# FIRST CROSS EMM/EXI AND TGO/ACS-MIR OBSERVATIONS OF MARTIAN WATER ICE CLOUDS.

**A. Stcherbinine,** *Dept. of Astronomy and Planetary Science, Northern Arizona University, Flagstaff, AZ, USA (aurelien.stcherbinine@nau.edu)*, **M. J. Wolff,** *Space Science Institute, Boulder, CO, USA*, **C. S. Edwards,** *Dept. of Astronomy and Planetary Science, Northern Arizona University, Flagstaff, AZ, USA*, **F. Montmessin,** *LATMOS/IPSL, UVSQ, Université Paris-Saclay, Sorbonne Université, CNRS, Guyancourt, France*, **M. Vincendon,** *Institut d'Astrophysique Spatiale, Université Paris-Saclay, CNRS, Orsay, France*, **O. Korablev, A. Fedorova, A. Trokhimovskiy,** *Space Research Institute (IKI), Moscow, Russia*, **M. Osterloo, R. Shuping,** *Space Science Institute, Boulder, CO, USA*.

## Introduction

Water ice clouds play an important role in the Martian water cycle and climate. They are a major actor in the inter-hemispheric water exchange and affect the radiative structure of the atmosphere, as their crystals absorb and scatter the incoming Solar radiation [2, 6, and references contained within]. Thus, monitoring the spatial and temporal evolution of the Martian water ice clouds, along with their physical properties (crystals size, opacity) is of importance to improve our understanding and modeling of the current Martian climate.

The Emirates Exploration Images (EXI) instrument onboard Emirates Mars Mission (EMM) "Hope" probe is a UV-Visible framing camera that is imaging the Mars full disk using 6 bandpasses since the beginning of its science phase in May 2021 [4]. With the nadir full-disk observations with limited bandpasses of EXI, we will be able to derive the optical depth of the Martian clouds and observe their global diurnal distribution. Plus, thanks to the Hope orbit, EXI will be able to provide a global view of most of the surface of the planet at all local times in about 10 days [1, 4].

The Atmospheric Chemistry Suite (ACS) MIR channel onboard the ESA-Roscosmos Trace Gas Orbiter (TGO) [5] probes the Martian atmosphere in the 2.3–4.2 μm spectral range using the Solar Occultation (SO) technique since April 2018. This observing geometry provided detailed vertical profiles of the atmospheric transmission, which allows us to detect and derive the physical properties of the Martian water ice clouds as a function of the altitude for more than one full Martian Year (MY) up to now [9].

## Methods

The ACS-MIR water ice clouds profiles are derived from the position 12 observations (i.e., measurements in the 3.1–3.4 μm spectral range) using the method presented in [10]. For each observed altitude, the measured transmission is converted into extinction coefficient ($k_{\mathrm{ext}}$) through a vertical inversion algorithm. Then, these extinction spectra are compared with models for dust and spherical water ice particles in order to constrain the presence and the size of water ice crystals in the atmosphere.

We also use the DISORT radiative transfer code [7, 8] through the *pyRT_DISORT* Python module [3] to retrieve the optical depth of the water ice clouds from the I/F reflectance at $\lambda = 320$ nm measured by EXI. Due to the SO observing geometry of ACS-MIR, the water ice clouds profiles are acquired close to the planet terminator, so these locations are associated with high incidence (and possibly emergence) angles (typically about 70°–80°). Thus, we will use the pseudo-spherical correction for curved atmosphere that has been implemented in version 4 of the DISORT code [7]. And in order to strengthen the retrieval of the optical depth for high incidence angles as it remains a tricky problem, we will also compare the values returned by the DISORT code with the results of a Monte Carlo radiative transfer code.

## Preliminary results

Up to August 2021, we have identified two couples of EXI/ACS-MIR observations for which the location of the ACS-MIR profile is visible on the EXI image, with less than 2 hours of difference between the observations. Figure 1 presents for these two observations the I/F reflectance at $\lambda = 320$ nm measured by EXI (panels a & b) along with the $r_{\mathrm{eff}}$ & $k_{\mathrm{ext}}$ vertical profiles derived from the ACS-MIR observations (panels c & d).

We observe that clouds are present in both cases, and well detected by the two instruments. The altitude and particle size of the water ice clouds detected in the ACS-MIR profiles are typical of the observed season and latitude regarding the global ACS-MIR dataset [9]. Regarding the EXI optical depth, it is $\sim 0.03$ for the first observation ($L_s = 43°$, lat = 43°S, cloud at 30–40 km) and $\sim 0.2$ for the second one ($L_s = 76°$, lat = 61°S, cloud at 10–15 km). Thus, the optical depth of the lower polar cloud is larger by one order of magnitude than the tropical one, while its extinction at 3.2 μm and the average size of its crystals is larger too. We also observe a difference of about one order of magnitude between the $k_{\mathrm{ext}}$ values of both clouds, as it remains lower than

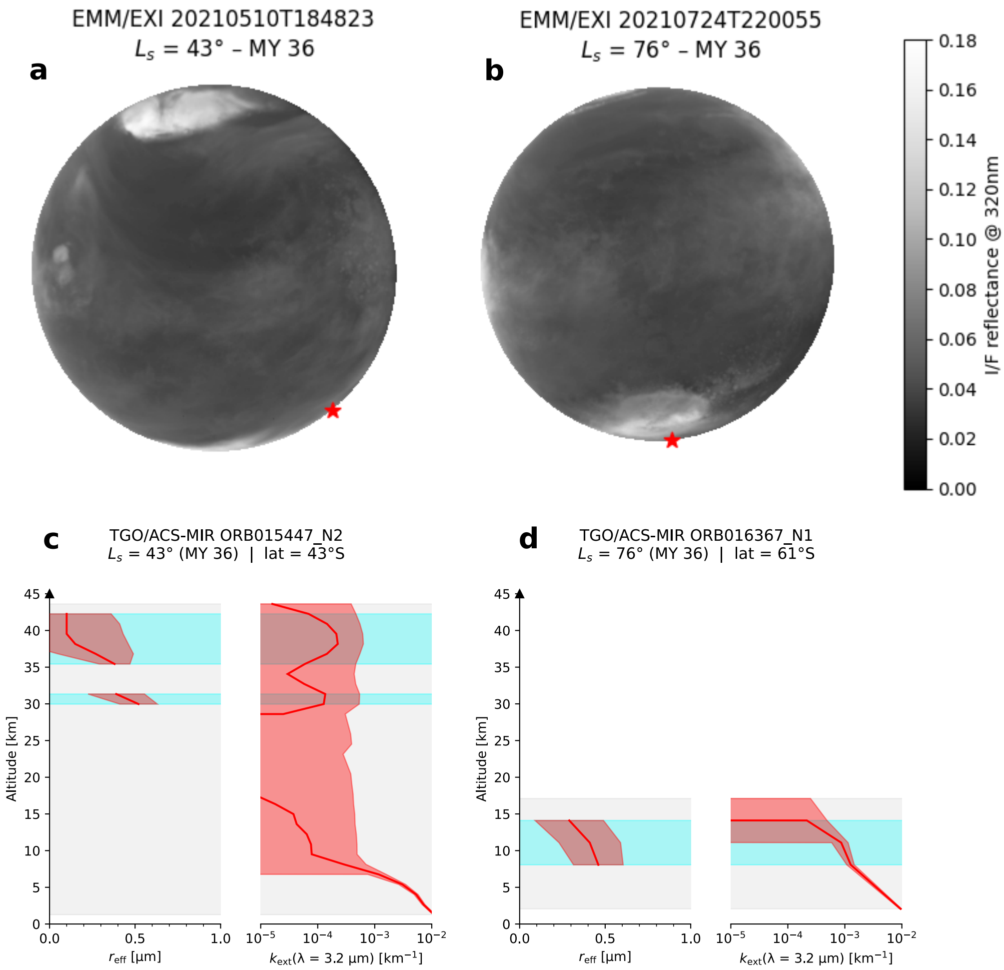


**Figure 1** – Co-observation of Martian water ice clouds by the EXI and ACS instruments.
**a. & b.** EXI reflectance at 320 nm, the red stars indicate the position of the ACS-MIR profiles.
**c. & d.** Corresponding ACS-MIR vertical profiles of the retrieved water ice crystal sizes (left) and the atmospheric extinction at 3.2 µm (right). The light blue areas represent the altitudes where water ice clouds have been identified.

$\sim 2 \cdot 10^{-4}$ km$^{-1}$ for the first profile at $\sim 40$ km while the extinction rises to $\sim 1 \cdot 10^{-3}$ km$^{-1}$ for the second profile at $\sim$ 10 km. If we integrated vertically the $k_{\text{ext}}$ values over the altitudes where the clouds have been detected, we obtain an infrared cloud optical depth of $\sim 1.5 \cdot 10^{-3}$ for the first profile and $\sim 5 \cdot 10^{-3}$ for the second one.

## Conclusion & Perspectives

We present here the preliminary results of the first simultaneous observations of Martian water ice clouds with the EXI and ACS-MIR instruments. With its full-disk observations, EXI will allow us to monitor the Martian water ice clouds at a global scale through their integrated optical depth, while ACS-MIR provides locally the vertical structure of the cloud's physical properties within the atmosphere. Thus, the comparison with ACS-MIR profiles will provide additional insight for the study of water ice clouds with EXI. Indeed, these coupled observations may provide reference points to link the EXI optical depth with the properties of the Martian water ice clouds.

We have only identified 2 sets of cross observations between EXI and ACS-MIR over the first 3 months of EXI operations, but as both instruments will continue to operate over the upcoming months and years, we hope to increase this dataset with future operations.

**Acknowledgments**

ExoMars is a space mission of ESA and Roscosmos. The ACS experiment is led by IKI Space Research Institute in Moscow. The project acknowledges funding by Roscosmos and CNES. Science operations of ACS are funded by Roscosmos and ESA. Science support in IKI is funded by Federal agency of science organization (FANO). Raw ACS data are available on the ESA PSA at `https://archives.esac.esa.int/psa/#!Table%20View/ACS=instrument`.

**References**

[1] Amiri, H. E. S., Brain, D., Sharaf, O., et al. 2022. The Emirates Mars Mission, *Space Science Reviews*, 218, 4. doi:10.1007/s11214-021-00868-x

[2] Clancy, R. T., Montmessin, F., Benson, J., et al. 2017, in The Atmosphere and Climate of Mars, ed. F. Forget, M. D. Smith, R. T. Clancy, R. W. Zurek, & R. M. Haberle, Cambridge Planetary Science, Cambridge: Cambridge University Press, 76–105. doi:10.1017/9781139060172.005

[3] Connour, K. & Wolff, M. 2022, pyRT_DISORT: A pre-processing front-end to help make DISORT simulations easier in Python. v 0.0.4. https://github.com/kconnour/pyRT_DISORT

[4] Jones, A. R., Wolff, M., Alshamsi, M., et al. 2021. The Emirates Exploration Imager (EXI) Instrument on the Emirates Mars Mission (EMM) Hope Mission, *Space Science Reviews*, 217, 81. doi:10.1007/s11214-021-00852-5

[5] Korablev, O., Montmessin, F., Trokhimovskiy, A., et al. 2018. The Atmospheric Chemistry Suite (ACS) of Three Spectrometers for the ExoMars 2016 Trace Gas Orbiter, *Space Science Reviews*, 214, 7. doi:10.1007/s11214-017-0437-6

[6] Montmessin, F., Smith, M. D., Langevin, Y., Mellon, M. T., & Fedorova, A. 2017, in The Atmosphere and Climate of Mars, ed. F. Forget, M. D. Smith, R. T. Clancy, R. W. Zurek, & R. M. Haberle, Cambridge Planetary Science, Cambridge: Cambridge University Press, 338–373. doi:10.1017/9781139060172.011

[7] Stamnes, K., Tsay, S. C., Jayaweera, K., et al. 2017. DISORT: DIScrete Ordinate Radiative Transfer, *Astrophysics Source Code Library*, ascl:1708.006

[8] Stamnes, K., Tsay, S.-C., Wiscombe, W., & Jayaweera, K. 1988. Numerically Stable Algorithm for Discrete-Ordinate-Method Radiative Transfer in Multiple Scattering and Emitting Layered Media, *Applied Optics*, 27, 2502. doi:10.1364/AO.27.002502

[9] Stcherbinine, A., Montmessin, F., Vincendon, M., et al. 2022. Monitoring of Martian Water Ice Clouds over One Martian Year with TGO/ACS-MIR, in EGU General Assembly 2022, EGU22–1114. doi:10.5194/egusphere-egu22-1114

[10] Stcherbinine, A., Vincendon, M., Montmessin, F., et al. 2020. Martian Water Ice Clouds During the 2018 Global Dust Storm as Observed by the ACS-MIR Channel Onboard the Trace Gas Orbiter, *Journal of Geophysical Research: Planets*, 125, e2019JE006300. doi:10.1029/2019JE006300