AuriGLOBES: Auriga GLOBular ClustEr Simulations

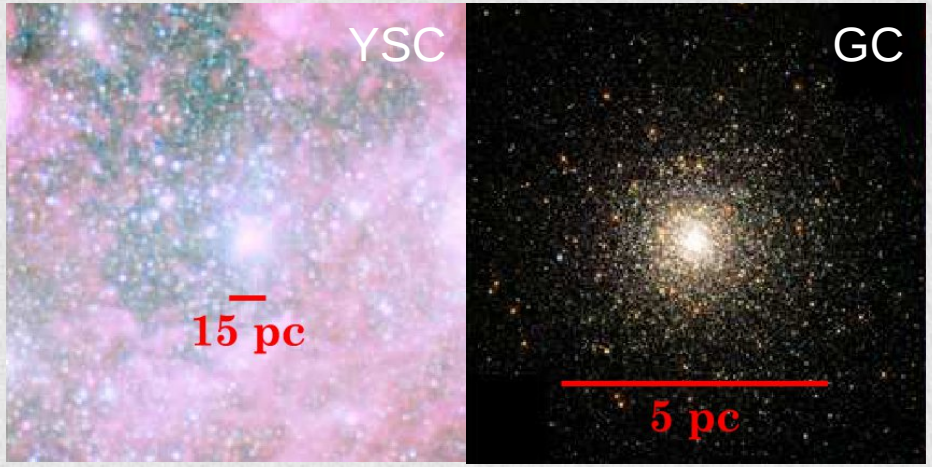
NAM 2025 - Durham

Pablo Daniel Contreras Guerra (IAC-ULL)
Supervisor: Robert J. J. Grand (LJMU)
Co-supervisor: Claudio Dalla Vecchia (IAC-ULL)

Introduction

- Star Clusters:
  - Fundamental blocks & tracers
- Globular Clusters:
  - ~ 10 Gyr, ubiquitous presence

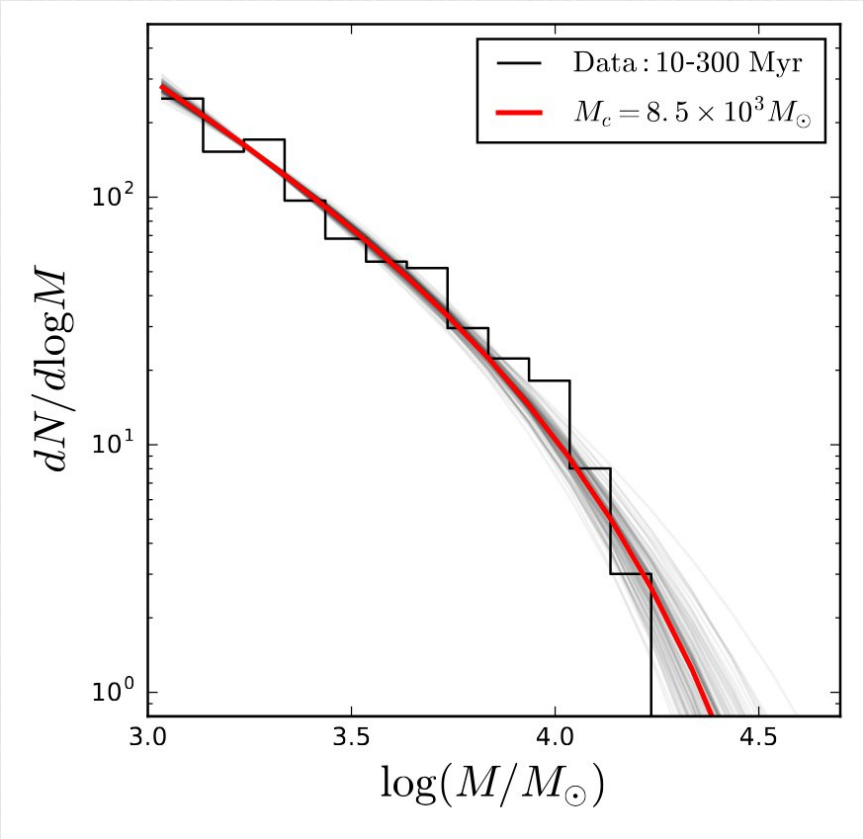
- Initial SC population → current GC population?
- Modeling in cosmological scenario. **Challenge: wide range of scales**



Kruijssen15

Kruijssen25

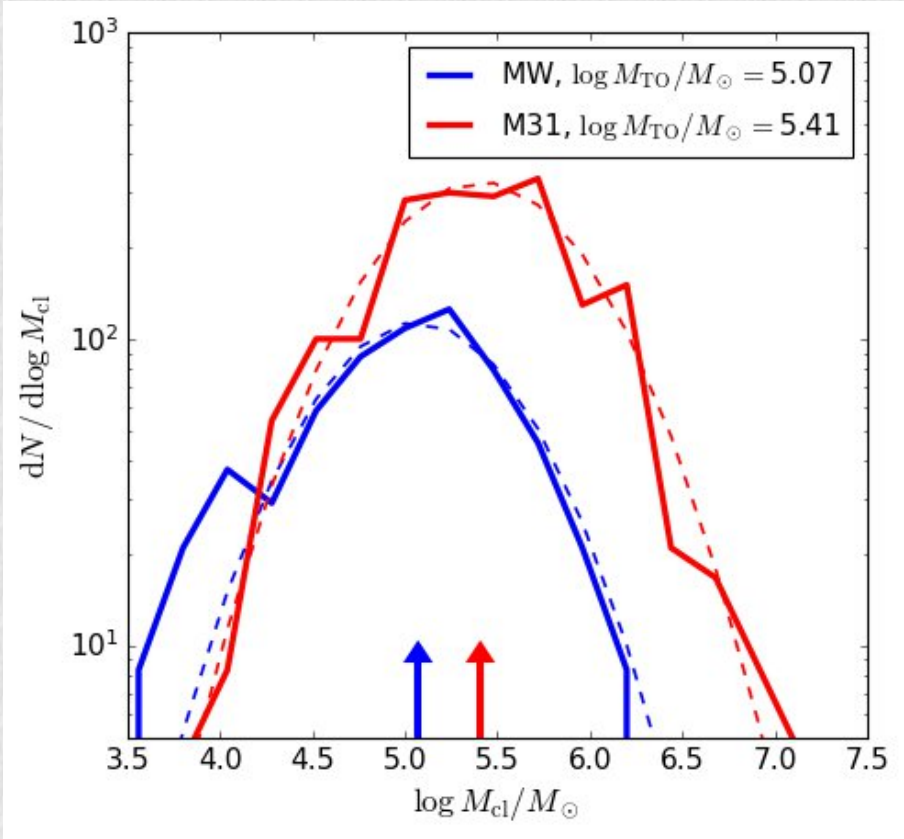
Young SCs MF to GCMF



M31 YSCs, Johnson+17

Power law

High-mass truncation

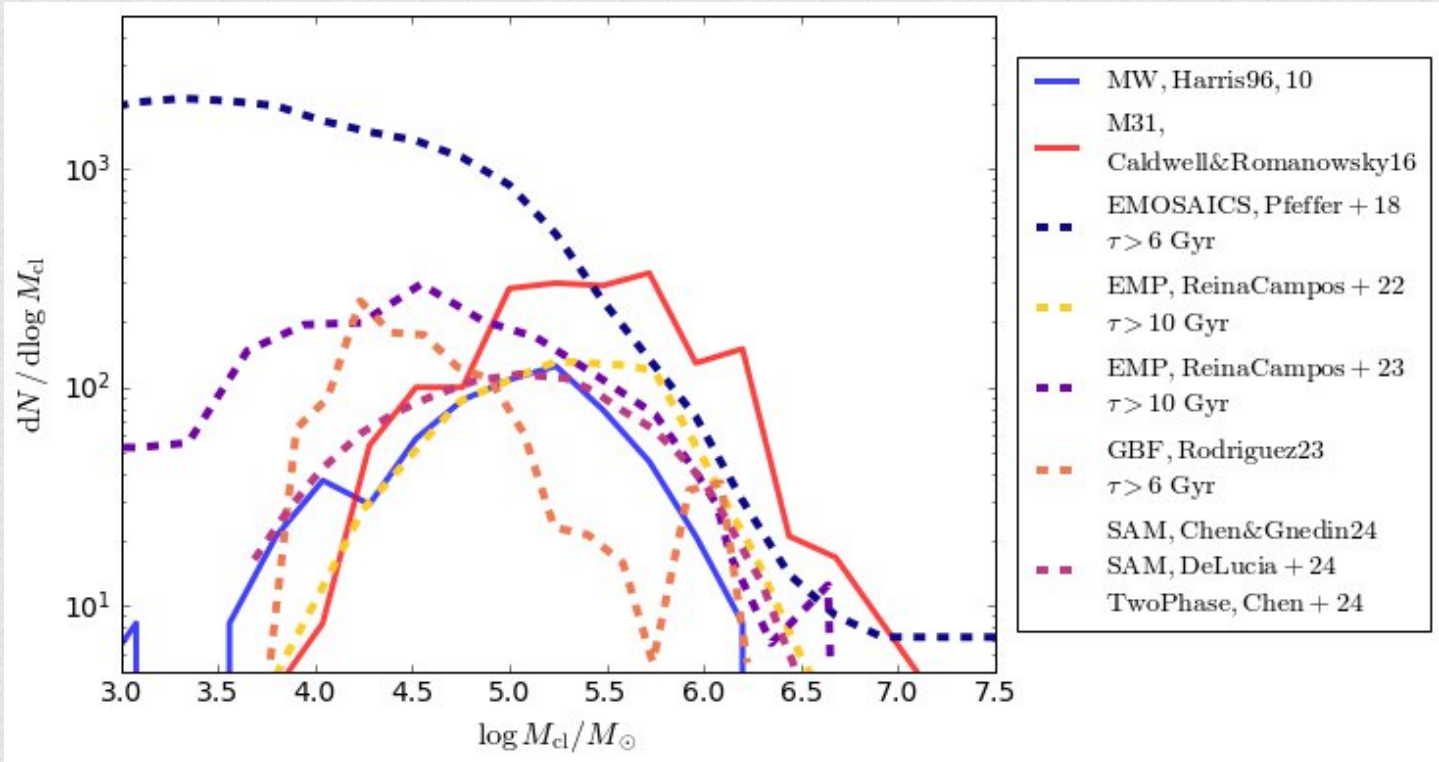


Peaked shape

$M_{TO} \sim 10^5 M_\odot$ **weak environmental dependence**

Young SCs MF to GCMF

- Two-body relaxation
  - $M_{TO} - R$ anticorrelation
- Tidal interactions (shocks)
  - Sensitive to r_h and ISM treatment
  - Early disruption
- General strong dependence on implementation and/or calibration

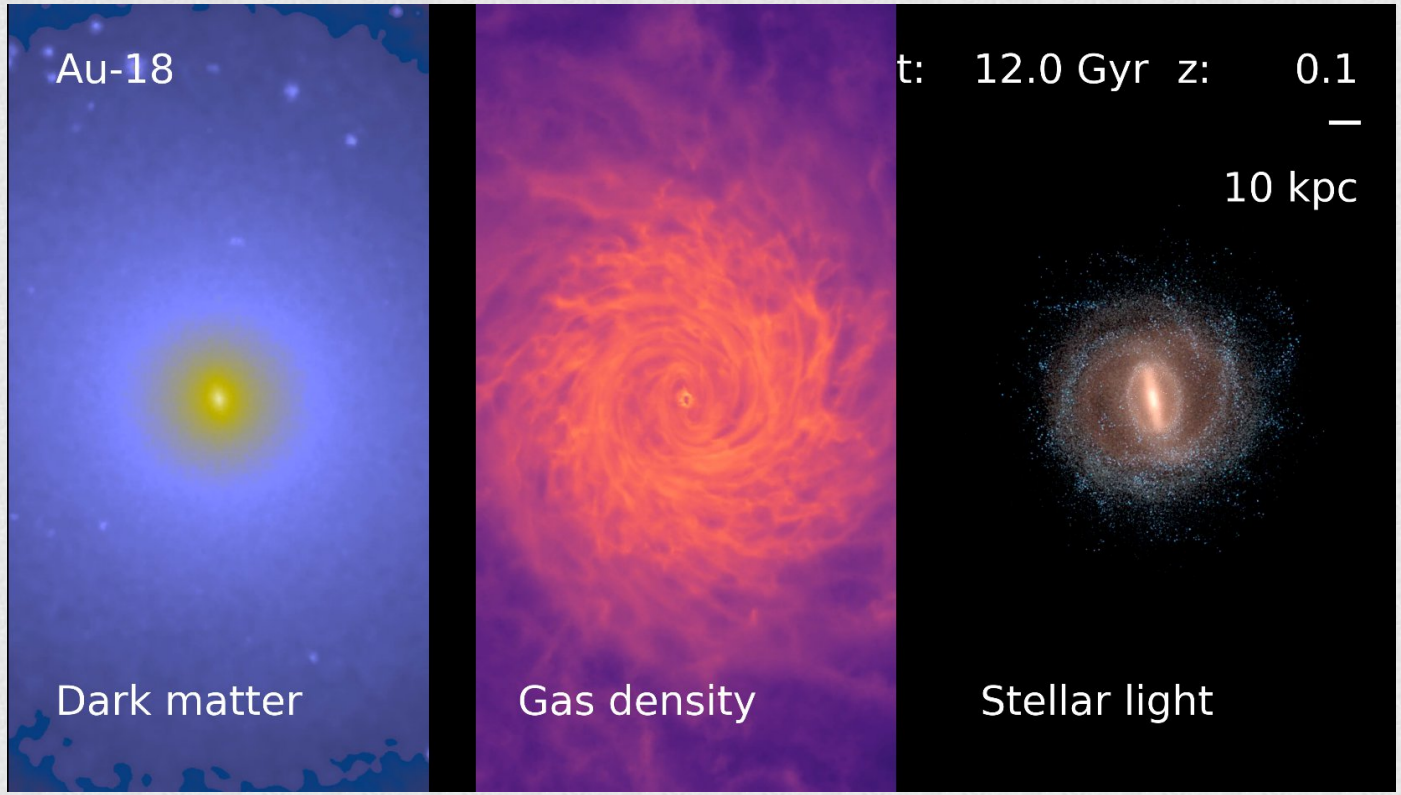


SCs Module in the Auriga Simulations

Auriga simulation suite:

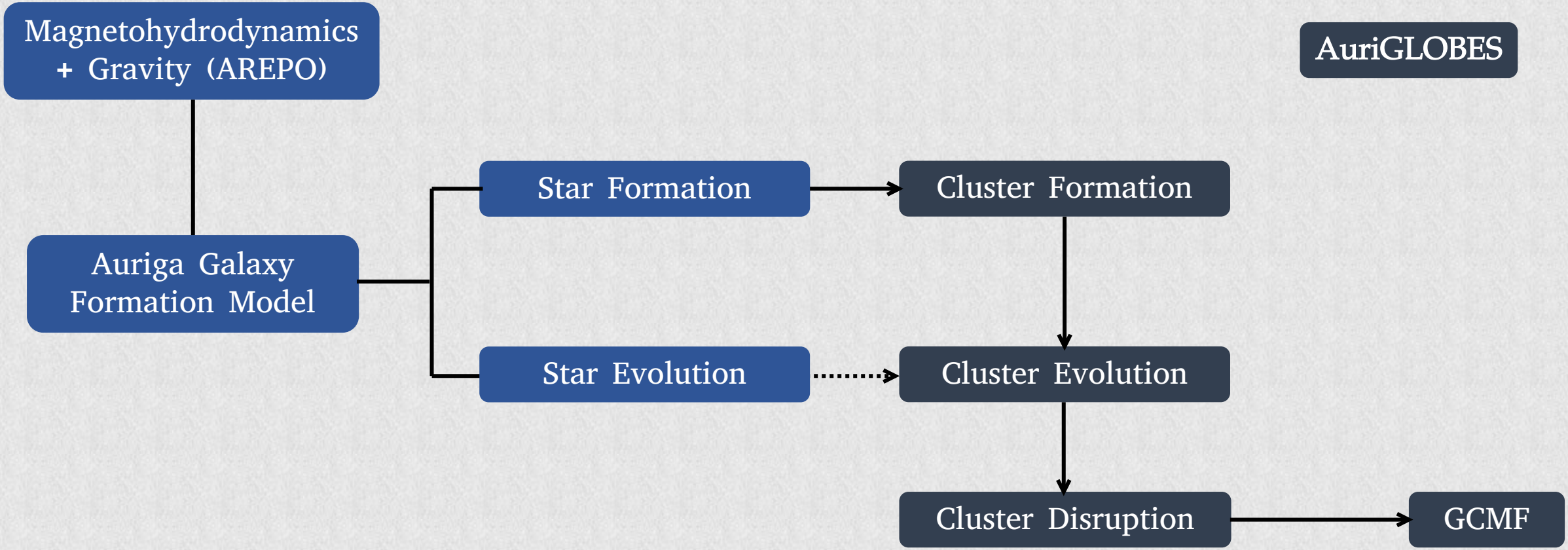
- 40 MW-like mass
- 24 dwarf-like mass
- $m_{\rm bary} = 5e4\ (6e3)\, M_\odot$

LCDM ICs	Stellar feedback
Gas accretion	Black holes
Star formation	AGN feedback
Stellar evolution	Magnetic fields



Grand+17,24. Publicly available @ https://wwwmpa.mpa-garching.mpg.de/auriga/data.html

SCs Module in the Auriga Simulations



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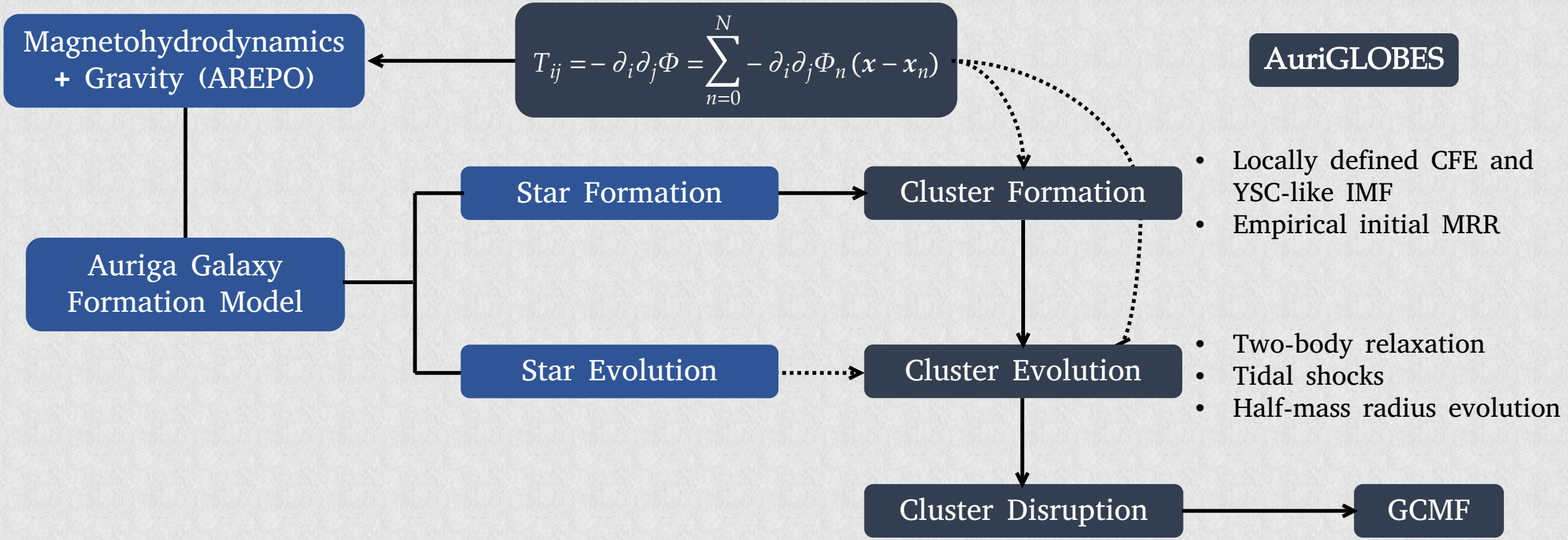

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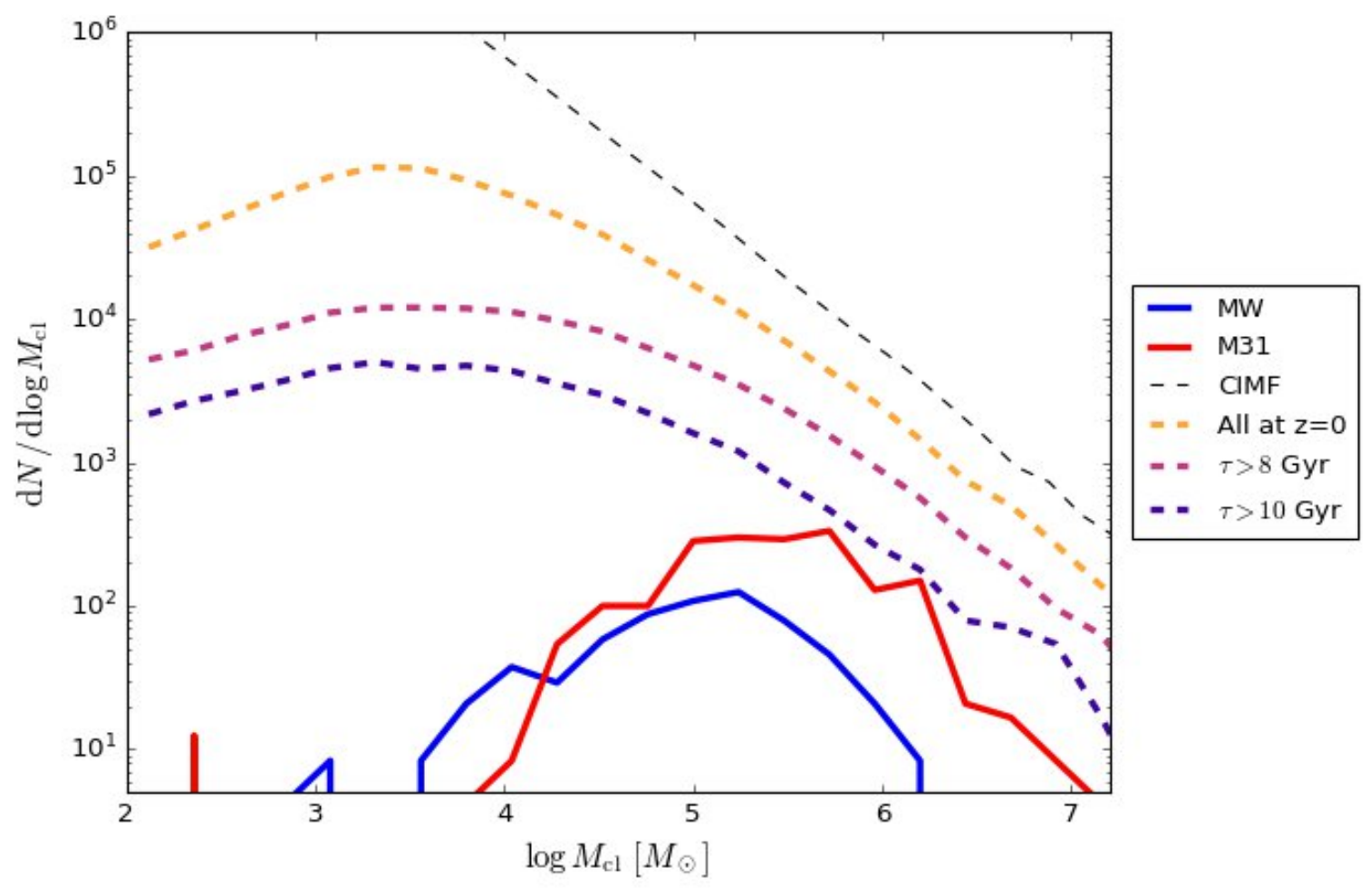
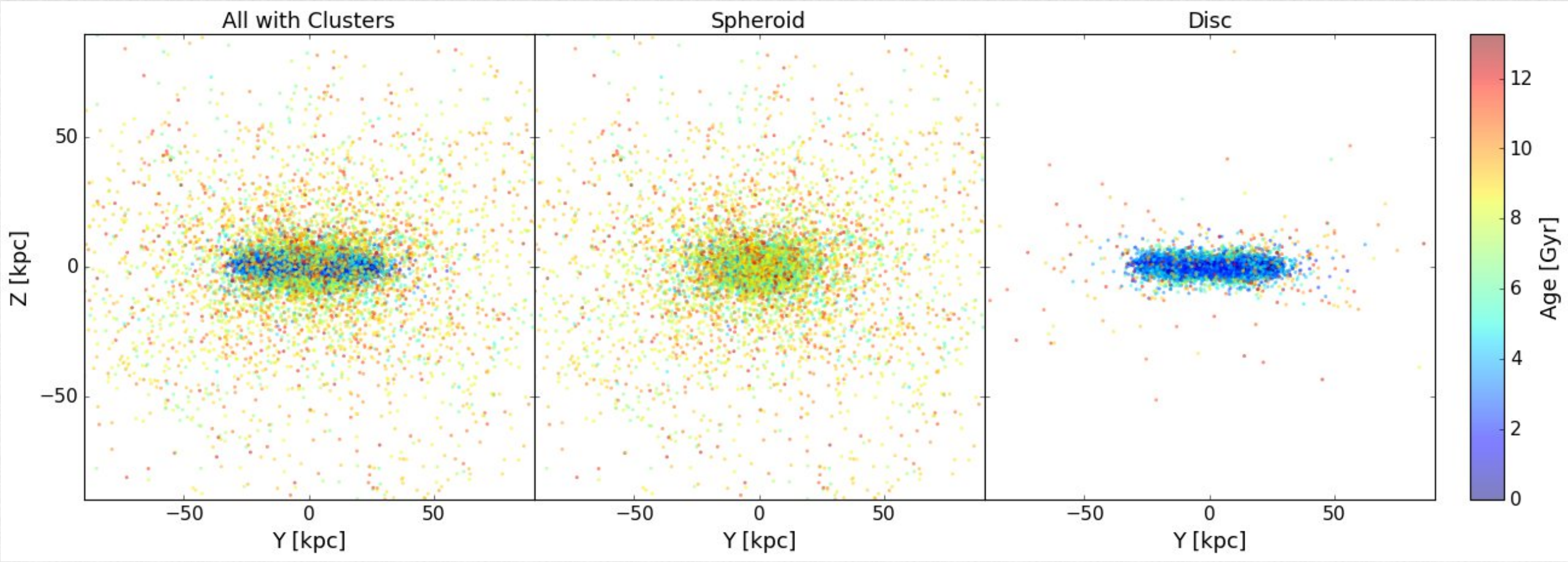


Globular Cluster Candidates Selection



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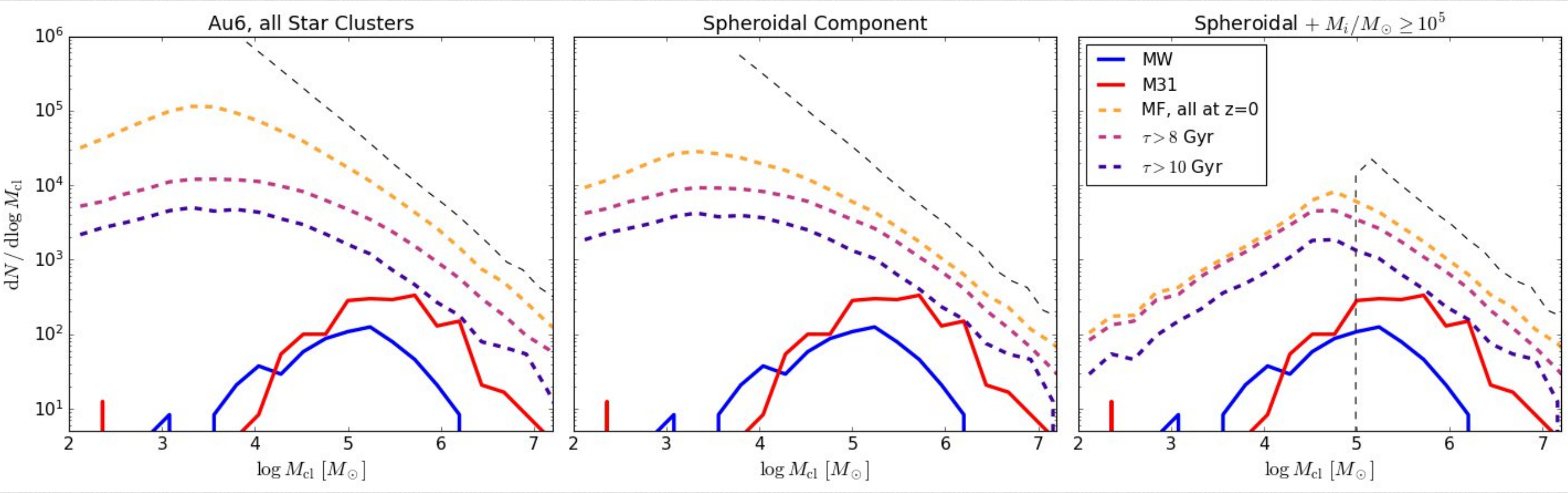
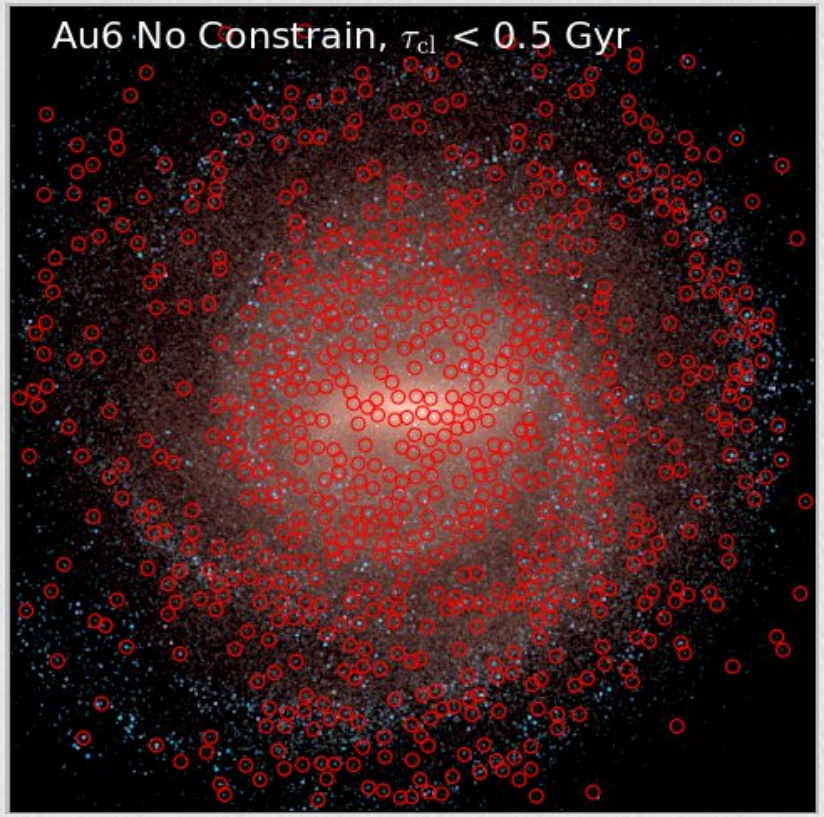
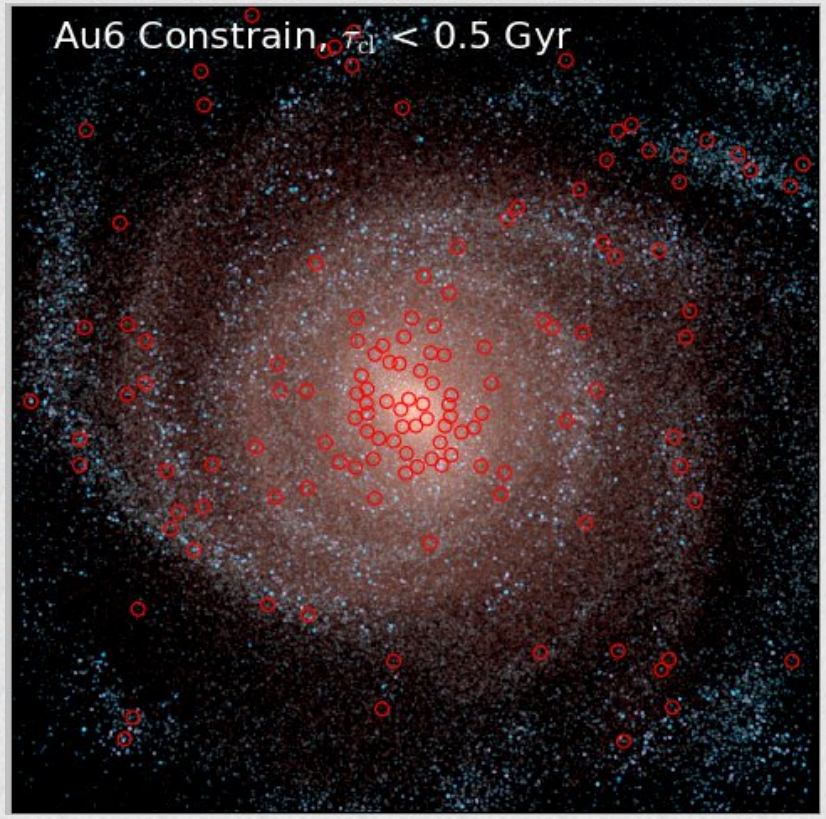


Tweaking Formation Model

- Formation in compressive ($\forall \lambda_i \left(T_{ij} \right) < 0$) environments only.





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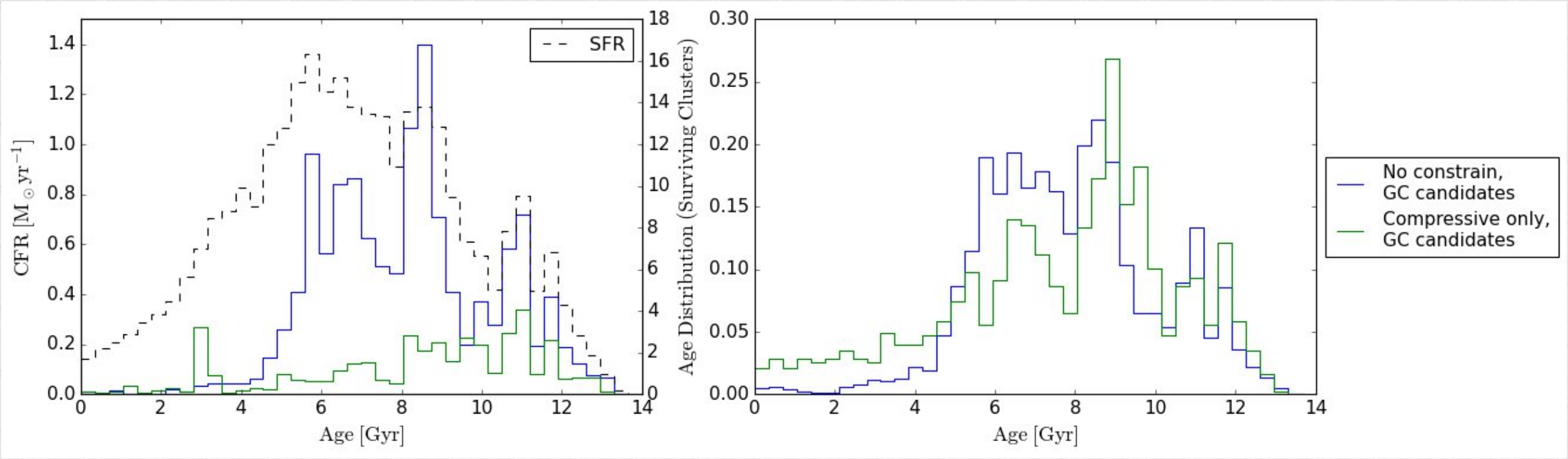
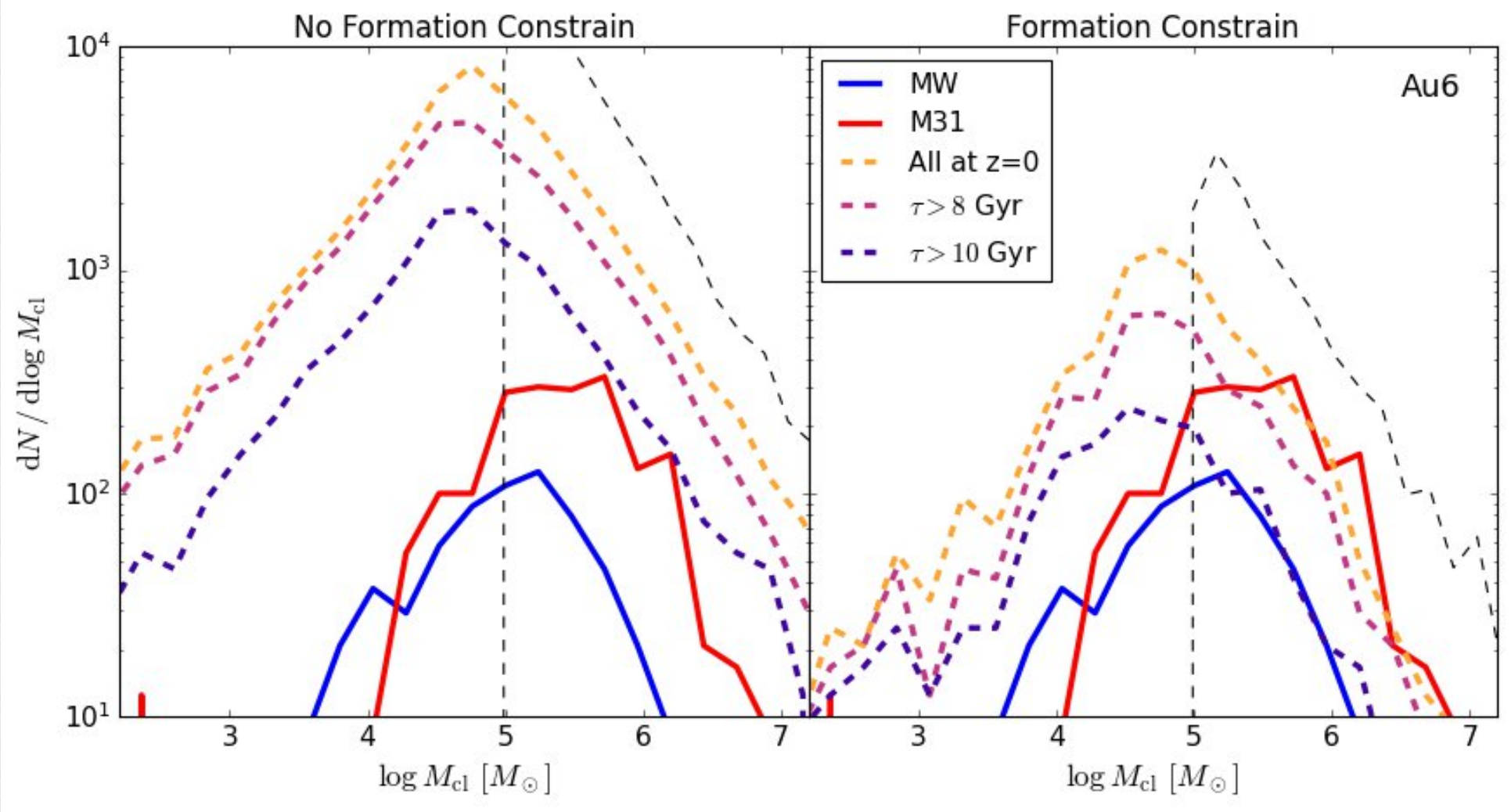
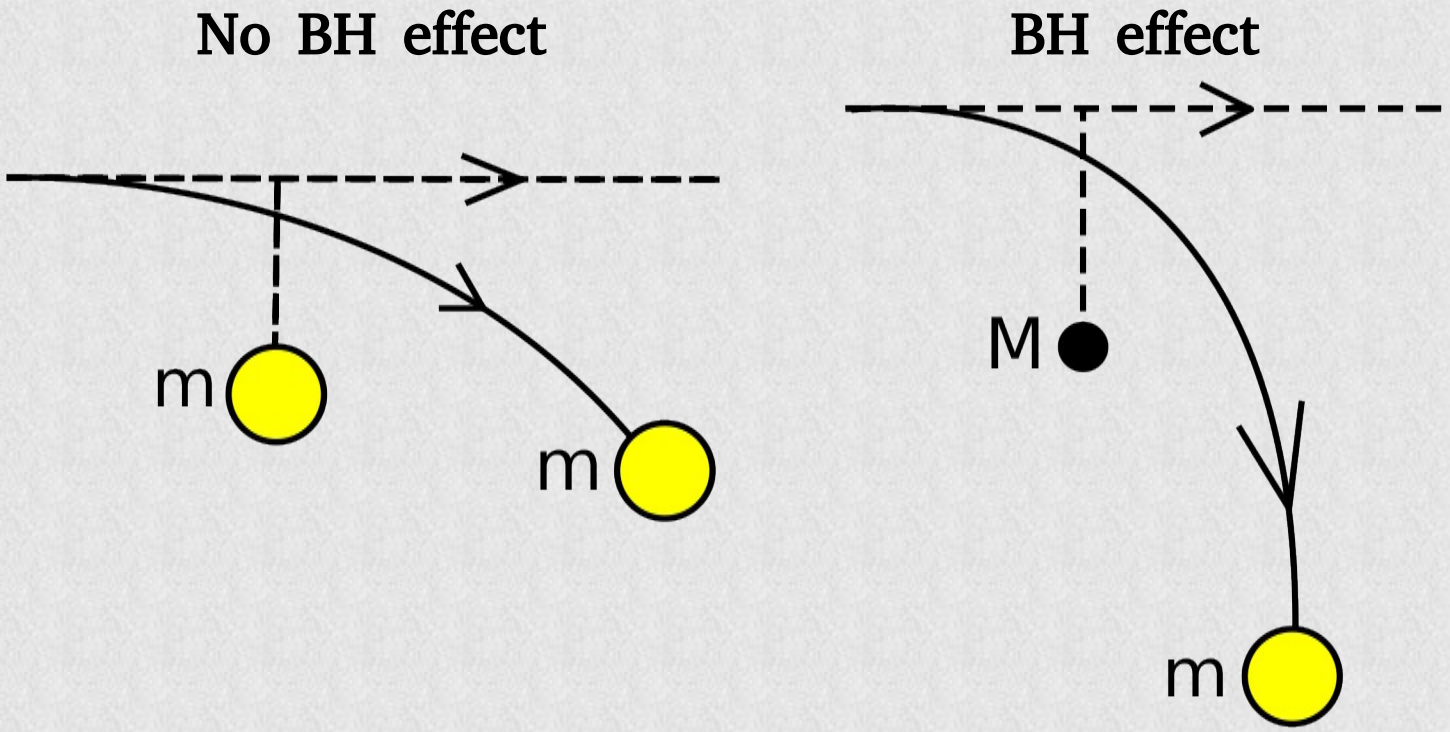


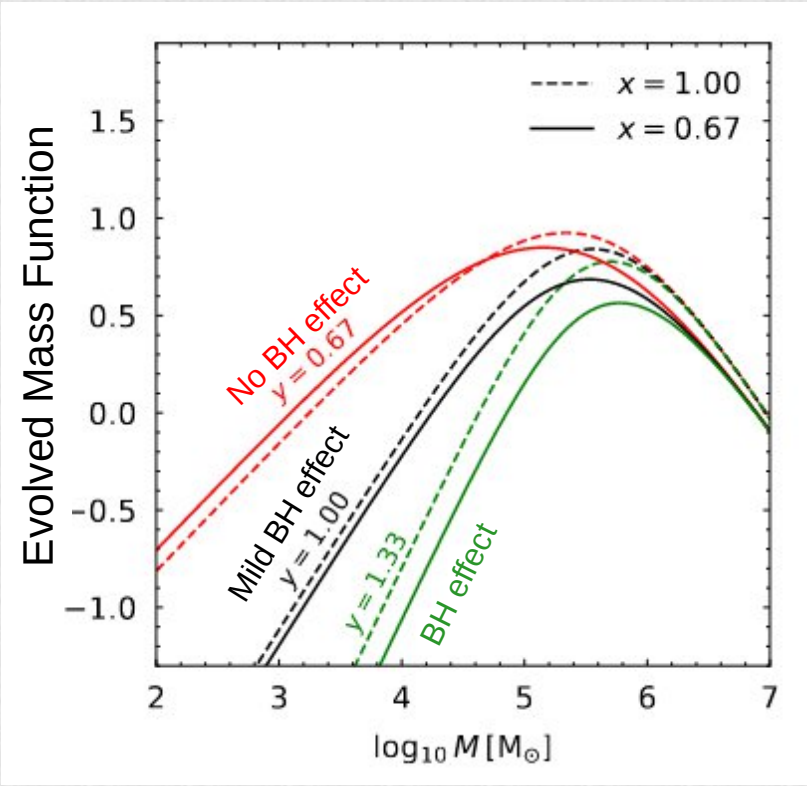
Effect on the GCMF



Tweaking Evolution Model

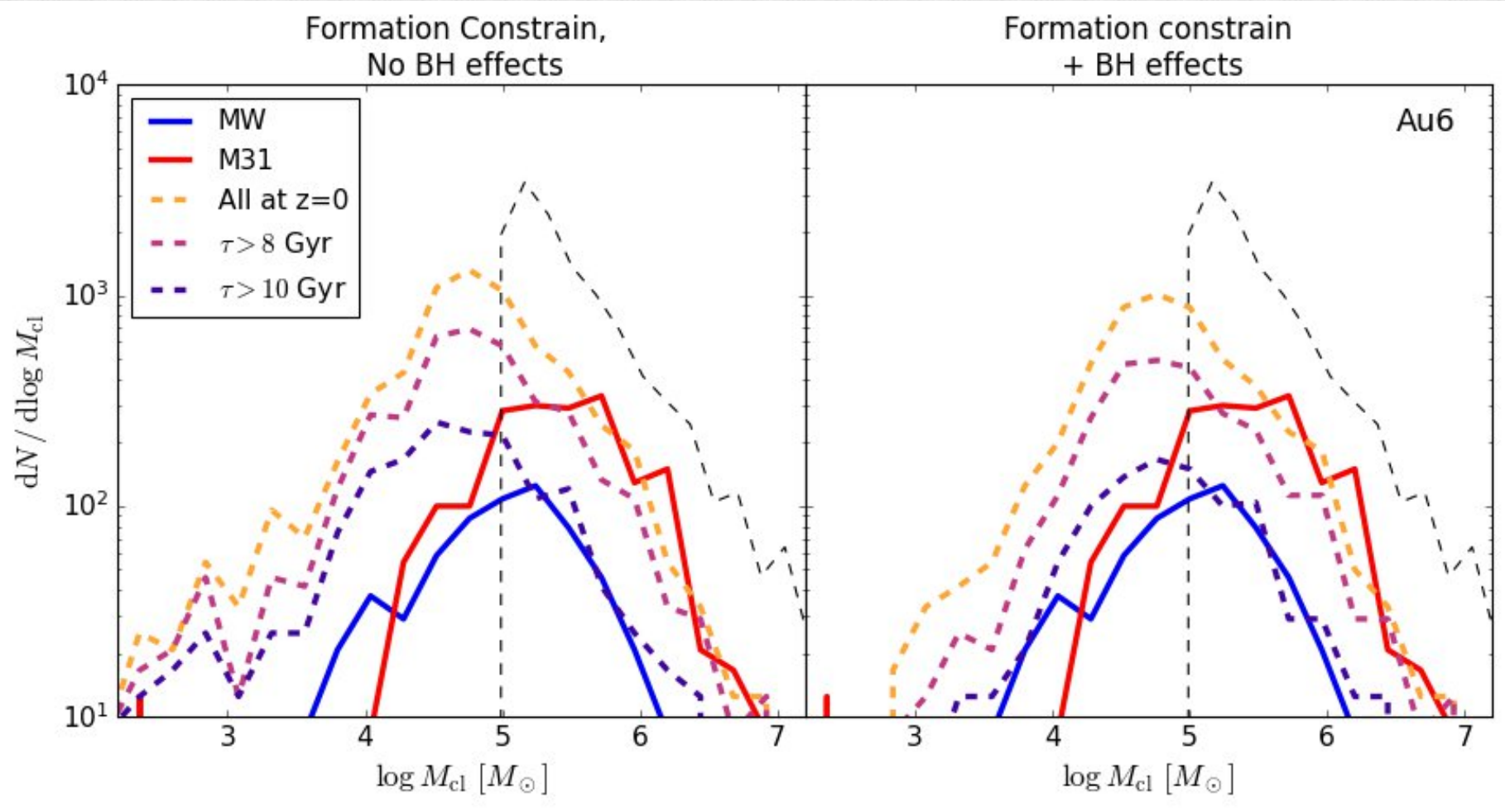
- Enhanced two-body relaxation mass loss (compact remnants)



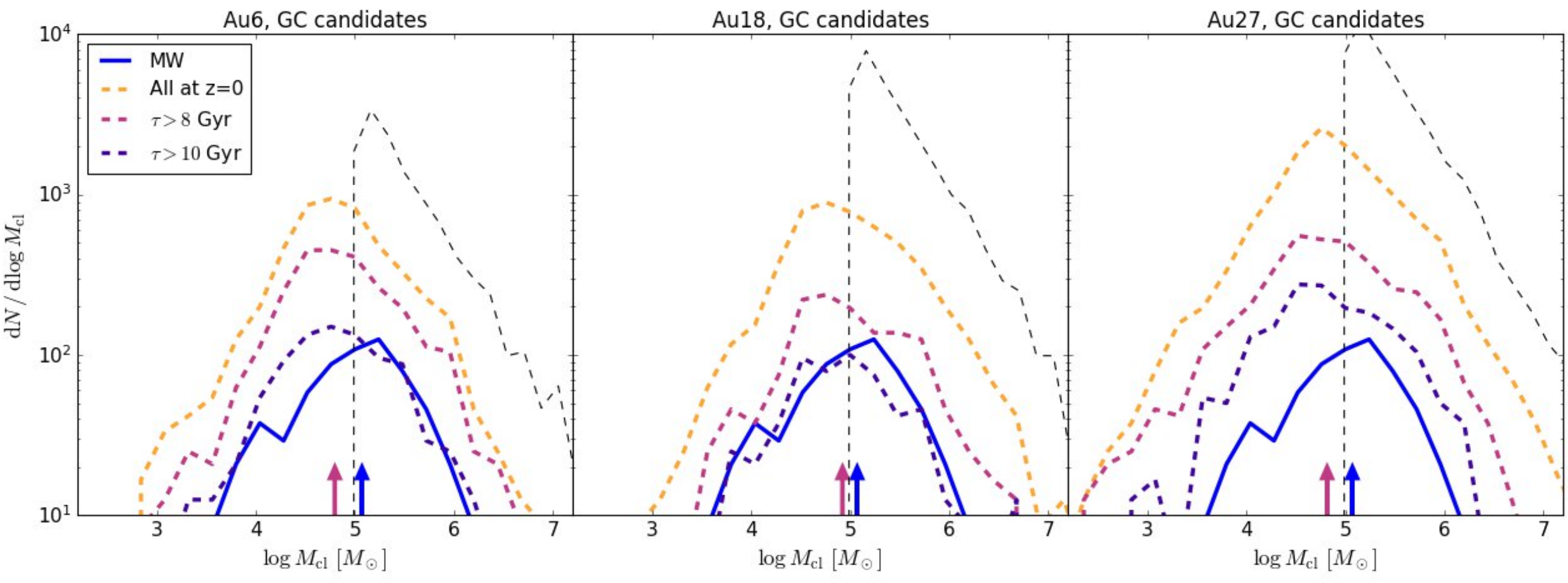


Gieles&Gnedin23

Effect on the GCMF



GCMF Assembly History Dependency?



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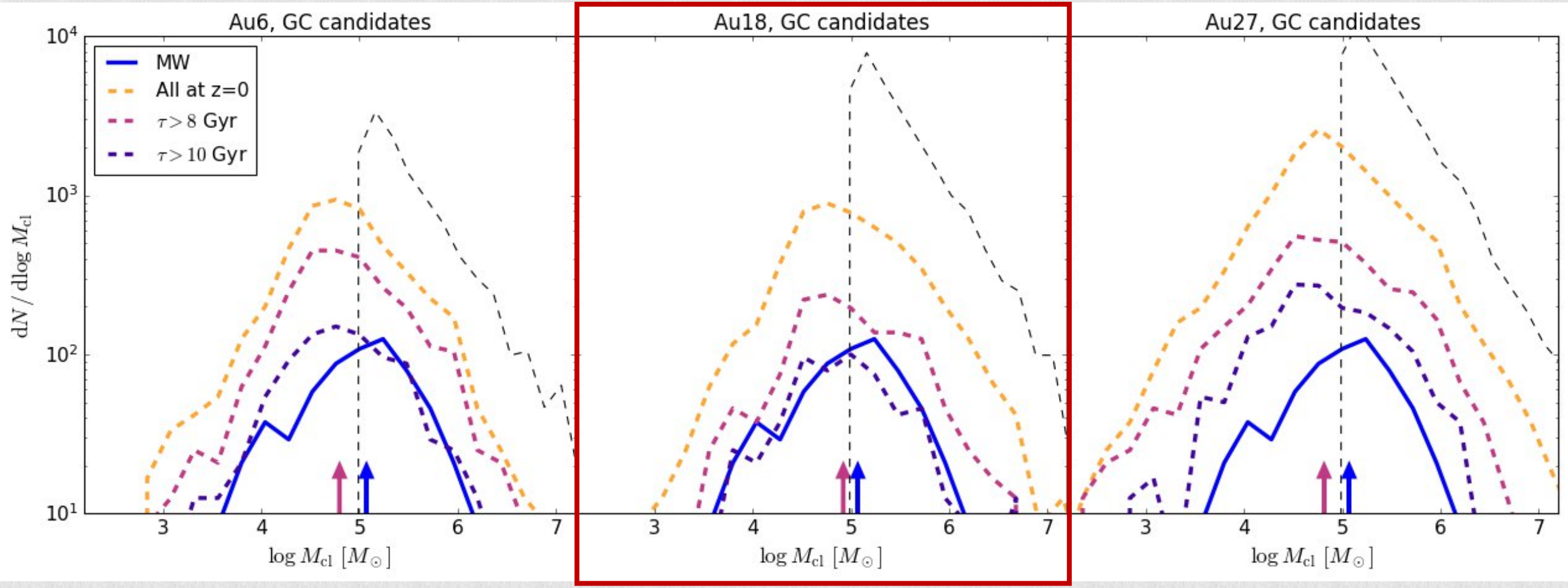

Conclusions

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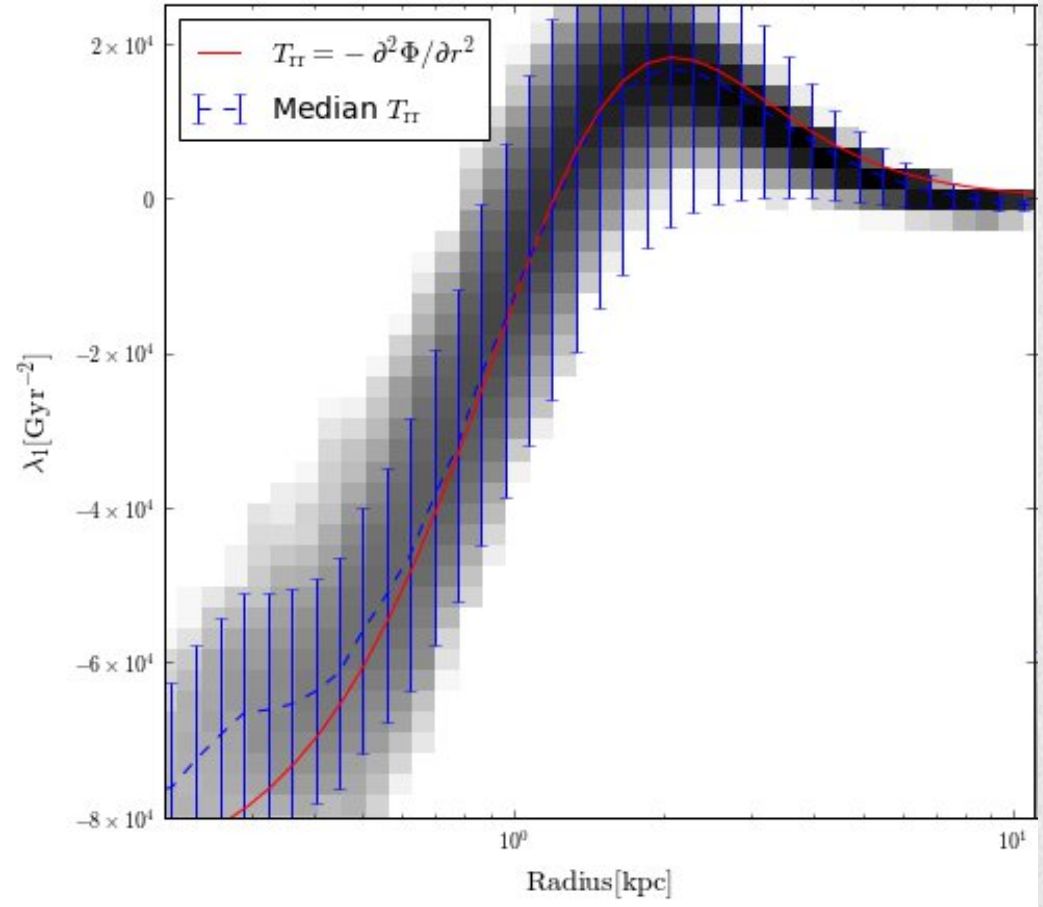
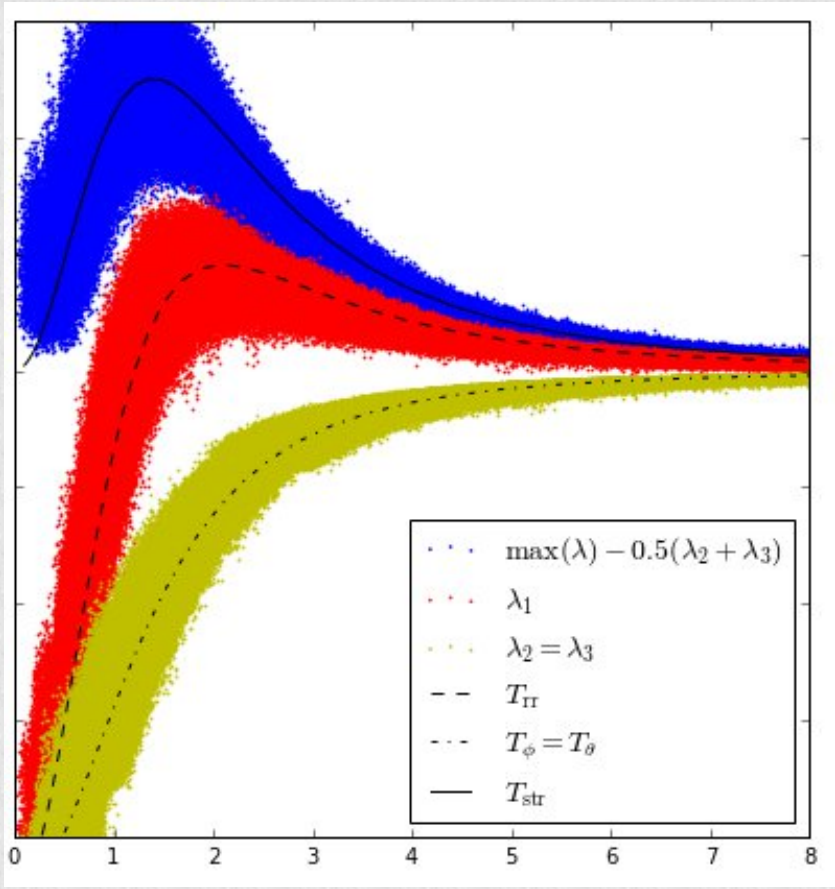
- Hints on recovering the GCMF:
  - Formation at high-density/pressure **compressive** environments
  - **Two-body relaxation mass loss enhancement** from compact object remnants effects
- GCMF weak host galaxy mass dependence recovered
  - MF peak ↔ assembly history
- Model limitation:
  - Early disruption underestimation (ISM model)

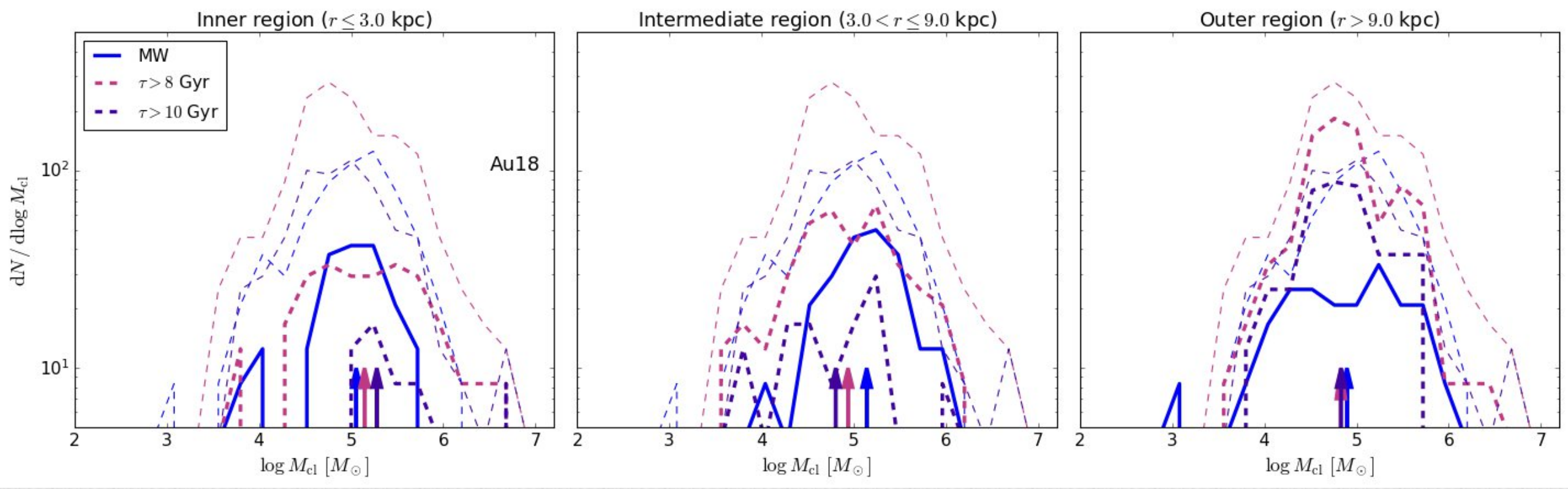
Extra Material

Tidal Field Calculus





GCMF $M_{TO} - R$ Anticorrelation?



SCs Module in the Auriga Simulations

FORMATION

$$\Gamma\left(\rho_g, \sigma_{\rm loc}, c_s\right) = f_{\rm bound} \quad \text{Kruijssen12}$$

$$N\,{\rm d}M \propto M^{-2}\exp\left(-M/M_{c,\rm max}\right)\,{\rm d}M$$

$$M_{c,\rm max} = \epsilon\Gamma M_{\rm GMC} \quad \text{Reina-Campos+17}$$

$$r_{\rm h}^{\rm init} = 2.365\ {\rm pc}\ \left(m/10^4 {\rm M}_\odot\right)^{0.18} \quad \text{Brown+21}$$

$$\sigma = 0.735\ {\rm dex}$$

EVOLUTION

$$\left(\frac{{\rm d}m}{{\rm d}t}\right)_{\rm rlx} = -\,\xi\,\frac{m}{t_{\rm rh}};\ \xi = f\left(m, r_{\rm h}, r_{\rm t}(T)\right)$$

Alexander&Gieles12

$$\left(\frac{{\rm d}m}{{\rm d}t}\right)_{\rm sh} = -\frac{m}{t_{\rm sh}};\ t_{\rm sh} = f\left(I_{\rm tid}(T_{ij})\right)$$

Prieto&Gnedin08

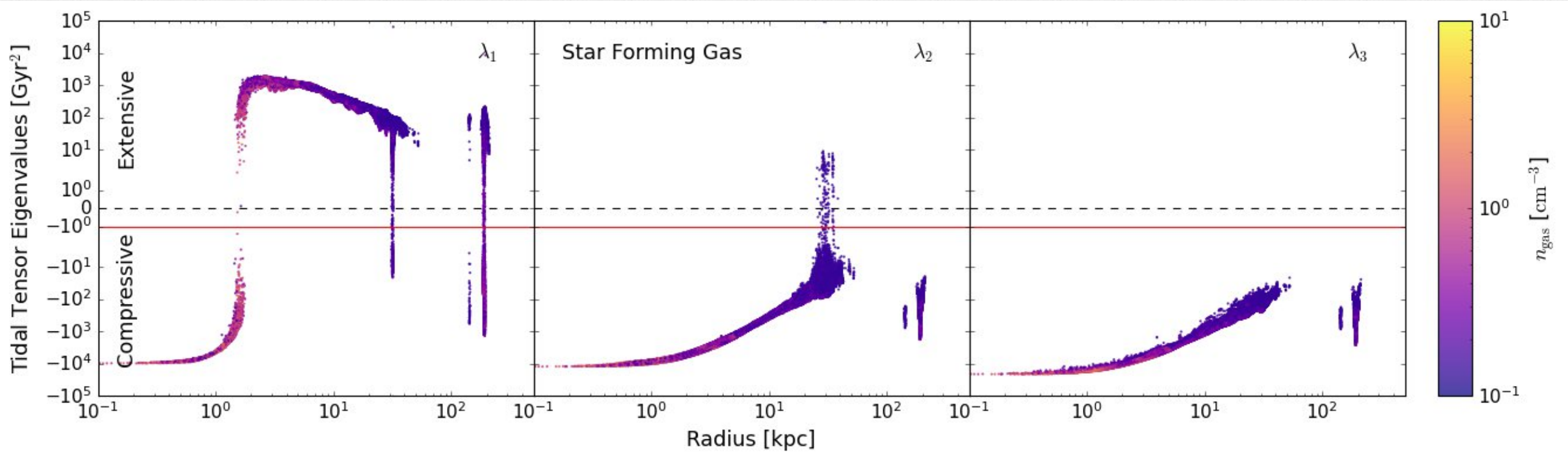
$$\frac{{\rm d}r_{\rm h}}{r_{\rm h}} = \left(2 - \frac{\zeta}{\xi}\right)\frac{{\rm d}m_{\rm rlx}}{m} + \left(2 - \frac{1}{f}\right)\frac{{\rm d}m_{\rm sh}}{m}$$

Reina-Campos+23

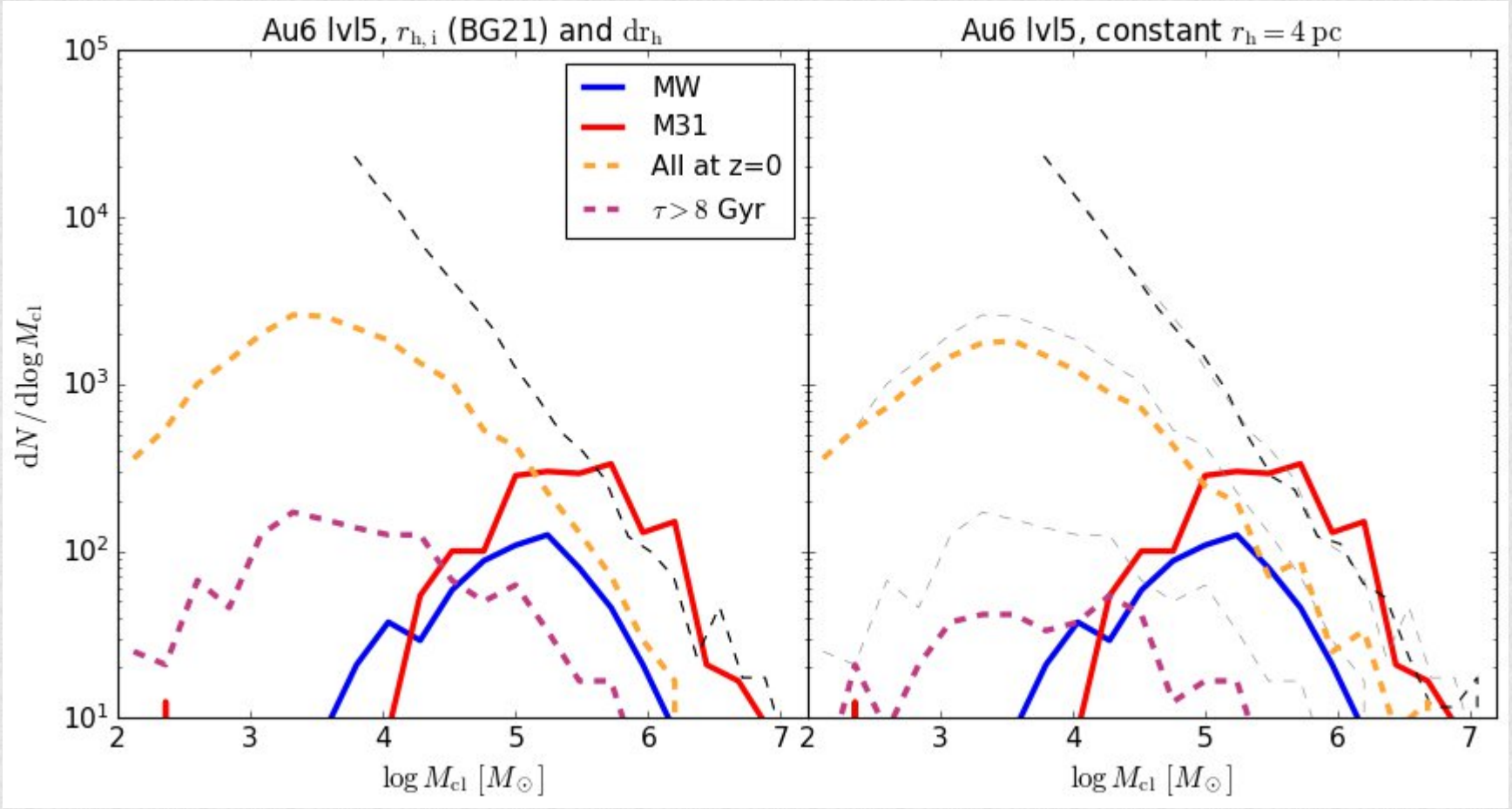
$$\dot{M} = \dot{M}_{\rm ref}\left(\frac{M}{M_i}\right)^{1-y}\left(\frac{M_i}{2\times10^5 M_\odot}\right)^{1-x}\frac{\Omega_{tid}}{0.32{\rm Myr}^{-1}}$$

$$\left(\frac{{\rm d}m}{{\rm d}t}\right)_{\rm rlx} = -\,\xi\,\frac{m}{t_{\rm rh}} \rightarrow \left(\frac{{\rm d}m}{{\rm d}t}\right)_{\rm rlx} = -\,a\xi\,\frac{m}{t_{\rm rh}}\left(\frac{m}{m_i}\right)^{1-y};\ a = 1.5,\ y = 1.33$$

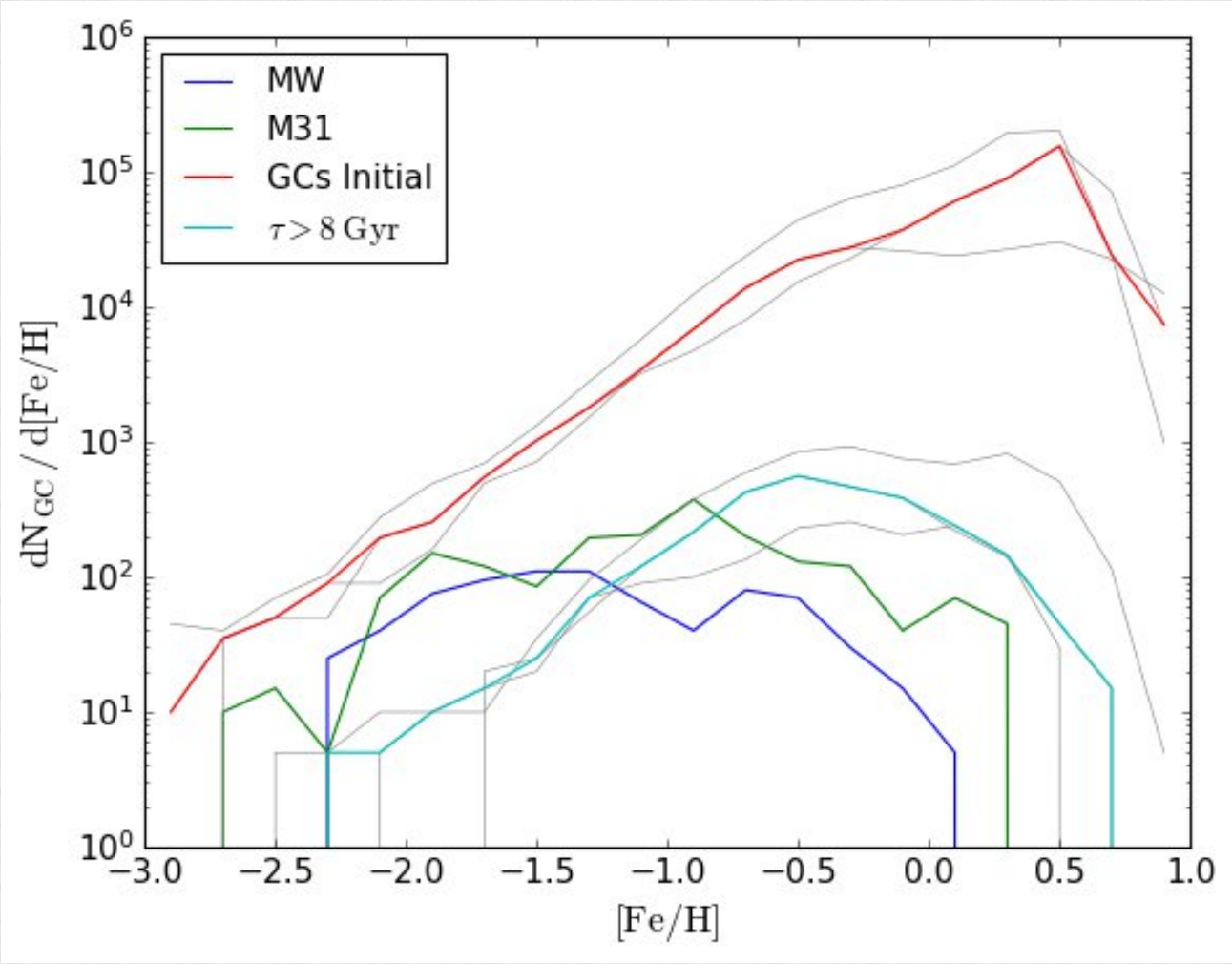
$$T_{ij} = -\partial_i \partial_j \Phi = \sum_{n=0}^{N} -\partial_i \partial_j \Phi_n (\boldsymbol{x} - \boldsymbol{x}_n)$$



Constant $r_h = 4$ pc (Analogous to EMOSAICS, EMP-Pathfinder)

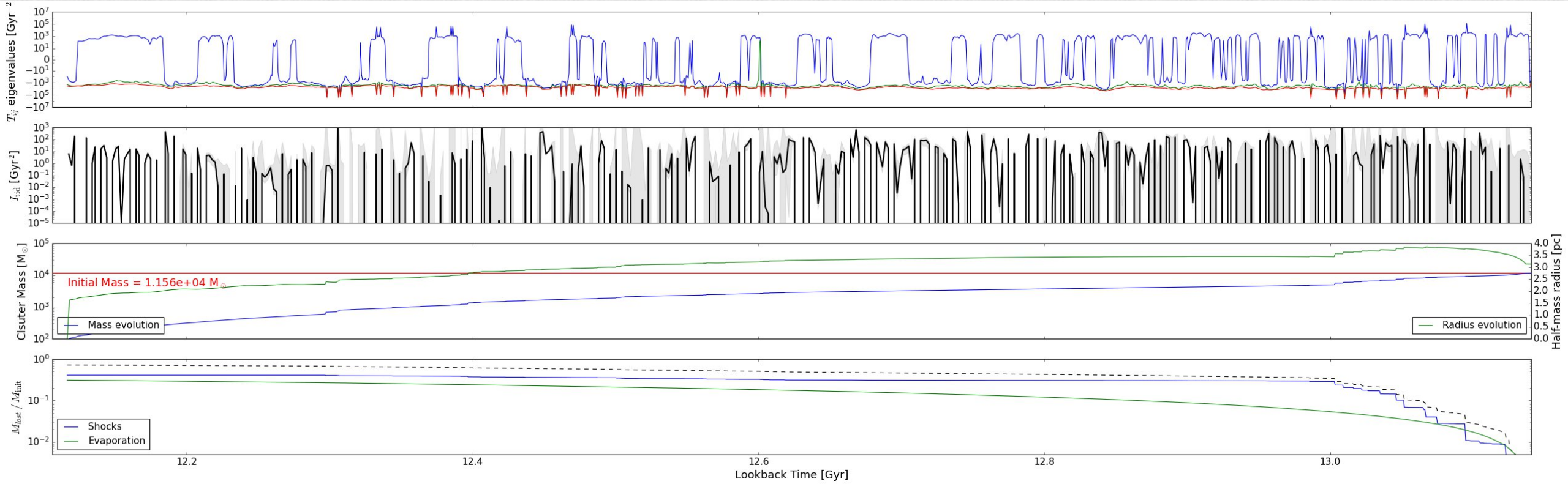


Metallicity Distribution Function



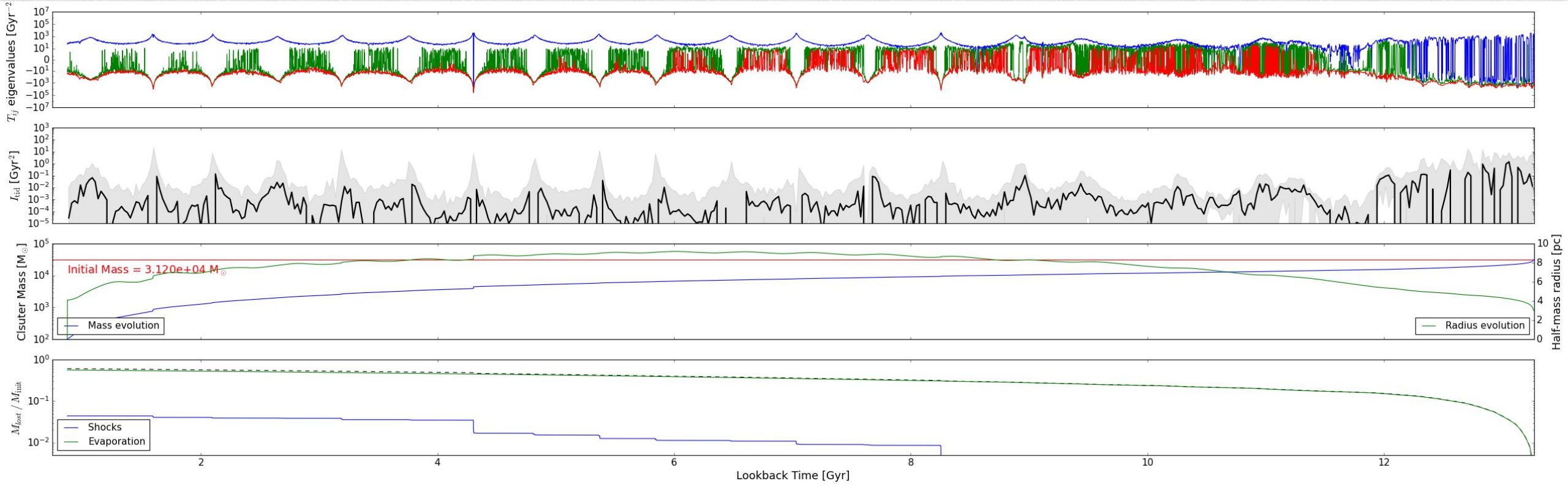
Individual Clusters Evolution

- Early disruption - shocks



Individual Clusters Evolution

- Long evolution – disruption



Individual Clusters Evolution

- Long evolution – no disruption