Introduction
Important advances in our understanding of the universe have always proceeded in conjunction with advances in observational instruments, starting with Galileo’s startling discoveries. The Hubble Space Telescope, arguably the most significant astronomical instrument ever built, has shown what can be achieved with a large-aperture, space-borne telescope. Emerging technologies now permit astronomers and engineers to contemplate an Advanced Technology Large-Aperture Space Telescope (ATLAST). Such a telescope would be capable of studying exo-planets for signatures of biological activity, investigating the structure and formation history of galaxies, and producing high-resolution images of distant Solar System objects to name just a few science programs. However, the most exciting discoveries are likely to come from observing phenomena that are unknown today. In this poster we discuss the conceptual optical design for a 16-m, segmented primary mirror version of ATLAST.

16-m ATLAST Conceptual Design
Telescope Requirements
As indicated by the title of this poster, the three fundamental requirements for this telescope are a 16-m entrance pupil diameter, a primary mirror consisting of segments, and a bandwidth from approximately 120 nm (Lyman α) to 2 μm. The wavefront error (WFE) requirement, as specified by the science team, is diffraction-limited performance (λ/14) at 500 nm. Of the allowed 36 nm rms WFE, we have allocated 25 nm (λ/20) to the design as a requirement with a goal of 20 nm (λ/25). This allocation is based on an error budget for a generic large aperture, segmented telescope with segment rigid body and figure control. It is recognized that the telescope will also need pointing control. However, the level of pointing stability is likely to vary between the instruments. For example, the visible imager will require sub-milliradian second pointing stability. We have opted to include pointing sensors as part of the instrument suite but let the individual instruments implement their own pointing mechanisms.

We have required the primary mirror (PM) focal ratio to be no slower than 1.5. This keeps the telescope reasonably compact, reducing structure mass, and increasing the stiffness of the secondary mirror (SM) support structure for a given mass. The secondary mirror itself is required to be approximately the size of a single PM segment. This requirement comes from one of the instrument, namely the visible nulling coronagraph (VNC). The VNC also imposes some “soft” requirements such as minimizing the number of reflections preceding the instrument and minimizing the angle of incidence of those reflections to reduce polarization-dependent phase shifts. The choice of the VNC for exo-planet characterization is discussed in companion poster 450.04 (J. Krist et al.). Other soft requirements are the desire for an accessible pupil image where one might locate a deformable mirror or fine/fast steering mirror for wavefront and pointing control. Also, compressing the beam prior to the instruments means smaller, lighter and cheaper optical elements within the instruments.

One of the most stringent requirements is the ability to package such a large telescope and its associated instruments in the launch vehicle fairing. It is anticipated that the 16-m ATLAST will be launched by an Ares V (see Lilley et al., poster 450.05). While several concepts exists for “folding” the PM, developing a suitable arrangement of the instruments within the allocated volume is still under study.

Instrument Suite
The telescope optical design and packaging concepts are intimately connected to the desired suite of instruments and their particular optical requirements. For this design work the science team has suggested the following instruments: (1) Visible/NIR imager with a 4 arcmin square field of view (FOV); (2) Visible/NIR multi-object spectrometer (MODS) with a 2 arcmin square FOV; (3) Visible/NIR integral field unit (IFU) with a 1 arcmin square FOV; (4) High-resolution UV spectrometer with a 15 arcsec diameter FOV; (5) VNC with ~1 arcsec diameter FOV; and (6) three fine guidance sensors (FGS) with a combined FOV of at least 8 arcmin2. It is clear from the above list that the instruments fall into two categories based on FOV. Furthermore, the two instruments with narrow FOV requirements, the UV spectrometer and the VNC, also benefit from a minimum number of reflections.

Optical Design and Performance
We have based an on-axis design form for the 16-m ATLAST for reasons of stability and optical performance. The on-axis form makes packaging and deployment of the SM easier while providing more SM stability for a given mass of the support structure. The instrument most affected by pupil obstructions caused by SM supports is the VNC. However, the diffraction effects from the SM support structure are dominated by the diffracted light from the PM segments. To meet the requirements of the instruments described above, the telescope optical train was bifurcated based on FOV and number of reflections. That is, the UV spectrometer and VNC receive light from a conventional Cassegrane telescope while the other instruments are preceded by an additional two powered elements to correct the wavefront over a larger field and three elements that re-image the pupil, and compress and collimate the beam. The two channels, referred to as the narrow and wide FOV, are shown separately in unfolded form for clarity in Figs. 1 and 2 respectively. In this design, the optical train for the WFOV channel ends at the compressed, re-imaged pupil. There are a number of options at the pupil for wavefront cleanup and fine pointing, depending on the particular requirements of the instruments. The fact that the light is collimated at this pupil allows each WFOV instrument to easily set the plate scale they desire with a single focusing element. The compression ratio is approximately 52 so the beam entering the WFOV instruments is 31 cm in diameter. The beam compression reduces the size and cost of the WFOV instruments.

The performance of the NFOV and WFOV channels, across the field is shown in Figs. 3 and 4 respectively. The figures show that the NFOV exceeds the design goal (λ/25) with considerable margin while the WFOV meets the design requirement. The location of the various instrument FOVs in shown in Fig. 5. As the figure illustrates, all the fields are symmetric about the telescope optical axis with the NFOV cut out of the center of the WFOV. This small “hole” in the WFOV was deemed acceptable by the science team. Note that the WFOV is shared by the visible/NIR imager and the combination of the MOS and IFU. This field splitting can be accomplished using a beam splitter; this arrangement trades improved optical performance at the cost of incident flux for the individual instruments.

Segment Technology
Future large optics programs, such as the 16-m ATLAST, will require a new paradigm for the design and fabrication of segmented mirrors for space telescopes. The technology development of meter-class, actuated hybrid mirrors (AHMs) specifically addressed the problem of how to provide tens of square meters of optical quality, lightweight, space-qualifiable optics with a reasonable cost and fabrication time. These AHMs, shown in Fig. 6, are a combination of three distinct technologies: (1) a metallic nanolaminate facesheet that provides a high optic quality reflective surface; (2) a SiC facesheet that provides structural support and houses actuators to provide an adaptive surface figure; and (3) wavefront sensing that provides active figure control. That is, the AHM replaces passive mass with actuators and controls, while maintaining a high level of optical performance (low-scatter and diffraction-limited imaging). They will reduce the mass area density of large mirrors to 12-15 kg/m2 while reducing the manufacturing cycle time from years to months.

Summary
We have shown a conceptual optical design that meets the performance requirements for a 16-m space-borne telescope operating over the spectral range from 100 nm to 2 microns and its proposed suite of instruments. The conceptual solution was to divide the optical train into two channels based on field of view. Each channel can be optimized for a particular set of instruments.

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