UV/Optical/IR Surveyor: The Crucial Role of High Spatial Resolution, High Sensitivity UV Observations to Galaxy Evolution Studies

Benjamin F. Williams and Julianne J. Dalcanton
(ben@astro.washington.edu; jd@astro.washington.edu)
University of Washington

Luciana Bianchi (bianchi@pha.jhu.edu)
Johns Hopkins University

Overview: Models of galaxy formation and evolution are only as reliable as our knowledge of the individual stars responsible for the light we detect. From the prescriptions for stellar feedback, to numerical simulations, to the interpretation of galaxy colors and spectra, galaxy evolution research depends at its core on reliable star formation and evolution models. These models are calibrated using observations of resolved stellar populations in a wide range of environments. Studies of stellar populations in the UV have made great strides in the past decade with the *GALEX* UV surveys and the UV-sensitive WFC3 camera on *HST*. While these missions have certainly shed light on the evolution of stars and star clusters, the picture is still far from complete. To fully understand the processes that shape star formation in galaxies with a range of masses, metallicities, and gas content will require a large UV telescope. To make significant progress, goals for this future instrumentation will need to include improved spatial resolution to resolve individual stars in crowded extragalactic environments and a larger field of view to cover nearby galaxies with fewer pointings. We now discuss several science questions that should be addressed by the next large mission.

What objects produce the UV light in distant galaxies? Nearly all galaxies in the universe can only be detected through their integrated starlight, even in *HST* (e.g., Coe et al., 2006) or simulated *JWST* images.[1] To interpret this light requires reliable, well-calibrated models of stars, especially the brightest stars that dominate the luminosity-weighted average. Such models rely on large libraries of photometry and spectra of individual stars (e.g. Bruzual & Charlot, 2003). Such libraries are improving, largely due to *HST*. However, because of the limitations of available telescopes and instruments, the libraries only sample a small fraction of star forming environments, and they contain little UV data. Such incomplete libraries render our interpretation of light from all distant galaxies highly uncertain.

At high-redshift, when the cosmic star formation rate was at its peak ($2<z<4$, e.g., Reddy et al., 2008), the optical light we observe is largely stellar light redshifted from the UV. For the highest redshift galaxies observed ($z\sim8$; Bouwens et al., 2010), the only light we detect is UV emission redshifted to the near infrared. At these redshifts, the UV emission is dominated by young, massive stars. Constraining the physical properties (temperature, mass, age) of these stars is of great interest not only for measuring their contribution to the total light emission from the galaxy, but also for constraining their effects on the surrounding interstellar, and potentially intergalactic, medium. A Surveyor mission would, for example, allow us to characterize massive-star binaries across a wide range of environments from UV—IR SEDs. The resulting ages and mass limits will tightly constrain massive-star formation and evolution models critical to interpreting the restframe-UV of light from distant galaxies.

In addition, UV observations have proven incredibly sensitive to the evolution of old, low-mass stars. In particular, with resolved UV photometry of old stellar populations, we have begun to constrain short-lived, UV-bright phases of evolution that can significantly affect the UV luminosity of galaxies and are relevant to the yield of chemical elements. Furthermore, this UV-sensitivity has proven itself capable of constraining generations of stars at very old ages ($>$10 Gyr), something that was not possible with optical data alone.

How does feedback from star formation affect the evolution of galaxies? During their short lifetimes, high-mass stars produce ionizing radiation, powerful stellar winds, supernova explosions, and heavy elements. All of these processes contribute significantly to the movement, temperature, pressure, and chemistry of the gas in the galaxy potential. The fate of this gas — whether it escapes the galaxy, forms a hot halo, or cools and forms more stars — fundamentally shapes the evolution of the galaxy.

Massive stars provide most of the rest-frame UV radiation we observe, which is then used to infer fundamental properties, such as the initial mass function (IMF) and star formation rates. The utility of UV measurements is crucial, but must be calibrated using large samples of individual massive stars in a variety of environments, as we have begun to do with *HST* in M31 and M33 (Bianchi et al., 2014; Simones et al., 2014; Williams et al., 2014). A comprehensive library of massive star UV fluxes covering as many galaxy

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[1] http://www.stsci.edu/jwst/science/simulations/

types as possible is necessary to provide the best calibration of these models. Such a library would be well-served to include high SFR galaxies like NGC 253 and M82, as well as all nearby dwarf galaxies. Such observations require higher spatial resolution and UV sensitivity than *HST*.

What is the impact of dust on UV radiation in different environments? Only with UV observations of individual stars is it possible to separate the effects of temperature and dust reddening, allowing reliable measurements of stellar temperature and radii. This ability is shown in Romaniello et al. (2002) and more recently in Bianchi & Efremova (2006); Bianchi et al. (2011, 2012). Only wide-field ($>10'$), high spatial resolution ($<0.1''$) imaging in the UV can provide the necessary data for a large enough number of stars over a sufficiently large portion of nearby galaxies to probe dust effects on the star-formation process.

What is the impact of short-lived, UV-bright stellar evolutionary stages on integrated UV-fluxes? Thanks to *HST*, we now have the ability to resolve some of the UV emission from the M31 bulge and M32 into individual stars (Brown et al., 2000; Rosenfield et al., 2012). The stars responsible for the bulk of the UV light from old populations are now known to be extreme horizontal branch (EHB) stars (O'Connell, 1999; Brown et al., 2000). However, we only cleanly resolve the bright end of the UV-bright populations in the M31 bulge and M32 with the current instrumentation. These brightest stars are the post-HB stars, not the much more numerous EHB stars responsible for the bulk of the UV flux, which cannot currently be probed directly. As a result, only a handful of these stars have been studied in detail in our Galaxy (Busso et al., 2005); however, detailed observations of a large sample will require the next generation UV telescope to have higher sensitivity and spatial resolution than *HST*.

How do massive star clusters form? Because the UV contains a strong nitrogen-sensitive absorption feature, the UV photometry easily separates multiple stellar populations within a single cluster (e.g., Milone et al., 2012). These measurements of processes that occurred more than 12 Gyr ago are made possible by high spatial resolution, high sensitivity UV observations. Performing such detailed studies on the younger and more metal-rich globular clusters in M31 (and some of the younger and lower metallicity clusters in M33) for example, would provide a significant leap forward in our understanding of the formation of globular clusters under more diverse conditions.

Technical Goals: The next mission would fundamentally improve our available libraries of resolved stars if one of its goals were to resolve the stars of interest in the nearest galaxies with star formation rates comparable to those at high-redshift. These are NGC 253 (Engelbracht et al., 1998) and M82 (Telesco, 1988), at distances of $\sim$4 Mpc. A new regime in observational experiments can be reached with a diffraction limit roughly a factor of 4 better than that of *HST*, *i.e.*, an 8–10 meter UV/Optical space telescope.

Furthermore, field of view is of great importance. Cameras with more than 100× the current number of UVIS pixels are under construction (Gilmore et al., 2012), suggesting a large increase in field of view may be possible for the next generation of space telescopes. Such an increase would boost the productivity of the observatory by an two orders of magnitude.

Finally, covering full stellar SEDs from the extinction bump at 2000 $\AA$ to the near-IR is ideal for separating the effects of temperature and dust. However, we note that the UV provides the most leverage at high temperatures and cannot be observed from the ground, making it the highest priority.

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