Post-Cluster: Need for a mission to understand Nitrogen in space

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

(A) Nitrogen is an essential element of life: **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).

(B) N/O ratio is quite different between the brother plants

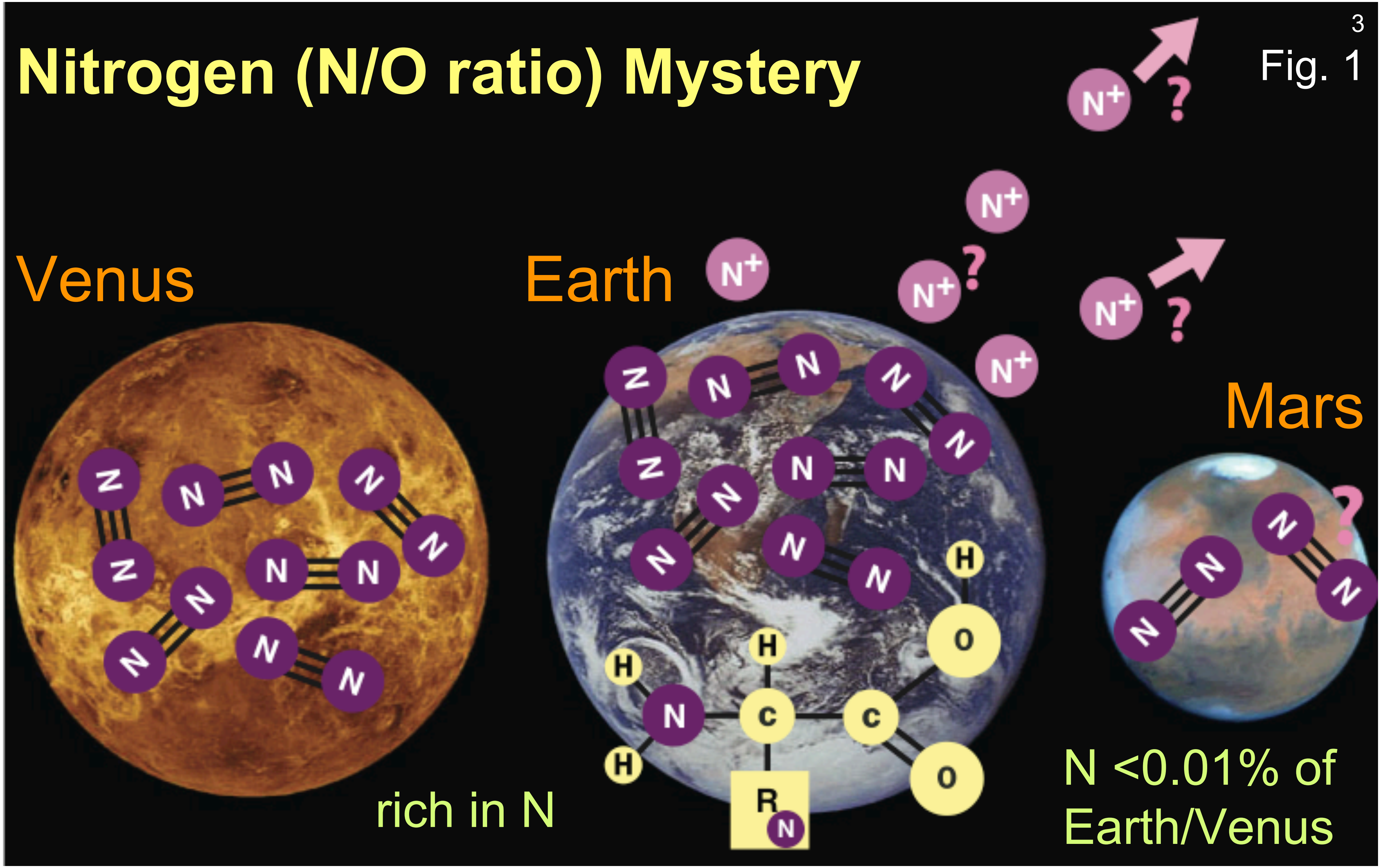
Earth: 75% of atmospheric mass (the amount in the soil, crust, and ocean are small)
Venus ~ 2.5 times as much as Earth (3% of $P_{atom.Venus} = 90 \times P_{atom.Earth}$)
Titan ~ 1.5 times as much as Earth (98% of $P_{atom.Titan}$)
Mars ~ only 0.01% of the Earth (note: $M_{Mars} \sim 10\%$ of M_{Earth}): This is a mystery because while O is abundant in all three planets (Martian case, exist in the crust as oxidized rocks)

(C) With similar mass, N^+ dynamics and O^+ dynamics are different

N is much more difficult to be ionized (to escape) than O due to triple chemical binding.

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

(D) But past instruments failed to separate N/O for 0.1 - 10 keV



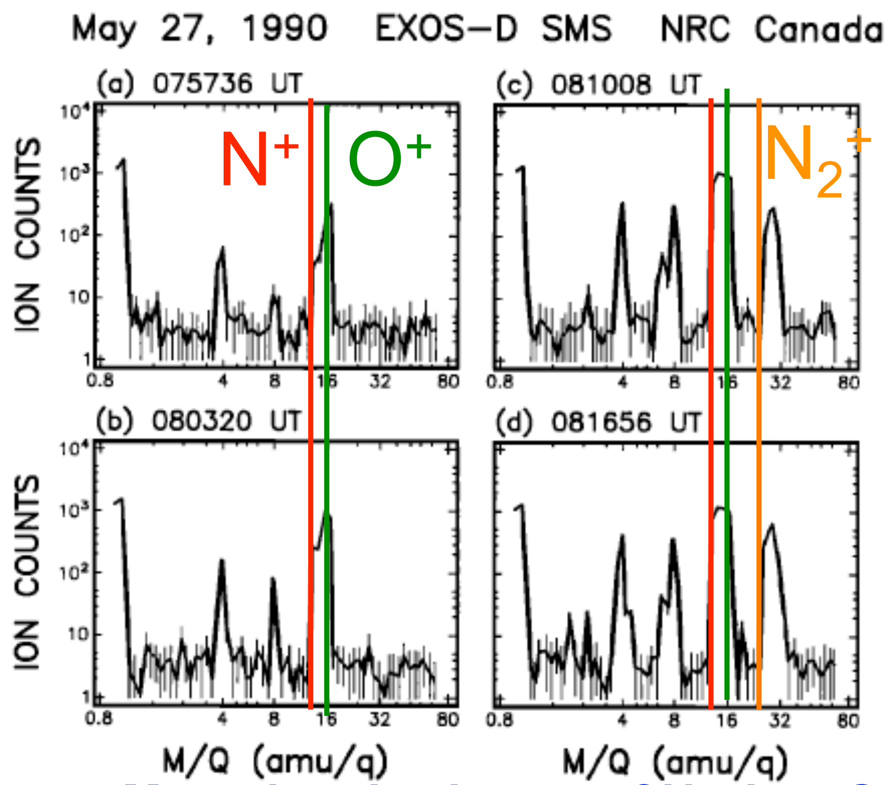
N/O ratio at Mars << at the Earth, Venus, Titan

Present knowledge on N^+ dynamics

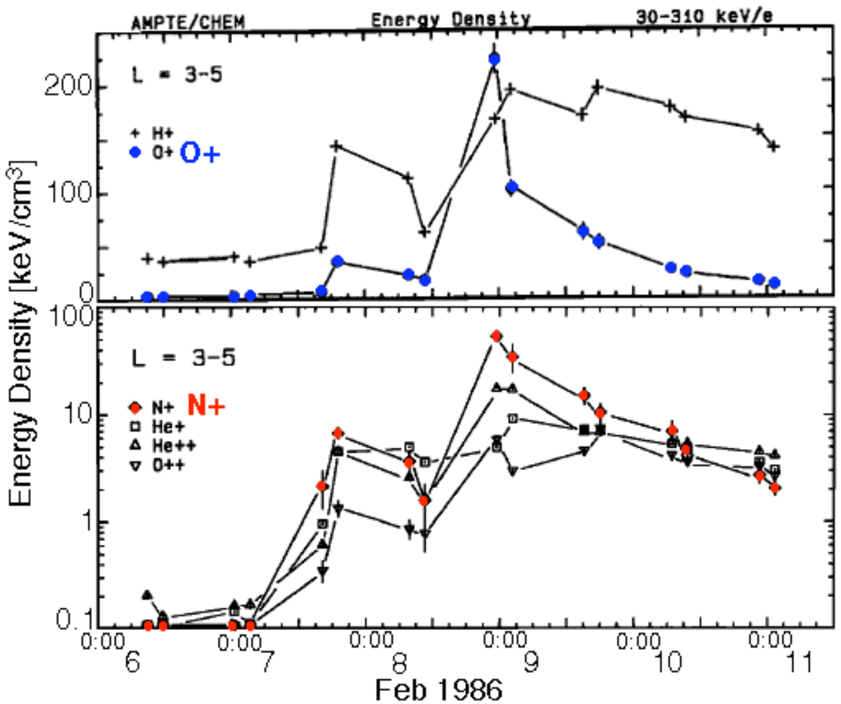
(a) N^+/O^+ ratio varies from <0.1 (quiet time) to ≈ 1 (large storm). What we call O^+ is eventually a mixture of N^+ than O^+.

(b) Dependence on geomagnetic activities is larger for N^+ than O^+ for both <50 eV (Yau et al., 1993) and > 30 keV (Hamilton et a., 1988).

(c) N/O ratio at Mars is extremely low compared to the other planets.



AMPTE/CHEM (Hamilton et al., 1988)

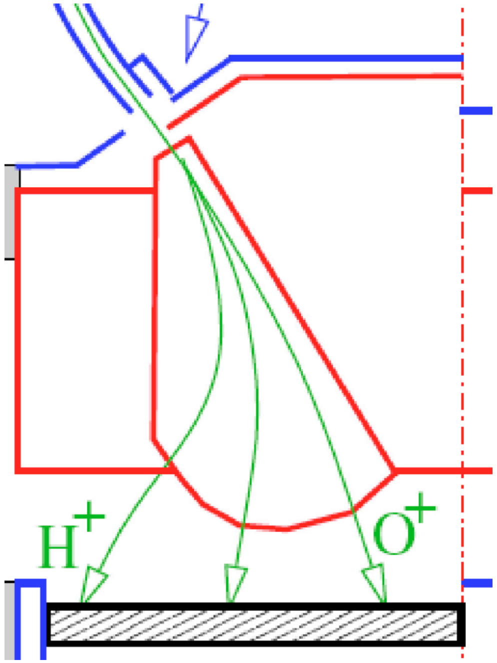


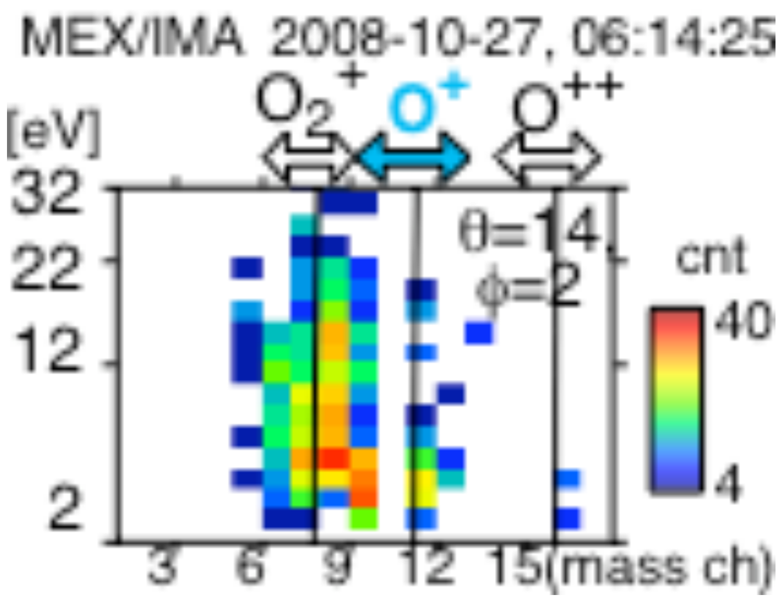
More drastic change of N^+ than O^+ for < 0.05 keV and > 30 keV.

(d) CNO group at <10 keV range is abundant in the magnetosphere.

Unfortunately, past magnetospheric mission have not yet separated hot N^+ from O^+ at 0.05~10 keV range. The past time-of-flight instrument did not perform the promised M/ΔM > 8 due to high cross-talk and scattering by start surface.

However, the technology is within reach!





example: MEX/IMA detected $C^+/N^+/O^+$ group in 4 mass channels (ch.10, 11, 12, 13) out of total 32 channels.

* IMA uses only 5 cm magnet to separate mass-per-charge, and by doubling the magnet to 10 cm, we may separate CNO.

⇒ Nitro Mission

First-time measurement of N^+ and N^+/O^+ ratio of the escape (>50 eV) to understand

(a) the history of oxydation state of the atmospheric N,

(b) Mars mystery on N/O ratio,

(c) acceleration mechanism,

(d) re-distribution of energy in the upper ionosphere,

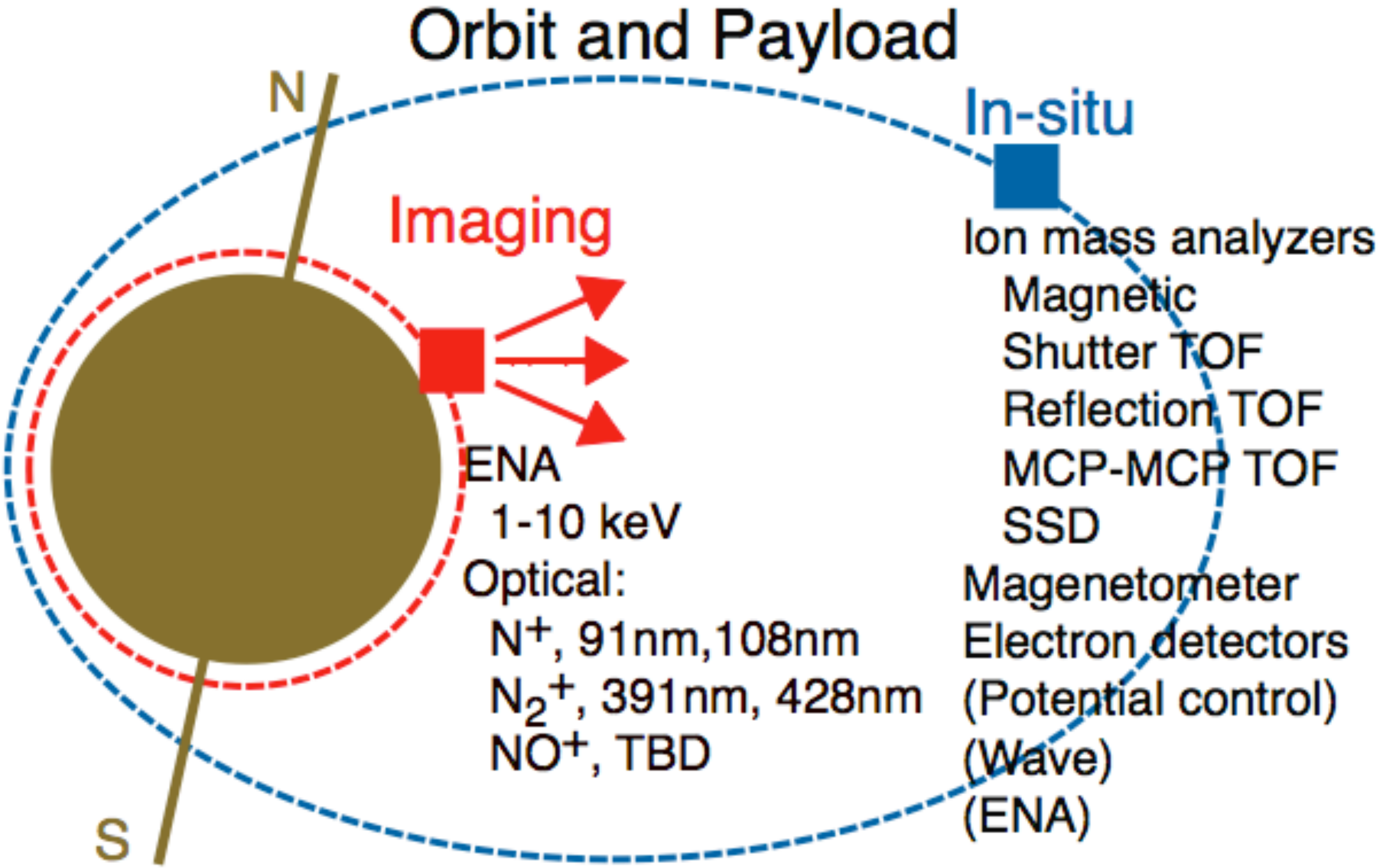
(e) ion injection and dynamics in response to substorm injections (can be monitored by ENA)

Table 3: scientific questions related to the N and N/O ratio measurement

Science Question	**What and where should we measure?**	**requirement**
N^+ escape history compared to O^+ or H^+	N^+, O^+ and H^+ at different solar and magnetospheric conditions.	**#1**, Δt<1min
Ion filling route to the inner magnetosphere	N^+, O^+ and H^+ at different solar and magnetospheric conditions.	**#1**, Δt<1min
N-O difference in energy re-distribution in the ionosphere	N^+, O^+, H^+, $J_{//}$, and e^- at different solar conditions.	**#1**, precipitating e^-, $J_{//}$, outflowing ions
Ion energization mechanisms	energy difference (including cutoff energy) among N^+, O^+ and H^+ at different altitude	**#1**, Δt<1min

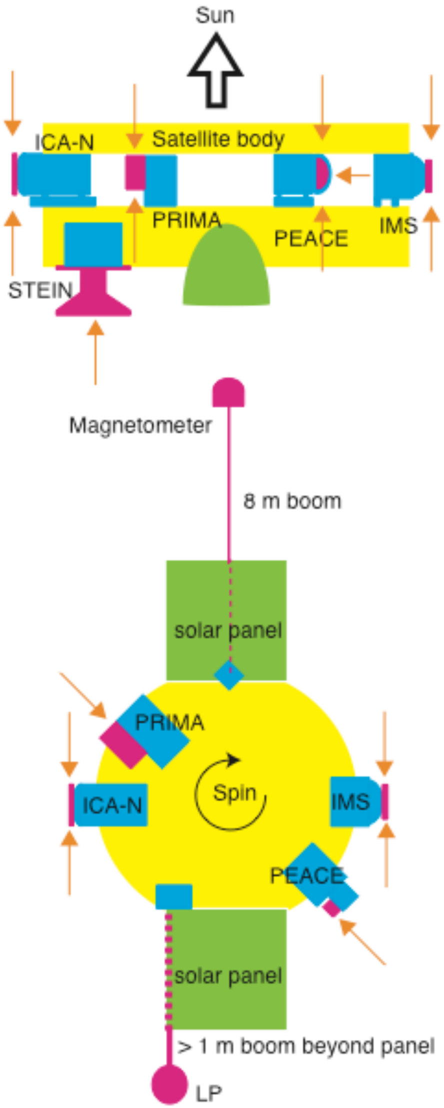
#1: N^+-O^+ separation ($M/\Delta M \geq 8$ for narrow mass) and H^+-He^+-O^+ separation ($M/\Delta M \geq 2$ for wide mass) at ⊥ and // directions at 10-1000 eV (11 km/s~9 eV for N) with $\Delta E/E \leq 7\%$ $((E_{O+}-E_{N+})/E_{N+}=15\%)$

Mission concept



S-class: In-situ small s/c only ⇒ **M-class: 2~3 medium-sized s/c**

SIs for ESA S-class proposals



SI mass(*a)	function	resolution	G-factor & Δt for full E
ICA-N <5.5 kg	**Magnetic ion mass seperation**	**ΔE/E=7%, 10-5000 eV/q m/Δm=8 (only m/q > 8)**	**$3.5 \cdot 10^{-4}$ cm²sr¹ <6s, (2kbps)**
IMS <6.0kg	**Ion: Time-of-flight with start-surface**	**ΔE/E=7%, 10-5000 eV/q, m/Δm~4 (m/q ≥ 1)**	**10^{-4} cm²sr¹ <1s, 7kbps**
PRIMA <2.4kg	**Ion: Time-of-flight with start-shutter**	**ΔE/E = 15%, 5-100 eV/q m/Δm=8 (m/q ≥ 1)**	**$0.5 \cdot 10^{-4}$ cm²sr¹ <1s, (0.5kbps)**
MAG <2.3kg	Ion cyclotron wave (can be simplified)	< 35 pT (SC cleanness limits to < 0.5 nT)	<0.1s, 1.5kbps
PEACE <4.0kg	Electron	ΔE/E= 13%, 1-10000 eV/q	$6 \cdot 10^{-4}$ cm²sr¹ <0.2s, 5kbps
STEIN <2.4kg	Energetic Neutral Atoms (no mass)	Σ5000-30000 eV/q	$2 \cdot 10^{-2}$ cm²sr¹ <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

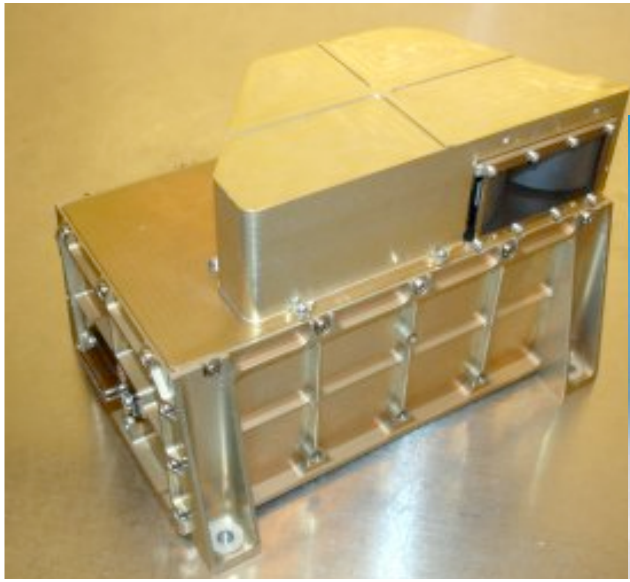
(1) Understanding the non-thermal nitrogen escape is important in modeling both the ancient atmosphere of the Earth and the Martian nitrogen mystery.

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

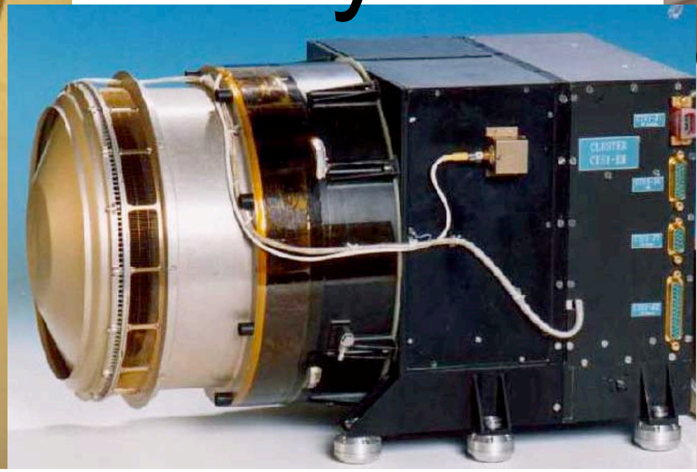
(3) Now, the technology to separate N+ and O+ with light-weight instrument just became available.

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

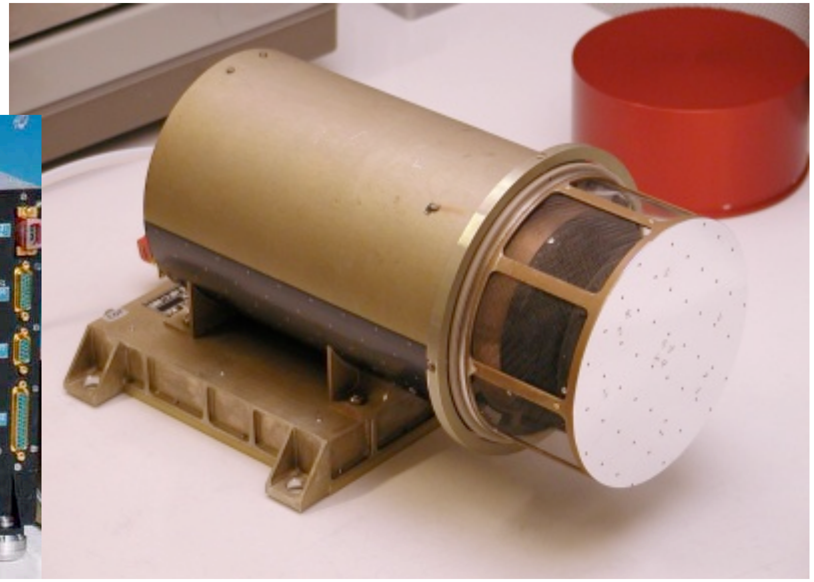
key SI



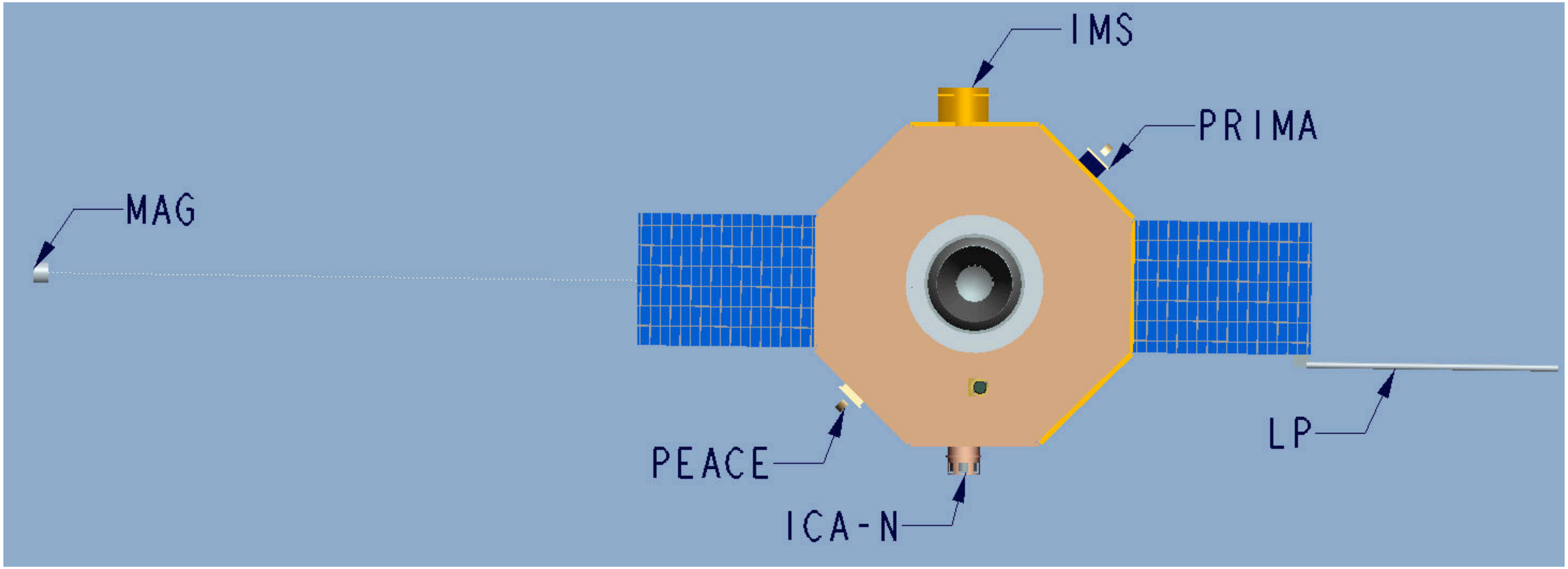
Prima



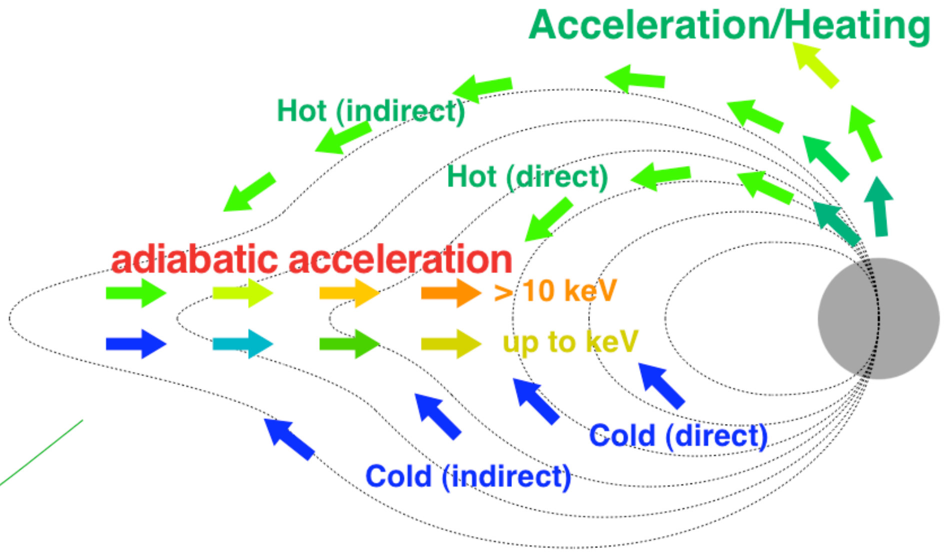
IMS



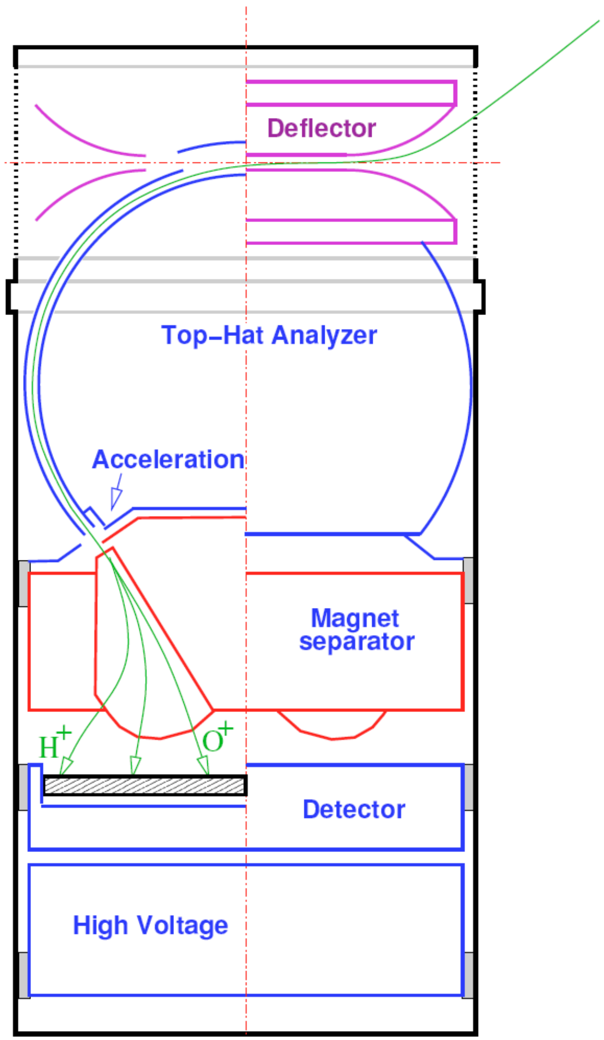
ICA



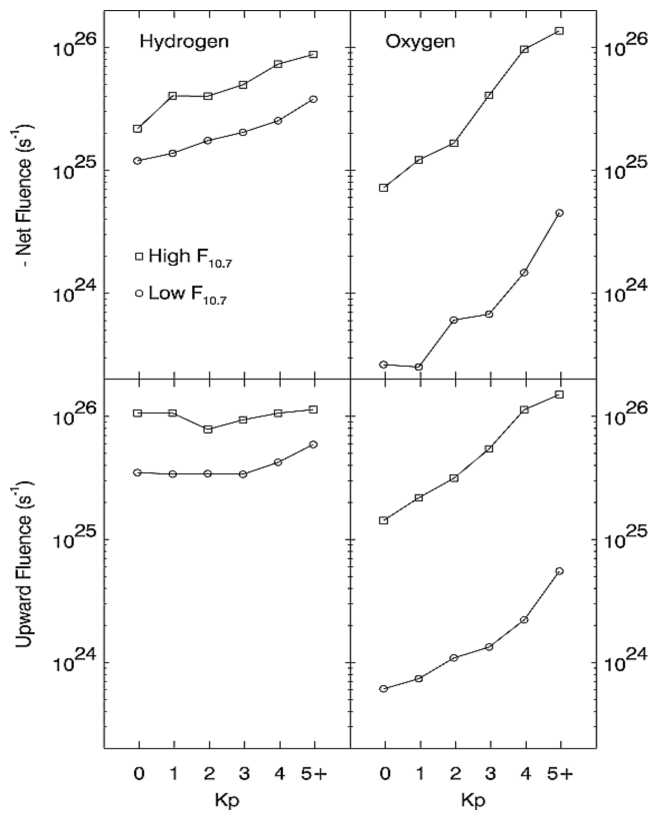
Appendix



Ion circulation in the magnetosphere



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



ion escape (Cully et al., 2003)

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: Escape estimate: 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 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	(?)	(?)	(?)	(++?)