The earliest epoch of star-formation in the very young universe

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Motivation: One of the most intriguing accomplishments in astrophysics during my lifetime has been the elucidation of the timeline of the origin and evolution of our universe. A particularly interesting and surprising discovery (to me) has been how quickly structures such as supermassive black holes, early galaxies and the first generations of stars got started. We see indications of Gamma Ray Bursts, quasars and proto-galaxies near redshift 7-8, corresponding to a time when the universe was barely 10% of its current age. Somewhere in this distant past, perhaps 12 billion years ago, a first epoch of star formation must have produced individual objects composed of primordial Hydrogen and Helium, whose supernova explosions started the enrichment of the otherwise pristine universe with the products of nuclear reactions in their cores and detonations. Although this scenario has been modeled and simulated with increasing sophistication, observation of these stars remains beyond the capabilities of current instruments. Studying the stellar astrophysics of this population and clarifying this period in the timeline of cosmic origins will be a worthy goal for a future large UV/Optical/IR Surveyor.

Relationship to other large missions: In the two decades before this observatory can be launched other facilities will make progress towards similar goals. JWST includes “first light” and the assembly of galaxies as important scientific themes. WFIRST-AFTA will conduct deep, high resolution surveys that will discover very young galaxies magnified by gravitational lensing. LSST will pursue sensitive time-domain science that may provide hints about SNe rates in high redshift galaxies. TMT and GMT may obtain spectra of distant star-forming regions in young galaxies. Radio experiments such as SKA and DARE may study conditions during the Dark Ages that led to the first luminous objects and reionization of the mostly neutral universe. The design and research program of the UV/Optical/IR Surveyor will benefit from these and other advances.

Some specific science objectives:

1. Show which candidate Pop III objects are stellar with core nuclear burning, not black hole accretion disks
2. Assess whether clusters of large number of objects formed together, or whether small numbers of more massive objects were favored
3. Measure their Spectral Energy Distributions over a wide wavelength range
4. Detect spectral features of H and He showing profiles attributed to stellar winds
5. Determine the highest redshifts at which stellar objects are detectable, establishing the earliest epoch of star formation
6. Measure their colors and luminosities, construct and interpret Color-Magnitude Diagrams, Luminosity Functions and/or Initial Mass Functions if statistics allow
7. Measure the sizes and environments of star-forming regions
8. Search for indications of gas or dust, such as H II regions
9. Detect the early signatures of non-zero metal content in nebular emission lines, revealing the products of p-p burning and later CNO processes, and those of explosive nucleosynthesis
10. Detect and characterize SNe events in the population of first-generation stellar objects
11. Identify the end of the epoch of first generation of stars in redshift and time.

Instrument capabilities needed:

- High spatial resolution imaging – resolve structures comparable to Carina or 30 Doradus at z=10
- Tunable filters – image in selectable rest-frame spectral bands at arbitrary redshifts
- Energy-sensitive detectors – enhance wavelength selection and rejection of out of band light
- IFS spectrograph to determine redshifts, measure SEDs and detect emission lines of H II regions

- Spectrograph capable of measuring interstellar, circum-galactic and inter-galactic absorption features at all redshifts along the line of sight

Characteristics of the telescope and observatory:

- It will be similar to HST in many respects, but may reach 5 magnitudes or more deeper
- To achieve the highest possible angular resolution the telescope will have a large diameter, 10m or more, and will be diffraction-limited in optical or shorter wavelengths
- To provide high sensitivity for faint objects it will need a large collecting area, efficient reflective coatings and instruments. V=30 may be a representative point source magnitude. $50m^2$ might be a starting point for size, as it was for the Modern Universe Space Telescope (MUST) Vision Mission concept study.
- The observatory will operate in "point and stare" mode, and will have the stability to point to a fraction of a spatial resolution element for the duration of longest exposures.
- The observatory will respond to detection of a SNe event by other facilities as a Target of Opportunity.

Technology development: If we make the reasonable assumption that the desired resolution and sensitivity will require an aperture greater than the largest fairings, then a monolithic primary seems unlikely, and technologies for a large segmented mirror will be needed. Many have been under study already. Progress on telescope and instrument technologies will need to be reported to the 2020 Decadal Survey. For example:

- It should be designed to fill the volume and mass capability of largest launch vehicle and fairing available at the time. It should not be limited by fairing diameter. This will require approaches for efficient and safe packaging, as suggested in the MUST study report.
- Technologies for robotic deployment or assembly in space.
- Robotic servicing of science instruments and observatory systems.
- IFU for IFS at all wavelengths, including UV. Does not need to be same technology for all wavelengths.
- Energy resolving detectors.
- Tunable filters with selectable central wavelengths and passbands.

Is it a large mission? In terms of physical size, versatility of its payload, operational capabilities, development cost and schedule required, yes, this will be a large mission.

- A primary goal is to provide the largest collecting area and angular resolution possible.
- Sun-Earth L2 is probably the right operational orbit.
- It will have access to the entire celestial sphere during its annual orbit.
- It will be required to remain on target for days to weeks at a time.
- It will have a lifetime of many years – long enough to observe a few SNe of Pop III objects.
- It is a general purpose observatory, available to a large community with a wide range of research interests.
- The observatory will support many science instruments, and will allow replacement and refurbishments.
- There will be a robust ground system for operations and user support, including superb communication of findings to the public.

Summary: The UV/Optical/IR Surveyor will be a worthy successor to HST, JWST and AFTA in scientific accomplishments, a decade or more of service to a large community of extremely capable researchers, and recognition by an informed and receptive public. Every mission pushes back farther in time and space. The investigations of the earliest epoch of star formation and production of heavy elements described here are unlikely to be accomplished by other ground or space-based observatories in the near future.