NEMESIS:
NEAR ENCOUNTERS WITH M-DWARFS FROM AN ENORMOUS SAMPLE & INTEGRATED SIMULATIONS

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Introduction

The latest spectroscopic catalog of M dwarfs identified in the Sloan Digital Sky Survey provides radial velocities, proper motions and distances for nearly 40,000 low-mass stars (West et al., 2011). Using the full 6D phase space coverage and a realistic Galactic potential (Binney & Tremaine, 2008), we calculated orbits for each star in the sample. The sample consists of stars from both the thin and thick disks, and the orbital properties between the two groups are compared. We also examine trends in orbital properties with spectroscopic features, such as molecular bands, that should correlate with age.

Below, we highlight the orbital properties (left panel) of our sample. SDSS M dwarfs are a powerful probe of the thin and thick disk, but also contain halo members. We also see evidence for larger motions in the Galactic radial direction (*R*) than in Galactic height (*Z*). In the right panel, we examine the local kinematic structure, which may show evidence for resonance with the Galactic bar. A possible correlation between metallicity and semi-major axis is is also shown.

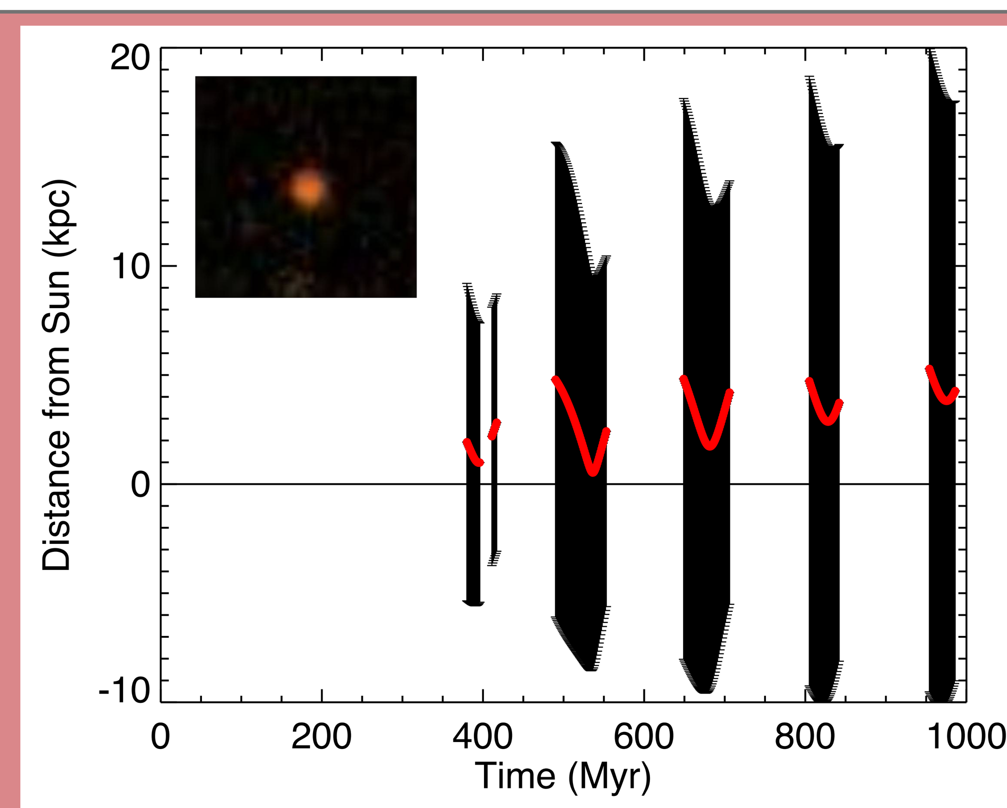

Figure 1 - Distance from the Sun vs. time for a "Nemesis" star (inset). The star encounters the Sun multiple times over the course of the simulation. The distance from the Sun (red points) and uncertainty are plotted for times in the orbit where the distance from the Sun in each coordinate (*xyz*) was less than the uncertainty in that direction.

Nemesis Found?

Within the entire sample, we identified 18 stars with orbits that take them close to the Sun over the lifetime of the simulation. These stars form the "Nemesis" family of orbits (named after the novel by Isaac Asimov). In general, these stars have little or no significant proper motion and radial velocities approaching the Sun.

The absolute distance from the Sun of one star versus time is shown in Figure 1. While the uncertainties in the calculation are large, this star does repeatedly encounter the Sun over the lifetime of the calculation. Any stochastic encounter (i.e., with a spiral wave or large molecular cloud) could perturb the orbit and result in close encounters with Oort cloud and outer solar system. These encounters may have been important in the formation and structure of the Oort Cloud (Kaib & Quinn 2010).

Orbital Properties

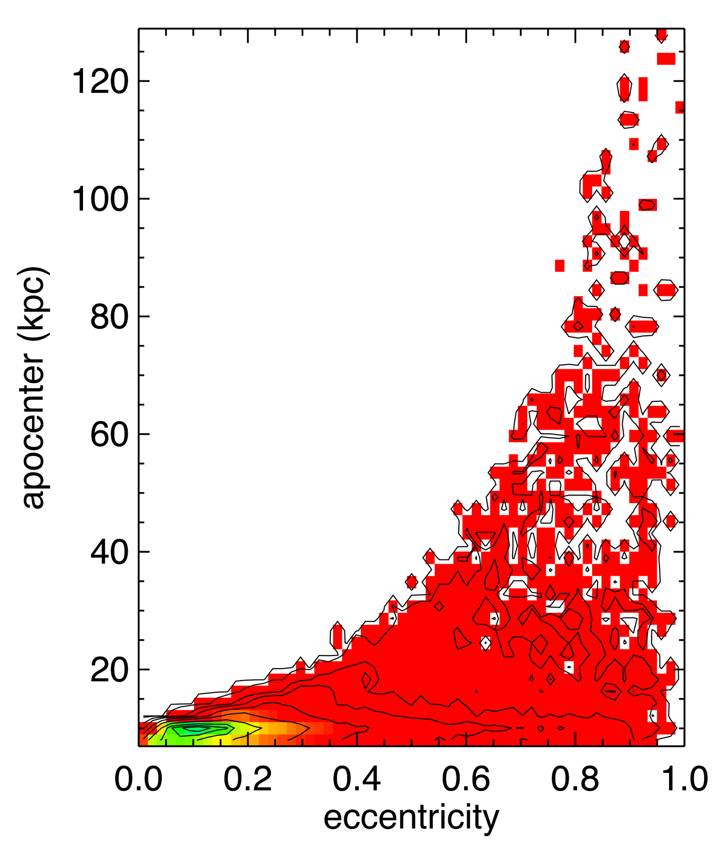

Figure 2 - Galactic apocenter vs. eccentricity. While the majority of stars in the sample follow low eccentricity orbits through the Milky Way, a small fraction of the stars probe distances up to about 80 kpc on highly eccentric orbits. Thus, M dwarfs observed in the local Milky Way can still probe the properties of the Milky Way's halo. The contours in this and all following figure contain 2, 12, 21, 33, 50, 68, 80, 90 and 95% of the stars.

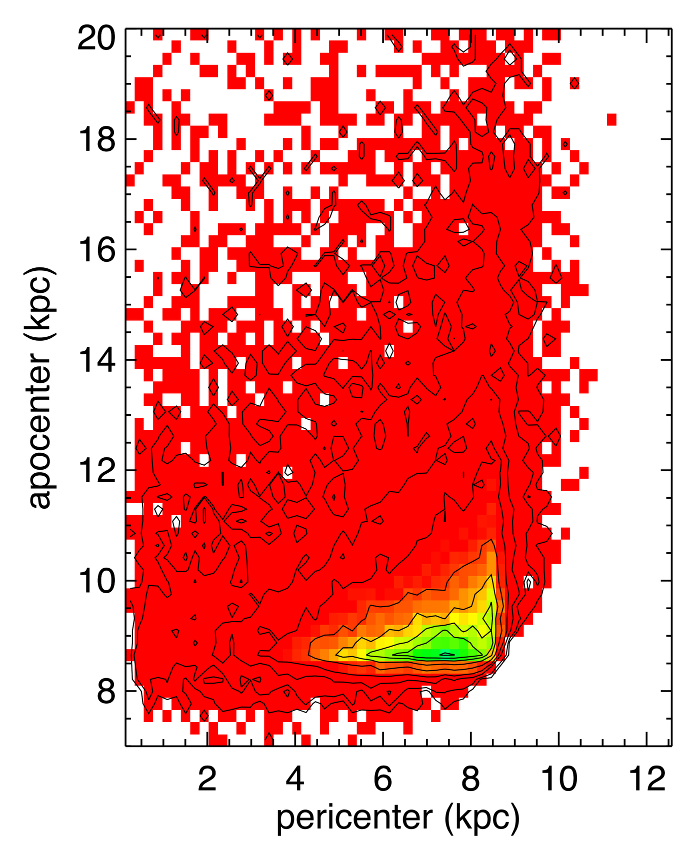

Figure 3 - Galactic apocenter vs. pericenter. Most stars in the sample follow fairly circular orbits, with distances of about 6 - 9 kpc from the Galactic center. However, as seen in Figure 3, there are stars in the SDSS sample that probe the Galactic halo. There are also stars that pass near the Galactic center, with pericenters < 2 kpc and apocenters close to the Solar circle.

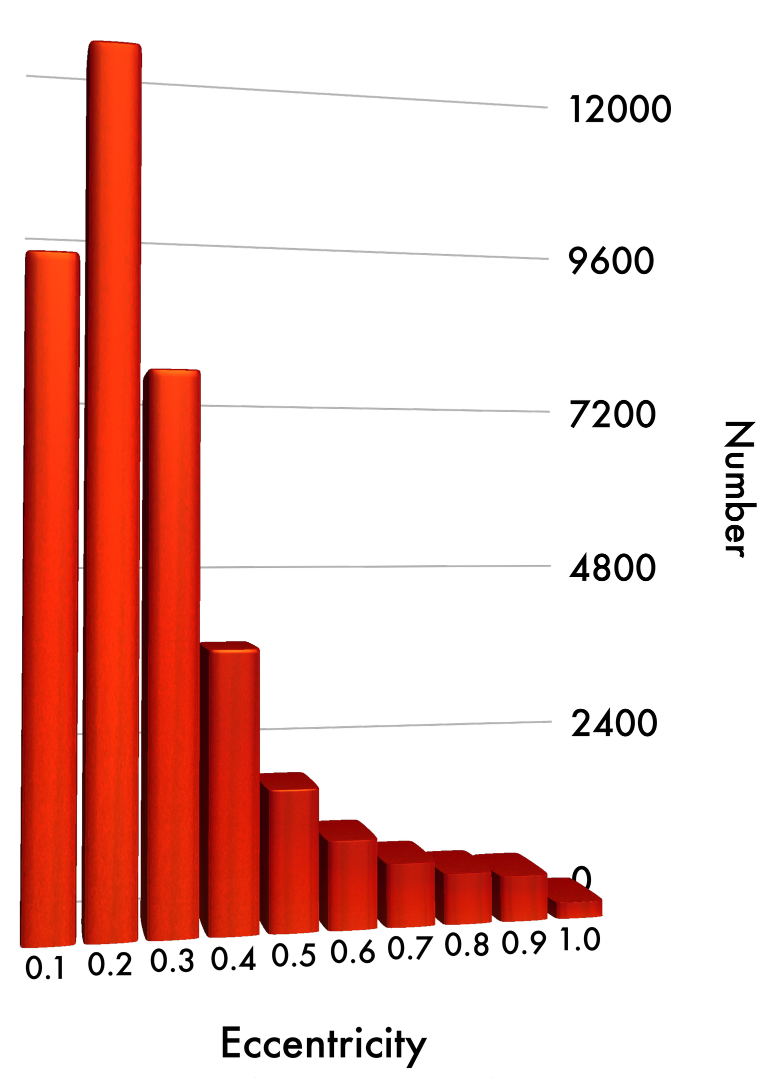

Figure 4 - Histogram of eccentricity for the sample. This distribution may be sensitive to thick disk formation mechanism (Sales et al., 2009). The peak at low eccentricities is suggestive of a migration (Roskar et al., 2008) or merger (Brook et al., 2004, 2005) formation scenario.

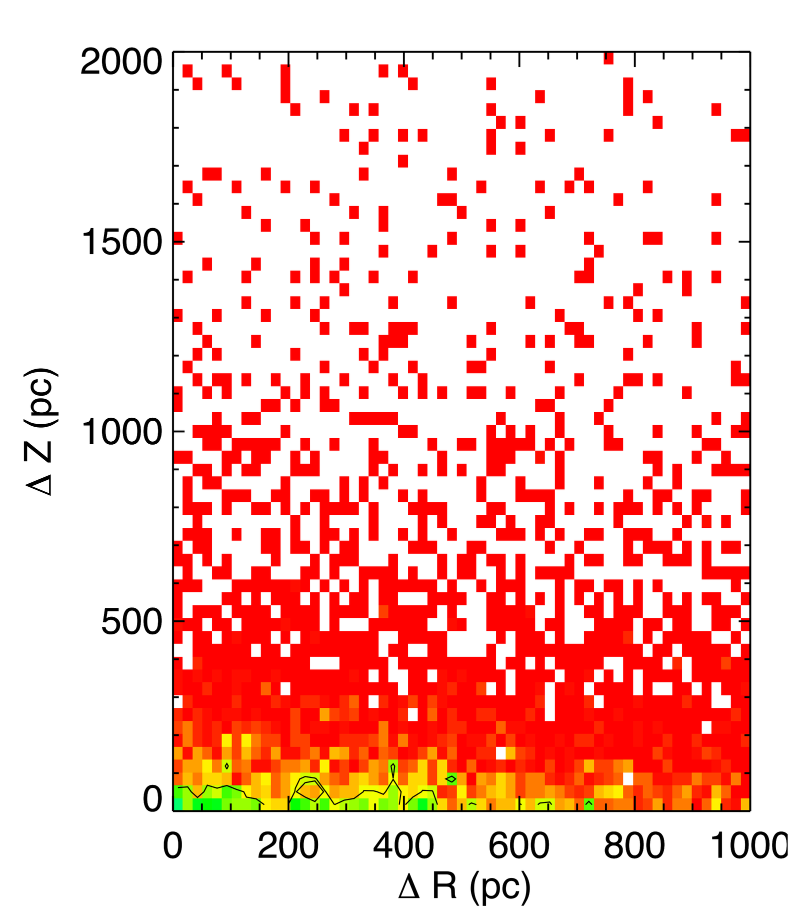

Figure 5 - ΔZ (pc) vs. ΔR (pc). Δ is defined as the absolute difference between the measured Galactic height (or radius) and the average Galactic height (or radius). Most M dwarfs in the sample exhibit larger difference in *R* than in *Z*, suggesting that the measured *Z* is indicative of the average height. The larger values of ΔR are due to the amplitude of epicyclic excursions.

Galactic Kinematics and Metallicity

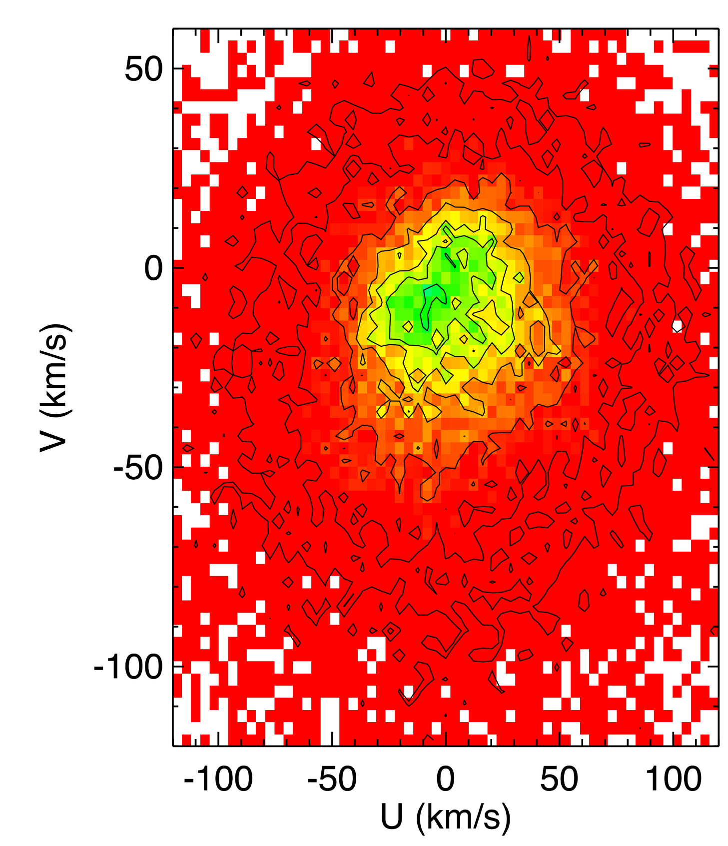

Figure 6 - The *U*,*V* velocity plane for stars with absolute Galactic heights < 250 pc. The larger number of stars with negative *V* velocities is due to the asymmetric drift. The structure of this distribution is sensitive to a resonance with the Galactic bar (i.e., Dehnen 2000). This may contribute to the asymmetry seen in this figure, with more stars seen at negative *U*.

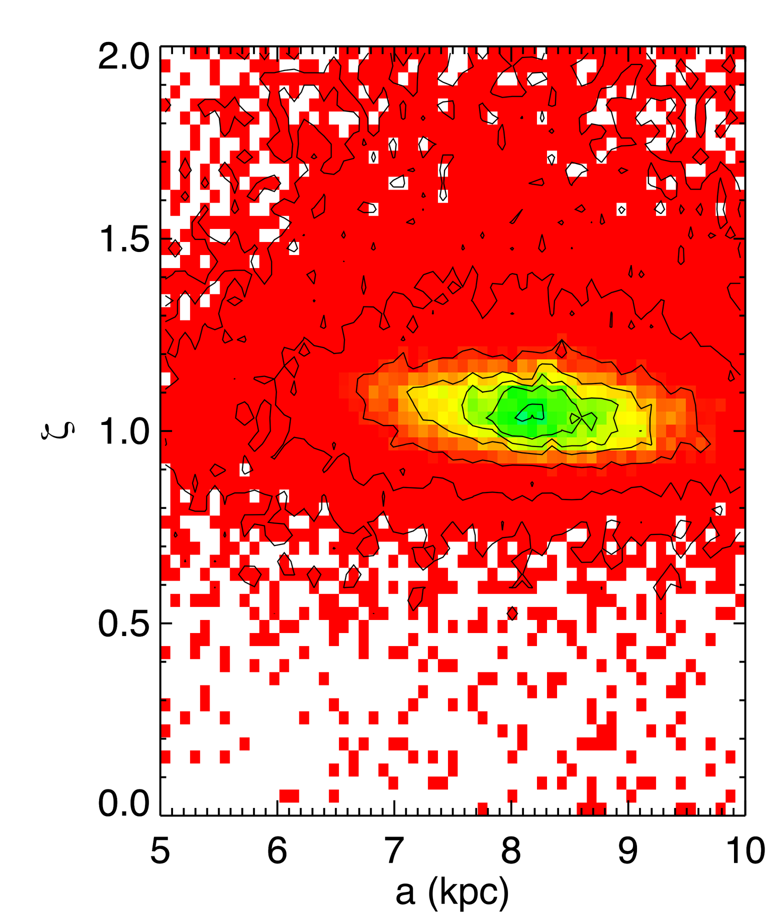

Figure 7 - The metallicity sensitive parameter ζ, (Lepine et al. 2007) vs. semi-major axis (*a*) for all stars in the sample. Large values of ζ correspond to higher metallicity stars. There is a slight gradient, with ζ decreasing for larger values of *a*. Note that most stars in the sample are near solar-metallicity (i.e. $\zeta \sim 1$).

Acknowledgements - JJB thanks Syd Blyth for his gracious hospitality and inspiration on this project. JJB acknowledges the financial support of Kevin Luhman and Adam Burgasser.