GESE: A Small UV Space Telescope To Conduct A Large Spectroscopic Survey of z~1 Galaxies

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ABSTRACT

One of the key goals of NASA's astrophysics program is to answer the question: How did galaxies evolve into the spirals and elliptical galaxies that we see today? We describe a space mission concept called *Galaxy Evolution Spectroscopic Explorer* (GESE) to address this question by making a large spectroscopic survey of galaxies at a redshift, z~1 (look-back time of ~8 billion years). GESE is a 1.5-m space telescope with an ultraviolet (UV) multi-object slit spectrograph that can obtain spectra of hundreds of galaxies per exposure. The spectrograph covers the spectral range, 0.2-0.4 μm at a spectral resolving power, R~500. This observed spectral range corresponds to 0.1-0.2 μm as emitted by a galaxy at a redshift, z=1. The mission concept takes advantage of two new technological advances: (1) light-weighted, wide-field telescope mirrors, and (2) the Next-Generation MicroShutter Array (NG-MSA) to be used as a slit generator in the multi-object slit spectrograph.
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Keywords: galaxy evolution, ultraviolet, multi-object spectroscopy, microshutter array, lightweight mirrors

1. INTRODUCTION: SCIENTIFIC RATIONALE

In 2010, the Committee for a Decadal Survey of Astronomy and Astrophysics (Astro-2010) issued its report, *New Worlds, New Horizons* (Astro-2010, 2010), which recommended priorities for the most important scientific and technical activities of the decade, 2010-2020. The Astro-2010 report noted, "While we have a rather good description of the properties of galaxies in the present-day universe, we have far less information about how these properties have changed over the 13.7-billion-year history of the universe." Consequently, "a high priority in the coming decade will be to undertake large and detailed surveys of galaxies as they evolve across the wide interval of cosmic time."

In response to Astro-2010, we are developing a mission concept designed to make a large UV spectroscopic survey of galaxies at redshift, z~1, corresponding to a look-back time of ~8 billion years. In the next section, we describe the "flow-down" from scientific goals and requirements to mission concept. In Section 3, we describe the mission concept itself, and in Section 4, we describe

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two technology innovations that will make our mission concept more affordable and robust.

2. FORMULATION OF MISSION CONCEPT

We formulated a mission concept, which we call Galaxy Evolution Spectroscopic Explorer (GESE), by considering several questions:

What is the scientific goal? We wish to understand the origin of the Hubble Sequence of galaxies. Deep-field imagery by the Hubble Space Telescope has shown that galaxies are identifiable as spiral or elliptical galaxies by z~1, but the physical processes establishing the Hubble Sequence are not well known. The rest-frame far-UV (0.1-0.2 μm) is by far the best spectral region for determining the physical conditions and processes controlling galaxy evolution, because it contains many resonance lines of abundant elements in many stages of ionization.

Why a spectroscopic survey rather than a purely imaging survey? Only spectra can provide accurate redshifts needed to identify high-density regions (galaxy clusters). They are also needed to stack spectra of similar galaxies to increase S/N; to make a clean separation of continuum, absorption lines, and emission lines; to detect outflows from galaxies; to determine the physical conditions of the interstellar medium (ISM), circum-galactic medium (CGM), and intergalactic medium (IGM); and to determine the metallicity of the gas and stars separately. As explained by Ellis et al. (2012), "While many of the basic physical processes that drive galaxy evolution (dark matter halo merging, gas accretion, star formation and associated energy release, galaxy merging, black hole accretion and associated energy release) are known, how, [where], and when they operate remain unknown". Only with spectra can we answer the questions: how, when, and where.

Why a space telescope? The primary reason for a space telescope is to gain access to the ultraviolet region of the spectrum. Most galaxies at z~1 are star-forming galaxies with strong ultraviolet radiation (Jouvel et al., 2009), and the rest far-UV radiation (0.1-0.2 μm) emitted by a galaxy is by far the richest spectral region for diagnostics of star-forming galaxies (Figure 1).

Since the observed wavelength of a feature is longer than the wavelength at which it was emitted by a factor (1+z), GESE need only be sensitive at wavelengths as short as 0.20 μm to observe the rest far-UV spectrum of a z>1 galaxy. This short-wavelength limit coincides nicely to the effective short-wavelength limit of CCD detectors like that on Hubble's WFC3 camera (STScI, 2013). No other survey instrument, current or planned, takes advantage of the diagnostic riches of the rest far-UV.

Why restrict the observations to the UV? There are ambitious plans for deep spectroscopic surveys of galaxies by ground-based telescopes, most notably the Prime Focus Spectrograph (PFS, 0.4-1.3 μm) on the Subaru 8-m telescope, and the Multi-Object Optical and Near-IR Spectrograph (MOONS, 0.8-1.8 μm) on the VLT. Thus, there is no need to cover the optical/near-IR. We can simplify our task by observing galaxies only in the ultraviolet spectral region that ground-based telescopes can't reach.

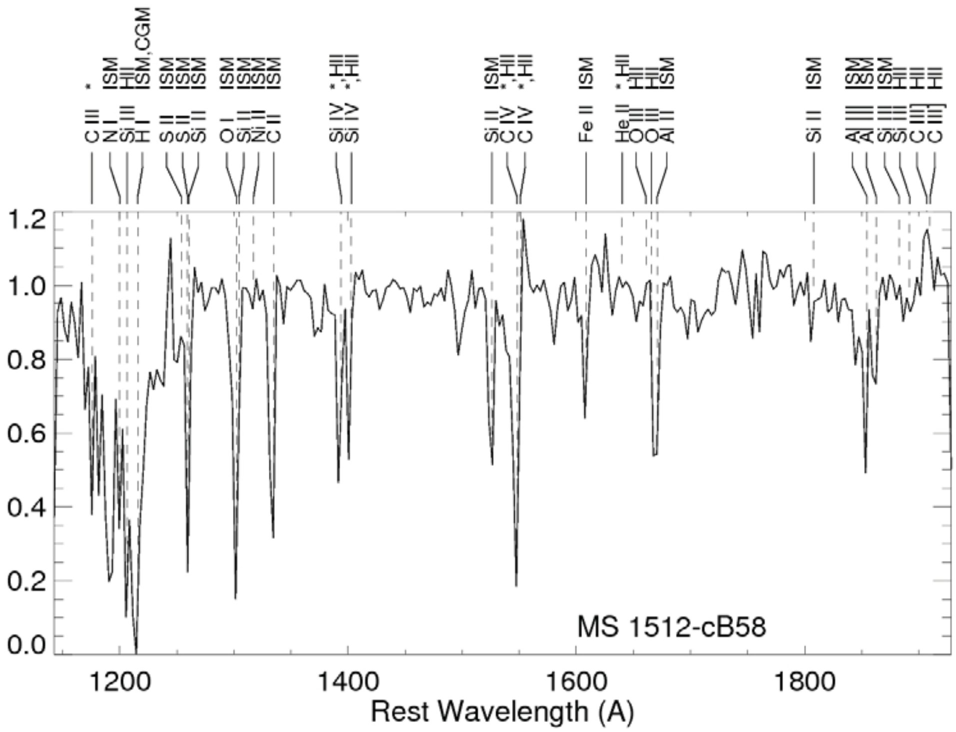

Figure 1. The rest far-UV is by far the richest spectral region for diagnostics of galaxies as illustrated by the observed spectrum of the z=2.7 star-forming galaxy, MS1512-cB58 converted to rest wavelengths (Pettini et al. 2000). The spectral data were binned to 3 Å per data-point in order to simulate the appearance of the spectrum at a resolving power, R~500. The spectrum shows diagnostic stellar lines (, e.g. Si IV, CIV), nebular lines (e.g. C III]), ISM (low-ionization lines), galactic outflow (Ly α and blueshifted ISM lines).*

There is much to be gained from combining the UV spectrum with optical/NIR spectra obtained by ground-based observatories. All three spectral regions – UV, optical, and IR – are needed to realize the full diagnostic power of any one spectral region. For example, the rate of star formation in a galaxy may be estimated from the luminosity of the Hα emission line as well as from its far-UV continuum flux. Sometimes these two estimates disagree, usually due to the presence of dust, which extinguishes UV radiation more efficiently than at the wavelength of Hα (6563 Å). The net result from the combined UV-optical-NIR spectrum is an estimate of the star-formation rate, dust extinction, and a measurement of the λ2200 extinction dip if present.

Information from ground-based observatories is essential just to select which galaxies to observe. We need to know the redshifts and magnitudes of candidate target galaxies already observed by observatories like Subaru/PFS and VLT/MOONS. GESE will therefore employ an optical camera to obtain an image of the field in an optical band (e.g. the SDSS *g* band) and compare it with *g*-band images obtained by Subaru or VLT. We will then use this information to acquire the target galaxies in the MSA shutters.

Why survey so many galaxies? There are basically two reasons. First, as pointed out by Gunn et al. (2009), there are many galaxy properties that can be derived from observation -- stellar mass, color, morphological type, rate of star formation, gas and dust content, etc. – but these properties are correlated. We need large samples to disentangle them in order to identify the main physical processes driving their evolution. Second, otherwise similar galaxies evolve differently depending on whether they are in the field or in clusters of galaxies. We need large samples of galaxies to cover a wide variety of environments.

How to obtain spectra of 10^5 galaxies at z~1? The Sloan Digital Sky Survey (SDSS) demonstrated that it is possible to obtain spectra of a million galaxies in a reasonable amount of time by making use of a multi-object spectrograph. In their case, they used over 640 optical fibers to isolate selected galaxies and obtain their spectra in a single exposure. In our case, we will use a Next-Generation Microshutter Array (NG-MSA) as a slit generator to obtain spectra of hundreds of galaxies in a single exposure.

Is it necessary to have a slit spectrograph? We need a multi-object spectrograph (MOS) with randomly selectable slits in order to eliminate confusion with nearby sources and to block out unwanted zodiacal background.

What size telescope? The target galaxies are faint. We need as large a telescope as is consistent with a NASA Explorer+ budget and as fast a telescope as allowed by the microshutter array (f/5). A 1.5-m telescope gives the best balance between light-gathering power and field of view vs. affordability on an Explorer-to-Probe budget.

3. GESE OPTICAL DESIGN

The overall optical design of GESE has been completed. It is based on a 1.5-m telescope feeding a MSA slit generator followed by a dichroic that directs the light to the UV spectrograph (0.2-0.4 μm) and optical camera (0.4-0.8 μm) simultaneously. Thus, the UV spectrograph and optical camera both view the MSA, which offers a field of view, ~1045" x 1045". The field of view of each microshutter is 0.83 x 1.65 arcsec (dispersion and cross-dispersion respectively). To acquire the target galaxies in the MSA shutters, we will first open all the shutters and obtain an optical image of the field in the SDSS *g* band. After identifying target galaxies selected from ground-based studies, we will close all shutters except those enclosing the target galaxies (and possibly guide stars). In the restframe far-UV, the typical half-light diameter of z=1 galaxies is ~1.5 arcsec (Ferguson et al 2004), but the brightness distribution of such galaxies is quite patchy, so a shutter will be opened on the brightest patch(es). In some cases, we may need to open two adjacent shutters to enclose a star-forming region and accept the consequent loss in spectral purity. After target acquisition, we will obtain an ~5-hour exposure (20-25 integrations) of the UV spectrum of the target galaxies.

Figure 2 shows the GESE optical design. The telescope is a three-mirror anastigmat (TMA) design. The UV spectrometer is an Offner-type spectrographs utilizing two concave mirrors and a convex reflective grating for dispersing the light. The mirrors are spherical, and the radius of curvature of the spherical mirrors is approximately twice that of the grating. We selected an Offner design, because it can accommodate a fast beam like that in GESE (f/5) and is very compact. Offner spectrographs are relatively new to astronomy. To our knowledge, BATMAN (Zamkotsian et al. 2013), being developed for the Telescope Nazionale Galileo is the only astronomical spectrograph with an Offner design. In contrast, Offner spectrographs are widely used for Earth science and remote sensing, where they work as a slit-image spectrometer (also called a hyperspectral imager). In our case, the field of view is not a slit but a 2D field, so it is more difficult to control the aberrations. We have therefore modified the basic design, using decentered spherical surfaces to provide good resolution.

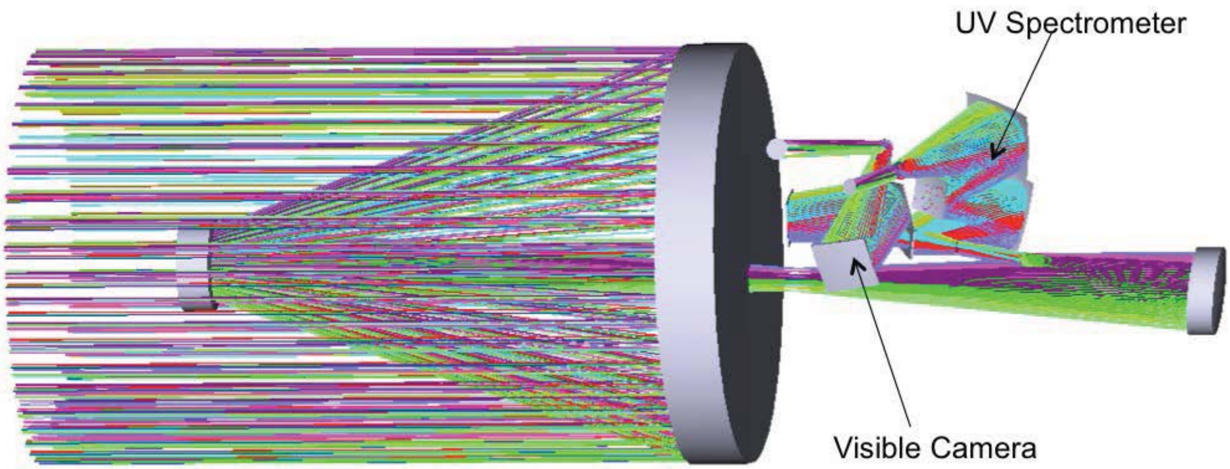

Figure 2. Preliminary optical design of GESE

4. TECHNOLOGY INNOVATIONS

Two new technologies – light-weighted telescope mirrors and microshutter arrays (MSA's) – promise to make GESE simpler, more affordable, and robust.

4.1 Schott's Lightweight Telescope Mirrors

The first major cost-cutting strategy is our selection of Schott's new lightweight mirrors for the GESE 1.5-m telescope for their technical, cost, and schedule benefits as summarized below. The mirrors are described in detail elsewhere (Hull et al., 2013). Here, we simply highlight the features that benefit GESE.

Technical benefits. The GESE mirrors will make use of Zerodur, the "gold standard" for thermally stable mirrors, for an ideal blend of lightweighting, low cost, short schedule, and minimal risk.

- The GESE 1.5-m primary may be lightweighted to a very respectable <50 kg/m^2

- Technical risk is minimized, because Zerodur is a proven material, having been used in HST, Chandra and 30 other space missions.
- Problems resulting from inhomogeneities within the mirror are eliminated, because Zerodur is monolithic and may be poured in monolithic homogeneous sizes to over 4-m diameter
- Other parts of the Optical Telescope Assembly (OTA) can be made lighter and less expensive, while meeting overall stiffness requirements for transport and launch, because the primary mirror is lightweight, yet stiff
- No discernible optical shifts in focus or alignment or line of sight are expected over the full operational temperature range, because of the exceedingly low thermal expansion characteristics of Zerodur
- Significant simplifications in OTA and payload requirements are possible since extensive passive and active thermal control become unnecessary
- The payload at large and even the spacecraft may be simplified since additional solar collectors and elaborate thermal controllers are not needed, nor power sources, wiring, logic and electronic complexity.

Cost benefits. With the reduction in mass and complexity, the cost profile for the GESE 1.5-m OTA resembles that of a much smaller telescope typical of most Explorer submissions. With the advantages from selecting this stable material, the GESE telescope has few complexities. There is no deployment, and it operates at near room temperature.

Schedule benefits. One of the benefits to come from Schott's Zerodur development is that fabrication times are greatly reduced. Schott produces several hundred metric tons of Zerodur each year for the most demanding requirements in the semiconductor market. Schott stores mirror blanks of the size we want, so build time for delivering a 1.5-m mirror substrate is less than 6 months, so the primary mirror is no longer a long-lead time item and no longer represents a major schedule risk. This is a major change in the mission development paradigm.

4.2 Next-Generation MicroShutter Array (NG-MSA)

The critical component of GESE science instrument is the slit generator. We plan to adopt the Next-Generation Microshutter Array (MSA), a step beyond the MSA's built for the Near-Infrared Spectrograph (NIRspec) on the James Webb Space Telescope. For our purposes the NG-MSA is similar to the MSA on NIRspec except that the shutters are considerably smaller (e.g 30x60 μm instead of 100x200 μm on NIRspec) and accommodates dramatically more shutters in the array. The NG-MSA is in the early stage of development at Goddard. Stay tuned!

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