A key component of our 2008 - 2009 NASA Astrophysics Strategic Mission Concept Study entitled "An Advanced Technology Large-Aperture Space Telescope (ATLAST)" is the identification of the astro-physical questions that can be uniquely addressed using a large, large-aperture UV/optical space telescope with an angular resolution 5 - 10 times better than JWST. We summarize four research areas that are amongst the prime scientific drivers for such a remarkable facility:

• The detection of habitability and bio-signatures on terrestrial extrasolar planets
• Direct constraints on the nature of dark matter by accurately determining the mass density profile of dark galaxies.
• The reconstruction of the detailed history of the formation and assembly of stellar mass in the universe.
• The precise determination of growth of structure in the universe by kinematic mapping of the dark matter halos of galaxies as functions of time and environment.

Abstract

A 6-meter to 16-meter UVOIR Space Telescope for the 2025 - 2035 Era

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The characterization of Terrestrial-Mass Exoplanets

"Does life exist elsewhere in the Galaxy?"

Terrestrial mass (<10Mrjpl) planets within the habitable zones (Kz) of nearby stars may harbor life as we know it. If that life alters the atmospheres of such planets as it has on Earth through the production of oxygen today or methane by anaerobic methanogens in early periods, ATLAST will detect the resulting bio-signatures in the planet spectra.

Dwarf spheroidal galaxies (dSph) are extraordinary sites to explore the properties of non-baryonic dark matter (DM). Their mass is dominated by DM – they are observed to have mass-to-light ratios 10 to 100 times higher than the typical L
• galaxy. They are abundant nearby – to date 23 dSph galaxies have been found in the Local Group. Most striking, is the discovery that nearly all dSph galaxies, covering more than four orders of magnitude in luminosity extent, have the same mass (~1012M
•) within their central 300 pc (see Fig. 3).

Comparison with Large Ground-based Facilities

High Angular resolution coupled with high sensitivity is increasingly a science-driven requirement for astronomy. The 20-m to 40-m ground-based telescopes using Multi-Conjugate Adaptive Optics Systems will redefine the capabilities of ground-based imaging and spectroscopy. But there remain unsustainable advantages of space in the UV+NIR range:

• Wide-fields (several arcmin) or panoramic imaging (tens of arcmin)
• Stable, high Strehl ratios (>90%)
• Precise wavefront sensing and control
• Highly stable PSFs (>2% variability spatially and temporally)
• Ultra precise photometry (>0.001 mag) and astrometry

We compare the "time to reach a S/N=10" as a function of spectral resolution for a 30-m ground-based telescope with that for 8-m and 16-m space telescopes. All assumed to have the same instrumental and wavefront stability and its wide-field imaging capability.

Determining the Nature of Dark Matter in Dwarf Galaxies

The ability of DM to cluster in phase space is limited by intrinsic properties such as mass and kinetic temperature. Cold DM particles have negligible velocity dispersion and very large central phase-space density, resulting in cuspy density profiles. Warm DM halos, in contrast, have smaller central phase-space densities, so that density profiles saturate to form constant central cores. The mean density profile of dSph galaxies is, thus, a fundamental constraint on the nature of dark matter.

To measure the DM profiles, one needs to measure the proper motions and the radial velocities of stars in dSph. Both measurements are needed to break dark dynamical degeneracies between the inner slope, mass profile and velocity anisotropies of stellar orbits. Fundamentally new constraints on DM can be reached by determining proper motions for ~100 stars per galaxy with accuracy <10 km/s at a distance of 60 kpc, plus ~1000 radial velocities (cf Bullock et al., 2009). ATLAST will have the required astrometric precision to perform these proper motion measurements owing to its very high wavefront stability and its wide-field imaging capability.

Precise determination of the Stellar IMF and the History of Stellar Mass Assembly

The stellar Initial Mass Function (IMF) is the fundamental parameter for quantifying the evolution of luminous baryonic matter. Yet current star formation theories cannot predict the shape of the IMF and whether or not it is "universal" (i.e., does the IMF depend on environment?). Observational constraints on the IMF are limited to the Milky Way and Magellanic Clouds - a limitation imposed by the angular resolutions and sensitivities of existing telescopes. An 8-m to 16-m space telescope with UV/optical sensitivity (to access the high-mass end of the IMF) working with a large (~30-m) ground-based telescope capable of diffraction-limited performance in the NIR (to access low-mass stars) will provide full IMF determination for all galaxies out to 2 Mpc. This will broaden the range of environments and morphological types in which the IMF is known, and will expand the predictive power of our theory of star formation.

Observations of solar-luminosity stars on the main sequence are essential to reconstructing the star formation history over the entire lifetime of a galaxy. An 8-m to 16-m space telescope will open the door to the "stellar history" of galaxies with masses that are 100 times smaller than those probed by current ground-based facilities. A space telescope will also enable the detailed study of the structure and kinematics of individual foreground galaxies. These histories hold fundamental (but as yet unknown) information about galaxy formation.

Precision Measurements of the Growth of Structure

The bulk of the stellar mass assembled in galaxies between z ~ 3 and z ~ 1, by which time the Hubble sequence was essentially in place. By carefully following the growth of mass and stellar populations over this key cosmic period, the total (dynamical) masses and metalloïd content of galaxies can be measured by means of gas kinematics from absorption spectroscopy of background galaxies, if sufficient spectroscopic sensitivity is available (see Figs. 4a,b), essentially using galaxies in the same way as quasars have been used to study the IGM.

Galaxies are vastly more abundant than quasars, especially at high redshifts, by ~100-fold down to a common flux level. This allows one to precisely map resolved kinematics of individual foreground galaxies. An 8-m to 16-m UVOIR space telescope can uniquely probe the 1<z<3.5 range where the absorption lines are superposed on nearly featureless profiles of the emitter’s rest-UV spectrum (Fig. 7).