Identifying substructure through orbital frequencies

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Abstract

We show that the space of orbital frequencies are very suitable to recover debris from accretion events. In this space individual streams can be easily identified, and their separation provides a direct measurement of the time of accretion. These features are preserved even in systems where the gravitational potential has (strongly) evolved in time.

Phase space and a time-independent potential

We simulate the evolution of a non self-gravitating satellite in a fixed potential (see Fig. 1). Our goal is to find the most suitable space to identify the debris from this event.

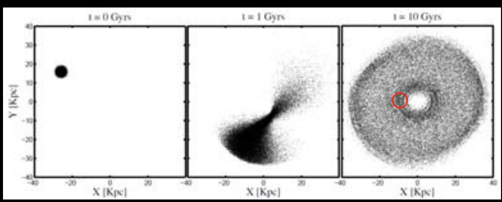

Figure 1.

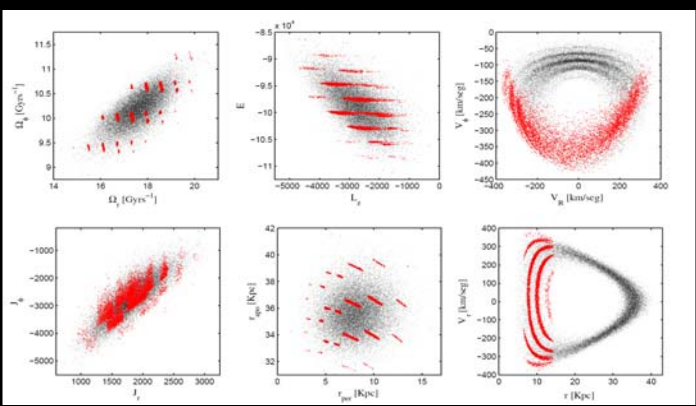

Figure 2. Comparison among different "integrals of motion" of spaces. Black dots represent all the accreted particles whereas red dots particles inside a sphere of 4 kpc radius at a distance of 10 kpc from the centre. The top left panel shows the distribution in frequency space. Particles are distributed in patches, each of them associated to a different stream. The network of patches can be characterized by lines of constant frequency. Note that in the other spaces, streams are not as well defined and are less easy to distinguish from one another.

The number of streams N at a given frequency Ω_ϕ is given by $N = \Delta\Omega_r t / 2\pi$, where $\Delta\Omega_r$ represents the extent of the system. The distance between two adjoin streams in frequency space depends only on the time elapsed since accretion: $\delta\Omega_r = \Delta\Omega_r / N = 2\pi / t$.

This quantity can be easily computed from the Fourier transform of the particle's distribution in frequency space (Fig 3).

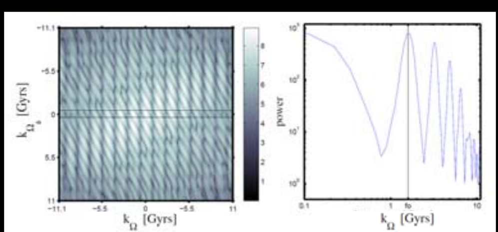

Figure 3: The region delimited by the black lines in the left panel is used to compute the 1D power spectrum, and corresponds to the wave number $k_{\Omega_\phi} = 0$, i.e. we consider only waves along the Ω_r direction. In the right panel the spectrum is shown. The location of the highest peak corresponds to a wavenumber $f_0 = 10/2\pi$ Gyrs $= 1/\delta\Omega_r$. The following peaks are the harmonics of f_0, i.e., $2f_0$, $3f_0$, etc.

Time-dependent potential

To test the effect of time-evolution onto the coherence of streams in frequency space, we model the accretion of a non self-gravitating satellite into a potential whose mass grows as $M(t) = M_0 \exp(t/t_{scale})$ with a t_{scale} of 3.3 Gyrs. This satellite's orbit is shown in Fig 4. Below we focus on particles in a small volume (as in the fixed potential case). To compute the frequencies we consider the instantaneous potential..

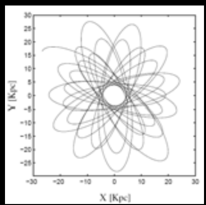

Figure 4.

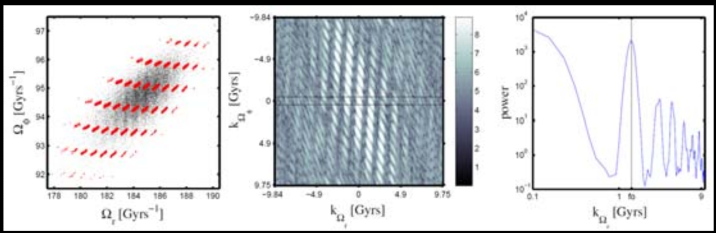

Figure 5. On the left panel we show with red dots the particle's distribution in frequencies space inside the solar neighborhood sphere after 10 Gyrs of evolution. Black dots are all the particles on the system. Streams are still very well defined in this space, but in comparison to the static case, there are many more of these. Note also that streams are distributed around lines with some small curvature, which is due to the (initial) finite extent of the system in frequency space.

In the middle panel we show the Fourier transform of the stream's distribution in frequency space. The black lines indicate the cut around $k_{\Omega_\phi} = 0$ taken to compute the power spectrum shown on the right panel. Its highest peak is denoted by the black line and correspond to a wavenumber $f_0 = 8.78/2\pi$ Gyrs which implies a time since accretion of 8.78 Gyrs, which is reasonably close to the true value...

Live potential

We have also tested the validity of the frequency space in a simulation of the accretion of a satellite galaxy into a host composed by a live disk and dark halo.

In Fig. 6 we show the stellar particles inside a solar neighborhood sphere of 4 kpc radius. Red dots represent disk particles whereas black dots satellite particles. Note that even in a live potential the space of frequencies is rich in (regular) substructure, which is associated to the streams going through this volume.

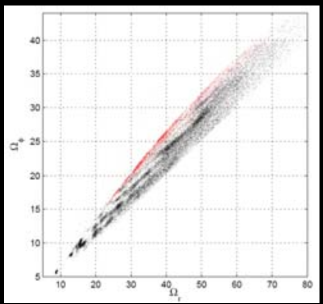

Figure 6.