Thermal Emission Imaging System (THEMIS)

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ABSTRACT

The Thermal Emission Imaging System (THEMIS) is based on “bolt-together” pushbroom optics and uncooled silicon microbolometer focal plane array (FPA) technology. Sometimes dubbed "Mars Landsat," THEMIS was launched in 2001 on Mars Odyssey, and provides guidance for future lander missions now in preparation for launch. Advanced materials and optical machining allow THEMIS low-scatter, reflective, wide field-of-view (WFOV) pushbroom optics for relatively long dwell-time compared to narrow FOV optics requiring cross-track scanning for equivalent spatial resolution. This allows uncooled silicon microbolometer FPAs, with less signal sensitivity than cryogenically cooled photo-diode FPAs, to meet the THEMIS sensitivity requirements.

INTRODUCTION

A major goal of the Mars Exploration Program is to help determine whether life ever existed on Mars via detailed *in situ* studies and surface sample return. It is essential to identify landing sites with the highest probability of containing samples indicative of early pre-biotic or biotic environments. Of particular interest are aqueous and/or hydrothermal environments in which life could have existed, or regions of current near-surface water or heat sources[1]. The search requires detailed geologic mapping and accurate interpretations of site composition and history in a global context. THEMIS was designed to do this and builds upon a wealth of data from previous experiments.

Previous experiments include the Mariner 6/7 Mars Infrared Radiometer (MIR) and Infrared Spectrometer[2], the Mariner 9 Infrared Interferometer Spectrometer (IRIS)[3], the Viking Infrared Thermal Mapper (IRTM)[4], the Phobos Termoscan[5], and the continuing Mars Global Surveyor (MGS) mission using the Mars Orbiter Camera (MOC)[6] and MGS Thermal Emission Spectrometer (TES)[7]. TES has collected hyperspectral images (up to 286 spectral bands from 6-50 um) of the entire martian surface, providing an initial global reconnaissance of mineralogy and thermophysical properties[8,9]. By covering the key 6.3 to 15.0 µm region in both TES and THEMIS, it is possible to combine TES fine spectral resolution with THEMIS fine spatial resolution to achieve a global mineralogic inventory at the spatial scales necessary for detailed geologic studies within the Odyssey data resources.

Indeed, THEMIS is providing global maps of unique compositional units and the identification of key minerals and rock types with thermal infrared multi-spectral observations in nine wavelengths at 100-m resolution and 18-m visible imagery in up to five colors. The thermal-infrared spectral region was selected for mineral mapping because virtually all geologic materials, including carbonates, hydrothermal silica, sulfates, phosphates, hydroxides, and silicates have fundamental infrared absorption bands that are diagnostic of mineral composition.

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THEMIS visible imaging provides regional coverage (with global coverage a goal) at spatial scales that are intermediate between those of Viking and the detailed views from the MGS MOC[6].

THEMIS REQUIREMENTS AND DESIGN

THEMIS must identify minerals and morphology, i.e., compositional units. Mineral mapping has three thermal infrared requirements: (1) radiometric precision and accuracy to resolve the expected band depths for minerals present at 10% abundance; (2) spectral resolution to identify key minerals; and (3) 100 m spatial resolution to isolate small mineral deposits. The predicted performance for infrared noise equivalent temperatures (NEΔT) range from 0.007 to 0.038 viewing Mars at surface temperatures of 245K to 270K. Most of the variation in SNR between bands is due to the variation in emitted energy for the 245 K reference temperature. As seen from these results, the THEMIS IR imager exceeds the proposed measurement requirements by a factor of two in most bands. The morphology objective yields a visible measurement requirement of 20 meters. Visible imager SNRs were computed for a low albedo (0.25), flat-lying surface viewed at an incidence angle of 67.5° under aphelion conditions. The SNR values for this case vary from 200 to 400.

THEMIS is shown in Figure 1 comprising two infrared and visible multi-spectral imagers that share optics and housing with independent power and data interfaces to the spacecraft for reliability, with a mass of 11.2 kg, dimensions of 29 x 37 x 55 cm, and 14 W orbital average power. The telescope is a three-mirror anastigmat with an f/1.6 12-cm effective aperture. A calibration flag, and the only moving part, provides thermal calibration and serves to protect the detectors from direct Sun. The electronics, on the left in the THEMIS artist concept, provide digital data collection and processing as well as instrument control and data to the spacecraft. An aluminum main frame provides the spacecraft mounting interface and supports the electronics and optics. Multi-layer insulation blankets and thermal control surfaces provide a stable thermal environment and a heatsink for the electronics and the thermal electric cooler (TEC) temperature controller on the focal plane arrays (FPAs).

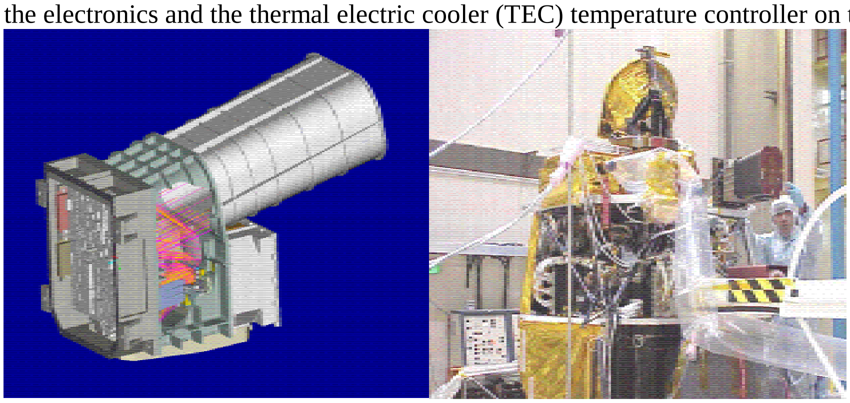

Figure 1: *THEMIS artist concept and flight instrument being installed on the Mars Odyssey Spacecraft.*

Diamond-turned, "bolt-together" telescope technology (Figure 2) was the first key to THEMIS affordability and success for a cost, mass, and volume constrained planetary science mission. Precision machining allowed the entire optical stage to be assembled without adjustments, yet with diffraction-limited performance in both the visible and infrared, with mounting surfaces machined to ±5 um tolerance. Optical surfaces were machined directly from high-order aspheric equations. Aluminum reduced cost, with nickel plating and automated post polishing to reduce surface scatter to levels unobtainable solely from diamond turning.

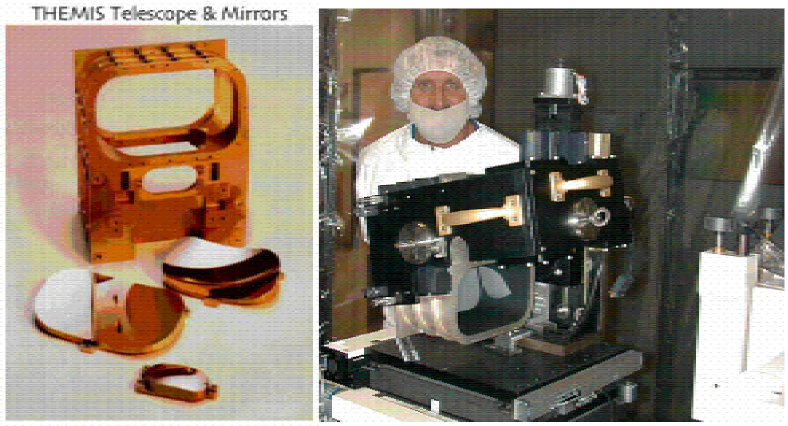

Figure 2. *THEMIS diamond-turned "bolt-together" telescope components prior to and after assembly.*

The second key to THEMIS success is the uncooled thermal IR microbolometer focal-plane array (FPA) operating at ambient temperature illustrated in Figure 3 to substantially reduced the complexity of fabrication, testing, spacecraft interfaces, and mission operations compared to what would have been necessary with cryogenically cooled photo-diode array technology. The array is 320 (cross-track) by 240 (along-track) with 50 μm unit cell dimension translating to 100 m geometric instantaneous field-of-view (GIFOV) and ~32 km swath width. A thermal electric cooler (TEC) stabilizes the IR FPA temperature to ±1 mK. THEMIS uses microbolometer FPAs produced by Raytheon Vision Systems (RVS) under license from Honeywell, Inc., and the THEMIS IR FPA is derived from a Raytheon hand-held imager developed for rugged military use, which significantly reduced development cost compared to a custom design. The microbolometer arrays were grown directly on the surface of RVS Readout Integrated Circuits (ROIC).

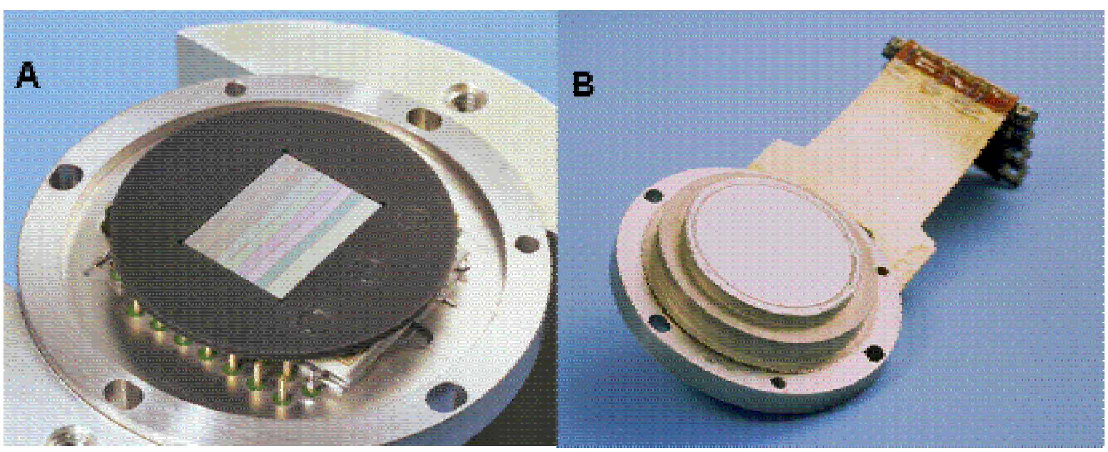

Figure 3: *(a) THEMIS infrared focal-plane and stripe-filter layout.(b) Complete uncooled FPA package.*

Figure 3 shows the stripe filters that produce ~1μm wide bands at nine wavelengths from 6.78 to 14.88 μm graphed in Figure 4. These include eight surface-sensing wavelengths and one atmospheric wavelength. Each covers 16 lines along-track (320 detectors per line cross-track) in time-delay and integration (TDI) to build SNR, with an 8-line "dead-space" between filters. To maximize manufacturing yield and reduce costs, the stripe filters were fabricated separately and butted together. The calculated dwell time for a single pixel, at an orbit of 400 km and a 100-meter GIFOV is 29.9 msec, closely matching the 30 Hz microbolometer array frame rate. The visible imager is a derivative of the Malin Space Science Systems (MSSS) Mars Polar Lander (MPL) MARs Decent Imager (MARDI), with a 5-filter subset of the MSSS MARs Color Imager (MARCI) developed for the Mars Climate Orbiter (MCO). The visible imager has 1,024 cross-track pixels with an 18-m IFOV covering a

18.4-km swath bore-sighted with the IR imager through a beamsplitter and has five stripe filters centered from 0.425 to 0.86 µm.

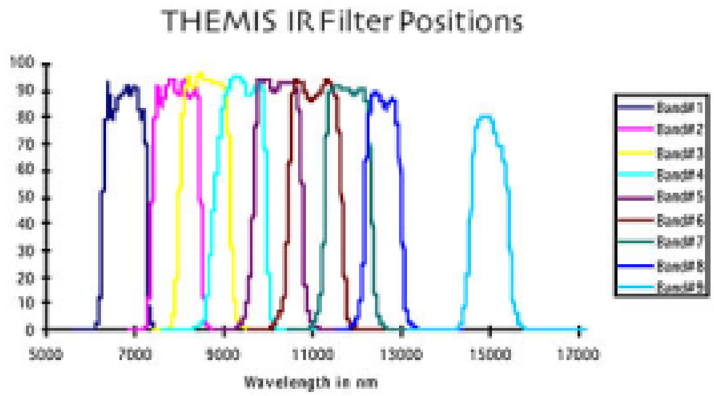

Figure 4: *THEMIS IR spectral bandpasses from data collected at SBRS prior to instrument delivery.*

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