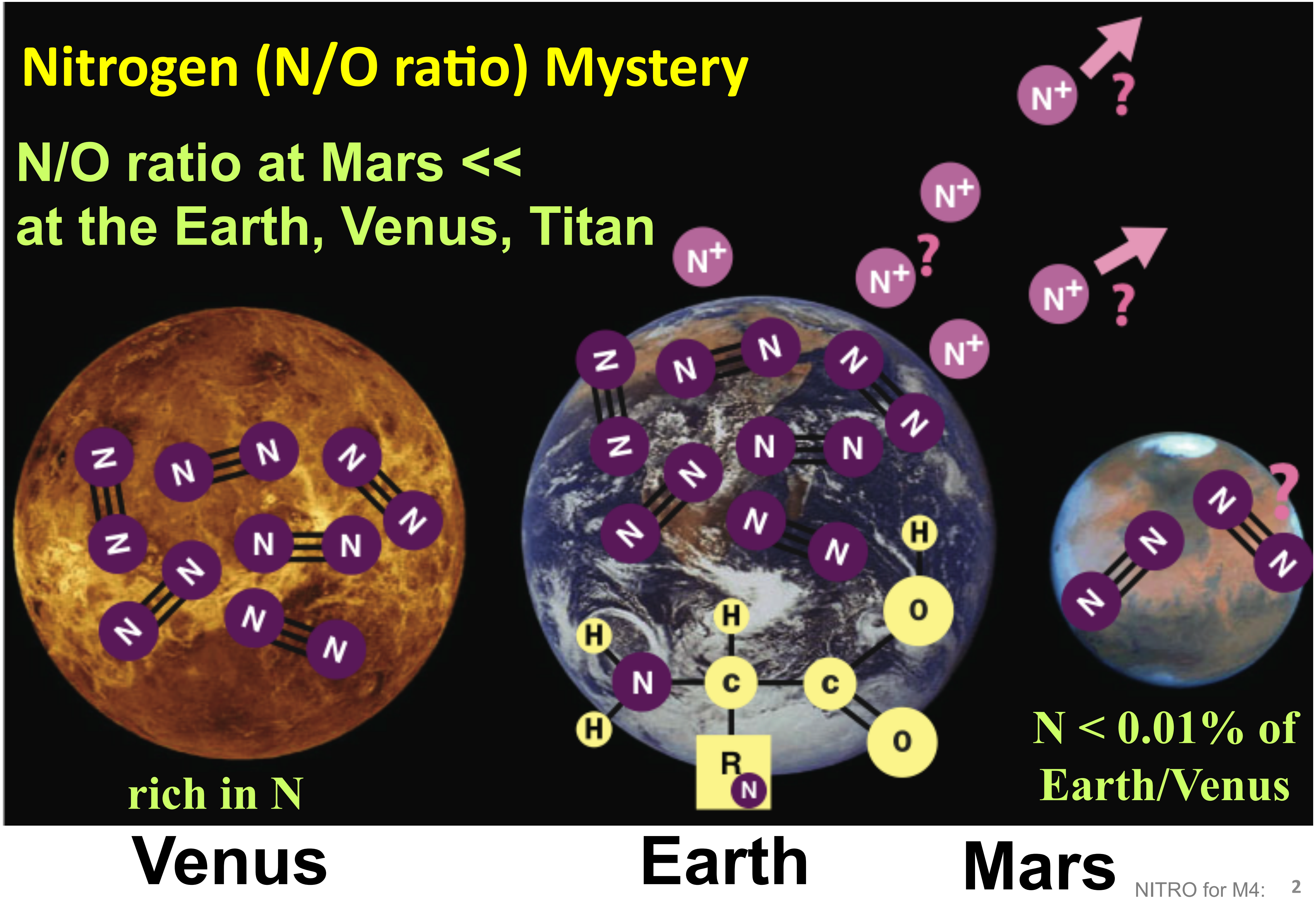
Nitrogen **I**on **TR**acing **O**bservatory (**NITRO**): for next ESA's M-class call

M. Yamauchi, I. Dandouras, and NITRO proposal team

IRF (Kiruna, Sweden), IRAP (Toulouse, France), UCL/MSSL (London, UK), LPP (Paris, France), U. Bern (Switzerland), Aalto U. (Helsinki, Finland), Inst Space Sci. (Bucharest, Romania), IWF (Graz, Austria), IAP/ASCR (Prague, Czech), IASB-BIRA (Brussels, Belgium), LATMOS/IPSL (Guyancourt, France), NASA/GSFC (USA), UNH (Durham, USA), SwRI (San Antonio, USA), UCB/SSL (Berkeley, USA), UCLA (Los Angeles, USA), U. Alberta (Edmonton, Canada), U. Iowa (Iowa City, USA), Tohoku U. (Sendai, Japan), IAXA/ISAS (Sagamihara, Japan), UNIS (Longyearbyen, Norway), FMI (Helsinki, Finland), etc.


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

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 in the magnetosphere (except Kaguya)

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

(1) In-situ method

Ion Mass Spectrometer: high $M/\Delta M$ but low g-factor or very heavy

Ion Mass Analyser: high g-factor but marginal $M/\Delta M$

Photoelectron: exact M but requires very high $E/\Delta E$

Wave ($\Omega_{O+} \neq \Omega_{N+}$): $M/\Delta M \propto f/\Delta f$ (better than 7%, a challenge)

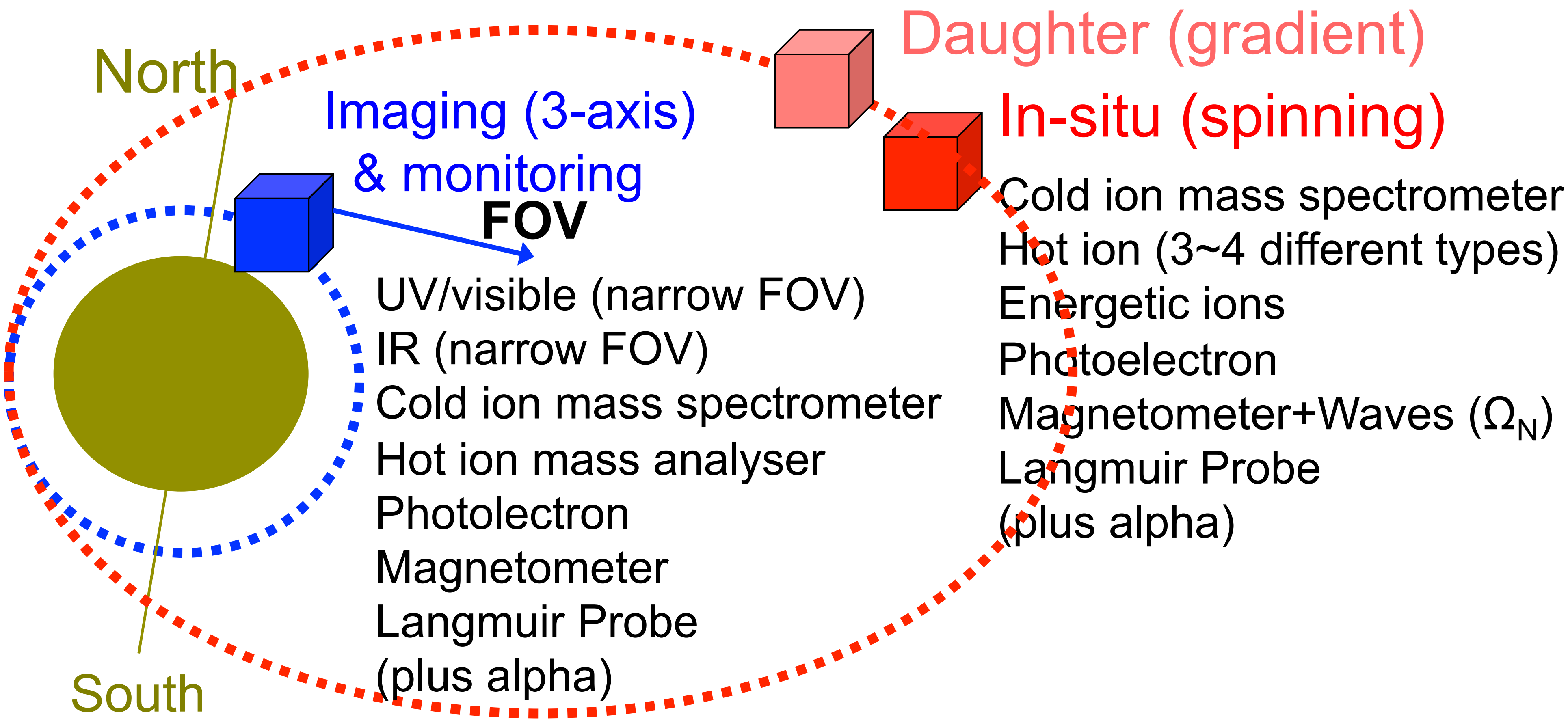
(2) Remote sensing of emission (line-of-sight integration) must fight against contamination from ionosphere ⇒ SC should fly above the topside ionosphere & outside the radiation belt

N^+ (91nm, 108nm), NO^+ (123-190nm=weak), O^+ (83nm),

N_2^+ (391nm, 428nm), NO^+ (4.3 μm), O^+ (732/733 nm)

(+) Monitoring of source (topside ionospheric) conditions

3-spacecraft mission (high inclination)



In-situ spacecraft start with 6-7 Re apogee outside the radiation belts during the first 2 years, and then gradually decrease the apogee altitude to explorer the "dangerous" region. Monitoring satellite flies just above the polar ionosphere at altitude ~2000 km.

Payloads

In-situ #1 mother (spinning)

* Mass spectrometer (cold) *(Bern)*
* Ion analyzers (0.03 – 30 keV):
  (1) Narrow mass range (Kiruna)
  (2) Wide mass range (Toulouse)
  (3) No mass (LPP)
  (4) low G-factor mass (Japan)
* Ion mass analyzer (> 30 keV) *(UNH)*
* Electron (photoelectron) *(London)*
* Magnetometer *(Graz)*
* Waves ($\Omega_N \neq \Omega_O$) *(Prague)*
* Langmuir Probe (*Brussels*)
* ENA monitoring substorm *(Berkeley)*

* *(Potential Control=SC subsystem)*

Possible methods for ion analyzers:
Magnet, Magnet-TOF, reflection-TOF, MCP-MCP TOF, shutter-TOF

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) *(Goddard)*
* Ion analyzer (< 0.1 keV) *(Kirina)*
* Electron (photoelectron) *(London)*
* Langmuir Probe *(Brussels)*
* Ionospheric sounder *(Iowa)*
* Magnetometer *(Graz/UCLA)*
* Waves ($\Omega_N \neq \Omega_O$) *(Prague)*
* Ionospheric optical emission (???)

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

Optical imager needs a scanner keep in-situ spacecraft within FOV.

Sprinter meeting on NITRO (ESA-M4) proposal

Saturday 11:30-16:00 (after coffee break)

Agenda

* PI and CoI distribution (more tuning + **new comers**)
* More ion mass instruments?
* 2-spacecraft vs. 3-spacecraft strategy
* Support letter from national funding agencies
* Work load distribution (science, instrument, requirement)
* NASA relation (how to apply for the third spacecraft)
* Orbit strategy
* How much EMC cleanness requirement do we ask?

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 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^+ than O^+.

(c) $[\text{CNO group}]^+$ 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) Ionization altitude of N is higher than for O in the ionosphere (when O^+ is starting to be heated, majority of N is still neutral).

(f) Isotope ratio (e.g., $^{15}N/^{14}N$) is different between different planets/ comets. But this requires $M/\Delta M > 1000$ spectroscopy, and is outside the scope of present study.

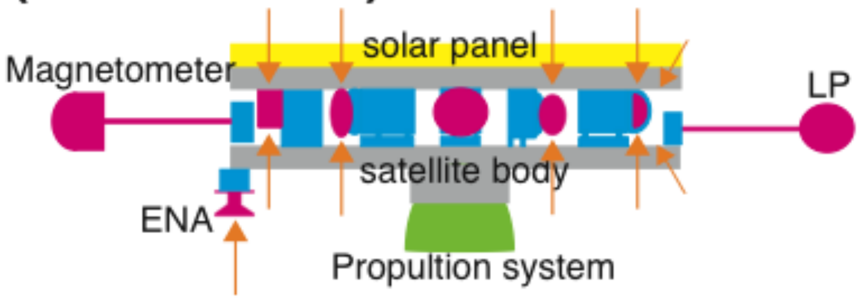
Science

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**, Δt~1min 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**, Δt<1min gradient, cyclotron Ω_i
Relation to substorm injection	correlation to ENA observation	**#1**, Δt~1min

#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

In-situ satellites (to be modified)

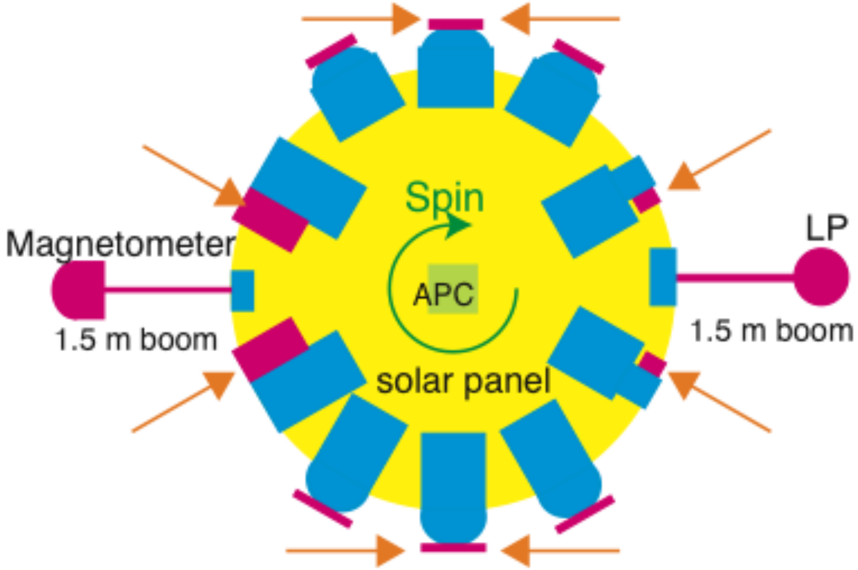
Daughter S/C : (without wave)



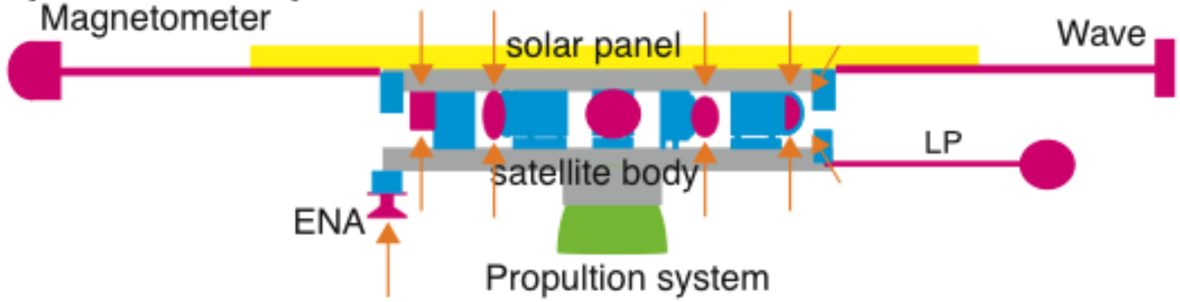
Satellite body = 1.5 m diameter

Up to 8 ion, 1 electron, 1 cold instruments

Active Potential Control is place in the center



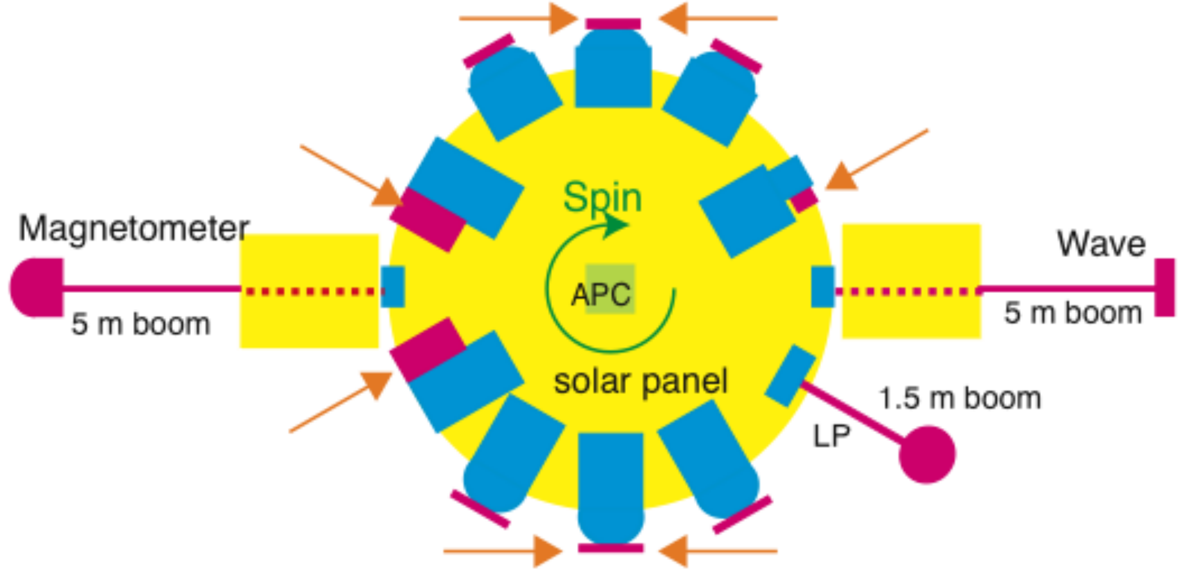
Mother S/C : (with wave)



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

Action Items on payload (as of August 2014)

How can we include ionospheric monitoring such as Sounder (by U. Iowa) and Optical instrument (N_2^+/N_2 ratio of airglow tells energization of topside ionosphere). The ion escape should directly be related to upper ionospheric condition. The concern is the weight (16 kg for Sounder) and we could not yet found European PIs that can make this instruments.

Do we need E-field measurement for accurate measurement of particles (but aren't LP and APC enough?).

Need to involve ground support team outside Europe.

Comparing with soil N_2-N_2O-NO-NO_2 ratio (by existing remote sensing satellite) to correlate the change of oxidation state of N (= escape of N^+ or N_2^+) is one possible additional issue (Question 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?

Other Action Items

* Clarify the need of instrument for science (going)

* Define spec (observation limit, resolution, integration time)

* Radiation dose for each SI

* How much EMC cleanness requirement do we ask?

* We need astrobiology team (who will contact?)

* Ground support requirement (e.g., optics)

* Should we call “remote sensing” or “monitoring”

Strategy

(1) We try first M-class (AO: 2014), and then S-class (2015/2016) or any NASA's call if we fail M-class. The M-class is "**comprehensive understanding of distribution using in-situ + imaging**" with 2-spacecraft (and additional in-situ daughter satellite by NASA or ISAS for gradient measurement) 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 NASA as possible partner or its own mission, but M-4 proposal is made as ESA-led mission.

(3) Launch is targeted for next solar maximum's declining phase (2025). This gives extra opportunity that makes ongoing Van-Allen Probes and ERG to be extended for stereo observations.

(4) If NASA agrees one spacecraft, we should shuffle the accommodation (which PI should go to which spacecraft). The easiest then is ESA makes Mother-daughter and NASA makes remote sensing (monitoring)

Multiple Ion Mass Analyzer

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

Energy resolution: $\mathbf{(E_{O+}-E_{N+})/E_{N+}=15\%}$, 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 **$M/\Delta M \geq 200$.** Low temporal resolution (5 min) is OK.

(2) Hot Ion 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.** **Wide FOV (separate $\perp$ and // directions)** and **without H^+** is OK.

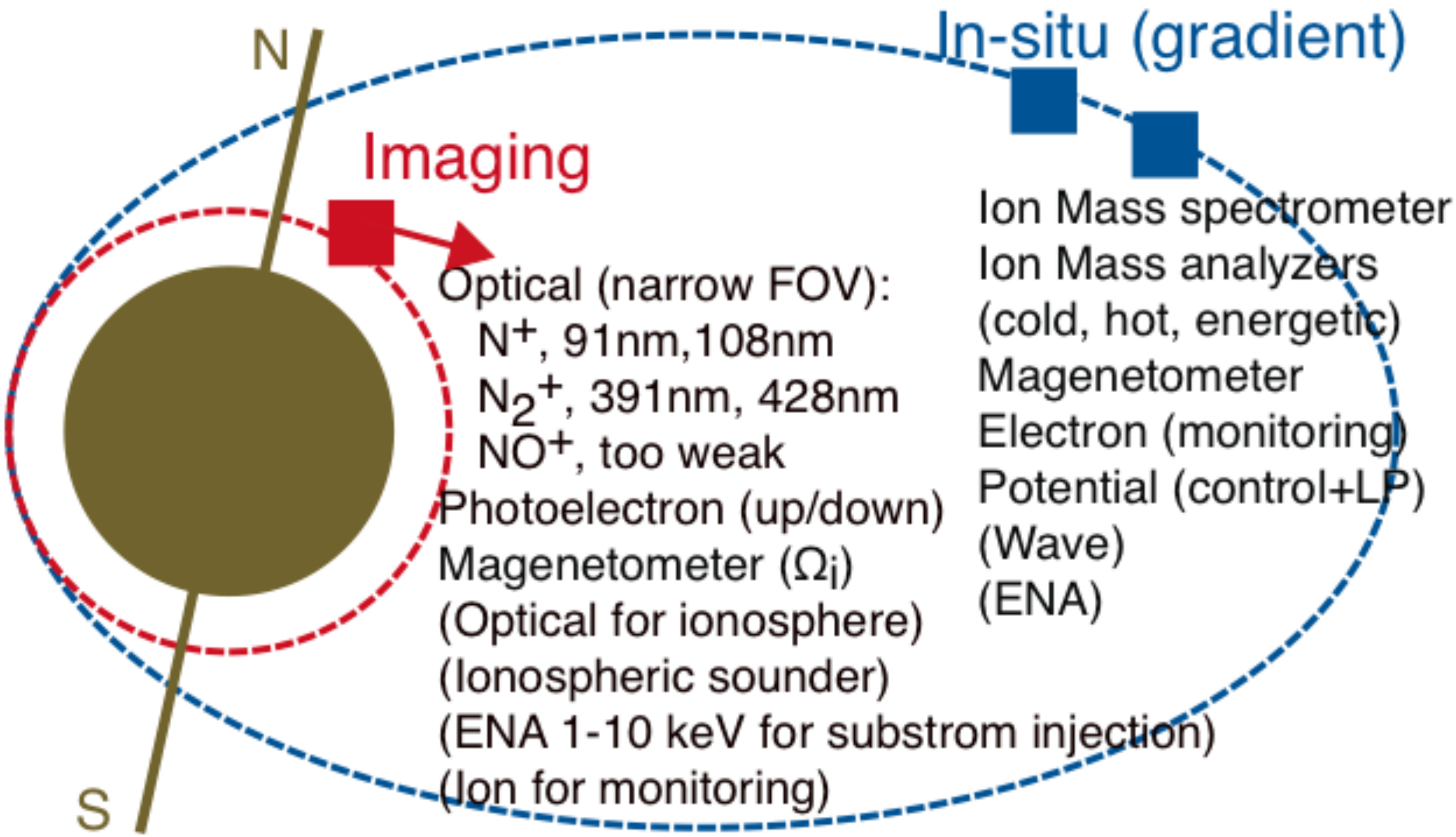
(3) Hot Ion analyser 2: **Narrow FOV with 2π (tophat) angular coverage and $\Delta E/E \leq 15\%$.** **$M/\Delta M \geq 4$** (H^+, He^{++}, He^+, CNO^+, molecule$^+$) is OK

(4) Hot Ion analyser 3: For high temporal/spatial resolution, it is nice to have simple ion energy spectrometer for **$\Delta E/E < 4\%$ and high- & temporal resolution**

(5) Hot Ion analyser 4: **Just detecting N^+ and N_2^+** is useful (like Kaguya and Suisei). Non-uniform low g-factor is ok.

END

Skip ...acecraft 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

日本への期待

ESAはsupport letterをcore instrumentに要求しているが、日本の事情も理解しているので、（大学レベルで）出せれば出すという程度。

1. 「ひさき」型の光学望遠鏡で磁気圏のN+, N_2+, O+等の視線積分を計る

   高度 2000kmの極域（radiation beltの外）から赤道面に向ける

   AA: スキャナーは必要か？

   AA: どのような軌道が良いか？

2. 「かぐら」「すいせい」に載せたような、1 keV 前後でN+とO+を分離できる質量分析器

   分離が優先（正確なg-factorが出せればもっと良い）

   他の国は尽く失敗している

3. イプシロンを使った同期衛星（daughter satelliteか新しい光学衛星）

   打ち上げは2025年なので時間がある

注：磁気圏関係はNITRO以外にAlfven（オーロラ）とTor（磁気乱流）が予定されている