Modelling the Milky Way - Dalia Chakrabarty

1 Motivation and Context

Why are galaxies stable? In astronomy, the notion of relaxation of a collisionless, multi-particle system, such as a galaxy, is often thought to be resulting solely from regular orbits going chaotic when affected by non-linearities in the potential, though such a model is not generally successful. The wider aim of this project is to test for the efficiency of this model based on regular orbits, as distinguished from stochasticity in rapidly changing potential - in our own galaxy. A useful corollary of such a pursuit is the estimation of important Milky Way parameters. From the methodological standpoint, this project will offer a template that can be used to analyse current and upcoming (the planned flight of GAIA in 2012, a mission of the European Space Agency), large data sets from any part of the Milky Way, towards better galactic models.

Consensus exists over the multi-modal and non-linear distribution of probability mass in the phase space W of the disk of the Milky Way (MW) in the neighbourhood of the Sun. The evolution of a sample of stellar orbits in the gravitational potential of MW has been reported to be non-linear, with the prevalence of strong to weak chaos quantified (Chakrabarty & Sideris 2008). The pursuit of a model of the time-dependent, non-axisymmetric perturbations, responsible for such a non-linear Galactic potential, given the solar neighbourhood data, is an interesting exercise, involving an expansive parameter space.

2 Background

In Chakrabarty (2007), a 2-perturber model for the MW potential was used to make inference on the location $\mathbf{s}$ of the observer, i.e. the Sun, while the ratio Ω of the frequency of rotation of the 2 perturbations, along with the other parameters of the perturbers were treated as fixed, input parameters. Ω crucially affects the degree of non-linearity in the solar neighbourhood. 2-D velocity data ($\mathcal{D}$) of observed stars in the neighbourhood of the Sun (available in the lietarture) have helped construct the *pdf* of the local velocity space V; this is found to be highly non-linear and multimodal. Evolution of a sample of phase space coordinates, in this model MW potential is carried out. Orbits that end up at different locations in the Milky Way disk are used to estimate a probability density $\nu_{ij}(v_1, v_2)$ in V, using a bivariate kernel density estimation. Chakrabarty (2007) tested for the hypothesis that $\mathcal{D} \sim \nu_{ij}(v_1, v_2)$. The locations at which the support in the data for this null is maximal (as quantified by the p-value of the test at that location), are used to advance an interval estimate for the solar position. Quantification of strong and weak chaos in these models of the Milky Way was performed by Chakrabarty & Sideris (2008). Strong chaos was identified in all models - both marked by and not by resonance overlap - as long as these models included the perturbing potential characterised by a high gradient.

3 Proposed project

We will recognise the importance of treating Ω as a model parameter that we can make inference on, given the observed data which has now improved to a larger sample of 3-D velocity data ($\mathcal{D}_{new}$). We will identify an empirical relation between Ω and the strength of chaos in models of the solar neighbourhood, with the aim of understanding the wider issue of relaxation in galaxies as discussed in Section 2.

In order to achieve this, we will proceed as in Chakrabarty (2007), except

- both $\mathbf{s}$ and Ω will be model parameters (ψ); the dimensionality of the function space will be higher.
- the multimodality and non-linear manifest by the estimated *pdf*s motivate a non-parametric density estimation over the kernel density estimate.
- a robust affinity measure between the velocity space *pdf*s estimated from simulated and observed data will be employed as an improvement over the Kullbeck-Leibler divergence employed by Chakrabarty (2007).

If time permits, chaos quantification in the best-fitting models will be pursued.

4 Prospects & Possibility of developing into a Ph.D problem

The immediate aim is to identify the range of Ω that explains the current data, while advancing to the community of galactic astronomers, a template for analysing observations (along with measurement uncertainties) in any part of the

MW, with the aim of producing a dynamical model for the Galaxy. As such data is envisaged to hit the stands, with the upcoming flight of GAIA (2012), this project would be high-impact. An independent result, important for the exploration of the relaxation of the MW, would be the issue of the importance of chaotic mixing. The wider aim is to link this project to the ongoing complimentary collaboration with statisticians to develop an integrated, Bayesian methodology to model the solar neighbourhood data.

It is possible that this project be taken forward into a Ph.D problem involving stochastic processes in systems that manifest complexity. The modelling techniques explored herein would be ideally suited to study galactic phase space structure in the presence of multistabile gravitational potentials of distant galaxies and model the relaxation time of such systems.

5 Requirements

The project will require moderately high computational skills - the current algorithm is written in C++. In addition to programming skills, the students will be working on a non-parametric density estimation technique and the exploration of distance measures between probability densities. A general familiarity with non-linear dynamics will help, especially, if time is left to undertake chaos quantification.