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

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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)

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

But, no observation of N^+/O^+ ratio at 0.1-10 keV range

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

(a) 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).

(b) 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^+.

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

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

(e) *Isotope ratio (e.g., $^{15}N/^{14}N$) is different between different planet/comet. But this requires M/ΔM > 1000 spectroscopy, and outside the scope of present study.*

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)**

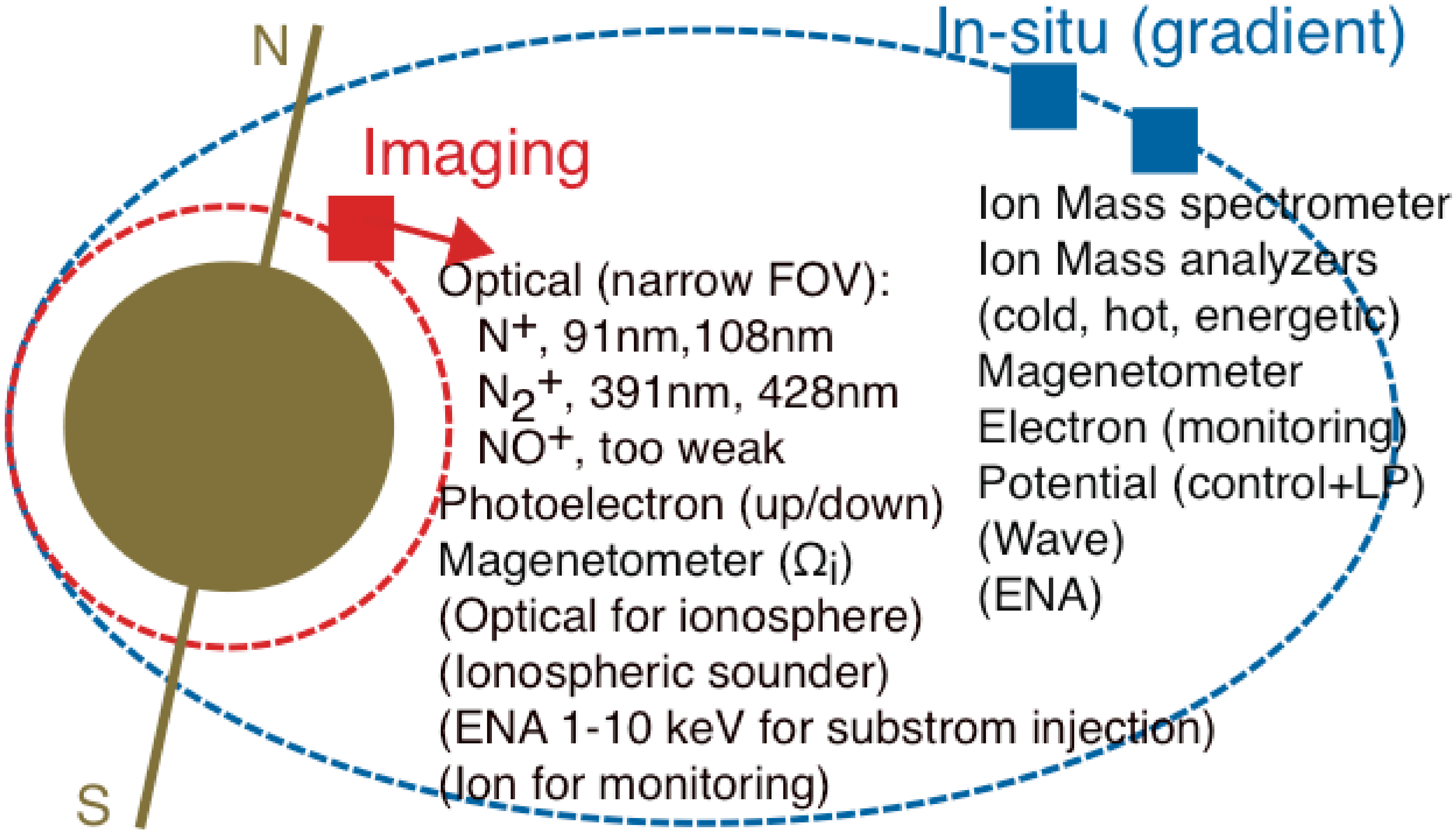
(2) Remote sensing (line-of-sight integration)

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: 3-spacecraft mission (high inclination)



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 first 1-2 year, and gradually decrease apogee to explorer “dangerous” region

Needed Payloads

In-situ measurement (spin)

* **Mass spectrometer:**
* **Ion mass analyzers** (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)

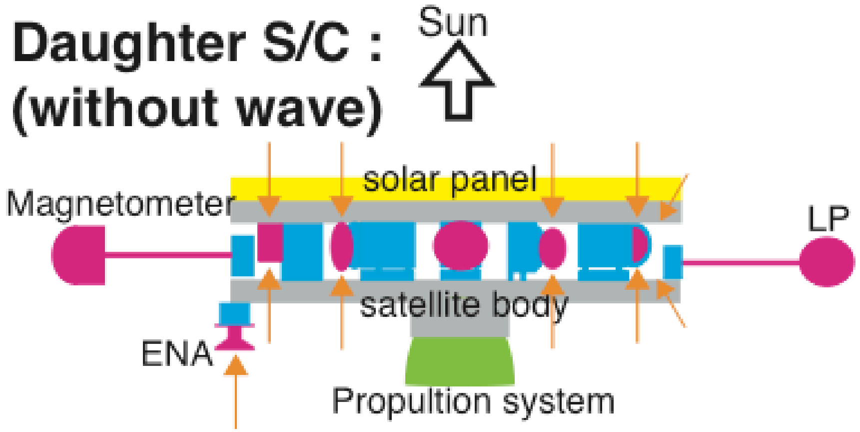
Remote measurement (3-axis)

* **Optical (emission)**
  - *(1) N^+: 91 nm, 108 nm*
  - *(2) N_2^+: 391 nm, 428 nm*
  - *(3) O^+: 83 nm, 732/733 nm*
* Electron (simple or advanced)
* Magnetometerr ($\Delta f < 0.01$ Hz)
* Ionospheric monitor (sounder, optical)
* 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)

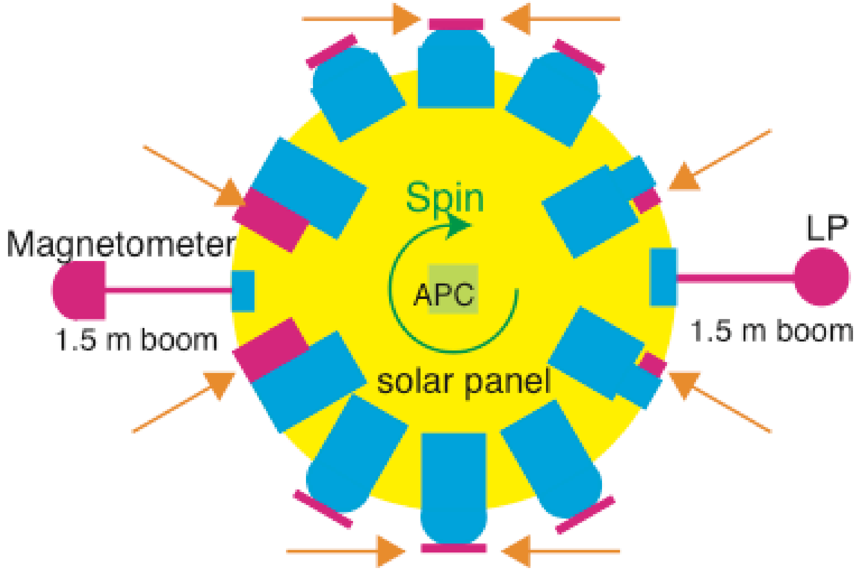
Daughter S/C : (without wave)



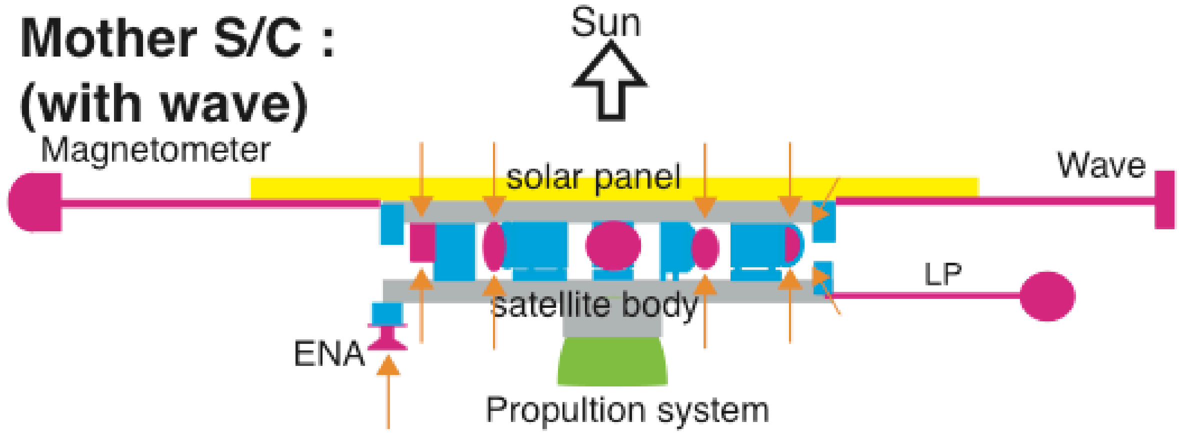
Satellite body = 1.5 m diameter

Up to 8 ion, 1 electron, 1 cold instruments

Active Potential Control is place in the center



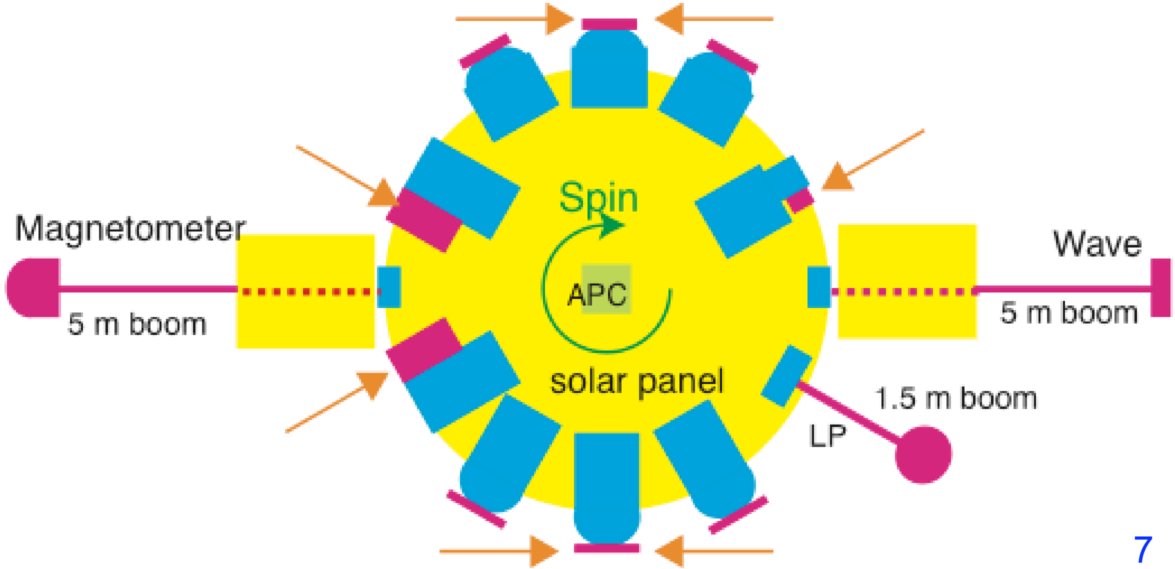
Mother S/C : (with wave)



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: $\mathbf{(E_{O+}\text{-}E_{N+})/E_{N+}=15\%}$, but stepping can be wider.

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

Time resolution: **Δt = few min** is sufficient after integrating over several spins (and slow spin is ideal)

↓

(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 ⊥ 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^+	**N^+, O^+ and H^+ observation @ escape route and destinations @ different solar & magnetospheric conditions.**	**#1**, $\Delta t \sim 1$min gradient + imaging
Ion filling route to the destination	same as above.	same as above.
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 substorm injection	correlation to ENA observation	**#1**, $\Delta t \sim 1$min

#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

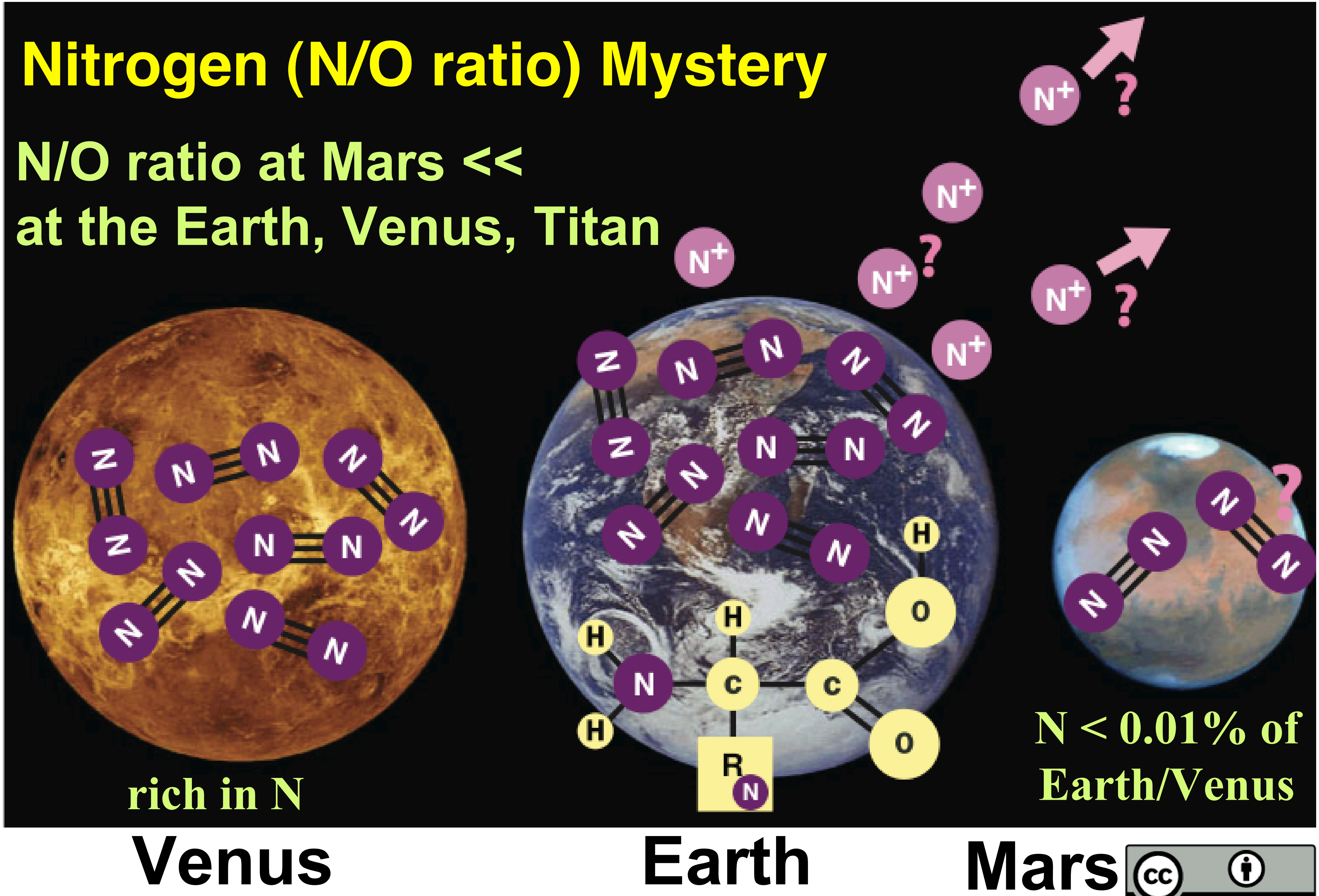
(1) We try first M-class (AO: 2014), and then S-class (2015/2016) if we fail M-class. The M-class is "**comprehensive understanding of distribution using 2-point in-situ plus imaging**" with full 3-spacecraft while S-class is "**first core-spacecraft is used as pioneer of N+ search**" with "core-spacecraft" only if M-class failed.

(2) We seek also NASA as possible partner or its own mission (in that case the European instrument should be co-I level).

(3) Launch is targeted for next solar maximum (before 2022). This gives extra opportunity that makes ongoing Van-Allen Probes and ERG to be extended for stereo observations.

(4) We welcome astrobiology team

(5) We welcome optical team


Nitrogen (N/O ratio) Mystery
N/O ratio at Mars <<
at the Earth, Venus, Titan
rich in N
N < 0.01% of
Earth/Venus
Venus
Earth
Mars

Action Items on payload (New feedback from EGU 2014)

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?)