REVIEW OF THE ISM INSTRUMENT AND RESULTS. John F. Mustard, Department of Geological Science, Box 1846, Brown University, Providence RI, 02912. (John_Mustard@brown.edu) #3040

Instrument Parameters: Detailed descriptions of the ISM instrument are provided by [1,2,3,4, 5]. The ISM instrument is a scanning imaging spectrometer that covers the spectral range 0.76 to 3.16 µm. For each pixel, 128 spectral measurements are acquired simultaneously. A 2-dimensional image of the surface was obtained by rotating the entrance mirror to scan in the cross track direction for the image samples and the forward motion of the spacecraft provides the image lines. The spectral dispersion is obtained by using a grating, whose the first and second orders are exploited. These two orders are separated by a beam-splitter and filters, and measured by four groups of 32 cooled PbS detectors, designated first and second order odd and even. Extensive evaluation of data quality and integrity has shown that the even detectors are superior overall to the odd detectors [4]. Therefore the even channels for the first and second order are used which results in 64 channel spectra for each pixel. The signal to noise of these data is extremely high and averages greater than 500:1 for data from 0.77 to 1.51 µm and 1.68 to 2.6 µm. The detector sensitivity drops off slightly at the extremes of the wavelength ranges, but only drops below 100:1 at wavelengths longer than 2.6 µm.

The ISM experiment acquired 11 imaging spectrometer data sets for the surface of Mars. These data sets, or windows, are 24 samples wide and up to 120 lines long. The IFOV of the instrument is 12'x12' which, from the altitude of orbit of 6300 km, corresponds to a surface resolution of approximately 22x22 km at normal incidence. In the rest position, the viewing plane of the instrument was oriented parallel to the sun's rays and therefore at the subsolar point, the incidence angle equals the emergence angle and the phase angle is 0°. The scanning mirror permits some variation from this geometry and the phase angle varies <5° for each window and is always less than 20°. Incidence and emergence angles are a function of longitude and latitude. The image data for a given window were acquired over a period of 25 minutes and therefore the effects of temporal variability in the atmosphere are minimal. There is a systematic increase in atmospheric path length with distance from the sub-solar point.

Strengths of the Data Set: At the time the data were acquired, ISM constituted the first imaging spectrometer data set acquired of another planet from orbit. The key strengths were the contiguous spatial pixels, the imaging format, and most importantly the SNR. The importance of the imaging format cannot be overemphasized, as this allowed checking of spectral feature mapping, and mapping of spectral properties of the surface across boundaries and geologic units. The calibration of ISM has been extensively studied and refined over time [4, 6, 7], but what allowed this to a large extent was the very high quality of the acquired data. However, the very high SNR allowed many analyses of relative surface spectral properties to proceed regardless of absolute calibration.

Significant Results: There have been 27 peer reviewed publications which concentrate on the data from the ISM spectrometer for Mars and Phobos [5] covering topics ranging from the atmosphere (including composition, aerosols, and variability), to the surface composition (mafic mineralogy, hydrated mineralogy, unusual materials), to the scattering of the surface. Important null results were the lack of any carbonate, sulphate, scapolite, or distinct clay features.

Atmosphere: The atmospheric opacity during the mission was uniformly low, estimated to be 0.2 - 0.3 [8, 9] while atmospheric H_2O showed a diurnal variability [10]. Detailed studies of aerosols revealed several important properties [7]. Scattering by aerosols and dust in the atmosphere is a function of atmospheric opacity and the ISM data were acquired during the period when atmospheric opacity is generally at its lowest. The magnitude and spectral characteristics of the atmospheric scattering were derived for the ISM data using two methods. The first used several spectra that were obtained of the limb permitting direct measurement of atmospheric scattering. The second method made use of regions which were measured during different observing runs. The results of this analysis are that the aerosol particles have an average radius of 1.2 +/- 0.2 µm. The spectrum of the aerosol contribution is dominated by a negative continuum slope which decreases exponentially toward a minimum near 2.6 µm. In addition, the spectral properties revealed a component of water ice, likely associated with atmospheric dust particles.

The total relative contribution to the surface signal is estimated to be 5-15%. Since this scattering is additive, analysis of differences in spectral slope between terrains due to surface spectral properties through derivatives (e.g. [6, 11]) is valid. This scattered component affects the position, shape and strength of mineral absorption features in two ways. First, absorption band strength is reduced which may explain why important crystalline ferric absorptions are observed at some times (e.g. [12]) but not others (e.g. [13,14]). The second effect is to cause an apparent shift to longer wavelengths of absorption band minima. This shift is small (<10-30 nm) and does not significantly change previous analyses of surface composition from ISM data, but should be factored into future analysis of surface composition from absorption band position and shape.

Mineralogy of Low Albedo Regions: The high spatial resolution, spectral coverage, and high signal to noise of the ISM data permitted the determination of a mineralogic basis for the spectral properties of several distinct morphogeologic dark regions on Mars [15, 16]. Through the use of the Modified Gaussian Model, it was shown that these areas are dominated by two-pyroxene basalts, analogous to the basaltic SNC meteorites, but that the plateau plains (e.g. Syrtis Major) are enriched in high-calcium pyroxene relative to the floors of Valles Marineris. Within this two-pyroxene model, there exists significant diversity in the spectral properties among relatively unaltered regions on Mars, and a central question is how is this spectral diversity related to mineralogic diversity. Then, once we understand the mineralogic composition, what does that tell us about volcanic processes and the composition of the source regions. Ultimately, however, the presence of two-pyroxene basalts implies they were derived from mantle depleted in aluminum relative to the original mantle composition inferred for Mars.

Mineralogy of Bright and Transitional Regions: While bright regions show a greater homogeneity than dark regions, they also exhibit important information related to their mineralogy. Murchie *et al*. [17] showed that the bright regions are largely consistent with the nanophase hematite model in an amorphous silicate matrix. However, most regions exhibited a very weak 2.2 µm feature consisted with a metal-OH band. Some regions, however, did not show this feature. In addition, there are significant variations in the strength of the water of hydration band near 3.0 µm, where layered terrains in Valles Marineris exhibited the strongest absorptions. Finally, many of the so-called dark red regions (e.g. Oxia Palus) exhibited features inconsistent with a simple mixture between bright and dark soils. Rather, they appear to be a unique material and may contain hydrated ferric oxides and oxyhydroxides.

Weak Points of the Instrument and Data Set: Perhaps the single largest problem to plague the ISM data set was calibration. There are several reasons for this. First, the instrument did not have as extensive an instrument check out as it could have. This is not a criticism of the personnel at IAS who did a remarkable job under a very tight schedule. However, several problems were revealed once the instrument arrived in orbit and it was necessary to conduct numerous analyses to identify and correct calibration problems. While these operations were ultimately successful, it resulted in a distrust of the data set by the larger community. Nevertheless, two studies showed an excellent agreement between ISM and independently acquired spectral data sets [18, 19]. Another weakness was spectral resolution. Although the instrument did have 128 channels, only 64 were used due to pointing and calibration. In addition, slight channel-to-channel offsets created artifacts in limited spectral regions at particular albedo boundaries. Finally, the lack of visible spectral information seriously hampered the ability to understand the ferric mineralogy and separate it from ferrous mineralogy.

Lessons Learned: ISM demonstrated the great value of imaging spectroscopy for Mars exploration. Despite the calibration criticisms, and the fact the Mars is remarkably homogeneous on a global scale, much important information was obtained. The extraordinary SNR permitted analysis of the calibration and the mapping of extremely subtle spectral differences on the planet. The most exciting features that unfortunately could not be pursued due to the lower SNR were in the water bands near 3.0 µm. There were distinct variations on the surface related to geologic features, but they were slightly beyond the spatial and spectral resolution. In my opinion, these are the most important items to consider for future missions:

- Signal to noise…sacrifice spectral and spatial resolution for signal to noise (to a point).
- Spectral range…cover the visible and near-infrared out to the 4.0 CO_2 band
- Spectral resolution…at least 10 nm in key wavelength regions.
- Calibrate, calibrate, calibrate!

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