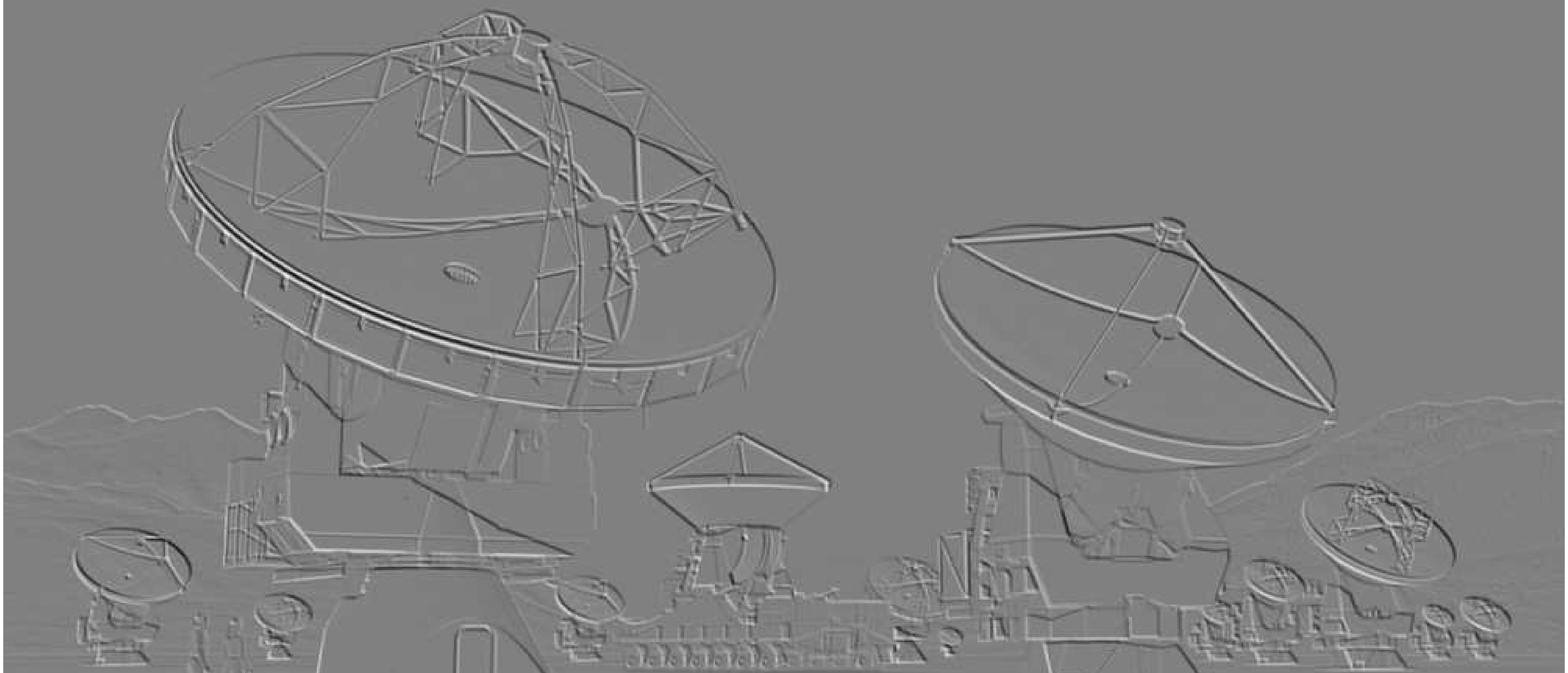
Unraveling the Envelope and Disk: The ALMA Perspective



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The Early Disk

- Disks are probable generic outcome of a collapsing core with a little angular momentum (e.g. Terebey, Shu, Cassen 1984)
  - Accreting material misses the star…
- Outflows are likely powered by star/disk magnetic interactions (e.g. Shang et al. 2007; Pudritz et al. 2007)
- Class 0 sources have disks or flattened envelope structures (e.g. Andre et al. 2000)
  - Envelope is >90% of emission on 10,000 AU sizes

The Early Disk

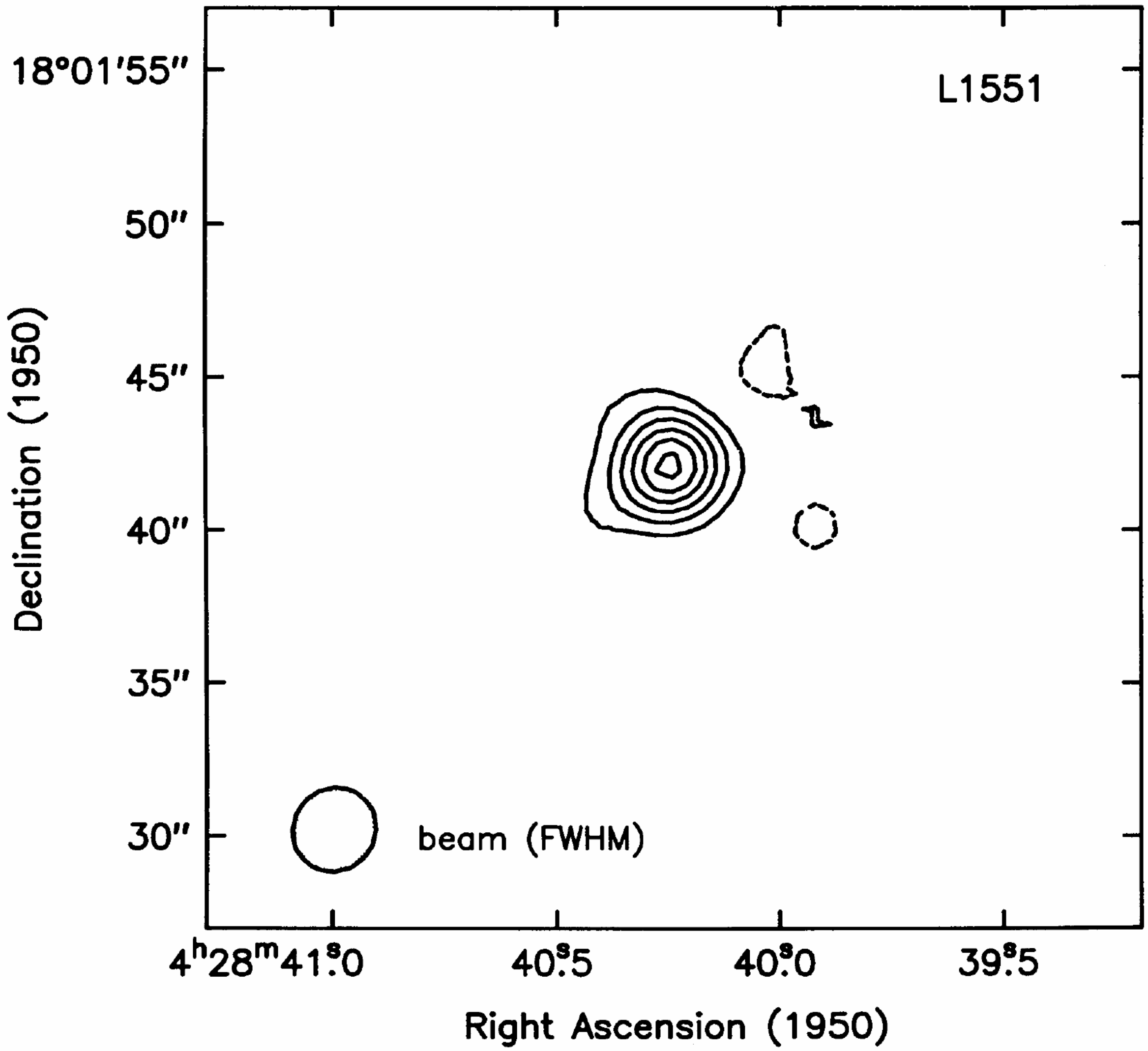
- How does the disk grow with time?
  - From simple arguments:

$$r = 0.3\,\mathrm{AU}\left(\frac{\mathrm{T}}{10\,\mathrm{K}}\right)^{1/2}\left(\frac{\Omega}{10^{-14}\ \mathrm{s}^{-1}}\right)\left(\frac{t}{10^{5}\ \mathrm{yr}}\right)^{3}$$

Stahler & Palla 2004

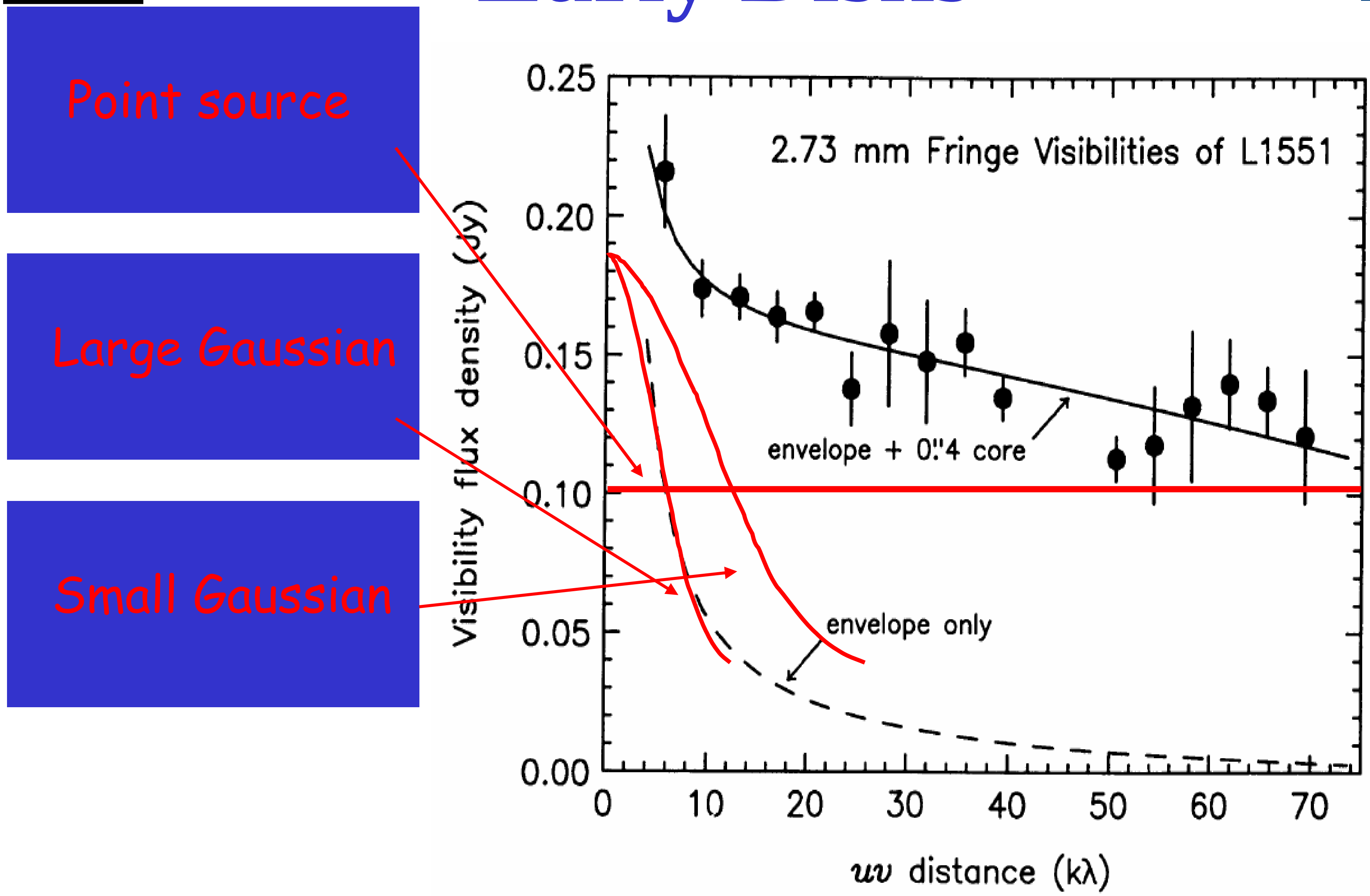
- Due to the large, massive, and bright (mm) envelope, it is a difficult question to address observationally
  - The disk is entangled with the envelope.
- Need to better understand the inner envelope (< 5000 AU)

Early Disks



Keene & Masson (1990)

Early Disks

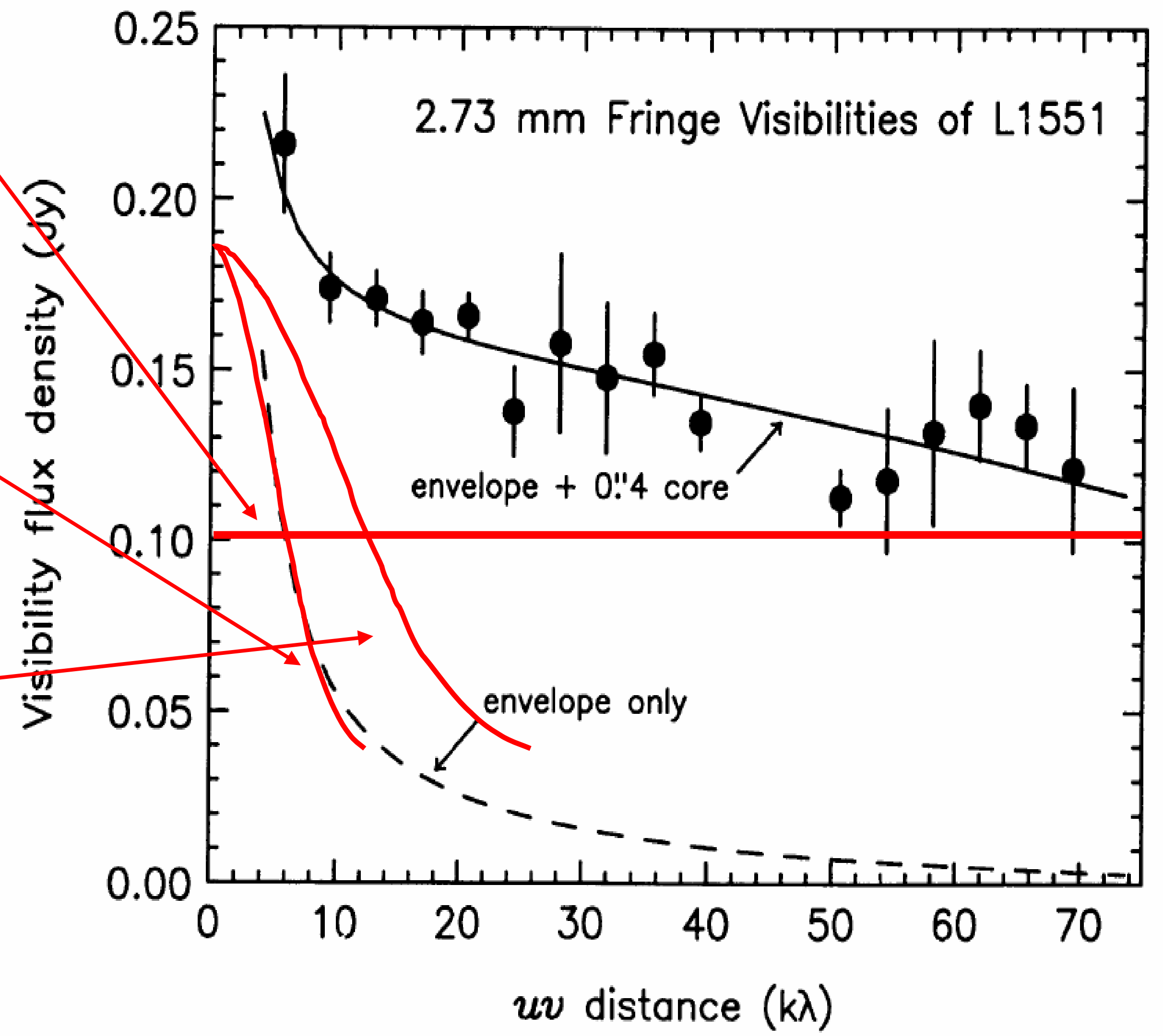


Keene & Masson (1990)

Early Disks

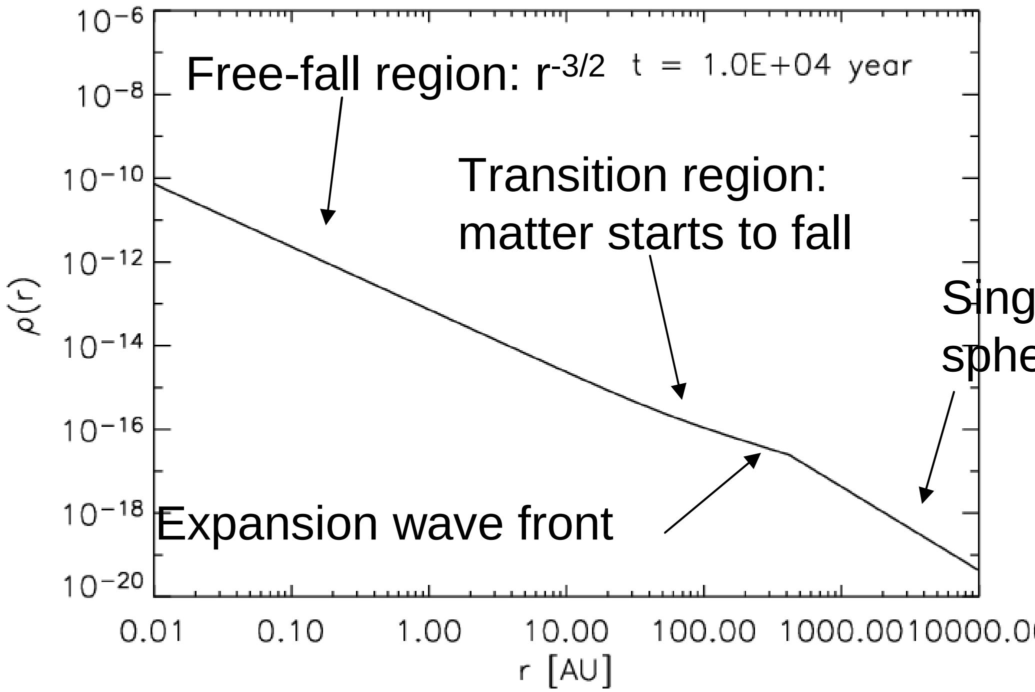
A power-law envelope model and power-law temperature model

Showed that the excess could be fit by compact emission: 45 AU circumstellar disk

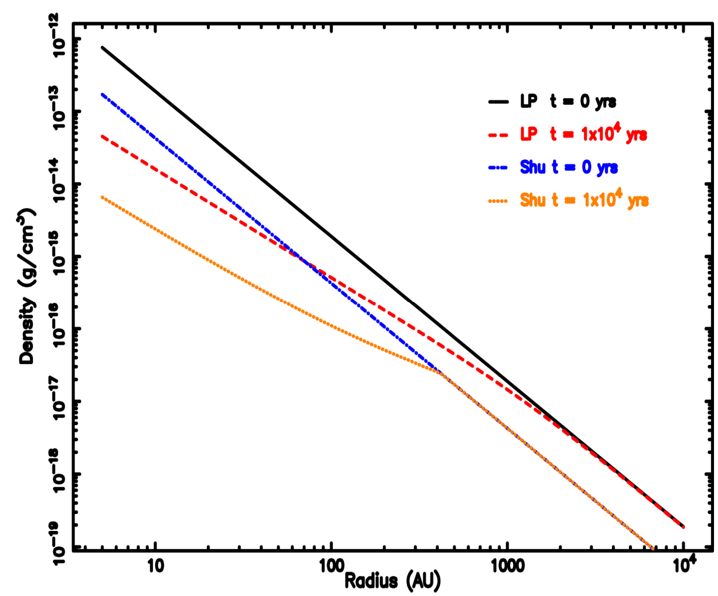


Keene & Masson (1990)

Core Formation



Shu 1977, Larson 1969, Penston 1969

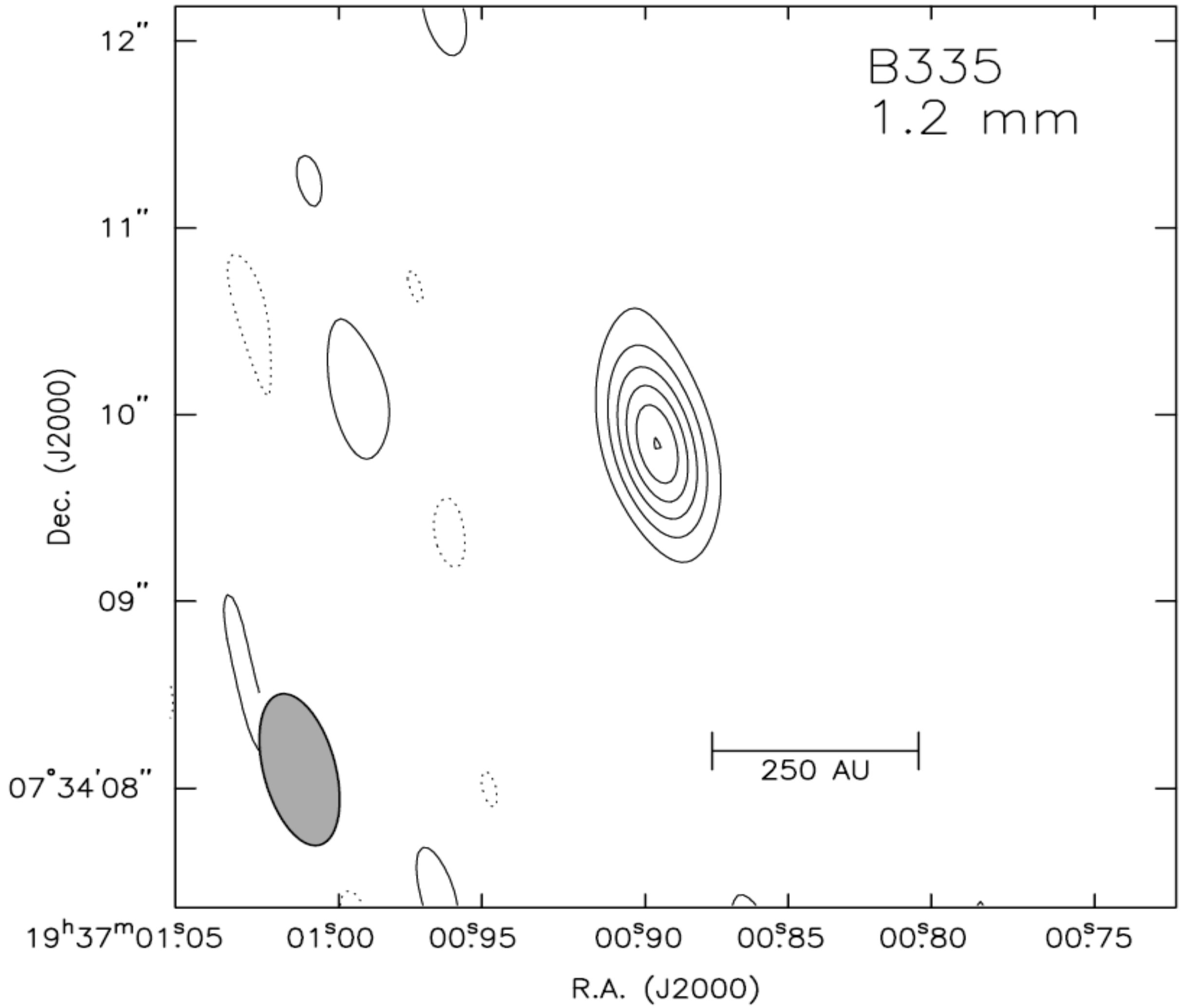


Common view:

Shu "inside out" collapse

Or similarly Larson-Penston type of solution to isothermal sphere gravitational collapse: without any other physical properties.

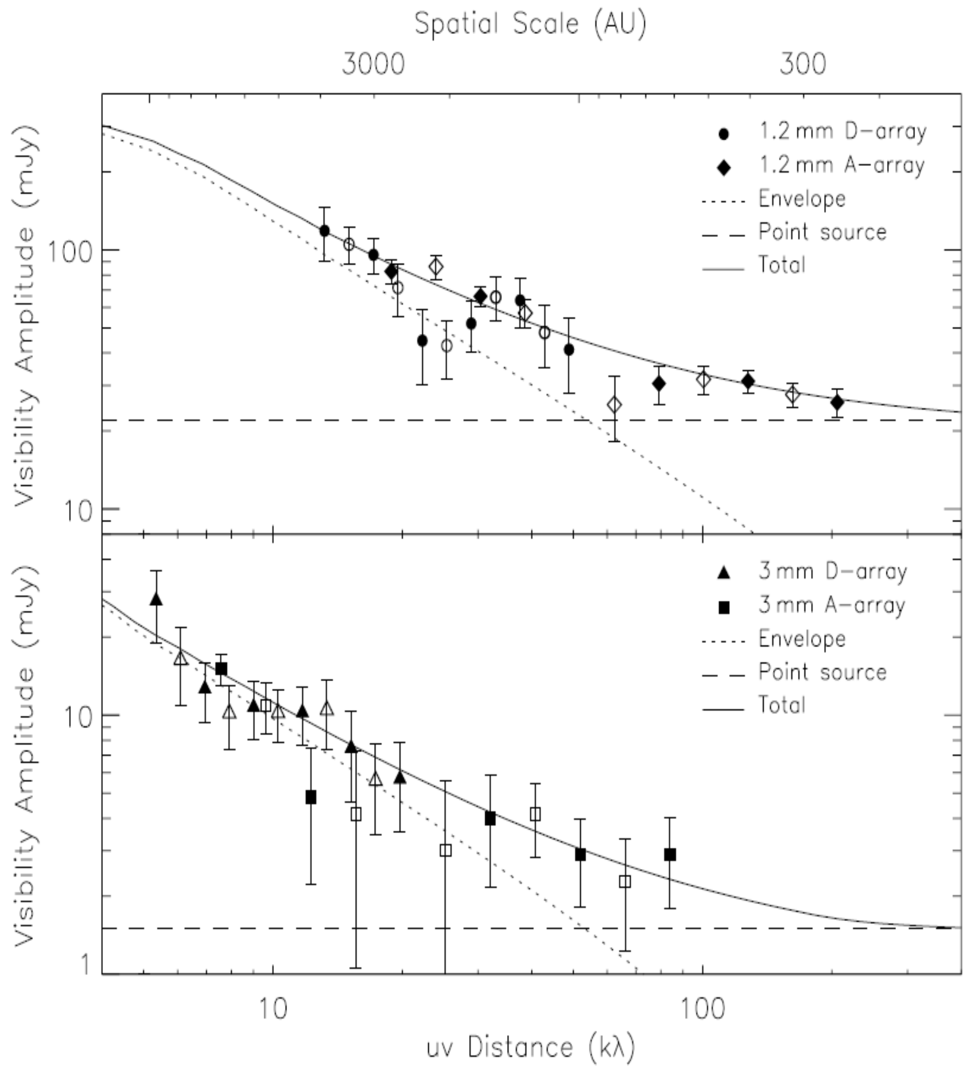
B335



Harvey et al. (2003)

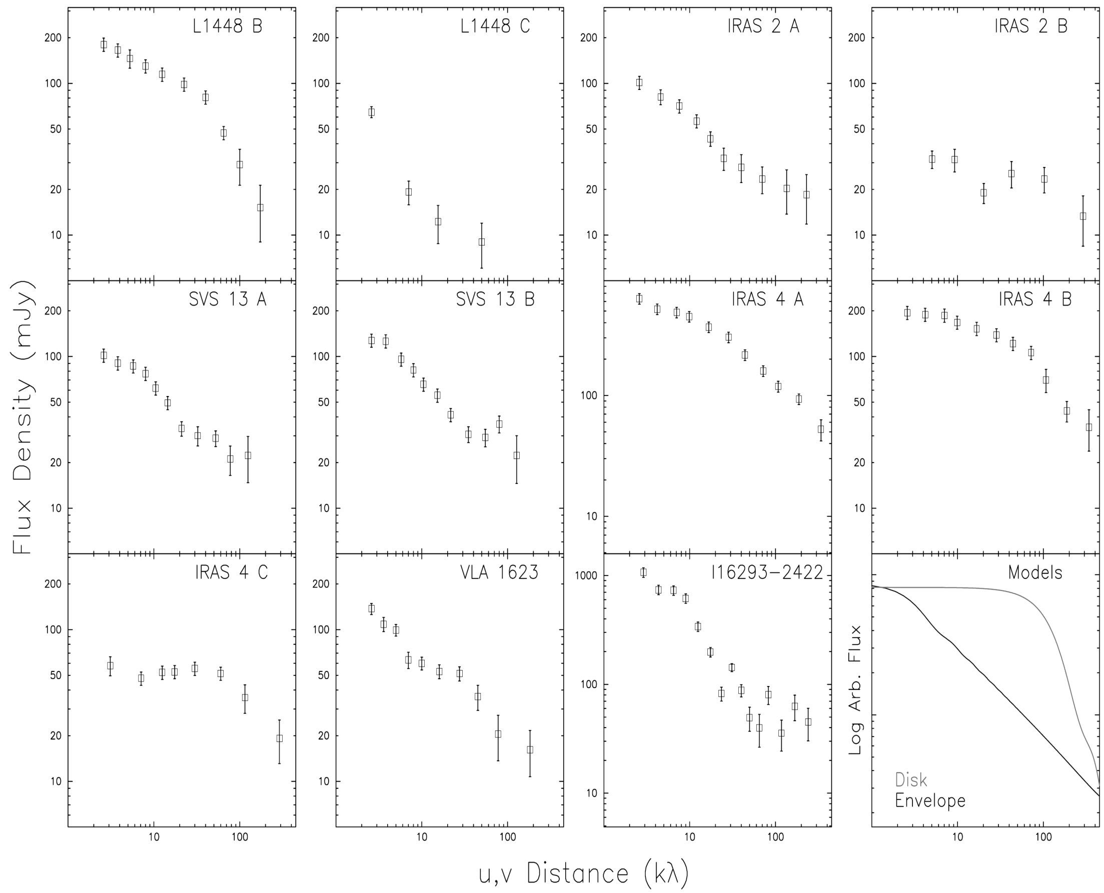
B335

- Used power-law density and power-law temperature model
- Two frequencies
- Constrained the power law to $r^{-1.5}$
- Argued for a compact, disk component of 0.004 $M_{\odot}$



Harvey et al. (2003)

Sampling Disks

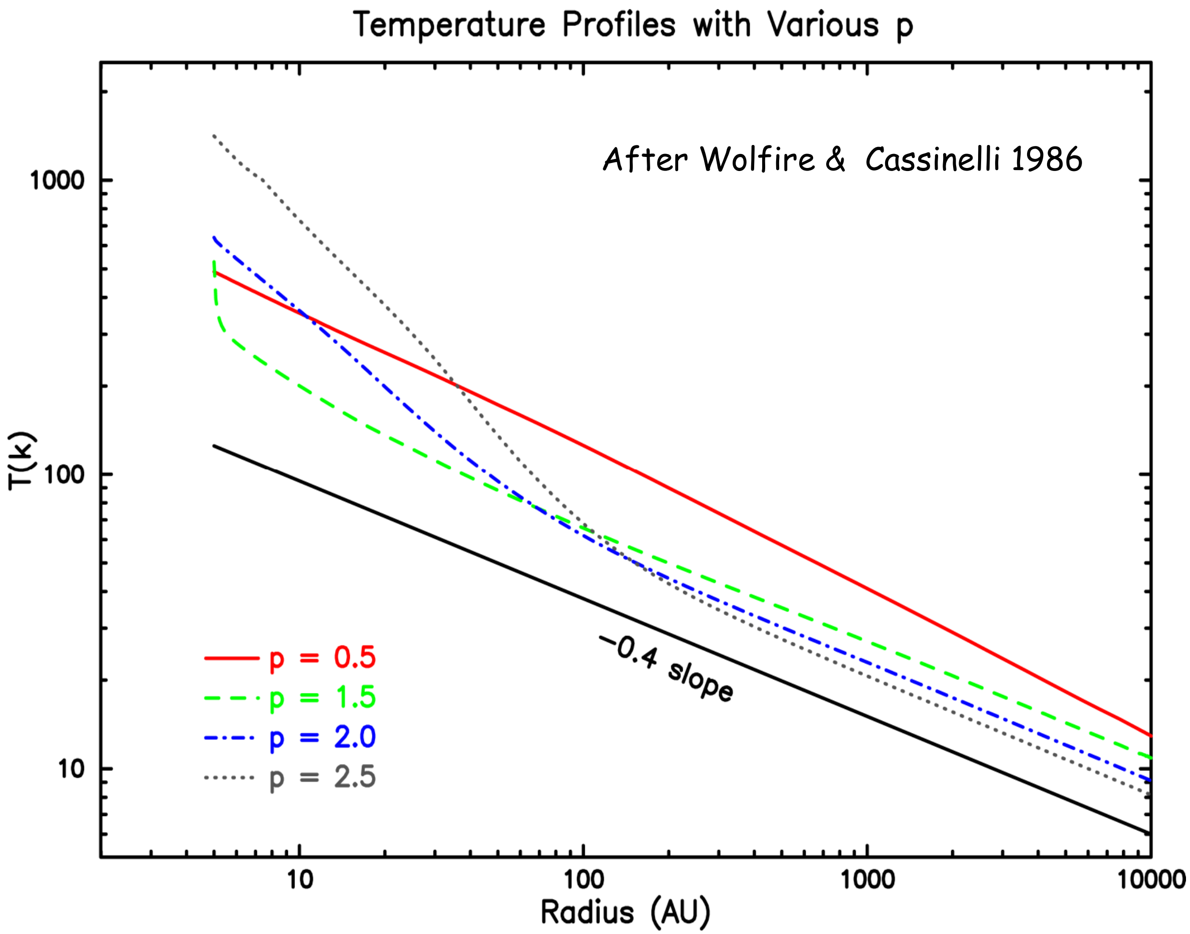


Looney et al. (2003)

Sampling Disks

Argued that the temperature profile can play an important role in models

Used power-law density and self-consistent temperature profiles



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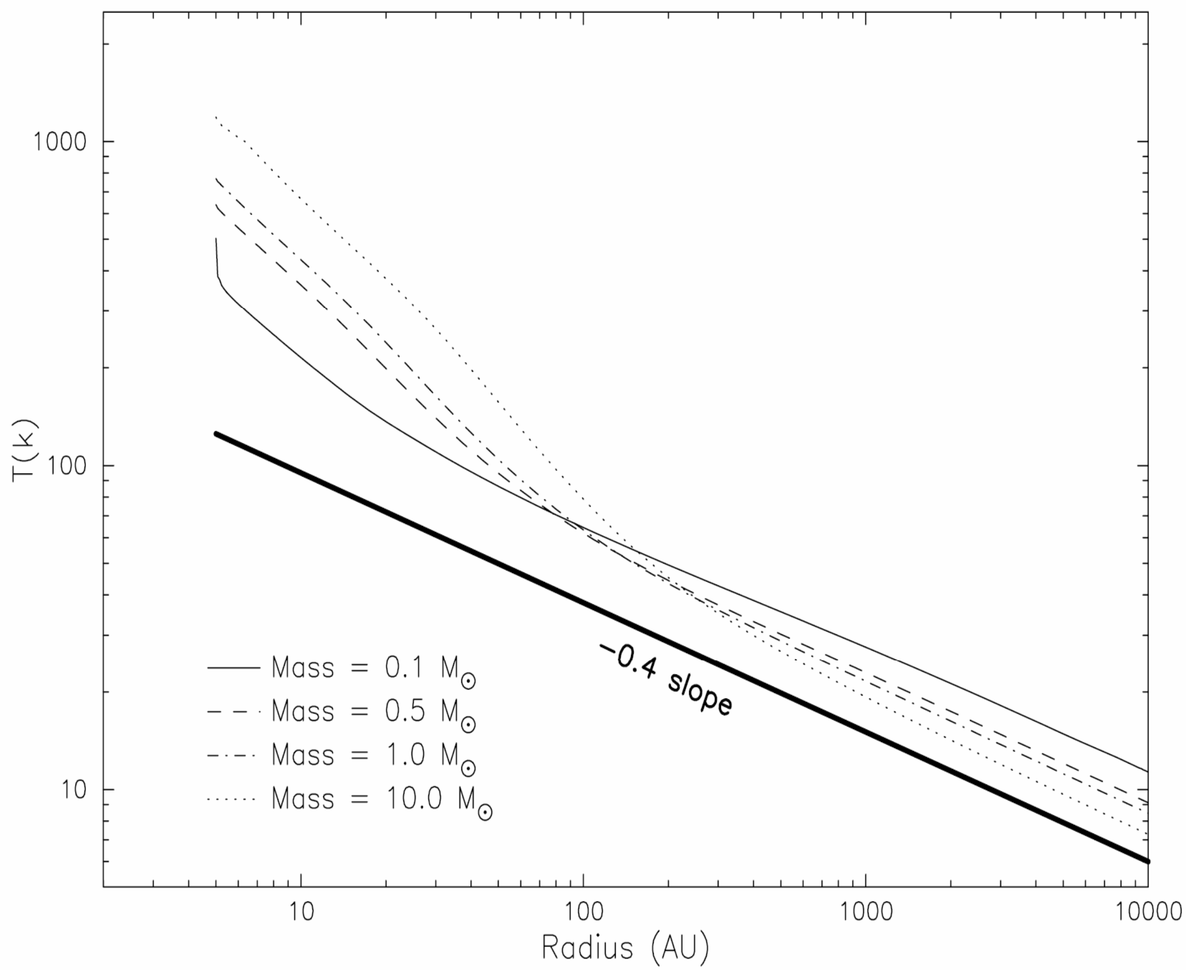
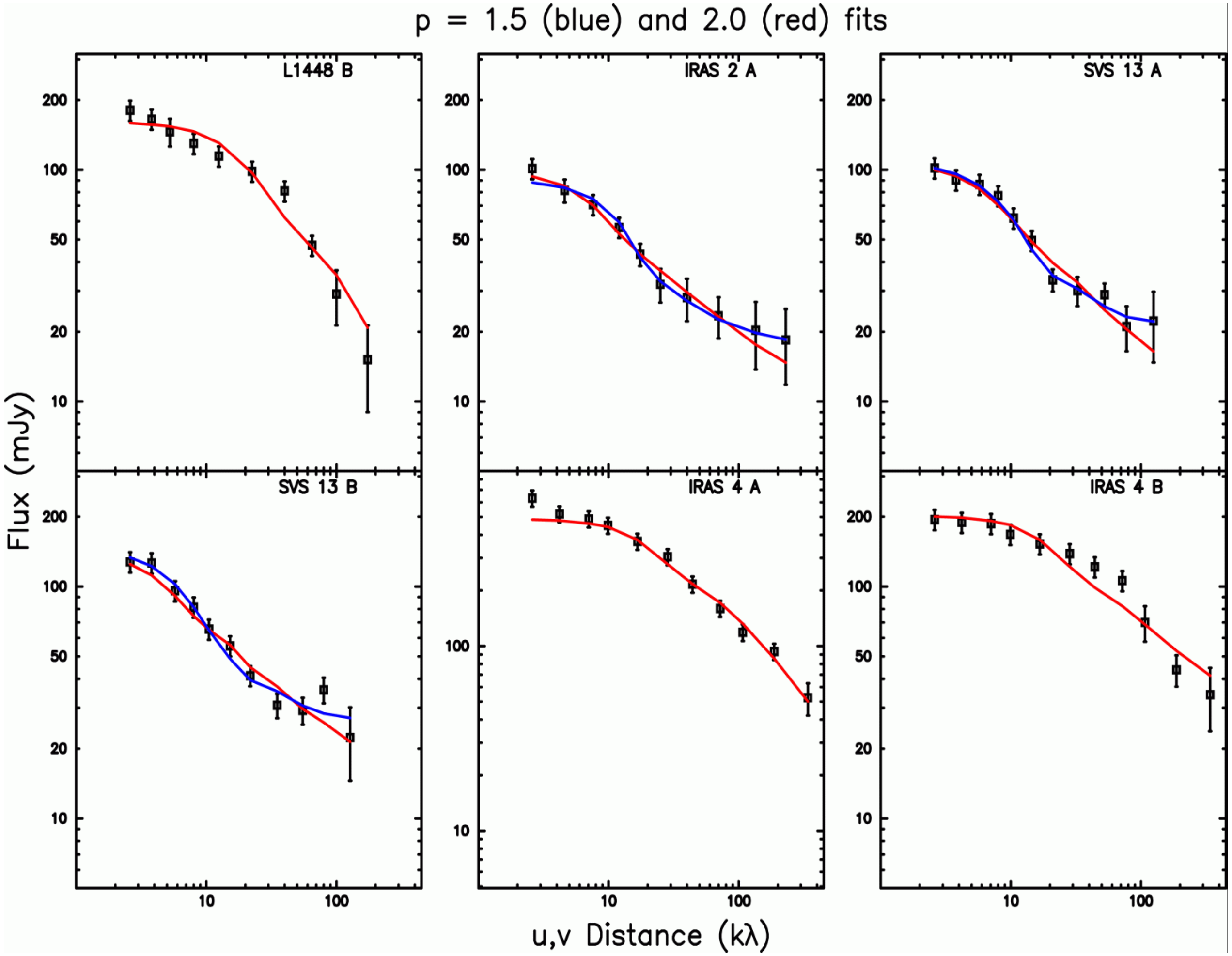


Looney et al. (2003)

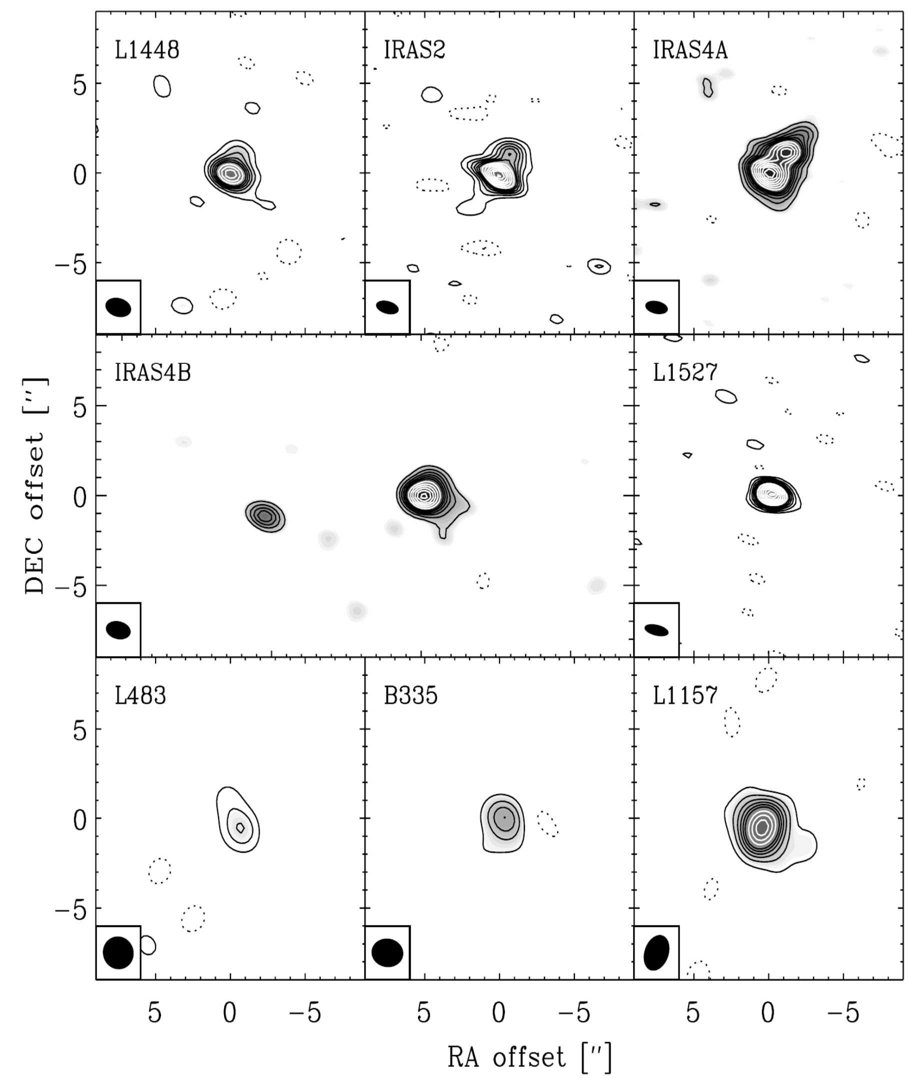
Density Profiles in Protostars

- The highest SNR sources can not be fit with $\rho \sim r^{-1.5}$
- Even with numerical LP or Shu models, the fits are not improved.
- Implied ages are 1000-2000 yrs– not consistent with luminosity or kinematic ages



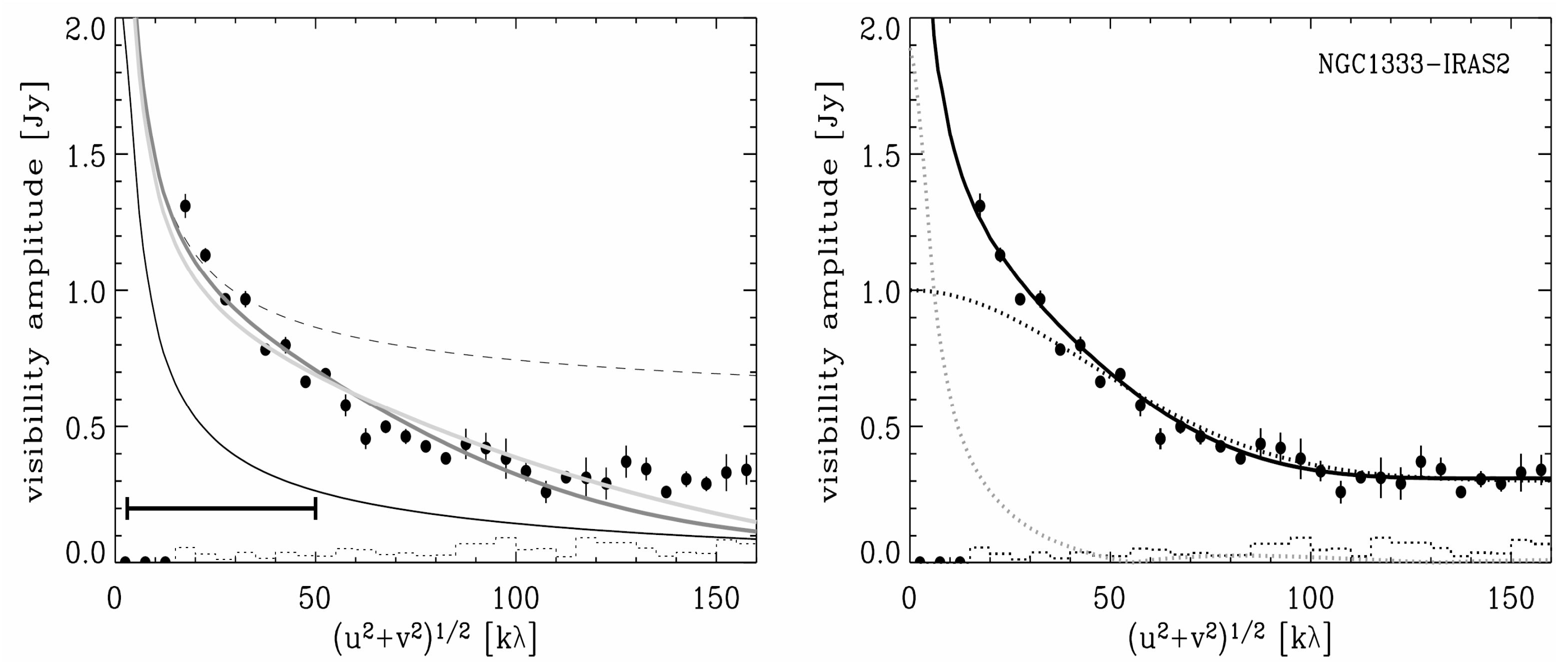
Looney et al. (2003)

Sub-mm High-Resolution



Jorgensen et al. (2007)

Sub-mm High-Resolution



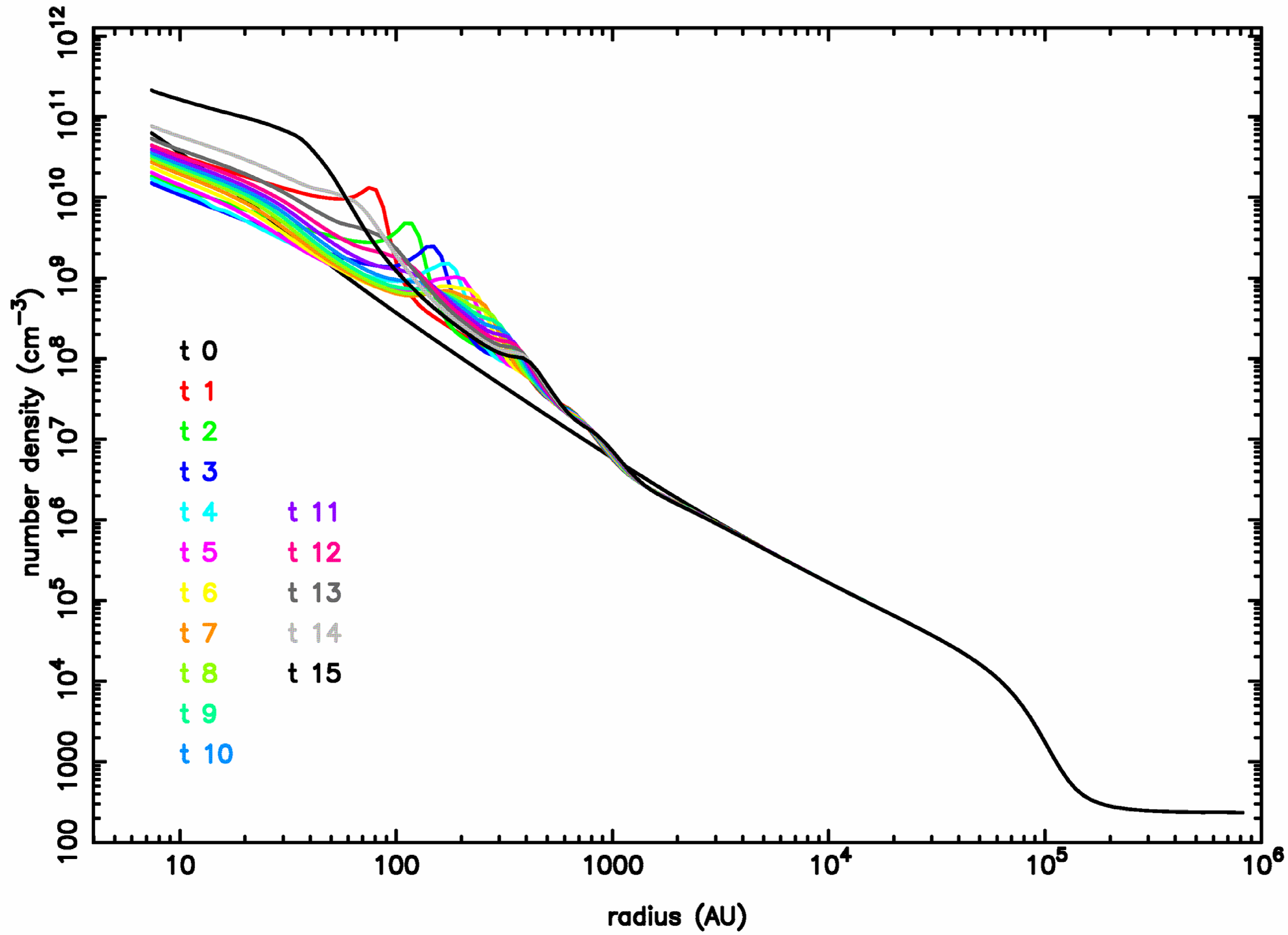
- Used low-resolution data to constrain envelope parameters
  - Line and continuum radiative transfer set p=1.8
- Able to constrain point source fluxes/disk parameters
  - 200-300 AU disk and ~0.01-0.1 $M_{\odot}$

Jorgensen et al. (2007)

Comparison to Millimeter Data

- The Shu model of collapse has many useful features (e.g. constant mass infall rate), but is pnot correct in Class 0 sources.
  - Underestimates the age of the systems
- More detailed models are necessary to model the early envelope and disk emission
  - Dynamic, turbulent picture does not yet provide models with the necessary density (e.g. Ballesteros-Paredes et al. 2003)
  - The slower quasi-static magnetically dominated core evolution picture does have models with appropriate density (e.g. Tassis & Mouschovias 2005)

Magnetically Driven Shocks



Shock propagates outward

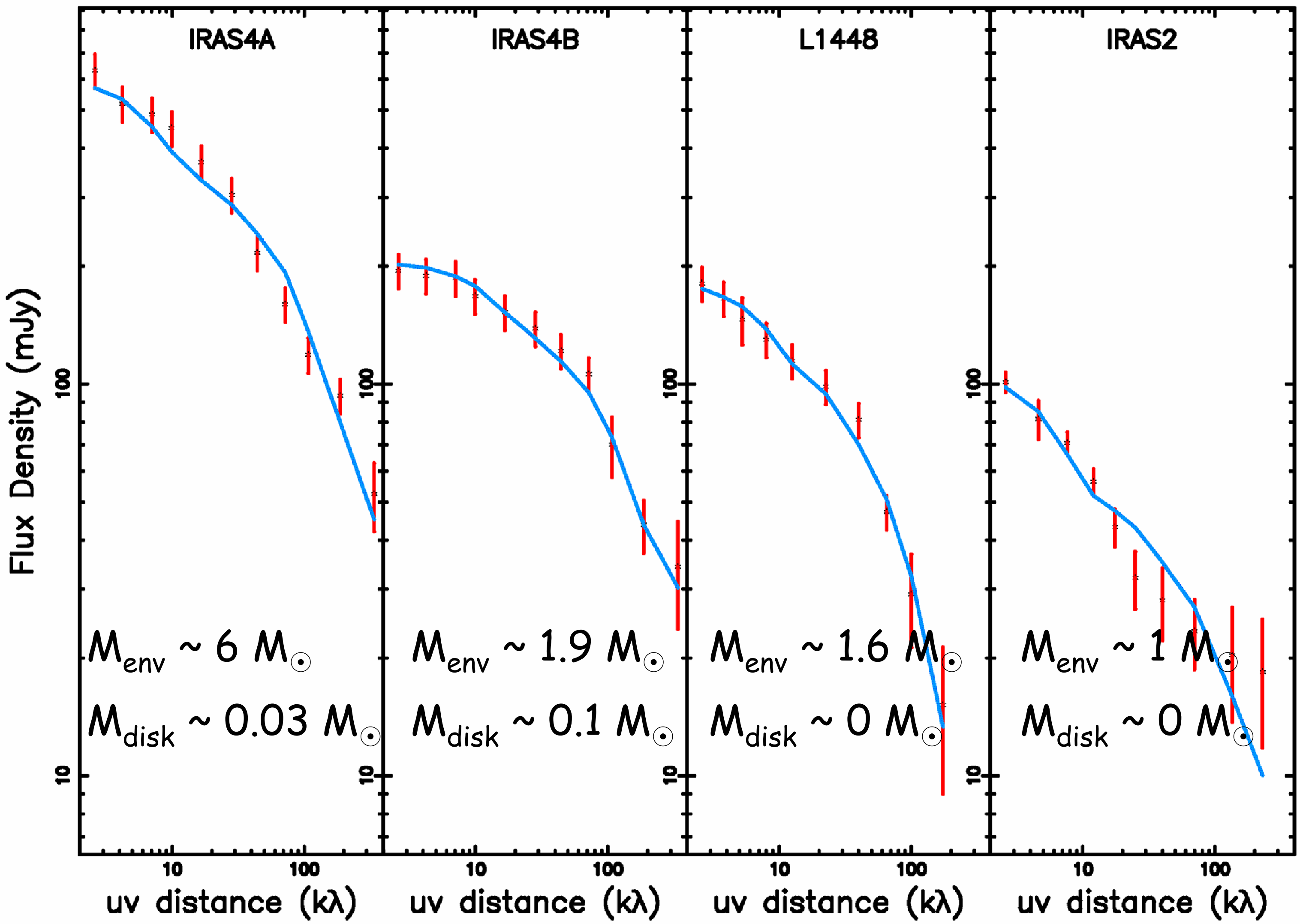
Matter accretes inward

Periodic cycle ~ 3000 yr

(Tassis & Mouschovias 2005)

Ambipolar diffusion simulation at the center of protostellar cores

New Fitting Results

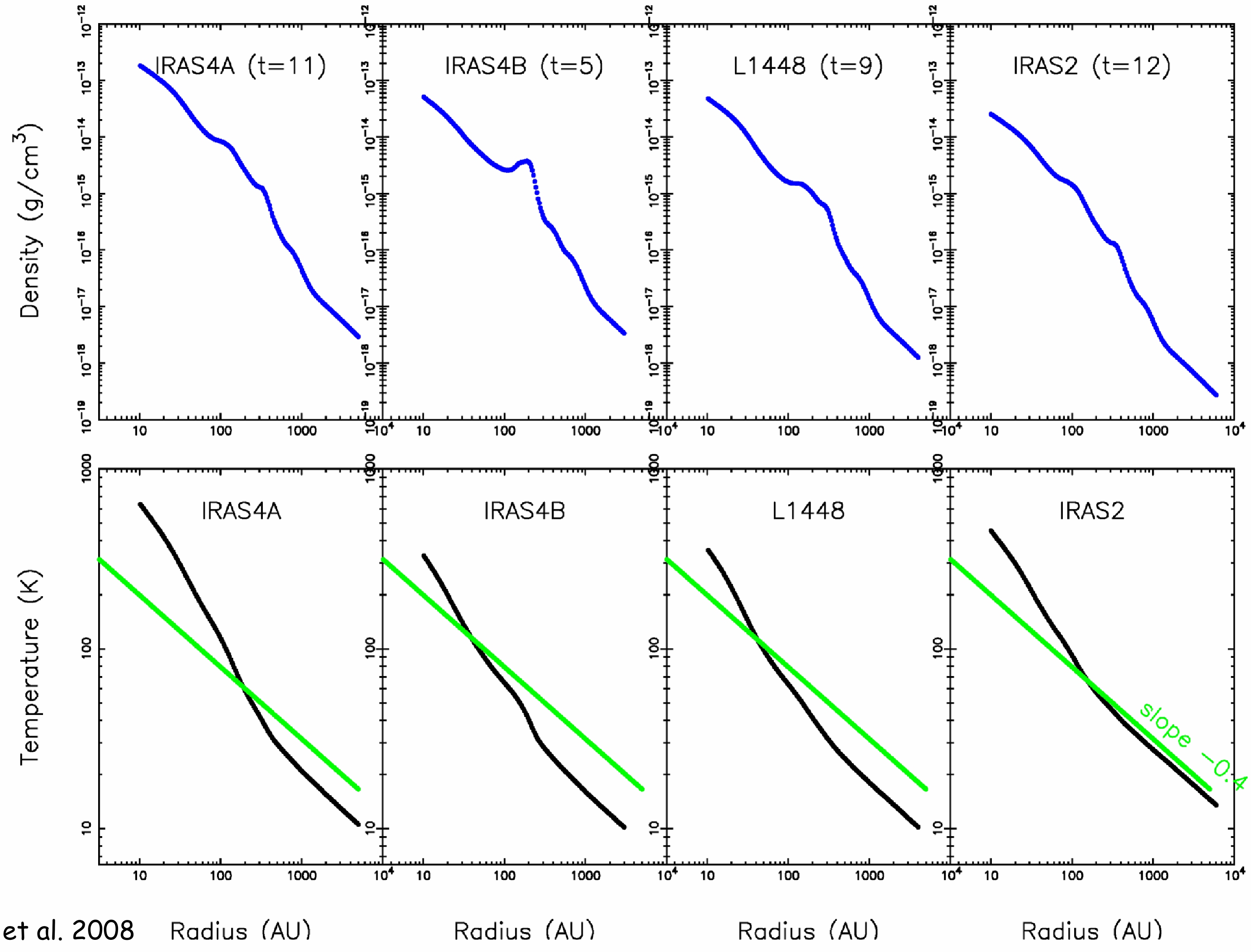


Chiang et al. 2008

Fits are still not unique.

Scatter of envelope radius, envelope mass, and disk

Density and Temperature



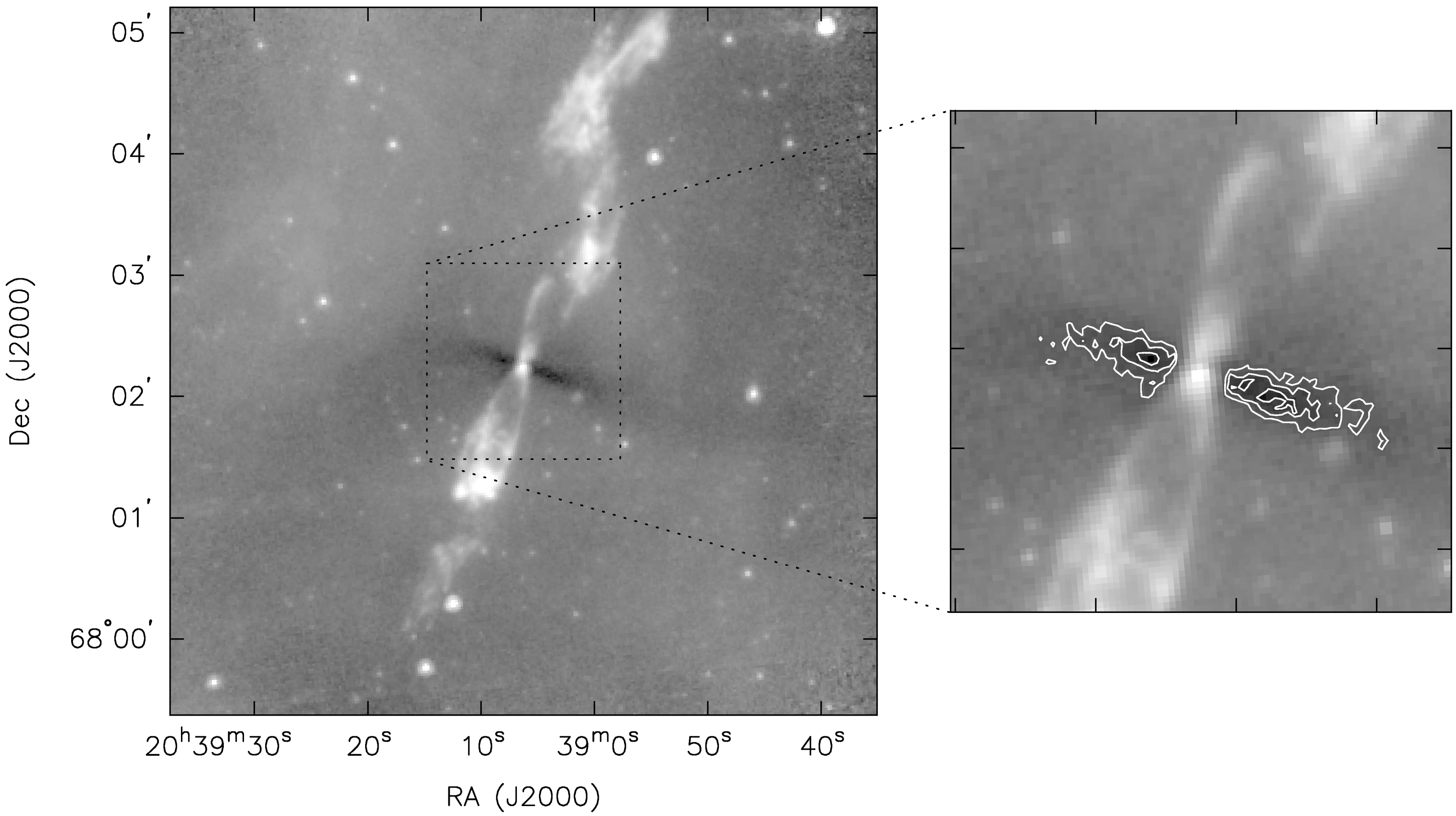
Chiang et al. 2008

CARMA Contribution

- CARMA will increase sample of sources with sufficient S/N in both compact and extended configurations
- Provide a better testbed for envelope models, which are the real key to solving this problem
- Inclusion of more wavelengths will increase likelihood of separation of model parameters

Other Issues

Non-symmetric density profiles are expected: e.g., L1157



Looney et al. 2008; Gueth et al. 2003

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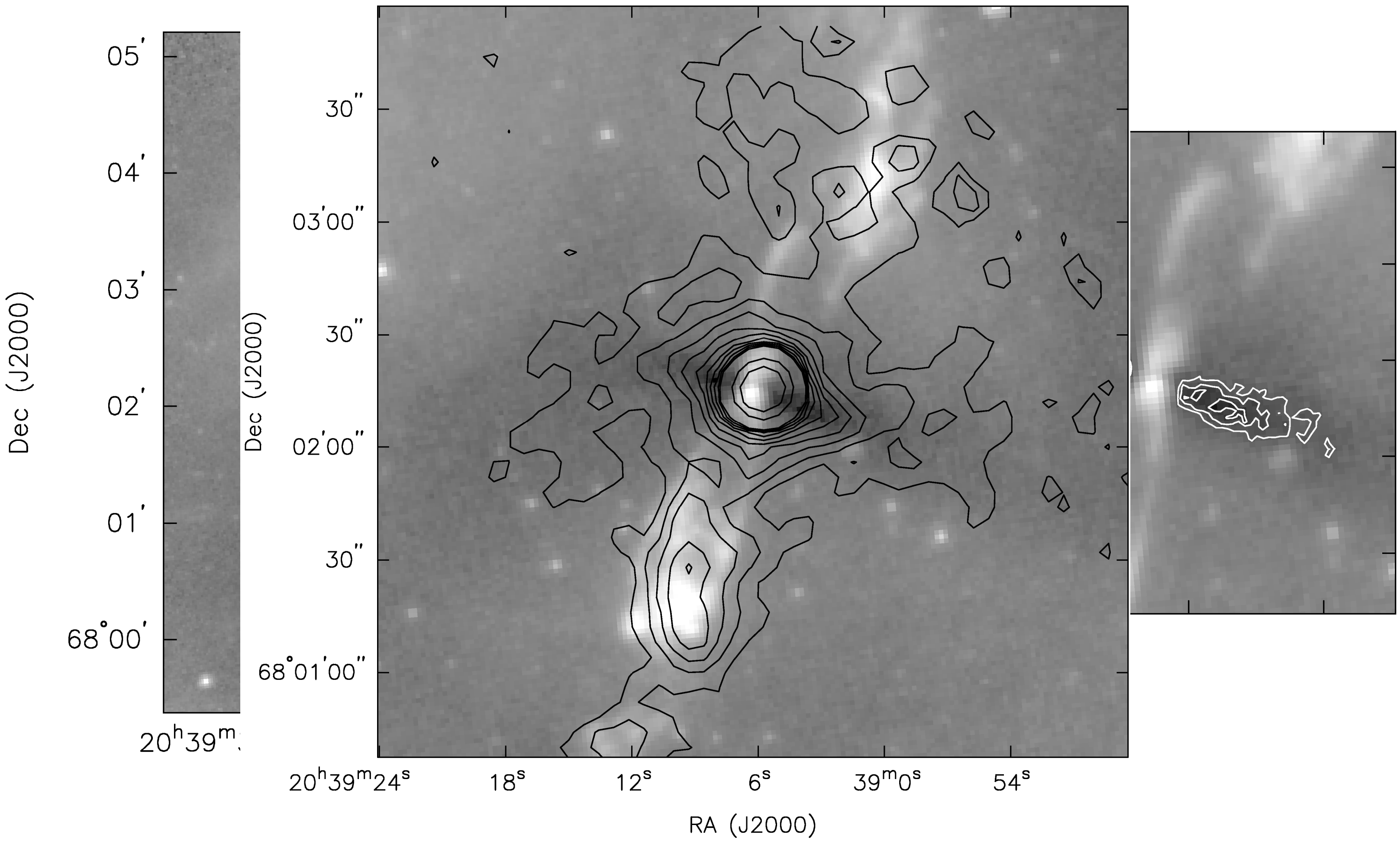


Looney et al. 2008; Gueth et al. 2003

ALMA Simulations: Model

- Tassis & Mouschovias (2005) models for envelope density
  - Truncated at outer radii
  - Scaled to envelope mass
- Point source to represent the disk, and simple disk model too
- Wolfire & Casenilli (1995), self-consistent temperature model
- Artificial inner hole of the envelope
  - Not realistic, causes problems in *u*,*v* space

ALMA Simulations: Array

- Used the 50 antenna Conway configurations
- 2 compact, 1 intermediate, and 2 extended configurations
- 1 hour in each configuration of the 4 configurations (4 hours total)
- Observations at 230 GHz
- Continuum emission only
- Used fine pixel size (0.007" /pixel), but large scale emission (> 10,000 AU)

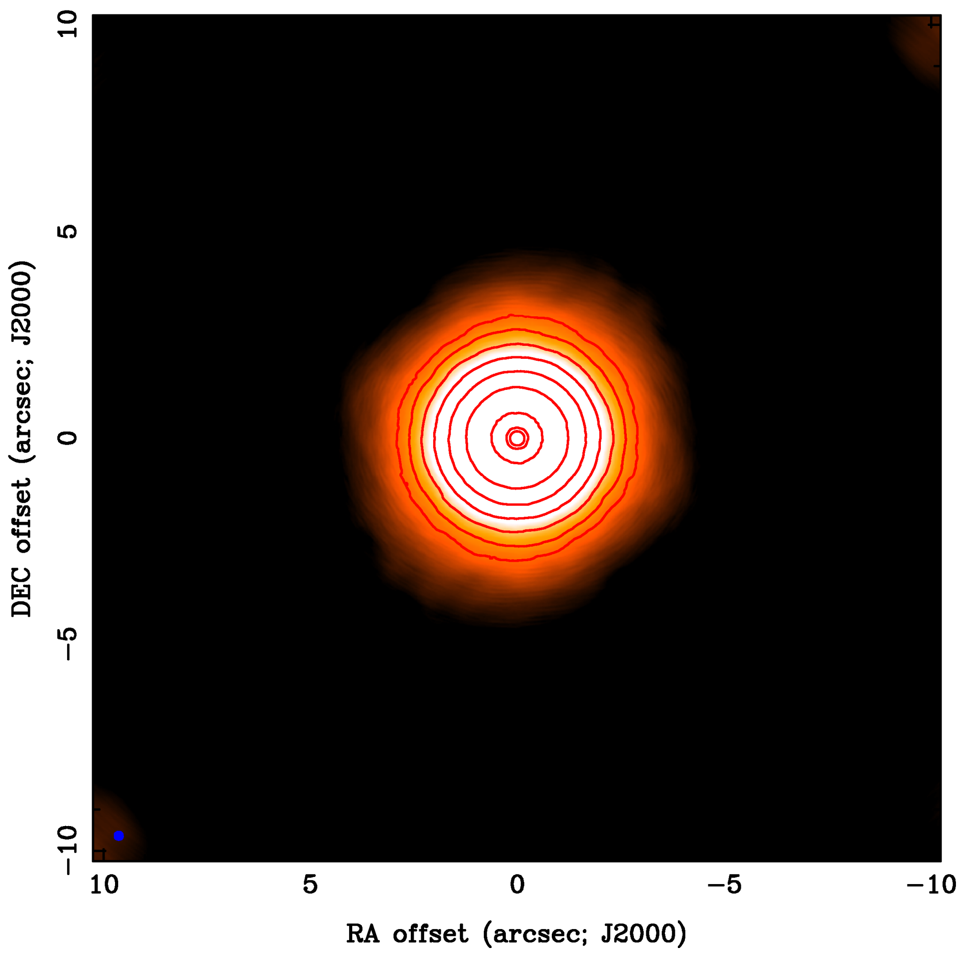
Continuum Simulations

- Dust is still the most likely tracer of material at all size scales
- Molecules are great tracers, but have to worry about
  - Heating
  - Shocks
  - Outflow versus infall
  - Abundances varying from 1 to many orders of magnitude
  - Chemistry

Simulation

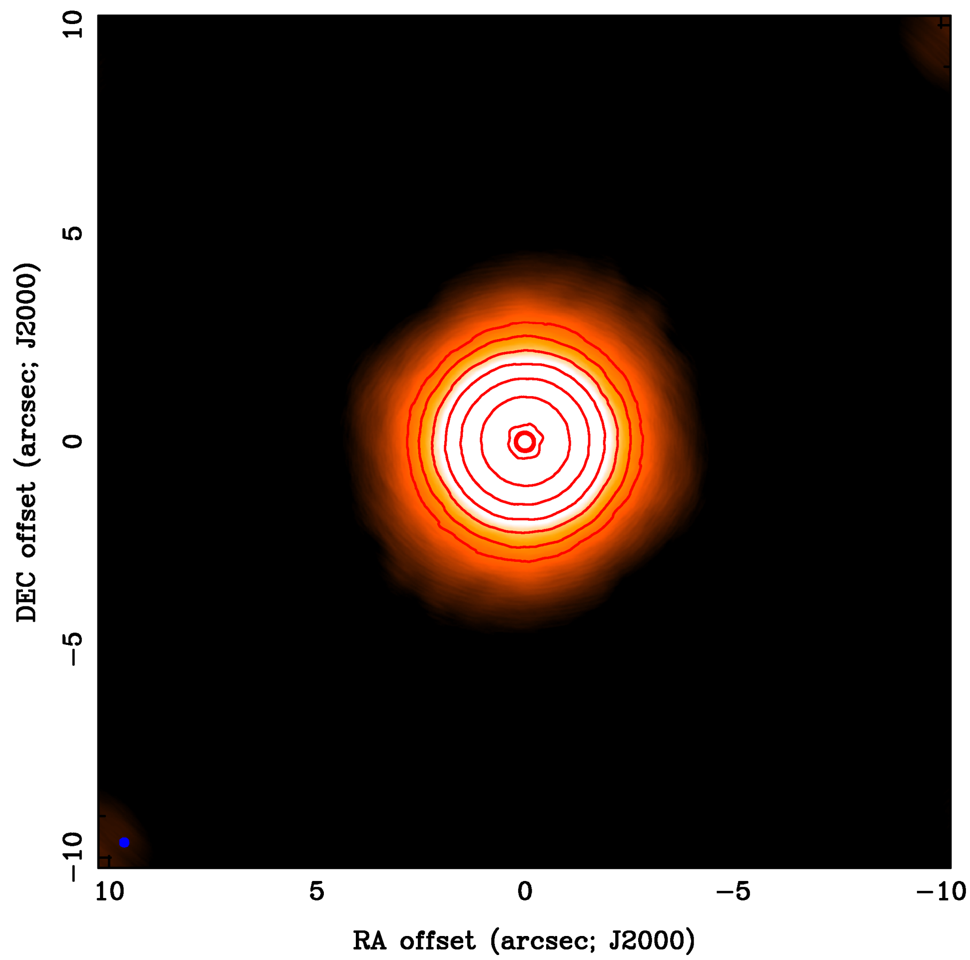
- Envelope only
- 2 $M_\odot$
- R_o = 5000 AU
- R_i = 10 AU
- Lum = 5 $L_\odot$

- Resolution
  ≈ 0.2“ ≈ 70 AU



Simulation

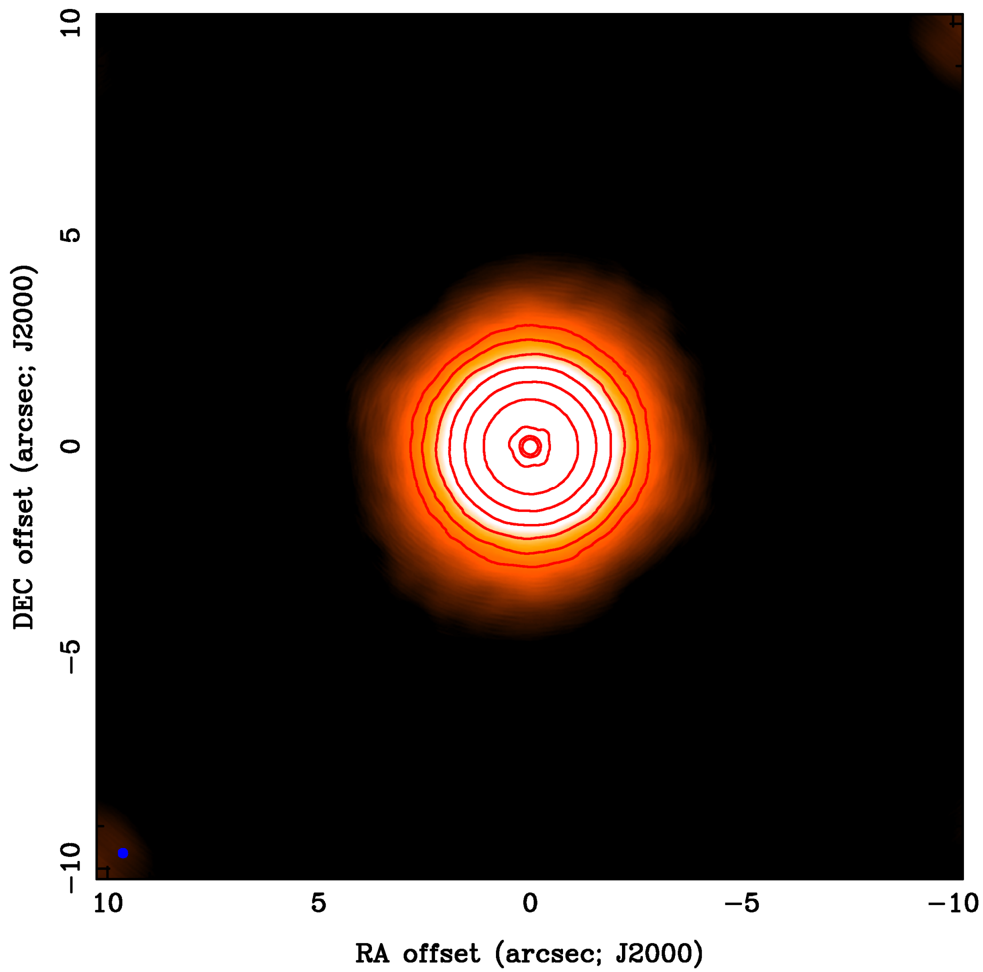
- Envelope & point source
- 1.8 $M_\odot$
- Point flux = 90 mJy
  (25% of flux)
- Ro = 5000 AU
- Ri = 10 AU
- Lum = 5 $L_\odot$



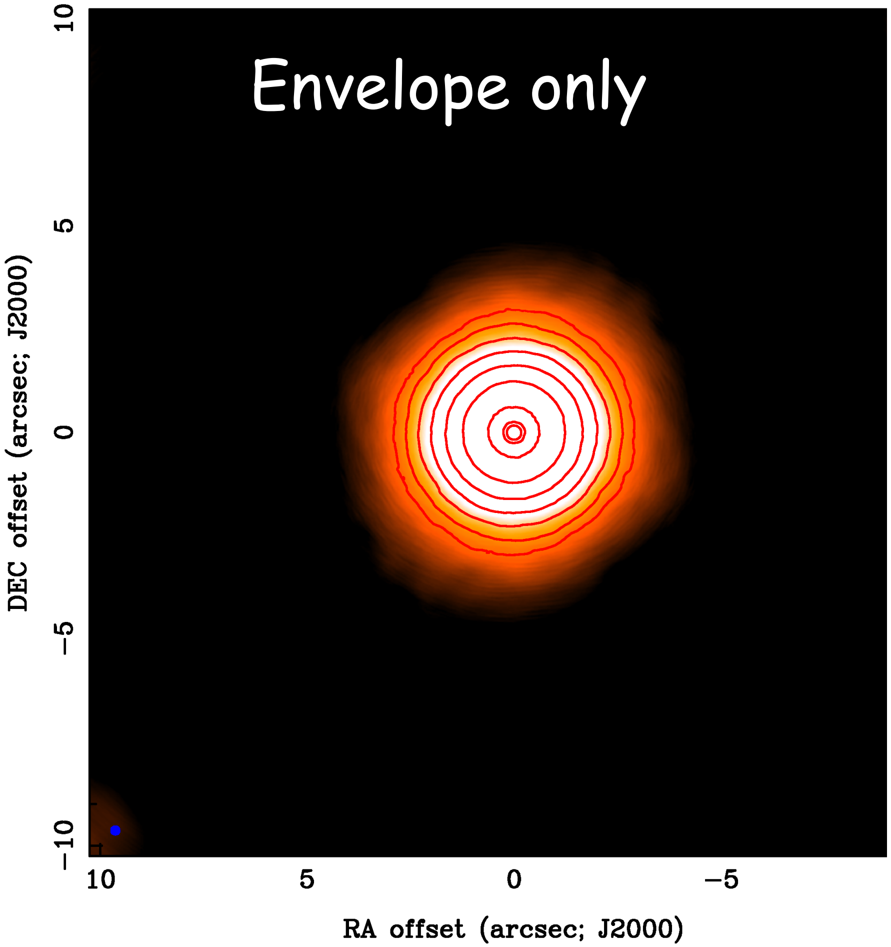
Simulation

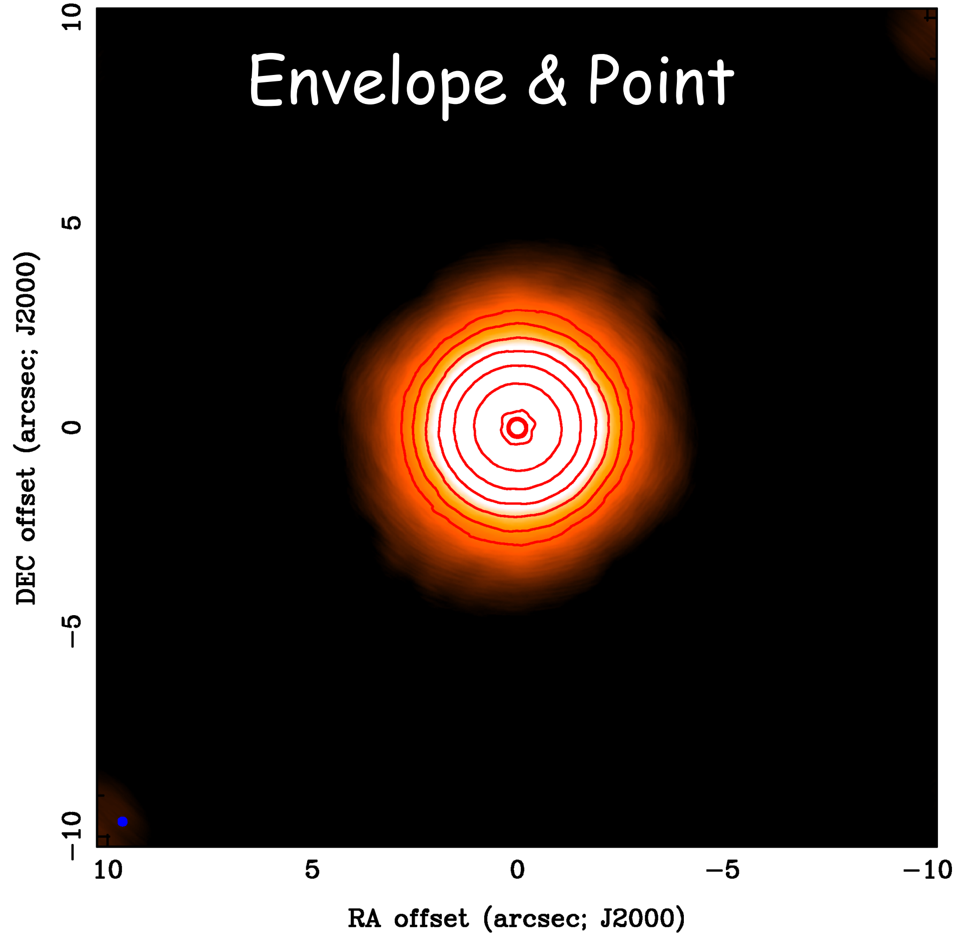
- Envelope & disk
- 1.8 $M_\odot$
- Ro = 5000 AU
- Ri = 10 AU
- Lum = 5 $L_\odot$

- Disk mass = 0.01 $M_\odot$ (10% of the flux)
- Disk Ro = 50 AU
- Face-on



Simulation: All Configs





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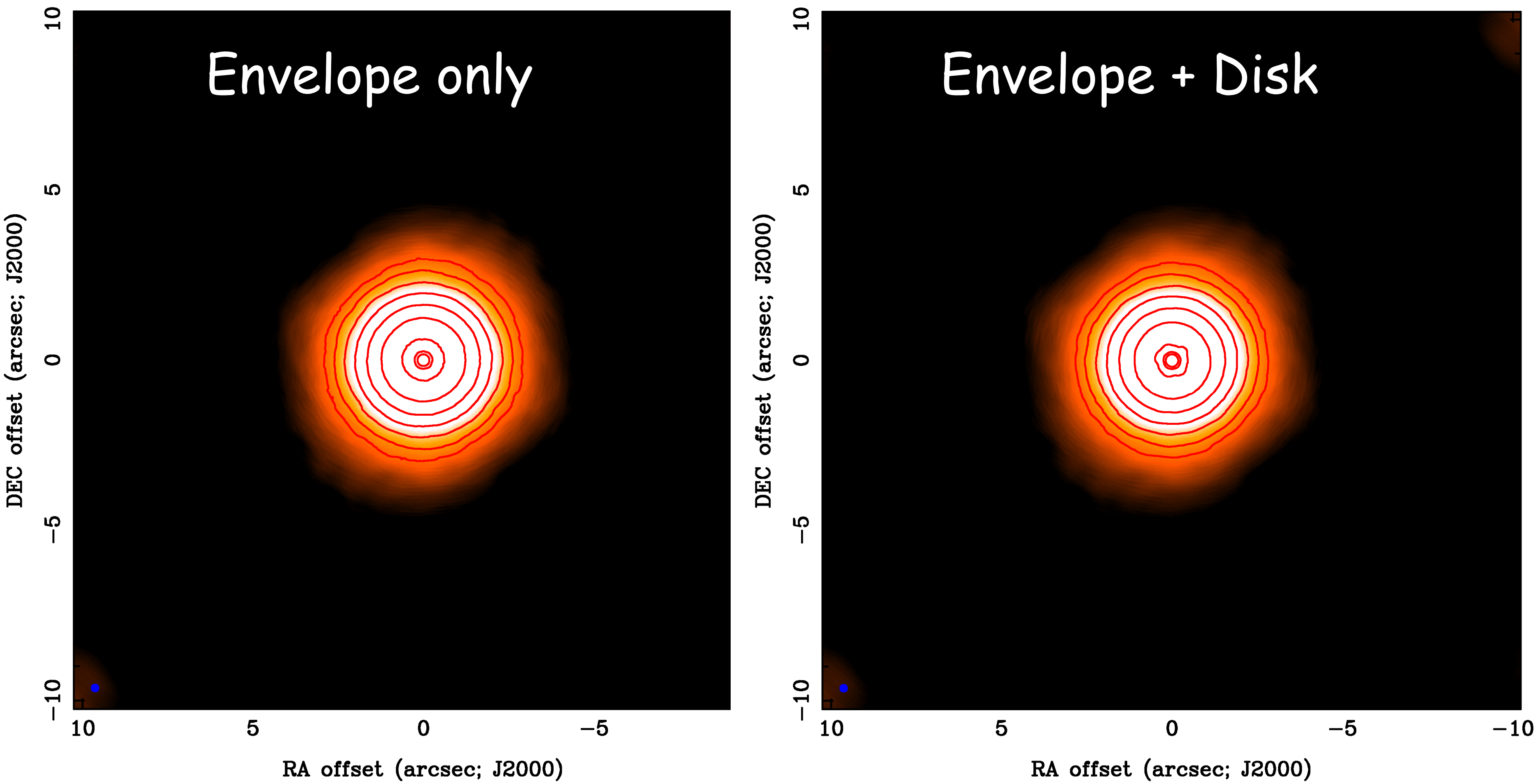
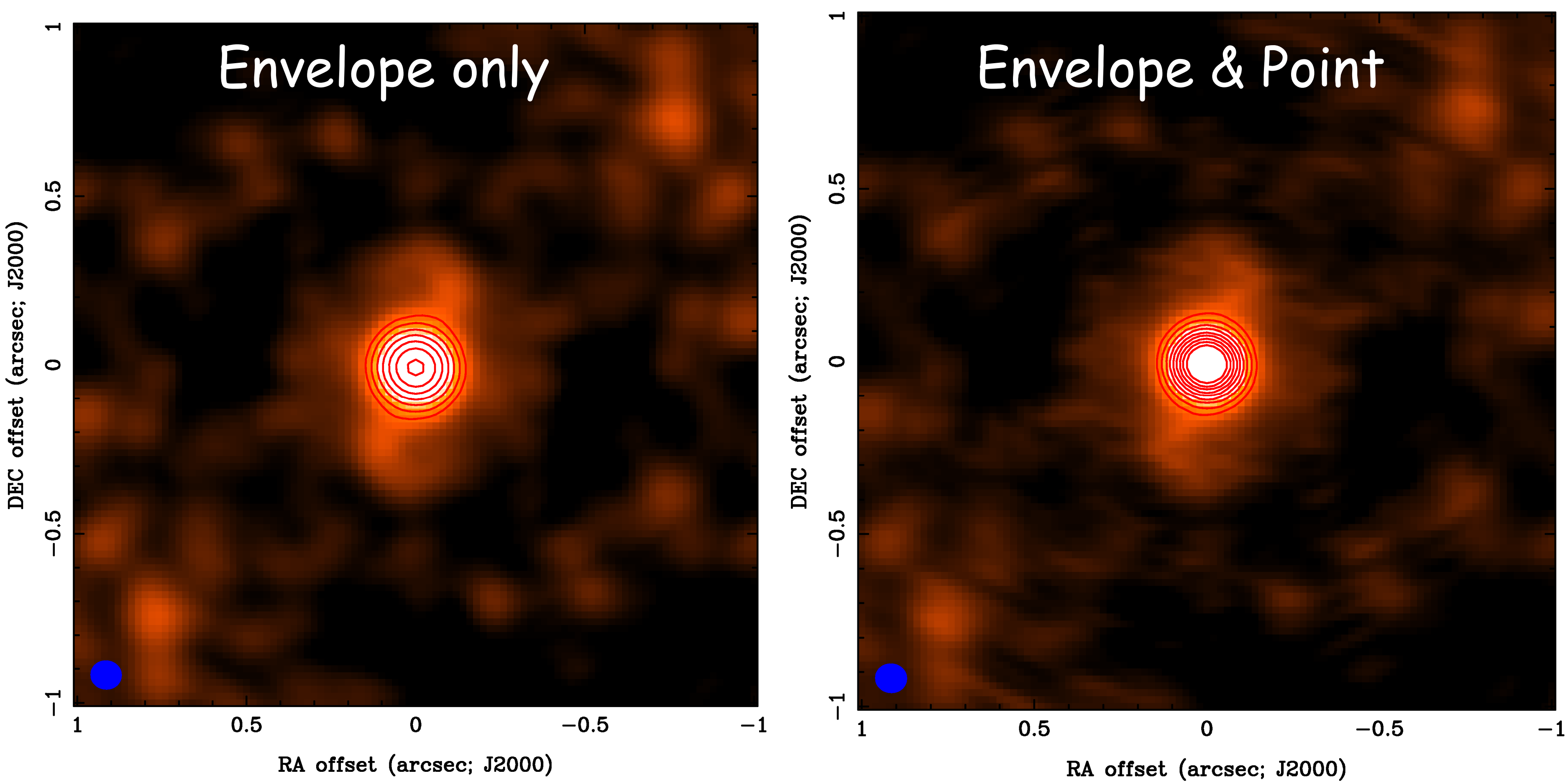
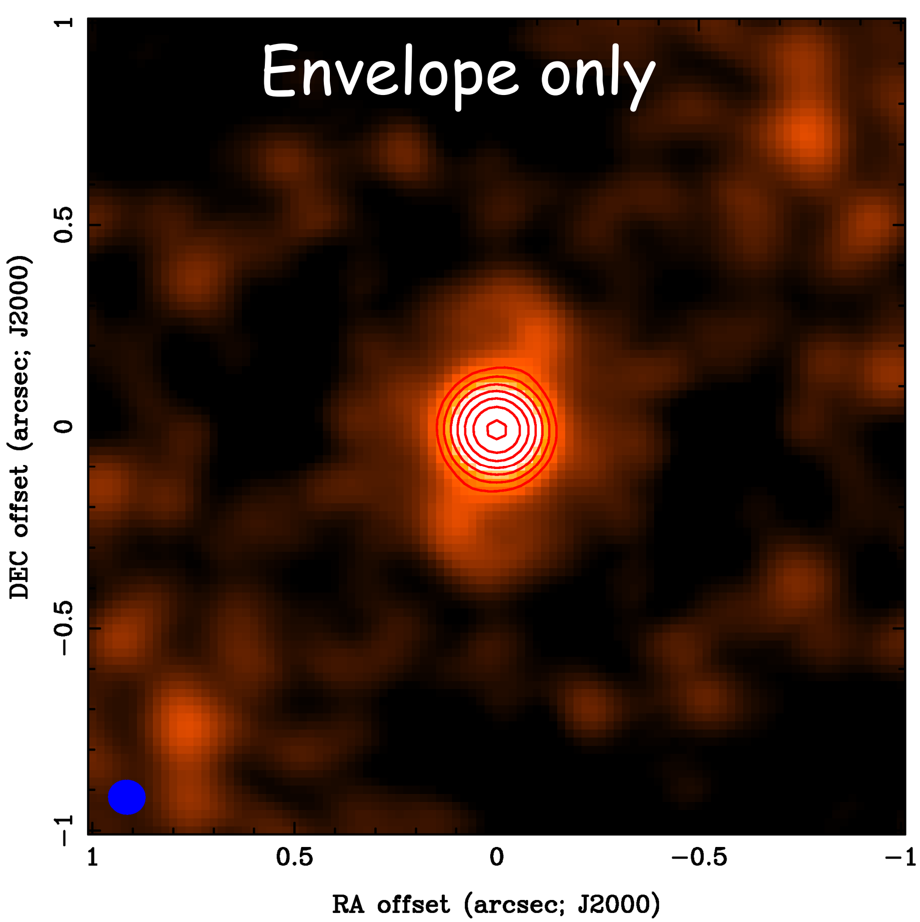


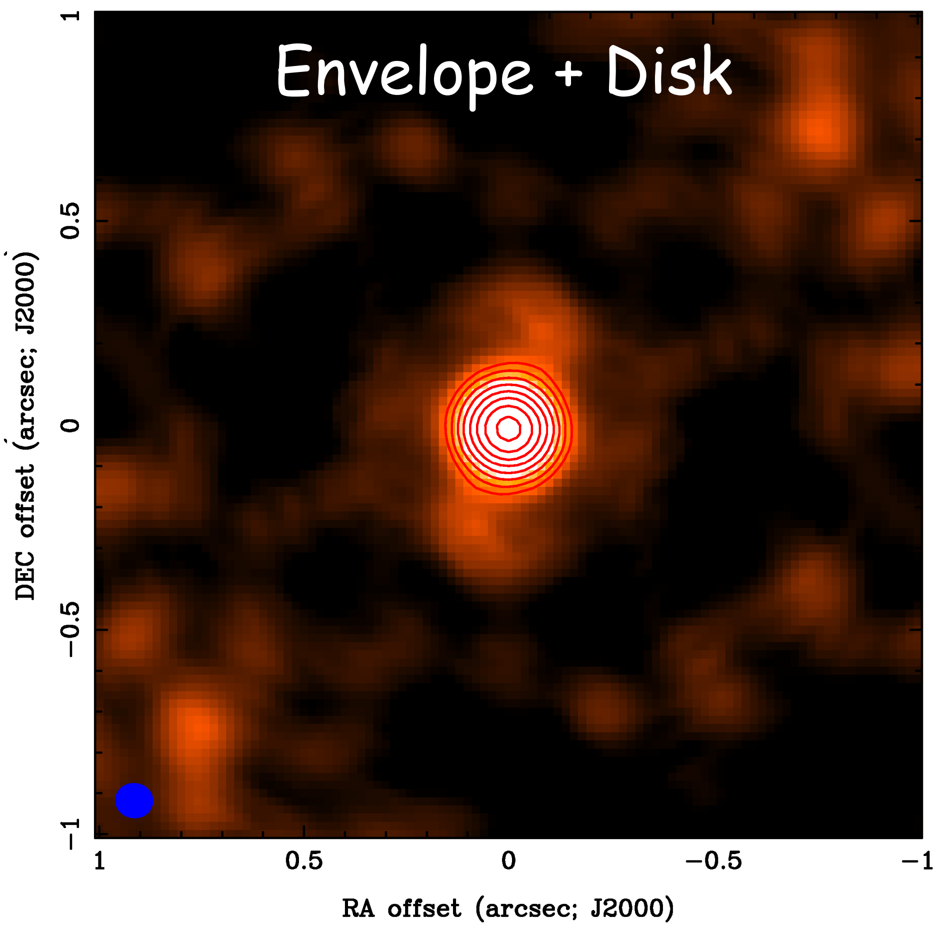
Simulation: Long Baselines Only



Resolution ≈ 0.09" ≈ 30 AU

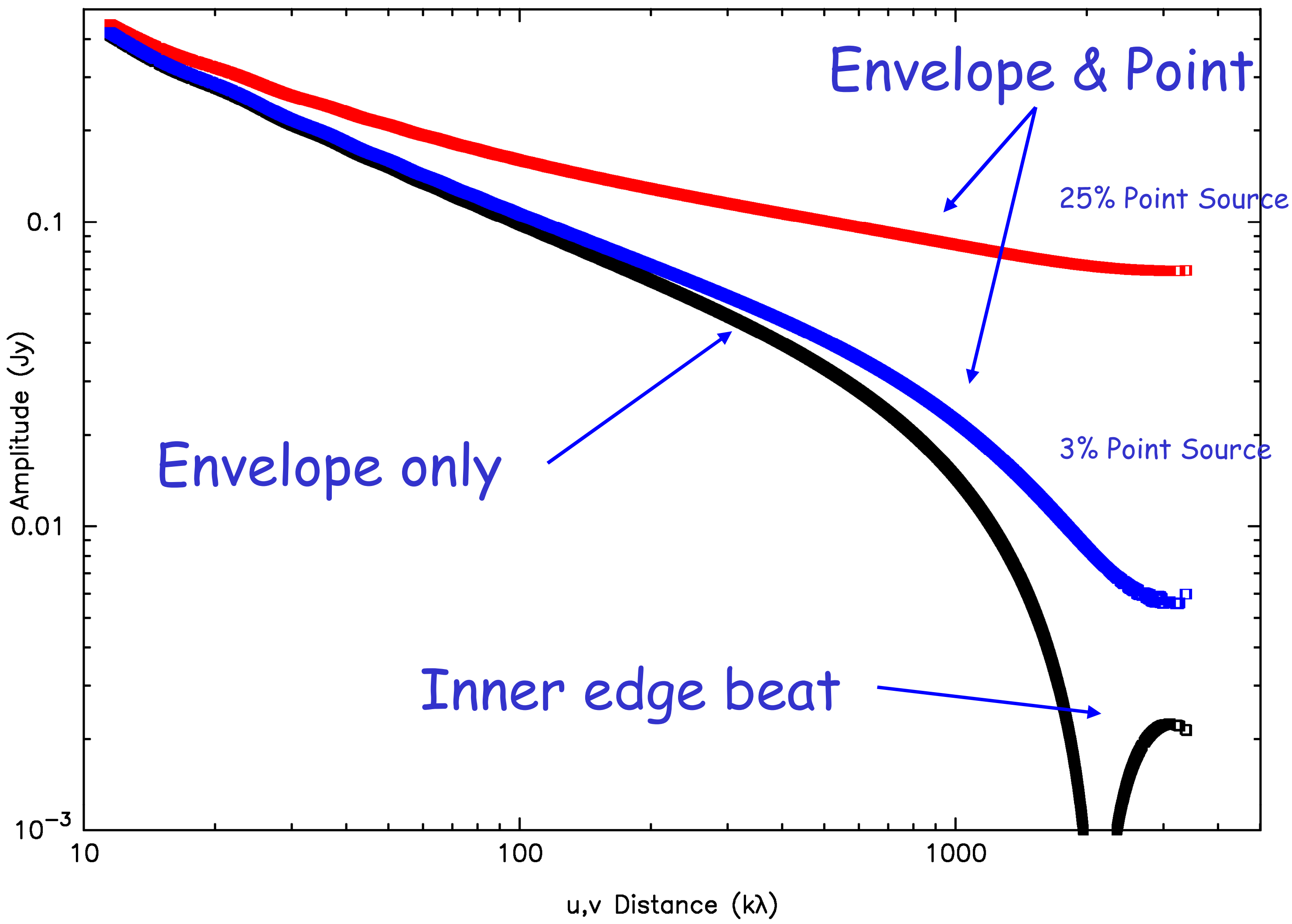
Simulation: Long Baselines Only



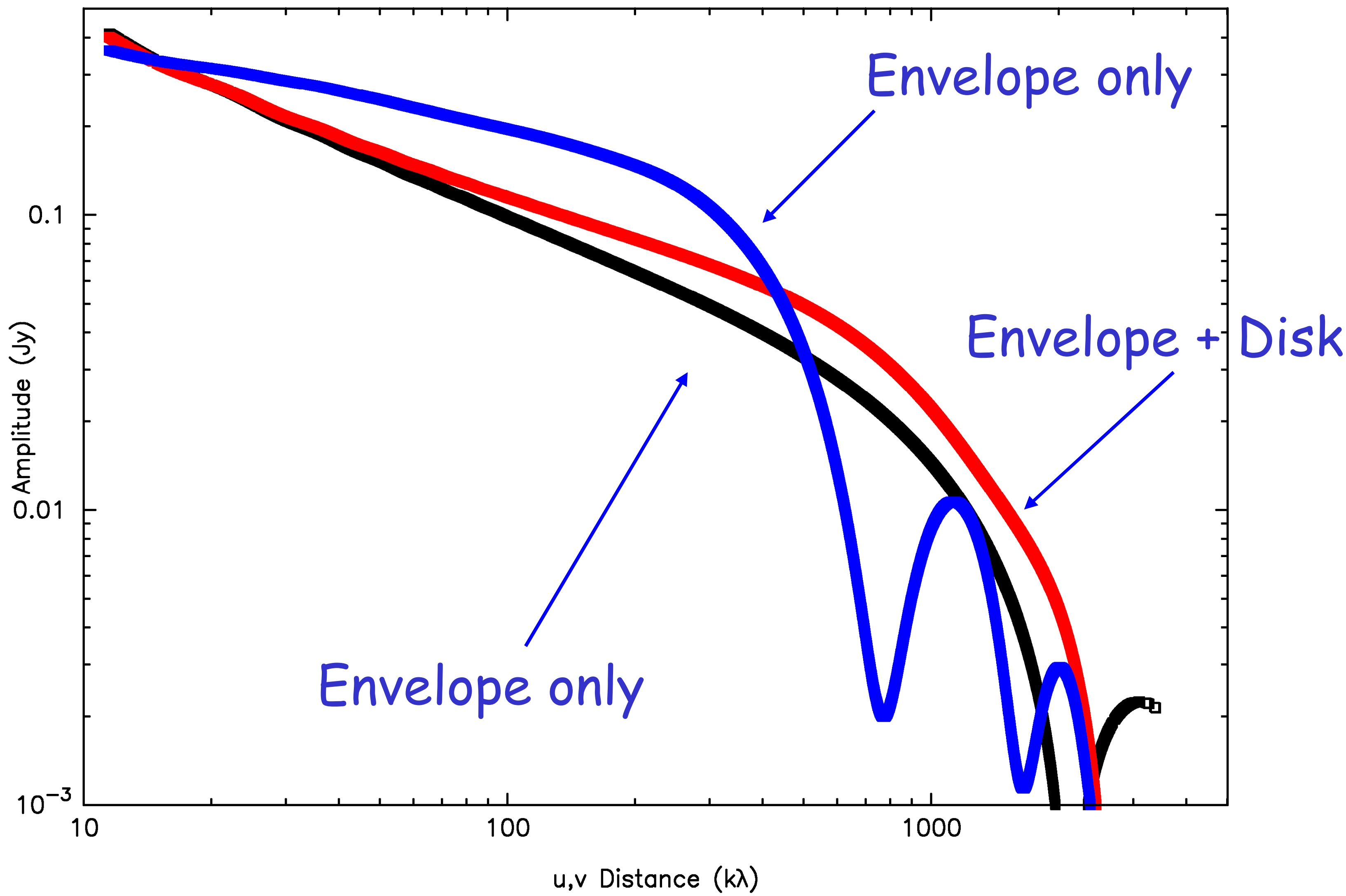


Resolution ≈ 0.09" ≈ 30 AU

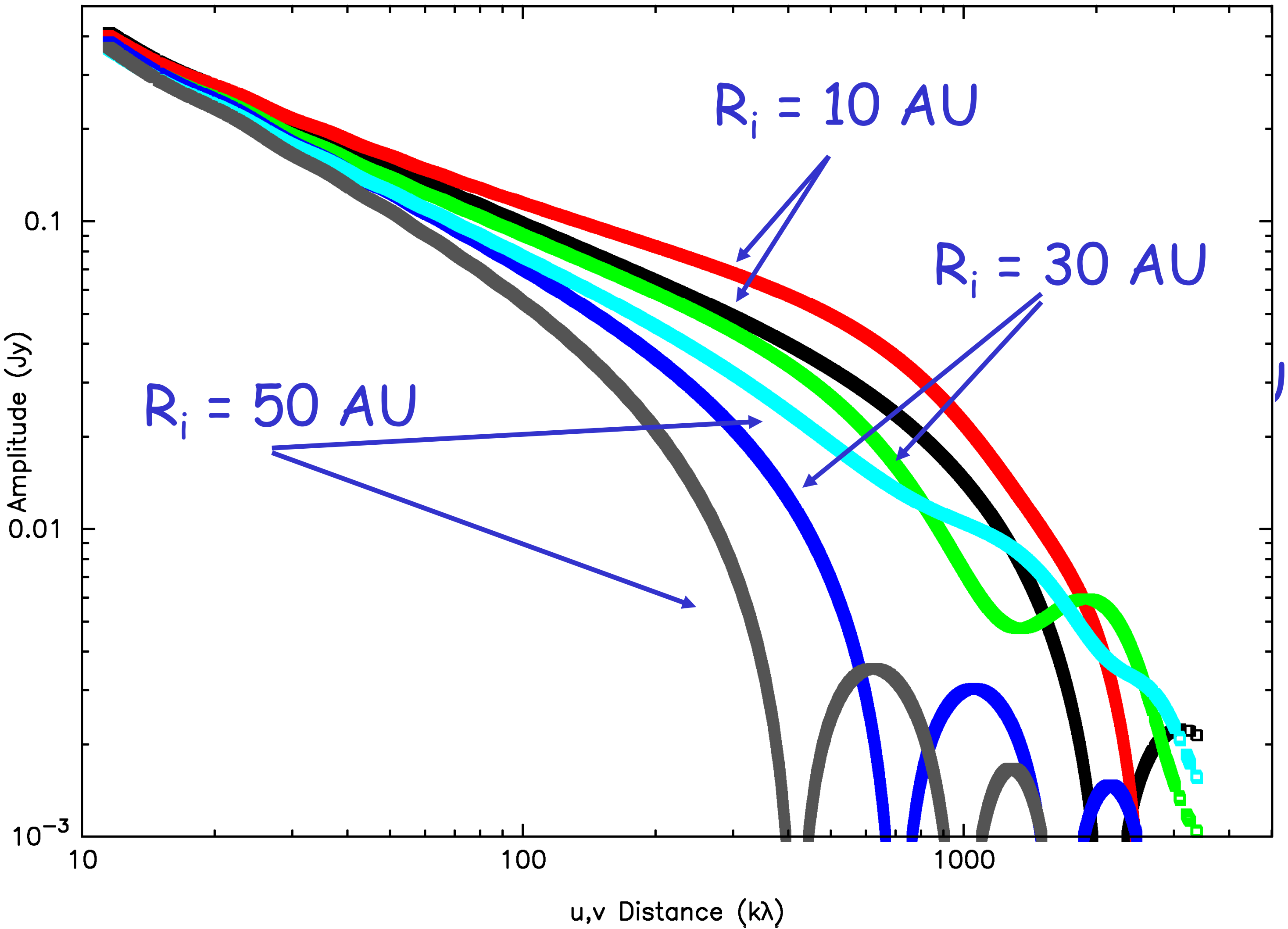
ALMA Simulation: Fourier Space



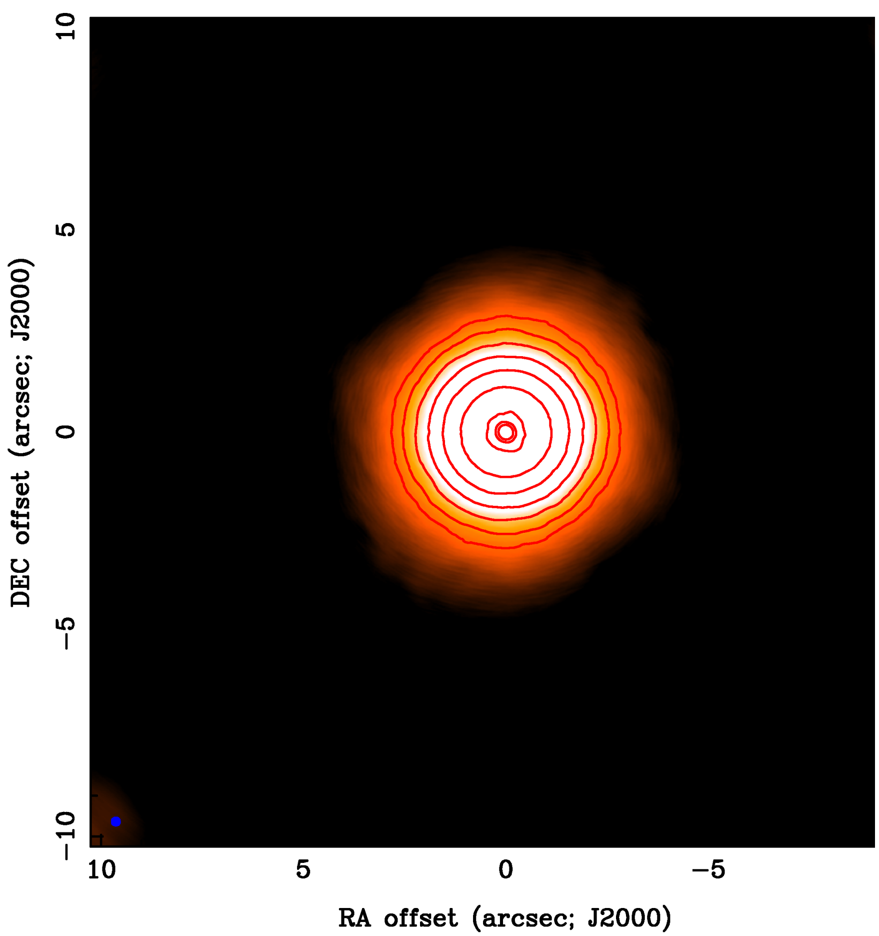
Where is the Disk?

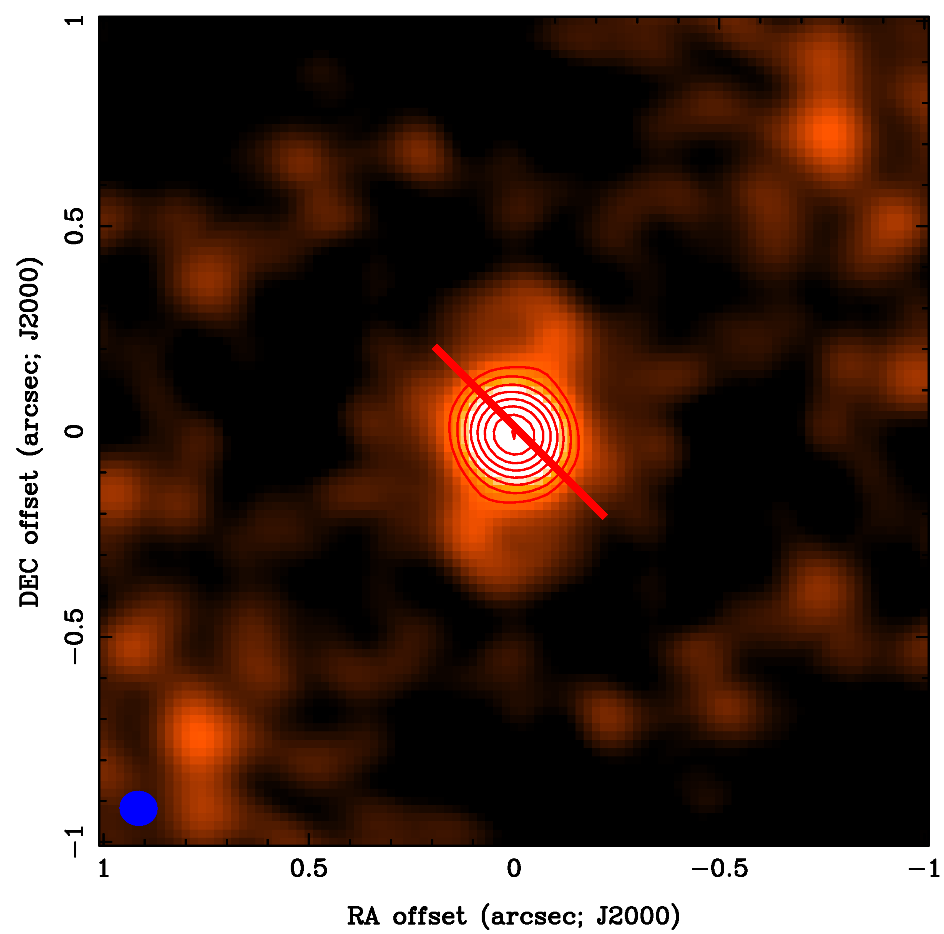


Disk Detections



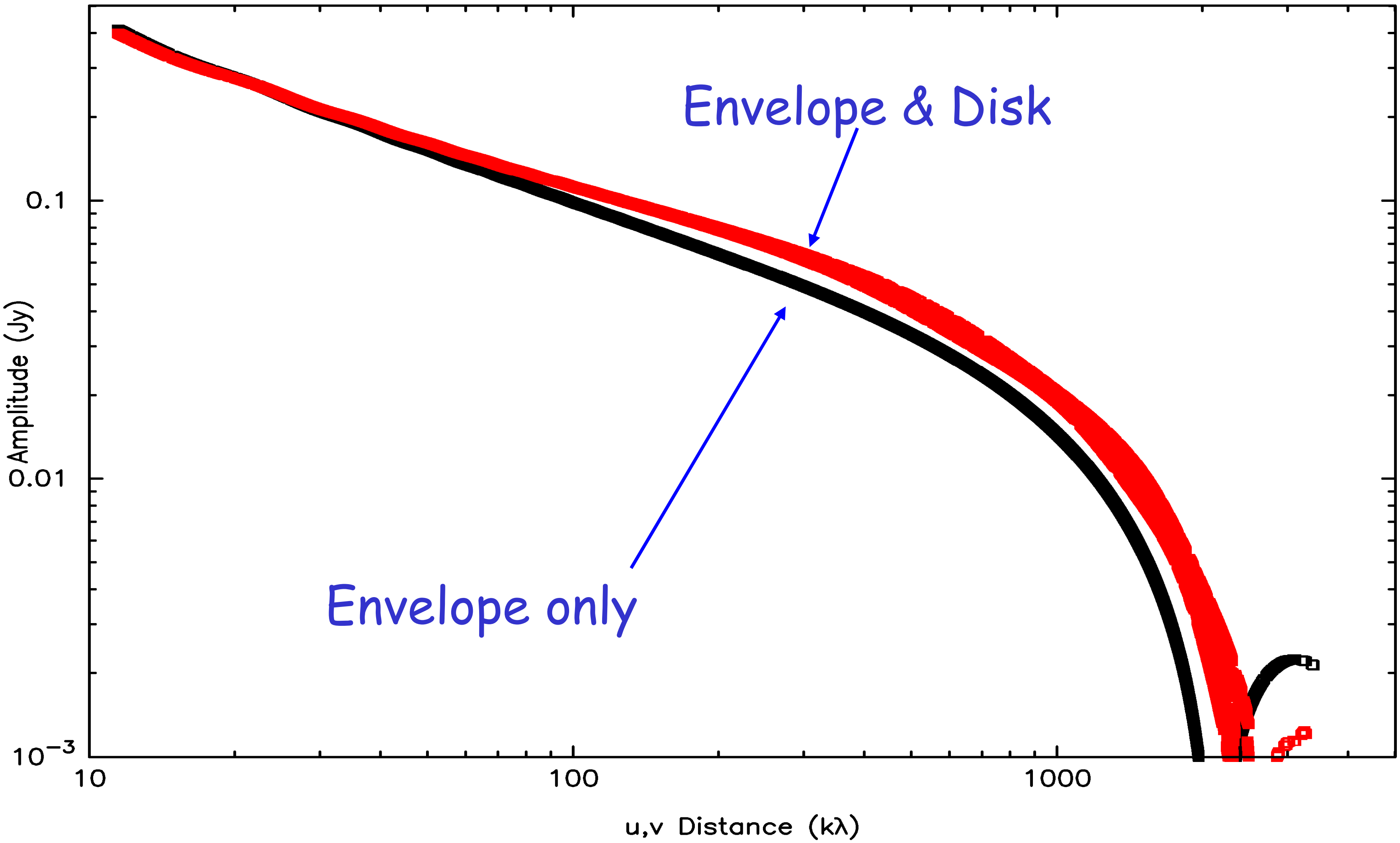
Simulations: Envelope + 100 AU Disk





PA = 45°

Fourier Space: Envelope and 100 AU disk



Uniqueness

- ALMA should break uniqueness of data by providing very high S/N with absolute calibration in the essential portion of the *u*,*v* plane
  - Also requires more theoretical assistance
- How is disk component behaving?
- Where does the high-angular momentum material fall?
- Better constrain the morphology of the early disk (both continuum and lines)
- How does the disk evolve?

Future is Bright

- ALMA data will be very sensitive to the disk/envelope transition region
- This will prove to be the essential aspect of the problem.
- Also the additional information of the velocity field will add significant information
  - Circumstellar disk will want to be Keplerian, envelope will not
  - Still velocity field has contamination effects
- Difficult problem, but with data and new analysis approaches (e.g. principal component analysis), there will be improved understanding of the earliest stages of disk evolution

Embedded Disks Take-Homes

- Still a lot to do here.
- We are beginning to probe the secret lives of the youngest circumstellar disks.
- Difficult problem.
- At this stage, we have placed limits on the disk component.
- They are **not** much more massive than the most massive T Tauri star (HL Tauri $M_{disk} = 0.1\ M_{\odot}$).
- But the secret life of embedded disks should be exposed soon!