Status of the GPS III Laser Retroreflector Array

Dr. Linda M. Thomas, NRL
Dr. Stephen M. Merkowitz, NASA GSFC

November 11-15, 2013
18th International Workshop on Laser Ranging
"Pursuing Ultimate Accuracy & Creating New Synergies"
Fujiyoshida, Japan

Overview

- History
- Design considerations
  - Link Budgets
- Corner Cube Selection
- Risk Reduction Work
- Flight Qualification Model Development
- Schedule

History

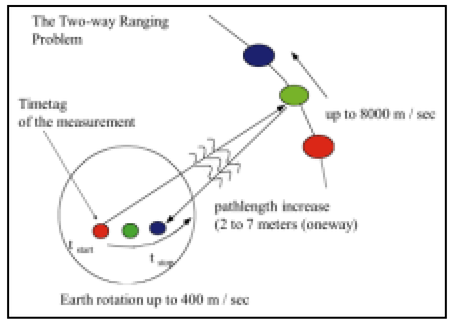
- 1993 GPS Laser Retroreflector Experiment*
  - Agreement between NRL, NASA GSFC, University of Maryland, USAF, and GPS Joint Program Office to fly a laser retroreflector array payload on vehicles 35 and 36
  - NRL approved to integrate the LRA through the "Advanced Clock Ranging Experiment" funded by Office of Naval Research. Goal to provide an independent high-precision measurement to compare or calibrate the GPS pseudorange signal.
- 2006 – US Civil and DoD working group identifies requirements to meet future geodesy and science needs
  - Laser Ranging identified as a key technique to account for systematic errors in satellite coordinates and reference frames
- 2012 – Multiagency group studied requirements and concluded room is available for an LRA on the nadir deck
- 2012 – Naval Research Laboratory commences trade studies, analysis and design of the future GPS III Laser Retroreflector Array
- 2013 – Official agreement signed between agencies to install laser retroreflector arrays on GPS Block III satellites starting with vehicle 9
- 2014 – Completion of flight qualification model of the GPS III Laser Retroreflector Array

*Pavils, E.C. and Beard, R.L., *GPS Trends in Precise Terrestrial, Airborne, and Spaceborne Applications,* "The Laser Retroreflector Experiment on GPS-35 and 36" 1996, p.154-158

Design Considerations

<u>Tracking Mission</u>

- Day/Night
- Elevation



<u>Fundamental</u>

- Velocity Aberration
- Link Budgets

<u>Space Vehicle</u>

- Interfaces
- Environment

LRA design driven by multiple sources

Link Budgets

η_D	Detector Quantum Efficiency	σ_{LRCS}	Laser Radar Cross Section
E_0	Transmit Energy	R	Slant Range
λ	Wavelength	A_R	Receiver Telescope Area
h	Planck's Constant	η_R	Receiver Efficiency
c	Speed of Light	T_a	One-way Atmospheric Transmission
η_T	Transmission Efficiency	T_c	One-way Cirrus Cloud Transmission
G_T	Transmitter Gain		

$$N_{\text{pe}} = \eta_D E_0 \left(\frac{\lambda}{hc}\right) \eta_T G_T \sigma_{\text{LRCS}} \left(\frac{1}{4\pi R^2}\right)^2 A_R \eta_R T_a^2 T_c^2$$

Transmitter
And divergence

Space segment

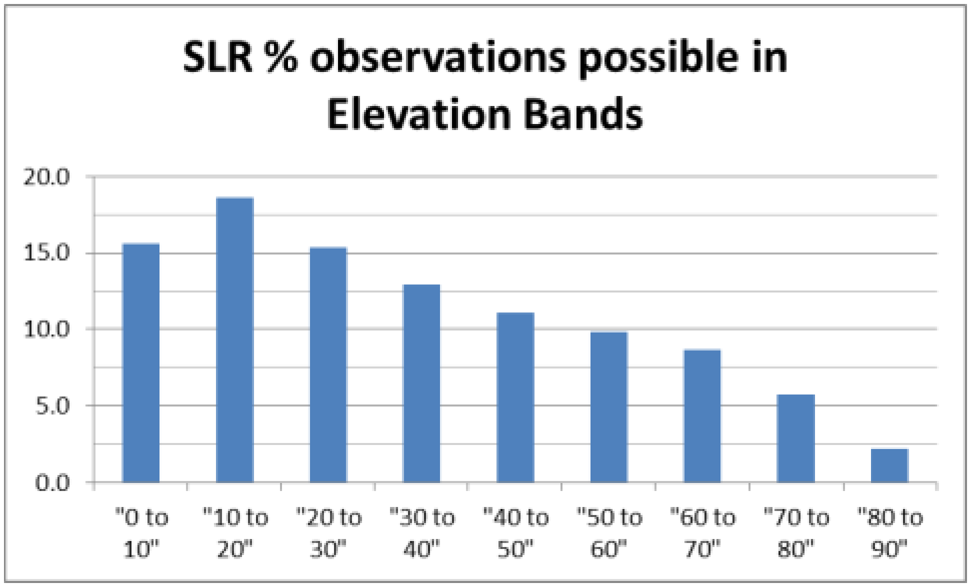
orbit

atmosphere

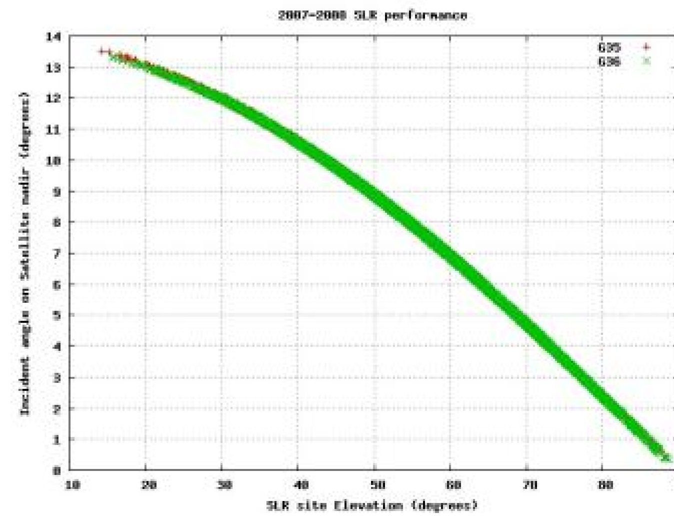
Investigate SLR link budget 'actuals' to ensure design is driven by real world performance

For reference, see: J. Degnan's 1993 paper:
http://ilrs.gsfc.nasa.gov/science_analysis/docs/degnan/Milimeter/MillimeterAccuracySatelliteLaserRangingReview.pdf
Mark Davis, "Performance and Prediction of SLR Tracking on Regional GNSS Constellations", Frascati, 2012

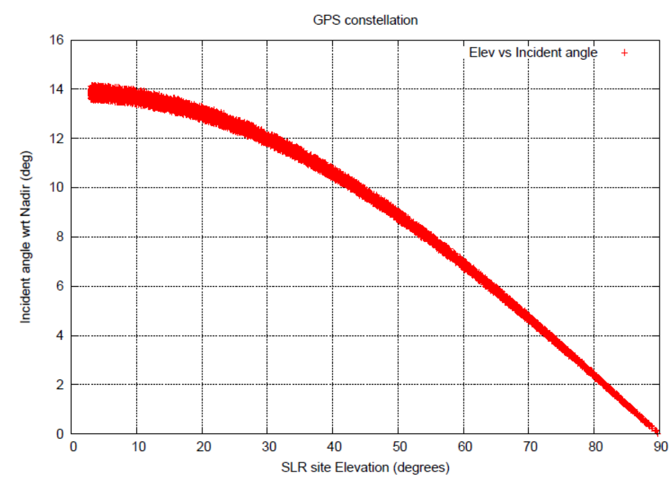
Where is the LRA used?



LRA optimized across various geometries, with emphasis on supporting lower elevation tracking (<40 deg)

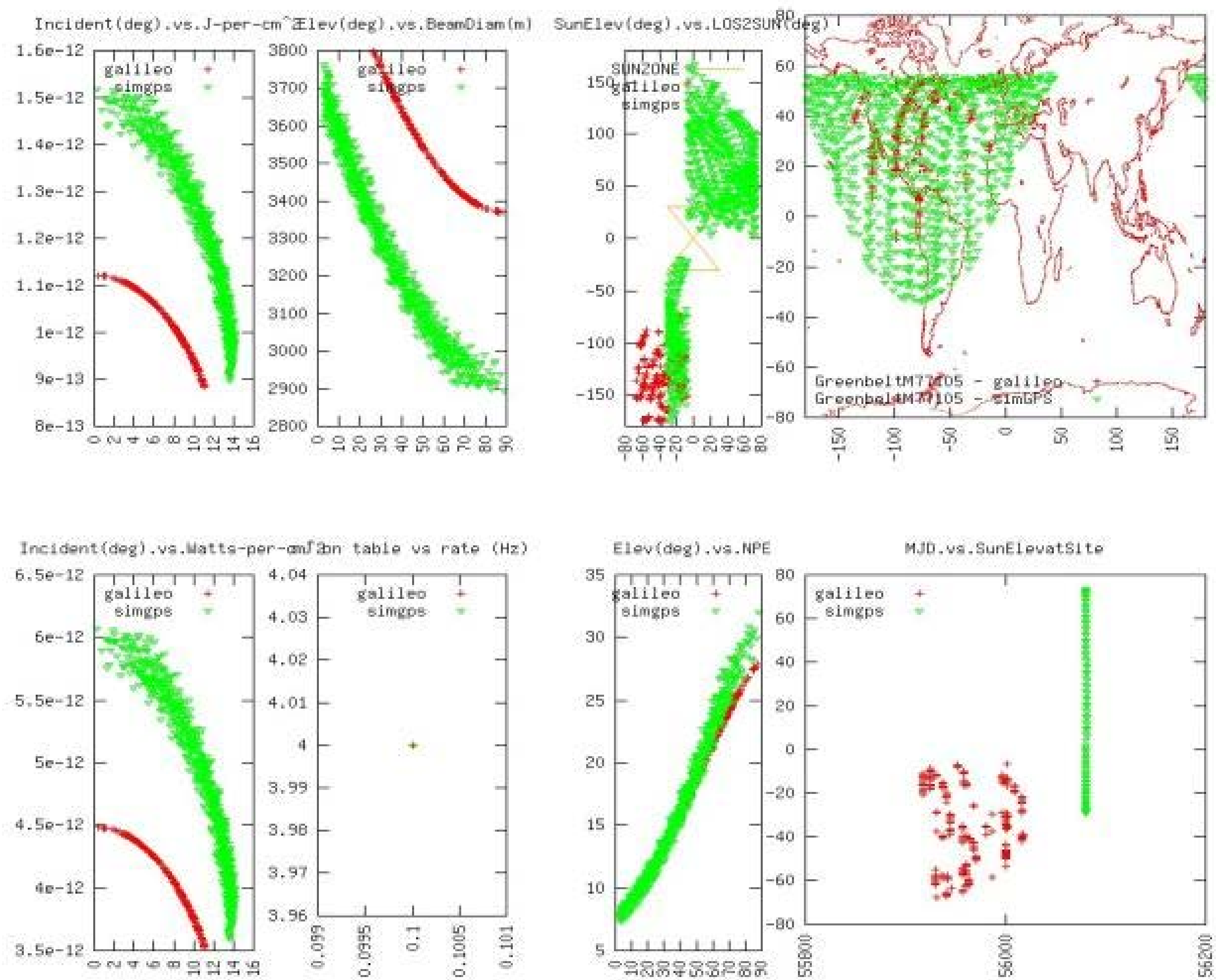


2007-8 performance



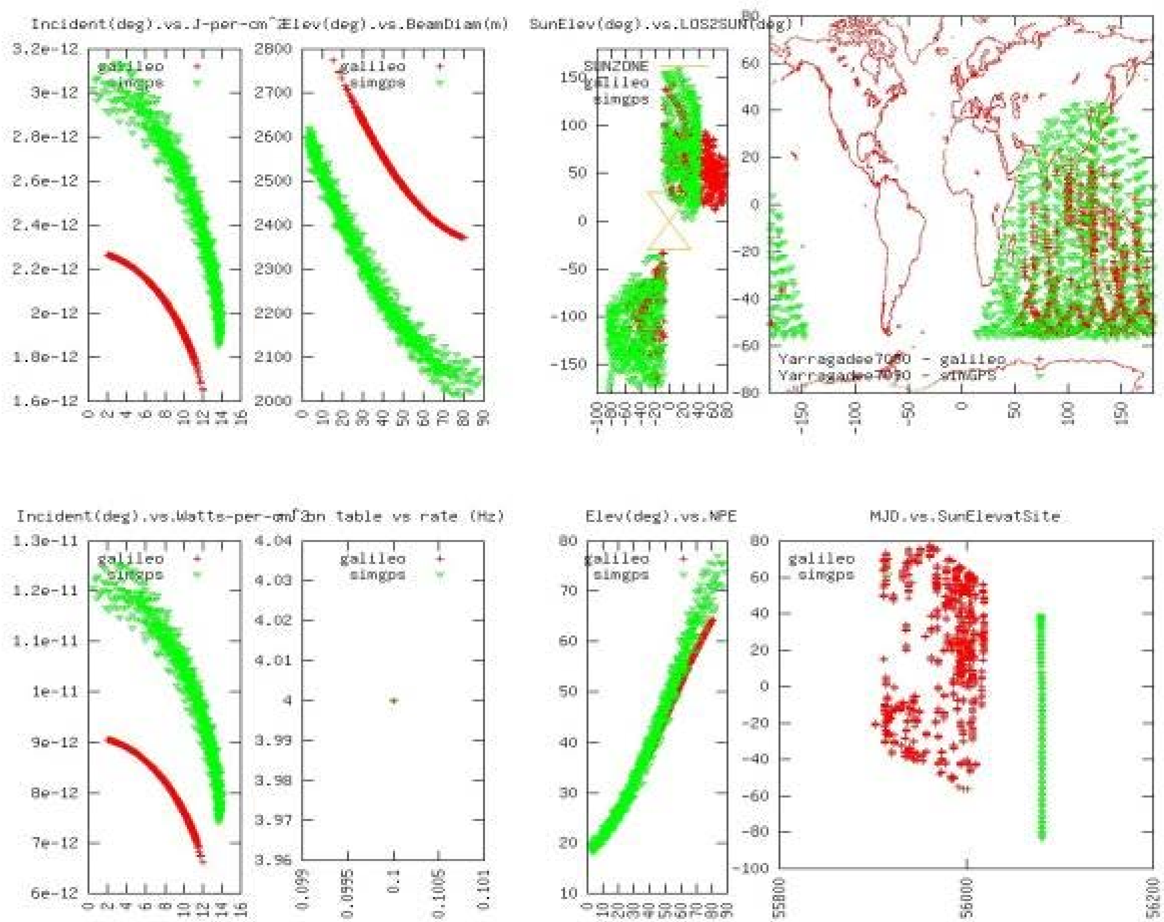
Prediction based on 2012 performance

NASA Greenbelt Link Budget



- Galileo data (red) for the 1st half of 2012
- Green indicates projected SLR GPS III link budget based on MOBLAS-4 station historical catch/fire ratio

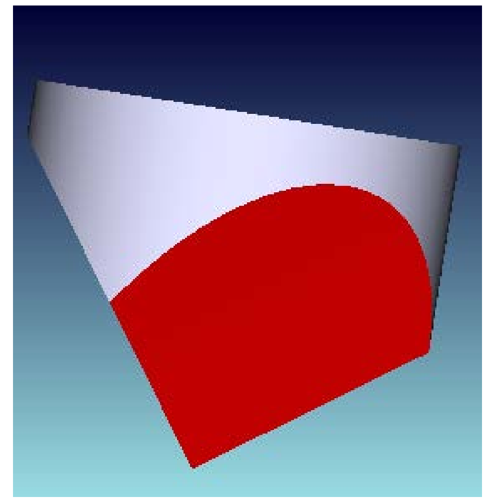
Yarragadee Link Budget

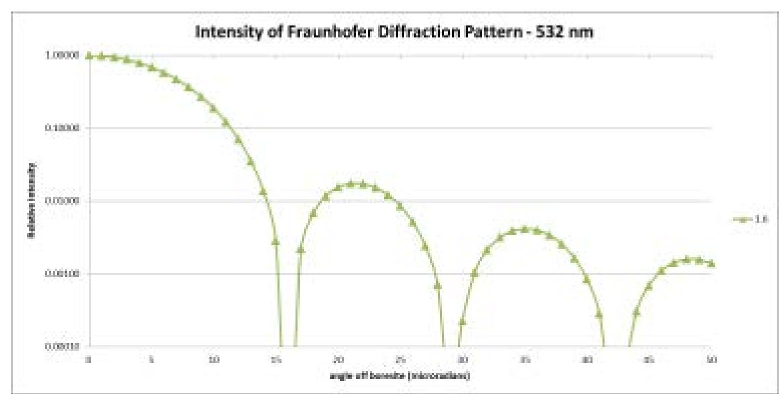


- Galileo data (red) for the 1st half of 2012
- Green indicates projected SLR GPS III link budget based on Yarragadee station historical catch/fire ratio

Corner Cubes

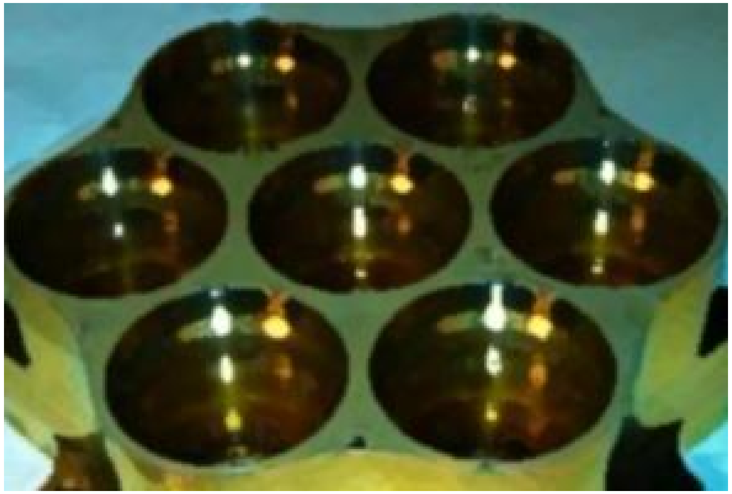
- Considerations:
  - Optical performance
    - Horizontal and circular polarizations
  - Manufacturability & tolerancing
  - Orbit constraints
    - Radiation environment, survivability
- Extensive simulations completed for 1.0 to 1.9 inch aperture uncoated cubes
  - 0.0 to 1.0 arcsec spoiling at 0.1” steps
  - Linear and circular excitation lasers
  - Incident angles: 0 deg, nominal (7 deg), and worst case (14 deg)
  - Thousands of diffraction patterns generated in ZEMAX optical design software
  - Evaluation at the working annulus
  - Validation with Legacy Analysis Codes
- 1.6 inch cube chosen
  - Provides >100MSM cross section with 48 CCRs
  - Using antireflection coating on front surface to improve link budget at 532nm





LRA Risk Reduction Work

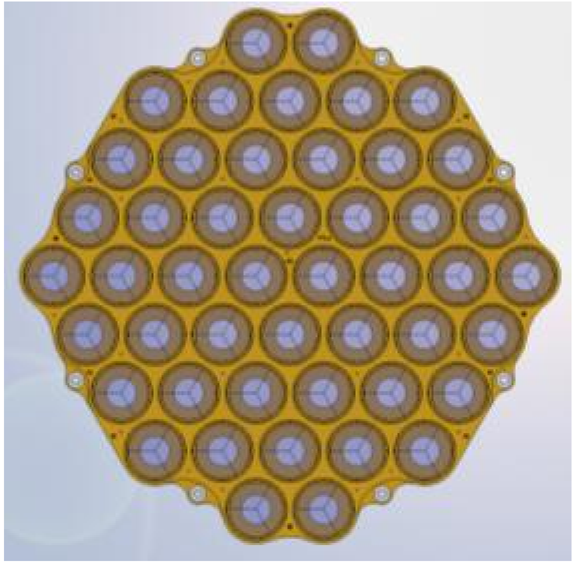
- Designed a 7-aperture subarray
  - Incorporate mission, SLR, and vehicle requirements
- Fabricate and test subarray
  - Evaluate mechanical performance
  - Validate assembly methods
  - Ensure EMI/EMC compatibility



Full Flight Array and Cross Section

Cubes	Wavelength	Orientation	Polarization	Cross Section
48 x 1.6”	532nm	0 deg	Horizontal	140MSM
48 x 1.6”	532nm	0 deg	Circular	155MSM
48 x 1.6”	532nm	12 deg	Horizontal	105MSM
48 x 1.6”	532nm	12 deg	Circular	120MSM

- Cube selection supports ILRS GNSS cross section specification
- FFDPs validated in Zemax
- On and off-axis performance evaluated



Rendering of flight model

LRA and Mission Information

- We are working with GPS program office to ensure sufficient detail will be released to the community to support reference frame accuracy improvements
- This information is expected to include:
  - Location of SV center of mass before launch
  - Location of the LRA on the SV
  - Optical phase center to CoM
  - Corner cube specification (DAO, flatness, etc)
  - Corner cube material
  - Coating specification
- Given the large number of LRA-equipped GPS satellites and to ensure maximum data utility, all tracking will be pre-coordinated with NASA

Schedule

- Risk reduction work completed
- Fabrication of the flight qualification model underway
- Environmental testing of qualification model in late 2013
- Flight check with SV integrator in 2014
- Launch of first vehicle equipped with GPS III LRA no earlier than 2019

Contributions from Mr. Mark Davis

Thank you!