CO2 ice grain size retrievals from SPICAM IR/MEX spectra

Alexander Lomakin[1, 2], Anna Fedorova [1], Jodi Berdis[3], Oleg Korablev[1], Franck Montmessin[4]

(1) Institute of Space Research, Moscow, Russia; (2) Moscow Institute of Physics and Technology (State University), Dolgoprudniy, Russia; (3) Astronomy Department, New Mexico State University, New Mexico, USA; (4) CNRS LATMOS, Université Versailles St Quentin en Yvelines, Quartier des Garennes, 11 bd d'Alembert, 78280 Guyancourt, France (aleksander.lomakin96@gmail.com).

Introduction

Martian polar caps have huge impact on atmosphere of Mars, defining key processes in Martian atmosphere, such as water cycle and CO_2 cycle [1]. It is crucial to know micro and macro parameters of ices on both polar caps in order to fully understand processes in Martian atmosphere and have some insights to history of Mars. There are huge number of papers [2-6] describing retrievals of number of ice microparameters such as grain size, dust wt%, water wt% and layer thickness from IR observations of Martian polar caps, since CO_2 and water ice have easily distinguishable features in this spectral diapason. All of them used mapping spectrometers like OMEGA or CRISM with good spatial resolution and good spectral diapason, but poor spectral resolution.

We use SPICAM-IR: IR spectrometer with spectral diapason from 1 to 1.7 µm and has resolving power of ~2000 [7]. This instrument can clearly resolve all sharp spectral features of CO_2 ice in its diapason on surface of Mars. SPICAM-IR performed continuous observations of Mars for 8 Martian Years, and now it is the only IR instrument on the orbit of Mars performing observation of polar caps.

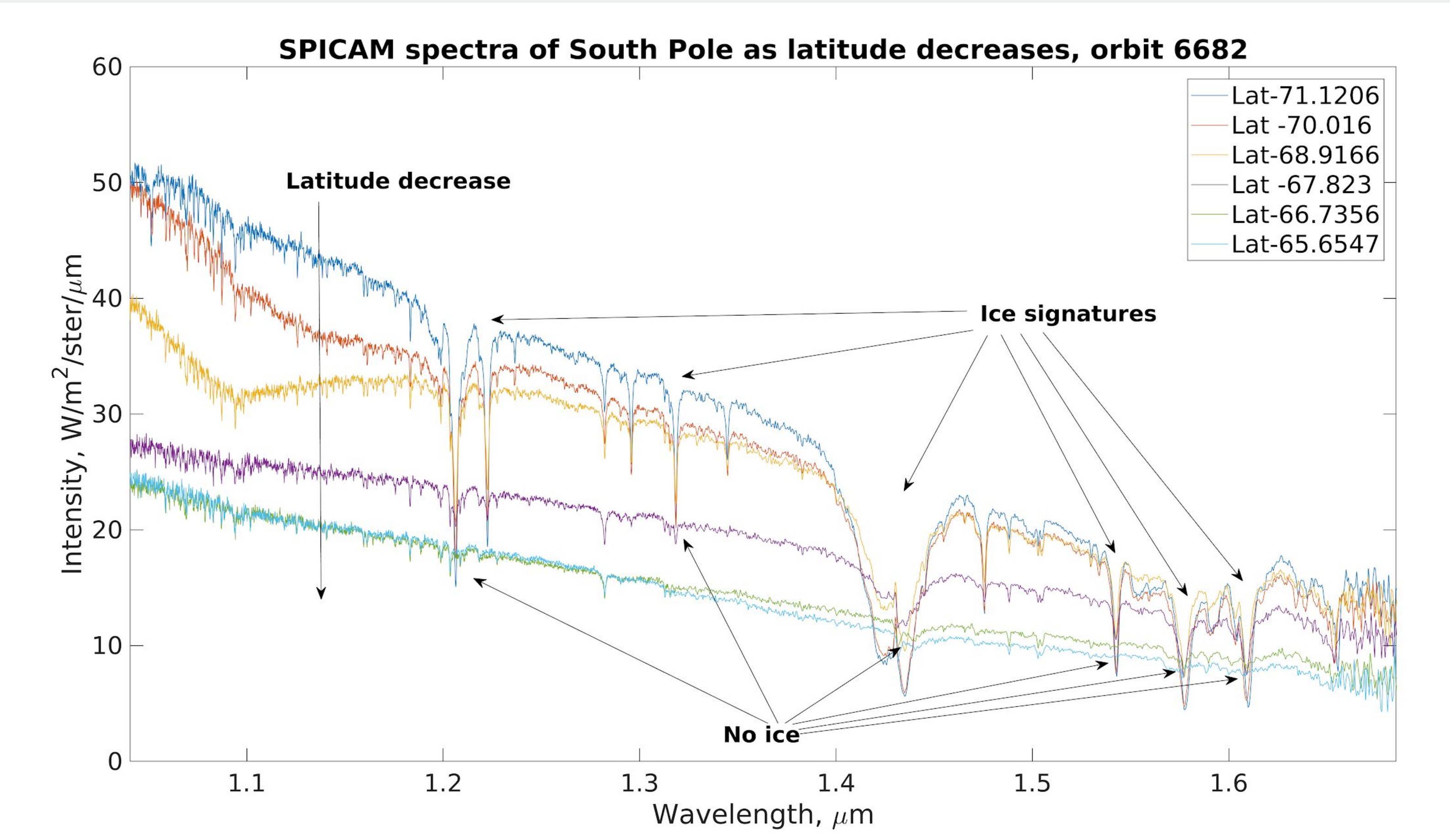

Figure 1. Example raw SPICAM-IR spectra over the south pole of Mars.

Obtaining reflectance

Atmospheric correction

In order to obtain a reflectance spectrum, we need to correct our data for atmospheric absorption and divide it by solar radiance as shown on figure 2. We use CAVIAR solar spectrum, HITRAN 2016 [8] and MCD 5.3 [9] for automatic correction of gaseous CO_2 and water vapour absorption in Martian atmosphere. We also correct minor wavelength shift in data.

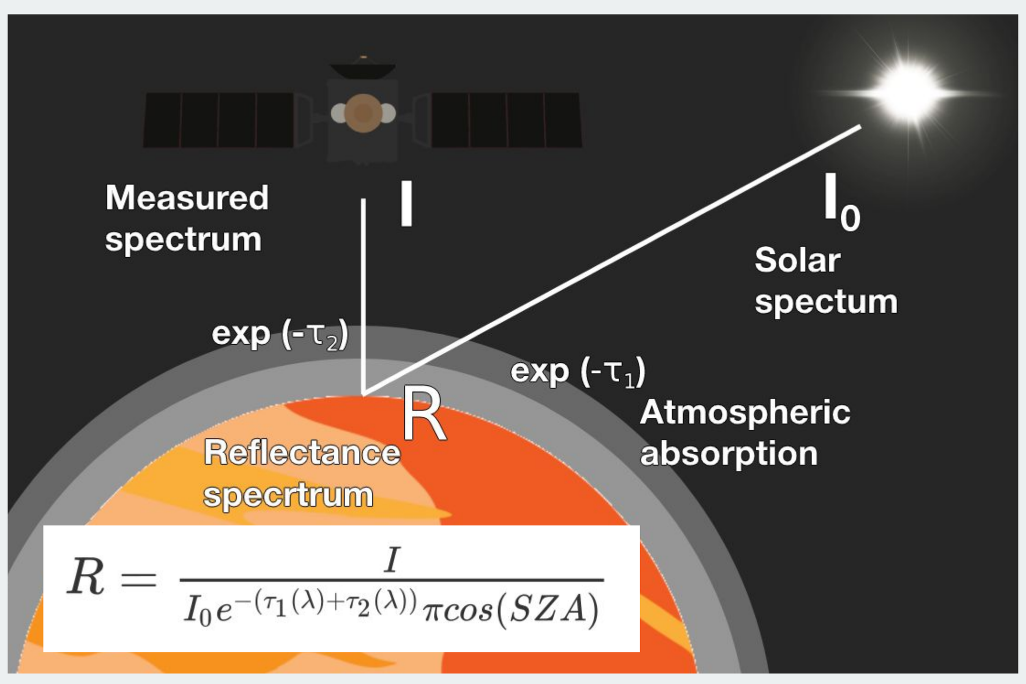

Figure 2. Scheme of SPICAM observations from orbit of Mars.

Since CO_2 ice has sharp feature on 1.4 µm width of which is connected to grain size and abundance of ice on surface, we can make a qualitative measure of grain size on surface using equivalent width of this band:

$$W_\lambda = \int (1 - F_\lambda/F_0) d\lambda$$

F_λ - intensity of absorption line
F_0 - intensity of continuum

Seasonal map of equivalent width is shown on Figure 4.

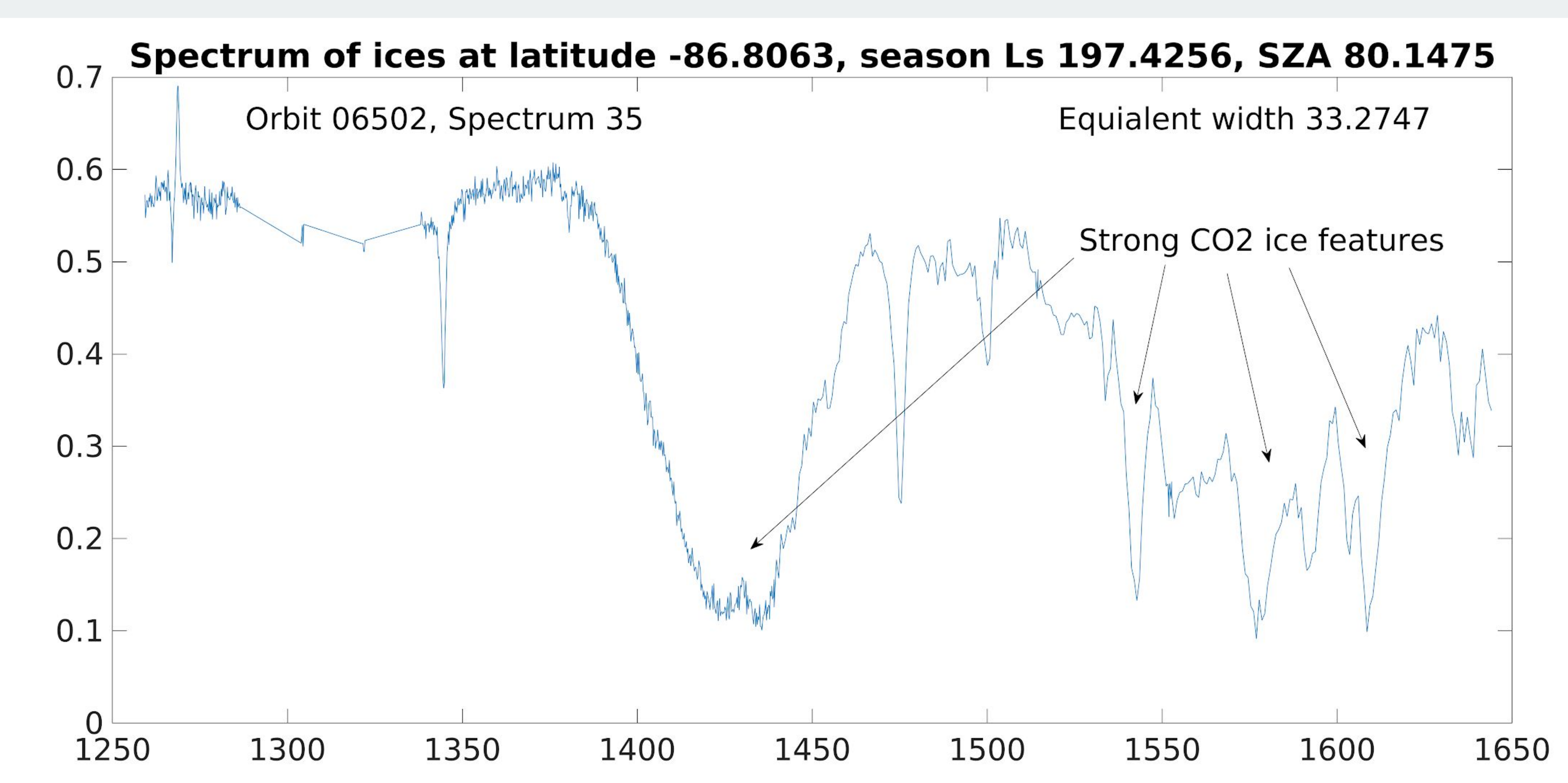

Figure 3. Example of spectrum with big grain size at south pole of Mars.

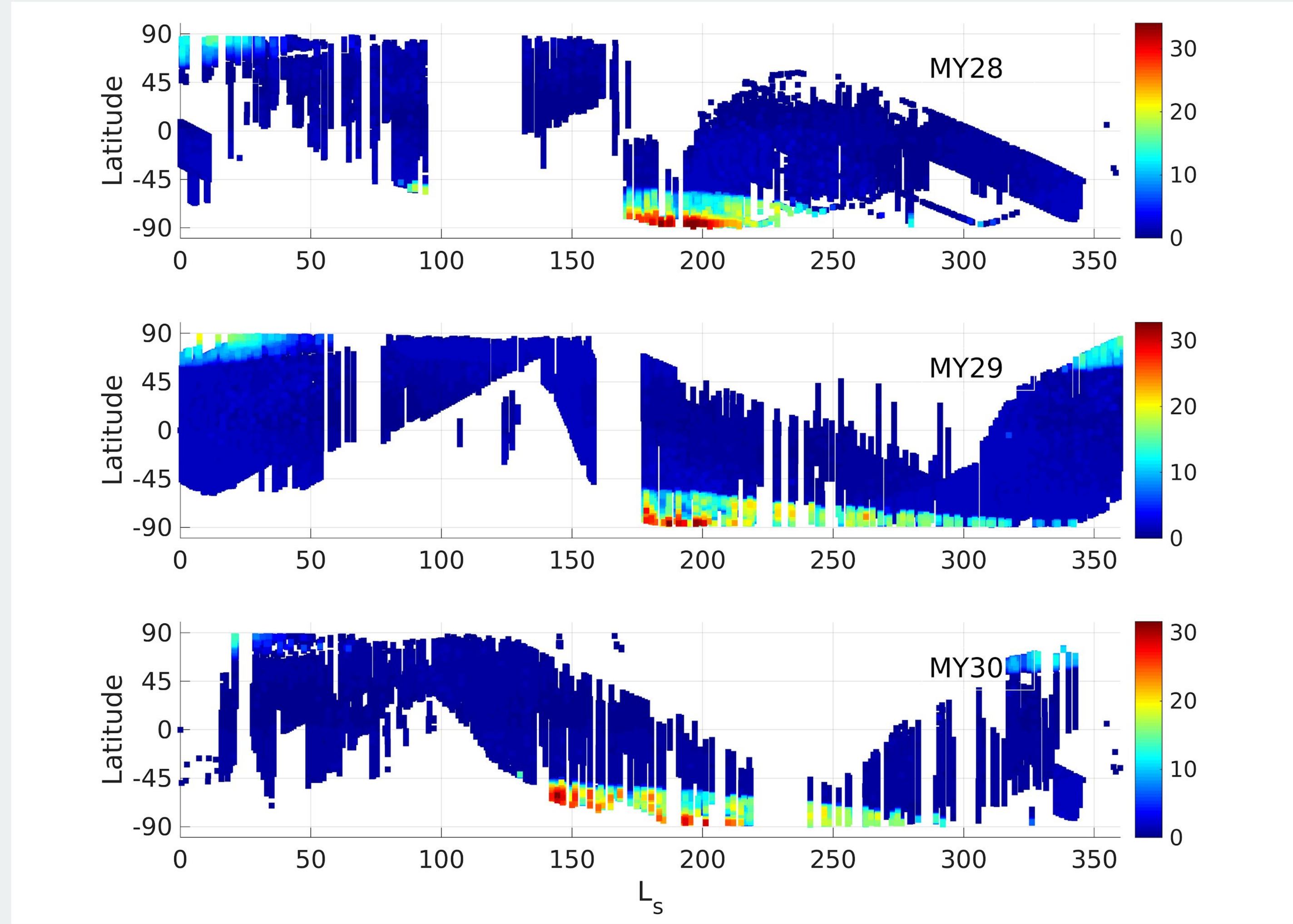

Figure 4. Seasonal map showing distribution of equivalent width of CO_2 ice band over three Martian years.

Chosing model for retrieval

There are only two models with code that is more or less publicly available: Hapke model [9,10,11], which is known for its simplicity and speed, and SNICAR [12], which was for a long time successfully applied for Earth snow studies.

Hapke model was used for years in planetary science for modeling different surfaces. It uses simple semiempirical approach to radiative transfer, which is the cause of some controversies [13] over the model results. Nevertheless, we applied Hapke model to retrieve grain size from SPICAM observations, there is an examples of retrieval:

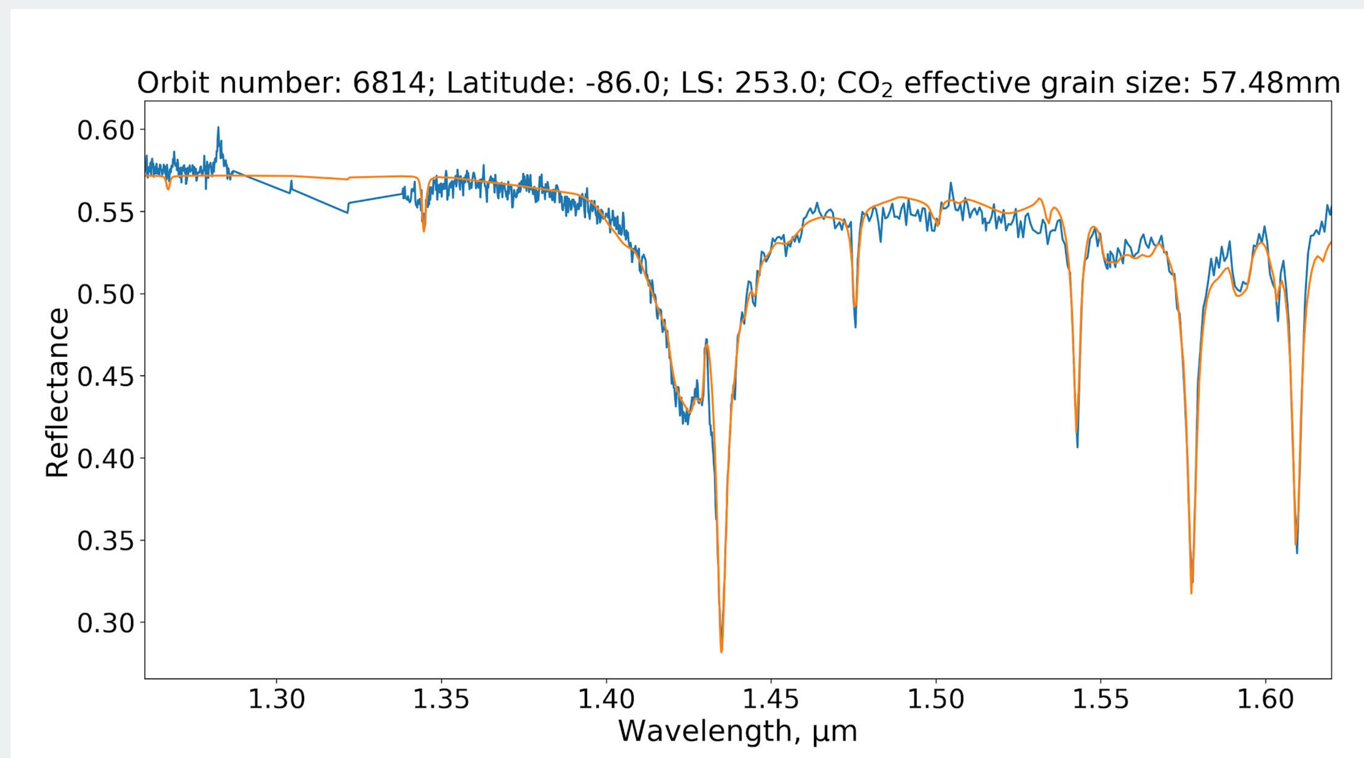

Figure 5. Sample retrieval of CO_2 grain size using linear unmixing with endmembers modeled with Hapke model.

SNICAR is model of snow surfaces, applied on Earth for a long time. It was recently applied to Martian conditions [6] and showed interesting results. Before using SNICAR model, we wanted to compare both model on laboratory spectrum to test both models and to see how good they are. With help of SSHADE database we found few open water ice laboratory experiments, best was Poch et al.[14]. The description of the experiment provided us with grain size distribution of material, layer thickness, observation geometry and temperature of ice. We did set all of this parameters with SNICAR; it is not possible to set layer thickness and grain size distribution, only the mean grain size with our implementation of Hapke model. We did compare the retrievals from two models: effective grains size of sample was 87µm, unmixing using Hapke model resultes 251.9µm, SNICAR - 35.67µm.

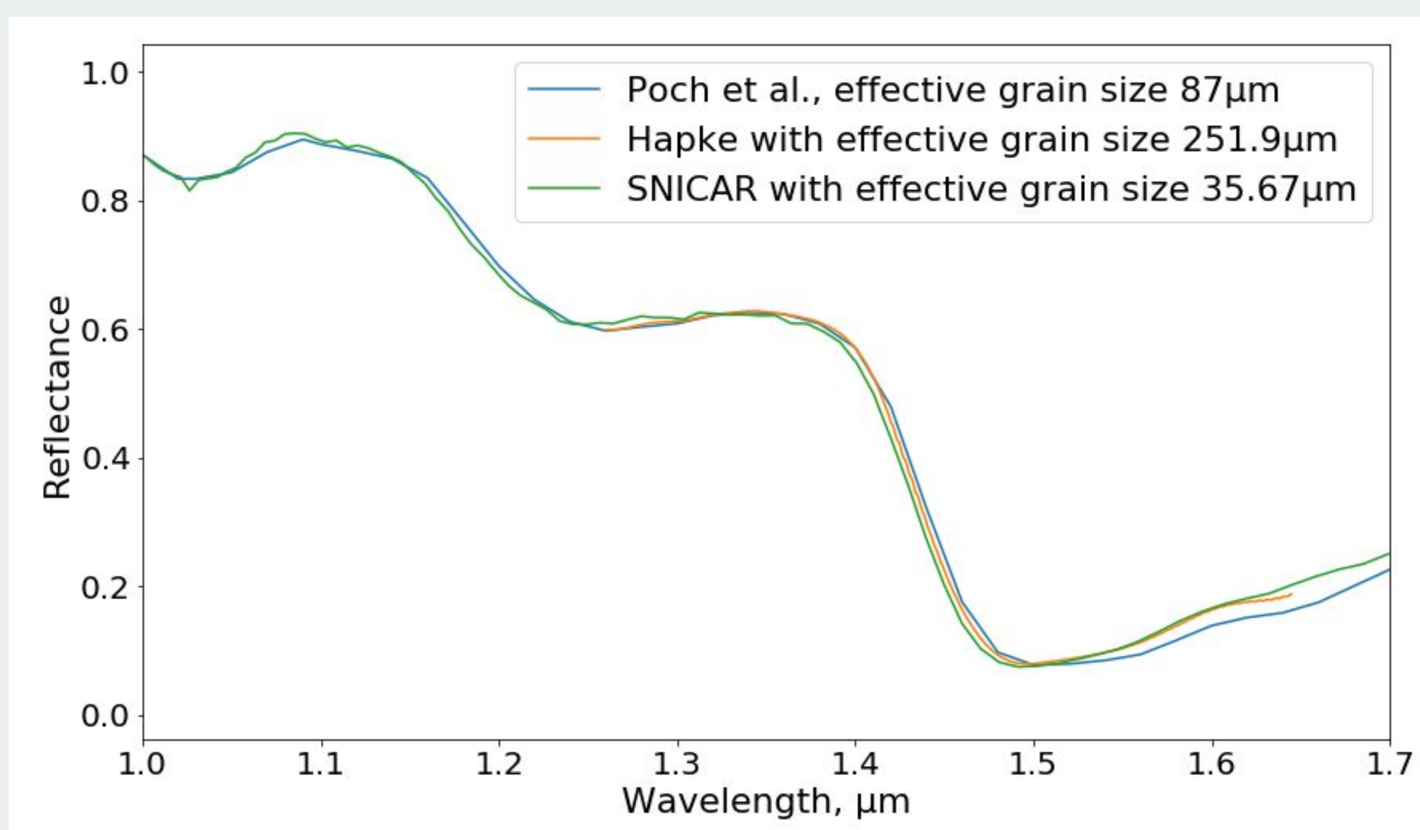

Figure 6. Retrieval of water ice grain sizes using linear unmixing.

Conclusions

We retrieved reflectance from SPICAM nadir measurements and successfully retrieved grain sizes of CO_2 ice from few spectra using Hapke model. Though, there are some controversies around Hapke model, and we tried to retrieve grain sizes from laboratory experiments using also SNICAR model. Retrieval has produced controversial results with Hapke model overestimating grain size and SNICAR underestimating grain size of water ice. Though, it is clearly possible to retrieve a lot of information can be retrieved and mapped properly using one of these models.

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References: [1] Hourdin et al., Workshop on Atmospheric Transport on Mars p 16-17; [2] Langevin, Y., et al. (2006), Nature 442(7104): 790-792; [3] Bernard-Michel, Caroline, et al. "Retrieval of Mars surface physical properties from OMEGA hyperspectral images using Regularized Sliced Inverse Regression." Journal of Geophysical Research: Planets 114.E6 (2009).; [4] Andrieu, François, et al. "Ice state evolution during spring in Richardson crater, Mars." Icarus 315 (2018): 158-173.; [5] Cull, Selby, et al. "Seasonal H2O and CO2 ice cycles at the Mars Phoenix landing site: 1. Prelanding CRISM and HiRISE observations." Journal of Geophysical Research: Planets 115.E4 (2010); [6] Singh, D., and M. G. Flanner. "An improved carbon dioxide snow spectral albedo model: Application to Martian conditions." Journal of Geophysical Research: Planets 121.10 (2016): 2037-2054; [7] Korablev, O., et al. (2006), SPICAM IR acousto-optic spectrometer experiment on Mars Express, J. Geophys. Res., 111, E09S03, doi:10.1029/2006JE002696.; [8] Gordon et al., J Quant Spectrosc Radiat Transfer, Volume 203, December 2017, Pages 3-69, doi.org/10.1016/j.jqsrt.2017.06.038; Millour et al., "The Mars Climate Database (MCD version 5.2)", European Planetary Science Congress 2015; [9] Hapke, Bruce. "Bidirectional reflectance spectroscopy: 1. Theory." Journal of Geophysical Research: Solid Earth 86.B4 (1981): 3039-3054.; [10] Grundy, William MacIntyre. "Methane and nitrogen ices on Pluto and Triton: A combined laboratory and telescope investigation." (1995).; [11] Berdis, Jodi R., et al. "Europa's surface water ice crystallinity: Discrepancy between observations and thermophysical and particle flux modeling." Icarus 341 (2020): 113660.; [12] Flanner, M. G., C. S. Zender, J. T. Randerson, and P. J. Rasch (2007), Present day climate forcing and response from black carbon in snow, J. Geophys. Res., 112, D11202, doi:10.1029/2006JD008003; [13] Tishkovets, Victor P., and Michael I. Mishchenko. "Coherent backscattering: Conceptions and misconceptions (reply to comments by Bruce W. Hapke and Robert M. Nelson)." Journal of Quantitative Spectroscopy and Radiative Transfer 111.4 (2010): 645-649.; [14] Poch, Olivier; Yoldi, Zuriñe; Jost, Bernhard (2016): Vis-NIR bidirectional reflection spectra of spherical water ice particles for different sizes (2 to 100 µm), temperatures (173 and 223 K) and temporal evolutions. SSHADE/BYPASS+CSS (OSUG Data Center). Dataset/Spectral Data. doi.org/10.26302/SSHADE/EXPERIMENT_OP_20171130_001;