MT MECHATRONICS

Background, theory and practical limitations of metrology systems at Radio Astronomy Antennas

Technical Workshop

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What is Metrology ?

μέτρον + λόγος

metron + **logos**

measurements + how to use the information ?

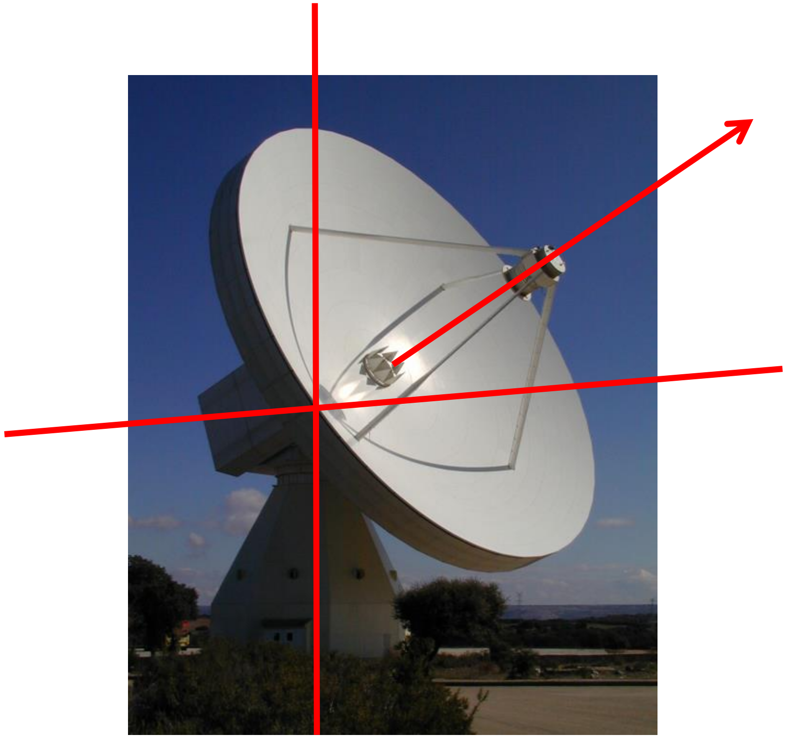
Metrology is the science of measurement. Metrology includes all theoretical and practical aspects of measurement. …

In Ancient Greek the term μετρολογία (*metrologia*) meant "theory of ratios".

source: wikipedia (en)

What are we looking for?

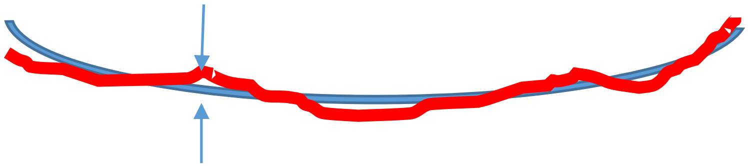
Task 1: Pointing accuracy:



Sometimes a 3. axis
(Tilt or XEl)

What are we looking for?

Surface Error



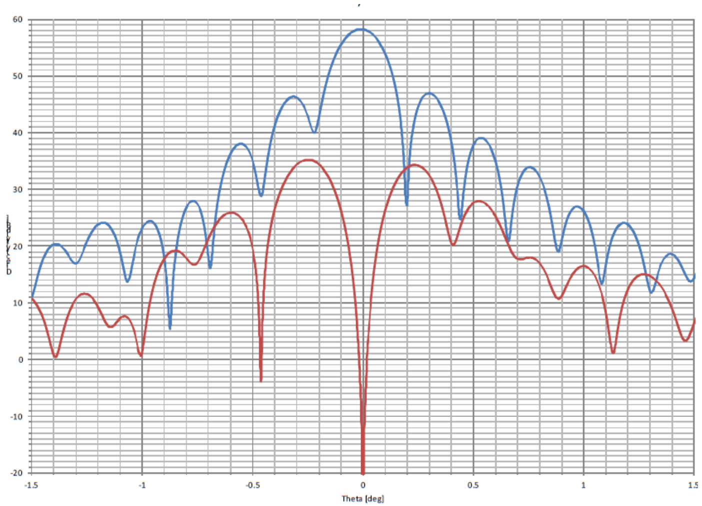
Task 2: Surface accuracy

Deviations of theoretical vs. actual reflecting surface

But careful:
Direction! (normal to surface / normal to ray ?)

Pathlength vs Surface

RMS – calculation: consideration of weighting



Error Budgets:

Dependent on the project`s scientific goals or systematic requirements (link budgets), both errors are restricted to acceptable figures, also mainly influenced by the frequency ranges to be observed and the antenna aperture.

Pointing error budget

Error Source	Contribution
Axis Alignement	25 %
Servo System	15 %
Environment	60 %
Gravity	20 %
Wind	80 %
Thermal	20 %

Surface error budget

Error Source	Contribution
Panel Manufacturing	30 %
Panel Alignement	30 %
Environment	40 %
Gravity	20 %
Wind	40 %
Thermal	40 %

Side-Note on the surface vs. pointing accuracy

Surface accuracy is analytically optimized by „best fitting“ an ideal paraboloid into the actual (deformed) shape.

„Best fitting“ = tbd DOFs !!! (dependent on the active DOFs of the system.

Least square fit, the fitting parameters are derived according to weighting factors, influence functions, etc.

Solving this equation delivers a unique solution for the minimum surface accuarcy. This solution may be disadvantageous for the use in pointing equations !!!

What can we do about it?

Radio Telescopes are suffering from 2 facts:
a.) 2-dimensional target acquisition (like on a optical CCD) to compensate for pointing (end 2 end)
b.) wavefront sensors to compensate for surface accuracy

Generally, there are two possible approaches:

Measuring the causes: (wind, gravity, temperatures)

(typically easy to measure, but how to handle the results?)

or

Measuring the consequences (tilts, offsets, pointing errors)

(typically very small, not easy to measure, but relevant for the final result)

What can we do about it?

Gravity: → mostly repeatable
→ look up- tables

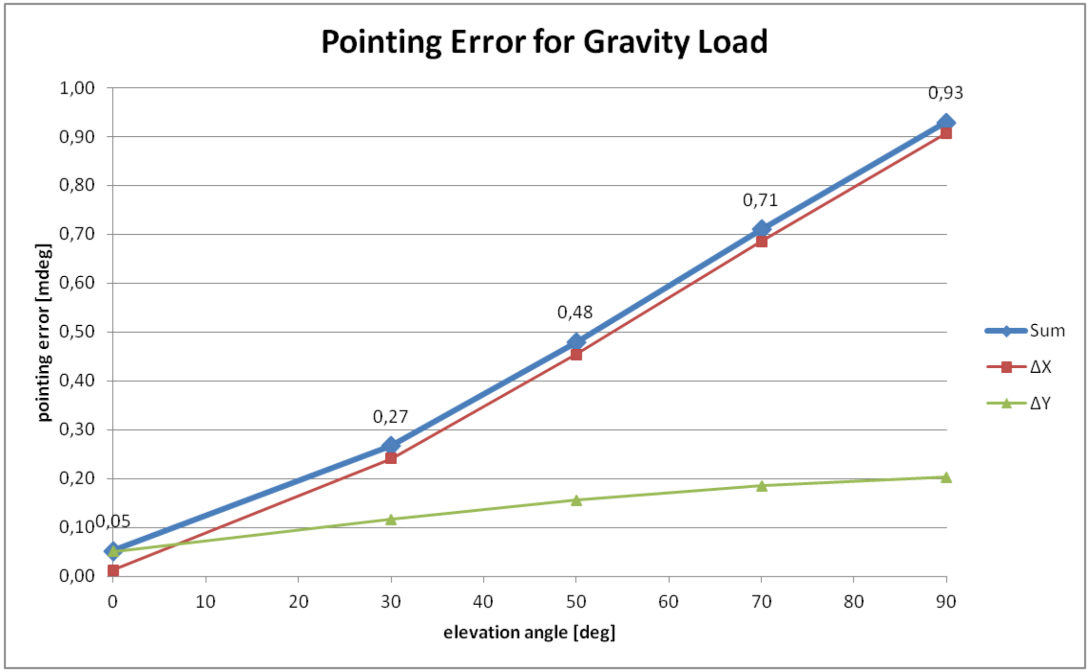
if not, accelerometers (not ground-based or other accelerations)

Thermal: → predictable, but many varying load case scenarios !!!

Wind: → partly, but hardly predicatable !!!

(separation into quasi-static and dynamical frequency range,
very much site specific !!!)

Gravity:



Easy to analyse and predict by use of FEM models.

Repeatable as a function of elevation

Standard compensation, but also some limited due to de-tuning of the optical system !

Gravity:

Pointing Sensitivity

Displaced Bo	DOF	Factors feed	DOF	Factors feed	Physical Unit
M1 tilt	rotx	**1,720**	roty	**1,720**	mdeg/mdeg
M1 trans	uy	**-19,022**	ux	**19,022**	mdeg/mm
M2 tilt	rotx	**-0,089**	roty	**-0,089**	mdeg/mdeg
M2 trans	uy	**8,995**	ux	**-8,995**	mdeg/mm
Feed	uy	**10,199**	ux	**-10,199**	mdeg/mm

(*) : Z-axis colinear to the pointing direction of the telescope

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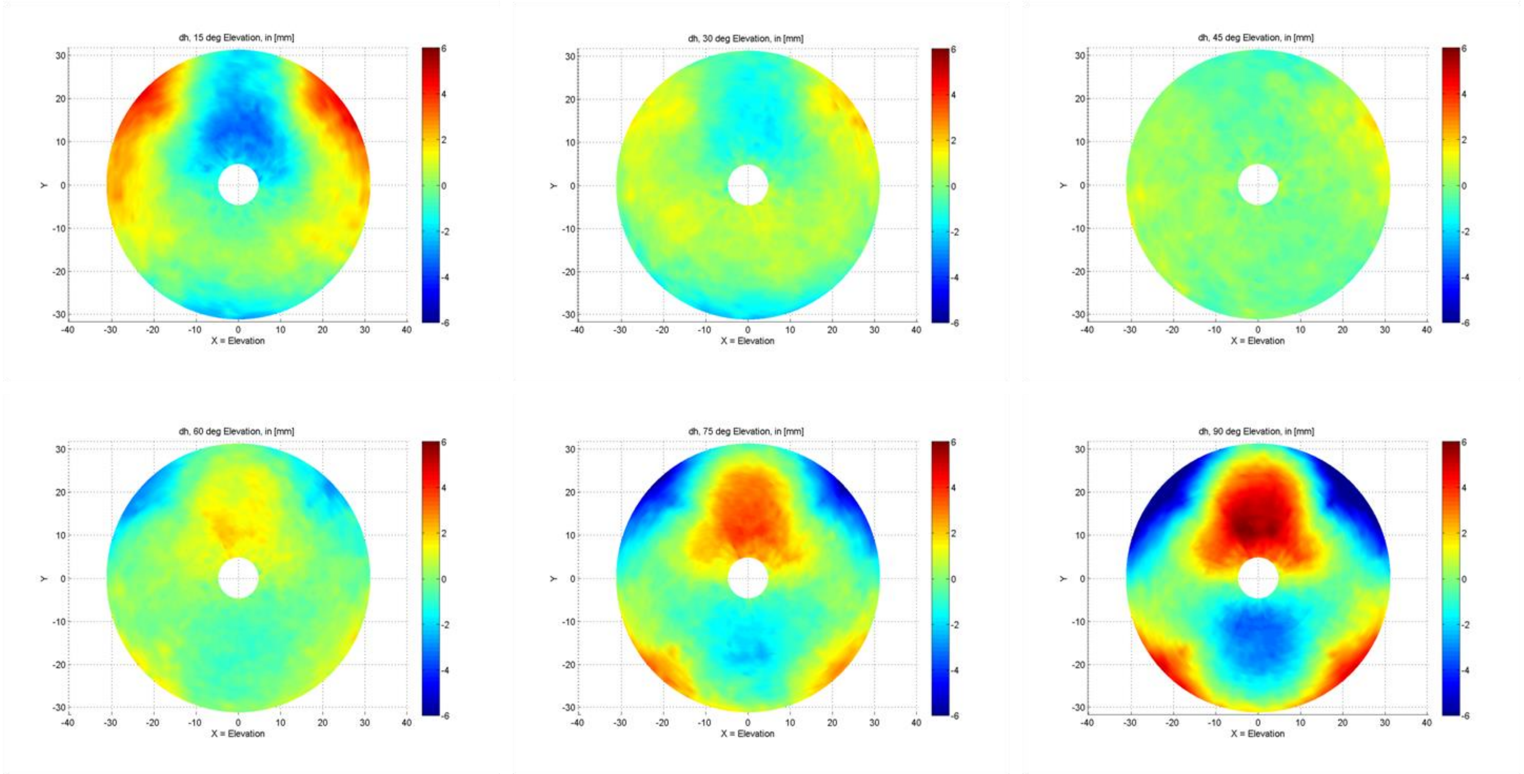
Gravity:



Easy to analyse and predict by use of FEM models.

Repeatable as a function of elevation

Compensation requires active surface → large number of actuators (or on M2 !) + no closed loop compensation

Wind:

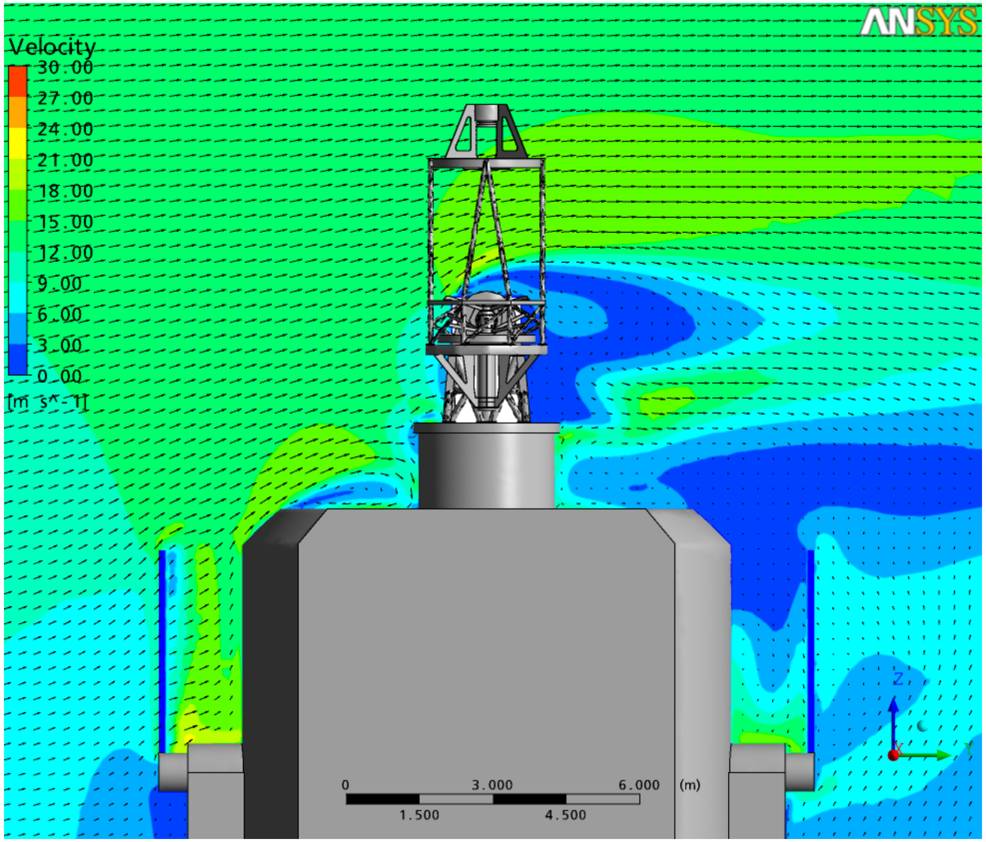
2 Scenarios:

a.) Static Wind:

Structural deformation
Servo Error small

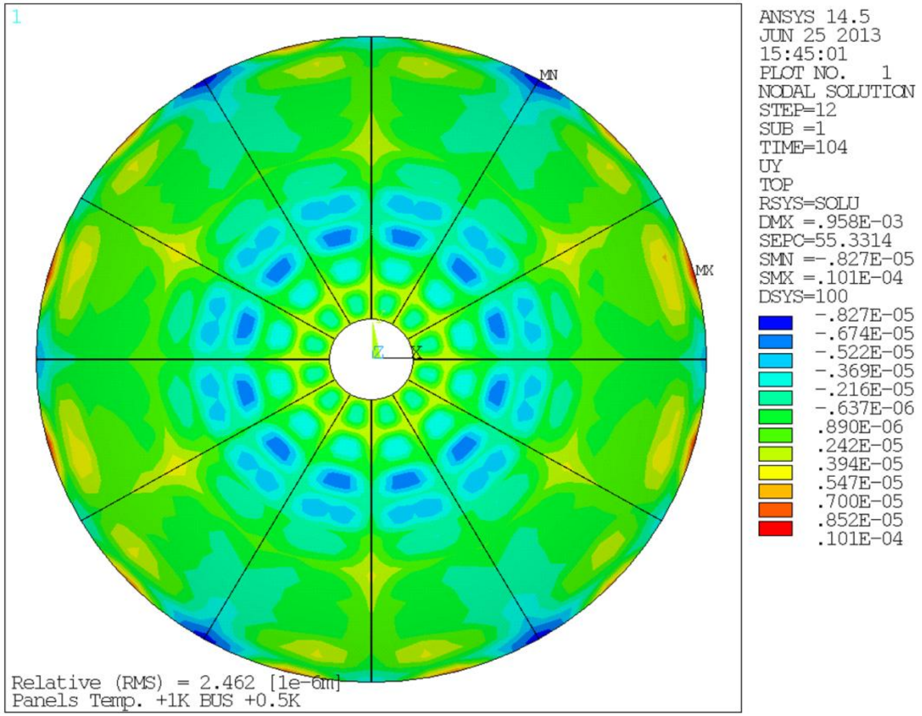
b.) Wind gust
Structural deformation

+ servo error



Can be large depending on closed loop performance (➔ high bandwith ➔ high eigenfrequency of the structure

Thermal:



2 Scenarios:

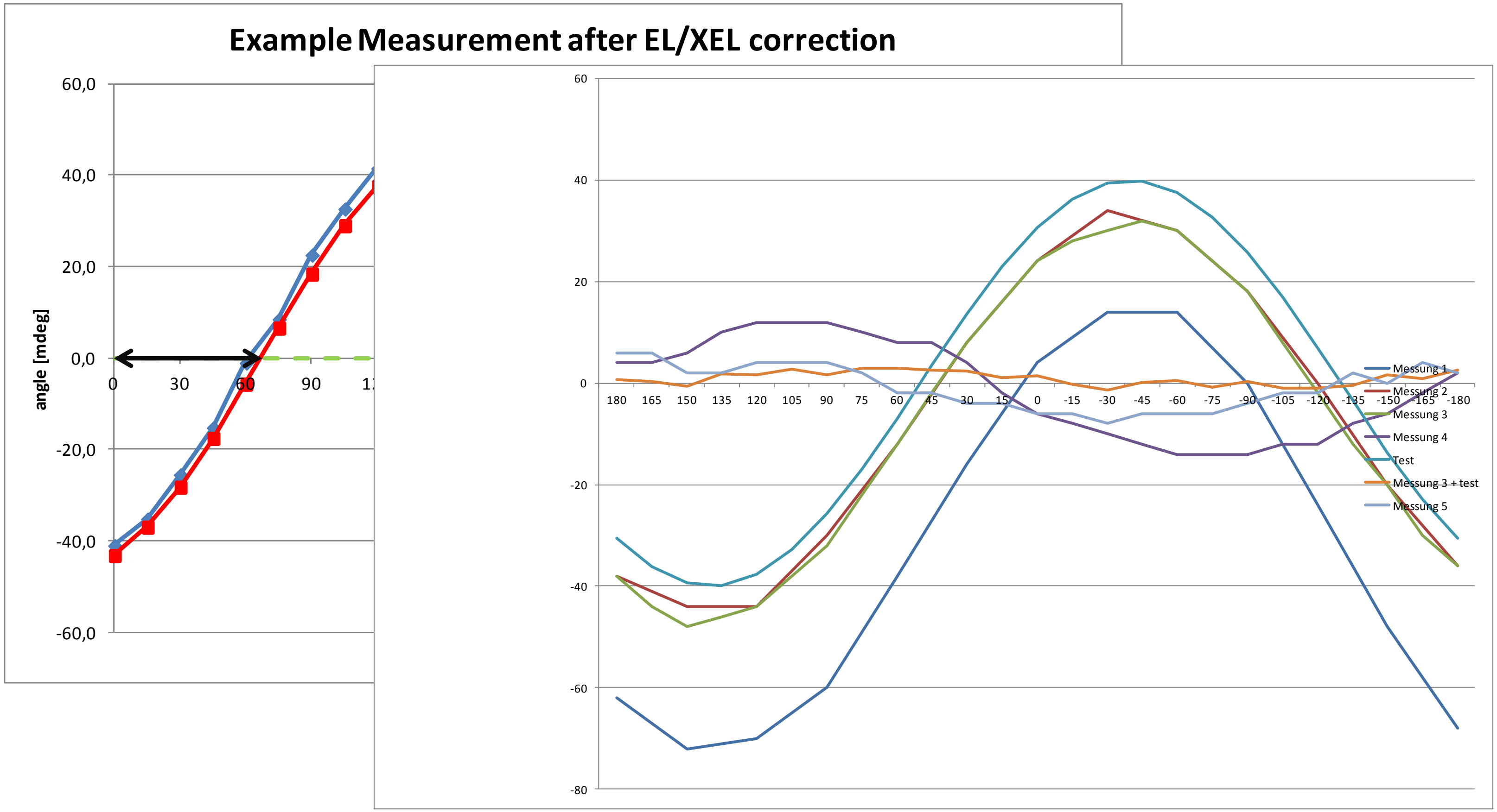
a.) constant ΔT:

b.) Temperature Gradients:

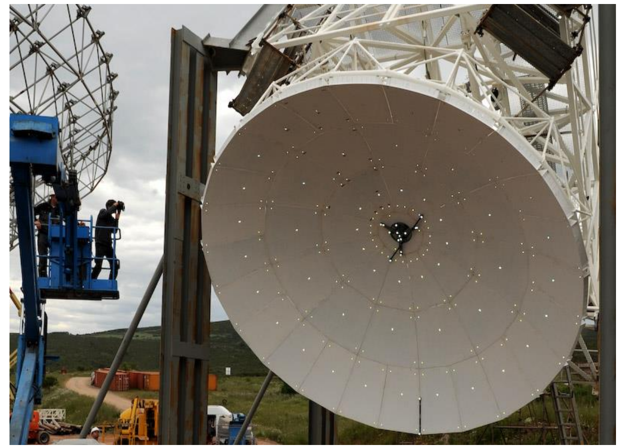
Analytically easily to resolve (linear theory)

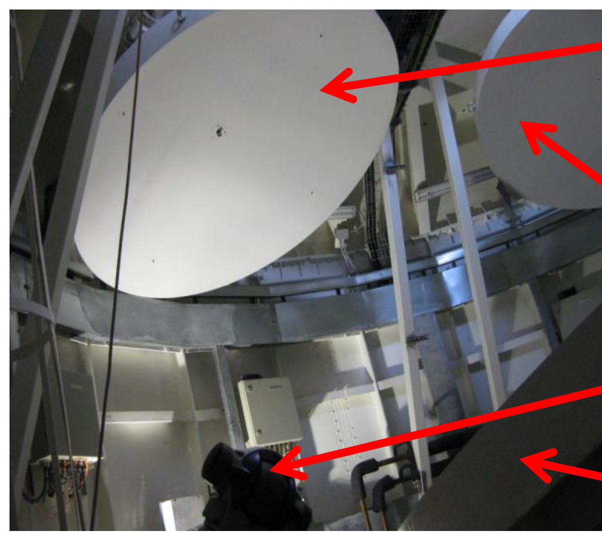
Practical difficulties: How to represent typical (actual) scenarios ???

Example: Axis Alignment procedure



Example: SRT Mirror Alignment





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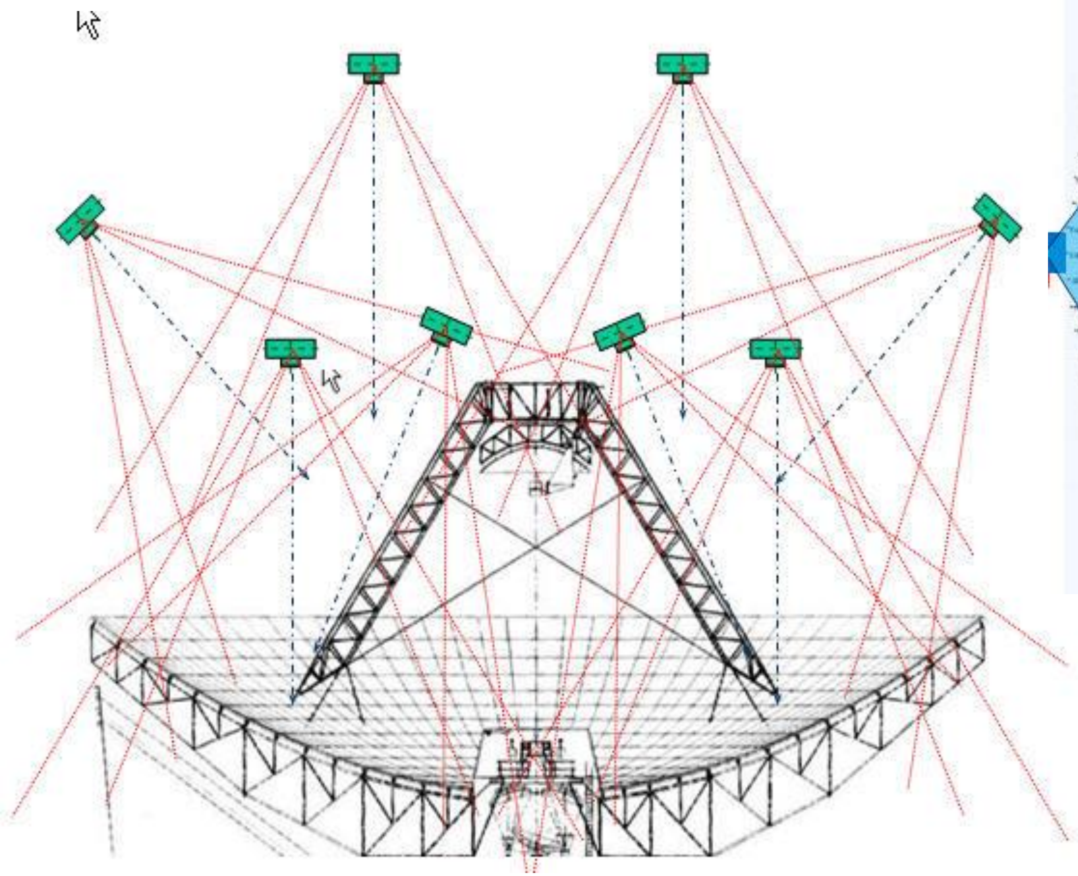
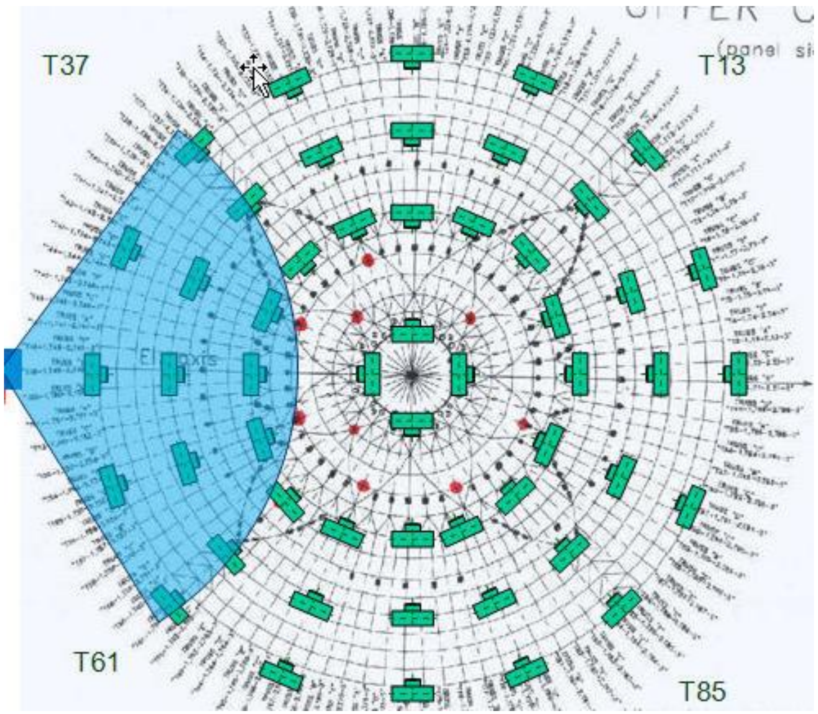
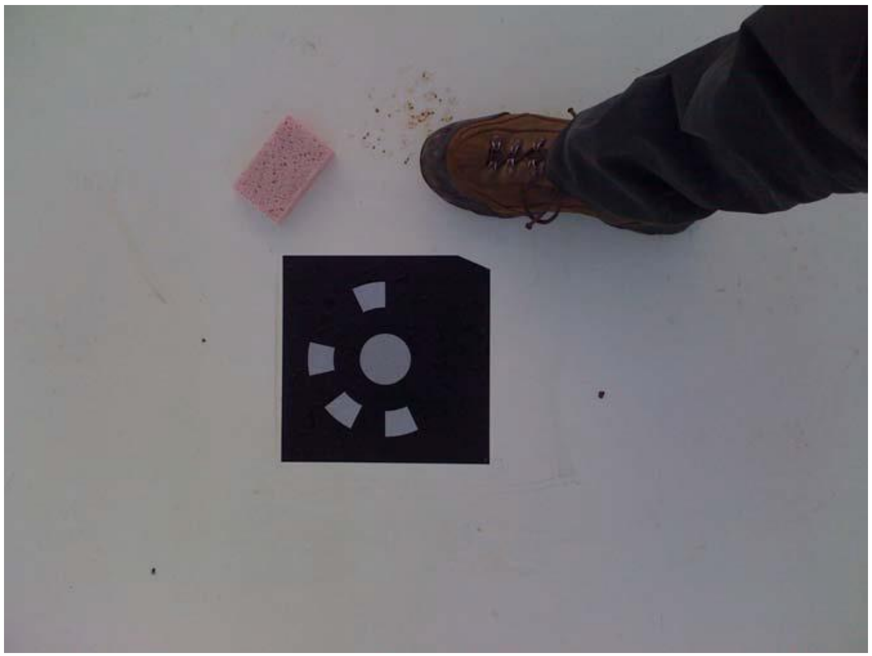


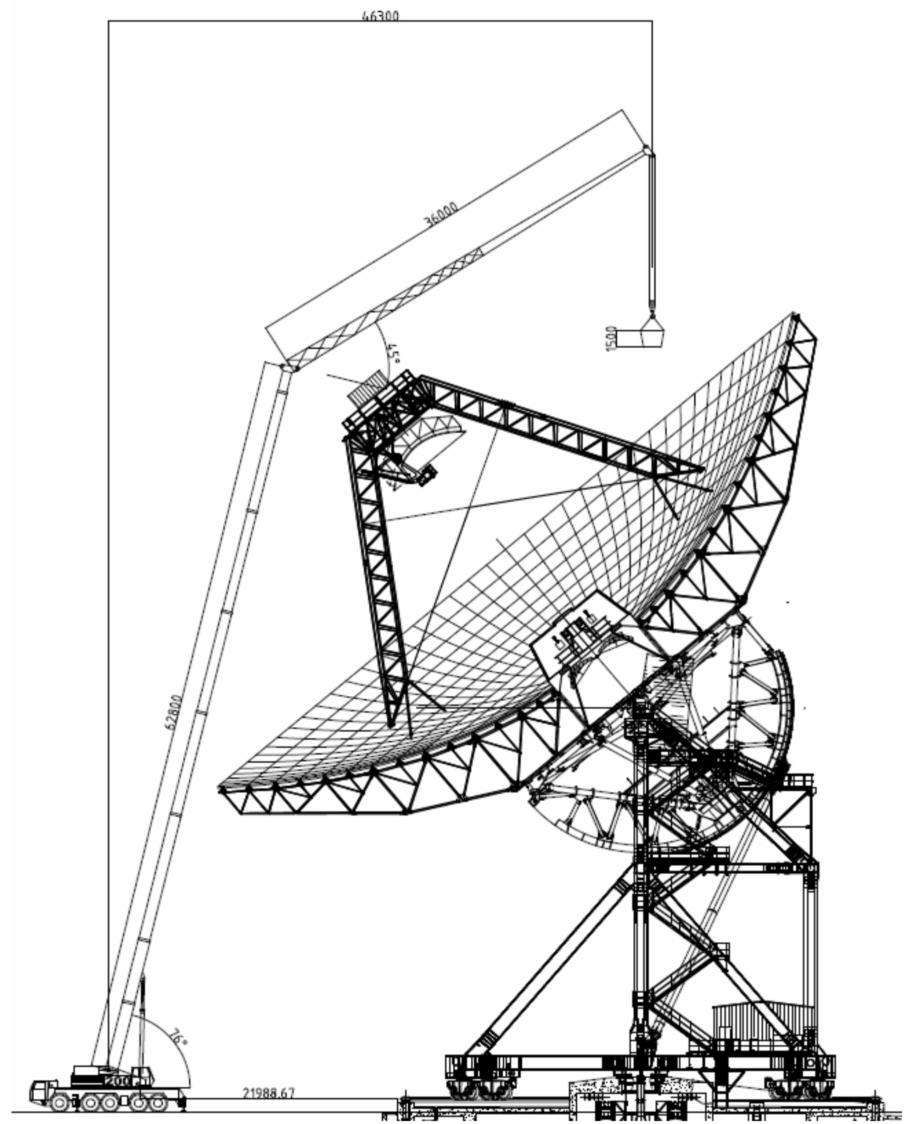


64m diam. ➔ ca. 33 µm accuracy

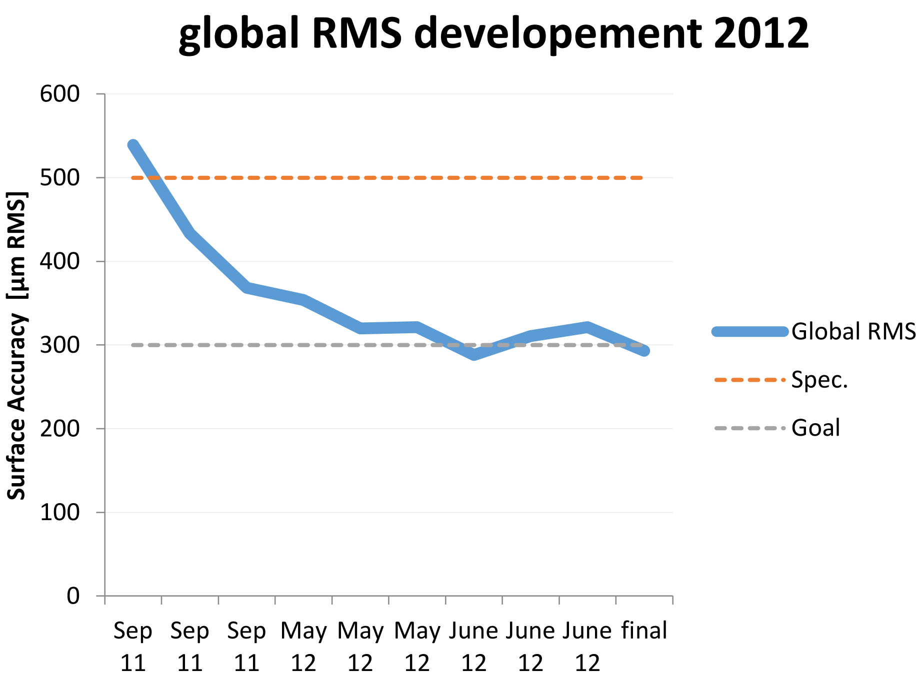
1 : 2.000.000 !!!

Example: SRT Mirror Alignment

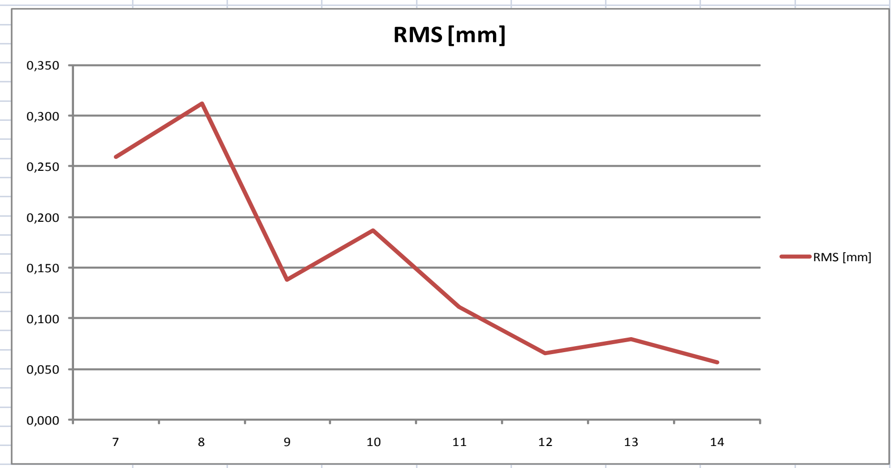




Example: SRT Mirror Alignment



Nr.	7	8	9	10	11	12	13	14
Messung	Messung04, 12.05.2010	Messung01, 13.05.2010	Messung02, 13.05.2010	Messung03, 13.05.2010	Messung03, 13.05.2010, gefittet	Messung01, 15.05.2010, gefittet	Messung02, 15.05.2010, gefittet	Messung02, 16.05.2010, gefittet
Mittelwert [mm]	0,010	0,004	-0,006	-0,018	-0,023	-0,02	-0,032	-0,024
RMS [mm]	**0,259**	**0,312**	**0,138**	**0,187**	**0,111**	**0,066**	**0,080**	**0,057**



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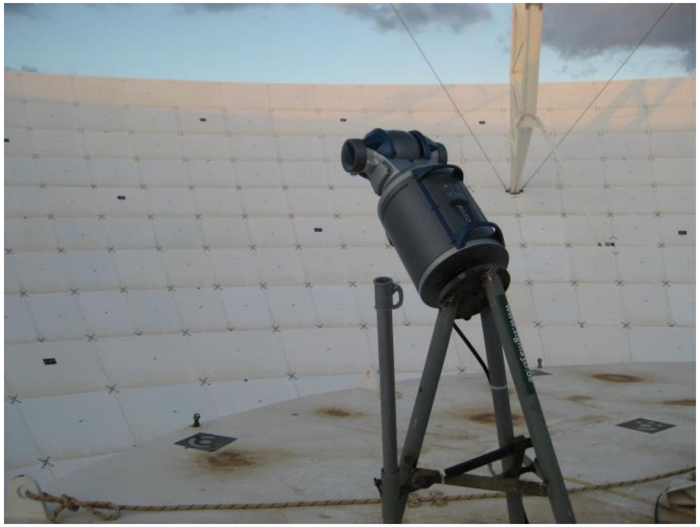
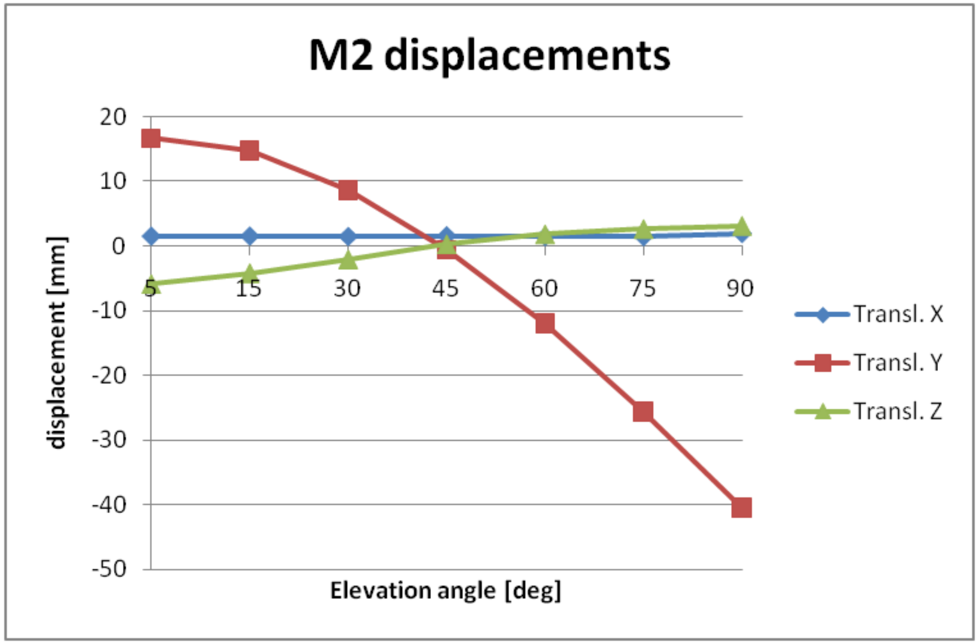
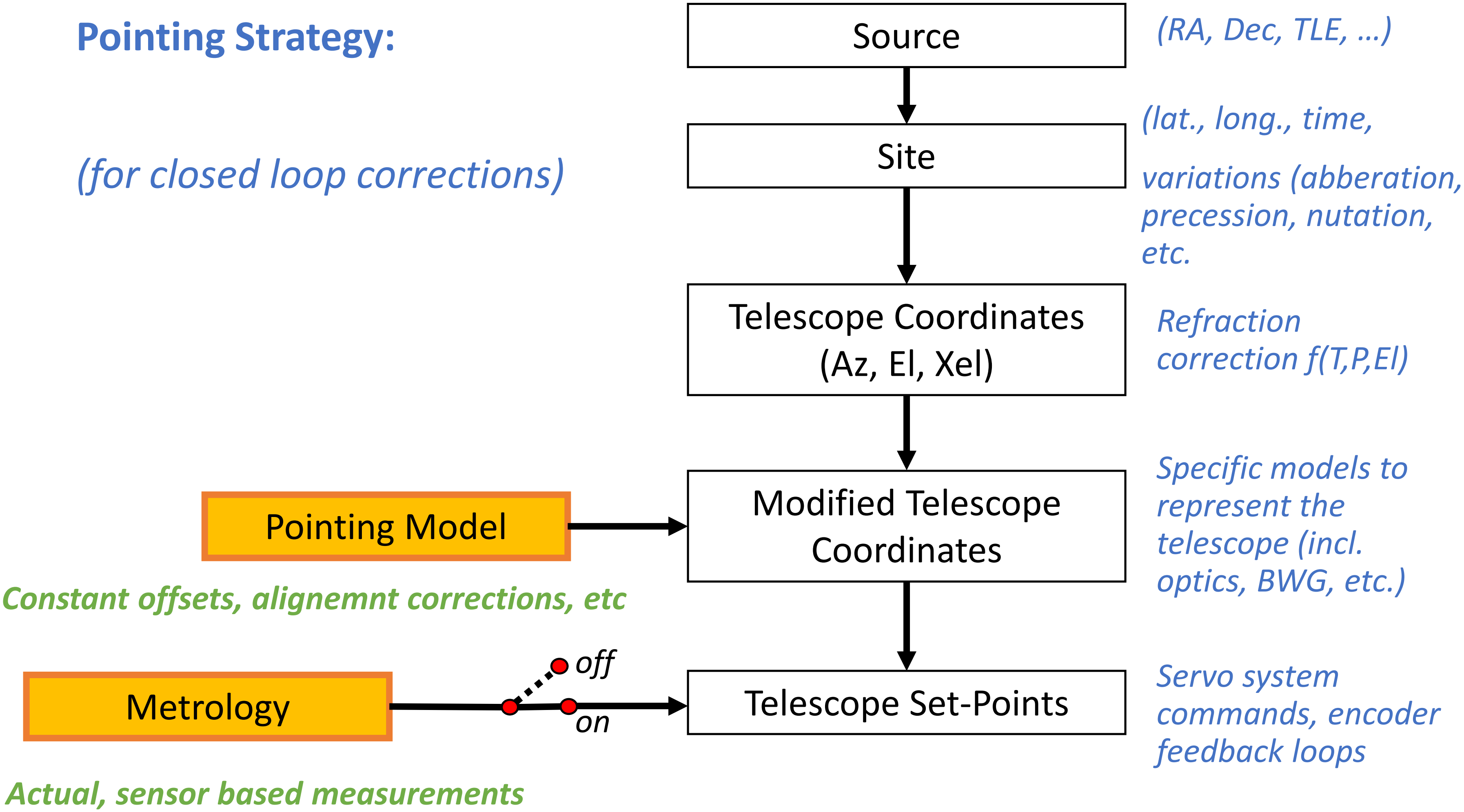




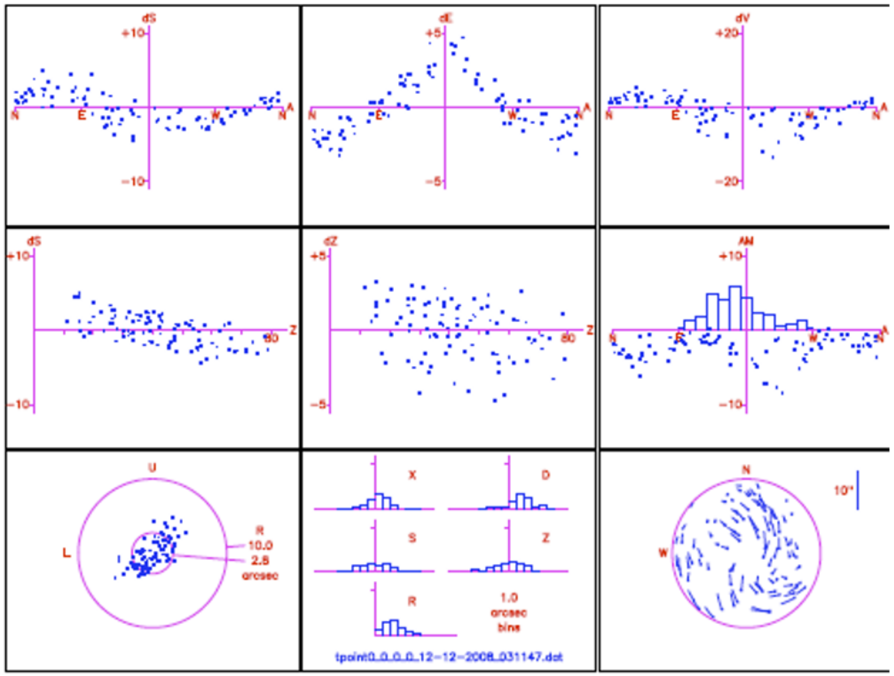
Pointing Strategy:

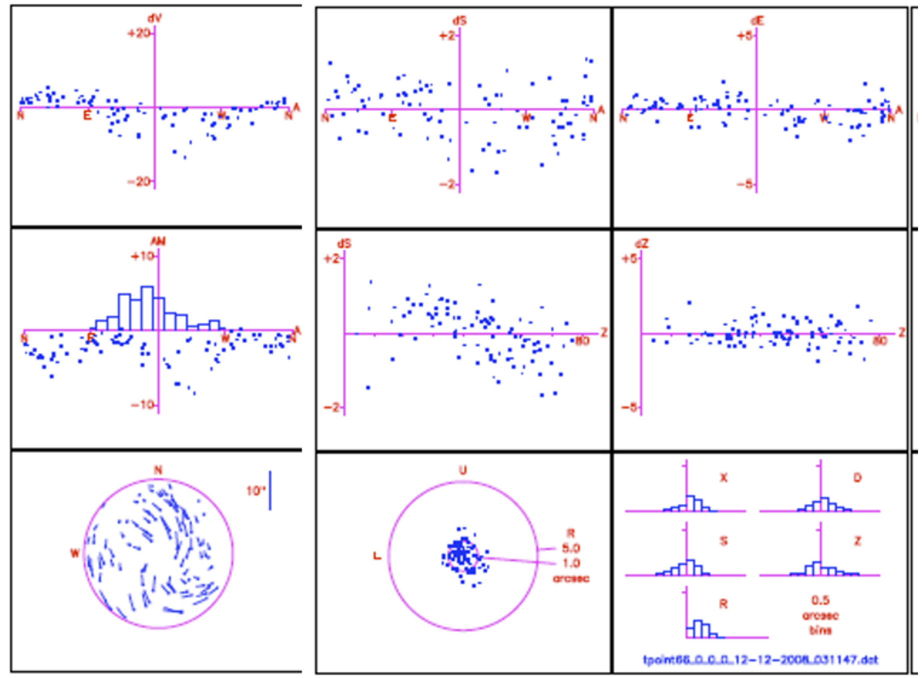
(for closed loop corrections)



(Concept similar to „ The ALMA Pointing System“ by Jeff Mangum)

Practical Results





Metrology off: 2.79“ rms

Metrology on: 1.01“ rms

(observed under transient conditions, approx. 2h during sunset,
200 stars, Metrology on / off every 10 stars, 5 sec integration time)

Conclusions:

Generally, there are two possible approaches:

Measuring the causes: (wind, gravity, temperatures)

or

Measuring the consequences (tilts, offsets, pointing errors)

Sometimes it is not distinguished between the two. If compensated by an active, closed loop metrology systems, this can cause „overcompensation“, meaning that you compensate twice for an error contribution that only occurs once!

This seems trivial, but to avoid, deep insight into all systems is required!

Conclusions:

Telescope performance can be improved by metrology systems under non-ideal conditions

Best observations achieved are during perfect conditions <u>without</u> metrology

Metrology systems are introducing addituional levels of complexity and sources of errors (calibration, noise in feedback loops)

Metrology is effort in terms of:

- infrastructure (sensors, actuators, wiring, control)
- Test and Comissioning
- Calibration time (lost for observation)
- **EXPERIENCE!**

Therfore: First design a proper telescope, then add metrology systems <u>AND</u> a button to switch them off in good nights !!!

Final Conclusion:

μέτρον + λόγος

Metrology is not **magic**, for 2 reasons:

1.) It can be done and works!

2.) does not enchant a poor design into a perfect beauty!