Snowmass2021 - Letter of Interest

Roman Space Telescope Stellar Halo Structures Probe Dark Matter Substructure

Thematic Areas: (check all that apply ☐/■)

☐ (CF1) Dark Matter: Particle Like
☐ (CF2) Dark Matter: Wavelike
■ (CF3) Dark Matter: Cosmic Probes
☐ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
☐ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
☐ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
☐ (CF7) Cosmic Probes of Fundamental Physics
☐ (Other) *[Please specify frontier/topical group]*

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Abstract: Resolved stellar population studies can provide some of the deepest probes of the structures of the stellar halos of galaxies, from the streams of disrupted satellite galaxies to the faint end of the dwarf satellite luminosity function. These structures are sensitive to the nature of dark matter and the evolution of the galaxies that form within its halos. The *Nancy Grace Roman Space Telescope (Roman)* will have spatial resolution of the *Hubble Space Telescope*, but cover over 100 times more area and have higher sensitivity in the near infrared. These characteristics will make *Roman* capable of producing the largest sample of deep, wide-area maps of the stellar halos of nearby galaxies ever observed, including color and brightness information of the individual stars in those halo structures. Herein we discuss prospects for applying such observations to the study of the nature of dark matter, including potential constraints on competing dark matter models.

Nancy Grace Roman Space Telescope (*Roman*) is a 2.4m space telescope scheduled to be launched in the mid-2020's by the United States National Aeronautics and Space Administration (NASA)[1;2]. The current baseline mission plan calls for 25% of the observing time to be allocated to the international astronomy community through a general observer (GO) program. A portion of this time will very likely be dedicated to multiband imaging of nearby galaxies and their surrounding halos with 0.1" spatial resolution, allowing for the detection and characterization of individual stars out to distances exceeding 10 Mpc.

Roman's wide FoV, sensitivity, and excellent star-galaxy separation can revolutionize the study of galactic halos as mapped by individual stars. For the volume ($R \lesssim 10$ Mpc) within which it can resolve stellar populations, *Roman* will be able to map the stellar halos for hundreds of galaxies, improving current sample sizes by *2 orders of magnitude*, down to surface brightness limits comparable to those currently reached only in the Local Group.

In addition to the global properties of stellar halos (mass, shape, etc.), *Roman* can measure the frequency, surface brightnesses, physical scales, and morphologies of the debris that remains after a lifetime of galaxy accretion and disruption. The physical debris looks dramatically different if the accreted material came from satellites biased towards being accreted early/late, on orbits of low/high eccentricity and from satellites of high or low luminosity (Figure 1). The observed properties of the substructure can be associated with fundamental physical quantities: the frequency of tidal debris reflects the recent accretion rate; the physical scales and surface brightnesses reflect the mass and luminosity functions of infalling objects; and the morphology reflects the orbits. Thus, the substructure in the halo offers a direct constraint on the history and nature of baryonic and dark matter assembly[3].

In addition to accretion histories, tidal debris probes the dark matter distribution around galaxies. Com-

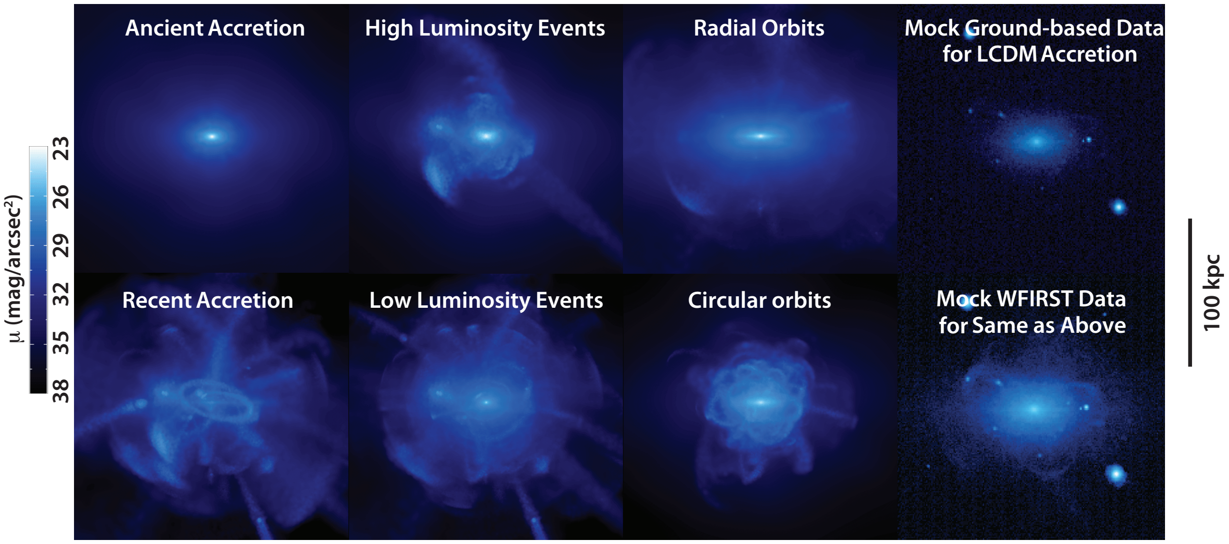

Figure 1: Left Panels: Examples of how halo morphology reflects the history of accretion, for old vs. young accretion events, for high- vs. low-luminosity accreted satellites, and for accretion along radial vs. circular orbits[3]. Right Column: Simulated optimal ground-based map (1 hour with Subaru in 0.7″ seeing) of a model halo is shown above a simulated deep, wide-field space-based map, possible with *Roman*, in the 2020s of the same model, which allows exquisite star-galaxy separation to faint magnitudes in low stellar density regions. Even higher resolution will be necessary to probe the more crowded inner and star-forming regions of galaxies. Degree-sized coverage is required to map these areas.

plexity arises beyond the conceptual interpretation described above because: (i) the morphology and frequency of debris structures can be affected by the triaxiality of dark matter halos (chaotic orbits can cause "fanning" of thin tidal streams[4]); and (ii) the *continuity* of streams can be interrupted by interactions with dark matter subhalos. However, these "complications" leave observable signatures that are potentially separable from the mass accretion history alone — and hence offer the additional possibilities of measuring the triaxiality distribution of dark matter halos as well as detecting substructure within them. Initial tests of the ability of *Roman* to detect such detailed structures suggest that we will both be able to find such structures[5;6] and use them to constrain the existence of low mass dark matter halos[7]

Furthermore, the high-resolution, wide-field imaging will provide the most complete catalogs of dwarf satellite galaxies yet achieved. The detailed number statistics on these small, faint galaxies provide a strong lever arm for testing dark matter models. The ΛCDM model predicts the numbers and masses of sub-halos surrounding higher mass galaxies (Figure 2). These halos should be observable in the form of lower mass satellites around larger galaxies. However, statistical tests of galaxy formation in a ΛCDM context face extensive challenges[8 9]. For example, studies of the most luminous MW dwarfs indicate that their central density profiles are flatter and their mean densities are substantially lower than those of simulated subhalos of the same mass (the 'core/cusp' and 'too big to fail' problems[10;11]).

Driven by these discrepancies observed in the Local Group, significant progress has been made towards reconciling theory and observation. Improved simulations with baryonic and dark matter physics show that some putative dwarf galaxies may never form stars and stay 'dark'[12–17]. New searches for dwarf galaxies in nearby groups have resulted in many new dwarf satellite candidates to the Milky Way (MW; e.g., DES Collaboration 2015) and several nearby large galaxies (e.g., M81[18;19]; M94[20]; M101[21–23]; NGC 5485[24]; Centaurus[25–27]; Leo I[28]; NGC 2784[29]; NGC 3175[30]). Many more such satellite candidates, as well as isolated ultra faint dwarf galaxies (probing low density environments), will be discovered by LSST and *Roman*. Confirmation, distances, and physical characterization of these ultra-faint galaxy candidates are difficult with current capabilities[31–34]. However, such targets will be characterized by future observatories (e.g., *James Webb Space Telescope* and 30-m facilities), and their statistics will be fundamental to galaxy formation models.

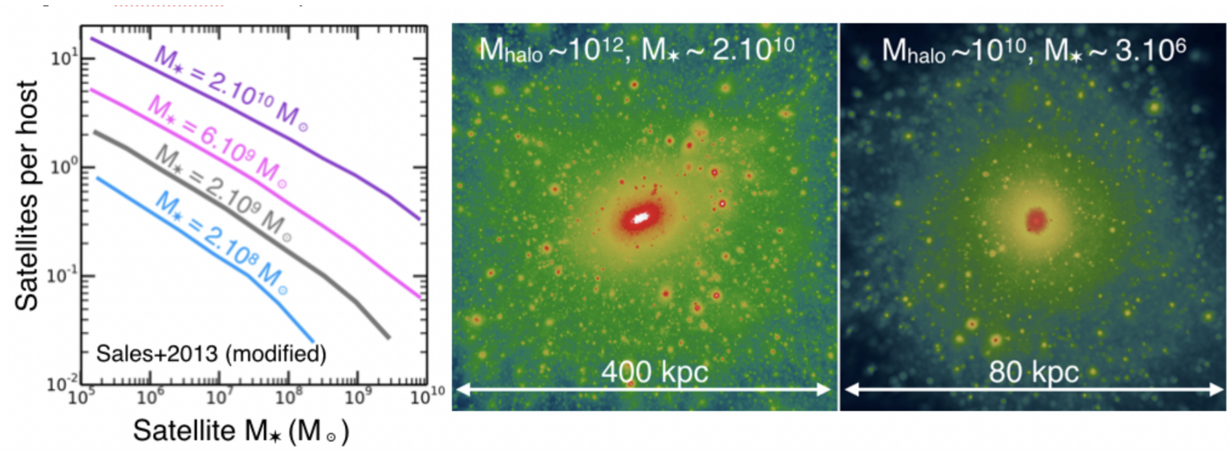

Figure 2: Left: Predicted number of satellite galaxies as a function of stellar mass based on simulations for four different central galaxy masses. These mass functions will vary for different dark matter and galaxy formation models. *Roman* could potentially measure these mass functions for hundreds of galaxies. Middle and Right: State-of-the-art dark matter simulations of a massive and low-mass galaxy, showing the large number of subhalos predicted down to small mass scales, even at low masses.

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