Meteorite Analogs for Phobos and Deimos: Unraveling the Origin of the Martian Moons

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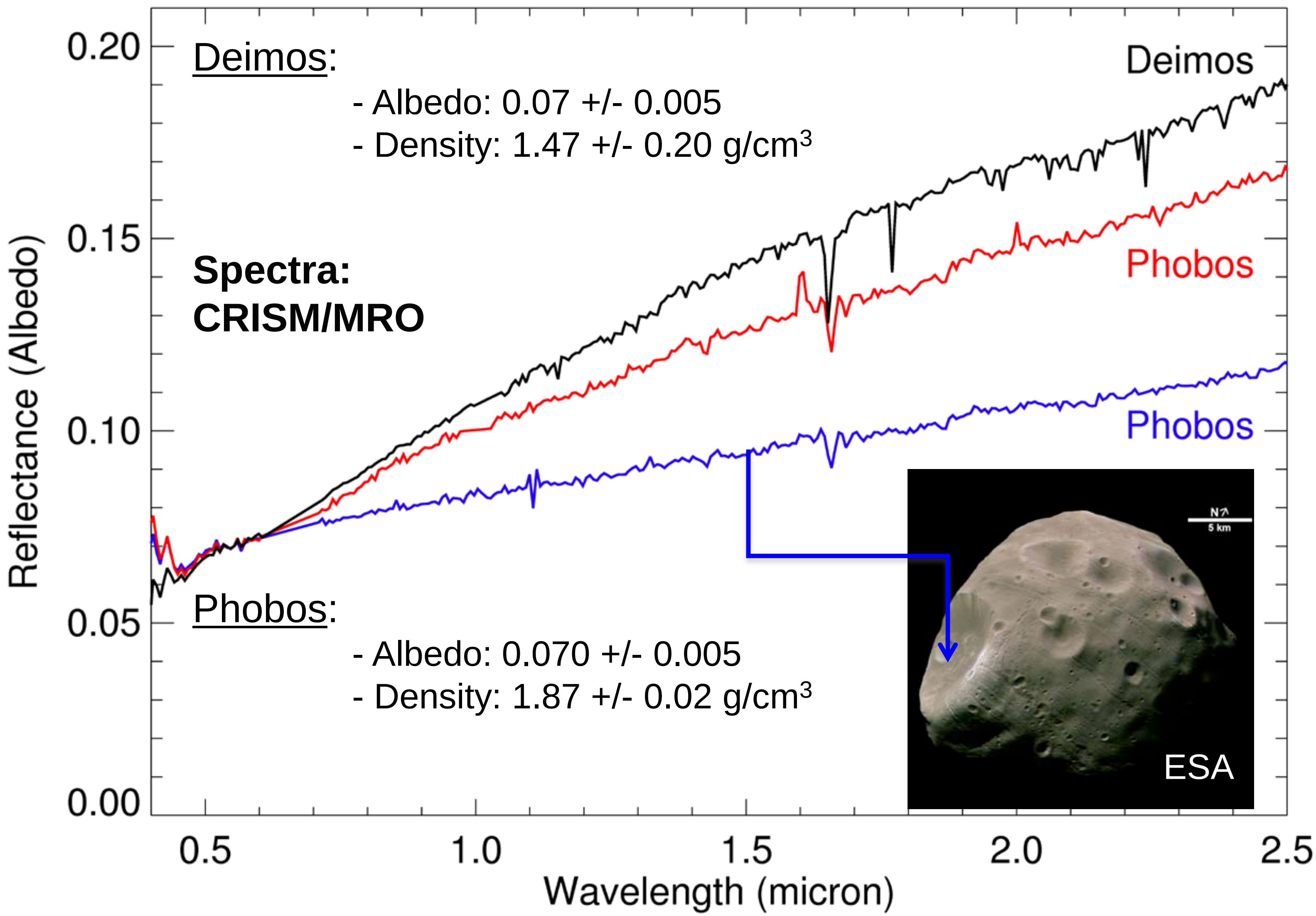
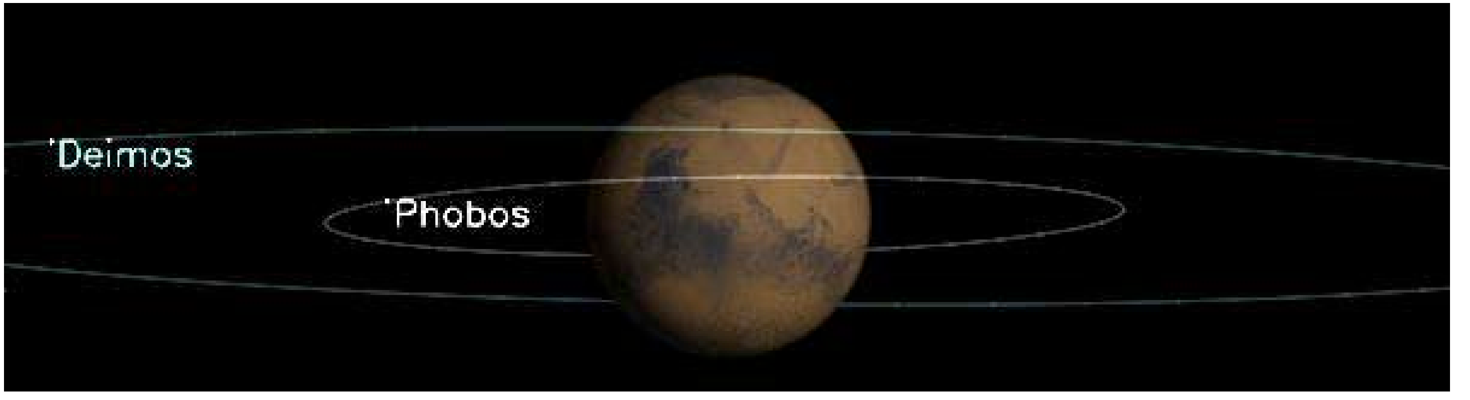
Current knowledge



Origin of the Martian moons



Three possible scenarios:

- 1) Capture of two distinct outer main belt asteroids
- 2) Formation in place
- 3) Origin as Mars impact ejecta

1) Capture of two distinct outer main belt asteroids

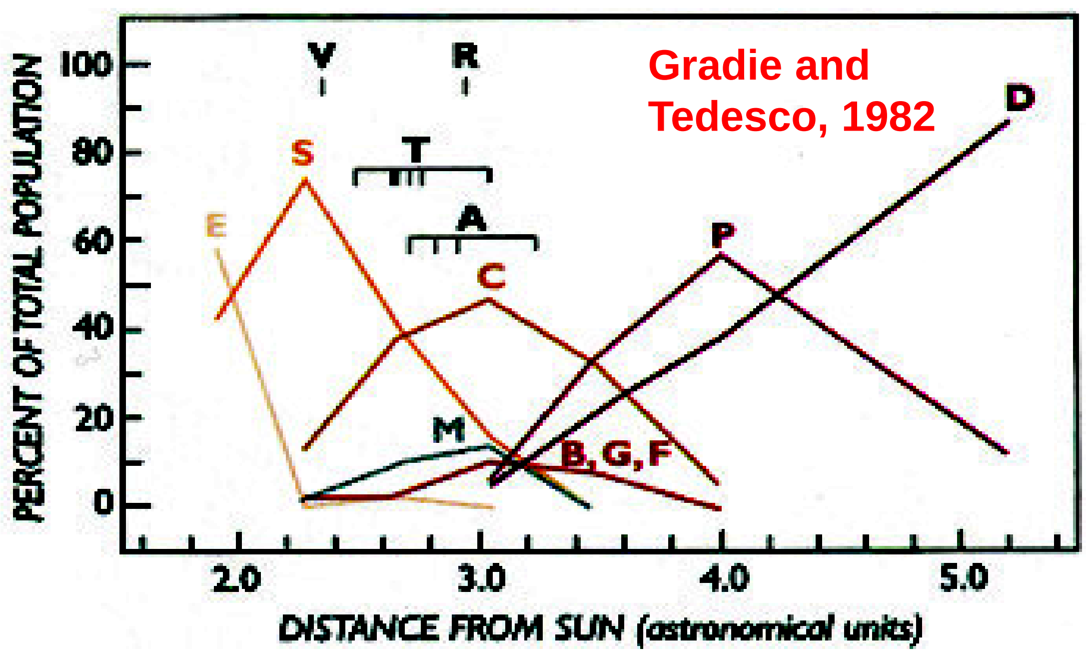
- Every observable physical property (albedo, VNIR reflectance, density) indicates that the Martian satellites are similar to outer main belt bodies (~3 AU), suggesting the objects must be captured

- However, dynamicists argue that the present orbits of Phobos and Deimos could not be produced following capture, and so they must have originated near Mars at 1.5 AU

2) Formation in place

Compositional gradient seen in the asteroid belt does not favor this scenario !

Class	Albedo	Density	Mineralogy
E, M, S	0.1 – 0.25	3.0 - 7.0	metal, silicates, sulfides
C	0.03 – 0.10	2.0 - 3.5	hydrated silicates, silicates
P, D	0.02 – 0.05	1.5 - 2.0	hydrated silicates



3) Origin as Mars impact ejecta

- Such scenario has not been modeled yet, but if correct one should keep in mind that:

  Dynamical constraints suggest that the satellites formed early in Martian history

  => The composition of the moons would be representative of the ancient composition of the Martian crust

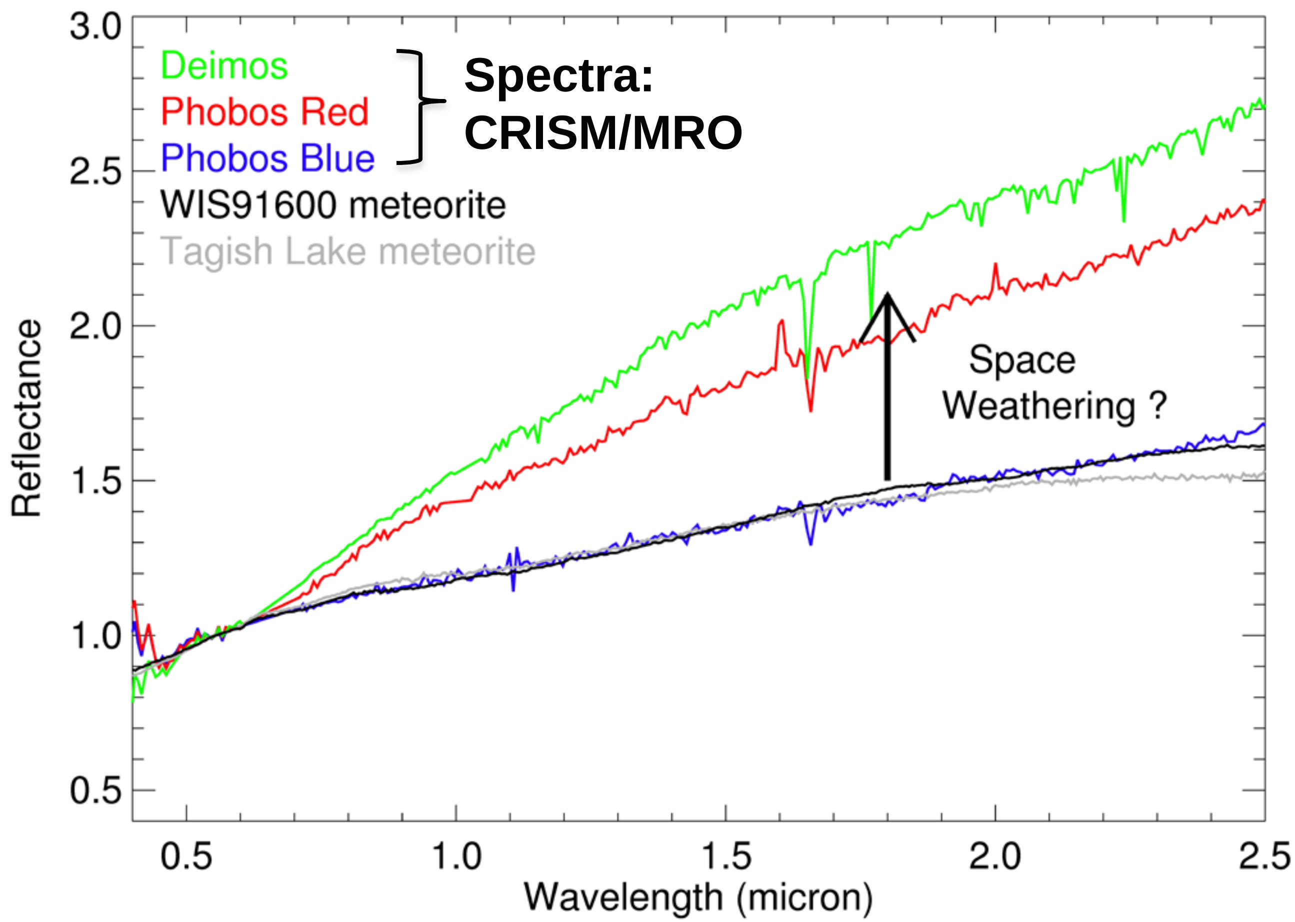
To solve the problem of the origin, one needs to

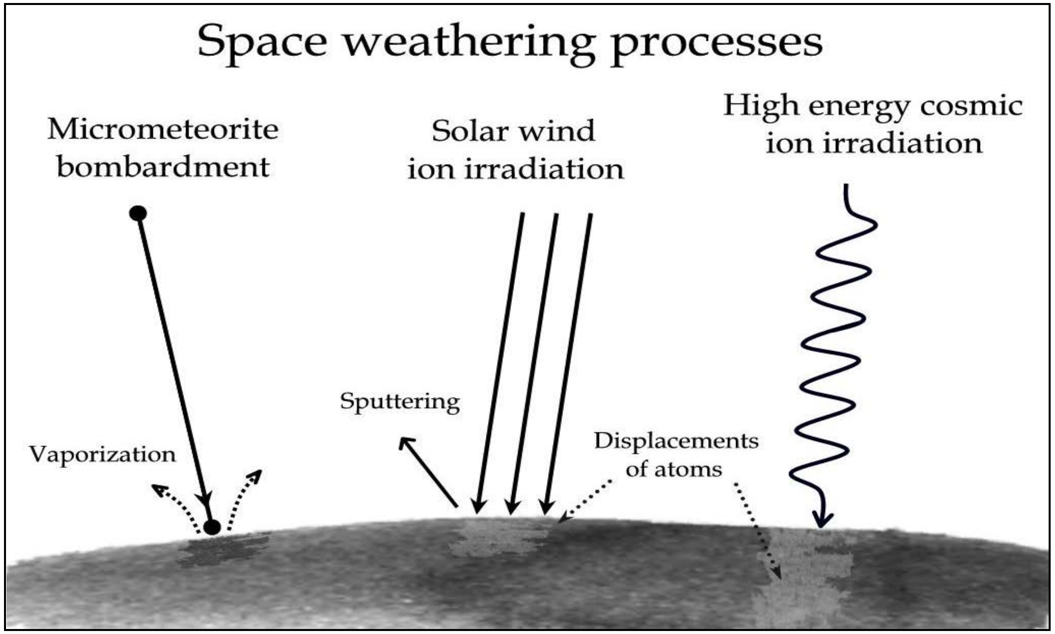
constrain the composition of both moons

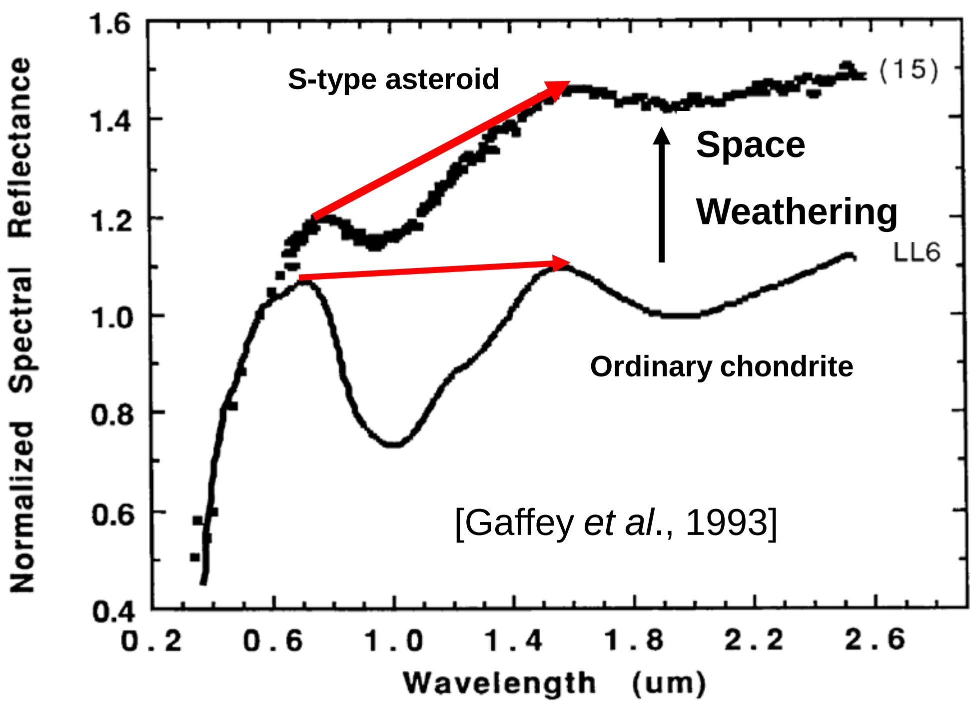
Step 1

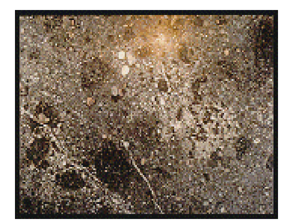
Search for plausible meteoritic analogs for Phobos and Deimos using the RELAB spectral database

Tagish Lake & WIS 91600: Phobos/Deimos analogs ?



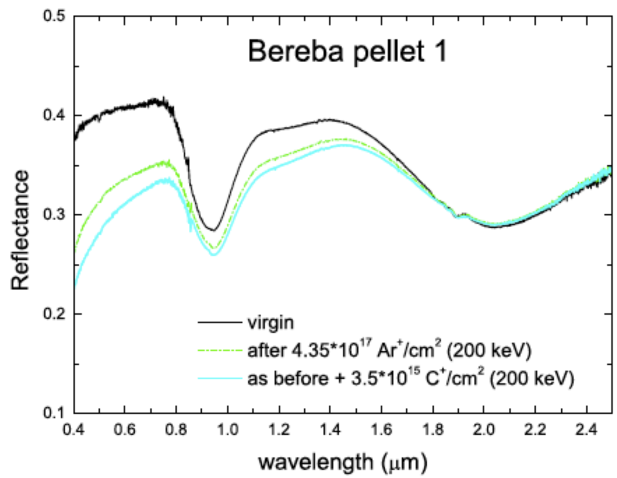

Space weathering processes
Micrometeorite bombardment
Solar wind ion irradiation
High energy cosmic ion irradiation
Sputtering
Vaporization
Displacements of atoms

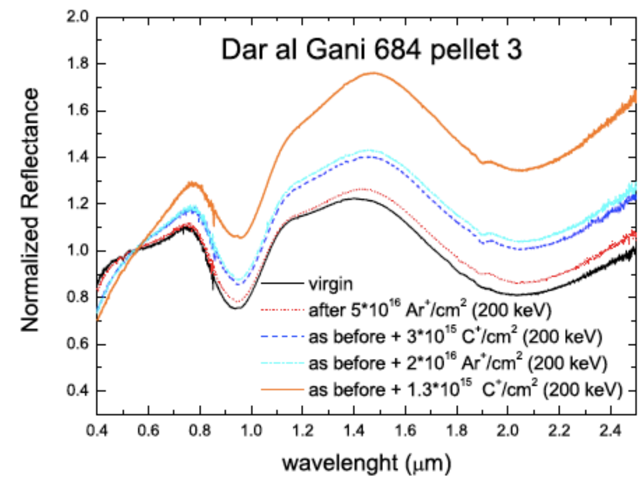

S-type asteroid
(15)
Space
Weathering
LL6
Ordinary chondrite
[Gaffey et al., 1993]
Normalized Spectral Reflectance
Wavelength (um)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.6
1.0
1.4
1.8
2.2
2.6



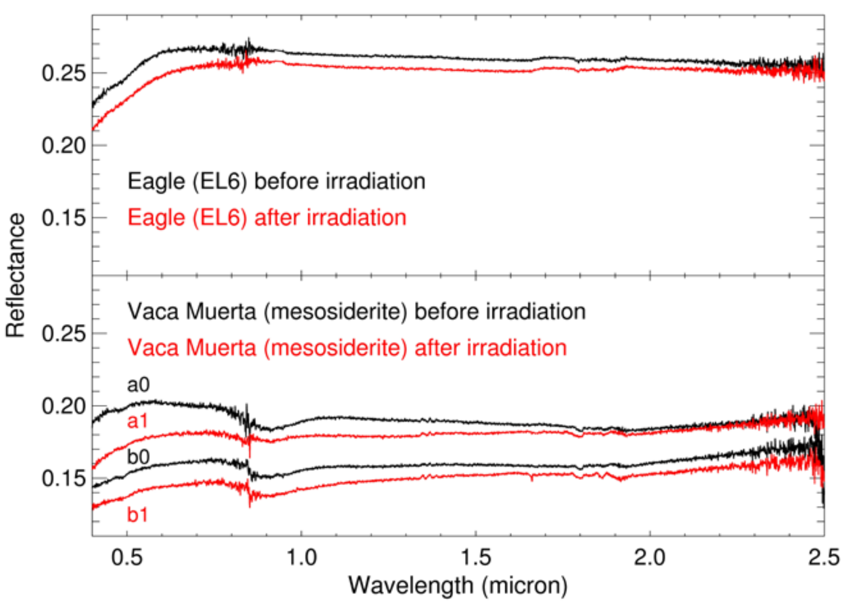
Results from previous ion irradiation experiments

Fulvio et al. 2012

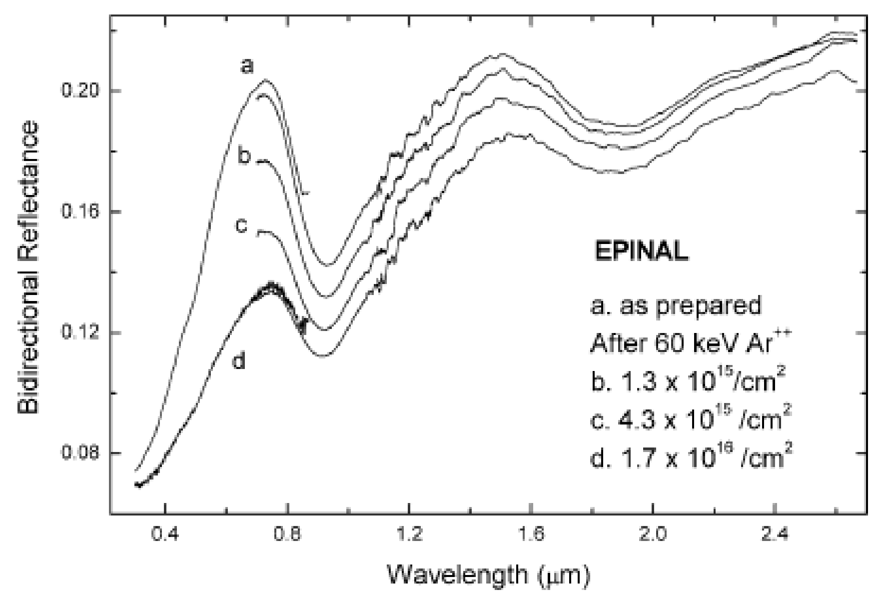




Vernazza et al. 2009



Strazzulla et al. 2005



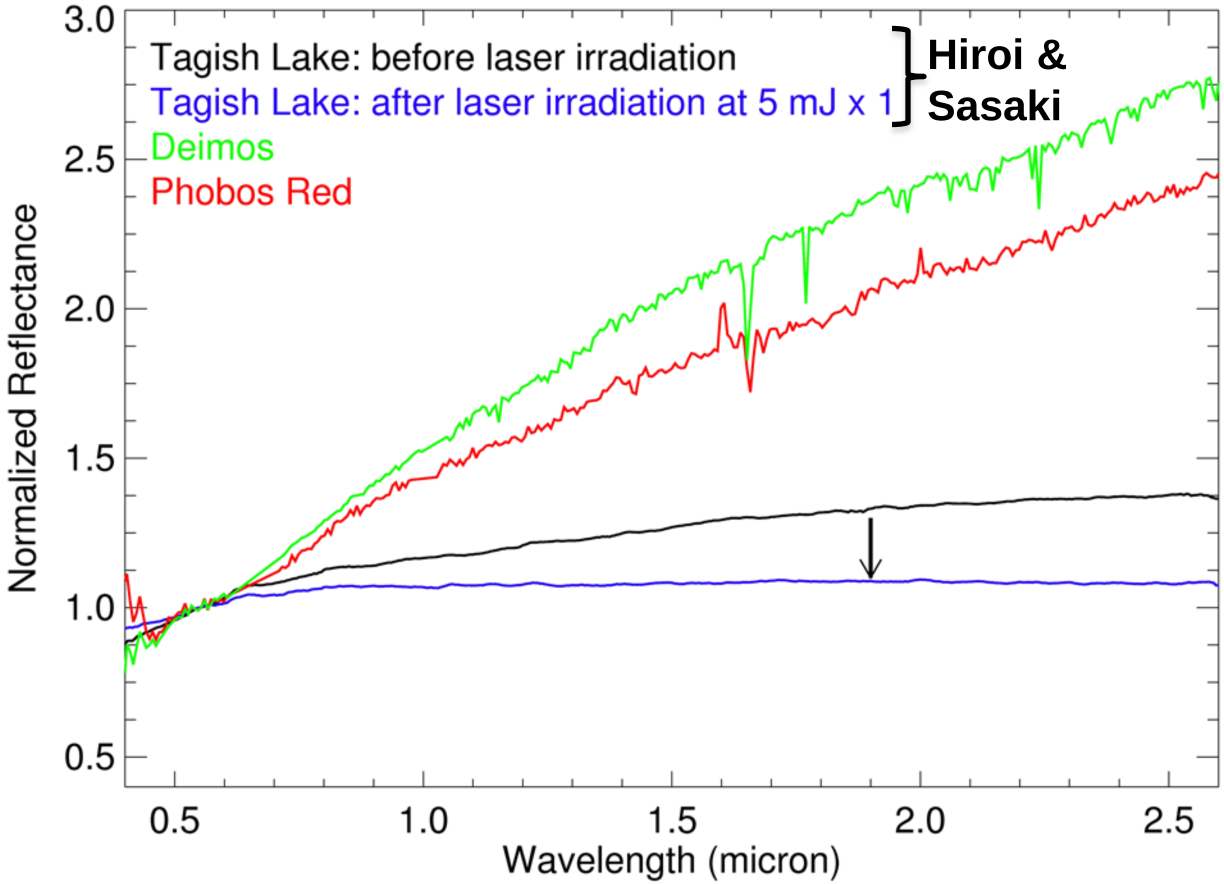
Modal composition of Tagish Lake and WIS 91600

Tagish Lake (Bland et al. 2004)	Vol (%)	WIS 91600 (this study; performed by K.T. Howard)	Vol (%)
Olivine	7.0	Olivine	15
Fe-Mg carbonate	11.7	Enstatite	1.5
Sulfide	5.6	Sulfide	3.5
Magnetite	4.5	Magnetite	6.5
Saponite-serpentine	71.2	Saponite	73.5

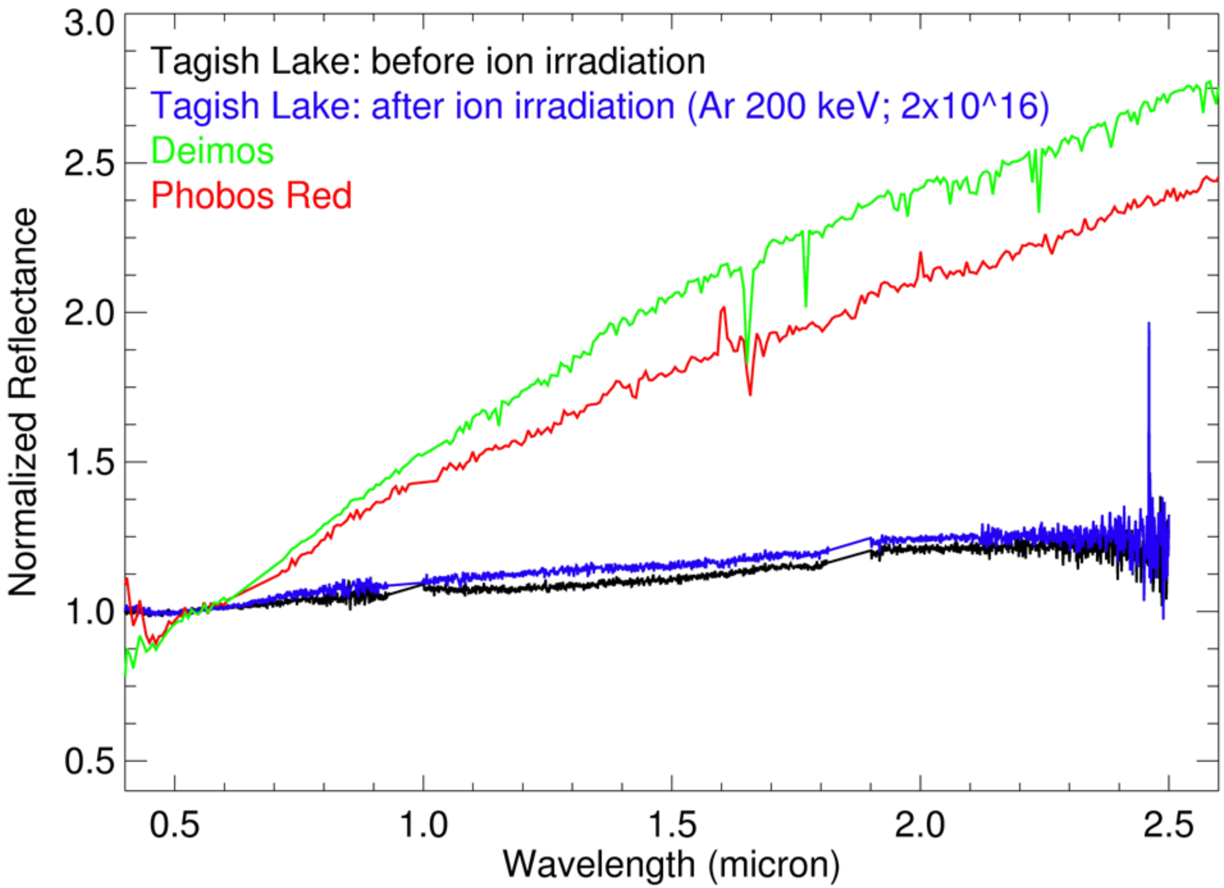
Step 2

Simulation of the space climate on Tagish Lake (both solar wind and micrometeorite bombardment)

Laser irradiation to simulate Micrometeorite bombardment



Ion irradiation to simulate the Solar wind bombardment



Moreover: Recent density measurements make a Tagish Lake-Phobos/Deimos association difficult

- Bulk density of TL :

  1.64 +/- 0.02 g/cm^3

  (from Hildebrand et al. 2006)

- Density of Phobos:

  1.87 +/- 0.02 g/cm^3

  (Andert et al., 2010)

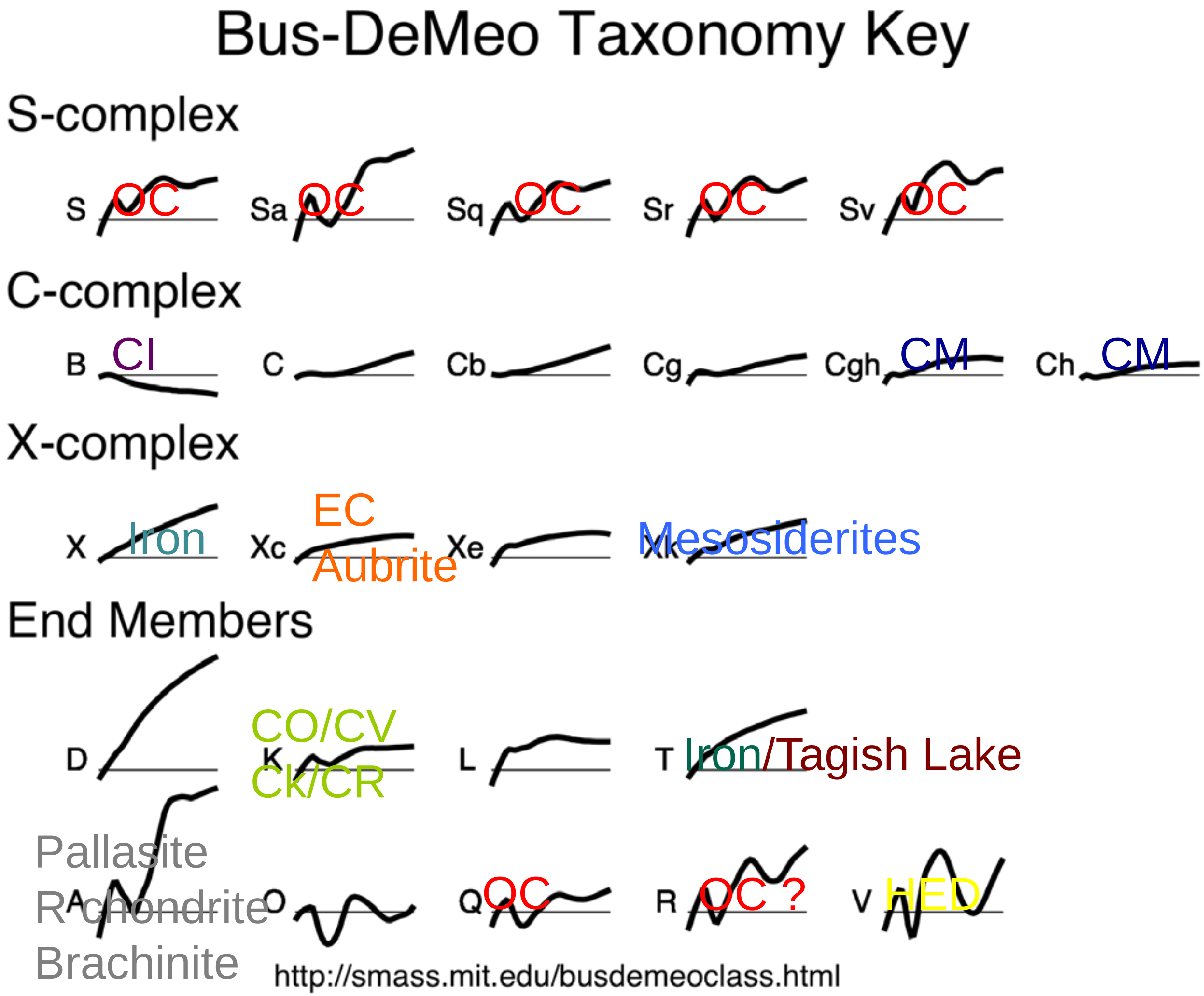
- Density of Deimos:

  1.47 +/- 0.20 g/cm^3

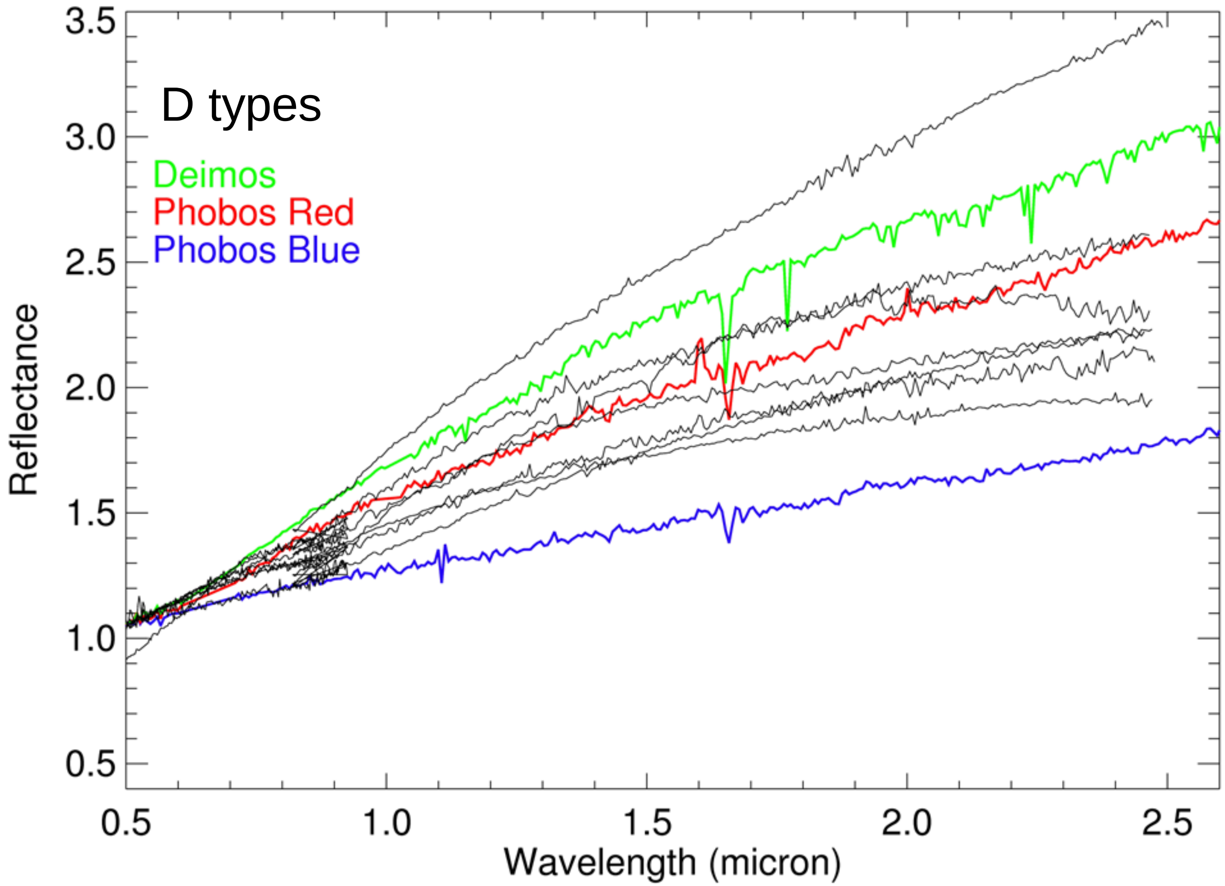
Assuming a usual macroporosity of 20-40%, the density of the Tagish Lake parent body should be in the 1-1.3 g/cm^3 range.

Preliminary conclusion

- Phobos and Deimos are unlikely parent bodies of the Tagish Lake meteorite (and WIS 91600).
- If Phobos and Deimos are captured asteroids, we currently have no meteorite sample in our collection that fits Phobos and Deimos' physical properties

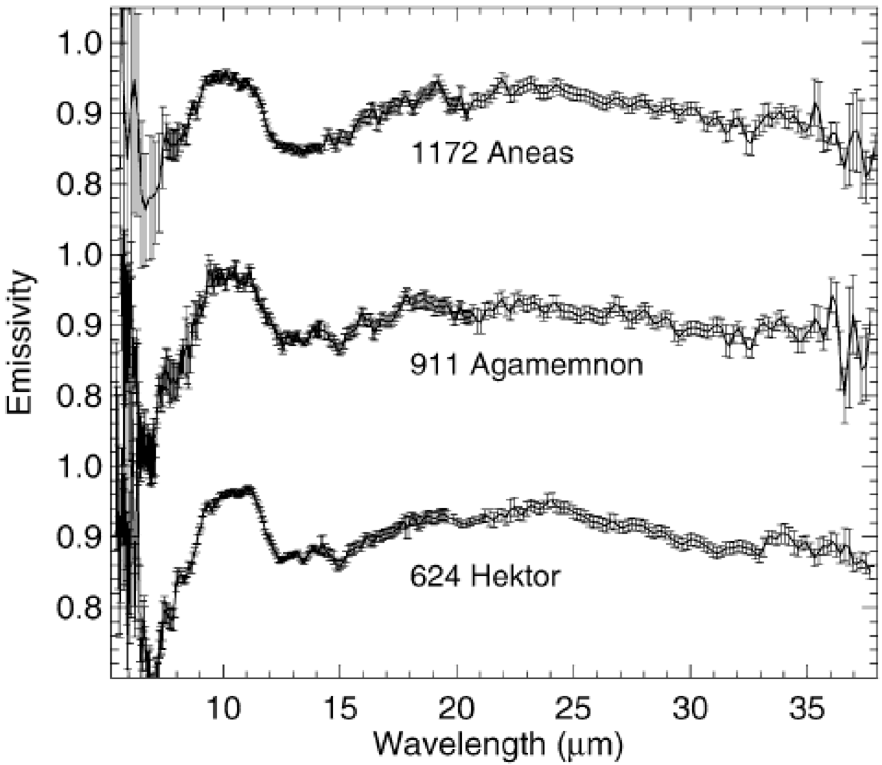

Bus-DeMeo Taxonomy Key
S-complex
S
OC
Sa
OC
Sq
OC
Sr
OC
Sv
OC
C-complex
B
CI
C
Cb
Cg
Cgh
CM
Ch
CM
X-complex
X
Iron
Xc
EC
Aubrite
Xe
Xk
Mesosiderites
End Members
D
K
CO/CV
Ck/CR
L
T
Iron/Tagish Lake
A
Pallasite
R chondrite
Brachinite
O
Q
OC
R
OC ?
V
HED
http://smass.mit.edu/busdemeoclass.html

D type asteroids do match in the VNIR…

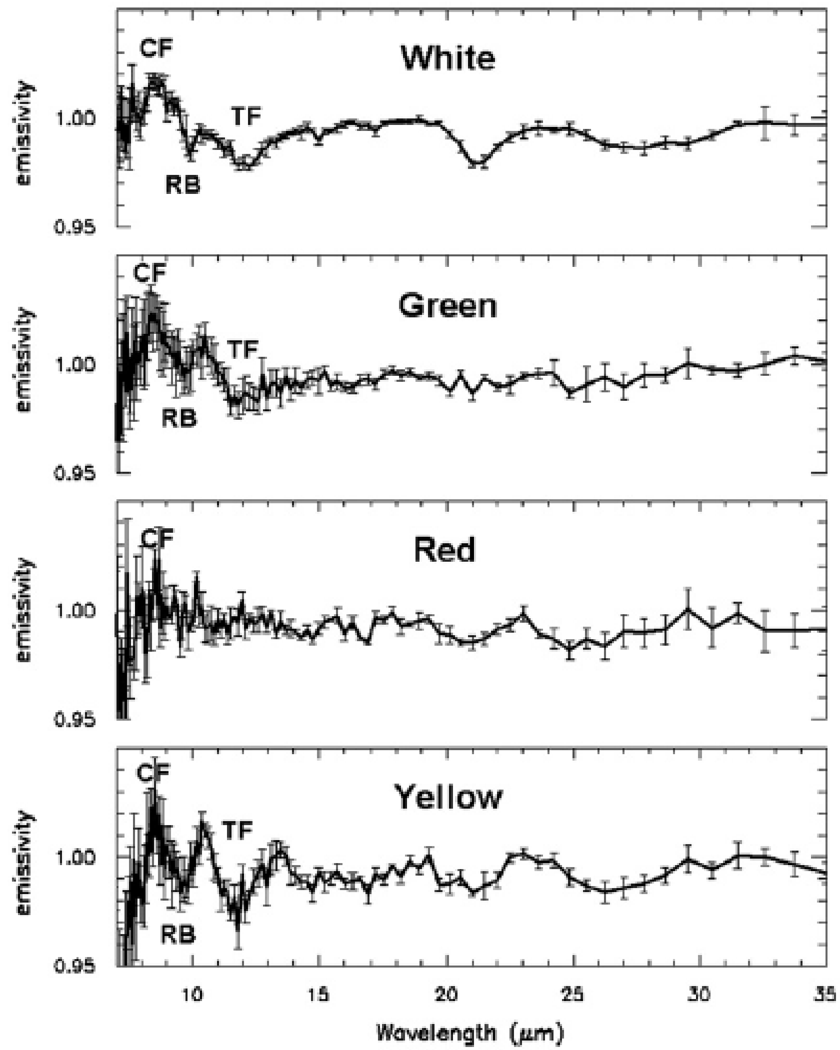


But in the Mid-IR ?

Giuranna et al. 2011



Emery et al. 2006



Mismatch in terms of density !

- Density of D-tyes :

  ~1.00 g/cm^3

  (F. Marchis, personnal communication)

- Density of Phobos:

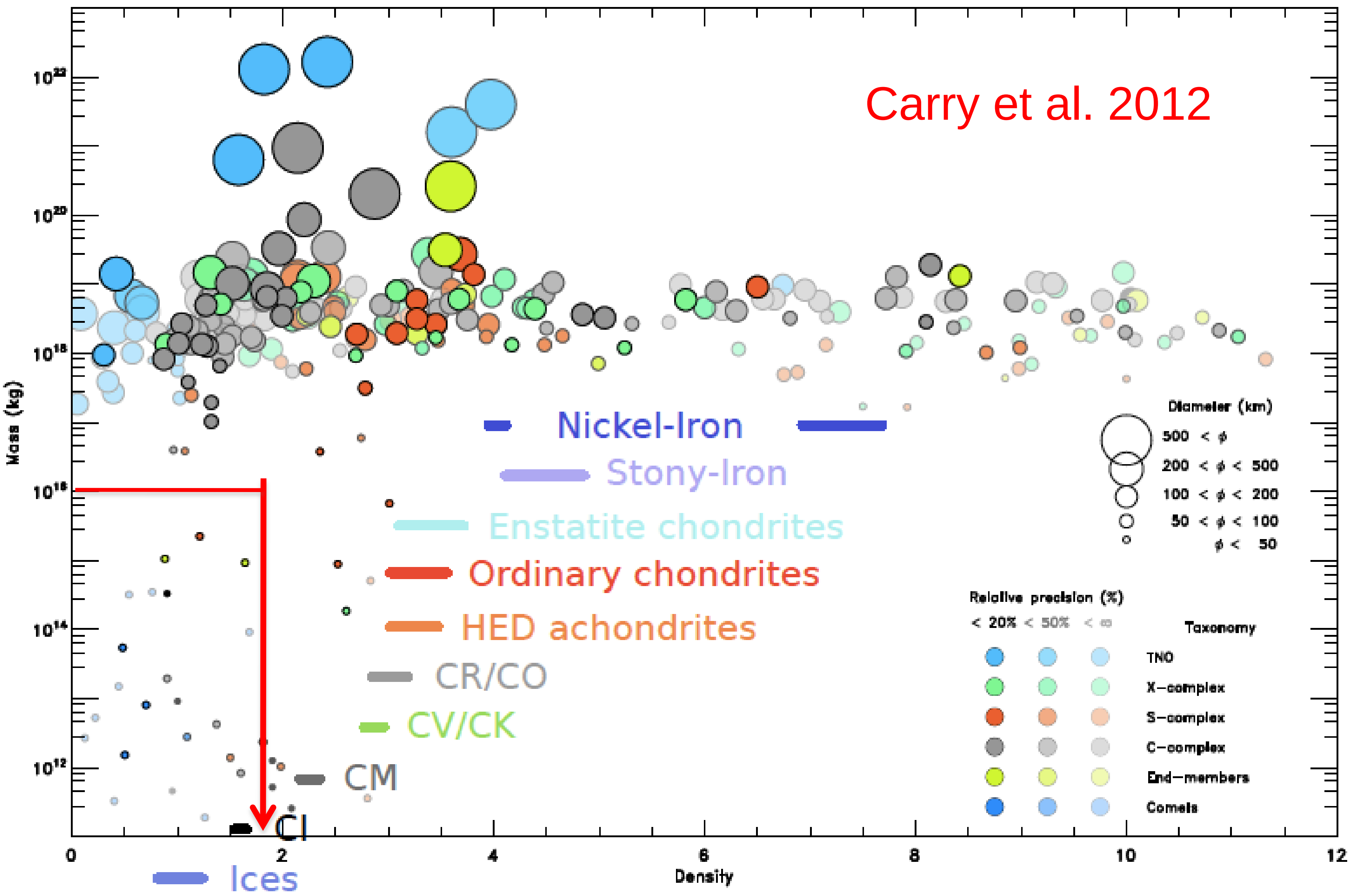
  1.87 +/- 0.02 g/cm^3

  (Andert et al., 2010)

- Density of Deimos:

  1.47 +/- 0.20 g/cm^3

Phobos density among the highest for its size !

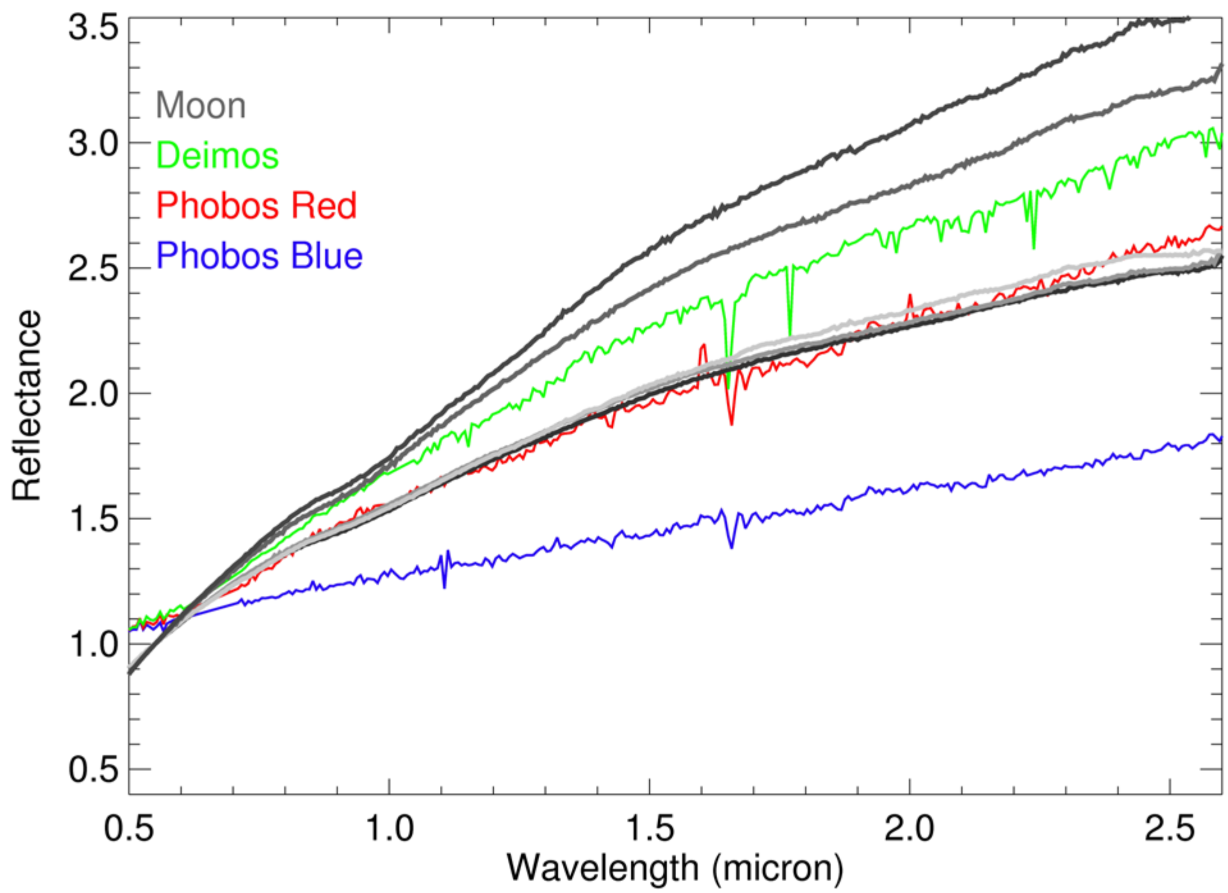


Phobos and Deimos both look different from any asteroid.

Does ‘anything’ else look similar to the Martian moons?

Yes !

Great match in the VNIR



Excellent match in terms of density

- Density of lunar crust:

  ~2.70 g/cm^3

  => 1.62-2.16 g/cm^3 assuming 20-40% macroporosity

- Density of Phobos:

  1.87 +/- 0.02 g/cm^3

  (Andert et al., 2010)

- Density of Deimos:

  1.47 +/- 0.20 g/cm^3

Implications/Conclusion

- We need much better data in the Mid-IR for both Moons.
- Lunar highlands currently provide the best match to Phobos and Deimos (VNIR, density, albedo).
- It is difficult to imagine that Mars had a Moon similar to ours that was disrupted. We would see a mix of crust and interior.
- Could the early Martian crust have been similar to the Lunar one?
- Today, feldspar is a common mineral on the Martian surface but is often mixed with pyroxene which displays features in the NIR..