The Galactic strudel

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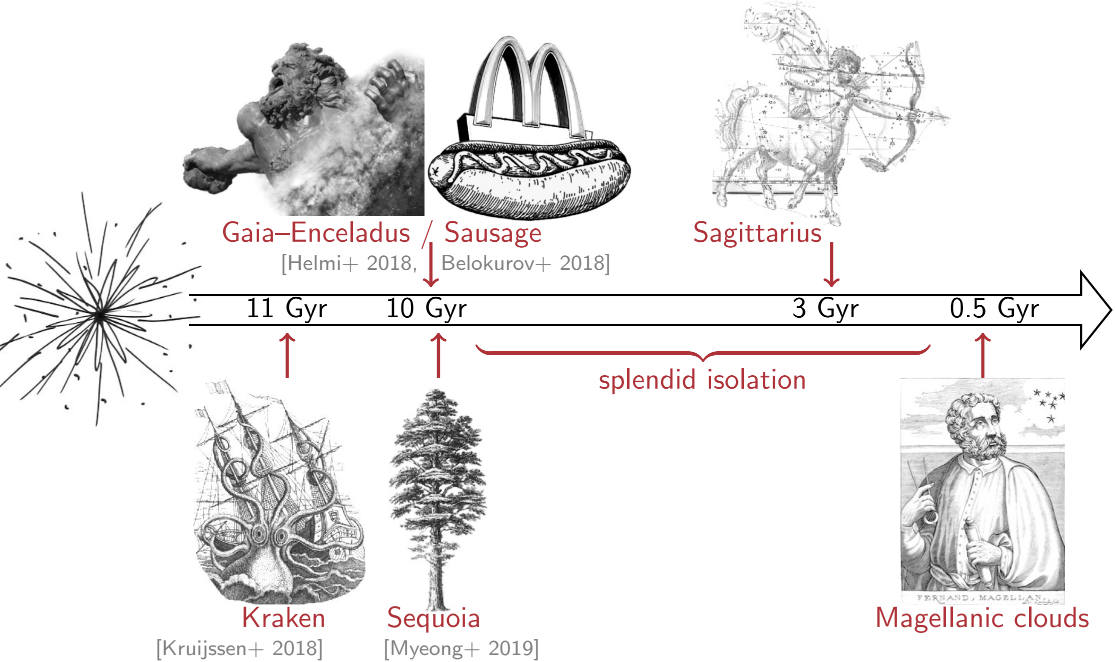
[2110.01060] Dong-Páez et al.

[2208.11135] Belokurov et al.

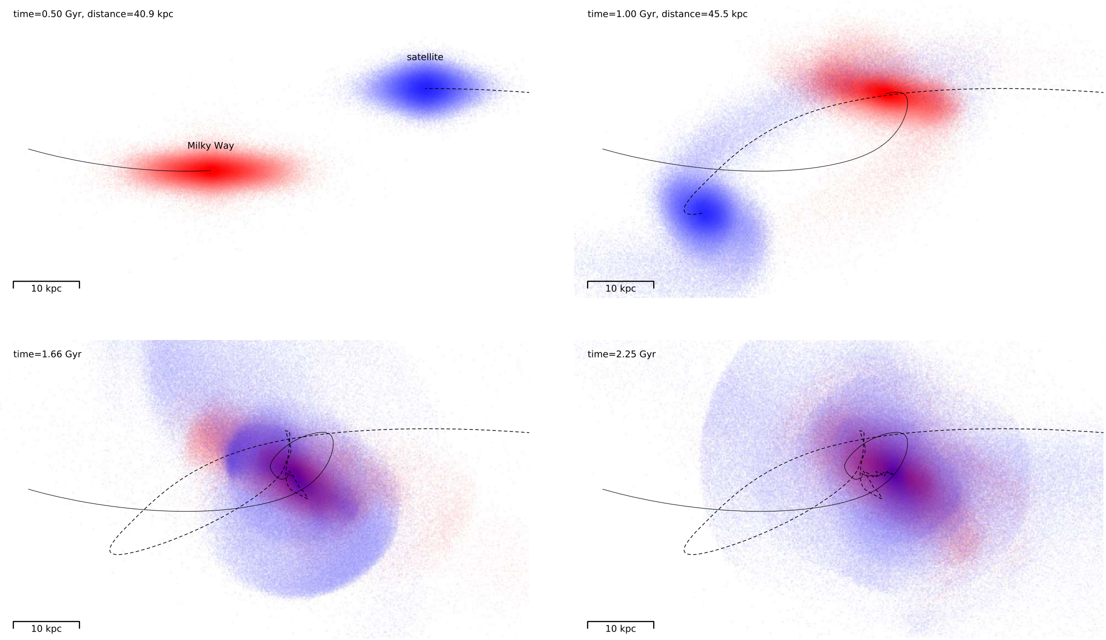
[2210.05679] Davies et al.

[Kandinsky 1923]

A brief history of the Milky Way



Formation of shells in eccentric mergers



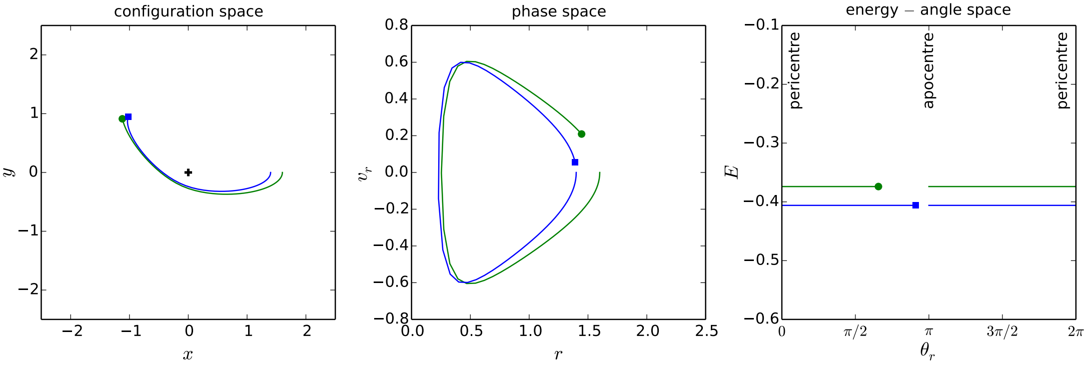
Shells in external galaxies

NGC 474 [credit: P.-A.Duc, J.-C.Cuillandre]

NGC 7600 [credit: K.Crawford]

Evolution of tidal debris

- stars from the disrupted satellite span a range of energies in the host potential
- each star travels on a closed loop in the $r - v_r$ phase space, or on a straight horizontal stripe in the $E - \theta_r$ space
- orbital period is shorter for more tightly bound stars, so they travel faster through these spaces



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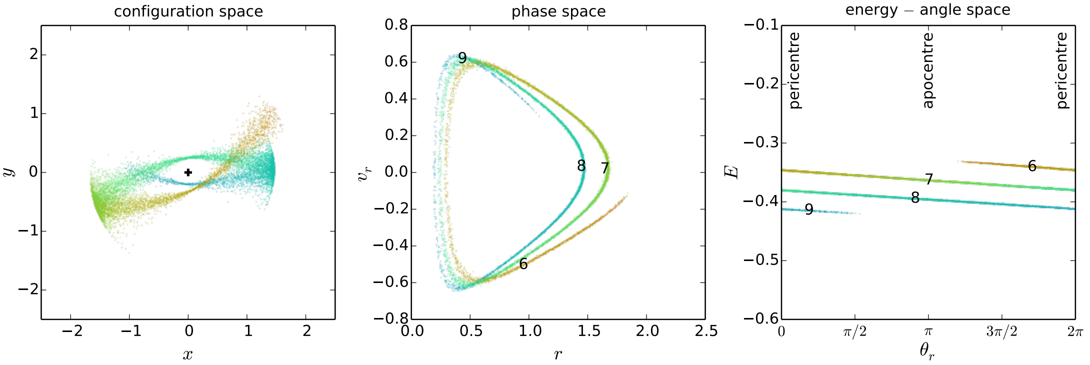
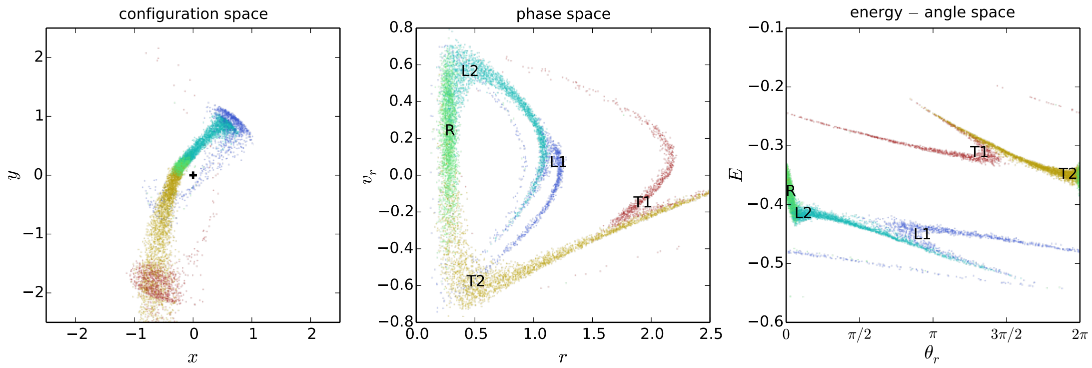
- orbital period is shorter for more tightly bound stars, so they travel faster through these spaces
- the number of folds in the $r - v_r$ space or stripes in the $E - \theta_r$ space increases with time



Gradual tidal stripping of a massive satellite

- usually a satellite is not abruptly disrupted but gradually stripped
- stars in the leading arm have lower energies than in the trailing arm
- each stripping episode thus produces two series of folds / shells / stripes
- these shells eventually overlap in all spaces!



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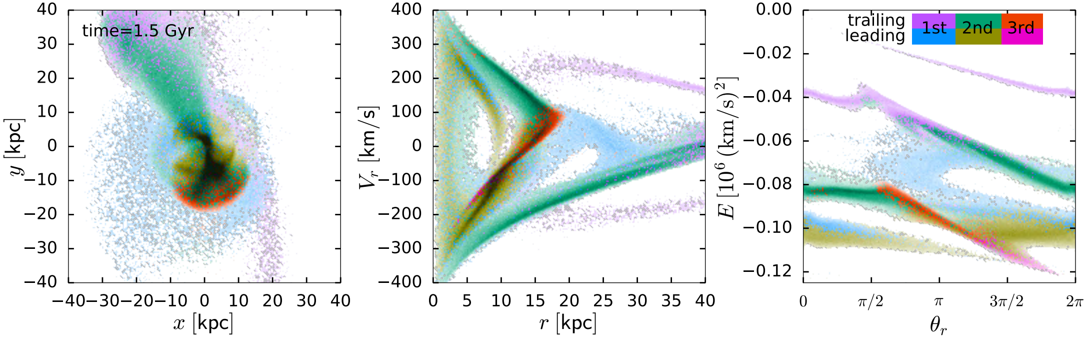

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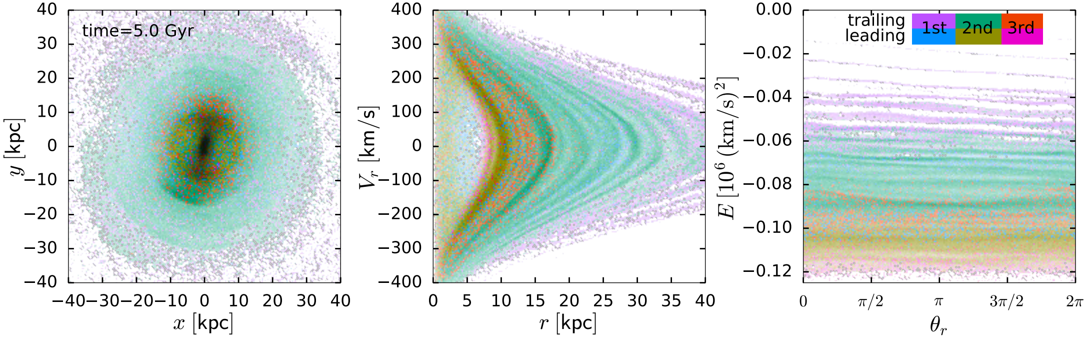

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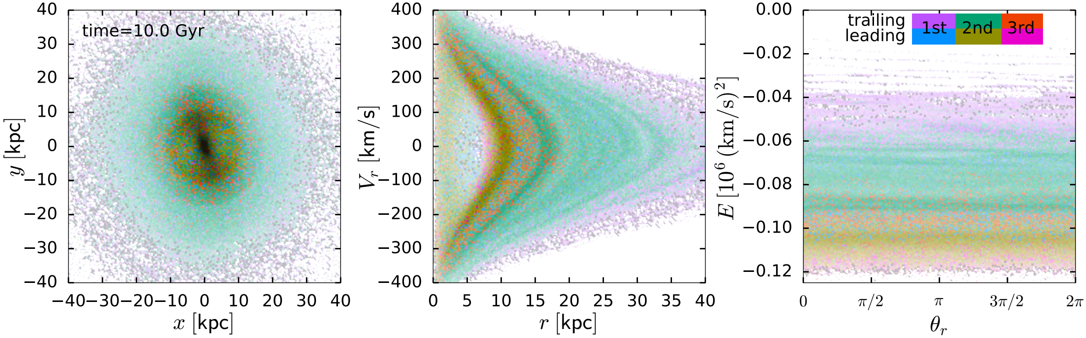
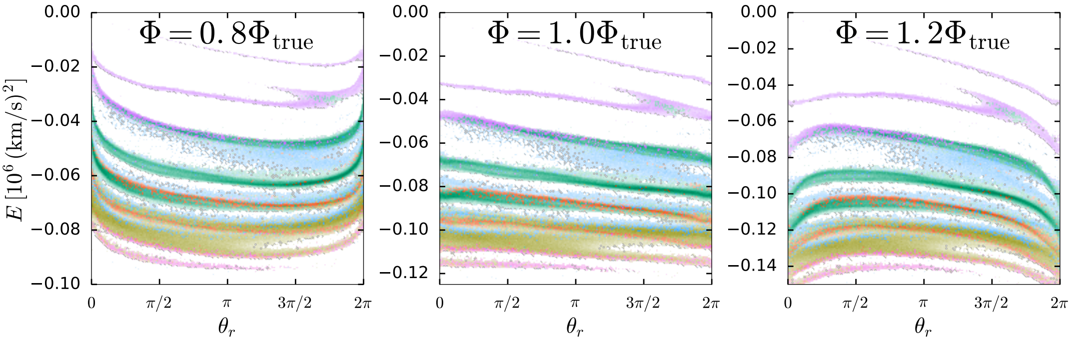


Using shells to constrain the host galaxy potential

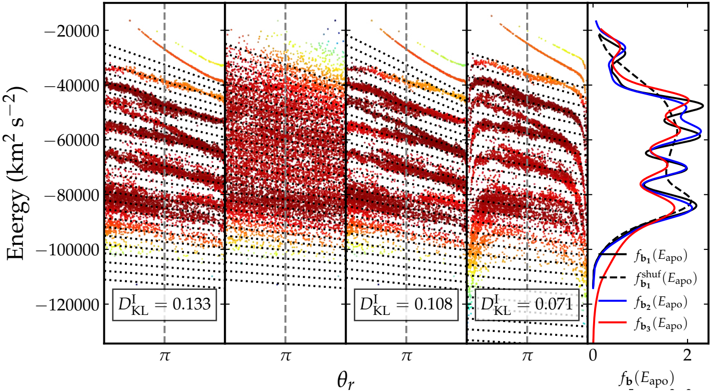
- folds in the $r - v_r$ space are independent of the potential, but stripes in $E - \theta_r$ space do depend on Φ, so may be used as a tool for constraining the potential [Dong-Páez+ 2022]
- if the potential is too shallow, the total energy $\Phi(r) + \frac{1}{2}v^2$ is higher at the pericentre, so the stripes curve up instead of being straight, and conversely if the potential is too deep, they curve down
- the correct choice of potential should maximize the straightness of stripes



Using shells to constrain the host galaxy potential

to measure the straightness of stripes, we use the following procedure:

- determine the expected slope of the stripes (depends on the number of wraps)
- project the distribution in the $E - \theta_r$ space along these slanted lines
- construct a "reference" background distribution by shuffling particles in θ_r and project it along the same lines
- compute the Kullback–Leibler divergence between the two 1d distributions



the correct potential maximizes the contrast (i.e. KLD)

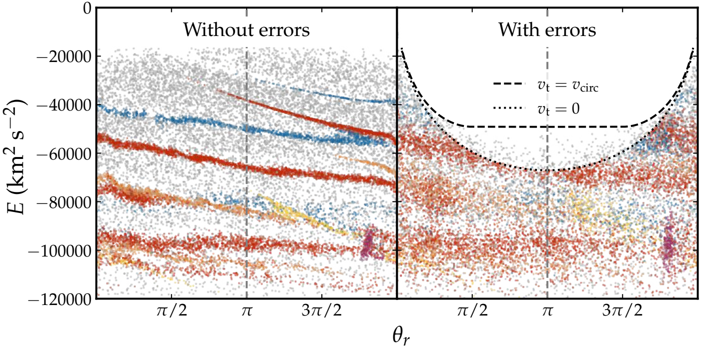
[Dong-Páez+ 2022]

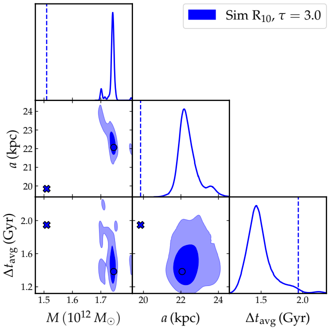
Using shells to constrain the host galaxy potential

practical challenges:

- the expected slope depends on the time since the formation of shells
- contrast is diluted by the smooth halo population
- observational errors blur the narrow stripes in energy
- limited survey volume imposes cuts in the $E - \theta_r$ space near apocentre

even with these caveats, the potential can be recovered to within 10-20%

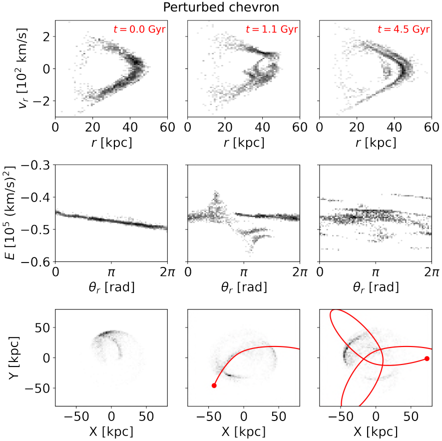




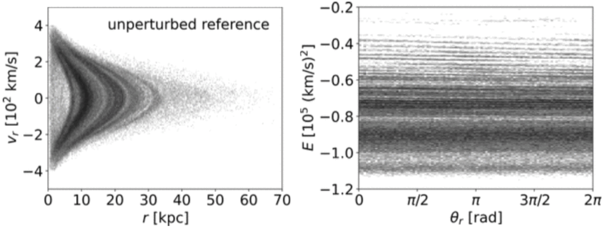
[Dong-Páez+ 2022]

Phase-space folds as the subhalo detector

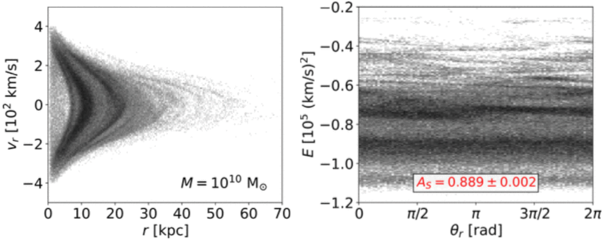
flybys of massive satellites or sub-haloes inflict perturbations on kinematically cold structures such as streams [e.g., Erkal & Belokurov 2015; Sanders+ 2016; Dillamore+ 2022] and shells [Davies+ 2022].



accreted halo population in a MW-like simulation



after repeated perturbation by a $10^{10}\ M_\odot$ subhalo

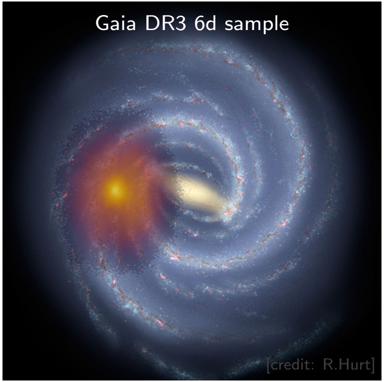


[Davies+ 2022]

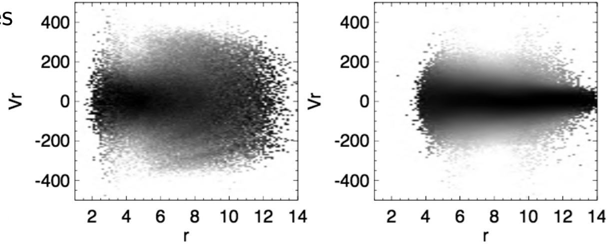
Phase-space folds in the Milky Way

Gaia DR3 (June 2022):
$\sim 26\times10^6$ stars with parallax precision $\varpi/\epsilon_\varpi > 10$ and line-of-sight velocities (99% within 5 kpc from the Sun):

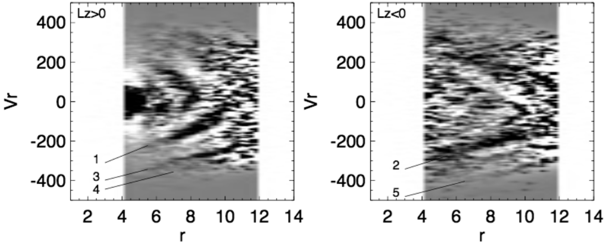
selecting high-eccentricity stars (accreted halo) reveals the folds



$|L_z| < 500\,\mathrm{kpc\,km/s}$ $\quad$ $L_z > 1000\,\mathrm{kpc\,km/s}$



$|L_z| < 850\,\mathrm{kpc\,km/s}$, after unsharp masking



[Belokurov+ 2022]


Kupka