Roadmap to Development of NASA GPS PNT Capabilities

48th Civil Global Positioning System Service Interface Committee

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Key Points

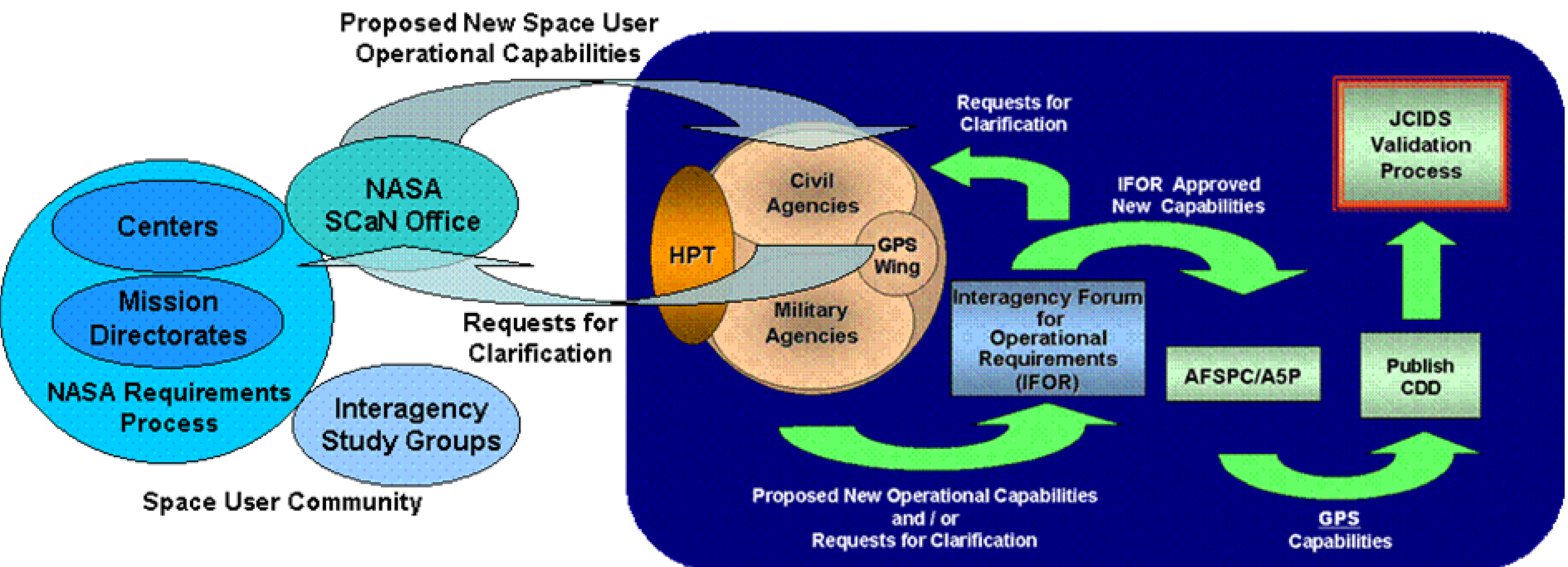
- Defining NASA Navigation Requirements from a "Network Perspective"

- Developing a "Near Earth Nav Roadmap" with GPS as a core enabler

- Organizing NASA GPS/PNT activities to support future space and science missions

NASA "Requirements Process" for GPS

- U.S. PNT Policy tasks the NASA Administrator to take the lead in developing GPS requirements for civil space users.
- Space Comm & Nav responsible for coordination among the NASA centers, and U.S. agencies, to develop and submit civil space requirements into the GPS requirements process.



GPS Requirements Process

Defining NASA Nav Requirements
Nav Workshop ⇨ Nav Roadmap

- **Define "Navigation"** as the integrated positioning, nav, and timing measurements required to fulfill a mission
- **Initiate a NASA-wide survey** of current and planned Navigation technologies and techniques
- **Catalogue and organize nav applications** according to space environment, service domain, and requisite timeframe
- **Conduct Workshops** to identify potential synergies, gaps, and interdependencies of Nav applications. Affects:

  (1) infrastructure (2) services (3) standards

  (4) systems planning & technology investment

- **Develop Strategic "Navigation Roadmap"** that identifies Nav mission interdependencies, promotes collaboration, and leverages resource needs to enable flexible architecture options

GPS is core to the Near Earth Navigation Environment

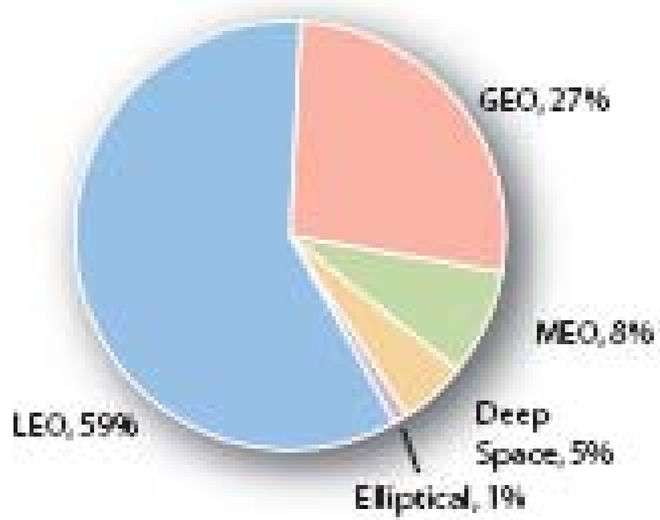
- Approx. 95% of projected worldwide space missions 2008-2027 to be Earth-orbiting
- Nearly 60% of missions will be in LEO well below 3000km (upper limit of GPS Terrestrial Service Volume)
- The purpose of the Near Earth Navigation Roadmap is to provide a framework for developing GPS PNT capabilities in space for the next 25 years
- Objective is to fully integrate these capabilities with NASA's infrastructure

WORLDWIDE MISSION MODEL: 2008-2027

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	Total
Total Payloads	257	270	308	234	157	75	105	81	68	42	43	37	29	32	22	27	50	47	51	39	1,974
PAYLOADS BY TYPE																					
Commercial	79	95	113	58	77	36	56	45	35	17	14	8	10	17	14	15	38	37	35	26	825
Civil	114	112	111	146	57	26	32	23	17	12	17	6	13	7	5	4	7	6	8	7	730
Military	43	49	41	28	22	13	17	12	16	13	12	23	6	8	3	8	5	4	8	6	337
University and Other	21	14	43	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	82
Total	257	270	308	234	157	75	105	81	68	42	43	37	29	32	22	27	50	47	51	39	1,974
PAYLOADS BY ORBIT																					
Low Earth Orbit	169	157	207	168	93	36	62	38	45	15	21	23	12	9	8	7	34	27	25	16	1,172
Geostationary	65	72	59	37	42	27	34	29	18	18	16	9	11	16	13	15	13	11	11	14	530
Medium Earth Orbit	6	18	20	19	11	6	5	7	2	5	2	5	2	4	1	5	2	9	12	8	149
Deep Space	12	18	15	7	10	5	4	3	2	4	4	0	4	2	0	0	1	0	3	0	94
Elliptical	5	5	7	3	1	1	0	4	1	0	0	0	0	1	0	0	0	0	0	1	29
Total	257	270	308	234	157	75	105	81	68	42	43	37	29	32	22	27	50	47	51	39	1,974
PAYLOADS BY MASS (KG)																					
1-500	95	90	138	117	41	2	14	6	5	0	3	0	3	0	1	1	0	0	1	0	517
501-1,000	33	66	68	42	47	20	41	26	31	9	10	13	1	2	0	0	27	28	27	17	508
1,001-5,000	94	87	72	51	48	31	35	39	22	27	23	18	18	22	15	20	17	12	17	16	684
More than 5,000	35	27	30	24	21	22	15	10	10	6	7	6	7	8	6	6	6	7	6	6	265
Total	257	270	308	234	157	75	105	81	68	42	43	37	29	32	22	27	50	47	51	39	1,974
PAYLOADS BY WORLD REGION																					
North America	107	73	114	155	62	30	44	39	40	13	16	17	9	7	4	6	30	24	23	13	826
Europe	54	93	95	37	32	19	13	18	8	6	7	8	7	7	5	5	6	11	11	14	456
Asia and Pacific Rim	47	47	54	16	16	18	18	10	8	12	11	3	6	5	4	5	6	3	5	3	297
Russia and CIS	35	34	28	20	40	6	26	12	9	9	8	9	6	10	6	8	7	6	10	6	295
Africa and Middle East	12	5	11	3	5	1	1	2	3	0	1	0	1	2	3	2	1	1	1	2	57
Latin America and Caribbean	2	18	6	3	2	1	3	0	0	2	0	0	0	1	0	1	0	2	1	1	43
Total	257	270	308	234	157	75	105	81	68	42	43	37	29	32	22	27	50	47	51	39	1,974

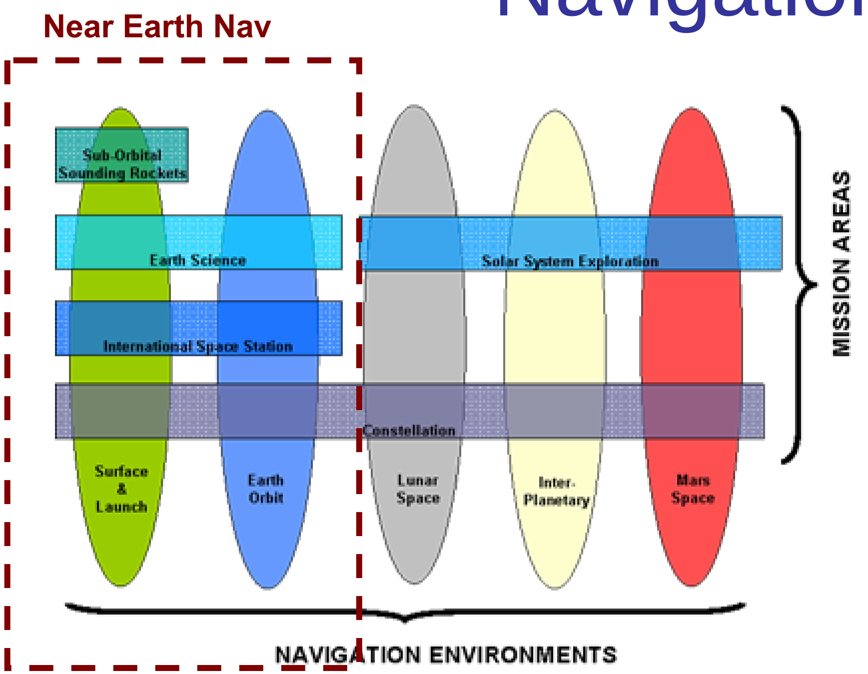
Now

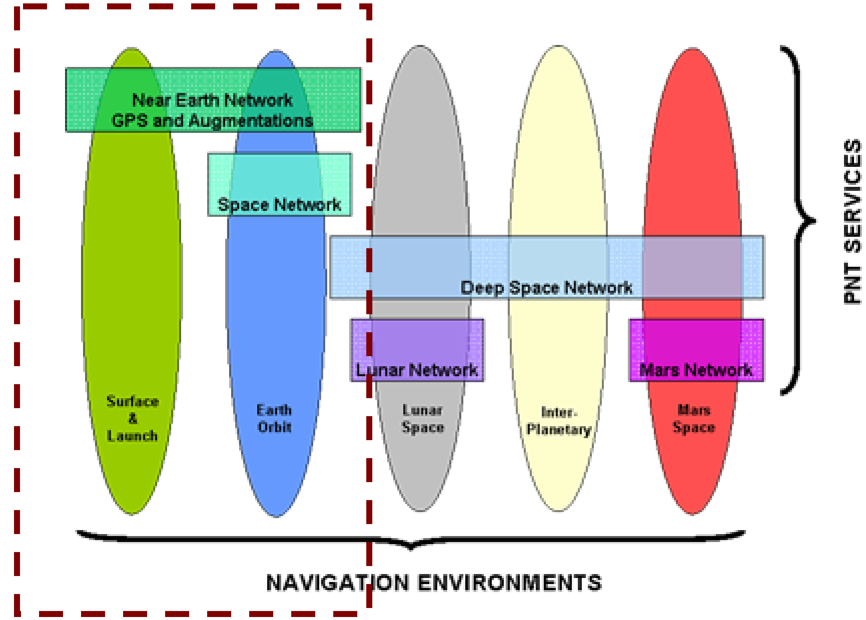
Projected 2025

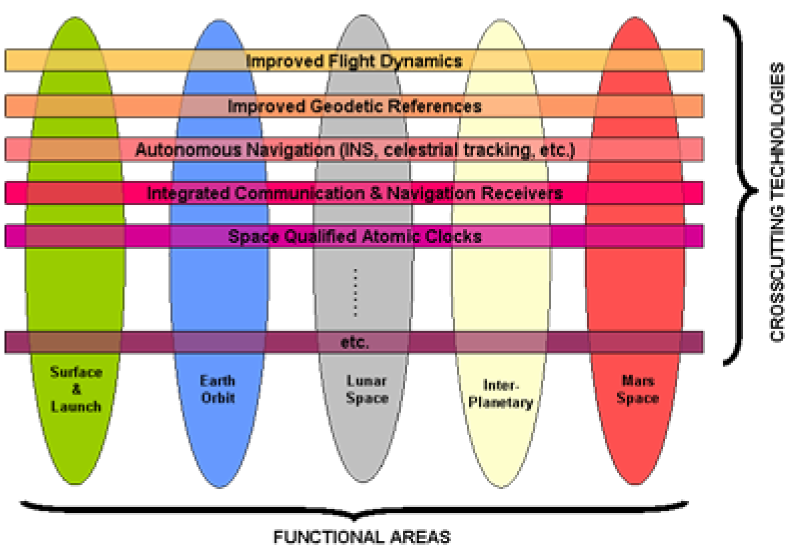


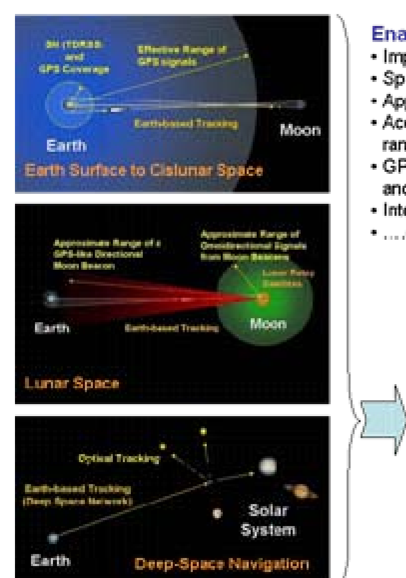
(*) Source: Aerospace America, Dec. 2007

Navigation Environments

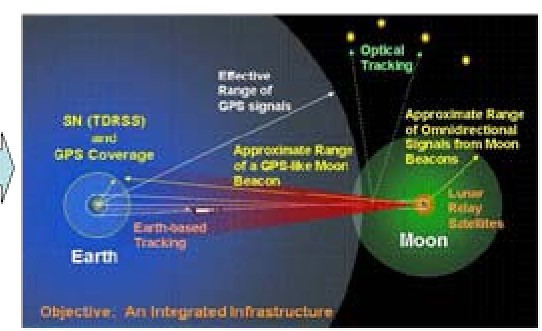




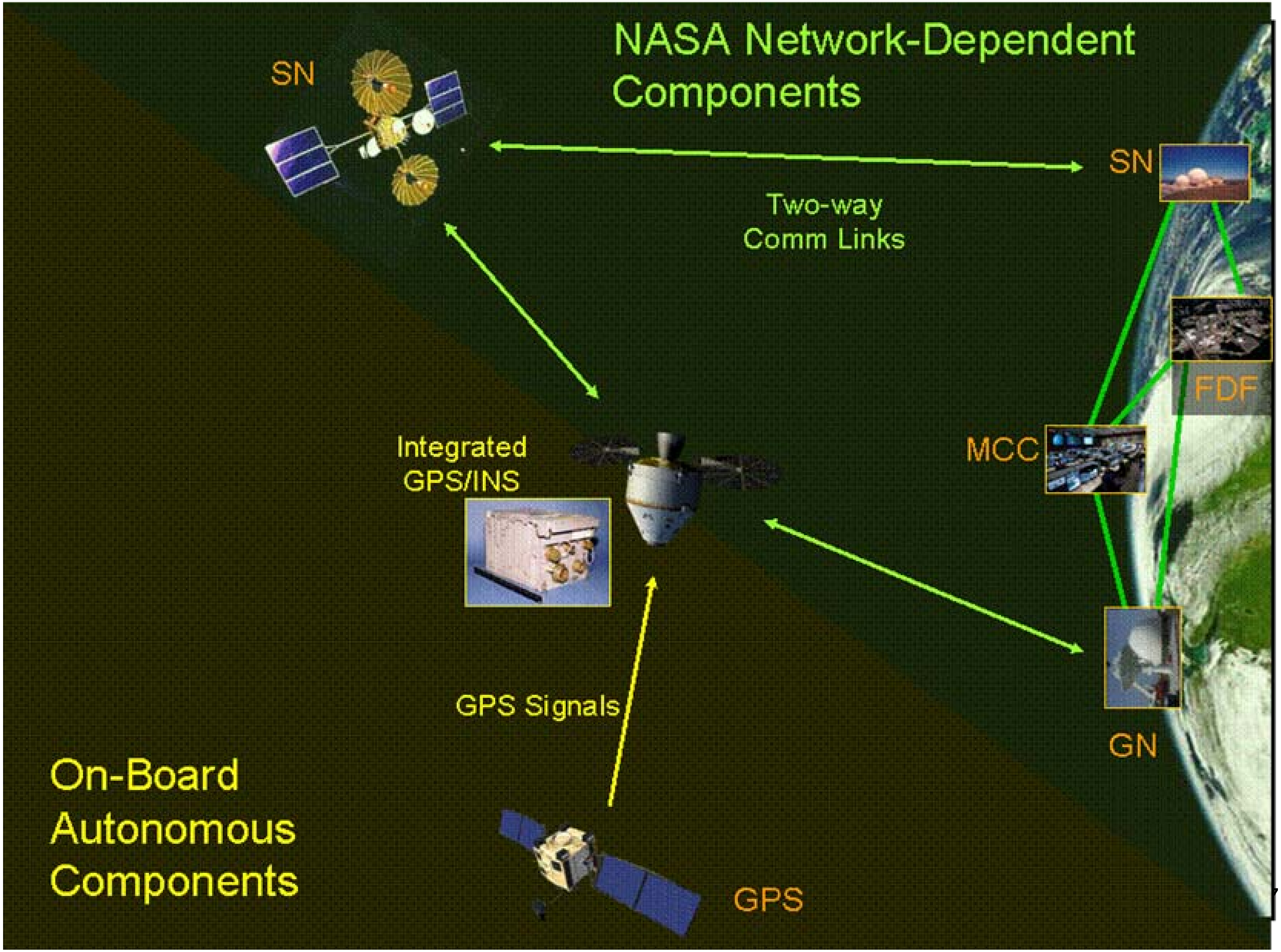




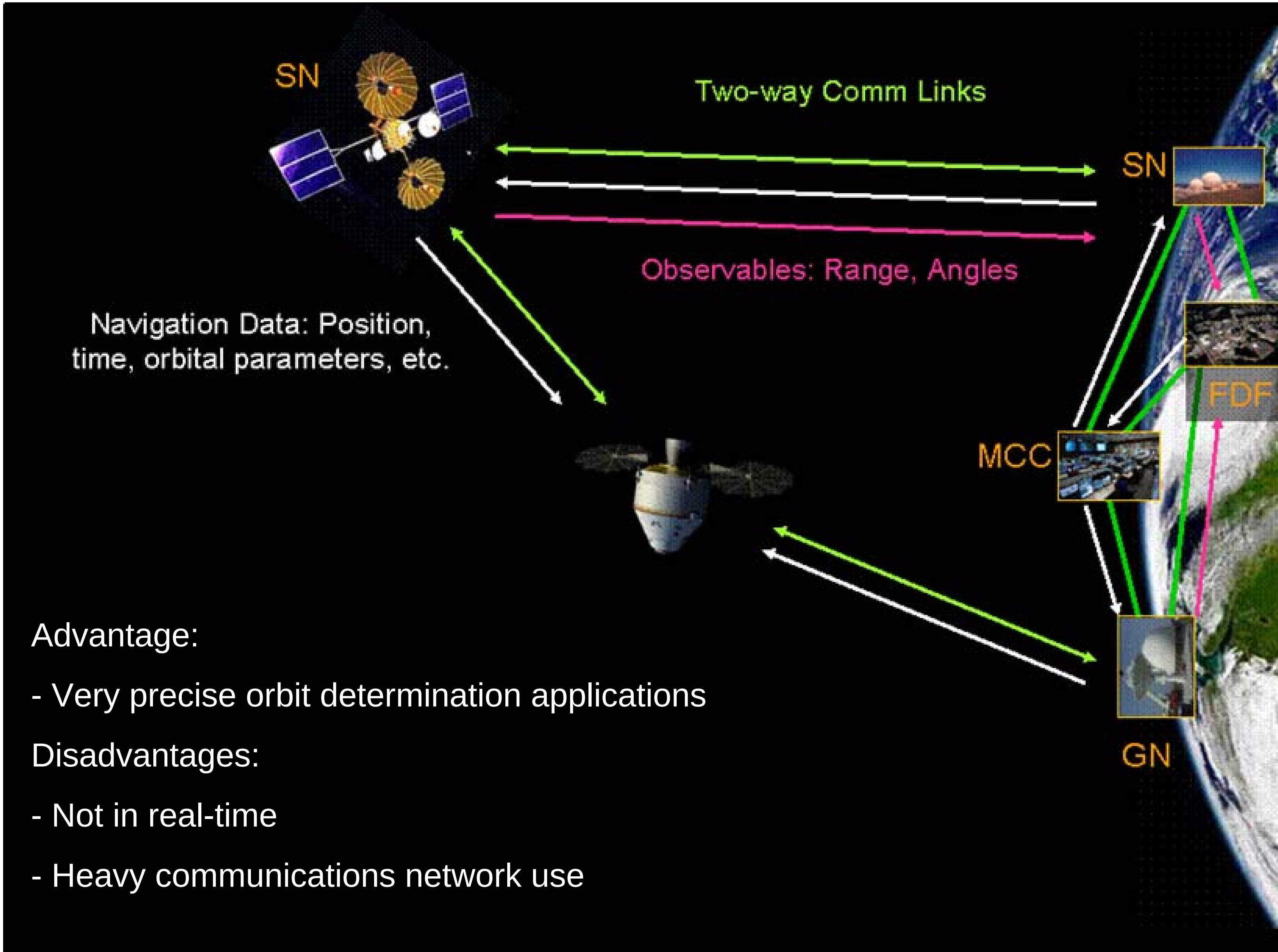
Enabling Technologies, including,
- Improved flight dynamics / trajectory modeling
- Space-qualified Atomic Clocks
- Appropriate relativistic time transformations
- Accurate geodetic reference frames (using VLBI, satellite laser ranging, etc. techniques)
- GPS/GNSS monitoring and distribution of differential corrections and integrity messages to space users
- Integrated communications and navigation receivers
- ....etc .



Near Earth Navigation Infrastructure



Network Dependent Navigation



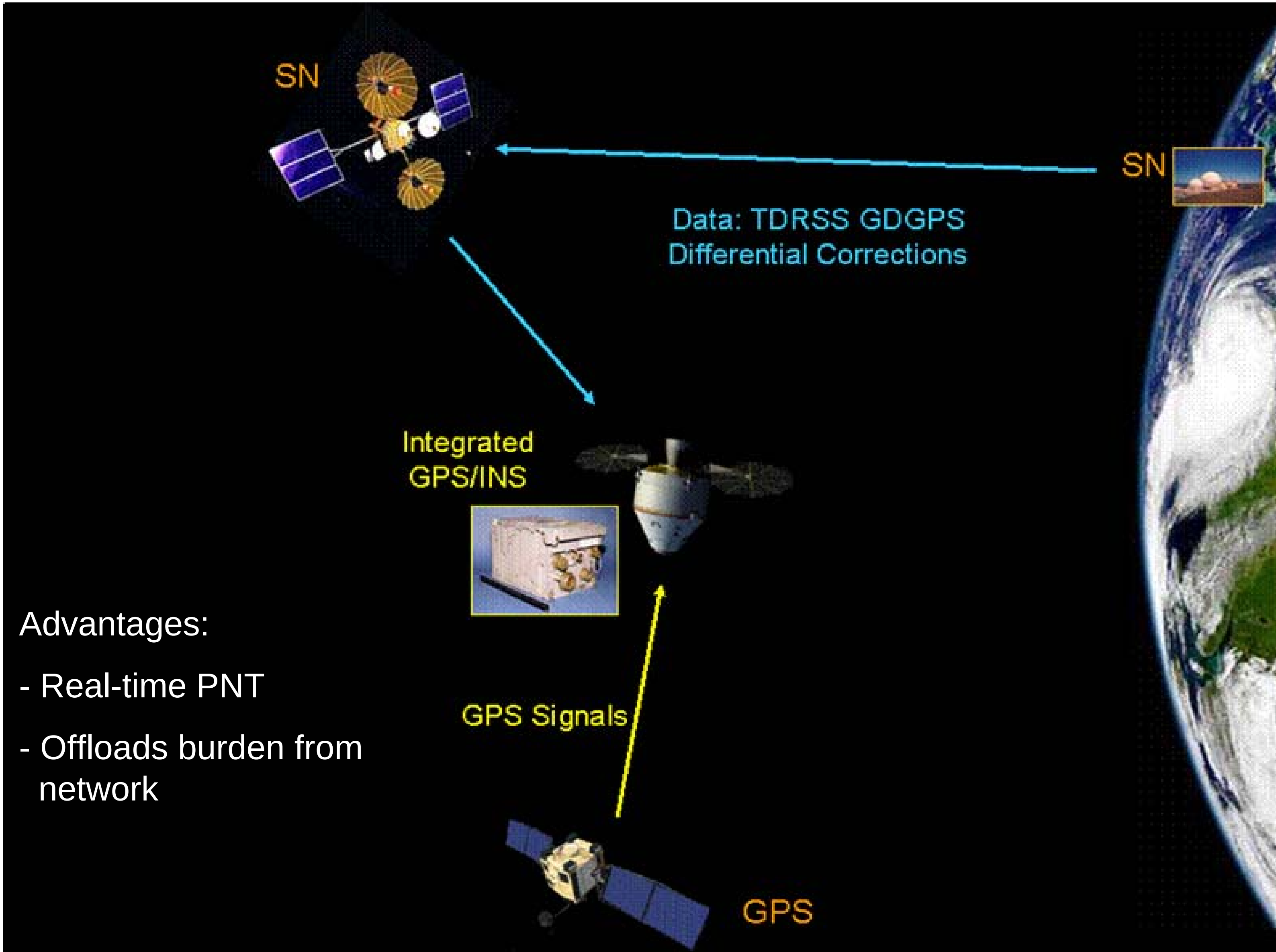
Advantage:

- Very precise orbit determination applications

Disadvantages:

- Not in real-time
- Heavy communications network use

On-Board ("Autonomous") Navigation



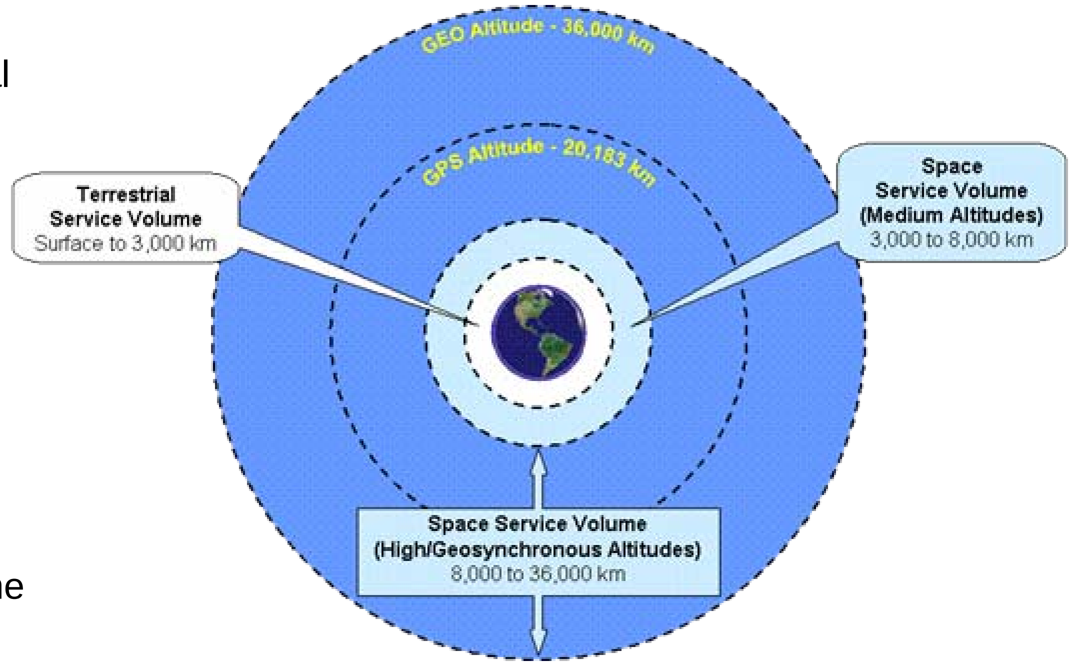
Advantages:

- Real-time PNT
- Offloads burden from network

GPS Space Capabilities

- **Terrestrial Service Volume**
  LEO (≤ 3,000 km) Characteristics
  - Same PVT performance enjoyed by terrestrial users
  - Uniform received power levels
  - Fully overlapping coverage of GPS main beams
  - Nearly 100% GPS coverage
  - Instantaneous navigation solutions
- **Space Service Volume**
  MEO (3,000 – 8,000 km) Characteristics
  - Four GPS signals typically available simultaneously
  - One-meter orbit accuracies feasible
  - GPS signals over the limb of the earth become increasingly important
  - Wide range of received GPS signal strength
- **Space Service Volume**
  HEO/GEO (8,000 – 36,000 km) Characteristics
  - Nearly all GPS signals received over the limb of the Earth
  - Users will experience periods when no GPS satellites are available
  - Received power levels will be weaker than those in TSV or MEO SSV
  - Properly designed receiver should be capable of accuracies ranging from 10s of meters to 100s of meters, depending on receiver sensitivity and clock stability.

Terrestrial and Space Service Volumes



Assuming a nominal, optimized GPS constellation and no GPS spacecraft failures, signal availability at 95% of the areas at a specific altitude within the specified SSV are planned as:

	MEO SSV		HEO/GEO SSV	
	at least 1 signal	4 or more signals	at least 1 signal	4 or more signals
L1	100%	≥ 97%	≥ 80% [1]	≥ 1%
L2, L5	100%	100%	≥ 92% [2]	≥ 6.5%

1. With less than 108 minutes of continuous outage time.
2. With less than 84 minutes of continuous outage time.

Objective Goals:

MEO SSV: 4 GPS satellites always in view
HEO/GEO SSV: at least 1 GPS satellite always in view

GPS and Human Space Flight

Miniaturized Airborne GPS Receiver (MAGR-S)

- Modified DoD receiver to replaces TACAN on-board the Space Shuttle
- Designed to accept inertial aiding and capable of using PPS
- Single-string system (retaining three-string TACAN) installed on OV-103 Discovery and OV-104 Atlantis, three-string system installed on OV-105 Endeavour (TACAN removed)
- GPS taken to navigation for the first time on STS-115 / OV-104 Atlantis
- GPS/INS – only navigation used on STS-118 / OV-105 Endeavour

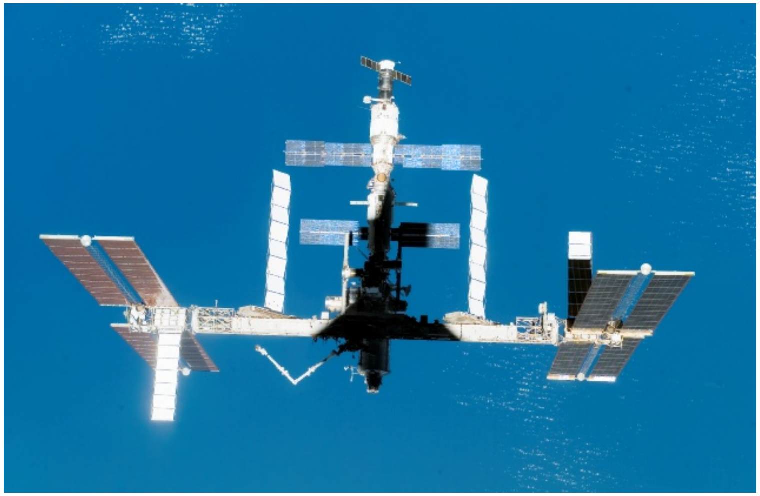
STS-115

MAGR-S

STS-118

Space Integrated GPS/INS (SIGI)

- Receiver tested on shuttle flights prior to deployment on International Space Station (ISS)
- The ISS has an array of 4 antennas on the T1 truss assembly for orbit and attitude determination
- In operation

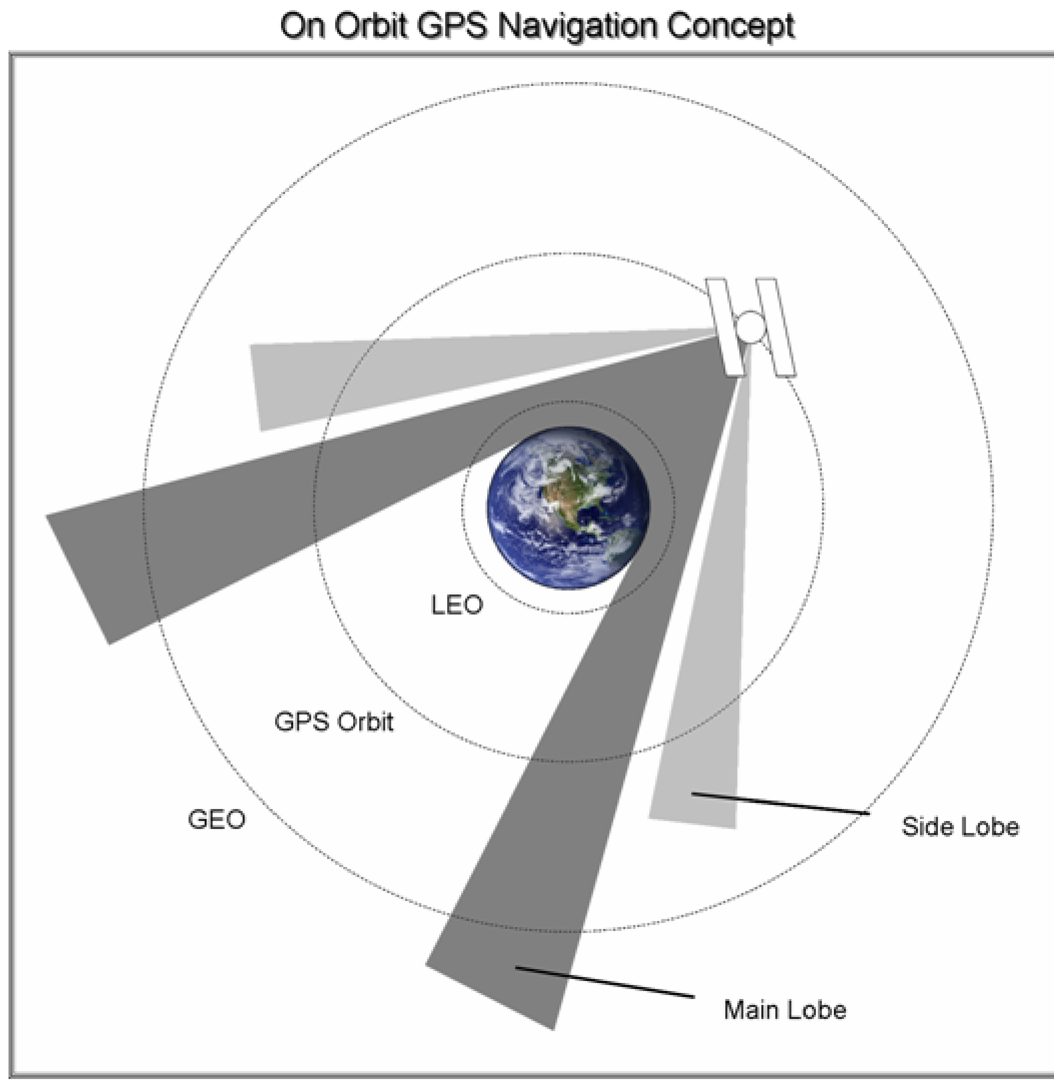


SIGI

ISS as viewed from STS-118

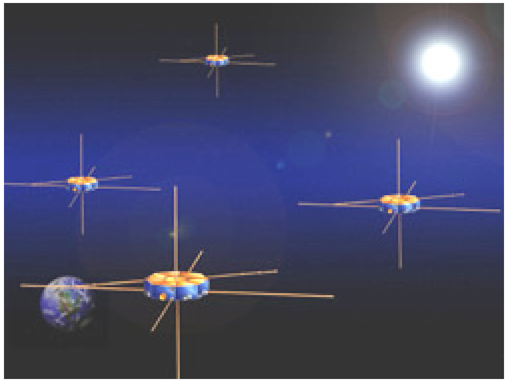
GPS Navigator Receiver Development at GSFC

- *Dynamic*
  - Receiver-transmitter relative dynamics much higher
  - Enlarges Doppler search space
  - Signal moves rapidly in search space
  - Acquisition must be *FAST*
- *Sensitivity*
  - Weak signals must be acquired and tracked to maximize signal availability



GPS Navigator Receiver Supported Missions

- HEO GPS navigation for Magnetospheric MultiScale (MMS) mission
  - *Navigator* is the GPS portion of the Interspacecraft Ranging and Alarm system (IRAS).
  - TRL 6 prototype IRAS scheduled for completion 3/09.
- Bistatic Radar Ranging on HST SM4
  - Navigator is part of Relative Navigation Sensor system. Flight unit delivery in 1/08. Launch; 10/08.
  - Will estimate range between Shuttle and HST from weak signal reflected GPS
- GOES
  - Project interested in commercializing high altitude GPS capability for potential vendors of next GOES spacecraft.
  - Prototype receiver being developed for in-house testing at Boeing, Lockheed Martin.
- GPM
  - Primary navigation and time reference
- Orion/CEV
  - Fast acquisition for re-entry navigation after blackout
  - Working with avionics subcontractor Honeywell



MMS Mission Formation Flying

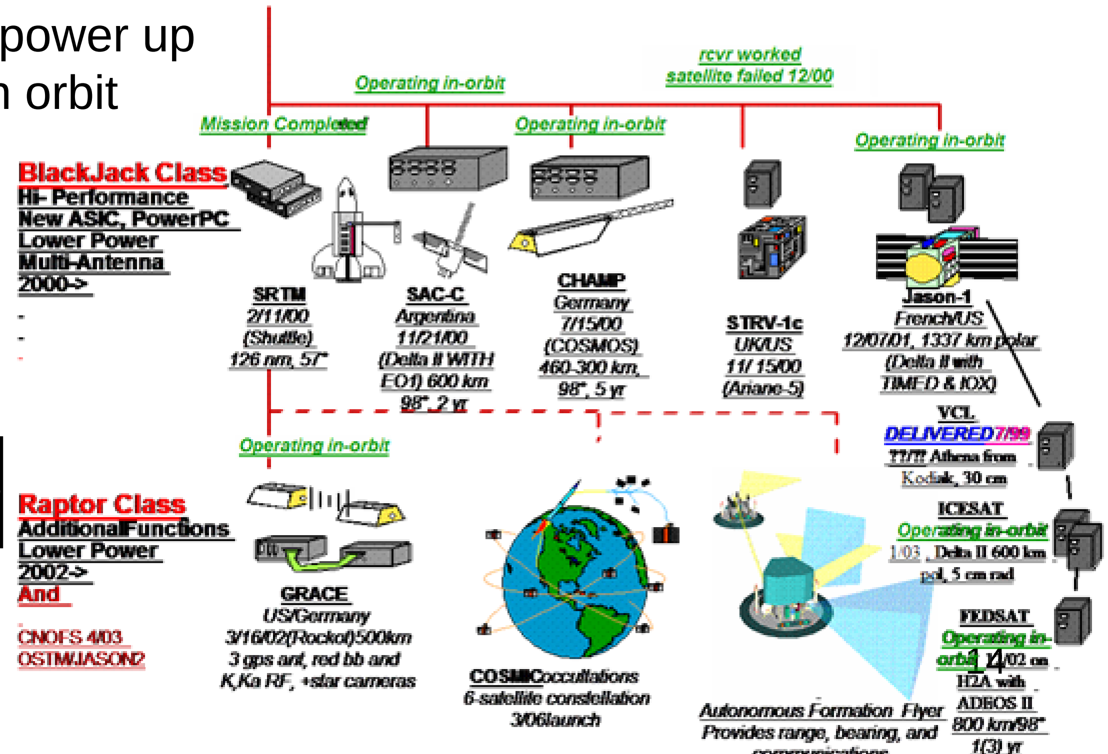
Orion/CEV Hardware Navigation Demo on Last Shuttle Mission

Orion/CEV Operations

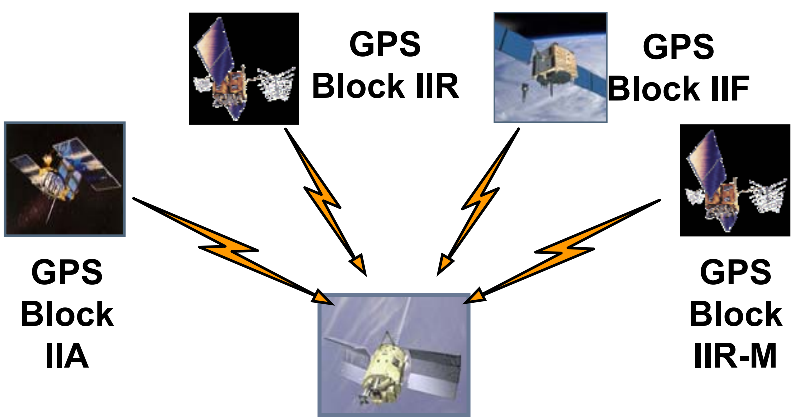
BlackJack Flight GPS Science Receiver Development at JPL

- Highest accuracy and flexibility for NASA science
  - Precise orbit determination (JASON, ICESat, SRTM missions)
  - Occultation science (CHAMP, SAC-C, FedSat, 2 GRACE , 6 COSMIC)
  - Gravity field (CHAMP, GRACE)
  - Surface reflections (SAC-C, CHAMP)
- Dual frequency, C/A code plus semi-codeless P(Y)1 and P(Y)2
- Status
  - 19 BlackJack receivers launched
  - 19 started autonomously on power up
  - 64 receiver-years powered in orbit

Missions Supported by Blackjack Receiver Family

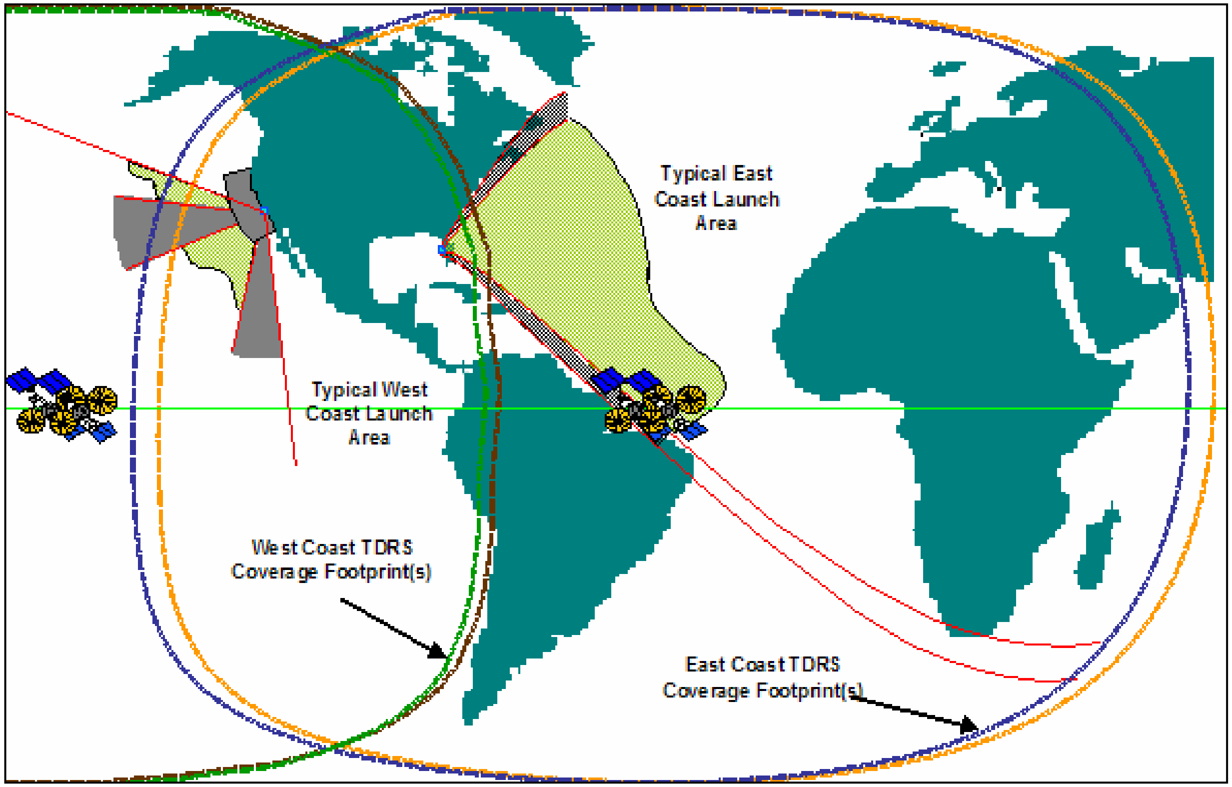


BlackJack in SAC-C Satellite Tracking of L2C Signal



GPS Metric Tracking & Space-Based Range

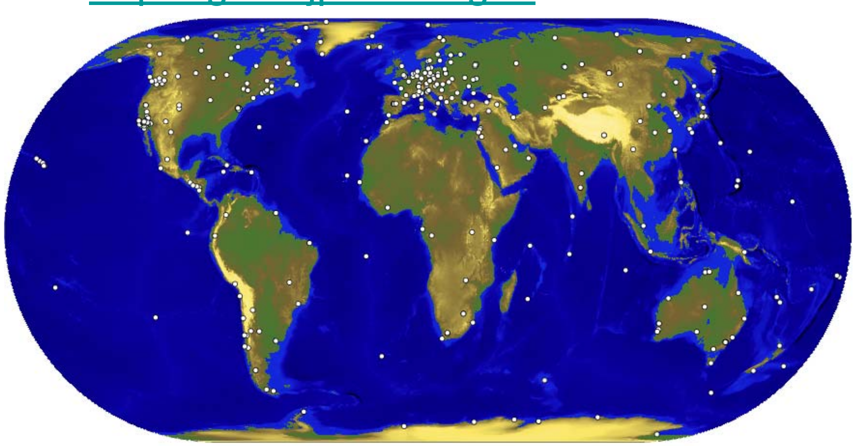
- Space-based navigation, GPS, and Space Based Range Safety technologies are key components of the next generation launch and test range architecture
- Provides a more cost-effective launch and range safety infrastructure while augmenting range flexibility, safety, and operability
- Status: Memorandum signed in November 2006 for GPS Metric Tracking (GPS MT) by January 1, 2011 for all DoD, NASA, and commercial vehicles launched at the Eastern and Western ranges



GNSS Monitoring: IGS and GDGPS

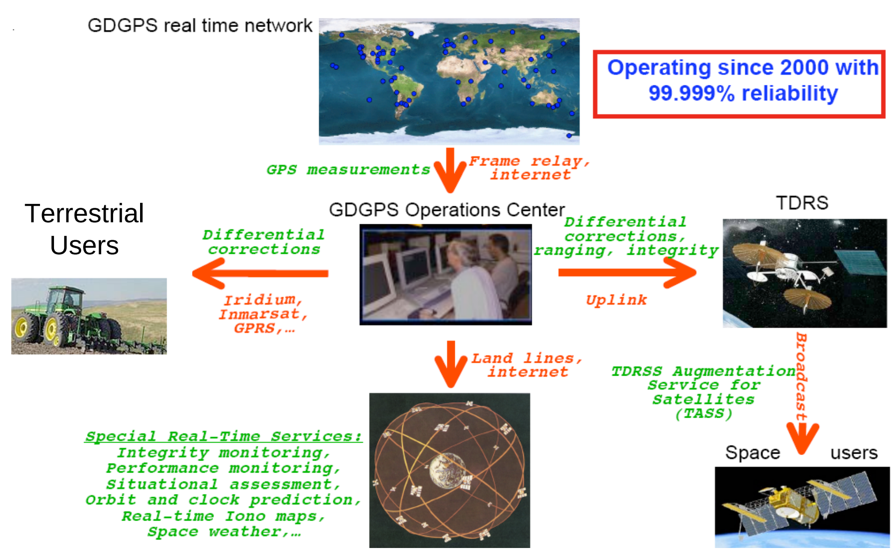
International GNSS Service (IGS)

- Global network of over 350 GPS monitoring stations from 200 contributing organizations in 80 countries.
- NASA funds the IGS Central Bureau at JPL and a global data center located at the GFSC.
- Mission to provide the highest quality data and products as the standard for global navigation satellite systems (GNSS) in support of Earth science research as well as to facilitate other applications benefiting society.
- Currently tracking GPS and GLONASS signals, also able to track Galileo signals.
- Approximately 100 IGS stations report with a latency of one hour.
- http://igscb.jpl.nasa.gov.

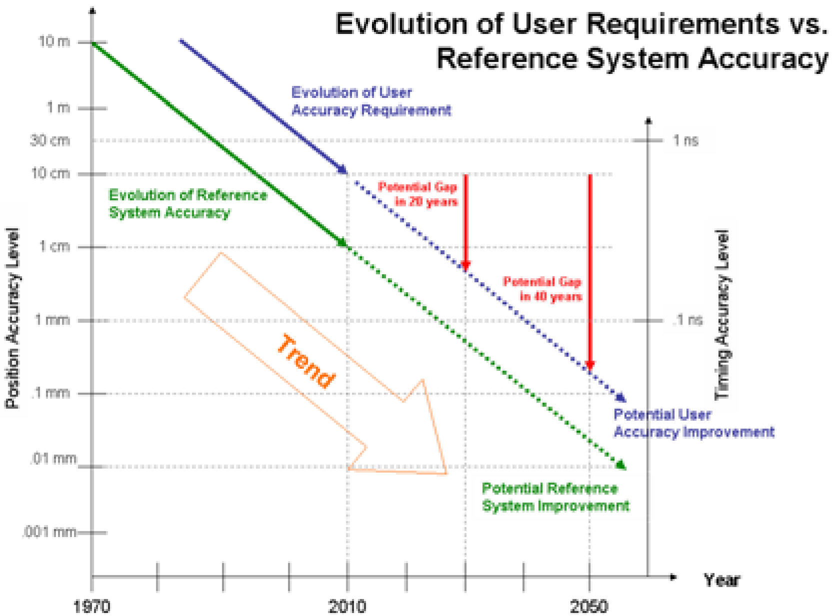


Global Differential GPS (GDGPS) System

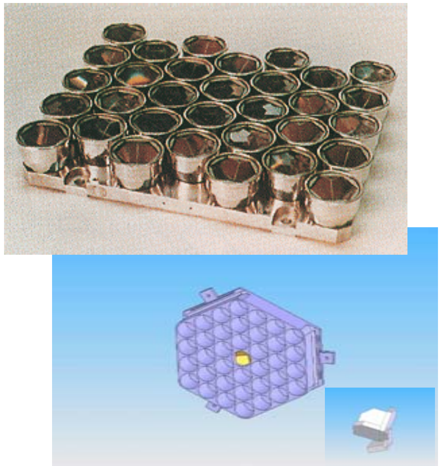
- Consists of 100+ dual-frequency, real-time GPS reference stations operational since 2000.
- High accuracy augmentation to support the real-time positioning, timing, and orbit determination requirements of NASA's science missions.
- Real-time products also used for GPS situational assessment, natural hazard monitoring, emergency geolocation (E911), and other civil and defense applications.
- Future NASA plans include developing the TDRSS Augmentation Satellite Service (TASS) to disseminate the GDGPS real-time differential correction message to Earth satellites.



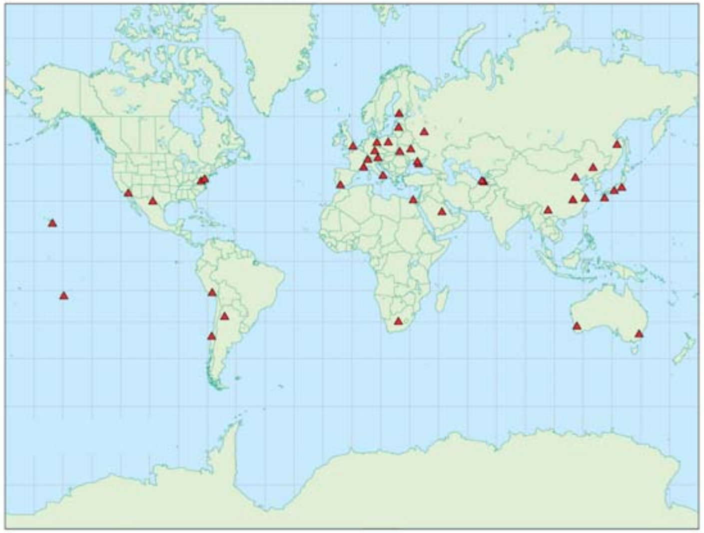
GPS Geodetic Requirements



NASA SLR 2000 Station



GPS 35/36 Solid Coated Retroreflector and Hollow Cube and Array



ILRS Tracking Sites

Anticipated GPS III Geodetic Requirements

1. Achieve a stable geodetic reference frame with an accuracy at least ten times better than anticipated user requirements
2. Maintain a close alignment of the WGS 84 reference frame with the International Terrestrial Reference Frame
3. Provide a quality assessment capability independent of current radiometric measurement used to determine GPS orbits and clock performance
4. Ensure interoperability of GPS with other GNSS's through a common, independent measurement technique

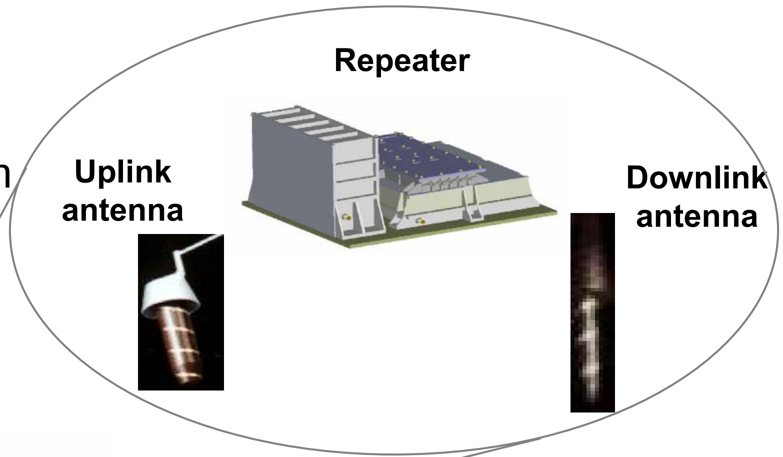
Status

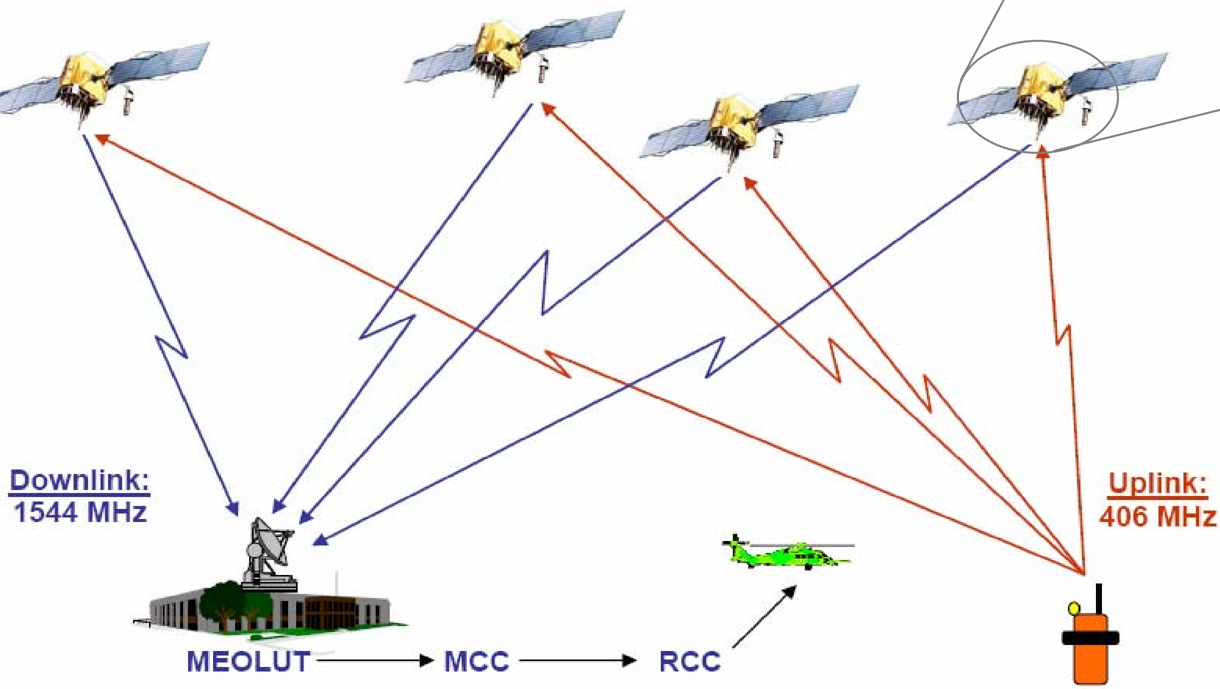
- SVN-35 withdrawn from service, one remaining reflector-equipped GPS vehicle in operation
- Interagency GPS III Geodetic Requirement in IFOR process

Search and Rescue 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 _20,000_ lives worldwide



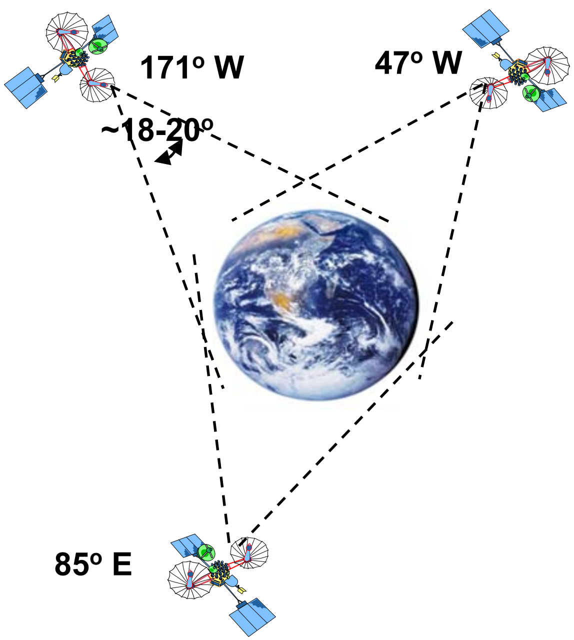


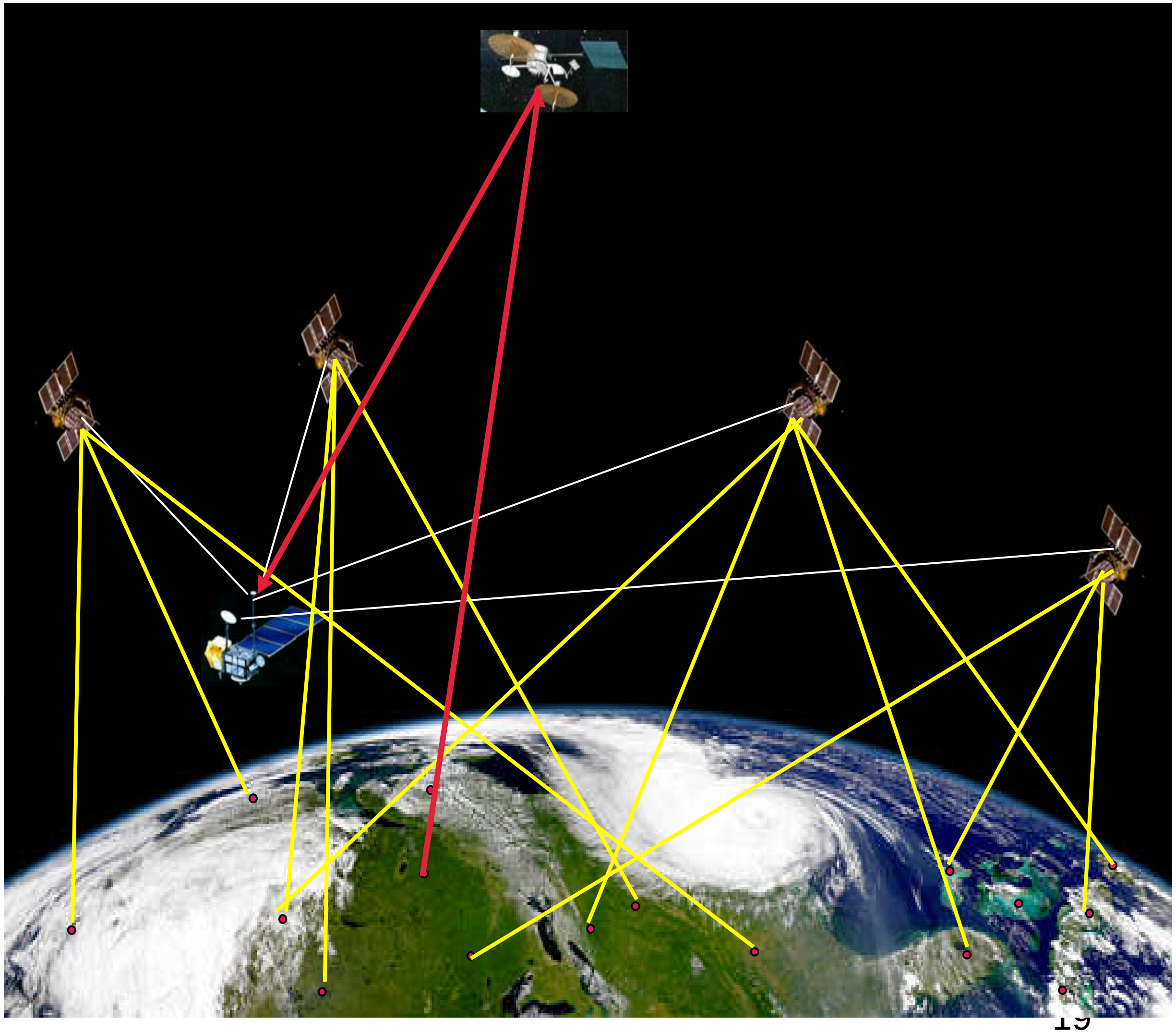
Status:

- Current COSPAS-SARSAT system to be discontinued as SAR payloads are implemented on Galileo
- Over $30M spent to-date by NASA on Proof-of-Concept
- On all GPS IIR(M) and IIF satellites
- GPS III DASS Requirement in IFOR Process

TDRSS Development and TASS

- **TDRS Augmentation Satellite Service (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**
- **TASS improves position accuracy below the 1-meter level**





Integrated Near Earth Navigation