KITP lunch talk, August 10, 2007

Primordial Star Formation

Naoki Yoshida
As a representative of PopIII community

Cosmological background, basics

State-of-the-art numerical simulations

Fragmentation and massive primordial stars

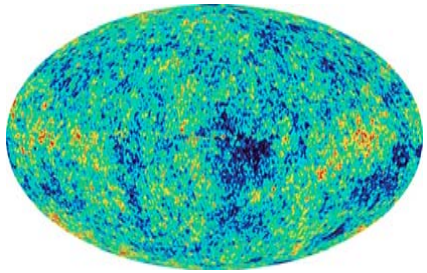
Simulating primordial star formation

With a little exaggeration, we say

we know:

1. **The initial condition**
   - parameter space exploration not needed
   - dark matter physics issue not serious
2. **The equations to solve**
   - gravity, hydro, chemistry, radiation transfer.
     well-established physics

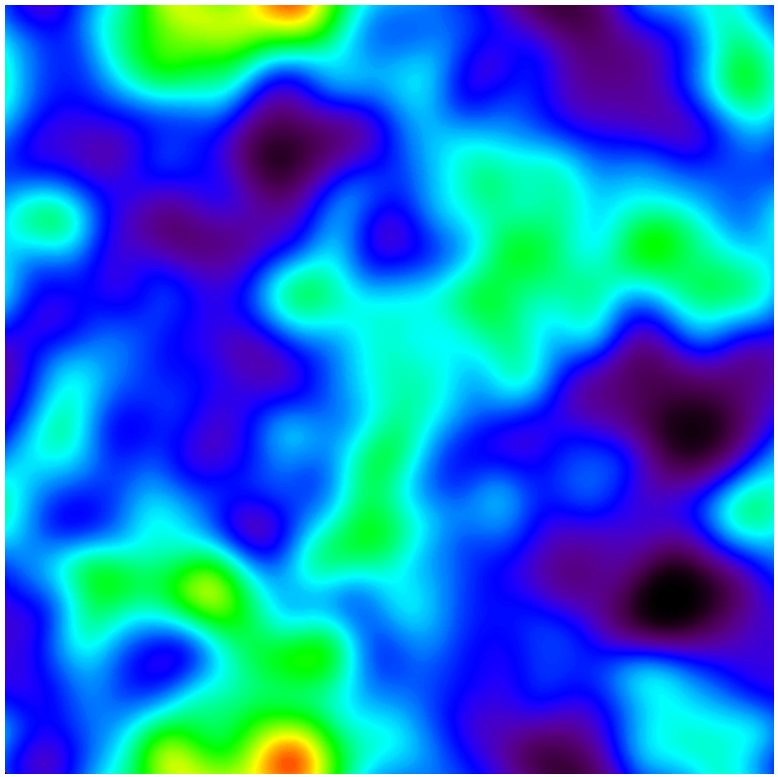
Furthermore, we believe
magnetic field, dust, cosmic-rays aren't important
within the standard model



←This is the initial condition

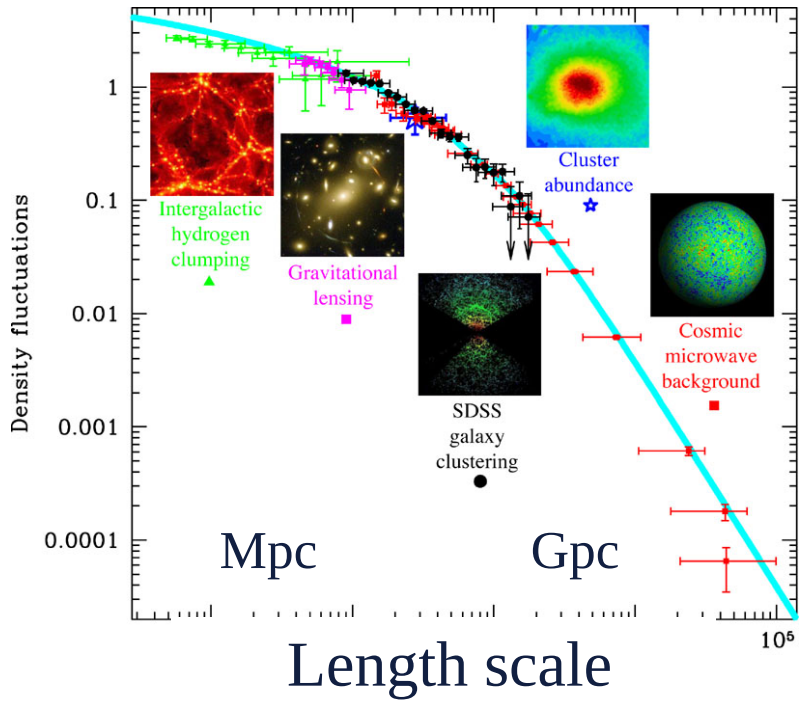
Λ + Cold Dark Matter model

Dark energy+dark matter+baryons (H, He, D)+CMB



Gaussian random field (inflation)

=> *We need only a power spectrum*



Star-formation in the early universe

Cosmological recombination at z = 1089

↓

Non-linear structure formation and dark halo assembly

↓

Virialization and H_2 formation
(gas-phase using the left-over electrons)

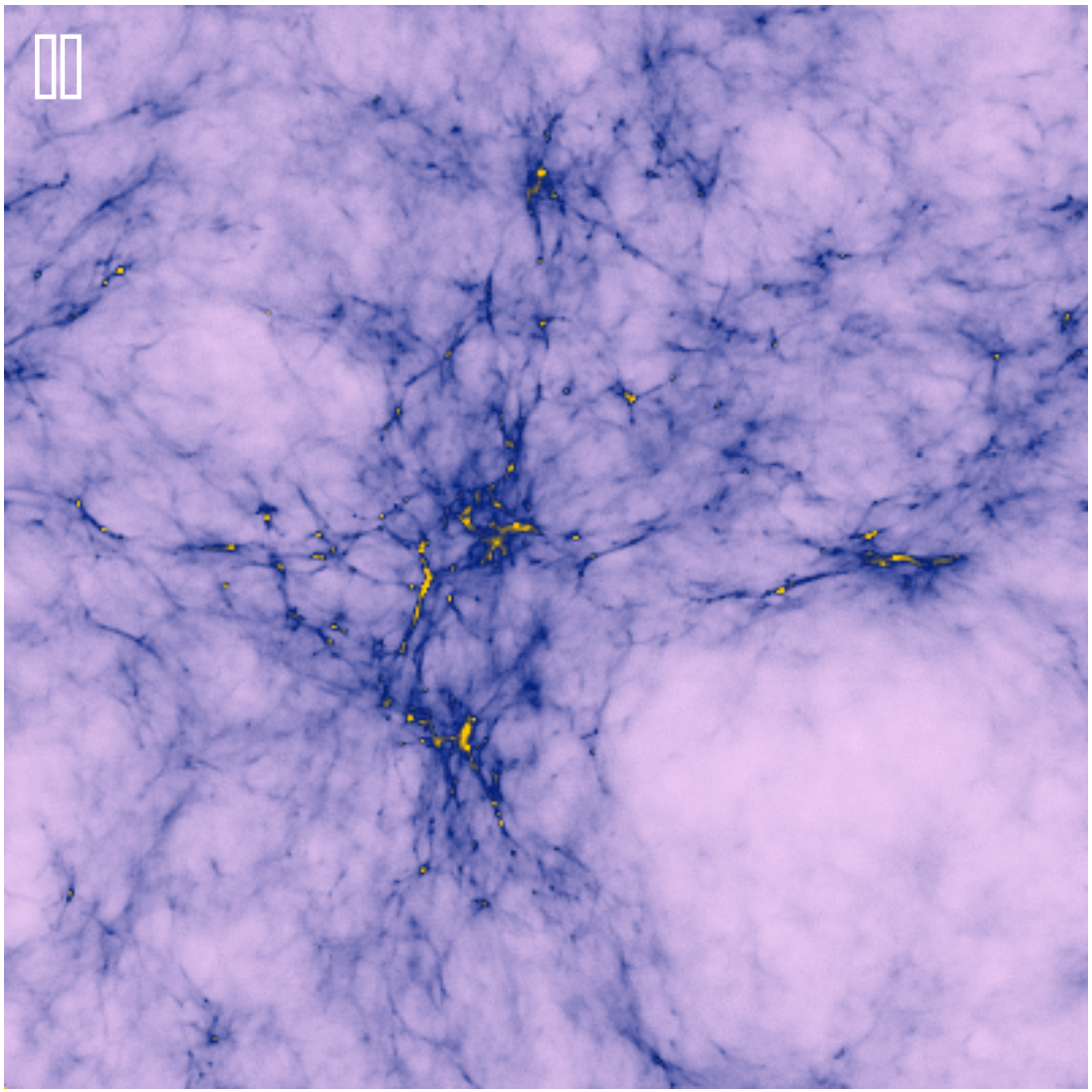
↓

Molecular cloud formation at the center of DM halos

↓

Runaway collapse when a cloud gets large enough
(=What cosmology people call “star-formation”)

“Cosmological” molecular gas clouds



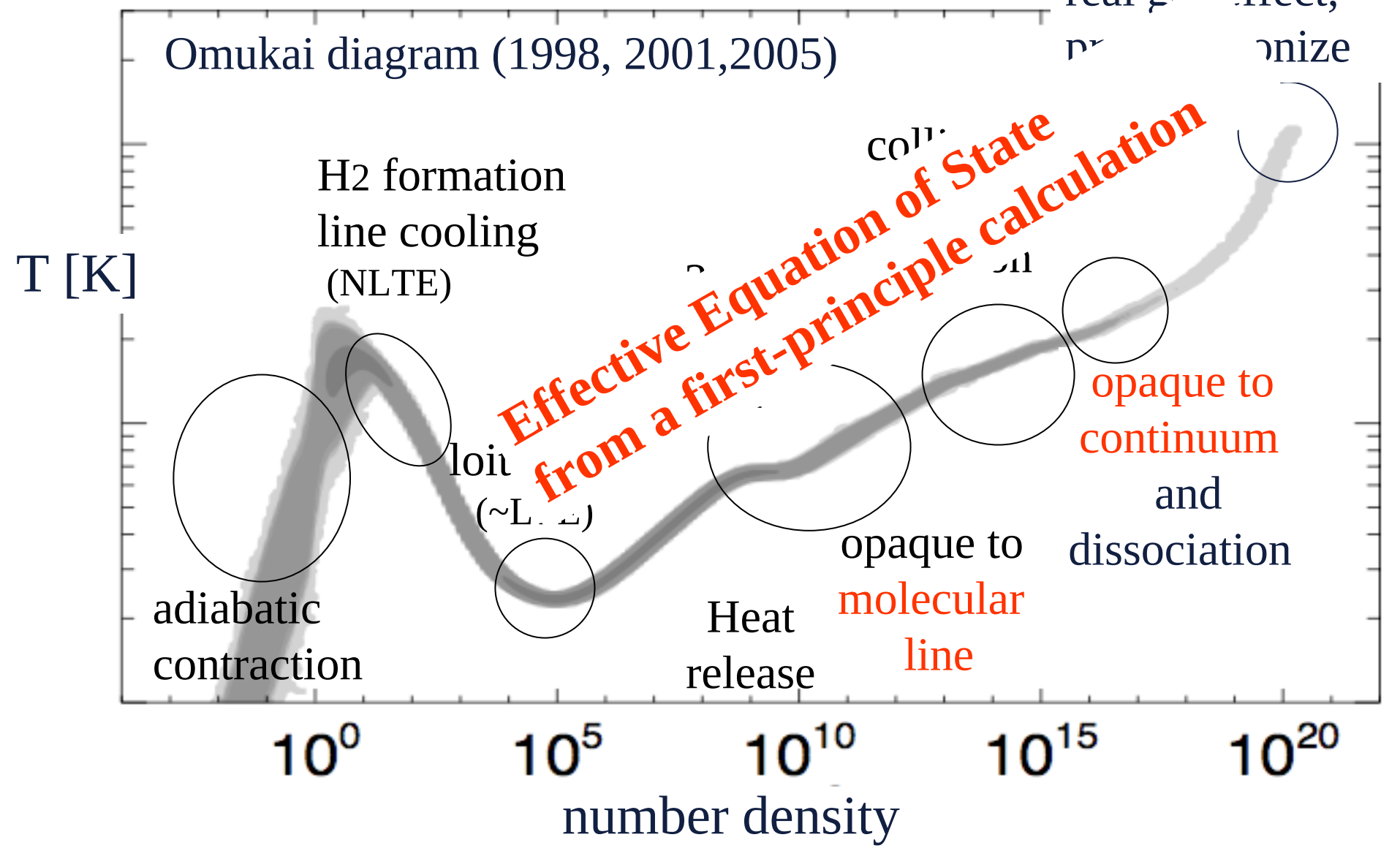
NY, Abel, Hernquist, Sugiyama (2003, ApJ)

Yellow spots at the intersections of filaments
“1 cloud per halo”

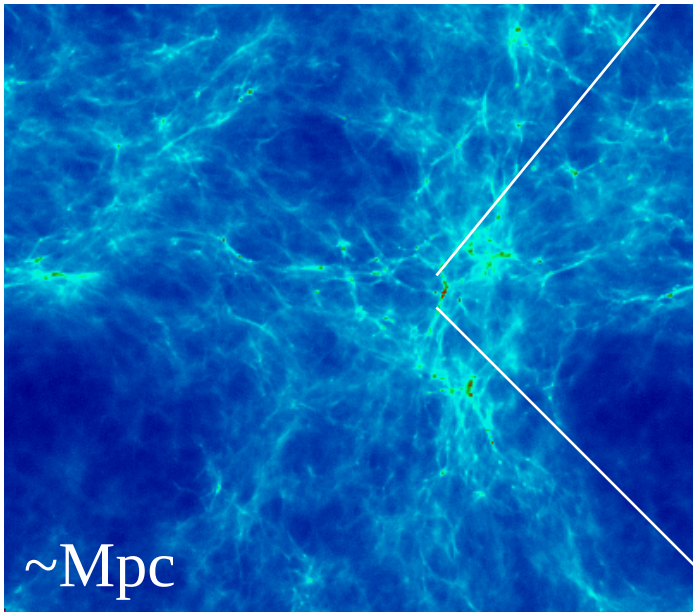
Host dark halos:
M ~ 10^6 Msun
Tvir ~ 1000 K

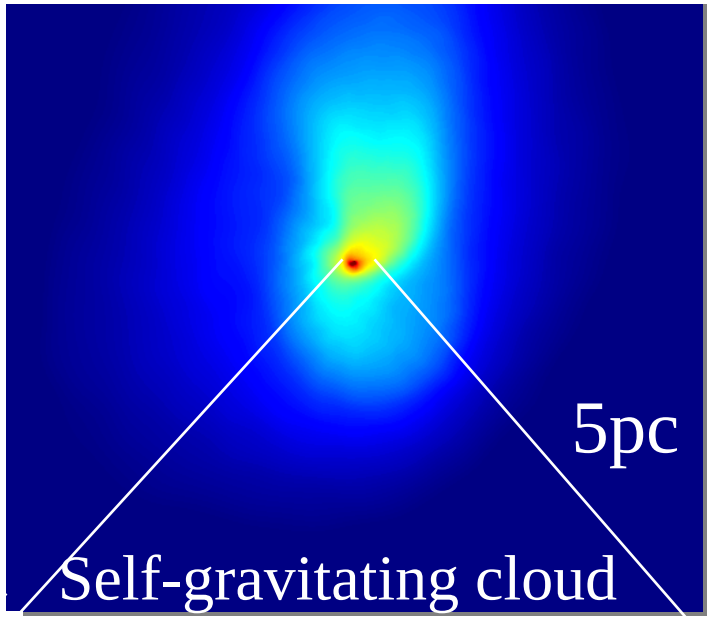
Strongly clustered, large bias

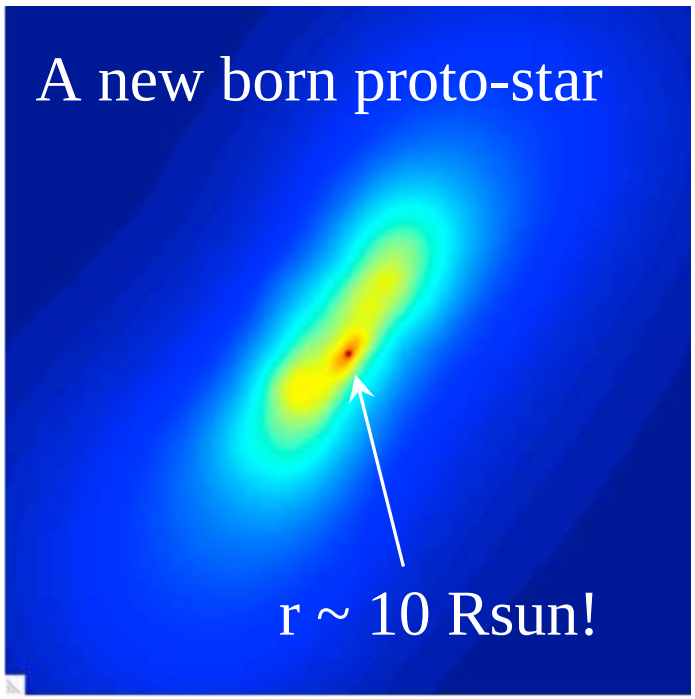
The Physics

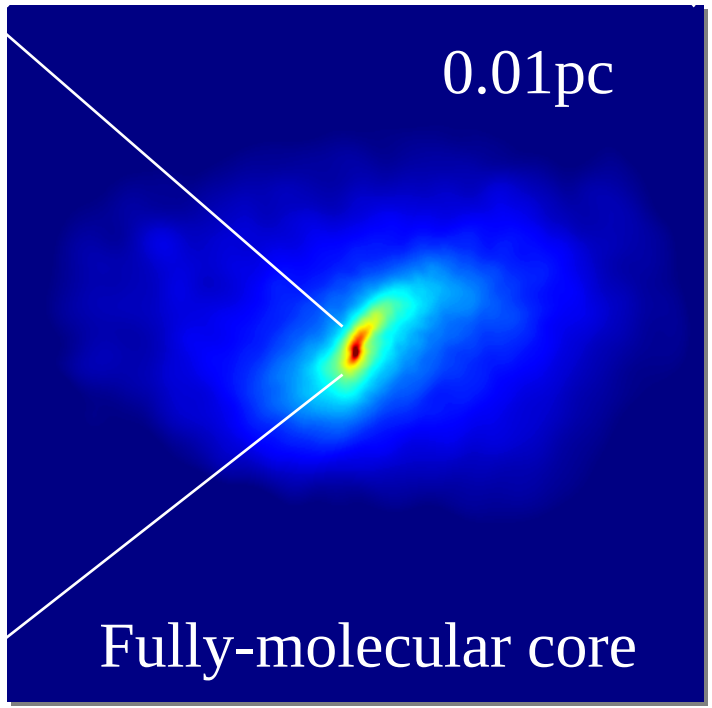

adiabatic phase
Omukai diagram (1998, 2001,2005)
H2 formation
line cooling
(NLTE)
T [K]
Effective Equation of State
from a first-principle calculation
opaque to
continuum
and
dissociation
opaque to
molecular
line
adiabatic
contraction
Heat
release
10^0
10^5
10^{10}
10^{15}
10^{20}
number density

Sufficient computer power, good enough resolution









First stars likely massive

Abel+02, Bromm+02, Omukai & Palla03, Yoshida+06

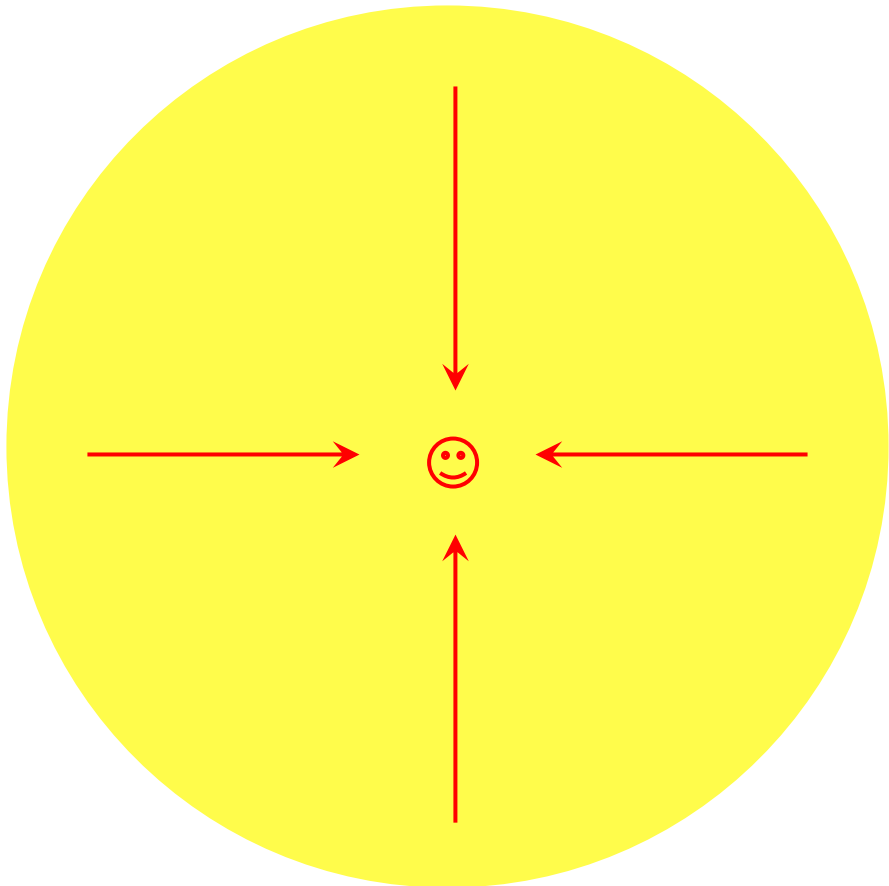
1 Large Jeans-mass at the onset of collapse
(a reservoir of ~ 1000 Msun gas,
but overall very low star-formation efficiency)

2 No vigorous fragmentation during
the final collapse

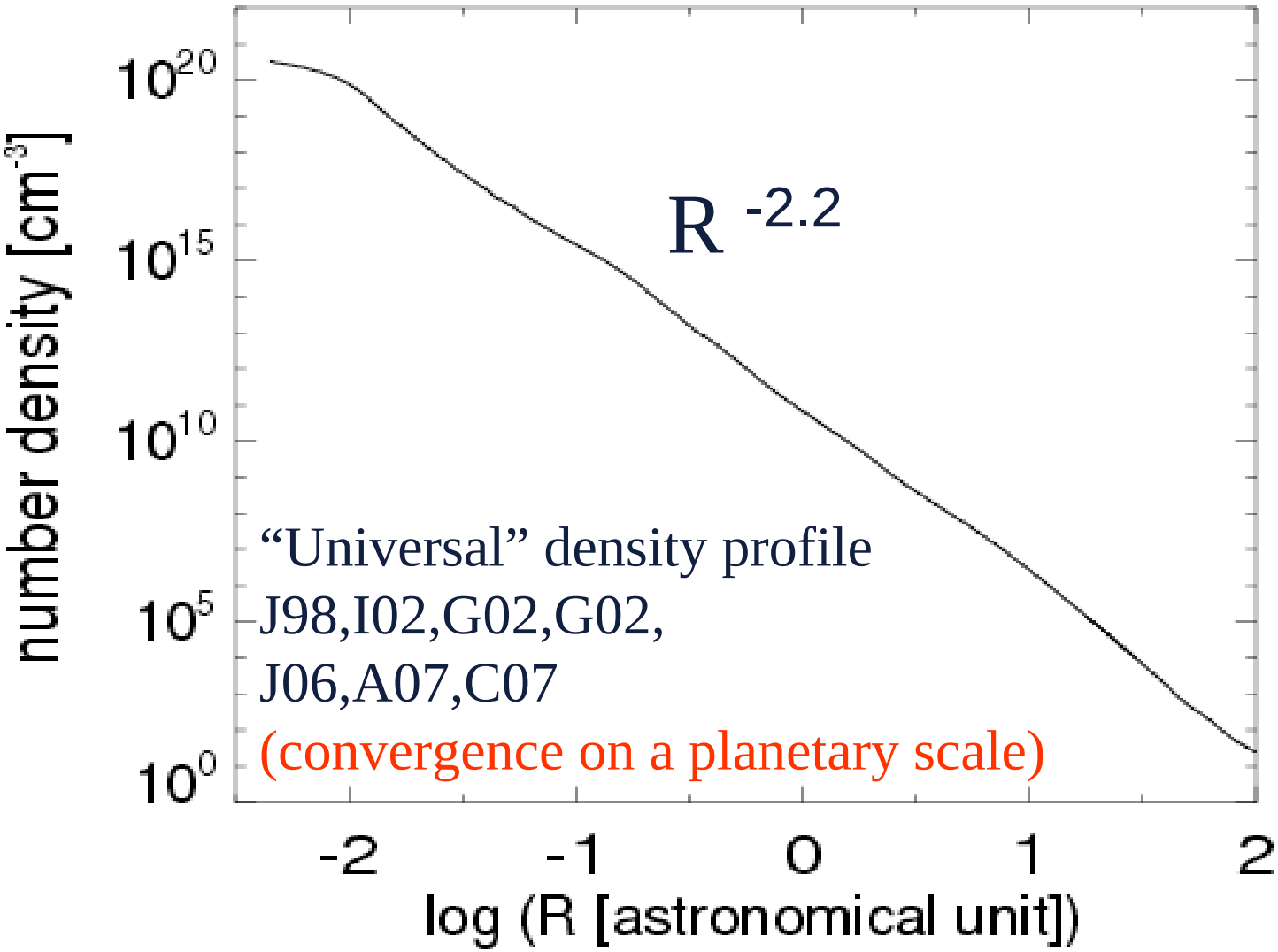
3 Large accretion rate (high $T_{\text{ambient envelope}}$)

$dM/dt \sim c_s^3/G > 0.01 - 0.001$ Msun/yr

Primordial proto-star: a tiny hyper-accreting seed in a large cloud



Convergence, discrepancy, but no puzzles



The (comlicated) issue of fragmentation

1 Chemo-thermal instability

Yes, but No in the end.

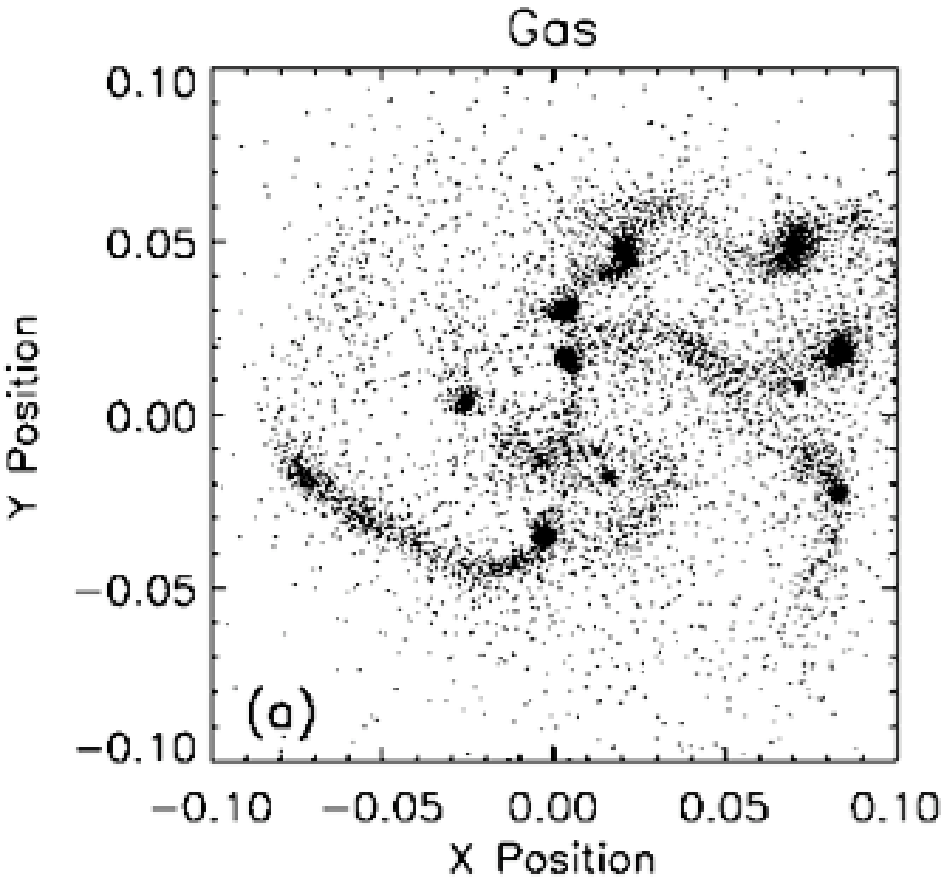
2 Gravitational deformation

No. Effective EoS marginally hard.

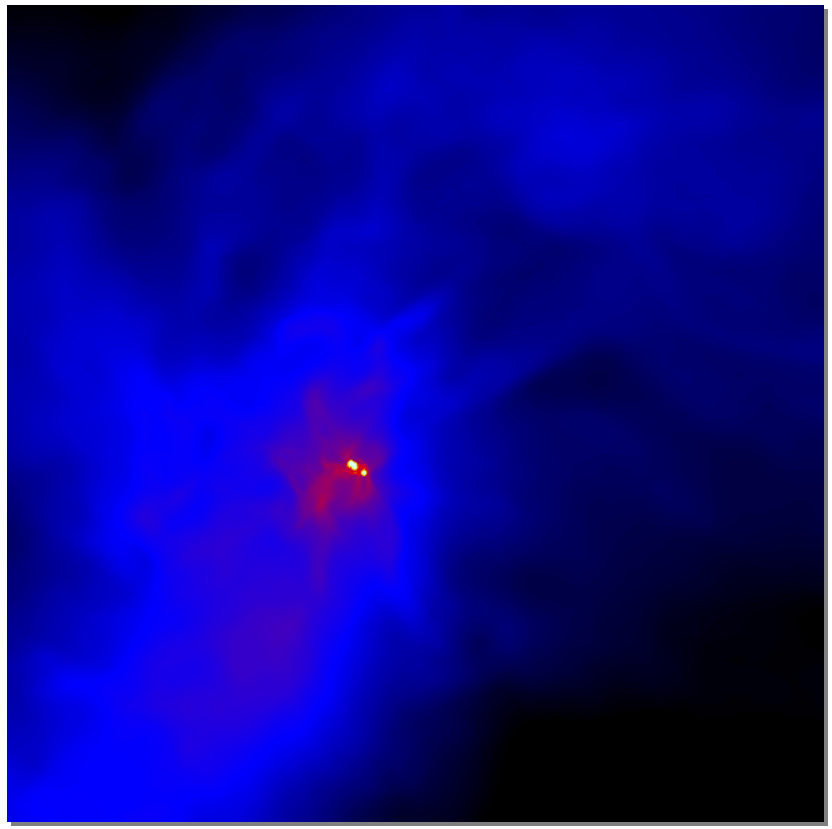
3 Rotation-induced break up

Much dependent of details.

A yet unsolved problem of fragmentation



Bromm et al. 99



Clark, Glover, Klessen 07

“From pre-stellar collapse to proto-stellar evolution” Things to explore further are:

0. ~~Prestellar collapse to the adiabatic phase~~
1. Accretion process, disk accretion
2. Feedback from the proto-star to its environment
3. “Cosmological” variance