Space Situational Awareness 2015: GPS Applications in Space

National Aeronautics and Space Administration

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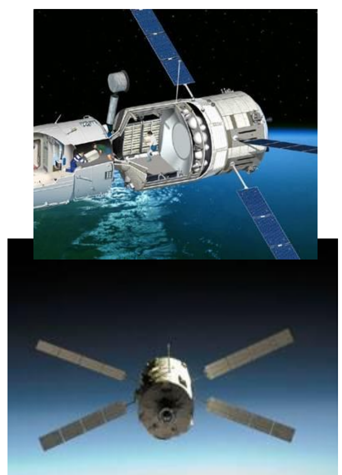
GPS Extends the Reach of NASA Networks to Enable New Space Ops, Science, and Exploration Apps

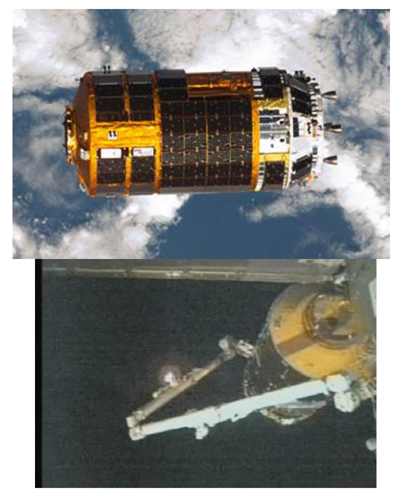
GPS PNT Services Enable:

- **Attitude Determination:** Use of GPS enables some missions to meet their attitude determination requirements, such as ISS
- **Real-time On-Board Navigation:** Enables new methods of spaceflight ops such as rendezvous & docking, station-keeping, precision formation flying, and GEO satellite servicing
- **Earth Sciences:** GPS used as a remote sensing tool supports atmospheric and ionospheric sciences, geodesy, and geodynamics -- from monitoring sea levels and ice melt to measuring the gravity field

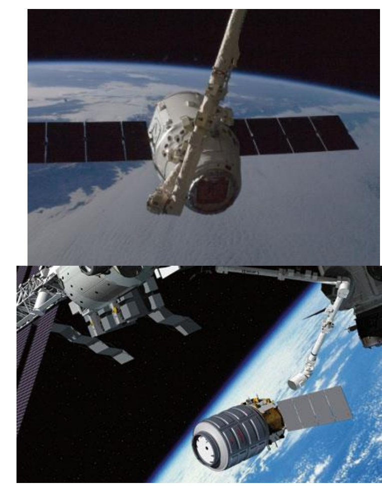
GPS Relative Navigation is used for Rendezvous to ISS



ESA ATV 1st mission to ISS in 2008



JAXA's HTV 1st mission to ISS in 2009



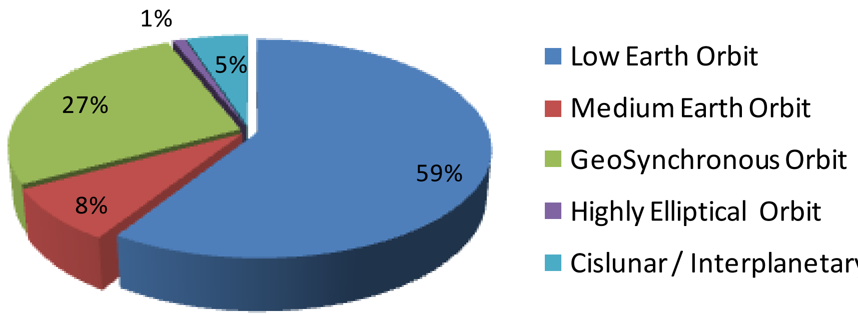
Commercial Cargo Resupply (Space-X & Cygnus), 2012+

Growing GPS Uses in Space: Space Operations & Science

- NASA strategic navigation requirements for science and space ops continue to grow, especially as higher precisions are needed for more complex operations in all space domains
- **Nearly 60%*** of projected worldwide space missions over the next 20 years will operate in LEO
  - That is, inside the Terrestrial Service Volume (TSV)
- **An additional 35%*** of these space missions that will operate at higher altitudes will remain at or below GEO
  - That is, inside the GPS/GNSS Space Service Volume (SSV)
- In summary, approximately **95% of projected worldwide space missions over the next 20 years** will operate within the *GPS service envelope*

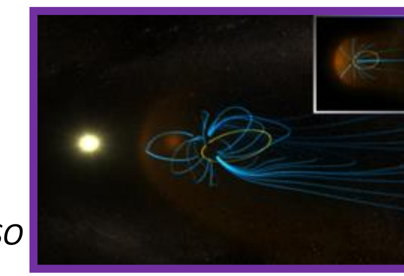
(*) Source: Aerospace America, American Institute of Aeronautics and Astronautics (AIAA), Dec. 2007

20-Year Worldwide Space Mission Projections by Orbit Type*



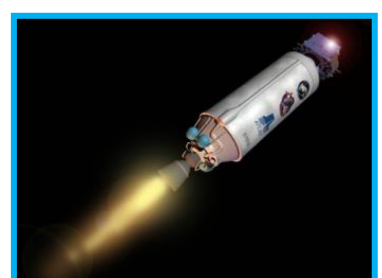
Highly Elliptical Orbits**: Example: NASA MMS 4-satellite constellation.

(**) Apogee above GEO/GSO



Medium Earth Orbit: GNSS Constellations, etc.,

GeoSynchronous: Communication Satellites, etc.,

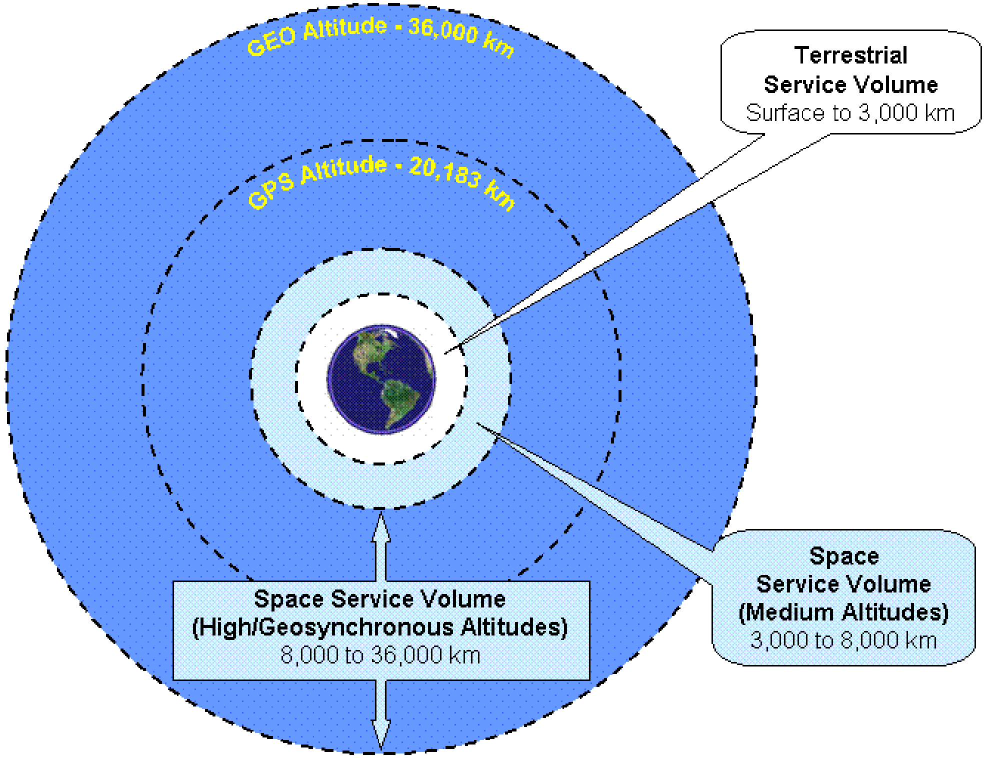


Orbital Transfers: LEO-to-GSO, cislunar transfer orbit, transplanetary injection, etc.

GPS Space Service Volume (SSV) Concept Partnership with DoD

Space Service Volume (Medium Altitudes)

- Four GNSS signals available simultaneously a majority of the time
- GNSS signals over the limb of the earth become increasingly important with altitude
- One-meter orbit accuracies

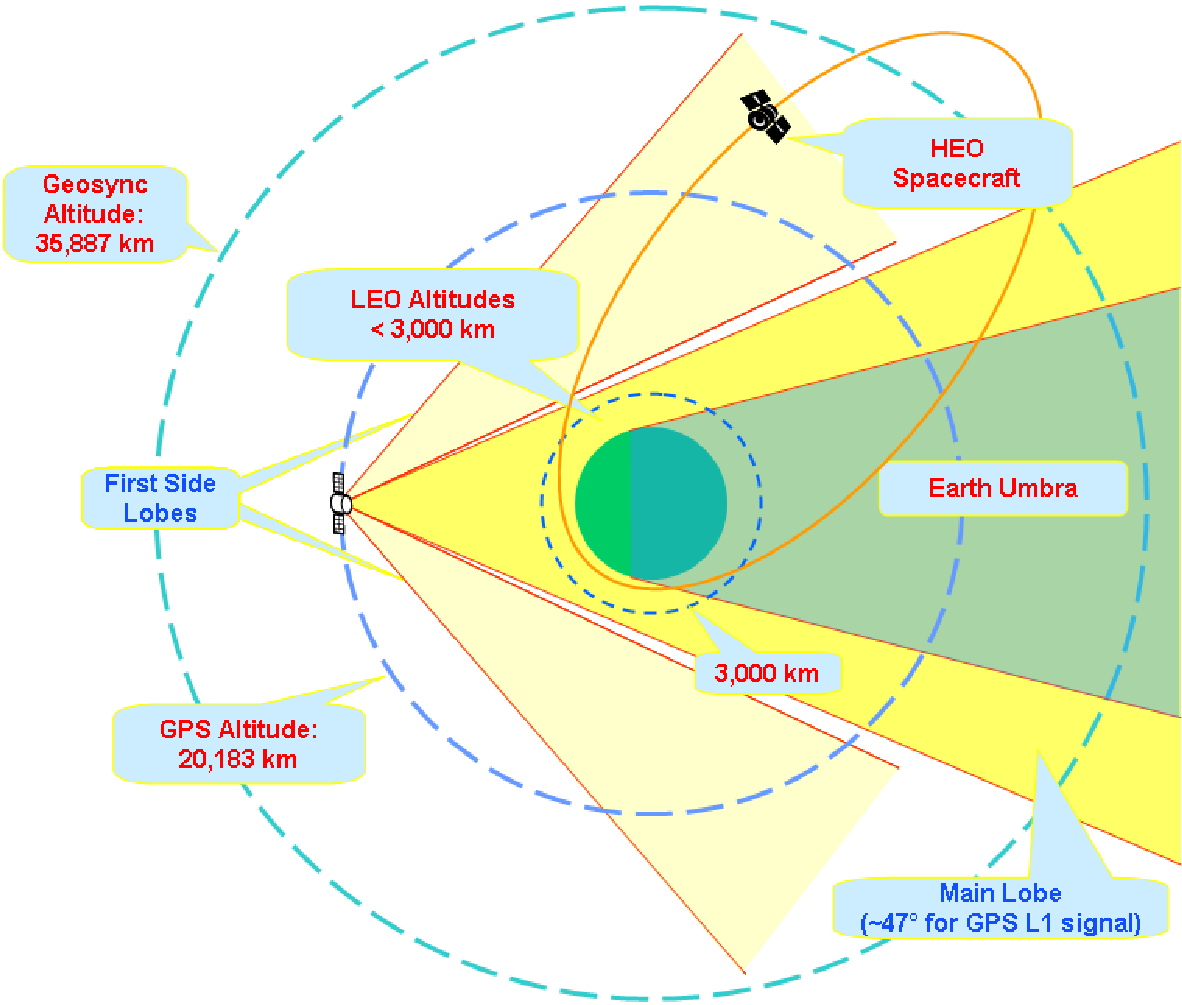


Space Service Volume (High Altitudes)

- Nearly all GNSS signals are received over the limb of the Earth
- Periods when no signals are available
- Signal levels will be weaker than those in Terrestrial Service Volume (TSV)
- Positioning software uses orbital physics, and/or stable on-board oscillators, to achieve orbit accuracy of tens of meters

Space Service Volume: Using GPS Beyond LEO and up to GeoSynchronous Altitude

- **3,000 to 8,000 km Medium Altitudes**
  - Four GPS signals usually available simultaneously, however poor geometry & coverage gaps cause harm
  - 1 meter accuracies still feasible, however space GPS receivers have more difficulty processing signals
  - GPS performance degrades with altitude due to geometry and classic near/far problem
- **8,000 to 36,000 km High Altitudes**
  - Users will experience periods when no GPS satellites are available – Point Positioning no longer available
  - Nearly all GPS signals received over limb of the Earth – High variability in signal strength and beam paths
  - Received power levels are weaker than those in TSV or MEO SSV – Side Lobe processing needed
  - Specially designed receivers will be capable of maintaining accuracies ranging from 10-100 meters depending on receiver sensitivity and local oscillator stability



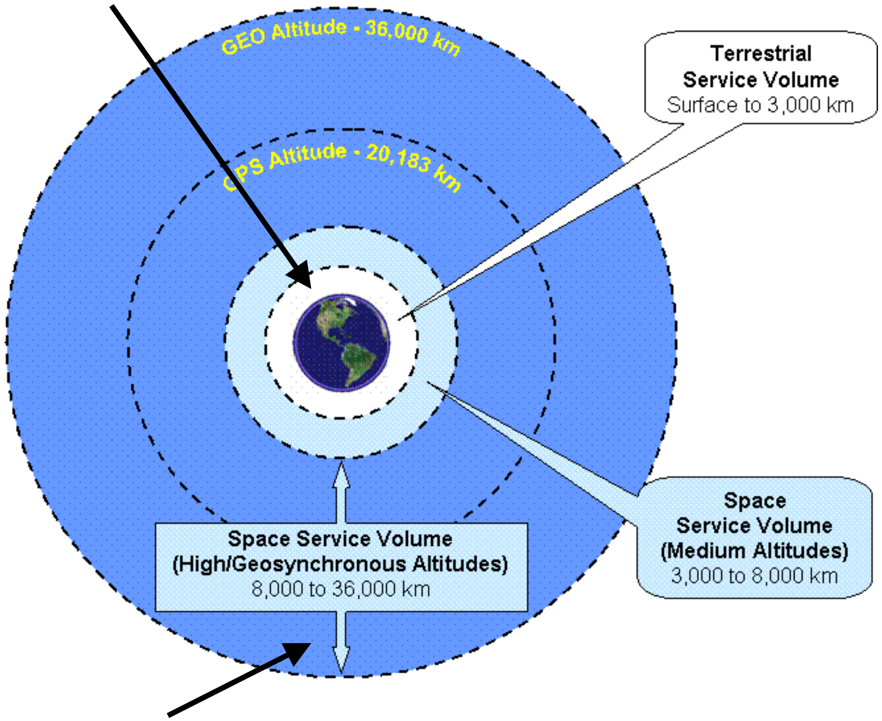
Expanding the GPS Space Service Volume (SSV) into a multi-GNSS SSV

- At least <u>four</u> GNSS satellites in line-of-sight are needed for on-board real-time autonomous navigation
  - GPS currently provides this up to 3,000 km altitude
  - Enables better than 1-meter position accuracy in real-time

- At GSO altitude, only <u>one</u> GPS satellite will be available at any given time.
  - **GPS-only** positioning at GSO is still possible with on-board processing, but only up to approx. 100-meter absolute position accuracy.
  - **GPS** + **Galileo** combined would enable 2-3 GNSS sats in-view at all times.
  - **GPS** + **Galileo** + **GLONASS** would enable at least 4 GNSS sats in-view at all times.
  - **GPS** + **Galileo** + **GLONASS** + **Beidou** would enable > 4 GNSS sats in view at all times. This provides best accuracy and, also, on-board integrity.

- However, this requires:
  - Interoperability among these the GNSS constellations; <u>and</u>
  - Common definitions/specifications for the Space Service Volume (3,000 km to GSO altitude)

≥ 4 GPS satellites in line-of-sight here (surface to 3000 km)



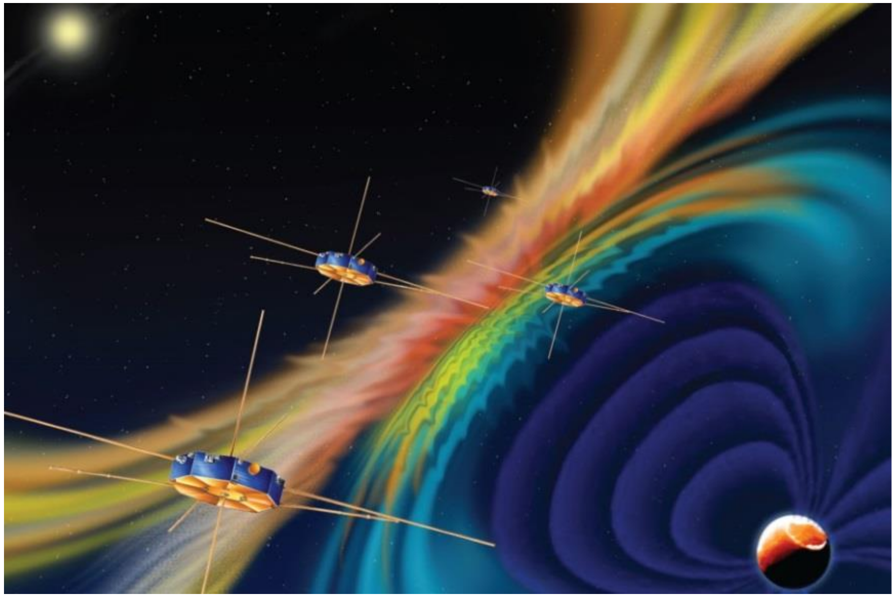
Only 1-2 GPS satellites in line-of-sight here (GSO)

... but, <u>if</u> interoperable, then GPS + Galileo + GLONASS + Beidou provide > 4 GNSS sats in line-of-sight at GSO

Using GPS above the GPS Constellation: NASA MMS Mission – GSFC Team Info

Magnetospheric Multi-Scale (MMS) Mission

- Launched March 12, 2015
- Four spacecraft form a tetrahedron near apogee for performing magnetospheric science measurements (space weather)
- Four spacecraft in highly eccentric orbits
  - Phase 1: 1.2 x 12 Earth Radii (Re) Orbit (7,600 km x 76,000 km)
  - Phase 2: Extends apogee to 25 Re (~150,000 km)

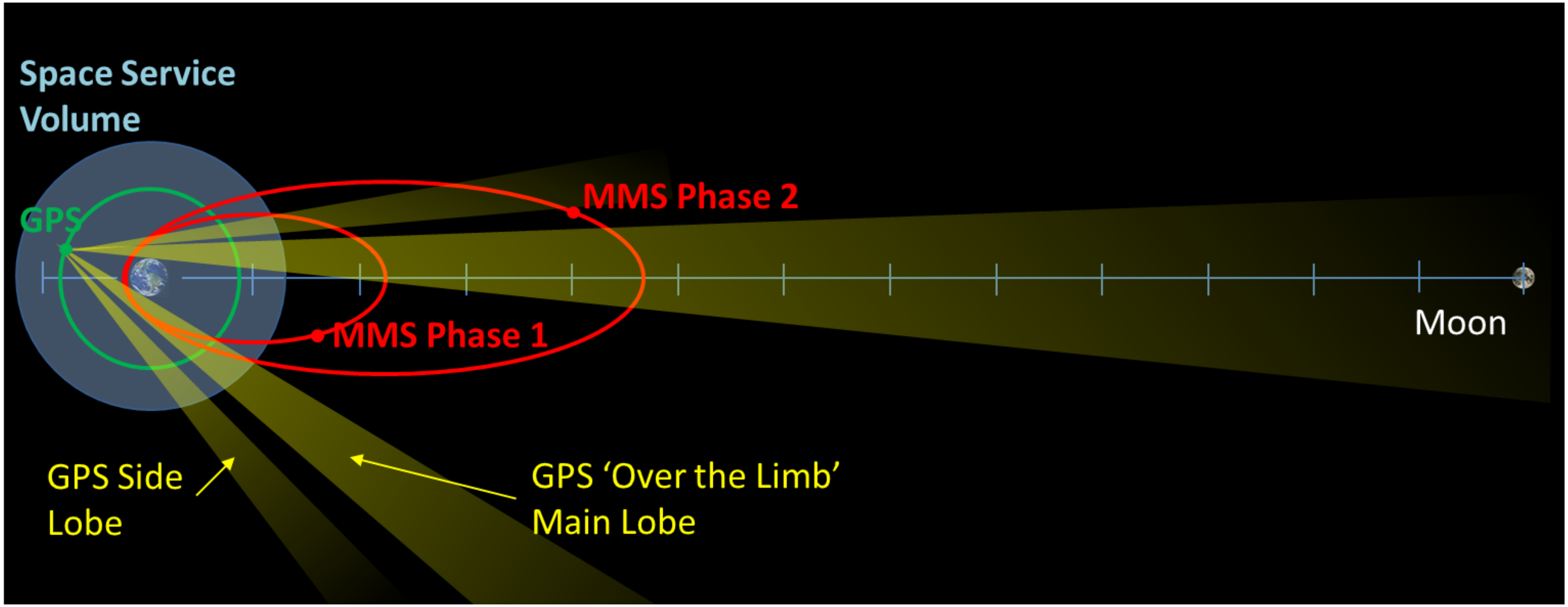


MMS Navigator System

- GPS enables onboard (autonomous) navigation and potentially autonomous station-keeping
- The MMS Navigator system exceeded all of the team's expectations, it has set the record for the highest GPS use in space
- At the highest point of the MMS orbit Navigator set a record for the highest-ever reception of signals and onboard navigation solutions by an operational GPS receiver in space
- At the lowest point of the MMS orbit Navigator set a record as the fastest operational GPS receiver in space, at velocities over 35,000 km/h

MMS Navigator System: Initial Observations

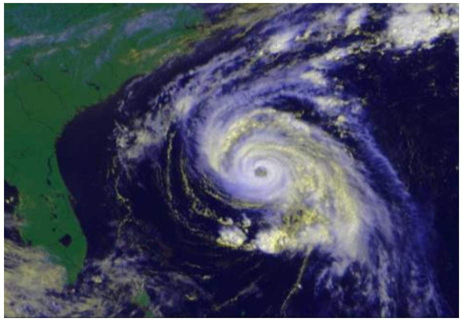
- In the first month after launch, the MMS team began turning on and testing each instrument and deploying booms and antennas.
  - During this time, the team compared the Navigator system with ground tracking systems and found it to be even more accurate than expected
  - At the farthest point in its orbit, some 76,000 km from Earth, Navigator can determine the position of each spacecraft with an uncertainty of better than 15 meters
  - The receivers on MMS have turned out to be strong enough that they consistently track transmissions from eight to 12 GPS satellites – excellent performance when compared to pre-flight predictions of frequent drop outs during each orbit



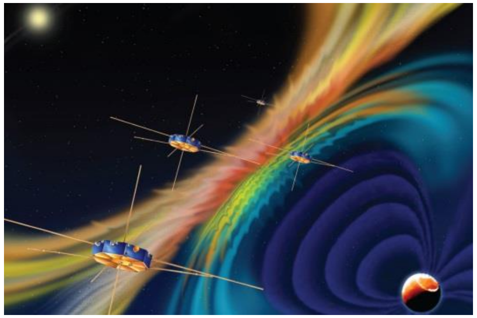
Why is the Space Service Volume Important?

SSV specifications are crucial for providing real-time GNSS navigation solutions in High Earth Orbit

- **Supports increased satellite autonomy for missions, lowering mission operations costs**
- **Significantly improves vehicle navigation performance in these orbits**
- **Enables new/enhanced capabilities and better performance for future missions, such as:**



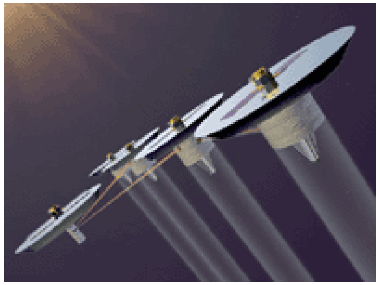
Improved Weather Prediction using Advanced Weather Satellites



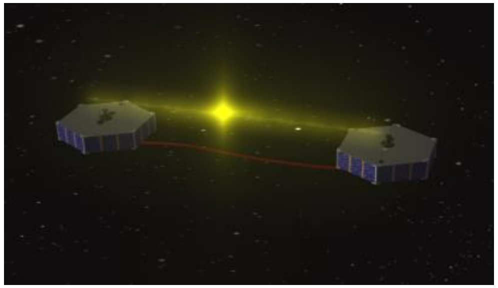
Space Weather Observations

Astrophysics Observations

En-route Lunar Navigation Support

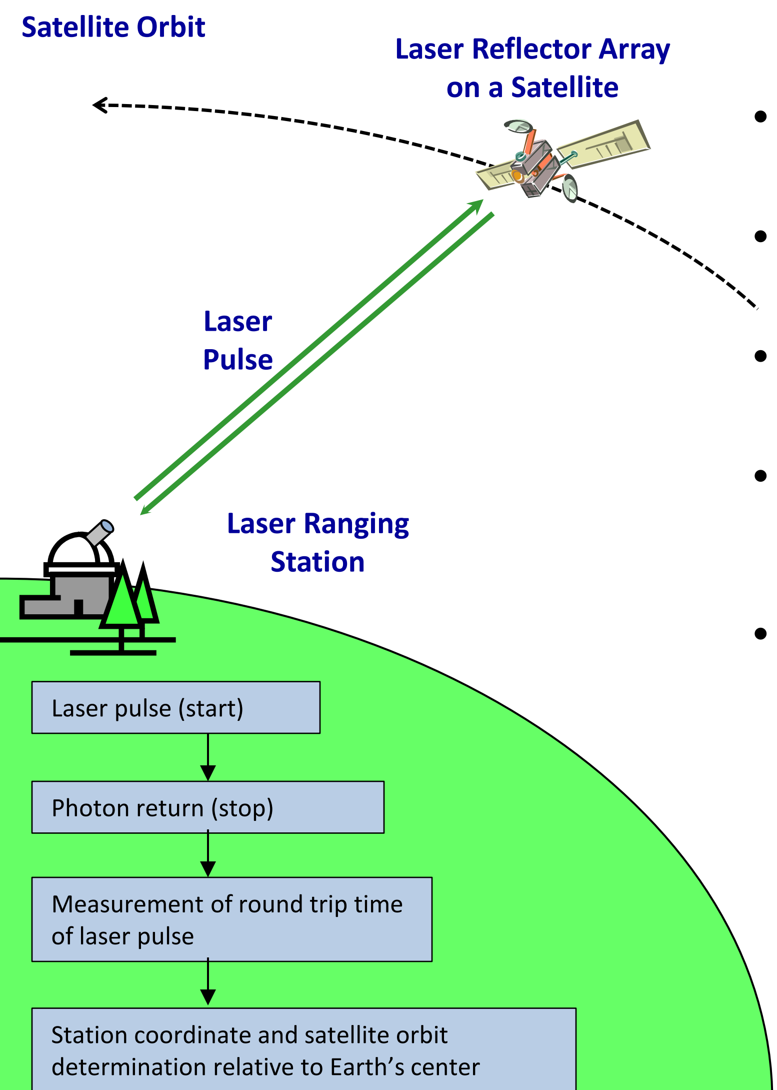


Formation Flying & Constellation Missions

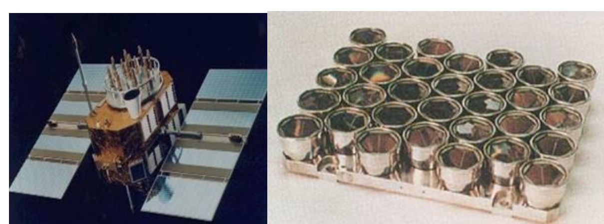


Closer Spacing of Satellites in Geostationary Arc

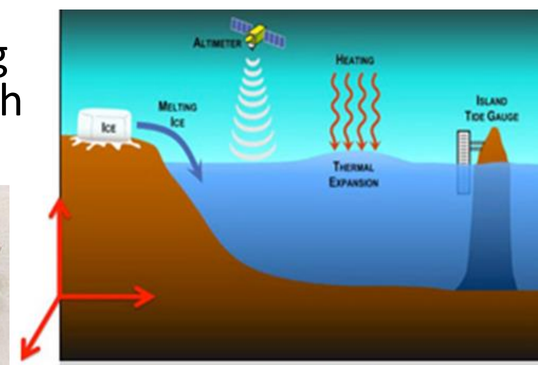
Satellite Laser Ranging (SLR) on GPS III



- Laser ranging to GNSS satellites enables the comparison of optical laser measurements with radiometric data, identifying systemic errors
- Post-processing this data allows for refining station coordinates, satellite orbits, and timing epochs
- The refined data enables improved models and reference frames
- This results in higher PNT accuracies for all users, while enhancing interoperability amongst constellations
- NASA Administrator Bolden worked with Air Force Gen Shelton & Gen Kehler to approve Laser Reflector Arrays (LRAs) onboard GPS III
- Plans are now underway to deploy LRAs on GPS III starting with Space Vehicle 9 for launch in the 2020 timeframe



GPS 35/36 (US Air Force)



Space Geodesy provides positioning, navigation, and timing reference systems and Earth system observations

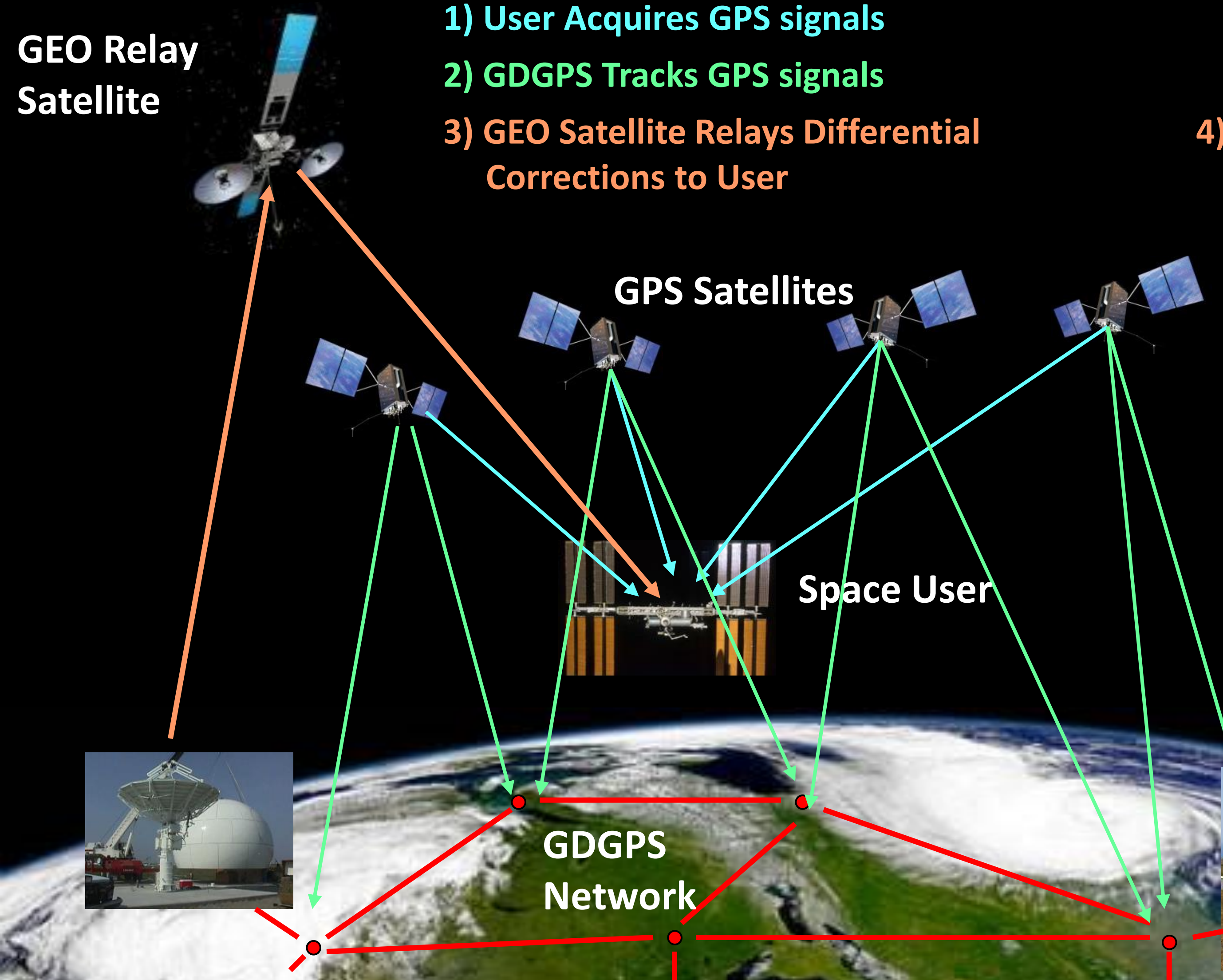
Augmenting GPS in Space with TASS

TDRSS Augmentation Satellite Service (TASS)

1) User Acquires GPS signals

2) GDGPS Tracks GPS signals

3) GEO Satellite Relays Differential Corrections to User



4) Evolved TASS could incorporate:
- GPS integrity information
- Tracking satellite information (health, ephemerides, maneuvers)
- Space weather data
- Solar flux data
- Earth orientation parameters
- User-specific commands
- PRN ranging code

Closing Remarks

- NASA and other space users increasingly rely on GPS/GNSS over an expanding range of orbital applications to serve Earth populations in countless ways
- The United States will continue to work towards maintaining GPS as the “gold standard” as other international PNT constellations come online
- NASA is proud to work with the USAF to contribute making GPS services more accessible, interoperable, precise, and robust for all appropriate users
- GPS precision enables incredible science, which in turn allows NASA to use this science to improve GPS performance

http://www.gps.gov/

“On Target with GPS Video”

www.youtube.com/watch?v=_zM79vSnD2M