Effects of dark matter subhalos on tidal streams

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Introduction

What are the FIRE-2 simulations?
- FIRE[1]: Feedback in Realistic Environments
- High-resolution simulations of Milky Way-mass galaxies
- Trace star, gas, and dark matter particles through time

What are tidal streams?
- Tidal streams are "strings" of stars (Fig. 2) orbiting a host galaxy such as the Milky Way
- Stars in tidal streams originate in dwarf galaxies or globular clusters
- The stronger gravity of the host creates a tidal force which strips stars from their progenitors into streams

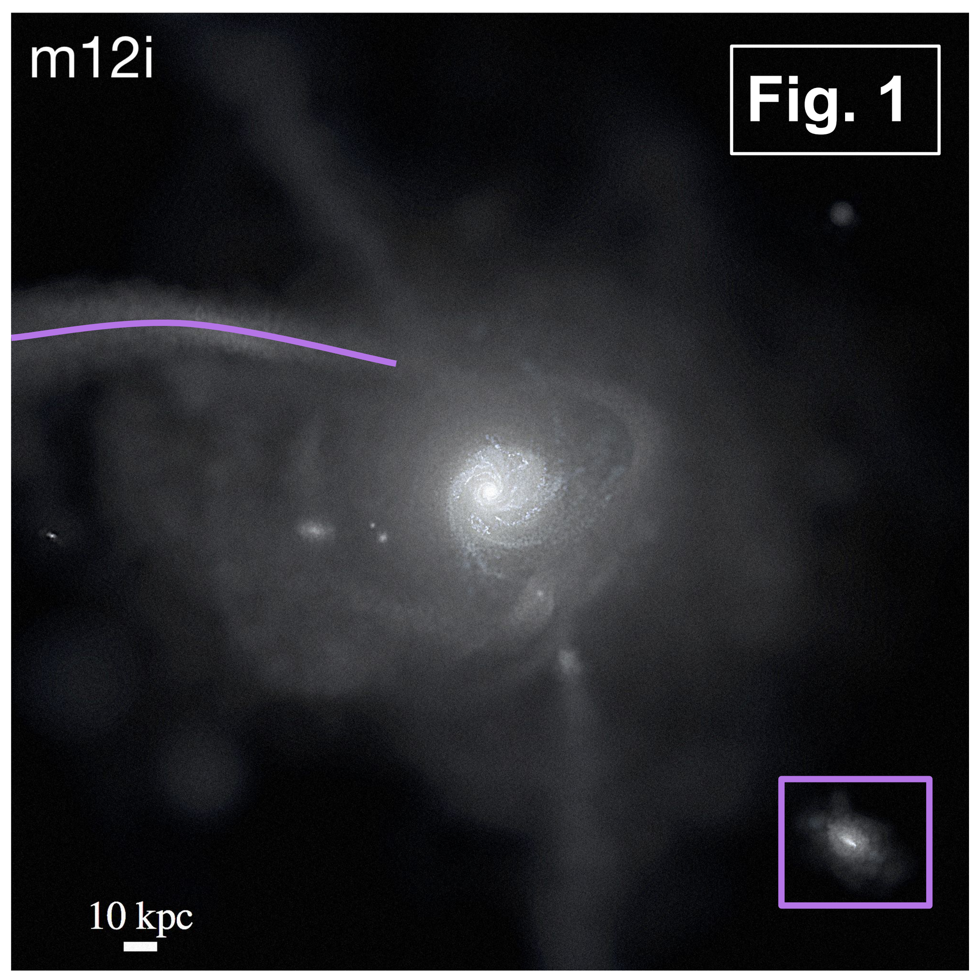


Figure 1. Render of Milky Way-mass galaxy from FIRE-2[2]. A section of a tidal stream and a dwarf galaxy are marked in purple.

What are dark matter (DM) subhalos?
- The successful (on large scales) Cold Dark Matter (CDM) theory describes DM as slow-moving, collisionless, and forming structures (subhalos)
- Studies propose that tidal streams are disrupted by interactions with DM subhalos, causing clumpy tidal debris[3]
- Observable tidal streams are promising DM probes, especially for small (mass ≈ 10^8 $M_\odot$)[4] subhalos which are difficult to detect and important for testing CDM

Goal:
Test whether DM subhalos cause gaps in tidal streams by:
1. Creating two groups of streams: those that develop with DM subhalos and those that develop without
2. Comparing density profiles between the groups using a proposed gappiness statistic, σ

Stripping time distribution is sharply peaked

- Select FIRE-2 tangential tidal streams[5] and allow them to develop in two different environments:
  1. For "lumpy" streams: evolve in FIRE-2 simulation environment with dark substructure
  2. For "smooth" streams: integrate stellar orbits in a smooth, time-evolving multipole model of host's gravitational potential[6]
- For smooth streams, begin tracking each star at its stripping time (when it becomes bound by the host's potential).

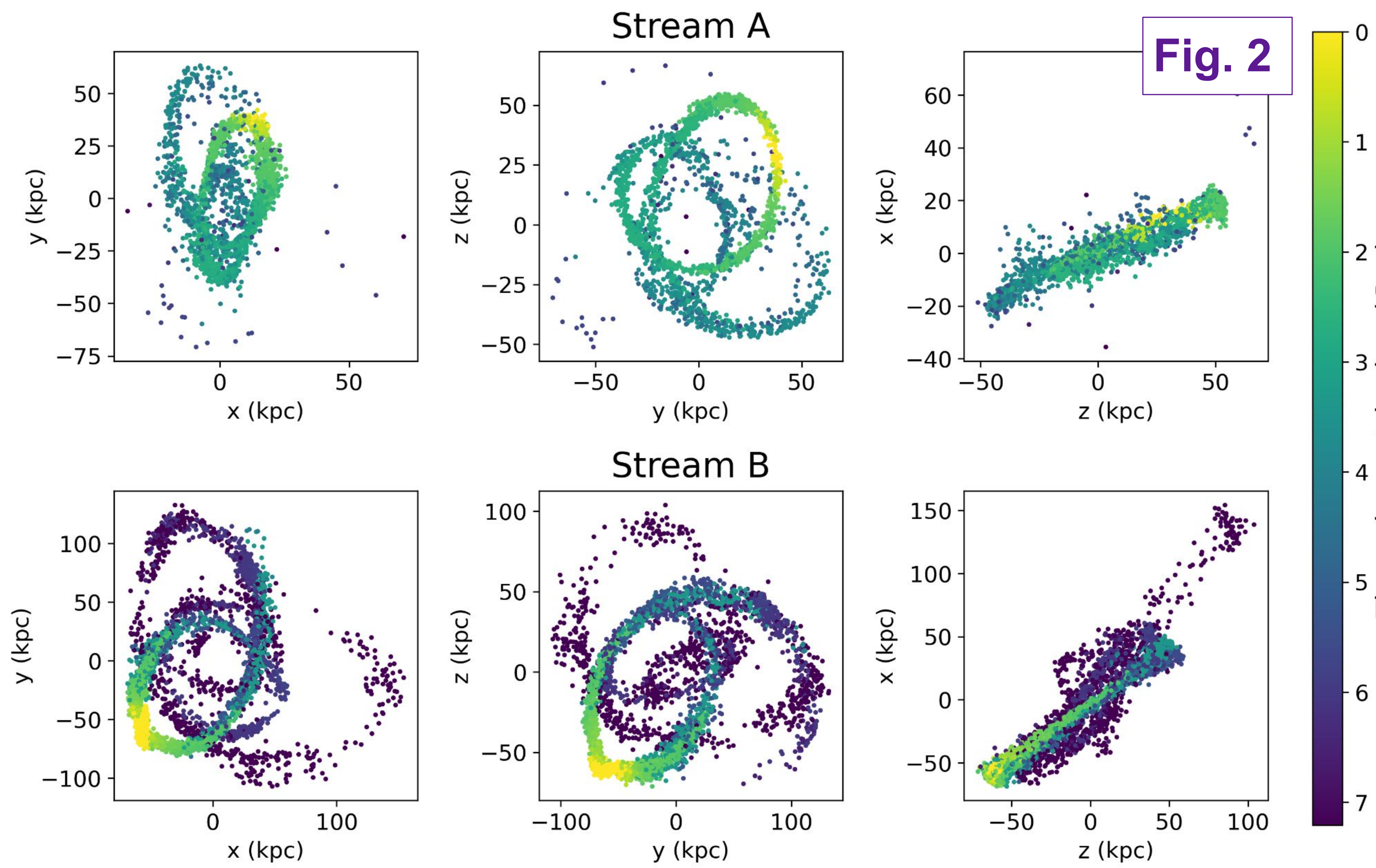
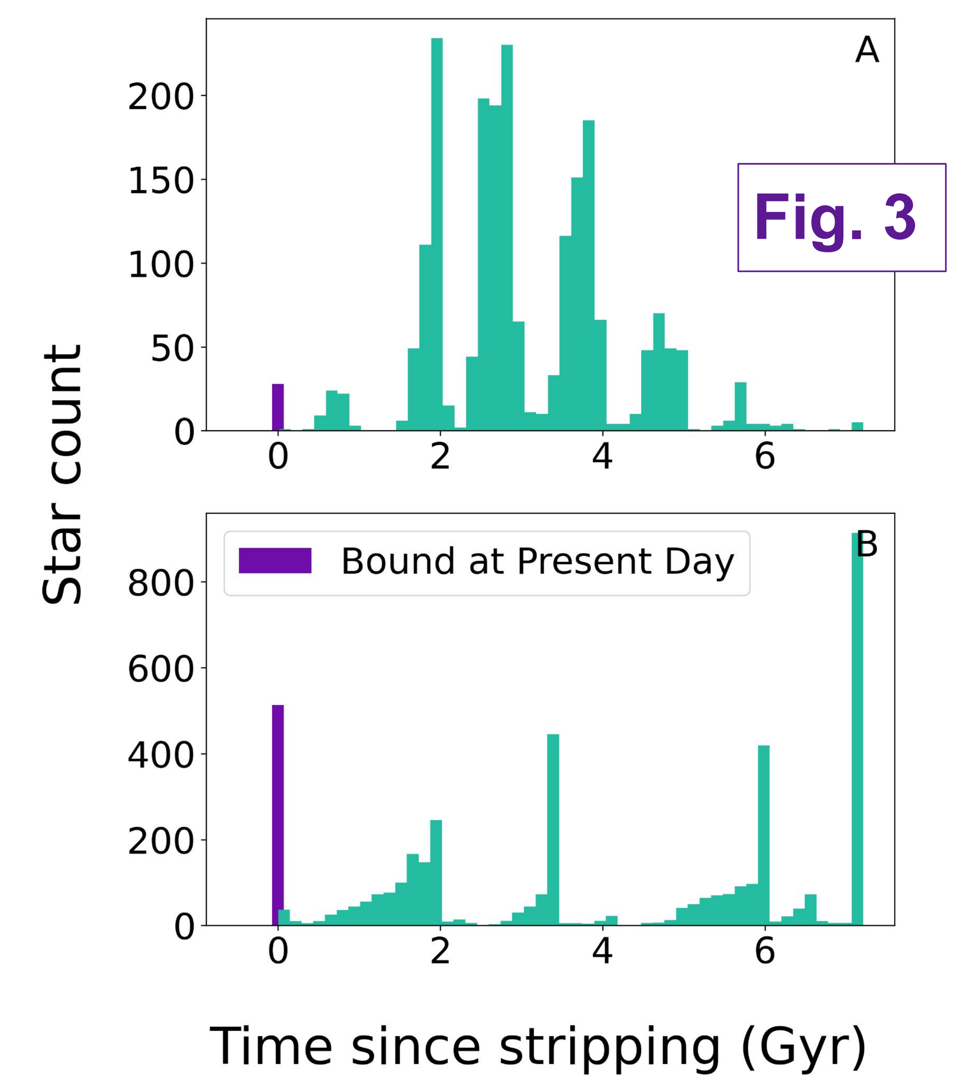


Figure 2. Visualization in 3D of stars in lumpy tidal streams at present day. Stars are colored by the time elapsed since their stripping (time = zero -> stars are bound at present day).

Figure 3. Histogram of stripping times for each stream (stars which are bound at present day plotted in purple).

We hypothesize that peaks in the distribution occur at progenitor pericenter where the tidal force is greatest, causing enhanced stripping.



Streams in smooth and lumpy potentials have similar gappiness (σ)

- Under-densities in tidal streams can occur without DM subhalos (Fig. 4)
- We propose a gappiness statistic, σ, which is sensitive to a combination of the number of local minima in the density, and the curvature at those minima

Table 1.	Lumpy σ	Smooth σ
Stream A	5.1	3.5
Stream B	2.6	2.9

- Mathematically, σ sums over positive eigenvalues of the Hessian (which correspond to negative curvature of the density field) at critical points.
- Table 1 compares lumpy and smooth streams based on the value of σ
- Streams that interact with DM subhalos (lumpy streams) are not always more gappy.

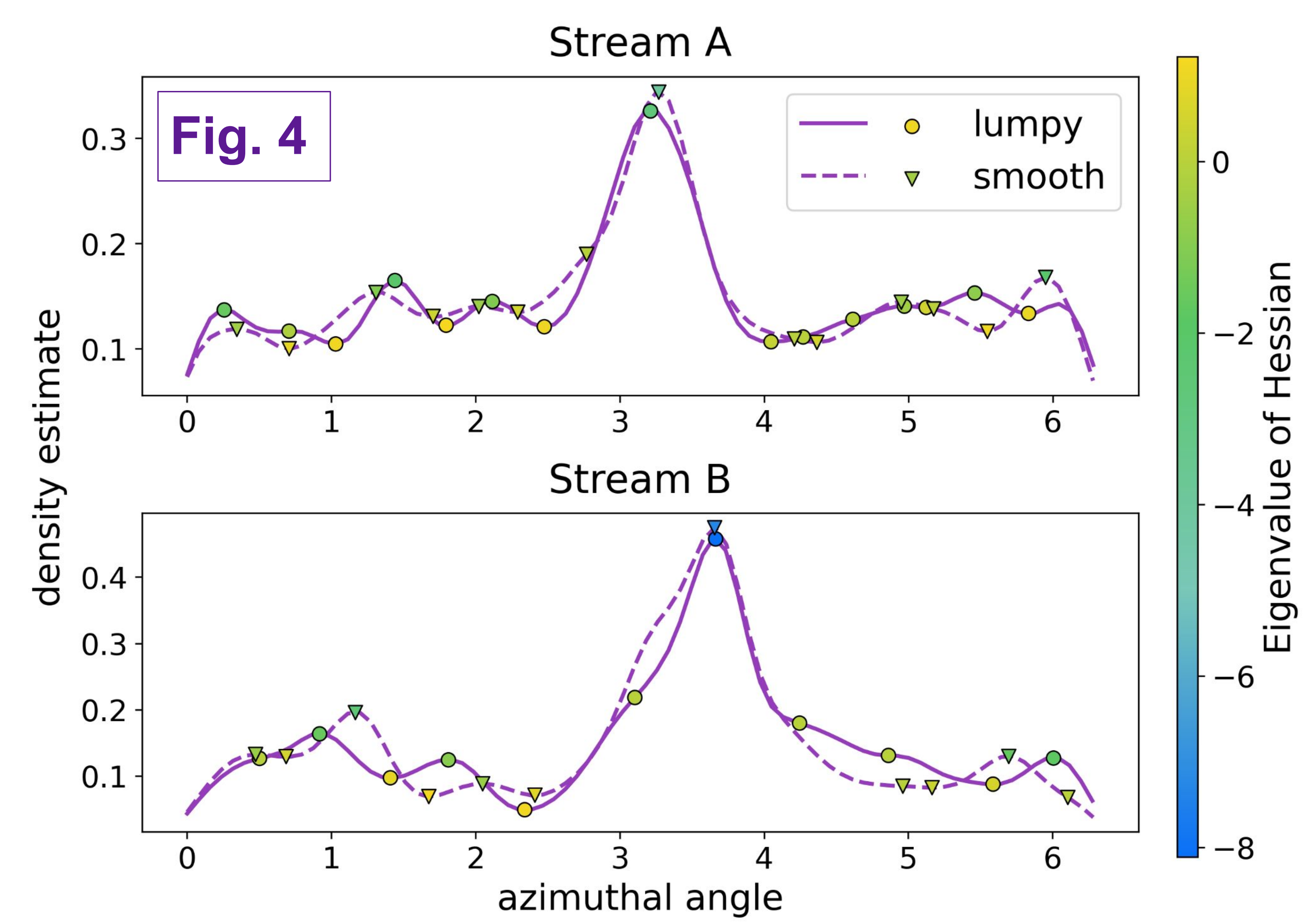


Figure 4. Density estimates (KDE; bandwidth = 0.15) and critical points[7], are compared for lumpy and smooth streams along azimuthal angle. Critical points are color-coded by the e-val of the Hessian at those points.

Conclusions

1. Gaps in tidal streams can occur without DM substructure (Fig. 4)
2. Streams that interact with DM subhalos are not universally "gappier" (greater σ) than those that do not. (Table 1)

We hypothesize that gaps in tidal streams are instead caused by reduced stripping at progenitor apocenter (Fig. 3) or by epicyclic motion of stars[8]. Further analysis is needed to test these hypotheses. Future research will also examine a larger sample of tidal streams, which is necessary to draw definitive conclusions.

References

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