N94-16429

THE SPECTRUM OF PHOBOS FROM *PHOBOS 2* OBSERVATIONS AT 0.3-2.6 μm: COMPARISON TO PREVIOUS DATA AND METEORITE ANALOGS

Scott Murchie[1] and Stephane Erard[2]. [1]*LPI, Houston, TX*; [2]*Instituto di Astrofisica Spaziale, Roma, Italy*.

Introduction. The surface of Phobos has been proposed to consist of carbonaceous chondrite [1,2] or optically darkened ordinary chondrite ("black chondrite") [3]. Measurements of Phobos's spectrum are key evidence for testing these hypotheses. Disk-integrated measurements were obtained by the *Mariner 9* UV spectrometer [1], *Viking Lander* cameras [2], and groundbased observations [4]. In 1989 disk-resolved measurements of Phobos and Mars were obtained by three instruments on *Phobos 2*: the KRFM spectrometer, which covered the wavelength range 0.32-0.6 μm [5,6]; the ISM imaging spectrometer, which covered the wavelength range 0.76-3.16 μm [7]; and the VSK TV cameras, whose wavelength ranges overlap those of KRFM and ISM [6,8]. Here we report analysis of the *Phobos 2* measurements completed since earlier results were reported [3-10]. We validated calibration of the Phobos measurements using observations of Mars for reference, and compared them with pre-1989 measurements. We also combined spectra from the three detectors to produce an integrated spectrum of Phobos from 0.3-2.6 μm. *Phobos 2* results agree well with previous measurements, contrary to some reports [9]. The general shape of the spectrum is consistent with both proposed analogs. However position and depth of the previously unobserved 1-μm absorption are more diagnostic, and indicate the composition of typical surfaces to be more consistent with black chondrite.

Background. The *Mariner 9*, *Viking*, and telescopic observations were combined by Pollack *et al.* [2] and Pang *et al.* [11] to produce disk-integrated spectra of Phobos from 0.2-1.1 μm. Both results indicate a flat spectrum at 0.4-1.1 μm and a falloff in reflectance at wavelengths below about 0.4 μm. However the two studies used different photometric functions to normalize data to 0° phase angle, and yielded slightly different geometric albedos at visible wavelengths, with a value of 0.05±0.01 reported by Pollack *et al.* [2] and 0.046±0.01 by Pang *et al.* [11].

The VSK cameras bracket the wavelength range having a "flat" spectrum, with a "visible" channel at 0.40-0.56 μm and a "NIR" channel at 0.78-1.1 μm. The average disk-resolved vis/NIR ratio was measured as 0.97±0.14 [6]. NIR reflectance is relatively homogeneous, but heterogeneities in the vis/NIR ratio occur due to spatial variations in visible reflectance [6]. These impart visible-wavelength albedo heterogeneities to different parts of Phobos, such that NIR measurements acquired at different times are more comparable than visible-wavelength measurements.

Observations by KRFM and ISM provide higher spectral resolution measurements at a lower spatial resolution than VSK. ISM spectra reveal an absorption near 1 μm consistent with the mafic minerals olivine or pyroxene [7]. Strength of the absorption is up to 5% and largely independent of brightness, but areas with higher vis/NIR ratios measured simultaneously by VSK exhibit stronger absorptions [10]. These relationships support an origin for the 1-μm absorption indigenous to Phobos: an origin due to scattered Mars light measured by the detectors would result in correspondence of stronger absorptions with poorly illuminated regions or lower vis/NIR ratios (because of the "red" color of Mars). KRFM observations also indicate heterogeneities in UV-visible spectral properties, with surfaces having high vis/NIR ratios as measured by VSK also having comparatively flat UV-visible spectra [5,6,10].

Comparison of Viking and VSK Results. VSK imagery is well suited to determination of photometric and color properties of Phobos: the data cover a wide range of phase angles (7°-88° [8]), and the vis/NIR ratio of Phobos was calibrated to telescopic observations of a part of Mars observed simultaneously with Phobos [6,8]. The average vis/NIR ratio near 1.0 agrees with the "flat" disk-integrated spectrum at comparable wavelengths reported by Pollack *et al.* [2] and Pang *et al.* [11]. However geometric albedo calculated from VSK measurements are more compatible with the spectrum of Pollack *et al.* [2]. (A value of 0.062±0.013 is reported for the NIR channel [8]). For this reason, we adopt the Pollack *et al.* disk-integrated spectrum as representative of pre-1989 measurements.

Validation of ISM and KRFM Spectra. ISM and KRFM spectra are critical to defining the 1-μm absorption and the UV falloff, whose positions and magnitudes differ between the proposed compositional analogs. Accurate calibration of these data is therefore crucial. ISM data were calibrated initially using instrumental parameters measured on-ground and in-flight [7,12]. The initial calibration was refined by applying multiplicative coefficients to each channel, based on a spectral model of Phobos. An early version of this procedure was reported by Erard *et al.* [12]. These coefficients have subsequently been refined, and tested by dividing a Mars spectrum calibrated in this way by a telescopic spectrum of the same region. This procedure yielded no absorption-like residuals, assuring that the position and strength of the 1-μm absorption on Phobos are free of calibration artifacts.

Two versions of KRFM spectra have been reported: calibrated to pre-1989 Phobos measurements [6], and calibrated to telescopic spectra of Mars using unobstructed KRFM Mars observations [9]. Surprisingly, these procedures yield different results. To address this dilemma, we rederived the calibration of KRFM using data acquired on 25 March 1989. At that time KRFM observed a groundtrack that covered a portion of Phobos shown by VSK and ISM to be homogeneous, crossed the terminator and entered the nightside, and emerged from occultation over a period of ~25 s into a uniform bright region of Mars. The time series of differing brightnesses of the two uniform regions provide test for inter-channel variations in gain and offset. Regression analysis of the brightnesses in different KRFM channels indicates significant offsets that were previously unrecognized, plus nonlinearity in gains at brightnesses typical of Mars filling the instrumental FOV. This non-linearity and the unremoved offsets explain the unusual spectrum of Phobos derived by investigators who calibrated Phobos observations using much brighter, unobstructed observations of Mars [9]. Fortunately, gains are linear across the brightness range encompassing both Phobos and Mars *while partly occulted.* With due caution, calibration of Phobos data can be checked against Mars.

Figure 1 shows a rederived KRFM spectrum of a portion of Phobos with an "average" vis/NIR ratio, calibrated using offset-removed data, observations of Mars while partly occulted, and telescopic spectra of Martian "bright regions" [13]. It agrees closely with the disk-integrated spectrum of Pollack *et al.* [2]. This KRFM spectrum differs from previously published KRFM spectra that were calibrated to pre-1989 Phobos measurements [6] only in the 0.4-μm wavelength region, which was undersampled by previous observations. This correspondence occurs despite the formerly unremoved offsets, because the previous spectra [6] were chosen to cover a restricted range of brightnesses.

Integrated spectrum of Phobos. An integrated spectrum of Phobos from 0.3-2.6 μm was derived for a small region where coverages by KRFM, VSK, and ISM overlap (Figure 2). This region corresponds to the "reddish gray" color unit of Murchie *et al.* [6]; the vis/NIR ratio is "redder" than average for Phobos but typical of the trailing hemisphere. The corresponding rederived KRFM spectrum and ISM spectrum were convolved with the response functions of the visible and NIR channels of VSK, respectively, and scaled using the measured vis/NIR ratio.

Discussion. The correspondence between properly calibrated KRFM spectra, VSK measurements, and the spectrum of Pollack *et al.* [2] supports the canonical view of a "flat" average spectrum of Phobos at 0.4-1.1 μm with a falloff in reflectance below 0.4-0.5 μm [1-3,6,10,11]. The general shape of Phobos's spectrum from 0.3-2.6 μm resembles both proposed analogs. However, position and strength of the previously unobserved 1-μm absorption are more diagnostic of proposed compositions. The band minimum for ordinary (including black) chondrites is typically at 0.90-0.95 μm [14]. Low-grade carbonaceous chondrites (CI,CM) exhibit little or no absorption, but in higher metamorphic grades (C3O,C3V) the band minimum is generally at longer wavelengths than in black chondrites (near 1.0 μm) due to more olivine-rich compositions [14]. Figure 2 shows that the band minimum on Phobos is near 0.93 μm, consistent with a relatively pyroxene-rich composition and best matched by black chondrites.

References: [1] K. Pang *et al., Science, 199*, 64, 1978. [2] J. Pollack *et al., Science, 199*, 66, 1978. [3] D. Britt and C. Pieters, *Astron. Vestnik, 22*, 229-239, 1988. [4] B. Zellner and R. Capen, *Icarus, 23*, 437, 1974. [5] L. Ksanfomality *et al., Planet. Space Sci., 39*, 311, 1991. [6] S. Murchie *et al., J. Geophys. Res., 95*, 5101, 1991. [7] J.-P. Bibring *et al., Proc. Lunar Planet. Sci. Conf. 20th*, 461, Lunar and Planetary Institute, Houston, 1990. [8] G. Avanesov *et al., Planet. Space Sci., 39*, 281, 1991. [9] J.-P. Bibring *et al., Lunar Planet. Sci. XXII*, 99, 1991. [10] S. Murchie *et al., Lunar Planet. Sci. XXII*, 943, 1991. [11] K. Pang et al., Nature, 283, 277, 1980. [12] S. Erard *et al., Proc. Lunar Planet. Sci. Conf. 21st*, 437, 1991. [13] R. Singer and T. McCord, *Proc. Lunar Planet. Sci. Conf. 10th*, 1837, 1979. [14] M. Gaffey, *J. Geophys. Res., 81*, 905, 1976.

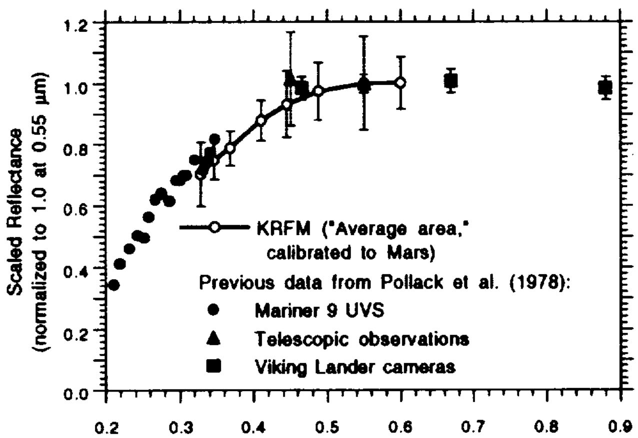

Figure 1. KRFM spectrum of a region of Phobos with an "average" vis/NIR ratio as measured by VSK, compared to previous spectral measurements of Phobos as presented by Pollack *et al.* [12].

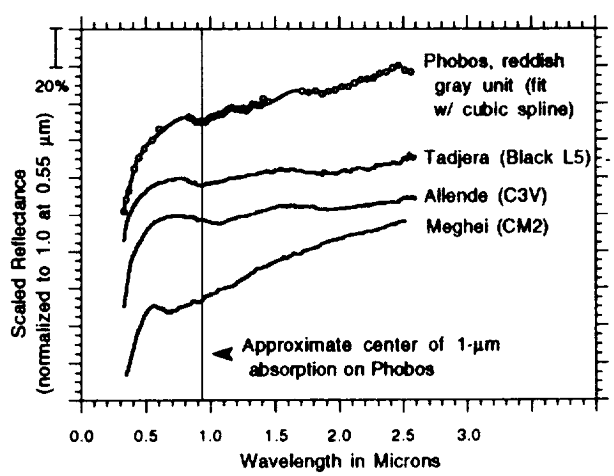

Figure 2. Integrated KRFM-ISM spectrum of Phobos, compared to spectra of proposed meteorite analogs. The verical line shows the approximate center of the 1-μm absorption on Phobos.