

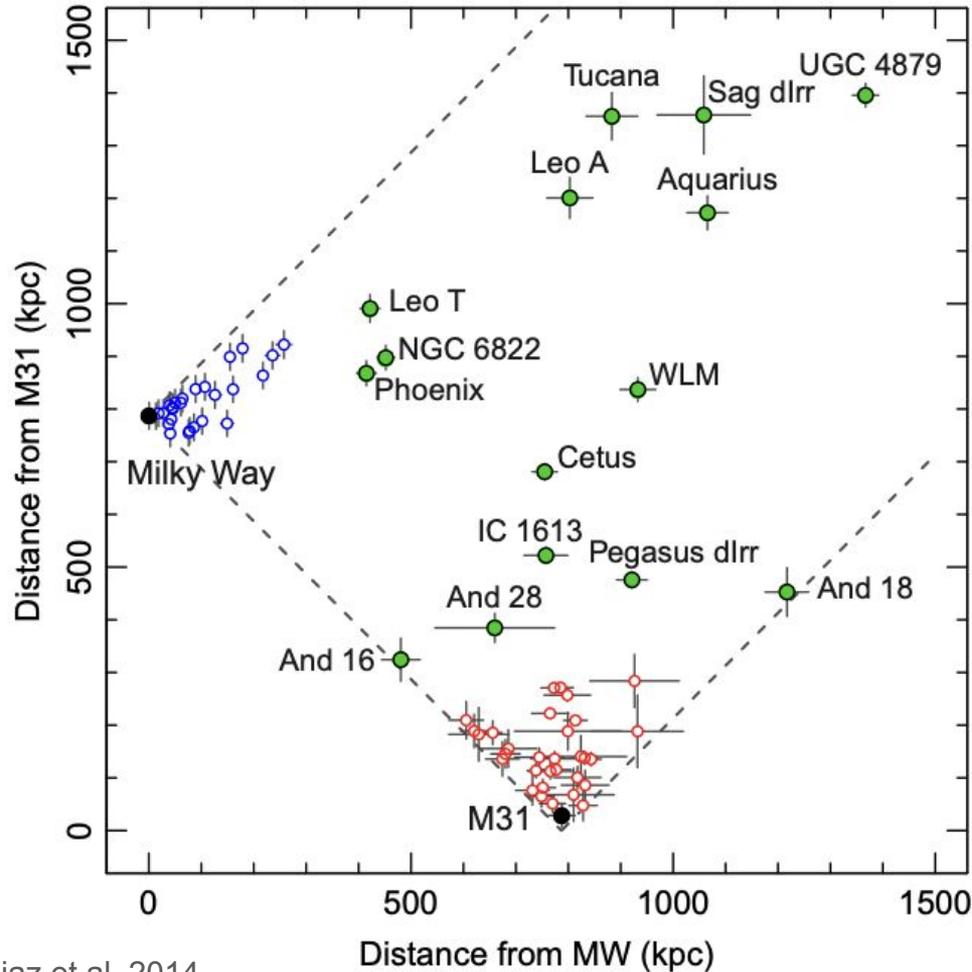
The Local Group: Orbital History of the MW and M31

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(On Job market this cycle!!)

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The Local Group -Observations

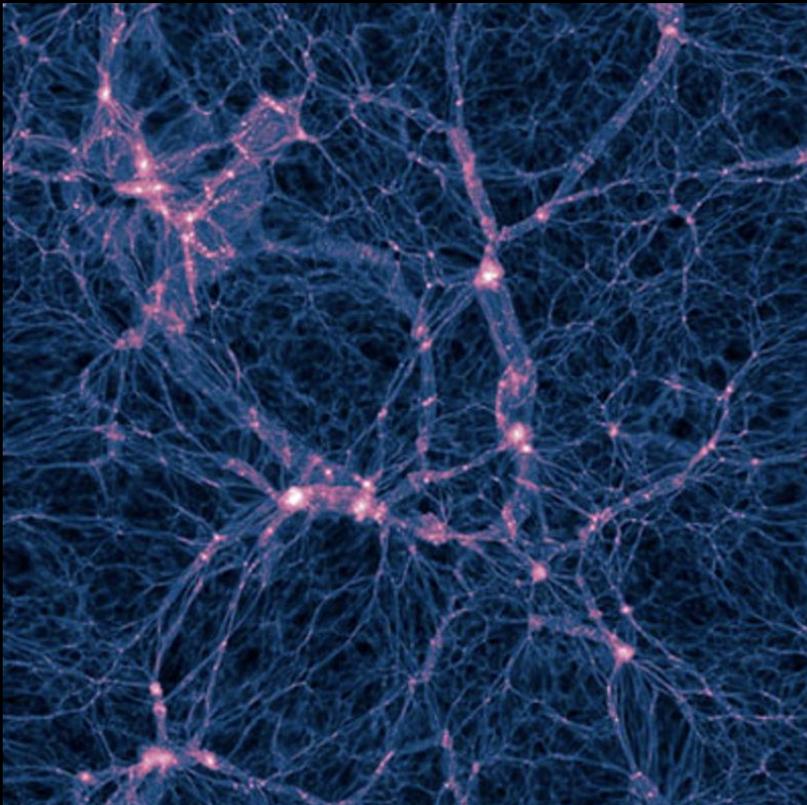


MW Satellite Galaxies
M31 Satellite Galaxies

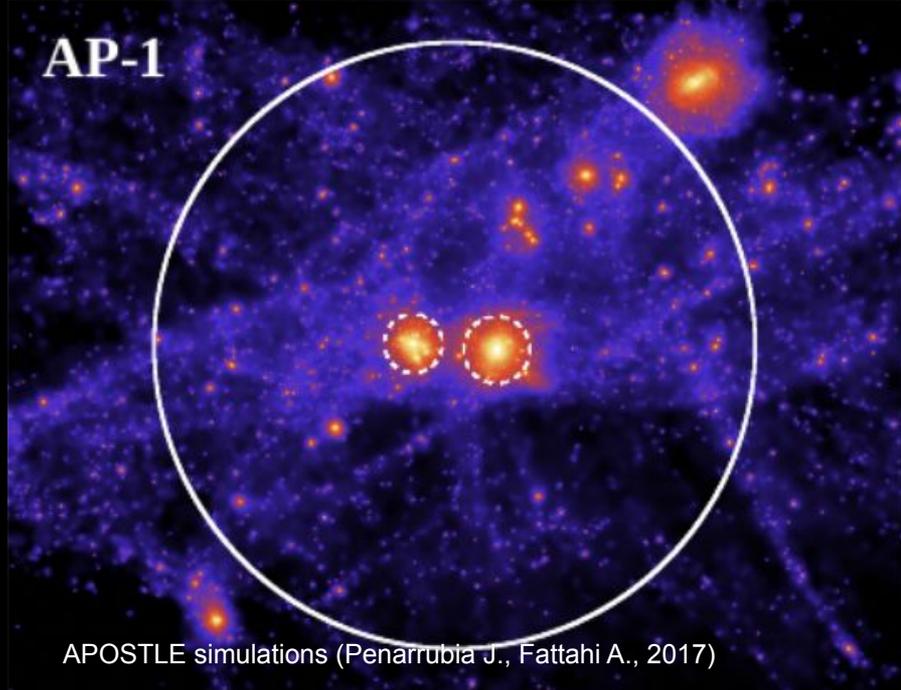
Outer Local Group
Members

Illustris-TNG Simulation

Large Cosmological simulation with
Baryon physics.



AP-1



APOSTLE simulations (Penarrubia J., Fattahi A., 2017)

Cut

$$-22.3 < M_B < -19.3$$

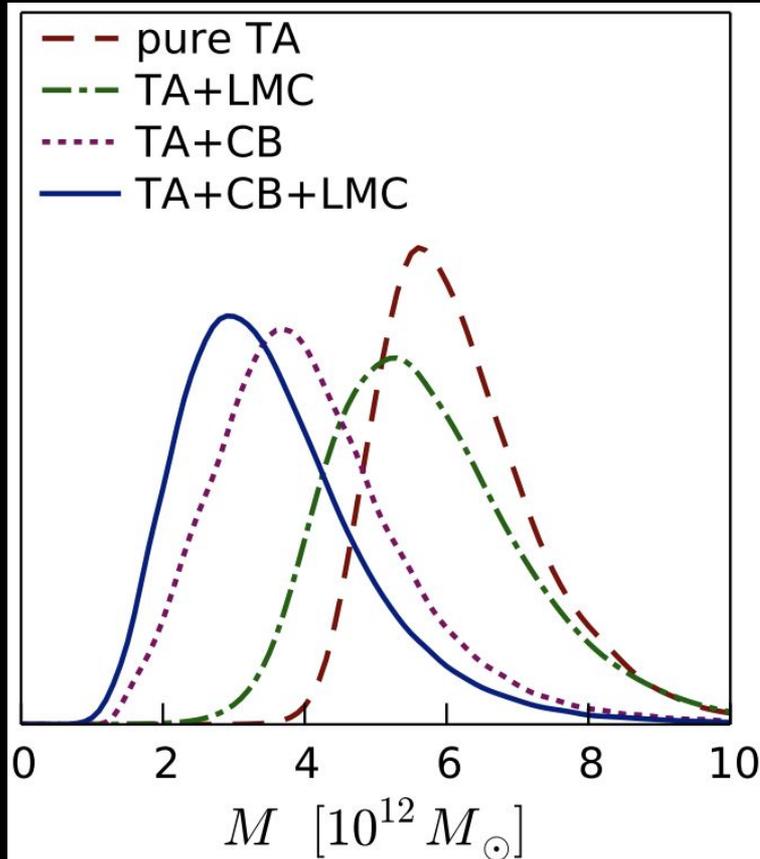
$$500 \text{ kpc} \leq |\vec{r}| \leq 1 \text{ Mpc}$$

Isolation

$$V_r < 0 \text{ km s}^{-1}$$

$$V_{max} < 300 \text{ km s}^{-1}$$

Timing Argument



TA- (Li & White 2008; Kahn & Woltjer 1959)

$$M = 3.1^{+1.3}_{-1.0} \times 10^{12} M_{\odot}$$

Taking the LMC into account (Chamberlain et al. 2022; Petersen & Peñarrubia 2020; Benisty et al. 2022) reduces the TA mass estimate (Benisty et al. 2022; Hartl & Strigari 2025); making it more consistent with the sum of the estimated masses for the MW and M31 (Watkins et al. 2010; 2019)

LG Kinematic Measurements

$$r_0 = 770 \pm 40 \text{ kpc}$$

van der Marel & Guhathakurta 2008

$$M = 3.1_{-1.0}^{+1.3} \times 10^{12} M_{\odot}$$

Benisty et al. 2022; Hartl & Strigari 2025

$$v_{\text{tan}} = 82.4 \pm 31.2 \text{ km s}^{-1}$$

van der Marel et al. 2019; Fardal et al. 2021; Salomon et al. 2021

$$V_{\text{rad}} = -114 \pm 1 \text{ km s}^{-1} \longrightarrow V_{\text{rad}} = -75 \pm 15 \text{ km s}^{-1}$$

Benisty et al. 2022; Chamberlain et al. 2022; Petersen & Peñarrubia 2020

Follow up - Questioning assumptions

Are MW and M31 on first infall?

How well can we determine the orbital history of the MW and M31 using this two body approximation?

Are the two bodies isolated (environmental effects)?

The Milky Way and M31 Orbital History: Did the Local Group evolve in isolation?

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LG Kinematic Measurements (Pre LMC correction)

$$r_0 = 770 \pm 40 \text{ kpc}$$

van der Marel & Guhathakurta
2008; van der Marel et al. 2012

$$V_{rad} = -114 \pm 1 \text{ km s}^{-1}$$

van der Marel et al. 2012

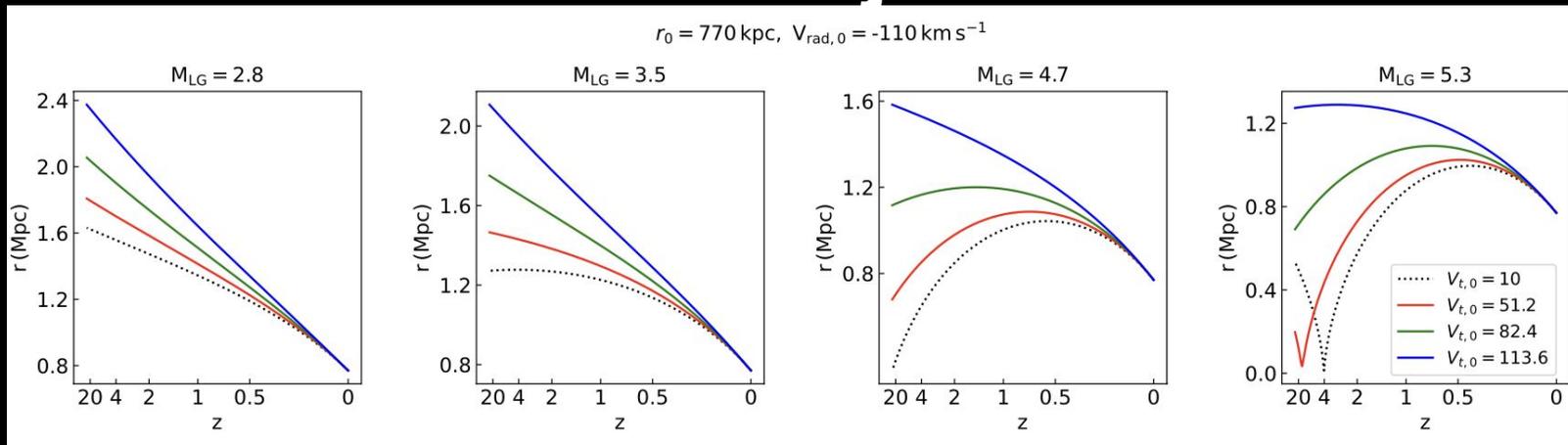
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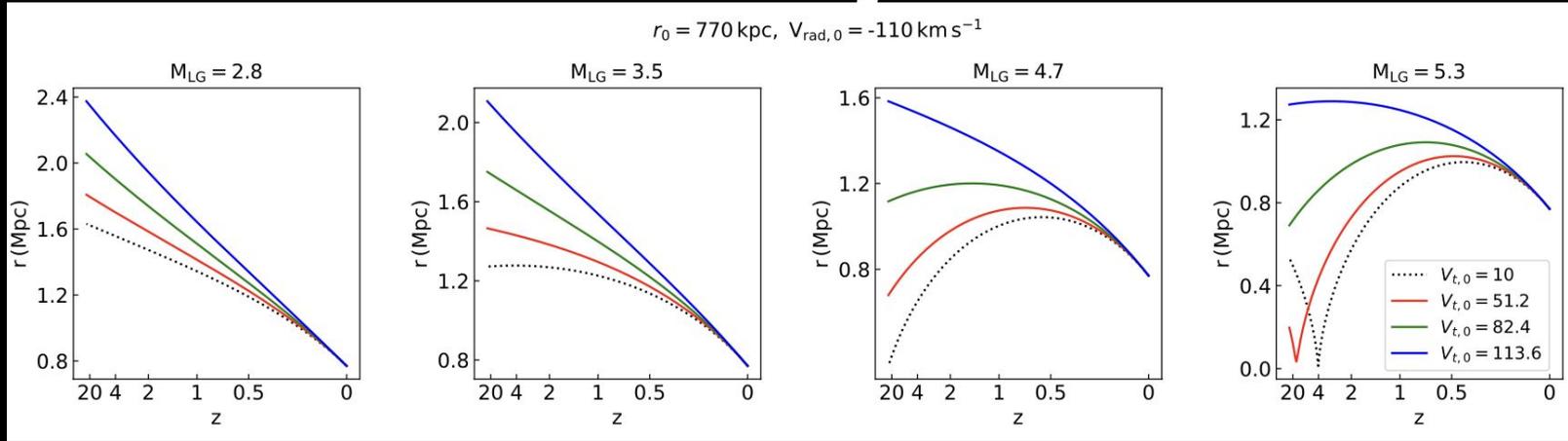
Possible MW/M31 Trajectories



$$v_{\text{tan}} = 82.4 \pm 31.2 \text{ km s}^{-1}$$

Hartl & Strigari (2025)

Possible MW/M31 Trajectories



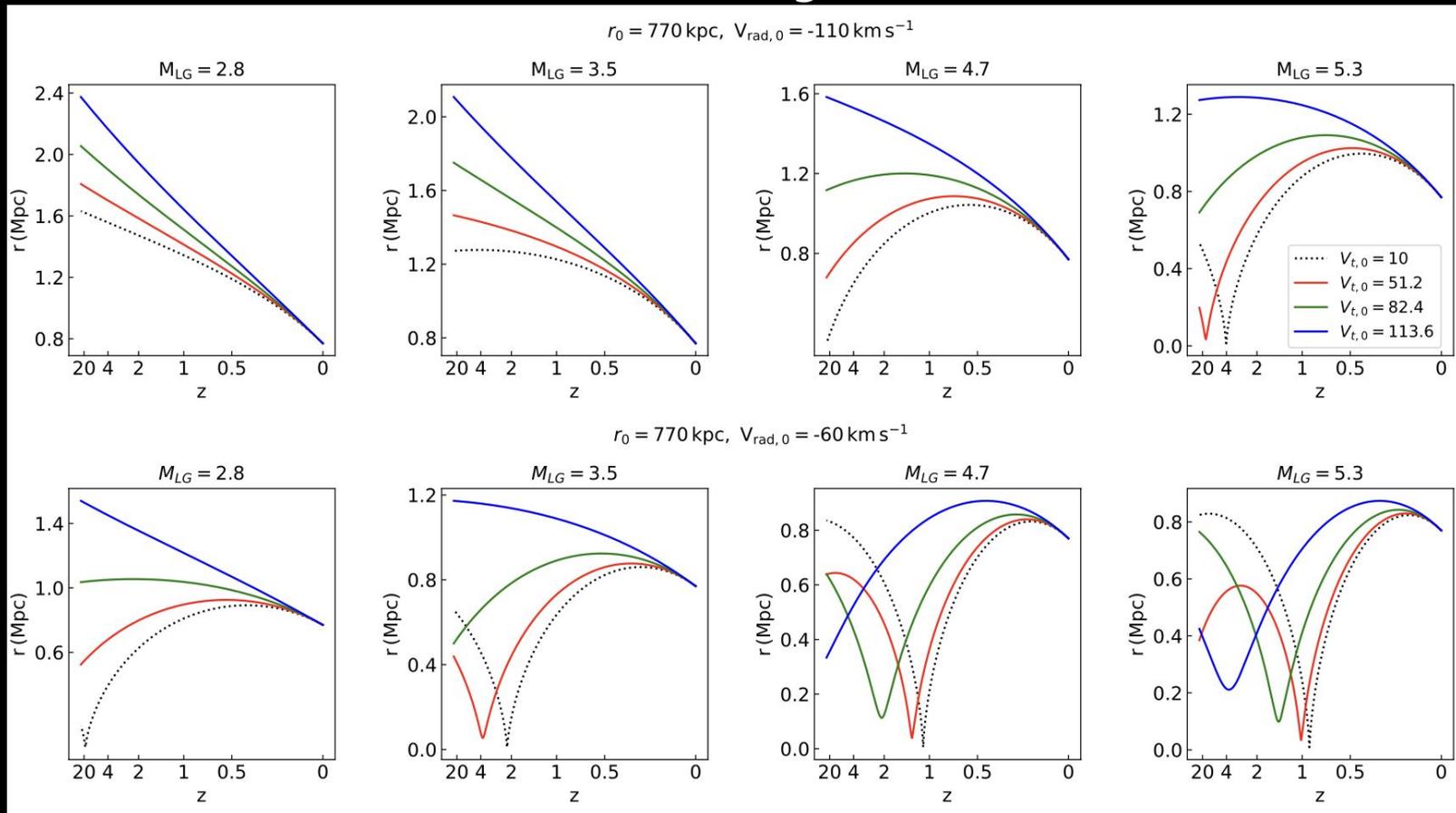
Hartl & Strigari (2025)

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LMC Adjustment:

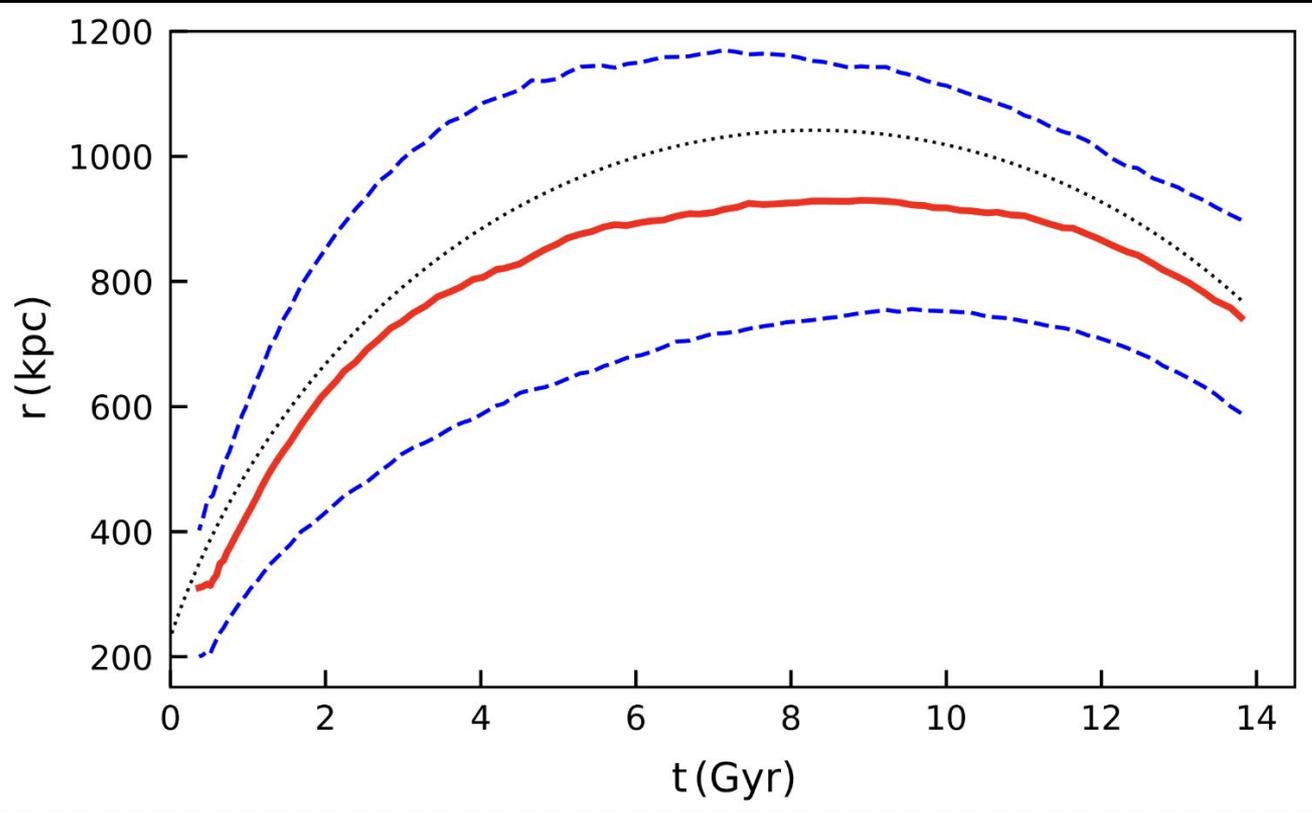
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Possible MW/M31 Trajectories



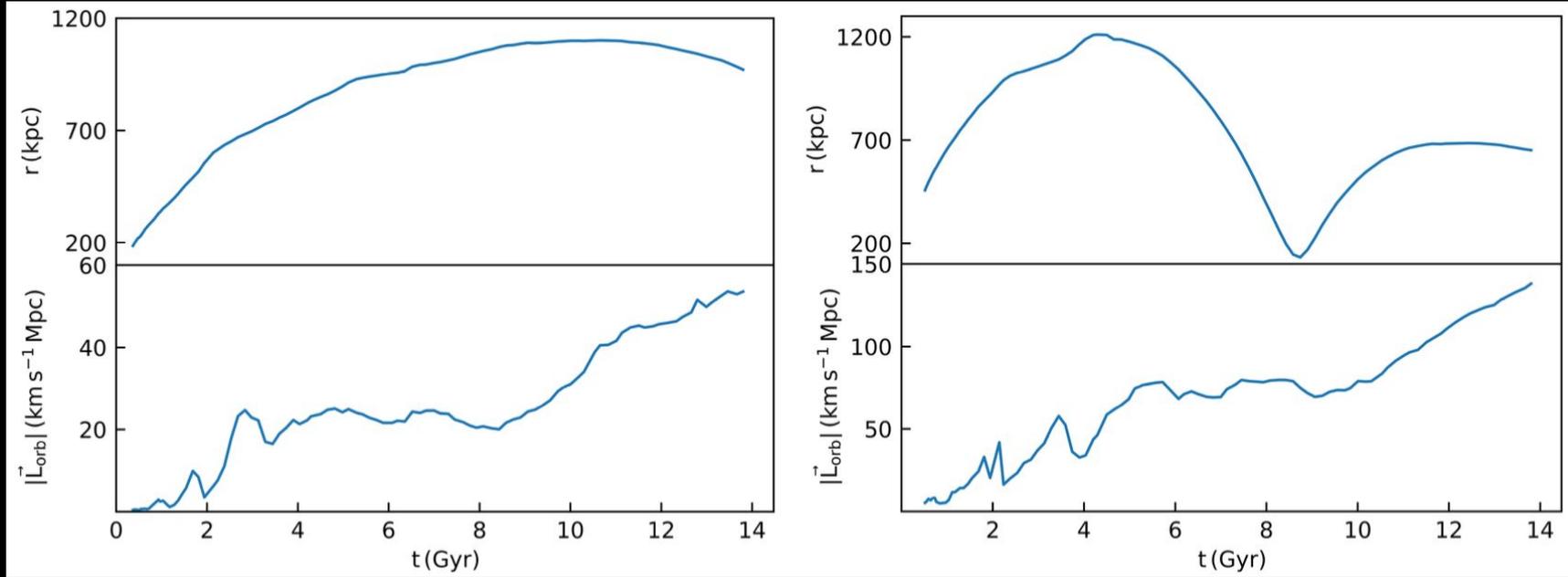
Can we determine the orbital history
of the MW and M31 using this two
body approximation?

Simulation Orbits



- Average orbits over all pairs is that of first infall orbit.

Example of Simulation orbits

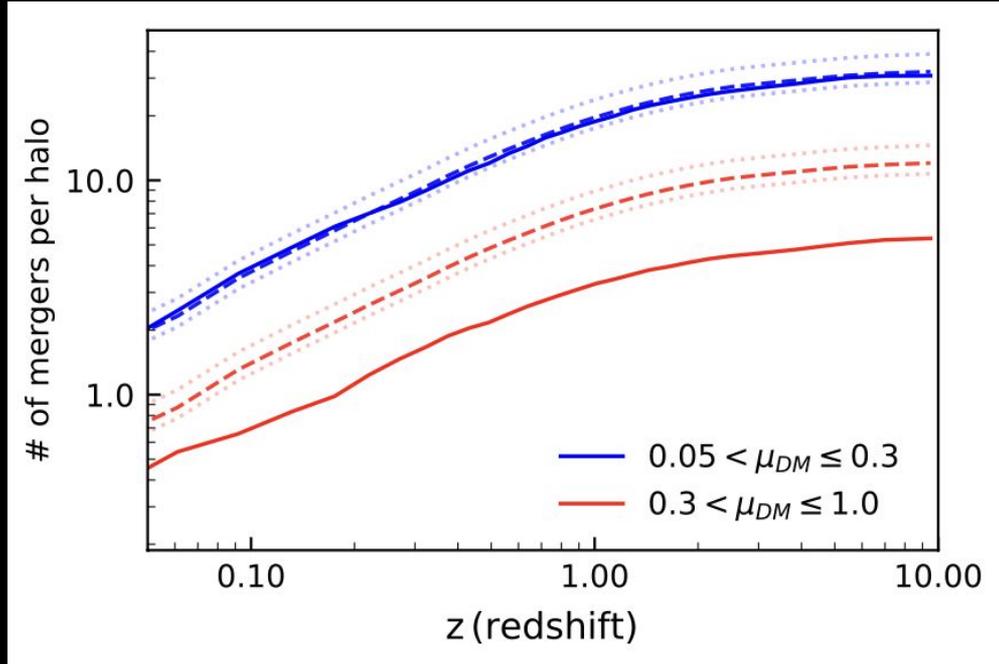


Hartl & Strigari (2025)

- 77/597 ($\sim 13\%$) of pairs have undergone a pericentric passage.
- 51/597 could only predict orbit for $\sim 9\%$ of pairs.

Are the two bodies isolated?

Merger History

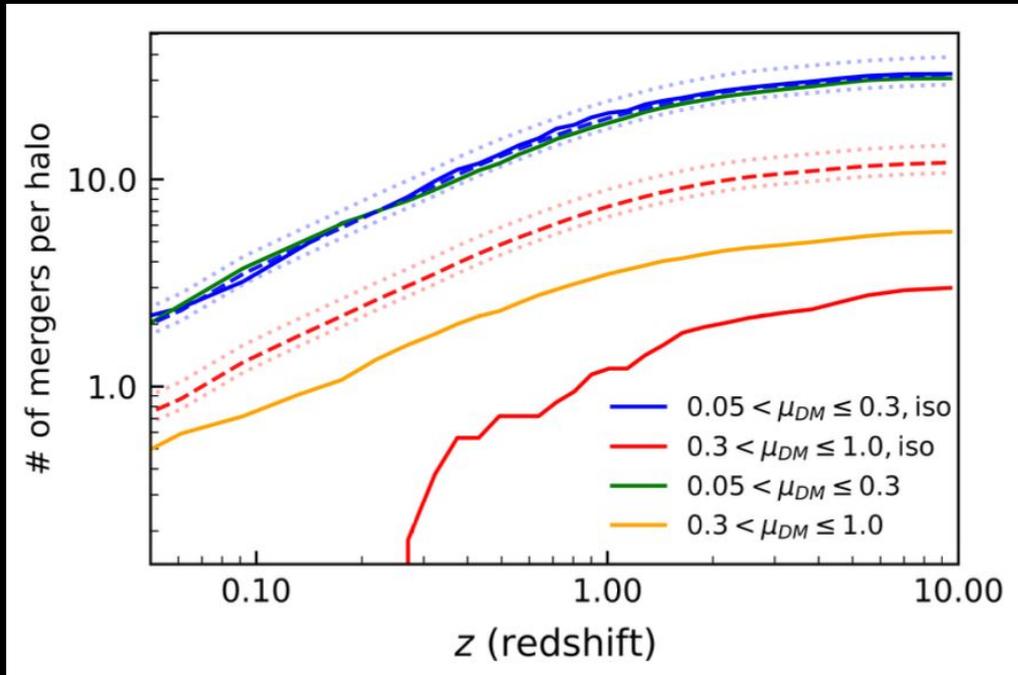


Hartl & Strigari (2025)

Minor Mergers
Major Mergers

- Merger history for MW/M31 type galaxy pairs is consistent with predictions for galaxies in their mass range.
- Note the normalization of the major mergers is attributed to the scatter in major merger rates across different simulations (Fakhouri et al. 2010).

Merger History



Hartl & Strigari (2025)

- The merger history for the 51 pairs whose orbit we were able to predict by the two-body approximation show a severely quiescent recent major merger history indicating an ‘isolated’ system is required to best predict the orbital history using this method.

Where does the tangential velocity
come from?

Orbital Angular Momentum - Tidal Torque Theory (TTT)

- Applies in the linear regime of structure formation.
- Proto-halos' (small mass fluctuations) have asymmetrical density distributions.
- The tidal field describing the surrounding matter induces a torque on the asymmetrical proto-halo causing it to rotate.
- Angular momentum arises from the misalignment between \mathbf{I} and \mathbf{T} .
- Can we apply this to larger region containing the two MW/M31 proto-halos and use TTT to describe and explain the orbital angular momentum?

Orbital Angular momentum (\vec{L}_{orb})

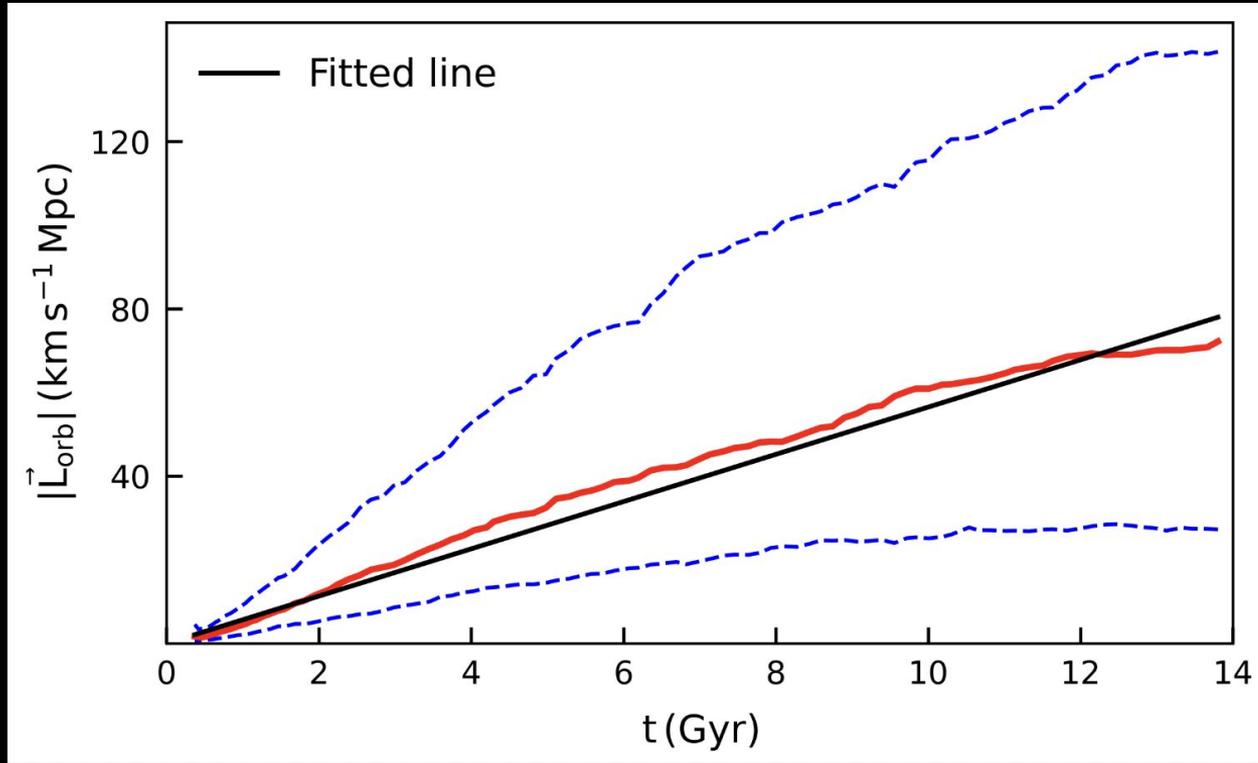


Fig shows on average the orbital angular momentum that a Local Group acquires throughout its evolution.

We find the growth matches Tidal Torque theory (TTT) for $\Lambda=0$ when density perturbations are linear.

Summary

- LMC impact on v_{rad} prefers past pericentric passage.
- Typical LG-like systems are consistent with a first infall model.
- Two-Body approximation holds for ‘isolated’ pairs.
- Can predict orbits for MW-M31 pairs that have not undergone a major merger since $z = 0.25$.

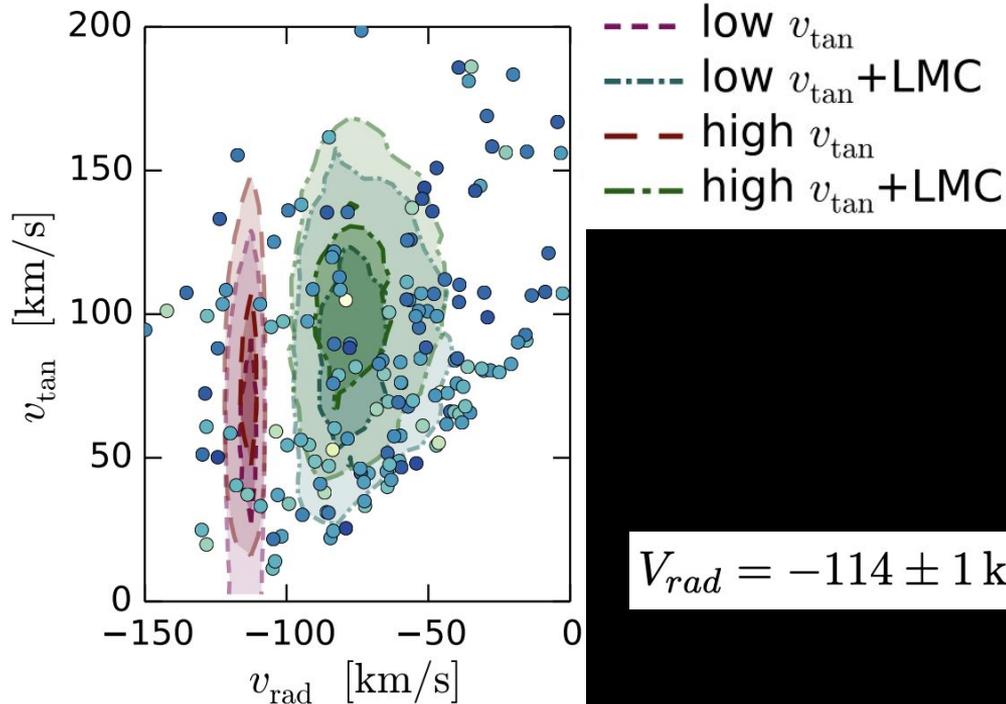
A complex network graph visualization with a dense web of blue edges and numerous red nodes. The nodes are concentrated in certain areas, forming a central cluster and several smaller clusters. The overall structure is highly interconnected and resembles a biological or social network.

Thank you (:

LMC Reflex-Motion

The Local Group Mass in the light of *Gaia*

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Wind the orbits back to when the LMC perturbation is negligible, remove the LMC and wind the orbits forward to find the change in the velocity due to the LMC.

$$V_{\text{rad}} = -114 \pm 1 \text{ km s}^{-1} \longrightarrow V_{\text{rad}} = -75 \pm 15 \text{ km s}^{-1}$$