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Beyond GPS II and Galileo I

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Q: What is coming after Galileo and GPS?

A: A New Era that begins now…

- **Global Adoption - Greater International Cooperation**
- **Technical Improvements - Better Performance**
  - Space Segment
  - Ground Segment
  - User Segment
- **New Frontiers - GNSS & Space Exploration**

US PNT Policy

- The 1996 policy introduced GPS as a dual-use system, and presented a strategic vision for management and use of GPS.
- The 2004 *US Space-Based Positioning, Navigation, and Timing (PNT)* policy responds to changing international conditions and the worldwide growth of GPS applications.
  - emerging navigation systems, and related augmentations, should be compatible with GPS – in short, no interference from future signals and ideally, interoperable with civil GPS services and their augmentations.

U.S. SPACE-BASED POSITIONING, NAVIGATION, AND TIMING POLICY

December 15, 2004

FACT SHEET

The President authorized a new national policy on December 8, 2004 that establishes guidance and implementation actions for space-based positioning, navigation, and timing programs, augmentations, and activities for U.S. national and homeland security, civil, scientific, and commercial purposes. This policy supersedes Presidential Decision Directive/National Science and Technology Council-6, U.S. Global Positioning System Policy, dated March 28, 1996.

I. Scope and Definitions

This policy provides guidance for: (1) development, acquisition, operation, sustainment, and modernization of the Global Positioning System and U.S.-developed, owned and/or operated systems used to augment or otherwise improve the Global Positioning System and/or other space-based positioning, navigation, and timing signals; (2) development, deployment, sustainment, and modernization of capabilities to protect U.S. and allied access to and use of the Global Positioning System for national, homeland, and economic security, and to deny adversaries access to any space-based positioning, navigation, and timing services; and (3) foreign access to the Global Positioning System and United States Government augmentations, and international cooperation with foreign space-based positioning, navigation, and timing services, including augmentations.

For purposes of this document:

- "Interoperable" refers to the ability of civil U.S. and foreign space-based positioning, navigation, and timing services to be used together to provide better capabilities at the user level than would be achieved by relying solely on one service or signal;
- "Compatible" refers to the ability of U.S. and foreign space-based positioning, navigation, and timing services to be used separately or together without interfering with each individual service or signal, and without adversely affecting navigation warfare; and
- "Augmentation" refers to space and/or ground-based systems that provide users of space-based positioning, navigation, and timing signals with additional information that enables

Global Adoption and Greater International Cooperation

- **Long cooperative relationship with Japan** on GPS and the US is looking forward to their progress on a GPS-compatible augmentation known as QZSS.
  - Joint Statement of the United States of America and Japan on Global Positioning System Cooperation in 1998.
- **On-going consultations with Russia** on potential cooperation, as well as compatibility and interoperability, between GPS and GLONASS.
- **On-going consultations with India** on their development of the WAAS-like aviation augmentation system known as GAGAN.
- The agreement in 2004 between the **US and the European Union (EU) on GPS and Galileo** recognized the benefits of interoperable systems for both parties.
- The EU and US agreed to implement a common, open, civil signal on both Galileo and future GPS III satellites.

June 26 Press Conference at US-EU Summit in Shannon, Ireland (left to right: US Sec. of State Colin Powell, Irish Foreign Minister Brian Cowen, EU Vice-President Loyola De-Palacio)

Space-based PNT services must serve global users and should have transparent interfaces and standards

Technical Improvements for Better Performance

- **Space Segment**
  - Constellation Configurations
    - More Satellites, Additional Signals, Longer lifecycles
  - Signal Enhancements
    - Higher Power, More Robust Codes, Anti-Jam, Anti-Spoof, Flex-Power
  - Integrity Alerting
  - Signal Authentication
  - Higher Data Rate
    - Search & Rescue, Value-Added Services
  - Greater System Accuracy, Availability, Continuity, and Utility

- **Ground Segment**
  - Satellite Tracking & Maintenance
  - Civil Signal Monitoring

- **User Applications**
  - Augmentations - Dissemination and use of PNT data
  - Receiver design - Ultra-sensitive, software-defined radios

Integration of Technology Advances in Space, Ground, and User Segments will enable GNSS for Space Exploration!

New Frontiers: The Vision for Space Exploration

- **January 14, 2004, the US President announced a new vision for NASA**
  - **Implement a sustained and affordable human and robotic program to explore the solar system and beyond;**
  - **Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;**
  - **Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and**
  - **Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.**

Challenges for GPS use in Space

- **Many emerging space users of GPS beyond Low Earth Orbit**
  - **Not just Geostationary Orbits**
- **Space users above the terrestrial service volume (>3000 km altitude) share unique GPS signal challenges**
- **GPS space flight experiments in high orbits have shown that existing signal availability becomes more limited due to:**
  - **Geometry between the SV and the space user**
  - **Vast signal strength changes due to signal path length variations (near/far problem)**
- **Robust GPS signals in the space service volume:**
  - **Needed to support future civil and military space requirements**
  - **Will open unprecedented science opportunities for 21st century space vehicles**

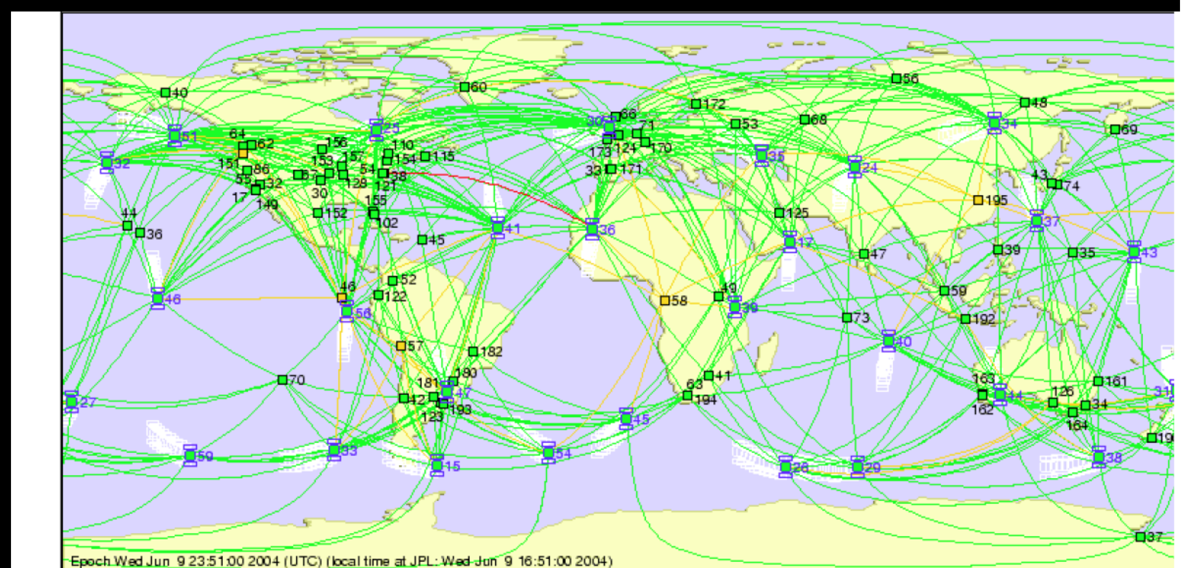
High Accuracy Monitoring and Augmentation with the Global Differential GPS System (GDGPS)

The GDGPS System tracks each GPS satellite by at least **12 sites**, and by **25 sites on average**, enabling robust, real-time GPS performance monitoring with **4 sec to alarm.**

Current real-time GPS products and services from the GDGPS System:

- **High-accuracy (10 cm) global differential corrections**
- **Global ionospheric (TEC) maps**
- **Earth orientation**
- **Broadcast and almanac service**
- **Precise orbit and clock states**
- **Performance monitor (broadcast quality and signal metrics, alarms)**
- **Predicted orbit and clock states**
- **Assisted-GPS data**
- **Time transfer service**

For more information see: http://www.gdgps.net



NASA's Global Differential GPS System

GDGPS Operations Center

TDRS

Land lines

Iridium

Inmarsat

Uplink

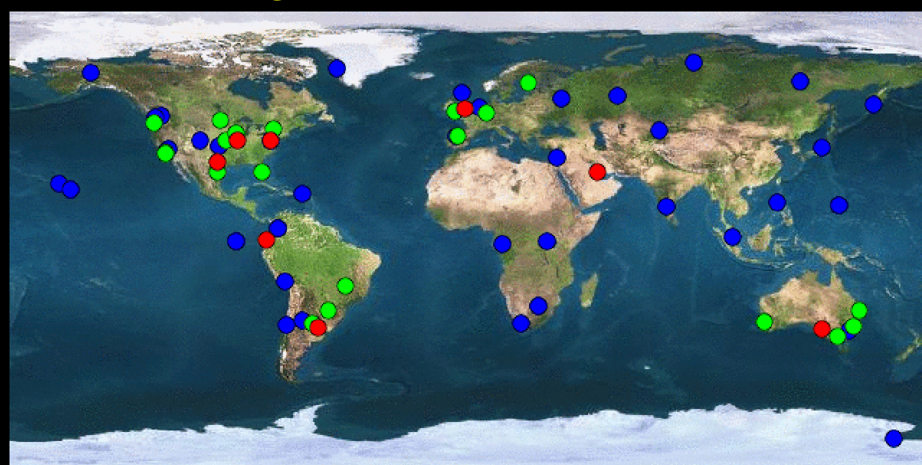
Terrestrial and airborne users

Frame

Internet

Broadcast

NASA's global real time network



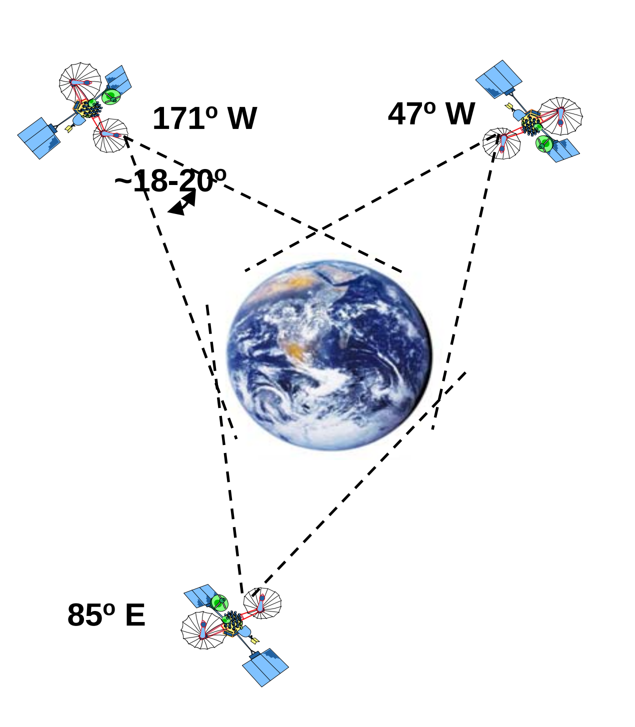
Space users

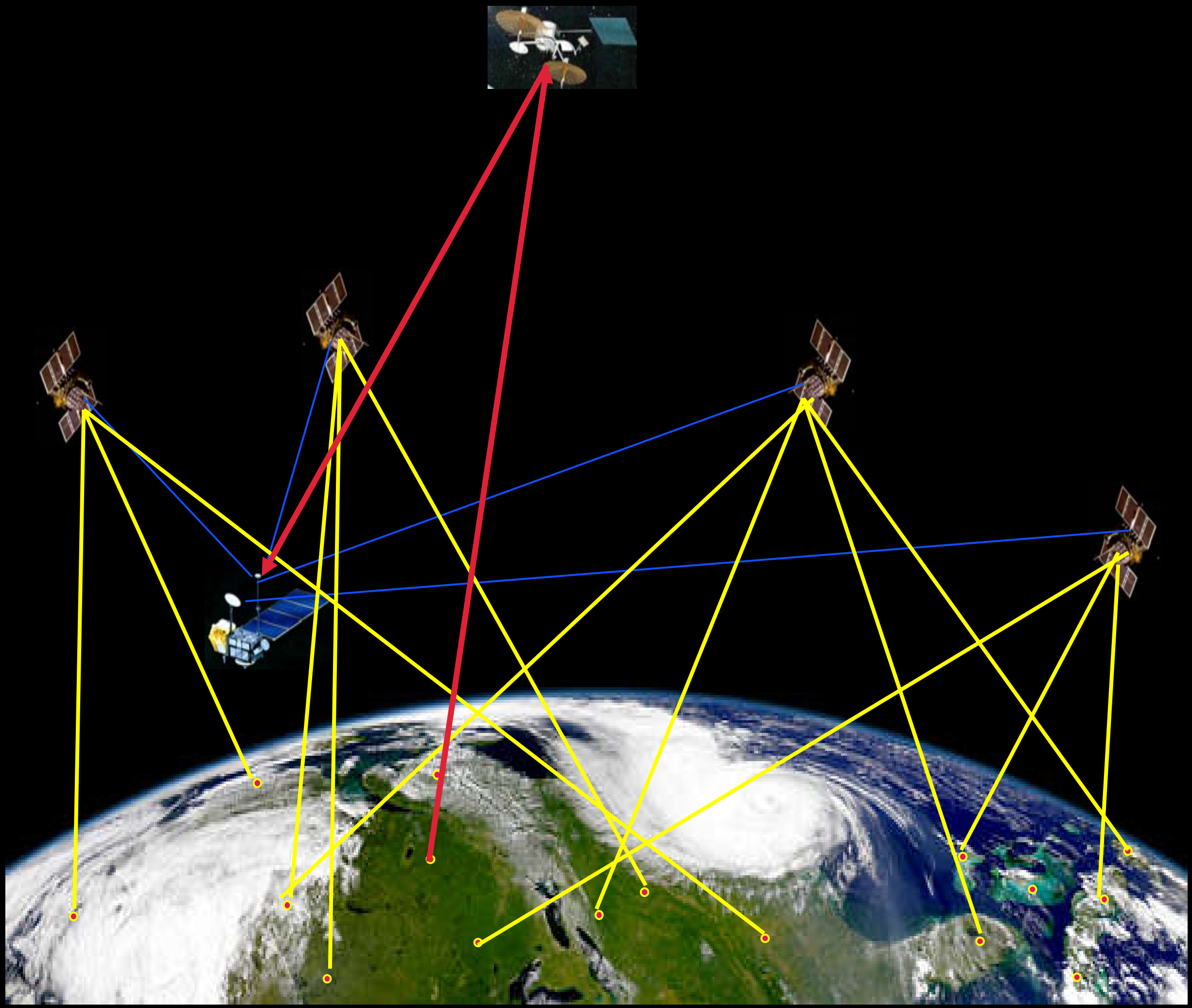
Fully operational since 2000

For more information see: http://gipsy.jpl.nasa.gov/igdg

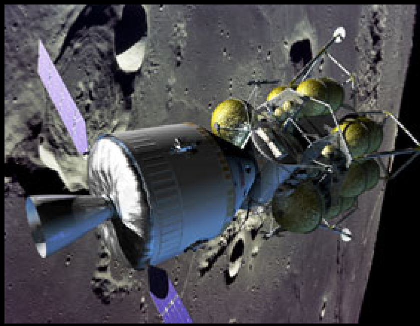
GPS & GDGPS & TDRSS = TASS
Tracking and Data Relay Satellite System Augmentation Service for Satellites

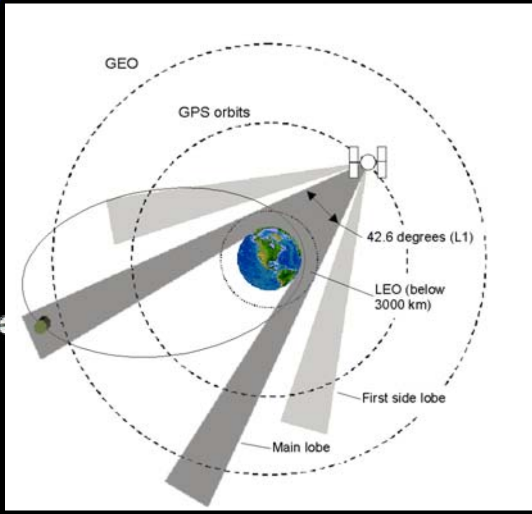
- Tracking and Data Relay Satellite System (TDRSS) Augmentation Service for Satellites (TASS) provides Global Differential GPS (GDGPS) corrections via TDRSS satellites
- Integrates NASA's Ground and Space Infrastructures
- Provides user navigational data needed to locate the orbit and position of NASA user satellites





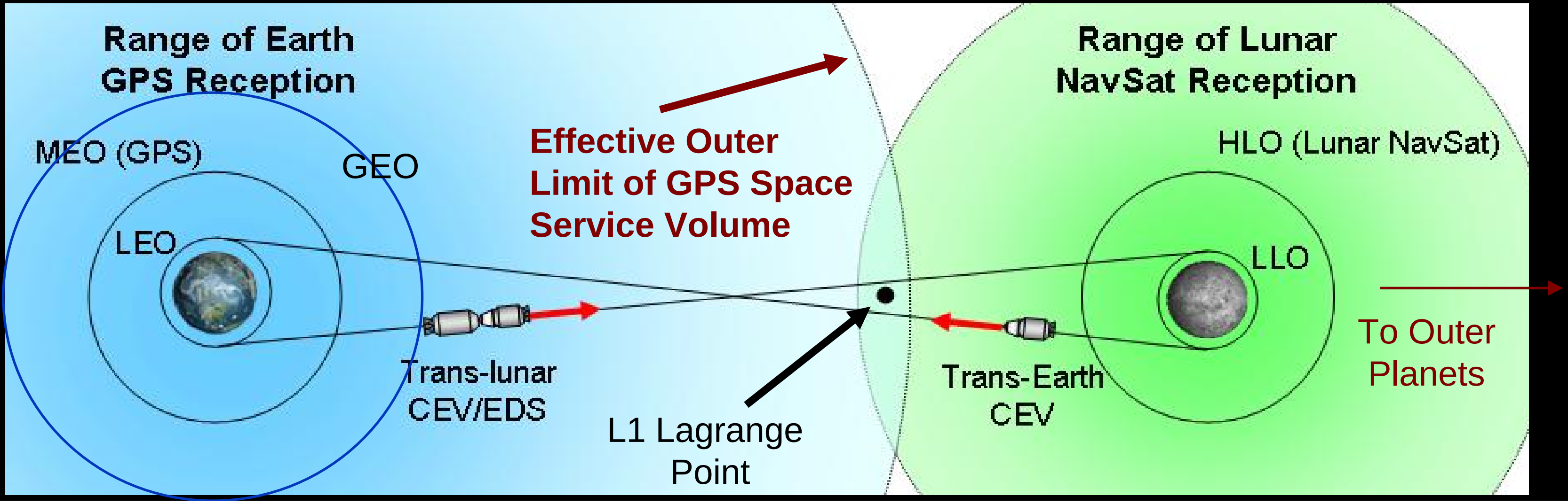
GPS and Planetary Navigation: Navigation Options





Lunar Mission Tracking Options:

- **Earth based tracking**
- **Satellite laser ranging stations**
- **Earth based relay (TDRSS and follow-on)**
- **GPS**
  - **Signals can be tracked to the surface of the Moon.**
  - **Signals effective up to approx. 322,000 km / L1 Lagrange Point (4/5 the distance to the Moon).**
  - **Probably will be used to support the 1st Translunar Correction Maneuver (TCM) at 12-20 hours after Trans Lunar Injection (TLI)**
- **Lunar based relay**

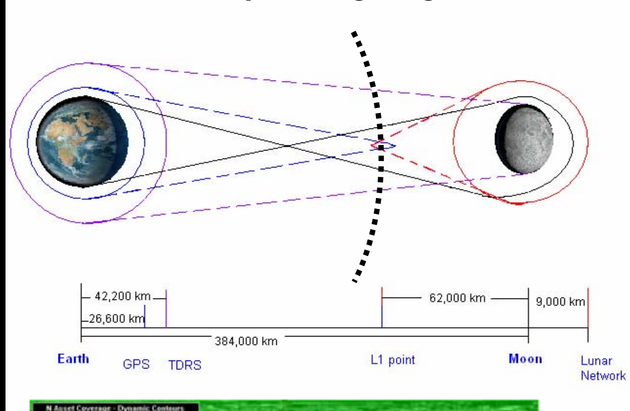


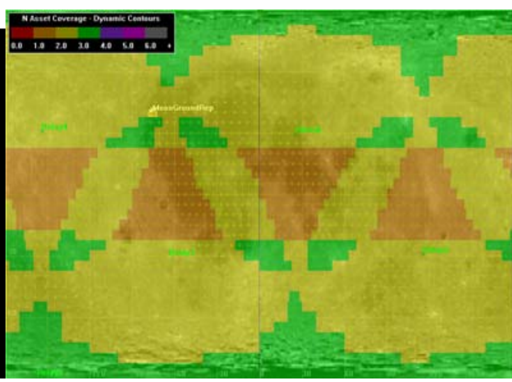
The Vision for Space Exploration: Support Infrastructure - 'another GPS?'

Lunar and Mars Network

- Integrated Navigation and Telecommunications
- Develop a communications capability to provide a substantial increase in data rates and connectivity
- Develop an in situ navigation capability to enable more precise targeting and location information.

GPS up to Lagrange L1?



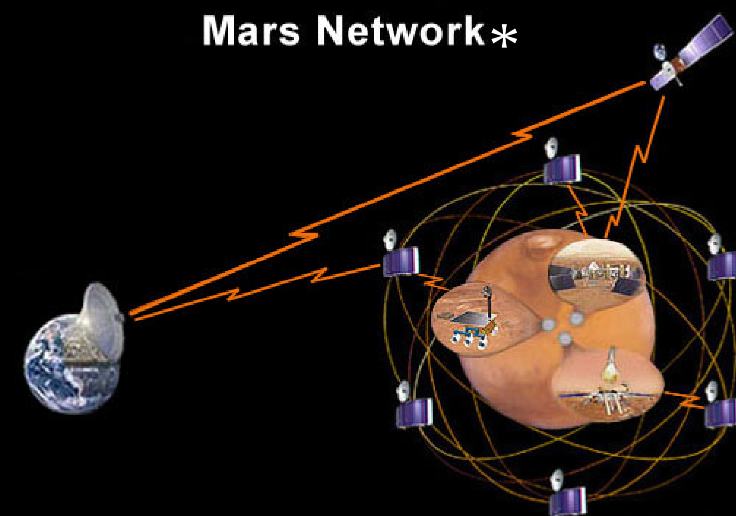


Polar 6/2/1 Coverage

Lunar * Network

Polar 6/2/1 Com/Nav Constellation

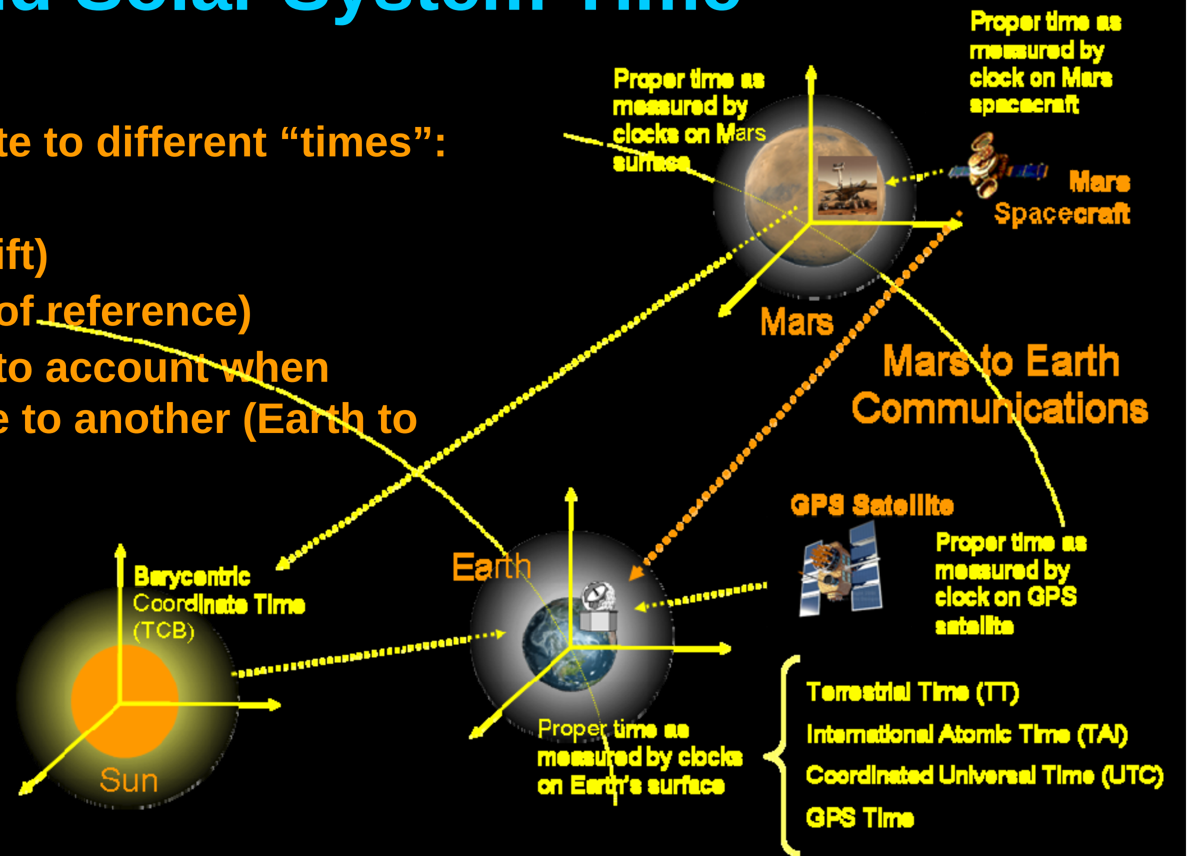
Mars Network*



(*) <u>concept</u> architectures

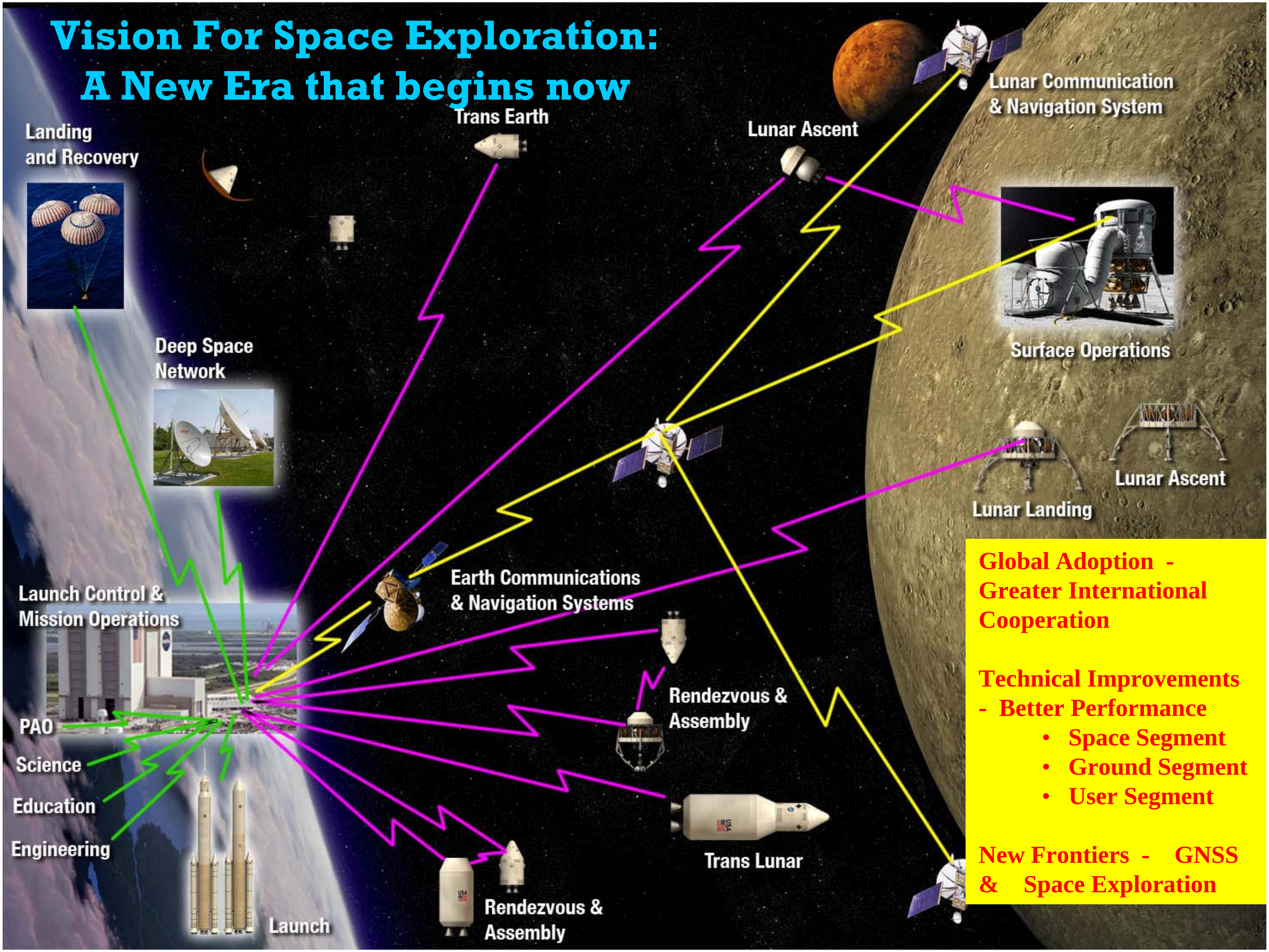
GPS and Solar System Time

Three relativistic effects contribute to different “times”:
(1) Velocity (time dilation)
(2) Gravitational Potential (red shift)
(3) Sagnac Effect (rotating frame of reference)
These effects need to be taken into account when adjusting from one time reference to another (Earth to Mars, Mars to Earth, etc.)



- GPS provides a model for timekeeping and time dissemination
- GPS timekeeping paradigm can be extended to support NASA space exploration objectives
- With appropriate relativistic transformations can provide a common reference system

Objective: Integrated Interplanetary Navigation and Communications


Vision For Space Exploration:
A New Era that begins now
Landing
and Recovery
Trans Earth
Lunar Ascent
Lunar Communication
& Navigation System
Surface Operations
Deep Space
Network
Lunar Ascent
Lunar Landing
Earth Communications
& Navigation Systems
Launch Control &
Mission Operations
Rendezvous &
Assembly
PAO
Science
Education
Engineering
Trans Lunar
Launch
Rendezvous &
Assembly
Global Adoption -
Greater International
Cooperation
Technical Improvements
- Better Performance
• Space Segment
• Ground Segment
• User Segment
New Frontiers - GNSS
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