Numerical Models of the First Cores: Comparison with Observed Candidates

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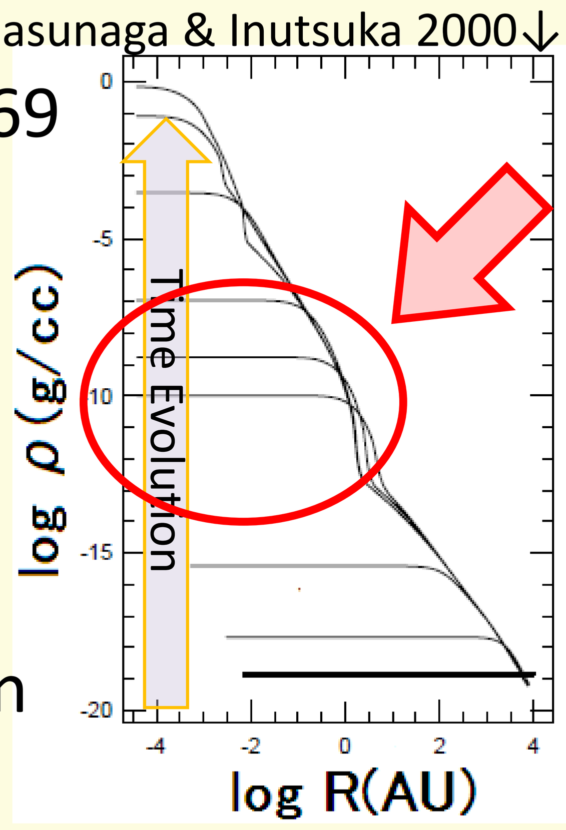
First Cores

What is the first (adiabatic) core?

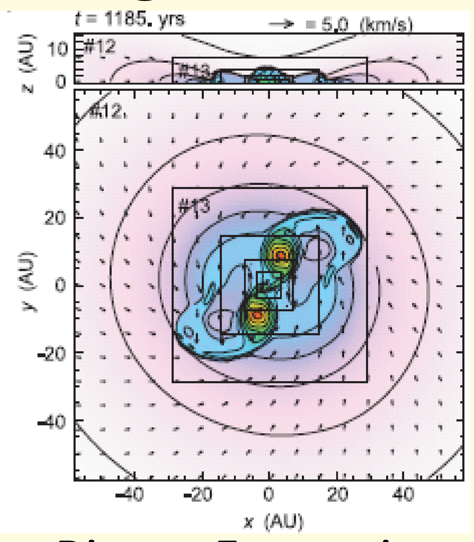
- First theoretically proposed by Larson 1969 but observationally not confirmed yet
- Highly optically thick and adiabatic
- Transient (τ ≲ 1000 yrs) but stable object supported by gas pressure and rotation

Masunaga & Inutsuka 2000↓

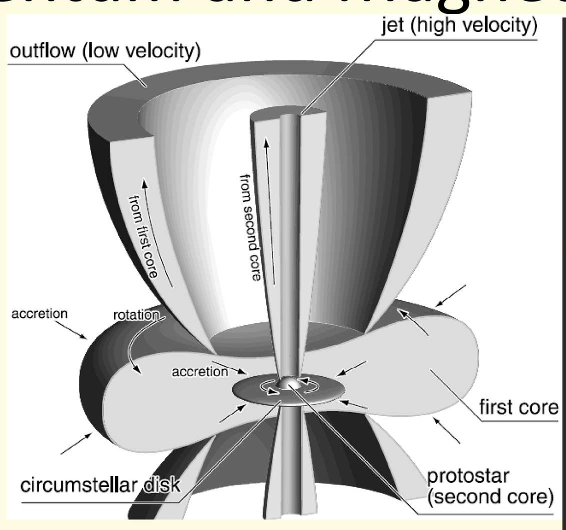


Why do we study the first core?

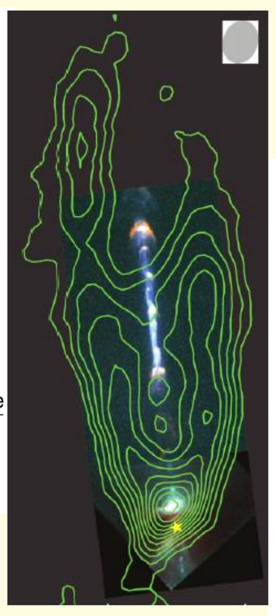
- We can confirm (constrain) star-formation theories if we could observe it directly!
- Angular momentum and Magnetic flux Problem



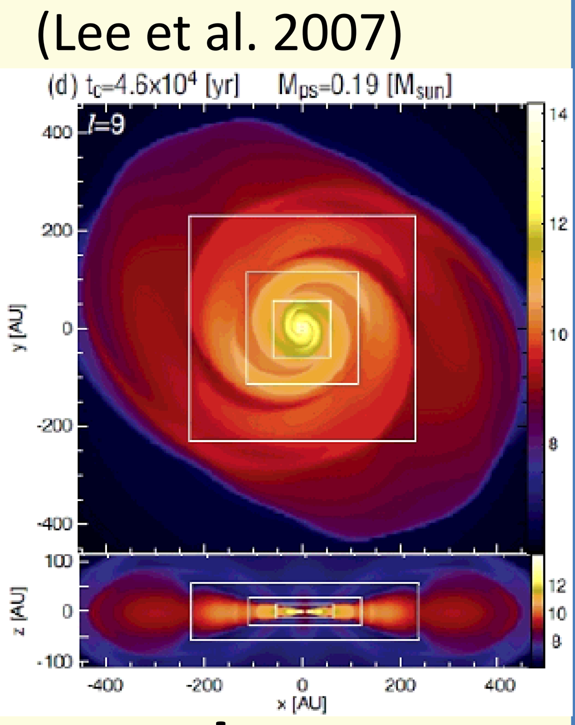
Binary Formation (Saigo et al. 2008)



Outflow Driving↑ (Machida et al. 2008)



←HH111 (Lee et al. 2007)



Circumstellar / proto-planetary Disk Formation (Machida et al. 2010)→

⇒ **First Cores are rich sites of many important phenomena**

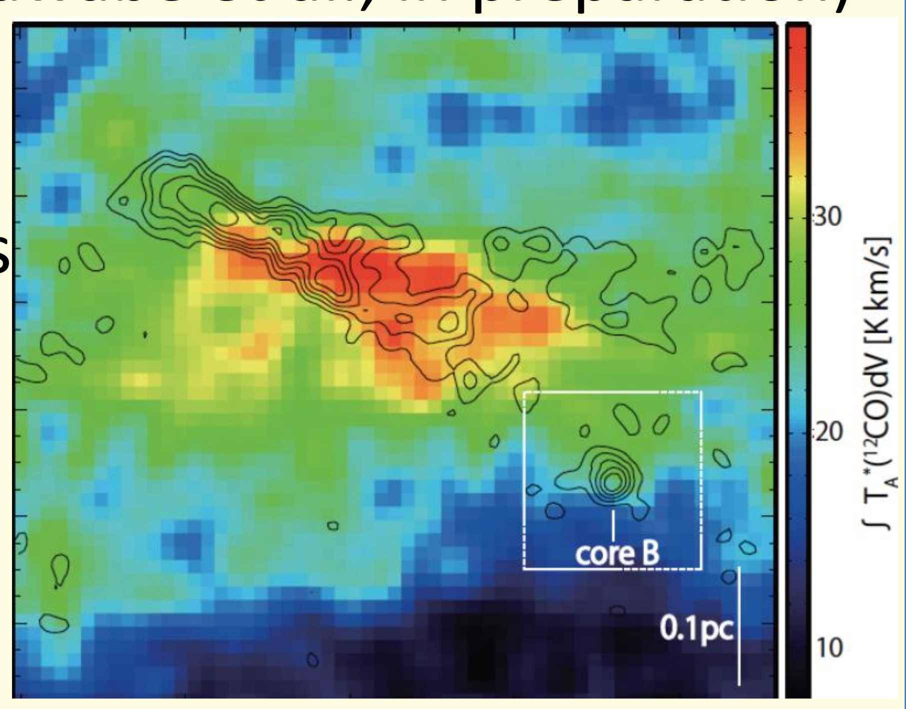
Observations of First Cores

First cores are difficult to observe because they are faint and rare due to short lifetime, **but**, very recently, several candidates are reported:

- L1448 IRS2E, Chen et al., 2010, ApJ, 715, 1344
- R CrA SMM 1A, Chen & Arce, 2010, ApJL, 720, 169
- Per-Bolo 58, Enoch et al., 2010, ApJL, 722, 33

Here, we report another first core candidate, "Core B" in Lupus-I star-forming region. (Kawabe et al., in preparation)

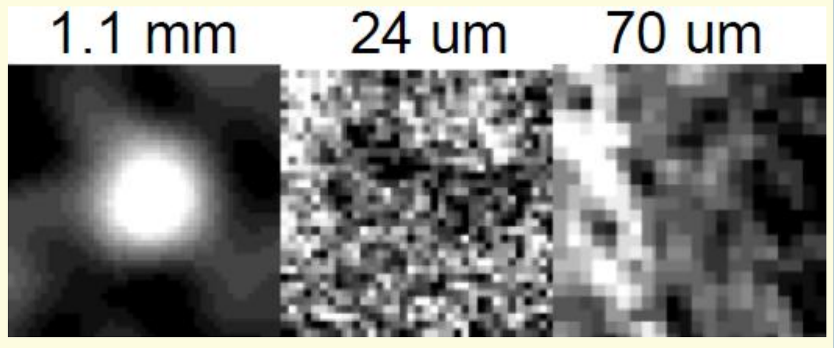
→Color: 12CO(J=1-0) map w/ Nobeyama 45m telescope
Contours(from 3 σ, at intervals of 1.5σ): 1.1 mm dust cont. w/ AzTEC on ASTE telescope



Features of "Core B":

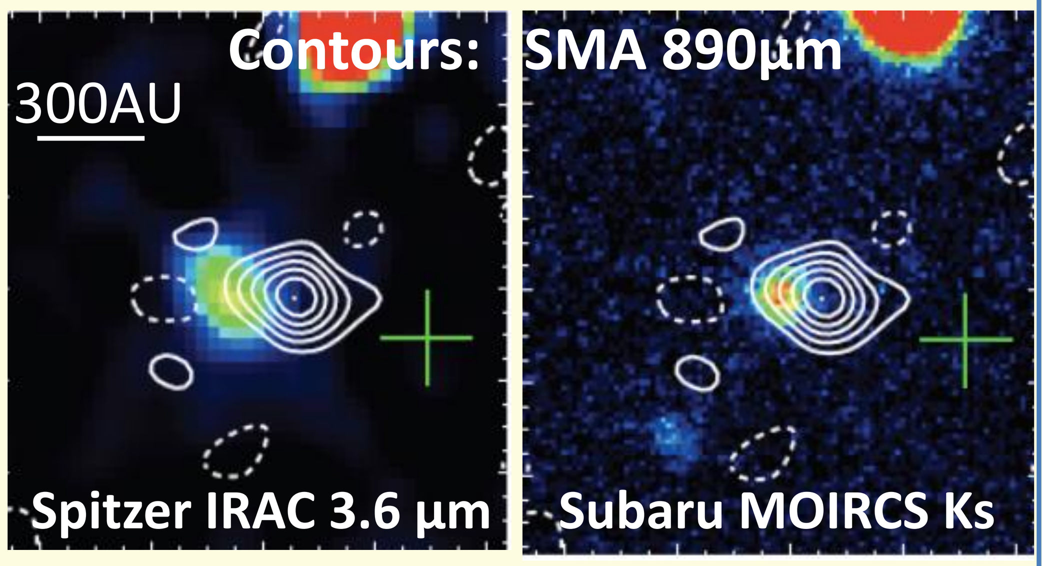
- **Very low mass**: M ~ 0.1 Ms (assuming Tdust=10K and $\kappa_{1.1mm}$=0.0052 cm²/g)
- **Very compact** (≲ 150 AU) in SMA 0.89 mm image
- **No stellar signature** in 24/70μm
- No high velocity(>10km/s) wing

⇒ Extremely young phase!!!



Note: In near-infrared region, weak emissions are detected, but we Find it difficult to explain the observed SED with a single object. Therefore, we consider it as a back-ground galaxy because:

1) its position/morphology is inconsistent with SMA image
2) its SED is well fitted by synthetic SED models constructed from the simple stellar populations (SSPs)



Comparison with RHD models

Features of our simulation code (Tomida et al., 2010, ApJL):

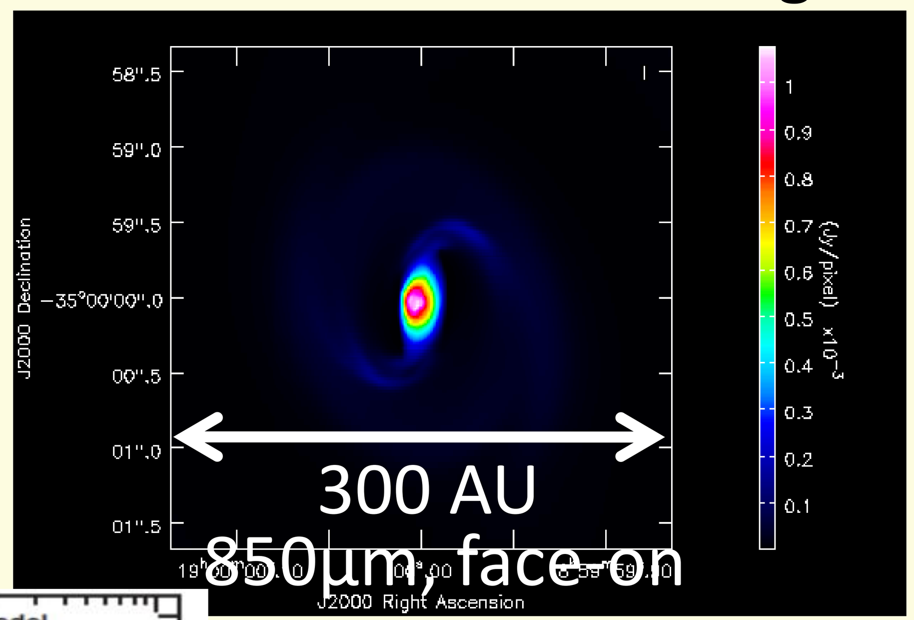
- 3D Nested-grids, synchronous timesteps
- (MHD: 2nd-order Roe with hyperbolic div **B** cleaning)
- Self-gravity: Multigrid ・**Radiation Transfer: FLD** (gray)
- Opacity: Semenov et al. 2003 + Ferguson et al. 2005
- Gas EOS: ideal, γ =1.4 (assuming diatomic molecules)

Post-Processing Radiation Transfer of Dust Continuum:

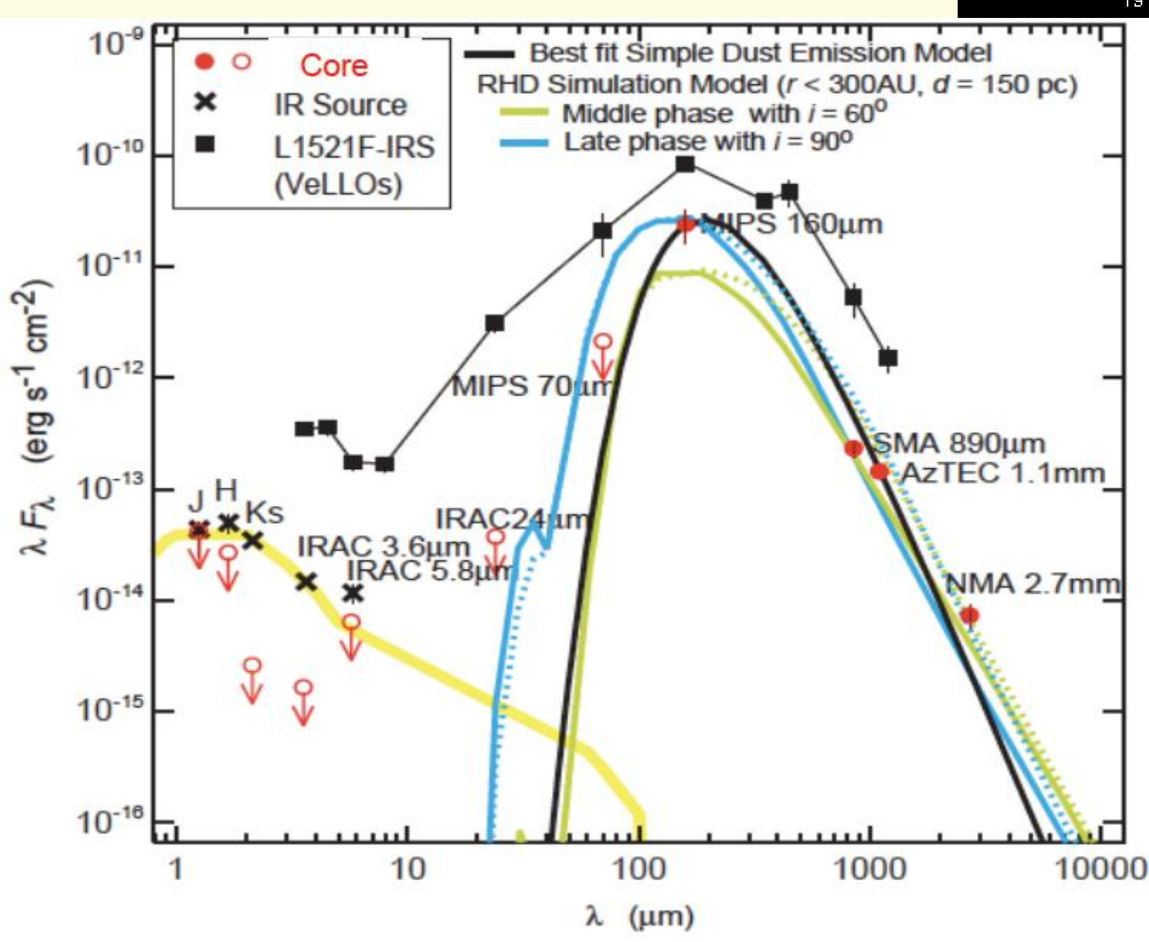
- Use the temperature dist. in the results of RHD simulations
- Ignore scattering (valid in mid-infrared ~ mm wavelengths)
- Solve 1-direction radiation transfer for various wavelengths:

$$\frac{dI_\nu}{ds} = \rho\kappa_\nu (B_\nu(T) - I_\nu)$$

- Obtained intensity map →
- Integrate in specific aperture to calculate model SEDs



Observed & Model SEDs:



●: detection above 3σ
○: 3σ upper-limit
Green: middle phase, i=60°
Blue: late phase, edge-on

Dust opacity models:
Semenov et al., 2003
- Homogeneous sph. (solid)
- Comp. aggregates(dotted)

Yellow: model SED of the back-ground galaxy

- The observed SED is well-fitted by rotating non-magnetized models with **very low mass, M_{cloud} ~ 0.1 Ms (!)**
- "Core B" is significantly fainter than a Very Low-Luminosity Object, L1521F-IRS (Bourke et al., 2006)
- Considering large uncertainty in MIPS 160 μm flux, we think the model at the middle phase is better.

Another possible interpretation:

Ultra bright submillimeter galaxy (SMG) at extremely high-z (z > 4 !) can explain the SED in radio wavelengths (only) if it is brightened by unusually strong gravitational lensing. Such an event must be very rare, and it cannot reproduce the observed SED in near infrared wavelengths (< 2 μm).

Conclusions

- We carried out multi-wavelengths observations in Lupus-I star-forming region, and detected a peculiar dense core, **"Core B"**, which is **a good candidate of a first core**.
- To directly compare the observations with theoretical models, we calculated model SEDs based on the results of **realistic RHD simulations**.
- The observed SED can be well fitted by **very low mass** first core models.
- Observing these first core candidates with **ALMA** must contribute to our understanding of star-formation!!