Response to NASA RFI NNH12ZDA008L
A UV/Optical/Near-IR Spectroscopic Sky Survey for Understanding Galaxy Evolution

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10 August 2012

Abstract

We outline the scientific benefits of a very large UV/optical/near-IR spectroscopic survey for understanding the evolution of galaxies, circumgalactic medium, and intergalactic medium in the era of galaxy assembly (z>1).

Scientific Goals

The prime objective of NASA's Cosmic Origins (COR) Program is summarized by the question, How did we get here? Important elements of this overarching question include: 1) How did galaxies evolve into the types we observe "in the here and now", and 2) When did supermassive black holes form and grow, and how have they have affected the lives of their host galaxies? 3) How are chemical elements distributed in galaxies and dispersed in the circumgalactic medium (CGM) and intergalactic medium (IGM)? 4) How does baryonic matter flow from the IGM into galaxies?

Hubble has already made great strides towards answering these questions. What we need now is to *understand* what processes are responsible for the evolutionary paths we see. Take for example, the first question on galaxy evolution. Thanks to the Hubble Space Telescope Deep Fields and surveys such as Galex and the Sloan Digital Sky Survey, we know that galaxies were more or less assembled by redshift z=1 (look-back time=7.7 Gyr), and most of the stars in the universe formed before z=1. The scientific frontier now is to look back further to z>1 galaxies to observe how galaxies evolved to form the familiar Hubble sequence of spirals and ellipticals and to establish which processes were responsible. Learning *how* galaxies evolved to the present day is the objective of WFIRST's near-IR *imaging* survey [1,2]; learning *what processes drove the evolution* is needed to *understand* galaxy evolution.

Scientific Investigation

Experience with the Sloan Digital Sky Survey of relatively nearby galaxies (z~0.1) suggests a s*pectroscopic* survey of a few times 10^5 to 10^6 galaxies at z>1 is essential for identifying the processes driving galaxy evolution, because only spectra can provide accurate redshifts, information on the kinematics of galaxies, physical conditions of the ISM, evolution of the mass-metallicity relation, co-evolution of black holes, etc. [3, 4]. Large numbers of galaxy spectra must be obtained in order to disentangle the effects on galaxy formation and evolution of accretion, interactions and merging, star formation and feedback, black hole growth and feedback. Similarly, a wide variety of environments must be studied in order to identify the processes that regulate cooling, condensation, and star formation. Thus, a wide-field telescope with a multi-object spectrograph(s) is needed.

Both the rest-frame UV and optical are rich in spectral diagnostics. The UV provides sensitivity to recent star formation, the properties of young stellar populations, the properties of the gas (column density and ionization state, metallicity and optical depth of the neutral gas, inflows and outflows, etc.), and properties of the dust component of galaxies [5]. The optical region provides accurate redshifts through sharp emission lines or the D4000 break, the stellar mass, and metallicity of the ionized gas. For z>1 galaxies, the observed wavelength range of these important diagnostics is 0.2-1.7 μ -- not quite the full expanse of Hubble (0.12-2.5 μ). This spectral range is covered well by a UV/optical/near-IR telescope with large-format CCD's and MCT detectors, just like on Hubble.

Note that the scientific benefits of the UV/Vis and near-IR are complementary; they usually do not overlap. For example, a UV/Vis spectrograph is uniquely capable of tracking Lyman α in the IGM and CGM around z>1 galaxies, while a near-IR spectrograph is uniquely capable of providing stellar mass of z>1 galaxies unbiased by star formation or dust. The point is that *spectroscopy over a wide wavelength range, 0.2-1.7 μ, viewing the same galaxies is required to obtain the full set of diagnostics that would lead to a physical understanding of galaxy evolution.* The Subaru/Prime Focus Spectrograph [3] is a first attempt at understanding galaxy evolution from simultaneous multi-object spectroscopy, but with a truncated spectral range, 0.38 – 1.3 μ, it cannot, for example, sample the all-important H I Lyα line in galaxies at z<2.2, or the Hα emission line in galaxies at z>1.0. A space-based mission is required to obtain all the important diagnostics.

Previous survey results [4] indicate that there are ~3,000 galaxies per square degree brighter than L* in each of 5 redshift shells: [0.6-0.8, 0.8-1.05, 1.05-1.35, 1.35-1.65, 1.65-1.95]. The rest-frame r-band flux of an L* galaxy at each of these 5 redshifts is [4.7, 2.4, 0.93, 0.50, 0.25]x10^{-18} erg/s/cm^2/A, respectively. These galaxies are faint! Worse, the zodiacal background is bright. Even worse for slitless spectrometers, the observed zodiacal background will be extremely bright because the background at each pixel is the integral of the zodi spectrum over the bandpass. The zodi may not be a problem for the slitless spectrograph on WFIRST, because it only needs to measure the redshift of relatively bright emission lines (~1x10^{-16} erg/s/cm^2), but it is a disaster for a telescope that needs to measure faint continuum fluxes (~1x10^{-18} erg/s/cm^2/A) of z>1 galaxies. The most promising approach is thus a multi-object slit spectrograph, employing a micro-shutter array or digital micro-mirror device for object selection.

Areas for Further Study

It is not clear what size telescope is needed or what difference-size telescopes can accomplish. To answer these questions, it will be necessary to carry out realistic simulations that will help us to evaluate the scientific yield of telescopes with diameters (0.5 m to 2.4 m) and spectral resolving power. Rough measures of the science yield are the time it takes to acquire satisfactory spectra (S/N>7 per resolution element) for 10^6 galaxies at z>1, the highest redshift shell that can be reached, and information on line widths.

Scientists involved in Euclid, WFIRST, or Subaru/Prime Focus Spectrograph have already carried out similar simulations. We would follow them in basing these simulations on the COSMOS Mock Catalog (CMC; [6]) of over 500,000 galaxies with redshifts in the range, z=0-6. Entries in the catalog give redshift, galaxy type, extinction, half-light angular radius, continuum fluxes in B, V, R, I, and K, as well as fluxes of important emission lines. The first step would be to predict the UV/optical/near-IR spectrum of each galaxy in the CMC using model stellar-population spectra + CMC emission-line strengths. Next, for each telescope aperture and associated slit mechanism, we would determine which galaxies can be observed and how many. Then, we would determine the time needed for various types of measurements, e.g. redshift, continuum fluxes, colors, and spectral breaks, and emission-line fluxes and line widths. Finally, we would analyze the data to estimate the science yield described by (1) the time it takes to acquire satisfactory spectra (S/N>7 per resolution element for 10^6 galaxies at z>1, (2) the highest redshift bin that can be reached, i.e. how far back in time can we look, and (3) possibility of measuring useful line widths. We would also use a modified version of the WFIRST exposure-time calculator [7] to predict the image properties and emission-line fluxes of galaxies in the CMC.

References

[1] New Worlds, New Horizons (2010), section 7, footnote 13: "Adopted by the committee, the name WFIRST was suggested … when the panel recognized a compelling opportunity in three separate inputs to Astro2010 (JDEM-Omega, the Microlensing Planet Finder, and the Near-Infrared Sky Surveyor) which, together, form the highest-priority activity".
[2] Stern et al. (2009) "The Near-Infrared Sky Surveyor", white paper submitted to Astro2010
[3] Ellis et al. (2012) "Extragalactic science and cosmology with the Subaru PFS", astro-ph/1206.0737v2
[4] Gunn et al. (2009), "Understanding the astrophysics of galaxy evolution: the role of spectroscopic surveys in the next decade", white paper submitted to Astro2010
[5] Martin et al. (2012), "Enabling Technologies for Next Generation Ultraviolet Astrophysics, Planetary, and Heliophysics Missions", http://kiss.caltech.edu/study/uv/UV_final_report.pdf
[6] Jouvel et al. (2009), " Designing future dark energy space missions I. Building realistic galaxy spectro-photometric catalogs and their first applications", A&A 504, 359
[7] Hirata, Gehrels, Kneib, Kruk et al. 2012, "The WFIRST Galaxy Survey Exposure Time Calculator", astro-ph/1204.515