

Venus, Earth, Mars: Comparative Ion Escape Rates

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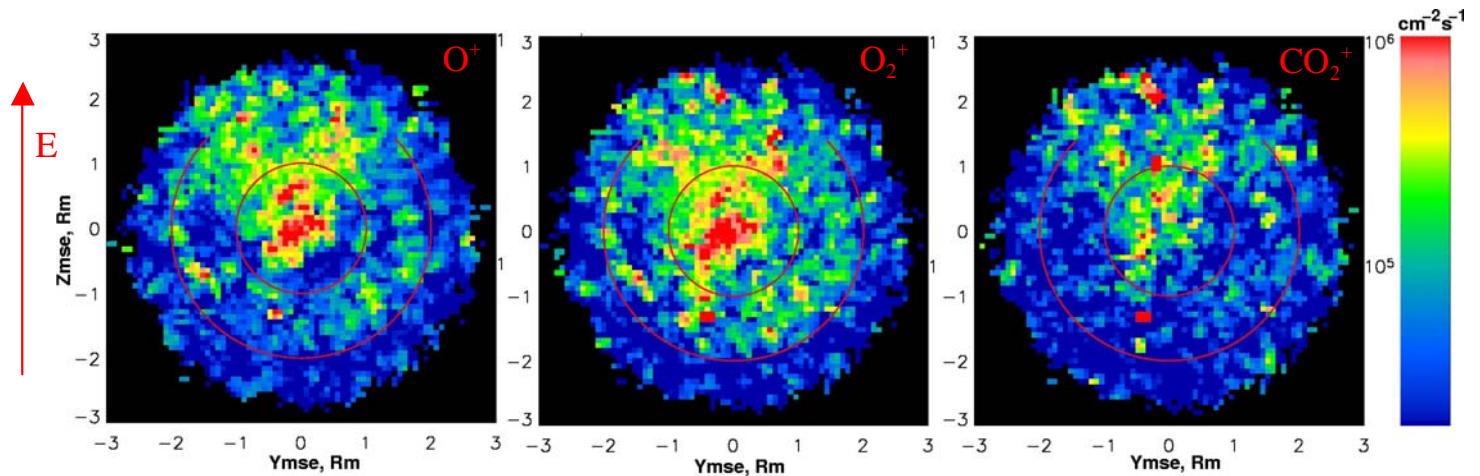
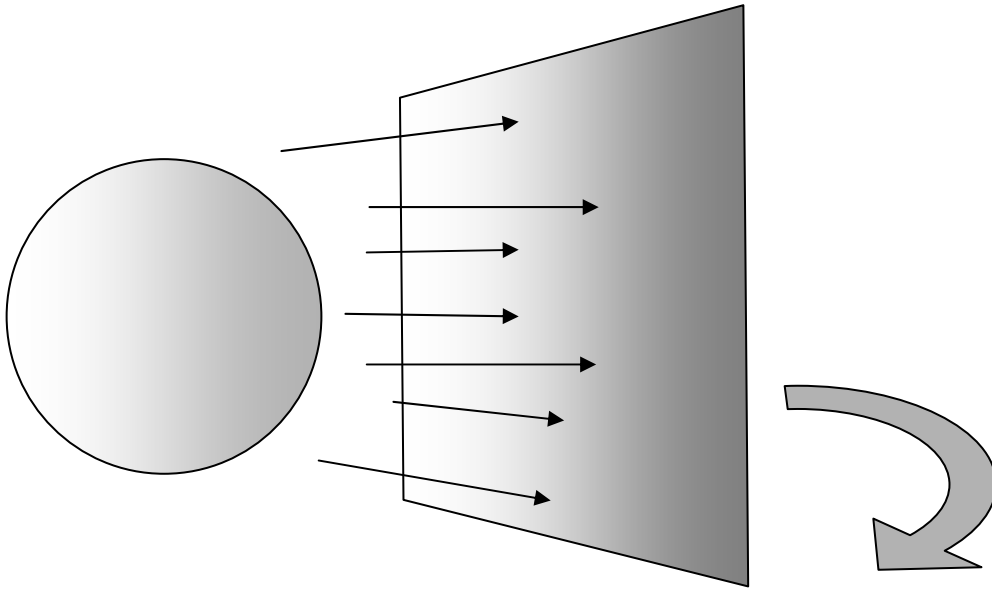
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Atmospheric escape processes

Process	Charge	Energy source
Jeans escape	N	Thermodynamic free energy
Chemical reactions	N	Thermodynamic free energy / inner energy
Photochemical reactions	N	Solar photon energy
Solar wind induced escape	I	Solar wind kinetic and magnetic energy
Polar wind	I	Electron thermodynamic free energy Magnetic field energy

Escape through a plane at 3R. Venus / Mars



Escape through a $5R_E$ sphere. Earth

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Escape rates

Planet	Escape rate	Reference
Venus	$3 \cdot 10^{24} \text{ O}^+/\text{s}$	VEX, <i>Fedorov et al., 2008</i>
Earth	$5 \cdot 10^{24} \text{ O}^+/\text{s}$ (total escape)	Geotail, <i>Seki et al., 2001</i>
	$43 \cdot 10^{24} \text{ O}^+/\text{s}$ (polar outflow, sol min)	DE-1, <i>Yau et al., 1988</i>
	$22 \cdot 10^{24} \text{ O}^+/\text{s}$ (total escape)	Cluster, <i>Arvelius et al., 2008</i>
	$67 \cdot 10^{24} \text{ O}^+/\text{s}$ (outflow)	
	$45 \cdot 10^{24} \text{ O}^+/\text{s}$ (inflow)	
Mars	$(2 \dots 9) \cdot 10^{23} \text{ O}^+/\text{s}$	MEX, <i>Science, 2007</i>

- The absolute escape for the magnetized Earth is **HIGHER** than non-magnetized Mars and Venus on a factor of 10-20
- Different conditions?

Normalized escape

$$Q'_E = \frac{Q E_{esc}}{P}$$

$$P \sim \rho V^3 A \sim \frac{A}{r^2} \quad \text{or} \quad P \sim B^2 V A \sim \frac{A}{r^2}$$

P total available power

A interaction area

r distance to the Sun

E_{esc} the escape energy

Ratios of normalized escapes

$$A (\textit{Venus}) \approx \pi (1.2R_V)^2$$

$$A (\textit{Earth}) \approx 2 \pi (2R_E)^2$$

$$A (\textit{Mars}) \approx \pi (1.5R_M)^2$$

$$\frac{Q'_V}{Q'_E} = 0.35 \quad \frac{Q'_M}{Q'_E} = 0.24$$

- The normalized escape rates relative to the earth for the terrestrial planets differ only on a factor of less than 2.
- The normalized escape for the magnetized Earth is still HIGHER than non-magnetized Mars and Venus
- More material?

Energy or matter limited?

$$\frac{M_V}{M_E} = 91 \quad \frac{M_E}{M_M} = 215$$

- The normalized escape rates for the terrestrial planets differ only on a factor of 2.
- The atmosphere's masses, M , of Venus, Earth, and Mars differs on a factor of 100 – 200.
- Escape is ENERGY limited and HIGHER from the magnetized Earth

Main point

- The large Earth magnetosphere
 - provides a larger interaction area
 - intercepts more energy from the solar wind
 - makes more energy available for ion acceleration
- Magnetospheres are NOT effectively protect atmospheres

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What does a magnetosphere?

- Escape at the Earth through the polar region is 2 times higher than the total escape
- Earth's atmosphere loses 4 times more material (relative) than Venus or Mars but 2/3 return.
- The magnetic field provides A PATH for escaping particles to return to the atmosphere

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Objections

- The escape numbers shown are wrong
 - Mars / Venus: ASPERA does not measure cold (< 10 eV) ions
 - Current re-analysis of the MEX/ASPERA-3 data may increase the escape numbers on a factor of 3
 - Earth: current measurements of the cold ion escape on Cluster
 - Hydrogen escape 10^{26} s⁻¹ (< 1 eV) is much larger than observed in the range few eV and higher (Cluster, *Engwall et al., 2009*). The earth escape should be also reconsidered!
- The atmospheric sputtering at non-magnetized planets caused by precipitated ions is the dominant escape mechanism
 - No direct measurements are available. Modeling is difficult and sensitive to not well-known diff. cross-section (0.15 - 3 bar escaped CO₂) (*Luhmann et al., 1992; Kass and Yung, 1995, 1996*)

Possible Implications

- The induced magnetospheres effectively protect the atmospheres:
- Mars lost its atmosphere due to the PRESENCE of the magnetic field for the first 1-1.5 Gy.
- Venus was not affected by the solar wind induced escape

Escape from Mars

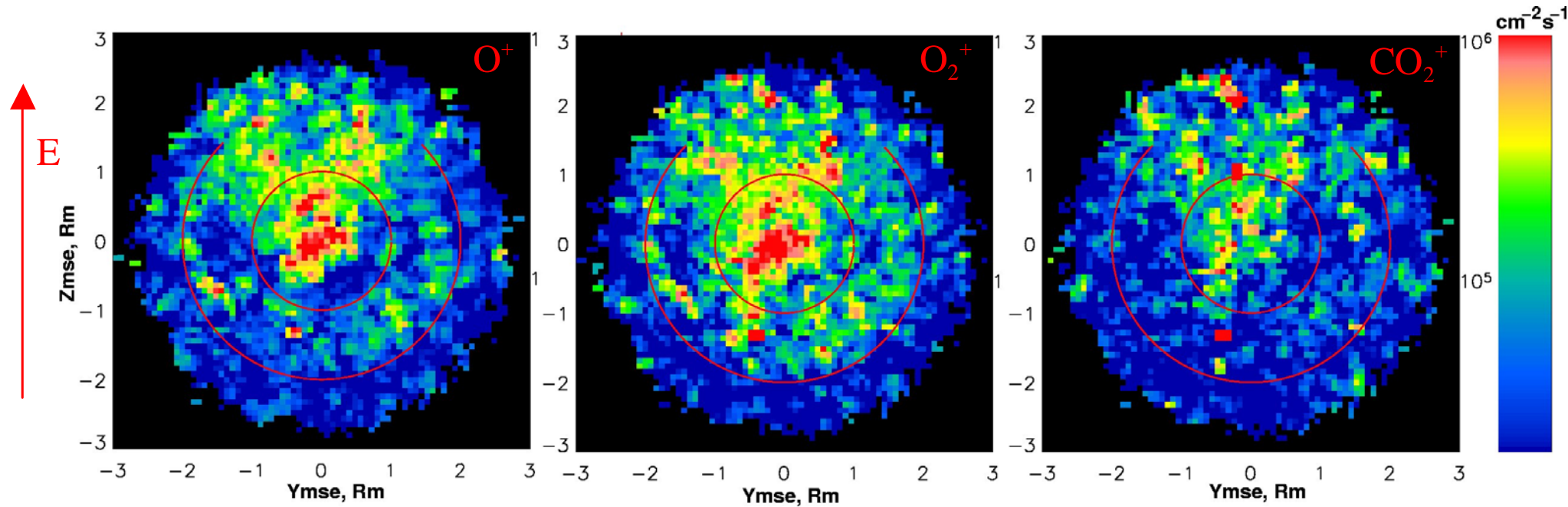


Figure 3. ZY maps of the integral fluxes ($cm^{-2} s^{-1}$) of O^+ , O_2^+ , CO_2^+ . The direction of the interplanetary electric field is shown by the red vector.

Escape from Venus

