Navigation Concepts for NASA's Constellation Program and Human Missions to the Moon

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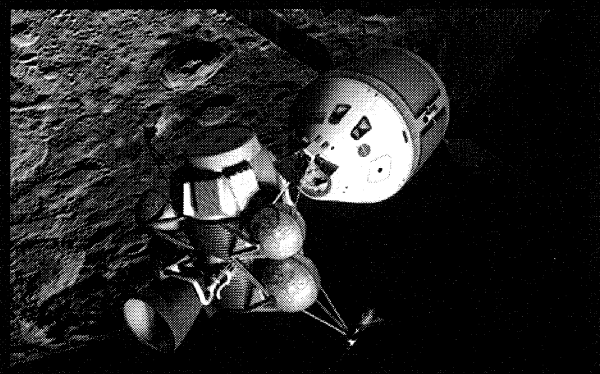
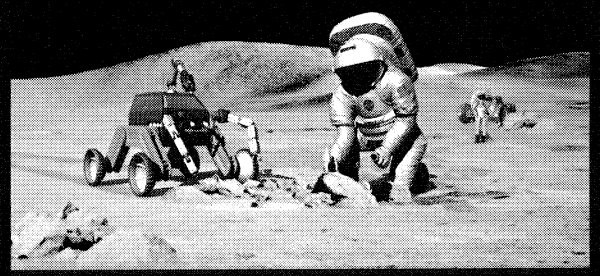
NASA

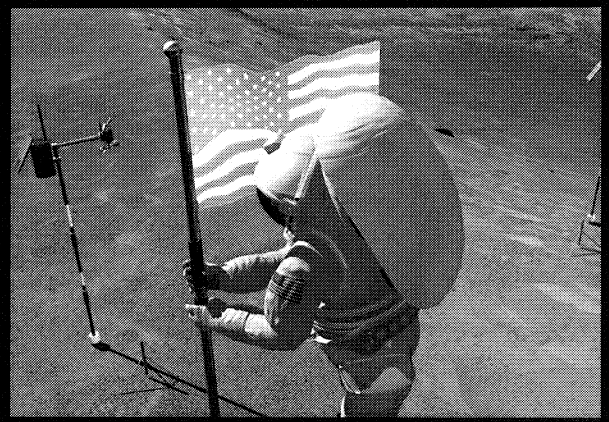
CONSTELLATION

Vision For Space Exploration

- Complete the International Space Station
- Safely fly the Space Shuttle until 2010
- Develop and fly the Crew Exploration Vehicle no later than 2014
- Return to the Moon no later than 2020
- Extend human presence across the solar system and beyond
- Implement a sustained and affordable human and robotic program
- Develop supporting innovative technologies, knowledge, and infrastructures
- Promote international and commercial participation in exploration



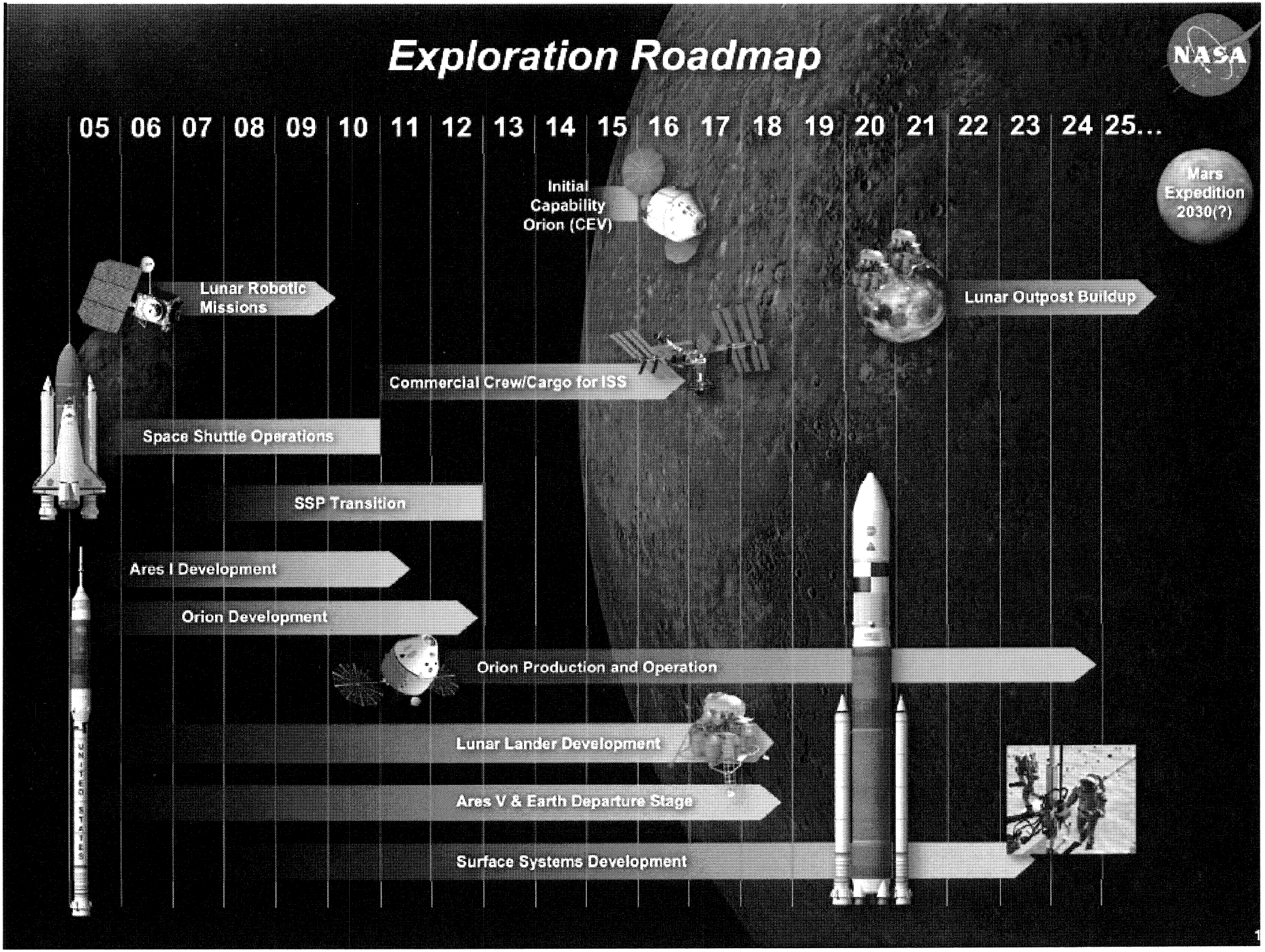




NASA Authorization Act of 2005

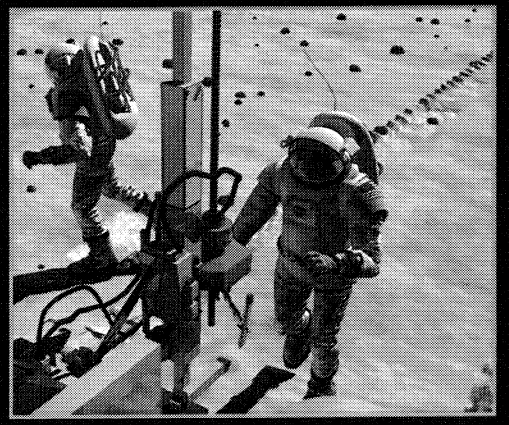
The Administrator shall establish a program to develop a sustained human presence on the Moon, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and as a stepping stone to future exploration of Mars and other destinations.

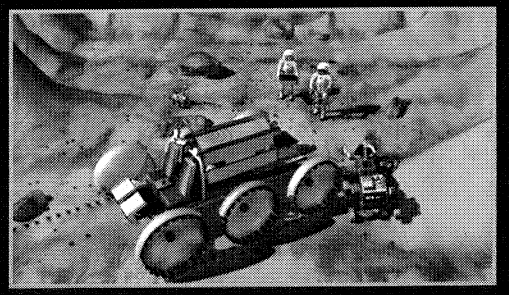
Exploration Roadmap



The Moon – the First Step to Mars and Beyond….

- **Gain significant experience in operating away from Earth's environment**
  - Space will no longer be a destination visited briefly and tentatively
  - "Living off the land"
  - Human support systems
- **Developing technologies needed for opening the space frontier**
  - Crew and cargo launch vehicles (125 metric ton class)
  - Earth ascent/entry system – Crew Exploration Vehicle
- **Preparing for human exploration of Mars**
- **Conduct fundamental science**



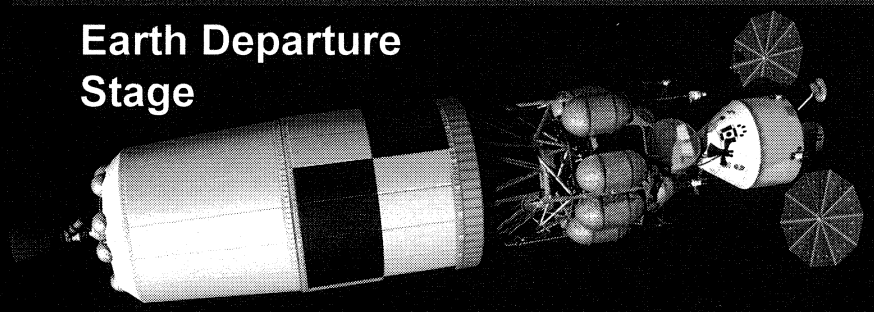


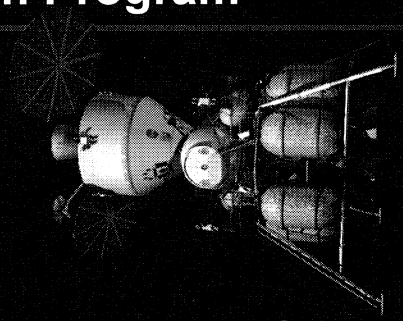
Next Step in Fulfilling Our Destiny As Explorers

How We Plan to Return to the Moon

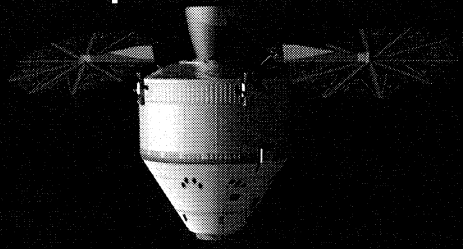
Components of Constellation Program

Earth Departure Stage

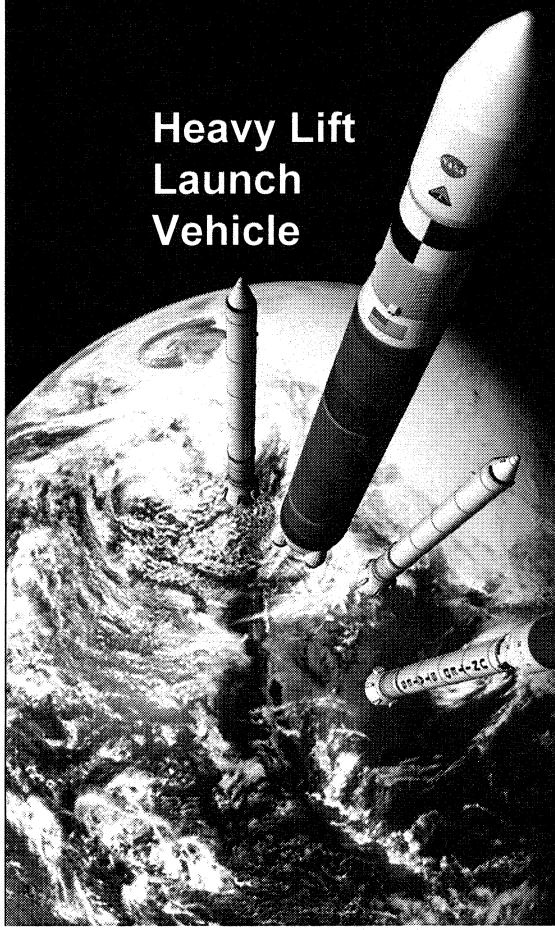




Orion - Crew Exploration Vehicle

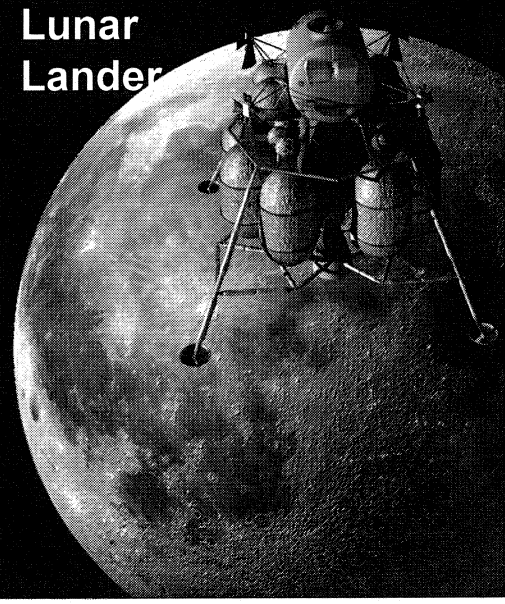


Heavy Lift Launch Vehicle



Crew Launch Vehicle

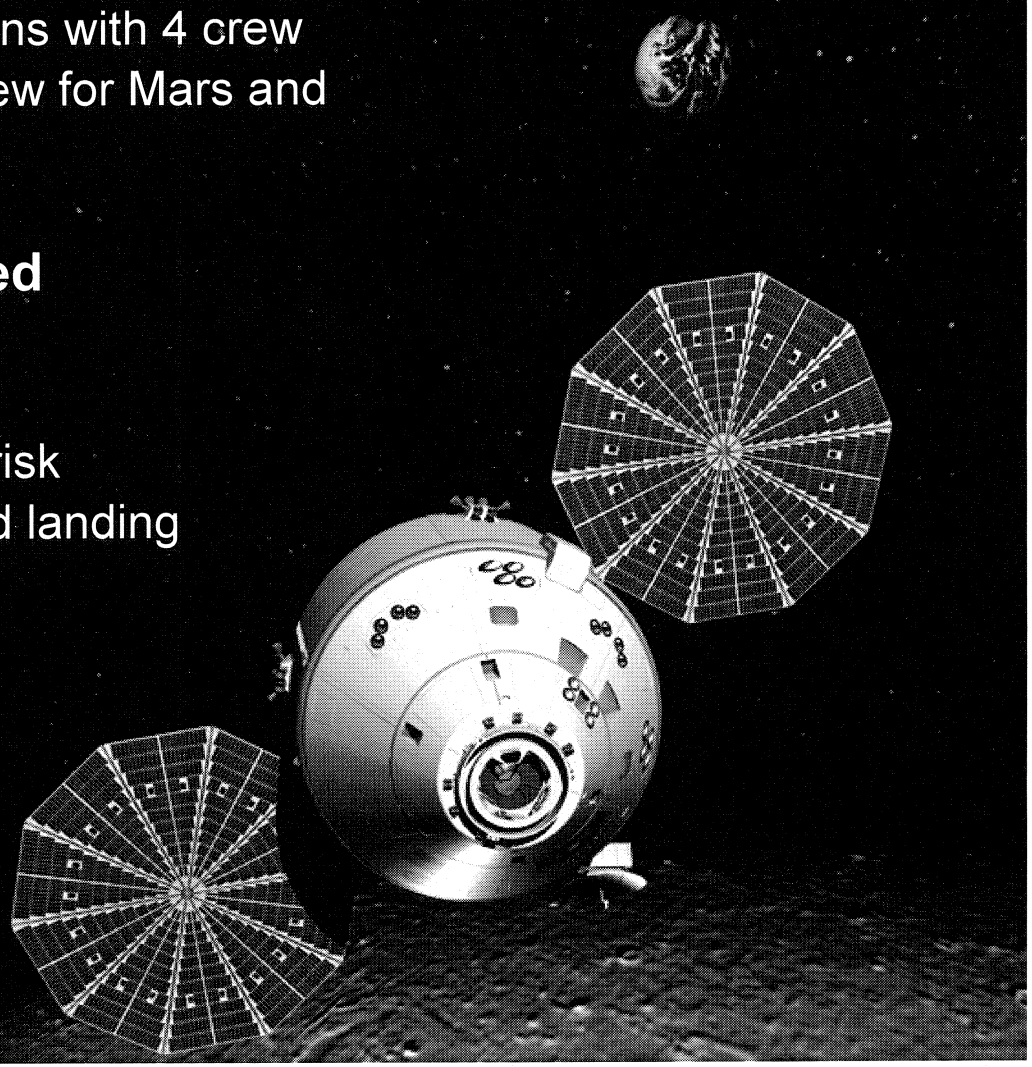
Lunar Lander



How We Plan to Return to the Moon

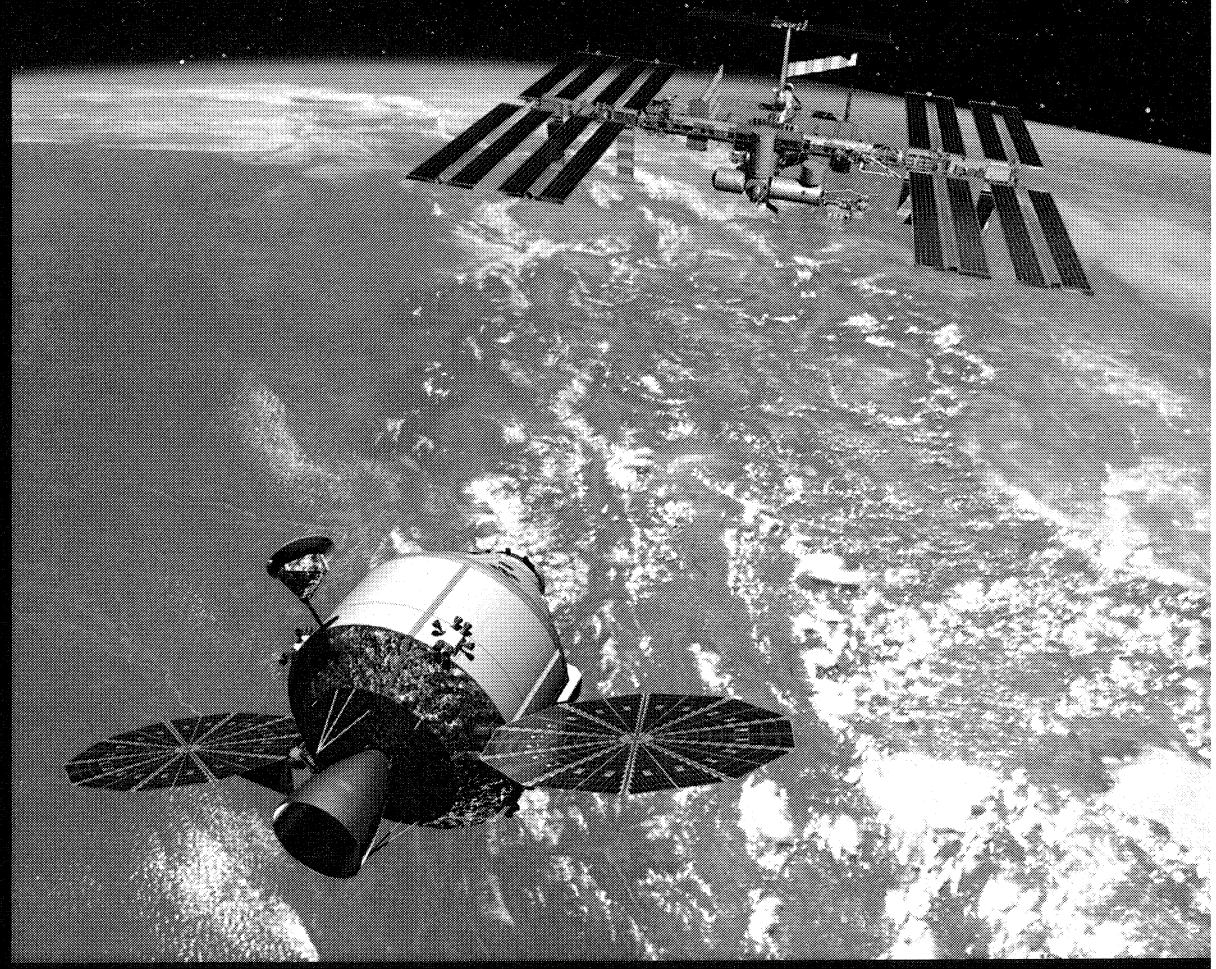
Orion - Crew Exploration Vehicle

- **A blunt body capsule is the safest, most affordable and fastest approach**
  - Vehicle designed for lunar missions with 4 crew
    - Can accommodate up to 6 crew for Mars and Space Station missions
- **5 meter diameter capsule scaled from Apollo**
  - Significant increase in volume
  - Reduced development time and risk
  - Reduced reentry loads, increased landing stability and better crew visibility



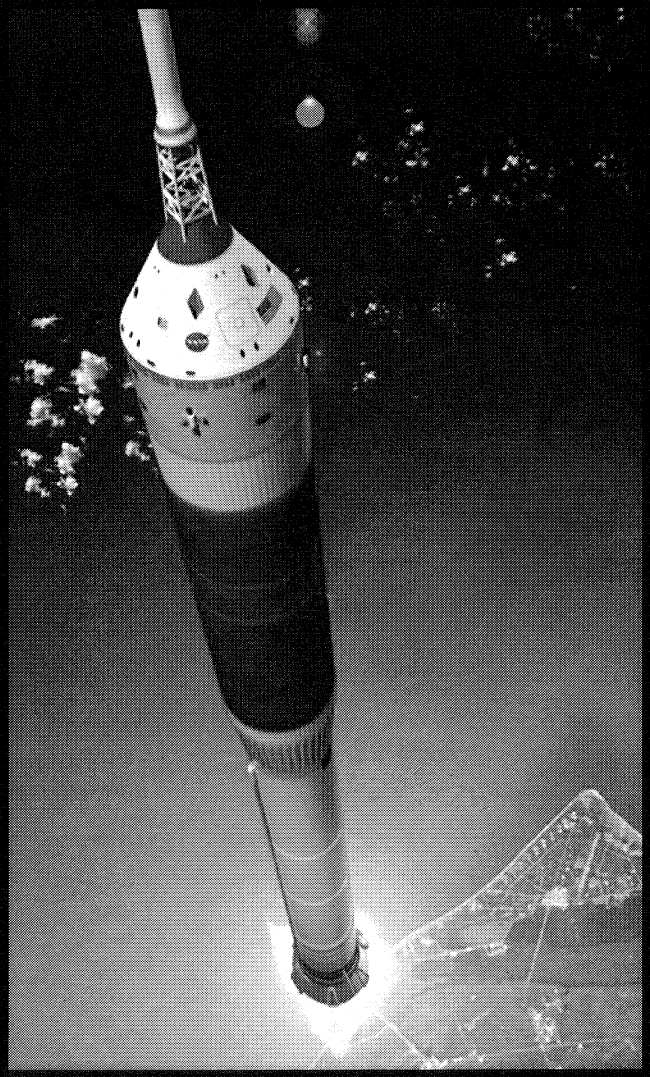
Orion will Initially be used to Support Space Station Missions

- Transport up to 6 crew members on Orion for crew rotation
- 210 day stay time at ISS
- Emergency lifeboat for entire ISS crew
- Deliver pressurized cargo for ISS re-supply

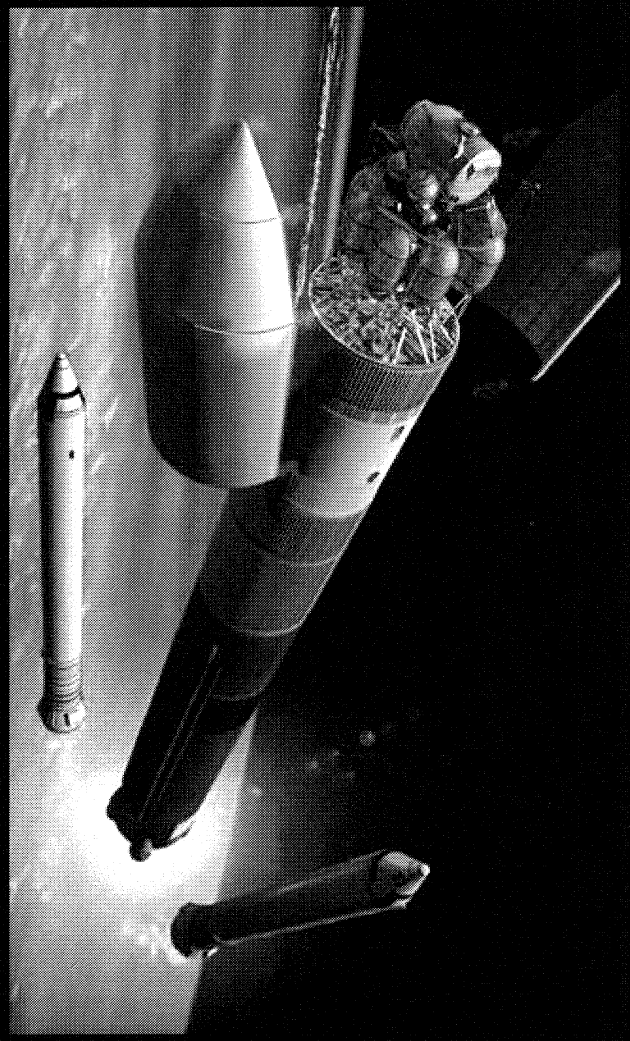


Ares I - Crew Launch Vehicle

- Serves as the long term crew launch capability for the U.S.
- 5 Segment Shuttle Solid Rocket Booster
- New liquid oxygen / liquid hydrogen upperstage
  - J2X engine
- Large payload capability

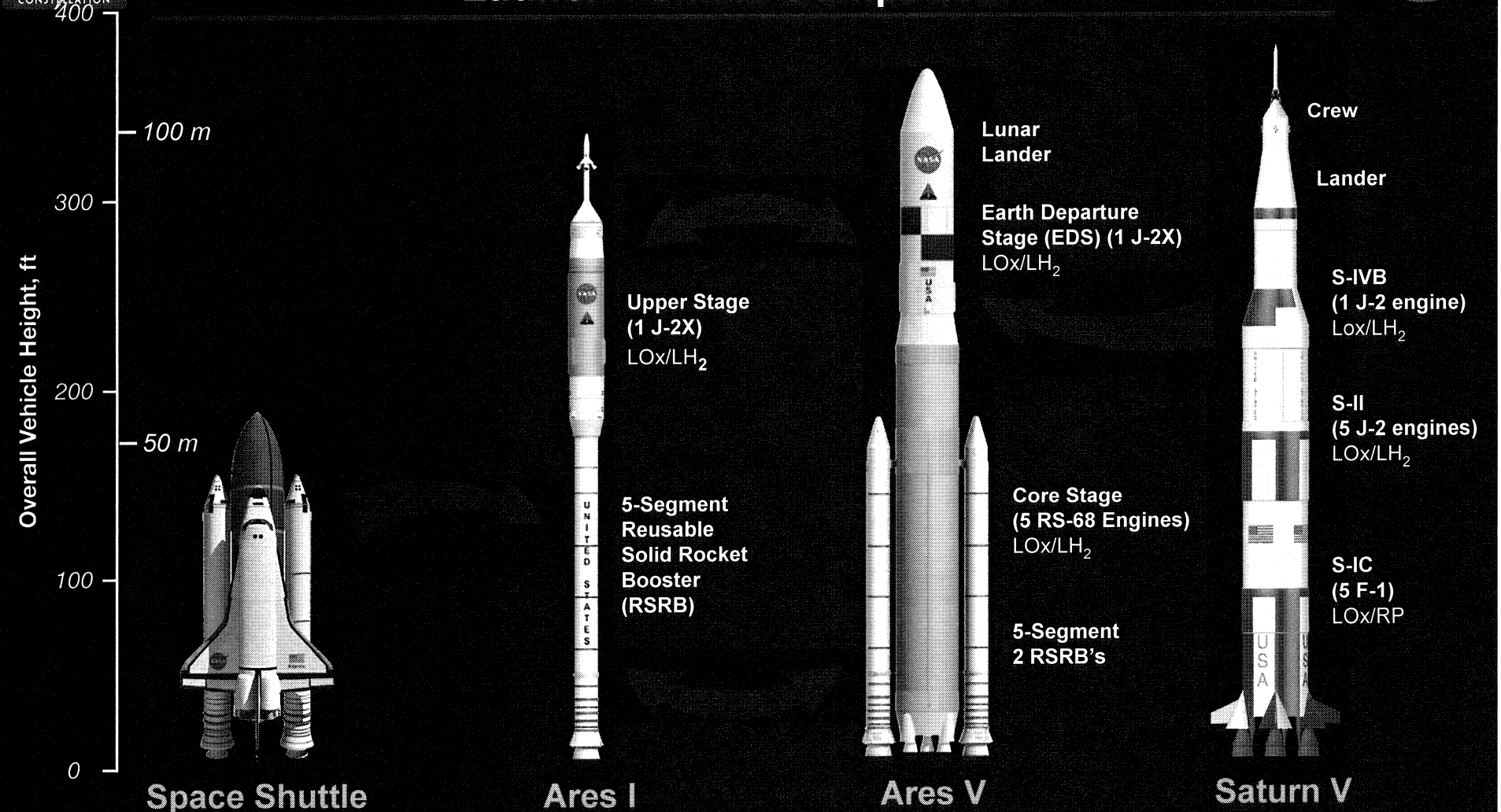


Ares V – Heavy Cargo Launch Vehicle



- **5 Segment Shuttle Solid Rocket Boosters**
- **Liquid Oxygen / liquid hydrogen core stage**
  - Heritage from the Shuttle External Tank
  - RS68 Main Engines
- **Payload Capability**
  - 106 metric tons to low Earth orbit
  - 125 Metric tons to low Earth orbit using Earth departure stage
  - 55 metric tons trans-lunar injection capability using Earth departure stage
- **Can be certified for crew if needed**

Foundation of Proven Technologies
Launch Vehicle Comparisons



Space Shuttle
Height: 56.1 m
Gross Liftoff Mass: 2041 mT

25 metric tons LEO

Ares I
Height: 97.8 m
Gross Liftoff Mass: 907 mT

22 metric tons to LEO

Ares V
Height: 109 m
Gross Liftoff Mass: 3311 mT

53 metric tons to TLI
65 metric tons to TLI in Dual-Launch Mode with Ares I
132 metric tons to LEO

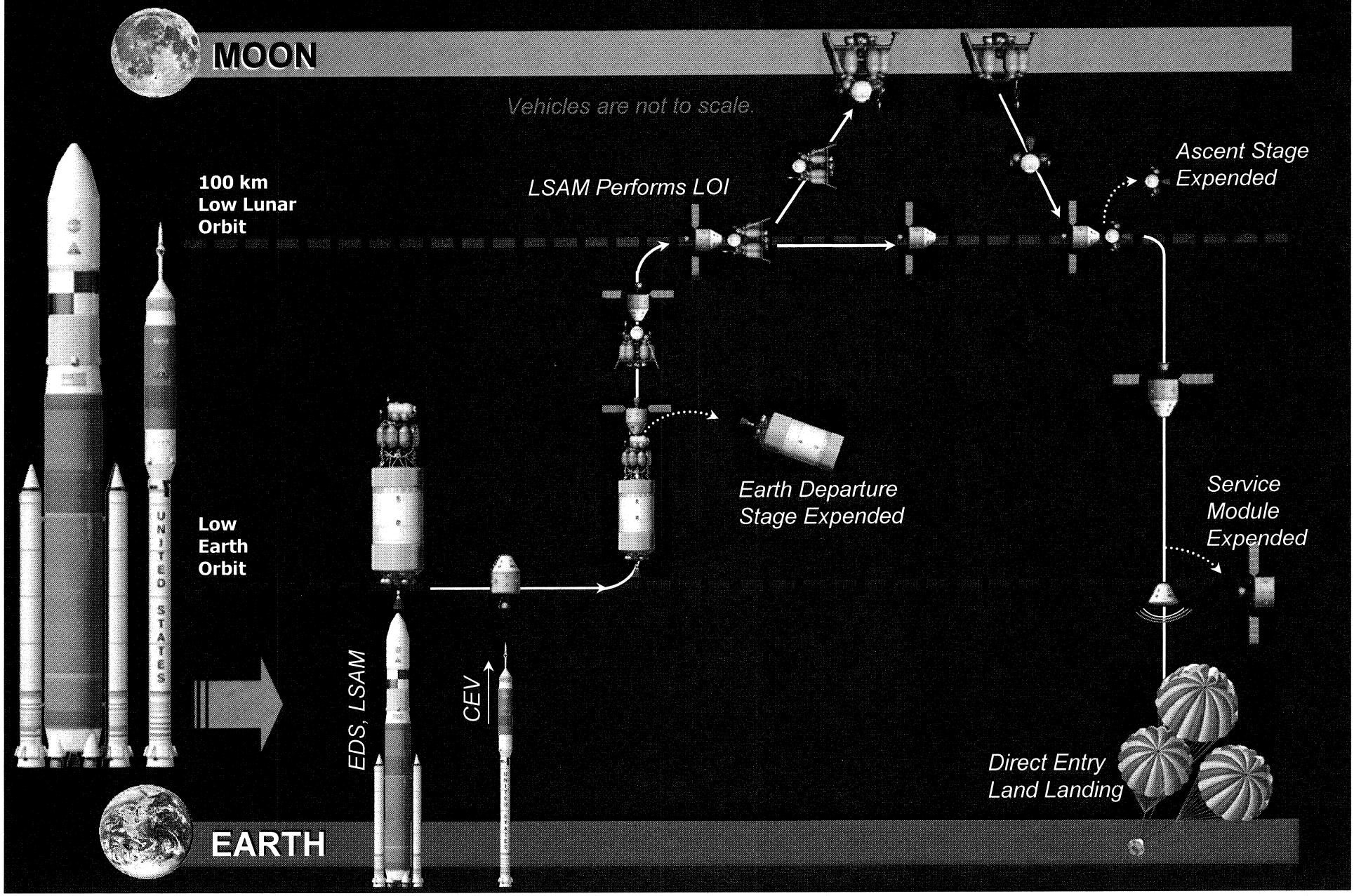
Saturn V
Height: 111 m
Gross Liftoff Mass: 2948 mT

45 metric tons to TLI
119 metric tons to LEO

Lunar Lander

- **Transports 4 crew to and from the surface**
  - Seven days on the surface
  - Lunar outpost crew rotation
- **Global access capability**
- **Anytime return to Earth**
- **Capability to land 20 metric tons of dedicated cargo**
- **Airlock for surface activities**
- **Descent stage:**
  - Liquid oxygen / liquid hydrogen propulsion
- **Ascent stage:**
  - Storable Propellants

Typical Lunar Reference Mission

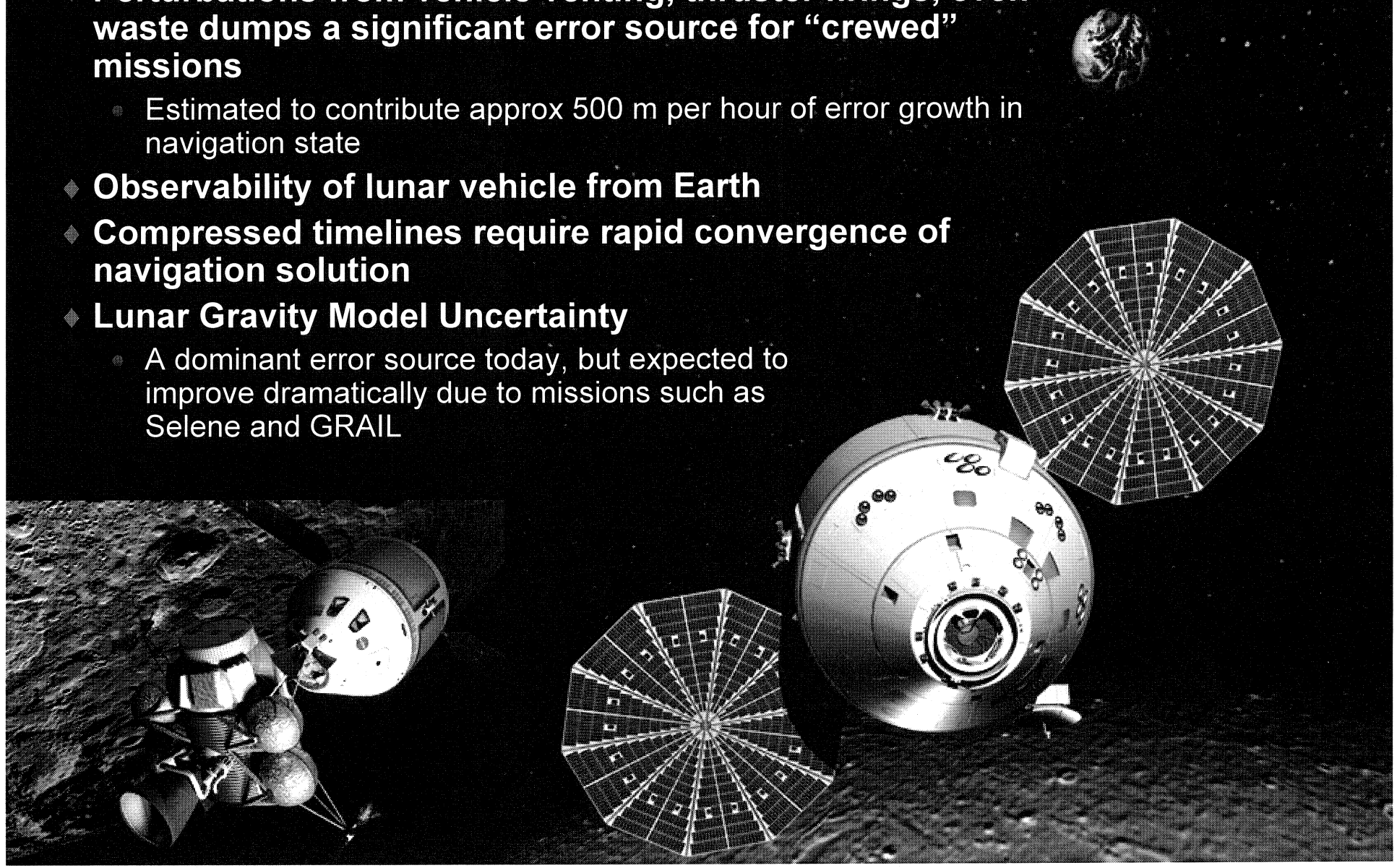


Comparison of Constellation and Apollo

Characteristic	Apollo	Constellation
Launch architecture	Single launch, Lunar orbit rendezvous	Dual Launch, Earth-orbit/Lunar Orbit rendezvous
Landing location	Near side; equatorial to mid-latitude; 1 time visits	Global including poles & far side; 1 time & return to site
Crew	2 crew to surface All missions piloted	4 crew to surface Piloted & robotic missions
Lighting condition	All missions during lunar day	Missions in lunar day & night
Rover Range	Range: 57 mi (92 km); 6 mi (9.7 km) range from LM per EVA	100 km < range < 1000 km; no limit due to EVAs
Earth tracking network	Apollo 17: ~12 sites	3 DSN sites + up to 3 secondary sites
In-situ tracking network	none	Range and Doppler tracking from 2-satellite lunar relay constellation
Resulting landing accuracy	Reqt: 3000 ft radius; Actual: Computer controlled accuracy (no piloting effects) ~1500 ft, 1 σ	Goal: 100 m unaided (1st landing at a site); <10 m aided (return to Outpost)
Surface navigation aids	None	Deployable sensors (UWB, WiMax, RFID), landing aids
Re-entry/landing	Direct-entry, water landing	Skip-entry, CONUS or coastal water landing zone
EVA navigation equipment	Maps; mission checklist	MEMS IMUs, LRS/LCT/DSN S-band tracking, hand-held optical

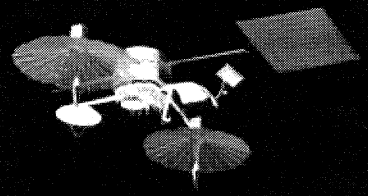
Navigation Challenges for Lunar Missions

- **Perturbations from vehicle venting, thruster firings, even waste dumps a significant error source for "crewed" missions**
  - Estimated to contribute approx 500 m per hour of error growth in navigation state
- **Observability of lunar vehicle from Earth**
- **Compressed timelines require rapid convergence of navigation solution**
- **Lunar Gravity Model Uncertainty**
  - A dominant error source today, but expected to improve dramatically due to missions such as Selene and GRAIL

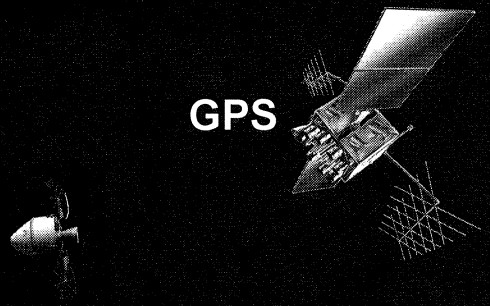


Navigation and Tracking Architecture for Lunar Mission

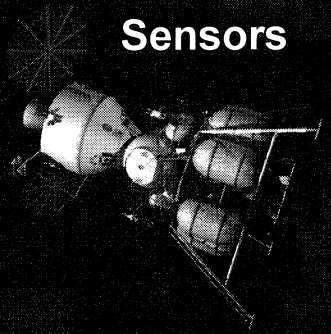
TDRS



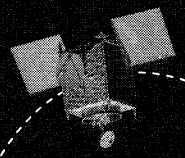
GPS



Onboard Sensors

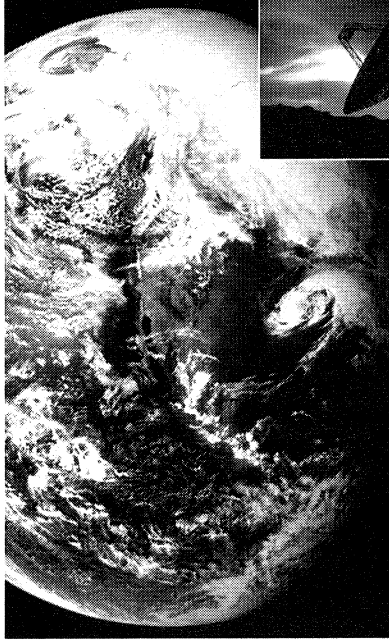


Lunar Relay Satellite



Surface RF Beacon

Ground Tracking



GPS

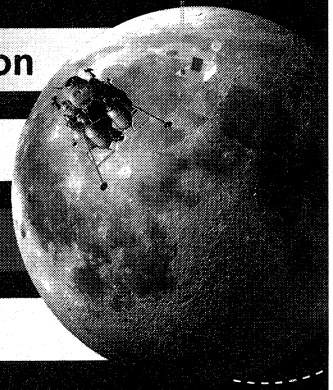
Surface Beacon

TDRSS

Lunar Relay

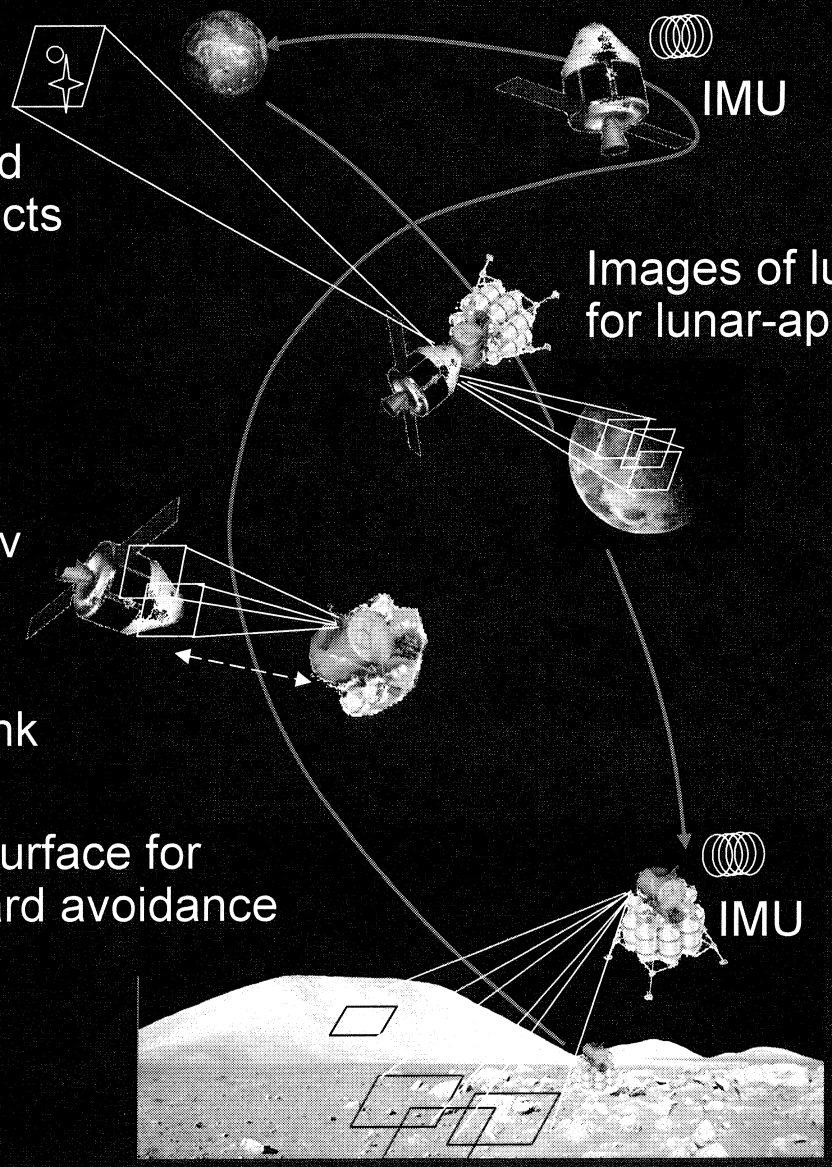
Earth-based Ground Station Tracking

Onboard Sensors/Inertial Nav



Onboard Navigation System Architecture

Optical Navigation and other Onboard Sensors



Navigation Sources for Launch/Ascent

Primary Navigation Sources

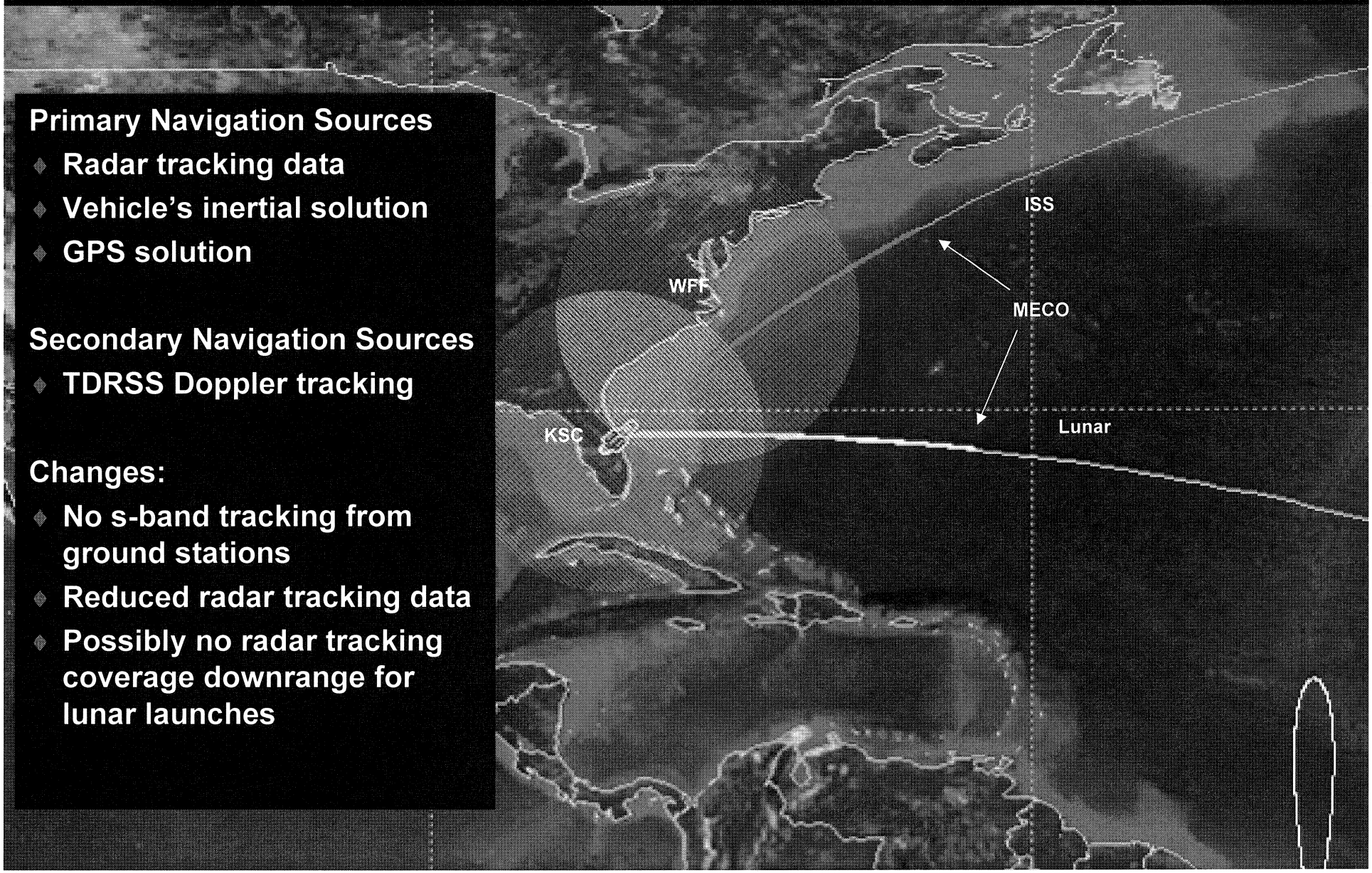
- Radar tracking data
- Vehicle's inertial solution
- GPS solution

Secondary Navigation Sources

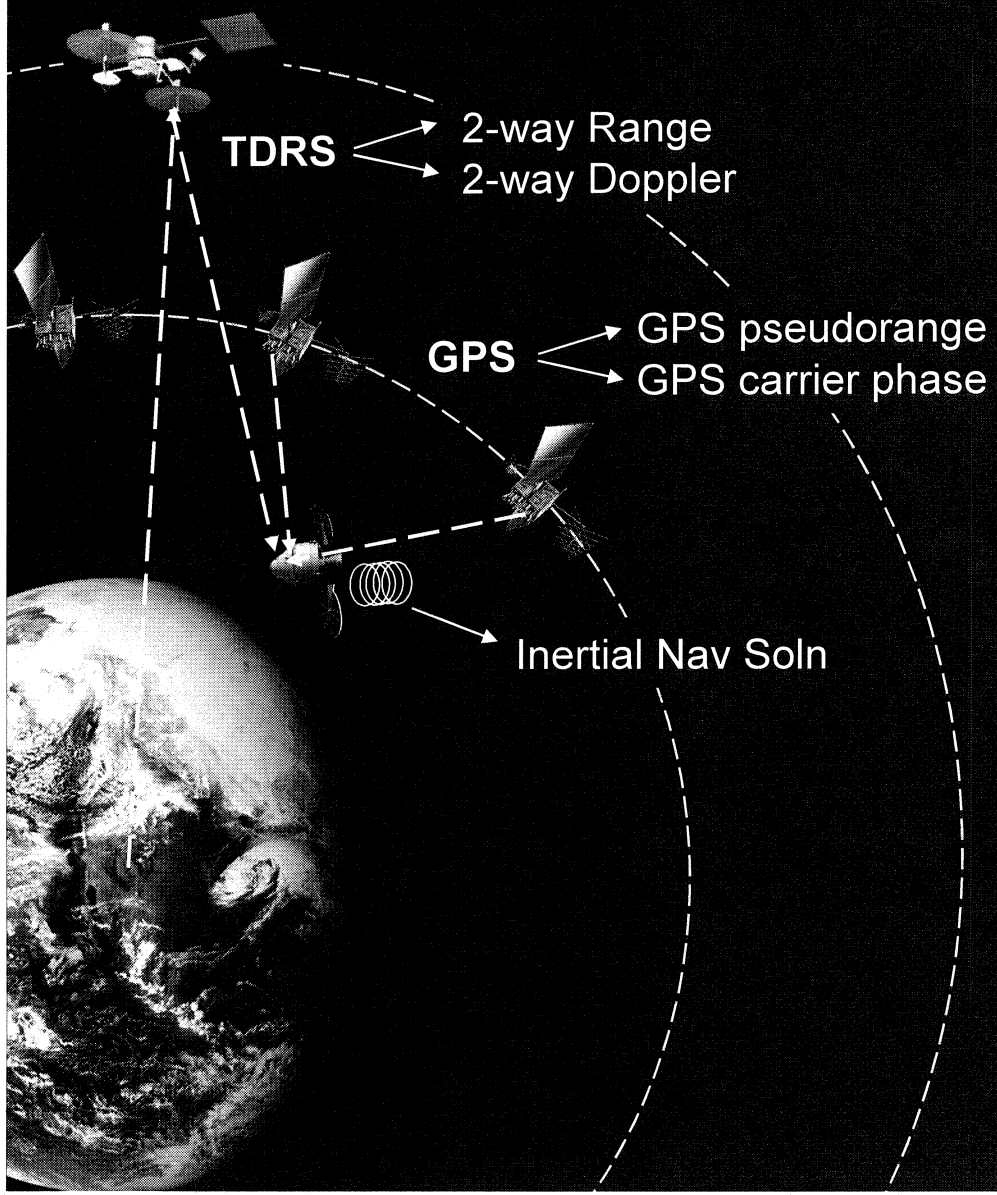
- TDRSS Doppler tracking

Changes:

- No s-band tracking from ground stations
- Reduced radar tracking data
- Possibly no radar tracking coverage downrange for lunar launches



Navigation Sources in Low-Earth Orbit

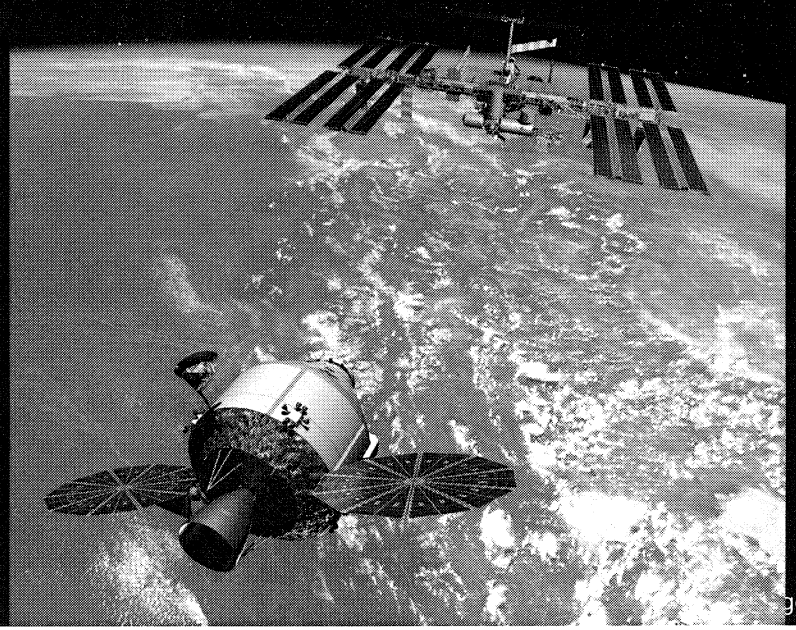


Primary Navigation Sources

- **Two-way Range and two-way Doppler tracking from TDRSS**
- **GPS**
- **Inertial Navigation Solution**

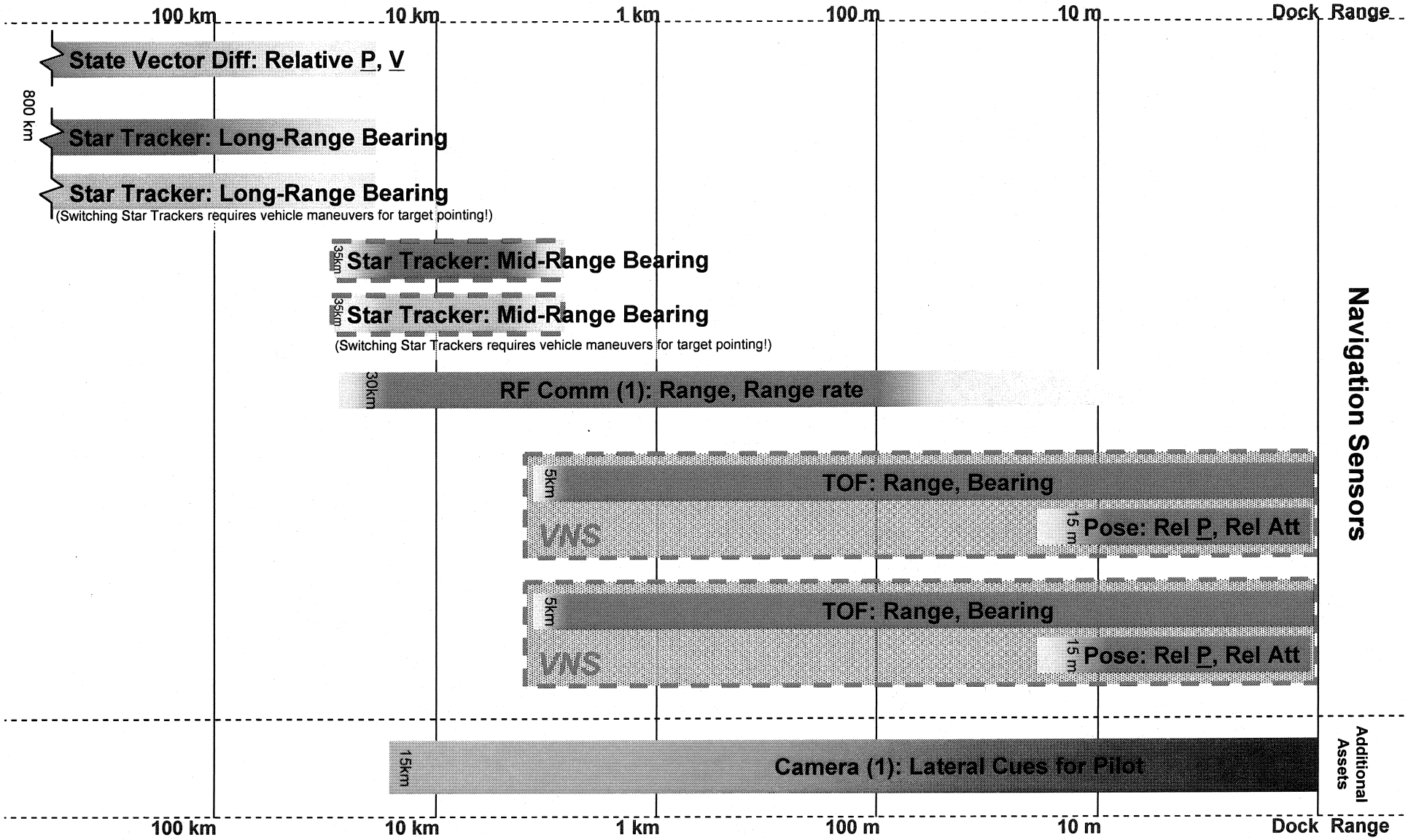
Changes:

- **No routine s-band or radar tracking for ground stations**



Relative Navigation Sensors and Operational Range for Orion Crew Exploration Vehicle

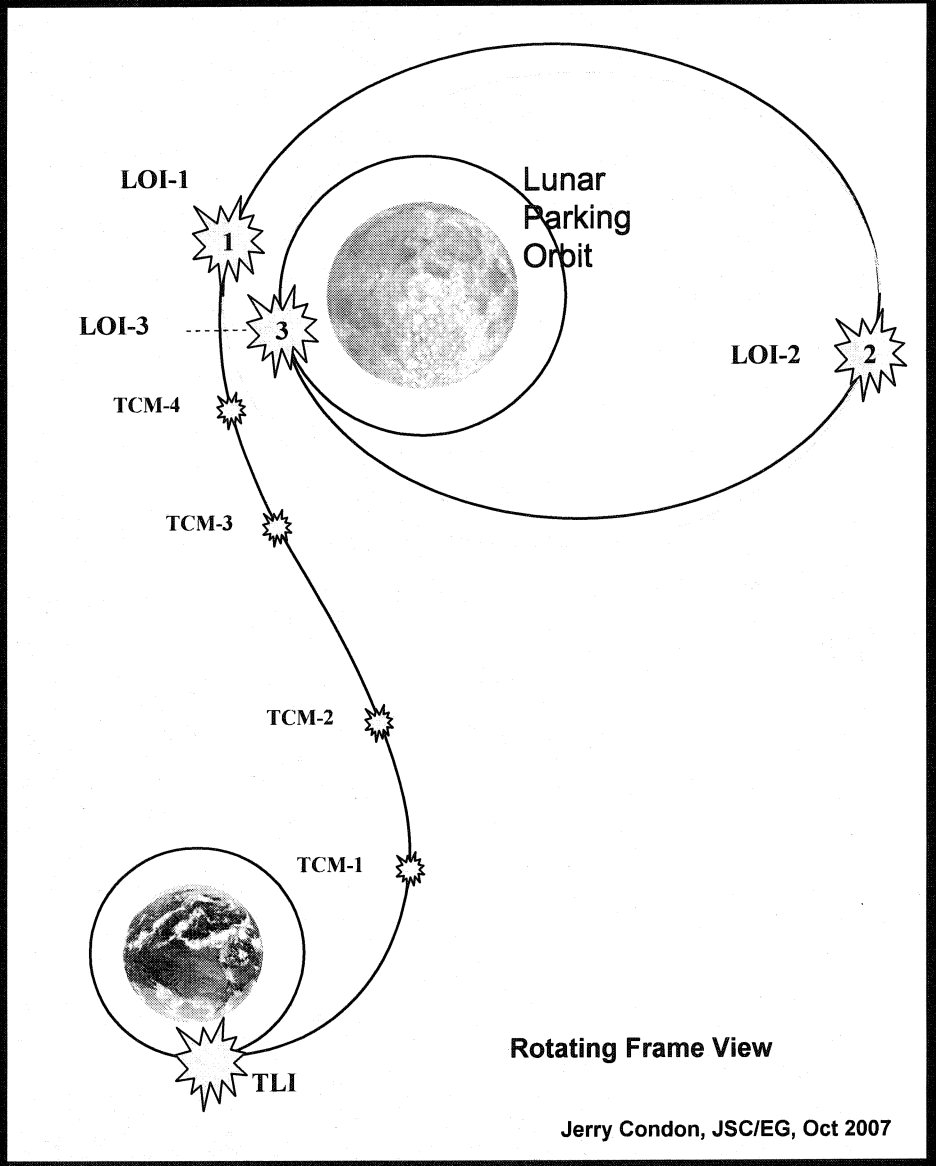
Modified release: Scott Cryan/NASA-JSC (EG2) 26 Dec 2007 -- 606C baseline



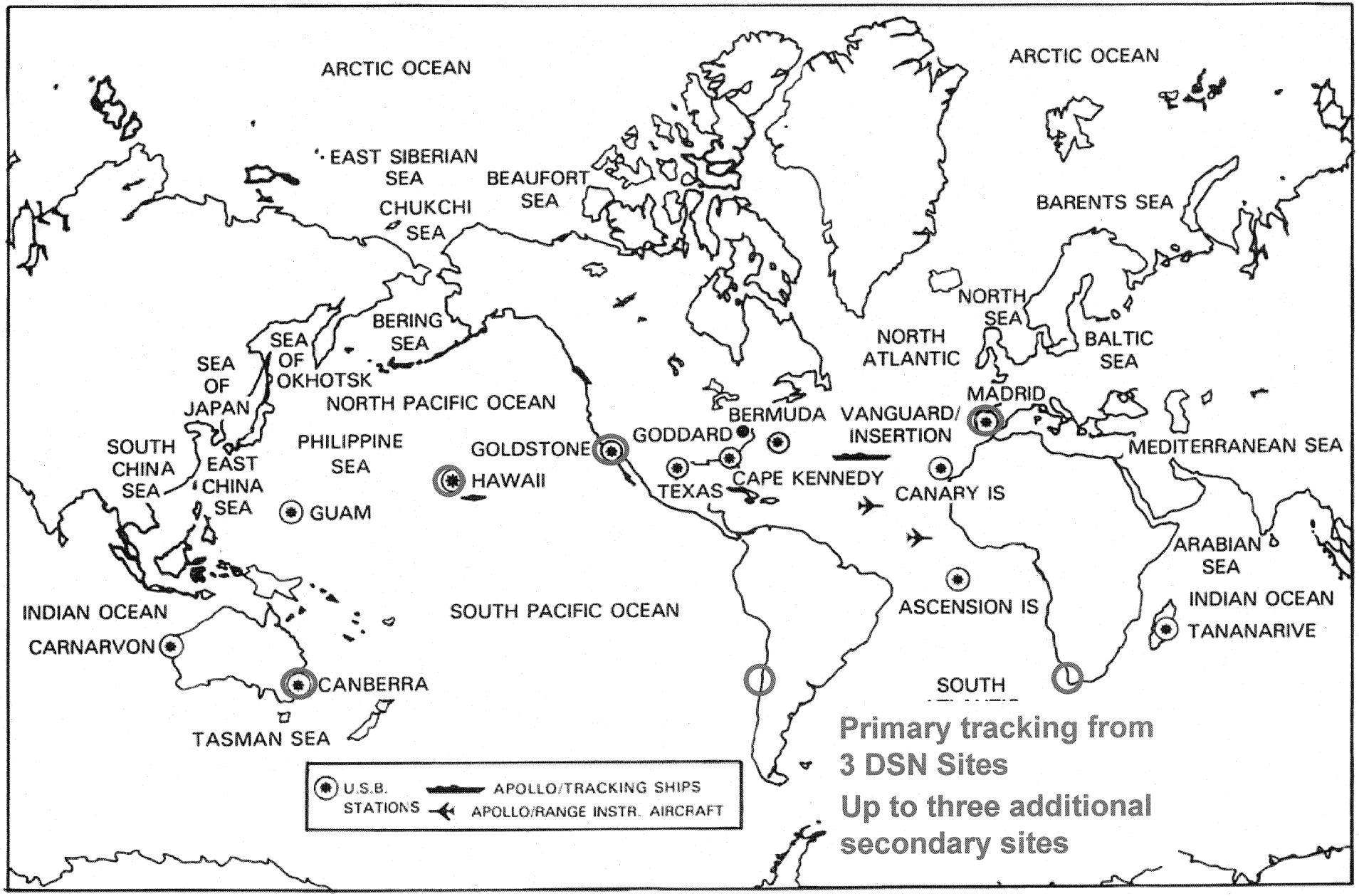
Legend: Primary | Secondary | Degraded | Functional

Critical Lunar Mission Events from a Navigation Perspective

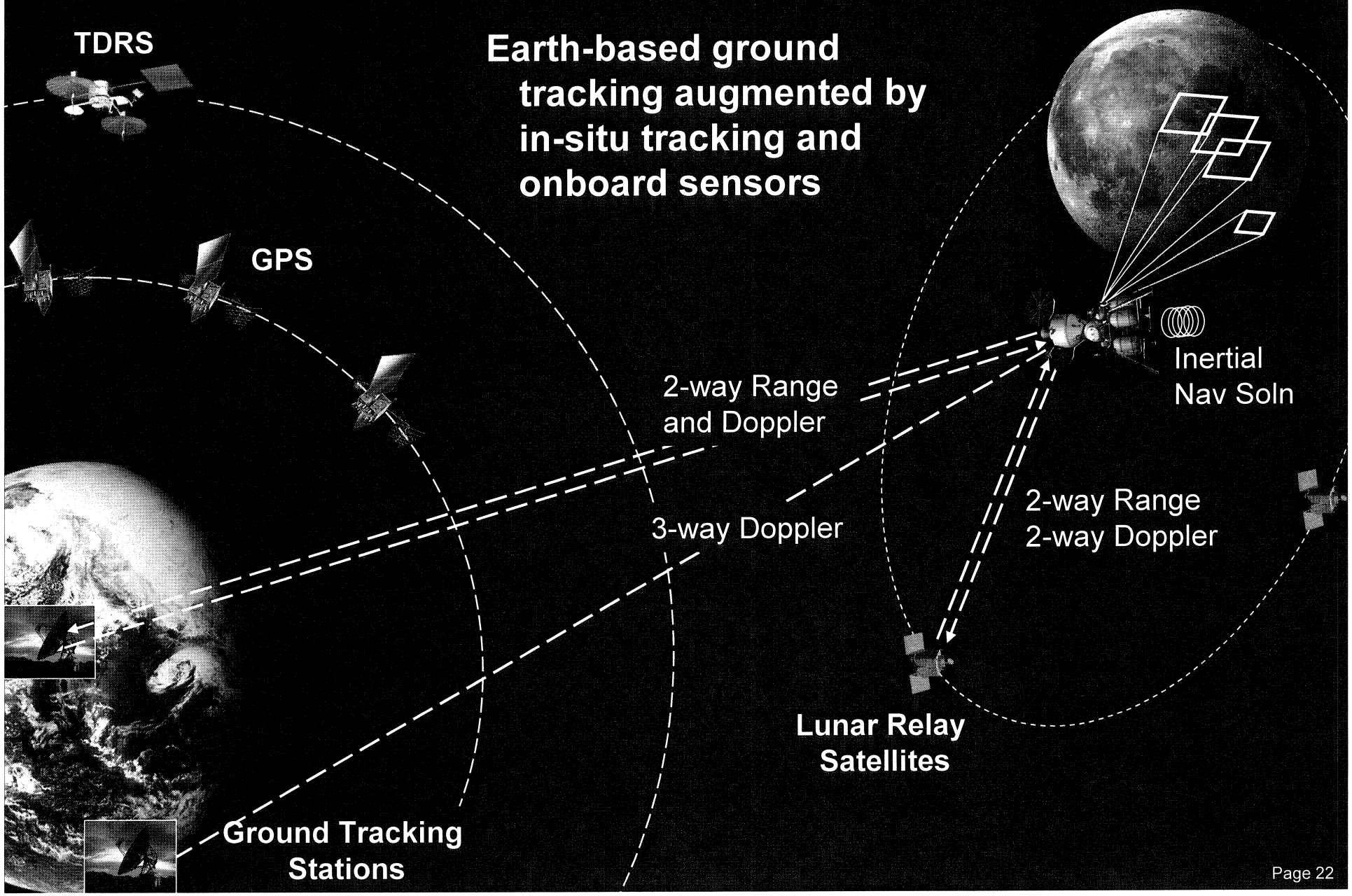
- Trans-lunar navigation targeting Lunar Orbit Insertion (LOI)
- Update to navigation state in lunar orbit prior to initiation of powered descent
- Powered descent/landing
- Trans-Earth Injection targeting an Earth-entry interface point
- Skip entry, chute deployments



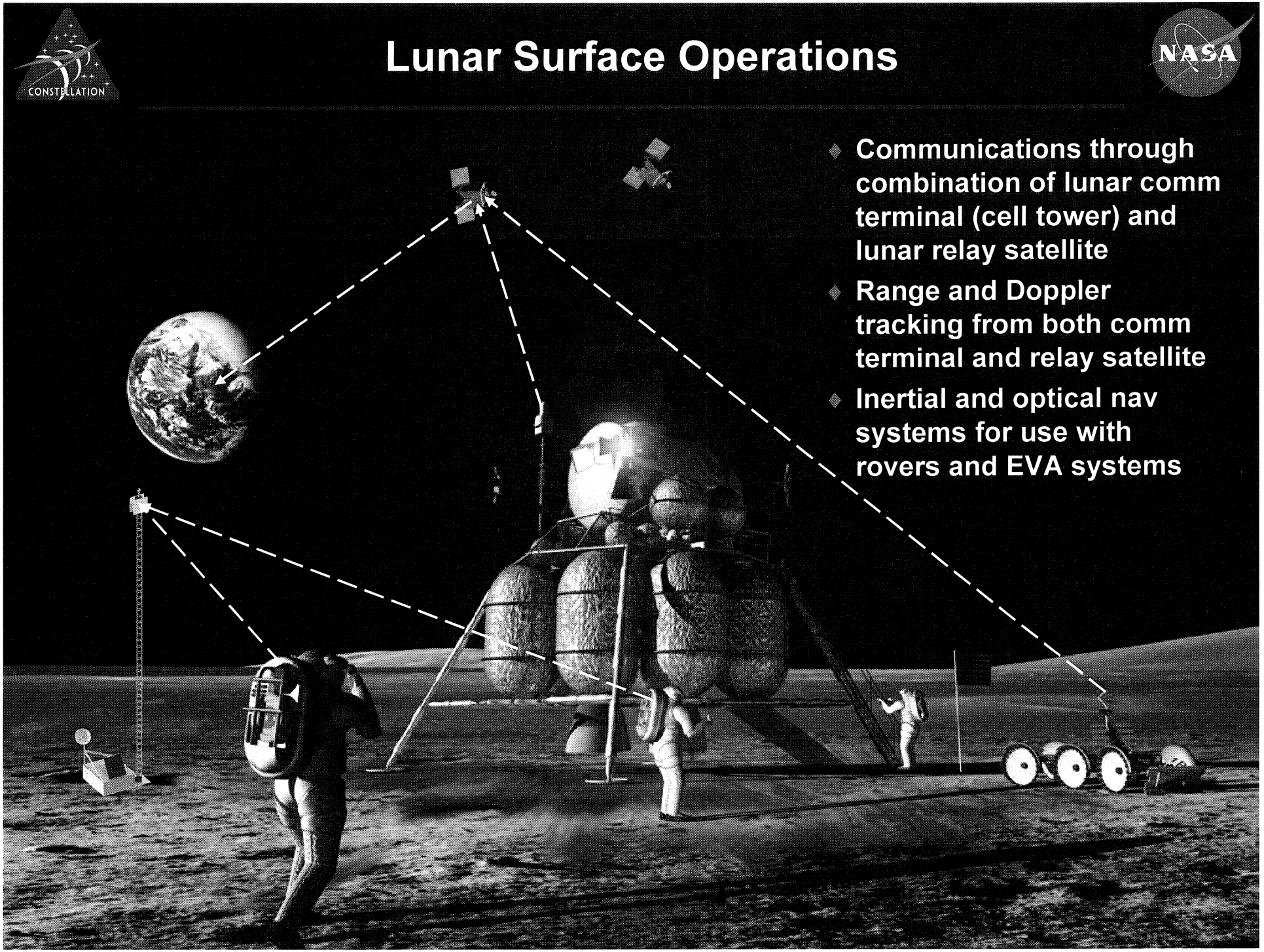
Constellation Ground Tracking Capability
Comparison to Apollo Tracking Network



Navigation Sources In Lunar Vicinity



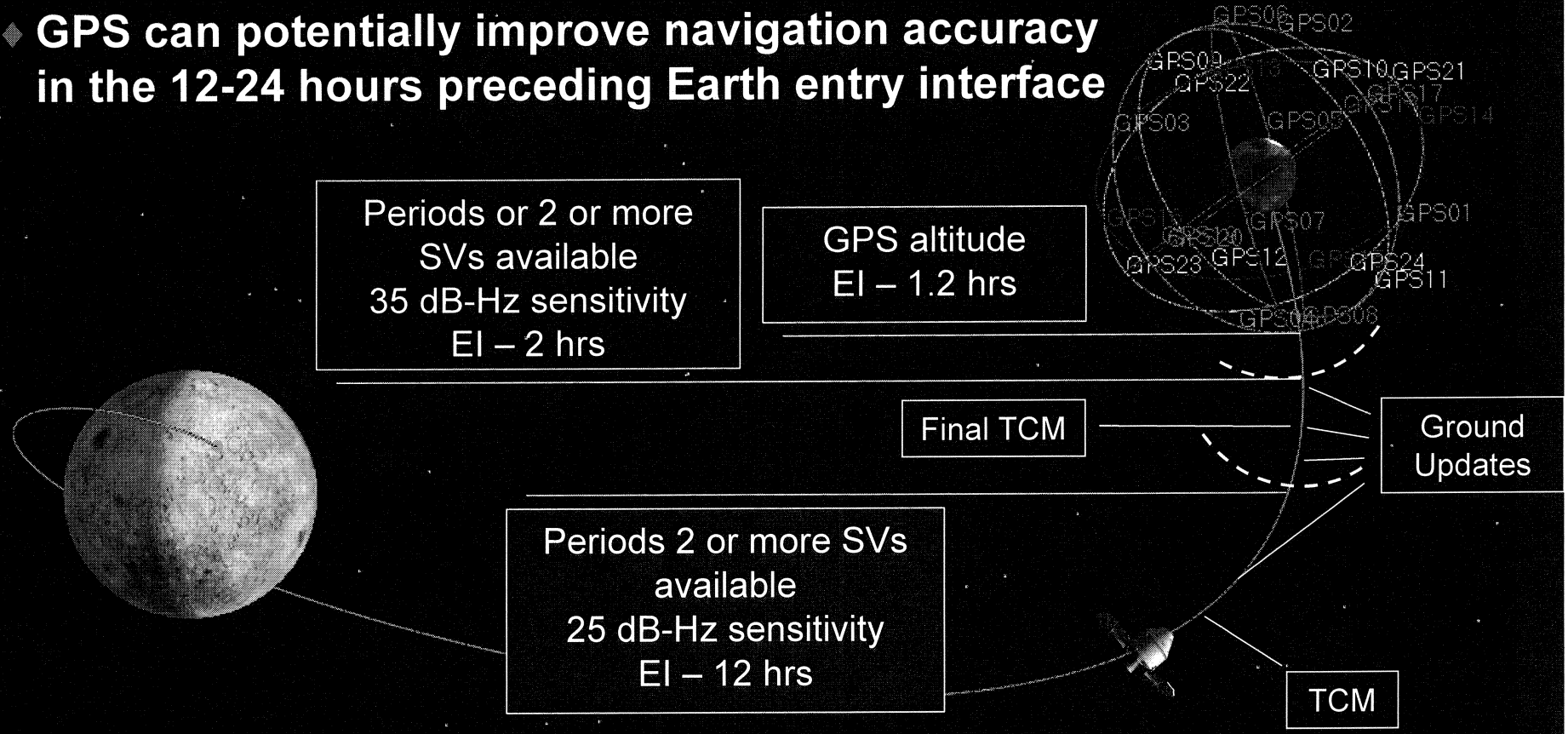
Lunar Surface Operations



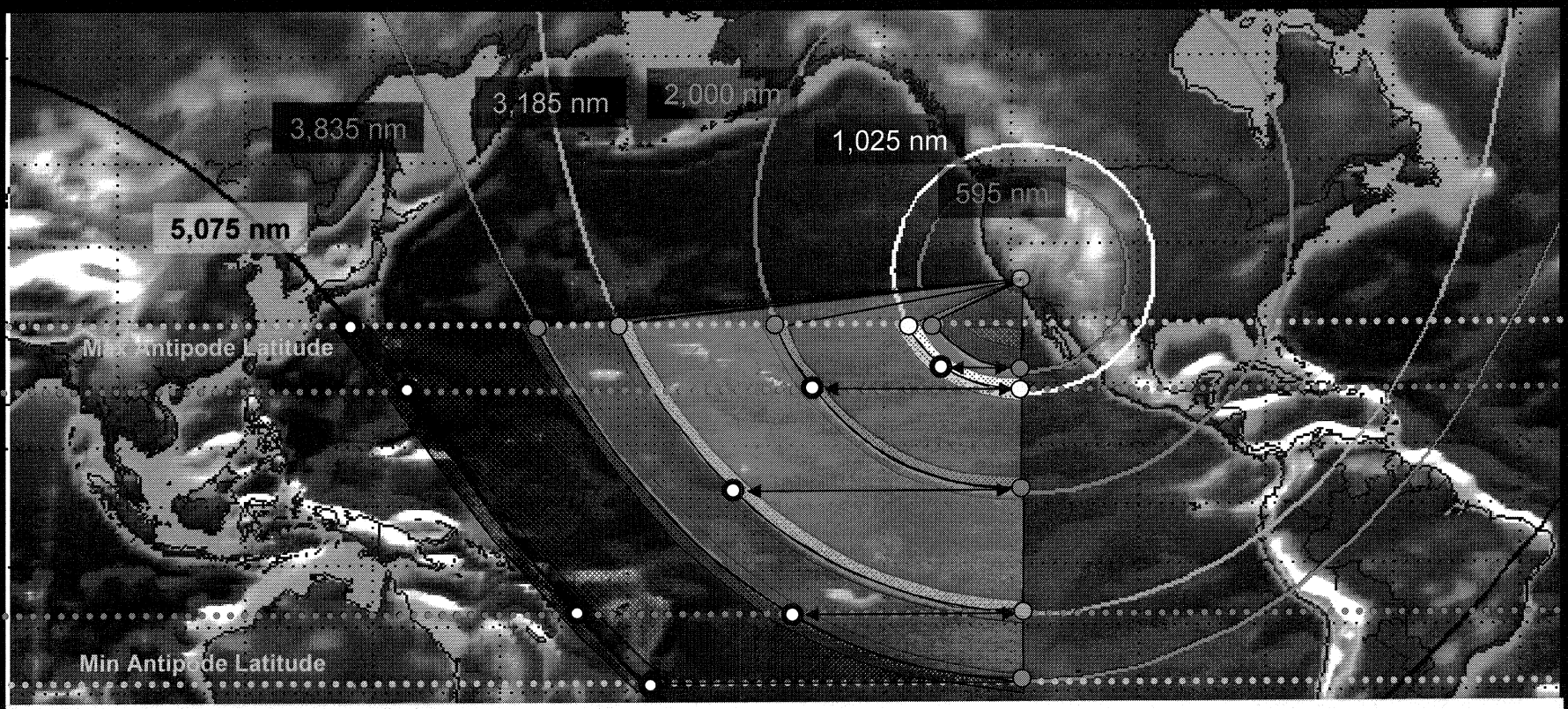
- Communications through combination of lunar comm terminal (cell tower) and lunar relay satellite
- Range and Doppler tracking from both comm terminal and relay satellite
- Inertial and optical nav systems for use with rovers and EVA systems

GPS Navigation Updates During Lunar Return

- **Weak GPS signal tracking technology enables tracking of GPS signals well beyond the GPS constellation sphere**
- **GPS can potentially improve navigation accuracy in the 12-24 hours preceding Earth entry interface**

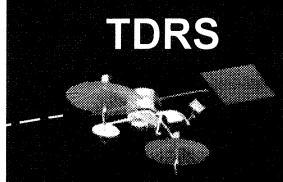


Skip-Entry Targeting
Coastal Landing Zone



- Skip entry capability enables return to CONUS (or coastal waters) for all potential Earth-Moon geometries
  - Reduces entry loads on crew
  - Increases cross-range capability
  - Enables entry from Mars Return
- Ground navigation solution during Earth-return is used to target the initial skip-entry interface point (Flight Path angle error <0.1 degrees 3-sigma)
- GPS required to perform chute deployment to achieve 5 km landing accuracy

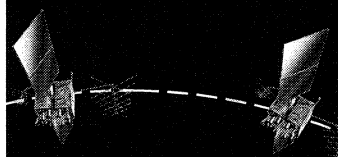
Elements of Navigation and Tracking Architecture and Navigation Data Types



TDRS

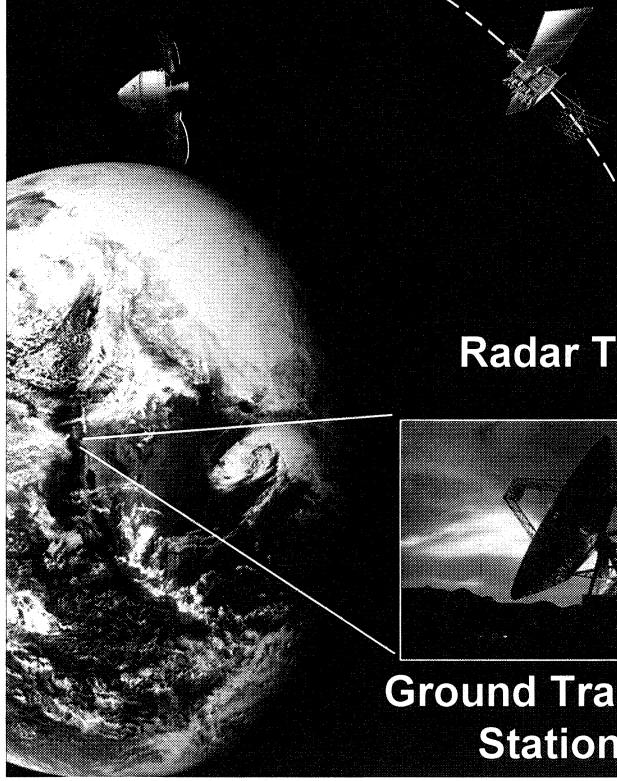
2-way Range
2-way Doppler

Onboard Sensors:
- Inertial Measurements
- Celestial object measurements
- Optical/landmark tracking
- Active ranging (RF or optical)



GPS

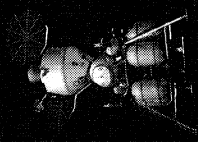
GPS pseudorange
GPS carrier phase



Radar Tracking

Ground Tracking Stations

2-way Range and Doppler
3-way Doppler

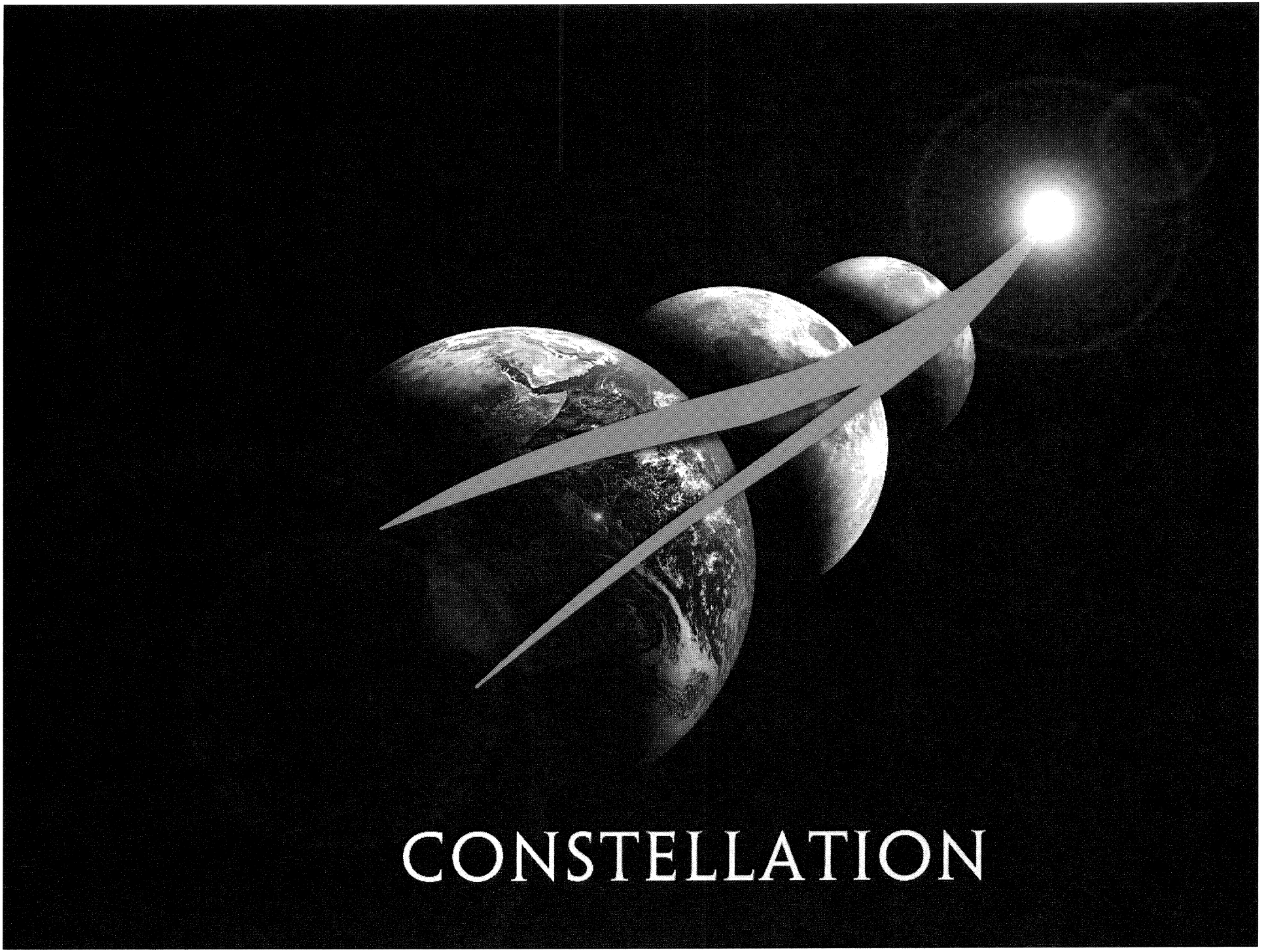


2-way Range
2-way Doppler

Lunar Relay Satellites

New Navigation Techniques to Enable Exploration Beyond the Moon

- **Laser communications**
  - For Mars missions, RF communications will likely only support uplink data rates on the order of 10 kb/sec – inadequate to support human missions
  - Laser communications and tracking will be used for Mars-Earth trunk links
- **X-Ray Pulsar Navigation**
  - Widely available – in locations where traditional tracking sources are not
    - Earth-Sun libration point orbiters
    - Interplanetary navigation
- **Advanced Onboard Navigation Techniques**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Acknowledgements

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