Deciphering the footprints of the Antlia dwarf galaxy on the Galactic disk

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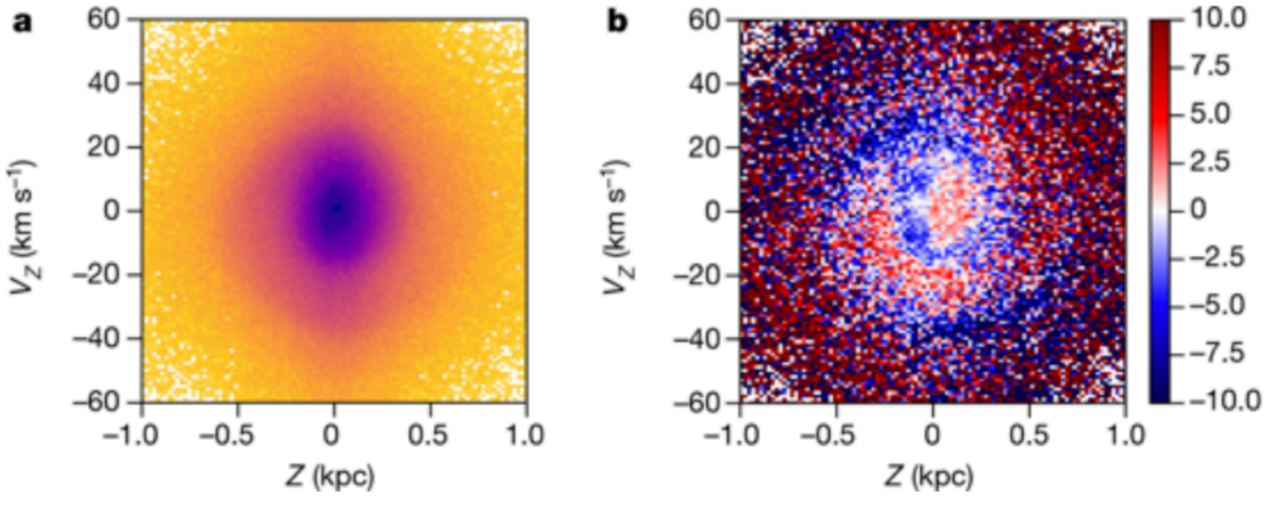
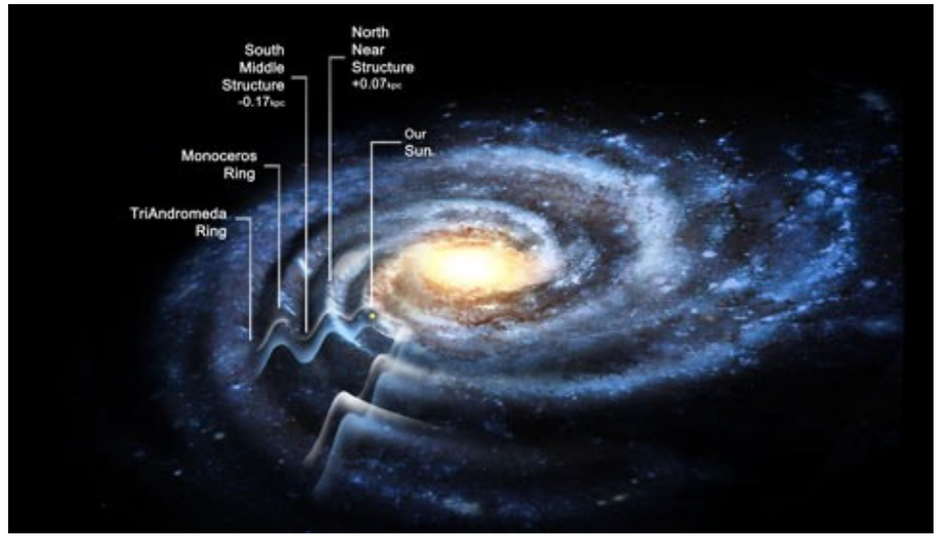
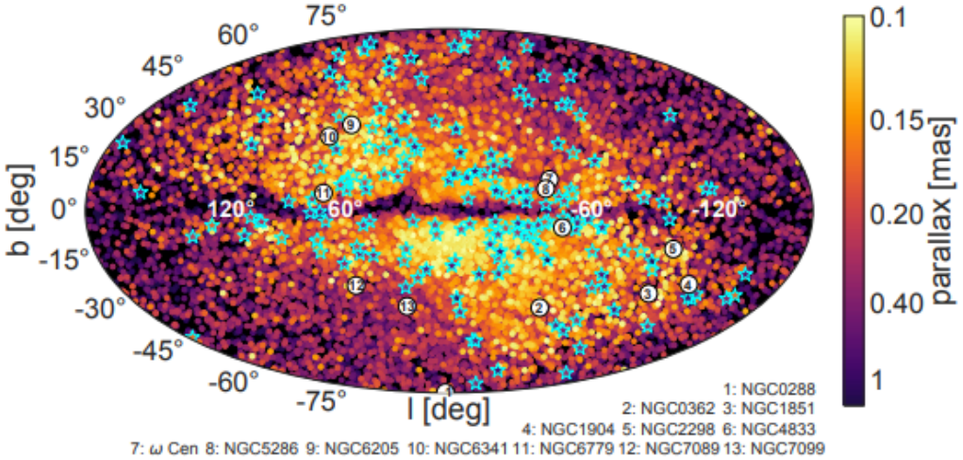
… the galaxy is a complicated place



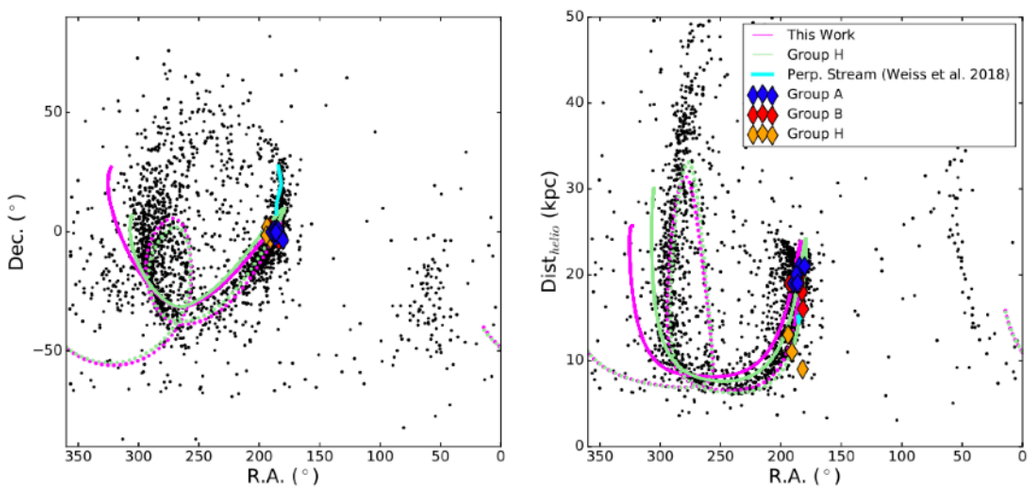
Antoja et al 2018



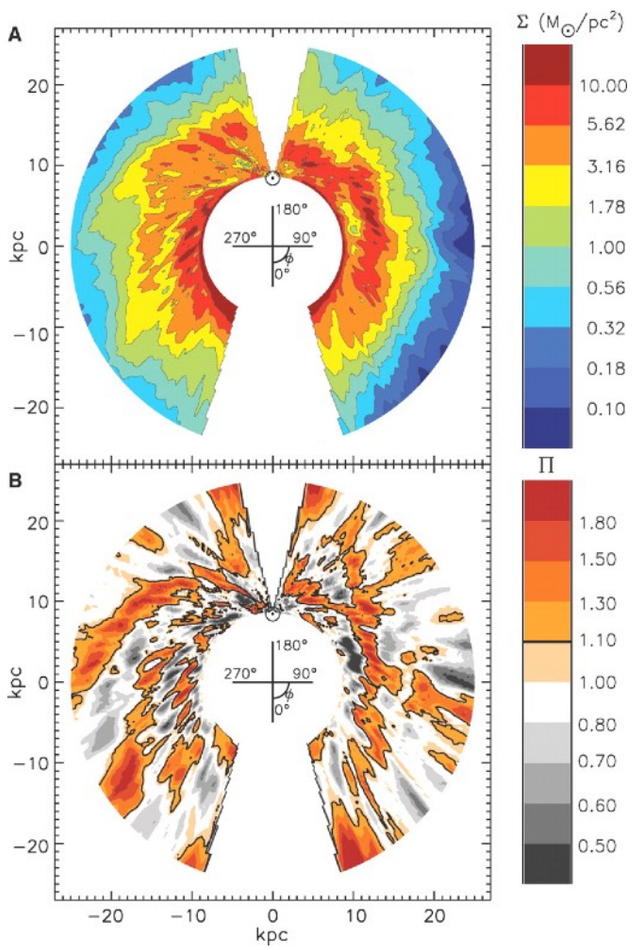
Ripples in the disk : Xu et al. 2015



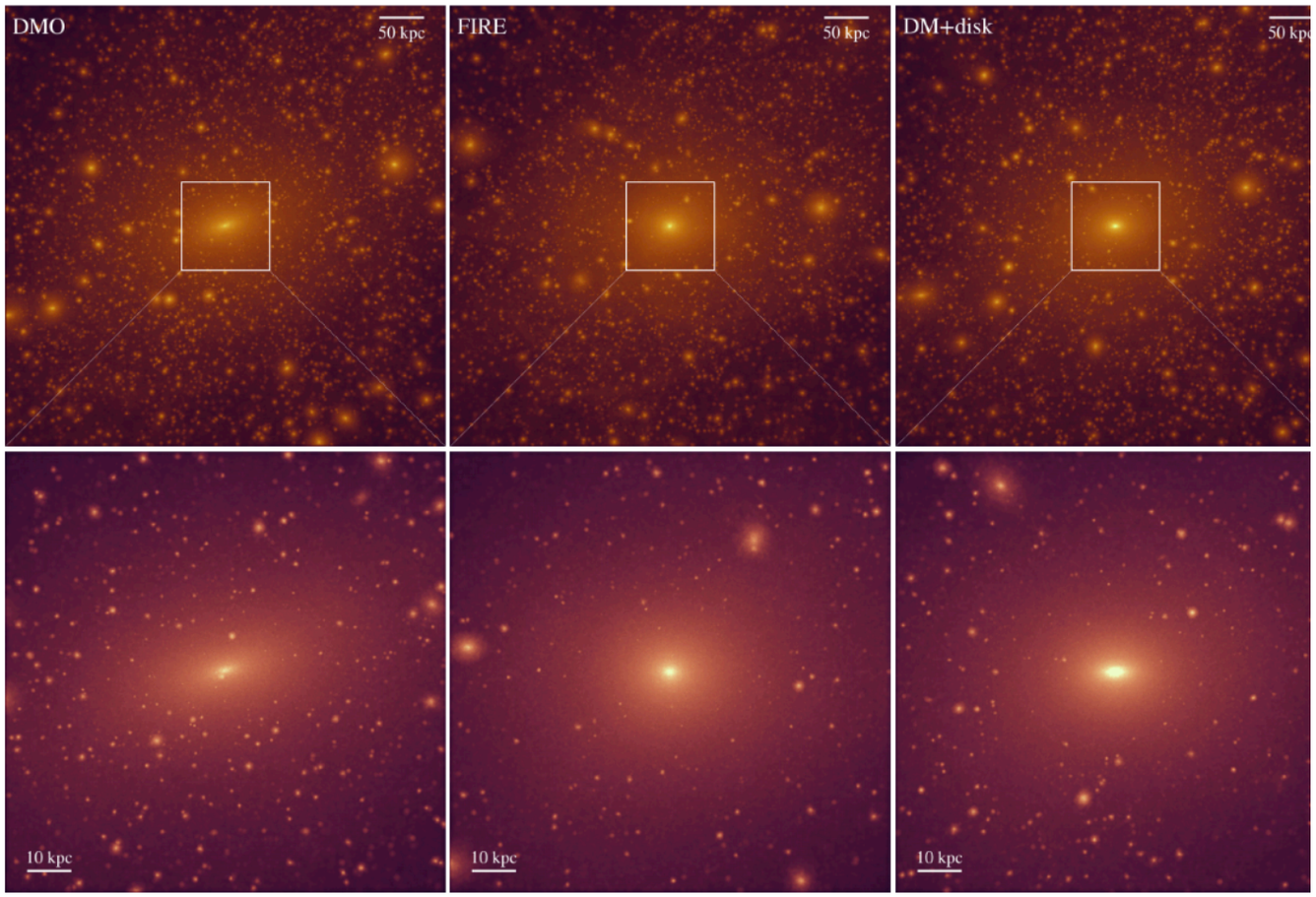
Helmi et al. 2019

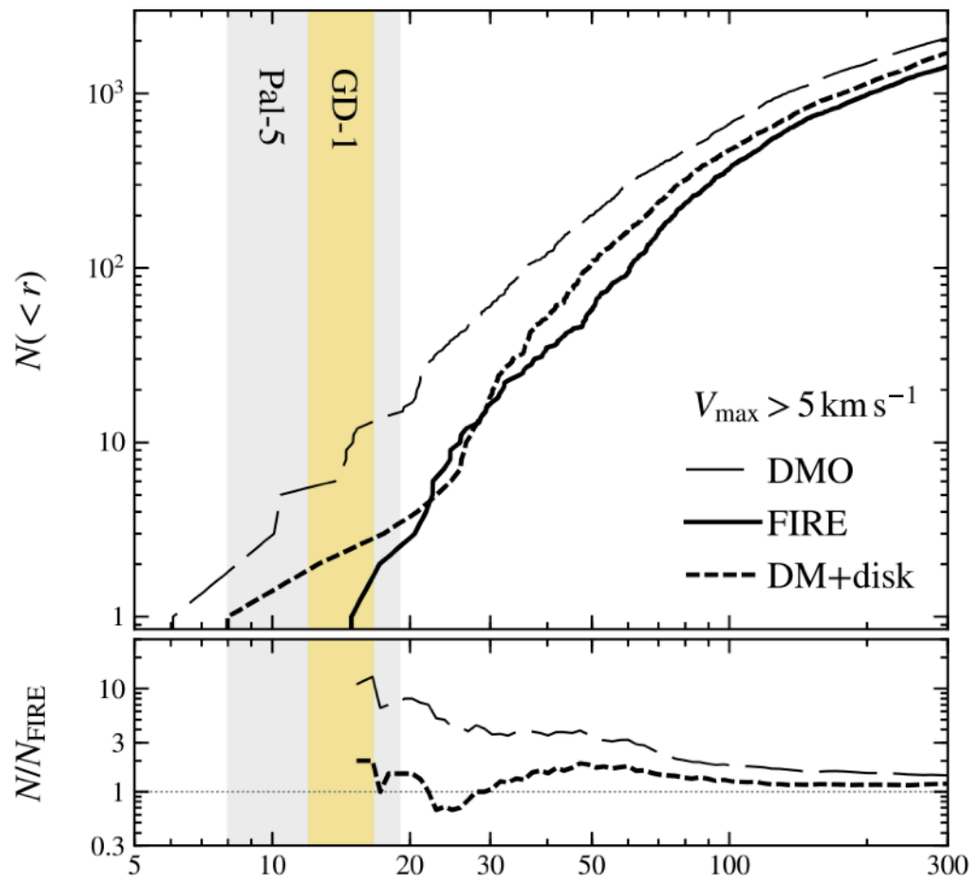


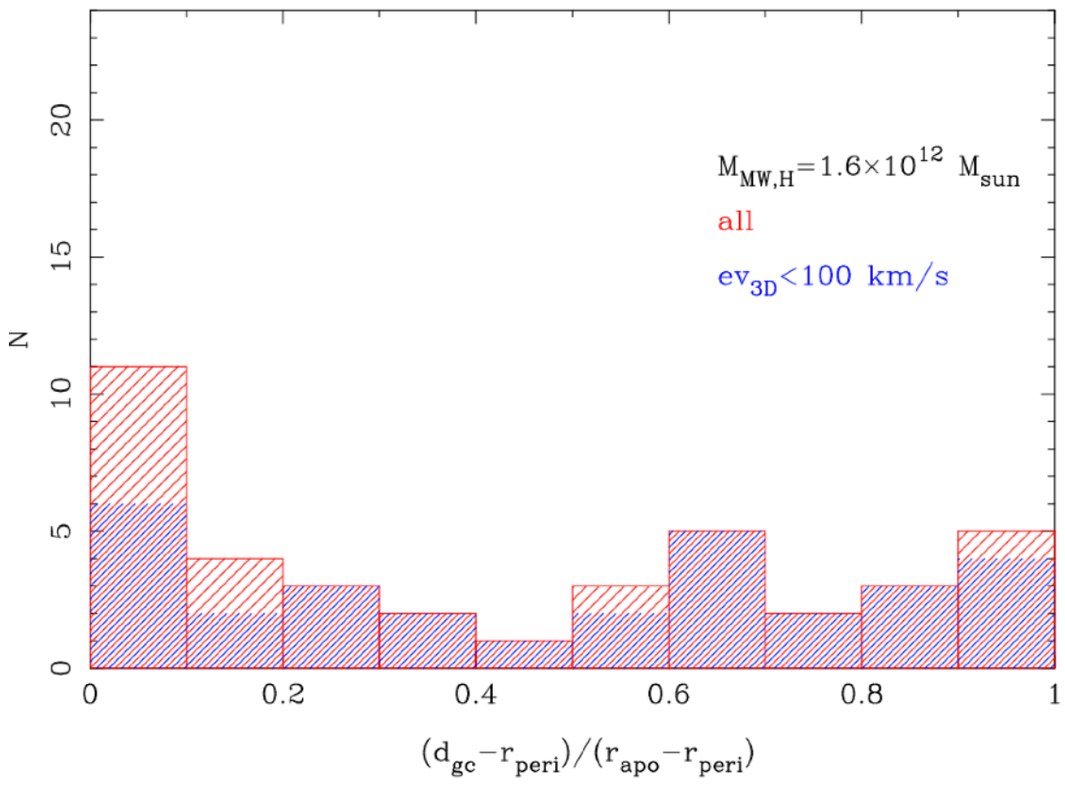
Virgo overdensity - Donlon et al. 2019



Levine, Blitz & Heiles 2006







Garrison-Kimmel et al. 2017

Could there by a couple of surviving (or about to be destroyed) dwarf galaxies that approached close to the disk? Also: Samuel et al. 2019; Fritz et al. 2018

Overview

- (Old) prediction for new dwarf galaxy from analysis of perturbations in outer HI disk (Chakrabarti & Blitz 2009; Chakrabarti & Blitz 2011). Inverse method.

- New Gaia observations of Antlia (Torrealba et al. 2019)

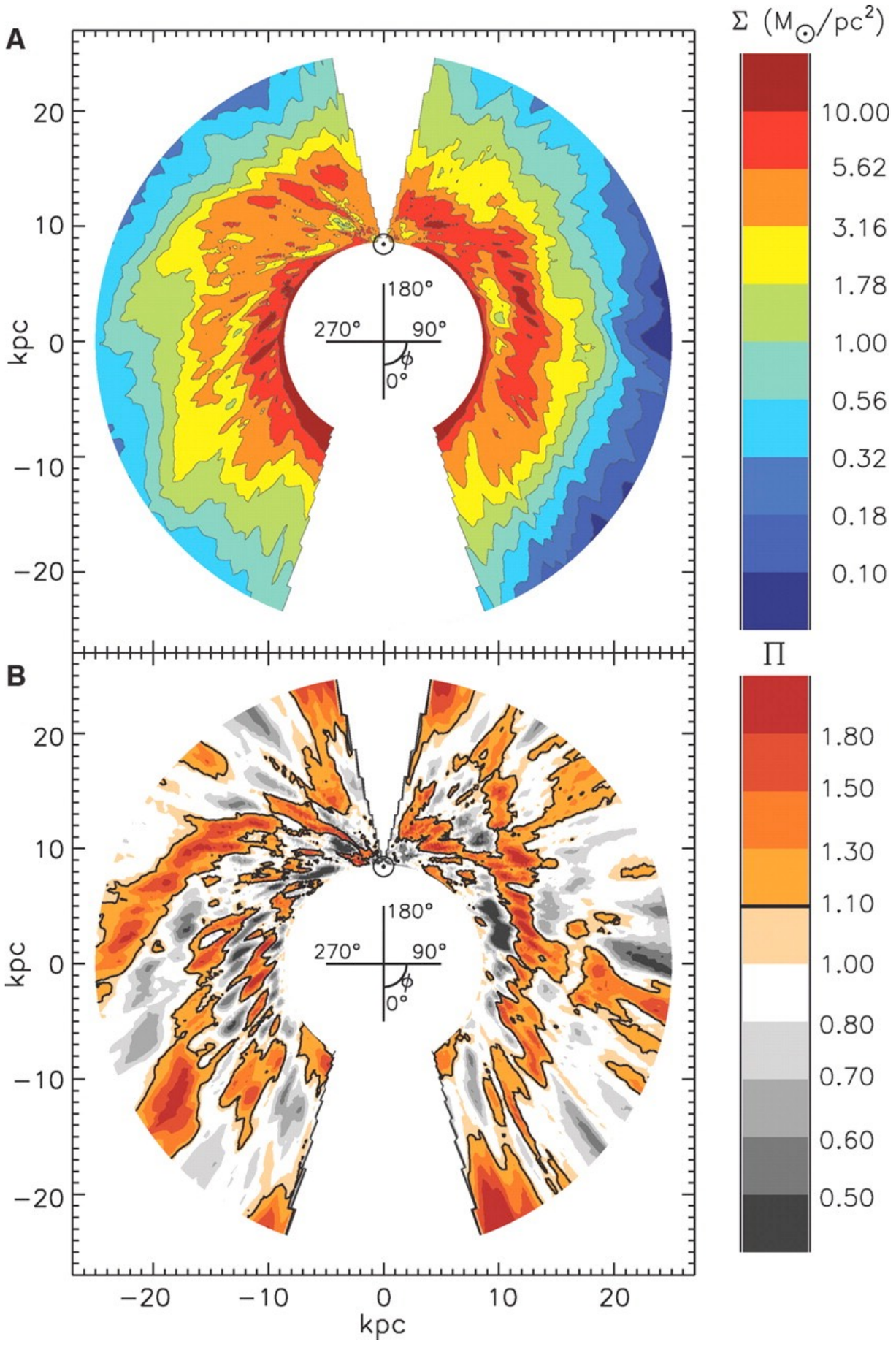
- Orbit distributions for Antlia satellite based on Gaia PMs

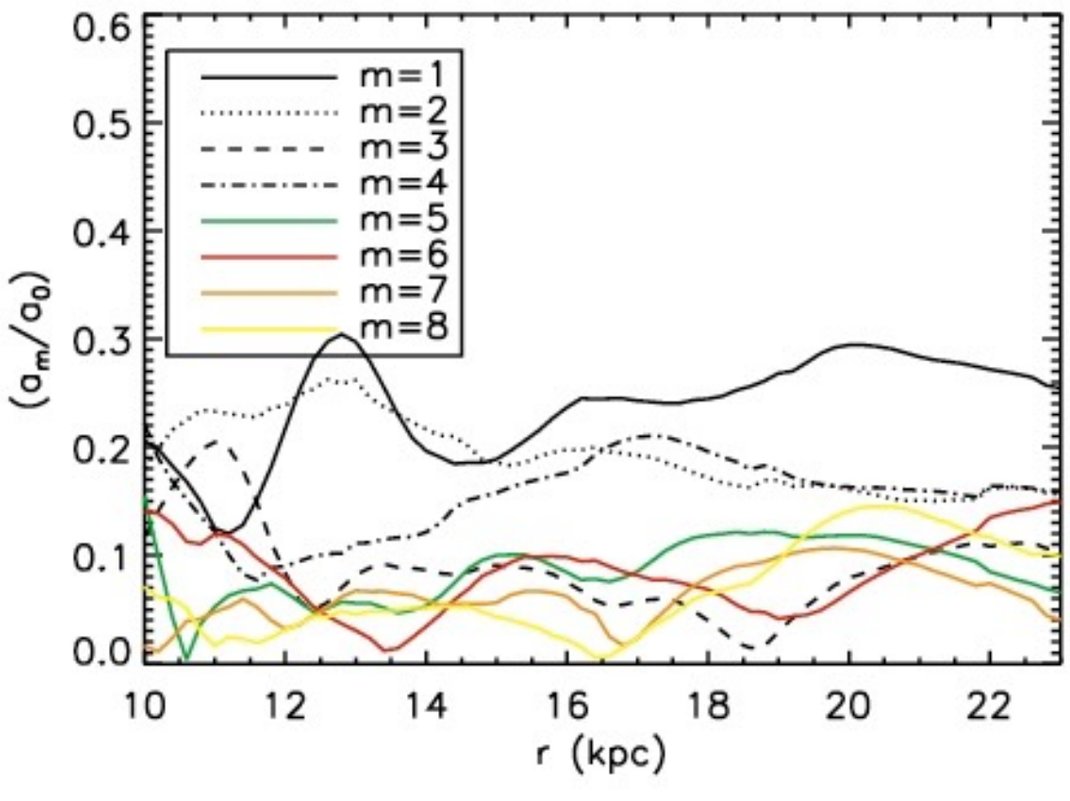
- Antlia's (and Sgr's) effect on the Galactic disk. HI planar disturbances in outer disk. Distinct from warp, phase space spiral, etc.

Planar disturbances in outer HI disk

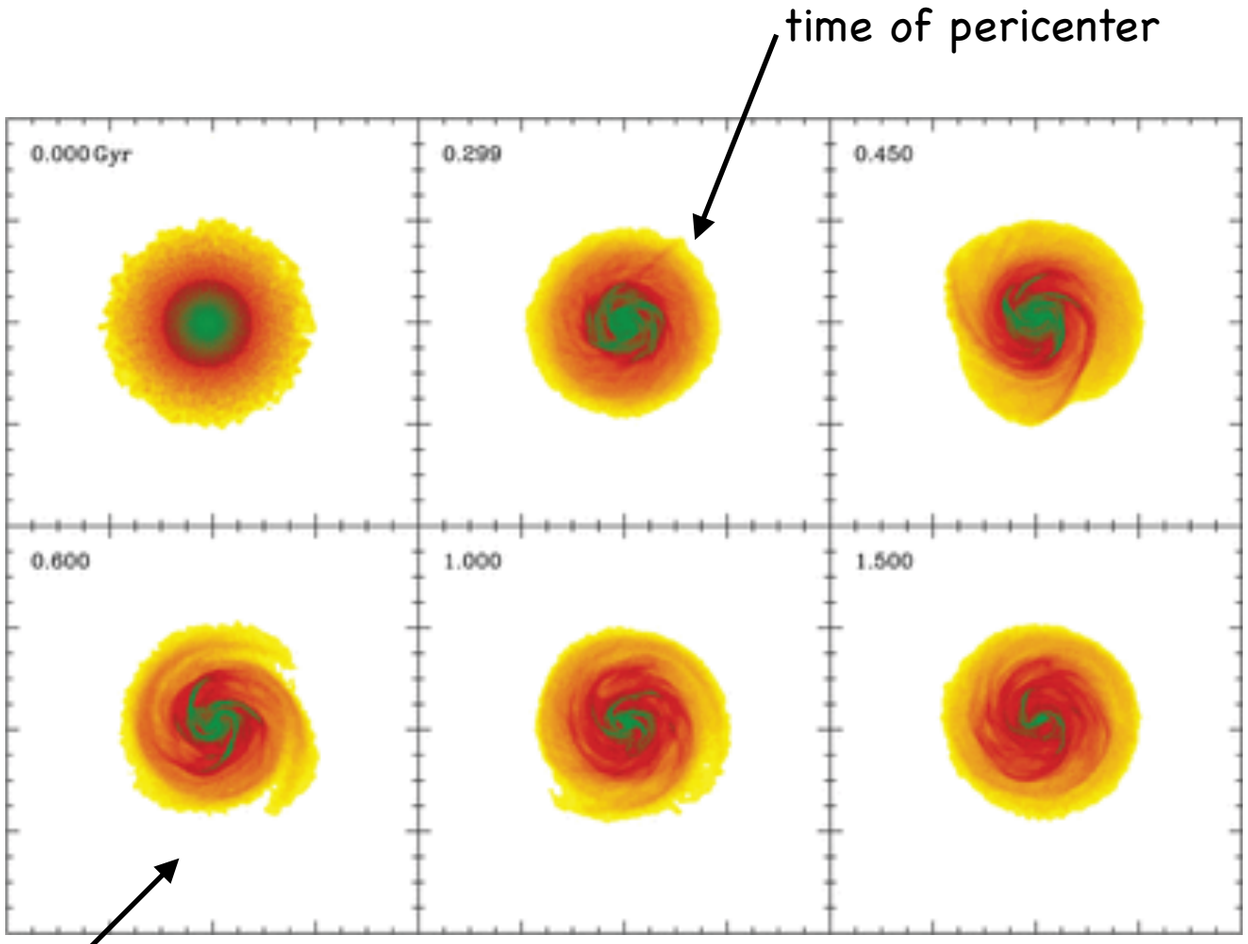
HI map of Milky Way (Levine, Blitz & Heiles 06). What caused these structures outside the solar circle?

$$a_m(r) = \int \Sigma(r,\phi) e^{-im\phi} d\phi$$

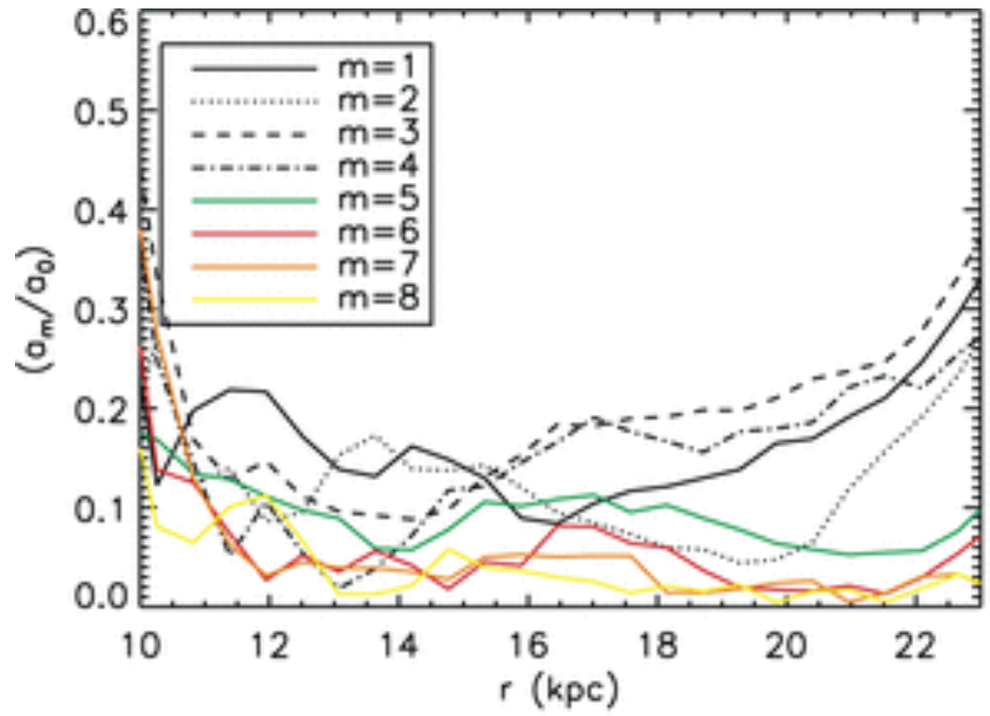


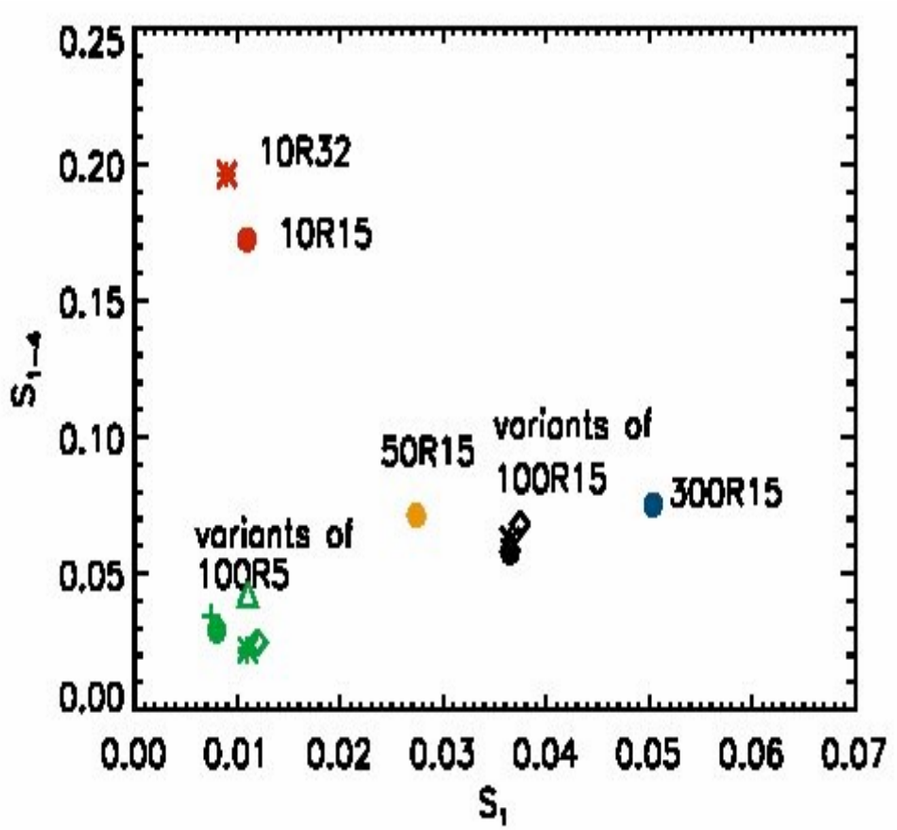


(Old) prediction for new dwarf satellite of Milky Way

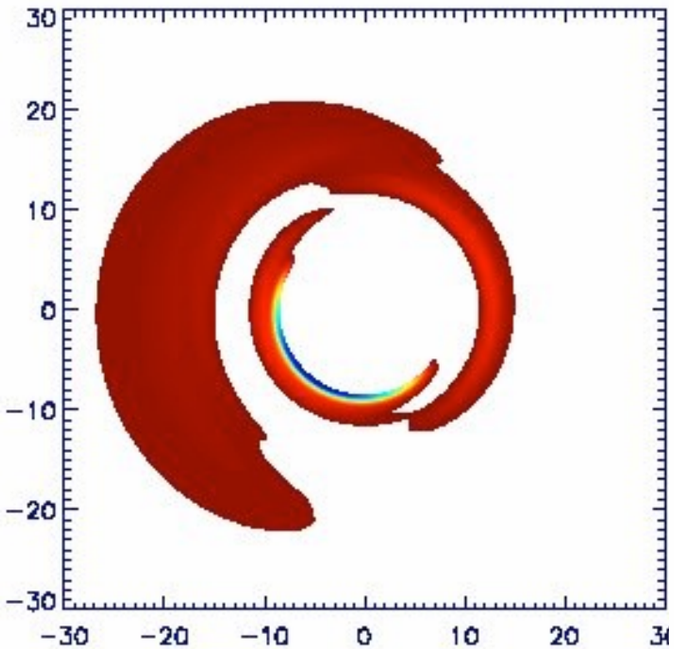


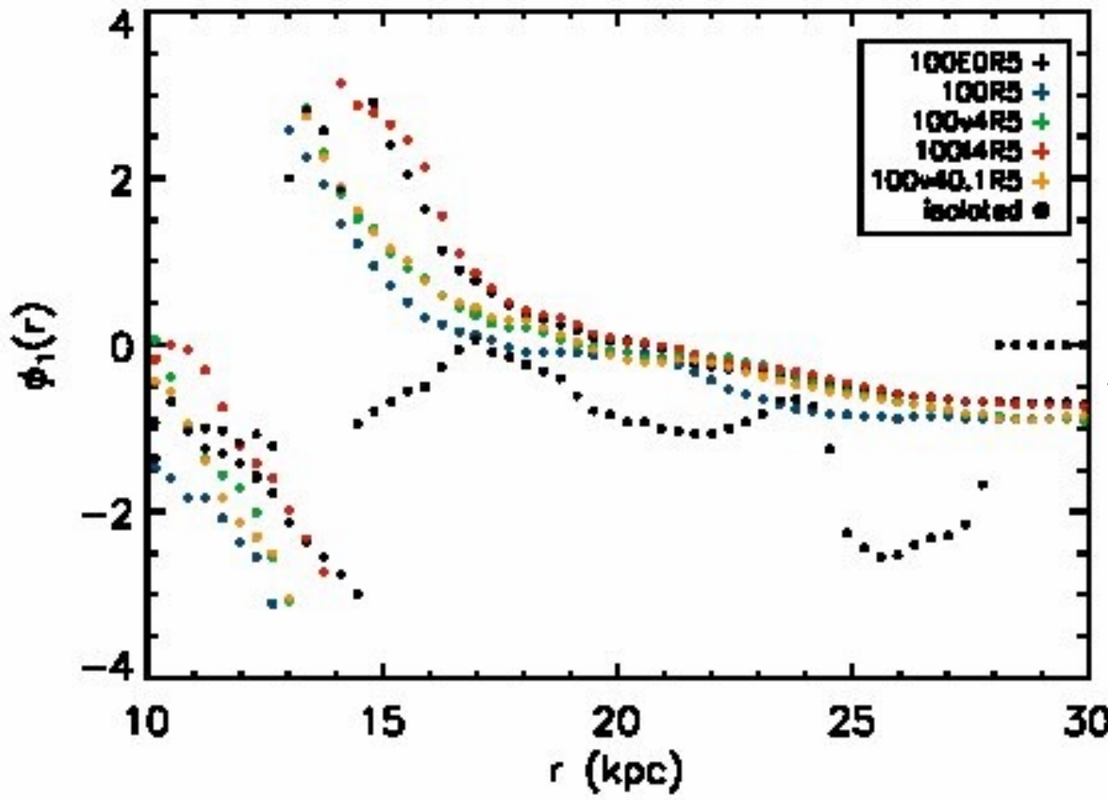
- Chakrabarti & Blitz (2009): ~ 1:100 perturber with pericenters (~ 7-10 kpc) needed to match disturbances in outer HI disk. Prediction: currently perturber is at ~ 100 kpc.



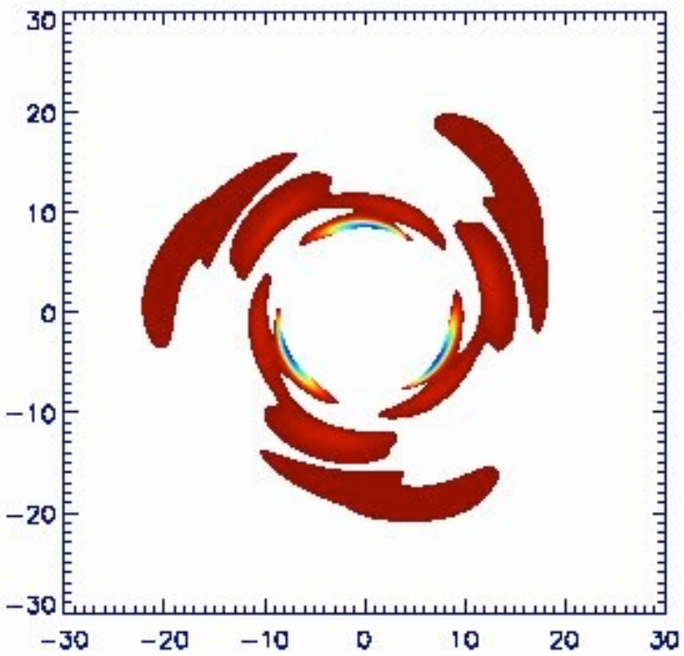


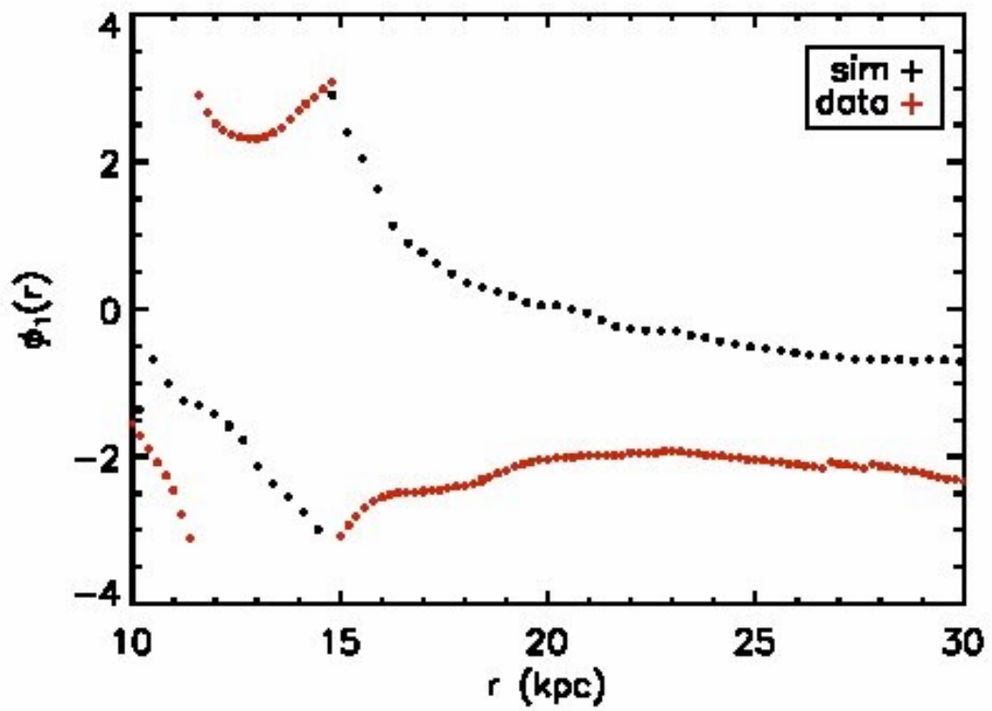
Prediction for azimuthal location





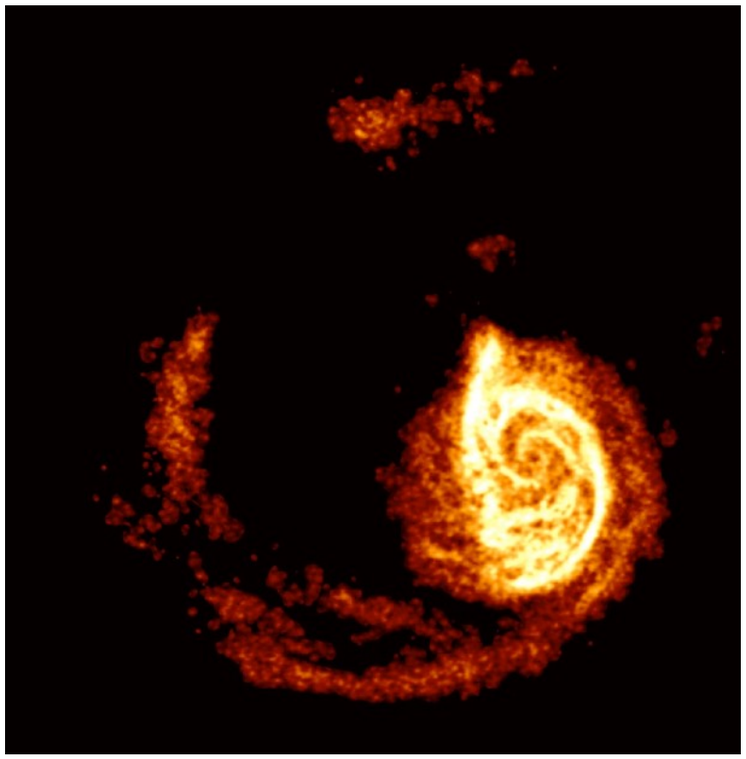
Chakrabarti & Blitz (2011).
Tidal interactions — flat phase variation

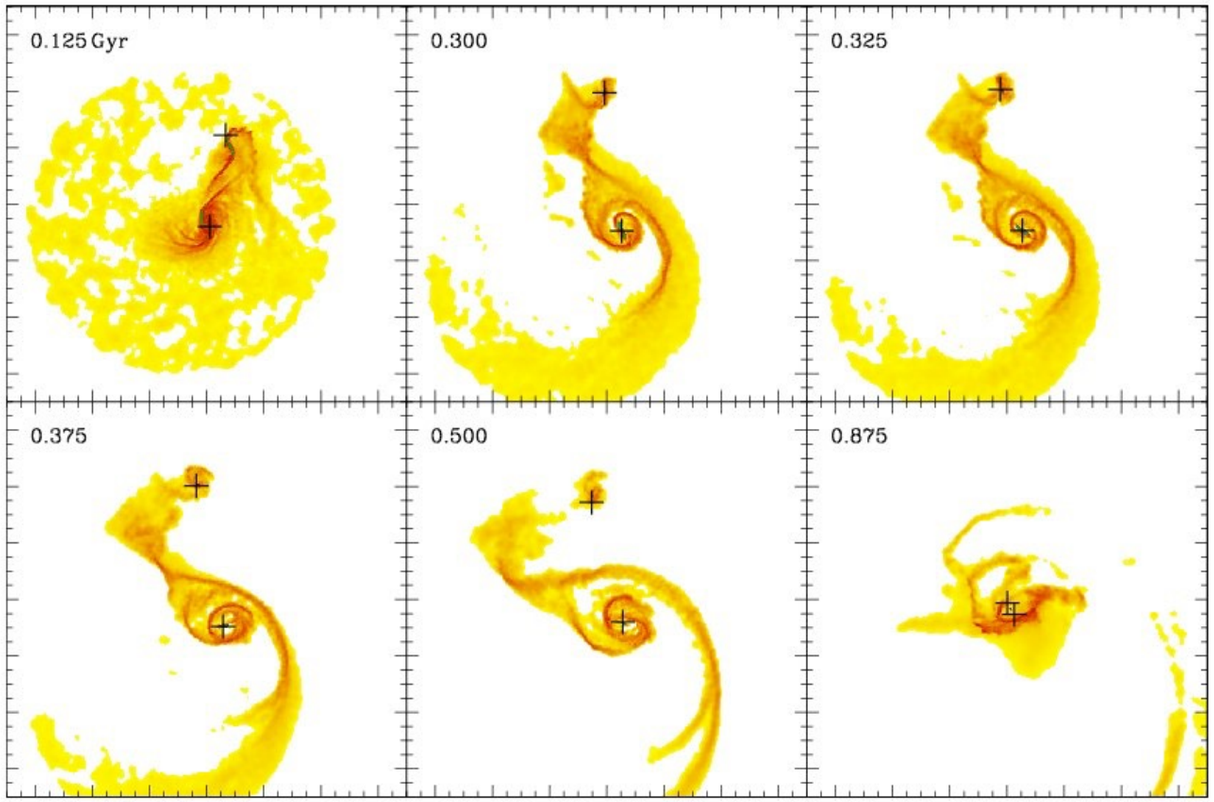


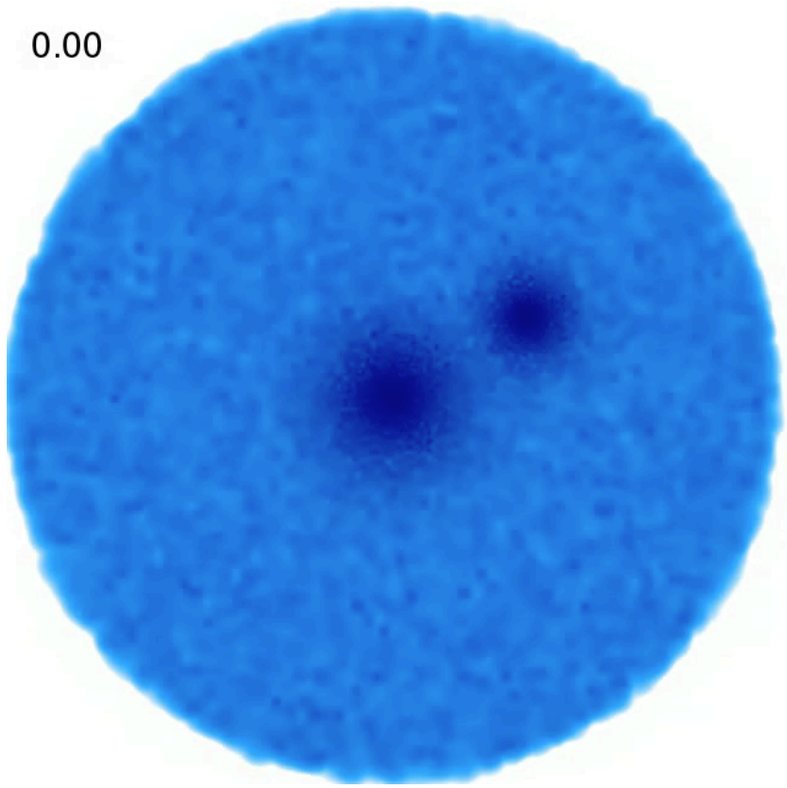


Phase variation for best -fit simulations (Chakrabarti & Blitz 2011)

Proof of principle of method







Chakrabarti, Bigiel, Chang & Blitz 2011

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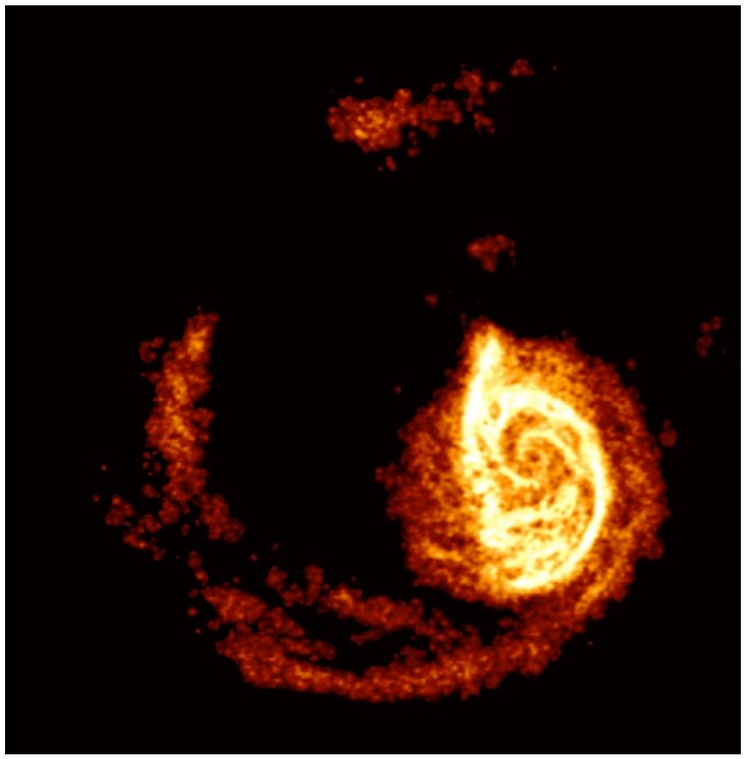

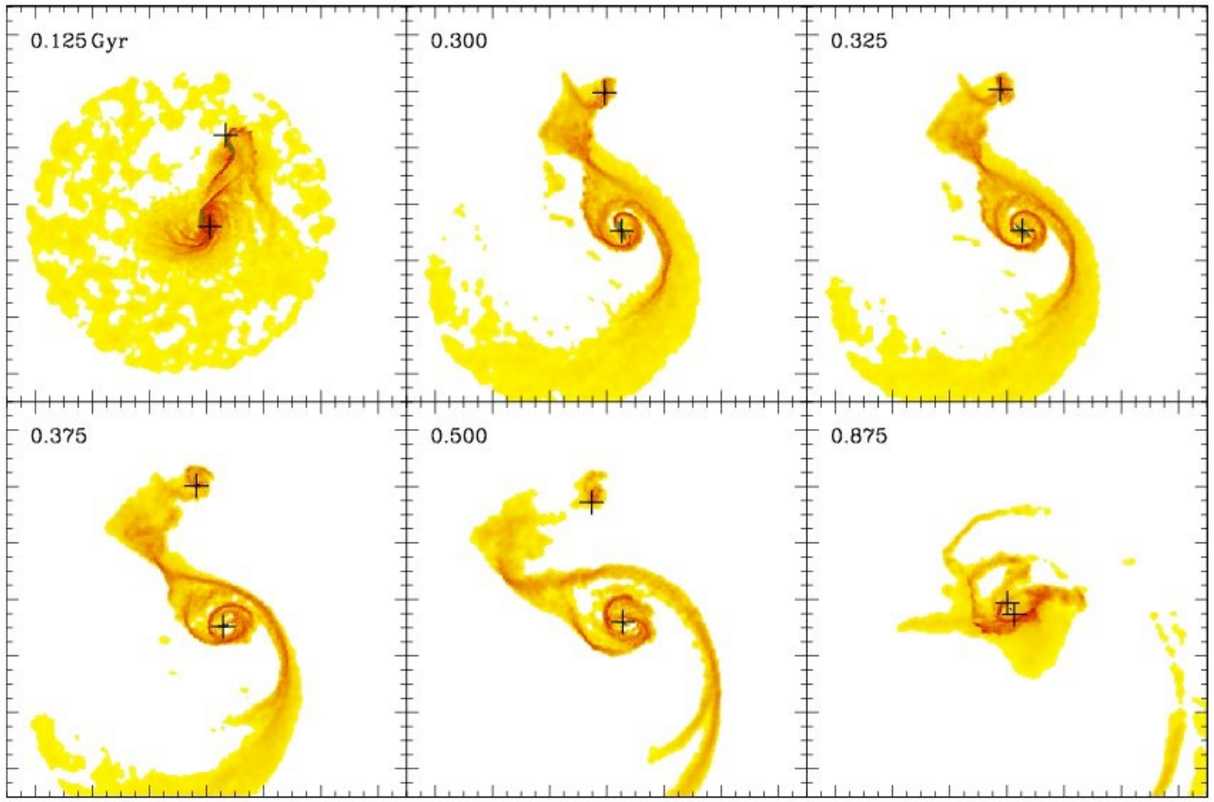

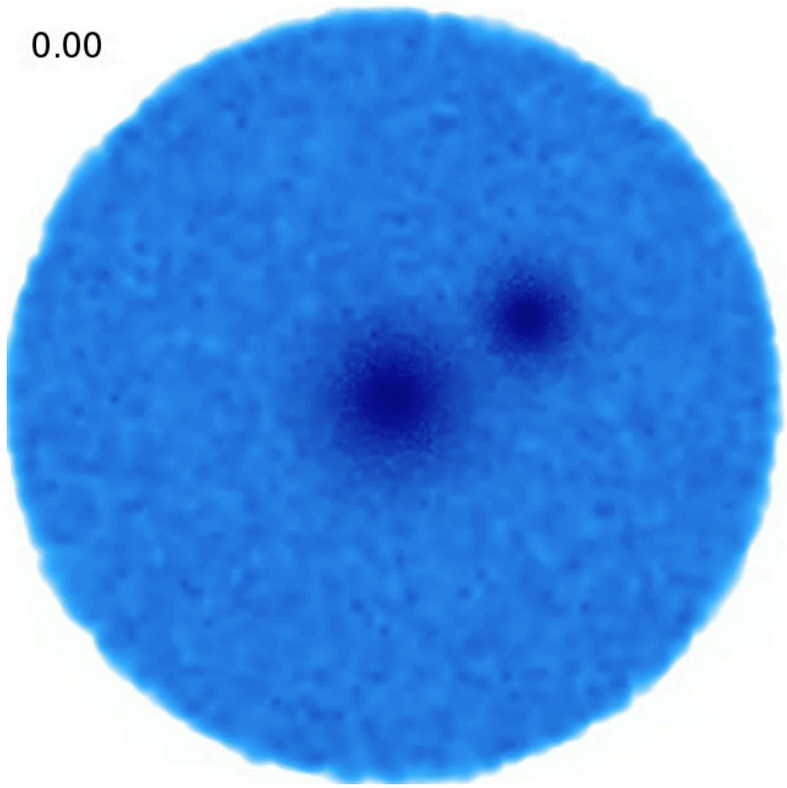

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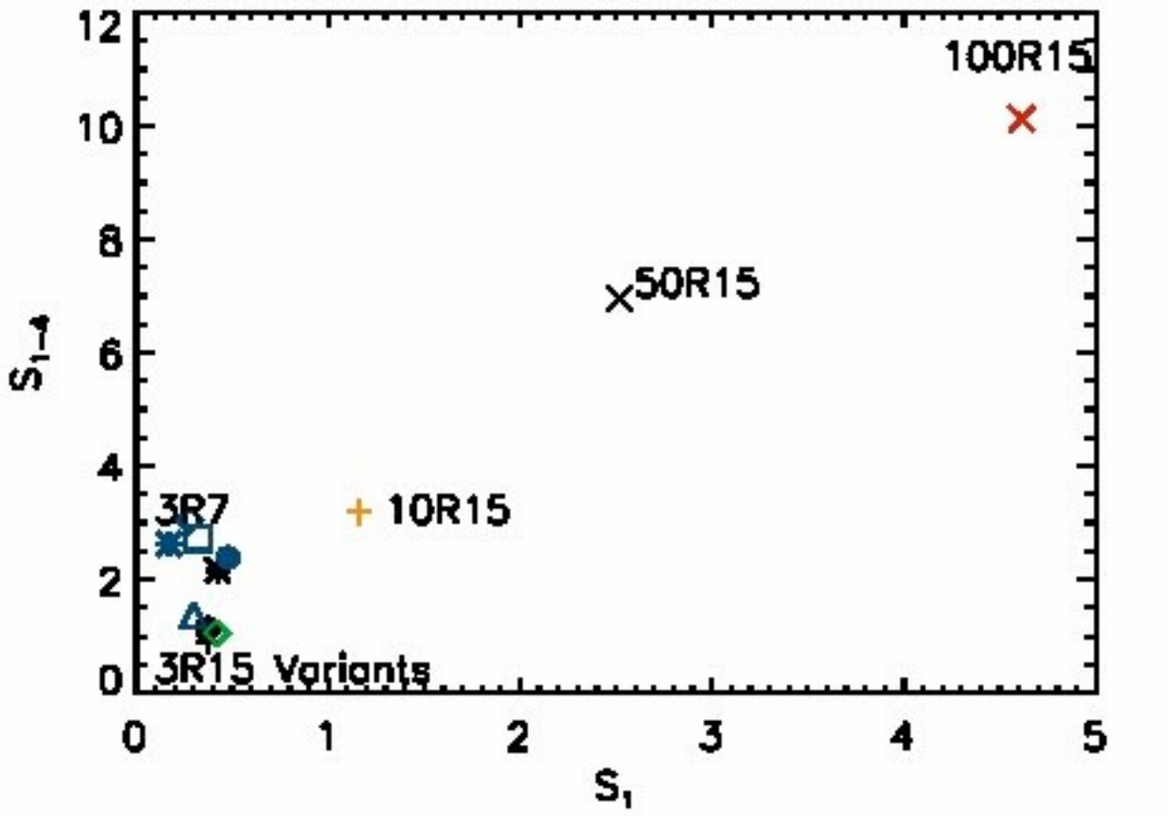
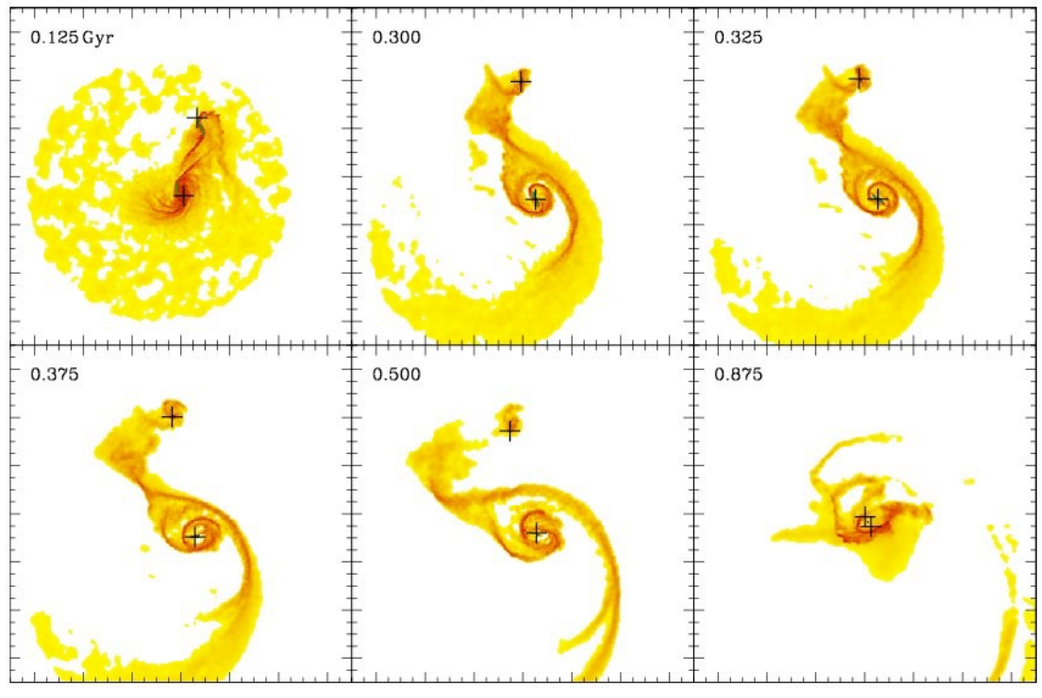


Best fits — close to origin at best-fit time. "Variants" — varying ICs, orbital inclination, ISM & SFR, etc



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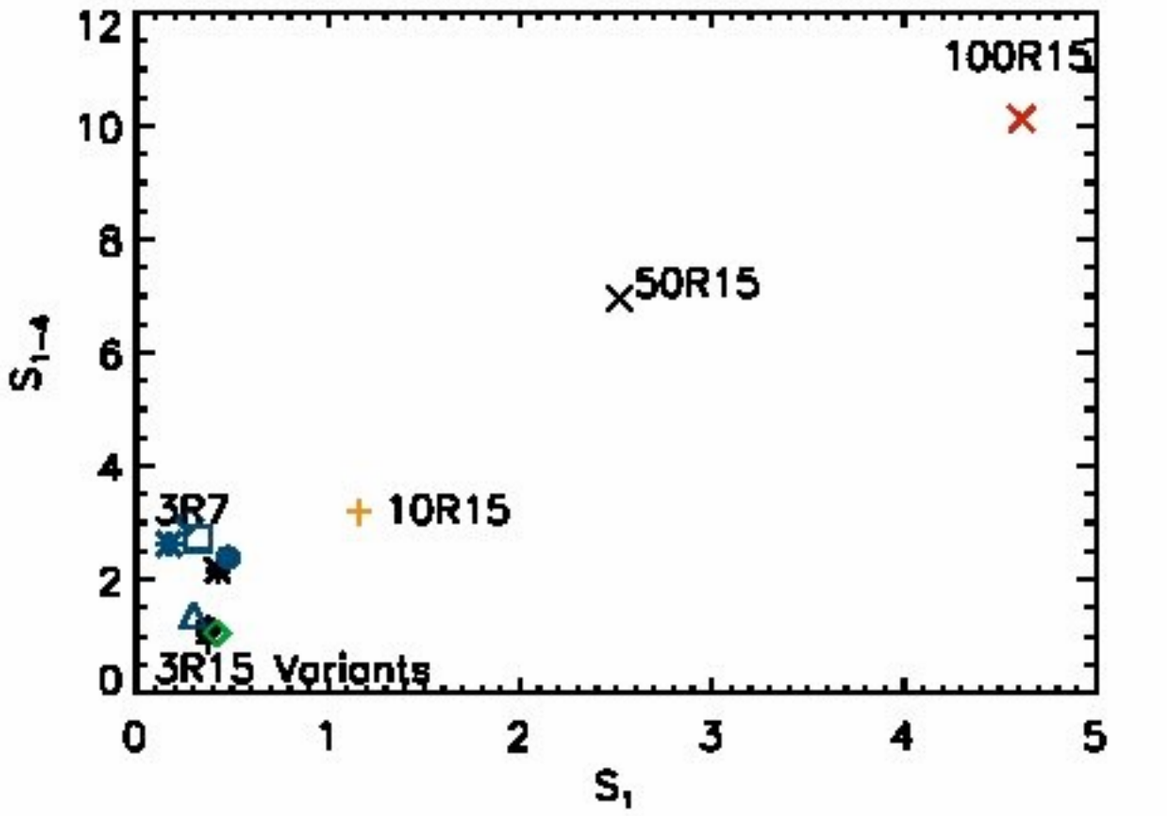

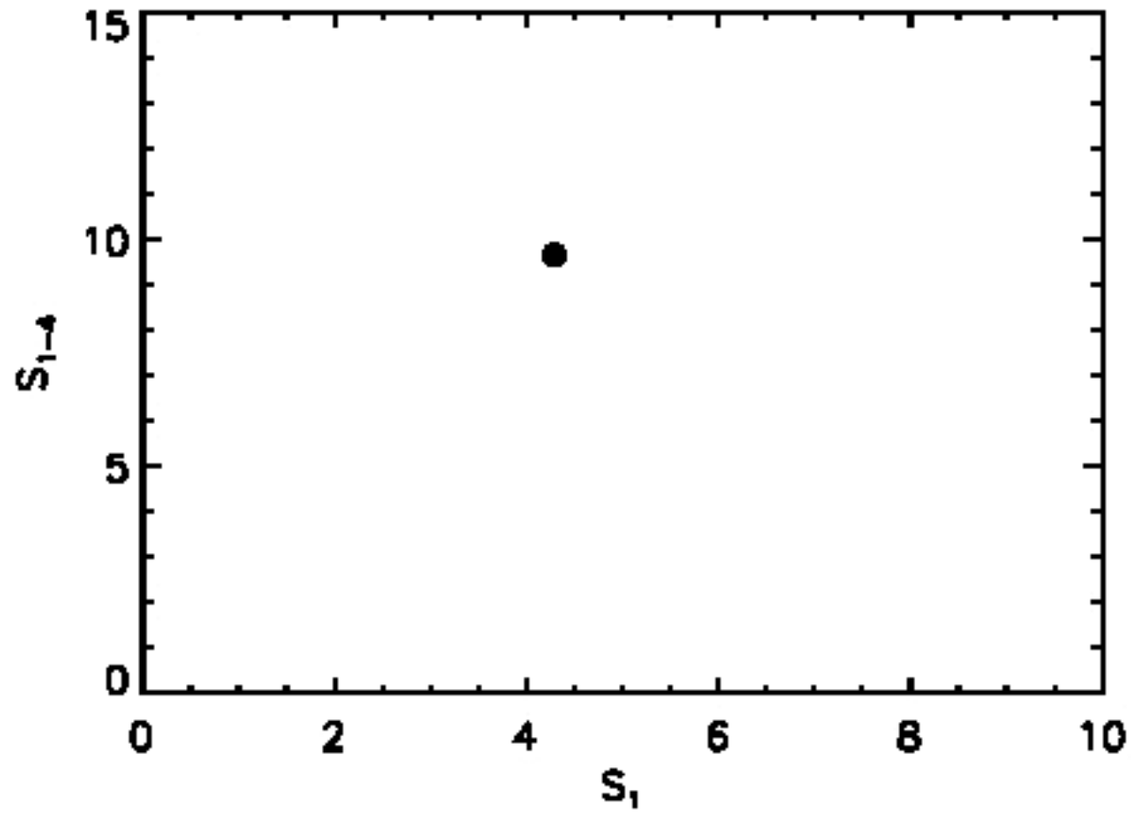

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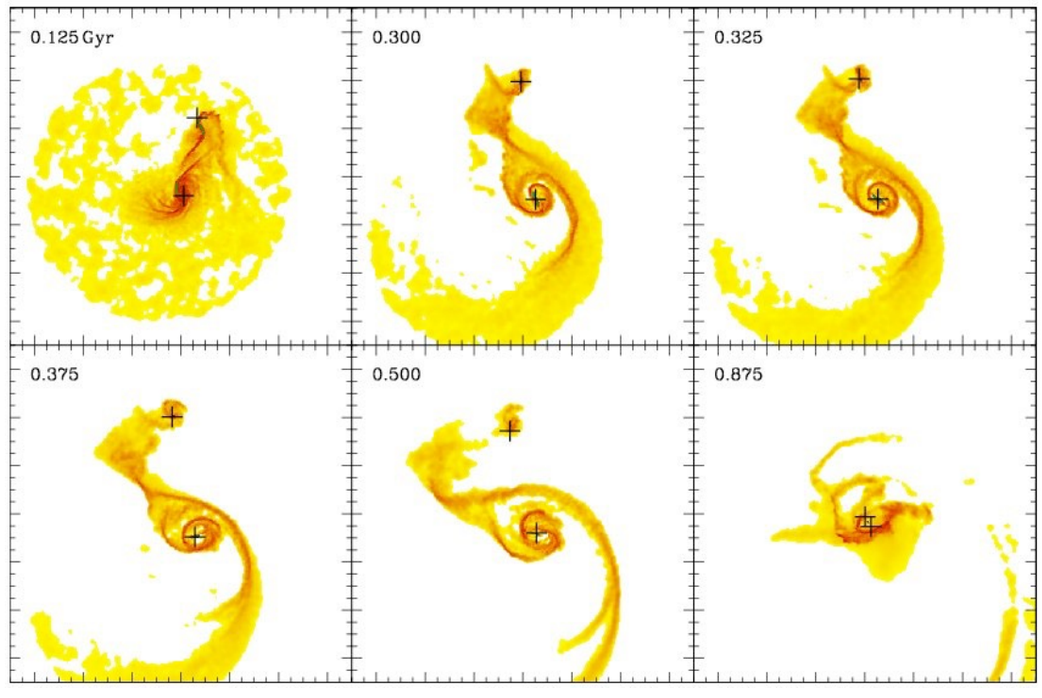
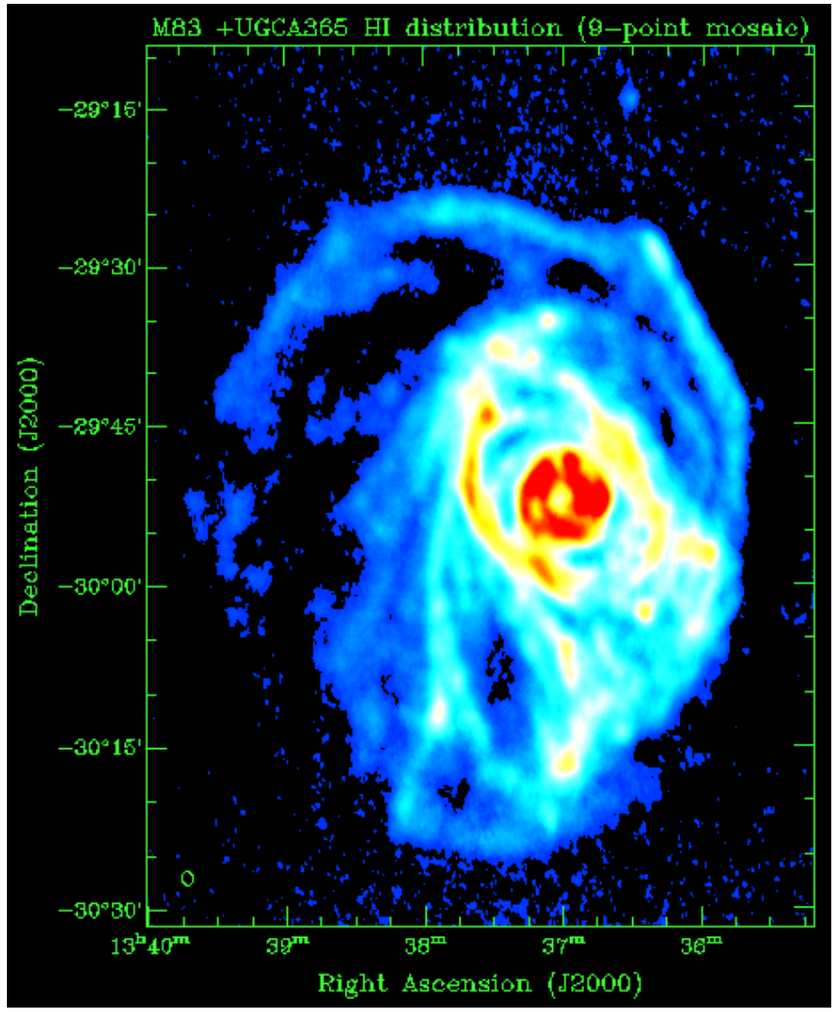
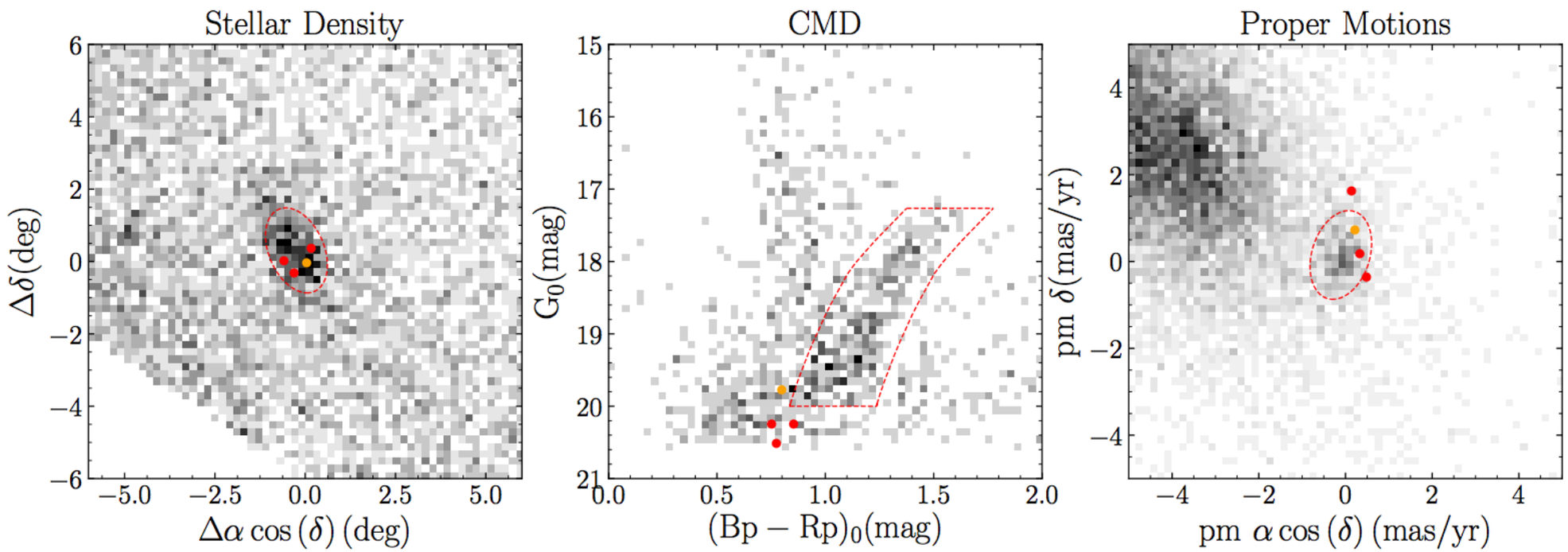


why look at the gas ?

- Coldest component responds the most
- Outer HI disks reach to several times the optical radius — largest cross-section for interaction
- Gas has short-term memory
- Outskirts are clean

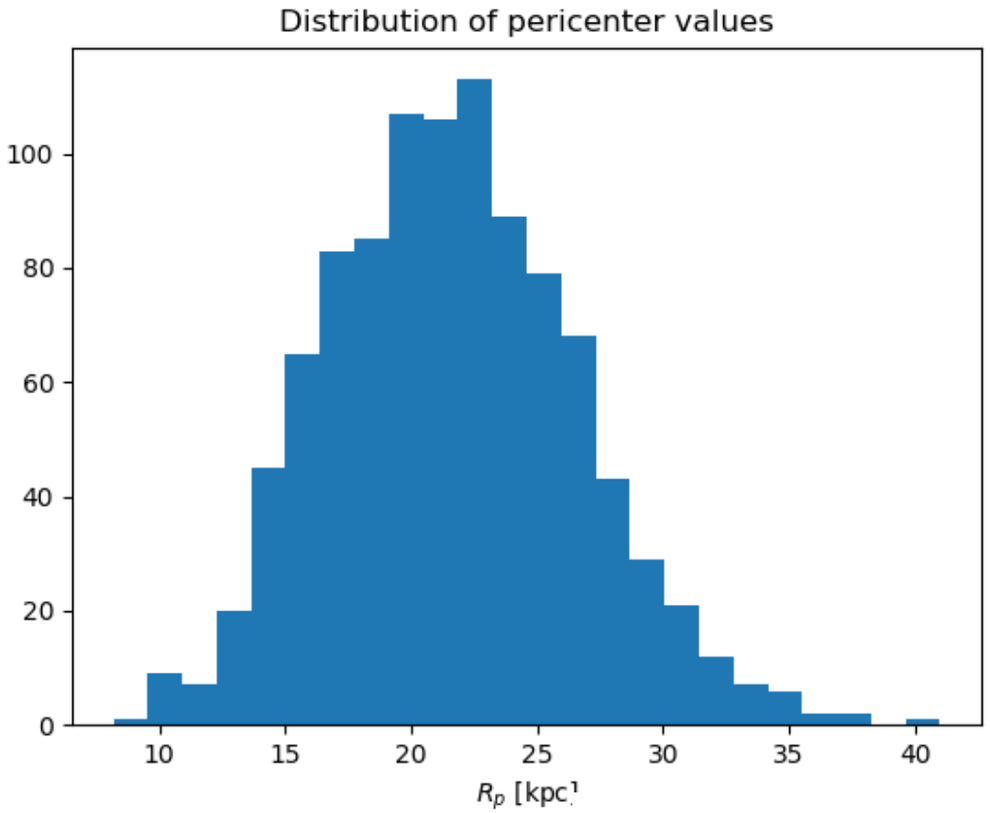


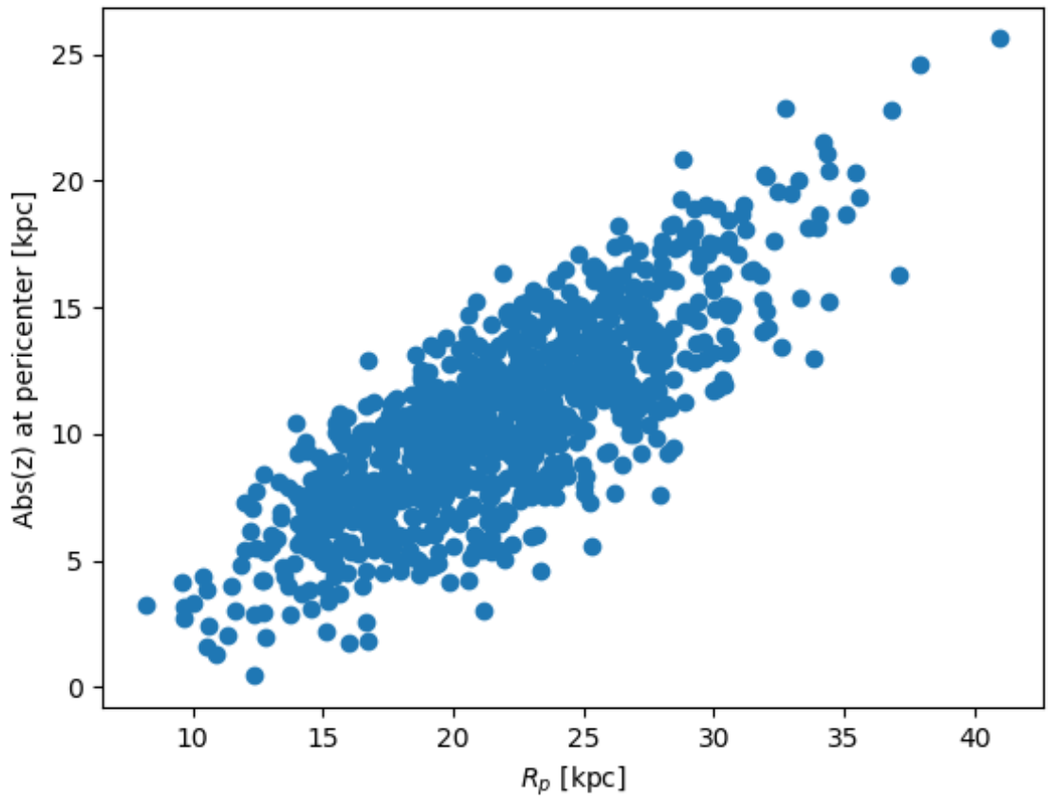
New Gaia observations of the Antlia dwarf galaxy



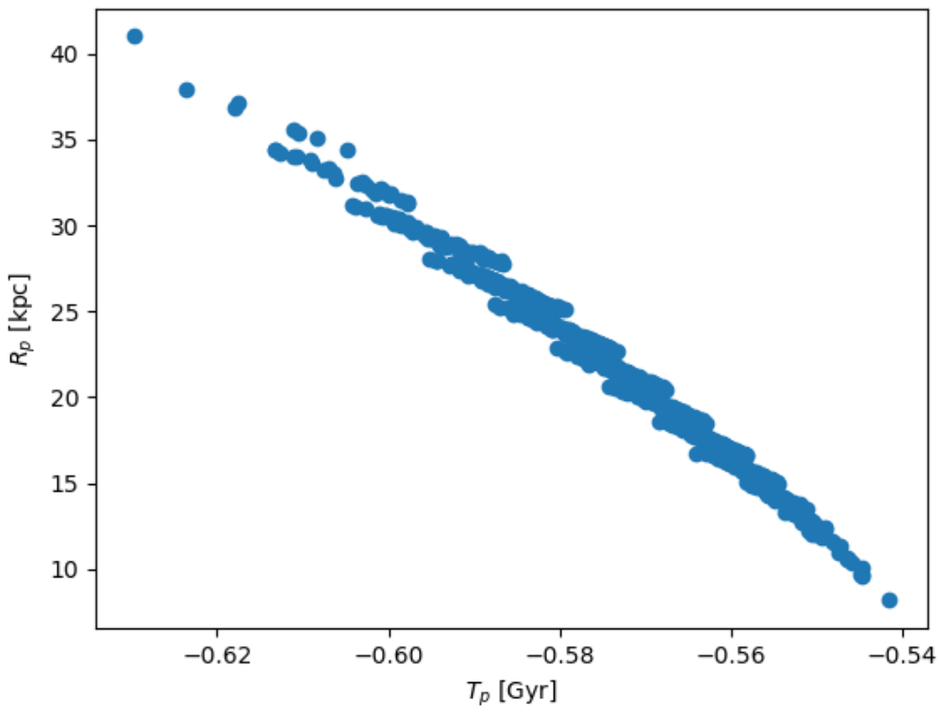
- similar in extent to LMC, but two orders of magnitude fainter (M_v = -8.5 mag)
- b ~ 11 degrees
- D = 129 +/- 6.5 (Torrealba et al. 2019)

Antlia's orbit distributions from Gaia proper motions





$\langle R_p \rangle$ = 21 kpc



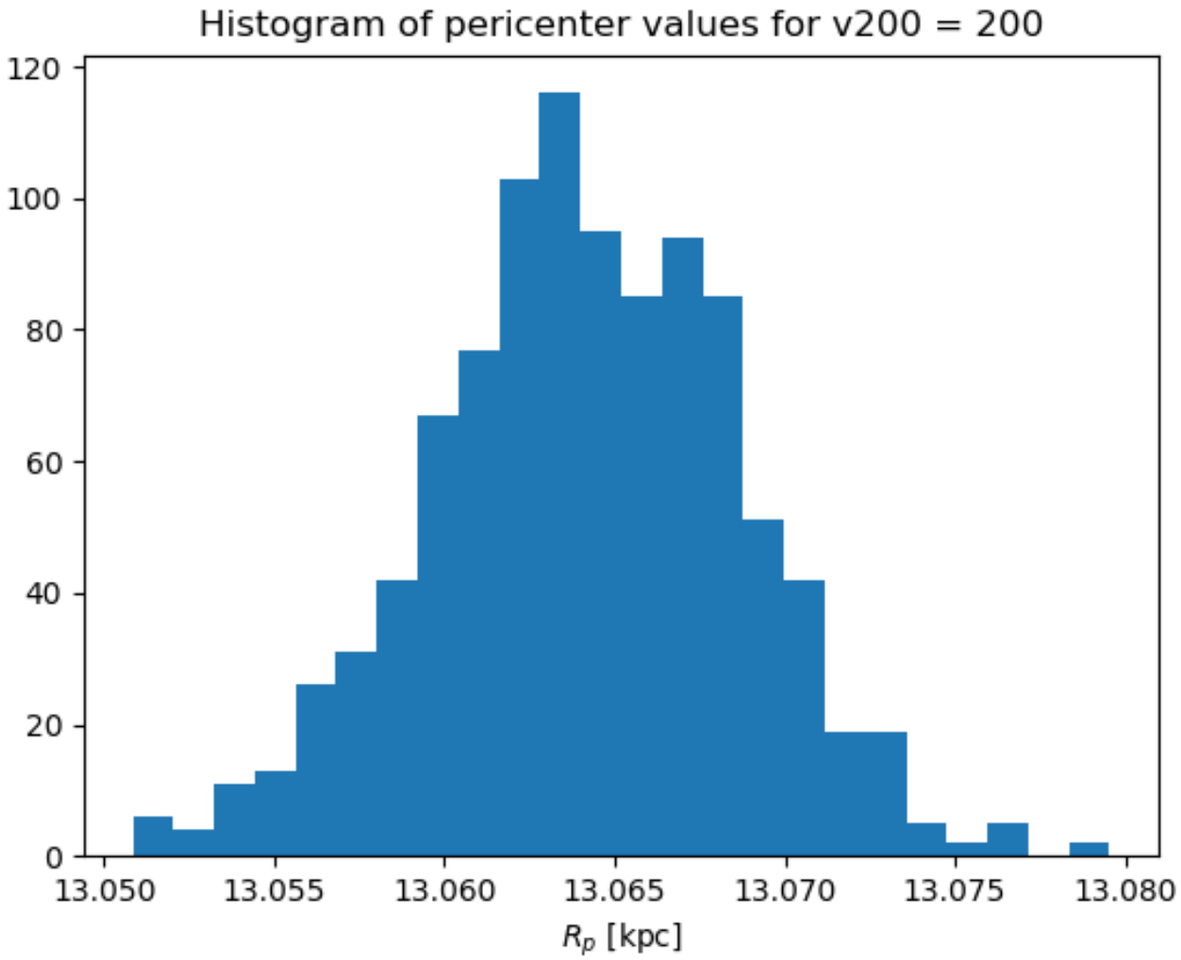
Using Gaia PMs:
(Torrealba et al. 2019)

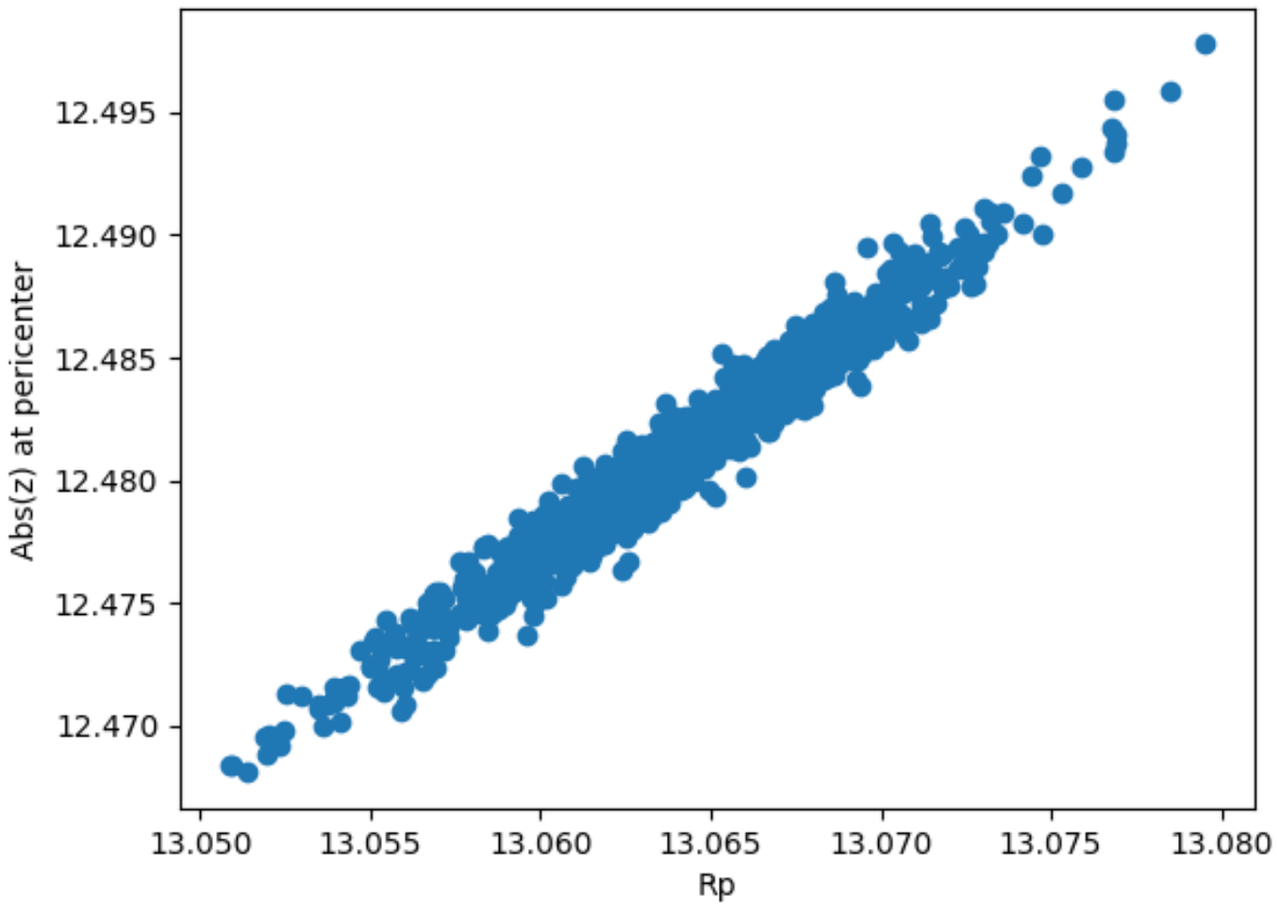
$$\mu_\alpha cos\delta = -0.095 \pm 0.018$$

$$\mu_\delta = 0.058 \pm 0.025$$

v_{200} = 200 km/s, M_{200} = 1.8×10^{12} M_{sun}

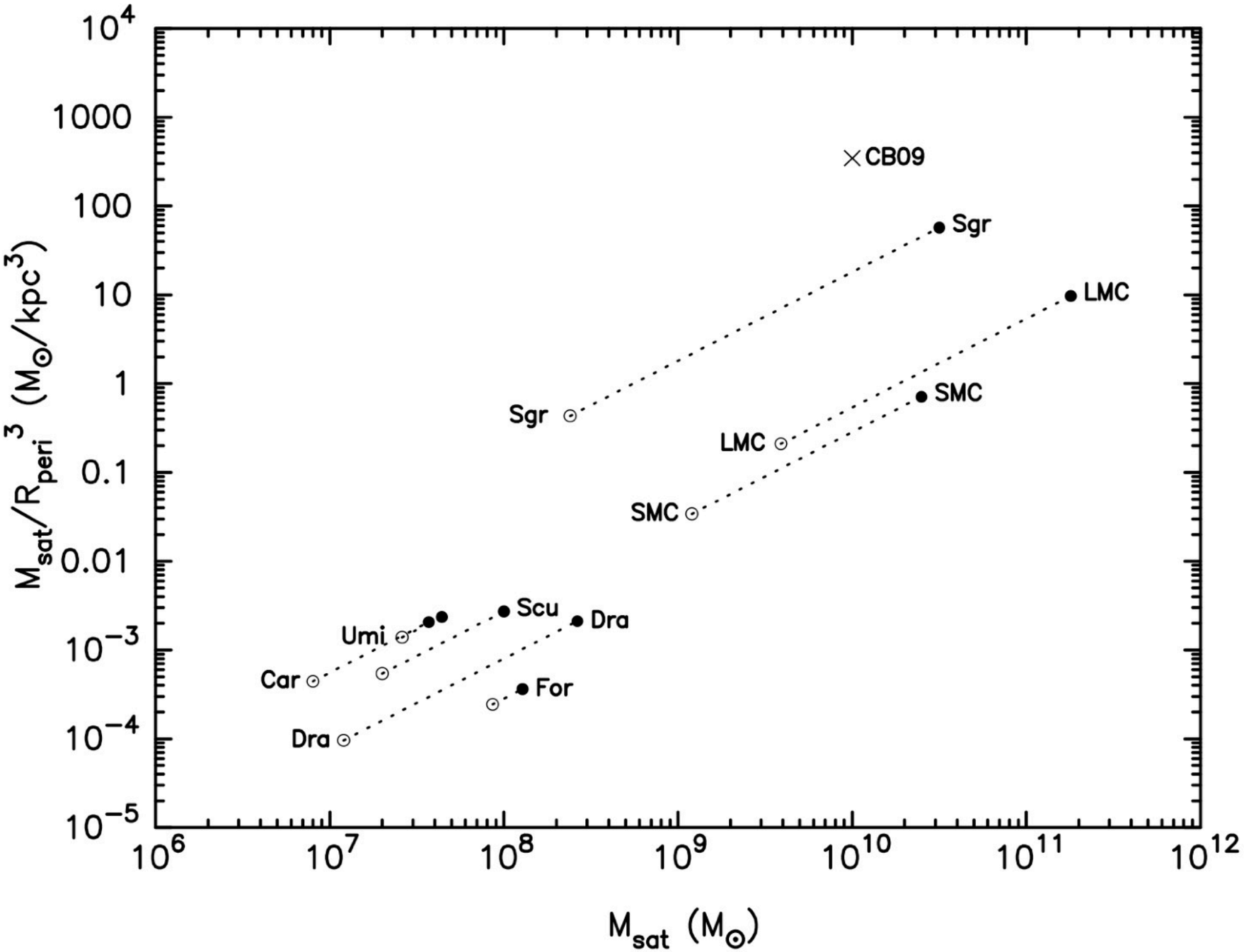
But wait! what about Sgr?



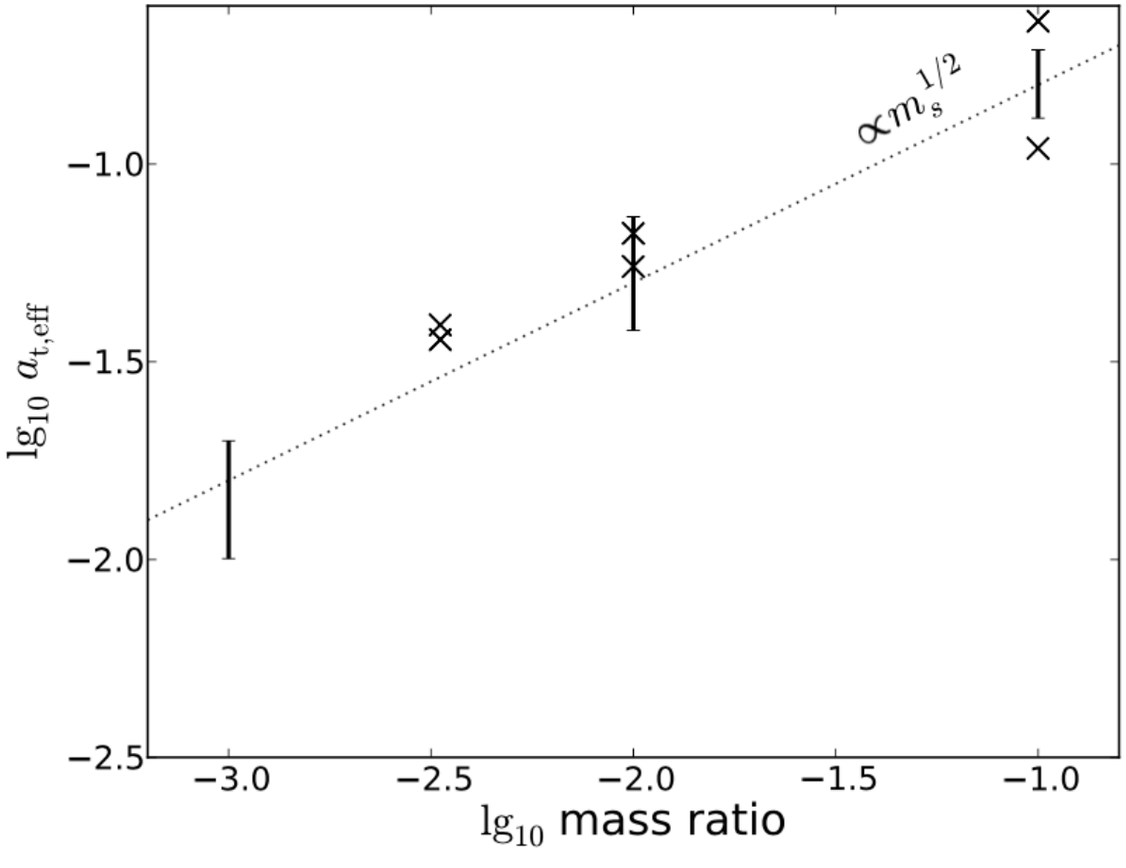


Sgr is on a polar orbit

The tidal players of the Milky Way



Our approach



Chang & Chakrabarti 2011

$$a_{m,eff}(t) = \frac{1}{r_{\mathrm{out}} - r_{\mathrm{in}}} \int_{r_{in}}^{r_{out}} |a_m(r,t)| dr$$

$$a_{t,eff}(t) = \left(\frac{1}{4} \sum_{m=1}^{m=4} |a_{m,eff}(t)|^2 \right)^{1/2}$$

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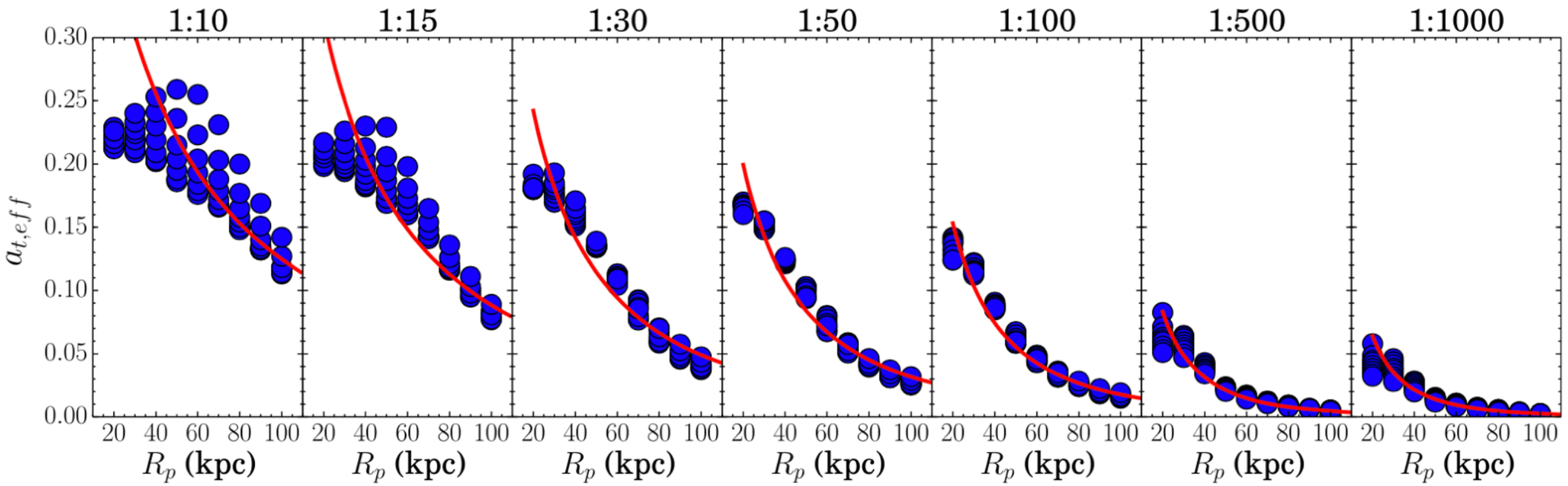

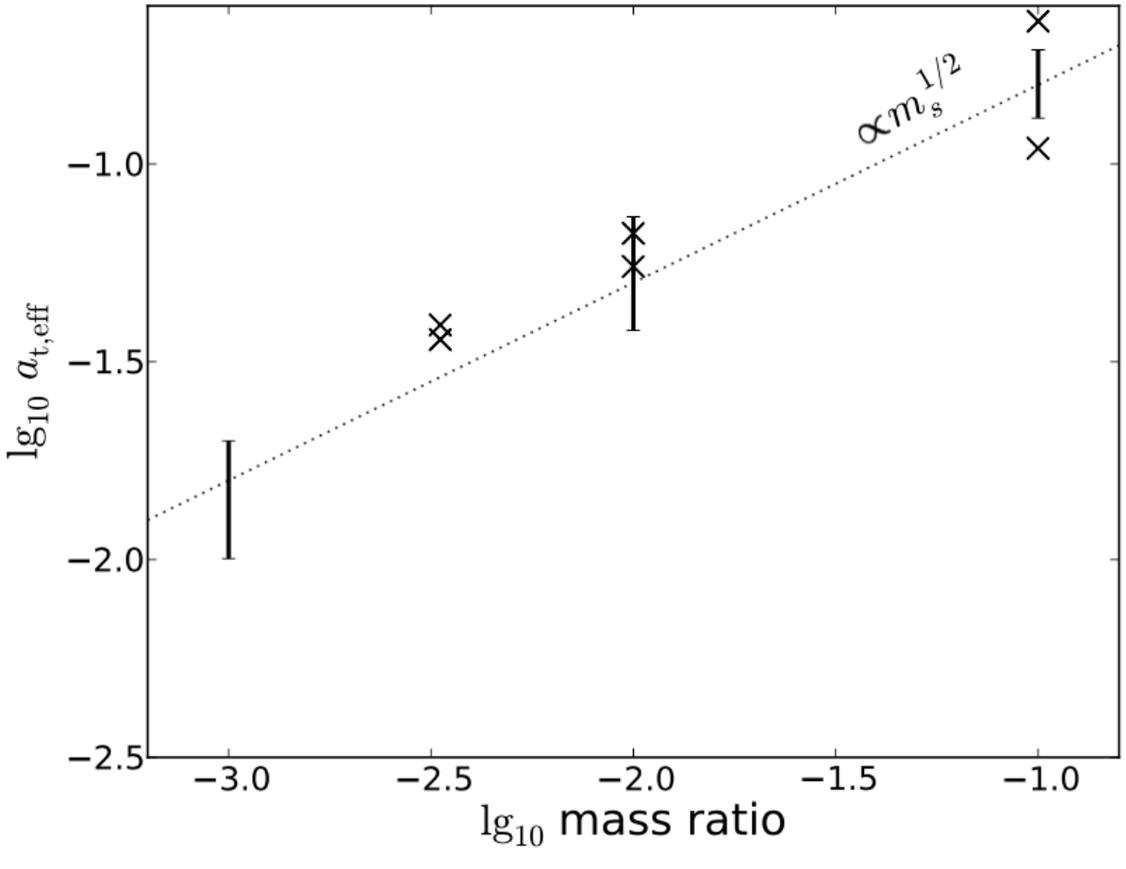

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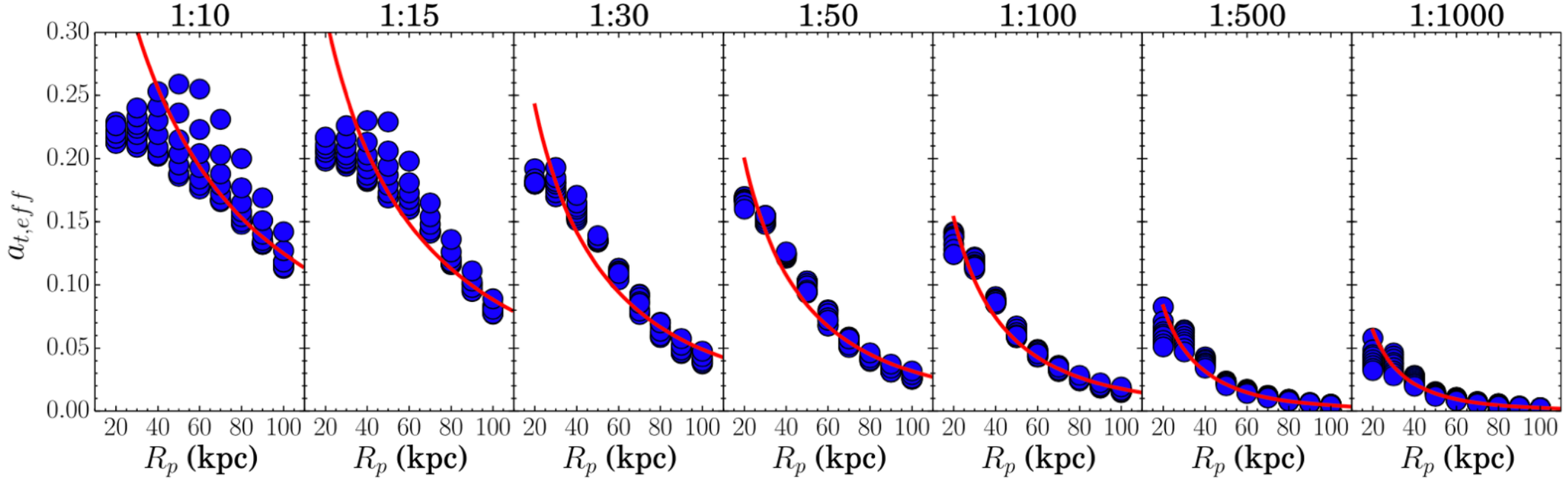

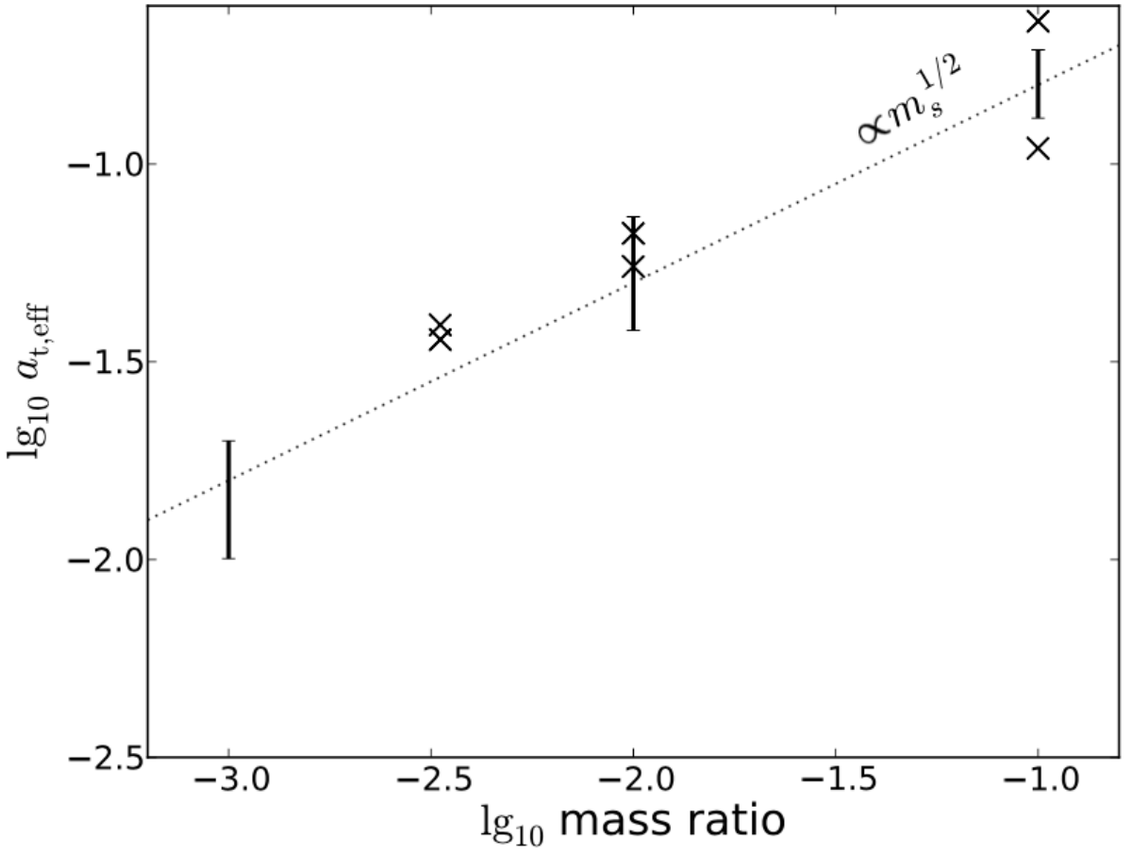

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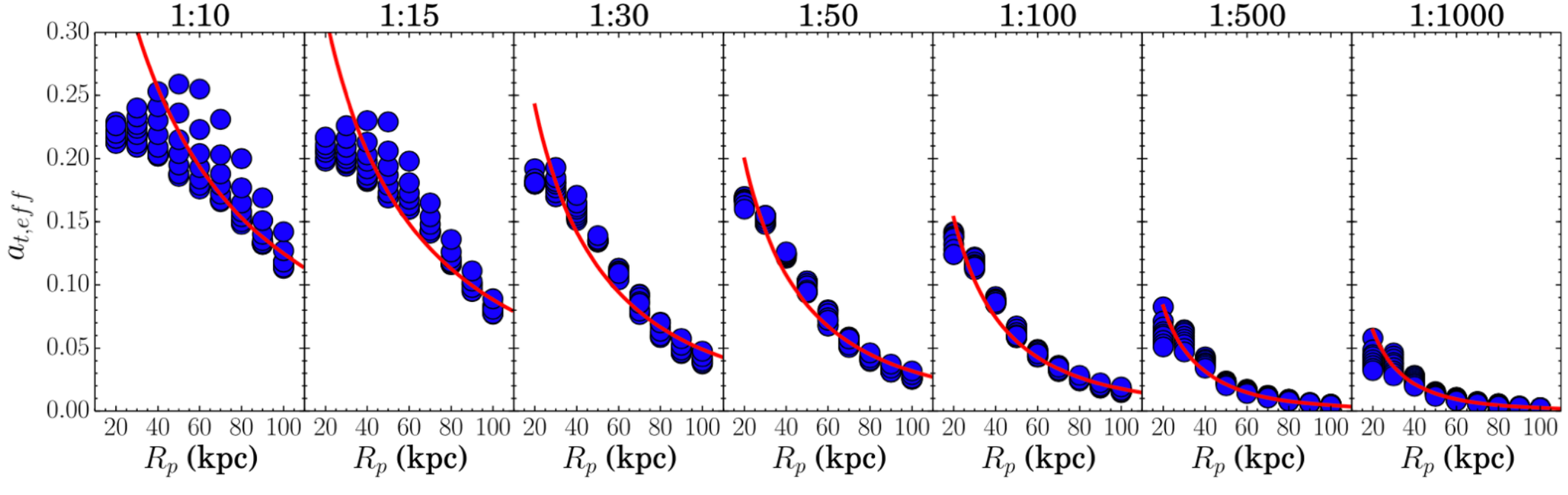

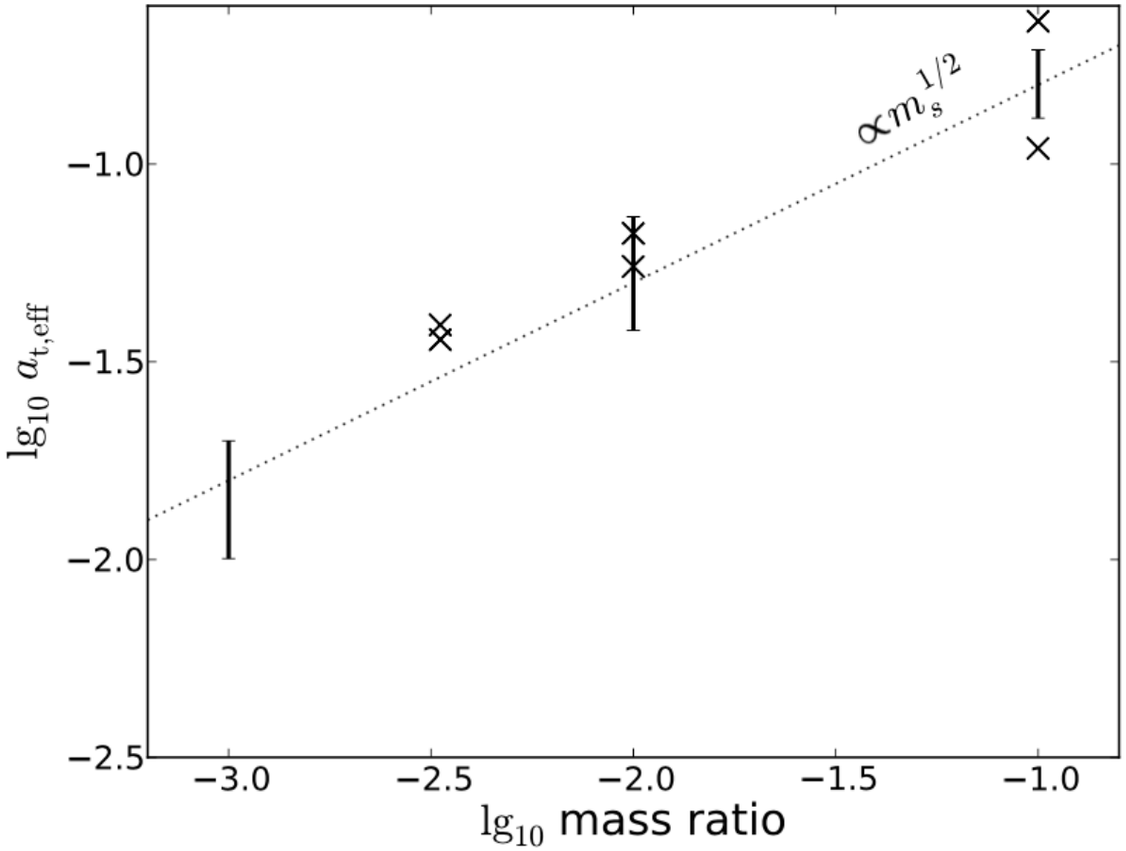

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$$a_{t,eff} = 0.88 \left(m_{sat}/M_{host}\right)^{0.6(R_p/50kpc)^{0.5}}$$

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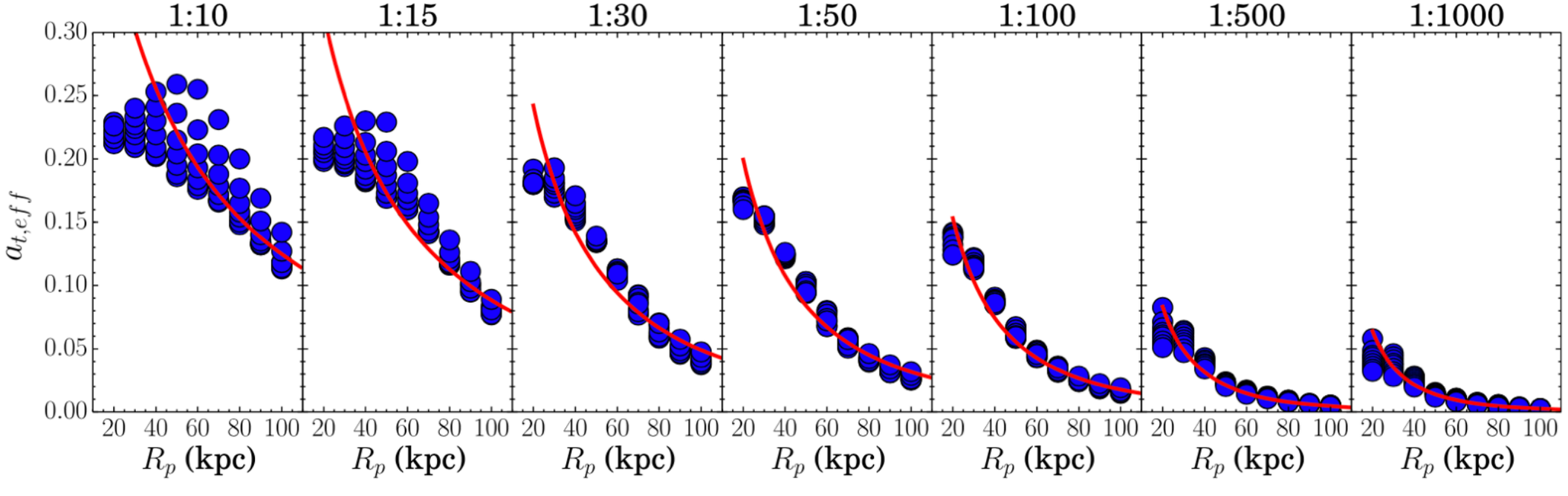

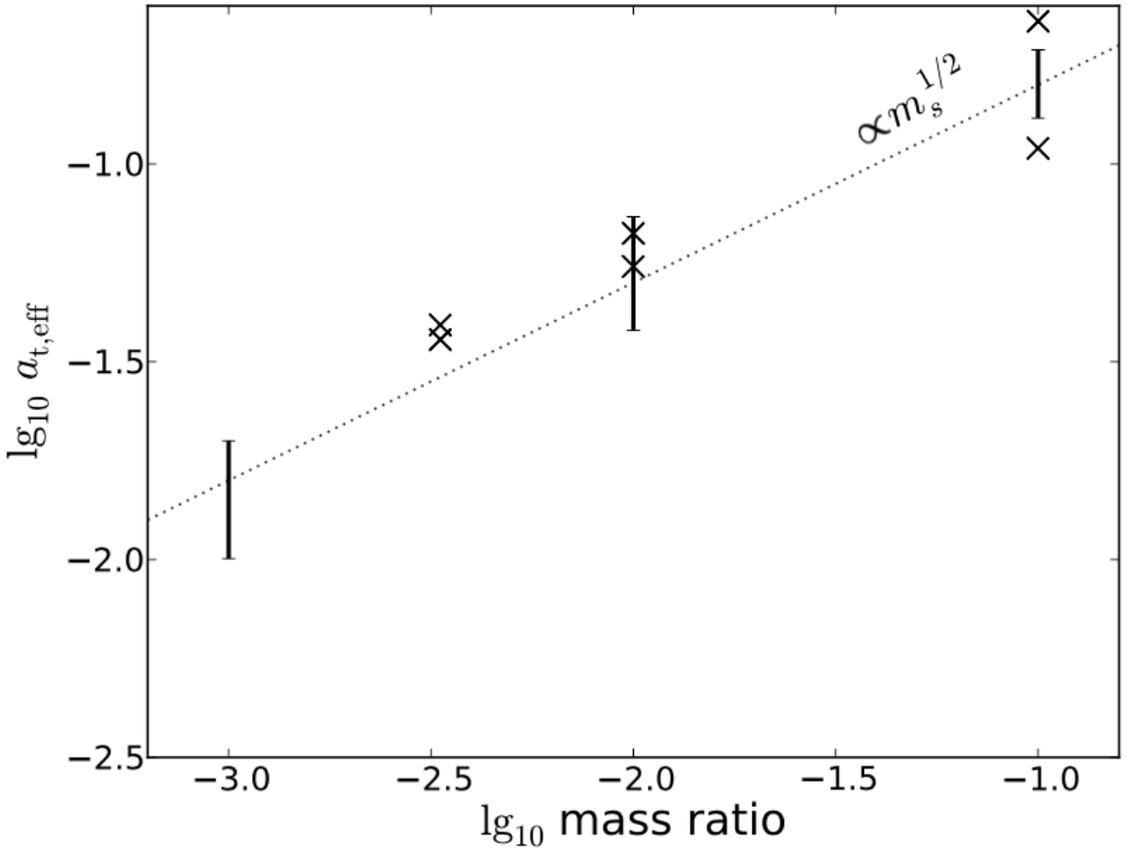

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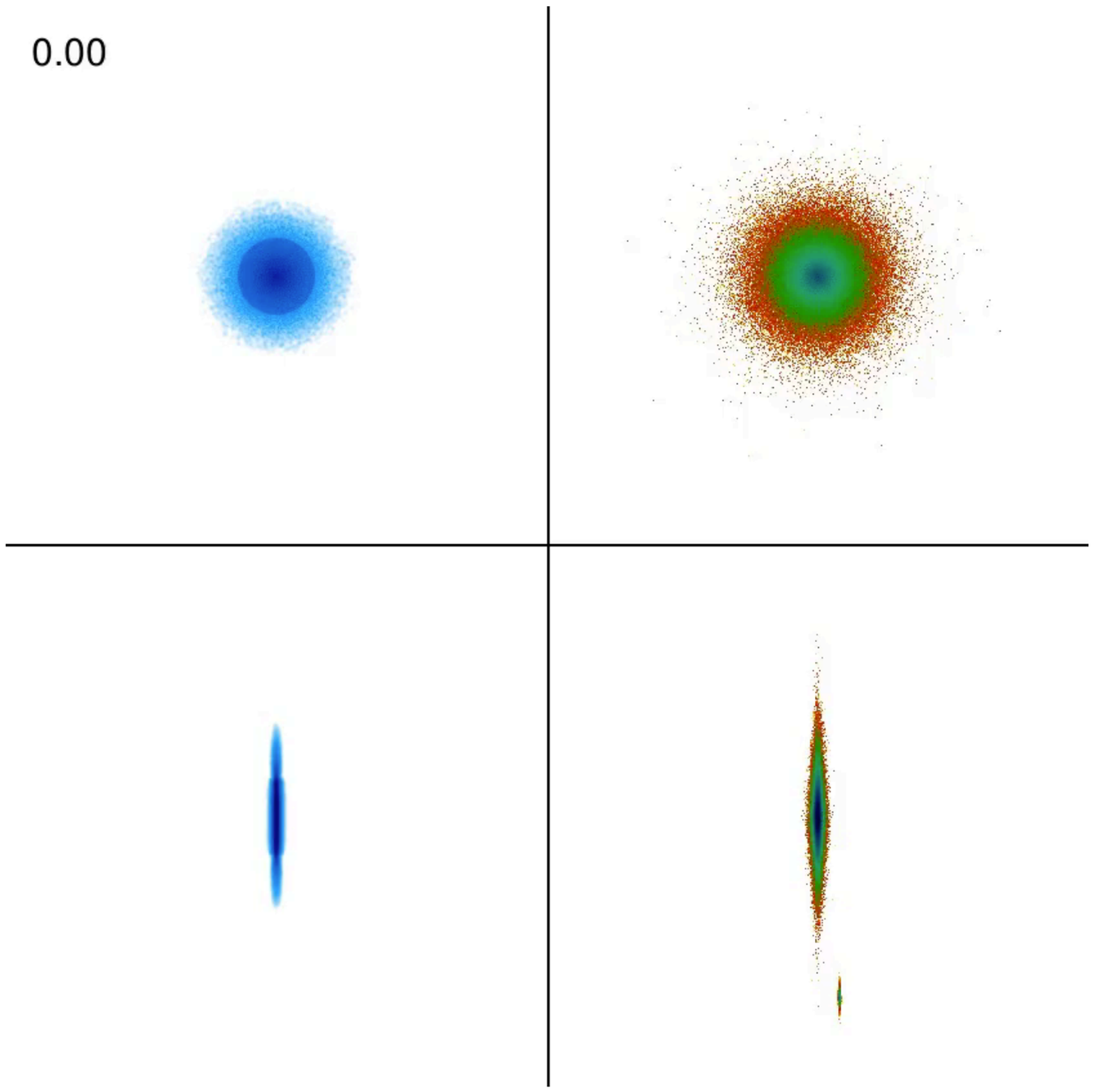
Observed $a_{t,eff}$ of HI disk: ~ 0.25,
for ~ 1:100 perturber,
→ R_p ~ 10 kpc

The response of the Galactic disk to Antlia



Rp = 8 kpc (also note outer stellar disk structures similar to Monoceros ring)

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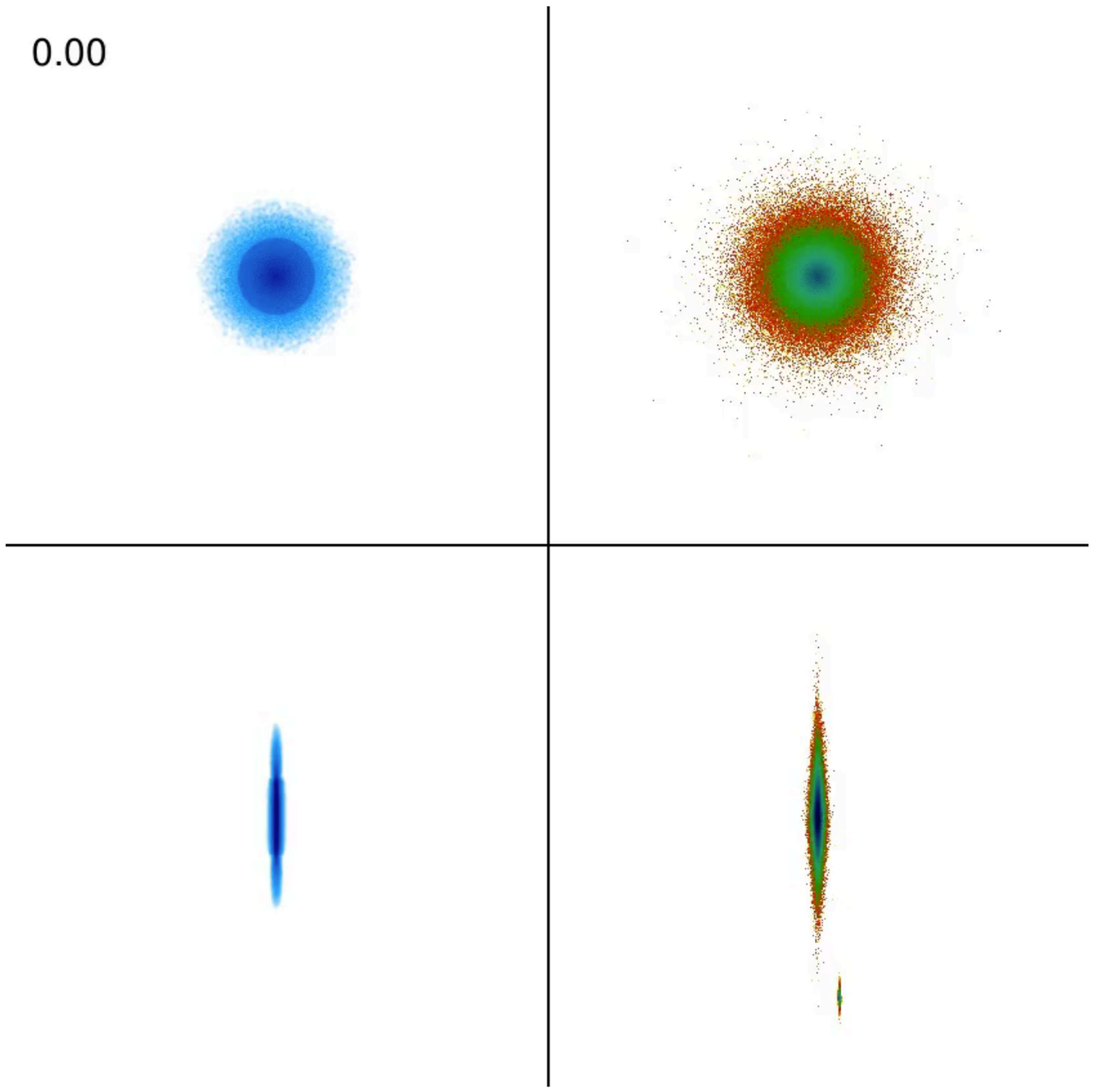

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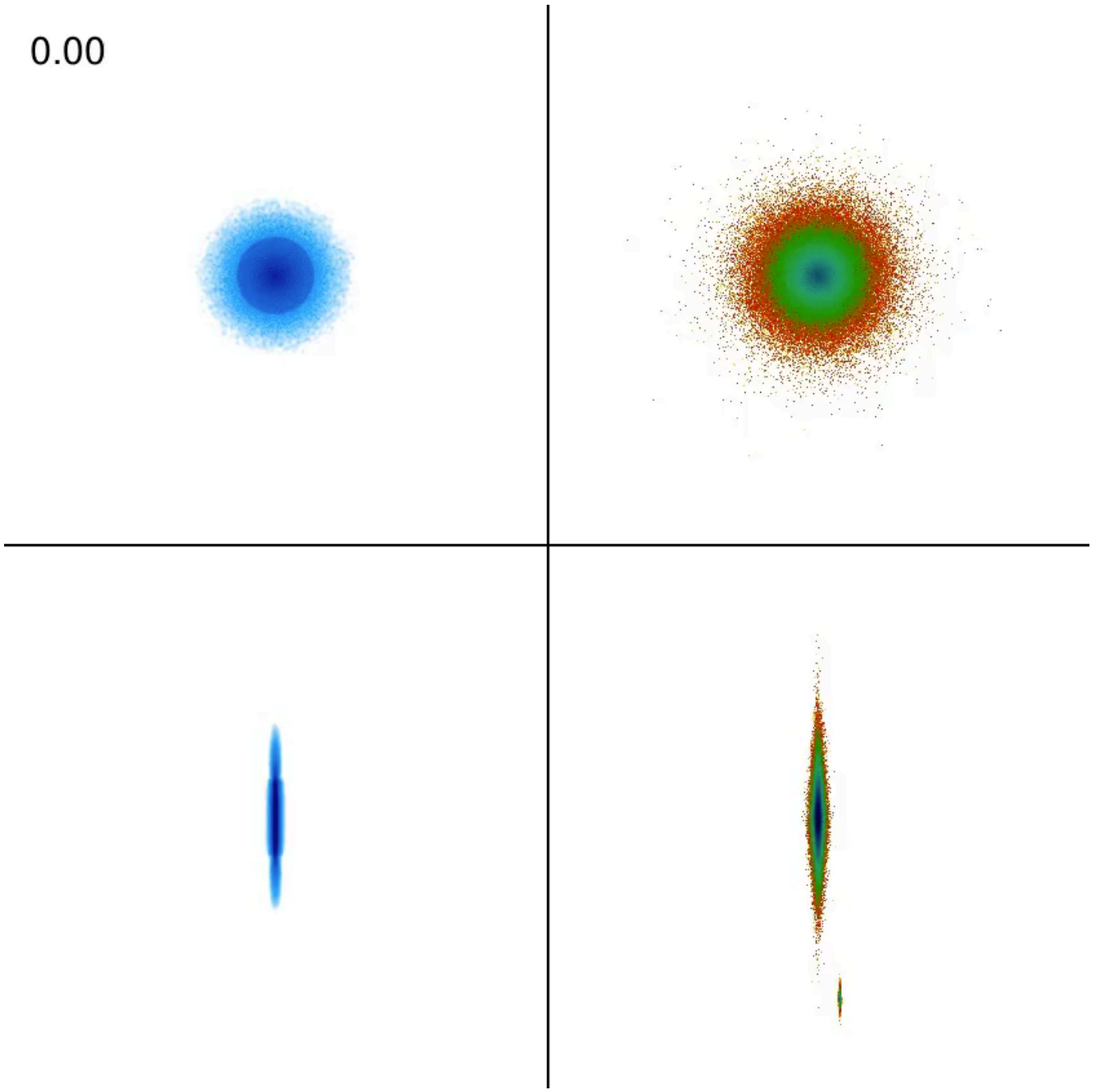

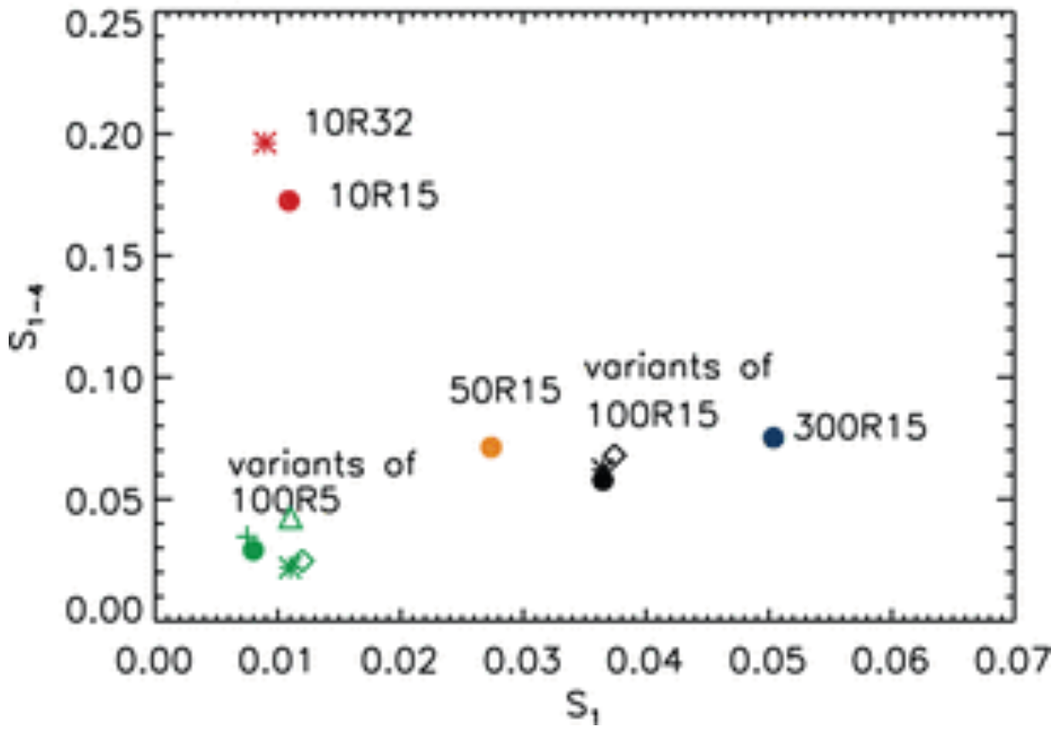

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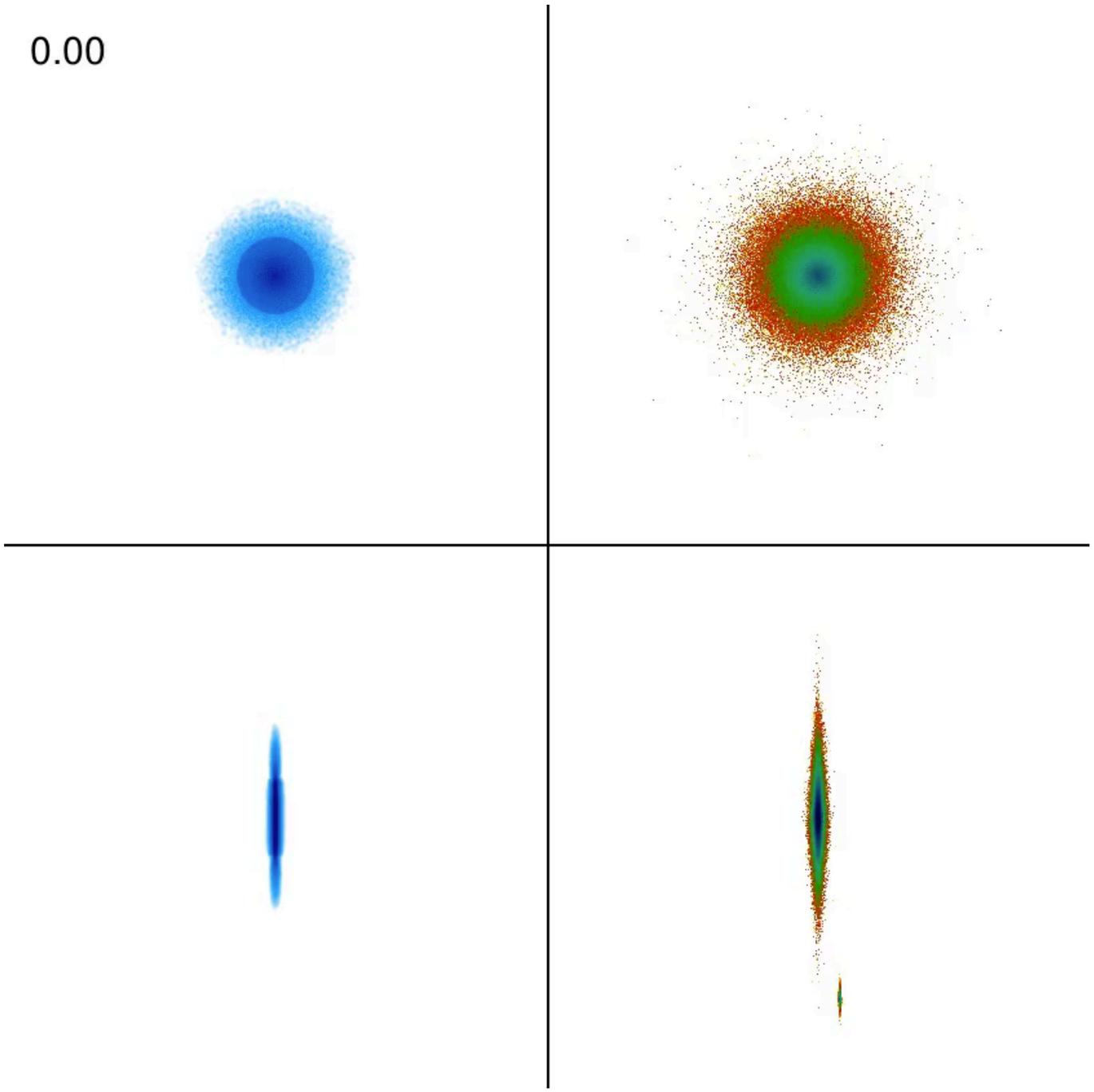
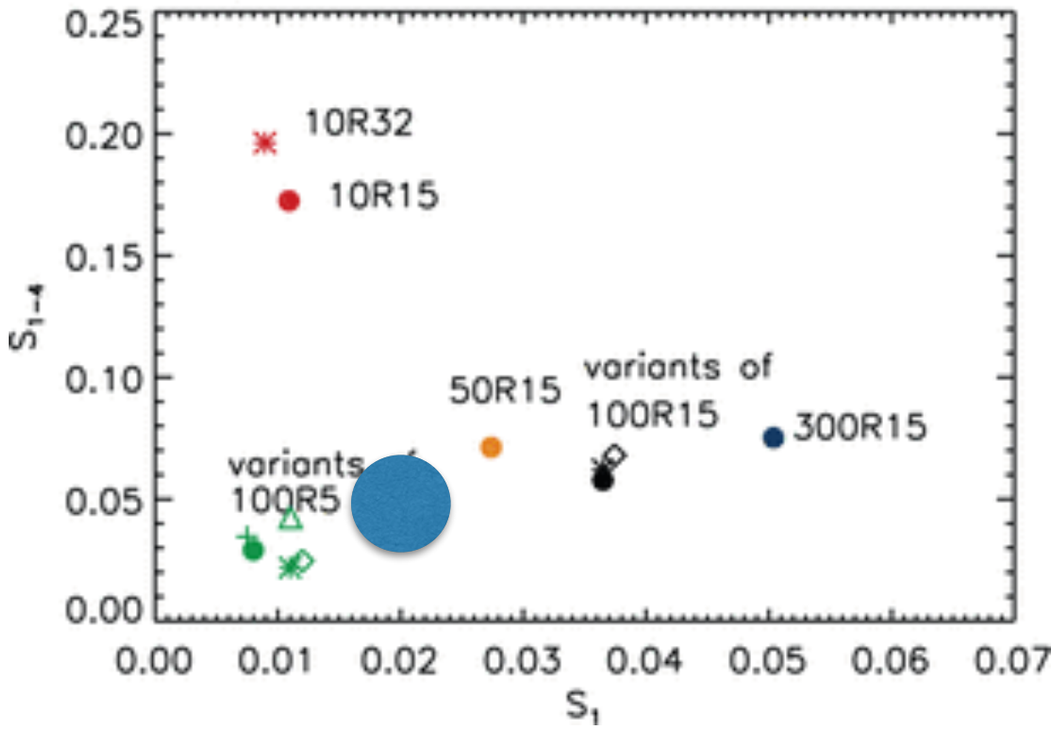
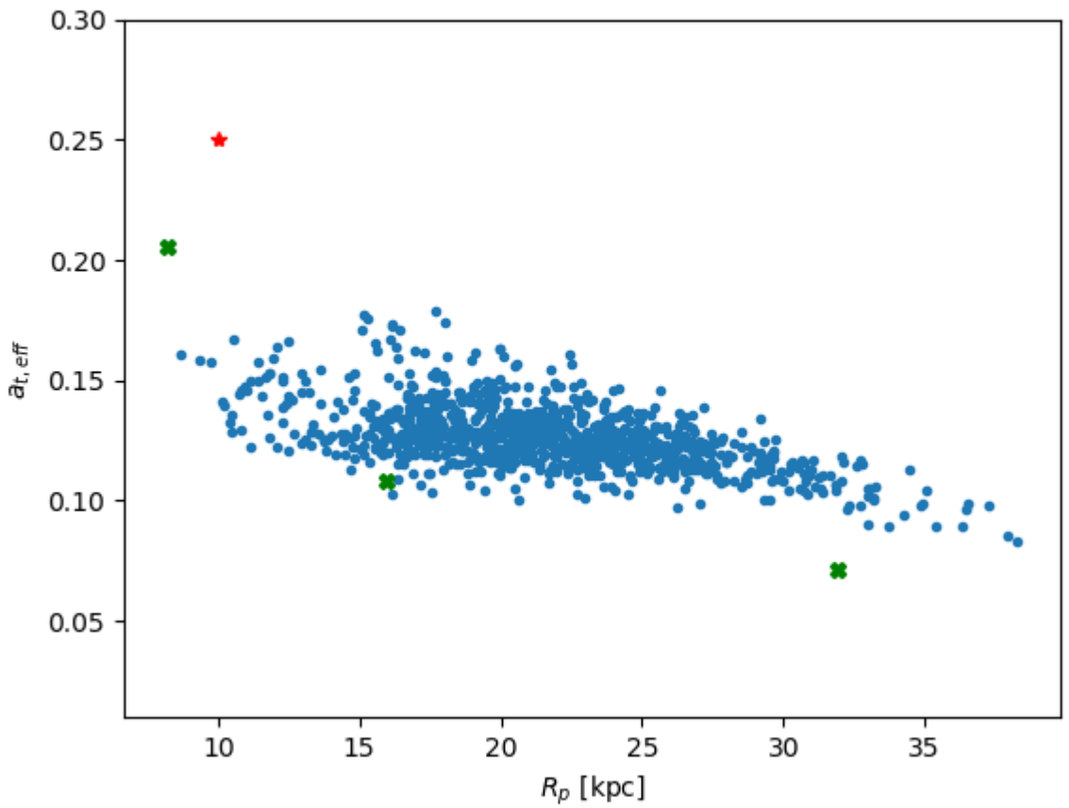
The response of the Galactic disk to Antlia





Rp = 8 kpc (also note outer stellar disk structures similar to Monoceros ring)

Power in Fourier modes & phase variation



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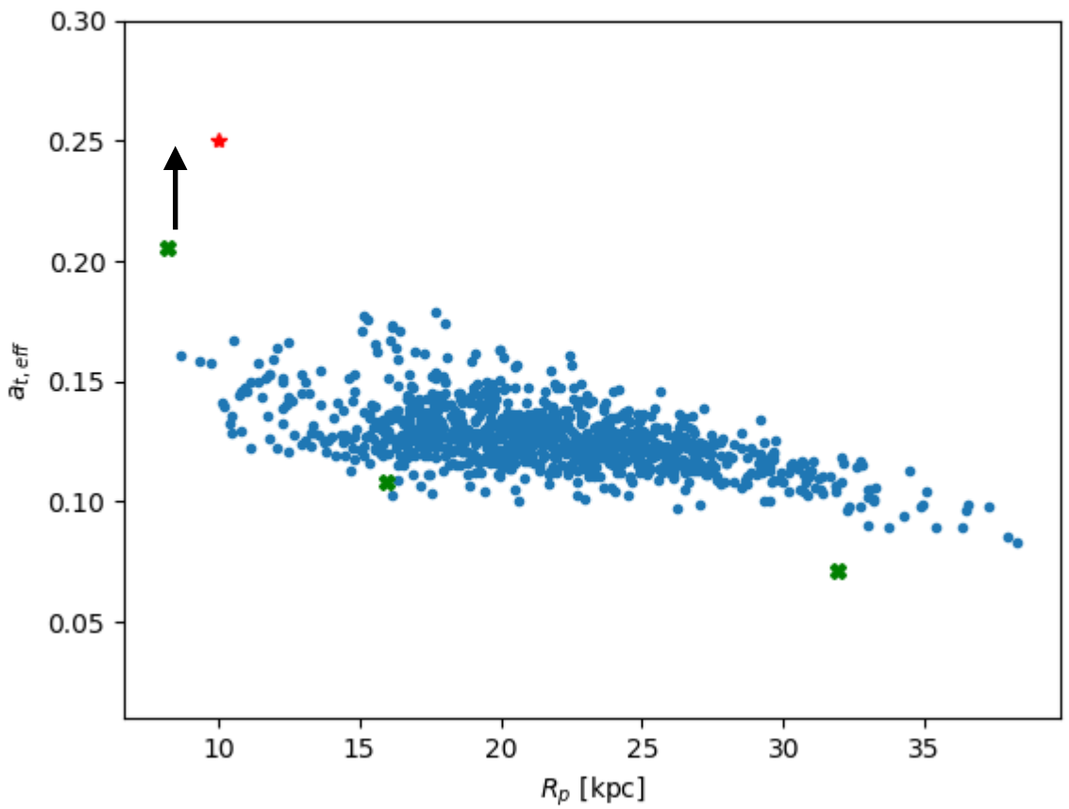

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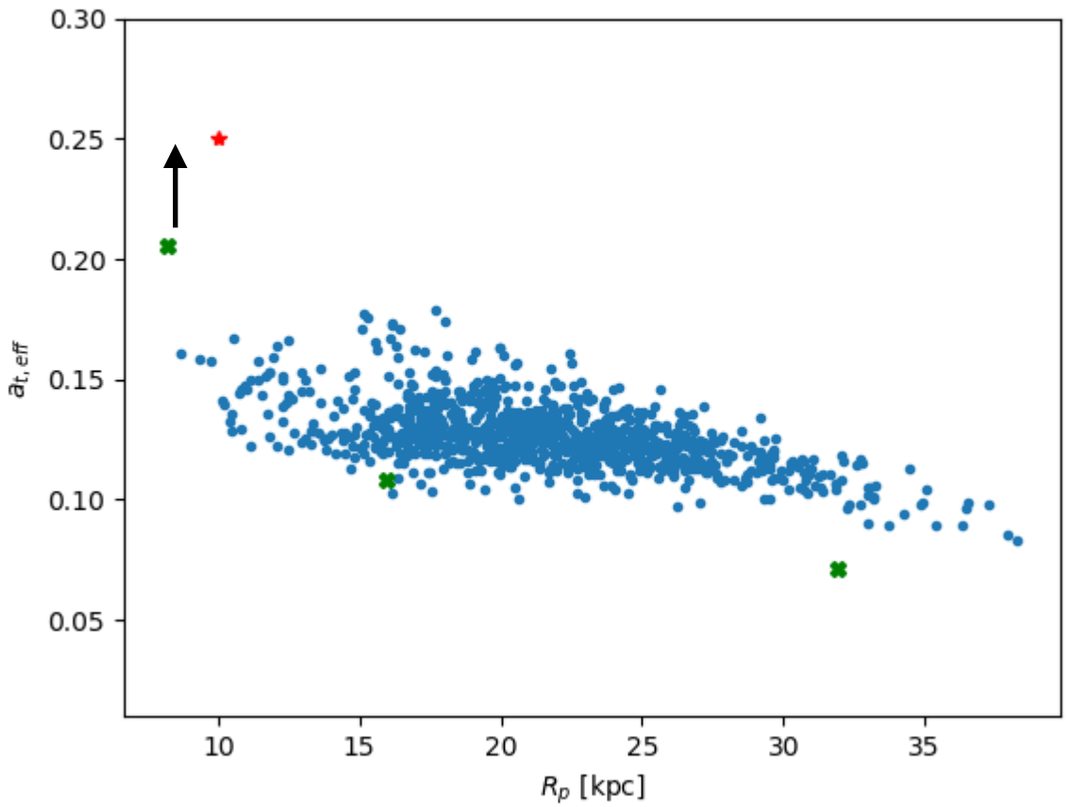

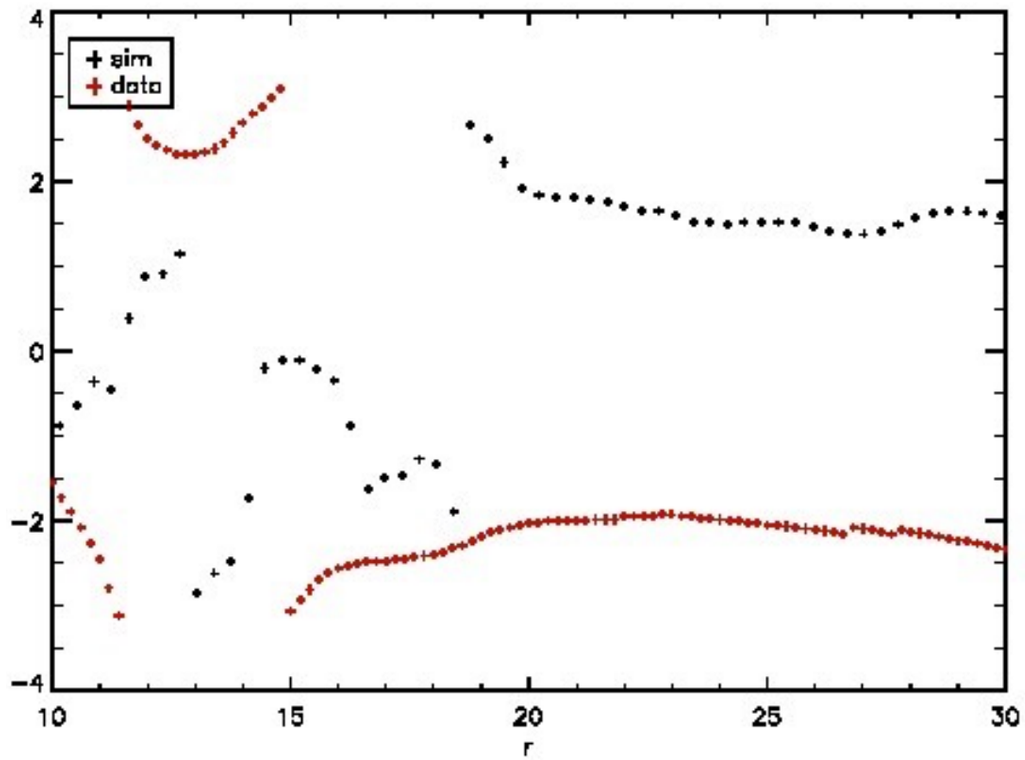

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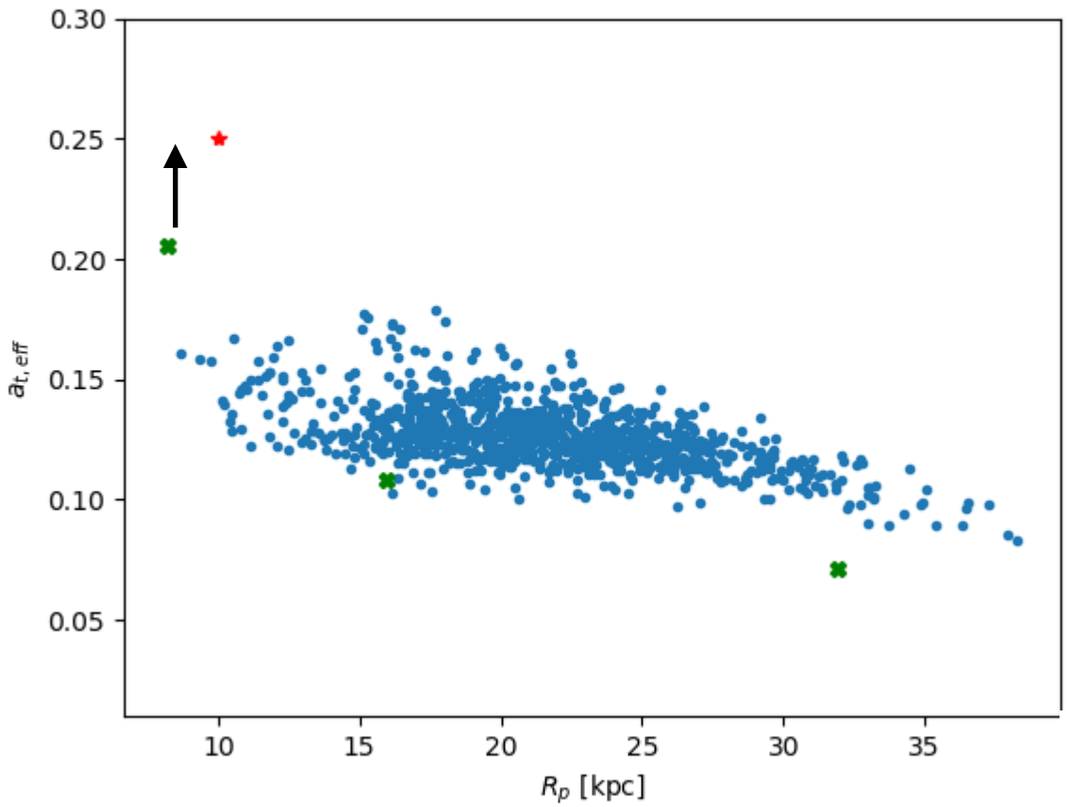

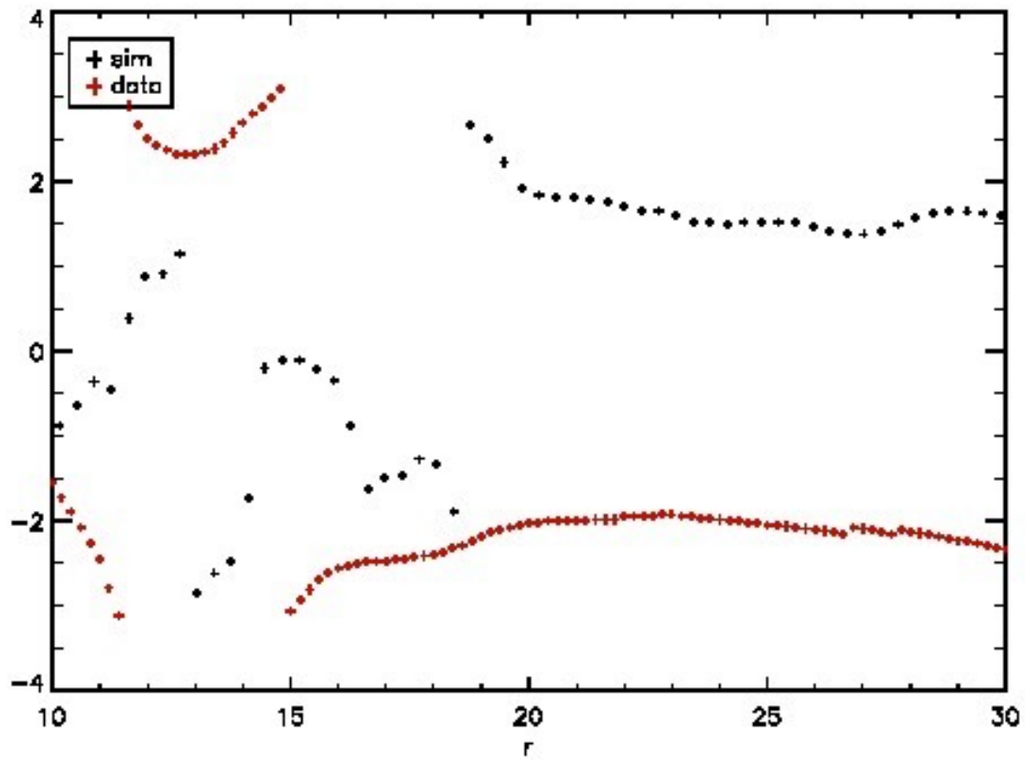

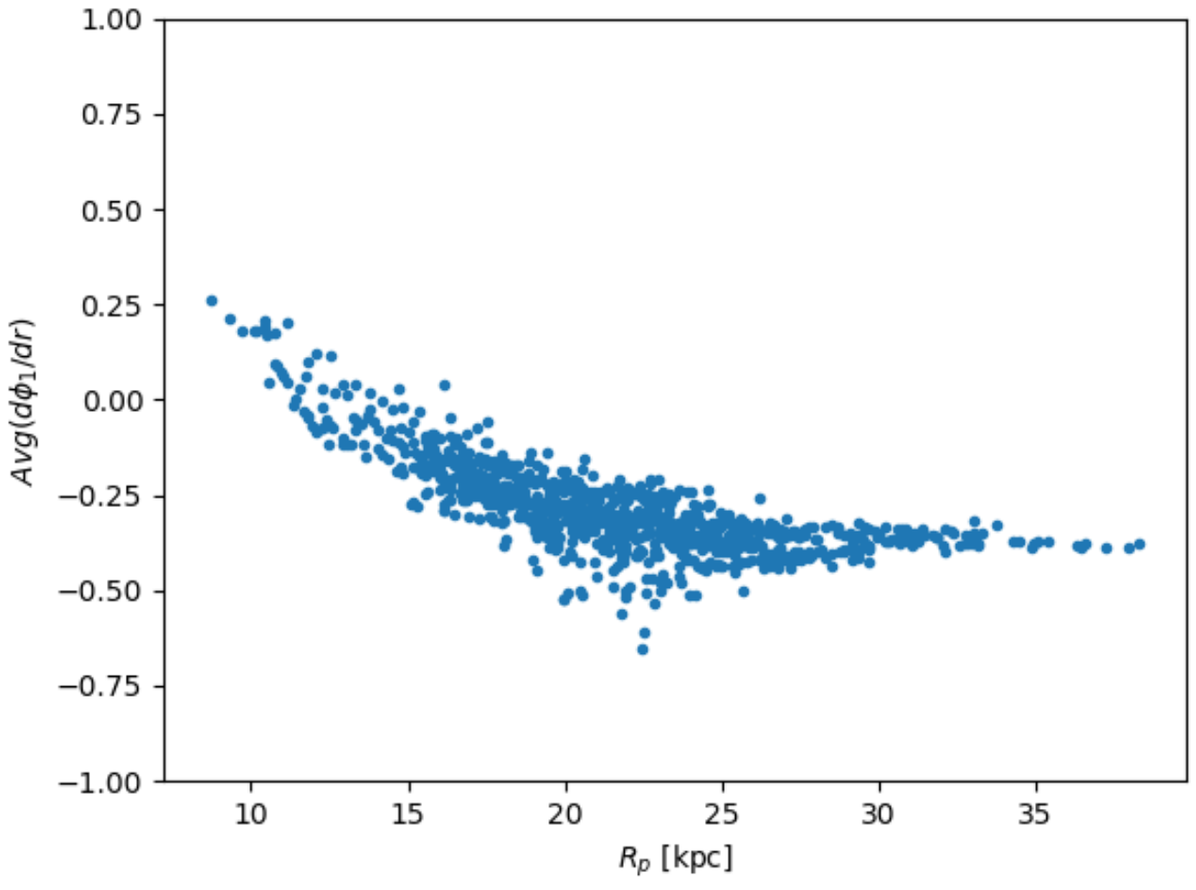

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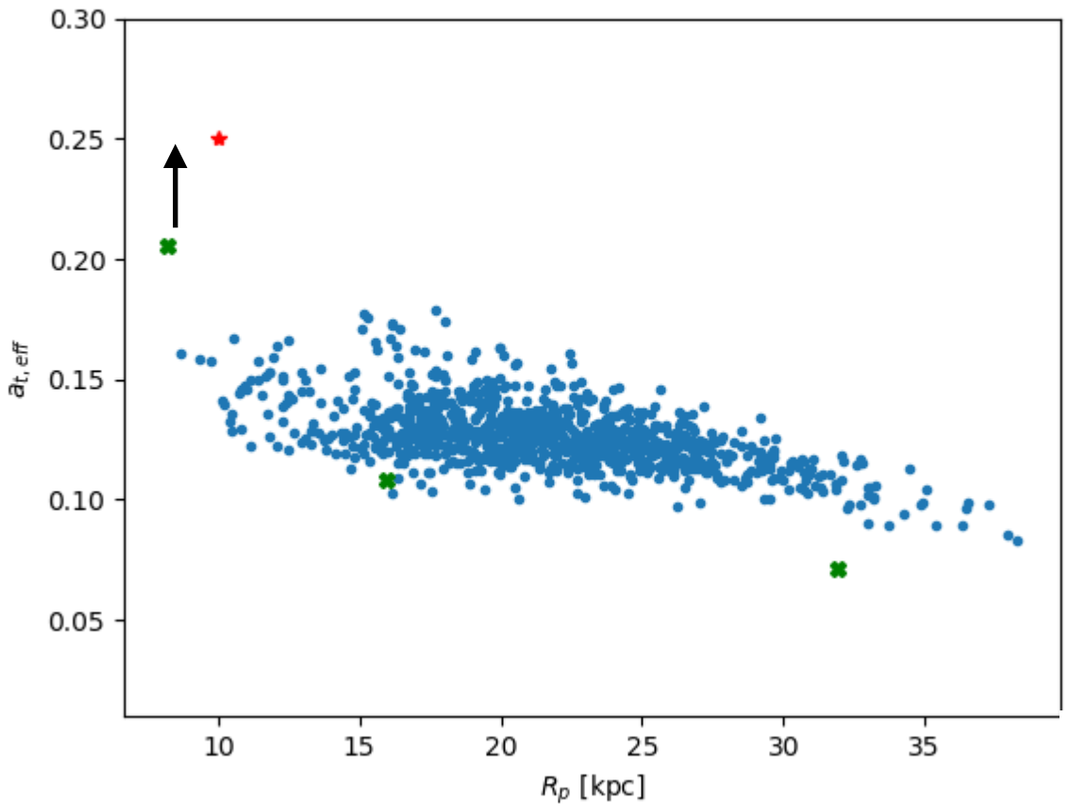
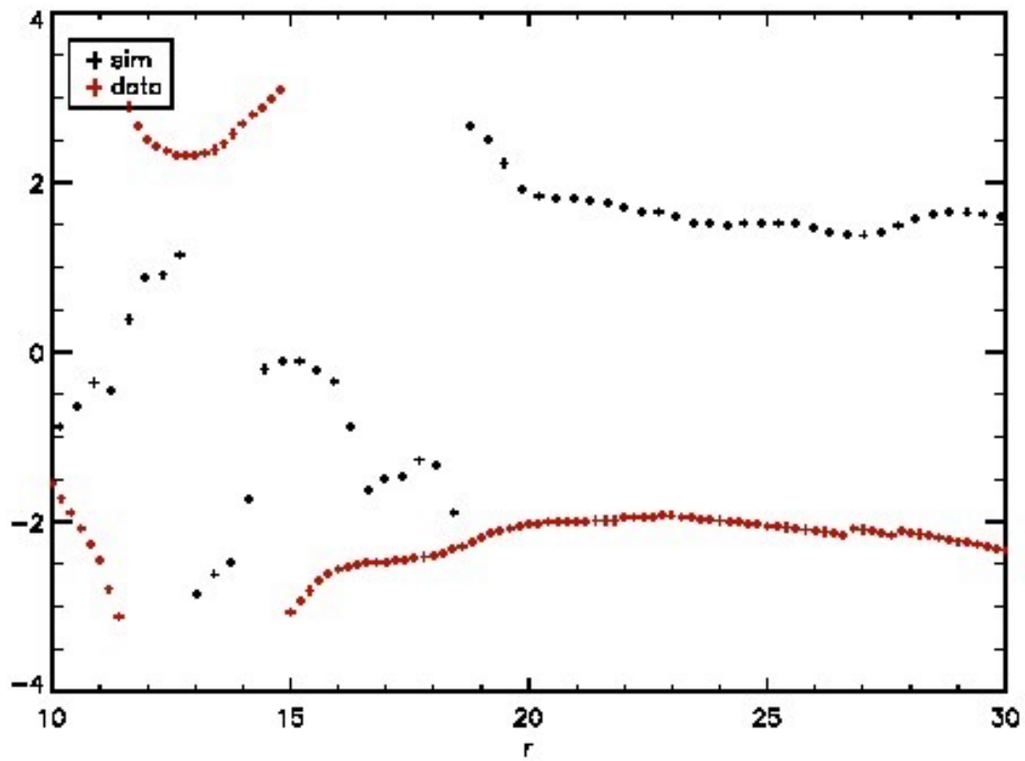
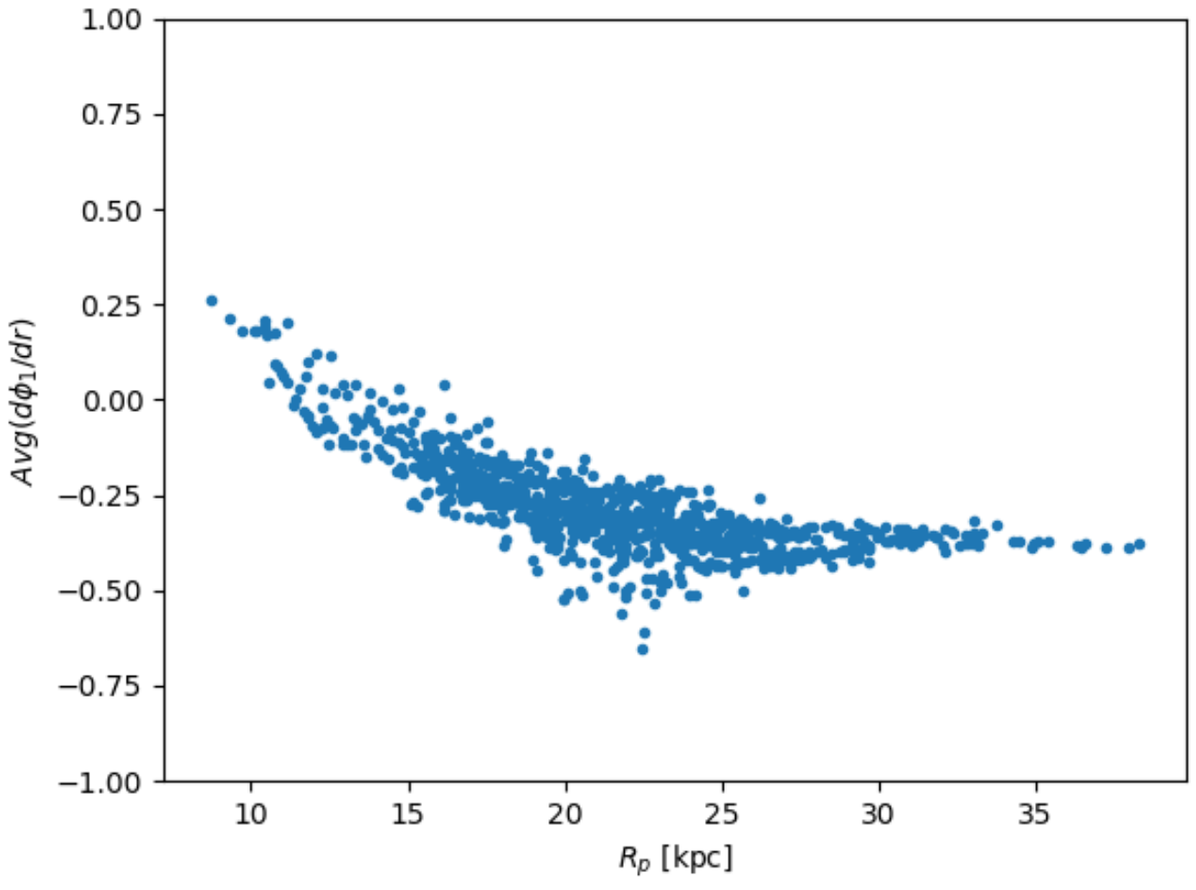


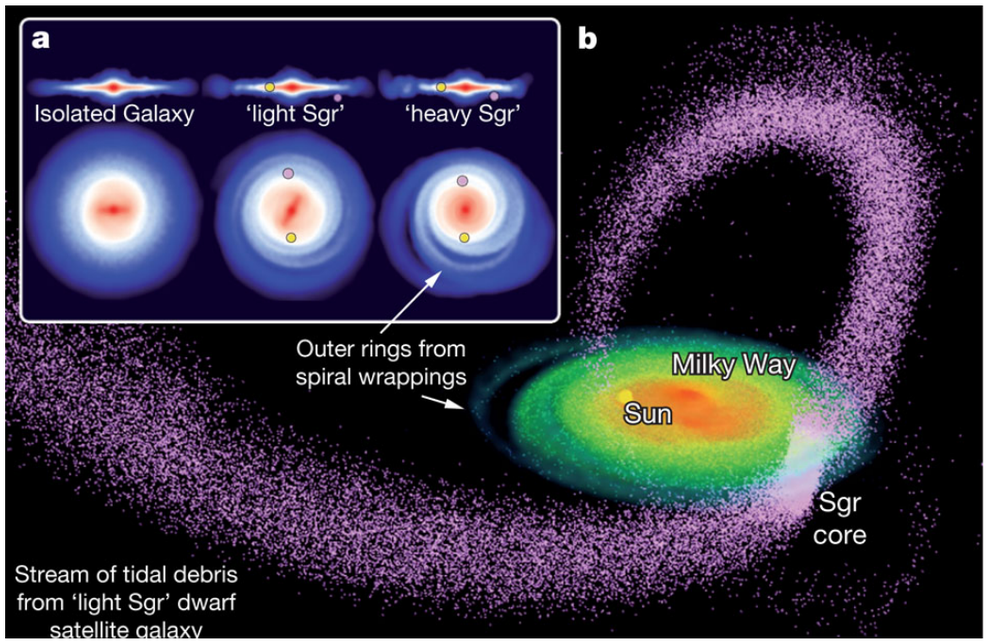


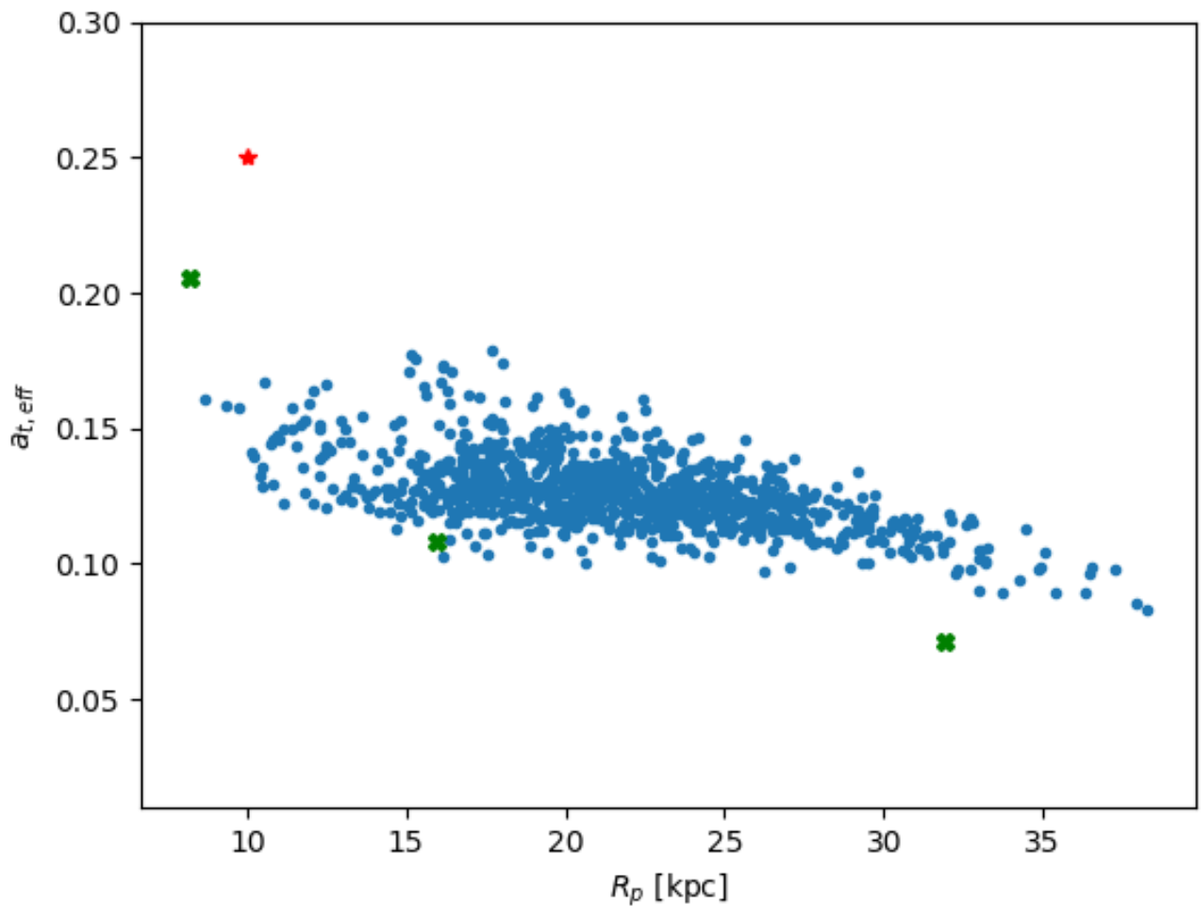
- Radially flat phase for Rp ~ 10 kpc



Sgr's effect on Galactic disk

- Purcell et al. 2011 (+Chakrabarti)
- Monoceros ?
- Sgr's effect on HI planar disturbances — too low; with 10^{10} Msun Sgr starting at t = -1 Gyr





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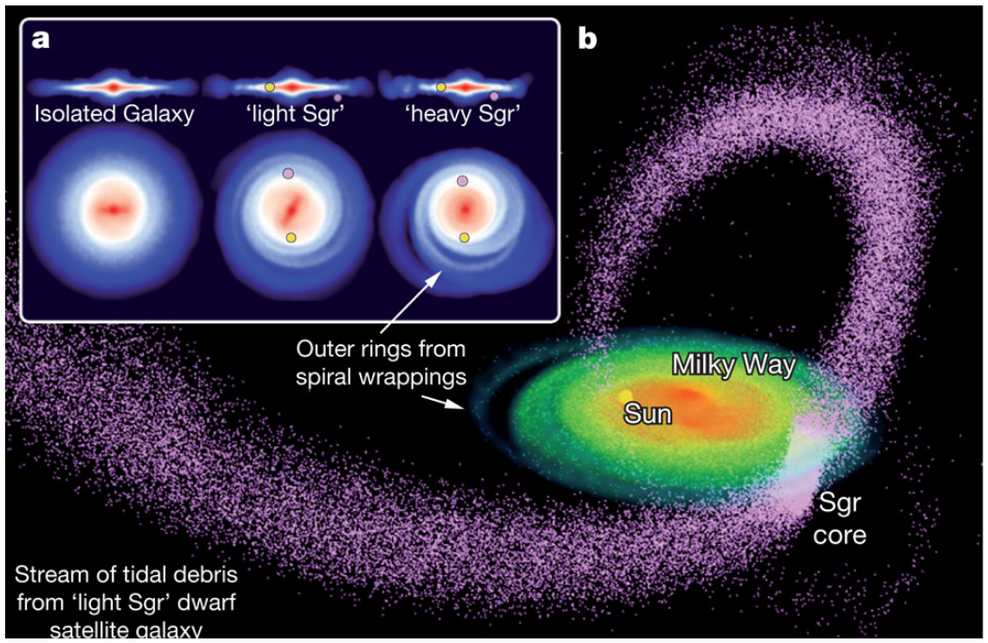

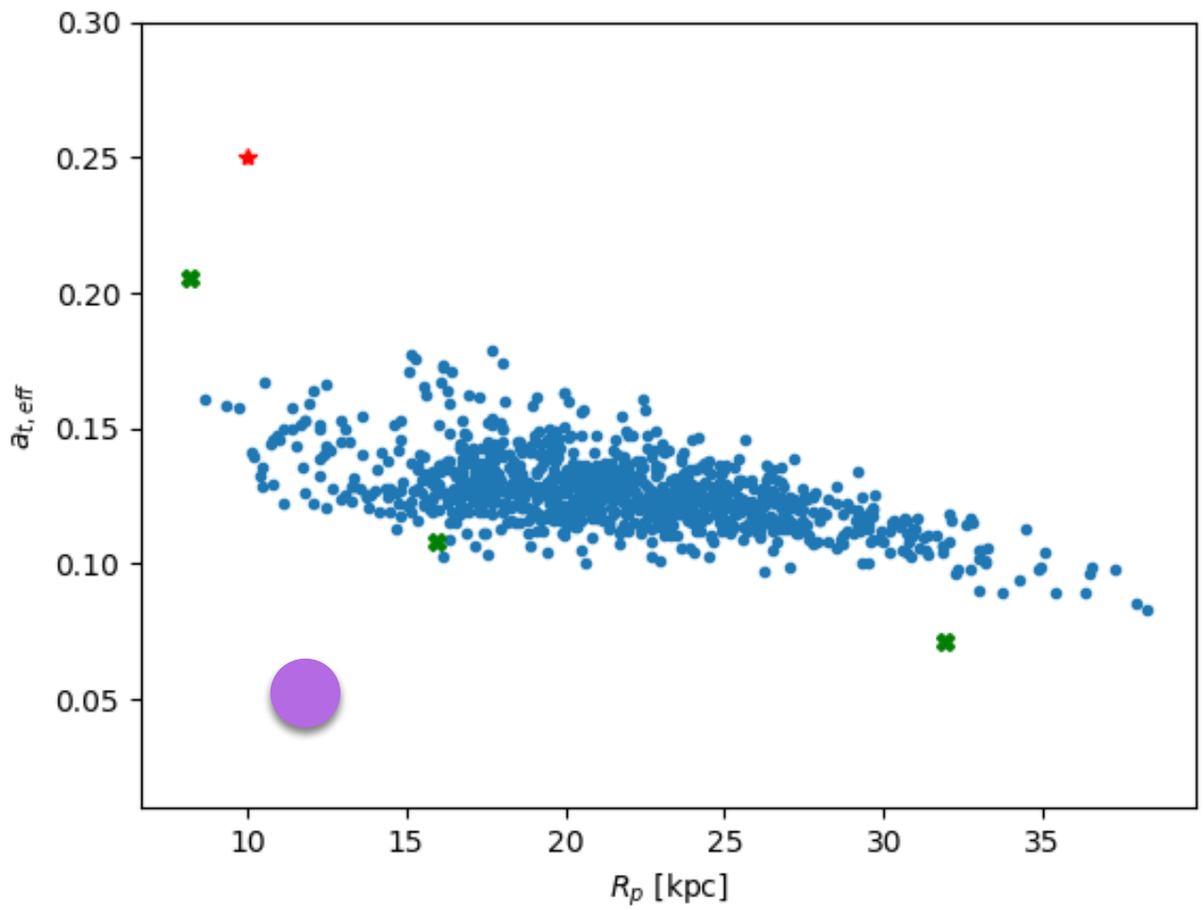

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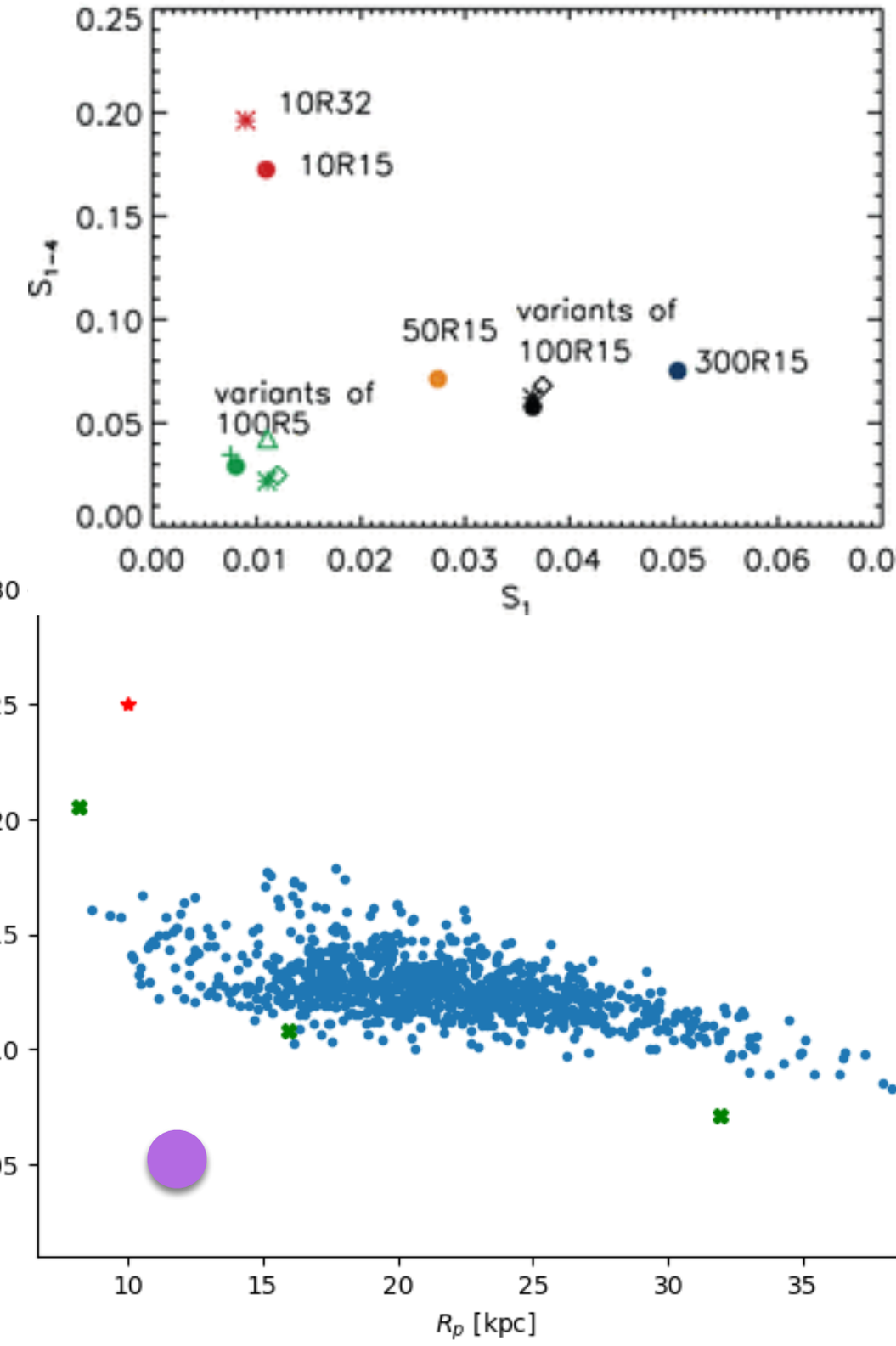

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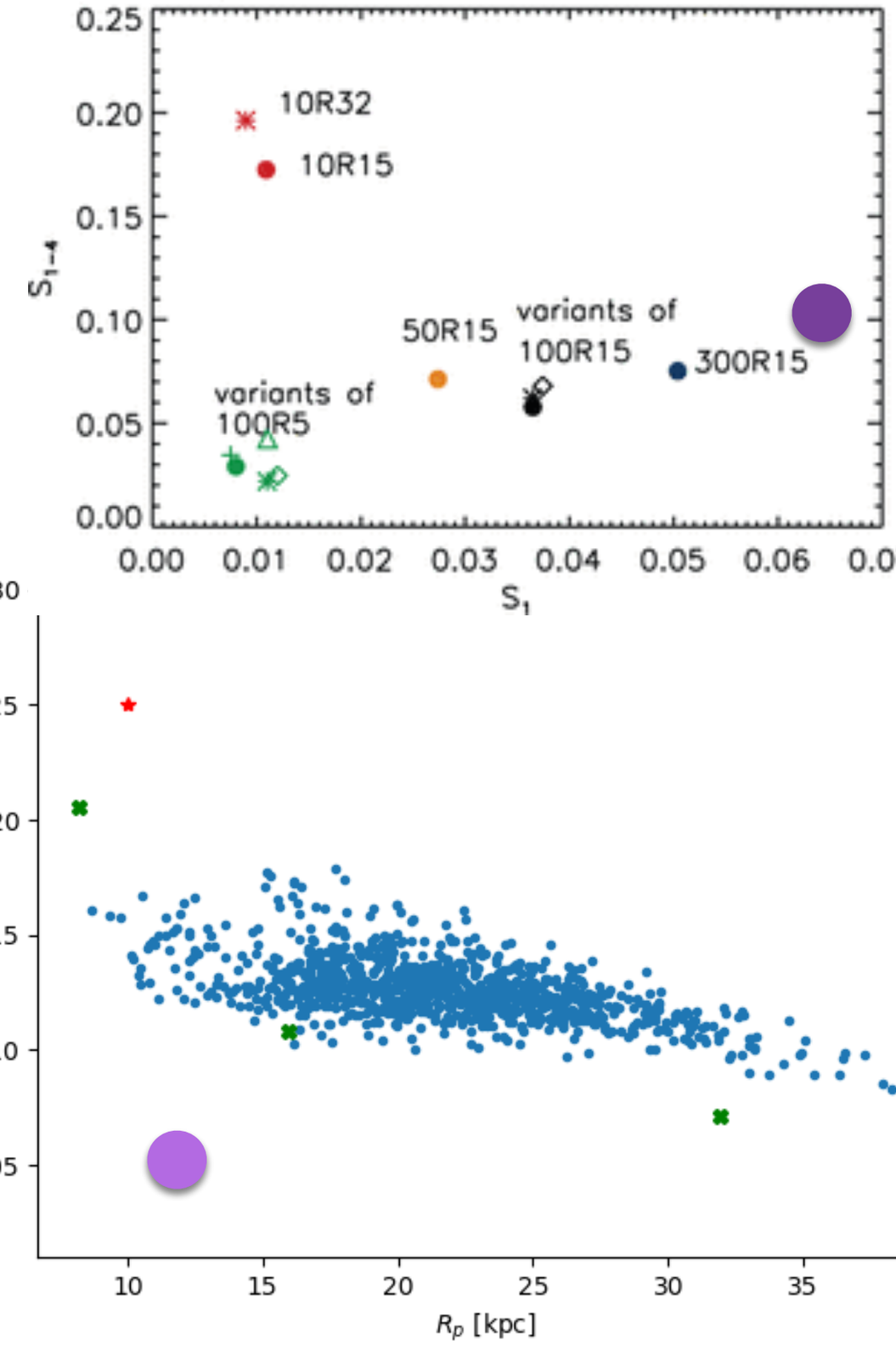

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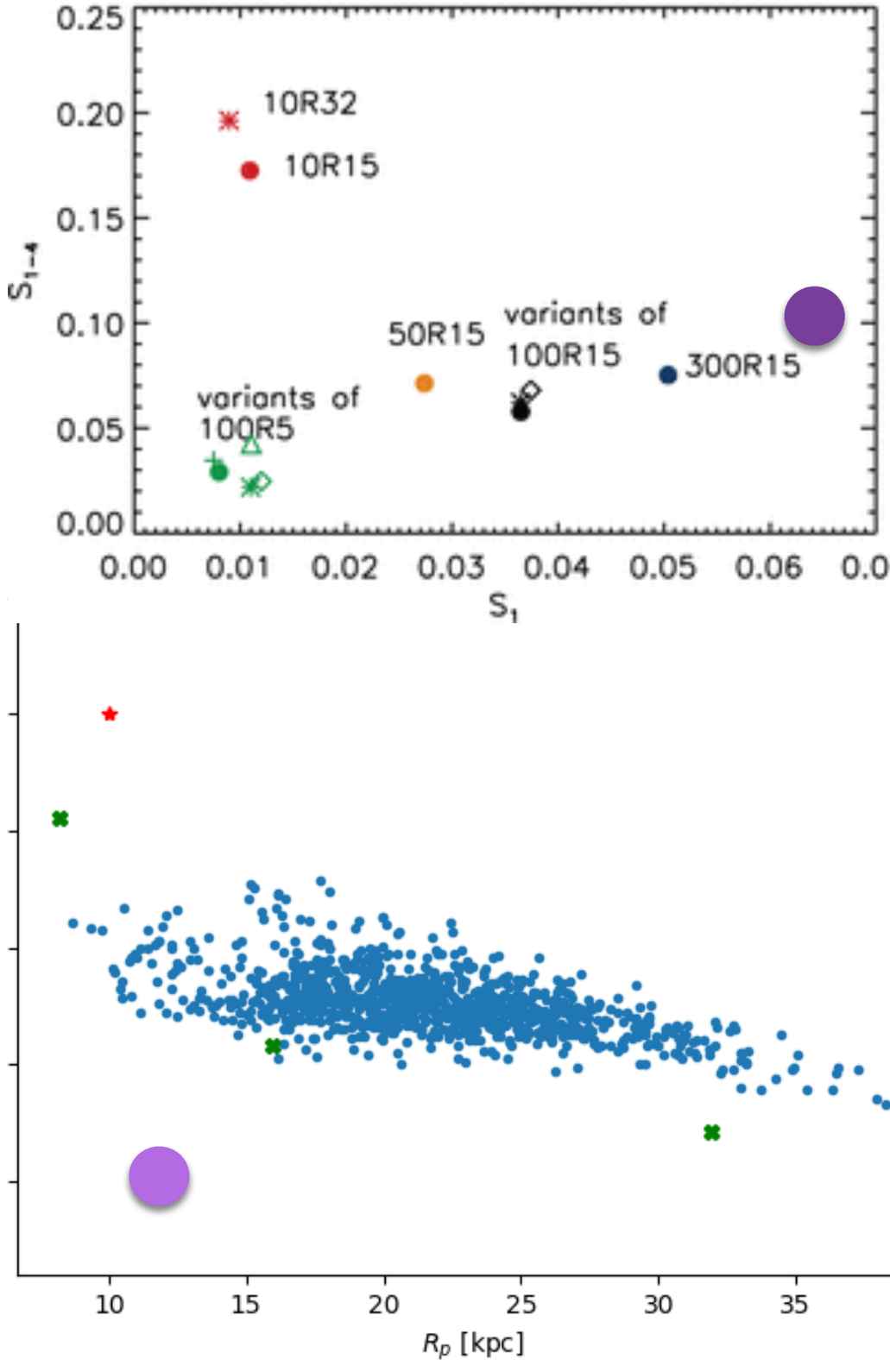

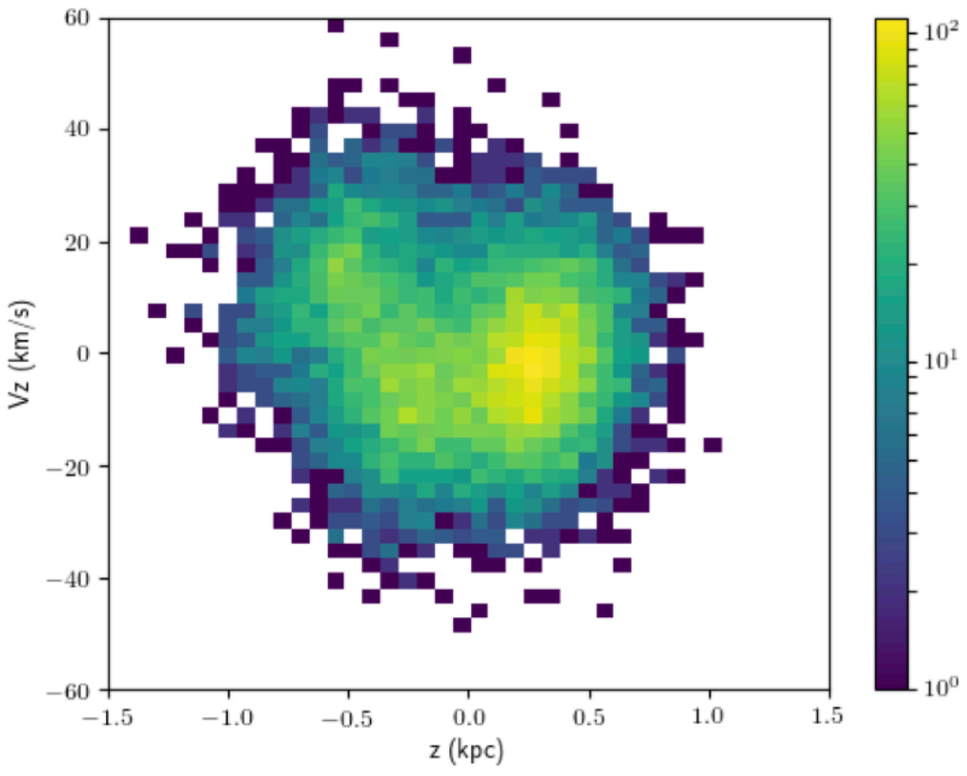

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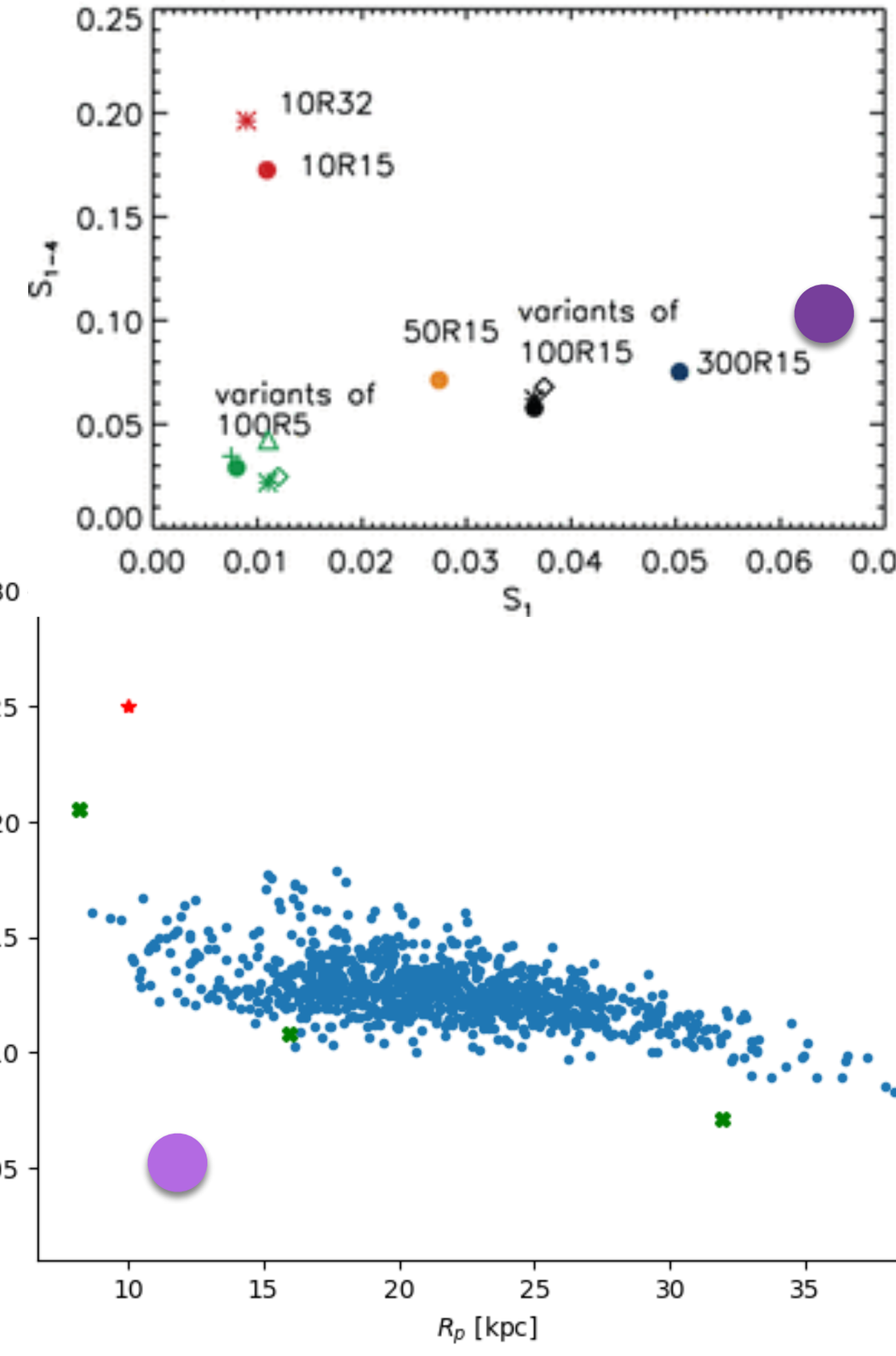
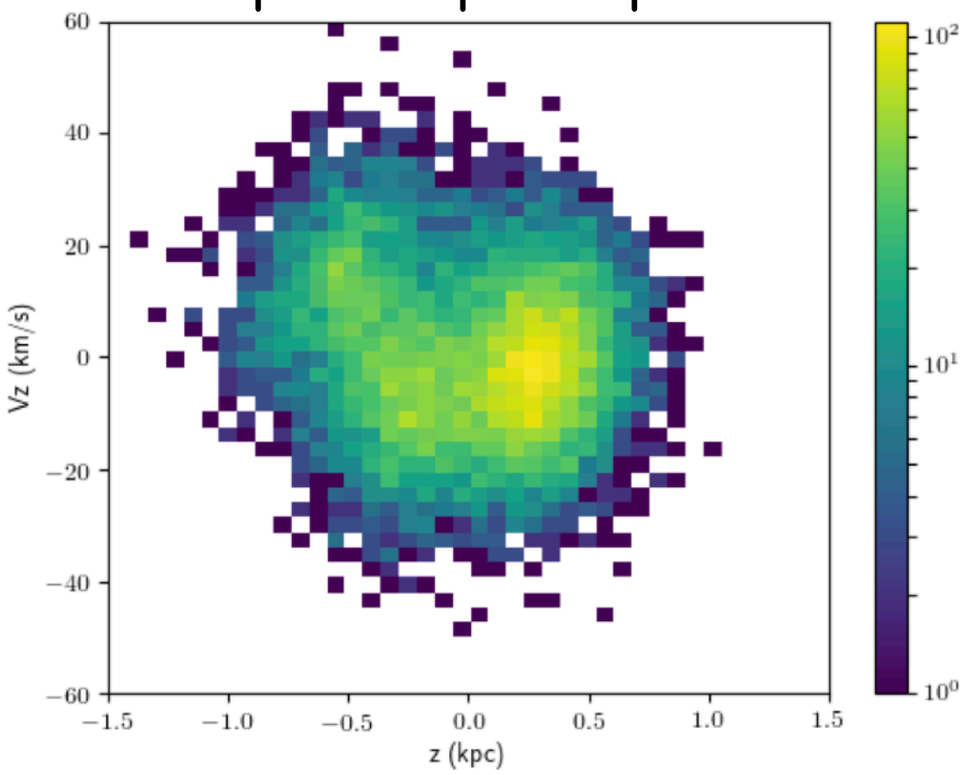
  - phase space spiral





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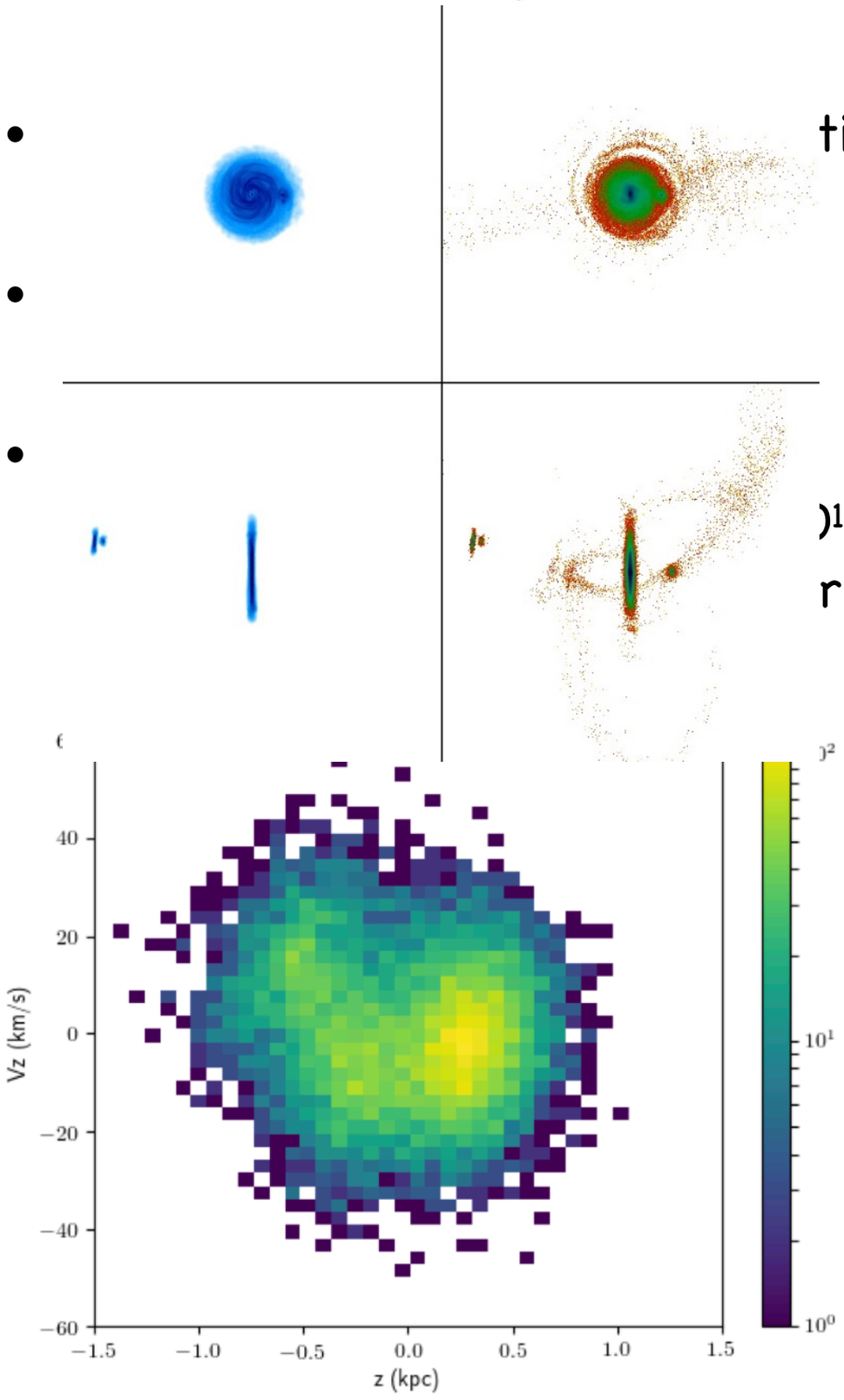
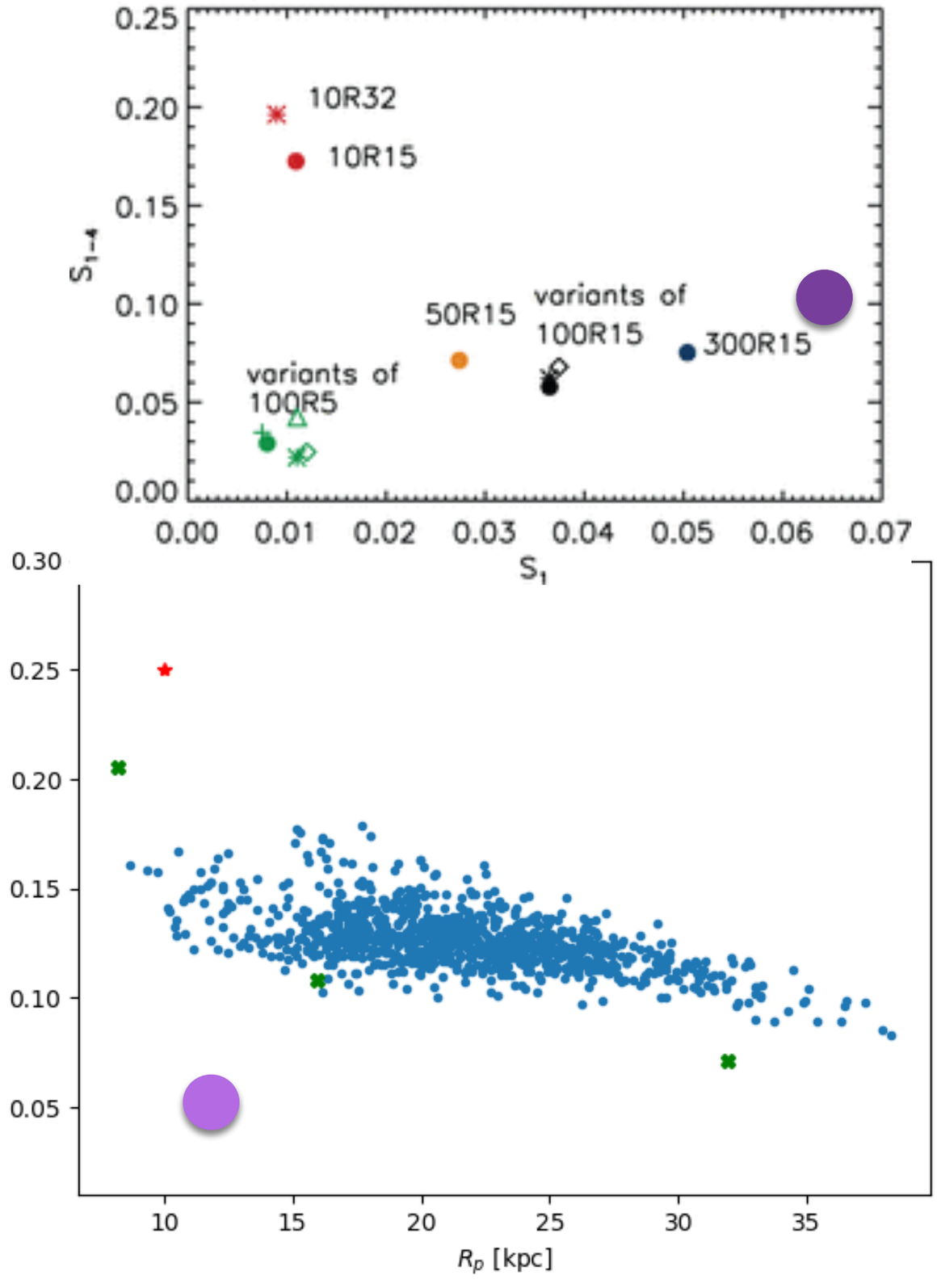
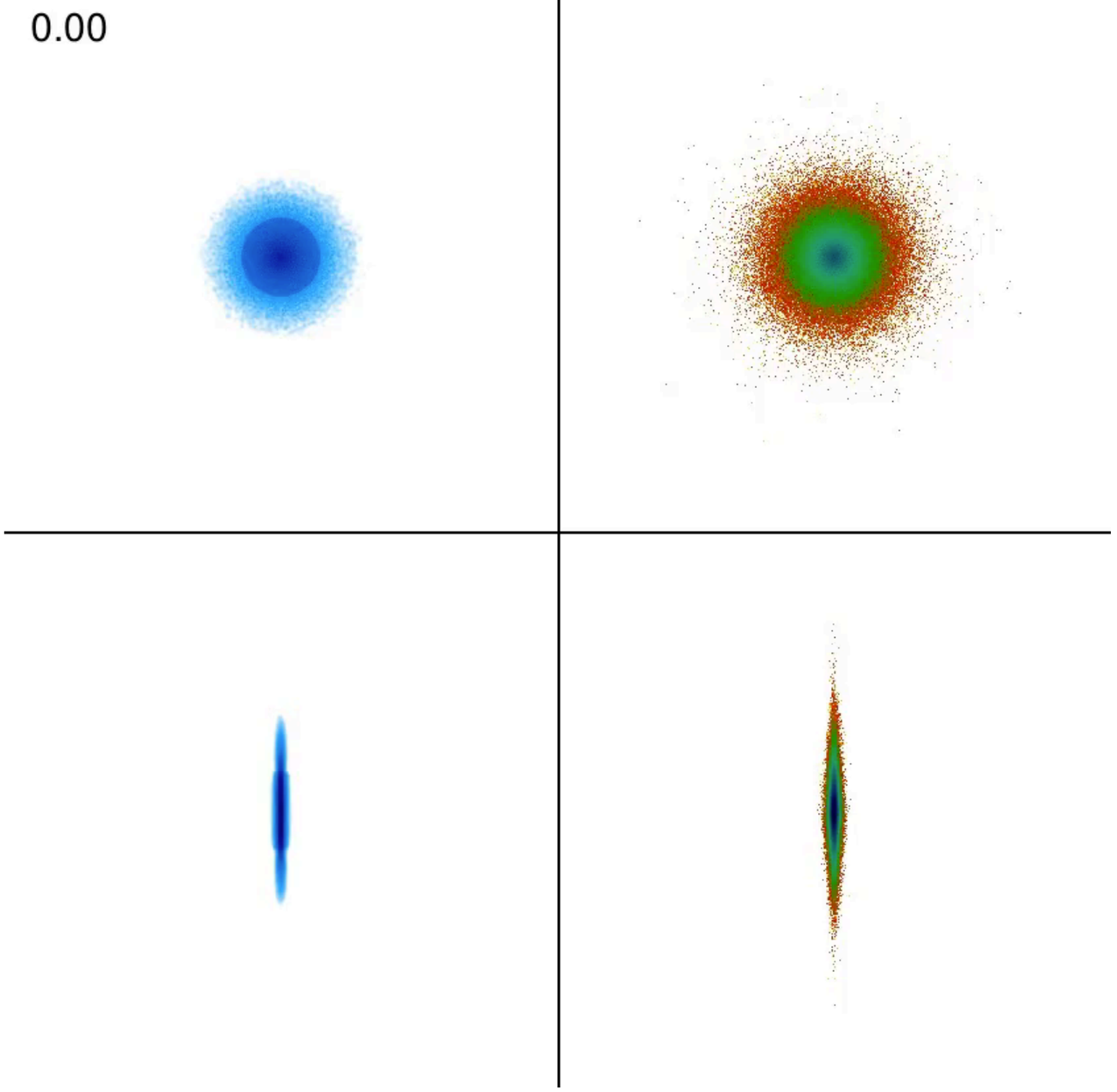




Future work

- structure of Antlia today

- Disclaimer — current errors in Gaia PMs for Antlia preclude accurate long time integrations (Lipnicky & Chakrabarti 2017)



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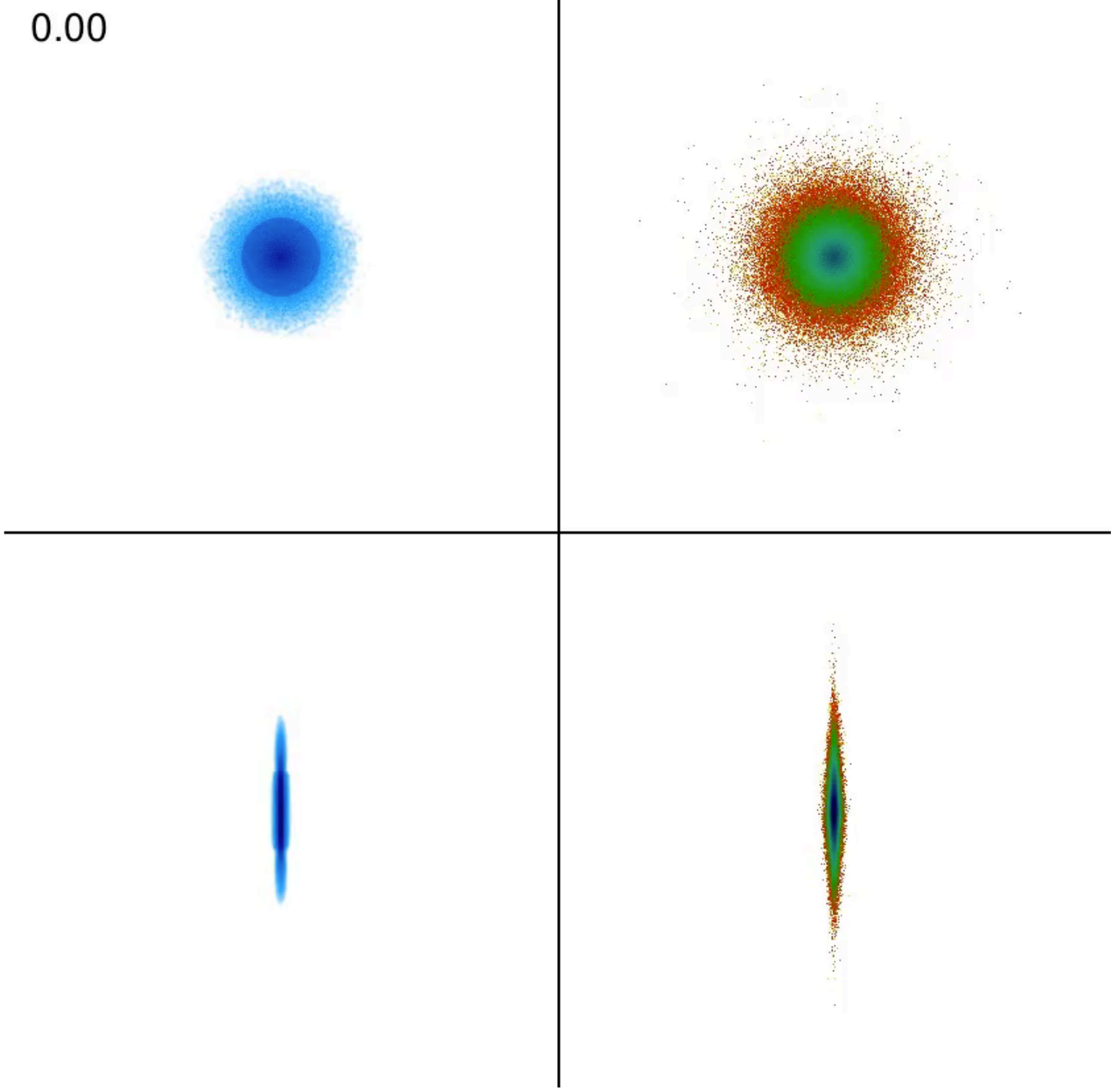

In closing …

- pre-Gaia prediction of dwarf galaxy parameters — close to what is observed for Antlia. Using orbits derived from Gaia PMs, Antlia matches observed HI disk disturbances.

- Galaxy is a complicated place .. which features are unique to model(s)? Is Monceros/phase space spiral unique to the Sgr interaction? or is it only produced in massive Sgr models?

- Double-blind comparison of data to a repository of simulations?