The Long Wavelength Limit of LUVOIR

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Initially the long wavelength limit of ATLAST[1] was set at 1.8 μm with a stretch goal of 2.5 μm. This choice was driven in large part by the perception that working at longer wavelengths necessarily requires a cooled telescope, and by the cost and complexity of that cooling.

However, it is easy to show that this perception is a misconception, and that a large space telescope >8 m in size, say, can do marvelous science from 2.5-to-5 μm even if it operates at a nominal temperature of 270-to-290 K. For many purposes, of course, colder is better, but for some important science drivers for ATLAST/LUVOIR, particularly in the exoplanet area, the telescope temperature does not significantly impact scientific productivity.

Or course, it is known from work on the ground that important infrared observations can be done with a large telescope working at the high background levels encountered from a warm telescope operating within the atmosphere. However, taking that same warm telescope and putting it into space provides the following advantages:

- Access to the entire infrared spectrum, a good bit of which is blocked out from the ground by the very molecules one might hope to study in exoplanet atmospheres
- Radiometric as well as Mechanical stability, which will facilitate achieving the high photometric precision [far in excess of 100 ppm] required for transit and eclipse spectroscopy of exoplanets and the wavelength stability needed for high-precision radial velocity
- Higher sensitivity, a consequence of the absence of atmospheric absorption, emission, and turbulence and the routine achievement of diffraction-limited performance
- Clear skies and long observations, which guarantee that a particular portion of a planet's orbit can be observed if it is accessible, with no worries about clouds, rain, or snow, and observed for many hours if needed without worrying about morning twilight. This is very important because long-period planets will have a transit only a few times per year, and phase-specific radial velocity or thermal flux observations must be carefully planned.

A group from JPL, GSFC, and STScI have taken a serious look at the exoplanet science which could be done from 1-5 μm on a LUVOIR without cooling. We focus on exoplanets because exoplanet studies are certain to be a major part of the rationale for any LUVOIR type system in the near future. We focus on 1-5 μm because that spectral band is rich in molecules, including CO, CO_2, H_2O, and CH_4, which have potentially interesting biogenic implications. Note that the strongest band of CH_4, which has been suggested as a biomarker in circumstances where O_2 andO_3 yield ambiguous results due to possible degeneracies, lies at 3.4 μm. Of course, with more time and greater resources, one could examine a wider range of long wavelength limits [note that radiation from 5-8 μm is absorbed in the Earth's atmosphere by water vapor, so extending the wavelength range to 8 μm has considerable appeal] as well as the benefits of cooling the telescope [our large space telescope will want to cool radiatively and will have to be heated to maintain a temperature of 273 K]. Finally, we note that millions of sources seen at 3.4 and 4.6 μm in the WISE survey, could be studied at resolving power R~200 by a warm space telescope of 8m+ diameter.

[1] In this memo, we use LUVOIR and ATLAST more or less interchangeably, although we recognize that they are in fact not necessarily identical; ATAST is one possible realization of LUVOIR.

Exoplanets orbiting the brightest stars will always be the most attractive targets, and will often put us into a regime where the main source of noise is the stellar photon noise rather than the background noise. In this limit, it is easy to show that a ~9.2-m diameter space telescope operating at 295 K will outperform the much colder James Webb Space Telescope, as is shown in the figure below.

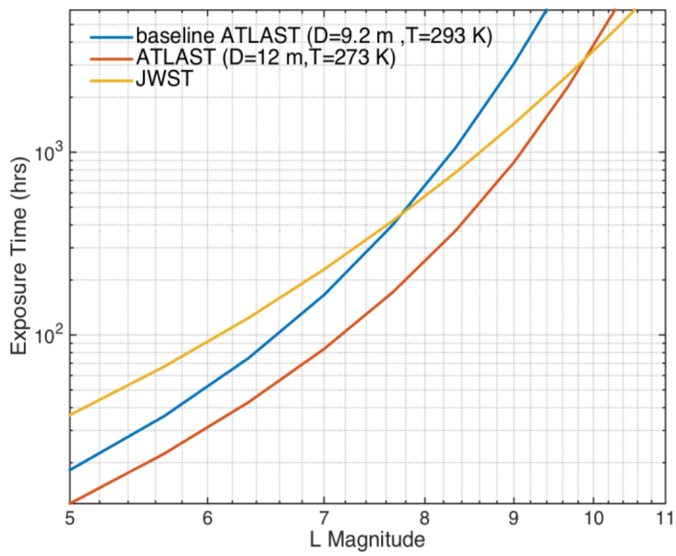

Figure: The time taken for three telescope configurations to detect at 5σ a small (10 ppm at R = 200) and narrow feature at 4 μm, as a function of the stellar magnitude at that wavelength, by transit spectroscopy. The configurations are baseline ATLAST, the larger and somewhat cooler "stretch goal" ATLAST, and JWST. As suggested above, ATLAST is more sensitive than JWST for bright host stars, with the 12-m ATLAST telescope taking ~4× less time to make the same observation, as is to be expected in the stellar photon limited case. The JWST curve is based on the predicted performance of NIRCAM; the ATLAST curve on the instrument described by Werner *et al*. in the SPIE Journal of Astronomical Telescopes and Instruments

This figure is taken from a paper by Werner *et al.*[2] to be published in the special issue of the SPIE Journal of Astronomical Telescopes and Instruments devoted to ATLAST. This paper also contains an elaboration of the scientific arguments for extending the wavelength range of ATLAST to 5 μm. It also presents a design concept for a small prism spectrometer which could provide the measurement capability required to achieve the performance simulated above. In this concept, the infrared starlight reaching the focal plane of the warm telescope is carried by an optical fiber to the slit of the spectrometer, which is mounted some 10 m away on the telescope backup structure in a manner which allows it to cool radiatively to the temperature required for satisfactory performance of its detector arrays, which are based on current JWST HgCdTe technology.

To conclude, there are substantial scientific benefits to be gained by extending the wavelength range of LUVOIR/ATLAST to 5 μm, even if the telescope is not cooled below room temperature. We have shown that this can be done with little or no impact on the rest of the system.

[2] M. Werner, *et al.*, "Extension of ATLAST/LUVOIR's capabilities to 5μm or beyond," *J. Astron. Telesc. Instr. Syst.* **2**(4), 041205 (Jun 22, 2016).