Alignment of Radio Telescopes

with Photogrammetry

Date: 23.11.2016

Outline

1. About sigma3D

2. Overview Radio Telescopes worldwide

3. Requirements / Accuracy Radio Telescopes

4. Measurement & Evaluation - Surface Alignment

5. Measurement & Evaluation - Various Elevation

6. Results & Summary

Mobile 3D Measurement Service

- ✓ Mobile 3D Measurement Service
- ✓ Scanning and Digitizing
- ✓ Verfication and Calibration tooling machines & CMMs
- ✓ Software development for 3D measurement tasks

- ✓ Since 8 years Radio Telescope Alignment

Design types Radio Telesopes

The performance of an antenna depends on several parameters:

- Diameter of the Main-Reflector -> Sensitivity / Resolution
- Surface accuracy / receiver equipment -> frequency range
- Turnable or static -> Application areas

Arecibo, Puerto Rico, 305m

Pico Veleta 30m, Spain

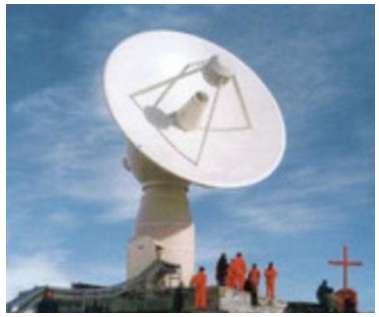
Application for Radio Telescopes & Antennas

Sat-data communication (data, pictures)

- d=1,8m to 13m (mostly under 10m)
- frequencies: S- and C-Band, 2-6GHz > RMS 2-3mm

Satellite control

- d= 6m to 18m
- frequencies: Ku-Band, 10,7 - 12,75GHz



Geodesy / Metrology

- d=13m to 35m
- frequencies: L- and M-Band, 40 - 100GHz

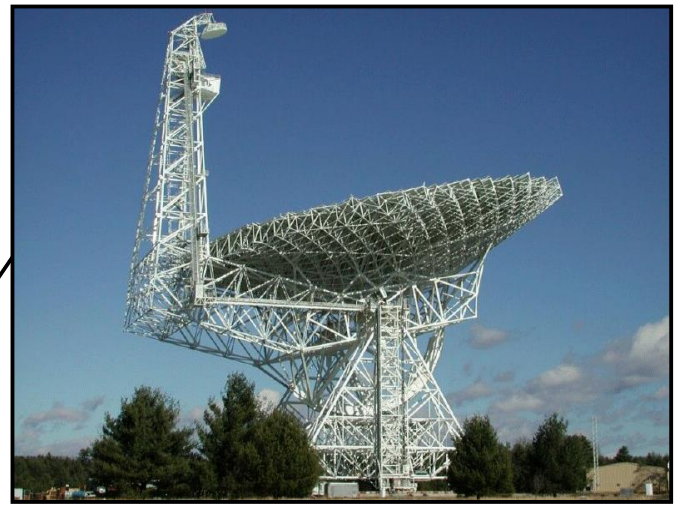
Geodesy / Deep-Space Missions / Astronomy

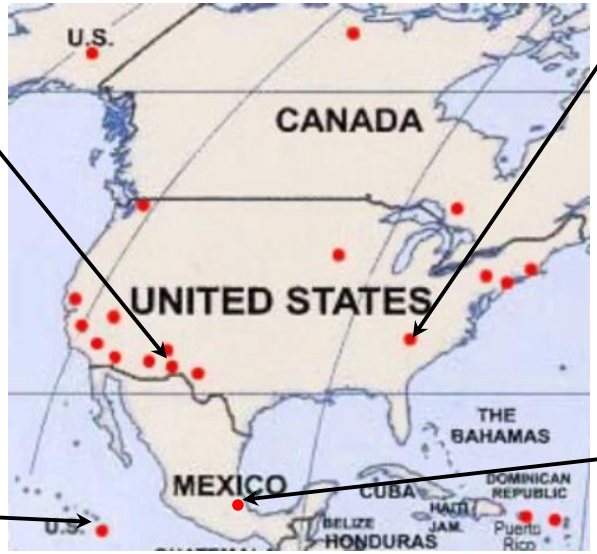
- d=35m to 100m
- frequencies M-Band, up to 200GHz

Radio Telescopes in America

Very Large Array, New Mexico. 27 x 25m

Green Bank Telescope, 110m x 100m





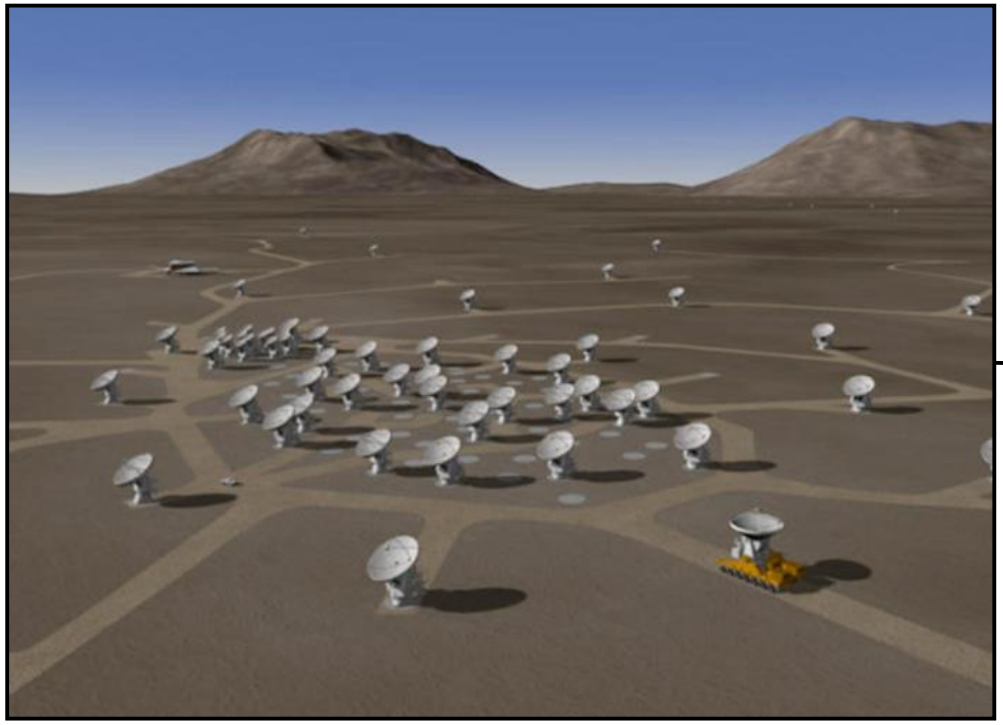
Mauna Kea, 25m, Hawaii

LMT, Mexico, 50m

The biggest Radio Telescope project

ALMA – Atacama Large Milimeter Array

- Location Atacama desert, Chile, 5000m o. sea-level
- 66 single Telesopes (54 x 12m und 12 x 7m)



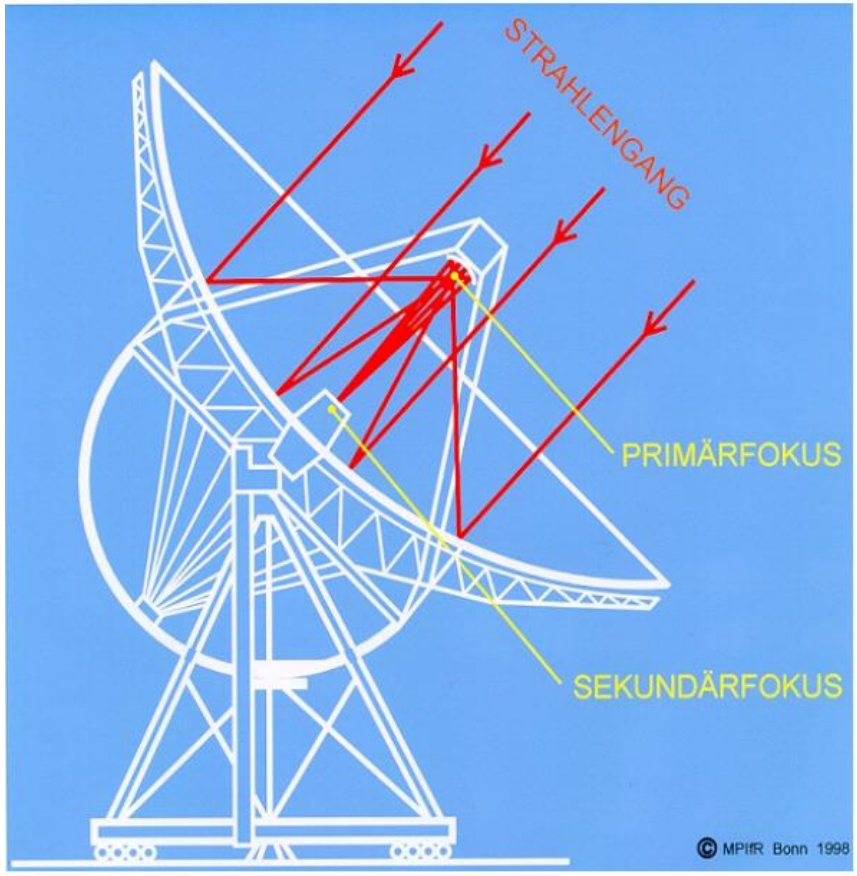
Radio Telescopes - Europe

Sardinia Radio Telescope, actual technology

Effelsberg, Germany, d=100m

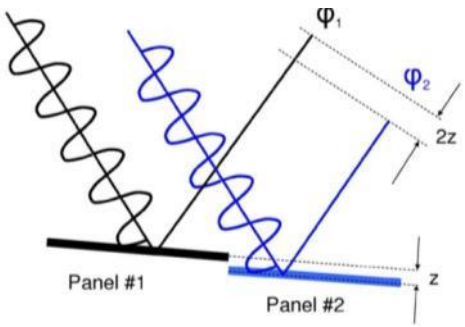
- ✓ Multiple receivers
- ✓ Sub-Reflector driven by Hexapod
- ✓ Active Surface of the Main-Reflector

3D Measurement Challenge



Efficiency depends on the accuracy of the panel surface.

The surface accuracy should be about **1/20** of the wavelength.



For the different frequencies, this means a surface accuracy of:

- X-Band (9 GHz, 33 mm) -> 1,65 mm (RMS)
- Ka-Band (32 GHz, 9,2 mm) -> 0,45 mm (RMS)

Sardinia Radio Telescope - SRT

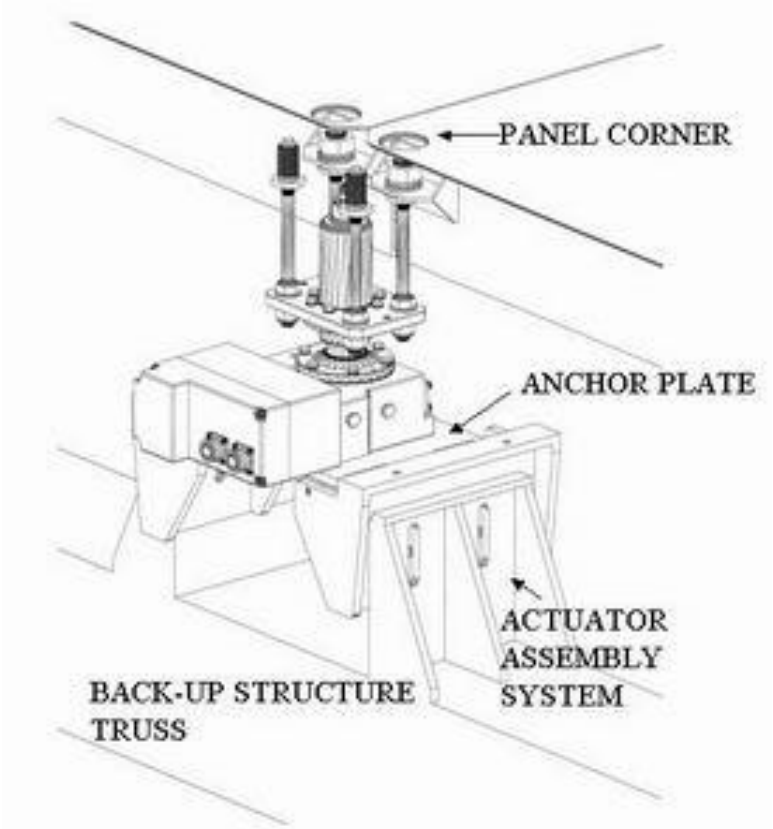
Technical Data SRT

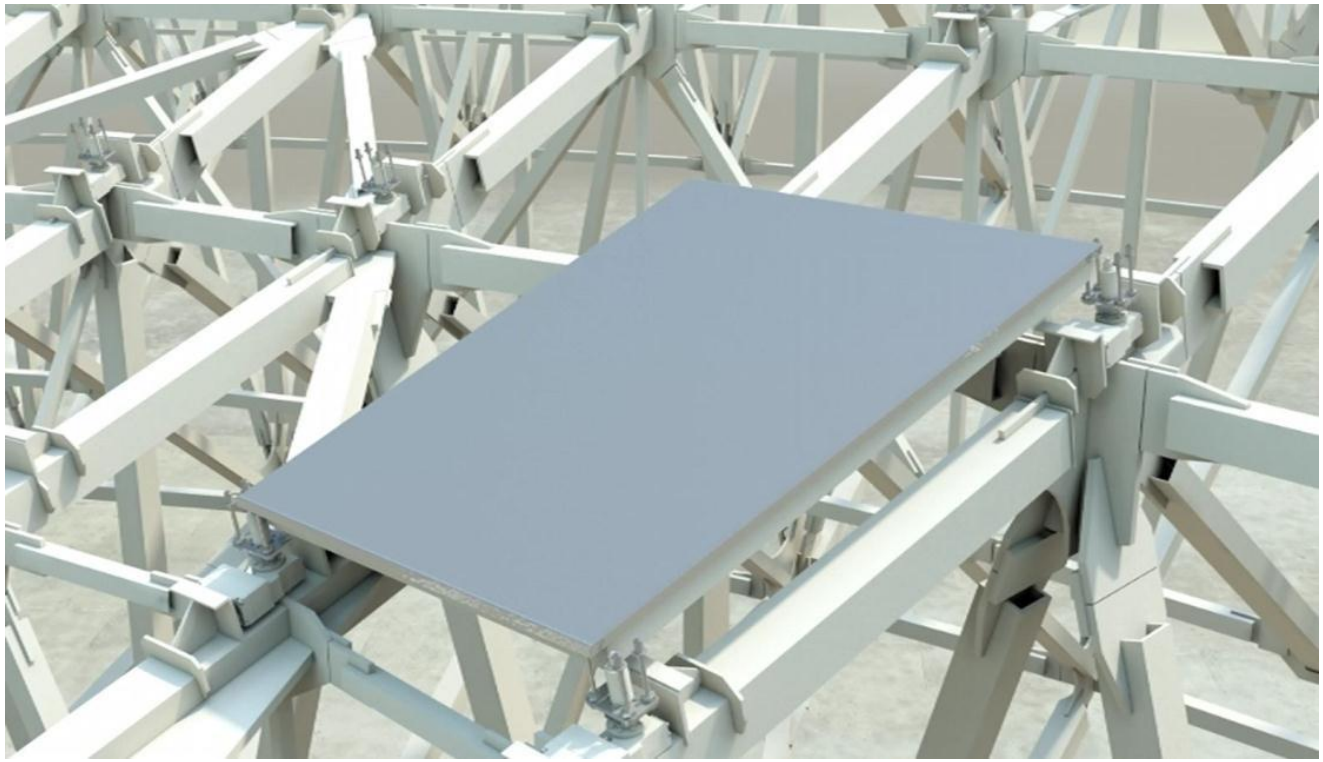
- 3rd largest Radio Telescope in Europe
- Main Reflector **64 m diameter**
- 1008 panels
- Sub-Reflektor 7,9 m diameter
- Gregorianische setup (concave Sub-Reflector)
- **Active Surface**

- Surface accuracy RMS 500 µm (guaranteed by the manufacturer)

- Need deformation information in six different elevation positions for Active Surface (look-up table)

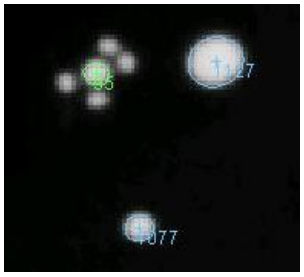
Active Surface





Measurement & Evaluation process

Image acquisition



x’ y’
2D coordinates

Calculate 3D coordinates

XYZ
3D coordinates

Determinate Surface deviation

Best-Fit Parameters
Δh

Components Measurement System

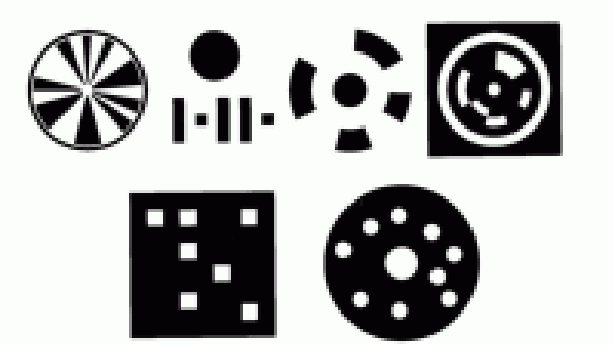
A modern photogrammetric measurement system consists of:

- ✓ 24 MPixel high resolution digital camera Nikon D3X
- ✓ Personal computer (Notebook) with analysis software
- ✓ Calibrated carbon fibre scale bar
- ✓ Coded targets to identify identical points during image processing

Coded targets to identify identical points

Coded targets are targets that serve to signal points in object space and are provided with a code.

This code number is a point at which the item is automatically identifiable.



Different codes available

Accuracy for Photogrammetry

In general, the following general approach applies to the measurement accuracy (Sxyz):

Sxyz = q * m * Sx‘y‘

1-σ value!

q = Quality factor for the geometry of the recordings
0.4 to 0.8 with a good configuration, 2 for bad configuration
m = Image scale
Sx‘y‘ = Image measurement accuracy

For panel alignment following theoretical results estimated:

- best-case Sxyz = 0,7 * 1200 * 0,06 µm -> 50 µm -> Surface RMS 175 µm
- worst-case Sxyz = 1 *1500 * 0,20 µm -> 300 µm -> Surface RMS 1050 µm
- average Sxyz = 0,8 * 1400 * 0,10 µm -> 112 µm -> Surface RMS 392 µm

Reachable: **Only with stable measurement conditions!**

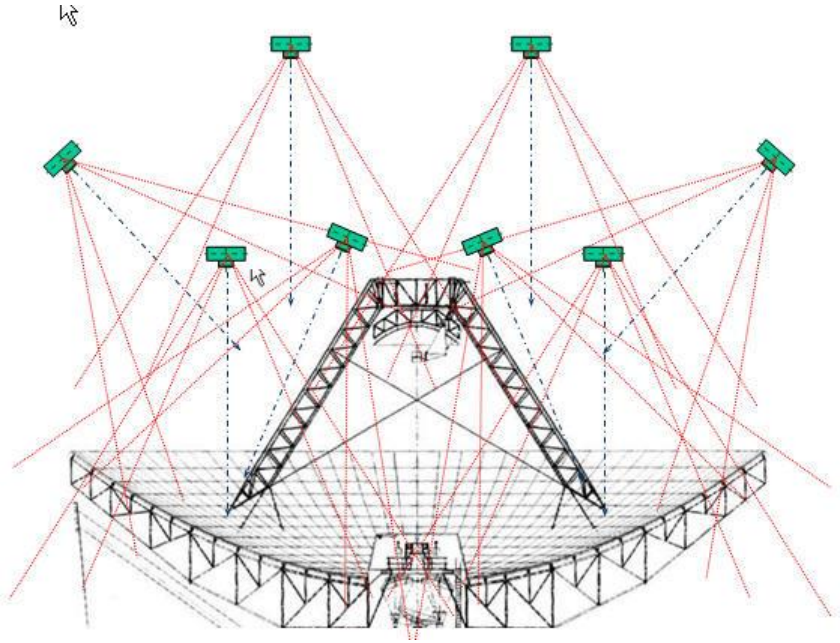
Camera Positions

“Best" camera positions for a high measurement accuracy have been defined apriory.

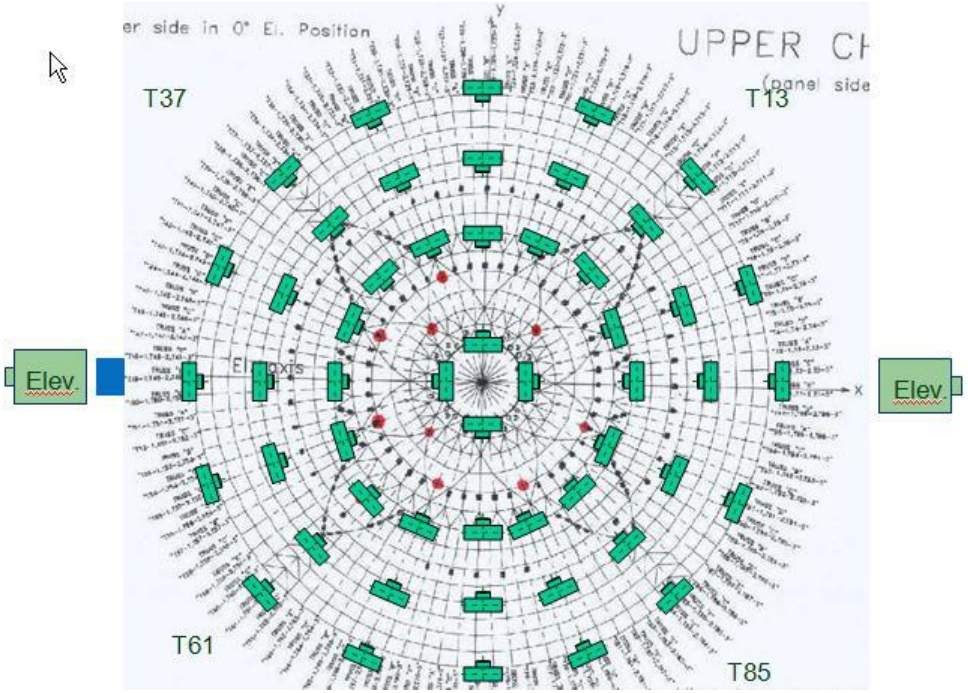
50 different positions

3-4 images in different orientations

Side view



Top view

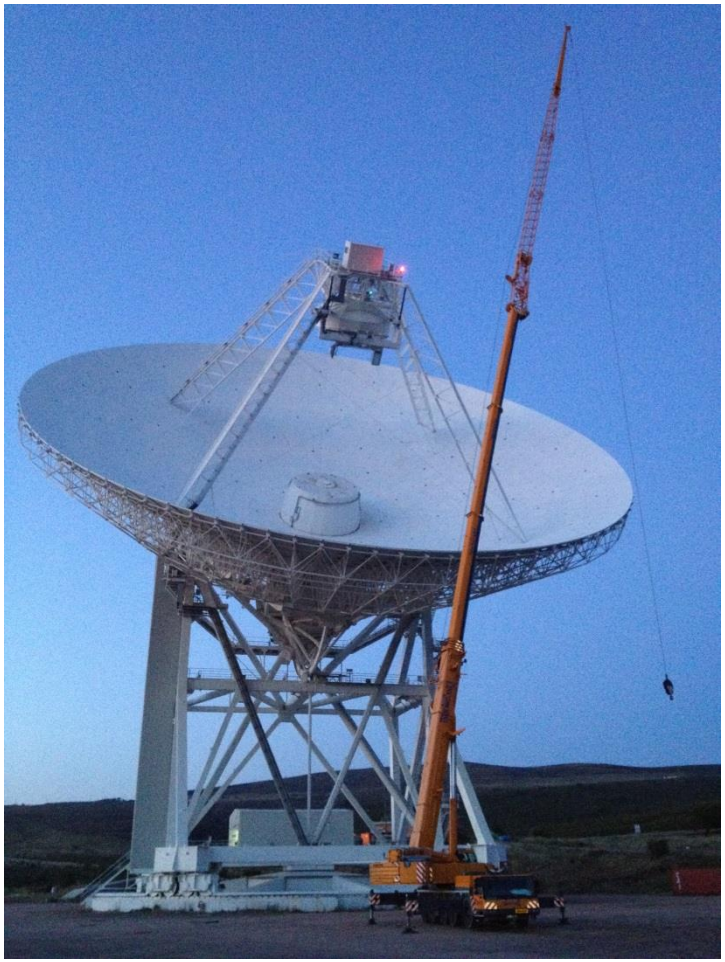


Platform options

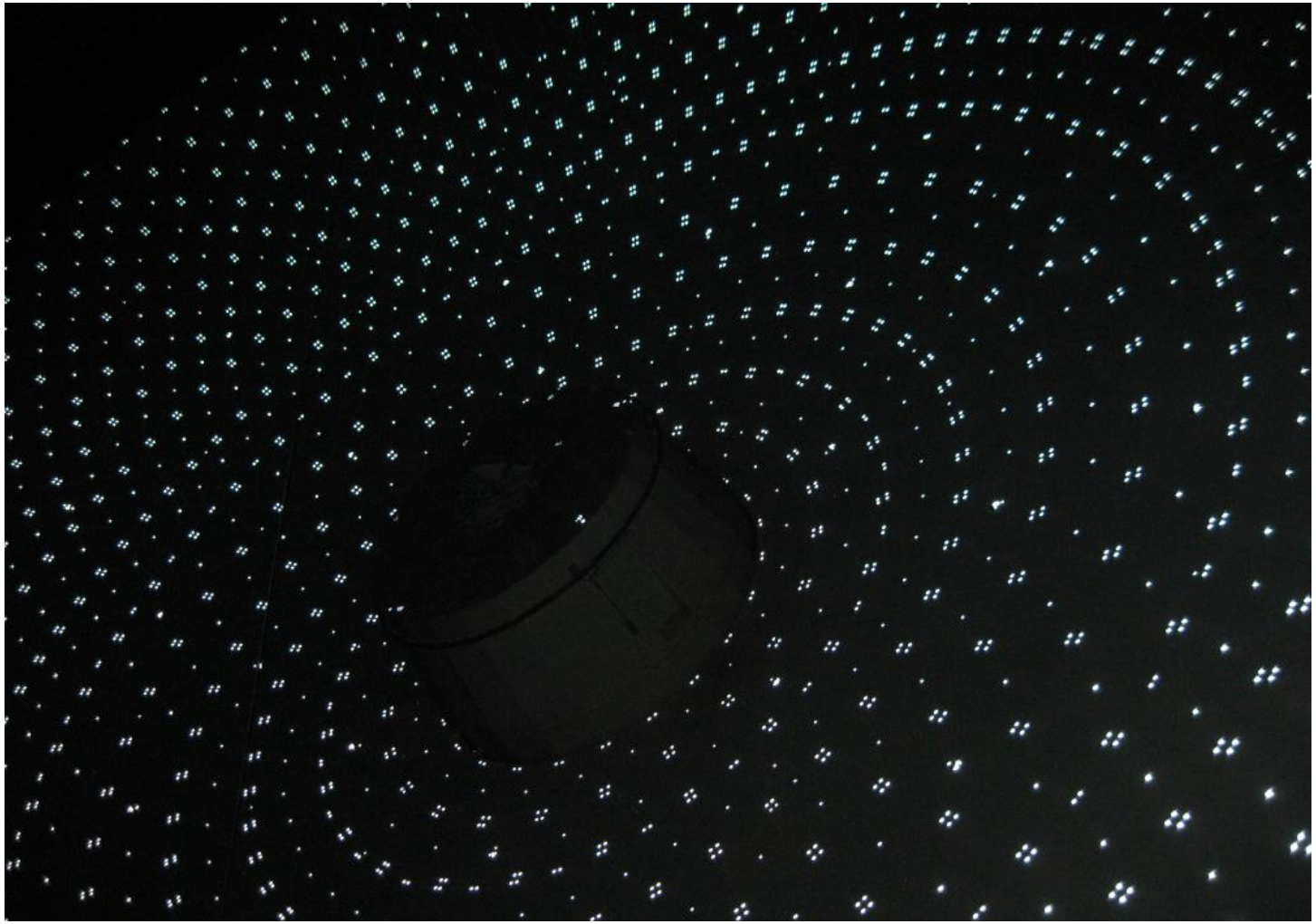
UAV
(unmanned aerial vehicle)

or

mobile crane

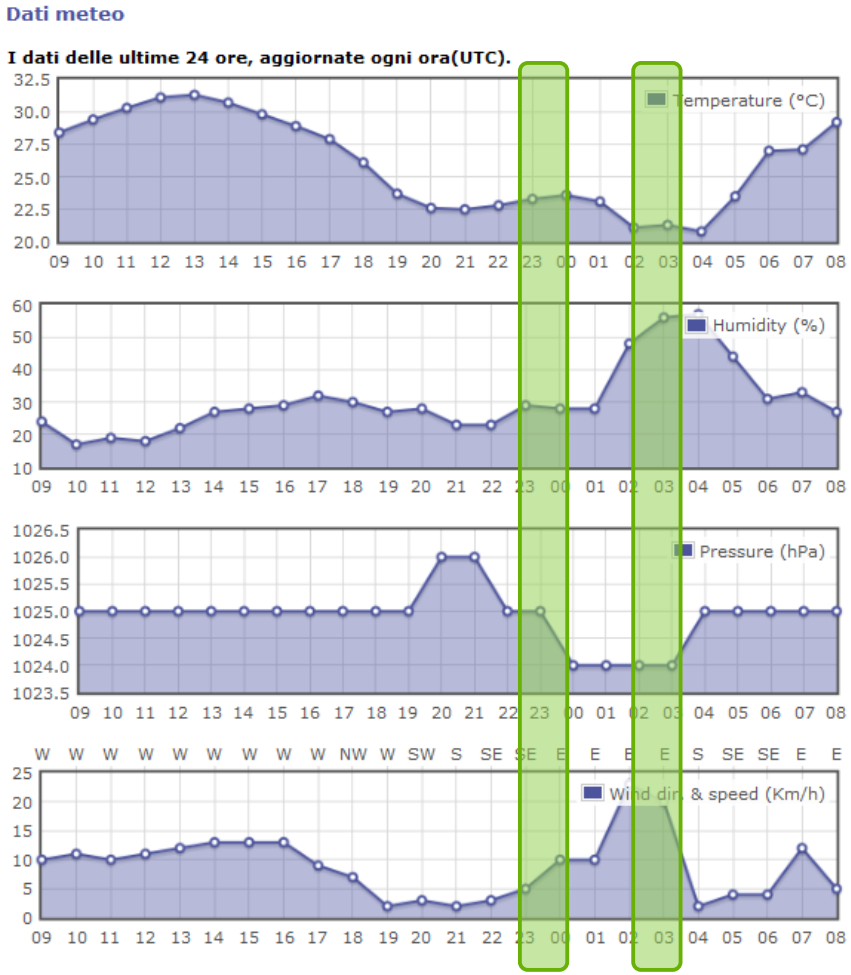


Measuring during night time



up to 300 pictures
5040 points
4x corner
1x center

Meteorological data



Meteo-station data

1. Temperature
2. Humidity
3. Pressure
4. Wind speed

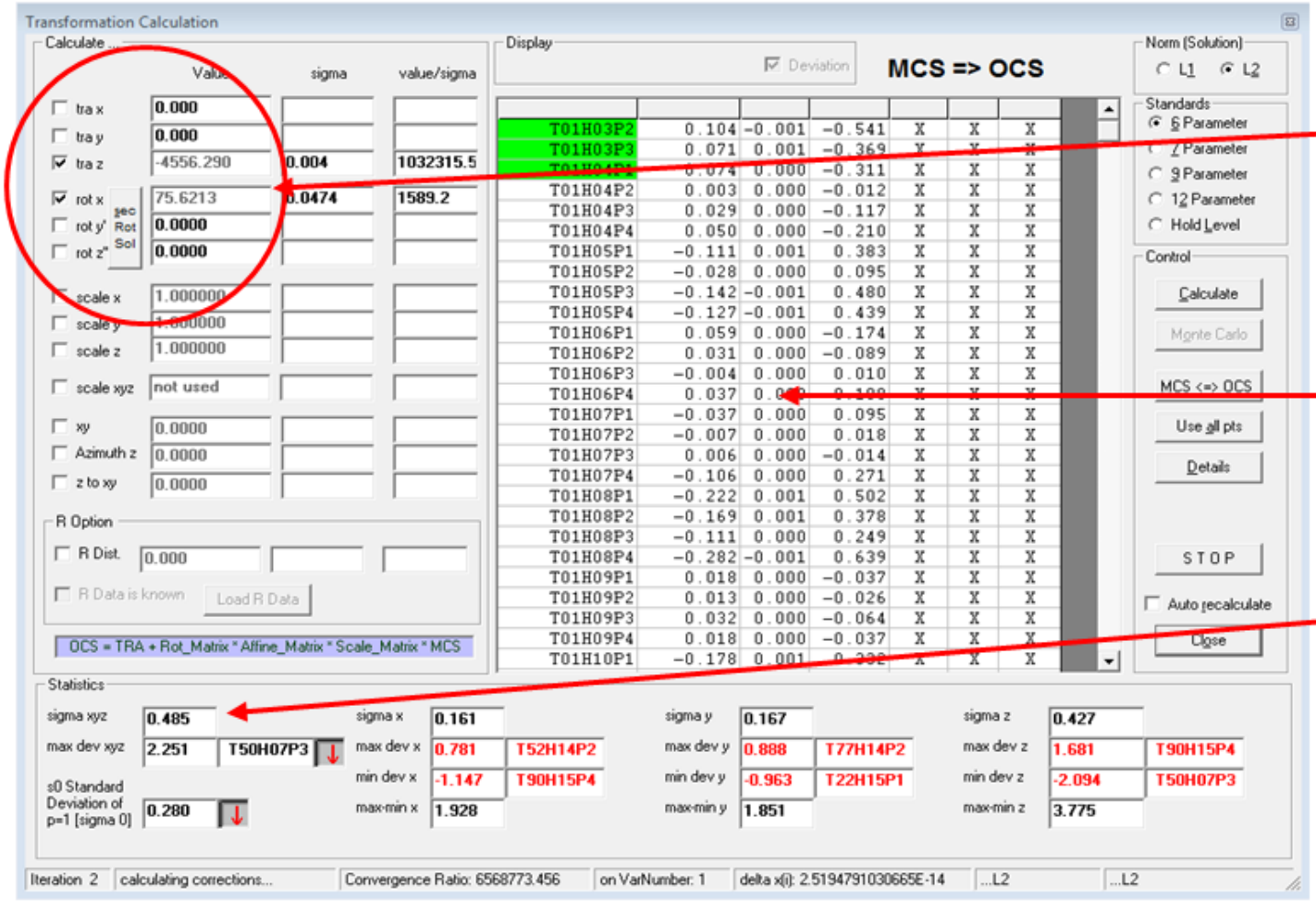
- 6 hours “stable“ conditions during night-time
- measurements over 80% humidity not necessary (no reflection from Retro-targets)
- sometimes very high wind speed

3D coordinate calculation with Bundle-Adjustment (AICON Software)

Statistik der Ausgleichung				
Sigma 0:			0.00057	
Median: [mm]	0.03	0.03	0.03	
RMS: [mm]	0.05	0.05	0.03	

Ergebnis der Ausgleichung								
Nr.	X [mm]	Y [mm]	Z [mm]	Sx [mm]	Sy [mm]	Sz [mm]	Strahl.	Aktiv
1226	3284.02	-3372.35	1339.80	3.99	9.63	2.34	3	☐
1223	1037.56	1065.57	3780.91	0.59	0.11	0.07	4	☐
31	-2409.45	-2469.55	2312.29	0.12	0.08	0.09	5	☑
41	-2296.80	2389.89	2455.04	0.09	0.08	0.09	10	☑
24	1273.49	-1295.97	3519.03	0.08	0.11	0.06	7	☑
40	-2206.31	2127.69	2645.18	0.10	0.06	0.07	8	☑
42	-1442.68	1358.99	3467.31	0.10	0.05	0.06	8	☑
44	-1209.09	1204.82	3608.59	0.10	0.06	0.06	6	☑
1120	5941.15	2566.27	2404.03	0.10	0.05	0.05	23	☑
1213	6459.76	96.01	2397.05	0.10	0.03	0.05	24	☑
1122	6003.03	2397.56	2398.19	0.10	0.05	0.04	26	☑
1212	6464.67	-84.13	2400.77	0.10	0.03	0.05	25	☑
1173	2388.65	-6000.75	2397.65	0.05	0.10	0.04	36	☑
1179	4506.60	-4633.90	2401.69	0.07	0.08	0.04	29	☑
1181	89.82	-6467.01	2402.81	0.03	0.11	0.04	38	☑
1180	4635.22	-4501.49	2399.46	0.08	0.08	0.04	30	☑
1185	-4512.01	4635.39	2394.05	0.08	0.08	0.05	23	☑
1184	-4639.77	4507.23	2393.83	0.08	0.08	0.05	23	☑
1172	2559.01	-5939.92	2404.17	0.05	0.10	0.04	37	☑
11	2153.71	2059.81	2689.59	0.07	0.07	0.07	6	☑
1182	-89.48	-6462.20	2399.28	0.03	0.11	0.04	39	☑
1157	-4511.10	-4634.07	2398.58	0.07	0.08	0.04	34	☑
1197	-2390.64	-6005.99	2399.15	0.05	0.10	0.04	31	☑
1105	-4635.72	-4502.58	2395.20	0.07	0.08	0.04	35	☑
1196	-2556.29	-5936.52	2398.48	0.05	0.10	0.04	30	☑

Determinate surface deviations with 4032 points (sigma3D Software)



Best-Fit Parameter

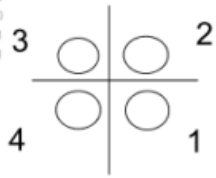
Abweichungen in X, Y und Z

RMS Wert der Kontur

6 Alignment Teams

ID	Abweichung [mm]	NOK
T13H03P2	0.00	0
T13H03P3	0.00	0
T13H04P1	0.13	1
T13H04P2	-0.12	1
T13H04P3	0.00	0
T13H04P4	0.41	1
T13H05P1	0.44	1
T13H05P2	0.45	1
T13H05P3	0.25	1
T13H05P4	0.25	1
T13H06P1	0.00	0
T13H06P2	0.00	0
T13H06P3	0.00	0
T13H06P4	0.00	0
T13H07P1	0.16	1
T13H07P2	0.12	1
T13H07P3	0.00	0
T13H07P4	0.38	1
T13H08P1	0.28	1
T13H08P2	0.00	0
T13H08P3	0.25	1
T13H08P4	-0.14	1
T13H09P1	0.00	0
T13H09P2	0.00	0
T13H09P3	0.00	0
T13H09P4	0.00	0
T13H10P1	0.16	1
T13H10P2	0.36	1
T13H10P3	0.30	1
T13H10P4	0.29	1
T13H11P1	0.29	1
T13H11P2	0.00	0
T13H11P3	0.14	1
T13H11P4	0.00	0
T13H12P1	0.17	1
T13H12P2	0.00	0
T13H12P3	-0.15	1
T13H12P4	0.16	1
T13H13P1	0.34	1
T13H13P2	0.00	0
T13H13P3	0.00	0
T13H13P4	0.19	1
T13H14P1	0.00	0
T13H14P2	0.14	1
T13H14P3	0.00	0
T13H14P4	0.00	0
T13H15P1	-1.08	1
T13H15P4	-1.01	1

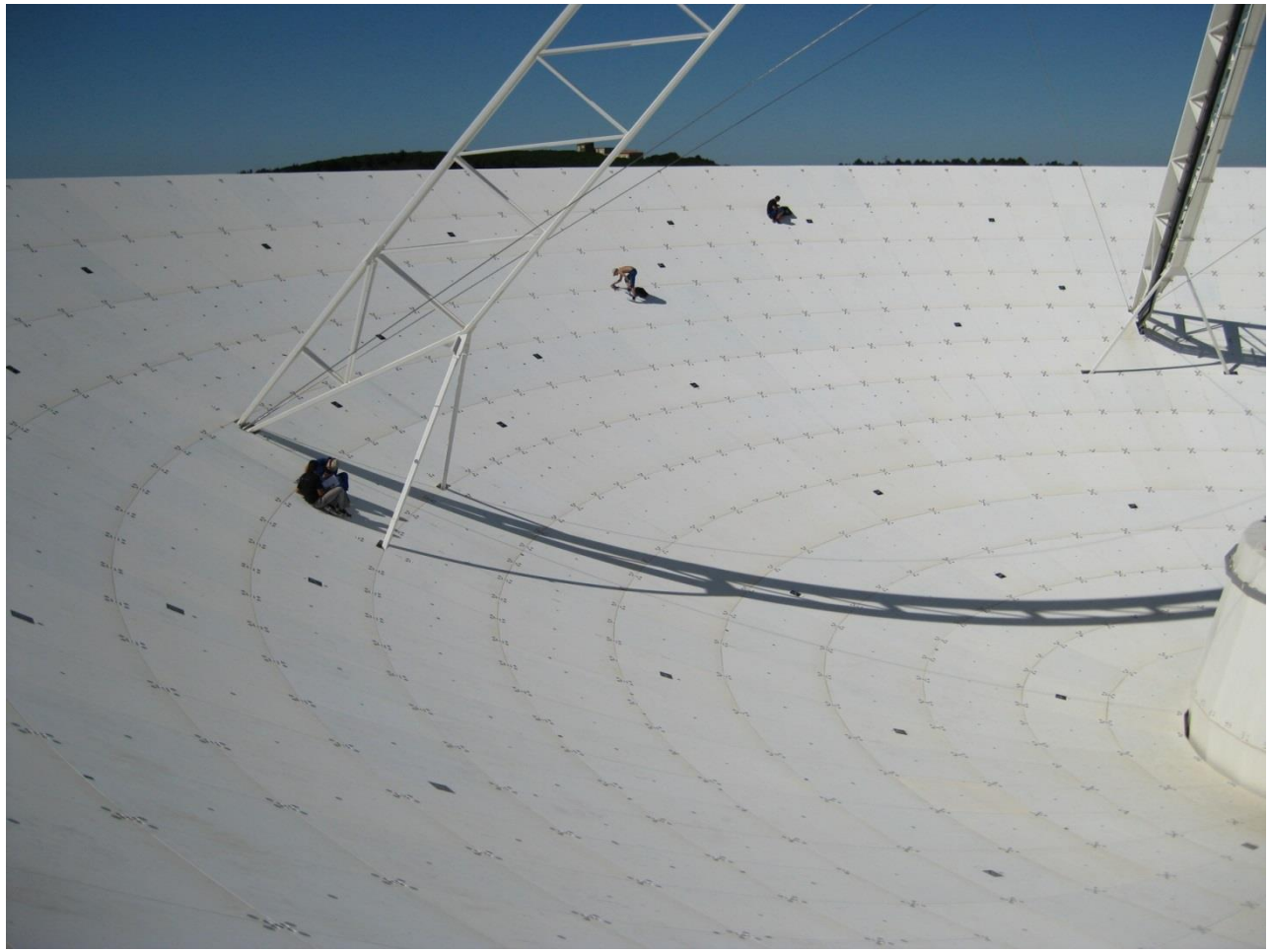
ID	Abweichung [mm]	NOK
T14H07P2	0.00	0
T14H07P3	0.00	0
T14H08P1	-0.19	1
T14H08P2	0.21	1
T14H08P3	0.27	1
T14H08P4	0.54	1
T14H09P1	0.00	0
T14H09P2	0.00	0
T14H09P3	0.00	0
T14H09P4	0.00	0
T14H10P1	0.37	1
T14H10P2	0.24	1
T14H10P3	0.00	0
T14H10P4	0.39	1
T14H11P1	0.27	1
T14H11P2	0.00	0
T14H11P3	0.29	1
T14H11P4	0.39	1
T14H12P1	0.35	1
T14H12P2	0.12	1
T14H12P3	0.40	1
T14H12P4	0.00	0
T14H13P1	-0.16	1
T14H13P2	0.18	1
T14H13P3	0.20	1
T14H13P4	0.00	0
T14H14P1	0.00	0
T14H14P2	0.00	0
T14H14P3	0.00	0
T14H14P4	0.00	0
T14H15P1	0.00	0
T14H15P4	0.00	0



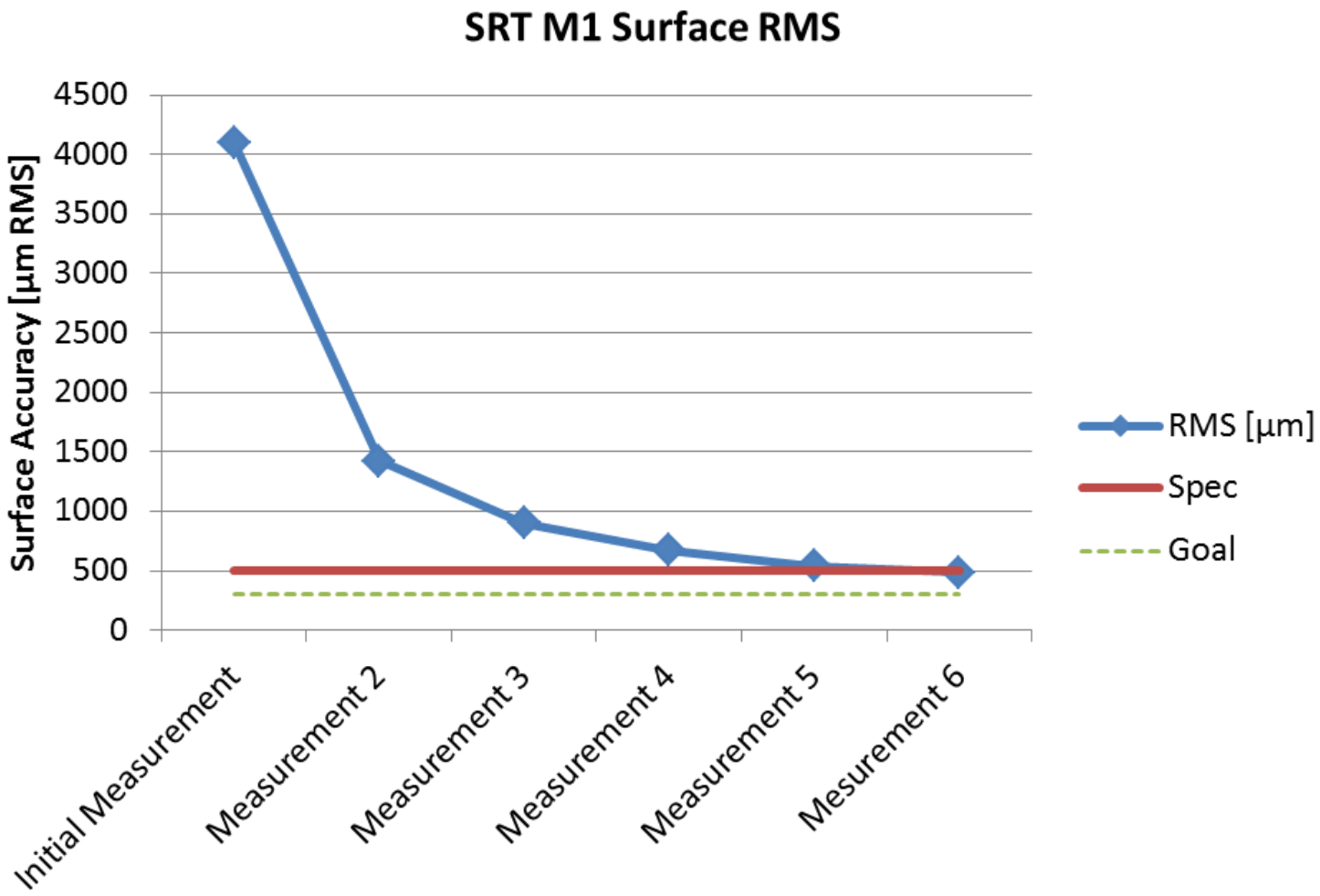
ID	Abweichung [mm]	NOK
T15H01P2	-1.16	1
T15H01P3	-1.53	1
T15H02P1	-1.24	1
T15H02P2	-1.63	1
T15H02P3	-1.38	1
T15H02P4	-0.90	1
T15H03P1	0.00	0
T15H03P2	0.13	1
T15H03P3	0.23	1
T15H03P4	0.30	1
T15H04P1	0.00	0
T15H04P2	0.19	1
T15H04P3	0.00	0
T15H04P4	0.00	0
T15H05P1	0.17	1
T15H05P2	0.18	1
T15H05P3	0.00	0
T15H05P4	0.17	1
T15H06P1	-0.28	1
T15H06P2	0.00	0
T15H06P3	-0.32	1
T15H06P4	-0.44	1
T15H07P1	0.00	0
T15H07P2	0.00	0
T15H07P3	0.00	0
T15H07P4	0.00	0
T15H08P1	0.00	0
T15H08P2	0.00	0
T15H08P3	0.00	0
T15H08P4	0.00	0
T15H09P1	0.00	0
T15H09P2	0.00	0
T15H09P3	0.00	0
T15H09P4	0.00	0
T15H10P1	0.21	1
T15H10P2	0.00	0
T15H10P3	0.15	1
T15H10P4	0.17	1
T15H11P1	0.00	0
T15H11P2	0.00	0
T15H11P3	0.00	0
T15H11P4	0.00	0
T15H12P1	0.25	1
T15H12P2	0.35	1
T15H12P3	0.33	1
T15H12P4	0.00	0
T15H13P1	0.22	1
T15H13P2	-0.16	1
T15H13P3	0.00	0
T15H13P4	0.00	0
T15H14P1	0.00	0
T15H14P2	0.00	0
T15H14P3	0.00	0
T15H14P4	0.00	0
T15H15P1	-0.20	1
T15H15P4	0.29	1

Finish Alignment within 5 days

Alignment teams	6
Number Targets (used)	4032
Number Pictures	250-300
Meas. Accuracy	130µm
RMS Surface	485µm



Alignment Iterations



Surface deviation in different elevation angles (90/75/60/45/30/15)





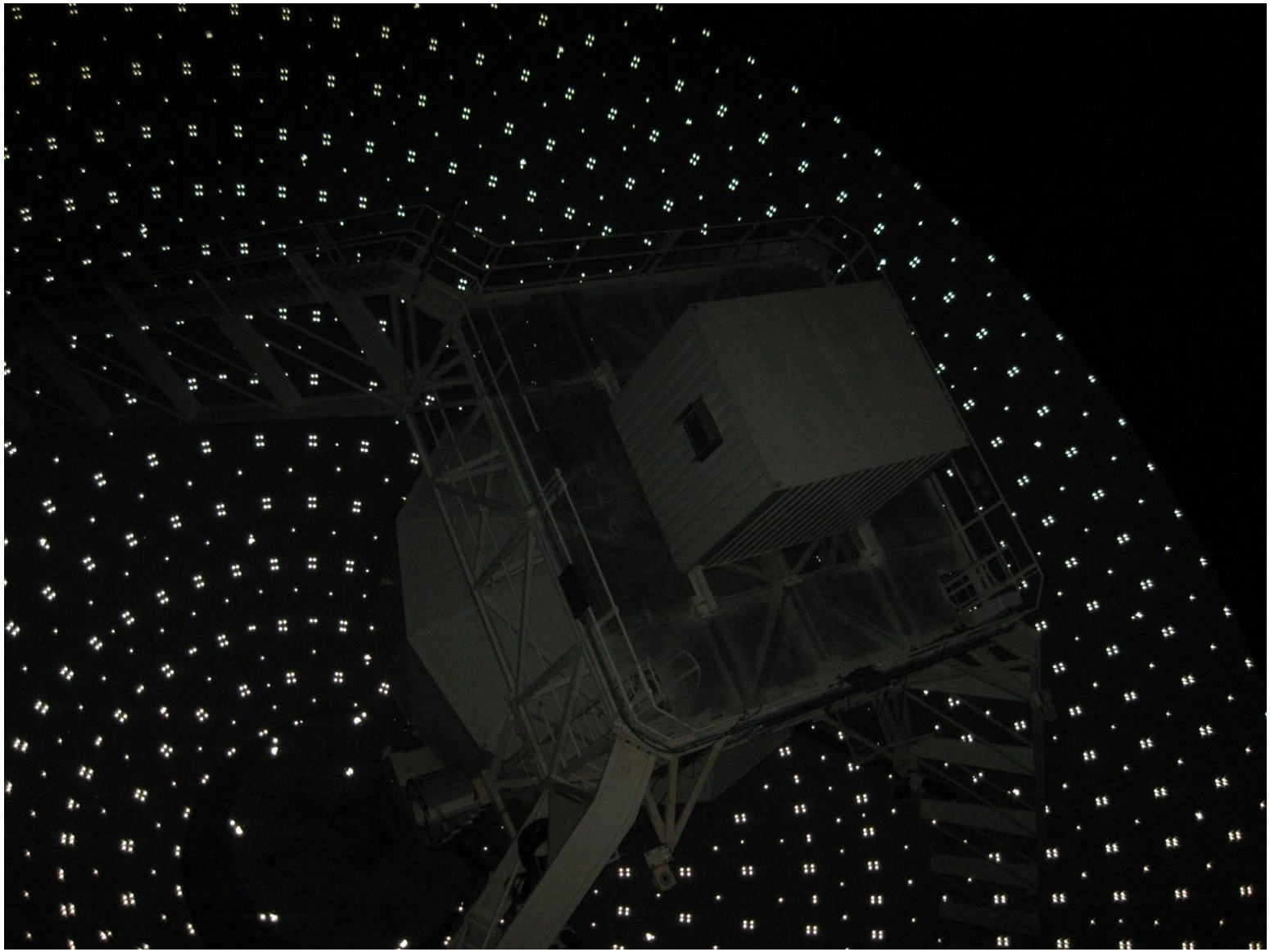

Main Reflector in various elevation (90°/75°/60°/45°/30°/15°)

All measurements in one night

Number elevation positions 6

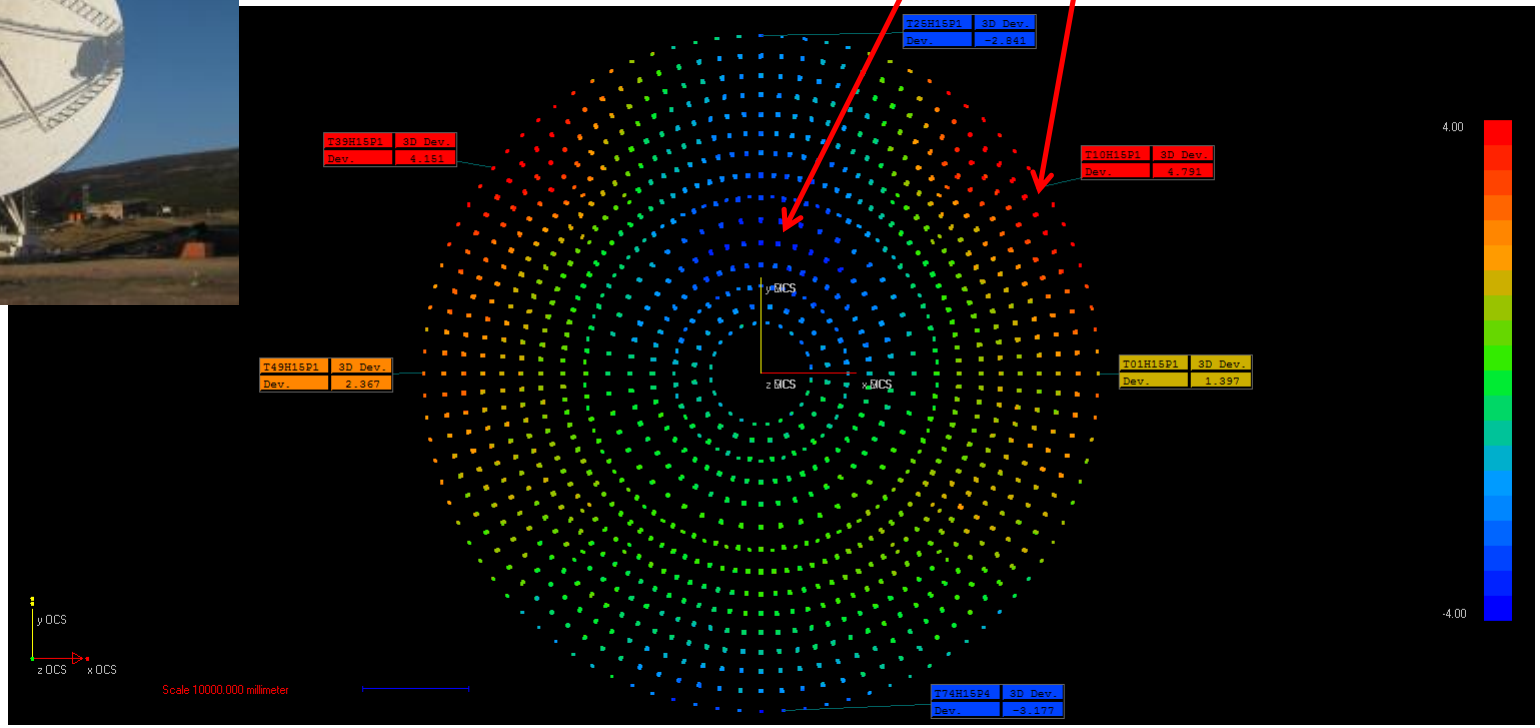
Mobile crane	110m (1 Pos.)
Number targets	4032 / 5040
Number pictures	200
Meas. Uncertainty	160 µm (1σ)

Turning Antenna in 75° und 90° azimuthal!

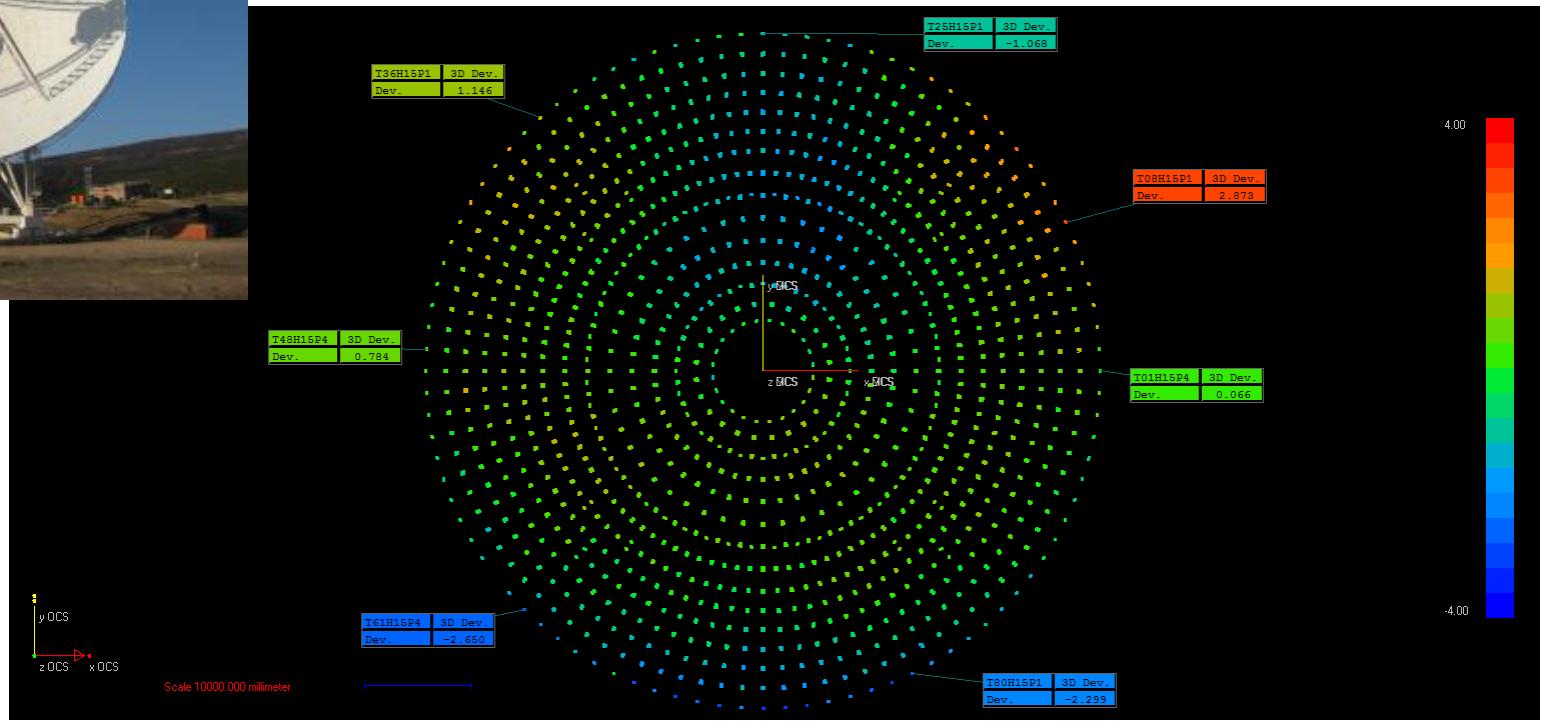


Main-Reflector in 15° elevation

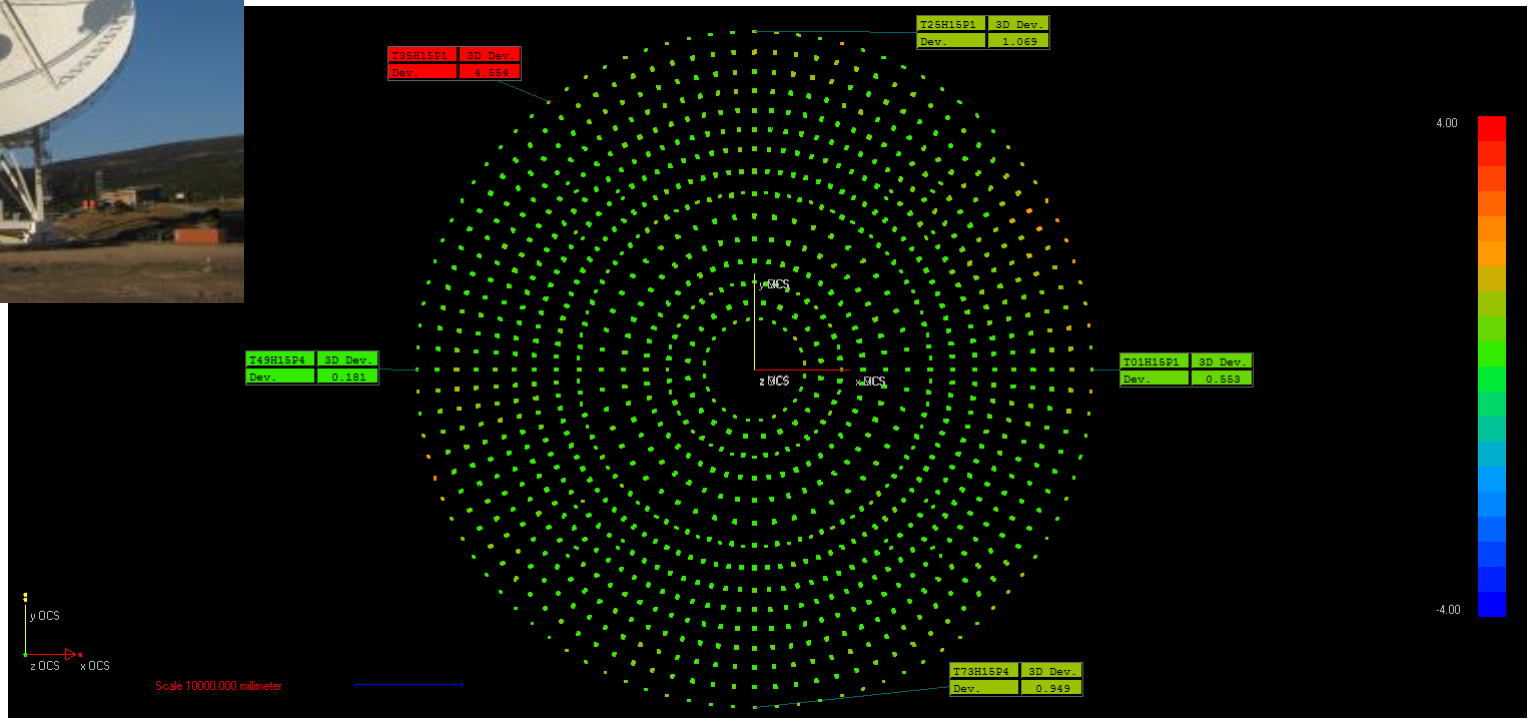
Surface deviation: -4mm to 5mm



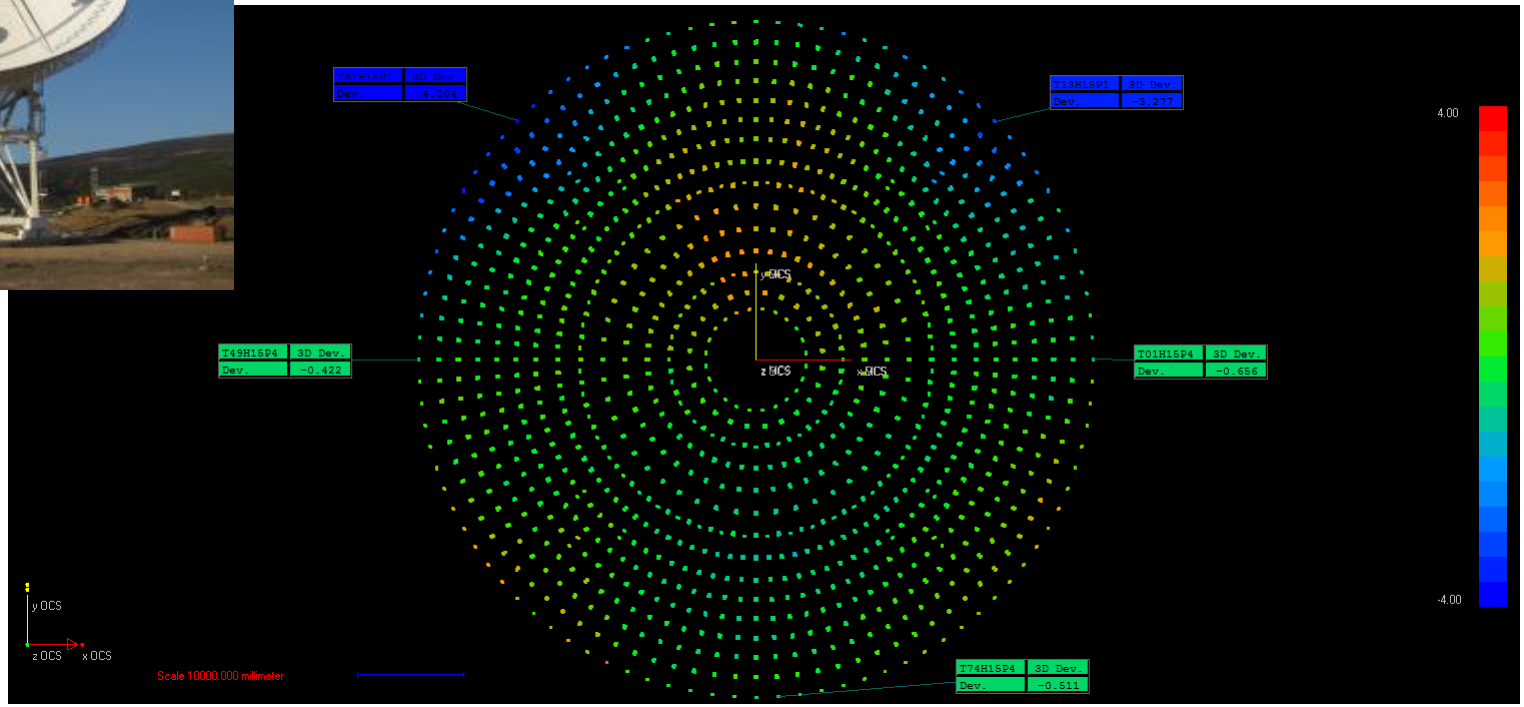
Main-Reflector in 30° elevation



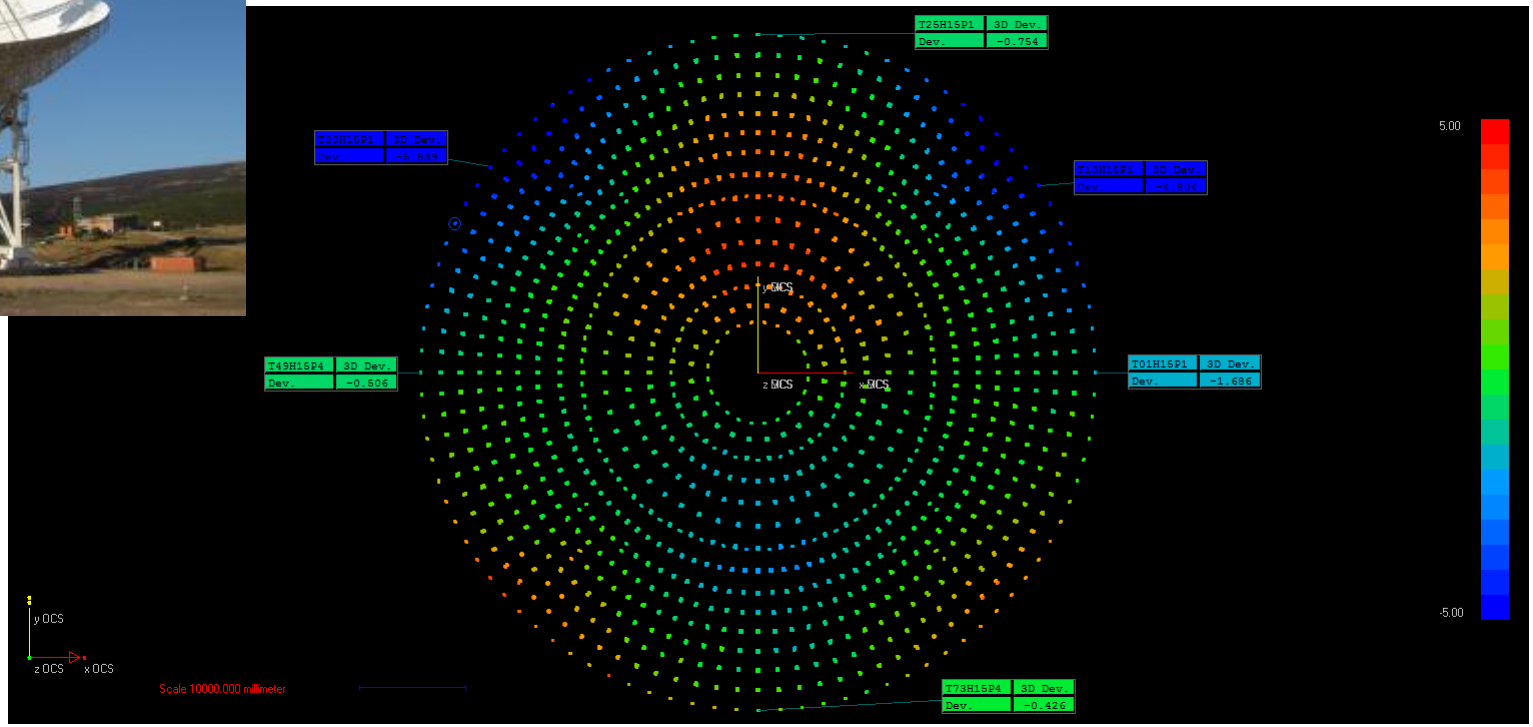
Main-Reflector in 45° elevation



Main-Reflector in 60° elevation

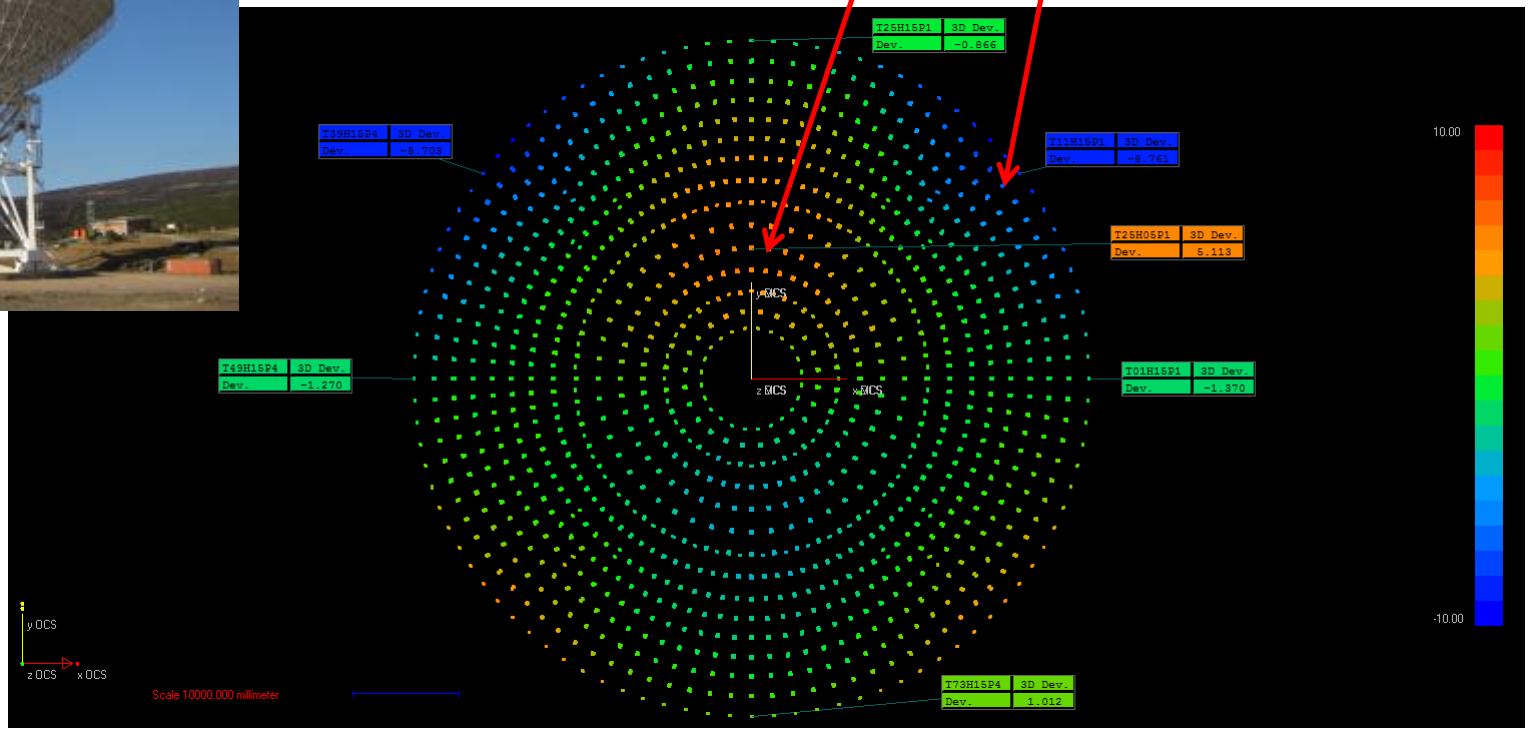


Main-Reflector in 75° elevation

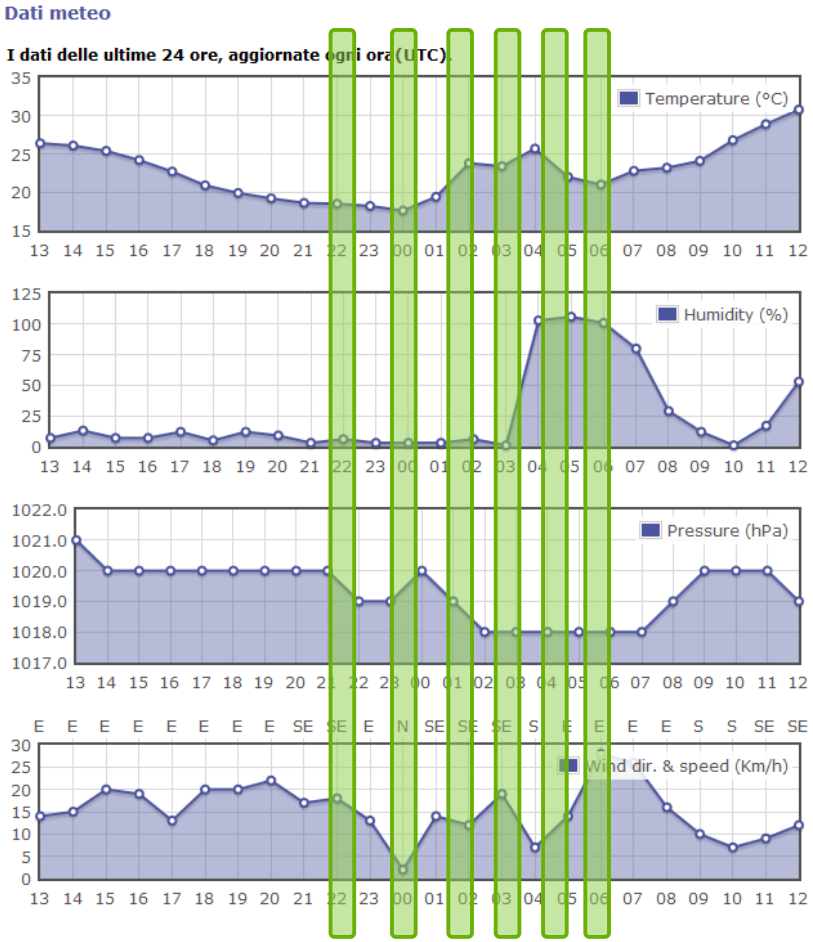


Main-Reflector in 90° elevation

Surface deviation: 5mm to -9mm



Meteorological data



Main Reflector in various elevation - Results

Elevation-Position	15°	30°	45° Panel Corner	45°	60°	75°	90°
Origin task	Various Elev.	Various Elev.	Global	Various Elev.	Various Elev.	Various Elev.	Various Elev.
ID	3D Dev. [mm]	3D Dev. [mm]	3D Dev. [mm]	3D Dev. [mm]	3D Dev. [mm]	3D Dev. [mm]	3D Dev. [mm]
R01_01_P5	-2.26	-0.74		-0.35	0.10	0.35	0.44
R01_02_P5	-2.27	-0.54		-0.41	0.37	0.85	1.26
R01_03_P5	-2.36	-0.45		-0.51	0.41	1.22	1.95
R01_04_P5	-2.24	-0.42		-0.02	0.86	1.92	2.47
R01_05_P5	-2.19	-0.22		0.07	1.04	2.53	3.16
R01_06_P5	-1.97	-0.25		0.17	1.19	2.64	3.45
R01_07_P5	-1.82	-0.54		0.07	1.26	2.68	3.69
R01_08_P5	-1.82	-0.48		0.24	1.66	2.75	3.63
R01_09_P5	-1.77	-0.34		0.02	1.43	2.25	3.33
R01_10_P5	-1.55	-0.11		0.02	1.36	1.78	2.88
R01_11_P5	-1.37	-0.33		0.12	0.99	1.30	2.36
R01_12_P5	-1.34	-0.29		0.16	0.68	1.13	1.71
R01_13_P5	-1.22	-0.08		0.06	0.40	0.61	0.99
R01_14_P5	-0.89	-0.06		0.10	0.30	0.14	0.21
R01_15_P5	-1.02	0.23		-0.16	0.13	-0.39	-0.51
R01_16_P5	-0.92	0.41		0.03	-0.03	-0.90	-1.06
R01_17_P5	-0.85	0.51		0.08	0.00	-1.04	-1.37
R01_18_P5	-0.77	0.62		0.08	-0.12	-0.72	-1.82
R01_19_P5	-0.52	1.10		0.29	0.07	-0.54	-1.73
R01_20_P5	-0.90	0.85		-0.26	-0.17	-0.64	-1.87
R01_21_P5	-0.89	0.59		-0.75	-0.39	-0.86	-2.30
R01_22_P5	-0.50	0.69		-0.10	-0.19	-0.33	-1.05
R01_23_P5	-0.77	0.61		0.18	-0.32	-0.37	-0.56
R01_24_P5	-0.77	0.36		0.35	0.28	0.22	0.20

Summary: Alignment with Photogrammetry

- ✓ Quick, reliable and scalable measurement technology for surface and deformation measurements
- ✓ User-Experience is much more important as in other 3D measurement technologies
- ✓ Need targets (retro or paper) for high accuracy
- ✓ Good weather conditions necessary

Thank you for your attention!

New Challenge for the future:

Square Kilometre Array (SKA)
in South Africa
Next generation Radio Telescope

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