Out of Focus Holography at Effelsberg

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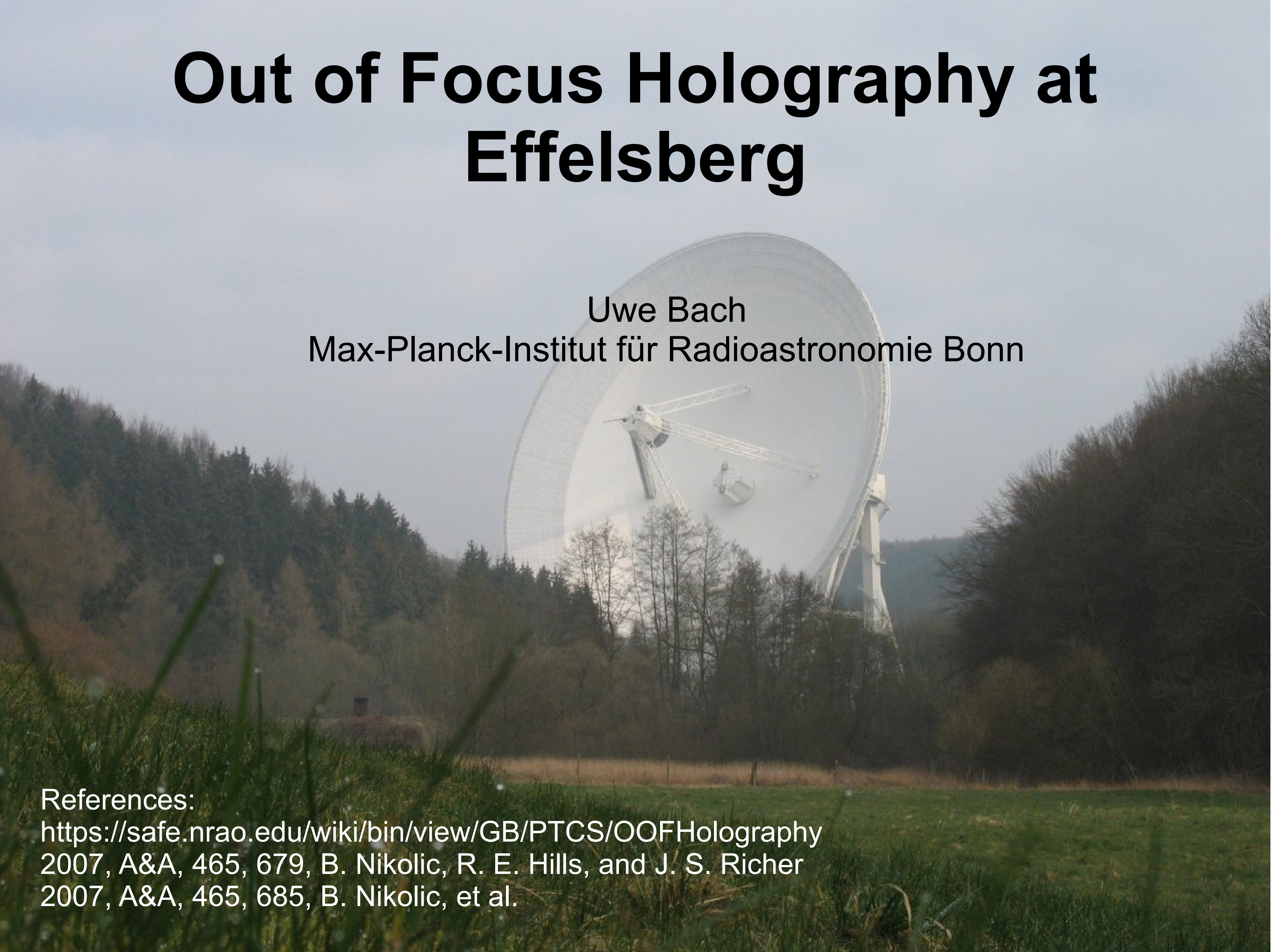
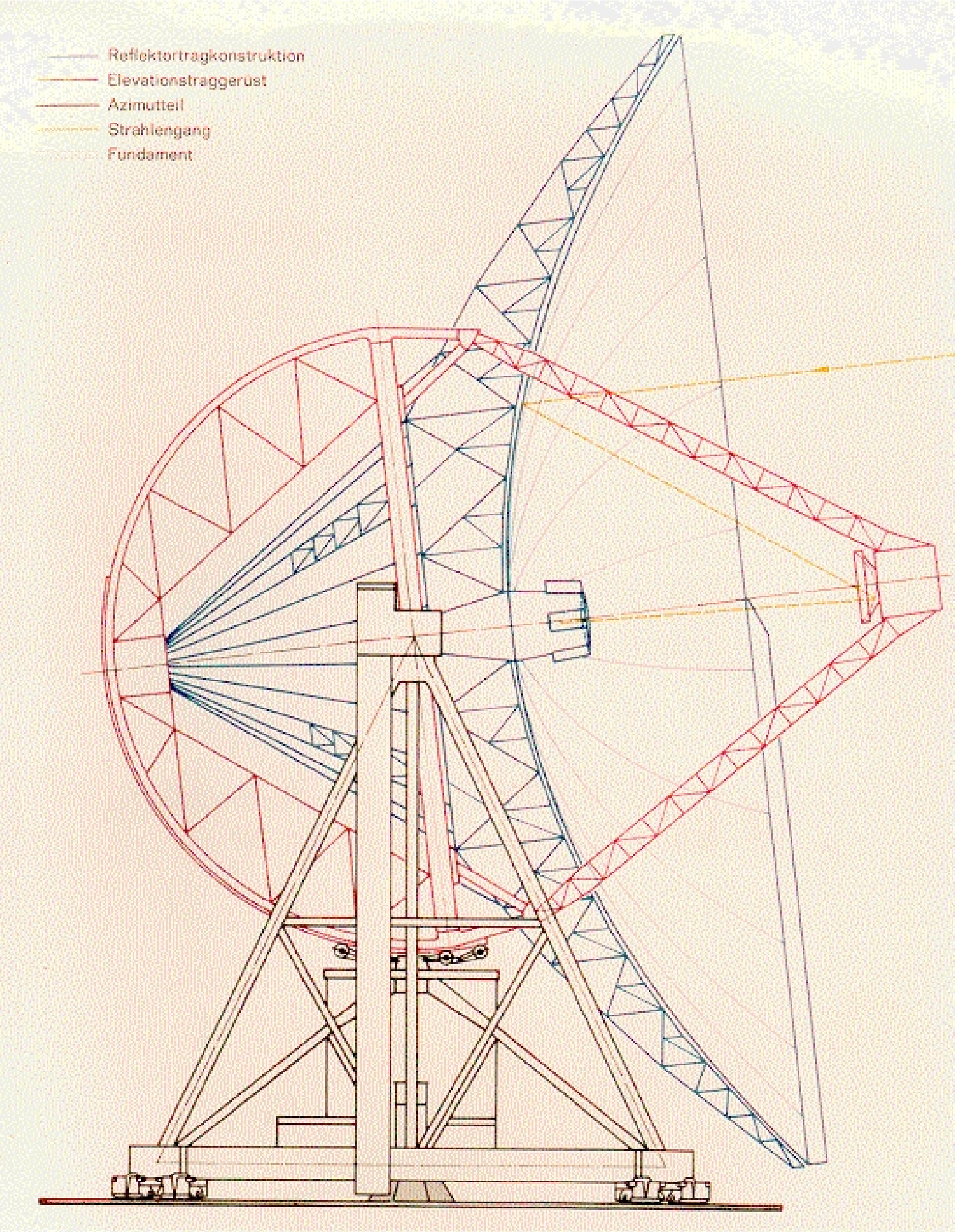


References:
https://safe.nrao.edu/wiki/bin/view/GB/PTCS/OOFHolography
2007, A&A, 465, 679, B. Nikolic, R. E. Hills, and J. S. Richer
2007, A&A, 465, 685, B. Nikolic, et al.

The Effelsberg 100m Antenna

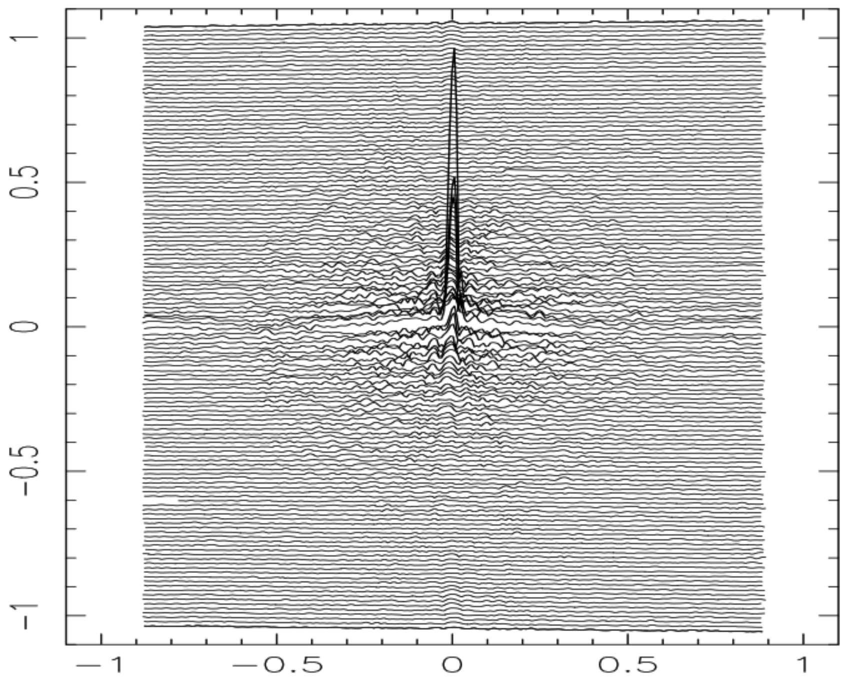
Azimuth part
Elevation support structure
Reflector support structure
Optical path

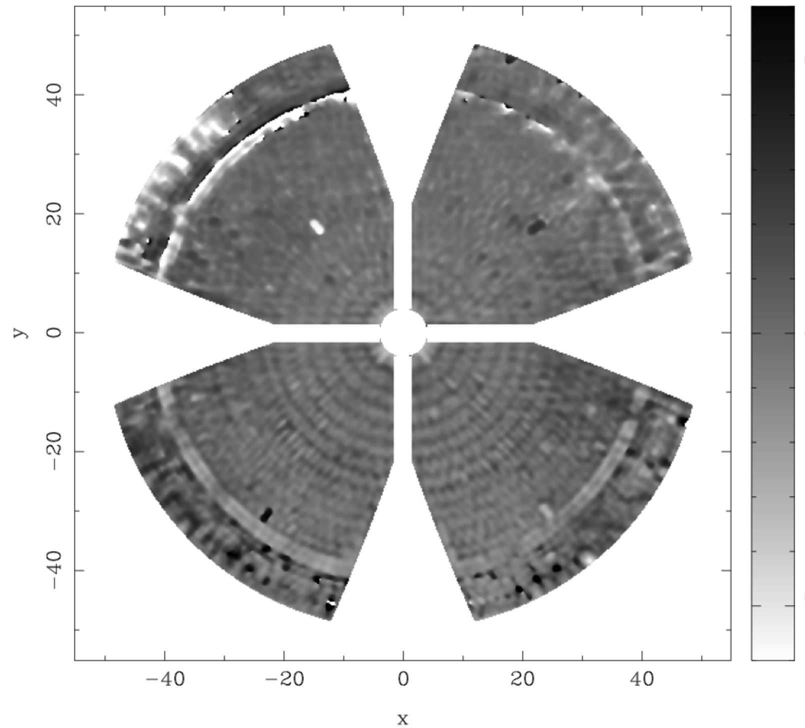


Traditional Holography

(Bennett et al. 1976)

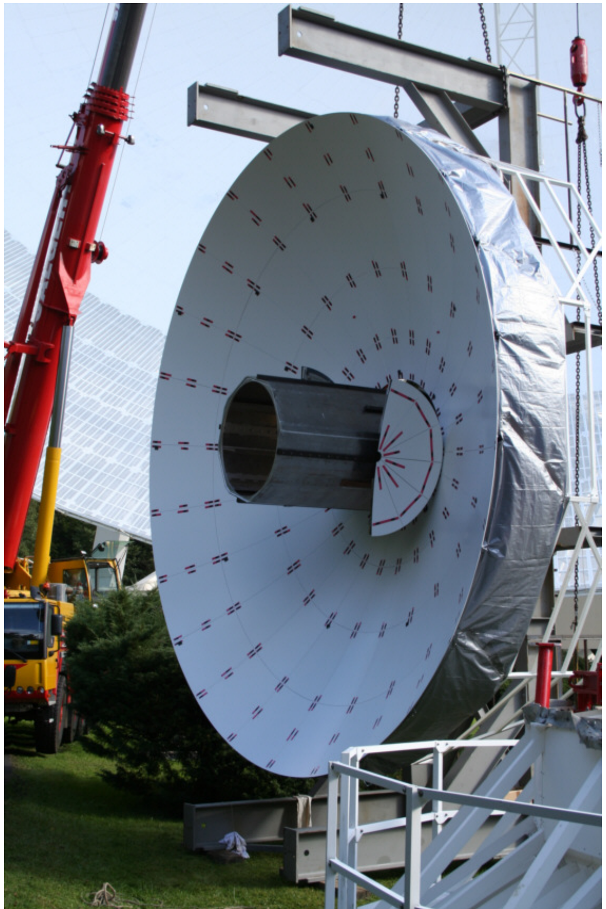
- Done with a special receiver at 11.7 GHz to receive the beacon signal of geostationary satellite and a 2nd reference antenna.
- Measure amplitude and phase of the beam-pattern.
- FFT to calculate E-field on the aperture plane and convert phase errors to surface errors.
- Disadvantages: Time consuming for Ef, very limited elevation range





A new sub-reflector for Eb

- In 2006 a new sub-reflector with an active surface was installed at the 100m telescope.
- The panels are adjustable by 96 actuators to compensate for known deviations of the main dish (finite element model).



OOF-Holography

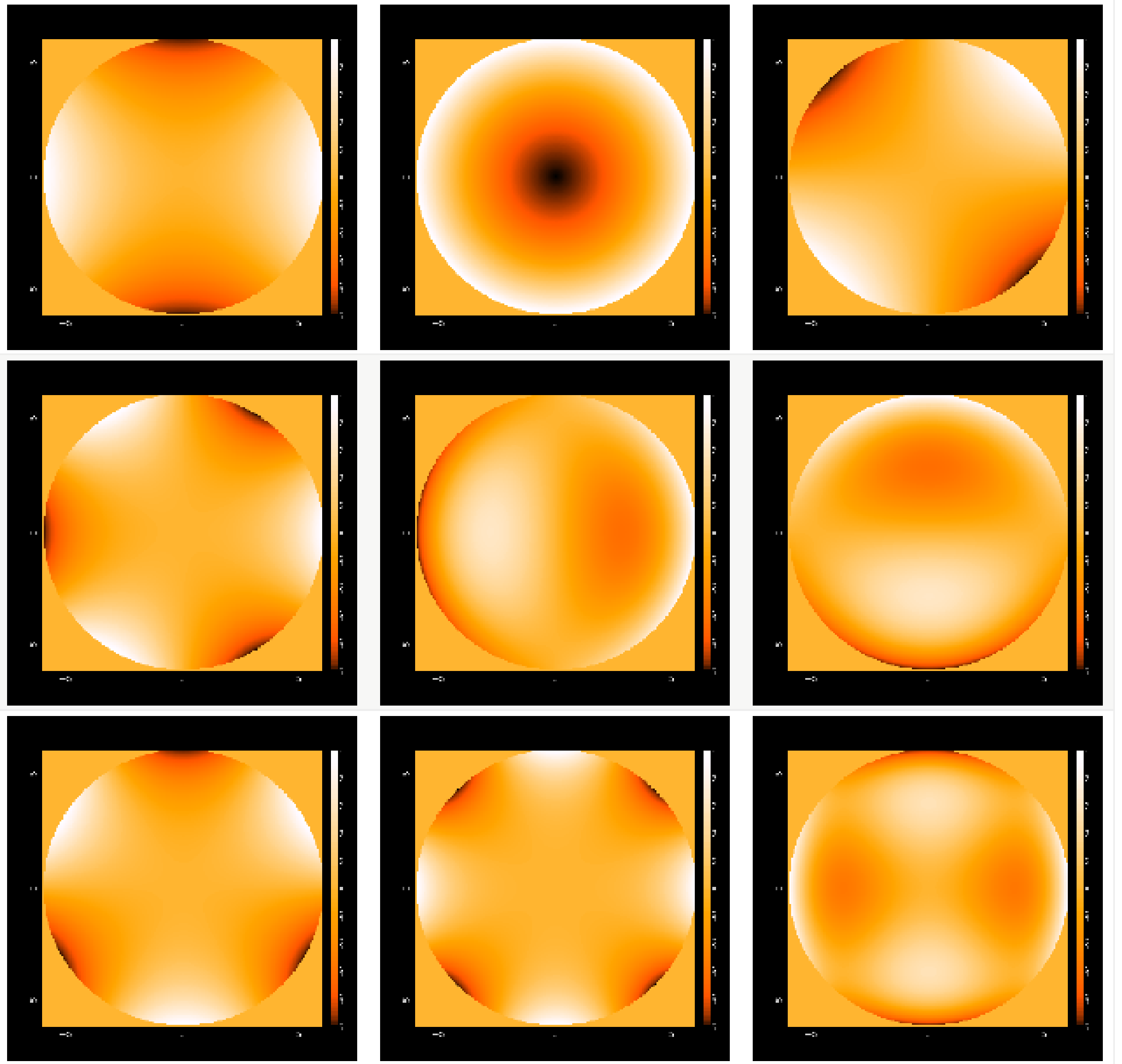
- Hills, Richer, & Nikolic (Cavendish Astrophysics, Cambridge) published a new method for „phase-retrieval holography“ in 2006 called Out-Of-Focus holography:
  - To reduce the number of free parameters the antenna surface is described by Zernike polynomials.
  - Modern minimization algorithms are use to estimate the coefficients.
  - Comparison of the model with the focus and defocused images.

Zernike Polynomials

Astigmatism / Focus / Astigmatism

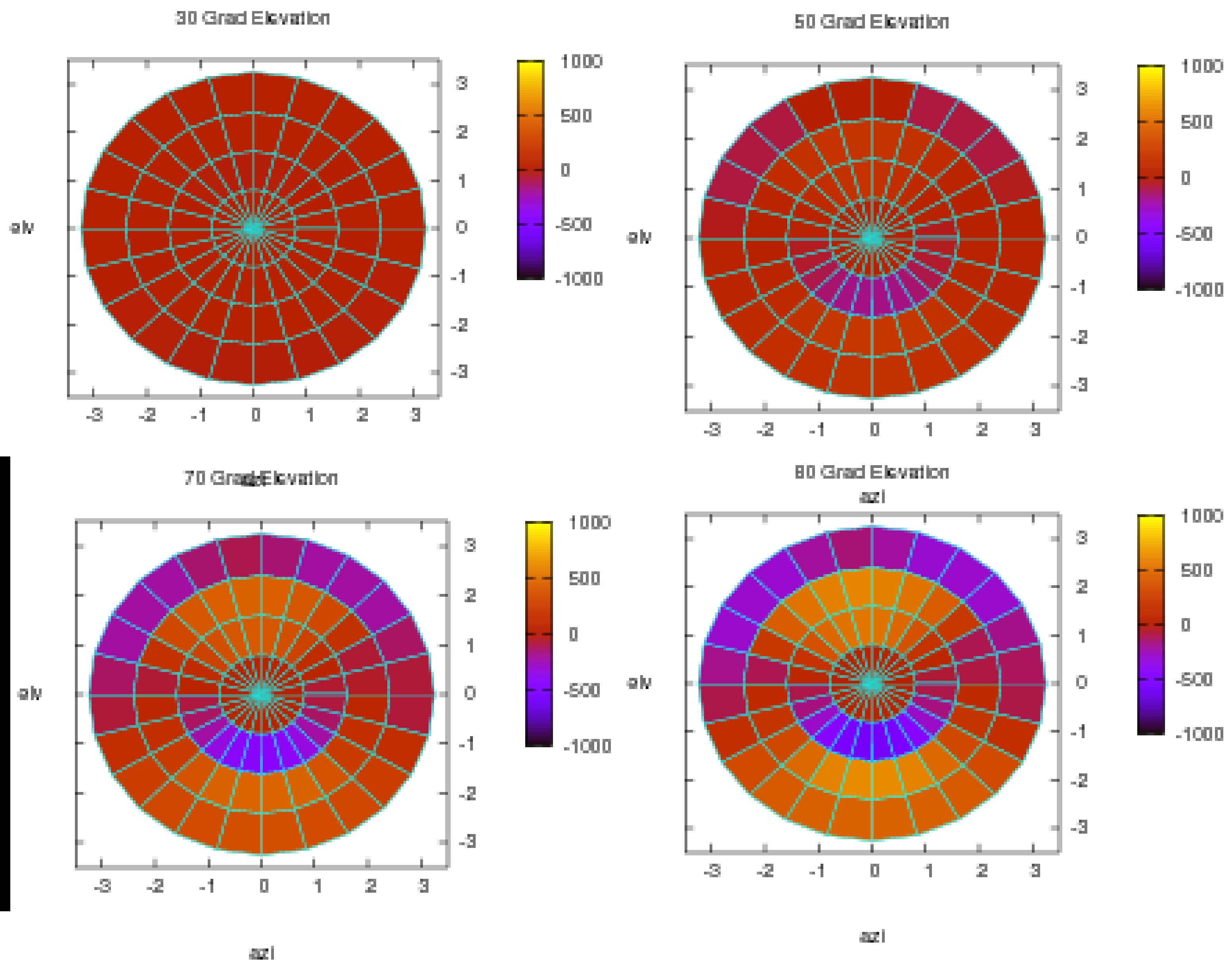
Trefoil / x Coma / y Coma

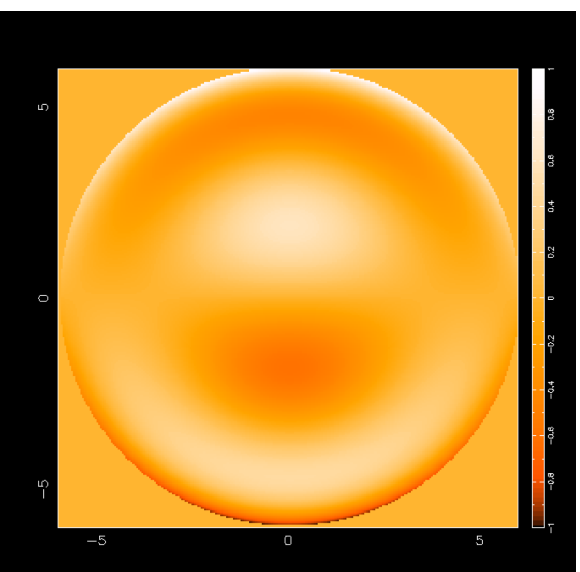
higher order errors ...



Corrections of the sub-reflector

Currently a static look-up table, calculated from a finite element models, is used to correct the surface.





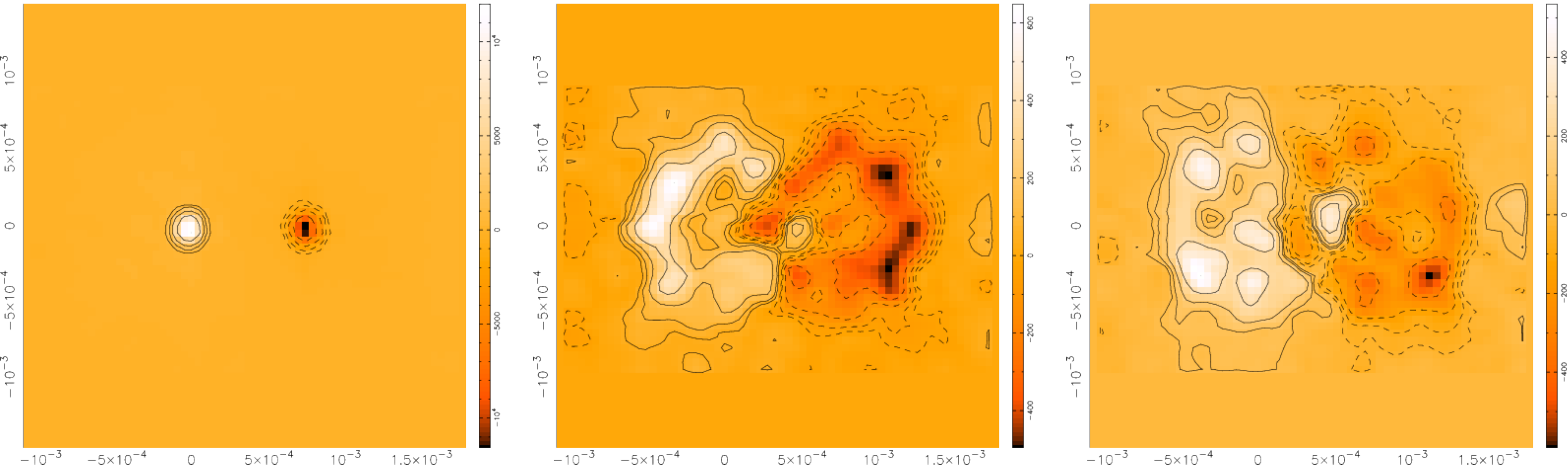
OOF-Procedure

- Measure three beam maps (Nyquist-sampled): One at perfect focus, two at +/- ~ 5 λ Defocus.
- Surface errors (phase errors) are modeled by the combinations of different Zernike polynomials.
- They are used to calculate theoretical beam maps that are compared with the actual measured maps.
- A loop starts that corrects the coefficients to minimize the differences between the modeled and measured beam maps.

OOF-Procedure

- Required SNR ~200.
- Is easily reached at Effelsberg at 9mm (32 GHz) using astronomical source of ~10 Jy, e.g. 3C84, 3C273, …
- Measuring a set of images takes ~45 min
  - 3 maps of 9.2'x6', using 10“ separation.
- Data analysis takes about 10 minutes:
  - Calibration of the maps is done in the Effelsberg nod3 software (baseline correction, amplitude calibrations, subtraction of the 2nd horn...)
  - Processing the maps using B. Nikolics OOF software.

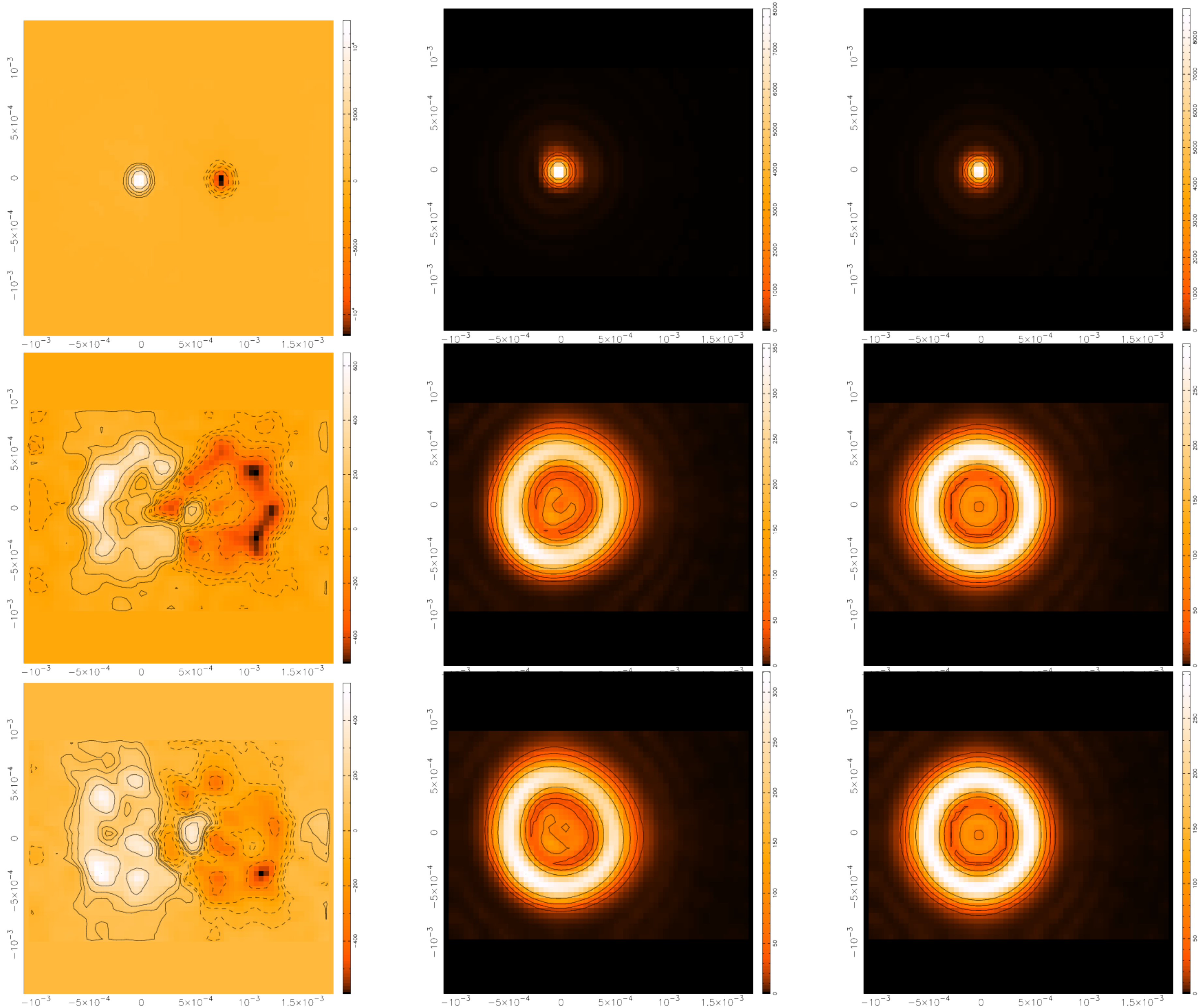
Effelsberg OOF images



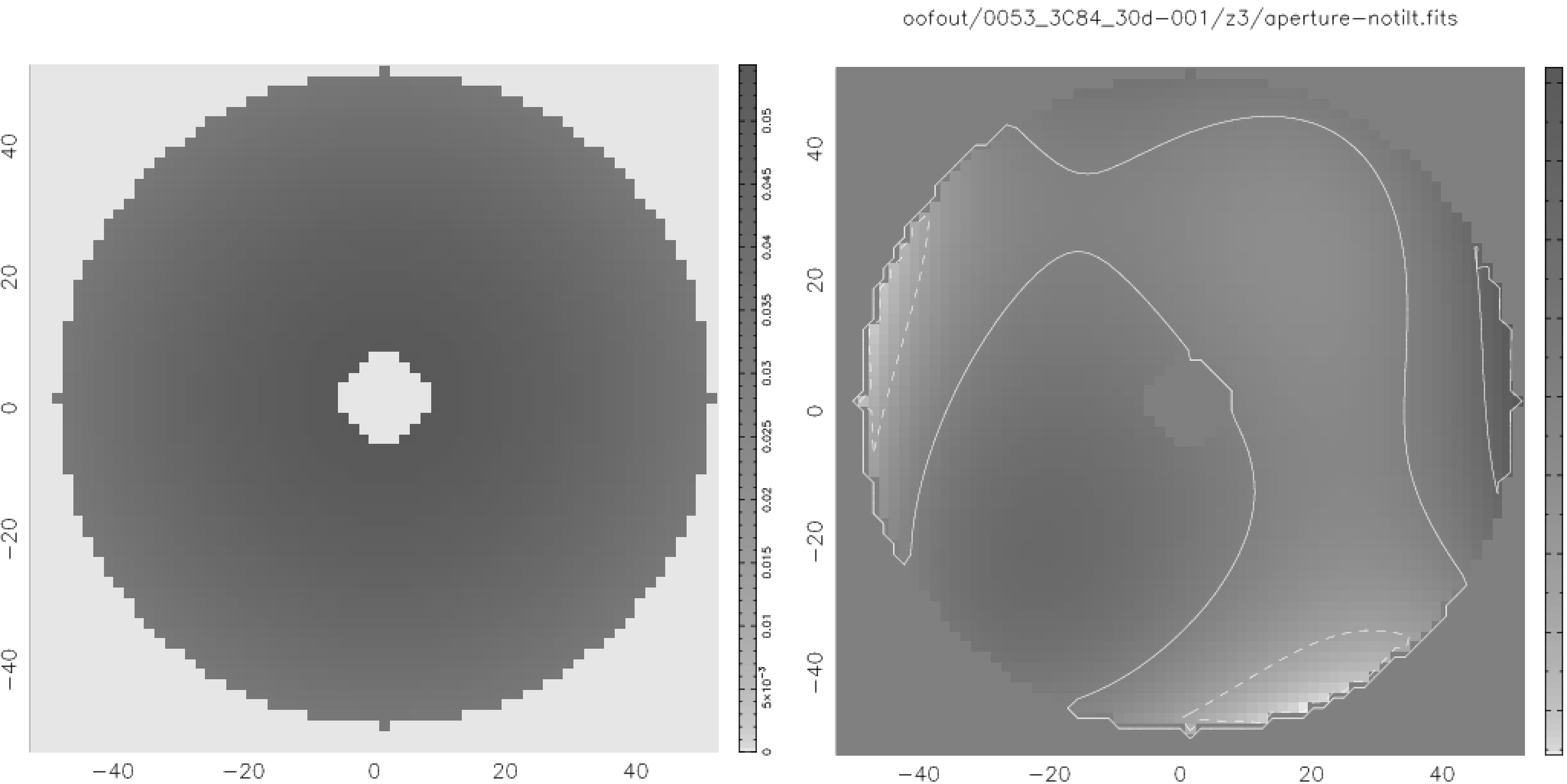
Focus image

+ 25 mm defocus

- 25 mm defocus



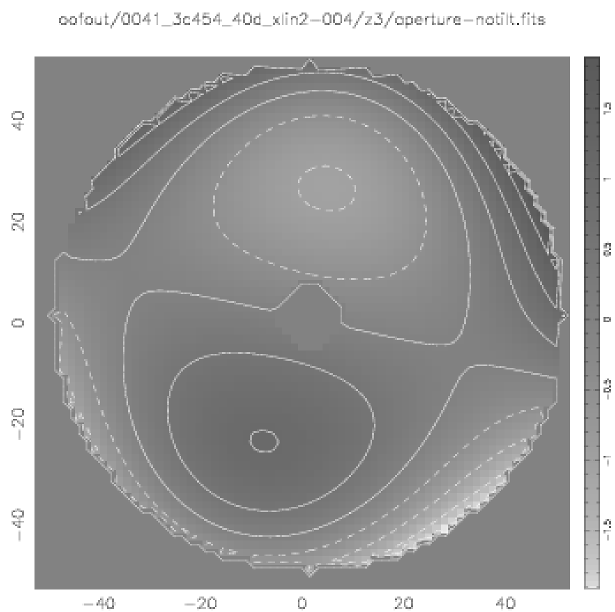
Aperture plane

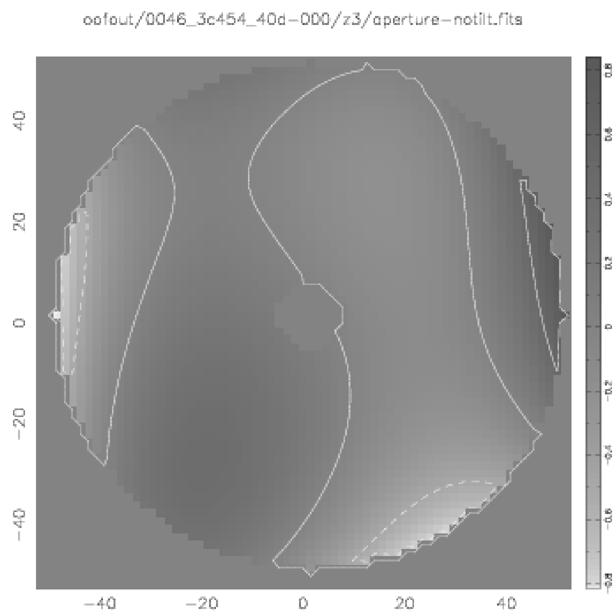


1 radian of phase error in the wavefront corresponds to 0.71 mm surface error.

Tests to recover know errors

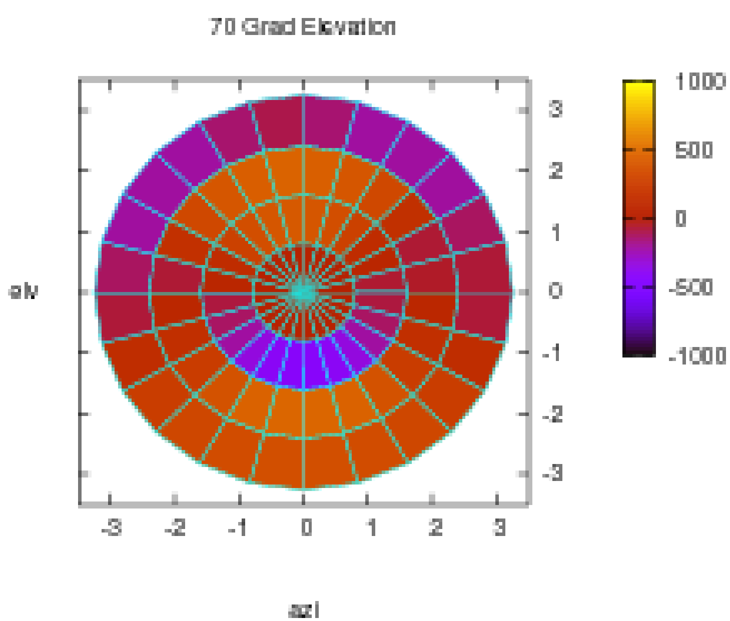
X-lin +9mm

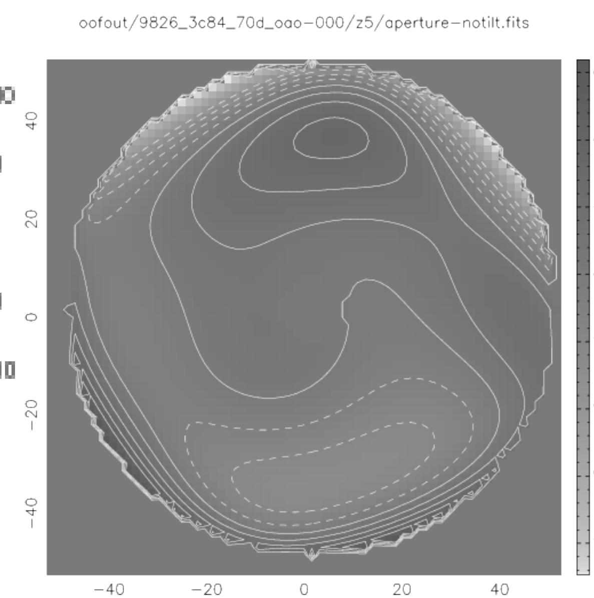




X-lin 0 mm

Active surface off

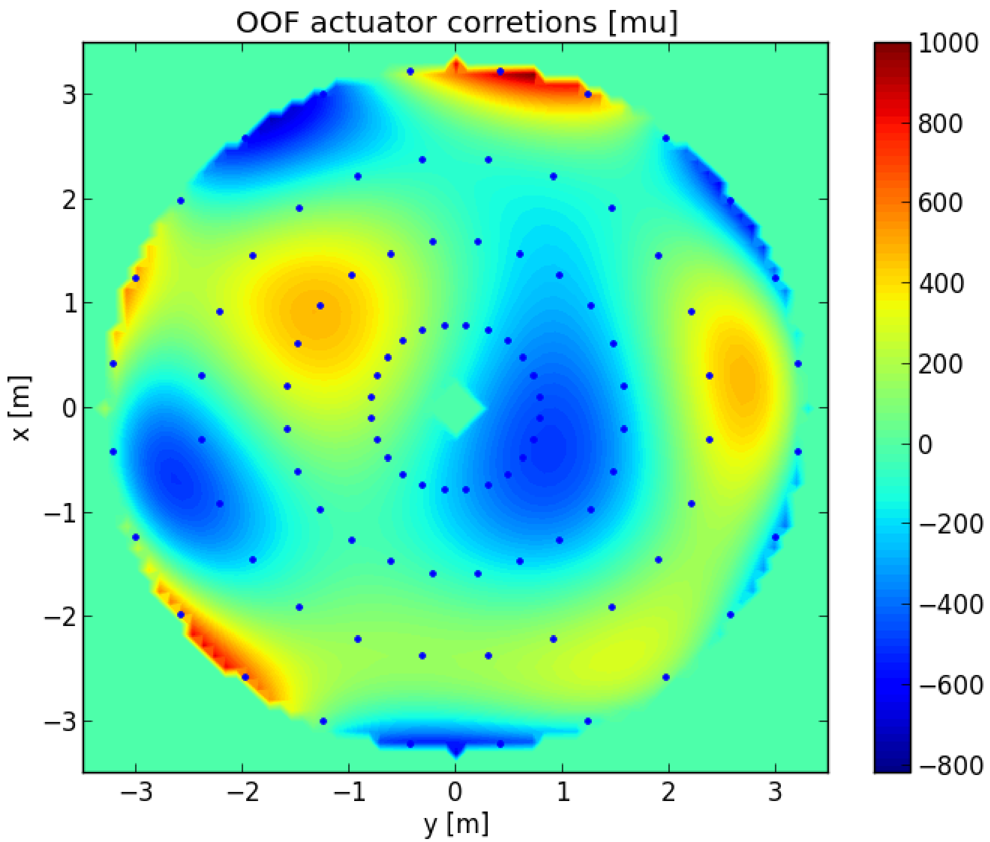


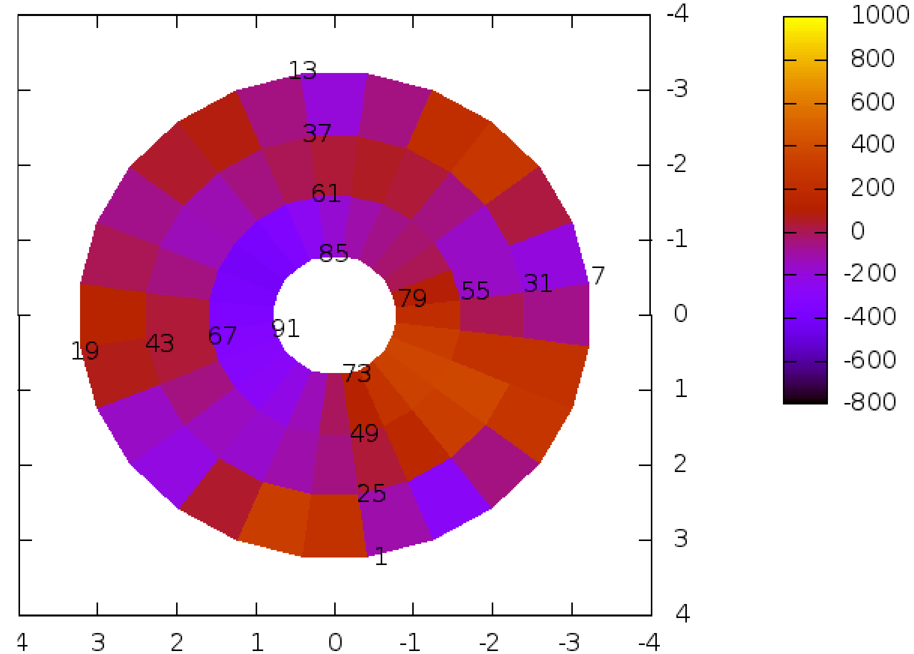


Identify geometry and direction

Introduce offset for a number of panels and try to find them in an OOF measurement

NR	1	ffff	-38	-31	-20	-4	0	16	39	64	91	119	147
NR	2	ffff	-15	-17	-12	-3	0	13	33	58	87	118	152
NR	3	ffff	-12	-15	-12	-2	0	12	31	55	83	113	145
NR	4	ffff	492	490	492	498	500	508	522	538	558	579	601
NR	5	ffff	530	519	510	502	500	495	490	488	487	490	493
NR	6	ffff	543	534	521	504	500	483	459	433	405	377	349
NR	7	ffff	43	34	21	4	0	-17	-41	-67	-95	-123	-151
NR	8	ffff	55	45	28	5	0	-23	-57	-94	-133	-174	-215
NR	9	ffff	30	25	16	3	0	-14	-33	-56	-80	-106	-132
NR	10	ffff	6	9	7	2	0	-8	-22	-39	-59	-81	-105
NR	11	ffff	18	16	10	2	0	-9	-22	-36	-52	-70	-87
NR	12	ffff	-21	-12	-5	-1	0	1	0	-3	-10	-18	-28
NR	13	ffff	-18	-10	-4	-1	0	1	0	-3	-9	-17	-27
NR	14	ffff	18	16	10	2	0	-9	-21	-36	-52	-69	-86
NR	15	ffff	5	8	7	2	0	-8	-22	-39	-59	-81	-105
NR	16	ffff	31	26	16	3	0	-14	-34	-56	-81	-106	-132
NR	17	ffff	56	46	29	5	0	-24	-57	-94	-134	-174	-215
NR	18	ffff	43	35	21	4	0	-17	-41	-67	-95	-124	-152
NR	19	ffff	31	20	10	1	0	-5	-10	-12	-13	-11	-7
NR	20	ffff	-7	-10	-8	-2	0	8	22	38	57	79	102
NR	21	ffff	-13	-15	-12	-2	0	12	31	55	83	113	145
NR	22	ffff	-17	-18	-13	-3	0	13	34	59	88	119	152





Conclusions and Outlook

- It is possible to do holographic measurements using astronomical sources.
- We can detected optical errors that we introduced deliberately.
- Measure more beam maps over the whole elevation range.
- Use this to actually improve the current version of the look-up table for the actuators.