The Currents of Space: The Effect of Baryonic Physics on Stellar Stream Formation

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Abstract

Cosmological zoom in **simulations** allow us to study galaxy formation and evolution from a **unique perspective**, providing information about otherwise hidden to observers across its history. One of such otherwise hidden information is the complete and **detailed accretion history** of the galaxies. In this work, we make use of eight VINTERGATAN zoom-in simulations (Agertz et al. 2021) to **constrain the internal and orbital parameter space** that leads to the **formation of the dynamically coherent substructure** found on stellar galactic halos, known as Stellar Streams.

Accretion History

We determine the accretion history of a Milky-Way analog following an approach similar to that presented in Riley et al. 2024, but incorporate particle kinematics to improve tagging during close encounters.

We employ a **Gaussian Mixture Model** and we enforce a **prior** on the **latent variable**, to ensure that the GMM produces physically meaningfull results.

The log-likelihood of the model is:

$$\mathcal{L}(\pi, \mu, \Sigma) = \sum_{i=1}^{N} \log \left(\sum_{k=1}^{K} \alpha_{nk}\, \pi_k\, \mathcal{N}(x_i \mid \mu_k, \Sigma_k) \right)$$

Unraveling the State of Accreted Systems

To unravel the dynamical state of the accreted systems we follow:

- Convert from typical {x,v} phase space to $\{\hat{E}/m, \hat{j}_z, \hat{j}_{perp}, \hat{j}/\hat{j}(E)\}$ **action-energy space**.
- Combine the phase-spaces of the 8 halos.
- Identify the two **principal components**.
- Fit a **logistic regression** over the PCA. We use as target variable the criteria given by Riley et al. 2024.

This produces a criterion that classifies particles individually and is very exportable:

$$(\hat{E}/m) + 0.86\cdot(\hat{j}_{perp}) + 2.1\cdot(\hat{j}/\hat{j}(E)) + 2.75 = 0$$

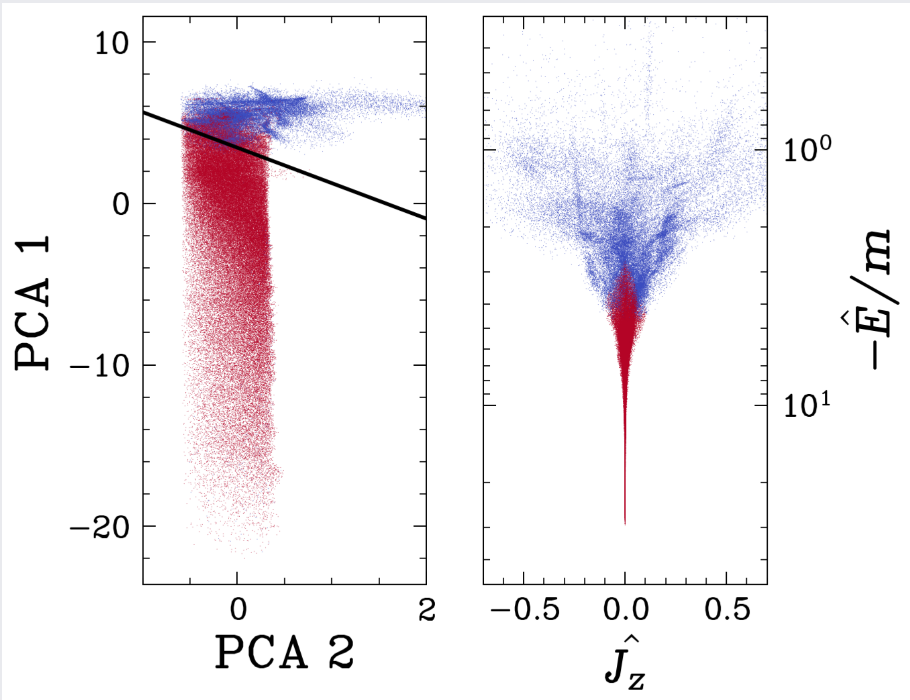

Figure 1: ***Left***: Logistic regression of first two principal components. Red/blue coloring corresponds to target variable mixed/coherent. ***Right***: Predicted state over $\hat{E}/m$ vs. $\hat{j}_z$ gives nonlinear boundary.

Effect of Internal and Orbital Properties

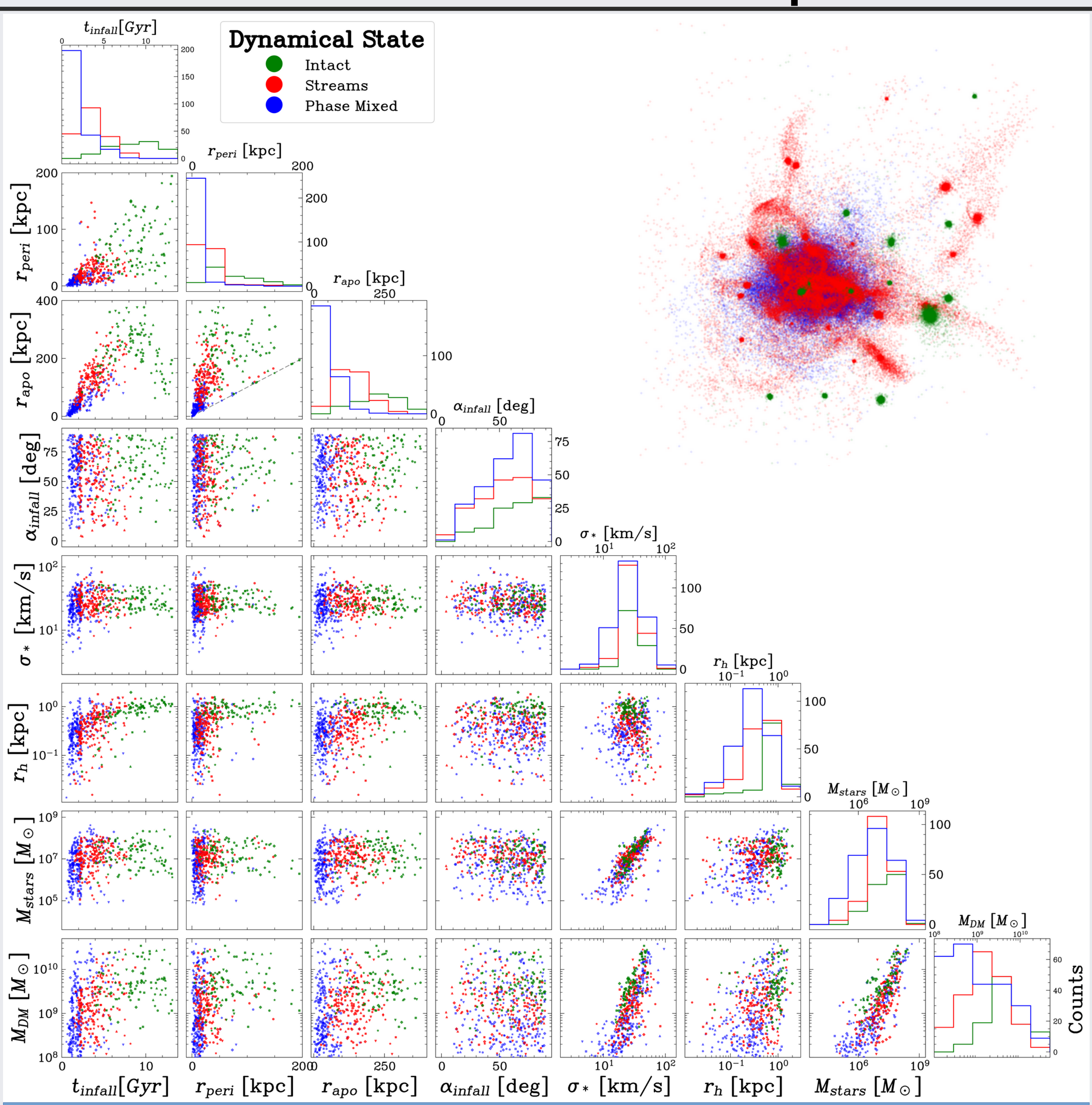

Figure 2: (a) Corner plot of the correlation between the different variables on the chosen parameter space. Green/Red/Blue coloring indicates dynamical state as deterined using the criterion above. **(b)** Selected halo at current time.

To **explore** the conditions that lead to **formation of dynamically coherent debris**, we define a parameter space consisting of **orbital** and **internal properties** for each accretion event.

We choose:

Orbital properties	Internal properties
Time of Infall (r_{vir})	Dark matter mass
First pericenter	Stellar mass
First apocenter	Half-mass radius
Orbit inclination at infall	Stellar mass

Figure 2 the distribution of phase-mixed, coherent and intact remnants over the chosen parameter distribution. **Orbital properties** seem to **dominate the landscape.** You can try fixing a range of parameters through the following QR code!

To see a detailed discussion about the **evolution of accretion events,** from intact to mixed, check out poster **P.64** lead by **Sergio Garcia-Moreno!**

Acknowledgments

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Future Work

- Separate the parameter space into regions where intact, phase-mixed and coherent structures live.
- Characterize the properties and morphology of the identified structures.
- Extend the analysis to multiple galaxy formation models.

References

Riley et al., MNRAS, 542, 2443-2463
Agertz et al., MNRAS 503, 5826-5845