A LARGE *MONOLITHIC*–APERTURE OPTICAL/UV *SERVICABLE* SPACE TELESCOPE DEPLOYED TO L2 BY AN ARES-V CARGO LAUNCH VEHICLE.

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Introduction: Seeking answers to fundamental questions in astrophysics will ultimately require the deployment of one or more large-aperture, space-based optical/UV telescopes sometime in the next decade or two. This scientific quest includes firmly establishing the timeline for the reionization of neutral Hydrogen in the Universe, mapping the large-scale distribution of baryonic ('ordinary') matter, identifying the processes that govern galaxy and star formation, establishing the processes that drive planet formation, determining the physical characteristics of a large sample of exosolar gas giant and terrestrial planets, and looking for biosignatures from planets orbiting within the habitable zones of nearby stars.

The diversity of these questions argues for a general purpose, large-aperture space-based observatory that can be placed at an optimal location (e.g., Sun-Earth L2) and, at the same time, allow for periodic instrument upgrades and system repairs. The wide fairing and heavy-lift capability of the Ares V Cargo Launch Vehicle provides a solution by enabling the deployment of a telescope that combines the light gathering power of the *James Webb Space Telescope* (JWST) with the serviceability of the *Hubble Space Telescope* (HST).

The Science Case: Recent discoveries by NASA missions (e.g., HST, WMAP, GALEX, Chandra, Spitzer) have raised new questions about the origin and evolution of the Universe, its structures, and life, and have given new urgency to the need of a large monolithic, UV/optical telescope in space. Those discoveries are an integral part of NASA's Origins roadmap, such as the Origin, Structure, Evolution and Destiny of the Universe, and the Search for Extra-Solar Terrestrial Planets.

A wide-field imager (~10 arcmin field-of-view) sitting behind a 6 to 8 meter class optical space telescope would provide break-through science by enabling surveys covering many square degrees of sky to sensitivities better than 30th magnitude, yielding a probe of the Universe that is 1,000 times the volume of the various *Hubble* deep fields combined. Such sensitivity when coupled with the high angular resolution (~0.02 arcsec; about 4 times better than that expected for the JWST) and a stable point spread function (PSF) will provide a completely new view of the distant Universe. However, observations of distant galaxies can tell us only part of the history of galaxy formation and evolution. They will *not*, for example, tell us the assembly histories (merger trees) of galaxies, even in a statistical sense. A complete understanding of galaxy formation requires <u>both</u> high-redshift observations *and* comprehensive studies of the present-day galactic and intergalactic structures, especially those features that provide fossil records of the events and processes involved in their formation. A 6-8m class space telescope with a UV/optical/nearIR wide-field imager will be a superb facility for studying the fossil record of galaxy evolution, through observations of resolved stellar populations both in the Milky Way and in nearby galaxies. With such a facility, accurate stellar photometry at magnitudes fainter than 28-28.5 in I (AB magnitudes) can be achieved. Red giant stars and blue Horizontal Branch stellar populations could be distinguished and studied in nearby galaxies up to distances of about 10 Mpc – ten times farther than is possible now. This capability would address standing questions in galaxy evolution, like the dearth of satellites around galaxies (a factor 10 lower than predicted by models and simulations), and the census of stars formed early in the Universe, before redshift 2 (older than 10 billion years).

Fig. 1: A distant galaxy (8 billion light years away) as seen by HST (left) and a diffraction-limited 8-m optical space telescope (right). The 8-m image enables studies of the stellar populations not possible with HST (or JWST).

Common or baryonic matter, albeit only a small fraction (~4%-5%) of the total mass – energy budget in the Universe, is of paramount importance for understanding the evolution of the Universe and its observable structures. Reionization, the last major phase transition for most of the baryonic matter in the Universe, started around redshift 12 (from WMAP results) and was completed around redshift 5-6. However, the source(s) of ionizing photons is not fully accounted for, yet. A wide-field optical imager with grism spectroscopy and the high angular resolution afforded by a space telescope would provide a full census of galaxies and quasars (and thus available ionizing photons) in the critical redshift range 5.5 – 7 (corresponding to a time when the Universe was ~7% of its present age).

While over 90% of baryonic matter is accounted for at high redshift (z>3), over 50% of the baryonic matter in the nearby Universe is unaccounted for. The '*missing baryons'* are predicted to be (according to cosmological simulations) in the form of warm-hot gas (10^5-10^7 deg K) in the intergalactic medium that has, so far, escaped detection. A UV spectrometer (only possible in space) on a 6-8m telescope would detect the weak UV absorption lines imprinted by the hot intergalactic medium on the faint spectra from distant quasars; this would constrain the models' predictions, and shed light on the evolution of 'normal' matter.

An ultra-sensitive, panchromatic wide-field imager in space is also an ideal instrument to directly address at least three key elements in NASA Origins roadmap, namely (i) to obtain a census of planetary systems around stars of all ages, (ii) to determine chemical and physical properties of giant extrasolar planets, and (iii) to determine how common are terrestrial planets. Although the last few years have witnessed dramatic progress in our knowledge of planets around other stars, many key questions remain unanswered. In particular: Are planets equally common around stars of different spectral types? Does planet formation require a special environment such as high metallicity? Are Earth-mass planets as common as the giant planets? *Kepler,* which is designed to detect planets down to earth-mass planets around F, G and K stars within about 200 pc, will answer some of these questions (it's launch is currently scheduled for late 2008). A wide-field imager on a large telescope will complement *Kepler* and can be used simultaneously for planetary transit surveys as well as a microlensing experiments to directly address the above questions. For example, because of its unsurpassed sensitivity, the wide-field imager should be able to detect one Earth-mass planet and 30 total planets in a single 21 day observation run, using microlensing. Furthermore, a 6 to 8-meter facility with a UV spectrograph will enable spectroscopic studies of the atmospheres of transiting extrasolar planets. Our understanding of the nature of extrasolar planets will be greatly increased by such a UV spectrograph, as it will observe the atmospheres of short period (~3 to 4 days) "hot Jupiters" orbiting relatively near bright stars, as they get `boiled' away by the central star.

All the fundamental unanswered issues discussed above require the ground-breaking capability of a 6-8 meter optical/UV telescope in space. Such a telescope will be 10 times more sensitive than Hubble, and will be diffraction limited at a wavelength 4 times shorter than JWST. All experiments described above rely on the higher sensitivity afforded by the large mirror, either to reach larger distances for galaxy populations or fainter mass limits for stars and planets. The higher sensitivity and the UV window (only accessible from space) will enable the imaging of faint hot stellar populations in nearby galaxies and enable spectroscopy of the faint absorption lines from the '*missing baryons*' and from hot Jupiters. A monolithic mirror will provide a circularly symmetric PSF with well-behaved wings, and the space environment will provide a narrower and much more stable PSF and a wider field-of-view than those provided by a 30-m telescope on the ground with adaptive optics.

Ares V Enables a Paradigm Change: For more than a decade, launch vehicle mass and volume constraints have limited space telescopes and driven programmatic cost and risk. ***The Ares V eliminates these constraints and enables the launch of a massive 8 meter class monolithic telescope to L2.*** The Ares V has the ability to deliver ~60,000 kg to L2 inside a 10 meter diameter by 30 meter tall fairing. Such a launch volume would allow the fielding of an observatory of size approximately equal to a Gemini or VLT – 8.2 meter diameter and ~15 meter tall. Furthermore, such an up mass capability allows one to use very low cost and low risk conventional mirror and structure technology. It is almost possible to fly a conventional ground based telescope mirror. Typical ground based 8 meter class mirrors have a mass of ~22,000 kg (440 kg/m^2) and are polished to better than 10 nm rms. To save mass, mirrors can be pocketed using conventional machining or casting techniques. Finally, the structure for such a telescope need only be sufficient to survive launch. Space eliminates the challenges of gravity sag and wind loading.

L2 as Virtual Mountain. Ground based telescopes have lifetimes greater than 50 years because optics are very long lived and instruments are serviced and replaced on a regular basis. *Hubble* has demonstrated this model in space and has proven the utility of on-orbit servicing. With development of in–space operations, such as autonomous rendezvous and docking and robotic servicing, it is time to bring this model to Sun-Earth L2. One could design an 8 meter class telescope that is completely passive to which is attached a spacecraft containing all electronic systems, mechanical control systems, propulsion and scientific instruments. Then, every 3 to 5 years, a new spacecraft could robotically replace the old one and start a new scientific observing campaign with all new avionics and instruments, making L2 the ultimate astronomical summit!