Earth-Moon L1 / L2 Infrastructure – What Role Does It Play?

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Human Exploration Community Workshop

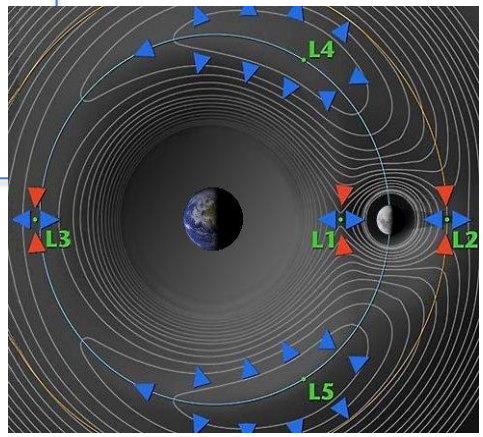
on the Global Exploration Roadmap

November 15, 2011

Some Context

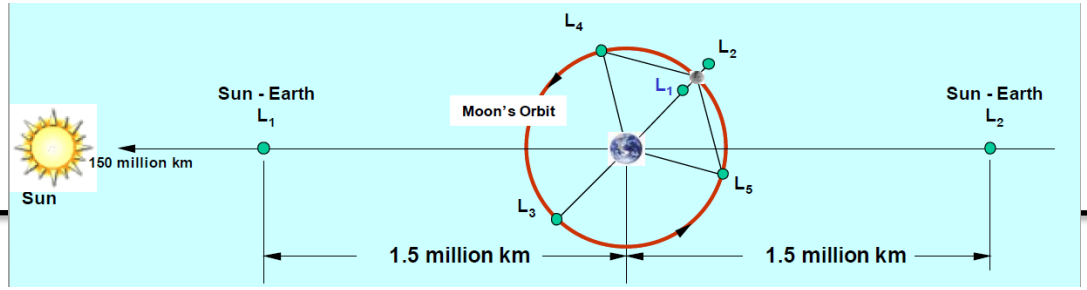
Cis-Lunar Destination

- Near-Earth Deep Space under gravitational influence of Earth-Moon system
- Volume between GEO & moon's orbit
  - Includes orbital locations: LEO, GEO, MEO, HEO, LLO
  - Libration / Lagrange Points: E-M L1, L2, L3, L4, L5



Cis-Lunar Destination Team Activities

- Notional crew + robot missions in cis-lunar space
- Requirements for mission support payload
- Robotic support capabilities
- Required technologies to enable cis-lunar missions
- *Identify activities associated with a facility at the E-M L1 or L2 libration points to serve as a "Stepping Stone" to BEO missions*
  - Focus = Human Space Exploration (HSE) crewed and uncrewed operations (2 weeks – long durations)
  - Extend HSE activities performed on ISS
  - Activities that benefit from E-M L1 / L2 Deep Space environment

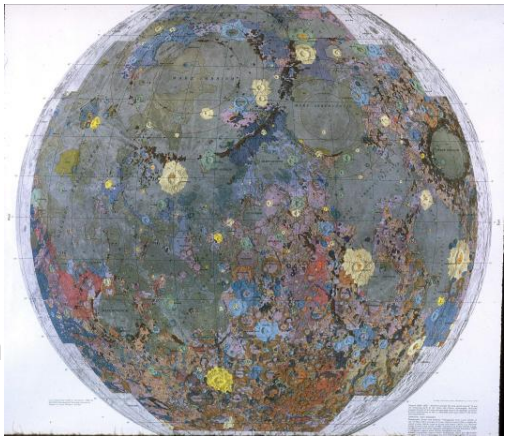


WHY Earth-Moon L1 or L2?

CHARACTERISTICS of OPERATIONAL INTEREST

- **Deep space location beyond Van Allen Belts**
  - **Demonstration & test site for long-duration HSE missions within easy return to Earth**
  - **For example, exploration vehicle systems, EVA systems and operations, autonomous mission operations, human + robot interactions, long-duration systems, radiation mitigation methods**

- **In "free space"**
  - **Avoids deep, expensive gravity wells of Earth and Moon**
  - **Avoids surface environmental issues (e.g., dust)**
  - **No hazard from artificial or natural space debris**
  - **Relatively low station-keeping propellant requirements**
  - **Travel between E-M L1 & L2 relatively easy**
  - **Travel among E-M and S-E libration points relatively easy**



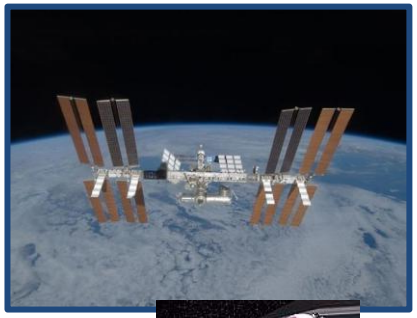
- **Supports near earth asteroid exploration**
  - **Early deployment of Deep Space Habitat to validate readiness for asteroid missions**
- **Supports lunar exploration**
  - **Easily reachable and accessible from Earth and Moon with minimum launch window constraints & low Delta-Vs**
- **Supports deep space science operations**
  - **Full view of Earth and Moon hemispheres**
  - **At E-M L2, tight halo orbit allows spacecraft to be within "radio quiet zone"**

E-M L1 / L2 FACILITY ACTIVITIES CATEGORIES IDENTIFIED

1) Develop & certify HSE deep space operational capabilities at location that offers ready Earth return
2) Serve as assembly point for large space structures
3) Conduct lunar support operations
4) Serve as off-Earth sample return quarantine & aggregation facility
5) Serve as initial node in HSE communications & navigation infrastructure
6) Serve as deep space node for international education & public outreach and media
7) Serve as a platform for science from unique L1 / L2 location

EARTH-MOON L1 / L2 FACILITY ACTIVITIES

1) Develop & certify HSE deep space operational capabilities at location that offers ready Earth return

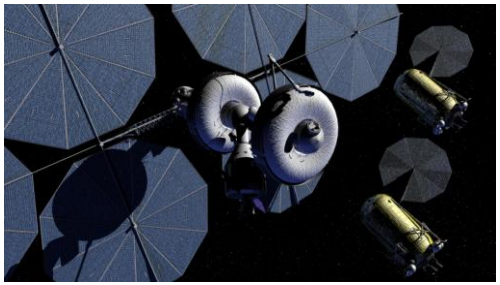


- L1 / L2 facility serves as first **"stepping stone beyond LEO"** to develop capabilities for missions beyond Earth-Moon system
  - Deep Space "high-fidelity" test & verification environment
  - Extends HSE research & technology development conducted on ISS
  - Verify countermeasures & technologies in operational environment prior to commissioning for 1st beyond-Earth HSE mission
  - Return from libration points to Earth is relatively easy (although not "anytime")
- Deep Space radiation biological effects & shielding materials / approaches
- Avionics / radiation shielding interaction & performance
- ECLSS reliability and performance
- Extend & certify crew autonomous mission operations
- Extend & certify crew + robotics operations
- Verify IVA robotics without crew present
- Verify & mature long duration crew medical care operations
- Test artificial gravity methods?
- Evaluate crew psychological health & performance far from Earth prior to 1st beyond-Earth HSE mission

EARTH-MOON L1 / L2 FACILITY ACTIVITIES

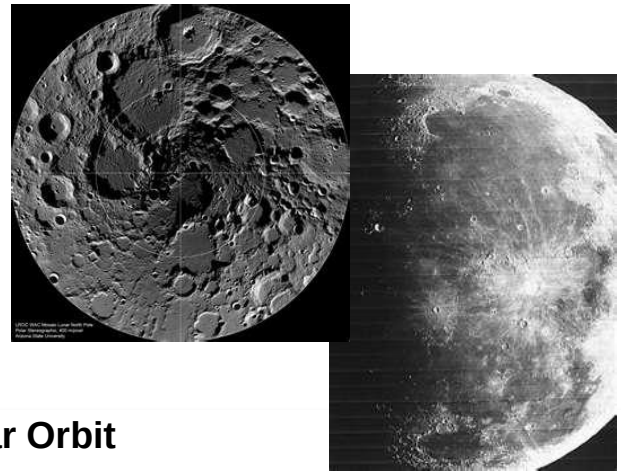
2) Serve as assembly point for large space structures

- Some of these operations would require in situ crew, others do not
- Operations could be conducted autonomously (via robotics) with crew oversight
- Potential large space structures
  - Observatory, multi-element habitat, free-flying instrument platforms, microgravity co-orbiter, deep space mission stack

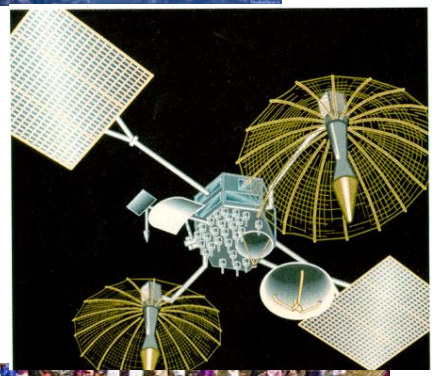


3) Conduct lunar support operations

- "Equal energy access" to entire lunar surface = no complex maneuvers (e.g., plane changes)
  - Dynamically, entire lunar surface is accessible from libration points – not the case from LLO
  - Velocities are such that it requires ~ 1 ½ days travel time from a libration point to lunar surface
- Perform Lunar exploration
  - Operate assets on lunar surface, including lunar farside from L2
  - Could teleoperate multiple rovers with very low latency
  - Nearly entire lunar hemisphere visible from E-M libration point
- Serve as:
  - Supply depot for human lunar surface operations
  - "Way station" to aggregate assets on the way to lunar surface
  - Lunar safe haven during abort from lunar surface
- Deploy spacecraft or instrument packages or rovers to Low Lunar Orbit



EARTH-MOON L1 / L2 FACILITY ACTIVITIES



4) Off-Earth sample return quarantine & aggregation facility

- "Off-Earth" facility for lunar, Mars, NEO, cometary dust, samples
  - Safe place for Mars samples for Planetary Protection
- Sample canister autonomous rendezvous & dock with L1 / L2 facility
- Aggregation & phased sample return to Earth

5) Node in HSE communications & navigation infrastructure

- Facility serves as communications / navigation relay
- Comm/nav asset @L2 would provide lunar farside access

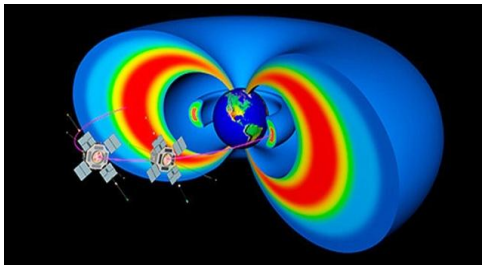
6) Deep space node for int'l education / public outreach & media

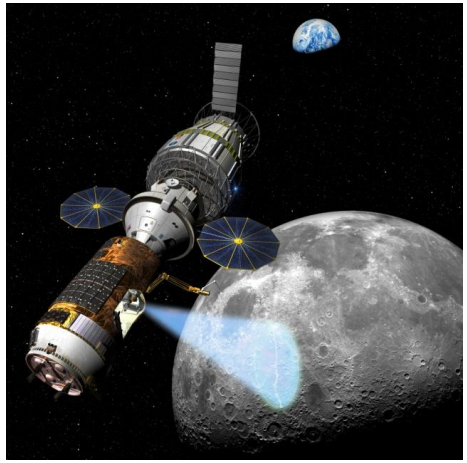
- IV & EV cameras provide live streaming on web 365/24/7
- Supports Global educational programs and media 24/7
  - E.g., Students on Earth could control lunar rovers through the L1 / L2 Relay Station
- Shares Human Space Exploration globally to people on Earth
  - Includes International / Global Stakeholder community
  - Serves as Earth's "foothold" in Deep Space – Humanity's first steps "off-Earth" into deep space

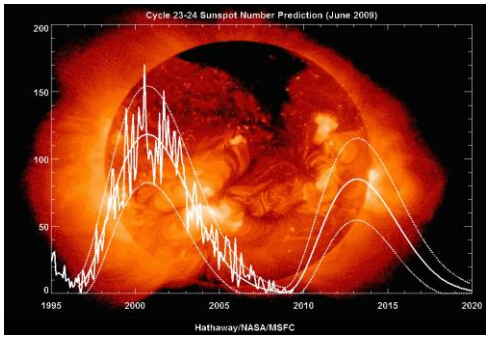
EARTH-MOON L1 / L2 FACILITY ACTIVITIES

7) Platform for science from unique L1 or L2 location

- Libration point facility operating as a site for autonomous "tag along" experiments
- Earth & Atmospheric Science: Climate, magnetic mapping, "Whole Earth" view
- Heliophysics
  - Fast Plasma and coronal heating @ L1
  - Solar wind & magnetotail
  - Solar coronal characterization @L2
- Astronomy & Astrophysics
  - Deep Space Observations
  - All-Sky X-Ray Survey
  - Radio Astronomy (within L2 quiet zone)
- Exoplanets
  - Small attached survey telescope to detect occultations as targets for subsequent in-depth study
- Fundamental Physics
  - Combustion, complex fluids, microphysics
- Materials science
  - LDEF-type measures
  - Radiation shielding
- Human health & performance
  - Radiation biological effects using Tissue Equivalent Materials
  - Crew physiological monitoring during crewed periods
  - Combined effects of microgravity & radiation
  - Psychological and Behavioral Health: isolation, distance from Earth, blocked Earth view







NOTE: International Telecommunications Union (ITU) regulation prohibits harmful interference to radio astronomy. Strategies to meet this requirement while stationing a facility at E-M L2 are under consideration.

SUMMARY: Earth-Moon L1 / L2 Infrastructure – What Role Does It Play?

- **Identified crewed & uncrewed activities that could be conducted at a facility based @ E-M L1 or L2**
  - **Focus on HSE activities – extend HSE activities performed on ISS**
  - **Begin with 2-week crew mission, build to longer durations**

- **Identified E-M L1 & L2 characteristics of interest**
  - **Deep space location beyond Van Allen Belts**
  - **In "free space"**
  - **Supports lunar exploration**
  - **Supports deep space science operations**

- **Identified seven primary activities to be conducted at an E-M L1 / L2 facility**
  - **Develop & certify HSE deep space operational capabilities**
  - **Assemble large space structures**
  - **Conduct lunar support operations**
  - **Serve as:**
    - **Off-Earth sample return quarantine & aggregation facility**
    - **Node in HSE communications & navigation infrastructure**
    - **Node for international education & public outreach and media**
    - **Platform for science**

HERITAGE: Selected References on Operations at Earth-Moon L1/L2

- Selected works on "future in-space operations" concepts: http://www.futureinspaceoperations.com
- Past presentations: "In-Space Operations" colloquia: http://spirit.as.utexas.edu/~fiso/telecon.htm
- Archived documents from the Decade Planning Team (DPT): http://history.nasa.gov/DPT/DPT.htm
  - *Notably: Decade Planning Team JSC 2001 "Gateway" architecture* (EX15-001-01)
- Selected reports on human habitation and operations at libration points (chronological order):
  - *The Utilization of Halo Orbits in Advanced Lunar Operations. NASA TN D-6365* (1971)
  - *Site Selection and Deployment Scenarios for Servicing of Deep-Space Observatories*. IEEE 0-7803-7231-X (2001)
  - *Conceptual Design of a Lunar L1 Gateway Outpost.* IAC-02-IAA.13.2.04 (2002)
  - *Utilization of Libration Points for Human Exploration in the Sun-Earth-Moon System and Beyond.* IAC-03-IAA.13.2.03 (2003)
  - *Strategies for Servicing the Single Aperture Far IR (SAFIR) Telescope.* SPIE 5899-21 (2005)
  - *Destinations for Exploration: More than Just Rocks? Space Review.* (July 16, 2007)
  - *Using NASA's Constellation Architecture to Achieve Major Science Goals in Free Space*. IAC-08-A5.3.6 (2008)
  - *The "Flexible Path" from The Review of US Human Space Flight Plans ("The Augustine Committee").* http://www.nasa.gov/offices/hsf/home/index.html
  - *First Stop for Flexible Path?* Space Review (November 30, 2009)
  - *Review of US Concepts for Post-ISS Space Habitation Facilities and Future Operations*. AIAA Space 2010; #818583 (2010)
  - *Human Space Exploration and Human Space Flight: Latency and Cognitive Scale of the Universe*. Space Policy (May, 2011)
  - *Human Operations Beyond LEO by the End of the Decade: An Affordable Near-Term "Stepping Stone*." Space Review (2011). http://www.thespacereview.com/article/1756/1