National Aeronautics and Space Administration

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ESC Exploration & SPACE Communications

More than you ever imagined...

Operations of the Optical Communications Demonstration for the Orion EM-2 mission

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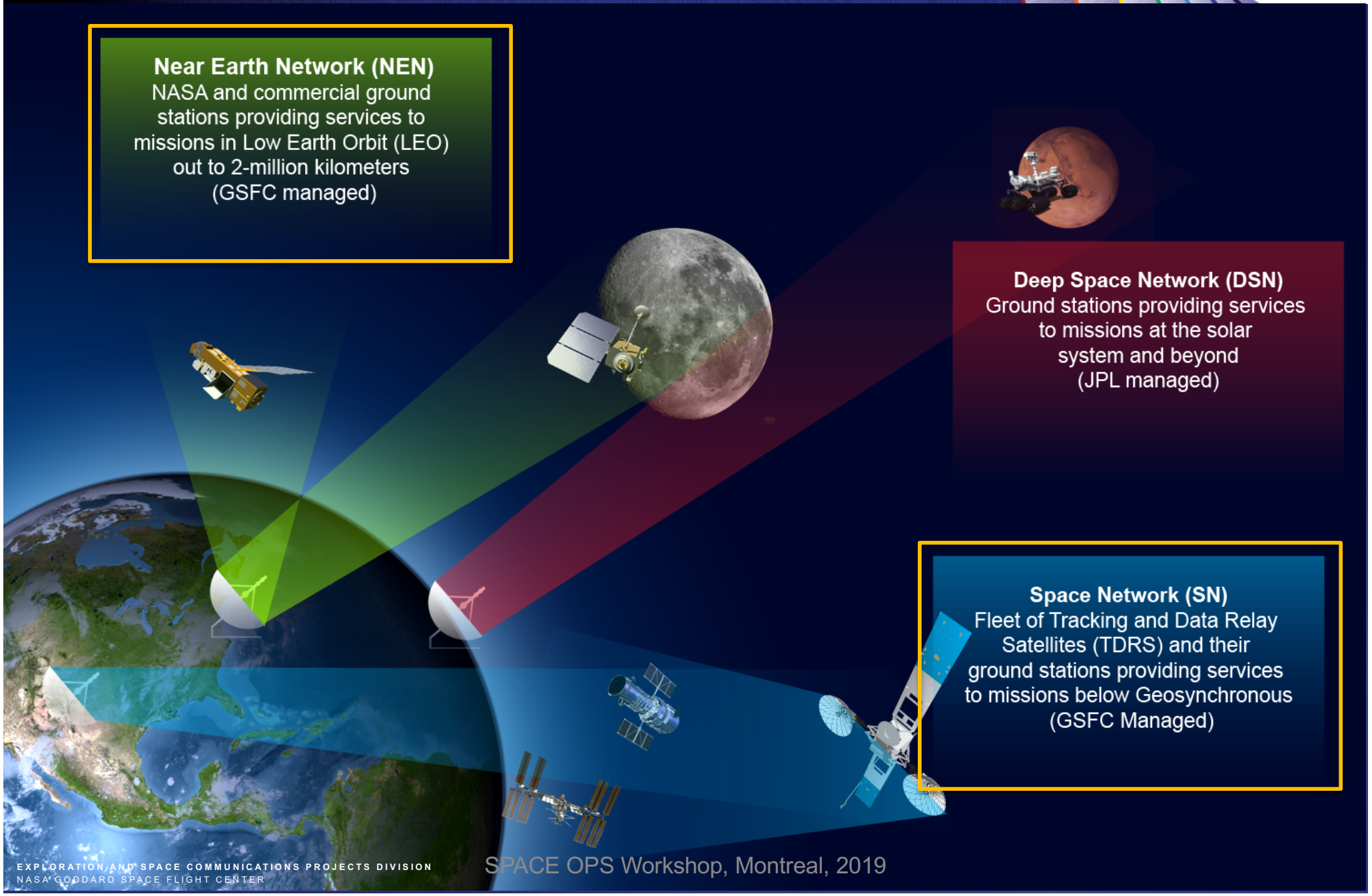
Outline

- Overview
- Space Network Services
- Current Space Network Ground Terminals

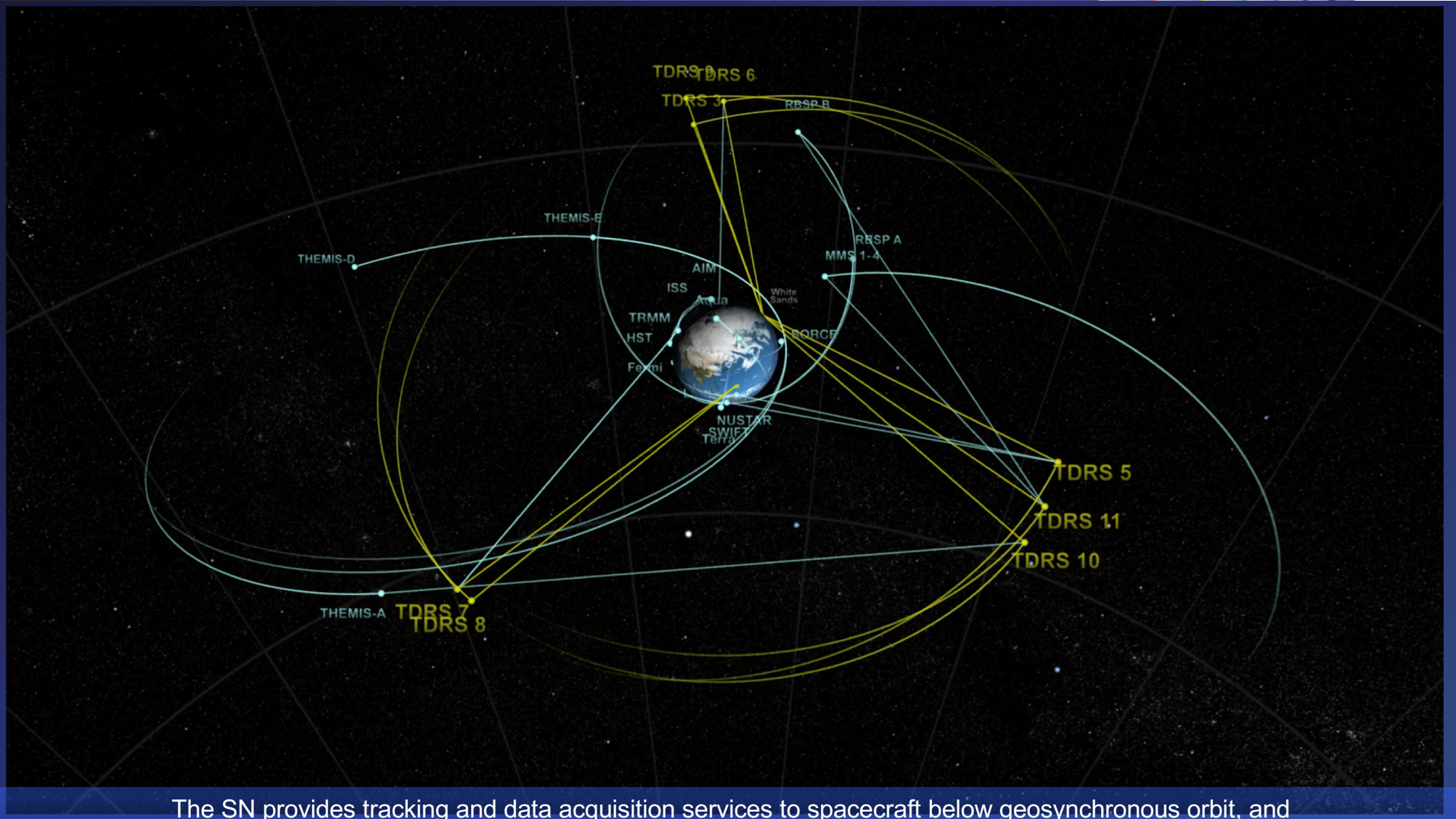
- Conclusion

NASA's Space Communications Networks:

Three networks: NEN, SN, DSN



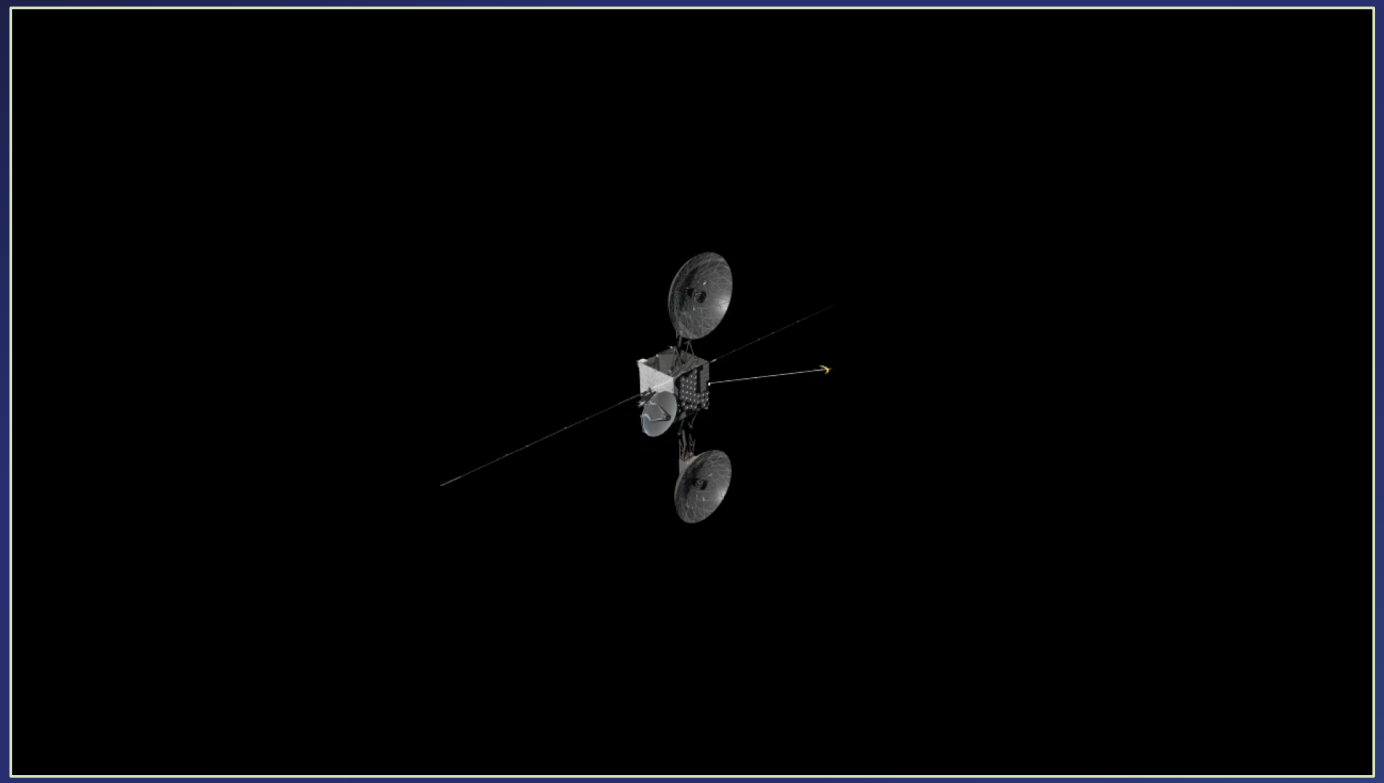
Space Network (SN)



The SN provides tracking and data acquisition services to spacecraft below geosynchronous orbit, and can connect customer spacecraft with **100% coverage of the customer's orbit**.

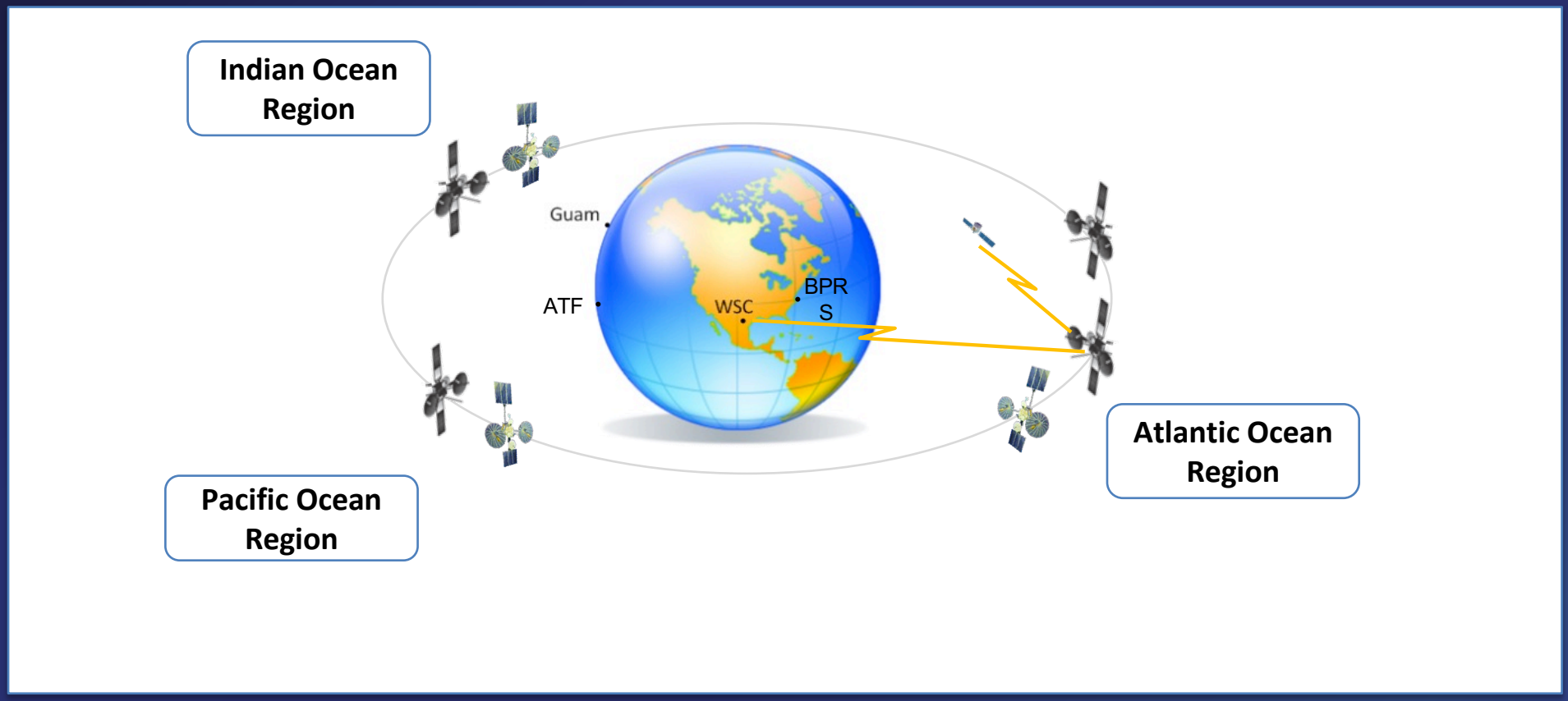
Tracking and Data Relay Satellites

The SN uses a constellation of satellites called TDRS to cover all types of space communications below geosynchronous orbit, including expendable launch vehicles and high-altitude platforms.



Space Network

The Space Network (SN) is a bent pipe data communication system comprised of a constellation of geosynchronous Tracking and Data Relay Satellites (TDRS) and a network of geographically diverse ground terminals.



The SN provides nearly 8 million minutes of S/Ku/Ka-band communications services per year.

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Optical Ground Station

The Lunar Laser Communications Demonstration Ground Terminal (LLGT) was built for supporting a short mission.

Two ground terminals:

- The LLGT at the White Sands Complex supported uplink and downlink: 622 Mbps downlink rates achieved from LADEE in orbit around the Moon. (~0.5W optical transmit power from the space terminal.)
  - LLGT had four 40-cm.-diameter receive telescopes and four 15-cm. transmit telescopes, each transmitting a 10-Watt uplink signal.
- The OCTL ground terminal supported downlink only: Transmit beacon only; no uplink communications.
  - OCTL used a single 1-meter telescope for receive and beacon transmission.

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LCRD Ground Terminals

- The Laser Communications Relay Demonstration (LCRD) allows relay of data between ground terminals at 1 Gbps data rates via a relay terminal at geosynchronous orbit.
- Due to the DPSK format, the ground terminals require adaptive optics.
- Ground terminals will be located at Haleakala and at the OCTL.
- With the addition of the ILLUMA terminal, LCRD will also relay data from the ISS to ground.

Exploration Missions

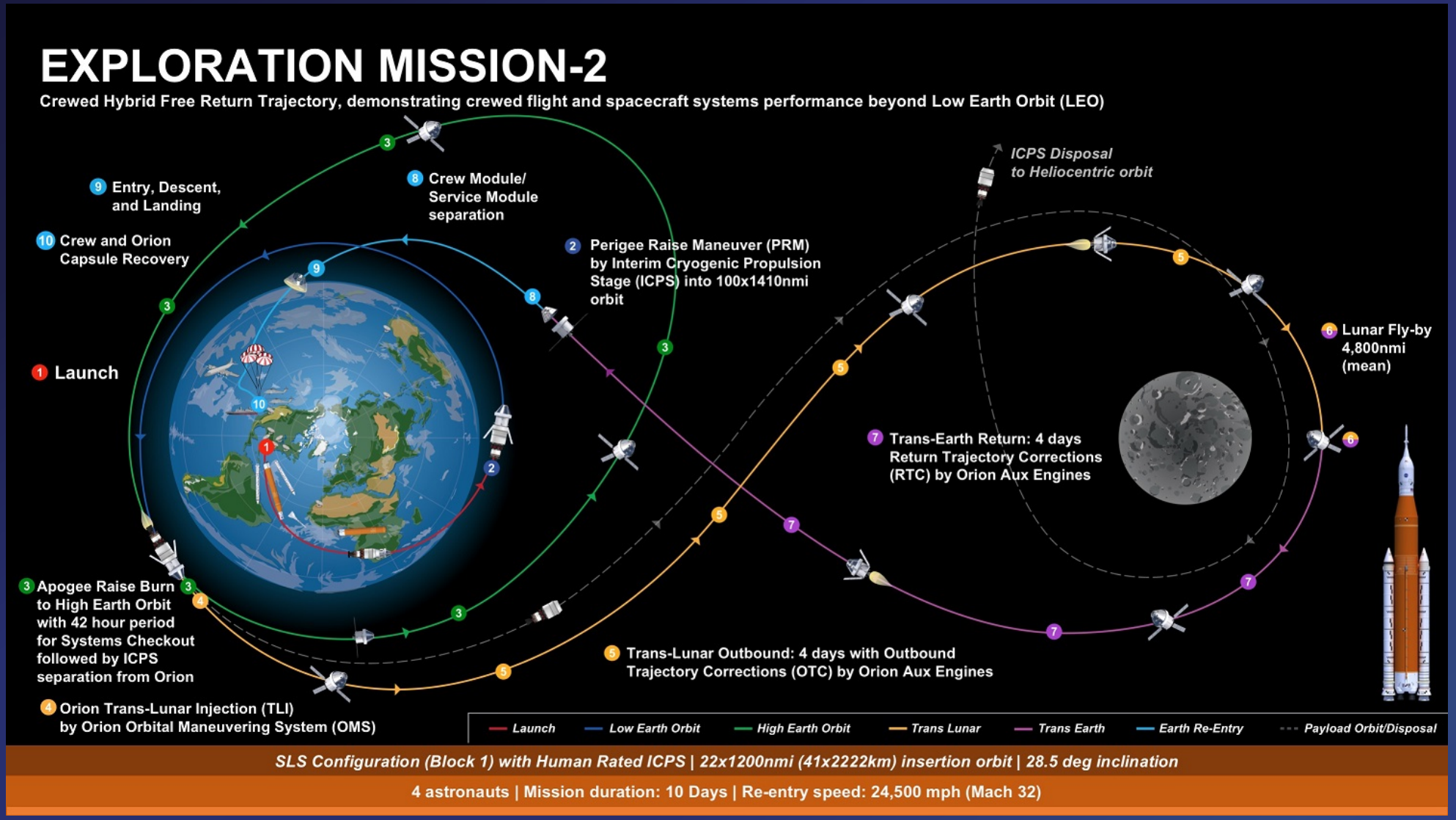
NASA's Orion spacecraft is an exploratory vehicle designed for longer-duration flights beyond the Moon.

Exploration Mission-1 (EM-1):
Orion spacecraft will travel beyond the Moon, enter a distant retrograde orbit around the Moon and return to Earth unmanned

Exploration Mission-2 (EM-2):
First crewed test flight of the Orion spacecraft, currently targeting a June 30, 2022 launch. EM-2 will see a crewed spacecraft complete a slightly different flight path. The mission involves:

- One revolution in Low Earth Orbit (LEO) parking orbit to verify basic Orion systems functionality and deploy solar arrays.
- A single 42-hour Highly Elliptical Orbit (HEO) intermediate checkout orbit allows characterization of the Orion vehicle system performance prior to committing to a cis-lunar flight.
- Trans Lunar Injection (TLI) burn using Orion Service Module (SM) main engine, which sends Orion on a lunar flyby and free return.
- Skip reentry at lunar return velocities to splashdown off the coast of San Diego.

EM-2 Mission Profile



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The Operational Utility for Exploration Missions

- EM-2 is the first crewed mission of the Orion Spacecraft
  - Flying a crew puts more demand on ability to move data on/off the vehicle
    - Real time HD video downlinks, file transfers, 2-way video conferences
  - Flying a crew also makes for “noisier” spacecraft
    - Crew exercise, thruster based attitude management, numerous venting sources

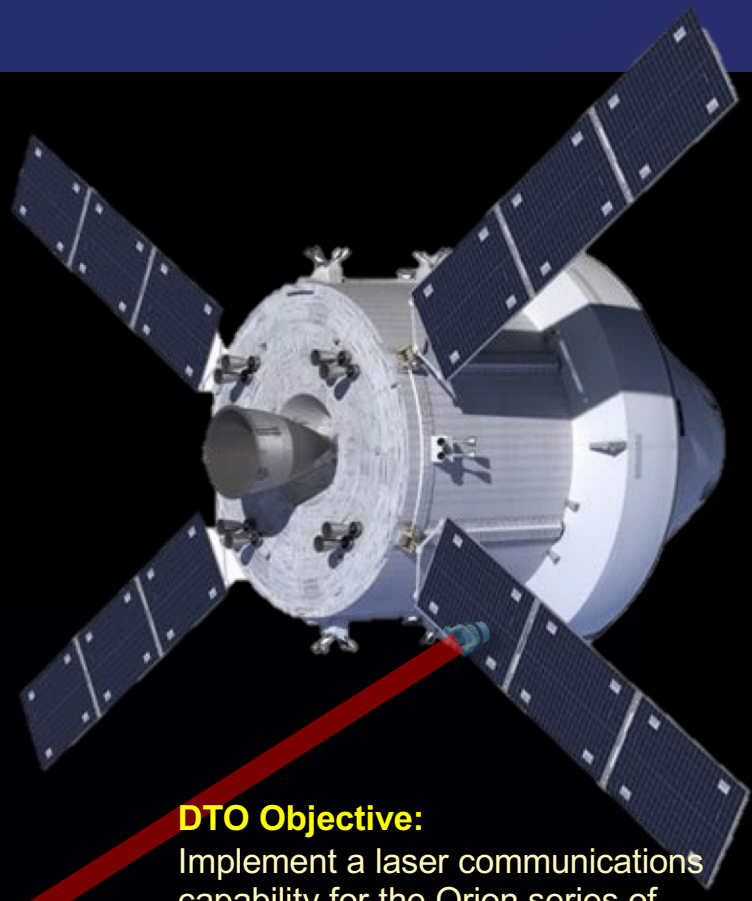
- O2O is a demonstration of operational utility fo extensibility to future missions
  - E.G. can optical achieve similar or better performance to a traditional RF-based high rate comm system on human spacecraft mission?

Orion Storage and Bandwidth

- Orion subsystems (video, DFI, etc) expected to generate ~250 GB of data in the first 24 hours of flight
  - Total data generated over the mission estimated to be more than 400 GB
- Using S-Band alone, Orion limited to ~ 6GB of data downlink per day
  - Because of this limitation, Orion is planning to limit live video downlinks on EM-1 in order to downlink high priority files
- With 1 hour/day of Optical Comm, Orion could downlink ~6x more data per day (~ 36GB/day)

EM-2 DTO Mission Objectives

1. Implement an Optical Comm System to plan and demonstrate an operational optical comm link for Orion EM-2
2. Maintain a development path to a fully operational Optical Comm System
3. Flow data from Orion through the Optical Comm Fight Terminal to the Optical Comm Ground Terminal
4. Flow data from Optical Comm Ground Terminal to Optical Comm Flight Terminal and forward to Orion
5. Distribute data to/from Orion MCC realtime or store and distribute later
6. Flight terminal conforms to the Orion accommodations, mission objectives, and environments
7. Ground terminal and data system developed using operational interfaces



DTO Objective:
Implement a laser communications capability for the Orion series of spacecraft, starting with EM-2, in order to enhance its operational utility

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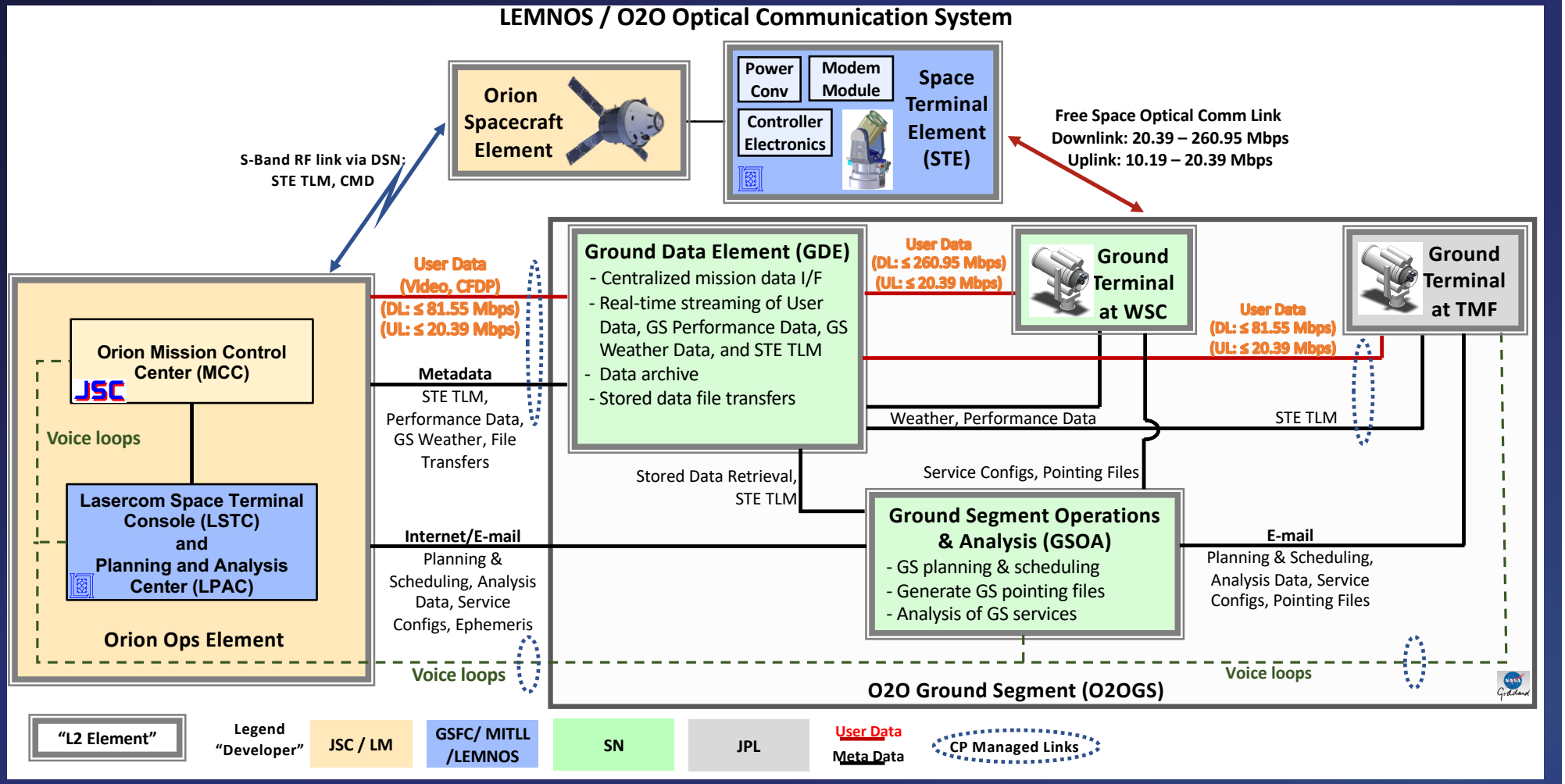
Goddard Space Flight Goals

- Implement an Optical Communication System to plan and demonstrate an operational optical communication link for Orion EM-2
  - this will be a base for providing an operational optical communications capability for future Orion missions
- Maintain a development path for the optical communication flight terminal
  - to allow commercialization and implementation on future Orion missions
- flow data from Orion through the Optical Communication Fight Terminal to the Optical Communication Ground Terminal and reverse
  - Due to the fact that Orion optical module part of the optical communications flight terminal and its control electronics have a common architecture with the ILLUMA-T optical terminal provided by GSFC for use on the ISS.

Requirements

- The optical communication system is capable of multiple data rates up to at least 80 Mbps downlink for the transfer of Orion data to Earth while Orion is operating in the Lunar vicinity.
- The optical communication links will operate in the 1550 nm wavelength range and use high efficiency signaling that is compatible with future deep space missions.
- The optical communication system is capable of multiple data rates up to 20 Mbps uplink for the transfer of data to Orion from Earth while Orion is operating in the Lunar vicinity.
- Orion data will be transferred to/from the MCC via operational links from the Ground Network Data Distribution System.
  - This System is capable of delivering data to the MCC in near real time and storing data for later transmission.
- The optical communications system is planned to be operated for a minimum of 60 min per day.
  - Link availability will be determined by atmospheric conditions at the ground station(s) and other system constraints, including EM-2 operations and ground network constraints.
- Ground terminal and data system developed using operational interfaces.
- The downlinked Orion data will be delivered to the Orion MCC at JSC where the Orion Laser Space Terminal Operator Console will be collocated.

Mission Level Architecture Diagram



Metrics for Meeting O2O DTO Objectives

Implement a laser communications capability for the Orion series of spacecraft, starting with EM-2, in order to enhance its operational utility

Objectives for Demonstrating "Operational Utility:"

1. Transfer Files from MCC to/from Orion
- Single small and large files
- Multiple contiguous files

Examples:
- PDF files: Crew Files, Local News and Sports
- Email, Word
- Recorded Data: DFI
- Procedures (non secure)
- Op Nav Files
- Recorded Video Files
- JPEG: Recorded Pictures

2. Transfer Real time Video Downlink to MCC
- Single SD and HD
- Multiple video

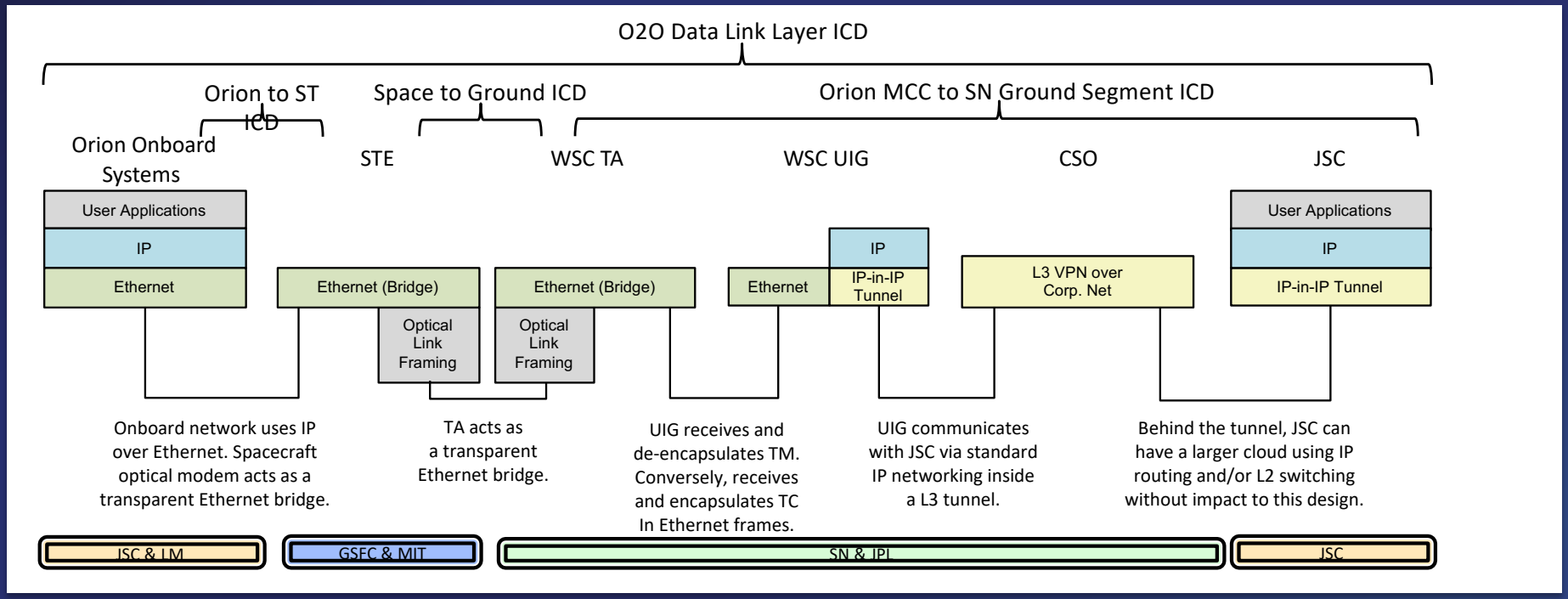
Examples:
- Solar Array Wing Cameras
- Op Nav Video?
- CMA High Rate Cameras HD
- Crew Cabin Cameras (GOPRO Preview)
- Video Conference

3. Utilize operational performance envelope
- Single small and large files
- Multiple contiguous files

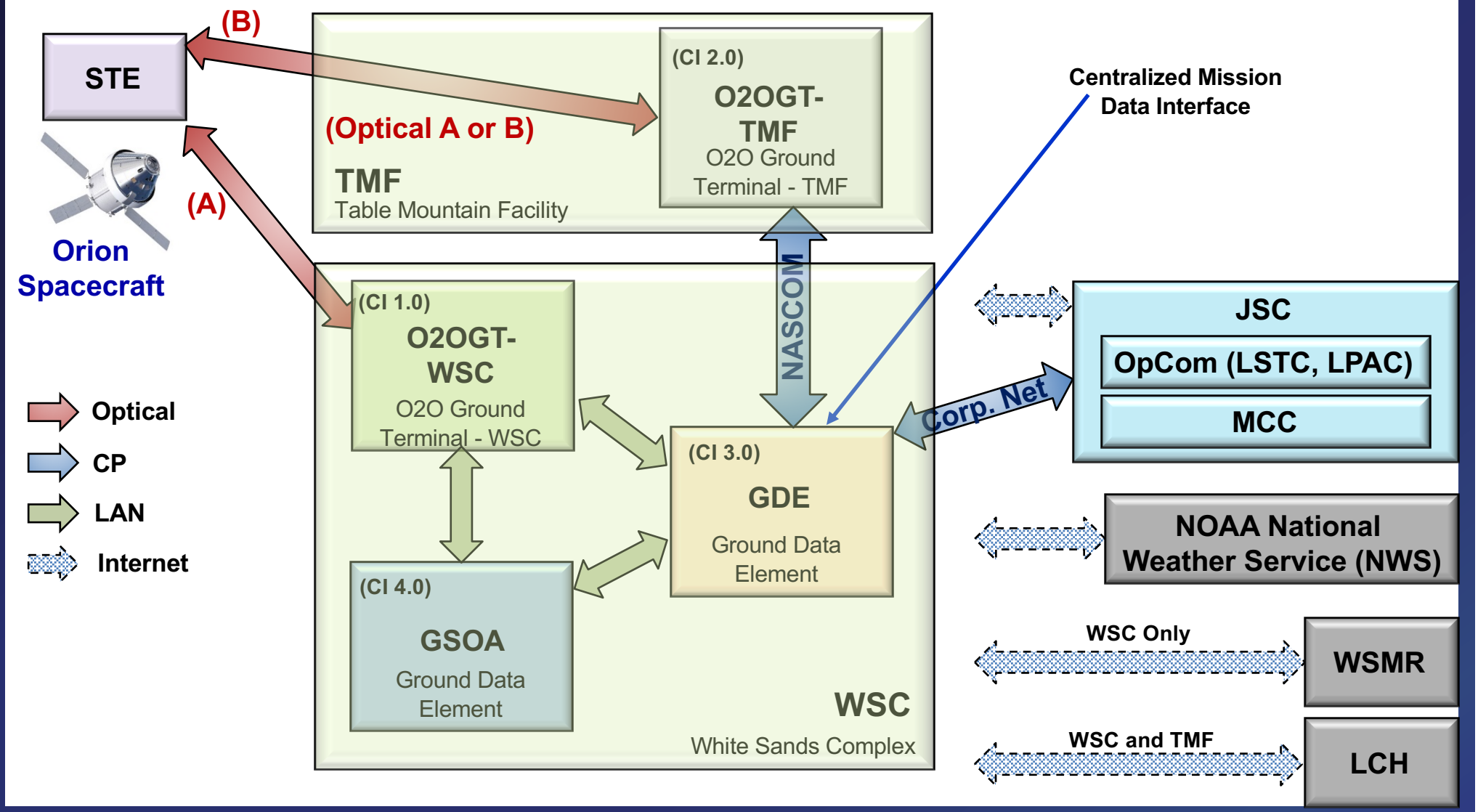
Examples:
- Ground Low/High Elev, Day/Night passes
- Acq/Track during with vehicle dynamics
  - Solar array track/step/slew
  - Crew activity/exercise
  - Thruster firing impulse
- Vehicle body rates, slew deg/min to deg/sec
- Link margin vs. data rate, interleaver
- Atmospheric effects (weather, clouds)
- Handover to backup ground terminal
- Thermal performance
- Thruster contamination effects

End to End Data Flow

- The figure below shows the end-to-end optical communications data flow used to transmit and receive data files and real time video
- Shared development JSC, MIT, O2O/GSFC, and SN
- The Space to Ground ICD Defines the Optical Link Signaling and Performance Parameters (Section n), Orion MCC to Ground Segment ICD (Section n)



O2O Ground Segment Overview



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Key Functions of the O2OGS Elements

- CI 1.0 O2O Ground Terminal – White Sands Complex (O2OGT-WSC)
  - Ground terminal for full-duplex optical communication with the Space Segment
  - Host the LAN that interconnects O2OGT-WSC, GSOA, and GDE.
  - Centralized M&C for O2OGT-WSC, GSOA, and GDE

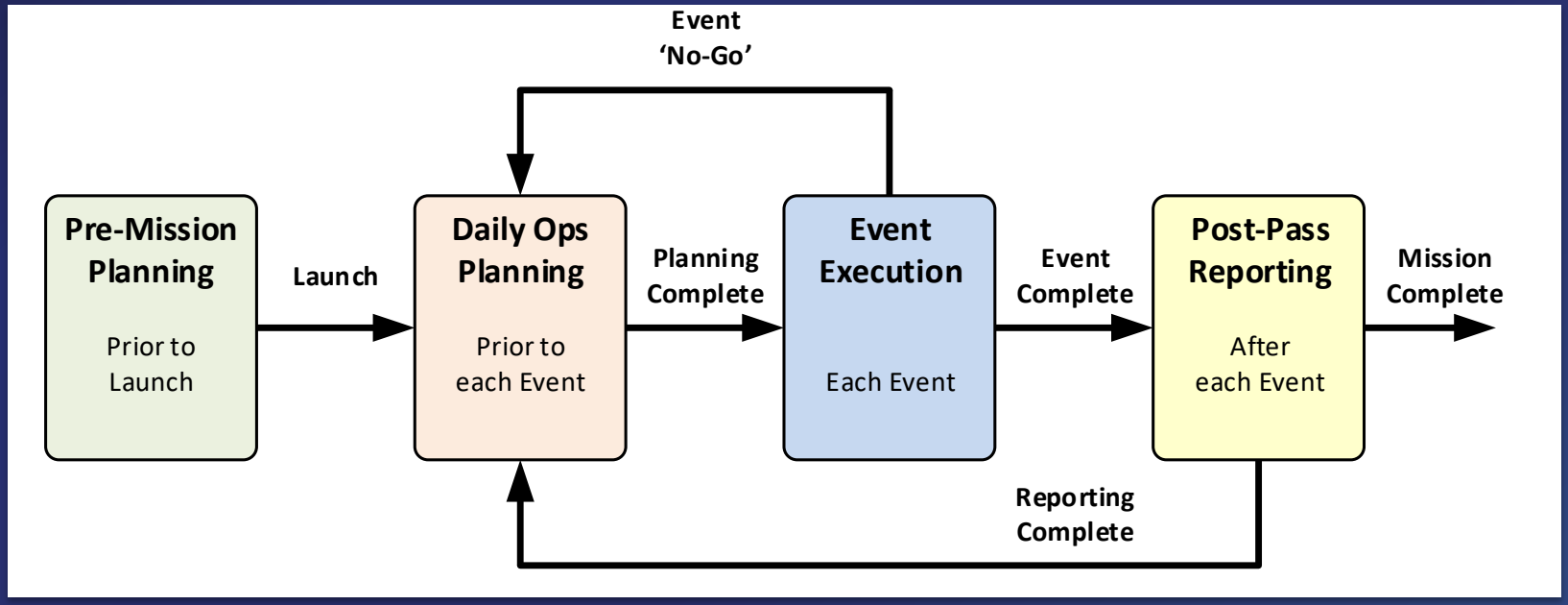
- CI 2.0 O2O Ground Terminal – Table Mountain Facility (O2OGT-TMF)
  - Ground terminal for full-duplex optical communication with the Space Segment
  - Provide inputs to GSOA for ground segment planning and scheduling.
  - Analyze GT performance for passes supported by O2OGT-TMF.

- CI 3.0 Ground Data Element (GDE)
  - Store all user data, ground segment performance data, health & status data, ground segment weather data, STE telemetry, Time of Flight data, mission ephemeris, and ground pointing files.
  - Provide a centralized mission data interface to JSC and to each ground terminal

- CI 4.0 Ground Segment Operations and Analysis (GSOA)
  - Centralized coordination of ground segment planning, scheduling, and operations
  - Coordinate with MCC, O2O Ops, O2OGT-TMF, LCH, and WSMR.
  - Operate GDE and O2OGT-WSC.
  - Analyze GT performance for passes supported by O2OGT-WSC.
  - Monitor and display STE and Ground Segment performance, weather, and health & status data.

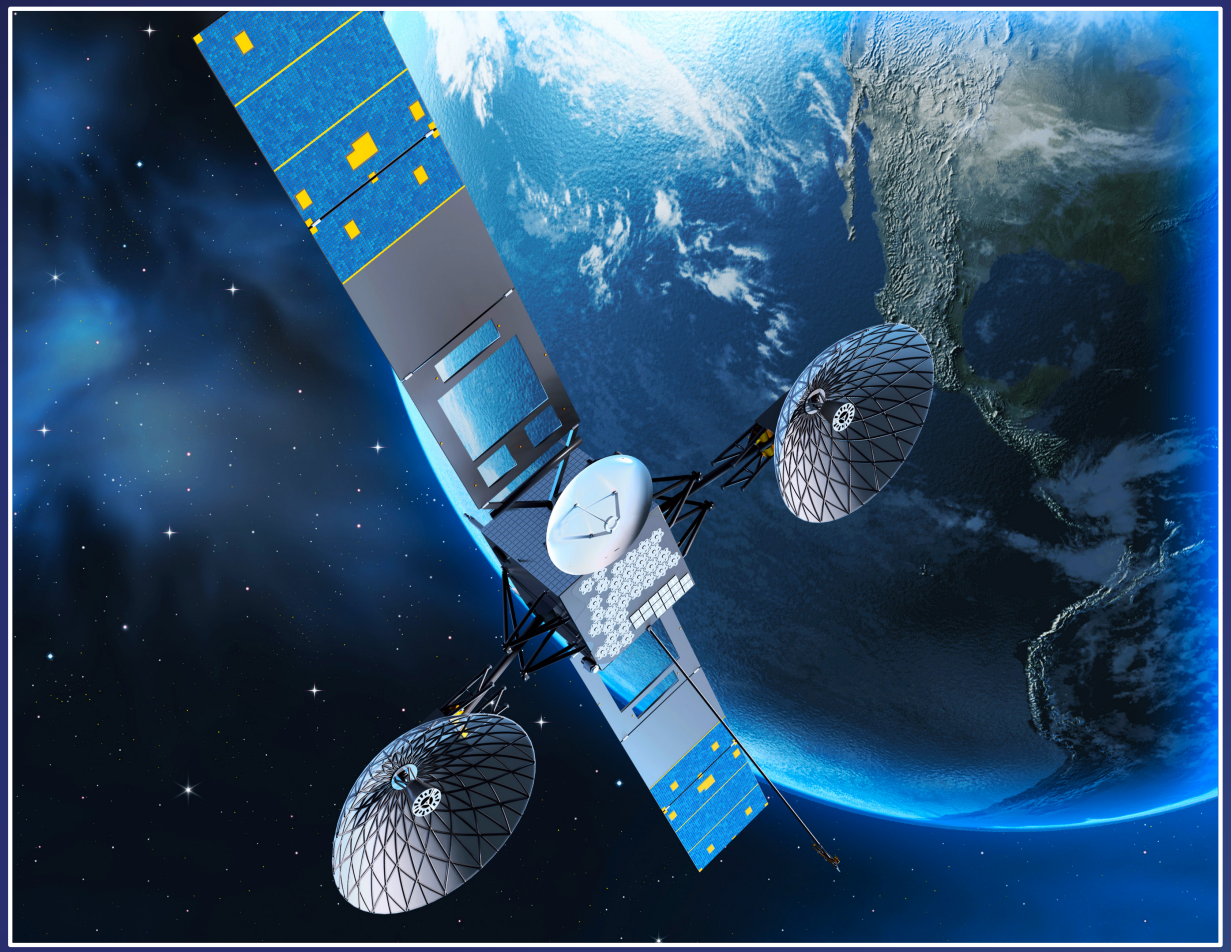
O2OGS Support Phases

- Pre-Mission Planning Phase ('Launch – 180 days' to 'Launch – 24 hrs.)
  - Activity Plan development, analysis & modeling to drive Activity Plan, LCH coordination, etc.
- Daily Ops Planning Phase ('Event Start – 24 hrs.' to 'Event Start – 1.5 hrs.)
  - Daily tag-up meeting, revise Activity Plan, weather monitoring, initial GT selection, etc.
- Event Execution Phase ('Event Start – 1.5 hrs.' to 'Event End + several mins')
  - Equipment configuration, updated GT selection as necessary due to inclement weather, go/no-go decision, monitoring of ground segment performance, health and status, weather and STE TLM, user data flows, etc.
- Post-Pass Reporting Phase ('Event End + several mins' to 'Event End + several hrs.')
  - Post-pass de-brief, performance assessments, etc.



Conclusions

NASA/GSFC continues to work toward the goal of extending Optical services to the Space community.



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Acronym List

- DAS: Demand Access System
- DSN: Deep Space Network
- EIRP: Effective Isotropic Radiated Power
- GEO: Geosynchronous Orbit
- GSFC: Goddard Space Flight Center
- GRGT: Guam Remote Ground Station
- ISAAC: Integrated Solar Array Antenna for CubeSats
- LCRD: Laser Communications Relay Demonstration
- LEO: Low Earth Orbit
- LLGT: Lunar Laser Communications Demonstration Ground Terminal
- NEN: Near Earth Network
- MA : Multiple Access
- SA: Single Access
- SN: Space Network
- SSPA: Solid-State Power Amplifier
- TDRS: Tracking and Data Relay Satellites
- WSC: White Sand Complex