THE HST SPECTRUM OF PHOBOS: COMPARISON WITH MARINER 9, VIKING, AND PHOBOS 2 RESULTS AND WITH METEORITE ANALOGS

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The Hubble Space Telescope (HST) acquired a spectrum of the leading hemisphere of Phobos [1], which we have used to evaluate previous spectral measurements from Mariner 9, Viking, and Phobos 2 and to assess spectral similarity of the satellite with proposed meteorite analogs. The HST spectrum is consistent with results from the Mariner 9 UVS spectrometer [2], and with properly calibrated measurements from Phobos 2's VSK TV cameras [3] and KRFM UV-visible spectrometer [4,5]. However the HST spectrum is much redder than the visible-NIR spectrum returned by Viking Lander 2 [6]. This discrepancy might arise from the fact that the two data sets sample different hemispheres of the satellite. The HST spectrum of Phobos is not uniquely consistent with any known meteorite analog, but it is matched most closely by high-grade carbonaceous chondrites or black chondrites. Alternatively Phobos's surface may consist of a material not represented among known meteorites.

HST Measurements. The HST Faint Object Spectrograph measured 210-900 nm spectra of the leading hemisphere of Phobos and two low-albedo C- and D-type asteroids (702 Alauda, 1144 Oda). The asteroid spectra agree well with results from the 8-color survey of Zellner *et al.* [7], indicating validity of the Phobos spectrum. Although the HST data are of some utility at wavelengths as short as 210 nm, in this analysis we use only the wavelength range 280-720 nm where the observational scatter is minimized..

Previous Measurements. Spectra of Phobos have been measured by three spacecraft in the satellite's vicinity. Mariner 9 and Viking measured disk-integrated spectra (Fig. 1). The Mariner 9 UV spectrometer acquired a 255-345 nm spectrum of the leading hemisphere [2], and the Viking Lander 2 camera measured the sub-Mars hemisphere with channels centered at 465, 669, and 880 nm [6]. Phobos 2 measured disk-resolved spectra using three instruments. The VSK camera acquired images in visible and NIR (~510-nm and ~910-nm) channels showing leading and trailing parts of the anti-Mars hemisphere and part of the sub-Mars hemisphere [3,9]. The 320-600 nm KRFM spectrometer scanned two groundtracks, also in the anti-Mars hemisphere [4,5,9]. The 760-3160 nm imaging spectrometer ISM imaged only the trailing part of the anti-Mars hemisphere [10]. The wavelength ranges of the KRFM and ISM overlap with those of VSK, so that the data sets can be joined to form composite spectra where their coverages overlap. In the leading hemisphere, observed by HST, the VSK images extend the wavelength range of KRFM. Composite spectra of that hemisphere are shown in Figs. 2 and 3.

Phobos 2 data were calibrated using parts of Mars observed by the instruments as spectral standards. Bright regions, which are stable and well-characterized spectrally, were used for KRFM so that these data are relatively reliable. Unfortunately the only suitable area observed by VSK is a dark region at 35°S,335°W, and dark areas exhibit albedo and color variations due to wind-transported dust. Initially the calibration area was modeled spectrally as purely low-albedo material [3]. This assumption produced vis/NIR color ratios for Phobos that are relatively gray (see Fig. 2). However telescopic images acquired 6 months prior to Phobos 2 data show the calibration area to have instead an intermediate albedo [11]. On this basis VSK images have been re-calibrated, by modeling the calibration area as a mixture of dark and bright components [5]. With this procedure vis/NIR color ratios of Phobos become uniformly 15% redder than reported previously [e.g. 3] (Fig. 3).

Evaluation of Previous Measurements. VSK images demonstrate significant color heterogeneity of Phobos's surface [3,5,12]. The trailing hemisphere contains a relatively redder unit, having a low vis/NIR ratio, but the leading hemisphere is covered by a relatively bluer unit with a higher vis/NIR ratio. Thus the well-controlled HST spectrum can be used to validate previous measurements covering the same wavelength range, but this comparison requires data sets that sample the same region (the leading hemisphere).

Fig. 1 compares pre-Phobos 2 observations with the HST spectrum. The Mariner 9 UVS spectrum, which like the HST spectrum samples the bluer unit in the leading hemisphere, exhibits a nearly featureless red-slope generally consistent with the HST spectrum where their wavelengths overlap. In contrast, the 3-color Viking Lander 2 spectrum of the sub-Mars hemisphere is much less red than the HST spectrum. The only independent measurements in which the sub-Mars face can be resolved separately from the rest of the leading or trailing hemisphere is VSK images. In VSK data, the only observed part of the sub-Mars hemisphere (around Stickney) has the bluest color of any part of the satellite. The most obvious explanation for the discrepancy between HST and Viking Lander 2 observations is that, on average, the sub-Mars hemisphere is intrinsically more blue than the leading hemisphere. Alternatively, there may have been calibration problems with Viking Lander 2 observations.

Figs. 2 and 3 compare Phobos 2 spectra with the HST spectrum. The HST spectrum is not significantly different from a representative KRFM spectrum of the leading hemisphere, calibrated as described by [4]. (In contrast the HST spectrum is markedly different from results of earlier attempts to process KRFM data [e.g. 13].) However the extension of the KRFM spectrum into IR wavelengths, using the NIR channel of VSK, differs

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between the original and revised VSK calibrations. In Fig. 2, based on the orginal VSK calibration, NIR reflectance is too low compared to the HST spectrum. In Fig. 3, based on the revised calibration, the composite spectrum instead closely matches the HST spectrum. Thus, previous spectra of Phobos appear generally consistent with HST data, provided that account is made of proper calibration and differing viewing geometries.

Comparison with Meteorite Analogs. CI and CM carbonaceous chondrites, higher-grade anhydrous carbonaceous chondrites, and black chondrites have all been proposed as spectral and compositional analogs to Phobos's surface [10,14,15]. Representative spectra of these meteorite classes covering the wavelength range of HST are shown in Fig. 4. Spectra of CI and CM chondrites, which are the generally cited analogs, exhibit an inflection near 500 nm [16] that is absent from the Phobos spectrum. This lack of evidence for a low-grade carbonaceous chondritic composition is consistent with most interpretations of Phobos 2 data [e.g. 3-5,8-10,12]. Instead the HST spectrum exhibits a shorter-wavelength inflection consistent with that in higher-grade carbonaceous or black chondrites, and most closely matches black chondrites. However the HST data do not cover the 1-μm mafic mineral absorption whose occurrence and position are diagnostic of the two meteorite classes [cf. 16]. Therefore the HST data are equally consistent with a composition not represented among known meteorites.

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