Observing the Earth as an Exoplanet: A Small Satellite Mission to Observe a Habitable World. J.Y. Coppin[1,2] and D.A. Caldwell[2], [1]Dept. of Mech. Engineering, Univ. of Puerto Rico, Mayaguez, PR (jorge.coppin@upr.edu), [2]SETI Institute, Mountain View, CA.

Introduction: Out of the multitude of extra solar worlds that have been discovered in the past decade thanks to missions like NASA's Kepler and the Transiting Exoplanet Survey Satellite (TESS), we only know one that is both habitable and inhabited. The Earth. Future missions like the James Webb Space Telescope (JWST) and Nancy Grace Roman Space Telescope (NGRST) as well as proposed concepts like the Habitable Exoplanet Observatory (HabEx) and the Large UV/Optical/IR Surveyor (LUVOIR) will be able to study exoplanets using detailed spectra to understand the conditions and compositions of their atmospheres and ultimately whether there are any detectable indicators of life. This will increase the amount of data we can retrieve from surveyed exoplanets for which currently there is only a paucity of data. These missions designed to look for life will produce massive amounts of exoplanetary atmospheric spectral data which will need to be combed through to build up sufficient signal to noise while simultaneously accounting for challenging systematic effects in finding habitable Earth-sized exoplanets. To know what we are looking for and automate the search for habitable worlds we need detailed models that allow for the retrieval of atmospheric composition and properties from the spectra of an inhabited world.

We describe here the design of a small satellite mission dedicated to measuring whole-Earth spectra and provide polarimetric imaging in order to measure the temporal variability of an inhabited planet The data would help improve models of habitable planets, guide analysis of exoplanet atmospheric measurements, and inform instrumentation for future NASA missions to search for signs of life on exoplanets.

Rationale: While there are detailed high-spatial resolution data of the Earth from weather and climate monitoring satellites, there are limited observations of the spectrum of the unresolved Earth seen as an exoplanet. To date some observations have been done during a lunar eclipse [1], but these have proven to be difficult endeavors which can only be done when the conditions allow it. Planetary missions like Galileo [2], LCROSS [3] and EPOXI [4] have trained their instruments towards the Earth to take whole-Earth spectra, but due to their serendipitous nature these observations lack the full range of variability of the Earth's atmosphere. While these observations have provided valuable ground-truth spectra for models, they only cover a very limited range of Earth observations.

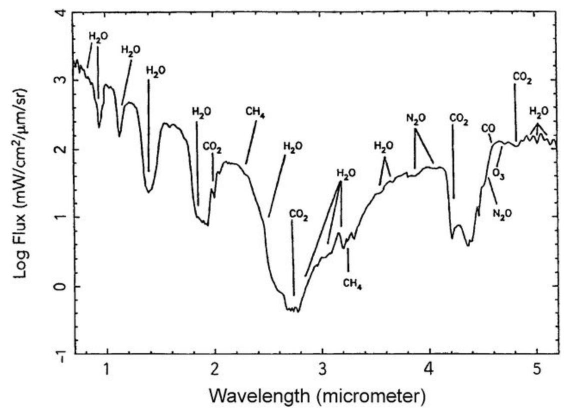

Figure 1: The spectrum of the Earth between 1 and 5 μm, recorder by the Near-infrared Mapping Spectrometer of the Galileo spacecraft during its flyby of the Earth in December 1990 [5].

Science Goals: The principal science goal for the mission is as follows: Given spatially unresolved photometric and polarimetric measurements of an Earth-like planet, can we unambiguously (1) determine planetary surface and atmospheric conditions, and (2) detect biosignatures? From this, multiple science questions arose, pertaining to what could we observe or detect from the unresolved Earth:

(1) Does the planet have an atmosphere, and what is the atmospheric composition?

(2) Does the planet atmosphere show high concentrations of oxygen and ozone?

(3) Does the planet have the conditions to support liquid water on the surface?

(4) What is the planet's rotation rate?

(5) Does the planet have continents and oceans?

(6) Does the planet have clouds? Are they variable?

(7) Does the planet show signs of Earth-like vegetation, or photosynthetic microbial?

(8) Does the planet have a magnetic field, or geologic activity?

From these questions a Science Traceability Matrix (STM) was made to determine measurement requirements. (See Appendix for full STM).

Orbital Parameters: Current Earth monitoring and observation satellites use a variety of orbits, mainly Low Earth Orbit (LEO) and Geostationary Orbit (GEO). These orbits don't work for a dedicated mission to study the Earth as an Exoplanet since LEO is too close to observe the whole-Earth disk, while GEO maintains its observations over the same region of the surface at all times not providing rotational variability. Spacecraft like the DSCOVR satellite which are stationed at Earth-

Sun Lagrange Points, while collecting variable data of the whole-Earth disk and rotation, don't cover illumination phase variability.

Because of this an appropriate orbit was evaluated on the following parameters: illumination phase variation, rotation variation (longitude coverage), latitude coverage, observation period, whole-earth disk visibility (earth angular diameter), radiation environment, orbital stability, and flight opportunities (rideshares options). Multiple orbits were identified, among those Molniya (Tundra), Semi-Synchronous, Super-Synchronous, Earth-Moon L1 Lagrange, Earth-Moon L4/L5 Lagrange, Highly Elliptical Transfer Orbit, and Polar Orbit. Preliminarily the Earth-Moon L1 has been chosen due to it presenting a number of advantages, although there are always trade-offs in the process of orbital selection.

Figure 2: View of Spacecraft sensor with FOV of 2° in Earth-Moon L1.

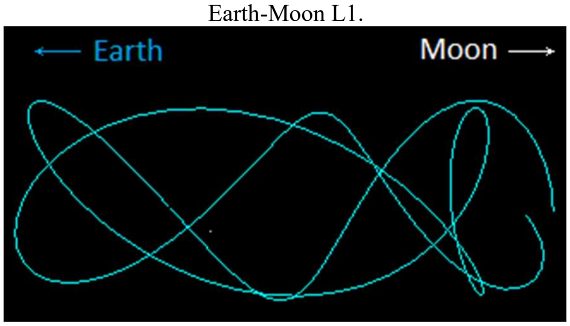

Figure 3: Top View of Earth-Moon L1 Lissajous Orbit [6].

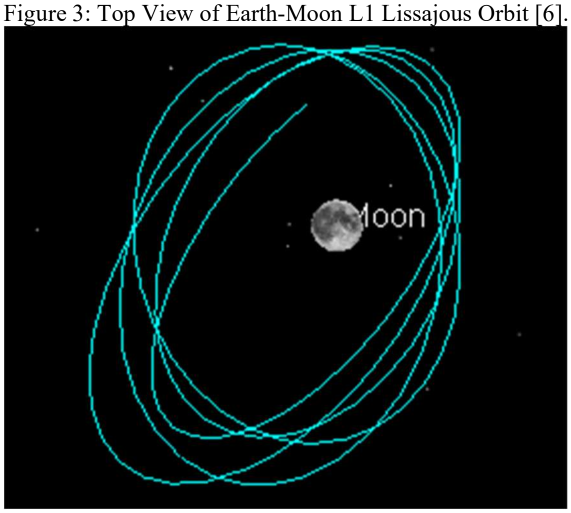

Figure 4: View of Earth-Moon L1 Lissajous Orbit as seen from the Earth Looking Towards the Moon [6].

A small number of spacecraft have traveled or are planned to travel to the Earth-Moon Lagrange Points. The ARTEMIS extension of the THEMIS mission [X] was a set of spacecraft that traveled to the Earth-Moon L1 and L2 points and the CAPSTONE mission will demonstrate the capabilities of a SmallSat to do a Near Rectilinear Halo Orbit, which is a type of Lissajous orbit on the Earth-Moon system.

Instrumentation: To get the full range of Earth spectra, the SmallSat will require a UV/Visible/NIR spectrometer (~200nm – 5μm) with an imaging Polarimeter (~400–1000 nm). The polarimeter will measure the spectral flux and polarization data of sunlight reflected by Earth. We will also include a visible imaging camera with moderate spatial resolution (~100 km) to aid in interpreting spectral data. This might be the same as the imaging polarimeter, depending on the polarimetry approach.

Future Work: The next step is to estimate various parameters relevant to mission design through numerous orbital simulations. These will help us determine things such as frequency of station-keeping and delta-V necessary, fuel usage, latitude coverage and time spent in the shadow of the Earth. After these have been determined, instrument details can be established.

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