NITRO
A Mission to "Planet Earth"

presented by

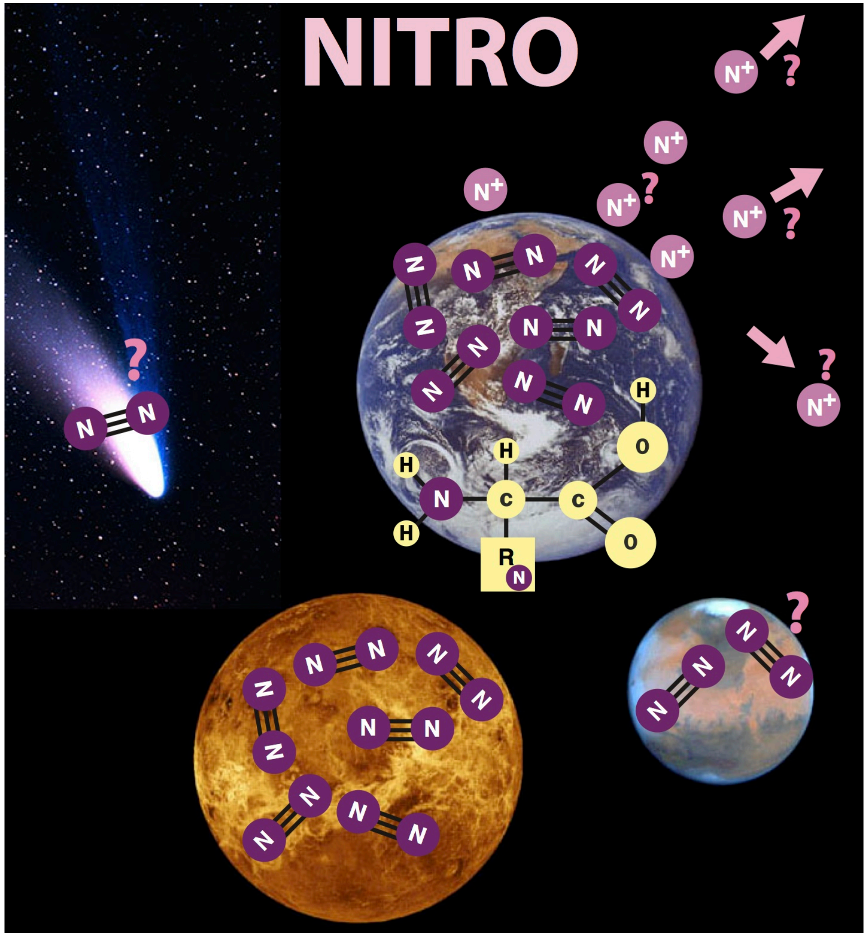
M. Yamauchi (Yama),
IRF (Kiruna, Sweden),

Iannis Dandouras,
IRAP (Toulouse, France),

Eric Quemerais,
LATMOS/IPSL (Guyancourt, France)

on behalf of the NITRO proposal team.

update from final presentation: p8, p11, p16, p25, p30 red text,
& addition of p17, p28, p29



Outline

Introduction (Objectives and tasks)

Science overview

1) Scientific rationale and goal: *Why nitrogen?*
2) Mission rationale: *What will NITRO answer?* (questions from SARP)

Mission overview

1) Orbit
2) Payload
3) Accommodation (questions from SARP)
4) One-spacecraft option (questions from SARP)
5) Measurements resolution (questions from SARP)

Extra science (questions from SARP)

Summary

Mission objectives

To measure non-thermal nitrogen budget and circulation with a quality that allows extrapolating over a billion-year timescale in the past

- "Past conditions" require **a wide range of solar EUV and solar wind** (velocity, density, and magnetic field) input conditions.

- "Good quality" requires measurements of **major volatile ratios**, i.e., N/O and O/H ratios (H and part of O comes from H_2O).

Nitrogen constitutes 78% of the Earth's atmosphere, and is always a part of the composition of amino-acids.

What is to be measured

(1) **Magnetospheric density distribution and fluxes** for N^+, N_2^+, O^+, and H^+.

(2) **Energy distribution** of each species in the magnetosphere.

(3) **Neutral and ion densities** at altitudes > 1000 km (**exosphere** / upper ionosphere).

(4) Low-frequency waves that significantly control the ion energization.

*** All the above data for a wide range of solar wind and solar EUV conditions**

Why nitrogen?

Different behavior from Oxygen

Escaped amount comparable to inventory

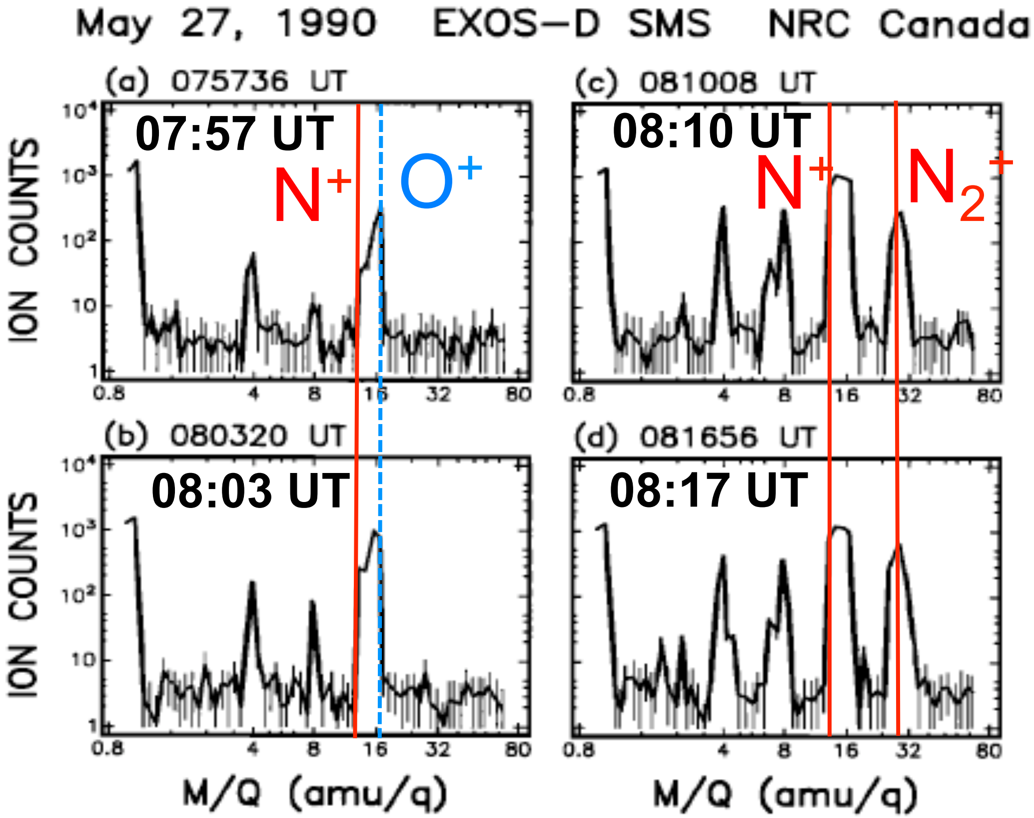
Scientifically important (e.g., planetary evolution)

Now possible to measure (was impossible 4 year ago)

Important also for magnetospheric / ionospheric science

Why nitrogen? 1a. Behavior

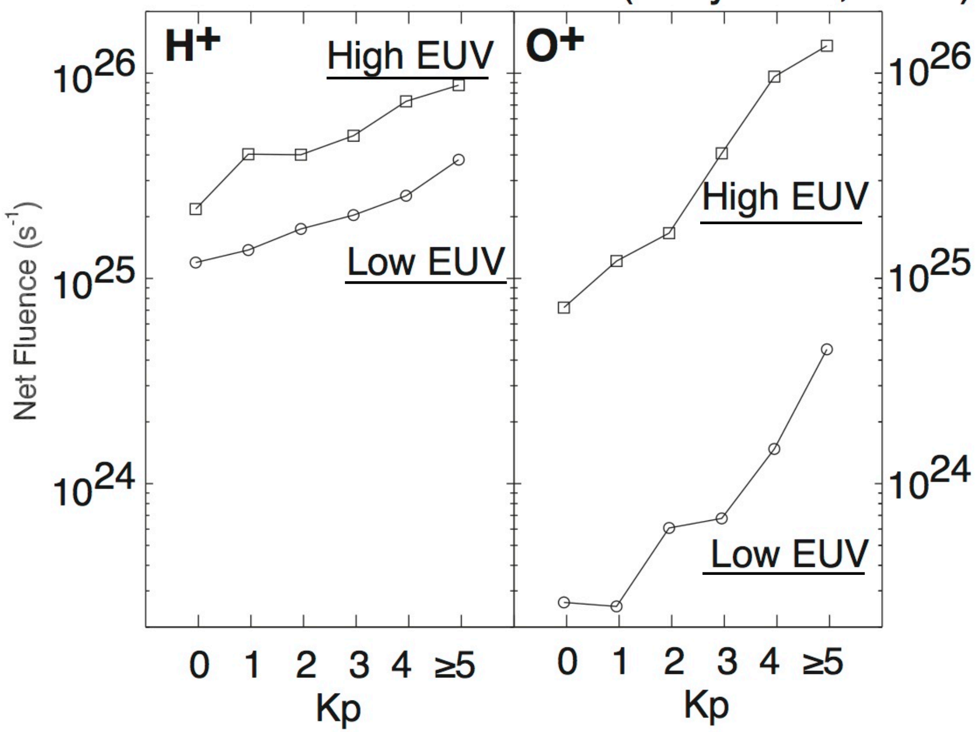
N^+/O^+ increase up to ~ 1



(Yau et al., 1993)

O^+/H^+ increase to >> 1

Akebono cold ion statistics (Cully et al., 2003)



energy < 20 eV, high EUV: $F_{10.7} > 150$

N and O behave independently

The same trend for 0.02-30 keV
(Polar/TIMAS, Peterson et al., 2002)

Why nitrogen? 1b. Amount

- Present nitrogen inventory = 4–5 x 10^{18} kg.

  ⇒ **Non-thermal escape matters if ≥ 10^9 kg/year ($>10^{27}$ ions/s)**

- Average O^+ escape rate is $10^{25\text{-}26}$ (Cluster, Polar, etc.)
- It changes by a factor of 10^3 during storms (Akebono)
- N/O ratio increases to 1 during storms (Akebono)

  ⇒ **N^+ escape of $>10^{27}$ ions/s is quite possible in the past.**

One may no longer ignore the non-thermal N^+ escape when modeling the ancient atmosphere.

Can we cover both escape & return?

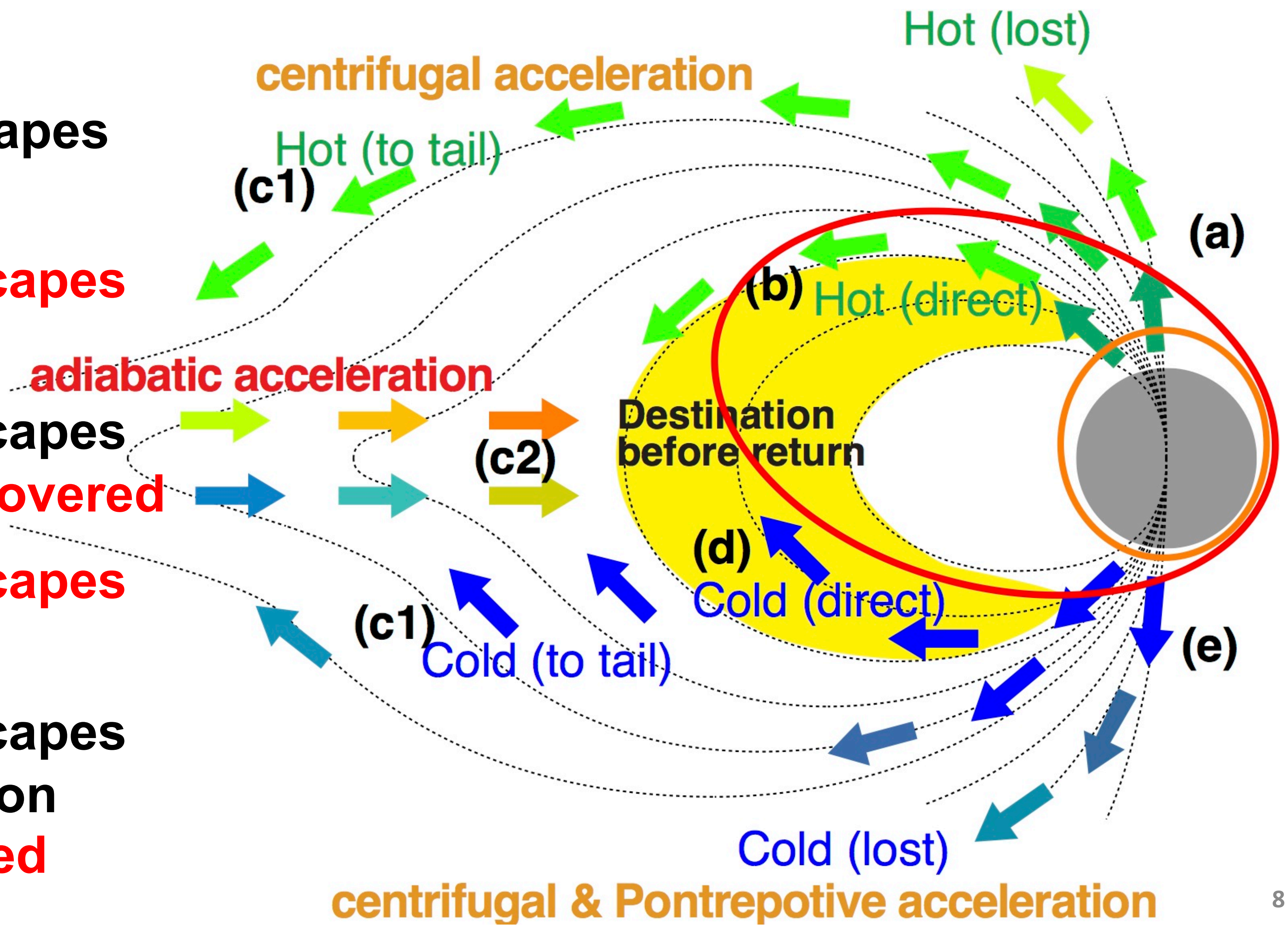
(a) directly escapes
=covered

(b) partially escapes
=both covered

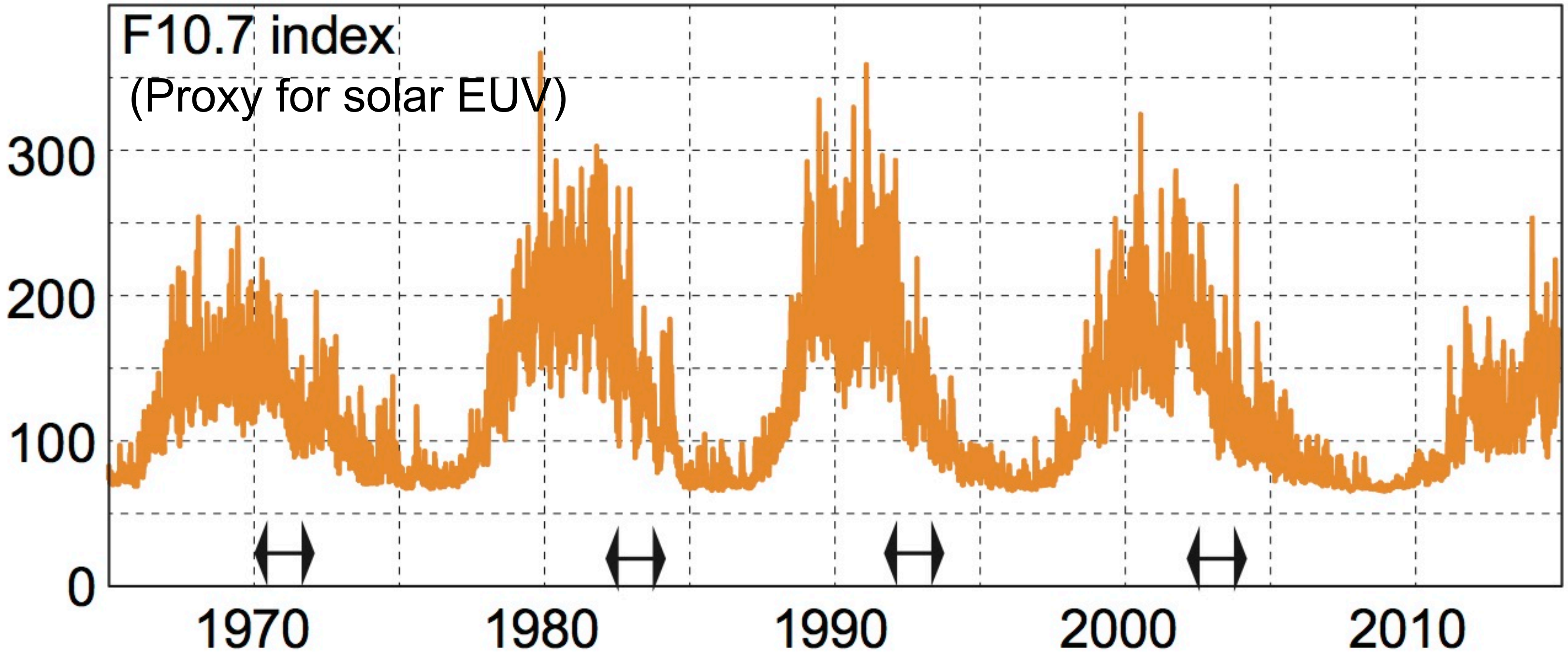
(c) majority escapes
=both mostly covered

(d) partially escapes
=both covered

(e) majority escapes
after acceleration
=escape covered

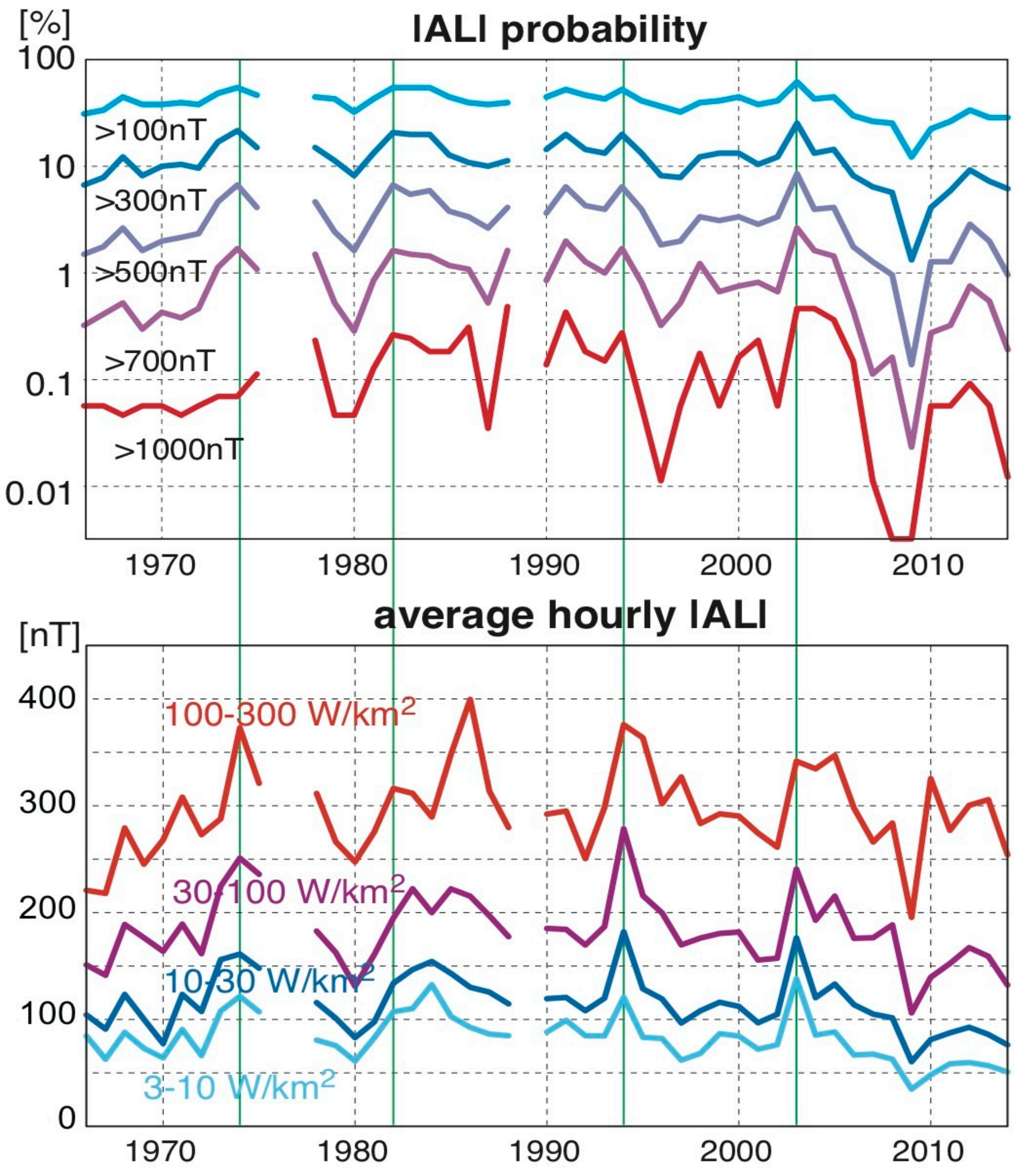


Are 3 years sufficient?



Wide range of EUV intensities within 2 years during each **declining phase**.

We expect the same during 2027-2028.



Geomagnetic activity

A peak year of geomagnetic activity (AL index) comes during the **declining phase** of each solar cycle.

We expect such a year sometime around 2027-2028.

Why nitrogen? 2. Importance

Estimating Chemistry of Ancient Earth

Amino acid formation **depends on oxidation state of N** (NH_3 or N_2 or NO_x).

Mars Nitrogen Mystery

N content is Venus > Earth >> Mars (0.01% of Earth for amount and 10% for N/C).

Terrestrial Exosphere

No knowledge for nitrogen exosphere > 1000 km (and for oxygen > 1500 km).

Ionosphere-Exosphere interaction

$N^+/N_2^+/O^+$ ratio @ **topside ionosphere** is not well understood.

Inner Magnetosphere (ion dynamics and ionosphere-magnetosphere coupling)

N^+ and O^+ are independent tracers.

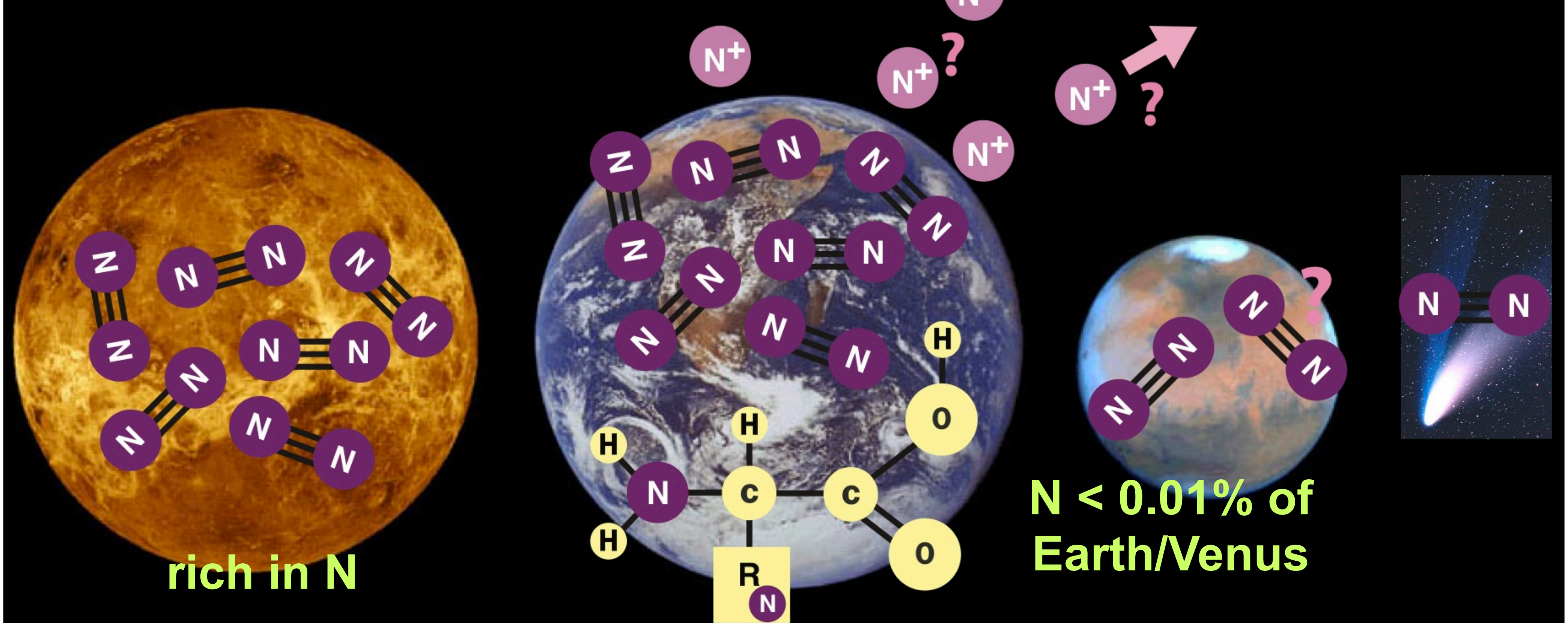
N_2^+ is the major molecular cold ion ($N_2^+ \gg NO^+$, O_2^+).

Space Plasma Physics (acceleration)

Different initial velocities between M/q=14 and M/q=16 give extra information.

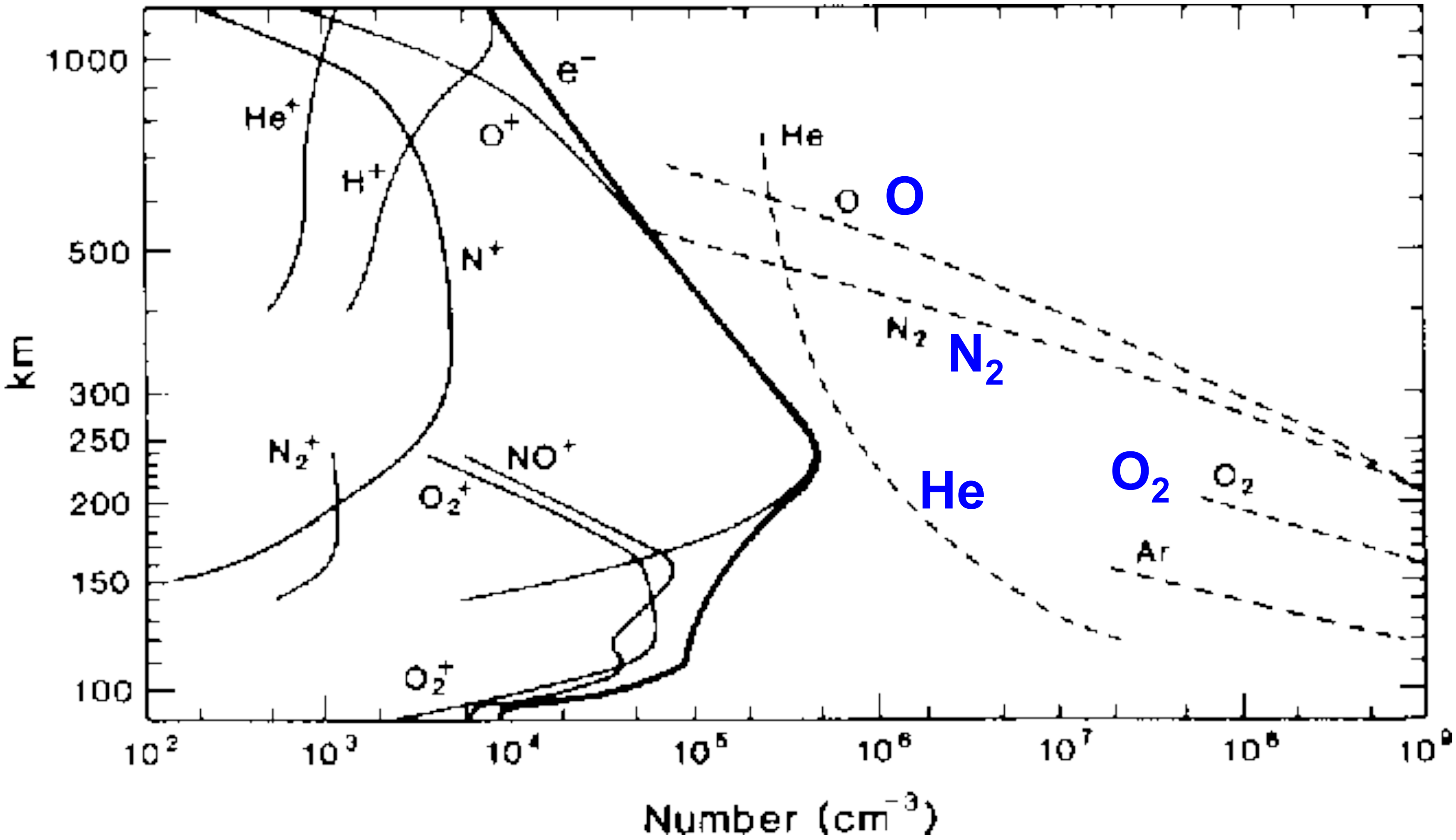
Open questions on Nitrogen

1. Nitrogen form @ ancient Earth?
2. Why nitrogen @ Mars
   << @ Earth, Venus, Titan



Venus **Earth** **Mars**

Exosphere:
No direct neutral observations > 1500 km



NITRO's contribution

Through the measurement of nitrogen budget
(escape and return rate), i.e.,
(a) direct ion measurements and
(b) column density measurements of emission lines,
NITRO will provide a quantitative estimate of past total escape.

Through **the first ever detailed measurement of exosphere** at > 1000 km, i.e.,
(a) direct neutral measurements and
(b) limb observation of emission lines,
Exospheric model (which is mandatory in all atmospheric evolution models) **can be validated against data.**

If the nitrogen escape is large, #1

We can compare the two competing models more quantitatively:

N_2 delivery model (from comets, asteroids)

Expect neutral form with N_2 in primordial Earth

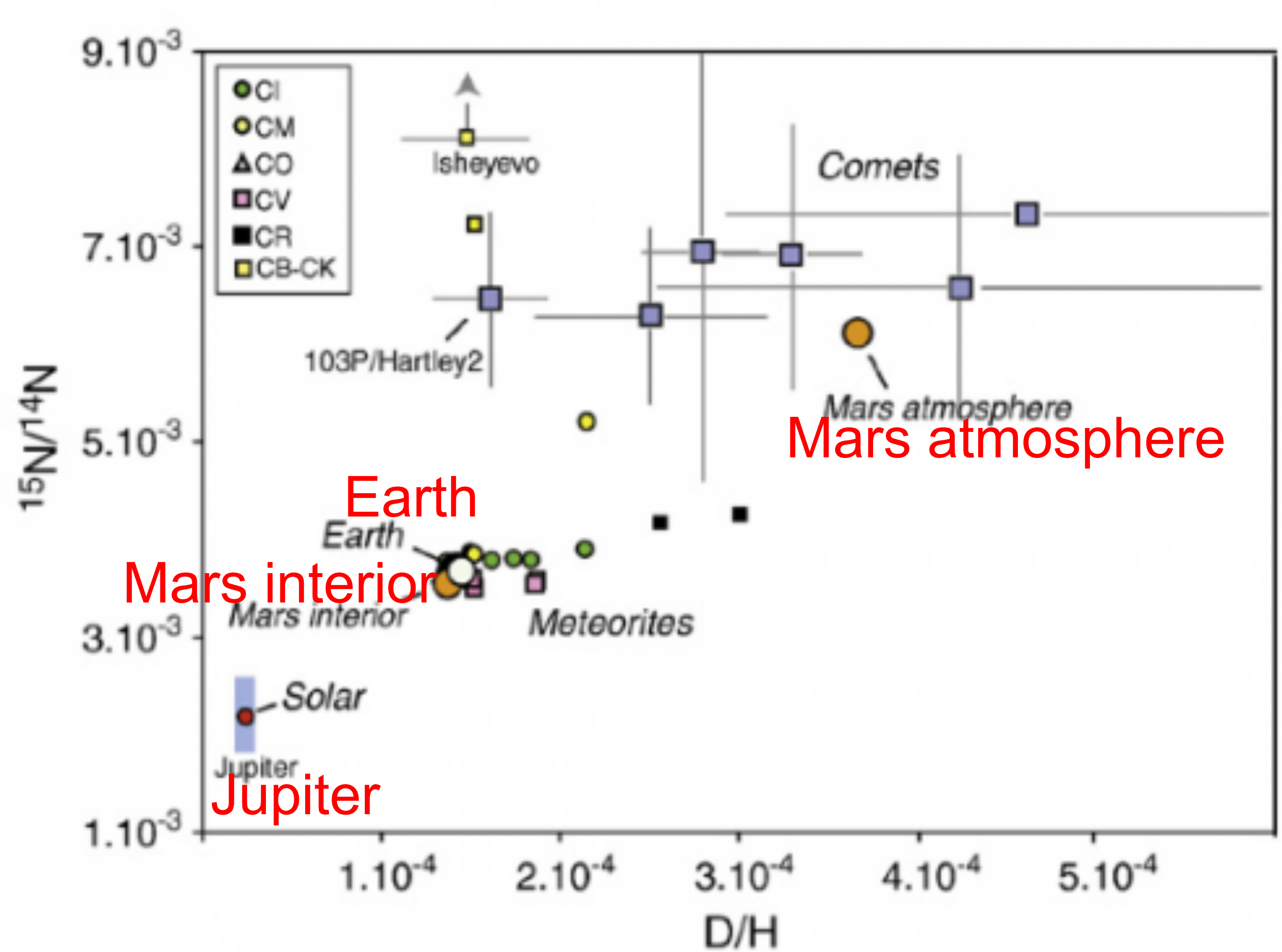
+ Volatiles are difficult to be included in proto-Earth (Temperature).
+ Volatiles should have escaped during the time of outgassing (EUV).
– But amount of delivery is uncertain.

•**Protection of nitrogen from outgassing NH_3**

Expect alkali form with NH_3 in primordial Earth

+ Naturally expected if the proto-Earth included nitrogen (as NH_3).
+ NH_3 rather than N_2 is expected because of higher $T_{condensation}$.
– But difficult to protect from hydrodynamic massive escape.

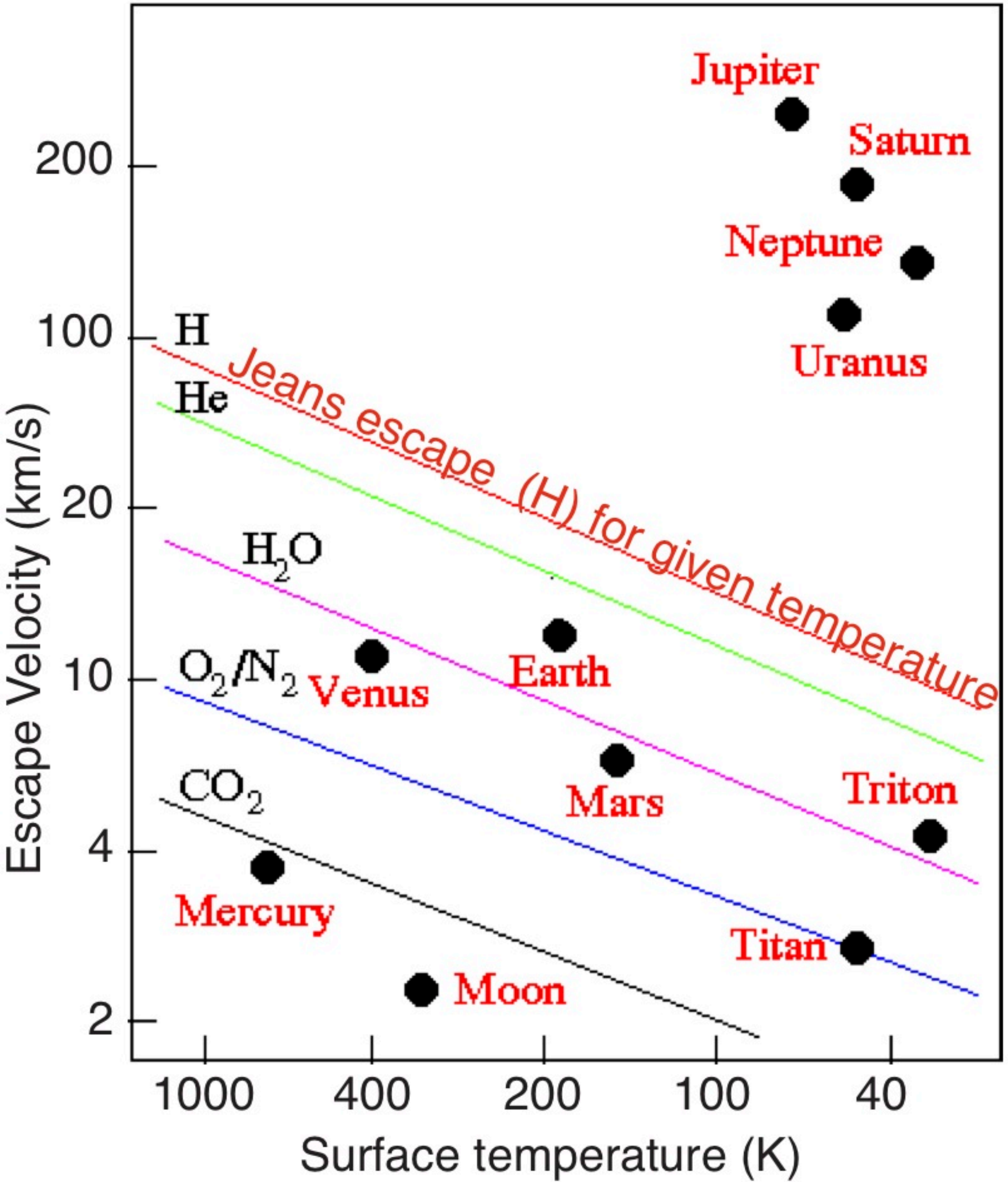
If the nitrogen escape is large #2



High $^{15}N/^{14}N$ and D/N ratios of Martian atmosphere have been interpreted by gravity-mass-filter (i.e., huge loss of nitrogen compared to its inventory).

However, this would instead be interpreted as different types of escape or formation of atmosphere

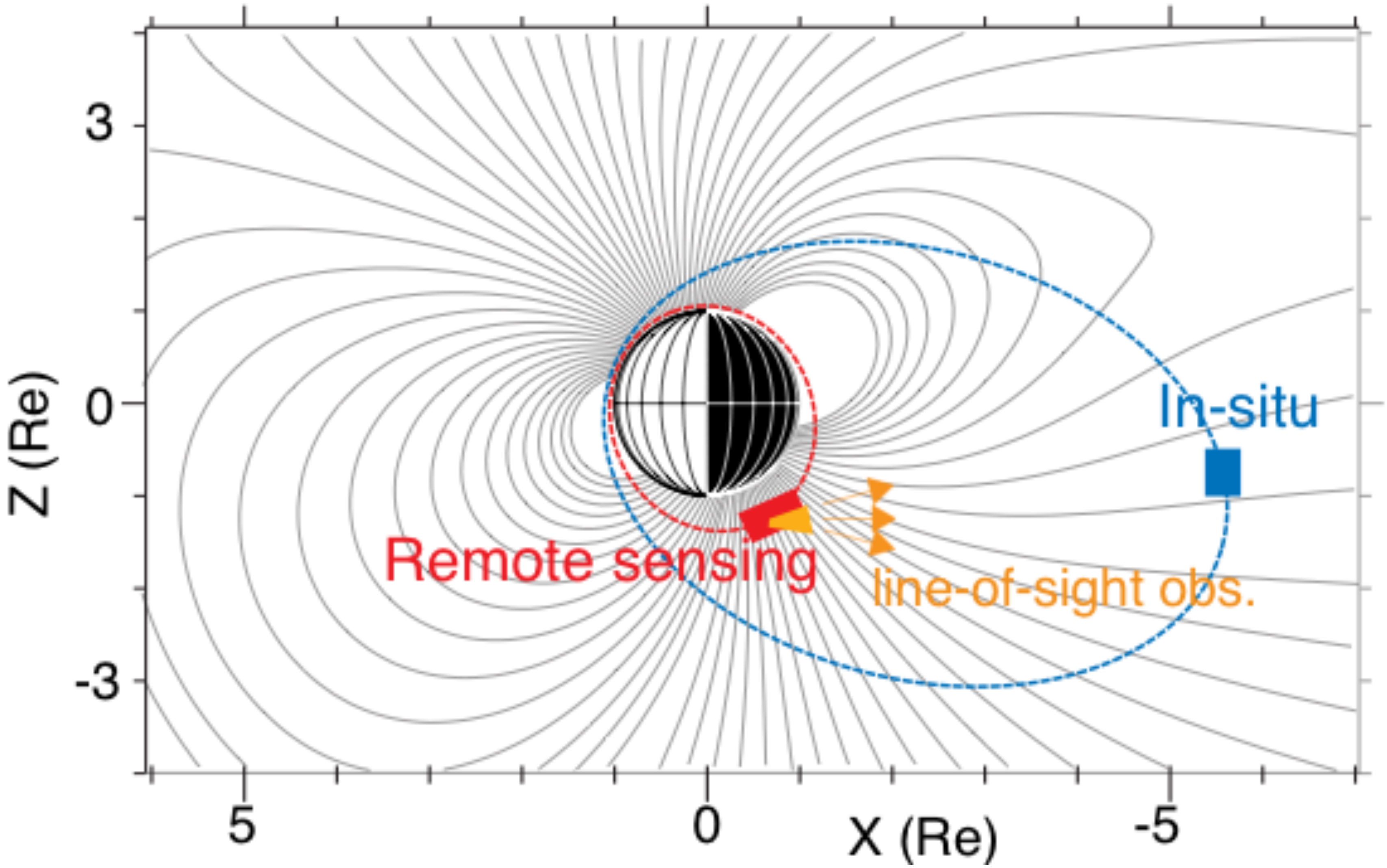
If the nitrogen escape is small



Initial inventory of nitrogen at Venus will be 3 times as much as that of the Earth.

This is difficult to be explained with the existing formation/ evolution models of planetary volatiles.

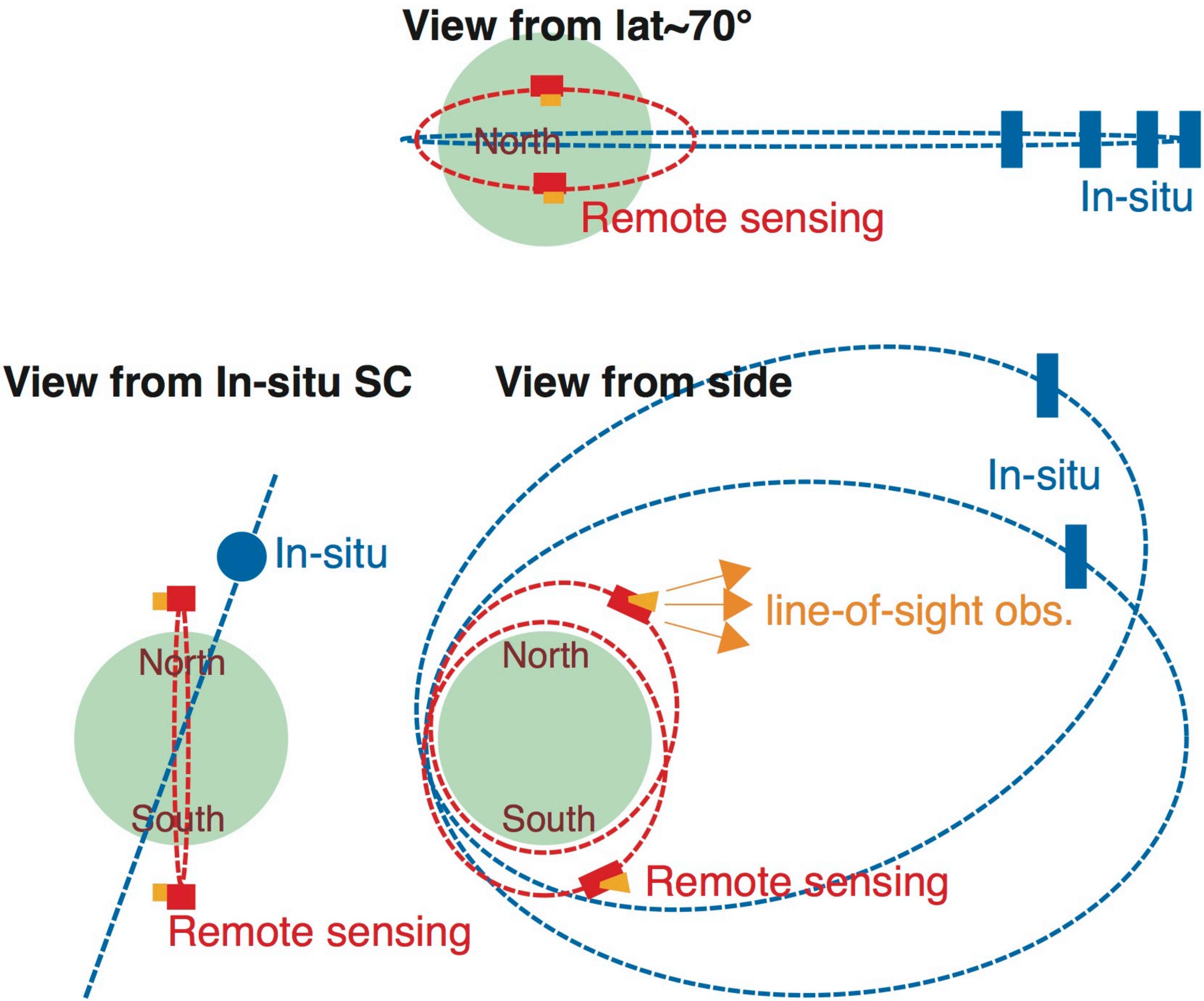
Mission Profile: Orbit



Mission Profile: Orbit Parameters

Spacecraft	**In-situ**	**Remote sensing**
orbit	800 km x 33000 km	500 km x 2400 km
period	589 min	115 min
inclination	$i = 68.5°$	$i = 88.35°$
latitudinal drift	$\omega = 2°$/month	$\omega = 75°$/month
longitudinal drift	$\Omega = 53°$/year	$\Omega = 53°$/year*
required shielding for < 50 krad/3 yr	5.3 mm aluminum	4.5 mm aluminum
ground contact	8 hour / 49 hours	100 min / day
ω (v_{lat}) at apogee	0.15°/min	2.47°/min

* Accuracy of injection: $\Delta i = \pm 0.15°$ ($\Delta\Omega < \pm 5°$/year)


View from lat~70°
North
Remote sensing
In-situ
View from In-situ SC
In-situ
North
South
Remote sensing
View from side
In-situ
line-of-sight obs.
North
South
Remote sensing

Mission Profile: Payload

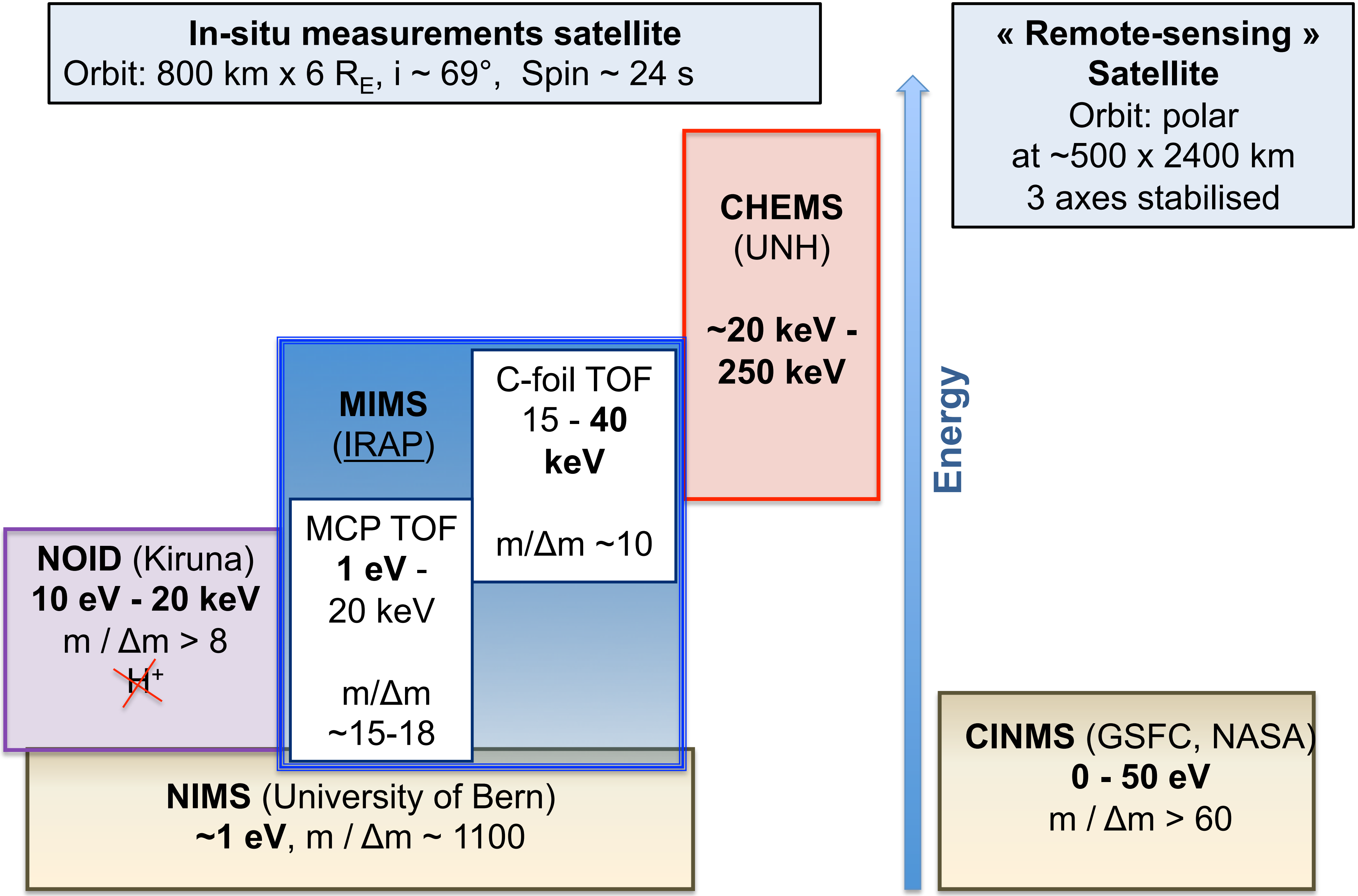
In-situ (**baseline**/optional)

* **Cold ion mass spectrometer** *(Bern)*
* **Ion mass analyzers (0.03 – 30 keV)**:
  (1) m/q < 20 *(Toulouse)*
  (2) m/q > 10 *(Kiruna)*
* **Energetic Ion mass analyzer** *(UNH)*
* **Magnetometer** *(Graz)*
* **Langmuir probe** (*Brussels*)
* **Waves analyser** *(Prague)*
* **Search coil (Ω_N)** *(Orleans)*
* **Electron analyzer** *(London)*
* **Radiation belts virtual detector** *(Athens)*
* ENA monitoring (Berkeley)
* (Pote*ntial Control=SC subsystem)*

Remote sensing (**baseline**/optional)

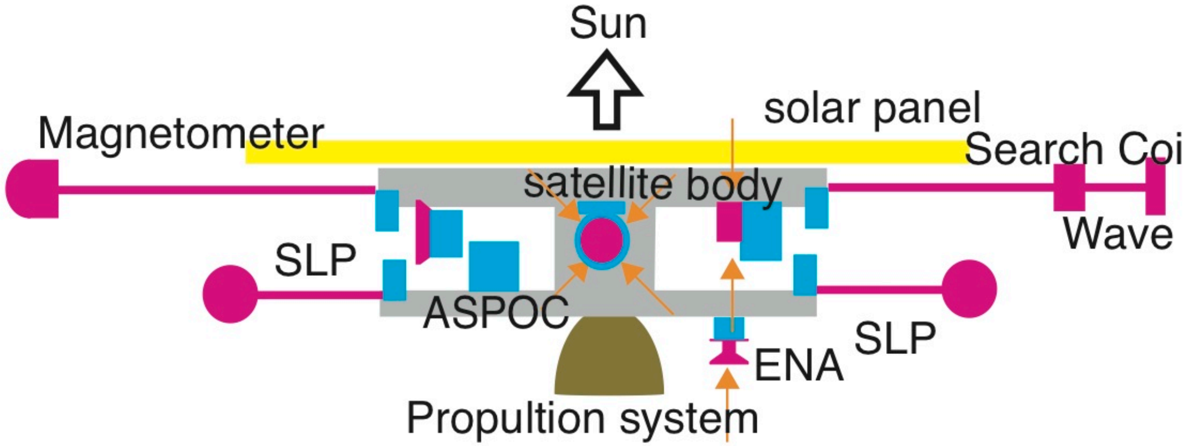
* **Optical emissions** *(LATMOS)*
  (1) N^+: 91 nm, 108 nm
  (2) N_2^+: 391 nm, 428 nm
  (3) O^+: 83 nm
* **Cold ion/neutral mass spectrometer** *(Goddard)*
* **Ion analyzer (< 0.1 keV)** *(Kiruna)*
* **Auroral / airglow camera** *(Tohoku)*
* Langmuir Probe *(Brussels)*
* Magnetometer *(Graz)*
* Electron analyzer *(London)*
* Waves analyser *(Prague)*
* Search Coil (Ω_N) *(Orleans)*
* Ion analyzer (< 50 keV) *(ISAS)*

NITRO Ion and Neutral Mass Spectrometers

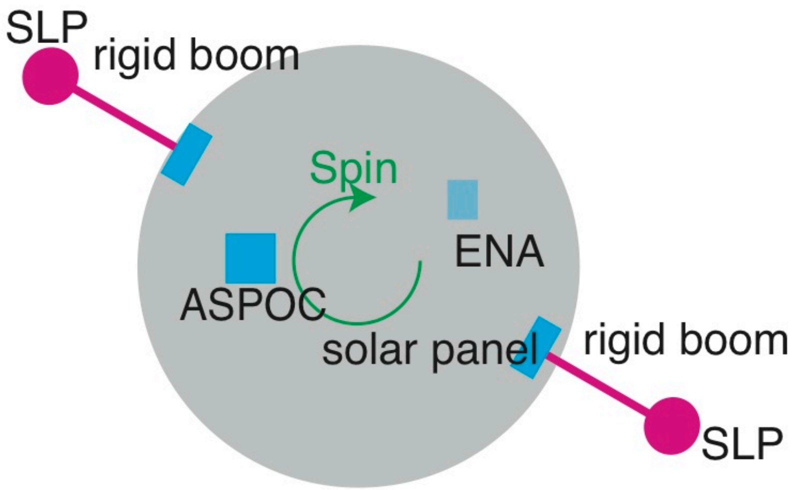


accommodation and FOV (in-situ SC)

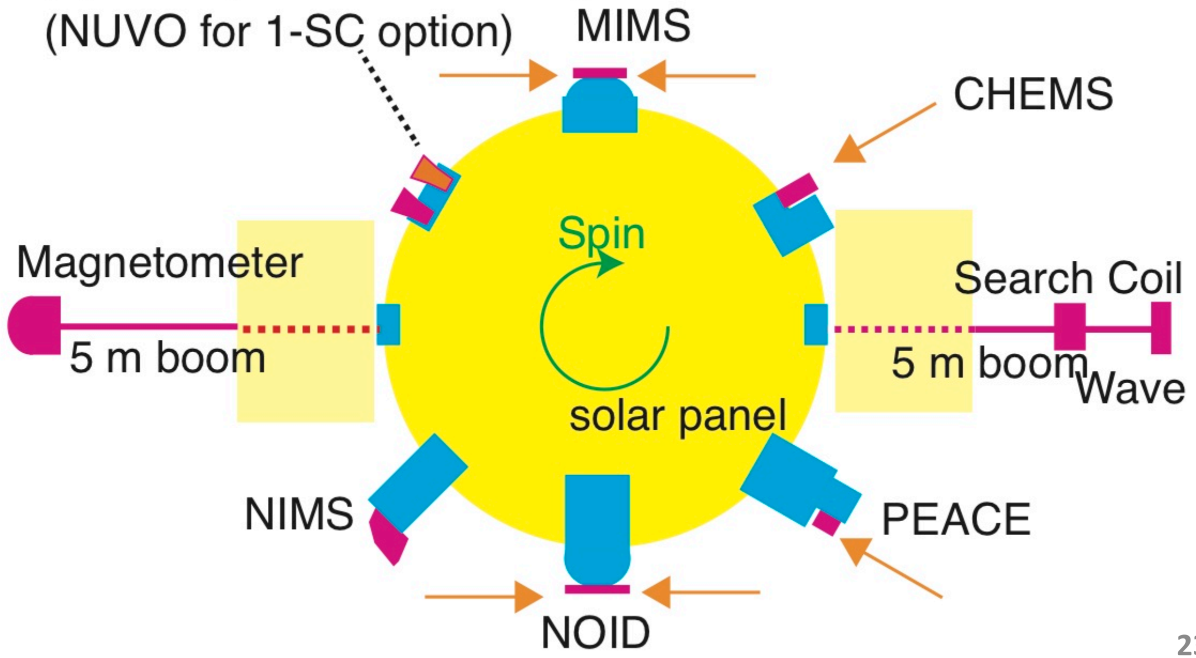
In-situ SC = 1.5~2 m diameter
Sun-pointing spinner



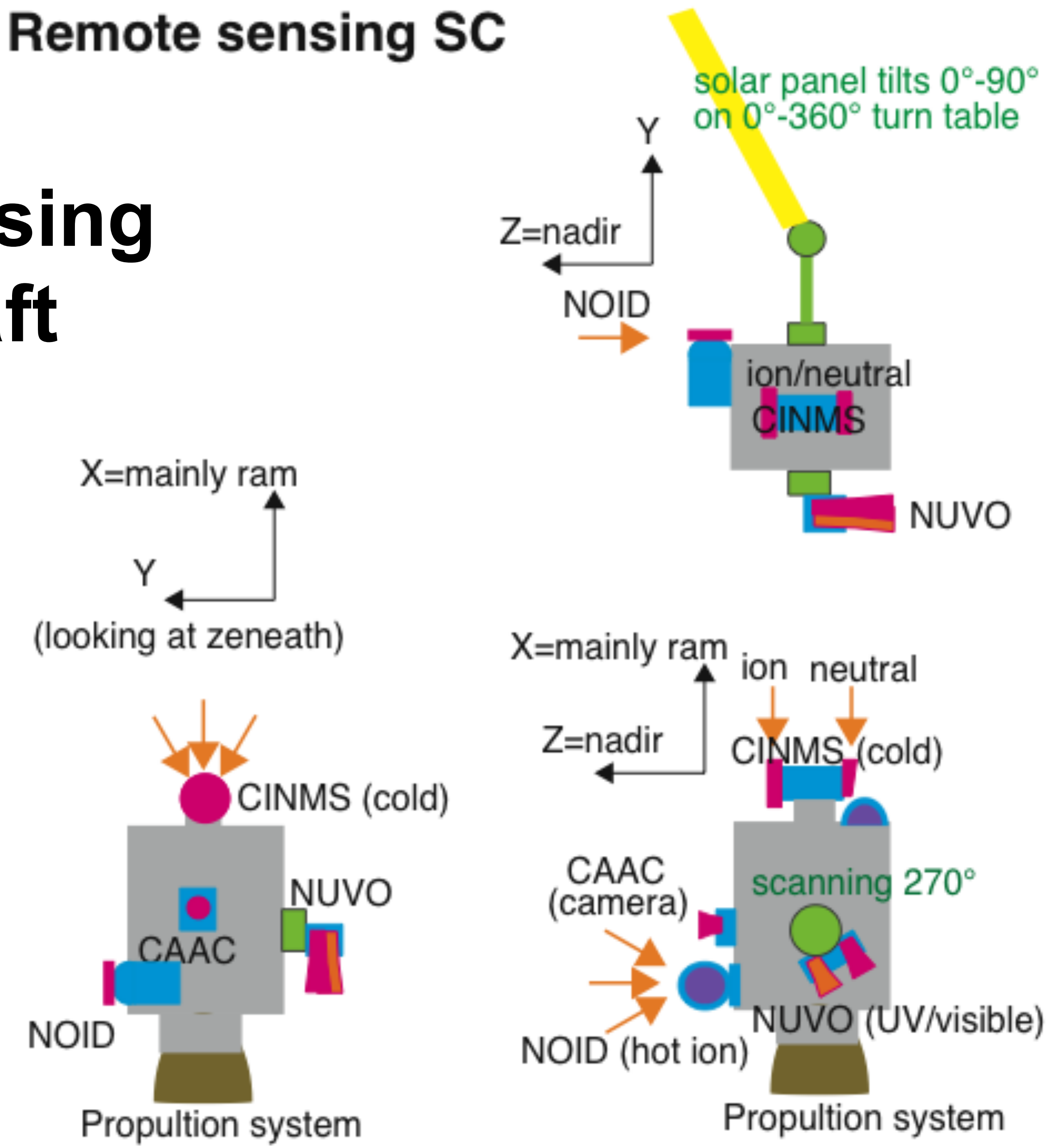
lower layer of SC body



upper layer of SC body

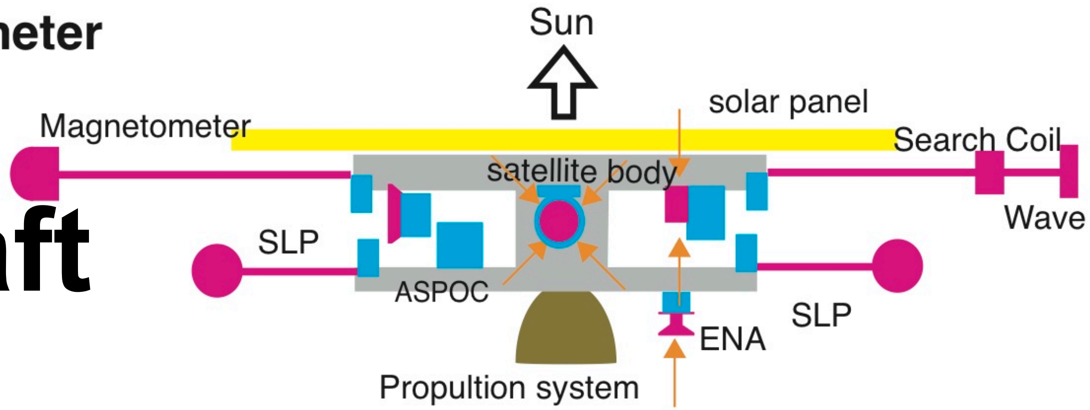


Remote sensing spacecraft



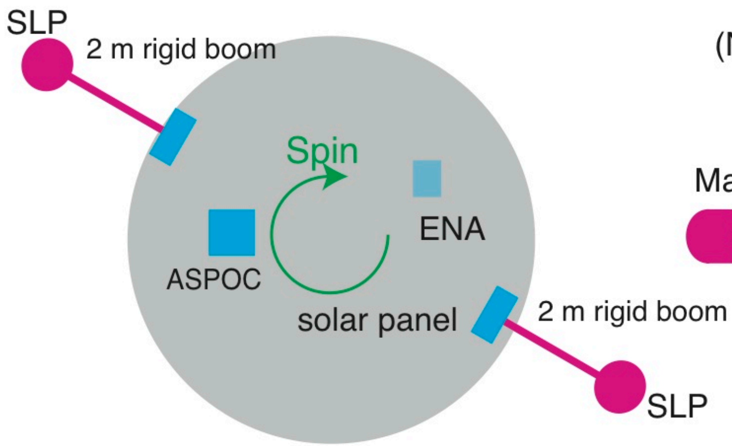
NUVO has clear field-of-view even with optional instruments.

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

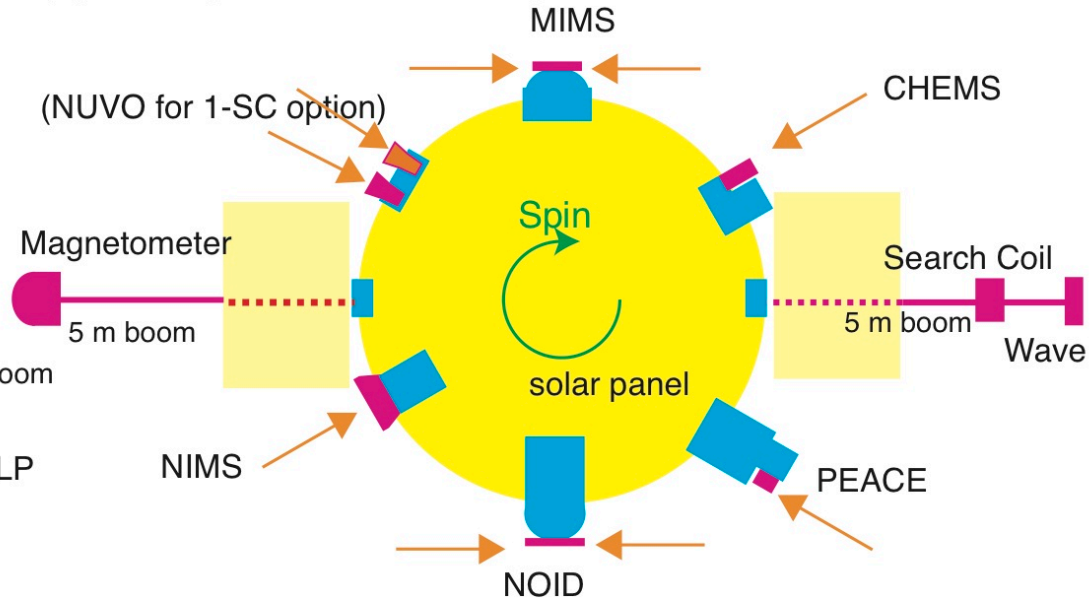


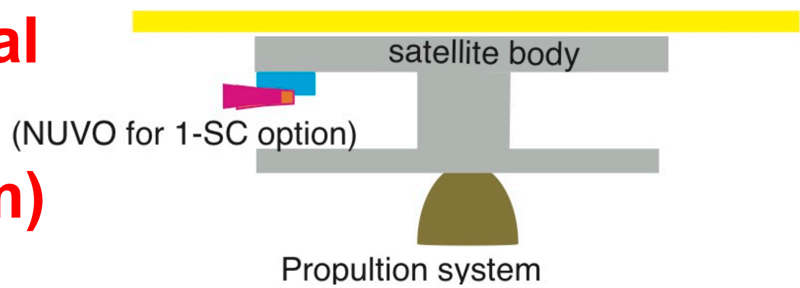
One-Spacecraft Option

lower layer of SC body



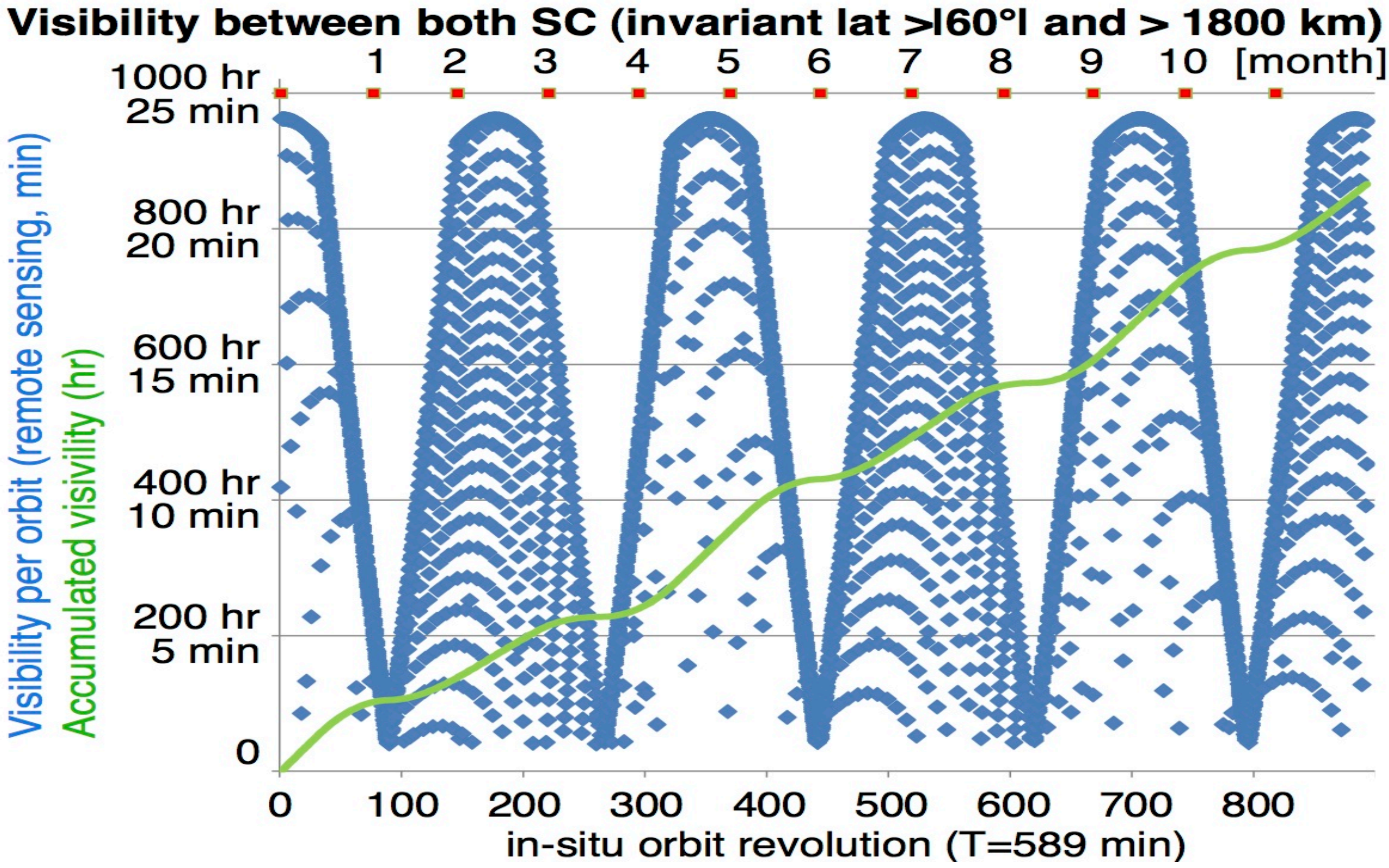
upper layer of SC body



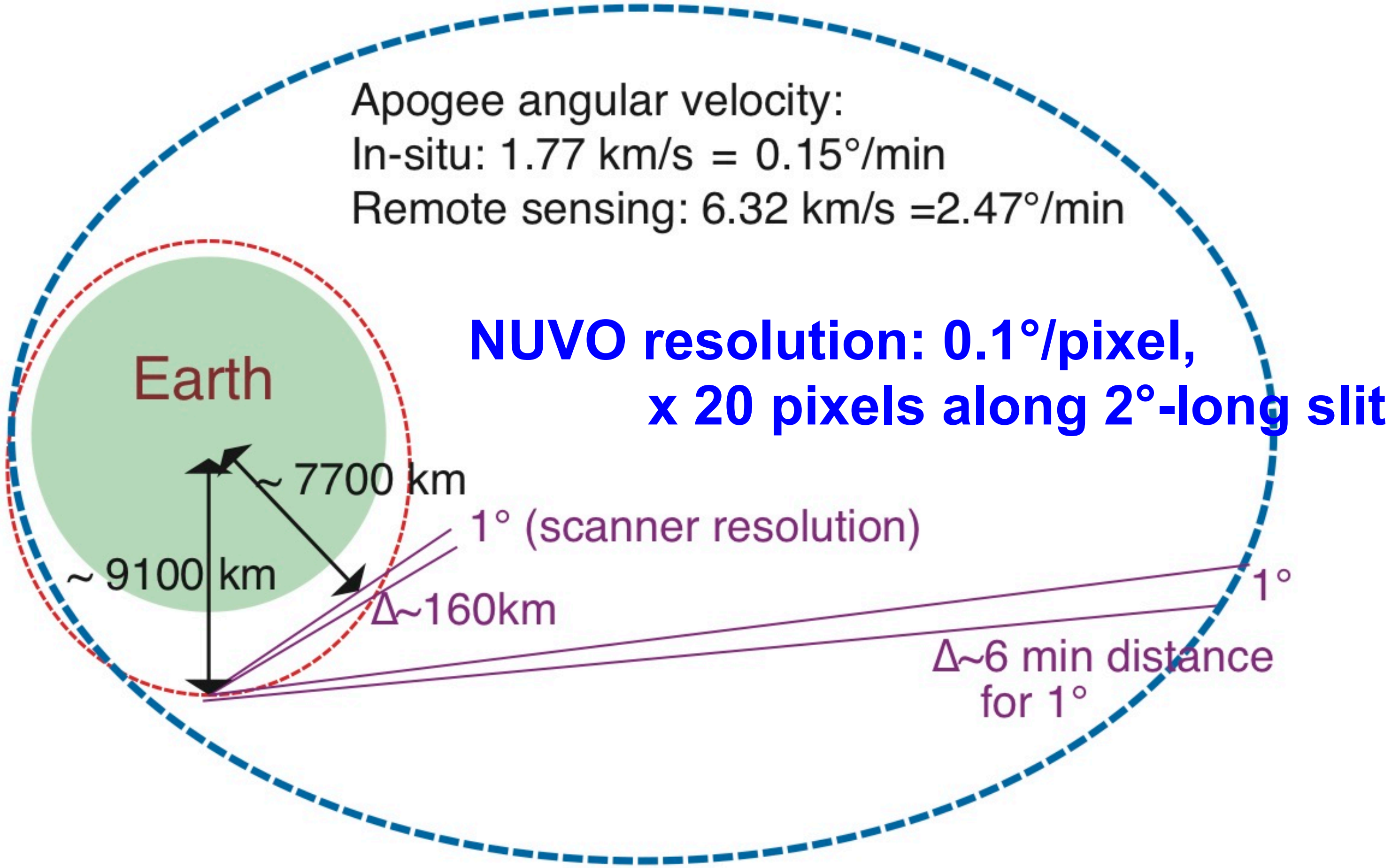


- **NUVO has clear FOV**
- **NIMS will also measure neutral (alternatively place CINMS neutral head at bottom platform)**

Mission Profile: Visibility

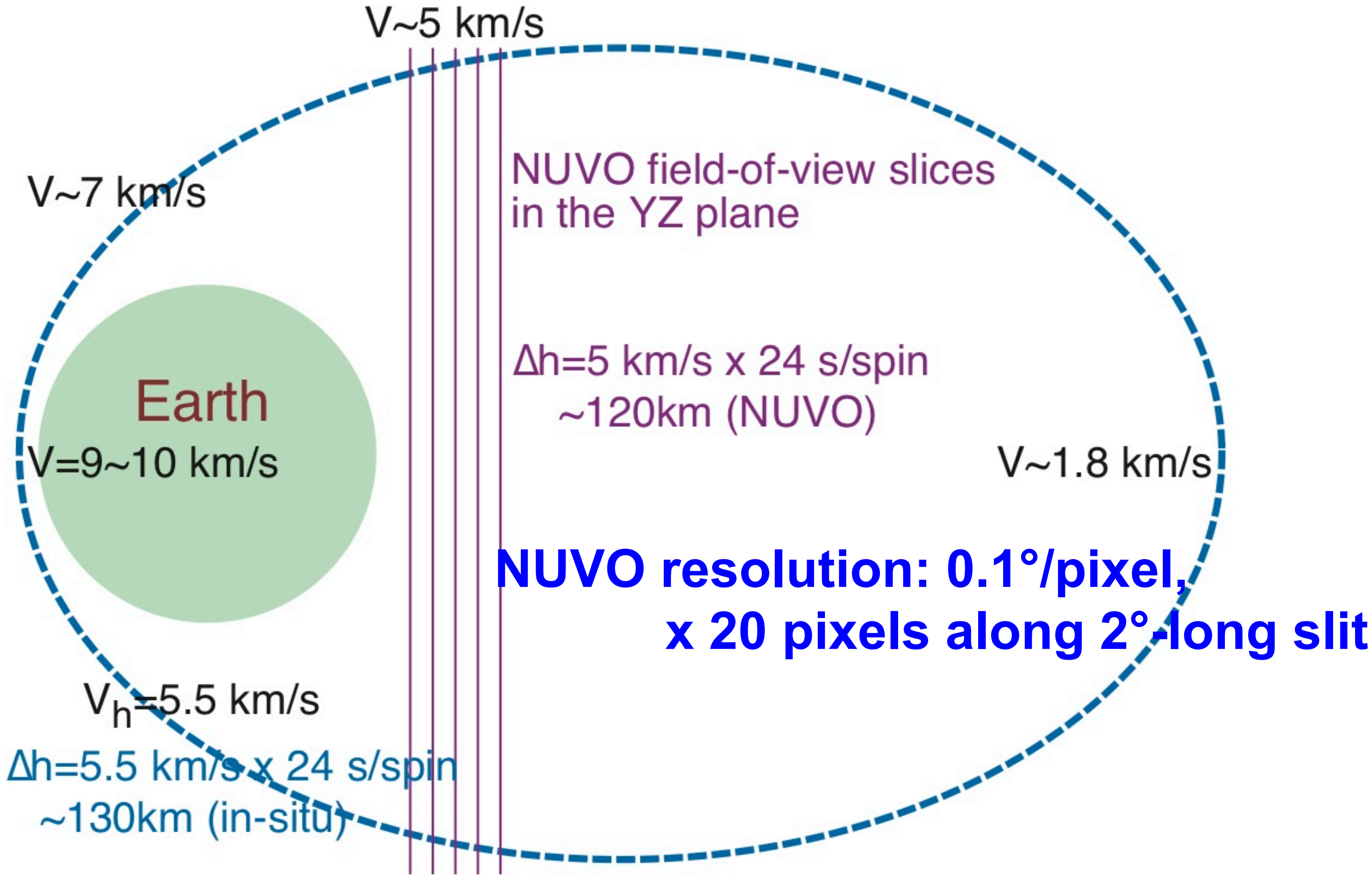


Measurements resolution of NUVO



- With good altitude resolution
- With good spatial-temporal separation

For one-spacecraft option



- Altitude resolution is similar
- Nearly no latitude resolution

One vs. Two spacecraft

Measurements	**two spacecraft**	**one spacecraft**
exospheric neutral	by remote-sensing (CINMS)	by in-situ (NIMS or CINMS)
imaging exosphere	by remote-sensing (NUVO)	by in-situ (NUVO)
inclination	68.5° (in-situ) and 88.35° (remote sensing)	~80° (in-situ)
Science	**two spacecraft**	**one spacecraft**
Total escape/loss	**yes**	**yes**
Exosphere	altitude distribution: **yes** latitude distribution: **yes**	altitude distribution: **yes** latitude distribution: **no**
Ionosphere	latitude distribution: **yes** N^+ production: **yes**	latitude distribution: **no** N^+ production: **yes**
Temporal-spatial	**yes**	**no**
M-I coupling	**yes** (detailed)	**yes** (limited)
Acceleration	**yes** (detailed)	**yes** (limited)

Science with optional payload

These optional payloads and subsystems just take advantage of the unique configuration of the mission.

Energetic Neutral Atom (ENA) detector for in-situ spacecraft
Monitoring substorm-related ENAs, from the tail.

Precipitating ions for remote-sensing spacecraft
To monitor the return flux of accelerated ions.

Electron and magnetometer for remote-sensing spacecraft
Total energy input to the ionosphere (which is available for outflow energy).

Wave package for remote-sensing spacecraft
Low-frequency waves that are associated with energization of ionospheric ions.

Long booms
4-5 m: Total density (by whistler waves) + average mass (field-line resonance frequency): are good to compare with the line-of-sight observations.
50 m (one-SC option): Stick always outside the satellite sheath

Summary

With a unique orbital configuration and recently developed reliable instrumentation, NITRO will reveal the present-day’s nitrogen dynamics and budget.

This knowledge is mandatory in understanding the evolution of "planet Earth" :

- in estimating the ancient Earth's nitrogen condition;
- in understanding the $^{14}N/^{15}N$ part of Mars nitrogen mystery;
- in making a reliable model for the ancient exosphere.

The required instrumentation can also answer key questions

- on Magnetospheric and Ionospheric dynamics; and
- on basic Space Plasma Physics.

Thank you for your attention

Roles of supporting instruments

Magnetometer (shortest boom will do the work)
Pitch angle information and ultra-low frequency wave detection.

Langmuir Probe (shortest boom will do the work)
Spacecraft potential for accurate ion energy measurements.

Electron detector
Identifying the region in terms of plasma region.
Photoelectron information gives connectivity to the ionosphere.

Wave package
Need to know what modes of waves are associated with energization of ions.

Auroral / airglow camera
Auroral (ion source) condition should be monitored. Context information.

Radiation warning
Adjust operation mode of ion detectors, to keep them safe.
Monitor radiation belt dynamics.

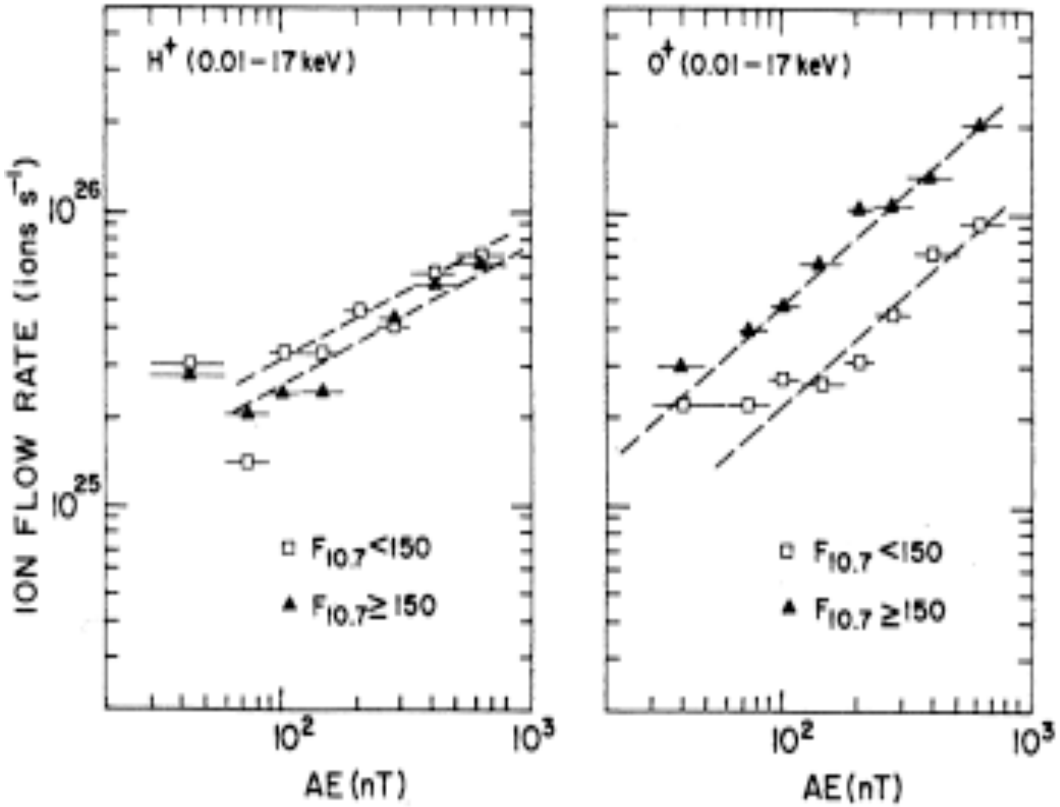
???

Why nitrogen? 1. Amount

Altitude (km)	H^+	O^+ (inc N^+)
50000 km (Polar)	$1\cdot10^{25}$	$1.5\cdot10^{25}$
20000 km (DE-1)	$1\cdot10^{25}$	$7\cdot10^{24}$
8000 km (Polar)	$3\cdot10^{24}$	$3\cdot10^{24}$
9000 km (Akebono)	$2\cdot10^{25}$	$2\cdot10^{24}$
3000 km (FAST)	-	$2\cdot10^{24}$

(Peterson et al., 2006)

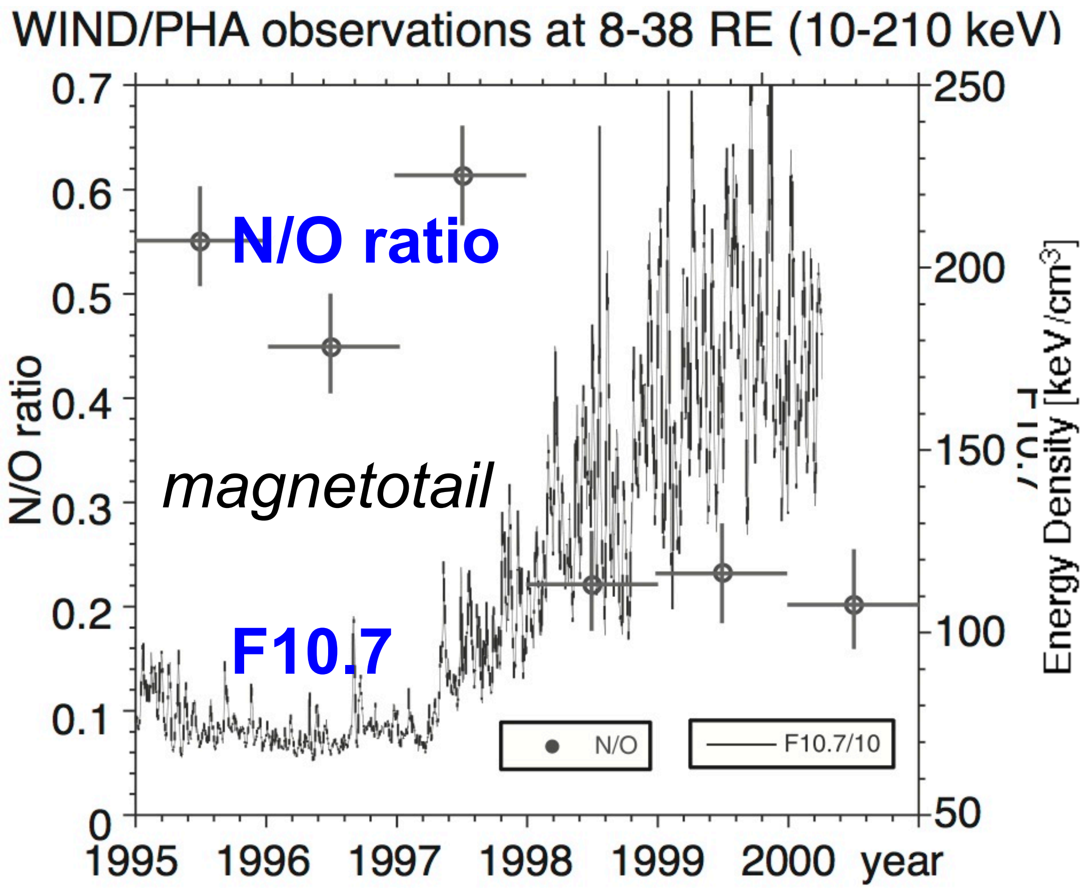
> 10 keV (Peterson et al., 2002)



Polar/TIMAS
(Peterson, 2002)

Omit

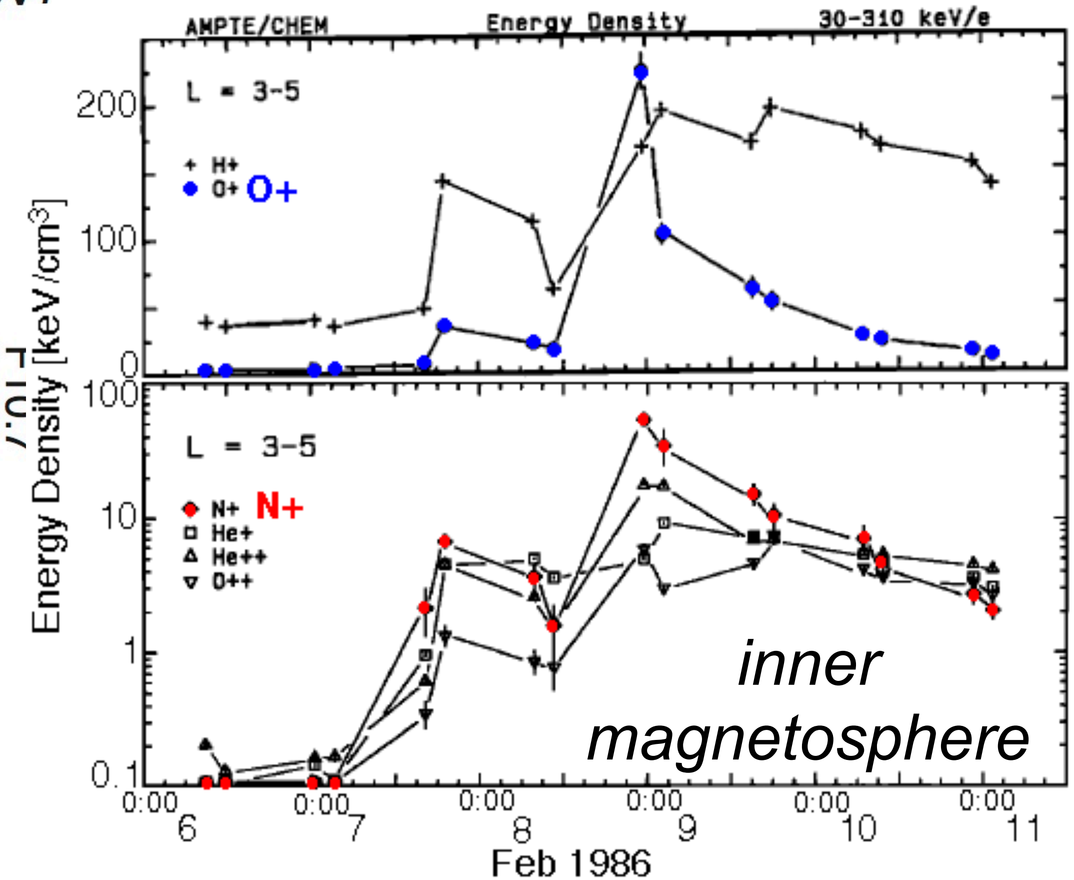
Why nitrogen? 1c. Not well known



(Mall et al., 2002)

N/O ratio in anti-phase with activity

AMPTE result

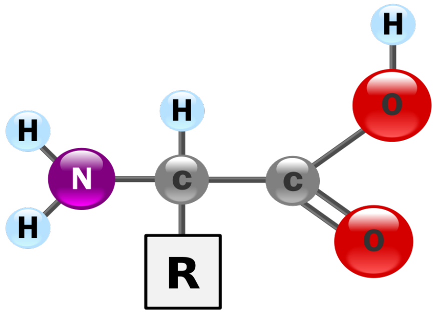


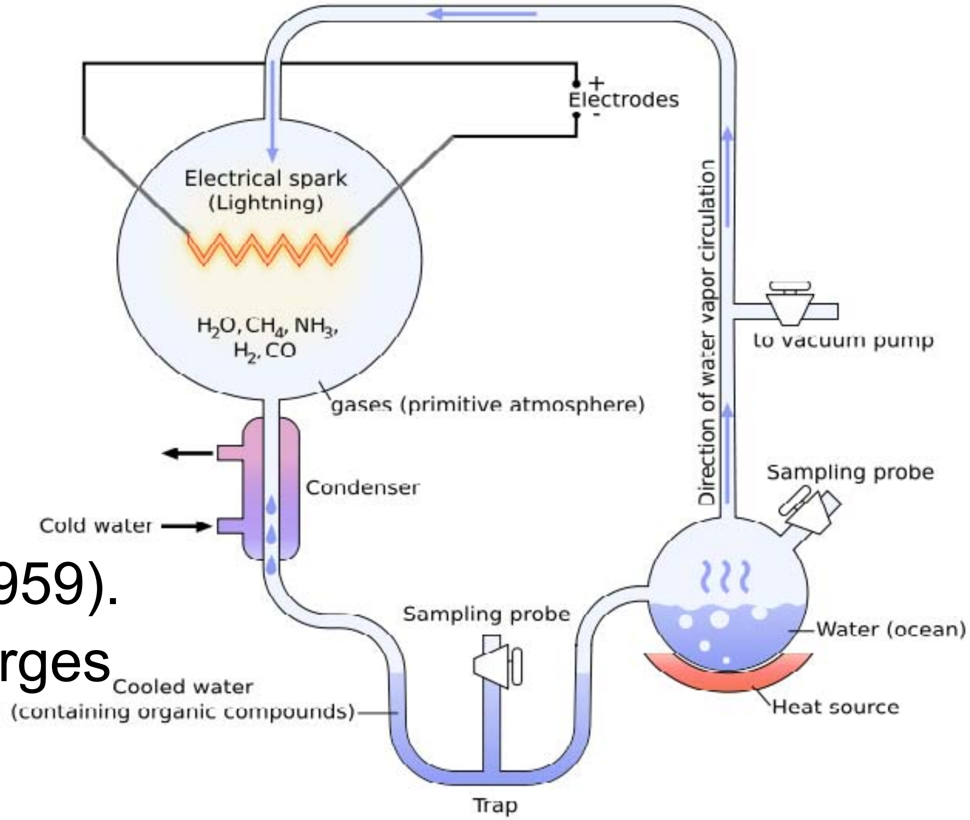
(Hamilton et al., 1988)

in-phase

???

Nitrogen is an essential element for life





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

Pre-biotic type atmosphere + discharges

$\Rightarrow$ formation of **amino-acids** !

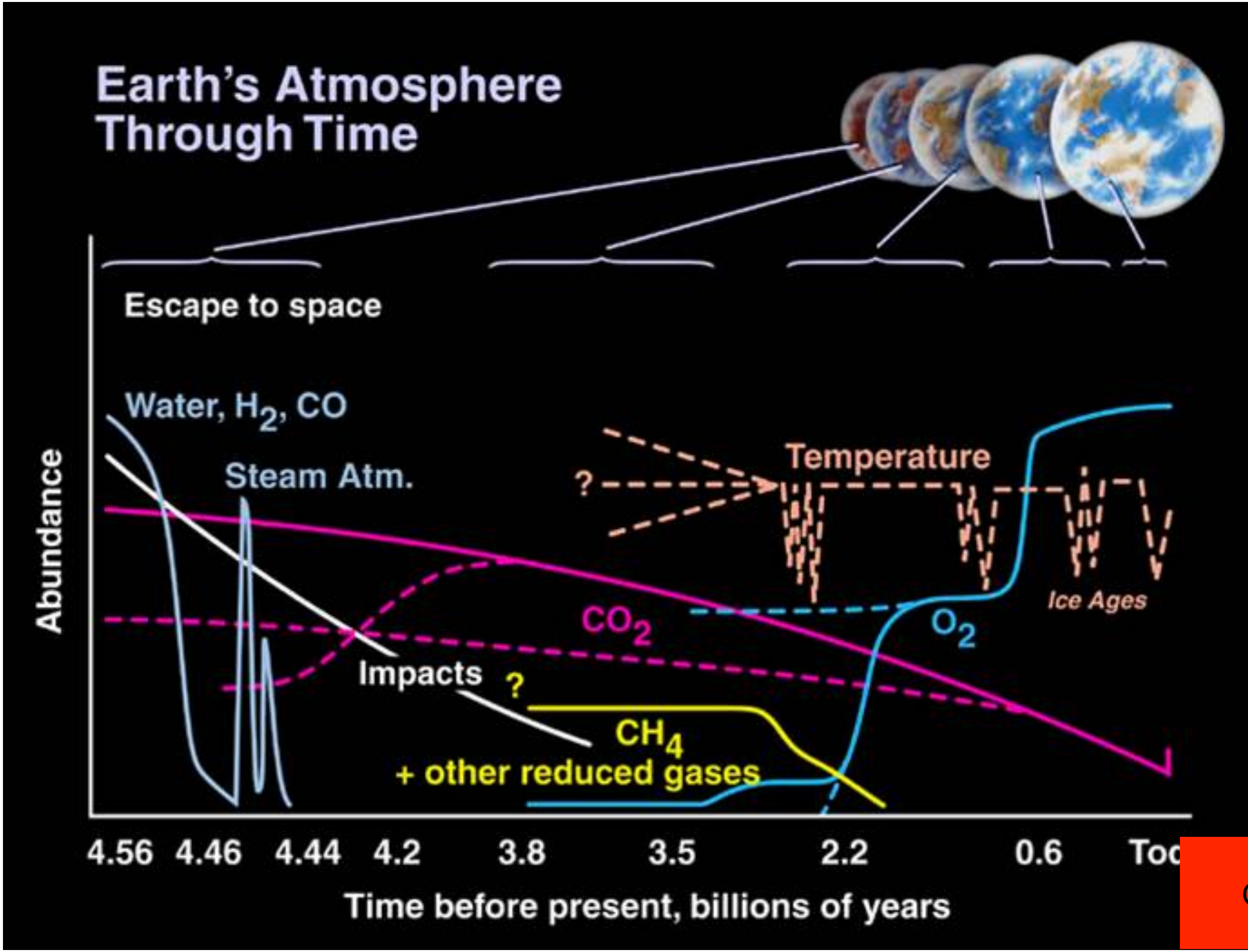
The result depends on the **oxydation state of N**

reduced form (NH_3)

neutral form (N_2)

oxidized form (NO_x)

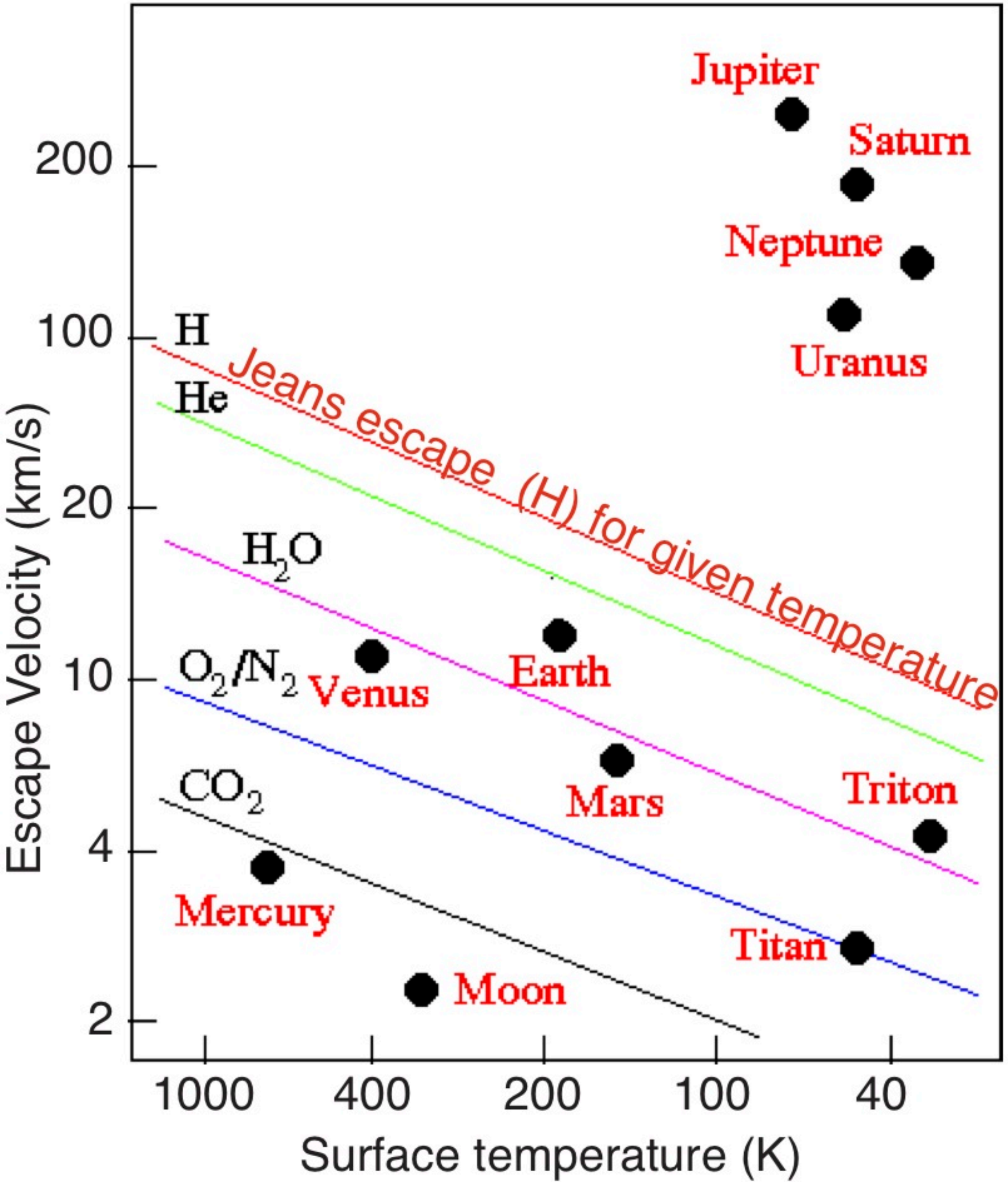
???


Earth's Atmosphere
Through Time
Escape to space
Water, H_2, CO
Steam Atm.
Abundance
Temperature
?
Ice Ages
CO_2
O_2
Impacts
?
CH_4
+ other reduced gases
4.56
4.46
4.44
4.2
3.8
3.5
2.2
0.6
Tod
Time before present, billions of years

Omit

Nitrogen is missing on Mars

Jeans escape does not explain it.



Planetary formation does not explain it.

Condensation temperature of

$T_C(N_2) \sim T_C(CO) << T_C(CO_2) \sim T_C(NH_3)$

indicates that condensation of N and C most likely occurred in the form of N_2–CO pair (~ 30°K) or NH_3–CO_2 pair (50 ~ 90°K). Therefore, N_2 content should be Mars > Earth > Venus.

N_2-Delivery model does not explain it.

It should deliver on Mars too

???

If the nitrogen escape is large #2

Interpretation of isotope ratio $^{15}N/^{14}N$ will be questioned because total nitrogen escape is comparable between the Earth and Mars

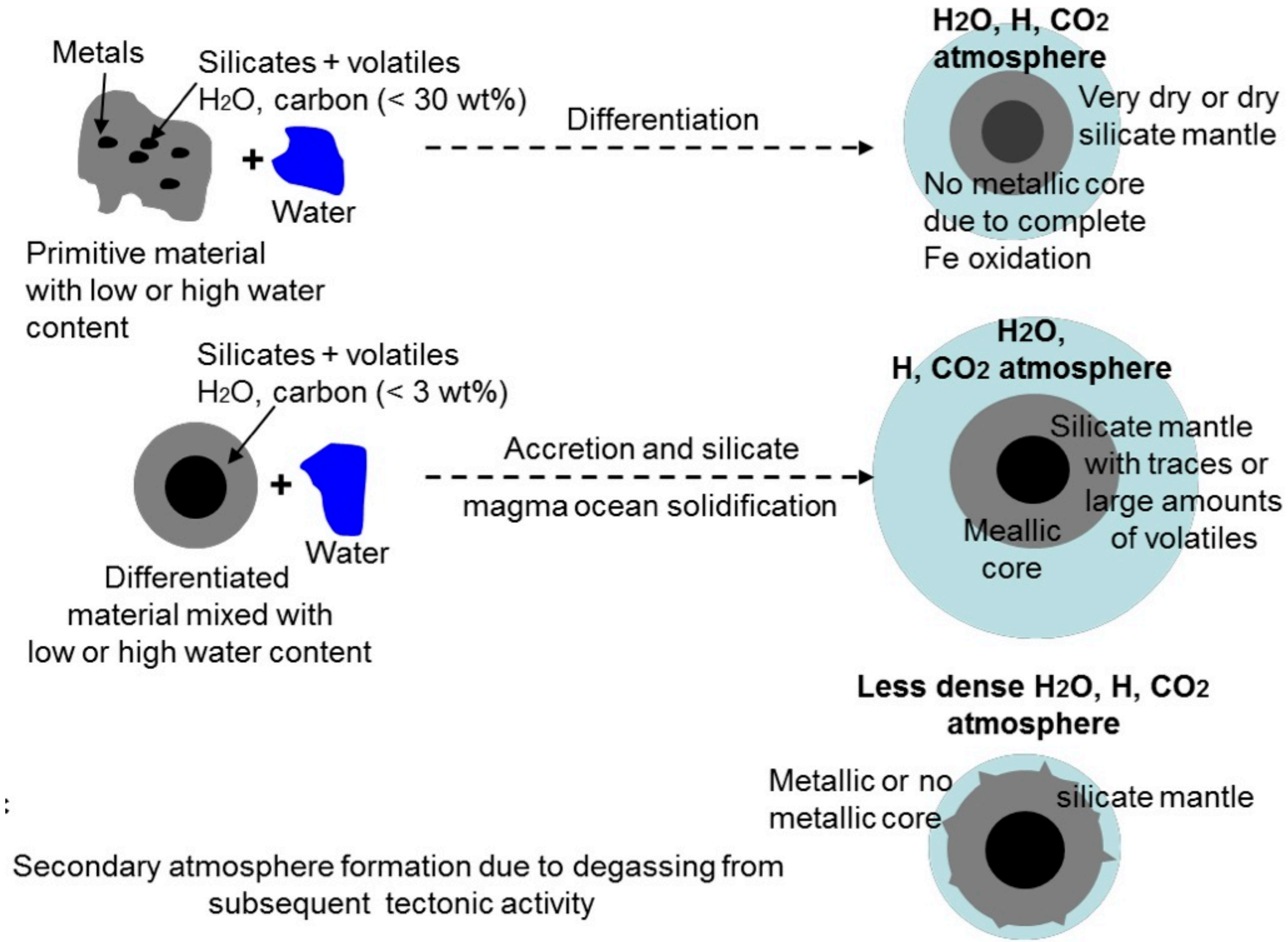
⇒ (a) Substantial Martian atmosphere could have been delivered by comet?

(b) Simple difference in the escape mechanism?

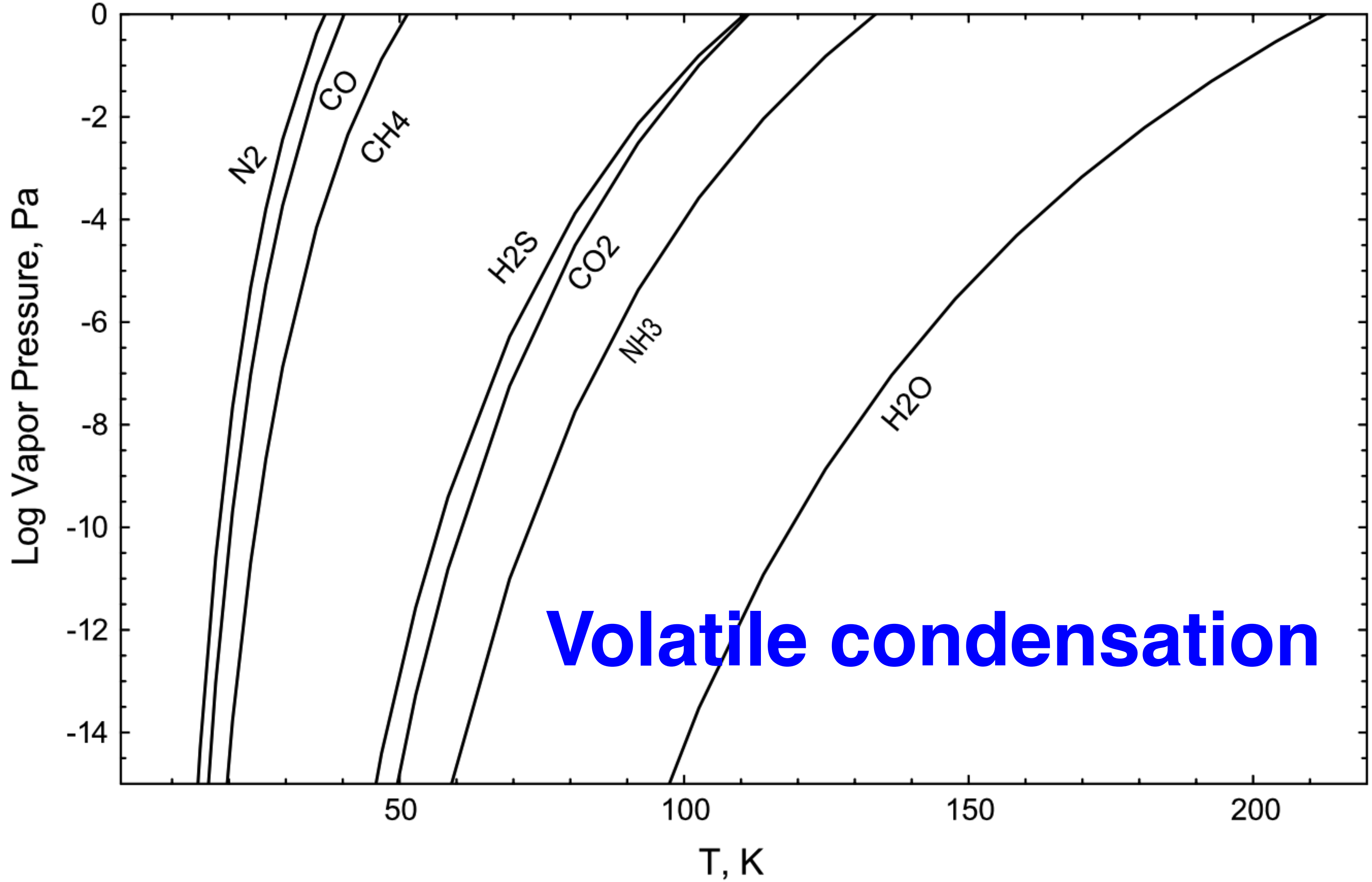
or (c) No outgassing happened, or all outgassed air has been lost at Early stage?

???

Atmosphere formation models



Omit

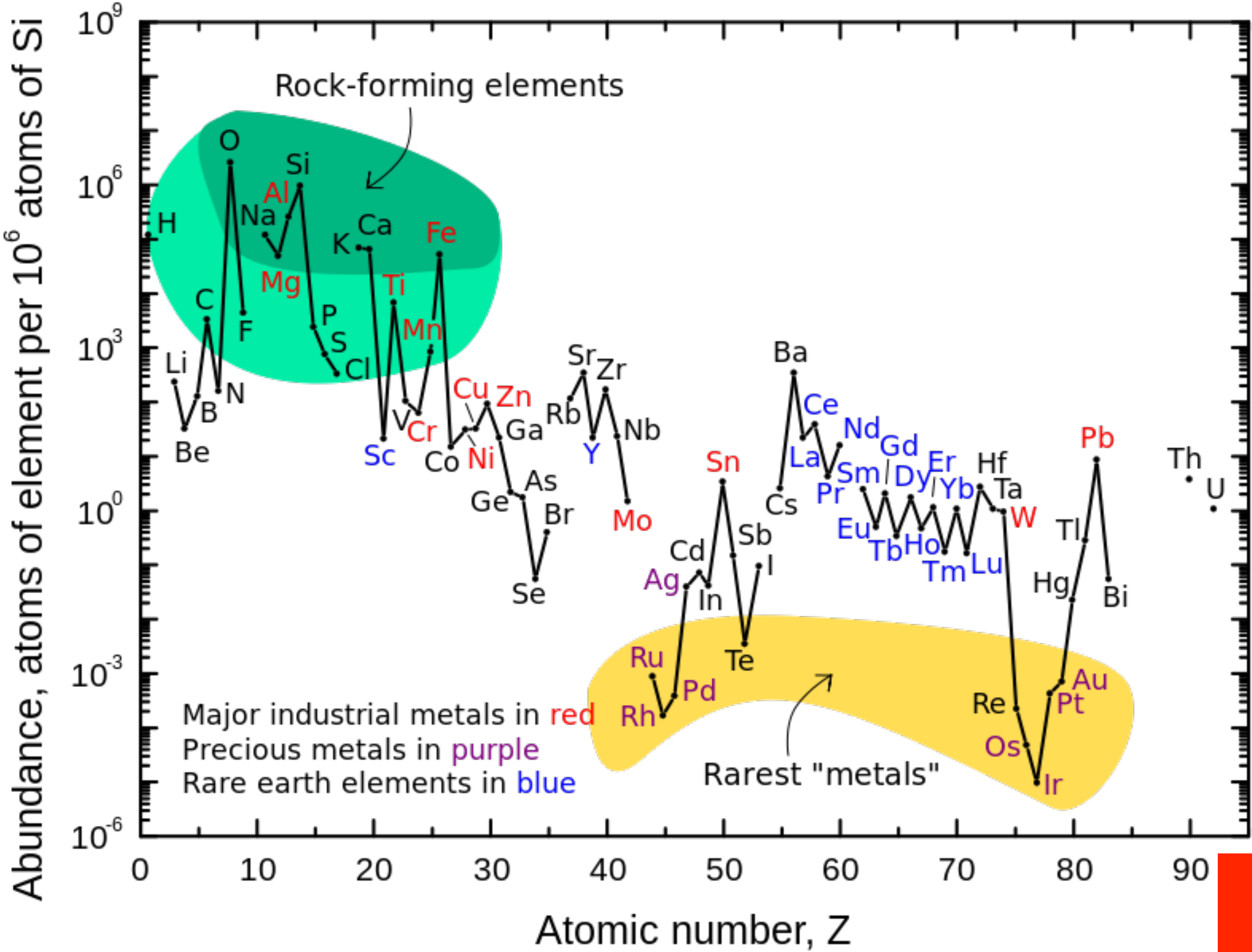


Condensation temperature T_C is

$T_C(N_2)$ ~< $T_C(CO)$ ~< $T_C(CH_4)$ << $T_C(CO_2)$ ~< $T_C(NH_3)$

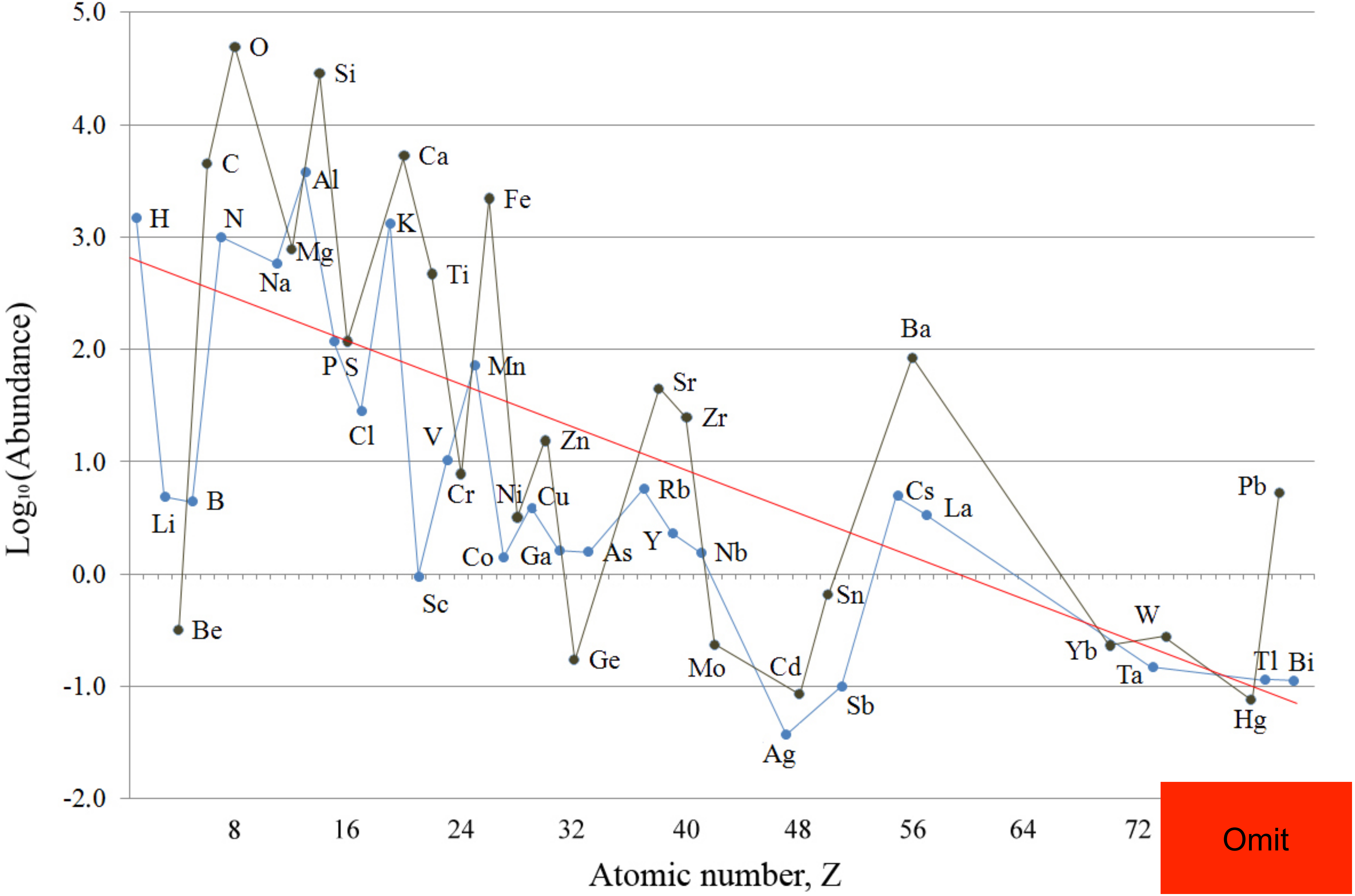
N/C ratio slowly in creases with Sun distance.

Omit



Rock-forming elements
Rarest "metals"
Major industrial metals in red
Precious metals in purple
Rare earth elements in blue
Abundance, atoms of element per 10^6 atoms of Si
Atomic number, Z

Omit

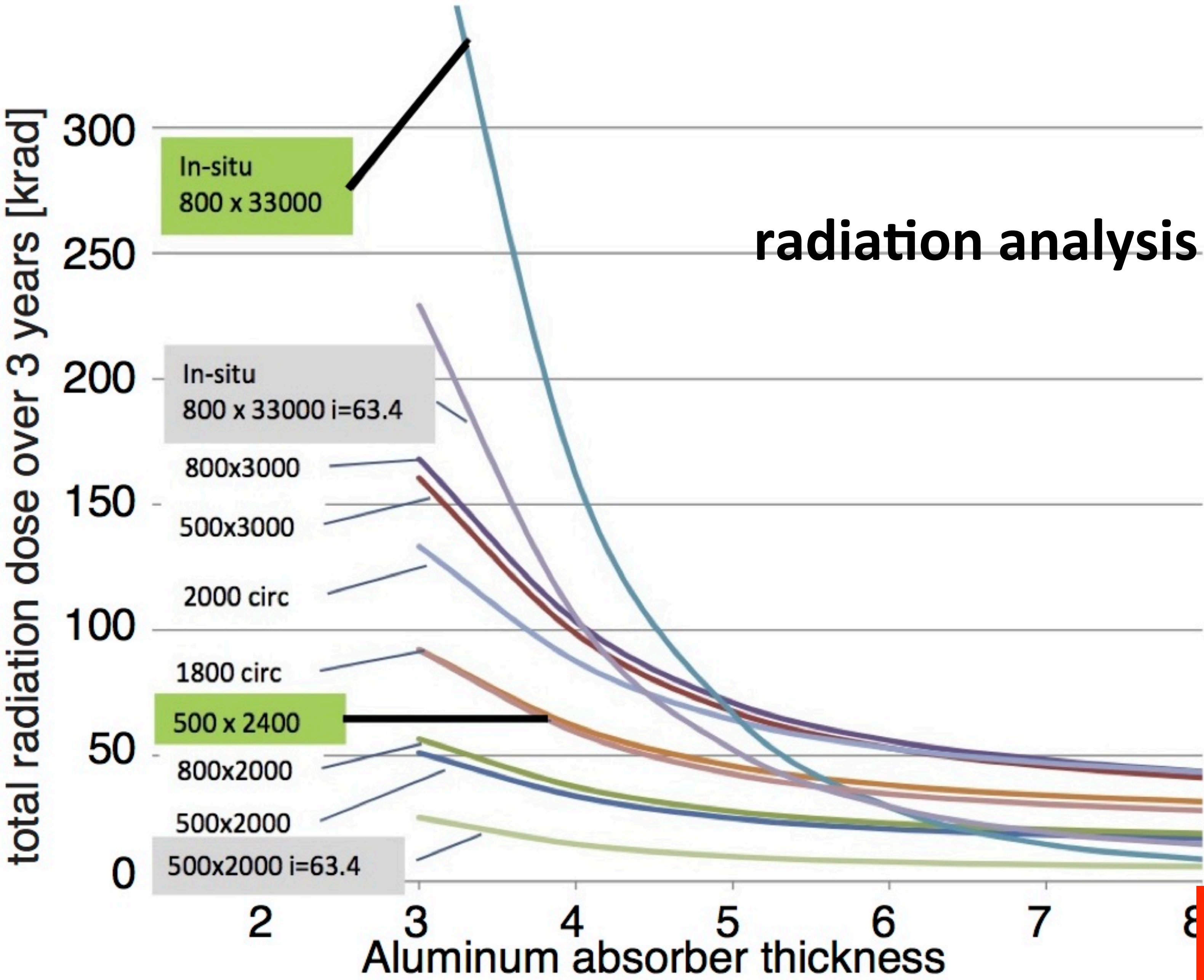

5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
Log10(Abundance)
H
Li
Be
B
C
N
O
Na
Mg
Al
Si
P
S
Cl
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Rb
Sr
Y
Zr
Nb
Mo
Ag
Cd
Sn
Sb
Cs
Ba
La
Yb
Ta
W
Hg
Tl
Pb
Bi
8
16
24
32
40
48
56
64
72
Atomic number, Z
Omit

Was atmosphere alkali / acidic?

- One method is delivery model (neutral) versus protection model (alkali).
- Also, the more the total nitrogen escape, the more NH_3 was needed as the mother form of N_2 (NH_3 should decay with time to NH_3). Here all O_2 can be assumed to have been CO_2 form.

Omit

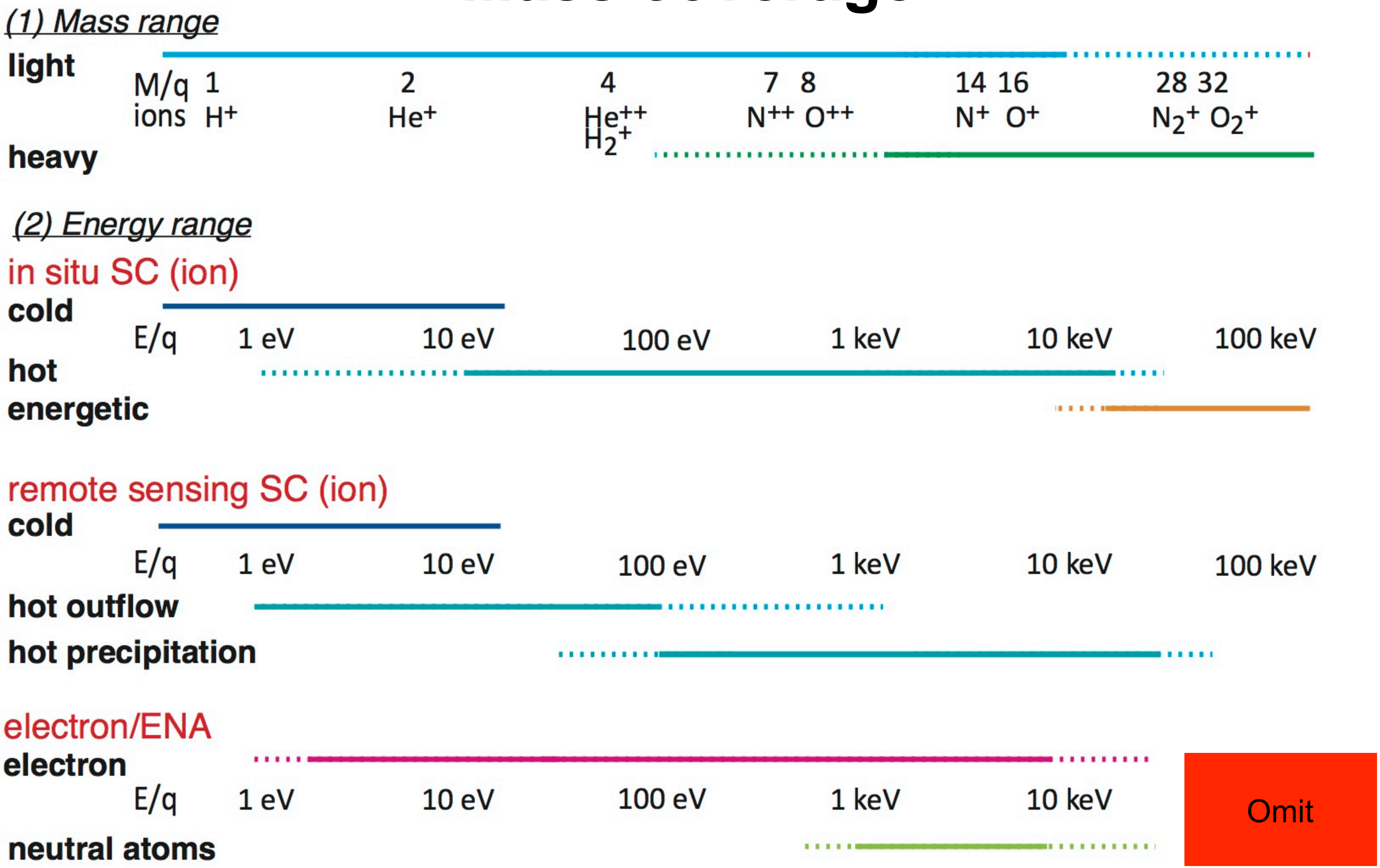
Total radiation dose befind Aluminum shielding



radiation analysis

Omit

Mass coverage



In-situ payload

Measurement	SI (PI institute)	Required ability to measure
light hot ions:	MIMS (IRAP)	H^+, He^{++}, He^+, O^{++}, N^+, O^+ (10 eV - 20 keV)
heavy hot ions:	NOID (IRF)	N^+, O^+, N_2^+ (10 eV - 20 keV/q)
cold ions:	NIMS (UBern)	H^+, He^{++}, He^+, N^{++}, O^{++}, N^+, O^+, N_2^+, O_2^+ (< 10 eV)
energetic ions:	CHEMS (UNH)	H^+, He^{++}, He^+, O^{++}, N^+, O^+ (20-200 keV/q)
SC potential:	SLP-IS (BIRA-IASB)	1 V accuracy, every spin
magnetic field:	MAG (IWF)	-5000 - +5000 nT
wave analyser	WAVES (ASCR/IAP)	10 Hz – 1 KHz
waves detector	SCM (LPC2E)	together with WAVES
electrons:	PEACE (MSSL)	10 eV - 10 keV
ENA	STEIN (UCB/SSL)	4 - 20 keV

Omit

Remote sensing payload

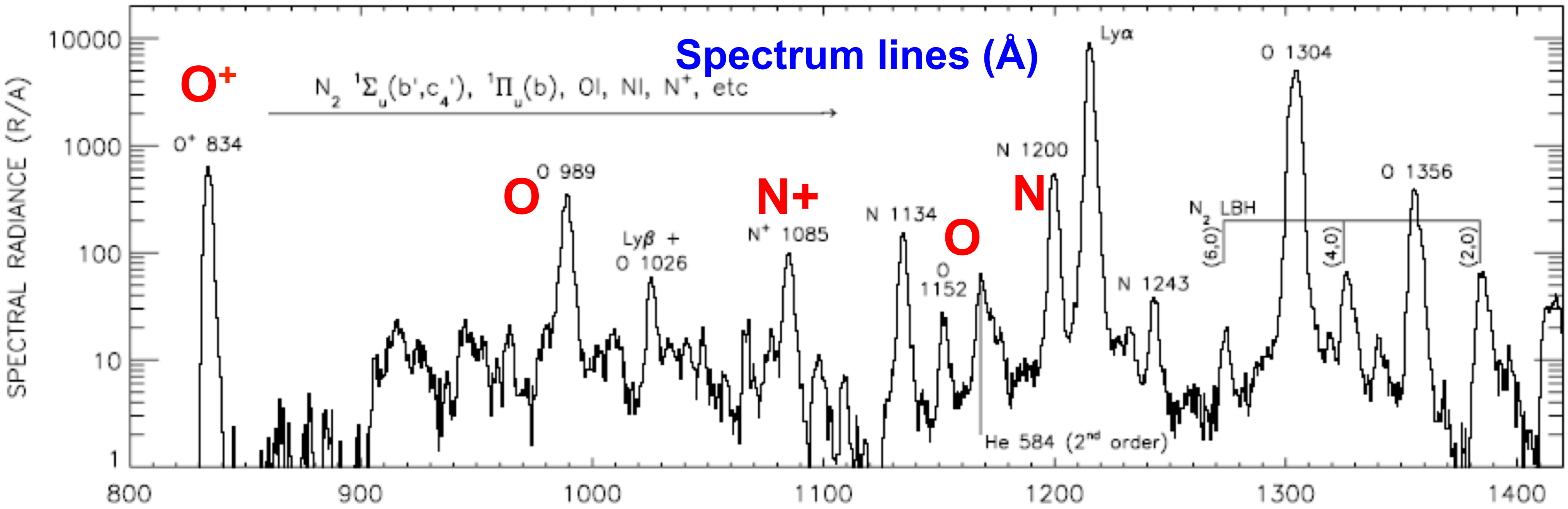
Measurement	SI (PI institute)	Required ability to measure
UV/visible emission:	NUVO (LATMOS)	91 nm (N+), 108 nm (N+), 391 nm (N2+), 428 nm (N2+)
cold ions and neutrals:	CINMS (NASA/ GSFC)	H+, He++, He+, N++, O++, N+, O+, N2+, O2+, N, O
airglow/aurora emission	CAAC (TohokuU)	two of auroral emission
outflowing ions:	NOID-RS (= in-situ)	N+, O+ (1 - 100 eV)
SC potential:	SLP-RS (= in-situ)	same as in-situ
(precipitating ions)	MSA (ISAS)	N+, O+ (100 eV - 30 keV)
(magnetic field)	MAG (= in-situ)	same as in-situ
(wave analyser)	WAVES (=s in-situ)	same as in-situ
(wave detector)	SCM (= in-situ)	same as in-situ
(electrons)	PEACE (= in-situ)	same as in-situ

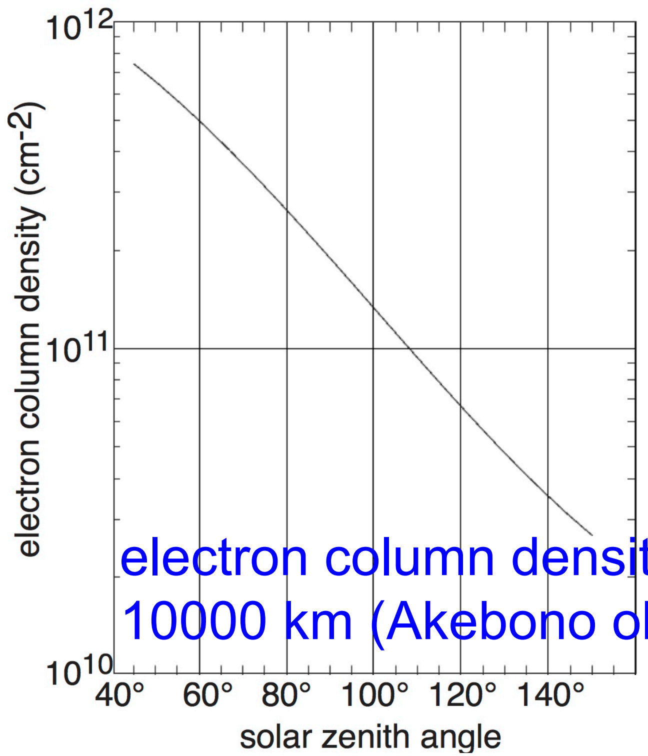
Omit

Mission Profile: Spacecraft

Spacecraft	**In-situ**	**Remote sensing**
attitude control	Spin (T=22-26 sec)	3-axis
attitude reference	Sun-pointing	facing to Nadir
control method	cold gas	momentum wheel
time resolution	≤ 2 min	≤ 2 min (remote) ≤ 1 min (local)
angular resolution	//, ⊥, and anti-//	no (plasma), 2° (optical)
telemetry	~ 80 kbps / 13-m dish	~ 350 kbps / 15-m dish
life time	3 year	3 year
boom	4	(1+2)

Omit





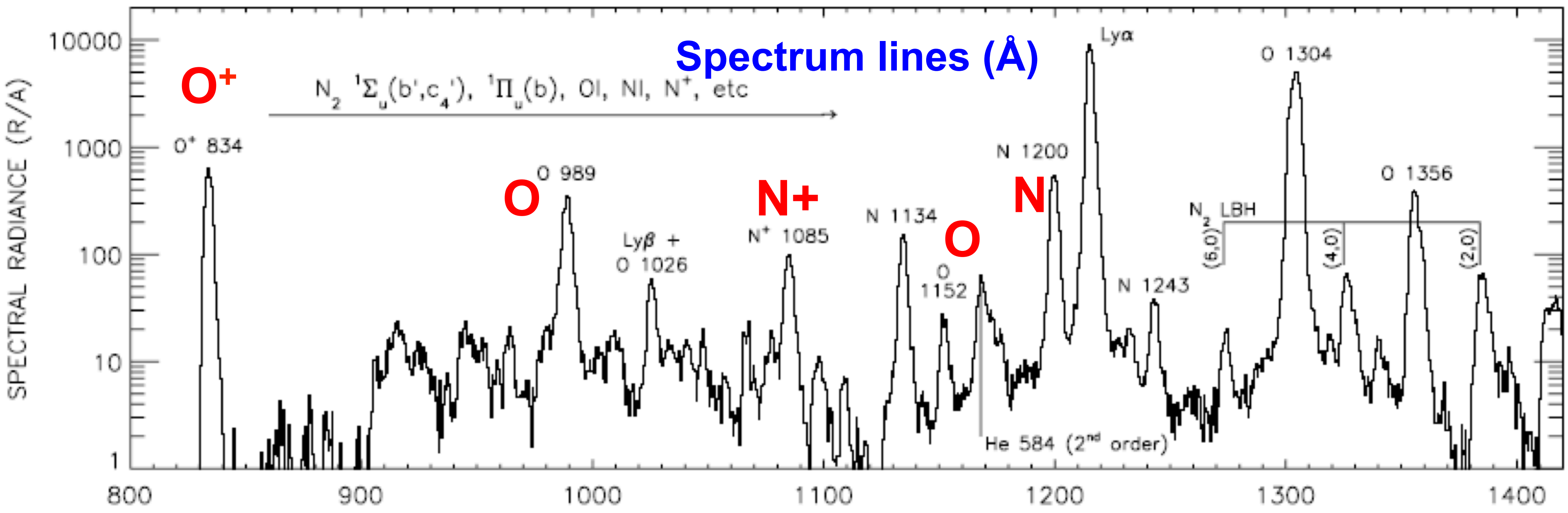
electron column density 2000–10000 km (Akebono obs.)

Target column density is 10^9 cm^{-2}

Omit

Exosphere:

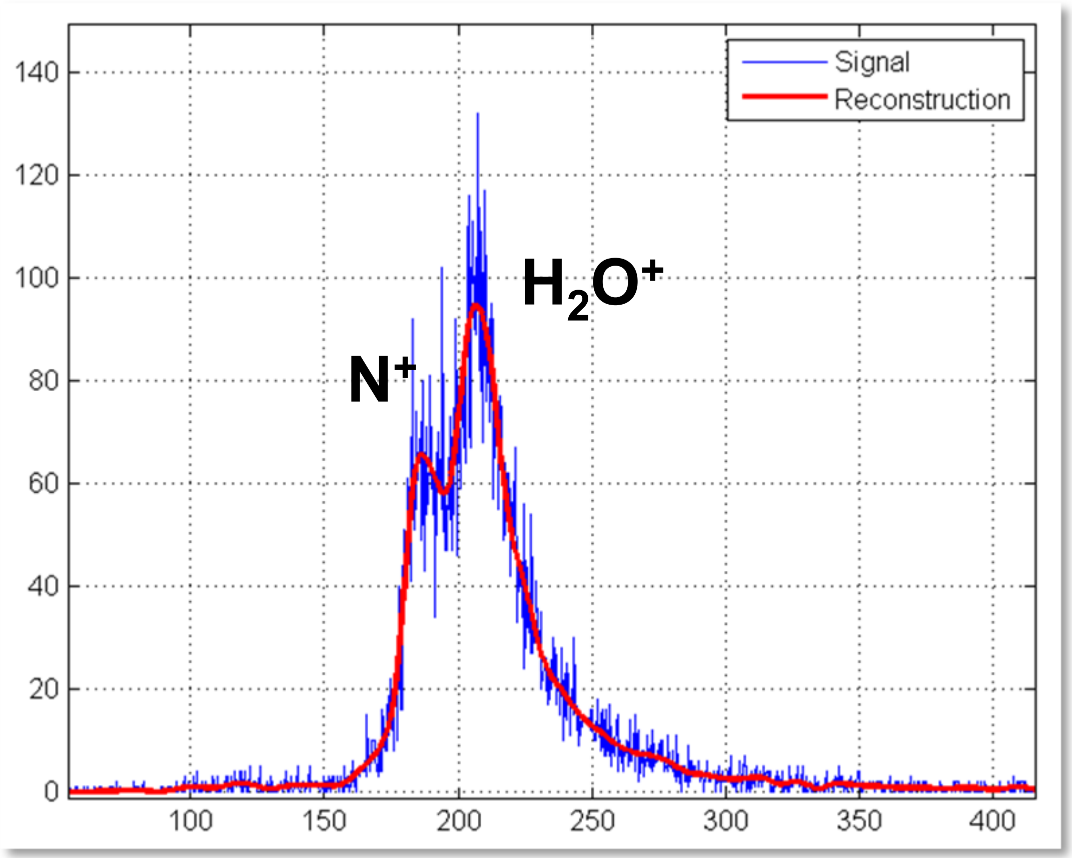
Target column density is $10^{8\text{-}9}$ cm^{-2}



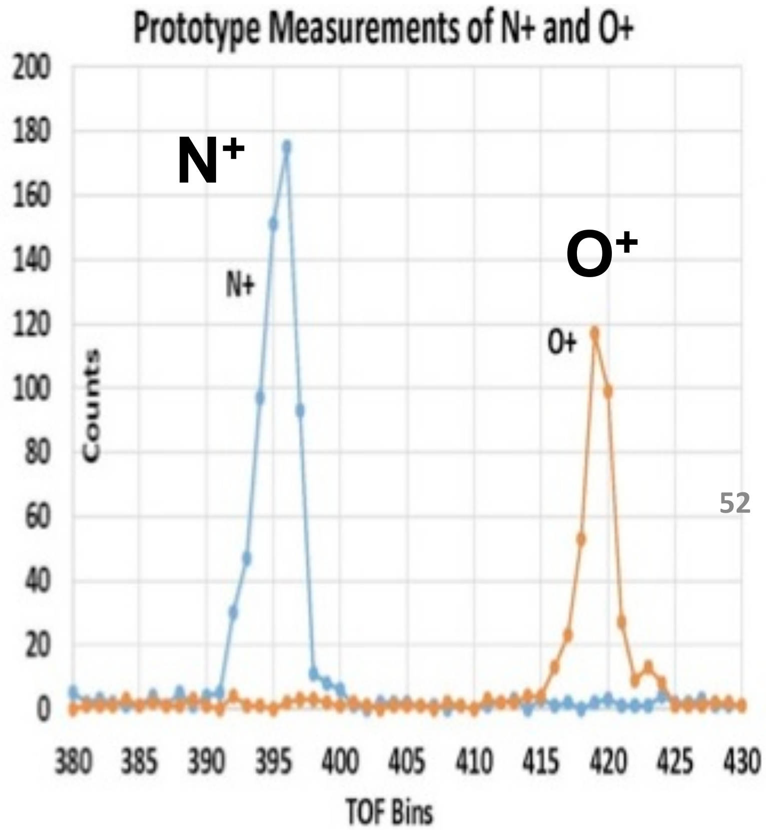
???

Ion sensitivity

Hot ion (lab calibration)



Cold ion (lab calibration)



Omit

- Life evolution problem (e.g., why life was formed only once after the present from of RNA is established?)

- What was the atmospheric composition before the photosynthesis started?

- What was the atmospheric composition at the time when the amino acid was formed (but long after the atmosphere was established)?

Omit

Mission objective

Earth evolution / origin of life: Amino acid formation depends on oxidation state of N (NH_3 or N_2 or NO_x) and the relative abundance of N, O, & H near surface. Current measurements can be used to determine how the atmosphere evolved on geological time scales.

Planetary atmosphere: N on Mars is only 0.01% of Earth ~ Venus ~ Titan). To understand the abundances on other planets, we first have to understand the Earth case.

Magnetosphere: cold N^+/O^+ escape correlates with F10.7 & Kp. With similar M/q, but with different ionospheric scale heights, they are good tracers to understand ion outflow dynamics and circulation.

Exosphere and Ionosphere: Our knowledge of exosphere > 1000km is very poor, and variability of ionospheric N^+/O^+ ratio is poorly understood.

Space Plasma Physics: Different V_0 between M/q=14 and M/q=16 gives extra information on plasma energization mechanisms.

Omit

Our knowledge on Earth's N^+ behavior is poor

(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 normally a mixture of **N^+** and **O^+**. This also applies to **O^{++}**.

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

(d) Ionization altitude of **N** (eventually **N_2**) 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) Molecular N_2 was detected Martian soil and comet, but the ratio was very low.

(g) Isotope ratio (e.g., **$^{15}N/^{14}N$**) is different between different planets/comets.

One thing clear is that O+ behavior and N+ behavior are completely different!

Omit

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

Estimating Chemistry of Ancient Earth (Earth Evolution & Origin of Life)
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.

Mars Nitrogen Mystery (Planetary 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.

Terrestrial Exosphere
no past measurement of terrestrial exosphere > 1500 km, and no knowledge for nitrogen exosphere > 1000 km.

Ionosphere-Exosphere interaction
$N^+/N_2^+/O^+/O^{++}$ ratio @ **topside ionosphere** depends on solar activity, but mechanism is unclear.

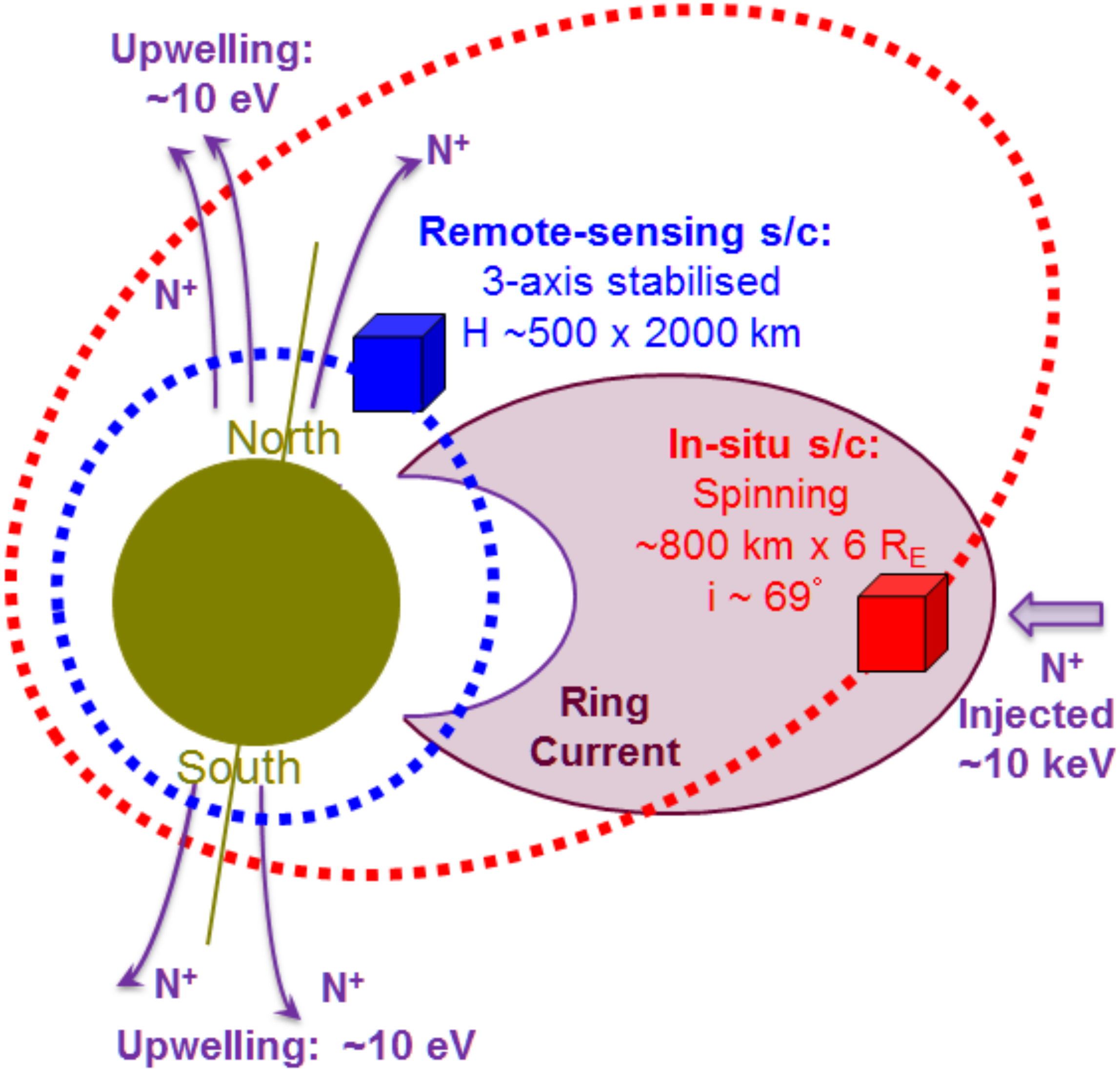
Inner Magnetosphere (ion dynamics and ionosphere-magnetosphere coupling)
N^+/O^+ changes with **EUV & Geomagnetic activities** (Akebono cold ion observations).
N_2^+ is the major molecular cold ion (N_2^+ >> NO^+, O_2^+).

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

Omit

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.

Can we estimate return?



Omit

Summary of requirement for ion instruments

Energy range: From cold (< 1 eV) up to energetic (> 100 keV) for in-situ spacecraft and from cold to about 100 eV for the remote sensing spacecraft. Since the detection method is different between different energies (cold < 20 eV, hot = 10 eV – 10 keV, and energetic > 30 keV), we need at least three ion instruments for in-situ spacecraft and two ion instruments for the remote sensing spacecraft.

Energy resolution for hot ions: Must be able to see the energy difference between N^+ and O^+ (12% difference if the velocity is the same) for 10 eV - 1 keV ions (majority of heavy ions) to guess the energization mechanism. This means 2 steps for 12% increases, i.e., 6% stepping with energy band of $\Delta E/E$=6% (40 steps for a factor 10 increase) for both spacecraft. A sparse resolution is ok for energetic ions.

Mass to separate: **H^+, He^+, N^+, O^+, N_2^+**, whereas we do not need to measure N^{++},O^{++}, O_2^+ because of O_2^+ << N_2^+ and $N^{++}/O^{++} \approx N^+/O^+$ from the cold ion data and ionospheric model. **The toughest is N^+ and O^+ ($M/\Delta M$>8).** For cold ions (that constitutes majority of the density), we further require N^+/O^+ ratio detection accuracy of 10% in both spacecraft, and therefore need 3-4 mass channels from M_N to M_O (**$M/\Delta M$ > 30**). Since hot ion instrument cannot cover both high mass and low mass with sufficient G-factor and $M/\Delta M$, we need two instruments for in-situ spacecraft. For the remote sensing spacecraft we need to monitor only outflow, i.e., **N^+, O^+, N_2^+**

Omit

Summary of requirement for ion instruments

G-factor and dynamic range: For cold ions, we would 0.1/cc accuracy up to 1000/cc (minimum 0.5/cc accuracy). G-factor for hot N^+ should be the same as for hot O^+, i.e.**, G>10^{-4} cm^2 str keV/keV without efficiency**. Dynamic range of N+ should be >1000. This applies both spacecraft. Time resolution: For in-situ spacecraft **Δt = 2-3 min** is sufficient, i.e., we can integrate over several spins (spin is about 20-30 sec). For the remote sensing spacecraft, we need better resolution (**Δt = 20-30 sec**) because spacecraft traverses over many latitude relatively quickly (0.05-0.1°/sec).

Angular coverage and resolution for hot ions: For the in-situ spacecraft, we need // direction, oblique direction and ⊥ direction to the geomagnetic filed. Converting to all directions of the magnetic field, we need about 22.5 x 45° resolution. For the remote sensing spacecraft, we monitor outflowing heavy ions, and single pixel that contains the geomagnetic nadir is the minimum requirement. Since the inclination is nearly 90° and spacecraft faces ram and nadir direction, geomagnetic nadir oscillate to the left and right against the ram direction about 10°, whereas there are more than 10 traversals every day. This means that relatively narrow and long FOV (e.g., 10° x 60°) is the minimum requirement while wider FOV (e.g., 30° x 60°) is ideal.

Omit

Validate exospheric models

Reliable exospheric model is mandatory in estimating escape

* By combining the first ever detailed measurements of exosphere using both emissions and direct neutral measurements, the exospheric model of N2-O2 dominant unique atmosphere becomes reliable. Such models are basis for all types of escape including neutral forms in the past. Ancient atmospheric escape is not the exception.

Omit

Requirement: in-situ spacecraft

Parameter	Cold Ions	Hot Light Ions	Hot Heavy Ions	Energetic
Performance				
Energy range	0 – 10 eV	10 eV – 10 keV	10 eV – 10 keV	30 – 300 keV
dE/E	no need	6%	6%	sparse
Mass range	1 – 40 amu/q	1 – 20 amu/q	10 – 40 amu/q	1 – 20 amu/q
Species	H^+, O^{++}, N^+, O^+, N_2^+	H^+, O^{++}, N^+, O^+	N^+, O^+, N_2^+	H^+, N^+, O^+
Angular resolution	no need	22.5° x 45° (//, oblique, perp)	22.5° x 45° (//, oblique, perp)	90° x 90° (//, perp)
Coverage	4pi	4pi	4pi	4pi
Time resolution	2min	2min	2min	2min
GF	can measure 0.1-1000 /cc	10^{-4} cm^2 sr eV/eV w/o efficiency	10^{-4} cm^2 sr eV/eV w/o efficiency	???
Resources				
Mass without shielding	Not constrained (reasonable)	Not constrained (reasonable)	Not constrained (reasonable)	Not constrained (reasonable)
Power	Not constrained (reasonable)	Not constrained (reasonable)	Not constrained (reasonable)	Not constrained (reasonable)
Radiation dose	50 krad / 3 year	50 krad / 3 year	50 krad / 3 year	50 k

Omit

Requirement: remote sensing spacecraft

Parameter	Cold Ions	Outflow Ions	Precipitating Ions
Performance			
Energy range	0 – 10 eV	1 – 100 eV	100 eV – 30 keV
dE/E	no need	6%	12%
Mass range	1 – 40 amu/q	10 – 40 amu/q	10 – 40 amu/q
Species	H^+, O^{++}, N^+, O^+, N_2^+	N^+, O^+, N_2^+	N^+, O^+, N_2^+
Angular resolution	no need	1 pixel	1 pixel
Coverage	4pi	60° x 8°, magn. Nadir covered	2pi zenith
Time resolution	30s	30s	30s
GF	can measure 1-10000 /cc	10^{-4} cm^2 sr eV/eV w/o efficiency	???
Resources			
Mass without shielding	Not constrained (reasonable)	Not constrained (reasonable)	Not constrained (reasonable)
Power	Not constrained (reasonable)	Not constrained (reasonable)	Not constrained (reasonable)
Radiation dose	50 krad / 3 year	50 krad / 3 year	50 krad / 3 year

Omit