NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

Know the Earth... Show the Way... Understand the World

SLR To GPS III

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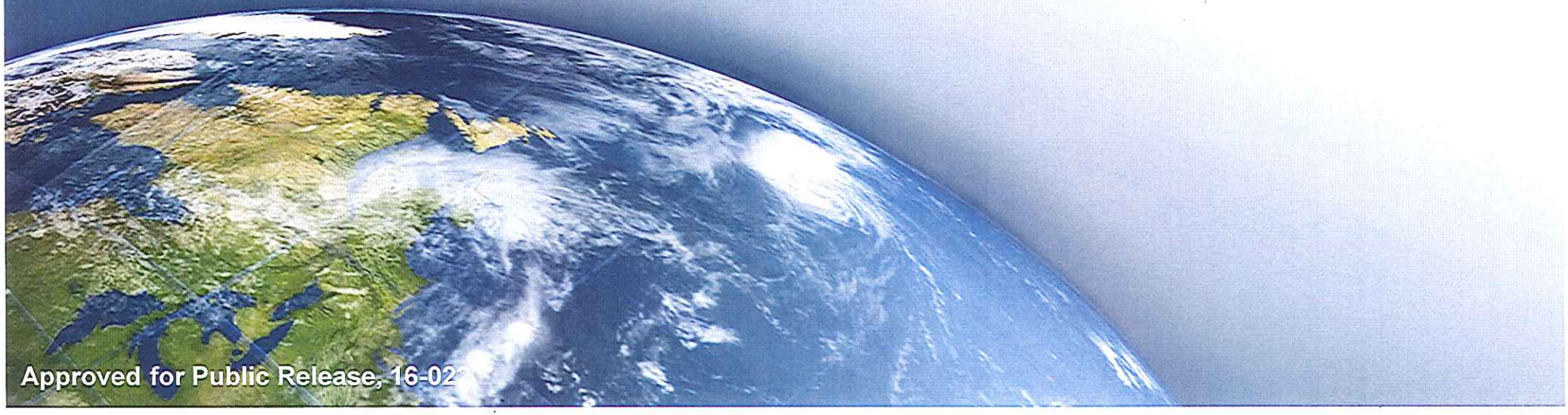

GPS III

SPACE AND MISSILE SYSTEMS CENTER

Status

- GPS III is the newest block of GPS satellites
  - 4 civil signals: L1 C/A, L1C, L2C, L5
    - First satellites to broadcast common L1C signal
  - 4 military signals: L1/L2 P(Y), L1/L2M
- SV01-SV08 on contract; SV09 & SV10 approved
  - 2 year delay due to technical challenges w/ payload
- SV01 System Module Core Mate completed 7 Apr 15
- Mission Data Unit software qualification complete 6 Aug 15
- SV-level thermal vacuum scheduled for Fall 2015
- SV01 available for launch Aug 2016

GPS Government Roadmap Schedule

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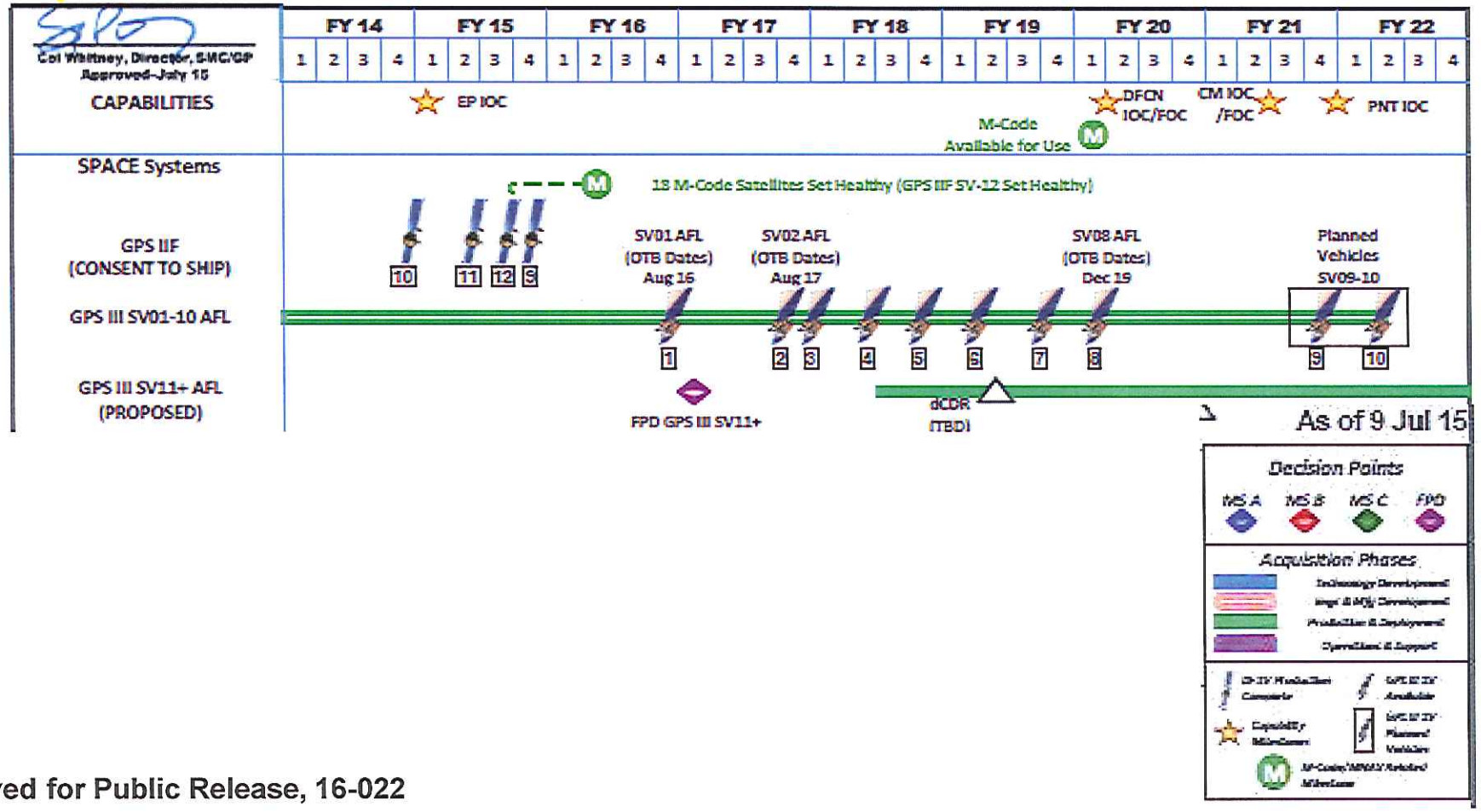
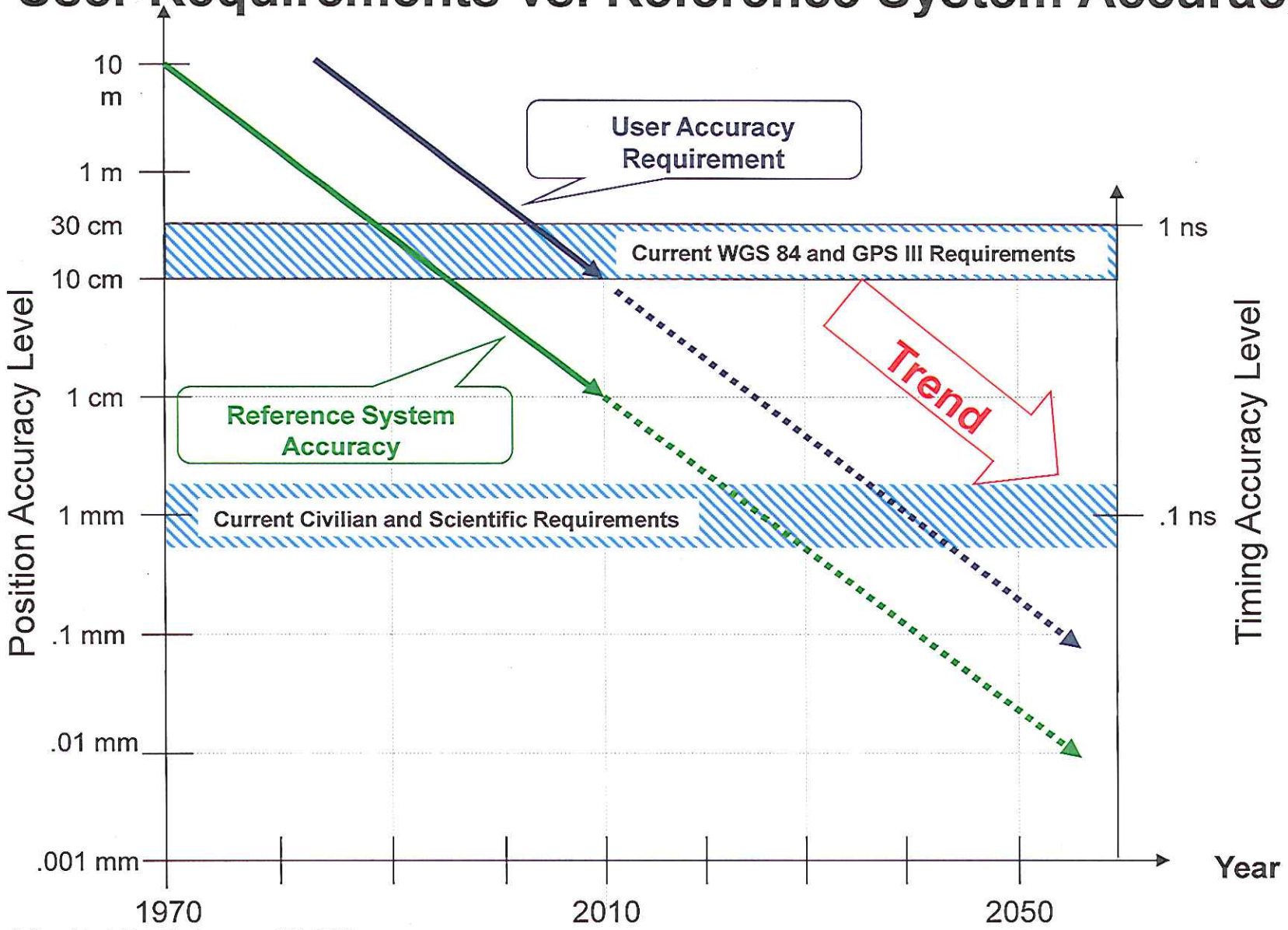


GPS III Geodetic Requirements

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

Result of Interagency Working Group that included members from: NASA, NGA, NRL, NOAA, USGS and USNO.

User Requirements vs. Reference System Accuracy

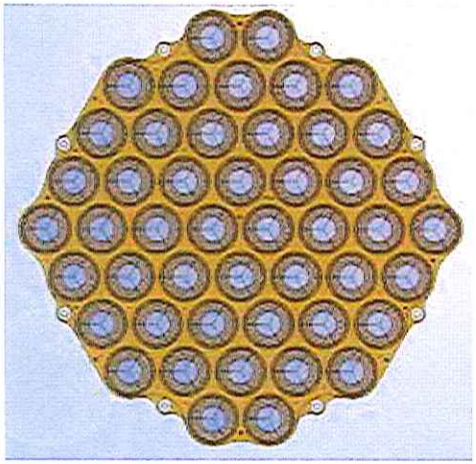


Making SLR to GPS III a Reality

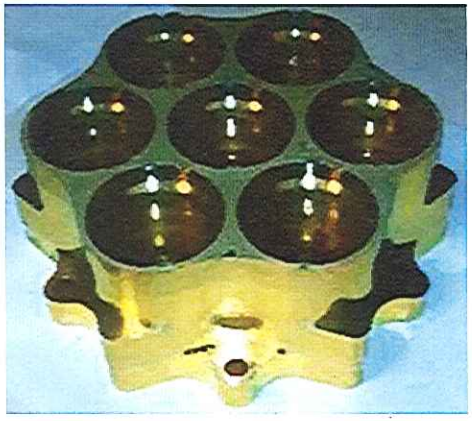
- In 2012, US Air Force (USAF) granted approval for the integration of LRAs onto GPS III satellites.
  - However, integration will be no earlier that SV9, but subject to change.
  - Approval granted with the understanding that the USAF Space Command would have review and approval authority of ranging schedule.
- NASA, NGA, and Naval Research Laboratory (NRL) have partnered on the Development and Implementation of the LRAs.
  - NRL will design and space qualify LRAs with NASA/GSFC.
  - NASA will procure the LRAs for the GPS III SV.
  - NGA will fund their integration onto the SV.

GPS Laser Retroreflector Array Design

- ✓ Successful LRA Preliminary Design Review
  - Design compliant with ILRS GNSS Cross Section Standards.
- ✓ Sub-array successfully demonstrated spacecraft compatibility in September 2013.
- ✓ Interface Control Document approved by GPS Change Configuration Board.
- ➢ GPS III Engineering Qualification Model (EQM) Hardware
  - Risk reduction work completed
  - EQM integration and test underway
- Launch of first vehicle equipped with GPS III LRA no earlier than 2019.
- NASA, NGA, NRL, and USAF continue to work together to solidify GPS III LRA integration plan.



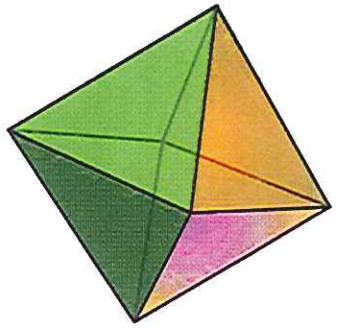
Rending of LRA Flight Model



7-Aperture Sub-Array

Preliminary Geodetic Studies

- E. Pavlis conducted 2 studies for NASA
  - Estimated origin and scale for one year's worth of data.
  - Examine the effects of a few difference variables:
    - # of Satellites, SLR Stations, cut-off elevations, etc…
- T. Johnson (NGA), M. Staley (USAF) and M. Davis (NRL) examined geometry and scheduling
  - Expanded upon Erricos' geometry idea.
  - Looked at geometries that used spare slots.
  - Examined 1 SV per plane limitation.



Results Roll-Up

- Geometry is Important
  - Restricting 1 SV per plane may be better for 3 and 6 SV scenarios but for 2, 4, and 5 SVs campaigns 2 SV per plane may be better.
  - Can live with an elevation cutoff of 45 deg. but 30 deg. would make things better.
- Accuracies Needed for 1 mm TRF can be Reached
  - Scale seems to be more sensitive of a constraint than Origin
  - Tracking 6 SVs (1SV/Plane) for 4-7 days a week better case
    - 45 deg. Min Elev 50%/75% good, 30 deg. better (more obs.).
    - This may not be practical or necessary, considering the other GNSS satellites.
  - Tracking 4 SVs, (1 or 2SV/Plane) for 4 days appears to be minimum case
    - 45 deg. Min Elev with 50%/75% okay, but 30 deg. better.
    - 2 SV/Plane appears to be better geometry.

Looks Promising But More Studies Needed.

More Studies Needed

- Need to examine everything for combining all GNSS satellites
- Examining networks of 12 - 18 SLR tracking stations
  - Geometry of stations in network important is more important than number of stations. What is the proper balance?
  - Less stations is better.
- Examined elevation cutoffs 20 to 45 degrees
  - What is a good cutoff? 45 deg. limits tracking to only one station at a time.
- Need to look at 25%/50%, 50%/75% and 100%/100% for day/night tracking ratios.
  - But need to be smart about this taking into account past performance.
- What combinations can be made of the different GNSS satellites?
  - How can 1, 2, 3, or 4 GPS III SVs contribute to reaching 1 mm?

Did I Forget Anything Erricos?

Tom's Notational Ideas on Timeline

- Planning for integration on GPS III SV09, subject to change.
- Interested in additional studies showing the utility of tracking of a smaller subset of vehicles (and interlaced with available GNSS satellites) while GPS III is being populated.
- A tracking schedule will be developed by NASA in conjunction with participating stations to optimize data utility
  - During checkout phase, a special schedule for ranging to that focuses on improve SV modeling, the orbit, and clocks.
  - The schedule for all GNSS satellites should be focus on 1 mm TRF goal without oversubscribing the ILRS. GPS III should be part of this effort.
- We would like feedback on station interest in coordinating tracking schedules and any suggestions on scenarios to evaluate through simulation to achieve 1mm TRF performance.
  - It is understood that this all depends on what orbital plane and slots the satellites are placed.

Summarizing

- While NASA/NGA have gained approval for LRAs on GPS III satellites, LRA integration will occur no earlier than SV09
- LRA design complete and EQM being tested.
- Need additional SLR studies and analysis on use of GPS alone and with other GNSS systems in the determination of TRF origin and scale.
- But, we have time.

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