On the puzzle of space weathering time-scale on asteroids

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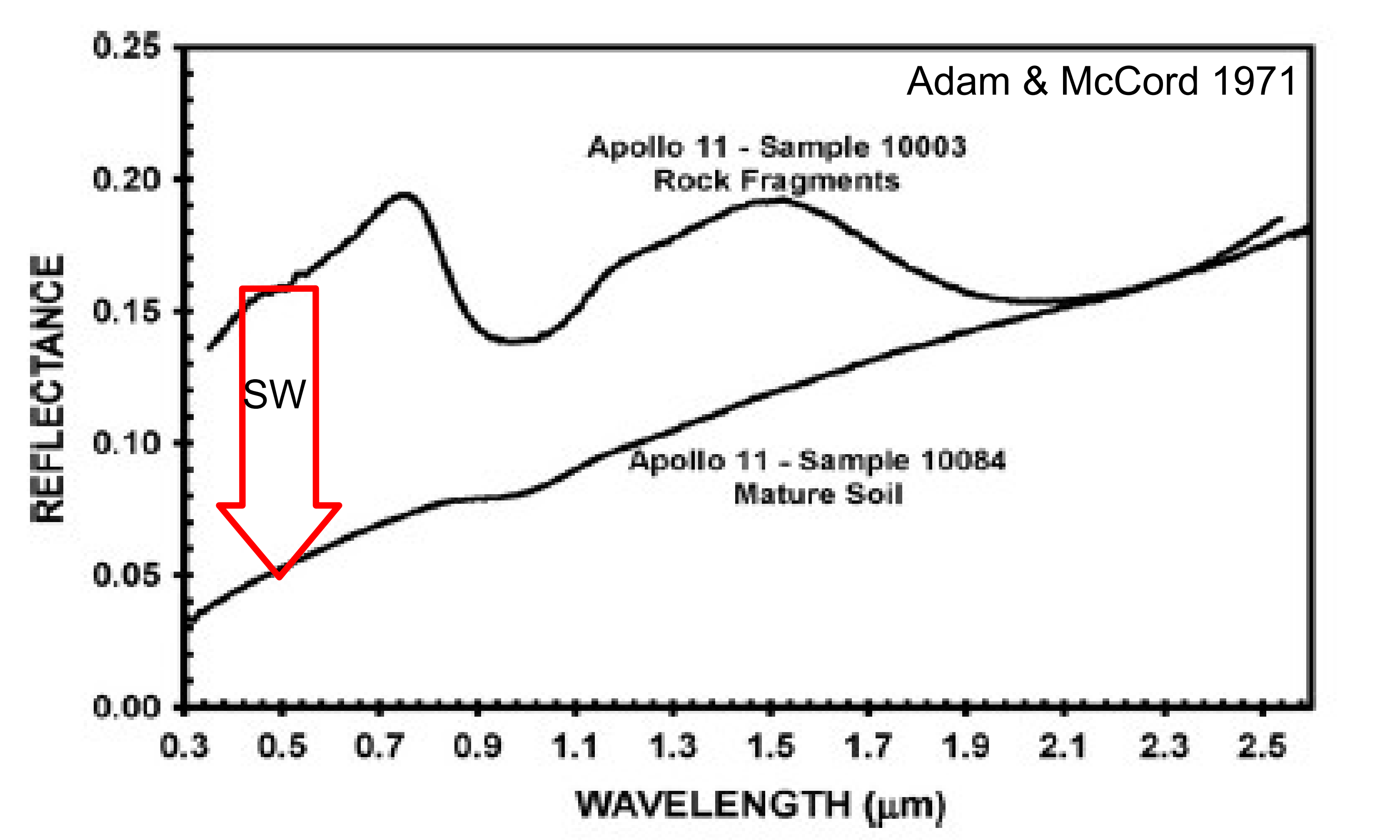
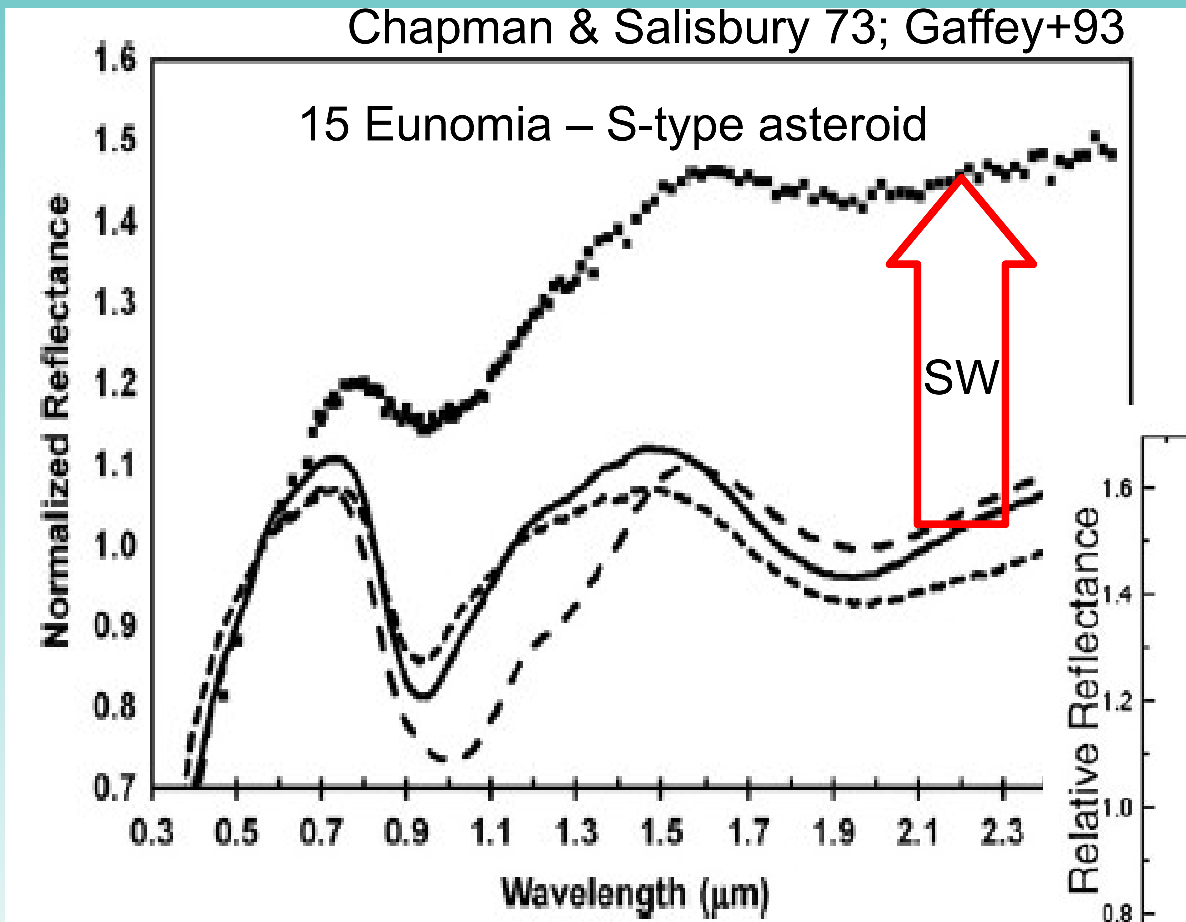
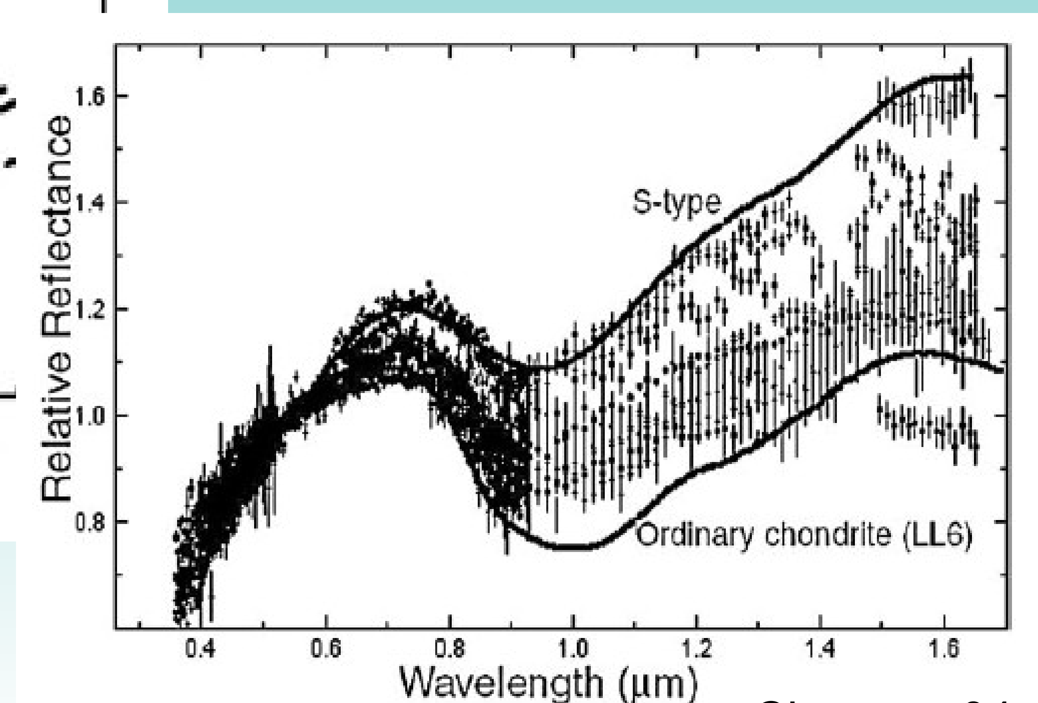
Space weathering (SW) on lunar samples



Asteroid spectra vs laboratory spectra of meteorites

- OCs are ~75% of falls.
- S-types are the second most common asteroid type. They exhibit the same suite of minerals found in OCs.
- Very few (if any) OC-like spectra are observed among S-types.

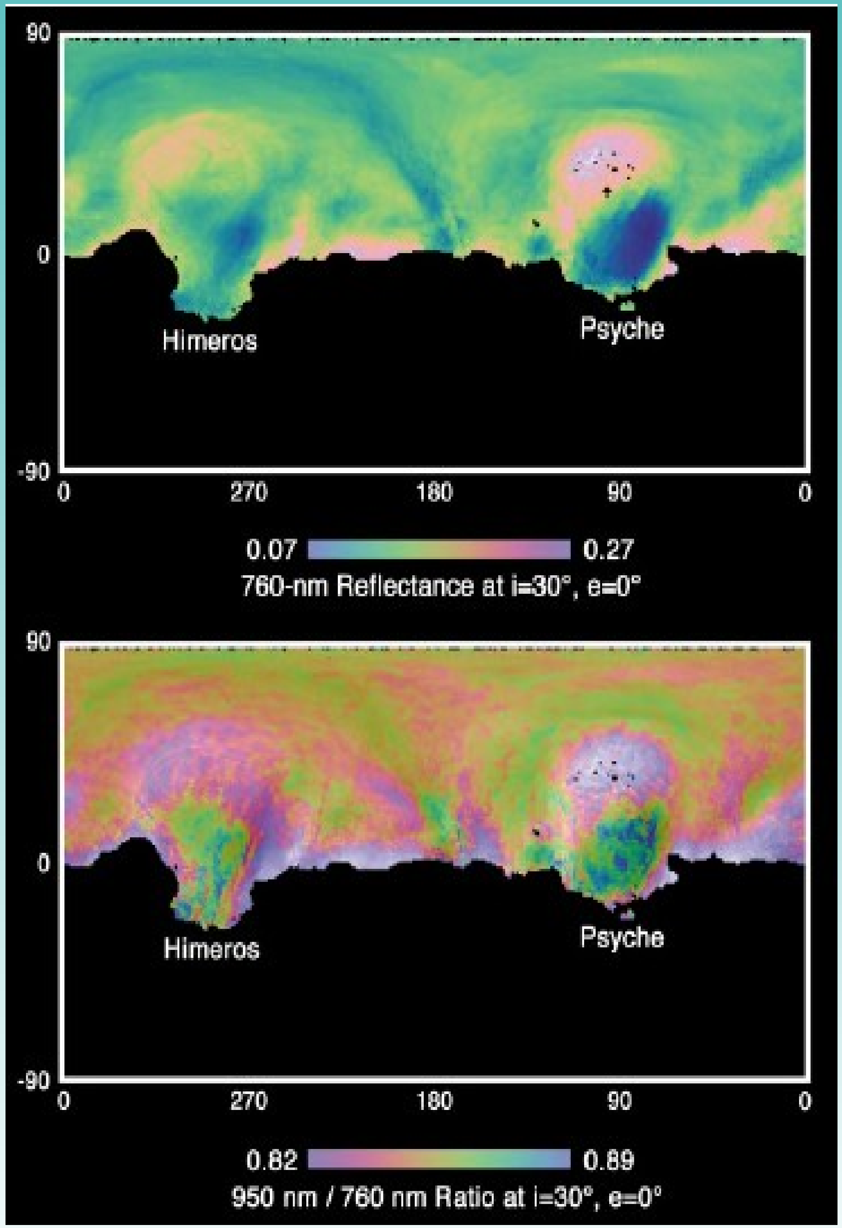


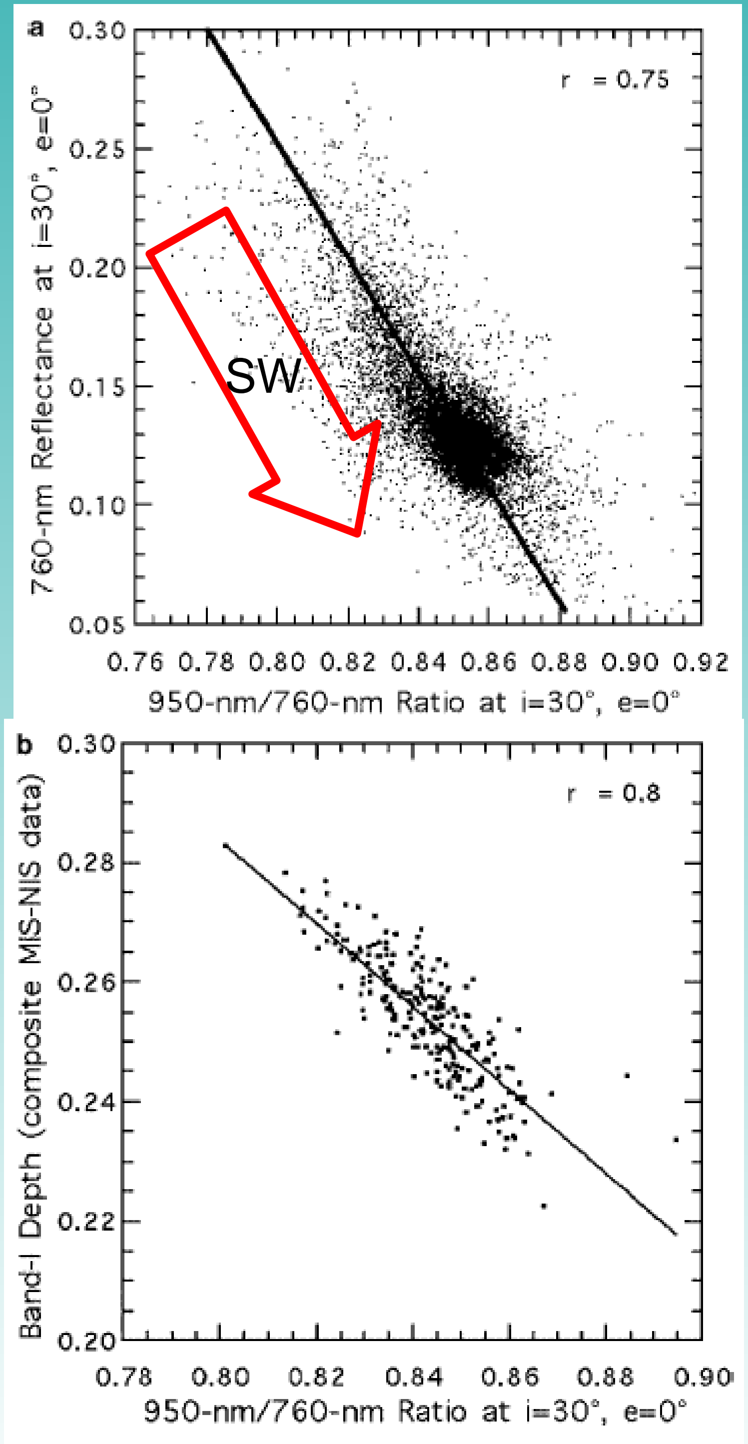


Chapman04

S-type asteroids visited by spacecrafts

Near-Earth asteroid Eros:

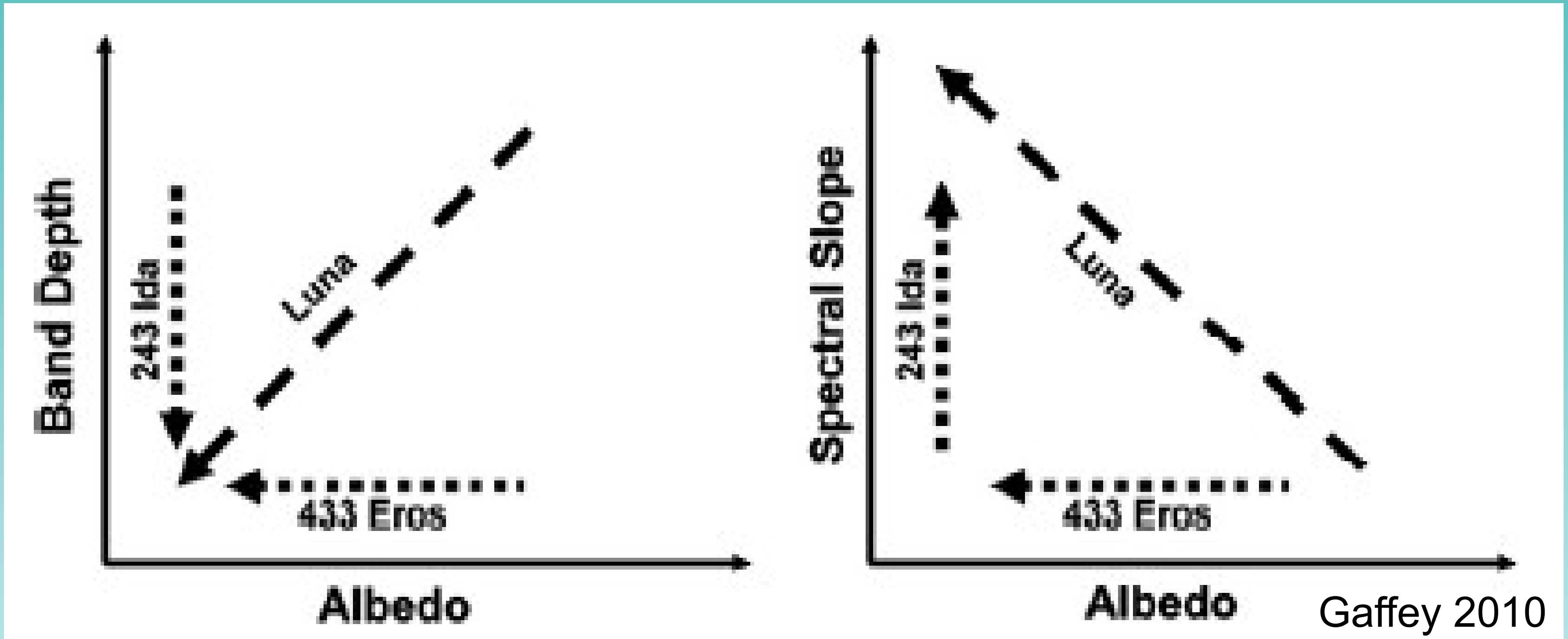




→Ida and Gaspra have a different spectral response to SW.

Murchie+02; Bell+02
Veverka+96; Helfenstein+96

The three kinds of space weathering



- Why do they have different behaviors?
- What are the SW time-scales?

Things to note: These bodies have three different histories, notably they stay in different environments (near-Earth space, Main Belt) and have different compositions.

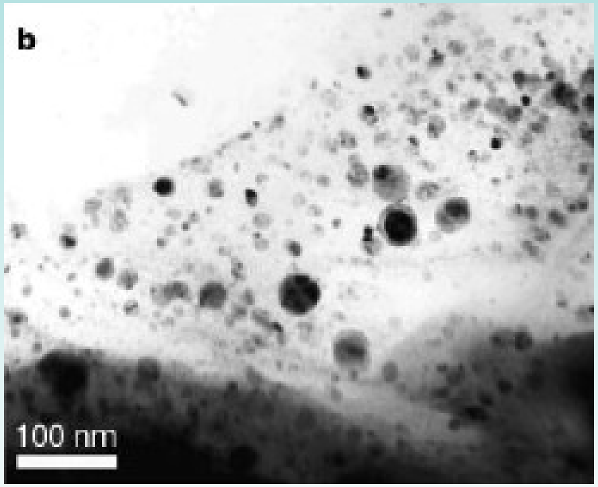
Laboratory experiments

1. Moon

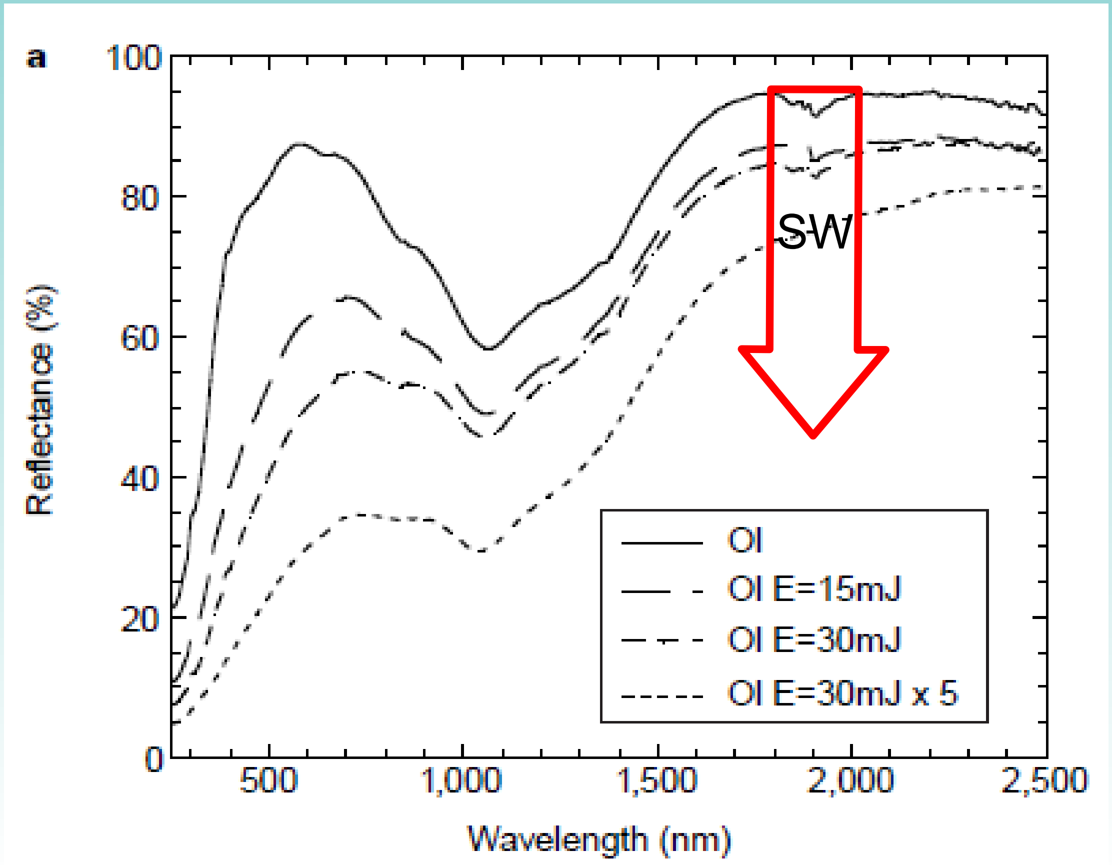
- Many experiments performed starting from late 60's: Vitrification, evaporation, light ion sputtering... (e.g. Hapke 01).

- SW effects due to formation of submicroscopic (4-30nm) particles of reduced iron (npFe0). For the Moon it is accepted that impact vaporization works. Possible contribute also from solar proton sputtering (Pieters+00; Hapke 01, Taylor+ 01, Sasaki+01).

- **Impact vaporization is simulated by irradiation with nanosec pulsed infrared laser.**

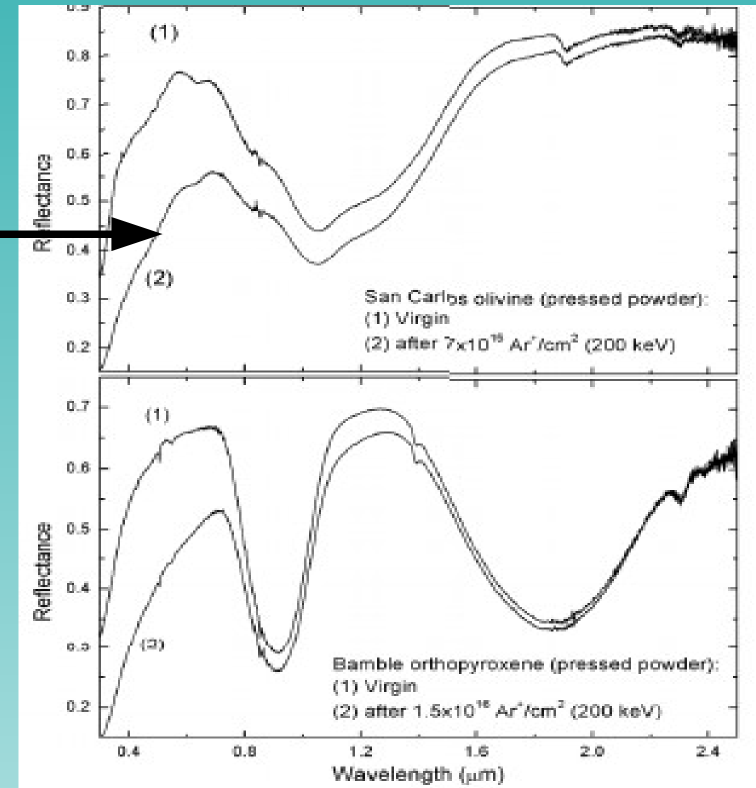


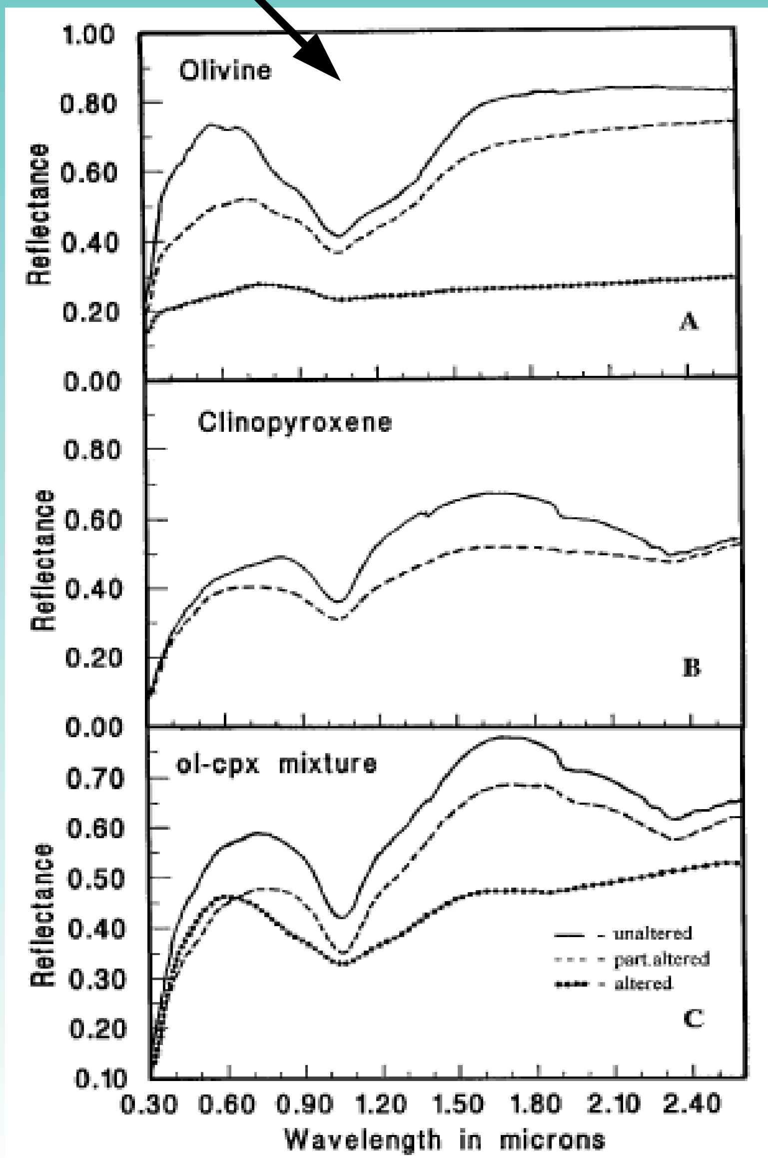
Sasaki+01



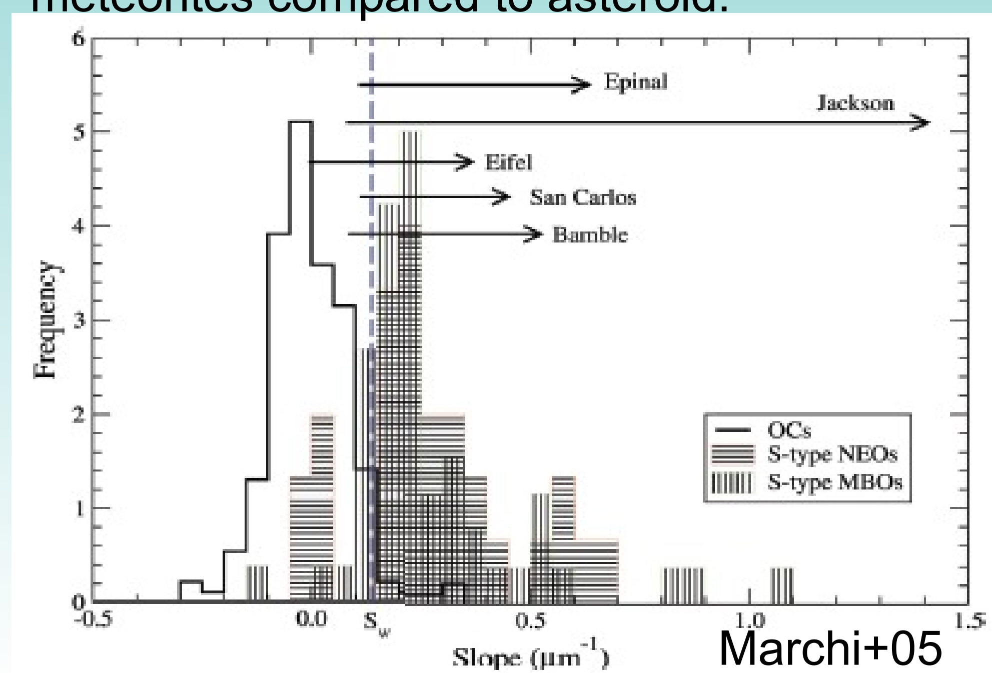
2. Meteorites/asteroids:

- Vaporization (Sasaki+01, previous slide)
- Heavy ion (Ar) bombardment (Strazzulla+05)
- Melting (Moroz+96)





Ion bombardment reddening of meteorites compared to asteroid:



Marchi+05

Conflicting laboratory time-scales

Vaporization experiment (e.g. Sasaki+01; Brunetto+06): **10^8 yr at 1AU**

Heavy ion bombardment (e.g. Strazzulla+05): **10^4-10^6 at 1AU**

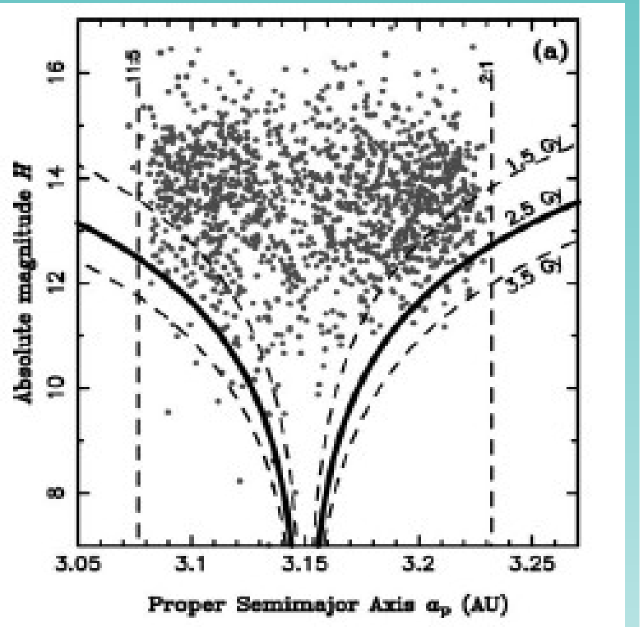
- The vaporization process requires the presence of FeO in minerals.
- Ion bombardment works with a range of compositions, it is not clear if FeO is required (may be not).
- In both cases, the derived time-scales depends on the mineral used for the experiments (e.g. ol vs px).

Asteroid SW modeling

1. SW level: derived by visible spectral slopes (from spectra or photometry)

2. Asteroid age:

2.1: asteroid families (MBAs)



Themis family
Nesvorny+05

2.2: collisional & dynamical evolution (NEOs+MBAs):

$$T_{MB} \simeq \tau_{coll}\left[1 - \left(1 + \frac{t_{LHB}}{\tau_{coll}}\right)e^{-t_{LHB}/\tau_{coll}}\right] + t_{LHB}e^{-t_{LHB}/\tau_{coll}}$$

$$T_{NEA} \simeq \frac{\tau_{coll}\left[1 - (1 + \tau_{Yark}/\tau_{coll})e^{-\tau_{Yark}/\tau_{coll}}\right]}{1 - e^{-\tau_{Yark}/\tau_{coll}}}$$

Marchi+06a

The quest for (hopefully significant!) correlations

$$\text{exposure} = \alpha \int \frac{1}{r(t)^2}\, dt,$$

where $r(t)$ is the Sun-asteroid distance as a function of time t and α is a constant. Since the angular momentum is conserved, the above integral can be simply written as

$$\text{exposure} = \alpha f(t)/l,$$

where l and f are the angular momentum per unit mass and the true anomaly. According to the above equation, the exposure grows linearly with t, with an additional periodic term depending on the eccentricity. Averaging over a period P, and thus eliminating the periodic term, we can define the mean exposure per unit time:

$$\text{exposure} = \langle \text{exposure} \rangle t = \frac{1}{P}\left[\oint \alpha\, f(t)/l\right] t.$$

Finally, in terms of a new constant α_1 we obtain

$$\text{exposure} = \alpha_1 [\Phi(a,\ e) \times \text{age}],$$

where

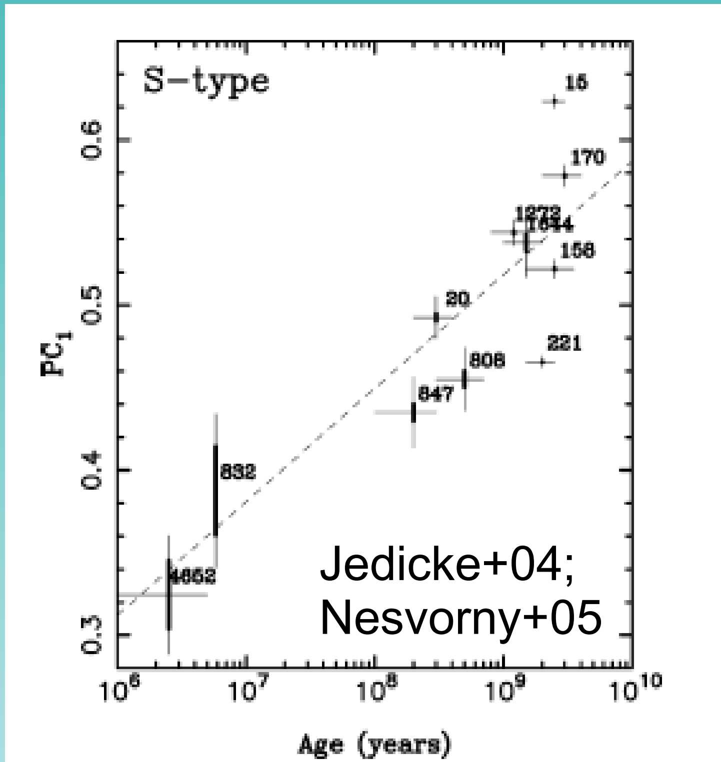
$$\Phi(a,\ e) = \frac{1}{a^2\sqrt{1-e^2}}$$

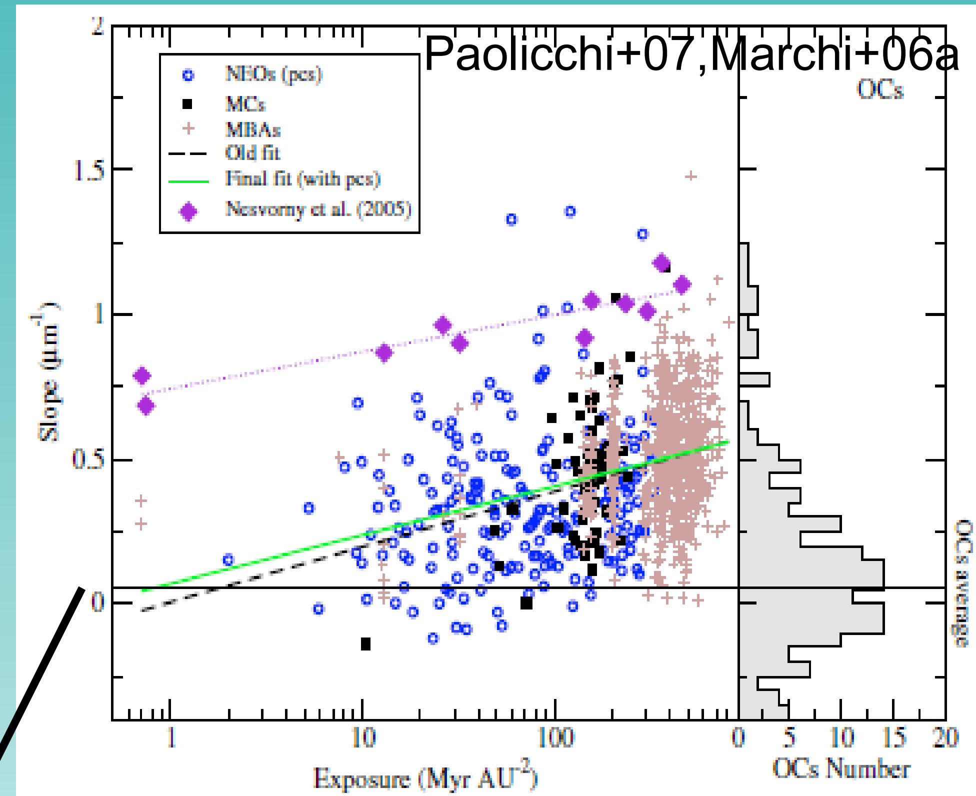
Marchi+06a

Correlations investigated:

- Age-color (Jedicke+04)
- Age-slope (Vernazza+09)
- Exposure-slope (Marchi+06a)

SW time-scale: To each his own!/1

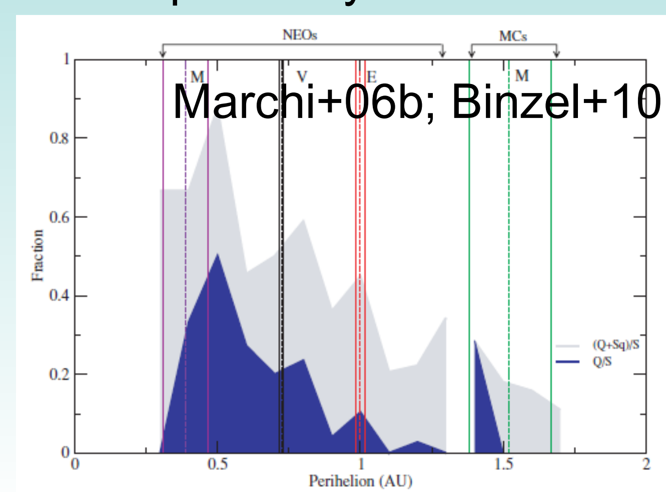




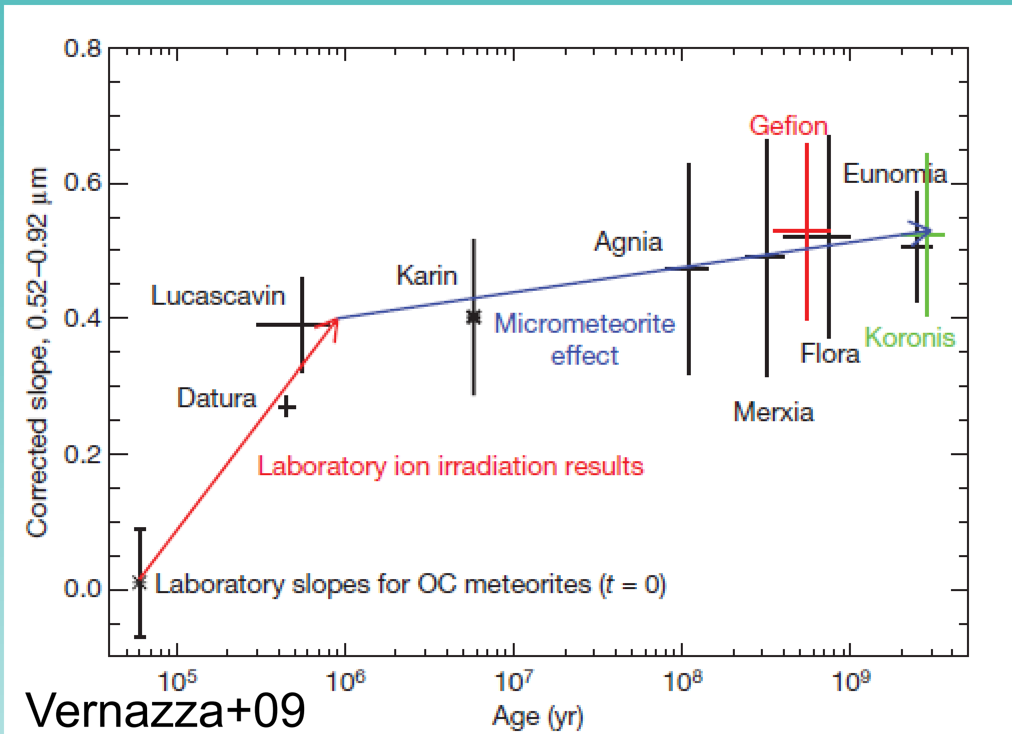
- PC1 increases with age by 0.55 from **2Myr to 3Gyr.**

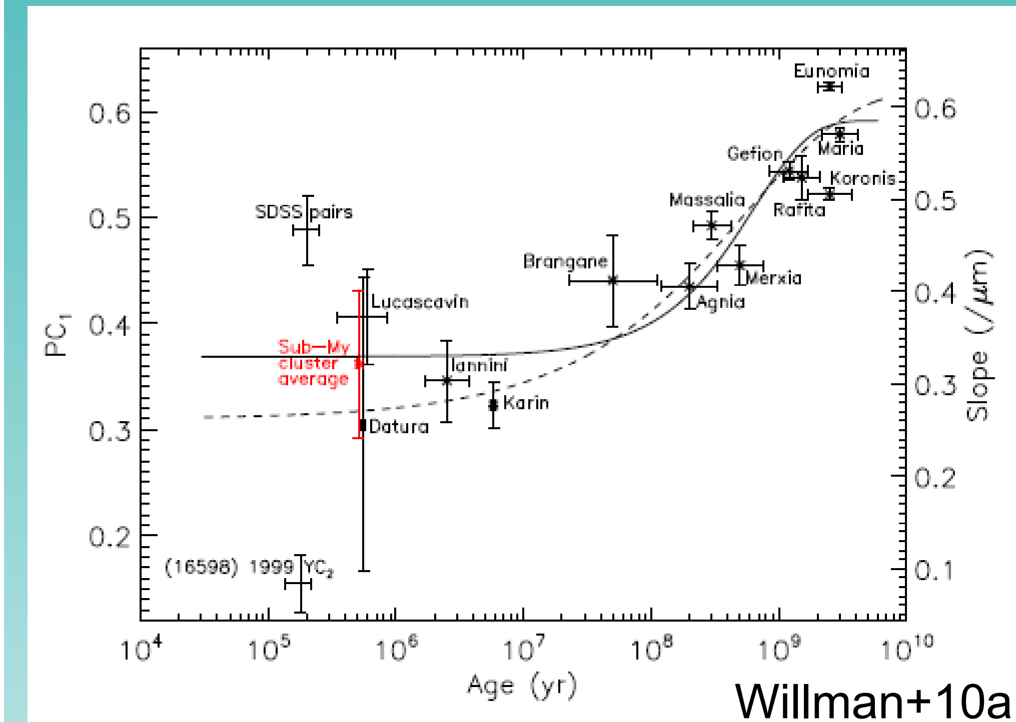
- Slope increases with exposure, for both NEOs and MBAs. Slope increases by ~0.5 in **0.8Gyr** at 1AU or **3.2Ga** at 2AU.

Note: spectral 'bluing' due to planetary encounters:



SW time-scale: To each his own!/2





Reddening time-scale: ~**0.9Gyr**
Gardening time-scale: ~**2Gyr**
PC1 increases by 0.33

→Slope increases by 0.4 in ~**0.5Myr**. Residual reddening in the range **1Myr-2.5Gyr.**

→In an improved analysis, Willman & Jedicke10b used non family MBAs to find an alternative estimate of SW time-scale, obtaining:
Reddening: ~**2Gyr**
Gardening: ~**4.4Gyr**

For the gardening effect, see also Paolicchi+09.

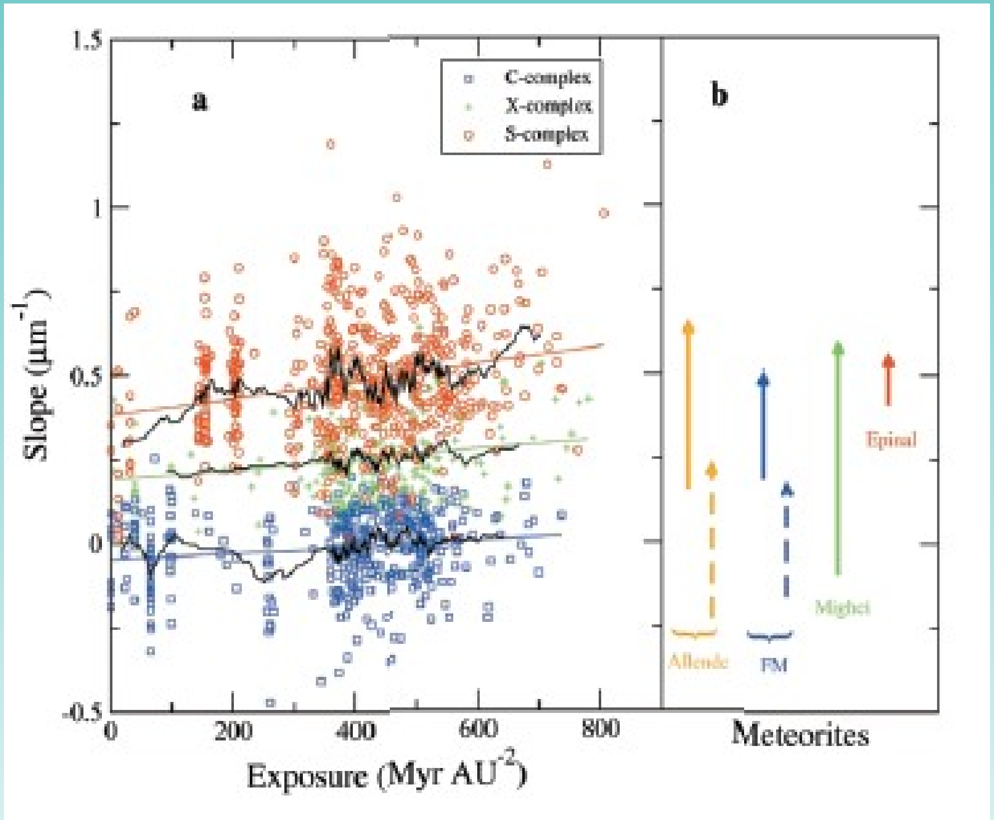
Time-scale Summary

- **Marchi et al:** Relatively slow SW (~Gyr in MB), due to an interplay of reddening and gardening.The exposure-slope trend entails SW due to solar wind.

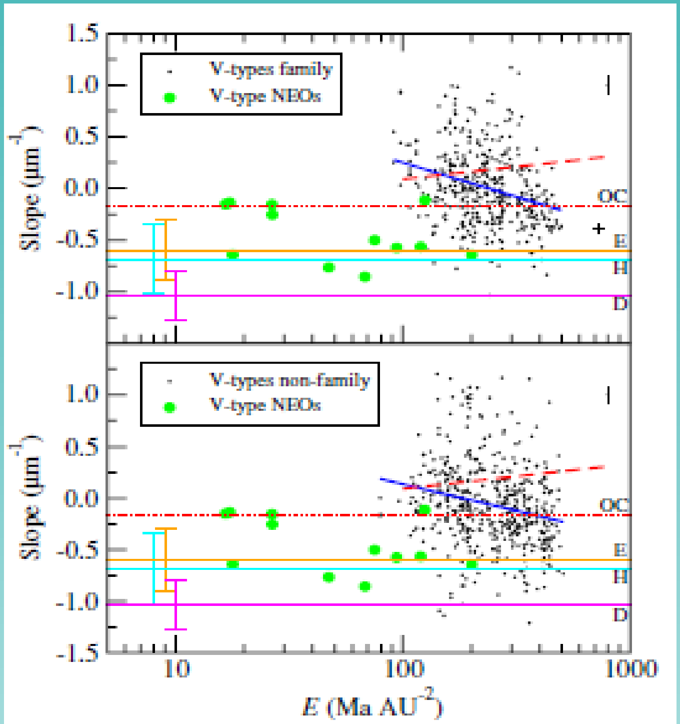
- **Vernazza et al:** very fast reddening (~Myr). Solar wind. Residual reddening due to micro-impacts.

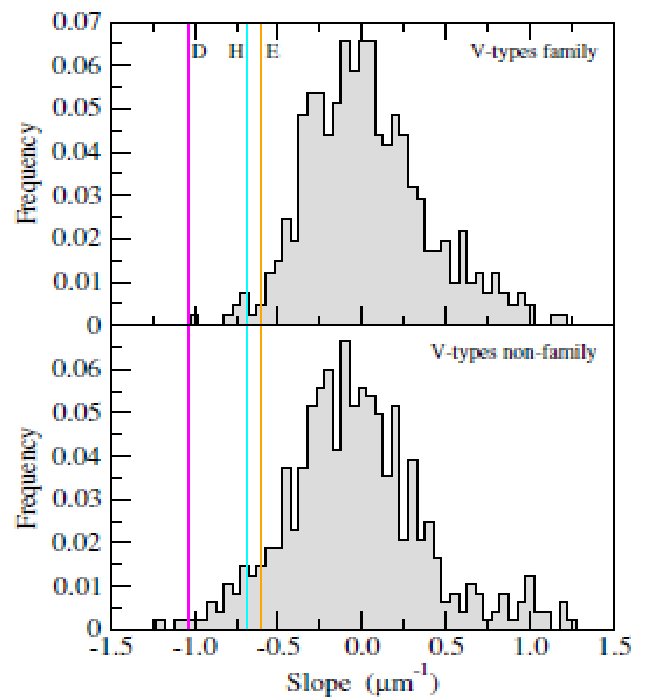
- **Willman et al:** Relatively slow SW (~Gyr), therefore due to micro-impacts.

SW on other asteroid types (C, V...)



Lazzarin+06





Marchi+10

A last remark

An improved model of regolith gardening of asteroids is required.

The gardening may hold the key for understanding the SW trend on S-types and other spectral types.