Miniature Integrated Camera Spectrometer (MICAS)

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Miniature Integrated Camera Spectrometer (MICAS) Validation Report

EXTENDED ABSTRACT

MICAS is an integrated multi-channel instrument that includes: an ultraviolet (UV) imaging spectrometer, two visible-wavelength imagers , and a short-wavelength infrared imaging (SWIR) spectrometer that was flown as a technology demonstration on the New Millennium Deep Space 1 Mission (Table 1). MICAS has no moving parts, uses a shared multi-wavelength long-focal length primary telescope and provides a multi-temperature set of focal planes. with different remote-sensing scales (i.e. μradians/mm). The MICAS optical layout is shown in Fig. 1.

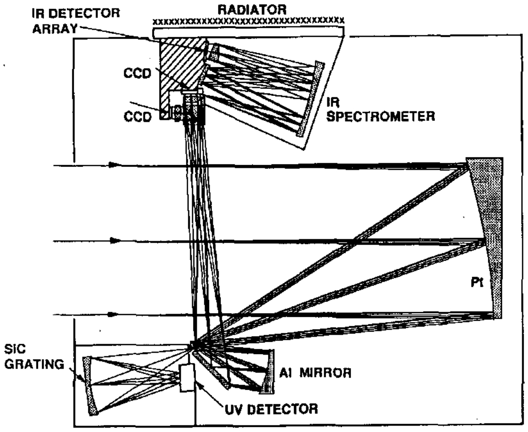

Figure 1 MICAS optical Ray-trace of Off-axis

Background and History: MICAS is a close derivative of PICS (Planetary Integrated Camera Spectrometer) that was originally developed under NASA PIDDP (Planetary Instrument Definition and Development Program) funding in response to a Pluto Fast Flyby instrument feasibility demonstration program (Beauchamp et. al. 1994). The program goal was to demonstrate the practicality of an instrument package with a mass and power <7kg and <7w that could meet the prime scientific objectives defined for the Pluto Fast Flyby Mission. PICS and MICAS were developed by a consortium of JPL, SSG, Univ. of Ariz., Rockwell, and the USGS. The additional goal, self-imposed by this consortium, was that PICS would achieve the sophisticated scientific capacity of similar instrument collections flown on Voyager, Galileo, and Cassini (at 10 times mass, 10 times the power, and 10 times the cost). More specifically this meant PICS performance goals included, for instance, *high-resolution* imaging (like Mariners, Voyager, Galileo or Cassini; e.g.~10μrad IFOV) and *imaging* spectroscopy in the short-wavelength infrared and ultraviolet, comparable to NIMS (Near Infrared Mapping Spectrometer) on Galileo or VIMS (Visible-Infrared Mapping Spectrometer) on Cassini.

PICS was developed, demonstrated, and tested to the level of a fully functioning breadboard (Beauchamp, et. al. 1994). The most crucial new technology key to PICS and MICAS is the monolithic SiC construction (silicon carbide) used for the integrated structure, optical bench, and optics. This material was essential to realize the very low mass and to achieve combined thermal and optical stability

Table 1 Summary of MICAS characteristics.

	UVCCD	APS Imager	VISCCD Imager	SWIR
Detector Type	1024x2048 FT CCD	JPL APS 256^2	1024x2048 FT CCD	Rockwell PICNIC
Wavelength Range (nm)	80-185	500-1000	500-1000	1200-2400
Aperture Diameter (mm)	100	100	100	100
Effective Focal Length (mm)	171	677	677	752
F/number	1.7	6.8	6.8	7.5
Detector Array Size	35x164	256x256	1024x1024	256x256
Pixel Size (microns)	54	12	9	40
FOV (deg.)	0.63x0.03	0.26x0.26	0.69x0.78	0.7x0.003
IFOV (microrad/pixel)	316	18	13	53
Spectral Sampling Interval (nm/pixel)	0.64	na	na	6.6
Average Spectral Resolution (nm)	2.1	na	na	12

requirements. This material has 1) very high stiffness to mass ratio & the strength to allow it to be thinned to reduce mass while retaining rigidity and exceptional optical performance and 2) high thermal conductance and a very low coefficient of thermal expansion giving very high thermal stability. The monolithic SiC structure meant that the instrument would expand or contract thermally as a unit and stay in alignment and focus over wide temperature ranges; the low coefficient of expansion meant it would expand or contract very little in the first place. This allowed 1) design that could be assembled at room-temperature and would stay aligned and in focus when cooled to cryogenic operating temperatures (reducing the cost/complexity of integration) and 2) making optical alignment immune to thermal gradients across an instrument with several focal planes held at different temperatures.

To meet the exceedingly low power requirement, the PICS electronics design that was developed consists of a simple single signal chain with minimal controllability, serialized operation, and run at low clock-rates to minimize power. State-of-the-art electronics packaging, hybrids, and gate arrays were employed to minimize mass and size. The PICS PIDDP effort also motivated (and partly funded) an improved short-wavelength infrared detector. The Rockwell PICNIC (a refined NICMOS detector) array using a sapphire-based substrate that provided improved radiation tolerance and a lower read noise (c.f. Beauchamp, et. al. 1994).

An essential requirement that drove directly the PICS design was that it be "self-sequenced" that by its very nature its operation would result in a conflict-free timeline. This would save enormously on the traditional science planning and sequence integration processes that are such a costly and time-consuming component of planetary mission operations. Traditionally the hour-or-so around closest approach is jammed full of conflict because many investigations place their highest priority demands on this period. The requirement for a conflict-free timeline, combined with restrictions on PFF data rate and power, led to an approach in which the major observations were serialized. Sharing the long-focal-length multi-wavelength primary telescope among the cameras and the imaging spectrometers led to a situation whereby the sequence of prime observations was naturally spread out in time: UV emission spectroscopy would be acquired days before closest approach (C/A); the prime global SWIR map acquired ~ 1 hour before C/A; and the high-quality, high-resolution global imaging centered at C/A.

MICAS Technology Contribution: MICAS as selected for technology flight demonstration for the New Millennium (NMP) Deep Space 1 Mission (DS1) was a direct derivation of PICS with only minimal design changes. Several aspects of the instrument should have been substantially revised to address the different target requirements, in particular, the electronics were designed for a very different operating environment. Severe DS1 budget and schedule constraints precluded addressing these liens.

Table 1 shows the basic characteristics of MICAS. The four channels include the single-octave UV and SWIR imaging spectrometers as they were designed for PICS (although the UV grating was blazed for slightly longer wavelength). Two new detectors were also key elements, the new technology contribution: the Rockwell NICMOS-based PICNIC infrared array, which as mentioned above, was developed under the original PICS PIDDP program, and the JPL 256x256 Active Pixel Sensor (APS) imaging array, a very low power (~10mw) CMOS-based device in which amplification and readout electronics are embedded within each pixel.

The principal MICAS technology (also the major NMP DS1 development investment) is the integrated low-mass SiC multi-temperature, multi-focal plane structure, optical bench, and multi-wavelength optics. Using methods and processes developed by SSG, both hot-pressed SiC (for the overall structure and optics) and composite SiC/SiC (for the SWIR spectrometer structure) were incorporated. The optics was fabricated from hot-pressed SiC forms that were cladded with silicon and then diamond turned. The optical and thermal designs of MICAS have novel elements as well. The SWIR focal plane uses a "direct-drive" radiative cooler; the optical configuration using off-axis diamond-turned aspheres and off-axis toroidal gratings enable higher through-put with improved point spread function performance. The goal for multi-wavelength optical performance (e.g. providing acceptable transmission from ultraviolet through near infrared: ~50-5000 nm) was accomplished with a series optical coatings: Pt for the primary mirror (best compromise for full wavelength range UV-SWIR), SiC for the UV alone, Al for combined VIS and SWIR, and Au for SWIR alone. The triangular structure with externally mounted optical elements provided easy access to all focal planes.

MICAS In-flight Testing: In-flight testing of the full set of MICAS channels was deferred multiple times during the first several months of DS1 flight. Originally, a major component of the validation was to observe the Earth-Moon system during the first few weeks after launch. This was to provide the entire set of channels with extended targets critical for many elements of the demonstration and validation; the loss of this opportunity adversely affected the early in-flight characterization of MICAS reducing its subsequent readiness for the Braille encounter. The cancellation of the Earth-Moon sequence stemmed from startup problems in getting the DS1 ion engine started and running smoothly. Once the engine was operating properly, the decision was to defer MICAS characterization even further in order to get the ion engine lifetime operating test underway and to insure the mission performance to reach the asteroid.

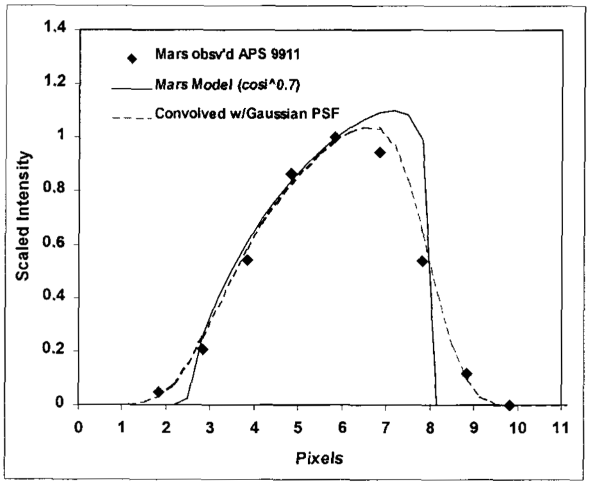

Figure 2 Model derivation of APS PSF function. Mars photometric model is convolved with Gaussian PSF function (Fig. 3) to fit APS Mars image.

Early in the DS1 flight OPNAV data were collected with the VISCCD channel of star fields and it became clear that MICAS was plagued by stray light. The stray light was due to reflected sunlight entering the aperture. This was caused by 1) location of MICAS on the DS1 S/C in a position that allowed scattered sunlight to reach the back of the sun shade and thereby into the aperture and 2) use of a reflective material in fabricating the occultation port in the sun-shade (leaving a reflective surface on its the inside edge). This stray light was pervasive, severely affecting optical navigation.

Validation Results: Validation criteria for the MICAS integrated multi-wavelength, multi-temperature, multi-focal-plane SiC structure and optics include 1) ability to easily assemble and align at room temperature, 2) retention of optical alignment as the instrument then was cooled to cryogenic operating temperatures, 3) demonstrated stable optical alignment in sustaining large temperature differences between focal planes, 4) demonstrated optical throughput over full wavelength range (ultraviolet through near infrared), and 5) maintain stable focal plane operating temperatures.

Thermal stability of the MICAS optical design was solidly demonstrated in pre-flight thermal vacuum tests. The system was aligned at room temperate and cycled down to cryogenic instrument operating temperatures through multiple cycles. The optical system exhibited no measurable change in alignment over these cycles; interferrometric measurement showed optical stability down to a precision of 1/10 wavelength. In addition the MICAS multi-wavelength performance was demonstrated in the laboratory to provide the optical throughput over the full wavelength range, ultraviolet through infrared.

Early during flight the MICAS ultraviolet channel detector failed. The device continues to respond to external stimuli (e.g. stray-light) and exhibits normal temperature-dependent characteristics, but the data are scrambled---pixels sheared, shifted, and summed. Tests by reading out the MICAS buffer have isolated the cause to the data scrambling to the detector itself. Currently the best candidate failure mode is a breakdown in a gate in the serial output circuit of the UV frame-transfer CCD.

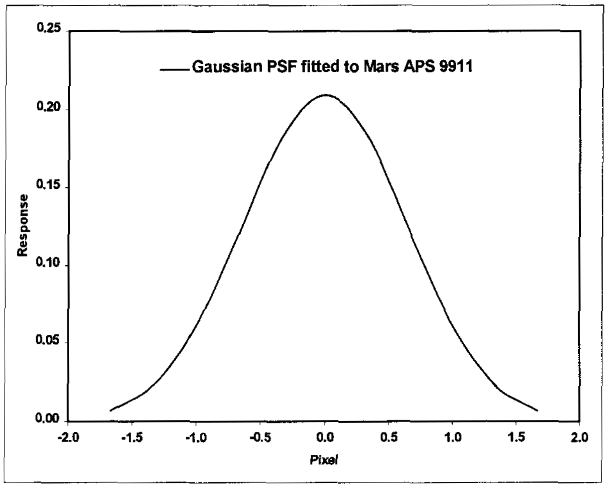

Figure 3 Gaussian PSF derived for MICAS APS Channel using Mars observations from Nov 1999.

Inflight tests of VISCCD, the APS, and the SWIR further validated the overall optical, thermal, and multi-wavelength performance of the integrated MICAS SiC optical/structural system. One of the best examples is shown in Figures 2 and 3. Early in November 1999 a series of APS and VISCCD images were acquired of Mars. Mars was at a range of roughly 5.5×10^7 km and subtended about 7 pixels in the APS and 9 in the VISCCD. Because they were relatively short exposures they provide excellent data to look at the point spread function (PSF) for both channels. Figures 2 and 3 show the results of such a analysis for the APS camera. The blue diamonds of Figure 2 represent the APS image profile across Mars (roughly equatorial from terminator to bright limb); the phase angle was ~52.8°. A photometric model for Mars was convolved with a Gaussian PSF function; the resultant fit is shown as the red dashed line in Figure 3. The model PSF derived in this process is shown in Figure 2. The full width at half maximum (FWHM) of this PSF is ~1.5 pixels consistent with the original design for the optical system for this channel. Similar images and analyses acquired for the VISCCD for the same November 1999 Mars sequence shows PSF with a FWHM ~2 pixels consistent with the IFOV ratios of the two channels (~1.5:1). These are quite sensitive measures of optical stability and shows the optical system to have stayed in alignment and to deliver design performance in flight.

In addition MICAS observations of Mars can be used for inflight validation of the SWIR imaging spectrometer (demonstrating spectro-optical, detector, focal plane, and thermal performance). This analysis shows the end-to-end performance of the SWIR was also successfully validated. During May of 1999 three observations were made of Mars

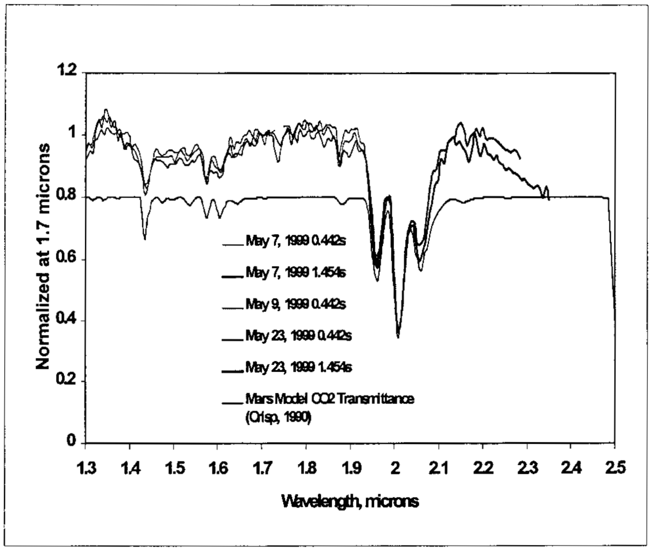

Figure 4 Collection of MICAS SWIR observations of Mars during May, 1999.

with the MICAS SWIR channel from a ranges of between 105 and 110 million kilometers at a phase angle of ~50 degrees. Two exposure times were used (0.442s and 1.454s the second of which saturated at shorter wavelength but provided better SNR at greater than 2μm). These observations were taken at three separate longitudes; all are dominated by bright regions. Mars was about 1 SWIR pixel (SWIR IFOV is 54μradian). Fig. 4 shows all five of these calibrated and reduced spectra along with a theoretical model of the transmittance of CO_2 computed by D. Crisp (1990). The agreement of the MICAS observations with the theoretical CO_2 transmittance is remarkable. The quality of the MICAS spectra in the 1.4 to 1.9 μm range far surpasses any observations to date, either ground-based or space-based. Two groups of features at ~ 1.74 μm and at ~1.87 μm in Fig. 4 are candidates for new surface features. Features due to sulfates this spectral range were recently suggested. Calvin .et. al., 1999 suggested a gypsum band might be visible in the Phobos ISM spectra at about 1.75μm and Bishop et. al. 1999 suggested that jarosite might produce a feature in the 1.85μm region. These are by no means suggested to be definitive identifications for the MICAS features but they do suggest that reflectance imaging spectroscopy as a viable scientific tool that should be flown to Mars in the next decade. They also constitute demonstrable validation of the overall end-to-end performance of the MICAS SWIR channel.

[1] P.M. Beauchamp et. al. (1994) AIAA Conference Utah; [2] D. Crisp (1990) JGR 95 pp. 14577-14588, [3] W. M Calvin et. al. 1999 5th Intl Conf. on Mars pp. 6125-6126, [4] J. L. Bishop (1999) 5th Intl Conf. on Mars pp. 6220-6221.

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