Disks in Class 0 protostars: The Resolved Massive Disk in Serpens FIRS 1

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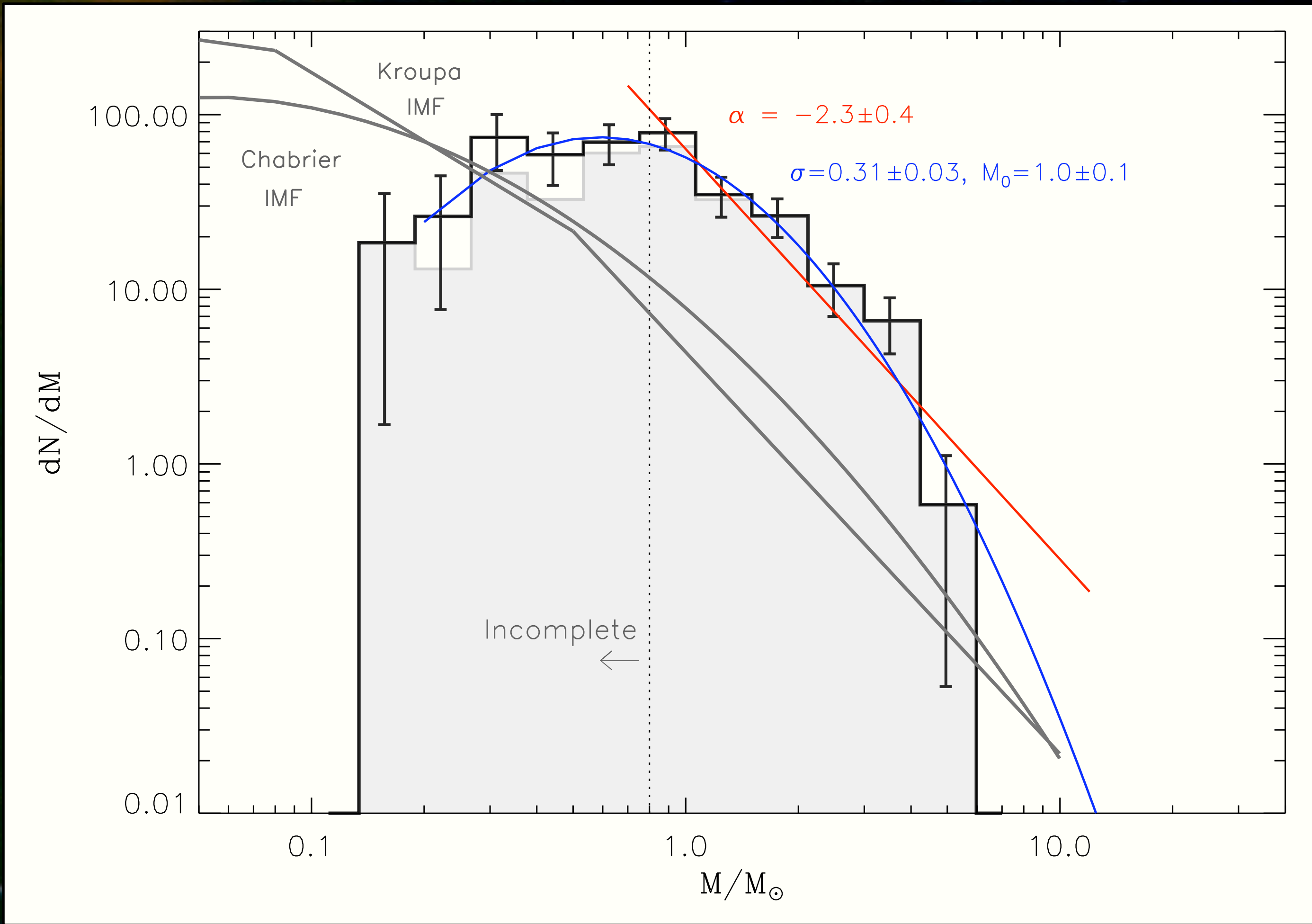
Monday, December 14, 2009

Project working on with...

Based on c2d, bolocam surveys, follow up on a large census of cores & protostars in per, ser, oph

Enoch et al. 2008

The mass distribution of lifetime of presteller cores in Perseus, Serpens, and Ophiuchus



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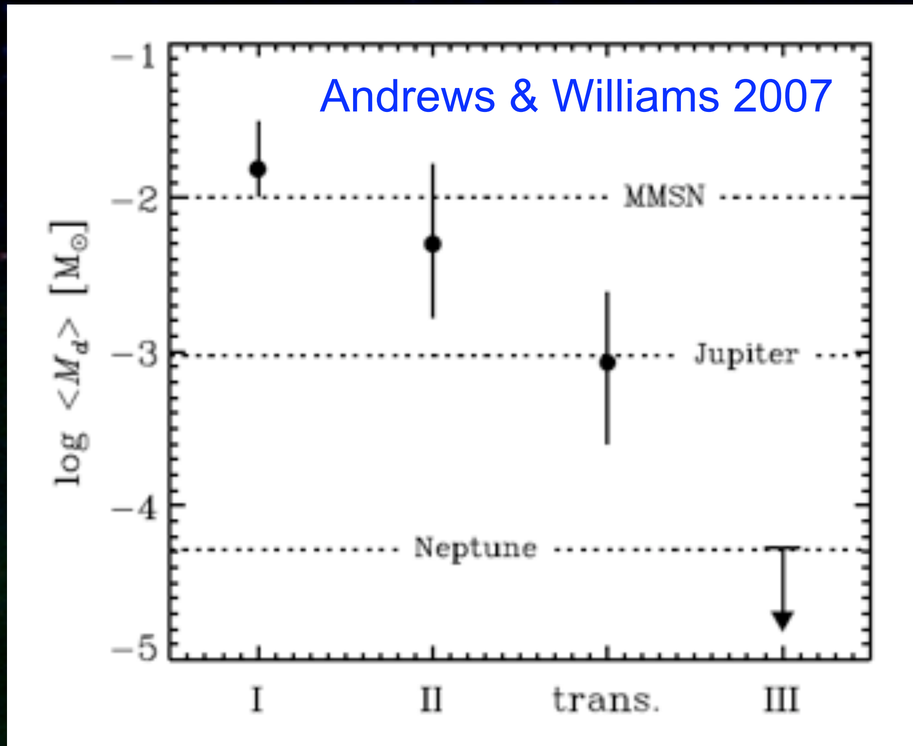
One of papers in mario's list should have had a red et al. Was lucky to have the king of cores' insight on our analysis of the starless cores... MF, lifetime

Class 0 disks

- Goals:
  - When does the disk form?
  - Typical mass?
  - What does the inner envelope look like?
- Previous work
  - Evidence for disks in a few Class 0 sources (Chandler et al. 95, Looney et al. 03, Jorgensen et al. 07)



- Need:
  - Representative sample of Class 0 protostars
  - Broadband SED, tracer of MIR flux
  - High resolution images at optically thin wavelengths

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That established... Like I said, this is follow up in a sense, looking deeper at subset populations from large sample.
Increase toward younger times (Andrews & Williams 2007) vs. Start small (theory)?
When form = do all class 0 have disks?   Envelope structure important as well, need both together.
Some measurements, but vary quite a bit, mostly “famous” sources (Jes exception).
Rep sample – from collapse to Mstar=Menv. Can constrain models with.... [SHOWN BY JES]

Class 0 disks

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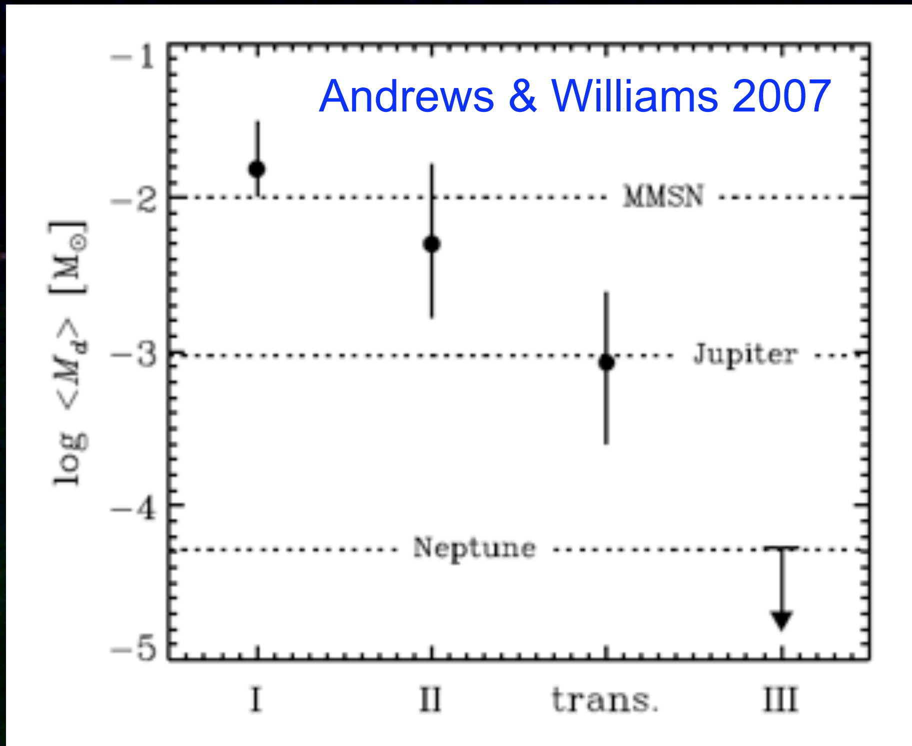

- Need:
  - Representative sample of Class 0 protostars
  - Broadband SED, tracer of MIR flux → c2d, IRS spectra
  - High resolution images at optically thin wavelengths → CARMA maps

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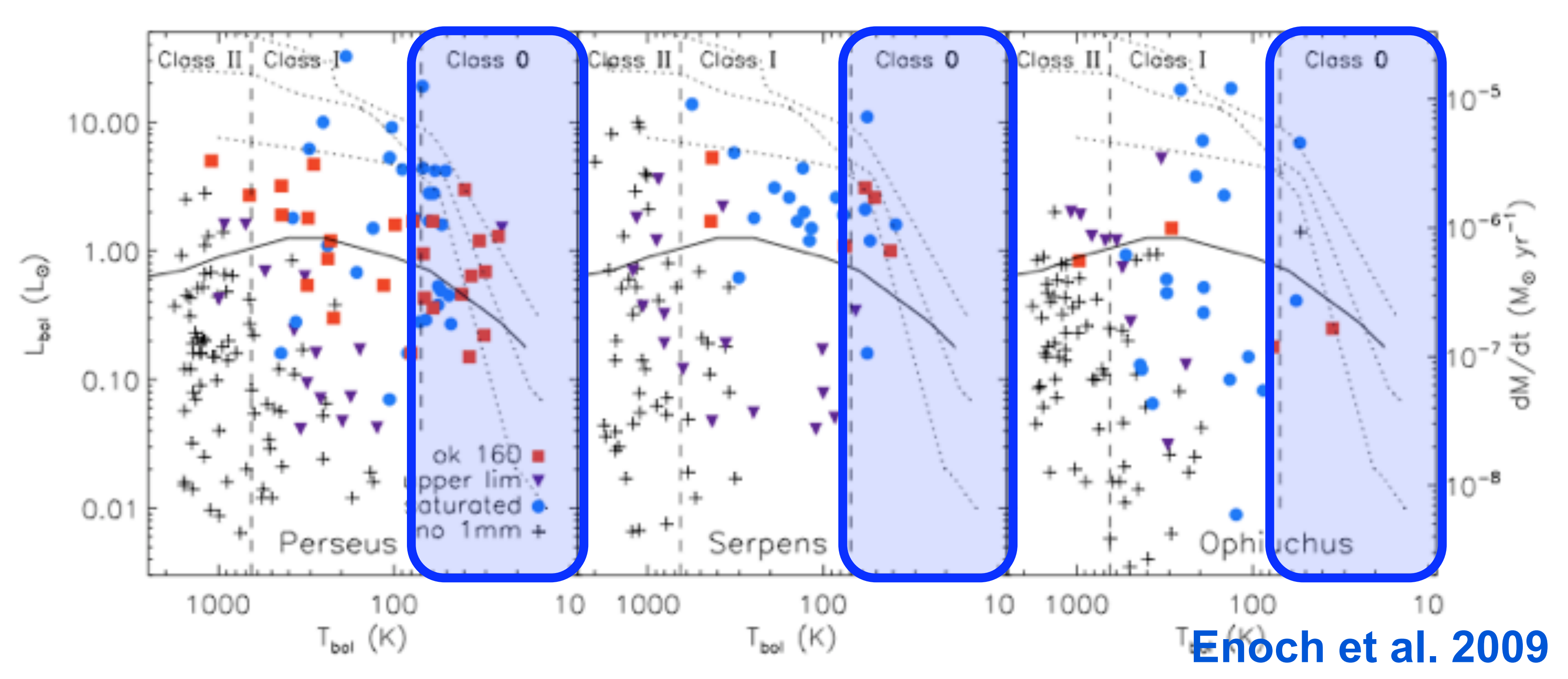
For

Sample: census of embedded protostars



- Spitzer IRAC/MIPS + Bolocam 1.1 mm surveys ("Cores to Disks"; Evans et al. 2003)
  - ~20 sq deg in Per, Ser, Oph
  - M_{env} limit ~ 0.1-0.2 M_{sun}
- ~40 Class 0 sources
  - Tbol < 70 K
  - Menv ~ 0.2 - 10 Msun
  - Lbol ~ 0.2 - 10 Lsun

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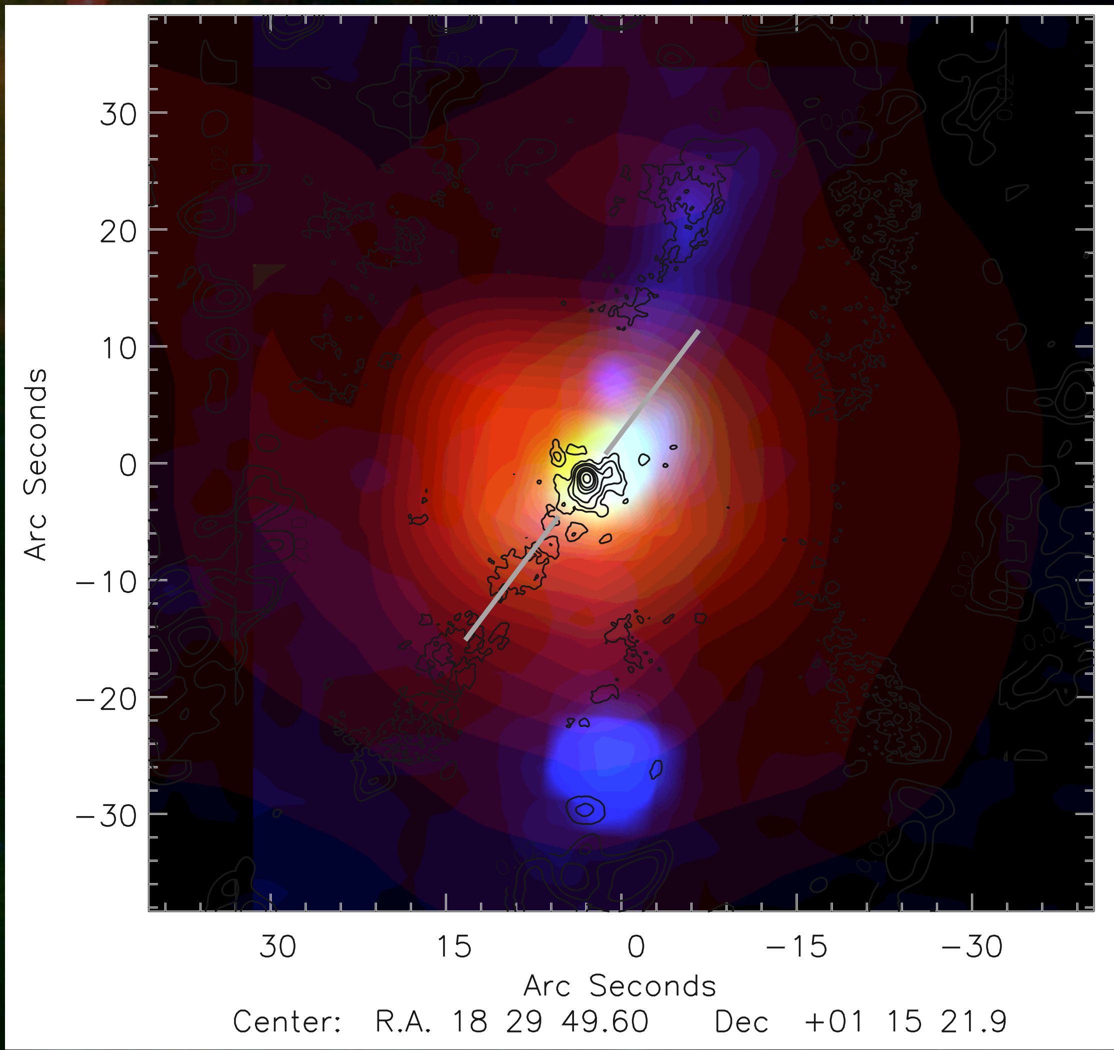
The sample is from census.... Complete to Menv & Lint limits.

40 class 0, defined by Phil's Tbol, having T<70K

Selected sample that do not have mid-IR spectra and/or high resolution millimeter maps.

Disk and Envelope Structure in Class 0 Protostars: I. The resolved massive disk in Serpens FIRS 1

(Enoch, Corder, Dunham & Duchêne, ApJ in press: astro-ph/0910.2715)



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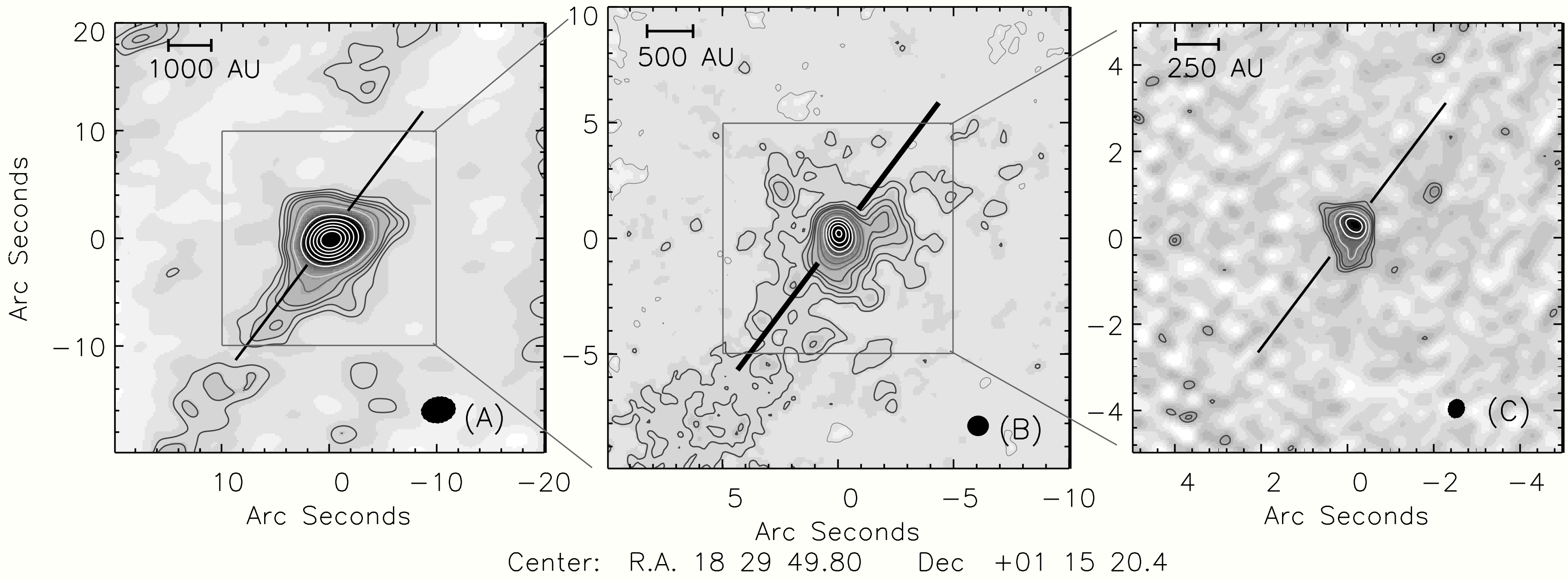
Modeling & testing completed for 1 source (brightest)
To serve as proof of feasibility of method.
Direction of cm jet from....

CARMA 230 GHz map

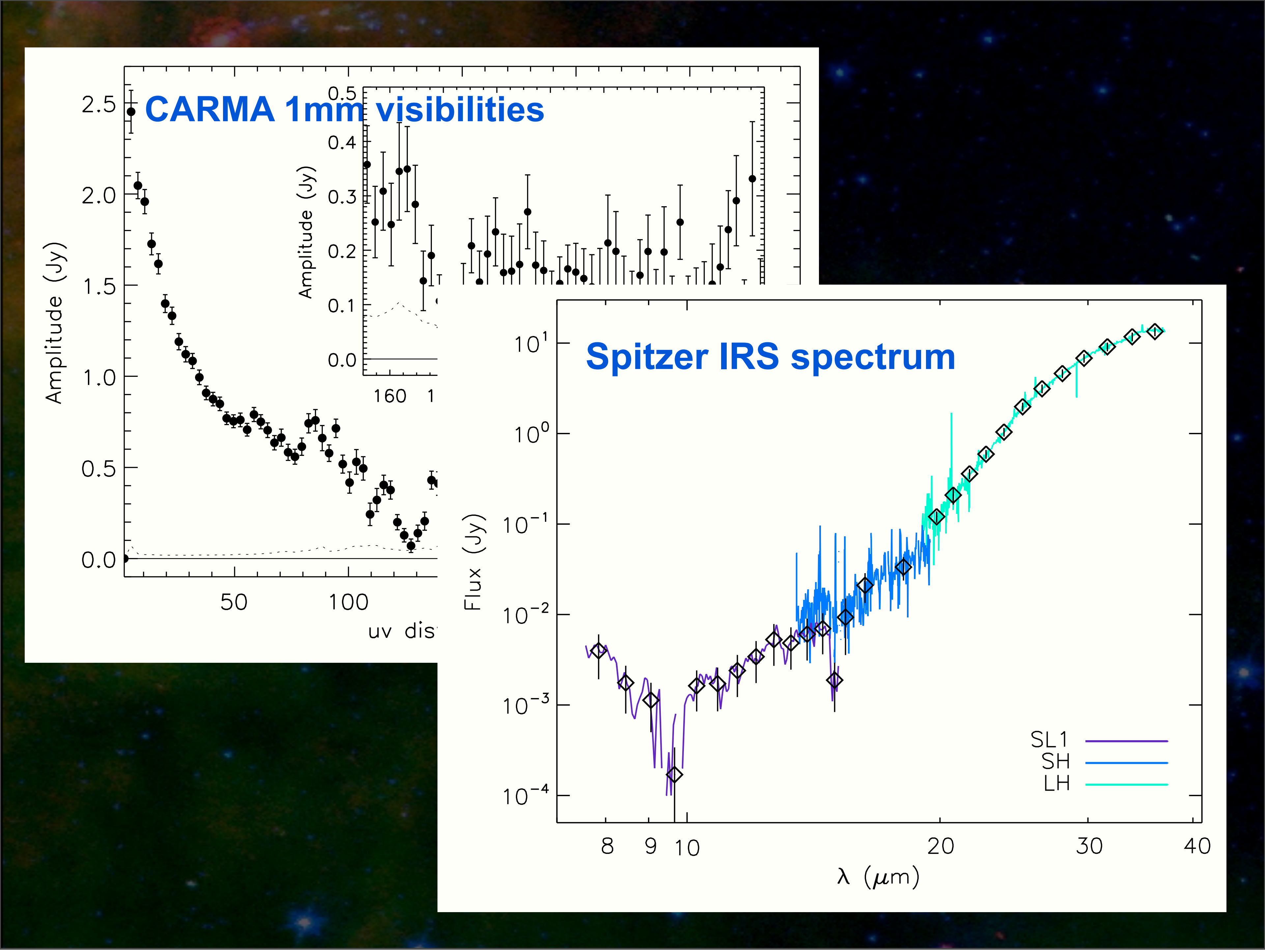


Short baseline data only (E,D array)

All data (B,C,D,E array)

Long baseline data only (B,C array)

Note pick up different structures with different configurations. Envelope, resolve out some env, disk.
Binary??



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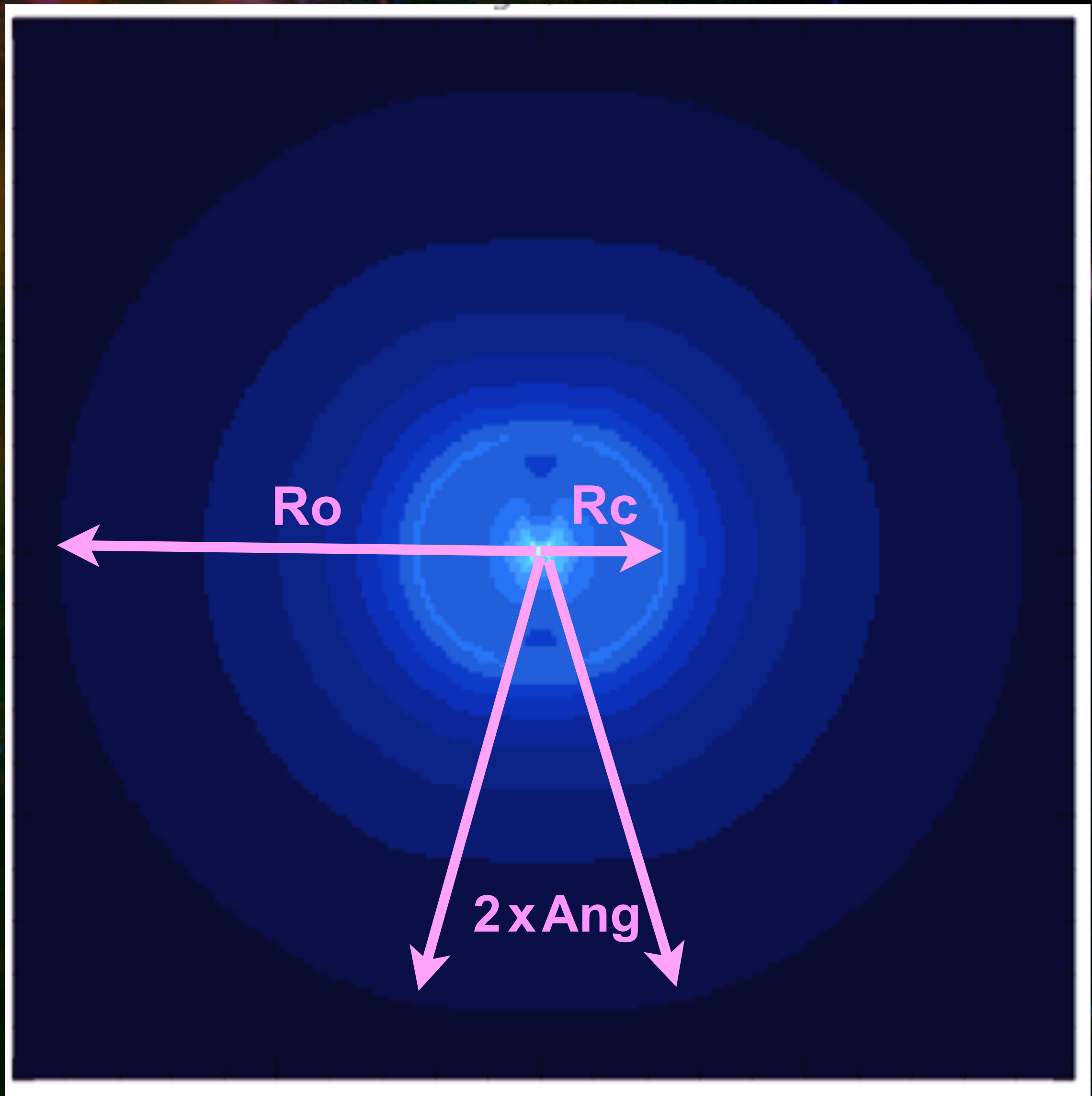
Really get more information from visibilities than map. Lots of emission at intermediate, maybe point like out at >200 klam....
Other new data is IRS spectrum. Binned points used in model fit.

Radiative Transfer Models
(RADMC; Dullemond & Dominik 2004)



- SED is sensitive to:
  - Rout, Rcent
  - Inclination, outflow opening angle
- 1mm visibilities are sensitive to:
  - Mdisk, Rdisk
  - (Rout, Rcent)
- Set by 1mm/Spitzer photometry:
  - Menv, Lstar

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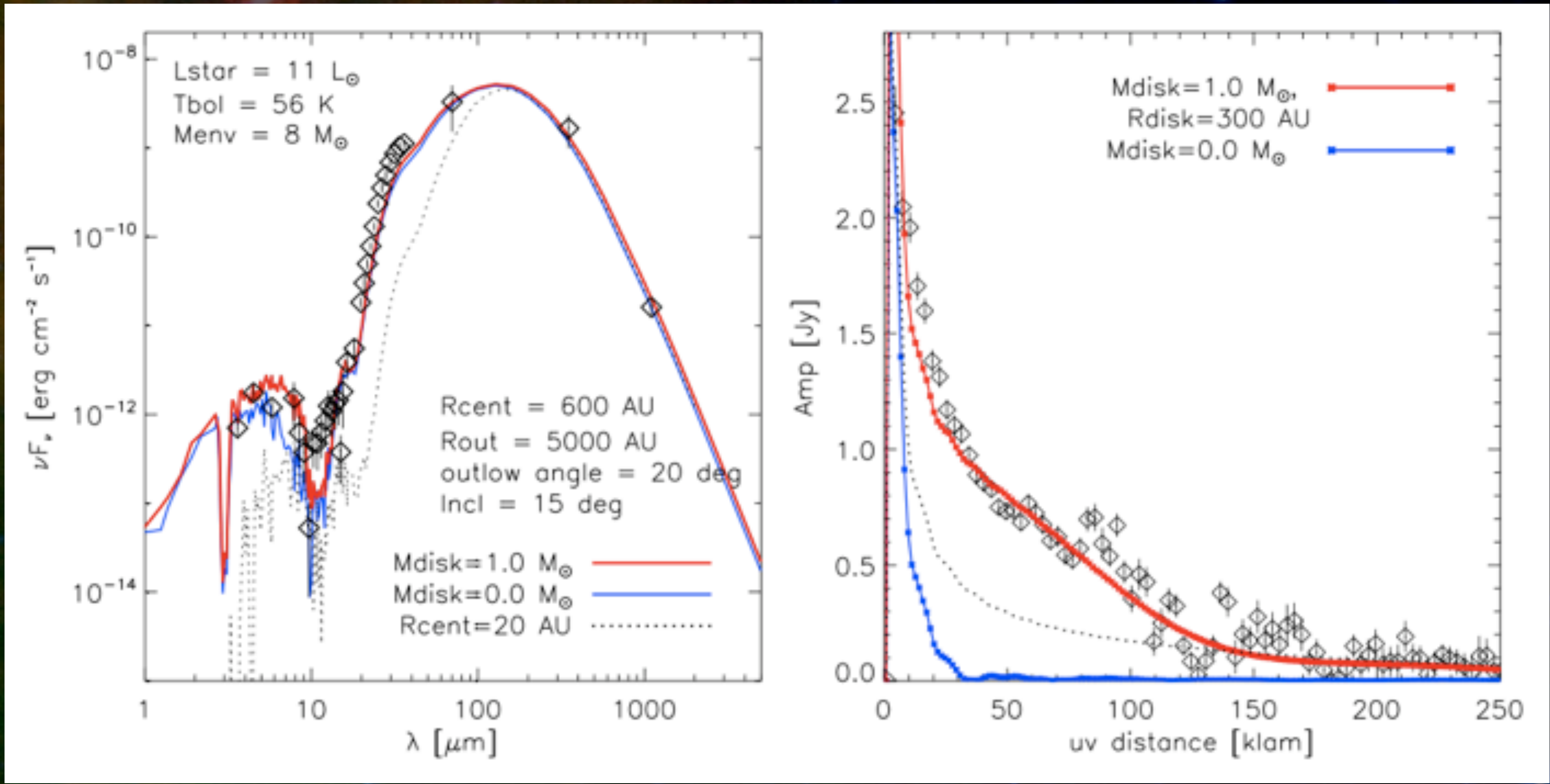
Model – RADMC, env of infalling rotating spheroid, w/ outflow & disk
SED & 1mm almost orthogonal constraints



Serpens FIRS 1: best-fit model

- Rcent ~ 600 AU, outflow full opening angle ~ 20 deg
- Disk mass ~ 1.0 Msun, Disk radius ~ 300 AU
- Disk-to-Envelope mass ratio ~ 0.13

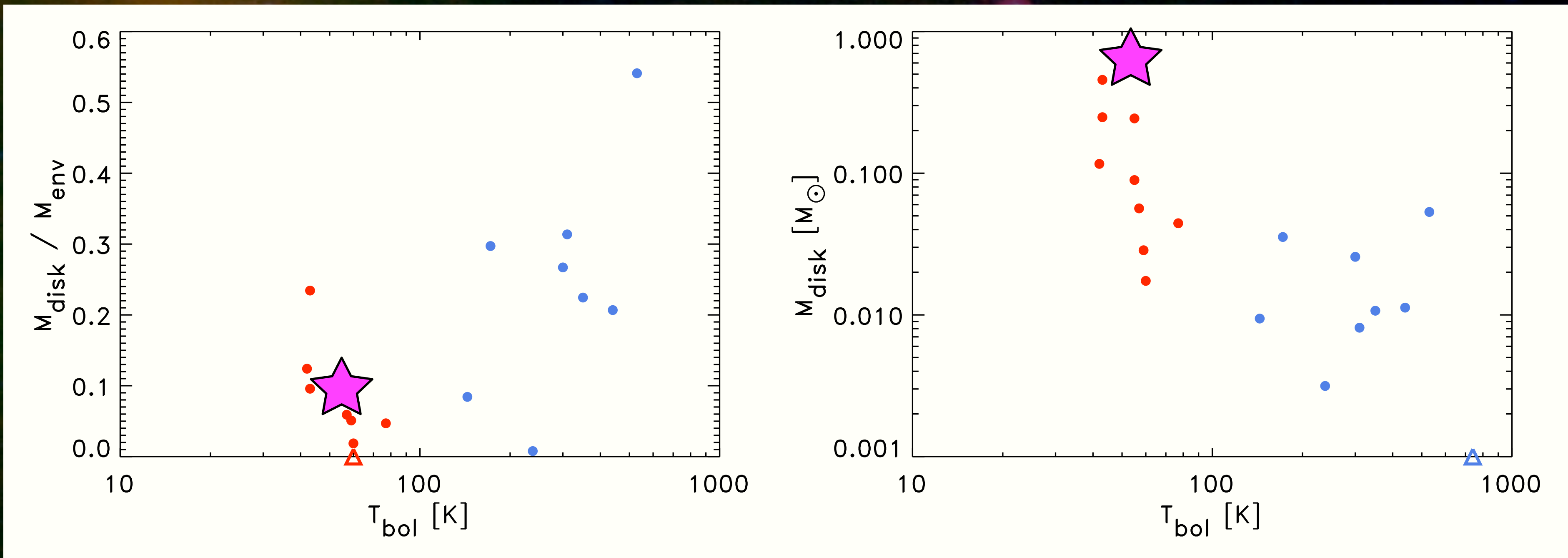
Blue=just envelope
500/6000 fits a bit better, but hard to fit intermed uv dist
Of course, a range of params works
HIGH MASS. Higher than would expect for young source, unless high env infall rate and/or very rapid rotation in initial core.

PROSAC: A Submillimeter Array survey of low-mass protostars

II. The mass evolution of envelopes, disks, and stars from the Class 0 through I stages

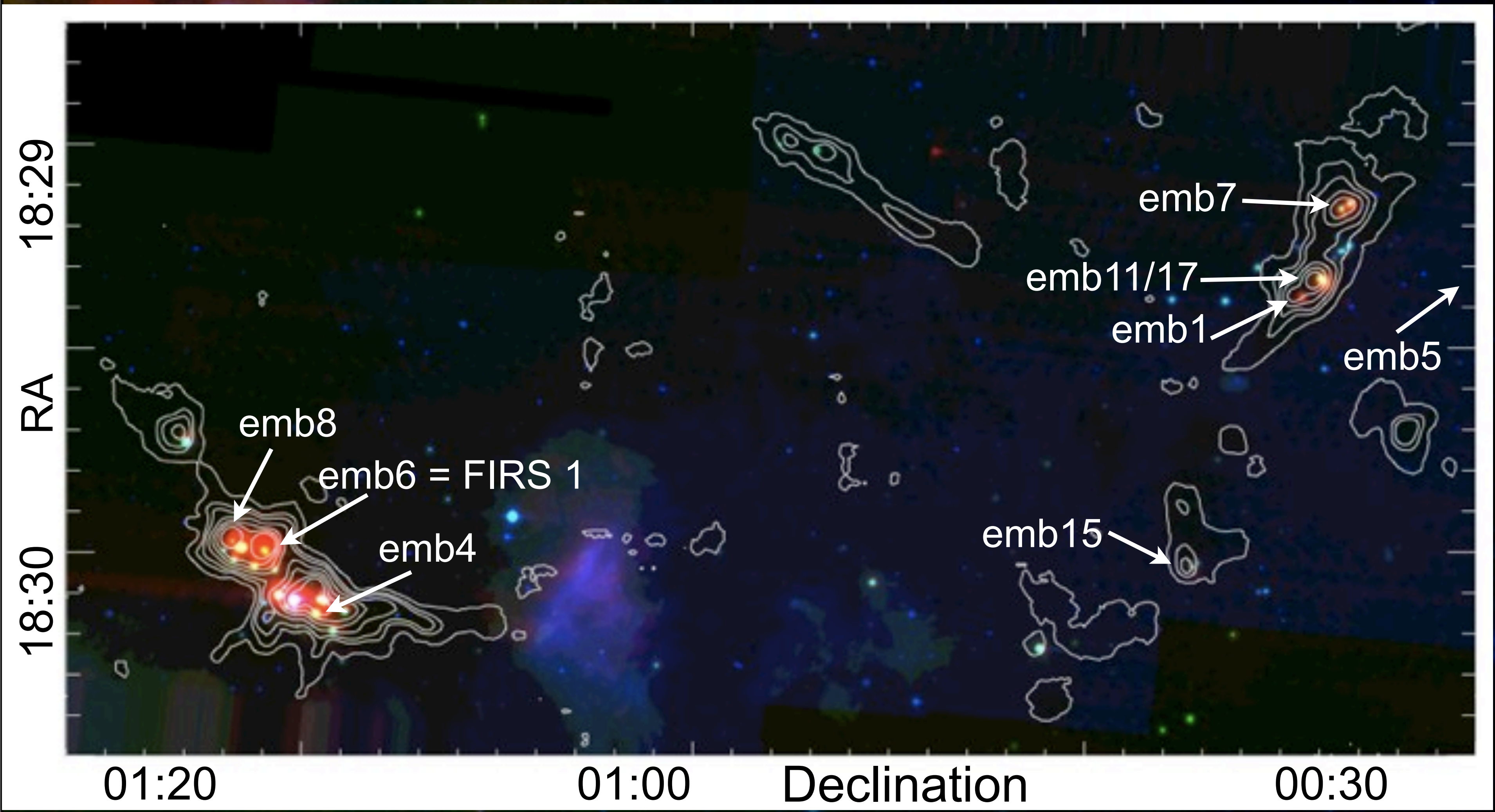
Jes K. Jørgensen[1], Ewine F. van Dishoeck[2,3], Ruud Visser[2], Tyler L. Bourke[4], David J. Wilner[4], Dave Lommen[2], Michiel R. Hogerheijde[2], and Philip C. Myers[4]

Jørgensen et al. A&A, in press (astro-ph: 0909.3386)



Estimate Mdisk from the 1mm flux at 50 klam. Subtract out fixed % from envelope.
If calculate in same way....
Average mass Jes ~0.05 both Class 0/Class I
COMPLEMENTARY STUDIES

Serpens Class 0 sample



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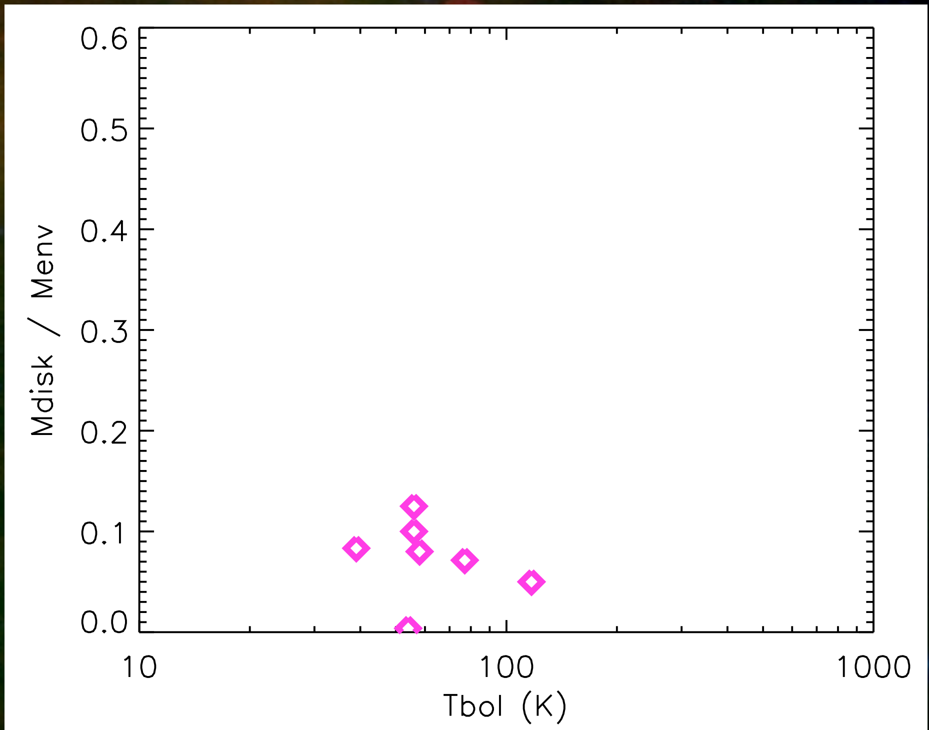
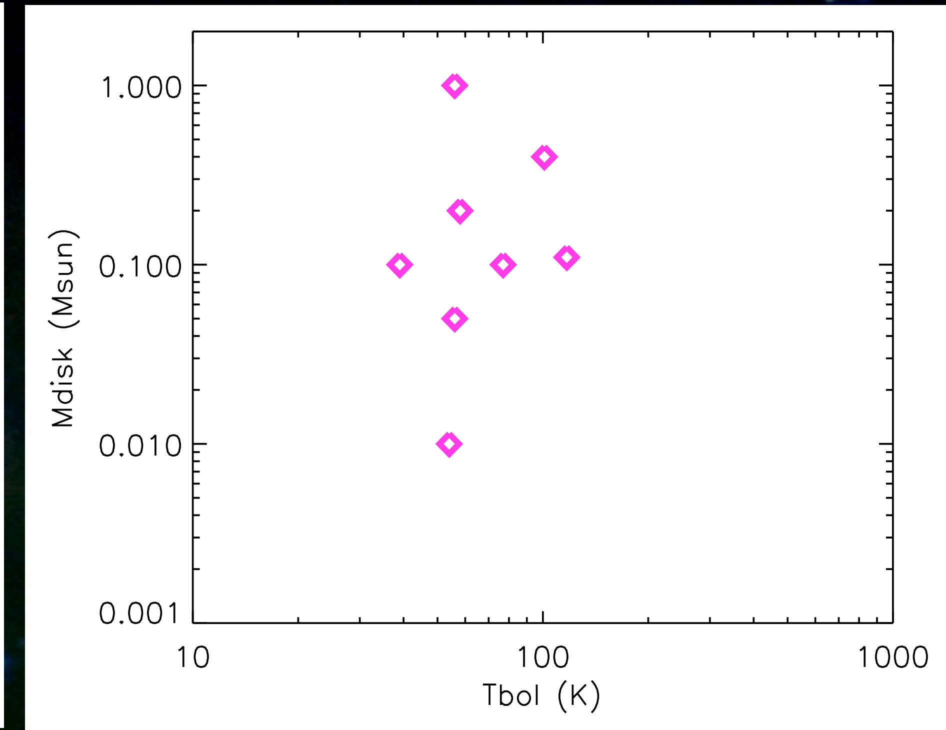
Start with Serpens sample, 7 sources, have most of CARMA data, preliminary models.

Serpens Class 0 sample





- Mdisk/Menv ~ 10%
- Median Mdisk ~ 0.1 Msun

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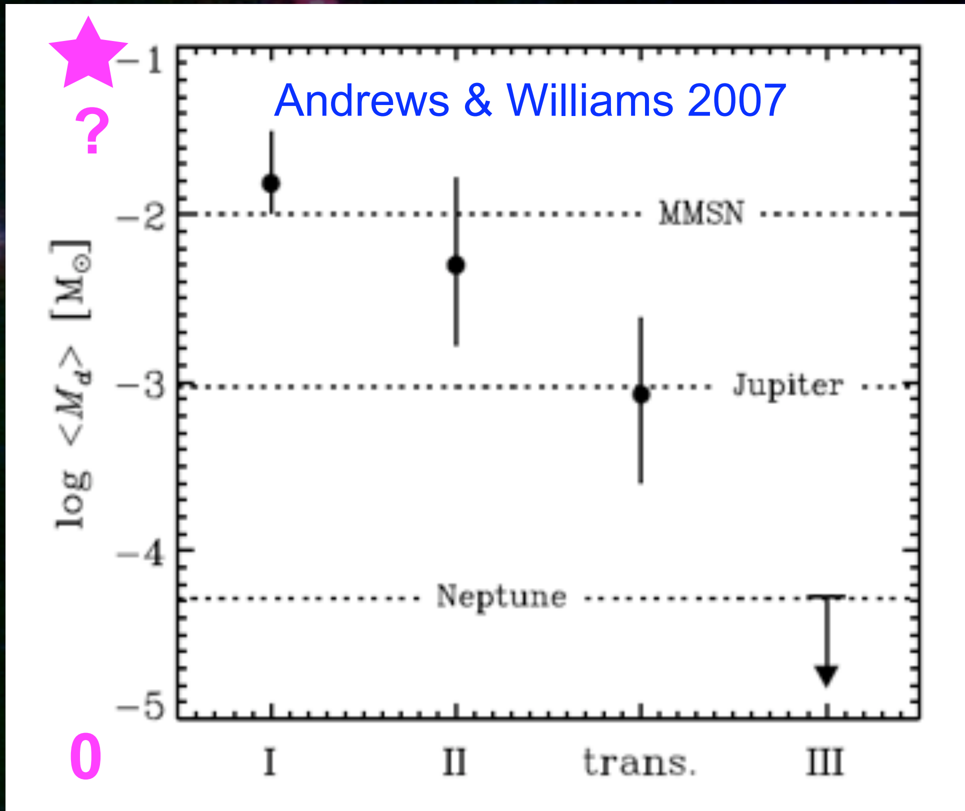
Only one with no disk, even in “complete” sample
Menv limit 0.1

Summary

- Radiative trasfer models w/ IRS spectra + millimeter interferometry constrain Class 0 disk & envelope structure
- Massive resolved disk in Serpens FIRS 1 (M~1 M_{sun}, R~300 AU)
  - May require high rotation or envelope infall rates
- **Preliminary** results for Serpens sample: disk-to-envelope mass ratios ~10%
- Disks are relatively massive at very early times?



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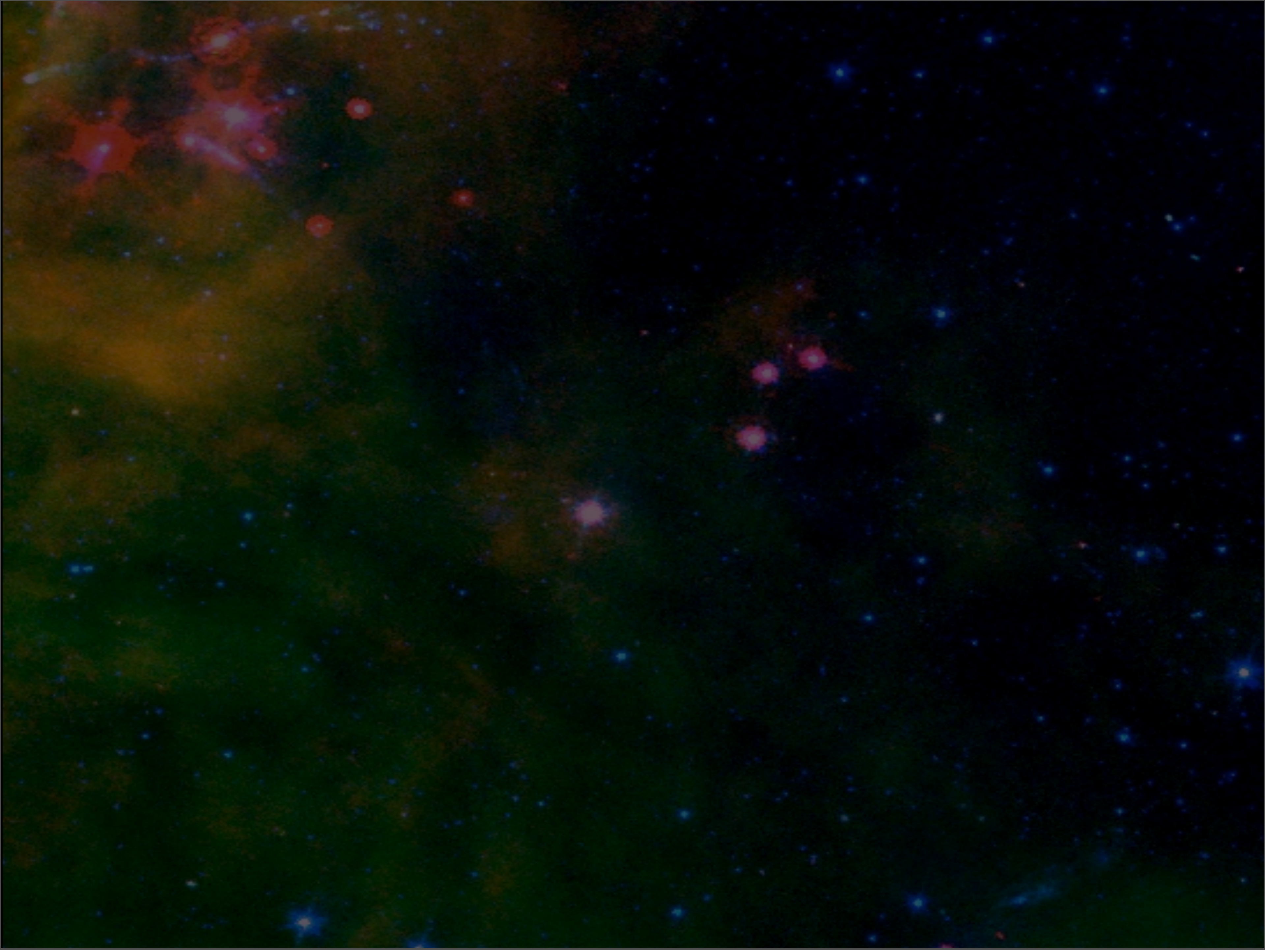
Use SED to get envelope params, w/ those, disk mass is robustly constrained. Need very good uv coverage.

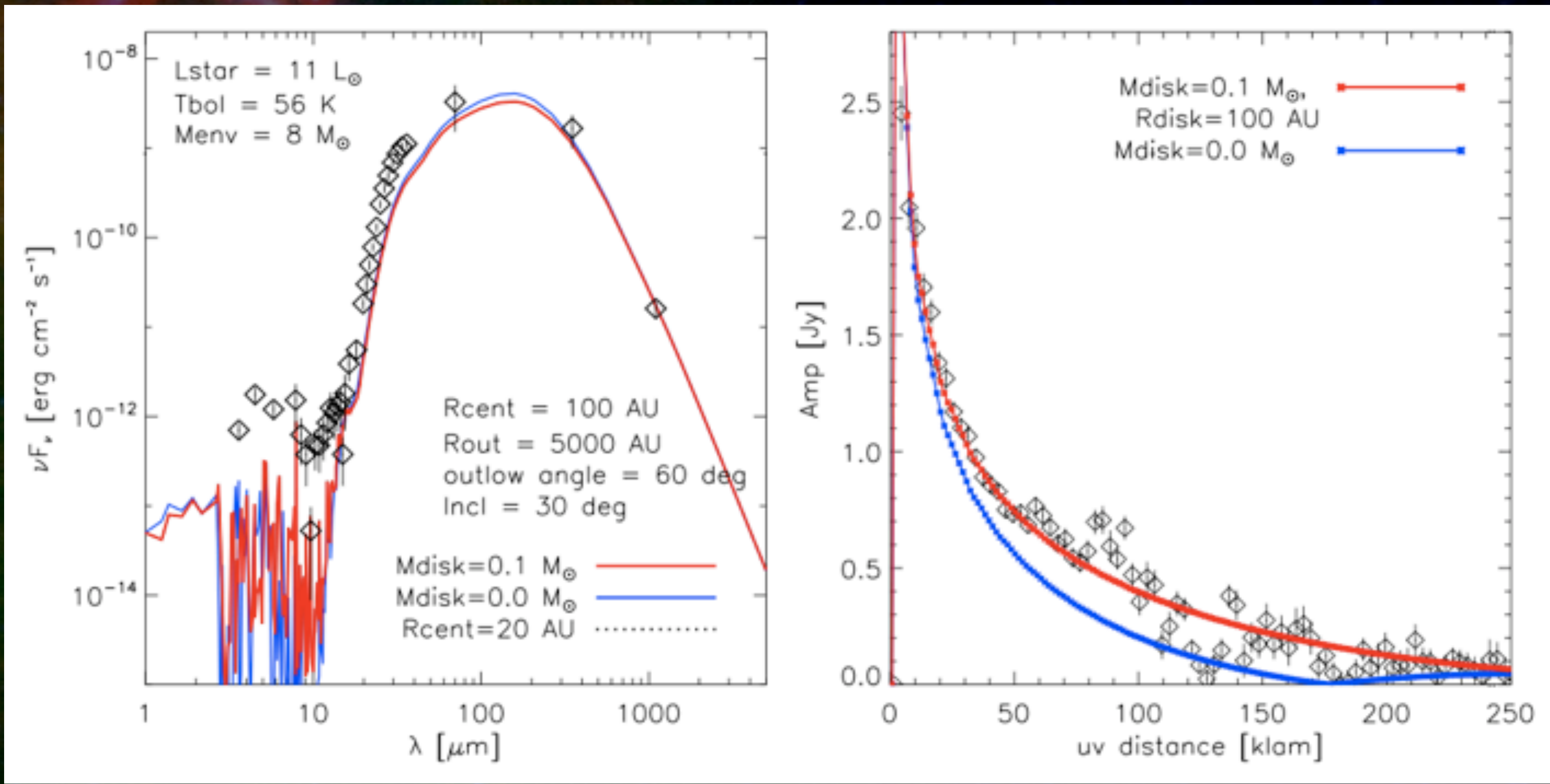
Obviously need larger sample to draw any general conclusions

Notable exceptions – FIRS 1, bolo 15 (large disk/env mass ratio). median mass ~0.1, mean ~0.25

Dust props, mostly long wavelength



Power law envelope model



- Only 0.1 Msun disk required, but doesn't reproduce MIR spectrum

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If really don't like large disks early on, may be able to get around it....
Lesson from this depends on point of view.
Prev results (looney et al) - can fit vis w/o disk. Yes, but doesn't fit sed. NEED TO FIT BOTH
If you don't like the large disk there are some ways around it

To appear in the Astrophysical Journal

MULTIPLICITY OF THE PROTOSTAR SERPENS SMM 1 REVEALED BY MILLIMETER IMAGING

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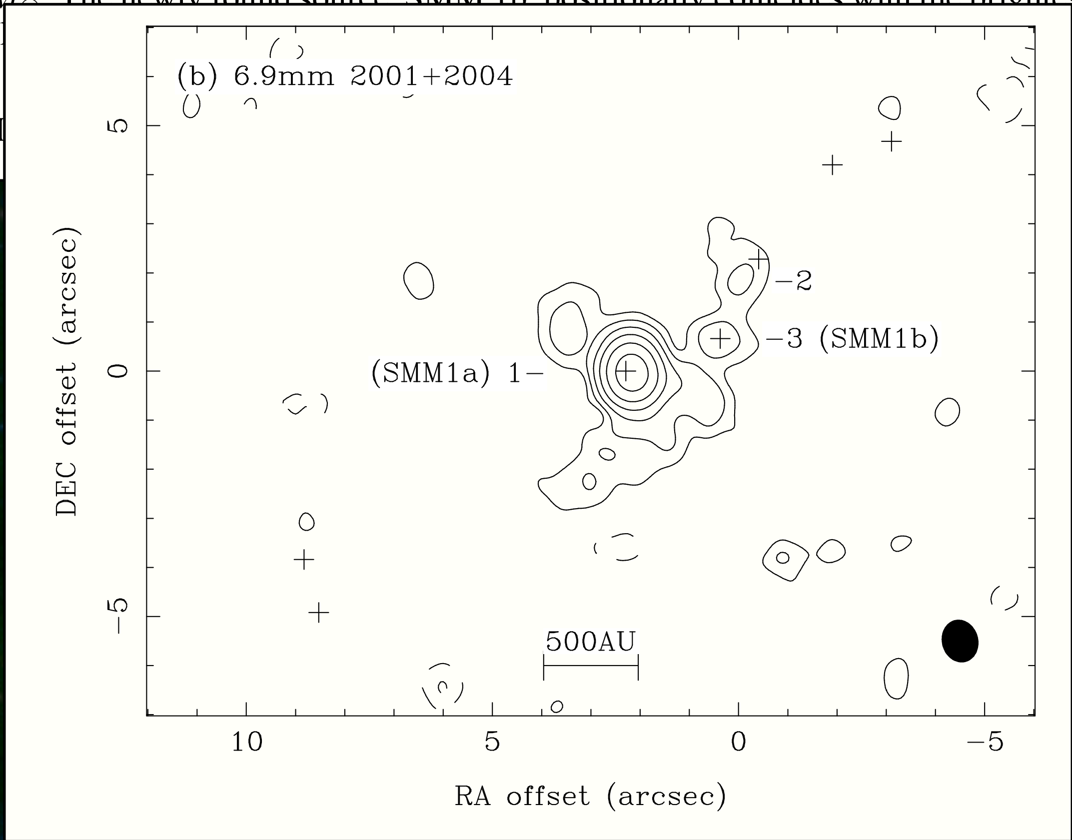
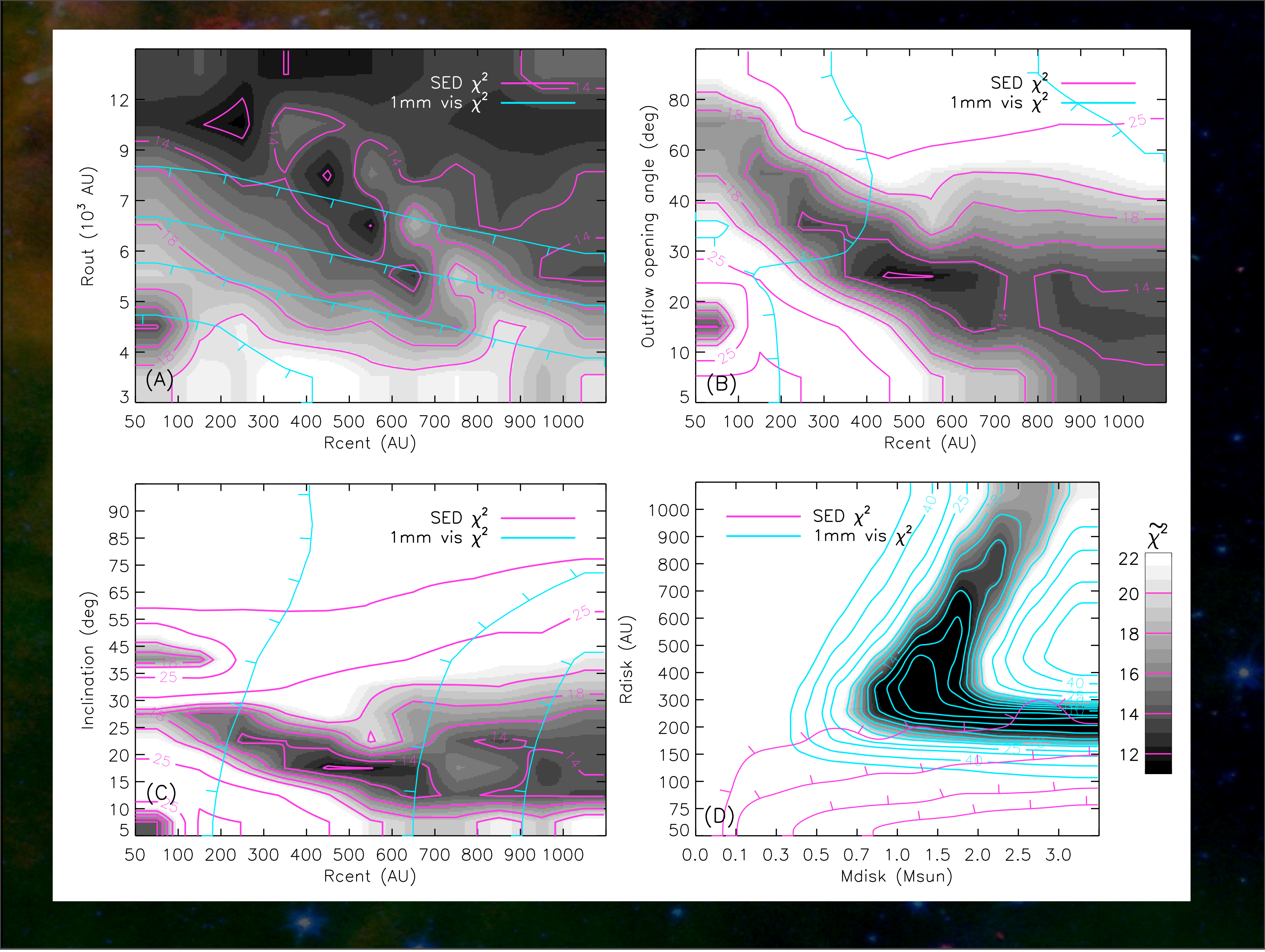
ABSTRACT

The Serpens SMM 1 region was observed in the 6.9 mm continuum with an angular resolution of about 0.″6. Two sources were found to have steep positive spectra suggesting emission from dust. The stronger one, SMM 1a, is the driving source of the bipolar jet known previously, and the mass of the dense molecular gas traced by the millimeter continuum is about 8 $M_\odot$. The newly found source, SMM 1b, positionally coincides with the brightest mid-IR source in this region, which imp… deeply embedded than SMM 1a. SMM 1…

Subject headings: ISM…





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Chisq – not perfectly constrained. Example = Rout
Disk well constrained by vis.

Implications for disk formation

- Disk growth via centrifugal balance (Terebey et al. 1984)

$$R_d = 7\left(\frac{c_s}{0.35\mathrm{km\ s^{-1}}}\right)\left(\frac{\Omega}{4\times10^{-14}\mathrm{s^{-1}}}\right)^2\left(\frac{t}{10^5\mathrm{yr}}\right)^3 \mathrm{AU}$$

  ➡ For t~10^5 yr, requires rapid initial rotation rate (4×10^{-13} s^{-1})

- Disk growth via accretion from the envelope (Shu 1977)

$$\dot{M}_{env} \sim c_s^3/G \sim 10^{-5}\ \mathrm{M_\odot\ yr^{-1}}$$

  ➡ Can accumulate 1Msun in 10^5 years

  ➡ Low viscosity disk or higher infall rate?

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Growth of disk via centrifugal support - for age of 1e5 yrs, has to have very rapid initial rotation (4e-13/s, typical -14 to -13).
Or, older.

Radiative transfer modeling

- RADMC (Dullemond & Dominik 2004)
  - 2D Monte Carlo radiative transfer and ray tracing
- Envelope parameterized according to Ulrich (1967); see also Crapsi et al. (2008)

ROTATING ENVELOPE

$$\rho_{env} = \rho_{env,1000} \frac{2.33 m_H}{100} \left(\frac{r}{1000AU}\right)^{-1.5} \left(\frac{1}{1+cos\theta/\mu_0}\right) \left(\frac{cos\theta}{\mu_0} + 2\mu_0^2 \frac{R_{cent}}{r}\right)^{-1}$$

, R_c is the centrifugal radius, $\mu = \cos\theta$, and μ_0 is the cosine polar angle of a streamline of infalling particles as $r \rightarrow \infty$. The equation for the streamline is given by

$$\mu_0^3 + \mu_0(r/R_c - 1) - \mu(r/R_c) = 0 \, . \qquad (2)$$

OUTFLOW CAVITY

$$\rho_{env} = \rho_{env}(\mu_0 \leq cos(An))$$

DISK

$$\Sigma_{disk} = \Sigma_0 \, (r/R_{disk})^{PL}$$

$$h = h_0 \, (r/R_{disk})^{PLH}$$

PL = -1

PLH = 2/7

Use spectral & spatial obs to constrain models & get at structure.
For infalling, rotating envelope, but replace dependence on dM/dt w/ rho_1000
0 values set by total mass. Den pile-up at Rcent
Disk PL in surf den w/ radius, and scale height (flaring).
Can change envelope to pl, whatever

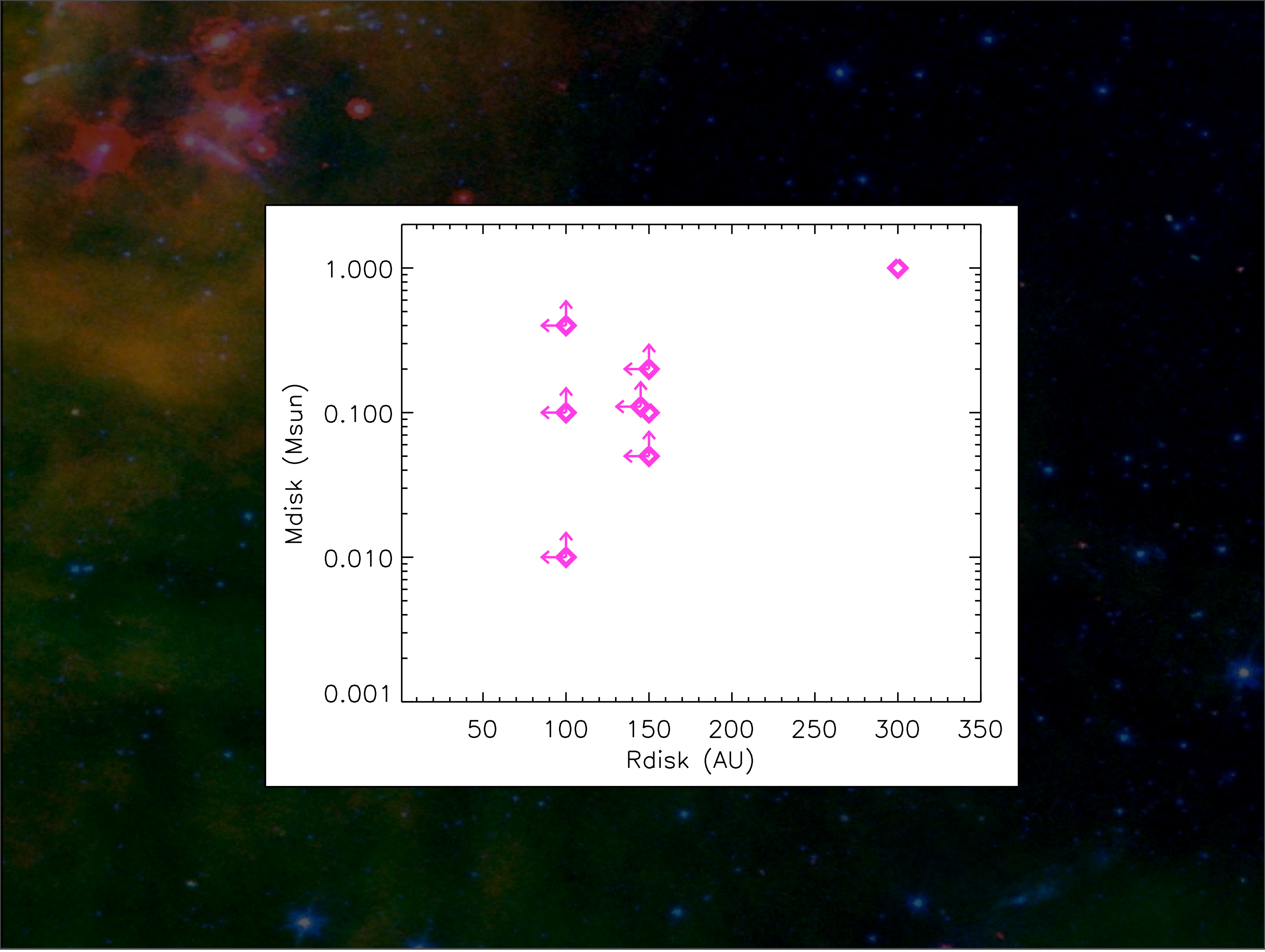
Model parameters

TABLE 2
RANGE OF PARAMETERS VALUES USED IN THE RADIATIVE TRANSFER MODEL GRID

Parameter	Fixed?	Range	Description
			Protostar
L_{star}	Y	11 $L_\odot$	Internal luminosity
M_{star}	Y	0.5 $M_\odot$	Protostar mass
T_{star}	Y	4000 K	Protostar effective temperature
R_{star}	Y	5 $R_\odot$	Protostar radius
			Envelope and outflow
M_{env}	Y	8.0 $M_\odot$	Total mass of envelope
R_{out}	N	3000 – 12000 AU	Outer radius of envelope
R_{cent}	N	50 – 1000 AU	Centrifugal (inner) radius of envelope
Ang	N	5 – 80 deg	Outflow opening angle
Incl	N	5 – 90 deg	Inclination angle
			Disk
M_{disk}	N	0.0 – 3.0 $M_\odot$	Disk mass
R_{disk}	N	50 – 1000 AU	Disk radius
H_0	Y	0.2 R_{disk}	Disk vertical pressure scale height
$p1$	Y	−1.0	Disk surface density radial power law ($r < R_{disk}$)
$p2$	Y	2/7	Power law for H(R) (disk flaring)

NOTE. — The internal luminosity is set by the bolometric luminosity of the source, determined from the broadband SED, and the envelope mass is set by the 1.1 mm Bolocam single dish flux (see Enoch et al. 2009). Ang is the full outflow opening angle. Incl is the line of sight inclination angle of the disk: 0 deg is face-on, 90 deg is edge-on. Stellar, envelope, and disk parameters are discussed in Section 3.

Some parameters held fixed, like..... Some testing to see if affect answers, some (lum) just have to characterize how affects...



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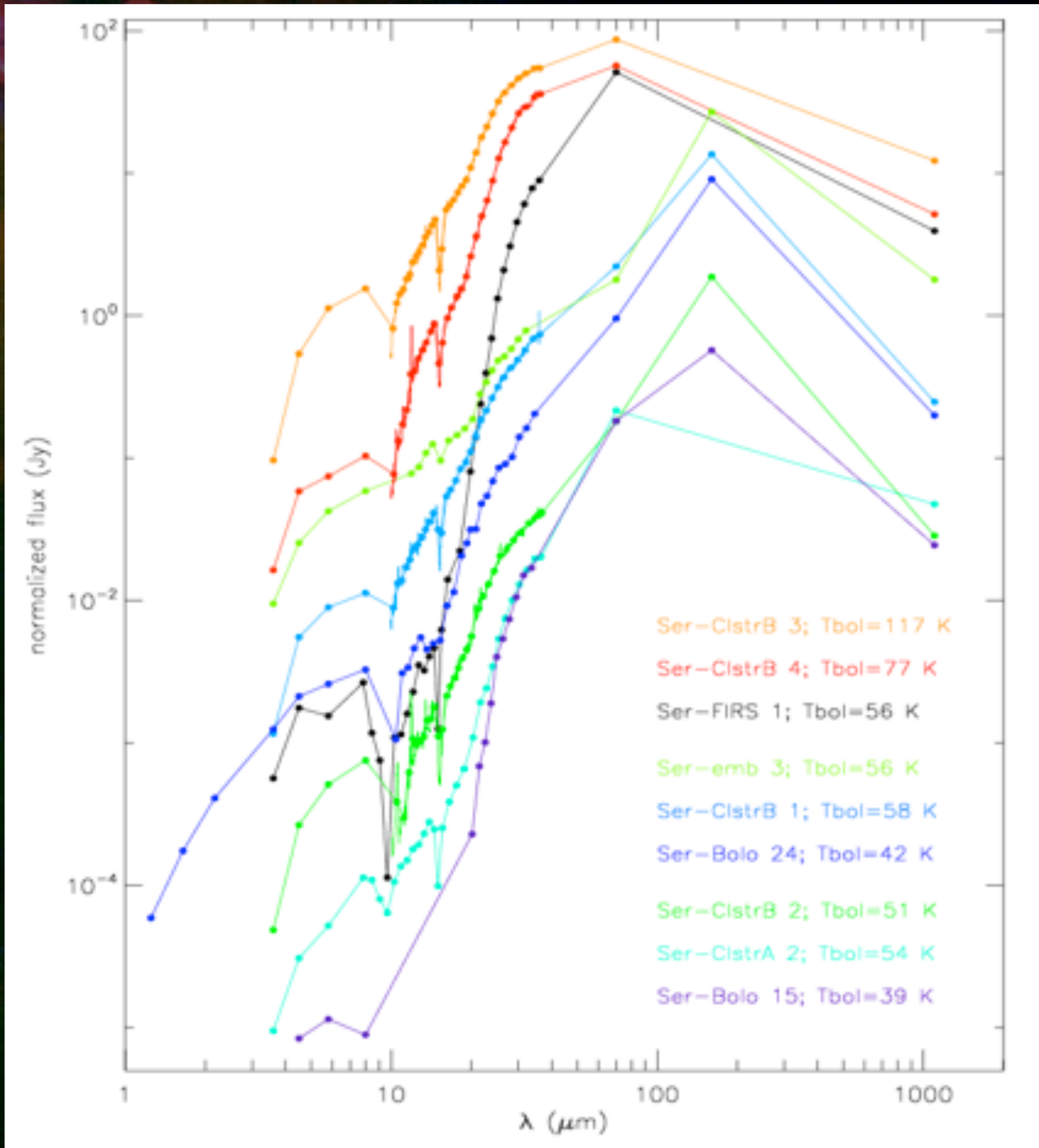
IRS Spectra: Serpens Class 0 protostars



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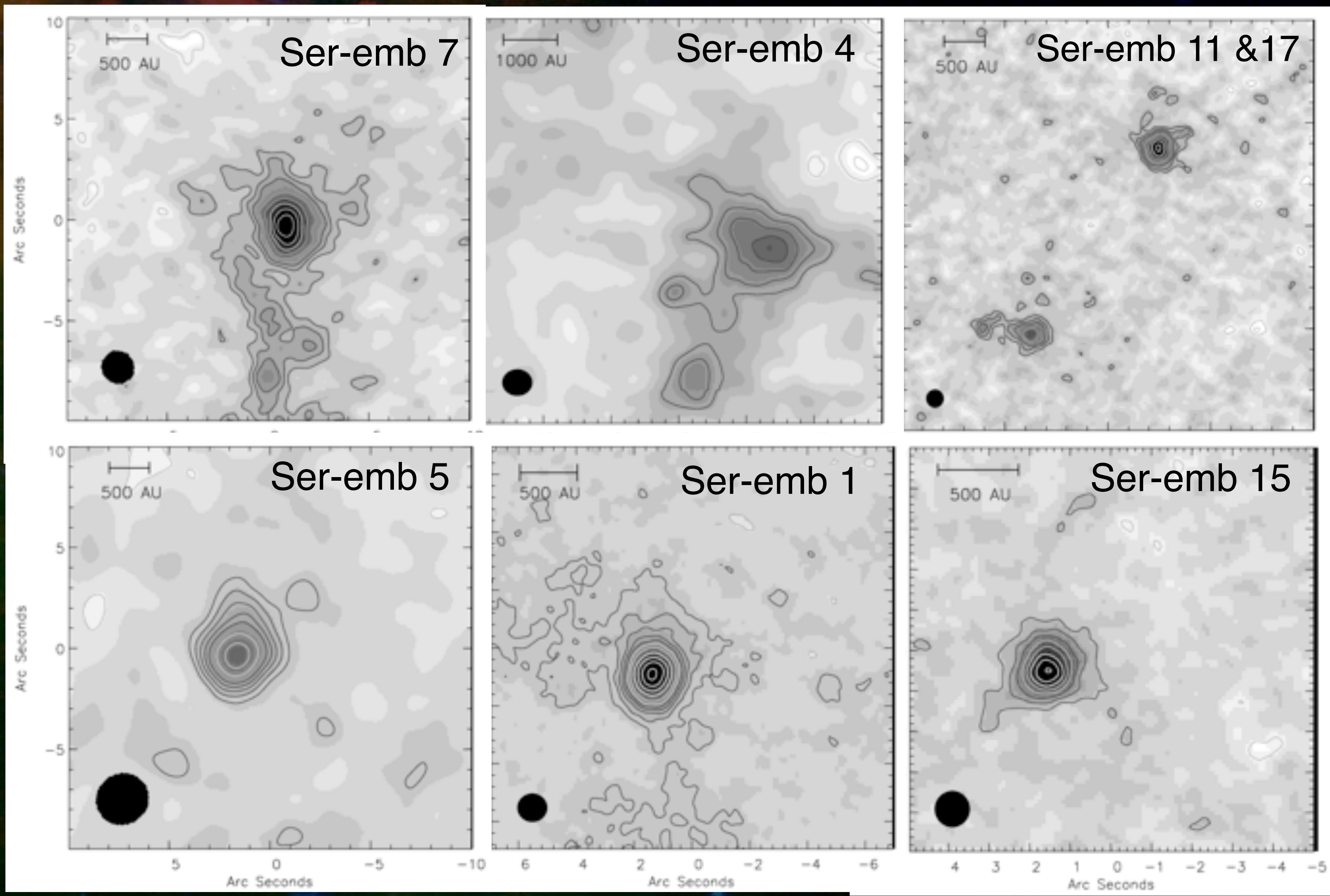
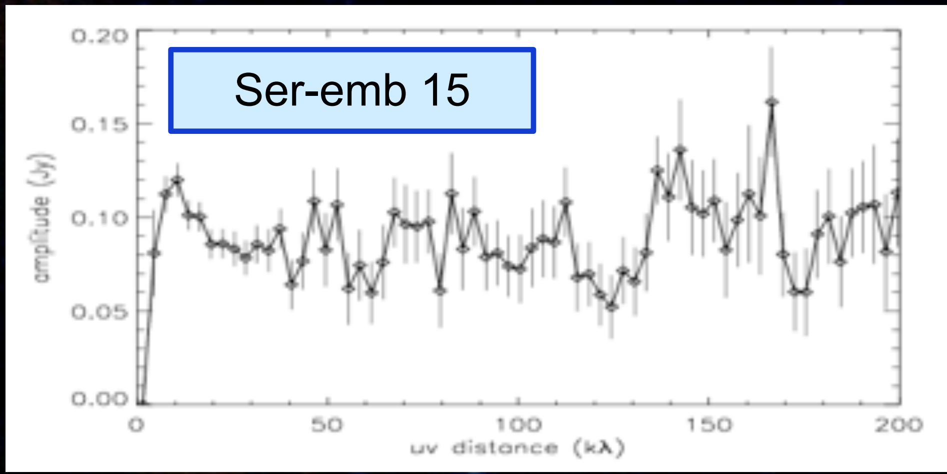
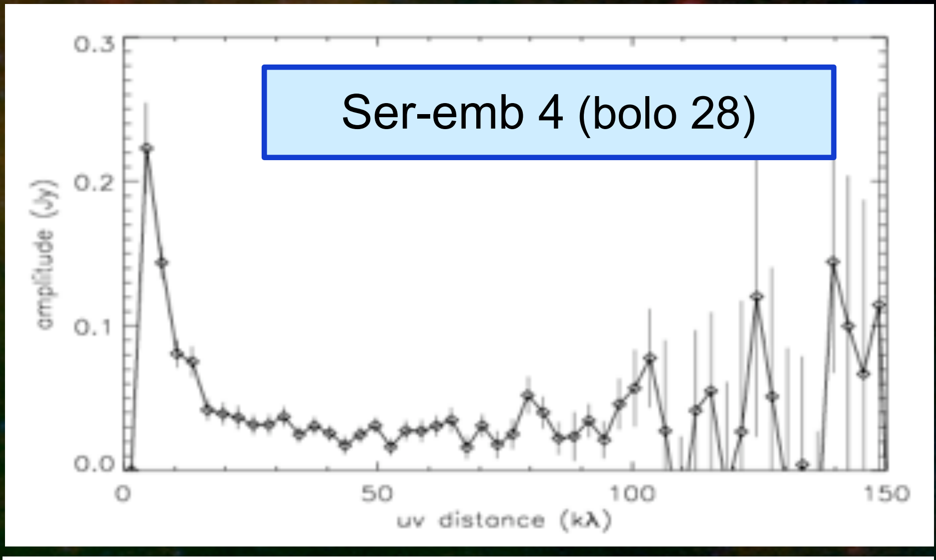
Serpens sources

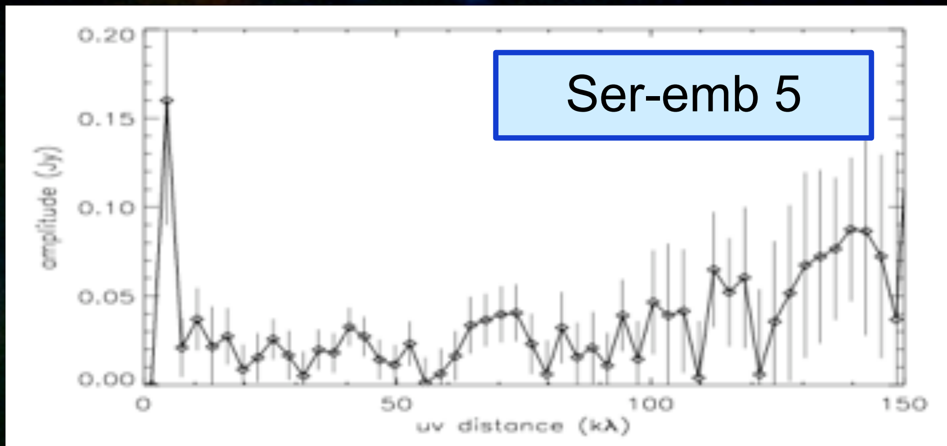
CARMA maps: Serpens Class 0 protostars

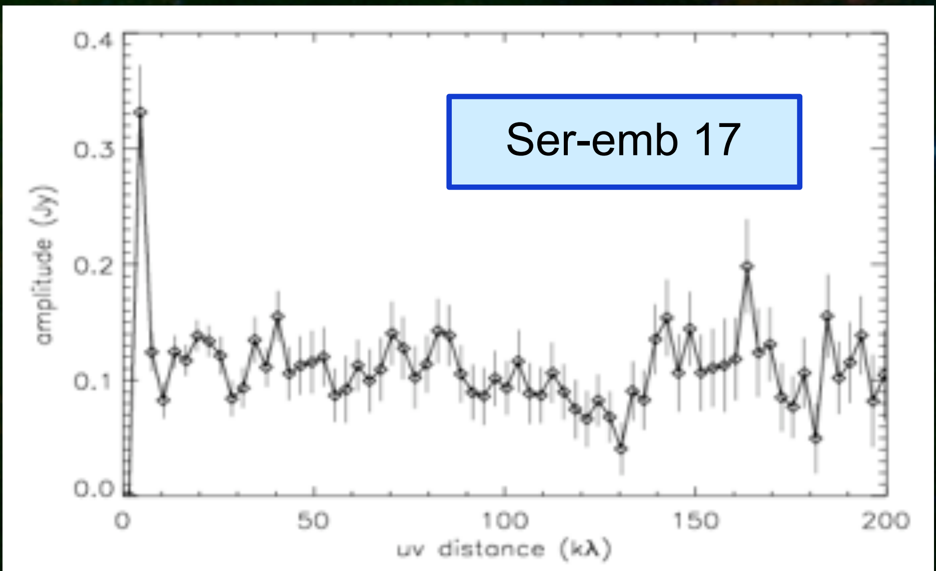


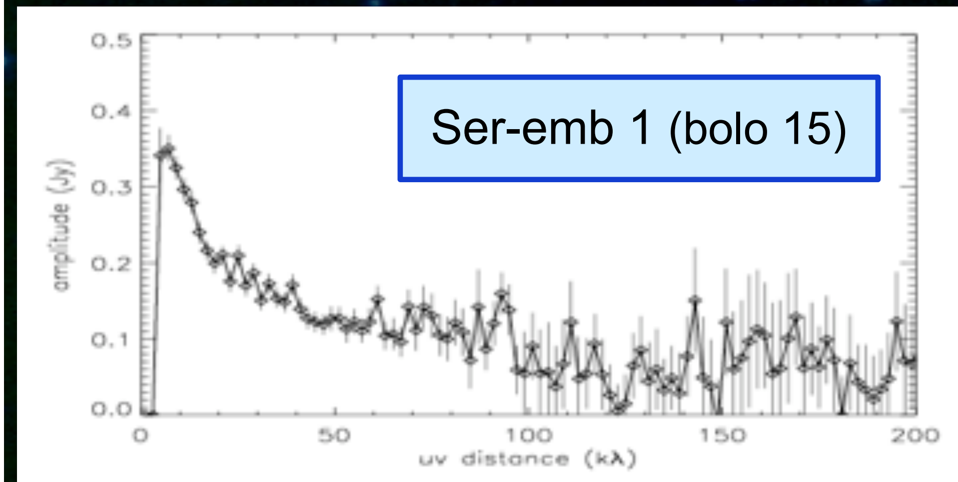
CARMA 1.3 mm visibilities











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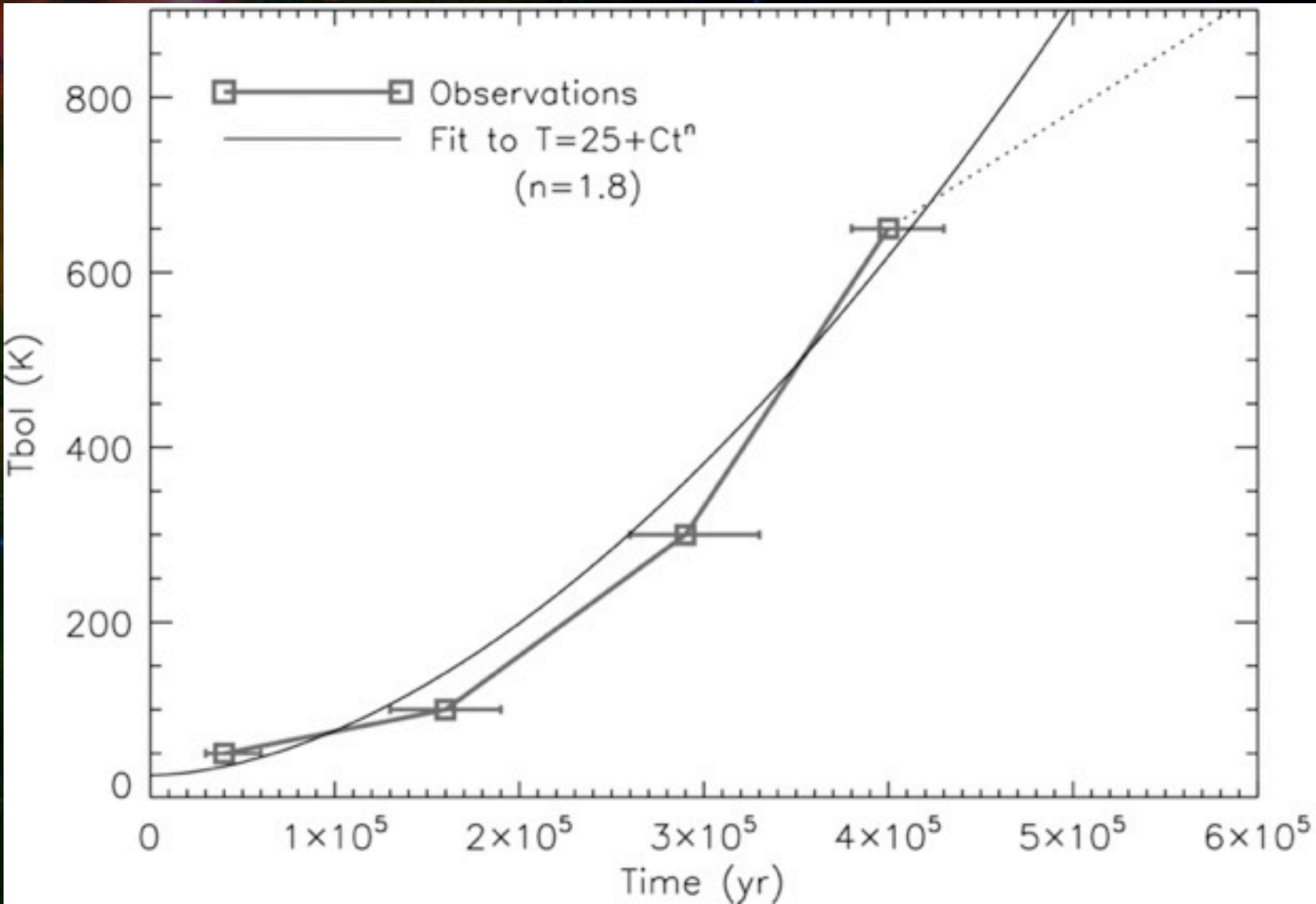
HAVE DATA FOR 8 SERPENS SOURCES SO FAR. Note uv coverage
Spitzer images (7,24,70 micron) with CARMA 1.3mm contours. Visibilities = amplitude as a function of uv-distance or baseline. Tell you more than images.
Another resolved, less resolved, unresolved with extended envelope, disk only?

Relationship between Tbol & "age"



Enoch et al. 2009

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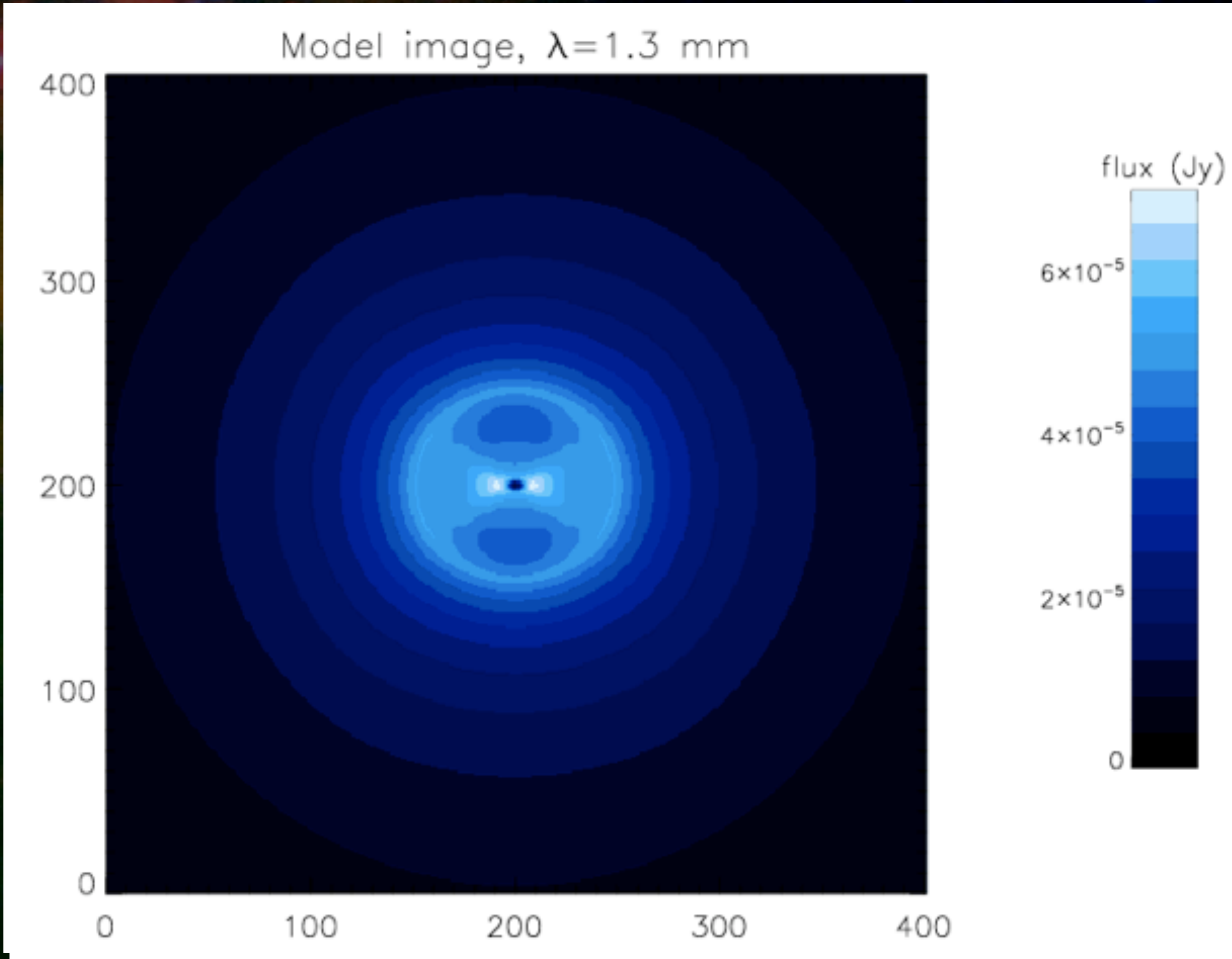
Based on number counts

Ser-Bolo 23



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First source. Both pretty low inclination. Larger outflow angle.

Serpens Class 0 sources

TABLE 3
BOLOMETRIC TEMPERATURES, LUMINOSITIES, AND ENVELOPE MASSES OF COLD PROTOSTARS IN SERPENS

	ID	c2d name/position (SSTc2dJ...)	T_{bol} (K)	L_{bol} ($L_\odot$)	α_{IR}	M_{env} ($M_\odot$)	Bolocam ID	Other Names	
	Class 0								
S,V →	Ser-emb 1	J182909.24+003132.3	39 (2)	1.6 (0.1)	2.27 (0.08)	1.16 (0.02)	Bolo 15		
S →	Ser-emb 2	J182952.44+003611.7	42 (10)	1.0 (0.1)	0.77 (0.05)	0.54 (0.03)	Bolo 24[a]		3mm (ND)
S →	Ser-emb 3	J182854.84+002952.5	51 (12)	2.6 (0.1)	1.91 (0.06)	1.54 (0.15)	Bolo 8[a]		3mm (MD)
S,V →	Ser-emb 4	J183000.72+011301.4	54 (16)	1.2 (1.6)	1.68 (0.08)	2.56 (0.03)	Bolo 28[a]		
S,V →	Ser-emb 5	J182854.84+001832.6	56 (12)	0.16 (0.1)	0.9 (0.06)	0.24 (0.02)	Bolo 7[a]		
S,V →	Ser-emb 6	J182949.56+011521.9	56 (12)	11.0 (6.0)	2.65 (0.07)	7.98 (0.07)	Bolo 23[a]	FIRS1	
S,V →	Ser-emb 7	J182854.12+002929.9	58 (13)	3.1 (0.1)	1.36 (0.06)	1.67 (0.17)	Bolo 8[a]		3mm
Prev →	Ser-emb 8[b]	J182948.12+011644.9	58 (16)	2.1 (2.4)	1.37 (0.06)	3.72 (0.37)	Bolo 22[a]	S68N	
	Ser-emb 9	J182855.92+002944.7	66 (21)	0.34 (0.63)	1.89 (0.06)	1.19 (0.12)	Bolo 8[a]		3mm (MD)
	Class I								
	Ser-emb 10[c,d]	J182845.12+005203.5	75 (14)	1.09 (0.05)	1.33 (0.06)	0.29 (0.03)	Bolo 3[a]	IRAS 1862+0050	3mm
S,V →	Ser-emb 11	J182906.72+003034.3	77 (12)	1.9 (1.2)	1.66 (0.06)	1.39 (0.14)	Bolo 14[a]		3mm
	Ser-emb 12[b]	J182952.08+011547.8	85 (9)	2.6 (1.2)	1.54 (0.06)	1.23 (0.12)	Bolo 23[a]	SMM 10 IR	
	Ser-emb 13	J182902.04+003120.6	86 (31)	0.05 (0.09)	0.24 (0.06)	0.17 (0.02)			
	Ser-emb 14	J183005.40+004104.5	100 (32)	0.08 (0.1)	1.3 (0.07)	0.19 (0.02)			
V →	Ser-emb 15	J182954.24+003601.3	101 (43)	0.17 (0.27)	-0.18 (0.06)	0.48 (0.05)	Bolo 24[a]		3mm
	Ser-emb 16[d]	J182844.76+005125.7	110 (26)	0.04 (0.6)	1.07 (0.05)	0.24 (0.02)	Bolo 3[a]		3mm (ND)
S,V →	Ser-emb 17	J182906.36+003043.2	117 (21)	1.5 (1.3)	1.7 (0.06)	1.38 (0.14)	Bolo 14[a]		3mm

- **S**=spectra (IRS), **V**=visibilities (CARMA), **Prev**=existing data, **3mm**=3mm flux (CARMA)

Try to do all Class 0 in the cloud. Few had spectra in archive already. Few class I for good measure. When got 3mm data w/ carma (lower res, for mult), found most of mass (at least compact) was assoc w/ one sometimes.... In case of Bolo 24, had picked the wrong one, only have vis. Didn’t do 1mm obs if not det at 3mm (maybe just no disk, but still have to quantify env)

PROSAC: A Submillimeter Array survey of low-mass protostars

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Jørgensen et al. A&A, in press (astro-ph: 0909.3386)

TABLE 1
Sample of Sources

Source: Full Name	Source: Short Name	Pointing Center[a]: α (J2000.0)	Pointing Center[a]: δ (J2000.0)	Association	Distance (pc)
L1448C(N)[b]	L1448	03 25 38.80	+30 44 05.0	Perseus	220
NGC 1333 IRAS 2A	IRAS 2A	03 28 55.70	+31 14 37.0	Perseus	220
NGC 1333 IRAS 4A	IRAS 4A	03 29 10.50	+31 13 31.0	Perseus	220
NGC 1333 IRAS 4B	IRAS 4B	03 29 12.00	+31 13 08.0	Perseus	220
L1527 IRS............................	L1527	04 39 53.90	+26 03 10.0	Taurus	140
L483 FIR..............................	L483	18 27 29.85	−04 39 38.8	Isolated	200
B335.....................................	B335	19 37 00.90	+07 34 10.0	Isolated	250
L1157 MM............................	L1157	20 39 06.20	+68 02 15.9	Isolated	325

Very similar program with SMA, but don't have SED info. Also have lines to trace outflows, etc, and keplerian motion in Class I. Still brightest most famous sources....