COMPOSITE KRFM-ISM SPECTRUM OF PHOBOS (0.315-3.1 μM).

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On 25 March 1989 two instruments on board the Phobos-2 spacecraft measured spectra of the satellite Phobos, covering together the wide range between 0.315 and 3.1 μm. Measurements of the spectral properties of Phobos over such a wide range were done here for first time. Also for the first time spectral observations of Phobos were provided with a spatial resolution of approximately 1/20 of its diameter. The instruments used were 1) a near infrared mapping spectrometer ISM / 2 / and 2) a spectrophotometer , which was the part of the KRFM instrument / 3 / . The spectral range of ISM is 0.85-3.1 μm with resolving power $\lambda/\Delta\lambda \sim 50$ and instantaneous FOV about 12'. The spectral range of KRFM is 0.32-0.6 μm. There are 10 spectral pixels in this range with $\lambda/\Delta\lambda \sim 10$. The FOV of KRFM is about 15', so the FOV of both instruments are comparable. The distance to the satellite Phobos was measured to be about 200 km and the spatial resolutions provided by ISM and KRFM on its surface were about 0.8 and 1 km correspondingly.

An important difference between the two instruments is that the ISM has a mirror before the telescope entrance with the ability of periodic angular motion, providing (together with orbital motion of the spacecraft) two-dimension coverage of the observed surface (multispectral imaging). The KRFM has no scanning mirror and makes measurements along a one-dimensional "track". This track is approximately coincident with the ISM track, corresponding to the zero position of its scanning mirror (this co-alignment for one of the ISM arrays was, from groundbase tests, almost exact; for the others there is ~ 30' displacement).

This co-alignment (if it was preserved in flight) makes it possible to combine results of both instruments and obtain for some set of points of the observed surface the spectrum in the full range covered by them, namely from 0.315 to 3.1 microns. KRFM obtained two tracks (Track 1 and Track 2, see Fig.1), ISM obtained simultaneously a set of spectra without angle scanning (with zero position of scanning mirror) in the first sequence and a multispectral image in the second. We do not use in this study track 1 for the ISM/KRFM comparison because ISM sequence 1 spectra are contaminated by scattered light from Mars, which was much nearer in this time to Phobos (in angular position) than in the second sequence. Track 1 of KRFM and the "zero position" line of ISM in the second sequence have 14 common points and data only obtained there will be discussed below.

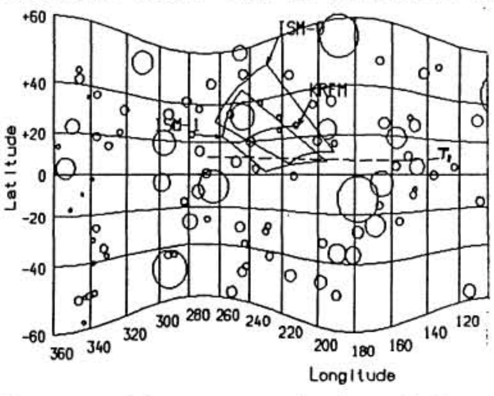

Fig.1. Position of the observed parts of Phobos: 0-ISM, sequence 2, Array 0,1-ISM, sequence 2, Array 1, T1-KRFM and ISM (Array 0) track in sequence 1.

Two problems required solution before this analysis could be made: 1) recovery of coordinates on the surface of Phobos, and 2) recovery of the intensity calibration for both instruments. Final orbital data for Phobos-2 were critical to find the coordinates, and only recently were provided by the astrodynamic team. Coordinates were retrieved from these data using the Duxbury / 4 / vector model of the Phobos figure by Khatuntsev and Nikolsky of the Soviet ISM team. The French ISM team / 5 / used the another method of coordinate retrieval based partially on the identification of one of the craters on the ISM image. The two last versions have only 5^0 (~1 km) difference in longitude and are almost coincident in latitude. The phase angle was about 29^0 in the second observational sequence. The terminator is positioned near the left side of the ISM field shown in Fig 1.The Sun's zenith angle is 60^0-70^0 and reflection angle 50^0-55^0 in most of the "common points".

Now we consider the calibration problems. Laboratory calibration of KRFM was recognized as unreliable after analysis of the results of measurements of Mars. Murchie et al. / 6 / proposed to use a spectrum of Phobos compiled by Pang et al. / 1 / from different observations for recalibration of KRFM. We now consider that this was not a good idea because the brightness of small areas of Phobos depends on the geometry of the observations (photometric angles) and by different amounts at different wavelengths. It is much better to use not Phobos itself, but Mars as a natural photometric screen.

Our newly calibrated spectrum of Phobos is presented in Fig.2a. It is substantially different from the "average" spectrum published by Pang et al. / 1 / in the common part of the wavelength range, and extends it far to the infrared. There are several reasons for the difference with Pang et al. (see Fig.2b): 1) The difference in phase angle. In the case of Pang et al. it is nominally zero, while in our case it is 29°. The phase function of Phobos has a strong maximum at 0° / 7, 8 /. The Phase function and other angular dependence explains satisfactorily the difference in the brightness for 0.55 microns. 2) The curve of Pang et al. / 1 / is a compilation of data obtained by different instruments, and from their paper it is not possible to understand how the normalization to phase angle 0° was made, or which phase functions (in principle, wavelength dependent) were used, etc. 3) Phobos has pronounced inhomogeneities in spectral properties, as was demonstrated clearly by comparison of Phobos disk photometry made by TV-camera on the Phobos-2 spacecraft in two wavelengths (0.5 and 0.9 microns, see / 10 /). For example, the ratio of brightness at these two wavelengths (0.5/0.9) is approximately 1.5 times large on the "Stickney" side of Phobos than on the "anti-Stickney" part, which we observed.

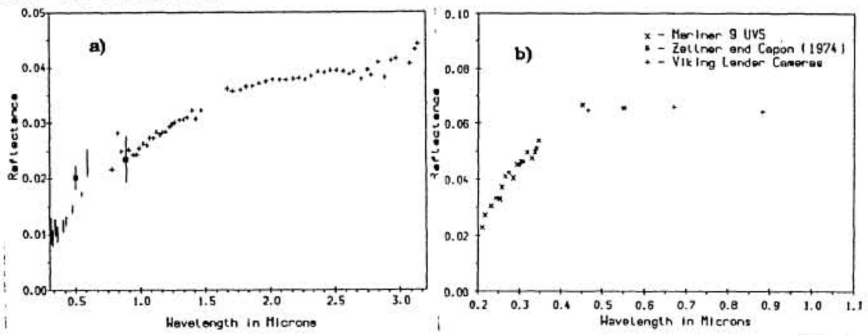

Fig.2. a) An example of combined KRFM and ISM spectra for one of the 14 common locations of sequence 2. Y axis is the measured brightness factor for ISM and KRFM and the phase angle dependent geometric albedo P(φ) for TV camera at the same phase angle φ=29°. TV camera values P(φ) were provided by B.S. Zhukov (improved version of phase curve published by Avanesov et al.,/ 7 /). The point at 0.6 μm for KRFM is doubtful because Mars KRFM photometrical data are absent (oversaturated) for this wavelength and an extrapolation based on laboratory calibration was used to restore the sensitivity level given here. b) The "average" spectrum of Phobos compiled from the Mariner-9 UV-spectrometer, Viking landers and groundbased data, according Pang et al. /1/ and Klaasen et al. /12/.

The spectrum shown on Fig.2a has no direct analogs among spectra of meteoritic samples presently available to us. It looks like C1 shorter 0.6 μm but is very different at λ>1 μm: 1)the slope is much more than for all type of carbonaceous and even enstatite chondrites and 2) there is no trace of the known hydration band near 3 μm. The same confusion arises in comparisons with C asteroids. Perhaps the CM meteorites are nearest to the observed part of Phobos in terms of spectral reflectivity. D asteroids have a large slope in near infrared / 10, 11 / but have no significant decrease in reflectivity in the blue. Gradie and Veverka / 10 / suggested that the low albedo and red spectra of some Trojan asteroids can be explained by the presence of kerogen-like organic compounds. Perhaps the same hypothesis applies to Phobos.

We can conclude that Phobos' surface, at least in the observed region, has a much more complicated composition than anticipated. It is probably a mixture of different sorts of materials including, for example, iron-bearing silicates (providing UV absorption), carbon and/or its compounds.

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