MEASURING EARTH'S RADIATION BUDGET FROM THE VICINITY OF THE MOON. W. H. Swartz[1], S. R. Lorentz[2], R. E. Erlandson[1], R. F. Cahalan,[3] and P. M. Huang[1], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd, Laurel, MD 20723 <bill.swartz@jhuapl.edu>, [2]L-1 Standards and Technology, 10364 Battleview Pkwy, Manassas, VA 20109, [3]NASA Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771.

Summary: We propose to measure Earth's radiation budget (ERB) from the Deep Space Gateway or a small satellite in lunar orbit using broadband radiometers and other technology that are being demonstrated in space. The radiometer instrument payload for measuring the integrated total and solar shortwave (SW) ERB, based on the Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) CubeSat, is compact, autonomous, and has modest resource requirements. The instrument could either be (1) externally mounted on the Gateway and pointed using an agile two-axis gimbal that provides a full hemispherical field of regard or (2) flown on a small satellite in nearby lunar orbit, relying on the Gateway as a communications relay.

Introduction: Climate change is driven by the small imbalance between incoming solar irradiance and the outgoing, combined reflected solar and terrestrial thermal emission [1, 2, 3]. Current space-based assets measuring Earth outgoing radiation (EOR) are in fixed local solar times, either in low Earth orbit (e.g., CERES) or at the L-1 Lagrange point (NISTAR).

The lunar vicinity provides a unique vantage point in that the full diurnal cycle of the Earth can be sampled, in combination with a good sampling of all Earth latitudes over the course of each month. The proposed observations will provide an independent measurement of EOR and will also complement the CERES and NISTAR datasets.

The lunar-based ERB total and SW measurements will improve our understanding of ERB, including the impacts of human activities and natural phenomena. The new information can also be used for climate science.

Operations Concept: The primary measurement will be Earth's outgoing total integrated and solar-reflected SW ($\lambda < 5.5$ μm) radiation using an array of broadband bolometers with fields of view marginally larger than the angular size of the Earth from the vantage point of the vicinity of the Moon (about 2°). In addition to absolute calibration in the laboratory prior to launch, on-board calibration will be provided by periodic observations of the Sun for absolute scale, deep space for dark offset, and an on-board gallium fixed-point black body calibration target to track long-term degradation of the total channel.

Independent instrument pointing is required, both for Earth observation and for solar/dark space calibration maneuvers. This will be provided either by an agile two-axis gimbal (if the radiometer instrument is externally mounted on the Gateway) or spacecraft attitude control (if the instrument is mounted on a free-flying small satellite). The decision whether to locate the instrument on the Gateway or a small satellite will be the subject of a trade study.

All the hardware described in the proposal is flying or has flown in space, significantly reducing risk.

Instrument Description: The proposed instrument is very similar to that flying on the RAVAN CubeSat (see Figure 1) [4, 5, 6]. RAVAN is a technology demonstration funded by the NASA Earth Science Technology Office. RAVAN comprises a pair of radiometers (total and SW channels) using carbon nanotube absorbers and an analogous pair using tradition cavity absorbers. In addition, two gallium black bodies are housed in the instrument's radiometer covers. Launched in November 2016, RAVAN has been operating in orbit for more than a year, and excellent instrument stability has been demonstrated.

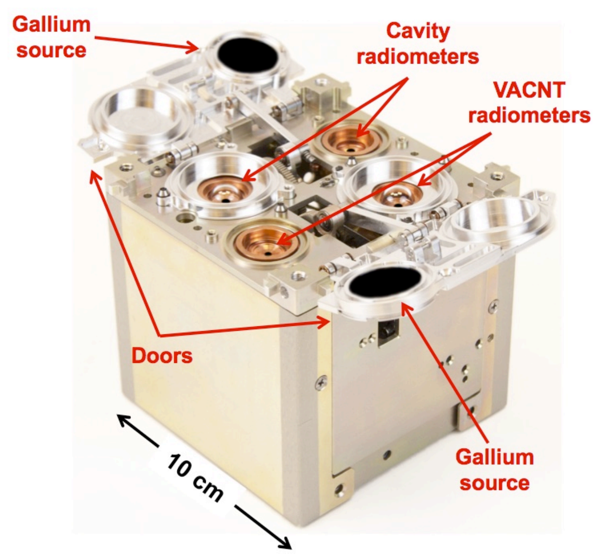

Figure 1: RAVAN payload.

The RAVAN-like instrument proposed here also comprises four radiometers, although they would all be based on the same technology, either carbon nanotubes or cavities. One (identical) pair would be used less frequently, thus reducing cumulative exposure and providing a means to assess degradation on orbit. RAVAN's wide field of view of 130° would be reduced to comfortably accommodate the 2° angular extent of the Earth as viewed from the Moon.

Resource requirements for the radiometer payload are listed in Table 1.

Table 1: Instrument Requirements (excluding pointing technology).

Parameter	Requirement (notional)
Mass	1 kg
Power	2 W (average)
Cost	~$2M
Volume	10×10×10 cm^3
Crew interaction	None
Desired orbit	TBD
Pointing	0.1° (see Pointing Technology section, below)
Other resources	Instrument interface temperature control

Pointing Technology: Relatively fine pointing control is required by the instrument, of the order of 0.1°. Two options to achieve this level of pointing are described here.

Two-axis gimbal. If the radiometer instrument is mounted on the Gateway itself, a gimbal will be needed to provide the required pointing. Our concept makes use of an agile two-axis gimbal that provides a full hemispherical field of regard, with a pointing accuracy of 0.04° and a maximum slew rate of 15° per second. The proposed gimbal is a low-cost system that has been space-qualified and is currently in orbit.

Small satellite host. It may be more advantageous to fly the instrument payload on a small satellite that in turn uses the Gateway as a communications relay. There are several commercial small satellite bus providers at this time. Blue Canyon Technologies, for example, provided the RAVAN CubeSat bus, exceeding our pointing requirement, and is developing hardware that will fly at the Moon and beyond. We therefore view the small satellite bus as a commodity that can be selected later.

Conclusions: We propose a low-cost means to measure the Earth radiation budget from the unique perspective of the vicinity of the Moon, contributing to a better understanding of Earth's energy budget and climate science. The proposed instrument and associated technologies are based on similar hardware that are currently flying in low Earth orbit.

References:

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