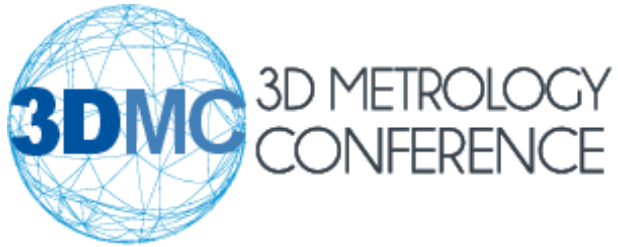
Radio Telescope Inspection by Terrestrial Laser Scanner



10./11. October 2017, Aachen, Germany

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University of Bonn, Germany

University of Bonn

- **Institute of Geodesy and Geoinformation**

- B.Sc. / M.Sc. Geodesy and Geoinformation (German)
- M.Sc. Geodetic Engineering (English)

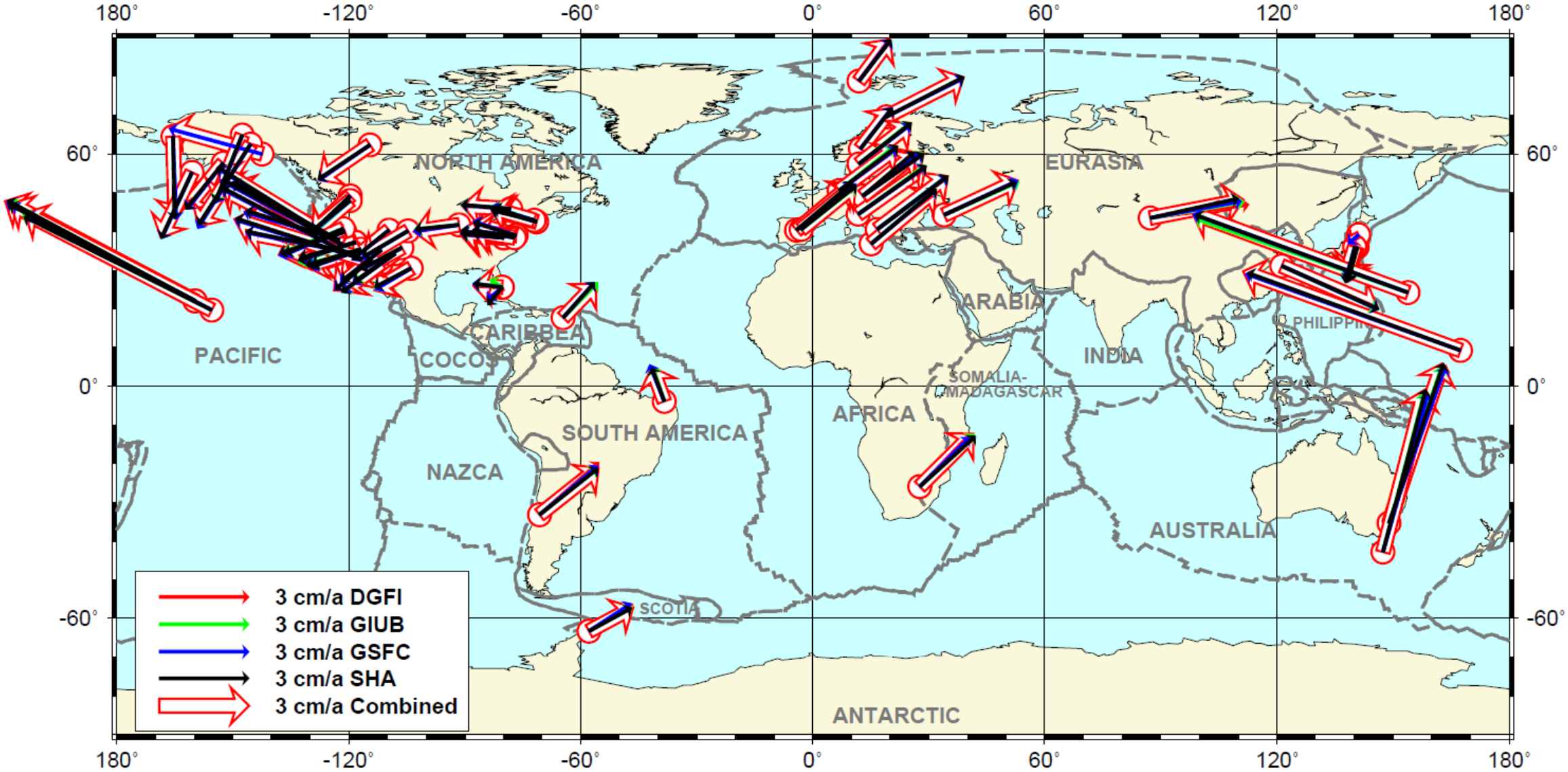
- Geodetic metrology
- Industrial metrology
- Data processing & accuracy analyses

- **… and also: global geodesy**




www.wylerag.com; www.leica-geosystems.com; www.hexagonmi.com; www.david-3d.com

Determination of plate tectonics

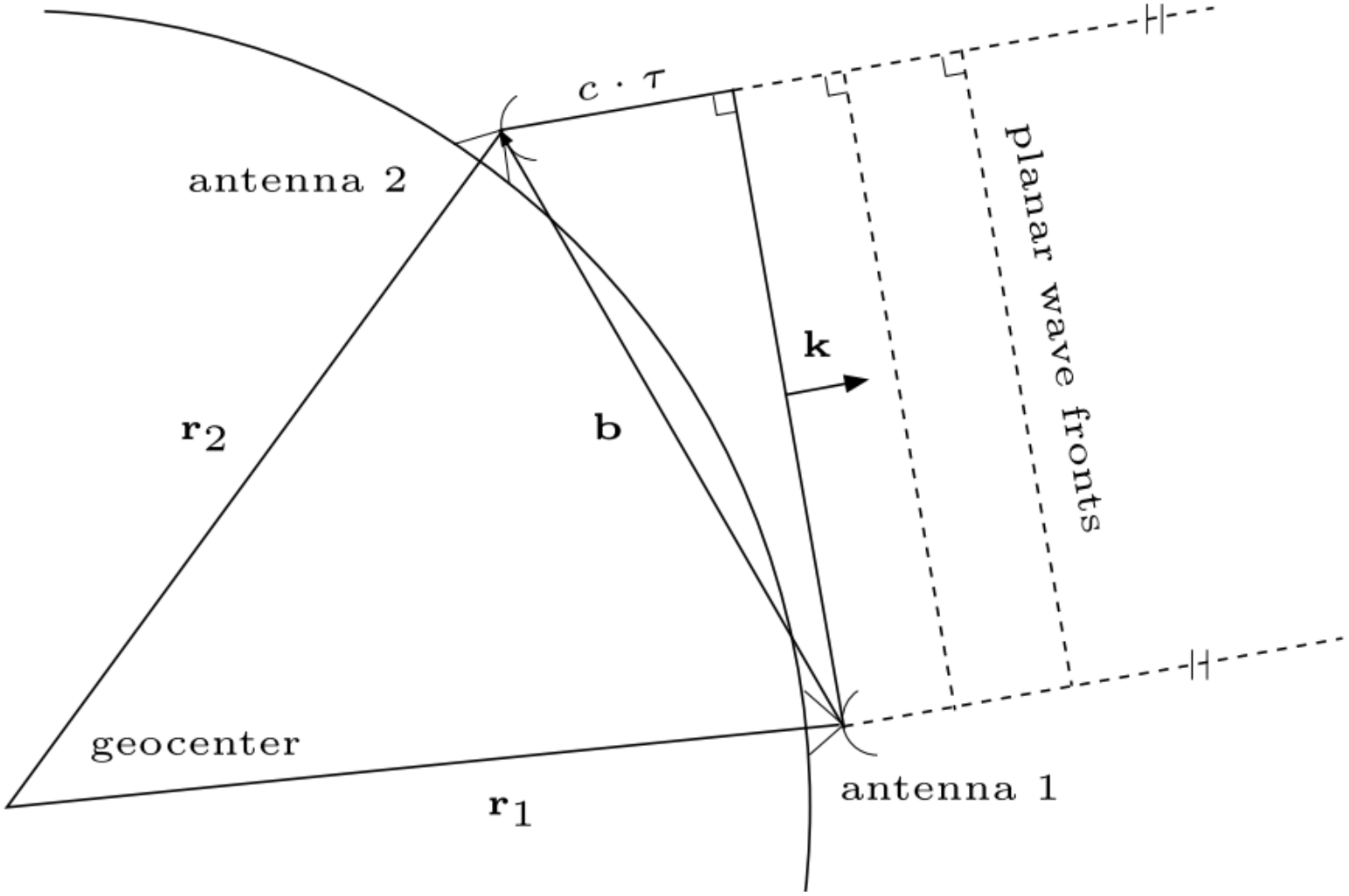


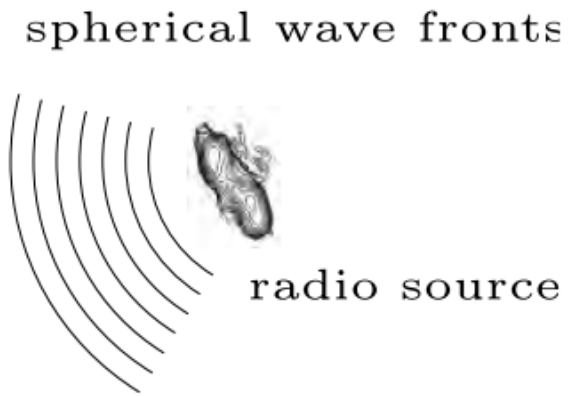
www.mpifr-bonn.de

Radio telescopes

www.mpifr-bonn.de

Very Long Baseline Interferometry (VLBI)





$$\tau = t_2 - t_1 = -\frac{1}{c} \cdot \boldsymbol{b} \cdot \boldsymbol{k}$$

$$\sigma_b \leq 1mm$$

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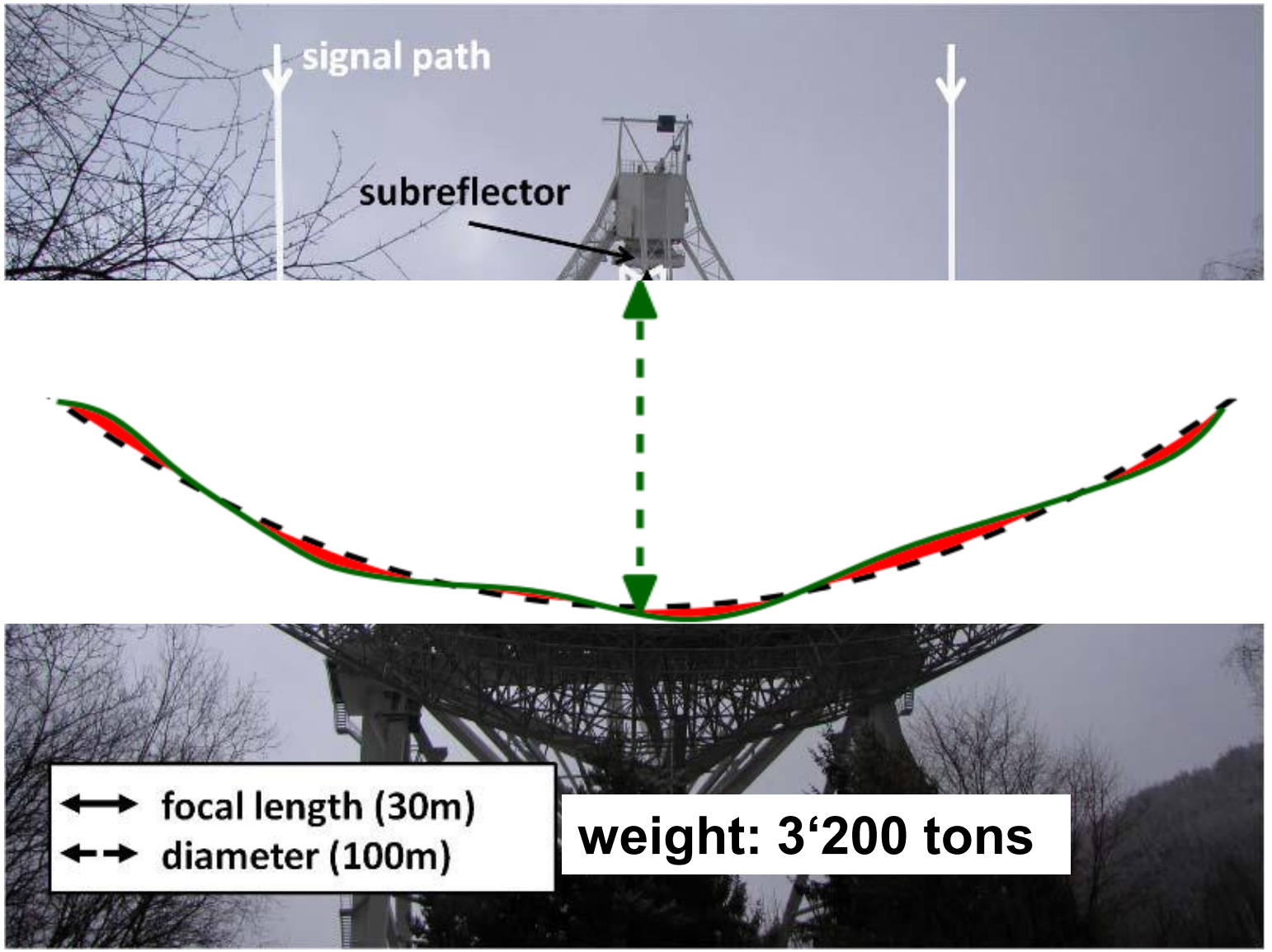
Radio telescope (Effelsberg)



Assumption:

shape = rotational paraboloid

Searched for:

focal length +

local deformations

… that depend on elevation angle

Onsala & Effelsberg

Onsala & Effelsberg

Diameter of 20m

Enclosed by a radome

Surface smooth

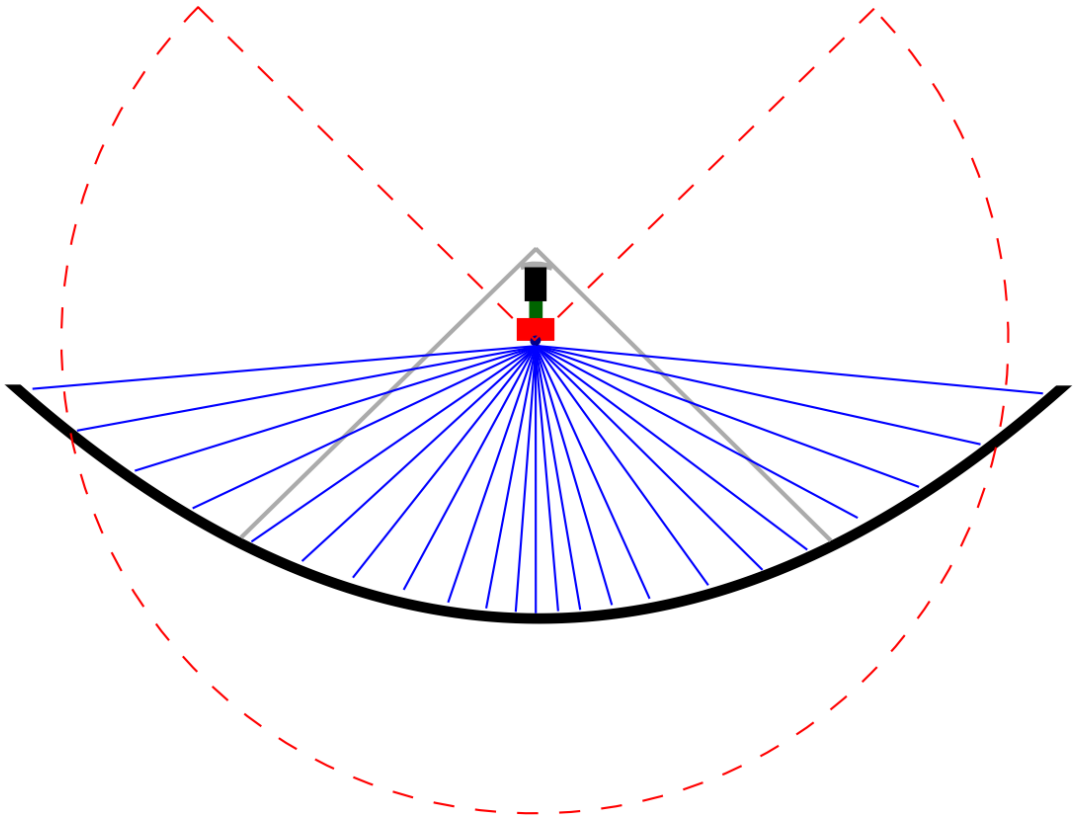
Diameter of 100m

Subject to wind and weather

Surface more rough

Data collection

- Overhead station: good incidence angles, no obstruction
- Scanning at 7 elevation angles from 90 deg to 7.5 deg
- Leica ScanStation P20



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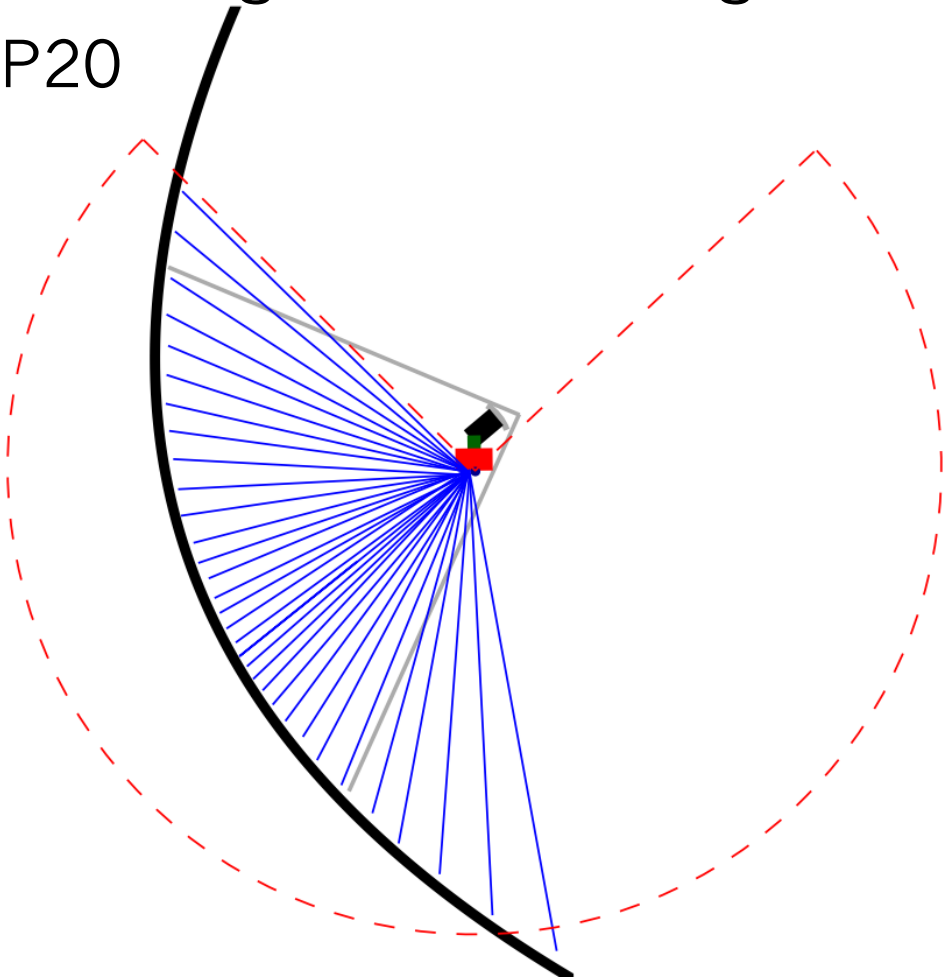
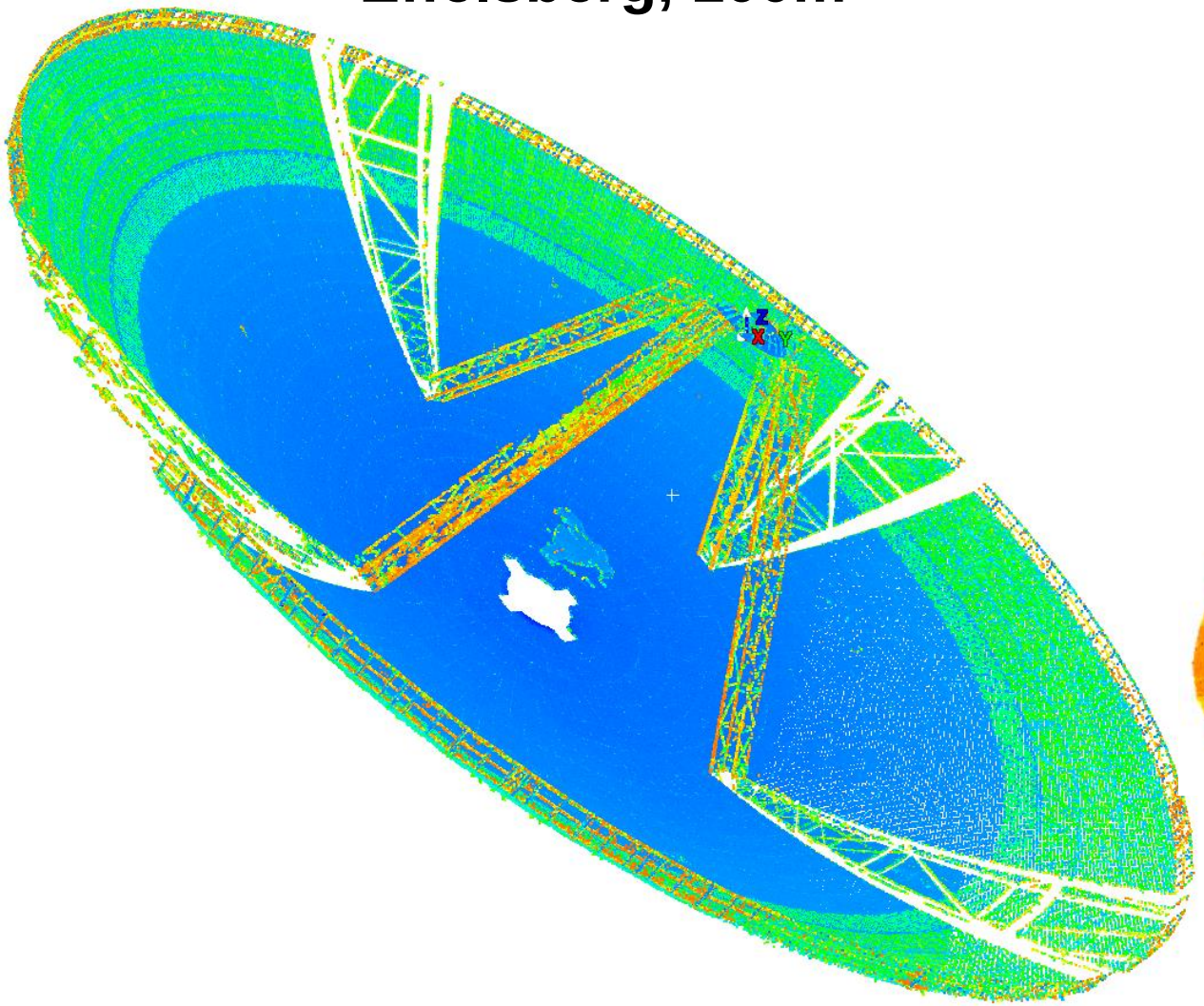
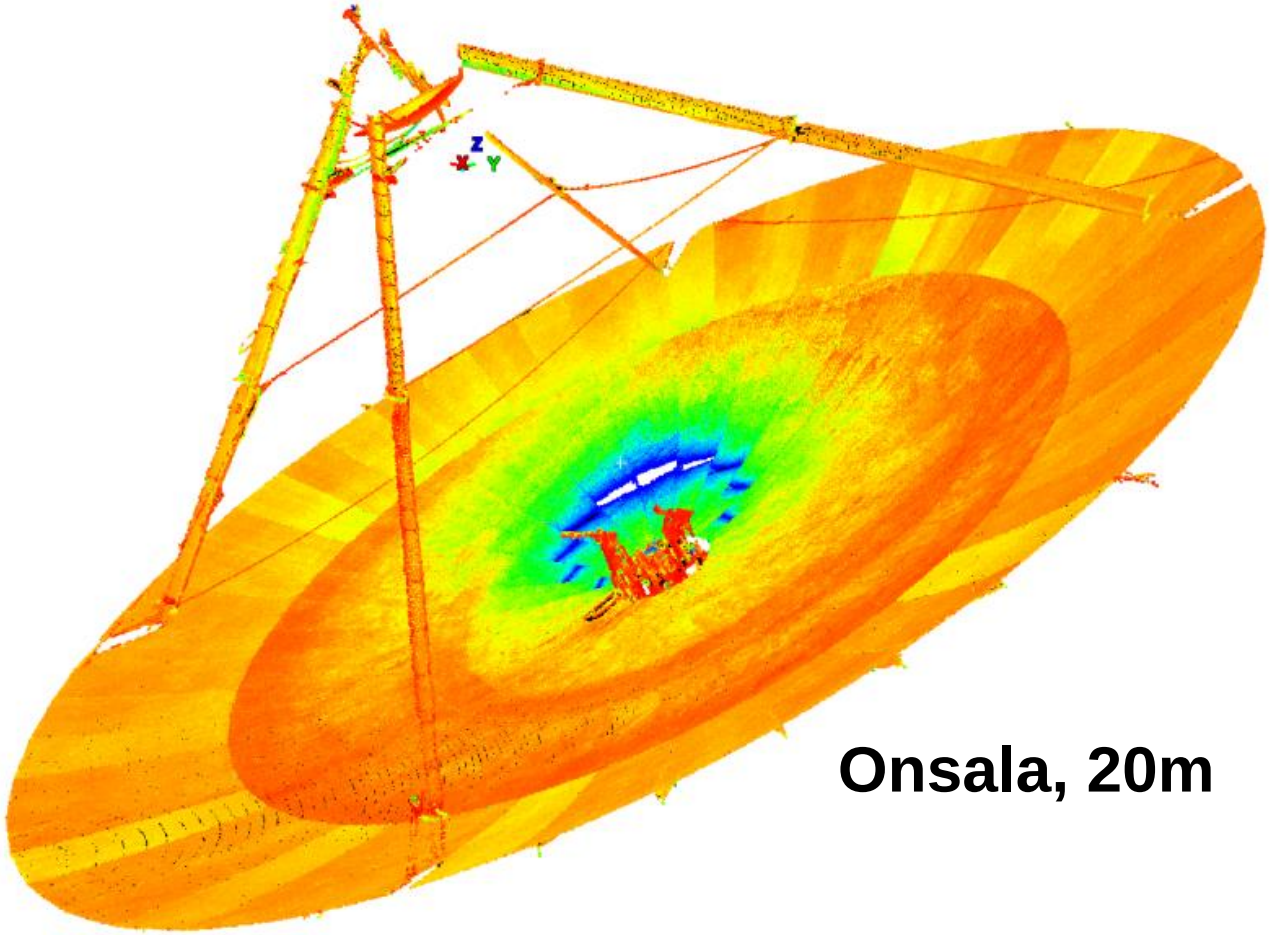


Point clouds

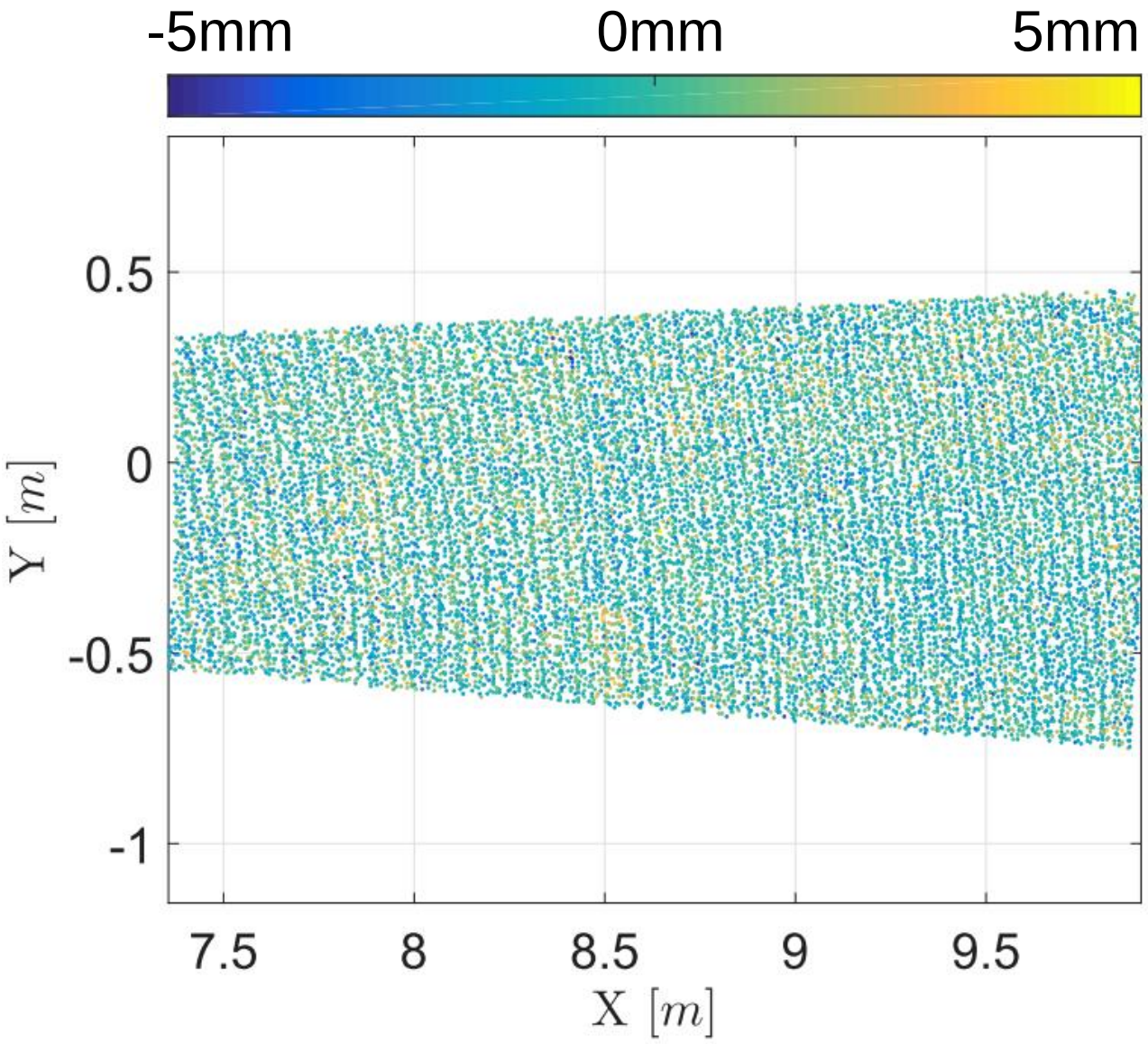
Effelsberg, 100m





Onsala, 20m

Noise of laser scan (Onsala)



σ < 1.5 mm

@ r = 7…15 m

Deformation analysis

1. Scanning of main reflector at several elevation angles
2. Parameterization as rotational paraboloid

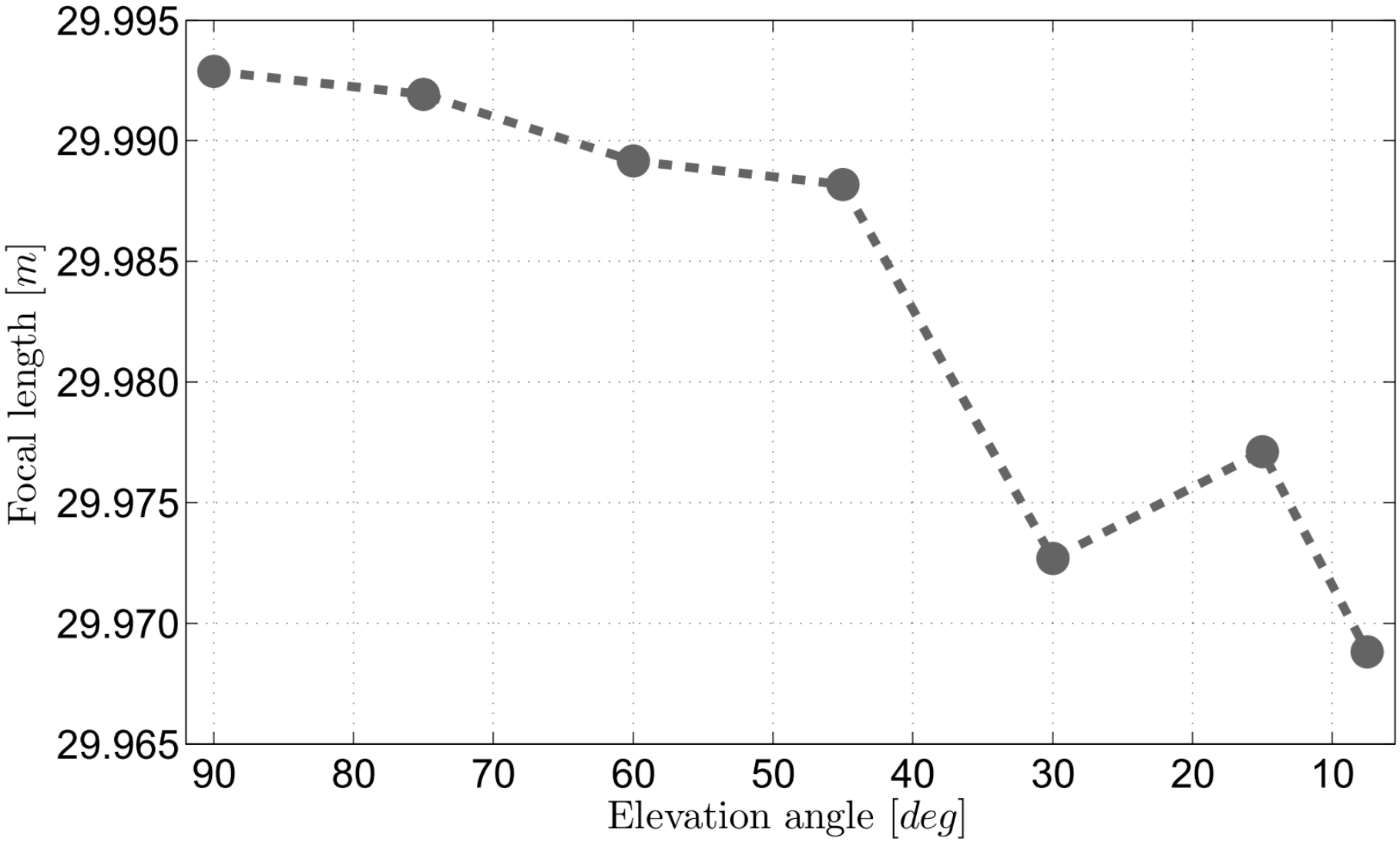
$$\frac{X_i^2 + Y_i^2}{4\boldsymbol{f}} - Z_i = 0$$

$$\mathbf{X_i} = \mathbf{R_y}(\varphi_y) \cdot \mathbf{R_x}(\varphi_x) \cdot \mathbf{x_i} + \mathbf{X_v}$$

3. Least-squares estimation of the parameters by minimizing $\boldsymbol{v}^T \boldsymbol{\Sigma}^{-1} \boldsymbol{v}$

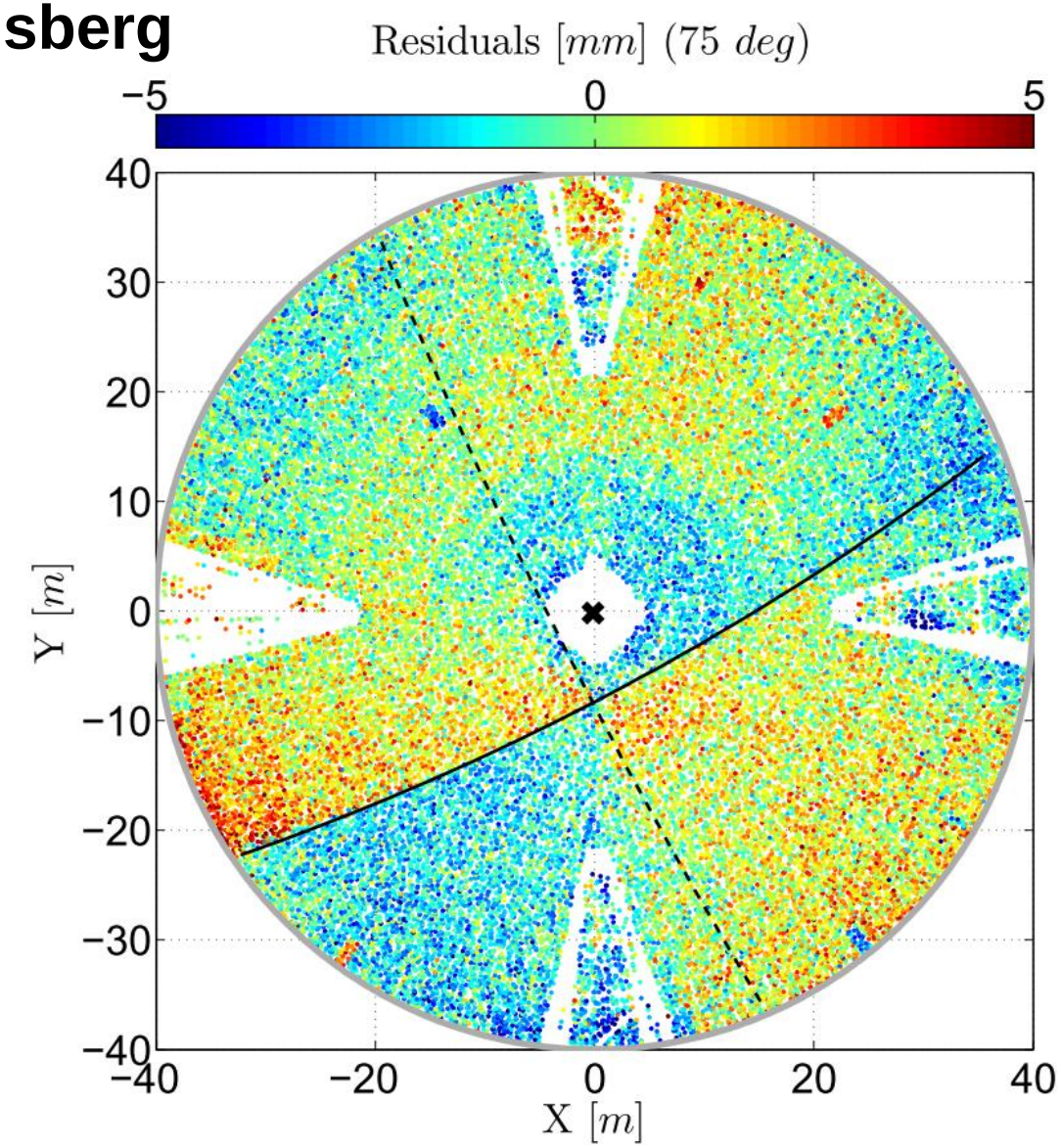
4. Analysis of results
   - **Global deformation**: variations of focal length f at different elevations
   - **Local deformation**: residuals from approximation

Focal length (Effelsberg)

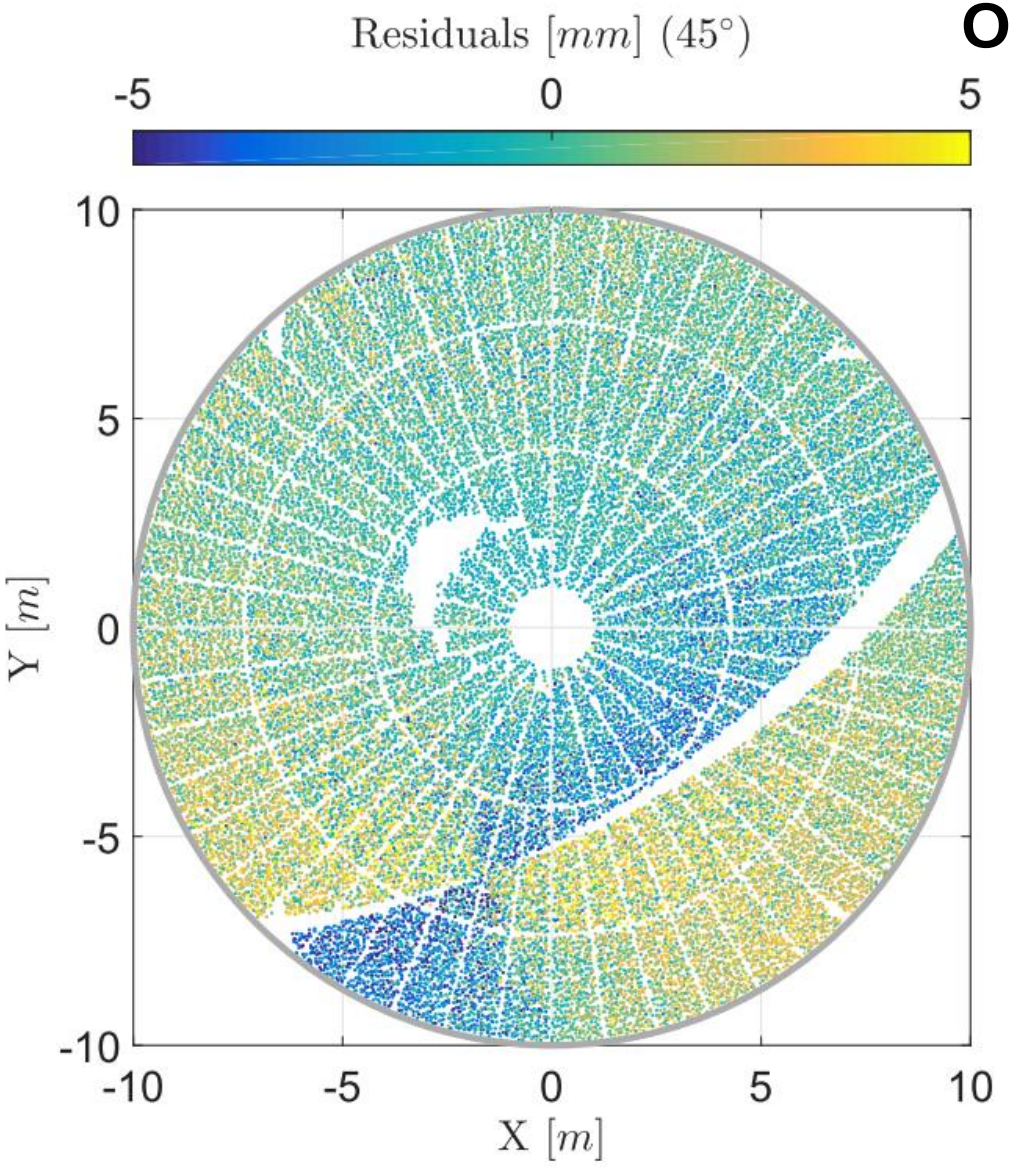


Local deformation

Effelsberg



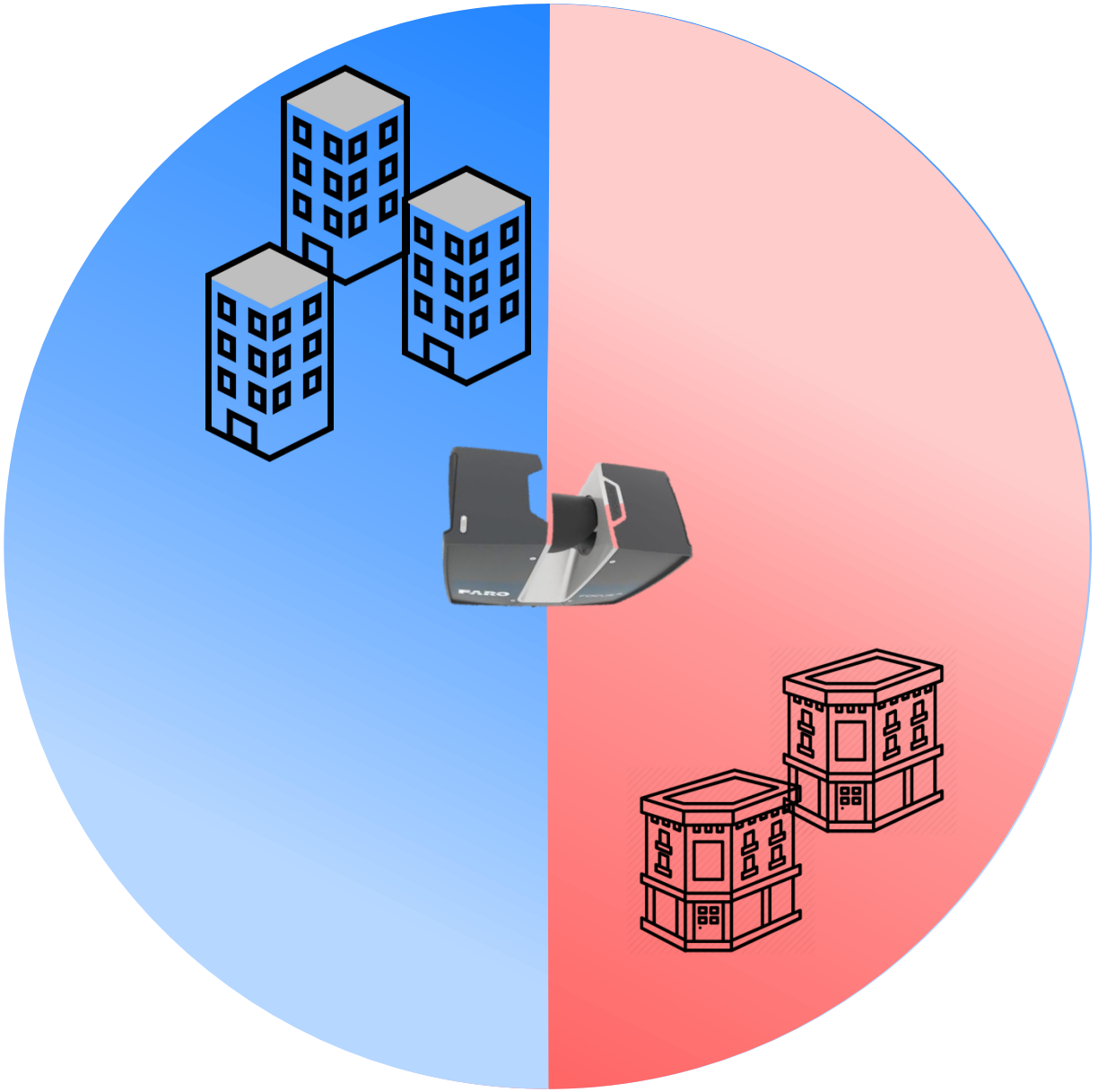
Onsala



Scanning in two faces

Face 1 =
FRONT SIDE

Face 2 =
BACK SIDE

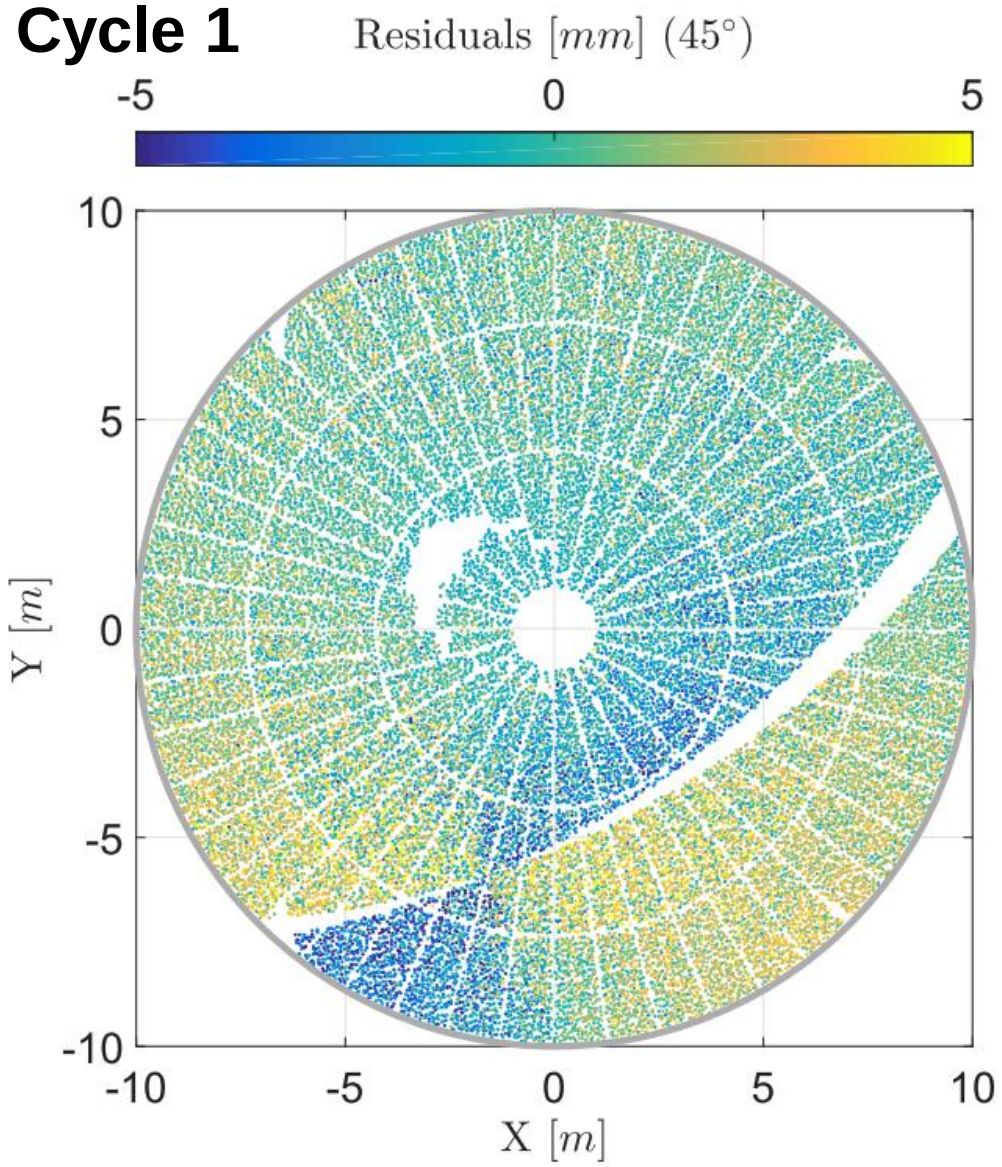


1st CYCLE (0° - 180°)

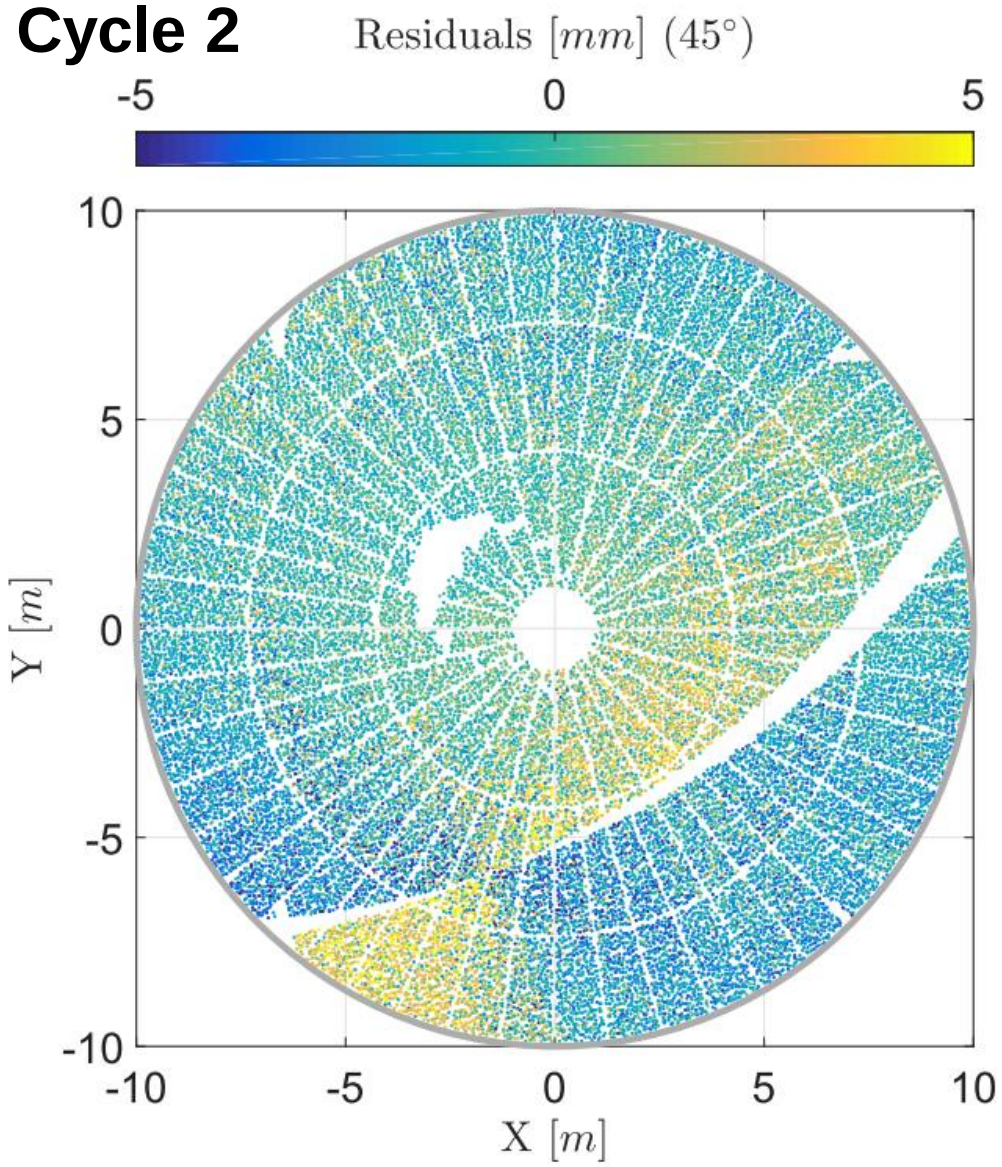
2nd CYCLE (180° - 360°)

Local deformation (Onsala)

Cycle 1



Cycle 2



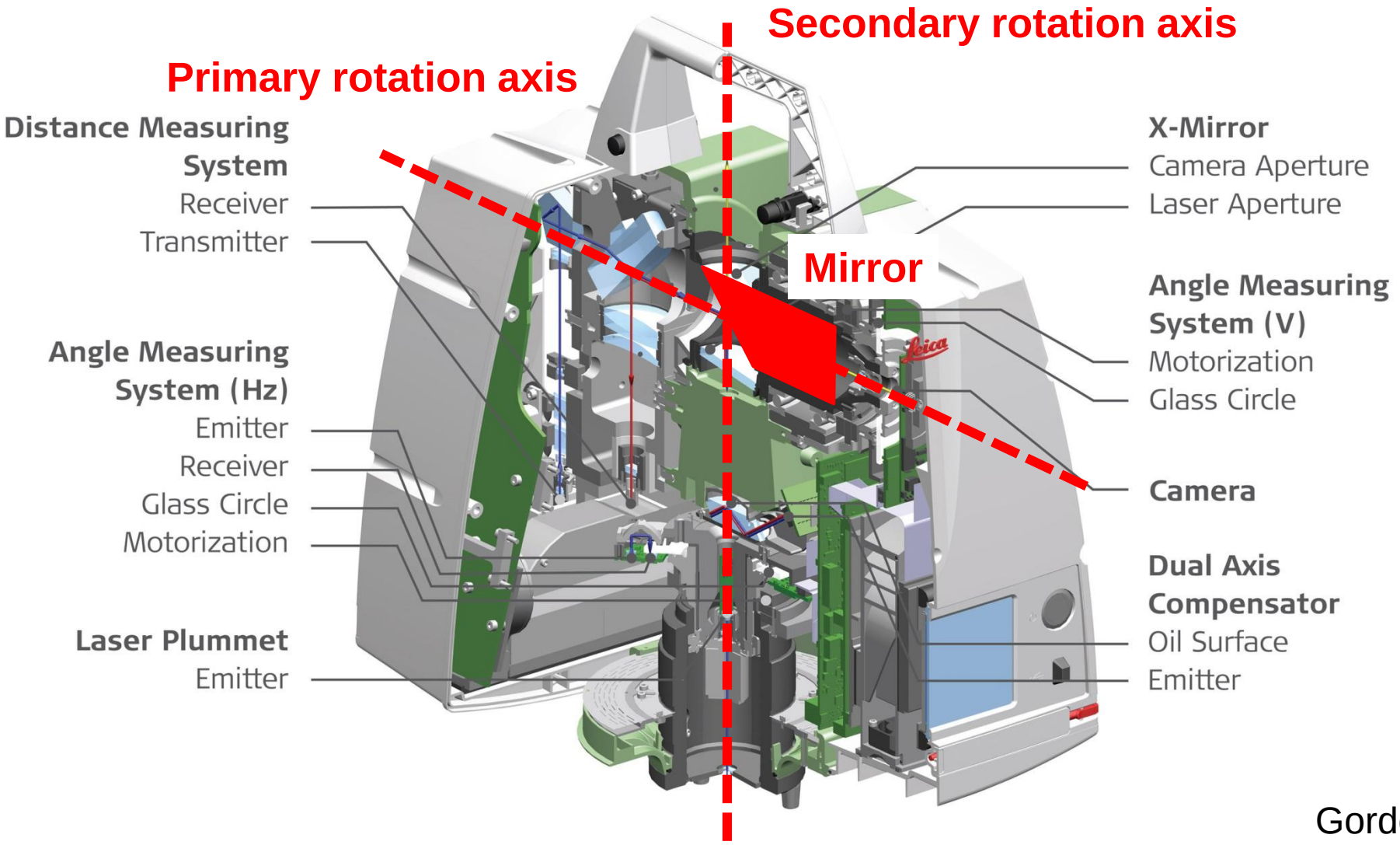
Results so far

Large systematic errors

Sign changes between face 1 and face 2

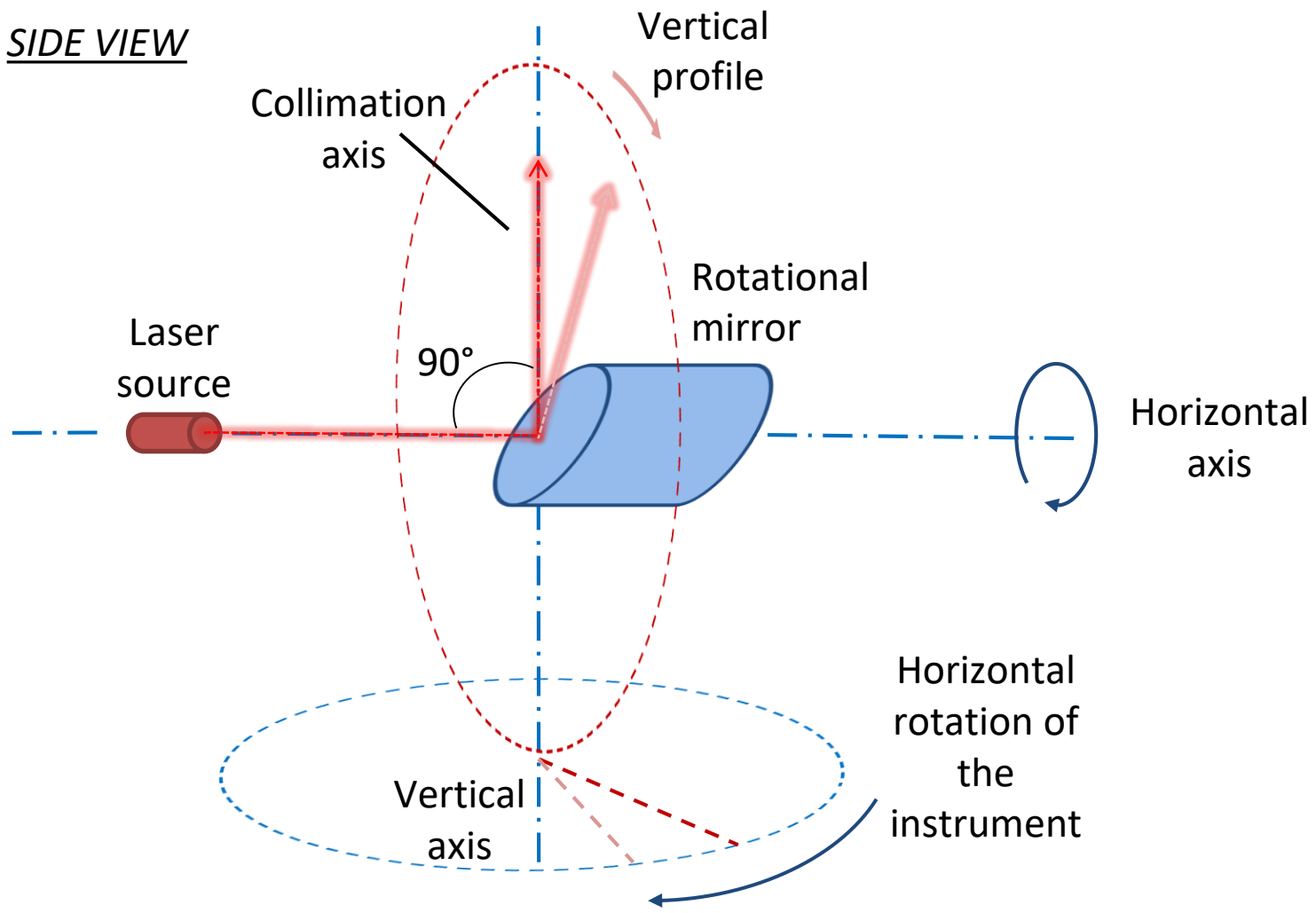
Inspection not meaningful

Construction of a laser scanner

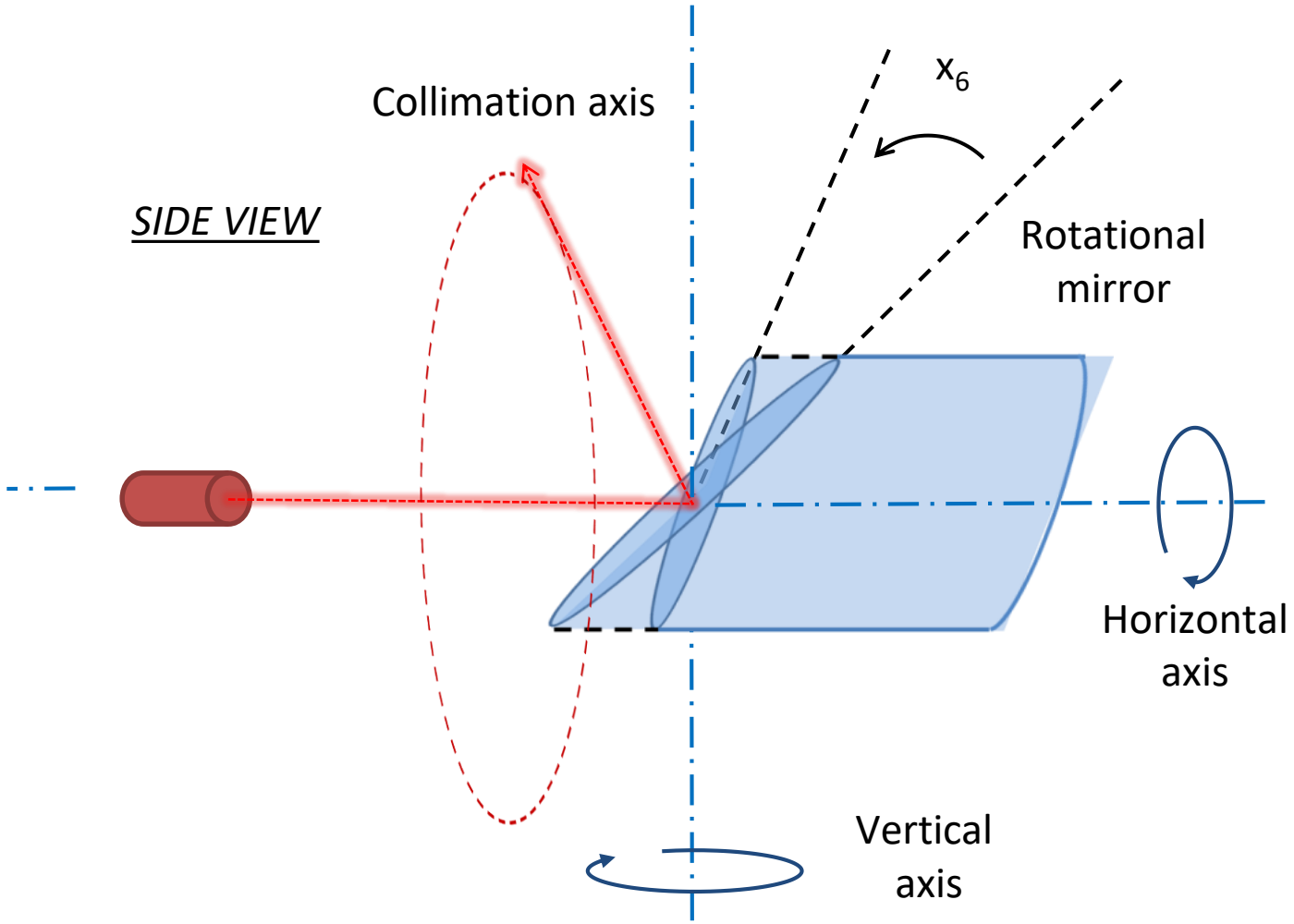


Gordon (2012)

Construction of a laser scanner



Possible misalignments: Mirror tilt



Error in horizontal angle in face 1:

$$\Delta\varphi_j^i = +\frac{2x_6}{sin(\theta_j^i)}$$

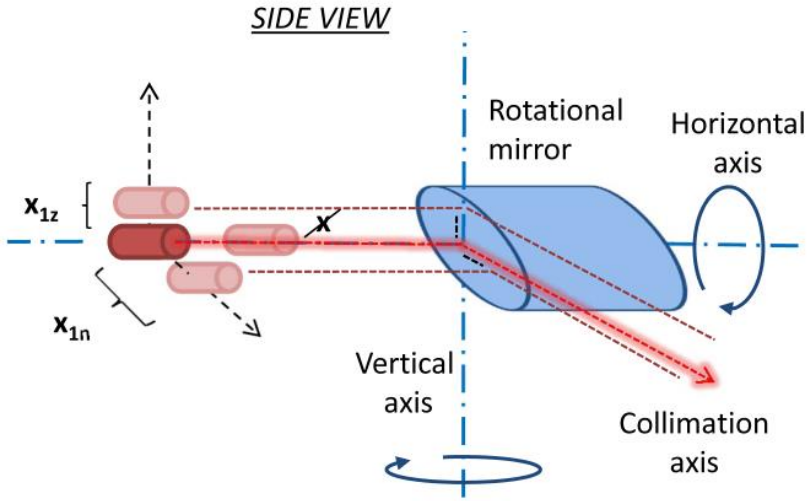
Error in horizontal angle in face 2:

$$\Delta\varphi_j^i = -\frac{2x_6}{sin(\theta_j^i)}$$

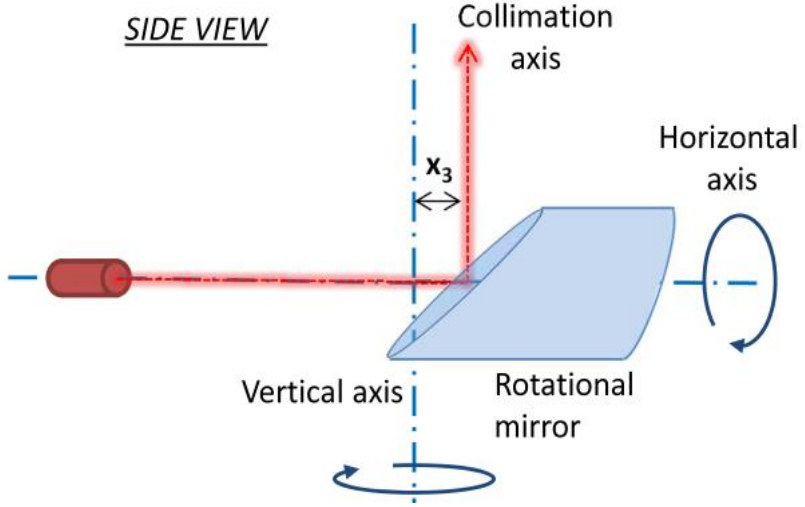
… with θ = vertical angle

Further possible misalignments

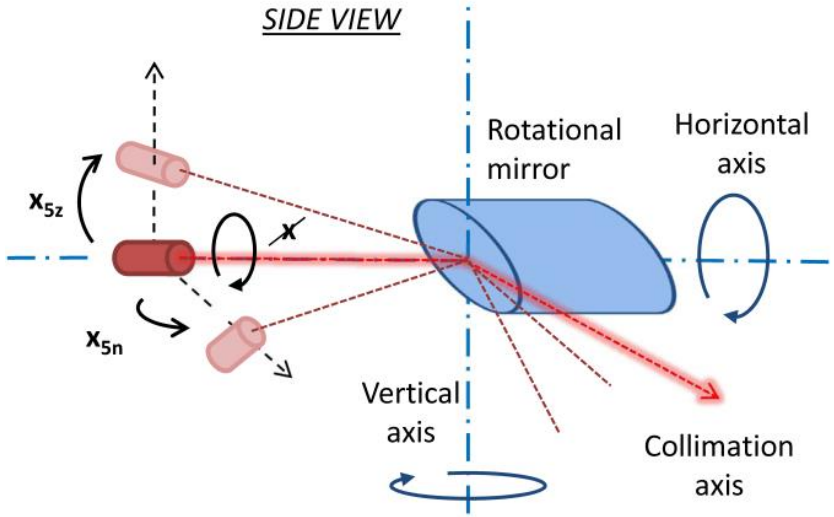
Eccentricity of laser



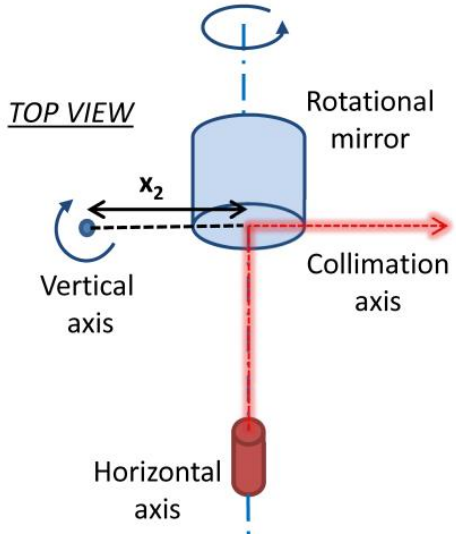
Eccentricity of mirror



Alignment of laser



Alignment of axes



Extended deformation analysis

1. Scanning of main reflector at several elevation angles **<= all in two faces**
2. Parameterization as rotational paraboloid

$$\frac{X_i^2 + Y_i^2}{} - Z_i = 0$$

3.

$$\Delta r_j^i = x_2 \sin(\theta_j^i) + x_{10}$$

$$\Delta\theta_j^i = \frac{x_{1n+2}\cos(\theta_j^i)}{r_j^i} + x_4 + x_{5n}\cos(\theta_j^i) - \frac{x_{1z}\,sin(\theta_j^i)}{r_j^i} - x_{5z}\,sin(\theta_j^i)$$

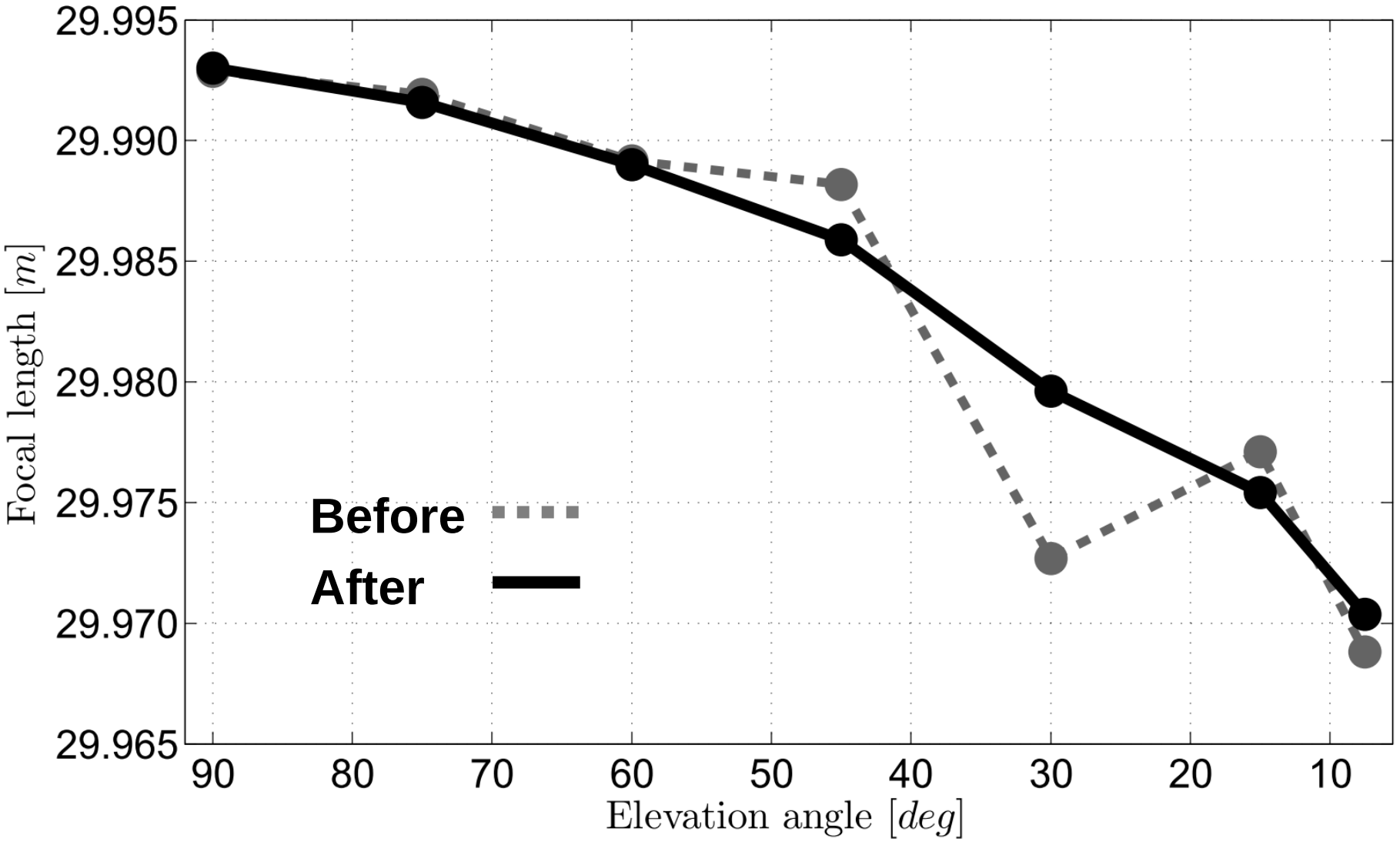
$$\Delta\varphi_j^i = \frac{x_{1z}}{r_j^i \tan(\theta_j^i)} + \frac{x_3}{r_j^i \sin(\theta_j^i)} + \frac{x_{5z-7}}{\tan(\theta_j^i)} + \frac{2x_6}{sin(\theta_j^i)} + \frac{x_{1n}}{r_j^i}$$

4.

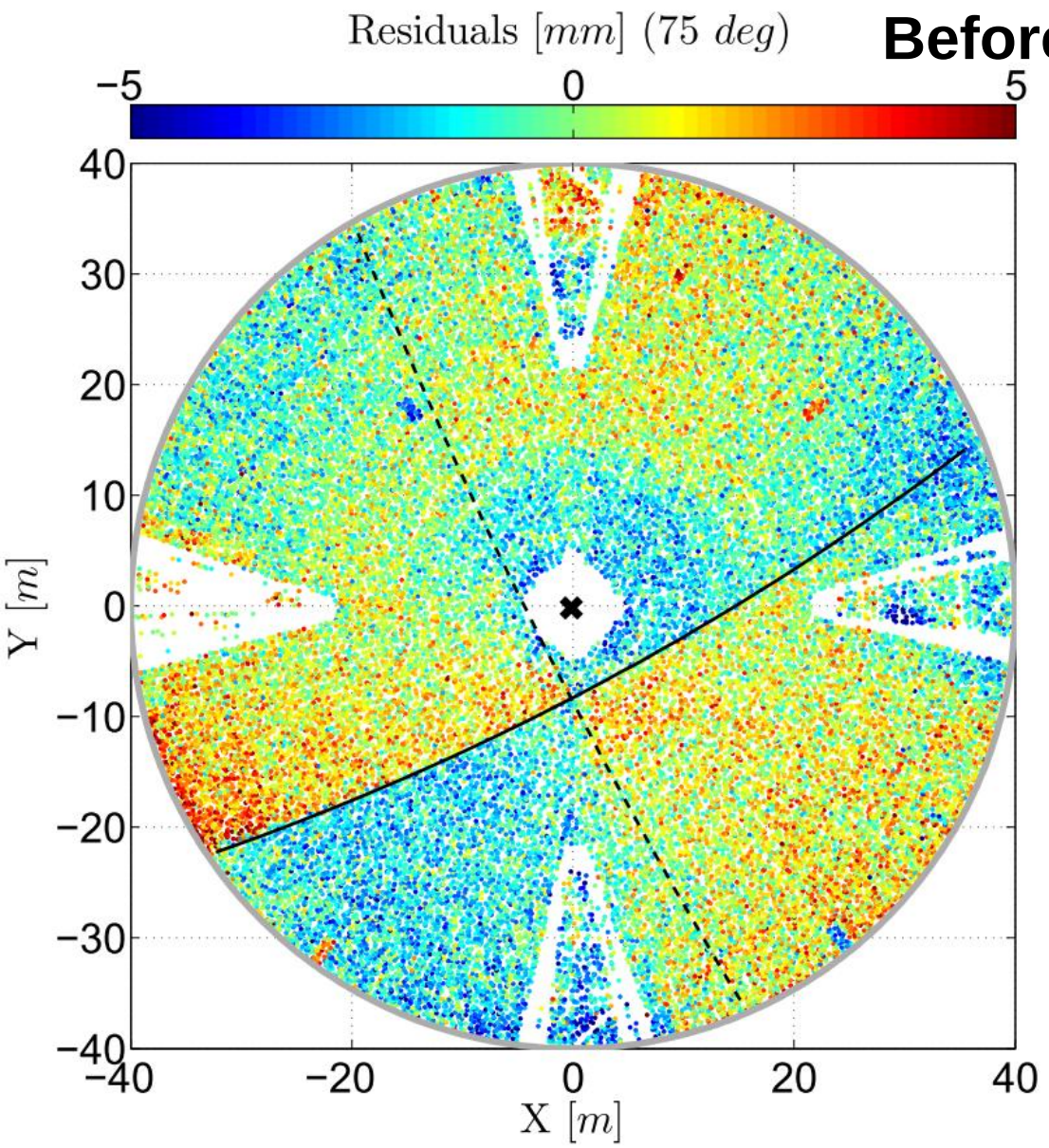
…. in-situ calibration using scans in two faces

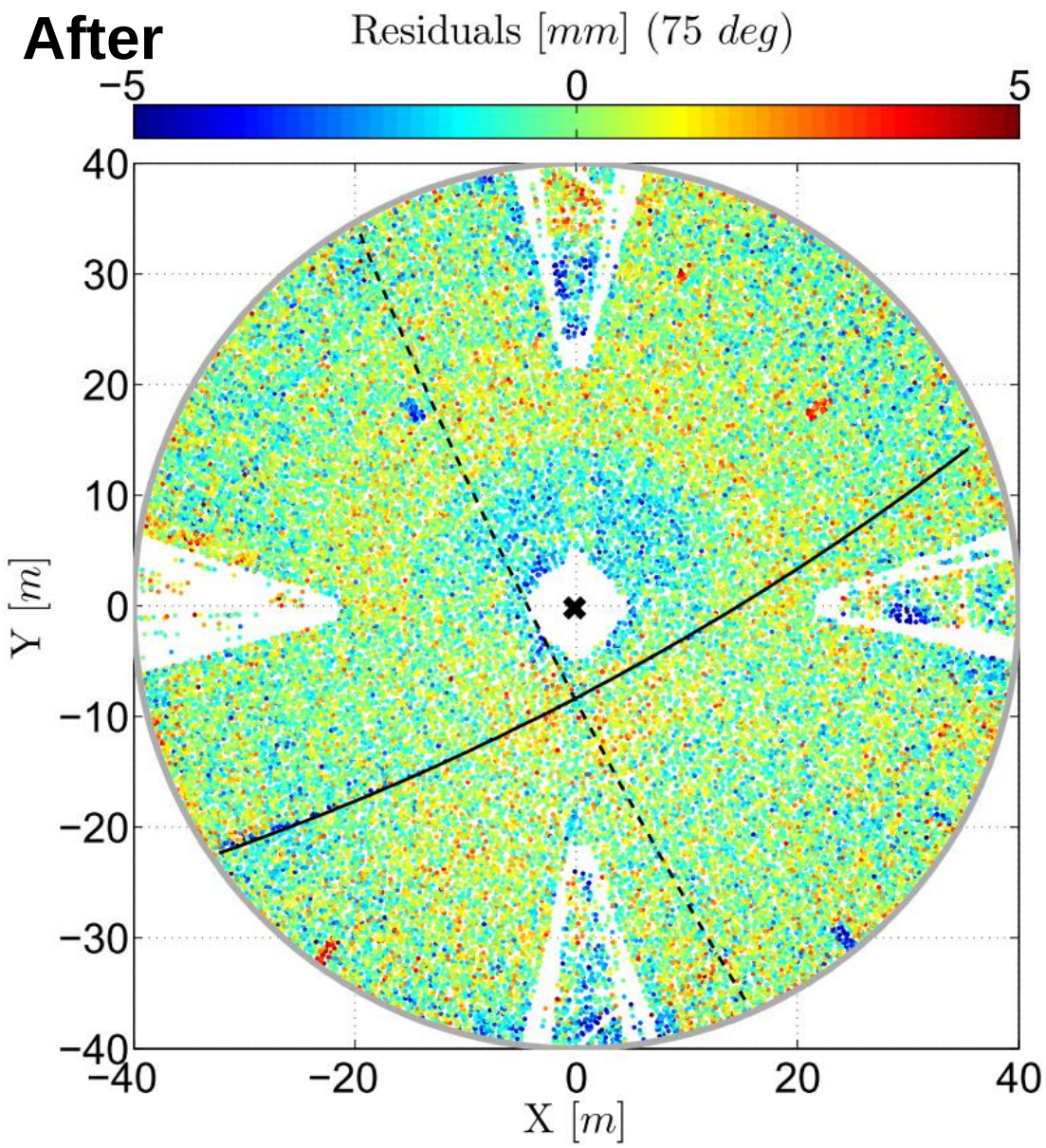
– **Local deformation**: residuals from approximation

Focal length (Effelsberg)

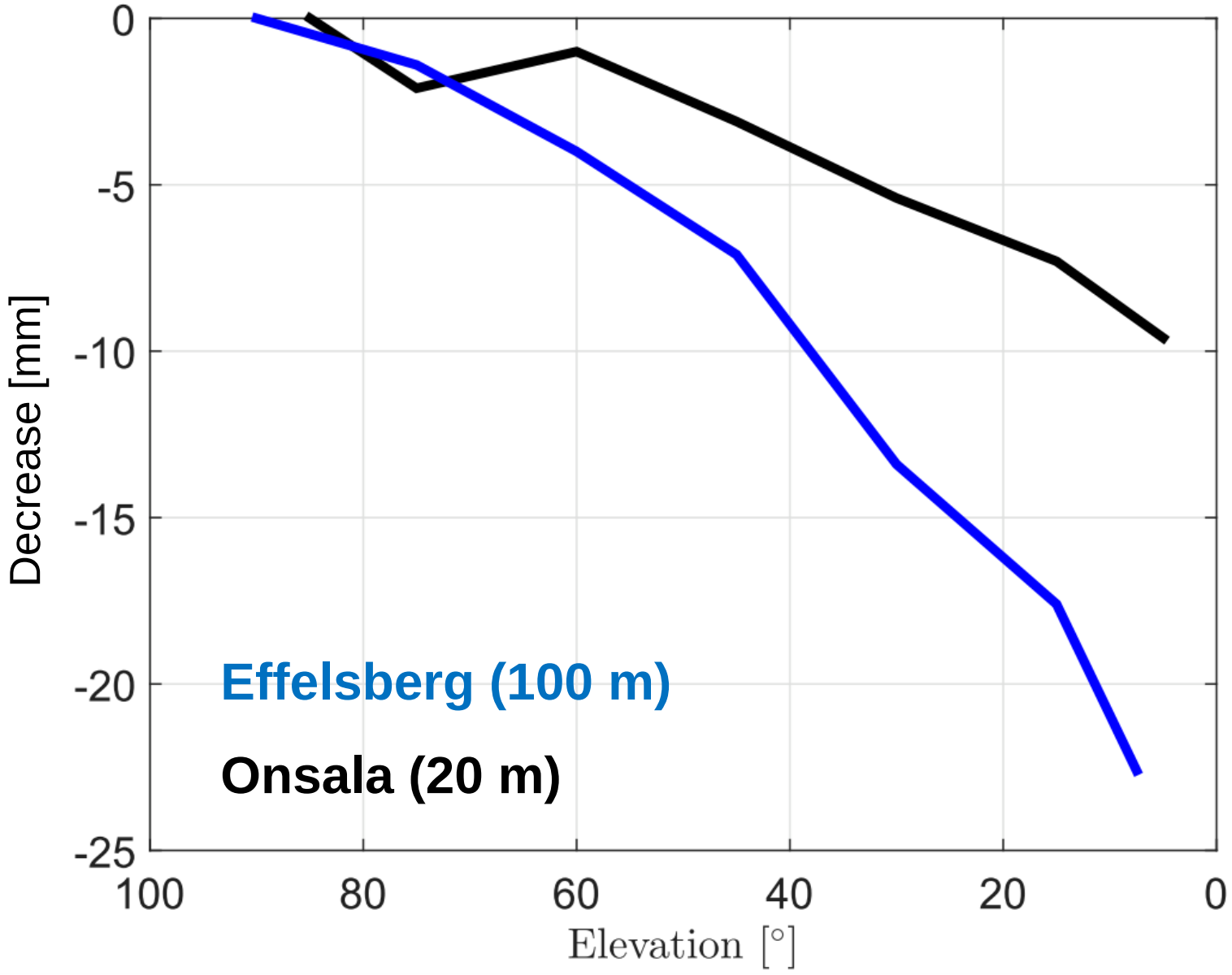


Local deformations (Effelsberg)



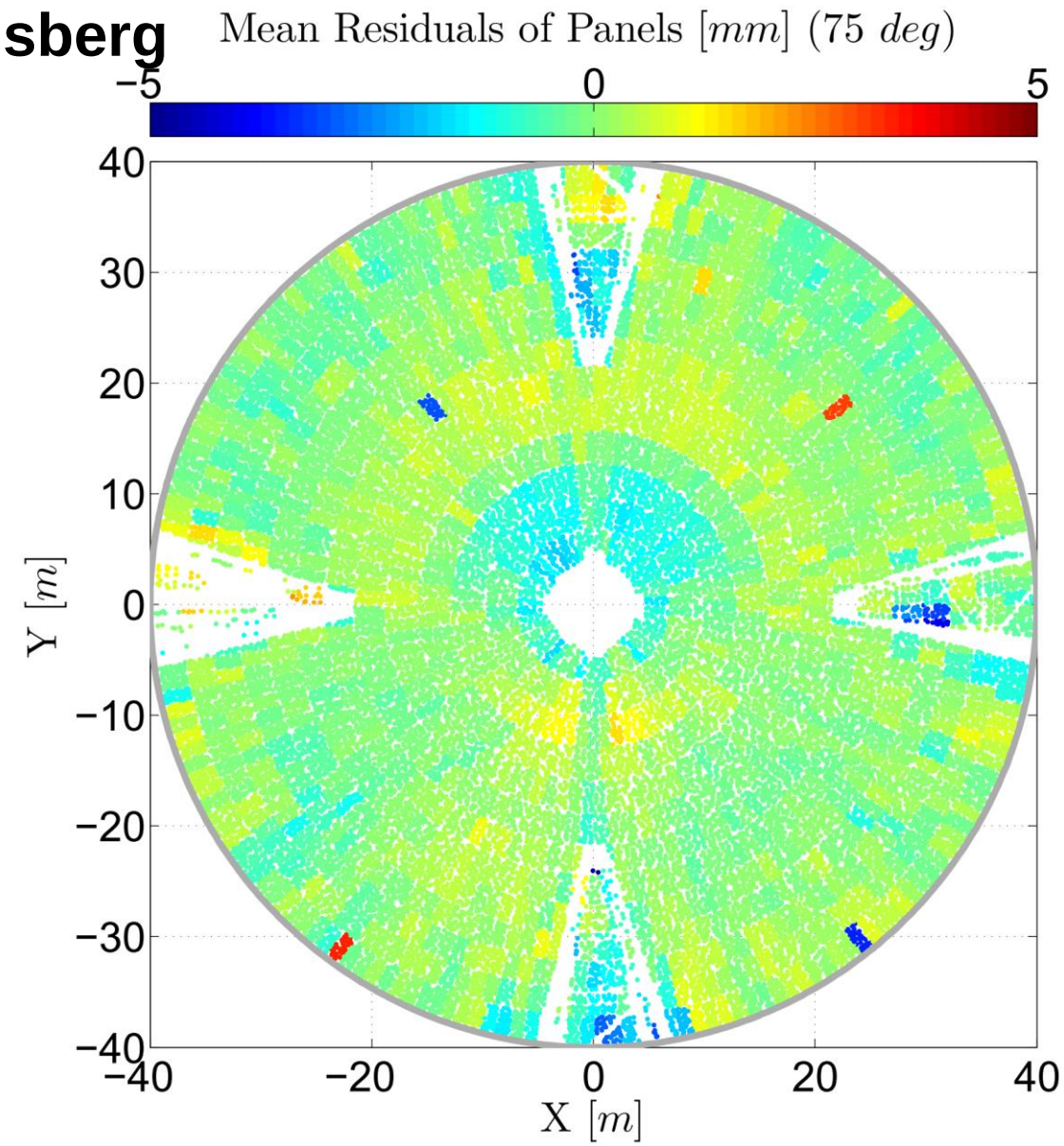


Final focal length decreases

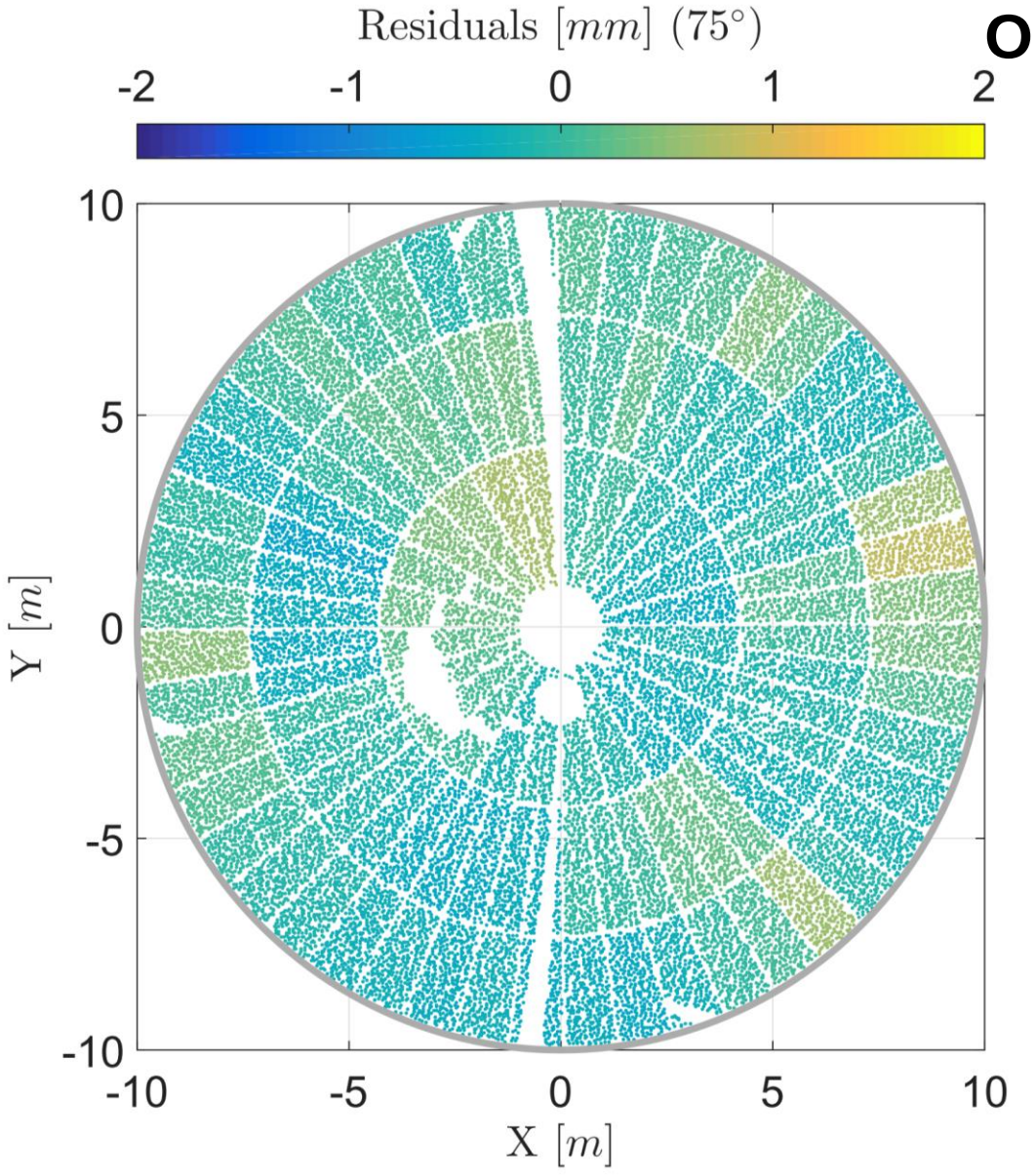


Final local deformations

Effelsberg



Onsala



Conclusion

- Focal length variations of up to 23 mm

- High-accuracy inspection of large object feasible with terrestrial laser scanner, but
  - **Systematic errors larger than random ones**
  - **Misalignment of laser scanner has to be taken into account**

- **Scanning in two faces + in-situ calibration of scanner improves inspection**

… Knowledge about sensor needed

- Transferable to other laser scanners and other objects

Still work to do…

Thanks for your attention!

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- Holst, C. et al. (2014): Aiming at self-calibration of terrestrial laser scanners using only one single object and one single scan, J. Appl. Geodesy, 8 (4), S. 295-310
- Holst, C. et al. (2015): Improved area-based deformation analysis of a radio telescope's main reflector based on terrestrial laser scanning, J. Appl. Geodesy, 9 (1), S. 1-14
- Holst, C. et al. (2017): Terrestrial laser scanner two-face measurements for analyzing the elevation-dependent deformation of the Onsala Space Observatory 20-m radio telescope's main reflector in a bundle adjustment, Sensors, 17 (8), 1833