NItrogen **I**on **TR**acing **O**bservatory (**NIITRO**) concept: a possible mission for next ESA's M-class call

The NITRO proposal team

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USA: SwRI (San Antonio), UNH (Durham), NASA/GSFC, UCB/SSL (Berkeley), UCLA (Los Angeles),

Other: U. Calgary (Edmonton, Canada), U. Alberta (Edmonton, Canada), Tohoku-U (Sendai, Japan)

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

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), and Oxidation (or N/O ratio for given temperature) of planet is Mars >> Venus > (Titan?) > Earth

Magnetosphere (ion dynamics and circulation)
N^+/O^+ changes with **F10.7 & Kp** (Akebono cold ion obs.)

Ionosphere (heating and ionization)
$N^+/N_2^+/O^+$ ratio @ **topside ionosphere** depends on solar activity

Plasma Physics (acceleration)
Different V_0 between M/q=14 and M/q=16 gives extra information

Present knowledge on N^+/O^+ ratio in space

(a) **no observation of N^+/O^+ ratio at 0.1-10 keV range**

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

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

(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 planet/comet.

Relevant Focus Groups

Most relevant: **The Ionospheric Source of Magnetospheric Plasma-Measuring**, Modeling and Merging into the GEM GGCM (MIC) ⇒ **Unless we understand the different dynamics of the N+ and O+ (and N+/O+ ratio of outflow and abundance), we cannot "complete" this focus group (need renaming it).**

Related: Storm-Time Inner Magnetosphere-Ionosphere Convection (IMS, MIC) ⇒ **N^+/O^+ difference = difference in the initial velocity**

Related: Tail-Inner Magnetosphere Interactions (Tail) ⇒ **ENA Monitoring tailward can add new science**

Tips for continued (renamed) FG

(1) The science is beyond just space physics, i.e., GEM can contribute the other science field such as origin-of-life.

(2) Inner magnetosphere is the region of highest chance for N^+ detection, and therefore, new FG is related to IMS

(3) The source is ionosphere, and therefore, new FG is related to MIC

(4) Idea include outward imaging (optical for N^+ and ENA for injections), and therefore, new FG might consider including Tail.

(5) The task is also good for instrument development, because we have now clear target of N^+-O^+ separation with high G-factor. At moment, surface-reflection type (at start surface) time-of-flight has problem with quite difference surface-ion interaction between N^+ and O^+ (N is easily neutralized!)

Possible methods separating $N^+ \Leftrightarrow O^+$ and $N_2^+ \Leftrightarrow NO^+ \Leftrightarrow O_2^+$

(1) In-situ method

Ion Mass Spectrometer: high M/ΔM but low g-factor

Ion Mass Analyser: high g-factor but marginal M/ΔM

Photoelectron: exact M but requires very high E/ΔE

Wave (Ω_{O+} & Ω_{N+})**: M/ΔM ∝ f/Δf (0.01 Hz accuracy @ L=3)**

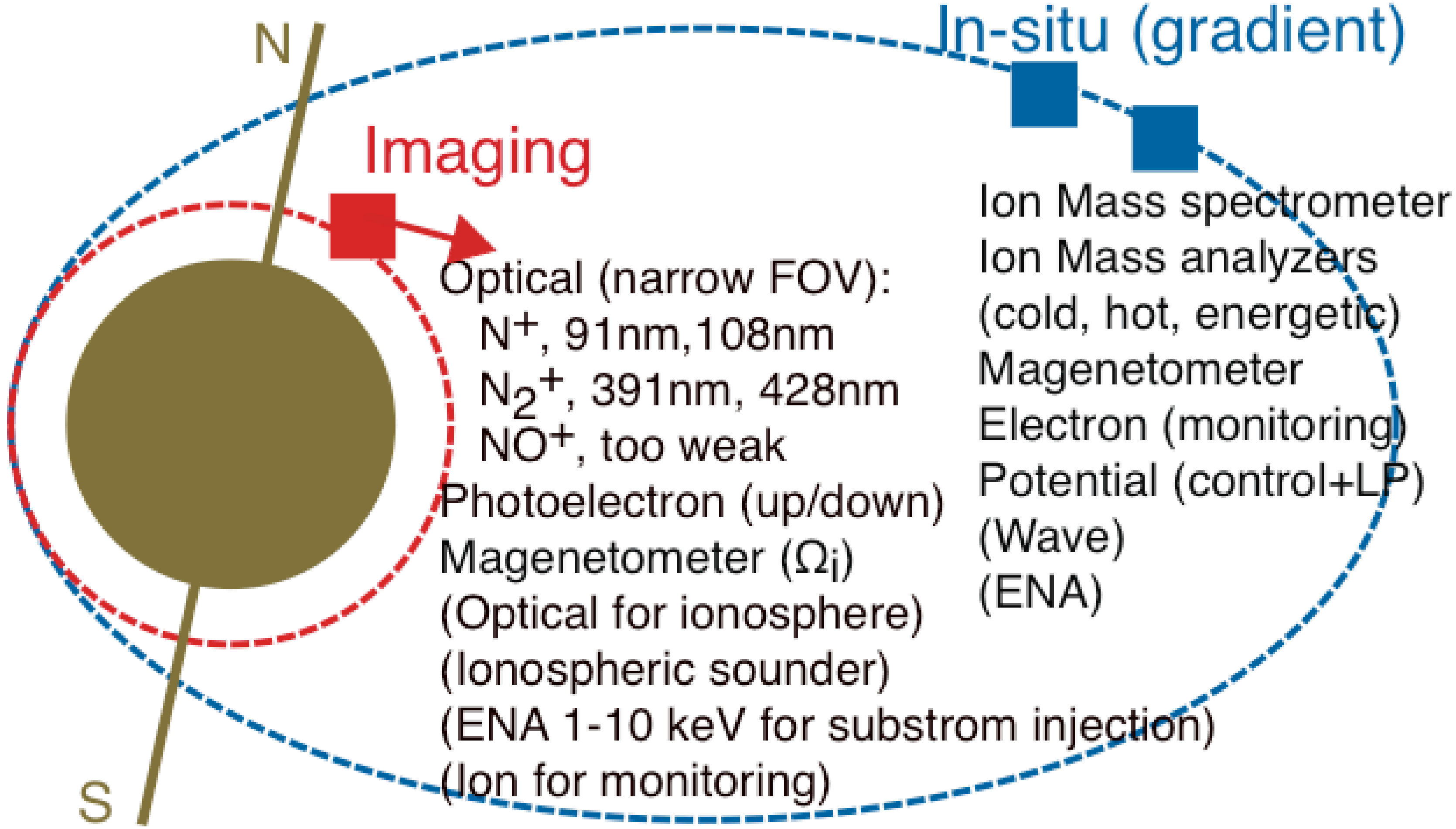
(2) Remote sensing (line-of-sight integration)

Optical N^+ line (91nm, 108nm) **& N_2^+ line** (391nm, 428nm)**: must fight against contamination from topside ionosphere**

Optical NO^+ line: low emission rate but yet might be useful for calibration purpose by estimating ionospheric contribution

⇒ must be above the ionosphere & outside the radiation belt

Propose a 3-spacecraft mission (high incli)



M-class: 3 medium-sized s/c S-class: 1 small in-situ s/c

We start with 6-7 Re x 2000 km orbit to avoid radiation belt, and then gradually decrease apogee to explorer "dangerous" region

Needed Payloads

In-situ measurement (spin)

* **Mass spectrometer:**
* **Ion mass analyzers 1&2** (hot):
  - *(1) Magnet only*
  - *(2) Magnet & TOF*
  - *(3) Shutter TOF*
  - *(4) MCP-MCP TOF*
  - *(5) Traditional reflection TOF*
* **Ion mass analyzers** (energetic):
* **Ion mass analyzers** (cold):
* Magnetometer
* Electron (simple or advanced)
* Potential Control
* Langmuir Probe
* Wave (correlation to N/O ratio)
* ENA (monitoring substorm)

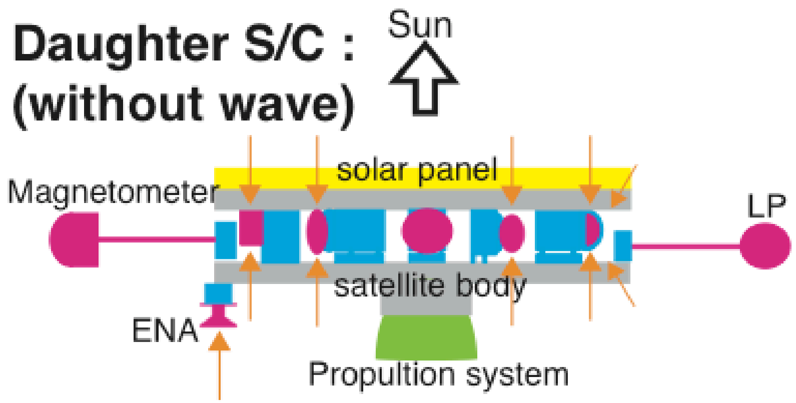
Remote measurement (3-axis)

* **Optical (emission)**
  - *(1) N^+: 91nm, 108nm*
  - *(2) N_2^+: 391 nm, 428nm*
  - *(3) NO^+: just try (ionosphere)*
* Electron (simple or advanced)
* Magnetometer (Δf < 0.01 Hz)
* ENA (1-10 keV): first time tailward monitoring of substorm injection

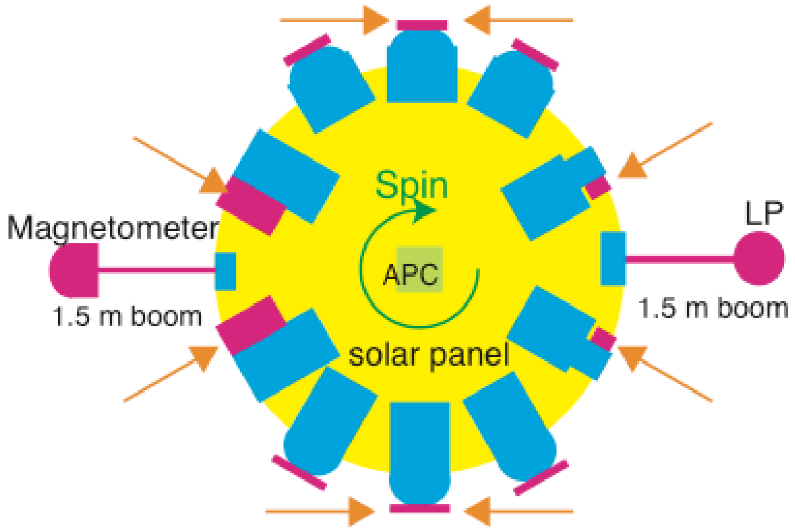
*** Two in-situ spacecraft is for gradient observation.**
*** Optical imager needs a scanner keep in-situ spacecraft within FOV.**

In-situ satellites (to be modified)

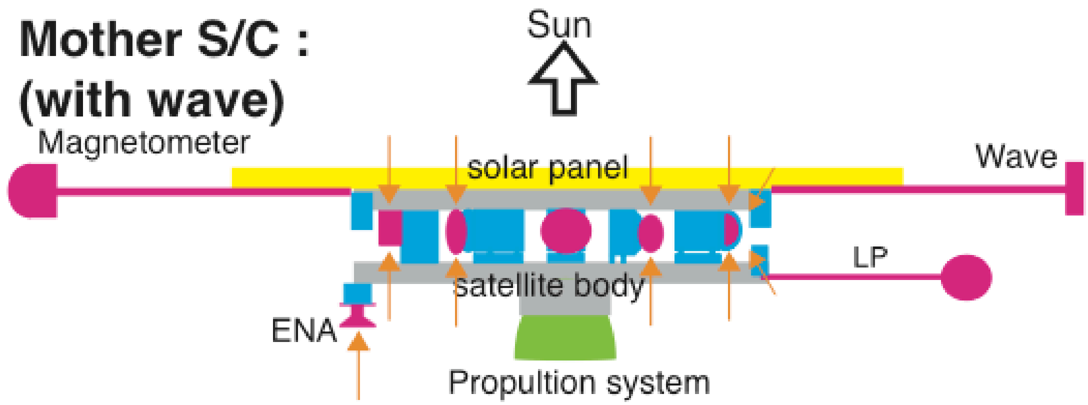
Daughter S/C : (without wave)



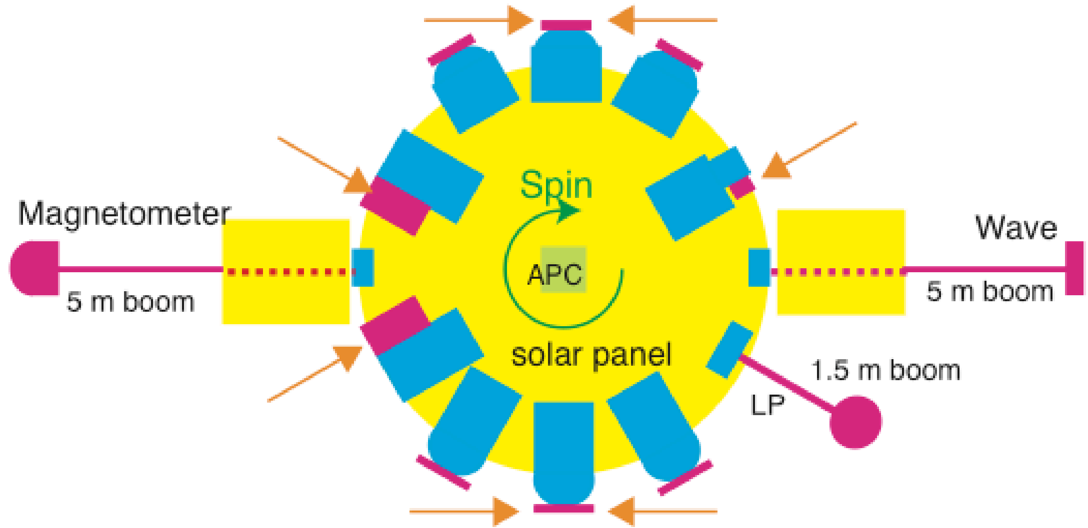
Satellite body = 1.5 m diameter
Up to 8 ion, 1 electron, 1 cold instruments
Active Potential Control is place in the center



Mother S/C : (with wave)



Satellite body = 1.5~2 m diameter
Up to 7 ion, 1 electron, 1 cold instruments
Active Potential Control is place in the center



Magnetic high-cleanness is required only for Mother A/C

Ion Instrument Requirement

Mass resolution: $\mathbf{M_O/(M_O\text{-}M_N) = 8}$
and $\mathbf{M_{NO}/(M_{NO}\text{-}M_{N2}) \approx M_{O2}/(M_{O2}\text{-}M_{NO}) = 16}$.

Energy resolution: $\mathbf{(E_{O+}\text{-}E_{N+})/E_{N+}=15\%}$ when $V_O=V_N$
and $\mathbf{(E_{O+}\text{-}E_{N+})/E_{N+}=7\%}$ when $E \propto \sqrt{M}$.

G-factor: G-factor N^+ should be the same as for O^+, i.e.,
$\mathbf{G>10^{-4}\ cm^2\ str\ keV/keV}$ without efficiency.

Time resolution: $\mathbf{\Delta t = 1\ min}$ is probably sufficient (integrating over several spins and/or slow spin)

$\downarrow$

No single ion instrument meets all the requirements ⇒ Divide roles

Roles of different hot ion instruments

(1) Ion Mass spectrometer (fine N/O ratio): If $N^+/O^+ = 1/100$ is to be detected for Gaussian spread, we need **$M/\Delta M \geq 200$.** Otherwise, low temporal resolution (5 min) is ok.

(2) Hot Ion Mass analyser 1 (changes of N/O ratio): If the data is calibrated, **$M/\Delta M \geq 8$ with $\Delta E/E \leq 7\%$ (ideally 4%) can do the job.** Otherwise, **wide FOV (separate $\perp$ and // directions)** and **without H^+** is OK.

(3) Hot Ion Mass analyser 2: **Narrow FOV with 2π (tophat) angular coverage and $\Delta E/E \leq 15\%$.** Otherwise, **$M/\Delta M \geq 4$** (H^+, He^{++}, He^+, CNO^+, molecule$^+$) is OK

(4) It is nice to have simple ion energy spectrometer (without mass) for **$\Delta E/E < 4\%$ and high- & temporal resolution**

Other sciences

Science Question	**What &where to measure?**	requirement
N^+ escape history vs O^+ or H^+ & **Ion filling route to the destination**	**N^+, O^+ and H^+ observation at escape route & their destinations at different solar/magnetospheric conditions.**	**#1**, $\Delta t \sim 1$min gradient + imaging
Ionospheric energy re-distribution to N & O	N^+, O^+, H^+, $J_{//}$, and e^- at different solar conditions.	**#1**, keV e^-, $J_{//}$, eV ions
Ion energization mechanisms	energy difference among N^+, O^+ and H^+ at different altitude, wave and field	**#1**, $\Delta t<1$min gradient, cyclotron Ω_i
Relation to injection from the tail	N^+, O^+, H^+ response to ENA monitor looking tail	**#1**, $\Delta t<1$min ENA

#1: N^+-O^+ separation (narrow mass range) and H^+-He^+-O^+ separation (wide mass range) at $\perp$ and // directions with $\Delta E/E \leq 7\%$ ($(E_{O+}-E_{N+})/E_{N+}=15\%$) but E-stepping an be wider

Strategy / Action items

(1) We try ESA M-class (AO: 2014) for "**comprehensive understanding of distribution using 2-point in-situ plus imaging**" with full 3-spacecraft. If M-class fails we might try (a) S-class is "**first core-spacecraft is used as pioneer of N+ search**" with core-spacecraft only, or (b) NASA program.

(2) Even for ESA's scheme, we need to contact NASA (by the US team member) as possible partner, either just instrument, or even providing one of three spacecraft (and downlink).

(3) Launch is targeted for next solar maximum (2023) to include the declining phase (2024-2027) when we expect large storms. If Van-Allen Probes survives, stereo observation is possible.

(4) We welcome more team members from space scientists, as well as astrobiology scientist. We also need optical people (at moment, design is by Japanese team)

Action Items on Payload

It might be a good idea to include ionospheric monitoring such as sounder or optical instrument (N_2^+/N_2 ratio tells energization of topside ionosphere). The ion escape should directly be related to the seed population, i.e., upper ionospheric condition. (But including sounder makes mission larger than M-class?)

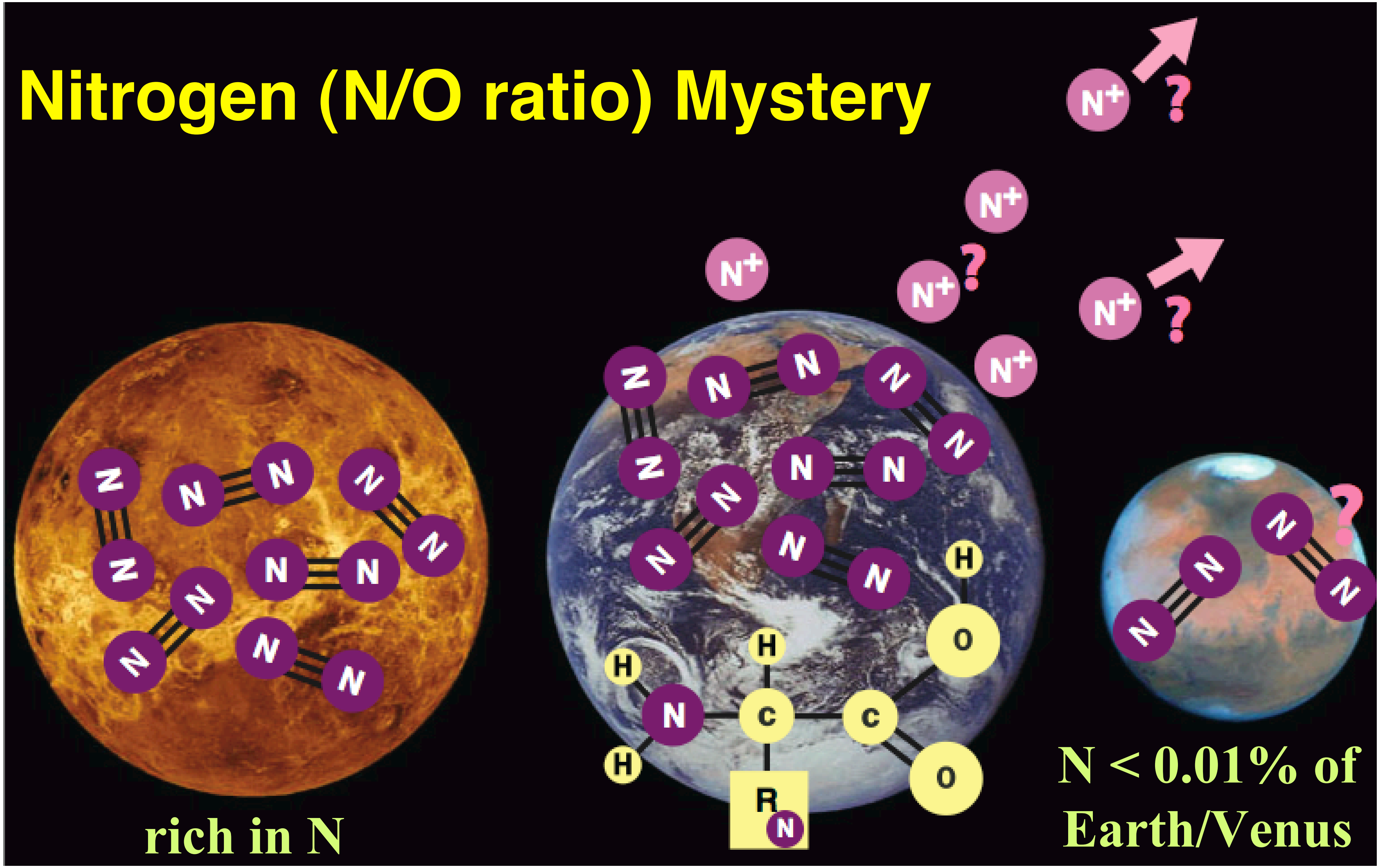
It might be a good idea to include soil N_2-N_2O-NO-NO_2 ratio remote sensing to correlate the change of oxidation state of N and and escape of N^+ or N_2^+. The remote sensing satellite already exists. (Quetion is how to compare?)

We have to define "purely supporting" instruments that should be paid as a part of spacecraft (not as SI), such as the Active Potential Control. How about Langmuir Probe?

It might be a good idea to measure E-field for accurate measurement of particles (but aren't LP and APC enough?)

Other Action Items (some are duplicated)

* Clarify the need of instrument for science
* Define spec (observation limit) vs science requirement
* Define resolution (integration time for one direction)
* How many different ion instruments are needed?
* **We need to involve astrobiology institutes**
* **We need to involve optical instrument team**
* We need more European instruments (for ESA's call)
* NASA relation (how to include US-lead instruments?)
* Radiation dose (homework for each SI)
* How much EMC cleanness requirement do we ask?



Venus Earth Mars

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

END

Skip

Mission orbit and Payload