Post-ISS Human Operations in Free Space:
Scenarios for Future Exploration Beyond LEO

"Gateway" concept at Earth-Moon $L_{1,2}$ as developed by the Future In-Space Operations (FISO) working group and John Frassanito & Associates (2006)

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September 2, 2009
See also: http://www.futureinspaceoperations.com

Exploration: from the ISS to the Depot Gateway

Presentation Summary:

Context for free-space operations: relevant goals of human exploration and science

Libration points: transfer among operations sites

The NASA Exploration Team architecture for human exploration out of the Earth-Moon libration point

The 2005 human-occupied "gateway" designed by the FISO working group and JF&A

ESA and Roskosmos scenarios for post-ISS operations in free space: contrast with DPT/FISO

A near-term "stepping stone" to human operations in cis-lunar space:
using the Cx architecture to enable satellite servicing

Conclusions

DPT/NEXT/FISO Architecture Context
Exploration: from the ISS to a Depot/Gateway

Priority goals of science and human spaceflight as enabled by extended ISS operations with a depot/gateway follow-on:

Understanding how to live and work productively in space:

The capabilities and experience being developed on the ISS, which are critical if humans are to live and work in space, will not be lost, but will be strengthened by a post-ISS depot gateway

Extensive participation by an international partnership:

European and Russian ISS partners are committed to long-term operations on ISS and have begun post-ISS design studies for astronaut in-space operations.

Human exploration of the lunar surface:

Astronaut operations from an Earth-Moon libration-point gateway permit sortie missions throughout the lunar surface, as well as depoting capabilities to support extended surface operations

Preparation for long human voyages beyond the Earth-Moon system:

Very long-duration human voyages will require capabilities that are in danger of being lost as a result of premature NASA retreat from ISS participation; capabilities being developed on ISS will be continued and developed further via a post-ISS libration-point depot gateway

On-orbit upgrade and maintenance of complex science facilities:

The series of successful shuttle missions to HST has demonstrated the effectiveness and popularity of astronaut in-space upgrade and maintenance of a major science facility: a libration-point gateway will continue this major capability

Just as it is critical to use fully the ISS to develop human capabilities to work productively in space, it is necessary now to assess what should follow the ISS to extend these capabilities further . . .

Earth-Moon $L_{1,2}$ provides an orbital staging point to enable global lunar access with anytime return capability to Earth. $L_{1,2}$ is a meta-stable gravitational point in space where objects can loiter with minimal prop usage.

Element phasing and rendezvous at the libration points makes it feasible and practical to deploy a human-occupied "Gateway," lunar lander, propellant depot, and other assets.

Being most of the way out of Earth's gravitational potential makes it a very attractive launching point for missions beyond cis-lunar space.

Operations out of E-M $L_{1,2}$ offer the possibility of achieving simultaneously multiple priority science and human exploration goals using common architecture elements.

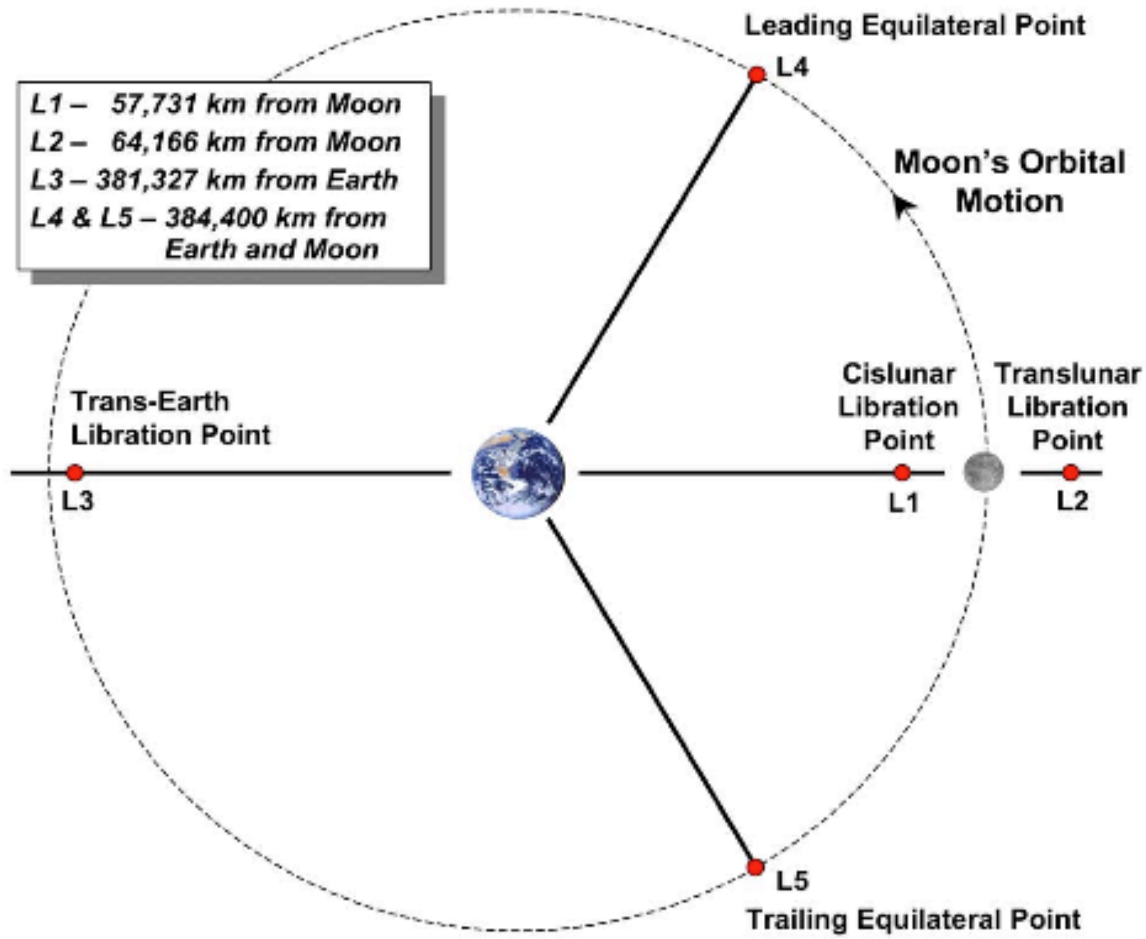


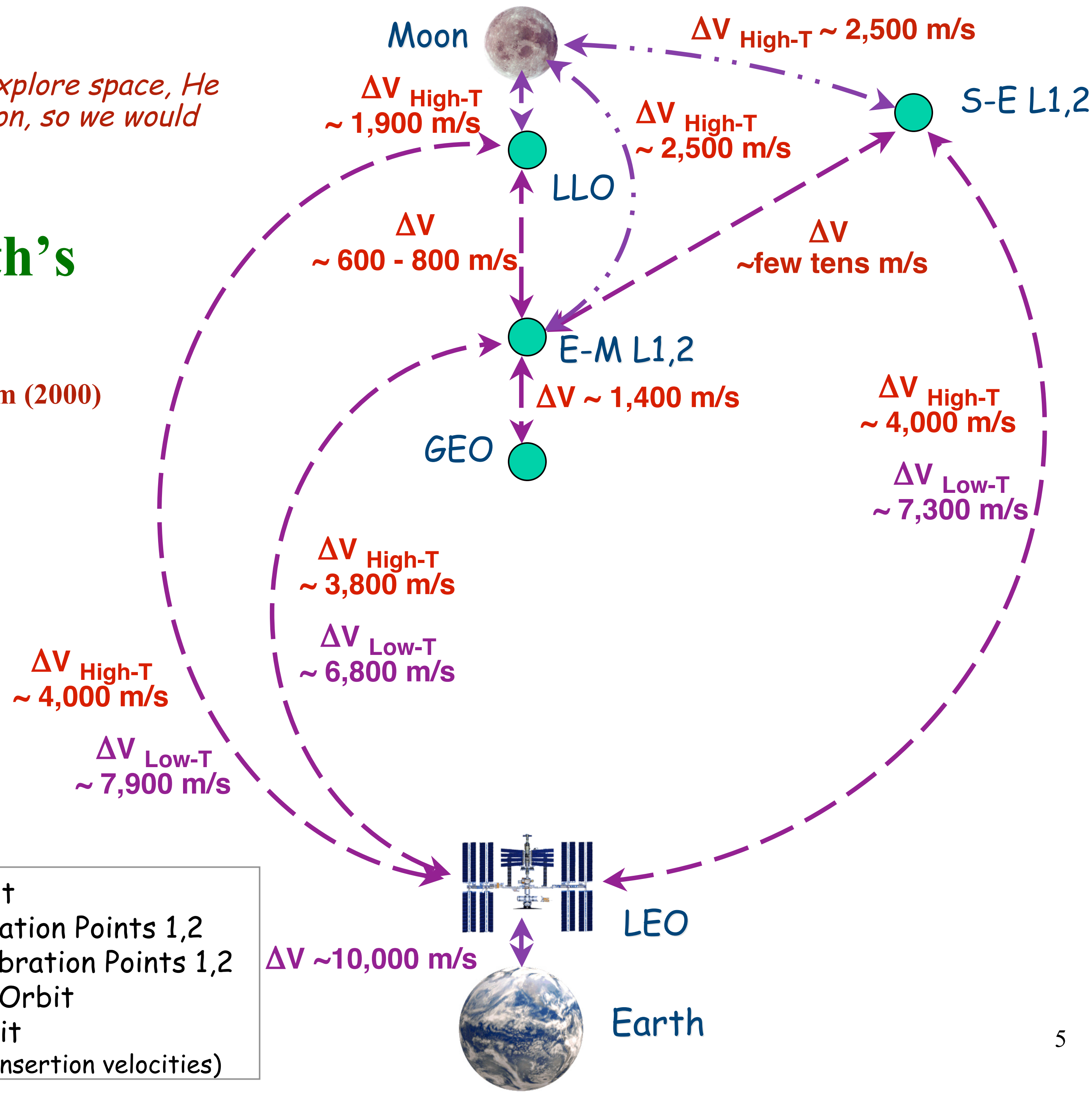
Figure 2.2-1: Earth-Moon Libration Points

Adapted from ESMD-RQ-0005 *Lunar Architecture Focused Trade Study Final Report* (February 2005)

"If God had wanted us to explore space, He would have created the Moon, so we would have libration points."

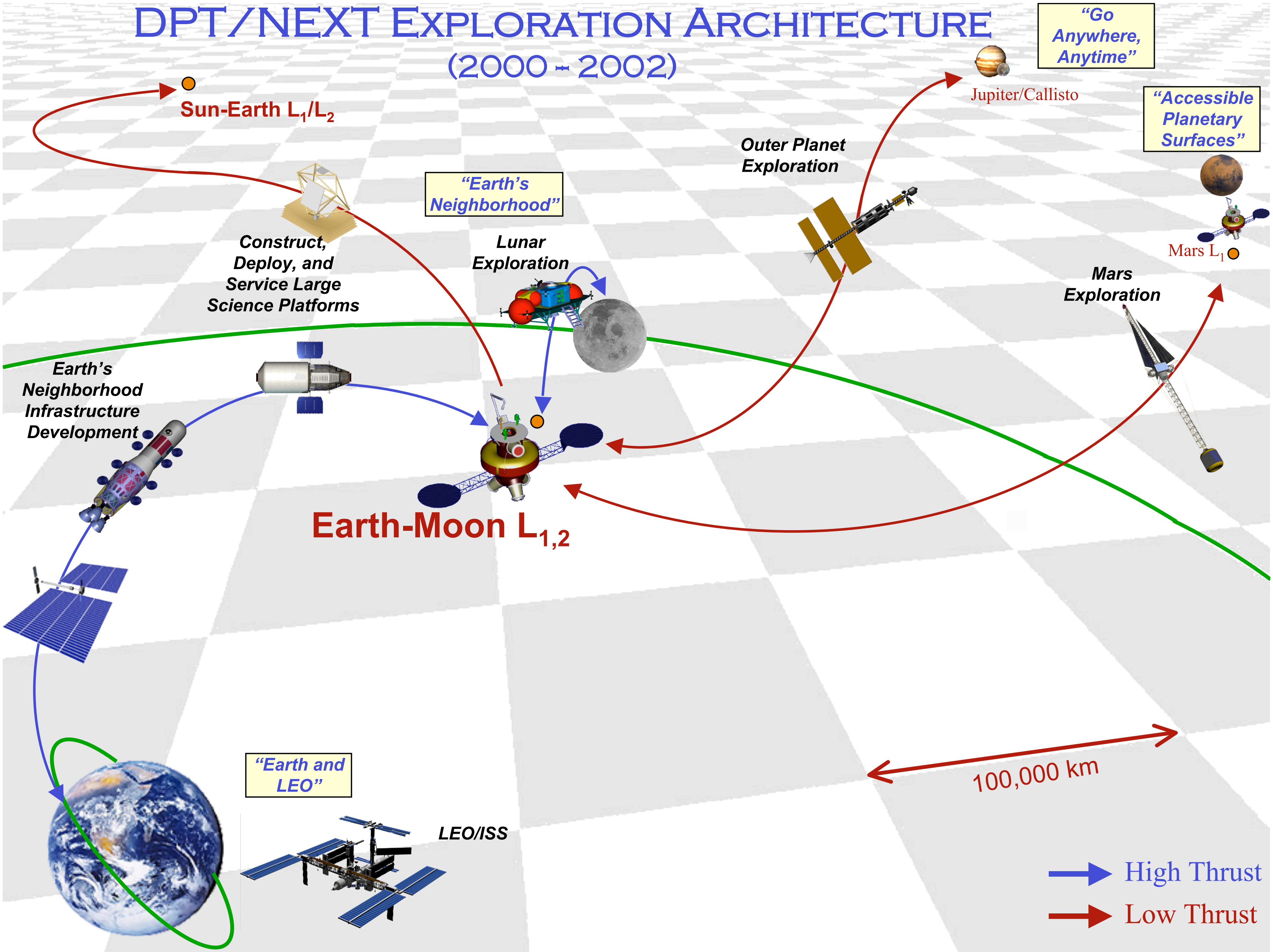
ΔV in the Earth's Neighborhood

<u>Source</u>: Decade Planning Team (2000)



LLO	Low Lunar Orbit
SE L1,2	Sun-Earth Libration Points 1,2
EM L1	Earth-Moon Libration Points 1,2
GEO	Geostationary Orbit
LEO	Low Earth Orbit

(velocities include estimated insertion velocities)


DPT/NEXT Exploration Architecture
(2000 - 2002)
"Go Anywhere, Anytime"
Jupiter/Callisto
"Accessible Planetary Surfaces"
Sun-Earth L1/L2
Outer Planet Exploration
"Earth's Neighborhood"
Construct, Deploy, and Service Large Science Platforms
Lunar Exploration
Mars L1
Mars Exploration
Earth's Neighborhood Infrastructure Development
Earth-Moon L1,2
100,000 km
"Earth and LEO"
LEO/ISS
High Thrust
Low Thrust

Summary Characteristics: Value of E-M $L_{1,2}$ and S-E L_2 Orbits

Sun-Earth L_2 (Optimum Astronomy Ops Site)	Earth-Moon $L_{1,2}$ (Optimum In-Space Job Site?)
← Dynamically Linked by ΔV ~ Tens of m/s →	
Thermally stable	Readily accessible with lunar-capable architecture (~ 4-day transfer time)
Large field of regard	Builds on lunar nav/comm network
Sources of heat and scattered light in same general direction	"Stepping stone" experience for longer human voyages and other in-space ops (e.g., depoting)
Continuous comm (to Earth) and solar power	Continuous comm (to Earth) and solar power
Very low debris, dust	Very low debris and dust

Plausible Astronomical Missions in the ~2020 - 2030 Timeframe

Single-Aperture Far-Infrared (SAFIR) telescope: ~ 8- to 16-m sub-millimeter telescope to study the cosmic history of star formation and the interstellar medium.

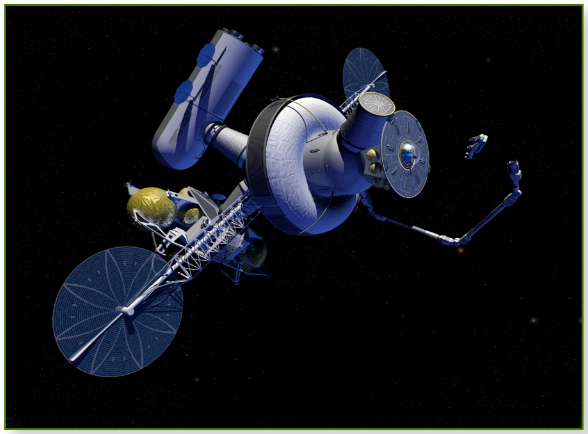
Advanced Telescope Large-Aperture Space Telescope (ATLAST): 8- to 16-m UV/visual/IR telescope to investigate how the present universe and galaxies formed and how planetary systems emerged from circumstellar disks.

International X-Ray Observatory (IXO): a very large x-ray telescope to investigate the very early universe and the most energetic phases of matter.

Stellar Imager (SI): a large UV/visual spatial interferometer capable of high-angular resolution observations leading to much-improved understanding of solar and stellar magnetic activity, as well as accretion mechanisms in objects ranging from planet-forming systems to black holes.

Servicing and upgrading these potential missions in orbit will continue NASA's most successful program of using astronauts to achieve major -- and very public -- scientific goals.

Architecture Elements
FISO Working Group (2005)



Earth-Moon $L_{1,2}$ Gateway

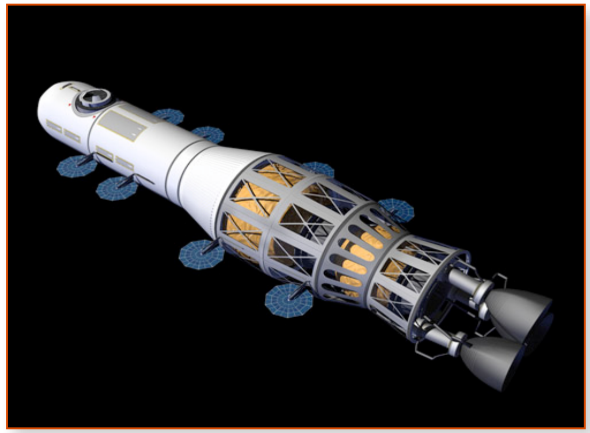
Mission: The Gateway is a mission-staging and crew-habitation platform stationed at the E-M $L_{1,2}$ venue for upgrading and maintaining large scientific facilities, supporting expeditions to the lunar surface, and preparing for long human voyages beyond the Earth-Moon system.

Element Mass:

– Launch:	23,000 kg
– Outfitting:	1,000 kg
– Post-outfitting:	24,000 kg

Requires two launches:

- Gateway to LEO
- Gateway Outfitting Mission



Crew Transfer Vehicle

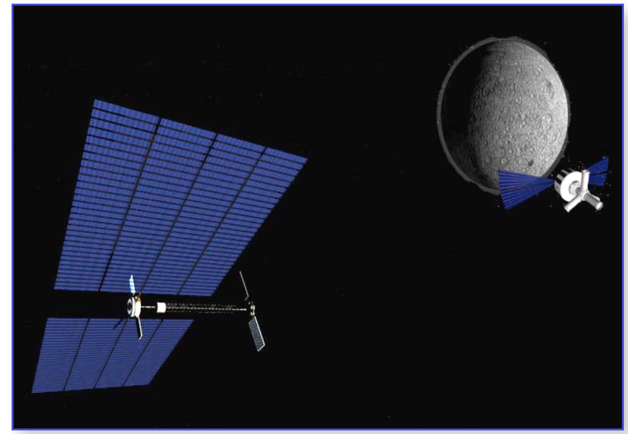
Mission: The CTV transports crews of four between ISS/LEO and E-M $L_{1,2}$. Upon completion of a mission, the crew aerocaptures into Earth orbit and docks to ISS. The crew returns to Earth via an independent return vehicle such as a Shuttle follow-on.

Element Mass:

– CTV:	25,000 kg
– Injection Stage:	48,000 kg
– Total Stack:	73,000 kg

Requires 3 launches:

- CTV to LEO/ISS
- Crew to LEO/ISS
- Injection Stage to LEO/ISS



Solar Electric Propulsion Stage

Mission: High-efficiency solar electric propulsion (SEP) is used in the Earth's neighborhood architecture to deliver uncrewed elements from low-Earth orbit to a final destination. The SEP stage subsequently returns to Earth for reuse.

Element Mass:

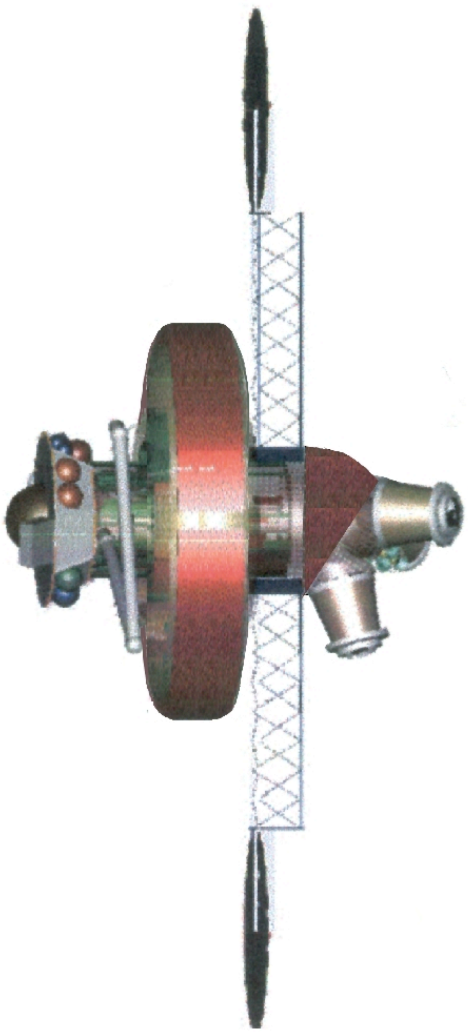
– SEP Stage:	35,000 kg
– Payload:	30,000 kg
– Total Stack:	65,000 kg

Requires 1 launch:

- Stage to LEO

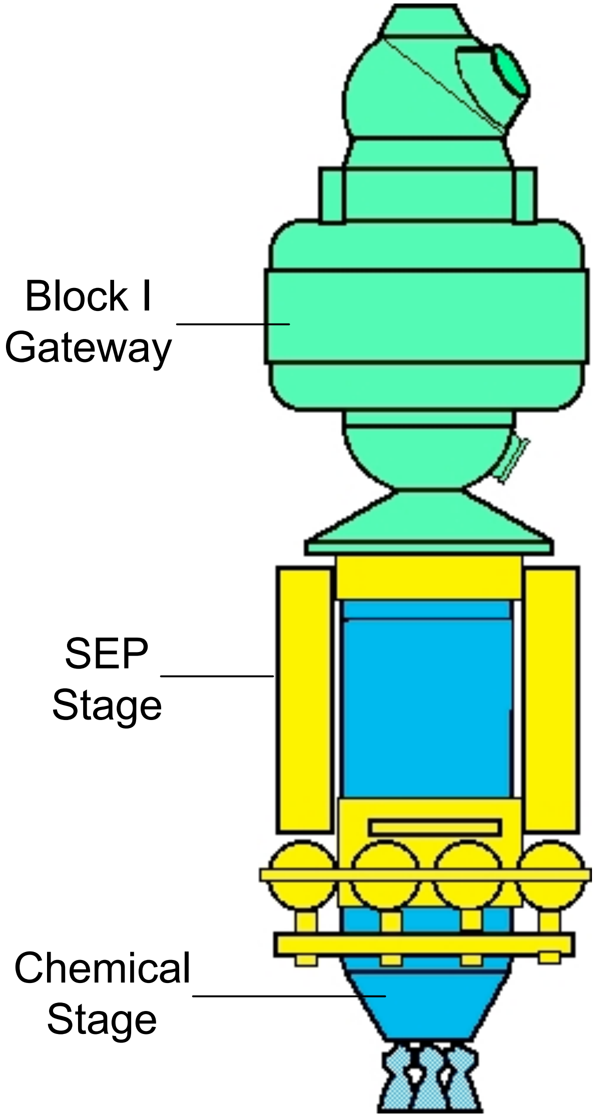
Design Overview - FISO Gateway (2005)

- Launched by 95 mT (to LEO) via heavy lift
- SEP to $L_{1,2}$, then deploy hab volume
- Supports 4 crew (launched separately)
- 12.8 m maximum diameter after inflation
- 575 m^3 hab volume (~ 47% of ISS-complete volume)
- Radiation protection added & storm shelter in core structure.
- 3 docking ports on rotating turret



Gateway Element	kg
Power System	1542
Avionics	251
ECLSS	3768
Thermal Control System	894
Habitability & Human Factors	2507
EVA Systems	900
Vehicle support for EVA	212
EVA Transition Aids	123
EVA Tools	132
Airlock	433
Structure	12321
Inflatable skin	3270
Core structure	1678
Turret mechanisms	400
Interstage adapter	200
Docking adapters (3)	1996
EVA work platform	100
Work platform support struts (8)	264
ORU/Robot storage	150
Radiation protection	2000
Cupola	198
Secondary structure (20% of structure)	1815
Hard shell MMOD	250
Robotics	227
Attitude Control System	424
Propulsion (RCS)	235
Subtotal (Inert Mass only)	23320
25 % Margin (Inert System)	5870
Propellant (RCS)	1268
Crew, Provisions, Consumables	0
Total	30458

"Block 1" Design Overview (2005)
Overall Stack at LEO Injection
[T. Talay and JF&A]



Overall mass: 95 mt
- Gateway: 30.5 mt
- SEP stage: 17.0 mt
- LOX/LH2 stage: 47.5 mt

Overall length: 19.8 m
Overall diameter (max): 5.8 m

Main chemical propulsion (Ref: P&W):
- 3 x RL-10 engines
- 25 Klbf
- LOX/LH2
- O/F=3.5
- Isp = 370 sec

Main SEP propulsion
- 6 Hall Effect 50 kW engines
- Cryo Xenon
- 3650 sq m PV arrays

NB: "Block 0" Gateway designed by DPT/NEXT (see http://history.nasa.gov/DPT/DPT.htm)

FISO/JF&A "Block 1" Operations Concept (2005)

Block 1 (2005) concept for a human occupied Gateway facility at an Earth-Moon $L_{1,2}$ position. A LEO-to-libration point transfer vehicle is shown at one of the three docking ports on the far side of the "gateway," next to a lunar lander. On the near side is the satellite upgrade, repair, and maintenance site with a robotic arm and airlock.

Credit: The Future In-Space Operations (FISO) working group and John Frassanito & Associates

Conclusion: Architecture Concepts
Status of 2005 Design Studies

The system- and element-level concepts are developed with sufficient fidelity to provide the "proof of concept" needed to support a given architecture implementation and to help determine requirements for technology development. These concepts are not intended to be final solutions, but to provide a baseline by which other element and system concepts can be compared.

The centerpiece element for operation throughout the Earth-Moon system is the depot gateway system at the Earth-Moon L_1 or L_2 location. This facility would extend capabilities being developed using ISS. It would enable the upgrade and maintenance of large space instrumentation, provide vehicle support for lunar surface missions, support on-orbit depot systems, and prepare for human exploration to deep-space destinations.

The crew transfer vehicle would operate between low-Earth orbit (perhaps based at the ISS, if still operational) and the L_1 libration point. Depending upon the launch capacity assumed, a solar-electric tug might prove advantageous for transfer of assembled flight elements from low-Earth orbit to L_1. An alternative concept involves a hybrid chemical/electric-propulsion vehicle which would take advantage on on-orbit propellant "farms" for refueling. A lunar landing vehicle would transport crews from L_1 to the lunar surface and back..

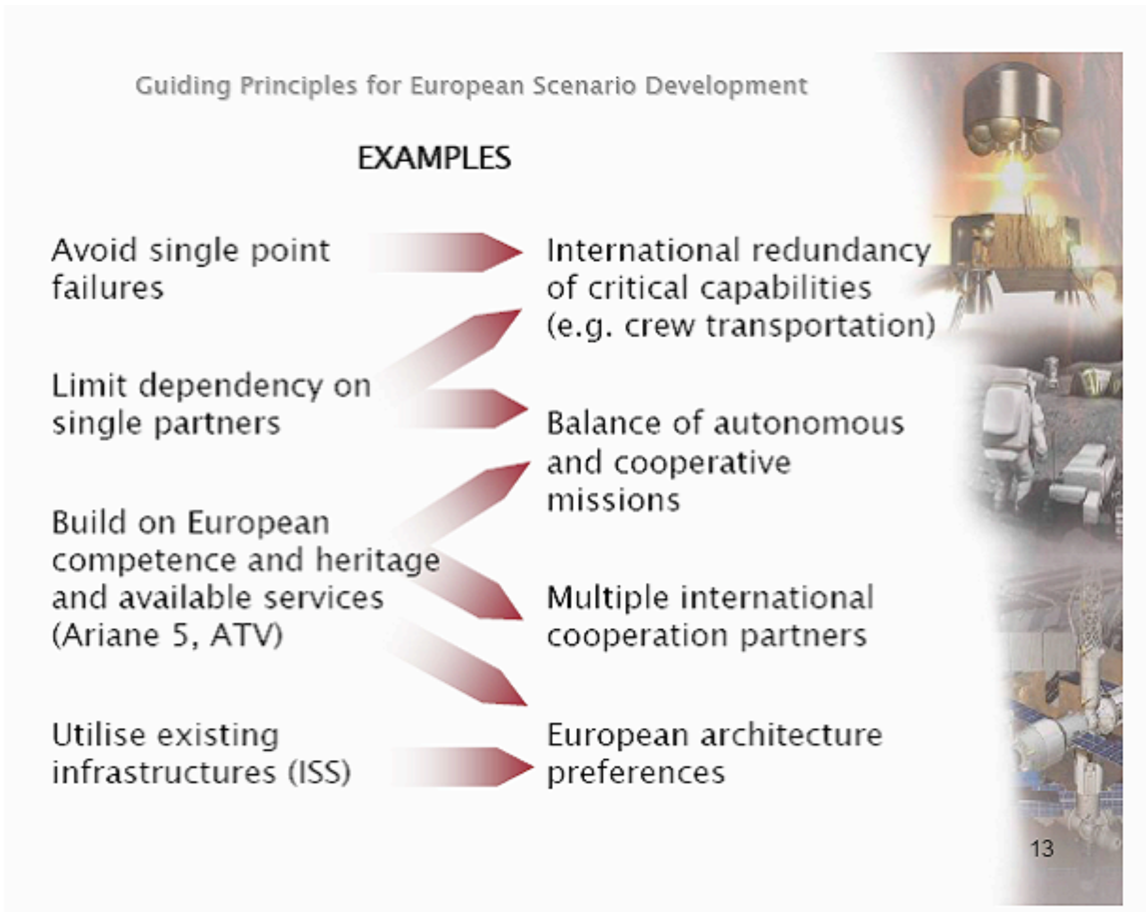
Mars and outer planet transit vehicles, perhaps employing artificial gravity, could be assembled and refurbished at L_1. In this architecture, the gateway would also serve as the precursor design for human missions to Mars.

This work was ordered stopped by NASA HQ ESMD in spring 2006.

ESA Evaluation of Post-ISS Scenarios (I): In-Space Staging of Lunar Surface Operations

ESA Exploration Architecture Trade Report (2008)

[HME-HS/STU/TN/JS/2008]



ESA Evaluation of Post-ISS Scenarios (II): In-Space Staging of Lunar Surface Operations

ESA Exploration Architecture Trade Report (2008) [HME-HS/STU/TN/JS/2008]

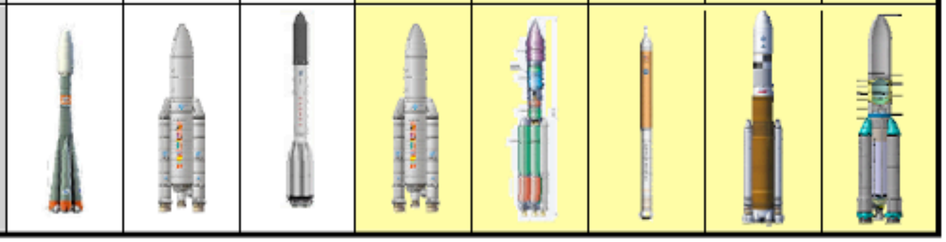
	Soyuz	A5 ECA	Proton	A5 ME	Angara 5	Ares I	Ares V	A5 50t
LEO (t)	8	20	20.6	23	25	25	125	50
LTO (t)	2.163	7	5.6	9.4	TBD	-	56.8	22.7
GTO (t)	3.15	9.4	TBD	12	TBD	-	70.3	
Image								

Table 2.2: Launcher performance summary for European and Russian launch systems

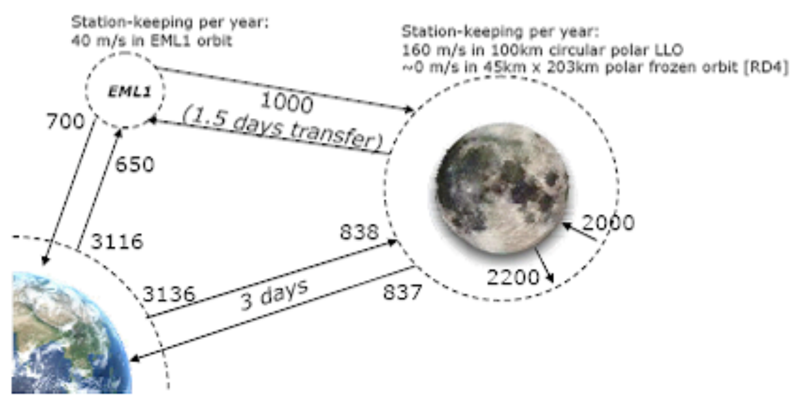


Figure 2.1: ΔV assumptions for cis-lunar transfers (all values in m/s, without margin)

ESA Evaluation of Post-ISS Scenarios (III): In-Space Staging of Lunar Surface Operations
ESA Exploration Architecture Trade Report (2008)
[HME-HS/STU/TN/JS/2008]

Infrastructures Trade	LEO station	EML1 station	LLO station
Characteristics	o Station of 70.4 tons o Crew of 3, permanent o 3 A5 50t for installation	o Core station of 25 tons o Crew of 3, man-tended o Halo orbit about EML1	o Core station of 29 tons o Crew of 3, man-tended o Polar frozen LLO o 2 A5 50t for installation
Advantages	o Assembly support for Moon/Mars transport-tation o Enables science con-tinuation from ISS o Potential continued permanent presence	o Lower Earth to EML transfer cost o Low station-keeping o Global access and anytime return	o Provides staging support and safe haven for crew in orbit o Enables science in LLO o NASA cooperation potential (CEV staging)
Risk and Drawbacks	o Fixed LEO constrains lunar transfer opportu-nities	o Higher requirements on lunar lander (ΔV, transfer time) o Higher overall lunar access round trip cost	o Fixed LLO constrains global access

Table 5.3: Characteristics and comparison of selected orbital infrastructure options

Due to the above discussions, the establishment of an EML station has been discarded from the reference architecture. The discussion of LEO an LLO stations is integrated into the following transportation scenario analysis.

"While general functionalities of a libration point station is similar to a LLO facility, the EML1 station was only found to be of limited value in the selected transportation architectures. Firstly, a staging in the libration point raises significant requirements on the lander element due to larger delta-V for descent, landing and especially ascent and to increased travel times of about two to three days. This led to a large lander design, impossible to be launched on a single Ariane 5 ME launcher and thus to the requirement for improved launcher performance which is met by the A5 50t. . . . Also, since <u>electric propulsion or long-duration cargo transfer options to EML 1 have been excluded</u>, the general lunar access budget is unfavorable in case of an EML station. Solely <u>the advantage of global access and permanent launch windows to Moon and Earth (e.g., for contingency situations) were in favor of the [EML] station</u>, while it seemed not of significant value for the transportation outline since these criteria can be met by an adequate LLO infrastructure and vehicle design as well." [pp. 20 - 21, emphasis added]

Russian Post-ISS Scenarios (I):
LEO Staging for Long-Duration Human Voyages
Moscow Aviation & Space Conference: August 18 - 23, 2009
http://www.russianspaceweb.com/

"Speaking at the 5th International Aerospace Congress in Moscow on August 29, 2006, Vitaly Davydov, deputy chief of the Federal Space Agency, said that Russia planned to abandon the International Space Station sometime between 2015 and 2025, and replace it with a domestically developed outpost in Earth's orbit. According to Davydov, the new station would be inserted into a high-inclination orbit, which would enable its crew to observe most of Russia. At the time, cosmonauts onboard the ISS could only see small fraction of the Russian territory due to the station's orbit, which had been compromised to allow cooperation with the United States.

Along with its role as a remote-sensing platform, the future station would be used for material processing research and the development of technologies for manned missions to the Moon and Mars, Davydov said. Prior to the development of the new station, Davydov promised to complete the Russian segment of the ISS by 2011.

On August 31, 2007, at a Roskosmos press-conference, its head, Anatoly Perminov, unequivocally described the purpose of the Russian successor to the ISS as an assembly platform for deep-space transport ships heading to the Moon and Mars. However, he added that the future station was still aimed for a high-inclination orbit to enable global remote-sensing of the Earth surface. In April 2008, Perminov reiterated the agency's goal to replace the ISS with an all-Russian station. Perminov said that the latest meeting of the nation's Security Council had approved the plan in general, without however setting a timeframe.

In January 2009, Aleksei Krasnov, the head of manned space flight directorate at the Russian space agency, echoed his boss, saying that the future Russian space station in low-Earth orbit would serve as a foundation for the lunar program and, later, for expeditions to Mars. At the time, the agency aimed for 2020 as the launch date of the new Russian outpost, to coincide with the expected deorbiting of the International Space Station. Krasnov stressed however that the project remained an unfunded proposal under evaluation by the Russian government. In any case, it was clear that the lifespan of the International Space Station would determine when, if ever, the new orbital facility would go into orbit.

The OPSEK project

By 2008, the Russian successor to the ISS was identified as Orbitalniy Pilotiruemyi Eksperimentalniy Kompleks, OPSEK, or Orbital Manned Assembly and Experiment Complex in English.* Unlike the previous designs of Mir, Mir-2 and the ISS, the heart of the station would be a four-ton ball-shaped node module. Equipped with six docking ports, this relatively small and simple element would be the only permanent element of the station. All other modules would come and go as their lifespan and mission required.

The initial architecture of the OPSEK complex could be built out of modules originally planned for the Russian segment of the ISS. The exact scenario of the OPSEK assembly would depend on the end of the ISS and the readiness of the latest Russian modules. According to a 2008 scenario, the MLM multipurpose module, the node module and a pair of NEM power platforms could be first launched to the ISS in 2011, 2013 and 2014-2015, respectively. With the deorbiting of the ISS looming around 2020, these modules could separate from the old outpost to form the core of the new Russian station. Another, more controversial scenario considered the separation of the practically entire Russian segment, including the MIM-2 docking compartment and the Zvezda service module, prior to the ISS deorbiting.

From official statements during 2008 and 2009, it is clear that one of the chief objectives of the OPSEK complex would be support for expeditions to Mars. All major elements of the Martian expeditionary complex would dock to the station before their departure from low-Earth orbit toward Mars. The Martian expedition would return to the OPSEK.

The station would also play a similar role in lunar exploration. Reusable space tugs could link OPSEK with the Lunar Orbital Station, (LOS), in orbit around the Moon, thus creating a transport chain for a permanent lunar base. Such tasks as the servicing of modular satellites by orbital tugs based at the OPSEK complex were also cited.

In broader terms, TsNIIMash research institute, a chief strategist of the Russian space agency, formulated the OPSEK concept as a foundation of the nation's space strategy. By 2009, the new station was seen as the cornerstone of a new space exploration plan.

Russian Post-ISS Scenarios (II): LEO Staging for Long-Duration Human Voyages

Artist rendering of the proposed orbital assembly workshop, the successor to the ISS, as it was envisioned around 2008 by Russian engineers. Instead of being a research lab, the new station was conceived as an assembly point for missions to Mars and lunar expeditions. Russia's next-generation transport ship can be seen approaching on the left. Copyright © 2009 Anatoly Zak

Are There Options for Early Deployment of Astronauts Beyond LEO?

Future ambitious science facilities, specifically large astronomical observatories orbited by very large launch vehicles, may be so expensive that astronaut and/or robot servicing will be extremely desirable.

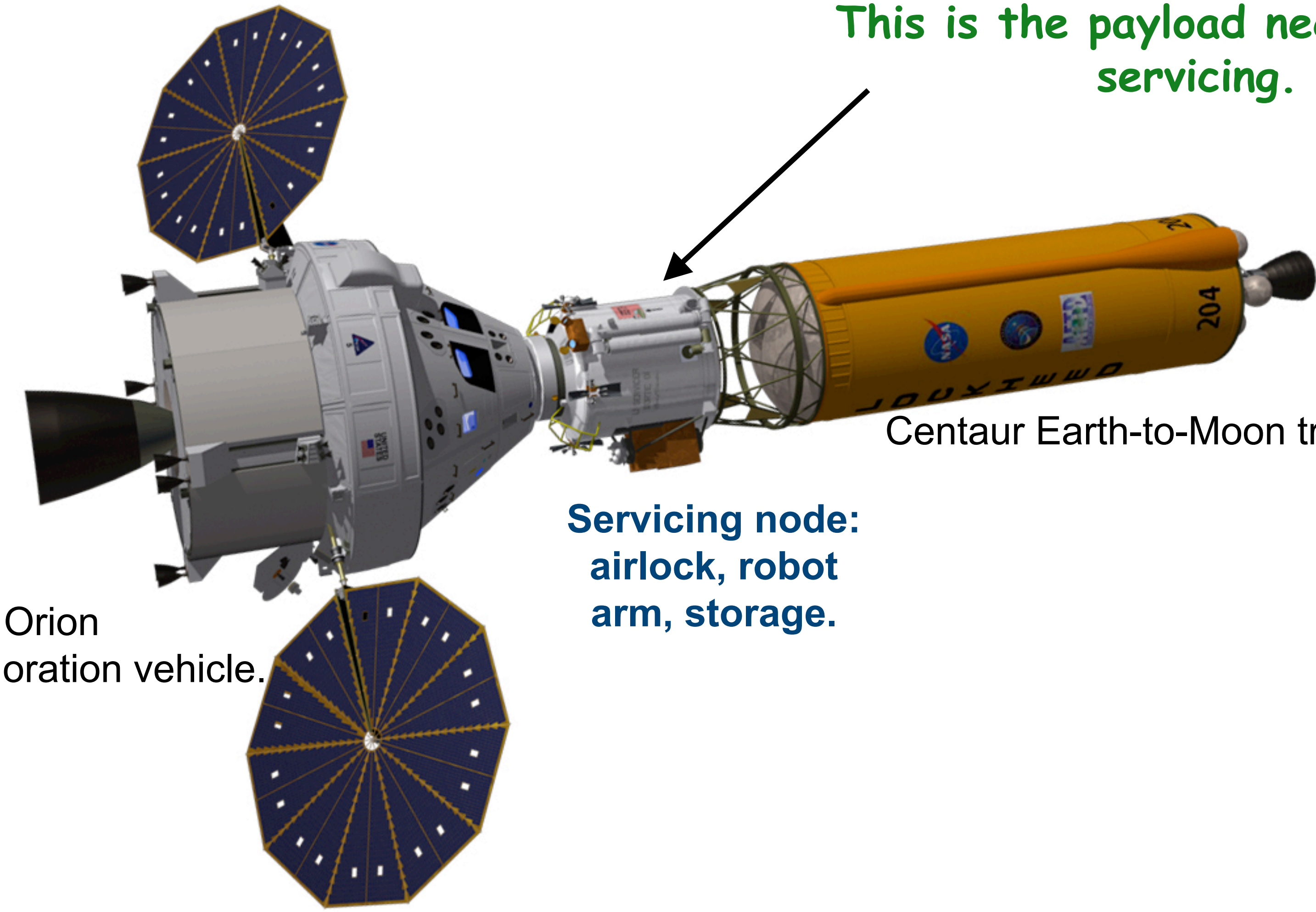
The libration points in the Sun-Earth-Moon system are (energetically) trivial to transfer among, which makes it very attractive to establish an astronaut/robot "jobsite" at E-M $L_{1,2}$.

Preliminary (2008) assessments of a handful of concepts for near-term application of elements of the Constellation architecture indicate that a pair of Ares I launches, one with a Centaur departure stage and the other with two astronauts in the Orion, is (barely) capable of reaching and operating at the E-M $L_{1,2}$ location using direct injection.

The capability to operate with astronauts and robots in free space builds upon almost a decade of successful assembly, servicing, upgrade . . . and appears to be an essential "stepping stone" for extended human operations beyond the Earth-Moon system.

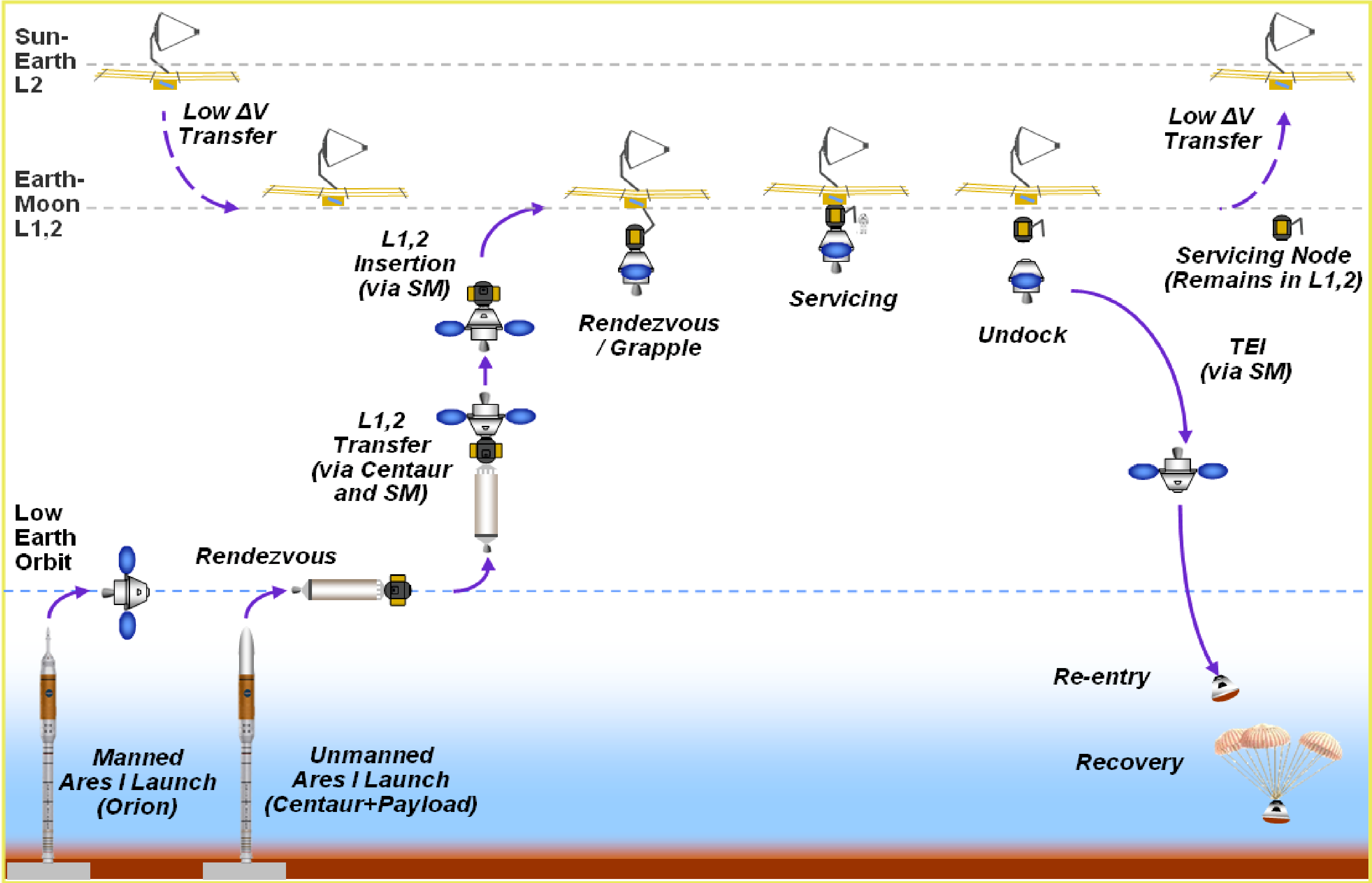
Basic Elements of An In-Space Servicing Capability at an E-M $L_{1,2}$ "jobsite" in the 2015+ Timeframe

[Thronson *et alia* 2008, IAC-08-A5.3.6]



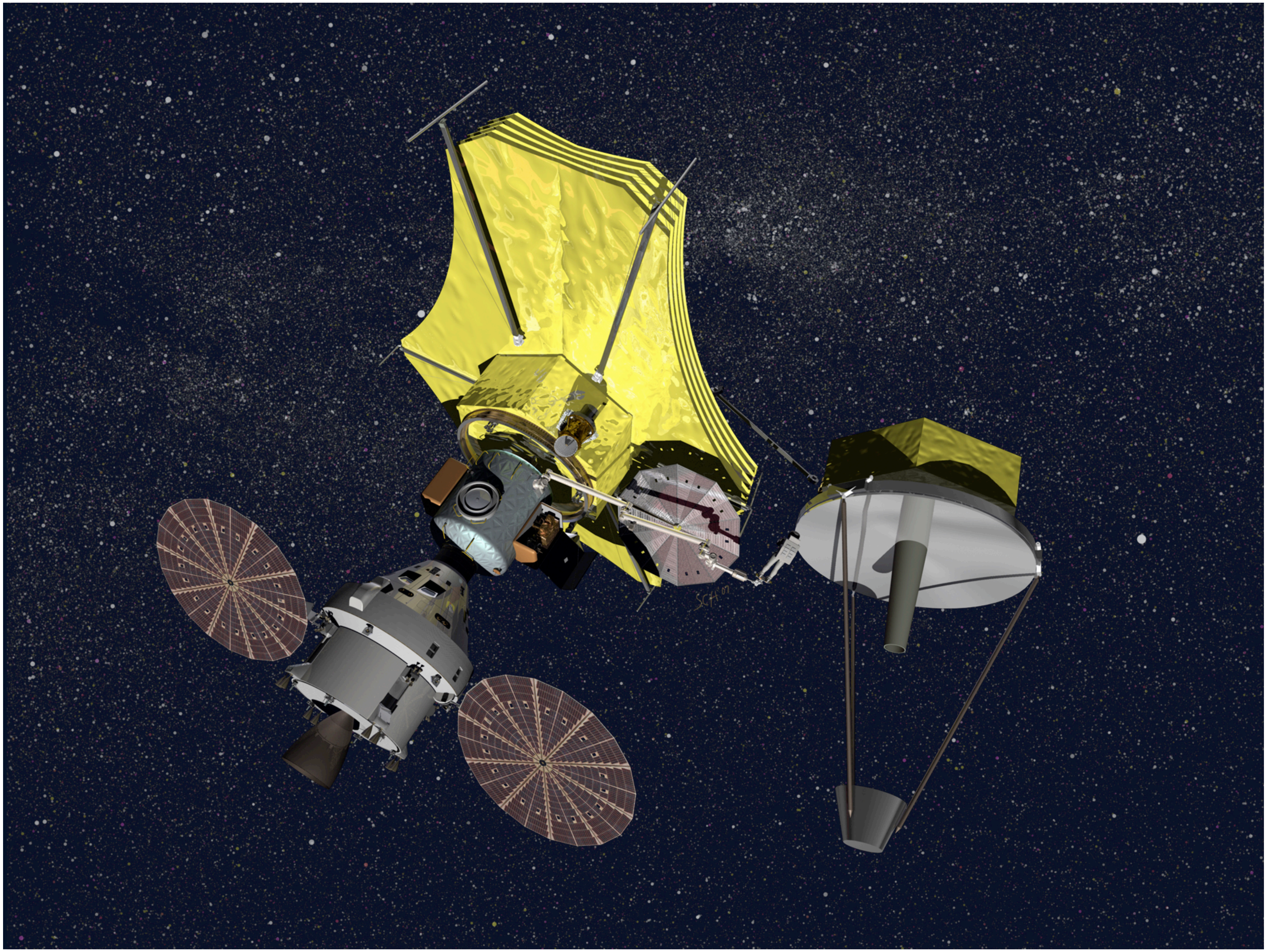
This Orion "stack" concept uses elements of the Constellation architecture intended to be developed within a decade. It appears at present to use the minimum number of elements necessary for 2 - 3 week operations throughout cis-lunar space.

Early Availability of Astronauts at Libration Points: Concept of Operations Using Cx Architecture (2008)



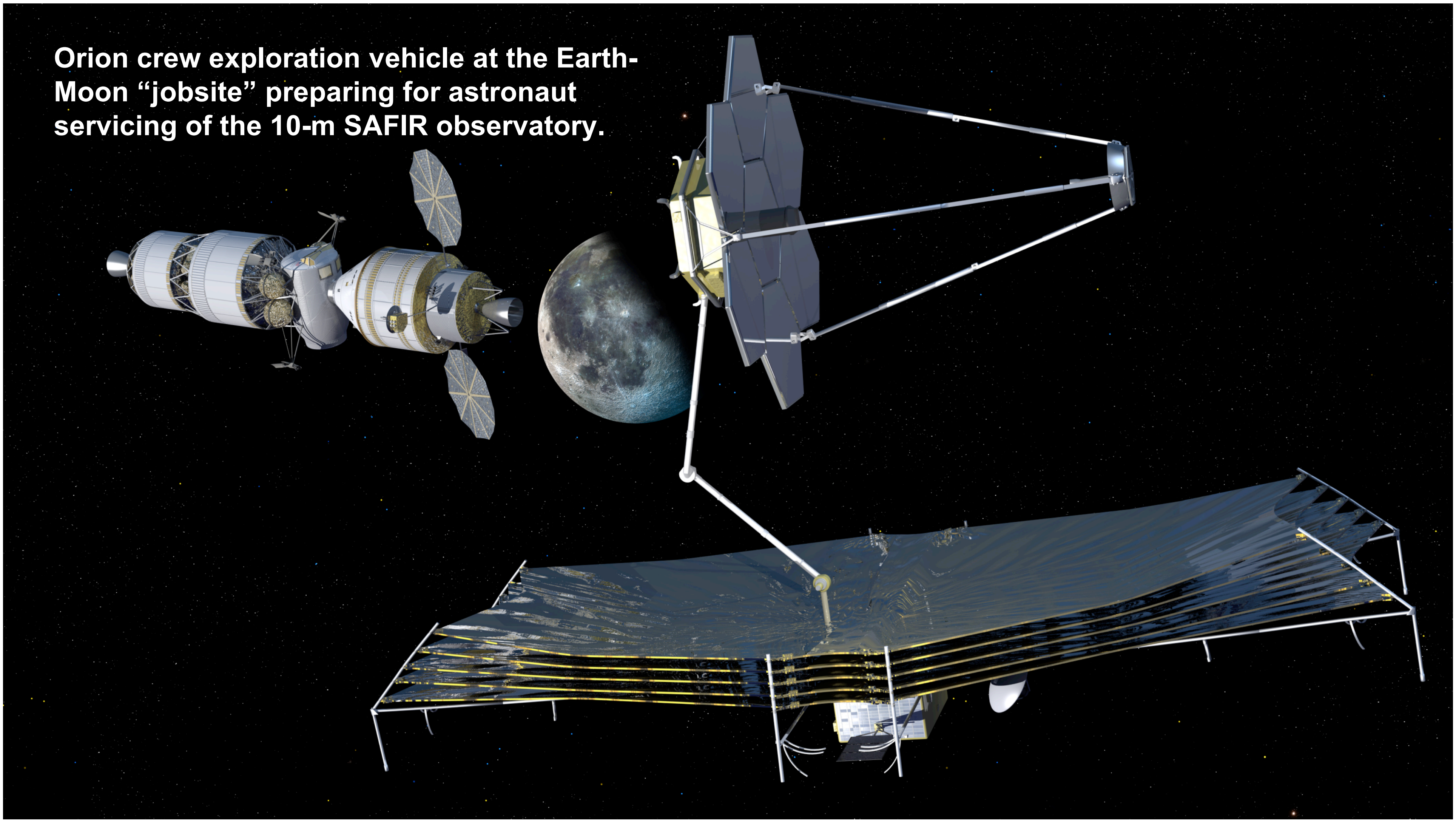
Ares I and Orion will be developed over the next half decade and, with a Centaur upper stage and airlock/servicing node, all of Earth-Moon space will be open to astronaut-based servicing as soon as about the middle of the next decade.

Baseline Concept: Orion/Servicing Node and SAFIR at EM L_1 (ca. 2020)



Key Question: Is there a Role for Multi-Billion Dollar "Throw-Away" Observatories in Astronomy's Future?

"It is dumb to launch complicated, expensive telescopes into space that cannot be serviced." **-- NASA Administrator Michael Griffin (Feb 2008)**



Orion crew exploration vehicle at the Earth-Moon "jobsite" preparing for astronaut servicing of the 10-m SAFIR observatory.

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References:

Recent lunar/free-space concept studies: ESMD-RQ-0005 *Lunar Architecture Focused Trade Study Final Report* 04 February 2005

Concepts for future space operations: http://www.futureinspaceoperations.com

Decade Planning Team/NASA Exploration Team space operations designs: http://history.nasa.gov/DPT/DPT.htm

ESA Architecture Trade Report (2008): ESA HQ Strategy and Architecture Office

ESA Aurora Program for human exploration: http://www.esa.int/SPECIALS/Aurora/

Recent Russian concepts for future human spaceflight: http://www.russianspaceweb.com/maks2009/index.htm