A LUNAR ORBITER FOR EARTH AND EXOPLANET STUDIES.

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The December 5, 2014 NASA test launch of the newly developed Orion spacecraft into deep space is a strong indication of NASA's unwavering commitment to future space exploration targeting asteroids and Mars. In 2019, the James Webb Space Telescope will be launched and placed at the Lagrangian point L2 on the night side of the Earth, 1.5 million kilometers away from Earth. One of its prime science objectives is to study exoplanets, especially those that are Earth-like. These developments provide a compelling case to explore the science and technology of building an Earth observatory in the Moon's orbit to deliver:

(1) Long-term, global, continuous full spectral view of the Earth from the UV to IR. This will enable a range of measurements from which the trends in the atmosphere, lithosphere, cryosphere, hydrosphere, and biosphere can be analyzed, and important science can be addressed. This includes tracking climate variability, air pollution sources and transport, natural hazards (e.g., extreme weather, volcanic plumes, hurricanes, lightning), seasonal and secular variations in polar ice, and vegetation health (e.g., spring greening).

(2) A testing and validation tool for Earth-like exoplanet observational studies. The real-time day /night, full disk, phase-changing Earth view can help us design and implement future exoplanet observational studies as they are in the form suitable for studying a planet around a distant star. There is a strong need to demonstrate that we can correctly interpret the data from an exoplanet in order to search for signs of habitability and life on that planet. In exoplanet studies, a planet is viewed as a single pixel with spectral information. The orbiter can make similar measurements of the Earth as a single pixel and then use the spatially resolved observations to properly interpret the single pixel data. The benefit of the lunar orbiter for exoplanet studies is that a several-year time-series of disk-integrated photometry of the Earth, in several wavelengths bands, will help us interpret future exoplanet observations in those same bands, to understand if we can detect oceans, continents, seasons, and vegetation on an Earth-twin candidate around a nearby star. In other words, the lunar orbiter is ideal for using the Earth as a proxy exoplanet to test the models developed for exoplanet studies, enabling better understanding of the range of uncertainties in the interpretation of observed exoplanet data. Data from the DSCOVR mission has been used for such a study (see, e.g. Jiang et al. 2017; Figure 1 below); however, the DSCOVR data has some limitations such as limited phase angle variation. Exoplanet observations will typically be at the stellar terminator line; we will not be able to see the full starlit planet. The lunar orbiter will solve this problem to give us a more useful Earth view. Furthermore, lessons learned from the lunar orbiter can also be used to build a future observatory in Mars orbit to further help exoplanet studies using the Earth as a proxy.

Key science elements of the lunar orbiter are to:

(1) Conduct full Earth-view multi-spectral observations at multiple incidence, emission, and phase angles, and provide more precise radiative balance calculations for climate studies that go beyond what is currently available from Earth orbiting satellites. The multispectral sensors can range from the UV to the Far IR for Earth atmospheric composition and climate studies, or monitor Earth's "hot spots" – thermally elevated features (e.g. volcanic, fire, military, and other anthropogenic activity) with high temporal frequency.

(2) Observe the dynamic spectral variation of Earth as a proxy exoplanet harboring life, and thus enable us to test spectral models in exoplanet studies.

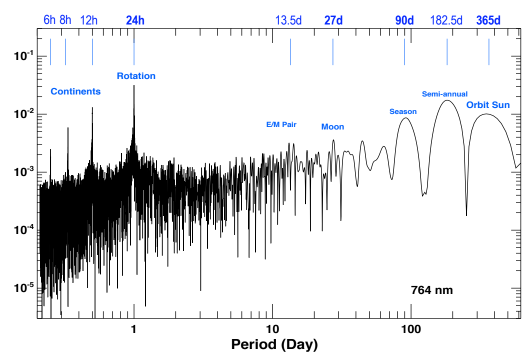

Figure 1: Fourier series power spectra of DSCOVR EPIC L1B 764 nm radiances after averaging to a single point. This technique yields information about the planet's rotation, its orbit around the Sun, and possible periodic variations due to weather (clouds) patterns, surface type (ocean, land, vegetation), and the moon.

Reference:

J.H. Jiang, A.J. Zhai, J. Herman, C.Zhai, H. Su, V. Natraj, J. Li, F. Xu, Y. Yung, Using Deep Space Climate Observatory Measurements to Study the Earth as An Exoplanet, *Proceedings of the National Academy of Sciences*, in review, 2017.