SPACE WEATHERING OF SILICATE ASTEROIDS: AN OBSERVATIONAL INVESTIGATION

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ABSTRACT

Solar wind exposure and micrometeoroid bombardment are known to cause mineralogical changes in the upper few microns of silicate grains (by forming amorphous "composition" rims with embedded nano-phase Fe^0). These processes, jointly called space weathering (SW), affect the light-scattering properties and subsequently the geometric albedo and spectral parameters (spectral slope and band depth). Earth's Moon exhibits the well known "lunar-style" of SW: albedo decrease, spectral slope increase, and absorption band suppression. However, space mission images of (243) Ida and (433) Eros suggest that different SW "styles" exist among the silicate-bearing (olivine and pyroxene) S-complex asteroids, which exhibit diagnostic absorption features near 1 & 2 µm. While Eros generally shows only albedo differences between younger and older locations, Ida's surface only shows changes in spectral slope and band depth. It is not clear if these SW styles are unique to Ida and Eros or if they can be observed throughout the entire asteroid population.

We hypothesize that the SW styles seen on Eros and Ida also exist on other asteroid surfaces. Additionally, we hypothesize that increased solar wind exposure, smaller regolith particles, higher olivine abundance, and older asteroid surfaces will increase the observed degree of SW. Our dataset includes publicly available Visible (0.4-0.8 µm) and Near Infrared (0.7-2.5 µm) reflectance spectra of silicate-bearing asteroids (those with 1 & 2 µm bands) from the PDS and the SMASS, S^3OS^2 and MIT-UH-IRTF spectral surveys. We have also conducted a spectral survey with the IRTF/SpeX targeting 52 silicate asteroids for which we have constraints for regolith grain sizes from interpretation of thermal-IR data. The relevant band parameters to SW and to interpreting mineralogical properties are calculated using the band analysis code, SARA. Geometric albedos are calculated using thermal-IR data from WISE/NEOWISE. Using these derived parameters, we search for potential SW styles among different spectral classes and for correlations with the factors listed above. Analysis on a subset of S-types suggests that heliocentric distance correlates with spectral slope and band depth but not albedo.

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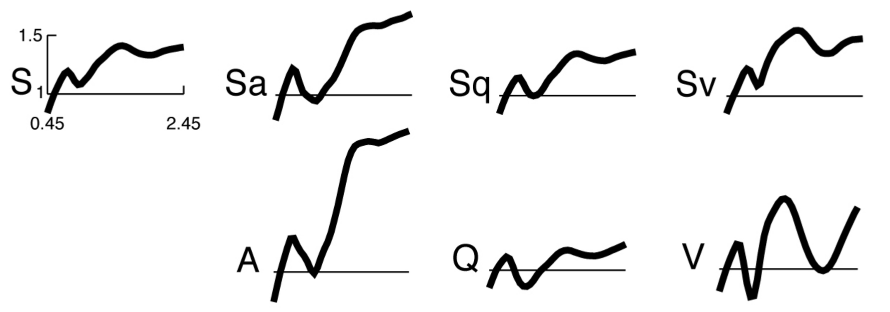
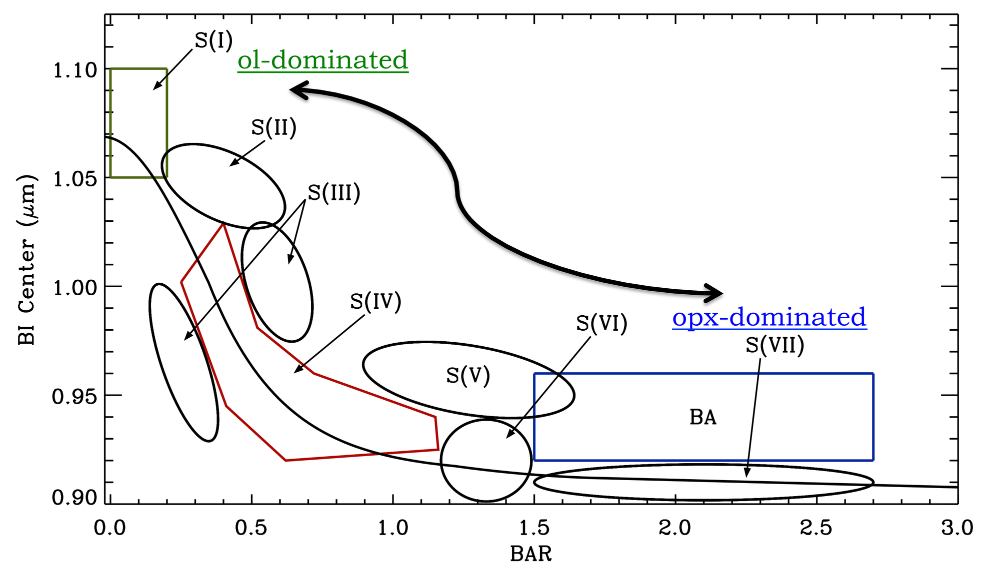
SILICATE ASTEROIDS

- Exhibit 1 & 2 micron absorption features due to Fe^{2+} in olivine and pyroxene
- Bus-DeMeo (feature-based) taxonomy:

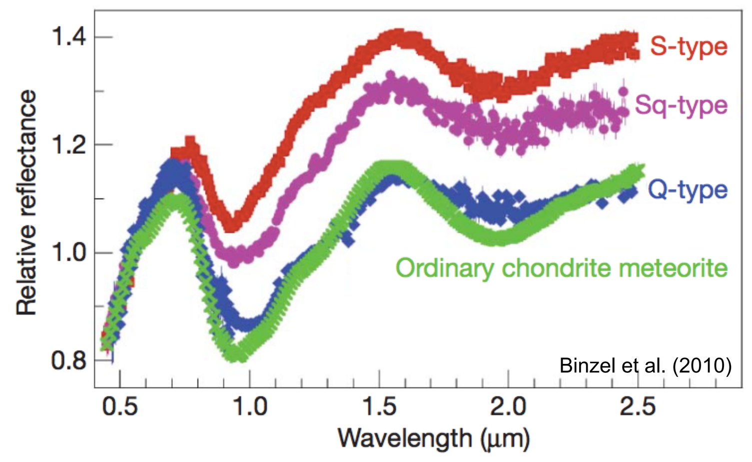


- Gaffey (mineralogy-based) taxonomy:
  - SI-subtype: olivine dominated (low pyroxene)
  - SIV-subtype: olivine/pyroxene
  - BA-subtype: basaltic (low olivine)



SPACE WEATHERING

- Q-types closely match OC meteorite spectra
- Fresh Q-type spectra weathers into S-type
  - Absorption bands suppressed
  - Spectral slope reddens

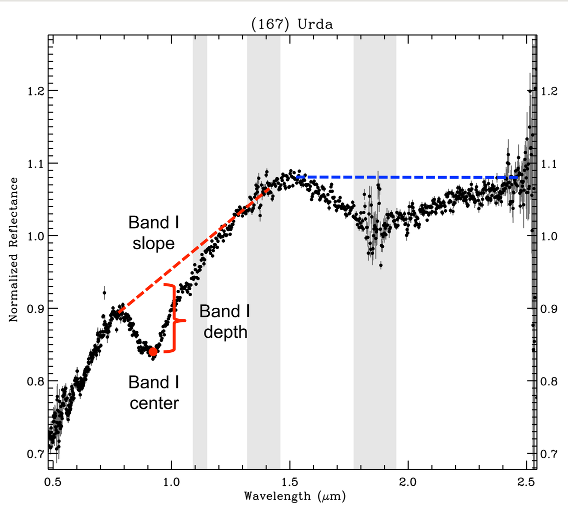


- Is this trend similar and consistent across other spectral types and mineralogies?

DATA & BAND PARAMETERS

- Band parameters (Fig 1.) are calculated using a Monte-Carlo algorithm implemented in R
- Each spectrum is run through an adaptive smoothing algorithm and continua are approximated as lines tangent to the reflectance
- Band area is defined as the area enclosed by the continuum and object spectrum

Figure 1. Depiction of band parameters.



Visible spectra:
SMASS
S^3OS^2
PDS: VilasVisSpec
PDS: SawyerVisSpec
PDS: MoskovitzVtype

Near-Infrared spectra:
MITHNEOS
PDS: BusIRTFSpeX
PDS: Feiber-BeyerSpeX
PDS: ReddySpeX

SPACE WEATHERING TRENDS

- Here we plot Band I Slope vs. Band I Depth; useful proxies for the degree of space weathering
- Spectral variation within each mineralogical subtype must be attributed largely to space weathering
- Meteorite analogs, which are "fresh" samples, should sit at the edge or outside of each cloud of asteroids

Figure 2. Band I slope and depth for 91 SIV type asteroids. The shaded region approximately represents "fresh" Ordinary Chondrite material.

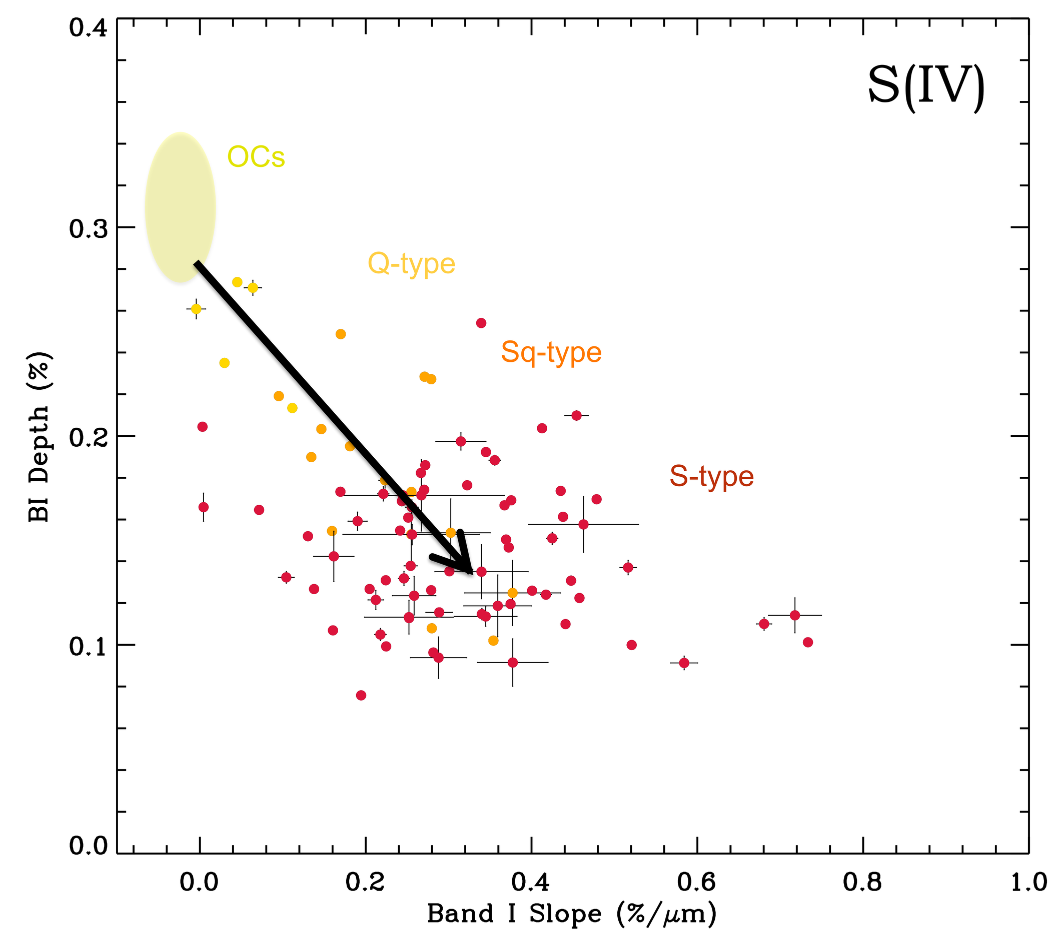


Figure 3. Same as Fig 2. but for 39 BA-subtypes and HEDs.

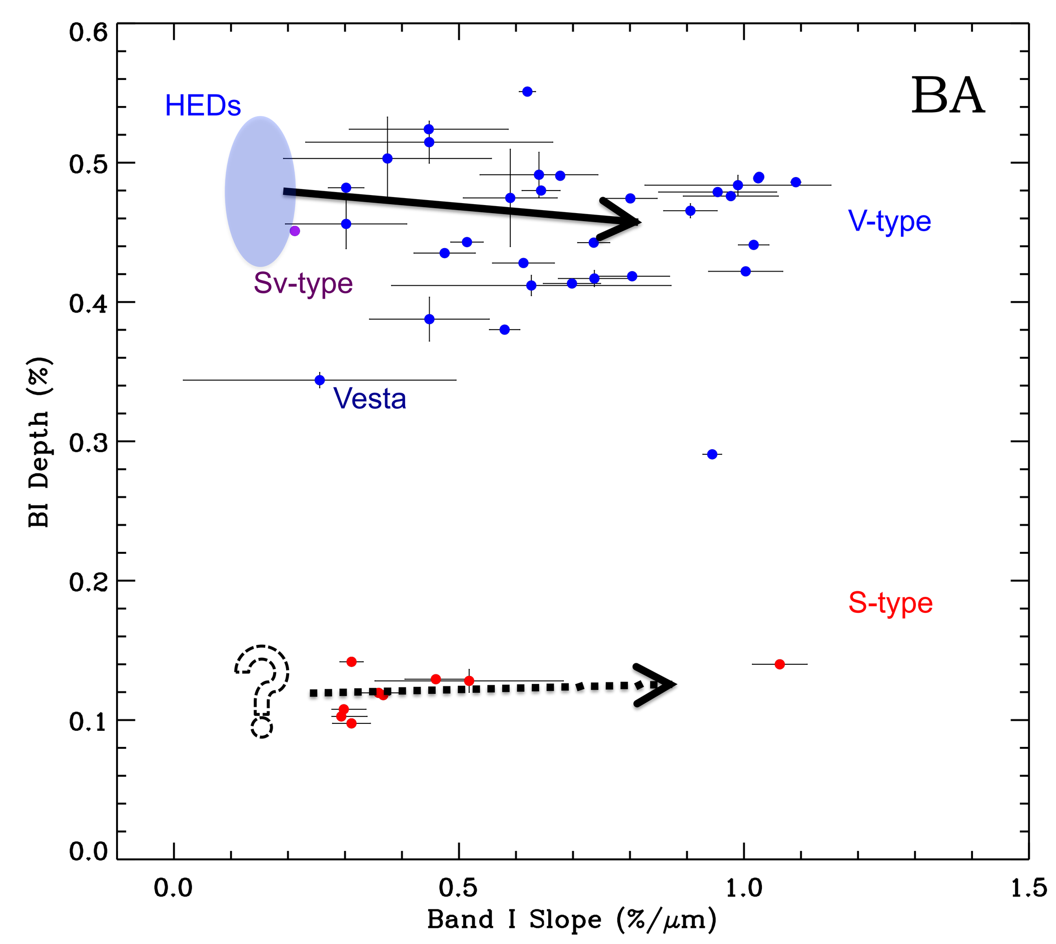
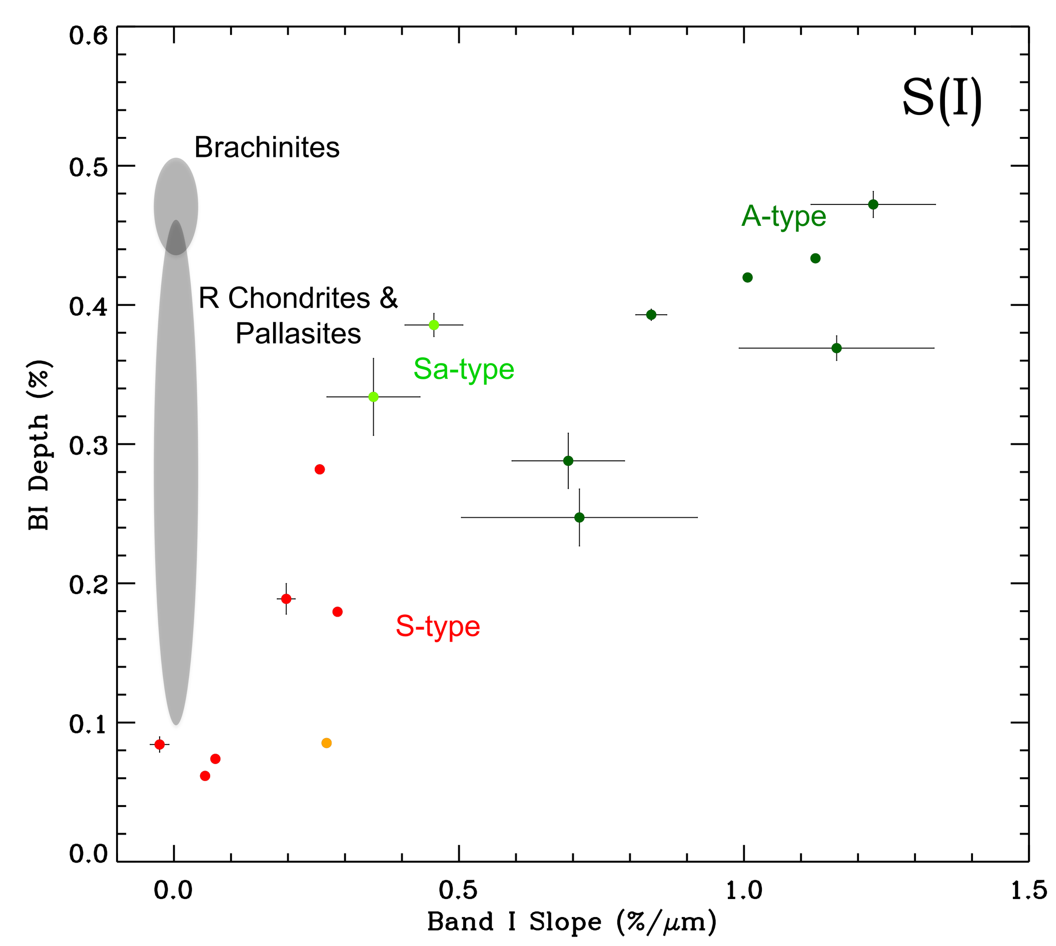
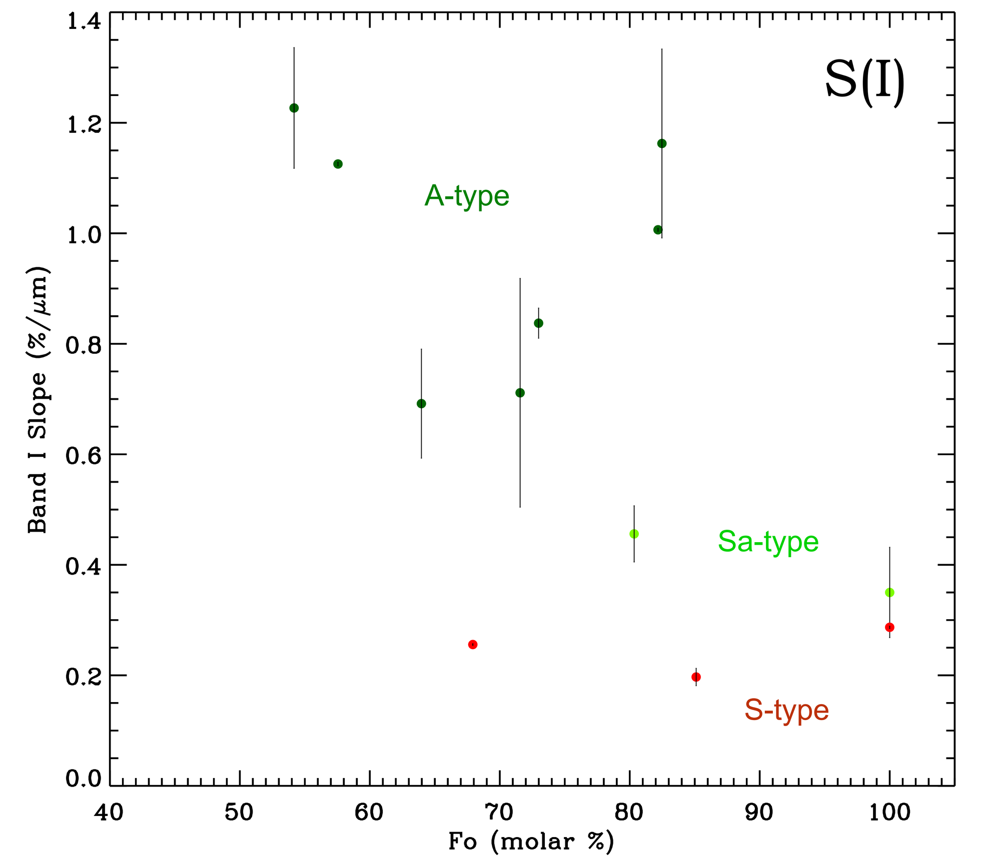


Figure 4. Same as Fig 2. but for 16 SI-subtypes and Brachinites, R Chondrites, and Pallasites; olivine-dominated meteorite classes.



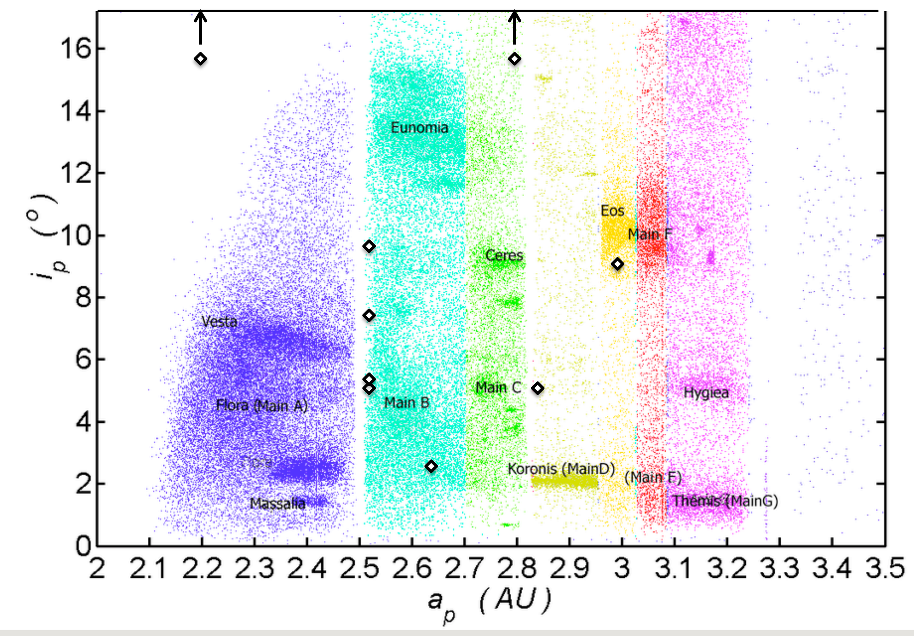
MINERALOGICAL EFFECTS



- Meteorite calibrations presented by Sanchez et al. (2013) give estimation of Forsterite (Mg_2SiO_4)
- Objects with lower Fo # exhibit greater slopes due to higher Fayalite (Fe_2SiO_4) abundance

S-TYPE BASALTIC ACHONDRITES

- Plotted below are S-types from From Fig 3.
- It is unlikely that they are fragments of Vesta and may represent fragments of another parent body



CONCLUSIONS

- Ordinary Chondrite-like asteroids exhibit a space weathering trend akin to the Moon
- Basaltic Achondrite-like asteroid slopes are affected by space weathering
- Olivine-dominated asteroids likely represent fragments of many distinct parent bodies

FUTURE WORK

- Characterize each space weathering trend by:
  - Quantify the difference between expected "fresh" material and space weathered asteroid
  - Develop a space weathered index (SWI), similar to lunar optical maturity index (OMAT)
- Further investigate potential space weathering dependencies (mineralogical, Fe content etc.)

REFERENCES

Binzel, R. P. et al. (2005) *LPSC XXXVI*, Abstract 36.1817; Binzel et al. (2010) *Nature*, 463, 331; DeMeo, F. et al. (2009) *Icarus*, 202, 160; Gaffey et al. (1993) *Icarus*, 106, 573-602; Pieters et al. (2000) *Meteor. Planet. Sci.,* 35, 1101-1107; Taylor et al. (2001) *Meteor. Planet. Sci,.* 36, 285–300; Bell et al. (2002) *Icarus*, 155, 119–144; Murchie et al. (2002) *Icarus*, 155, 145-168; Helfenstein et al. (1996) *Icarus*, 120, 48-65; Veverka et al. (1996) *Icarus*, 120, 66-76; Hiroi et al. (2006) *Nature*, 443, 56; Ishiguro et al. (2007) *Meteor. Planet. Sci.*, 42, 1791-1800; Sanchez et al. (2013) *Icarus*, 228, 288-300