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WHAT WE CAN LEARN FROM TIDAL TAILS

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We show, with our numerical simulations of dwarf galaxies, orbiting the Milky Way, that over-densities in tidal tails are a natural outcome of their formation process. We analyse the short-falls of the published analytical predictions and show which parameters can be deduced from measuring the tidal tails.

Whenever a small object orbits inside (at distance d) the potential of a larger object, e.g., a dwarf galaxy inside the halo of the Milky Way (MW), the region in which the self-gravity of the small object dominates is truncated at the equipotential surface, also known as Jacobi radius or tidal radius ($r_{\rm J}$):

$$r_{\rm J} = \left(\frac{m_{\rm dwarf}}{3M_{\rm MW}(d)}\right)^{1/3} d. \qquad (1)$$

Stars of the smaller object can gain sufficient kinetic energy by various processes (e.g. two-body relaxation, tidal shocks, etc.) and are able to leave their host through the Lagrangian points L1 and L2. These stars are not left behind but are now orbiting the MW themselves on very similar orbits than the dwarf. Stars leaving through L1 are closer to the centre of the MW and are somewhat faster, building with time the leading arm of the tails. The opposite is true for L2 and the trailing arm. To describe the orbits of the lost stars we can use the epicyclic theory (see Kuepper et al. 2010, 2012):

$$x = \frac{4\Omega^2}{\kappa^2} r_{\rm J} + \left(1 - \frac{4\Omega^2}{\kappa^2}\right) r_{\rm J} \cos \kappa t \qquad (2)$$

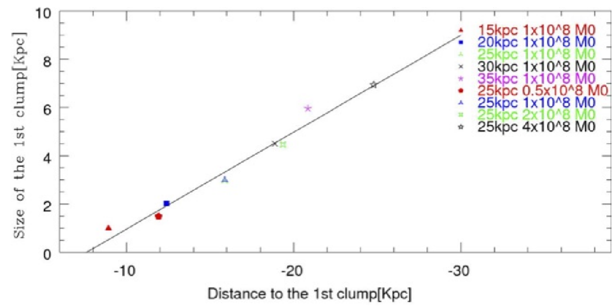
$$y = -\frac{2\Omega}{\kappa} \left(1 - \frac{4\Omega^2}{\kappa^2}\right) r_{\rm J} (\sin \kappa t - \kappa t). \qquad (3)$$

This theory predicts that we obtain over-densities in the tails at certain turn-around points ($y_{\rm c}$) forming after a time ($t_{\rm c}$):

$$y_{\rm c} = -\frac{4\pi\Omega}{\kappa} \left(1 - \frac{4\Omega^2}{\kappa^2}\right) r_{\rm J} \qquad (4)$$

$$t_{\rm c} = \frac{2\pi}{\kappa}. \qquad (5)$$

As these quantities depend on the mass of the object ($m_{\rm dwarf}$ via $r_{\rm J}$) as well as the properties of the MW halo (Ω: angular speed, κ: epicyclic frequency) we might be able to constrain the mass distribution of the MW by investigating the tidal tails of orbiting objects (like Pal 5; Odenkirchen et al. 2003).



S = −0.401396 D −3.04852

Fig. 1. Connection between size of the first over-density (S) and its distance to the object (D).

Our results show that the theory (Eqs. 4 & 5) is a good approximation for the formation time of the over-densities but is under-predicting the locations by a factor of 1.5 for the leading and 2.0 for the trailing arm. We further determine that the growth of the tails depend only on the mass of the satellite in the case of circular orbits and unluckily also on the eccentricity of the orbit. The distance of the first over-density to the object is depending on the mass of the object and the properties of the MW halo, so we try to disentangle the internal and external effects by also determining the size of the over-density, hoping for different dependencies, but the answer is, unluckily again, that the results are degenerate between the mass of the object and the properties of the MW halo at the chosen orbit (see Fig. 1).

Help could come in the future, if we know more about the initial properties of the satellites or if we could observe a large sample of similar objects.

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