



# Estimation of satellite antenna phase center offsets for Galileo



**Peter Steigenberger, Oliver Montenbruck**  
German Space Operations Center (DLR/GSOC)



**Mathias Fritsche, Maik Uhlemann**  
Deutsches GeoForschungsZentrum (GFZ)



**Rolf Dach, Lars Prange**  
Astronomical Institute, University of Bern (AIUB)

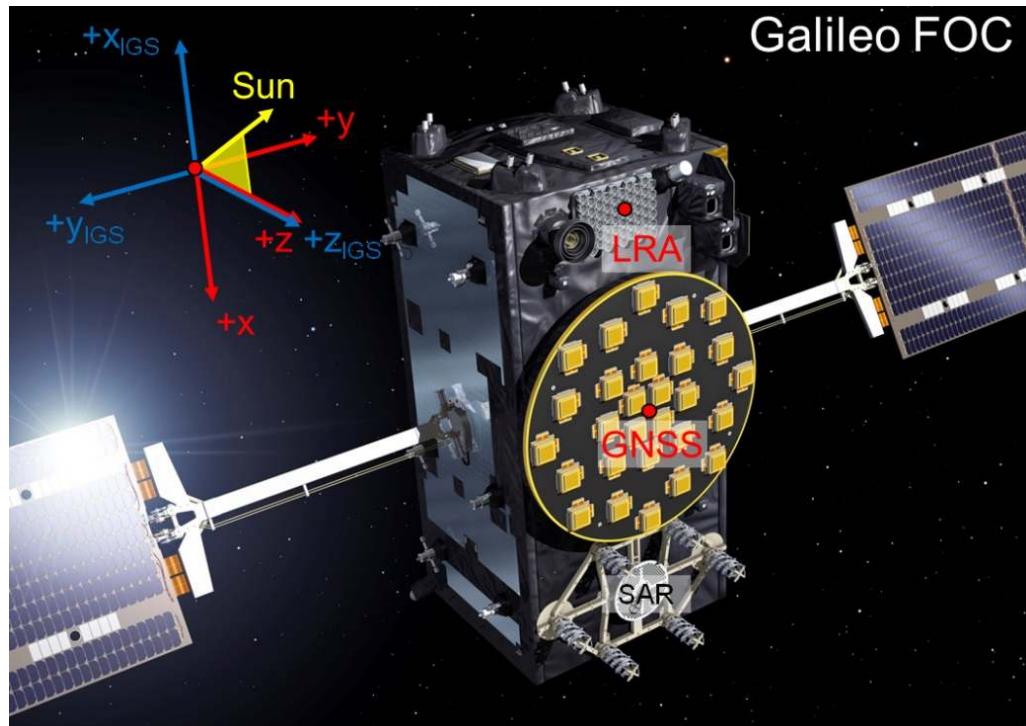


**Ralf Schmid**  
Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)



# Galileo Phase Center Offset Estimation

- Phase Center Offset (PCO): center of mass → mean antenna phase center
- Global GNSS solutions including estimation of station coordinates, troposphere parameters, ERPs, and satellite orbits



## PCO estimation:

- NAPEOS@DLR
- EPOS@GFZ

## PCO validation:

- NAPEOS@DLR
- Bernese@AIUB



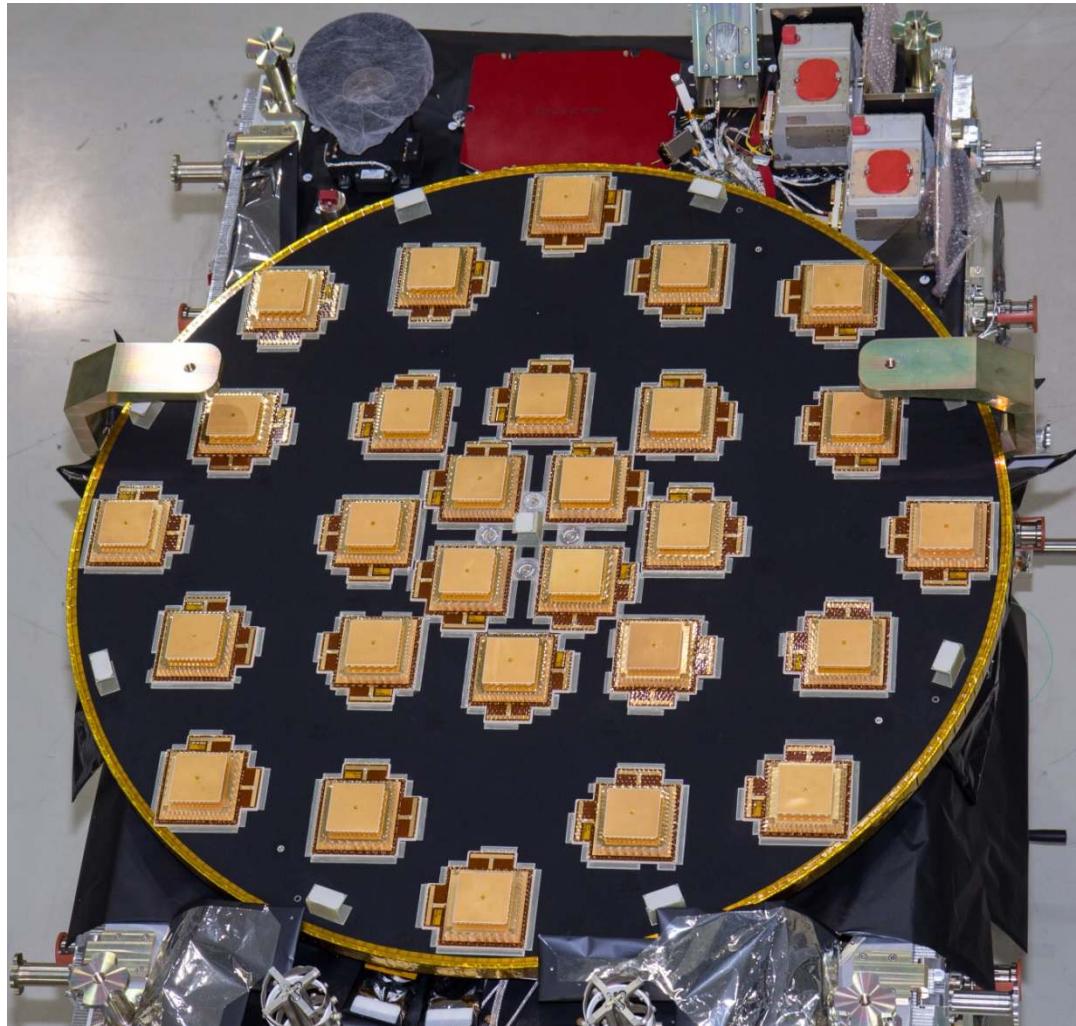
# Galileo In-Orbit Validation (IOV) Antenna

- Dual-band right-hand circularly polarized
- Array of 45 photo-printed stacked patch elements





# Galileo Full Operational Capability (FOC) Antenna



- Similar to GIOVE-A antenna
- Dual-band right-hand circularly polarized
- Array of 28 stacked patch elements
- Launch anomaly of first pair of FOC satellites resulting in highly eccentric orbit
- Center of mass changes for GAL-201/202 due to orbit raising maneuvers



# Orbit Modeling

## 1. Empirical CODE Orbit Model (ECOM)

Constant plus sine and cosine terms  
in a Sun-oriented DYZ frame

## 2. ECOM-2

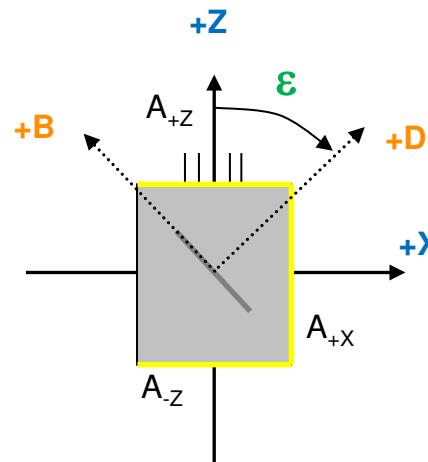
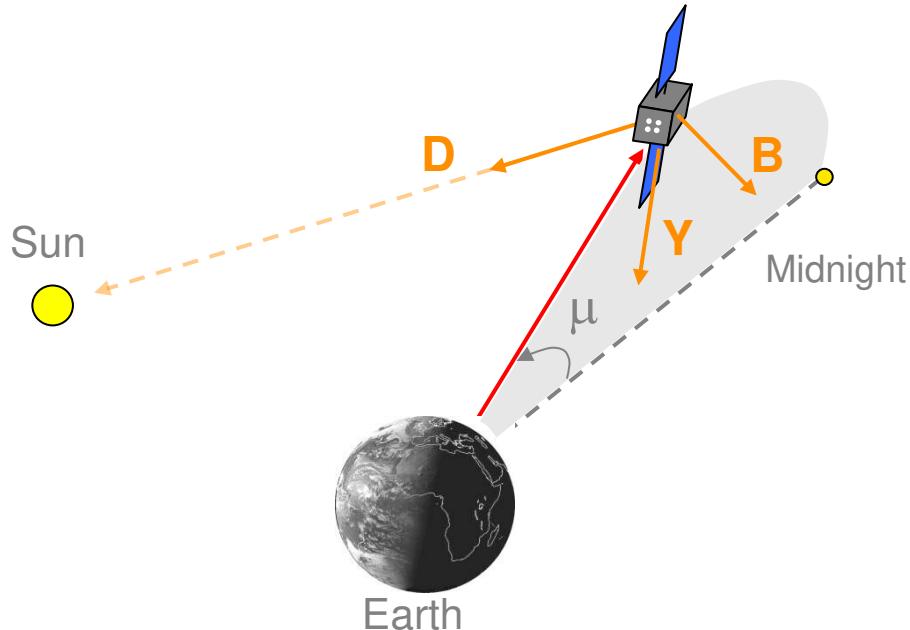
Additional estimation terms:

$D_2$  for GPS,  $D_2$  and  $D_4$  for Galileo

## 3. Box-wing model (BW)

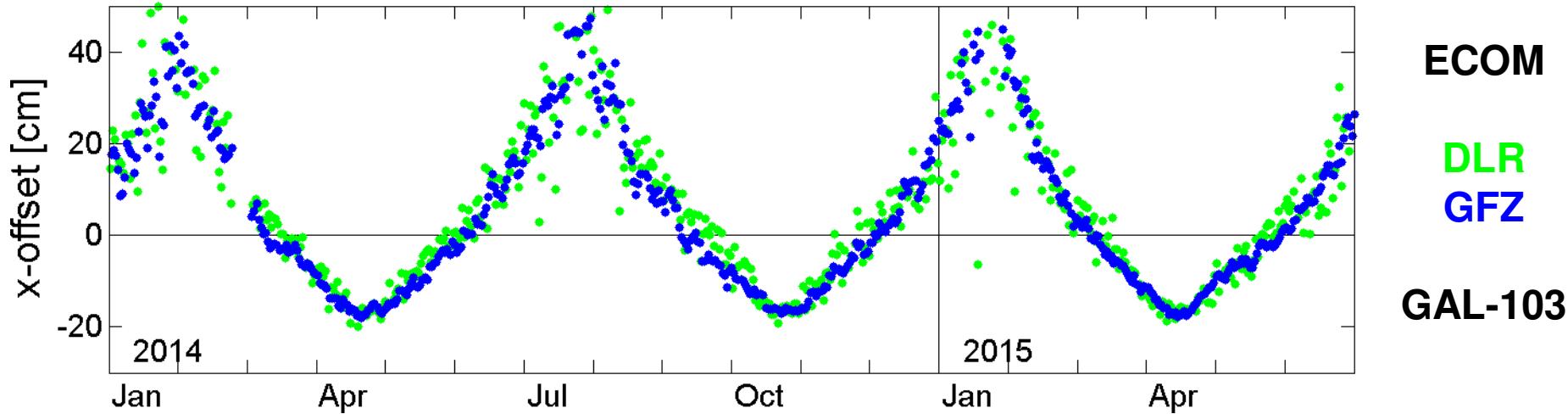
“Cubicness” and “stretchedness”  
parameters based on  $a_{+Z}$ ,  $a_{+X}$ , and  $a_{-Z}$

## 4. Box-wing model and $D_0$ constraint



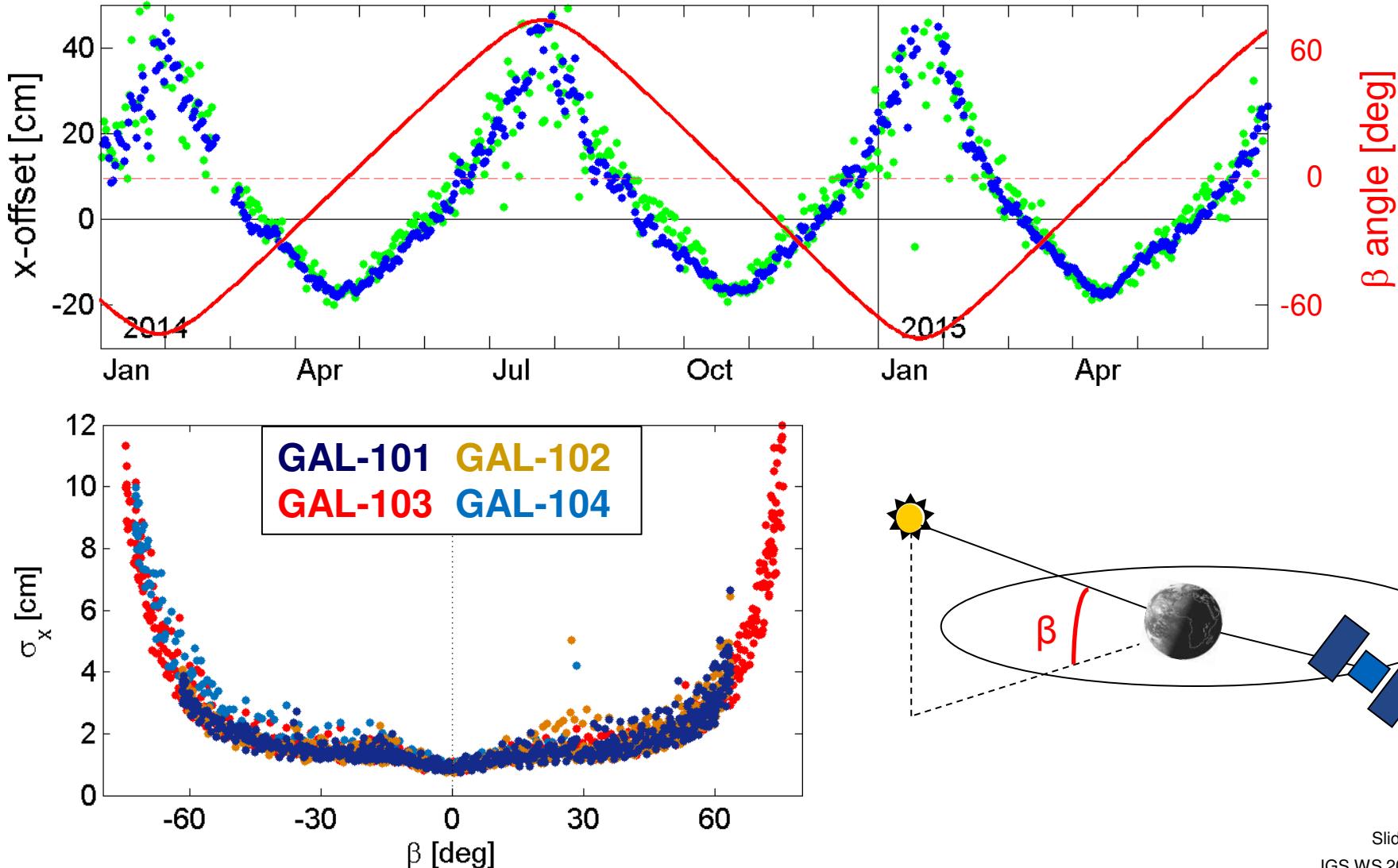


# Impact of Orbit Modeling on x-Offset Estimation (1)



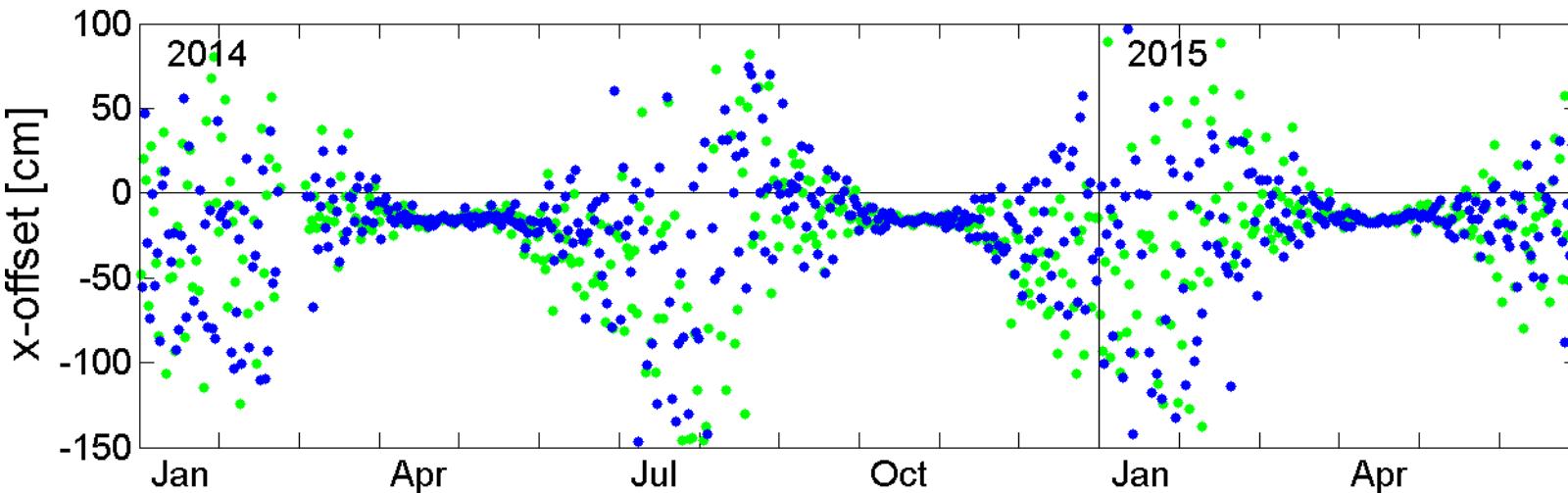


# Impact of Orbit Modeling on x-Offset Estimation (1)





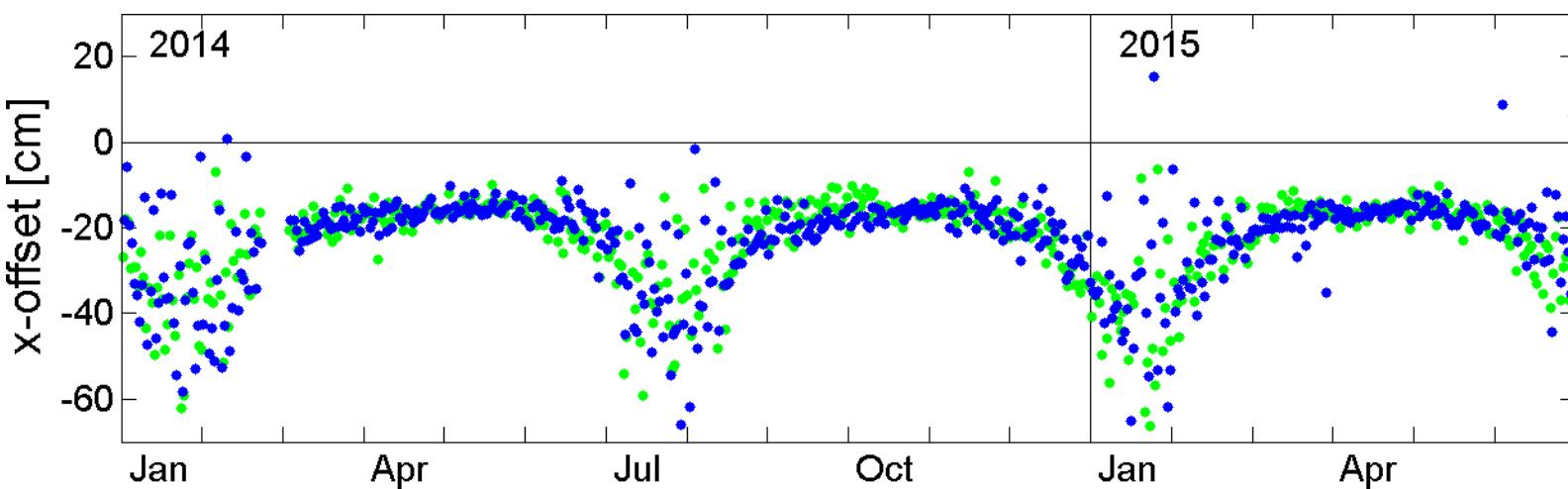
## Impact of Orbit Modeling on x-Offset Estimation (2)



GAL-103

ECOM-2

DLR  
GFZ



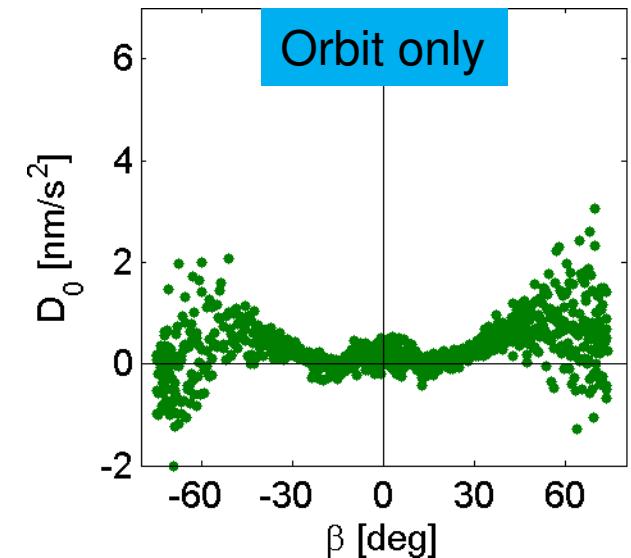
GAL-103

Box-wing

DLR  
GFZ

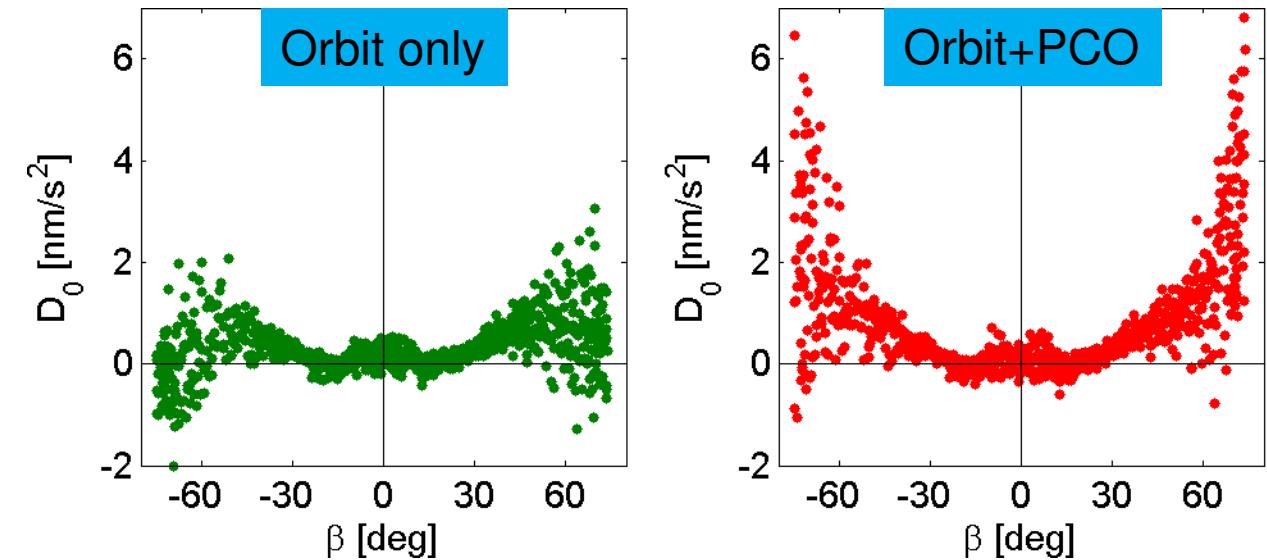


# Correlations between PCOs and Orbit Parameters



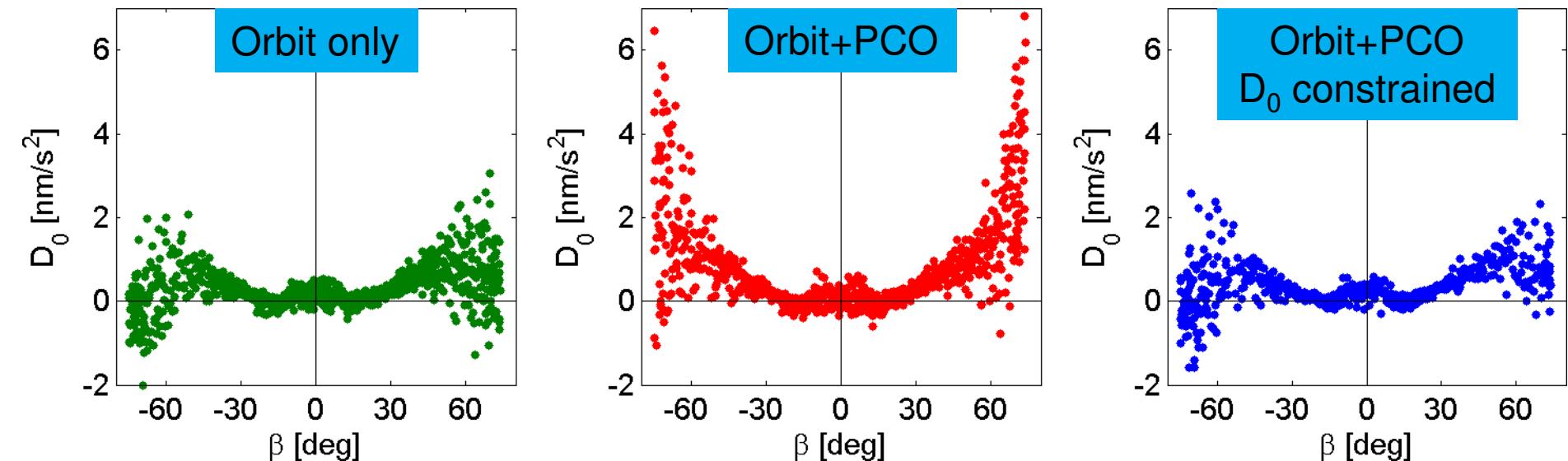


# Correlations between PCOs and Orbit Parameters



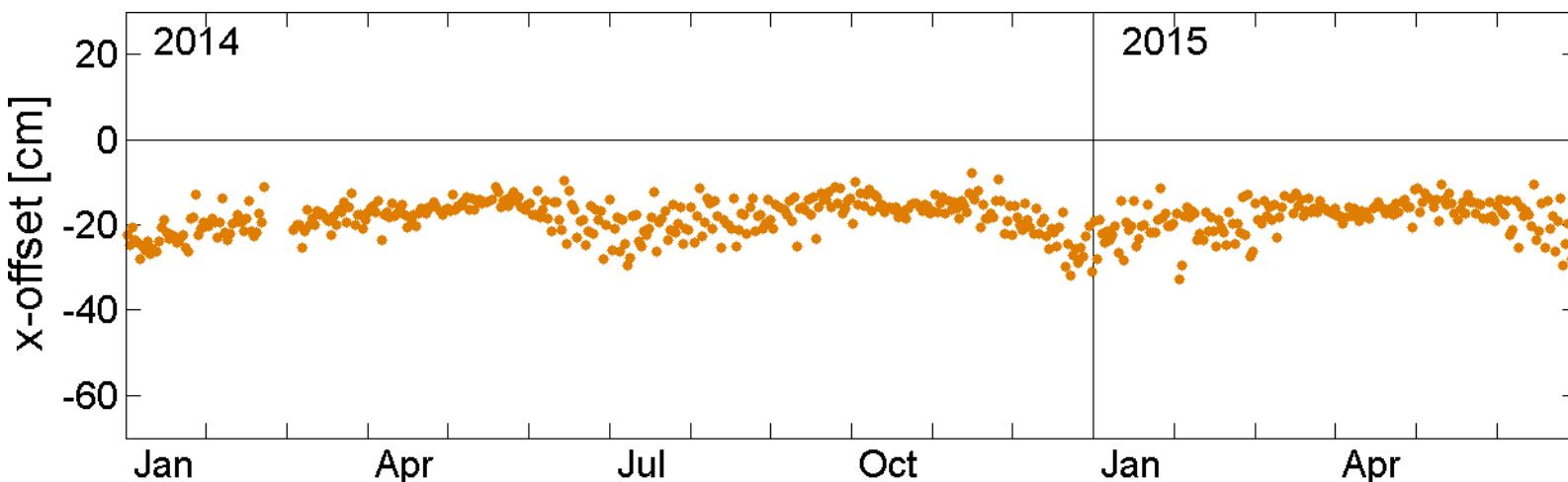
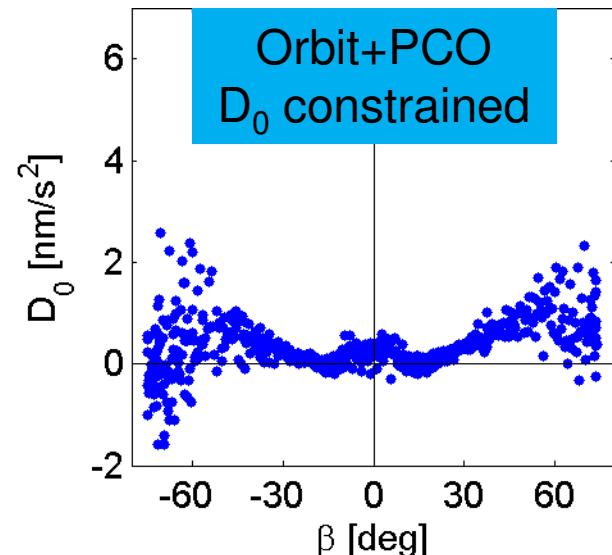
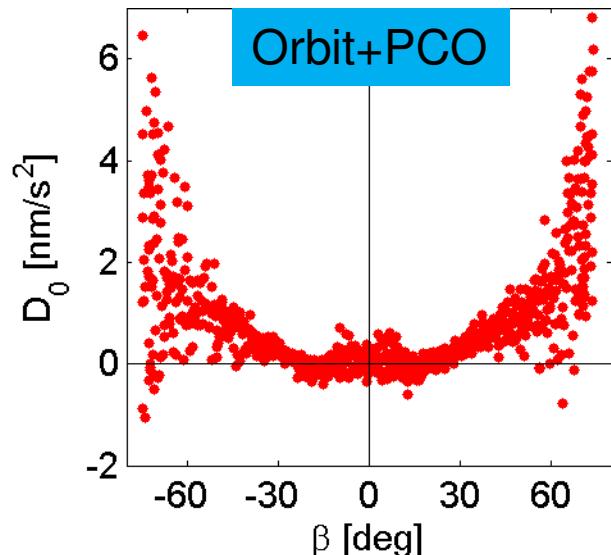
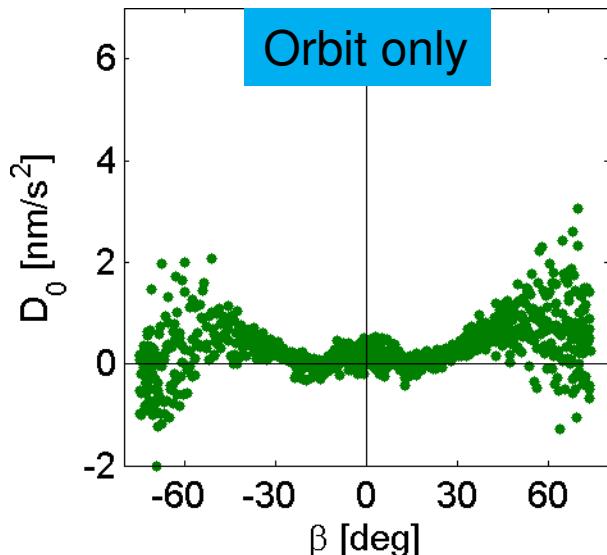


# Correlations between PCOs and Orbit Parameters





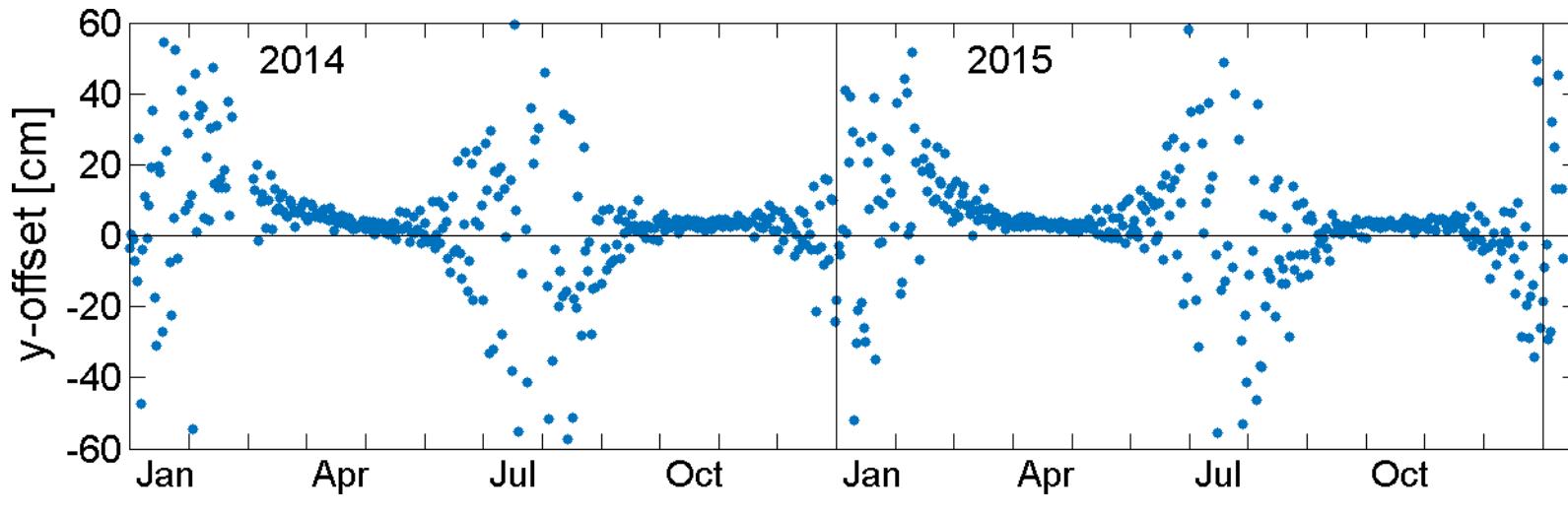
# Correlations between PCOs and Orbit Parameters



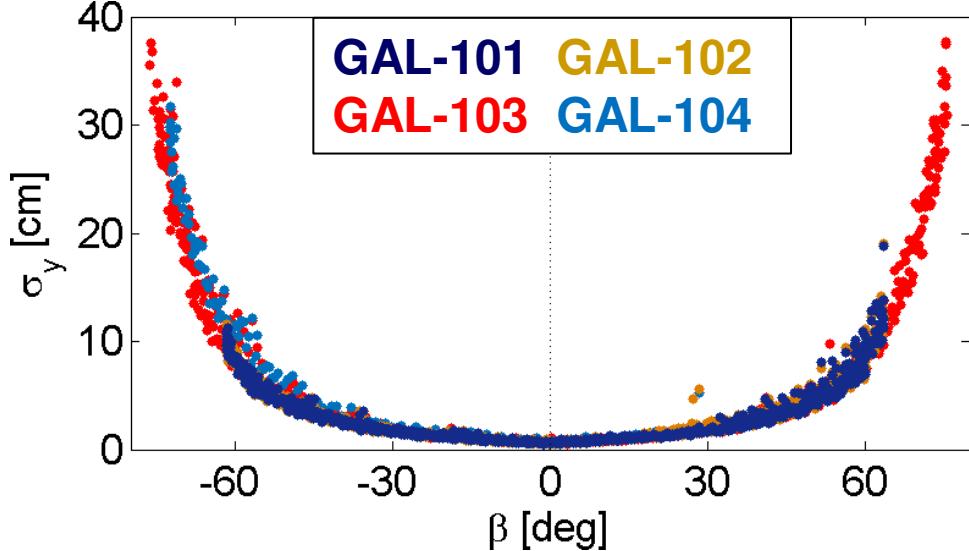
**GAL-103**  
**BW constr.**



# Galileo IOV y-Offsets



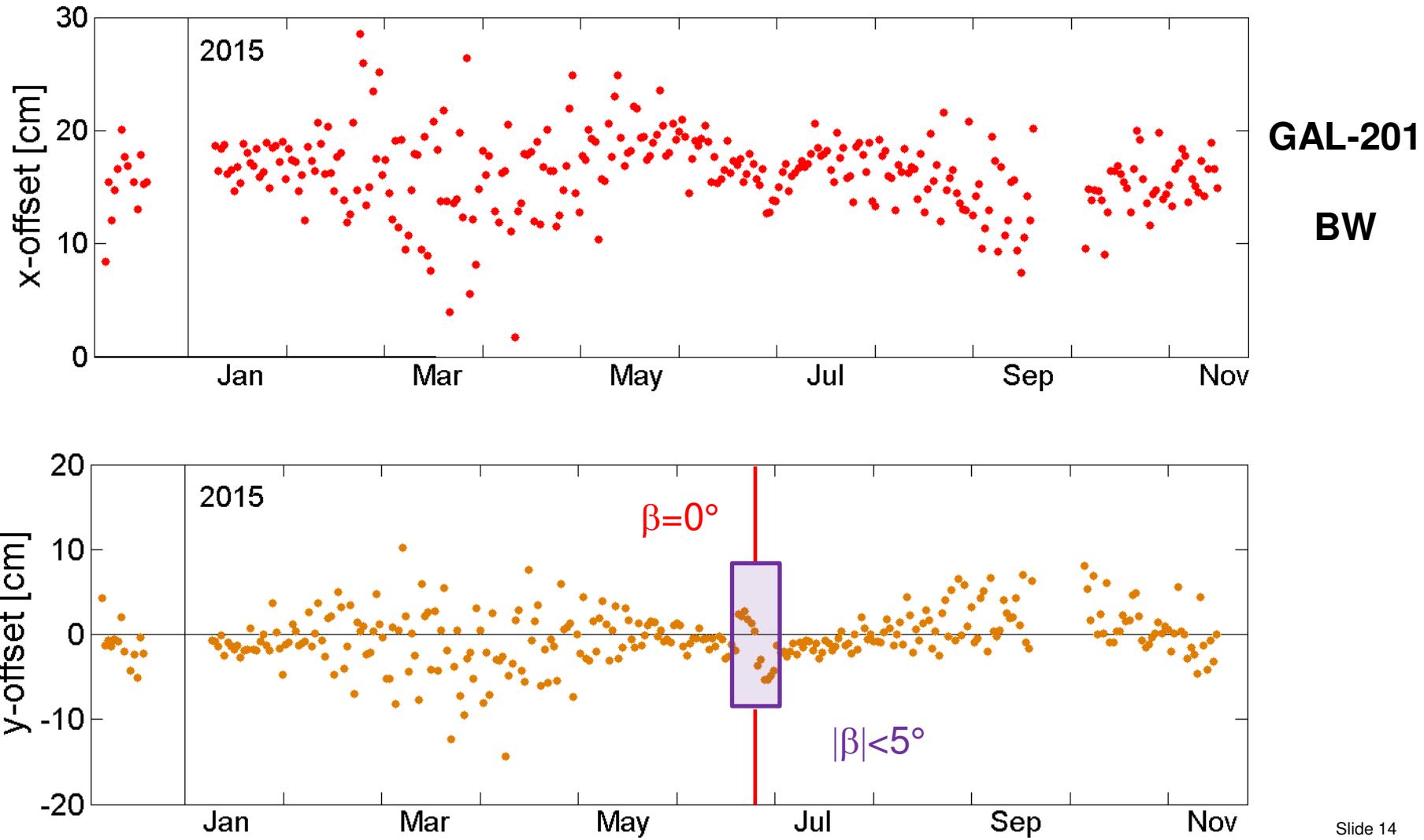
**GAL-103**  
**BW**



- No impact of orbit modeling on y-offset estimation
- Different approaches to form mean values agree within few mm

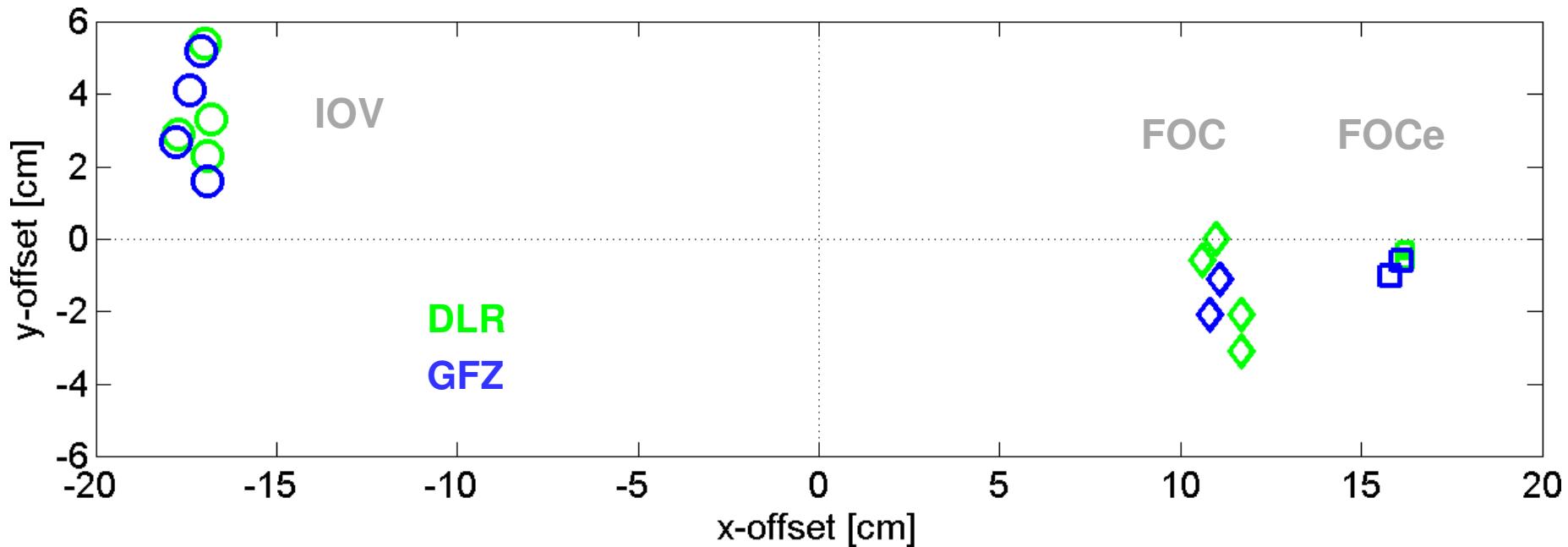


# Galileo FOC Horizontal PCOs





# Mean Horizontal Galileo PCOs



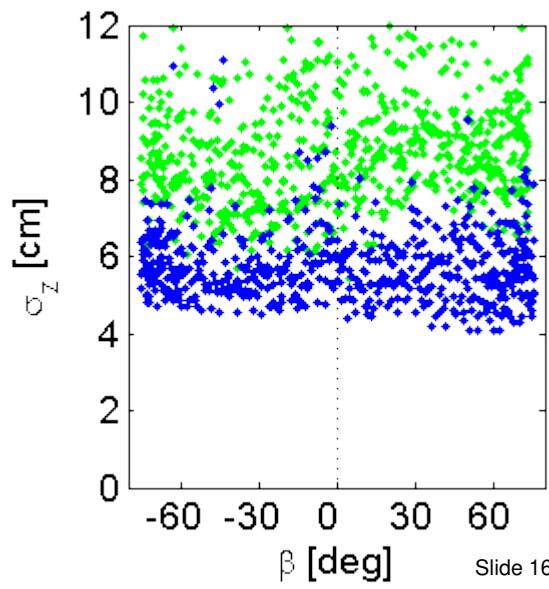
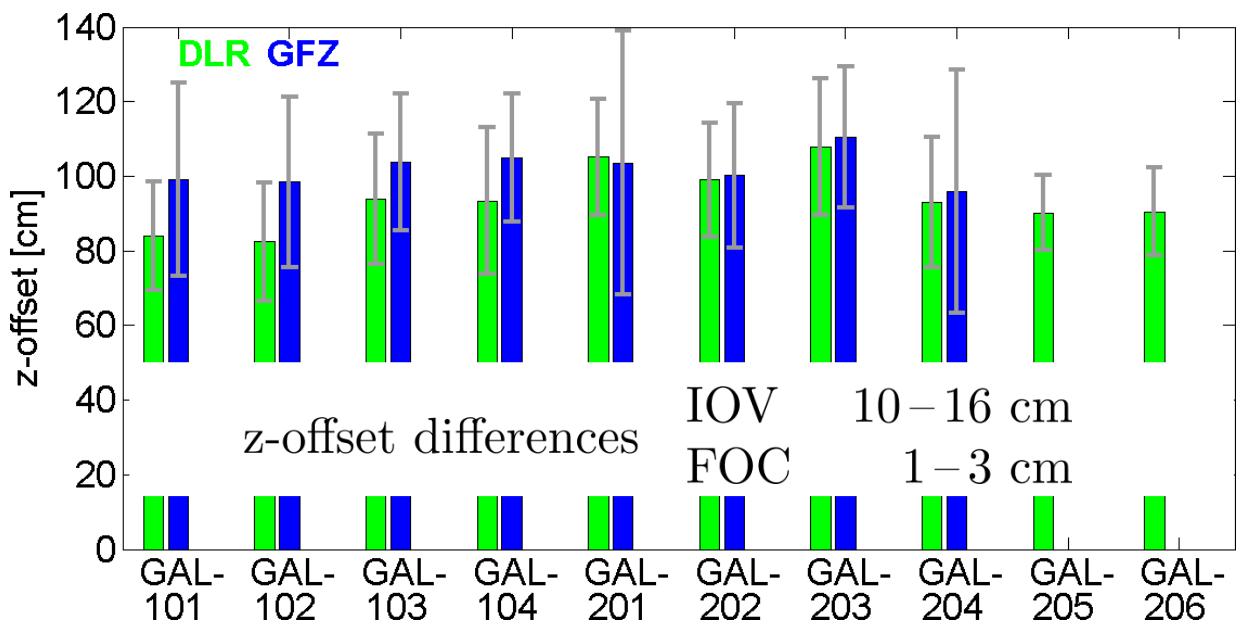
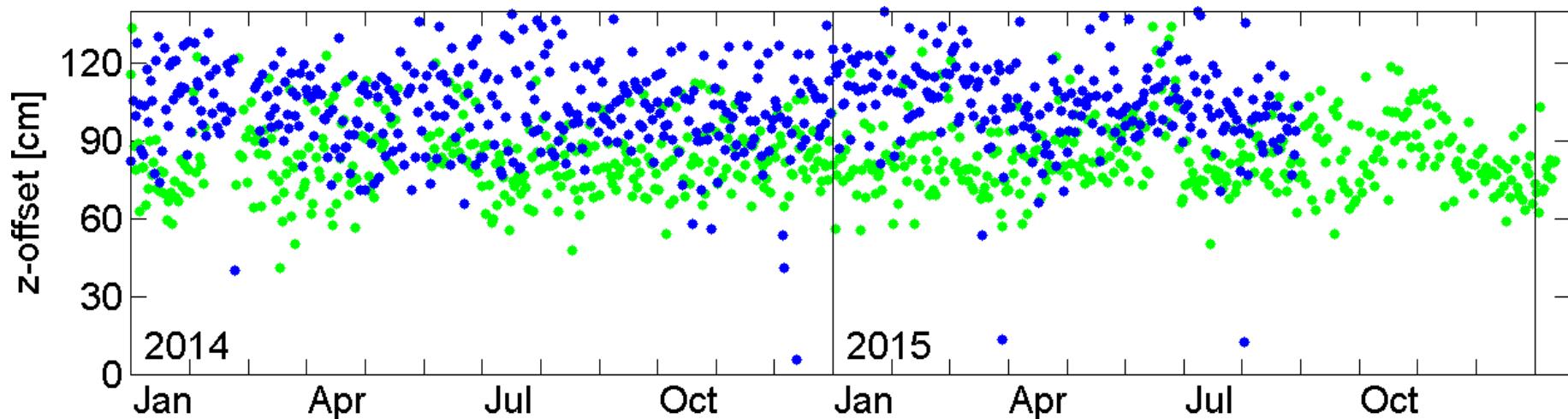
- Significant x-offset bias for FOC satellites in eccentric orbit due to fuel consumption
- AC agree on the 1-2 cm level
- Mean values per satellite group rounded to 1 cm

Satellite	x [cm]	y [cm]
Galileo IOV	-17	+3
Galileo FOCE	+16	-1
Galileo FOC	+12	-1



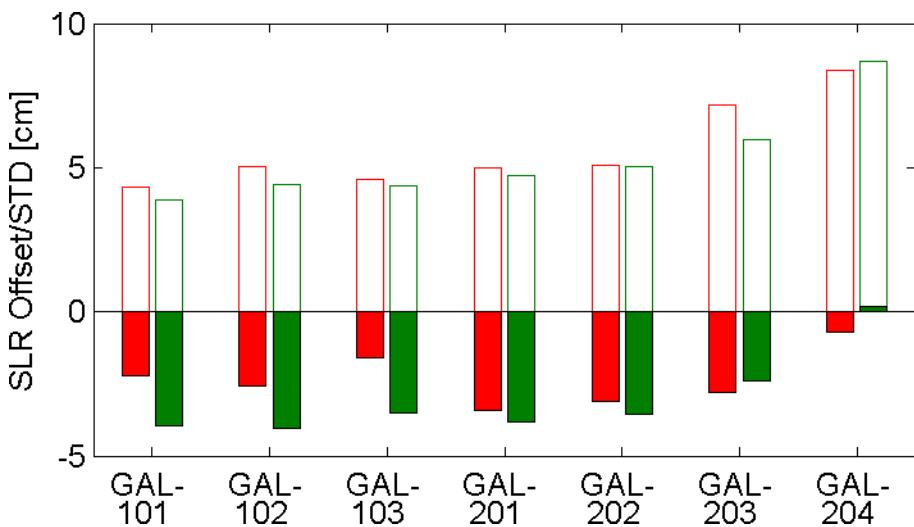
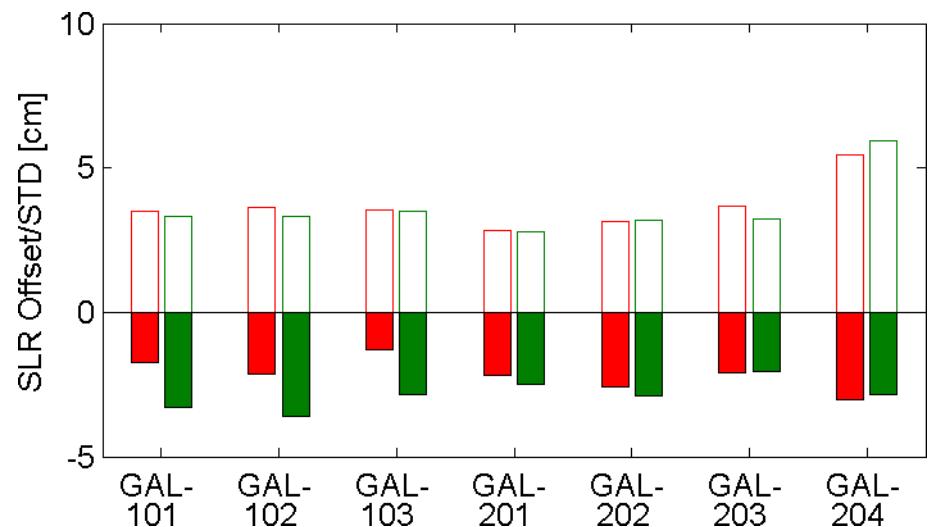
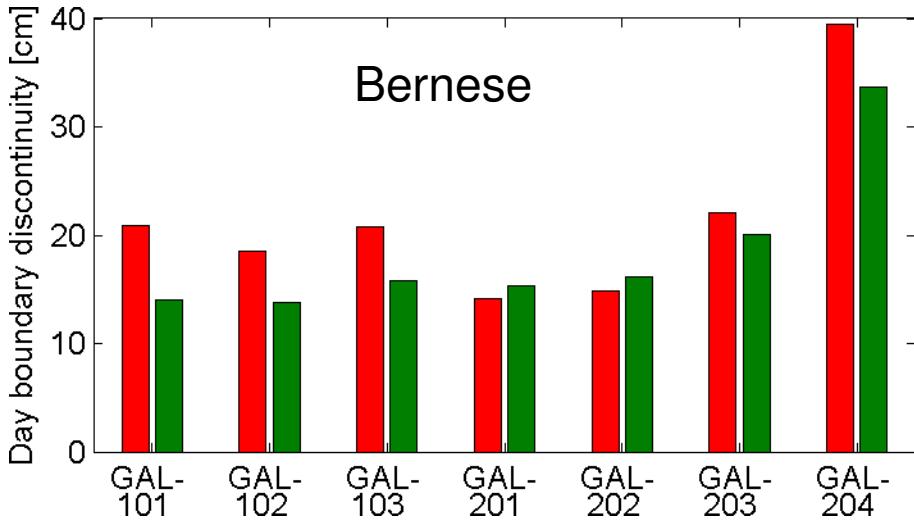
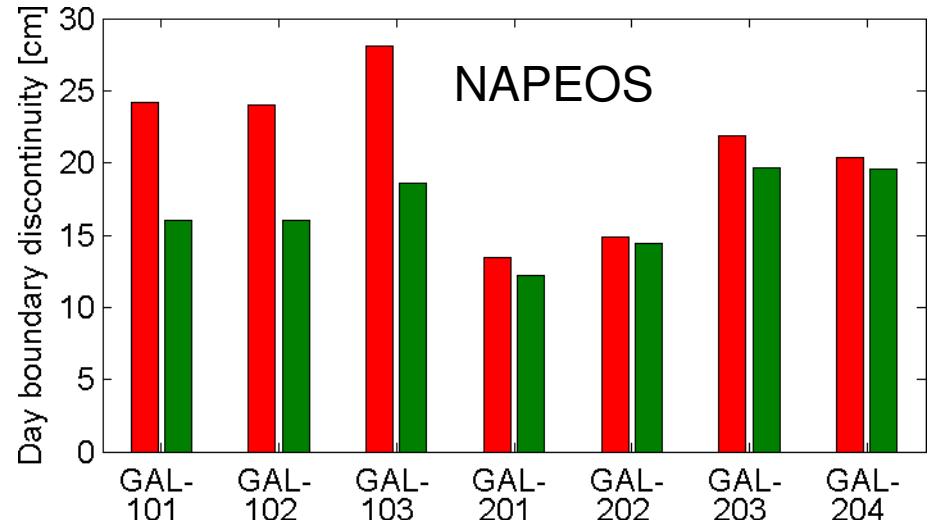
# Z-Offsets

GAL-103 DLR GFZ





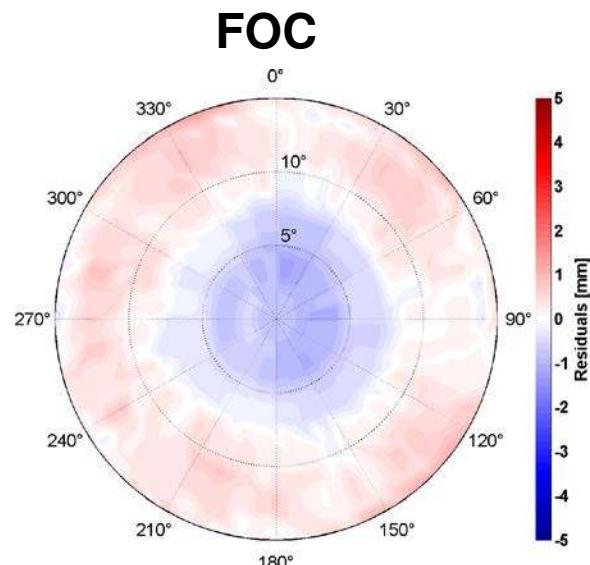
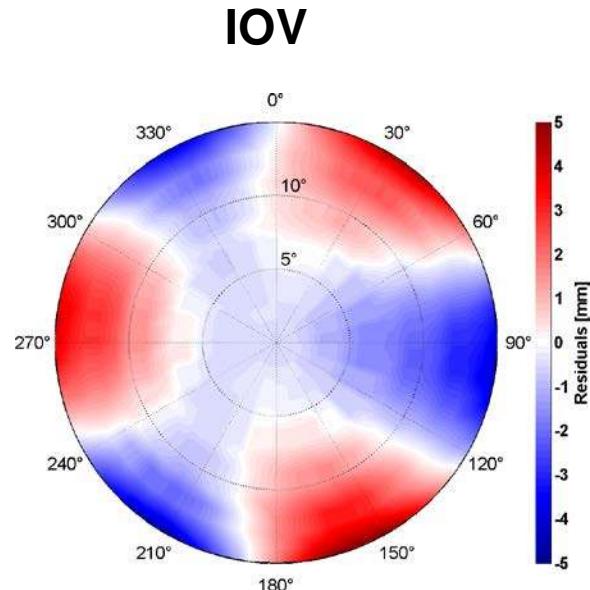
# Validation of MGEX and New PCOs

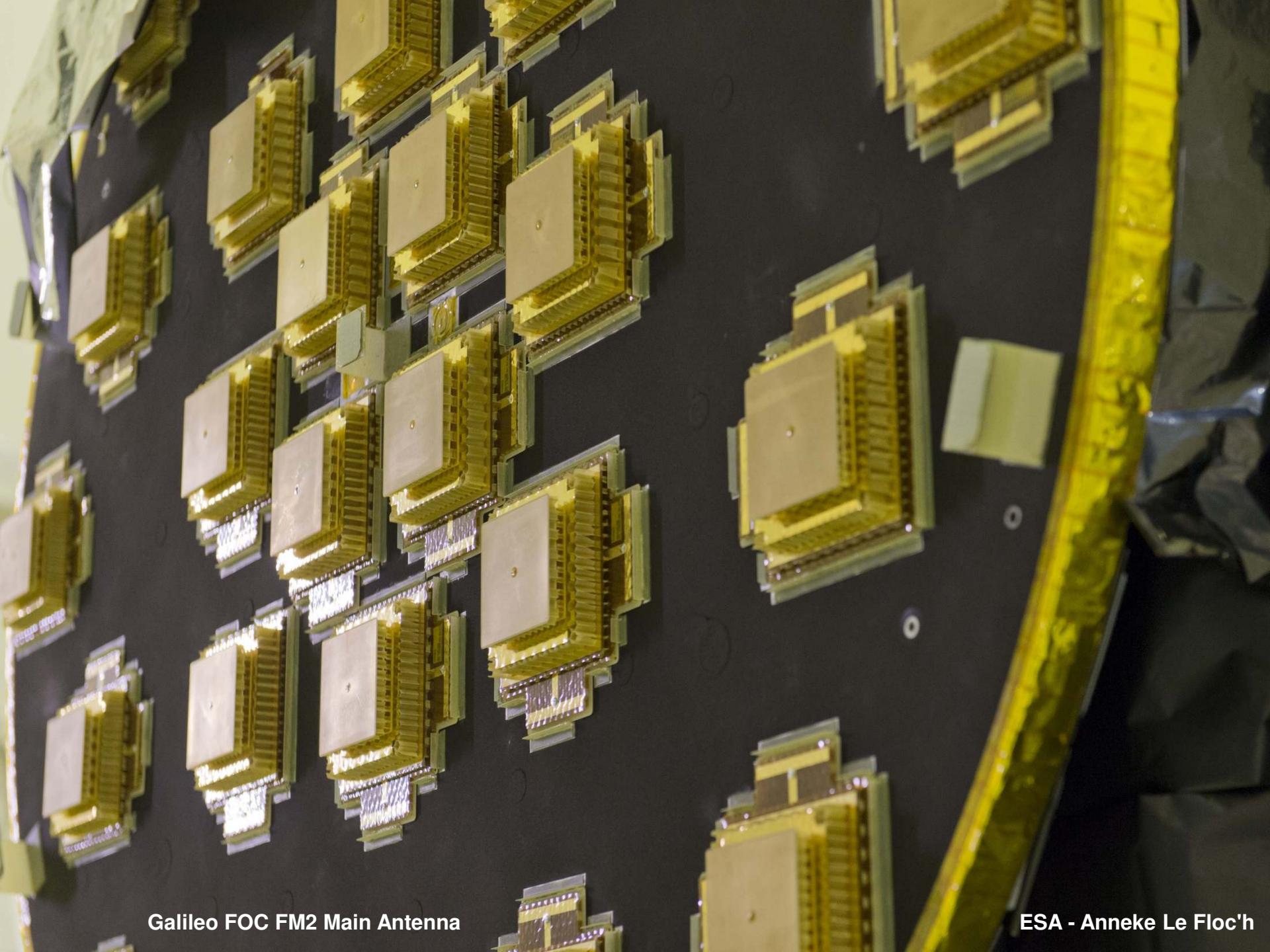




# Summary and Outlook

- Pronounced  $\beta$ -dependent effects in horizontal PCO estimates, strong correlation with solar radiation pressure parameters
- Few cm level agreement for DLR/GFZ mean horizontal PCOs, 2-15 cm level agreement for z-offsets
- Appropriate orbit modeling essential for reliable and stable PCO estimation
- Update of conventional MGEX PCOs recommended, in particular for IOV
- Distinct differences in IOV and FOC phase residual maps
- Next step: estimation of satellite antenna PCVs





Galileo FOC FM2 Main Antenna

ESA - Anneke Le Floc'h