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Nearby Hills ejecta as a probe of the gravitational potential of the Milky Way

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Abstract. Stars ejected from the Galactic Center can be used to place important constraints on the Milky Way potential. We have used Hills stars to constrain models for the Galactic potential, demonstrating that meaningful constraint can be obtained if we have samples of around 50 nearby Hills stars.

Keywords. stars: kinematics, gravitation, black hole physics

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1. What is a Hills star?

It is now known that the Milky Way hosts a supermassive black hole. This black hole can disrupt nearby stellar binaries, due to dynamical interactions, resulting in one of the stars being flung from the center of the Galaxy at exceptionally high speeds. These stars are often referred to as Hills stars, after the name of the person who first proposed this mechanism (Hills 1988), or hyper-velocity stars (HVS), due to their high speeds. Brown *et al.* (2005) found the first hypervelocity star (HVS) in the outer parts of the Milky Way, at 106 kpc from the Galactic center. The Galactic rest-frame velocity of this star is $v_{rf} = 709$ km s^{-1}. To date 28 high-mass HVSs have been confirmed from their radial velocity (e.g., Hirsch *et al.* 2005; Edelmann *et al.* 2005; Brown *et al.* 2014; Zheng *et al.* 2014; Huang *et al.* 2017; Li *et al.* 2018l Koposov *et al.* 2019). In addition to these, a number of B- and F-type hyper-velocity stars have been confirmed from their total velocity (e.g., Heber *et al.* 2008; Li *et al.* 2015; Boubert *et al.* 2018). By integrating their orbits back through time, we can see that most of them appear to originate from the Galactic center (GC), as predicted by the Hills mechanism.

2. Why can Hills stars constrain the gravitational potential of the Milky Way?

McMillan (2017) constrains a Galactic mass model based on a variety of observational data (e.g., maser velocities, terminal velocity curves, vertical force, Solar velocity, mass at large radii). However, these observational data are unable to provide tight constraints on the thin disk scale height. We will now demonstrate that Hills stars are a new and powerful resource to constrain the scale height. The orbits of nearby Hills stars can be traced back in time using parallax and proper motion data from Gaia, in combination with radial velocity data from spectroscopic surveys (eg. LAMOST, SEGUE/APOGEE, RAVE, Gaia RVS). The potential can be constrained by utilising the fact that the orbit of a Hills star will only pass through the GC if the model for the potential is correct.

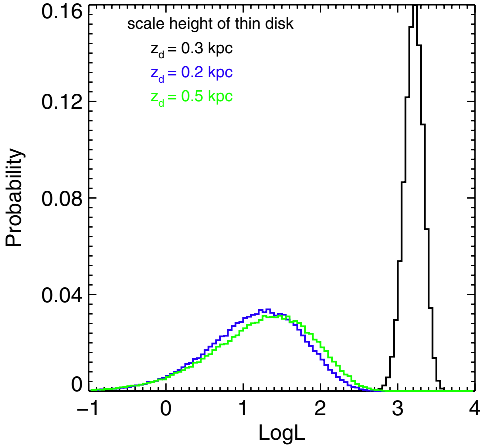

Figure 1. The distribution of likelihoods for 50 Hills stars ejected from the GC. The black histogram corresponds to the likelihoods calculated using the correct potential (i.e. $z_d = 0.3$ kpc). The blue and green histograms correspond to likelihoods calculated using incorrect potentials ($z_d = 0.2$ kpc and 0.5 kpc, respectively).

An incorrect potential (for example from an incorrect thin disc scale height) will result in an orbit which does not precisely intersect the GC.

3. How to constrain the gravitational potential of the Milky Way?

In our Hills population synthesis model (Zhang *et al.*, in prep), mock Hills stars were ejected from the GC and orbits were calculated using a Galactic mass model with the thin disk scale height equal to 0.3 kpc (McMillan 2017). From this we chose mock A- and B-type Hills stars within 3 kpc of the Sun and assign errors according to the Gaia science performance. Orbits were then integrated backwards and uncertainties in the last disc crossing position were calculated using a Monte Carlo approach. This was repeated for three different values of the thin disc scale height (Zhang *et al.* 2016). We assumed all observational errors are Gaussian and generated 10000 realisations for each Hills star. We account for all sources of uncertainty, namely the heliocentric distance, radial velocity, proper motion, together with uncertainties in the LSR and solar radius. For each Hills star we took the Monte Carlo distribution of last disc crossing positions and used this to obtain the likelihood that it was ejected from the GC. We found that a single Hills star is unlikely to provide strong constraints on the Galactic mass model, but if we have an ensemble of such stars then this becomes feasible.

Figure 1 shows the distribution of likelihoods for 50 Hills stars ejected from the GC. The black histogram corresponds to the likelihoods calculated using the correct potential (i.e. $z_d = 0.3$ kpc). The blue and green histograms correspond to likelihoods calculated using incorrect potentials ($z_d = 0.2$ kpc and 0.5 kpc, respectively). This shows that a sample of 50 nearby Hills stars is sufficient to clearly distinguish between these three models of the Galactic potential.

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