Snowmass2021 - Letter of Interest

Illuminating the Dark Universe with ATLAS Probe

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: ATLAS (Astrophysics Telescope for Large Area Spectroscopy) Probe is a concept for a NASA probe-class space mission, with 1.5m telescope aperture and 0.4 deg^2 field-of-view. ATLAS Probe will provide definitive measurements of dark energy, and high precision measurements of neutrino mass and other cosmological parameters. The mission is the spectroscopic follow-up to the Nancy Grace Roman Space Telescope, multiplexing its scientific return by obtaining deep slit spectroscopy with $R = \lambda/\Delta\lambda = 1000$ over the wavelength range of 1-4μm for $\sim$ 200M galaxies imaged by Roman out to $z = 7$ in three tied surveys (Deep, Medium, and Wide), and deliver spectra that enable a wide range of diagnostic studies of the physical properties of galaxies over most of cosmic history. ATLAS Probe's wide area spectroscopy at 1-4μm will be powerfully complementary to future ground-based facilities limited to $\lesssim 1\mu$m due to absorption by the Earth's atmosphere.

Introduction and Motivation. Observational data from recent years have greatly improved our understanding of the Universe. The fundamental questions that remain to be studied in the coming decades include: What is the dark energy that is driving the accelerated expansion of the Universe? It has been over 20 years since cosmic acceleration was discovered[1,2], yet we are still in the dark about its cause. Dark energy might be an unknown energy component in the Universe, or the consequence of the modification of general relativity (GR). Astro2010 top priorities, Rubin Observatory (optical imaging) and Nancy Grace Roman Space Telescope (NIR imaging & slitless spectroscopy), will carry out ambitious dark energy projects. DESI (optical spectroscopy) and Euclid (optical/NIR imaging & slitless spectroscopy) will precede and complement these. These projects will significantly advance our understanding of the nature of dark energy, but they do not provide definitive measurements for its resolution, due to limits inherent to each (the loss of sensitivity due to telluric effects from the ground & the observational systematics intrinsic to slitless spectroscopy).

Modified GR models may predict the same cosmic expansion history as a dark energy model, but would generally predict different growth history of cosmic structure. The precise and accurate measurement of both the cosmic expansion history $H(z)$ and the growth rate of cosmic large-scale structure $f_g(z)$ is required to solve the mystery of dark energy[3]. This can be accomplished by a suitably designed galaxy redshift survey.

ATLAS Probe[4,5] is the NASA Probe mission concept that will carry out a very high number density galaxy redshift survey (GRS) over a wide area (ATLAS Wide) using space-based slit spectroscopy in the IR, the lowest risk way to obtain definitive measurements on dark energy over the entire relevant redshift range[6]. ATLAS Probe has a 1.5m telescope aperture, and uses digital micro-mirror devices (DMD) for massively parallel slit spectroscopy at $R = \lambda/\Delta\lambda = 1000$ over 1-4 μm with 0.4 deg^2 field-of-view. ATLAS Wide minimizes observational systematic errors by design. The theoretical systematic uncertainties (nonlinear structure growth, redshift-space distortions, and the bias between galaxy and matter distributions) can be mitigated through advanced modeling. ATLAS Wide will also provide invaluable constraints on dark matter by tracing the cosmic web of dark matter, and enabling the measurement of dark matter filament mass[7], as well as high precision measurements of neutrino mass and other cosmological parameters. ATLAS Probe will be a game changer in providing spectroscopic coverage of cosmological surveys not accessible from the ground, providing a useful reference for optimizing ground-based facilities.

Definitive Measurements of Dark Energy. Given our ignorance of the nature of dark energy, it is critical that we obtain measurements on dark energy that are model-independent (i.e., $H(z)$ & $f_g(z)$ as free functions) and definitive (high precision and accuracy) over the entire redshift range over which dark energy influences the expansion of the Universe (i.e., $0 < z < 4$). Galaxy clustering data from 3D distributions of galaxies can provide both. The baryon acoustic oscillation (BAO) measurements provide a direct measurement of $H(z)$ and angular diameter distance $D_A(z)$[8,9], and the redshift--space distortions (RSD) enable measurement of $f_g(z)$[3,10]. The measurements at $z < 1$ or even 1.5 can be made from ground-based facilities, thus the focus of ATLAS Wide is $1 < z < 4$. The overlap of $0.5 < z \leq 1.5$ with ground-based projects is important for cross-check and mitigation of systematic effects. ATLAS Wide covers 2000 deg^2 at $0.5 < z < 4$, with a galaxy surface number density ~12 times that of the Roman GRS and ~50 times that of Euclid, with spectroscopic redshifts for ~183M galaxies (~70% of the galaxies from the Roman weak lensing (WL) sample with Hα emission line flux $> 5 \times 10^{-18}$erg/s/cm^2). If early dark energy remains viable in the 2020s, it can be measured by enhancing ATLAS Wide with a high z only ATLAS GRS, targeting Hα emission line galaxies at $3 < z < 5$ selected from Roman imaging beyond that of the WL sample.

The very high number density galaxy samples from ATLAS Wide enable robust and multi-tracer BAO/RSD measurements. They also provide the ideal data sets for studying higher-order statistics of galaxy clustering, which places the tightest constraints on dark energy and gravity. For a galaxy sample with number density n, the shot noise scales as $1/n$ for galaxy power spectrum (2pt), and $1/n^2$ for galaxy bispectrum (3pt). Fig.1 shows that ATLAS Wide 3pt galaxy clustering gives definitive measurements on dark energy, outperforming all other measurements[12]. Since the 3pt statistics provides information not contained in the 2pt statistics,

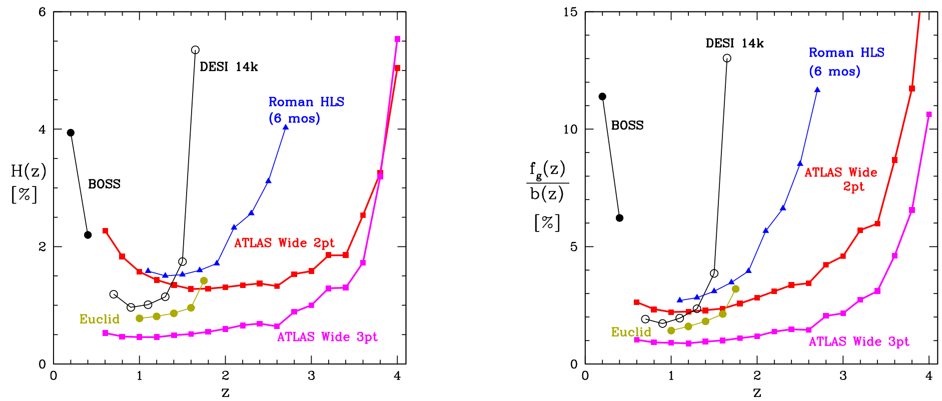

Figure 1: Expected constraints on cosmic expansion history $H(z)$ and growth rate of cosmic large scale structure $f_g(z)$ from future surveys. "2pt" and "3pt" refer to the galaxy power spectrum and bispectrum respectively. Constraints are derived following the methodology that we have developed [11,12]. For the slitless surveys, we assume an efficiency of 75% for Roman (to be launched in 2025), and 40% for Euclid (to be launched in 2022), since the signal-to-noise thresholds for Roman and Euclid are 6.5σ and 3.5σ respectively. The ground-based projects BOSS (completed) and DESI (first light 2019) are complementary to the space-based surveys. The bias between galaxy and matter distributions is $b(z)$.

the combination of these is needed to optimally extract the cosmological information from galaxy clustering data [13], and enables the direct measurement of galaxy bias $b(z)$. ATLAS Wide in the next decade will take advantage of the anticipated future advances in galaxy 3pt statistics.

ATLAS Wide places additional constraints on dark energy through the following: **(1) 3D WL with Spectroscopic Redshifts.** ATLAS Wide replaces photometric redshifts with spectroscopic redshifts for $\sim$70% of the lensed galaxies in the Roman WL sample. This eliminates the photo-z calibration ladder as a major source of systematic uncertainty in WL. **(2) Joint Analysis of Weak Lensing and Galaxy Clustering.** Most galaxies in the Roman WL sample will not have Roman spectroscopy; but $\sim$70% will have spectroscopy at $z > 0.5$ from ATLAS Wide. **(3) Type Ia Supernovae (SNe Ia).** ATLAS Wide will easily include the host galaxy redshifts of nearly all 30,000 SNe Ia that will have lightcurves measured by the Rubin Deep Drilling Fields and Roman SN surveys [14], over the redshift range of $0.2 < z < 2.0$. These will provide a powerful measurement of $H(z)$, and the matter clustering amplitude σ_8 via SN Ia weak lensing magnification measurements [15]. **(4) Clusters.** The abundance of mass-calibrated galaxy clusters provides complementary measurements of cosmic expansion history and growth rate of large-scale structure [16]. ATLAS Wide will determine cluster membership using spectroscopy for the 40,000 clusters with $M > 10^{14} M_\odot$ expected to be found by Roman HLS imaging [17]. **(5) Voids.** Cosmic voids provide powerful tests on the modifications of gravity from GR [18], for which the ATLAS Wide void data set will be ideal: the dense sampling means that we will pick up many galaxies close to the void centers, which contain the most information.

Summary and Conclusion. ATLAS Probe is the spectroscopic follow-up mission to Roman Space Telescope, with a 1.5m aperture telescope and a field of view of 0.4 deg^2, and uses Digital Micro-mirror Devices (DMD) as slit selectors for $R = \lambda/\Delta\lambda = 1000$ multi-object slit spectroscopy at 1-4 μm, with a multiplex factor $\sim$ 6000. ATLAS Probe is designed to fit within the NASA probe-class space mission cost envelope. ATLAS Probe will be able to execute the ATLAS Wide survey in 1.6 years of observing time, to provide definitive measurements on dark energy [5]. These will illuminate the nature of dark energy, and lead to revolutionary advances in particle physics and cosmology. ATLAS Probe can be launched as part of the probe portfolio by NASA in the next decade. It will produce a spectacular and unprecedented dark energy and legacy science data set of $\sim$200M galaxy spectra over 1-4 μm, and provide powerful complementarity to ground-based facilities (limited to $\lesssim 1\mu$m by the Earth's atmosphere), which could target similar galaxies in the lower redshift range or different tracers of large scale structure over the same redshift range.

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