Acta Astronautica 128 (2016) 628–639

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/aa

Dual-telescope multi-channel thermal-infrared radiometer for outer planet fly-by missions

Shahid Aslam [a,*], Michael Amato [a], Neil Bowles [b], Simon Calcutt [b], Tilak Hewagama [a], Joseph Howard [a], Carly Howett [c], Wen-Ting Hsieh [a], Terry Hurford [a], Jane Hurley [d], Patrick Irwin [b], Donald E. Jennings [a], Ernst Kessler [e], Brook Lakew [a], Mark Loeffler [a], Michael Mellon [c], Anthony Nicoletti [a], Conor A. Nixon [a], Nathaniel Putzig [c], Gerard Quilligan [a], Julie Rathbun [f], Marcia Segura [a], John Spencer [c], Joseph Spitale [f], Garrett West [a]

[a] NASA, Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt 20771, MD, USA
[b] Atmospheric, Oceanic and Planetary Physics, Clarendon Laboratory, University of Oxford, Parks Rd., Oxford OX1 3PU, UK
[c] Southwest Research Institute, 1050 Walnut St., Suite 300, Boulder 80302, CO, USA
[d] RAL Space, Rutherford Appleton Laboratory, Harwell, Didcot, Oxford OX11 0QX, UK
[e] Leibniz Institute of Photonic Technology, Albert-Einstein-Straße 9, Jena 07745, Germany
[f] Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson 85719, AZ, USA

ARTICLE INFO

Article history:
Received 11 January 2016
Received in revised form
11 August 2016
Accepted 13 August 2016
Available online 24 August 2016

Keywords:
Dual-telescope
Dual-field-of-view
Filter radiometer
Icy moons
Thermal emission
Surface temperature
Europa

ABSTRACT

The design of a versatile dual-telescope thermal-infrared radiometer spanning the spectral wavelength range 8–200 μm, in five spectral pass bands, for outer planet fly-by missions is described. The dual-telescope design switches between a narrow-field-of-view and a wide-field-of-view to provide optimal spatial resolution images within a range of spacecraft encounters to the target. The switchable dual-field-of-view system uses an optical configuration based on the axial rotation of a source-select mirror along the optical axis. The optical design, spectral performance, radiometric accuracy, and retrieval estimates of the instrument are discussed. This is followed by an assessment of the surface coverage performance at various spatial resolutions by using the planned NASA Europa Mission 13-F7 fly-by trajectories as a case study.

© 2016 Published by Elsevier Ltd. on behalf of IAA.

1. Introduction

A major challenge for thermal-infrared radiometer imaging instruments on fly-by missions to the outer planets, icy moons and primitive bodies in the solar system is to make high-fidelity thermal emission measurements of the target at large distances while retaining the ability to also make measurements when at closest approach. In an ideal case, the instrument would employ a telescope able to zoom continuously between field-of-view limits commensurate with science requirements. However, complexities in zoom mechanisms introduce additional risks and failure modes. A low risk solution that achieves fly-by mission science goals is to use a dual-telescope system that has two fields-of-view that are switchable. The wide-field-of-view (WF) or low magnification mode is used for observing a large scene area and searching for possible interesting features. The narrow-field-of-view (NF) or high magnification mode is then used for close-up recognition and identification ("zooming-in"). The two modes significantly enhance the effectiveness of a radiometer imaging system by providing two distinct operating modes that will enable reconnaissance and science objectives over a greater portion of the trajectory than with the use of a single telescope tuned to a specific field-of-view.

Infrared (IR) spectrometers and radiometers have flown previously on fly-by trajectories of the outer planets [1–4], but all these instruments had fixed-telescope aperture diameters; for example, Cassini/CIRS uses a 50-cm diameter telescope, which allows for a 16-fold field reduction from similar IR spectrometers flown previously on Earth- and Mars-orbiting spacecraft [5–7]. With this telescope, Jupiter filled the field-of-view (FOV)

* Corresponding author.
E-mail address: shahid.aslam-1@nasa.gov (S. Aslam).

http://dx.doi.org/10.1016/j.actaastro.2016.08.009
0094-5765/© 2016 Published by Elsevier Ltd. on behalf of IAA.

approximately four weeks before Voyager's closest approach. More recent thermal radiometers *e.g.* Mars Climate Sounder on MRO [8], Diviner on LRO [9] and MERTIS on Bepicolombo [10]) with fixed FOVs were designed for optimal spatial resolution from an orbiting spacecraft.

Future multi-year tours of the outer planet systems - and to the gas giants in particular, with many choreographed fly-by trajectories of their icy moons - will require a number of changes to earlier radiometer instrument designs: (i) an optimization of the fields-of-view in order to maximize surface data coverage at various spatial resolutions from farthest to closest approaches; (ii) a reduction in the noise equivalent spectral radiance (NESR) of the instrument by using higher sensitivity detectors and low-noise radiation-hard readout electronics; (iii) a reduction of the thermal background radiation contribution by operating the instrument at an optimal temperature; (iv) careful consideration to the number and band passes of the spectral channels in order to uniquely determine the surface temperature and emissivity of the surface under investigation; and (v) attention to radiation-hardening of the instrument and electronics to ensure proper operation in high-energy and high-fluence particle environments (*e.g.*, Jovian magnetosphere).

The dual-telescope multi-channel thermal-infrared radiometer concept described here evolved out of a series of thermal instrument concept studies that, collectively, addressed all of the concerns above: in particular, "Jupiter Europa Thermal Sounder," for the NASA-led Jupiter Europa Orbiter (JEO) of the Europa Jupiter System Mission (EJSM) in 2011 [11]; "Oxford RAL Terahertz-Infrared Sensor (ORTIS)", a composite IR/THz instrument that was proposed for the ESA Laplace Mission [12], subsequently renamed JUpiter ICy moons Explorer (JUICE); which then, by dropping the THz capability ORTIS evolved into the "Jupiter System Thermal Infrared Mapper (JSTIM)", which was proposed for the ESA-led JUICE Mission call in 2012 [13]. Continuing studies evolved JSTIM into the "Thermal Imager for Europa Reconnaissance (TIMER)", a NASA-funded instrument concept in 2013 [14]; which then with maturation and risk mitigation studies subsequently developed into the "Thermal Imager for Europa Reconnaissance and Science (TIMERS)", which was proposed for the NASA-led Europa Mission announcement opportunity call in 2014 [15].

Although, the TIMERS instrument, designed specifically for thermal-infrared emission measurements from Europa's surface, was not selected in May 2015 as part of the science instruments suite on NASA's Europa Mission it still remains a highly versatile thermal instrument for inclusion on-board future fly-by missions to icy planets, bodies and satellites. In this paper, a brief description of how thermal emission measurements from icy surfaces help characterize thermo-physical properties is given followed by a discussion on the optical and electronic readout design, radiometric performance and accuracy of the evolved dual-telescope TIMERS concept, hereon called the thermal radiometer; an assessment is given of the thermal radiometer performance, of the surface coverage at various spatial resolutions that can be attained, by using the planned Europa Mission 13-F7 fly-by trajectories [16] as a case study; and finally an example of how the dual telescope design will provide observations at multiple scales. The thermal radiometer's WF and NF telescopes and filter channels, described here, are specifically optimized for multiple Europa fly-by's, in which the farthest approach is 60,000 km and the closest approach is 25 km. The thermal radiometer filter channels are optimized for measuring Europa's surface temperature in the range of 53–135 K, with a noise equivalent temperature difference (NETD) of ≤ 2 K, using five spectral pass bands, 8–14 μm, 12.5–25 μm, 25–50 μm, 50–100 μm and 100–200 μm, defined by a combination of filters and windows. The reflected solar radiation contextual information is derived from a bore-sighted visible-near infrared camera as part of the mission payload, or alternatively if this capability is not available then the 100–200 μm channel can be replaced with a solar channel (0.35–2.8 μm).

For fly-by missions to other planetary targets, the WF and NF telescope fields-of-view can be appropriately resized for optimal spatial resolution, coverage and radiometric performance specific for the planned fly-by trajectories; if required the NF telescope can be descoped, resulting in a lower-mass instrument while maintaining high-fidelity thermal imaging and signal-to-noise ratio (SNR) performance; albeit with less flexibility in the ability to gather higher spatial resolution data from a distance. Furthermore, the filter channel specifications can easily be changed, to accommodate the shift in planetary Planck function peak as a function of target temperature, since the filter assembly is at an intermediate focus in the optical system.

The thermal radiometer described here will have particular relevance to future Flagship Missions (*e.g.*, Uranus and Neptune or Enceladus [17]) and potential New Frontiers Missions (*e.g.*, Io Mission [18] or Trojan Asteroids [17]).

2. Planetary satellite surfaces

For satellite science, judiciously selected bands in the 8–200 μm spectral range provides sensitivity to sub-pixel temperature variations since the 53–135 K Planck function inflection points are optimally bracketed as shown in Fig. 1. In contrast to devices with purely sub-mm bands, which do not fully sample the inflection points in this temperature range, a thermal radiometer can easily detect and characterize sub-pixel temperature variations, including small, unresolved endogenic hot spots. In addition, the broad wavelength coverage means that it is more suited for mapping surface thermo-physical properties and composition than a sub-mm device focused on a very narrow range of frequencies and a single FOV.

The wavelength coverage and high spatial resolution is also ideally suited for measuring the endogenic heat flow and volcanic activity (*e.g.* from Io), as it is also sensitive to the shorter wavelength radiation associated with Io's hotter volcanic thermal emission.

Characterization and comparison of the surface properties of the major satellites of the outer planets will provide key information on their formation and evolution and could provide unique discoveries of any near-surface heat sources, *e.g.*, the 'tiger stripes' of Enceladus [19] and thermal contrasts associated with

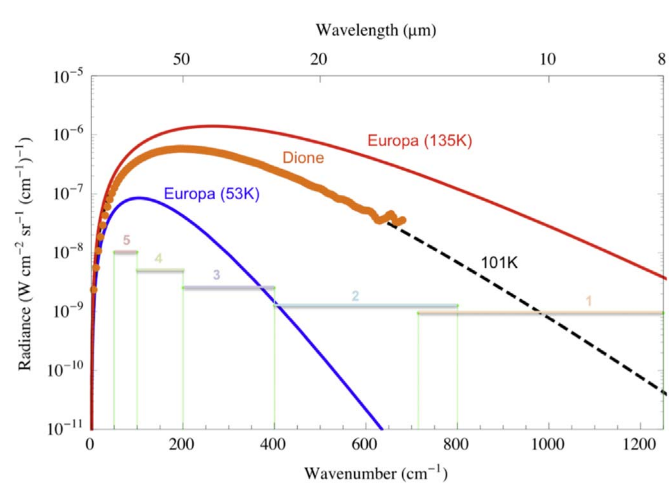

Fig. 1. Measured radiance spectrum of Dione (Cassini/CIRS) together with estimated dayside/night-side spectra of Europa and location of radiometer IR filter band channels.

Download English Version:

https://daneshyari.com/en/article/1714185

Download Persian Version:

https://daneshyari.com/article/1714185

Daneshyari.com