Observations of the Earliest Stages of Protostellar Disks

How do disks form and evolve during the embedded protostellar stages?

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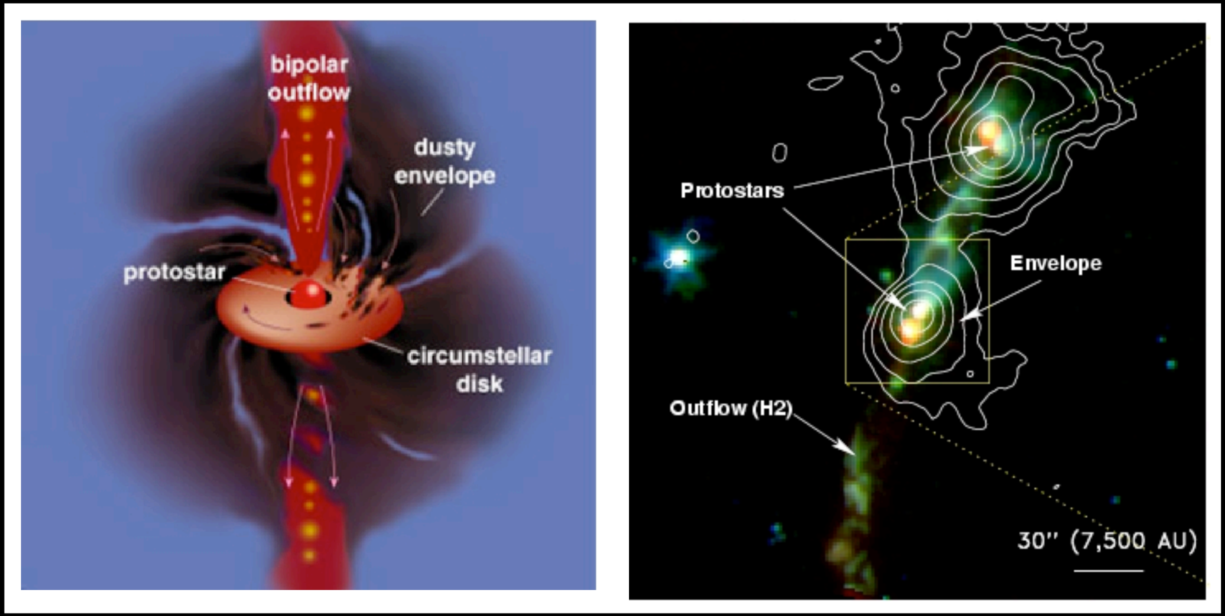
Resolving the complex details of embedded protostars



Cartoon from Greene (2001), Spitzer data (Jørgensen et al. 2006) compared to JCMT/SCUBA data (Jørgensen et al. 2007).

The Spitzer observations are probing emission from warm dust in the inner highly extincted regions; the submillimeter single-dish data the larger scale cold envelope. How are the two related?

Framework

Single-dish submm/FIR dust continuum emission → Envelope large scale physical structure (temperature, density)

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High resolution (sub)mm data → Confirm/disprove envelope model, R_{in}

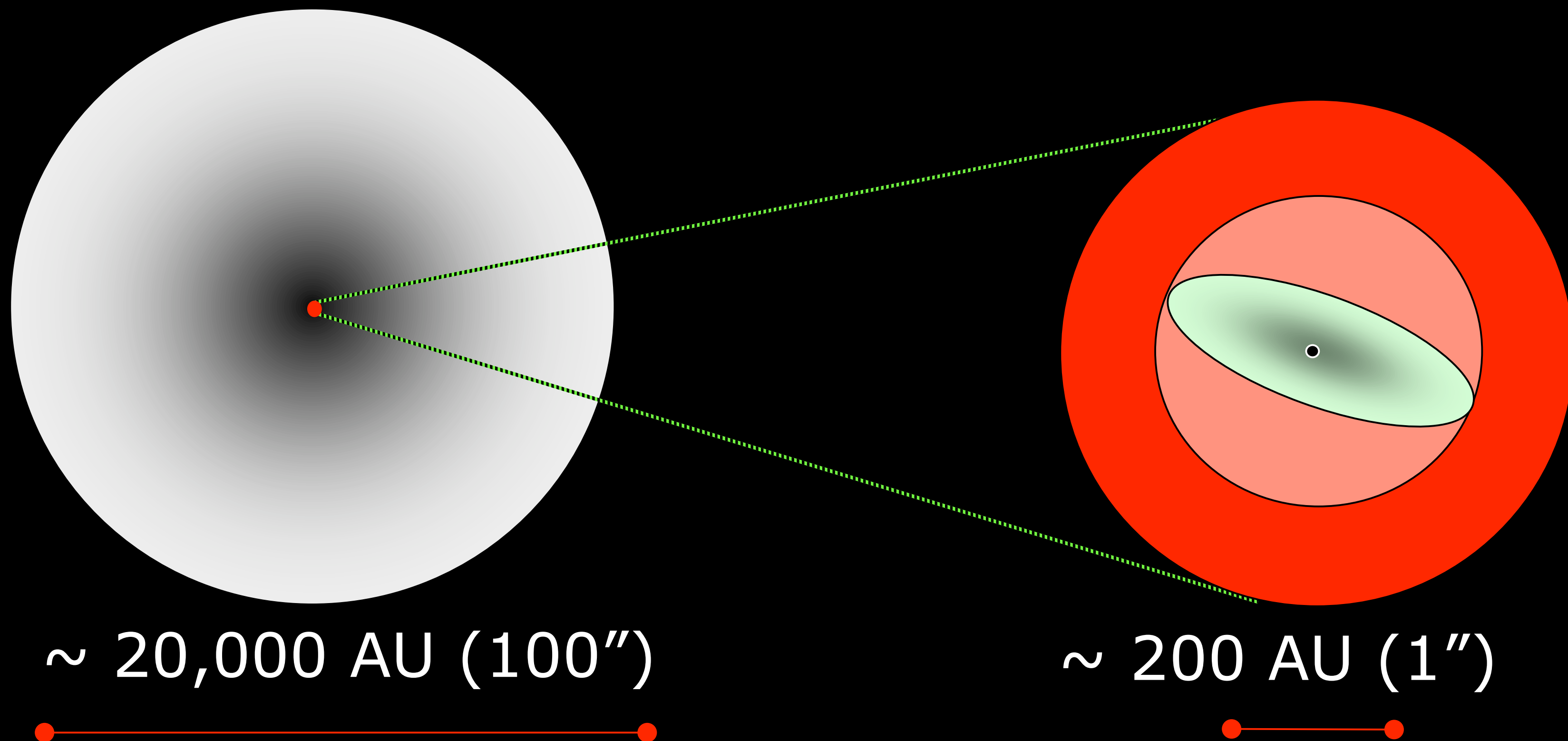
Mid-infrared observations → Confirm/disprove envelope model, R_{in}

↓

High resolution (sub)mm data → Disk: existence, SED, structure (physical, chemical)

Mid-infrared observations → Disk: existence, SED, structure (physical, chemical)

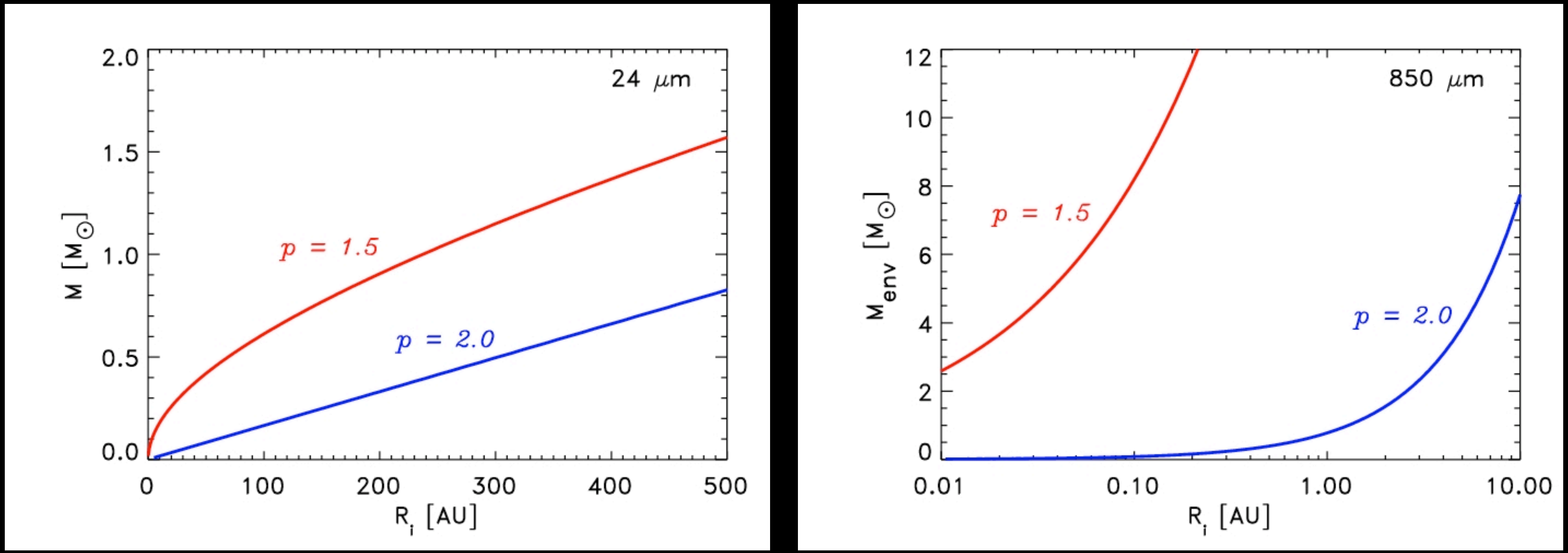
Low-mass protostars



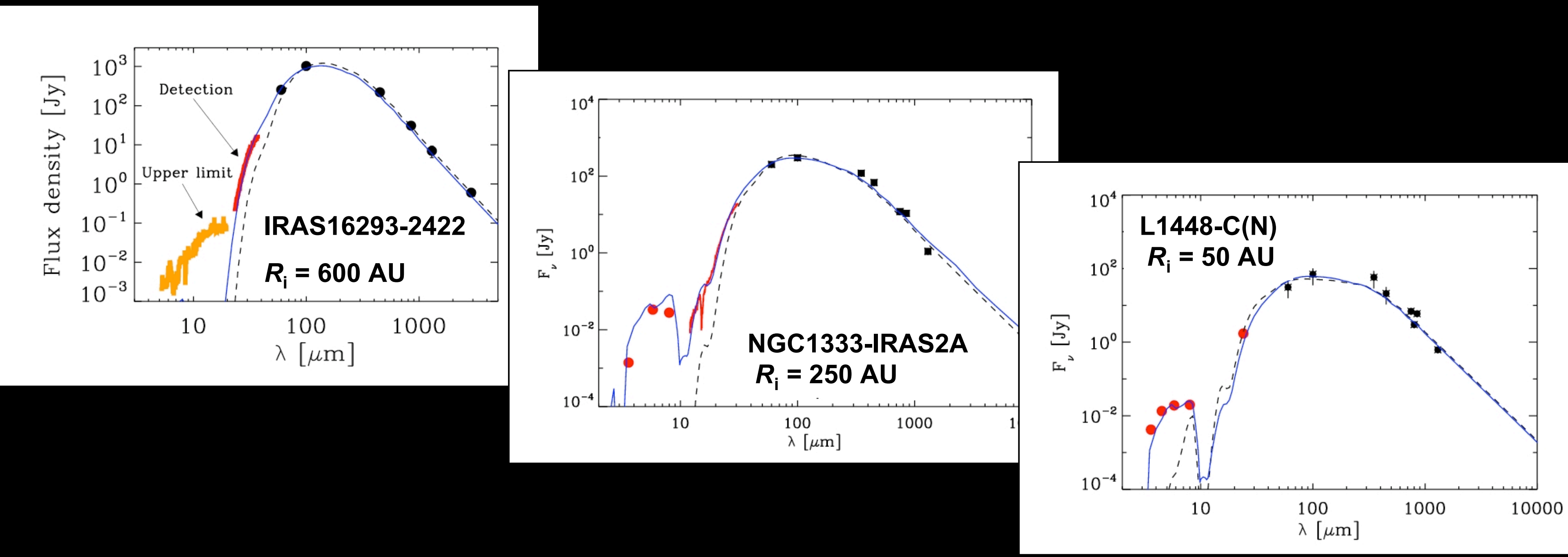
- Densities ranging from 10^4 cm^{-3} to 10^7-10^8 cm^{-3} (H_2)
- Temperatures ranging from ~10 K to a few hundred K.

Column density and mass

- Typical envelopes have $n \propto r^{-p}$ with $p \approx 1.5\text{-}2.0$.
- The mass is on large scales (single-dish beam) whereas the line of sight column density/extinction is on small scales (IR pencil-beam).

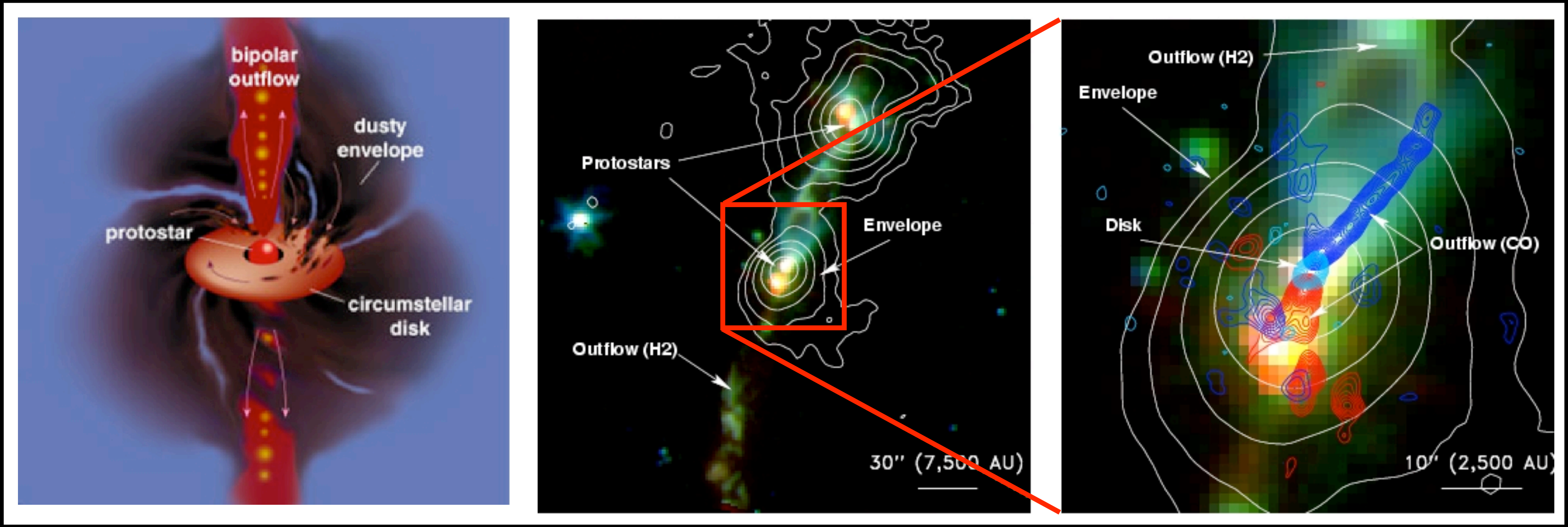


Mid-infrared “excesses” generally seen



If “inner cavity” is introduced (i.e., inner radius wherein envelope profile flattens), the SED is well-reproduced *(solid lines)*. Otherwise envelope severely optically thick at mid-IR wavelengths (Spitzer; red); not enough emission escapes from the central source(s) *(dashed)*. Radii correspond well to size of binary/disk structures.

Resolving the complex details of embedded protostars

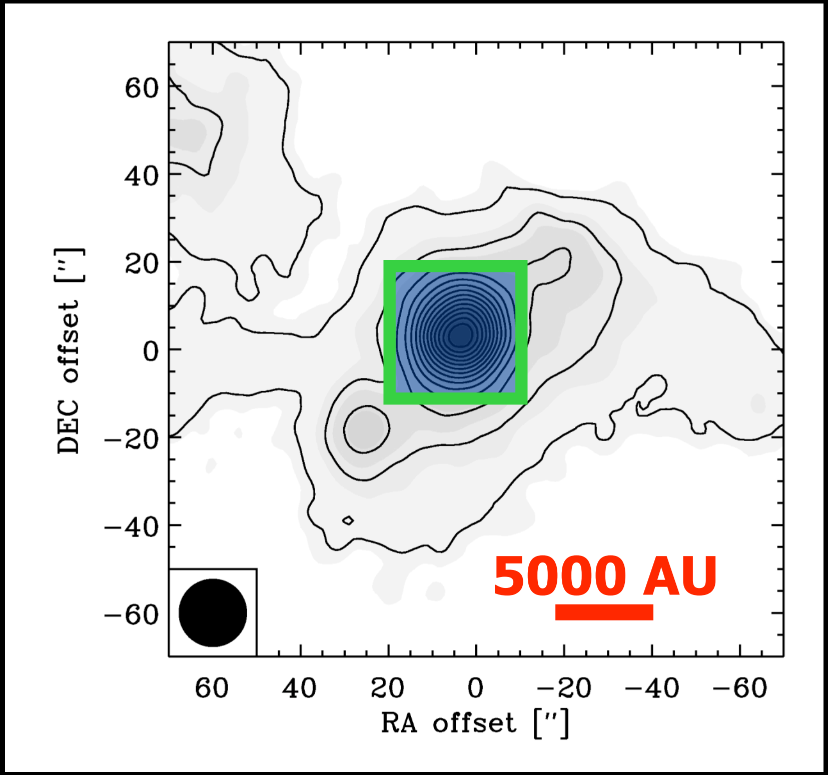


Data: Large SMA survey, "*PROSAC*", of 20 embedded Class 0/I protostars in a wide range of submm lines and continuum.

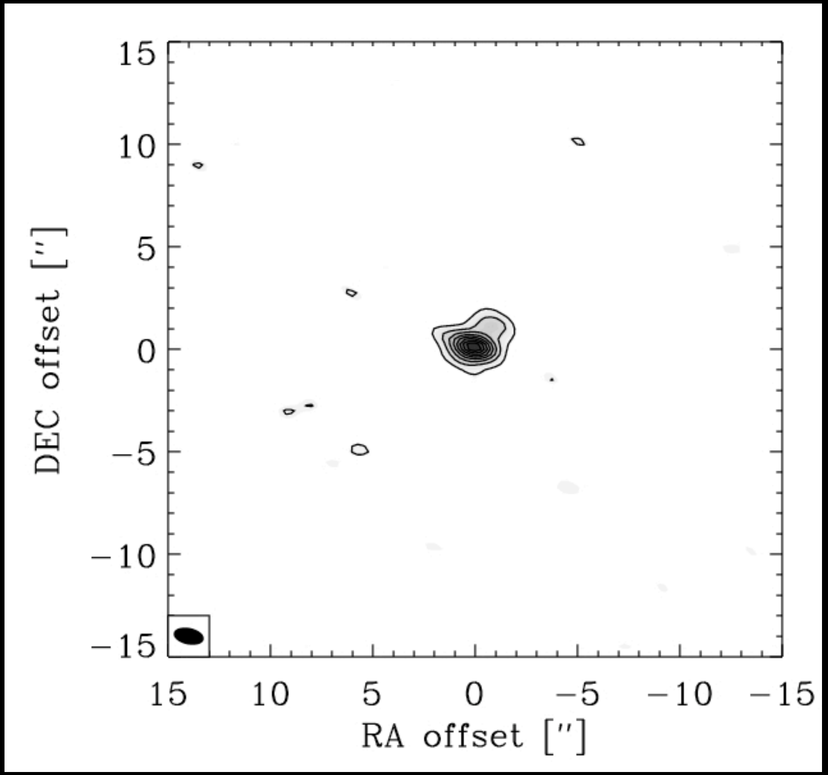
Cartoon from Greene (2001), Spitzer data (Jørgensen et al. 2006) compared to SMA and JCMT/SCUBA data (Jørgensen et al. 2007).

NGC1333-IRAS2A: 850 µm dust continuum

SCUBA 850 µm

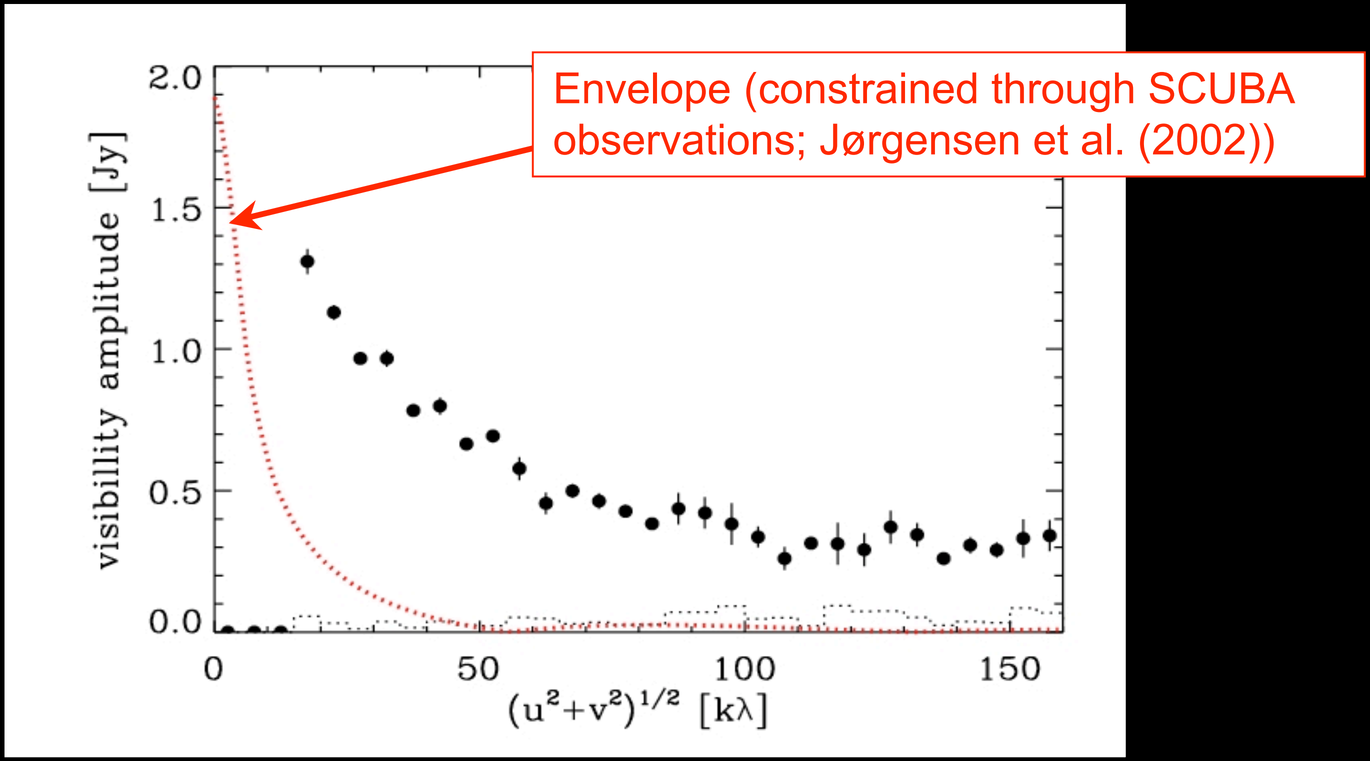


SMA 850 µm



Jørgensen et al. 2005, ApJ, 632, 973

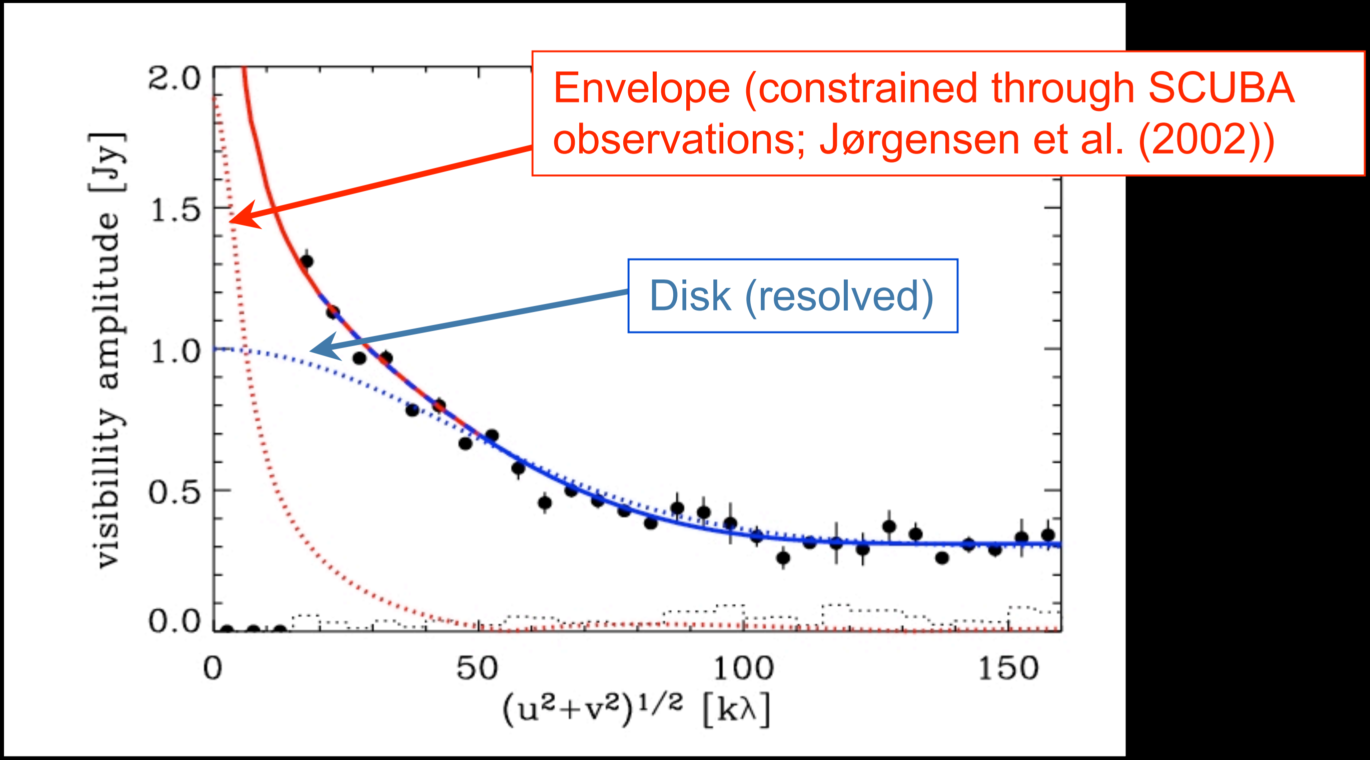
NGC1333-IRAS2A: 850 μm dust continuum



Extended structure Compact structure

Jørgensen et al. 2005, ApJ, 632, 973

NGC1333-IRAS2A: 850 μm dust continuum

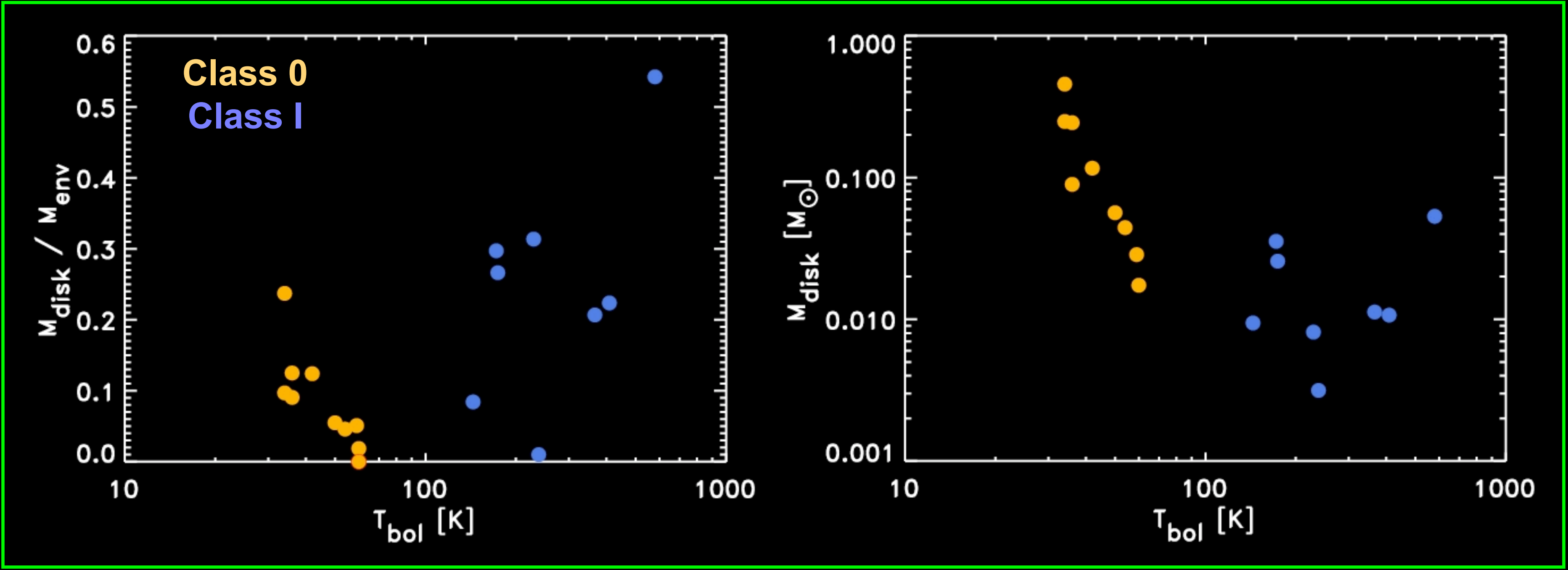


…the SMA resolves the warm dust in the inner envelope *and the (300 AU diameter) circumstellar disk.*

Jørgensen et al. 2005, ApJ, 632, 973

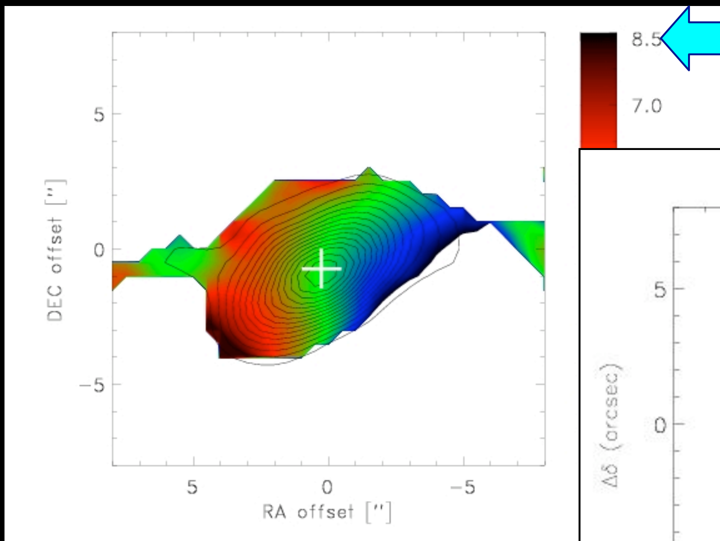
Embedded disk evolution?

Continuum observations of full sample of 18 Class 0 and I objects



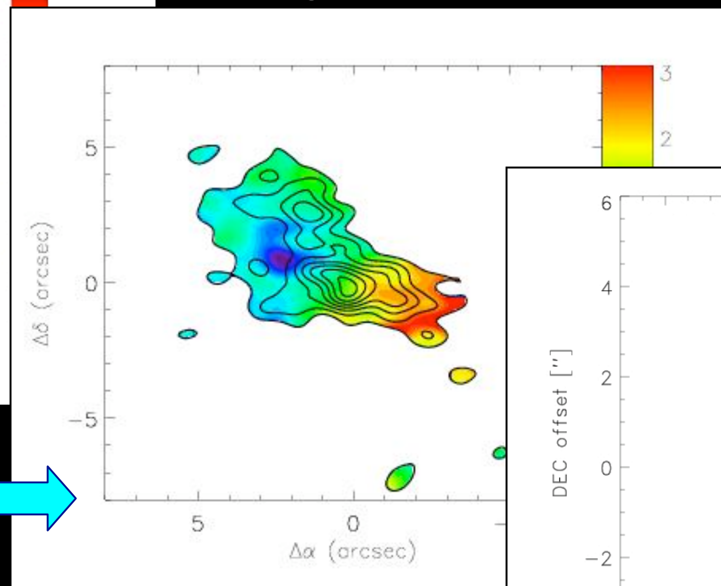
Disks around Class I sources are not more massive than those around Class 0's. Rapid formation/build-up of disks?

Keplerian rotation in inner envelope/disk



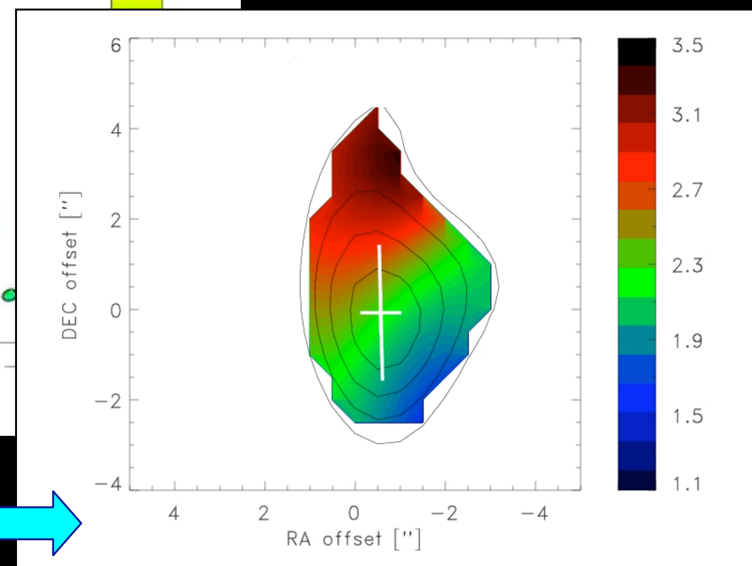
IRS43: 1.0 $M_\odot$

Jørgensen et al., in prep.



L1489-IRS: 1.4 $M_\odot$

Brinch et al. 2007

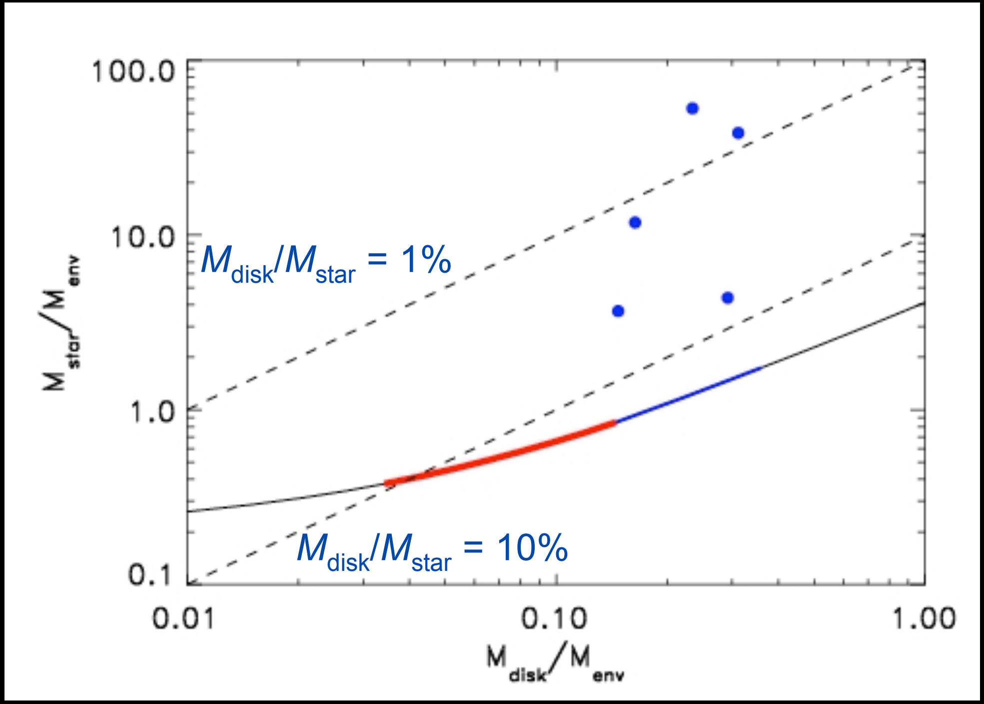


IRS63: 0.37 $M_\odot$

Lommen et al. 2008

Keplerian rotation pattern in circumstellar (Class I) disks allow direct estimate of stellar masses.

Model comparison



Model track from Visser et al. simulation.

At late stages disk/stellar mass ratio overestimated by model (obs. M_{disk} / M_{star} ~ 1%).

Early disk formation and growth.

Provide direct constraints on evolutionary models.

M_{core} = 1 $M_{\odot}$, c_s = 0.19 km/s, $\omega = 10^{-14}$ s^{-1}. Red/blue part of line indicate ranges of M_{disk}/M_{env} for Class 0 and Class I sources, respectively. Symbols indicate Class I sources with stellar masses determined from dynamics. Dashed lines indicate M_{disk} / M_{star} of 1% and 10%, respectively.

Conclusions

- High-angular resolution observations coupled with detailed radiative transfer models of available multi-wavelength data reveal the structure of protostars from 10,000 to 100 AU scales.
- Structure of the inner envelopes (“cavities”) reflects the disk formation.
- Even deeply embedded protostars posses circumstellar disks - with significant masses (~0.05-0.1 $M_\odot$) and sizes (~100 AU).
- Together with stellar masses from disk dynamical signatures, we are building up a complete picture for the evolution of young stellar objects.