Formation of early-type galaxies

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Introduction

According to the observations of line indices and stellar population synthesis, early-type galaxies (ETGs) underwent very rapid star formation (Cowie et al. 1996; Thomas et al. 2005; Recchi et al. 2009; McDermid et al. 2015; Liu et al. 2016; Yan et al. 2021). Cowie et al. (1996), was the first to suggest the name "downsizing" because the less massive galaxies have an extended SFH compared to the massive ones. This star-formation time scale for ETGs is expressed in Thomas et al. (2005), Recchi et al. (2009) and McDermid et al. (2015) in terms of the downsizing time which is a function of the mass of the galaxy. These downsizing timescales corresponds to approximately 0.34 Gyr for a galaxy mass of 10^{12} $M_\odot$ and approximately 3.1 Gyr for a galaxy mass of 10^9 $M_\odot$

MOND

Milgrom (1983) suggested correction to the non-relativistic theory of gravity, MOND, which could be a consequence of the quantum vacuum (Milgrom 1999; Pazy 2013; Verlinde 2017; Smolin 2017). Milgromian dynamics theory (Bekenstein & Milgrom 1984) can be constructed by varying the action with position space and potential respectively, which, upon extremization, yields a generalised (MOND) Poisson equation,

$$\Delta\Phi(\vec{x}) = 4\pi G\rho_b(\vec{x}) + \vec{\nabla}\cdot\left[\tilde{\nu}\left(\left|\vec{\nabla}\phi\right|/a_0\right)\vec{\nabla}\phi(\vec{x})\right] \qquad \Delta\Phi(\vec{x}) = 4\pi G\left[\rho_b(\vec{x}) + \rho_{ph}(\vec{x})\right]$$

where $\Phi(x)$ is the total gravitational potential, $\rho_b(\vec{x})$ is the baryonic matter density and $\rho_{ph}(\vec{x})$ is the phantom dark matter (PDM) density, which is a mathematical ansatz that allows to compute the additional gravitational potential predicted by the Milgromian framework. $\tilde{\nu}(y)$ is a transition function (Milgrom 2010), $\phi(\vec{x})$ is the Newtonian potential and $a_0 \approx 1.2\times10^{-10}$ m s^{-2} ≈ 3.8 pc Myr^{-2} is the Milgrom's constant.

Star-forming timescales

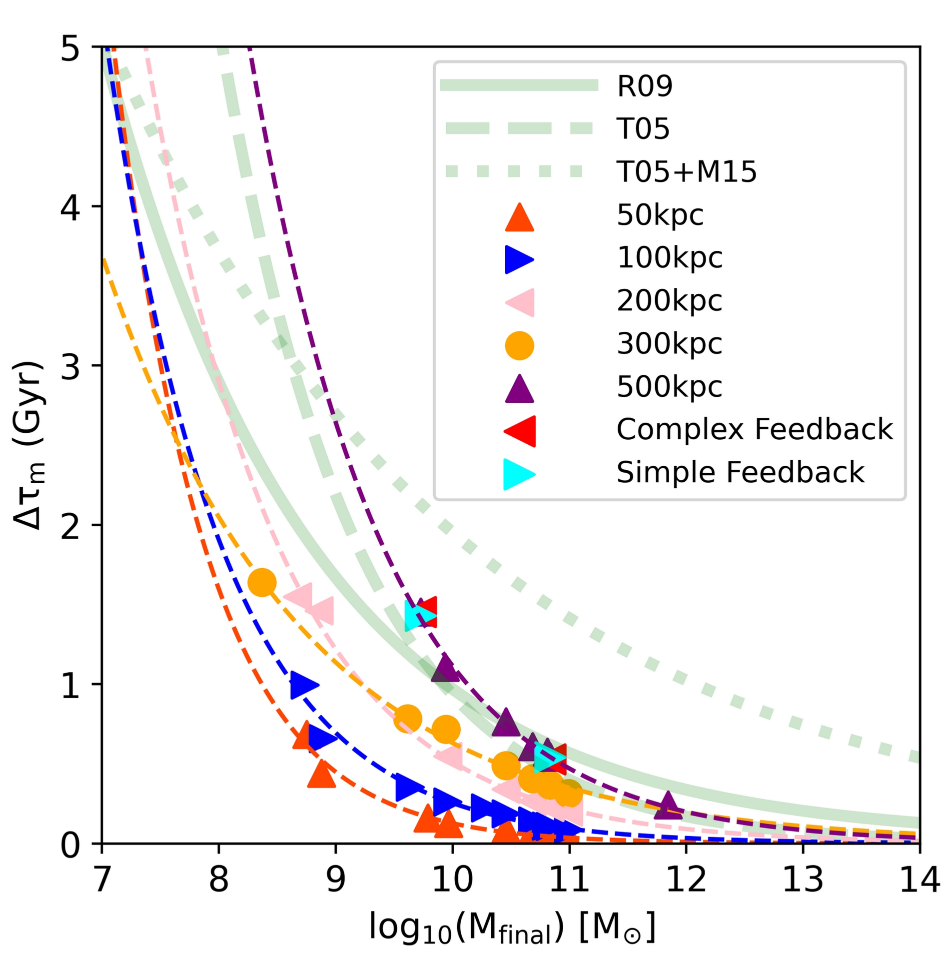

Figure 1. Eappen et al. (2022 their figure 3) shows the SFT-mass relation. The green curves are the observations and coloured markers are the model galaxies in this work. $\Delta\tau_m$ is the width of the star-formation history (SFH), I.e. the SFT.

- The monolithic collapse of post-Big-Bang gas clouds of different initial radii with no initial rotation, set-up using Phantom of RAMSES (POR), form model galaxies.
- The model galaxies are found to follow a similar downsizing behavior as documented in Thomas et al. (2005, 2010).
- The star-formation timescales (SFTs) are found to be similar to the observed ETGs.
- The addition of complex feedback mechanisms does not affect the SFTs of the model galaxies.

Bibliography

- **Milgrom M., 1983a, ApJ, 270, 365**
- **Lüghausen F., Famaey B., Kroupa P., 2015, Canadian Journal of Physics, 93, 232**
- **Eappen R., Kroupa P., Wittenburg N., Haslbauer M., Famaey B., 2022, MNRAS, (DOI: 10.1093/mnras/stac2229)**

Forming too early?

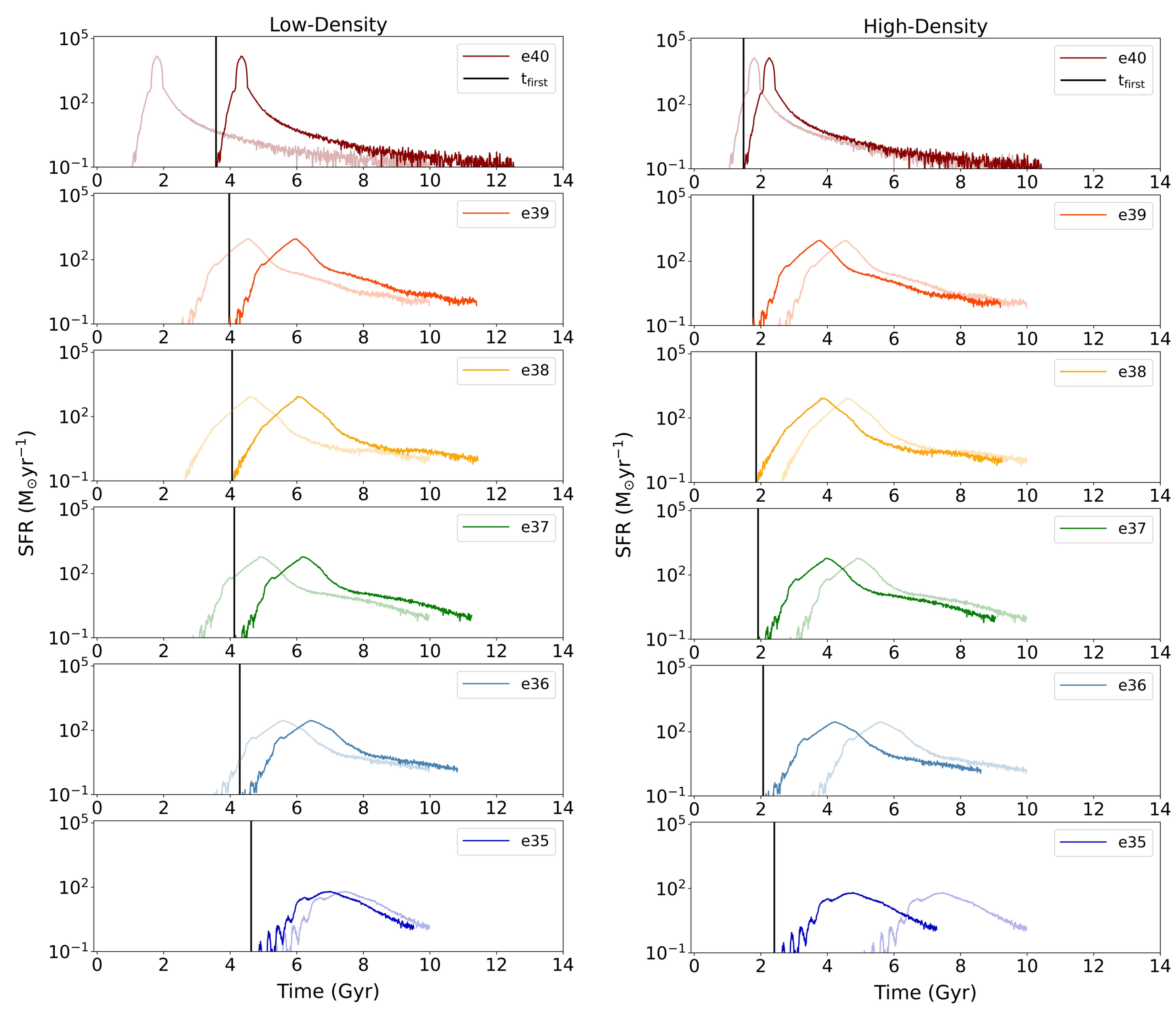

Figure 2. Eappen et al. (2022, their figure 6) shows the SFH in the low and high – density environments. The transparent SFHs are relative to the start of computation at *t=0.* The thick curves represent the SFH relative to the Big Bang. The black line is the time when the first star is formed in the model galaxy.

Assuming the standard age of the Universe is 13.8 Gyr and the age-dating deduced by Thomas et al. (2005) for ETGs is valid, the SFH of the model galaxies are shifted to calculate the time when the first stars would have formed in the observed Universe. The results indicate that the first stars in the ETGs would have started to form much earlier, as observed in the recent JWST data.

Size-mass relation

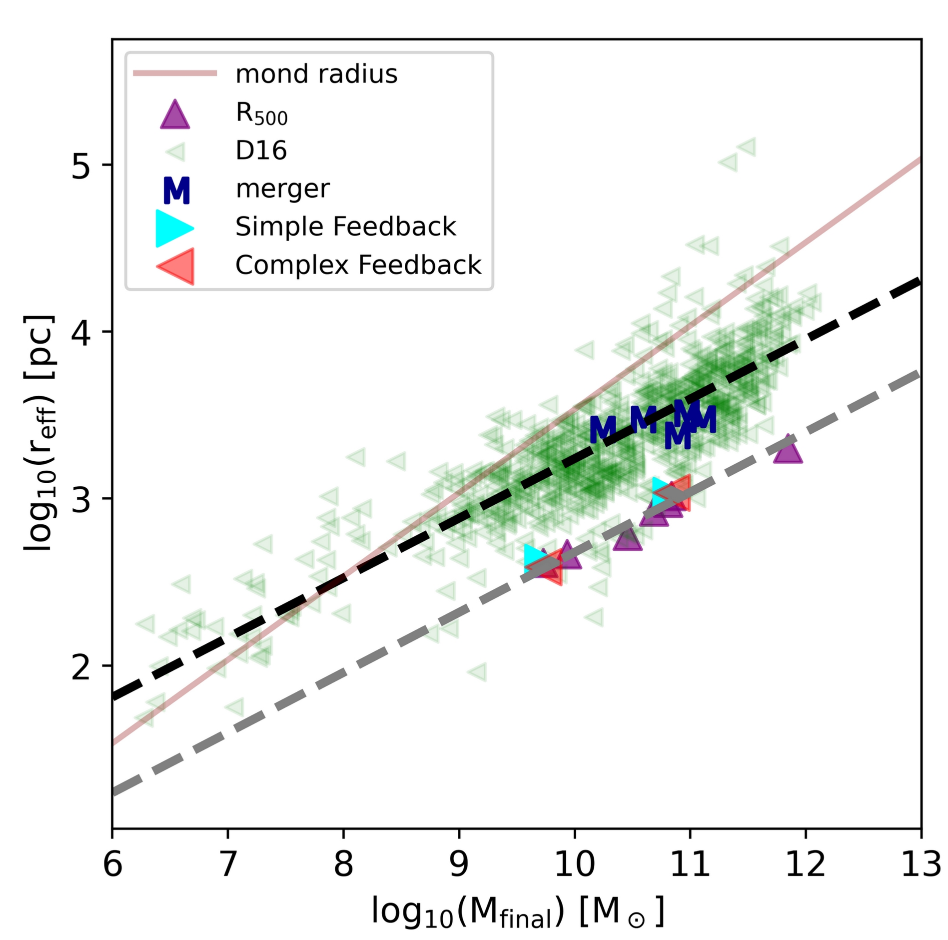

Figure 3. Eappen et al. (2022, their figure 7) shows the effective-radius - mass relation. Dashed black line is the observational result, dashed grey line is the size-mass relation for model galaxies and $M_\odot$ are the single merger models.

- The model galaxies fall slightly below the observed size - mass relation.
- The single merger model which is formed through the merger of the comparable mass model galaxies reaches the size-mass relation.
- These mergers could take place in the densest part of the Universe (e.g. central regions of galaxy clusters).

Conclusions

- This work for the first time shows that the SFTs observed for ETGs is a natural occurrence in MOND.
- The observed Universe would have started to form ETGs as early as 1.8 Gyr after the Big Bang.
- The size-mass relation is found to be consistent with observations.

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