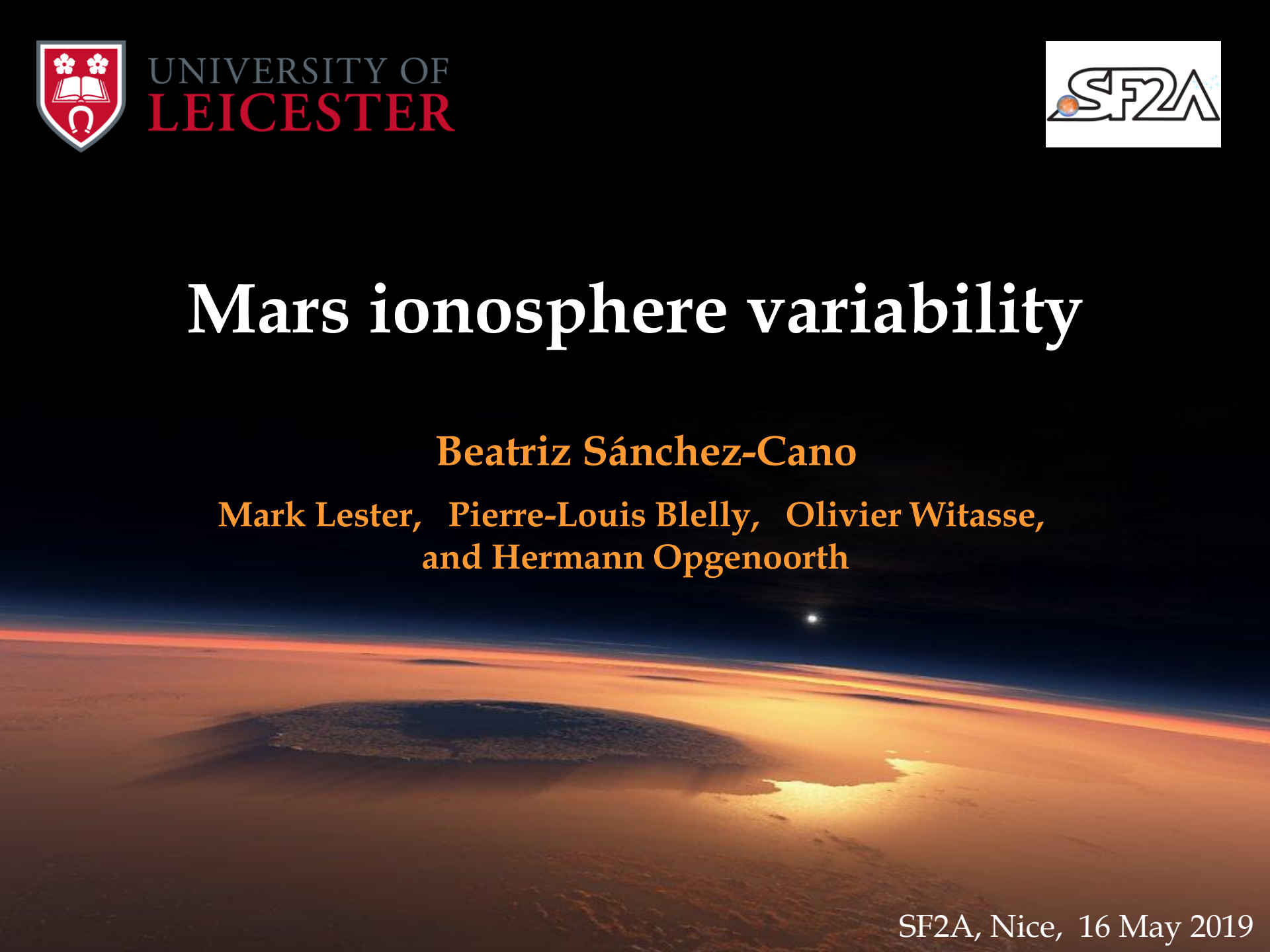

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Mars ionosphere variability

Beatriz Sánchez-Cano

Mark Lester, Pierre-Louis Blelly, Olivier Witasse, and Hermann Opgenoorth

SF2A, Nice, 16 May 2019

Scheme

Mars' ionosphere

Internal sources of variability

External sources of variability

Conclusions

Credits: MEX VMC image

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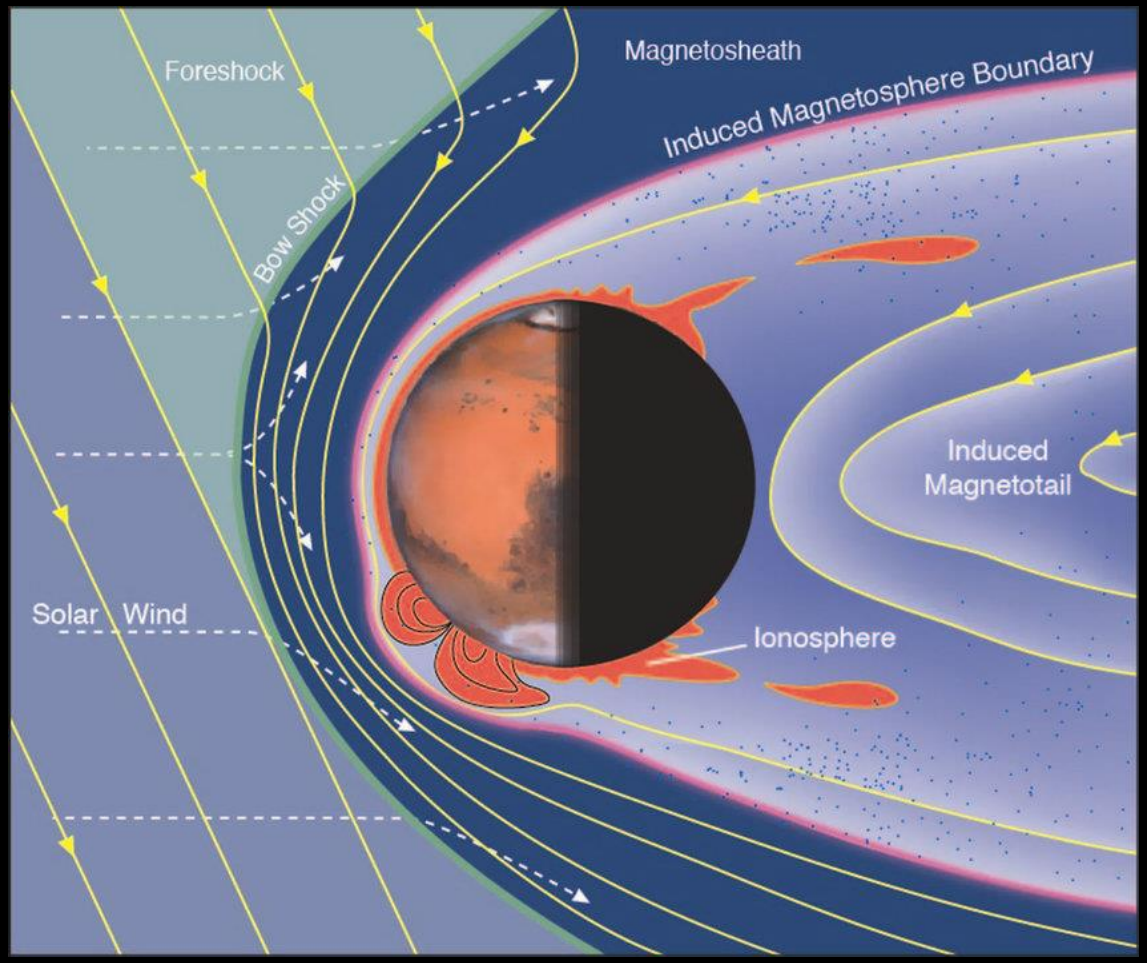
The Mars' plasma environment

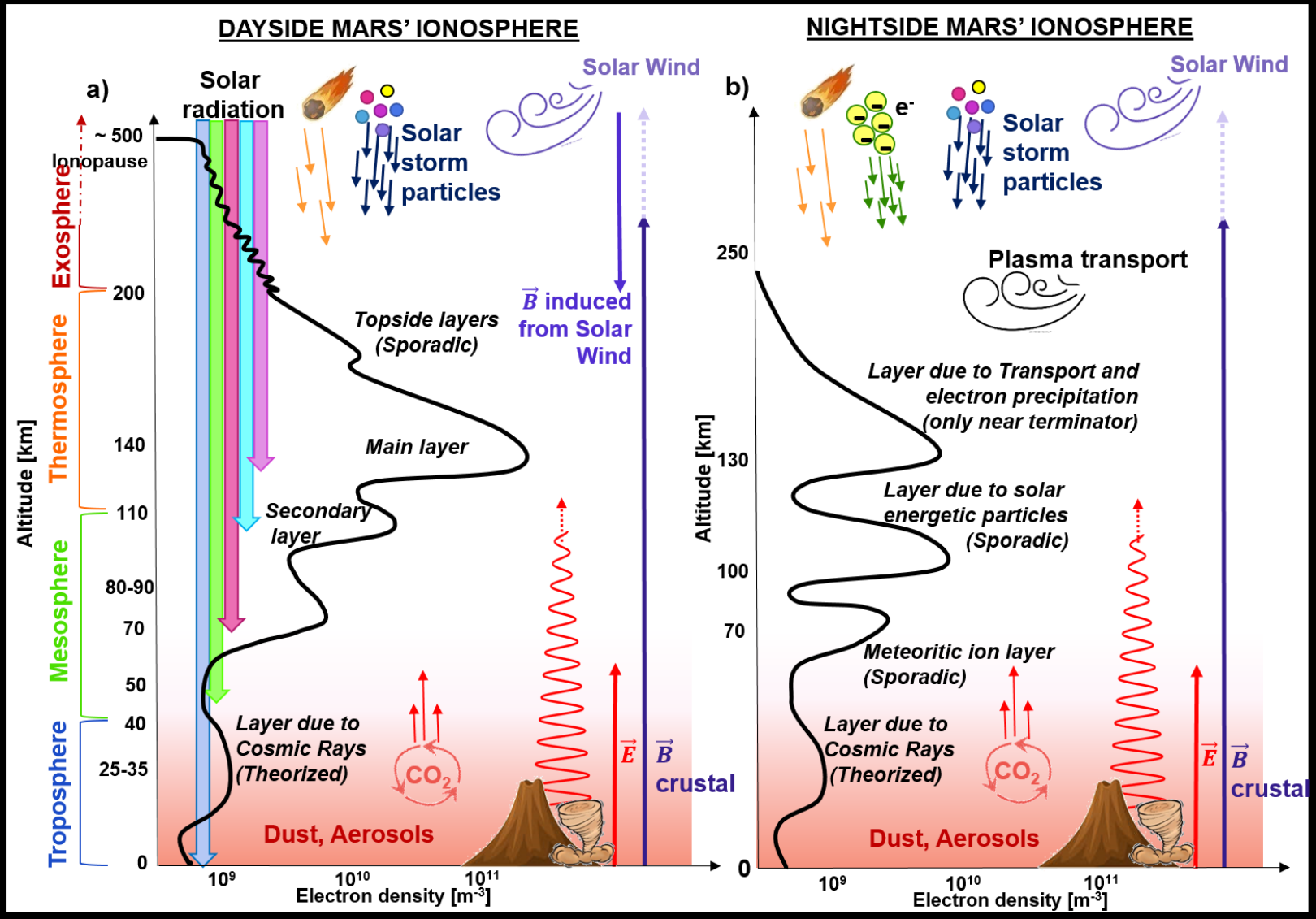
Half unmagnetized

Half magnetized

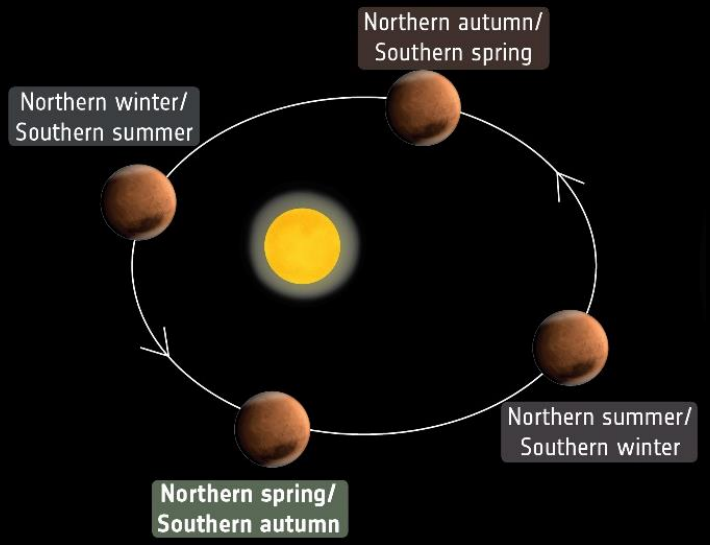


Lillis et al., 2015

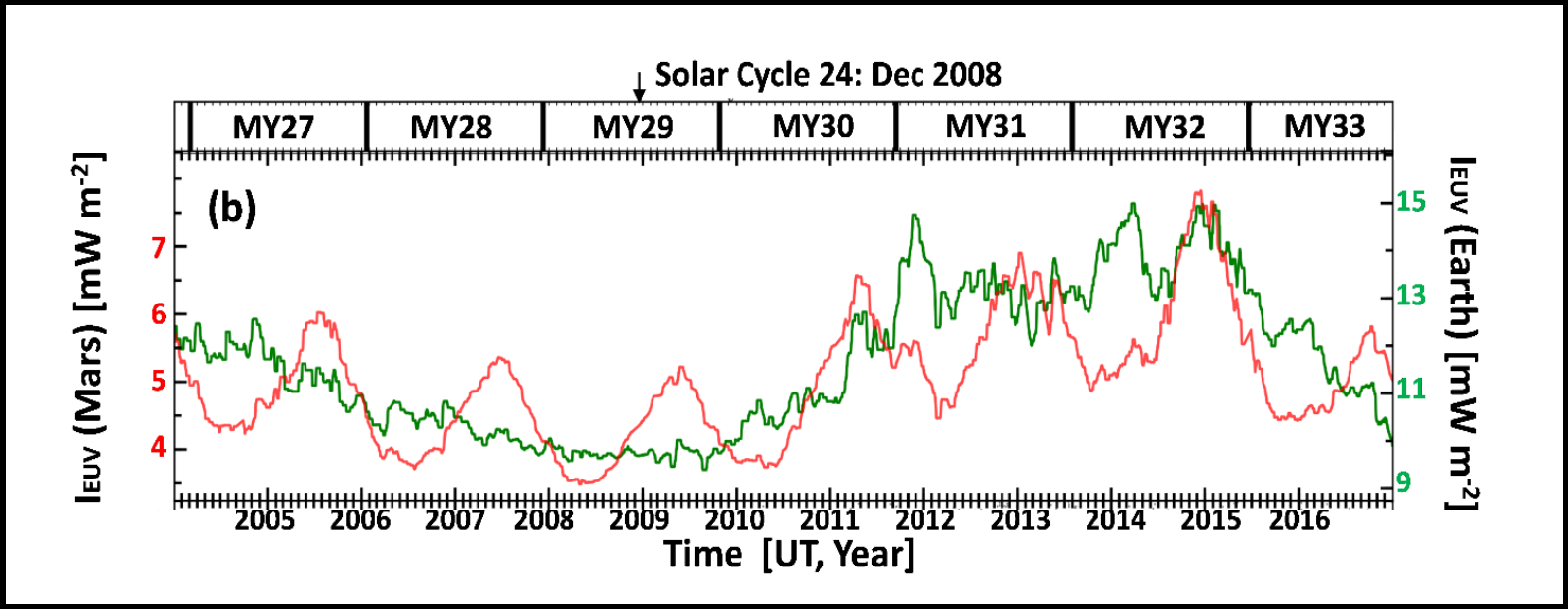
Mars' ionosphere



Solar cycle at Mars



The large Mars' orbit eccentricity dominates the amount of solar radiation that reaches Mars



Sanchez-Cano et al., 2015b, 2016a,b; Hall et al., 2016; 2019

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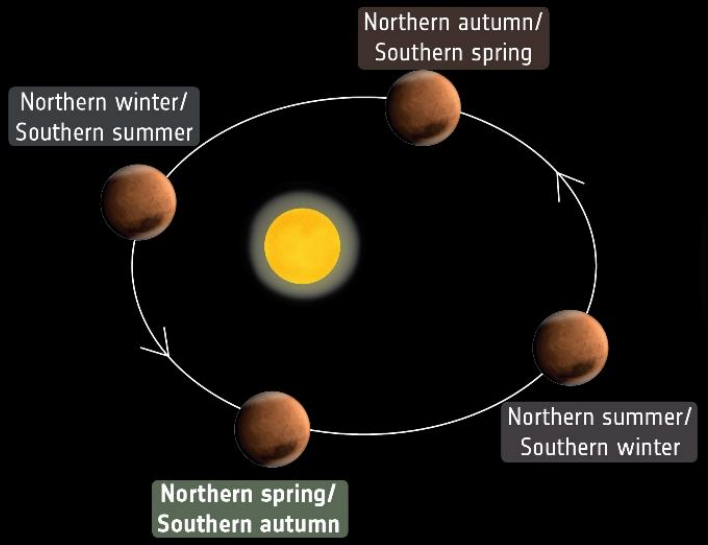
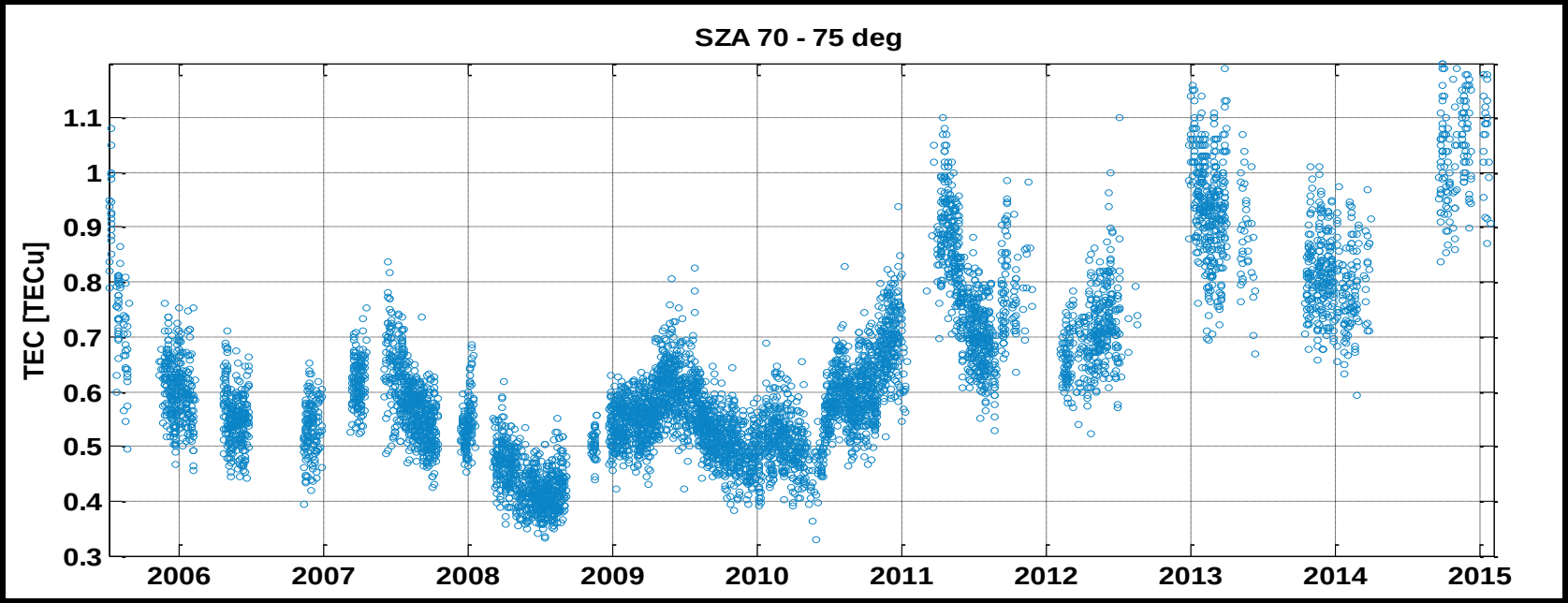
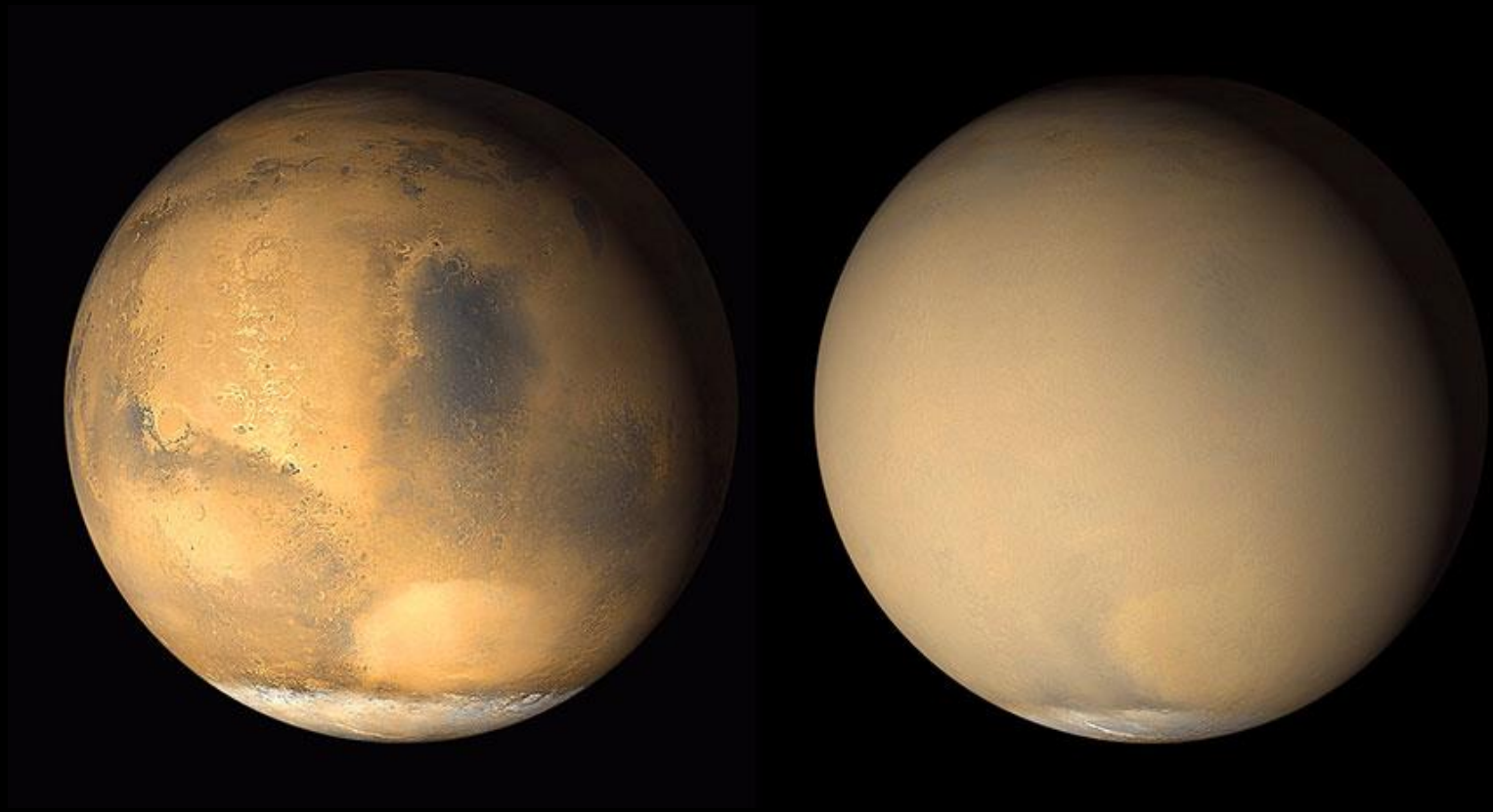
Solar cycle at Mars



As consequence, the ionosphere has a strong dependence on the heliocentric distance.



Internal sources of variability



Courtesy of MSSS/JPL-CALTECH/NASA

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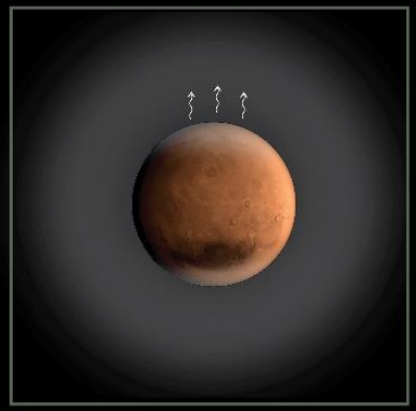
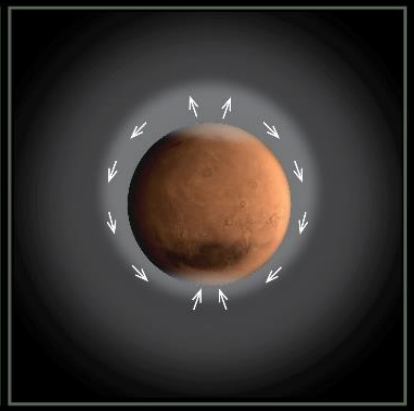
Atmospheric cycles

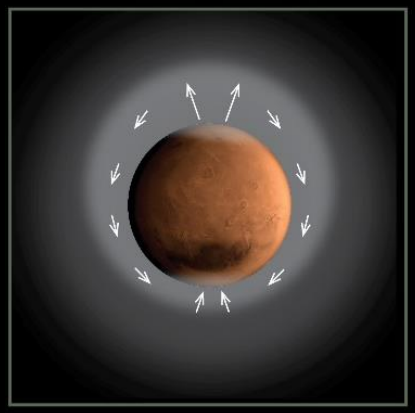
Atmospheric cycles, like the CO_2 cycle, change the mass of the Martian atmosphere by 30% each year



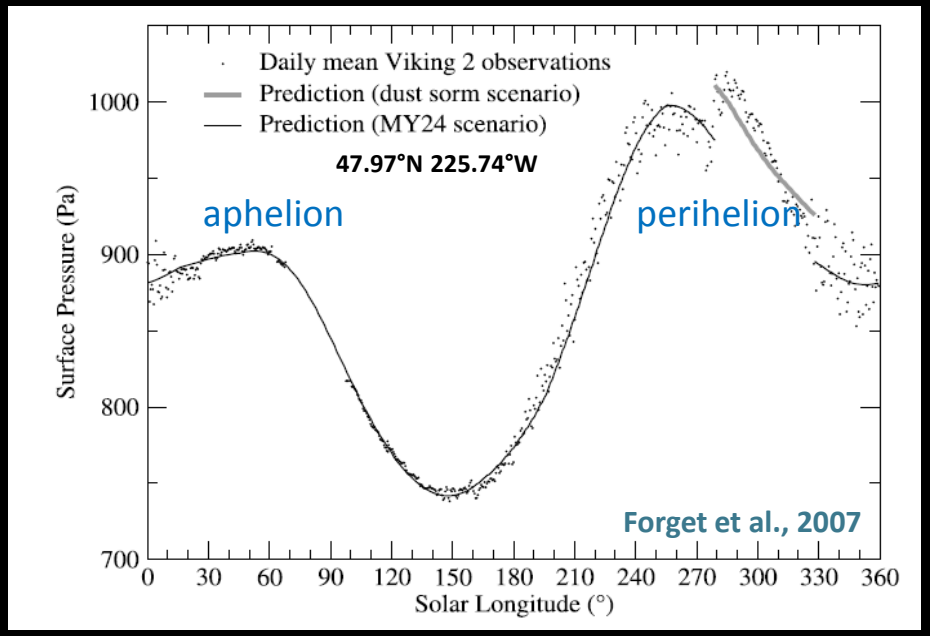
Solar illumination causes polar cap ice to sublimate



Mass loading of lower atmosphere



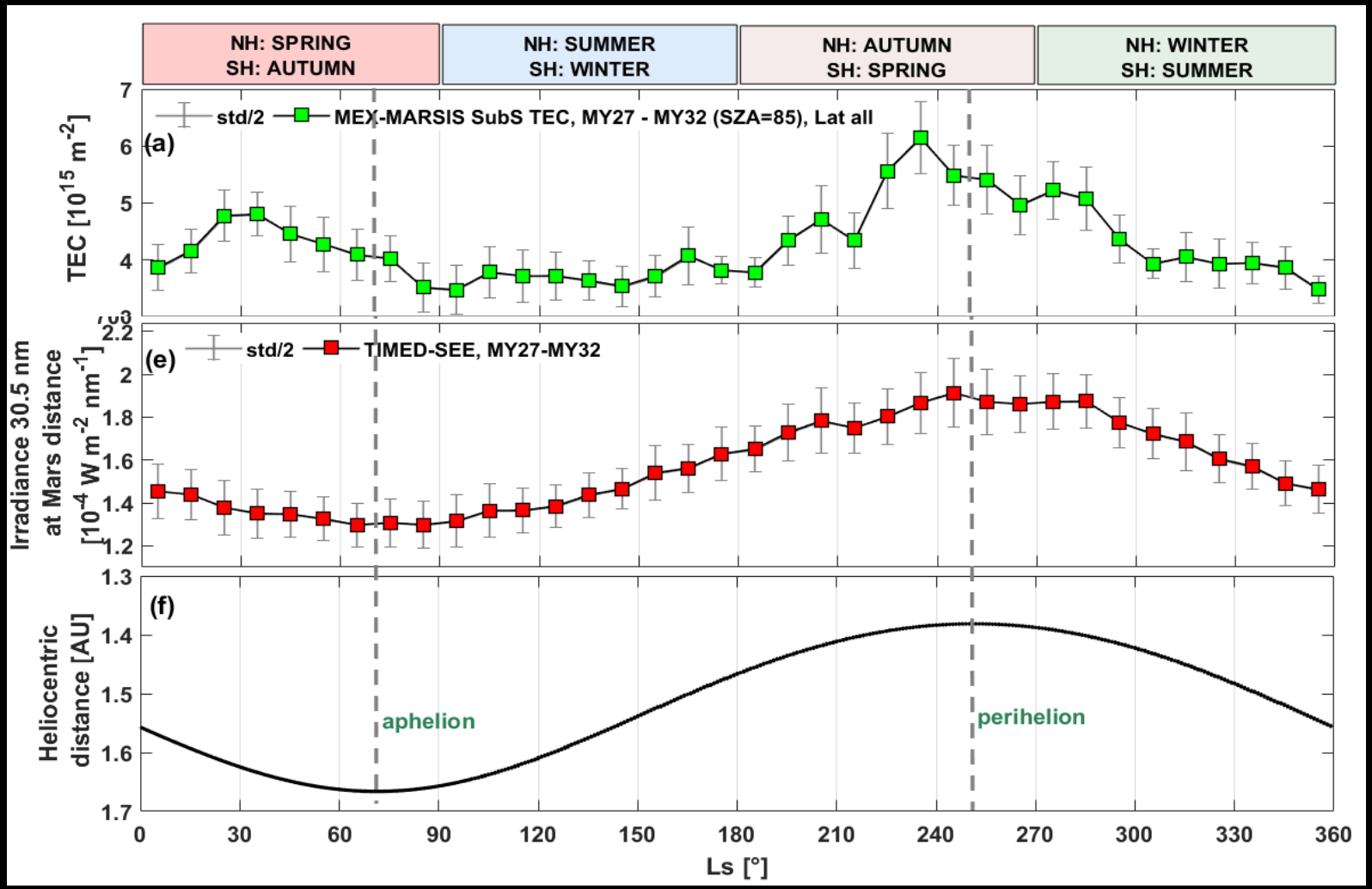
Mass loading of upper atmosphere



Spring NH Summer NH Autumn NH Winter NH

What happens to the upper atmosphere??

TEC annual variation



TEC variation

TEC

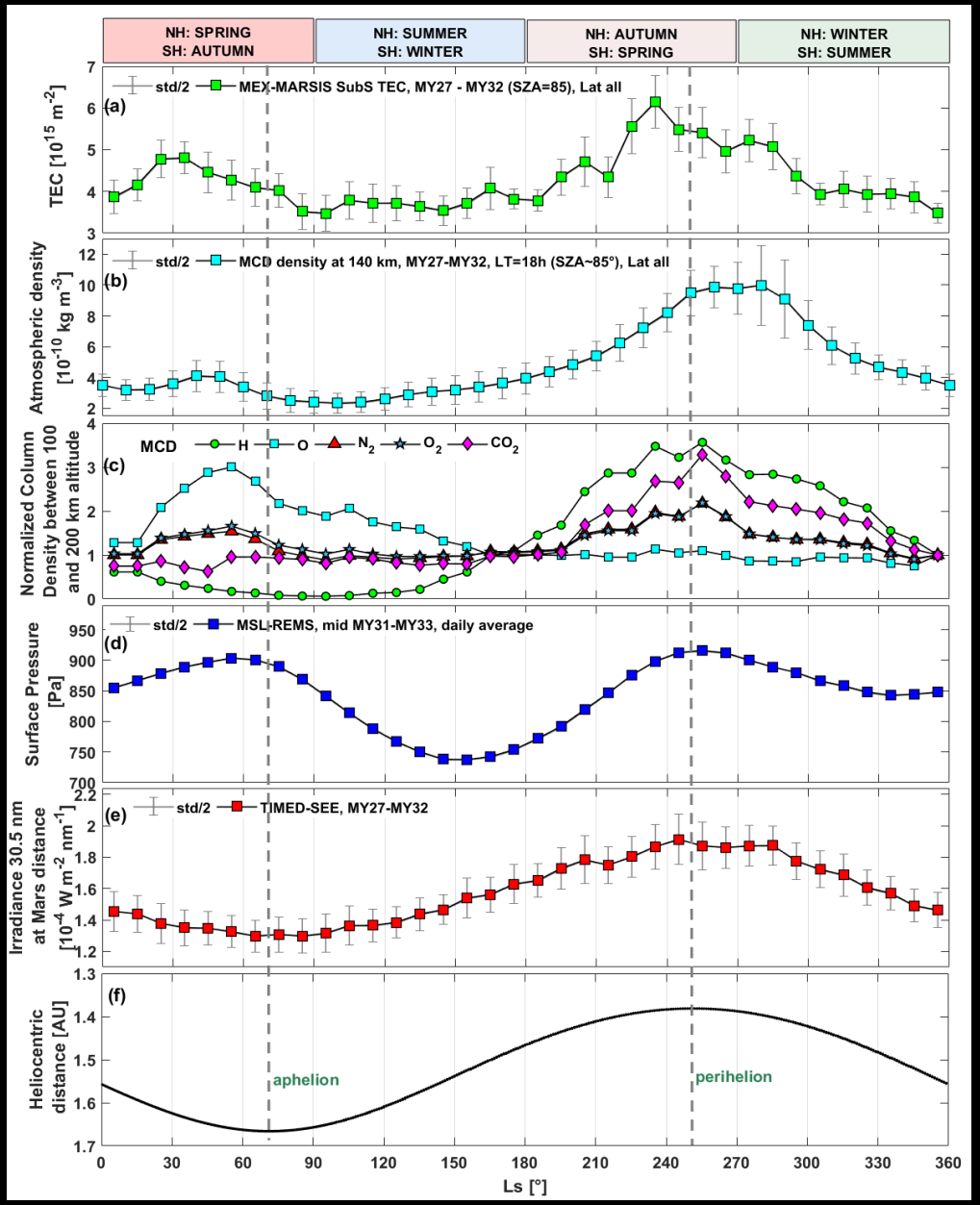
Density at 140 km

Column density 100-200 km

Surface pressure

Solar irradiance

Sun-Mars distance



Ionosphere-thermosphere simulation

We have performed a simulation with the **IPIM model** for **SZA=85°, local time 18h,** and keeping the **solar flux constant**

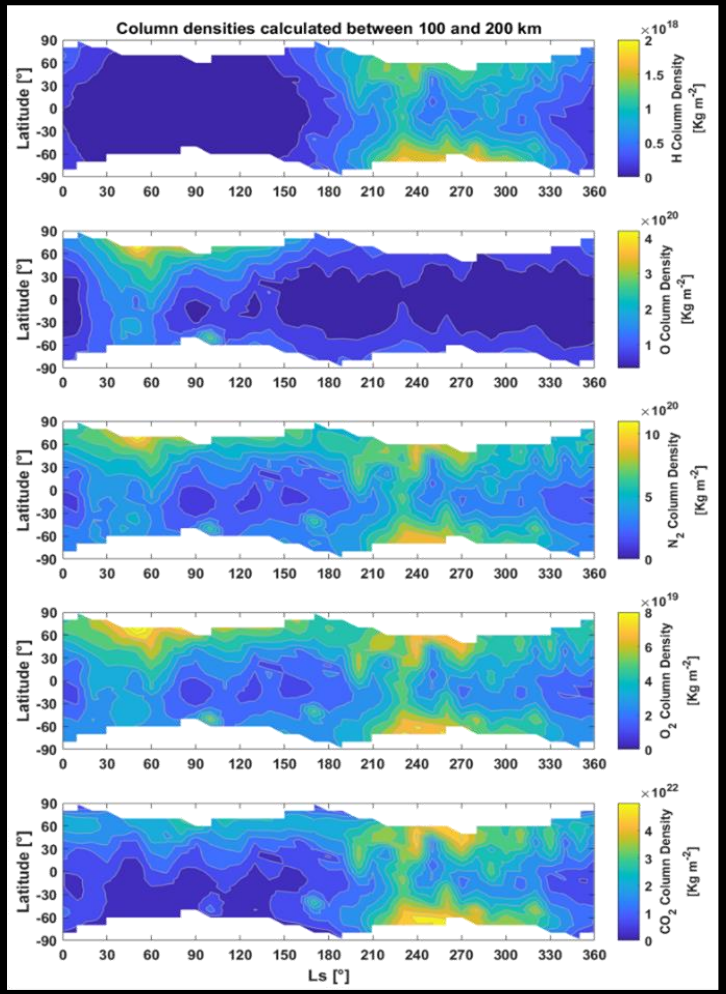
H

O

N_2

O_2

CO_2



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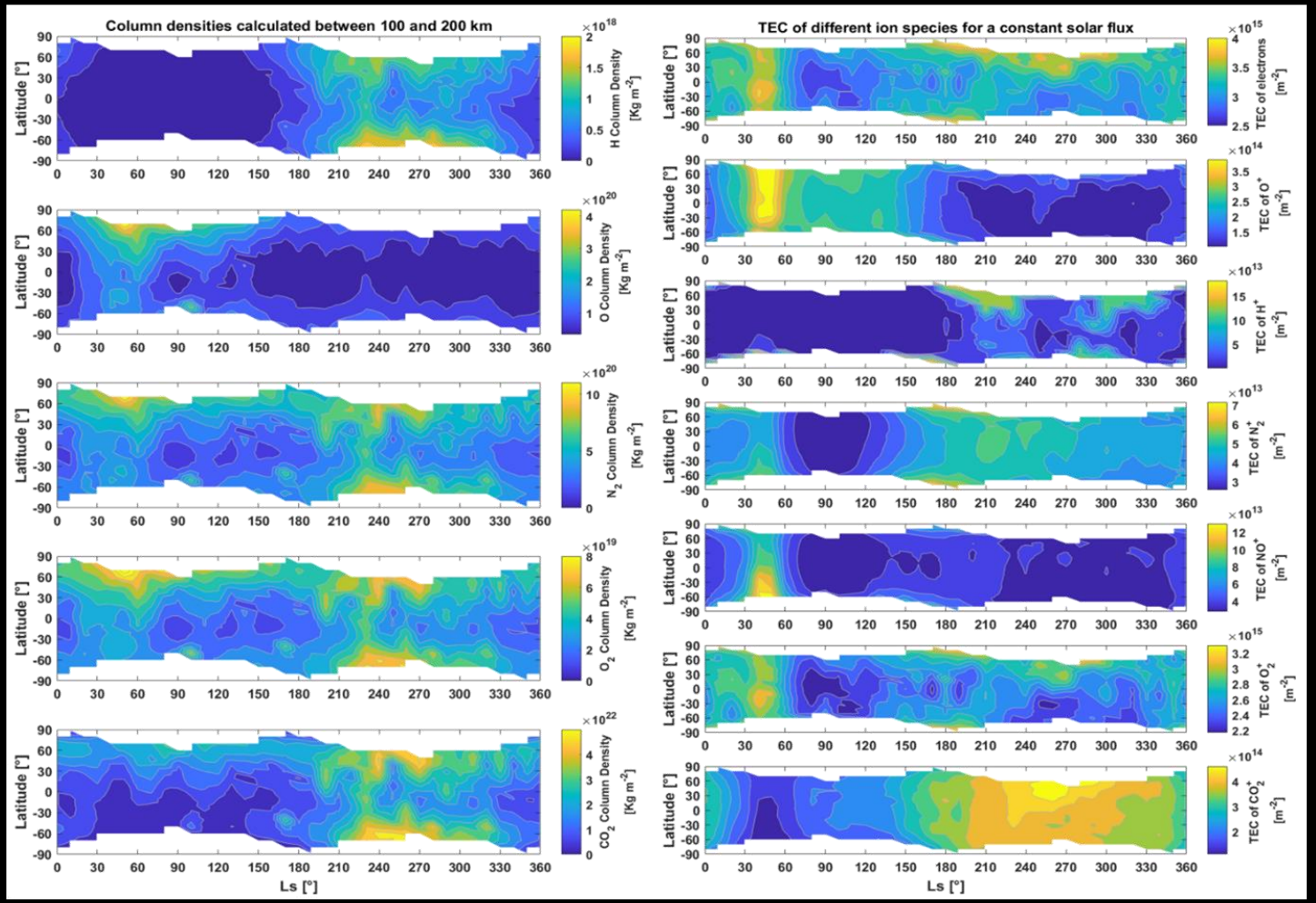


e^-

O^+

H^+

N_2^+

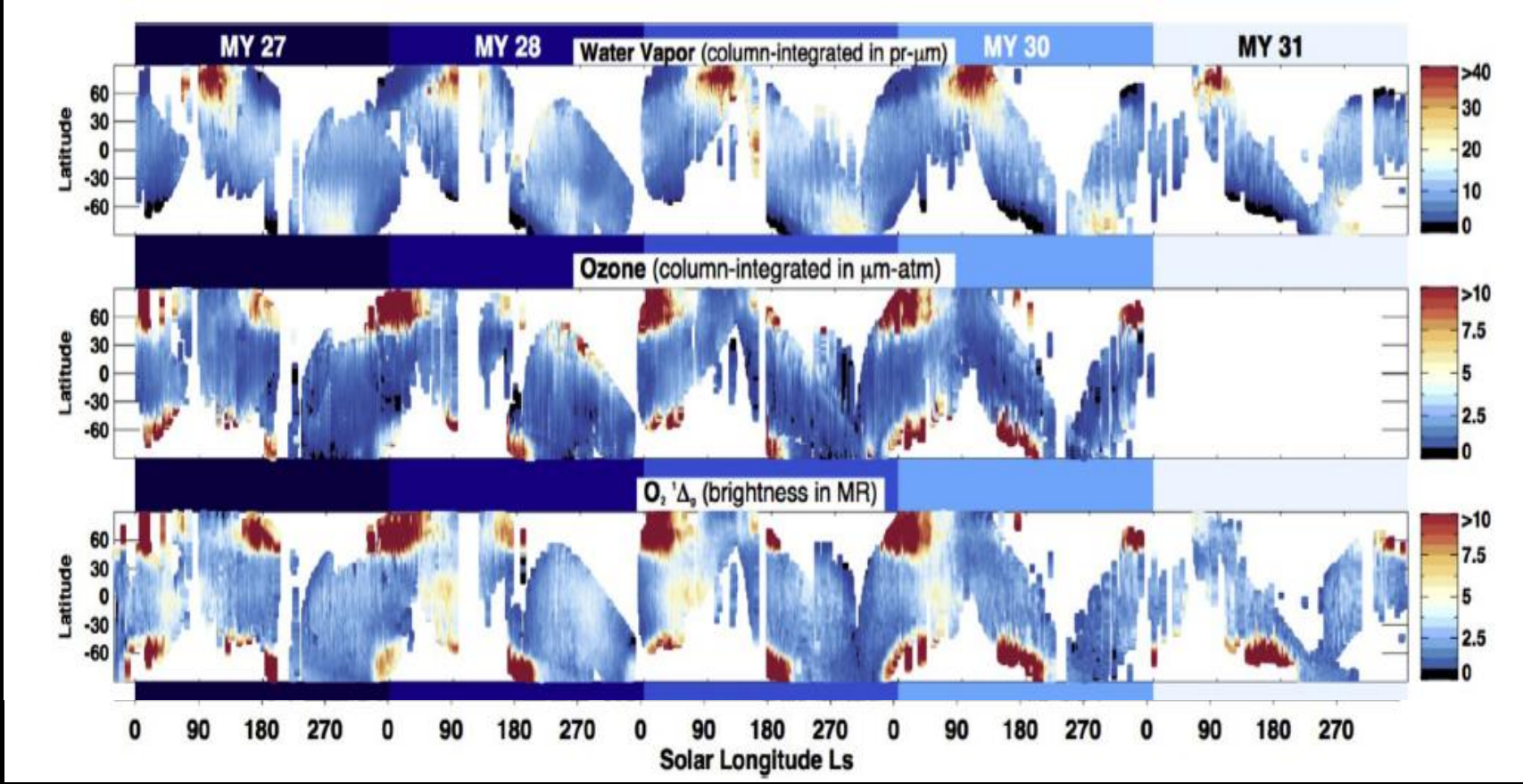
NO^+

O_2^+

CO_2^+

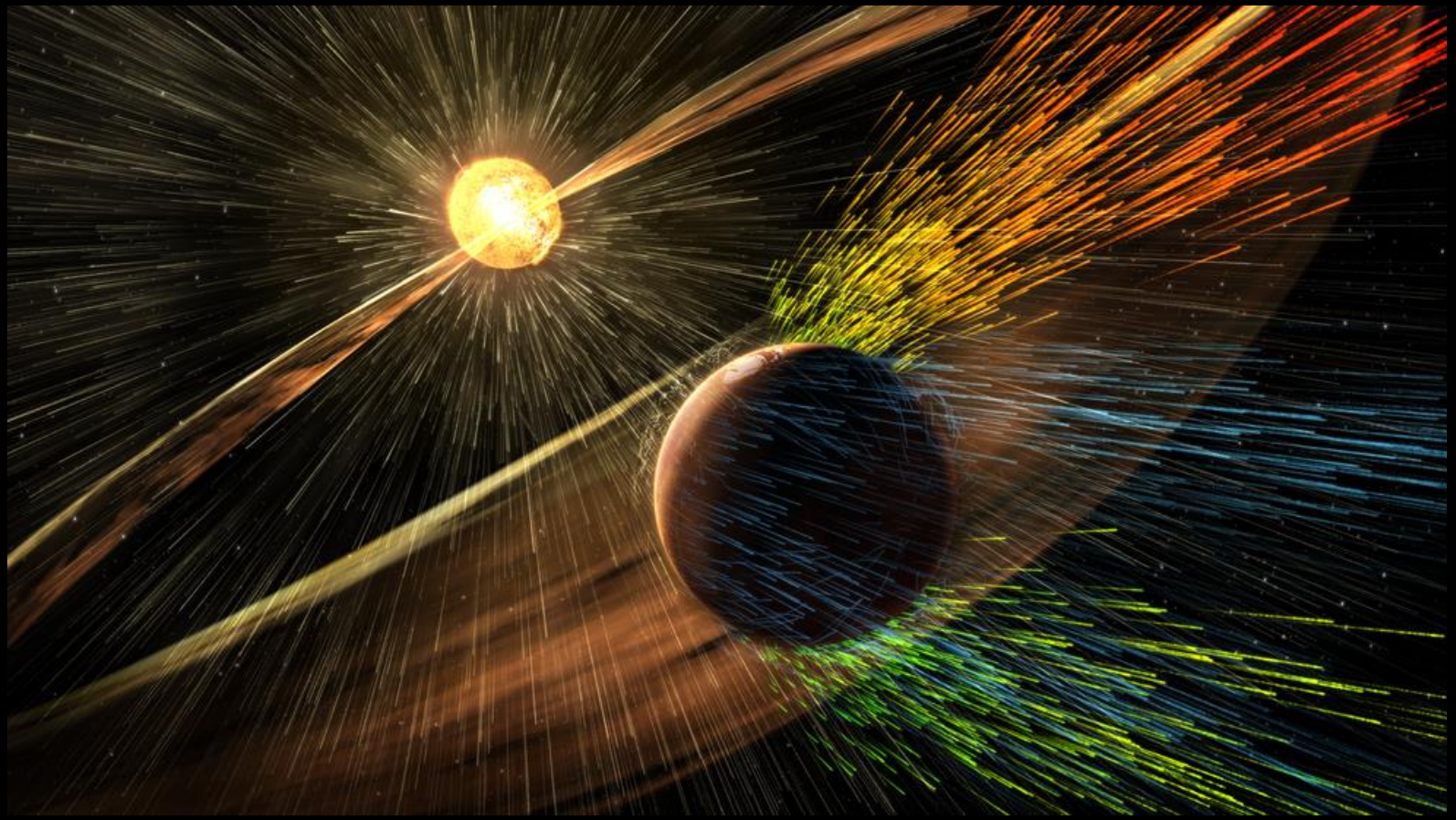
Is the TEC a good tracer for atmospheric cycles?

Mars Express - SPICAM instrument have shown that while the polar cap sublimation is occurring, oxygen species below 50 km have a cyclical annual behaviour that agrees pretty well with our ionospheric observations and modelling (both temporal and location-wise).



Adapted from Montmessin et al., 2017

External sources of variability



Courtesy of NASA/GSFC

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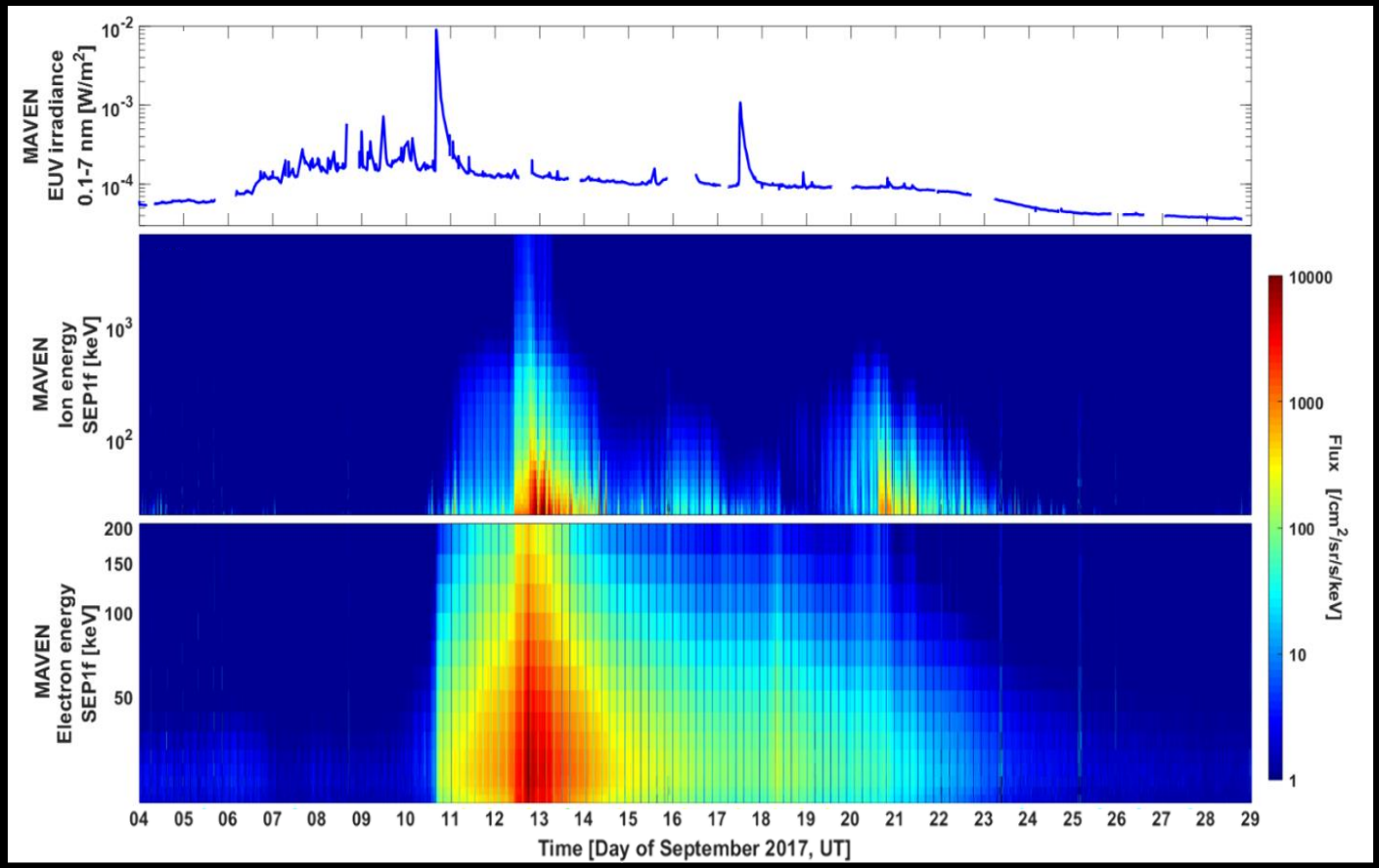
Space weather context

On September 10th, 2017 the Sun emitted a X8.2 flare in Mars' direction, followed few hours after by a large SEP, and 3 days later for a powerful coronal mass ejection.

EUV

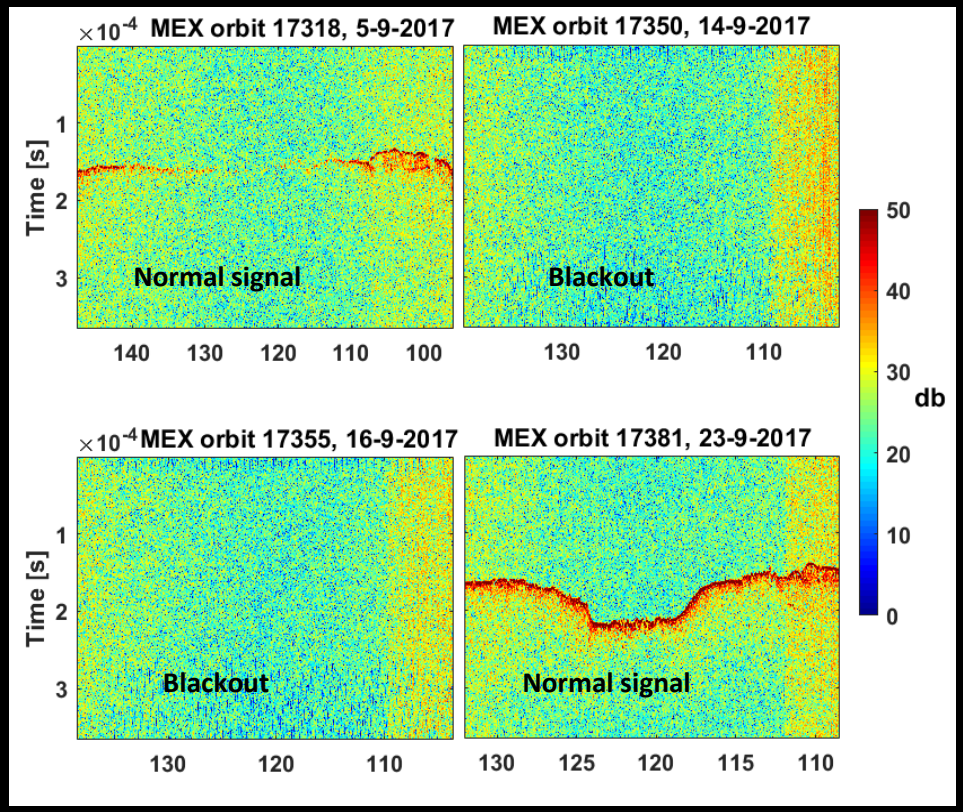
SEP ions

SEP electrons



MARSIS radio blackouts

The SEP precipitation in Mars' atmosphere coincided with an extended blackout in HF signals that lasted for **~10 days**, when Mars Express was sounding the deep nightside. Potential cause is a low ionospheric absorption layer formed by SEP precipitation.



3-5 MHz

Sanchez-Cano et al., 2019

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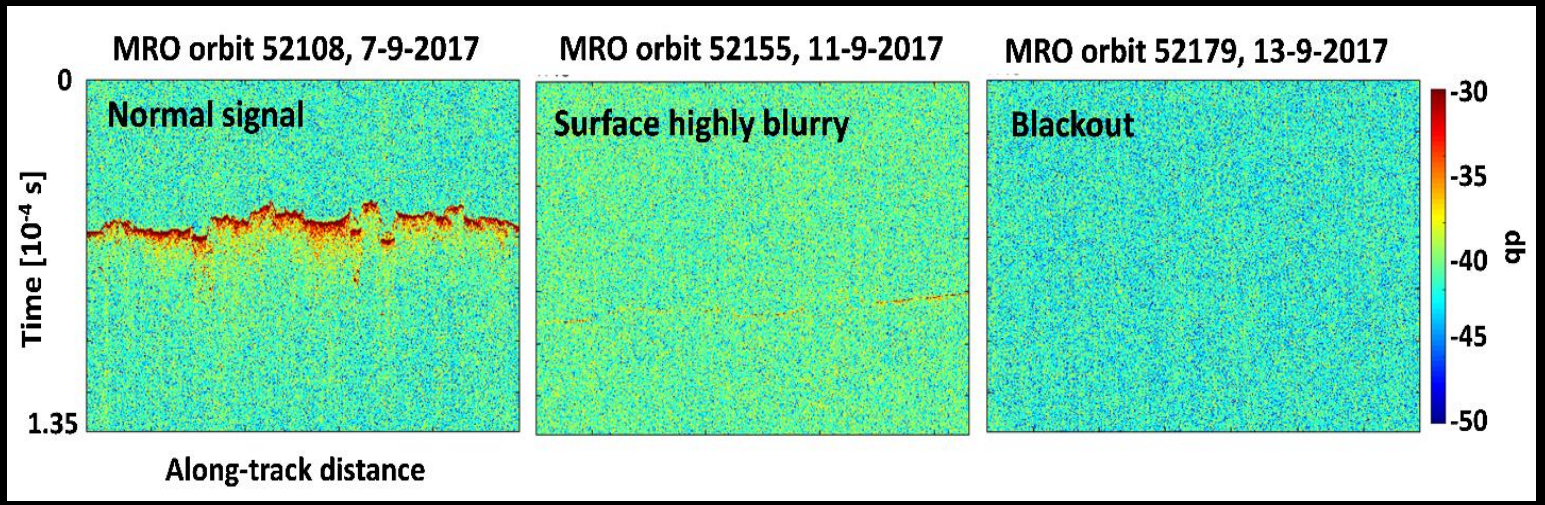
SHARAD radio blackouts

The SHARAD radar on board the MRO mission also experienced a blackout operating at a central frequency of 20 MHz that lasted **~3 days**. This is most probably because of the low absorption layers on the ionosphere are frequency-dependent:

$$A(db/m) = 46.1\, N_e(h)\, \frac{\nu(h)}{(2\,\pi\, f)^2 + \nu^2(h)}$$



20 MHz

Radio blackouts

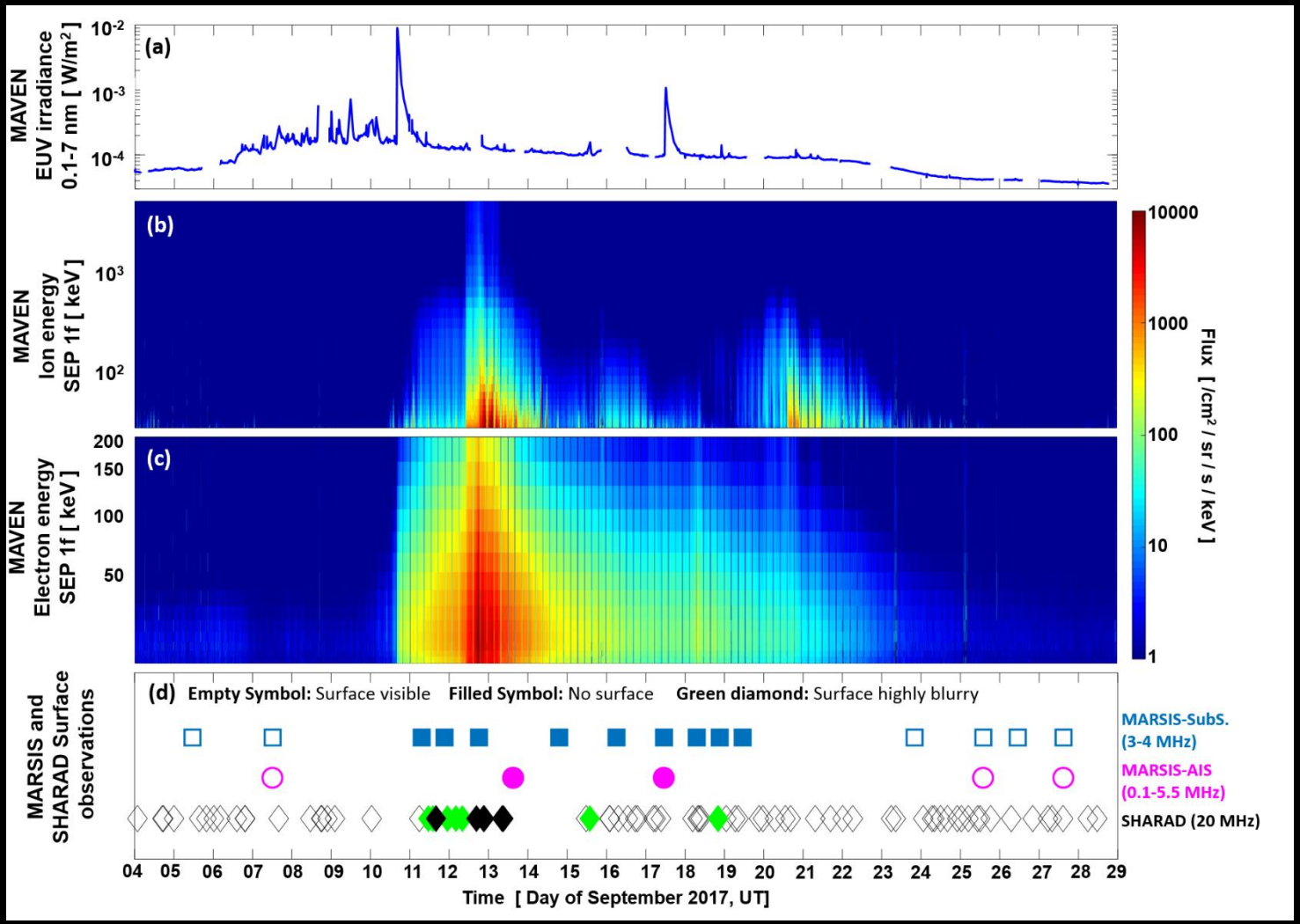
EUV

SEP ions

SEP electrons

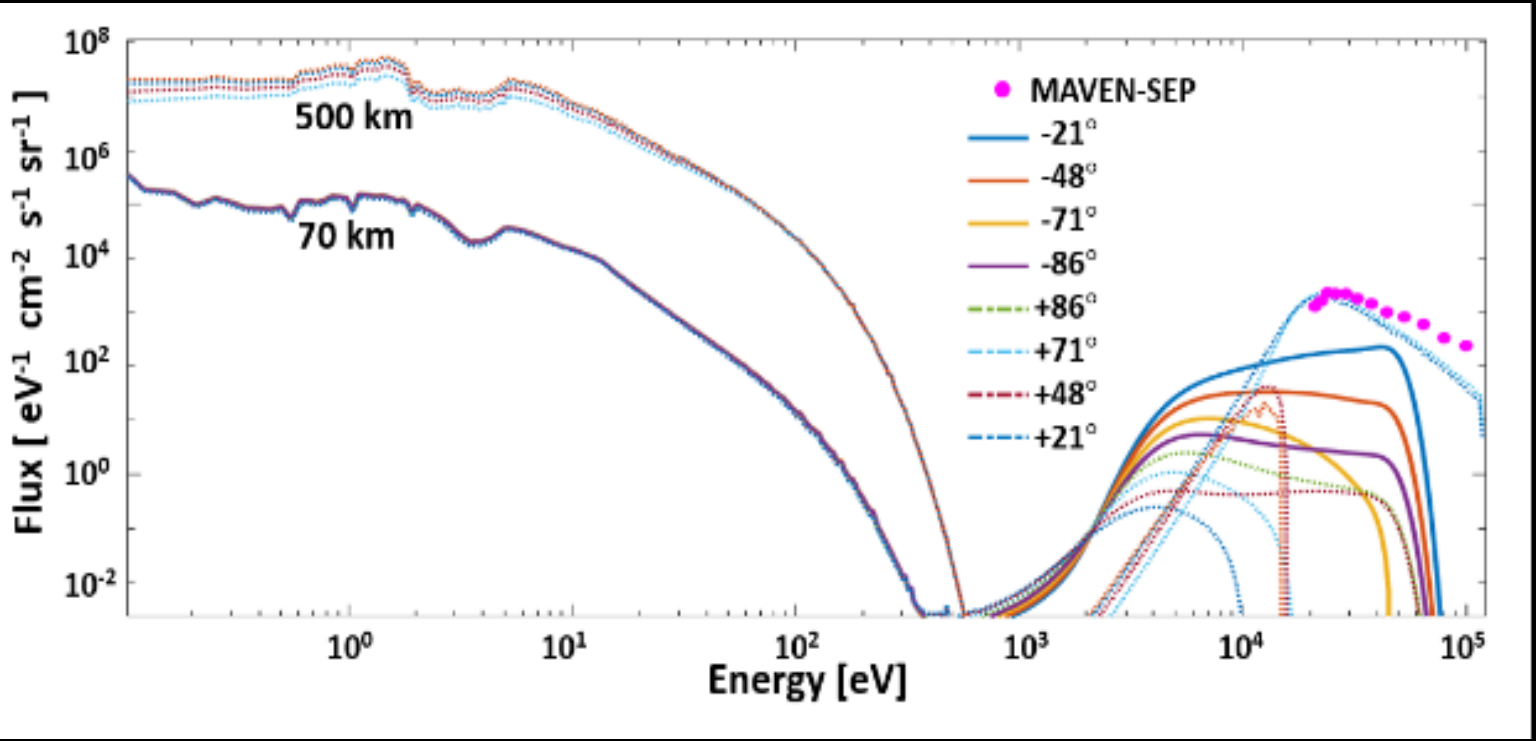
MARSIS

SHARAD



Electron penetration depth

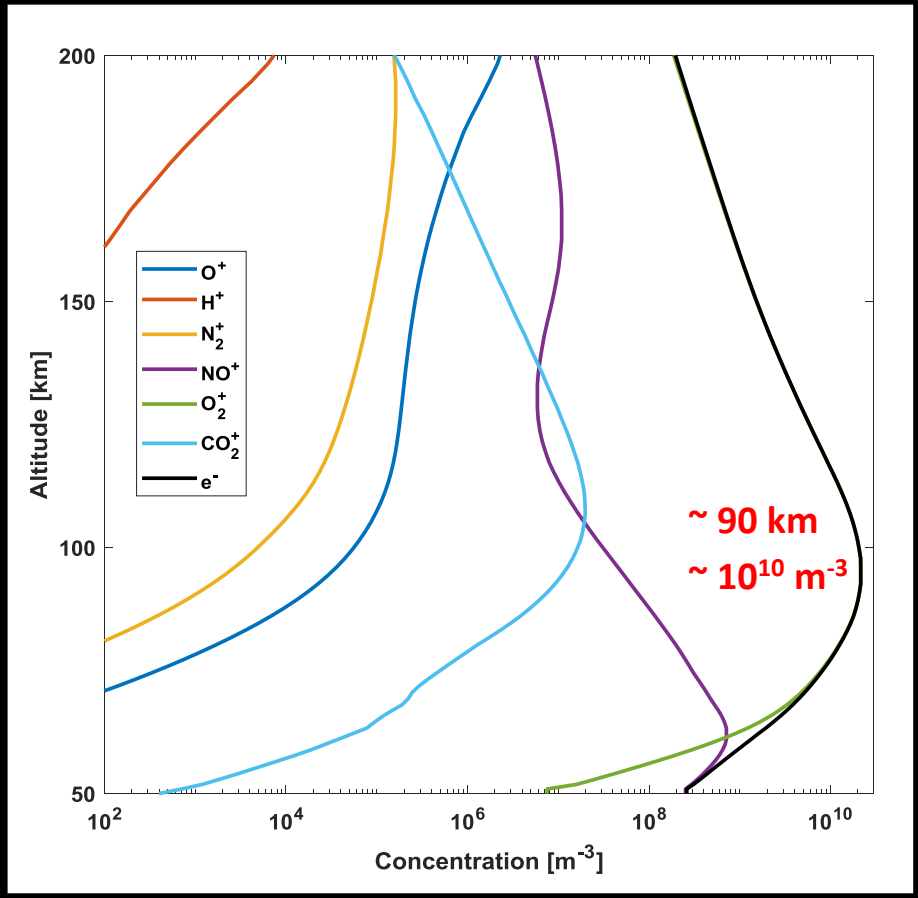
We perform a simulation with the IPIM model considering as input the energy spectrum of the SEP electrons as recorded by MAVEN.



Ionospheric layer

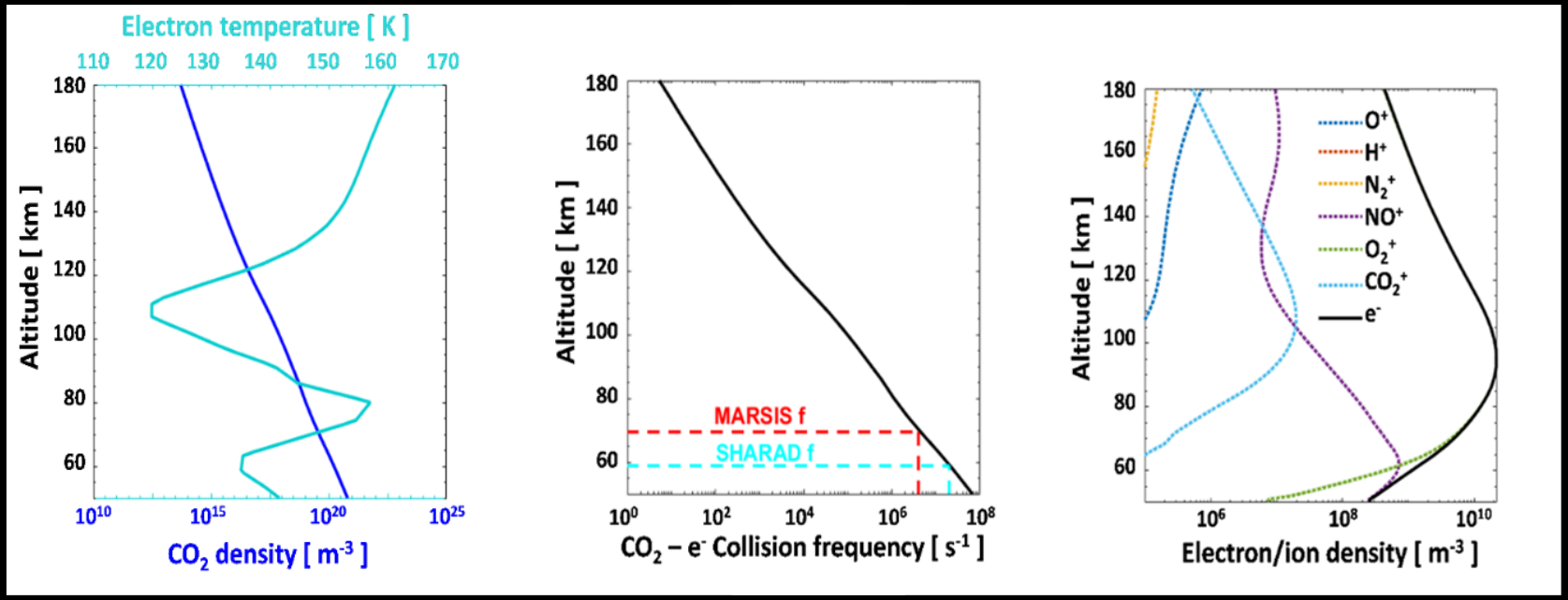
We find that the SEP electron precipitation creates a main O_2^+ layer formed at ~90 km, which bottom part is at ~60km and it is mainly formed by NO^+.

The peak magnitude is ~10^{10} m^{-3}, which is of the same order of the dayside ionosphere secondary peak which is typically found at 110 km.



Ionospheric absorption

$$A(db/m) = 46.1\, N_e(h)\, \frac{\nu(h)}{(2\,\pi\, f)^2 + \nu^2(h)} \qquad \nu\,(e^- - CO_2) \propto n(CO_2)\ \&\ T_e$$



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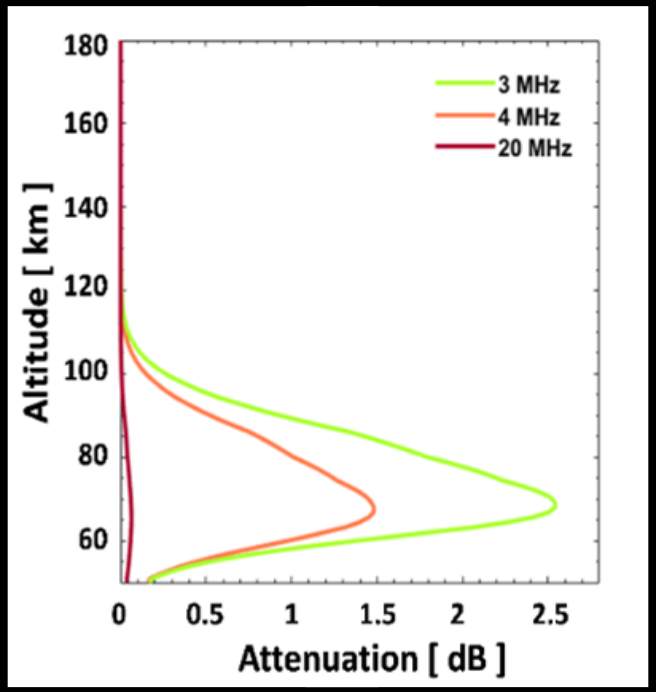
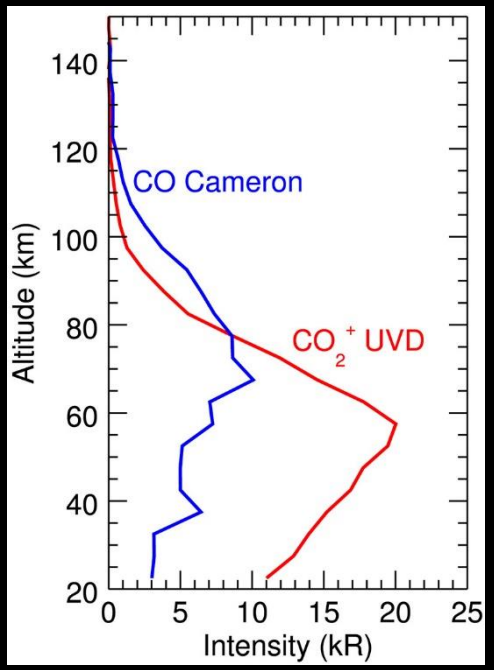


~70 km

Auroras??



Schneider et al., 2018

3 MHz: 79 dB **4MHz: 50 dB** **20 MHz: 4 dB**

Conclusions

Credits: ESA/DLR/FU Berlin (G. Neukum)

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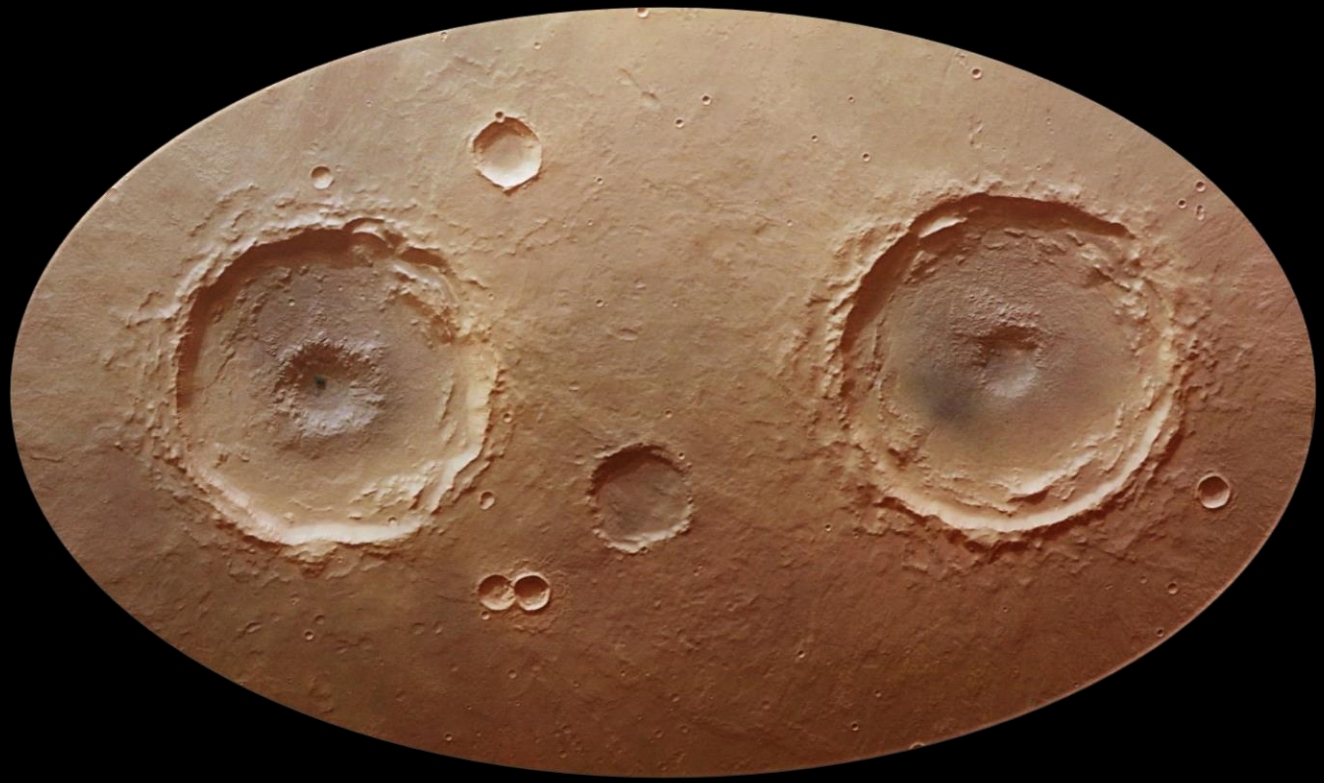
Closing thoughts

- Mars' ionosphere behaviour is strongly influenced by internal and external processes, even more than Earth's ionosphere.

- TEC is a good proxy for systematic assessments of the thermosphere-ionosphere coupling, and track the evolution of low atmosphere cycles.

- For the first time, we can conclude that high energetic electron precipitation (>50 keV) is the responsible for the low-altitude absorption layers at Mars.

Thank you very much for your attention!!



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