9.7 Evaluation of NITRO proposal

9.7.1 Requirements

a. Completeness of proposal
[Is the information of sufficient quality to allow for an informed opinion?]

More information about the one spacecraft option would have been useful.

b. Mission scientific value
[Is the mission of the right scientific calibre to be considered in the frame of the present call?]

It would provide measurements not yet performed, but the objectives look limited.

c. Need for access to space
[Does the proposed science need to be performed from a space facility?]

Yes, it needs to be performed from space.

9.7.2 Science value

How valuable is the science return from the proposed mission?

Strengths:

The proposed mission intends to measure the nitrogen budget of the Earth's exosphere and magnetosphere, both neutrals and ions, tracing the latter inside the magnetosphere and determining the escape rate. Apart from some occasional measurements by previous magnetospheric spacecraft this has not been done before, in particular in the upper part of the exosphere (above 1,500 km). Since most instruments flown in the past were unable to clearly separate nitrogen ions from those of oxygen, there is a clear gap of knowledge. Therefore, the mission will provide novel data. However, this is not the only objective. Determining the nitrogen escape rate relative to that of oxygen is intended to serve as a tool for analysing the history of the nitrogen abundances of Earth and Mars. A key aspect is to study the nitrogen budget variation under different geomagnetic and atmospheric conditions, the latter being subject to the solar UV output.

Weaknesses:

1.- Origin of life : chemical state on ancient Earth
The arguments provided in the proposal that one can obtain insights into the nitrogen abundance of the ancient Earth and its impact on the formation of pre-biotic molecules does not appear convincing. The intended re-calibration of the nitrogen abundance by taking into account the much higher solar activity in the past rests on the observed increase of the N^+/O^+ abundance in the magnetosphere with enhanced solar and geomagnetic activity. The N^+/O^+ ratio of up to 0.1 during quiet geomagnetic activity has been found to increase to 1 during geomagnetically active periods. Present oxygen and nitrogen escape rates from the Earth's atmosphere are rather low. The present ionospheric O^+ outflow rate is $\approx 7\ 10^{25}\ s^{-1}$ (Tian et al., 2014), but the loss rate from the magnetosphere is 10 times smaller (Seki et al., 2001). Possibly, there is a strong return flux into the ionosphere. However, this is disputed on the basis of numerical simulations (Ebihara et al., 2006). The N^+ escape flux should therefore be $\approx 10^{24}\ s^{-1}$ on average, but may be up to $10^{26}\ s^{-1}$ at high solar activity. This means that under present solar conditions the fraction of the present nitrogen that would be lost to space within 4 Gyr lies in the region of about 0.1%. This is quite small. Note that this number is at least one order of magnitude smaller than the non-atmospheric inventory of

nitrogen (2% of N_2 in seawater nitrates, Lecuyer et al., 2000). Although this escape flux may have been substantially greater in the past due to higher solar EUV flux and geomagnetic activity, it seems hardly believable that the ionospheric escape of nitrogen may have significantly depleted the atmosphere. If the Earth did not possess an intrinsic magnetic field 4 Gyr ago, this would be a different matter. Hydrodynamic escape may have removed more nitrogen but, if so, the loss mechanism is completely different and extrapolating present escape rates to ancient Earth would be invalid. Furthermore, calibration of the nitrogen abundance by the N^+/O^+ ratio makes little sense, since the amount of oxygen in the atmosphere has been driven by biological processes, not only by escape. In view of the many uncertainties about the Earth's geomagnetic history, on the one hand, and the various scenarios of nitrogen acquisition by the atmosphere, the present day determination of its escape flux by NITRO would be unable to provide significant information on the "relative abundances of nitrogen, oxygen and hydrogen" on the ancient Earth.

2.- Planetary evolution: Mars nitrogen mystery
The SARP doesn't see any obvious "Mars nitrogen mystery" as claimed in the proposal. The volatile inventory of Mars is still not well understood. All noble phases are depleted by a similar factor of ≈100 on Mars with respect to Earth. This is customarily interpreted as the result of massive outgassing and escape at the end of Mars' accretion. Comparison of the isotopic ratio $^{40}Ar/^{36}Ar$ of 2,000 on Mars with that on Earth (300) indicates progressive outgassing from the crust during the first billion years, probably as the result of the small size of Mars. Carbon and nitrogen are more depleted than noble gases, for unclear reasons, but the global picture is the same one as for noble gases. The depletion of N vs. C on Mars with respect to the Earth could be due to non-thermal escape, mainly through dissociative recombination (a mechanism which doesn't occur on Earth), as suggested by the enrichment of ^{15}N with respect to ^{14}N by a factor 1.6 in the present Martian atmosphere, as confirmed by the Mars Science Laboratory (MSL) mission. Using the N/O ratio as an indicator of the nitrogen inventory is not sound. Most of the oxygen is in H_2O, not in CO_2. The N/O ratio therefore depends on the history of water, which is probably mainly driven by crust oxidation, not by oxygen escape (Chassefière and Leblanc, 2011). It is hard to see how the determination of the terrestrial nitrogen escape could shed light on the various possibilities for the low nitrogen abundance discussed in the proposal.

Conclusions:

The NITRO mission would be focused on studying the hitherto little known nitrogen inventory in the Earth's space environment. Some interesting results could be obtained on the exosphere, acceleration and transport inside the magnetosphere, and its escape rate dependence on geomagnetic and solar activity, but conclusions on the nitrogen abundance of the early Earth and the low nitrogen abundance of Mars would have to be based on a significant number of uncertain assumptions. Although the scientific product of the NITRO mission may be quite valuable, the wider impact on planetology appears to be limited.

9.7.3 Scientific feasibility

a. Can the proposed science be achieved with the proposed mission?

A major problem for the feasibility of the scientific goals is that the proposed two spacecraft (S/C) mission does not fit into the M4 budget envelope. With the one S/C option, i.e. the in-situ spacecraft in an elliptical orbit, the scientific return of the mission is severely reduced. It is said in the proposal that almost 70% of the scientific objectives can be accomplished (four out of six key questions and 2 out of 5 secondary questions can be addressed). However, as the proposal clearly states, without the low-orbiting remote sensing spacecraft it would not be possible to disentangle the relationship between the source conditions in the topside ionosphere and the nitrogen budget and dynamics in the magnetosphere.

Strengths:

The reduced mission can clearly perform much of the in-situ science, foremost the relative abundance of nitrogen and oxygen and the tracing of the ions in the magnetosphere, also the dependence on solar transient activity. A very strong complement of particle detectors and high-resolution mass analysers with good heritage from earlier missions covers all relevant energies and allows clear separation of the two elements and other light ions. In this context, it will be an important asset that different time-of-flight techniques are to be employed. Potential control of the in-situ S/C will allow access to the lowest energies. Overlapping energy ranges of different instruments allows intercalibration. Some remote sensing of the upper atmosphere and exosphere can also be achieved with the one-spacecraft option, but the orbit would be less favourable for this task than with a low orbiting S/C.

Although the solar and geomagnetic activities vary considerably with the solar cycle, a 3-year mission duration during the declining phase of the cycle would be enough to check the possible dependence of the nitrogen abundance on solar activity, since a wide range of geomagnetic conditions should be encountered.

Weaknesses:

The assessment of the energized nitrogen ion constituent in the magnetosphere cannot be converted reliably into an overall escape rate, unless additional information would be available. Furthermore, it is not properly explained in the proposal how much of the remote sensing of the base of the exosphere can be achieved with the NUVO experiment mounted on board the spinning in situ spacecraft. That implies that the main goal of the mission, simultaneous measurements of nitrogen emissions from the atmosphere and tracing of the ionic component in the magnetosphere is strongly jeopardized. Furthermore, some of the more detailed objectives, as for instance determining particle acceleration by waves, would suffer from insufficient instrumentation for recording the electromagnetic fields, particularly at the low frequency end. Mounting and length of the E-field booms are regarded to be insufficient to correct for the photoelectron and wake asymmetries of the electric potential distribution introduced by the spacecraft. The option for long wire booms does not seem to be achievable. It is, in general, not convincingly demonstrated that the obtained measurements allow the scientific interpretations that are described.

With the scenario of just one S/C, STEIN would most likely be lost with its capability of detecting energetic neutral particles. Furthermore, the ability to assess the ionospheric neutral and ion outflows by remote sensing from the orbit of the in-situ spacecraft is strongly diminished with respect to the two spacecraft option. It remains uncertain whether the sensitivity of the NUVO instrument is sufficient.

Conclusions:

A strong complement of particle instruments will allow a thorough in-situ assessment of the light ion and neutral particle population of the magnetosphere, in particular the little known nitrogen constituent. However, deriving from that the total escape rate involves significant uncertainties. Unclear is the ability to monitor simultaneously the thermal neutral and ion nitrogen flux from the upper ionosphere by the remote sensing instrument in the one spacecraft option. The d.c. and low-frequency electric field measurements would be insufficient to evaluate the acting acceleration processes. In total, it is not convincingly argued whether the measurements obtained will allow drawing the essential scientific conclusions as described in the proposal. Although it is claimed that 70% of the science can be achieved with a single satellite, it is to be feared that the main goal of the measurements, namely to determine the escape rate, will suffer severely.

b. Are there any issues not mentioned in the proposal that could hamper the proposed scientific return?

Nothing obvious discovered.

9.7.4 Timeliness of mission

Is the M4 time frame compelling for this mission? Why?

The M4 time frame is appropriate. In any case the mission duration should be tuned to last sufficiently long in order to obtain a statistically significant correlation of solar variability and ion escape rate.

9.7.5 Competitiveness and complementarity with other projects

a. Are there other space- or ground-based facilities addressing similar science goals?

Similar goals, in particular particle acceleration in the magnetosphere, are very convincingly pursued by the two Van Allen probes of NASA. The scientific objectives of the mission can only be accomplished by measurements in near-Earth space.

b. If so, how does the proposed mission compare with them or complement them?

The distinguishing element of NITRO is the focus on nitrogen and oxygen by in-situ as well as remote sensing instruments.

c. Is the science output of the mission self-contained or does it require complementary data from other missions or from ground-based observations?

Input on solar activity and on its impact on the ionosphere would be important background information, but otherwise the mission would be self-contained.

d. What is the expected impact of the proposed mission in the relevant scientific field(s)?

Strengths:

NITRO will allow for the first time detailed nitrogen atom and ion measurements in the near-Earth environment and potentially determine the nitrogen escape rate in comparison with that of oxygen and its dependences on solar activity. This will surely represent a substantial advance of our knowledge of the magnetospheric/ionospheric/exospheric processes and may provide some valuable input into considerations of the evolution of planetary atmospheres.

Weaknesses:

The assured science return of the mission is rather narrow in scope. The probability that the envisaged applications, in particular the far-reaching conclusions on the nitrogen abundances of early Earth and Mars, can be achieved is regarded to be low.

Conclusions:

There are no competitive or complementary projects with respect to a detailed assessment of the nitrogen inventory of the Earth's environment and the escape rate. However, there are doubts about the full feasibility of the intended measurements with the one spacecraft option and the wider relevance of the science return of the mission.

9.7.6 Collaborative environment

Is the proposed scientific collaboration scheme likely to produce the promised results? Why?

Strengths:

The instrument/scientific consortium is well established and has experience from previous missions.

Weaknesses:

The scientific returns will suffer from the limitations resulting from a one spacecraft mission.

Conclusions:

The collaborating team would probably be able to handle building the instrumentation and reducing the data, but the restrictions from the reduced spacecraft and payload complement would not permit the realisation of the full promised results.

9.7.7 Overall assessment of the proposal

NITRO will focus on the study of the distribution, budget, and dynamics of nitrogen around the Earth and its escape rate. This is to be achieved by monitoring magnetospheric nitrogen ions (N^+ and N_2^+) and exospheric nitrogen and by distinguishing N^+ from O^+ in the inner magnetosphere, polar cap, and just above the ionosphere at all relevant energies. An essential aspect is the dependence on solar and geomagnetic activity. The distinguishing characteristic of the mission rests on the not yet available ability to separate reliably the nitrogen constituent from oxygen and other light ions. The fact that the financial constraints will allow only for the one-spacecraft option will lead to a significant loss of information, in particular with respect to the remote and in-situ sensing of the nitrogen escape from the ionosphere. Also the desired simultaneity of the latter measurements and the in-situ tracing of the ions in the magnetosphere will be strongly jeopardized. The conversion of the population of energized nitrogen ions in the magnetosphere into an overall escape rate has inherent uncertainties. However, the SARP concludes that, even if the two-spacecraft configuration could be realized, the ambitious conclusions on the evolution of nitrogen on Earth and Mars on the basis of a determination of the nitrogen escape rate, as laid out in the proposal, would not be possible. Besides this major shortcoming there is a lack of concrete information on the capability of the remote sensing instrument vis-à-vis the available photon fluxes. The choice of booms for the electric field instrument appears to be insufficient to reliably measure the quasi-d.c.

electric field, which is essential for studying the plasma dynamics and the energisation and transport of the ions. Thus the SARP concludes that a mission along the lines of the NITRO proposal would not have the scientific impact that is to be expected from an M4 mission.