Nitrogen Ion TRacing Observatory (NITRO): Toward understanding the Earth-Venus-Mars Difference of N/O Ratio

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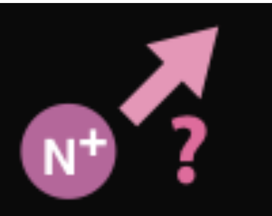
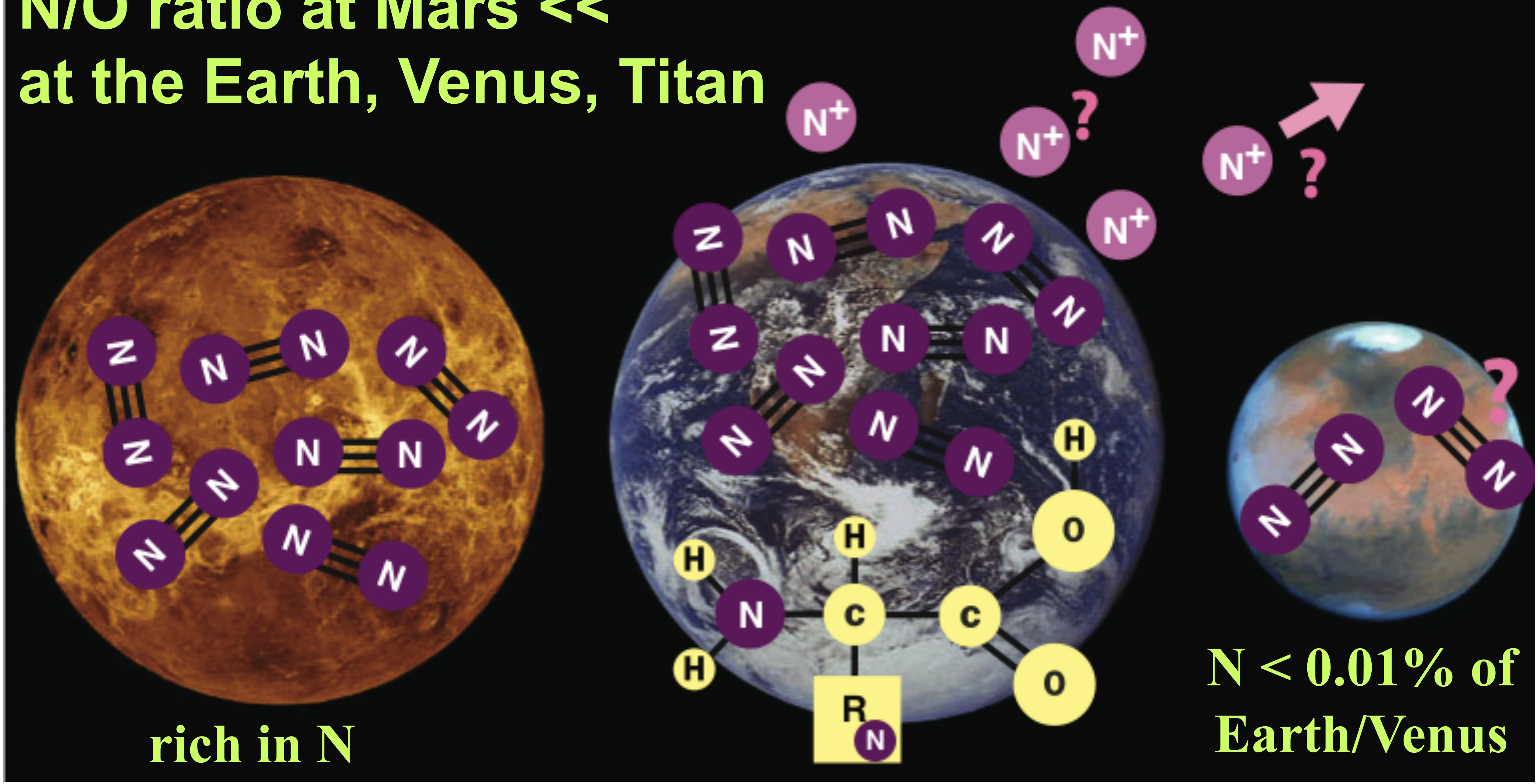
Nitrogen (N/O ratio) open question



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



Venus **Earth** **Mars**

Multi-disciplinary aspects of N^+ and N_2^+ ions

Origin of Life (ancient atmospheric composition)

Amino acid formation depends on **oxidation state of N** (NH_3 or N_2 or NO_x) = **relative abundance of N, O, & H** near surface.

Planetary atmosphere (origin and evolution)

N is missing on Mars (0.01% of Earth ~ Venus ~ Titan). This could be even be the reason why we could not find life on Mars.

Magnetosphere (ion dynamics and circulation)

N^+/O^+ changes with **F10.7 & Kp** (Akebono cold ion observations).
N_2^+ is the major molecular cold ion ($N_2^+ \gg NO^+$, O_2^+).

Ionosphere (heating and ionization) + Exosphere !

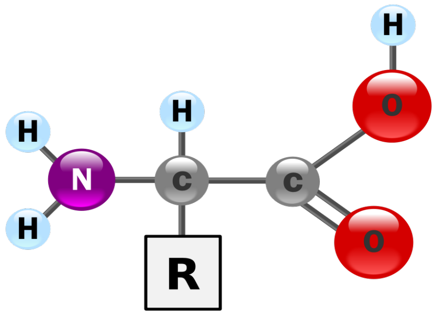
$N^+/N_2^+/O^+/O^{++}$ ratio @ **topside ionosphere** depends on solar activity.

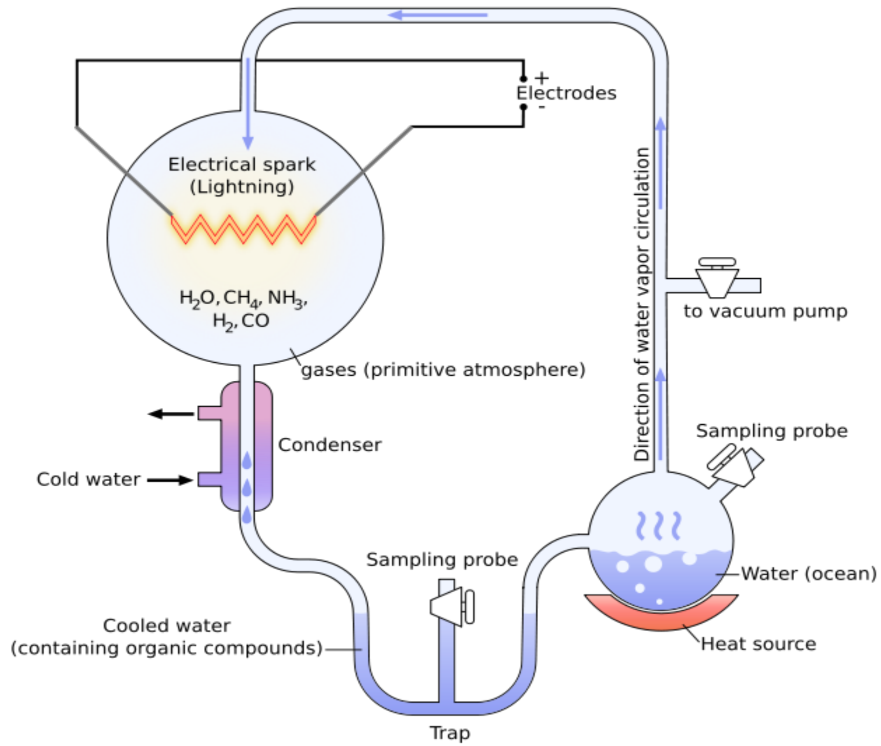
Plasma Physics (acceleration)

Different V_0 between M/q=14 and M/q=16 gives extra information.

But, no observation of N^+/O^+ ratio or $N_2^+/NO^+/O^+$ ratio at 0.03-30 keV range in space near Mars/Venus/Earth.

Nitrogen is an essential element for life





Miller's experiment (Miller and Urey, 1959).

Pre-biotic type atmosphere + discharges

⇒ formation of **amino-acids** !

The result depends on the **oxydation state of N**

reduced form (NH_3)

neutral form (N_2)

oxidized form (NO_x)

⇒Formation of pre-biotic molecules is most likely related to the **relative abundance of N, O, and H** near the surface

⇒**(not only the amount !)**

To understand N problem,

We must first investigate the near-Earth space because N^+ was poorly understood even there.

What we know are:

(a) Dependence on geomagnetic activities is larger for N^+ than O^+ for both <25 eV (Yau et al., 1993) and > 30 keV (Hamilton et al., 1988).

(b) N^+/O^+ ratio varies from <0.1 (quiet time) to ≈ 1 (large storm). What we call O^+ is eventually a mixture of N^+ and O^+. This probably applies even to O^{++}.

(c) [CNO group]$^+$ at <10 keV range is abundant in the magnetosphere.

(d) Ionization altitude of N is likely higher than for O in the ionosphere (when O^+ is starting to be heated, majority of N is still neutral).

(e) N/O ratio at Mars and C/O ratio at Moon are extremely low compared to the other planets.

(f) Isotope ratio (e.g., $^{15}N/^{14}N$) is different between different planets/comets. (But instrumentation related to this requires $M/\Delta M$ > 1000, and is outside our scope.)

Possible methods of separating $N^+ \Leftrightarrow O^+$

(1) In-situ method

Mass Spectrometer (cold): high $M/\Delta M$

Mass Spectrometer (energetic): high $M/\Delta M$

Ion (Mass) Analyser (hot): high g-factor & marginal $M/\Delta M$ is improving

— *Magnet, grid-TOF, reflection-TOF, MCP-MCP TOF, shutter-TOF, etc* —

Photoelectron: exact M but it gives only connectivity from ionosphere

Wave ($\Omega_{O+} \neq \Omega_{N+}$): a challenge because of $\Delta f/f \propto \Delta M/M < 7\%$

(2) Remote sensing of emission (line-of-sight integration) from above the ionosphere (>1800 km) & outside the radiation belt (>60° inv)

N^+ (91nm, 108nm), N_2^+ (391nm, 428nm), NO^+ (123-190nm=weak),

NO^+ (4.3 µm), O^+ (83nm), O^+ (732/733 nm): exact M but must fight against contamination from ionosphere and sensitive to radiation belt background

⇒ By combining both methods (i.e., at least two spacecraft), we have 3-D mapping of N/O in the magnetosphere

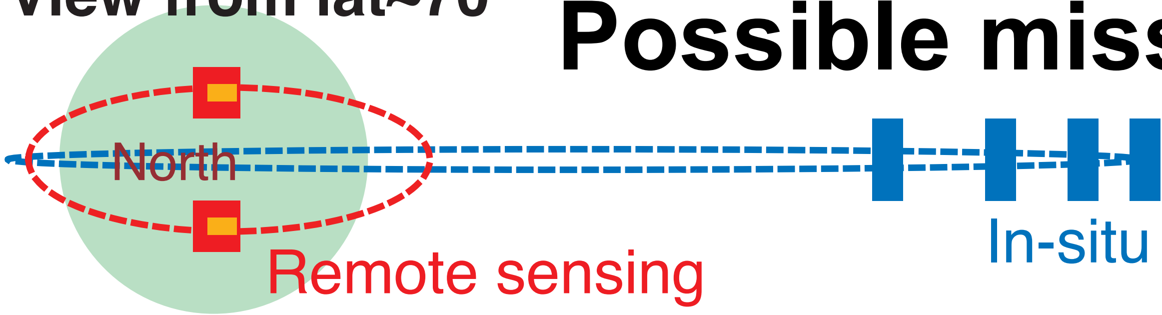
Possible mission

Orbits of:

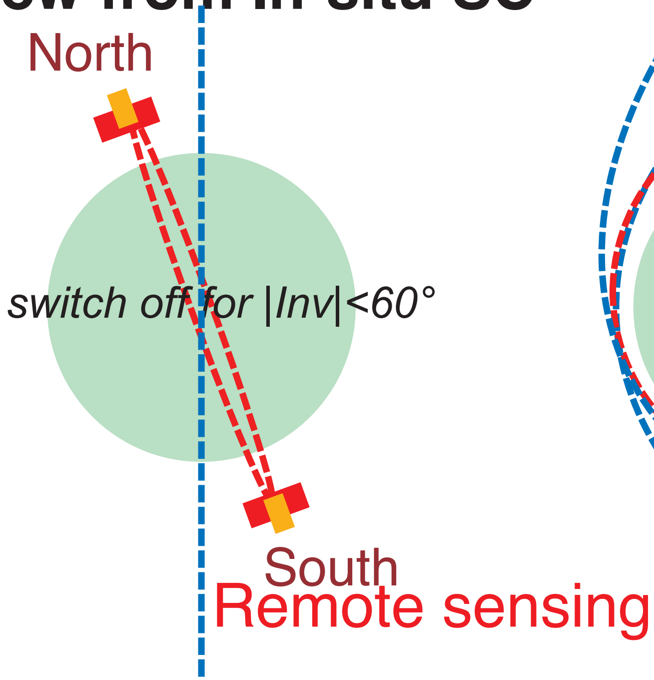
- **In-situ SC**
  800 km x 33000 km
  inclination = 68.5°
  latitudinal drift = 2°/month
- **Remote Sensing SC**
  500 km x 2000~2500 km
  inclination = 88.2°~88.5°
  latitudinal drift = 82°~75°/month

* Remote Sensing SC has the same longitudinal drifts as the In-situ SC. Orbital plane is about 20° off.

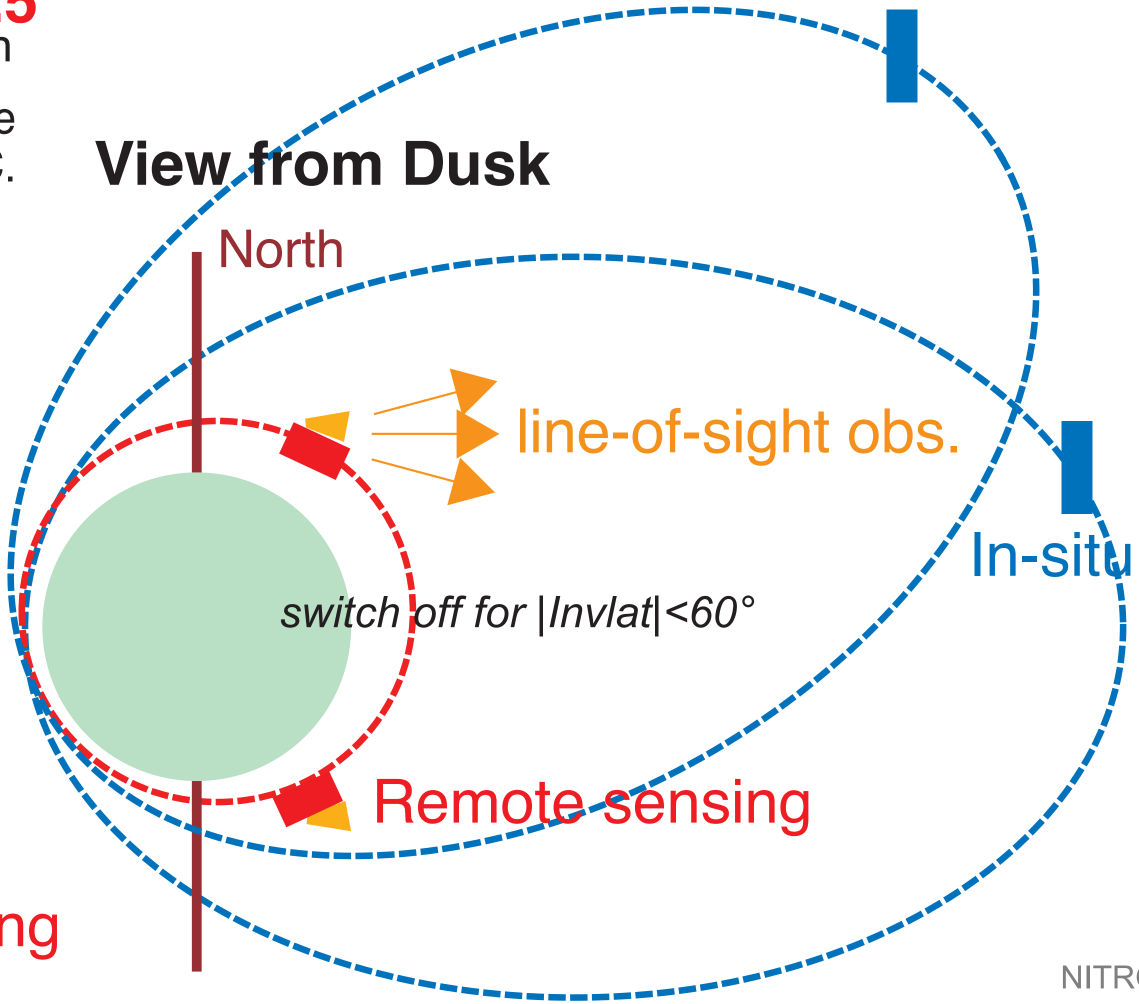
View from lat~70°



View from In-situ SC

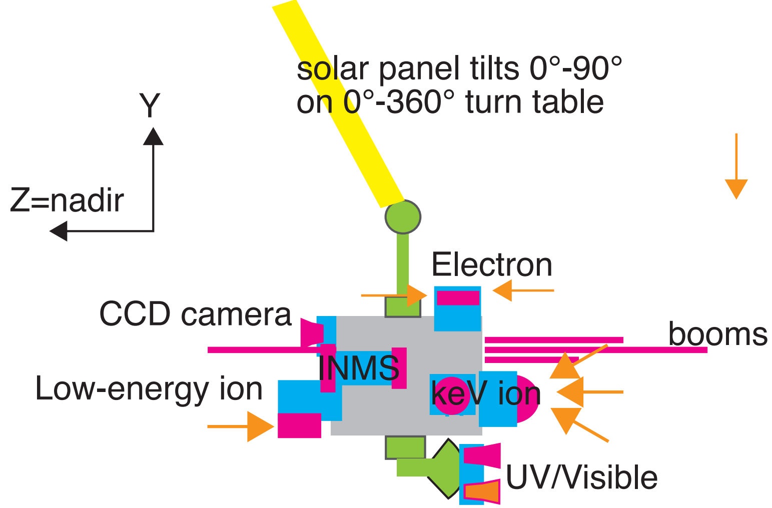


View from Dusk

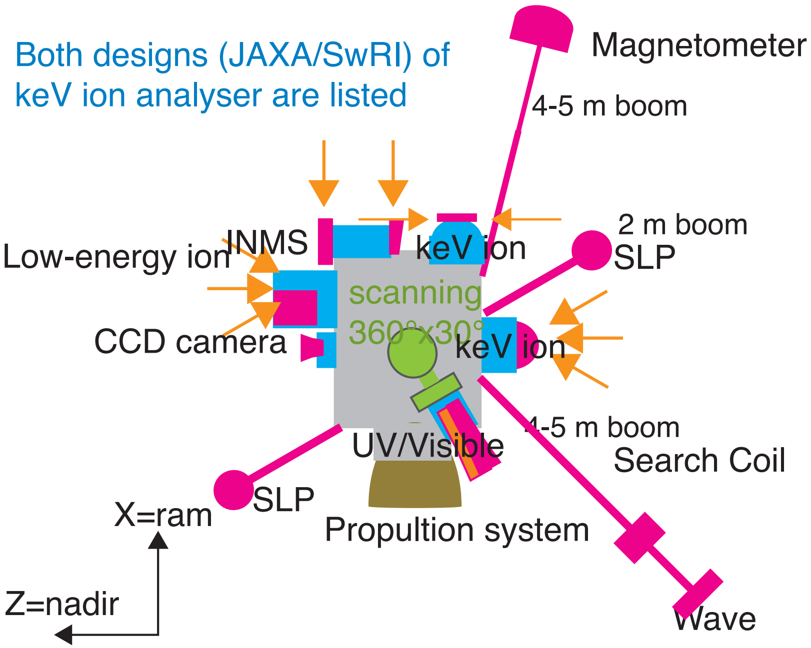


Instrument accommodations

Remote sensing #2 SC = square

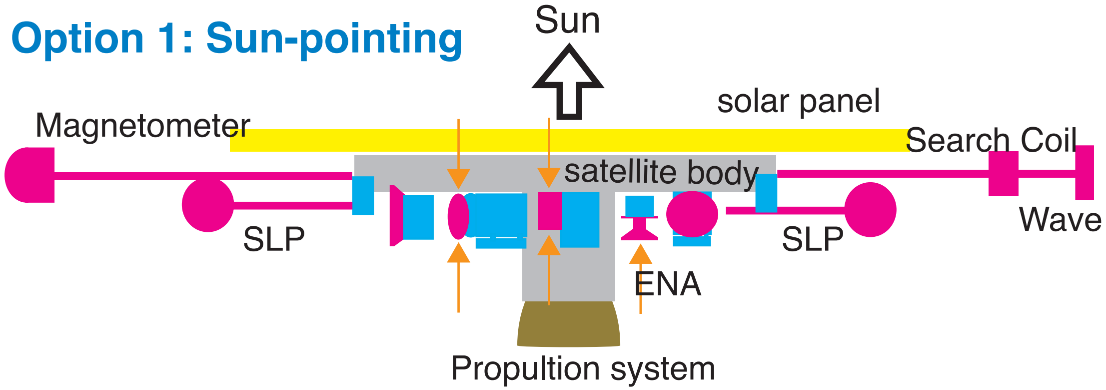


Both designs (JAXA/SwRI) of keV ion analyser are listed

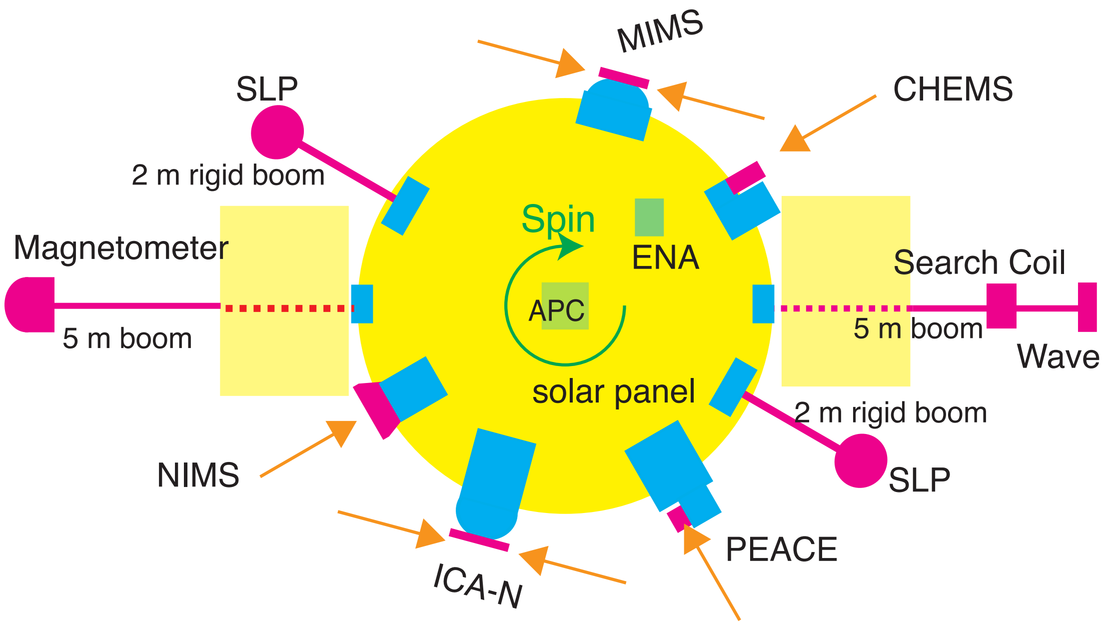


In-situ #1 SC = 1.5~2 m diameter

Option 1: Sun-pointing



6 ion, 1 electron, 1 cold instruments
Active Potential Control is place in the center



Option 2: North-pointing
=> same as Cluster with extra arm for particles

Payloads

In-situ #1 mother (spinning)
* Mass spectrometer (cold) *(Bern)*
* Ion analyzers (0.03 – 30 keV):
  (1) Heavy ions only (Kiruna)
  (2) Wide mass range (Toulouse)
* Ion mass analyzer (> 30 keV) *(UNH)*
* Magnetometer *(Graz)*
* Langmuir Probe (*Brussels*)
* Waves ($\Omega_N \neq \Omega_O$) *(Prague)*
* Search Coil ($\Omega_N \neq \Omega_O$) *(Orleans)*
* Electron analyzer *(London)*
* ENA monitoring substorm *(Berkeley)*

* *(Potential Control=SC subsystem)*

Remote sensing & monitoring (3-axis)
* Optical (emission) *(LATMOS & Japan)*
  (1) N^+: 91 nm, 108 nm
  (2) N_2^+: 391 nm, 428 nm
  (3) NO^+: 123-190 nm, 4.3 μm
  (4) O^+: 83 nm, 732/733 nm
* Mass spectrometer (cold N^+ and neutrals) *(Goddard)*
* Ion analyzer (< 0.1 keV) *(Kiruna)*
* Langmuir Probe *(Brussels)*
* Magnetometer *(Graz)*
* Ionospheric optical camera (***TBD***)
* Electron analyzer *(London)*
* Waves ($\Omega_N \neq \Omega_O$) *(Prague)*
* Search Coil ($\Omega_N \neq \Omega_O$) *(Orleans)*
* Ion analyzer (< 50 keV) *(Japan)*

**** underline: core,***
**** colored: important,***
**** black: optional***

Summary

With an unique orbital configuration and recently developed instrumentations, NITRO can target Nitrogen 3-D dynamics for the first time in the Earth's magnetosphere, as the first step in understanding the nitrogen differences in the terrestrial planets.