Scientific report

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1 PURPOSE OF THE VISIT

At ETH Zurich, they are currently building a model for the merger history of the Milky Way. This builds on previous work published in Read et al. (2008) and Read et al. (2009). The Zurich model is derived by fitting merger simulations to SDSS data from $\sim$1 kpc to $\sim$6 kpc above the Galactic plane (Liu et al. 2010, in prep.). Daniel Adén has a wide range of data for the Milky Way thick disc and stellar halo from sight lines to dwarf galaxies. In this proposed project, Daniel will confront the Zurich numerical model with this new data set. If the same mergers that match photometric SDSS data also match Daniel's data, then this builds further confidence in the model. Daniel's data will also allow us to constrain the kinematics and chemistry of these accreted stellar discs.

The project has two key goals:

(i) Constraining the merger history of our Galaxy; and
(ii) Determining whether or not the Milky Way has one or several accreted discs of stars.

This latter point is a natural prediction of our current cosmological model. But it is also interesting because it would imply that our Galaxy also has an accreted disc of dark matter (Read et al. 2008). This 'dark disc' has wide implications for experiments designed to detect dark matter in the laboratory (Bruch et al. 2008, 2009).

Daniel will learn how to work with and manipulate numerical simulation data. He will also run additional simulations to test how sensitive results are to the orbit, mass ratio and number of satellite mergers impacting the Milky Way disc. This work will provide Daniel will a valuable skill-set to complement his observational work. He will be working with and learning from leaders in the field of computational astrophysics. At the ETH he will work directly with the new SNF professor Justin Read, but will also benefit from the broad expertise available in Zurich: Prof. Lucio Mayer and Dr Francesco Miniati at the ETH; and Prof. Ben Moore, Prof. George Lake and Dr Joachim Stadel at the University of Zurich.

The ETH Zurich will similarly benefit from Daniel's expertise. Daniel is now an expert in resolved stellar populations and spectroscopy. He has priority access to several large data sets for the Milky Way and its surrounding satellites. This provides a unique resource with which to constrain the numerical simulations. Ultimately, this collaboration will help us to unravel the merger history of our Galaxy. This will give us vital clues as to how galaxies form and evolve in the Universe and place new constraints on a potential 'dark disc' in the Milky Way. These results will help pave the way for a more detailed analysis that will become possible with the advent of the Gaia satellite mission (Perryman et al. 2001; Wilkinson et al. 2005).

2 DESCRIPTION OF THE WORK CARRIED OUT AND RESULTS OBTAINED.

The observational data. Initially, time was mainly spent on analysing the observational data. We established the necessary error cuts to get a clean sample of the observational data, and applied the necessary equations to translate the heliocentric radial velocities to an estimate of the azimuthal streaming velocities (V_ϕ). Following Wyse et al. (2006), we constructed a histogram of V_ϕ. Figure 1b shows the histogram together with the expected kinematics for standard galaxy models. For this expected velocity distribution, we adopted the population (thin and thick disk and halo) characteristics from Wyse et al. (2006), and fraction of the different populations as presented in Gilmore et al. (2002). We note that, as highlighted in Wyse et al. (2006), there is an over abundance of stars with kinematics in the range $60 < V_\phi < 140$. This over abundance is believed to be debris from a merging dwarf galaxy.

A method for finding trends/components. The strength of the observational data that we have worked with is that in addition to the estimate of V_ϕ, we also have an estimate of [Fe/H] for each star. Given that the distribution of [Fe/H] is different for the Milky Way disk components, henceforth we focus our investigation to the [Fe/H] vs. V_ϕ parameter space. In Fig. 1a we show [Fe/H], as determined from photometry, vs. V_ϕ. Obviously, isolating components, such as a thin disk or halo, in this sample is very difficult. This since the distributions of [Fe/H] and V_ϕ in the Milky Way components over-

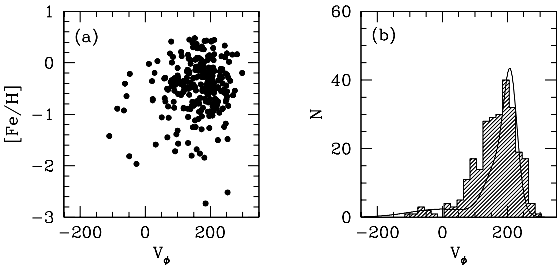

Figure 1. a) [Fe/H] vs. V_ϕ. **b)** Distribution of V_ϕ. The solid line indicates expected distribution if the contribution from a debris disk is negligible i.e., thin disk, thick disk and halo only.

lap significantly. Based on this we began to develop an algorithm that is able to isolate features, that are difficult to outline using a visual inspection, in two dimensional data. Initially, the algorithm converts the observational data to a smoothed distribution on a grid in parameter space. Key to this smoothing is that each observation point is assigned a Gaussian function with a dispersion that depends on the density near the point i.e., data points in crowded regions will be described by a narrow Gaussian, whilst outliers will be described with a wider Gaussian. In Fig. 2, left hand side, we show the smoothed distribution for our observed data as created using our algorithm (compare Fig. 1a). Next, we construct a model of the observation using a Gaussian function in two dimensions. n number of stars are then drawn from this distribution using the rejection method, where n is the number of elements in the observed distribution. A smoothed distribution map is then created based on these points from the model, and χ^2 between the model and data is calculated. Finally, we iterate the process using a Monte Carlo Markov Chain to find the parameters for the model that best describe the observational data. In Fig. 2, right hand side, we show the result if only one Gaussian is used for the model. We note that the algorithm has successfully found a Gaussian function that agrees with the observation. In the coming weeks, we will implement more Gaussians in the Markov Chain to reveal more components in the observational data. This method will later be applied to the simulated data in order to constrain the different merger scenarios.

Converting a simulation to an observation. During the ETH Zurich visit, we developed the necessary tools that provides us with the data of interest from the simulation. There are mainly three conditions to take into account when selecting data from the simulation: 1) The pointing of the telescope, i.e., the coordinates of the dwarf galaxies relative to the Sun. 2) The area of the wide field camera field of view. 3) The distribution of distances for the observed stars. The Draco and Sextans dwarf spheroidal galaxies are at galactic longitudes ~ 90 and ~ 270 degrees, respectively, and the area of the

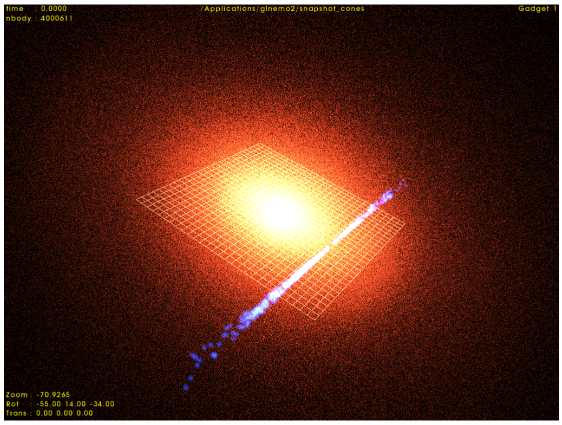

Figure 3. A visualisation of how the stars in the simulation are selected. Blue dots indicate stars selected to represent an observation. Orange/Yellow dots indicate dark matter from the simulation. The grid is positioned in the XY-plane and each grid cell is 1 kpc across. The aim of the cones corresponds to the location of the Draco and Sextans dSph galaxies in the Milky Way.

observations is about 0.282 degrees squared. Thus, initially, two cones were defined and stars from the simulation in those cones were selected. However, given the moderate resolution of the simulation, we found that one location in the disk were not enough to give us a sample with enough elements. Thus, instead of keeping the location of the Sun in the simulated data fixed, we moved the location of the Sun in a circle with radius 8.5 kpc. This gave us a sample size that was comparable to the observed sample. In Fig. 3 we show stars selected for one position of the Sun.

3 PROJECTED PUBLICATIONS/ARTICLES RESULTING OR TO RESULT FROM YOUR GRANT

Given that we now are equipped with the necessary tools for the extraction of the data from the simulation, and the algorithm that will identify trends in both the observed and simulated data, a new simulation that incorporates the effect of gas will be enough for a very interesting article. Additionally, we are confident that our method where we identify trends/components in two dimensional data will be of great value for other studies as well. During the visit to Zurich, we discussed how it could be used for studies of colour-magnitude diagrams and/or studies of the velocity dispersion profiles for dwarf galaxies. An article that describes the algorithm in detail, and where it could be of use, has therefore been discussed.

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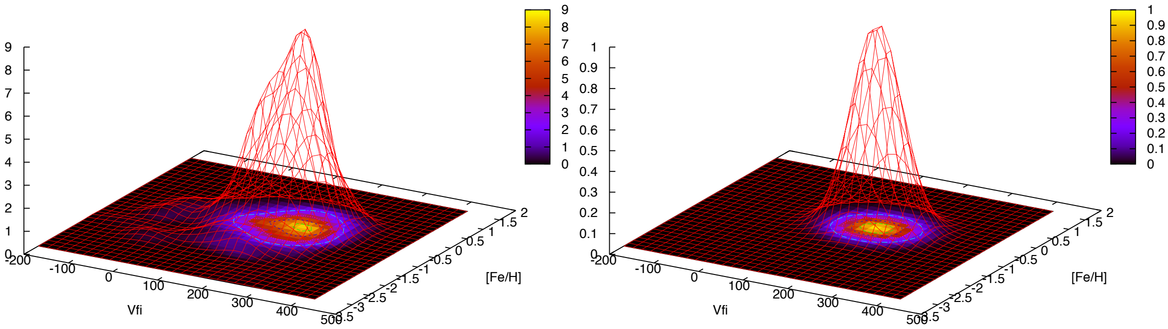

Figure 2. [Fe/H] vs. V_ϕ as constructed using our smoothed density mapping. Left hand side shows the observational data. Right hand side shows the gaussian function as obtained from the Monte Carlo Markov Chain.

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