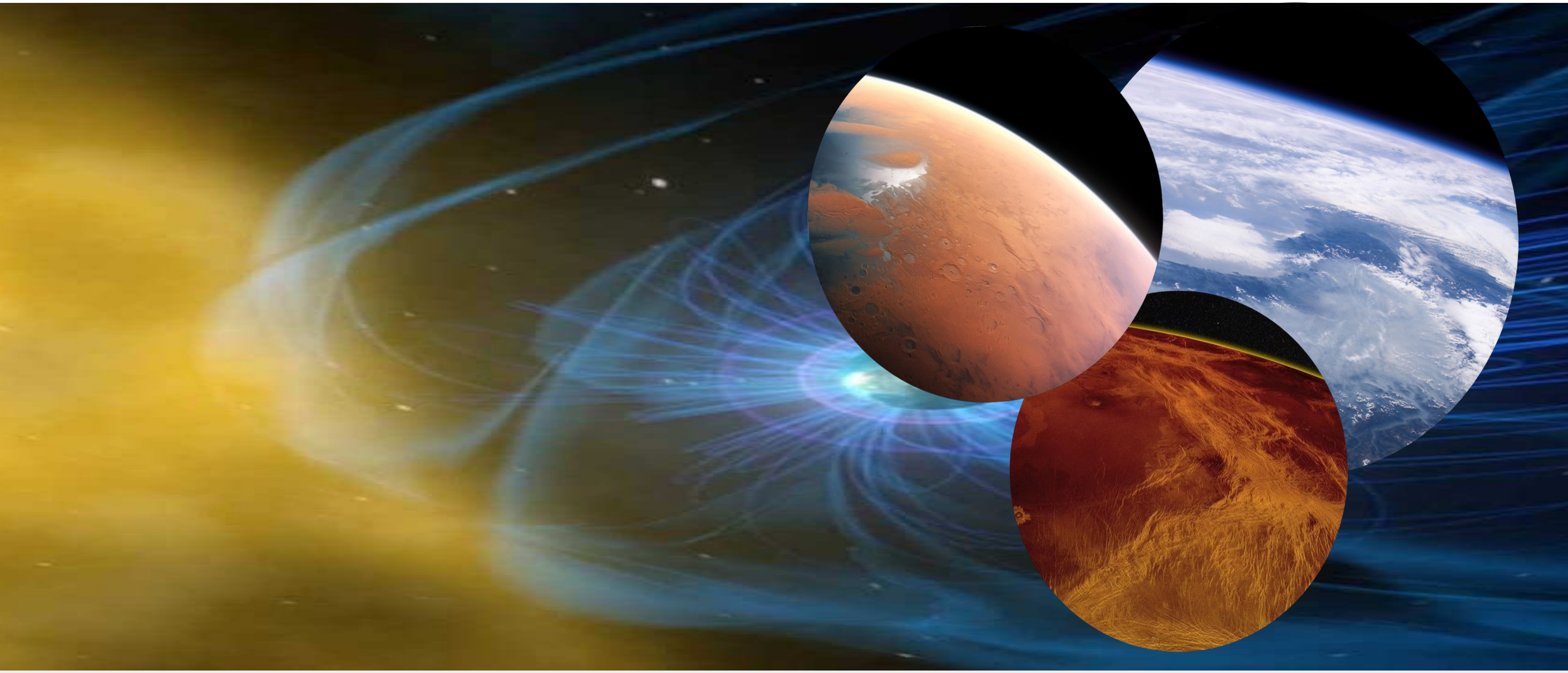

Atmospheric Erosion for the Terrestrial Planets: A Semi-Empirical Model

M. L. Alonso Tagle[1,2], R. Maggiolo[1], H. Gunell[3], J. De Keyser[1,2], G. Cessateur[1], G. Lapenta[2], V. Pierrard[1], A. C. Vandaele[1]

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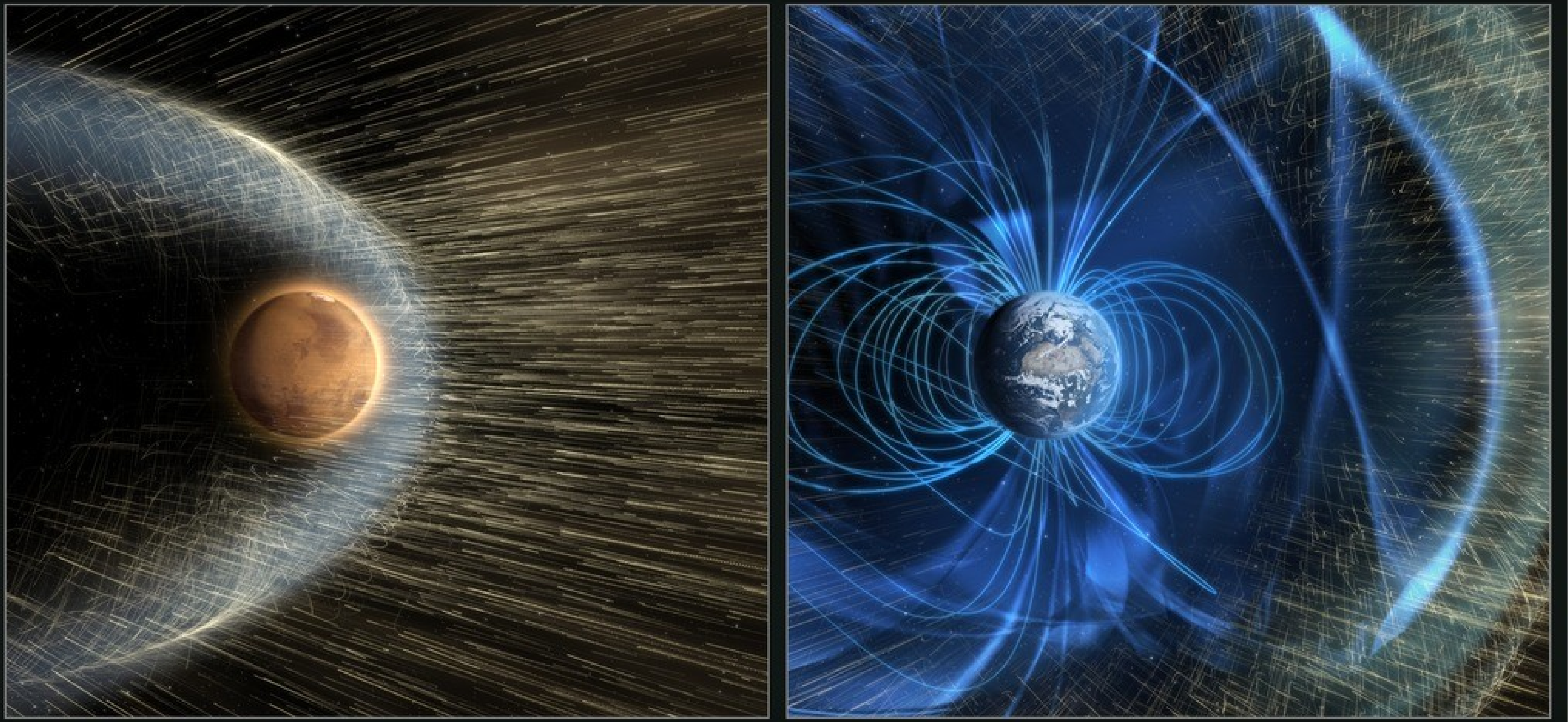
ROYAL BELGIAN INSTITUTE FOR SPACE AERONOMY

Magnetospheres interact with the solar wind depending on the planetary magnetization



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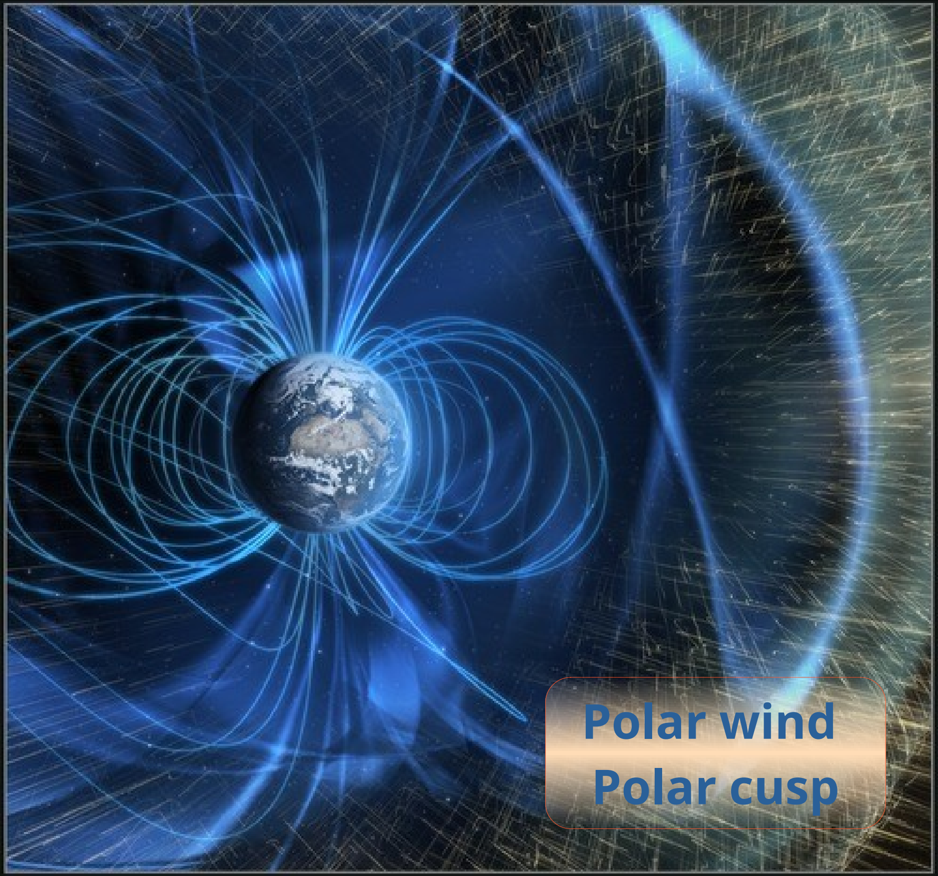
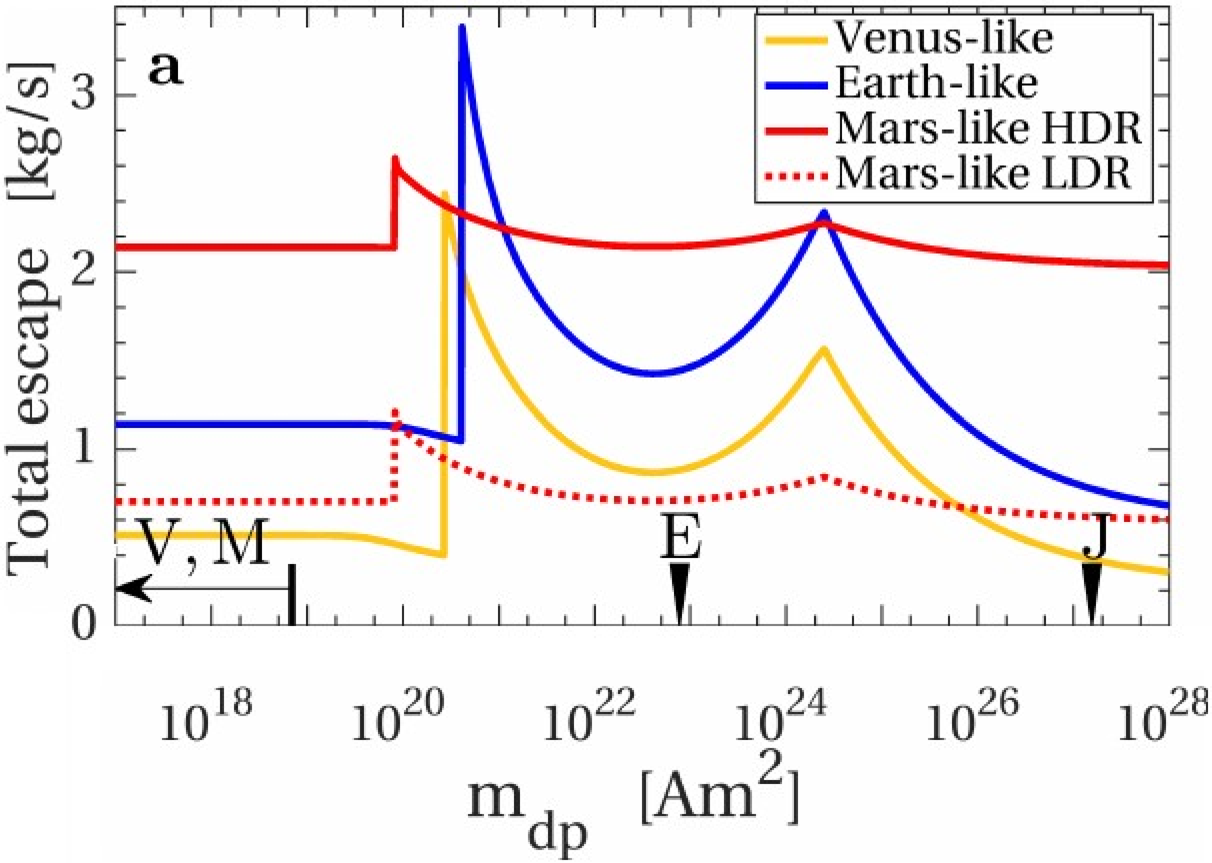


A semi-empirical model allow us to estimate the erosion rates in uncertain conditions

$Q_{method,\tau}\left(M_{dp}\right)$

Gunell et al. 2018.



SEVEN different mechanisms were used.

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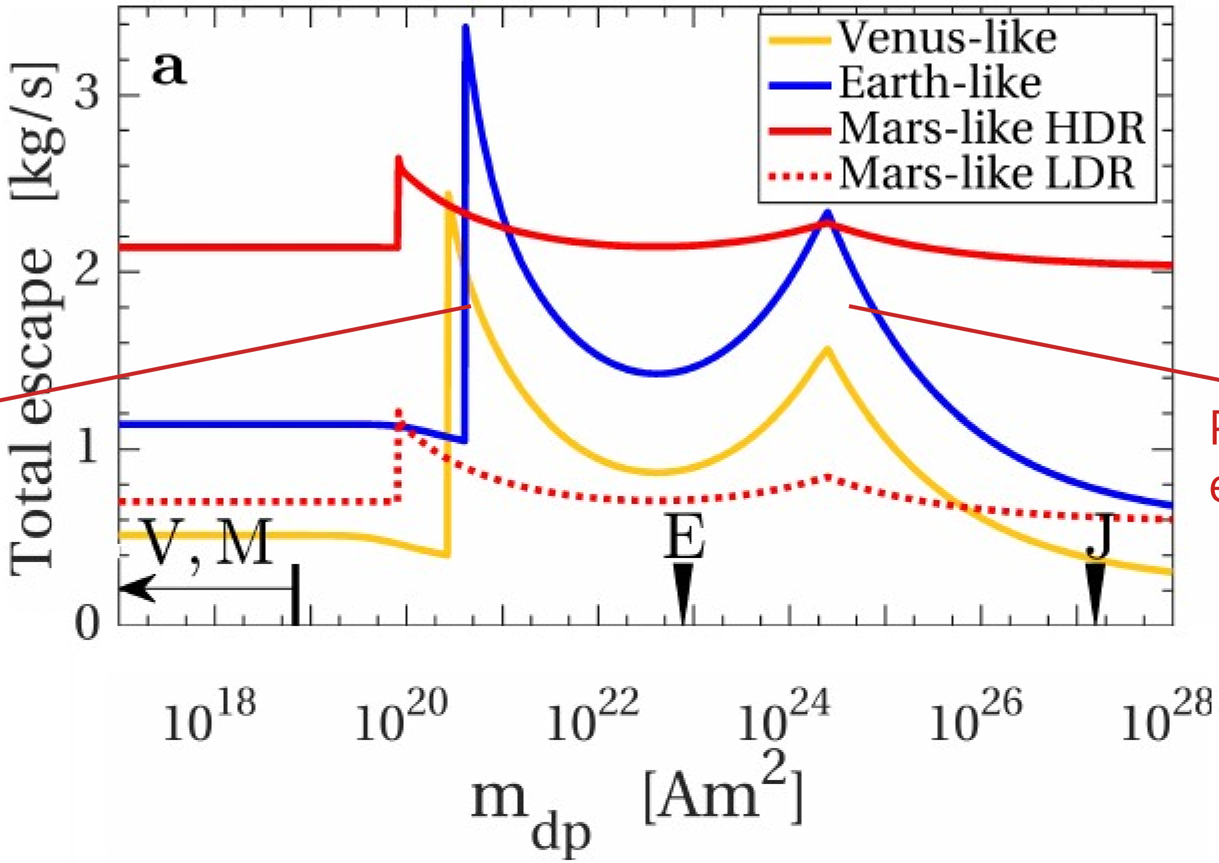
Polar wind



Polar cusp escape

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A semi-empirical model allow us to estimate the erosion rates in uncertain conditions

$$Q_{method,\tau}(M_{dp}) = Q_{method,\tau}(M_{dp}, P_{SW})$$

$$Q_{method,\tau} = q_{ref} \times S \times A$$

1. Jeans escape
2. Photochemical escape
3. Ion Pickup
4. Sputtering
5. Polar wind
6. Polar cusp escape
7. Cross-Field ion loss

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Reference by measurements.

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Physical scaling of the process

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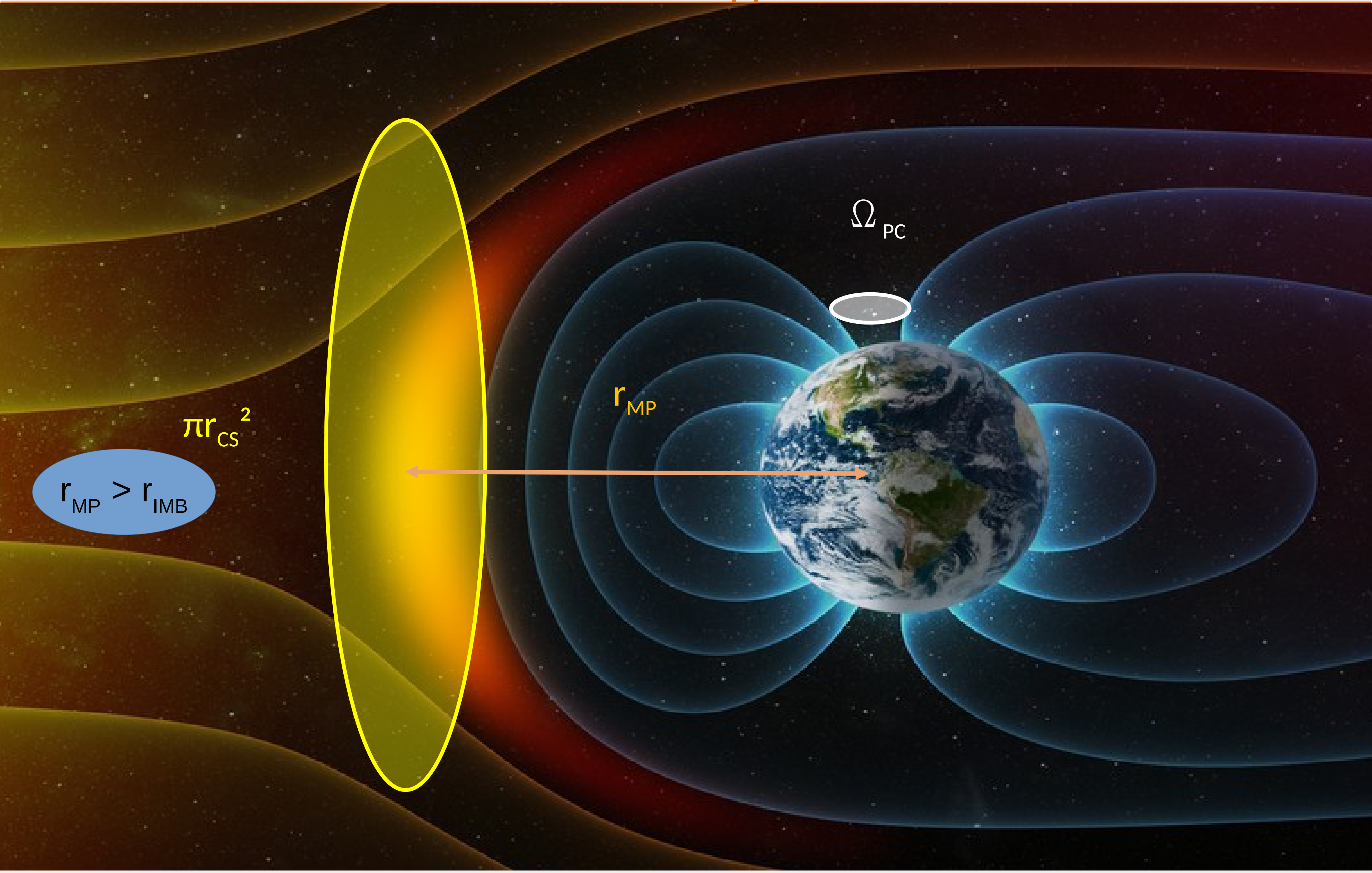
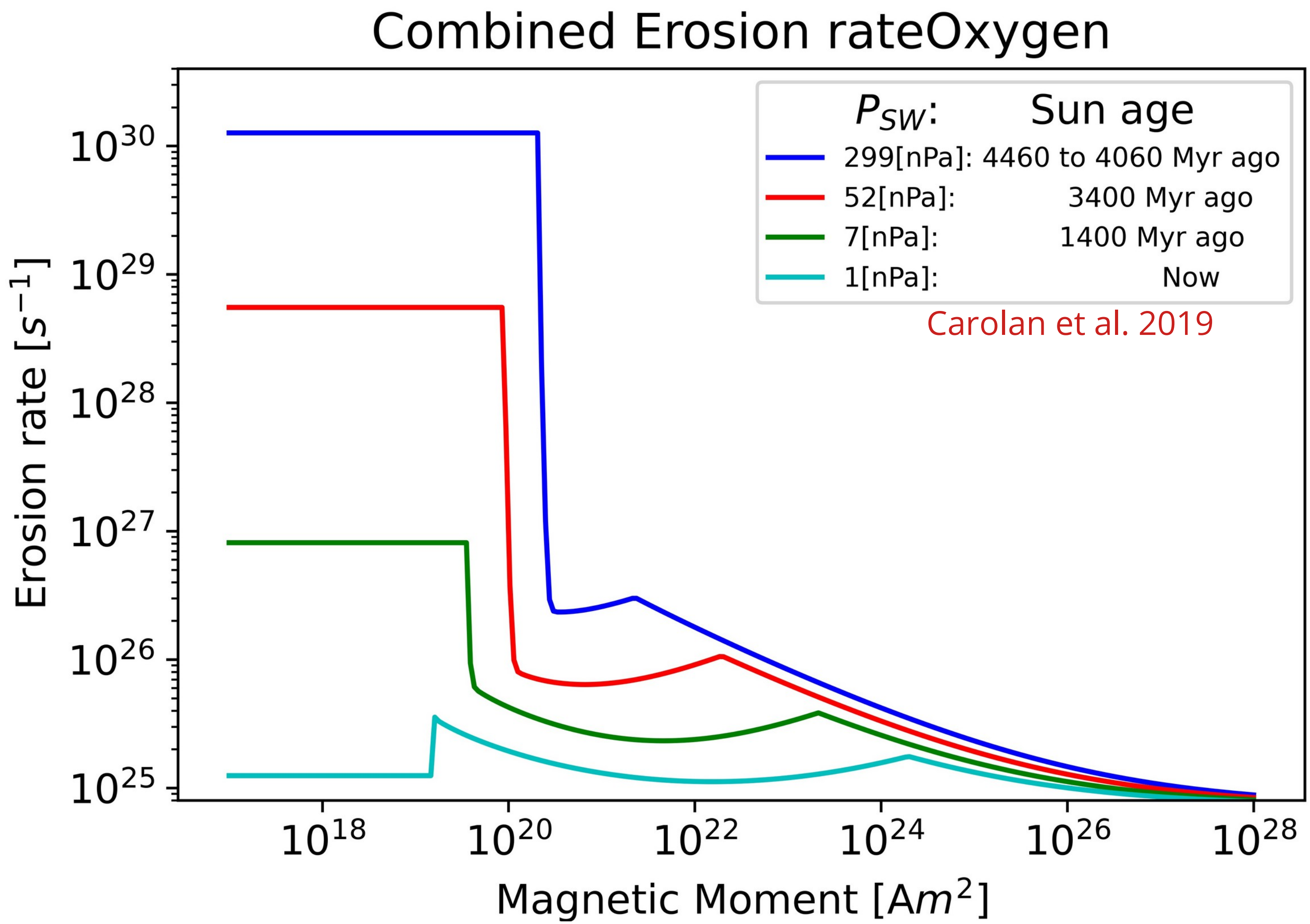
Geometrical scaling

The magnetic model shapes the geometrical scaling.



Solar Wind pressure increases erosion rate, Mars as example.



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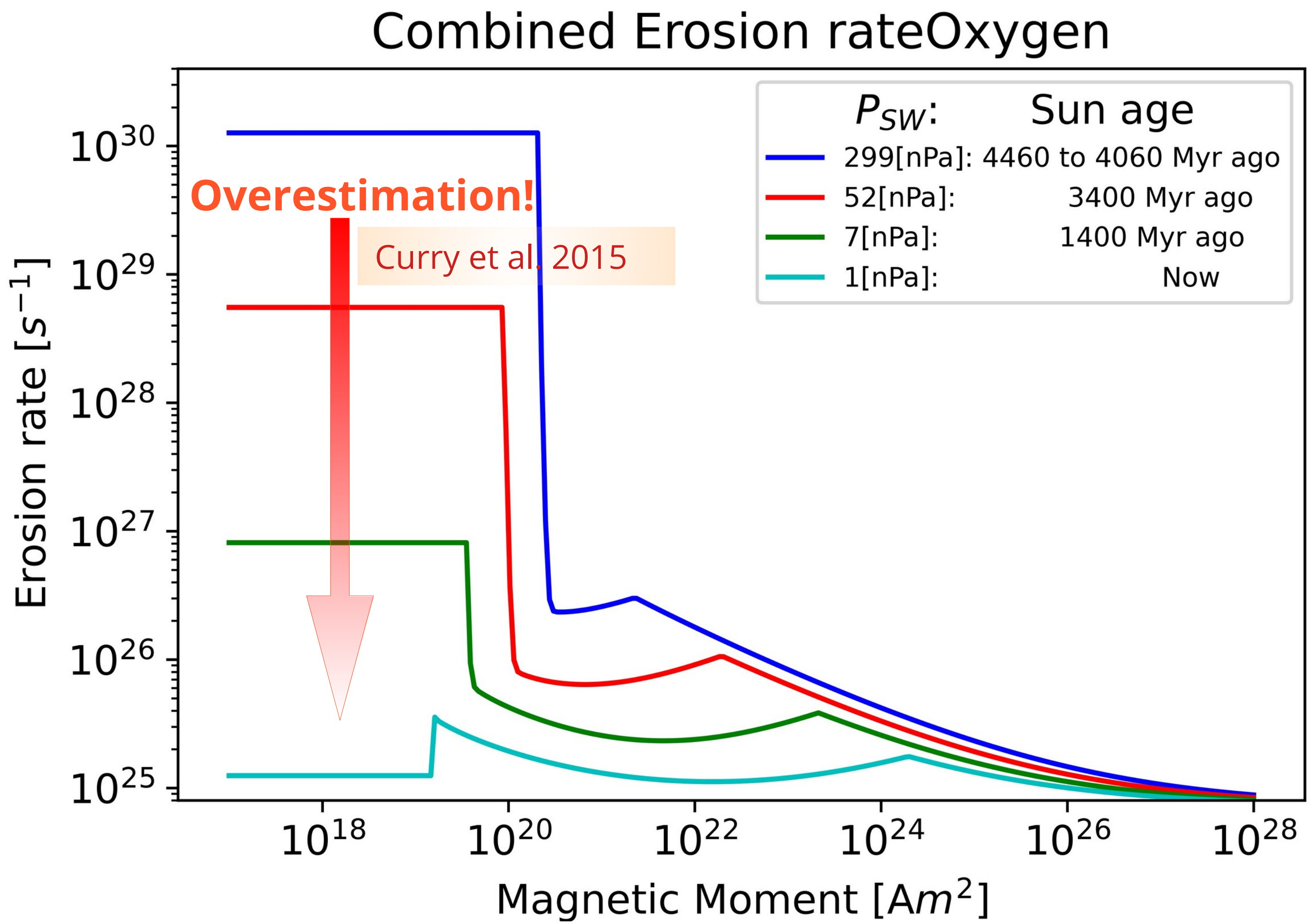

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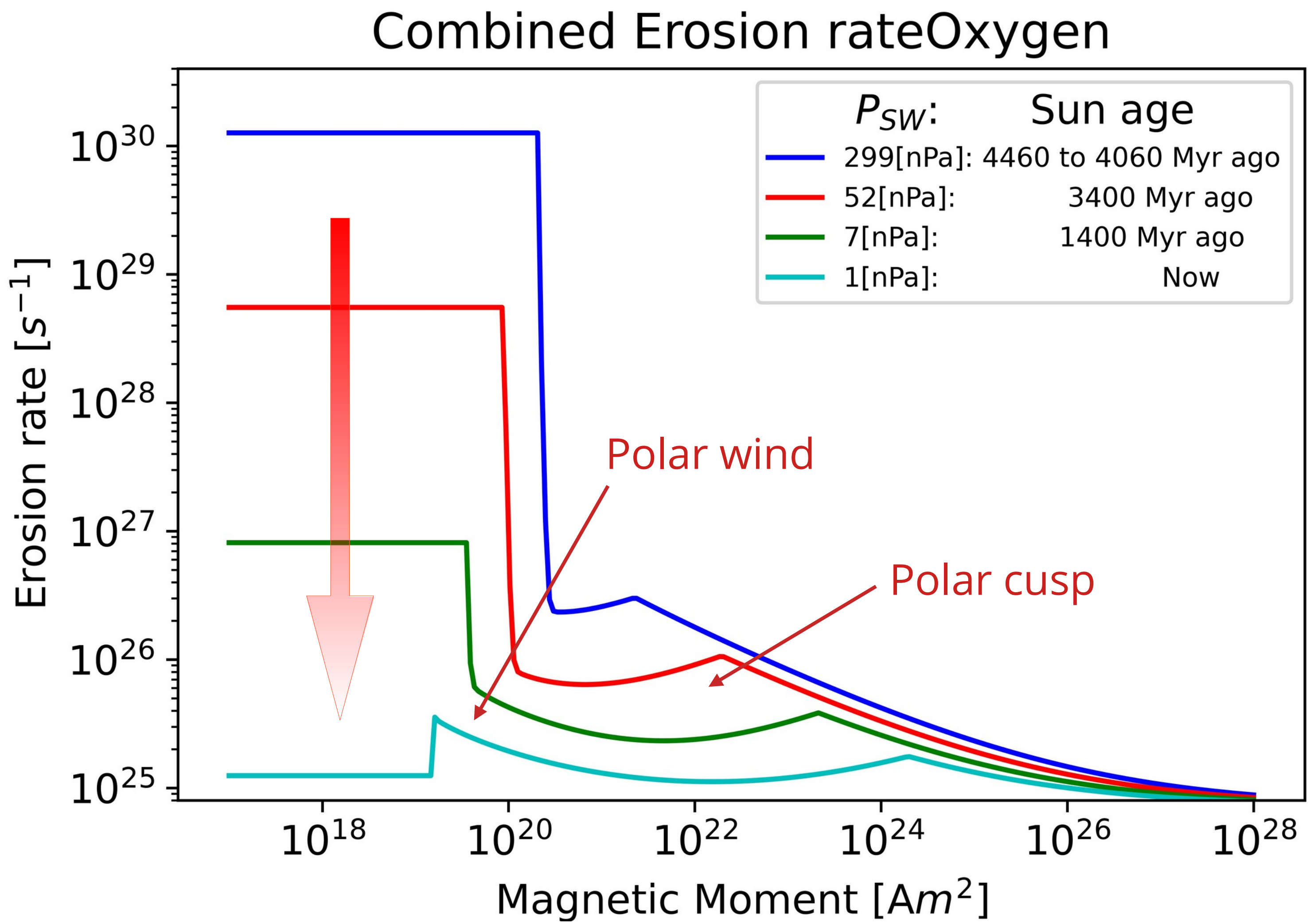

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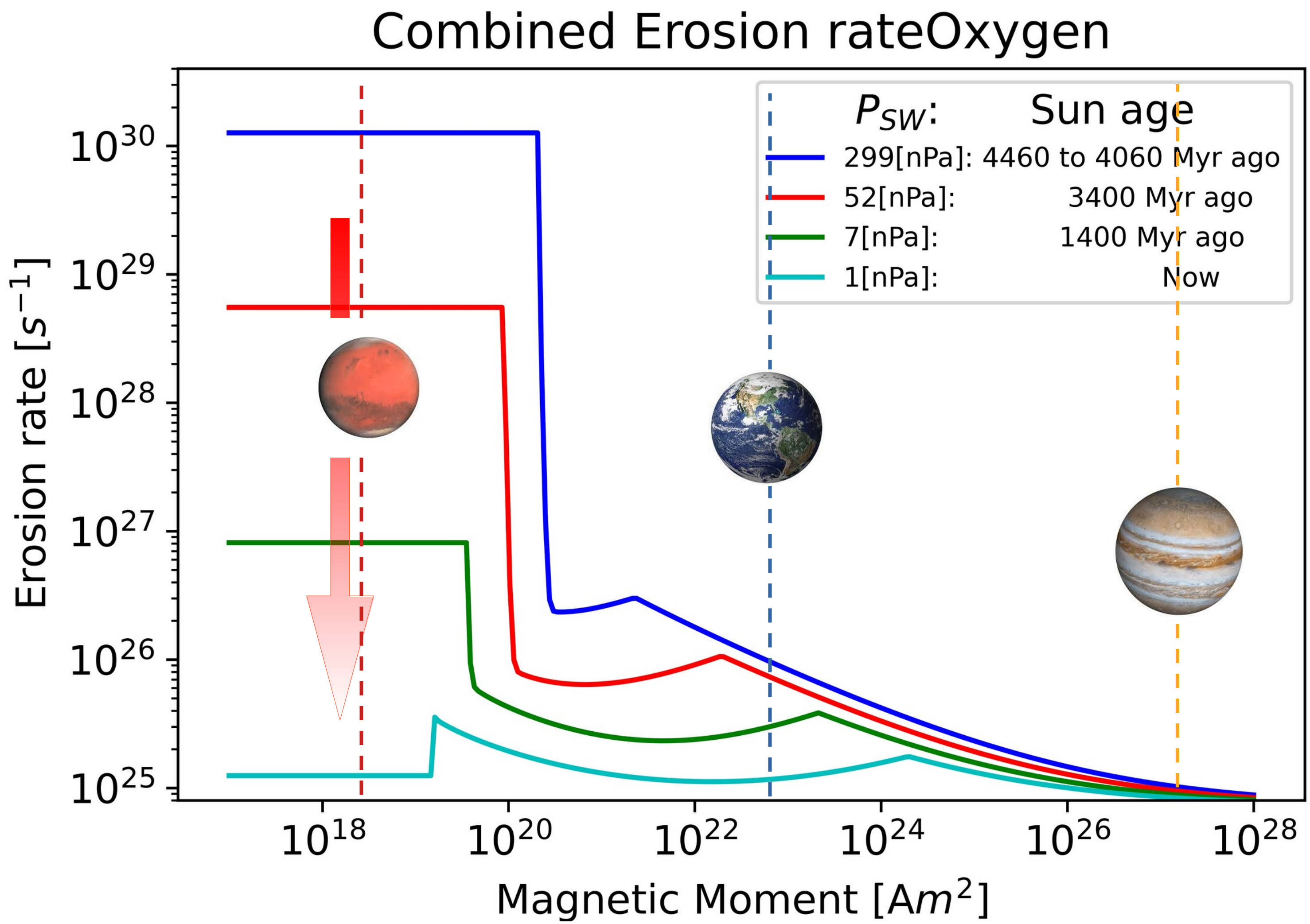

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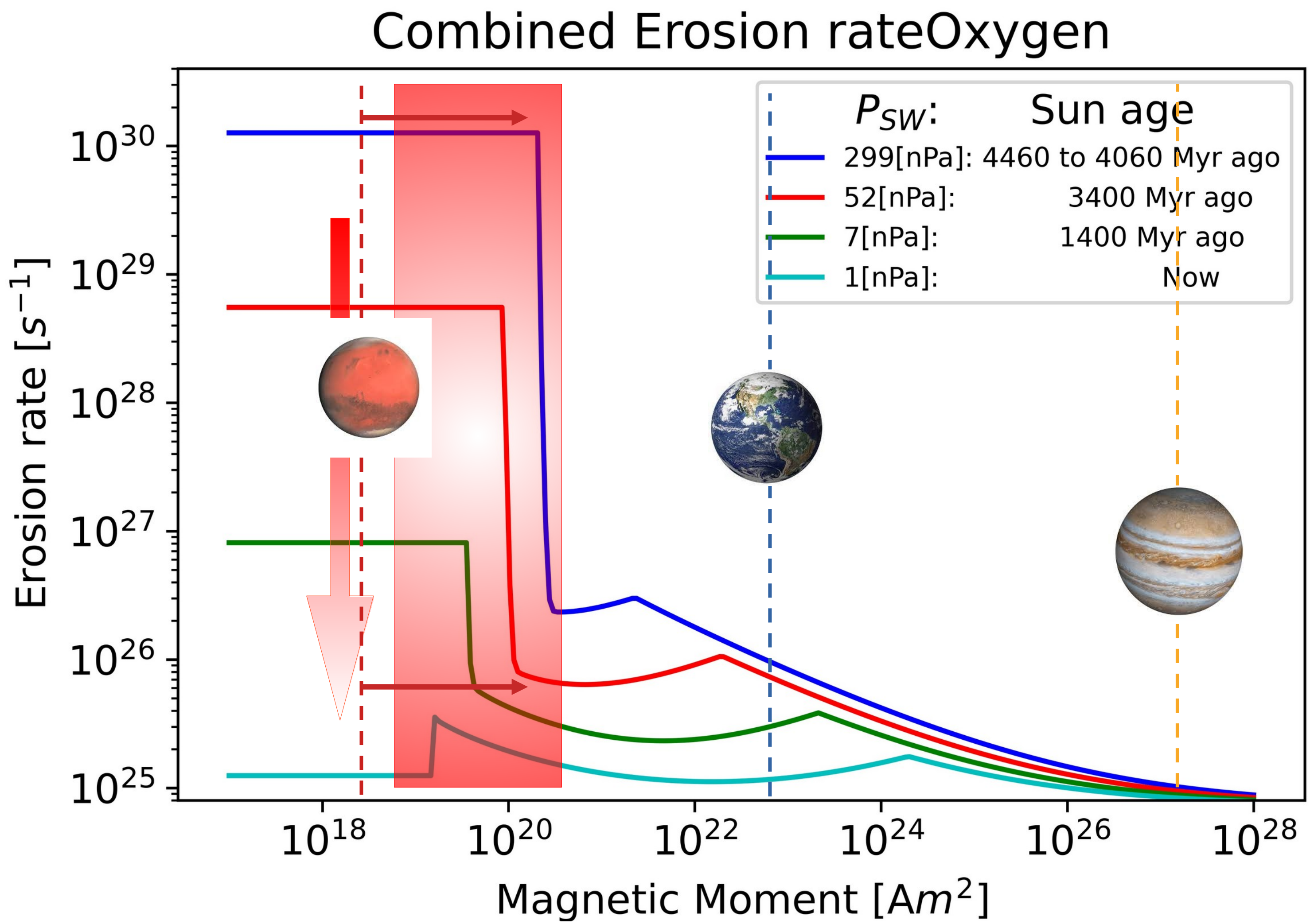
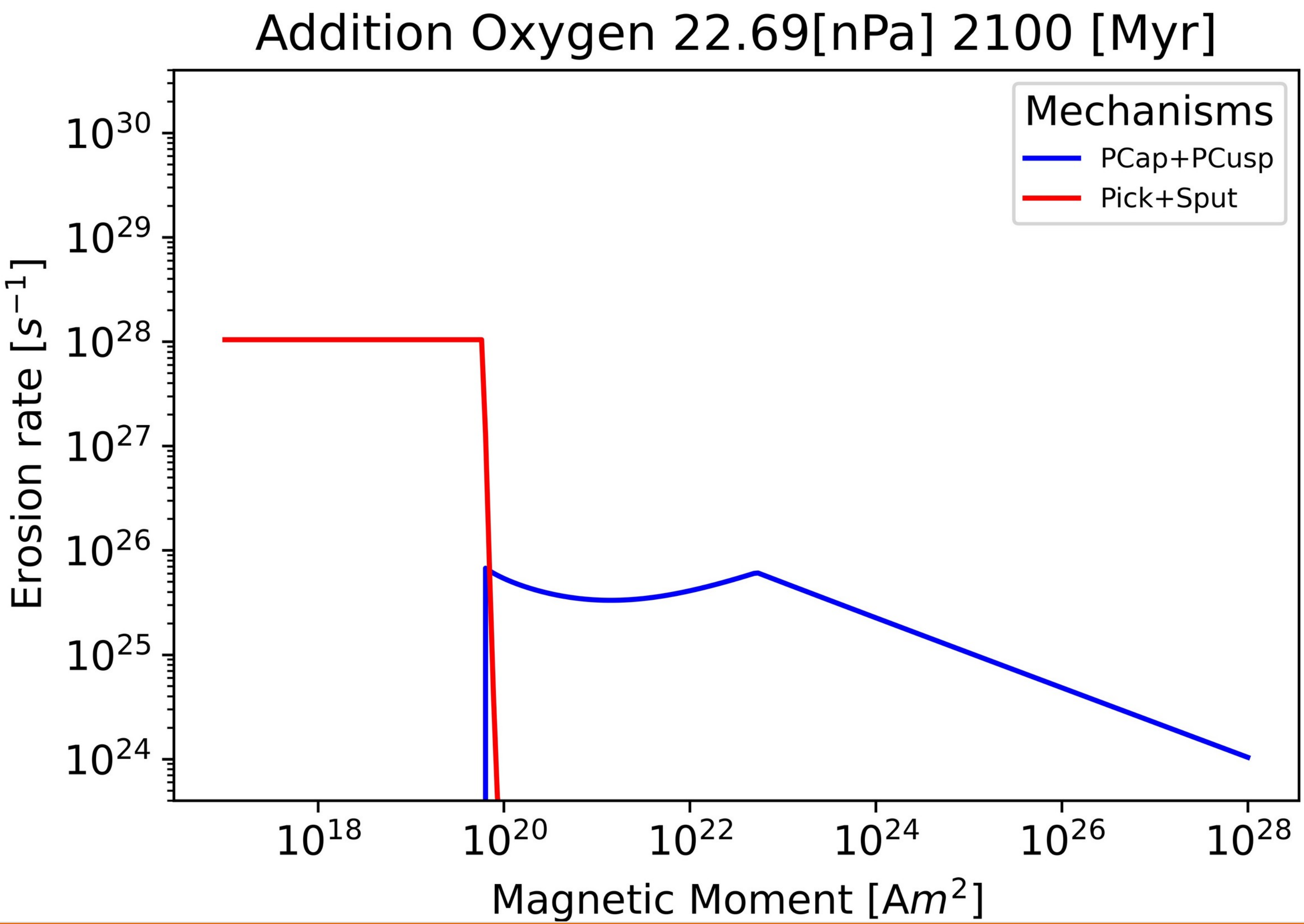


Weakly magnetized planets have coexisting erosion mechanisms.



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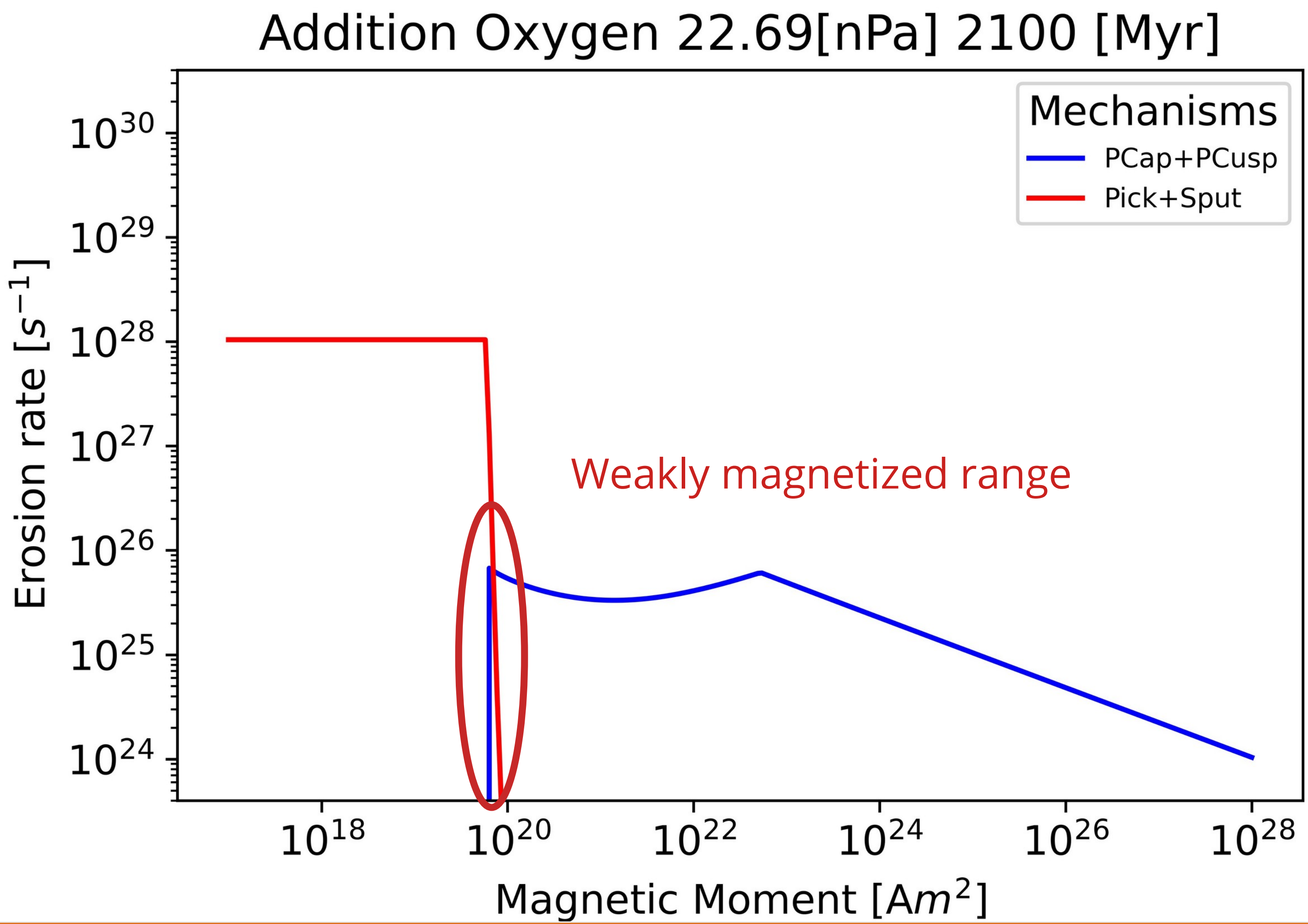

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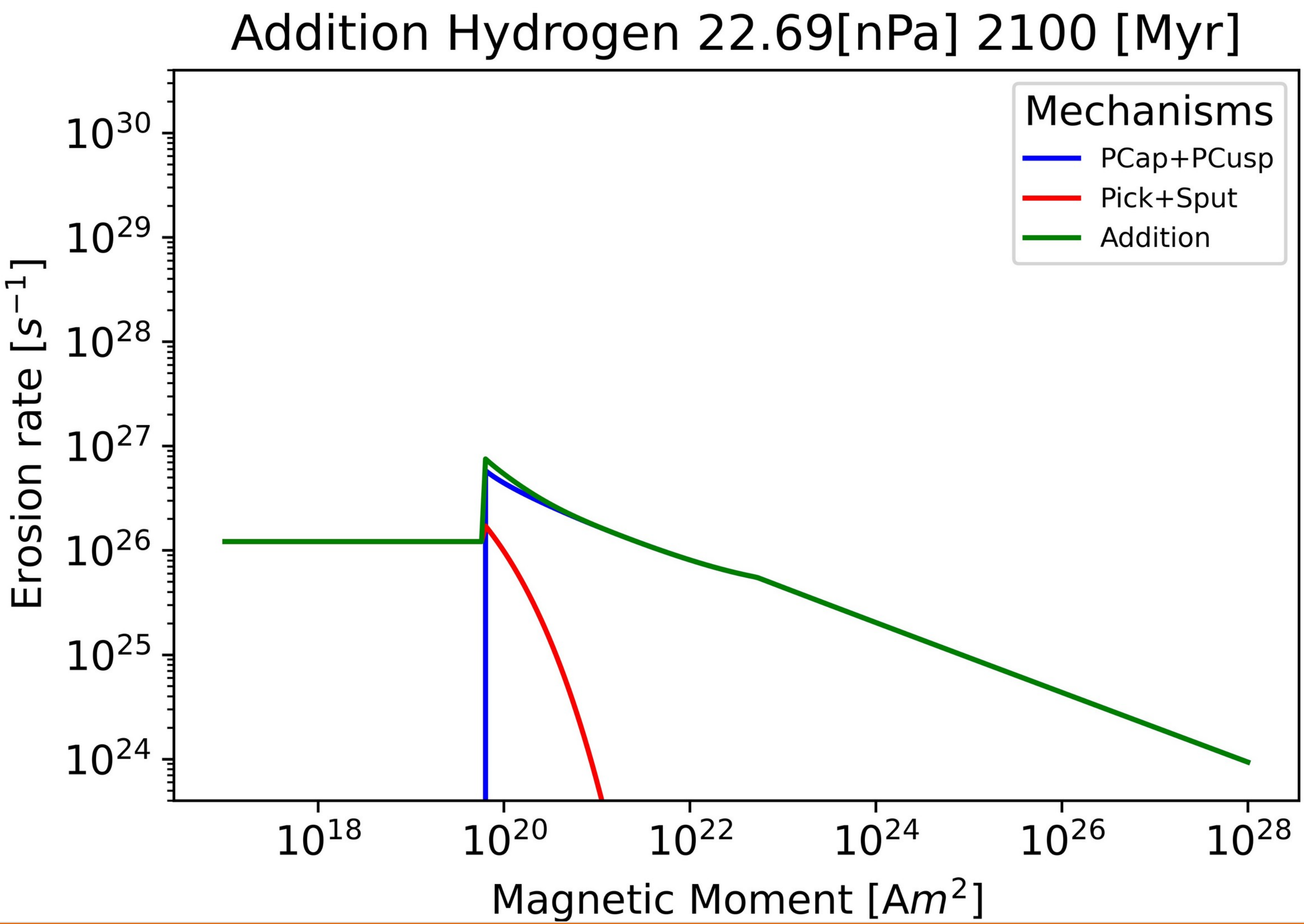

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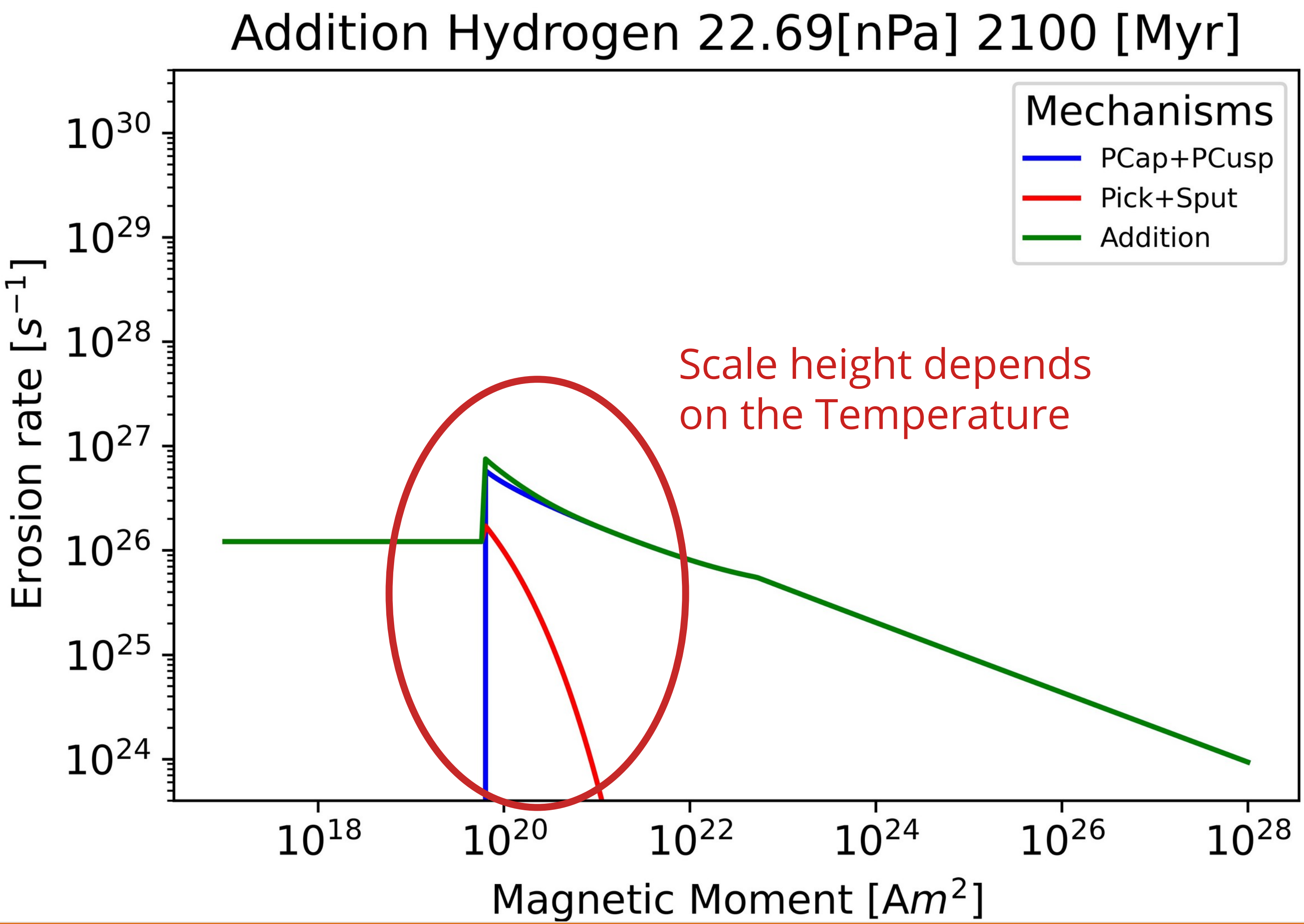
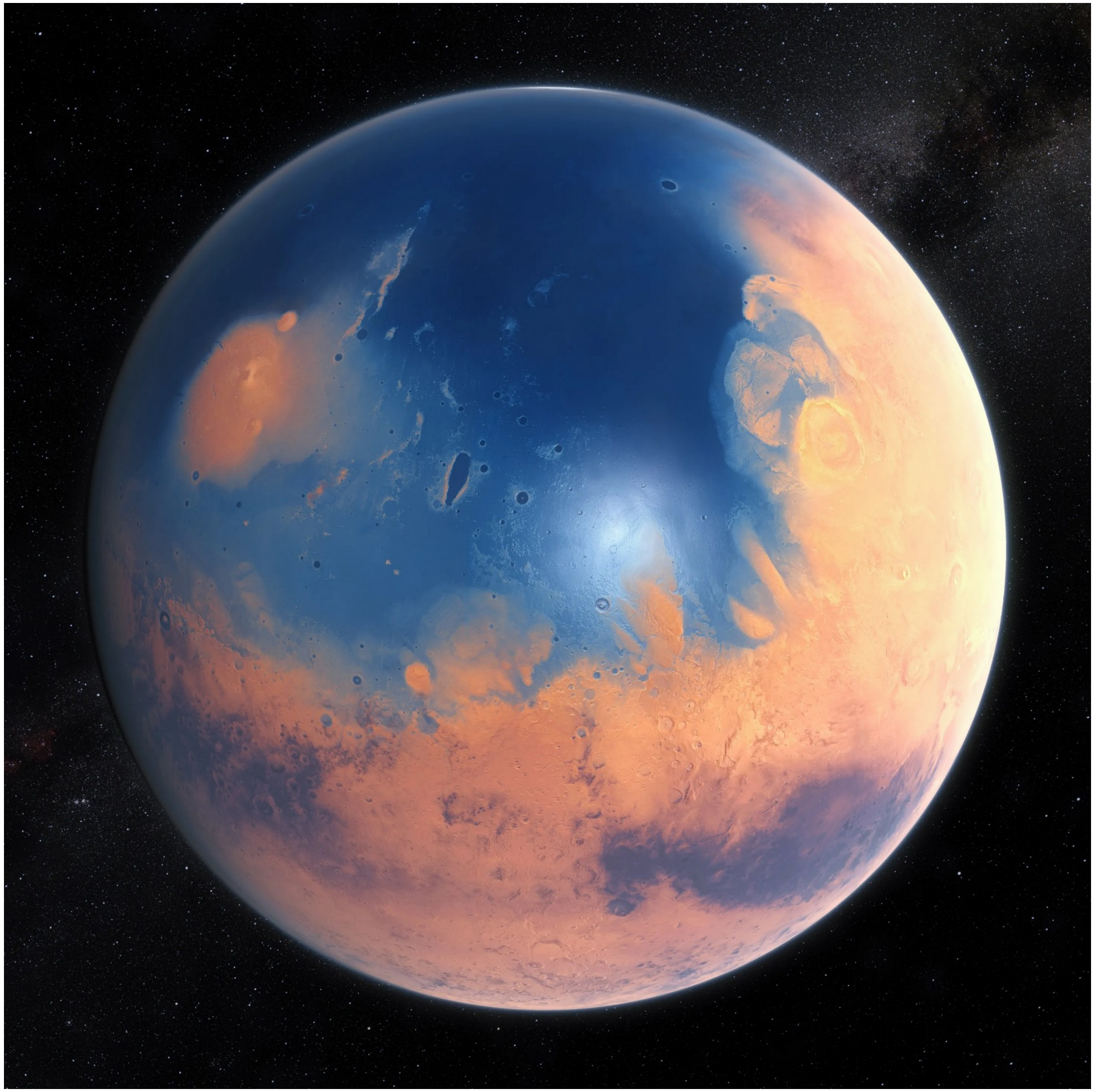


Transition region to the magnetized range is particular interesting due to the simultaneity of erosion mechanisms.



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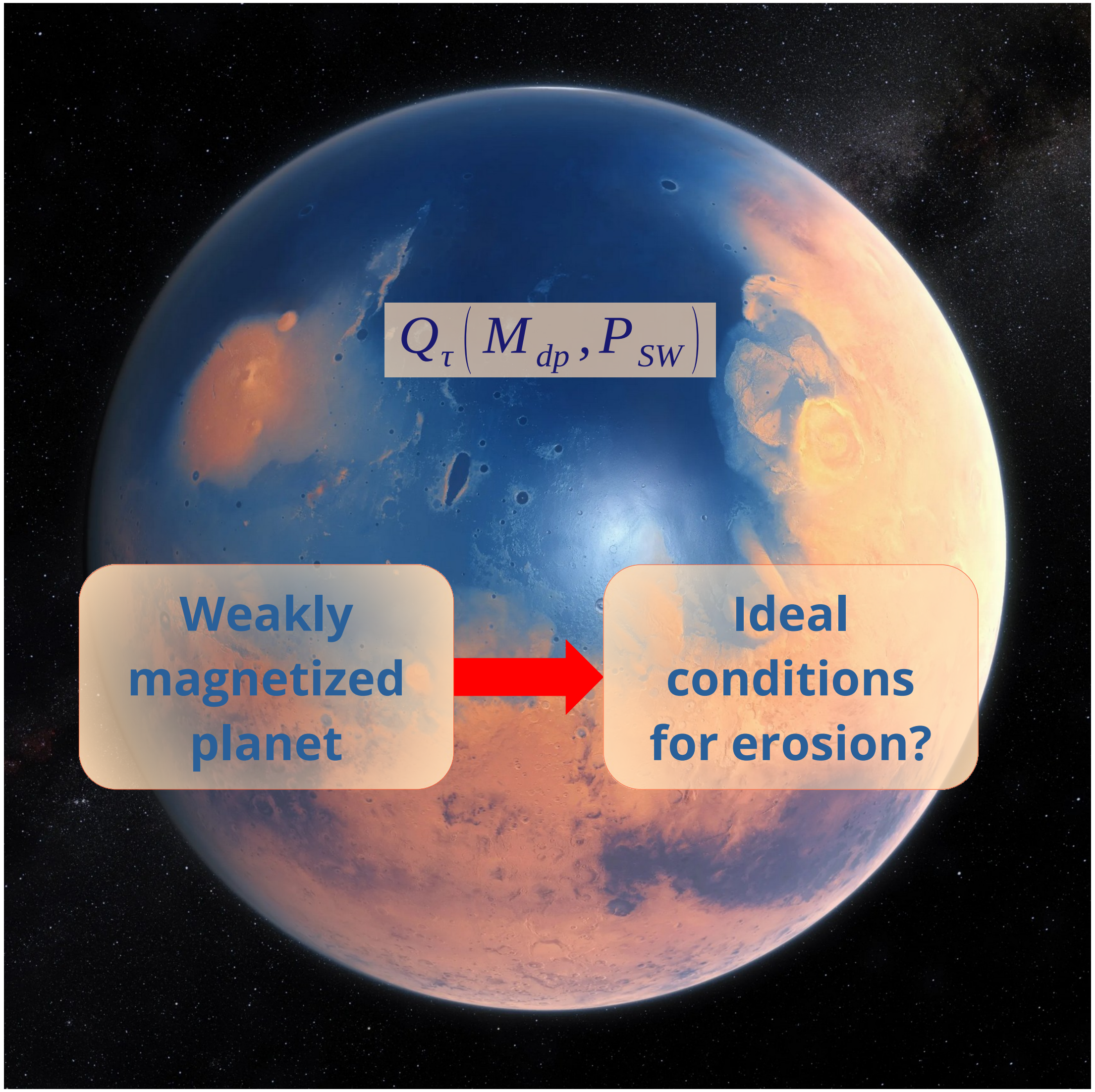

THANK YOU!
MORE INFO?

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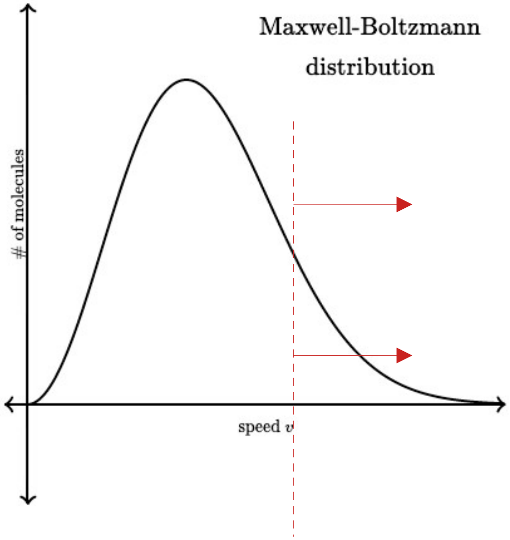
Jeans escape



The flux or particle velocity doesn't get altered by SW flux or the magnetic moment of the planet.

$$Q_{Je,\tau} = 4\pi r_{exo}^2 \sqrt{\frac{k_B T_{exo,\tau}}{2\pi m_\tau}} \rho_{exo,\tau} \left(1 + \frac{r_{exo}}{h_\tau}\right) e^{-\frac{r_{exo}}{h_\tau}}$$

with

$$h_\tau = \frac{k_B T_{exo,\tau} r_{exo}^2}{G M_{\text{planet}} m_\tau}$$

Photochemical Escape

It combines different process of escape: we will focus on dissociative recombination.

Only relevant in Mars, where dissociative recombination dominates. SW electrons recombine with O^+, creating a neutral O.

It is not altered by SW flux nor the planetary magnetic moment.

Ion pickup

Exospheric atoms are ionized by the SW. Then, they are picked up by it. It depends on the SW flux for some inonization, and the amount of neutrals that can be ionized is a function of r_{MP}.

$$Q_{pu,\tau} = Q_{0,pu,\tau}\left(\beta_{photo} + (\beta_{elec} + \beta_{ce})\frac{\rho_{SW} v_{SW}}{\rho_{SW,ref} v_{SW,ref}}\right) \times \frac{2\int_{-\pi/2}^{\pi/2}(2h_\tau^3 + 2h_\tau^2 r(\theta) + h_\tau r(\theta))e^{-\frac{r(\theta)}{h_\tau}}d\theta}{2\int_{-\pi/2}^{\pi/2}(2h_\tau^3 + 2h_\tau^2 r_{ref}(\theta) + h_\tau r_{ref}(\theta))e^{-\frac{r_{ref}(\theta)}{h_\tau}}d\theta}$$

Sputtering

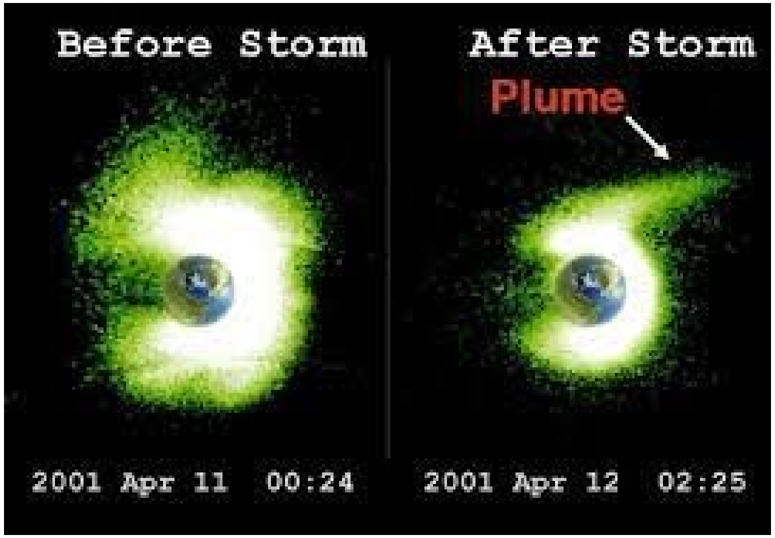
Some of the O^+ swept up and accelerated by the SW, reimpacting the exospheric atoms, giving them enough energy to escape. It depends on the particles recently picked up, as well as the neutrals in the relevant region.

$$Q_{sp} = Q_{0,sp} \frac{Q_{pu,\mathrm{O}^+}}{Q_{pu,ref,\mathrm{O}^+}} \times \frac{\int_{r_{MP}-r_g}^{r_{MP}} r^2(\theta) e^{-\frac{r(\theta)}{h_O}} dr(\theta)}{\int_{r_{MP,ref}-r_{g,ref}}^{r_{MP,ref}} r^2(\theta) e^{-\frac{r(\theta)}{h_O}} dr(\theta)}$$

Cross-Field ion loss

This includes all escape processes across magnetic field lines like plasmaspheric plumes, plasmaspheric wind.

$$Q_{cf,\tau} = Q_{0,cf,\tau}\left(\frac{1-\frac{\Omega_{pc}}{4\pi}}{1-\frac{\Omega_{pc,ref}}{4\pi}}\right)$$



Polar cap escape

Polar wind is ions that escape through the open field lines.

$$Q_{pc} = 2 \times min\left(1.1 \times 10^{12} e^{0.216 P_{SW}}, q_{max}\right) \Omega_{pc} r_{exo}^2$$

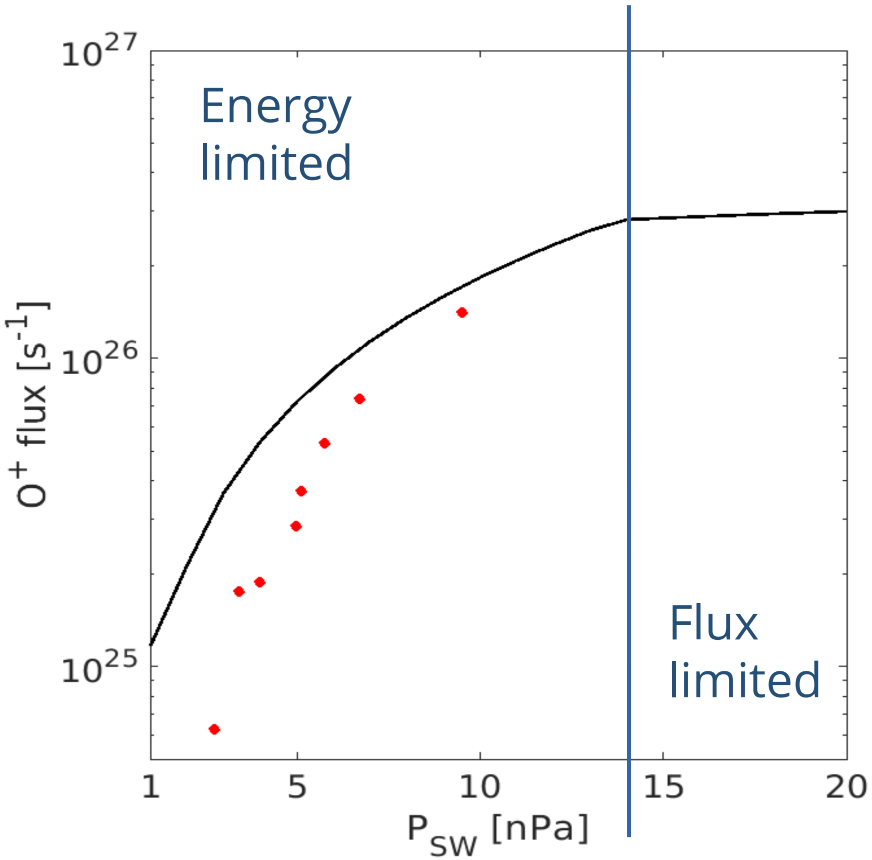
Polar cusp escape 7/7

The cusp is a section in the polar cap, to the dayside. It receives energy from the SW, mainly kinetic energy.

$$Q_{c,\tau} = min\left(Q_{0,c,\tau}\frac{r_{cs}^2}{r_{cs,E_{ref}}^2}\frac{\rho_{SW}v_{SW}^3}{\rho_{SW,ref}v_{SW,ref}^3}, Q_{max,\tau}\right)\frac{\Omega_{pc}}{\Omega_{pc,E_{ref}}}\left(\frac{r_{exo}}{r_{exo,E_{ref}}}\right)^2$$

Polar cusp escape 7/7

$$Q_{c,\tau} = min\left(Q_{0,c,\tau}\frac{r_{cs}^2}{r_{cs,E_{ref}}^2}\frac{\rho_{SW}v_{SW}^3}{\rho_{SW,ref}v_{SW,ref}^3}, Q_{max,\tau}\right)\frac{\Omega_{pc}}{\Omega_{pc,E_{ref}}}\left(\frac{r_{exo}}{r_{exo,E_{ref}}}\right)^2$$



Model: Polar observations (Pollock et al. 1990).

Observations: Cluster (Schillings et al. 2019).