SPACE WEATHERING ON ASTEROIDS: NEW RESULTS FROM THE ULTRAVIOLET. F. Vilas[1] and A. R. Hendrix[2], [1]MMT Observatory, P.O. Box 210065, University of Arizona, Tucson, AZ 85721, [2]Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Dr., MS 230-250, Pasadena, CA, 91109, fvilas@mmto.org.

Introduction: We present evidence that space weathering manifests itself at near-ultraviolet wavelengths as a bluing of the spectrum, in contrast with the spectral reddening that has been seen at visible-near-IR wavelengths. This UV bluing often results in a spectral reversal, where surfaces that are bright at visible-near-IR wavelengths are relatively dark at UV wavelengths, and vice-versa. Furthermore, the effects of space weathering at UV wavelengths tend to appear with less weathering than do the longer-wavelength effects, suggesting that the UV wavelength range is a more sensitive indicator of weathering, and thus age. We report result from analysis of existing near-ultraviolet measurements of S-type asteroids from IUE and HST to support this hypothesis, and compare with laboratory measurements of meteorites.

Space weathering is also an important process in the asteroid belt, and is the hypothesized cause of spectral differences between ordinary chondrite (OC) meteorites and their proposed parent bodies, S-class asteroids [1,3]. The visible/near IR spectral characteristics of weathering of asteroids could be similar to those seen on the Moon (i.e., darkening, red spectral slope, decreased strength of near-IR absorption features). The addition of SMFe-bearing coatings to the grains of an OC meteorite sample results in spectral reflectance features similar to those of an S-class asteroid [3].

Space Weathering: Space weathering, the bombardment of airless bodies by micrometeoroids and irradiation by solar wind particles, affects spectra of solar system bodies by darkening and 'reddening' (where the spectral reflectance increases with wavelength) their surface materials, as well as degrading absorption features (1) at visible/near IR wavelengths. These effects are well documented for the Moon (e.g., 2), where they are apparent in spectra of natural lunar soils, but not seen in spectra of powdered lunar rock samples. The cause of these weathering effects is likely vapor deposition of submicroscopic iron (SMFe) (3), through solar wind irradiation and micrometeorite bombardment of the bodies' surfaces.

Effects of Weathering in the UV: Apollo 17 UVS measurements first displayed the lunar spectral reversal, where it was noted that the visibly dark lunar maria are 5-10% brighter than the highlands at far-UV wavelengths (147 nm) [4]; the phenomenon was confirmed in EUVE images [5]. The lunar spectral reversal was linked to space weathering when it was found that lunar soils, which have been exposed to more weathering, exhibit the spectral reversal, while powdered lunar rocks do not [6].

We are conducting a long-term study of the UV effects of space weathering on asteroids, in an effort to determine the nature and extent of these effects on asteroid surfaces. Previously, we have addressed rotational UV coverage of asteroid 4 Vesta, and currently we are addressing the effects on S-class asteroids. Ultraviolet spectra of Vesta display evidence of lunar-like ultraviolet space weathering on a global scale (compared with meteorite spectra), as well as in relative amounts across the surface. At UV-visible wavelengths, Vesta has been shown to be spectrally bluer than Howardite – Eucrite - Diogenite meteorites (meteorites potentially derived from Vesta), particularly diogenite and eucrite samples [6,7]. Because it is known that Vesta's visible/near IR spectra do not display strong lunar-like space weathering characteristics, these results suggest that Vesta has undergone enough weathering to affect the blue part of the spectrum moderately, but not enough to strongly alter the visible/near IR spectrum. Recent analysis of IUE data of [7] covering more than one rotation period indicates that Vesta's UV lightcurve is offset by almost 180° from the visible lightcurve, indicating that this asteroid displays a spectral reversal.

New analysis of IUE observations of asteroids shows that, for both lunar samples and S-class asteroids, a strong trend in spectral slope is seen between 300-400 nm. The slope in this range is significantly bluer for S-class asteroids than for OC meteorites, and for lunar soils than for lunar rocks. An explanation for the bluing is that the UV absorption band, which is present in nearly all of these types of surfaces (due to an Fe^{3+} charge transfer transition in silicates) is degraded in the weathered surfaces. This is analogous to the diminished absorption features seen in weathered surfaces at NIR wavelengths.

Such an effect is consistent with the presence, in the weathered bodies, of additional iron or iron-bearing minerals. Opaque materials (such as iron) are dominated by surface scattering, controlled by Fresnel reflection [6] and are thus spectrally flat over a wide range of wavelengths. In contrast, at visible-near-IR wavelengths, non-opaque materials are dominated by volume scattering, where the intensity of the reflected light is inversely proportional to wavelength. In non-opaques, the transition to surface scattering occurs in the 150-450 nm region [6] and is marked by a minimum in reflectance. Thus, compared to materials such as pyroxenes and feldspars, iron-bearing minerals can be relatively bright at FUV-NUV wavelengths. In the 150-450 nm range, iron-bearing minerals also vary from non-opaques in spectral shape, where the non-opaques are experiencing a decrease in brightness as they transition from reflectance dominated by volume scattering to reflectance dominated by surface scattering and opaques tend to be spectrally flat. Thus, in the 150-450 nm range, we expect surfaces consisting of iron-bearing minerals to be less spectrally red and possibly even brighter than surfaces with lower amounts of iron-bearing minerals.

New HST Results: We have recently obtained HST ACS data of several asteroids to test the hypothesis that relatively small amounts of space weathering effects can be measured at UV wavelengths by studying the spectral slope. To this end, we have looked at members of the young (5.8 My) S-class asteroid family Karin including 832 Karin and two daughter asteroids. It is expected that the daughter asteroids are more pristine ("fresher," or less-weathered) than the parent Karin; UV spectral comparisons are made to check whether weathering has occurred in the last 5.8 My. We have also measured two V-class asteroids with HST to compare them with existing IUE measurements of Vesta.

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