New Models of the Milky Way's Dark Matter Distribution for the Era of High Precision Astrometry

Scientific Category: Stellar Populations

Scientific Keywords: Astrometry, Evolution, Halos, Local Group Galaxies, Magellanic Clouds

Alternate Category: Cosmology

Budget Size: Regular

Theory: Yes

Abstract

Understanding the assembly history and dark matter distribution of our Milky Way (MW) is a major challenge for astrophysics. Thanks to the unique capabilities of HST, proper motions of satellite galaxies, globular clusters and stellar streams have been measured with accuracies of order ~0.05 mas/yr (~10 km/s) at distances of 50-300 kpc. When combined with detailed models of the MW's halo potential, such measurements become high-precision tools to constrain the dark matter mass profile of the MW and compute accurate orbital histories of satellites. However, the MW hosts a pair of massive dwarf galaxies, the LMC and SMC, that contribute to its dark matter distribution and change the shape of the potential in a non-symmetrical, time evolving manner. To date, these effects have not been accounted for in existing models of the MW halo. We propose to develop high resolution simulations to quantify the time evolving structure of the MW's dark matter halo owing to the influence of the LMC and SMC. These novel models will enable rapid orbital integration of halo objects (satelllites, globular clusters, stellar streams), using high accuracy HST proper motions, while also capturing the complex halo potential resulting from the LMC-SMC-MW interaction. The era of high-precision astrometry has arrived, yet we do not currently have an appropriate theoretical framework to study the assembly history of MW-like galaxies in the presence of massive satellite perturbers. Our proposed program is thus critical to ongoing HST programs and all efforts to understand the structure and evolution of the dark matter halo of our Galaxy and analogous systems like M31 and its massive satellite, M33.

- **Scientific Justification**

The Need for New Milky Way Halo Models and the Role of the Magellanic Clouds

Astronomy has entered an era of high precision astrometry. Data from the *Hubble Space Telescope (*HST*),* the *James Webb Space Telescope (*JWST*),* and survey missions, such as *Gaia* and *LSST* have/will be used to identify substructure about the Milky Way (MW) and measure their kinematics with unprecedented accuracy. For example, the recently approved HST Large Cycle 24 program GO-14734 (PI Kallivayalil; Co-I Besla) will result in first epoch imaging to lay the foundation for proper motion measurements for *all* satellite galaxies of the MW (precision of ~0.05 mas/yr, or ~10 km/s). High accuracy, 6-D phase space information of halo tracers (satellites, globular clusters, stellar streams) over a wide range of Galactocentric distances is thus imminent. When combined with detailed models of the MW's halo potential, such measurements become high-precision tools to constrain the dark matter mass distribution about the MW and compute accurate orbital histories of satellites/streams, revealing the MW's assembly history.

There is, however, a problem with all existing MW models. HST proper motions imply that the MW has recently captured a pair of massive, high-speed satellites: the Large Magellanic Cloud (LMC) and Small Magellanic Cloud (SMC) (Besla+2007; Kallivayalil, van der Marel, Besla+2013). These galaxies are cosmologically expected to contribute ~2 x 10^{11} M⊙ of dark matter to the MW halo (Besla+2012,2010). This is roughly ~20% of the total expected mass of the MW (Boylan-Kolchin, Besla+2011). Thus, the Clouds are not small galaxies. Indeed, the stellar disk of the LMC has a radius that is ~ half its current separation to the MW!! (Besla+2016; Fig. 1). As such, the Clouds cannot be treated as simple point mass tracers of the halo potential – rather, such massive satellites will *contribute* to the dark matter distribution of the MW, changing the shape of the potential in a non-symmetrical, time evolving manner. This effect has not yet been accounted for in existing models of the MW, but has the potential to perturb the kinematics of *all* tracers of the halo potential.

We propose to create needed N-body models of the LMC+SMC+MW system with mass resolution 3 orders of magnitude higher than any created to date (10^9 particles). By applying a basis expansion method, we will extract the shape, density and potential of the dark matter halo in the simulated combined MW+LMC+SMC system as a function of time and radius. These simulations will be the *first of their kind*, accounting for our new understanding of both the large mass and HST proper motions of the Clouds. Our solutions for the time evolving potential of the MW will be released to the community, providing necessary tools to interpret existing and upcoming astrometric data sets from HST, JWST and *Gaia,* and facilitate the orbital analysis of new substructure as it is discovered. This program is thus both critical and timely.