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INPPS Flagship: 2020th and 2030th Mars Explorations

Frank Jansen [a]*, Benedikt Bergmann [b], Tim Brandt [b], Friedrich Damme [c], Emmanouil Detsis [d], Simona Ferraris [e], James AP Findlay [f], Ikkoh Funaki [g], Oliver Funke [h], Jan Thimo Grundmann [a], Lamartine Nogueira Frutuoso Guimaraes [i], Martin Hillebrandt [j], Anatoly S. Koroteev [k], Daniel Kühn [l], Jim C. Kuijper [m], Frederic Masson [n], Volker Maiwald [a], Jürgen Oberst [o], Stephane Oriol [n], Stanislav Pospisil [b], Martin Richter [j], Lars Schanz [a], Alexander V. Semenkin [k], Alexander E. Solodukhin [k], Ivan Stekl [b], Tim Tinsley [f], Maria Cristina Tosi [e], Jean-Claude Worms [p]

[a] *DLR Institute of Space Systems, Robert-Hooke-Str. 7, 28359 Bremen, Germany, frank.jansen@dlr.de, volker.maiwald@dlr.de, lars.schanz@dlr.de*
[b] *Czech Technical University Institute of Experimental and Applied Physics, Husova 240/5, 110 00 Prague 1, Czech Republic, benedikt.bergmann@utef.cvut.cz, tim.brandt@utef.cvut.cz, stanislav.pospisil@utef.cvut.cz, ivan.stekl@utef.cvut.cz*
[c] *Technical University of Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany, friedrich.damme@tu-berlin.de*
[d] *European Science Foundation, 1, quai Lezay-Marnésia, BP 90015 67080 Strasbourg, France, edetsis@esf.org,*
[e] *Thales Alenia Space Italia, Strada Antica di Collegno 253, 10146 Torino, Italy, simona.ferraris@thalesaleniaspace.com, mariacristina.tosi@thalesaleniaspace.com*
[f] *National Nuclear Laboratory, Havelock Rd, Workington CA14 3YQ Sellafield, United Kingdom, james.ap.findlay@nnl.co.uk, tim.tinsley@nnl.co.uk*
[g] *JAXA/ISAS, Tokyo, Japan, funaki.ikkoh@jaxa.jp*
[h] *DLR Space Administration, Königswinterer Str. 522-524, 53227 Bonn, Germany, oliver.funke@dlr.de, daniel.noelke@dlr.de, bernd.sommer@dlr.de*
[i] *Instituto de Estudos Avancados, San Jose dos Campos, Brazil, guimarae@ieav.cta.br*
[j] *DLR Institute of Composite Structures and Adaptive Systems, Lilienthalplatz 7, 38108 Braunschweig, Germany, martin.hillebrandt@dlr.de, martin.richter@dlr.de*
[k] *Keldych Research Centre, Onezhskaya 8, 125438 Moscow, Russian Federation, koroteev@kerc.msk.ru,* semenkin@kerc.msk.ru, solodukhin@kerc.msk.ru
[l] *DFKI, Robert-Hooke-Str. 5 · 28359 Bremen , Germany, Daniel.Kuehn@dfki.de*
[m] *NUCLIC – Nuclear Innovation Consultancy, Iepenlaan 129, 1741TD Schagen, The Netherlands, kuijper@nuclic.nl*
[n] *Centre National d'Etudes Spatiales CNES, rue Jacques Hillairet 52, 75612 Paris, France, frederic.masson@cnes.fr, stephane.oriol@cnes.fr*
[o] *DLR Institute of Planetary Research, Rutherfordstr. 2, 12489 Berlin, Germany, juergen.oberst@dlr.de*
[p] *c/o COSPAR, 500 rue Jean-François Breton, 34093 Montpellier Cedex 5, France, doc42jc@bbox.fr*
* Corresponding Author

Abstract

The presentation summarizes INPPS (International Nuclear Power and Propulsion System) flagship non-human (2020th) and human (2030th) Mars exploration missions. The 2020th first flagship space flight is the complex, complete test mission for the second flagship towards Mars with humans (2030th). The most efficient approach is the completely tested first INPPS in the 2020th as the preparation of the second flagship with humans on board. The second INPPS (2030th) is also the regular space transportation tug Mars-Earth.

International requests for human Mars space flight is realizable by rationales for pursuing two INPPS Mars missions in the proposed period: 1) successful finalization of the European-Russian DEMOCRITOS and MEGAHIT projects with their three concepts of space, ground and nuclear demonstrators for INPPS realization (2017), 2) successful ground based test of the Russian nuclear reactor with 1MWel plus the important thermal emission solution by droplet radiators (2018), 3) reactor space qualification by Russia until 2025 and 4) the perfect celestial Earth-Mars-Earth-Jupiter/Europa trajectory in 2026-2031 to carryout maximal INPPS space flight tests. Set of issues of INPPS space system and all subsystems became identified and studied during DEMOCRITOS. Consequently critical performance will be studied by parallel realizations of the ground and nuclear demonstrators (until 2025). The INPPS space demonstrator considers directly results of ground and nuclear demonstrator tests. Realization of the space demonstrator in form of the first space qualification of INPPS with all subsystems in the middle of the 2020th plus INPPS tests for about one to two years - first in high Earth orbit and later in nearby Earth space environment means a complete concepts driven approval for all INPPS technologies for non-human/human INPPS-Mars missions.

Space subsystem results of MARS-INPPS design (with arrow wing shaped radiators) will be described. In dependence - from a cluster with worldwide selected electric thrusters - the MARS-INPPS payload mass is up to 18 tons. This very high payload mass allows to transport three different payloads at once - scientific, pure commercial and new media communication. The realization including tests is sketched: especially the need of non-human flagship Mars flight, the test towards Europa (including real time radiation monitoring) for maximal human Mars mission preparation for the second INPPS with humans to Mars. INPPS missions implicate Apollo and ISS comparable outcomes for science technologies, international dedication and in addition for space commercialization. Insofar - this MARS-INPPS presentation - convince high attendance of conference participants, commercial and new media investors.

Keywords: 1) Mars-INPPS Flagship, 2) Non-human & Human High Power Space Transportation Hybrid Space Tug, 3) DEMOCRITOS / MEGAHIT INPPS Flagship System, Sub-Systems including Reactor, 4) DEMOCRITOS Ground, Space and Nuclear Demonstrators 5) 2025 to 2030th: Mars-Earth-Mars-Earth-Jupiter/Europa missions and INPPS Flagship, 6) INPPS with science, commercial and communication payloads.

Acronyms/Abbreviations ALL

Artificial Intelligence (AI)
Third US human space flight program (Apollo)
Demonstrators for Conversion, Reactor, Radiator And Thrusters for Electric Propulsion Systems (DEMOCRITOS)
Disruptive technologies for space Power and **P**ropulsion (DiPOP)
International Nuclear Power and Propulsion System (INPPS)
International Space Station (ISS)
Megawatt Highly Efficient Technologies for Space Power and Propulsion Systems for Long-duration Exploration Missions (MEGAHIT)
Nuclear Electric Propulsion (NEP)
Nuclear Power Source (NPS)
Nuclear Thermal Propulsion (NTP)
Nuclear Power and Propulsion System (NPPS)
Nuclear Power Source (NPS)
Power and Processing Unit (PPU)
Science, Commerzialisation and Communication payload on INPPS (SC^2)
Transport and Power Module (TPM)
Valles Marineris Explorer (VaMEx)

1. Introduction

In EC funded DEMOCRITOS, MEGAHIT and DiPoP projects [1] NEP / NPS was studied. The results are the European low power (kW) and high power (MW) roadmaps, plus developments for the core, ground and space concepts and their realizations are finalized. In addition, in successful ground based test of the Russian MW class reactor was announced in 2018 [2]. Therefore, re-design of the DEMOCRITOS INPPS flagship focused on 2025 space qualification will be carried out in 2020. This re-design in a concurrent design study will include detailed droplet radiator [3] applications, selection of appropriate international EP's and payload candidates. Moreover – also in 2020 - it is foreseen to carry out a concurrent engineering study for autonomous robotic assembly (in higher Earth orbit) of the re-designed INPPS flagship.

Additionally, the tight schedule is caused by the relatively narrow locations of Earth, Mars and Jupiter between 2025 and about 2030 (Fig. 1).

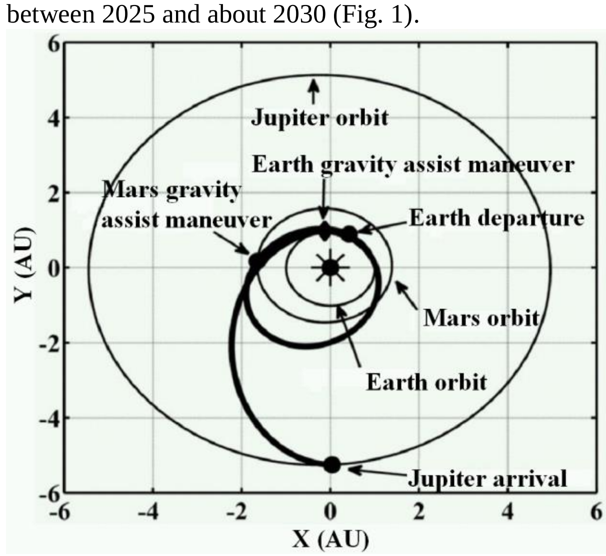

Fig. 1. Earth-Mars/Phobos-Earth-Jupiter/Europa trajectories of INPPS flagship in time frame 2025 – 2035 [4]).

Chapter 2 explains the European-Russian DEMOCRITOS project and progress beyond. The subsections 2.1 and 2.2 describes the MARS-/EUROPA INPPS flagship. Subsection 2.3 sketches the UN NPS principles specified for the 2020th and 2030th non-human and human Mars explorations as well as commercialization and communication aspects. Finally, in chapter 3 follows realizable conclusions and the call to actions.

Details of all technological, scientific, safety, commercialization and communications are presented in four different IAC DC papers ([5] to [8]).

2. European-Russian DEMOCRITOS Project and Progress Beyond

DiPOP was the first strategic orientated EC project for NEP in the 2010th. The deliverables contain the low power (kW) European roadmap, which includes documents related to scientific, technical status, exploration mission targets as well as European space industry, organization and universities interests in preparation of a human Mars flight. DIPOP also contains a study for public acceptance of NPS. The European – Russian MEGAHIT was the second strategic orientated EC project - for high power NEP. The results are readable in the high power EC MEGAHIT roadmap. This high power roadmap has already included relationships focused on MW class reactor, as well as international prospections plus usable European, Russian and US high power electric thrusters including first dependencies between specific impulses for Mars, Moon, Europa, Titan and asteroid exploration missions and transported payload mass. In the focus of the third strategic EC project for NEP – the European-Russian DEMOCRITOS project the first steps for MEGAHIT roadmap realization started – with studies for the core, ground and space concepts.

The core concept included studies towards the reactor core like nuclear physics, comparisons with US PROMETHEUS SP-100 reactor [9], operation, shielding and safety. The INPPS MW reactor will have about 3 - 4 MW_{th} and 1 MW_{el} energy available for the entire space system. In DEMOCRITOS it was studied and finally preferred a core outlet temperature of the reactor in the order of 1300K with a He-Xe gas reactor cooling.

The ground concept contain results for ground based subsystem tests like especially conversion test for example in France or long term electric thruster tests in Germany or complete subsystem test in Russia – instead with the MW reactor with a gas heater. Cost estimations for these three ground based tests are done.

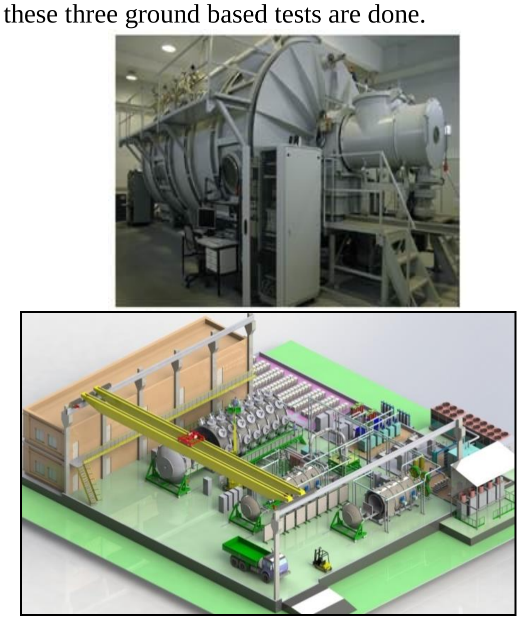

Fig. 2. Example for INPPS ground demonstrator tests facility. Above: already existing test bench facility at Keldysh Research Center Moscow foreseen to be used and integrated into INPPS ground demonstrator / EP tests. Image below: the final deliverable of the DEMOCRITOS ground demonstrator was this CAD design.

In parallel with realization of the ground concept, the DEMOCRITOS space concept is intended to become realized. The space concept documents contain answers to subsystem transport to high Earth orbit and the INPPS flagship first concurrent engineering study with additionally inputs from NASA Glenn Research Center, JAXA Tokyo and Airbus Germany. The study philosophy for the two futuristic like designed flagships in the Concurrent Engineering Facility at DLR Bremen: beautiful and similar layout like supersonic French-British Concorde / Soviet Tu-144 aircrafts with a maximum of commonly used sub-systems (by building blocks for the non-nuclear parts). The study philosophy result – the bow with same reactor nose, same conversion plus boom plus payload plus PPU and electric thruster cluster at the rear end. Differences – due to the Mars / Europa flight destinations and radiation test aspects for the radiators are the shielding, radiator and rear auxiliary solar power supply sub-systems.

2.1. Mars-INPPS Flagship

The Mars-INPPS flagship and subsystems are displayed in Fig. 3. It has a cone-like shielding sub-system and arrow wing like structure for the radiators. The perpendicular wings are caused by the demand to dissipate the heat directly – without interactions - into free space. The four wings and the radiation area (in the order of 1000 m^2) are necessary to radiate the heat completely into space. Notable is the comprehensive usage of building blocks, so called iBOSS [10].

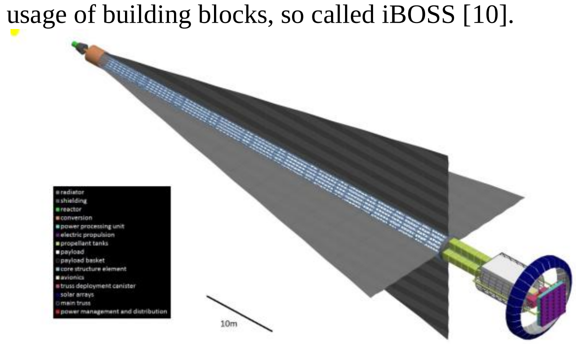

Fig. 3. DEMOCRITOS MARS-INPPS flagship. Arrow wing (radiators) designed space system – layout leaned to supersonic turbojets. From core at the bow (in front left: small green cylindrical structure) to solar light power supply ring and cluster of ion thrusters (turquoise plate with purple circles) at the rear end. The great white structure is the payload basket (for up to 18 t scientific instruments, commercial products and communication infrastructures). The colored agenda

describes the other non-nuclear sub-systems and the core. The displayed length scale is 10 m.

Mostly all non-nuclear sub-systems (but not shielding, conversion and payload parts) are mounted with / within iBOSS. Some sub-systems using only iBOSS interfaces. The following sub-systems were studied to be hosted in about 15 – 20 iBOSS blocks: boom, tanks, partially the payloads, power management, PPU, core avionics and secondary solar power photovoltaic cells.

iBOSS, funded by DLR and developed in Germany offers a very important fact: box shaped units will host the sub-systems with iBOSS standardized mechanical, thermal, electrical and fluid interfaces. This is an immeasurable advantage for combining flagship designs, developments, tests, improvements (like AI systems for the sub-systems), replacements on ground, at higher Earth orbit and interplanetary operations. Up-to-date usage of iBOSS: within the used iBOSS the sub-systems parameters of tanks etc. can be directly monitored and elaborated for AI systems mounted within iBOSS. Thereby these AI systems are trained by empirical experiences – already during flagship's higher Earth orbit flight and especially during long interplanetary flights. These trained AI systems realizes in real time potential sub-system faults and may learn to intervene. This raises considerably the (non-human / human robots) flagship safety. This tested combination of iBOSS with AI also levels up the human flagship preparation and flight safety.

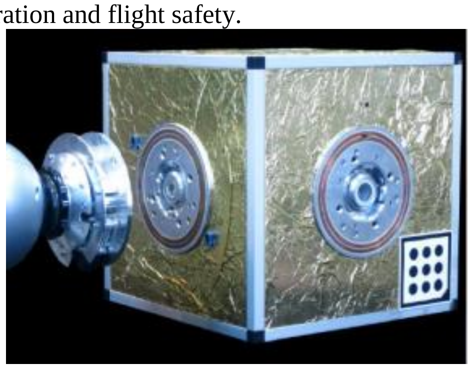

Fig. 4. Building block iBOSS. Autonomous robotic assembly will start in higher Earth orbit with iBOSS sub-systems mounting of non-nuclear INPPS parts. First starts the rear end construction, continued via boom mounting – the last iBOSS equipped subsystems - and finally ends with the physical non-critical core. This to be monitored procedure displays directly the successful realization of the launch and assembly for the flagship. This order of assembly sustains the safety of the third big space project after Apollo and ISS.

The arrow wing shaped version of MARS-INPPS has a total mass of 45.3 t, a final mass launch (including all margins) of 95 t and a propellant mass of 31 t. These mechanical characteristics plus arrow wing INPPS width/weight/length marks it as 'quarter ISS'.

In Fig. 5 is displayed the results of calculations for the transportable payload mass via NEP by INPPS flagship to Mars. Amazing is the order of magnitude (compared to chemical rocket transport) heavy payload mass transport (up to 18 t) to Mars. EP thrusters have already shown that they can achieve the necessary Isp of 4000 s.

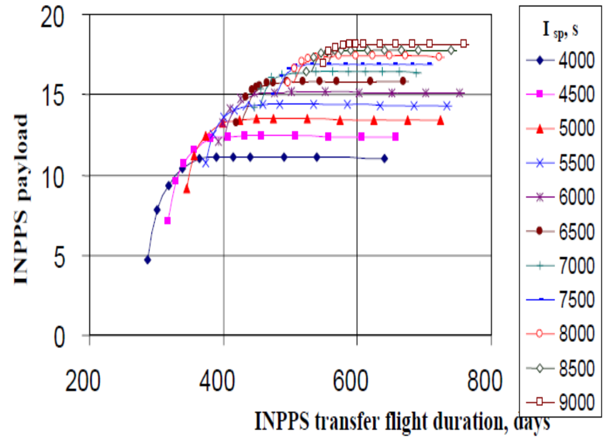

Fig. 5. MARS-INPPS payload mass. The mass is displayed as a function of Earth-Mars transfer flight duration with the specific impulse as a parameter. Isp was considered from 4000 s to 9000 s. The result: the payload mass is between 5 t to 18 t!

2.2. EUROPA-INPPS Flagship

The EUROPA-INPPS flagship and subsystems are displayed in Fig. 6. The first visible layout difference to Mars-INPPS is the propeller wing like shielding sub-system. This propeller wing like shielding is crossed to shade and protect the radiators. Additionally it decreases in flight direction the potential radiation damage of the radiators in the intensive radiation environment of Jupiter / Europa as well as the higher energy galactic cosmic ray flux with it's higher intensity at Jupiter distance within the heliosphere. The second visible layout difference to MARS-INPPS is the wide wing like structure for the radiators. The more extended perpendicular wings are also necessary by the demand to dissipate the heat directly and completely – with nearly any interactions - into free space. The radiator radiation area is smaller than the area in MARS-INPPS flagship.

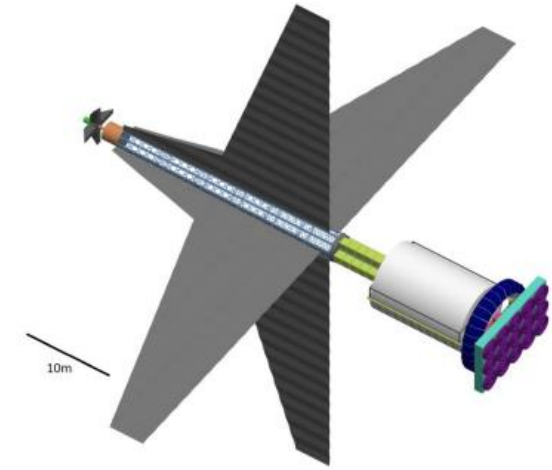

Fig. 6. DEMOCRITOS EUROPA-INPPS flagship – the wide wing (radiators) designed space system. From core at the bow (in front left: small green cylindrical structure) to solar light power supply ring and cluster of ion thrusters (turquoise plate with purple circles) at the rear end. The great white structure is the payload basket (for up to 12 t scientific instruments, commercial products and communication infrastructures). The colored agenda describes the other non-nuclear sub-systems like in figure 5 for MARS-INPPS. The displayed length scale is 10 m.

iBOSS is applied very similar like in MARS-INPPS. AI equipped iBOSS in EUROPA-INPPS tests both systems towards deep space outer planetary exploration flight and increases strongly the reliability for MARS-INPPS human flight. The wide wing version of EUROPA-INPPS has a total mass of 56 t, a launch mass of 116 t and propellant mass of 38 t (including all margins). Insofar it is slightly heavier but shorter (more compact) than the MARS-INPPS. The weight of EUROPA-INPPS is in the order of 25% of ISS.

Fig. 7 displays the calculation results of heavy payload mass via NEP by EUROPA-INPPS to Jupiter icy moons location. Impressive is the one order of magnitude heavier payload mass transport (up to 12 t) to Europa: chemical rockets with similar 100 t launch mass at Earth will transport only about less than 10% payload mass to Jupiter! EUROPA-INPPS also offers short transfer flight time to Jupiter / Europa – between 800 days and 1500 days. The minimum necessary Isp is of 5000 s. Maximum necessary Isp is 9000 s for 12 t payload mass.

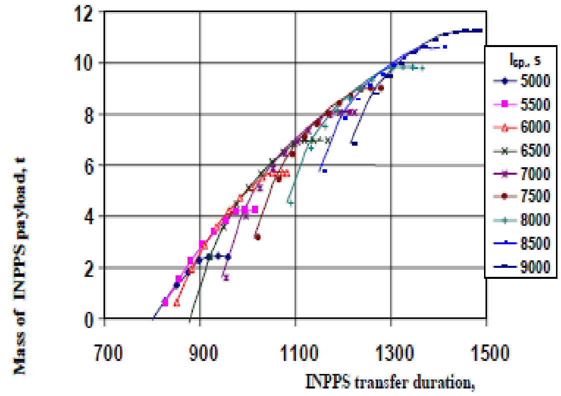

Fig. 7. EUROPA-INPPS payload mass. The mass is displayed as a function of Earth-Jupiter/Europa transfer flight duration with the specific impulse as a parameter. Isp was considered from 5000 s to 9000 s. The result: the payload mass is between 1 t to 11 t!

2.3 UN NPS Principles, Mars-INPPS Flagship SC² Explorations to Mars

All UN NPS regulations (for additional details read in [8]) will be fulfilled by the following eight measures

1) early information about INPPS flagship in respective panels and full view of the public,
2) first, different launchers carry all non-nuclear subsystems to higher Earth orbit (above 800 km – 1200 km, at least),
3) after complete successful robotic assembly of non-nuclear subsystems, a Russian heavy launcher transports the core to high Earth orbit and robotic assembly and mounting to non-nuclear subsystems will be carried out,
4) it follows the step by step activation of all subsystems and extensive testing of entire space system is carried out before interplanetary departure,
5) by real-time video and charged particle & electromagnetic radiation monitoring of the INPPS Flagship (via MEDIPIX / TIMEPIX on board),
6) the launch of a co-flying monitoring small spacecraft to accompany INPPS in interplanetary cruise will be envisaged,
7) auxiliary kW-scale solar power supply by photovoltaic arrays for the assembly and non-nuclear operations phases and
8) building blocks (like iBOSS) with standardized interfaces, which are used for many non-nuclear subsystems. Advantages are the maximum and flexible use of subsystems in both Flagships plus artificial intelligence (AI) applications for subsystem analysis including fault detection, isolation and recovery (FDIR).

In Fig. 8 is visible the first view of the MARS-INPPS flagship for interplanetary cruise in timeframe 2025 to 2030.

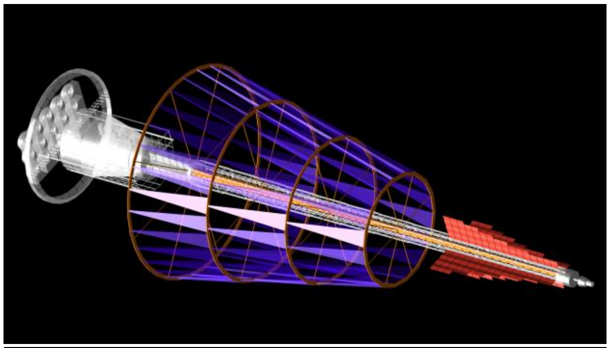

Fig. 8. Potential combination of Russian TPM/NPPS and DEMOCRITOS MARS-INPPS, resulting from MW class reactor tests. From right to left – four deployed standard radiator plates (red) and conical droplet radiator rings (purple – again outlining the shielded volume).

Descriptions of droplet radiators, electric thrusters and all other subsystems for this MARS-INPPS are sketched in [7] and are foreseen to be published in detail in [2020]. On board of this MARS-INPPS will be distinguished between pure scientific, pure commercial and pure communication payload (SC^2).

MARS-INPPS flagship payload basket includes science, commercial and communications parts (SC^2).

For example, the potential INPPS science payload candidate 'VaMEx – Valles Marineris Explorer' consists of various individual components and drones that can be launched from Earth in several independent steps and being implemented to the payload basket of the INPPS flagship. As soon as the INPPS reaches Mars, its first target destination, the complete VaMEx system can be dropped at once to land at the surface (mobile lander with drone swarm) or being released into orbit (navigation satellites), respectively. Details are described in [11] and [6].

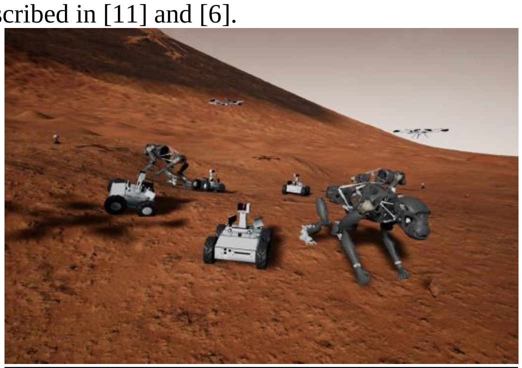

Fig. 9. VaMEx multiple swarm units foreseen to be deployed on Mars surface.

The immediately discernible difference between human Moon and Mars flights is the direct departure from the vicinity of Earth and the long duration, which decrease at first glance the attraction and attention of the public. Therefore it is envisaged to have a pure commercial and a pure communication part in the payload basket too (for details see in [8]): with all five human senses (visual, auditory, kinaesthetic, olfactory and gustatory) it will be given a complete 'feeling' from space time during interplanetary cruise.

Via humanoid robots in the INPPS communication payload section, not only video and audio signals but also the three additional human senses could be implemented as far as possible in ways remotely measurable and transmittable to Earth to accompany expedition activities. Advanced high data rates achievable via laser communications to Earth orbiting telecommunication satellites could make activities aboard tangible for all in near real time.

It is also envisaged to perform virtual reality derived from the INPPS communication payload section. First efforts started at DLR and German SMEs to install, for example, virtual class and conference rooms in the payload section to reach out by virtual reality means (including up to five human senses for the user on ground). Time slots for observations with on-board astronomical telescopes may be also offered, beyond the usual advantages of space-based astronomy also creating long stereoscopic baselines with Earth for simultaneous activities. Finally, the demand of a market for on board virtual reality from the cruising flagship in space time to Mars and Europa for the real users on Earth ground will be well worth exploring.

The first economic aspect for INPPS flagship commercialization is primarily given by international economic developments respectively prospects to reach the space qualified flagship by 2025, the interplanetary non-human Mars and Europa flights, and then the ultimate goal of a human MARS-INPPS Flagship cruise. That means it will create - with time and along the ways during the years - economic and international benefits.

A second economic aspect is the new interplanetary economy, here via commercialisation of INPPS flagship payload capabilities. iBOSS and NANORACKS – originally initiated in LEO are building blocks and modules which may also be applied in and mounted to the INPPS payload basket (see also in [7]). Different products – from simple processed goods to high-tech products – may be produced under near zero gravitational force conditions during interplanetary cruise, but also during Earth or Mars departure and approach periods. These manufactured 'Made in Interplanetary Space' items are released or transported back to Earth by small spacecraft (possibly down to cube-sat size). These new trademark items open completely new business cases. This is a logical step after present first space commercialisation enterprises such as the reusability of launchers. Interplanetary economy would work in parallel to the already well established orbital economy and potentially a developing lunar economy.

It is synergy between elementary particle and space physics - which makes INPPS missions attractive: originally CERN developed semiconductor chips, space qualified by ESA ProbaV and in ISS cupola are foreseen for the real time monitoring in all phases of INPPS missions. In the order of 20 – 50 MEDIPIX / TIMEPIX detectors [12] will be mounted on the INPPS surfaces. The data and processing software are available on board in real time.

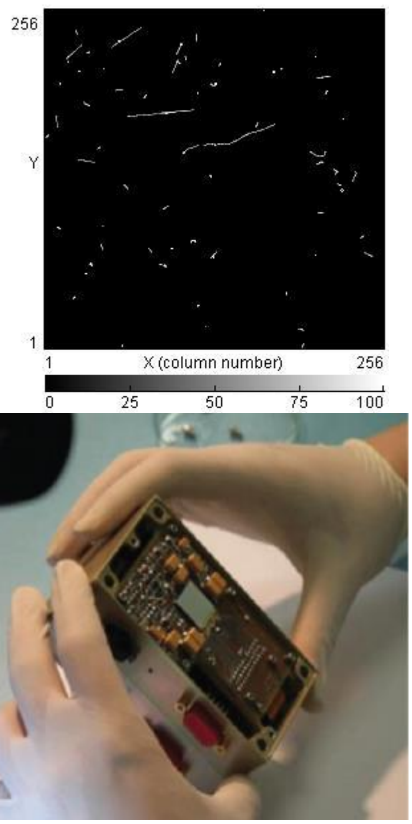

Fig. 10. MEDIPIX / TIMEPIX for INPPS. Above: the 256 x 256 detector ship for gamma-ray, x-ray, proton, electron and light nuclei / ion spur identifications. Below in the middle: advantages of the detectors for INPPS are the very high time, angle resolutions and the measurable energy ranges. Therefore MEDIPIX / TIMEPIX is also a considerable scientific payload instrument for solar energetic particles and high energy galactic cosmic ray measurements. In addition, these data alerts in real time humans on board for space weather forecast purposes.

It became known, that the MARS-INPPS with humans have to fly during solar activity maximum period. Because the more dangerous galactic cosmic ray flux is lower (for instance at nearby Earth space environment by about 20%) due to adiabatic interaction of outward moving solar wind and inward moving galactic cosmic ray particles. In case of a predictable arriving solar storm, the INPPS can be rotated such that massive elements provide optimal protection for the crew compartment.

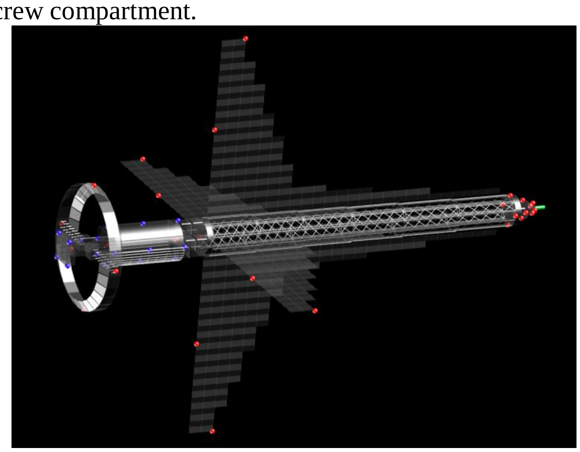

Figure 11. Illustration of EUROPA-INPPS with MEDIPIX / TIMEPIX detectors and video cameras. Red and blue spheres are the widely distributed radiation detectors respectively video cameras. The detectors completely monitor the flagship. The cameras offer brilliant real time view on operating, entire flagship and celestial sky including disappearing Earth and approaching Earth moon, Mars, asteroids as well as Jupiter / Europa.

3. Conclusions and Call to Actions

In summary: the main importance is the current high level of INPPS flagship preparations.

The conclusions are

- the main, nearby extension of the work is the focus on complete space flight qualification in 2025 time frame,
- the necessary extensions are directed towards – again focused on 2025 flight qualification – on low level, very detailed studies with subsequent laboratory plus flight preparations including developments for a SC^2 payload concept,
- additional extensions are the envisaged re-design by a concurrent design study of the INPPS flagship due to the confirmed successful ground based 1MW reactor test with droplet radiators,
- it must follow the robotic assembly concurrent engineering study of the re-designed INPPS flagship,

- extensions have to start for an INPPS flagship co-flying small satellite and
- strengthening of the world-wide public and politic support.

According to these conclusions a call to actions is necessary and will be prepared.

Acknowledgments

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In memory for Hartwig Bischoff (†), who was a colleague and friend. He was in charge for NEP at EC and initiated and strongly supported the three projects.

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