SATELLITE® 2013

The On-Going Modernization of GPS

James J. Miller, NASA Headquarters

Panel Discussion: The On-Going Modernization of GPS

GPS is a capability that almost everyone uses on a daily basis. While the associated applications are common knowledge, the advancement and modernization of GPS is a constant, ongoing mission.

- **Mr. Jim Miller**, Deputy Director, Policy & Strategic Communications, Space Communications and Navigation (SCaN), NASA Headquarters
- **Dr. Scott Pace**, Director, Space Policy Institute, Elliott School of International Affairs, The George Washington University
- **Dr. Linda Thomas**, Sr. Research Engineer, Naval Center for Space Technology, Naval Research Laboratory
- **Dr. Chris Hegarty,** Director for CNS Engineering & Spectrum, MITRE Corporation

Space Communications & Navigation: SCaN Networks, Spectrum, Standards, & PNT Policy

- **Networks:** Responsible for acquiring and operating NASA space communications and navigation network infrastructure

Near Earth Network - NASA, commercial, and partner ground stations and integration systems providing space communications and tracking services to orbital and suborbital missions	**Space Network** - constellation of geosynchronous relays (TDRSS) and associated ground systems	**Deep Space Network** - ground stations spaced around the world providing continuous coverage of satellites from Earth Orbit (GEO) to the edge of our solar system

- **Spectrum & Standards:** Manage NASA radio spectrum and provide technical expertise in international standards setting bodies

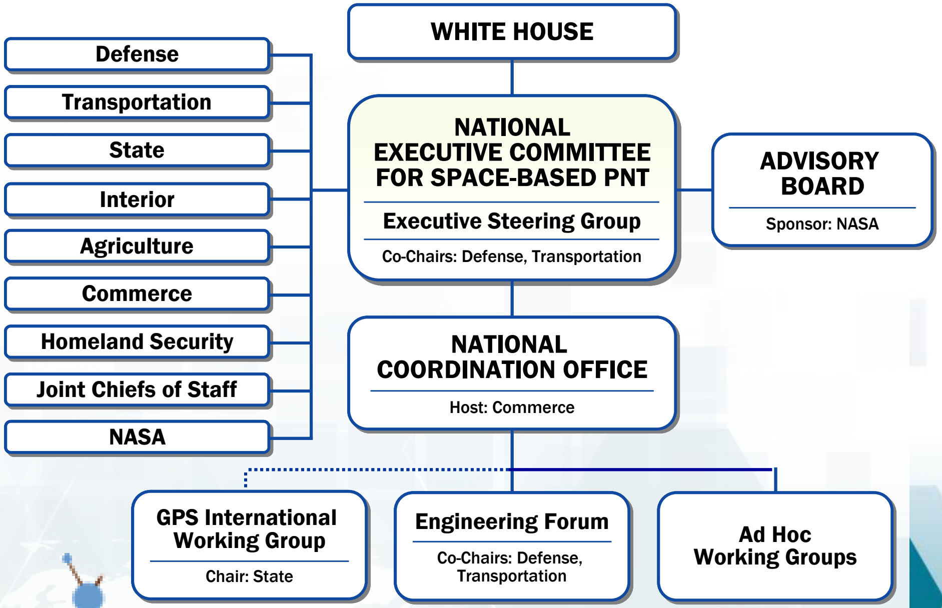
- **PNT Policy:** Coordinate NASA's interagency and international GPS activities and serve on Positioning, Navigation, and Timing (PNT) Executive Committee

NASA's Role: U.S. PNT / Space Policy

- The 2004 U.S. Space-Based Positioning, Navigation, and Timing (PNT) Policy tasks the NASA Administrator, in coordination with the Secretary of Commerce, ***to develop and provide requirements for the use of GPS and its augmentations to support civil space systems.***

- The 2010 National Space Policy reaffirms PNT Policy commitments to GPS service provisions, international cooperation, and interference mitigation.

- NASA is engaging with other space agencies to seek similar benefits from other PNT constellations to maximize performance, robustness, and interoperability for all.



2010 U.S. National Space Policy

Space-Based PNT Guideline: Maintain leadership in the service, provision, and use of GNSS

- Provide civil GPS services, free of direct user charges
  - Available on a continuous, worldwide basis
  - Maintain constellation consistent with published performance standards and interface specifications
  - Foreign PNT services may be used to complement services from GPS
- Encourage global ***compatibility*** and ***interoperability*** with GPS
- Promote transparency in civil service provision
- Enable market access to industry
- Support international activities to detect and mitigate harmful interference

GPS Constellation Status

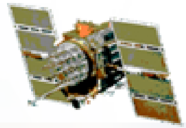
- Robust constellation
  - 31 space vehicles currently in operation
  - 9 GPS IIA, 12 GPS IIR, 7 GPS IIR-M, 3 GPS IIF
  - 3 additional satellites in residual status
- Extensive civil and international cooperation and coordination
  - 1 billion civil/commercial users
  - Countless applications … and growing
- Global GPS civil service performance commitment met continuously since Dec. 1993

GPS IIF-3 Launch
Oct. 4, 2012

GPS Modernization: Space and Control Segments

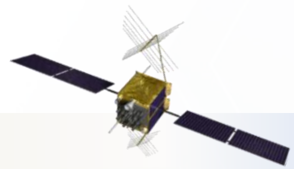
Space Segment

1995 — GPS IIA



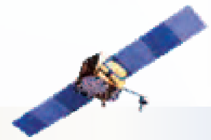
- Standard Service
  - Single frequency (L1)
  - Coarse acquisition code navigation
- Precise Service
  - Y-Code (L1Y & L2Y)

2005 — GPS II R / IIR-M



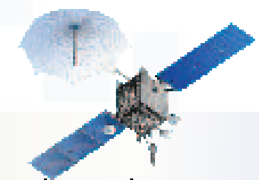
- IIA/IIR capabilities plus
- 2nd civil signal (L2C)
- M-Code (L1M & L2M)

2010 — GPS IIF



- IIR-M capability plus
- 3rd civil signal (L5)
- 12 year design life

2014 - 2025 — GPS III

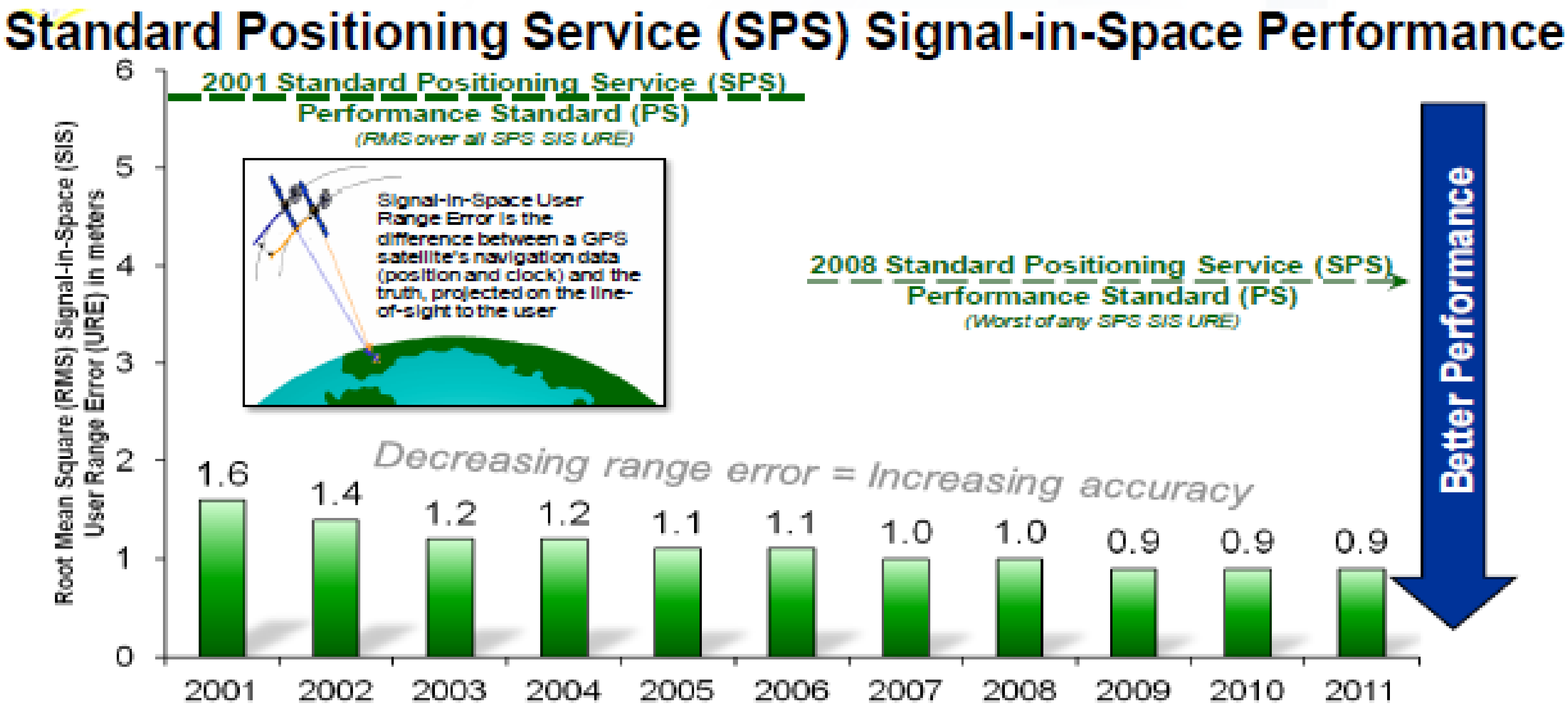


- Backward compatible
- 4th civil signal (L1C)
- Increased accuracy
- Increased integrity
- Increased AJ
- 15 yr design life

Control Segment

Legacy Control System	Architecture Evolution Plan (AEP)	Next Generation Operational Control System (OCX)

GPS Signal in Space Performance: Continual Improvements

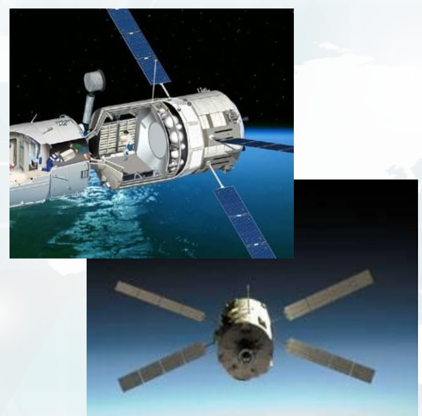


GPS Extends the Reach of Communications Networks to Enable New Space Ops, Science, and Exploration Apps

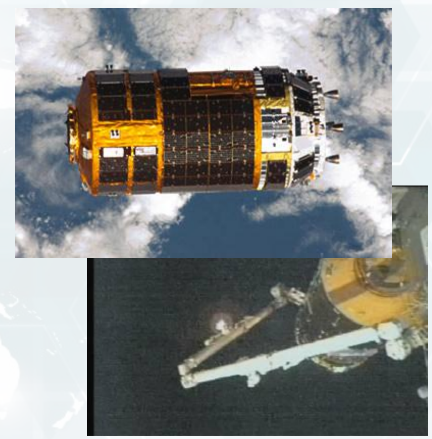
GPS services enable:

- **Real-time On-Board Autonomous Navigation:** Allows NASA to maximize the "autonomy" of spacecraft and reduces the burden and costs of network operations. It also enables new methods of spaceflight such as precision formation flying and station-keeping
- **Attitude Determination:** Use of GPS enables some missions to meet their attitude determination requirements, such as ISS
- **Earth Sciences:** GPS used as a remote sensing tool supports atmospheric and ionospheric sciences, geodesy, and geodynamics -- from monitoring sea level heights and climate change to understanding the gravity field

GPS Relative Navigation is Used for Rendezvous to ISS



ESA ATV 1st mission to ISS in 2008

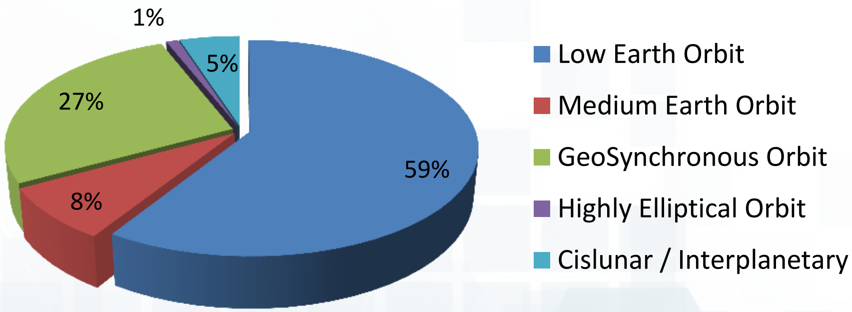


JAXA's HTV 1st mission to ISS in 2009

Growing GPS Uses in Space: Space Operations & Science

- Projections show that over the next 20 years:
  - Approximately 60% of space missions will operate in LEO (< 3,000 km)
  - Approximately 35% of space missions will operate at higher altitudes up to GSO (36,000 km).

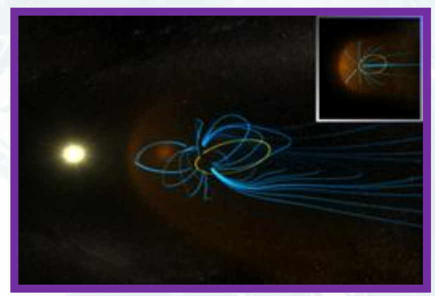
20-Year Worldwide Space Mission Projections by Orbit Type



Low Earth Orbit: Earth Observation, LEO communication constellations, etc.

Medium Earth Orbit: GNSS Constellations

GeoSynchronous: Communication Satellites, Regional Navigation Satellite Systems



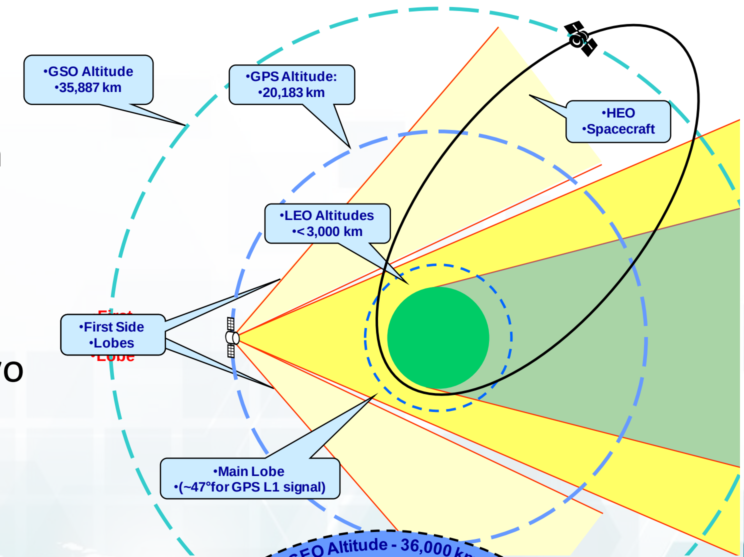
Highly Elliptical Orbits*: Examples: NASA MMS 4-satellite constellation, communication satellites, etc.

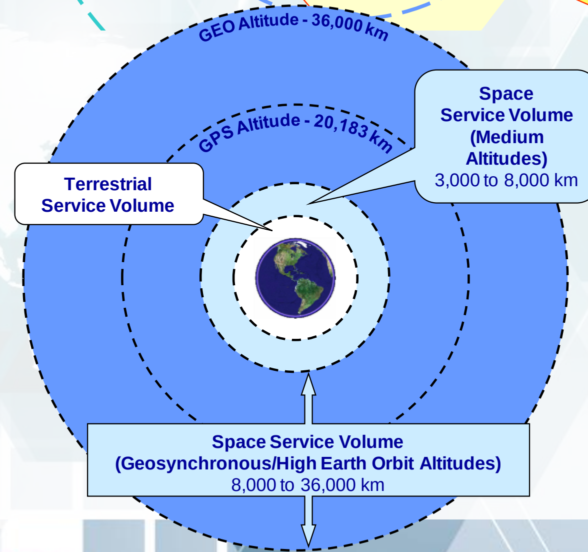
(*) with Apogee above GEO/GSO

Orbital Transfers: LEO-to-GEO, cislunar transfer orbit (figure), transplanetary injection, etc.

GPS/GNSS Space Service Volume: Navigation Beyond LEO

- When operating at higher orbits we are tracking the GPS signals broadcast "over the limb" of the Earth. Sometimes referred as 'above the GPS constellation' navigation. Earth is blocking most of the GPS signals, so the availability is much smaller.
- Due to GPS performance variations based on altitude and geometry, the overall GPS SSV is in turn subdivided into two separate service domains.
- SSV for Medium Altitudes:
  - 3,000 to 8,000 km altitude
  - Visible GPS satellites can be present both above & below the user
  - One-meter orbit accuracies are feasible
- SSV for GSO/HEO Altitudes:
  - 8,000 to 36,000 km altitude
  - Visible GPS satellites are predominantly below the user
  - A properly designed receiver should be capable of accuracies ranging between 10 and 100 meters depending on receiver sensitivity and local oscillator stability

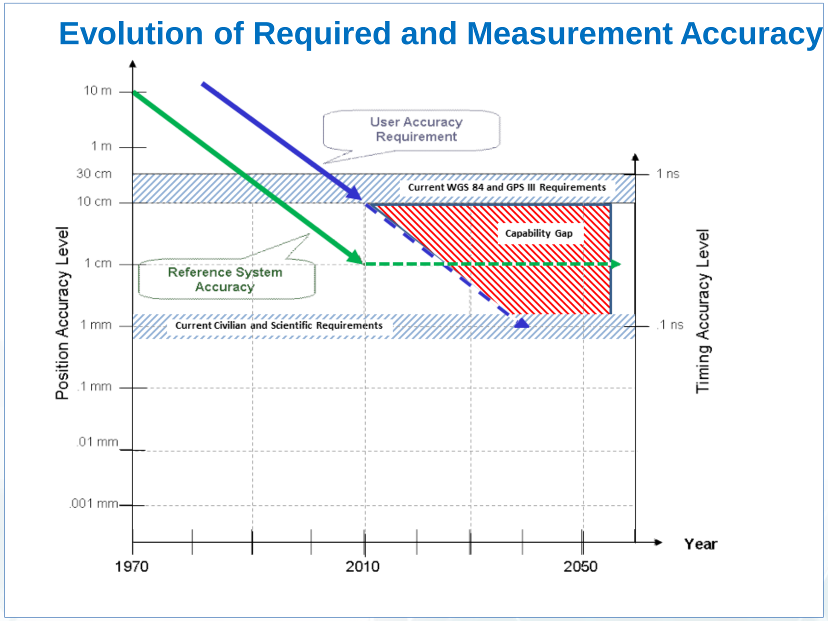


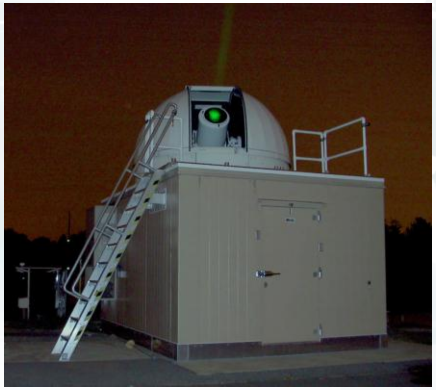


Satellite Laser Ranging to GPS

Laser Ranging to GNSS enables:

- Comparison of collocated radiometric and optical measurements used for model improvements
- Isolation of systematic errors in GNSS constellations and improves the reference frame accuracy
- Improved models and reference frames necessary to support civilian and scientific requirements for higher PNT accuracy
  - Global sea height change measurement from space requires 1 mm/year precision, so reference frame needs to be constant to 0.1 mm/yr

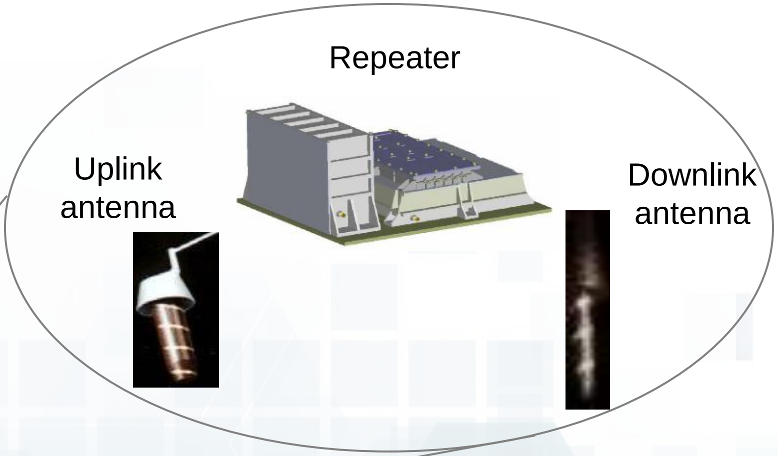


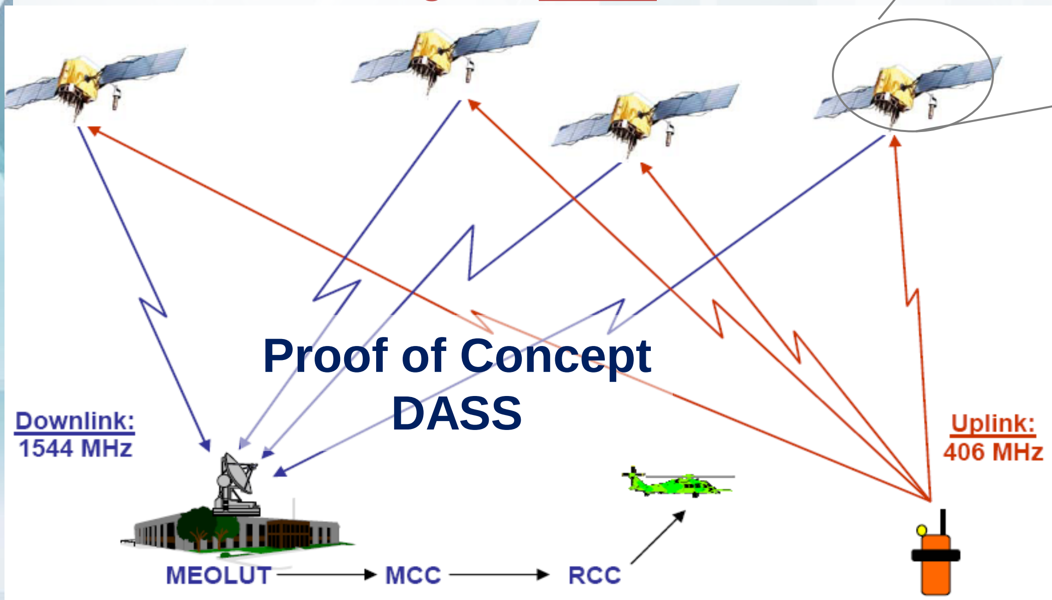


Search and Rescue from Space with GPS: Distress Alerting Satellite System (DASS)

SARSAT Mission Need:

- More than 800,000 emergency beacons in use worldwide by the civil community – most mandated by regulatory bodies
- Expect to have more than 100,000 emergency beacons in use by U.S. military services
- Since the first launch in 1982, current system has contributed to saving over _40,000_ lives worldwide





Status:

- SARSAT system to be discontinued as SAR payload implemented on Galileo
- NASA (with over $35M invested) and Air Force developed options for U.S. SAR system
- **Successful NASA Proof-of-Concept DASS on GPS IIR(M) and IIF satellites**
- **Transition to GPS III transition underway ; known as GPS-SAR**

Augmenting GPS in Space with TASS

- **TDRSS Augmentation Service for Satellites (TASS)**
- **Supports <u>all</u> space users**
  - **Communication channel tracking / ground-in-the-loop users**
  - **GNSS-based on-board autonomous navigation**

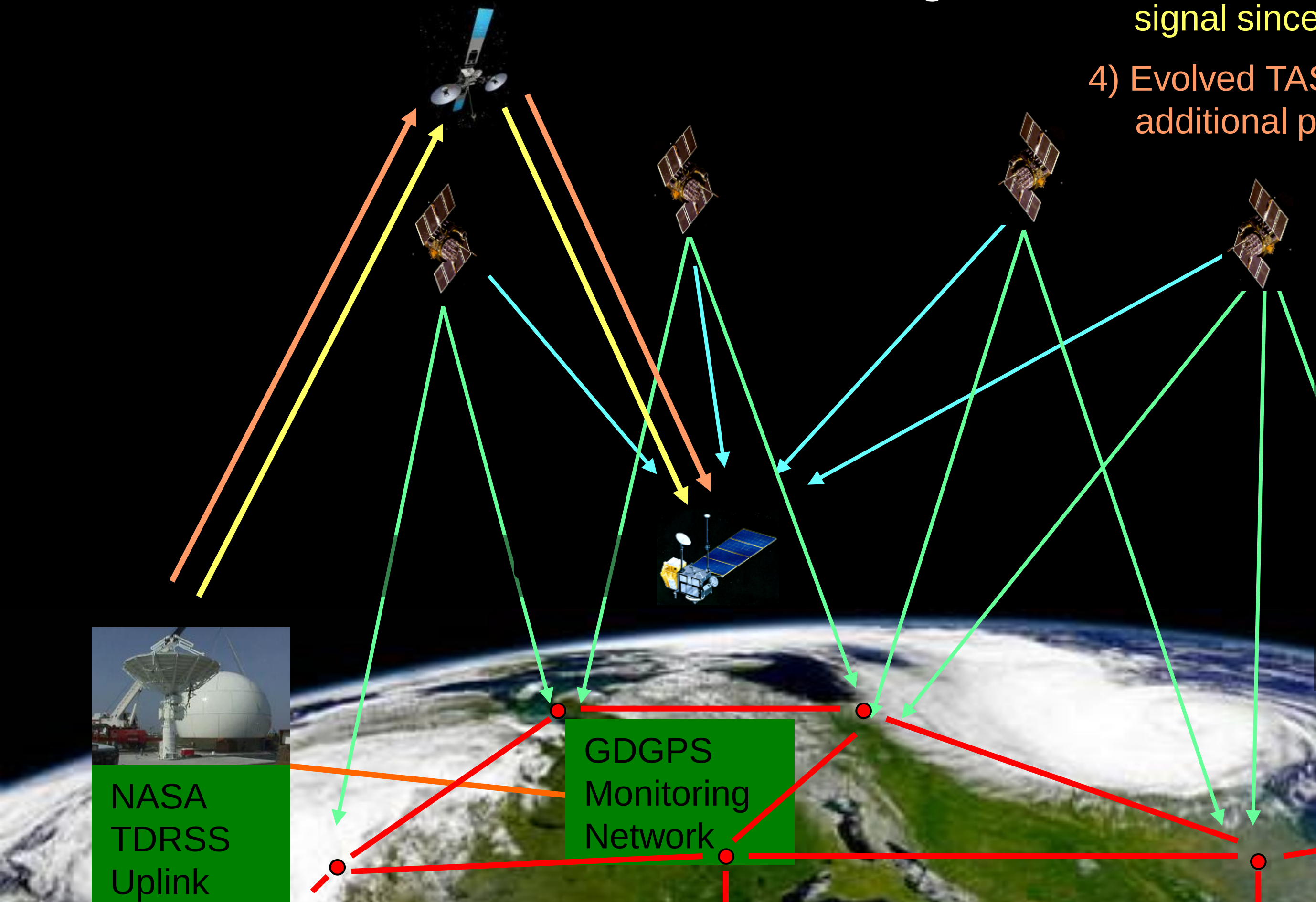
1) User spacecraft acquires GNSS signals

2) A ground network monitors GNSS satellites

3) GEO Space Network satellites relay GNSS differential corrections to space users on an S-band signal (demo signal since 2006)

4) Evolved TASS signal incorporates additional parameters

- GNSS integrity Information
- Tracking Satellite Information (health, ephemerides, maneuvers)
- Space Weather Data
- Solar Flux Data
- Earth Orientation Parameters
- User-specific Command Fields
- Pseudorandom Noise (PRN) ranging code



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