Milky Way Cosmology: Laying the Foundation for Full 6-D Dynamical Mapping of the Nearby Universe
HST Proposal 14734

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Proposal Abstract

High-precision astrometry throughout the Milky Way halo is a unique capability of HST, with potential for transformative science, including constraining the nature of dark matter, probing the epoch of reionization, and understanding key physics of galaxy formation. While Gaia will provide unparalleled astrometric precision for bright stars in the inner halo of the Milky Way, HST is the only current mission capable of measuring (1) accurate orbital proper motions for systems at greater distances (> 80 kpc), in order to measure the total mass profile of the Milky Way, or (2) internal kinematics of stars in dwarf galaxies, to test the cusp versus core nature of their inner density profiles. We propose to initiate the next-generation, high-precision, proper-motion survey of all known dwarf galaxies within the Milky Way halo, thus laying the foundation to dynamically map the nearby Universe in full 6-D orbital phase space. Specifically, we propose to use ACS/WFC3 to establish a first-epoch baseline for proper-motion measurements for the 32 known dwarf galaxies within 420 kpc that currently lack sufficient first-epoch imaging. These observations will provide the critical anchor point for forefront scientific results within the next 4 years of HST's life, which can be extended with future missions, including JWST, over 10+ years to obtain unprecedented astrometric accuracy, ensuring that HST leaves a unique and lasting legacy for decades to come.;

■ Scientific Justification

Introduction: The field of astrometry is poised to produce fundamental advances in our understanding of the local Universe in the coming decade. The remarkable stability and resolution of ACS and WFC3 position HST to play a leading role, enabling precise measurements of proper motions (PMs) that complete the full 6-dimensional orbital phase space of nearby galaxies. HST astrometry measured by our collaboration already has led to breakthroughs such as (1) determining the orbit of the Large and Small Magellanic Clouds (LMC and SMC) (Kallivayalil et al., 2013), (2) detecting internal rotation in the LMC (van der Marel & Kallivayalil, 2014), (3) measuring the tangential motion of the distant satellite Leo I, as well as M31 (Sohn et al., 2012, 2013), and (4) constraining the presence of intermediate-mass black holes in globular clusters (Anderson & van der Marel, 2010). Simultaneously, the satellite dwarf galaxies around the MW have emerged as key testbeds for ΛCDM, the epoch of reionization, and the physics of galaxy formation. However, progress in all of these areas is significantly limited by the lack of comprehensive, unbiased, and robust PM measurements. Of the 51 known dwarf galaxies within $\approx 400\,\mathrm{kpc}$, only 10 (20%) have well-measured PMs, and these form a biased sample, being relatively nearby and/or massive ("classical") dwarfs (Figure 2). Furthermore, 32 (two-thirds) do not have good ACS/WFC3 imaging for even the first epoch of a PM measurement, even though HST can readily measure them.

Through this Treasury program, we propose a comprehensive survey to provide robust imaging for optimal first-epoch proper-motion measurements for all known dwarf galaxies out to $420\,\mathrm{kpc}$*, encompassing the MW's full halo profile out to its virial radius.* Specifically, we will target the 32 known dwarf galaxies that currently do not have adequate ACS/WFC3 imaging. Here, we propose for exclusively first-epoch imaging, to provide a solid foundation to be followed up with second-epoch baselines by HST and JWST over the next 4 - 11+ years, to enable unprecedented proper-motion measurements.

Because we do not know how long HST will last beyond 2020, it is "now or never" to start such a PM survey that can be realized by HST. Even more excitingly, JWST will have similar resolution and capabilities for PM measurements as HST, so it can be used to leverage HST first-epoch data over an 11+ year baseline. Given the relatively short proposed lifetime of JWST, it is critical that HST establishes first-epoch baselines now, to leverage JWST's full lifetime for optimal PM measurements. As we argue below, this will allow HST to do transformative science on many fronts, uniquely addressing critical issues related to galaxy formation, cosmic reionization, and the nature of dark matter.

Motivation for a Comprehensive Proper-Motion Survey around the Milky Way: Measuring high-precision PMs of *all* dwarf galaxies within the MW halo will enable an overwhelming breadth and depth of science applications. This represents a long-term project, but we must lay the groundwork now to achieve this goal in the era of JWST. We outline the five most critical science drivers, any one of which is compelling in its own right.

(1) *Direct dynamical measurements of the mass profile of the Milky Way halo.* A high-precision measurement of the total mass of the MW's dark-matter halo will represent a