銀河形成初期における多重超新星の影響

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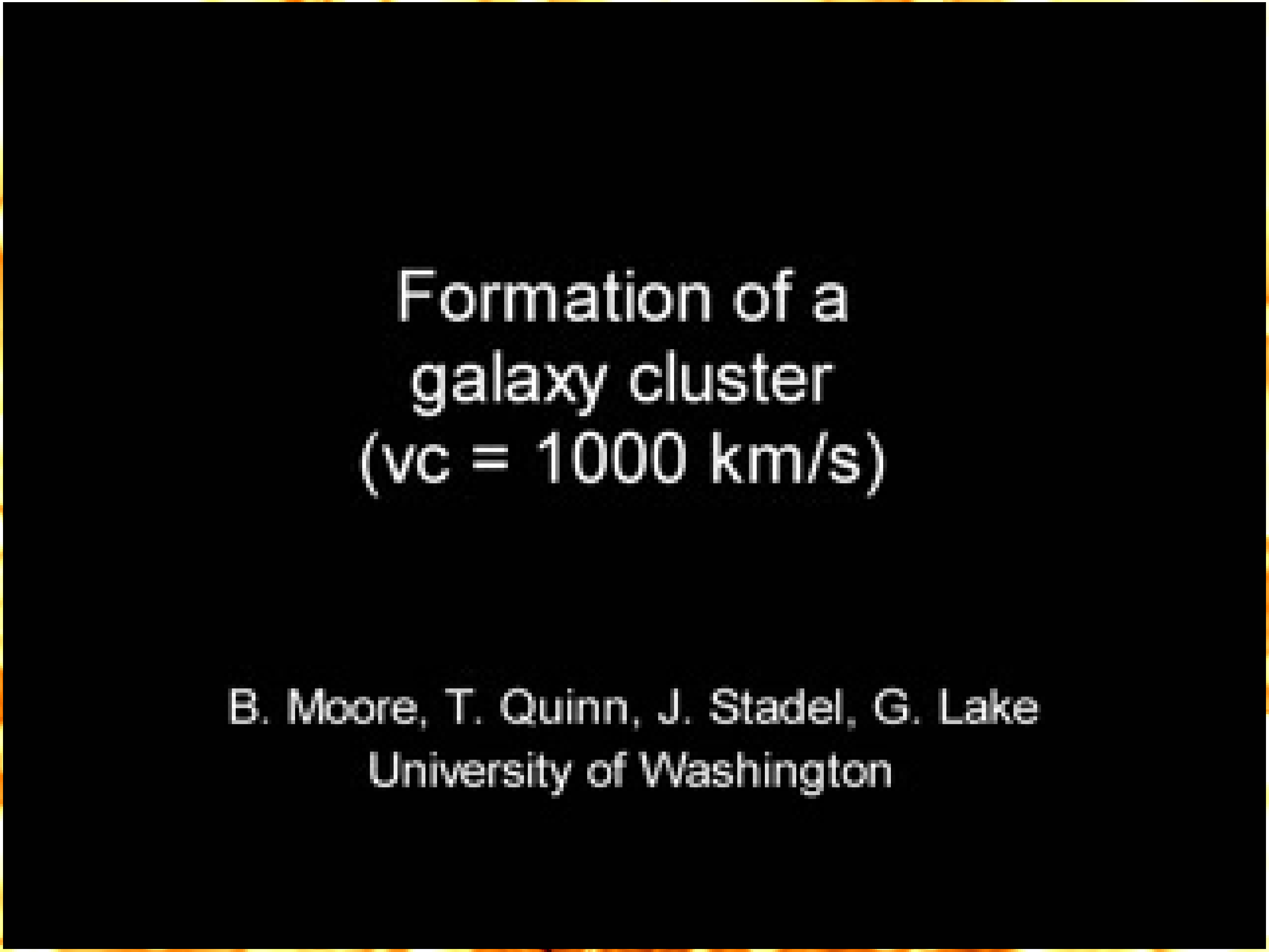
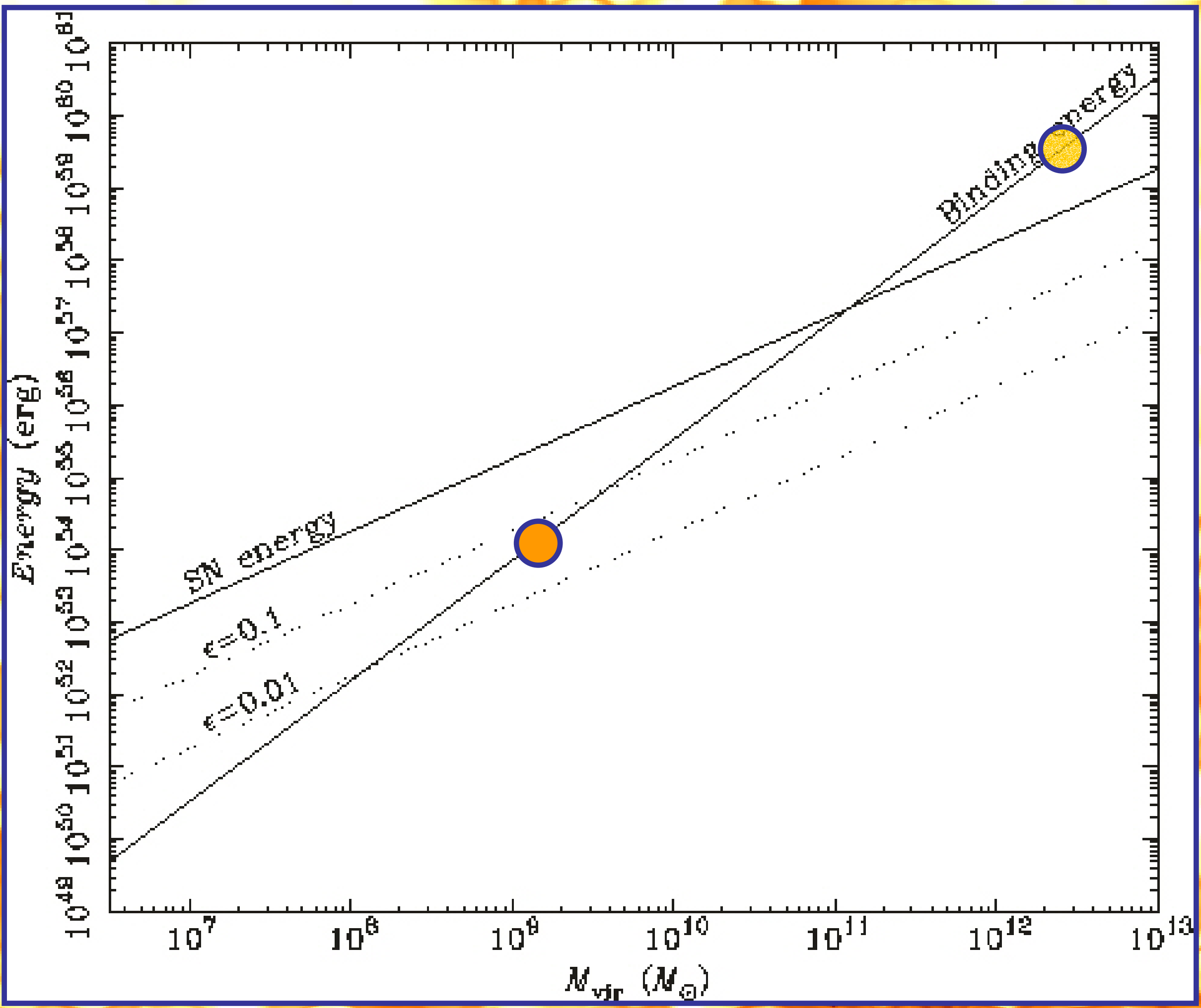
Cold Dark Matter による構造形成



3D Hydrodynamic Model:
Gas and Dark Matter Halo



Dark matter: NFW profile

Stars: 1% of total mass

$E_{SNII} = 10^{51} N_{SNII}$ with

$x = 1.35$,

$m_u = 120$, $m_l = 0.1$, $m_{sn} = 8$

3D Hydrodynamic Model: Stars

Dwarf Galaxies:

$M_{t,DG}=1.4\times10^{9}\ M_{\odot}$

$M_{b,DG}=5.5\times10^{7}M_{\odot}$

$dM_{g}(t)/dt=-M_{g}(t)/\tau_{sf}$

$\tau_{sf}=10^{8}$ yr

$R_{vir,DG}=8.6$ kpc

$N_{OB}=100$

$\rho_{OB}\propto[r(1+r/r_{s,DG})^{2}]^{-\alpha}$

OB associations:

$M_{OB}=5.3\times10^{4}\ M_{\odot}$

$N_{SN}=396$

$E_{SN}=3.96\times10^{53}$ erg

$dM_{SN}/dt=1.4\times10^{22}$g/s

$dZ_{SN}/dt=3.2\times10^{21}$ g/s

Total System:

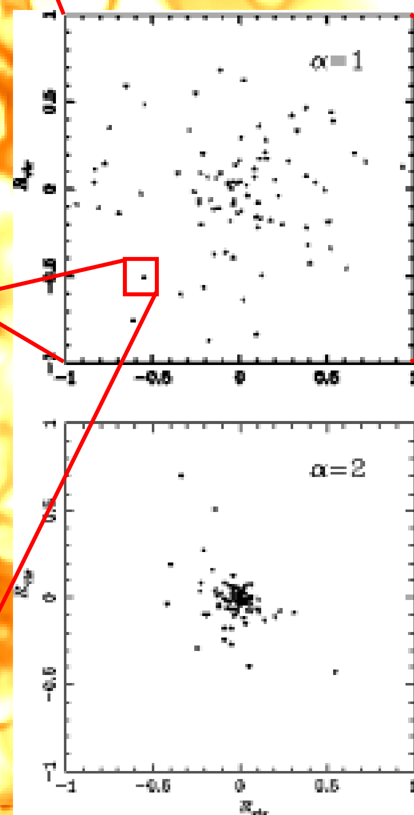
$M_{t,TS}=2.7\times10^{12}\ M_{\odot}$

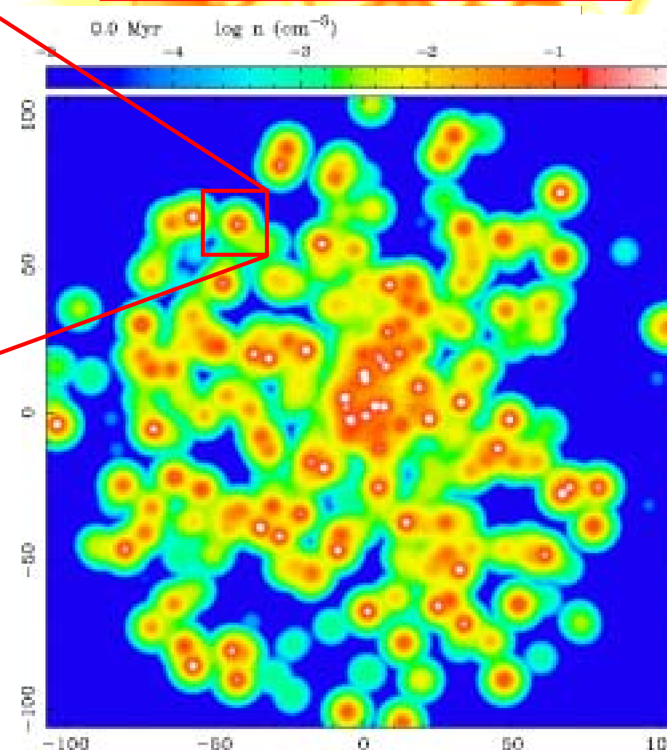
$M_{b,TS}=1.1\times10^{11}M_{\odot}$

$R_{vir,TS}=106.4$ kpc

$N_{DG}=1900$

$\rho_{DG}\propto[r(1+r/r_{s,TS})^{2}]^{-\beta}$





AFD Code

- **オイラー方程式、カーテシアン座標**

ρ : density

v : velocity

e : total energy

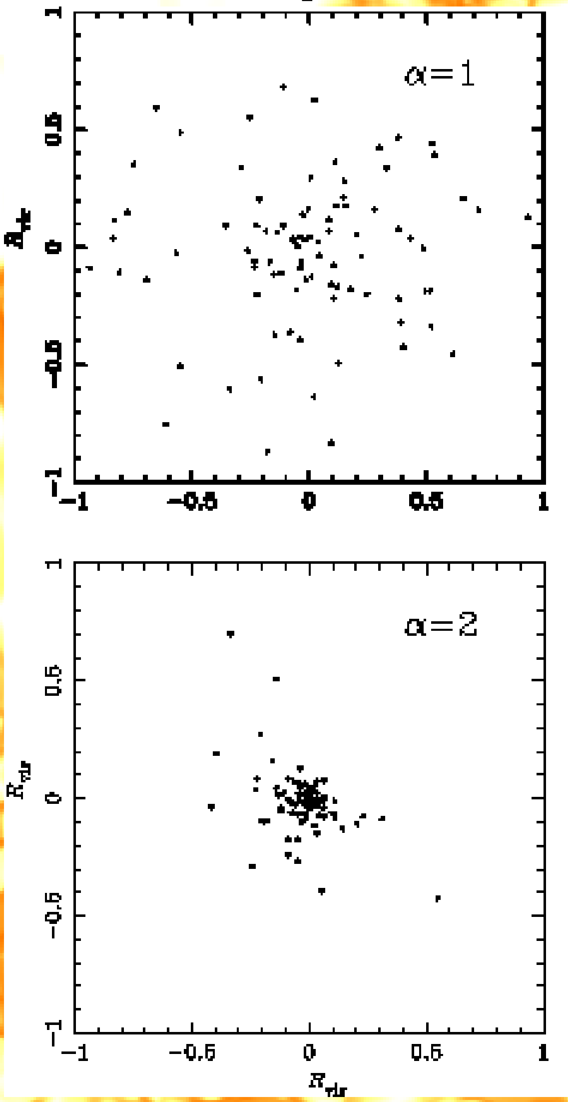
$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}}{\partial x} + \frac{\partial \mathbf{G}}{\partial y} + \frac{\partial \mathbf{H}}{\partial z} = \mathbf{S}$$

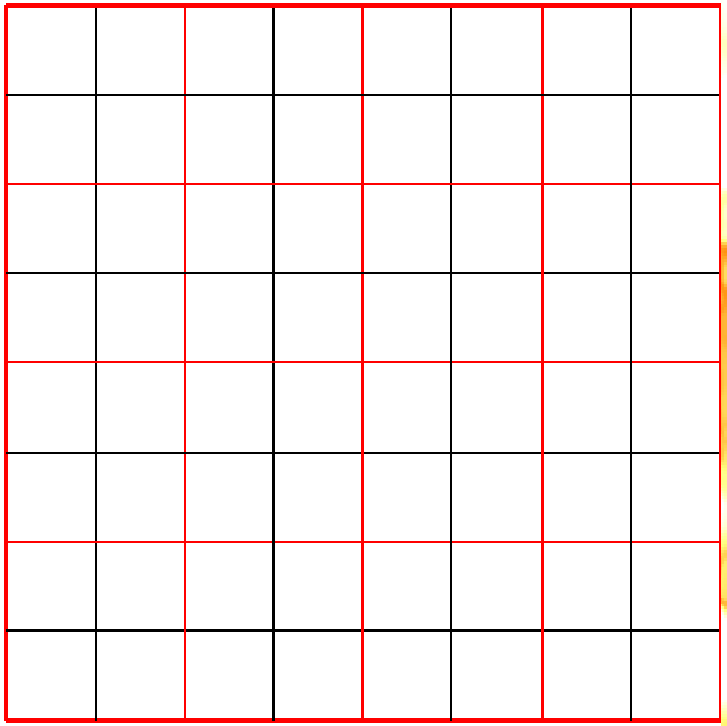
with

$$\begin{aligned}
\mathbf{U} &= (\rho, \rho v_x, \rho v_y, \rho v_z, \rho e)^T, \\
\mathbf{F} &= (\rho v_x, \rho v_x^2 + p, \rho v_x v_y, \rho v_x v_z, \rho v_x h_e)^T, \\
\mathbf{G} &= (\rho v_y, \rho v_x v_y, \rho v_y^2 + p, \rho v_y v_z, \rho v_y h_e)^T, \\
\mathbf{H} &= (\rho v_z, \rho v_x v_z, \rho v_y v_z, \rho v_z^2 + p, \rho v_z h_e)^T, \\
\mathbf{S} &= (\dot{\rho}_s, \rho g_x, \rho g_y, \rho g_z, \rho \mathbf{v} \cdot \mathbf{g} + \Gamma_s - \Lambda)^T.
\end{aligned}$$

- **フラックスの評価**：AUSMDV + MUSCL
- **放射冷却、超新星加熱**
- **重力**（Dark Matter） --- **時間変動しない**

Spatial decomposition





ロードバランスの均衡
通信の隠蔽

Simulations

- Machine

  CP-PACS: 1024 PEs (University of Tsukuba),

  Fortran + MPI

  1024^3 grid points

  ~70 hours/run

- Model

  α : Distribution of OB associations in a Dwarf Galaxy

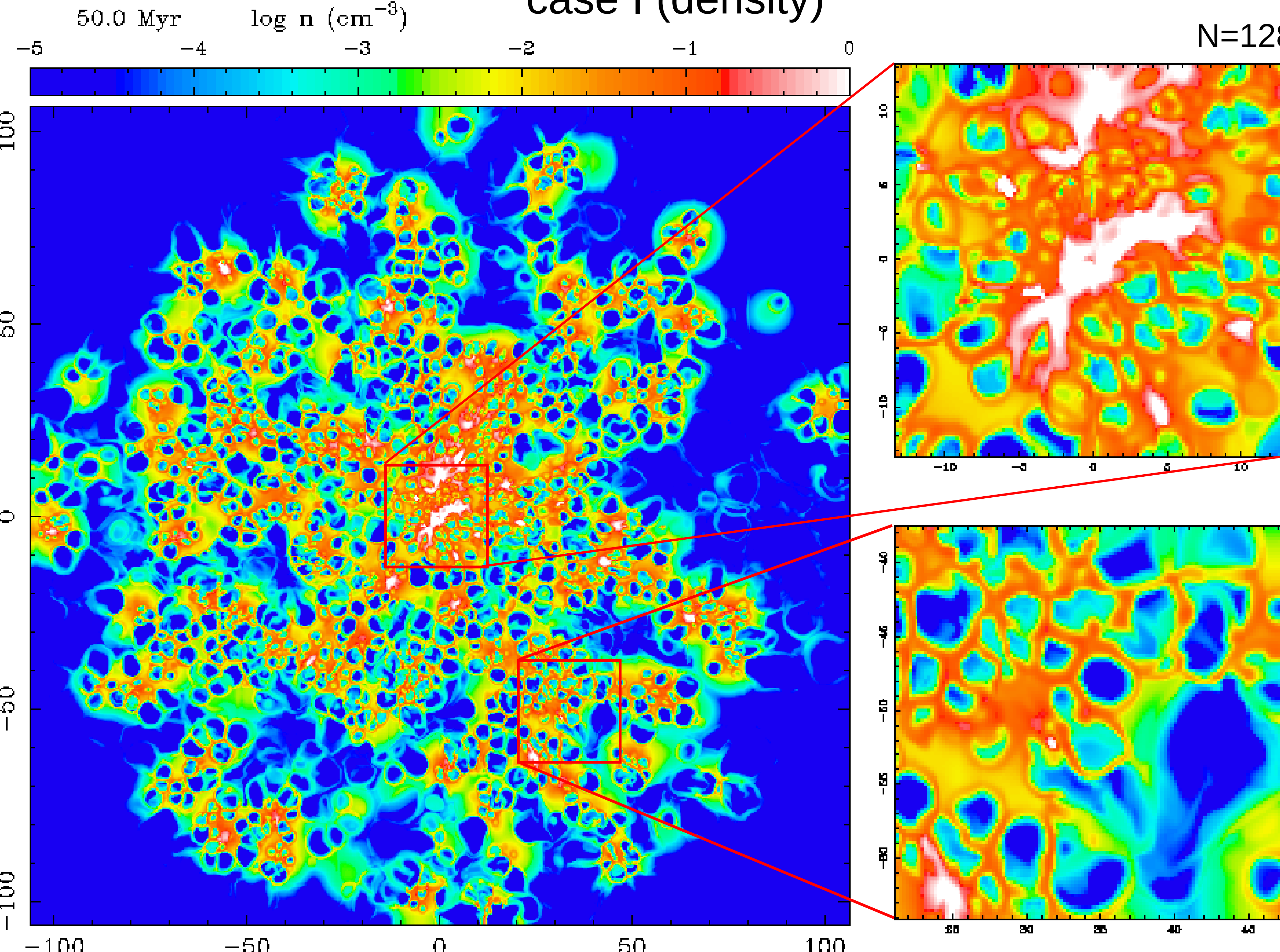
  β : Distribution of Dwarf Galaxies

  (1)Case 1 : α=1, β=0.5 [Standard Model]

  (2)Case 2 : α=1, β=0.5

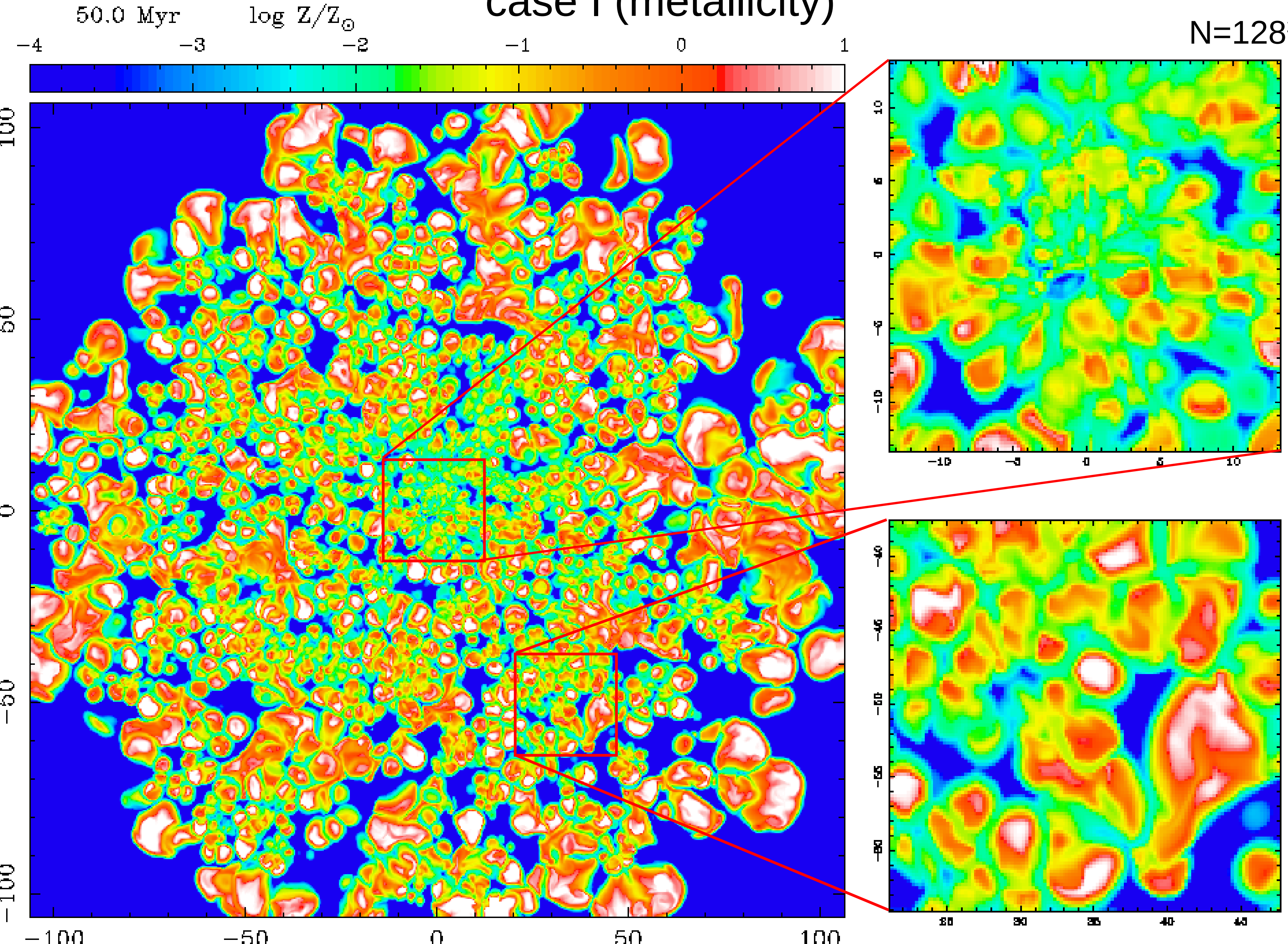
case I (density)

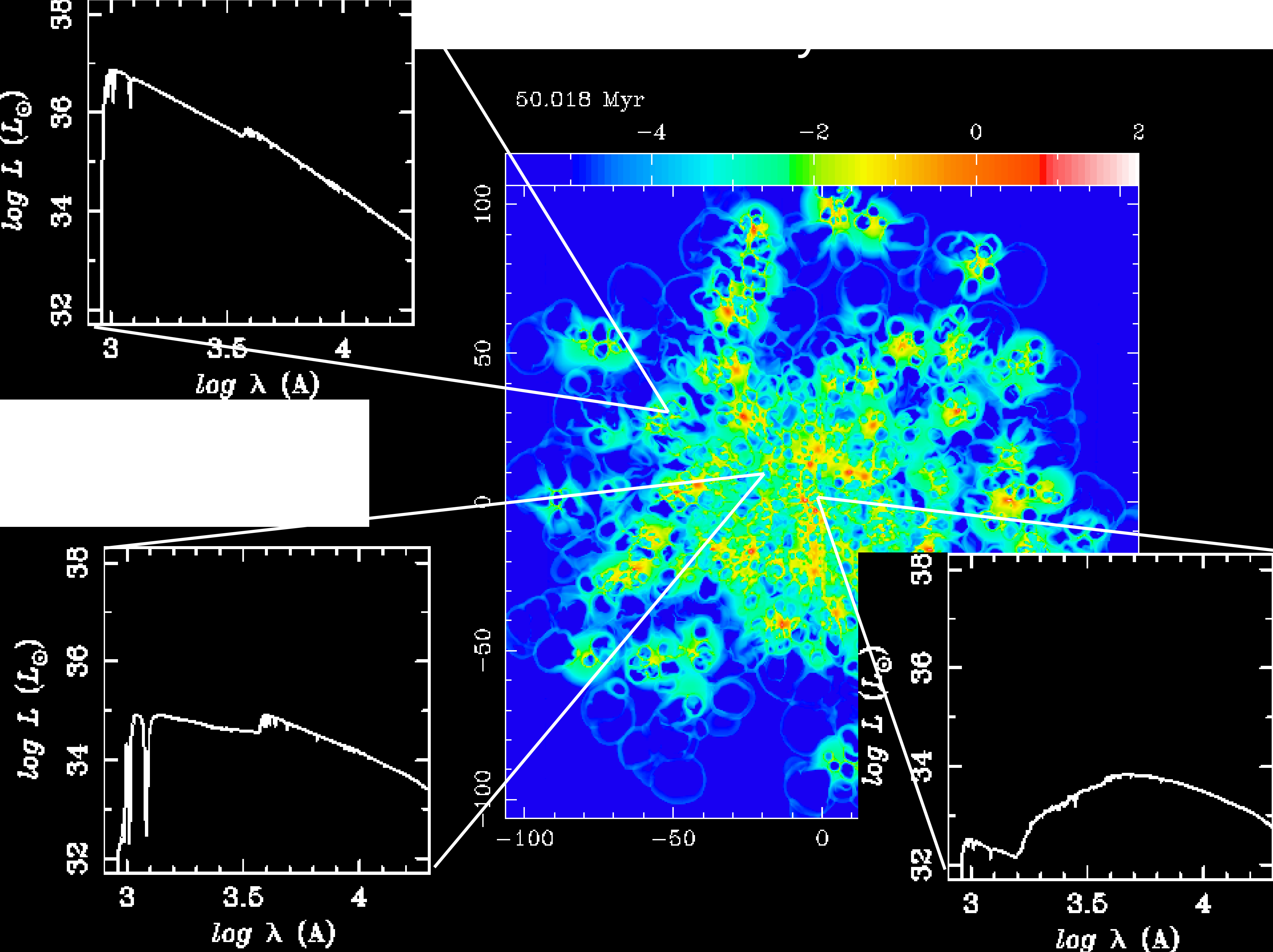
$N=128^3$



case I (metallicity)

N=128^3





50.018 Myr
−4
−2
0
2
100
50
0
−50
−100
−100
−50
0
log L ($L_\odot$)
32
34
36
38
3
3.5
4
log λ (A)

Spectral Energy Distribution

Emission from stars

Population synthesis model:

Fioc 1997 (PÉGASE)

Assuming $[Z_{stars}]=-3$

Emission from gas

Collisional ionization equilibrium:

Sutherland & Dopita 1993 (MAPPING III)

- Bound-bound emission
- Free-bound emission
- Free-free emission
- Two-photon emission

Dust extinction

$E(B-V)=(N/4.77\mathrm{x}10^{21}\ cm^{-2})(Z/0.02)$

Black 1987

Extinction curve: $\langle A_\lambda/A_v \rangle$

Pei 1992

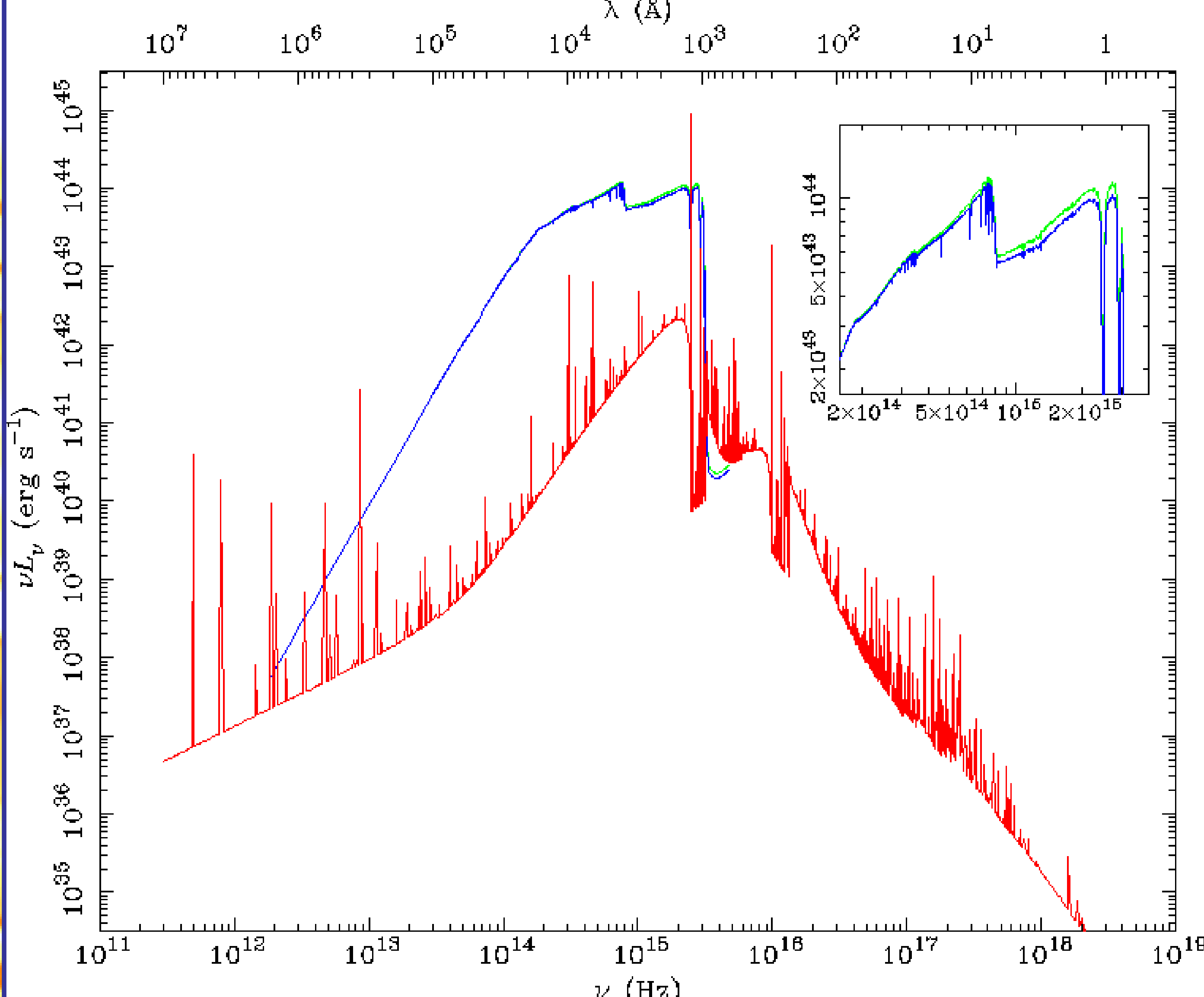
$\Delta\tau_i(\lambda)=R_v/1.0857\ (N_i/4.77\mathrm{x}10^{21}\ cm^{-2})(Z_i/0.02)$

with $R_v=A_v/E(B-V)=3.1$

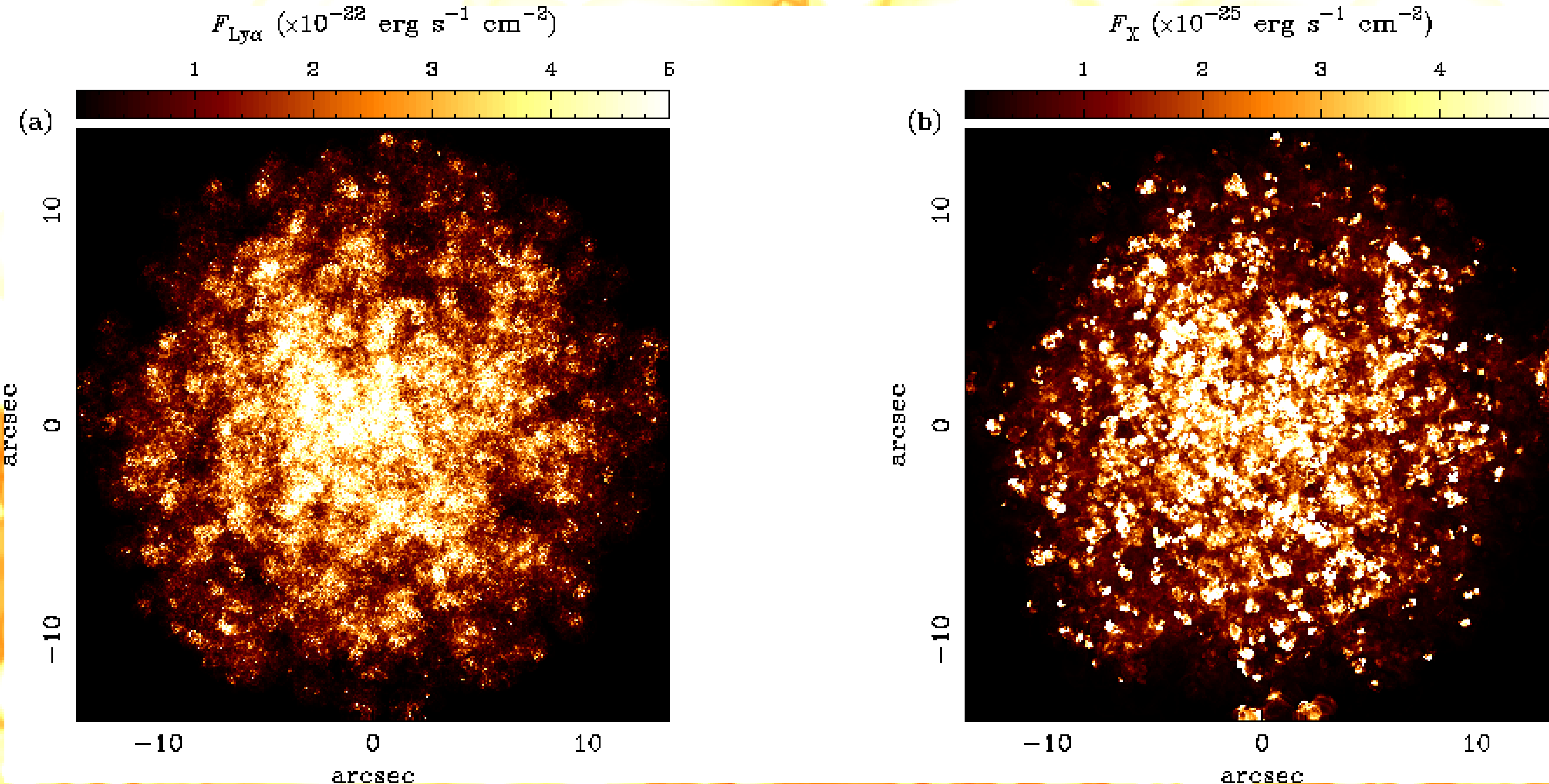
$\tau_k(\lambda) = \Sigma^k_i\ \Delta\tau_i(\lambda)$

$L_\lambda = \Sigma^{Nobs}_k\ l_{\lambda 0,k}\ \exp(-\ \tau_k(\lambda))$

Theoretical
SED



SED GREEN: emission from stars without dust extinction
BLUE: emission from stars with dust extinction
RED: emission from gas



Ly **α** :

$L = 9.70 \times 10^{42}$ erg s^{-1}

$F = 1.25 \times 10^{-16}$ erg s^{-1} cm^{-2}

X-ray (0.2-2 kev):

$L = 1.15 \times 10^{40}$ erg s^{-1}

$F = 1.49 \times 10^{-19}$ erg s^{-1} cm^{-2}

$\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$ and $H_0 = 70$ km s^{-1} Mpc^{-1}

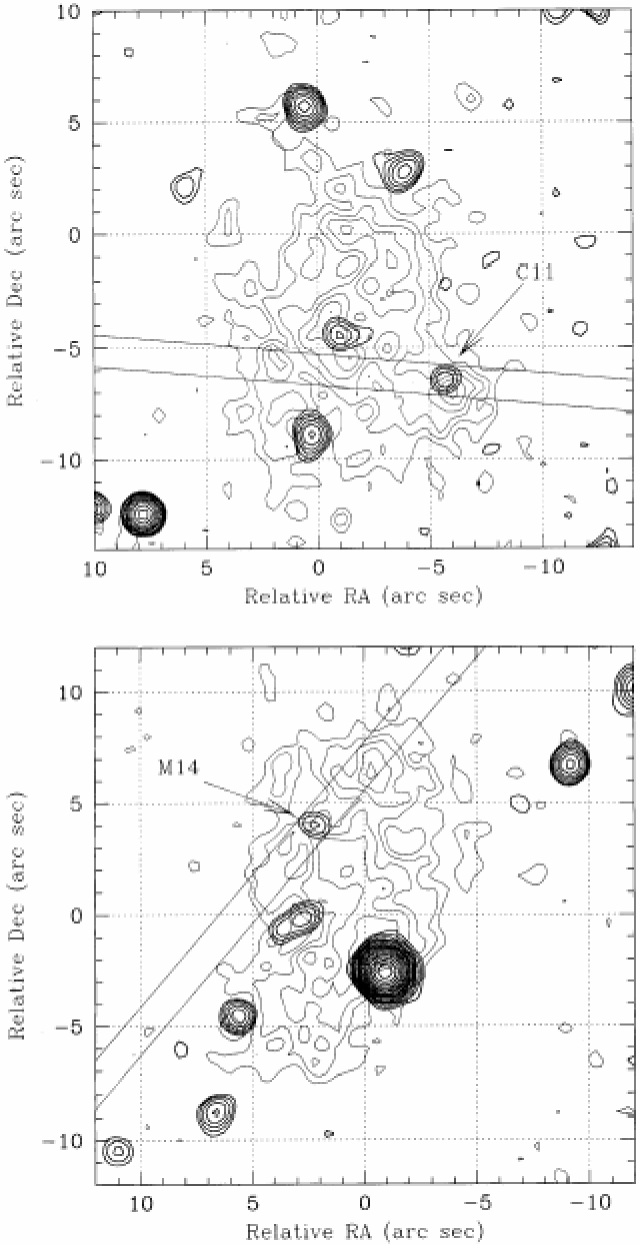


FIG. 7.—Contour maps of blob 1 (*top*, *light contours*) and blob 2 (*bottom*, *light contours*) in NB-continuum light, with Keck K_s images superposed; north is up, east is to the left. Note that there is a K_s band source that is spatially coincident with the central knot in blob 1. It is estimated that this object has a color of $R - K_s \gtrsim 4.5$, making it about 1.9 mag redder in that color than the known LBG, C11 (see Fig. 6 for comparison).

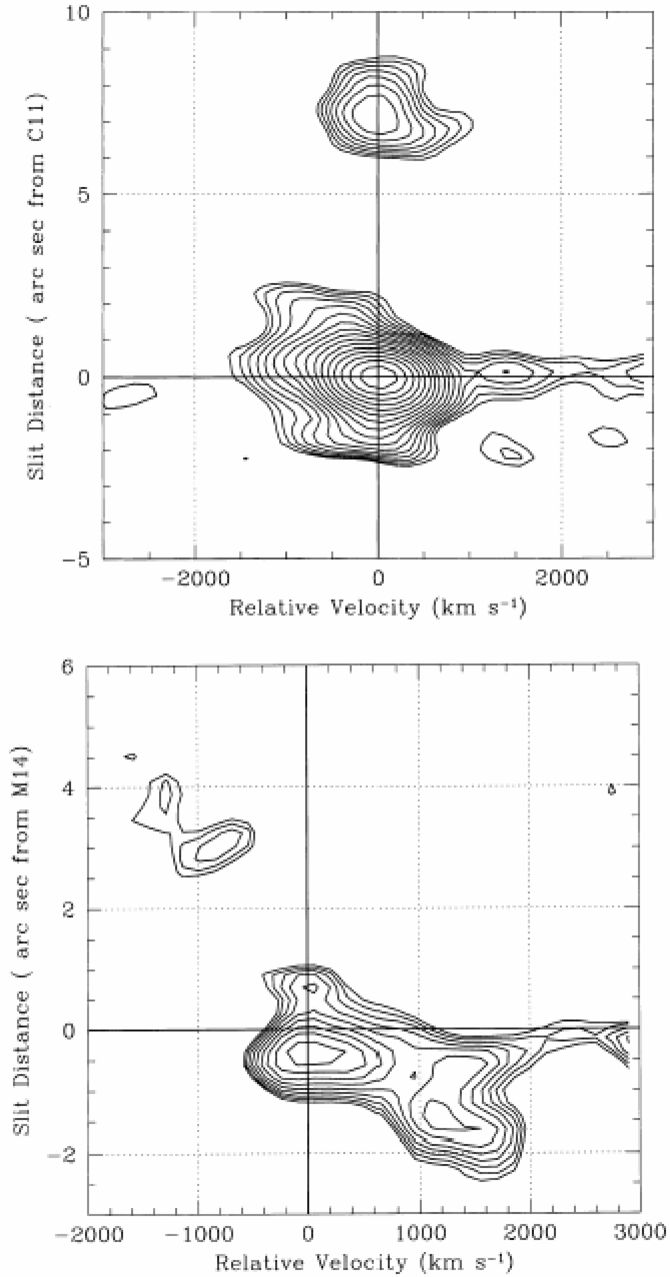


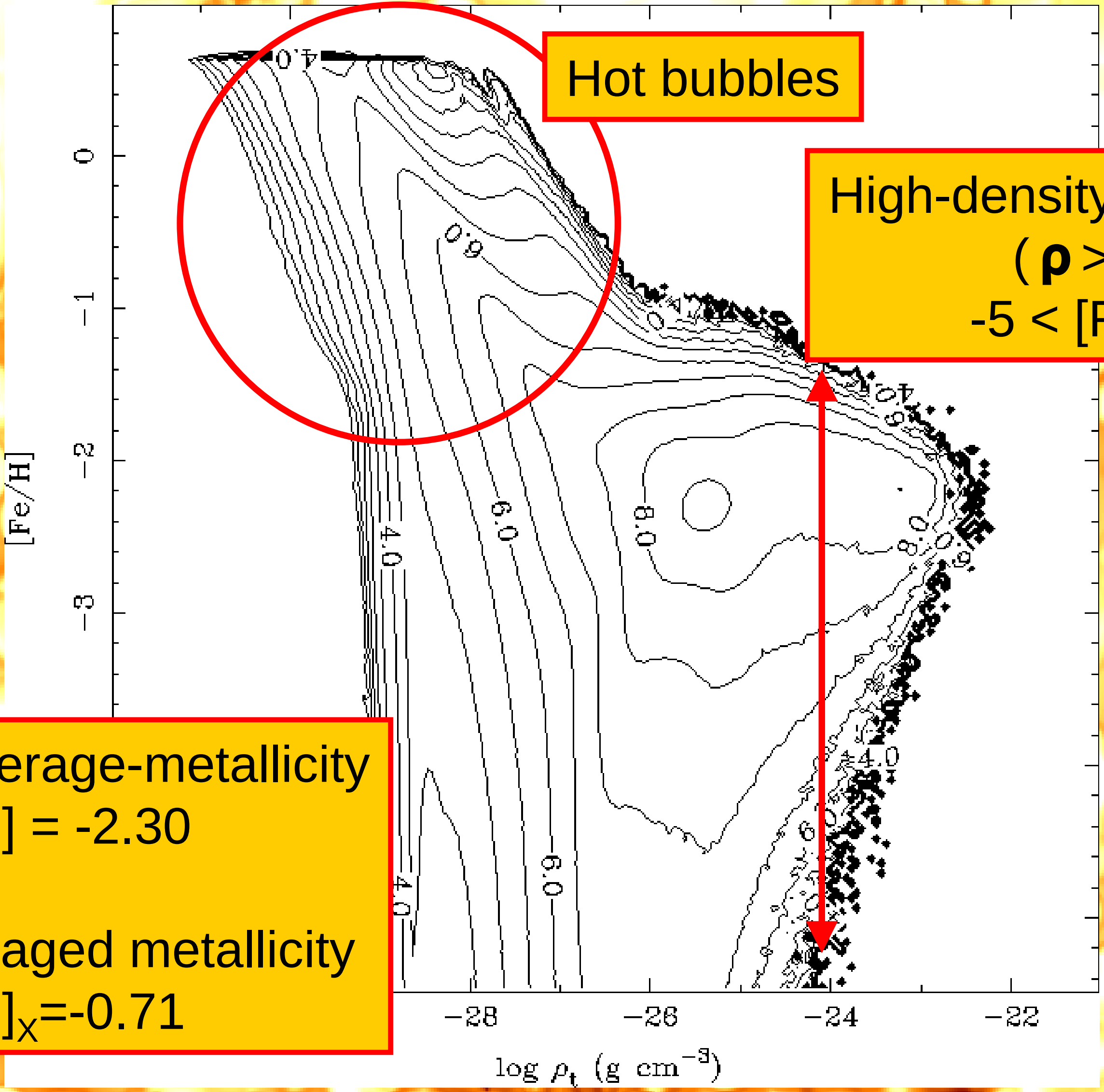
FIG. 8.—Spectra in the vicinity of Lyα for C11 (*top*; east is toward positive slit positions) and for M14 (*bottom*; southeast is toward positive slit positions). Note the apparent velocity shear of the Lyα emission near M14, and the clear detection of the emission knot 7″ east of C11.

Lya Blobs

~100 kpc

~10^{43} ergs s^{-1}

Density-Metallicity diagram



Hot bubbles

High-density region:
(**ρ** > 10^{-24} g cm^{-3})
-5 < [Fe/H] < -1

Simple Average-metallicity
[Fe/H] = -2.30

X-ray averaged metallicity
$[Fe/H]_X$=-0.71

Summary

- **大質量銀河の形成初期をシミュレーションした。**
  銀河形成初期では、ガスの混合は充分でない。
  重元素の非一様混合過程 [Fe/H]＝-2.5

- Shock heating**されたガスからの**Lyα
  $\sim 10^{43}$ erg s^{-1}
- Hot Bubble**からの**X**線** (0.2-2 keV)
  $\sim 10^{40}$ erg s^{-1}

研究計画

1024^{3}の規模シミュレーション

CP-PACS：1024PE

(1)　長時間積分

(2)　自己重力

Dark Matter、星系の力学運動

(3)　星形成