Chemodynamical Evolution of the Galaxy

Chiaki Kobayashi, Naohito Nakasato, & Ken'ichi Nomoto

1. Abstract

We discuss the chemodynamical evolution of the Galaxy using our GRAPE-SPH code. It treats dark matter, gas, star particles and contains the physical processes of cooling, star formation, feedback from Type Ia and II supernovae (SNe Ia and II) and stellar winds, and chemical enrichment. For SNe Ia, we adopt the single degenerate scenario with the metallicity effect. The simulated galaxy has the three components: bulge, disk, and halo, of which dynamical, chemical and photometrical properties are consistent with the observation. In the solar neighborhood, we reproduce the age-metallicity relation and the [O/Fe]-[Fe/H] relation. For the metallicity distribution, the G-dwarf problem exists, which cannot be solved by the introduction of the UV background radiation.

2. N-body+SPH

- GRAPE-SPH code (Nakasato 2000)
- formulation: the same as Navarro & White (1993)
- sline kernel
- smoothing length: variable both in space and time
- integration: Leap-frog method
- inidividual timestep

$$\frac{D\rho}{Dt} + \rho\nabla\cdot\mathbf{v} - 0$$

$$\frac{D\mathbf{v}}{Dt} = -\frac{1}{\rho}\nabla P - \nabla\Phi$$

$$\frac{Du}{Dt} = \frac{P}{\rho^2}\frac{D\rho}{Dt} + \frac{\nabla\cdot(\kappa\nabla T)}{\rho} + \frac{\Gamma-\Lambda}{\rho}$$

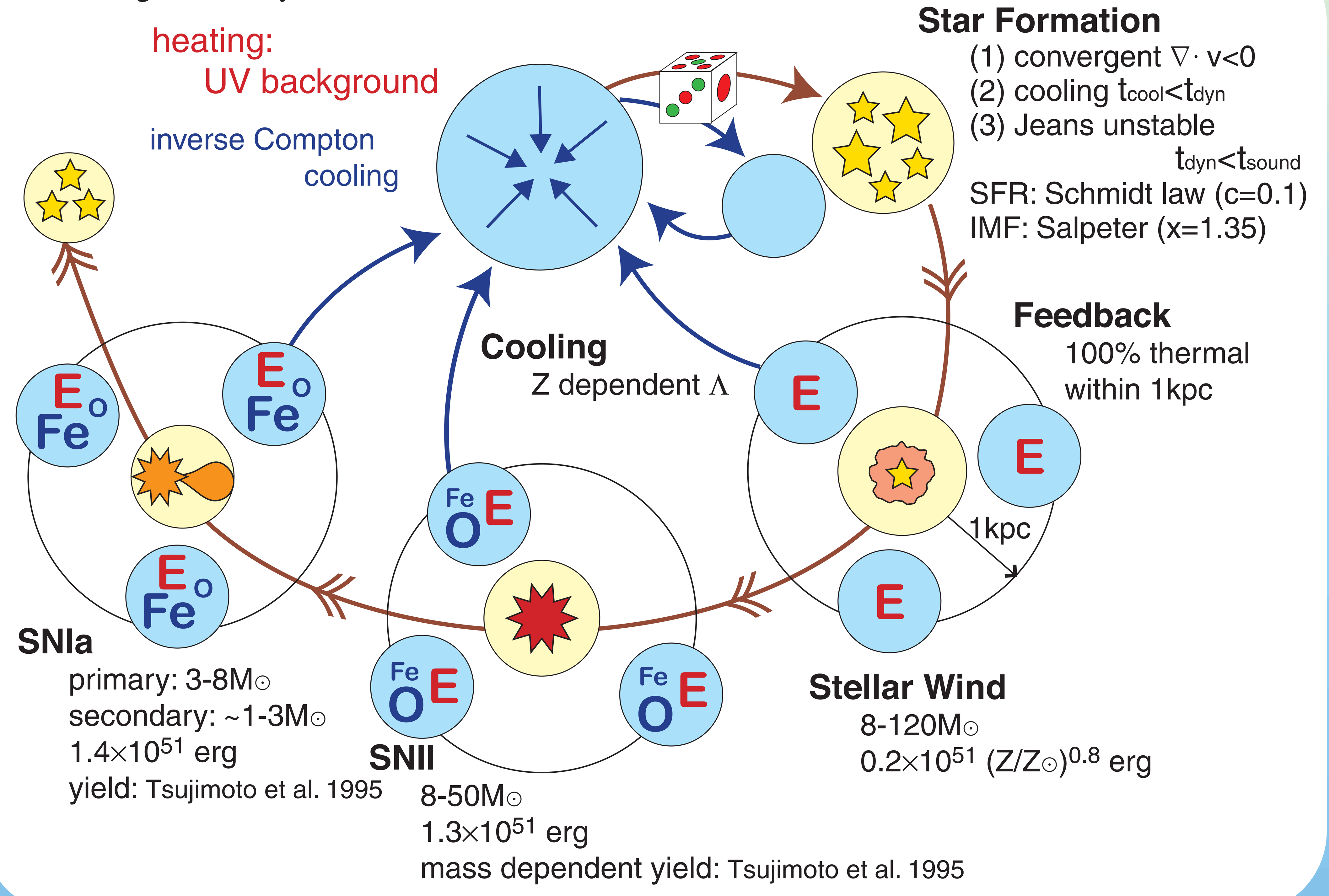
$$\nabla^2\Phi = 4\pi G\rho$$

$$\rho_i = \sum m_j W(\mathbf{r}_i - \mathbf{r}_j; h)$$

$$\frac{D\mathbf{v}_i}{Dt} = -\sum m_j\left(\frac{P_i}{\rho_i^2} + \frac{P_j}{\rho_j^2} + \Pi_{ij}\right)\nabla_i W(\mathbf{r}_i - \mathbf{r}_j; h) - (\nabla\Phi)_i$$

$$\frac{Du_i}{Dt} = -\sum m_j\left(\frac{P_i}{\rho_i^2} + \frac{1}{2}\Pi_{ij}\right)(\mathbf{v}_i - \mathbf{v}_j)\nabla_i W(\mathbf{r}_i - \mathbf{r}_j; h) + \frac{\Gamma-\Lambda}{\rho}$$

3. Physical process



3-1. Star Formation

- conditions
  - (1) convergent $(\nabla\cdot\mathbf{v})_i<0$
  - (2) cooling $t_{cool}<t_{dyn}$ $t_{cool}=\frac{\rho u}{\Lambda}$, $t_{dyn}=\frac{1}{\sqrt{4\pi G\rho}}$, $t_{sound}=\frac{h_i}{c_s}$
  - (3) Jeans unstable $t_{dyn}<t_{sound}$
- Star Formation Rate : Schmidt law

$$\frac{d\rho_*}{dt} = -\frac{\rho}{t_{sf}} = -c_{sf}\frac{\rho}{t_{dyn}} = -c_{sf}\sqrt{4\pi G}\rho^{\frac{3}{2}},\quad c_{sf}=0.1$$

- probability criterion : P>random value

$$P = 1-\exp\left[-\frac{\Delta t}{t_{sf}}\right],\quad \Delta t = 0.002\ \mathrm{Gyr}$$

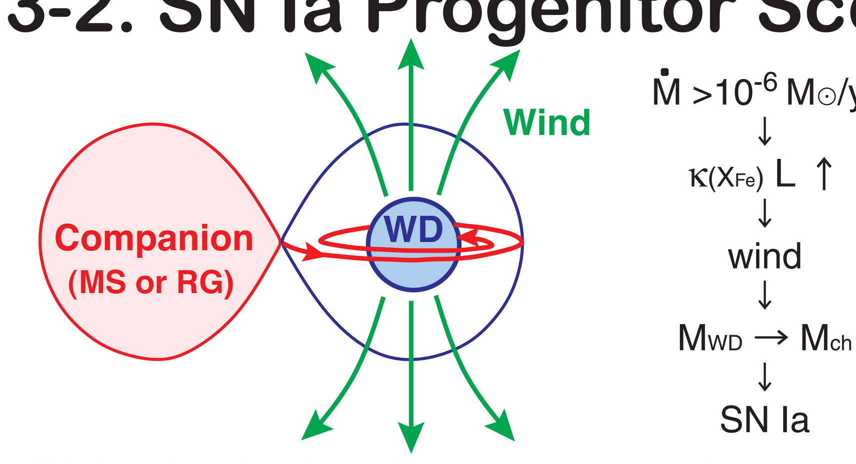
- stellar mass that is formed in Δt

$$m_* = \left[1-\exp\left[-\frac{\Delta t}{t_{sf}}\right]\right]\pi h_i^3\rho_i$$

- Initial Mass Function : Salpeter

$$\phi(m)\propto m^{-x},\quad x=1.35,\quad \text{for}\ \ 0.05M_\odot < m < 120M_\odot$$

3-2. SN Ia Progenitor Scenario



We introduce the single degenerate (SD) senario (Hachisu, Kato & Nomoto 1996; 1999). In a binary system, the matter accretes on a C+O WD, the optically thick wind blows from the WD, and M_{WD} reaches M_{Ch} to explode as an SN Ia. There are two systems for the companion stars: 0.9-1.5M⊙ red-giants & 1.8-2.6M⊙ main-sequence. The metallicity effect on SNe Ia (Kobayashi et al.1998) is included: if [Fe/H]<-1.1, then no wind and no SN Ia.

3-3. Cooling Rate

- Radiative Cooling
  - ionization equilibrium
    primordial gas: H, He
    metal enriched-gas:
    MAPPINGS III
    (by R.S.Sutherland)
- background UV radiation
  - homogeneous & isotropic

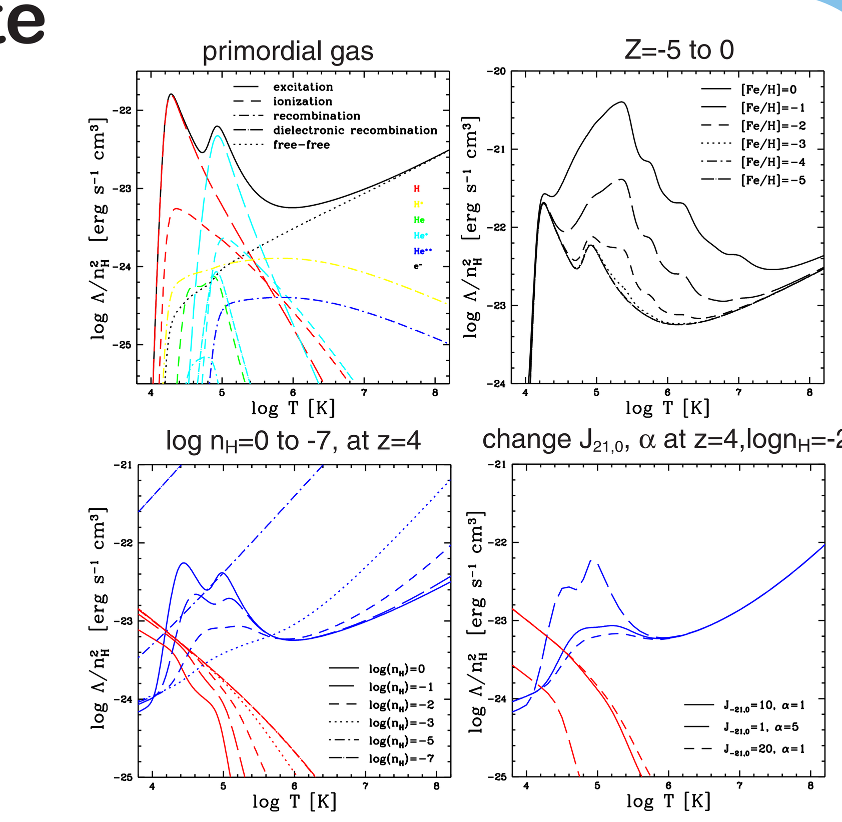
$$J_\nu(z) = \frac{J_{-21,0}\times10^{-21}}{1+[5/(1+z)]^4}\left(\frac{\nu}{\nu_L}\right)^{-\alpha}$$

$$\Gamma_i = \int_{\nu_i}^{\infty}\frac{4\pi J_\nu(z)\sigma_i(\nu)}{h\nu}d\nu$$

$$H_i = n_i\int_{\nu_i}^{\infty}\frac{4\pi J_\nu(z)\sigma_i(\nu)(h\nu-h\nu_i)}{h\nu}d\nu$$

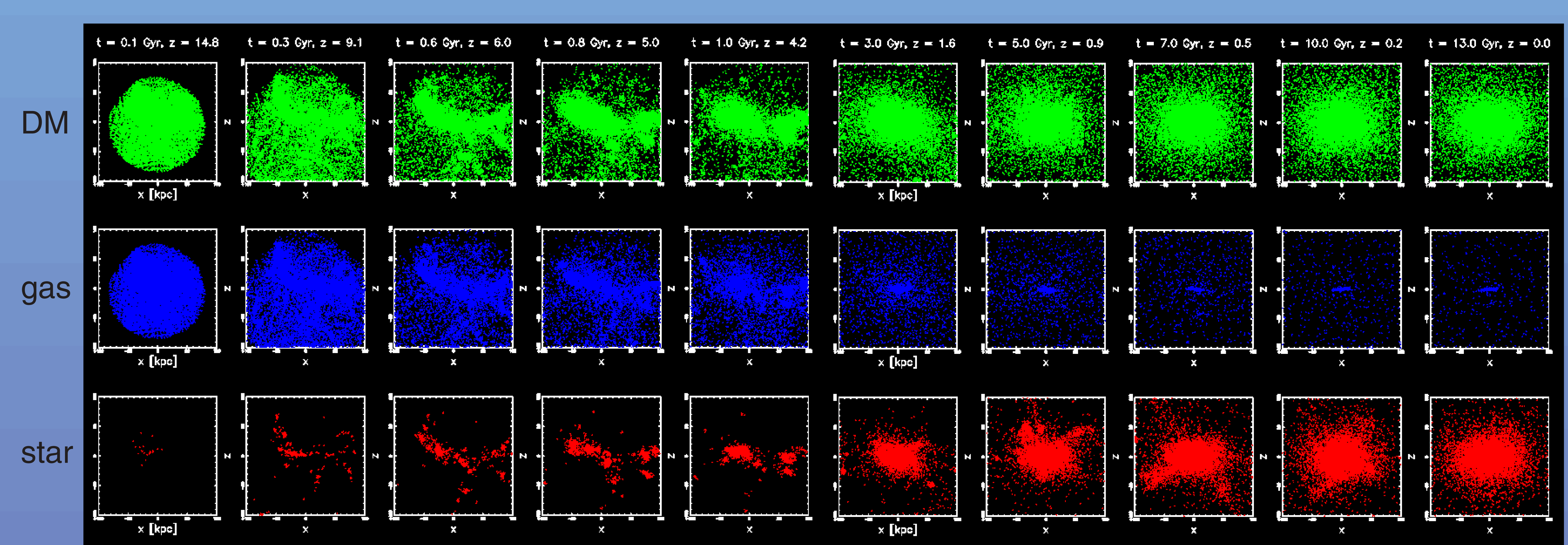
- inverse Compton cooling

$$\Lambda_C = 5.41\times10^{-36}n_e T(1+z)^4$$



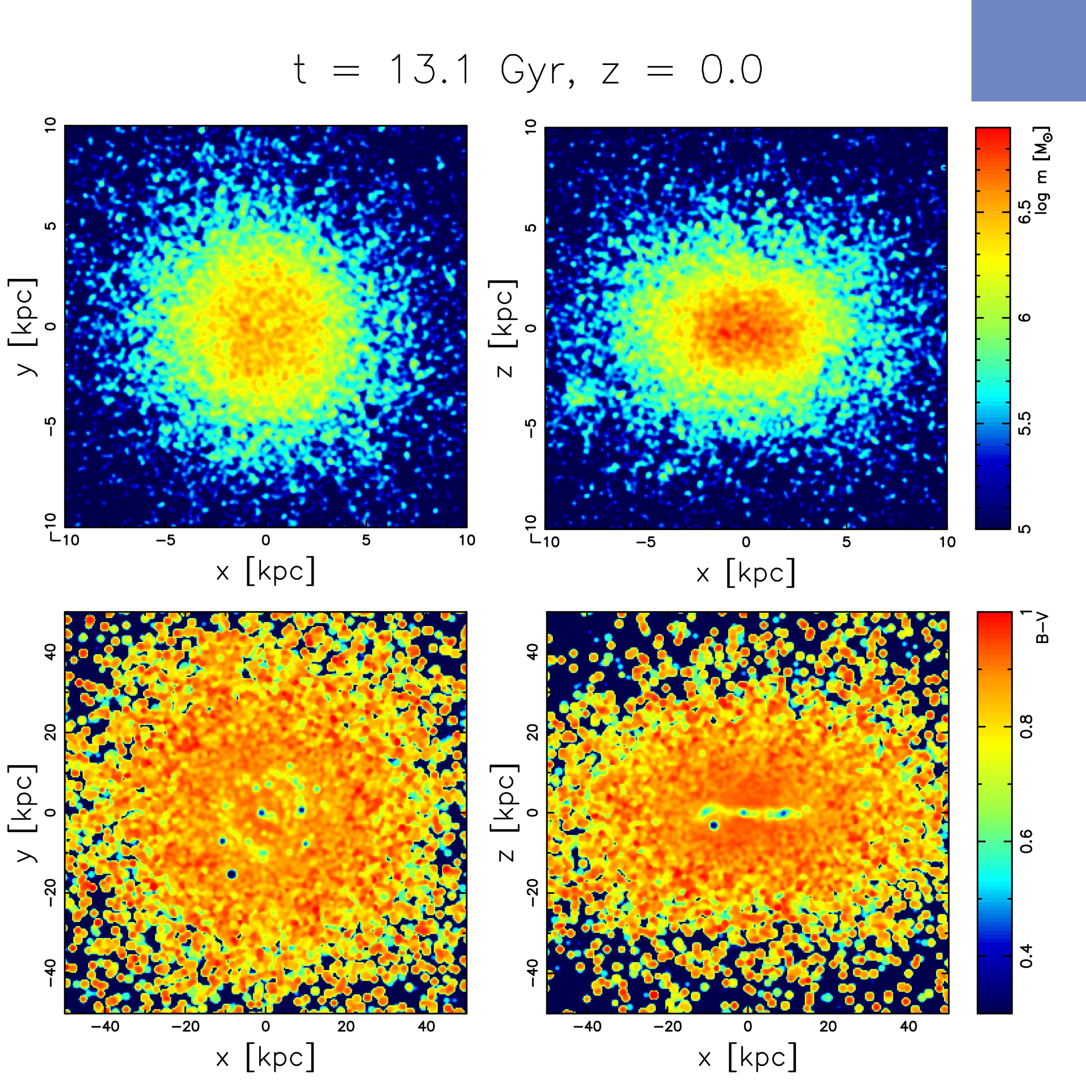
4. Initial Condition

- cosmological initial condition
  GRAFIC (Bertschinger 1995)
- H_0=50, Ω_0=1.0, λ_0=0.0, σ_8=1, z_c~23
- N_{tot}~40000, N_{gas}~20000, N_{DM}~20000
- $M_{tot}=10^{12}$ M⊙, baryon fraction=0.1
- $M_{gas}\sim5\times10^6$ M⊙, $M_{DM}\sim4.5\times10^7$ M⊙
- region: a sphere with 50 kpc radius
- spin parameter λ~0.1

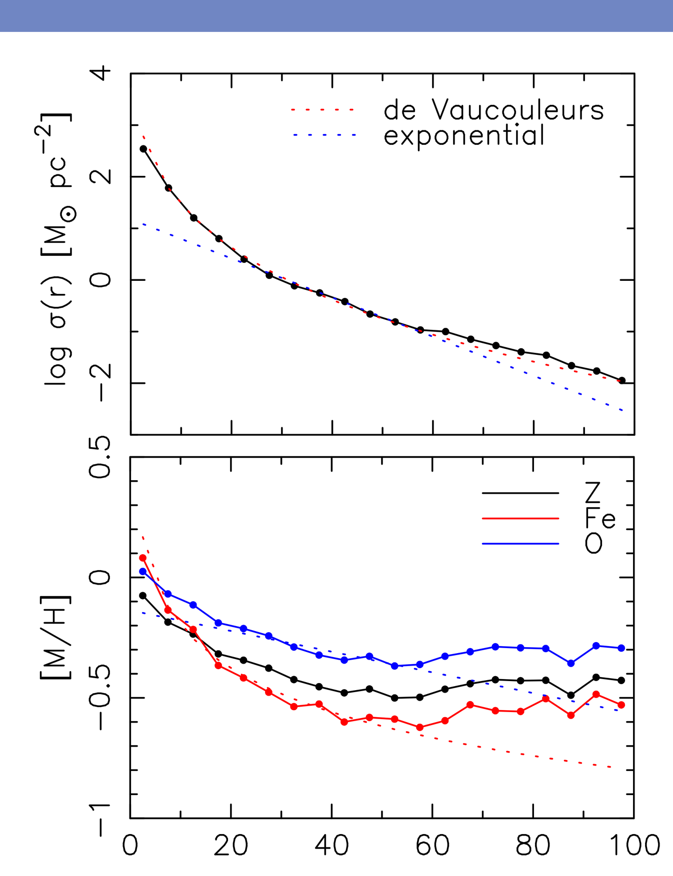


5. Results and Discussion

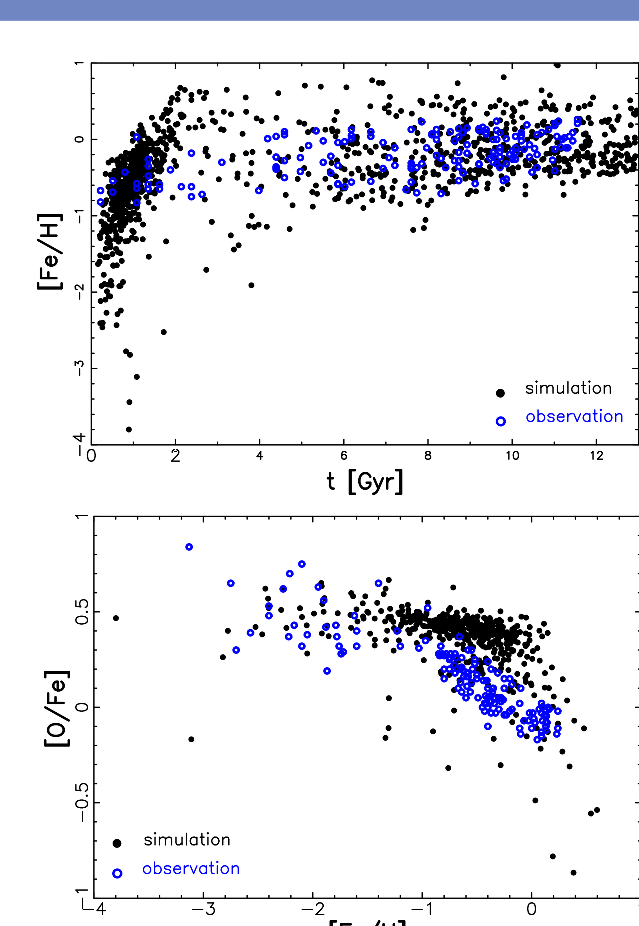
We show the results without the UVB effect, but for the last figure.



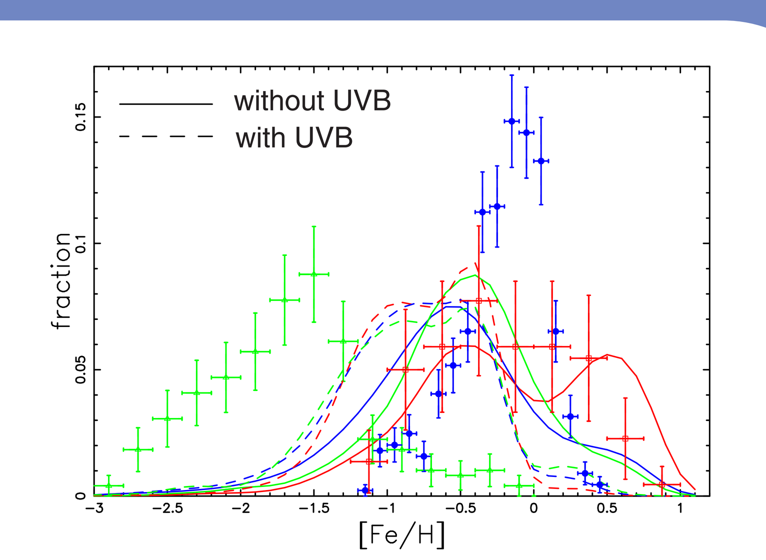
Right: Face on view, Left: Edge on view.
Upper panels: Projected mass distribution.
Lower panels: Projected B-V color distribution.
On the disk (left) and in the spiral arms (right), the star formation is ongoing.



Upper panel: Surface brightness profile.
The disk (|z|<2kpc) shows exponential law, the bulge (r<2kpc,|z|<2kpc) de Vaucouleurs law.
Lower panel: Metallicity gradients of stars.
The disk has d[O/H]/dr~-0.1 (obs.-0.05 to -0.1), the bulge d[Fe/H]/dlogr~-0.4 (obs.-0.2 to -0.4), which are consistent with the observations.



Solar neighborhood:7<r<8,|z|<1.5kpc
Upper panel: Age-metallicity relation, well consistent with the observation.
Lower panel: [O/Fe]-[Fe/H] relation.
[O/Fe] decreases because of the delayed Fe production of SNe Ia.



Metallicity number distribution.
For the bulge, the simulated distribution is consistent with the observations (symbols).
For the solar neighborhood, the peak is smaller and the number of metal poor stars are larger, i.e., the G-dwarf problem exists.
For the halo, the peak is much higher.
These are because the star burst occurs at the very early epoch before the gas accrete onto the disk. After the disk formed, the star formation is not effective and few stars are born from the metal enriched gas. To solve the problem, we introduce the effects of the UV background radiation as a heating source at the early epoch. But, the effect can't solve it.