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# GALILEO ATTIUTUDE DETERMINATION



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21st International Workshop on Laser Ranging, Canberra, 2018

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# ALCANTARA Initiative

ESA project within Alcantara Initiative:

Verification of mm SLR measurements to Galileo satellites by variation of laser beam polarization plane orientation

Outline / project goals:

- mm SLR measurements to Galileo varying the laser beam polarization
- Ground based range measurements to ESA IOV spare retroreflector panel
- Transfer of know how Austria –> Argentina: build-up of AGGO SLR station

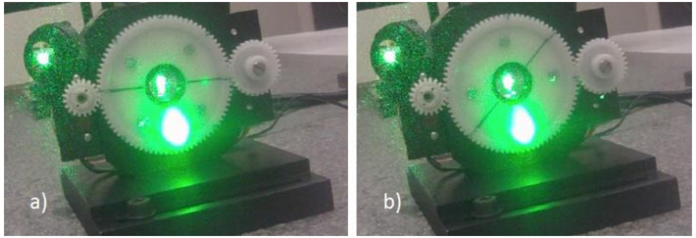
esa ÖAW IWF AGGO CONICET Bundesamt für Kartographie und Geodäsie

Alcantara Study Reference No.: 15 / P28
Contract number: 4000117654/16/F/MOS

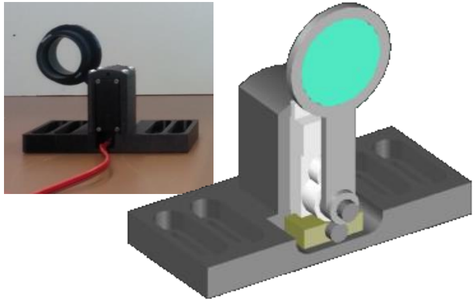
# LASER BEAM POLARIZATION

- Laser beam: fixed linear polarization at laser table
- Polarization varied according to orbit
  - along satellite track
  - across satellite track
  - circular polarization
- Principle behind
  - λ/2 wave plate (rotatable): set arbitrary linear polarization plane
  - λ/4 wave plate (switched in and out): linear -> circular

λ/2 wave plate rotator




λ/4 wave plate switch



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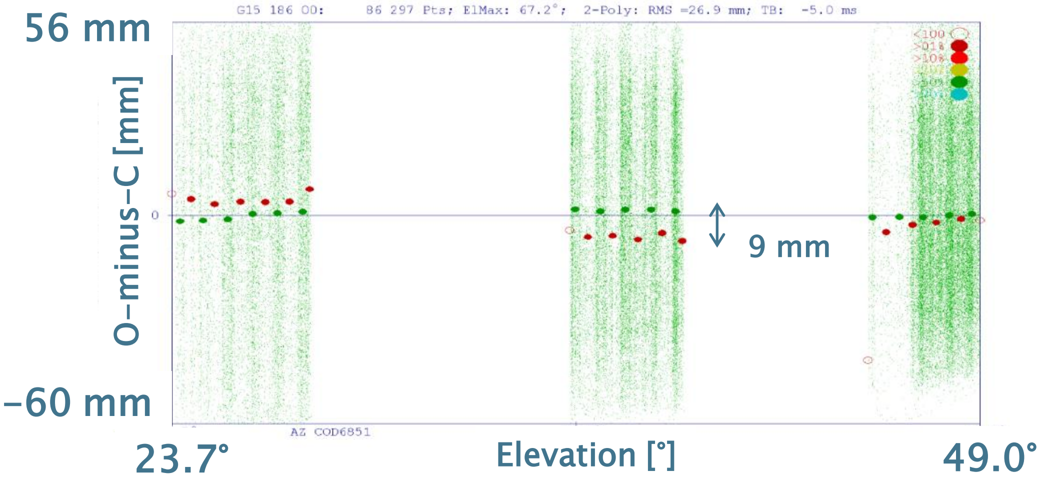
# PRE-Alcantara Results

Certain Glonass satellites (e.g. Glonass 115 (NORAD 33467 / 2008-067B)

- Differences of up to 9 mm between two polarization states (along, across)

Project goals -> Galileo satellites:

- Determine laser polarization induced offset / influence of clocking quality of Galileo panels
- Statistical evalulation of a large data set with different pass geometries




green ... polariaztion along satellite track

red ... polarization accross satellite track

x–axis ... elevation [°]

y–axis ... Observed–Minus–Calculated [mm]

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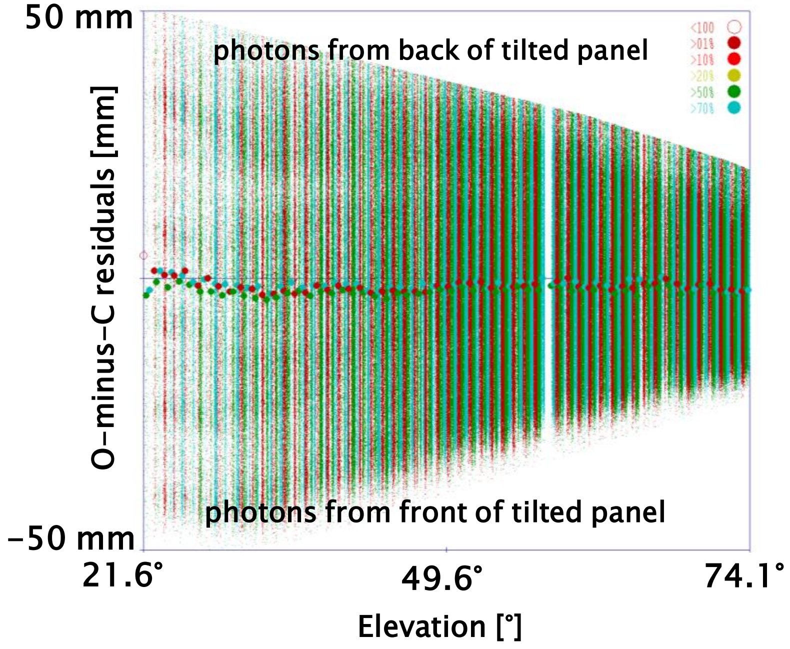
# Results: polarization plane switching

- Full rate data of Galileo103: x-axis: Elevation [°], y-axis: O-minus-C residuals [mm]
- Polarization: Red: linear along track, green: linear across track, cyan: circular)

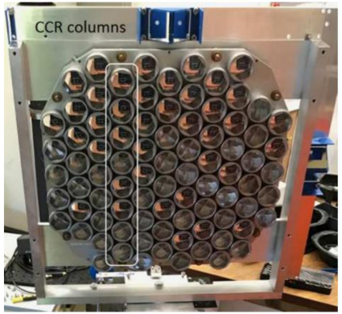


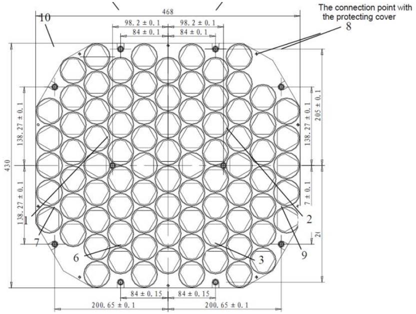

Offsets between normal points: < 2 mm (close to SLR accuracy)

Low elevations: tilt of panel --> increased jitter between photons from front and back of panel

9 cm @ 21.6° elevation
4 cm @ 74.1° elevation

Maximum jitter: 10 cm @ 12.4° tilt: (panel width: 46.8 cm)



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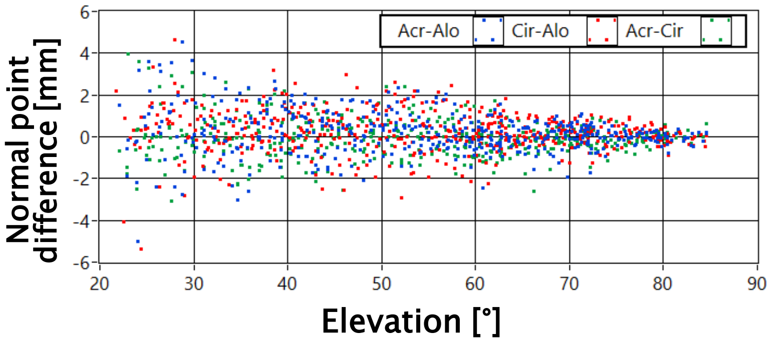
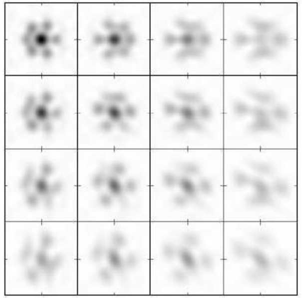
# 13 Galileo satellites / 27 hours observations
# 1600 1-minute normal points

Y-axis: Range difference of normal points at different polarization states (across-along, across-circ)

- No trend visible -> averages to zero -> good quality of ESA panels
- Jitter of normal point difference dependent on elevation (incidence angle on panel)
- Jitter increases from ±1 mm (large elevations) to ±4 mm (low elevations)
  - Possible explantation: far field diffraction patterns of CCR separate further the larger the incident angle
  - Different linear polarizations rotate the whole field diffraction pattern
  - Different position within far field diffraction pattern --> retros with a certain clocking contribute more --> slightly different reflection point --> offset / jitter between normal points




Incident angles single CCR x– and y–tilt; 5° steps [1]

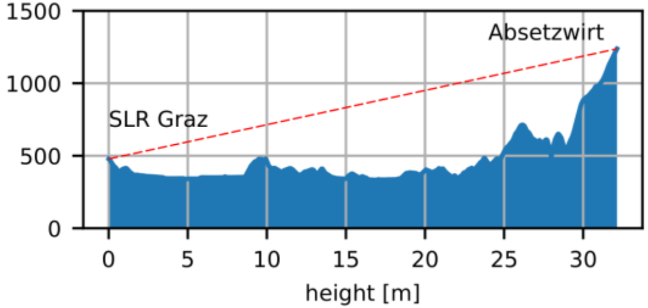




Polarization and far–field diffraction patterns of total internal reflection corner cubes; Murphy, Goodrow; Appl Opt 53 (2); 2013

# SPARE PANEL

- ESA provided a spare IOV panel to perform ground based measurements
- Panel was mounted on an astronomical tripod
- Panel rotatable between -18° and +18° (around azimuth axis) / 0.1° steps
- Panel first time out of a clean room -> we asked ESA first :-)
- Remote location 32 km outside of Graz (Absetzwirt)

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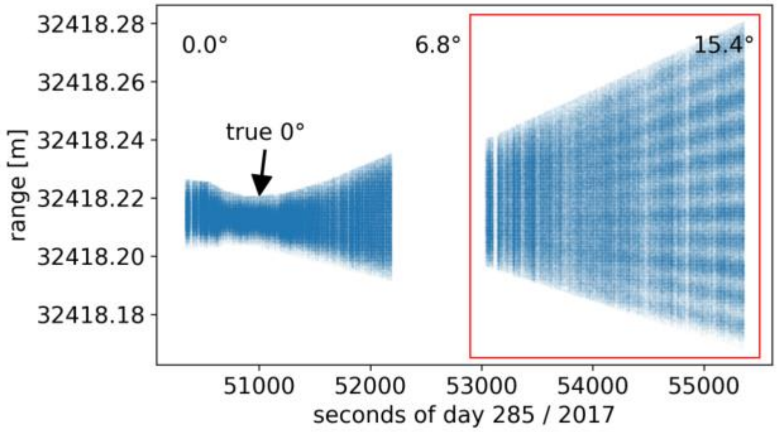
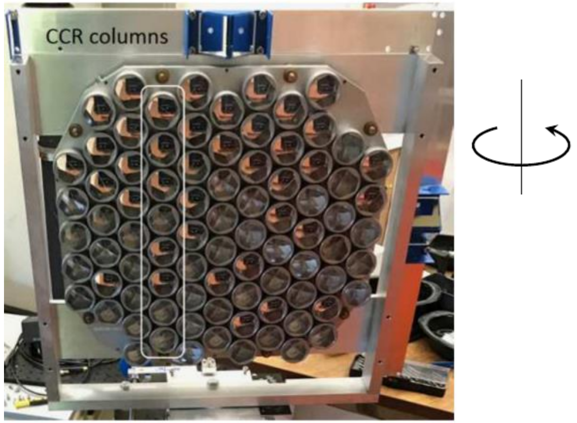
# Measurements to spare panel

Range measurements to Absetzwirt (analyze full rate data): y-axis: range [m], x-axis [seconds of day]

- Panel: 0° laser beam incident angle alignment of: using four 45° mirrors, 4 orthogonal screens
- Panel tilt angle around azimuth axis: increased from 0.0° to 18° (laser beam incident angle)
- Range jitter increases (photon statistically from front or back of tilted panel)
- True 0° incident angle (minimum jitter) 0.3° / 1.3° after mechanical 0° alignment (alignment errors)
- 11 clearly distinguishable tracks which separate from each other -> <u>**11 retroreflector colums**</u>

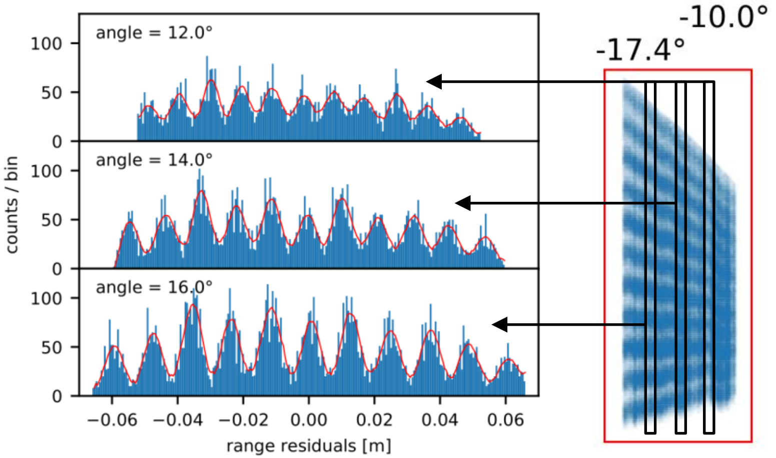


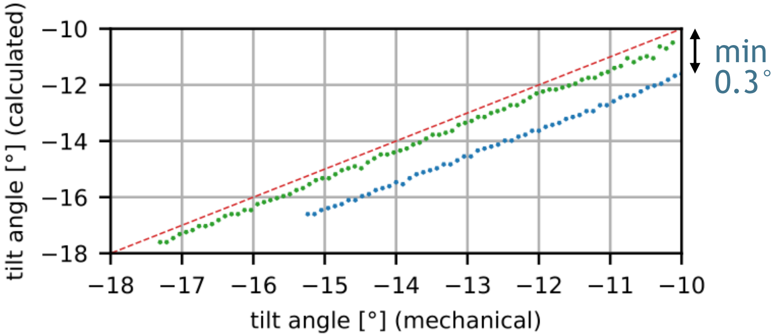

11 CCR columns



# Histogram analysis

- Histogram through range data (at incident angles above 10° )
- Number of photons / 500 µm bin at different ranges; Fitted with a smoothing function (red)
- Peak distance calculated (autocorrelation
- Incident angle calculated from peak distances (42 mm CCR distance)




Compared to mechanical (red, dashed) incident angle

alignment offset:
- 0.3° (green dotted, measurement day 1)
- 1.3° (blue dotted, measurement day 2)

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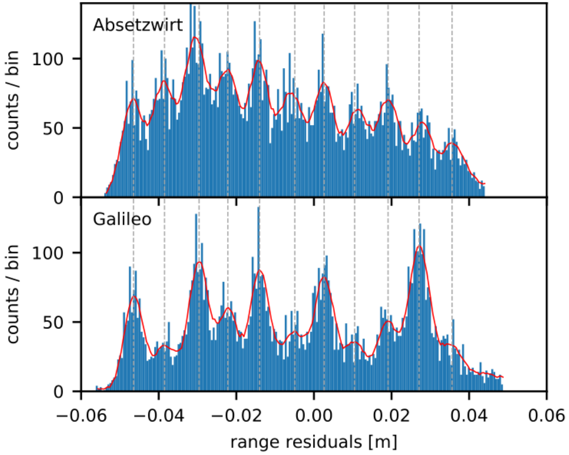
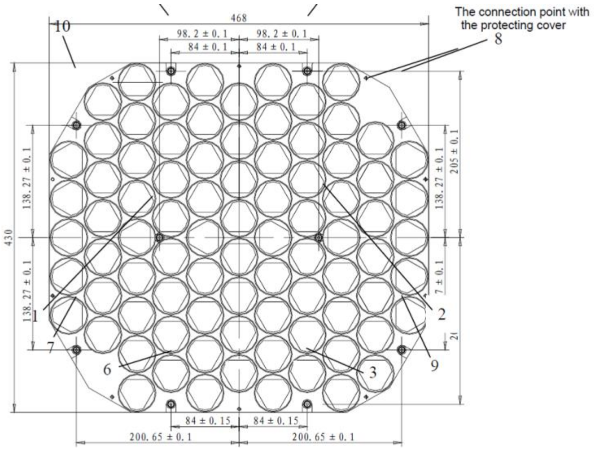
# Comparison: Absetzwirt vs. Galileo 103

Comparison to space-based measurement to Galileo 103

- SLR station Graz seen from Gal. ref. frame : 11.37° elevation / 90° azimuth (Yaw steering)
- From histogram: CCR column distances -> incident angle re-calculated: 11.38°
- Very good agreement: Unique method to verify the attiude of CCR panels




- Peak heights : Galileo vs. spare panel -> clocking orientation contributing more to measurement

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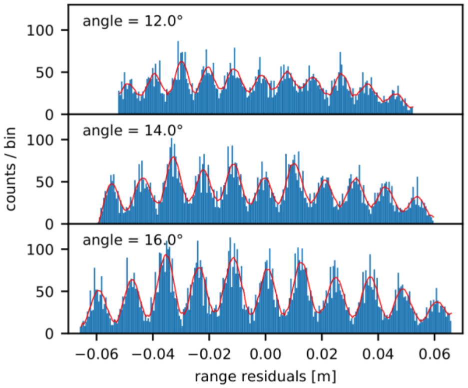
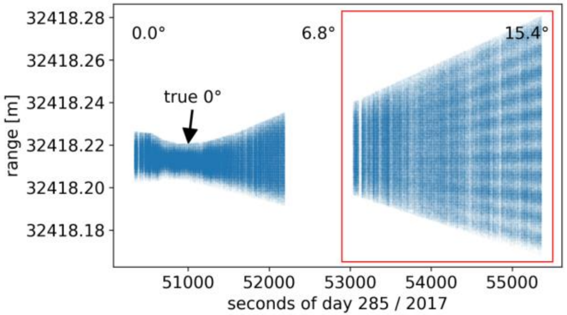
# Summary

- Laser beam polarization switching
- 1600 1-minute normal points to 13 different Galileo satellites
- Very good clocking quality of Galileo panels
- Maximal offsets between polarizations of 4 mm

- Spare ESA retroreflector panel mounted at at 32 km distance
- Different columns of retroreflectors clearly visible
- From distance offsets tilt angles calculated
- Method to verify attitude of Galileo satellites < 0.1°

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# !!! Thank You !!!