Final Report for Project:4650

Using High Resolution Simulations to Understand the Signatures of Formation in the Bulge of the Milky Way

Summary

We broke up the project into two visits: One by Melissa Ness (MN) to UCLAN, and the other by Victor Debattista (VD) to the MPIA. These visits took place over the following weeks:

Exchange Period 1	03/01/2014 - 13/01/2014 (2 weeks)	MN to UCLAN
Exchange Period 2	27/10/2014 - 31/10/2014 (1 week)	VD to MPIA

Table 1: GREAT Supported Collaboration

Purpose of the Visit

For this project, we compared observational data of the stars in the Milky Way's bulge from the stellar surveys ARGOS and APOGEE to advanced N-body simulations that are performed by Debattista and his group at the University of Central Lancashire (UCLAN). This work represents the second phase of our collaboration which has already produced a letter that was accepted in June of 2014 (Ness et al., 2014., http://arxiv.org/pdf/1401.0541.pdf).

Description of work carried out during the visit & main results

Our outcomes are 1) we have one published paper from this (Debattista et al., 2015., http://arxiv.org/pdf/1507.0143v1.pdf) and 2) our collaboration is continuing with two papers in preparation with important results from comparisons between the simulations and observations and predictions for new datasets.

These results we have obtained all demonstrate that the observational data is consistent with simulations where the bulge of the Galaxy has formed out of the disk. This is including for observational results that have previously been used to argue for a classical bulge in the Milky Way, formed separately from the disk.

Our papers in preparation will show that:

1. *There is a metallicity dependence of the X-shape in the simulation that is seen in the ARGOS spectroscopic survey Ness et al., 2012 http://arxiv.org/abs/1207.0888)* This is a consequence of stars on x1 orbits that comprise this structure, but depending on their initial phase space, stars are distributed into different orbits that more strongly or more weakly underlie this structure. The simulation does not

quantitatively match the Milky Way but the overall trends in the metallicity dependence are apparent.

2. *The density distribution of stars is a function of their age: different ages show different distributions*. We have compared our simulation used in our accepted letter to the results of (Dekany et al., 2013., http://arxiv.org/abs/1309.5933) , who propose that the old metal-poor stars ([Fe/H] ~ -1.0) are part of a classical bulge component as they are not part of the barred structure. From our analysis, the metal-poor stars show a comparable density distribution to that found by Dekany et al., 2013., (http://arxiv.org/abs/1309.5933) for the old stars (see Figure 1). This challenges their conclusion that density distribution is a signature of a classical component which they propose for their metal-poor stars; from our comparison, this appears to also be produced naturally via internal evolution of the disk.

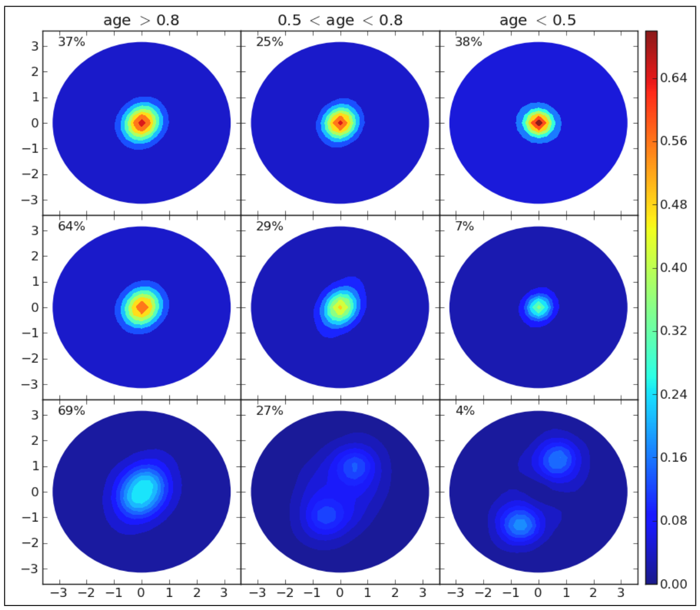

Figure 1: Density distribution of stars at three different heights from the plane: at latitudes at the bulge centre of $|b|<1°$, $1°<|b|<3°$ and $3°<|b|<6°$.

Finally, our published paper (Debattista et al., 2015., http://arxiv.org/pdf/1507.0143v1.pdf) provides an explanation for the high velocity peak seen in the APOGEE data (Nidever et al., 2013 http://arxiv.org/abs/1207.3797) for fields along the plane. The abstract of this paper is provided below:

Gas in the Milky Way is driven inwards by its bar, some of it settling into a disk extending to Galactocentric radius $\sim$ 1.4 kpc. The stellar distribution in this region has not been well understood because of stellar crowding and high extinction. Here we use a high resolution simulation of a barred galaxy, which crucially includes gas and star formation, to guide our interpretation of the Apache Point Observatory Galactic Evolution Experiment (APOGEE) stellar velocity data for the inner Milky Way. We show that the data favor the presence of a thin, rapidly-rotating, nuclear disk extending to $\sim$ 1 kpc. This is the first detection of a nuclear stellar disk in the Milky Way.

Two Figures from this paper are shown. Figure 2 shows the velocity histogram for stars in the plane (red) and stars off the plane (blue). The two component fit to the velocity distribution in the plane is shown in black. The high velocity peak that is seen around $\sim$ 220 kms^{-1} is likely associated with a stellar disk in the plane of the Milky Way. Figure 3 shows our simulation: at left before the disk is formed and at right after the disk has formed. The red lines shows the velocity distribution stars off the plane (to compare with the data off the plane in Figure 2) and the black lines shows the velocity distribution of stars in the plane. The nuclear disk in the simulation comprises a much larger mass than can be inferred from the APOGEE observations, but qualitatively reproduces the observation of a second high velocity peak in the velocity distribution seen in APOGEE data.

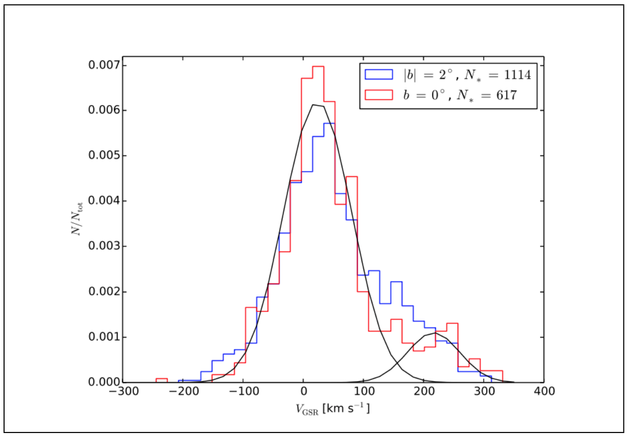

Figure 2: Velocity histograms for APOGEE data.The red histogram is for the fields in the plane, $b < 1^\circ$ and the blue histogram is for fields off the plane $b = 2^\circ$. The black gaussians represent the best two-component fit to the in-plane velocity data.

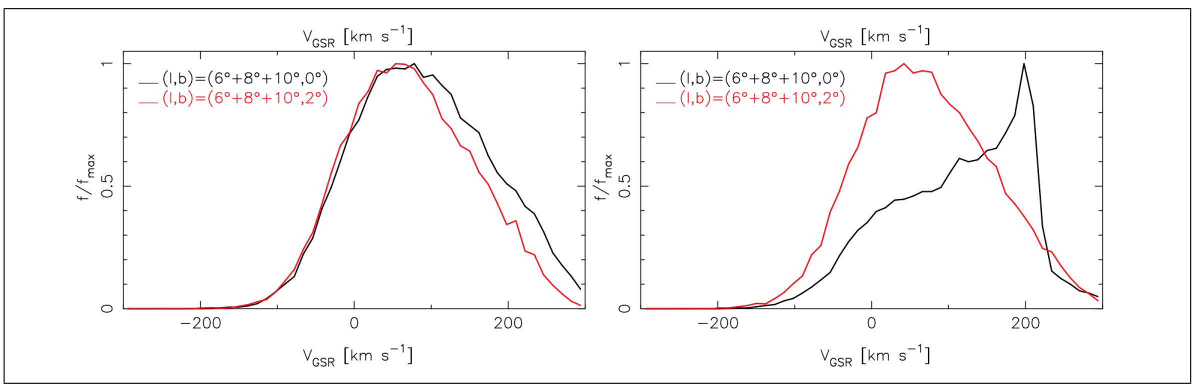

Figure 3: Our simulation, at left, before the nuclear disk had formed and at right after the disk had formed. The black lines are the velocity distributions of stars in the plane and the red lines are the velocity distributions of stars off the plane.

Future Collaboration & Projected Publications

We are currently finalising our next two papers described above and intend to have one of these submitted by the end of 2015.