Star formation and spiral structure of Milky Way Galaxy models

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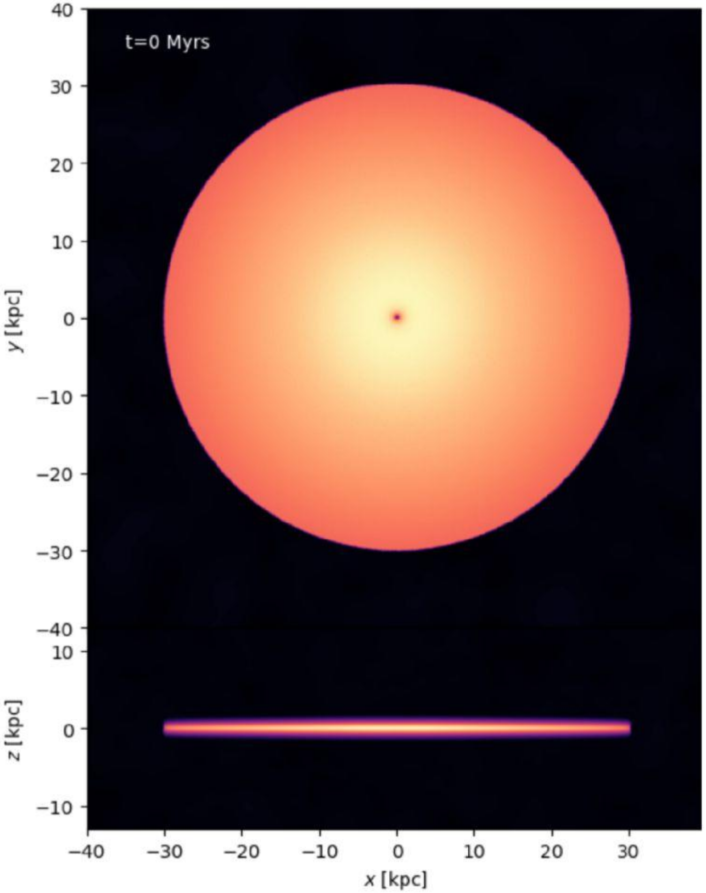
What do we do?



- moving mesh hydrodynamical simulation (Arepo, Springel 2010, Weinberger+ 2020)
- Two potentials:
  - Flat: Analytic logarithmic potentital
  - Milky Way: Numeric potential tailored to Milky Way (see Hunter+ in prep.)
- Mass of gas disk: $1.2 \times 10^{10}\,\mathrm{M}_\odot$
- Radius of gas disk: 30 kpc
- Stars-to-gas ratio: $\sim 16\%$
- Chemical network (Glover & Clark 2012)
- Supernova feedback
- Magnetic field: $3\,\mu\mathrm{G}$

What do we do?

Milky Way potential

(Hunter+, in prep.)

- tuned to fit Milky Way
    - Sagittarius A*
    - Nuclear stellar cluster
    - Nuclear stellar disk
    - Galactic bar
    - Galactic disk (axisymmetric & spiral component)
    - DM halo
- time dependent

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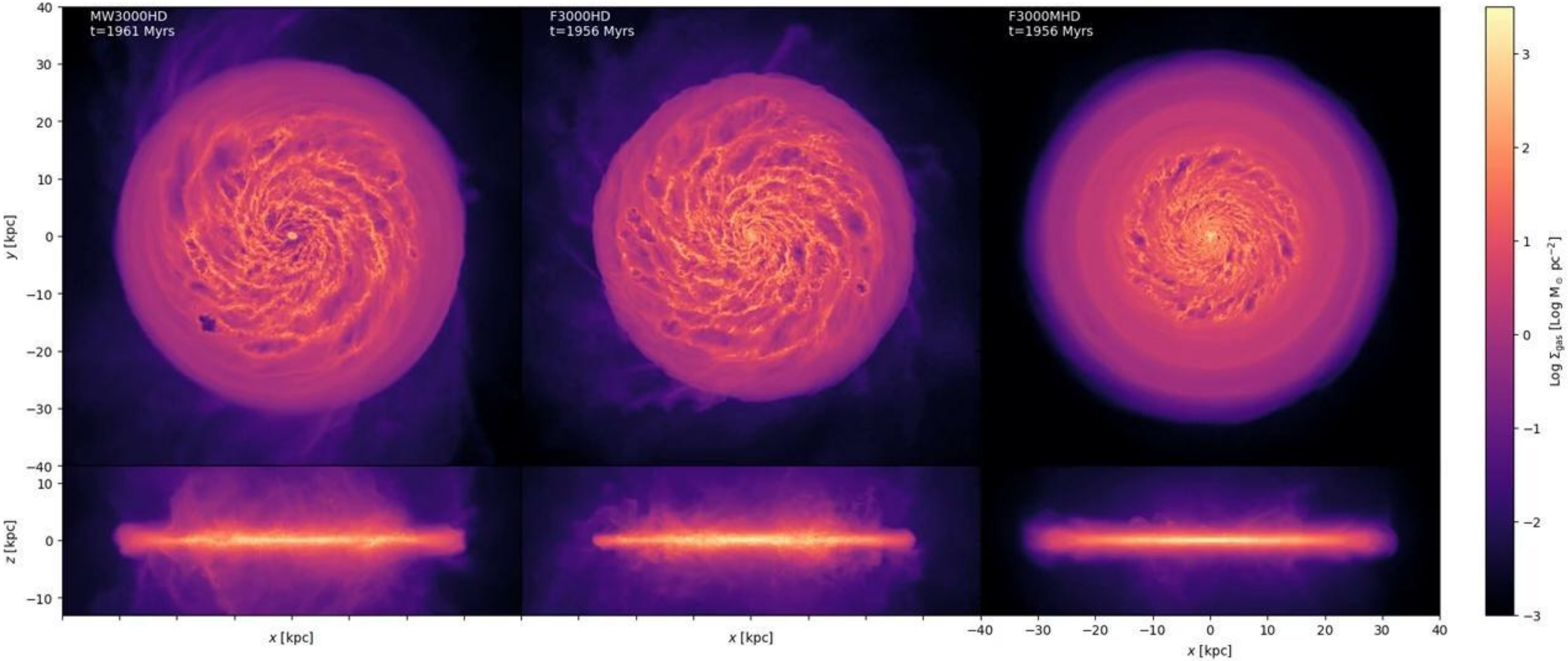
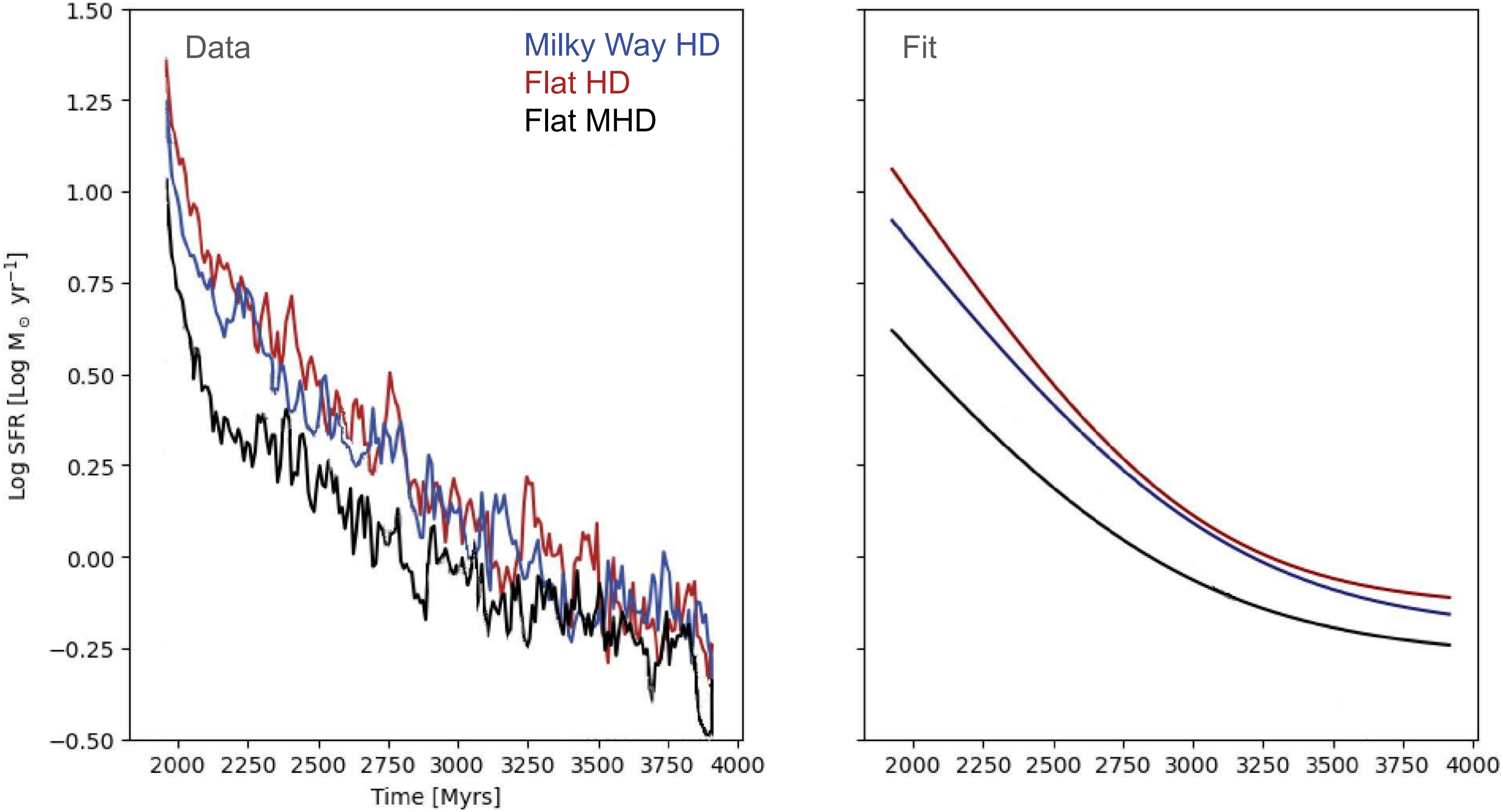
Star formation & feedback

- formation controlled by Jeans mass
- probabilistic (local free-fall time)
- star particles populated according to IMF
- SN feedback with momentum & energy injection

Milky Way HD Flat HD Flat MHD



What is the star formation rate over time?



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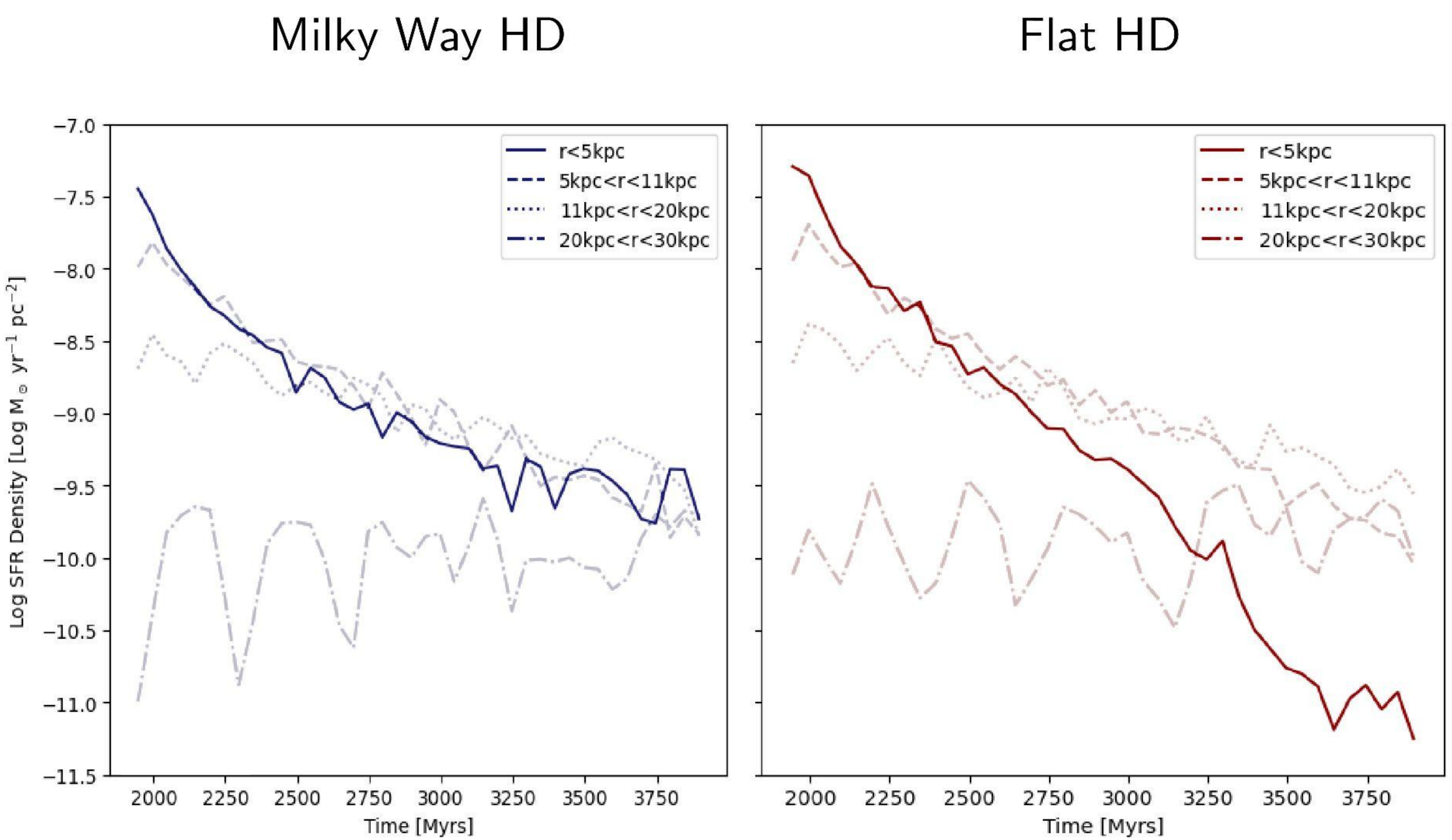

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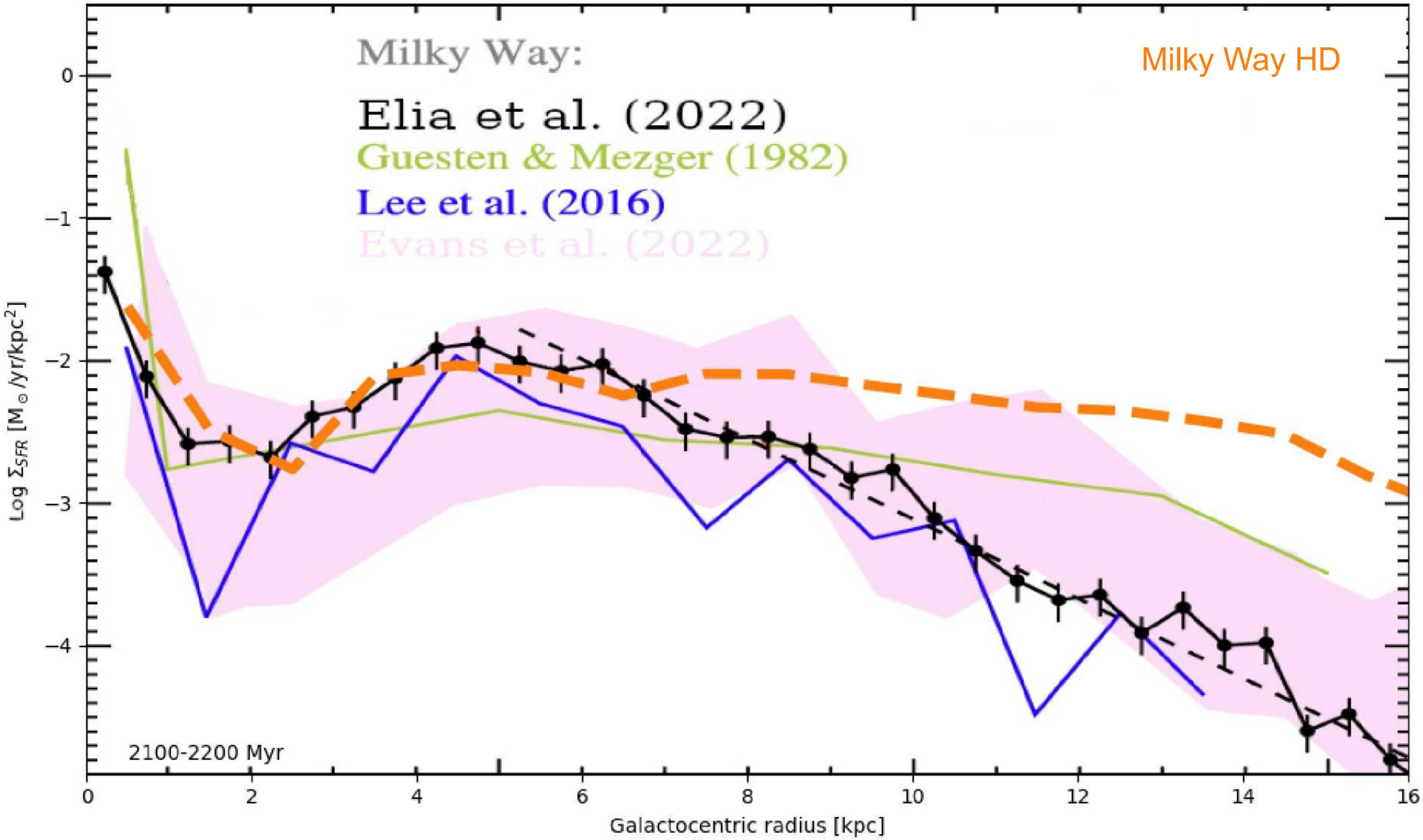

adapted from Elia+, 2022

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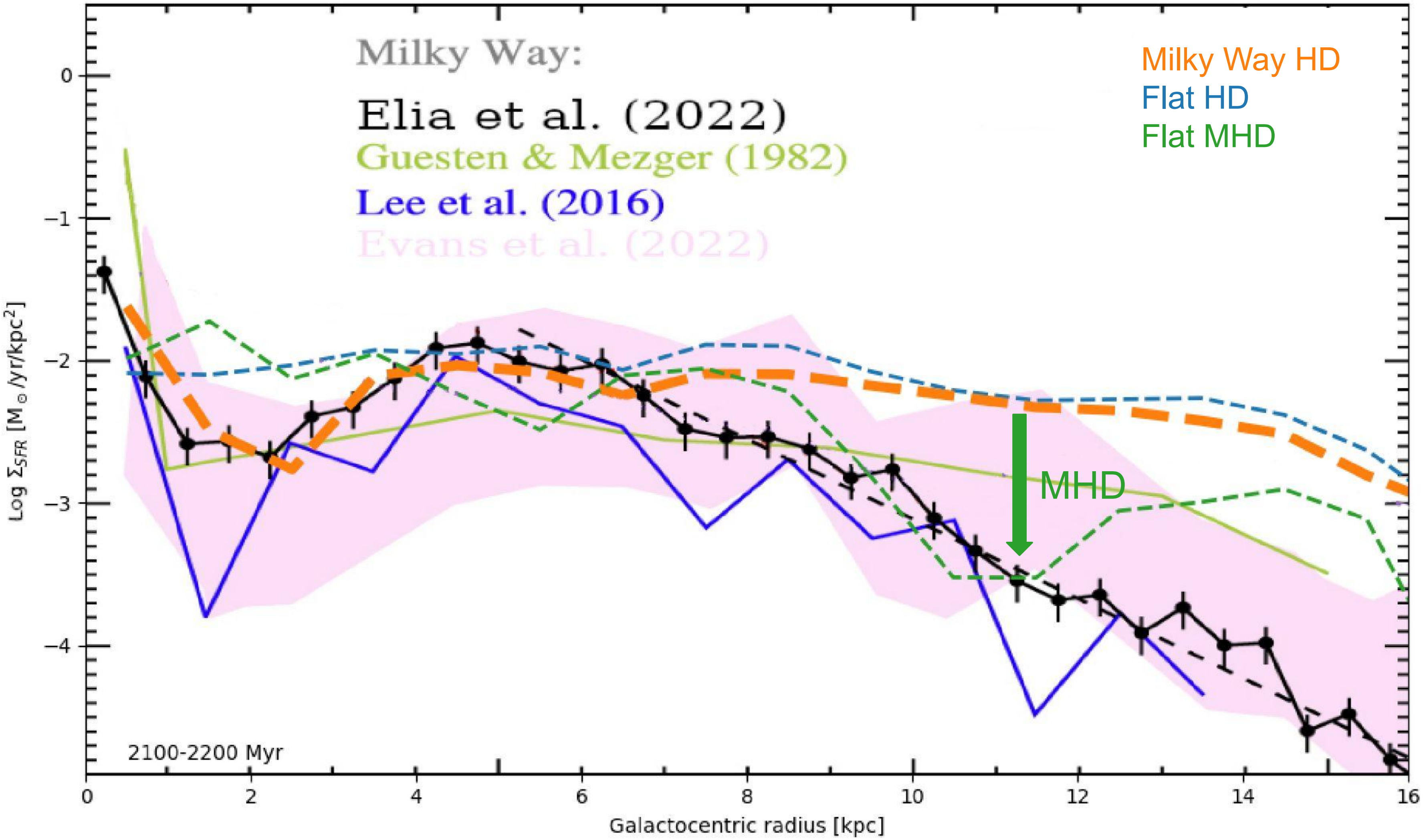

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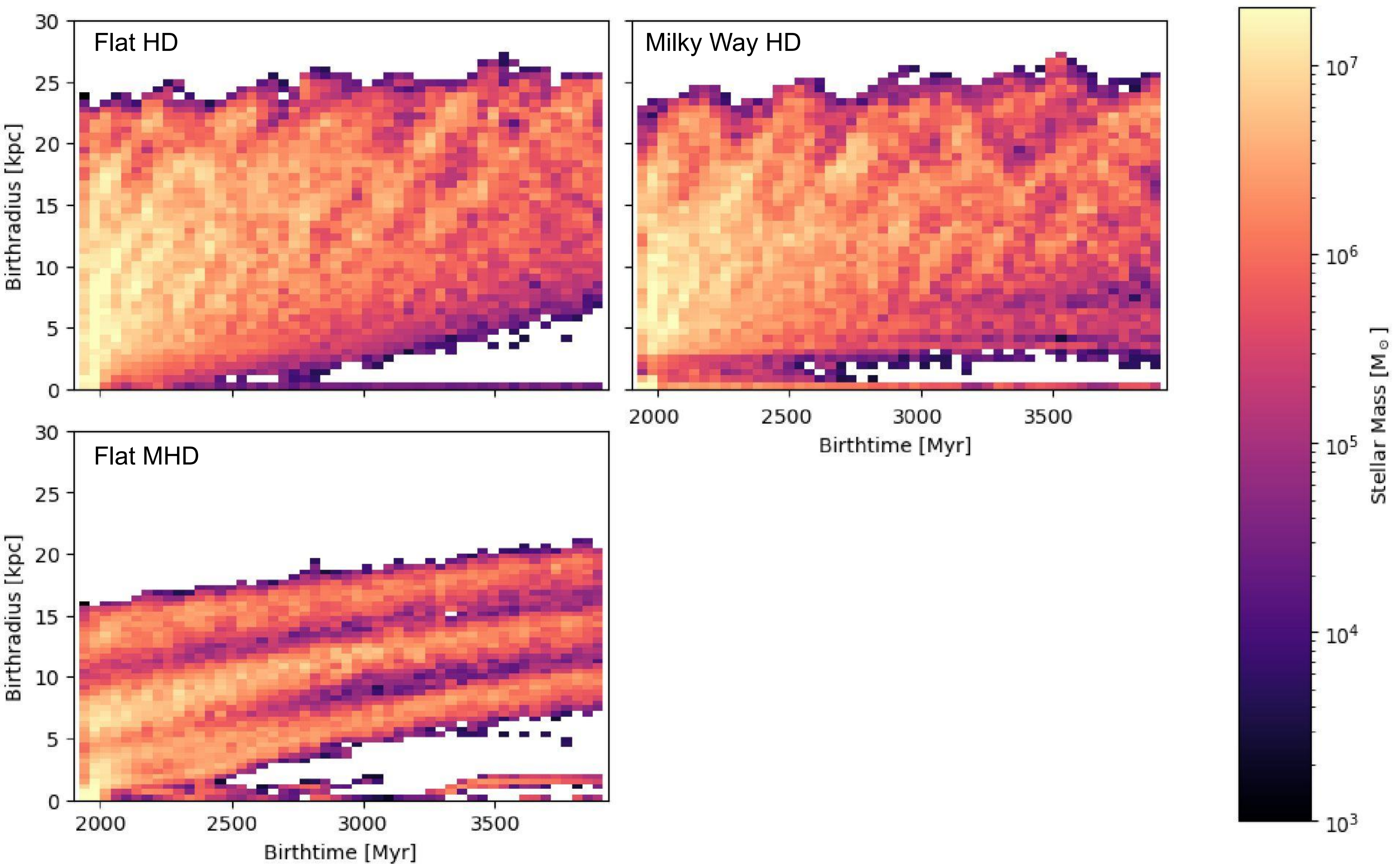
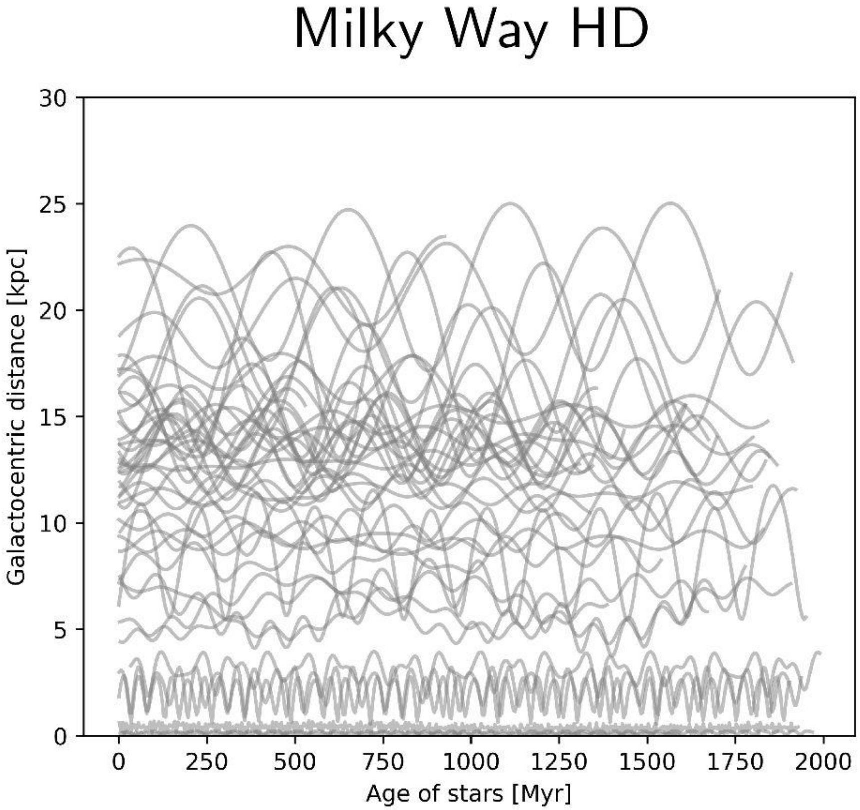
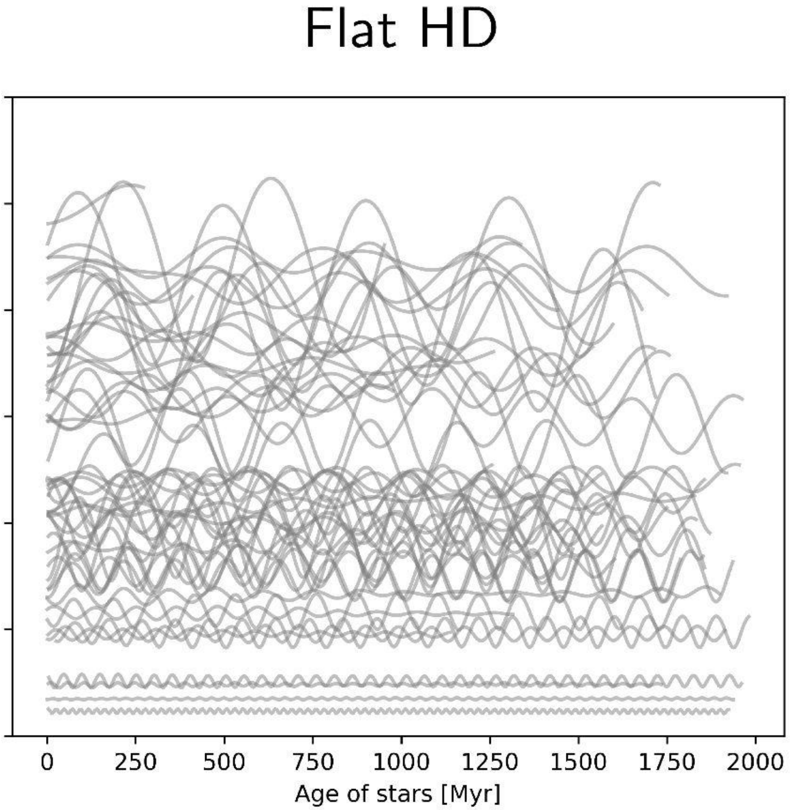


Do the stars stay where they are born?





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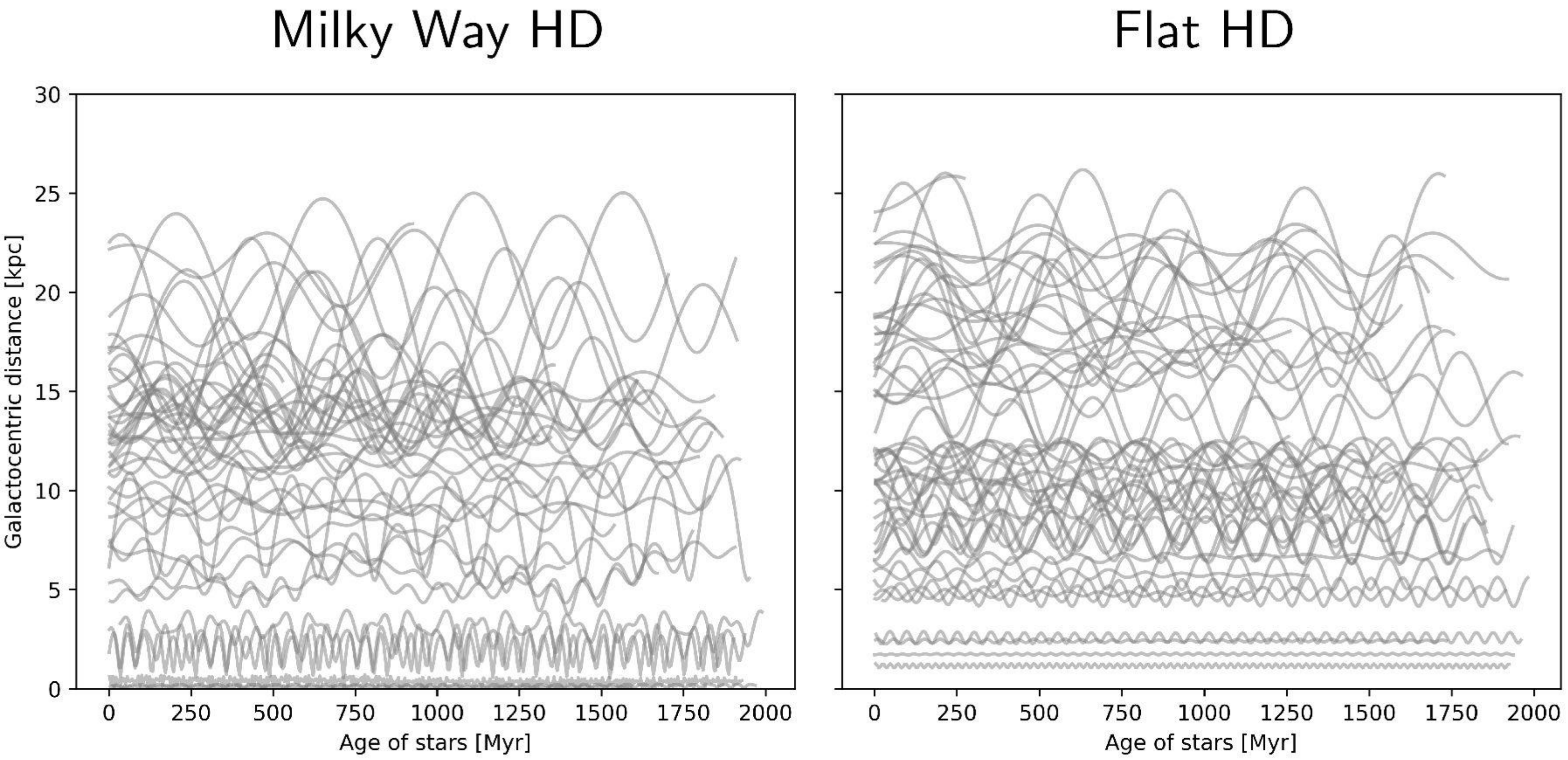

Individual stars can oscillate radially by many kpc.

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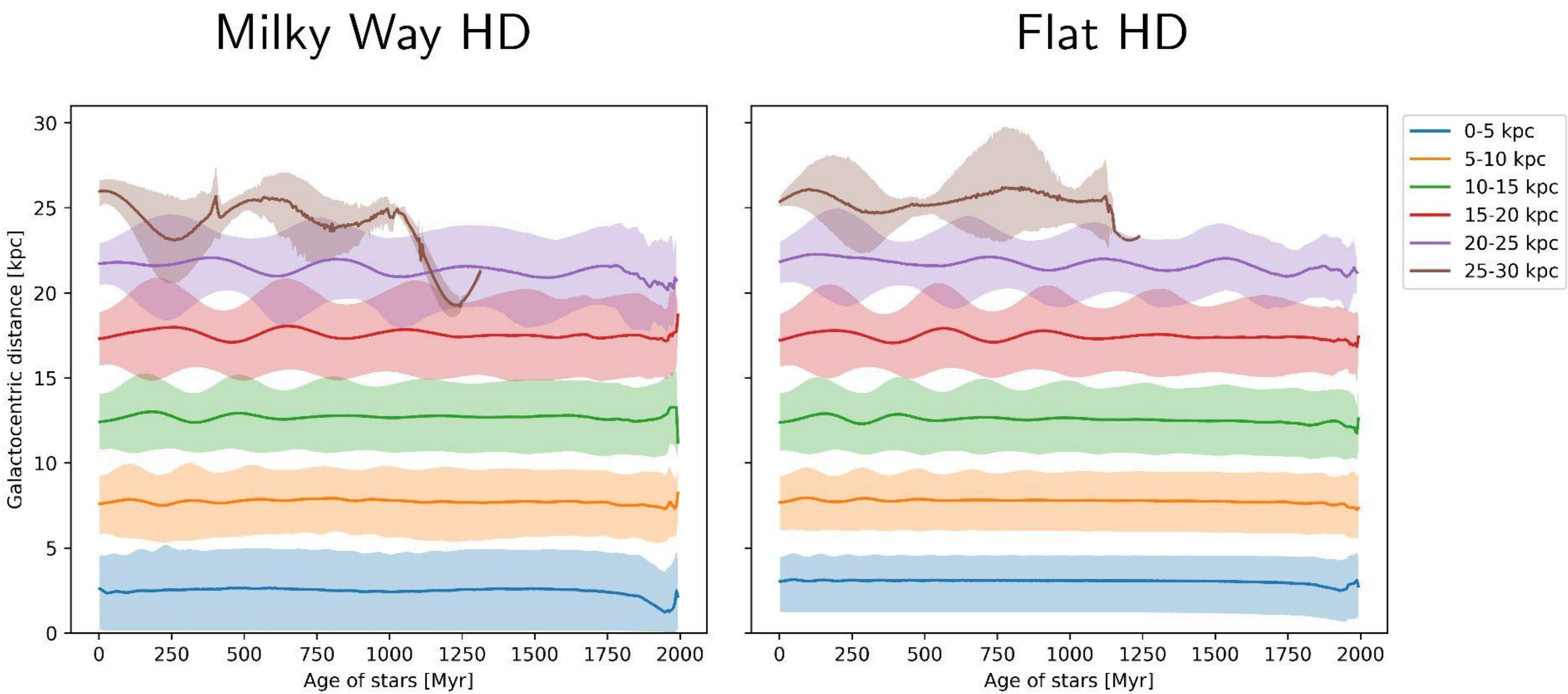

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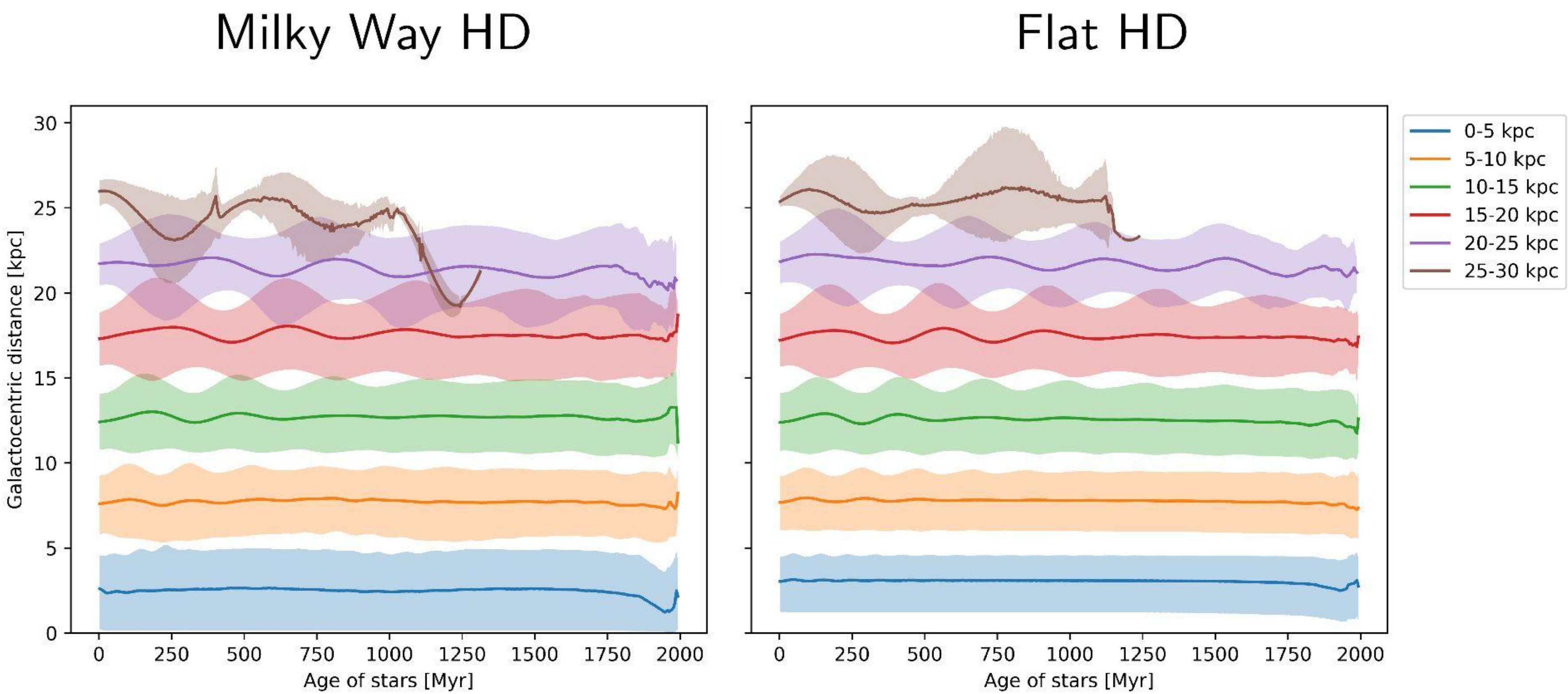

On average, no radial migration.

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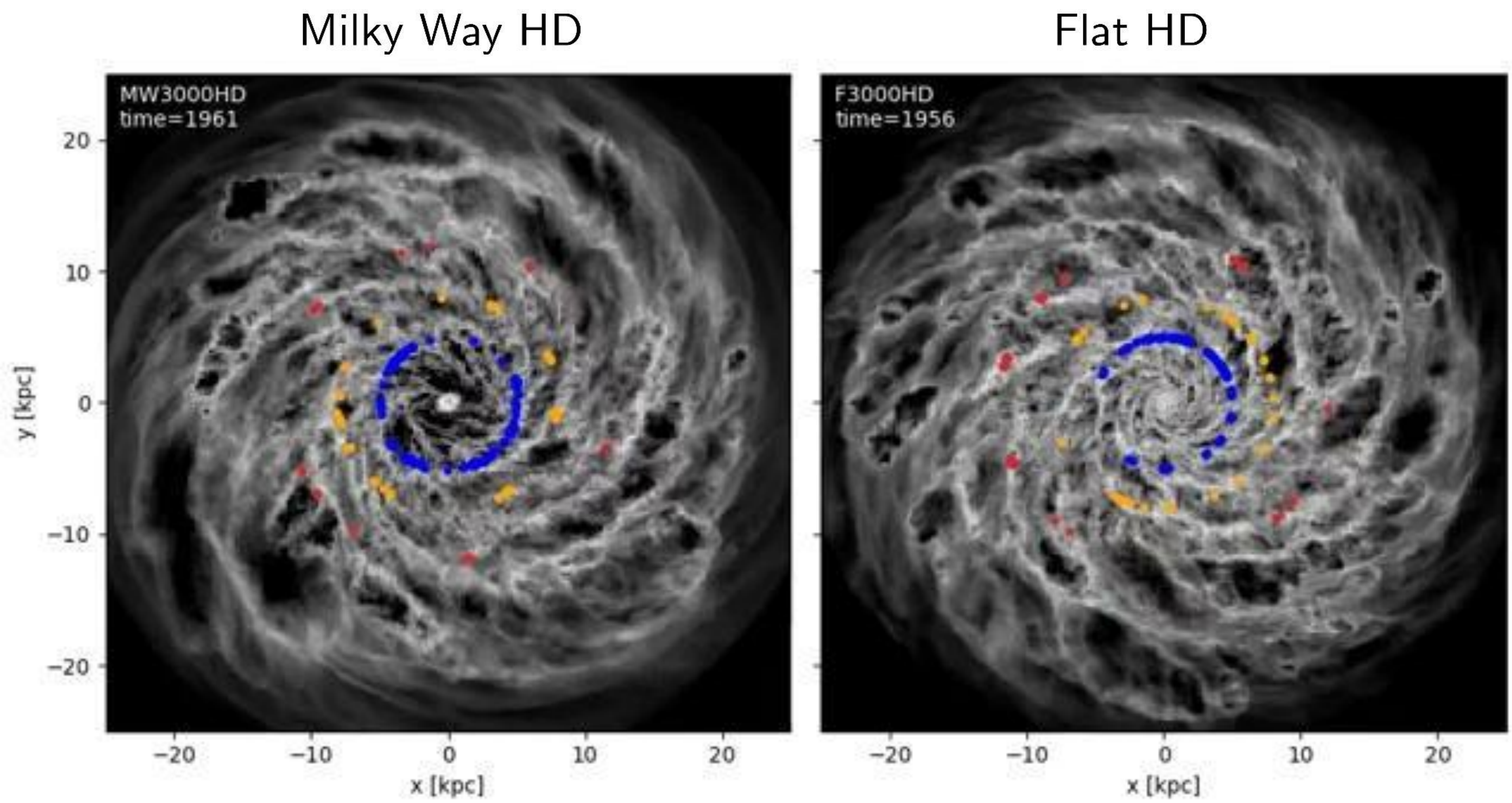
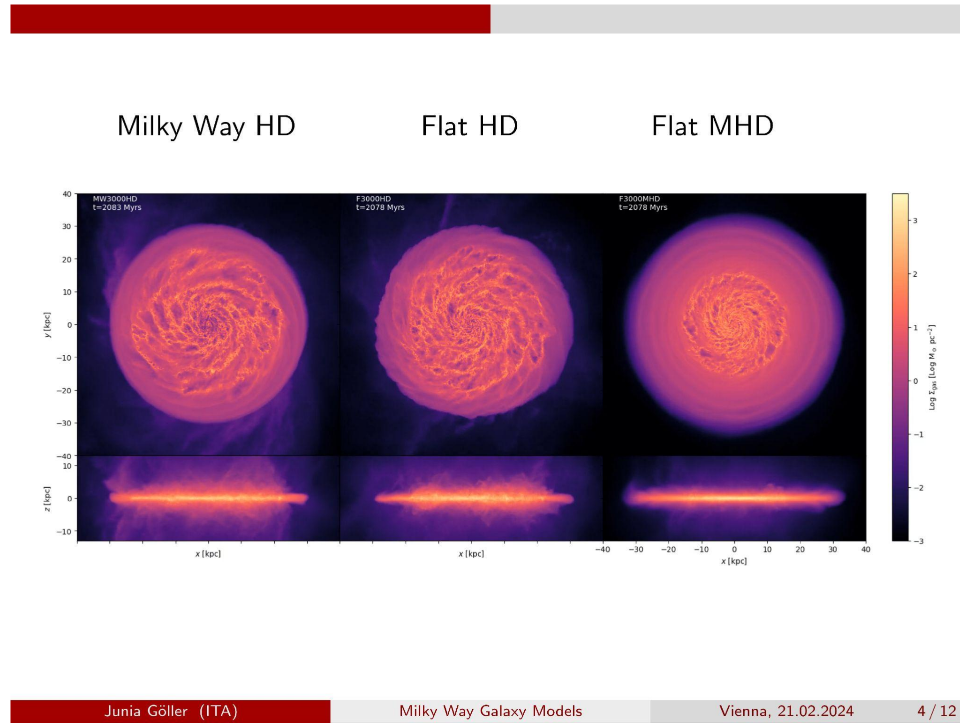


Summary

- Simulations of isolated Milky Way
    - Milky Way and Flat
    - HD and MHD



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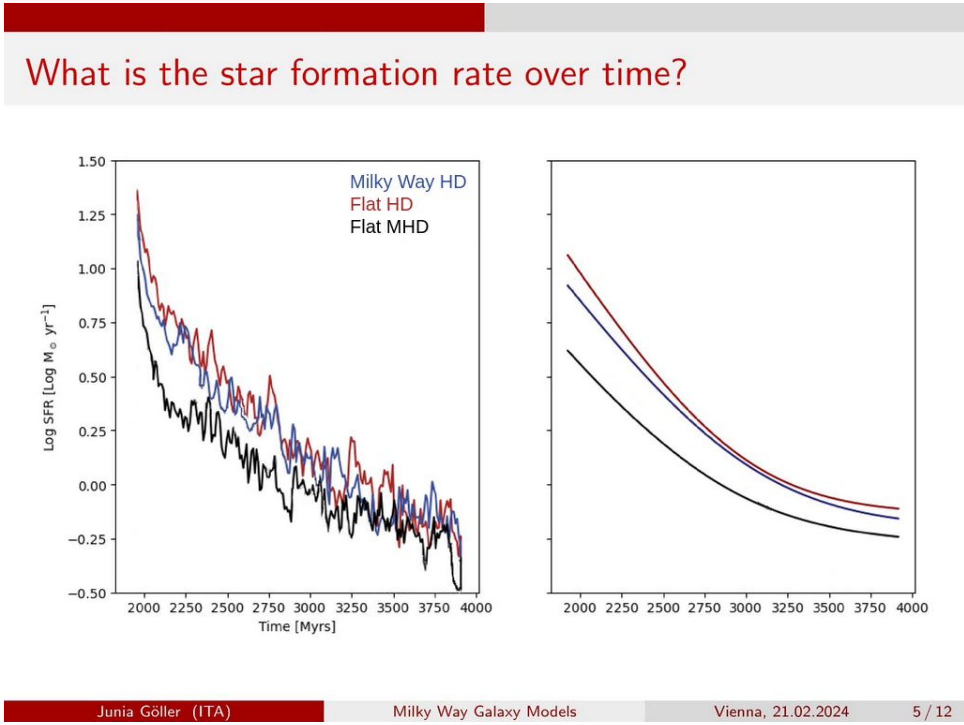

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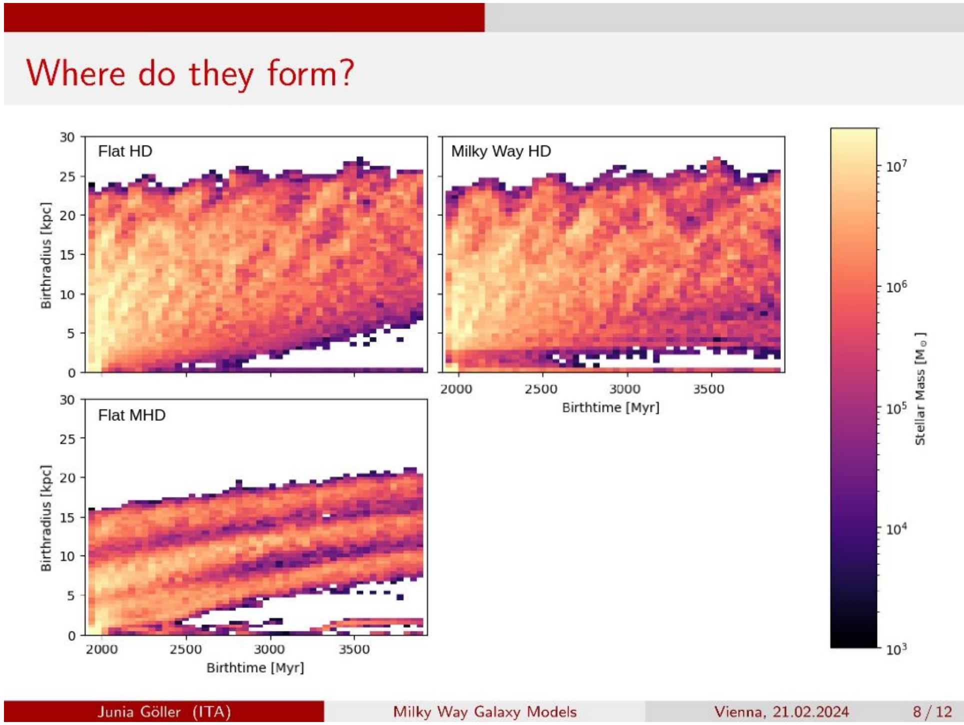

Summary

- Simulations of isolated Milky Way
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- Global star formation rates similar between Milky Way and Flat
- Dynamics of star forming regions over time differ
- Radial oscillations in individual stars, but no net migration

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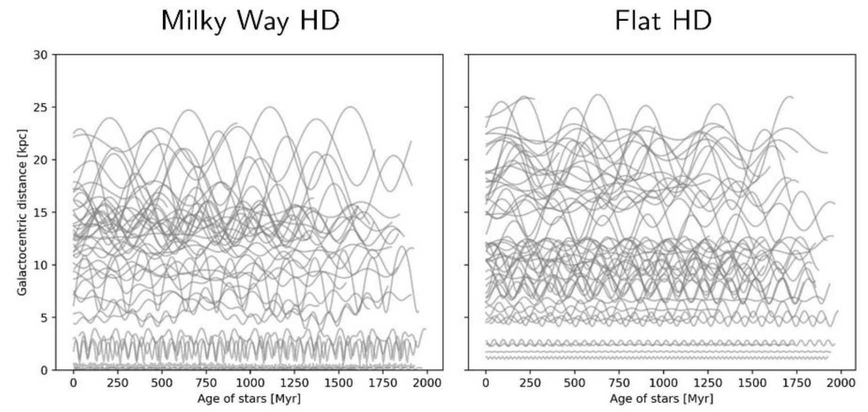

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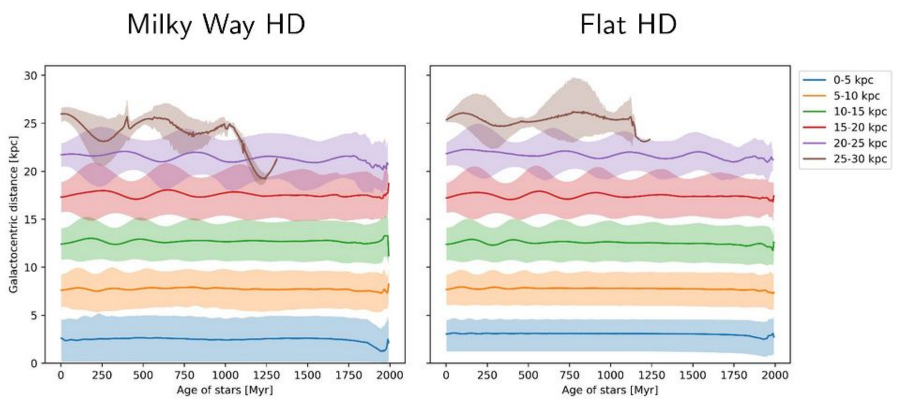


On average, no net migration.

Equations: Initial density distribution

$$\rho_{\mathrm{gal}}(R,z) = \frac{\Sigma_0}{4z_{\mathrm{d}}} \exp\left(-\frac{R_{\mathrm{m}}}{R} - \frac{R}{R_{\mathrm{d}}}\right) \mathrm{sech}^2\left(\frac{z}{z_{\mathrm{d}}}\right) \tag{1}$$

with $z_{\mathrm{d}} = 85\,\mathrm{pc}$, $R_{\mathrm{d}} = 7\,\mathrm{kpc}$, $R_{\mathrm{m}} = 1.5\,\mathrm{kpc}$ and $\Sigma_0 = 50\,\mathrm{M}_\odot/\mathrm{pc}^2$

Equations: Logarithmic potential

$$\Phi_L = \frac{1}{2} v_0^2 \ln \left(R_c^2 + R^2 + \frac{z^2}{q_\Phi^2} \right) + \mathrm{const.}, \tag{2}$$

where $R_c = 100\,\mathrm{pc}$ and $v_0 = 220\,\mathrm{km/s}$ are constants and $q_\Phi = 0.8$ is the axis ratio of the equipotential surfaces

Equations: Probability of star formation

$$\lambda = SFR \frac{\Delta \mathrm{t}}{M_{\mathrm{cell}}}, \tag{3}$$

$$p = \frac{M_{\mathrm{cell}}}{M_{\mathrm{starP}}}(1 - \exp(-\lambda)), \tag{4}$$

where Δt is the size of the timestep that the cell is on

Equations: Supernova feedback

SN explode in one of two modes: energy or momentum injection. The decisive factor here is the radius of the supernova remnant at the end of the Sedov-Taylor phase:

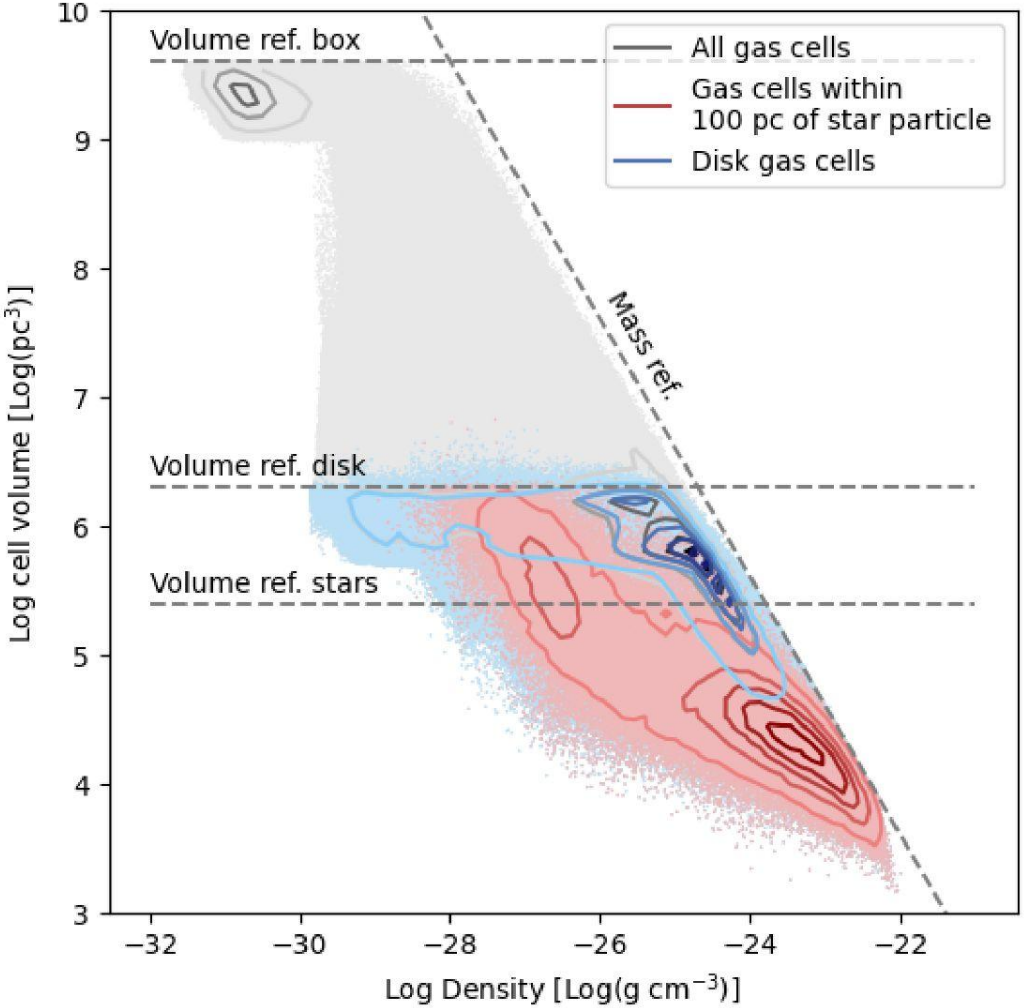
$$R_{\mathrm{ST}} = 19.1 \left(\frac{\bar{n}}{1\,\mathrm{cm}^{-3}} \right)^{-7/17} \mathrm{pc}, \tag{5}$$

where $\bar{n}$ is the local mean number density. If $R_{\mathrm{ST}} > R_{\mathrm{inject}}$, an energy of 10^{51} erg is injected isotropically in the injection region (cells within R_{inject}) as thermal energy and the contained gas is fully ionized. Otherwise the terminal momentum

$$p_{\mathrm{fin}} = 2.6 \times 10^5 n^{-2/17}\, \mathrm{M}_{\odot}\, \mathrm{km\,s}^{-1} \tag{6}$$

is injected directly into the cells within the injection region. In this case the temperature or ionization state of the gas is not changed. We use an injection radius of $R_{\mathrm{inject}} = 100\,\mathrm{pc}$.

Resolution



Volume ref. box
Volume ref. disk
Volume ref. stars
Mass ref.
All gas cells
Gas cells within
100 pc of star particle
Disk gas cells
Log cell volume [Log(pc^3)]
Log Density [Log(g cm^{-3})]
10
9
8
7
6
5
4
3
−32
−30
−28
−26
−24
−22