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Time evolution of the properties of gaps in stellar streams in axisymmetric potentials

Helmer H. Koppelman and Amina Helmi

Kapteyn Instituut, University of Groningen,
P.O. Box 800, 9700 AV, Groningen, the Netherlands
email: h.h.koppelman@rug.nl

Abstract. We present here a model that allows us to predict the properties of gaps in stellar streams, and how these depend on the parameters of the encounters (satellite mass, size and relative velocity). Since the gaps we consider are created by dark matter satellites we hope to use our understanding to constrain the properties of dark matter.

Keywords. Galaxy: halo, Galaxy: structure, Galaxy: kinematics and dynamics

1. Introduction & Motivation

In ΛCDM we expect Milky Way-like galaxies to host thousands of dark satellites (Springel *et al.* 2008). We are interested in using stellar streams as probes of these dark satellites. An interaction between a dark satellite and a stellar stream will leave in the latter a visible imprint in the form of a gap. By modeling the full 6D properties of the gap we hope to be able to derive the properties of the dark matter satellite that created the gap. The work presented here builds on Helmi & Koppelman (2016), now for streams orbiting in a more realistic (Stäckel) Galactic potential including a disk and a halo component. We focus here on the evolution of the size of a gap and of its density.

2. Modeling the size and density

The size of the gap is modeled analytically as a separation of two orbits, A&B, in phase-space ($\Delta\boldsymbol{X} = \boldsymbol{x}_A - \boldsymbol{x}_B, \Delta\boldsymbol{V} = \boldsymbol{v}_A - \boldsymbol{v}_B$). Their initial separation ($\Delta\boldsymbol{X}_0, \Delta\boldsymbol{V}_0$) reflects the impulse received during the encounter with the subhalo (Erkal & Belokurov, 2015a,b), and can be transformed to action-angle space $[\boldsymbol{\Theta}_0, \boldsymbol{J}_0] = M_0[\Delta\boldsymbol{X}_0, \Delta\boldsymbol{V}_0]$ where $M_0 = \partial(\Theta, J)/\partial(X, V)$. In action-angle space the evolution in time is simple, which allows us to derive at each time step the separation vector in Cartesian coordinates locally using the matrix M_t^{-1}. The result of this procedure allows us to follow the evolution of the gap size for different halo masses, as is shown in the left panel of Fig.1 where it is compared to N-body simulations.

To model the density of stars in a gap we describe their distribution as a Gaussian in 6D $f(\boldsymbol{x}, \boldsymbol{v})$, inspired by the work of Helmi & White (1999). Using the same procedure as before we may obtain the distribution as a function of time: $f(\boldsymbol{x}_0, \boldsymbol{v}_0) \xrightarrow{M_0} f(\boldsymbol{\Theta}_0, \boldsymbol{J}_0) \rightarrow f(\boldsymbol{\Theta}_t, \boldsymbol{J}_t) \xrightarrow{M_t^{-1}} f(\boldsymbol{x}_t, \boldsymbol{v}_t)$. If we integrate the distribution function over the velocities we obtain the density of the stars in the gap: $\int f(\boldsymbol{x}, \boldsymbol{v})\, \mathrm{d}\boldsymbol{v} = \rho(\boldsymbol{x})$. At late times ($t > t_0$) we find that the density behaves as t^{-3} for the axisymmetric Milky Way-like potential, as shown in the right panel of Fig. 1. Again we find excellent agreement with the N-body simulations.

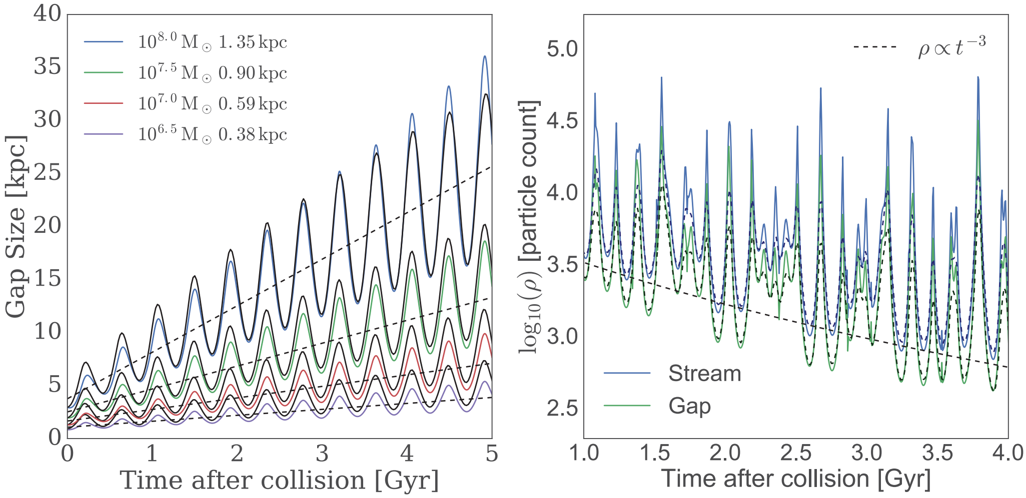

Figure 1. Left: Size of gaps growing in tidal streams. The colored lines show the predicted sizes from our model, the solid black lines show those measured in N-body experiments. The fitted dashed lines show the linear rate of growth of the size of the gap with time for these experiments run in a realistic (axisymmetric) Galactic potential. Right: Time evolution of the density of a gap in a stream. The solid lines show the density calculated from our model, the corresponding dashed lines show the behavior as measured in N-body experiments. The top lines, dashed and solid, correspond to an unperturbed stream, the bottom lines show the density of a stream with a gap. The average $\rho \propto t^{-3}$ behavior is shown with a black dashed line.

3. Results & Conclusions

We find that gap sizes grow linearly with time, both for spherical (Helmi & Koppelman, 2016) and axisymmetric potentials. However, for the latter, the density of stars in the gap decreases more quickly, as t^{-3}. The evolution of both size and density depend on the parameters of the impact: the subhalo mass and size, and the relative velocity of the stream and the subhalo. Although there are degeneracies between these impact parameters, we find that the lowest gap densities can in general only be reached via encounters of the most massive subhalos.

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