Using Velocity Dispersion Profiles in N-body Simulations to Search for GD-1's Progenitor

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Introduction

A stellar stream is a product of a bound stellar system, likely a globular cluster (GC) or dwarf galaxy, being stripped by tidal forces as it orbits its host galaxy. Some streams show visible remnants of their progenitor which allows more accurate modeling of their formation and evolution. However, **GD-1**, one of the brightest and heavily studied streams, does not have a known progenitor location.

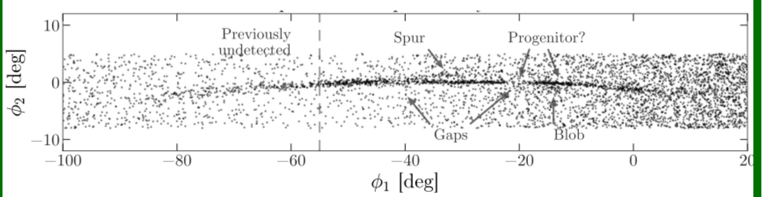

Figure 1: GD1 stream from Gaia DR2 data, from Price-Whelan & Bonaca (2018)

What can velocity dispersion tell us?
In this project, we search for GD-1's progenitor using the shape of the radial velocity dispersion curves. These curves reflect the distribution of radial velocities along the stream, and may help constrain the location of the progenitor, and interactions of the stream with dark matter halos.

Goal

1. How does the velocity dispersion curve change with different progenitors?
2. What is the validity of using velocity dispersion to locate the progenitor?

Methods

In order to recreate GD-1, in its on-sky position and length, the initial conditions are set with **Gala -** used to generate the bulk initial positions and velocities of the cluster, and

McLuster - used to model the internal dynamics of the cluster.

PeTar uses this initial cluster and simulates the orbits of each particle under the influence of the cluster itself and the Milky Way potential.

Across simulations we vary the following initial parameters: progenitor mass, scale radius and location, as well as integration time.

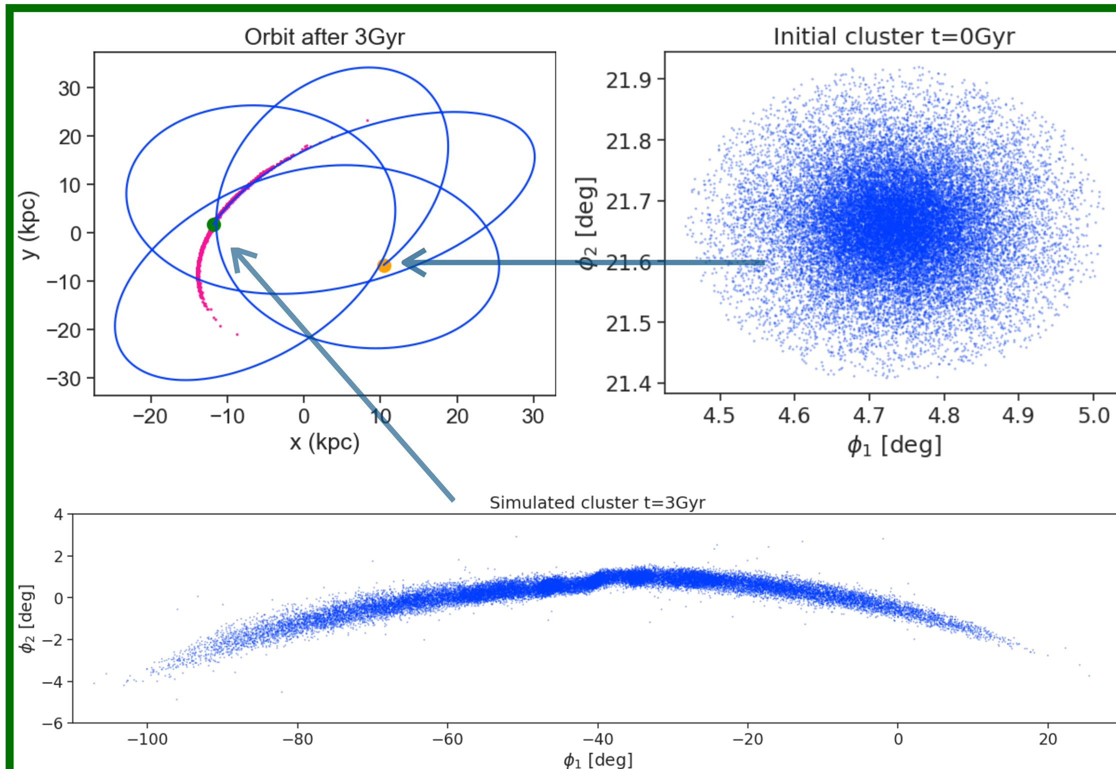

Figure 2: This shows a visualization of the steps taken to run the simulation. The stream begins as a cluster (top right panel), and is set on an orbit around a Milky Way-like potential for 3 Gyrs (top left panel), and the cluster becomes a stream (bottom panel).

Results

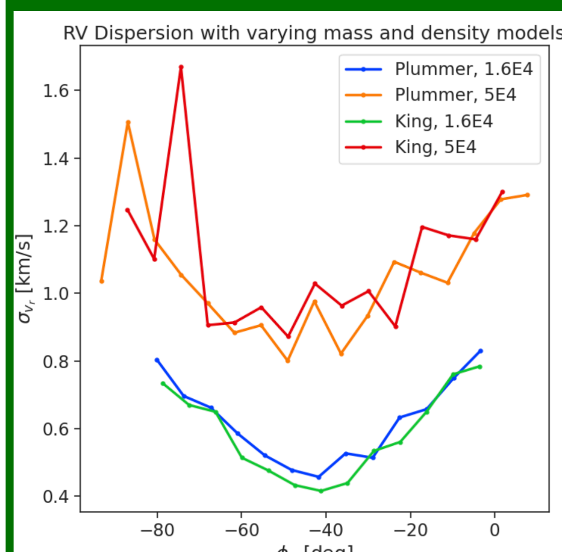

Figure 3: Radial velocity dispersion of GD-1 models initialized with 2 density models as GCs: Plummer and King, and each at 2 different masses: 5×10^4 and 1.6×10^4 solar masses

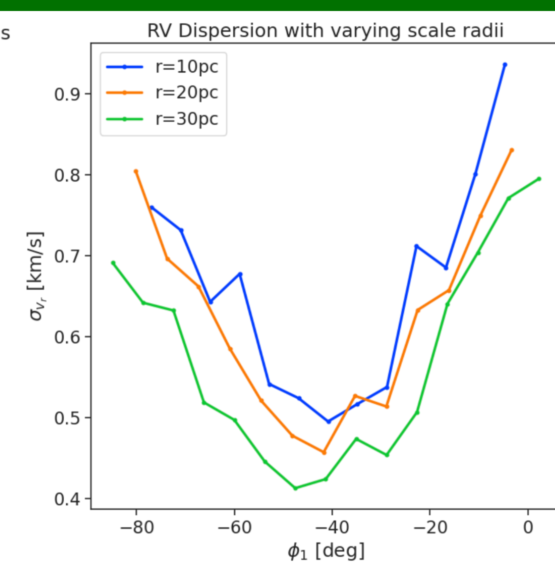

Figure 4: Radial velocity dispersion of GD-1 models initialized with scale radii of 10pc, 20pc, and 30pc

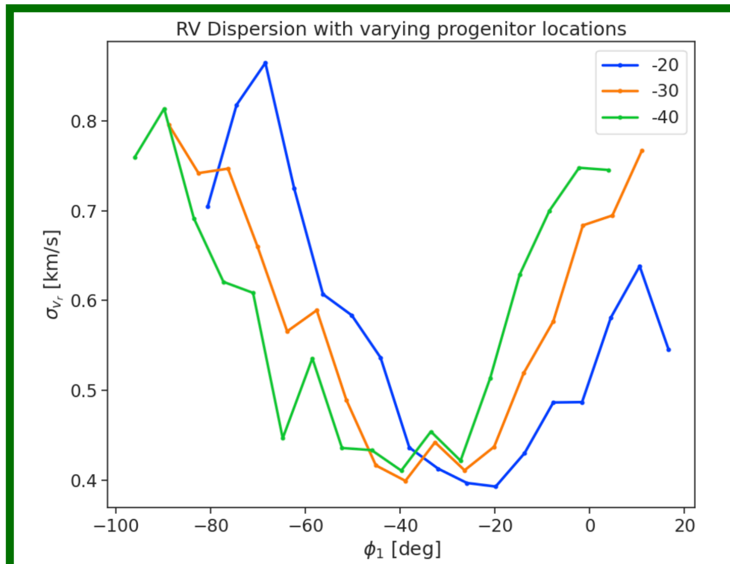

Figure 5: Radial velocity dispersion of GD-1 models initialized with progenitors at $\phi_1 = -20, -30, -40$°

Conclusions & Next steps

Velocity dispersion curve shape
We find that the radial velocity dispersion profile is sensitive to the initial conditions along a few different axes. Specifically:

1. Higher velocity dispersions with higher mass clusters
2. Narrower profiles with decreasing scale radii
3. Location of the trough of the velocity dispersion curve shifts along phi1 with the progenitor's on-sky position

This demonstrates the possibility of using velocity dispersion curves as tools to better understand the history of streams.

Next steps: We aim to quantitatively compare profiles from simulated and observed data, and understand how different dark matter models change the velocity dispersion profile.

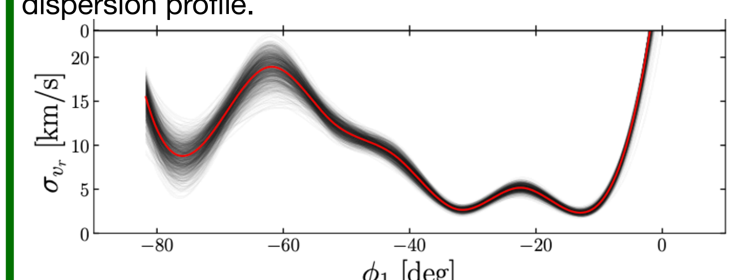

Figure 6: Radial velocity dispersion of GD-1 from Gaia DR3, from Tavangar & Price-Whelan (2025)

References:
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