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Humans to Mars: by MARS- plus EUROPA-INPPS Flagship Mission

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Abstract

The first non-human INPPS (International Nuclear Power and Propulsion System) flagship flight with orbits Earth-Mars-Earth-Jupiter/Europa (after 2025) is the most maximal space qualification test of INPPS flagship to carry out the second INPPS flagship flight to Mars with humans (in the 2030th). This high power space transportation tug is realistic because of A) the successful finalization of the European-Russian DEMOCRITOS and MEGAHIT projects with their three concepts of space, ground and nuclear demonstrators for INPPS realization (reached in 2017), B) the successful ground based test of the Russian nuclear reactor with 1MWel plus important heat dissipation solution via droplet radiators (confirmed in 2018), C) the space qualification of the Russian reactor by 2025 and D) the perfect celestial constellation for a Earth-Mars/Phobos-Earth-Jupiter/Europa trajectory between 2026 and 2035.

Therefore the talk sketches the preparation status of INPPS flagship with its subsystems. Critical performance will be studied by parallel realizations of the ground and nuclear demonstrators of DEMOCRITOS (until 2025). The space qualification of INPPS with all subsystems including the nuclear reactor in the middle of the 2020th plus the INPPS tests for about one to two years - first in high Earth orbit robotic assembly phase of INPPS and later extended in nearby Earth space environment flight - means a complete concepts driven approval for all applied INPPS space subsystem technologies.

It is also important to consider wider aspects for the overall mission implementation phase. Component like the nuclear reactor as the power source for the propulsion system will have to agree with the 1992 UN principles relevant to the use of nuclear power sources (NPS) in outer space. Therefore this talk will look into the

legal and policy issues of nuclear space systems related to the international realization of mission design, requirements of associated safety regulations (including AI applications in the subsystems) and new aspects for INPPS flagship commercialization and new media communication on board.

1. International NPS Status

Since many decades in Russia and in the USA several efforts were carry out to establish nuclear powered space flights. The main difficulty was the successful technological development of Nuclear Power Source (NPS) as part of the energy supply subsystem for a spacecraft.

Since about one decade, the main progress grew out by the MW class reactor developments in Russia, as a NPS in the Russian TPM (Transport and Power Module) respectively in the NPPS (Nuclear Power and Propulsion System). Main progress, especially means the planned and fulfilled successful MW class reactor ground based test already in 2018 in Russia. In this decade, the envisaged highlight is the announced and planned first space flight of the NPS space system with Nuclear Electric Propulsion (NEP). Many technological, demonstrators and infrastructures developments already started and are foreseen to be finalized within less than ten years. The launch of the Russian MW class space system is planned from Vostochny Cosmodrom by 2030! For several aspects see in [1].

In Europe started - less than ten years ago - related activities by funding the DiPoP project (development of a low power NPS roadmap) via the European Commission. Hence those activities in Europe and Russia, the European Commission funded the two European-Russian projects MEGAHIT and DEMOCRITOS. The result of these cooperation: a high power NEP roadmap plus concepts for nuclear, ground and space based demonstrators and first concurrent designed space system with the Russian MW class core – the International Nuclear Power and Propulsion System INPPS flagship. Very important: NASA Glenn Research Center (GRC) Cleveland, JAXA Tokyo and Airbus Germany gave inputs to the study too. The Institute of Advanced Studies San Jose dos Campos in Brazil started to be a guest observer, for instance by means of inputs and expertise related to their core experiences. For several results see in [3] to [7].

In parallel, in the USA – due to the PROMETHEUS study with the NEP spacecraft to Jupiter – the reactor developments were successful applied to KRUSTY. This system, with about 7kW to 10kW nuclear power is a very useful for nuclear power supply on Moon and Mars surfaces [8]. KRUSTY system may also be interesting for small NPS satellites.

In the last years, several detailed publications related to NPS were published by Chinese experts (see reference [9] to {12]). With a one sentence summary: two different NPS systems with several 100kW power are very well simulated and currently in the final phases of laboratory tests.

Two important final remarks:

1) The European-Russian DEMOCITOS consortium, including inputs from JAXA Tokyo, GRC Cleveland, RIAME / MAI Moscow scientists plus inputs from Austrian ENPULSION, German Airbus and Italian SITAEL electric propulsion expert will publish soon [13]: the robotic and crewed INPPS flagship transport with a Cluster of Electric Thruster (CET) only (nearly none chemical propulsion is needed) humans or up to 18 t to Mars and up to 11 t to Jupiter moon Europa.
2) The first robotic INPPS flagship flights Earth to Mars, back to Earth and than to Europa moon and the second human INPPS flagship flight Earth to Mars and back to Earth completely fulfill, but also overfulfil (via co-flying satellites) the UN NPS principles (for details see in the GLEX talk [1]).

Two main, focused conclusions form the international NPS status chapter:

1) Only by NEP with the INPPS flagship humans can be transported to Mars and back in the period 2030 to 2035!
2) The celestial - relatively nearby constellation of Earth-Mars-Jupiter/Europa between about 2028 and about begin of the 2030th is perfect to constitute soon a 'human constellation' on Earth to realize - in space the peaceful cooperation - of the fourth giant leap of crewed Mars flagship flight after Gagarin, Apollo and ISS.

2. The INPPS Flagship Status

In Fig. 1 is displayed the MARS-/EUROPA-INPPS flagship.

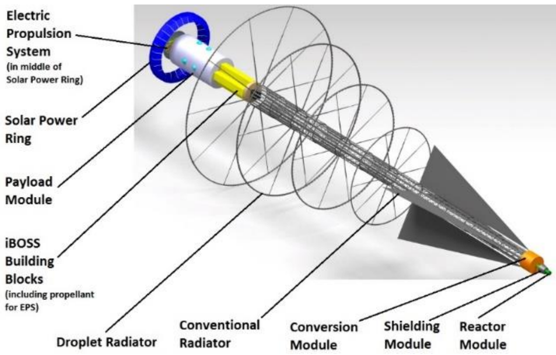

Fig. 1 The 1MW electric class reactor plus all non-nuclear subsystems of the futuristic designed INPPS flagship are displayed.

During the IAC in DC 2019 (celebration of 60 years of Apollo Moon landing), the INPPS flagship related references talks and papers were discussed (see in [3] to [7]). These talks and papers described the strategy and benefits to prepare crewed space flight to Mars via first robotic space flight Earth to Mars, return to Earth and most maximal flagship test (for first human INPPS flight) by testing via robotic space flight to Europa. This is new compared to Lunar Gateway and Mars human space flights. Moreover, all these papers IAC 2019 explained the INPPS flagship subsystems purpose/characteristics. This includes shielding, conversation, boom, radiators, building blocks, payload basket, secondary power supply ring (via photovoltaic thin film elements), power processing units and electric thruster. In addition the papers contain the strategy behind autonomous robotic assembly of the flagship in high Earth orbit: this is a profitable business for interested companies worldwide. It should be mentioned a second profitable business – the usage of building blocks for non-nuclear subsystems in the first flagship to Mars, plus additional/new building blocks after return from Mars and start to Europa and within the second crewed flagship to Mars. The idea's behind third very profitable business (a worldwide one, especially for Startups / SMEs from non-space industry too) – the pure commercial and new media communication payload modules – are also sketched. A successful, interactive poster about all aspect of the INPPS flagship including promotion videos are available on request [14].

An additional space industry / space organization / video camera and detector producers related interest may come due the following reason: during cruising to Mars/Earth/Europa the flagship will be accompanied co-flying small satellites / cubesat's. On these small space systems plus on the flagship surface will be mounted video cameras (working in visual range) to transfer to Earth ground real time images of the entire flagship. Moreover on the flagship surface will be also mounted - in minimum - 20 Timepix detectors to measure in real time particle and electromagnetic radiations potentially released by the flagship and naturally arriving from the Sun and the Galaxy.

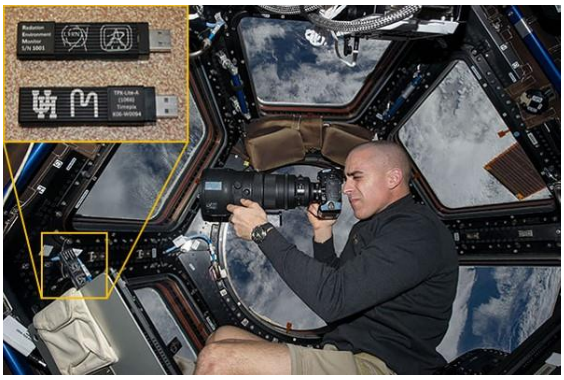

Fig. 2 Space qualified miniaturized Timepix detector (in both yellow boxes) mounted in the cupola of the ISS. These detectors on ESA Proba V satellite are used for years to monitor the dangerous particle radiation in the South Atlantic Anomaly (SAA).

2.1. High Power Space Transportation INPPS

Already in DEMOCRITOS project was calculated for INPPS flagship flights to asteroids, Moon, but also for Mars and Europa. The results for Mars and Europa was the feasibility to transport up to 18 t payload to Mars and up to 11 t payload to Jupiter / Europa moon. The dependencies of the maximal transported payload mass is not only given by the distance to these celestial bodies, but especially from the power and specific impulse of the electric thruster.

In 2020/2021, those partners, already involved in the flagship electric subsystem calculations, plus additional experts from the University of Stuttgart, SME's Enpulsion Vienna and Sitael S.p.A. Pisa studied in details the Cluster of Electric Thrusters (CET) for all three space flights of the first flagship. This is also a milestone breakthrough for safety – the robotic and crewed INPPS flagship is able to fly nearly all three orbits with pure electric propulsion from different nations.

In the next two subchapters, some study results for the flagship CET towards optimized combinations of German / European electric thruster alone or European and Russian electric thruster together or combined European / Russian / Japanese and US electric thrusters (ETs).

2.1.1. Flagship Cluster with European Electric Thrusters

A possible cluster of ETs for the INPPS is shown in Figure 3 with thruster types developed by European companies and institutions. As a suitable combination of European thrusters this configuration seems to be advantageous for the INPPS with regards to determined requirements, e.g. a high TRL and a good modulation between achieved and required thrust level. A selection between following thruster types has been received (see in Fig. 3).

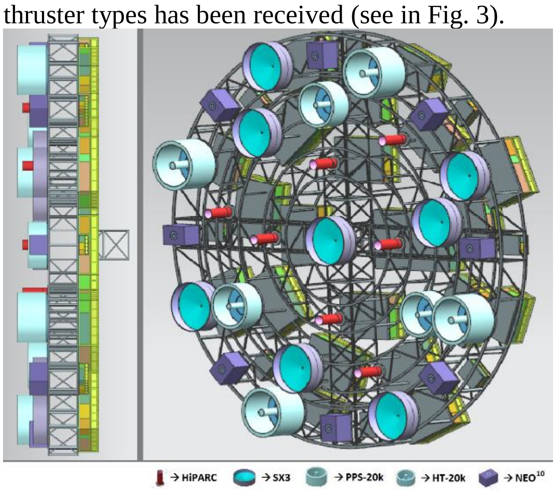

Fig.3 CAD design of gridded cluster plate including European electric thrusters with redundant PPUs for each thruster at the backside for the MARS/EUROPA-INPPS flagship.

According to results of achieved thrust levels, seven German HiPARC, three Italian HT20k, eight Austrian NEO^{10} and four French PPS-20k thrusters have finally been selected. However, it is necessary to mention that this thruster selection is only one of several possible options already considered – for instance for German ETs only are very good option and other combinations with several European ETs can also be preferred.

As shown in Figure 4 it is important to use the high-power thrusters only during the high-thrust phases, where other thruster types can not achieve required thrust to remain at a minor propellant consumption. On these reasons the Italian HT20k and French PPS-20k thrusters are operated between low and high thrust sections. For the transfer from Mars back to Earth a relatively high thrust compared to other trajectory sections is necessary for deceleration at Earth. On these reasons HiPARC is intended to be operated during this phase until required thrust is no more achieved.

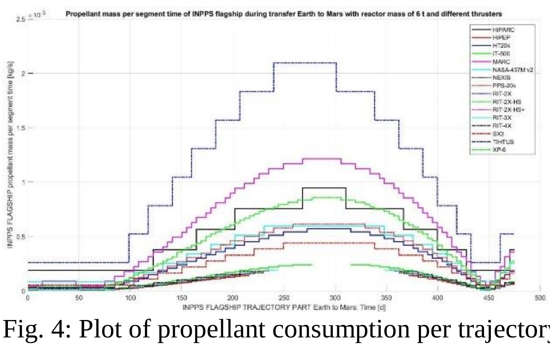

Fig. 4: Plot of propellant consumption per trajectory section over mission time of transfer Earth to Mars showing relevant thruster types. Breaks show that required thrust is not achieved with this thruster.

In general, it is possible during each trajectory section to operate with another thruster type as indicated. Consequently, HiPARC with a quantity of one thruster can achieve required thrust With this thruster configuration a total operation of HiPARC is intended during 24.8 % of transfer to Mars, 29.7 % of transfer from Mars back to Earth and 55.4 % of transfer to Jupiter. An operation with the AF-MPD SX3 will be during 43.6 % of trajectory Earth-Mars, 37.6 % of trajectory Mars-Earth and 16.8 % of trajectory Earth-Jupiter. The French HET PPS-20k is intended to generate the required thrust for only a few trajectory parts, only 5.9 % of transfer to Mars, 4.0 % of transfer back to Earth and 5.0 % of transfer to Jupiter. The second selected HET HT20k is a feasible option for 22.8 % of transfer to Mars, 15.8 % of transfer back to Earth and 12.9 % of transfer to Jupiter. Furthermore, NEO^{10} will take the last trajectory parts, namely: 3.0 % of trajectory Earth-Mars, 2.0 % of trajectory Mars-Earth and 9.9 % of trajectory Earth-Jupiter.

The propulsion system, consisting of only European thruster types, features a total mass of ETs, PPUs and PFS of approximately 4784 kg. This is lower than the determined limit of maximal ten percent of flagship initial mass and will not exceed this value even with an additional mass of necessary electrical harness, propellant feeding components and cluster plate.

2.1.2. Flagship Cluster with International Electric Thrusters

Because the configuration of European thrusters is a feasible option, a selection of only European and Russian thrusters is preferred as well. In the same way an operation with a cluster plate featuring Japanese, Russian and US thrusters is feasible. For further considerations following international thrusters has been preselected to analyze its performance data as a feasible electric propulsion system for the INPPS: ion thruster IT-500 (Keldysh Research Center, Russia), HiPEP and NEXIS (NASA, USA), as well as HET XP-6 (JAXA, Japan) and NASA-457M v2 (NASA, USA). It has been analyzed whether a cluster of European and Russian, Japanese and Russian or Japanese, Russian and US thrusters can achieve required thrust levels during the trajectory sections.

Due to the Russian ion thruster IT-500, that has been chosen instead of the Italian and French HETs compared to the European cluster of ETs, a higher specific impulse can be achieved during trajectory sections. This leads to a minor propellant consumption that can be achieved with this thruster combination. The other thruster types of the European selection remain to this option due to their good performance of achieved thrust levels. Therefore, the European and Russian propulsion system selection is made of seven HiPARC and IT-500 thrusters as well as eight NEO^{10} and SX3 thrusters. The German, Russian and Austrian ETs are an interesting option. The entire quantity is up to 30 thrusters on the cluster plate, but with the Austrian low-power FEEPs, lighter thrusters with smaller dimensions are chosen. The PS features a weight of 5438 kg and the thruster arrangement is shown in Figure 5. The partition of trajectory sections to this cluster configuration is similar to the European thruster cluster but instead of the French and Italian HET the Russian ion thruster is operated. To ensure a most symmetric thruster positioning, this cluster option has been considered, trying to assemble each thruster of the same type not directly next to each other. With regards to the determined filling density of cluster plate, its area should be at least 9.718 m². This leads to a minimum diameter of a cylindrical cluster plate of approximately 3.518 m.

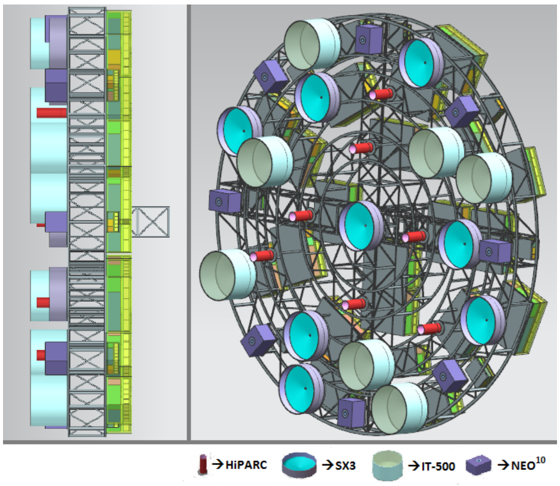

Fig. 5 CAD design of gridded cluster plate including European and Russian electric thrusters with redundant PPUs for each thruster at the backside. Thruster colours show the colour of the expected plume colour (depending on preferred propulsion).

Similar to the cluster of European thrusters, it is possible to operate with HiPARC or SX3 as substitution for IT-500 and NEO[10] if these thruster types feature a failure. In the same way it is possible to operate with the Russian ET as alternative operation for the Austrian thrusters. With this thruster modification a worse performance of trajectories is accepted, but in case of a failure an alternative is possible. With this thruster configuration a total operation of HiPARC is intended during 23.8 % of transfer to Mars, 27.7 % of transfer from Mars back to Earth and 56.4 % of transfer to Jupiter. An operation with the AF-MPD SX3 will be during 43.6 % of trajectory Earth-Mars, 34.7 % of trajectory Mars-Earth and 16.8 % of trajectory Earth-Jupiter. IT-500 is intended to generate the required thrust for following trajectory parts: 29.7 % of transfer to Mars, 24.8 % of transfer back to Earth and 16.8 % of transfer to Jupiter. Furthermore, NEO[10] will take the last trajectory parts, namely 3.0 % of trajectory Earth-Mars, 2.0 % of trajectory Mars-Earth and 9.9 % of trajectory Earth-Jupiter.

In addition to combination of Japanese and Russian thruster types, the US HET NASA-457M v2, developed by NASA, can successfully be operated during high-thrust phases. A necessary quantity of 14 thrusters is able to achieve required thrust levels even for peak acceleration to Jupiter. In addition to these thrusters, a further decision between eight ion thrusters HiPEP, IT-500 or NEXIS has been determined to use the Russian thruster type IT-500 as more suitable trajectory sections are possible compared to the US thrusters. A single Japanese HET XP-6 is intended to operate during low-thrust phases as shown for the Russian-Japanese thruster configuration. This thruster quantity can be increased to achieve better approximated thrust levels for more trajectory sections but would accept a higher total thruster quantity. Every transfer is feasible with this thruster configuration except of the last deceleration at Earth for trajectory Mars-Earth. The entire PS comprises 22 thrusters featuring a total mass of approximately 5603 kg.

With this thruster configuration a total operation of NASA-457M v2 is intended during 61.4 % of transfer to Mars and back to Earth and 74.3 % of transfer to Jupiter. An operation with the ion thruster IT-500 will be during 30.07 % of trajectory Earth-Mars, 21.8 % of trajectory Mars-Earth and 9.9 % of trajectory Earth-Jupiter. Furthermore XP-6 will take the last trajectory parts, namely 7.9 % of trajectory Earth-Mars, 6.9 % of trajectory Mars-Earth and 15.8 % of trajectory Earth-Jupiter.

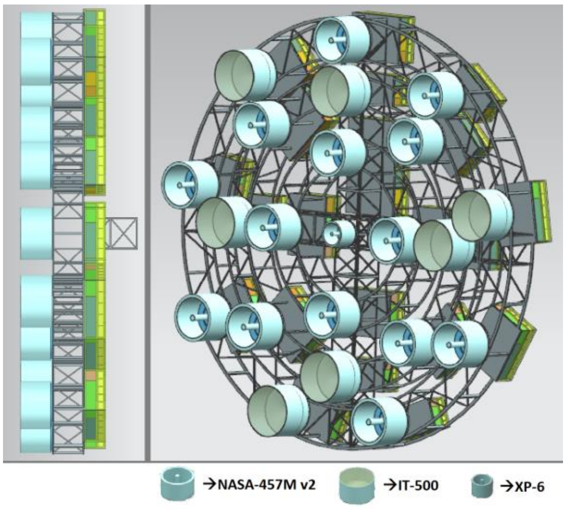

Fig. 6 CAD design of gridded cluster plate including Japanese, Russian and US electric thrusters with redundant PPUs for each thruster at the backside of the INPPS.

In summary: a cluster of Japanese, Russian and US thrusters, is possible for the INPPS but not as suitable as the European or European / Russian option. The Japanese thruster XP-6 can not achieve the required thrust as accurately as the Austrian thruster NEO[10] is able. In the same way it is necessary to operate with 14 NASA-457M v2 to achieve high-thrust levels compared to only seven thrusters of HiPARC. As exemplary shown in Figure 7 mass of PS is further increased with a higher thruster quantity for transfer to Mars. Regardless, this selection shows that a non-European thruster option is possible, even if it is not optimal. Other thruster configurations are possible as well, the selection features only a preliminary feasible option of the preselected electric thrusters.

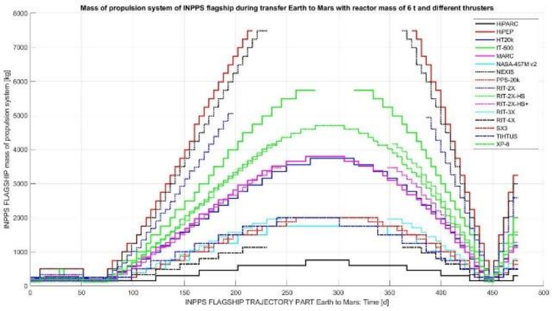

Fig. 7 Plot of PS mass including thruster, redundant PPU and PFS (Propellant Feed System) over mission time of trajectory Earth-Mars featuring relevant thruster types. Breaks show that required thrust is not achieved with this thruster.

3. Summary and Conclusions for Future

Russia has planned - until 2030 - to have the space qualification of an NPS space system [15[. In China, Europe and the USA related activities are in progress.

Ambitious future space exploration missions will depend on advanced high power space transportation systems.

The detailed INPPS flagship simulation for high power electric thrusters results into several options for a cluster of electric thrusters to Mars, back to Earth and to Jupiter / Europa for the robotic and crewed flights.

Electric propulsion is the only feasible option to transport humans to Mars by the INPPS flagship.

The Cluster of Electric Thruster for the INPPS can be developed in a network of international cooperation – as a business case.

INPPS is embedded in the necessary safety requirements, taking into account especially the UN NPS Principles and the Safety Framework for NPS Applications in Outer Space.

The INPPS flagship project is in line with UN safety requirements, LTS-Guidelines and thematic priorities of UNISPACE+50, such as: international cooperation, access for all and capacity building.

The awareness-building is supported by the NPS-Principles and the Safety Framework with the Russian version of the Commentary on the UN NPS Principles and the Safety Framework for NPS Applications in Outer Space.

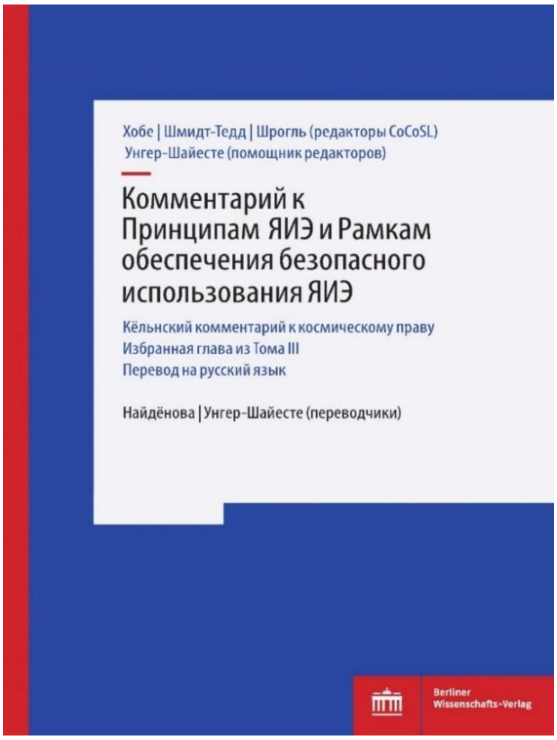

Fig. 8 Book – published in June 2021 - of the Russian translation of the NPS chapters in Volume III of the Cologne Commentary on Space Law.

The INPPS flagship and related NPS projects are world-wide intensively and high level studied from reactor, technology, science, explorations and safety points of view with the result of realization and space qualification as a space system and with all subsystems within the next ten years – internationally.

The next multilateral steps must be directed towards a High Power Space Transportation Program (HST – program) with its technological, political, funding, exploitation, dissemination, promotion and public acceptance inputs and decisions. This will result in many contracts worldwide - for organizations, industries, SMEs and Startups.

HST-program as the fourth giant space flight program – after Gagarin, Apollo and ISS is completely long-hauling attractive all over the world by itself, but moreover – via the extra commercial productions on board and new media communication from the flagship to Earth – online 24 hours per day / 7days per week / 365 days per year.

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