# Measuring GNSS Satellite Transmit Power

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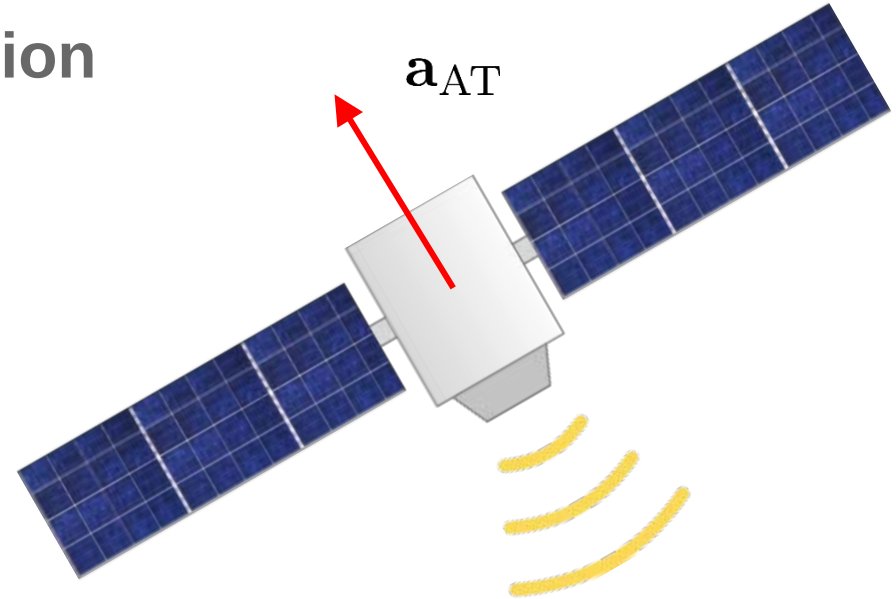
# Motivation




$$\mathbf{a}_{\mathrm{AT}} = \frac{P}{c \cdot m} \cdot \frac{\mathbf{x}}{|\mathbf{x}|}$$

$$\Delta r_{\mathrm{AT}} = -\frac{1}{3}\left(\frac{T}{2\pi}\right)^2 |\mathbf{a}_{\mathrm{AT}}|$$

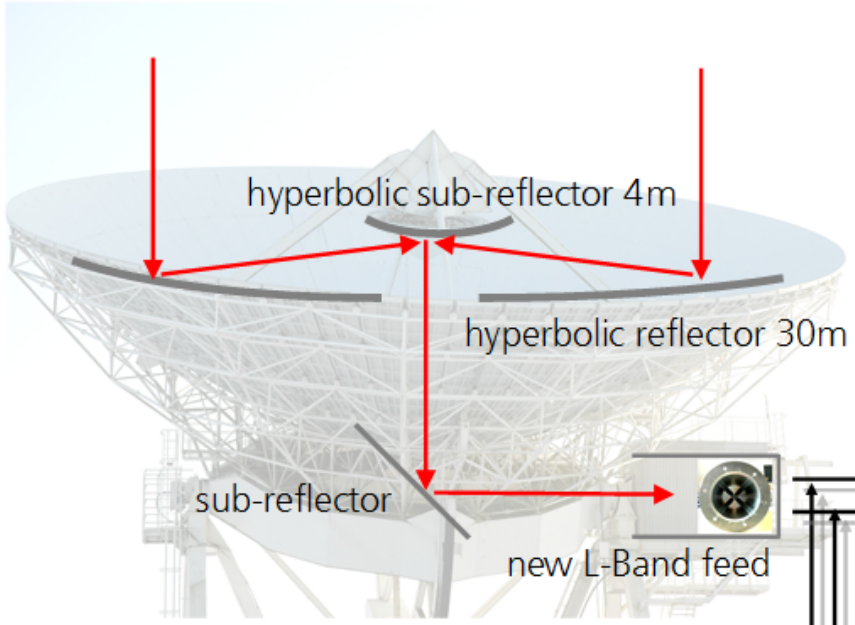
- **Antenna thrust** is caused by transmission of GNSS navigation signals, mainly radial effect
- IGS GPS power model based on minimum received RF power from IS-GPS and empirical scaling factors
- Scaling factors too large by 1.5 dB
- No/limited data for other GNSS

| | |
|---|---|
| $P$ | transmit power [W] |
| $c$ | vacuum speed of light |
| $m$ | satellite mass [kg] |
| $\mathbf{x}$ | position vector of the satellite |
| $T$ | orbital period [s] |

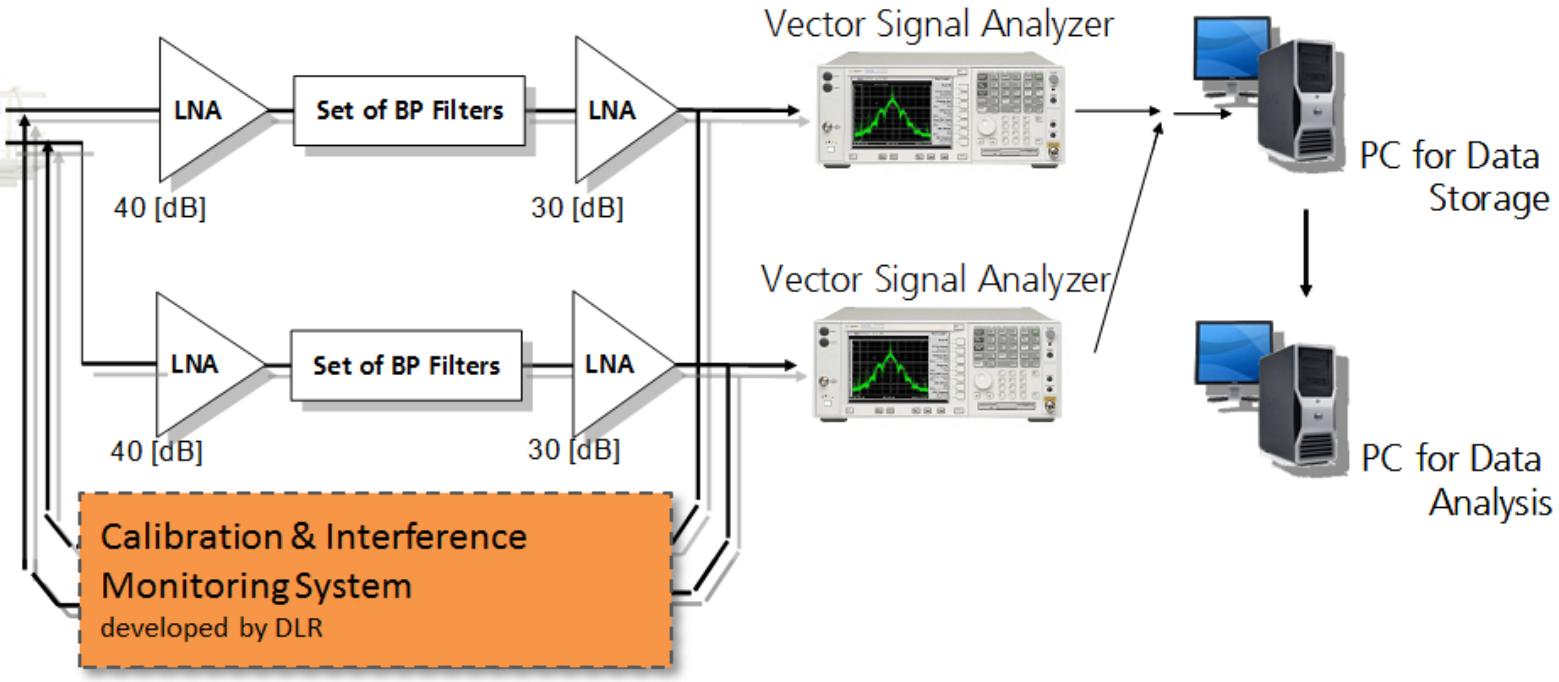
# Measurement Facility

- DLR ground station Weilheim (Germany)
- 30 m dish antenna, L-band 50 dB gain
- Operated by German Space Operations Center (GSOC) of DLR

# Measurement Setup




- Calibrated receive power and spectrum measurements
- Two independent RF chains for RHCP and/or LHCP
- Data acquisition up to 120 MHz signal bandwidth

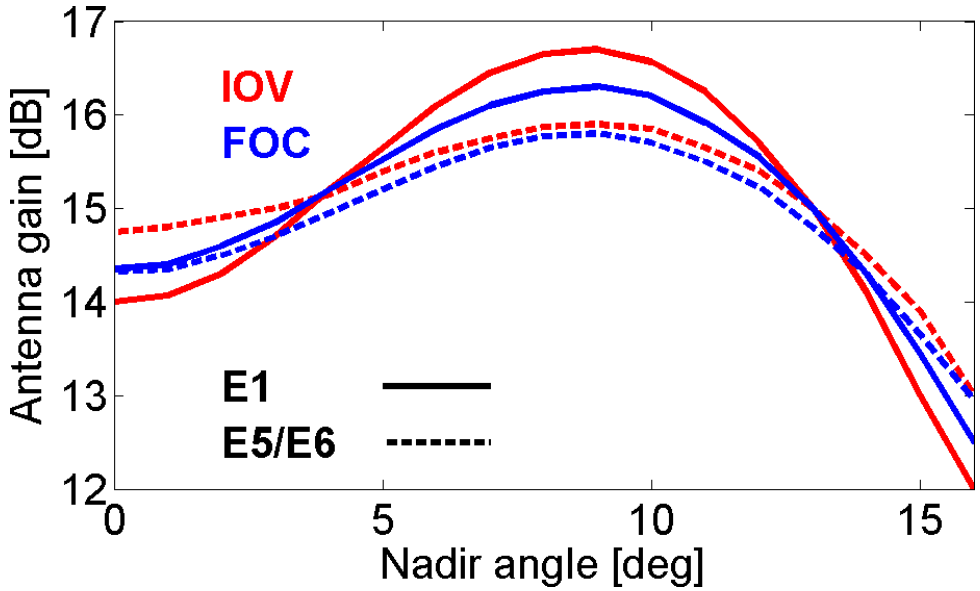


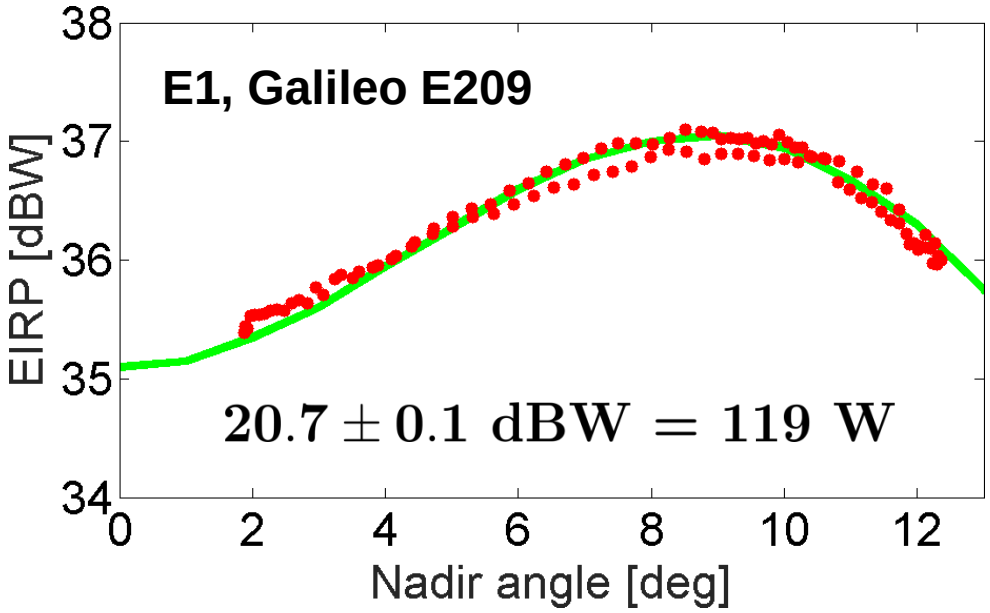

# Link Budget and EIRP Estimation

$$P_r = P_s + G_s + G_r - L_0 - L_a$$

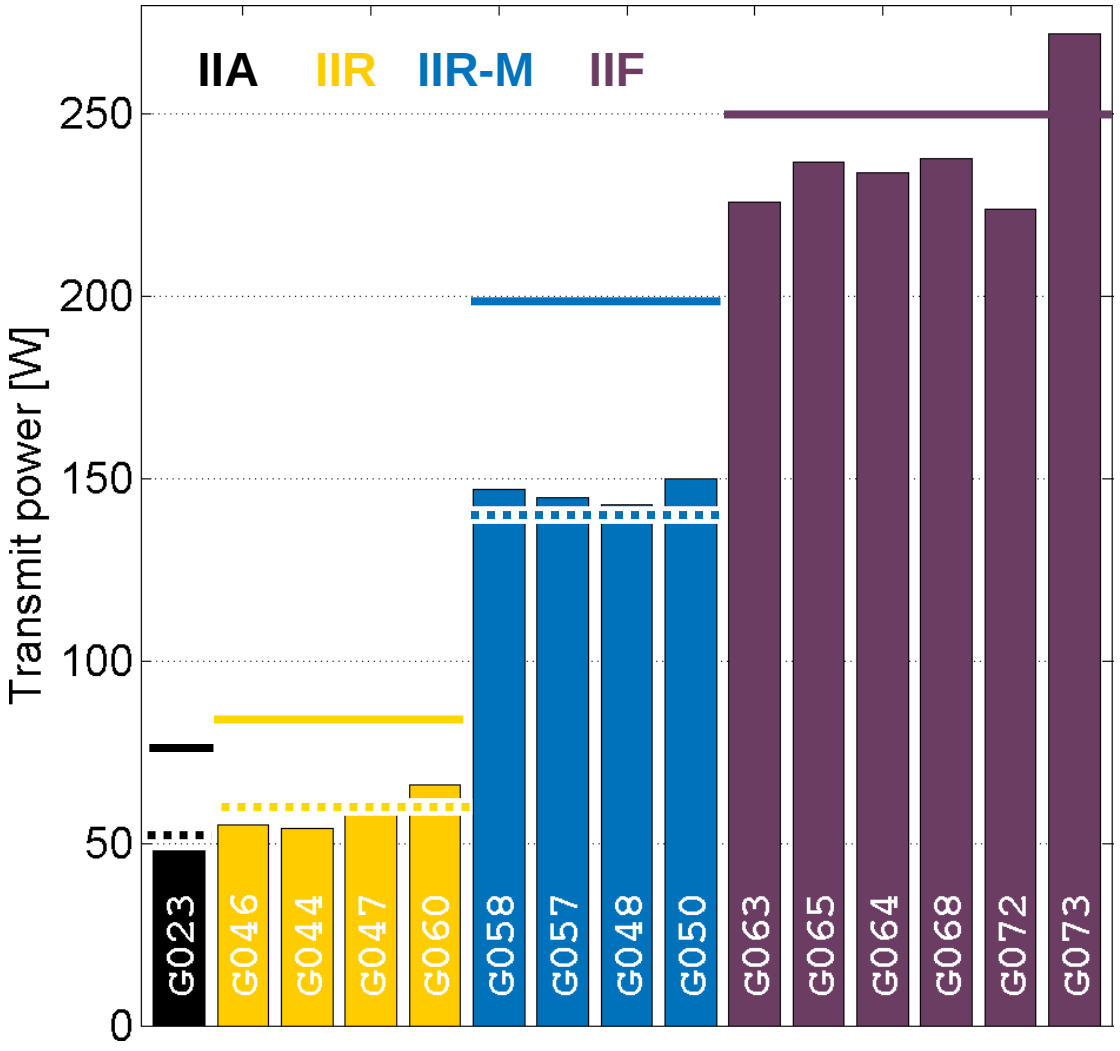
| | |
|---|---|
| $P_r$ | received power [dBW] |
| $P_s$ | transmitted power [dBW] |
| $G_s$ | transmit antenna gain [dB] |
| $G_r$ | receive antenna gain [dB] |
| $L_0$ | free space loss [dB] |
| $L_a$ | atmospheric loss [dB] |

Measured Effective Isotropic Radiated Power (EIRP)

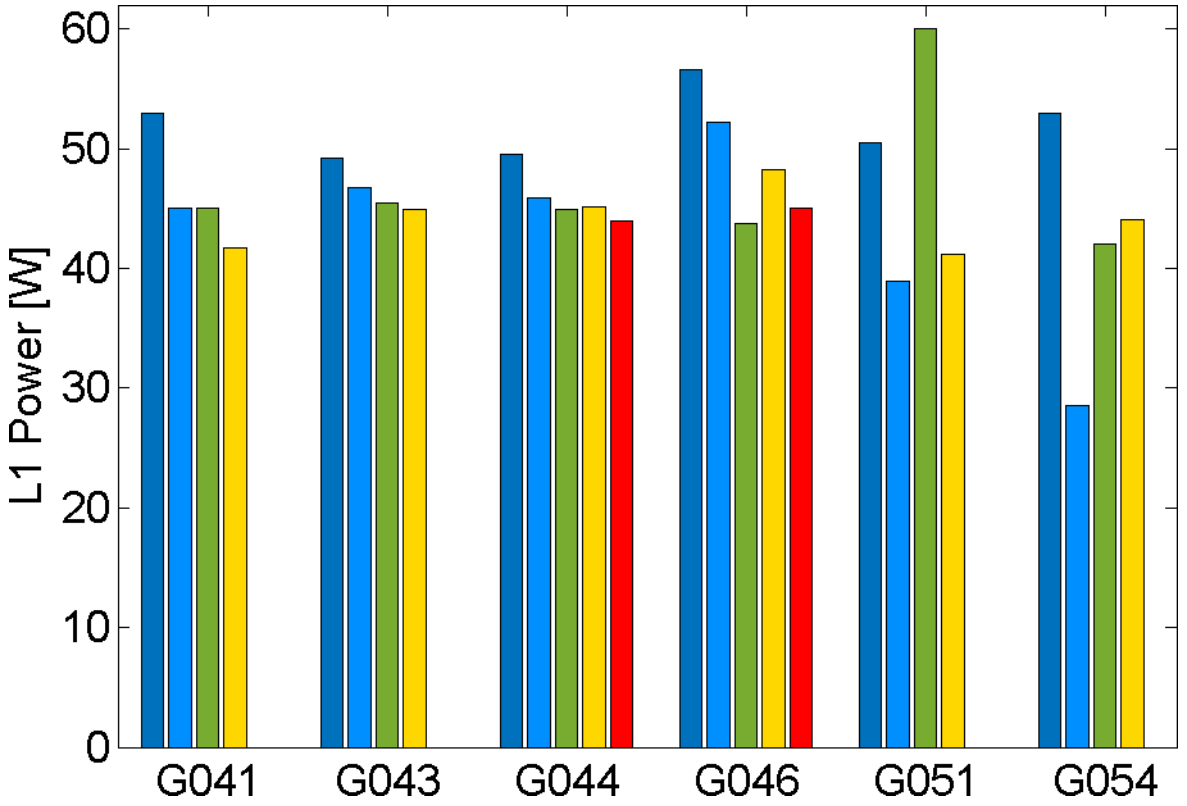



# Transmit Power GPS




## Comparison Block IIR with Wu (2002)

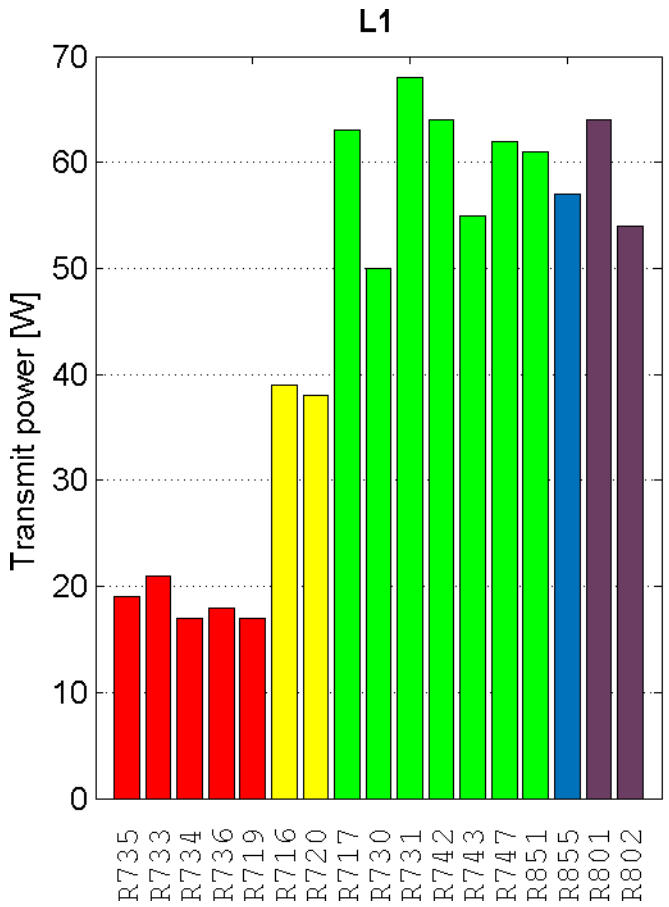


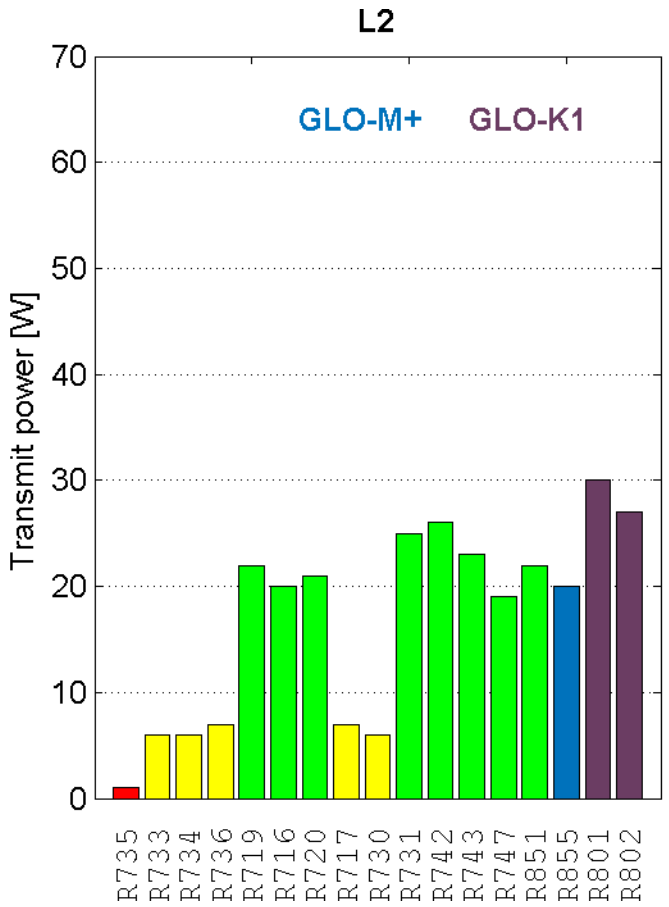

**Preflight LM** **Onboard** **Ground SRI**

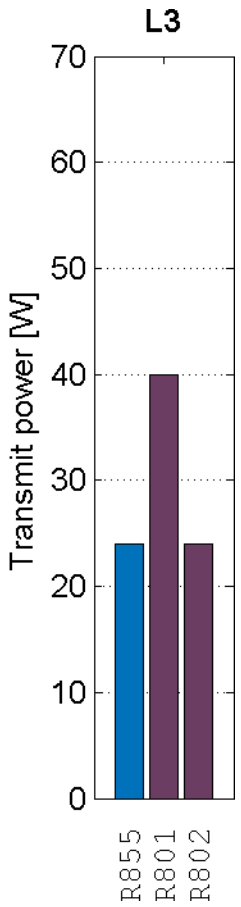
**Preflight ITT** **Ground DLR**

Wu A. (2002) Predictions and field measurements of the GPS Block IIR L1 and L2 ground powers. ION NTM 2002, pp 931–938

# Transmit Power GLONASS



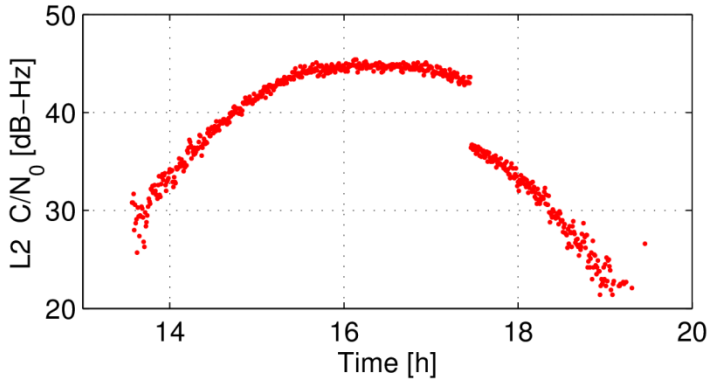




GLONASS-M:

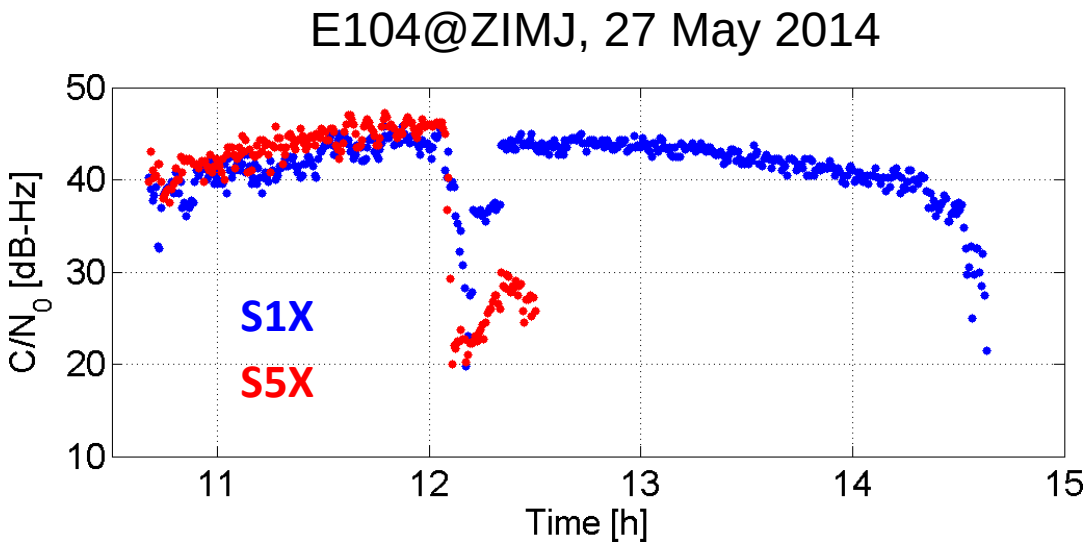
– three groups of transmit power levels for L1 and L2 frequencies

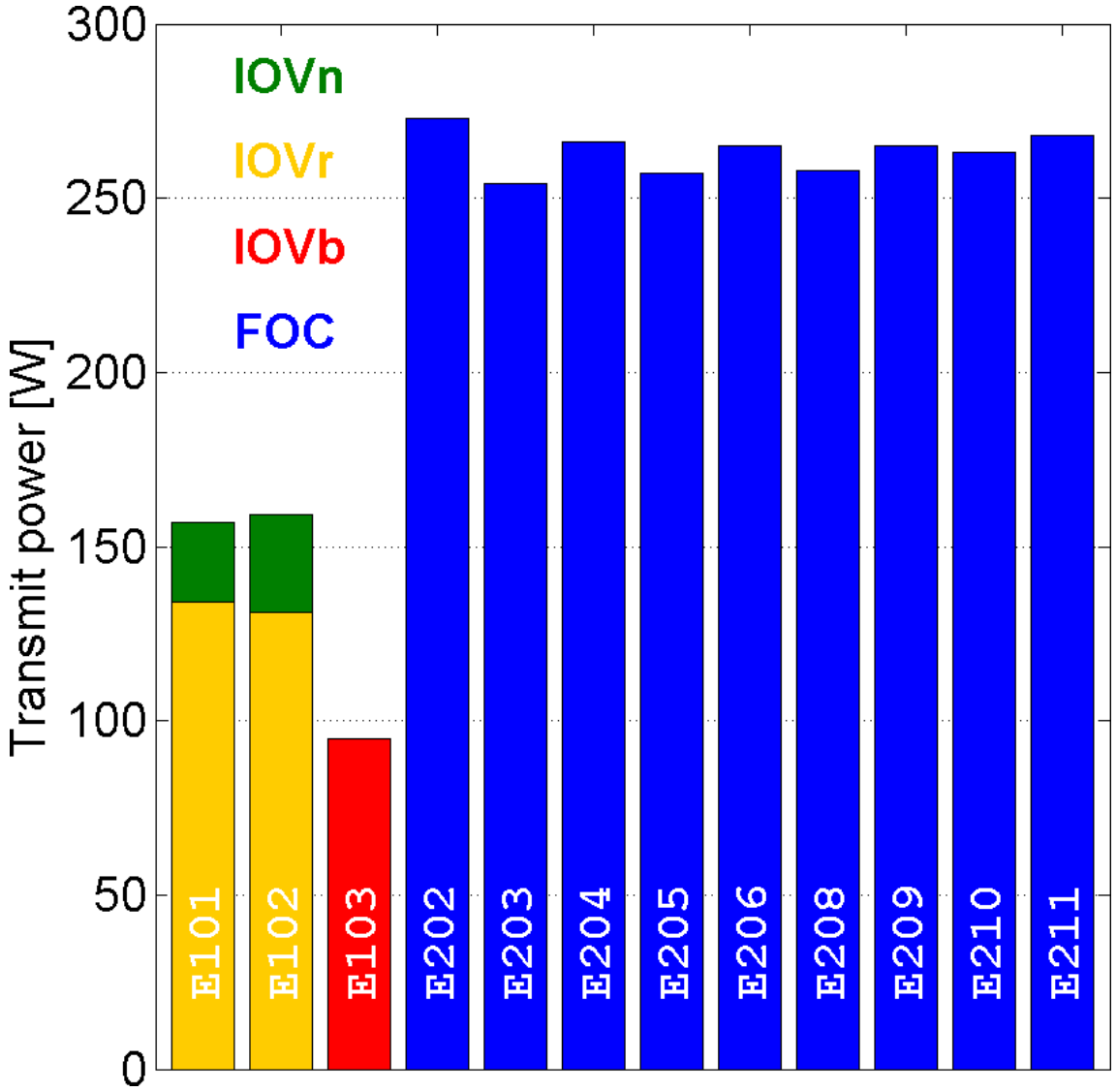
– 6 subgroups of satellites

R735@RGDG, 2 Feb 2016




# Transmit Power Galileo

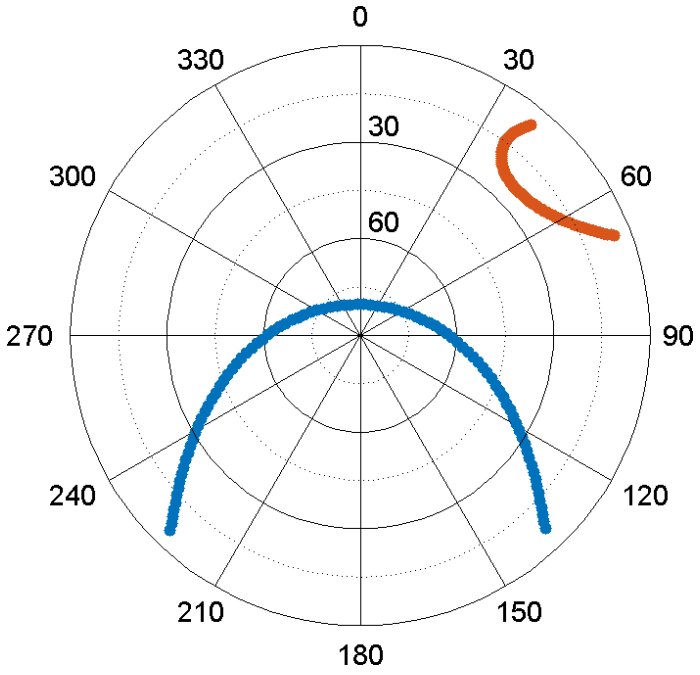


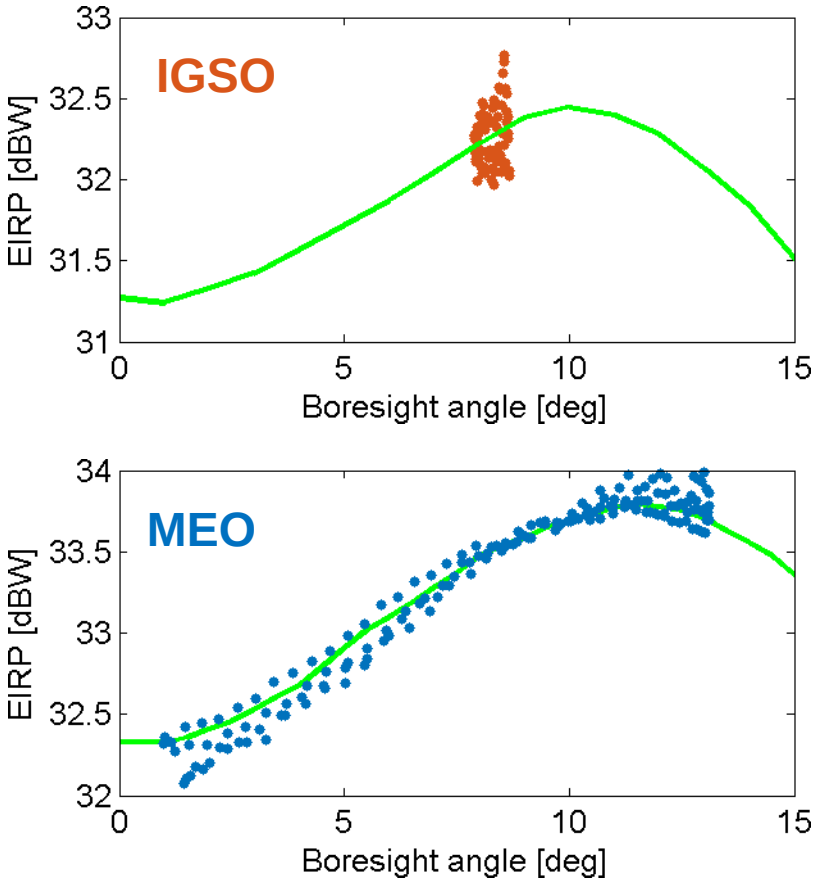



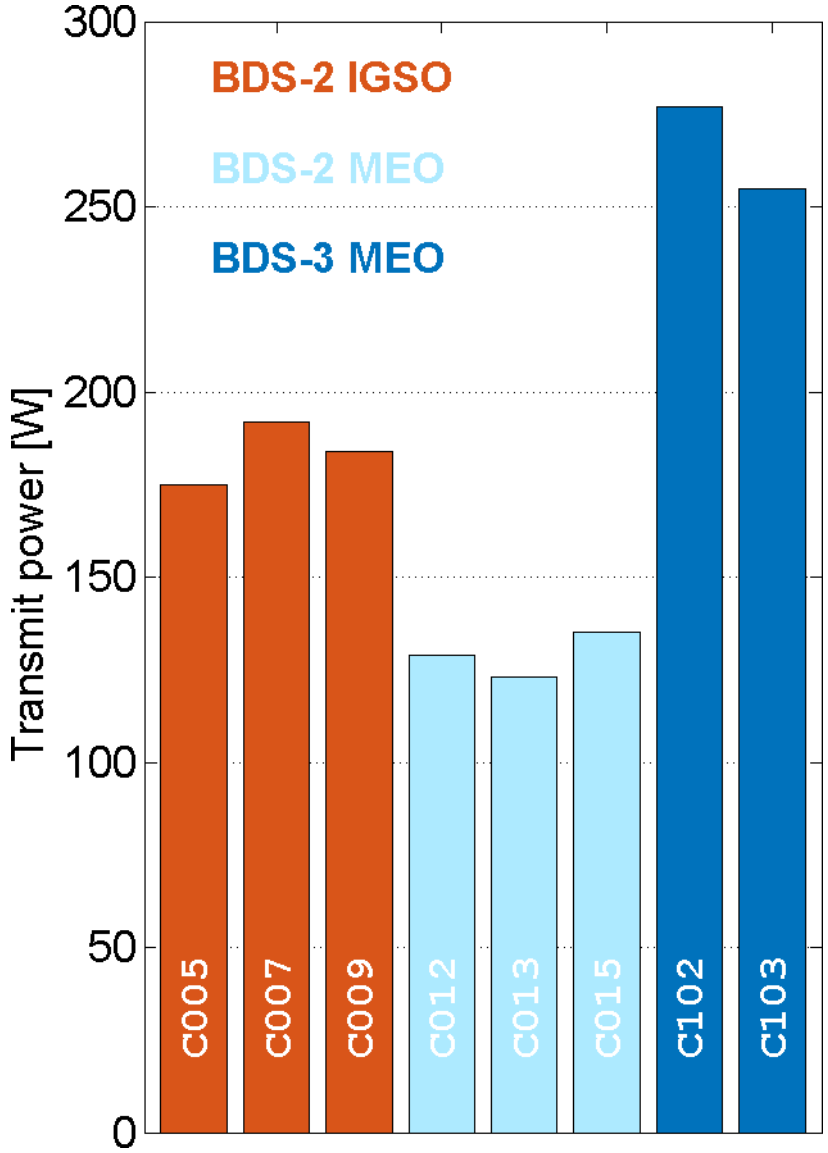

- **IOVn** Nominal transmit power before July 2014
- **IOVr** Reduced transmit power after July 2014 with status “all bands aligned”
- **IOVb** Reduced transmit power after July 2014 with status “temporary back-off”

# Transmit Power BeiDou

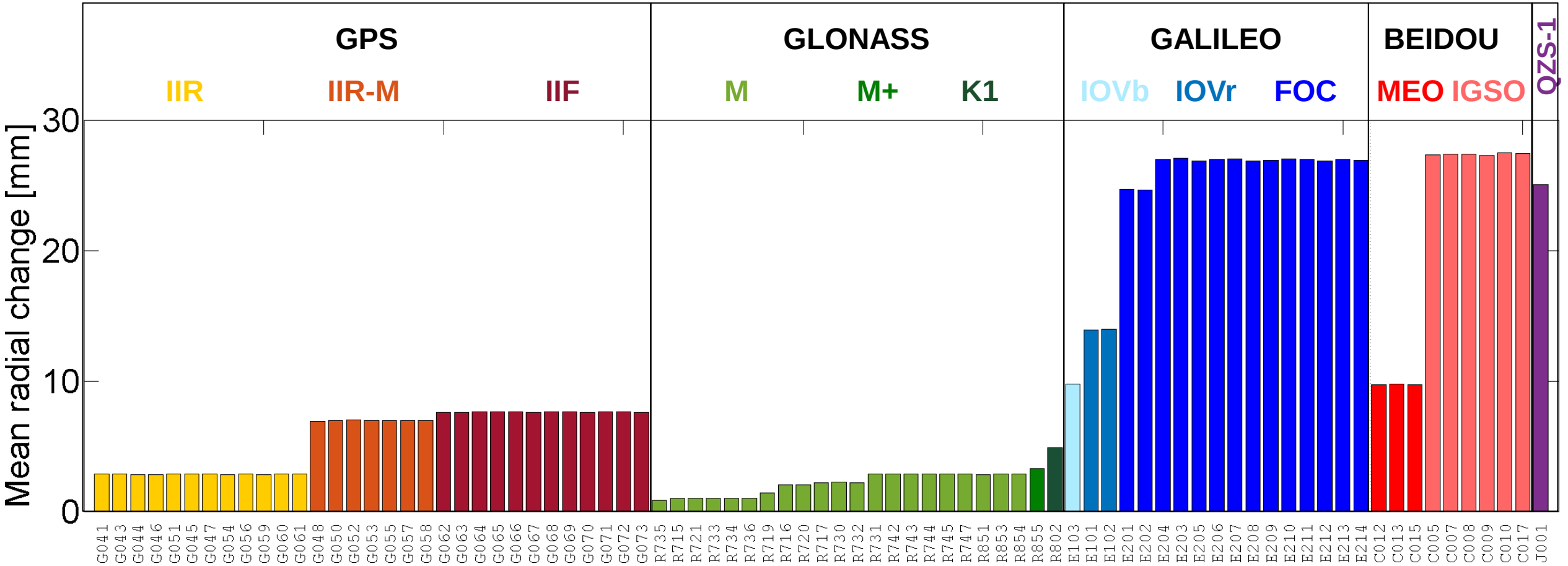
- Only low elevation observations for IGSO satellites



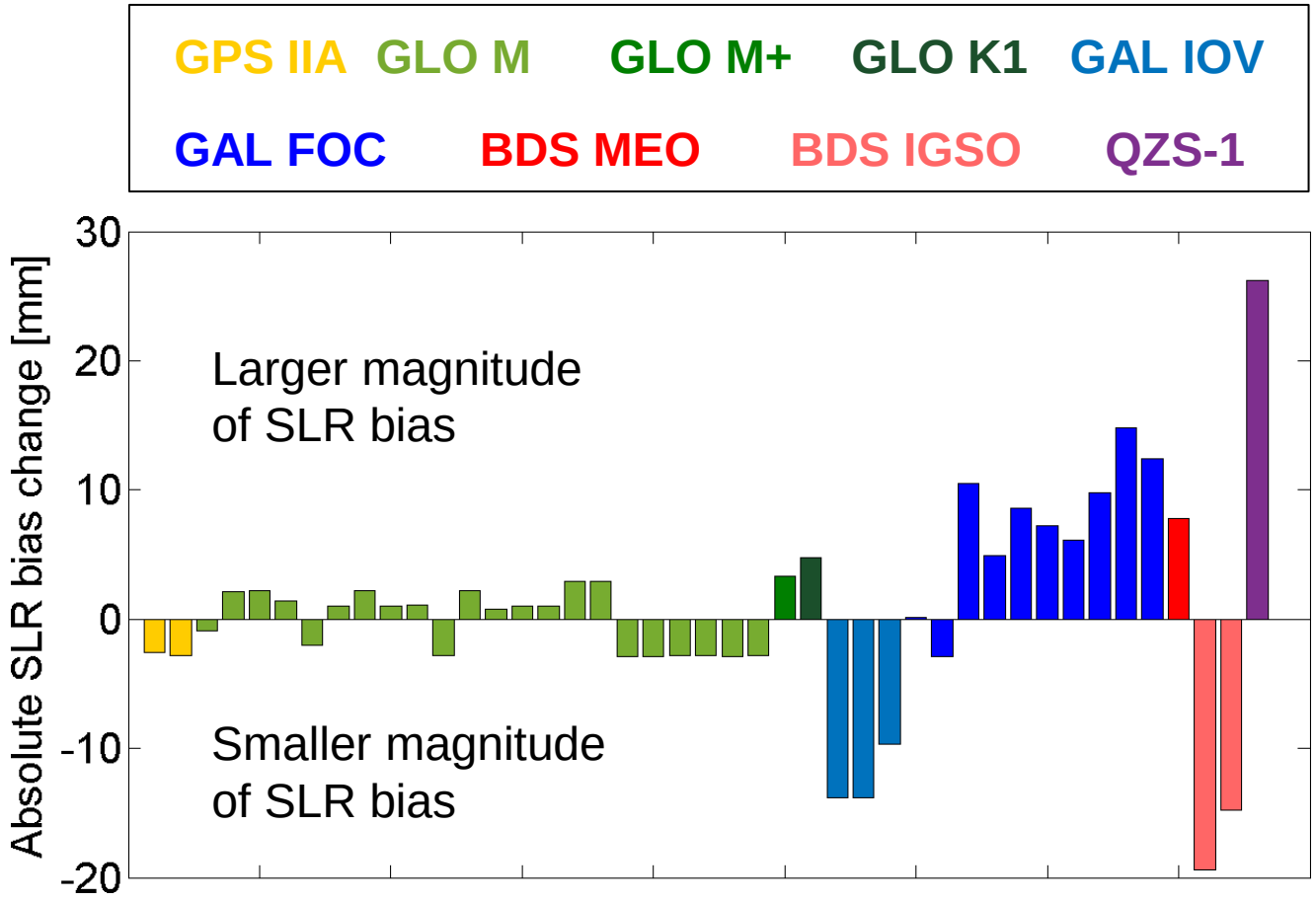




# Impact of Antenna Thrust on Precise Orbit Determination




# SLR Validation

- October 2012 – March 2013 for GPS
- December 2016 – May 2017 for other GNSS
- Station coordinates fixed to SLRF2014
- Residuals between orbit derived from GNSS measurements and range observed by SLR
- SLR biases typically in the range of -2 to +3 cm
- Deficiencies in solar radiation pressure modeling have impact on SLR bias (e.g., 10 cm for GIOVE-B)




# Summary and Outlook

- Modeling of **antenna thrust** requires knowledge of GNSS satellite transmit power
- Transmit power **measurements with 30 m dish** antenna:
  - Generally 20 – 280 W depending on satellite block
  - Changes with time: Galileo IOV, one GLONASS-M
  - Six different transmit power levels on L1 and L2 frequencies for GLONASS-M
  - GPS transmit power in general smaller than the current IGS model
- Impact on orbit determination **1** – **27 mm** depending on transmit power, mass, and orbit height
- Uncertain satellite mass for
  - BeiDou
  - QZSS
- Uncertain GPS IIF transmit antenna gain pattern
- Lack of publicly available transmit antenna gain pattern for
  - GLONASS
  - BeiDou
- **Support of GNSS providers needed** for historic data, mass, gain pattern
- Regular monitoring of GNSS transmit power necessary

# Proposal for SINEX Metadata Blocks

- Proposed extension of SINEX format to document transmit power in machine-readable format
- See MGEX splinter meeting on Tuesday 4 July 2017, 15:30 – 17:00

```
+SATELLITE/TX_POWER
*SVN  VALID_FROM____ TO_____________ P[W] COMMENT_____________________________
 E101 0000:000:00000 2014:147:86399  150 Galileo IOV nominal power
 E101 2014:148:00000 2016:137:86399   95 Galileo IOV temporary back off
 E101 2016:138:00000 0000:000:00000  135 Galileo IOV reduced power
 …
 G061 0000:000:00000 0000:000:00000   60 GPS IIR-B
 G062 0000:000:00000 0000:000:00000  240 GPS IIF
 …
 J001 0000:000:00000 0000:000:00000  244 QZS-1
-SATELLITE/TX_POWER
```