Understanding the Earth-Venus-Mars difference in Nitrogen

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Why study Nitrogen (& N/O ratio) in space?

Nitrogen (N) is a key element for life as an inevitable part of the amino acid and protein.

(A) Formation of many pre-biotic molecules is most likely related to the **amount** and the **oxidation state** of N (reduced form like NH_3, neutral form like N_2, and oxidized form like NO_x) near the surface in the **ancient** Earth (Miller and Urey, 1959). One cannot use the present abundance of N, O, H as the ancient value because of the significant escape of ions from the ionosphere that are observed (Chappell et al., 1982, Nilsson, 2011). ⇒ Table 1&2.

(B) Abundance of N is quite different between Mars and The Earth/Venus ⇒ Figure 1.
Earth: 75% of atmospheric mass (the amount in the soil, crust, and ocean are small)
Venus ~ 2.5 times as much as Earth (3% of $P_{atom.Venus} = 90 \times P_{atom.Earth}$)
Titan ~ 1.5 times as much as Earth (98% of $P_{atom.Titan}$)
Mars ~ only 0.01% of the Earth/Venus (note: M_{Mars} ~ 10% of M_{Earth}): This is a mystery because
(1) O is abundant in all three planets (Martian case, exist in the crust as oxidized rocks);
(2) N is much more difficult to be ionized than O due to triple chemical binding (i.e., more difficult to escape).

(A)&(B) ⇒ **Need a good observation-based model of atmospheric evolution (escape), for both the total amount of N and its relative abundance against O and H (for oxidation state of nitrogen).**

⇒ Need to understand the dynamic of N (& its difference from O) at different solar conditions for whatever the planet.

Magnetized (Earth)

Increase in	FUV (or T)	P_{sw}	B_{sun}	MeV e^-
Pick-up (small)	unchange	(+?)	unchange	unchange
Large-scale	(unchange?)	++	+(+++?)	(unchange?)
Non-thermal heating	+++	+++	++	(+?)
Jeans & photo-chemical	+++ for H+	unchange	unchange	(+?)
O^+/H^+ ratio of escape	??	+++	++	(++?)
N^+/O^+ ratio of escape	(+?)	(+?)	(?)	(++?)

Table 1&2: Expected change in the escape of H, O, N (increase level +, ++, or +++) in response to enhanced input from the sun. Inside parenthesis () means no relevant observation, and the increase is guessed from physical consideration. The effect of FUV increase is mainly through heating at upper atmosphere (increase in T). Increase in solar B causes increase in |B| and variation dB, latter of which is largely influenced by the sunspot activities.

Unmagnetized (Mars/Venus/ Ancient Earth)

Increase in	FUV (or T)	P_{sw}	B_{sun}	MeV e^-
Pick-up (important)	++	++	+	(unchange?)
Large-scale	(+?)	(++?)	(++?)	(unchange?)
Non-thermal heating	(++?)	++	++	+++
Jeans & photo-chemical	+++ for H+	unchange	unchange	(+?)
O^+/H^+ ratio of escape	??	(+++?)	(+?)	(++?)
N^+/O^+ ratio of escape	(?)	(?)	(?)	(++?)

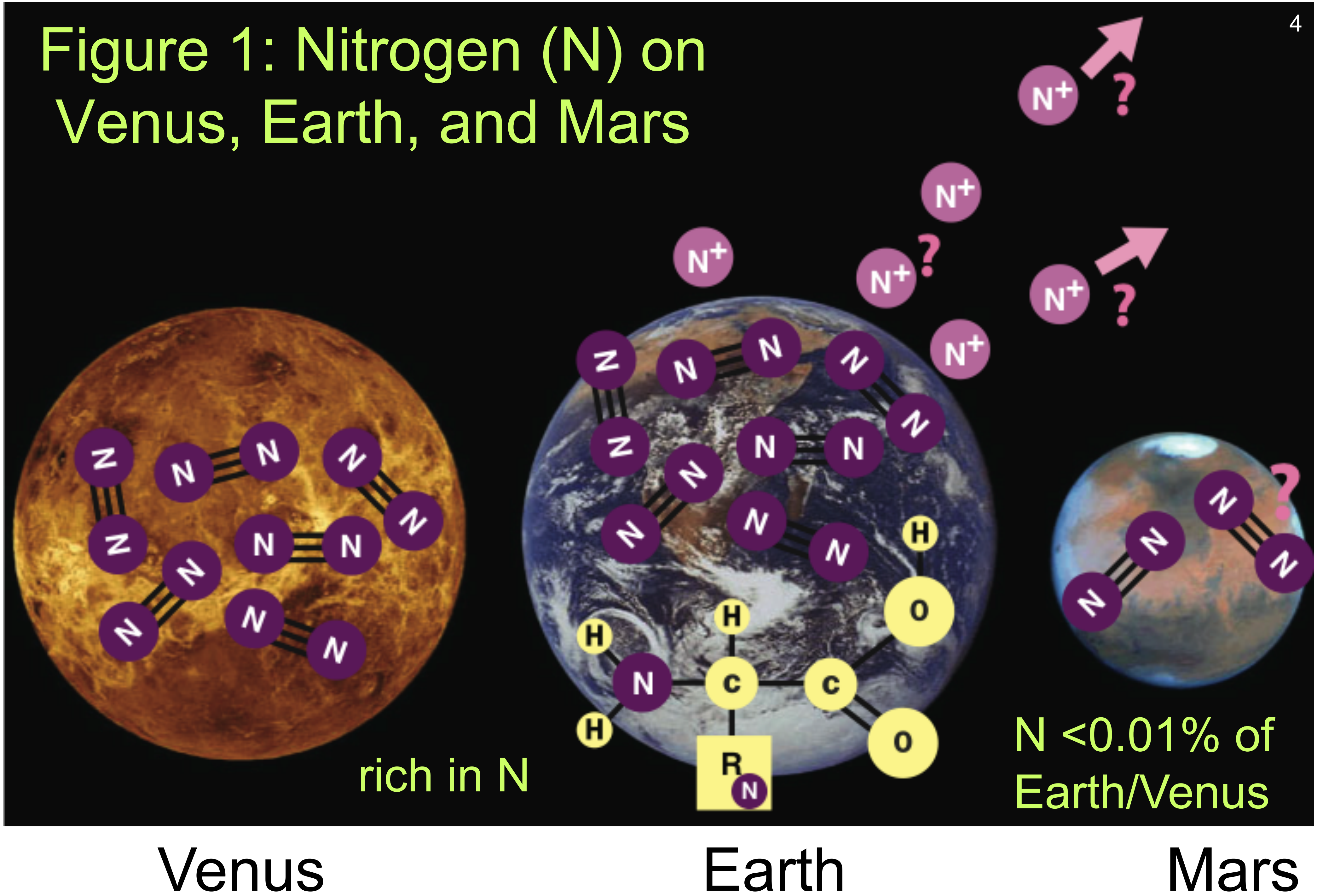


Figure 1: Nitrogen (N) on Venus, Earth, and Mars

Unfortunately, N^+ observation is missing

Despite
(a) N^+ behavior is quite different from O+ behavior according to ion observation at < 50 eV (triple-binding N_2 with triple binding is more difficult to be dissociated than double-binding O_2);
(b) <CNO group>$^+$ at this energy range is abundant in the magnetosphere,

all magnetospheric mission failed to separate non-thermal N^+ or N_2^+ from O^+ or O_2^+ at energy range 50 eV ~ 10 keV (N^+ was separated from O^+ only at < 50 eV by RIMS on board DE-1 and by SMS on board Akebono). This is because the time-of-flight instrument did not perform the promised M/ΔM > 8 due to high cross-talk from H+ and scattering by start surface.

However, the technology is within reach!

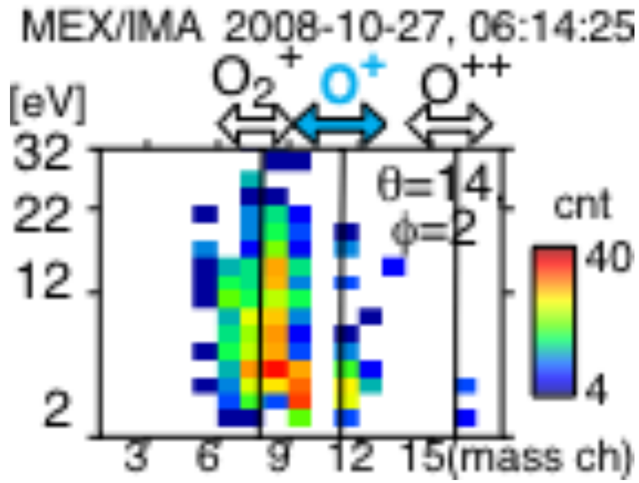


Figure 2: Mars Express (MEX) Ion Mass Analyser (IMA) detected $C^+/N^+/O^+$ group in 4 mass channels (ch.10, 11, 12, 13, where ch.11 was not working for MEX) out of total 32 channels. IMA uses only 5 cm magnet to separate mass-per-charge, and by doubling the magnet to 10 cm, the mass resolution most likely achieve M/ΔM = 8 if we allow to miss H^+, He^{++}, and He^+ (they will be bent by the magnetic field toward outside the detector).

Table 3: scientific questions related to the evolution of the atmospheric N and N/O ratio

Science Question	**What and where should we measure?**	**requirement**
Nitrogen (N) escape history compared to oxygen or hydrogen	N^+, O^+ and H^+ at different solar and magnetospheric conditions at both high and low latitude.	**#1**, $\Delta t<1$min
Filling route to the inner magnetosphere of N^+, O^+, H^+	N^+, O^+ and H^+ at different solar and magnetospheric conditions at low latitude.	**#1**, $\Delta t<1$min
N-O difference in energy gain in the ionosphere in response the input energy	N^+, O^+ and H^+ at different solar conditions, field-aligned current, and electron precipitation at high latitude	**#1**, precipitating electron, $J_{//}$ and outflowing ions
Relative contribution of each energization mechanisms for ion acceleration	energy difference (including cutoff energy) among N^+, O^+ and H^+ at different altitude	**#1**, $\Delta t<1$min

#1: N^+-O^+ separation ($M/\Delta M \geq 8$ for narrow mass) and H^+-He^+-O^+ separation ($M/\Delta M \geq 2$ for wide mass) at $\perp$ and // directions at 10-1000 eV (11 km/s~9 eV for N) with $\Delta E/E \leq 7\%$ ($(E_{O+}-E_{N+})/E_{N+}=15\%$)

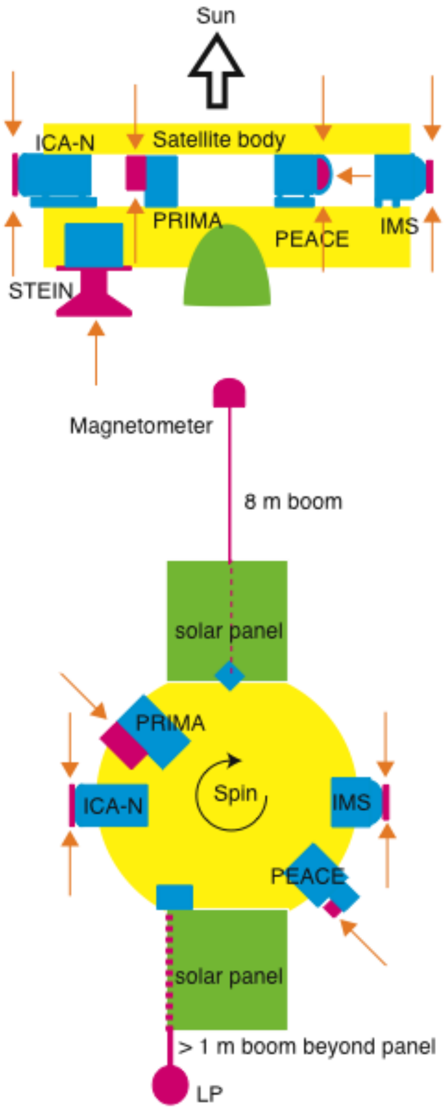
⇒ Nitro Mission

Submitted to ESA's call for small mission (2012.06).

Further study (2012.08).

(1) evolution of the atmospheric N that is different from O
(2) ion circulation in the magnetosphere
(3) ion acceleration in the magnetosphere
(4) local ion energization processes in the inner magnetosphere
(5) polar ionospheric response to input energy
(6) compliment RBSP, ERG, and e-POP missions.

Nitro scientific instruments



SI mass(*a)	function	resolution	G-factor & Δt for full E
ICA-N <5.5 kg	**Hot ion (N^+-O^+ separation)**	**$\Delta E/E$=7%, 10-5000 eV/q m/Δm=8 (only m/q > 8)**	**$3.5\cdot10^{-4}$ cm^{2}sr^1 <6s, (2kbps)**
IMS <6.0kg	**Hot ion (H^+-He^+-O^+-O_2^+ separation)**	**$\Delta E/E$=7%, 10-5000 eV/q, m/Δm~4 (m/q ≥ 1)**	**10^{-4} cm^{2}sr^1 <1s, 7kbps**
PRIMA <2.4kg	**Cold ion (N^+-O^+ separation)**	**$\Delta E/E$ = 15%, 5-100 eV/q m/Δm=8 (m/q ≥ 1)**	**$0.5\cdot10^{-4}$ cm^{2}sr^1 <1s, (0.5kbps)**
MAG <2.3kg	Ion cyclotron wave	< 35 pT (SC cleanness limits to < 0.5 nT)	<0.1s, 1.5kbps
PEACE <4.0kg	Electron	$\Delta E/E$= 13%, 1-10000 eV/q	$6\cdot10^{-4}$ cm^{2}sr^1 <0.2s, 5kbps
STEIN <2.4kg	Energetic Neutral Atoms (no mass)	∑5000-30000 eV/q	$2\cdot10^{-2}$ cm^{2}sr^1 <60s, 7kbps

(*a) mass includes shielding against radiation belt particles

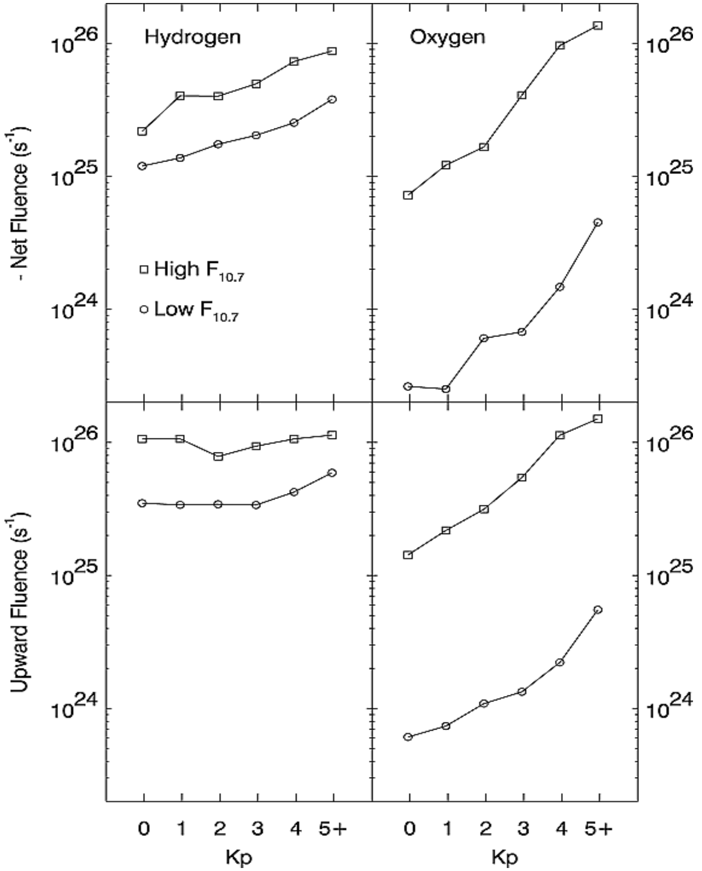
Orbit: 3~6 R_E x 800~2000 km polar (inc=90°) orbit, with total payload of about 21 kg including shielding against radiation belt particles

Summary

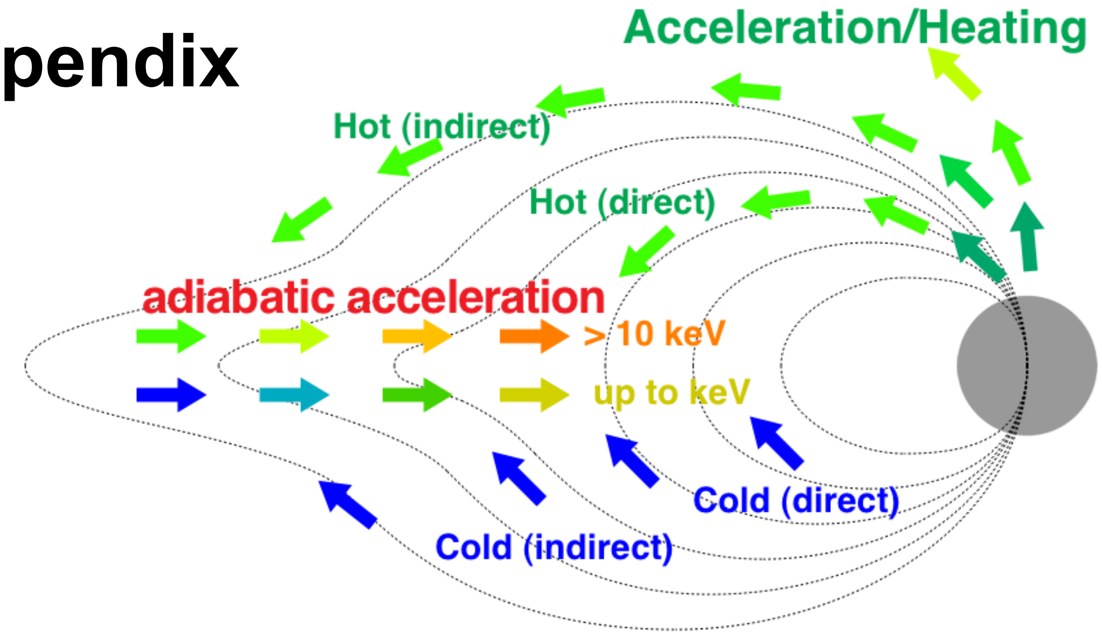
(1) Understanding the non-thermal nitrogen escape is essential in modeling both the ancient atmosphere of the Earth and the Martian nitrogen mystery.
(2) Technology to separate N+ and O+ with light-weight instrument just became available, and therefore, we need a dedicated mission to understand N+. This is mission Nitro.

Appendix

H^+< 50 eV O^+< 50 eV



ion escape (Cully et al., 2003)

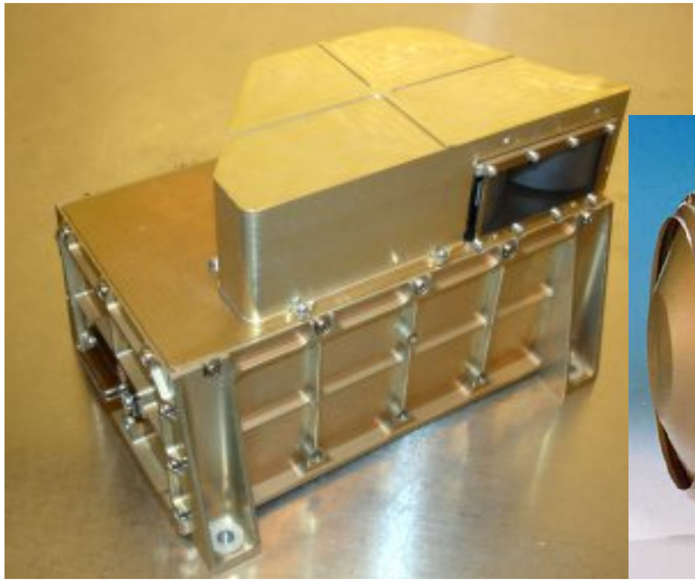


Ion circulation in the magnetosphere

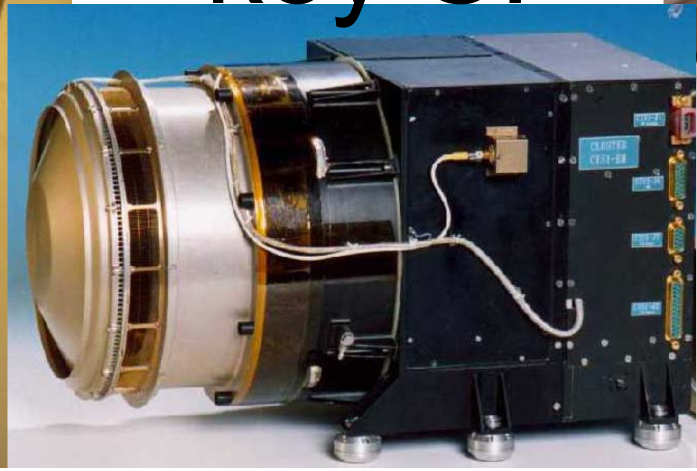
Species	H^+	O^+	N^+	Meteor
Out (2~4 R_E)	$10^{25\sim26}$/s	$10^{25\sim26}$/s	?	0
In (800km)	$10^{24\sim25}$/s	?	?	0.5 kg/s

Mass budget for the Earth

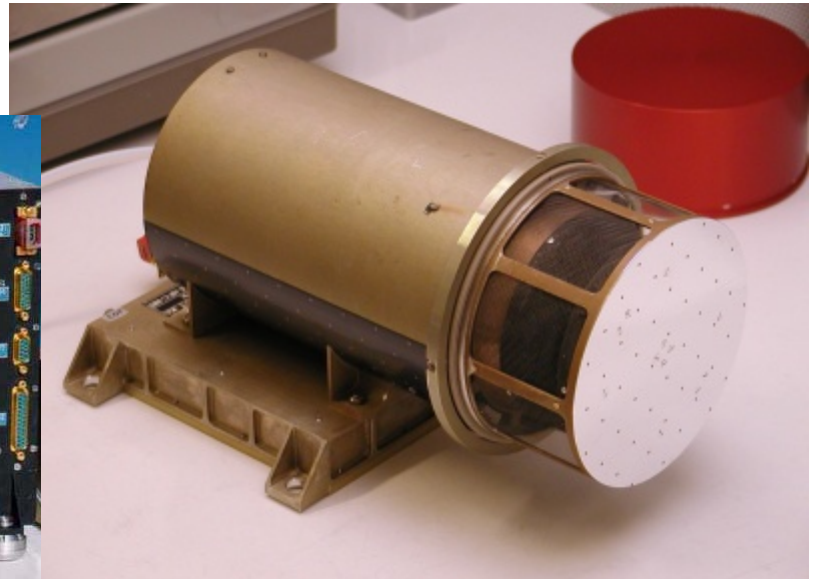
key SI



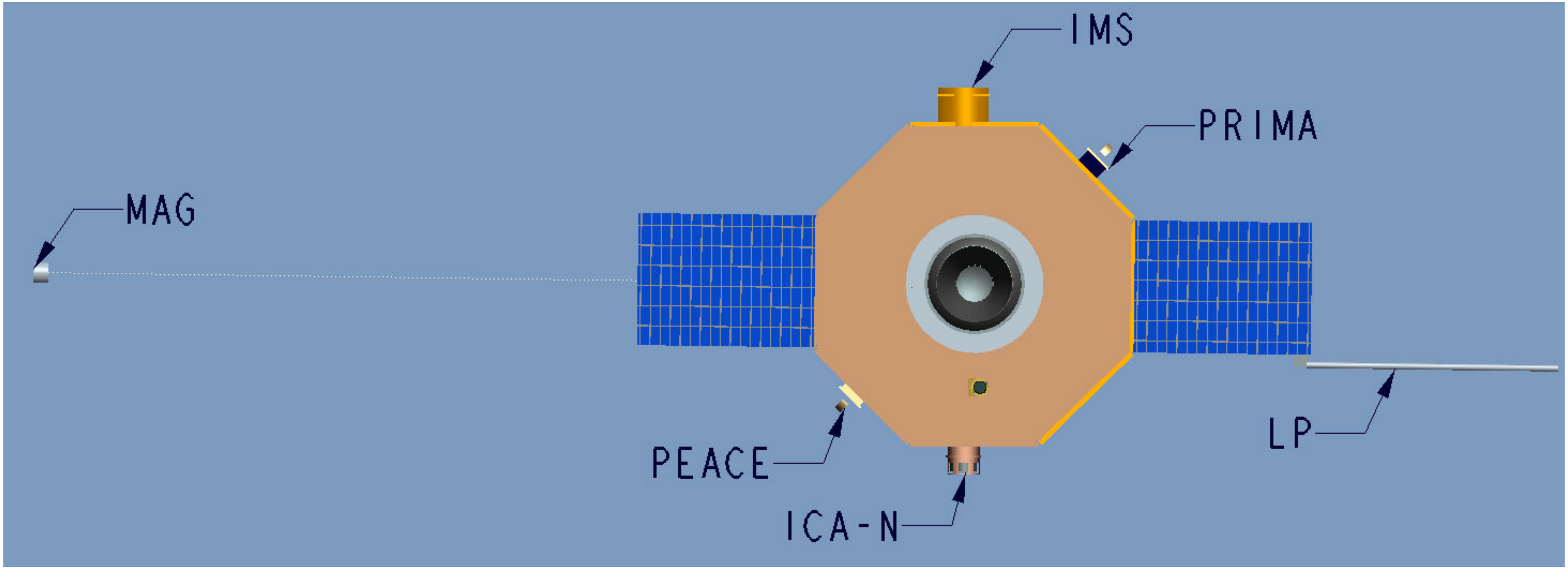
Prima



IMS



ICA



Summary

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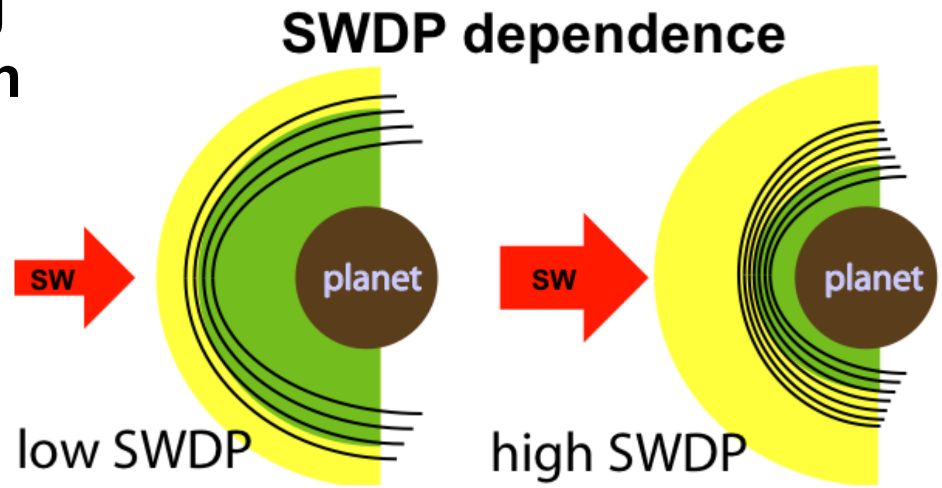
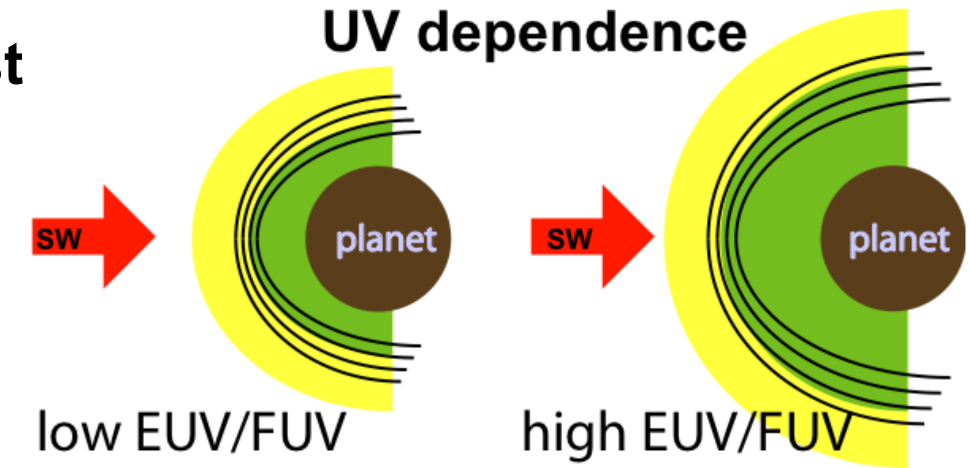
(1) Understanding the non-thermal nitrogen escape is essential in modeling both the ancient atmosphere of the Earth and the Martian nitrogen mystery.



(2) Unfortunately, past magnetospheric missions could not N^+/O+ for < 50 eV because of high cross-talk in TOF instruments.

(3) Now, the technology to separate N+ and O+ with light-weight instrument just became available.



(4) Therefore, we need a dedicated mission to understand N+. This is the Nitro mission, that was proposed to ESA.