Thermal Emission Observations of Phobos: Compositional Interpretations

Ted Roush
NASA Ames Research Center

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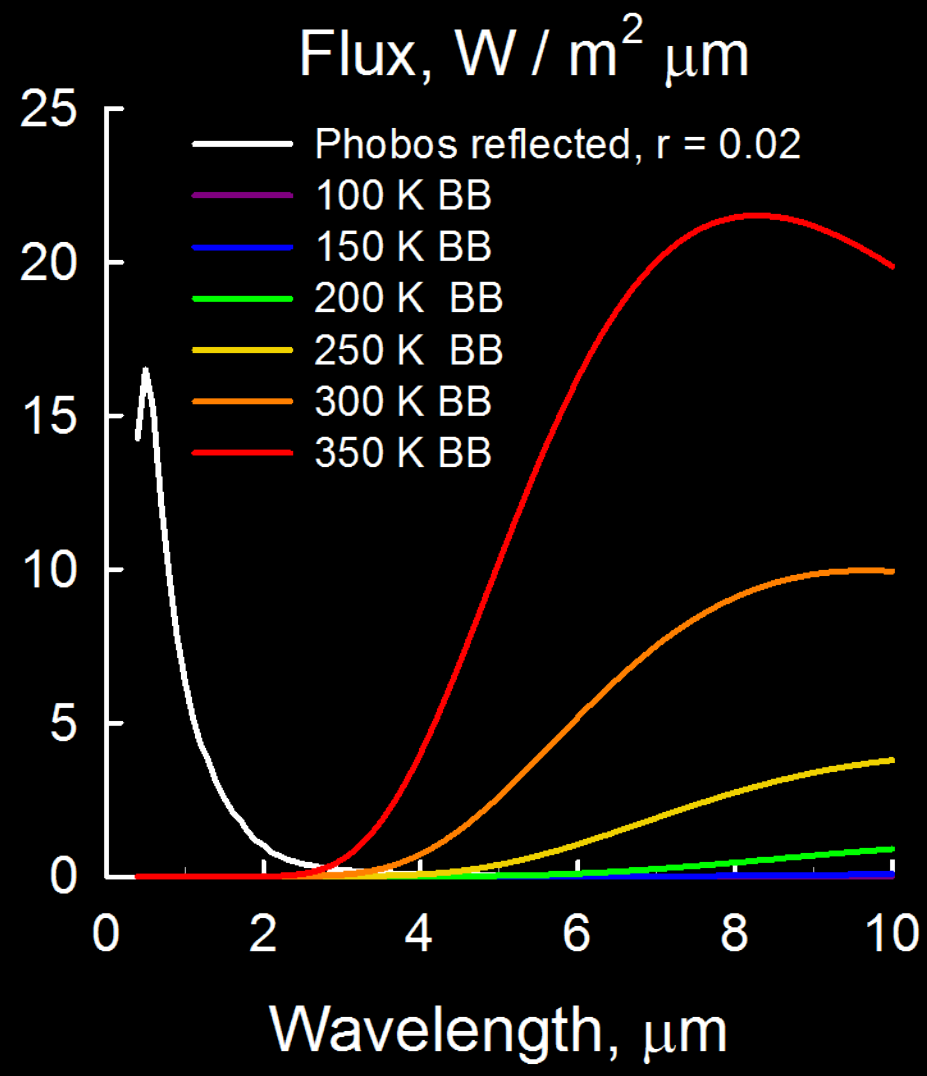
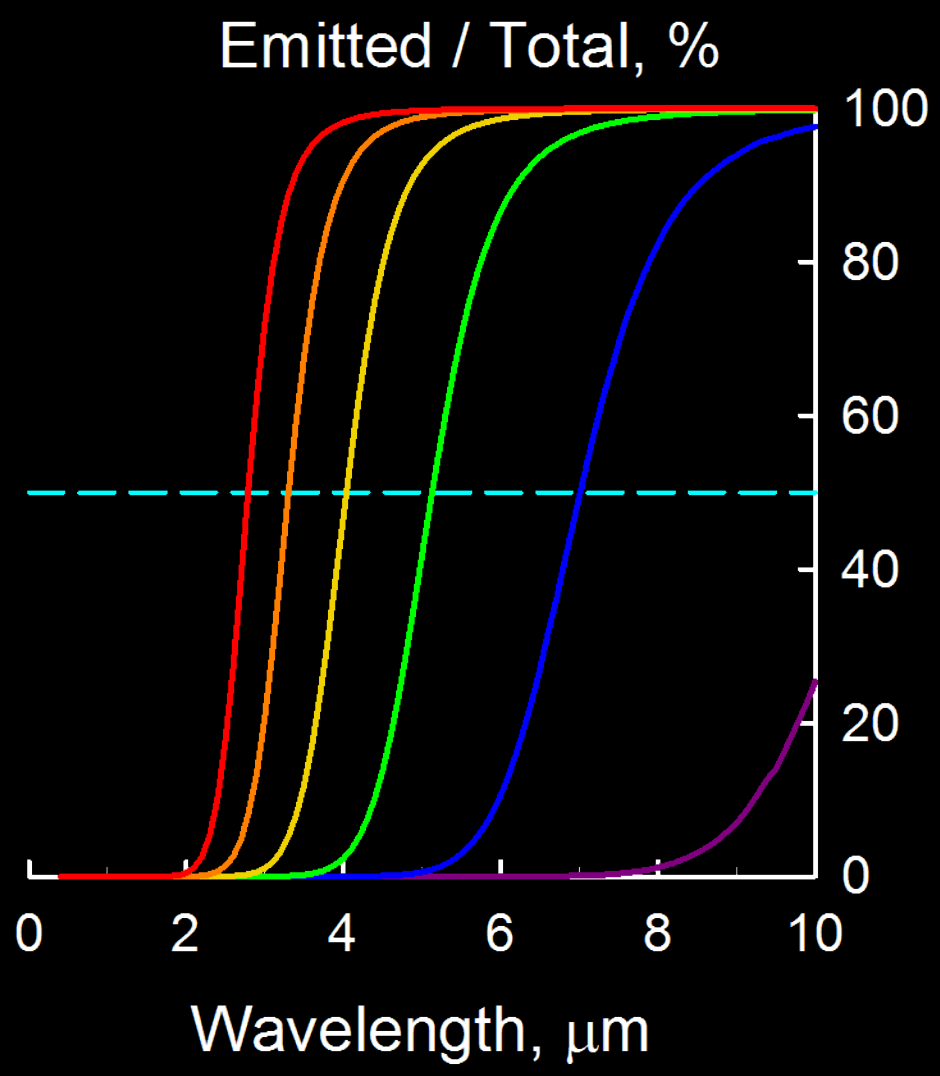
15-16 February 2016

My thanks for
1) workshop organizers invitation
2) ELSI staff assistance

感謝します
1) ショップ主催者の招待状
2) ELSI スタッフの支援

Reflected vs. Emitted Flux

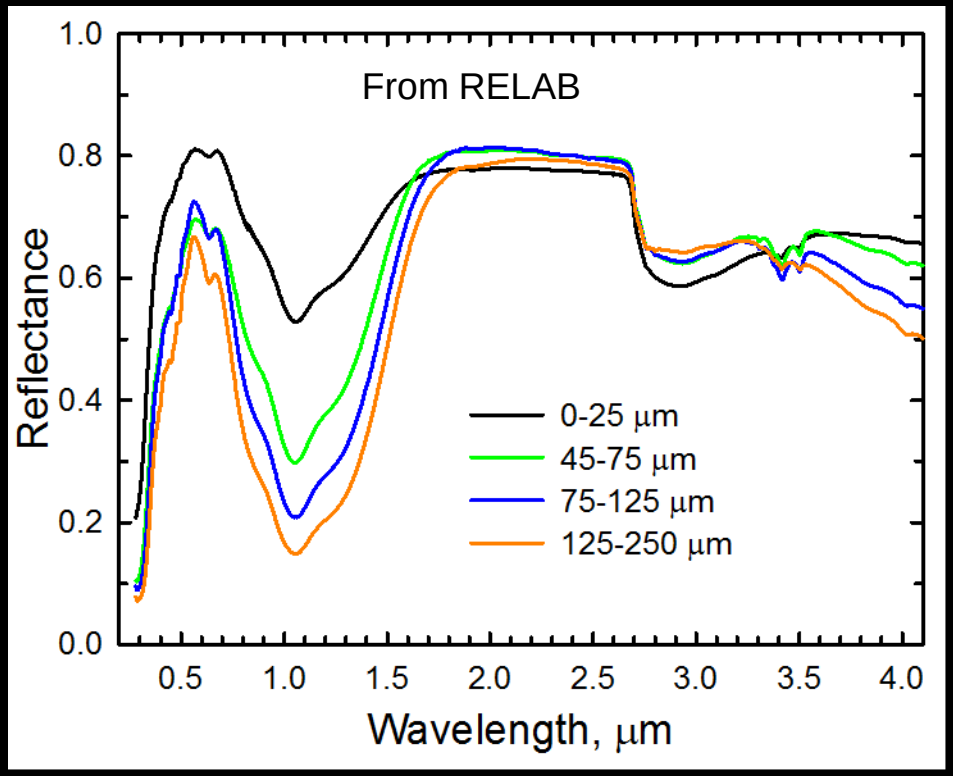




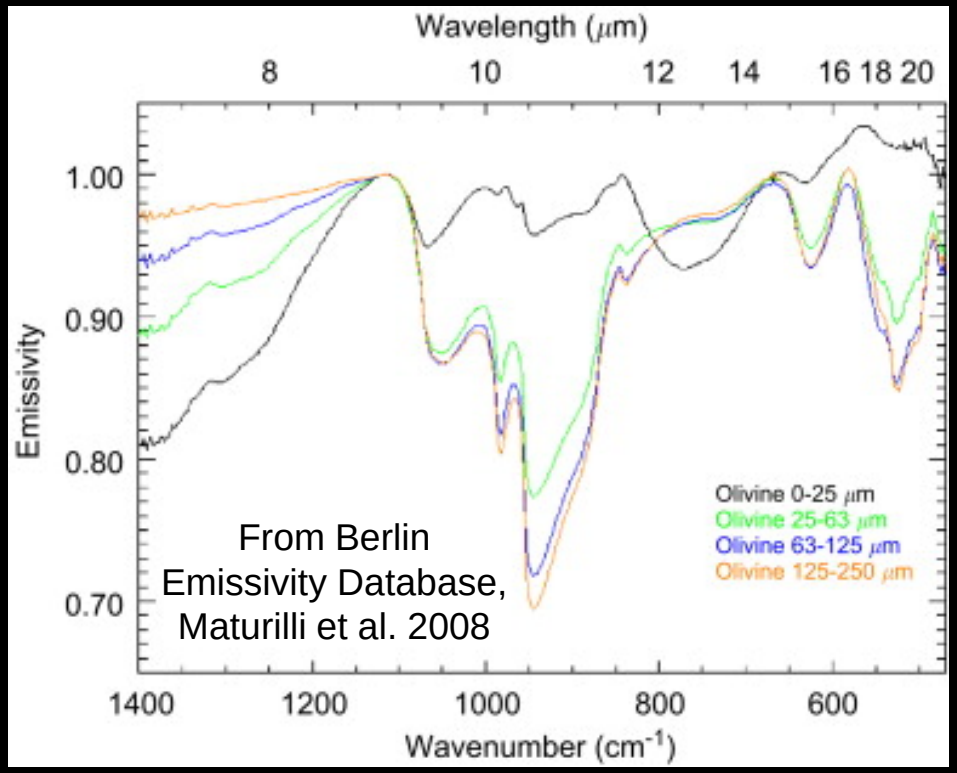
Reflected vs. Emitted Measurements

Particle Size

Visible-NearIR



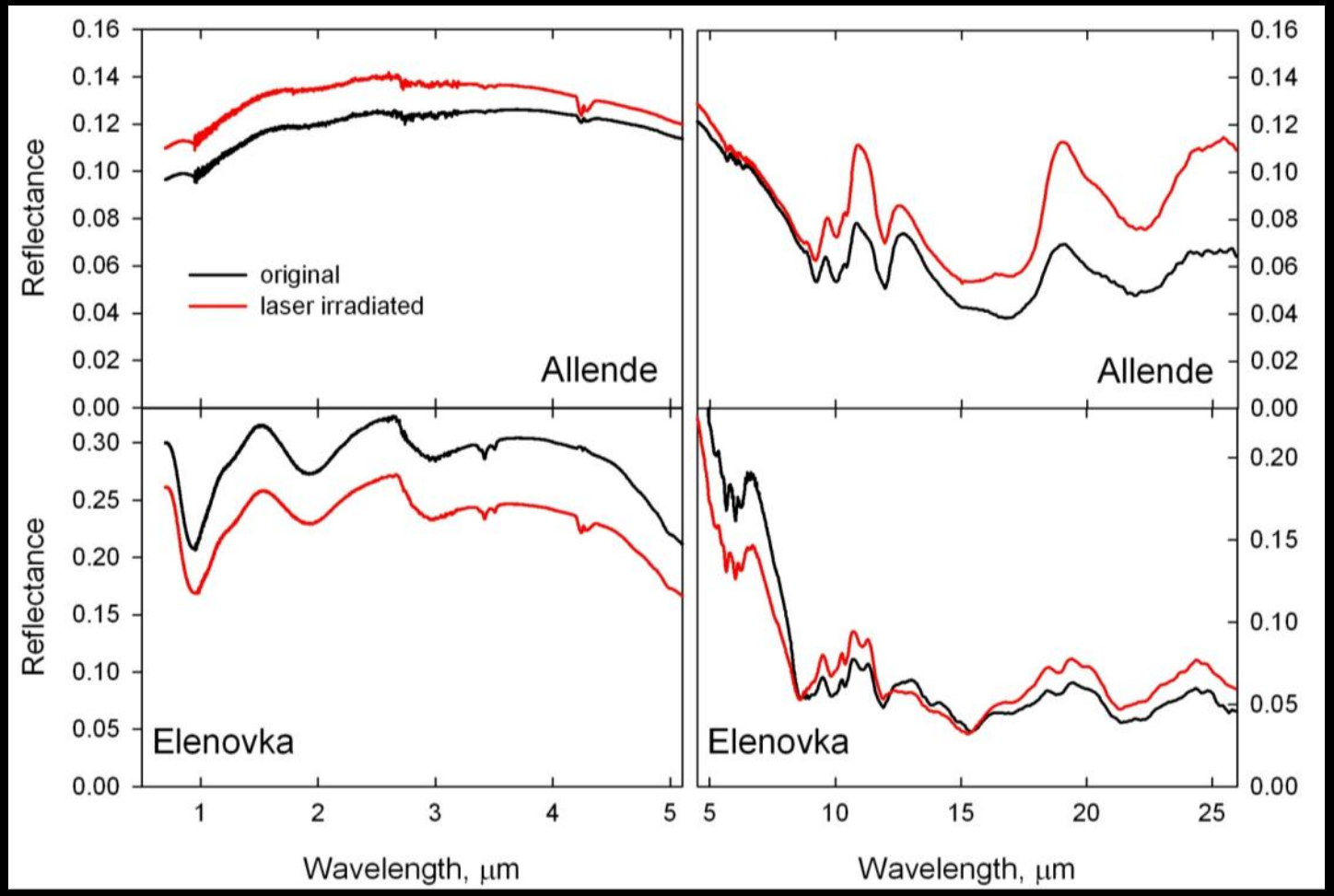
Thermal IR



Increasing particle size decreases the reflectance/emittance and increases contrast of spectral features for both VNIR and TIR

Reflected vs. Emitted Measurements

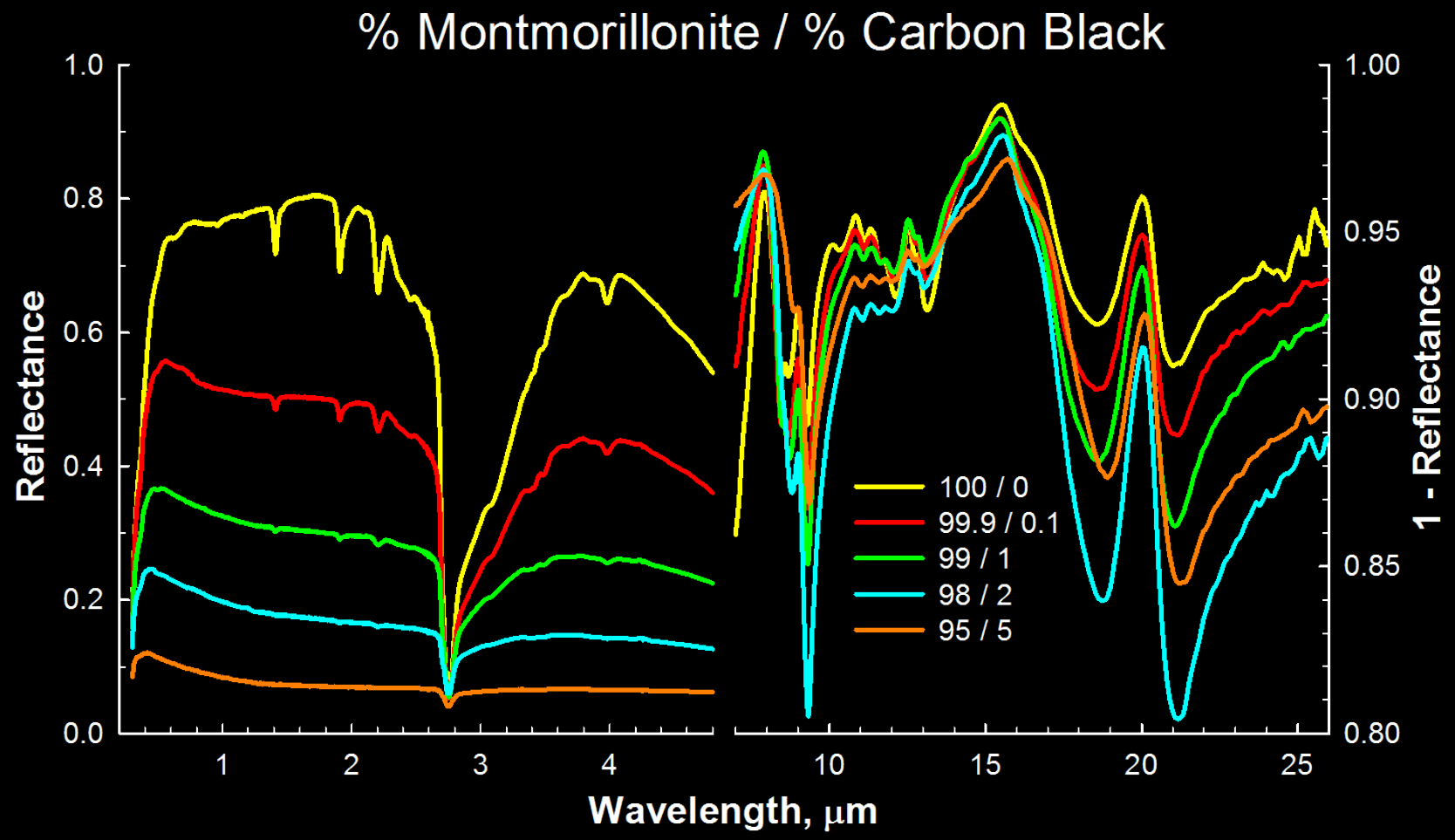
Space Weathering



Simulated impact melting increases the spectral contrast in the TIR

Reflected vs. Emitted Measurements

Mixing



Contaminant has greater impact on VNIR versus TIR

Thermal Emission Observations of Phobos

Multiple Phobos observations by Mariner 9 InfaRed Thermal Mapper (IRTM) were used to derive minimum / maximum temperatures of 140 / 300 K (Lunine et al. 1982).

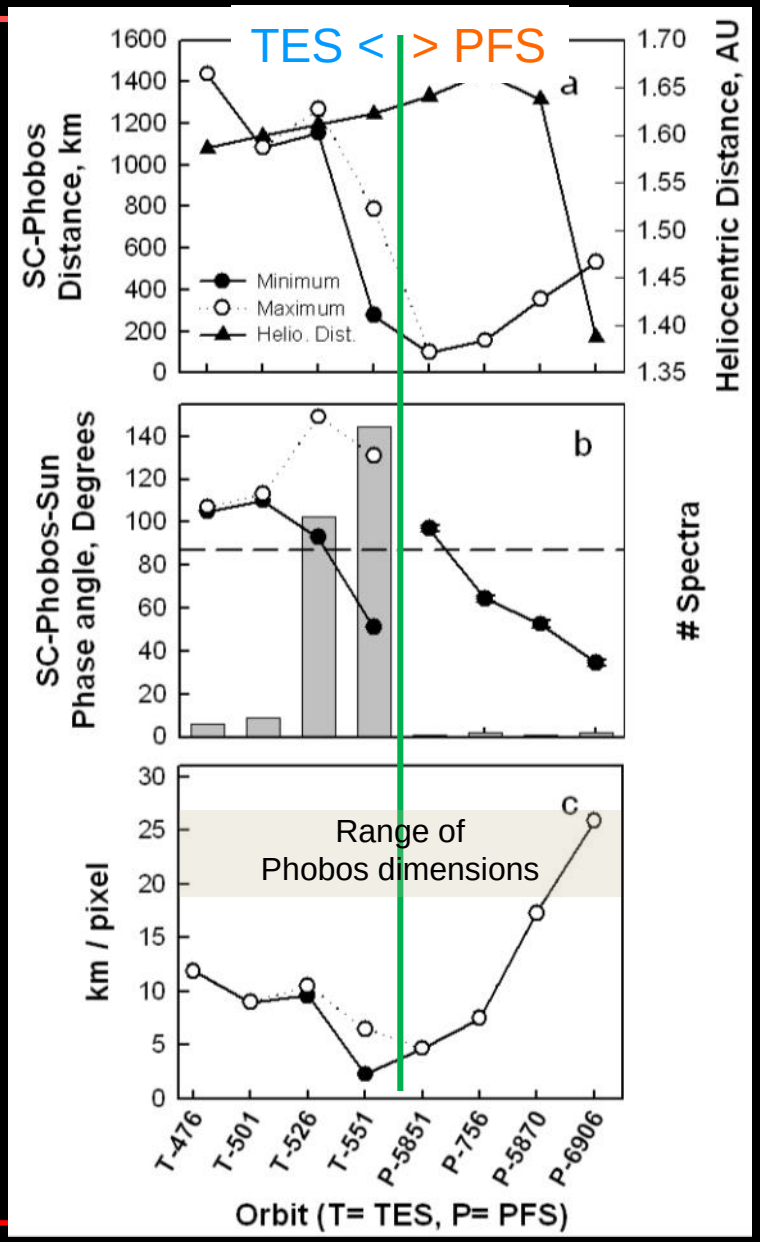
Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) measured from 1700 to 200 cm^{-1} (~6 to 50 μm) with spectral resolutions of 6.25-12.5 **cm^{-1}** (Christensen et al., 1992, 1998).

Mars Express (MEX) Planetary Fourier Spectrometer (PFS) measured wavenumbers 8200-1700 cm^{-1} (SWC, 1.2-5.9 μm) and 1700-250 cm^{-1} (LWC 5.9-40 μm) with a spectral resolution of ~ 2 cm^{-1} (Formisano et al. 2005) Today I only discuss data from LWC.

At these wavelengths, TES & PFS provide a sensitive means of determining mineralogy. They sample minerals fundamental vibrational modes whose number, position, intensity, and shape depend upon the atomic masses, inter-atomic force fields, and molecular geometry.

Thermal Emission Observations of Phobos

- Both TES and PFS observed Phobos multiple times
- The spacecraft (SC)-Phobos distances result in a relatively large coverage of the surface (panel a)
- During half of the encounters TES and PFS viewed the unilluminated hemisphere of Phobos (above dashed line in panel b)
- The illuminated hemisphere of Phobos (below dashed line panel b) was observed with resolutions of a few to ≈ 25 km (panel c)



Emittance from Data

1) Three black bodies used to fit the data
2) Results used to create an upper hull fit to the radiance maxima
3) Emittance is produced by dividing the measured radiance by the hull

Inst-Orb #	Solar dist., AU	Avg. T1, K	Avg. T2, K	Avg. T3, K
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TES-501	1.59916	194±15	139±20	102±25
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TES-551	1.62260	271±51	206±44	143±51
PFS-756	1.66508	265±5	260±5	250±5
PFS-5851	1.64121	240±5	160±5	130±5
PFS-5870	1.6374	270±5	265±5	260±5
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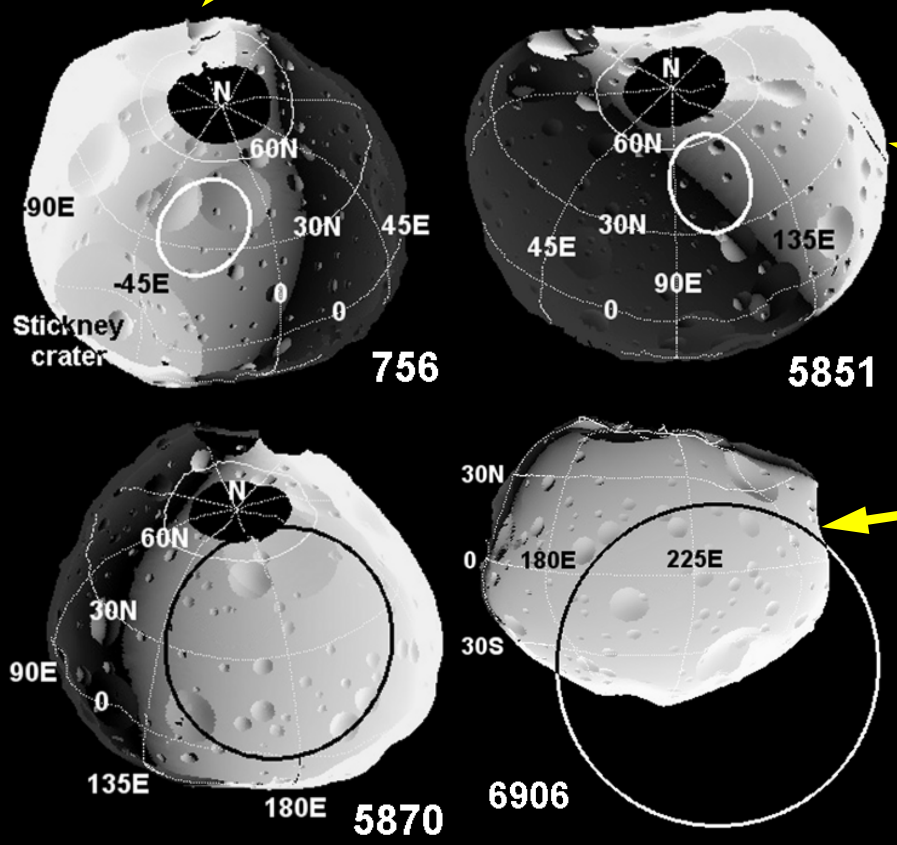
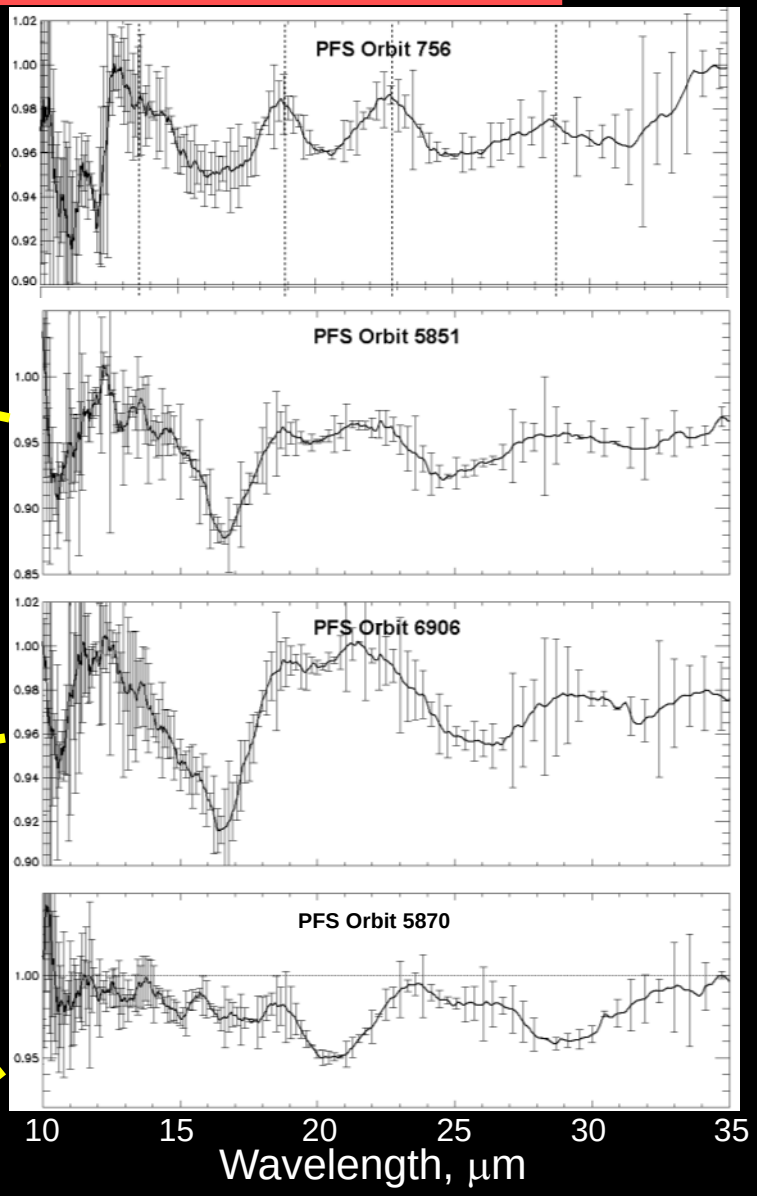
TES and PFS minimum, 130-140 K, and maximum, 270-353 K, temperatures are consistent with Viking IRTM; night 140 K, day 300 K (Lunine et al. 1982)

The maximum temperature of PFS-6906, 353±5 K, ≈1.39 AU, is consistent with Earth-based observations, ≈1.38-1.39 AU, yielding 320-340 K (Lynch et al. 2007)

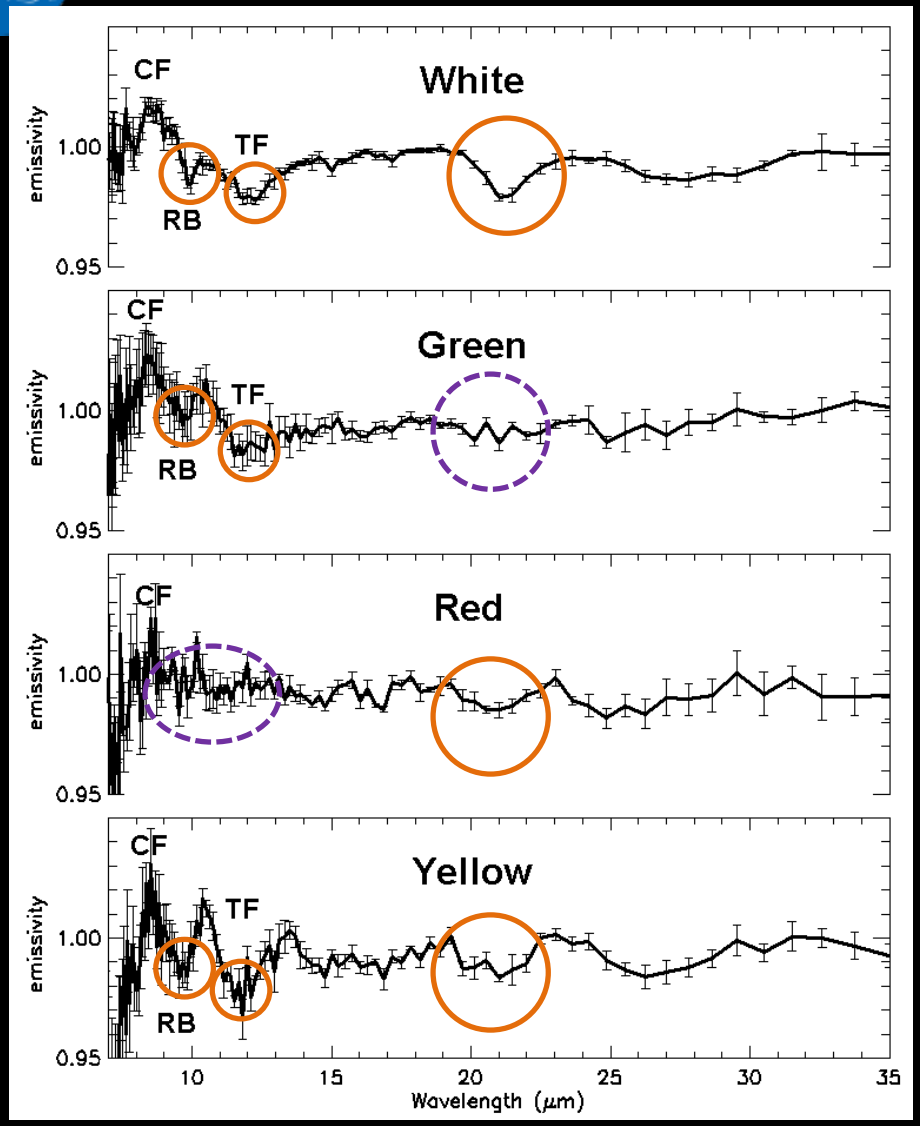
PFS Emissivity

PFS regions from the 4 encounters, from Giuranna et al. 2011

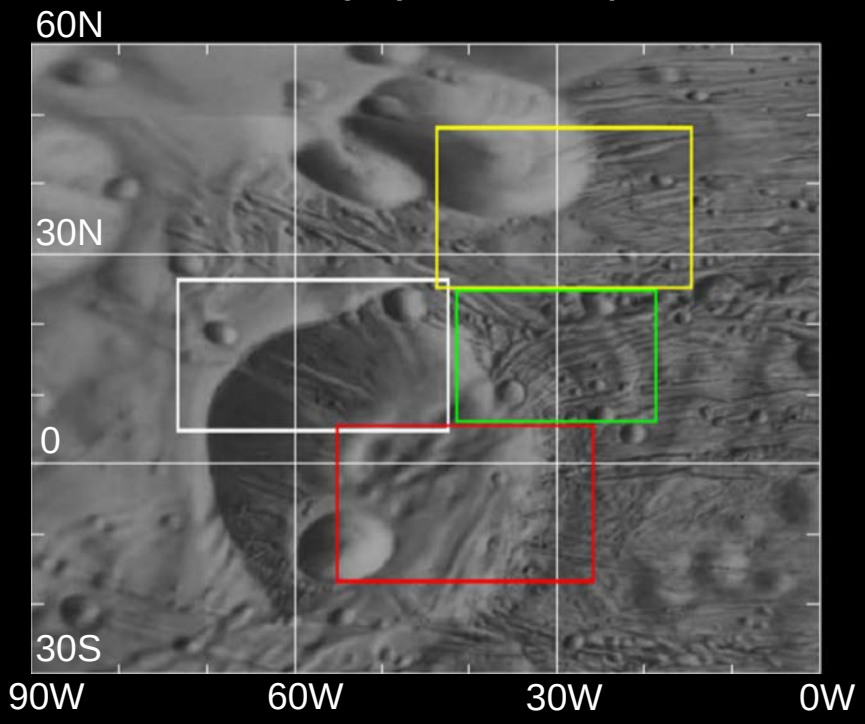




TES Emissivity



TES observations near Stickney (orbit 551)

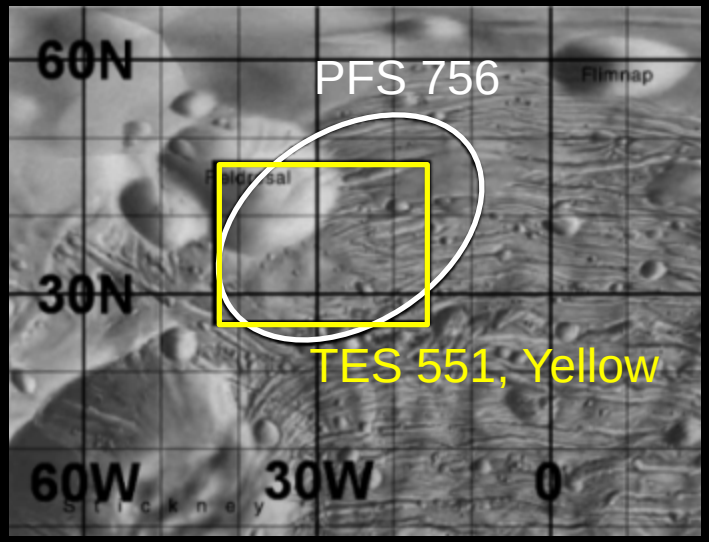


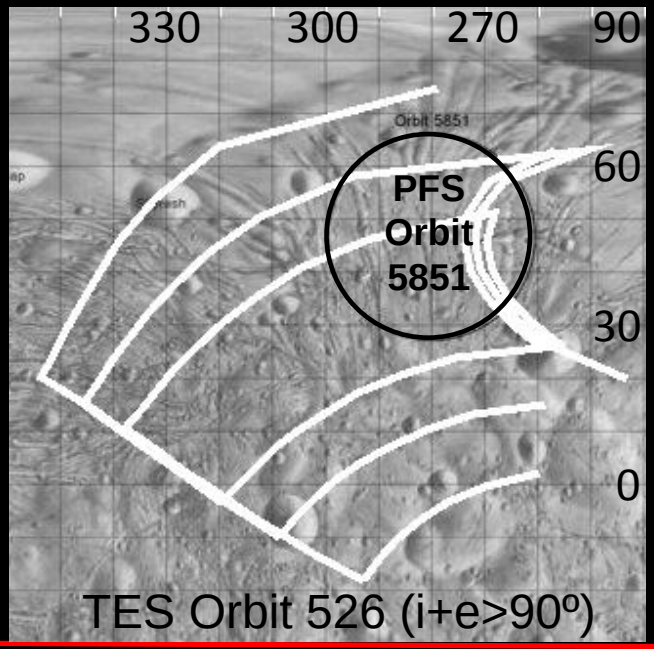
Statistically distinct (K-means clustering) spectra exist within each box

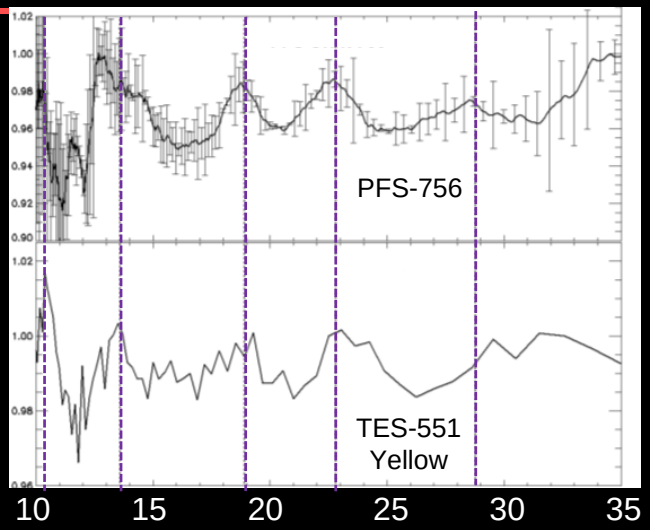
CF = Christiansen feature, RB = Reststhralen band, TF = transparency feature

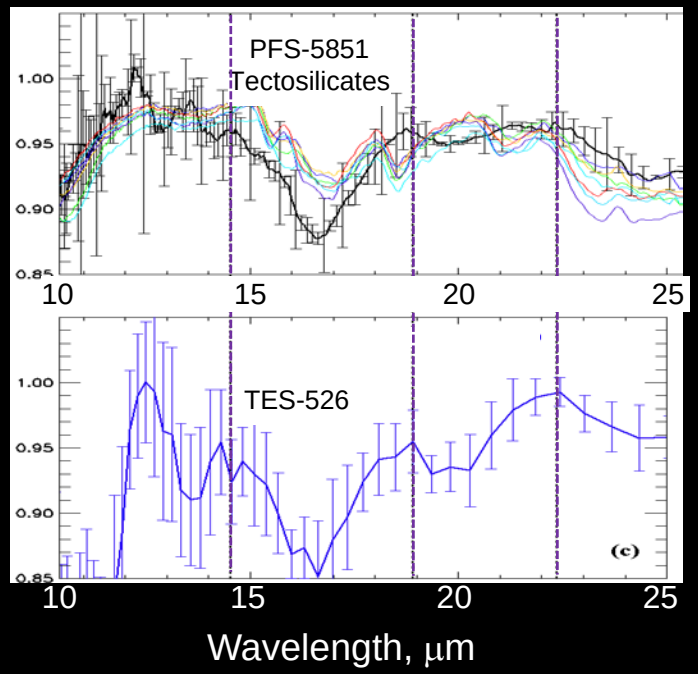
PFS – TES Comparisons (Giuranna et al. 2011)

When areas overlap, similar spectral features





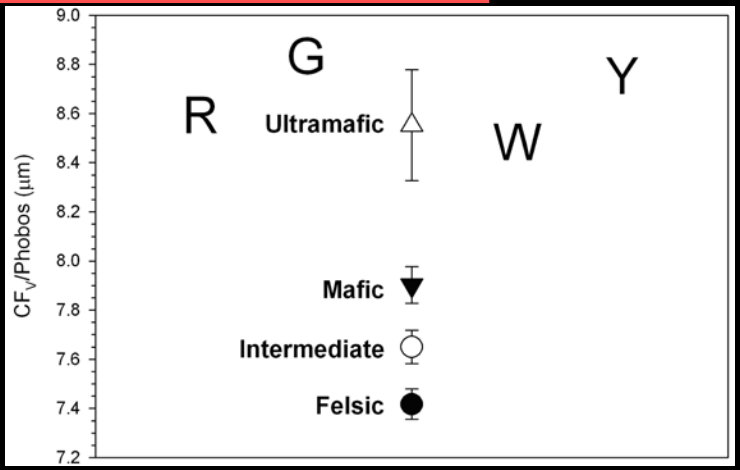


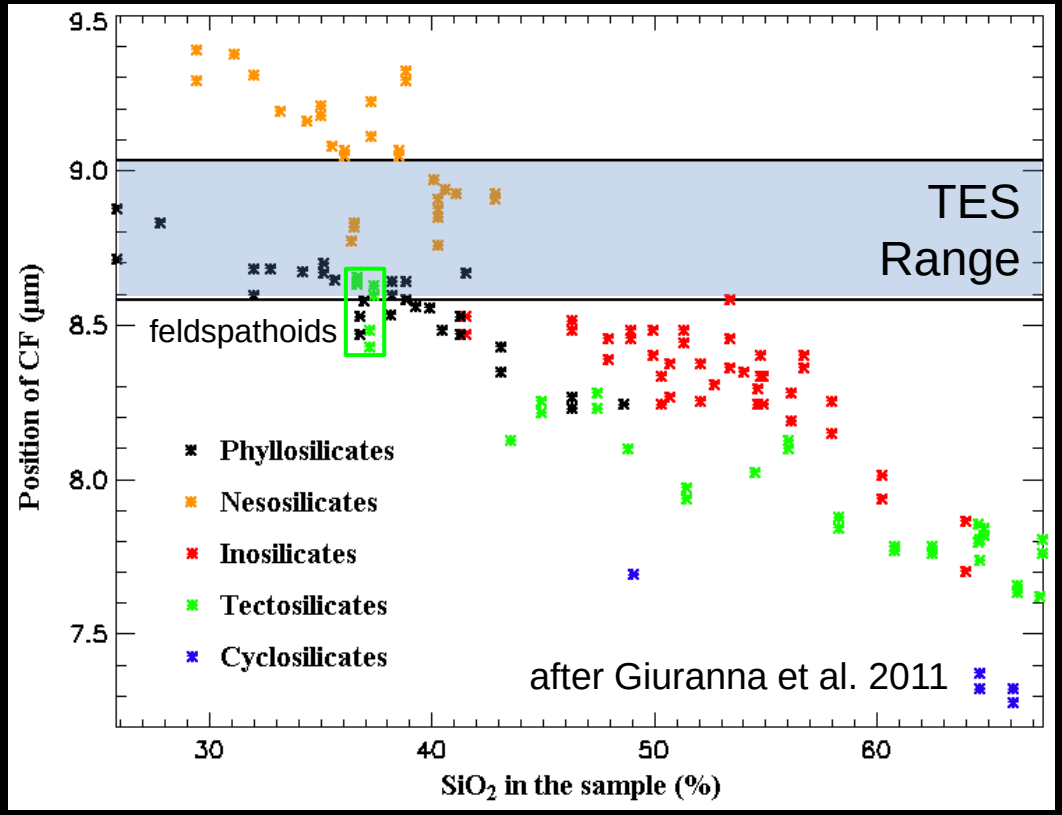


TES compositional Analyses: CF of Terrestrial Samples

Christiansen frequency (CF) related to rock type (Salisbury and Walters, 1989). Created averages for igneous rocks from their Table 2 (points ±1σ).

4 Stickney classes CFs determined using quadratic fit (7.1-9.8 μm, letters) are similar to ultramafic rocks





TES CF range is consistent with phyllosilicates (e.g., clays & micas), nesosilicates (e.g., olivines) & limited tectosilicates (e.g., feldspathoids).

TES Compositional Analyses: Spectral Library Comparison

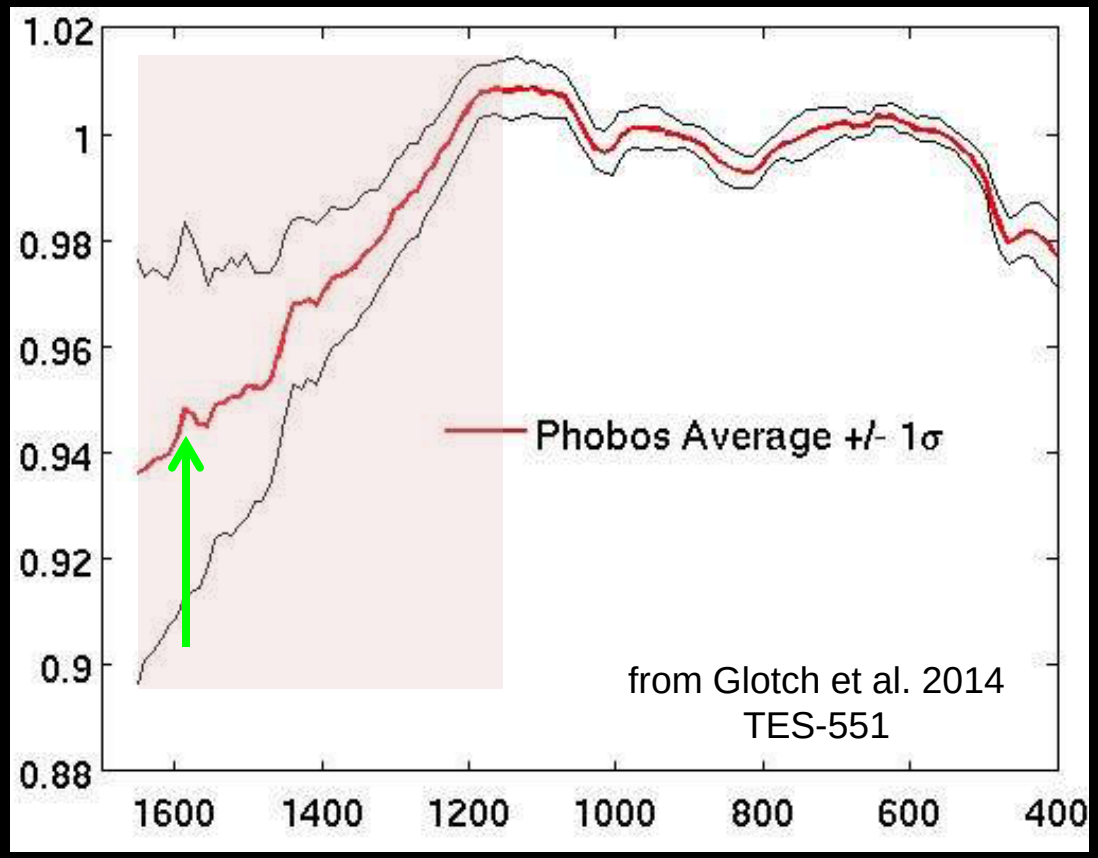
1) Spectral Analysist (IDL-ENVI) spectral feature fitting for comparison to libraries
2) Evaluations of TES clusters over full and restricted ranges
3) Record top 10 matches

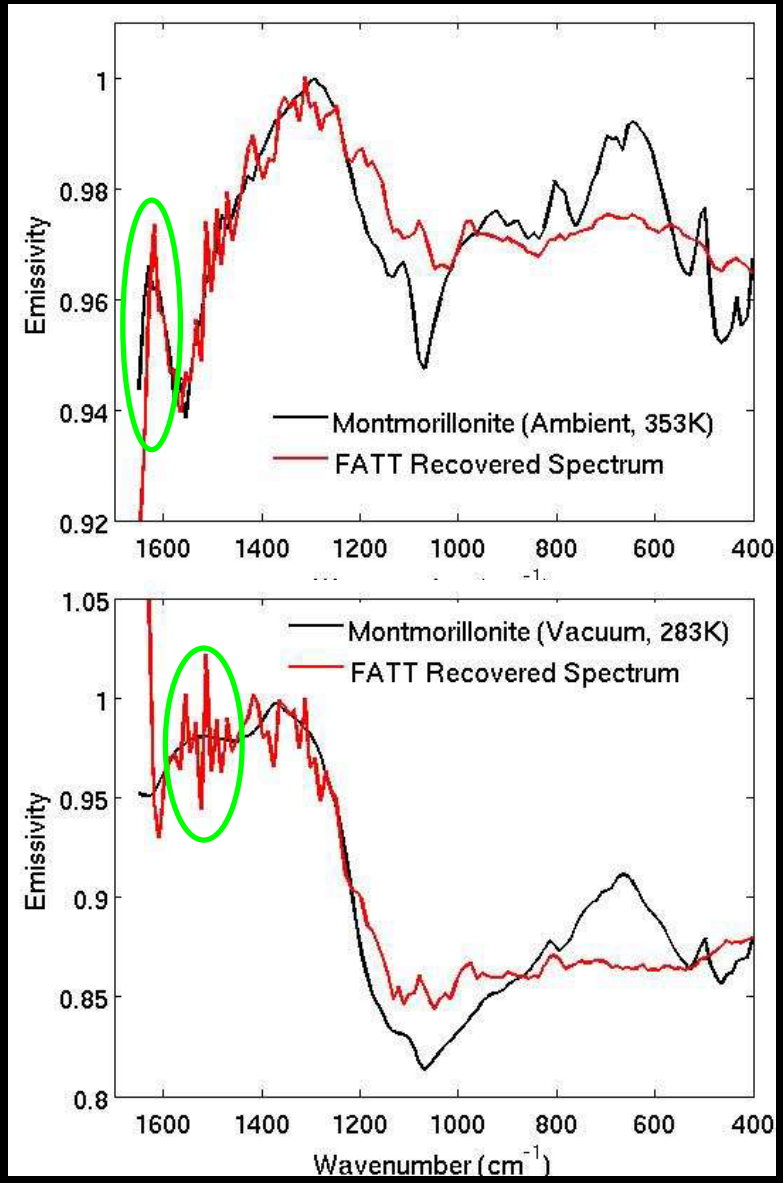
Library	White	Green	Red	Yellow
ASU, 8-35 μm	PS	PS	PS	PS
8-18 μm	PS, IS, TS	PS, IS, salts	PS	PS, salts
18-35 μm	PS, IS	PS, IS, salts	PS, IS	IS, TS
ASTER meteorites, 8-25 μm	AC, CC	AC	AC, OC	AC
8-18 μm	AC, CC	AC, CC	AC, OC	AC, OC
18-25 μm	AC, CC	AC	AC, CC	AC
ASTER Terrestrial Rocks, 8-14 μm	Ba, Di, Ij	Ba, Ij, No	Ba, An	Ba, Ij, No
ASTER Lunar Samples, 8-14 μm	LM, LT	LT	LM, LT	LM, LT

PS = phyllosilicates, IS = inosilicates, TS = tectosilicates
AC = achrondites, CC = carbonaceous chrondrites, OC = ordinary chondrites
Ba = basalt, Di = diorite, Ij = ijolite, No = norite, An = andesite
LM = lunar maria, LT = lunar transitional

TES Analyses of Glotch et al. 2014

Short-wavelength "roll-off", structure, and 1590 cm^{-1} (6.3 μm) feature.

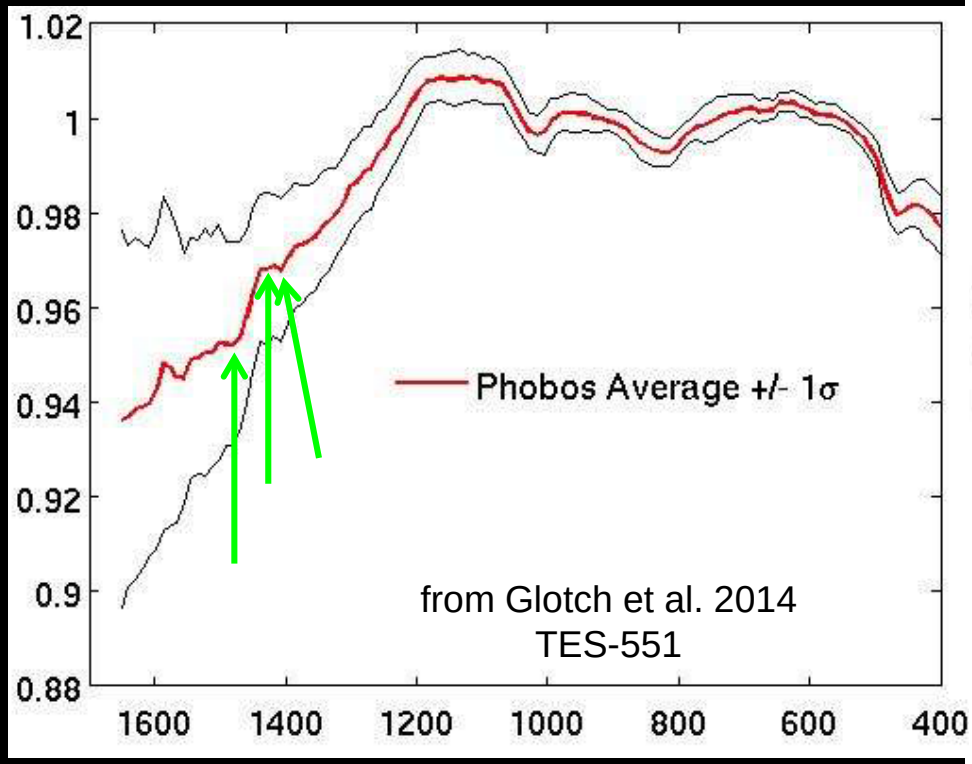


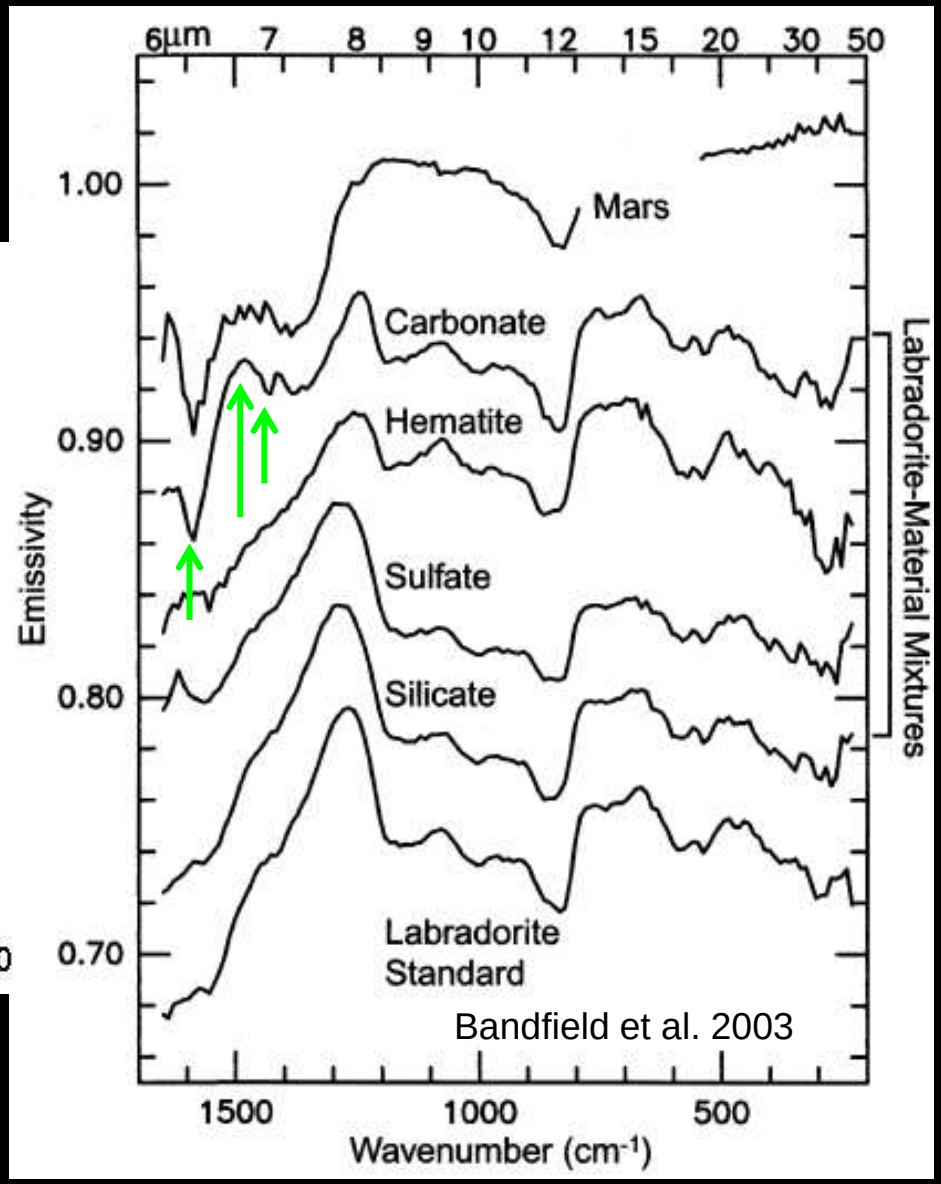


Suggestive of H_2O associated with phyllosilicates.

TES Analyses of Glotch et al. 2014

Minimum-maximum-minimum near 1340-1415-1522 cm^{-1} (7.5-7.07-6.6 μm).





Suggestive of carbonates

Phobos Composition via Different Wavelengths

Suggested materials	VNIR-SWIR	Thermal
Phyllosilicates	Y	Y
Tectosilicates		Y
Asteroids/Meteorites	Y	N?
Lunar, or basalt-like	N?	Y
Carbonates		Y
Ultramafic		Y

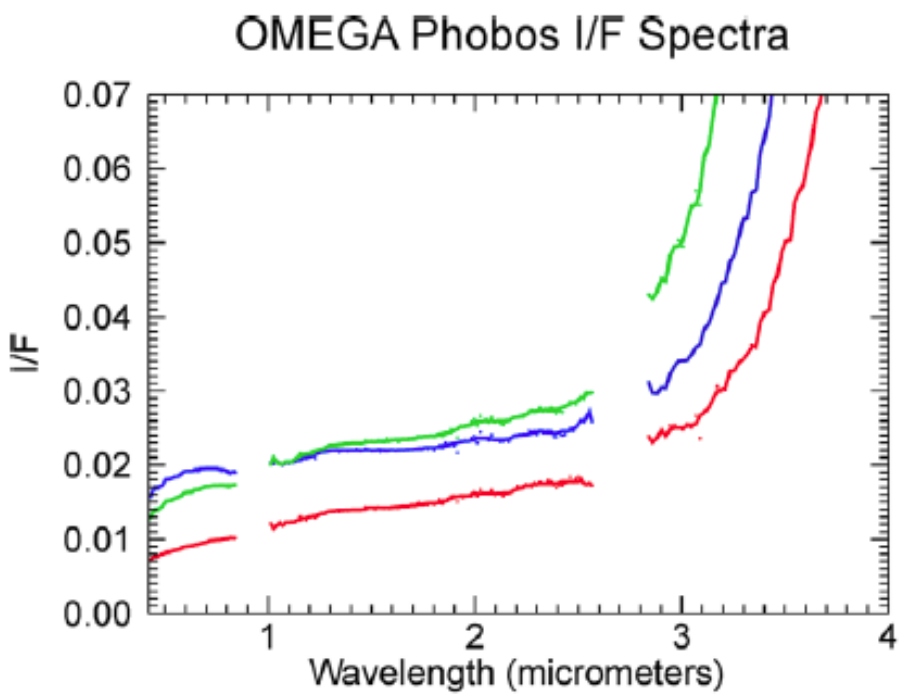
Phobos Composition Summary

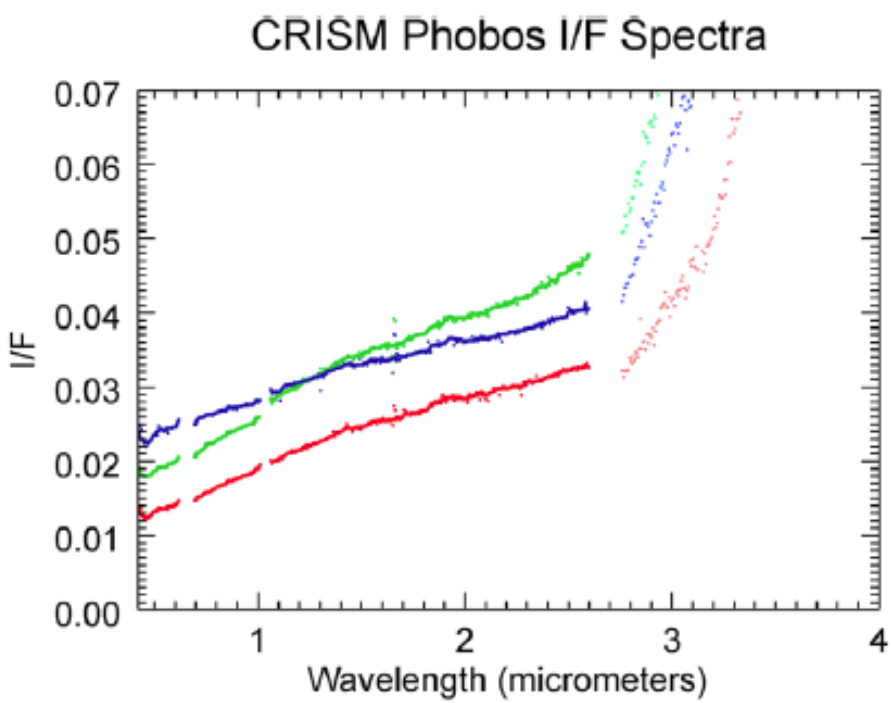
- Presence of phyllosilicates via VNIR-SWIR and TIR data
- Presence of basaltic/lunar compositions, carbonates, and tectosilicates supported by TIR data
- Presence of asteroidal or meteorite compositions supported by VNIR data

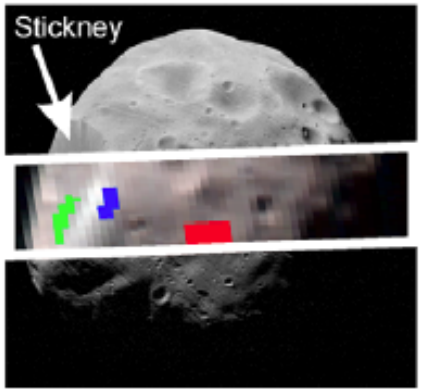
Thank you for your attention

Backup Slides

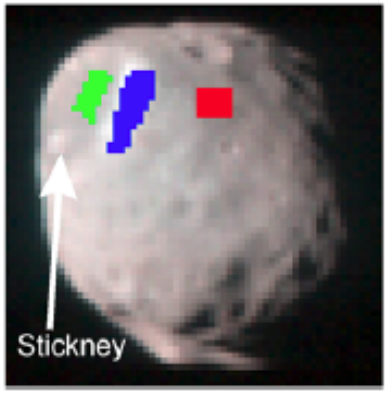
CRISM & OMEGA Phobos Observations







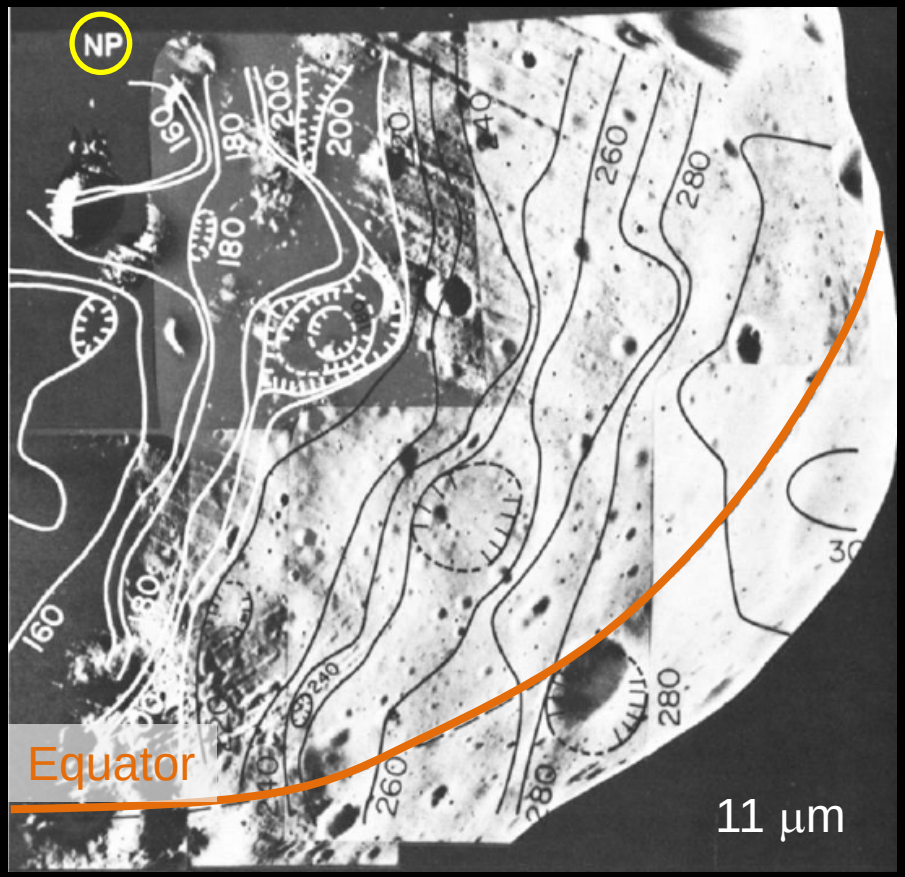
From Fraeman et al. 2012

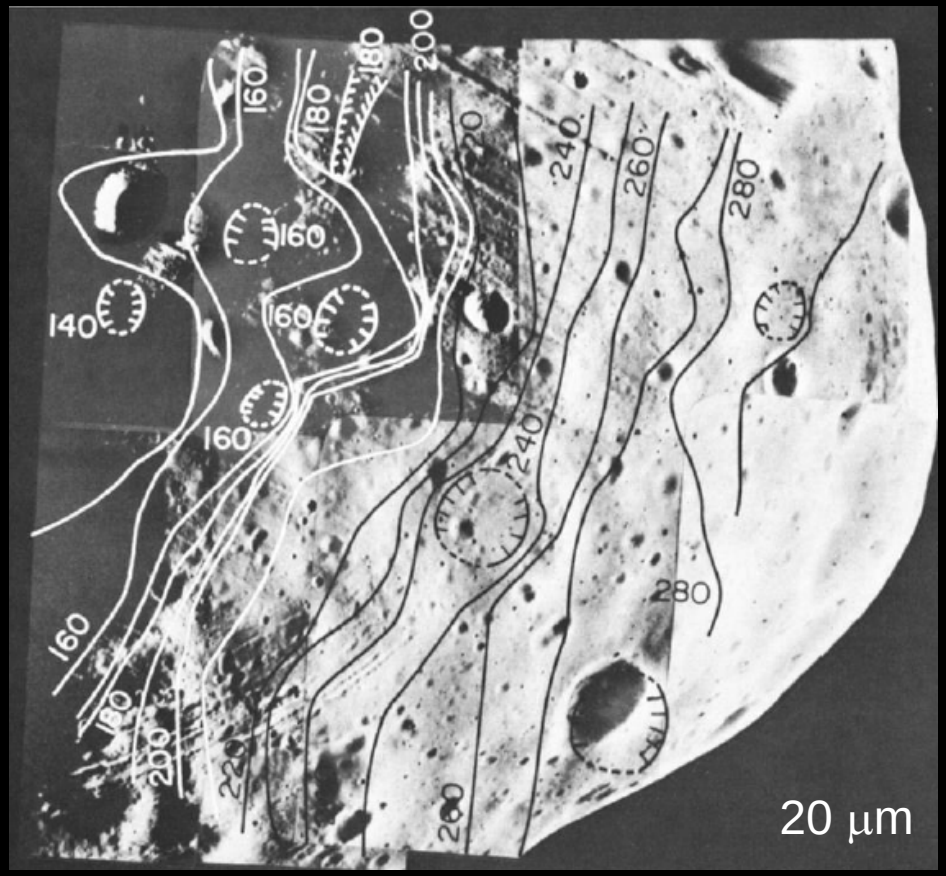


Thermal Emission Observations of Phobos

Mariner 9 InfRared Thermal Mapper (IRTM) had multiple Phobos observations used to create 11- and 20-μm thermal contour maps

minimum / maximum temperature 140 / 300 K

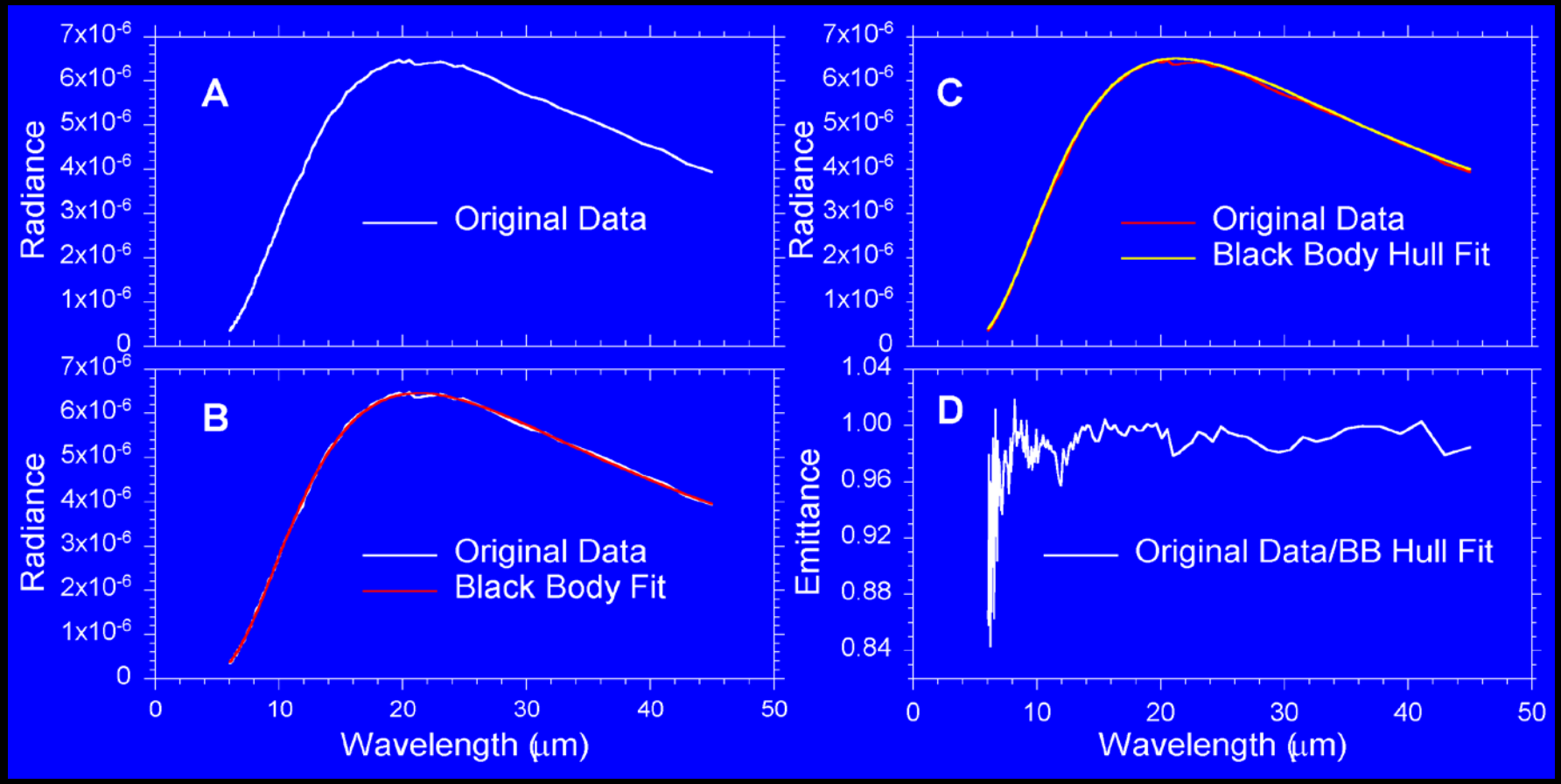




From Lunine et al. 1982

Emittance from Data

- A linear combination of 3 black bodies is used in a least squares fit (B)
- Using these results, an upper hull is fit to the radiance maxima (C)
- Emittance is produced by dividing the measured radiance by the hull (D)
- Same approach is used for PFS so derived temperatures can be compared



Emittance from Data

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TES-501	1.59916	17	194±15	139±20	102±25
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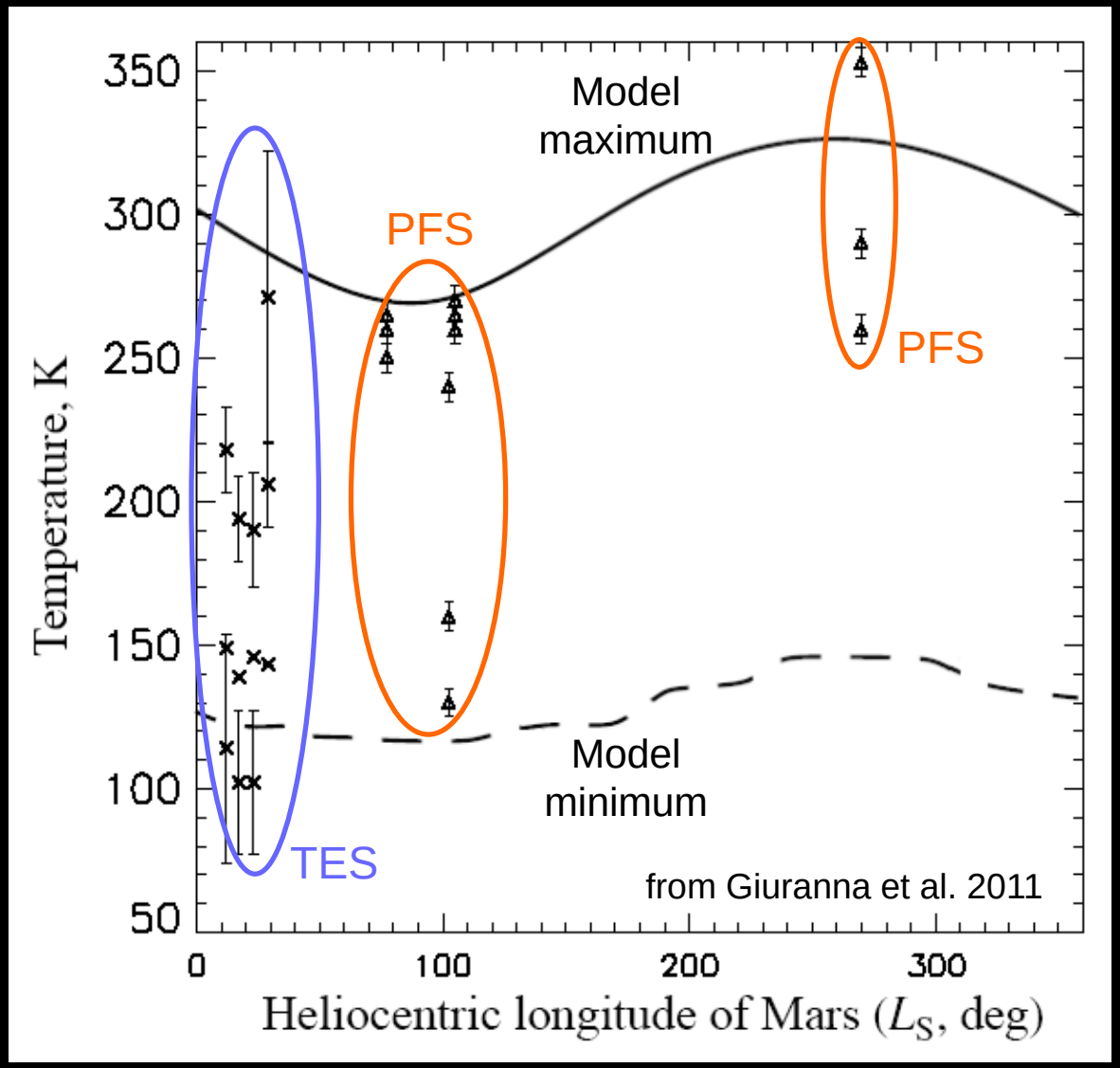
The maximum temperature of PFS-6906, 353±5 K, ≈1.39 AU, is consistent with Earth-based observations, ≈1.38-1.39 AU, yielding 320-340 K (Lynch et al. 2007)

Derived Versus Model Surface Temperatures



Kuzmin and Zabalueva (2003) used a numerical model of the thermal regime of Phobos' surface regolith layer to predict minimum and maximum surface temperatures (black lines) as a function of season.

TES (×) and PFS (▲) derived values are mostly within the predicted diurnal temperature ranges for Phobos surface.

The seasonal temperature variability predicted by the model is also reproduced by TES and PFS results.

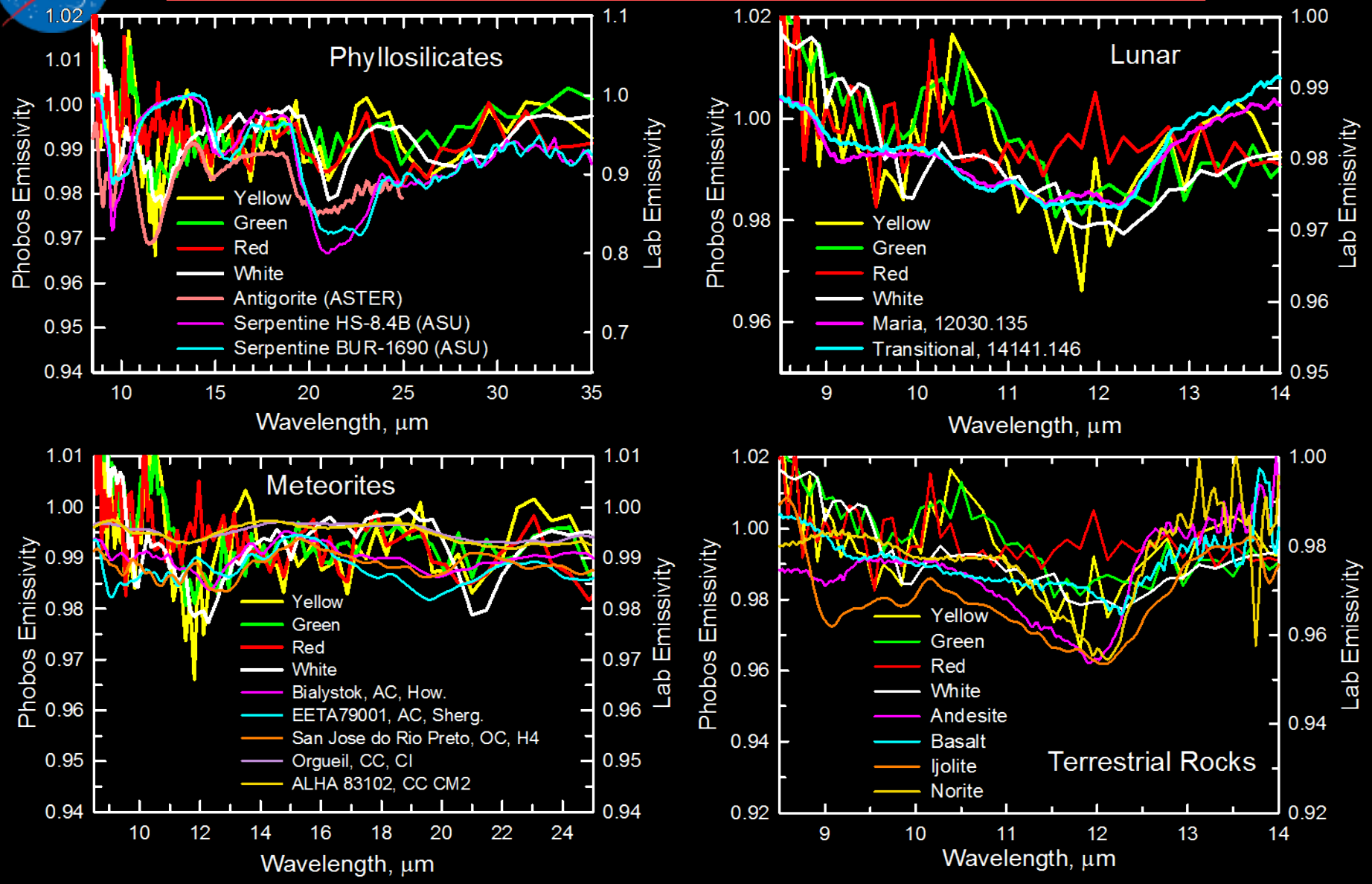
Thermal Emission Observations of Phobos

TES and PFS Phobos Observational Information

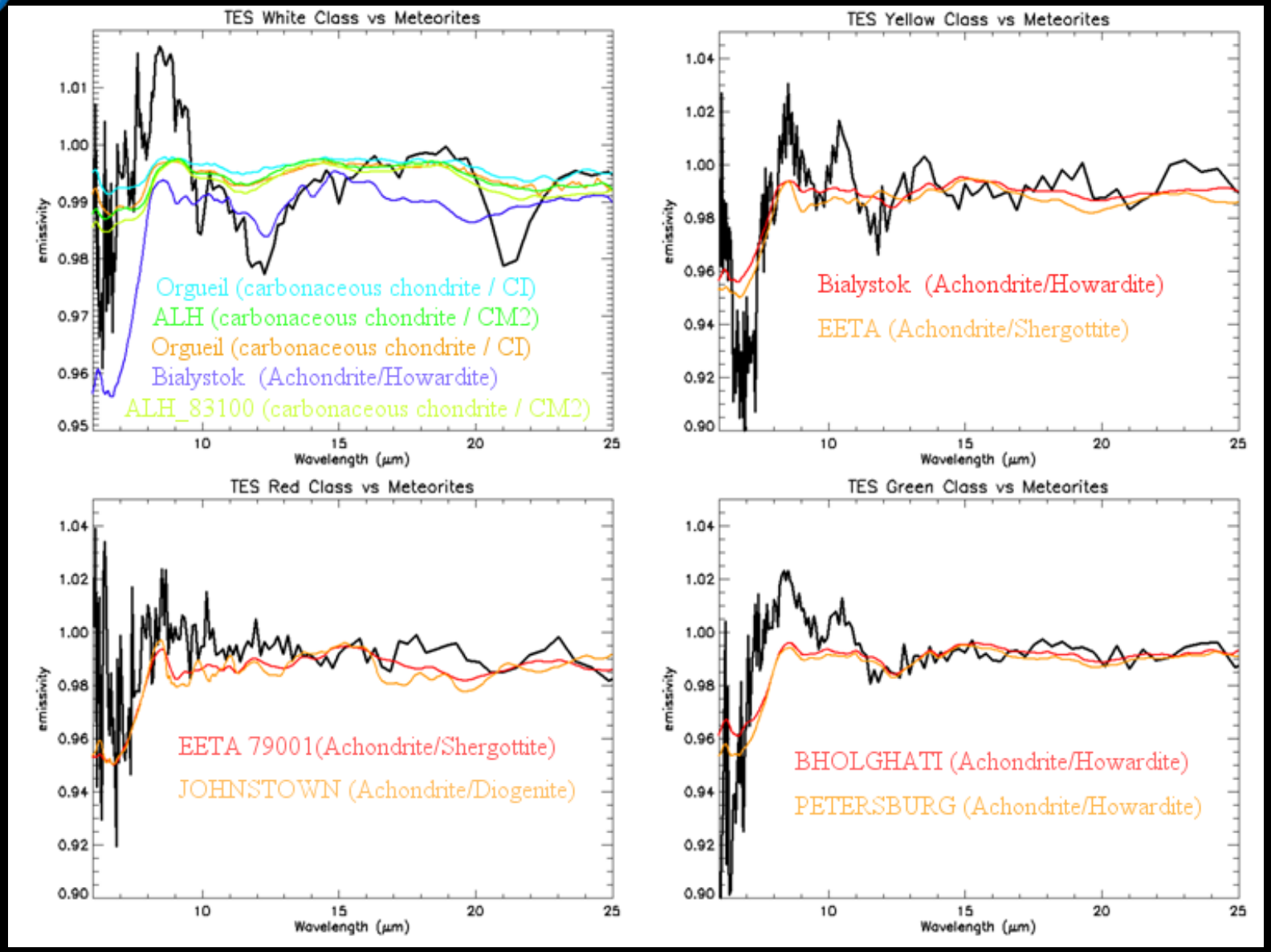
Inst-Orb #	SC-Phobos range,km	Solar dist., AU	Phase ang[a] (°)	km / pixel	# of Spect.	L_s[b] ,(°)	Avg. T1, K	Avg. T2, K	Avg. T3, K
TES-476	1437	1.58587	105–107	12	6	12	218±15	149±30	114±40
TES-501	1081	1.59916	110–113	9	9	17	194±15	139±20	102±25
TES-526	1152–1269	1.61140	93–149	10	106	23	190±20	146±27	102±25
TES-551	275–785	1.62260	51–131	2–7	149	29	271±51	206±44	143±51
PFS-756	155	1.66508	64	7.5	2	77.3	265±5	260±5	250±5
PFS-5851	97	1.64121	99	4.7	1	102.5	240±5	160±5	130±5
PFS-5870	354	1.6374	53	17	1	104.9	270±5	265±5	260±5
PFS-6906	530	1.38759	35	26	2	269.7	353±5	290±5	260±5

[a] Sun-Phobos-Spacecraft, [b] solar longitude

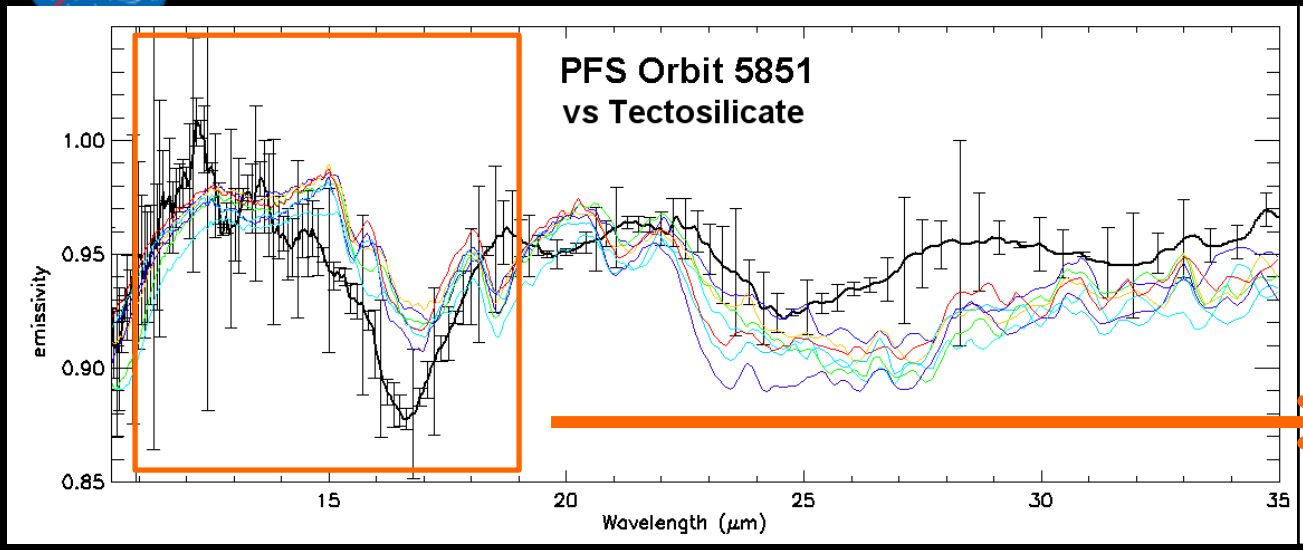
TES, Near Stickney Compared to Library Data

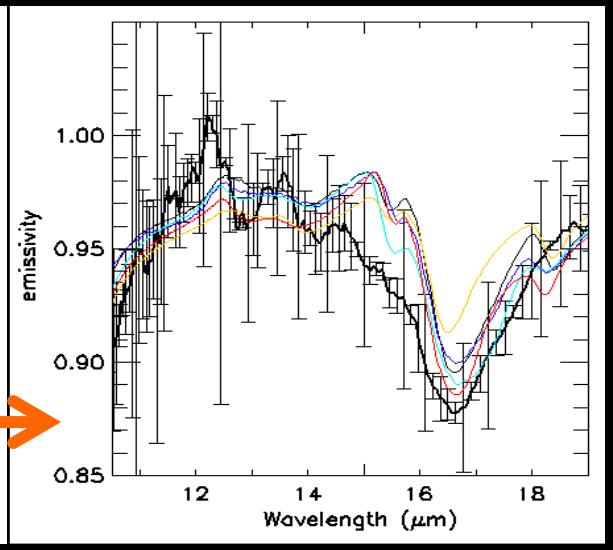


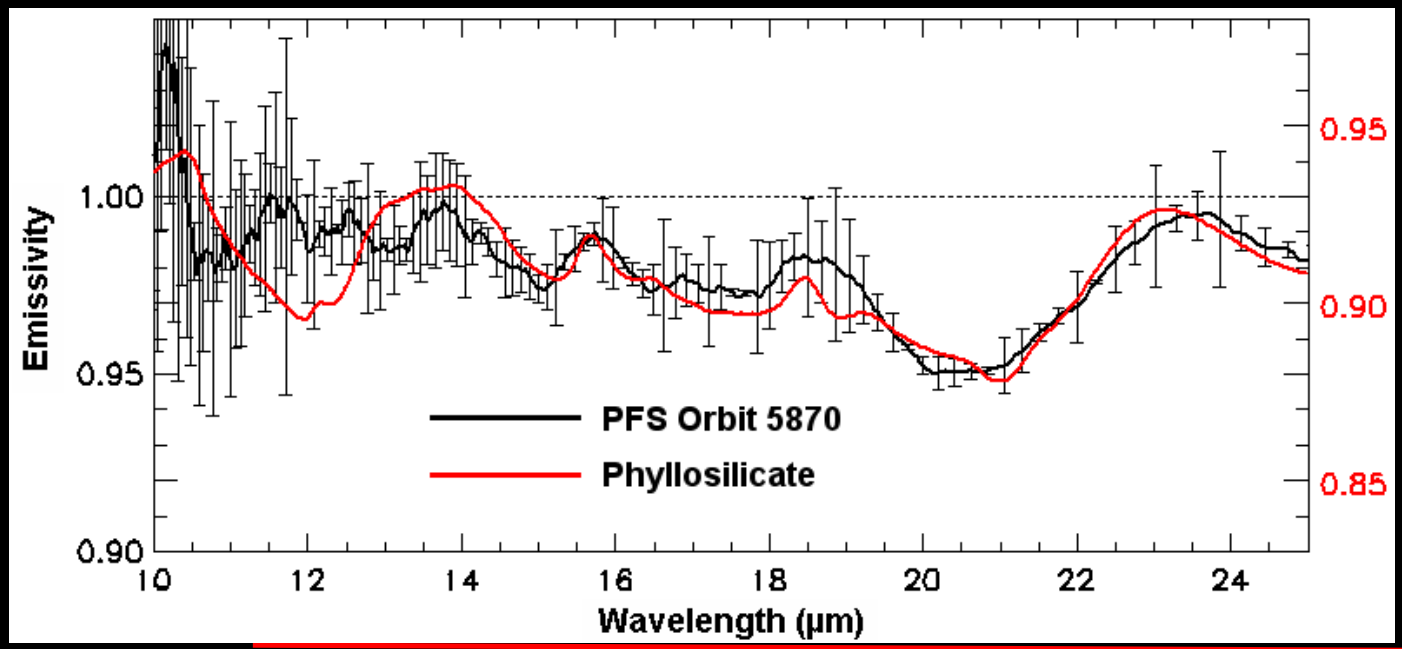
TES Compared to Meteorites



PFS Compared to Library Data







TES + PFS Phobos Compositions

	1	2	3	4	Summary
Phyllosilicates		Y	Y	Y	Y
Tectosilicates		Y	Y		Y
Meteorites	N?		N		N
Lunar, or basalt-like	Y	Y	Y?		Y
Carbonates		Y?		Y	Y
Ultramafic			Y	Y	Y

[1]Roush and Hogan 2000 [2]Roush and Hogan 2001
[3]Giuranna et al. 2011 [4]Glotch et al. 2014

VNIR-SWIR Phobos Compositions

	1	2	3	4	5	6	7	8	9	10	Summary
Phyllosilicates			?		N	?				Y	Y
Tectosilicates											
Meteorites	Y	Y	N				Y	Y	Y	Y	Y
Lunar, or basalt-like			Y	Y	?	Y?	N		Y	N	N?
Carbonates											
Ultramafic											

[1]Pang et al. 1978 and Pollack et al. 1978 [2]Murchie et al. 1991 [3]Murchie and Erard 1996 [4]Murchie et al. 1999 [5]Rivkin et al. 2002 [6]Gendrin et al. 2005 [7]Fraeman et al. 2012 [8]Pajola et al. 2012 [9]Pajola et al. 2013 [10]Fraeman et al. 2014