DESIGNING VISIBLE THROUGH FAR INFRARED REMOTE-SENSING INSTRUMENTS BASED ON A NEW GENERATION OF THERMOPILES

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1. Introduction: We present the capabilities of three different multi-spectral visible to far-infrared (0.3-200 µm) radiometers for the Trojan Tour and Rendezvous, Europa Clipper and Earth thermal climate sounder space missions. In all three types of mission, the thermal properties of the target objects are best determined by spectrally resolved 2-dimensional mapping of the temperature distribution and spectral emissivity across the atmosphere or surface of the body.

For such multi-spectral radiometers to be as compact and cost effective as possible, an uncooled detector technology is highly desirable, as long as it is able to fulfill accurately the scientific objectives of their mission. In this paper, we will present how the new generation of uncooled thermopile arrays developed at JPL can fulfill these requirements. Previous generations of thermopile arrays developed at JPL have already provided great scientific results with the Mars Climate Sounder (MCS) [1] instrument aboard the Mars Reconnaissance Orbiter spacecraft and the Diviner Lunar Radiometer Experiment (Diviner) [2] aboard the Lunar Reconnaissance Orbiter spacecraft. The promising new generation of thermopile arrays developed at JPL can be used as a baseline to design the compact multi-spectral radiometers that will enable these space missions to accomplish their scientific objectives. Indeed, there are currently no other space qualified uncooled thermal detector technologies available in array format and sensitive to wavelengths longer than 20 µm, corresponding to scene temperatures lower than 150 K.

In particular, a trade-off analysis is conducted taking into account both the scientific objectives of each of the space missions, and the measured performance of the focal plane arrays, to yield three instrumental concepts tailored to the Trojan Tour and Rendezvous, Europa Clipper and Earth thermal climate sounder space missions needs.

2. Hyperspectral far-infrared imaging spectrometer for Earth radiation budget: Tracking the radiation budget of the Earth is key to understanding climactic changes that are taking place across the planet. Measurements of the thermal evolution from the surface to the top of our atmosphere are essential to study its consistency with the observed heat build up in the global oceans (ARGO) [3] . Presently, there is a significant gap in the climate data for the far-infrared region, although this spectral region contains up to 50% of the variability in the terrestrial radiation budget. In this context, it is essential that compact, low-cost far infrared imaging spectrometers with a good spectral resolution be developed to enable these measurements.

SpectRE: SpectRE (Spectral Radiation Experiment) is a conceptual Thermal Infrared Climate Sensor that could be installed on several Earth observing platforms including the ISS. Designed to be extremely compact (Fig. 1), it is based on an isothermal all-reflective Offner relay diffraction grating design. The instrument projected performance enables the scientific objectives presented above while relying on the uncooled thermopiles arrays built at JPL. This extremely lightweight architecture allows SpectRE to fit in a CubeSat.

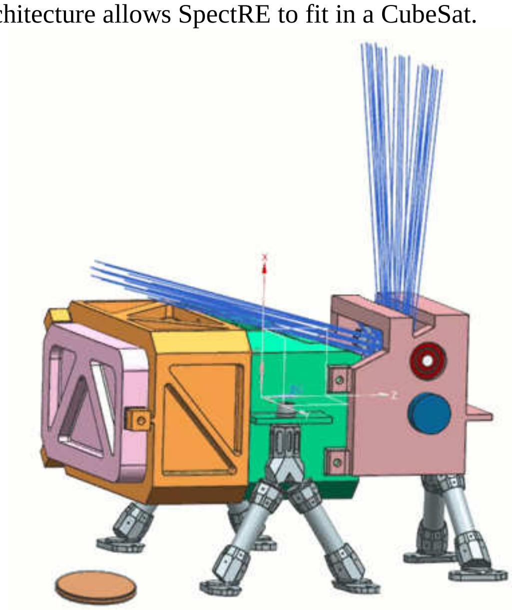

Fig 1- SpectRE instrument design compared to the size of a penny (0.75 inches).

3. Multispectral far-infrared radiometer for Europa Clipper: Europa is a satellite of Jupiter famous for showing strong evidence of an ocean of liquid water beneath an ice shell, protecting it from the extreme levels of radiation of the Jovian system. This ocean world is extremely interesting as it could host conditions favorable for extraterrestrial life. Mapping of the thermal environment of Europa would allow us to assess both its habitability and characterize its surface composition, surface temperature and emissivity.

These objectives, along with a geological study, are part of the science rationale of the planned Europa Clipper mission [4]. A thermal imager dedicated to the spatially resolved pushbroom imaging of Europa's surface is part of the core scientific instruments needed for this mission.

Instrument: In addition to being uncooled and sensitive to Europa's surface temperatures (50 to 125 K), thermopiles are intrinsically radiation hardened [5] and thus perfectly suited to this mission. We will discuss the design and expected performance of a radiometer based on thermopiles tailored to the objectives of the Europa-Clipper mission.

4. Multispectral far-infrared radiometer for Trojan Tour and Rendezvous: The Trojan asteroids are a group of asteroids orbiting around the L4 and L5 Lagrange points of the orbit of Jupiter. The characterization of the thermal properties of Trojan asteroids contributes extensively to the knowledge of their global physicochemical properties [6,7]. The determination of these properties allows us to constrain the current geologic state of the surface (roughness, presence of regolith), the surface mineralogical composition [8], the internal structure through the thermal inertia, and the physical processes occurring on the surface (radiation, sublimation of volatiles). Obtaining these results for several Trojan asteroids would allow us to infer their past evolution, and offer a possible validation of the planetary migration model of Morbidelli et al. [9] that presents these objects as a readily accessible depository of Kuiper belt material.

All of these scientific objectives are to be fulfilled with the measurements of a thermal far-infrared multispectral imager (25-200 μm) during successive fly-bys of several targets aboard the New Frontiers program Trojan Tour and Rendezvous mission spacecraft.

TIMBRE: For this mission, the TIMBRE filter radiometer was redesigned to take advantage of the larger new generation thermopile arrays and to accommodate more filter bands to fulfill scientific objectives and/or to maximize the throughput. In this concept, the filter block is no longer collocated with the thermopile array at the focal plane like for Diviner but moved to an intermediate focus (Fig. 5). The magnification at the intermediate focus is twice (F/4) that of the focal plane (F/2) to be able to: (i) eliminate large angle scattering and detector/filter radiative coupling, (ii) double the size of the filter block, (iii) lower thermal gradients in the filter block (Fig. 6), (iv) allow a simpler baffle design. The possibility to either increase the number of filter bands or the filter strips width to perform time delay integration makes this design more flexible and adaptable to the constraints set by the mission science objectives.

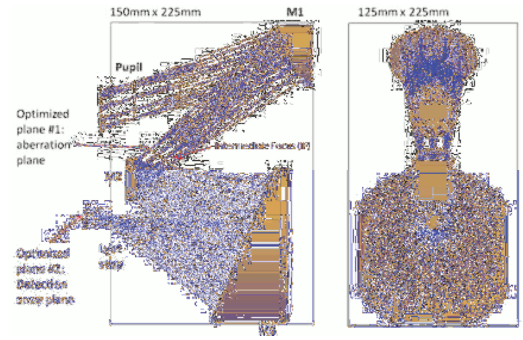

Fig 5- Compact three mirror anastigmatic optical design with an intermediate focus with a overall focal number of F/2 and an intermediate focal number of F/4.

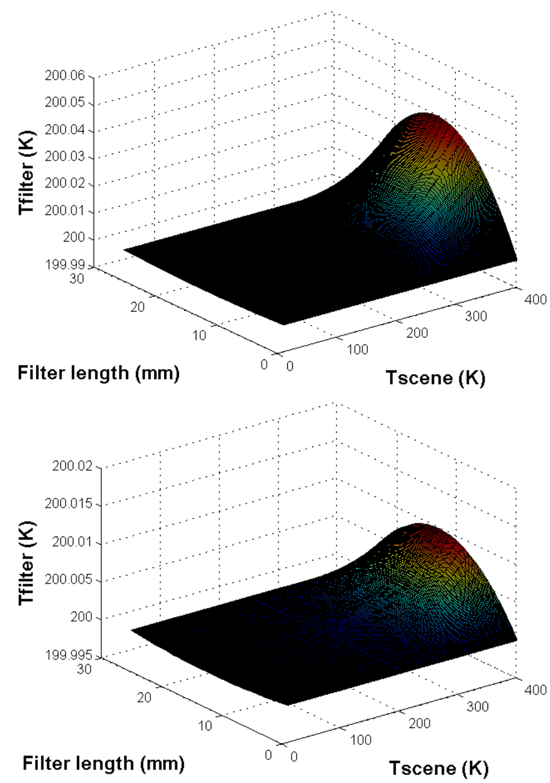

Fig 6- Temperature gradient along the filter strip for a 100-400μm bandpass (worst case) as a function of scene temperature when the filter is placed at the intermediate focus (top) or colocated with the detector (bottom) and the instrument temperature is 200K.

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