System Engineering and Surface Control

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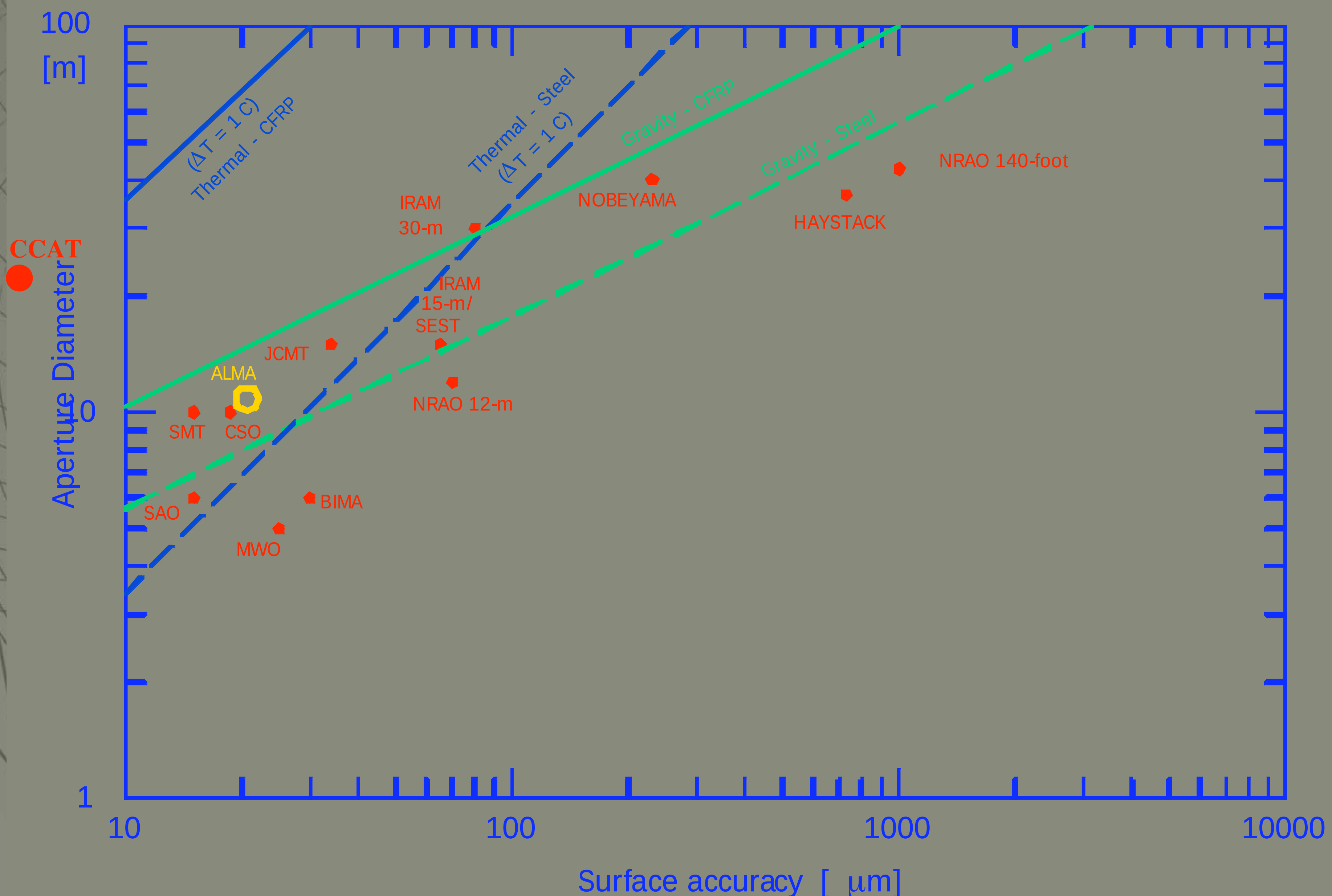
outline

- Concentrate on RMS wavefront error
  - Not pointing
  - Not image quality
- CCAT in perspective
- Surface maintenance
- Bottom up error budget calculator
- Next steps

Updated von Hoerner Plot

(Lamb ALMA memo)



Context for CCAT

- Physical limits shown in updated Von Hoerner plot
  - CFRP, etc.
  - Homology
  - Dome
    - No solar heating
    - Minimal wind
- CCAT will have an active surface
  - Passive would represent large risk at this point
    - Telescopes close to the limits on the plot already employ CFRP and high degree of homology
  - Active surface reduces risk and increases complexity

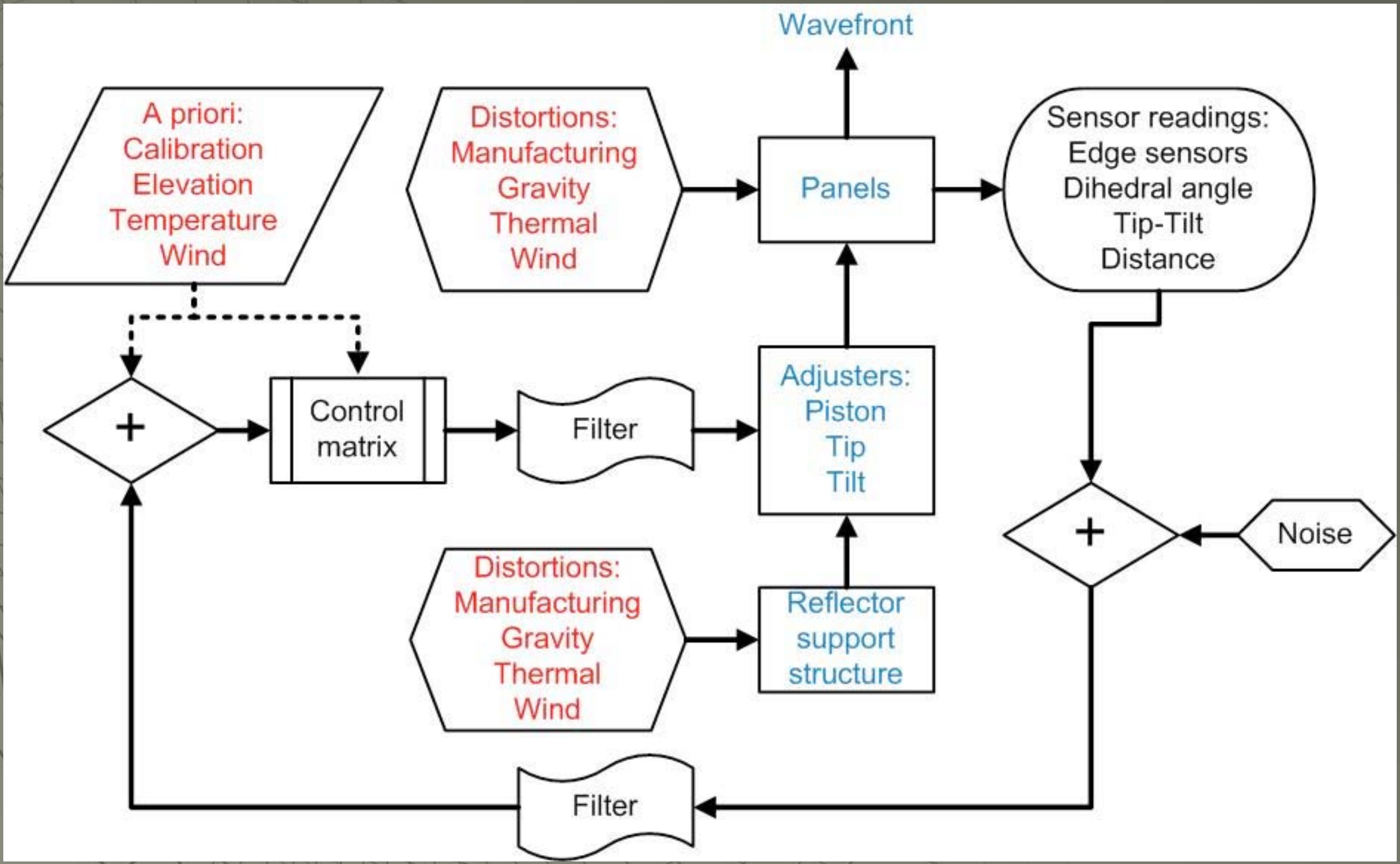
Top-Down error budget

1/2 Wavefront Error Budget			
	ALMA RFP template [microns]	CCAT [microns]	
Total Panel (RSS)	11.8	5.0	
Total Backing Structure	7.5	4.0	wind, vibration, panel xy
Total Panel Mounting (RSS)	5.4	4.0	Active Surface Control
Total Secondary Mirror (RSS)	8.4	3.5	
Total Tertiary Mirror (RSS)	0.0	3.5	
Total Measurement and Setting (RSS)	10.0	4.0	Astro. WFE & Holography
Other Errors not Included Above	2.0	1.5	
TOTAL (RSS)	20.0	10.0	

7.5 microns for primary

6.5 microns for rest

Surface control diagram



Control Matrix

Mirror motions produce an array of sensor measurements

$$s_i = \sum A_{ij} a_j$$

To control the system you need to find actuator positions from sensor measurements

$$a_j = \sum B_{ji} s_i$$

Can make a pseudo inverse of the forward matrix by using singular value decomposition

$$A = U w V^T$$

$$B = A^{-1} = V \frac{1}{w} U^T$$

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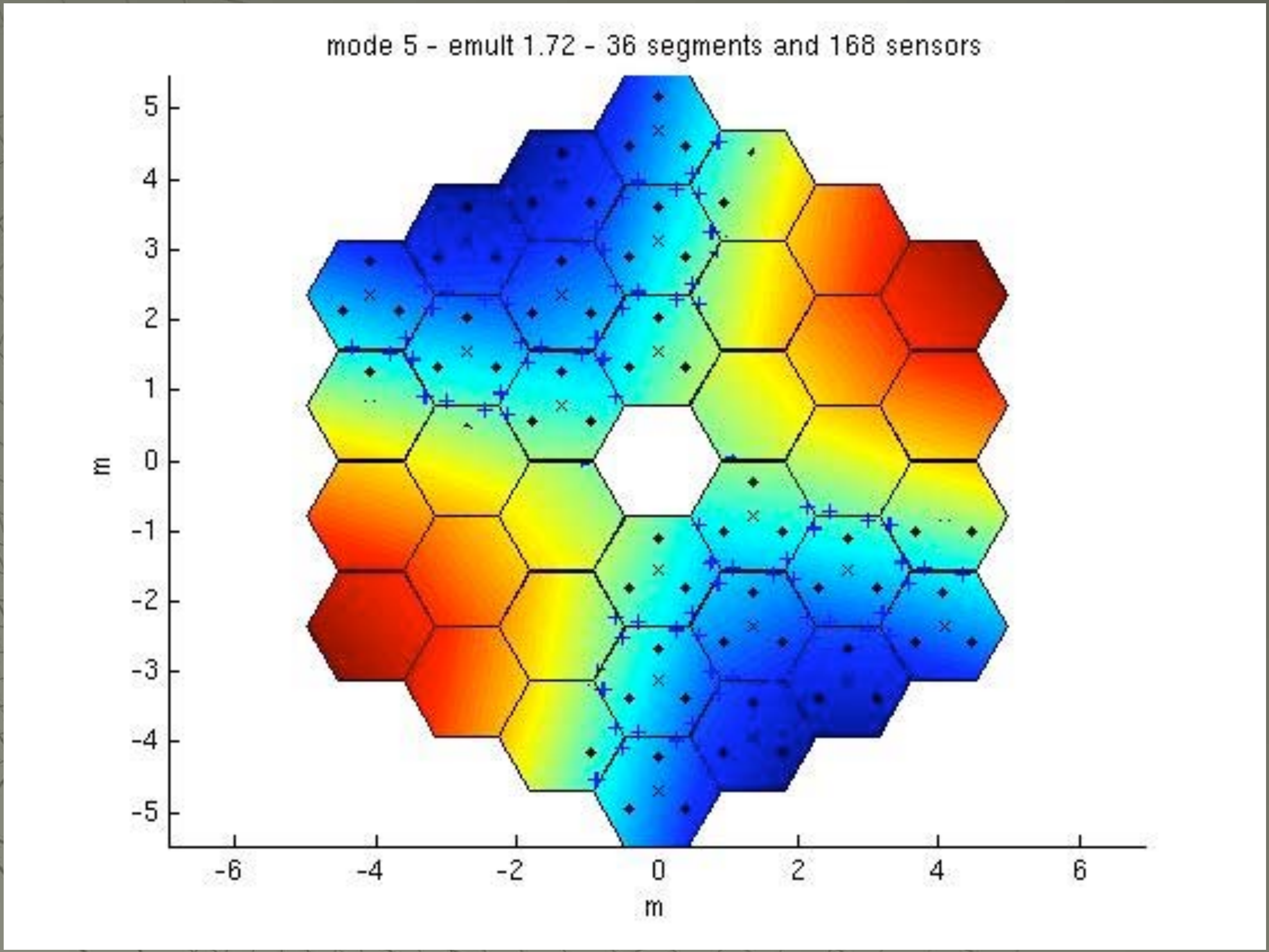
Analysis program capability

- Segmented mirror with 3 DOF (3 actuators) per segment
- Non-rigid mounting structure
- Non-rigid panels
- Telescope initially aligned (only maintain)
- Changing environment
- Arbitrary sensing of positions
- Actually two parallel attacks (C++ and MathCad)

Verify against Keck



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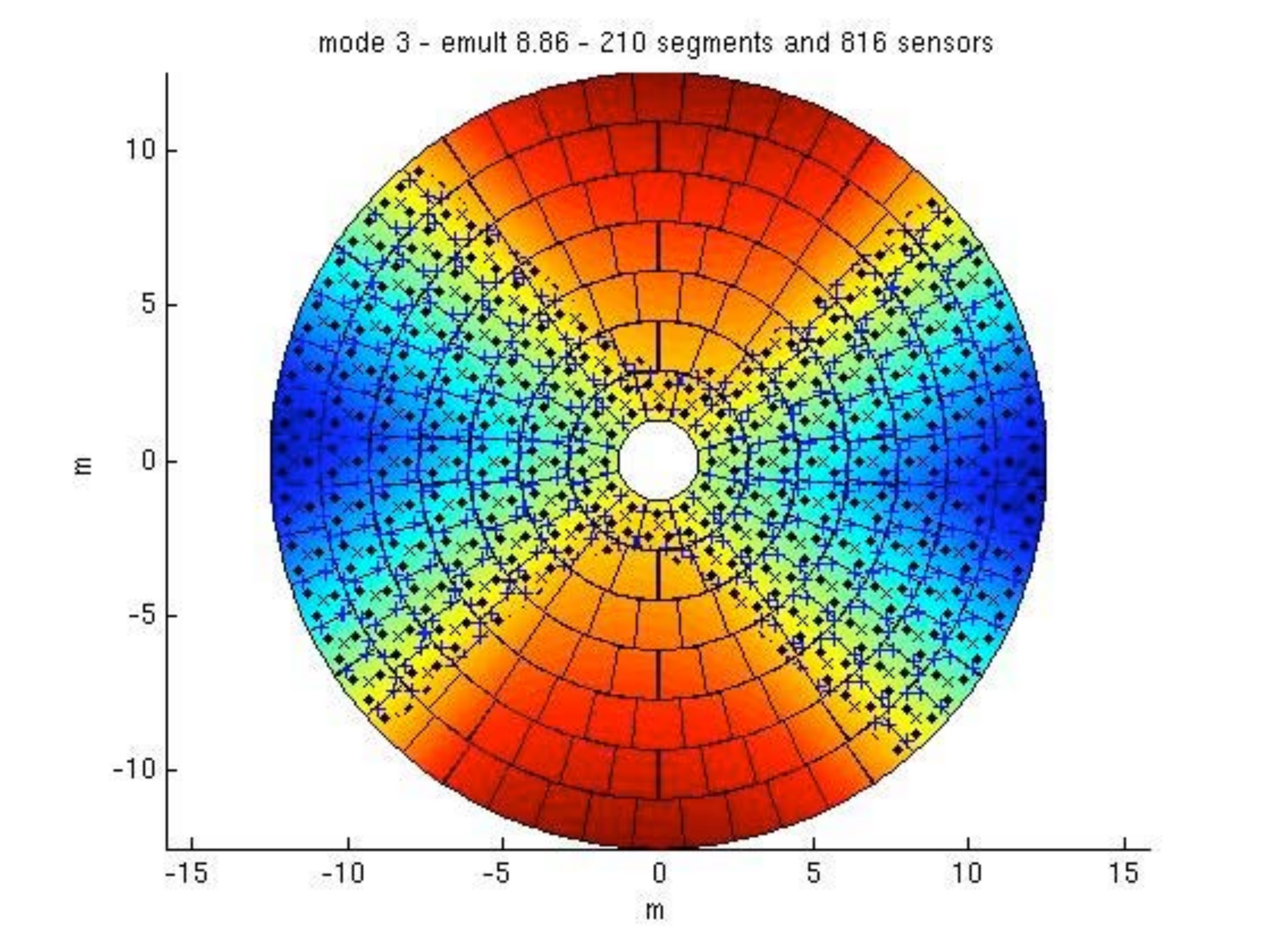
Sample Eigen Mode



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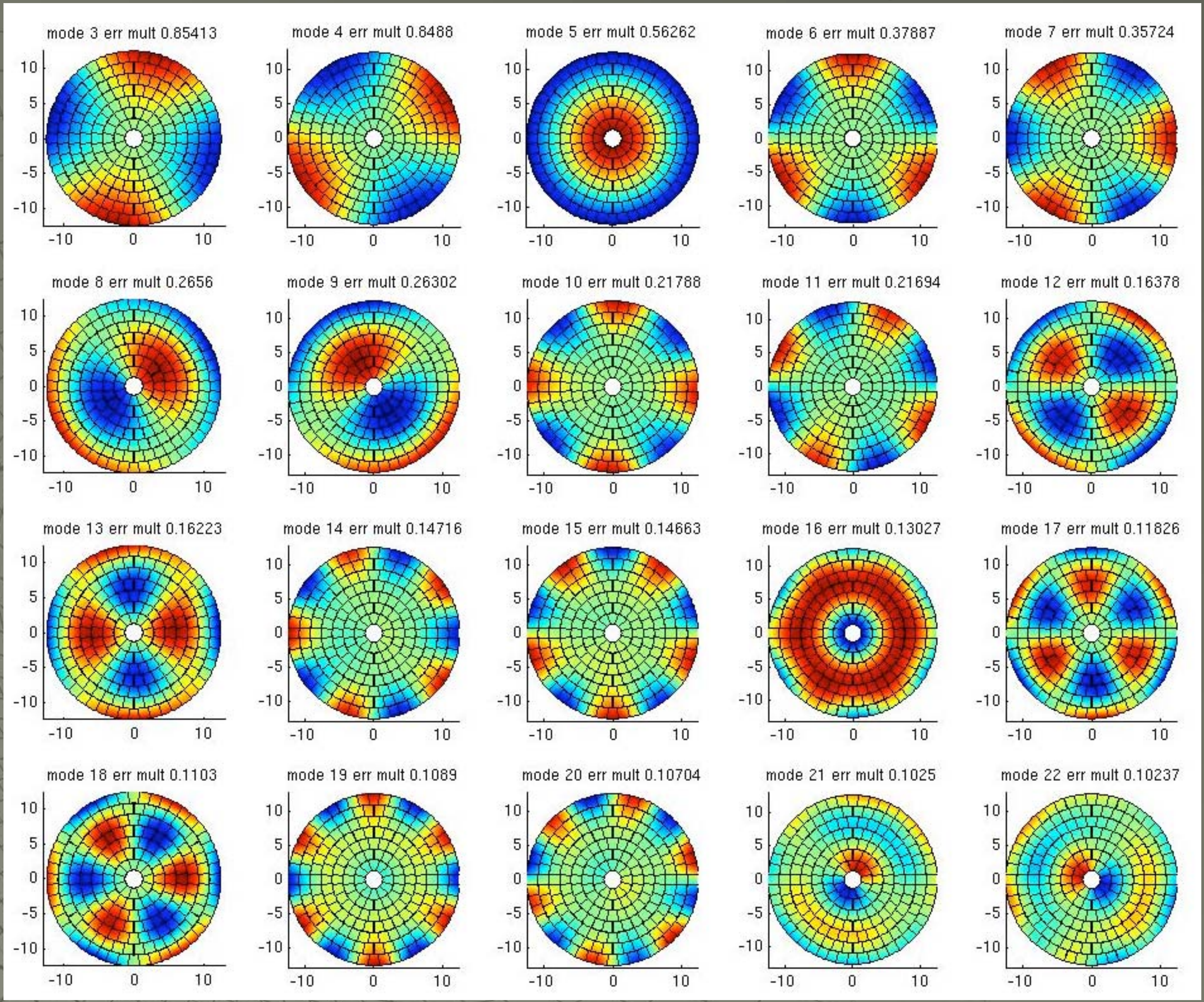
Mirror modes with dihedral angle sensors



Edge and dihedral angle sensors. Solid body modes 0-2 (tip, tilt and piston) are not sensed by edge and dihedral angle sensors

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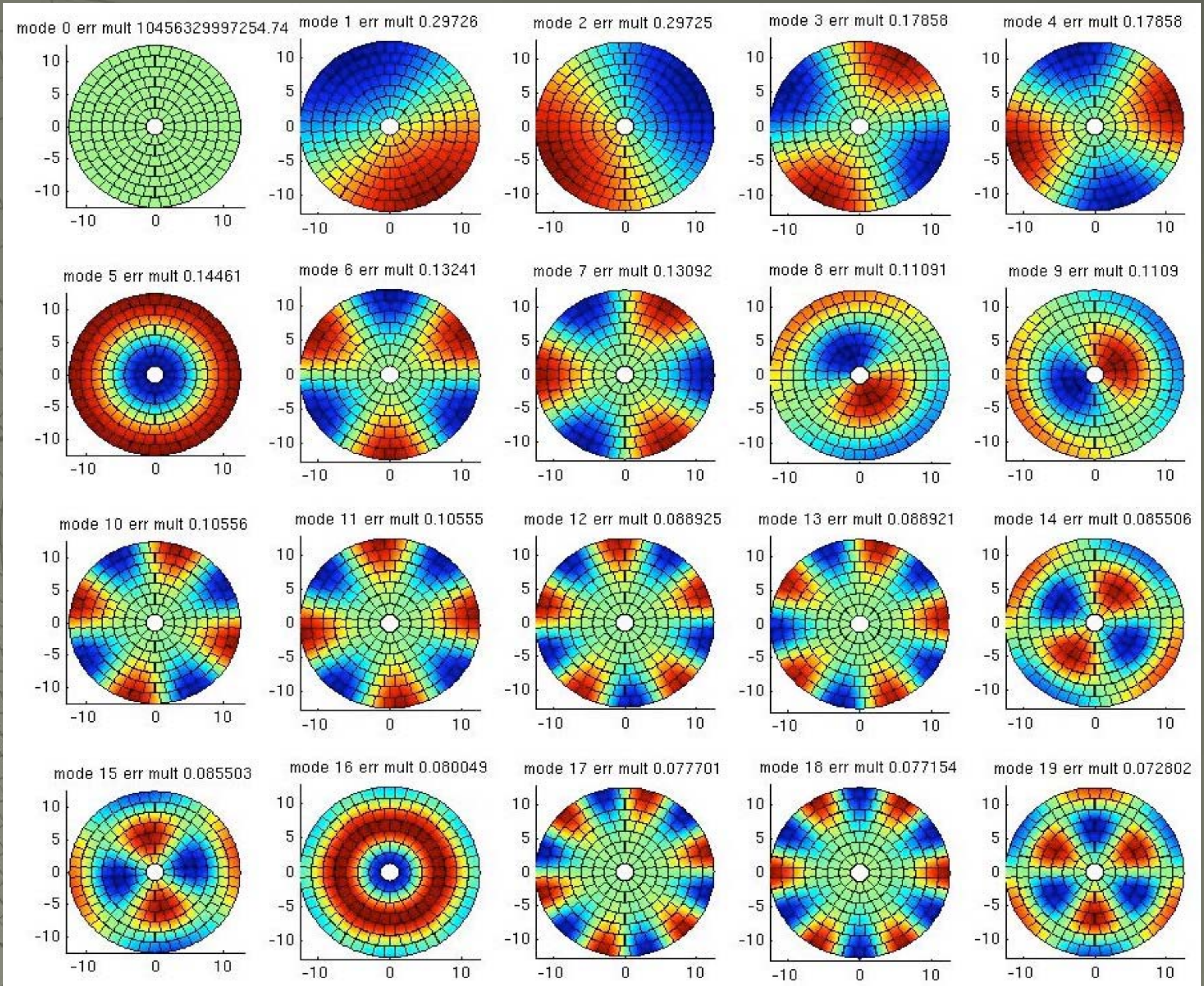
Mirror modes with tip-tilt sensors



55 mm offset mirror modes with absolute angle sensors (shack-hartman like sensors.) Piston is the only unsensed mode.

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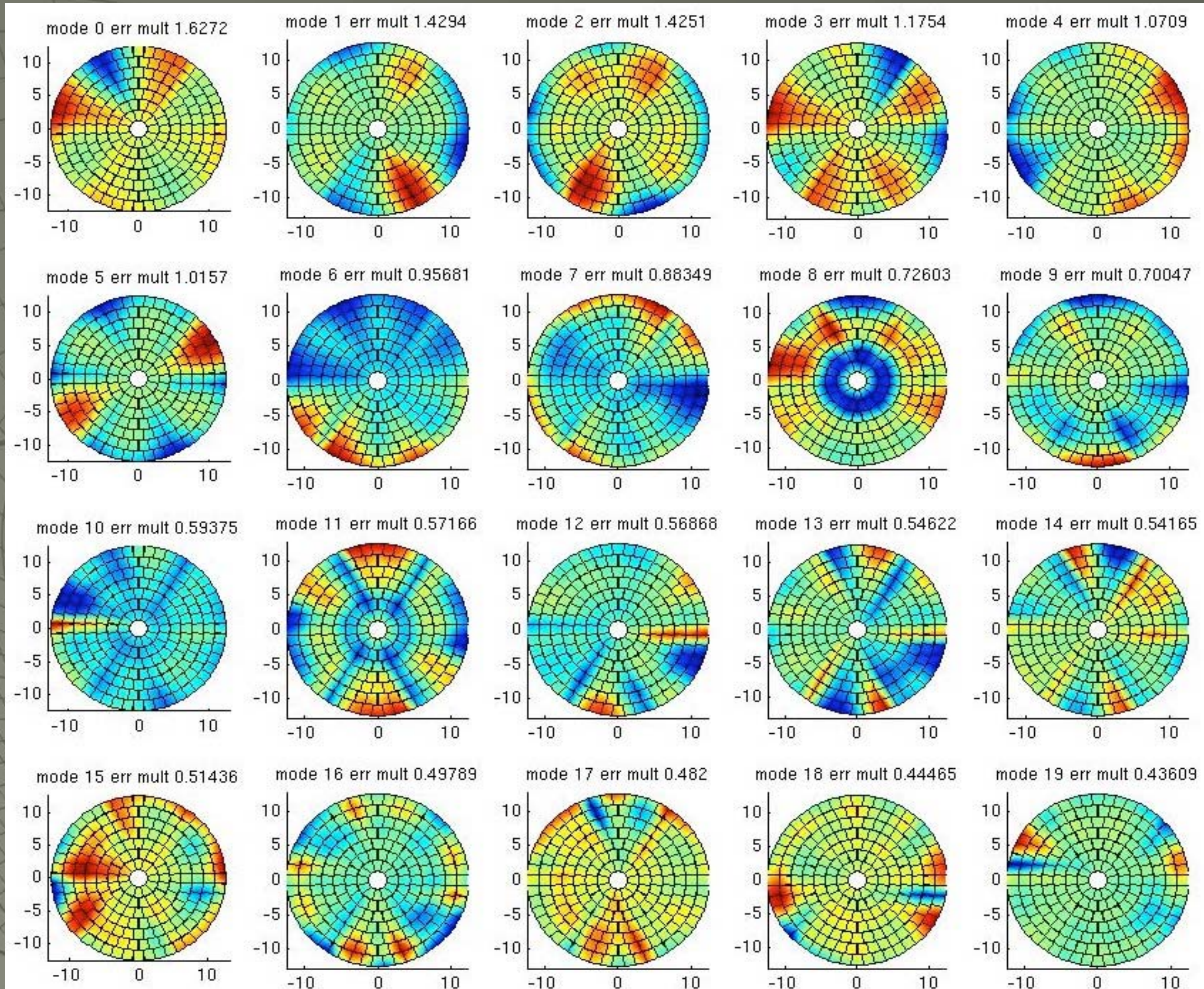
Mirror modes with 20 metrology beams



55 mm offset mirror modes with metrology sensors. Solid body modes are sensed by metrology beams

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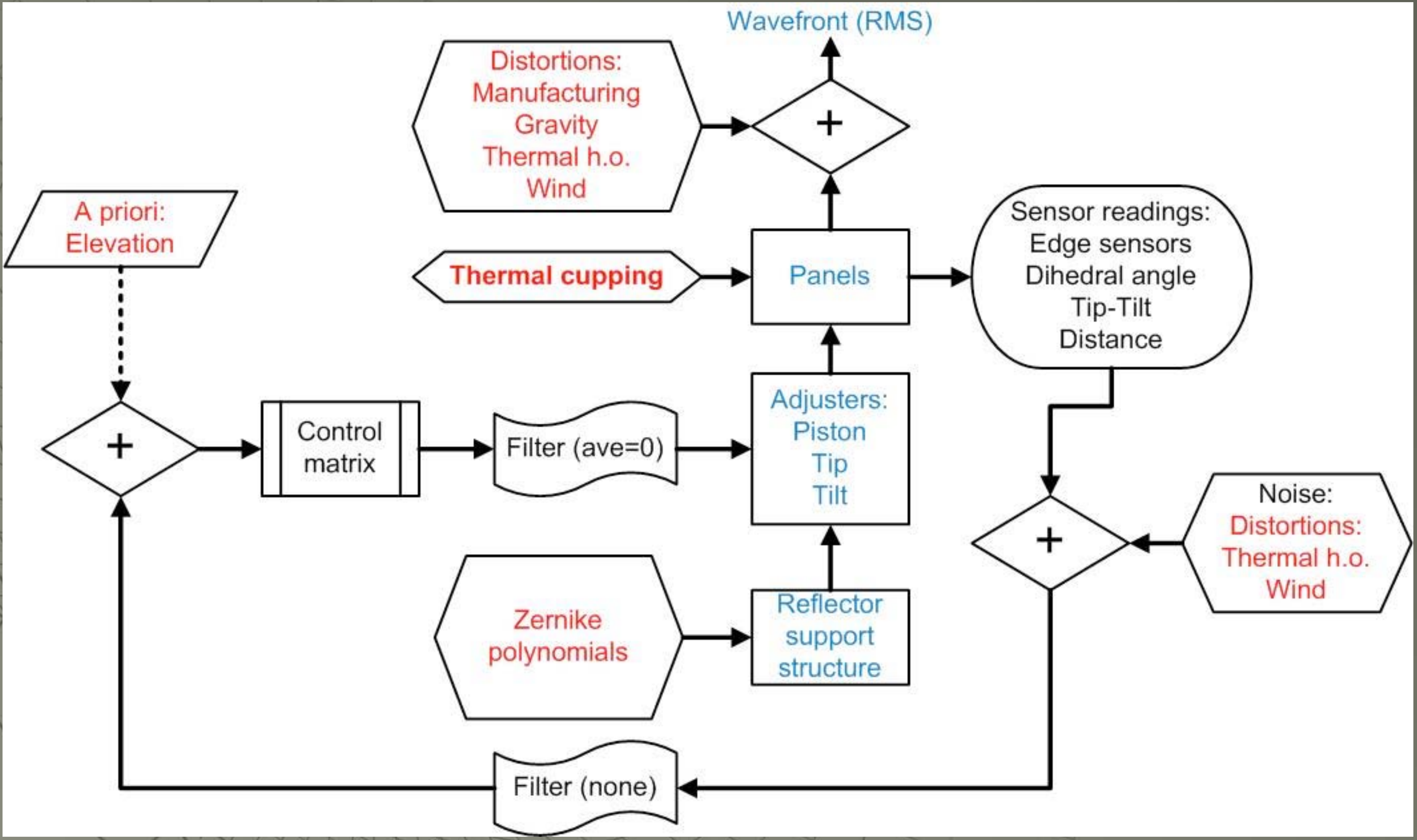
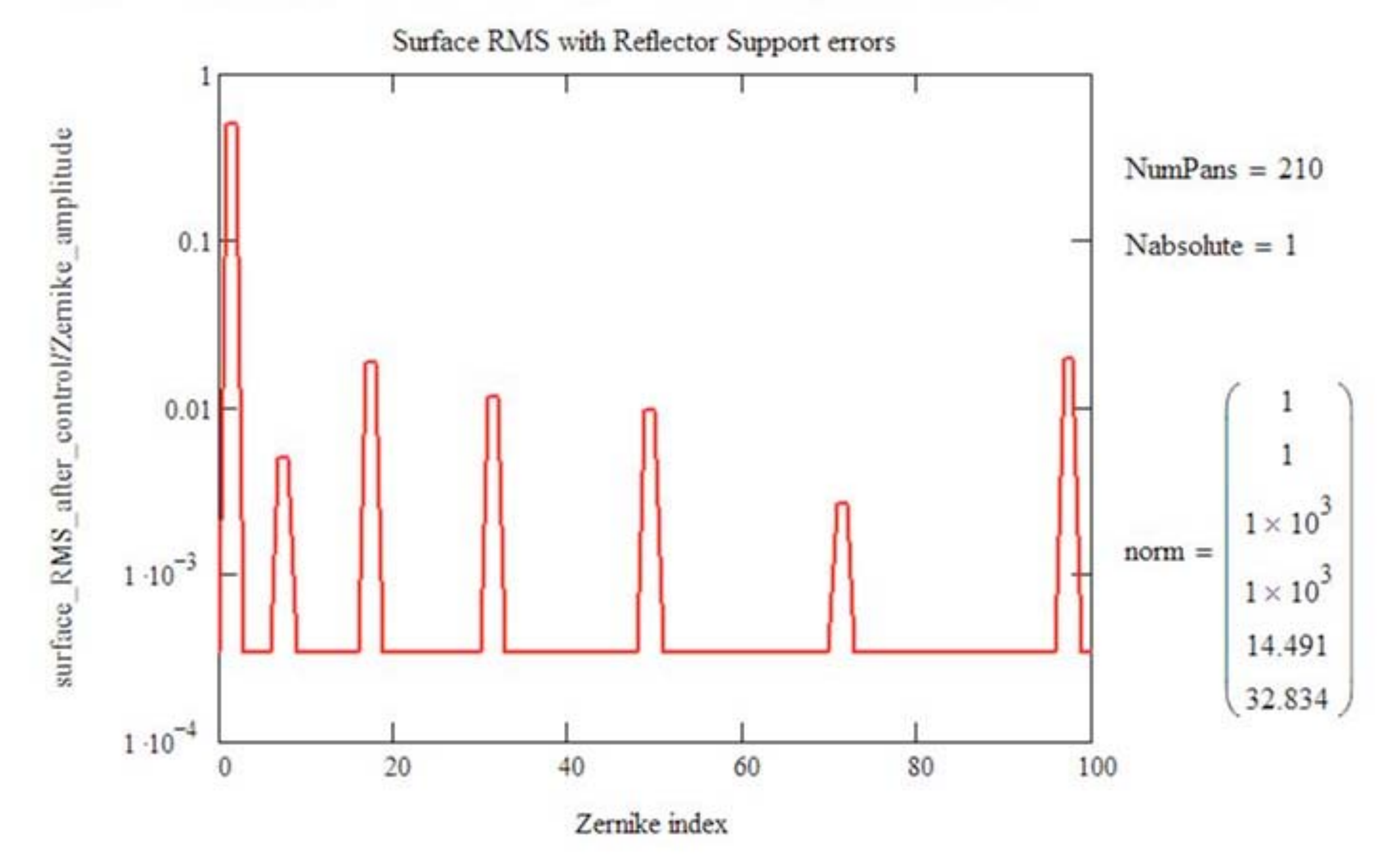
Surface control simulation



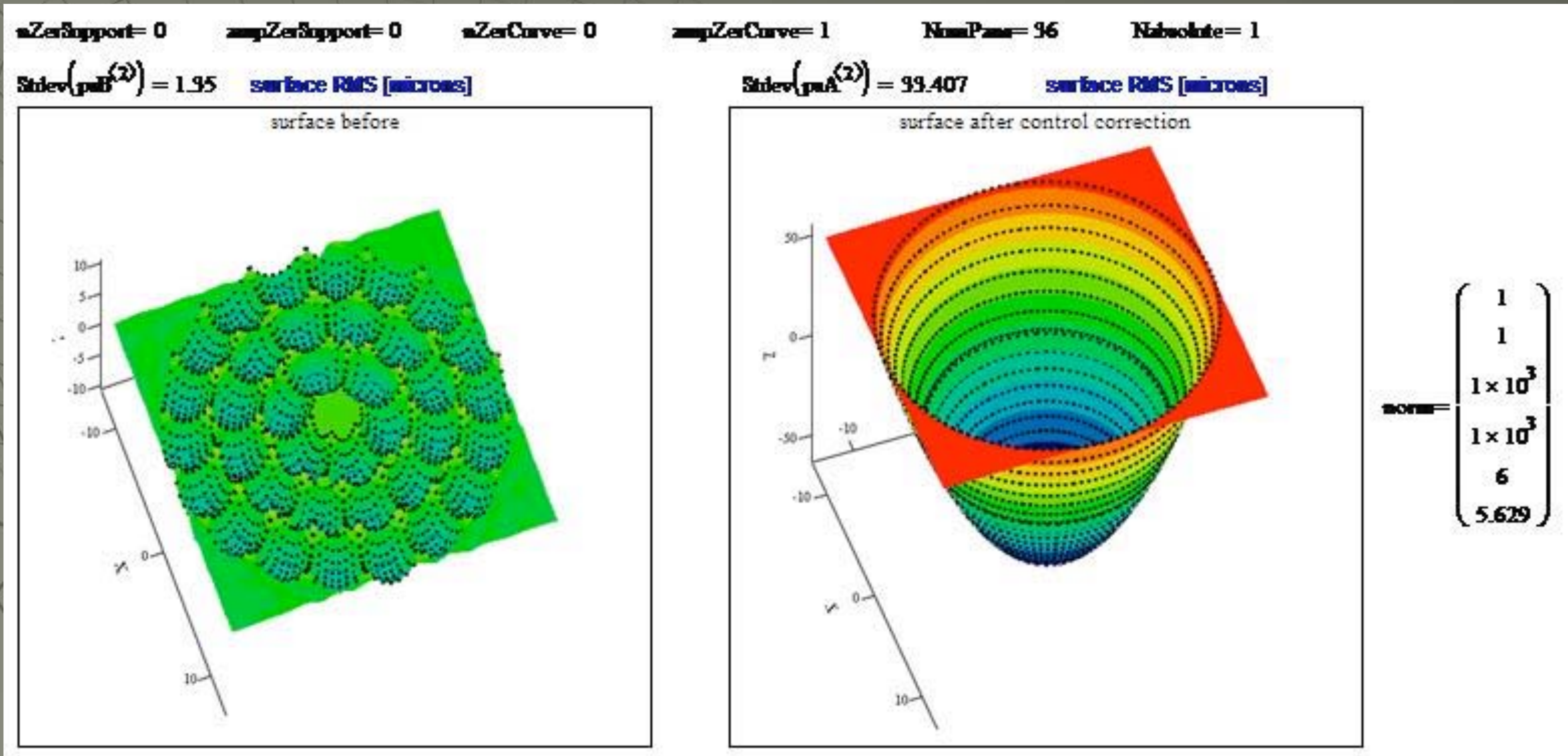
Correcting Reflector Support distortions



Peaks are solutions producing a tilted plane. This response will be filter out.

Effect of thermal cupping

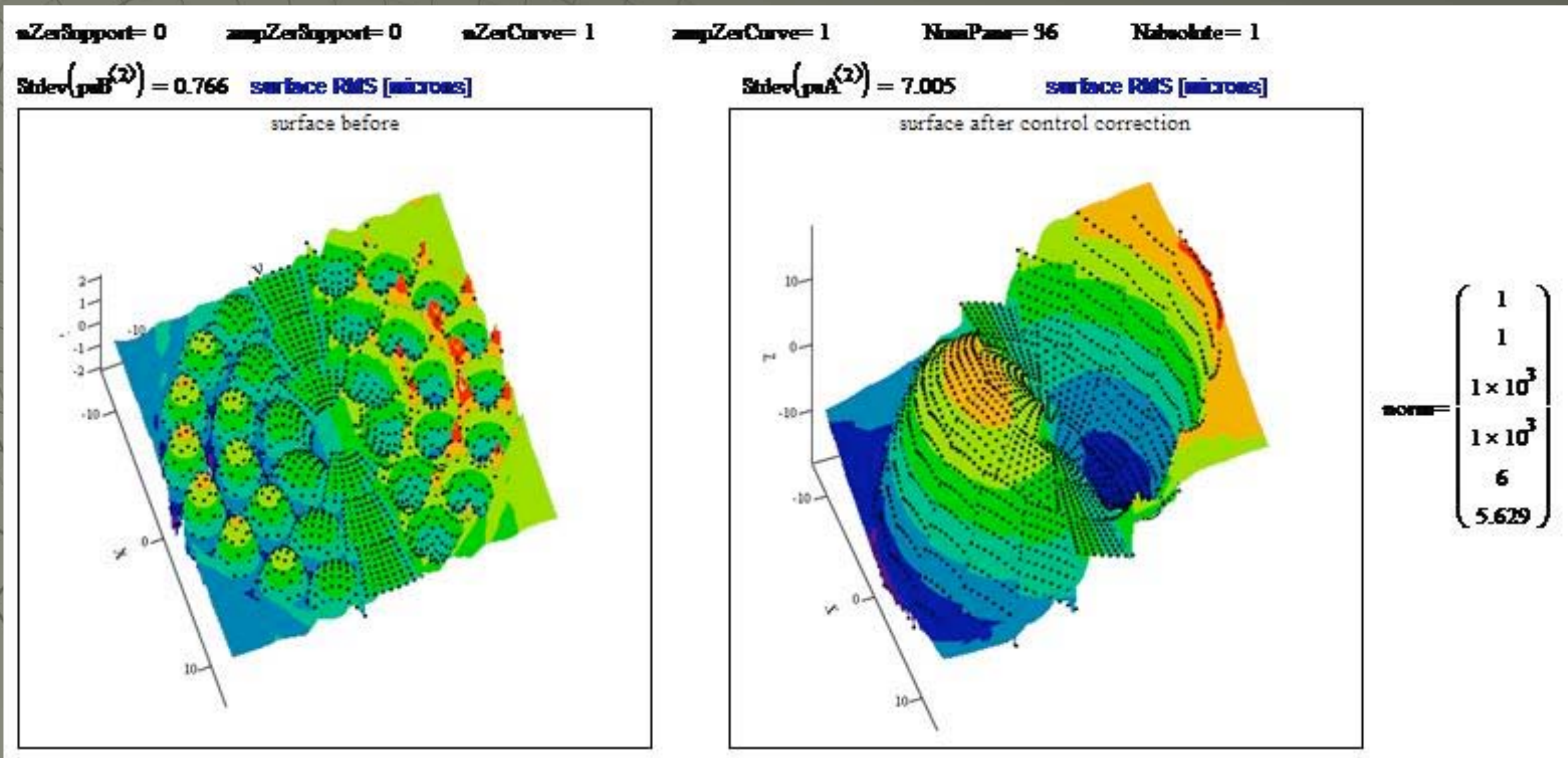
36 panel telescope with edge and dihedral sensors
Uniform curvature for all panels



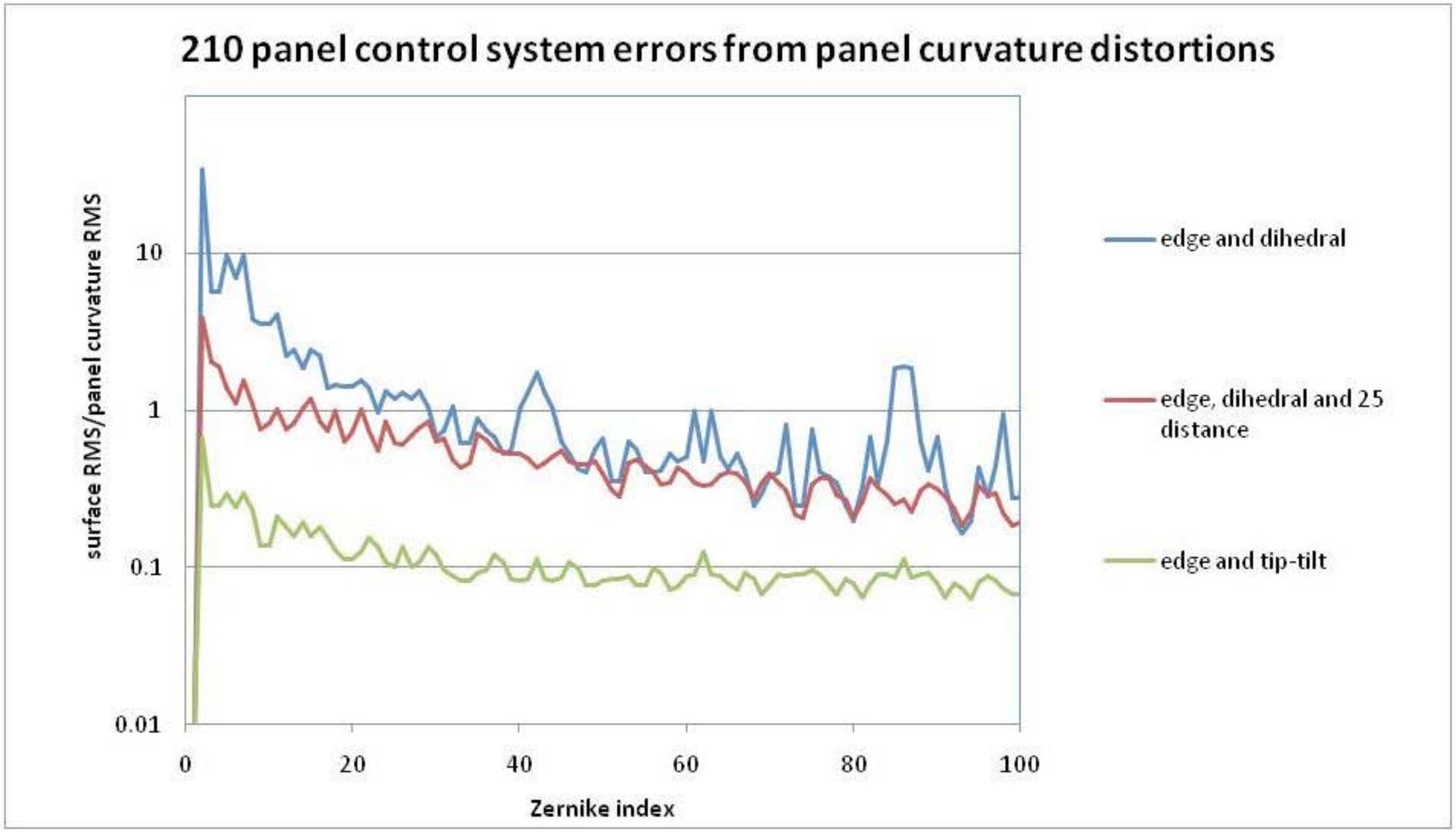
Applying the panel curvature coherently to the whole surface results in sensor readings of zero.

Curvature varies across the telescope

36 panel telescope with edge and dihedral sensors
Curvature amplitude given by Zernike #2



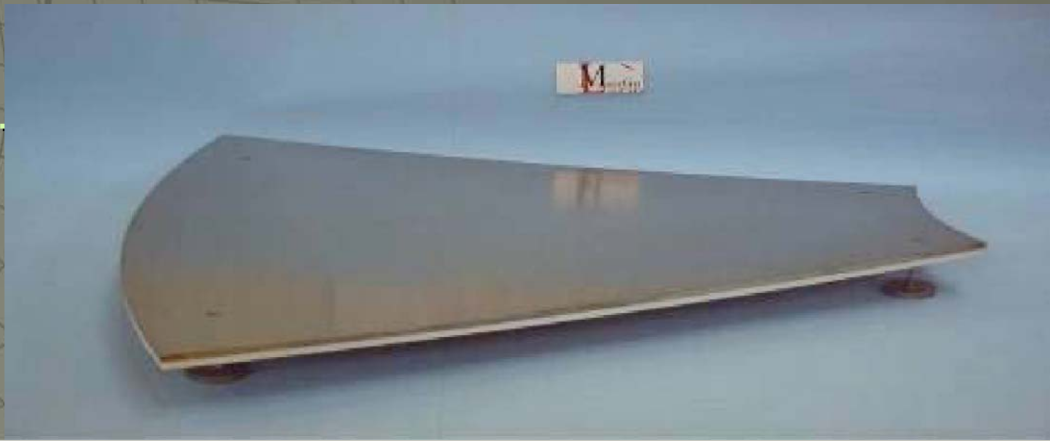
Effect of panel curvature errors



Distribution of panel curvature given by Zernike functions across the aperture.

Panel analysis

- Generic parametric model
  - Plate-core-plate laminate
  - Materials
    - Al, CFRP high strength, CFRP low CTE, Ni, steel, Invar, Beryllium, Borosilicate glass, ULE glass, SiC
  - Geometry
    - Panel size
      - Keystone supported at optimal three points
    - Plate thickness
    - Core thickness and densi



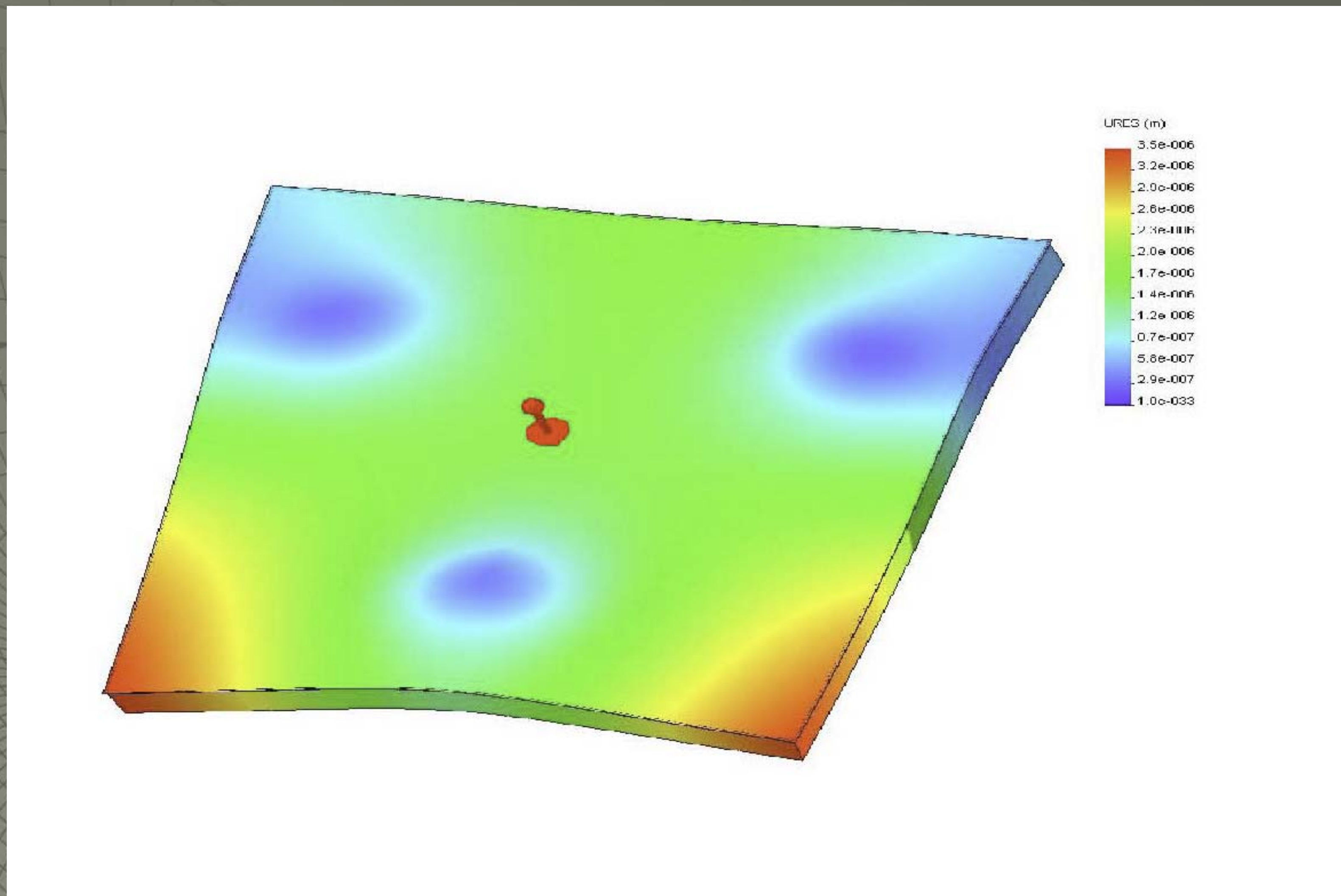
Panel errors

- Loads
  - Thermal: ΔT CTE
    - Uniform: D^2
    - lateral RMS: h
    - axial through segment: D^2/h
      - Radiative
      - Air and insulation
  - Gravity: $\rho\ t\ D^4 / Y\ h^2$
  - Wind: $v^2\ D^4 / Y\ h^2$
- Other errors
  - Fabrication: D^2
  - Aging: D^2
- Comparable to other detailed designs

Panel Deformations under Gravity

7-ring Segmentation panel:

- 100 mm thick
- 1.57 m R side
- 8.3 Kg/m²



2μ RMS Gravity With Little or No Optimization

Dual beam setup in vertical configuration with 2m path

Laser metrology system determines the absolute distance between two reflectors using heterodyne mixing process with 1.6 μm lasers

Developed at JPL for space applications but effects of atmosphere may be critical

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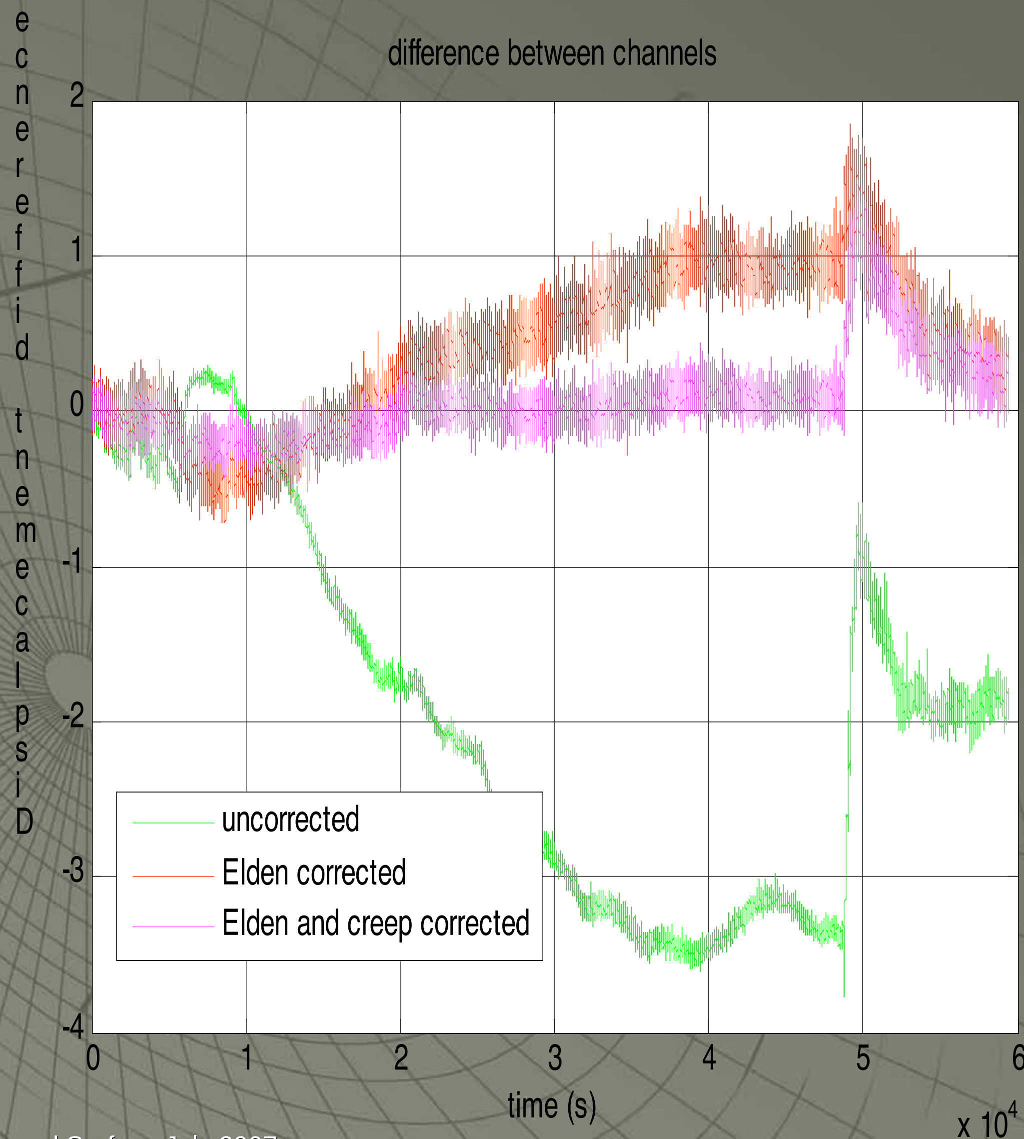
Long term distance monitoring – dominant effect is temperature changes of structure which can be corrected



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Laser metrology and turbulence: summary, status, and prospects

- Laser metrology may have important role in dealing with active surface modes not sensed by edge sensors and also measurement of secondary position
- Effects of air turbulence on 2m path are not excessive
- Extension to 4m path in next few weeks will give important baseline for scaling to CCAT distance scale

Alex Ksendzov, JPL

Error budget input parameters

- Panel design
  - dimensions: d, t, h, f
  - Materials
  - Fabrication errors for 1 m dia panel, typical value 1 micron
- Panel thermal environment
  - Change in average temperature
  - RMS air temperature over 1 m, $d^{1/2}$
  - Dome temperature
  - Insulation thickness
  - Thermal emissivity
  - Cold sky coverage
  - Boundary layer thickness
- Sensor configuration
  - Number of distance measuring devices and noise
  - Sensor noise
  - Number of panels (from panel dia)
  - (Panel errors feed into sensor errors)
- Misc. error sources
  - Panel location
  - Wind
  - Surface measurement map resolution
  - Vibration

Sample bottom up error budgets

1	**Telescope design case**	1	2	3	4	5	6	7	8	9
2	28-Jun-07	CMA					MLT			
3	**panel design**									
6	face sheet material	CFRPH	CFRPL	CFRPL	CFRPL	CFRPL	Ni	Ni	Ni	Ni
13	core material	Al	Al	Al	Al	CFRPL	Al	Al	Al	Al
26	manufact RMS for a 1m panel [micron]	0.30	0.30	0.60	1.00	0.50	0.30	0.30	0.30	0.30
29	**Telescope configuration**									
30	dia [m]	25	25	25	25	25	25	25	25	25
31	**segments**									
32	panel size, diagonal [m]	2.46	2.16	2.16	1.70	2.80	1.83	1.83	1.83	2.16
35	number of panels	162	210	210	340	125	293	293	293	210
36	areal density [kg/m^2]	9.96	8.75	8.75	6.88	12.20	12.18	12.18	12.18	14.37
38	panel errors [microns]									
39	gravity	1.78	3.43	3.43	2.12	2.03	3.88	3.88	3.88	5.41
40	wind	0.31	0.62	0.62	0.53	0.29	0.55	0.55	0.55	0.65
41	Temp. change	0.01	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.15
44	thermal cupping	0.47	0.04	0.04	0.02	0.11	3.59	3.59	3.59	4.82
45	lateral Trms	2.50	2.05	2.05	1.43	0.02	1.60	1.60	1.60	2.05
46	manufacturing errors	1.82	1.40	2.80	2.89	3.92	1.00	1.00	1.00	1.40
48	net panel error	3.7	4.3	5.0	3.9	4.5	5.7	5.7	5.7	7.7
50	**primary figure maintence**									
51	number of distance measurements	1	1	1	1	1	1	1	25	25
52	distance measuring error	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
56	surface error from edge sensors	1.06	1.08	1.08	1.28	0.18	5.95	5.95	0.24	0.23
59	tip-tilt angle meas. improvement	1.00	1.00	1.00	1.00	1.00	1.00	0.10	1.00	0.10
60	surface error from angle sensors	1.41	1.81	1.81	2.79	0.77	2.43	1.86	0.10	0.05
61	panel curvature control effect	4.80	0.38	0.38	0.25	1.11	36.97	3.70	7.39	0.99
62	net surface maintenance error	5.1	2.1	2.1	3.1	1.4	37.5	7.2	7.4	1.0
64										
65	vibration, wind, panel xy setting	5.36	5.00	5.00	4.65	5.91	4.73	4.73	4.73	5.00
66										
67	**total primary 1/2WFE**	8.3	6.9	7.4	6.8	7.6	38.2	10.3	10.4	9.2
69	other non-primary surface 1/2WFE									
70	secondary	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49
71	tertiary	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49
72	wavefront measurement	4.16	4.16	4.16	4.18	4.15	4.17	4.17	4.17	4.16
73	**total other contrib. 1/2WFE**	6.5	6.5	6.5	6.5	6.4	6.5	6.5	6.5	6.5
74										
75	**total telescope 1/2WFE**	10.5	9.5	9.8	9.4	9.9	38.8	12.2	12.3	11.3

Current Status and Bullets

- Have a nearly complete set of tools for analyzing CCAT configurations including the surface maintenance and control system
- Panel design is critical
  - Thermal cupping
  - Fabrication errors with 3 point support
  - Interactions with sensors and control system are important
- Tip-Tilt (Shack-Hartmann) sensors would be extremely useful
- The very challenging CCAT specifications should be achievable with careful design and fabrication

Future work at JPL and OVRO

- Continue adding to the tools
  - Incorporate FEA of panels and reflector support
  - Add more of the control system into the simulations
  - Continue work on the error budget calculator
- Explore design space
  - Critical aspects of panels
    - Size
    - Thermal distortions
    - Sensor configuration
    - Etc.
  - Critical aspects of the reflector support
    - Distortion amplitudes
    - Actuator properties
    - Etc.