Dust Workshop at IPMU, 2010

Population III to II Transition
-The Role of Dust -

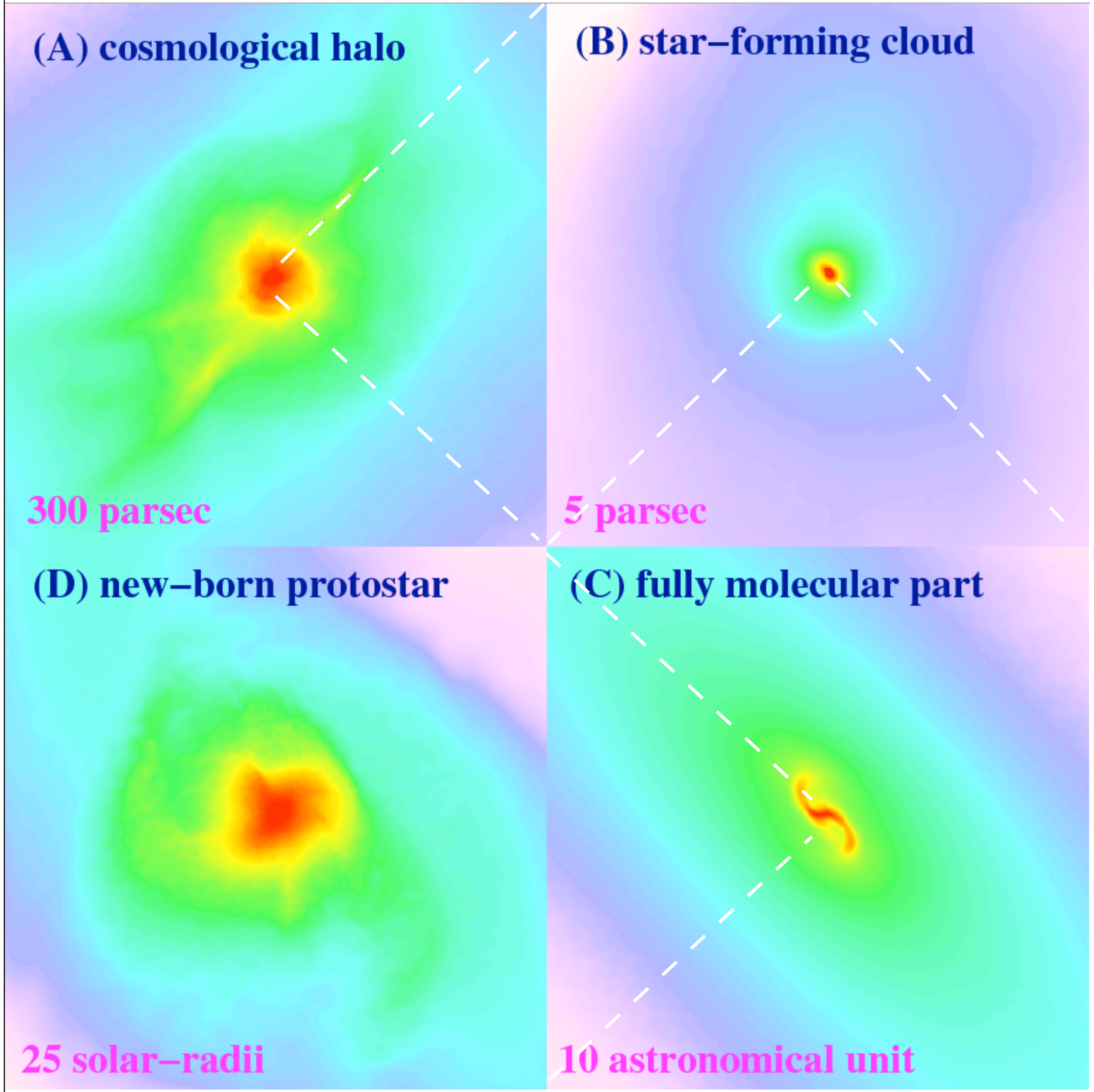
Naoki Yoshida (IPMU)

with

Kazu Omukai

Takashi Hosokawa

Primordial Star Formation

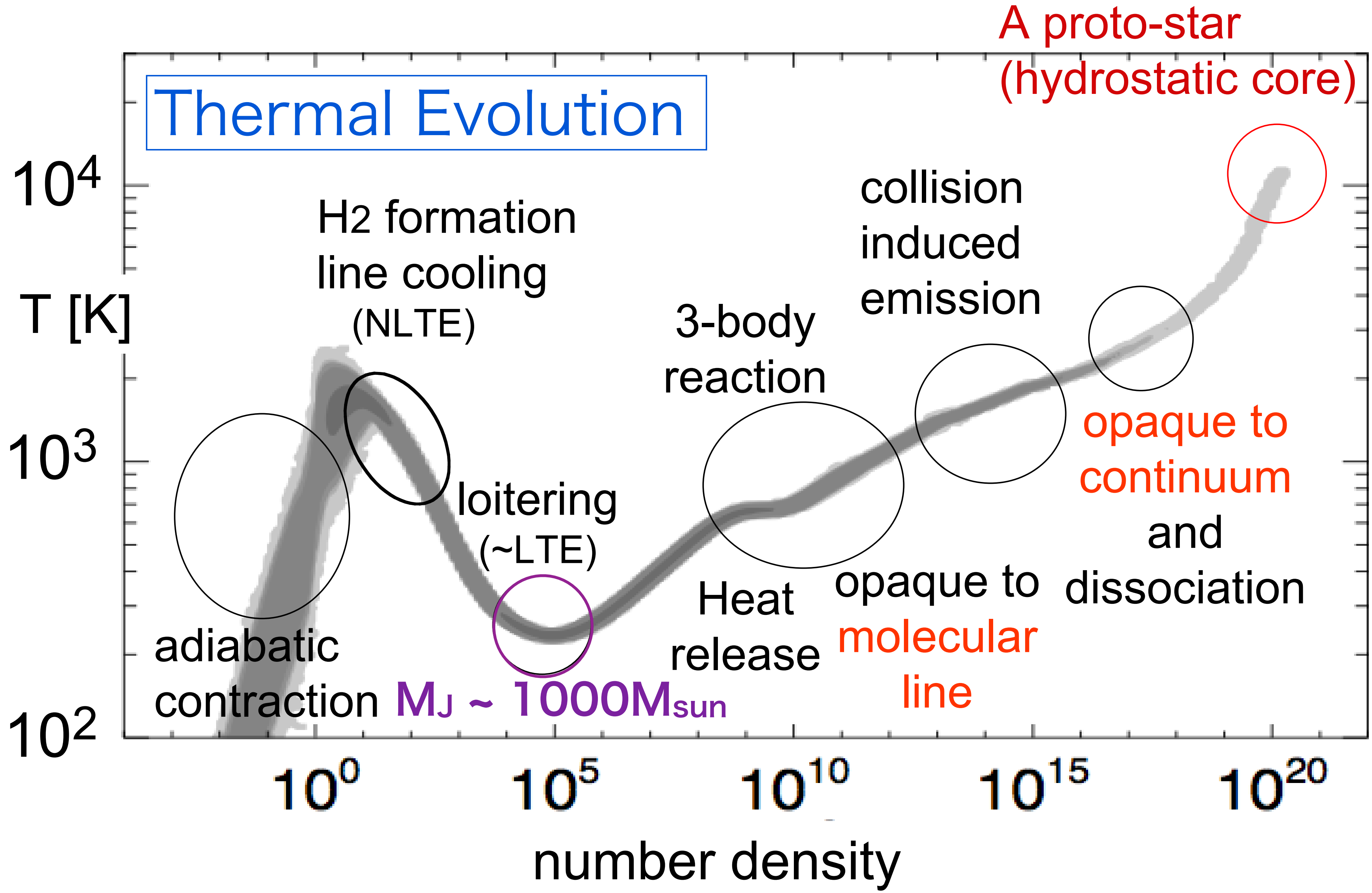


A complete picture of the formation process of a primordial protostar.

Dynamic range 10^{13}
Resolving planetary scale structures in a cosmological volume!

NY, Omukai, Hernquist
Science 2008

An early universe “experiment”



Primordial Star Formation

1. The large mass (~1000Msun) at the onset of collapse.
2. High temperature (~1000K) gas surrounding the protostar
   = Very large accretion rate
3. Lack of opacity source
   = no efficient way of stopping accretion

So far, so good...

What if the gas is enriched with metals ?

PopIII to PopII

PROBABLY:

Turbulence,

Metal enrichment, DUST,

Magnetic field,

Cosmic rays, etc etc...

PopIII to PopII

Is there a “critical metallicity” for cloud fragmentation ?

If so, what determines it ?

Bromm et al.
atomic cooling
by C, O
@low-density

vs.

Omukai, Schneider
cooling by dust
@high density

Toward a direct simulation

Chemistry and radiative transfer in a gas with heavy elements and dust :

1 Cooling by CI, CII, OI

2 Dust thermal emission

3 Molecular cooling by H_2O, OH, CO

4 New cooling rates for H_2, HD

Chemistry

In addition to H, H_2, He, D, HD :

C, C^+, CO, CO^+, CO_2,

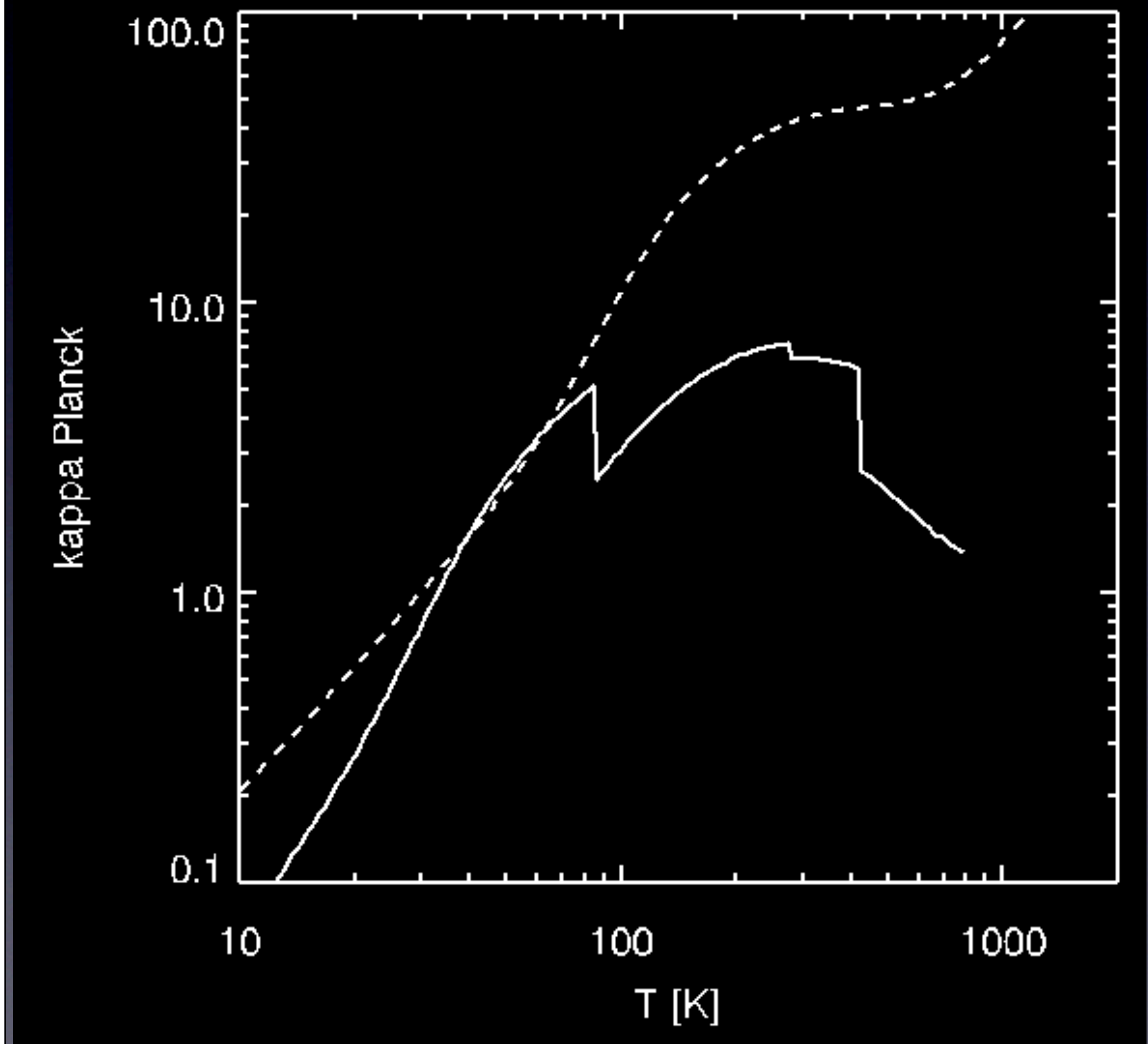
O, O^+, OH, H_2O, O_2, H_2O^+, OH^+,

CH, CH_2, H_3O^+, O_2^+

+39 reactions

Chemical equilibrium for those in yellow

Dust opacity



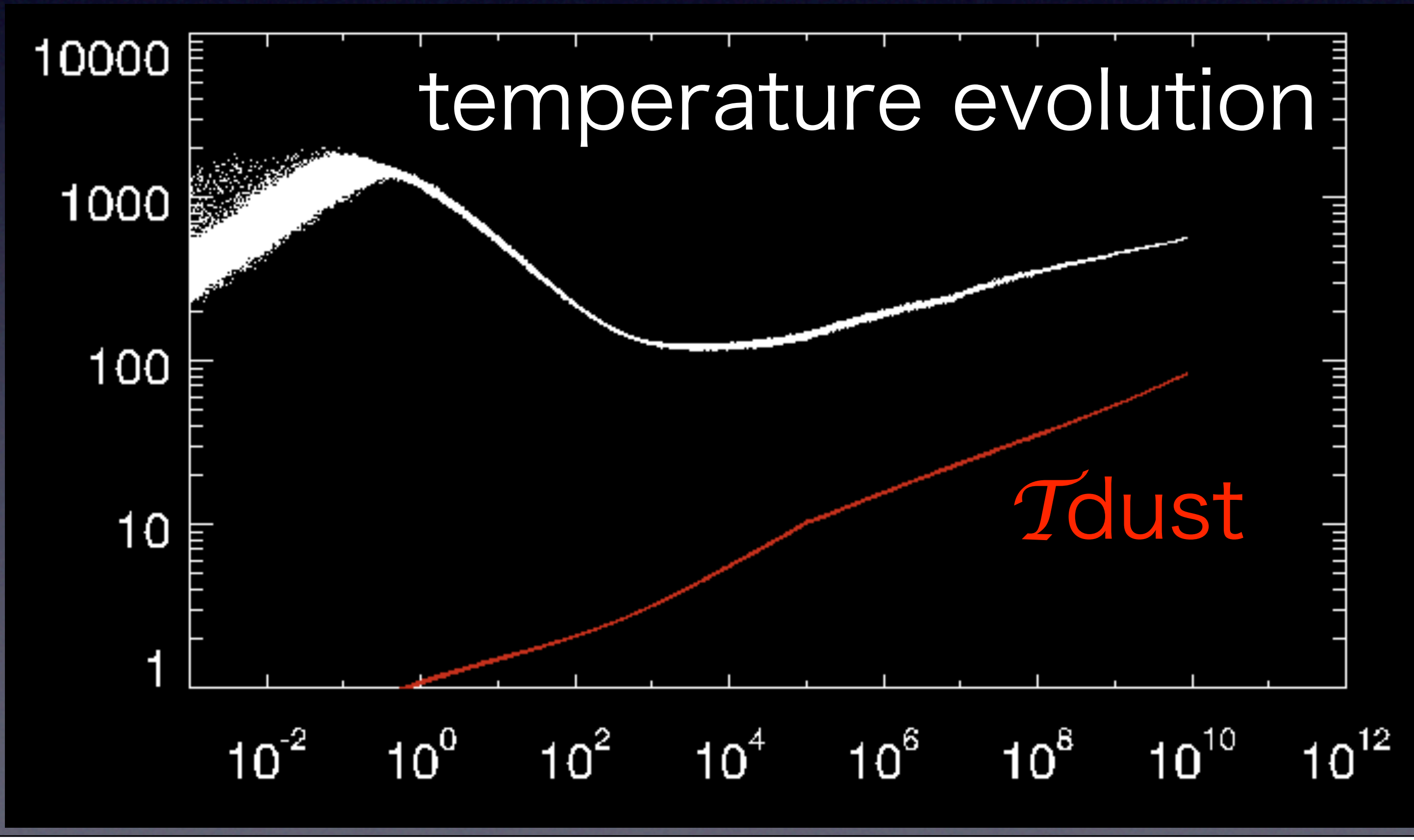
Planck mean
Semenov+ 03
Solar composition
(solid)

Nozawa+ 05
First SN,
carbon dominated
dust (dashed)

Dust cooling

Tdust determined by the thermal

balance: $4\,\sigma\,T^4\,\kappa = \mathcal{L}_{\text{gr (gas -> dust)}}$



Molecule formation

H + H + dust grain → H2 + dust grain

Tielens - Hollenbach 1985 rate

$$k_{\mathrm{H8}} = 6.0\times10^{-17}(T/300\ \mathrm{K})^{1/2} f_a \times[1+4.0\times10^{-2}(T+T_{\mathrm{gr}})^{1/2}+2.0\times10^{-3}T+8.0\times10^{-6}T^2]^{-1}\times Z/Z_{\mathrm{local}}$$

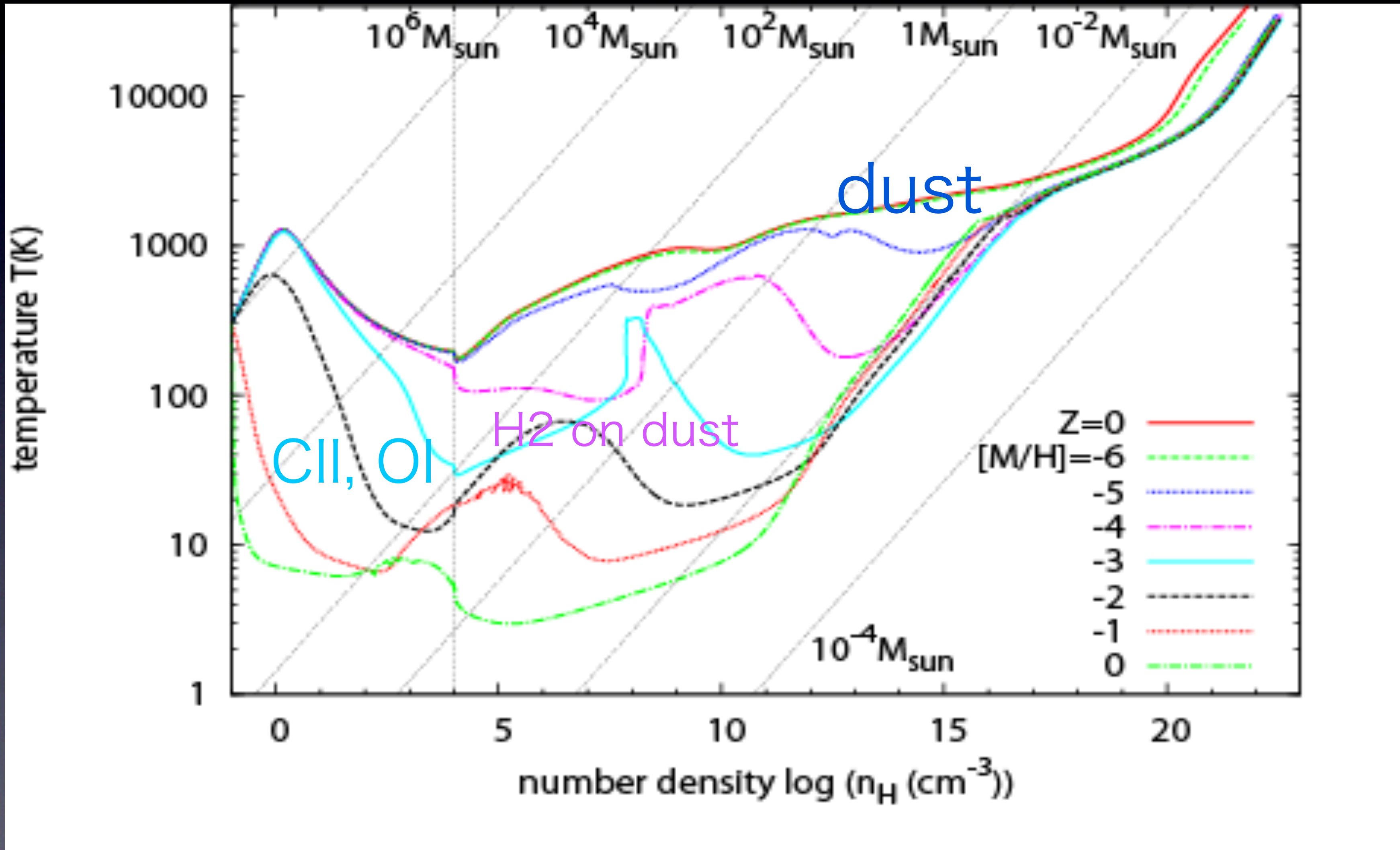
$$f_a = \{1+\ \exp[7.5\times10^2(1/75-1/T_{\mathrm{gr}})]\}^{-1}$$

Chemical heating

0.2 + 4.2/(1+ncr/n) eV

per formed molecule

1-D calculation



Omukai, Hosokawa, NY (2010)

3D simulation set-up

A NFW sphere (static potential)

5×10^6 Msun @ z=10; Tvir ~ 2000 K

1 million gas particles (multi-level)

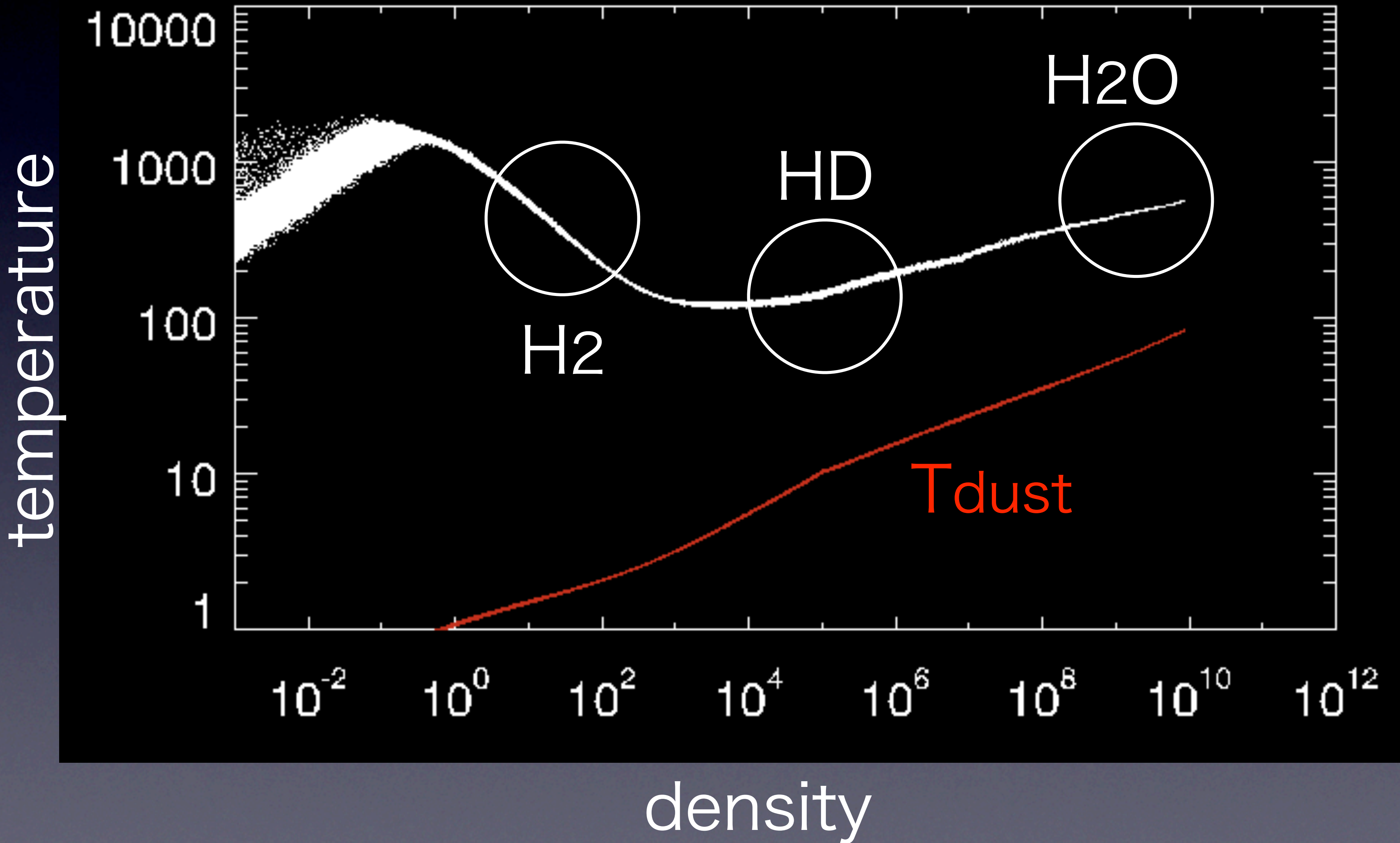
Mass resolution at the center
~ 0.004 Msun

Solar composition, dust-to-gas ratio fixed

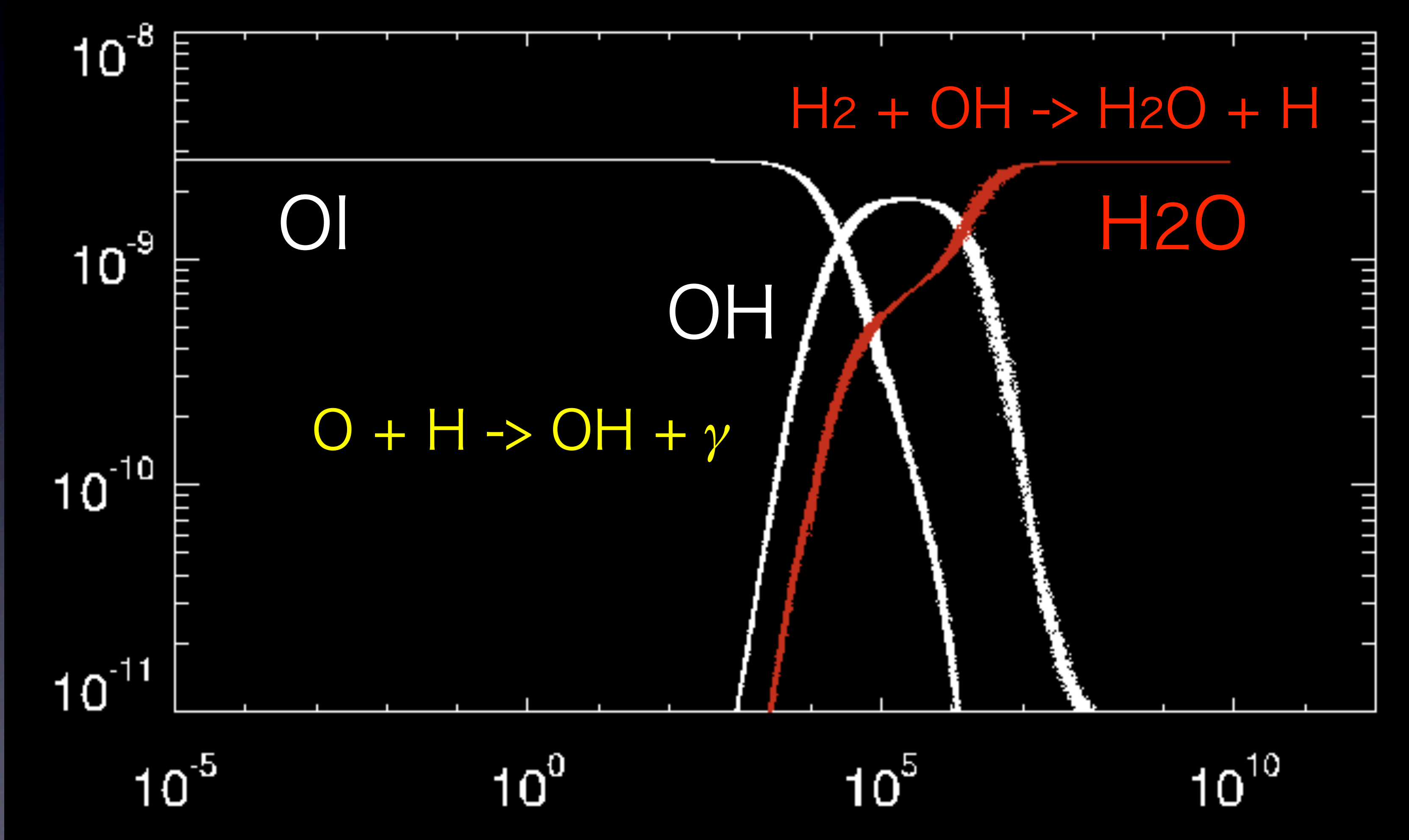
$y_{C,gas} = 9.27 \times 10^{-5}$, $y_{O,gas} = 3.57 \times 10^{-4}$

scaled by metallicity Z.

3D Results: Z=-5

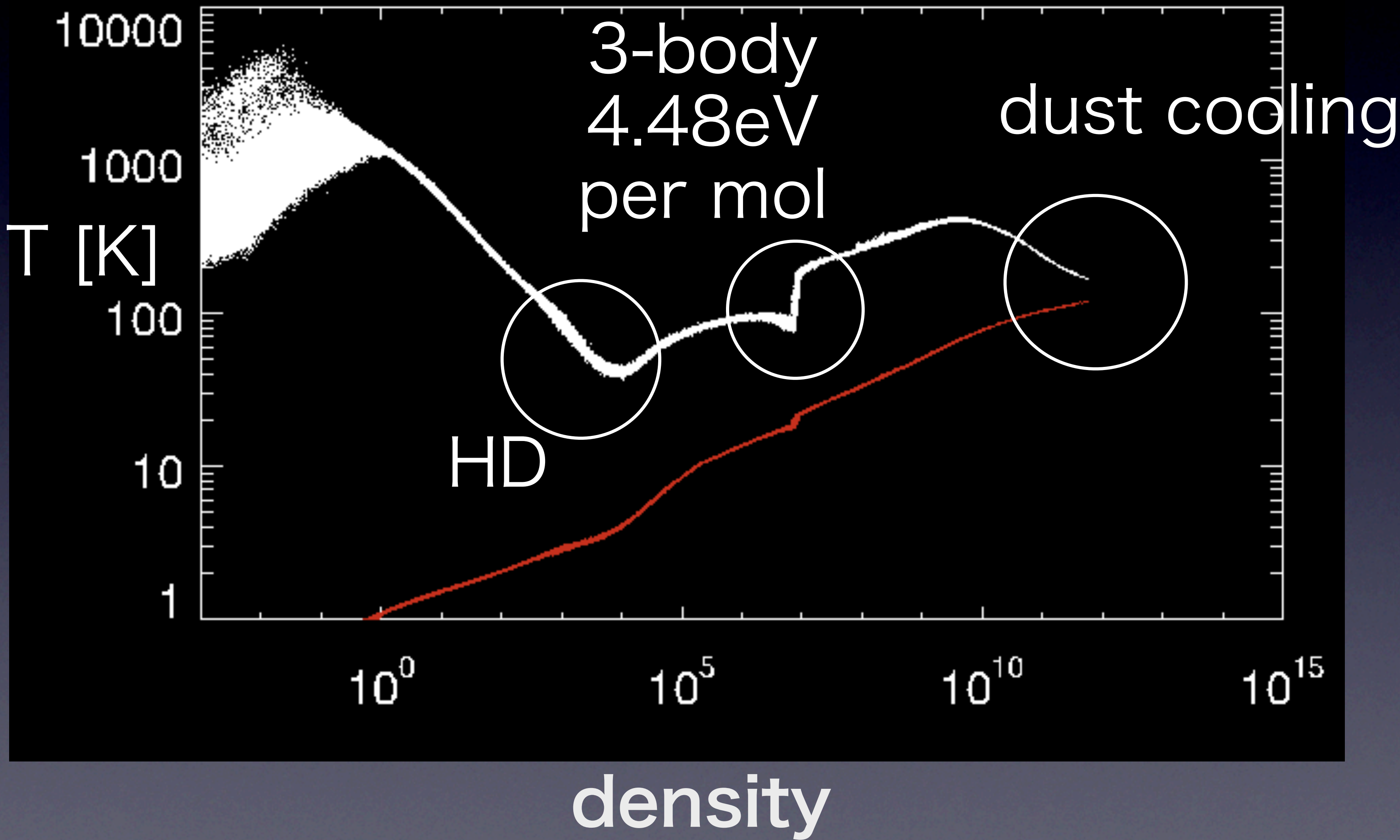


Oxygen chemistry : Z=-5

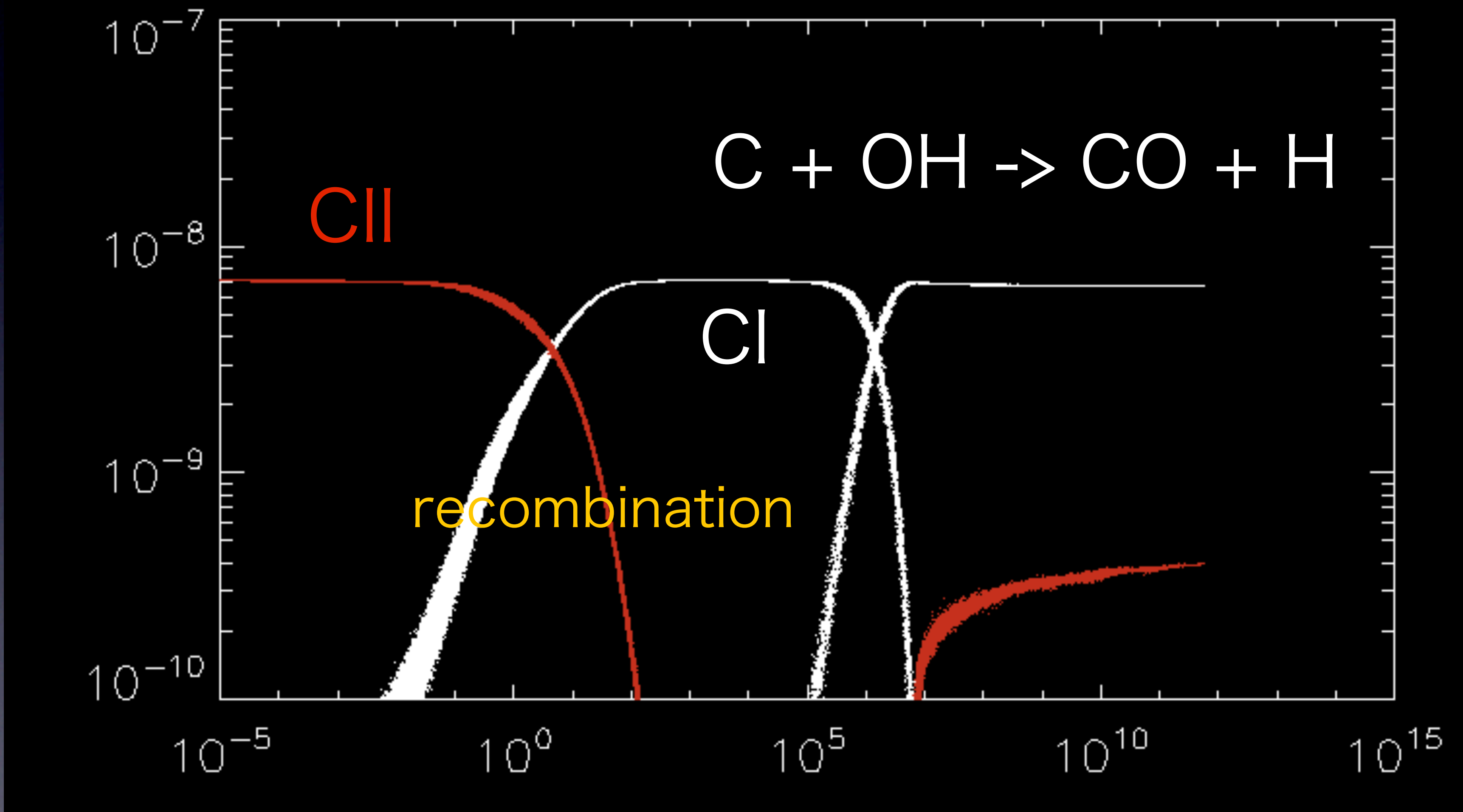


密度 [/cc]

Result : Z=-4

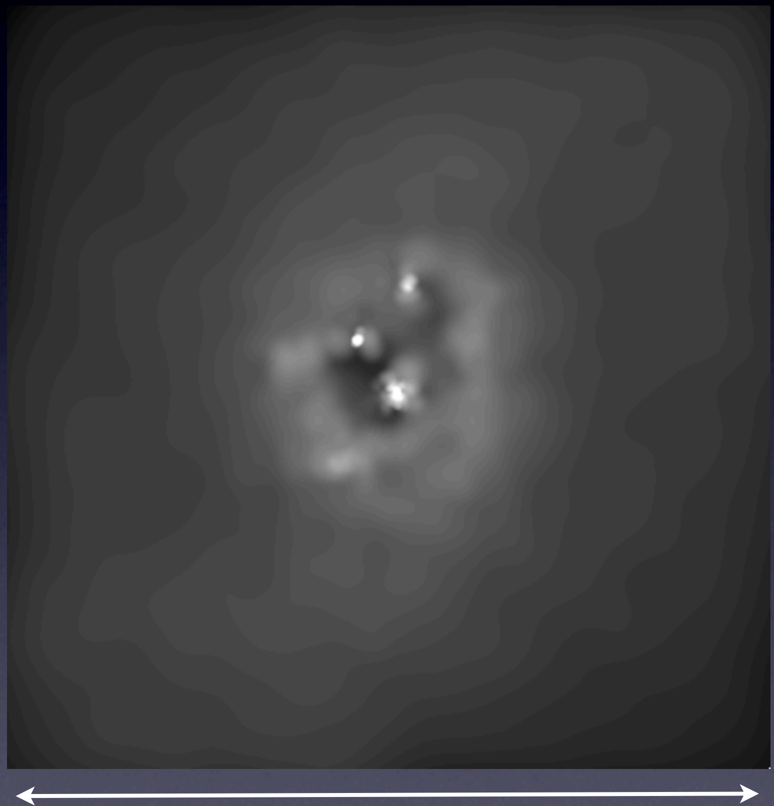

10000
1000
100
10
1
T [K]
3-body
4.48eV
per mol
dust cooling
HD
10^0
10^5
10^{10}
10^{15}
density

Carbon chemistry : Z=-4

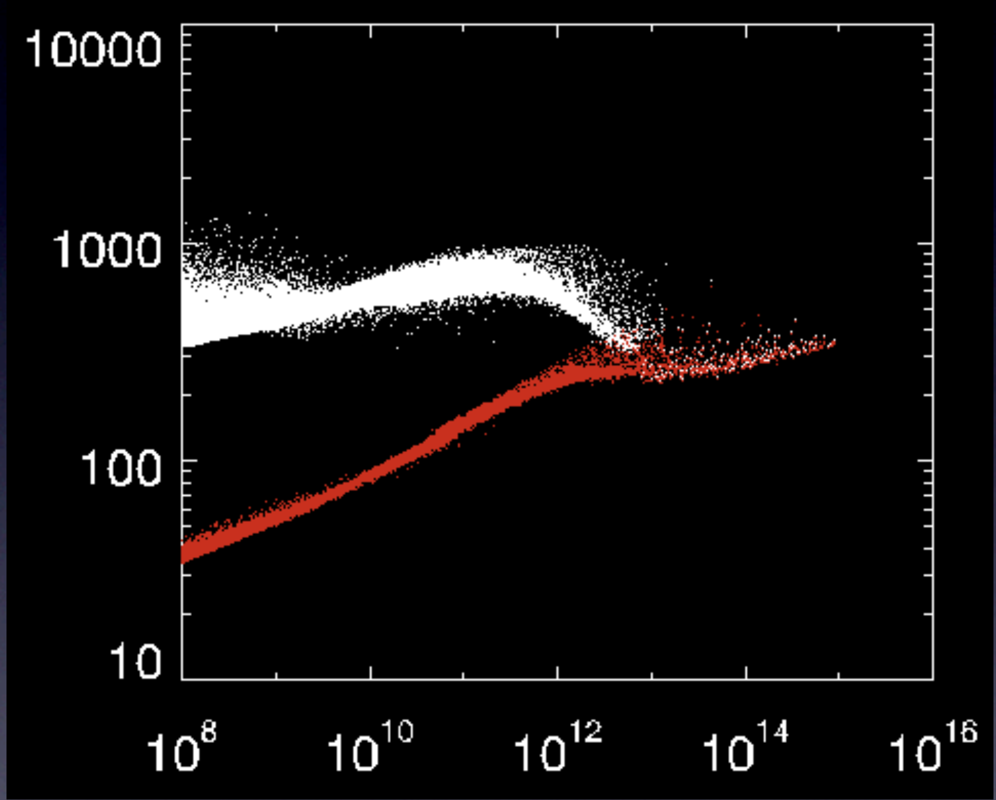


density

Fragmentation



5AU



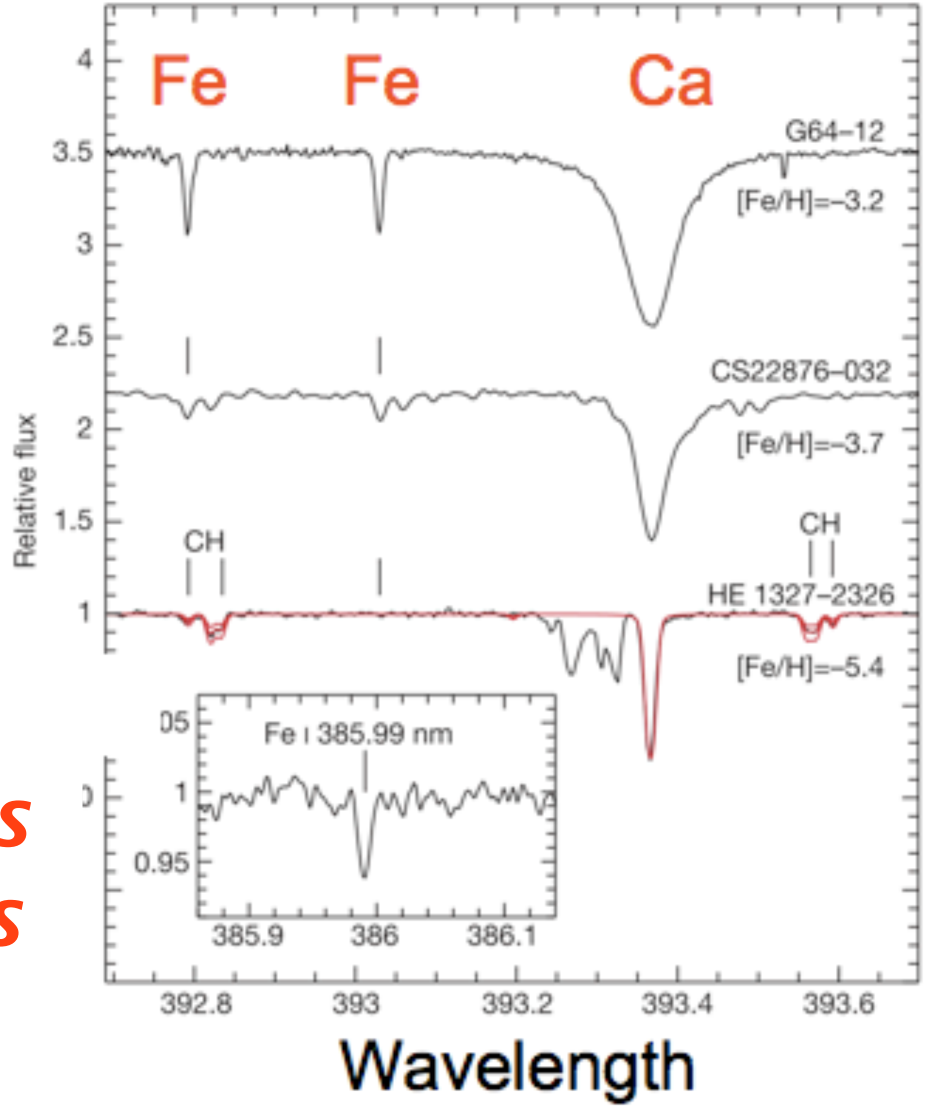
Fragment mass ~ 0.1 Msun

Speculation: low-Z subsolarmass stars at high-z

Stellar Relics in the Galaxy

How and where were these low-mass low-metallicity stars formed ?

EMP star with Fe/H < -5



My questions

- Should we follow the evaporation features in the dust opacity ?

  (Sudden jump in tau over a small δT)

  Remember t_collapse@(n=10^{15}) is 1year.
- If not, what would be the best way (computationally) to follow the “evolution” of tau.
- When we include dust, should we also start with some amount of molecules ?

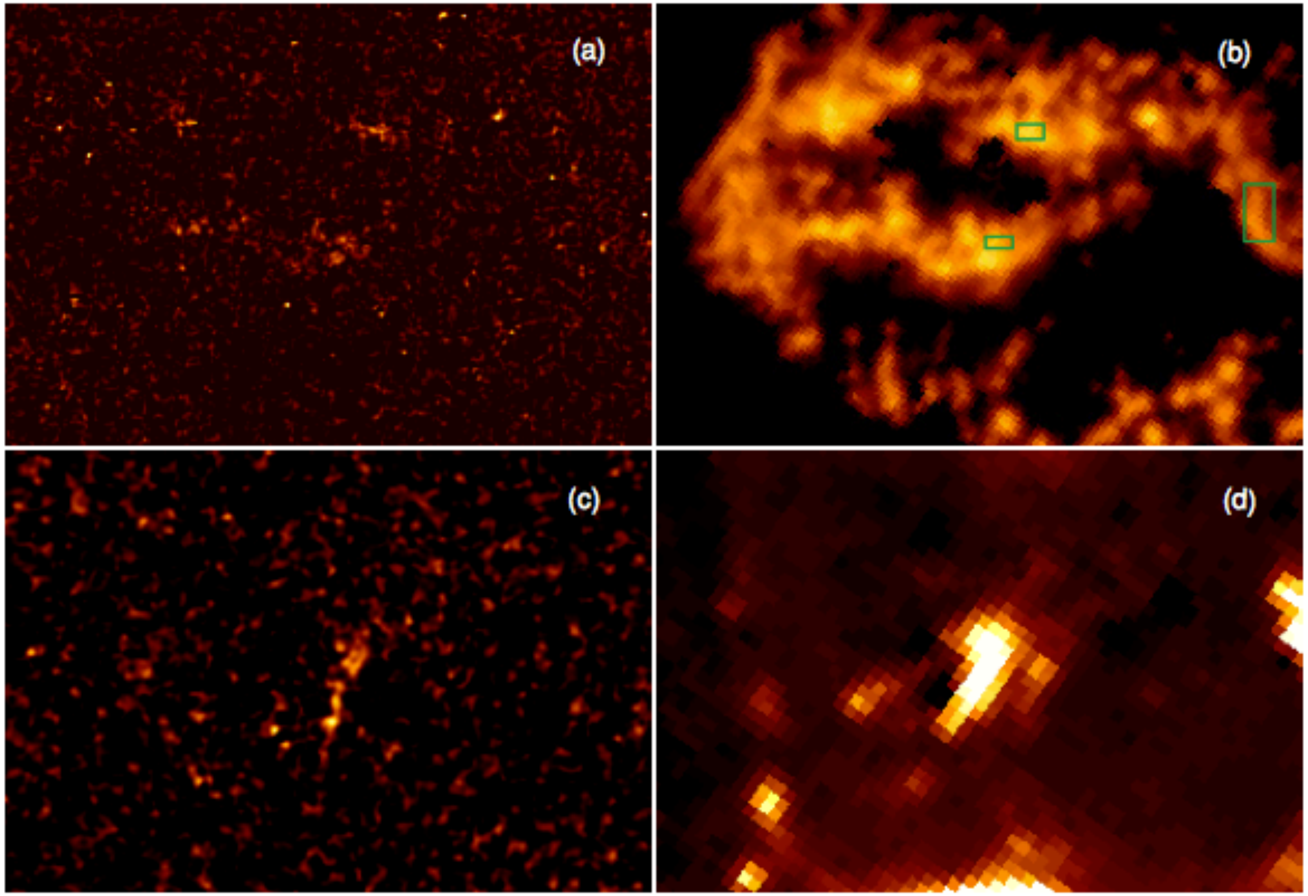
My questions

- Finally, does the concept of "dusticity" appear useful (to you) ?

  Mdust/Mgas,

  Mdust/Mgas / [Mdust/Mgas]solar

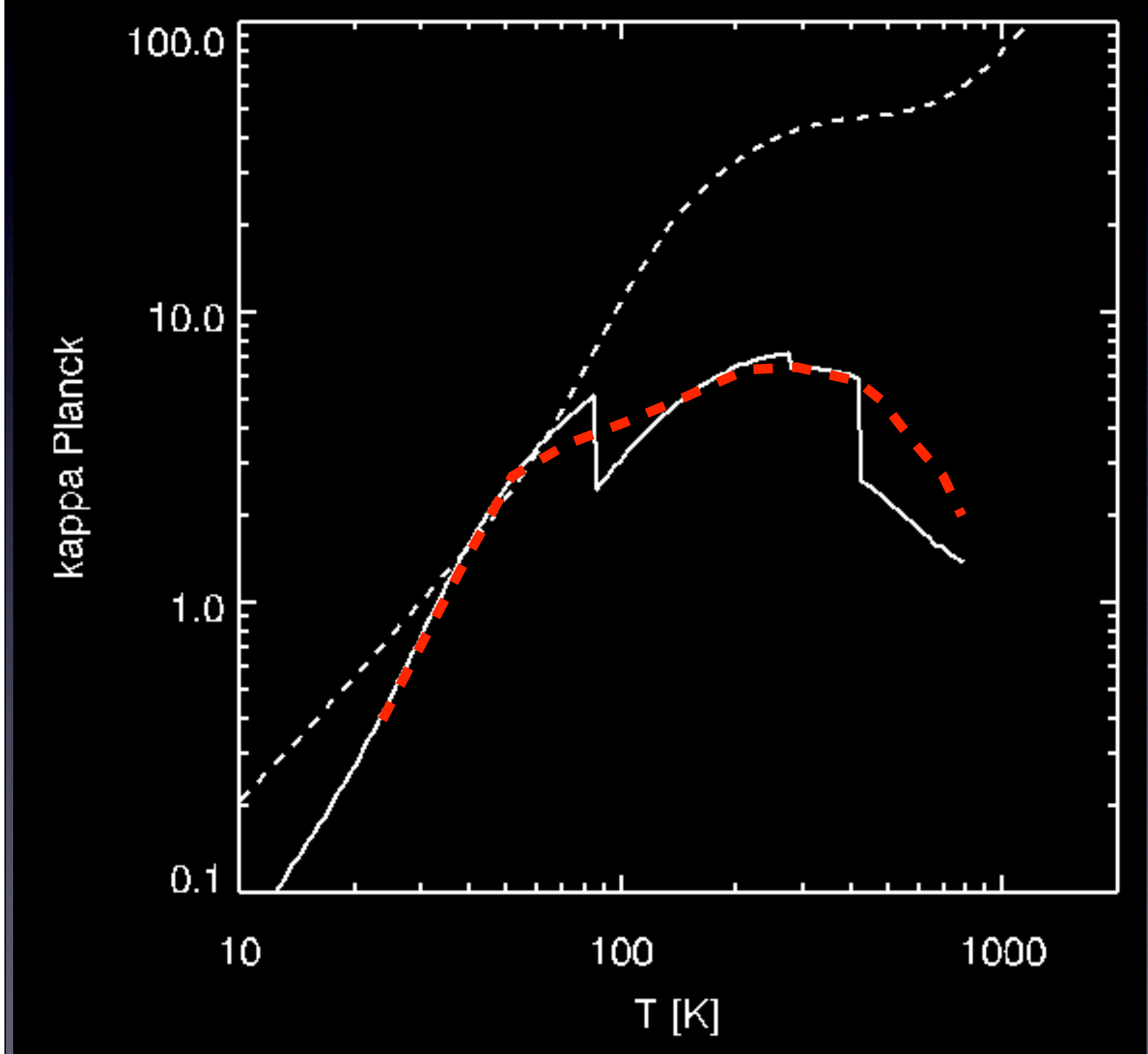
CO in(toward) Cas A



Rho et al. 2009

Detection of 2.29 micron CO emission

Dust opacity



Planck mean
Semenov+ 03
Solar composition
(solid)

How quickly should each component get evaporated ?