# Resolved Stars in Nearby Galaxies with the HLWAS

**Roman Core Community Survey Category:** High Latitude Wide Area Survey (Imaging)

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ABSTRACT

The Nancy Grace Roman Telescope's High Latitude Wide Area Survey (HLWAS) will undoubtedly result in remarkable advancements in cosmology measurements from weak lensing, baryon acoustic oscillations, and other analysis techniques for measuring the integrated properties of distant galaxies. However, detailed and significant constraints on the nature of dark matter as well as the formation and evolution of galaxies can be gleaned from studies of the resolved stars in the nearby galaxies covering the foreground of the HLWAS footprint. The virial radii of these galaxies are large on the sky, and as a result their diffuse stellar halos have yet to be characterized. We advocate for choosing a region of the sky with several nearby galaxies within the LSST footprint (for example, the Sculptor Group), and for modifying the exposure sequences within the virial radii of these galaxies. By making special allowances for these regions, we can enable resolved stellar populations studies in addition to the planned cosmology measurements. These observations will reach extremely low surface brightness regions and be able to leverage LSST full depth photometry in these regions for panchromatic spectral energy distribution fitting of the stars resolved by Roman. Furthermore, they will provide an excellent medium depth complement to wide and shallow, as well as narrow ultra-deep core surveys.

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## 1. SCIENTIFIC IMPACT OF RESOLVED STELLAR POPULATIONS

The Λ-cold dark matter (ΛCDM) cosmological model and its viable alternatives appear equally successful in reproducing the large-scale (>1 Mpc) distribution of galaxies (e.g. Planck Collaboration et al. 2020). The main variance between viable dark matter (DM) models is on very small scales, in the number and properties of low-mass galaxy halos Bullock & Boylan-Kolchin (2017); Sales et al. (2022). Numerical simulations predict that 'cold dark matter' (CDM) forms gravitationally bound structures (called halos) far below the total mass needed to host a galaxy ($M_{\rm halo} \gtrsim 10^7 M_\odot$; Barkana & Loeb 2006; Bovill & Ricotti 2009, 2011; Bullock & Boylan-Kolchin 2017), implying the existence of a multitude of dark substructures around galaxies.

**Dwarf Galaxy Census and Properties:** Dwarf and satellite galaxies, in particular ultra-faint dwarf galaxies ($M_V > -7.7$; Simon 2019), are the primary observational probe of low-mass DM halos Moore et al. (1999). The smallest of these halos (and their associated stars) are predicted to have formed very early (e.g. Bullock et al. 2000; Bovill & Ricotti 2011; Wheeler et al. 2015; Jeon et al. 2017; Applebaum et al. 2021), making them incredibly sensitive to the joint physics of DM, galaxy formation and reionization.

Of all upcoming observatories, Roman promises the most progress in this critical area—even deep lensed JWST fields cannot resolve the precursors to ultra-faint dwarf galaxies Weisz & Boylan-Kolchin (2017). If well-optimized, Roman should recover and map the extended structures of ultra-faint dwarf galaxies out to a distance of ∼10 Mpc—a thousandfold increase in volume—both as massive galaxy satellites and in the field Bell et al. (2021); Mutlu-Pakdil et al. (2021), revolutionizing our ability to jointly constrain on galaxy formation physics, reionization and DM.

**Stellar Stream Properties:** As the tidally stripped remnants of accreted dwarf galaxies, stellar streams and other substructure encode both the accretion history of the host galaxy and the evolution of low-mass galaxies (Helmi et al. 1999; Johnston et al. 1999, 2001, Starkenburg et al. in prep.). Additionally, streams from dwarf galaxies or globular clusters (GCs) are dynamical tracers of the host halo mass, and thin tidal streams from GCs indirectly probe encounters with DM halos too small to host galaxies. To date, such structures have only been detected in the MW (e.g., de Boer et al. 2018; Price-Whelan & Bonaca 2018; Bonaca et al. 2020). However, Roman will be sensitive to these streams out to ∼6 Mpc Pearson et al. (2019, 2022a) and to stream gaps out to ∼2–3 Mpc Aganze et al. (2023), allowing for the first time statistical comparisons of stream structure to predictions from various DM candidates Bullock & Boylan-Kolchin (2017).

**Star Formation Histories:** A galaxy's star formation history (SFH) describes its rate of star formation and metal enrichment over cosmic time, telling the story of how the galaxy formed and evolved. SFHs reconstructed from resolved stellar populations are the current gold standard approach (e.g., Kennicutt & Evans 2012; Conroy 2013; Annibali & Tosi 2022). With proper planning, Roman's potential to cover hundreds of galaxies from the Local Group to ∼10 Mpc could yield SFHs over a broader range of galaxy types than has ever been attempted, with coverage that can measure population gradients and structural variations. HST has delivered exquisite SFHs, but the restrictive FoV has limited this work almost exclusively to dwarf galaxies (e.g., McQuinn et al. 2010; Weisz et al. 2011; Skillman et al. 2017). Even in this limited regime, the small area probed may not be representative of the galaxy as a whole Graus et al. (2019).

**Merger Histories using Stellar Halos:** In addition to the growth histories of the galaxies themselves, Roman will provide an unprecedentedly detailed view of their diffuse outskirts. As galaxies merge, much of the resulting debris is deposited on orbits that extend to large galactocentric distances, forming an extended, richly-structured stellar halo Bullock et al. (2000); Bullock & Johnston (2005); Cooper et al. (2010). The largest individual mergers deposit the most debris and therefore dominate measurements of the stellar mass, metallicity, and SFH of stellar halos Cooper et al. (2010); Deason et al. (2016); D'Souza & Bell (2018a). Halo *metallicities* measured using the metal-sensitive colors of red giant branch stars Monachesi et al. (2016), complemented where possible using ground-based spectroscopic metallicities for 'bright' stars identified in Roman imaging Toloba et al. (2016), can constrain the time evolution of the halo mass–metallicity relation, while Halo *SFHs* can constrain the merger time D'Souza & Bell (2018b); Harmsen et al. (2021); Panithanpaisal et al. (2021). The *structure* of stellar halos reflects primarily recent mergers whose debris has not yet had time to phase mix Johnston et al. (2008); Panithanpaisal et al. (2021), probing the galaxy's recent interaction history and providing the stellar streams that can map its DM halo (e.g., Fardal et al. 2013; Pearson et al. 2022b).

The scientific promise of these techniques has only been partially realized for the MW and M31, revealing many streams (Belokurov et al. 2006) as well as massive mergers in the MW ∼4–9 Gyr ago Helmi et al. (2018); Belokurov et al. (2018); Donlon et al. (2022) and in M31 ∼2 Gyr ago D'Souza & Bell (2018b) that likely had profound influence on the galaxies' disks (e.g. Dalcanton et al. 2015; Williams et al. 2017; Hammer et al. 2018; Laporte et al. 2019; Belokurov et al. 2020; Hunt et al. 2021, 2022). Roman is the only mission that can extend these insights to a statistically-meaningful sample of nearby galaxies, connecting galaxy properties/SFHs with satellite populations, DM halo masses and merger histories for the very first time, offering the first-ever comprehensive test of galaxy formation models.

## 2. SUGGESTIONS TO CONSIDER FOR HLWAS OBSERVING STRATEGY

With a few relatively straight-forward considerations, the HLWAS could be designed in a way that could make the resulting data significantly more valuable to the stellar populations and near-field cosmology communities.

### 2.1. *HLWAS Footprint Considerations*

First, the area of the sky covered could be chosen to be within the full depth LSST footprint to maximize the potential SEDs of the stars found in the outskirts of these nearby galaxies[1]. We suspect that there will be many science advantages to this accommodation, and that several other white papers will be requesting the same. However, we would also request that within that very broad constraint, the coverage should contain several nearby galaxies. One area that would be of particular interest to cover could be the Sculptor Group (∼4 Mpc), which covers about 500 square degrees around RA=1H and Dec=-25d (Galactic Latitude $\sim -87$), containing several known spiral, irregular, and dwarf galaxies, with many more faint dwarfs likely to be discovered. By covering this

[1] further down to ∼ 2300 Å in the UV when considering the future Canadian-led CASTOR telescope that plans to cover Roman's footprint in their primary survey (Cote et al. (2019))

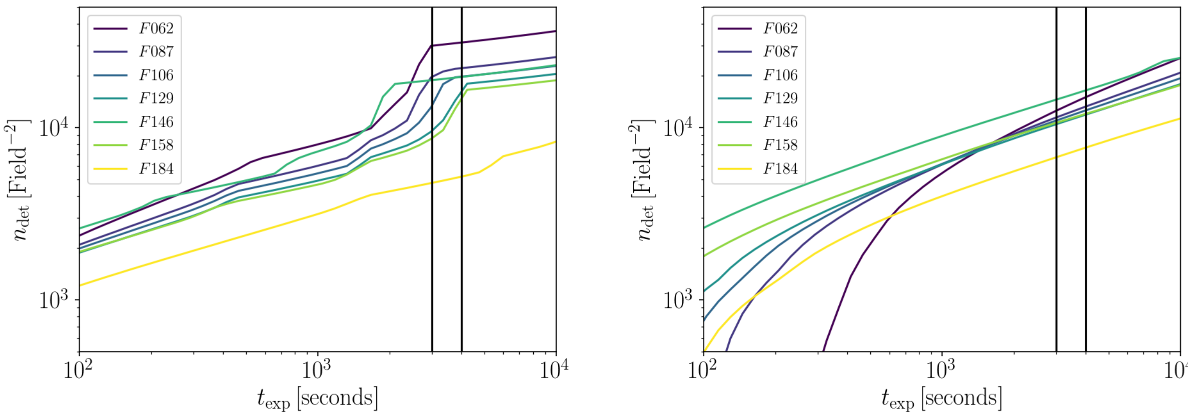


**Figure 1.** *Left:* Plot from `walter` (Lancaster et al. 2022) calculations showing the number of stars detected by Roman in a single pointing in a region at 4 Mpc (Sculptor Group distance) with a surface brightness of 32 mag per square arcsecond as a function of exposure time for 7 Roman bands. This calculation assumes a population with an age of 10 Gyr and metallicity of [Fe/H]=-1.0. By exposing for 3 ks and 4 ks (vertical lines) in F062 and F158, respectively, we optimize the efficiency by detecting red clump stars (steep increase just left of the vertical lines). *Right:* Same as *left*, but for a distace of 10 Mpc. At these distances, red clump stars won't be reached, but with similar exposure times, we still detect $\sim 10^4$ stars per field in these diffuse halos.

region, the HLWAS would be virtually guaranteed of including many nearby galaxies and having a lasting impact on near field cosmology.

## 2.2. *Depth and Filter Selections*

A slightly more advanced accommodation for near-field cosmology involves considering the depth of the exposure and the filters included when observing within the virial radius of a known nearby (<10 Mpc) galaxy. The most knowledge is gained from star colors when a large color baseline is available. In fact, one of the arguments for including the F062 filter in the mission was its ability to hep distinguish populations of different ages and metallicities. We have found that a combination of F062 and F158 takes the most advantage of the sensitivity of Roman while providing the most information about the stars detected. We have written a robust code for predicting the number of stars detected by Roman as a function of surface brightness and distance (Lancaster et al. 2022), and it shows that the most efficient exposure times for detecting stars in the low surface brightness ($\mu \sim 32$ mag arcsec$^{-2}$) outer halos of galaxies at 4 Mpc (the galaxies in the Sculptor Group) is 3000 seconds in F062 and 4000 seconds in F158 (Figure 1, left), detecting $\gtrsim 10^4$ stars per pointing, with a large gain made by reaching the jump in the stellar luminosity function associated with the red clump. The same calculations for low surface brightness regions at 10 Mpc show that similar numbers of stars can be detected per pointing with these exposure times. Thus, aiming these total exposure times in regions covering known galaxies within 10 Mpc would greatly increase the value of the HLWAS.

## 2.3. *Proper Motions*

Roman is going to be capable of extremely precise proper motion measurements (WFIRST Astrometry Working Group et al. 2019). We therefore advocate for the HLWAS being taken in 2 epochs with maximum time baseline to reach full depth. Such a strategy would require the one epoch be observed early in the mission to maximize the baseline and in turn, the potential proper motion science. With a long enough baseline, it may even be possible to measure proper motions of galaxies in the Sculptor Group itself.

### 2.4. *Complementing the Main HLWAS*

By customizing parts of the HLWAS in this way, these sections of the survey will serve to complement any wider, shallower surveys that Roman may choose to complete, such as the multiple white papers suggesting a very large area, or even all sky, single band survey. While these surveys would be phenomenal for very detailed Milky Way studies, our proposed customization would allow detailed studies of many other galaxies providing a much needed and reliable context for the Galactic measurements.

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