Thick disc and pseudobulge formation in a clump cluster

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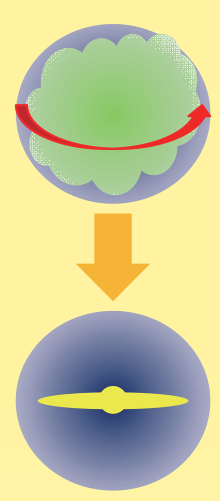
Among nearby disc galaxies, the galaxies have a clean-cut and beautiful figure. On the other hand, in the high-z Universe, disc galaxies in its formation stage are observed to be shapeless and clumpy: “clump clusters” and “chain galaxies”. In this study, I investigate by N-body/SPH simulation how the clump clusters evolve into the current disc galaxies.

Conclusion 1: Clumps formed in the clump clusters merge into a single bulge (Noguchi 1998,1999). I found that this bulge (clump-origin bulge) is similar to pseudobulges, but old and metal-rich.

Conclusion 2: I found that a thick disc is made from clumps disrupted by galactic tide. In my simulation, nearly 80% of mass of the thick disc originates from the clumps.

The setting of simulation



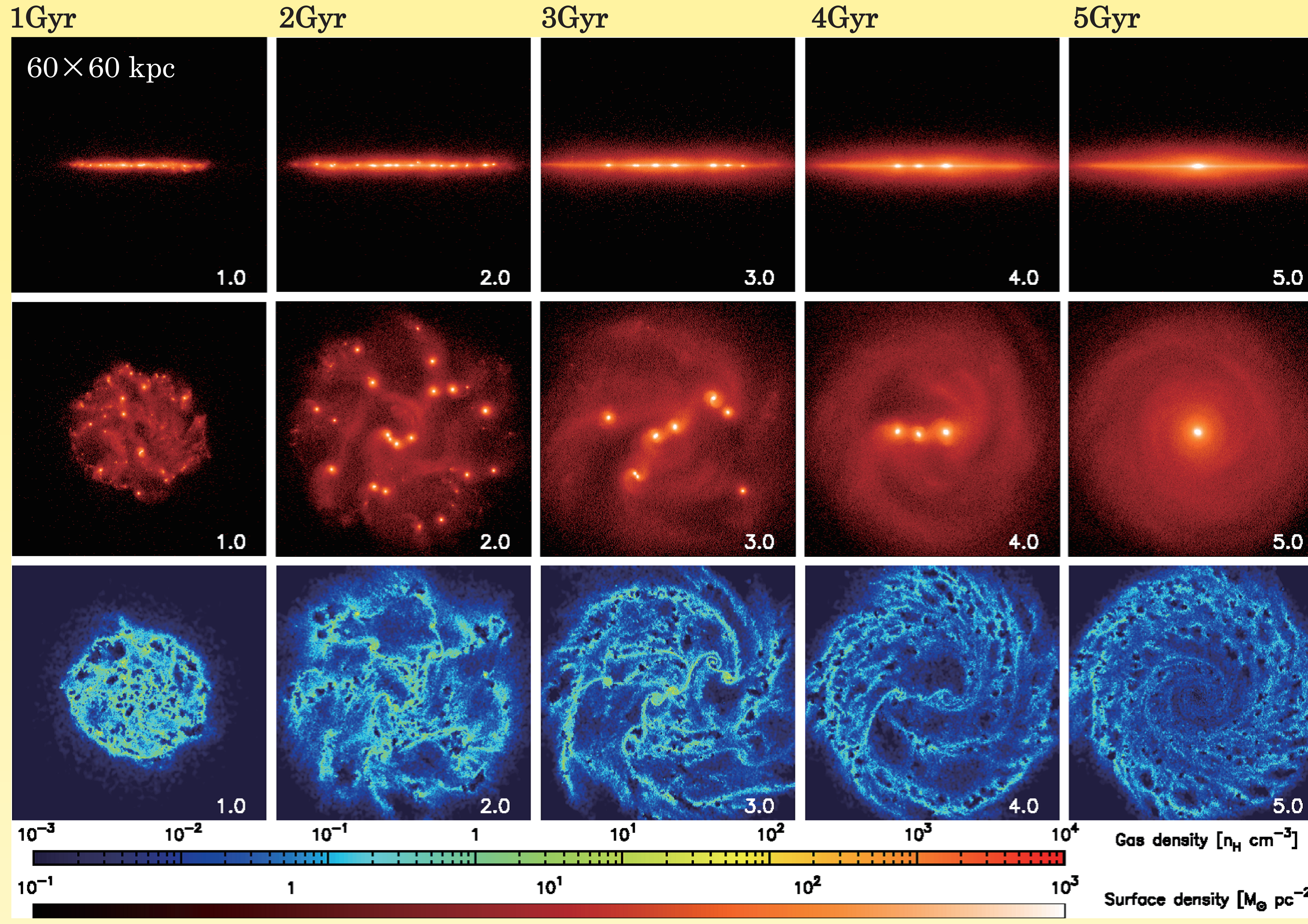
- NFW profile
  - $M_{vir} = 5 \times 10^{11} M_{\odot}$
- $N_{DM} = 10^7,\ N_{gas} = 5 \times 10^6$
  - $\varepsilon_{DM} = 8pc,\ \varepsilon_{gas} = 2pc$
- spin parameter $\lambda = 0.1$
  - AM distribution $j \propto r$
- $T(r) = virial\ temperature$

Initial condition:

As the initial condition, I assume a rotating gas sphere in a dark matter halo. The density distribution of DM and gas are represented by the same NFW profile. Initial gas fraction is 6%, initially zero-metal.

Numerical code:

The simulation is operated by a N-body/SPH code, ASURA (Saitoh et al. 2008,2009). Metal-dependent radiative cooling, star formation, far UV and supernova feedbacks are taken into account. The cooling function covers a wide range, 20-10^8 K. Star formation criteria are $\rho_{gas} > 100$ atm/cc, T < 100K, and $\nabla \cdot v < 0$.

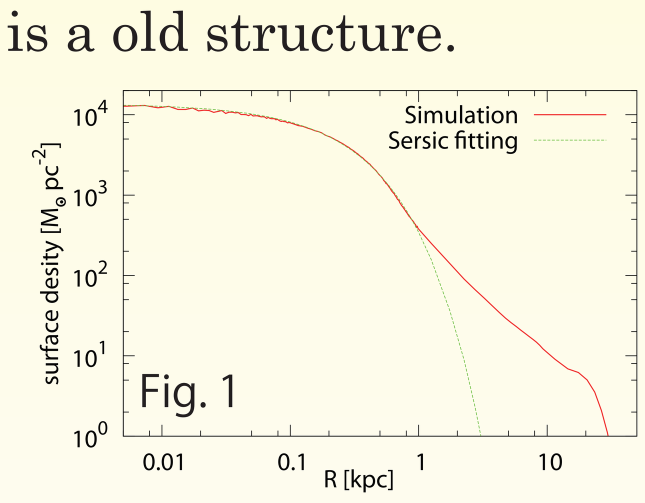


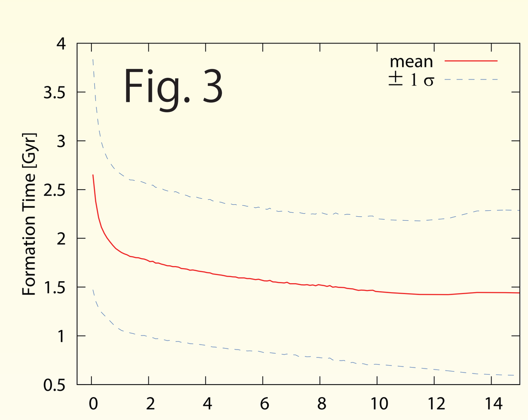
The bulge

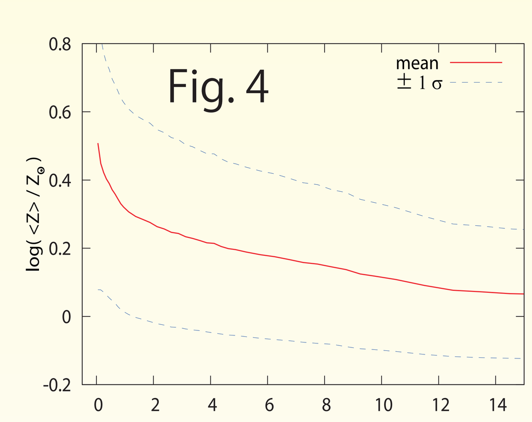
Galactic bulges are supposed to be classified into classical bulges or pseudobulges. The classical bulges appear simlar to elliptical galaxies, $R^{-1/4}$-low; spherical shape; little rotation; old structure. The pseudobulges are similar to disk galaxies, exponential profile; oblate shape; significant rotation; young stars. Into which type should the clump-origin bulge be classified?

The clump-origin bulge can be fitted by Sersic profile with index, n=1.16 (nearly exponential) (Fig. 1) and shows bar-like structure in face-on view, boxy shape in edge-on view (Fig. 2). These features are pseudobulge signatures. Nevertheless, the formation scenario is largely different from the pseudobulges.

On the other hand, formation time of stars (Fig. 3) indicates that the clump-origin bulge forms simultaneously with the disc. This disc is supposed to be a thick disc (see below). This means that the bulge is a old structure.







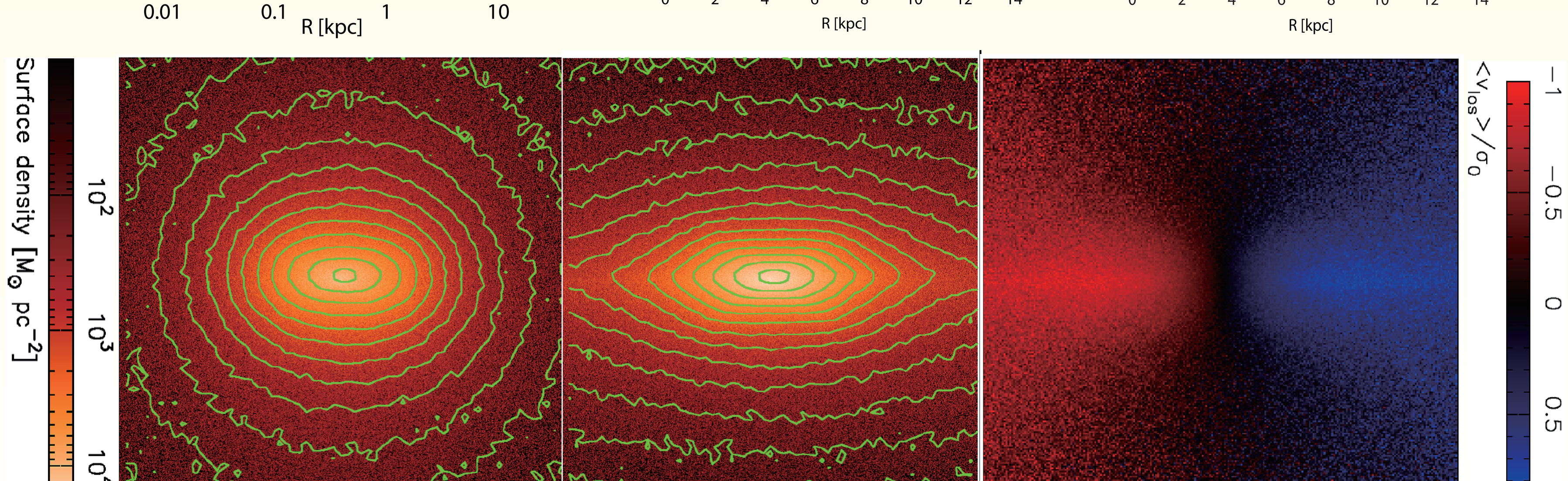


Fig. 2: Stellar density map in central 6×6 region kpc from face-on (left), edge-on (centre) view. Right panel indicates line-of-sight velocity from edge-on view.

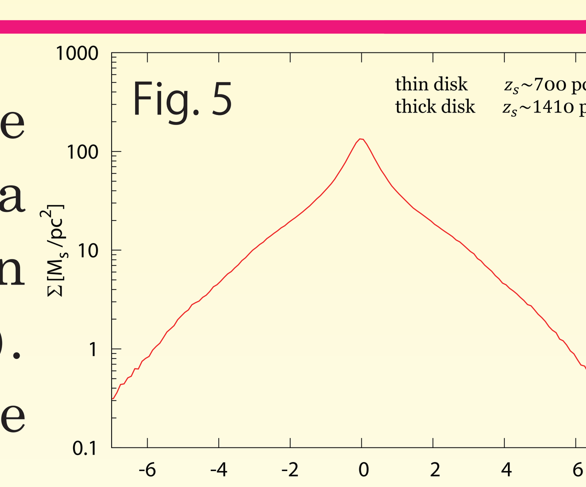
Metallicity distribution is plotted in Fig. 4. The bulge is highly metal-rich. It is just because of rapid star formation caused in gas collapse resulting in clump formation.

The natures of the clump-origin bulge shown above implies that this bulge can not be simply classified into classical nor pseodobulge.

The Milky Way bulge is also observed to be a pseudobulge, but, has log been known that the bulge stars are old and metal-rich.

The disk

Bournaud et al. (2009) has suggested that the disc forming in clump cluster by the clumps is a thick disk. Also, a thick disk forms and a thin disc hardly forms in my simulation (Fig. 5). Therefore, The disc simulated is supposed to be a thick disc.



In the simulation, star forming region is strongly confined within clumps. On the other hand, inter-clump region has little star formation. Nevertheless, however, the disk was indeed formed. This implies that the disk is made from stars released from the clumps. Tidal force pounds the clumps to pieces, and the stars form the disk.

I imprement friends-of-friends (FOF) method in order to identify all clumps in the simulation, estimate stellar mass released from the clumps into the disk. As a result, I find that nearly 80% of the disk mass originates from the stars released from clumps heavier than 10^5Msolar. This means that the thick disk is made from the clumps smashed by the galactic tide.

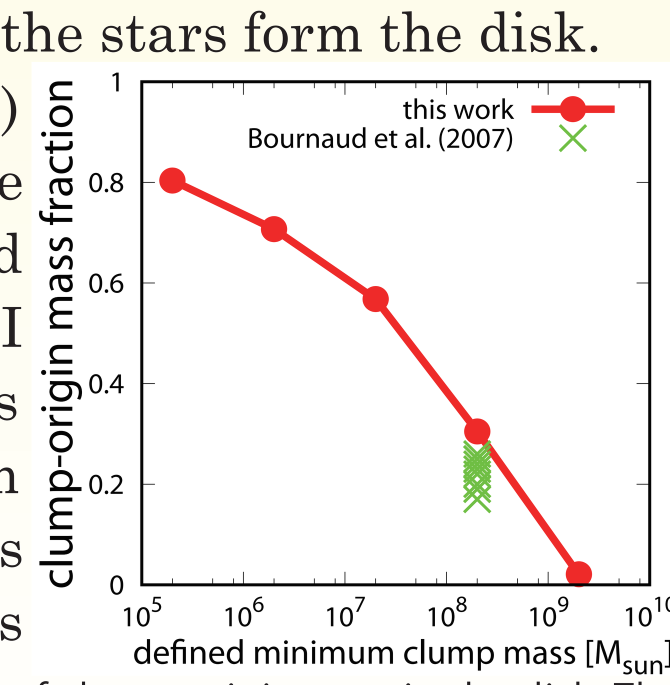


Fig.6: Mass fraction of clump-origin stars in the disk. The abscissa means the minimum mass criterion in the FOF finder.