Snowmass2021 - Letter of Interest

Roman Space Telescope Strong Lensing Probes of 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: *Nancy Grace Roman Space Telescope*, formerly known as the *Wide Field Infrared Survey Telescope*, is scheduled to launch in the mid-2020's and will provide a multi-band, high-resolution view of the cosmos. Equipped with a mirror the size of *Hubble Space Telescope* and a $0.3\ \mathrm{deg}^2$ infrared-sensitive camera $\sim 100\times$ larger than *Hubble/Wide Field Camera 3*, *Roman* will efficiently and sensitively map large areas of the sky with ~ 0.1" resolution. This resolution will enable the discovery of ~ 1000 gravitationally-lensed quasars, which in turn provide detailed constraints on the properties of dark matter substructures. We review the promise of *Roman* for achieving dark matter constraints through strong lensing, both as stand-alone lensing experiment and in collaboration with other facilities.

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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]. Formerly known as the *Wide Field Infrared Survey Telescope*, *Roman* will undertake an ambitious set of mission surveys including a large area cosmology survey ($\sim 1600\ \mathrm{deg}^2$) with multiband imaging (~ 26.7AB flux limit) and slitless grism spectroscopy ($\sim 10^{-16}\ \mathrm{deg\ s^{-1}\ cm^{-2}}$ line sensitivity).

While the cosmology mission surveys are designed to constrain structure formation and the expansion history through weak lensing and baryon acoustic oscillations, *Roman* can test our picture for small-scale dark matter structure formation more directly through gravitational lensing. The cold dark matter plus cosmological constant (ΛCDM) paradigm forms one of the pillars of our models for the origin and evolution of cosmic structures. While remarkably successful at matching observations on large scales, there have been persistent observational challenges to the cold, collisionless dark matter expectations on dwarf-galaxy scales. These "small-scale controversies" may simply stem from a poor understanding of the baryonic processes involved in galaxy formation, or indicate more complex dark sector physics[3].

Detailed testing of the standard paradigm on small scales remains one of the most pressing issues in cosmology. Numerical simulations in ΛCDM predict a rich spectrum of substructure in galaxy halos. Small fluctuations in the galaxy-scale lensing potential caused by these substructures should result in measurable "flux anomalies" in the magnifications of quadruply-lensed quasar images[4]. While discrepancies between the observed flux ratios and those predicted by a smooth lens model may have been found in radio quasar lenses[5–7], the small sample size ($\lesssim 100$ lenses) of current samples limits our understanding. *Roman* HLS will revolutionize this field by increasing the sample of quad lenses more than $10\times$[8]. More recently, methods have been developed to use extended lensed sources, in addition to the point-like AGN, to identify substructures through distortions of lensed images. Extended sources are imaged into arcs and rings that probe a larger volume in the lens halo, increasing the number of subhalos that can be sensed. They also can be drawn from larger populations of background sources, typical galaxies rather than bright AGN. Vegetti & Koopman (2009)[9] described a method for identifying subtrsuctures with high-resolution optical/IR imaging of extended galaxies, with Vegetti et al. (2012)[10] reporting a detection of a dark substructure in a gravitational lens at $z = 0.9$. In related work, Hezaveh et al. (2013, 2016a)[11,12] described the use of (sub-)millimeter spectral lines from dusty lensed galaxies to search for subhalos in the lenses. The wide survey area of HLS, along with its combination of multi-band imaging and spectroscopy, will provide many avenues for identifying large samples of lensed galaxies for such substructure searches.

DES and GAIA strongly lensed quasar[13]

DES 34 lensed quasars[14]

stacked density profile SLACS[15]

systematic issues iwth flux anomalies[16]

line flux ratios WFC3[17]

sterile neutrinos[18]

constraints from 8 lenses[19]

millimerter discovery[20]

group to cluster scale lenses[21]

baryonic effects on the clumpiness[22,23]

inner slope[24], statistical approach[25]

The EXPO team will explore the substructure science achievable from the HLS and various GO options. We will predict survey yields for lenses that will be suitable for all three substructure probes. These counts will be synthesized into constraints on the substructure mass function, factoring in the parameters of realistic followup campaigns.

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