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# Measuring Focal-Length Variations of VGOS-Telescopes Using Unmanned Aerial Systems

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# VLBI Radio Telescopes...

- Disturbing forces affect radio telescope main reflector
  - Temperature / wind / insolation
  - Snow load / dead load of dish
- Deformations of main reflector impair receiving properties
  - Form stability of surface / stability of focal length
  - ... and variations in time

- VGOS specifications in general
  - More compact design / Faster movements
  - Improved main reflector design (ring focus paraboloid)
- Accuracy requirements:
  - Residuals of surface $< 200\ \mu m$ (RMS)
  - Focal length $< 300\ \mu m$ (RMS)

# Close Range Photogrammetry...

Photogrammetric markers for adjusting the panels of the main reflector

- $\ll 50\ \mu m$ for discrete marked points
- contact-free observation strategy

Crane is necessary

# UAS and Close Range Photogrammetry...

Unmanned aerial system

- Unmanned aerial vehicle (UAV, drohne) instead of crane
- Consumer camera Sigma DP3 Merrill (with Foveon chip for full color information; weight 380 g)
- gimbal-mount below UAV for camera
- Remote control via ground-based station
- Rechargeable batteries

# UAS for Photogrammetry...

Photogrammetric coded markers

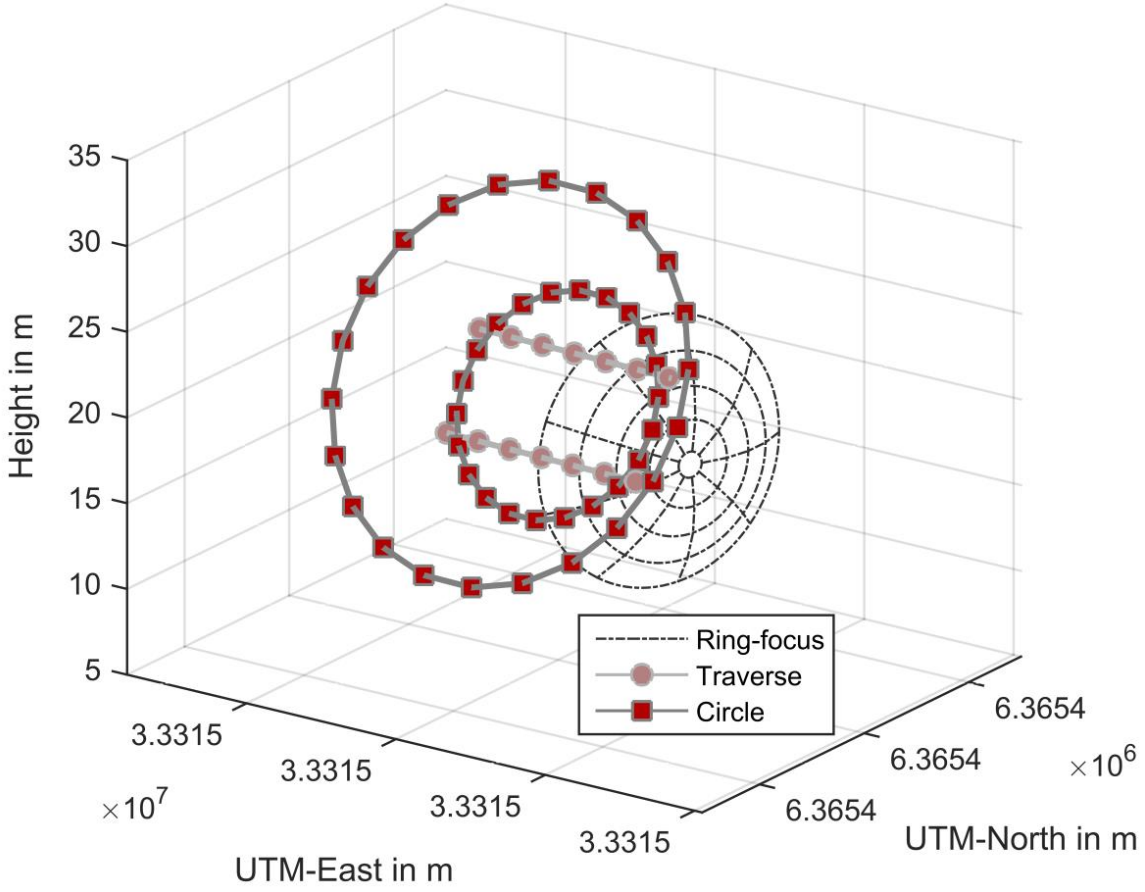
- 60 markers on the surface of the telescope
- Six calibrated scale bars
- Coordinate cross for preliminary orientation of the pictures

# UAS and Close Range Photogrammetry...

Flight plan

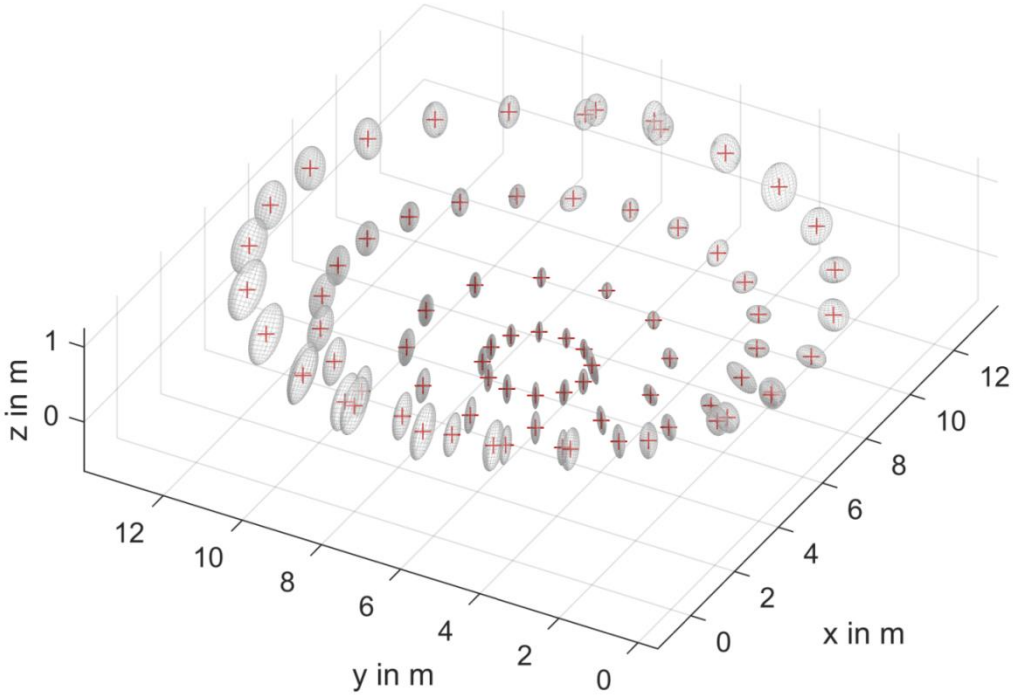
- Waypoints of UAV
- Trigger points for camera to take pictures

- Two circles and two traverses per telescope position
- Altogether ten different elevation positions
- Each elevation position two times
- Flight time about 25 min



# Results from Bundle Adjustment...

- In situ calibration
- Bundle adjustment of about 150 pictures for each elevation position
- Over 500 connecting points (markers, screws, etc,) for each elevation position
- Outlier detection during bundle adjustment




*Confidence ellipsoides for 40° elevation position (only markers)*

# Results from Bundle Adjustment...

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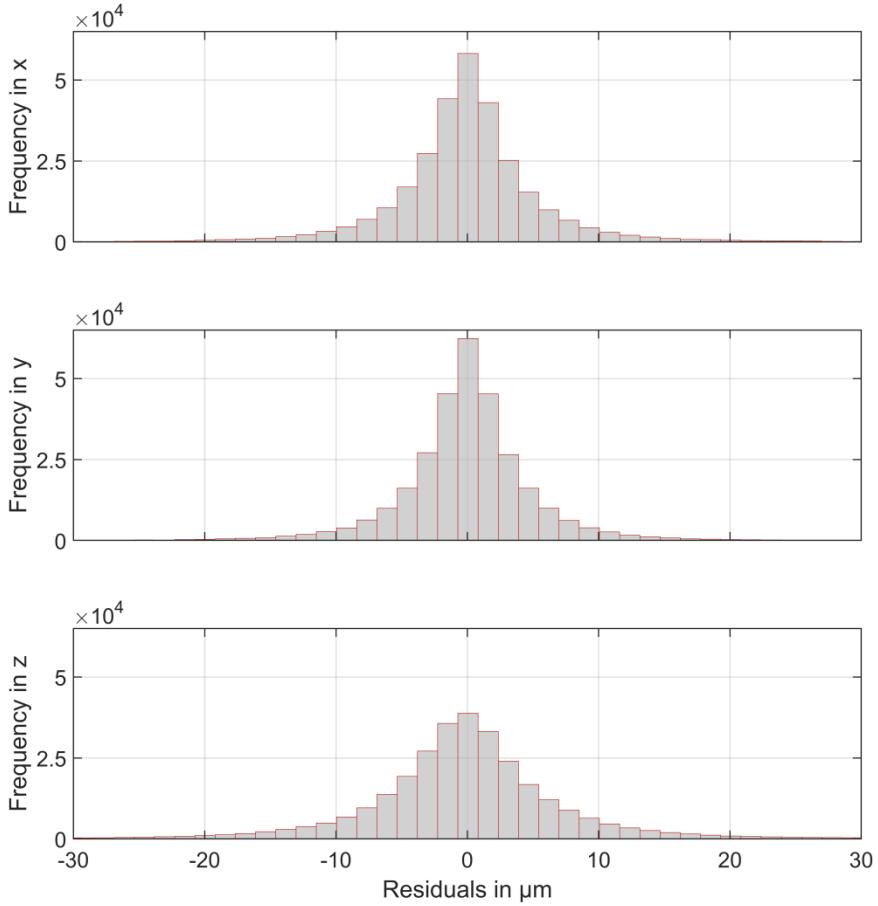
- Formal error 10 µm
- Over all uncertainty 80 – 120 µm



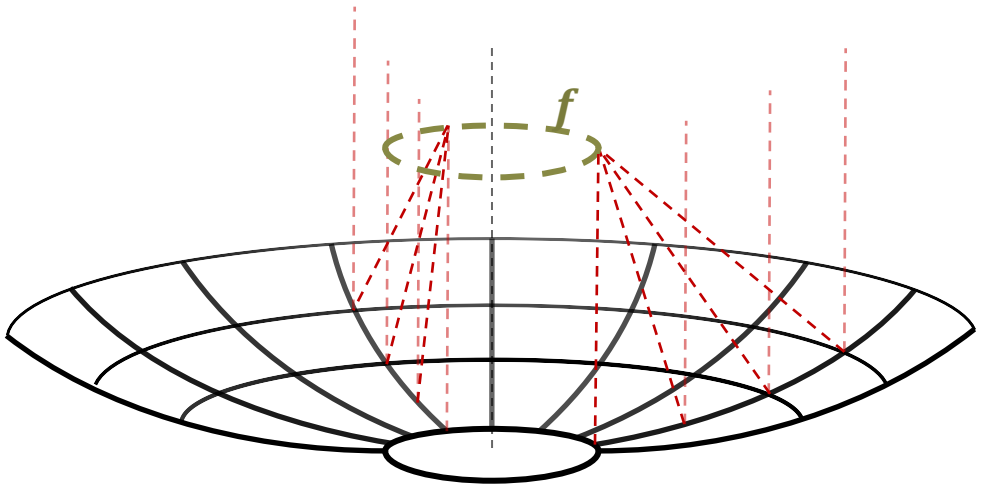

*Residuals of markers over all elevation positions*

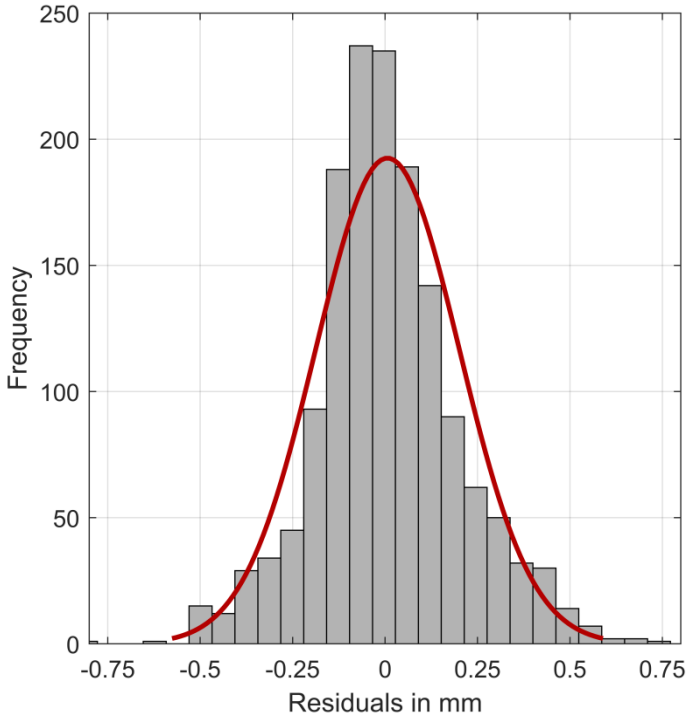
# Results from Ring-Focus Paraboloid Fitting...

Rotational symmetric ring-focus paraboloid in canonical form

$$a^2\left(\left(x_i - rn_{x,i}\right)^2 + \left(y_i - rn_{y,i}\right)^2\right) = z_i$$

with estimated focal length $f = \frac{1}{4a^2}$



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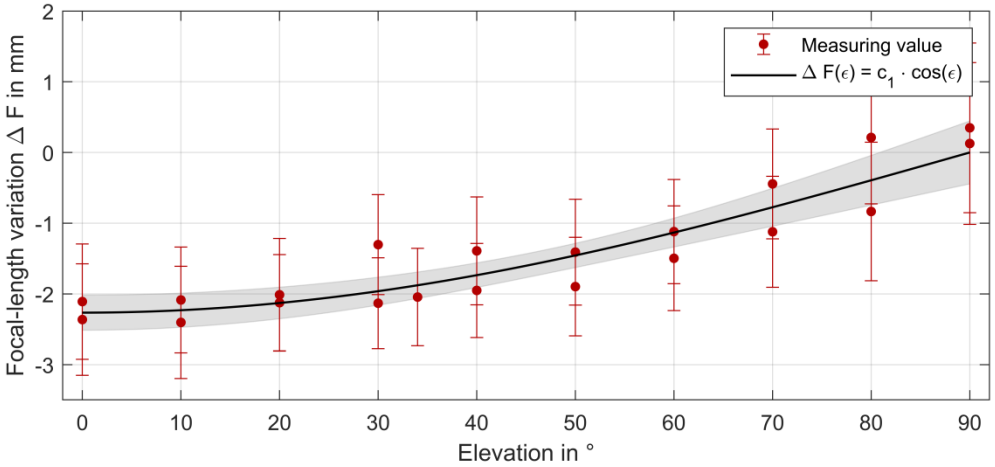


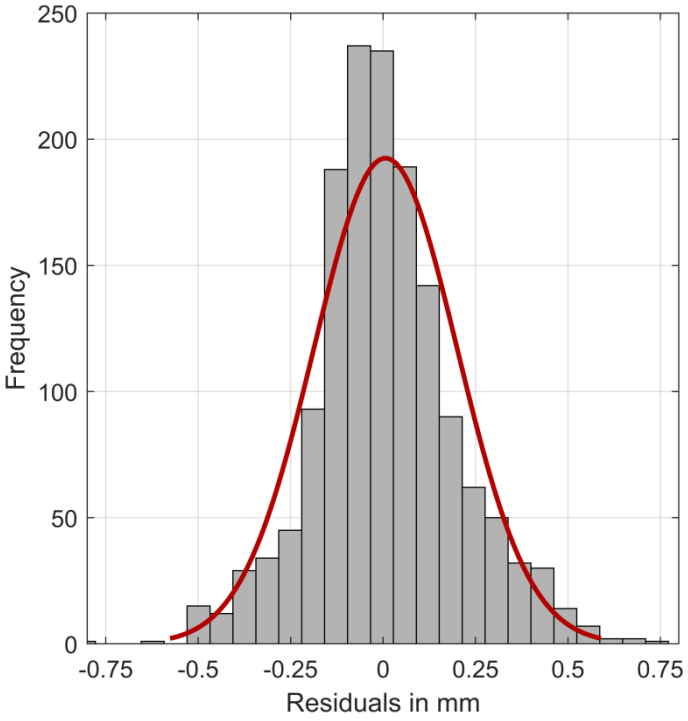

# Conclusion...

First investigation of a VGOS-specified VLBI radio telescope

- Proof of feasibility: UAS for photogrammetric survey of a radio telescope surface
  - Less effort than using a crane
  - No further deformations occure due to additional weight

- Estimation of focal length variation due to elevation position
  - Focal length variation of about $2\ \mathrm{mm}$ is about ten times smaller than for conventional radio telescopes

# Thank you for your attention…