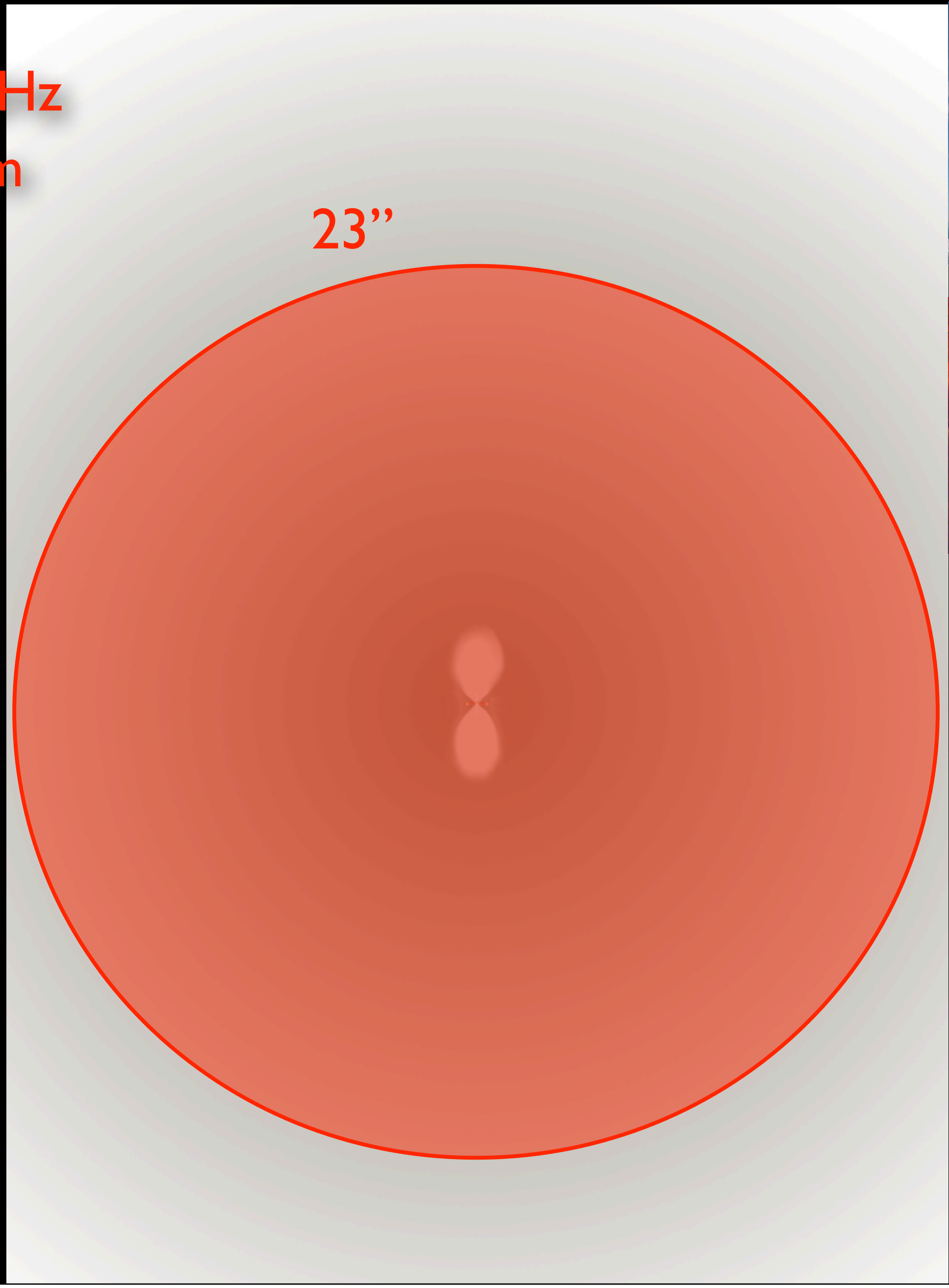
Circumstellar structure

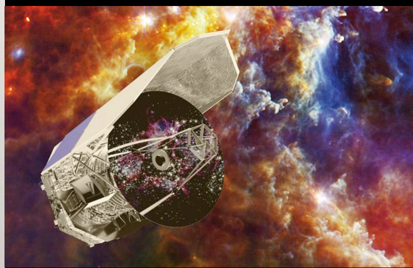


Circumstellar structure

IRAM 30m @ 110 GHz

Herschel @ 350 µm

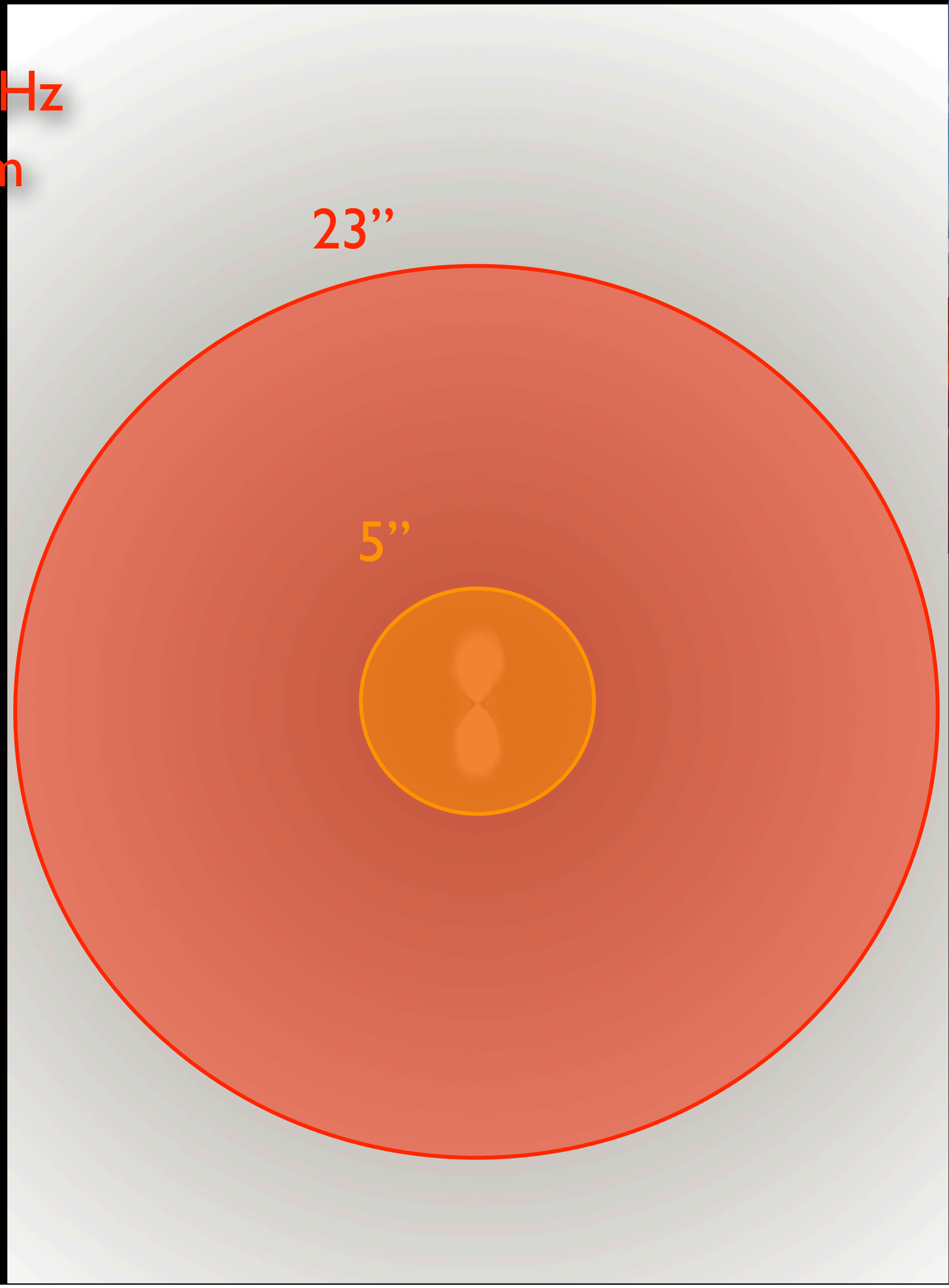


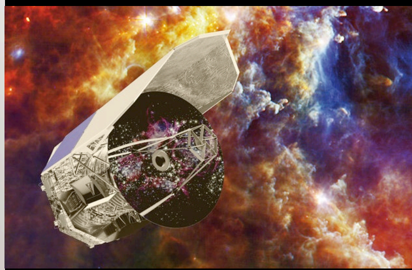


Circumstellar structure

IRAM 30m @ 110 GHz
Herschel @ 350 µm

Herschel @ 70 µm



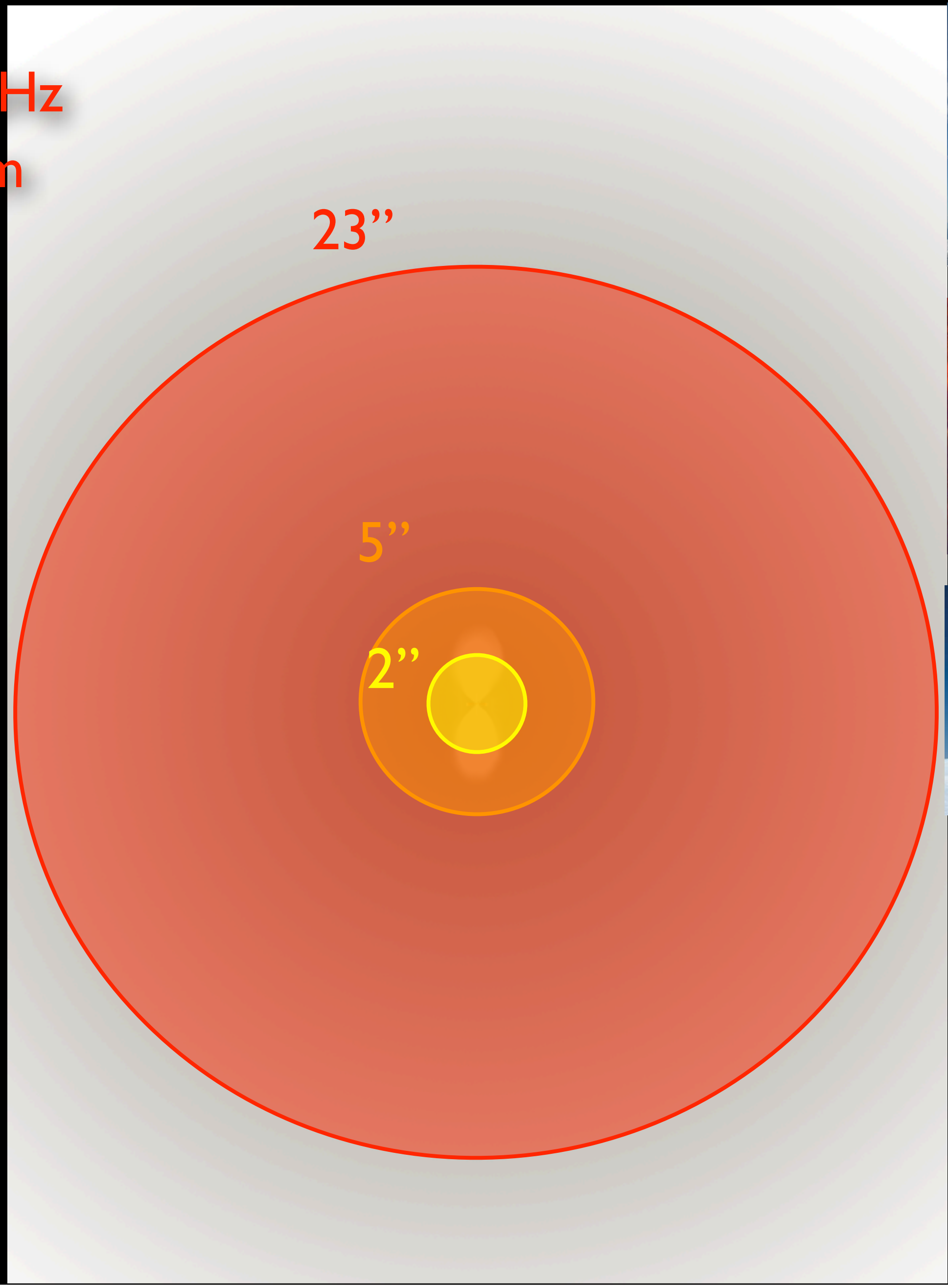


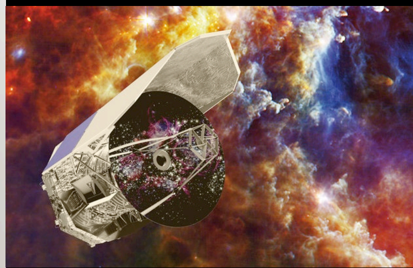
Circumstellar structure

IRAM 30m @ 110 GHz
Herschel @ 350 µm

Herschel @ 70 µm

PdBI @ 110 GHz





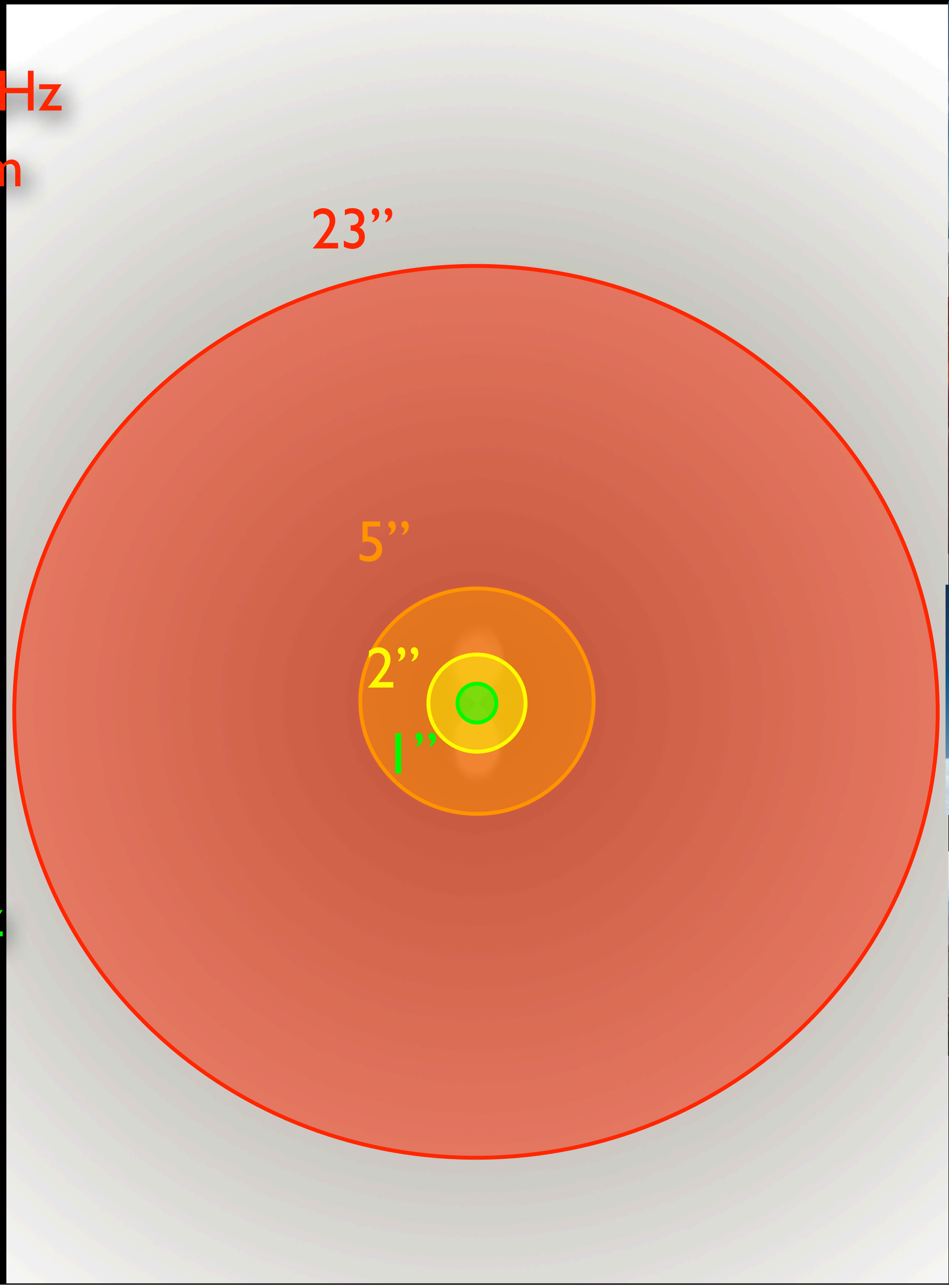
Circumstellar structure

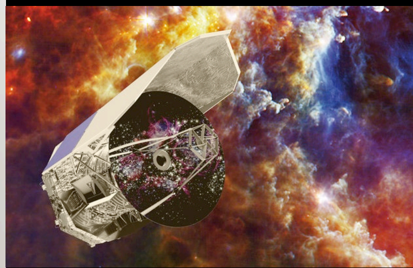
IRAM 30m @ 110 GHz
Herschel @ 350 μm

Herschel @ 70 μm

PdBI @ 110 GHz

CARMA @ 230 GHz





Circumstellar structure

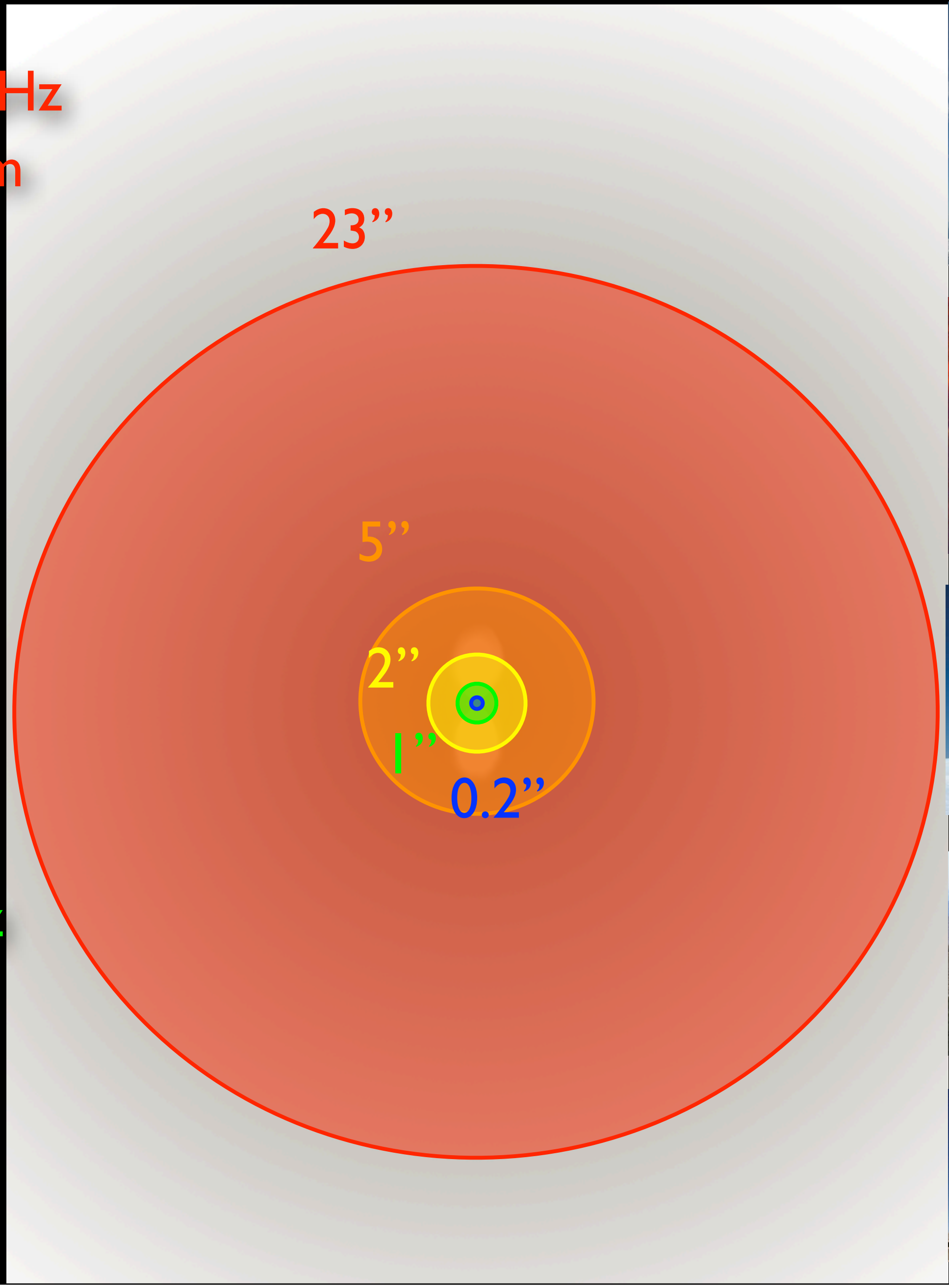
IRAM 30m @ 110 GHz
Herschel @ 350 µm

Herschel @ 70 µm

PdBI @ 110 GHz

CARMA @ 230 GHz

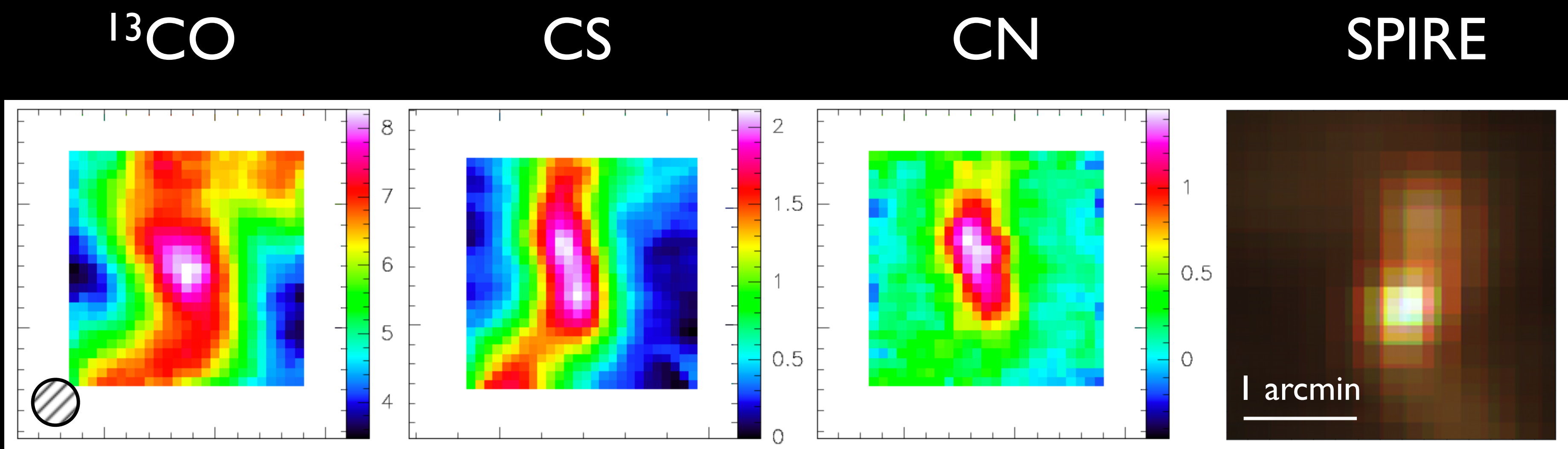
ALMA @ 230 GHz



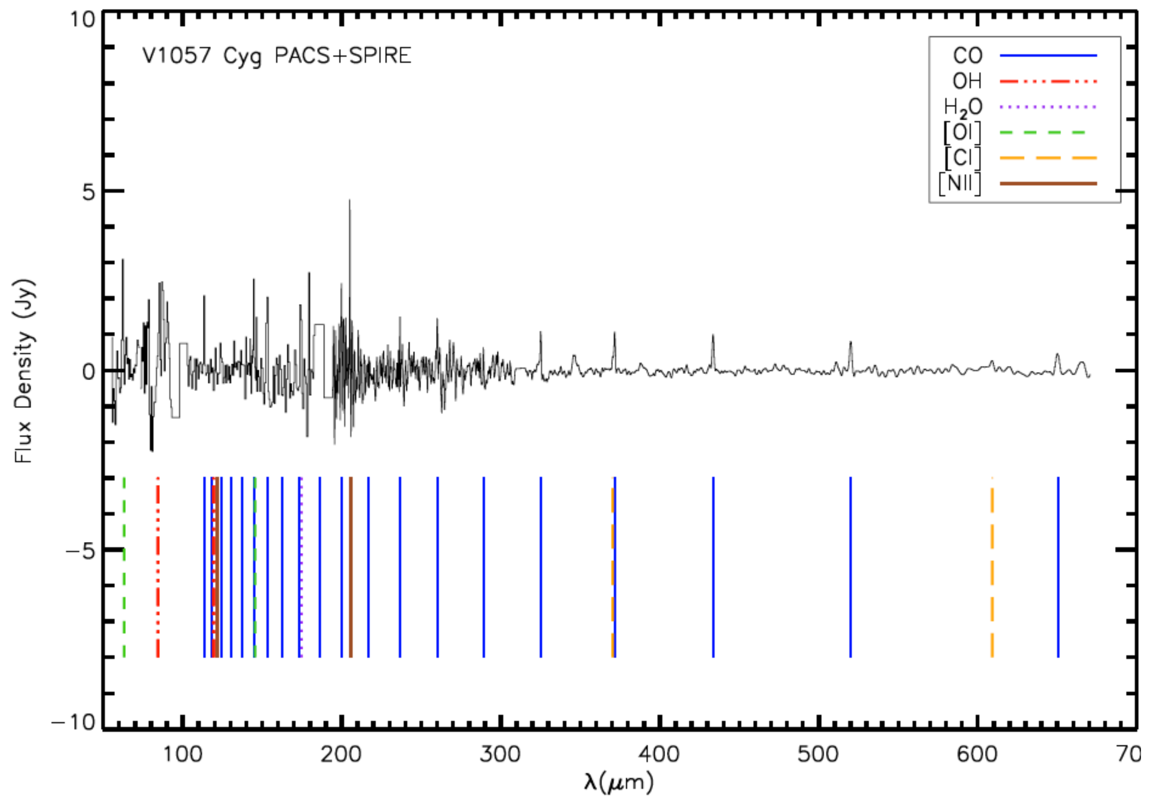
Single aperture data

Case study: V1057 Cyg

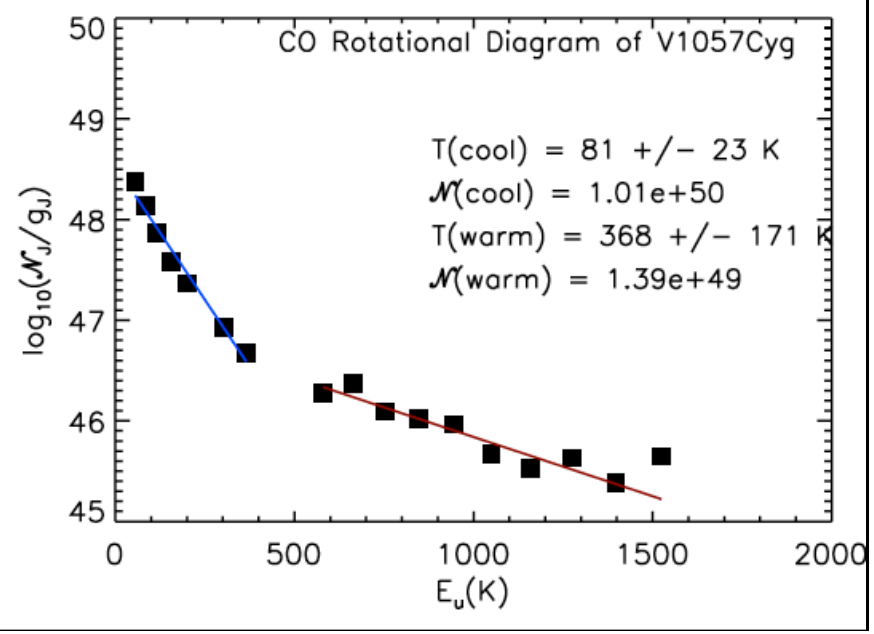
- IRAM single dish observations display rich chemistry: ^{13}CO, $C^{18}O$, $C^{17}O$, CS, C_2S, CN, HC_3N
- Herschel continuum: complicated area
- The object is not isolated, but sits on top of a filament



Single aperture data



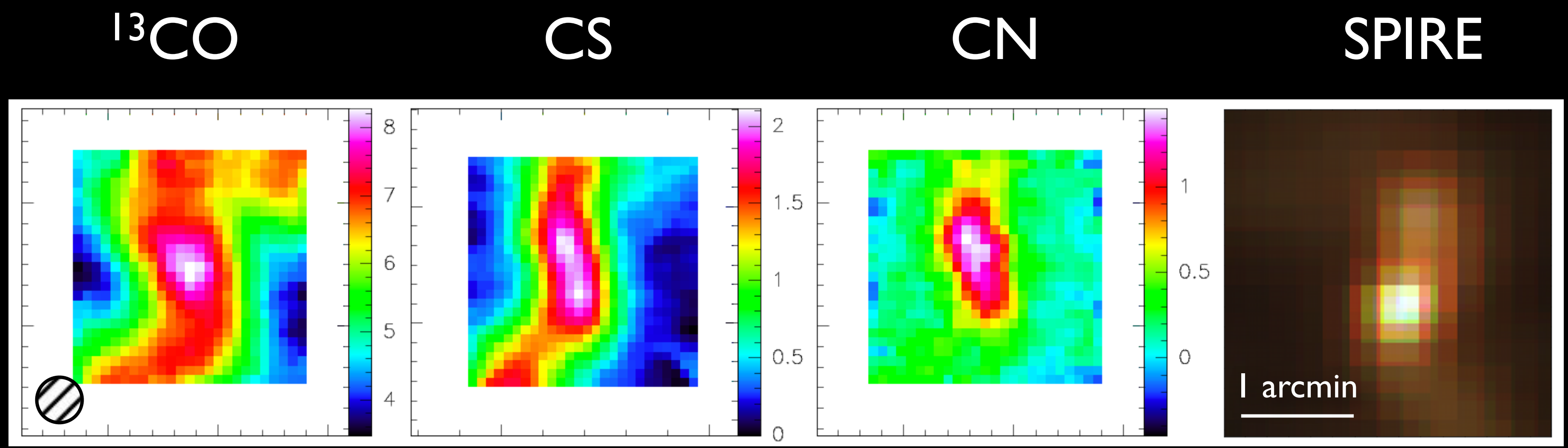
- CO lines from J=4-3 to J=23-22
- OH
- H_2O
- [OI], [CI], [NII]



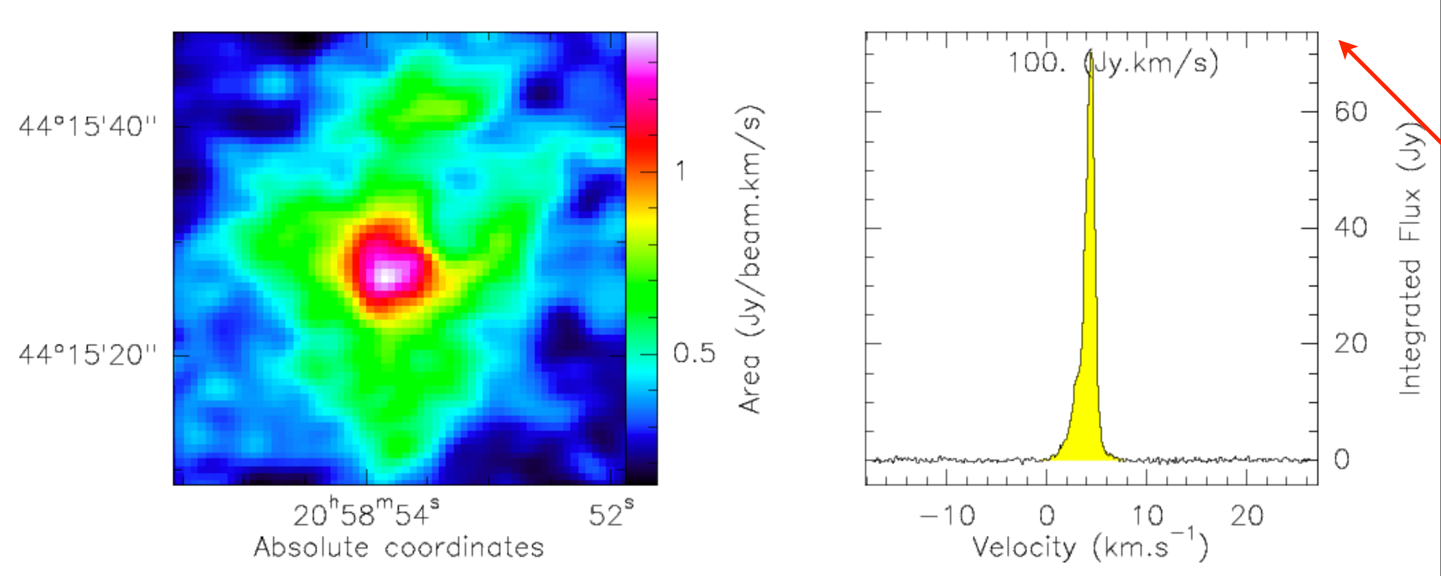
- Rotational line emission typical of Class I sources
- Cool + warm gas → heated envelope

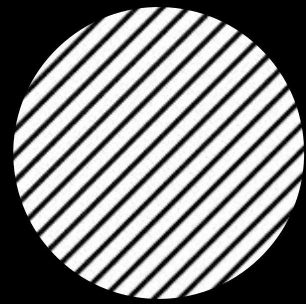
Single aperture data

The envelope is practically unresolved (within the central beam)
beam size: 22" or 11 000 AU



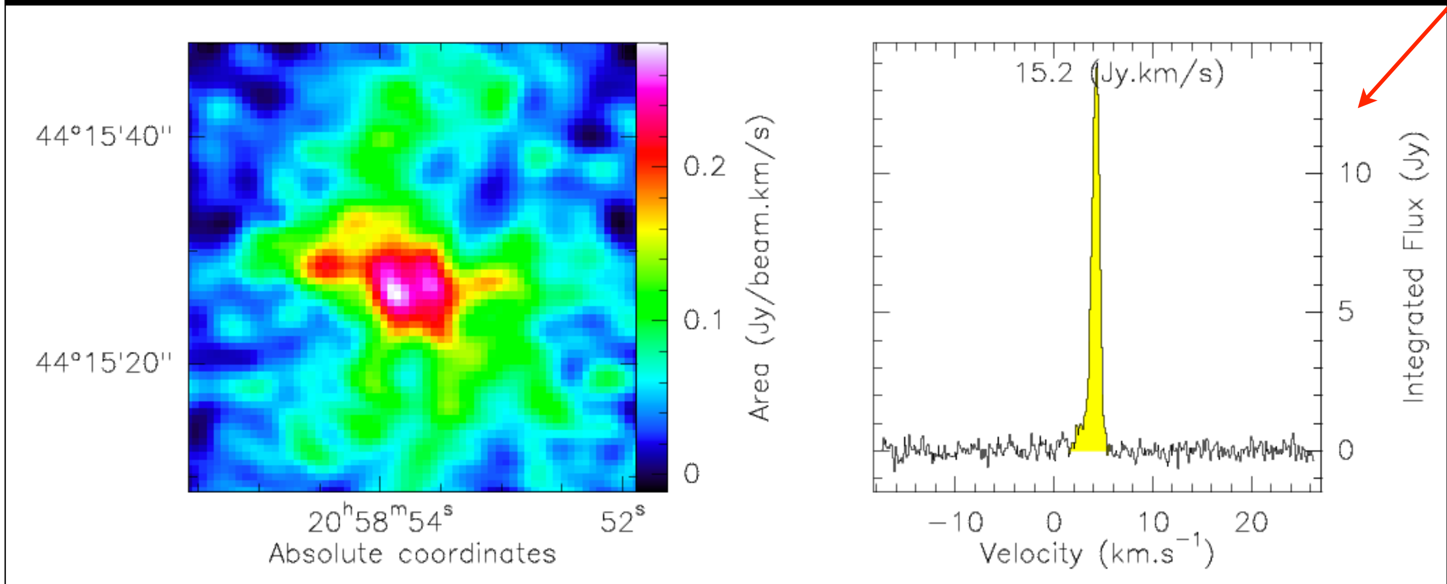
Interferometric images



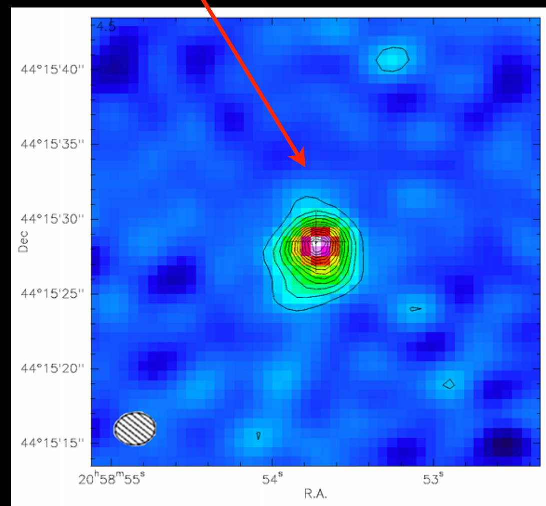


^{13}CO

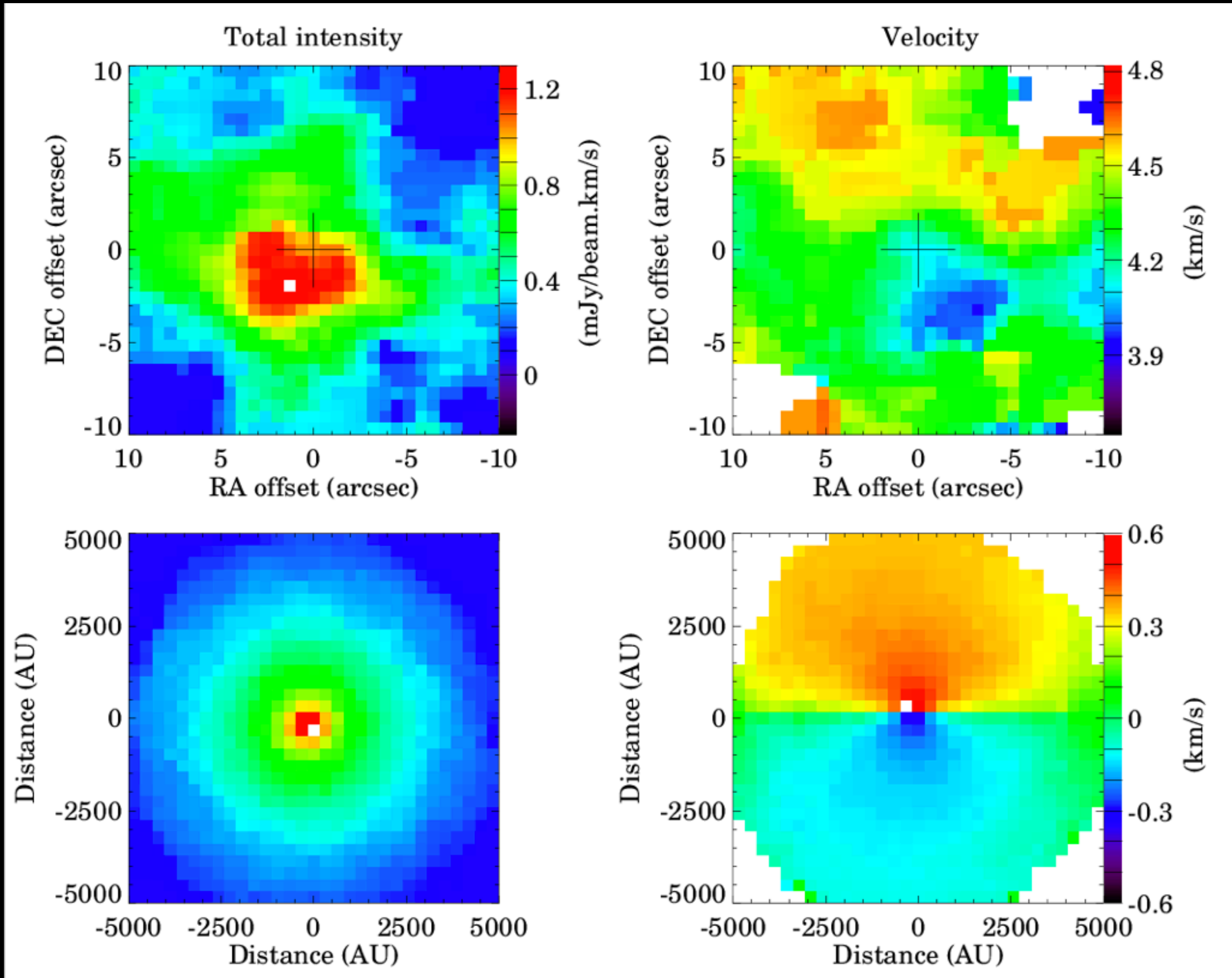
C^{18}O



3 mm continuum



Preliminary modeling



Future plans: ALMA

- Currently 34 antennas offered
- Baselines up to 1.5 km (0.2" at 230 GHz)
- ALMA will make it possible to:
  - Survey the southern and equatorial FUors
  - Map the CO distribution with unprecedented spatial resolution to reveal the envelope fine structure
  - Map the velocity pattern of the envelope with high S/N ratio, in order to measure the rotation/infall structure
  - Study the evolution of envelopes on the full sample of FUors
- Deadline for proposals: 5 December 2013