

Modelling Star Clusters in Cosmological Simulations

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Overview

- Dense clusters observed out to $z \sim 10$ with JWST (Adamo+24, Claeysens+26)
- ~ 13 Gyr of subsequent evolution (Myeong+19; Kruijssen+19)
- Collisional dynamics is expensive (Lahen+20,23,24)
- Or subgrid (Pfeffer+18, Li+17, Grudic+23)
- Can we bridge the gap?



Globular Cluster

ESO/Nogueras-Lara et al.

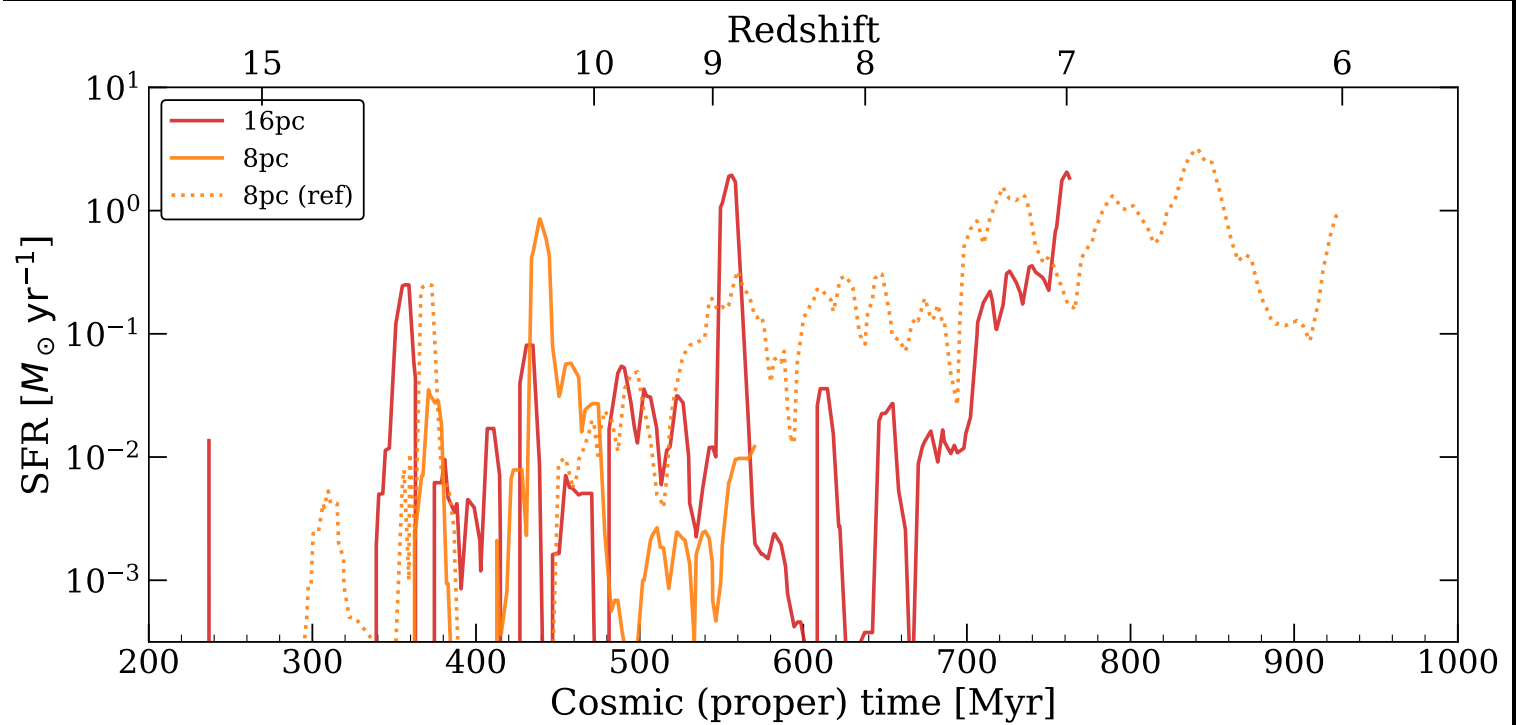
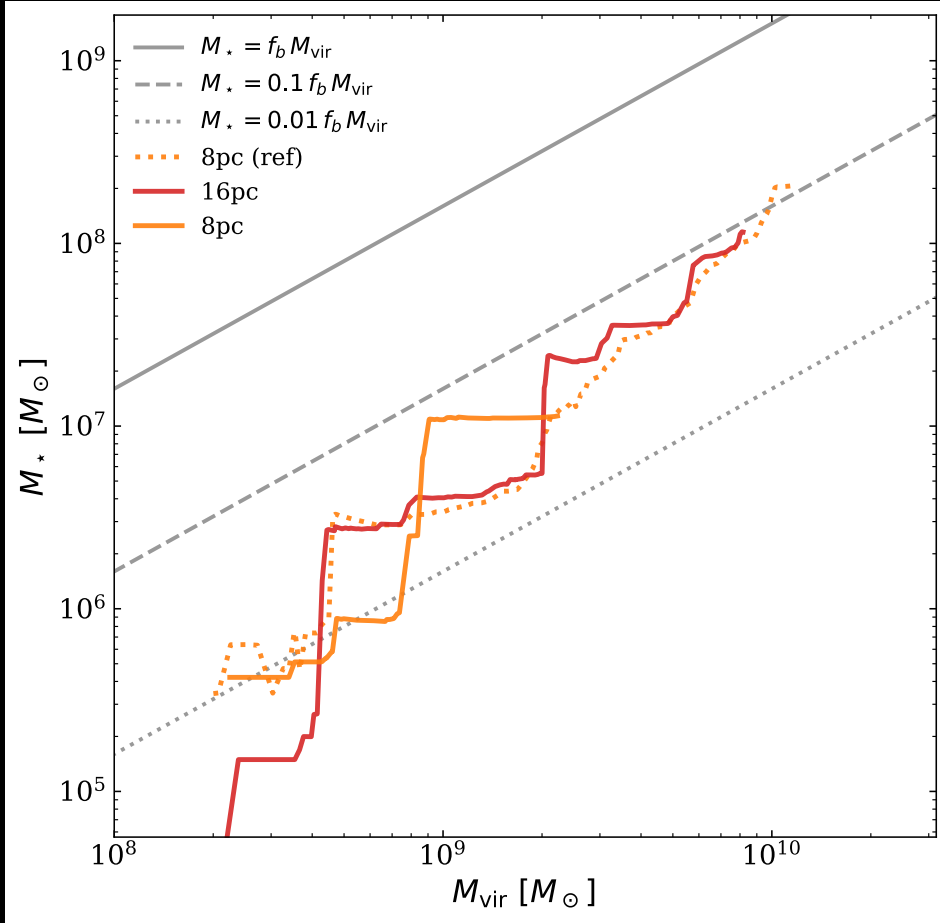


Nuclear Star Cluster

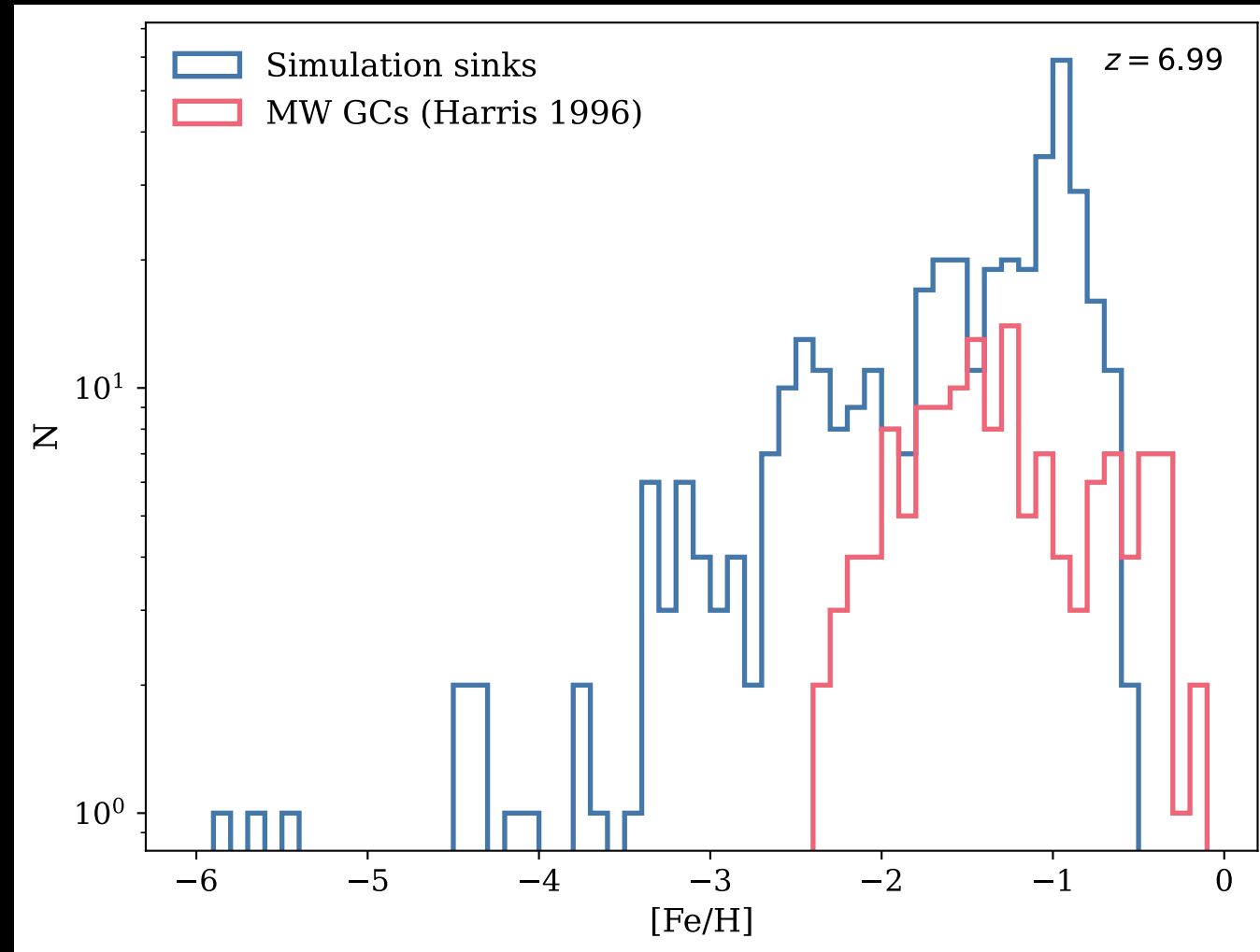
How?

- Extension to Kang+2024 sink star formation algorithm:
 - Seed sink particles in collapsing clouds
 - Accreted mass is converted into stars
 - Newly formed stars are retained “inside” the sink

Integrated Galaxy Properties

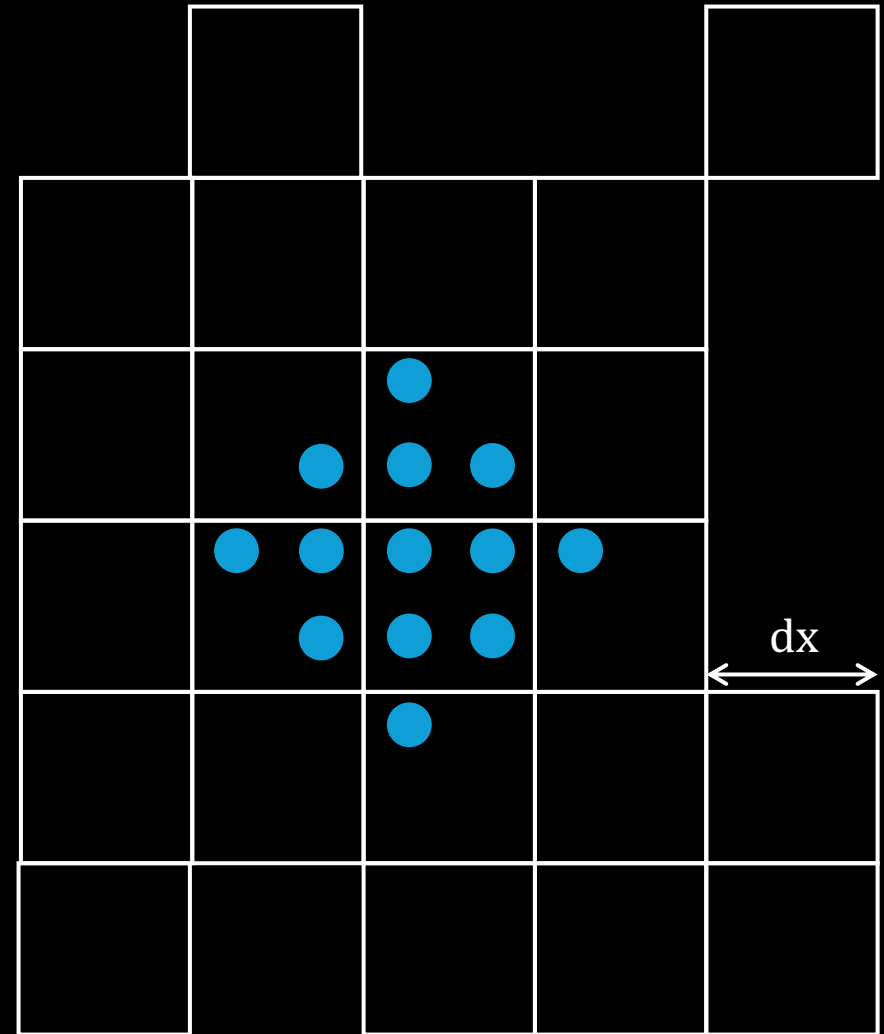


Cluster Formation



The Tidal Field

$$T_{ij} = - \frac{\partial^2 \Phi}{\partial x_i \partial x_j}$$

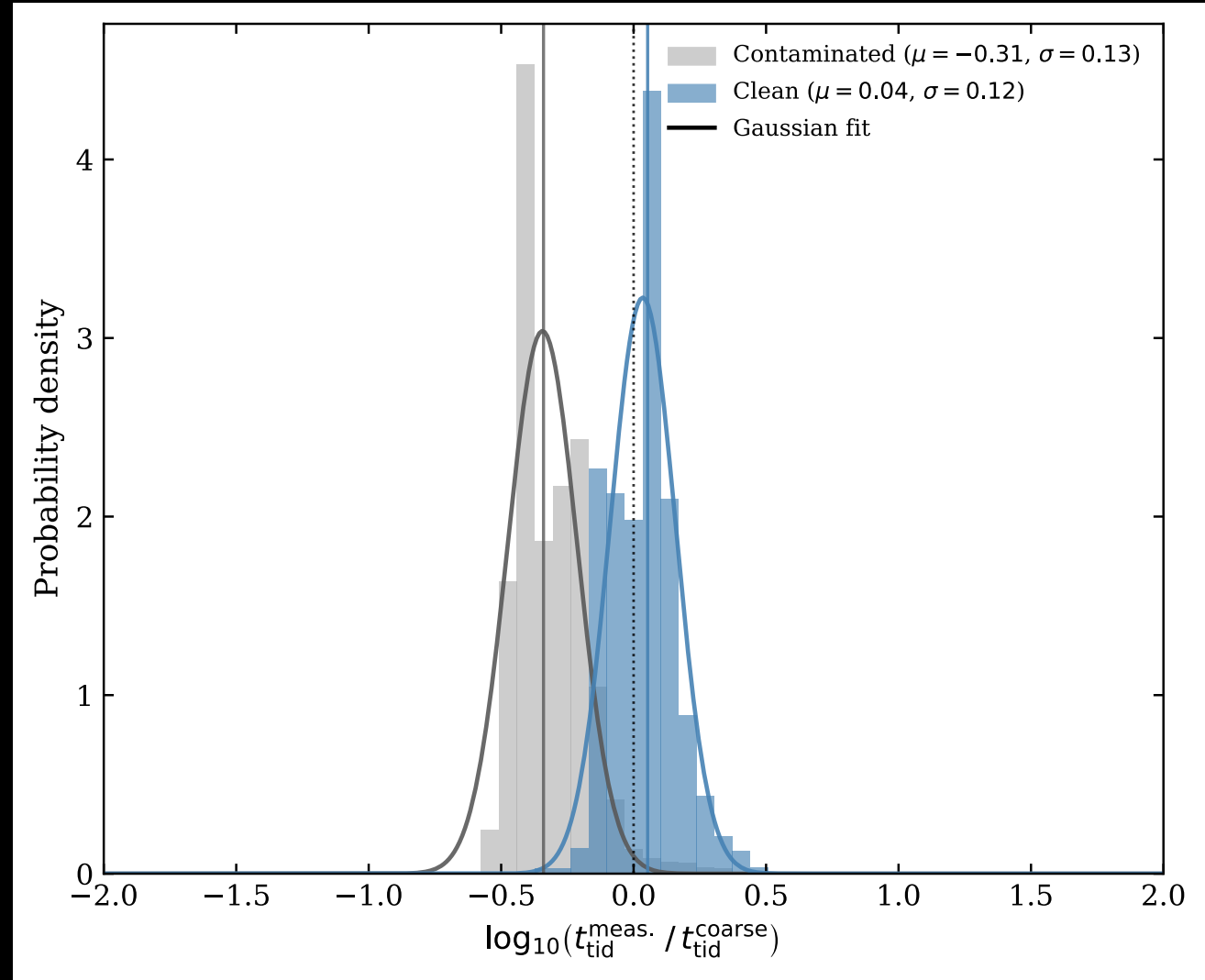


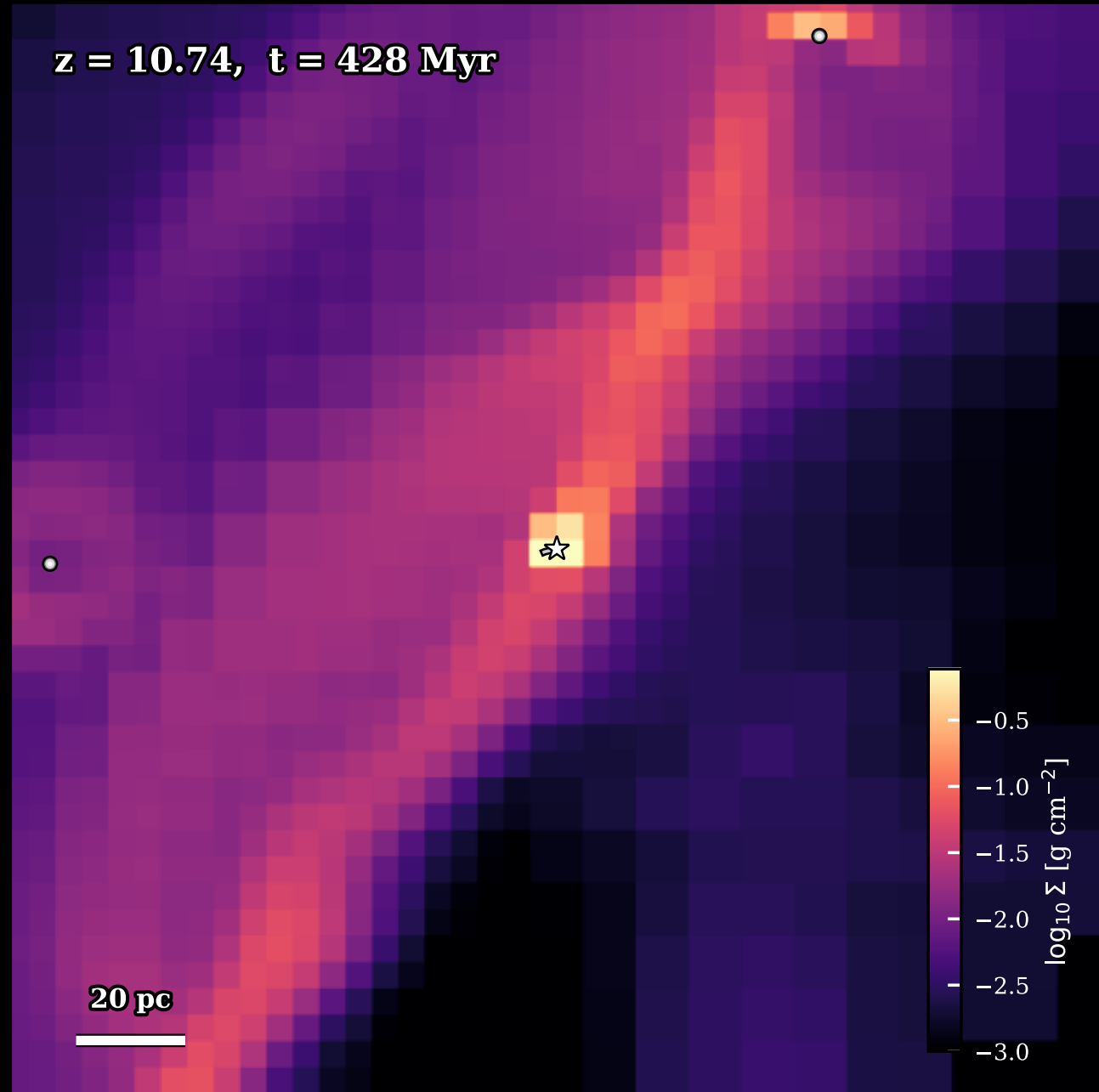
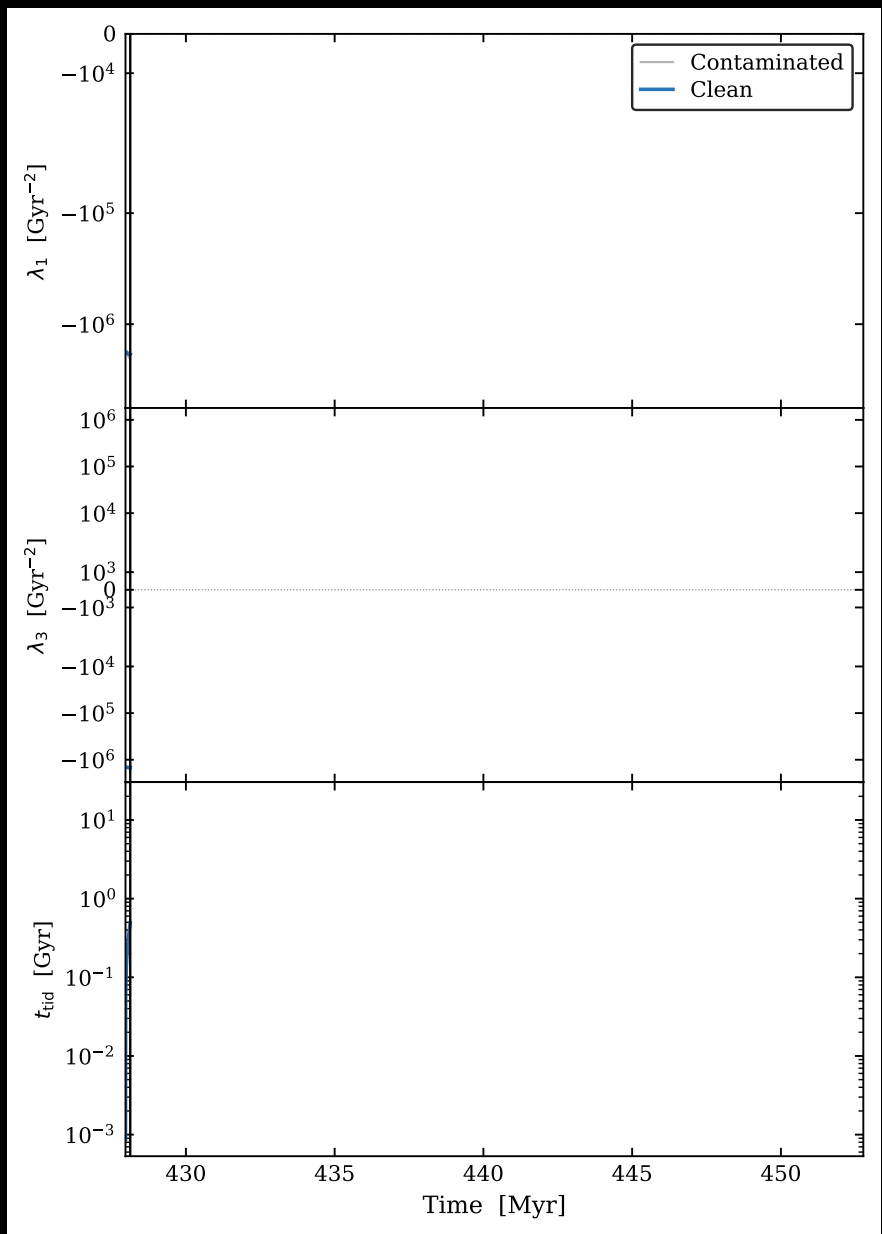
The Tidal Field

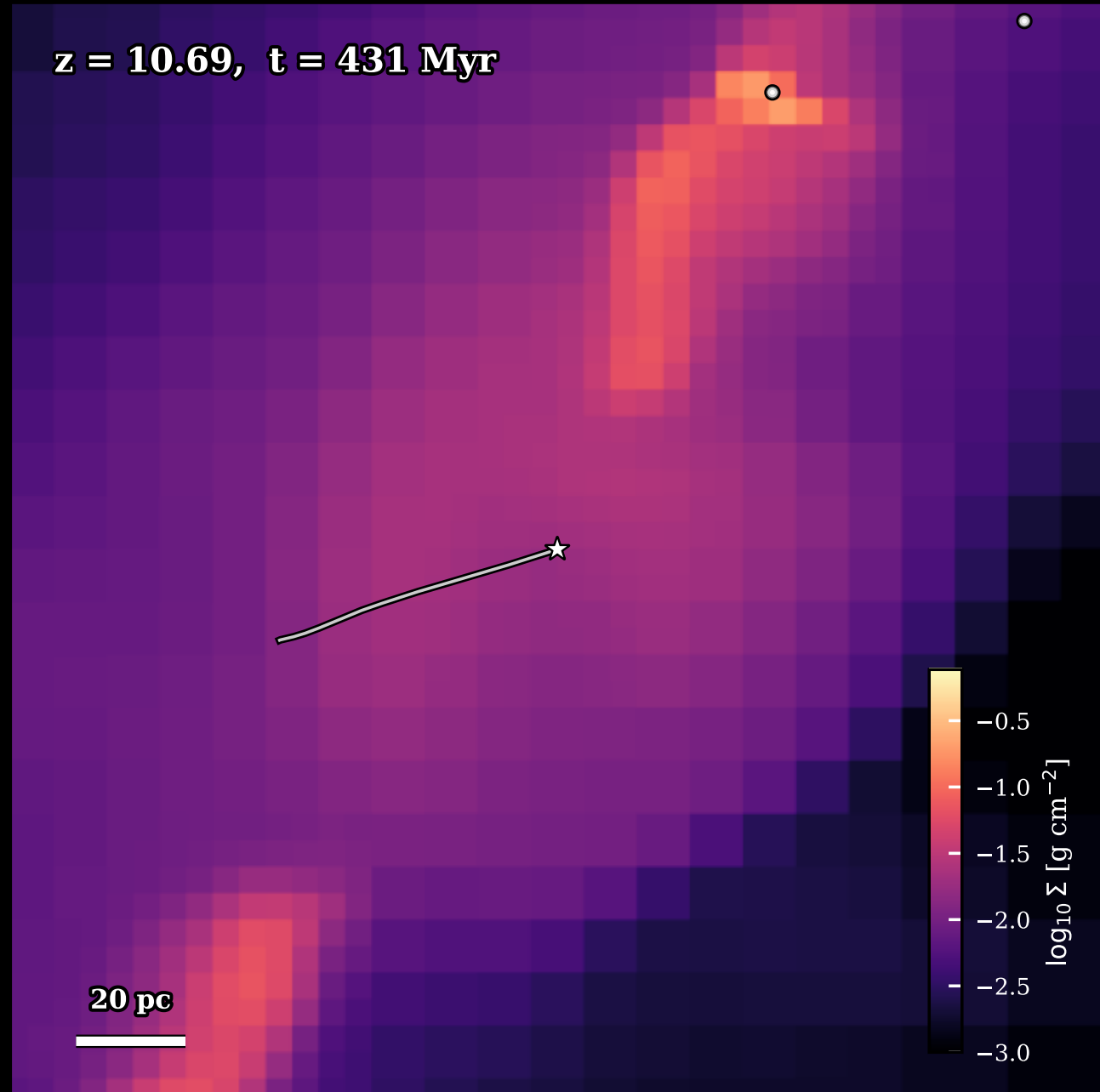
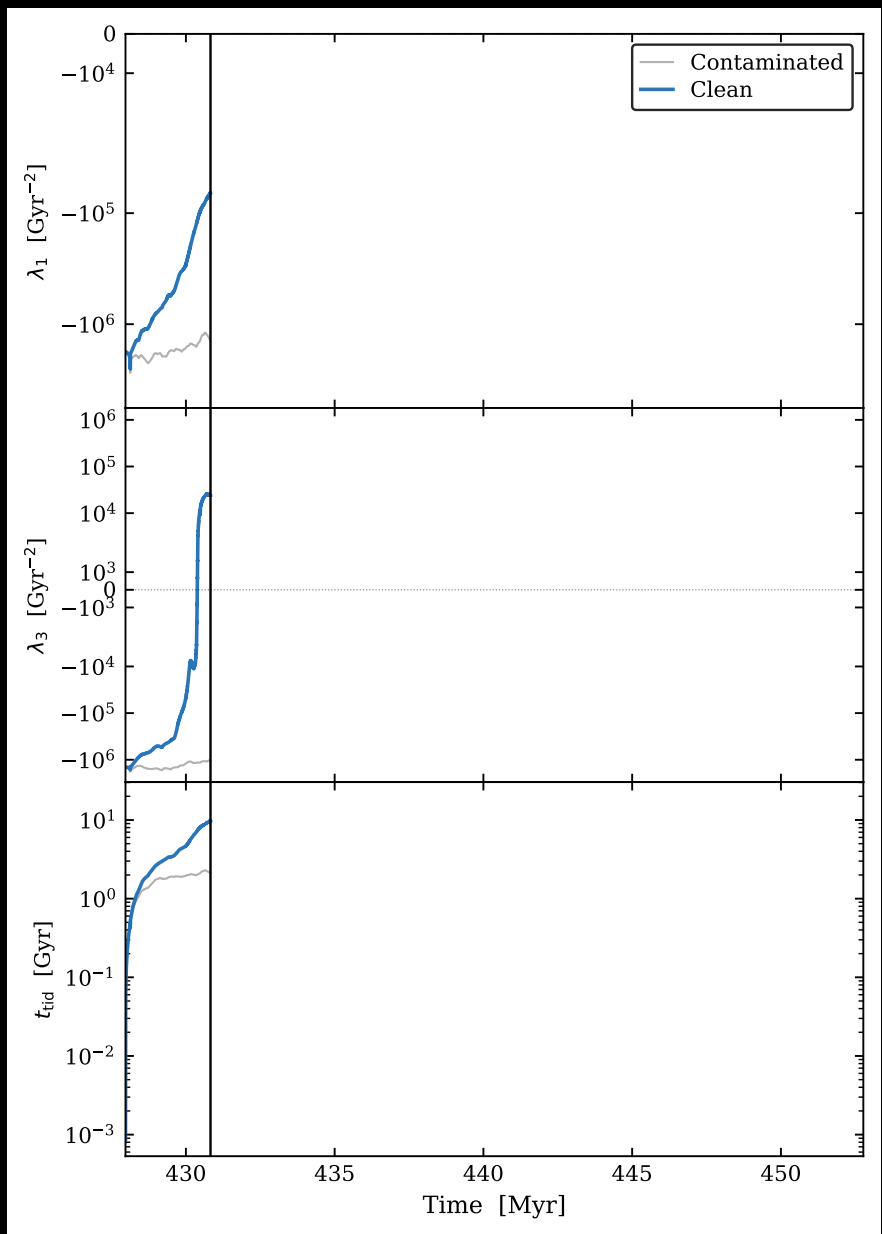
$$t_{\text{tid}} = 10\text{Gyr} \left(\frac{M(t)}{2 \times 10^5 M_{\odot}} \right)^{2/3} \frac{100\text{Gyr}^{-1}}{\sqrt{\max|\lambda_i|/3}}$$

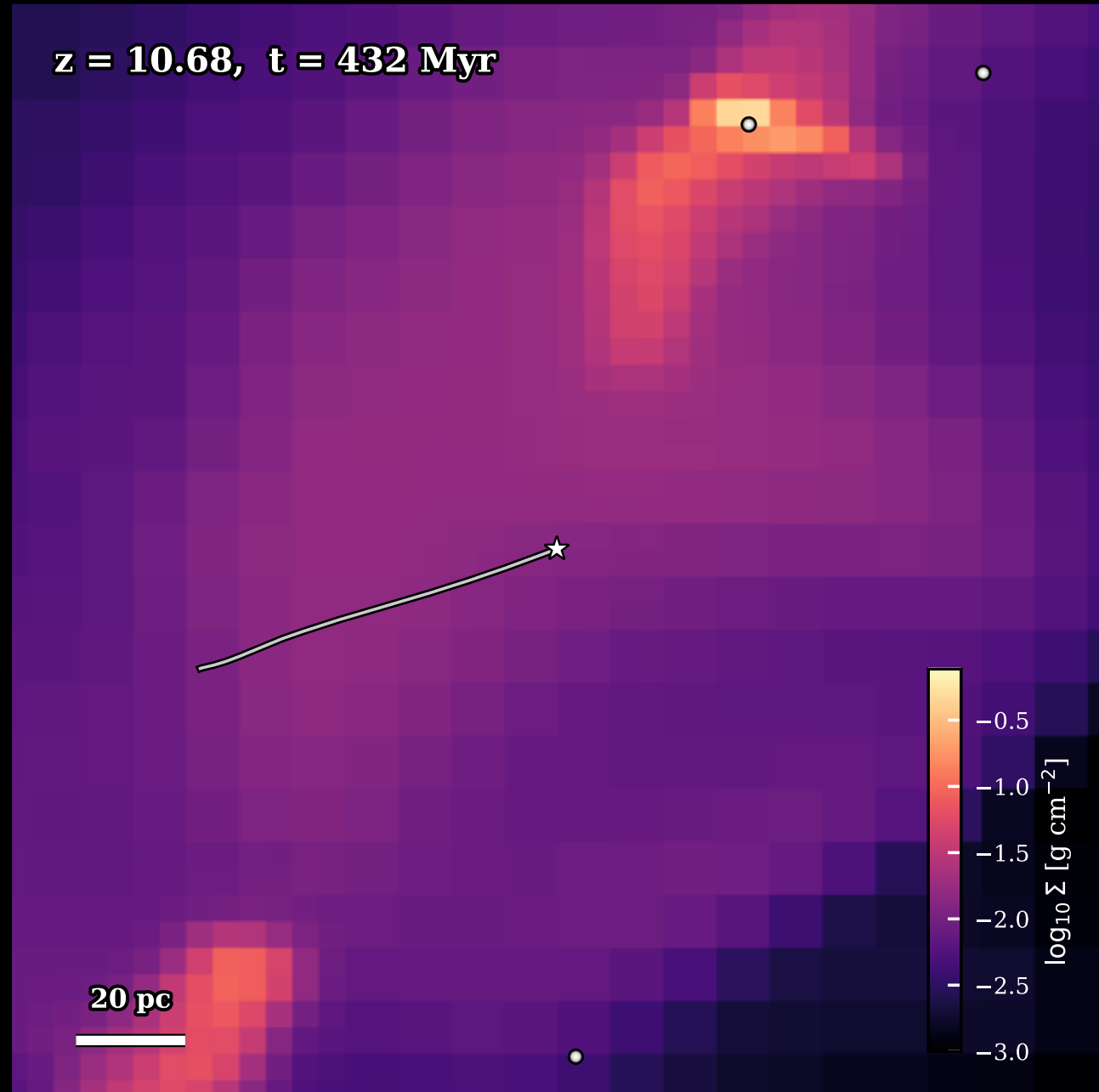
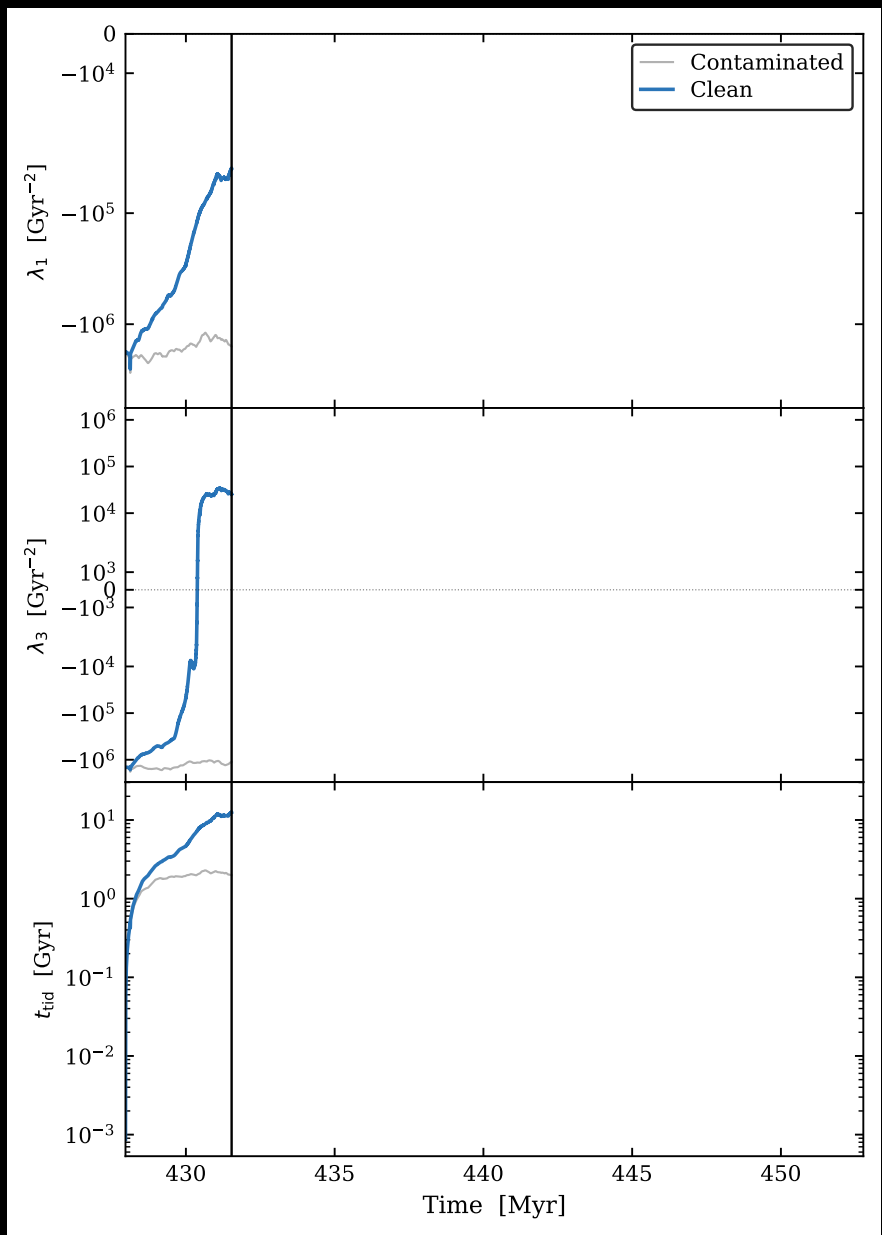
Li+2019

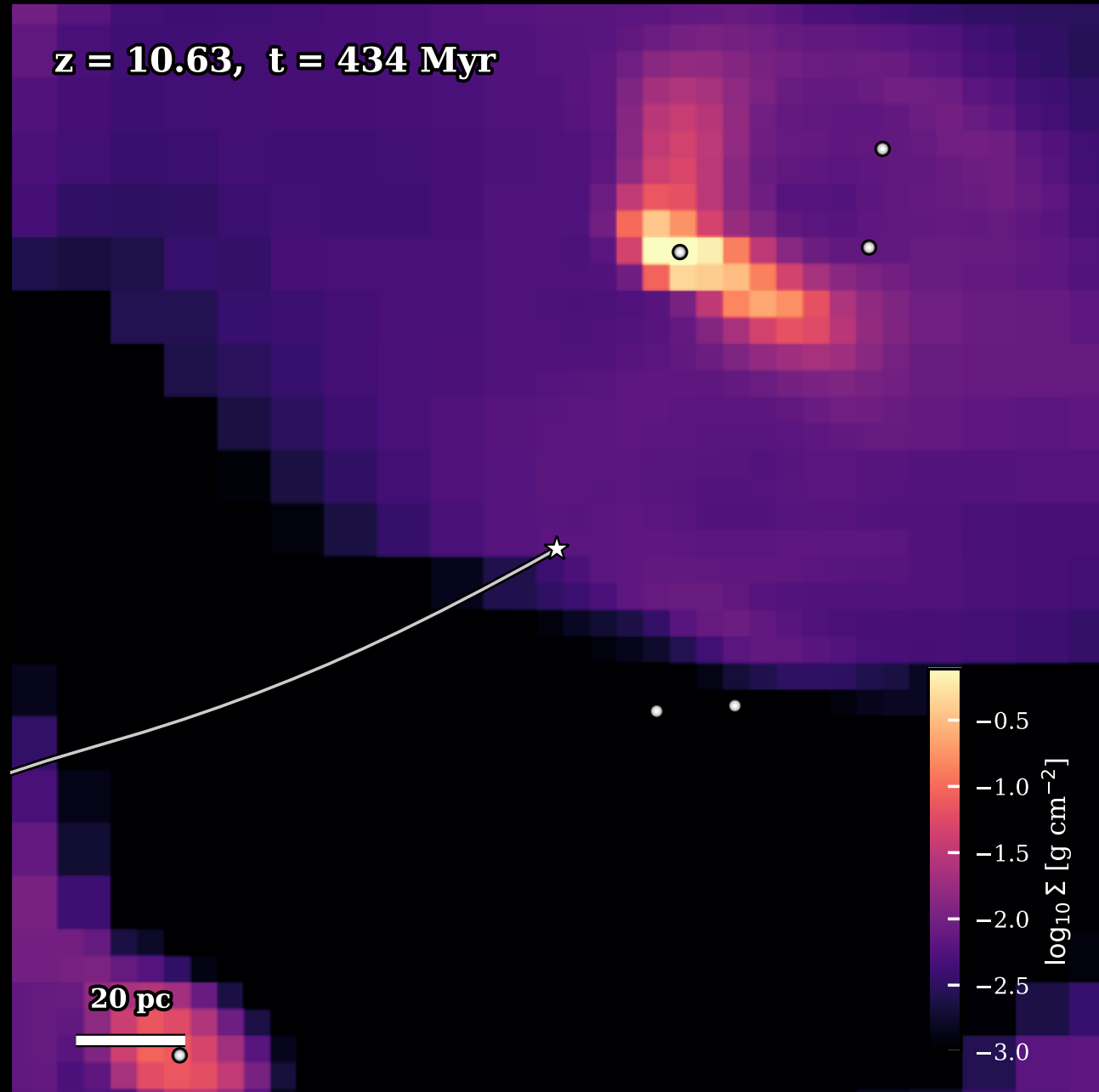
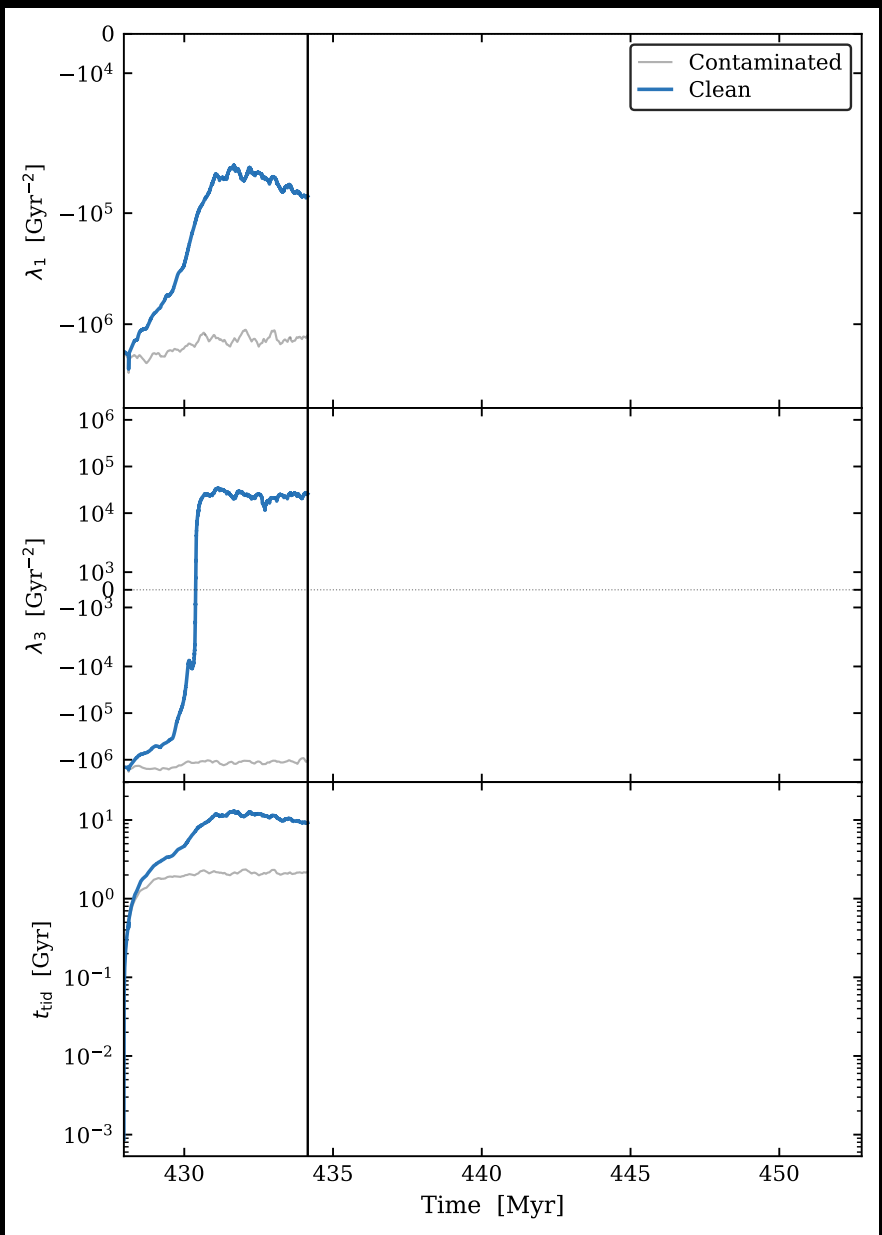
$$\frac{dM}{dt} = -\frac{M}{t_{\text{tid}}}$$

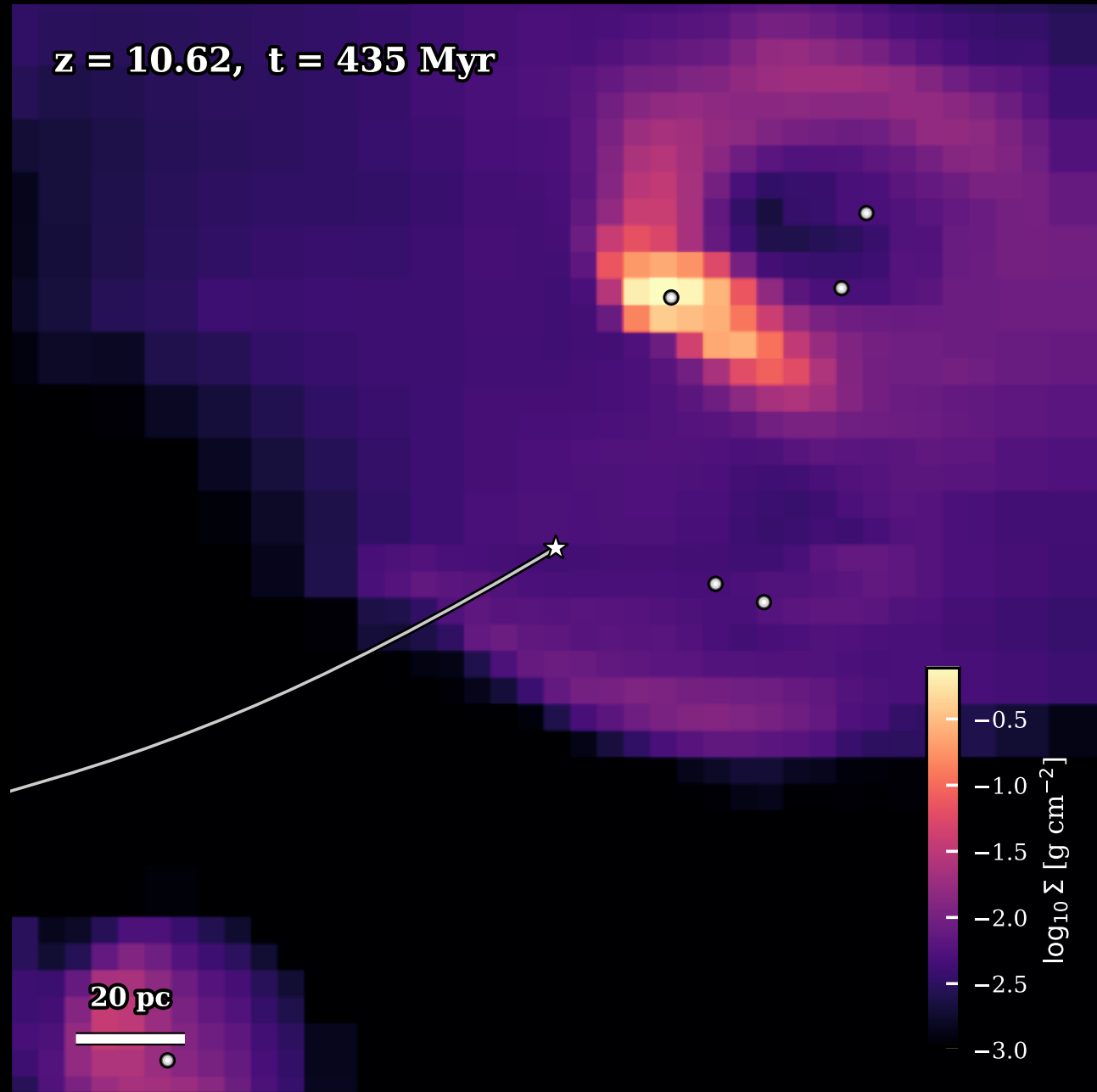
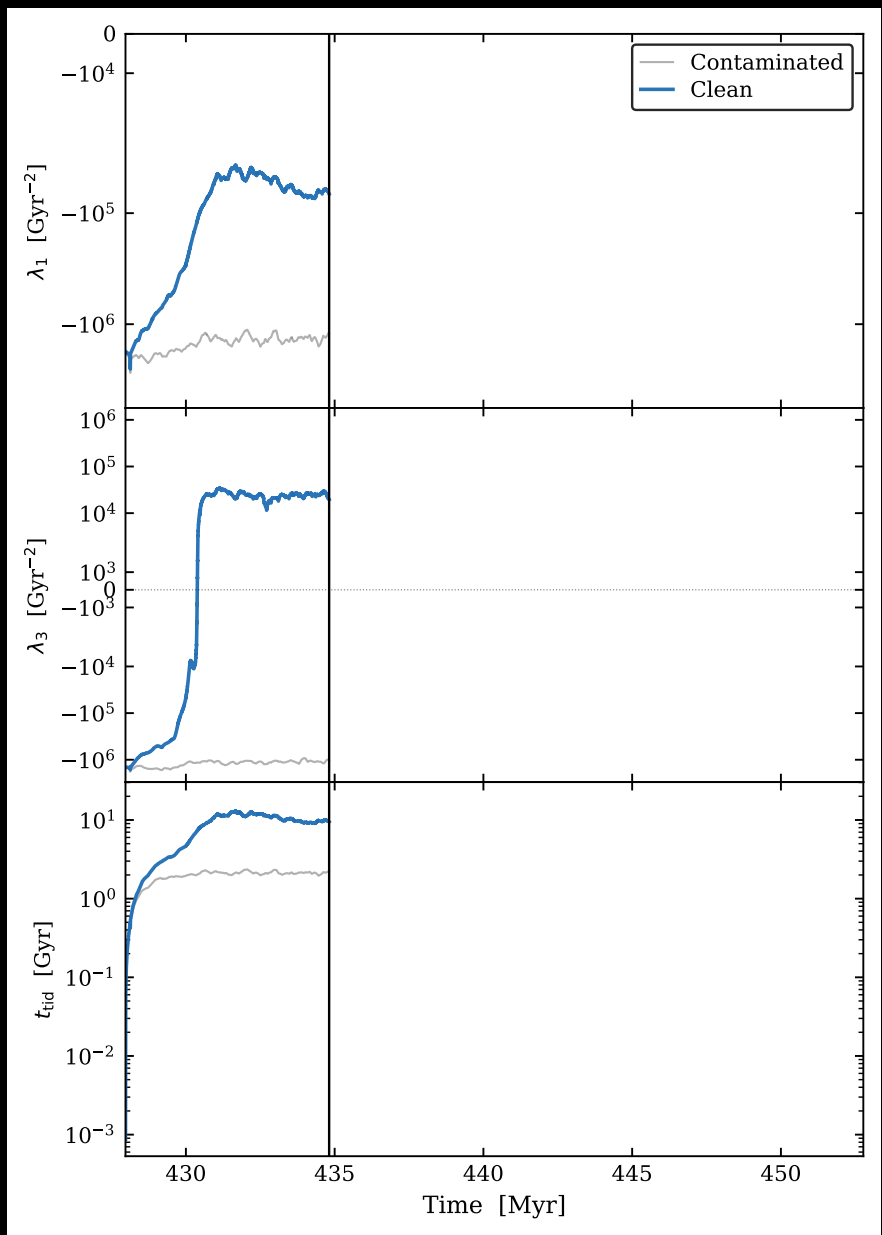


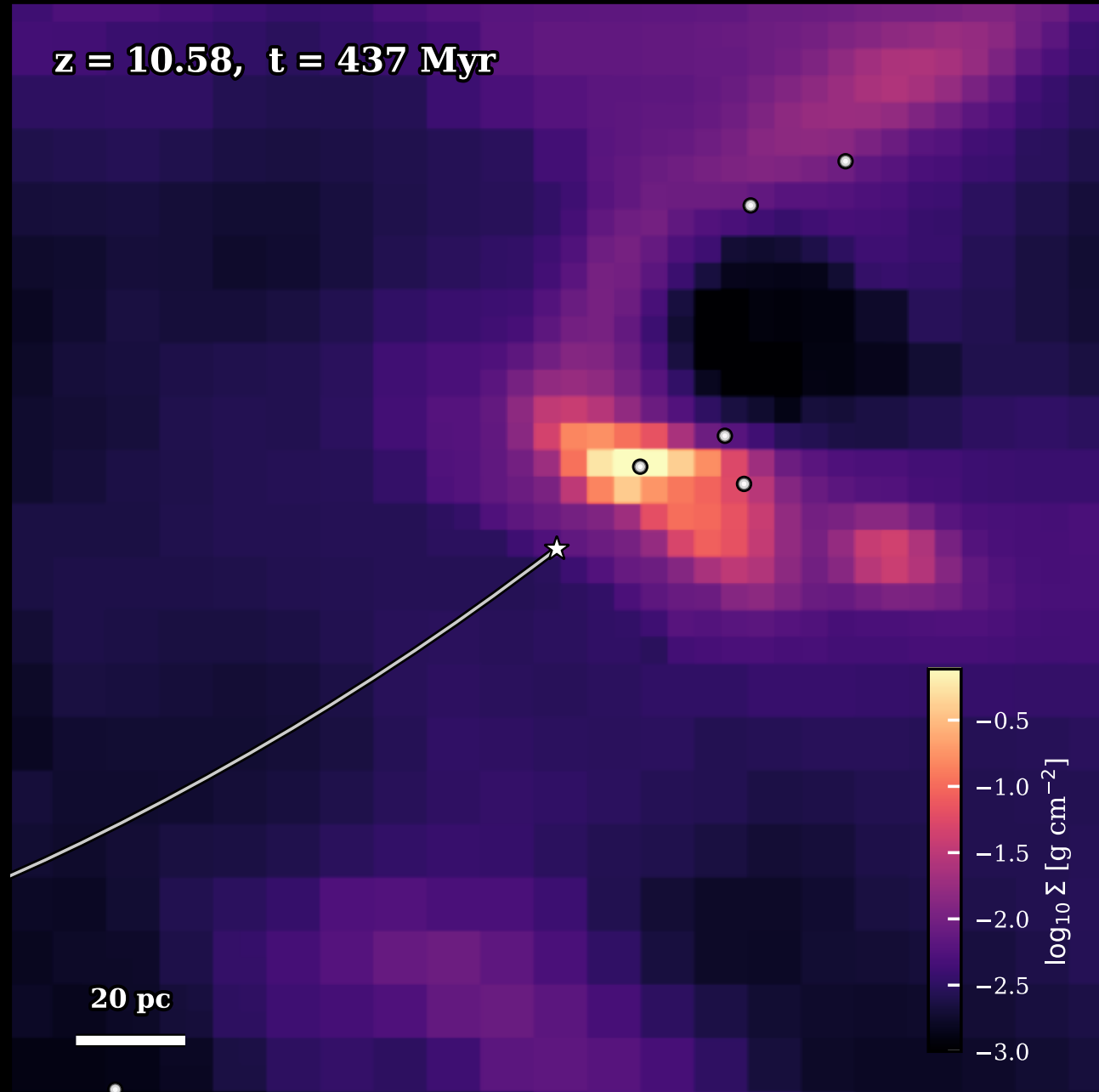
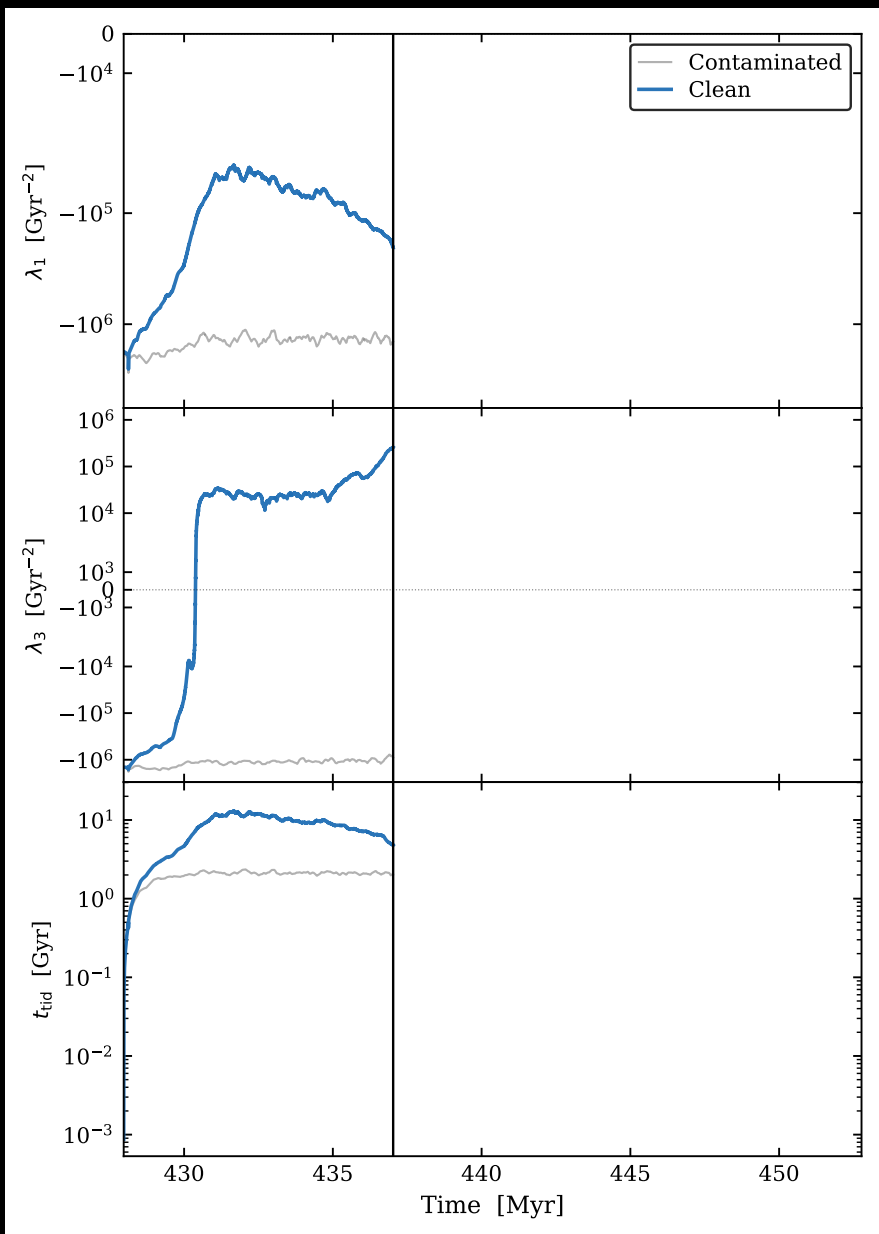


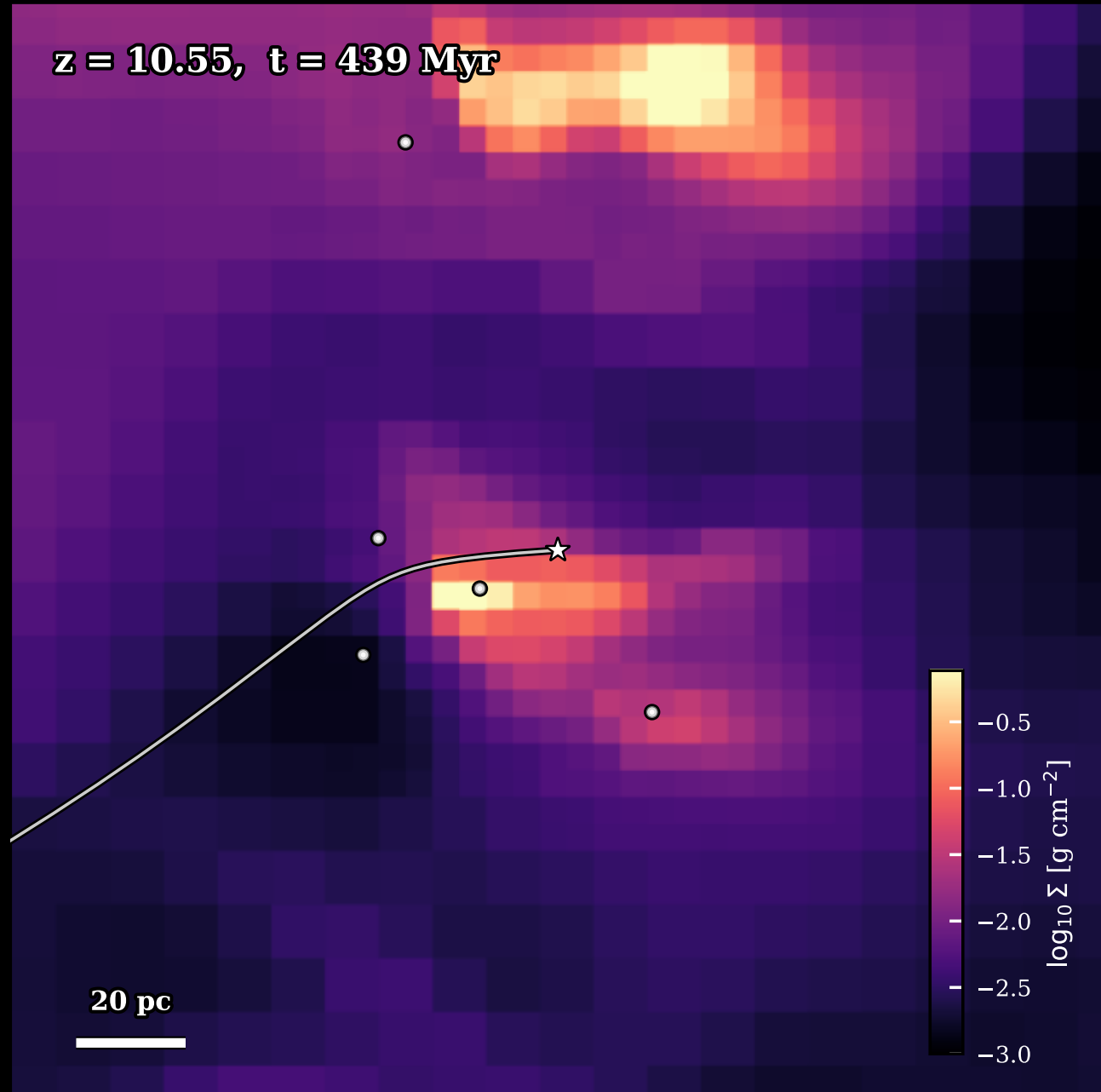
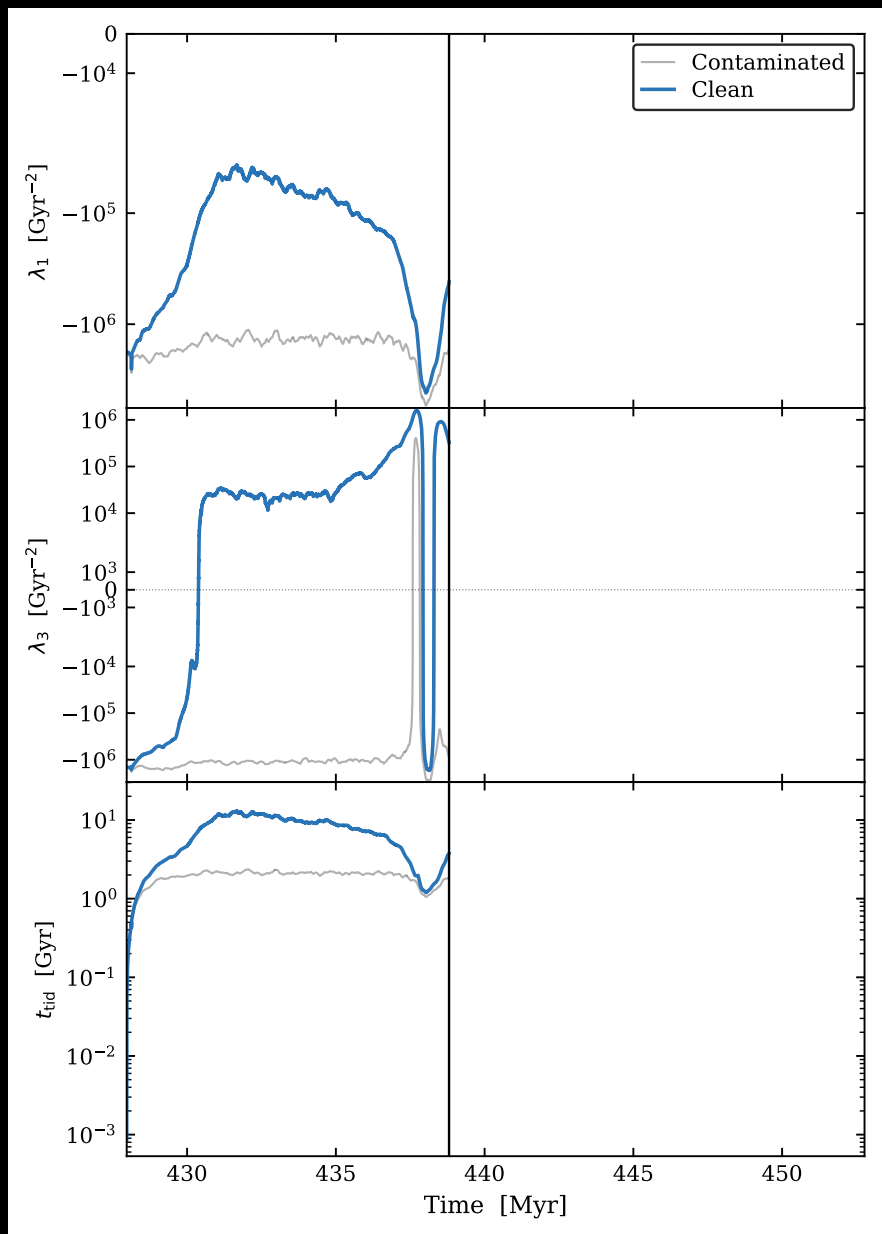


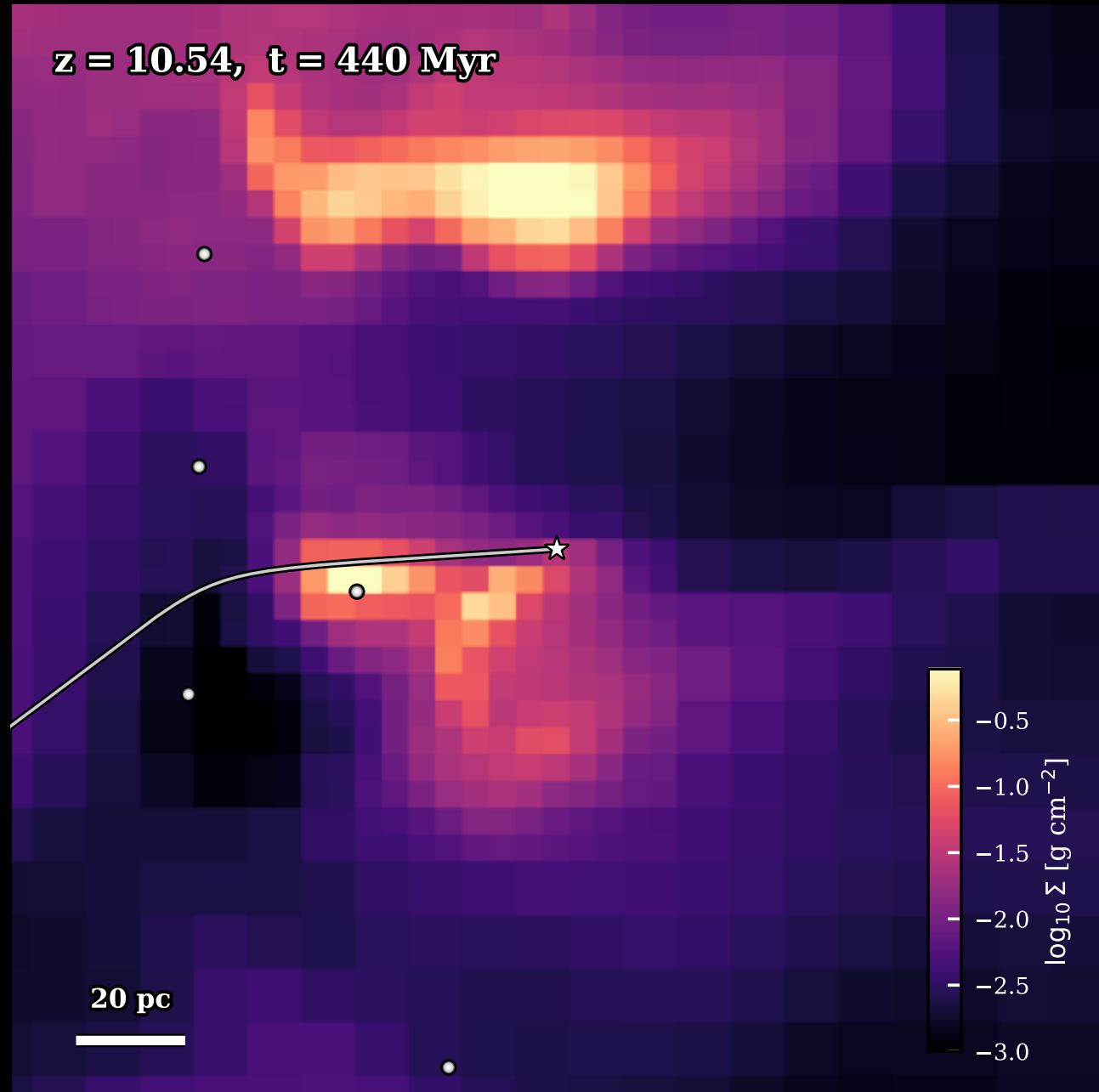
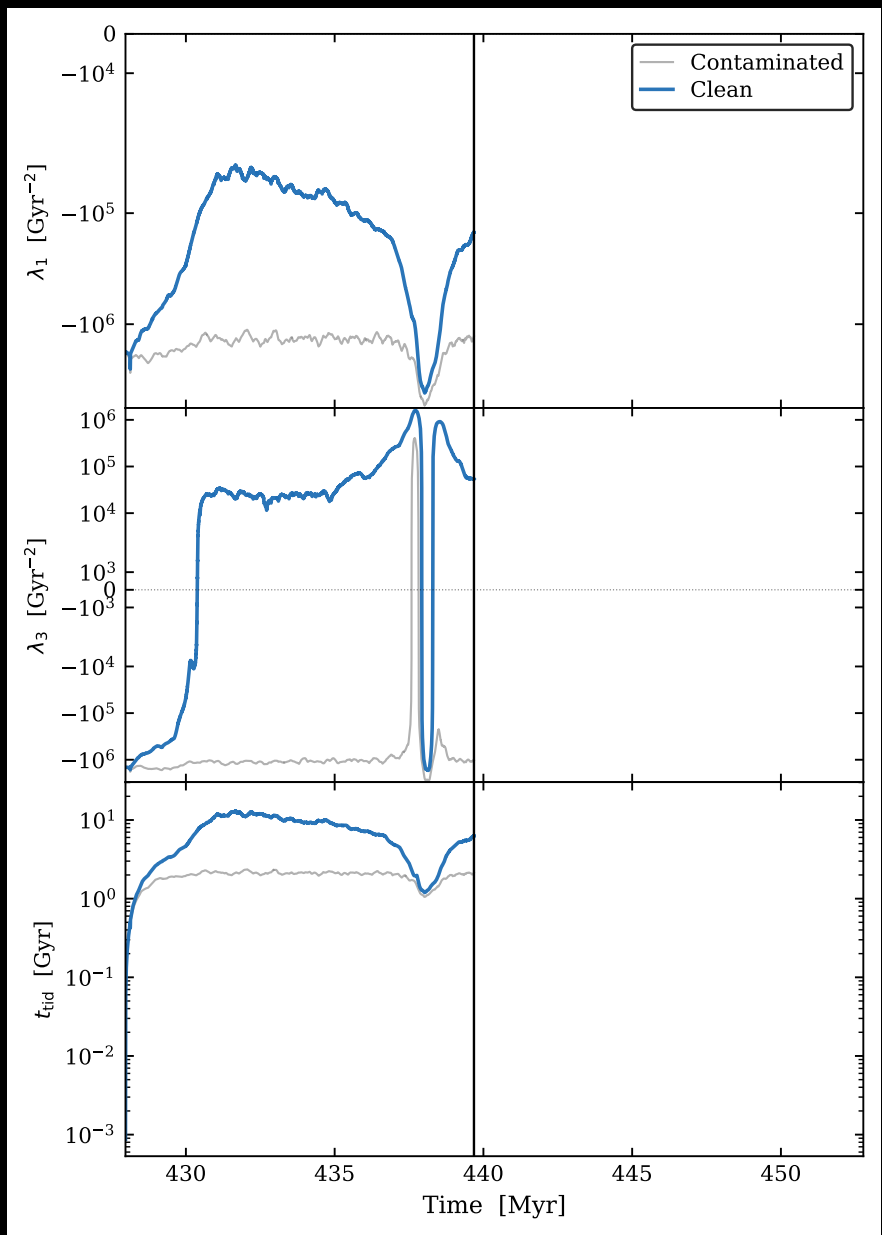


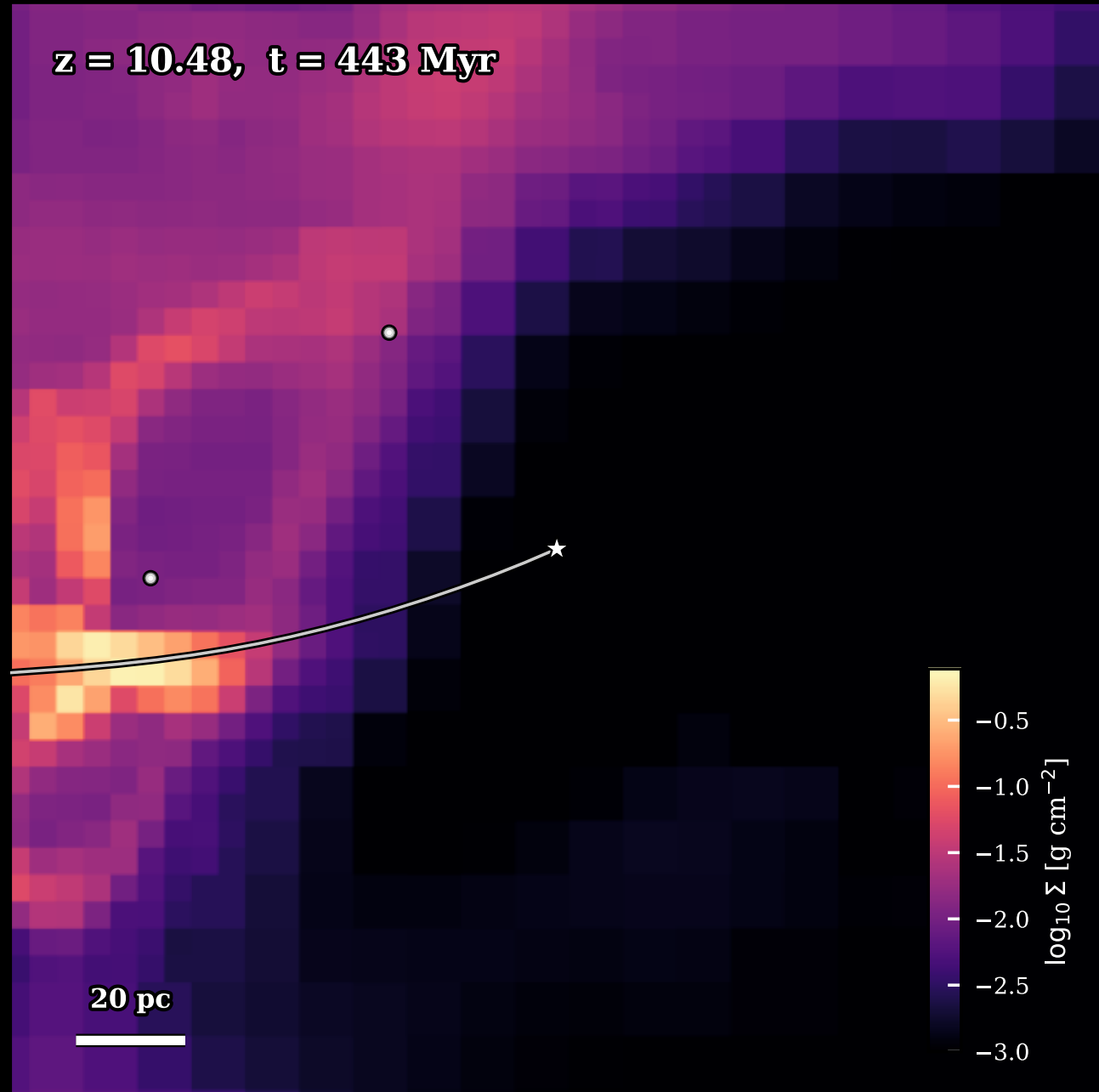
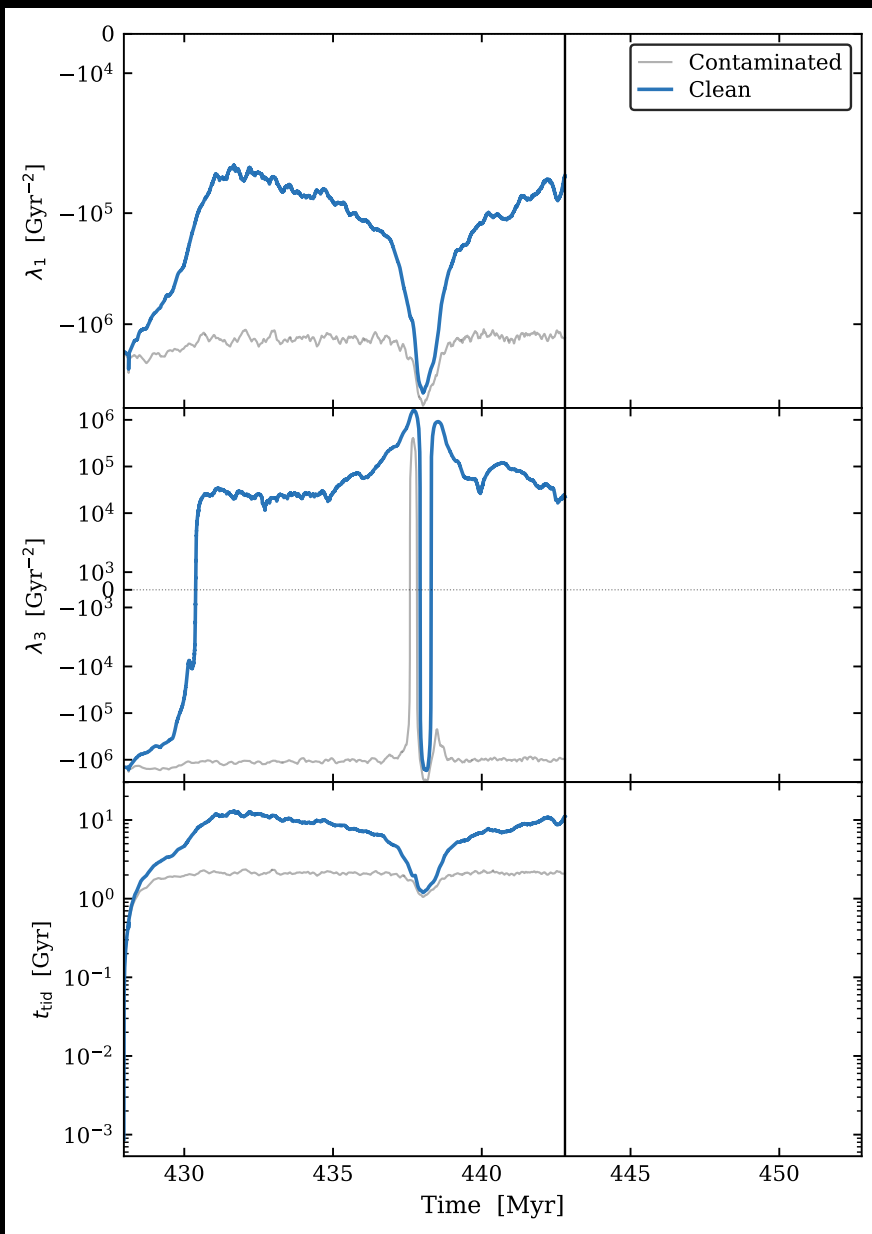


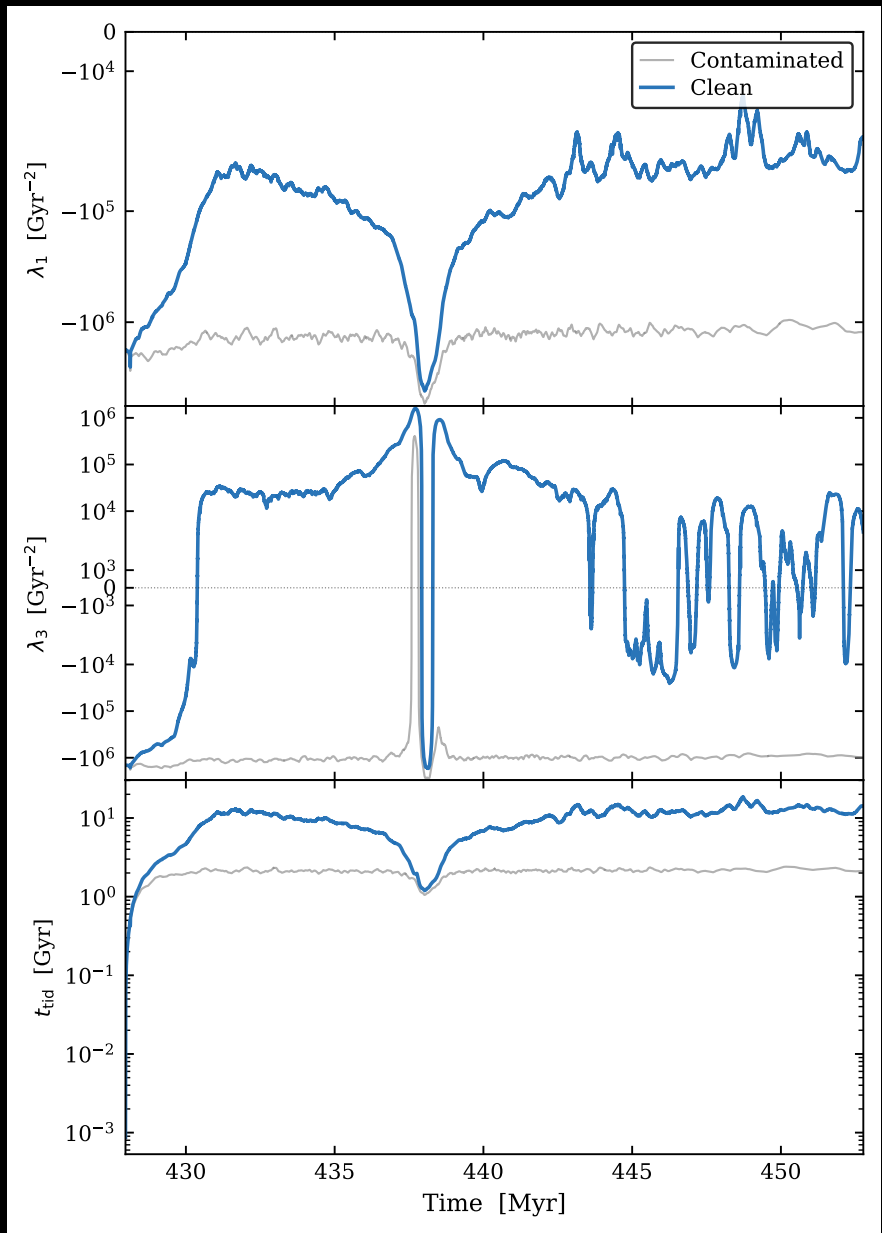




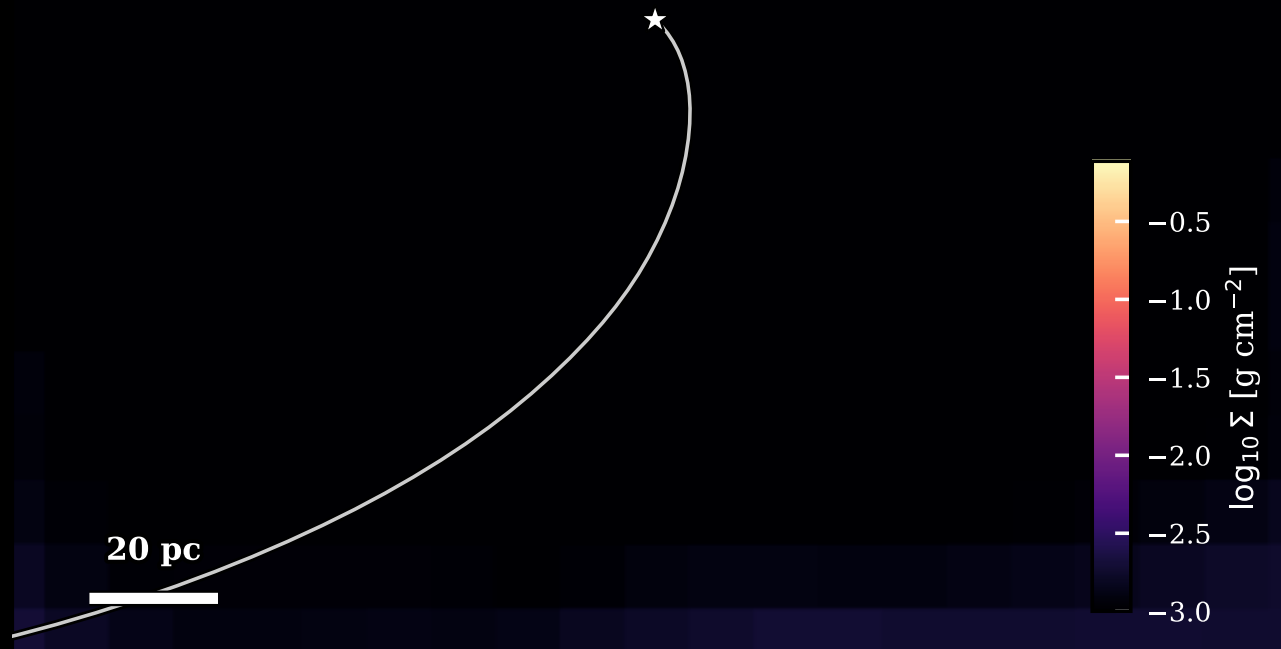




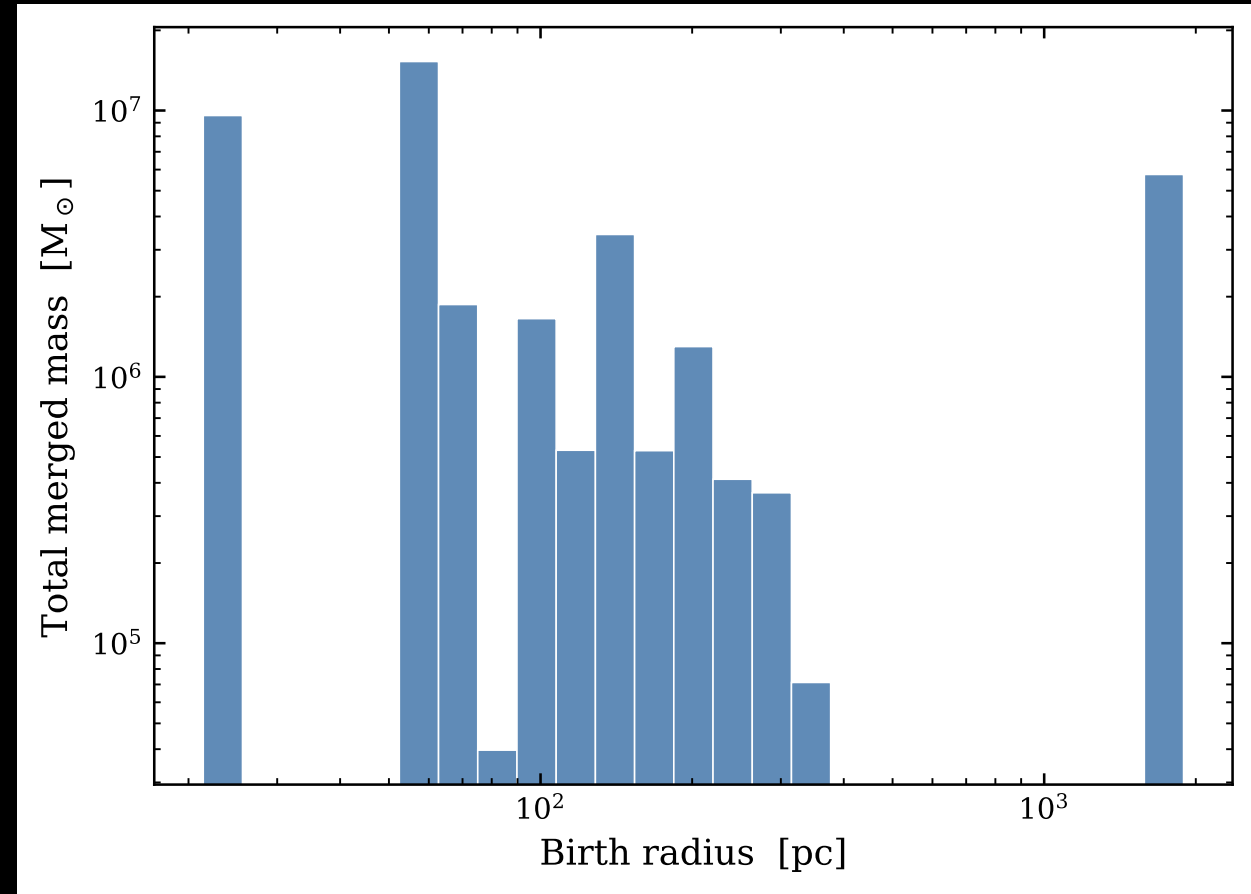
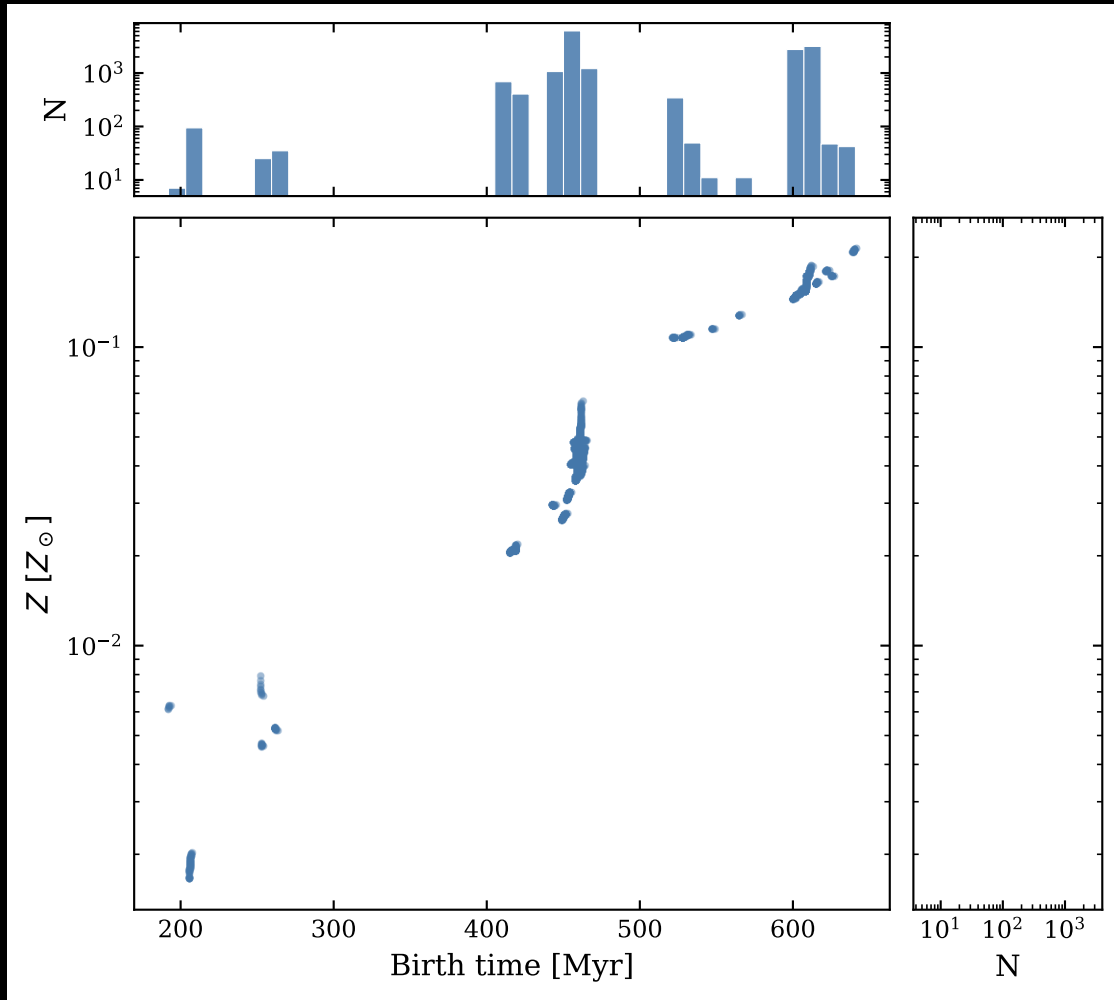




$z = 10.32, t = 453 \text{ Myr}$



Hierarchical Assembly



Conclusions

- Collisional dynamics is hard!
- But, we can capture hierarchical cluster assembly and approximate subsequent tidal evolution with sink particles
- Future avenues:
 - Stellar streams?
 - Galactic archaeology?
 - IMBH seeding?
 - Chemical enrichment?