Coordination and Prioritization of Laser Ranging on Retroreflector Equipped GNSS

***Gerald Bawden* – NASA**

Frank Lemoine, Stephen Merkowitz, & Carey Noll – NASA Goddard

Erricos Pavlis – University of Maryland

Michael Pearlman – Harvard University

Mission of the ILRS

- Laser ranging activities are organized under the International Laser Ranging Service (ILRS) which provides global satellite and lunar laser ranging data and their derived data products to support research and applications in geodesy, geophysics, Lunar science, and fundamental physics. This includes data products that are fundamental to the **International Terrestrial Reference Frame** (ITRF), which is established and maintained by the **International Earth Rotation and Reference Frame Service** (IERS).

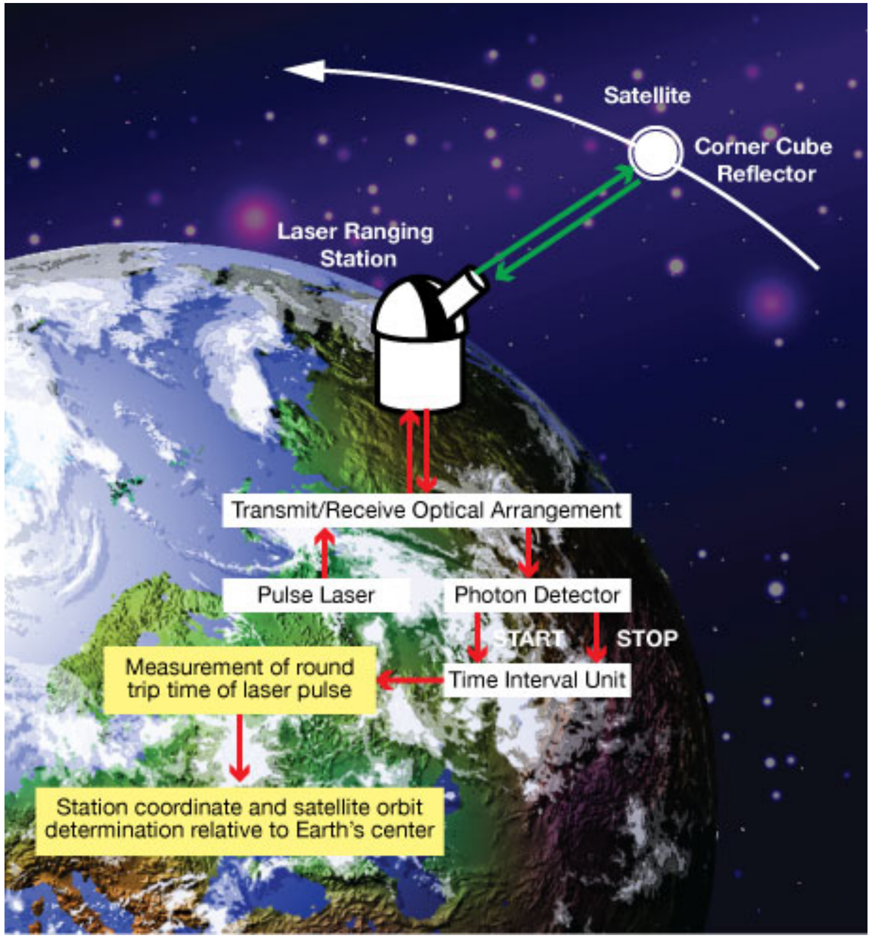
- The ILRS is one of the space geodetic services of the **International Association of Geodesy** (IAG) and is a member of the IAG's **Global Geodetic Observing System** (GGOS). The services, under the umbrella of GGOS, provide the geodetic infrastructure necessary for monitoring global change in the Earth system (Beutler and Rummel, 2012).

ILRS services are fundamental to ITRF

International Laser Ranging Service

SLR and LLR

- Satellite Laser Ranging and Lunar Laser Ranging
- Space Segment:
  - Satellites equipped with corner cube reflectors
  - **100+ satellites (including the Moon)**
- Ground Segment:
  - Short-pulse laser transmitter (generally 532 nm)
  - **~40 sites tracking**
- Observable:
  - **Two-way round trip range measurement to the satellite**
- Characteristics:
  - Passive space segment
  - Simple range measurement
  - **Optical technique less susceptible to uncertainties in atmospheric propagation delays**



Lasers resolve accurate distances to reflectors

ILRS products

- ***Three-dimensional coordinates and velocities of the ILRS tracking stations for the International Terrestrial Reference Frame (ITRF)***
- ***Earth orientation parameters*** (polar motion and length of day)
- ***Centimeter-accuracy satellite ephemerides*** for all satellites, including radar and laser altimeter, INSAR and other remote sensing satellites
- Time-varying coordinates for the geocenter of the Earth
- Static and time-varying coefficients of the Earth's gravitational field
- Fundamental physical constants
- Lunar ephemerides, librations, and orientation parameters
- ***Accurate time transfer***
- Tracking of space debris targets (e.g., Envisat, TOPEX, and others)
- One-way range tracking to lunar and planetary distances (e.g., LRO)

Products are used for cm-accuracy satellite ephemerides, ITRF, geodesy, time transfer, etc.

Synergism: SLR and GNSS (1 of 2)

- **Satellite Laser Ranging (SLR) to GNSS targets is currently used to *calibrate* their orbits derived from microwave data**
- Conceivably, the combined data can produce *improved geodetic products*
- Independent GNSS orbits can be produced if sufficient SLR data are collected from a reasonably uniform global network (~16 sites)
- SLR data are used to "center" the GNSS orbits, putting them in a geocentric frame and with the proper scale, so that the GNSS constellations can be used as the wide distributors of the ITRF
- The ITRF development is based on an inter-technique combination and benefits from the co-location of the two techniques in space: constrains systematic errors
- It is the responsibility of each technique to determine and assess their systematic errors. Co-location in space allows the two techniques to efficiently accomplish this very

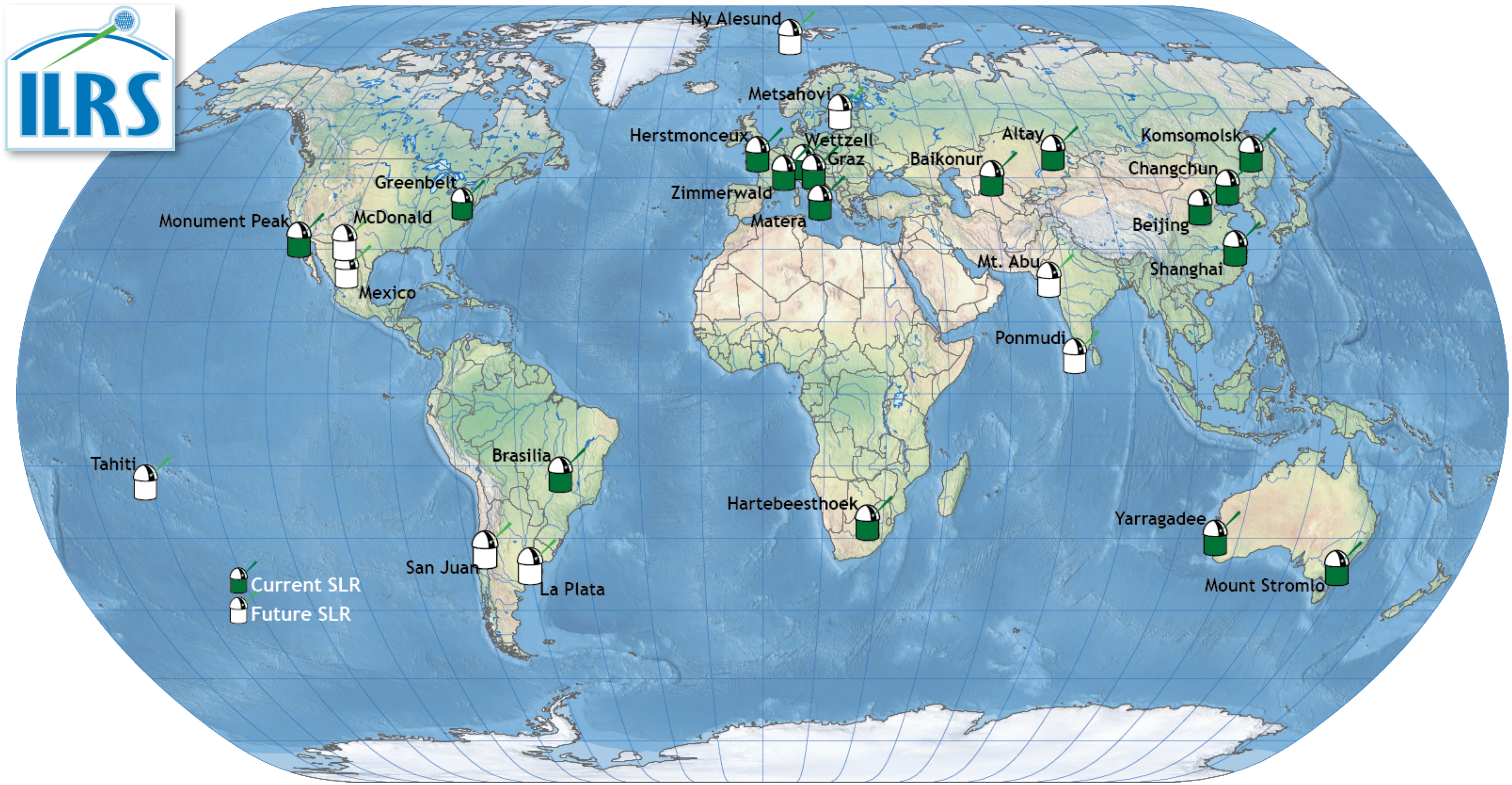
SLR data are used to "center" GNSS orbits into geocentric frame, co-location of sites constrains systematic errors

Synergism: SLR and GNSS (2 of 2)

- SLR to GNSS targets can be used to validate various model improvements on the GNSS spacecraft associated with:
  - Solar radiation pressure models;
  - Antennae phase center offsets and their variations;
  - Clock behavior and monitoring their aging;
  - Orbital attitude models;
  - Other non-conservative force effects on the dynamics of the GNSS orbits
- GNSS is the preferred technique for orbit determination of low-orbiting missions and SLR is routinely used to validate these orbits as well as precise baseline solutions in case of formation flying missions (e.g., Swarm, GRACE, TanDEM-X/TerraSAR-X, etc.)
- SLR facilitates time-transfer over intercontinental distances

GNSS preferred orbit determination technique for low-orbit missions -– SLR facilitates time-transfer

ILRS network tracking GNSS



Map reflects ILRS network stations tracking GNSS satellites since November 2016 as well as plans for future stations capable of tracking GNSS

For Official Use Only

Current ILRS tracking support of GNSS

Constellation	Satellites Tracked by ILRS	
GLONASS	26 (8 on priority list)	
Galileo	18 (14 FOC, 4 IOV)	
Beidou	11 (5 MEO, 6 GEO)	
QZSS	4 (1 GEO)	
IRNSS	5	
Future: GPS-III	24?	

The problem…

- **The ILRS supports users on a wide variety of missions**, *with the highest priorities being the ITRF and some of the Earth remote sensing satellites* (e.g., altimetry, gravity field missions), trying to set priorities to maximize the utility of the network

- **The global ILRS network is tracking 42** (and more!) GNSS satellites selected by the Galileo, GLONASS, Beidou (and QZSS and IRNSS) missions, but tracking on individual satellites is sparse

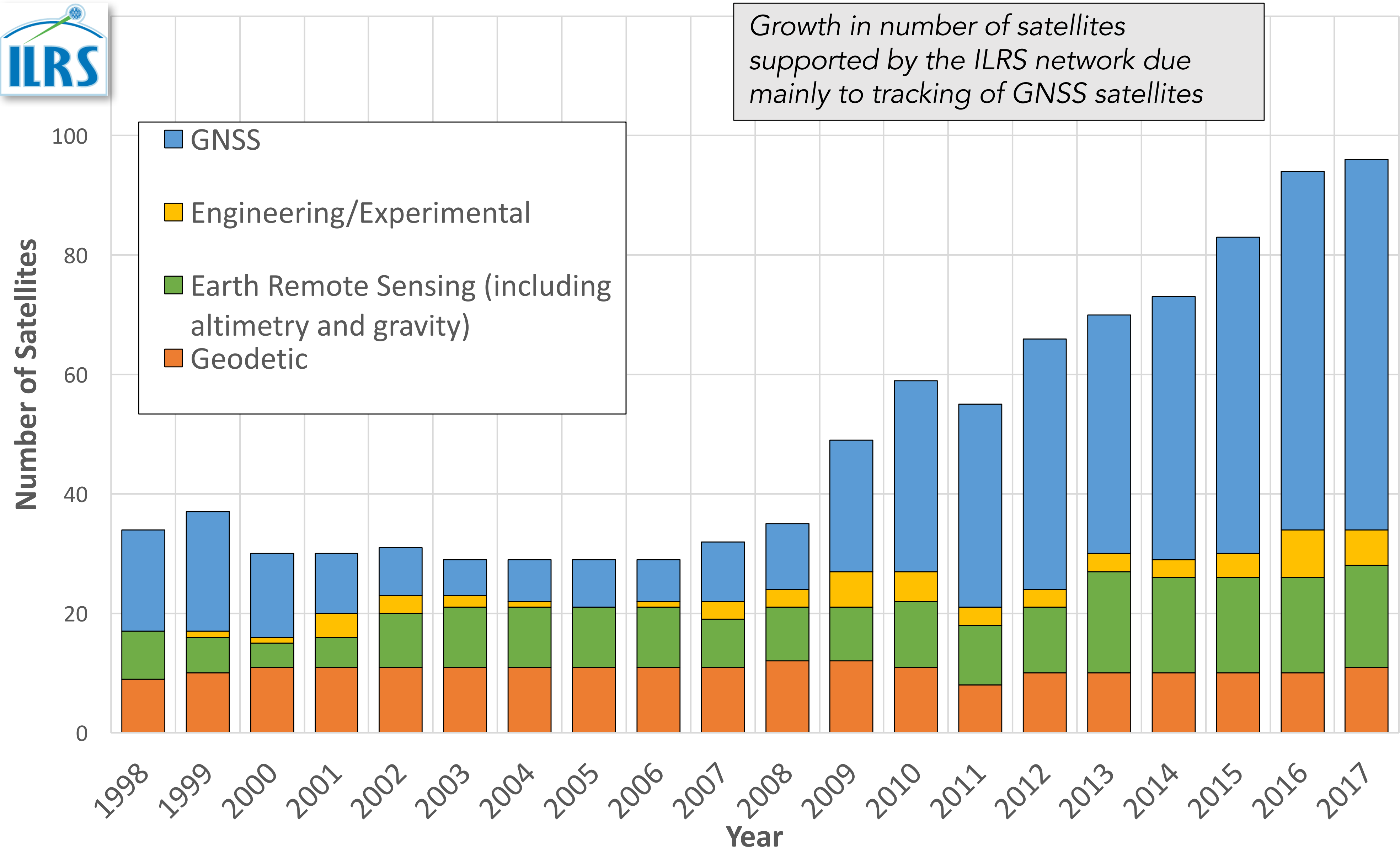
- The addition of the future GPS-III satellite constellation and their data requirements must also be considered and addressed

- **The ILRS is looking to reduce the number of GNSS satellites on its tracking roster to devote more time on a smaller set of satellites**

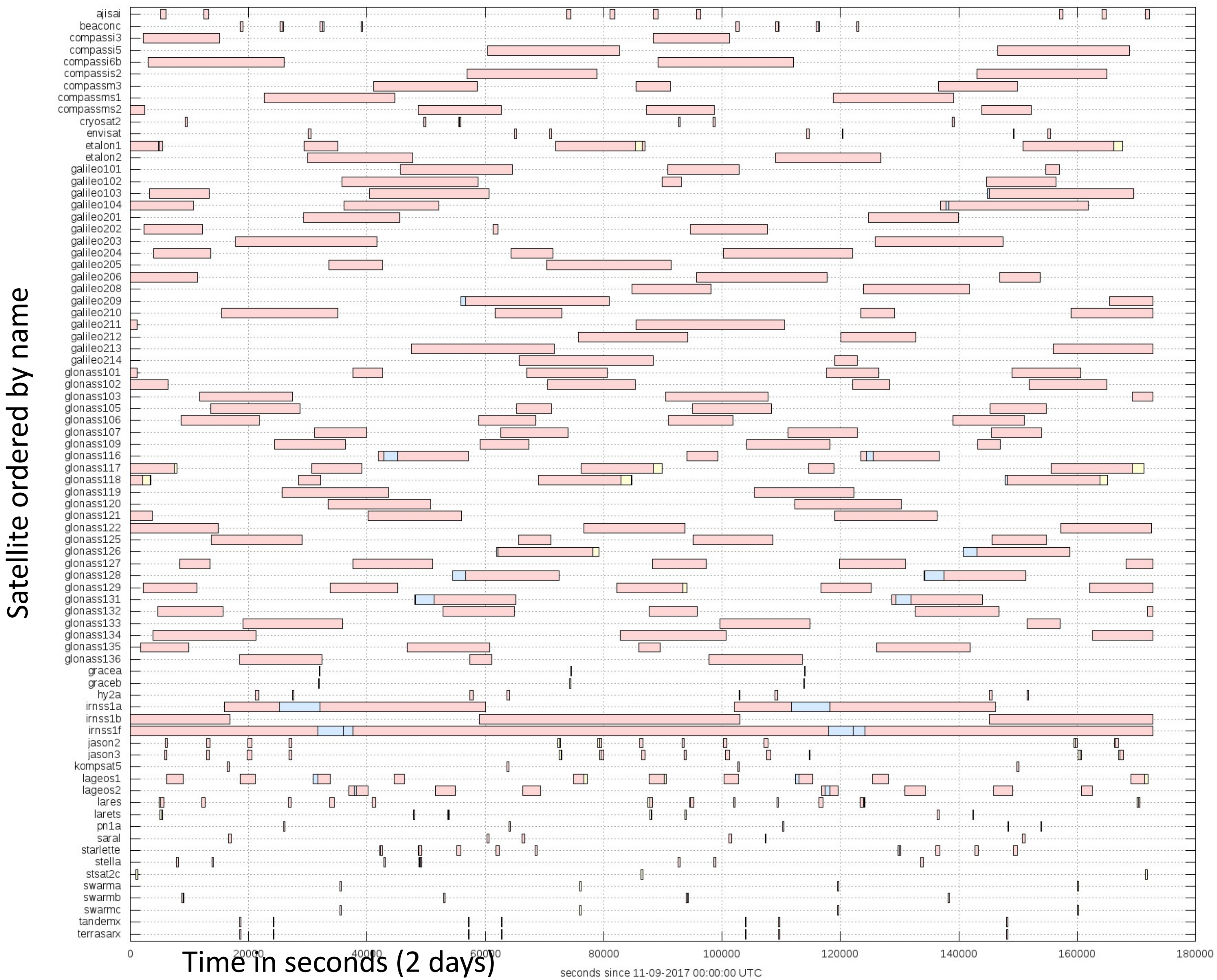
- At the moment, there is **no coordination** among the constellations except what the ILRS provides *(ILRS specifies the priorities for station tracking)*

ILRS is looking to reduce the number of GNSS satellites on its tracking roster… there is no coordination

ILRS satellite tracking



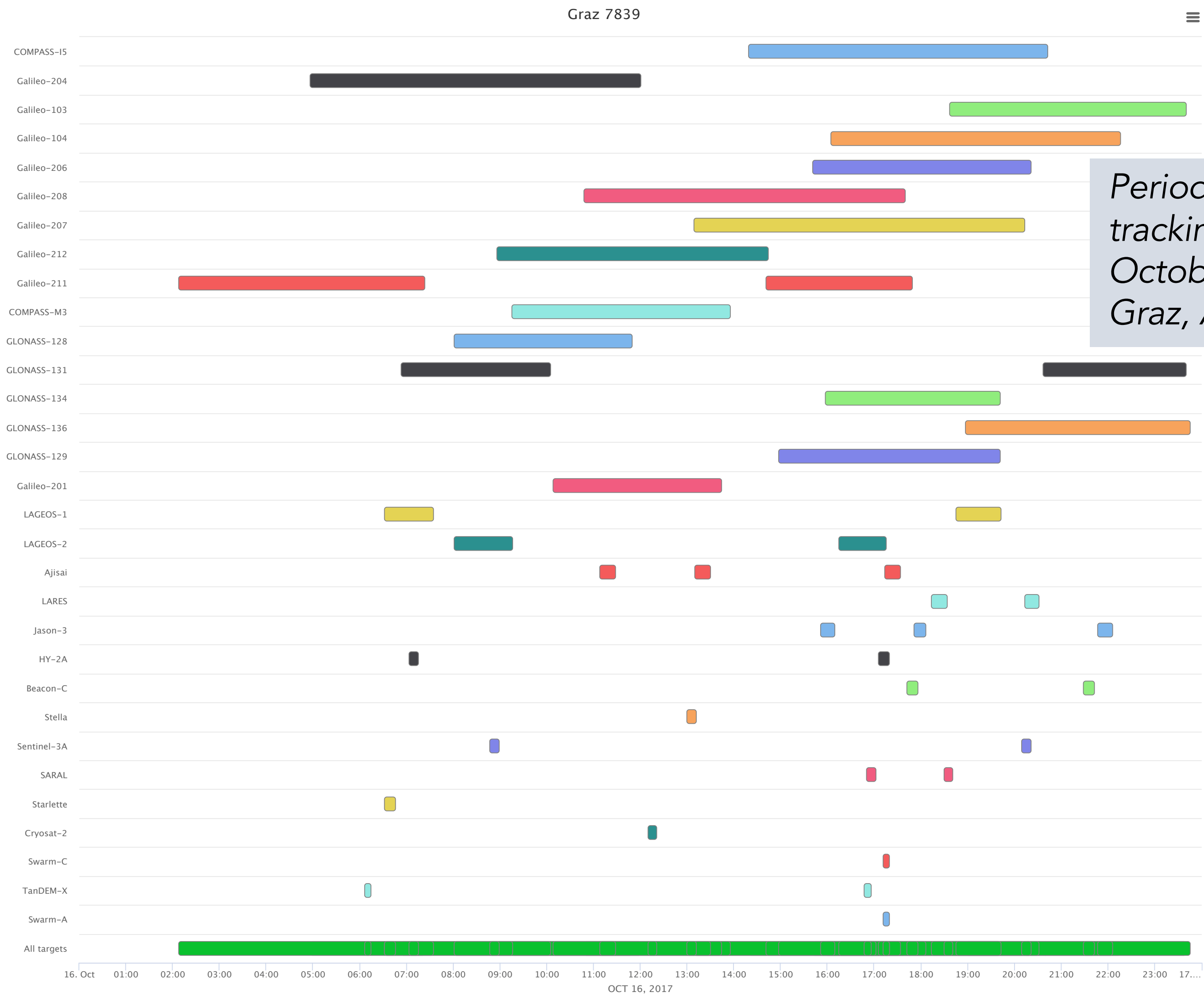
ILRS stations are overloaded (1 of 2)



- *Typical satellite visibilities above Wettzell Germany station for two days*
- *Plot shows overlapping targets*

Presented at 2017 ILRS Technical Workshop, October 02-05, 2017 in Riga Latvia, "Automatic scheduling of satellite passages at the SOS-W" by S. Riepl

ILRS stations are overloaded (2 of 2)



Satellite ordered by name

Time in hours – 1 day

Periods over which Satellite tracking data was taken on October 16, 2017 at the Graz, Austria SLR station

How are GNSS targets selected by the ILRS?

- Each GNSS constellation provides the list of its satellites it wants tracked, specifying the relative priority
- ILRS orders the overall priority list which includes geodetic, Earth observation, experimental/engineering satellites, and GNSS targets
- **At present, all satellites requested by GNSS constellations are accommodated, none are left off**
- ILRS organized some campaigns to stress tracking of a subset of satellites in each GNSS constellation
  - Results showed some improvement for targeted satellites
  - However, some stations continued to track all GNSS satellites
  - These campaigns pointed out the possible benefit of a higher level of coordination (network and constellations)

ILRS organized campaigns collected more data on a subset in each GNSS constellation: results showed some improvement for targeted satellites

Approaches under consideration

- **Limit all of the constellations to a list of 4 to 6 satellites** for ILRS tracking (with the possibility to switch to a different selection over agreed upon intervals)
- Ask the stations to take more robust sampling of the selected satellites
- Make satellite predictions available to network stations for only the GNSS satellites approved for tracking and on the ILRS priority list

Beidou laser retroreflector array
(31.6 x 28 cm, planar, hexagonal array; 2.5 kg)
(Chinese Academy of Sciences)

Role of ICG WG-D

- Investigate the possibility that some coordination of SLR tracking among the GNSS constellations might lead to better utility of the network, resulting in benefits for the users
- This coordination may be difficult since each GNSS constellation has its own vested interests

- **Furthermore, encourage national and space agency support for stations in the ILRS network (a resource issue: operations and technological upgrades required to deliver more data to GNSS and other users)**
- **New SLR stations or upgrades to current would expand capacity**

International Laser Ranging Service

Gerald.W.Bawden@NASA.gov