Star07 @ KITP
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The role of dust in metal-poor star formation

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Outline

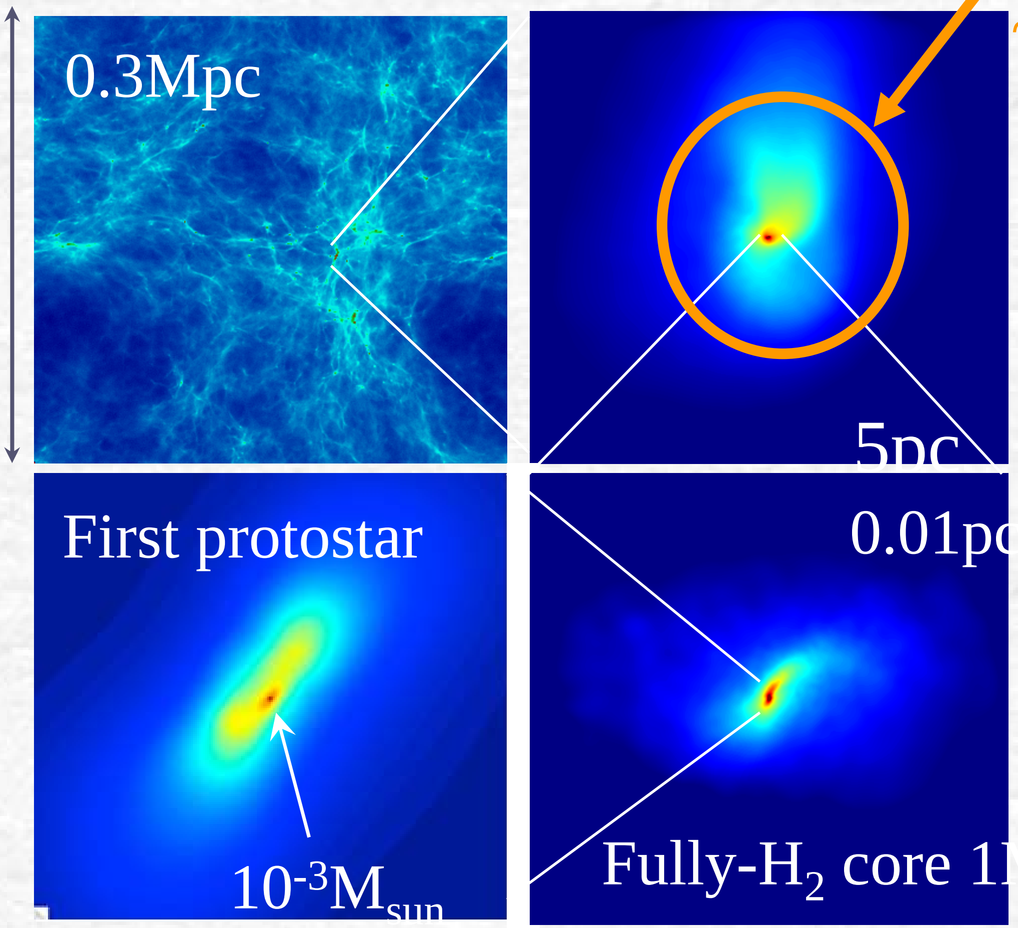
- Thermal evolution of low-Z gas
- The critical Z for low-mass star formation
- Origin of cutoff at in MDF

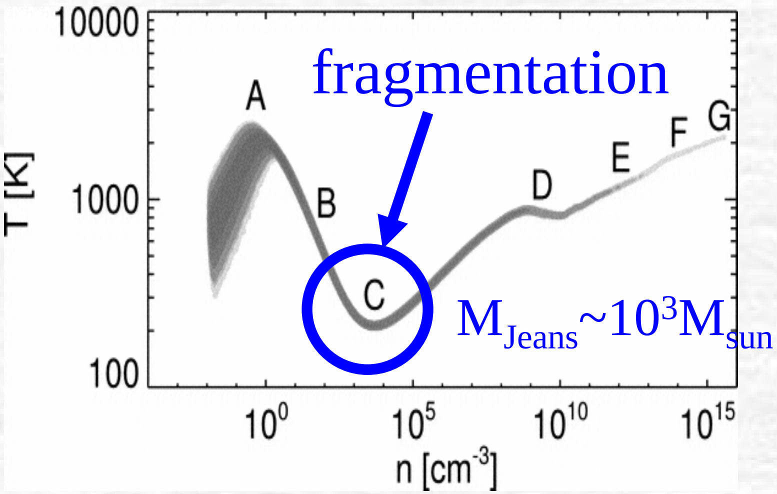
+

- first-star binary formation

Mass of primordial-gas dense core

dense core (fragment)
~1000M_{sun}





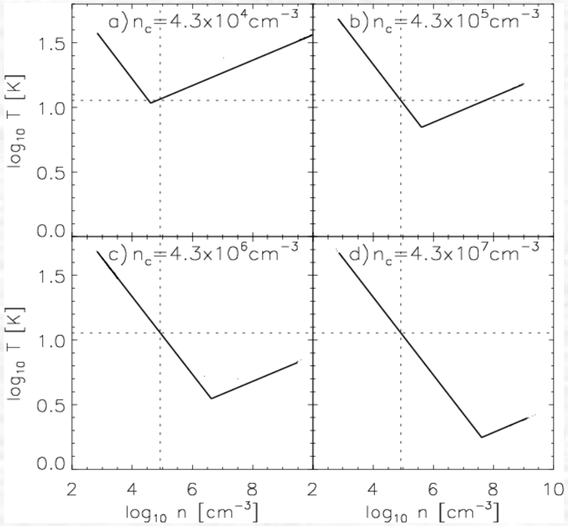
M_{frag}~ M_{Jeans}@T min

Yoshida et al. in prep.

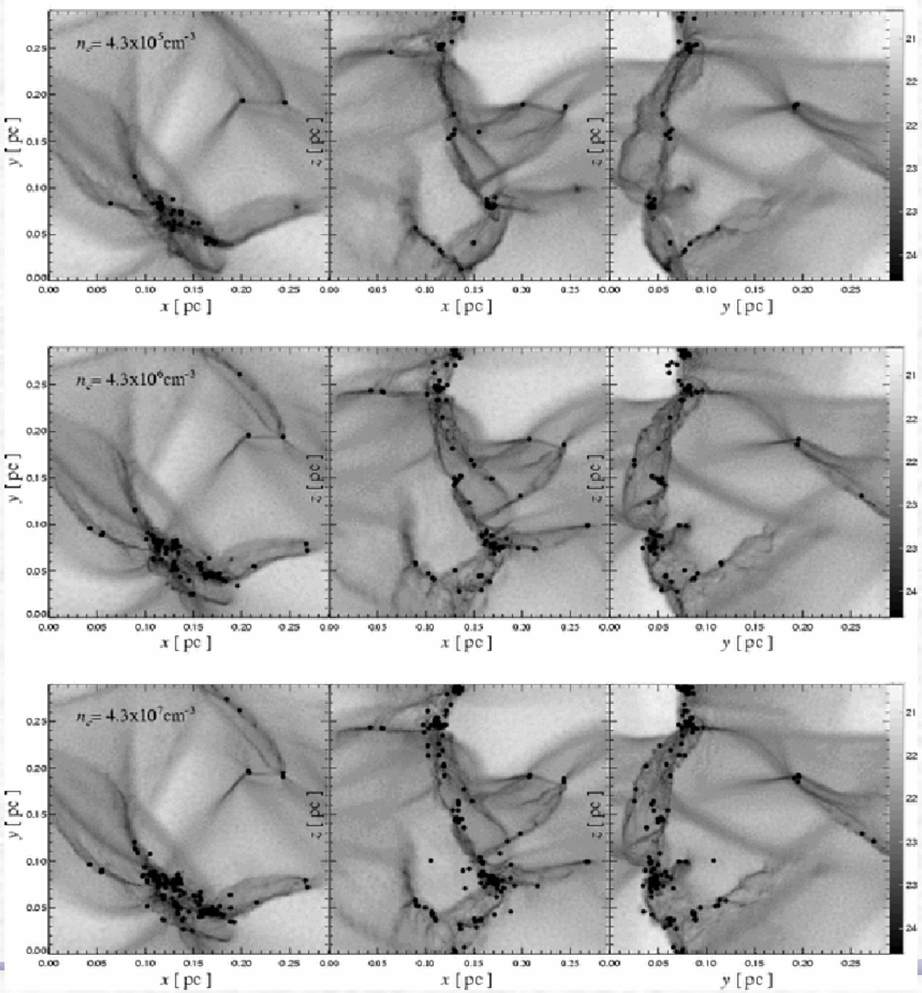
Fragmentation of turbulent cloud

(Jappsen et al. 2005)

Assumed EOS



At the time 50% of mass is accreted

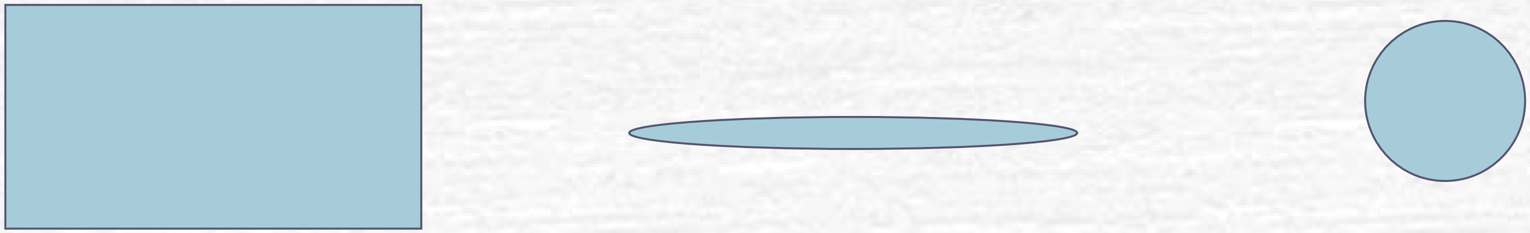


- Vigorous fragmentation for $\gamma<1$, fragmentation suppressed for $\gamma>1$
- Characteristic mass~ Jeans mass at temperature minimum

Fragmentation and thermal evolution

γ=dlog p/dlogρ

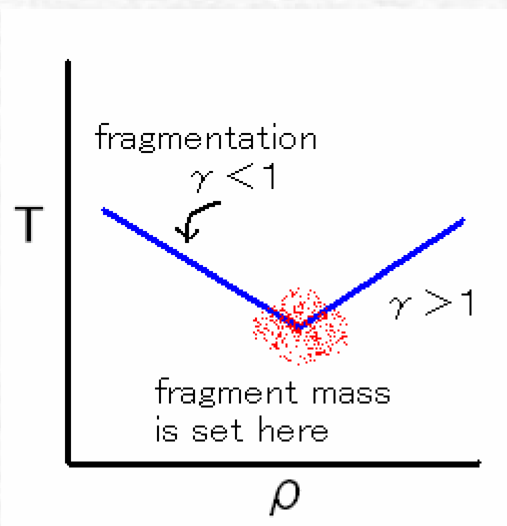
If $\gamma > \gamma_{crit}$, the collapse stops



sheet: $\gamma_{crit} = 0$

filament: $\gamma_{crit} = 1$

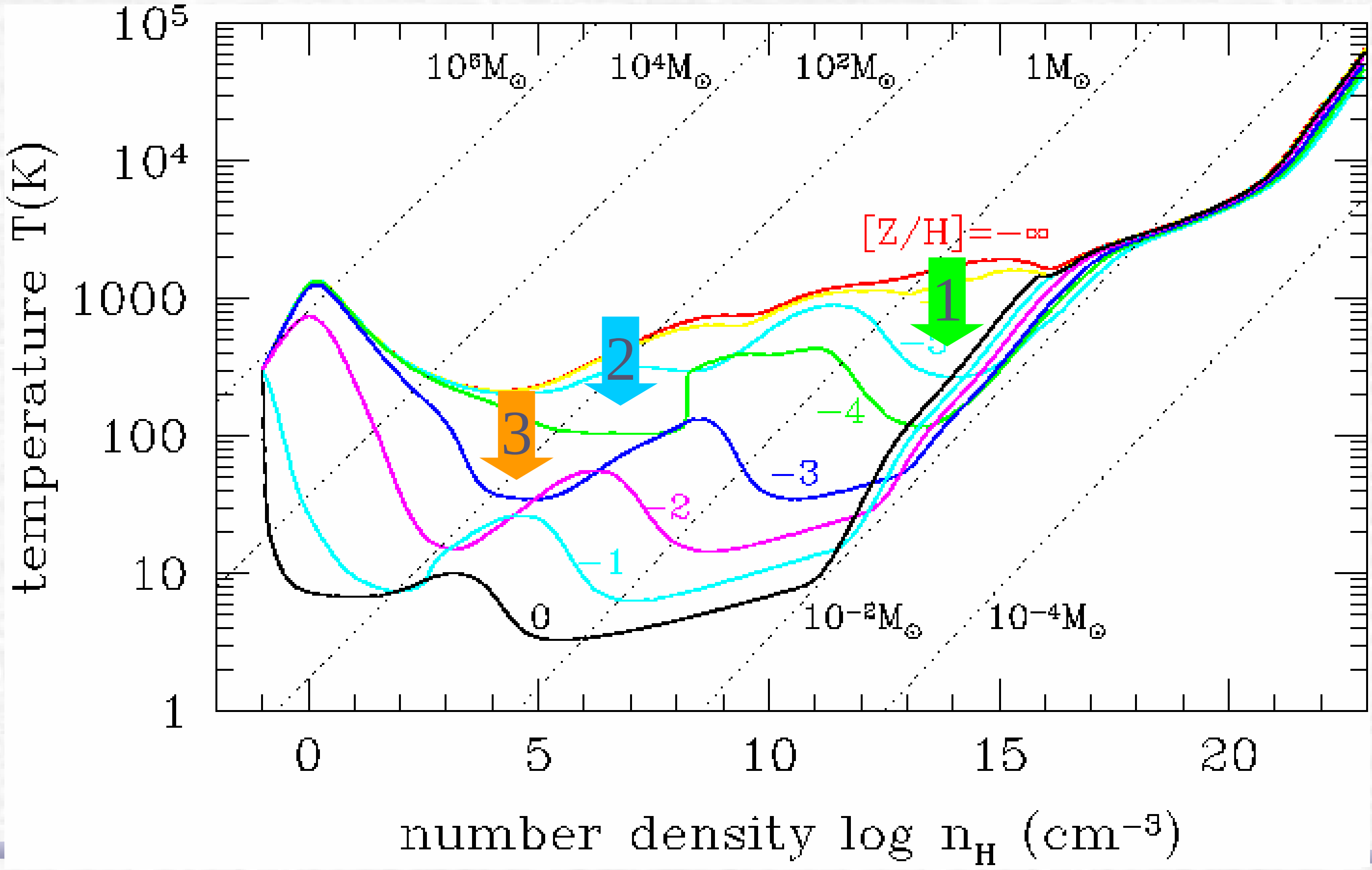
sphere: $\gamma_{crit} = 4/3$



Initially the cloud takes complicated shape.
Before the fragmentation, it is filamentary.
As a thumb rule,
Fragmetation occurs while $\gamma < 1$, and stops while $\gamma > 1$

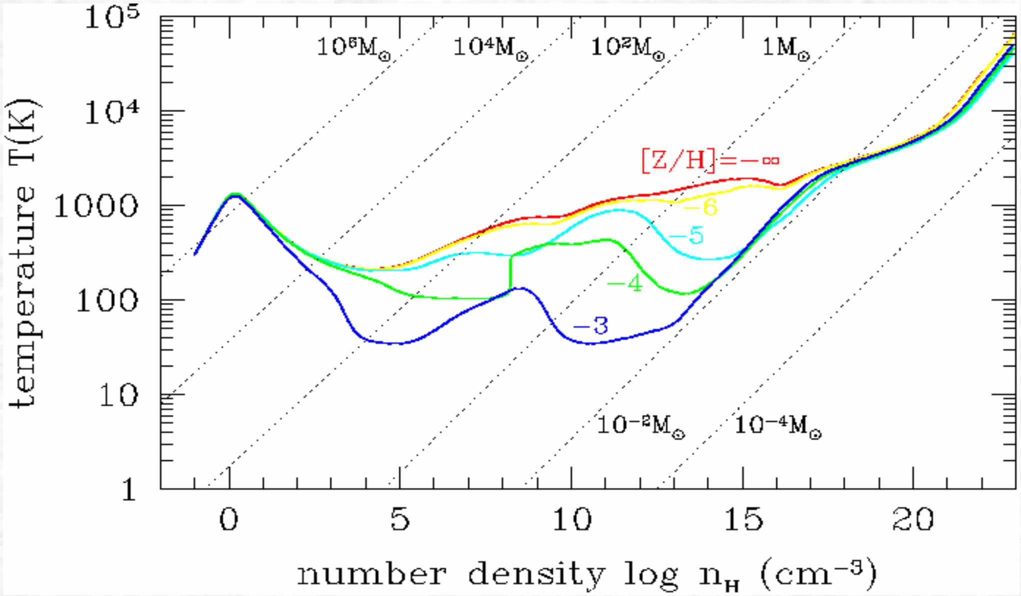
Thermal Evolution of clouds with different Z

1) Cooling by dust thermal emission: [Z/H] > -5
2) H_2 formation on dust : [Z/H] > -4
3) Cooling by metal lines: [Z/H] > -3



K.O., Tsuribe, Schneider & Ferrara (2005)

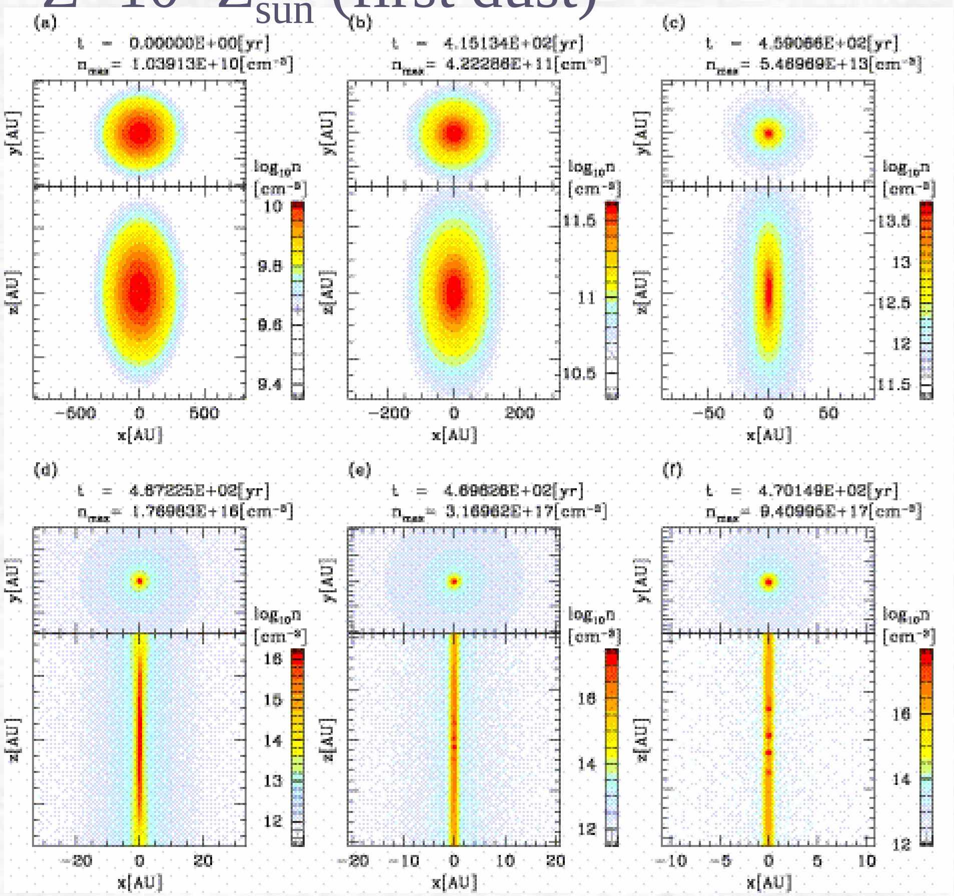
How much is the critical metallicity (gas-dust ratio) by dust cooling ?



Dust-induced fragmentation

Tsuribe & K.O. (2006)

$Z=10^{-5}Z_{sun}$ (first dust)



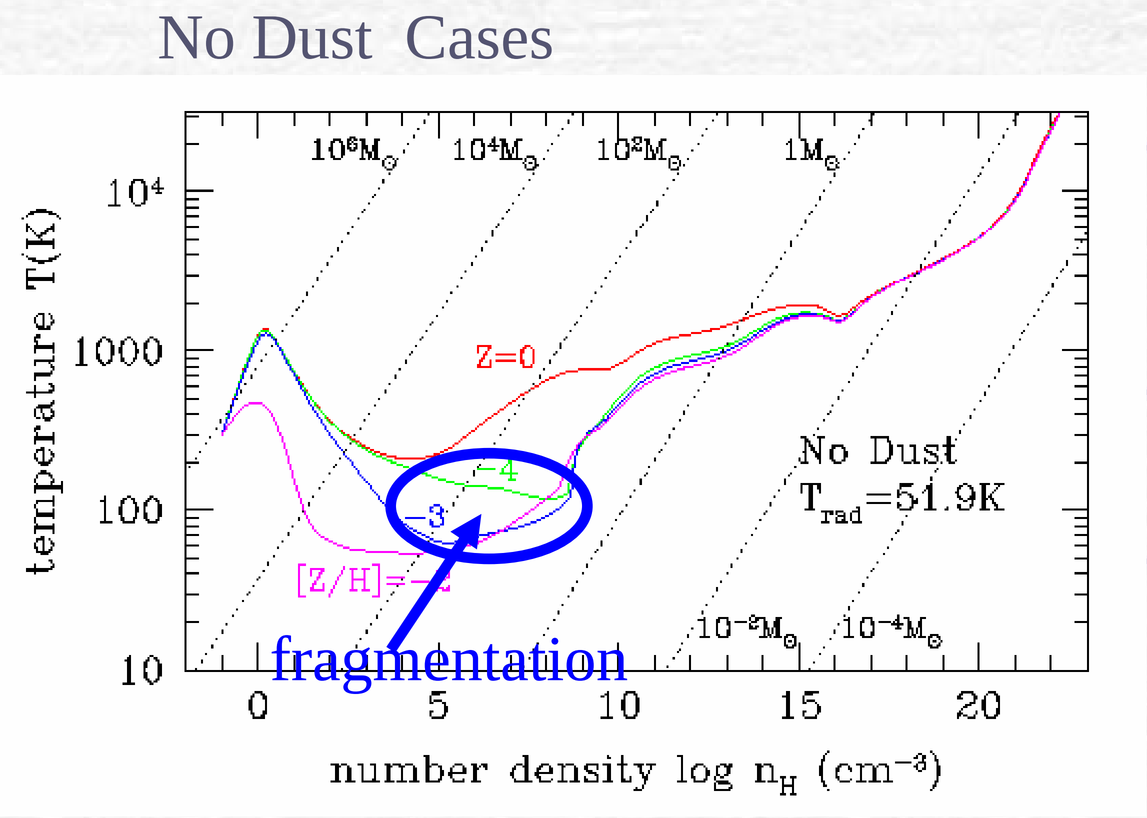
- With gas-dust ratio $Z>\sim10^{-6}Z_{sun}$ (first dust: smaller grains)
  ➔low-mass fragments by dust cooling

Standard dust

$$Z_{cr}\sim10^{-6}\text{-}10^{-5}\ Z_{sun}$$

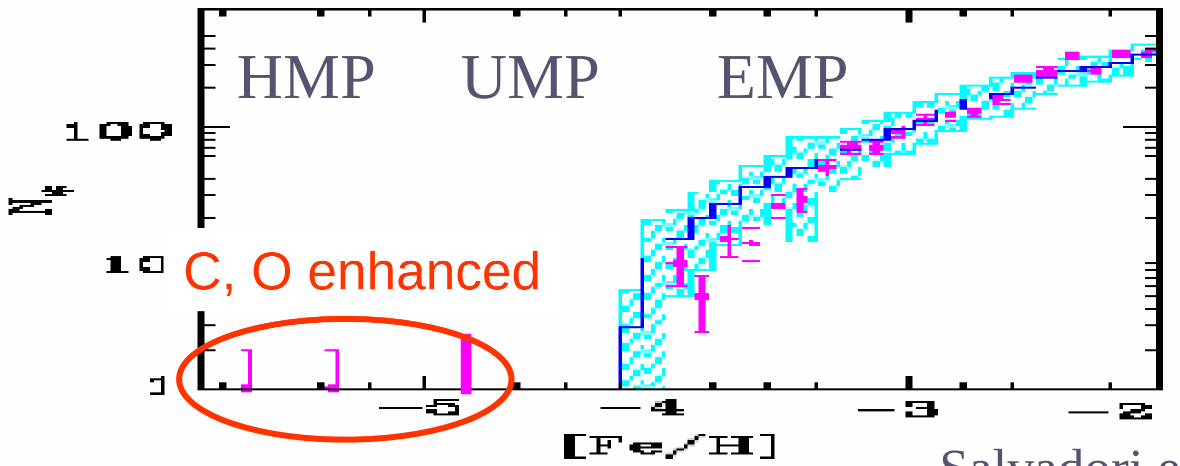
First dust

If there were no dust…



- With only metal-line cooling, T increases for n>~10^8cm^{-3}
- Fragmentation mass ~10-100M_{sun}
- Dust is indispensable for low-mass star formation

Cutoff at [Z/H]~-4 in stellar metallicity distribution function

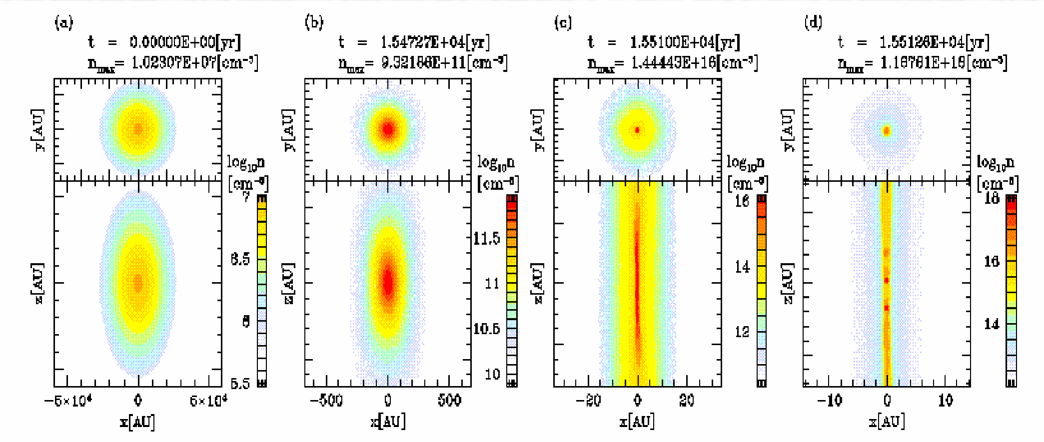


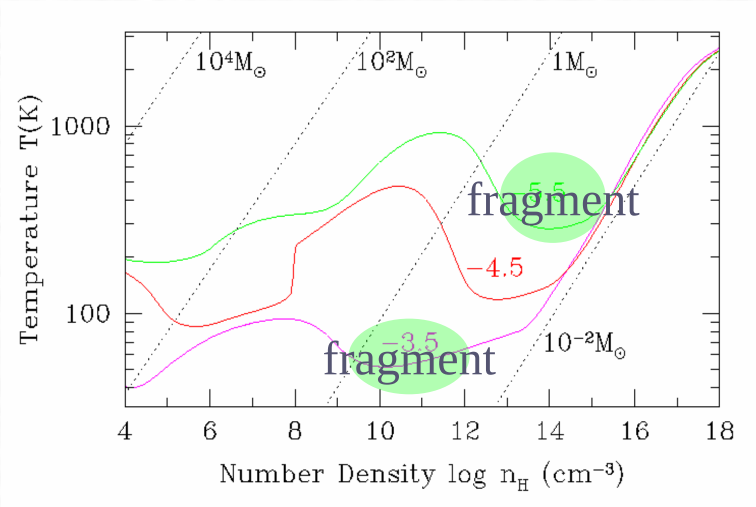
Salvadori et al. 2006

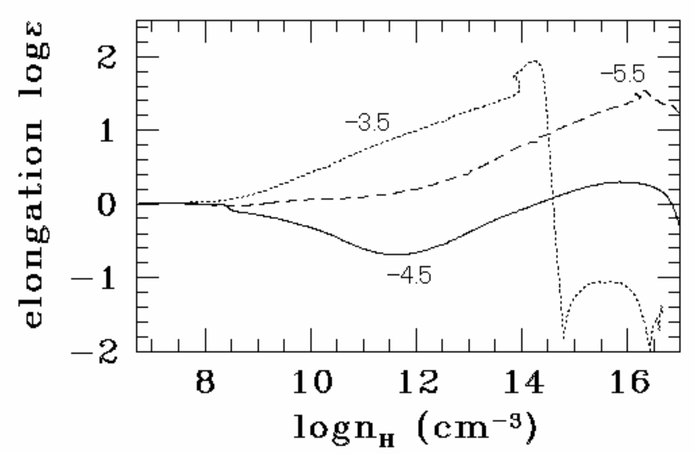
- Several 100 of EMP stars
- Only three HMP or UMP stars:
  all C, O enhanced with [Z/H]>-4
  ➔Sharp cutoff at [Z/H]~-4
- Even if C,O in HMP stars are *a posteriori* (e.g., accretion from a binary companion), scarcity of UMP stars remains a mystery.
  (“metallicity desert”)

Cases of [Z/H]=-5.5, -3.5

[Z/H]=-5.5





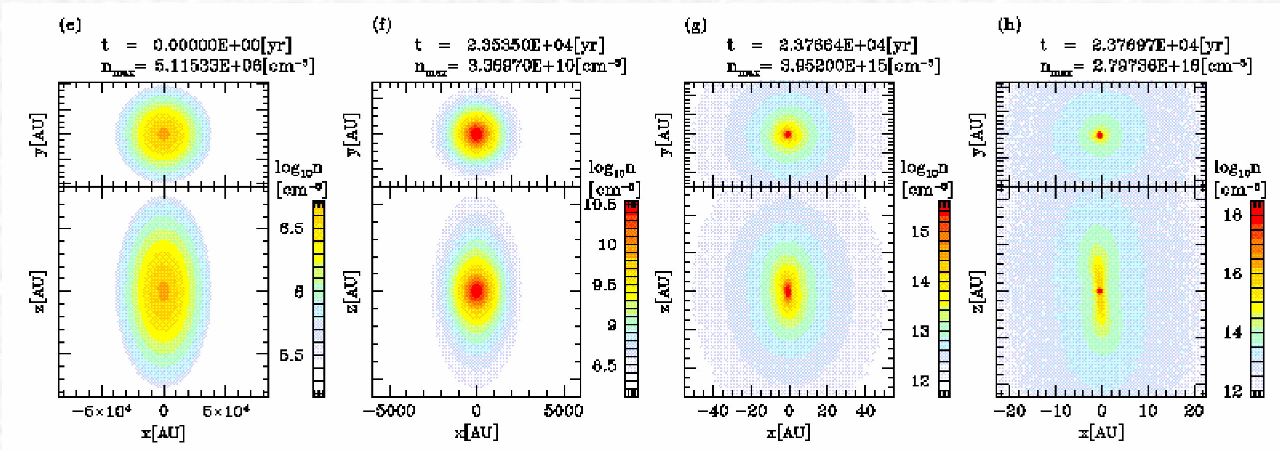


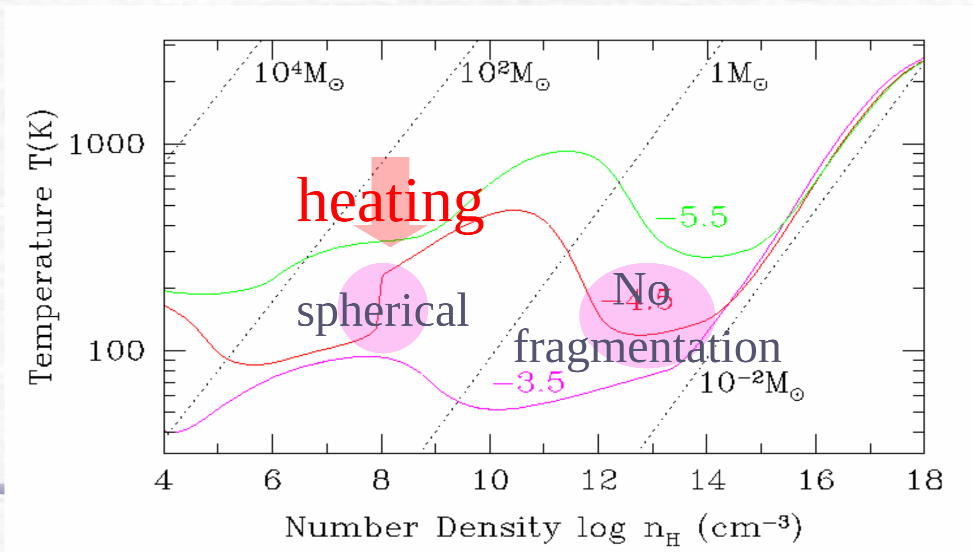
- Long filament formation during dust-cooling phase
  ➔ fragmentation

Case of [Z/H]~-5…-4

Tsuribe & K.O. (2007) in prep.

[Z/H]=-4.5, first dust

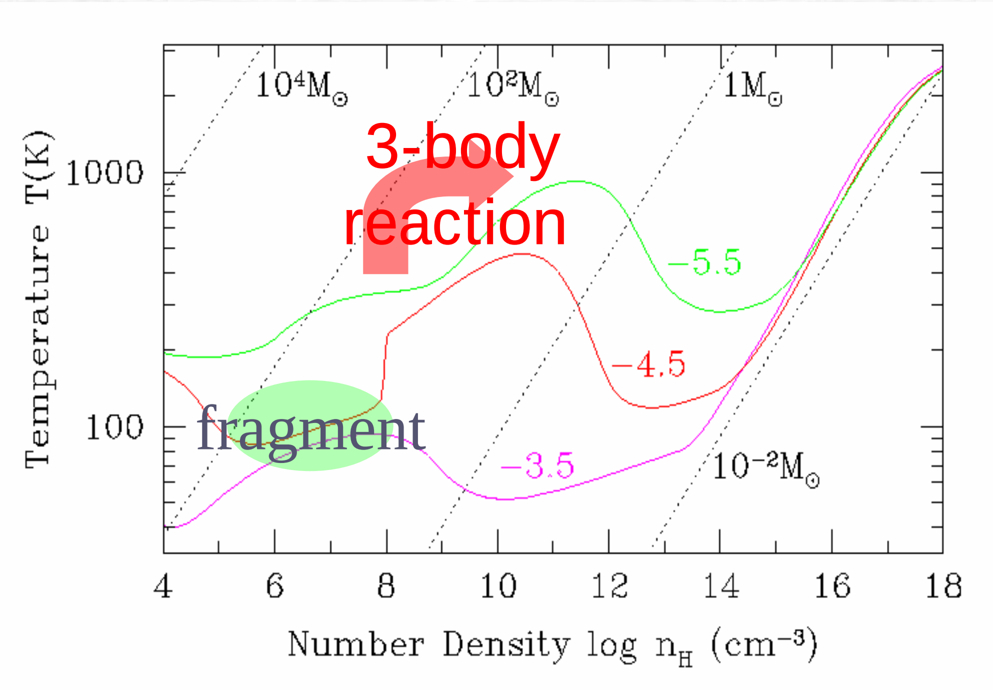




- Sudden H_2 formation heating ➔ very spherical hydrostatic core
- No fragmentation in the dust-cooling phase

Why sudden heating only at [Z/H]~-4.5 ?

Temperature evolution



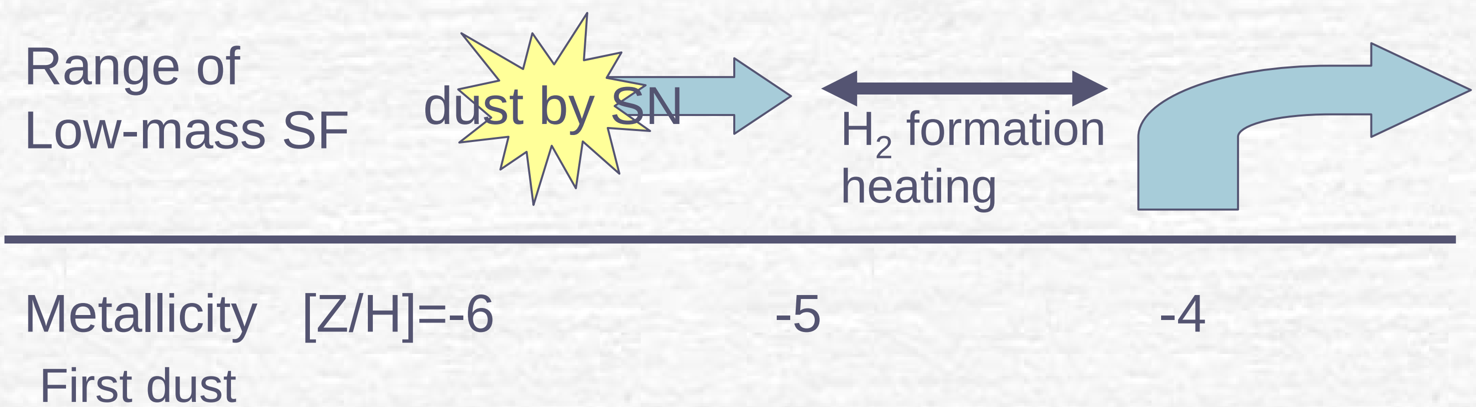
- 3-body reaction $n>10^8 cm^{-3}$
- At [Z/H]~-5.5, temperature is already high and heating is not so remarkable.
- At [Z/H]~-3.5, H_2 formation is almost completed by dust reaction before 3 body reaction starts.
- At [Z/H]~-4.5, 3-body reaction starts at low-temperature. This results in sudden heating.

➔fragment mass ~10-100M_{sun}

Summary of low-metallicity SF

- Dust is indispensable for low mass SF
- Critical metallicity for low-mass SF
  Z_{cr}~$10^{-6}Z_{sun}$ (first dust)
- H_2 formation heating prevents low-mass SF in [Z/H]=-5..-4

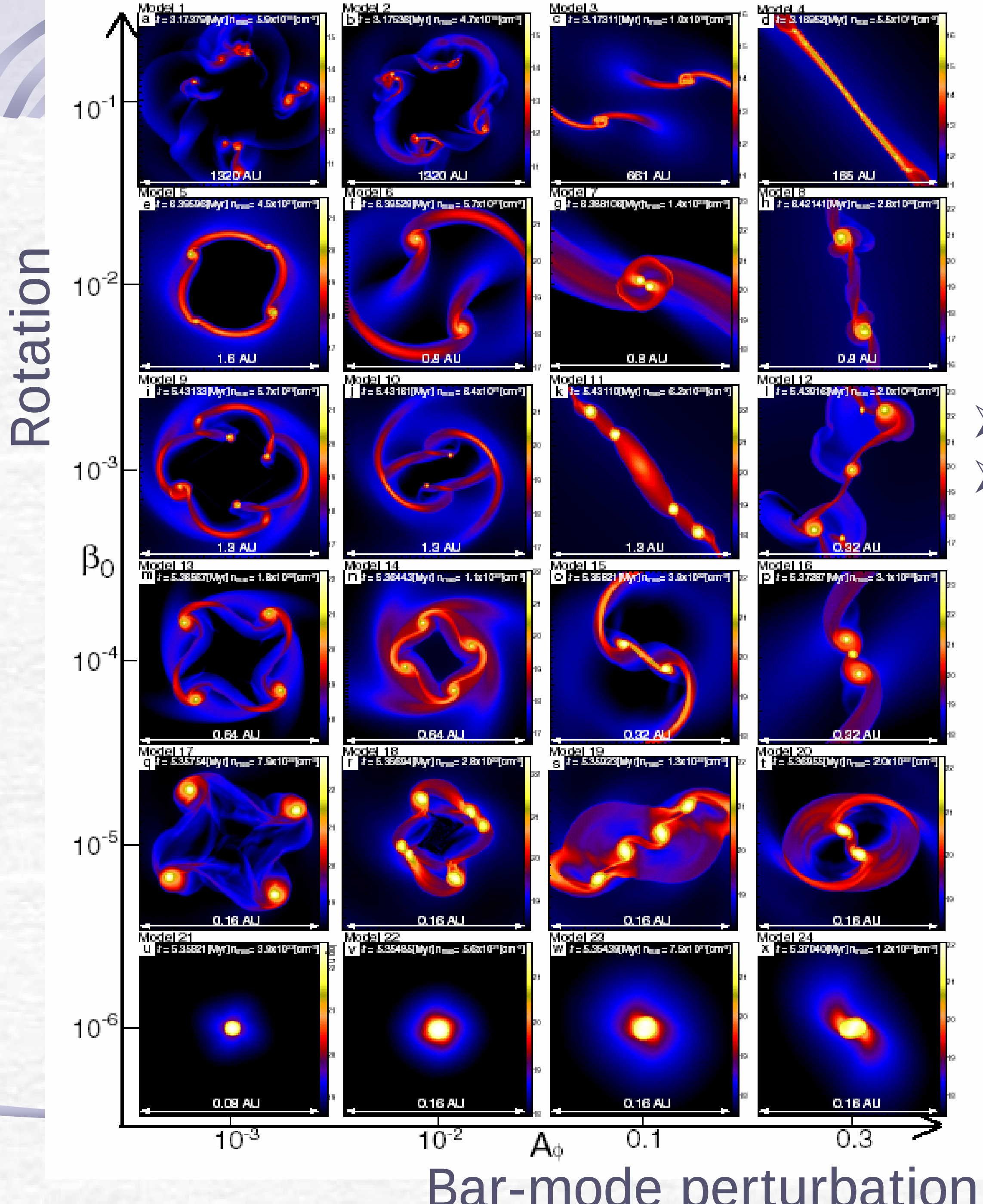
Dust nature in the early universe is quite uncertain.



First-star binary formation

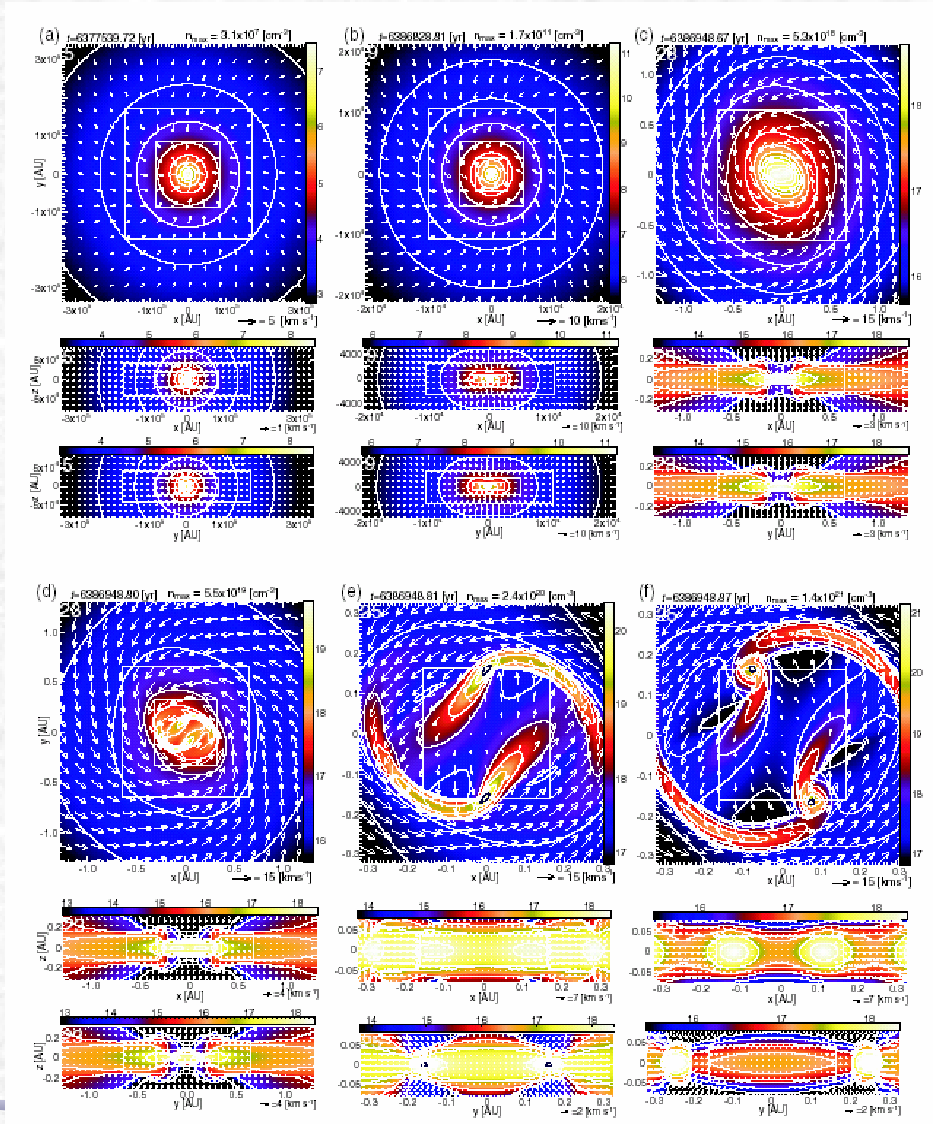
Machida, K.O., Matsumoto, Inutsuka in prep.

- Uses barotropic relation p=p(n)
- initial cores:
  - BE sphere ($10^3 cm^{-3}$) density x 1.01 (α_0=0.83)
  - Rotation β_0
  - Perturbation (bar A_ϕ + m=3)



All the cores with β_0> 10^{-6} - 10^{-5} fragment

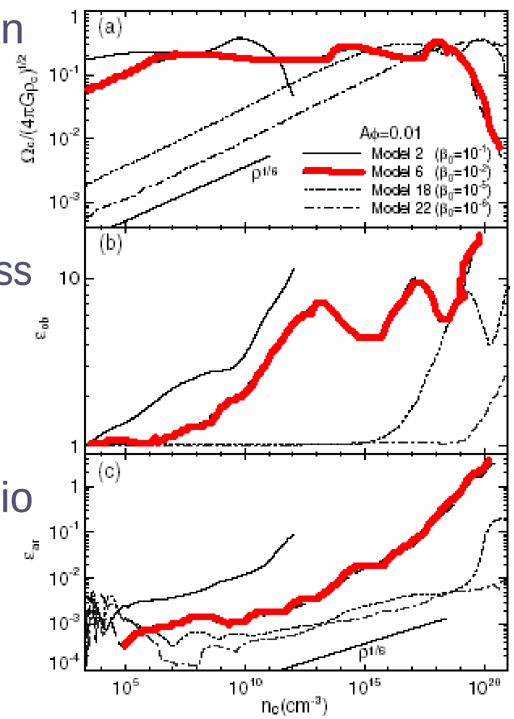
Core fragmenting by ring mode: model 6



rotation

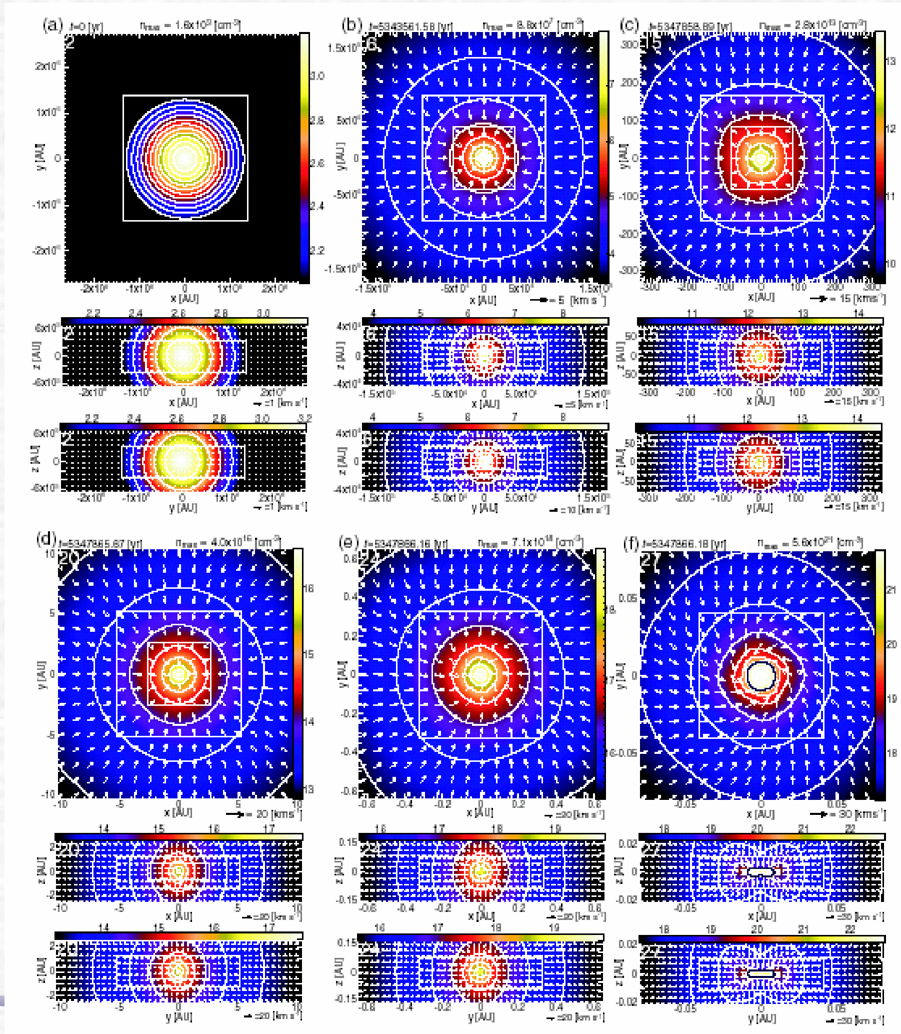
oblateness

axis ratio



Thin disk forms
during the collapse
➔ fragments to binary

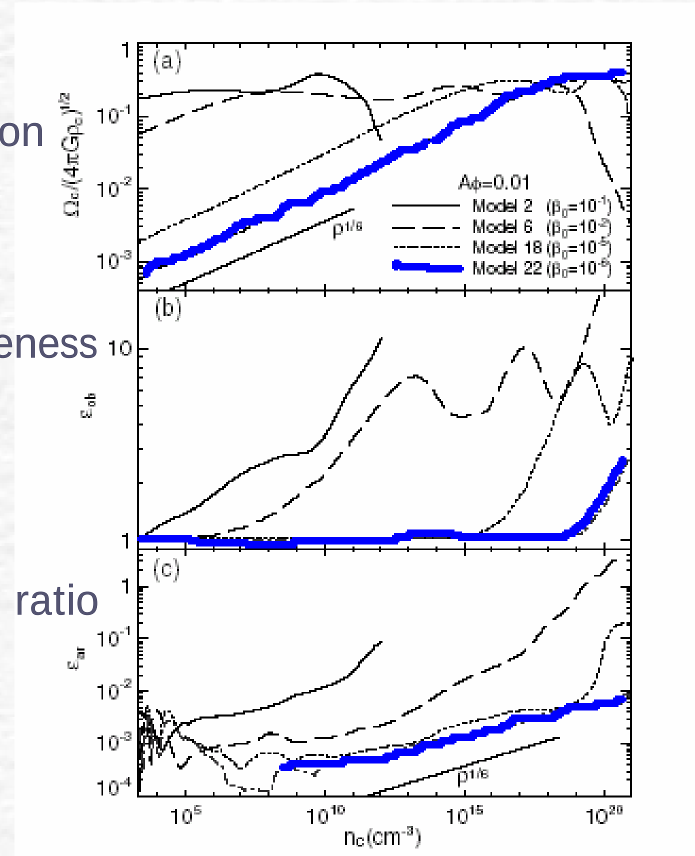
Non-fragmenting core: model 22



rotation

oblateness

axis ratio



Thin disk not formed
before stellar core formation