DM wakes and n-body–data comparison

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Part I

- Newton's Laws makes distinct predictions about the response of DM by bars, spirals, and satellite wakes
- The existence of DM wakes is not an optional prediction
- No wakes implies an incorrect DM theory

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Part II

- Detailed predictions from a few very complex simulations . . .
- We can use our new found data wealth to compare classes of models

The basic dynamics

- Consider a drum
  - normal modes
  - Hit it with a mallet and get the sound which is the projection of the impulse onto the model spectrum
- Halos (and disks) are the same way
  - Main difference: continuous and normal modes
  - Normal modes nearly always damped
- Example: hit a halo with a satellite and you get a dynamical friction wake + the excitation of weakly damped modes

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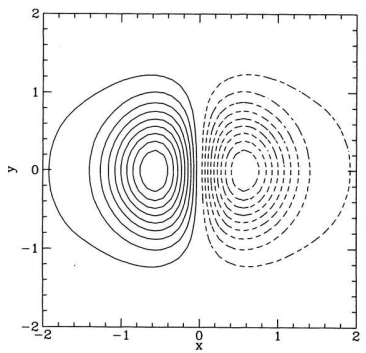

FIG. 4.—Contours of the density perturbation for the $l = m = 1$ mode for the $W_0 = 5$ model on the x-y plane. Only the inner region of the model is shown; the tidal radius is $r_t = 8.72$. Overdensity (underdensity) is shown as a solid (dashed) line.

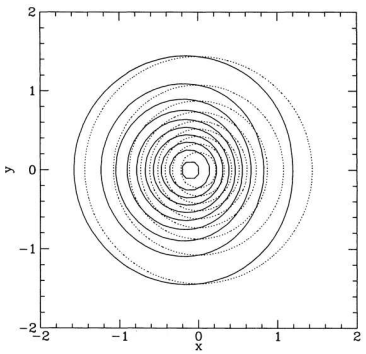

FIG. 5.—Effect of the density perturbation shown in Fig. 4 on the background model. The peak perturbation is 30% of the background. Note the shift of the central density peak. The core radius is at 0.81 in these units. The dotted contours show the unperturbed background at the same levels.

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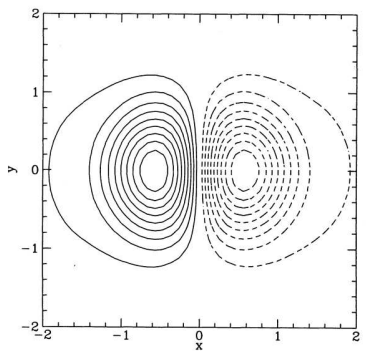

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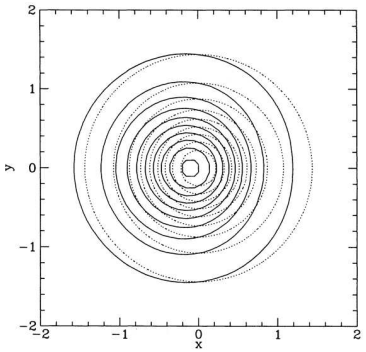

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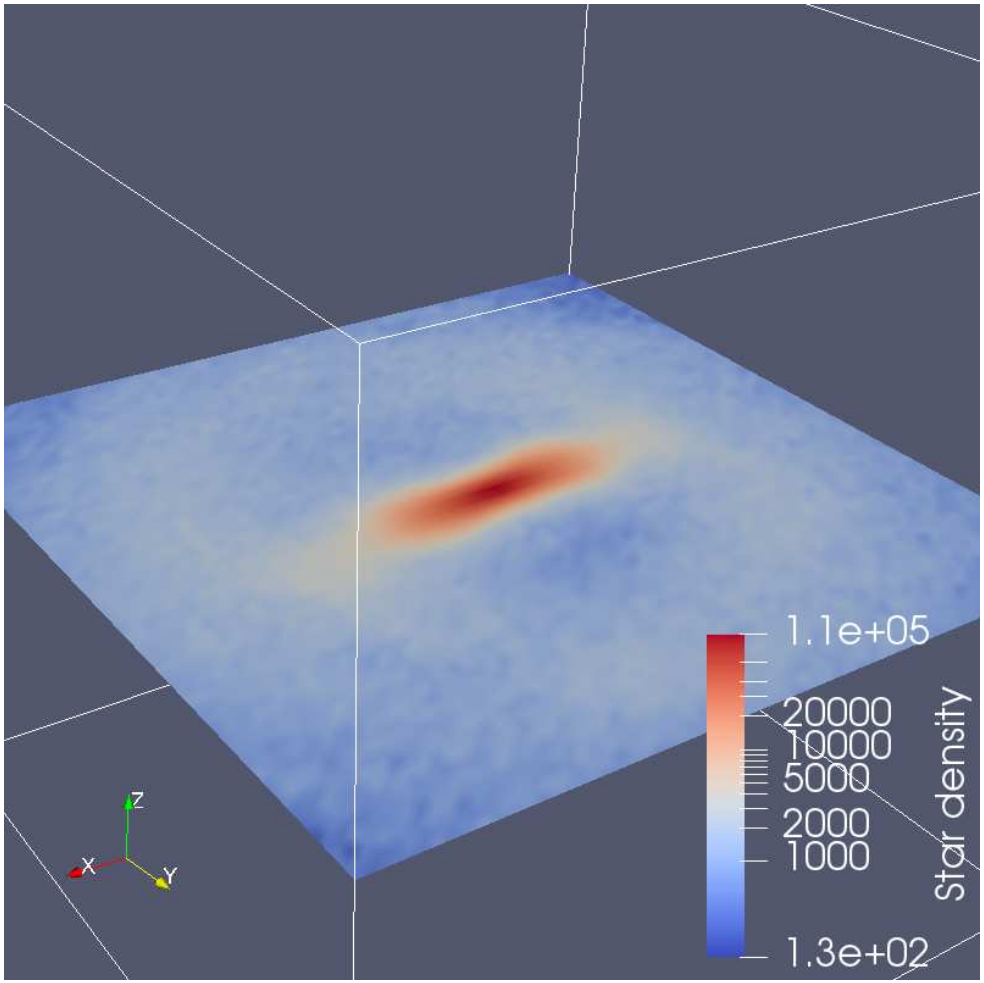

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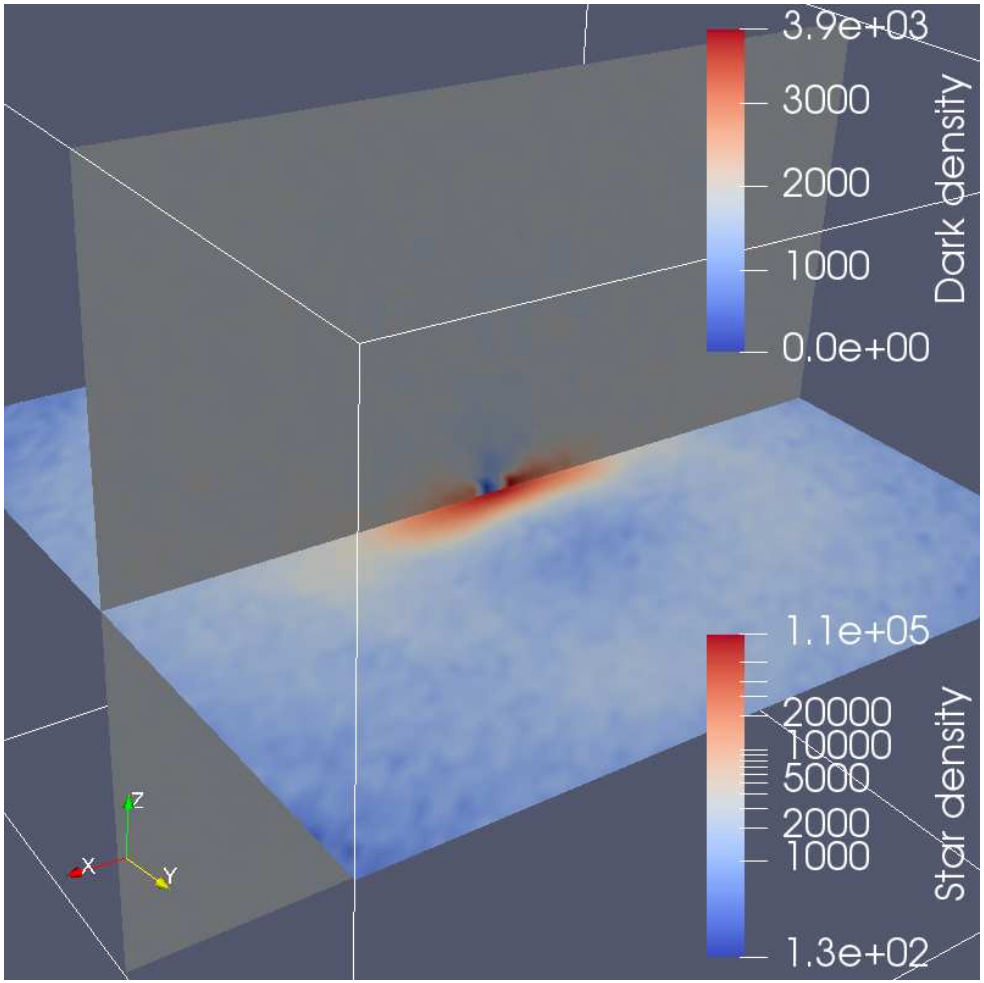

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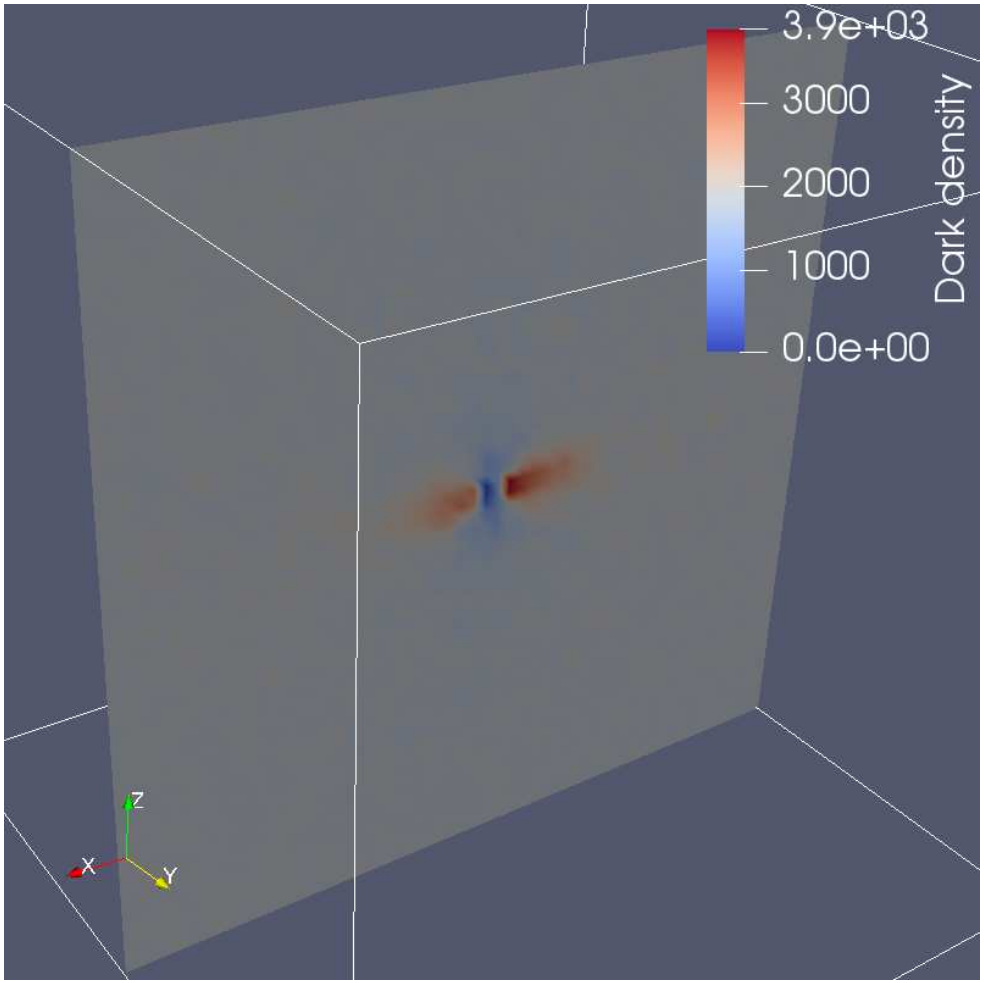

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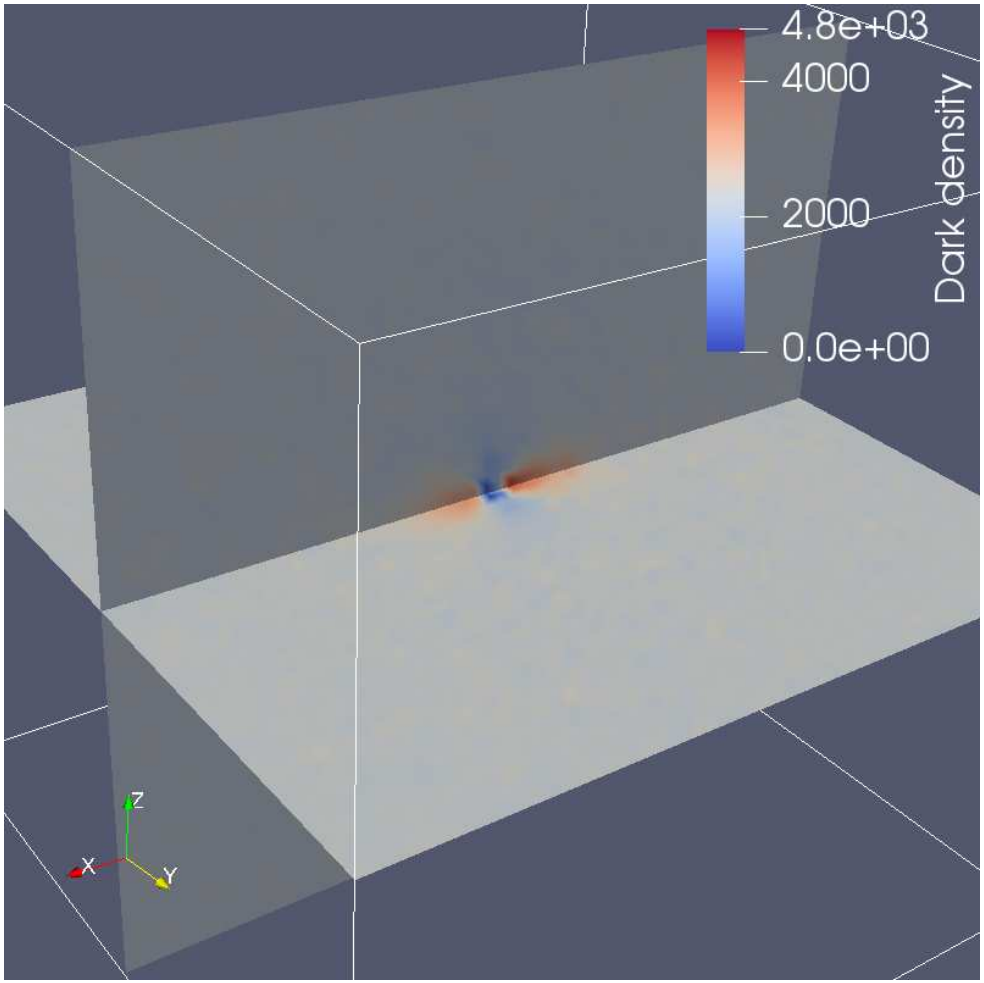

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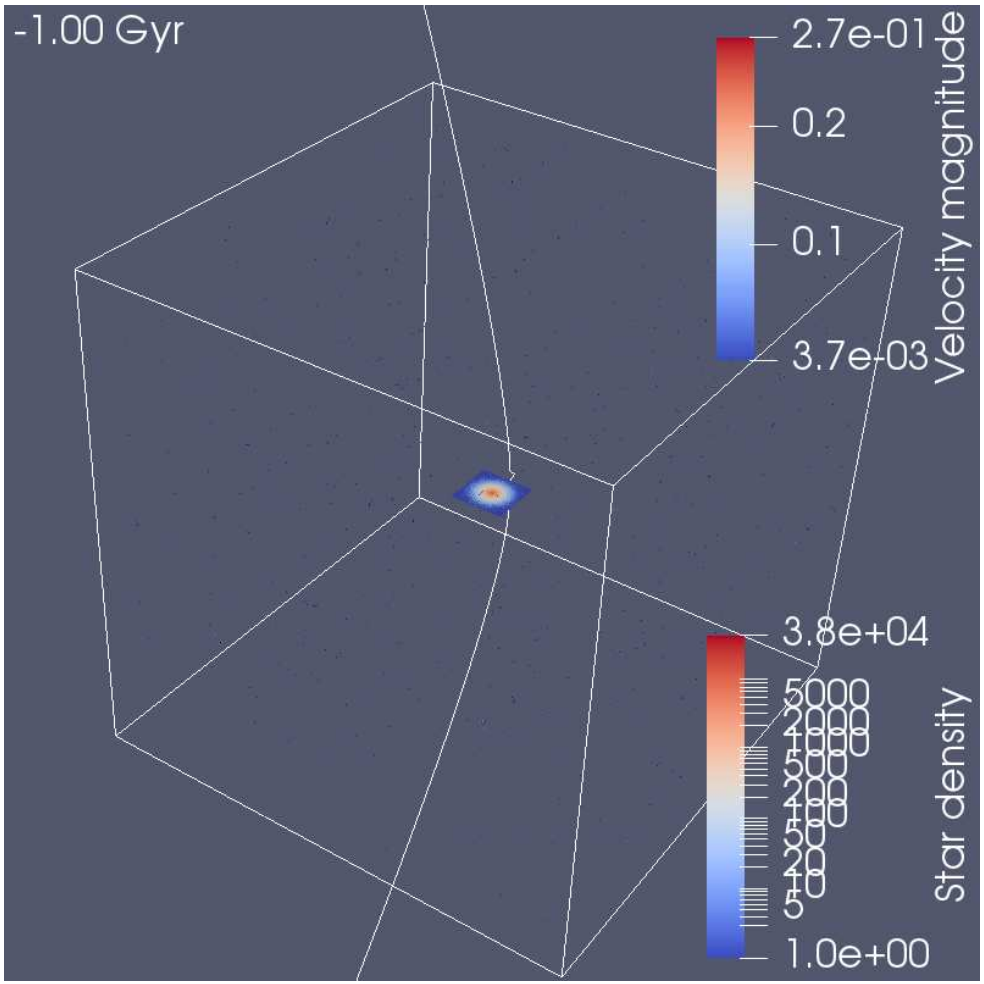

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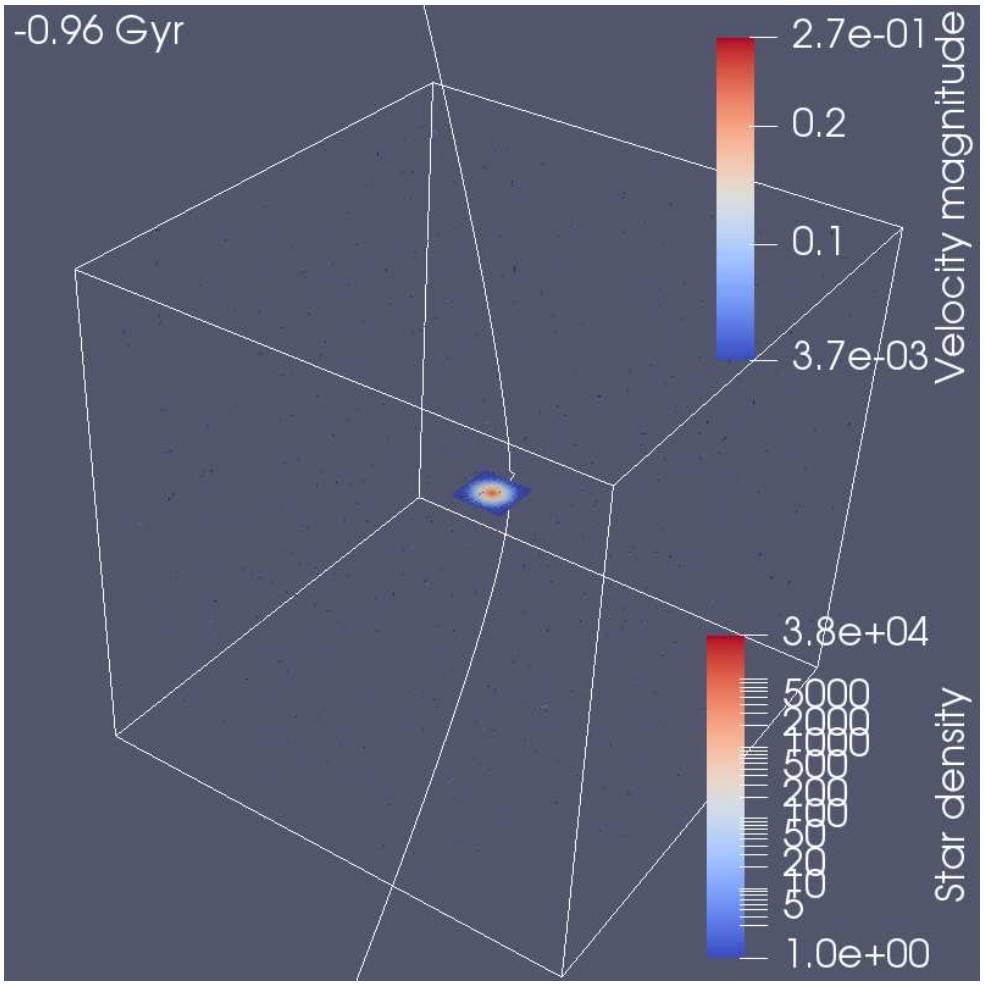

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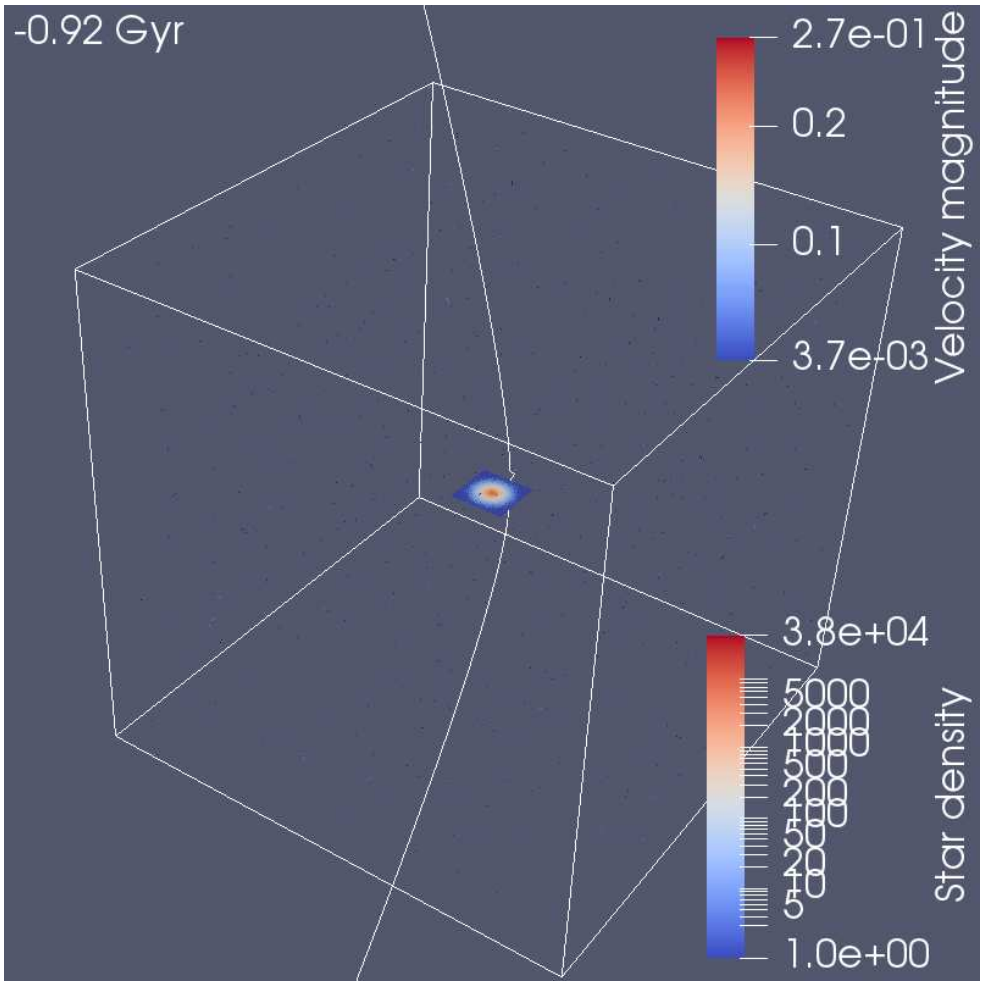

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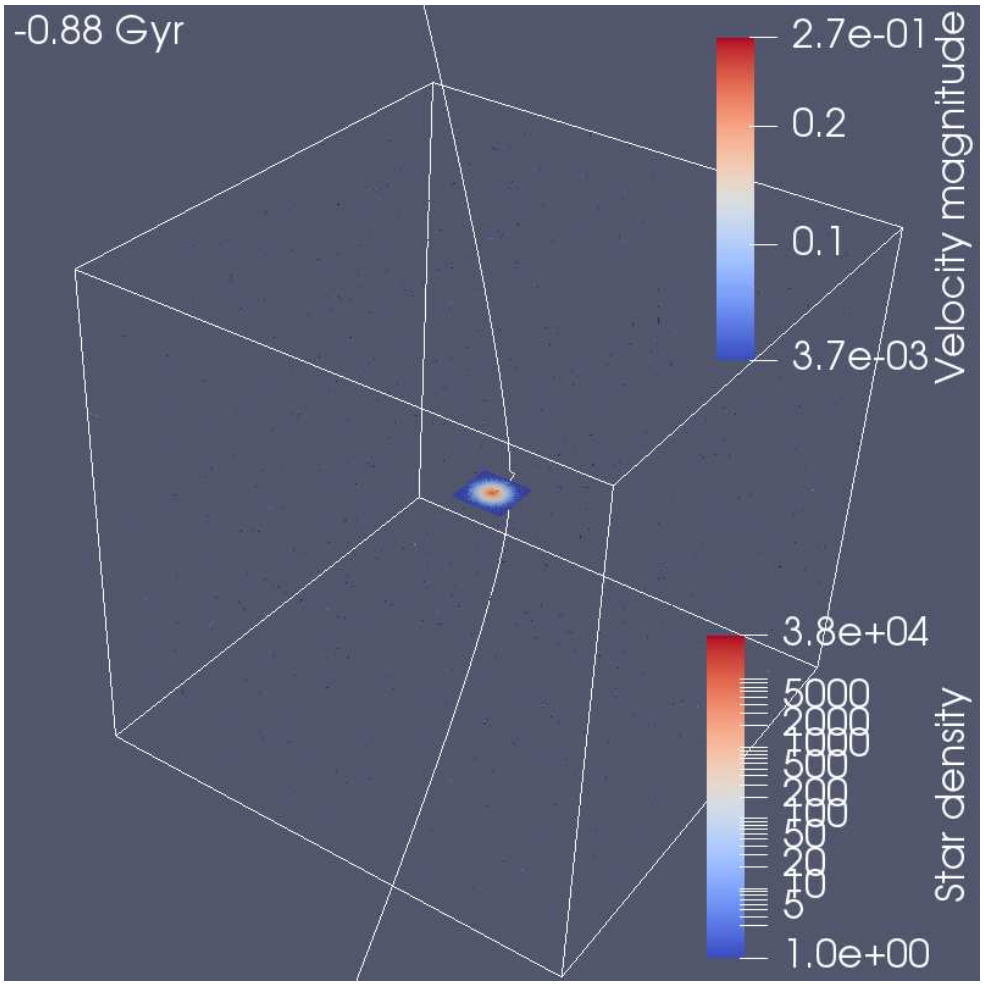

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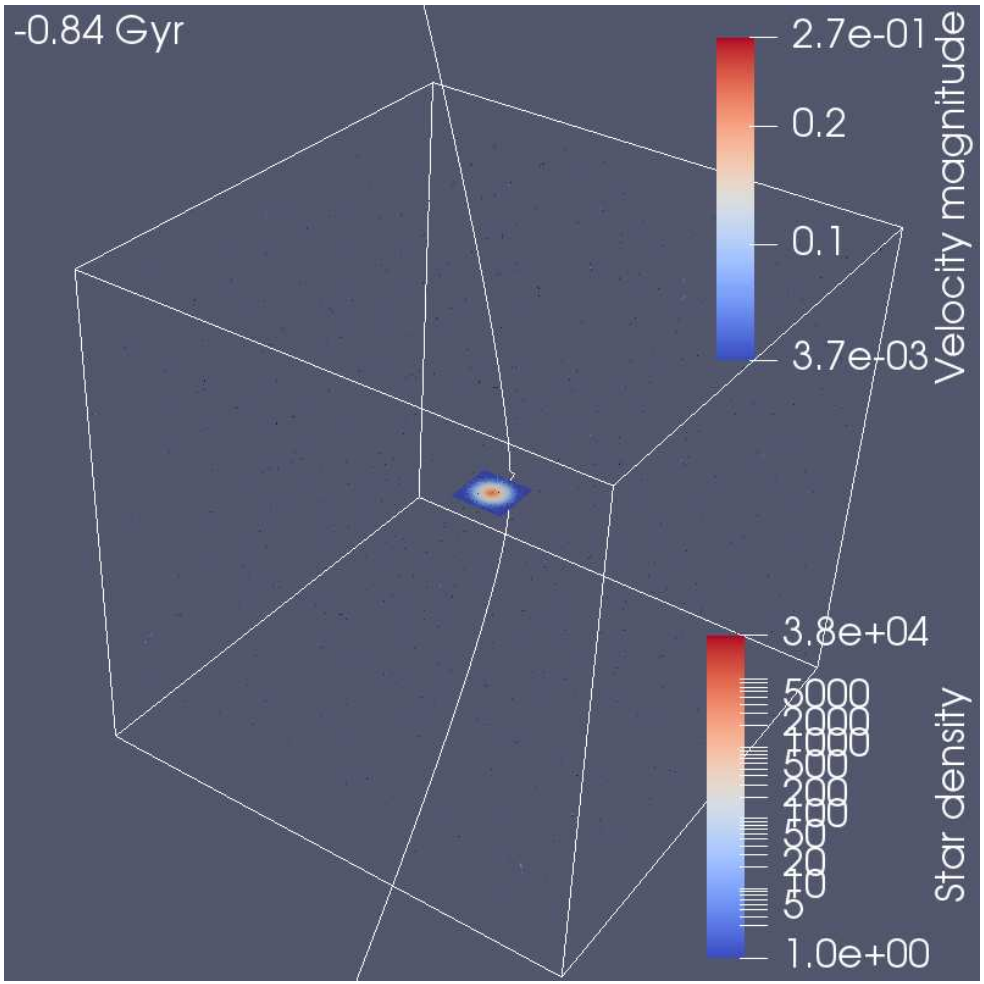

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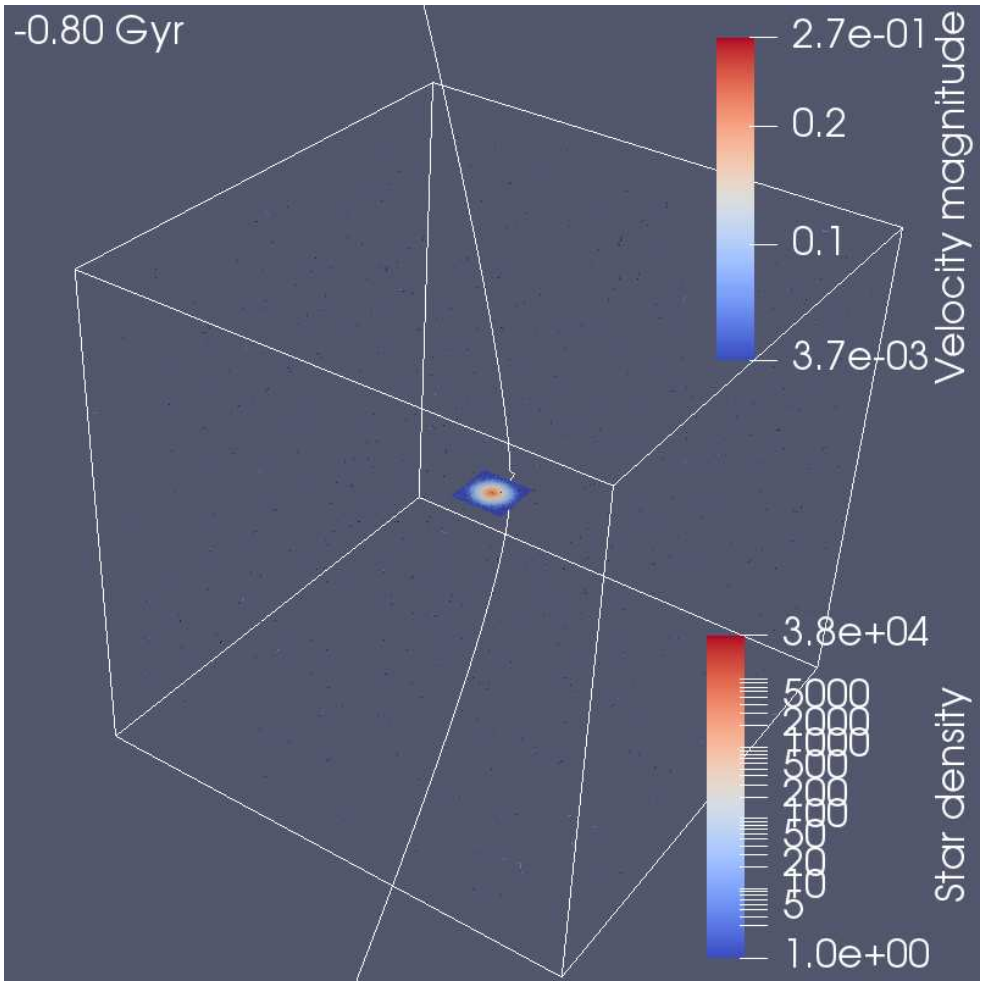

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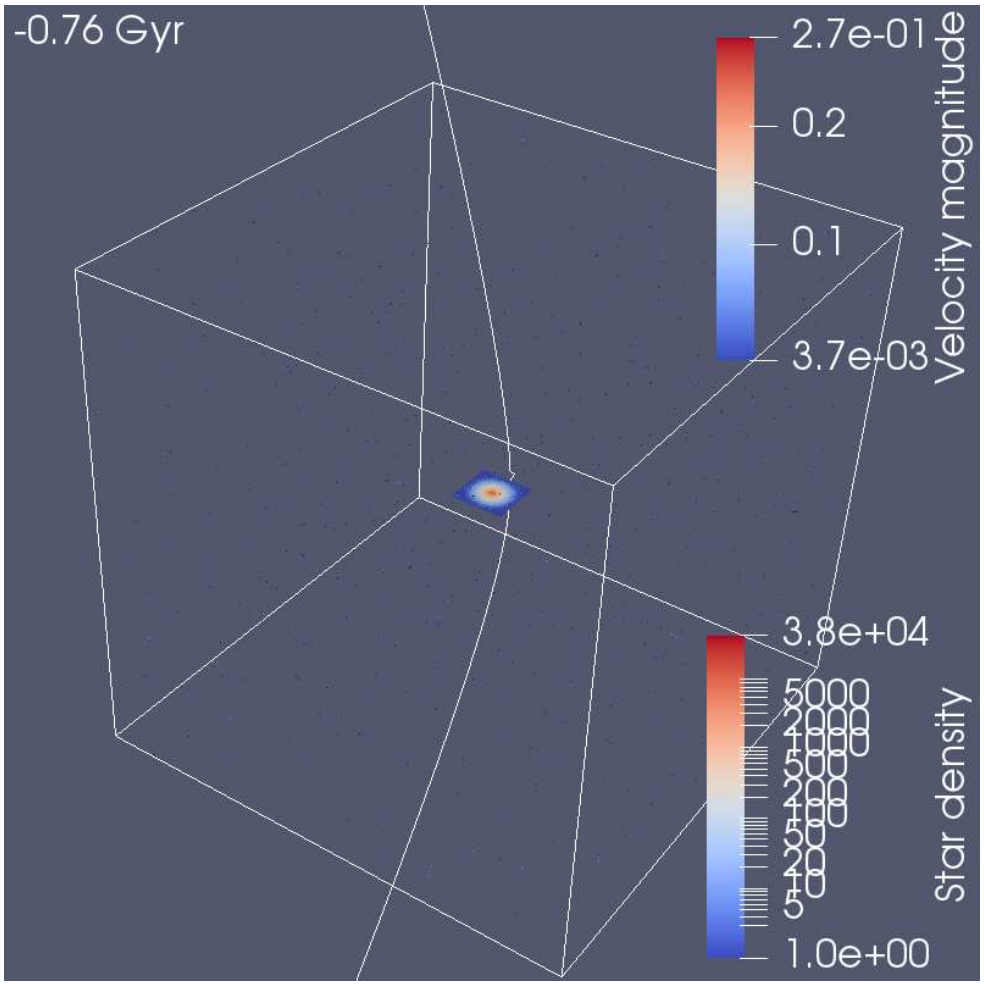

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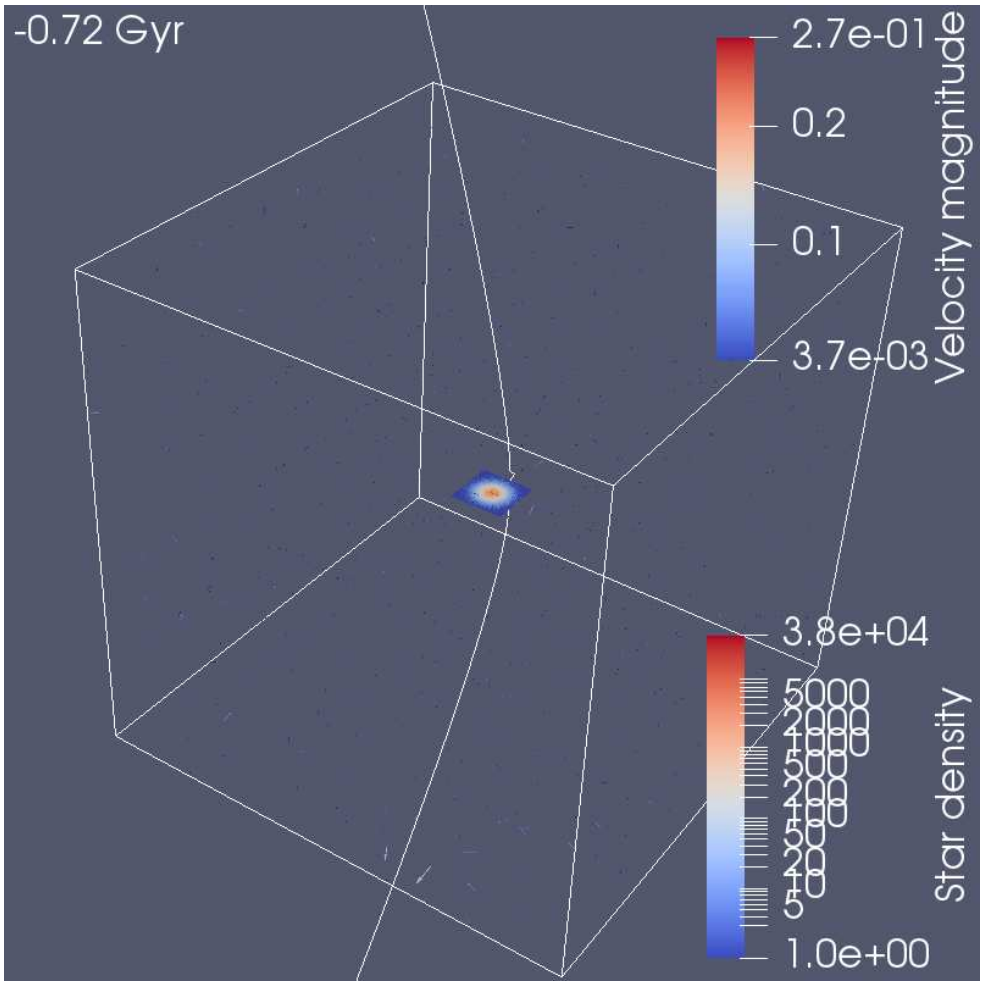

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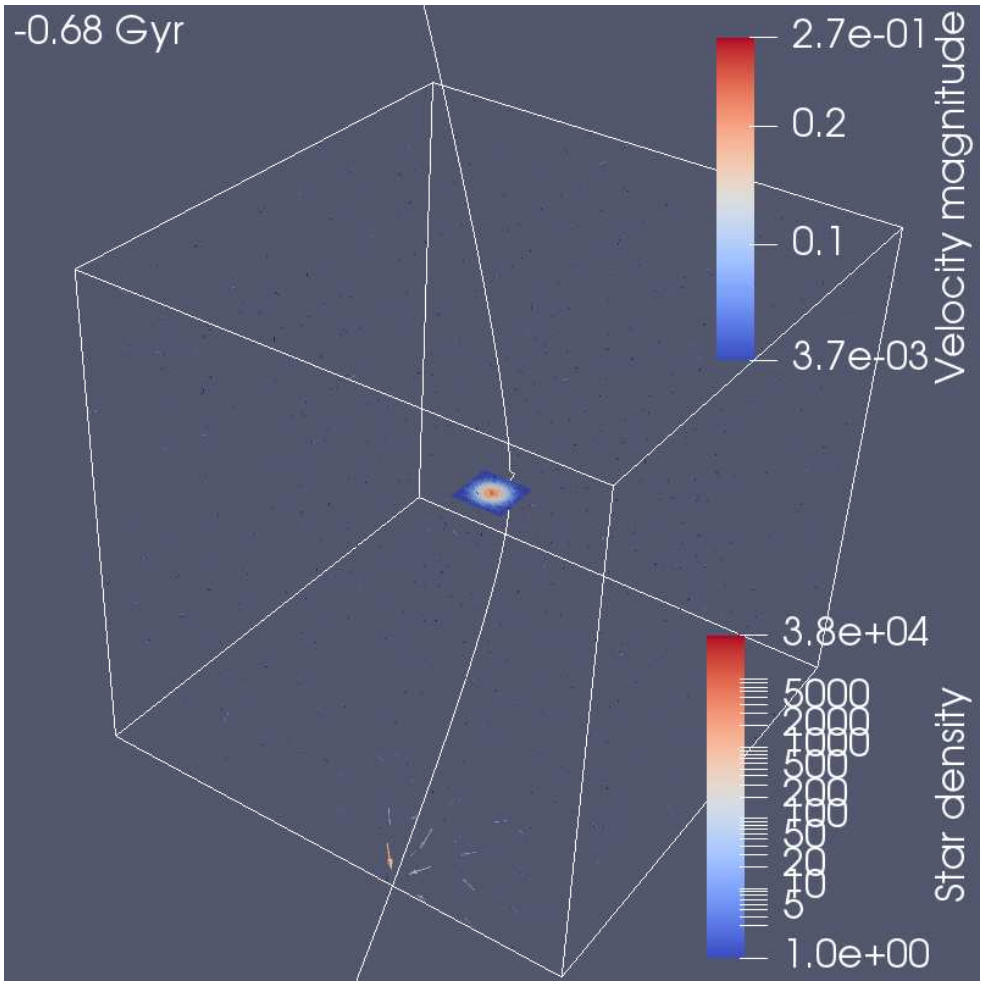

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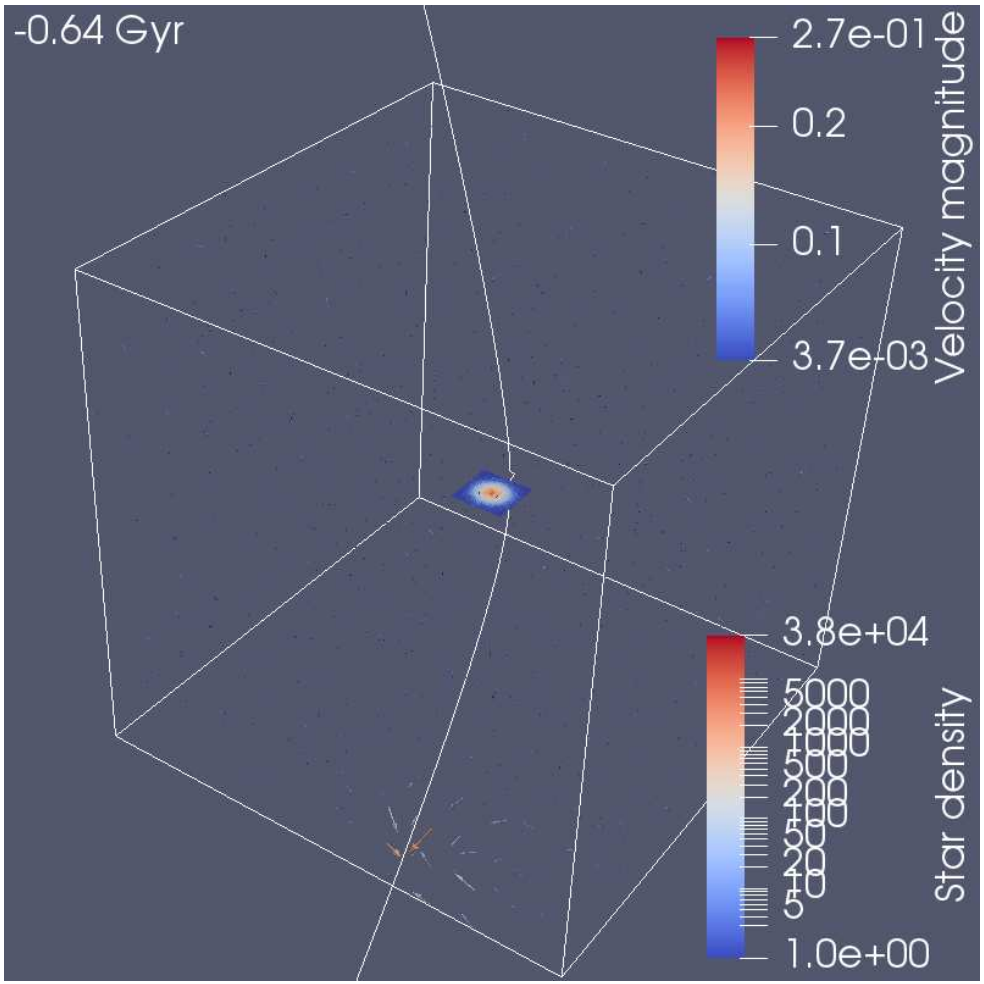

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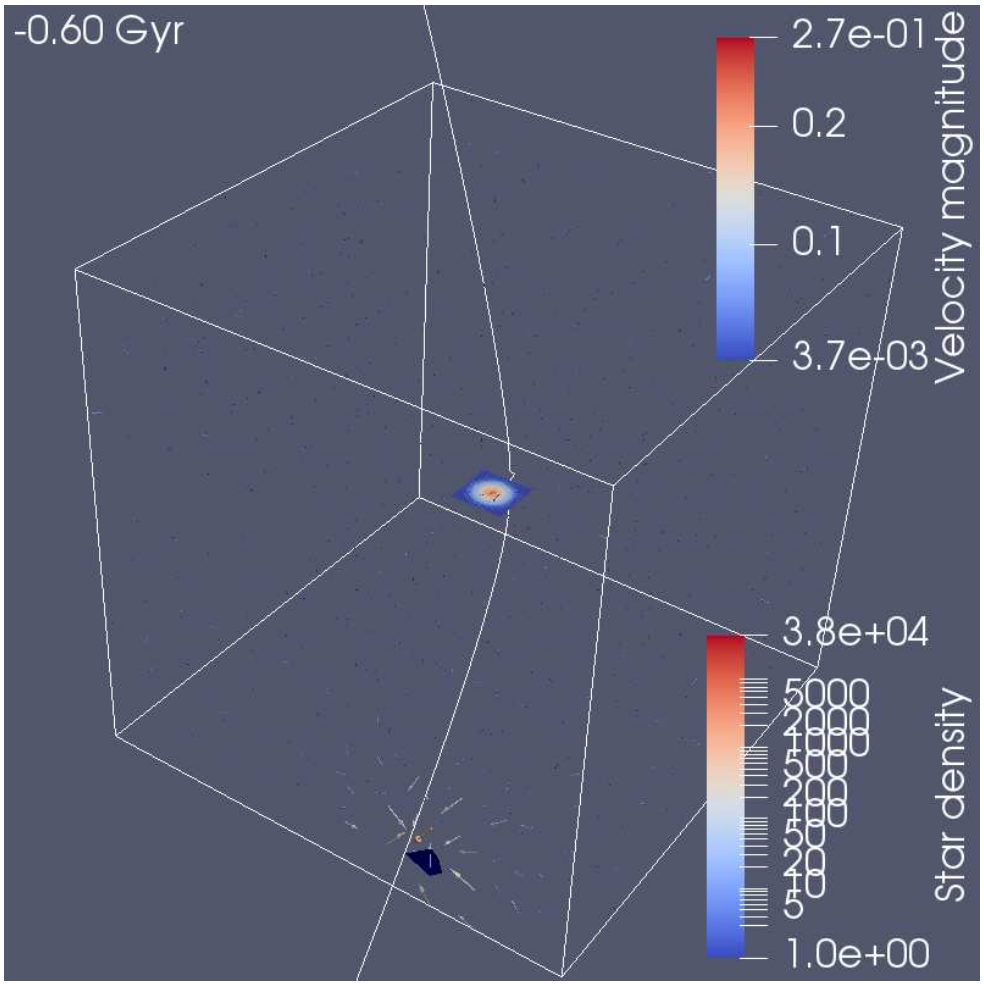

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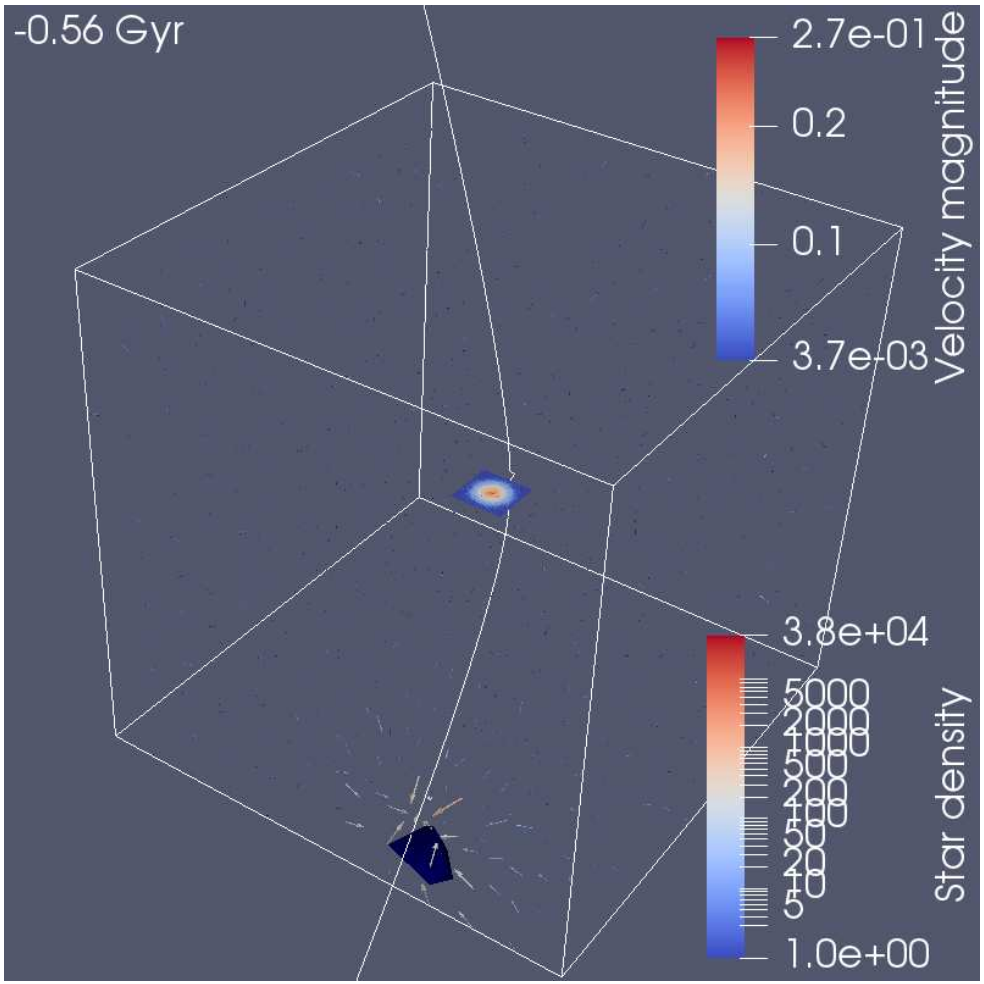

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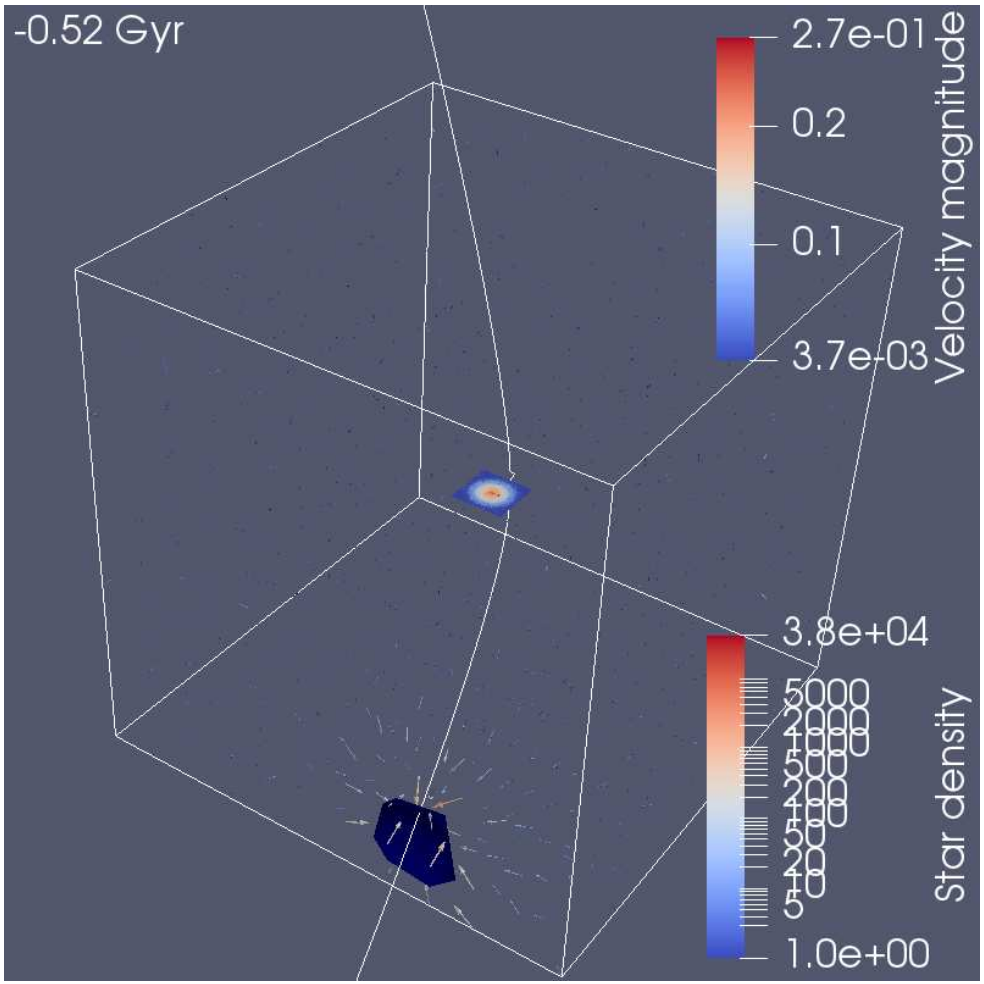

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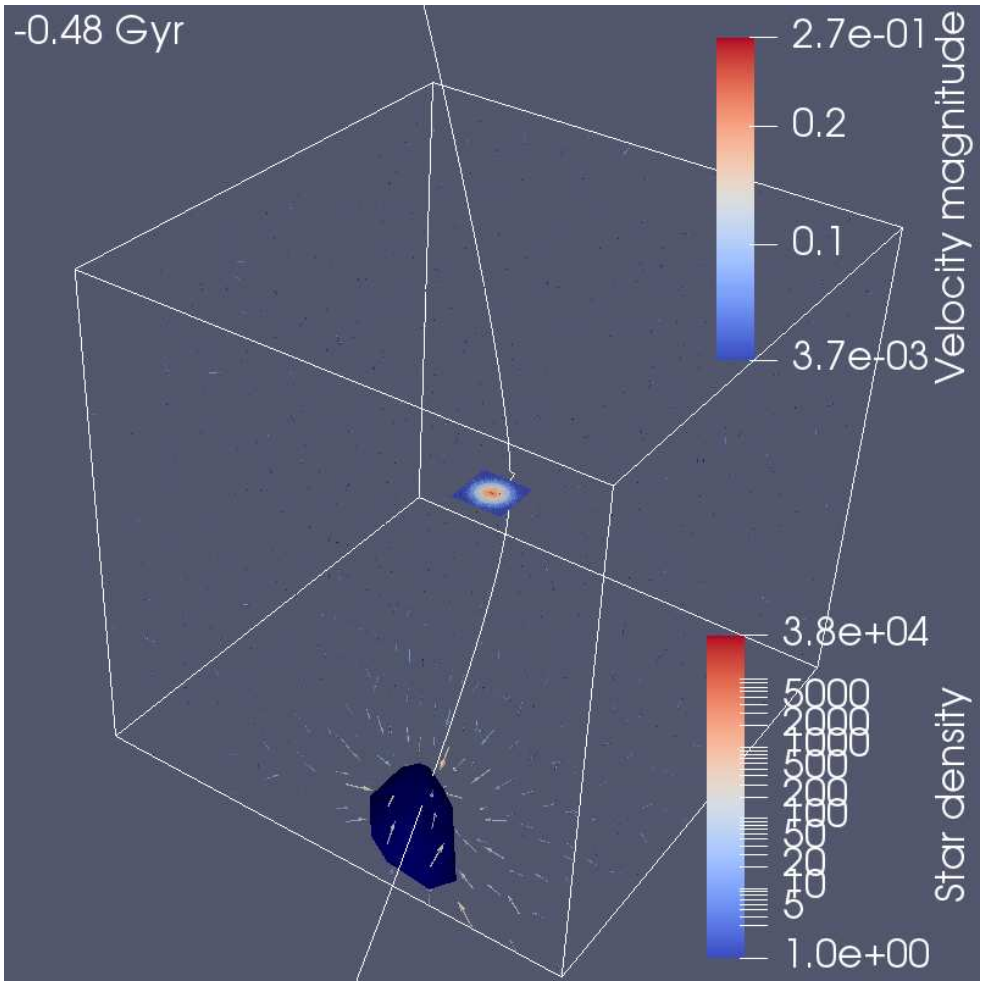

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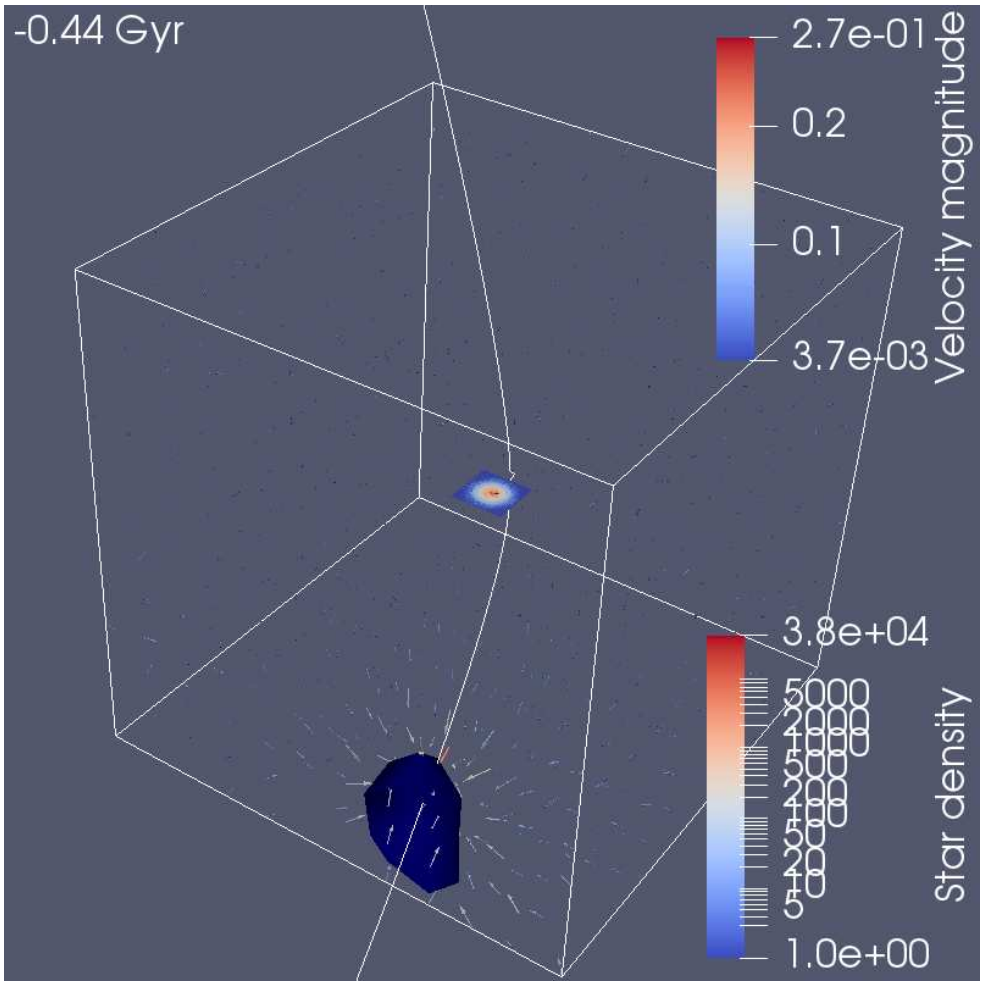

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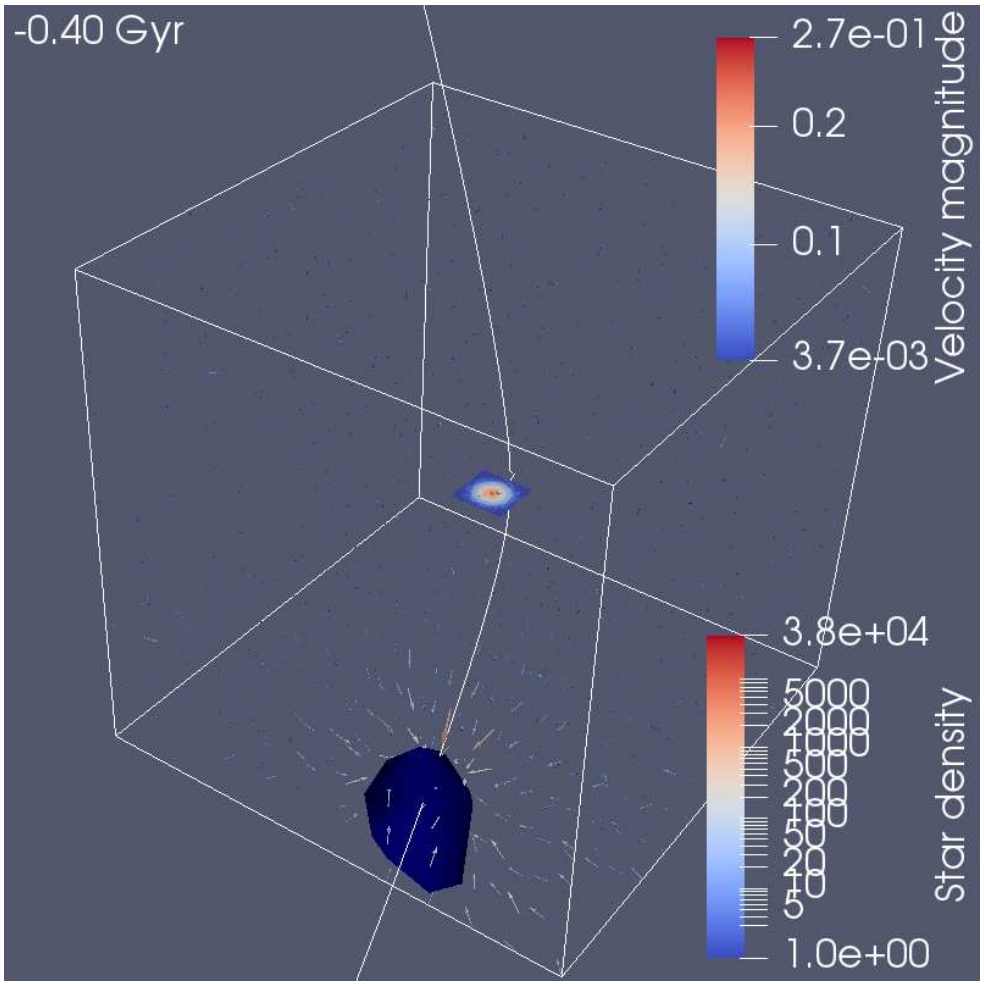

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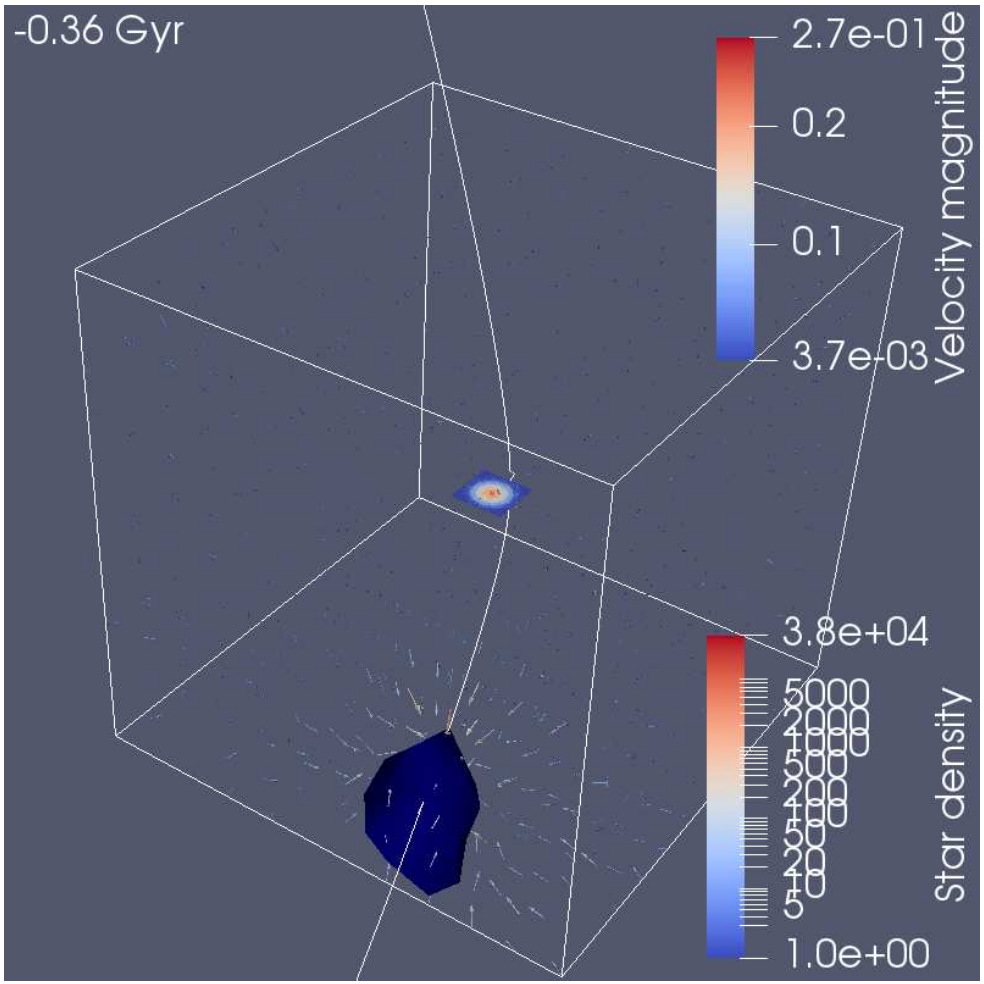

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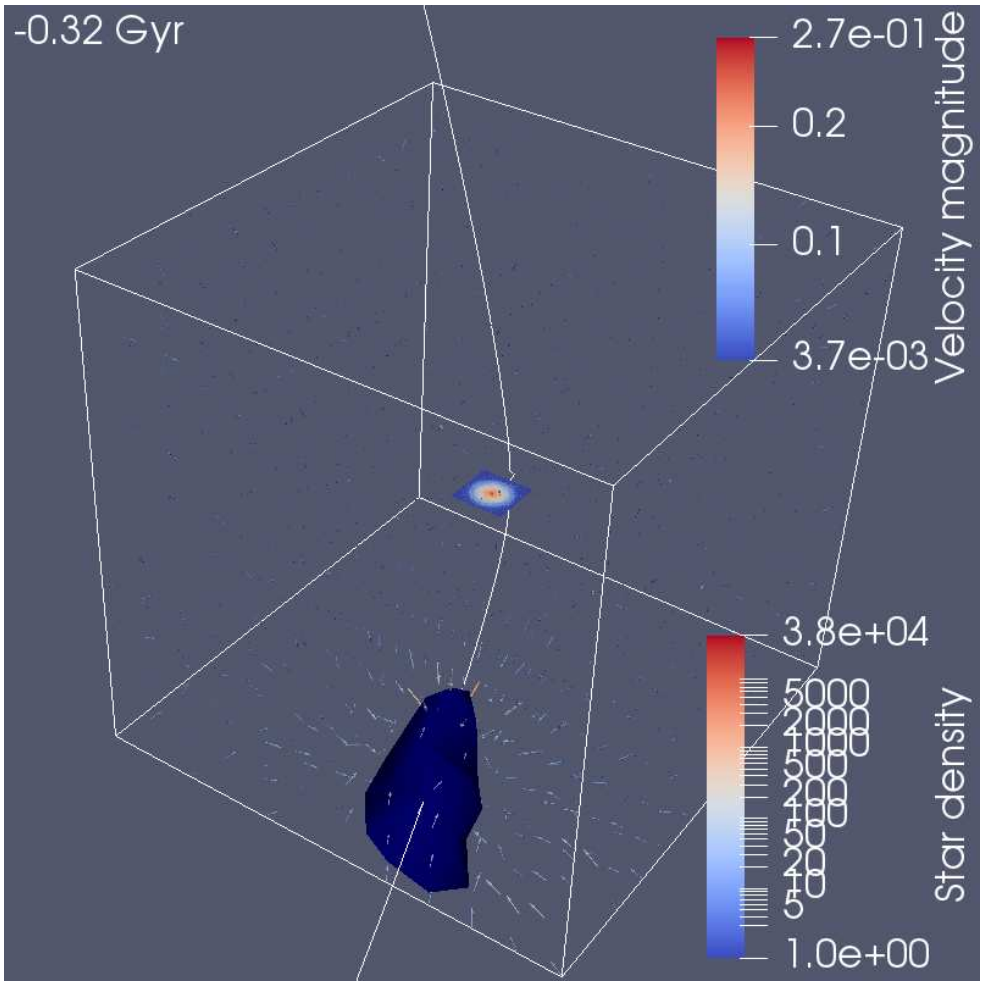

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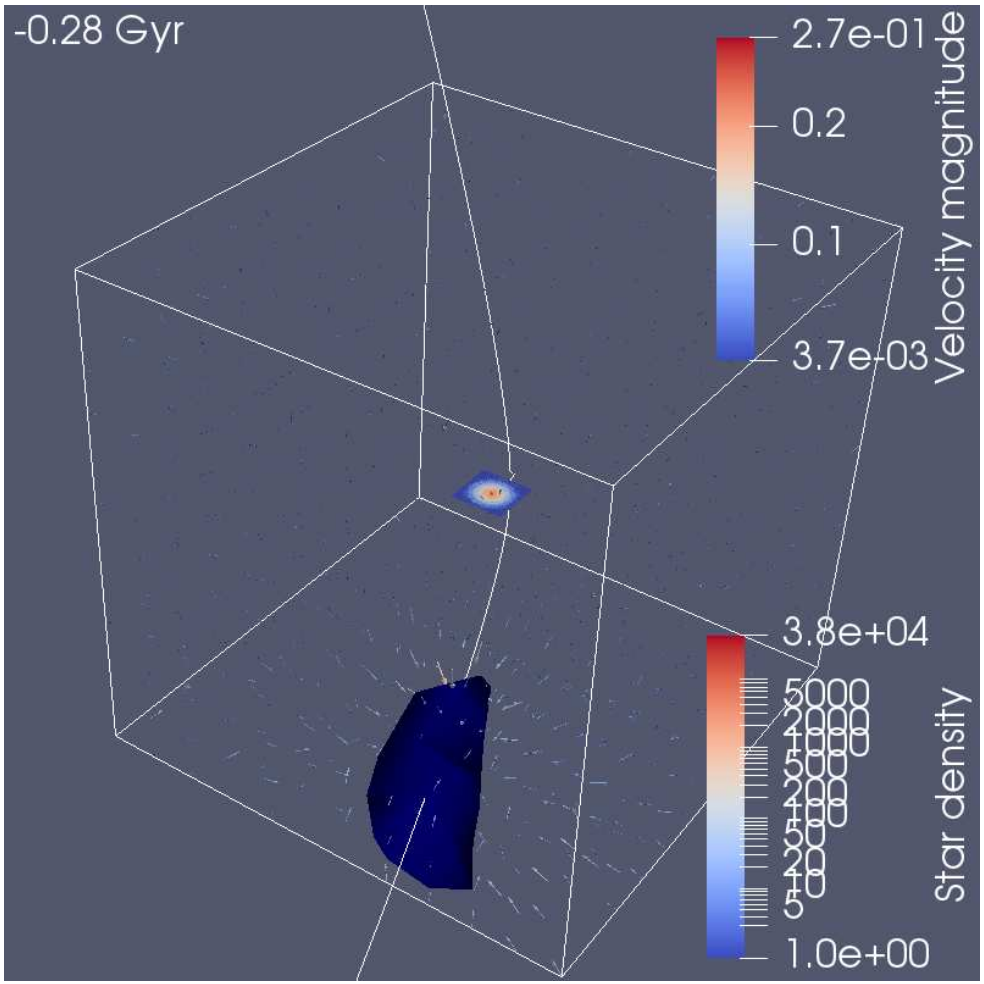

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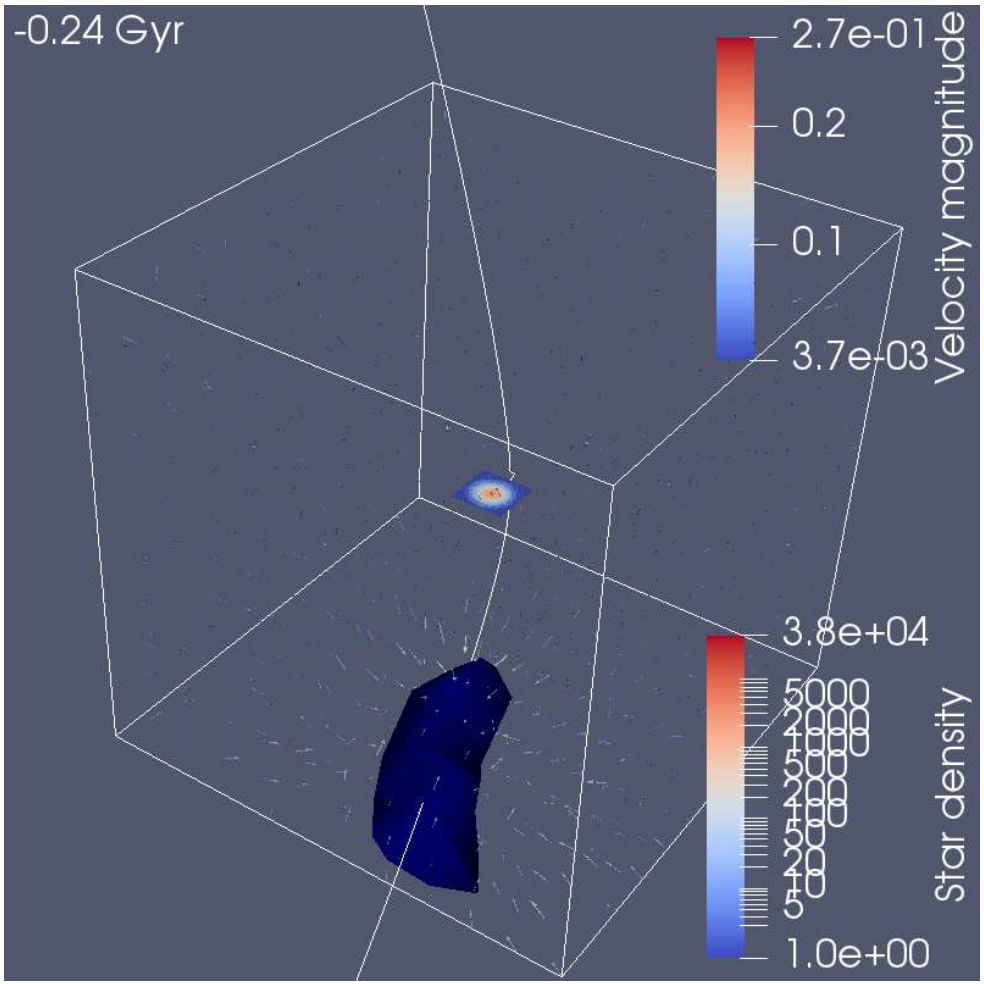

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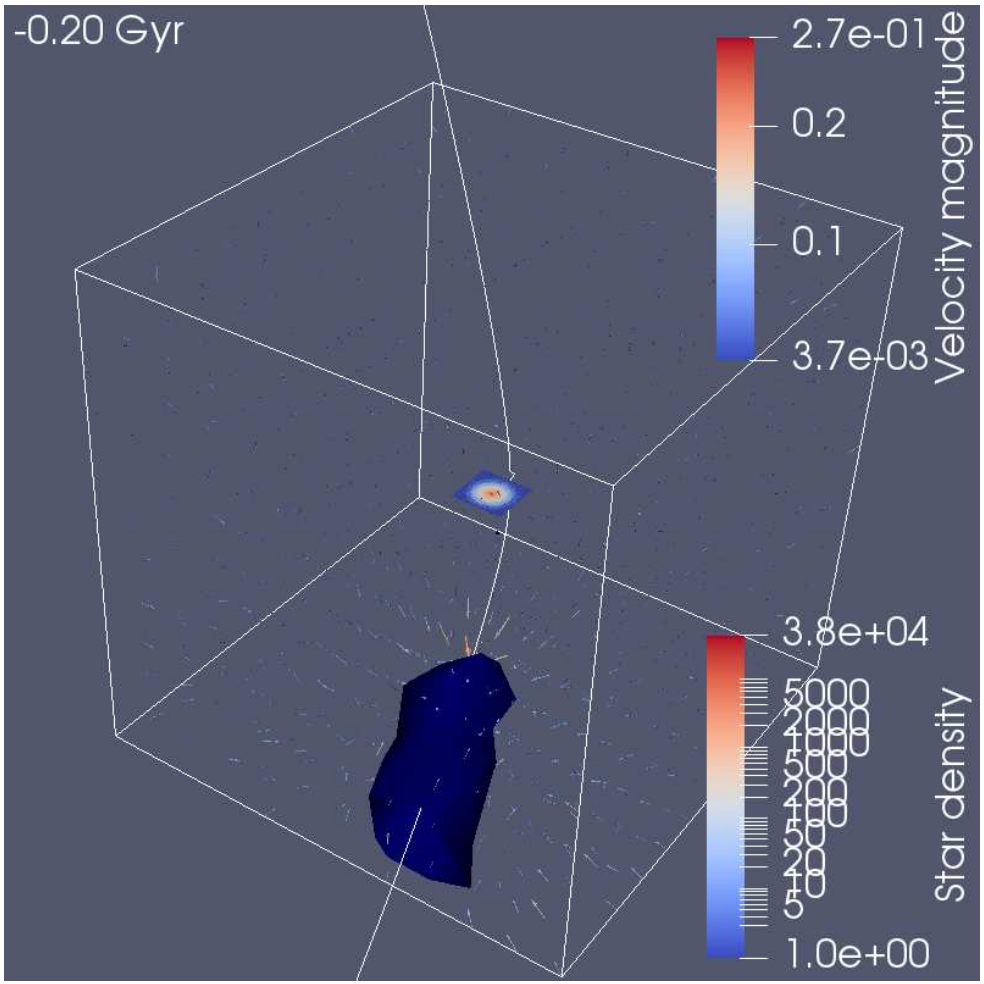

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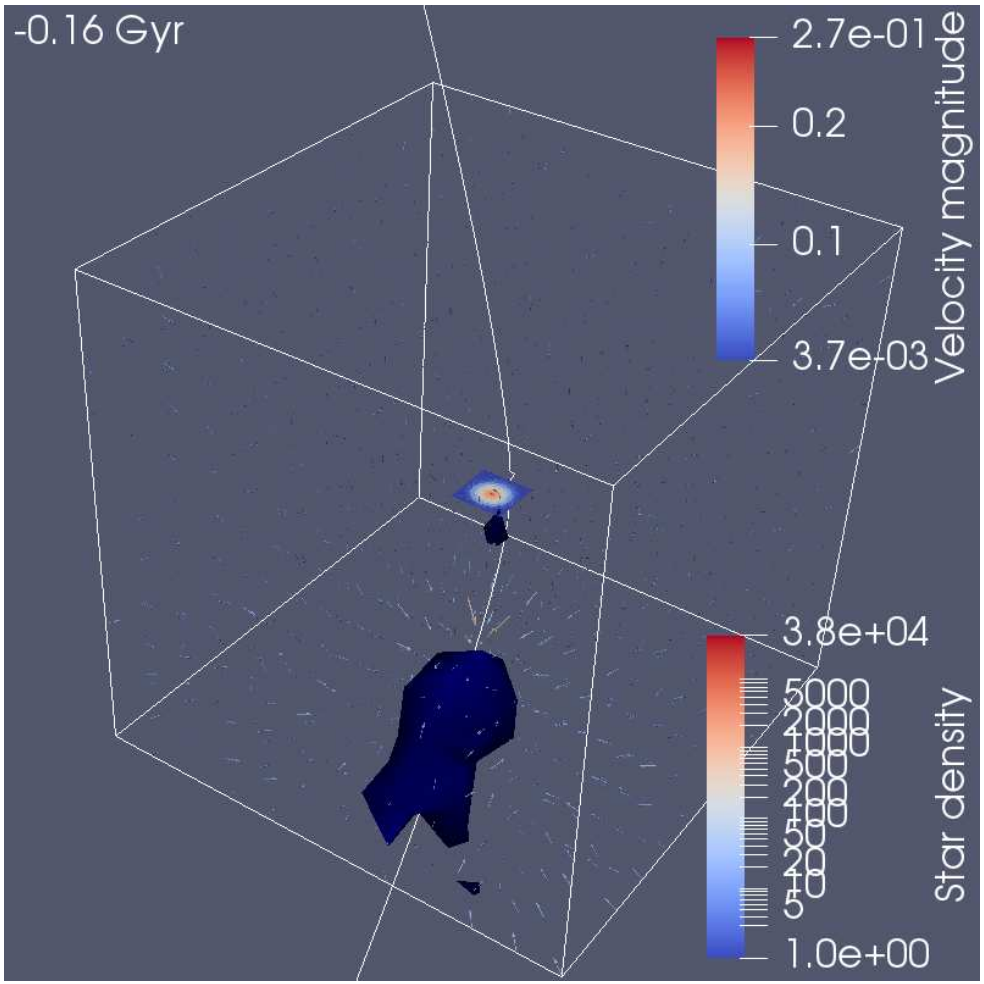

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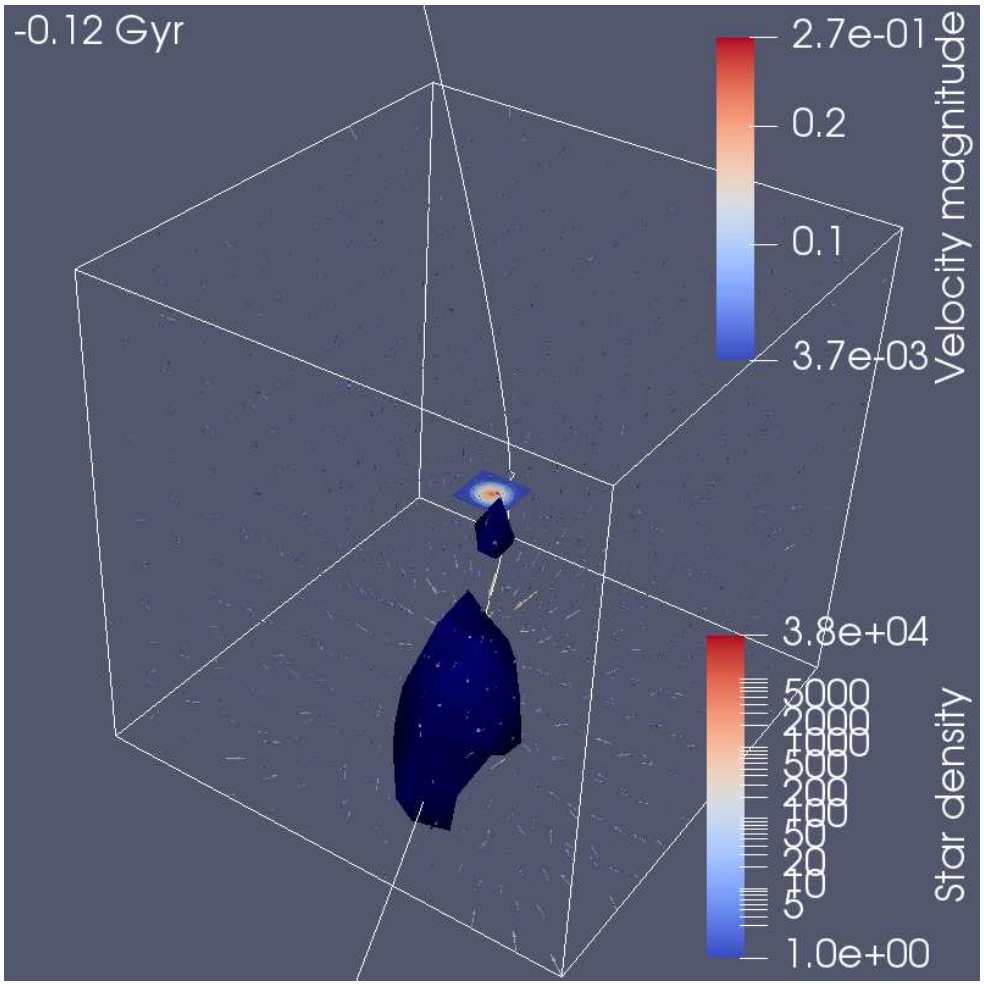

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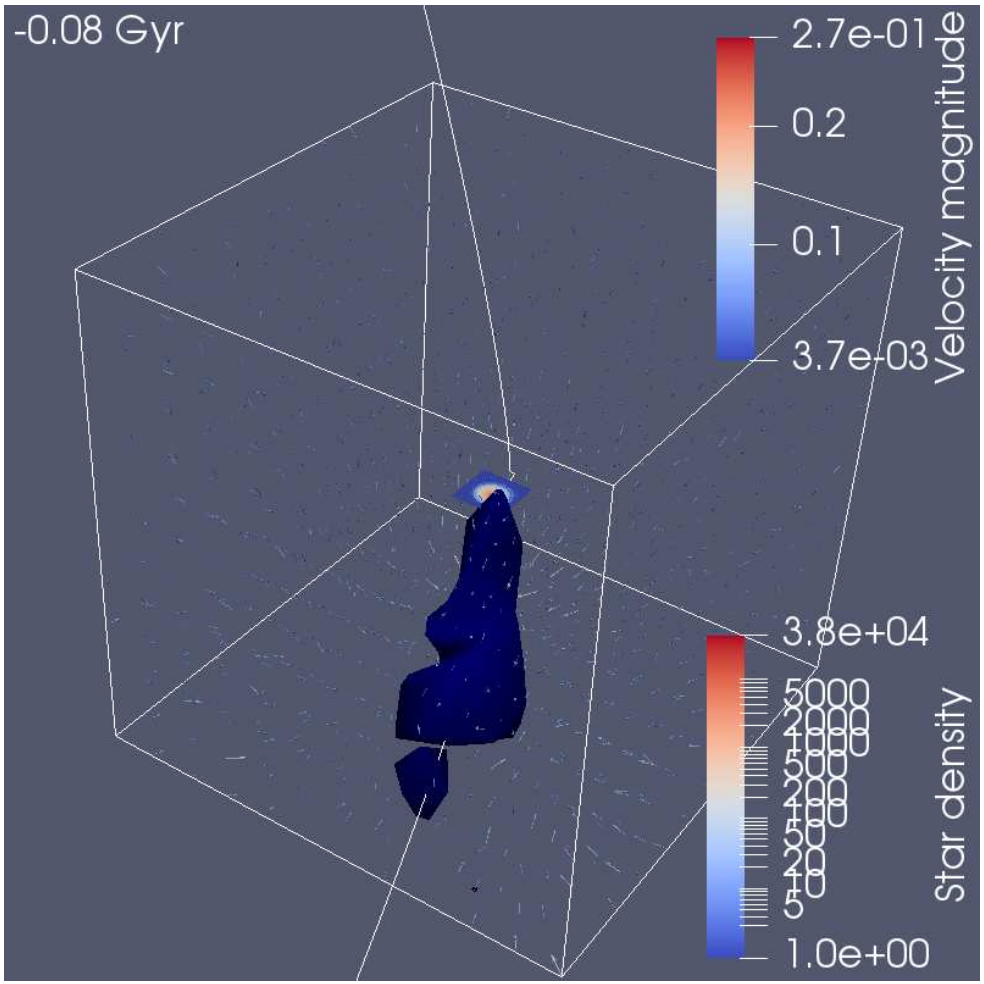

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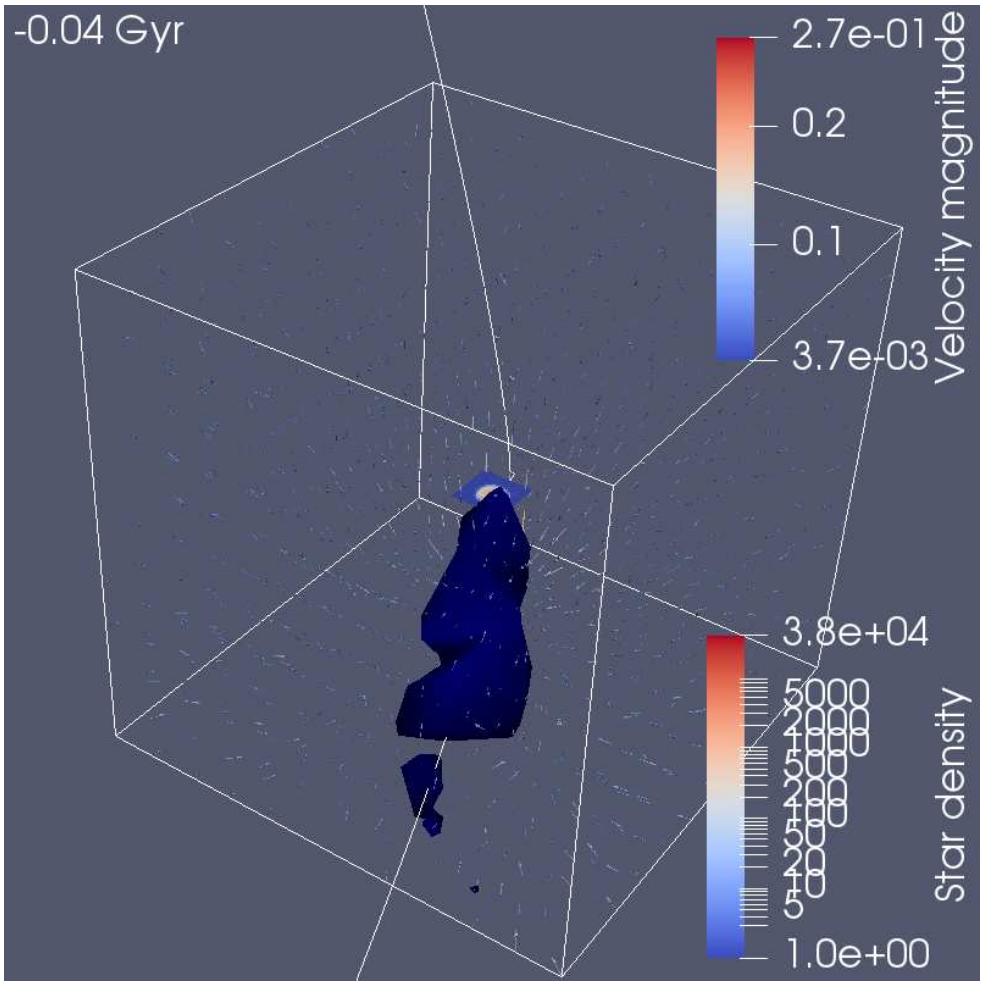

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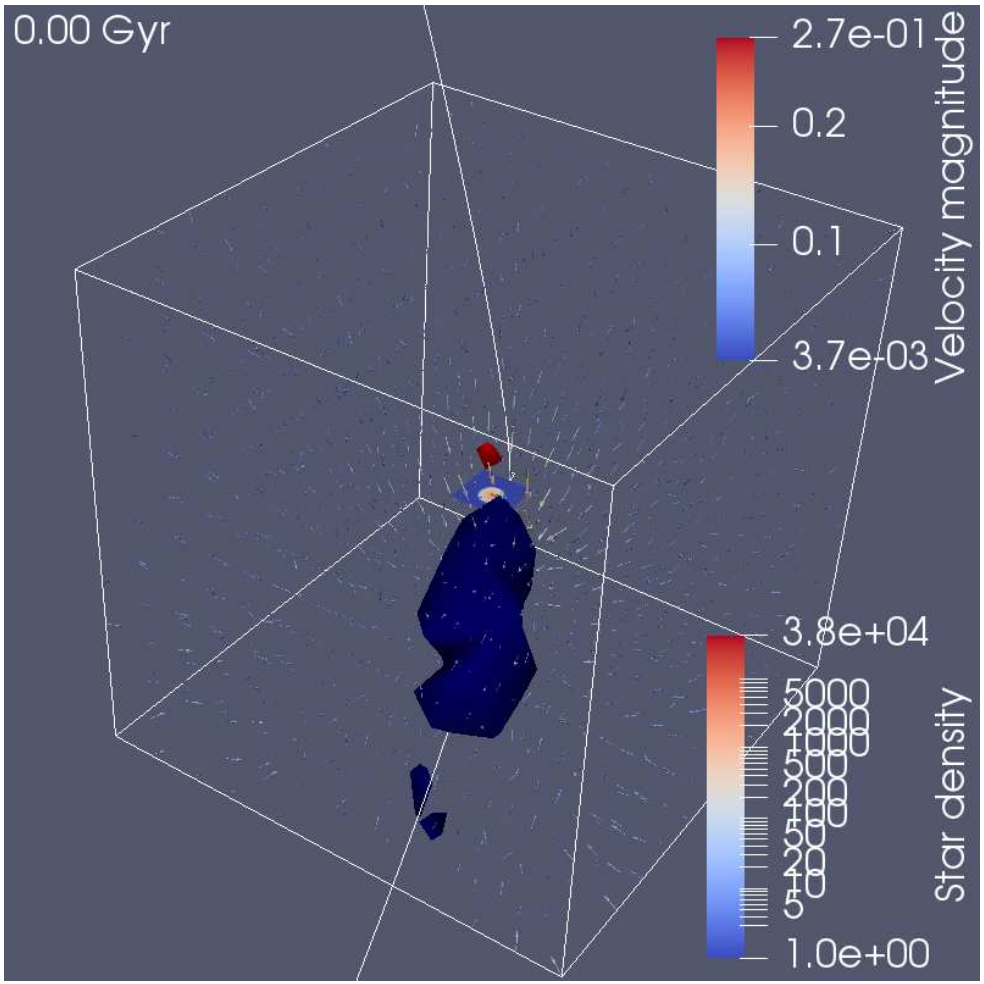

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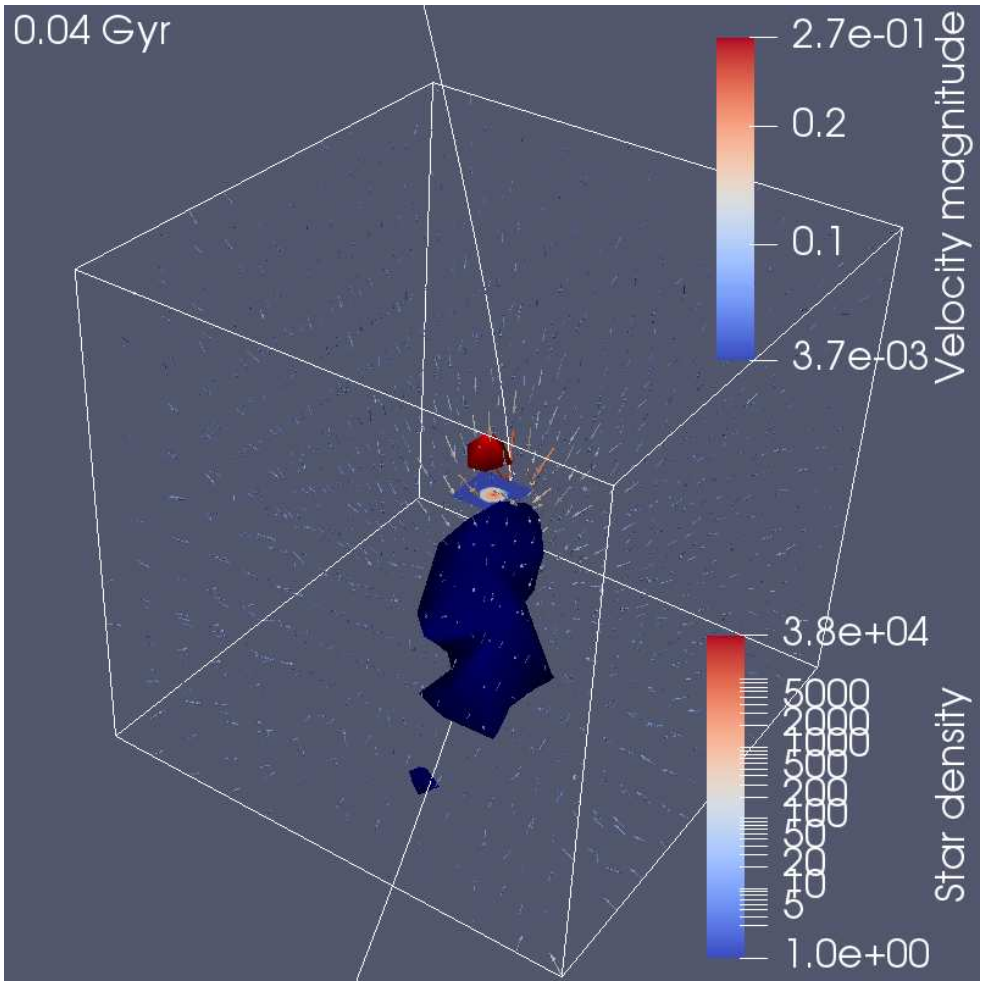

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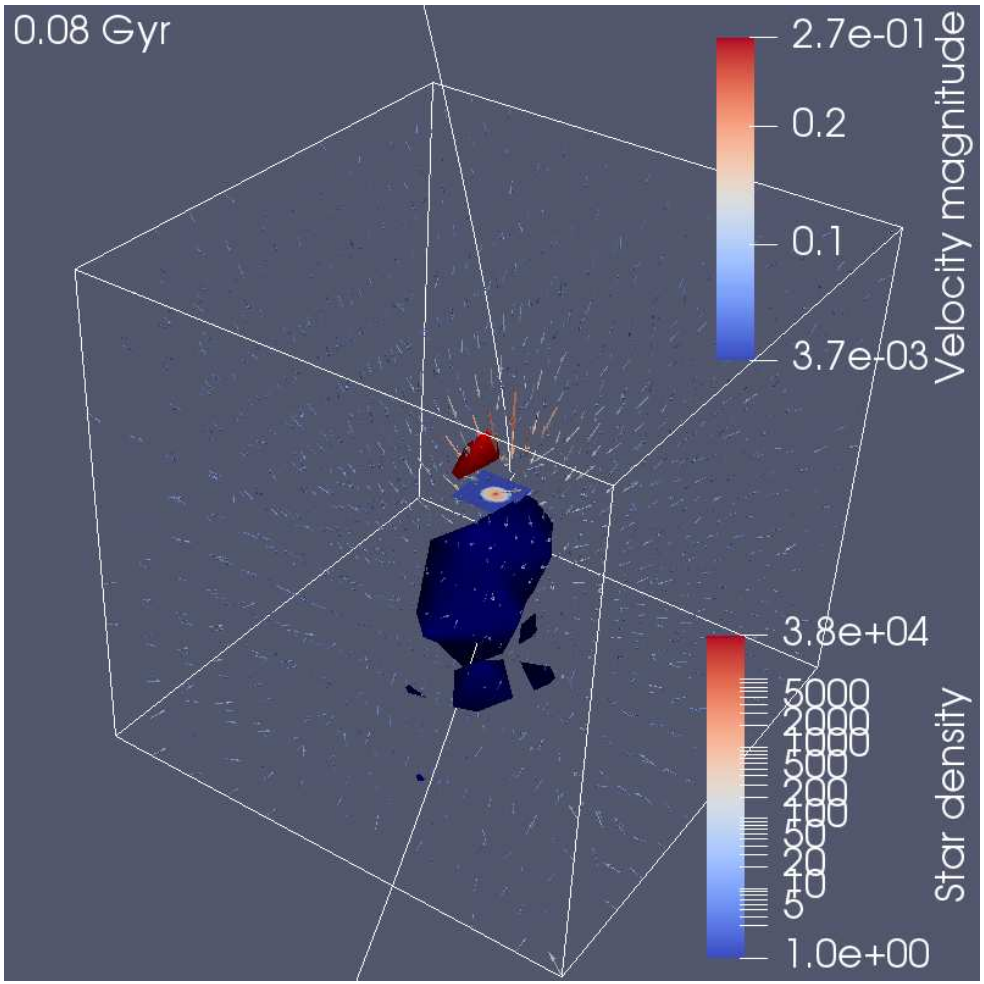

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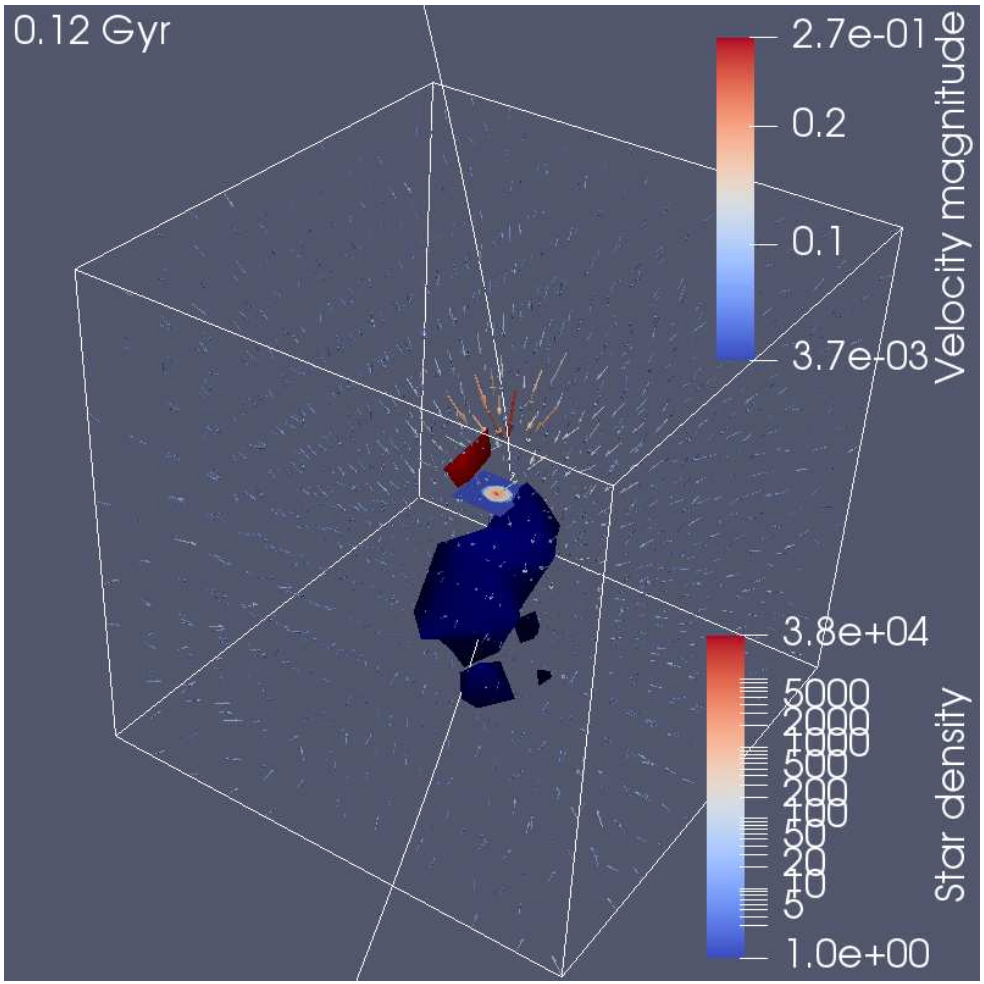

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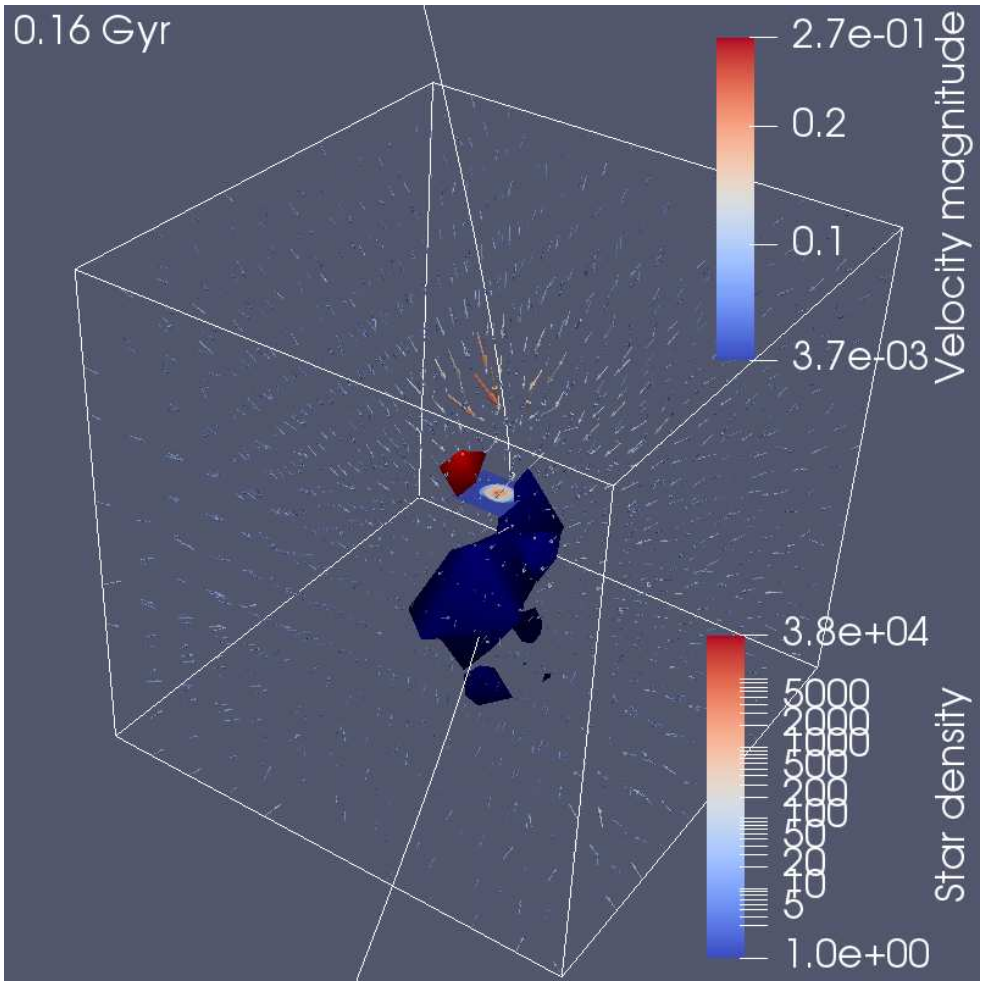

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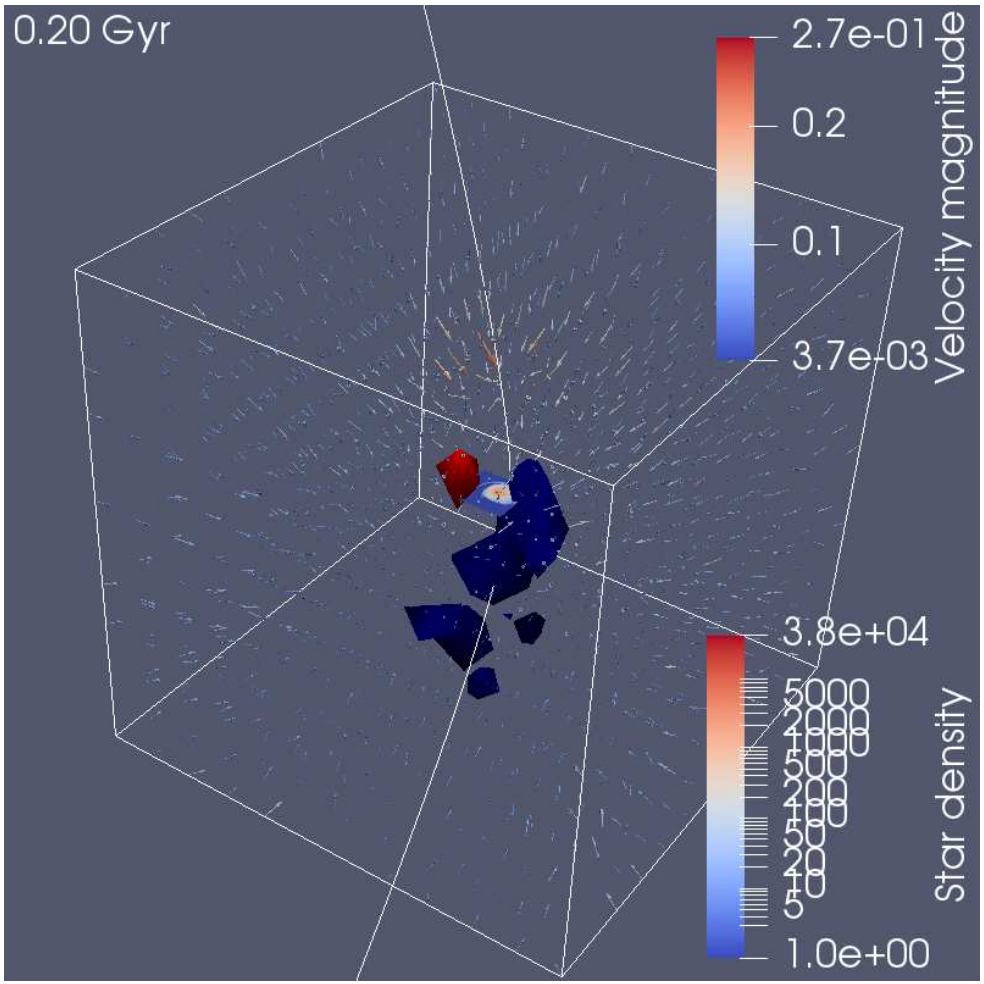

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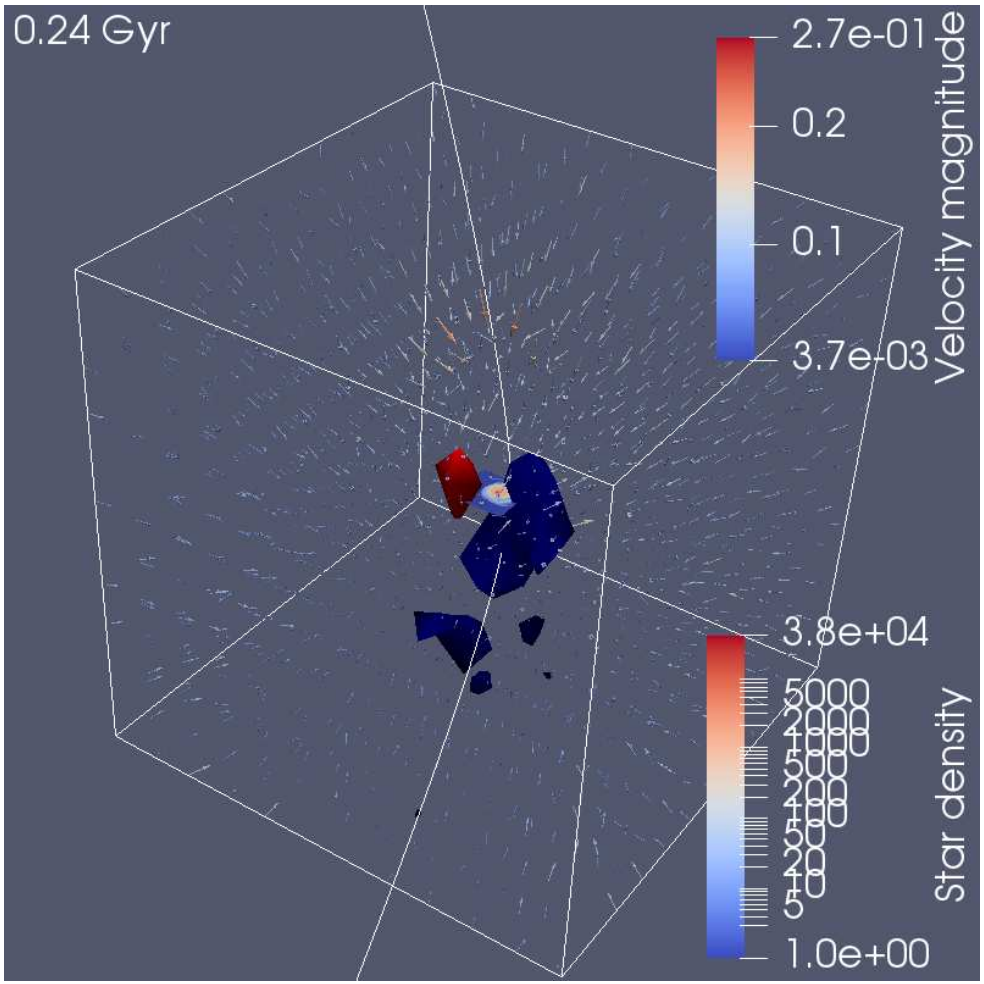

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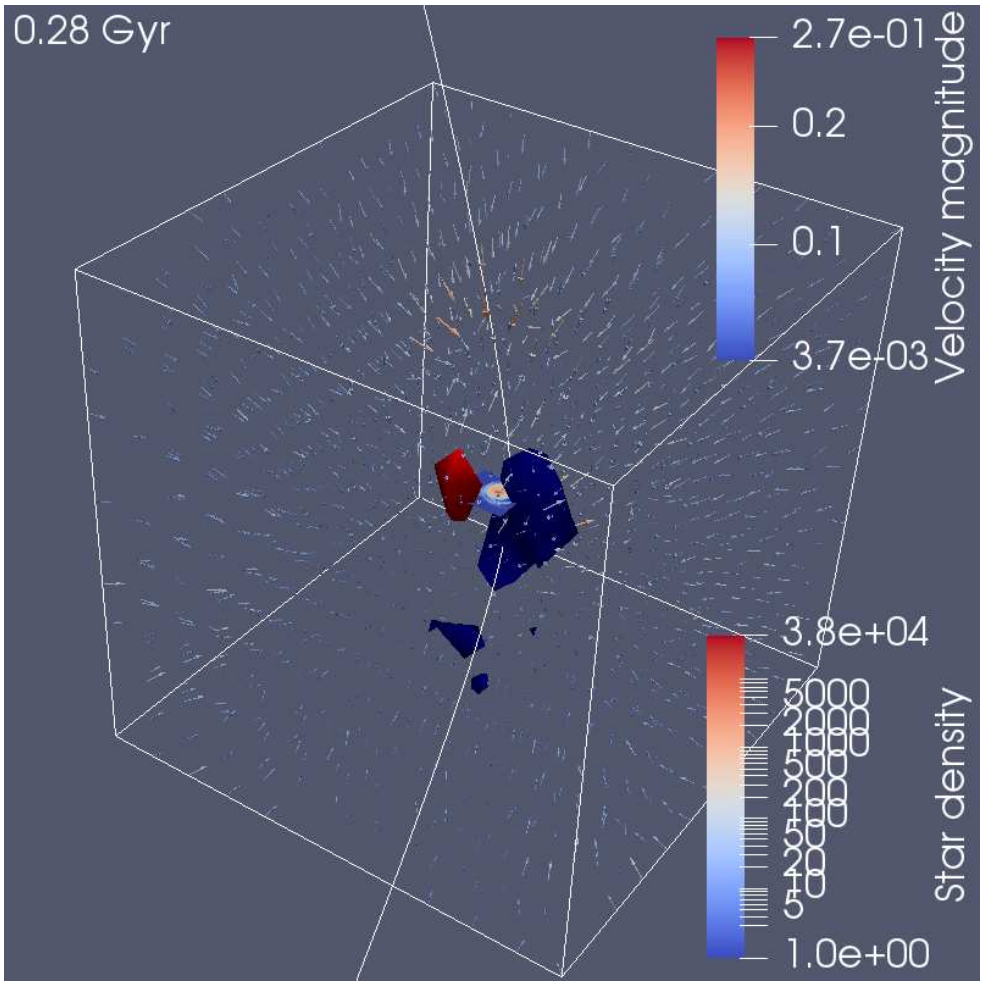

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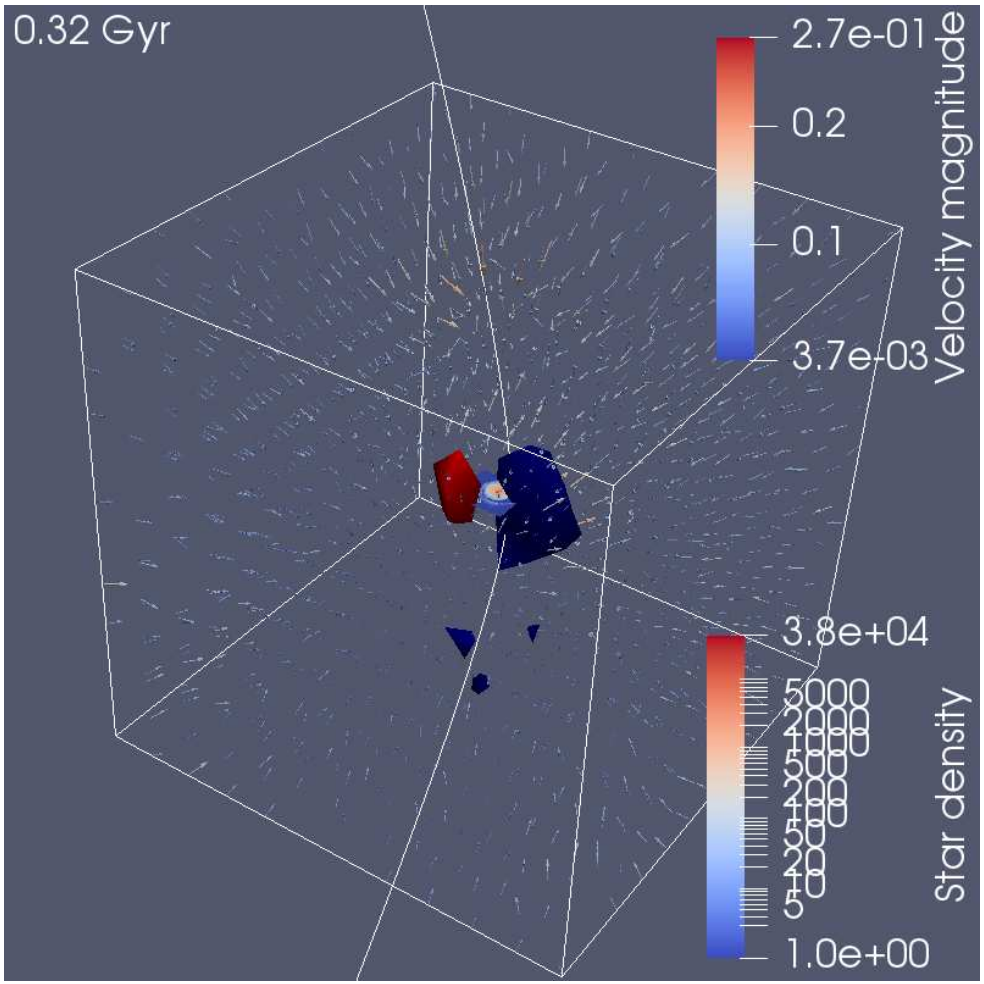

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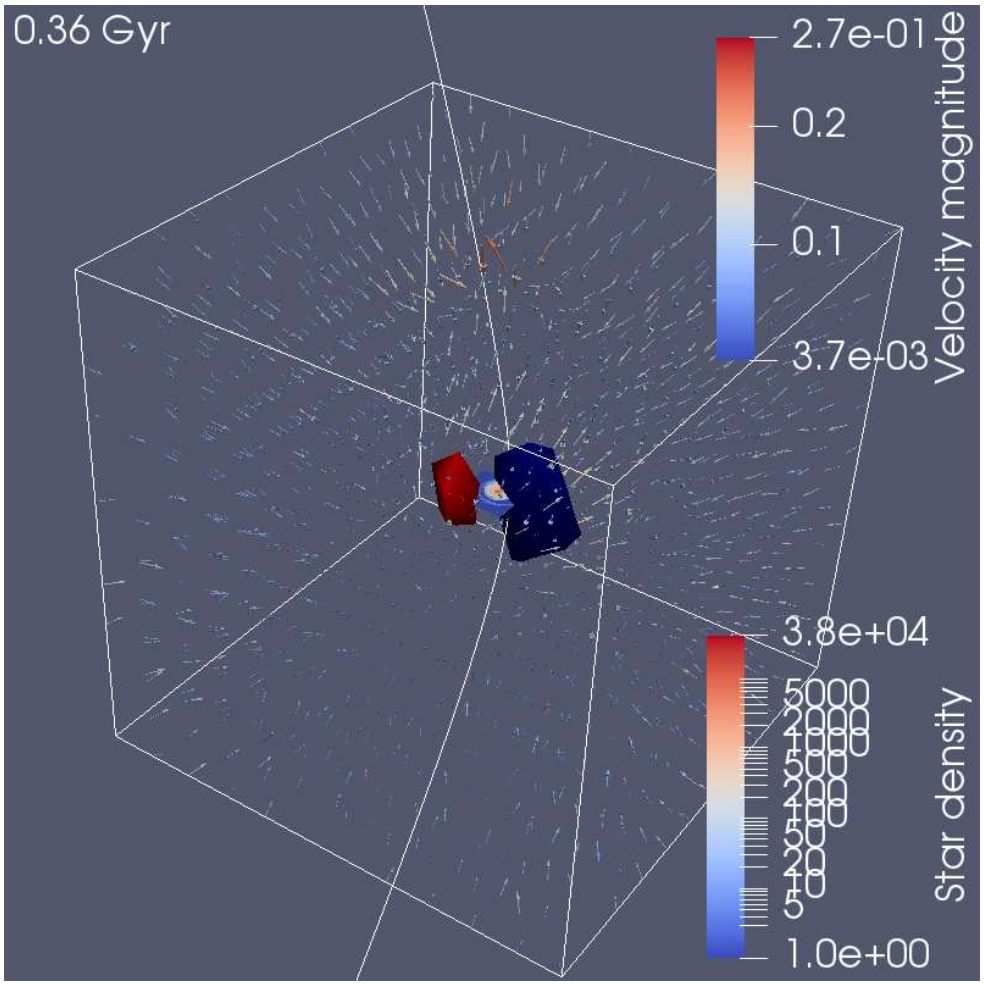
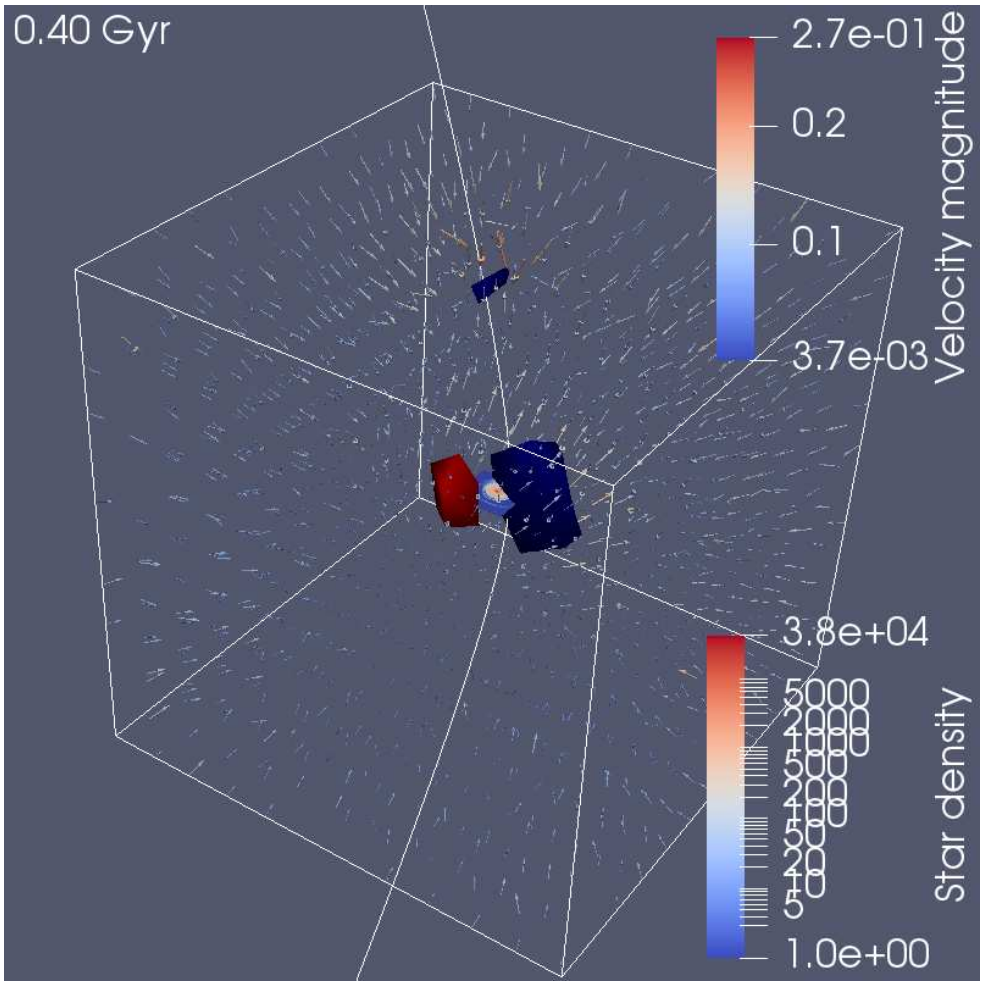


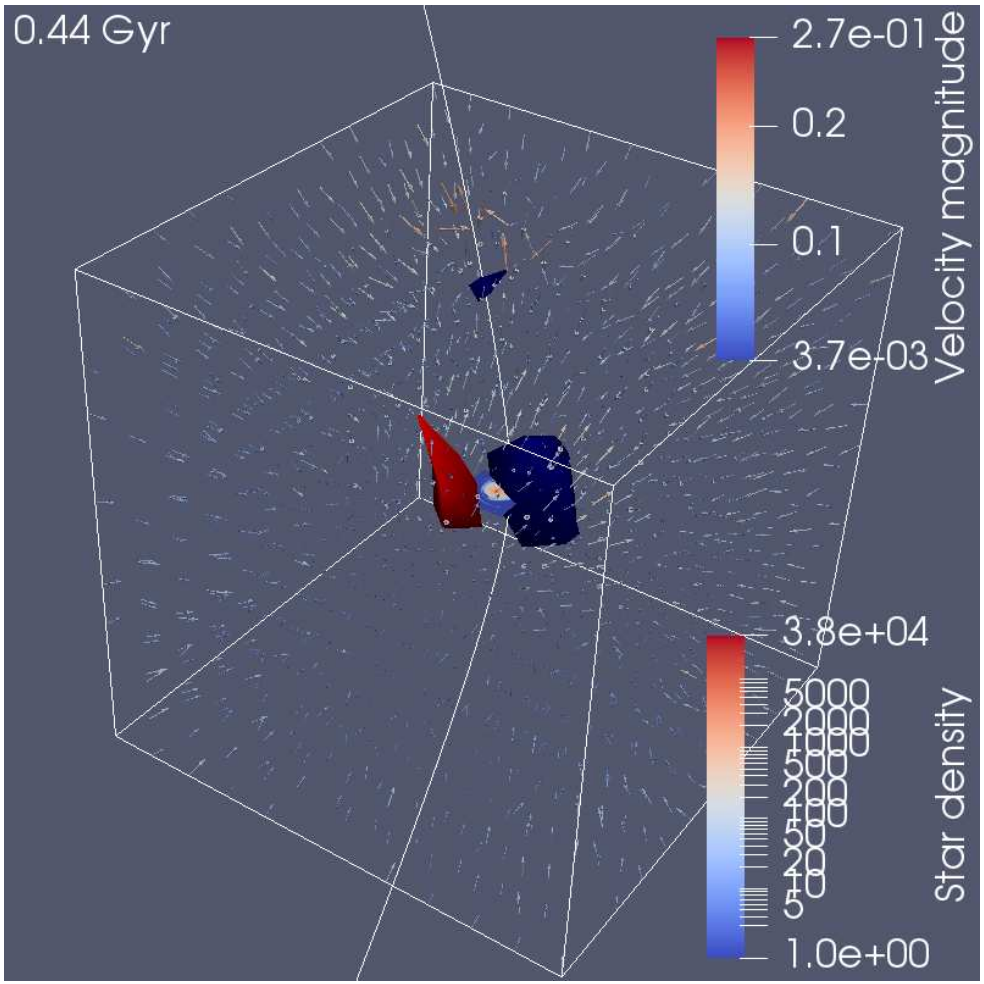
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



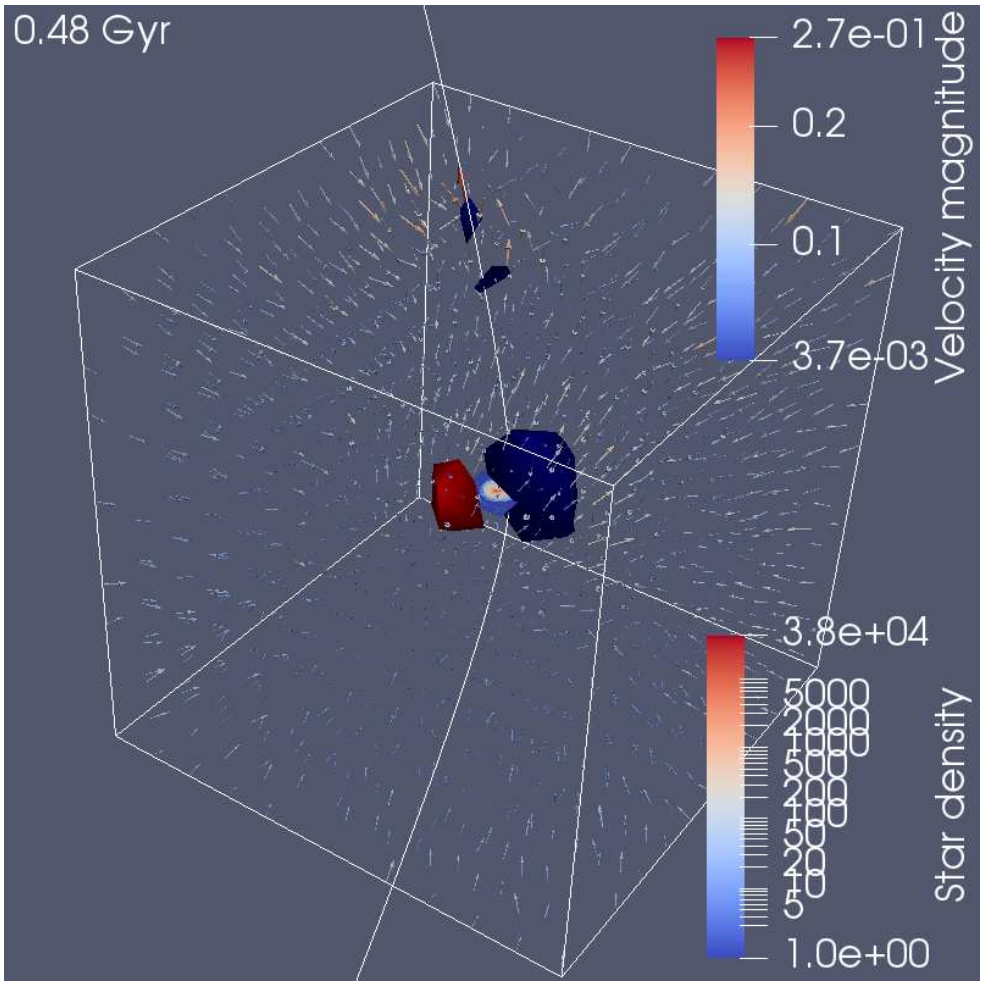
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



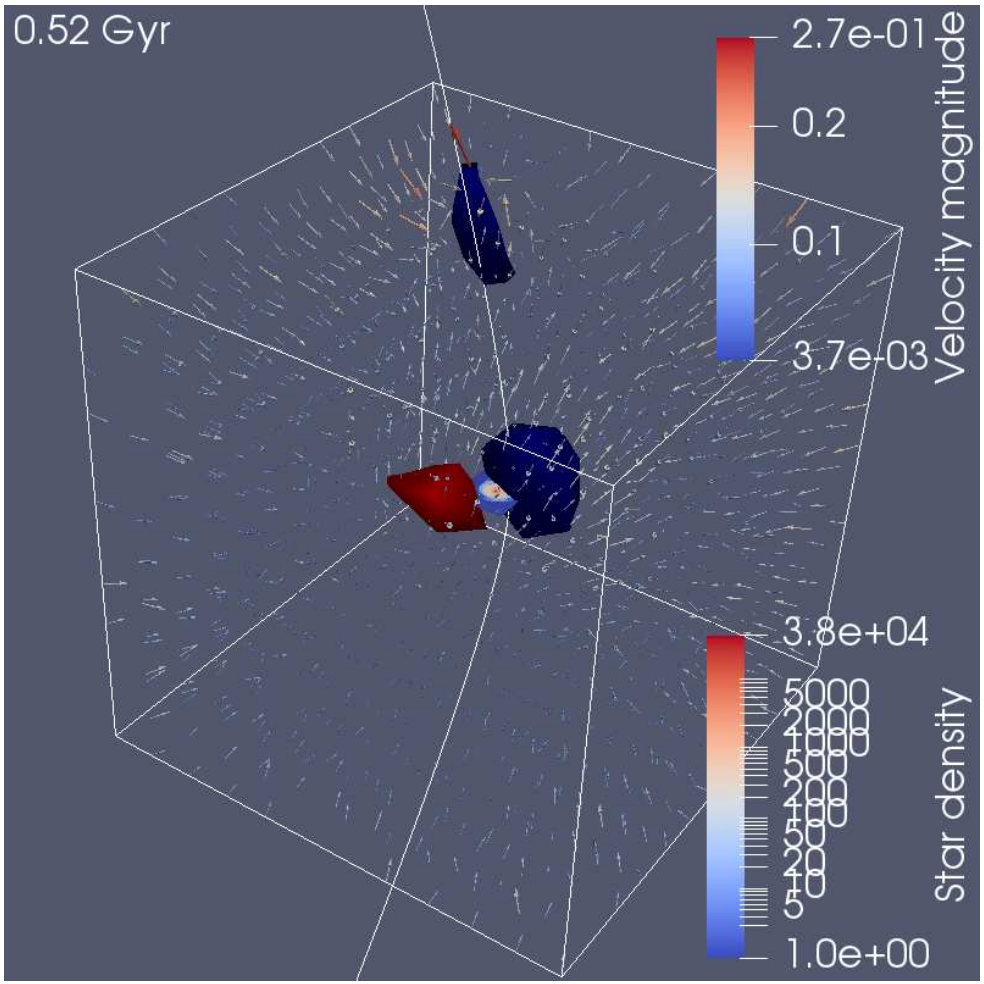
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



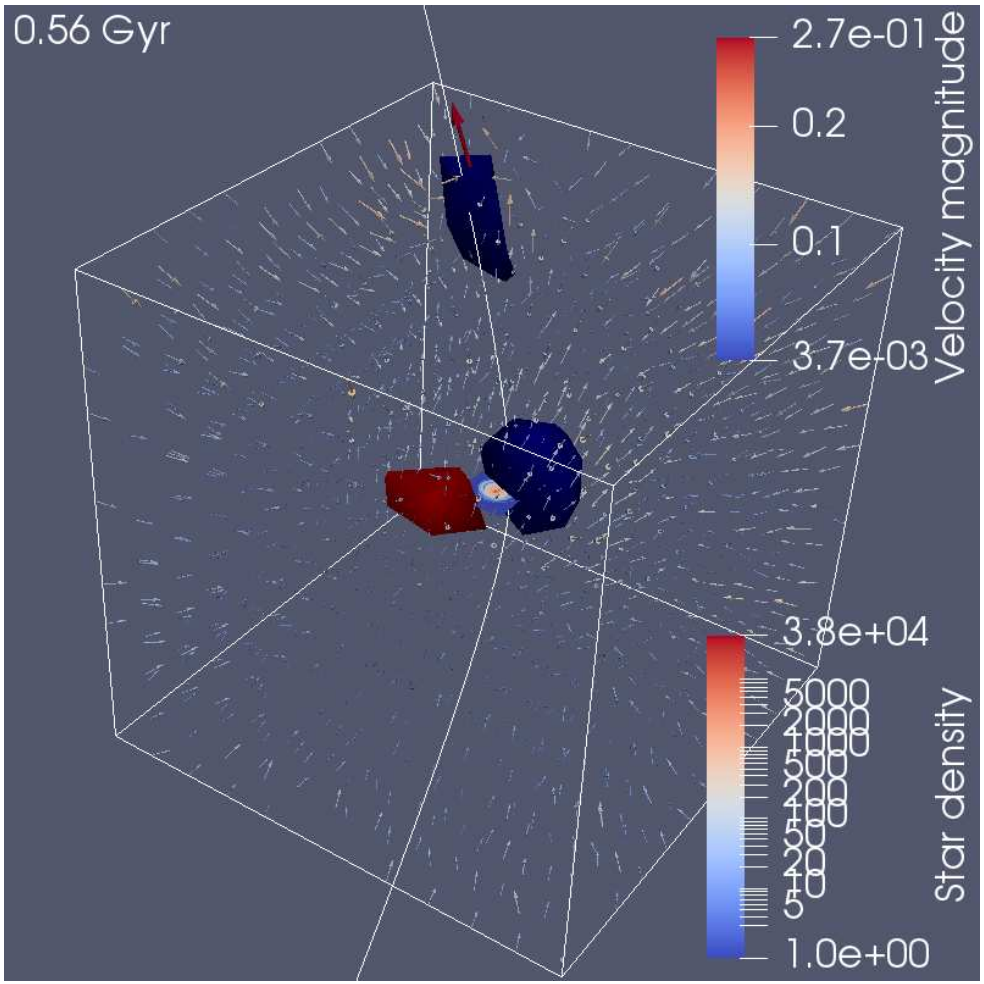
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



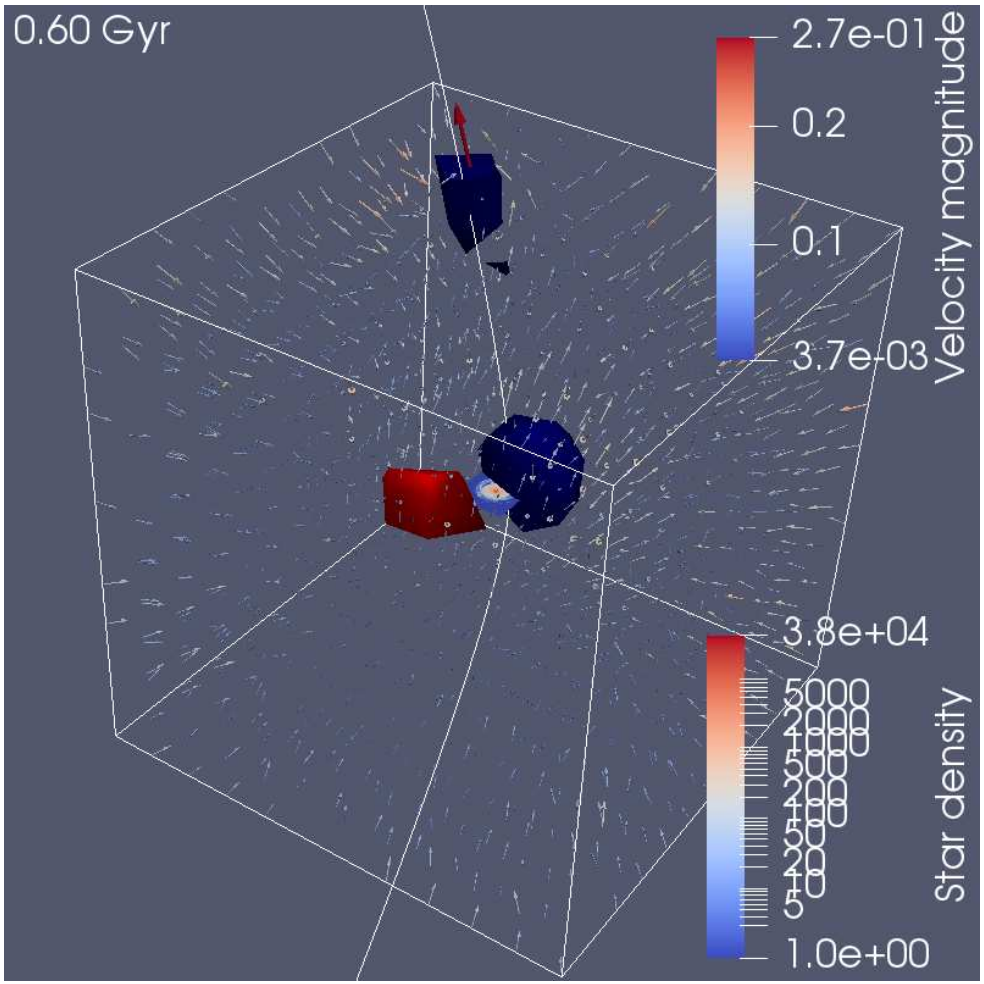
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



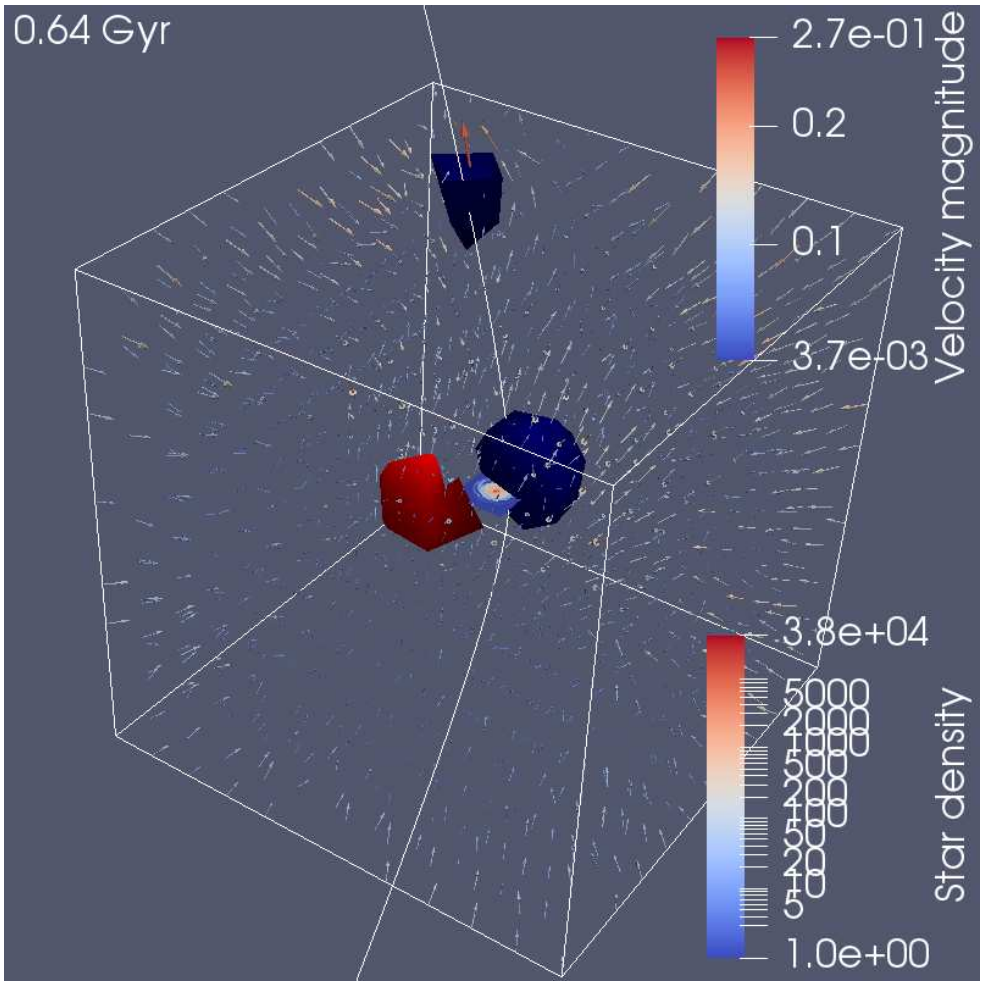
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



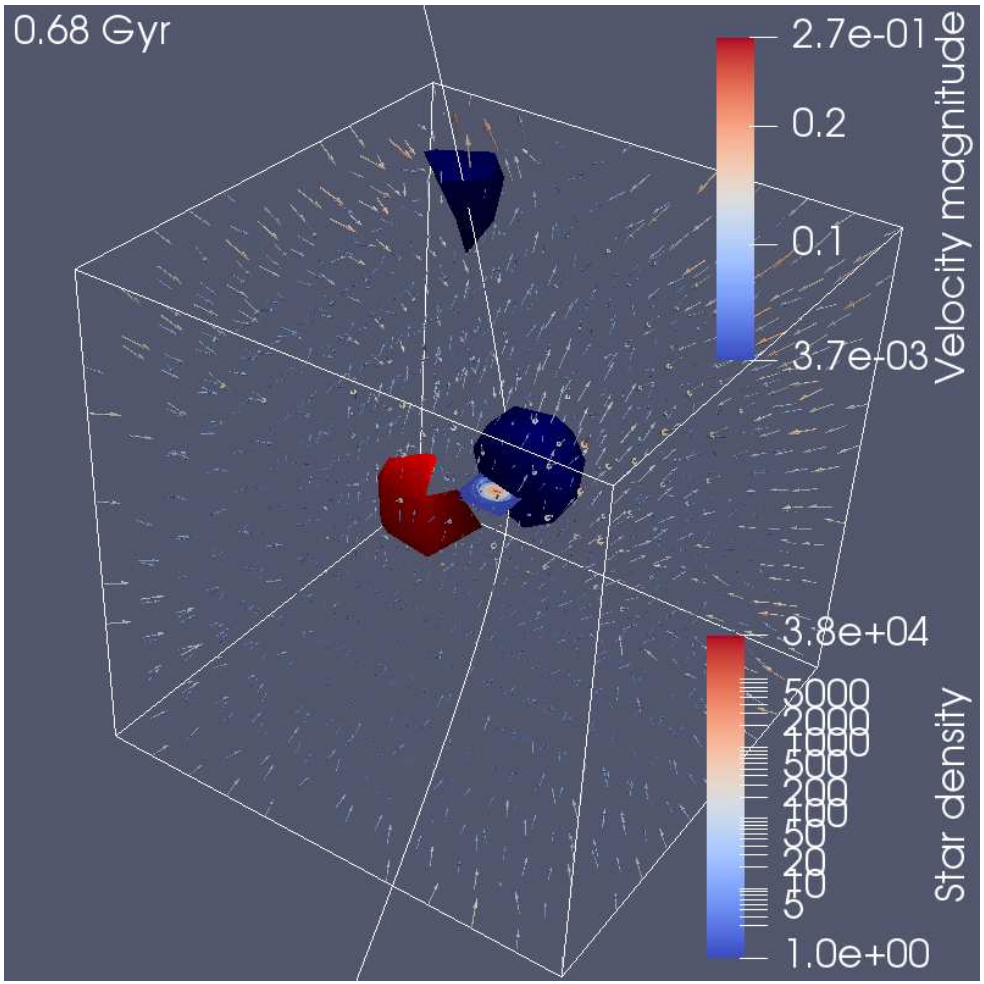
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



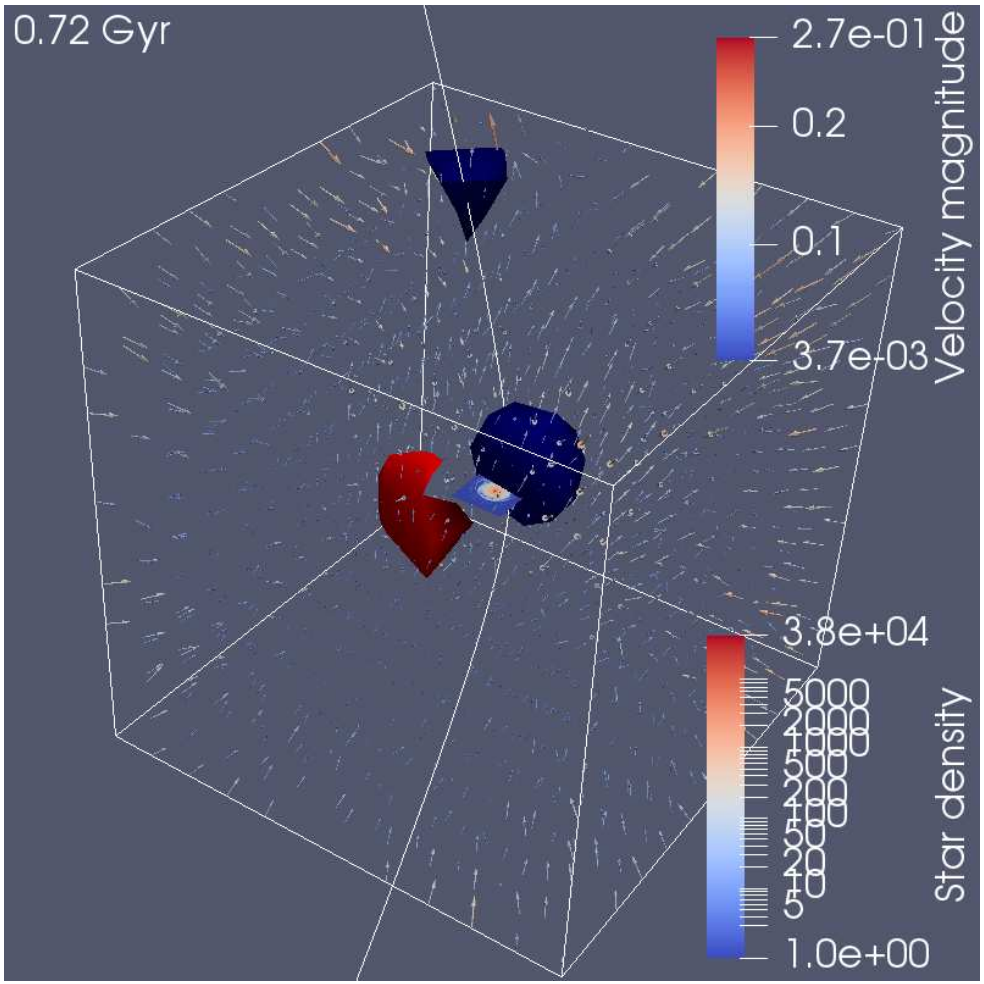
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



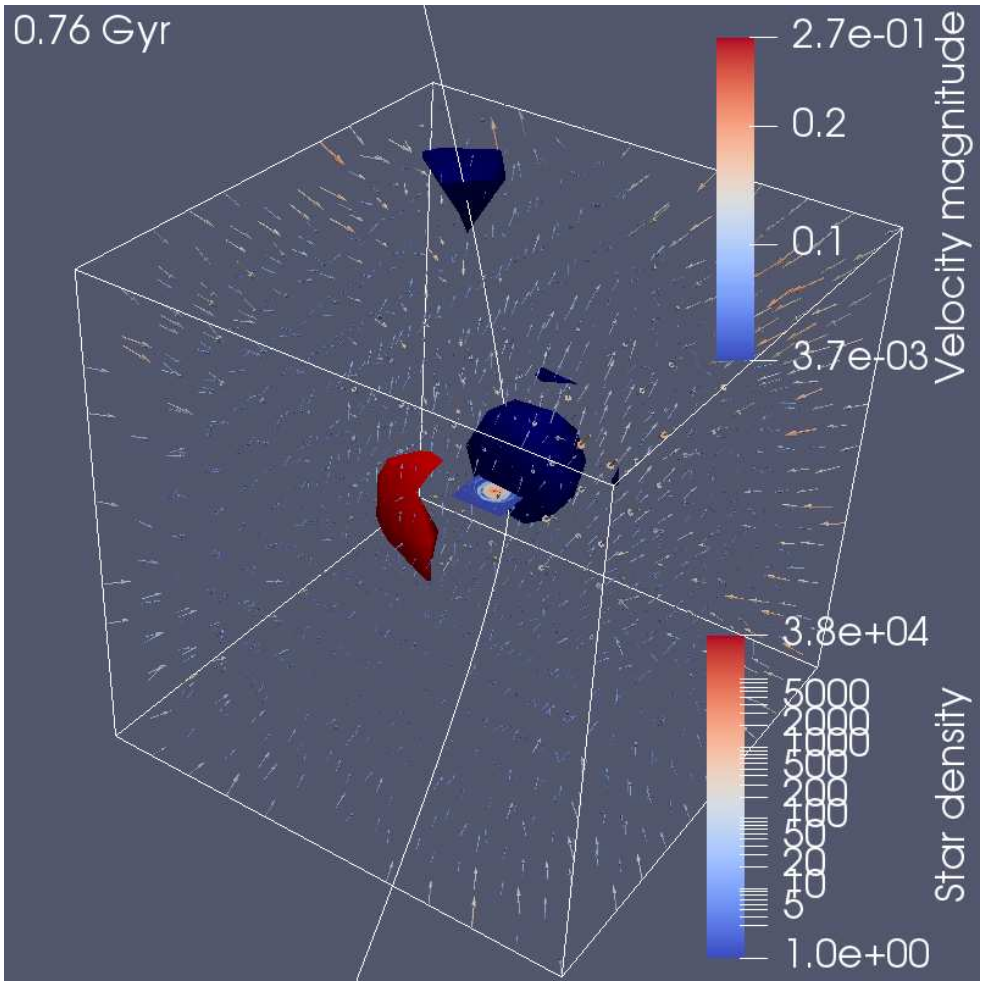
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



Satellite wake

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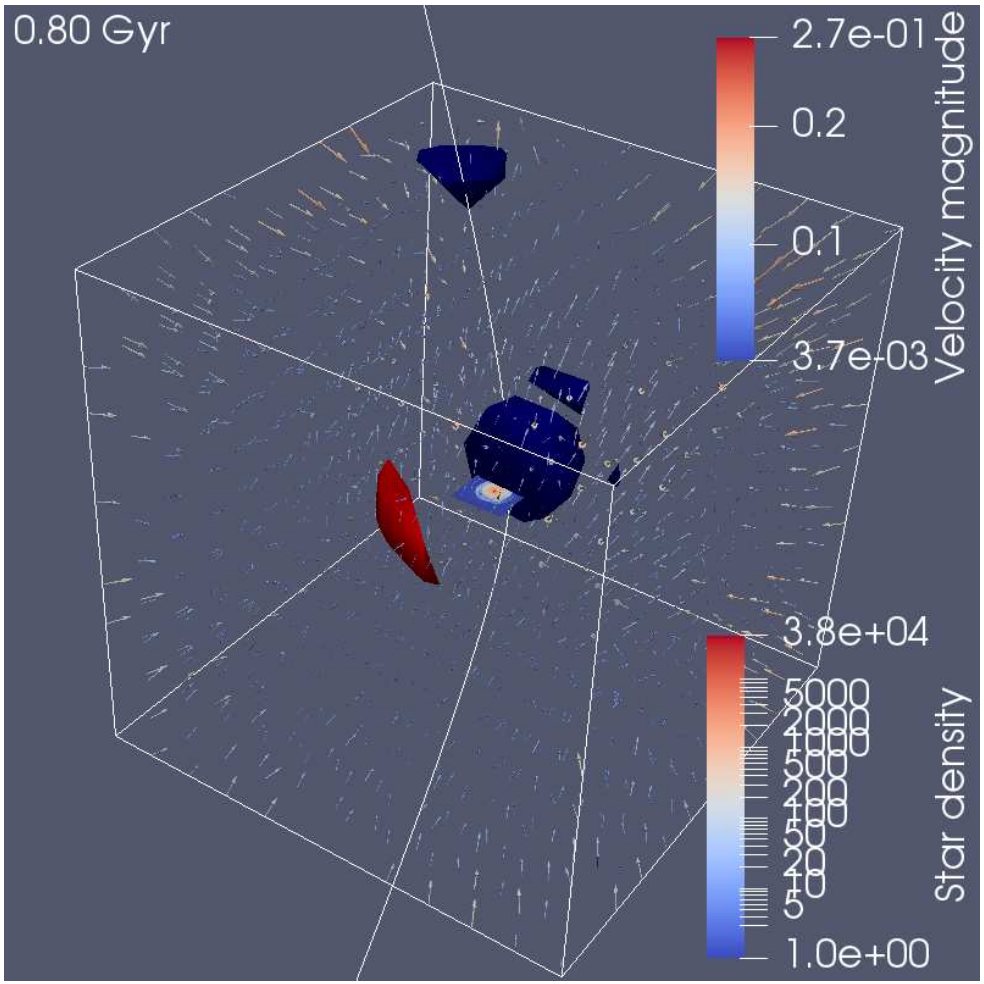
- First-passage orbit: see Garavito-Carmargo et al. 2019



Satellite wake

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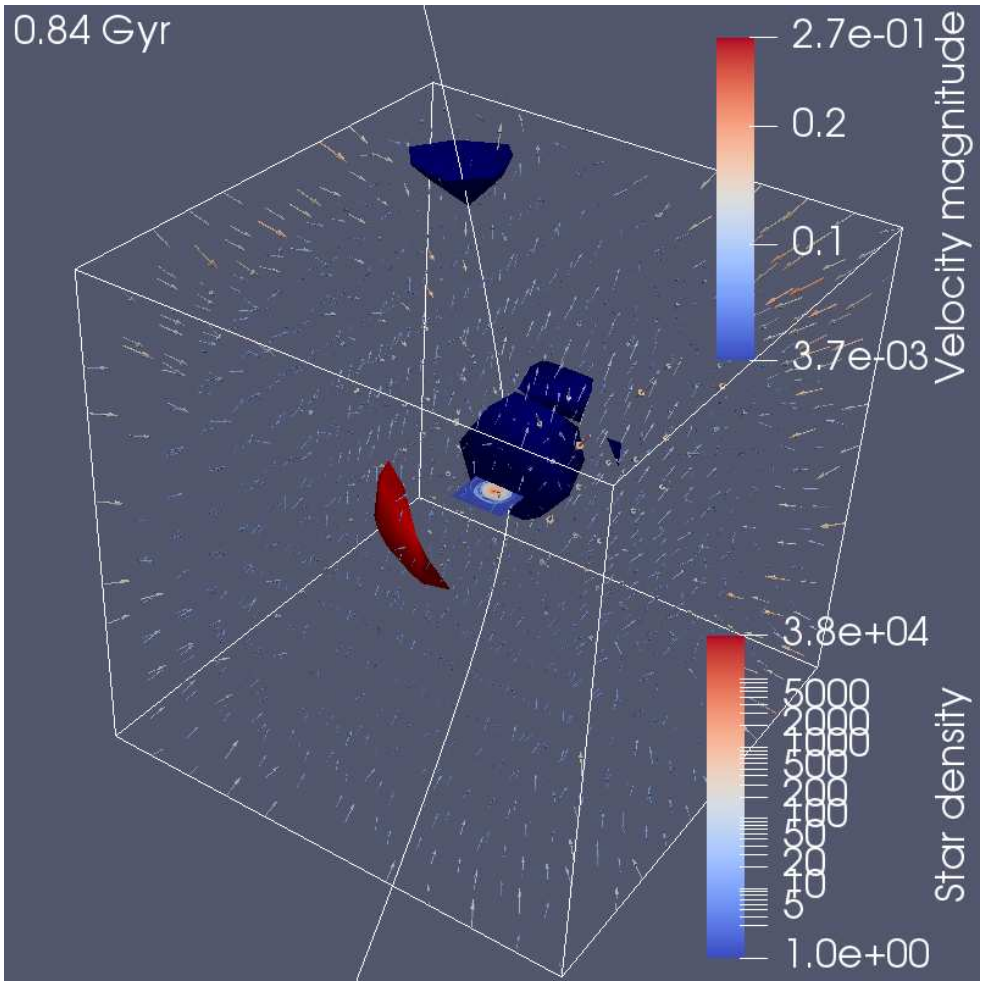
- First-passage orbit: see Garavito-Carmargo et al. 2019



Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
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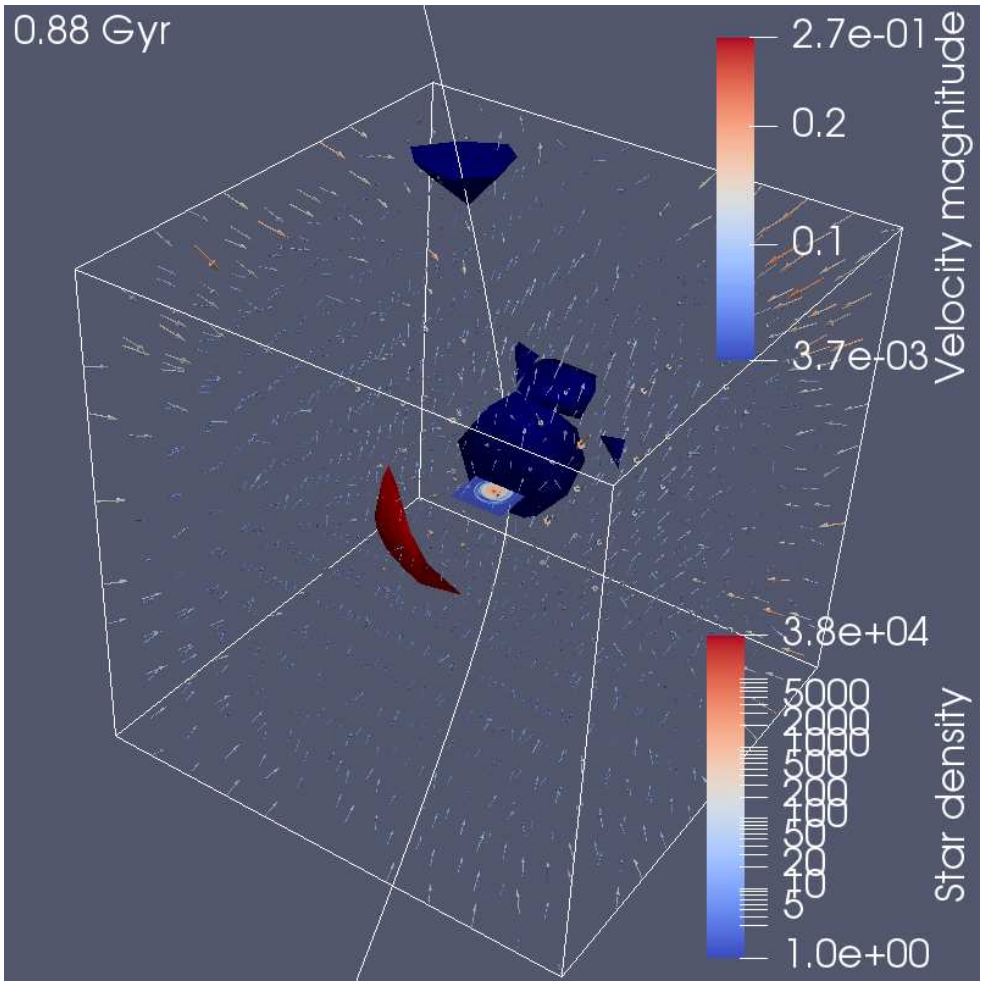
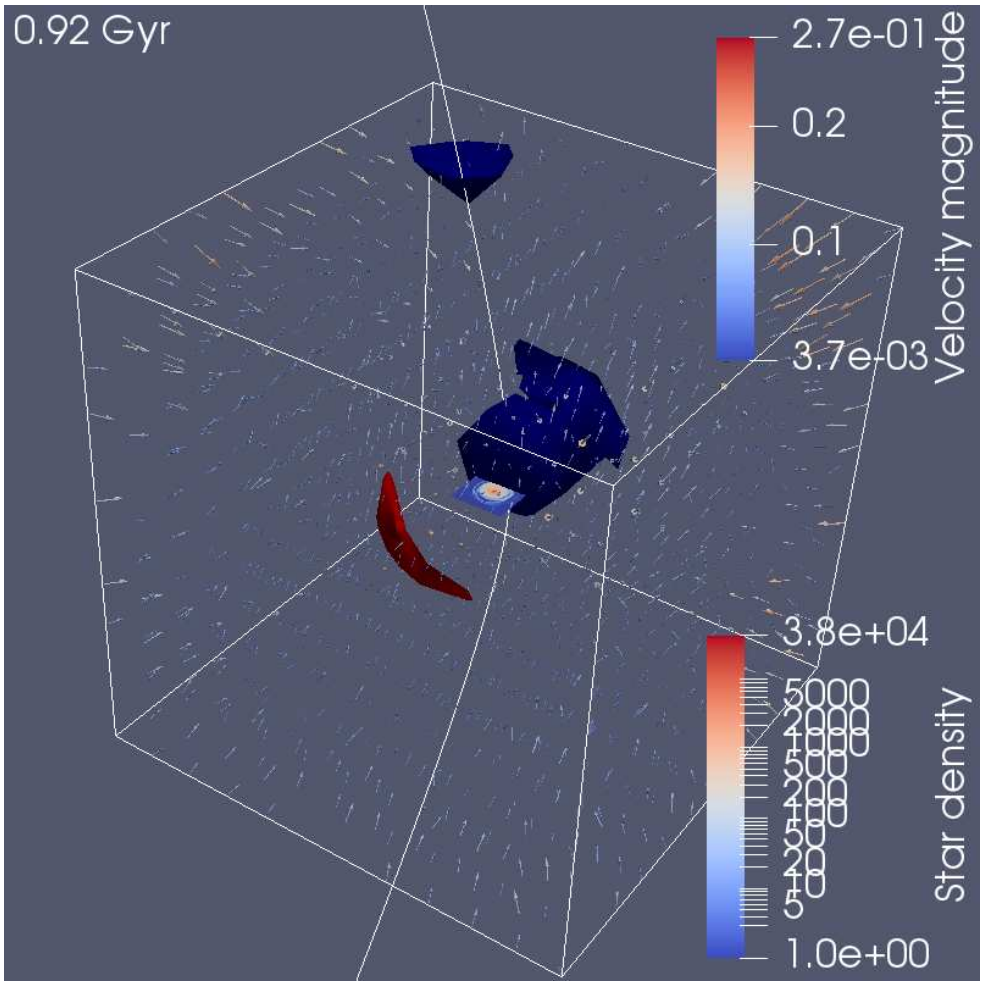


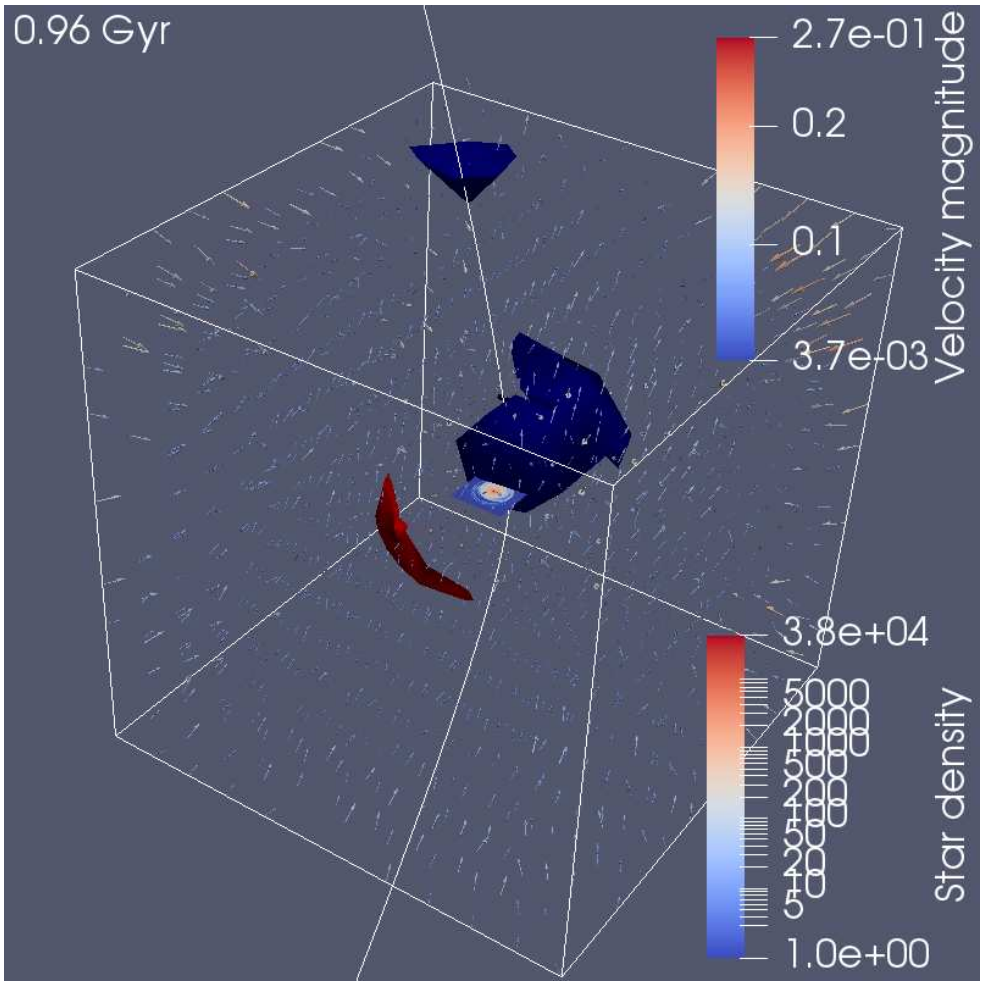
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



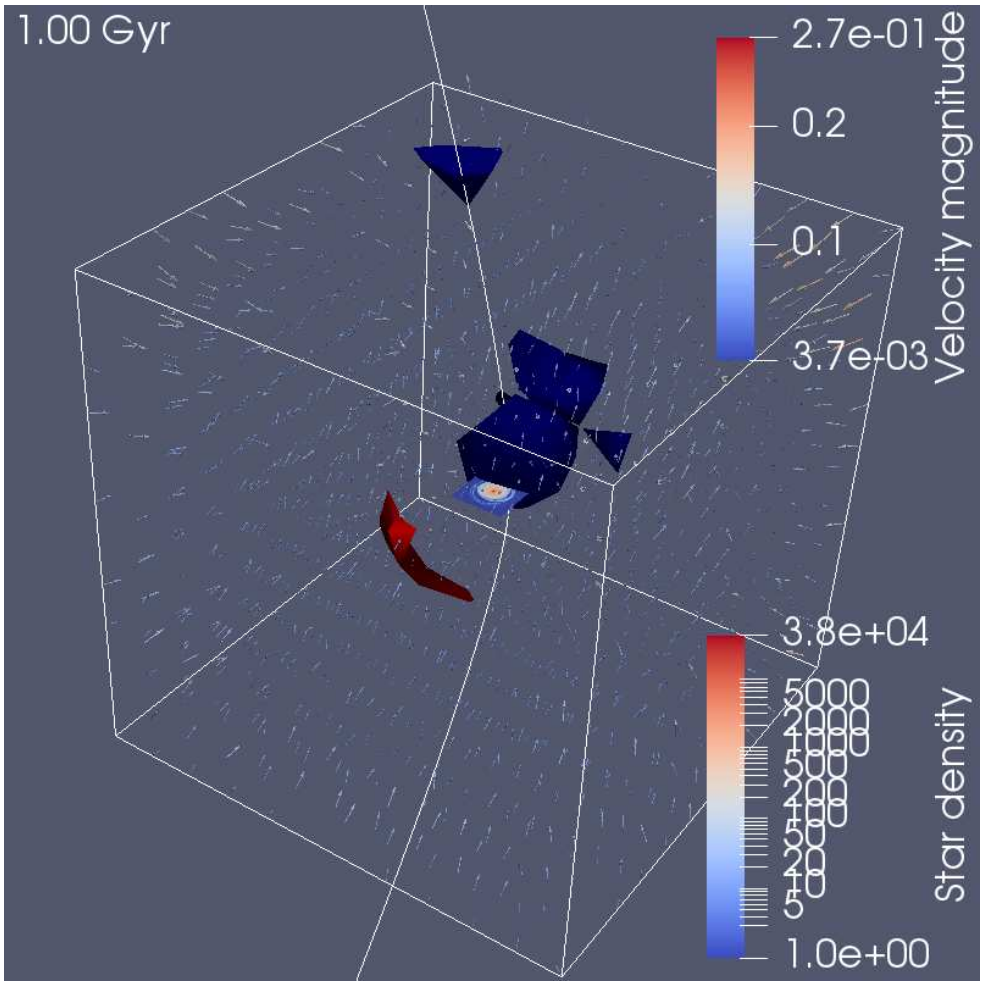
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



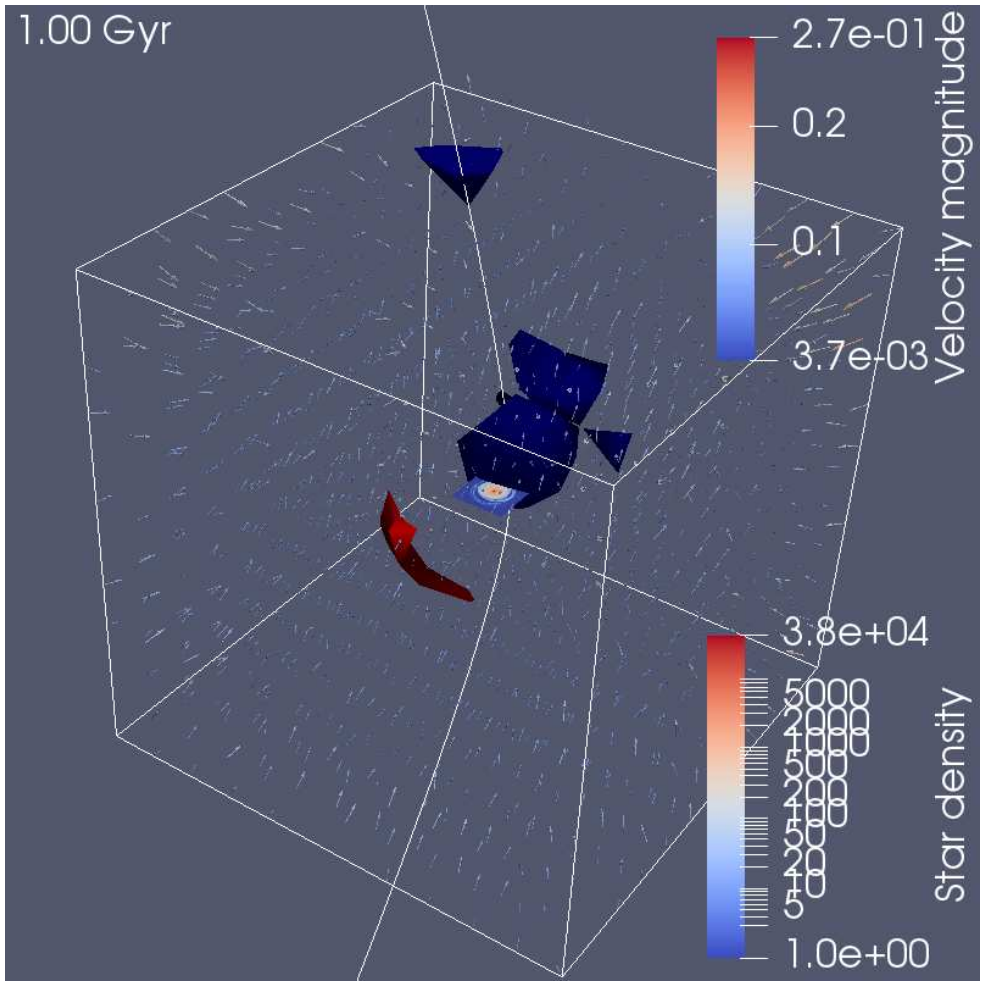
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit: see Garavito-Carmargo et al. 2019



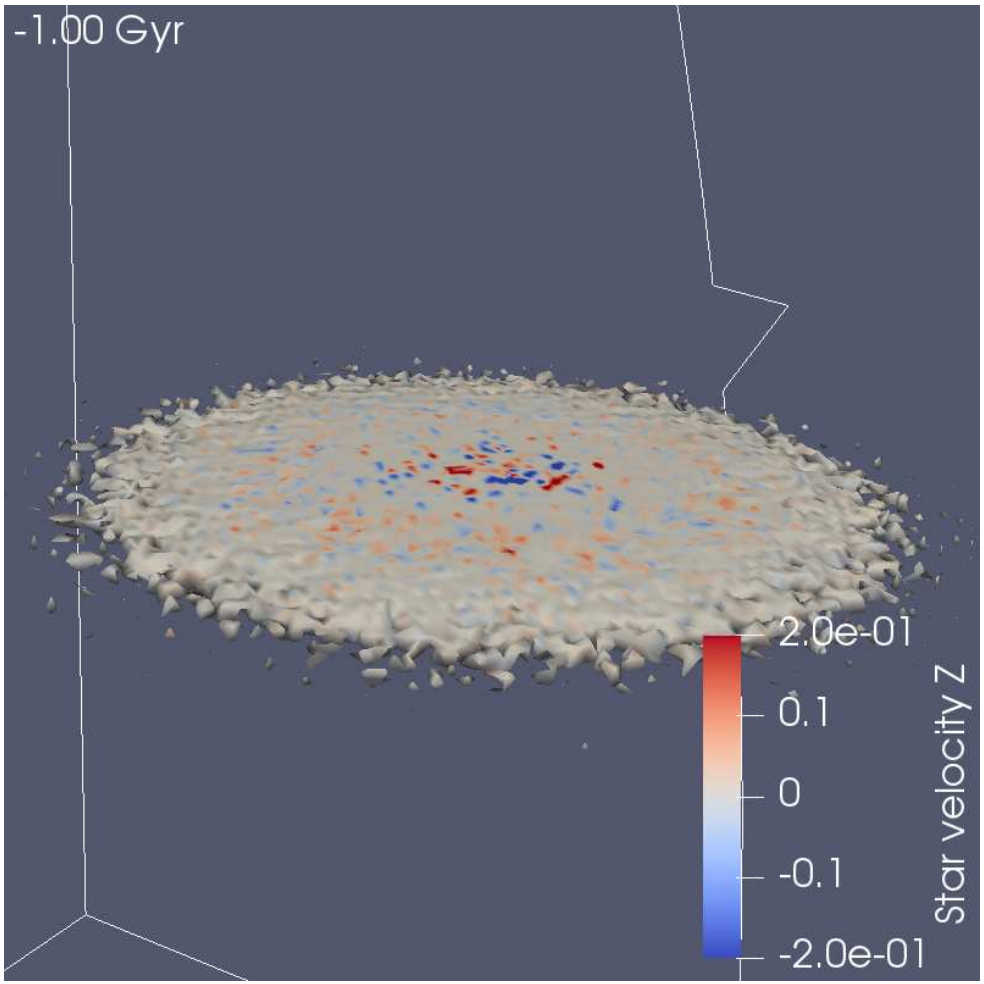
- Multiple-passage LMC orbit has strong damped mode with much less DF transient

Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit

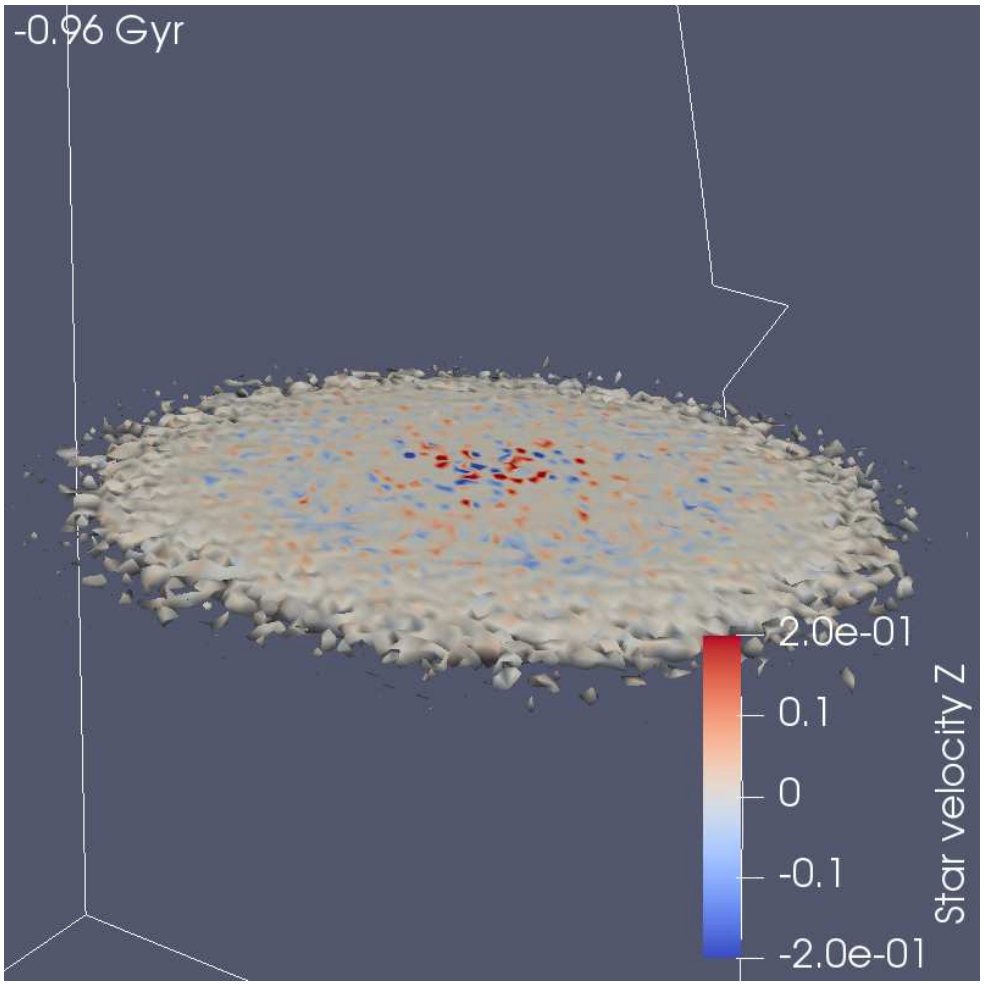
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit



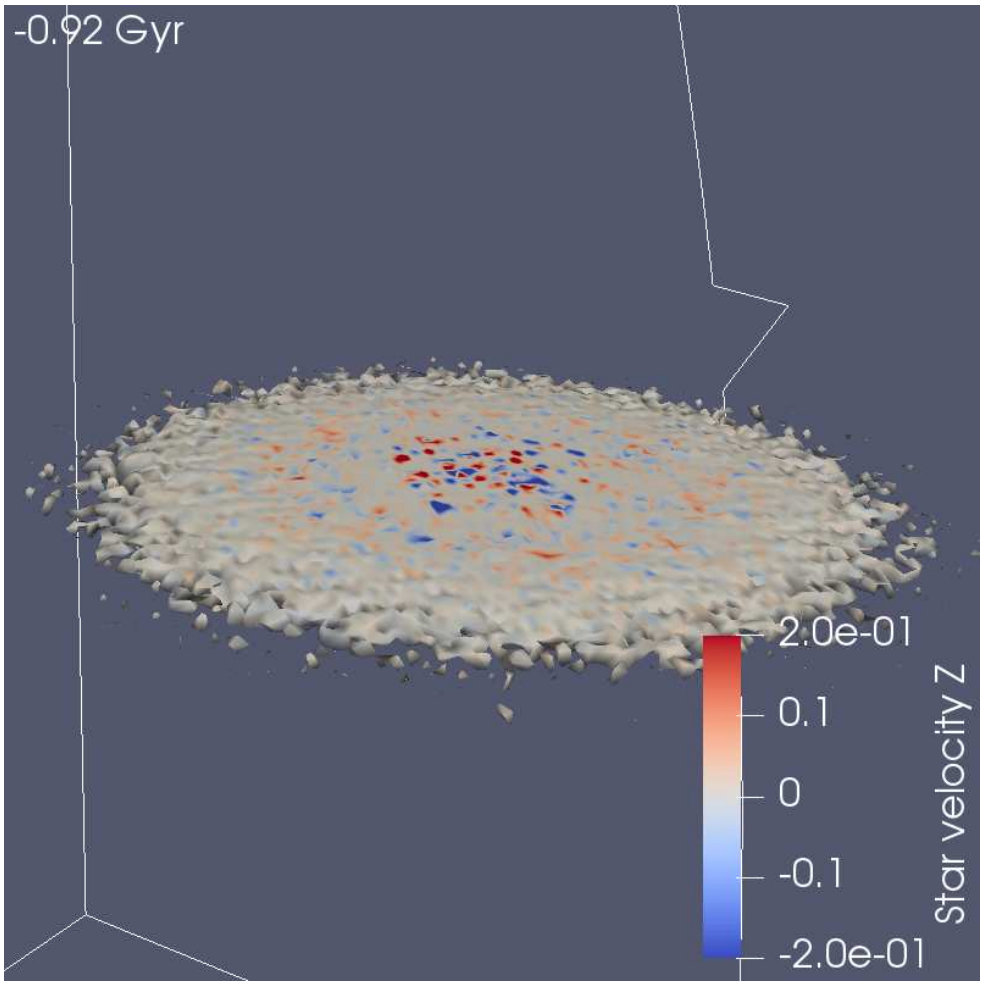
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit



Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit



Satellite wake

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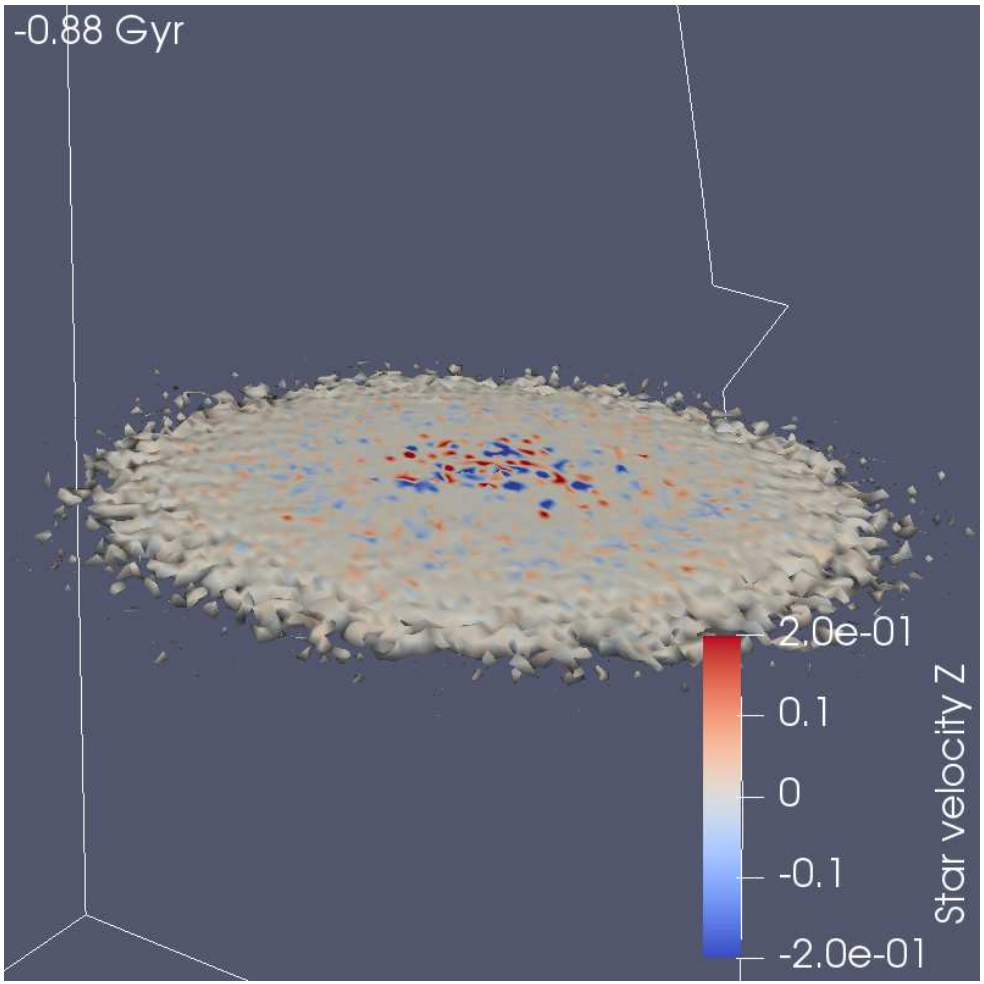
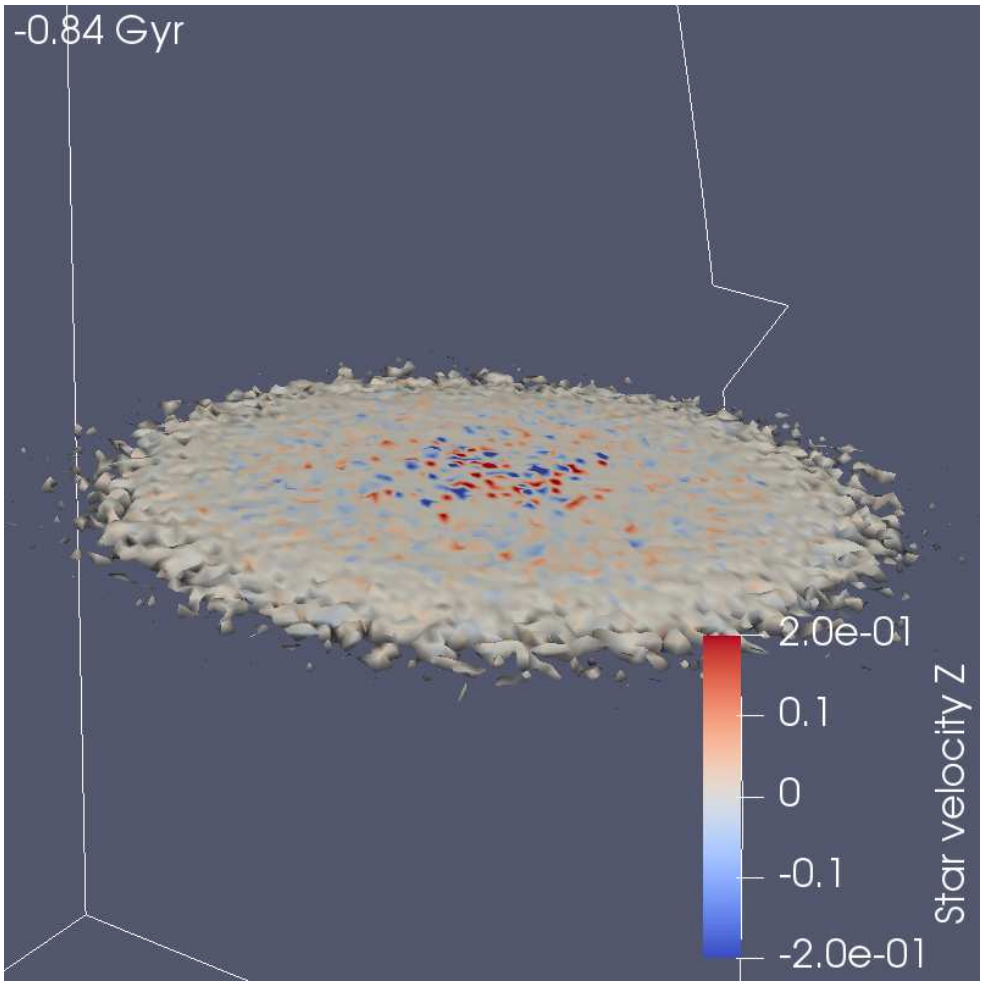
- First-passage orbit



Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit



Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
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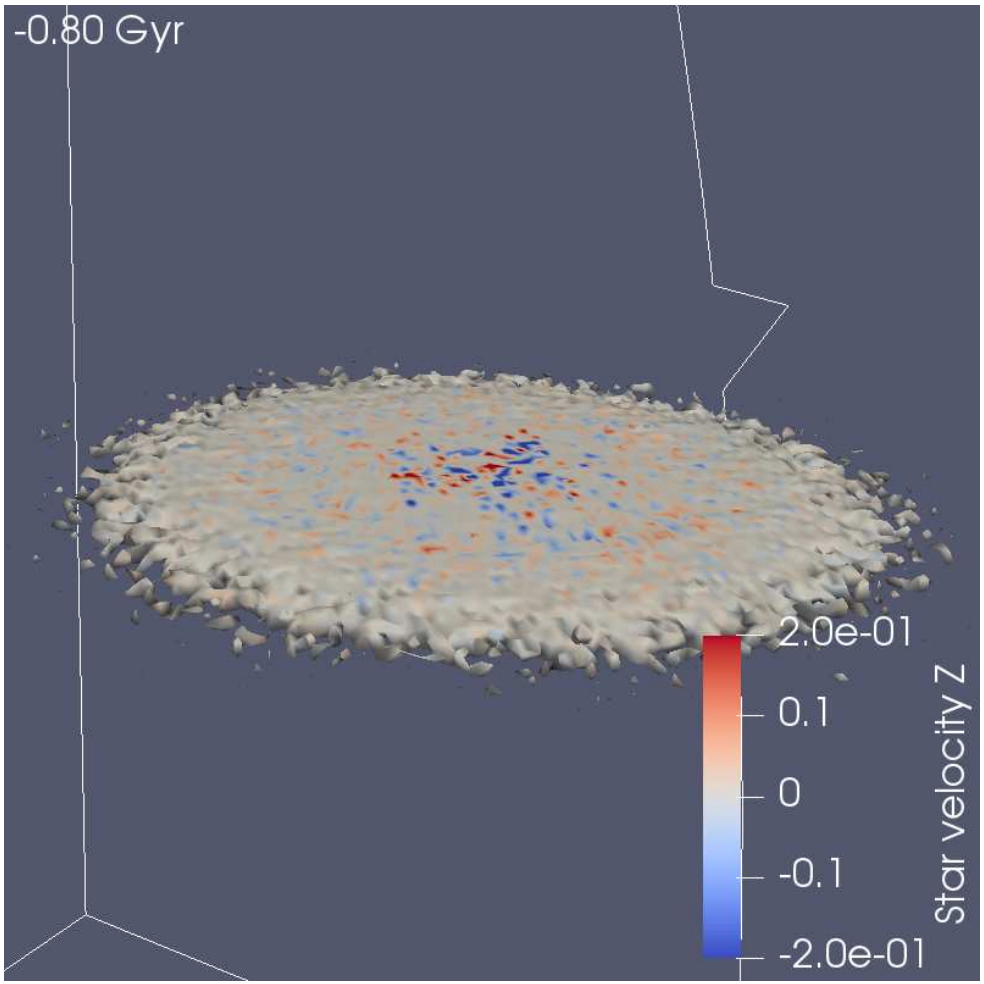

Satellite wake

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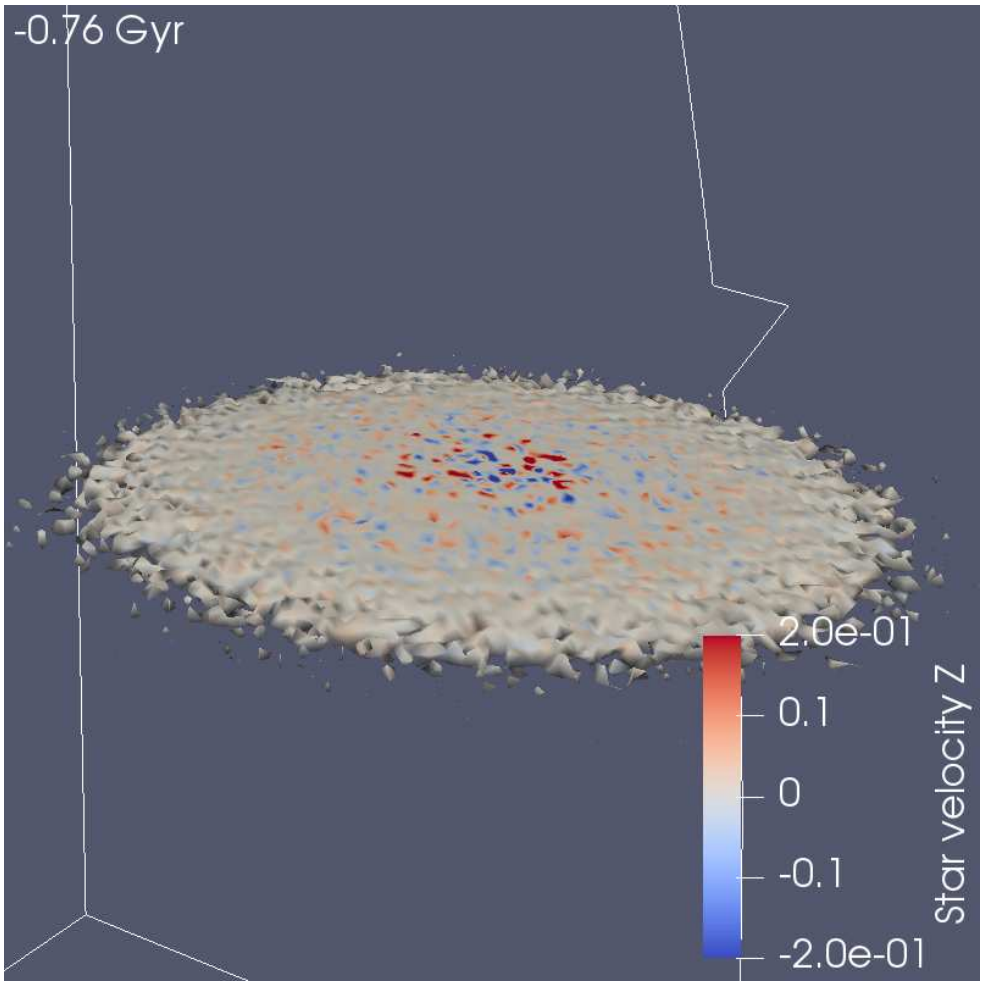

Satellite wake

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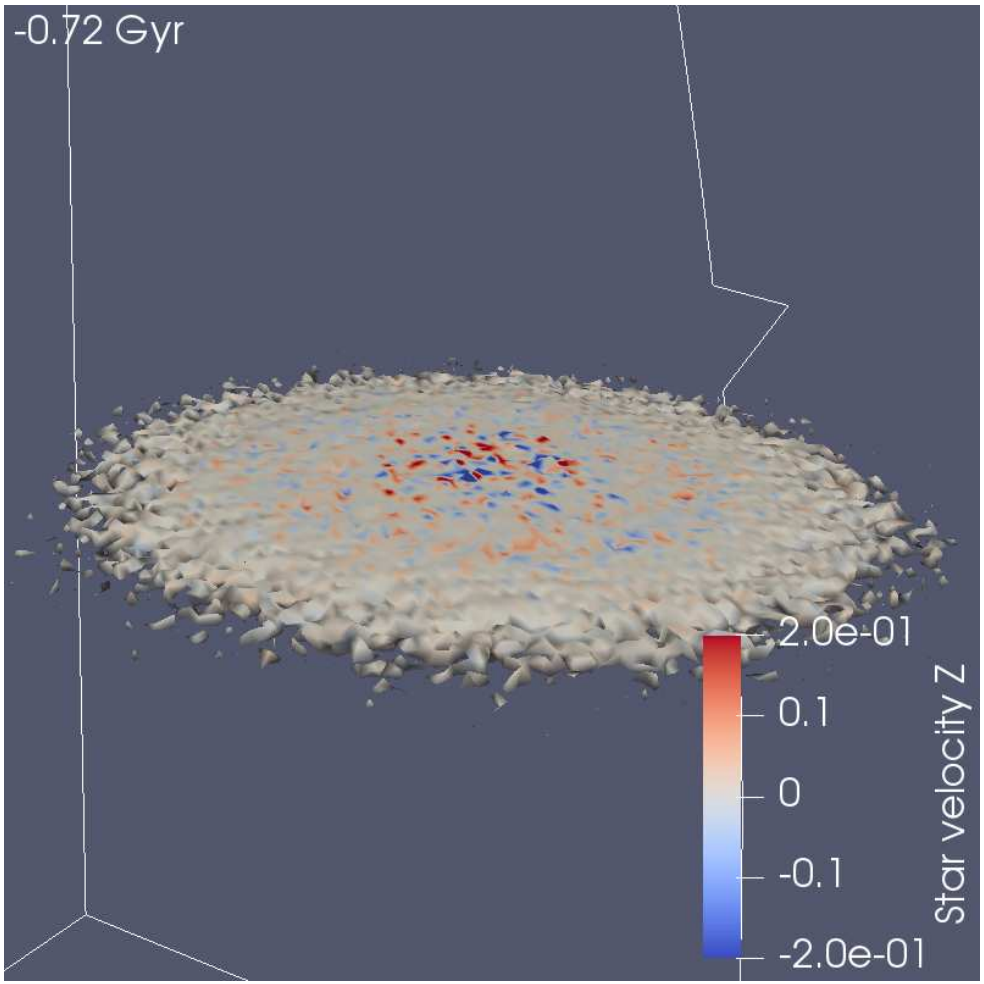
- First-passage orbit



Satellite wake

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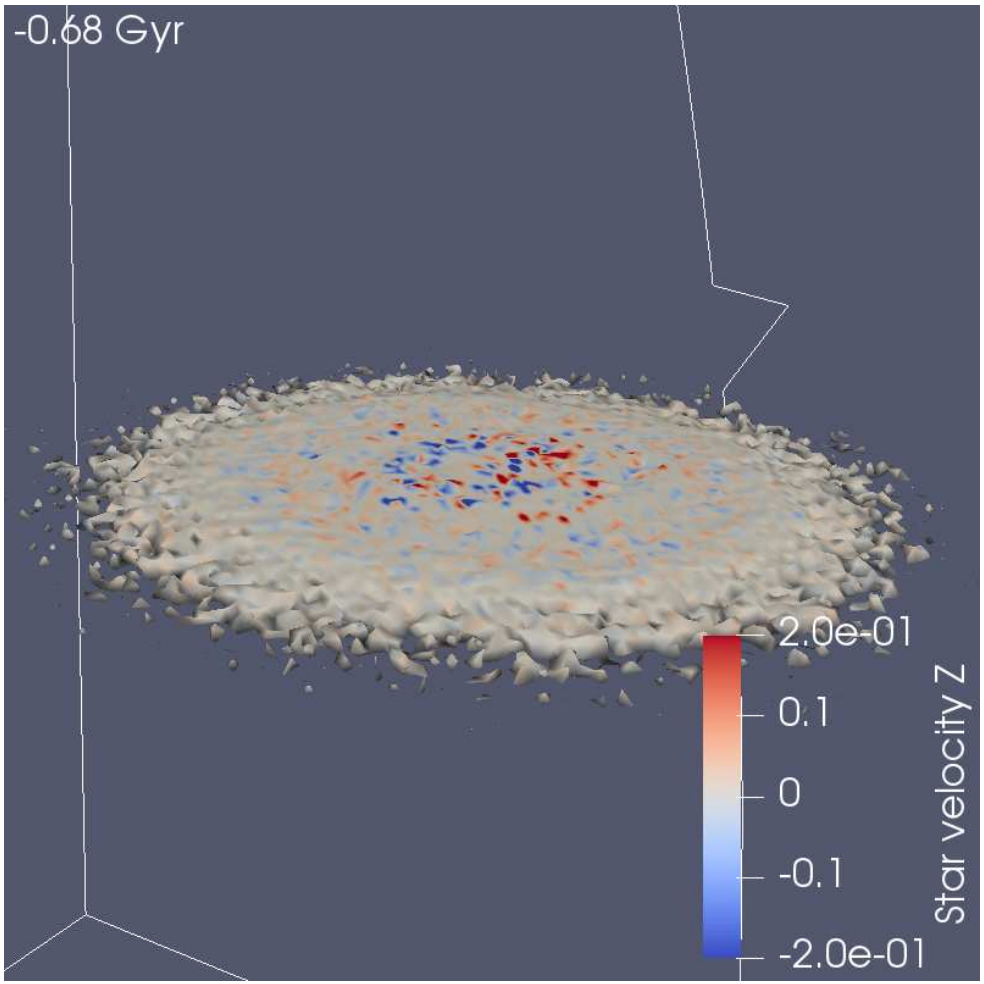

Satellite wake

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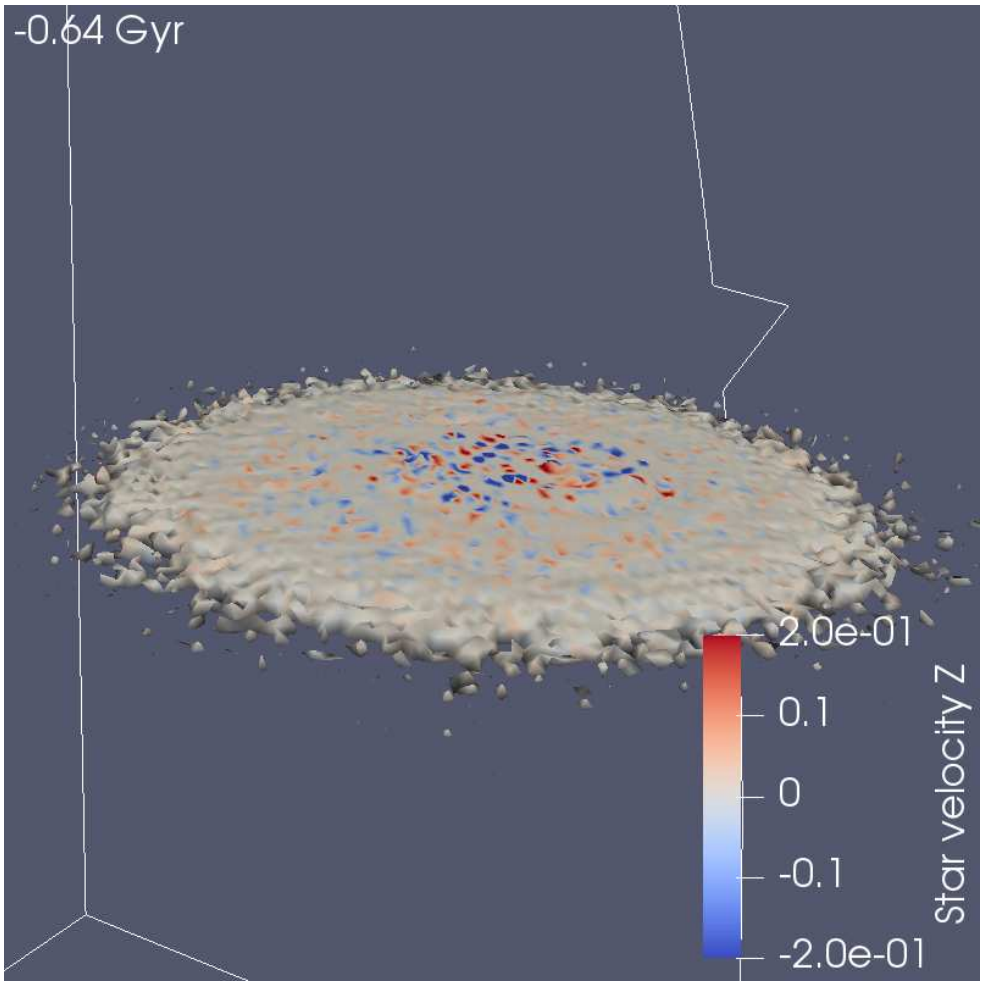

Satellite wake

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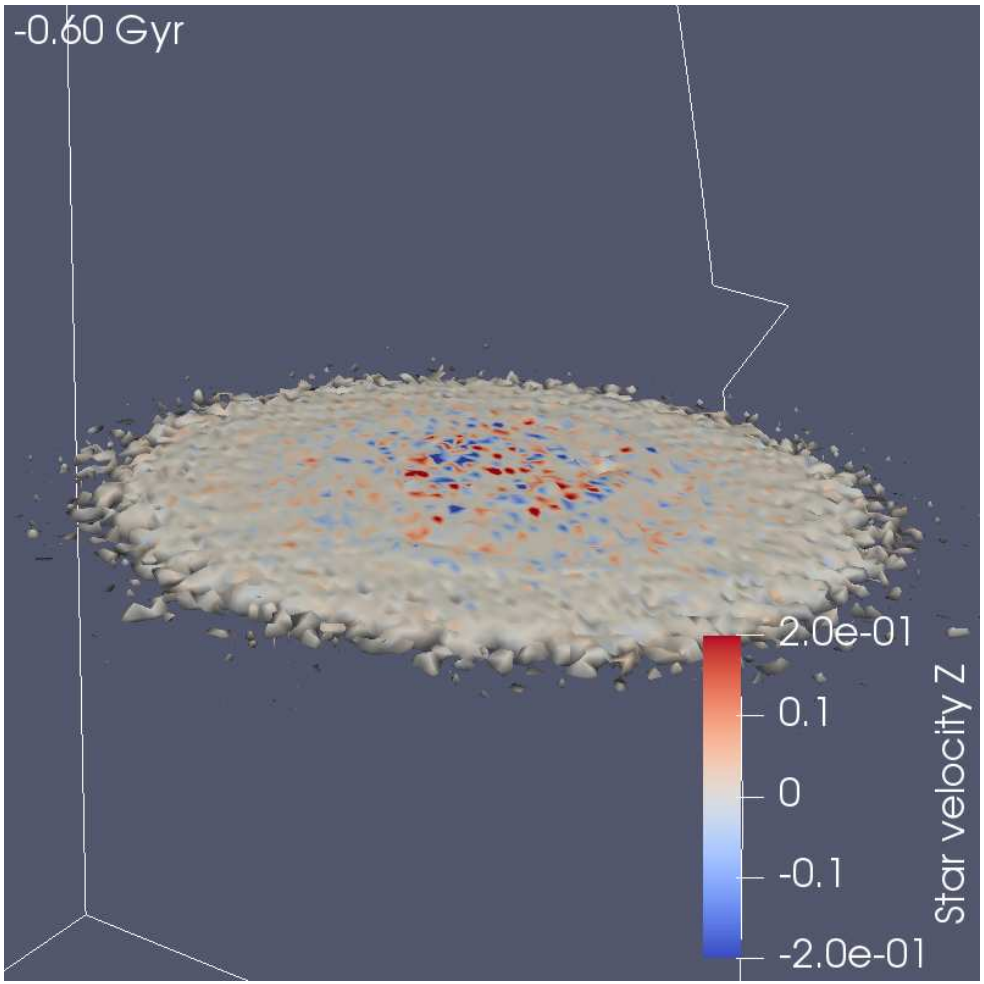

Satellite wake

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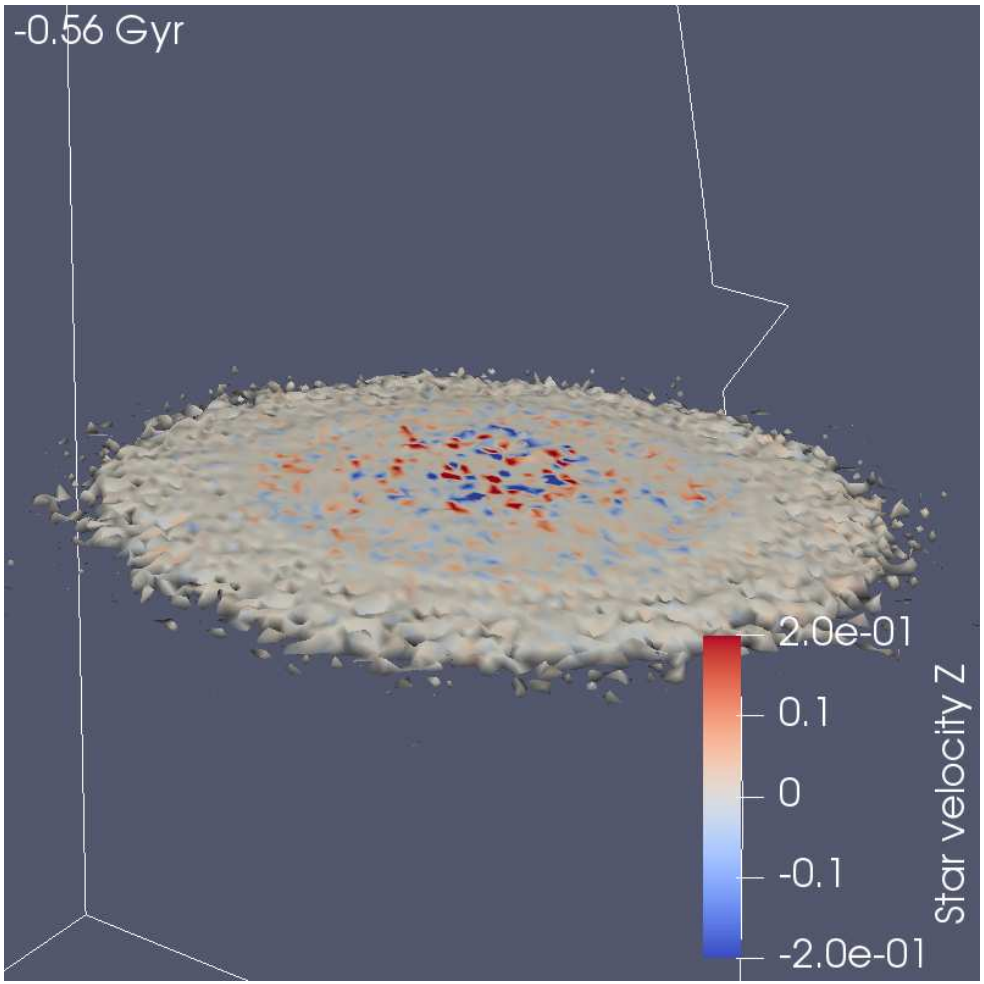

Satellite wake

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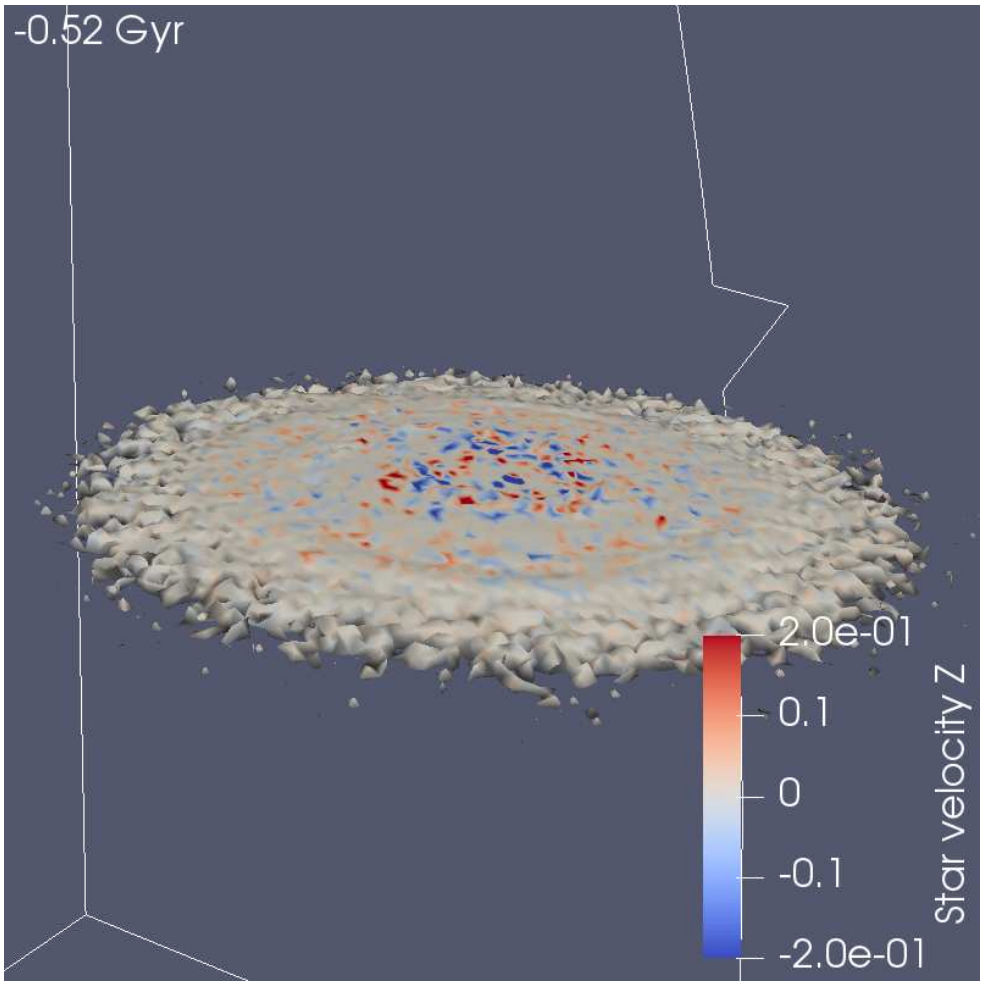

Satellite wake

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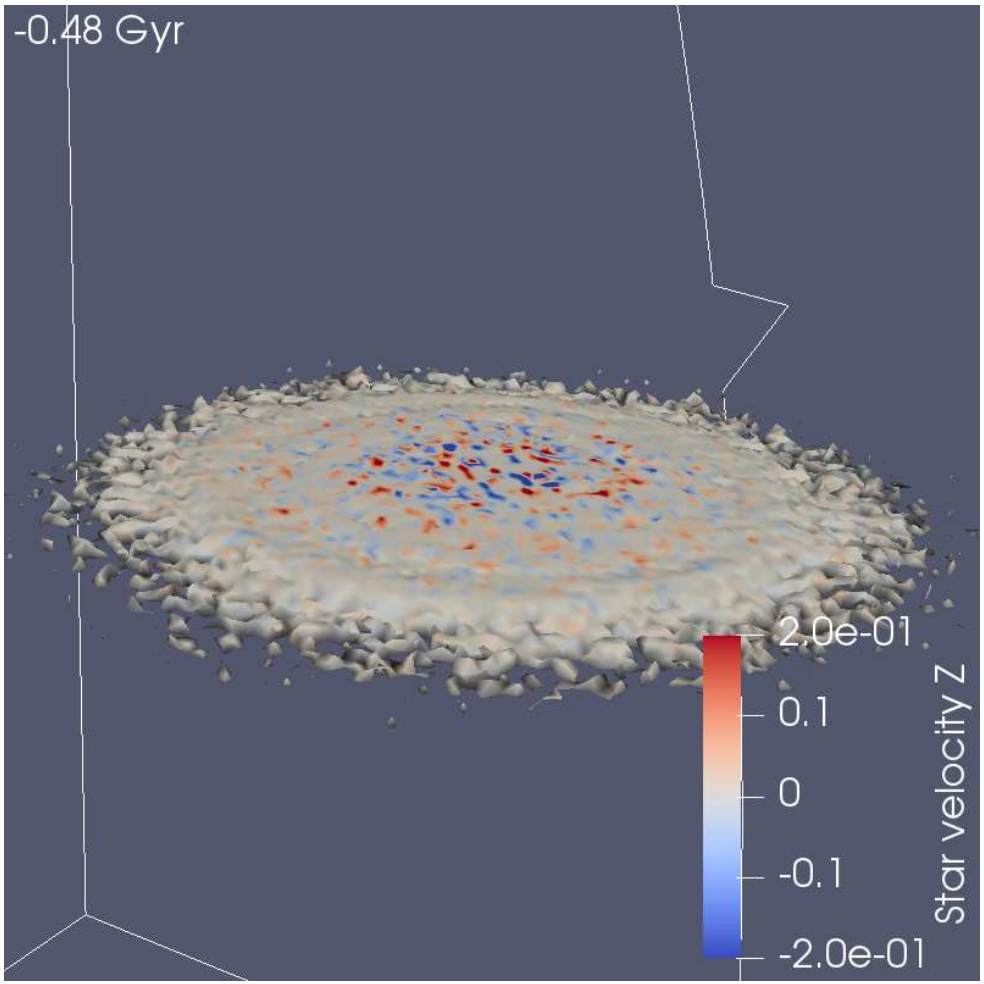

Satellite wake

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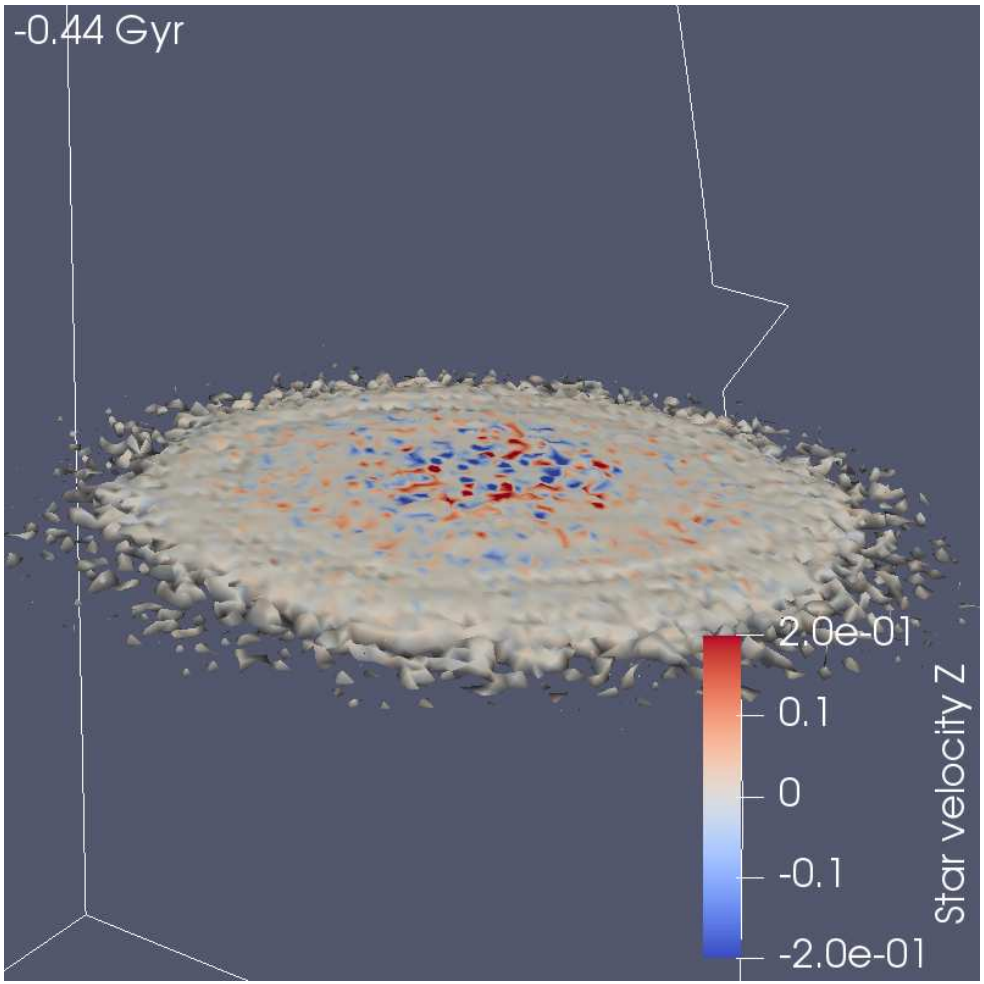

Satellite wake

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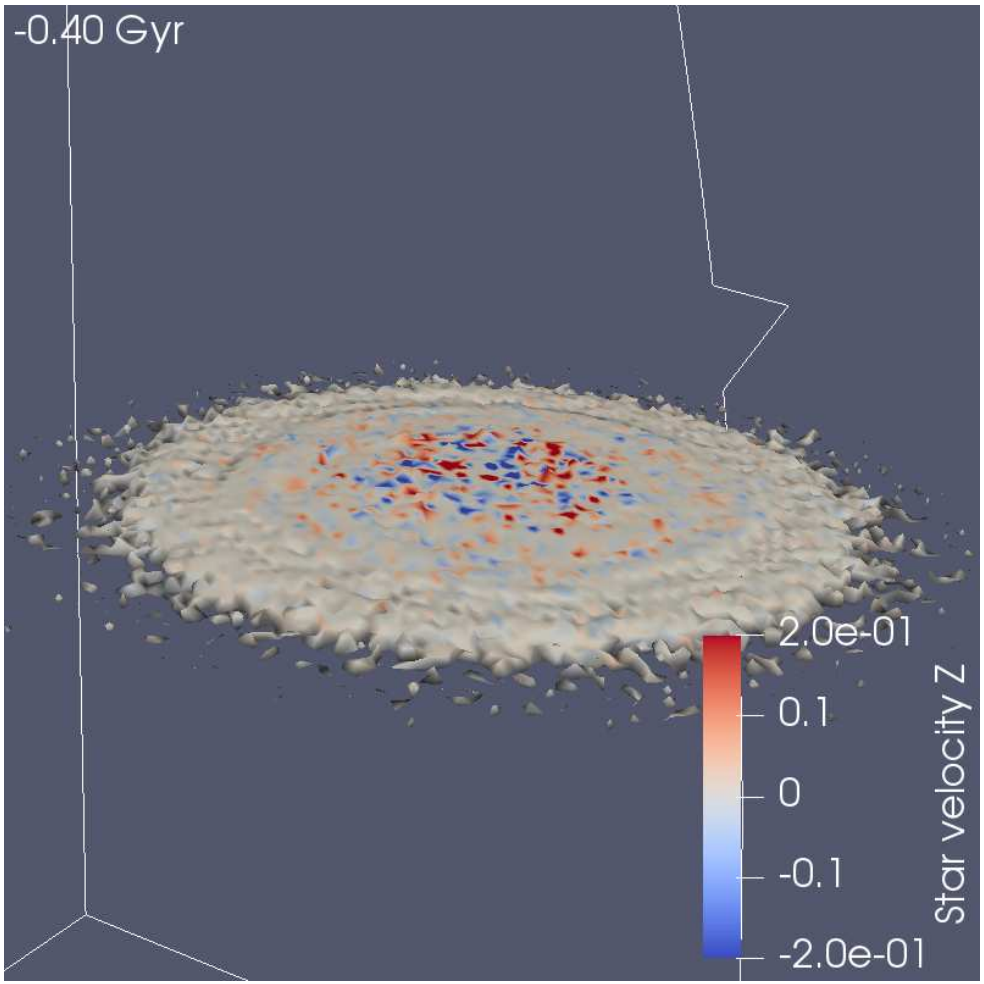

Satellite wake

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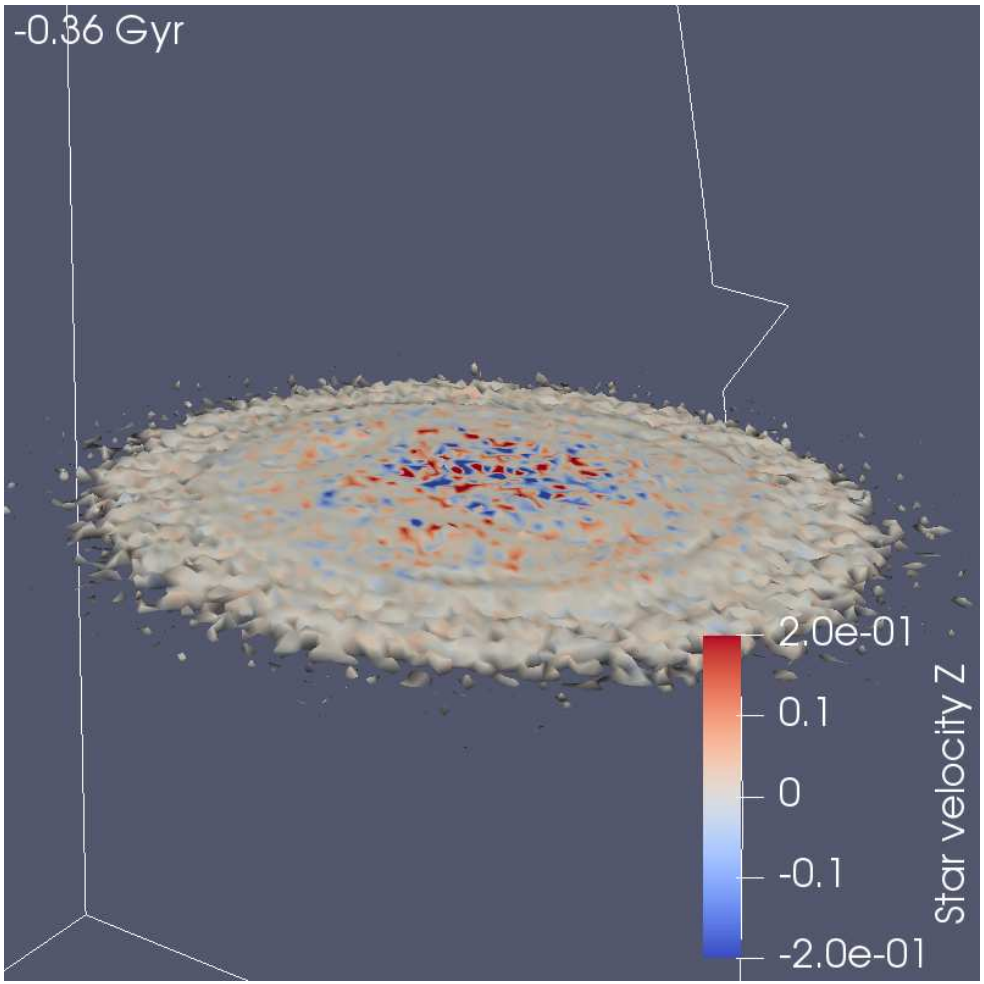

Satellite wake

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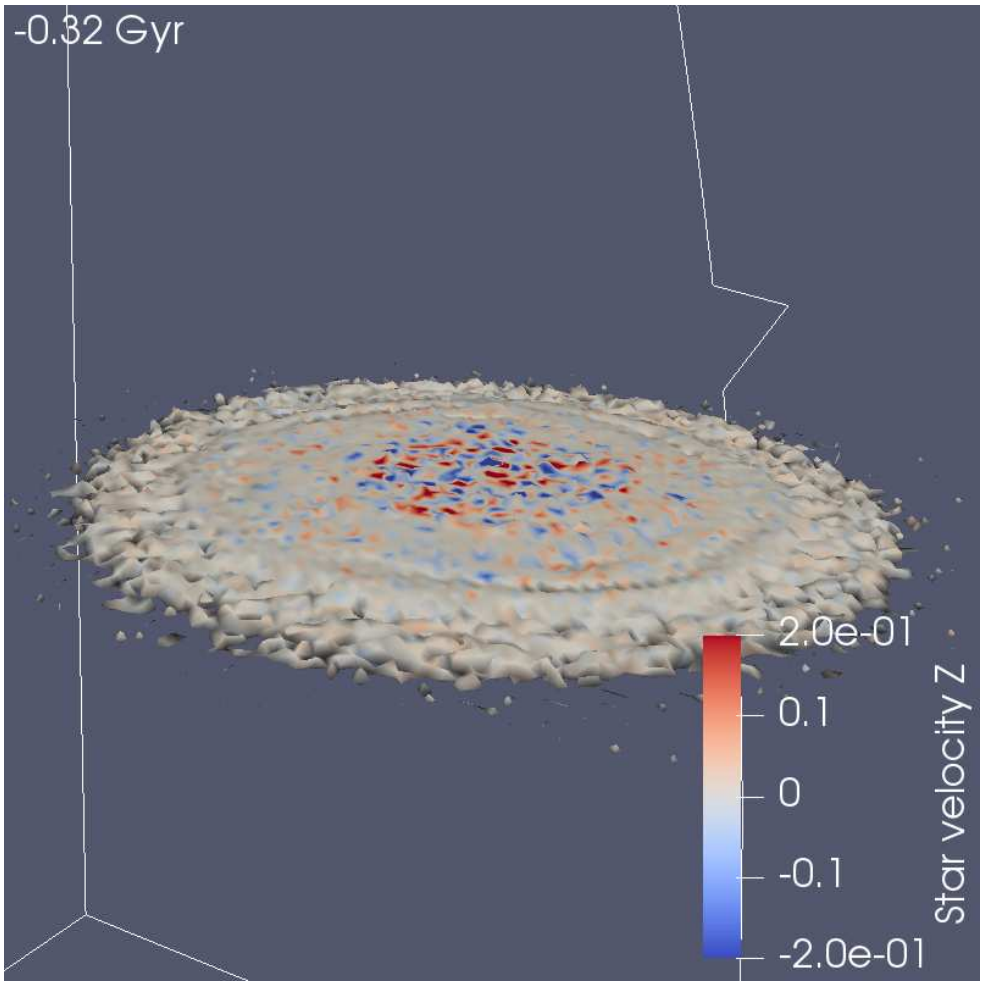

Satellite wake

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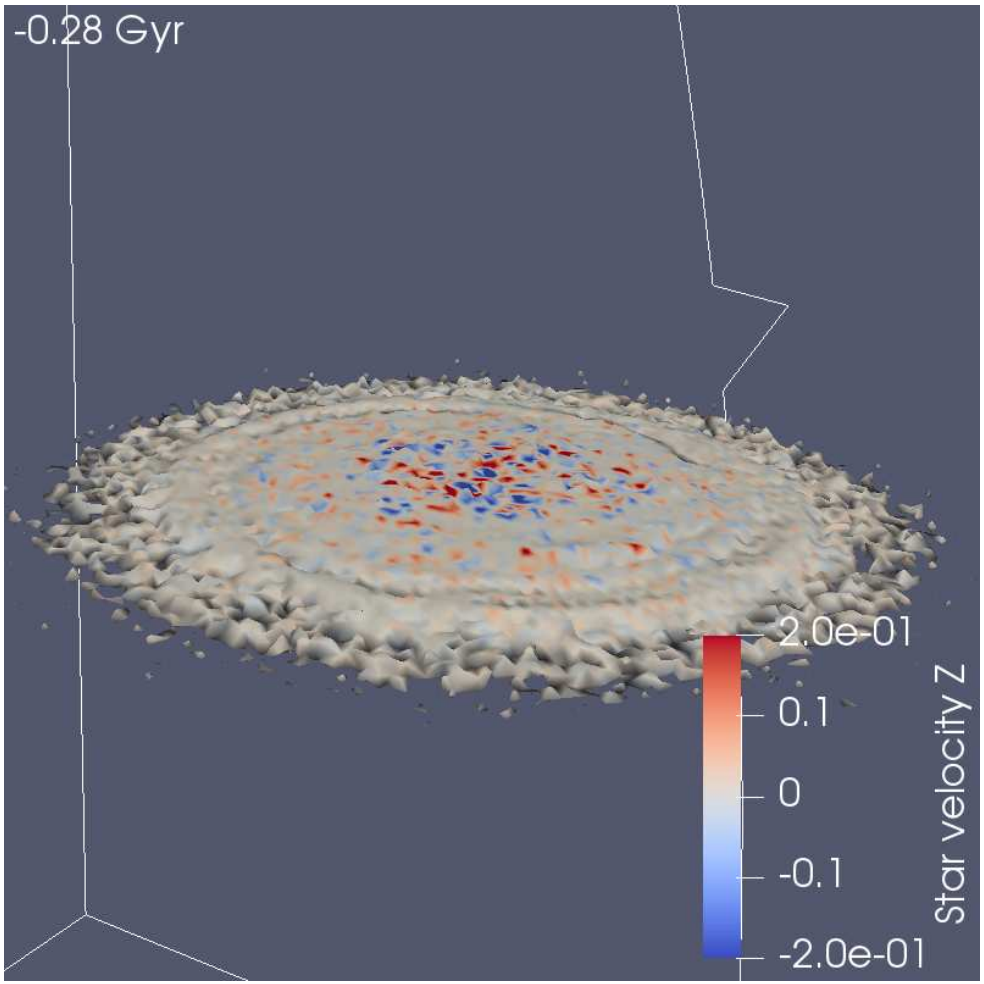

Satellite wake

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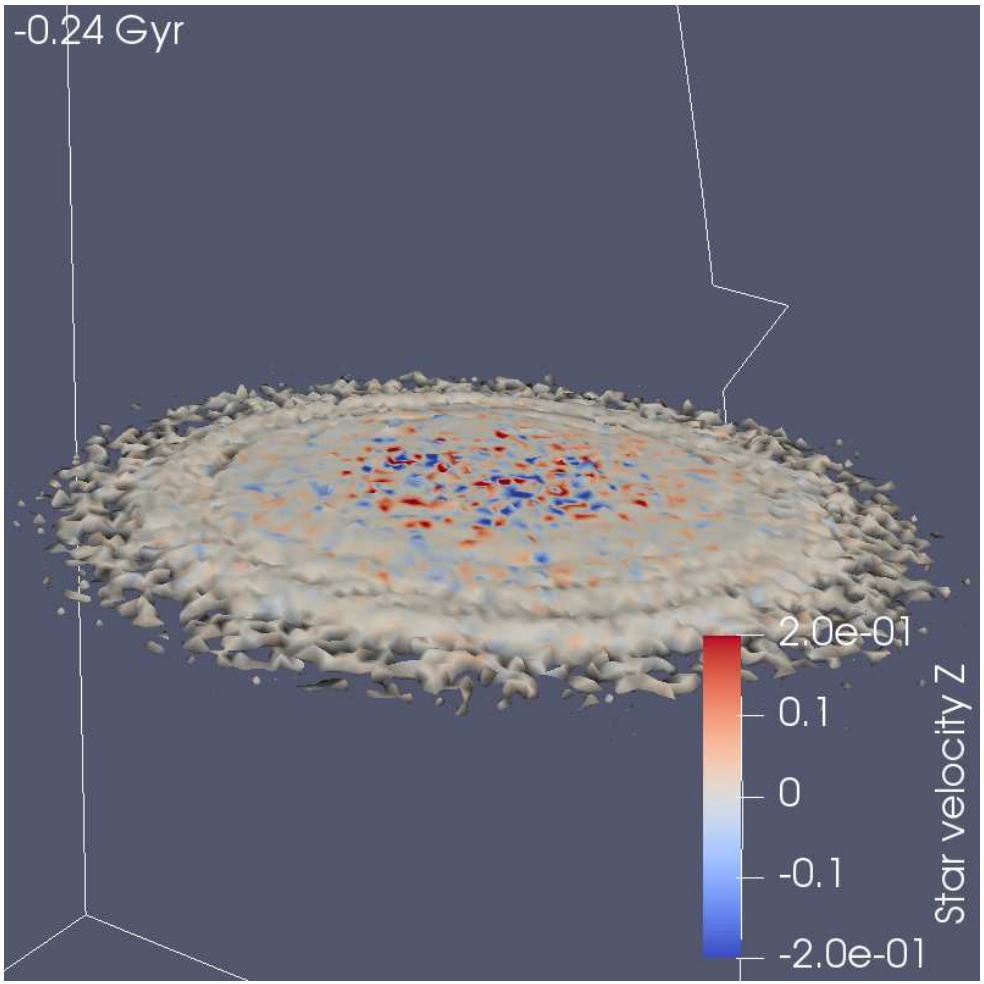
- First-passage orbit



Satellite wake

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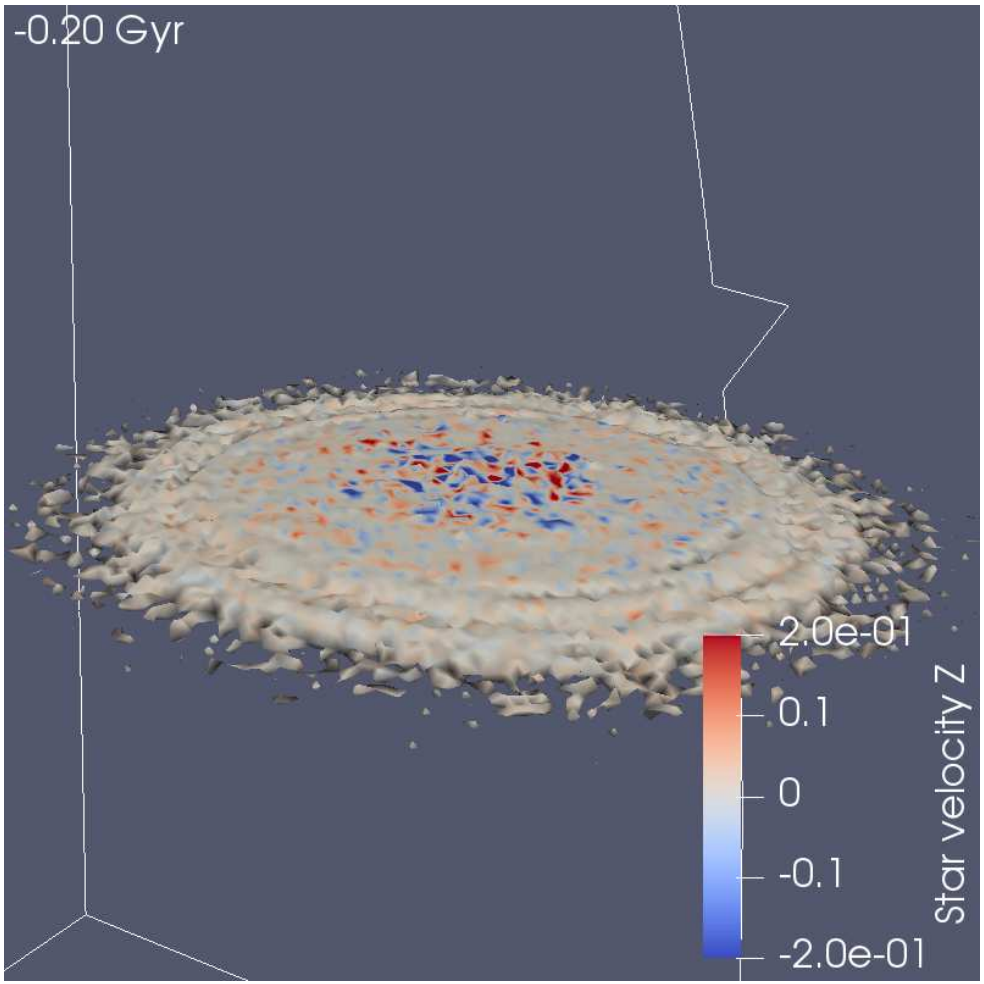

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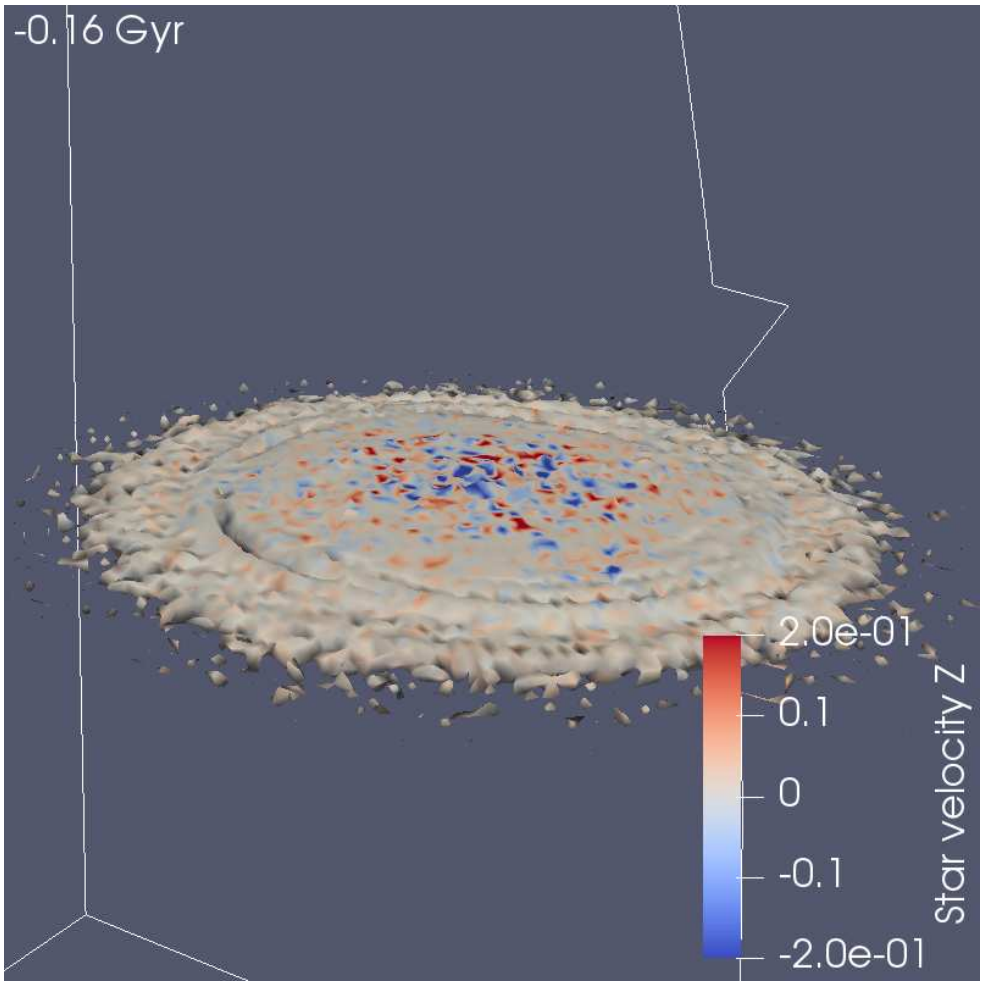

Satellite wake

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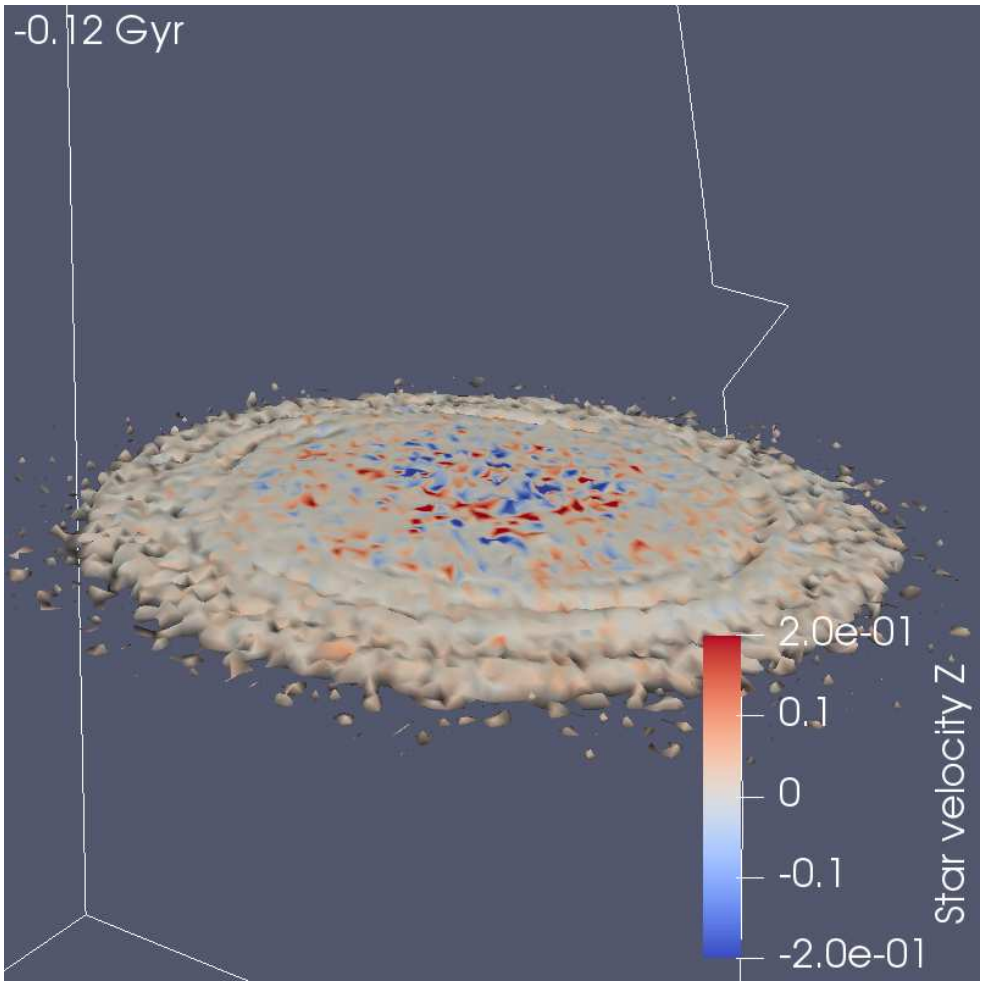

Satellite wake

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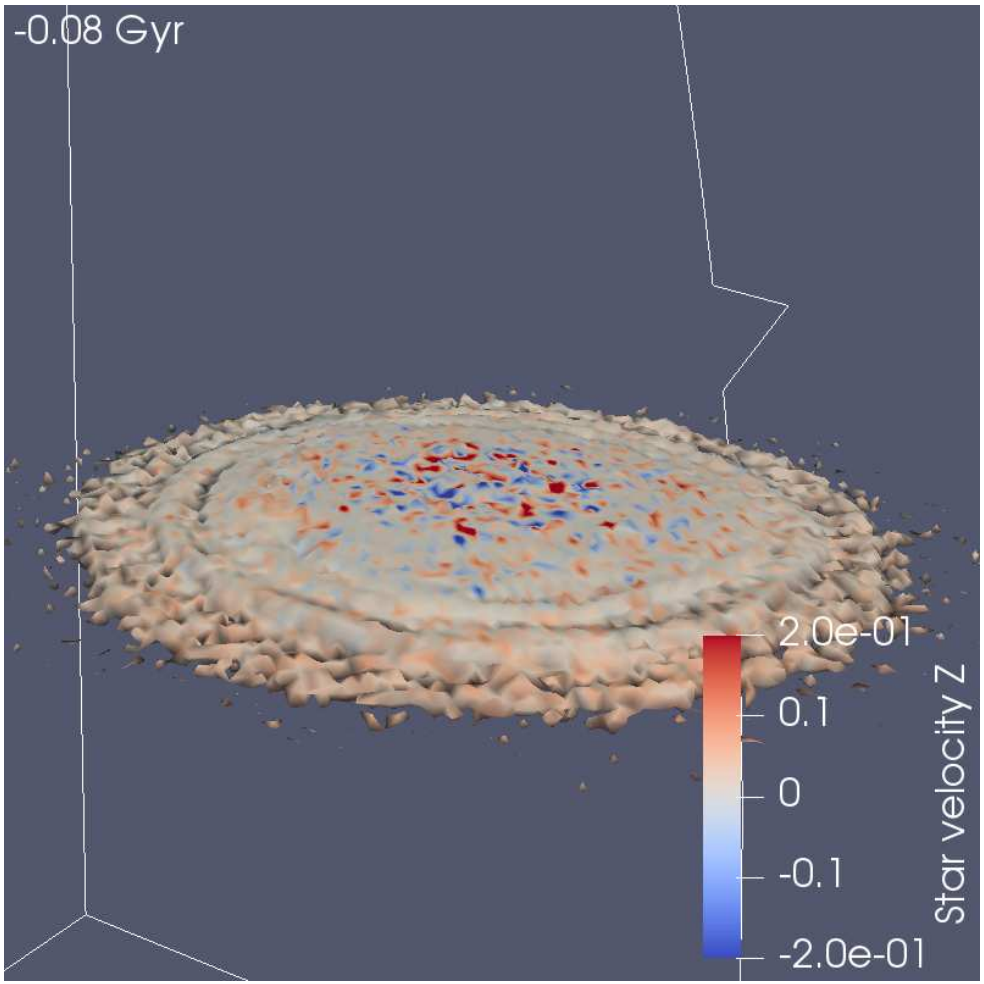

Satellite wake

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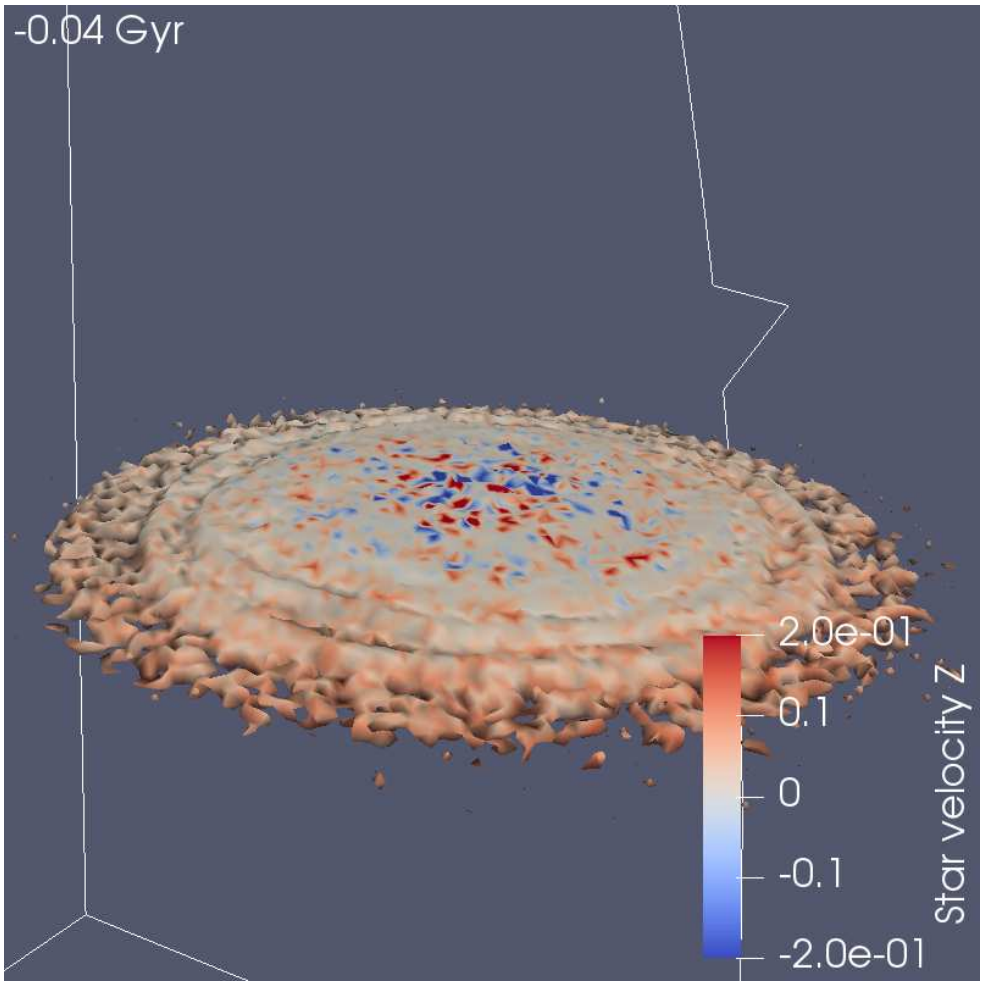

Satellite wake

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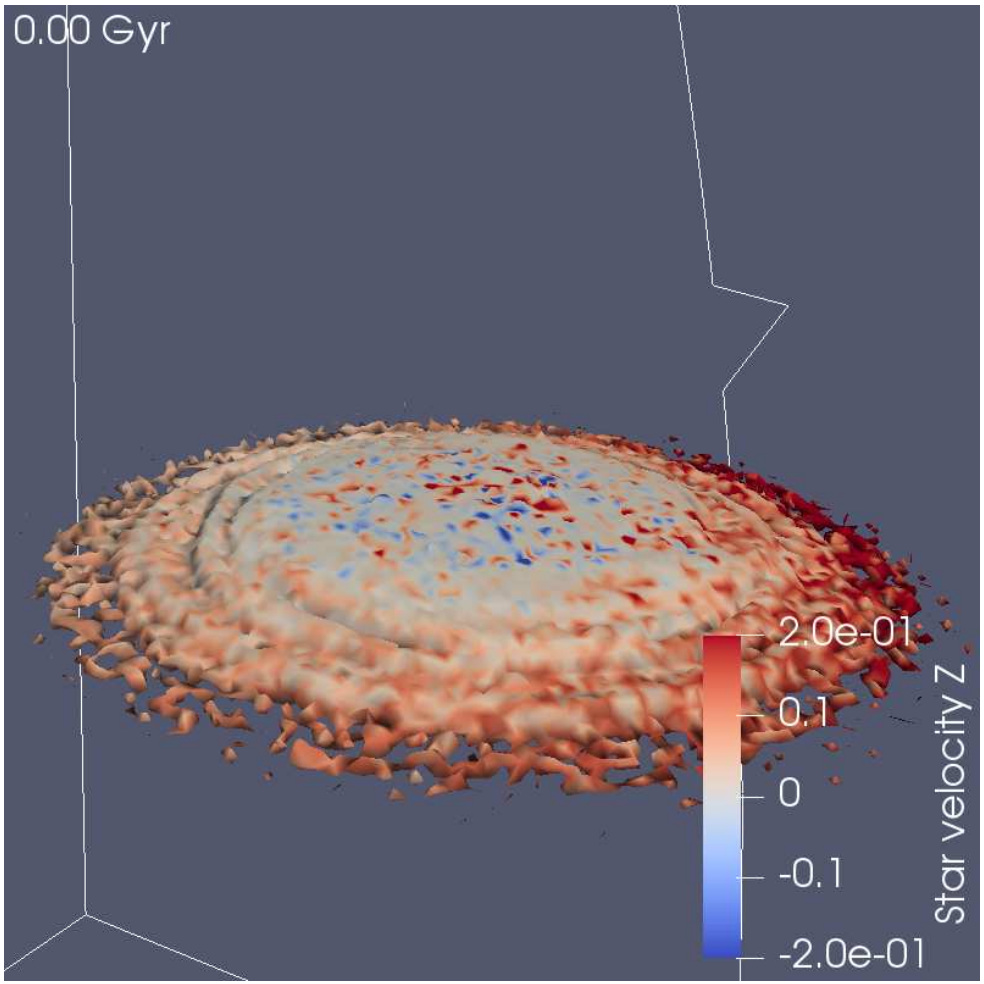

Satellite wake

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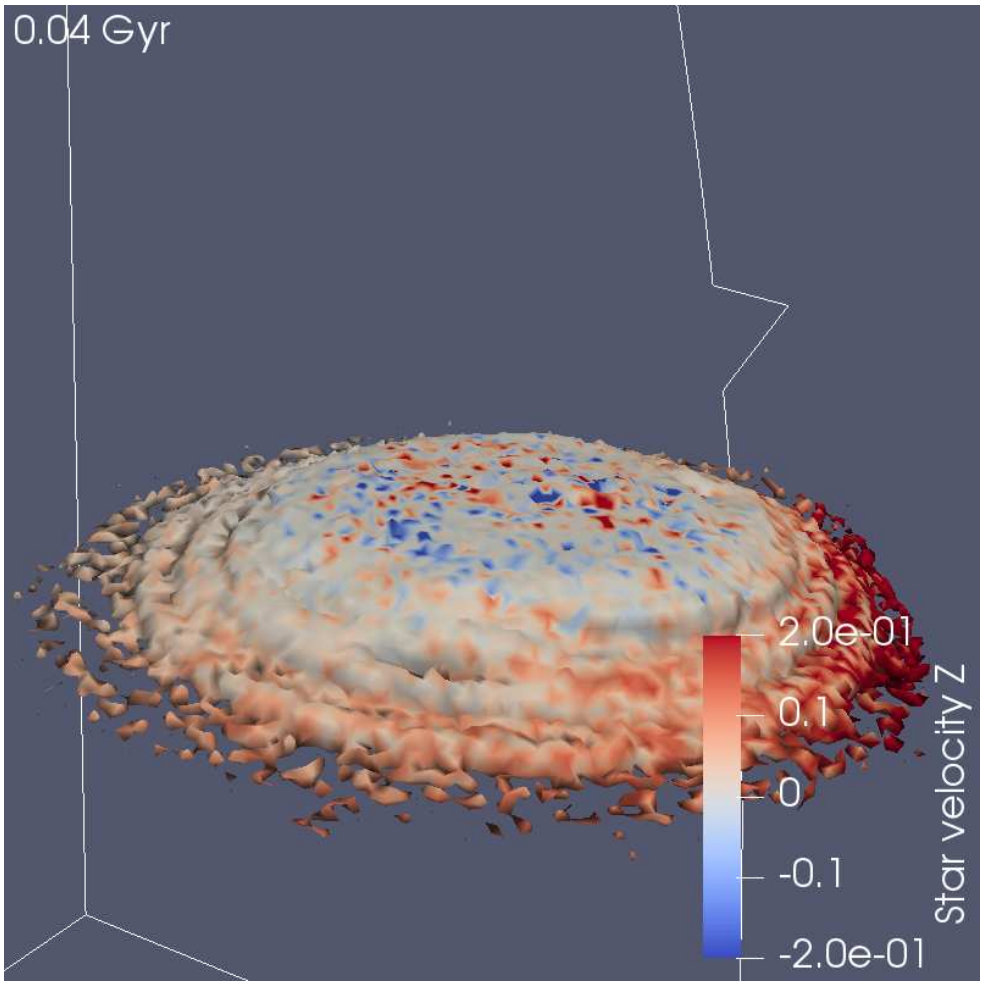

Satellite wake

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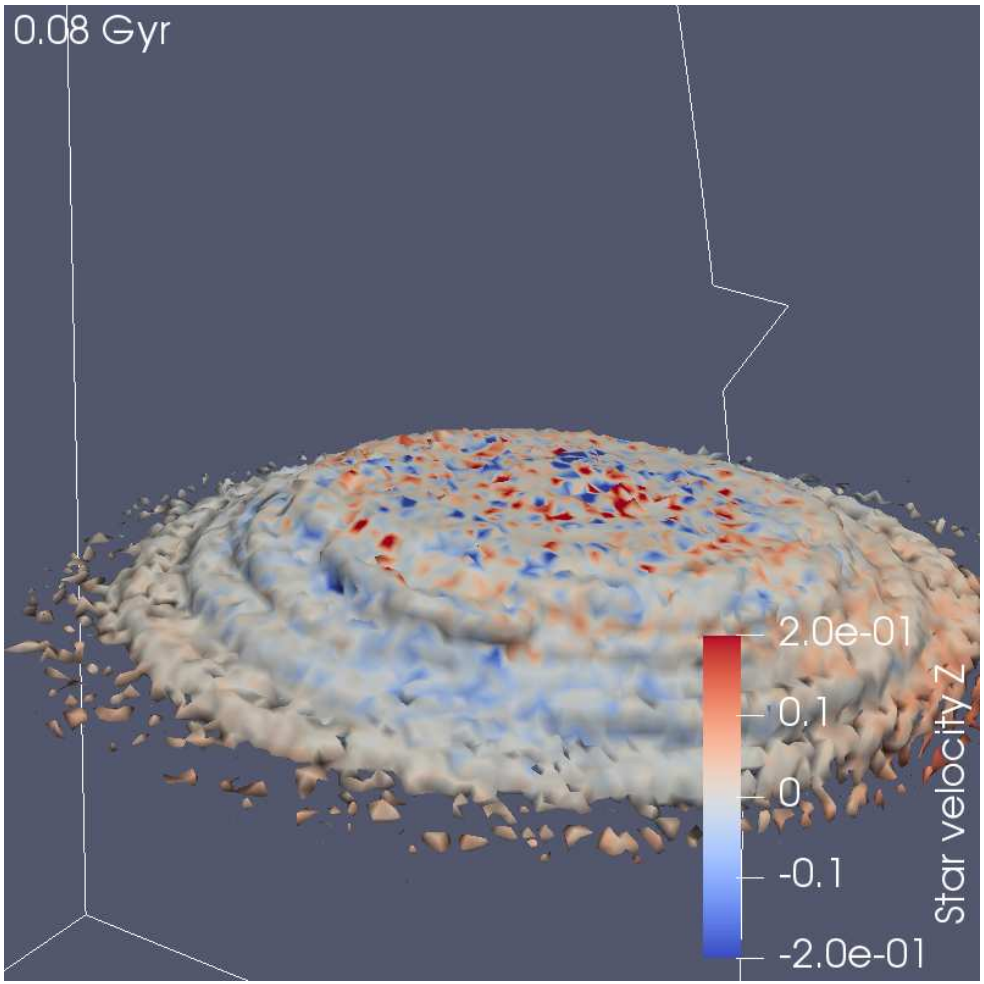

Satellite wake

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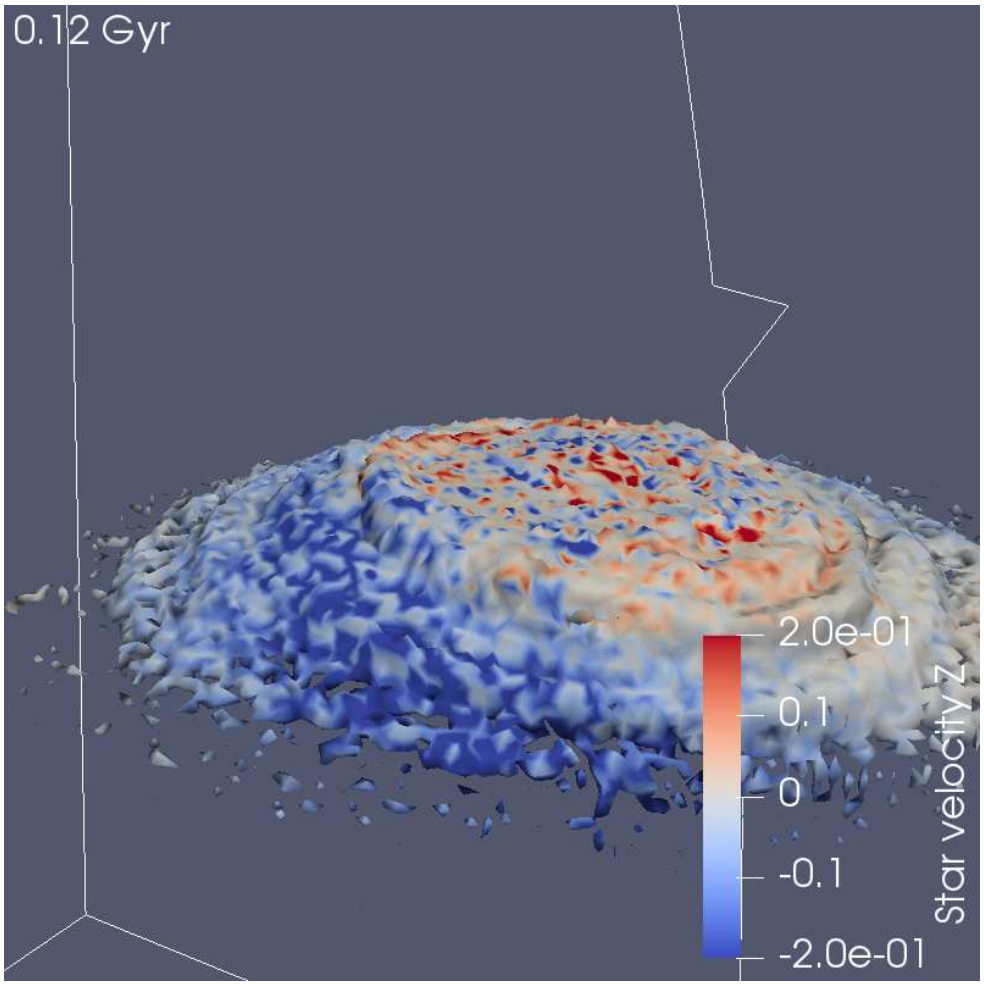
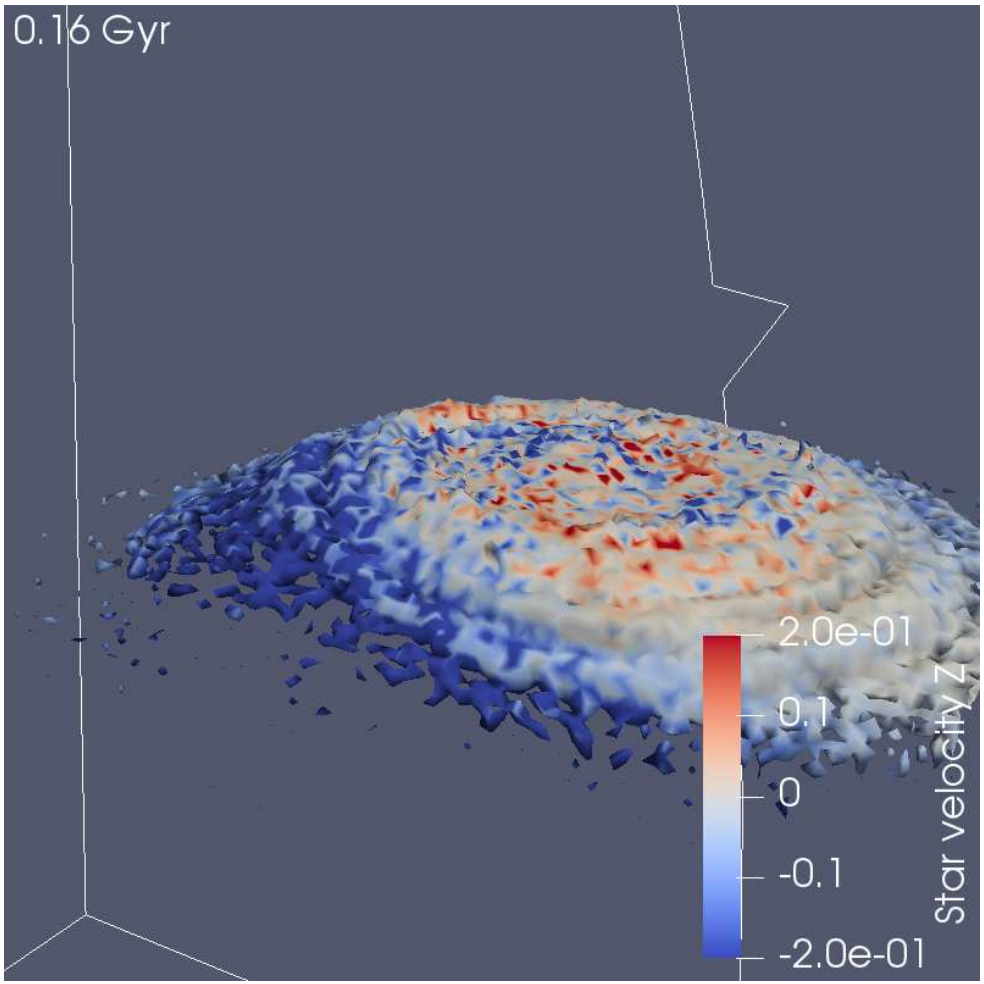
- First-passage orbit



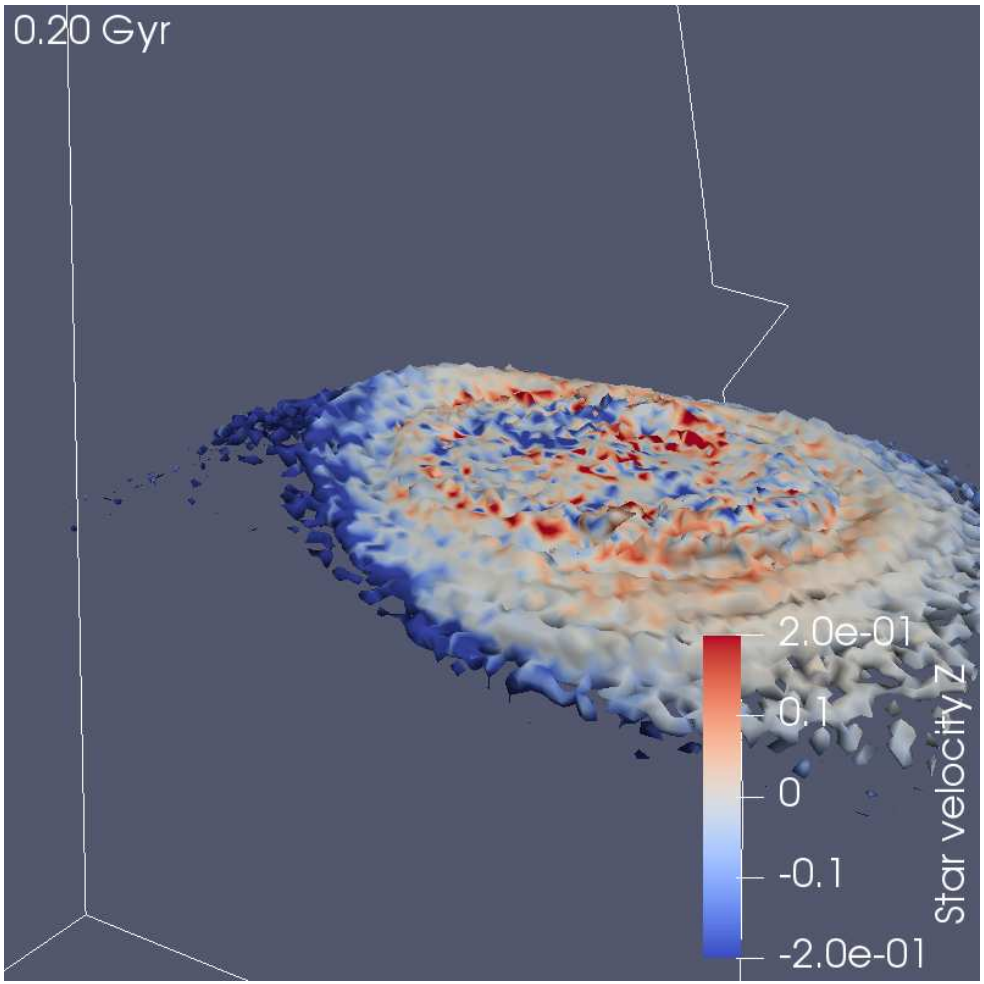
Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit



Satellite wake

- LMC with $5 \times 10^{10}\,\mathrm{M}_{\odot}$
- First-passage orbit



Satellite wake

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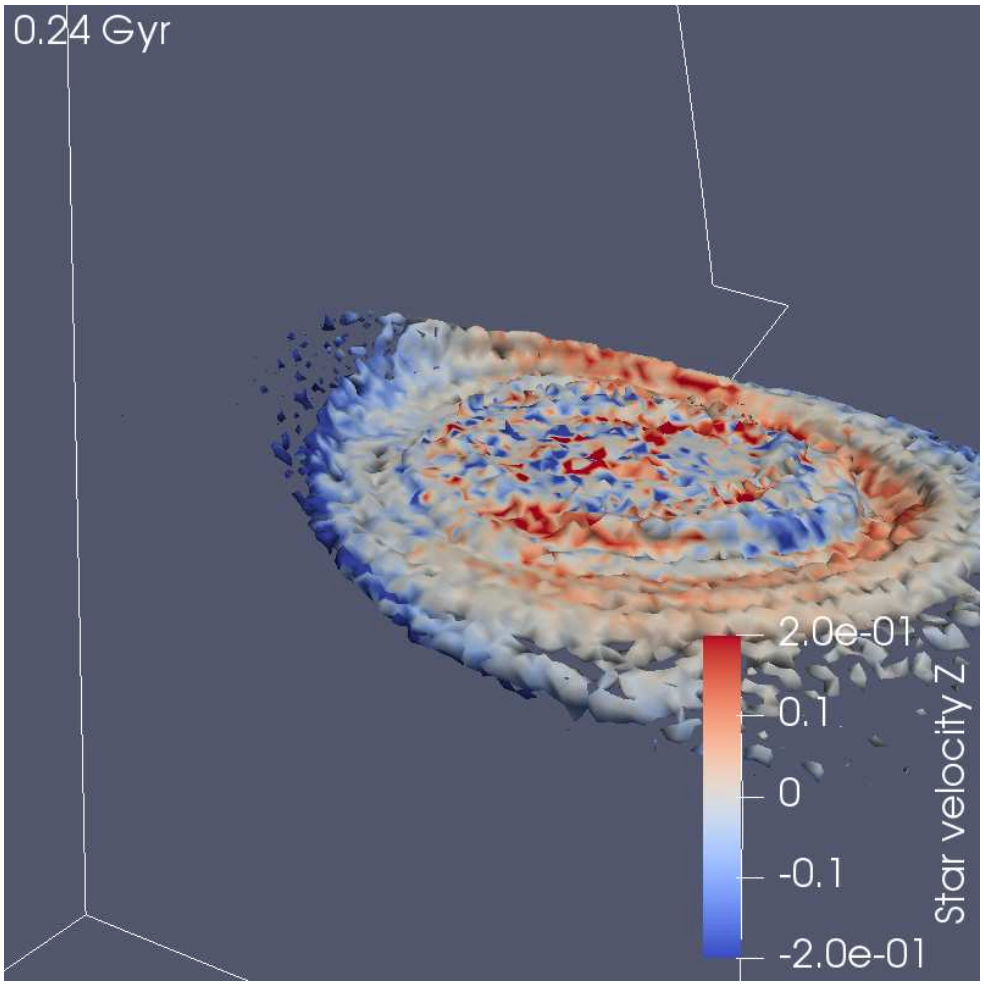

Satellite wake

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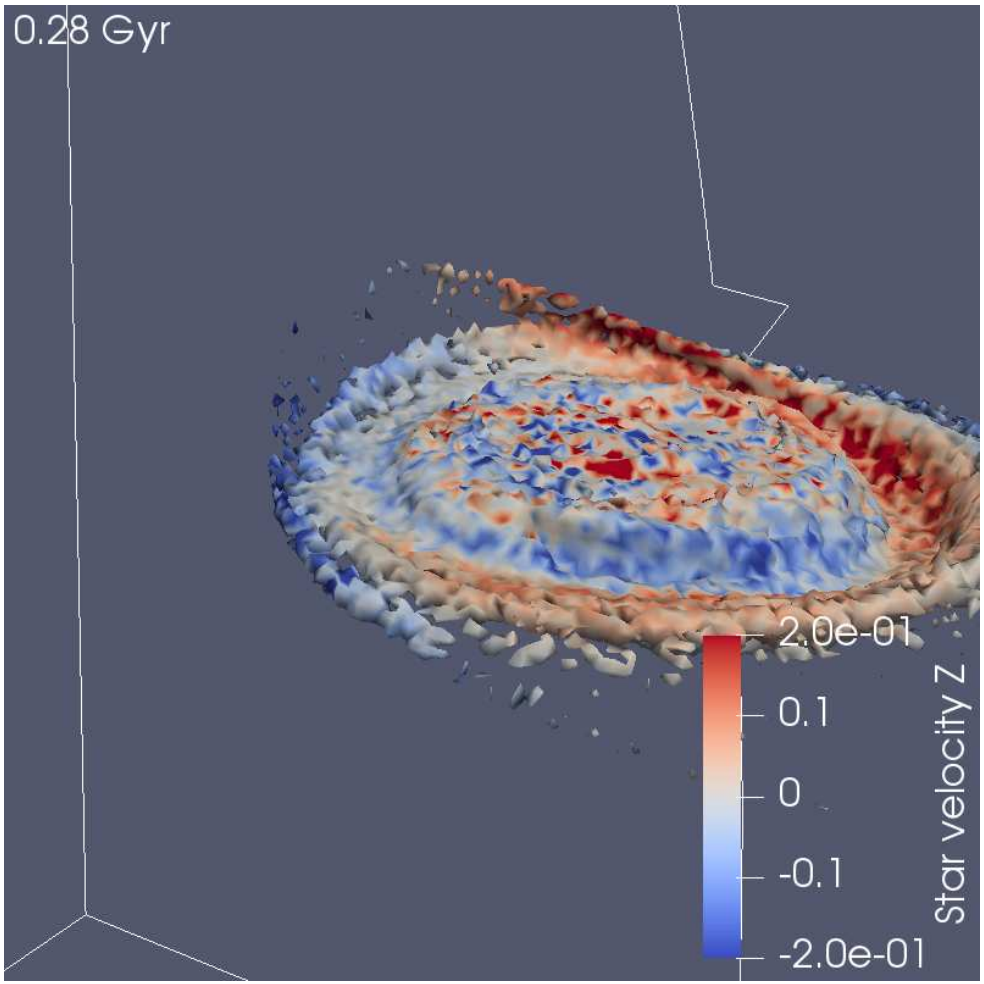

Satellite wake

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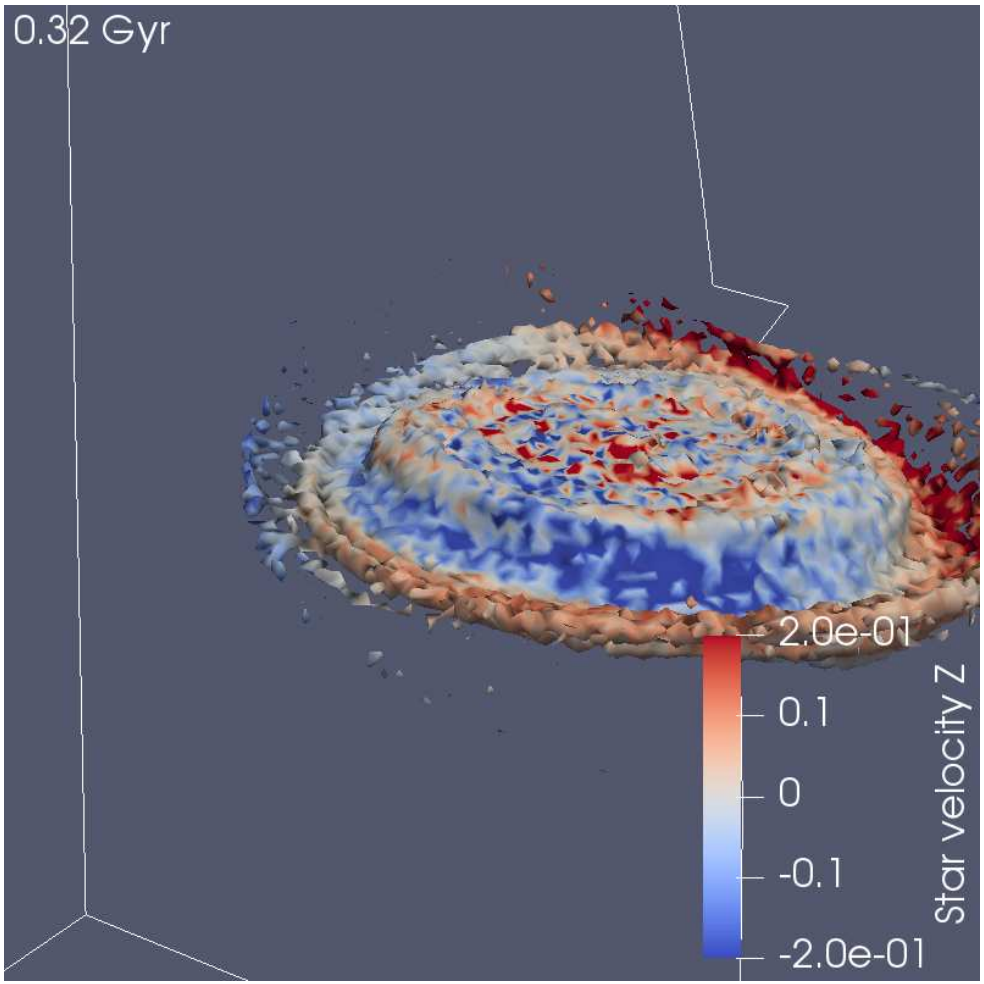

Satellite wake

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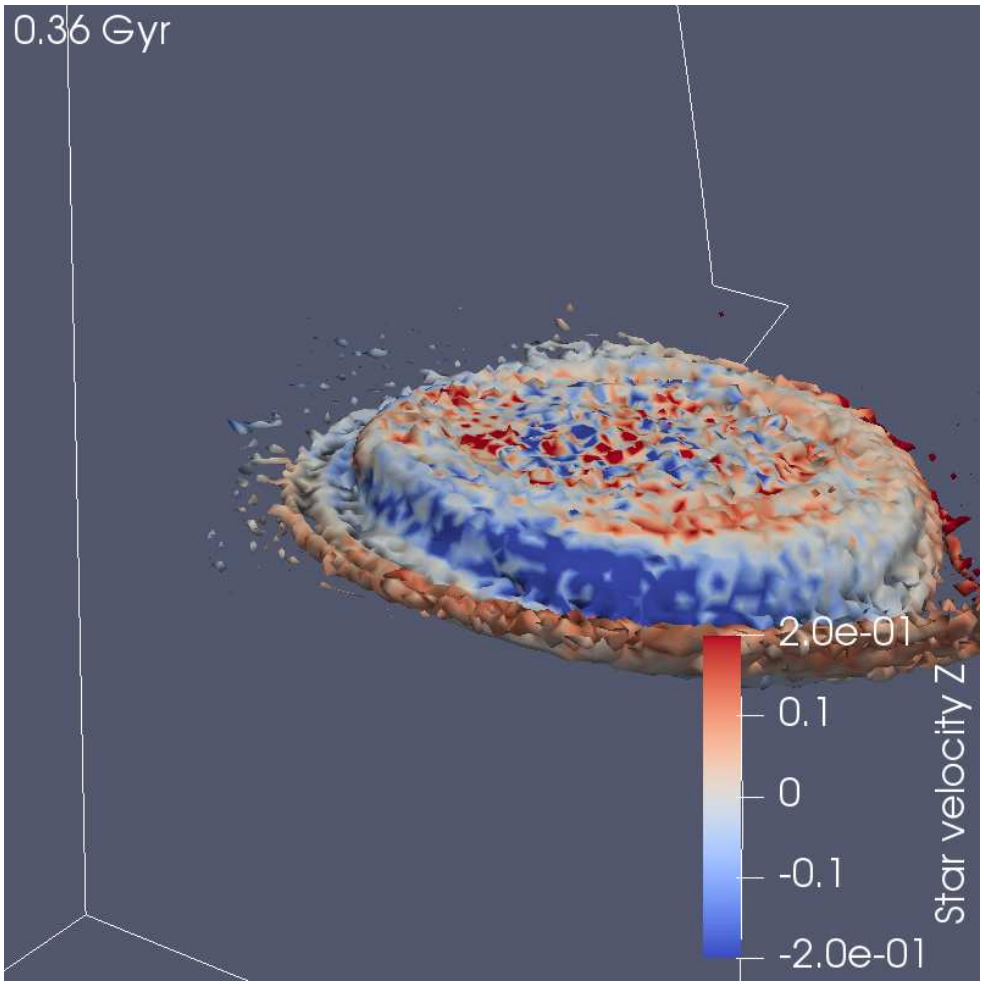

Satellite wake

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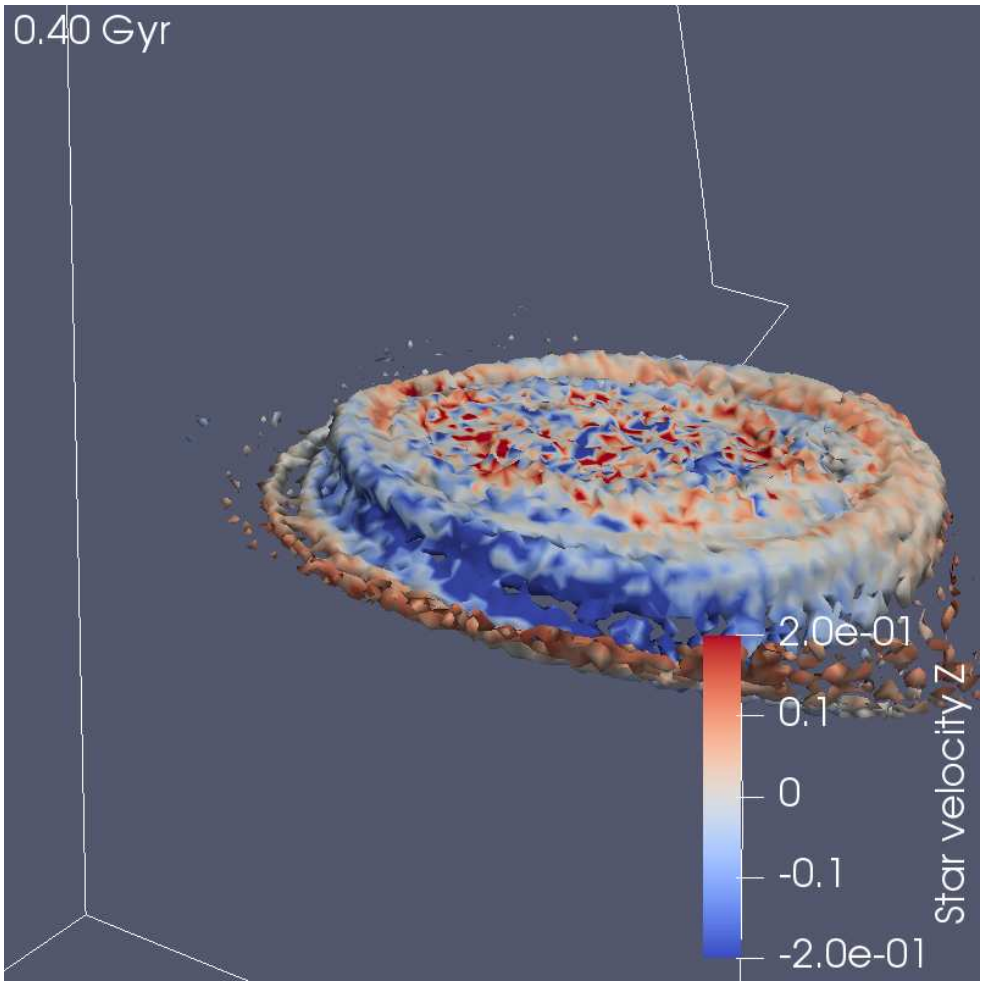

Satellite wake

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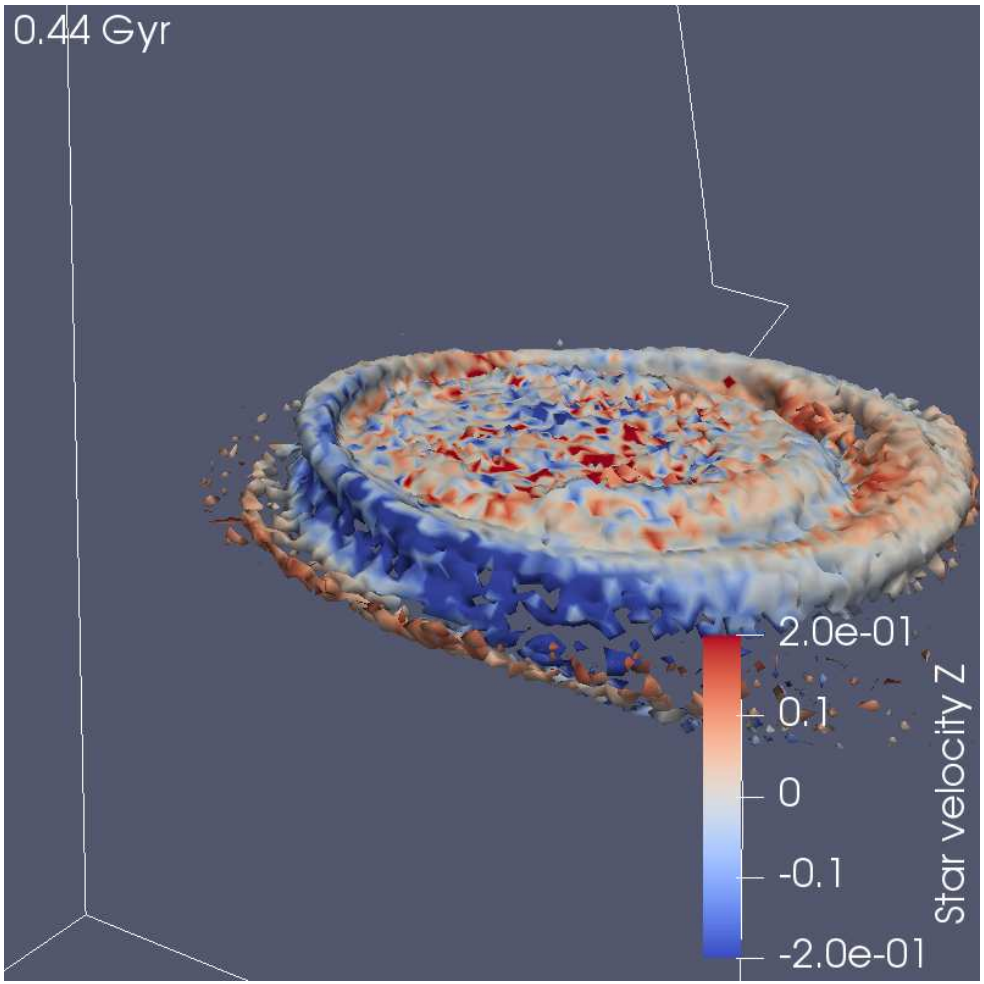

Satellite wake

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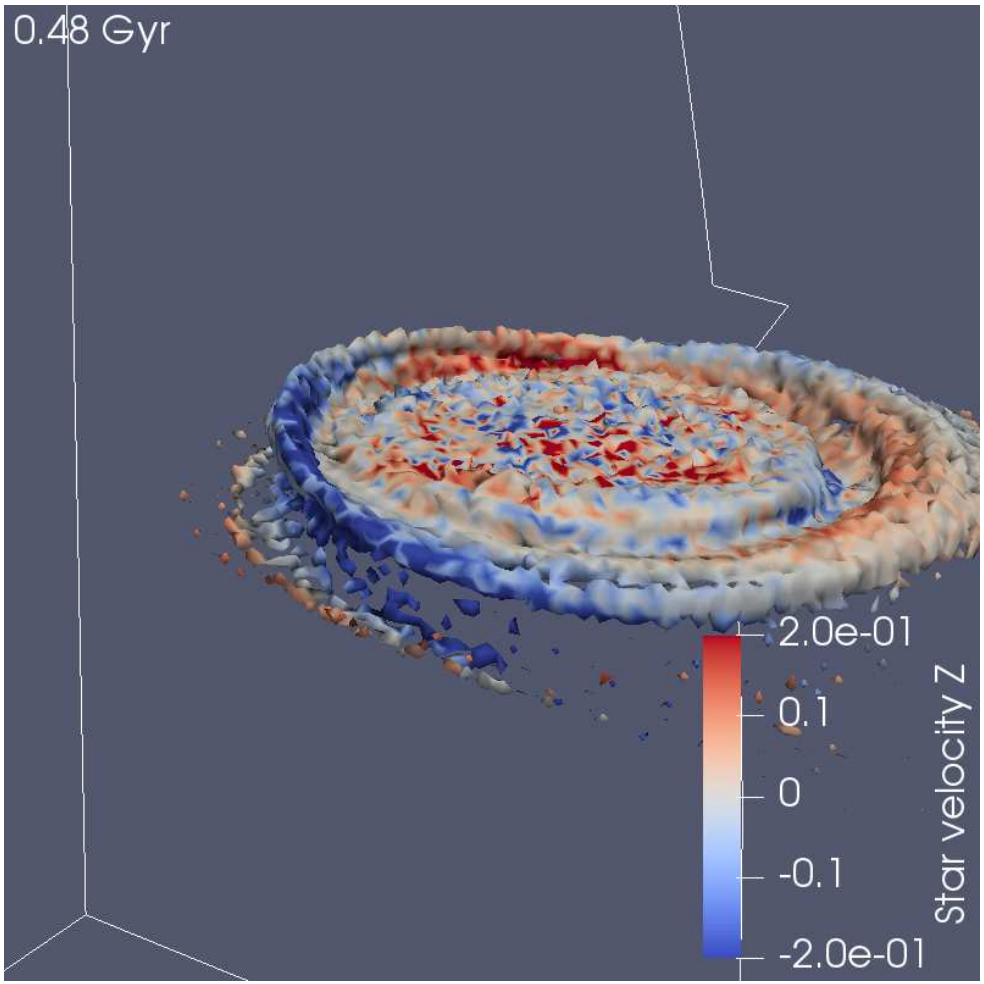

Satellite wake

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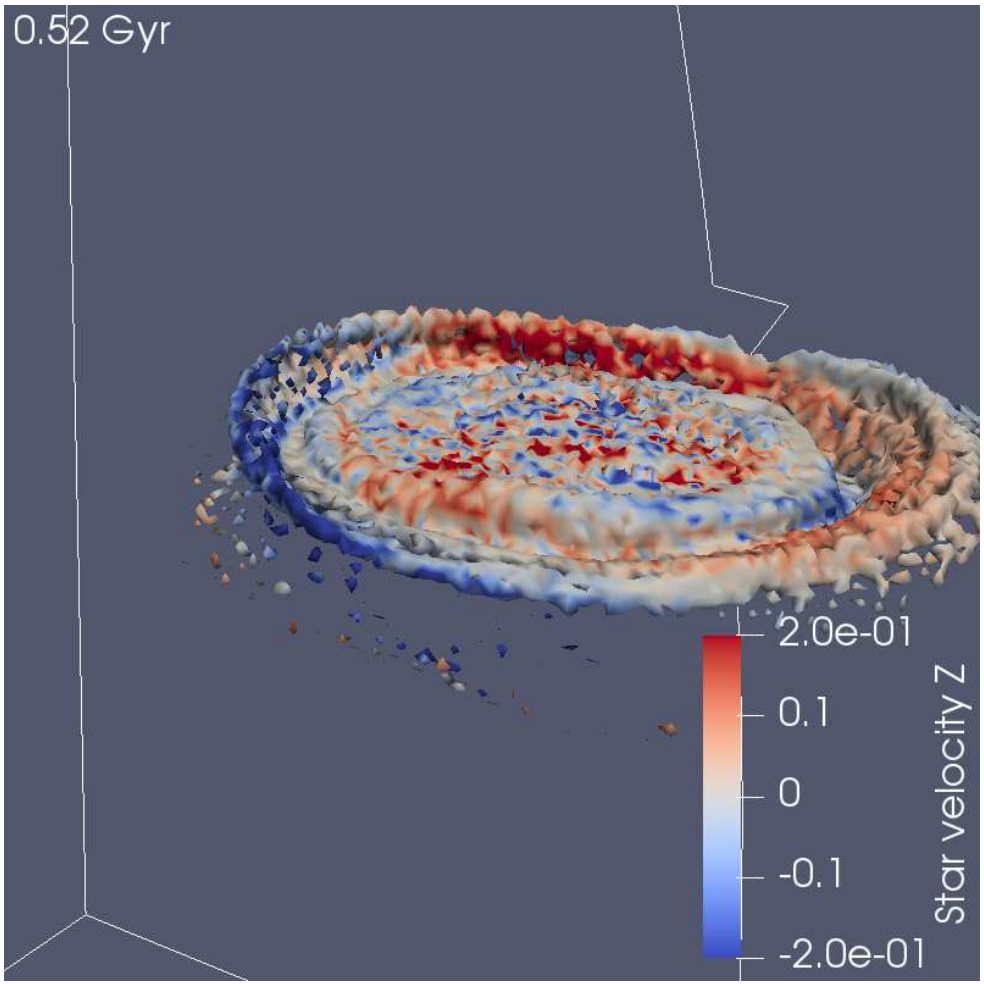

Satellite wake

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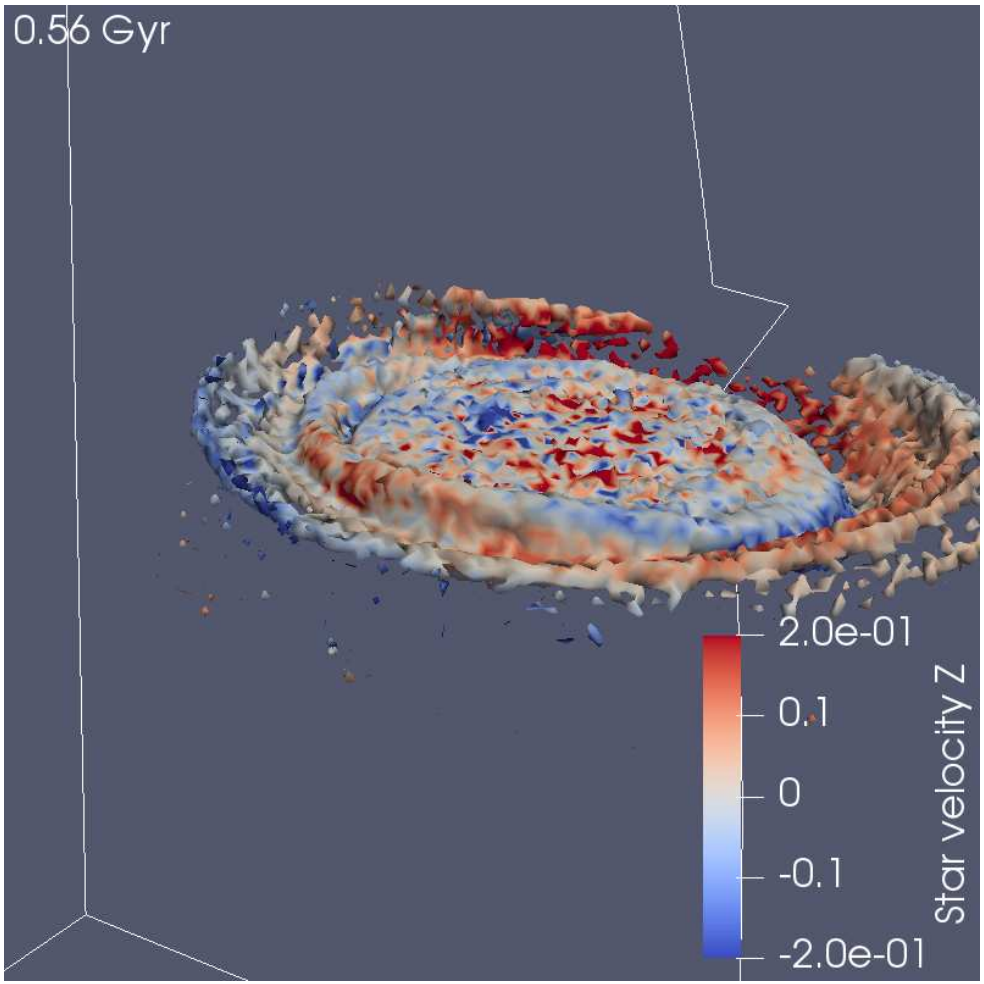

Satellite wake

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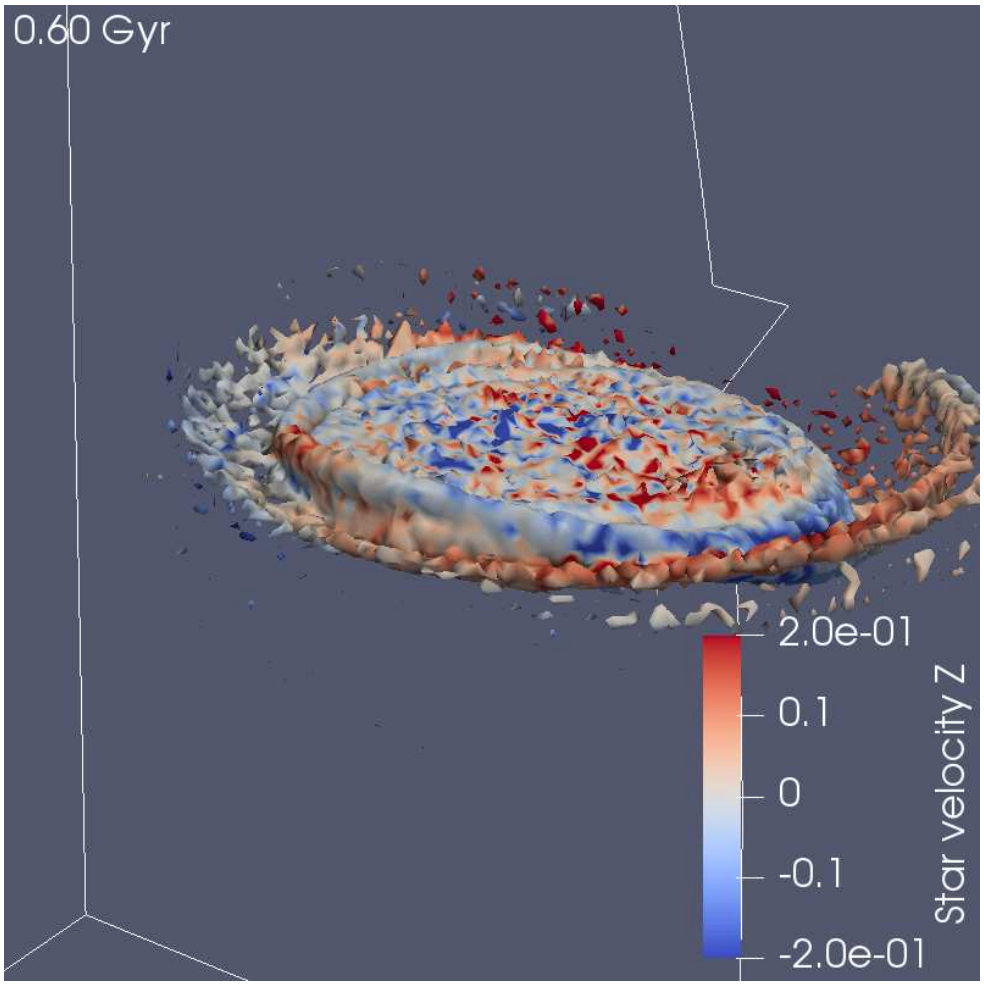

Satellite wake

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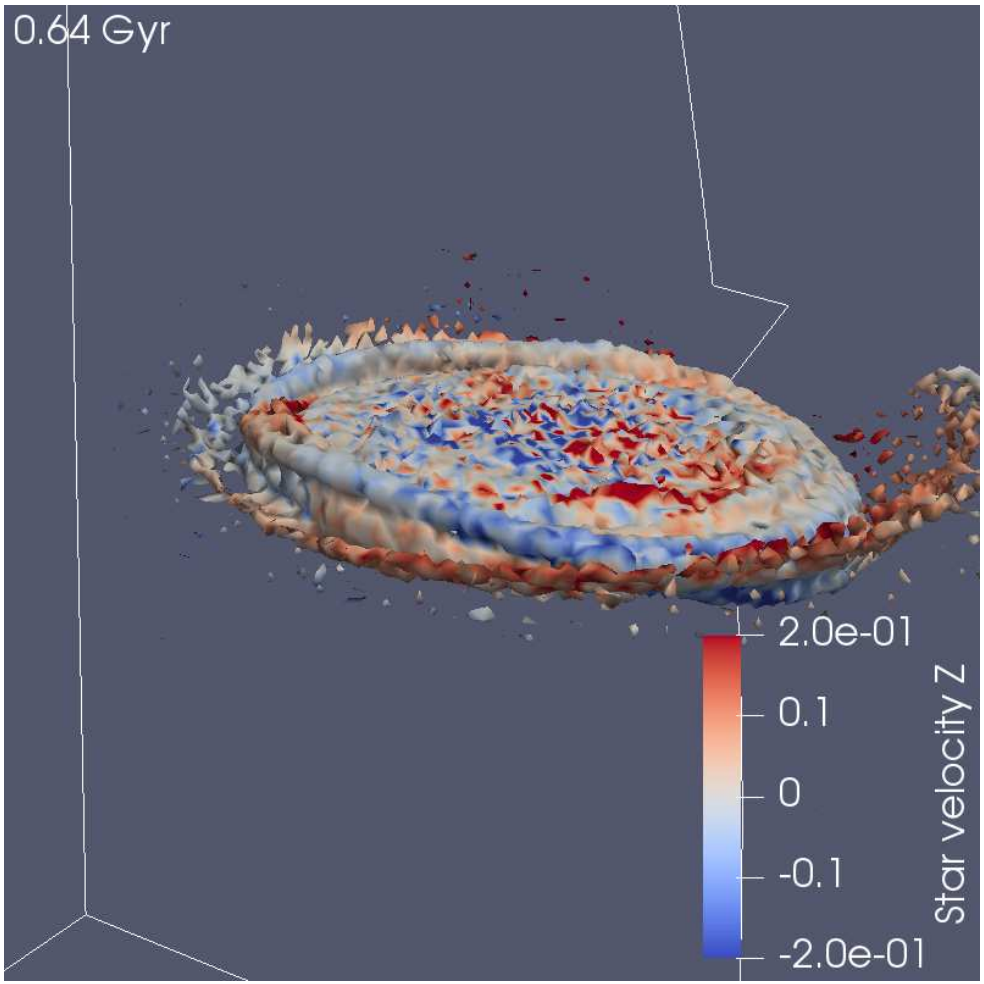

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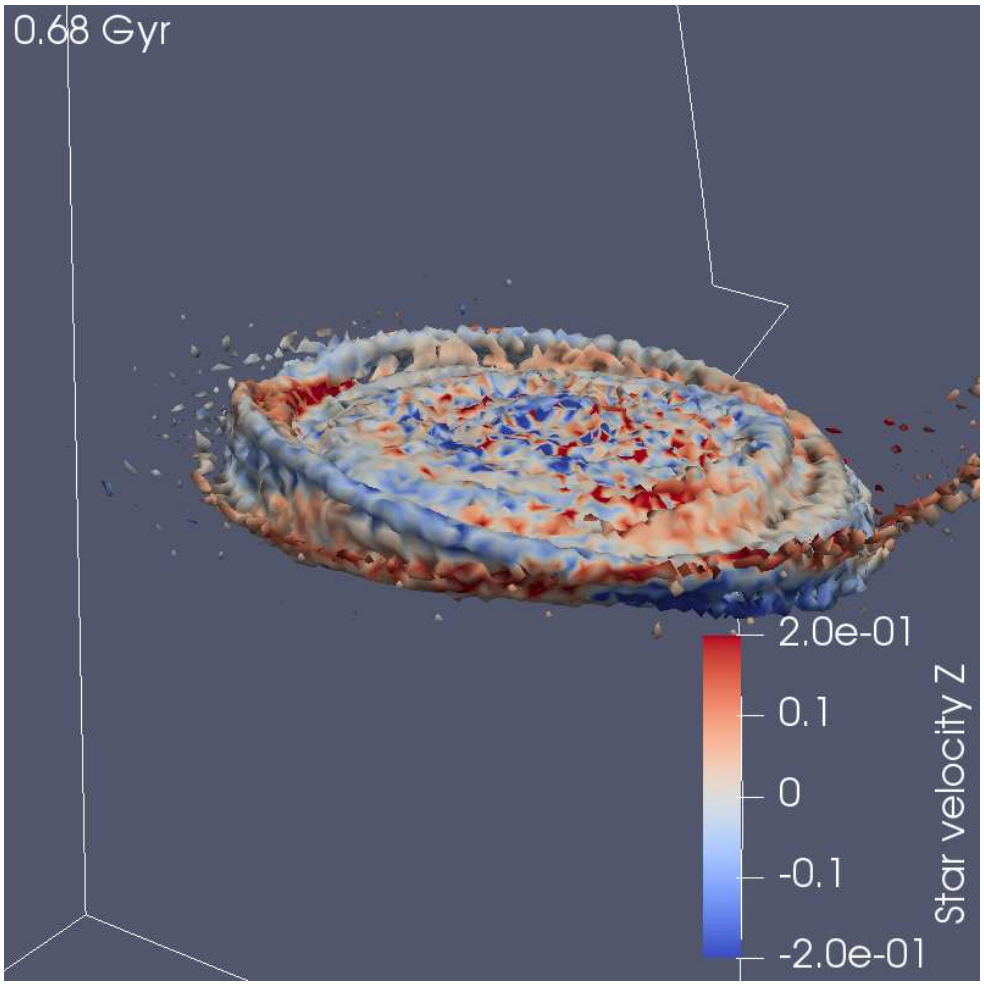

Satellite wake

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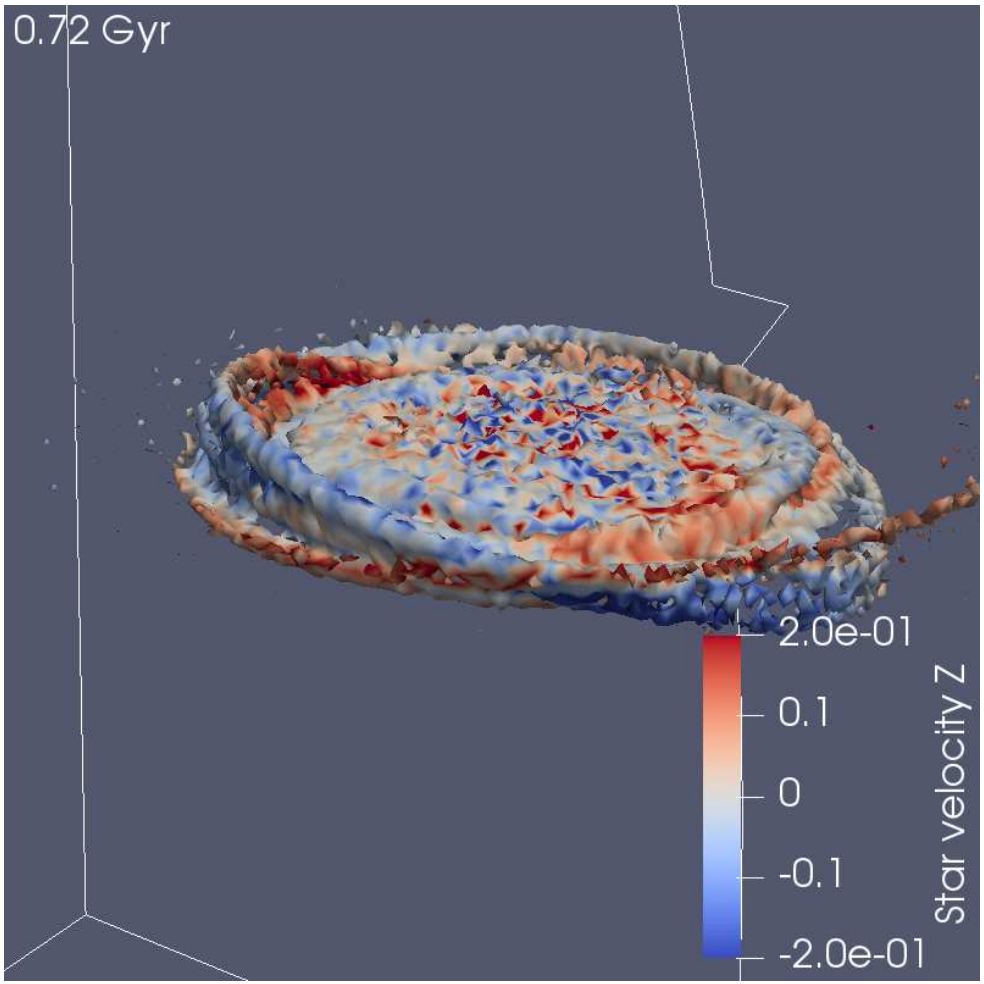

Satellite wake

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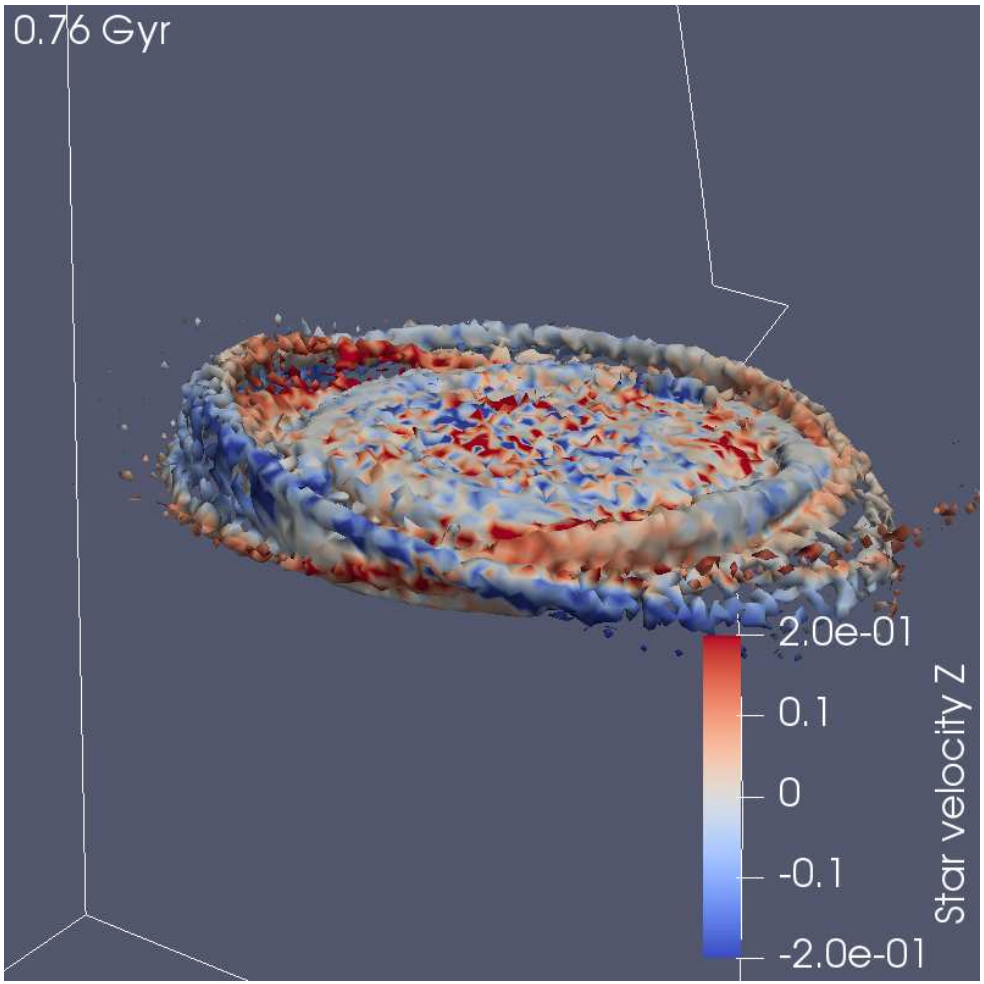

Satellite wake

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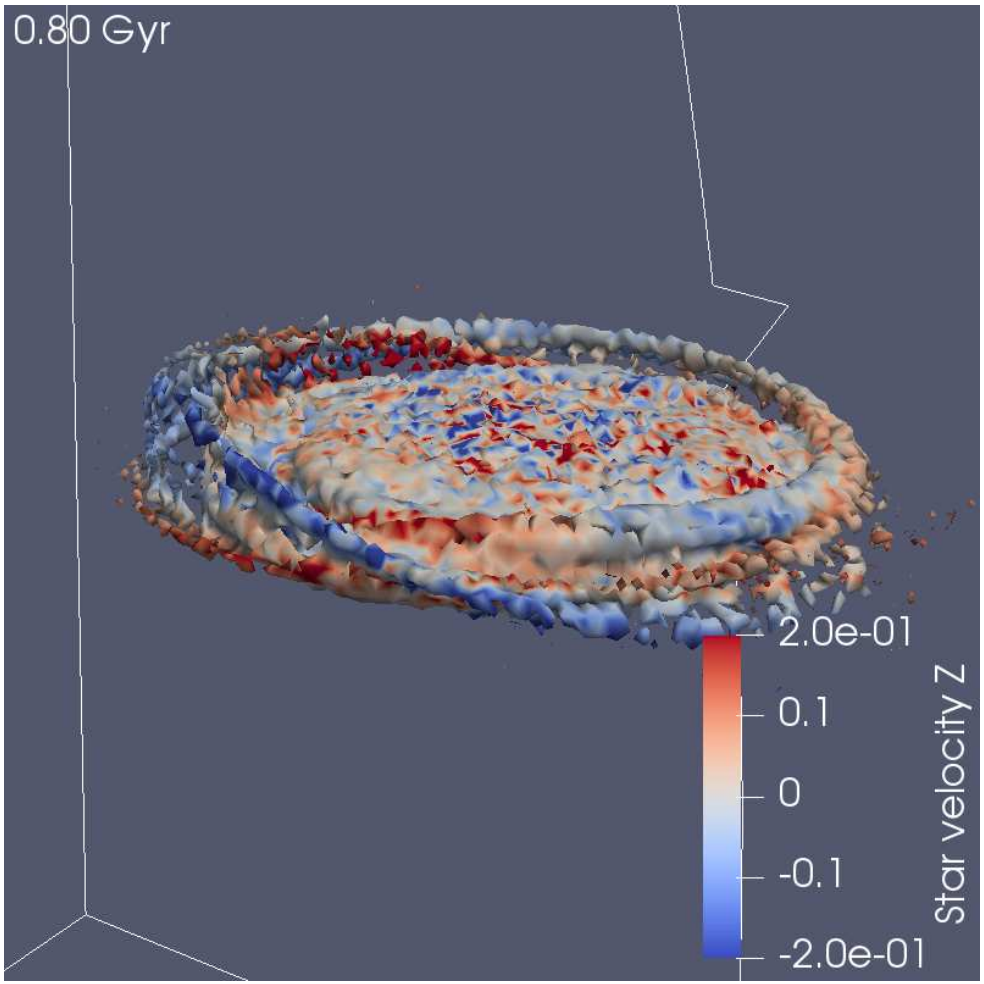

Satellite wake

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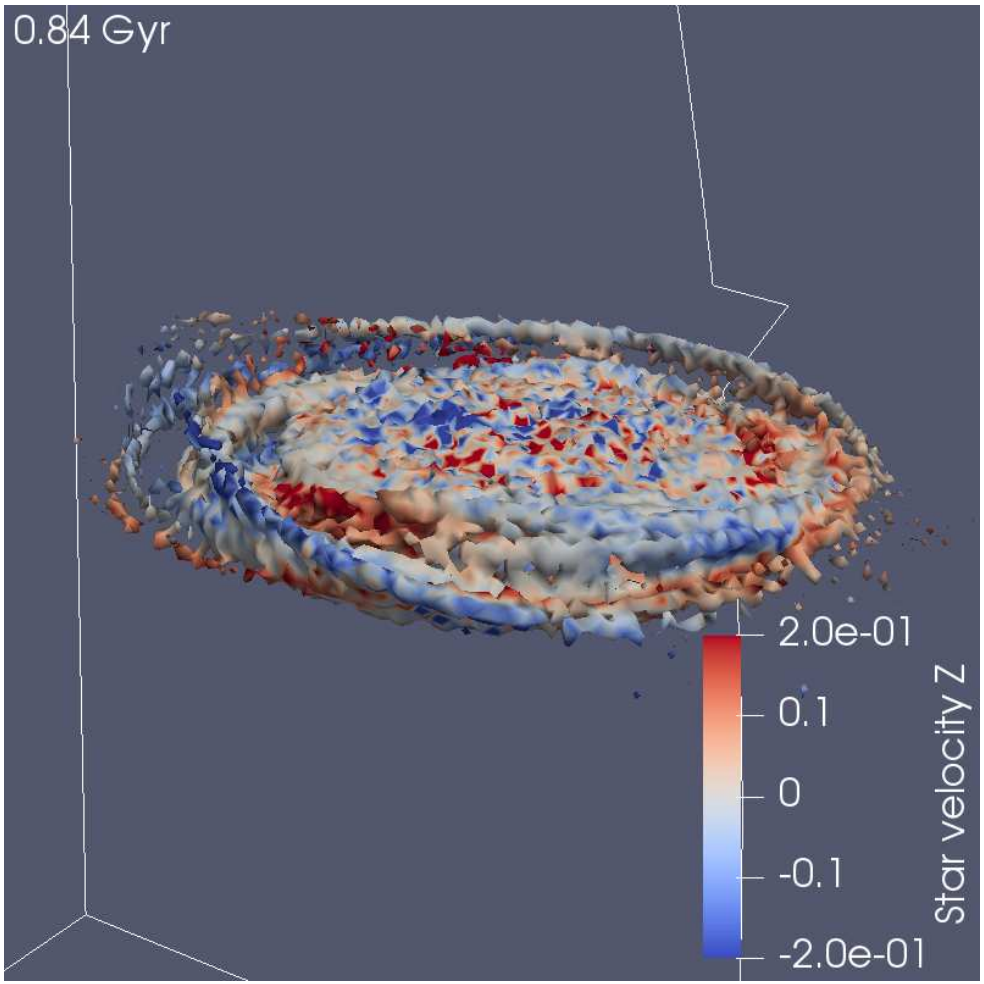

Satellite wake

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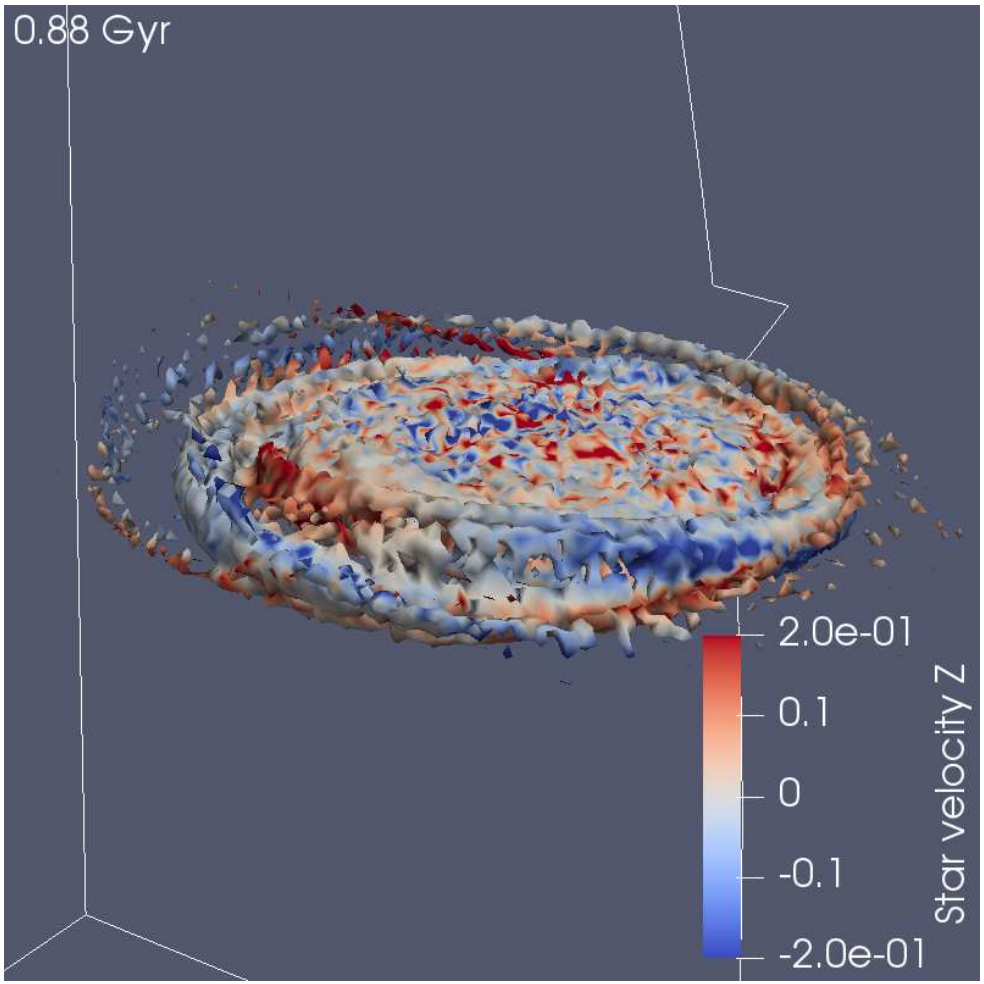

Satellite wake

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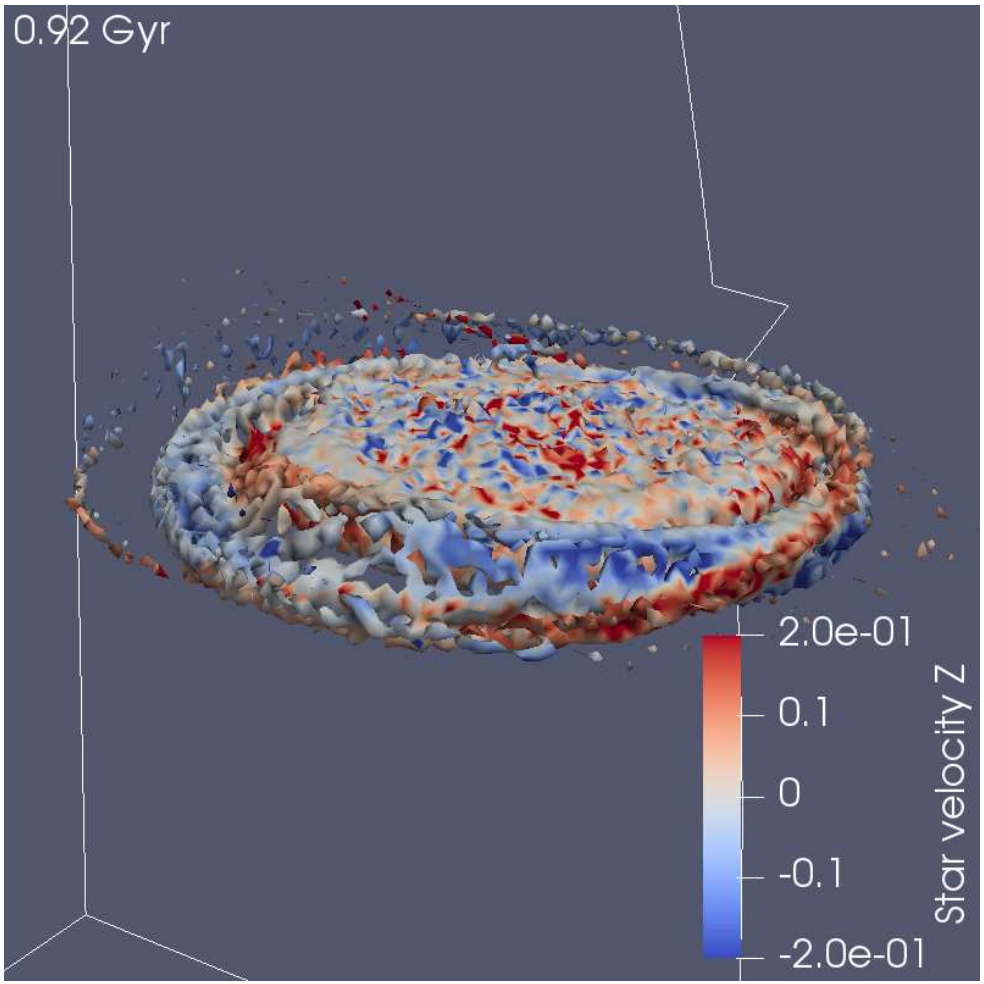

Satellite wake

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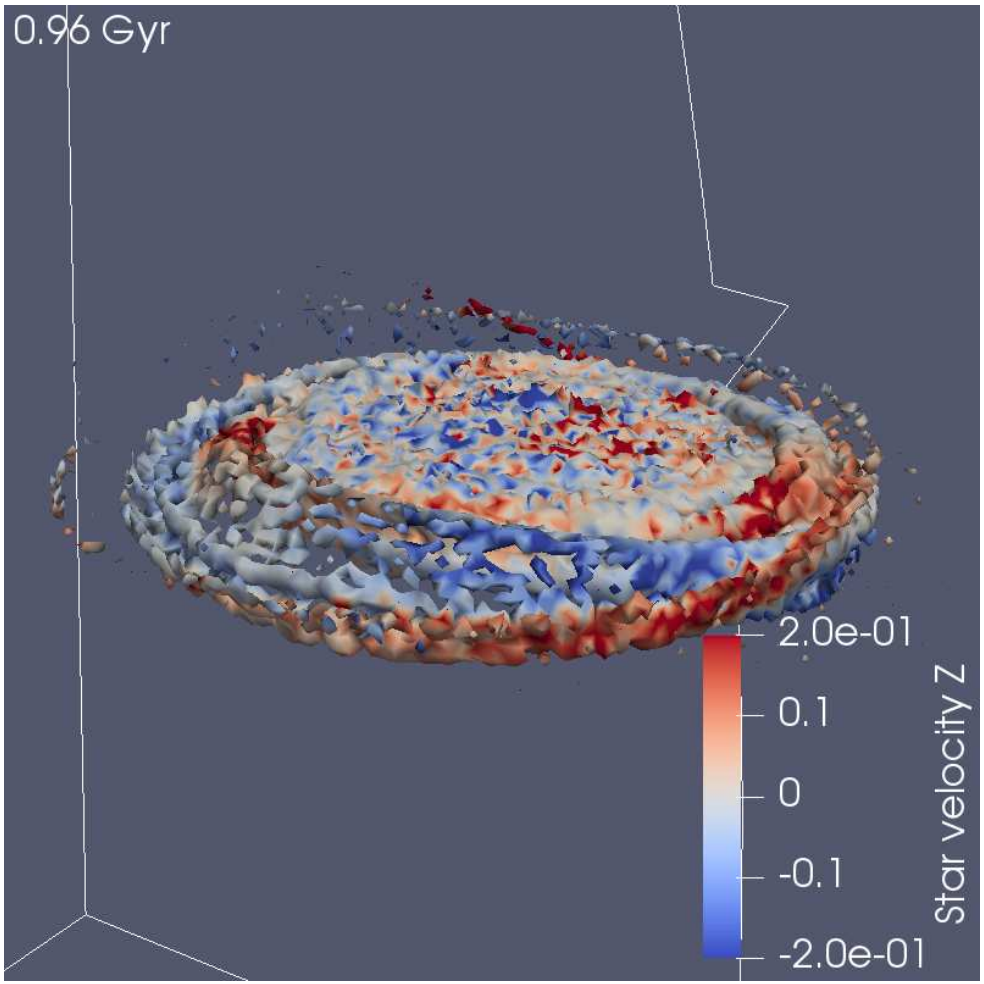

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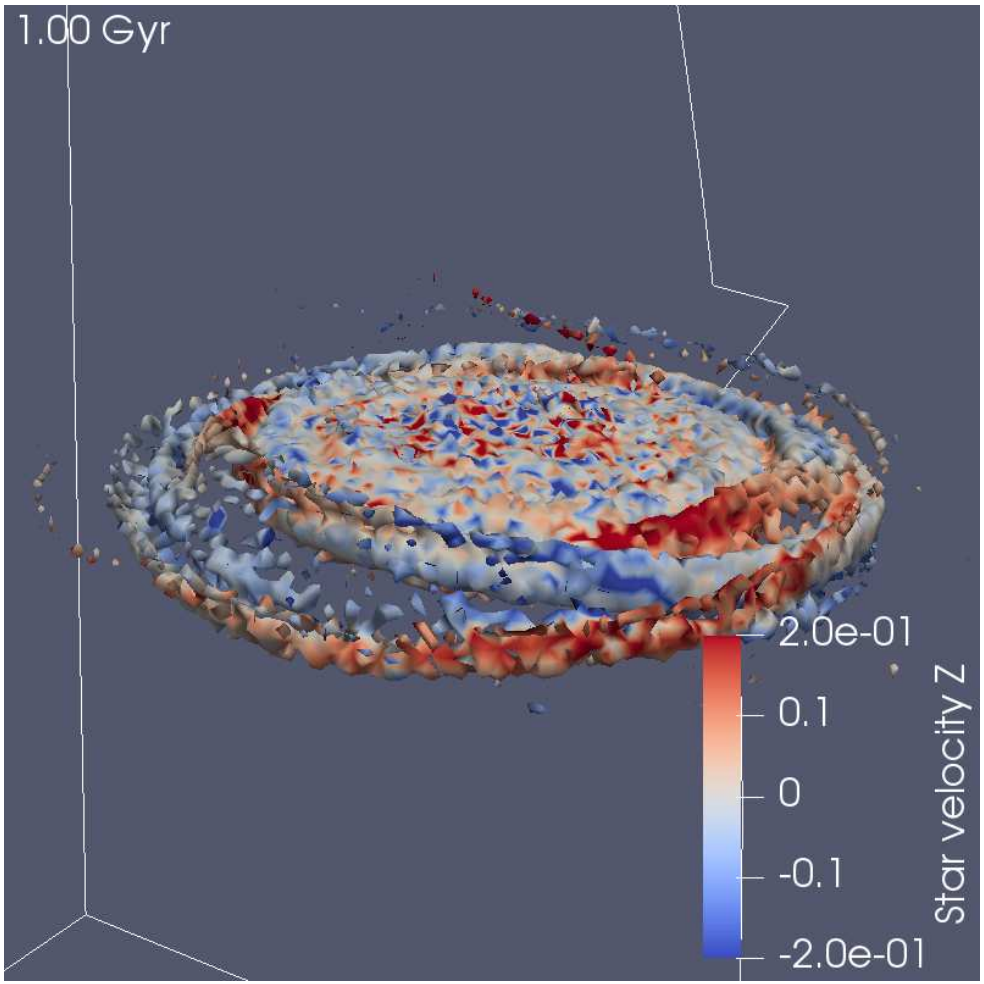

DM wakes

- The halo profile matters
  - The distribution of frequencies by mass in phase space matters
  - Example: Hernquist and NFW will have different wake, maybe very different
  - Example: multiple-passage LMC wake has strong point mode, less classic DF wake

General data-theory comparison

- Use orthogonal functions to characterize and filter features in data
  - Example: construct likelihood functions
- Analyze space and time together
  - Multivariate Singular Spectral Analysis (MSSA)
  - Based on Karhunen–Loéve theorem for stochastic processes
- Works for any type of simulation (e.g. GADGET, GIZMO, . . .)
- Expansion coefficients can be analyzed in time to compress and discover important features in simulations
- Efficient summary of dynamical ‘signal’ in n-body

Example: application of MSSA to simulation with bar