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Precise GNSS orbit determination using an adjustable box-wing model for solar radiation pressure

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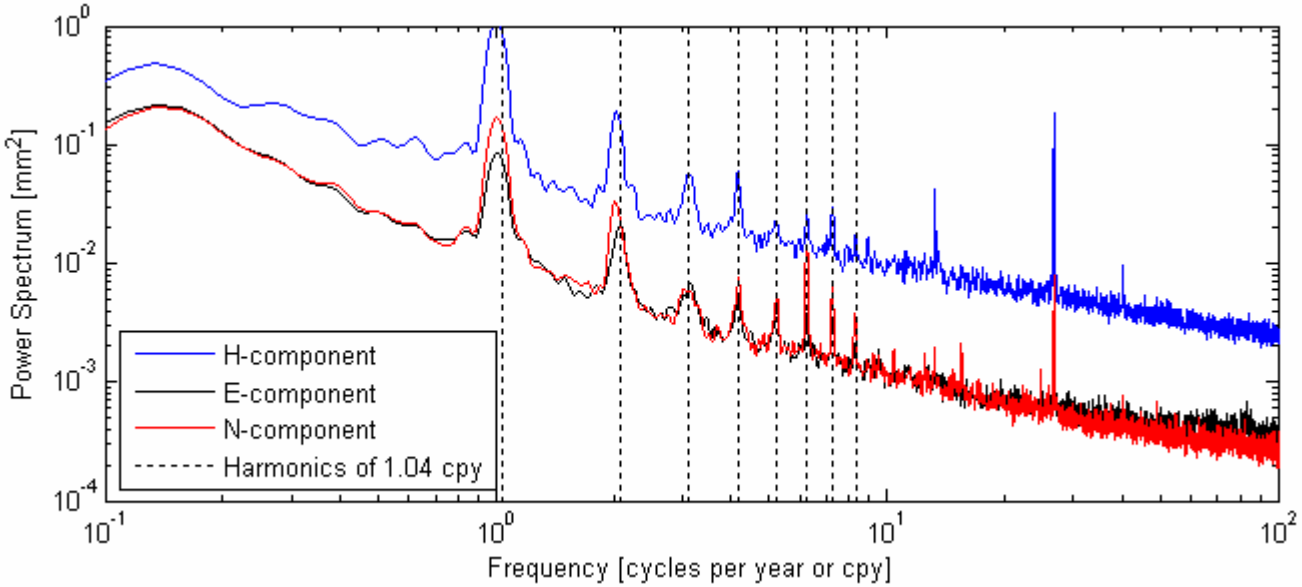
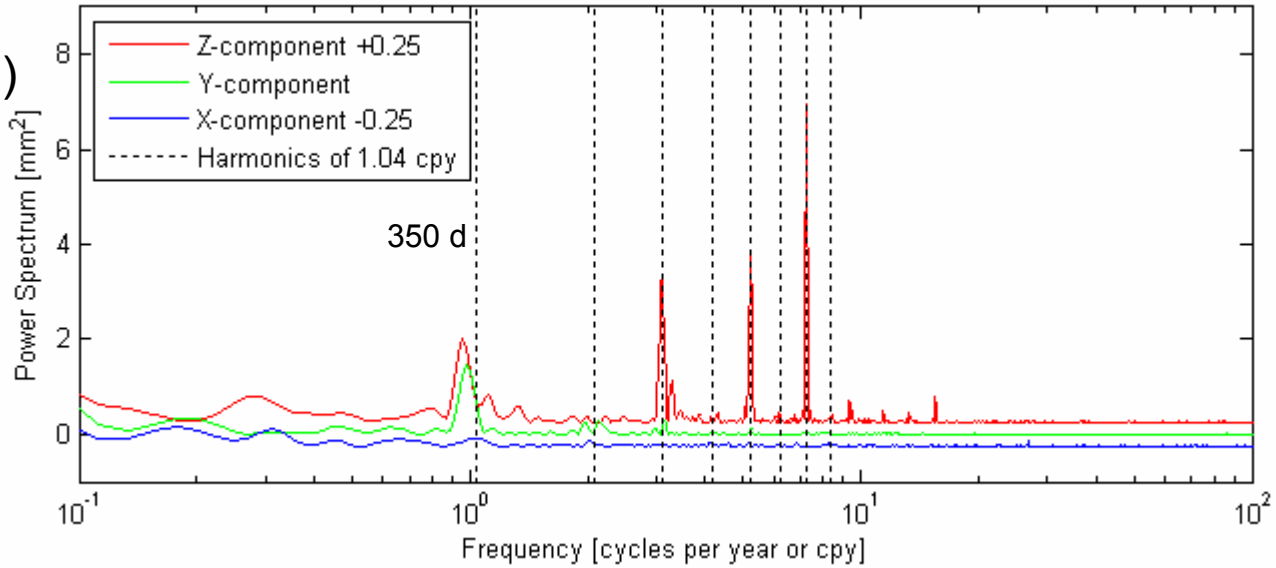
Motivation

- **Orbit-related frequencies** in geodetic time series
- Station coordinates
  Ray et al. (2009)

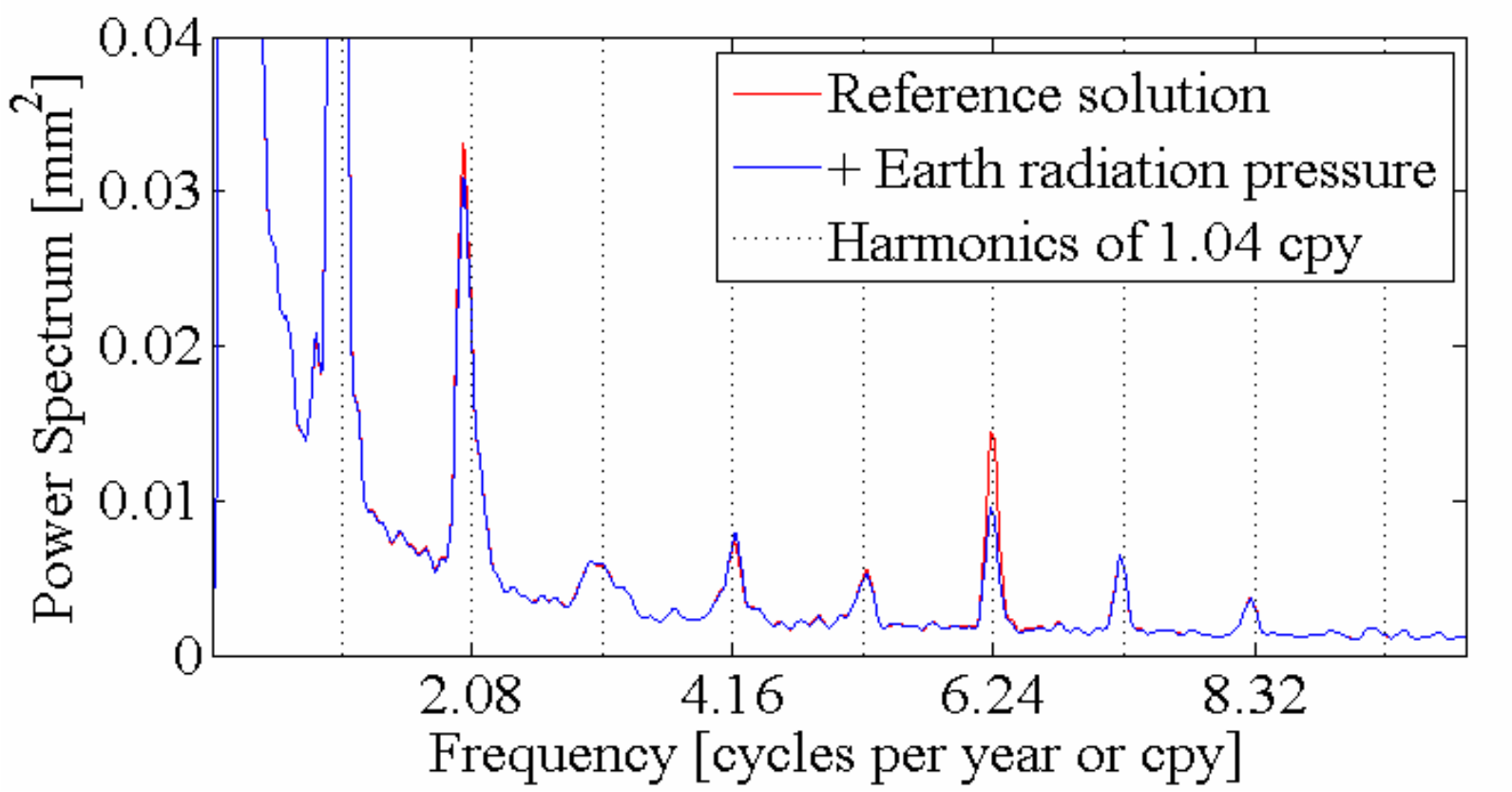


- Geocenter position
  Hugentobler et al. (2006)



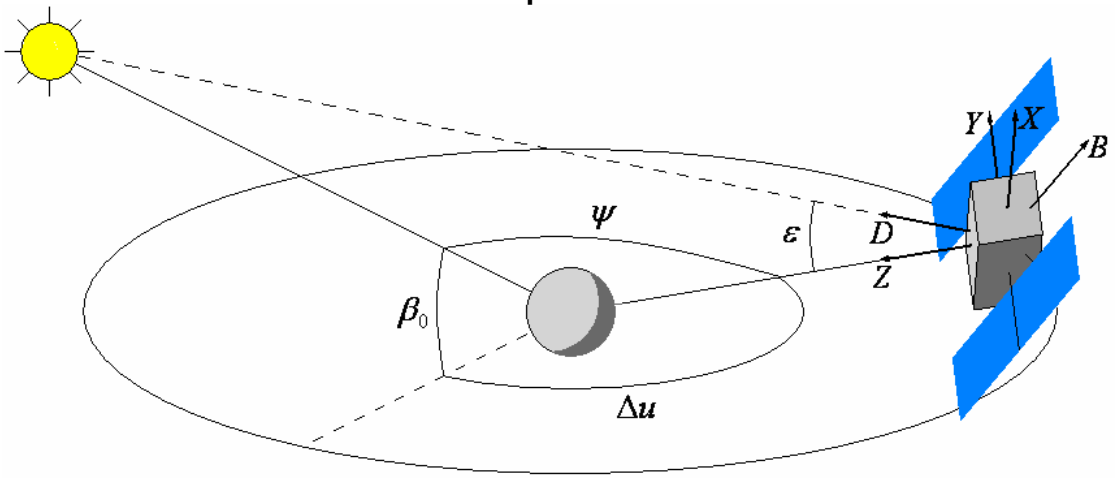
Motivation

- Impact of **Earth radiation pressure** on GPS position estimates (Rodriguez-Solano et al., 2011)



Empirical and analytical SRP models

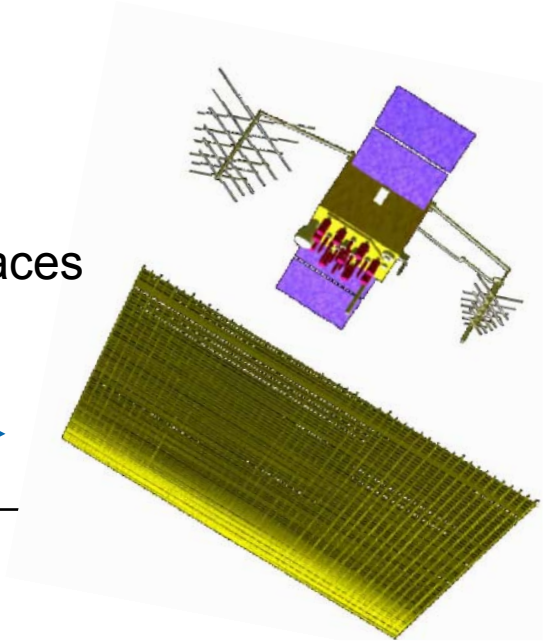
- **CODE empirical model:**
  - 5 empirical acceleration parameters [m/s^2] per arc
  - constant and periodic in **DYB** directions



- 3 stochastic pulses per day
  - radial
  - along-track
  - cross-track

- **Analytical models:**
  - knowledge e.g. from satellite manufacturers
  - nominal attitude
  - physical interaction between radiation and satellite surfaces

- Examples: **ROCK** (Fliegel et al., 1992, 1996)
  UCL (Ziebart et al., 2005)

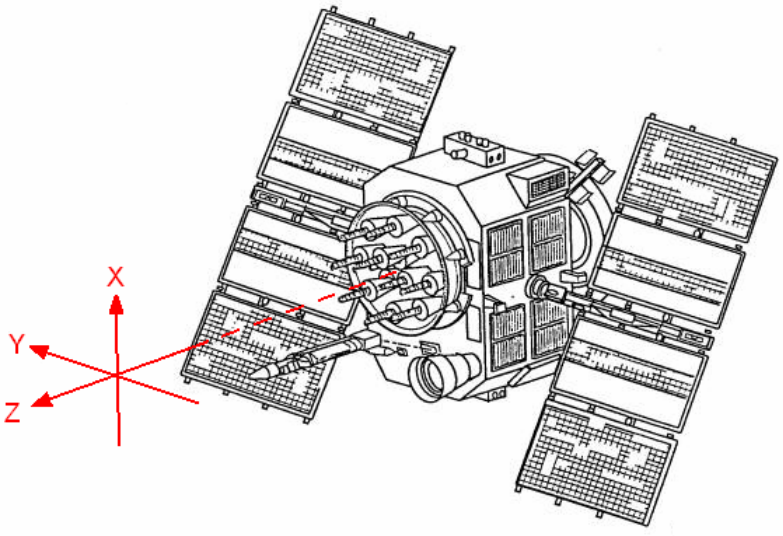


Adjustable SRP box-wing model

- **Physically based model:**

  Simple box-wing model for SRP

- Four main surfaces:
  - Solar panels front
  - Bus +X side
  - Bus +Z side
  - Bus –Z side



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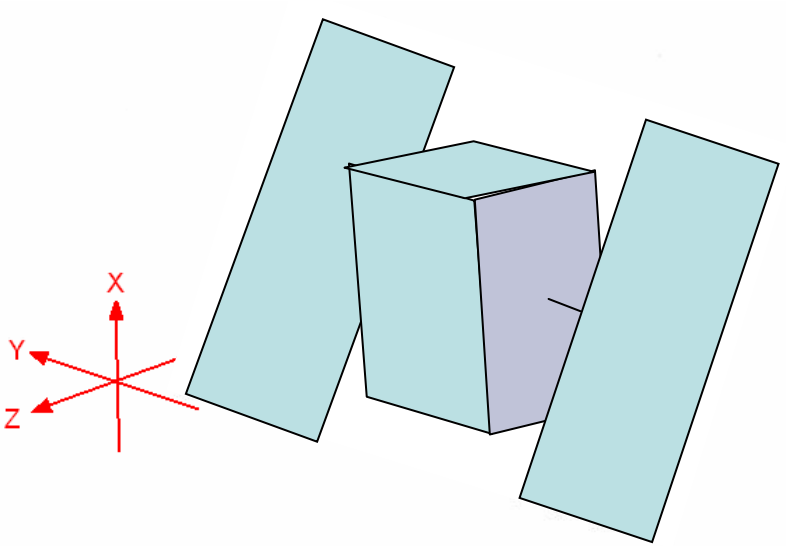


- Model capable of fitting the GNSS tracking data

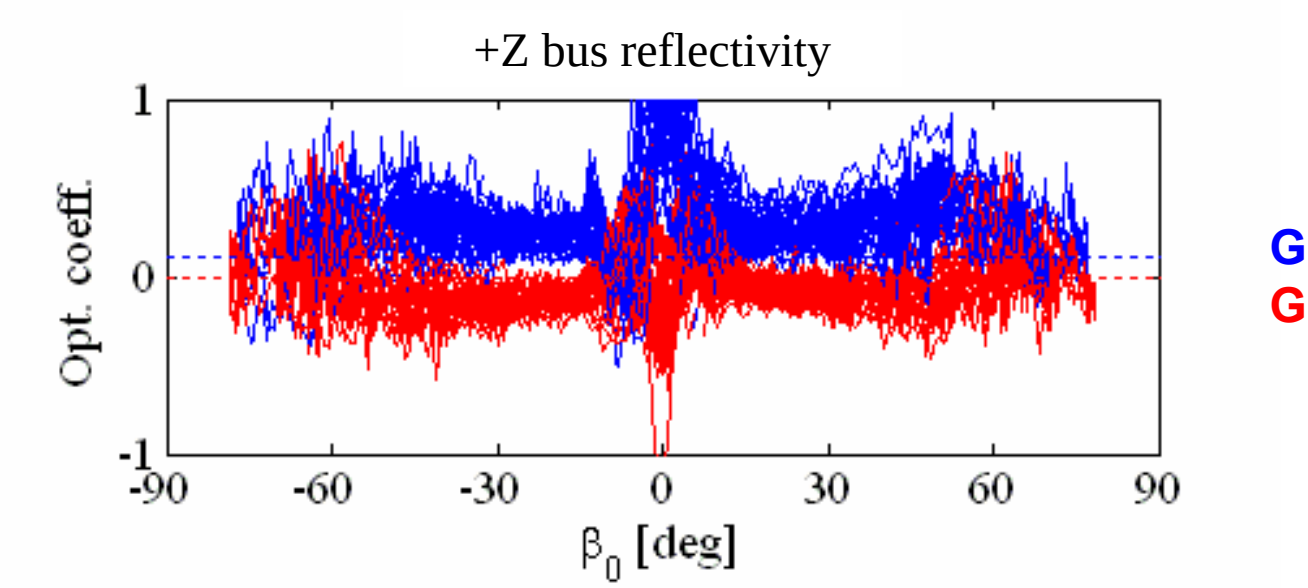
  ➔ adjusting the optical properties of the satellite's surfaces

- Additionally: Adjustment of y-bias and stochastic pulses

- Model tests based on IGS tracking data of full year 2007

Optical properties of satellites

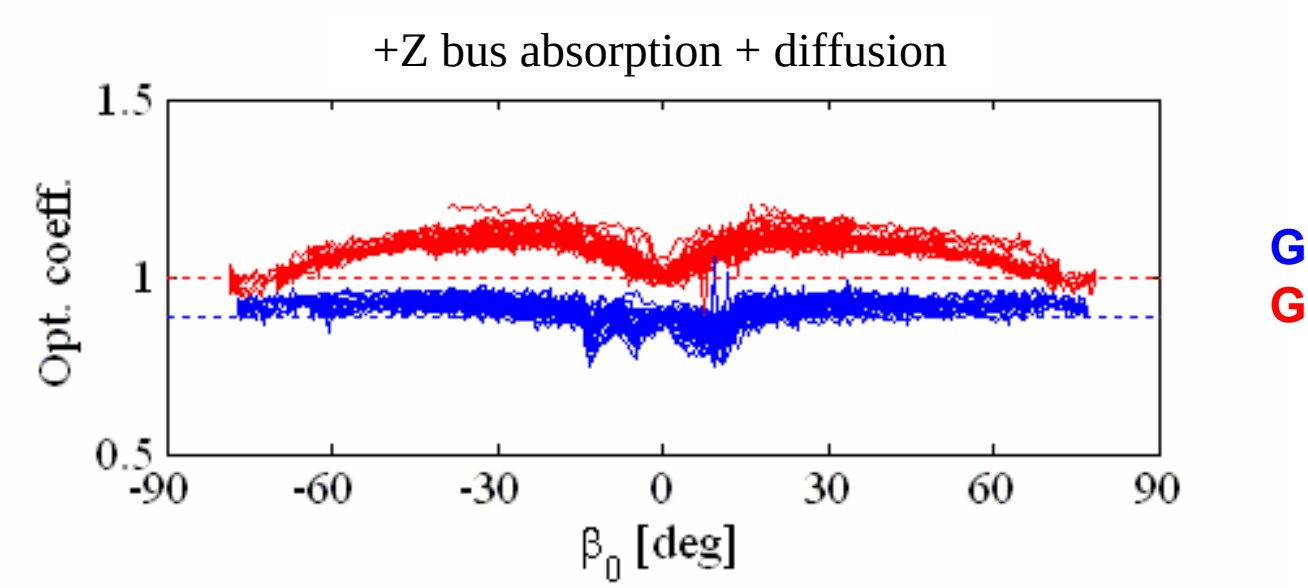
- Results for **all GPS satellites** as function of
  - ➔ β_0: the Sun elevation angle above the orbital plane
- **Reflectivity:** fraction of specularly reflected photons
- **+Z surface:** pointing always to the Earth (navigation antennas)



GPS IIA
GPS IIR

Optical properties of satellites

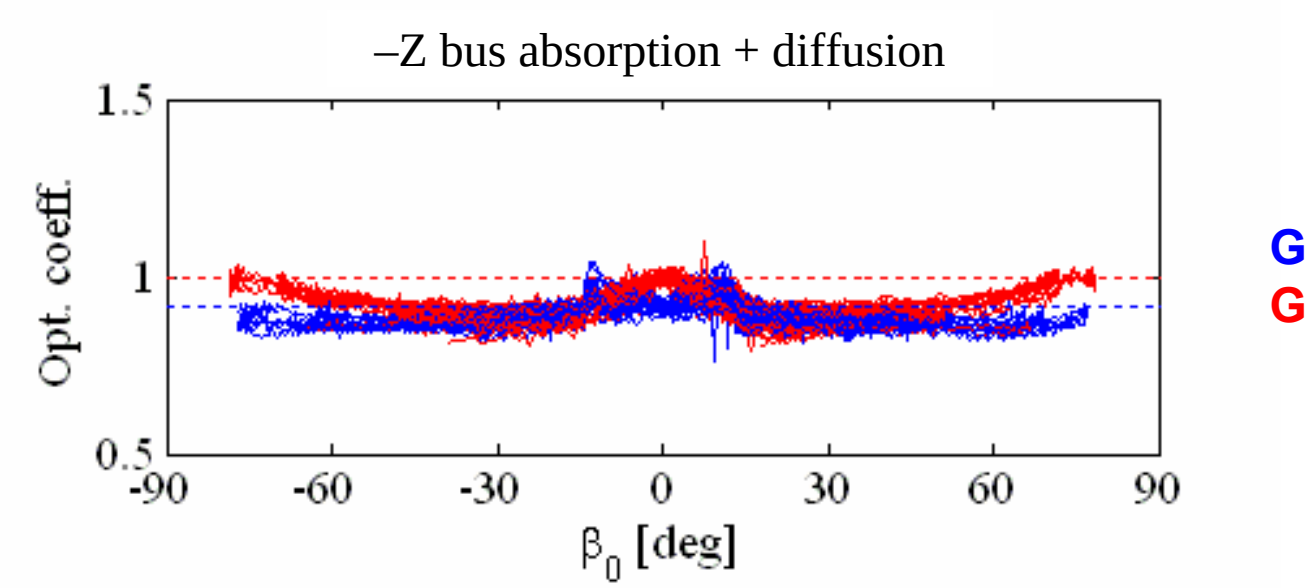
- **Absorption + diffusion**
  - ➔ highly constrained, correlation with other parameters
- **+Z surface:** pointing always to the Earth (navigation antennas)
- Modeling problems for Block IIR satellites



GPS IIA
GPS IIR

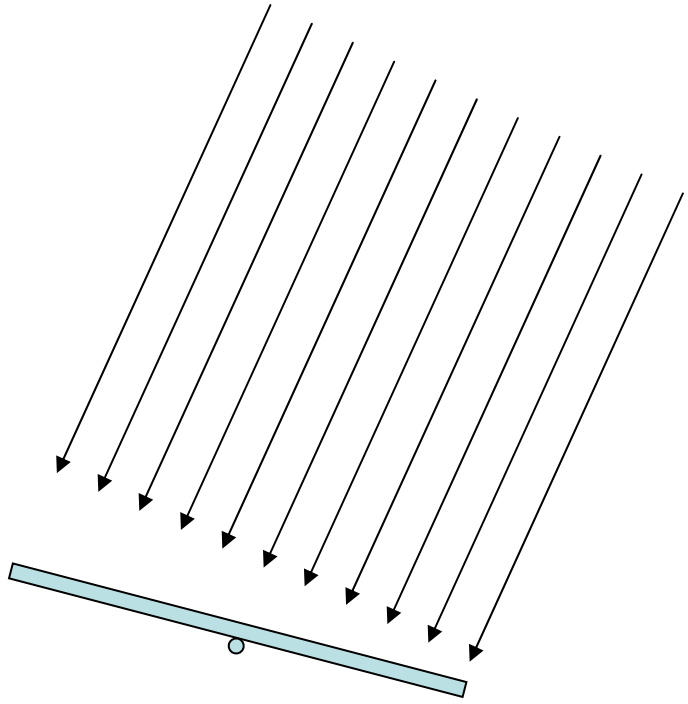
Optical properties of satellites

- **Absorption + diffusion**
  - ➔ high constrained, correlation with other parameters
- **–Z surface:** pointing always away from the Earth
- Asymmetry between +Z and –Z surfaces of Block IIR satellites



Solar panel rotation lag angle

- Solar panel rotation around y-axis lagging by few degrees behind motion of the Sun

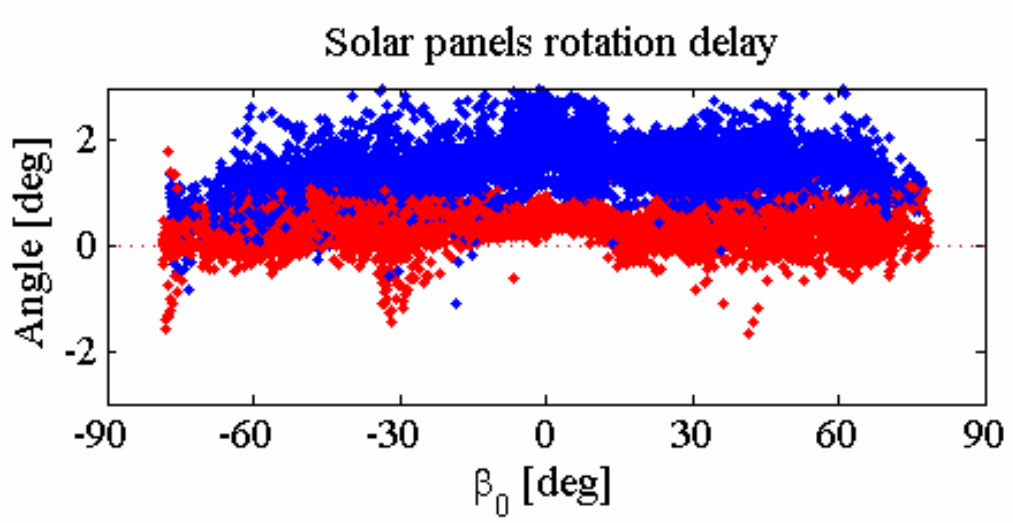


Solar panel rotation lag angle

- Estimated angle ➔ deviation from nominal attitude
- Results for all GPS and GLONASS satellites for 2007

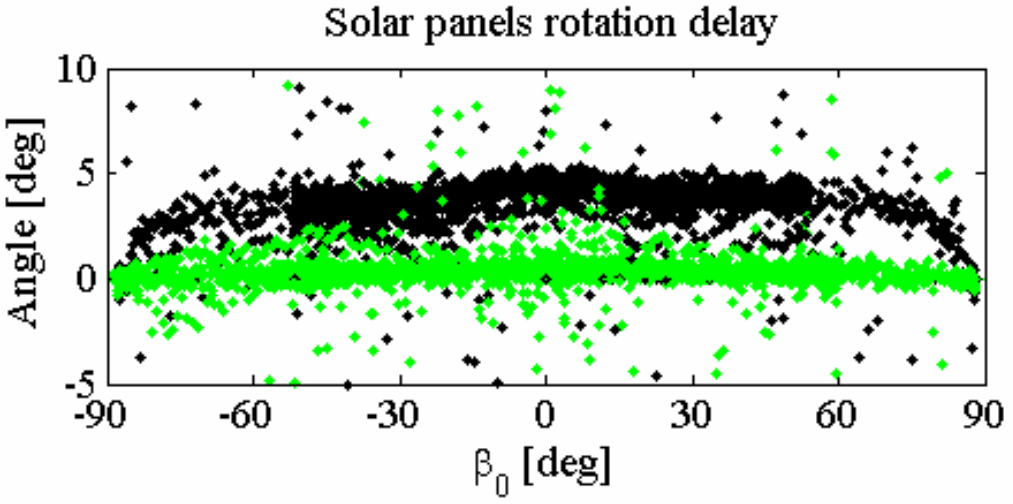
GPS IIA: 1.5 ± 0.5 deg

GPS IIR: 0.4 ± 0.4 deg



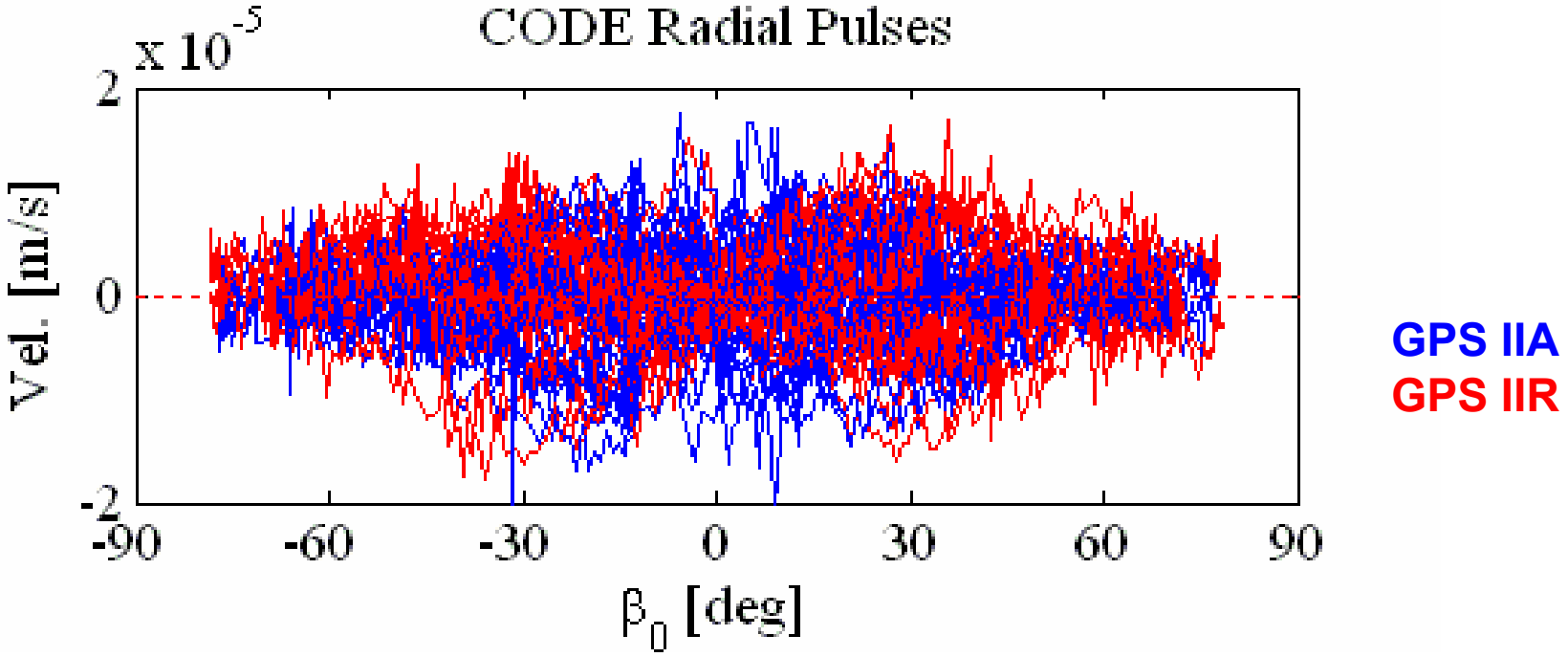
GLONASS: 3.5 ± 3.3 deg

GLONASS-M: 0.4 ± 4.3 deg



Quality of orbits

- How to validate that orbit gets more physical?
- Improvement visible in radial pseudo-stochastic pulses
- **CODE empirical model:**



Quality of orbits

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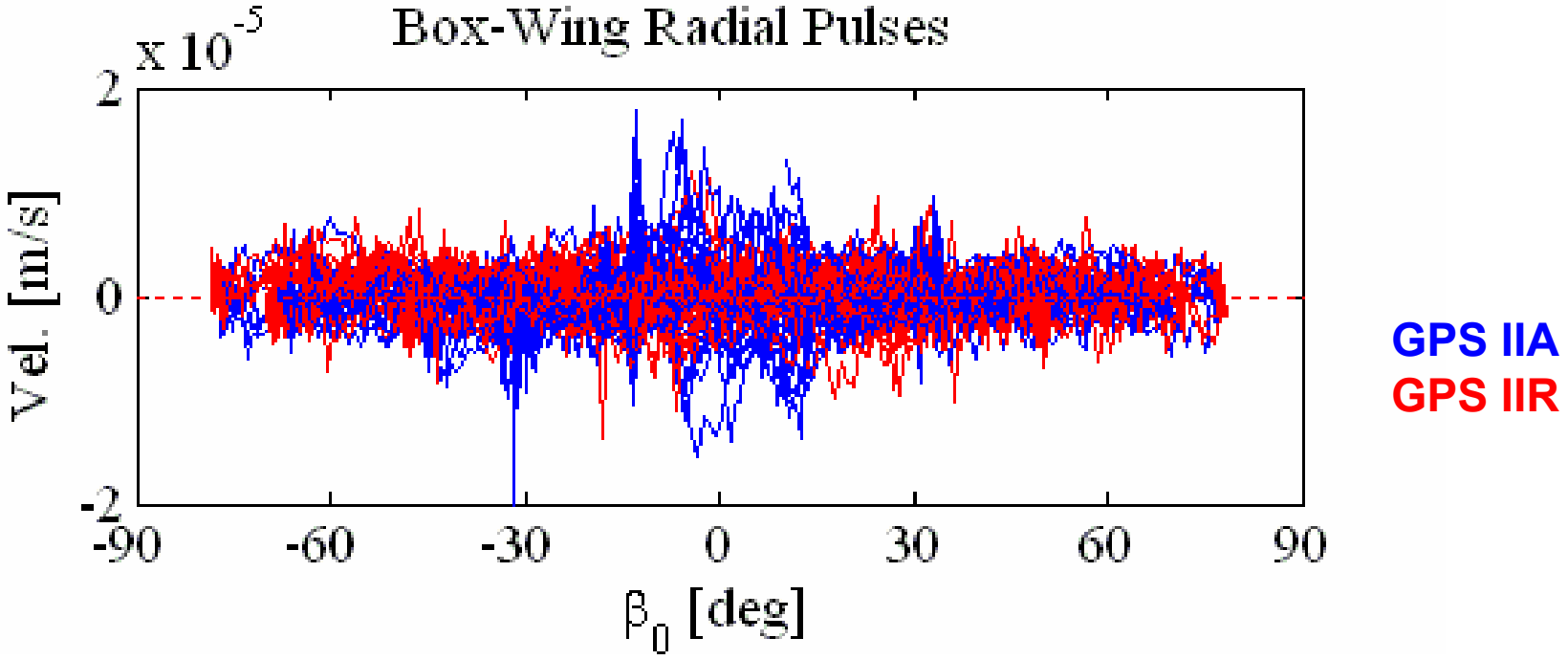
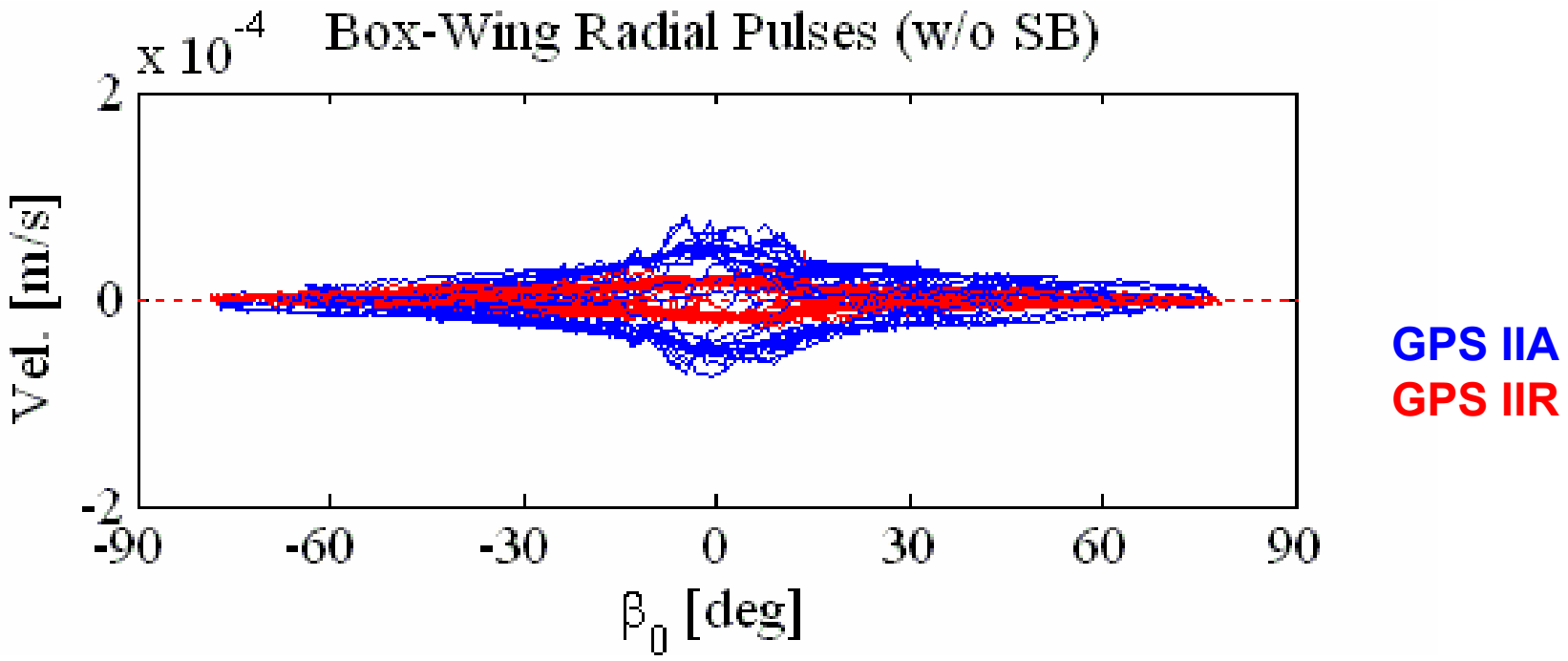
- Improvement visible in radial pseudo-stochastic pulses
- **Box-wing model:**



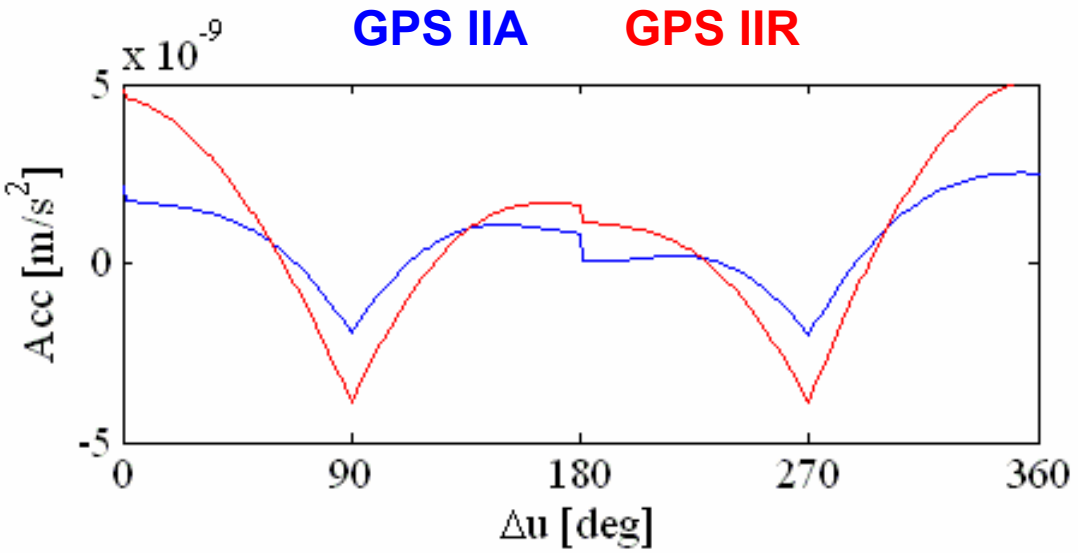
Quality of orbits

- How to validate that orbit gets more physical?
- Improvement visible in radial pseudo-stochastic pulses
- **Box-wing model without rotation lag:**

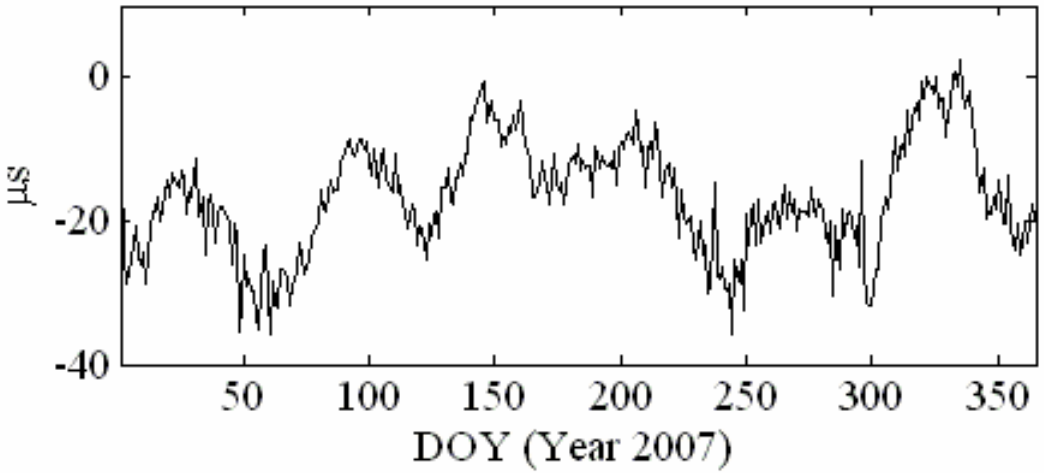


Cross-track accelerations ➔ Impact on LOD

- **Box-wing minus CODE**
  (β_0 = -45 deg)
- Once per revolution terms
  ➔ Secular change in RAAN



- **Length of Day difference**
  (Box-wing minus CODE,
  GPS-only solutions)
- Systematic negative shift:
  ~20 µs

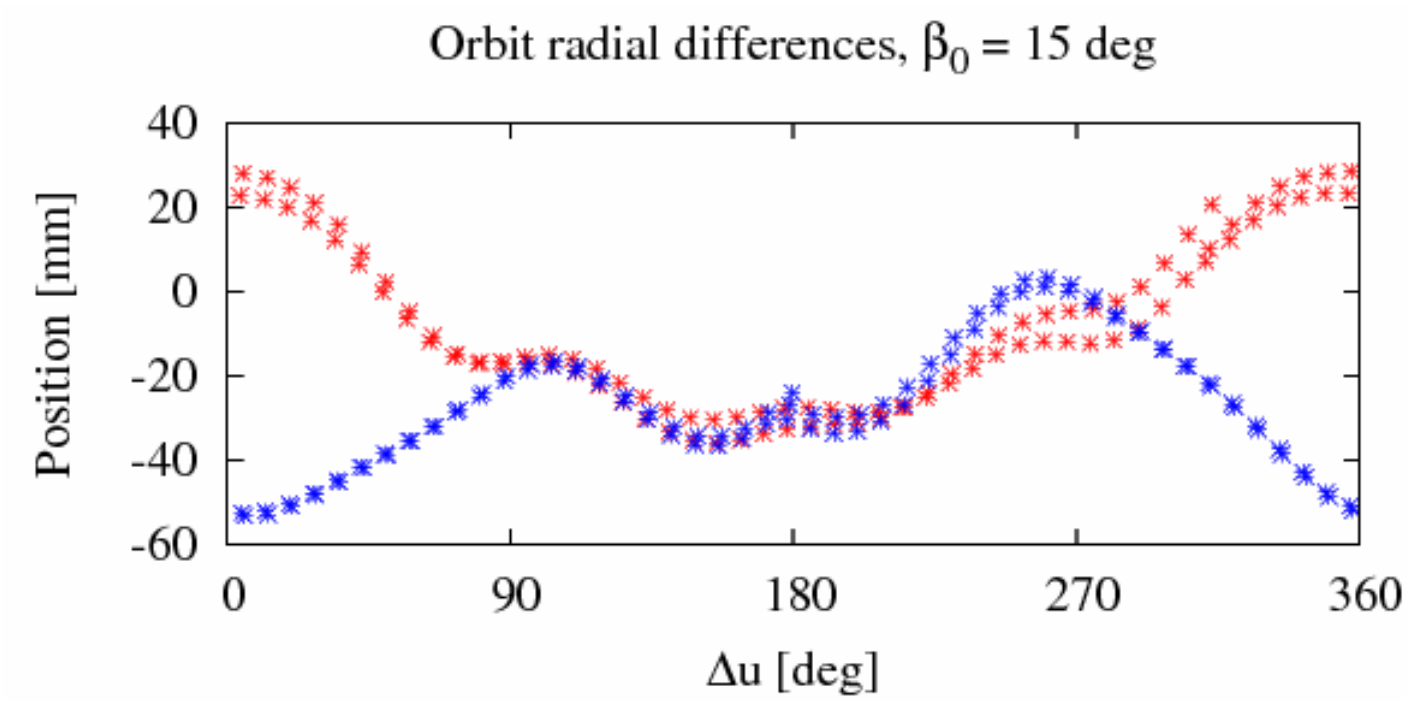


Orbit radial differences ➔ Impact on SLR residuals

- **Box-wing minus CODE** ➔ differences of **few centimeters** in the orbits

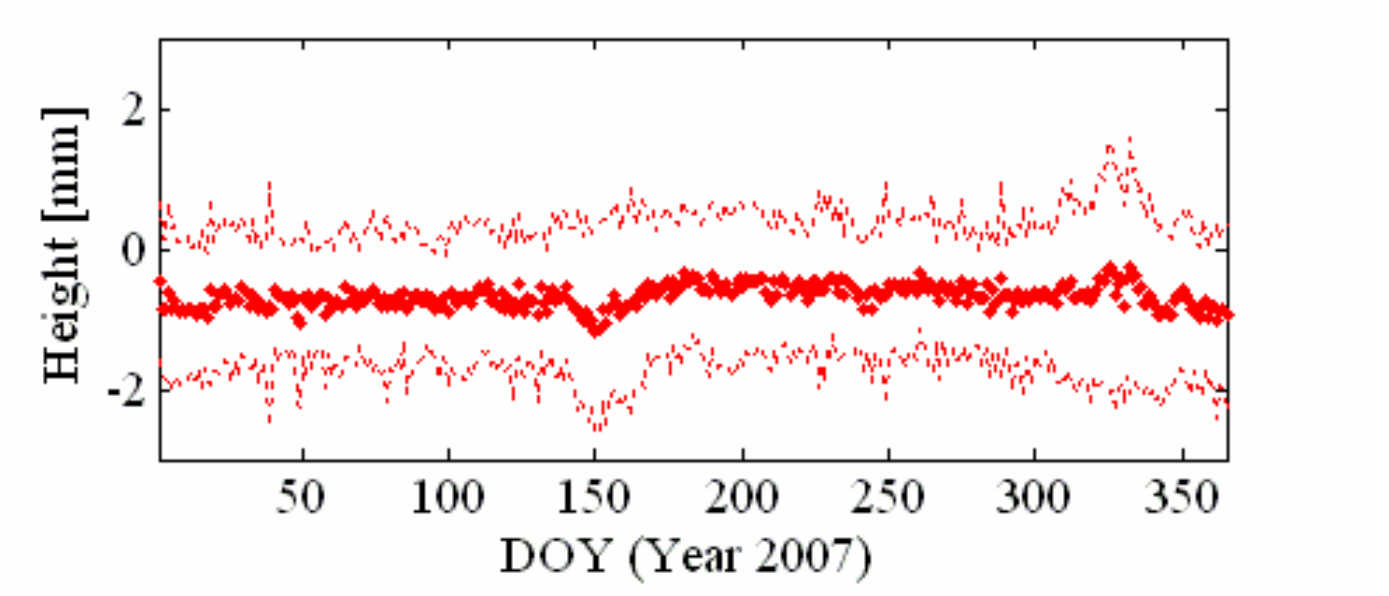
- Radial shift of Block IIA orbits in the “correct” direction
  ➔Further reduction of SLR – GPS bias possible

GPS IIA, PRN 06 **GPS IIR, PRN 17**



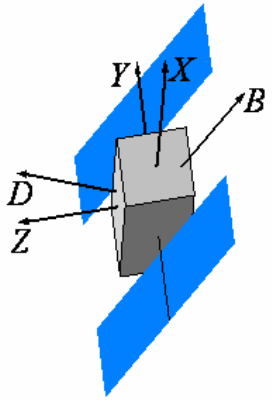
Ground stations coordinates

- Box-Wing minus CODE (GPS-only solutions)
  - ➔ differences of **few millimeters** in North, East and Height
- Height ➔ mean and STD of around 175 ground tracking stations
- **Systematic negative shift in the Height component: -0.7 mm**
  - ➔ **0.1 ppb = 0.64 mm**



Conclusions

- Orbit modeling problems remain in GNSS orbits ➔ non-conservative forces
- Main non-conservative force ➔ solar radiation pressure, but:
  - Not nominal attitude: solar panels rotation delay
- Similar performance of adjustable box-wing model vs. CODE empirical model
- The bus of the satellite, not considered by the CODE empirical model, introduces:
  - Accelerations in the cross-track direction
  - Negative shift in the LOD of around 20 μs
  - Orbit radial differences of few centimeters (negative bias for GPS IIA)
- Impact on station coordinates:
  - Few millimeters in North, East and Height
  - Negative shift of 0.7 mm in Height component ➔ 0.1 ppb



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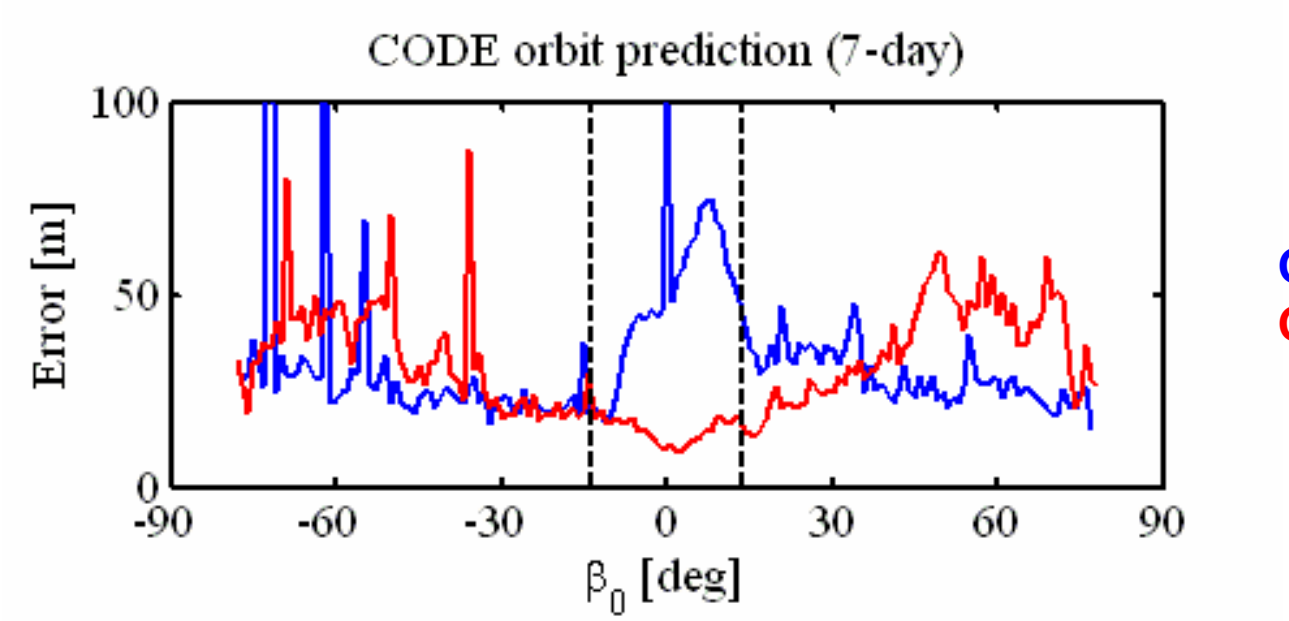
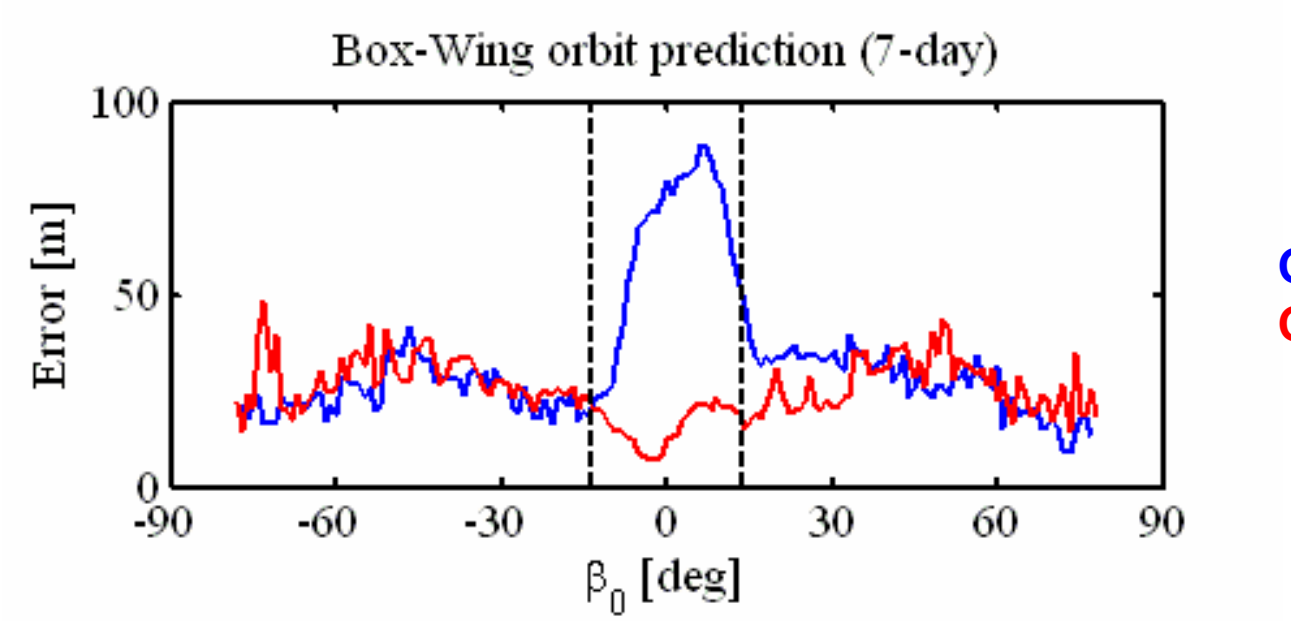
Orbit prediction error

- Orbit prediction error after 7 days
- Average over all GPS satellites and β_0
- **CODE empirical model**



Orbit prediction error

- Orbit prediction error after 7 days
- Average over all GPS satellites and β_0
- **Adjustable box-wing model**



GLONASS attitude accuracy

	GLONASS	GLONASS-M
	Uragan (11F654)	**Uragan-M (11F113)**
Mass	1,415 kilograms	1,570 kg (1,415-1,450 kg)*
Payload mass	180 kilograms	250 kilograms
Onboard power supply	1,000 Watts	1,450 Watts
Payload power consumption	600 Watts	580 Watts
Attitude control accuracy	0.5 degrees	0.5 degrees
Solar panel orientation accuracy	5 degrees	2 degrees
Operational life span	4 years	7 years
First launch	1982 Oct. 12	2003 Dec. 10

http://www.russianspaceweb.com/uragan.html