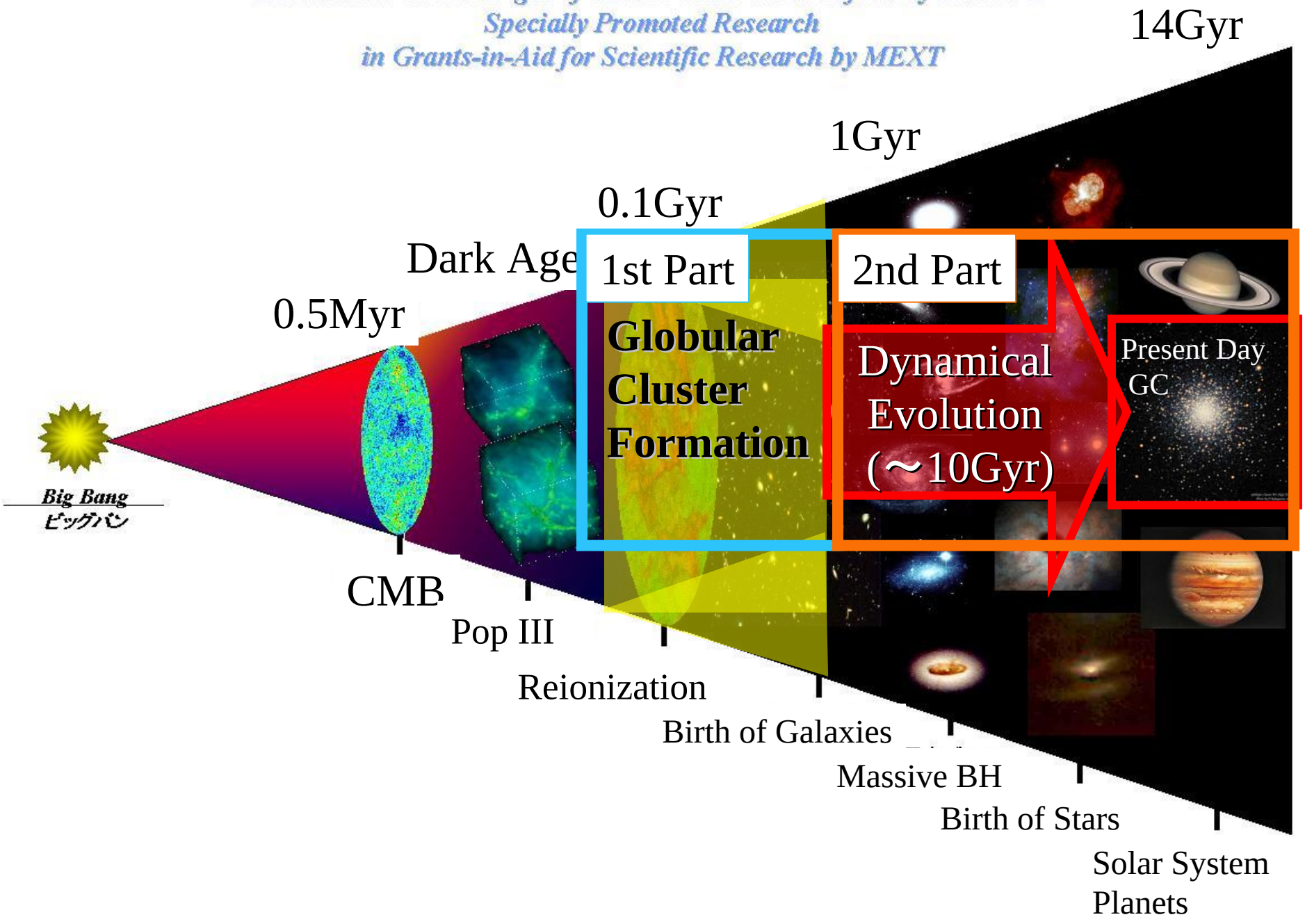
Formation and Dynamical Evolution of Globular Cluster

Kenji Hasegawa

(Univ. Tsukuba, Doctoral Candidate)

Elucidation on the Origin of FIRST Generation Objects by HMCS-E
Specially Promoted Research
in Grants-in-Aid for Scientific Research by MEXT



1st PART

Formation of Globular Cluster within UV Radiation Field

Collaborators

Masayuki Umemura (U. Tsukub)

Tetsu Kitayama (U. Toho)

Reionization and GC Formation Epoch

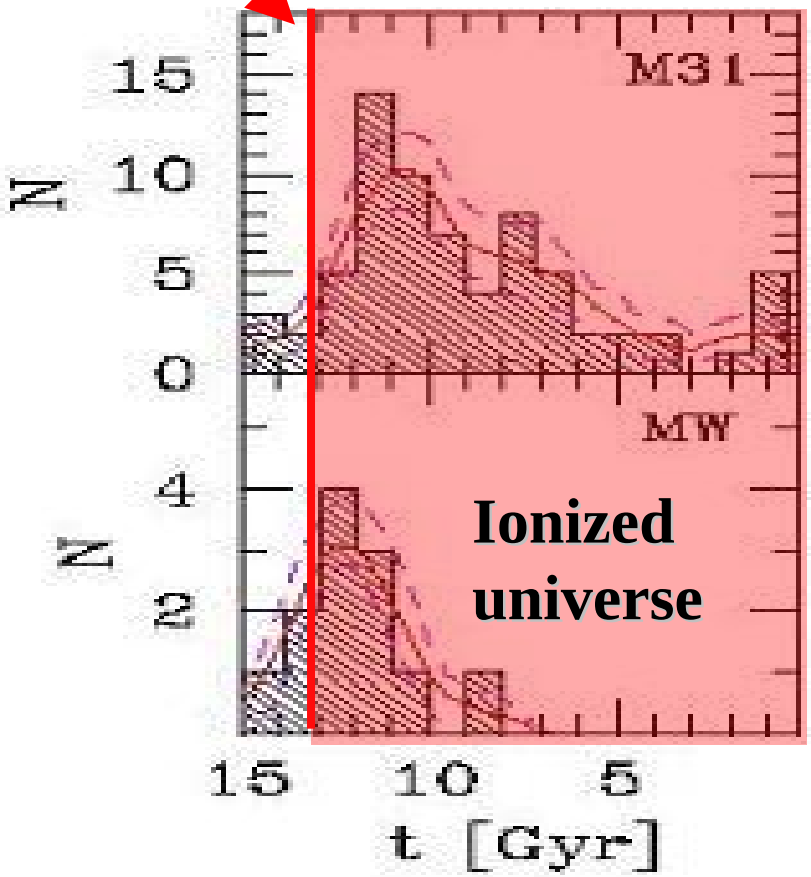
WMAP 3year (Page et al. 2006)

Reionization epoch **~13Gyr ago**

V.S

The age distribution of GCs

Mean age of GCs **~12Gyr**



Puzia et al. (2005)

It indicates that **many GCs formed after cosmic reionization !!**

GCs could form within UV radiation field ?

Importance of UV Radiation

negative

✓**Photoheating**

➡ Gas temperature ~ **10^4K**

✓**Photodissociation(H_2)**

➡ Gas clouds can not cool below 10^4K

➡ UV radiation might suppress the formations of GCs?

★OBJECTIVE★

We explore the possibility that GCs form within UV radiation field !!

Simulation of GC Formation within UV Radiation

1D spherical symmetric Lagrangian scheme (Kitayama et al. 2001)

ΛCDM universe:

Ω_0=0.3, Ω_b=0.05, Λ_0=0.7, h=0.7

Gas dynamics

$$\frac{dm_b}{dr_b} = 4\pi r_b^2 \rho_b$$

$$\frac{d^2 r_b}{dt^2} = -4\pi r_b^2 \frac{dP}{dm_b} - \frac{GM(<r_b)}{r_b^2} + \Lambda_0 H_0^2 r_b + f_{rad}$$

$$\frac{du}{dt} = \frac{P}{\rho_b^2}\frac{d\rho_b}{dt} + \frac{\Gamma - \Lambda}{\rho_b}$$

$$P = (\gamma - 1)\rho_b u = \frac{k_B \rho_b T}{\mu m_p}$$

$T < 2000$ K

$V_r < 0$

$\frac{d\rho}{dt} > 0$

$\frac{dT}{dt} < 0$

SF criteria

DM dynamics

$$\frac{d^2 r_d}{dt^2} = -\frac{GM(<r_d)}{r_d^2} + \Lambda_0 H_0^2 r_d$$

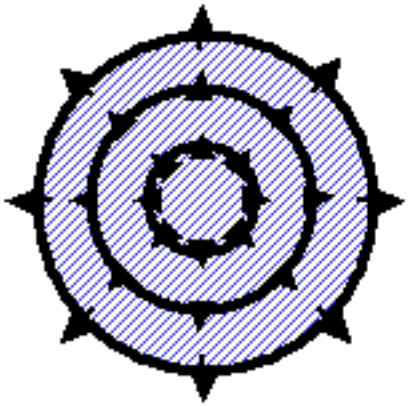
Star dynamics

$$\frac{d^2 r_s}{dt^2} = -\frac{GM(<r_s)}{r_s^2}$$

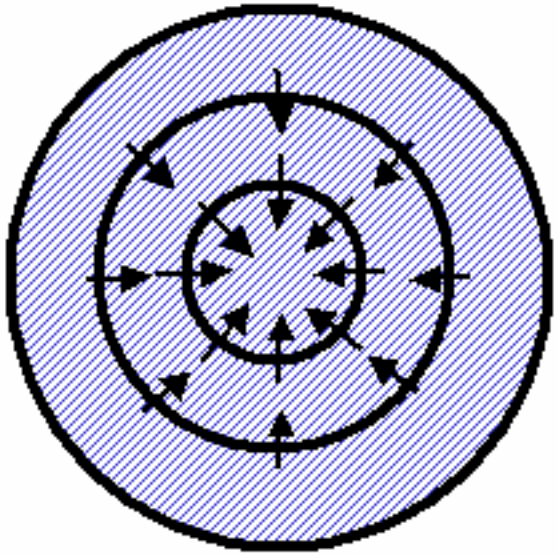
- RT of UV photons ⇒**Determine the heating and the chemical reaction rate**
- Non-equilibrium of chemistry ⇒**Determine the cooling rate (H2)**

Calculation Procedure

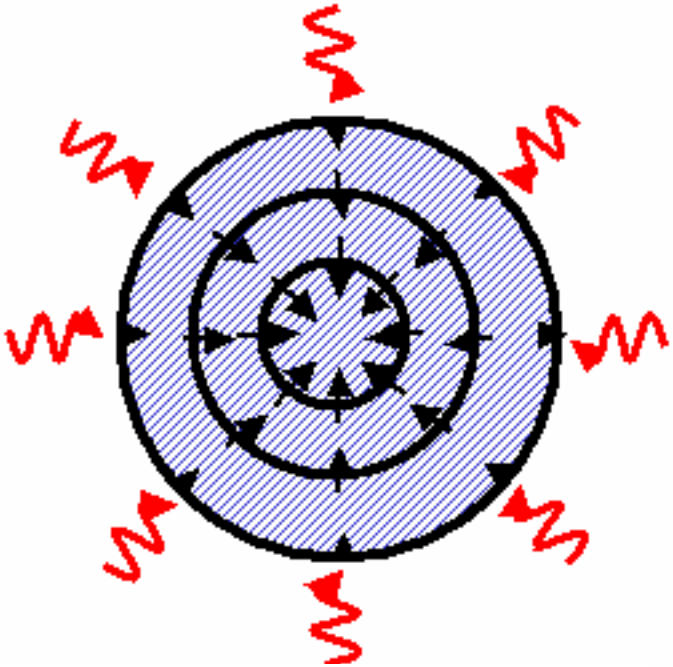
The cloud expands on the Hubble flow



The cloud turnarounds.



The contracting cloud is exposed by UV radiation!!

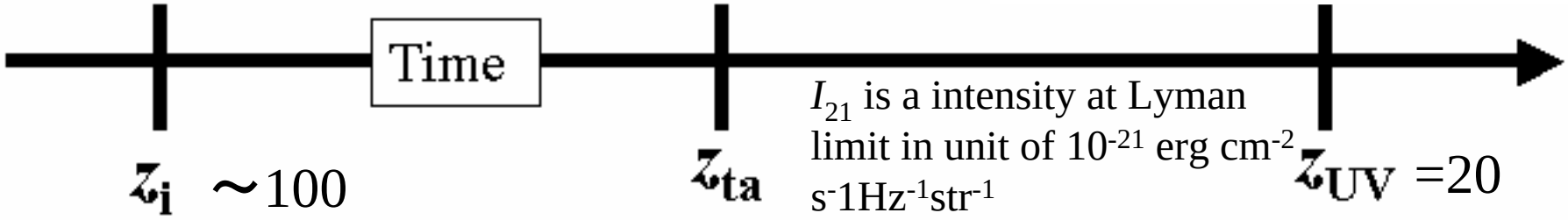


START

The cloud is still in linear regime.

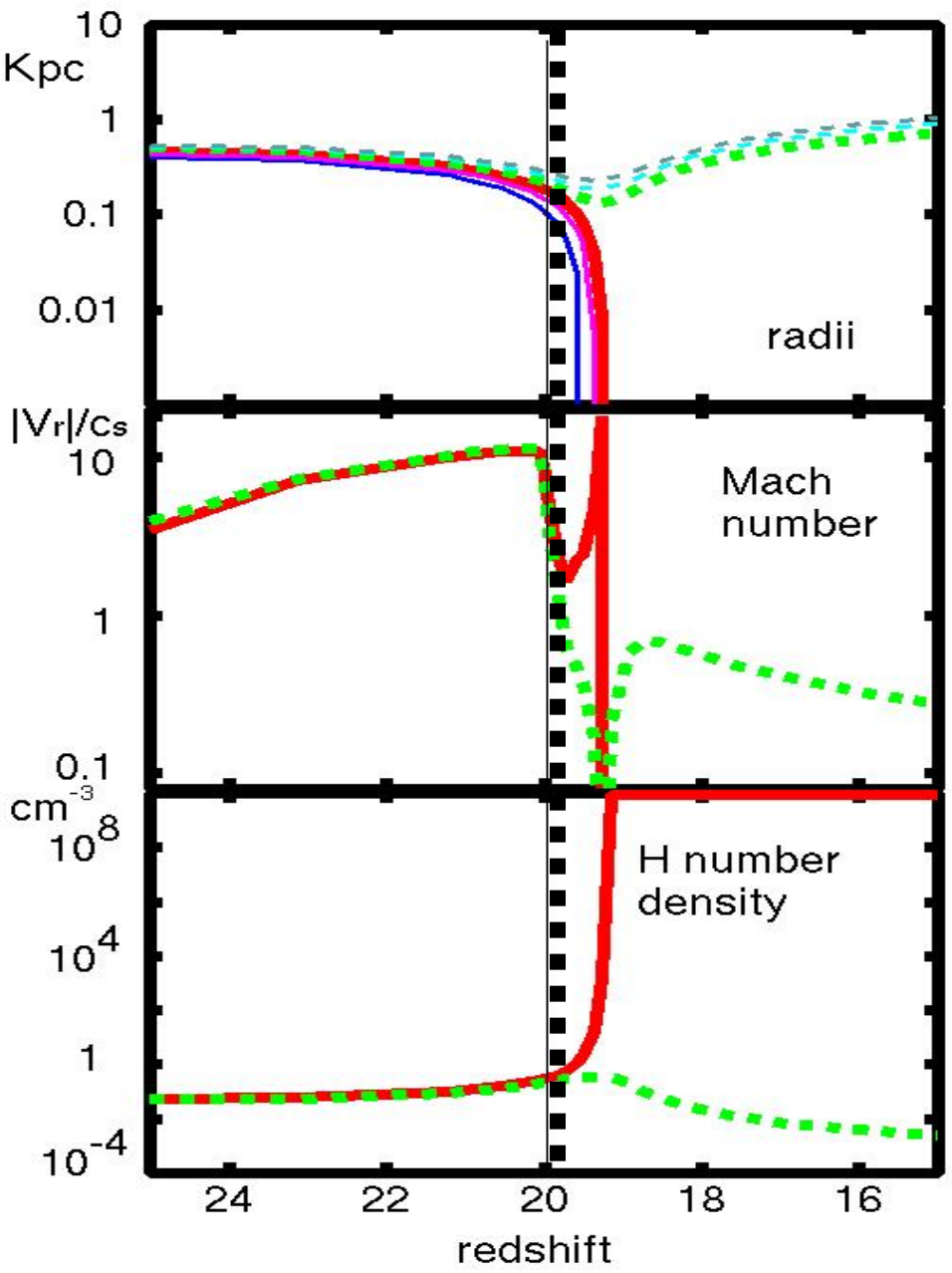
UV radiation on !!

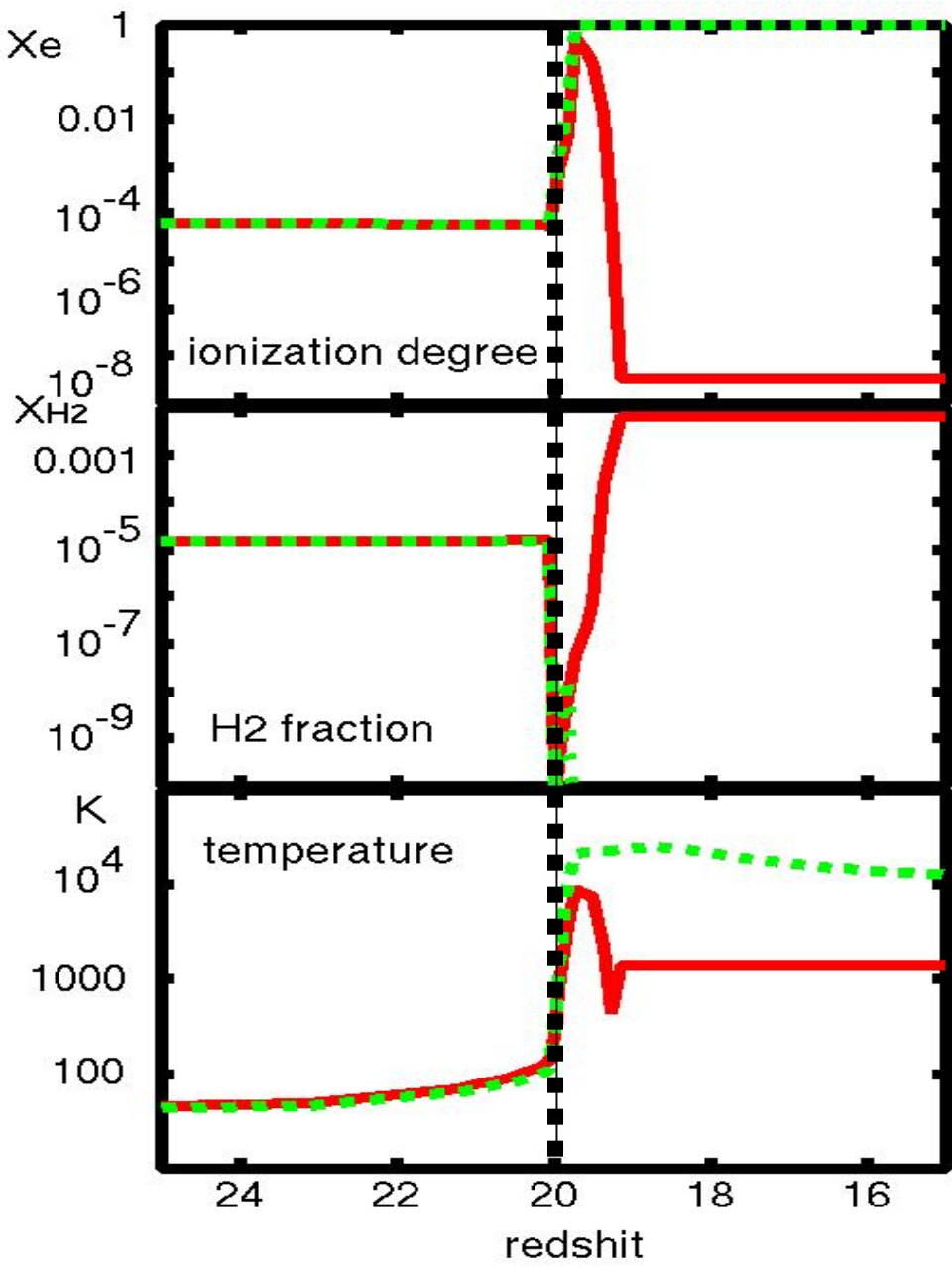
- ✓**Black Body with $T_{eff}=10^5$K**
- ✓**$10^{-3} < I_{21} < 10^3$**



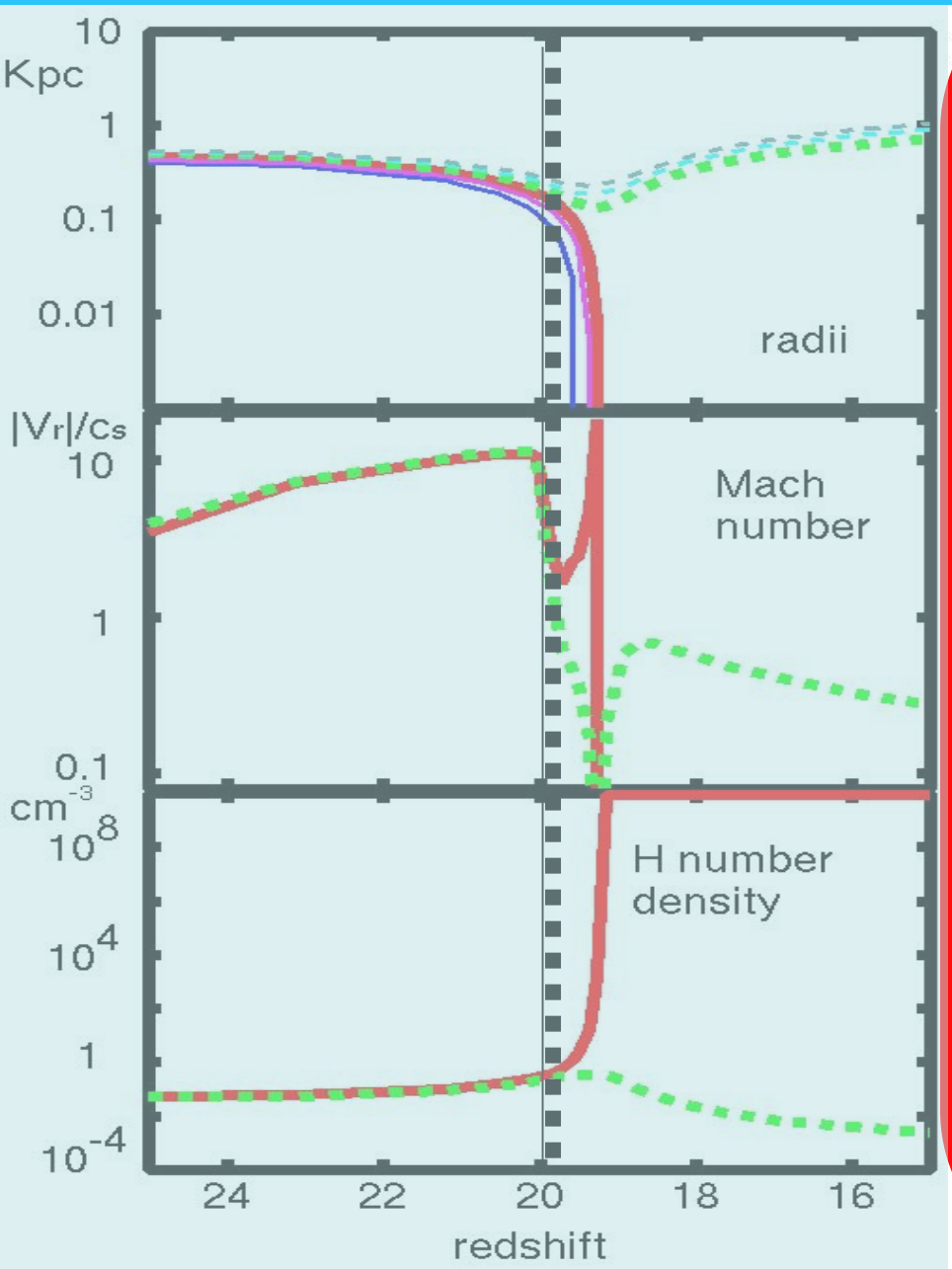
I_{21} is a intensity at Lyman limit in unit of 10^{-21} erg cm^{-2} s^{-1}Hz^{-1}str^{-1}

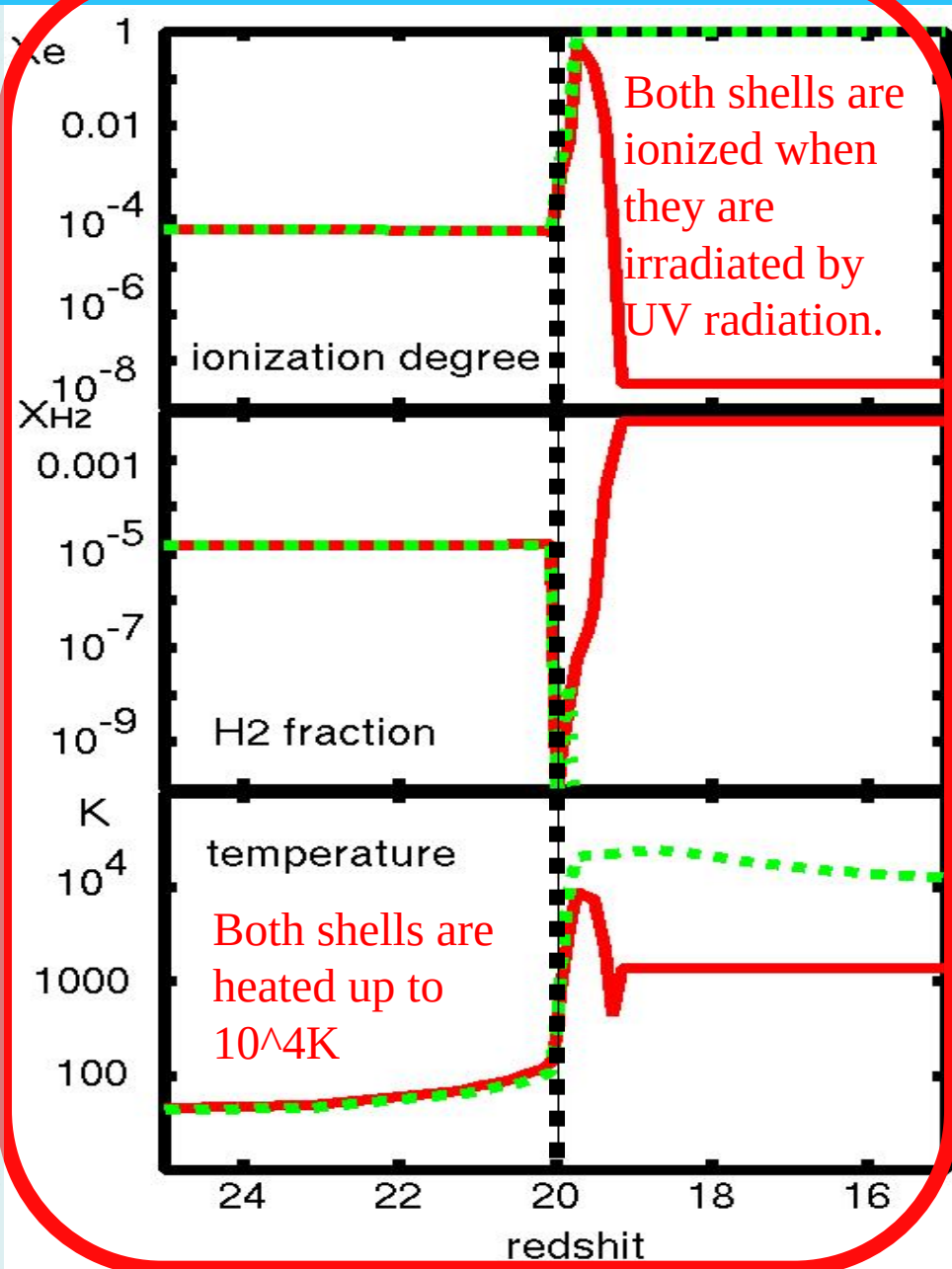
Evolution of the Cloud



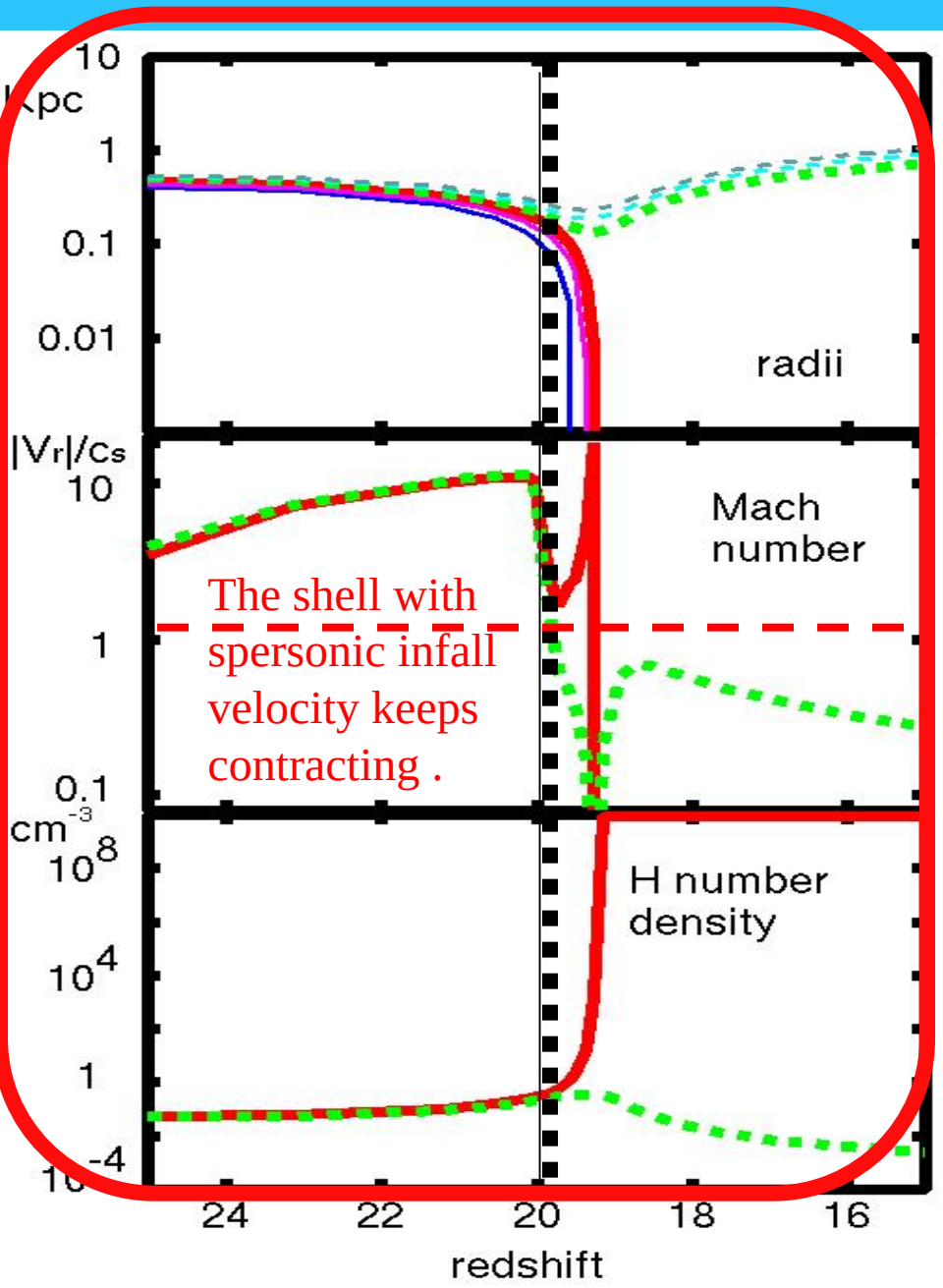


Evolution of the Cloud

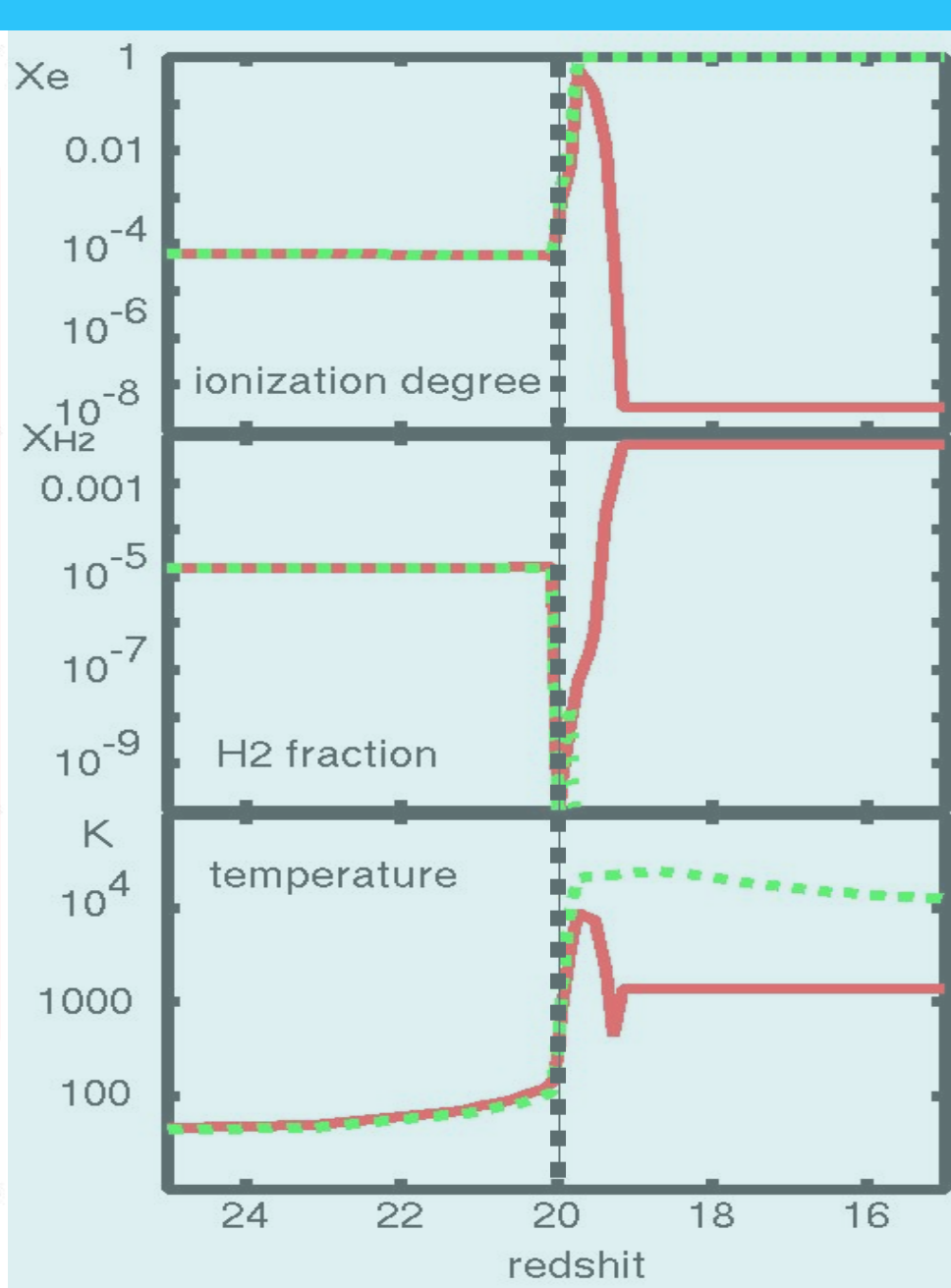




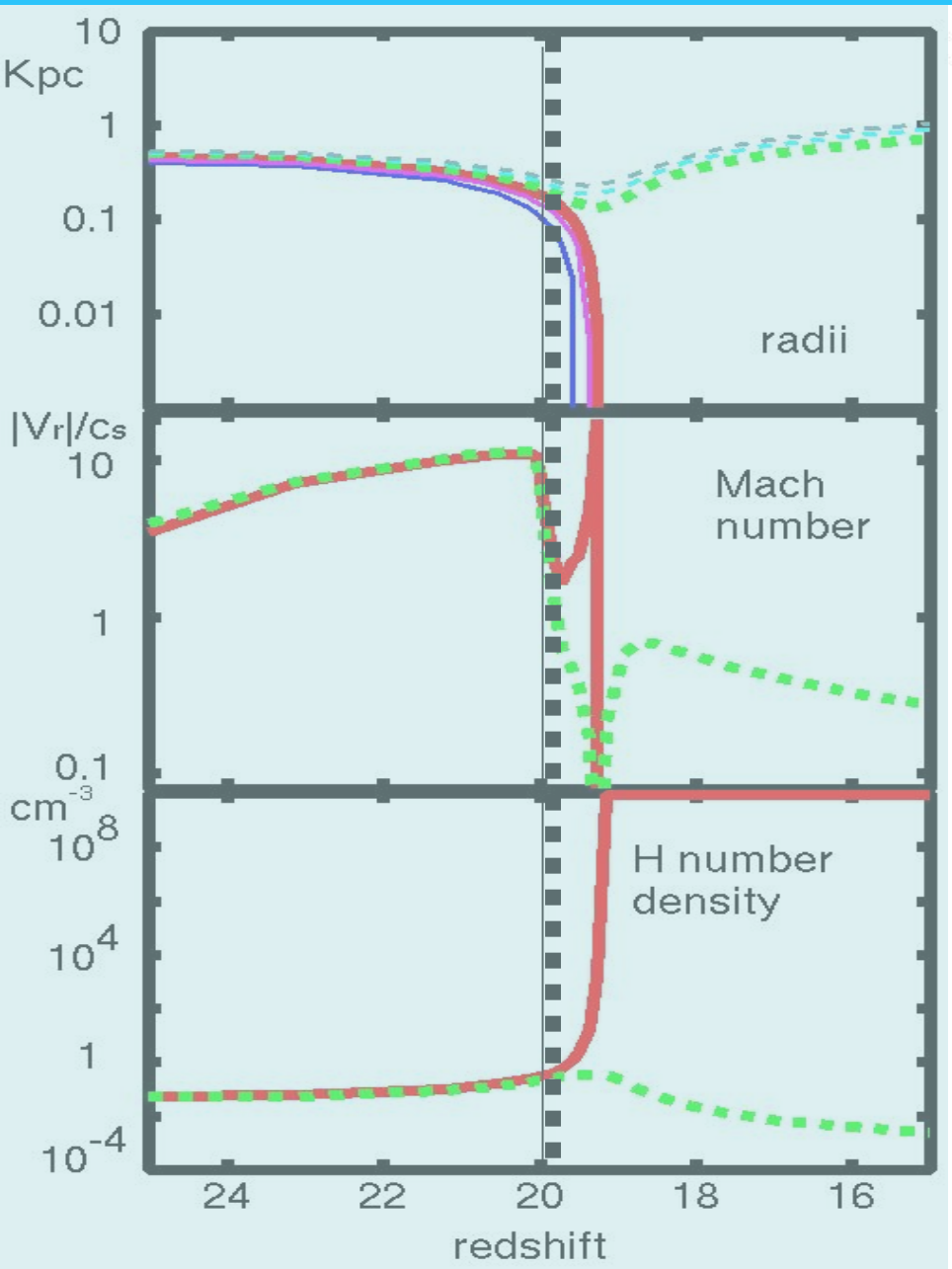
Evolution of the Cloud

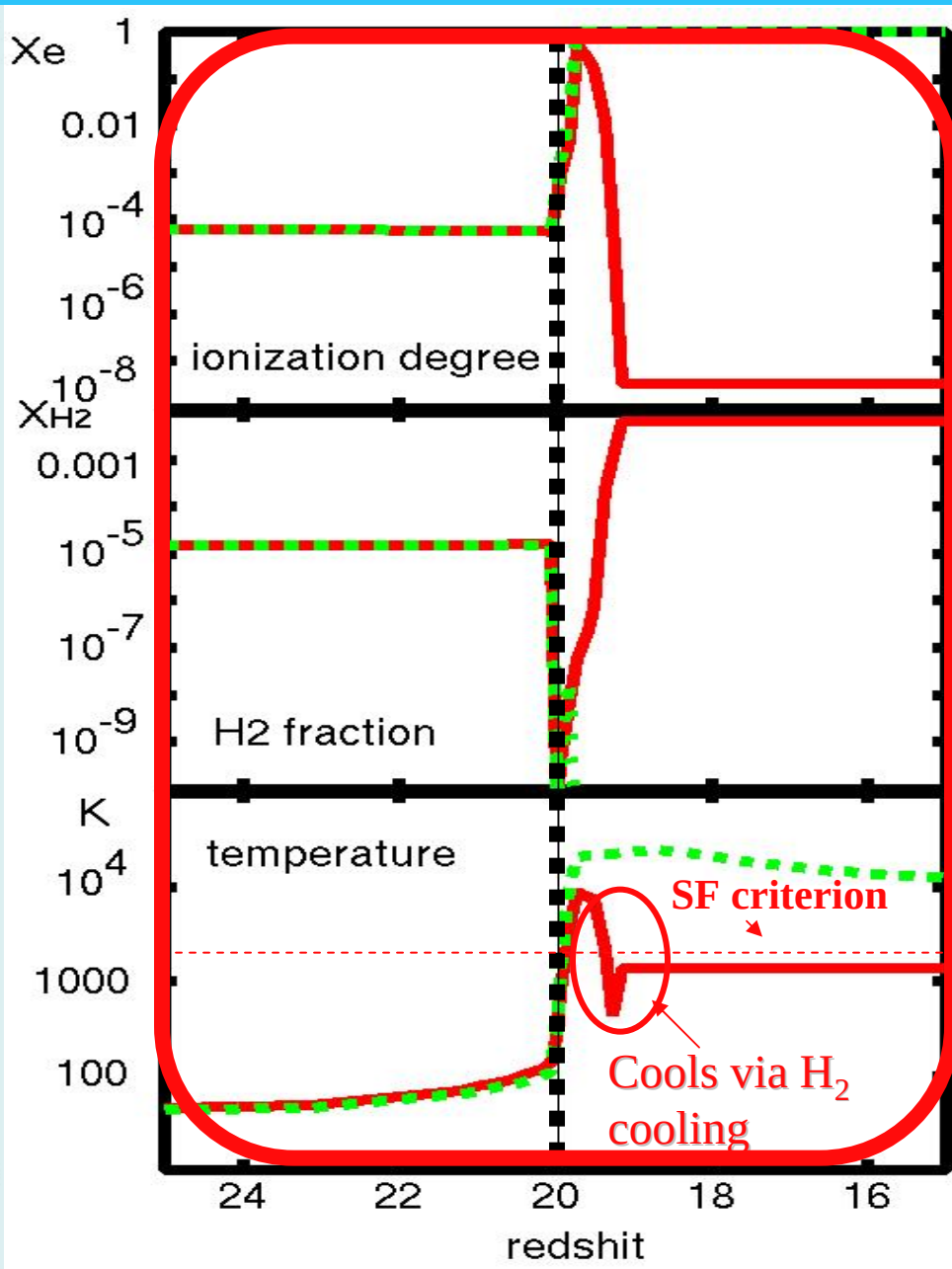


The shell with spersonic infall velocity keeps contracting .



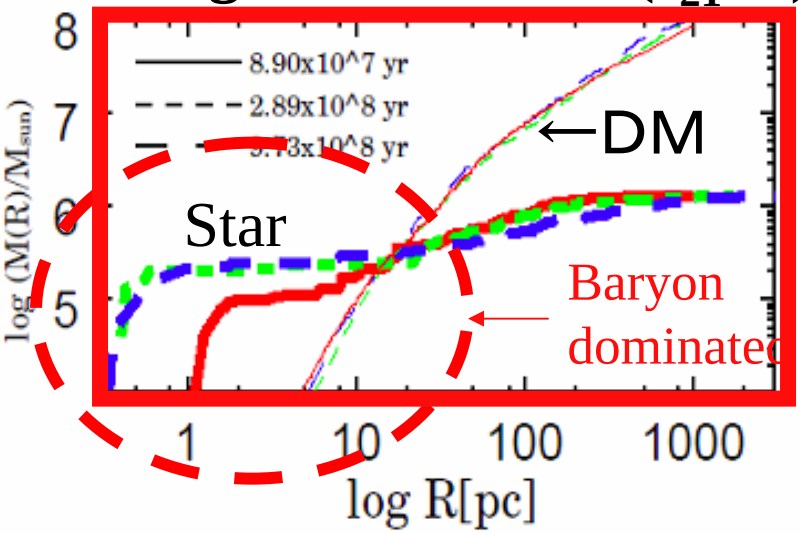
Evolution of the Cloud





Mass Distribution

Strong UV radiation (I_{21}>1)

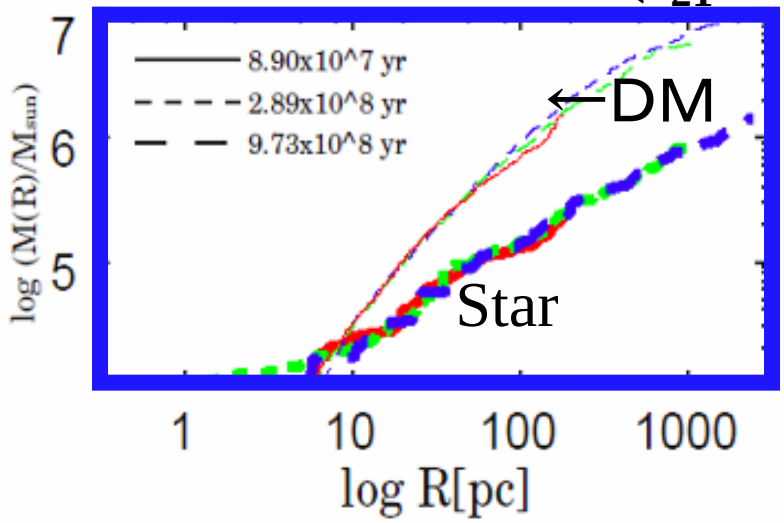


Star are born at inner region of the cloud. The energy dissipation is strong !!

Compact star cluster forms !!

⇨ **GC like (with DM halo)**

Weak UV radiation (I_{21}<0.1)



Stars are born at earlier dynamical stage.

DM dominated and low density star cluster forms ! ⇨ **dSphs like**

2nd PART

Dynamical Evolution of Globular Cluster

Collaborator

Masayuki Umemura (Tsukuba University)

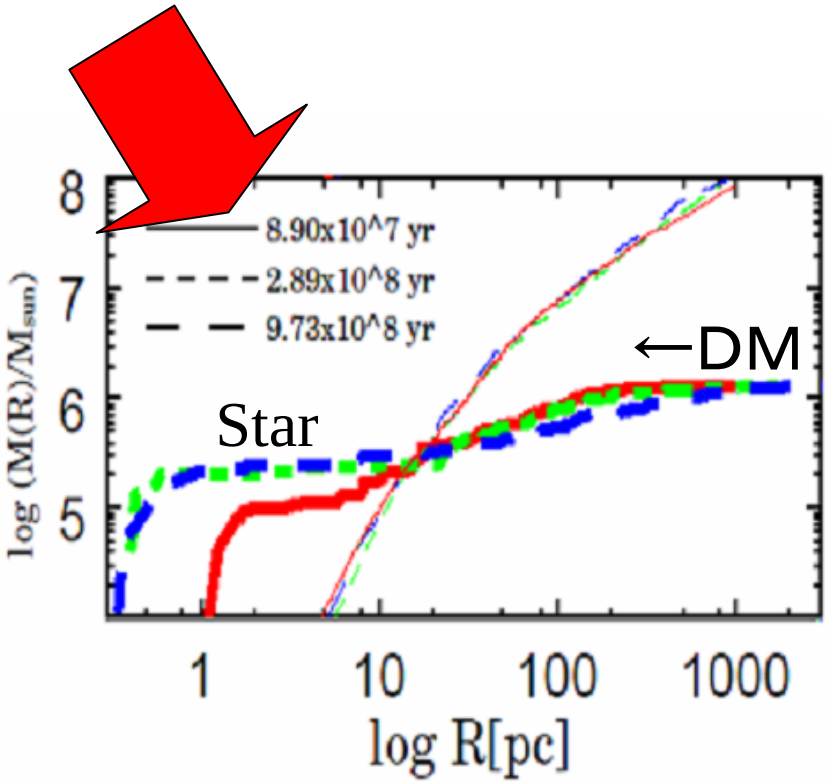
FIRST Project Team

Setup for the Simulation

- Number of particle : N_*=2^{14}, N_{DM} = 2^{18} (m_*/m_{DM}= 10.39)
- External tidal field

  *NFW type potential (with M_{gal}= $10^9 M_\odot$, R_{vir} = 294pc, c = 10)

- **Initial condition : Obtained by our simulation of GC formation.**



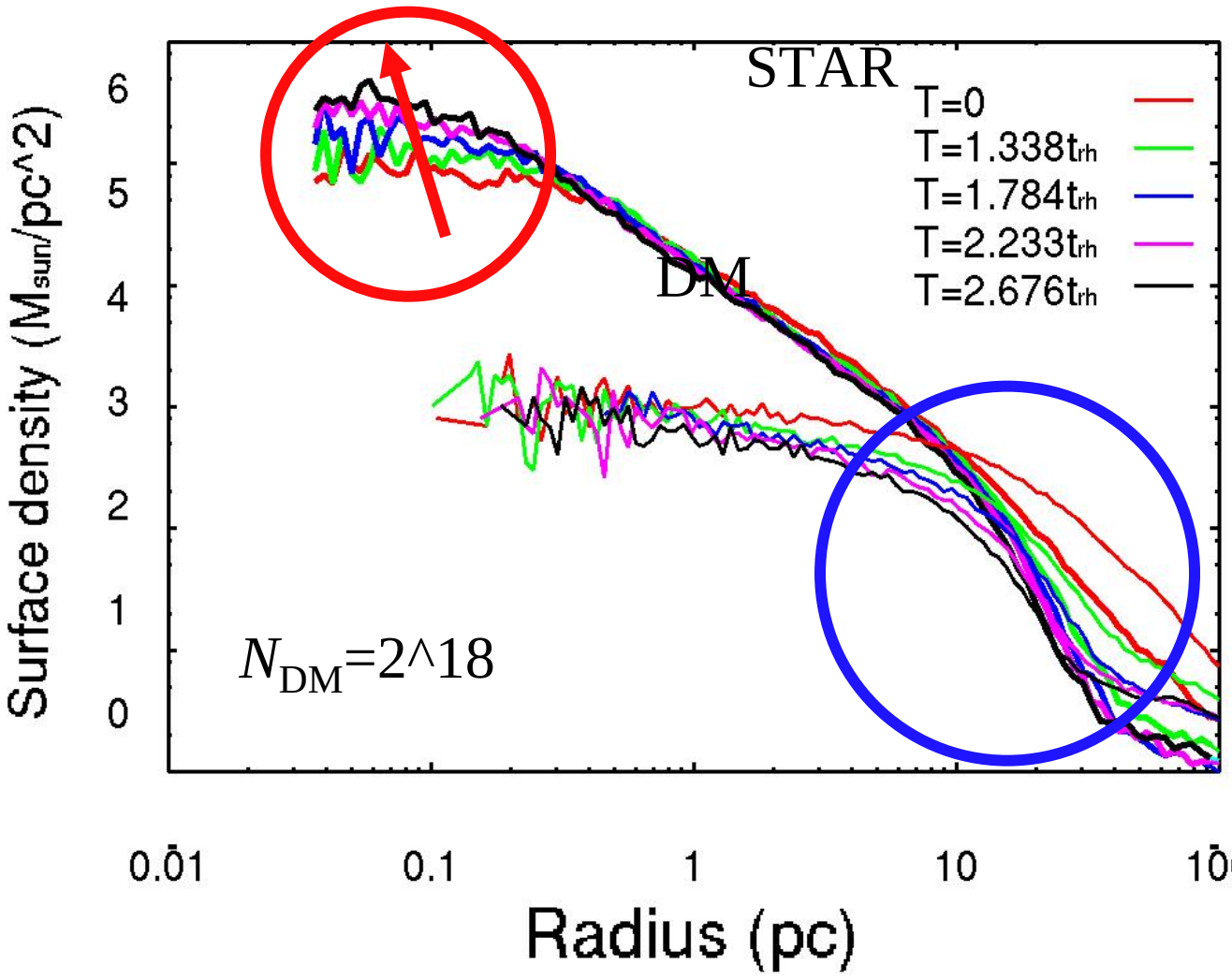
★Two-body relaxation (Spitzer & Hart 1971)

$$t_{rh} \approx 5.76 \times 10^9 \left(\frac{M}{10^6 M_{sun}}\right)^{1/2} \left(\frac{1 M_{sun}}{m}\right) \left(\frac{r_h}{10pc}\right)^{3/2}$$

Cosmic age(~14Gyr)
corresponds to 2.6 t_{rh}.

Evolution of Observable Profile

✓The profile changes as the star cluster evolves !!



Inner part

The core shrinks via two-body relaxation.

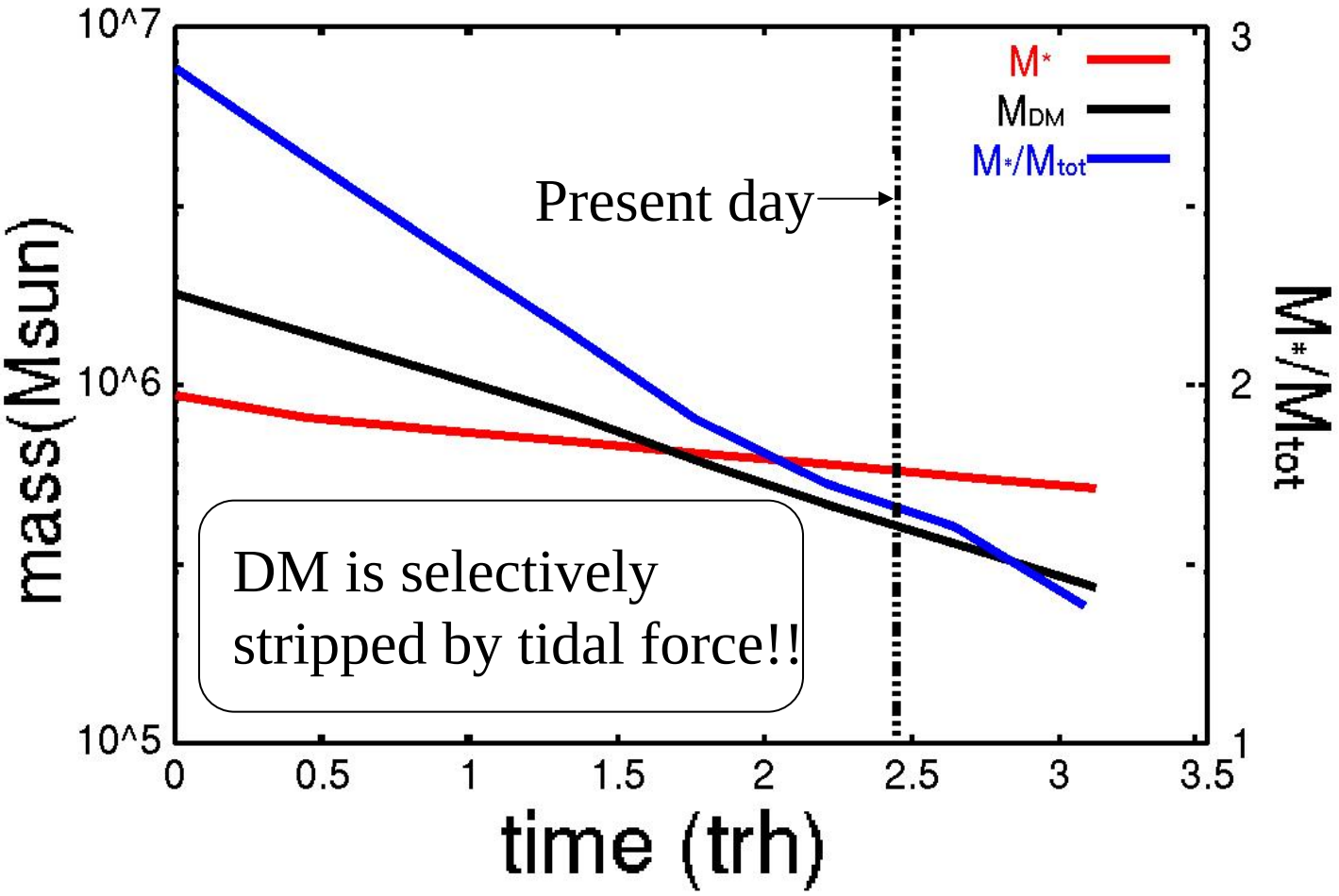
Outer part

Tidal stripping

⇨ The cluster mass decreases !!

Evolution of the Cluster Mass

We assume a mass within 50pc from the center as the cluster mass.



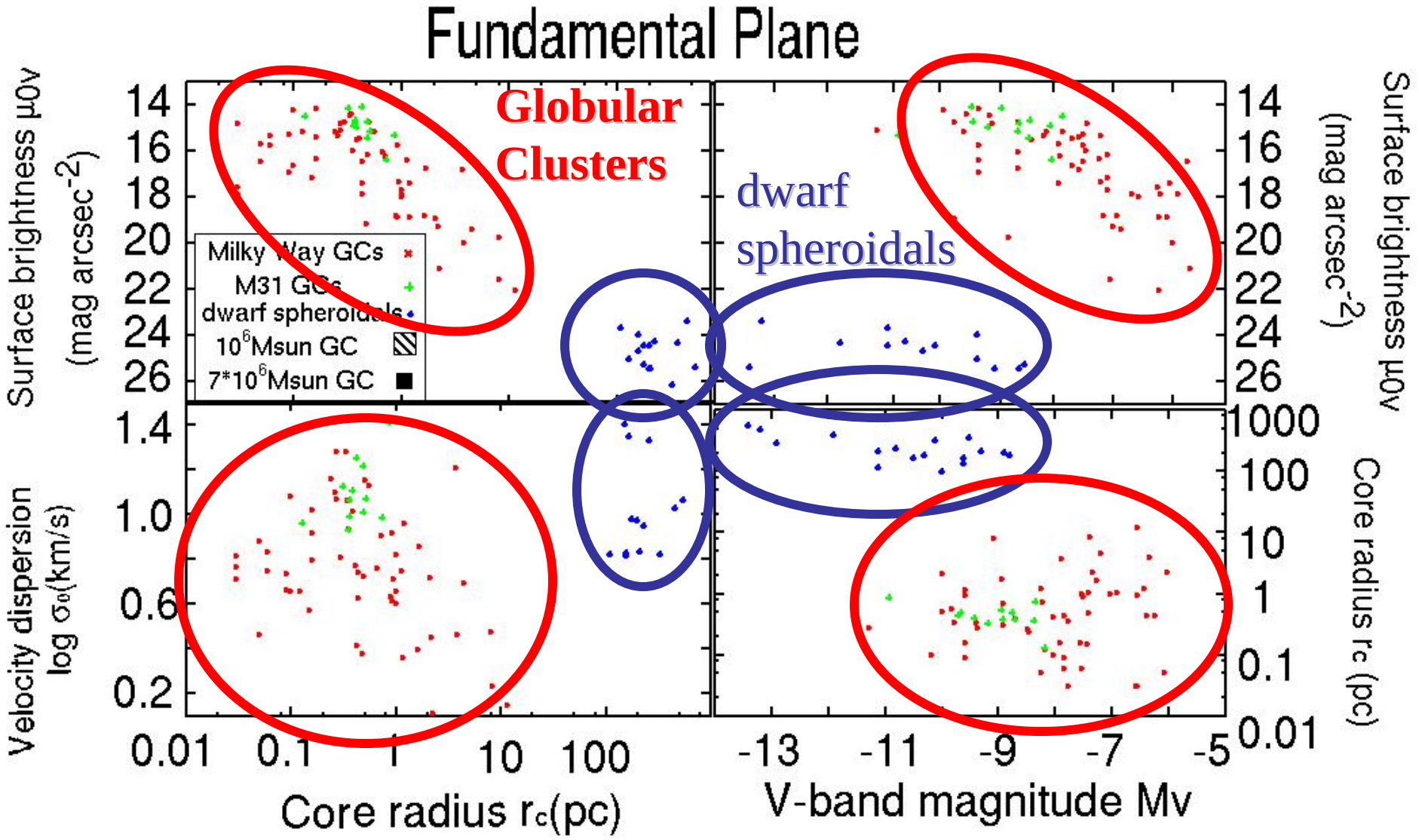
Simulation

The star cluster with a small amount of DM survive !!

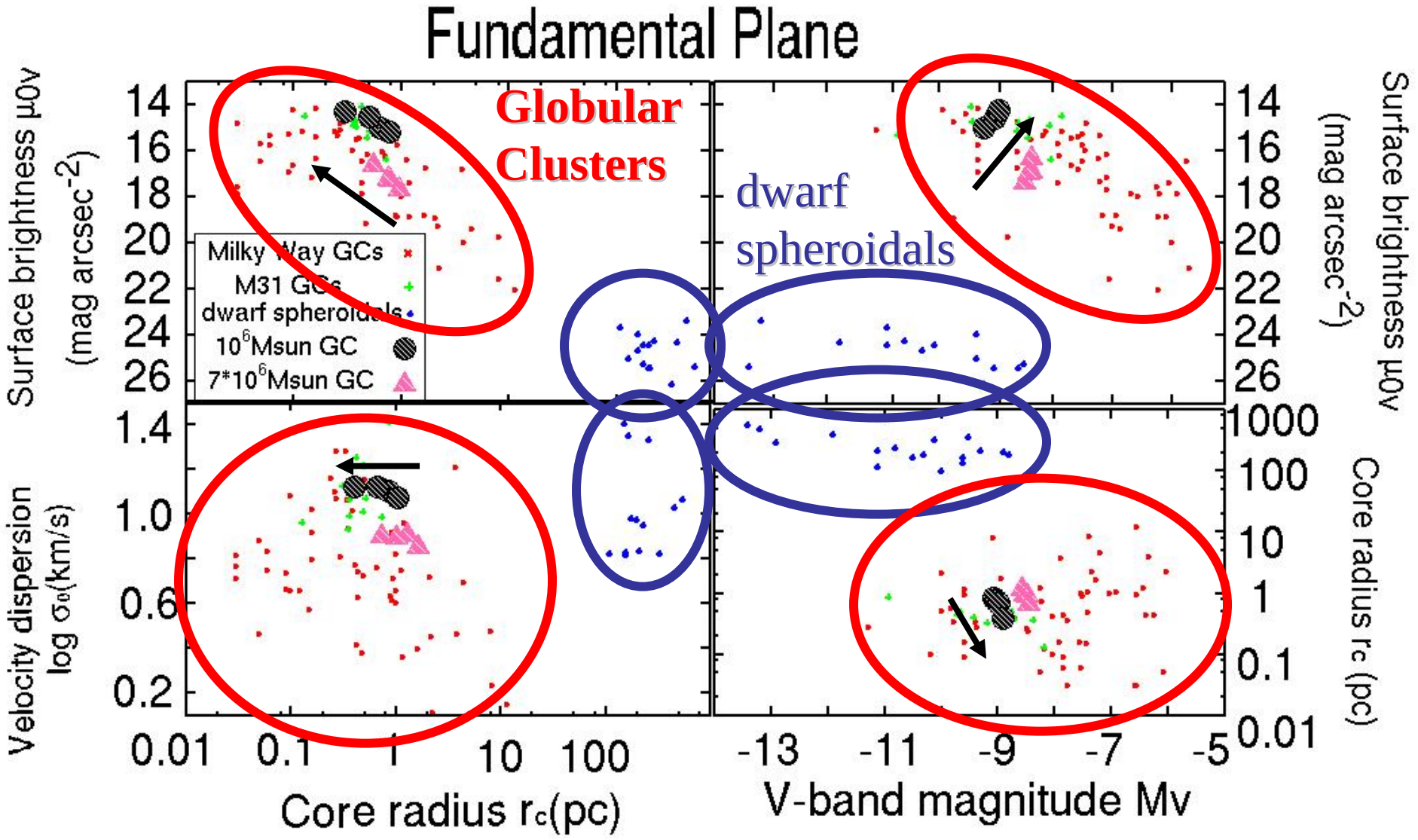
Observation

GCs have low mass-to-light ratio M/L ~ 2

Comparison with observations



Comparison with observations



T = 1.338, 1.784, 2.233, 2.676t_{rh} are shown

Summary

★Globular Cluster Formation within UV radiation Field

Strong UV radiation ⇨ The cloud is ionized !!

If the cloud has supersonic infall velocity, the cloud keeps contracting.

⇨ **Star formation is delayed and stars are born at inner region of the cloud**

Compact star cluster forms

Weak UV radiation ⇨ Shielding effect works well !!

⇨ **Stars are born at earlier dynamical stage.**

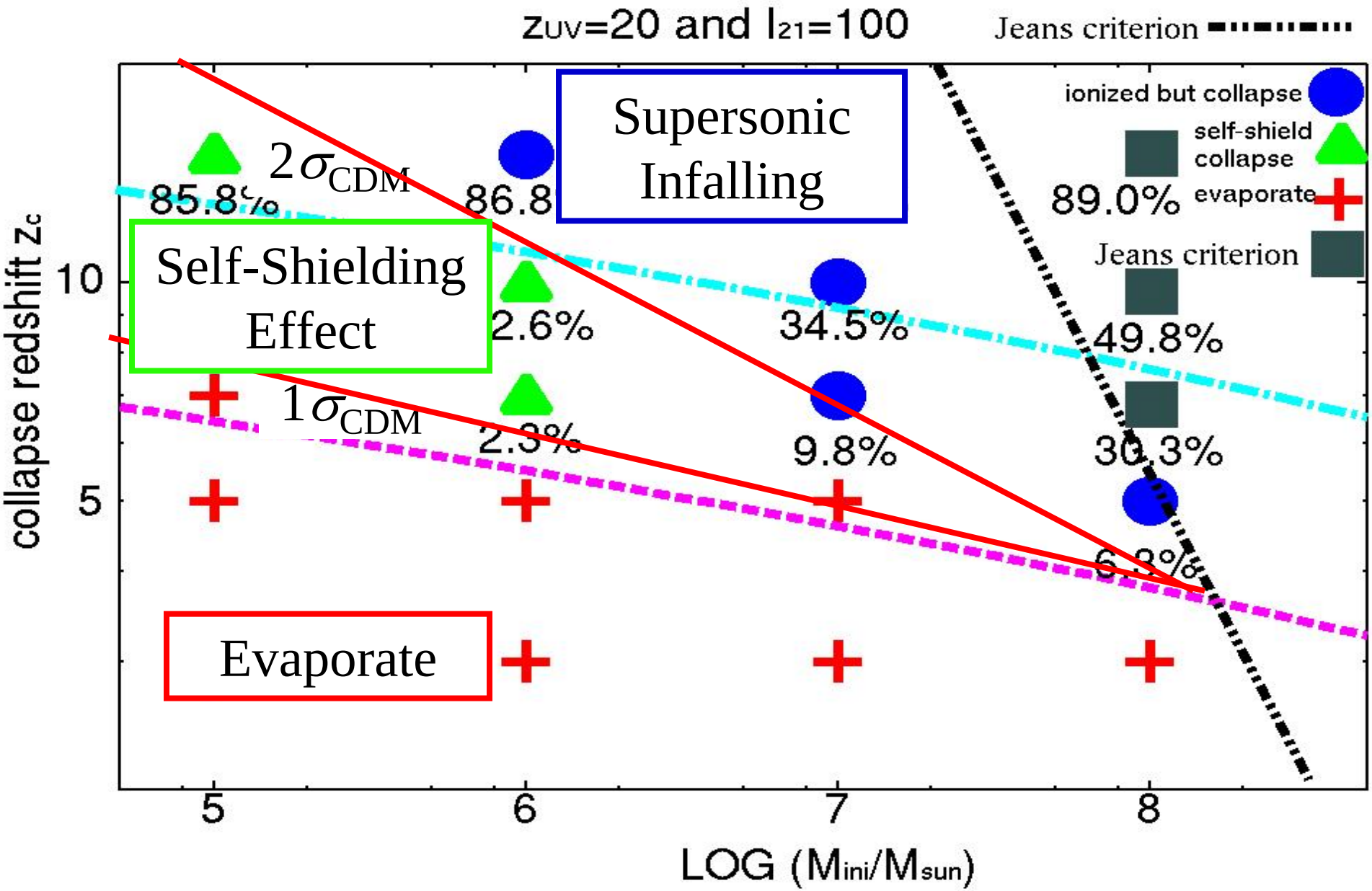
Diffuse star cluster forms

★Dynamical Evolution of Globular Cluster

- ✓**Observable profiles change as the cluster evolves.**
- ✓**DM halo is stripped by tidal interaction with the host galaxy. ⇨ Low mass-to-light ratio.**
- ✓**Simulation results are well consistent with observations.**

Our GC formation scenario is plausible to explain the observed GCs

Result: Strong UV case



Result: Weak UV Case