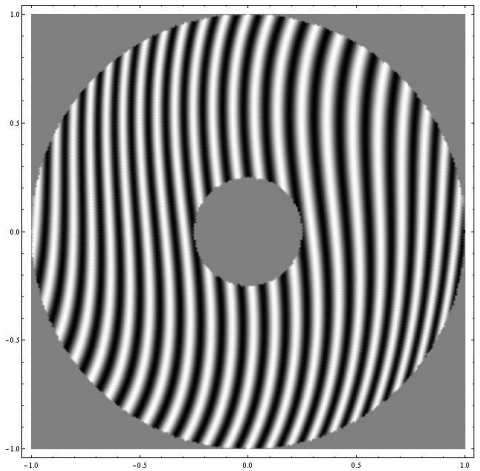
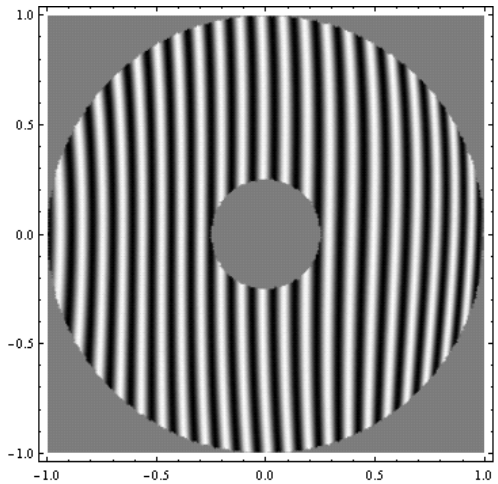
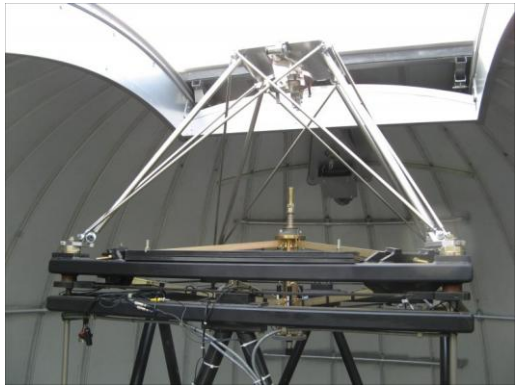
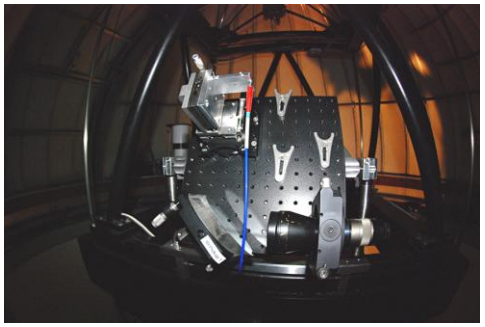
Telescope Alignment

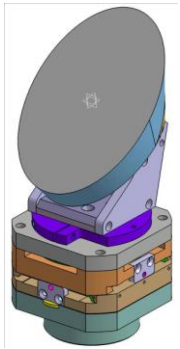
Laszlo Sturmann

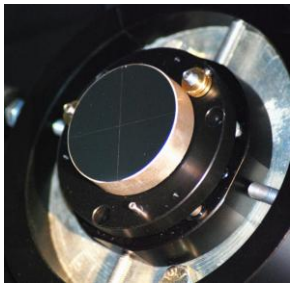
How do we get from  to  ?

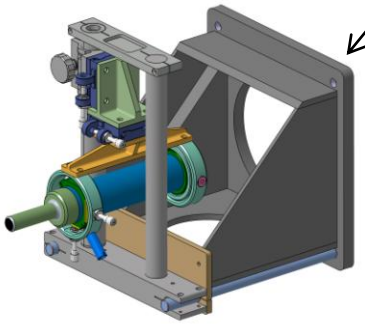
Perhaps Photoshop? (Nils)

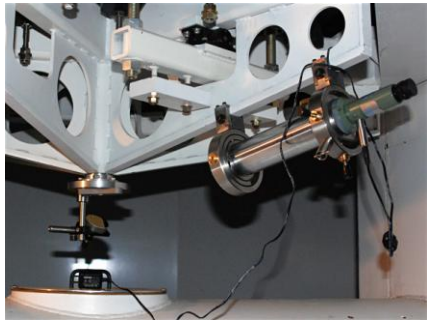








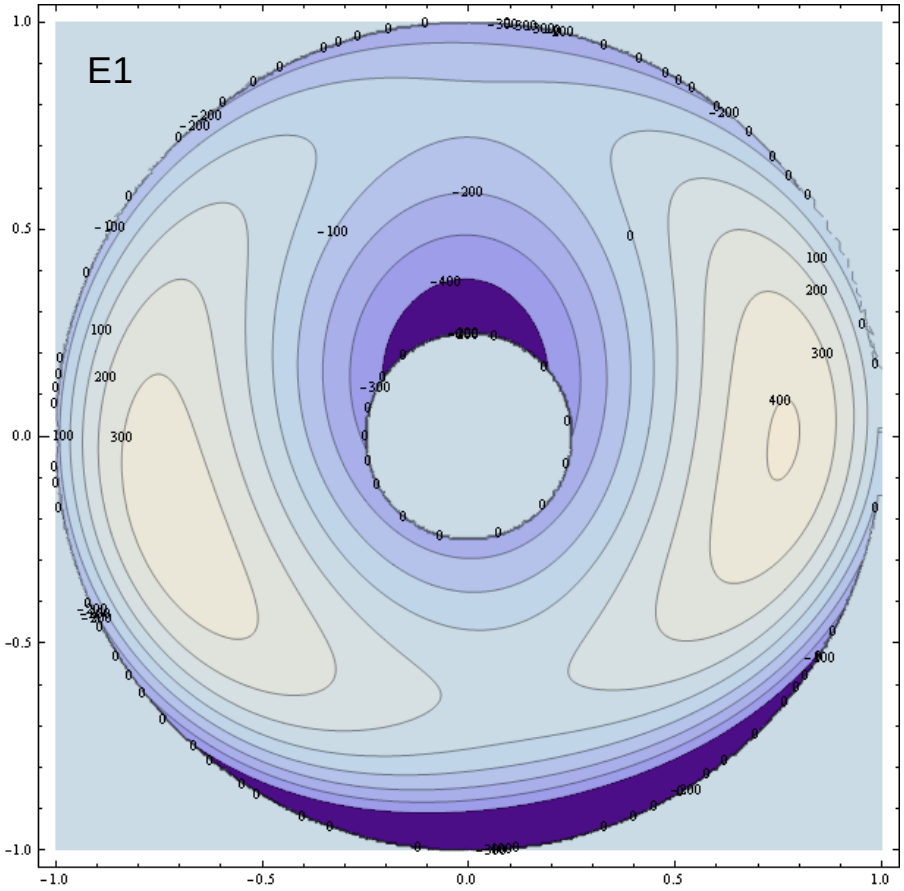




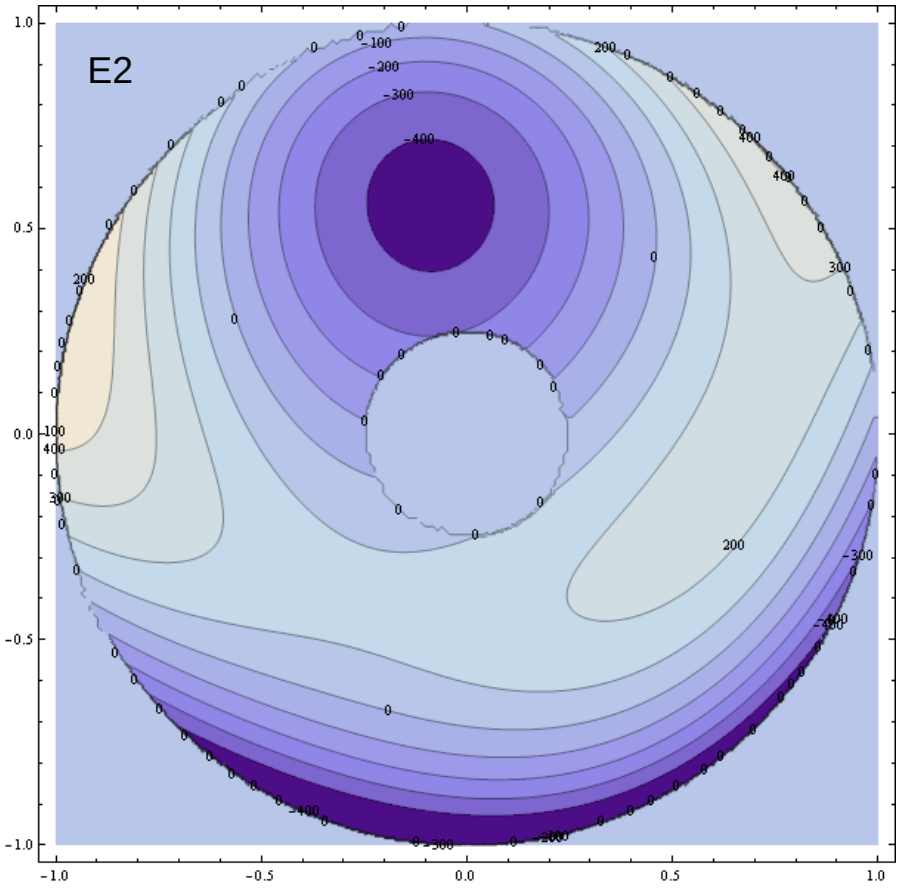
a precise telescope alignment procedure was applied to E1, E2 and W1 in Spring 2009

Wavefront Contour Plots

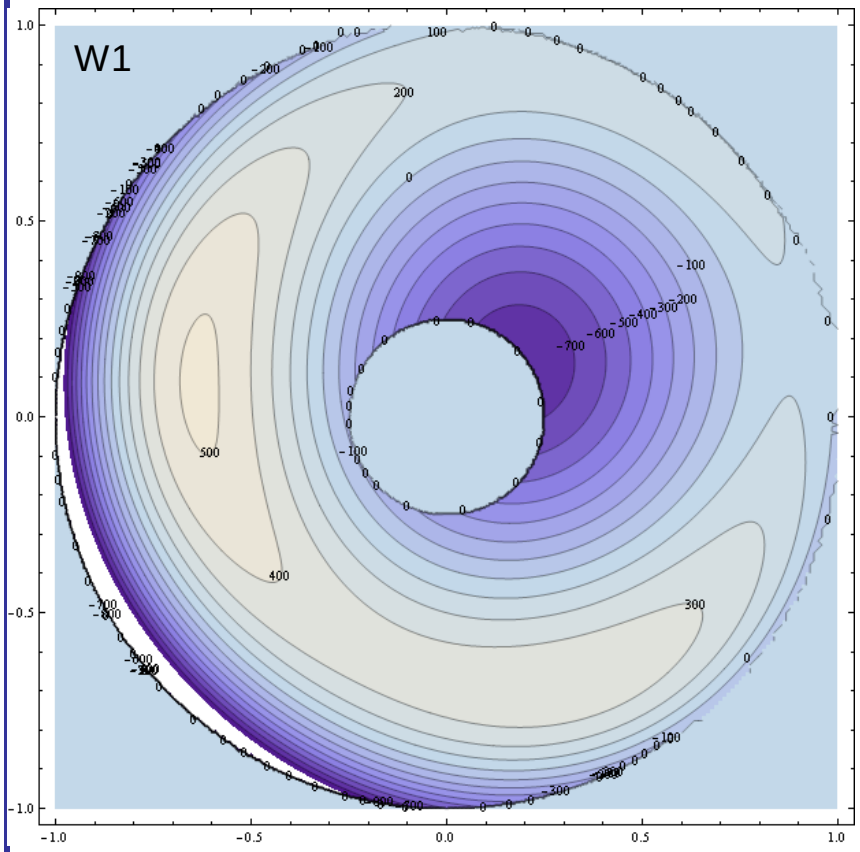
4/14/2009 P-V = 710 nm



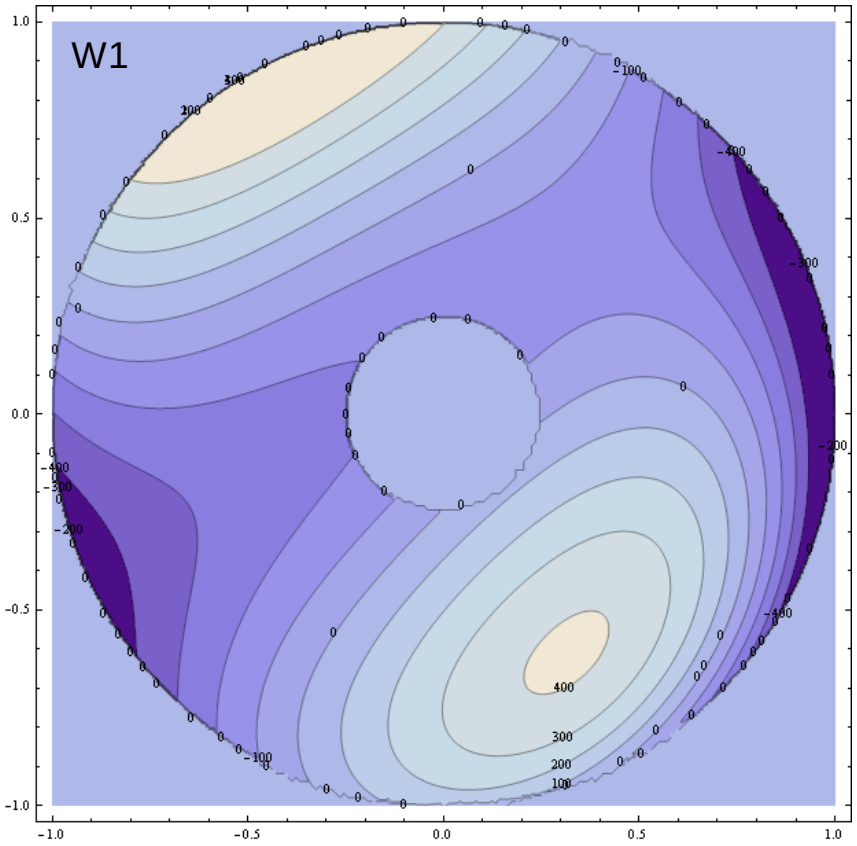
5/18/2009 P-V = 960 nm



4/4/2009 P-V = 1940 nm



5/31/2009 P-V = 1280 nm

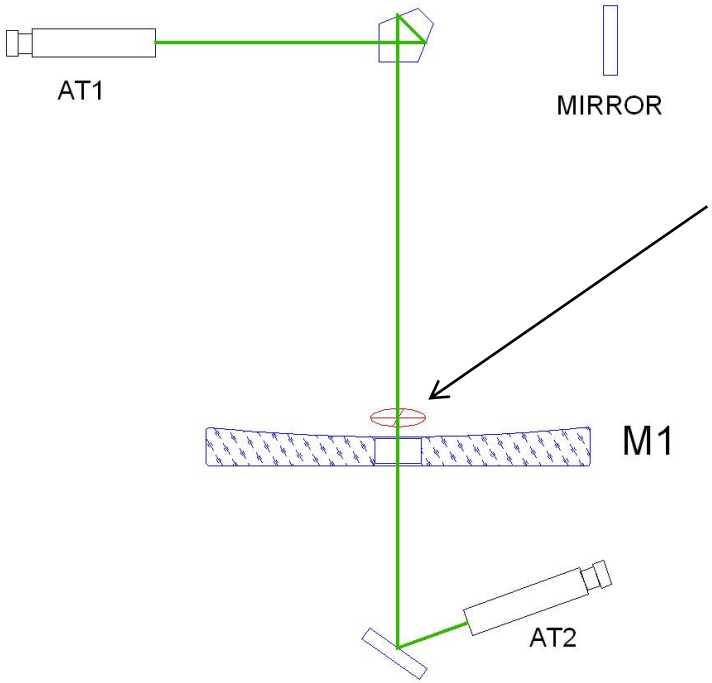


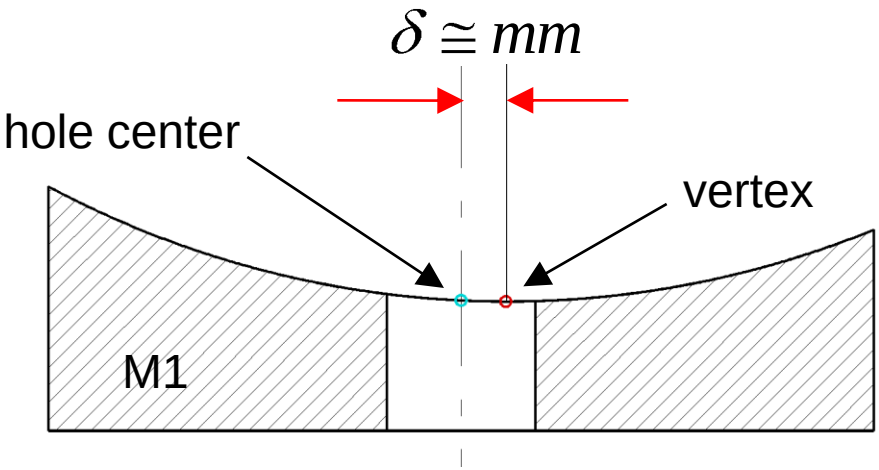
ef

Zernike [nm]	Name	E1 (4/14/2009)	E2 (5/18/2009)	W1-A (5/31/2009)	W1-B (4/4/2009)
4	focus	346	364	-842	-661
5	astigmatism	30	29	-96	-152
6	astigmatism	134	146	-31	-145
7	coma	93	154	136	70
8	coma	-6	-41	224	-81
9	trefoil	-12	45	13	22
10	trefoil	24	-48	-22	21
11	spherical	-152	-28	-191	-44

concentrating on these

The new alignment procedure is precise, but not necessarily accurate

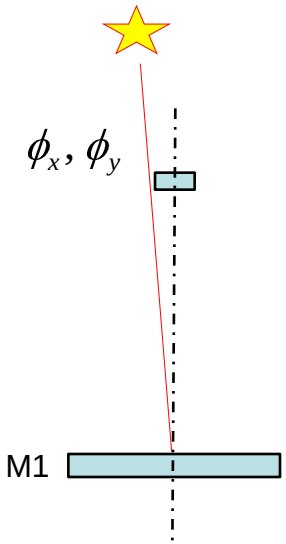


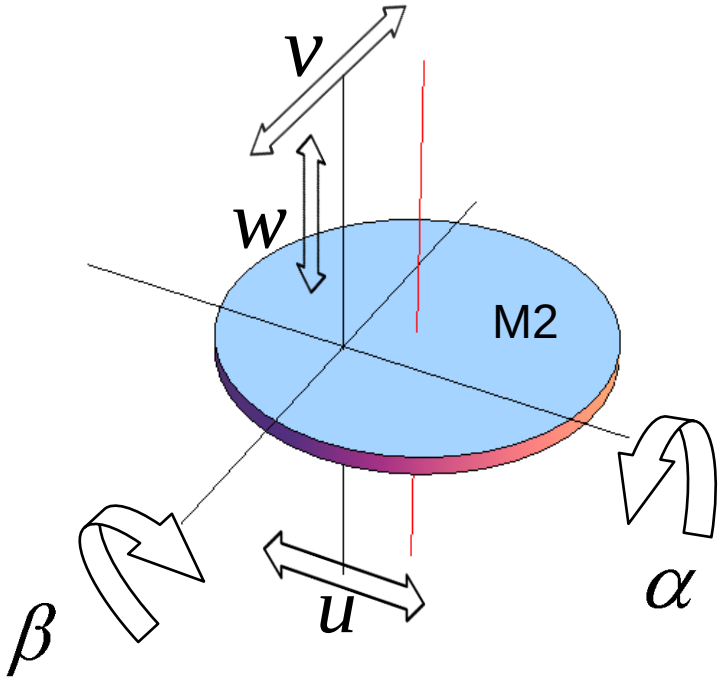


δ is unknown and may result in misalignment

Hypothesis

M2 is misaligned and star is off-axis

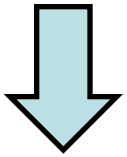




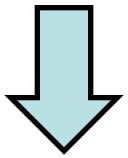
7 parameters

Action

slow beam quality evaluation due to seeing and 7 parameters

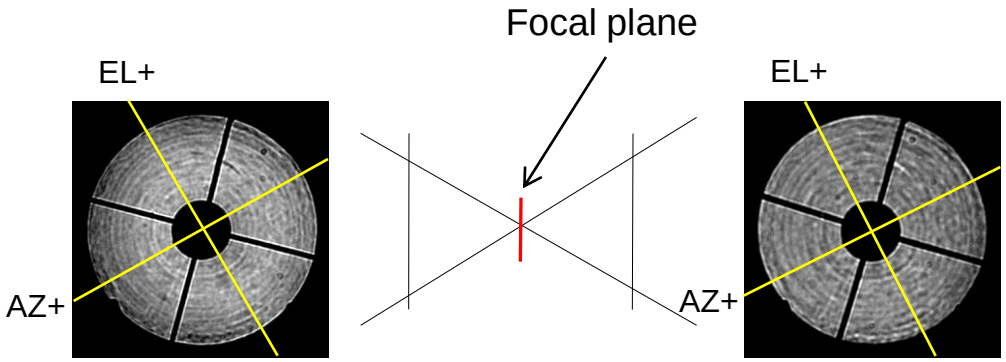


Random search for the best position/orientation of M2 is not feasible



?

ef expands the wavefront into annular Zernike polynomials



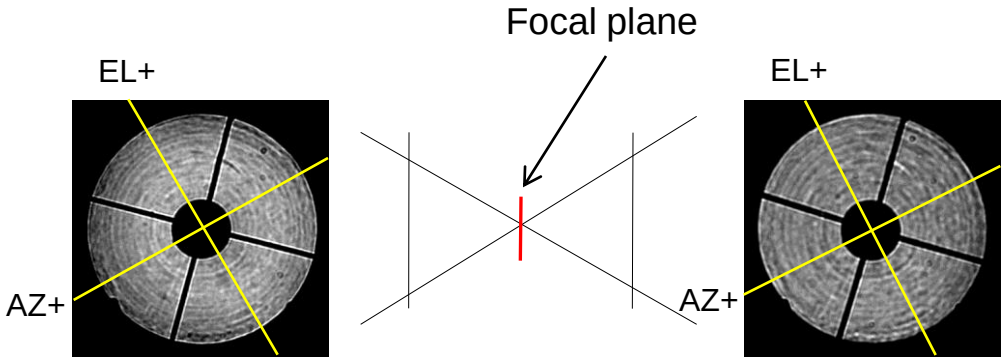
ef

Zernike annular coeffs.

$$(a_1, a_2, a_3, a_4, \ldots, a_n)$$

$$W(\alpha, \beta, u, v, w, \phi_x, \phi_y) \cong \sum_i a_i Z_i(\rho, \theta, \varepsilon)$$

ef expands the wavefront into annular Zernike polynomials



ef

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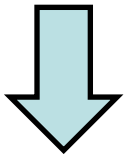
$$(a_1, a_2, a_3, a_4, \ldots, a_n)$$

$$W(\alpha, \beta, u, v, w, \phi_x, \phi_y) \cong \sum_i a_i Z_i(\rho, \theta, \varepsilon)$$

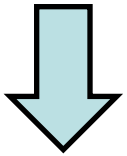
$$a_i \xrightarrow{?} (\alpha, \beta, u, v, w, \phi_x, \phi_y)$$

Action

slow beam quality evaluation because of seeing and 7 parameters

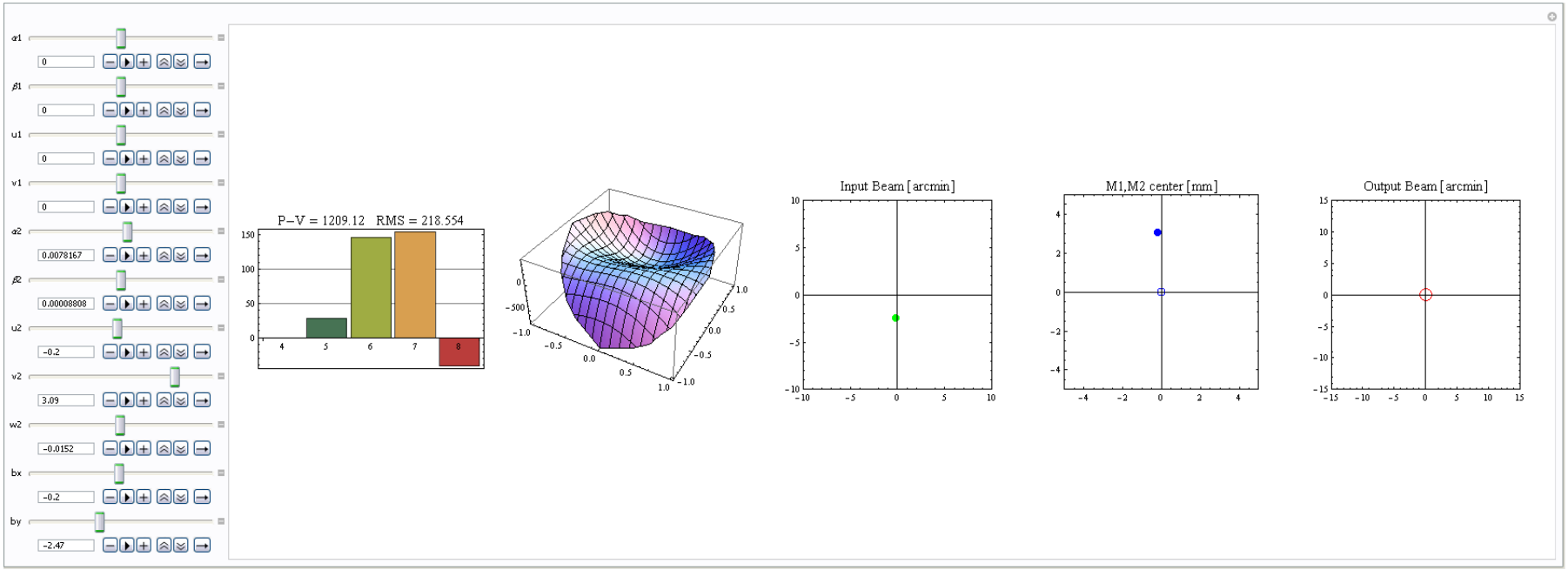


Random search is not feasible



Estimating the position/orientation of M2 from Zernike coefficients

SIMULATOR



Simulations showed:

$$(\alpha, \beta, u, v, \phi_x, \phi_y) \rightarrow a_5, a_6, a_7, a_8$$

$$w \rightarrow a_4, a_{11}$$

The effect on other coefficients is not significant.

GRID SEARCH

Algorithm:

- given a set of $\vec{a} = (a_5, a_6, a_7, a_8, a_{11})$ from measurements

- generate grid

- compute wavefront W in each grid points and expand it to annular Zernike polynomials $\vec{b} = (b_5, b_6, b_7, b_8, b_{11})$

- compute the weighted average of grid coordinates of those points for which $\Delta = (\vec{a} - \vec{b})(\vec{a} - \vec{b})$ is less than a certain limit

$$\Rightarrow (\alpha', \beta', u', v', w', \phi'_x, \phi'_y)$$

Parameter Space:

$$-5 \le u[mm] \le 5, \Delta u = 0.2mm,$$
$$-5 \le v[mm] \le 5, \Delta v = 0.2mm,$$
$$-3 \le \phi_x[arc\ \min] \le 3, \Delta\phi_x = 0.2arc\ \min,$$
$$-3 \le \phi_y[arc\ \min] \le 3, \Delta\phi_y = 0.2arc\ \min,$$
$$-40 \le \alpha[arc\ \min] \le 40, \Delta\alpha = 1arc\ \min,$$
$$-40 \le \beta[arc\ \min] \le 40, \Delta\beta = 1arc\ \min .$$

Brute force is not “brute” enough

# of grid points: $51 \times 51 \times 31 \times 31 \times 81 \times 81 = 16{,}399{,}619{,}721$

Simplification is needed!

Assumption: the direction of the outgoing beam is close to be correct

$$\alpha = \alpha(v, \phi_y) = \frac{v - 0.735\phi_y}{628},$$

$$\beta = \beta(u, \phi_x) = \frac{0.735\phi_x - u}{628}.$$

5 free parameters

Treated separately

$$(\alpha(v, \phi_y), \beta(u, \phi_x), u, v, \phi_x, \phi_y) \rightarrow a_5, a_6, a_7, a_8$$

$$w \rightarrow a_4, a_{11},$$

All other $a_i \equiv 0$

4 parameter grid search provides unique solution

$$(u, v, \phi_x, \phi_y)$$

Simplified Algorithm

given $\vec{a} = (a_5, a_6, a_7, a_8)$ from ef

grid points $(\alpha(v_j, \phi_{y,l}), \beta(u_i, \phi_{x,k}), u_i, v_j, \phi_{x,k}, \phi_{y,l})$

W in each grid point expanded into annular Zernike polynomials

$$\vec{b} = (b_5, b_6, b_7, b_8)$$

Compute $\Delta = (\vec{a} - \vec{b})(\vec{a} - \vec{b})$ for each grid point

Select the grid point where Δ is minimum

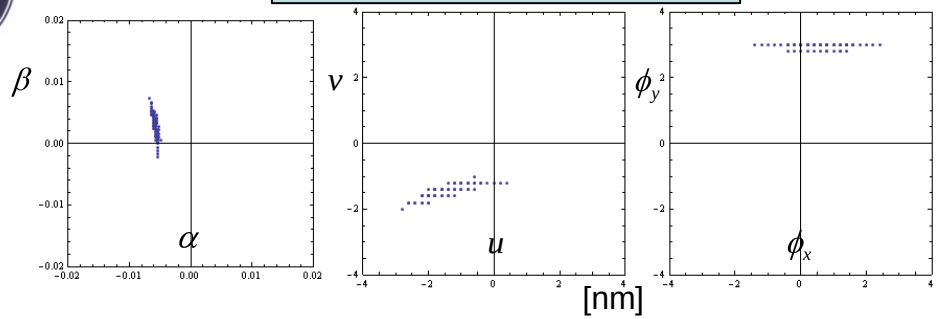
repeat it on finer grid around minimum

Adjust w to match a_{11}

Found a unique solution!

W1

Clustering in parameter space



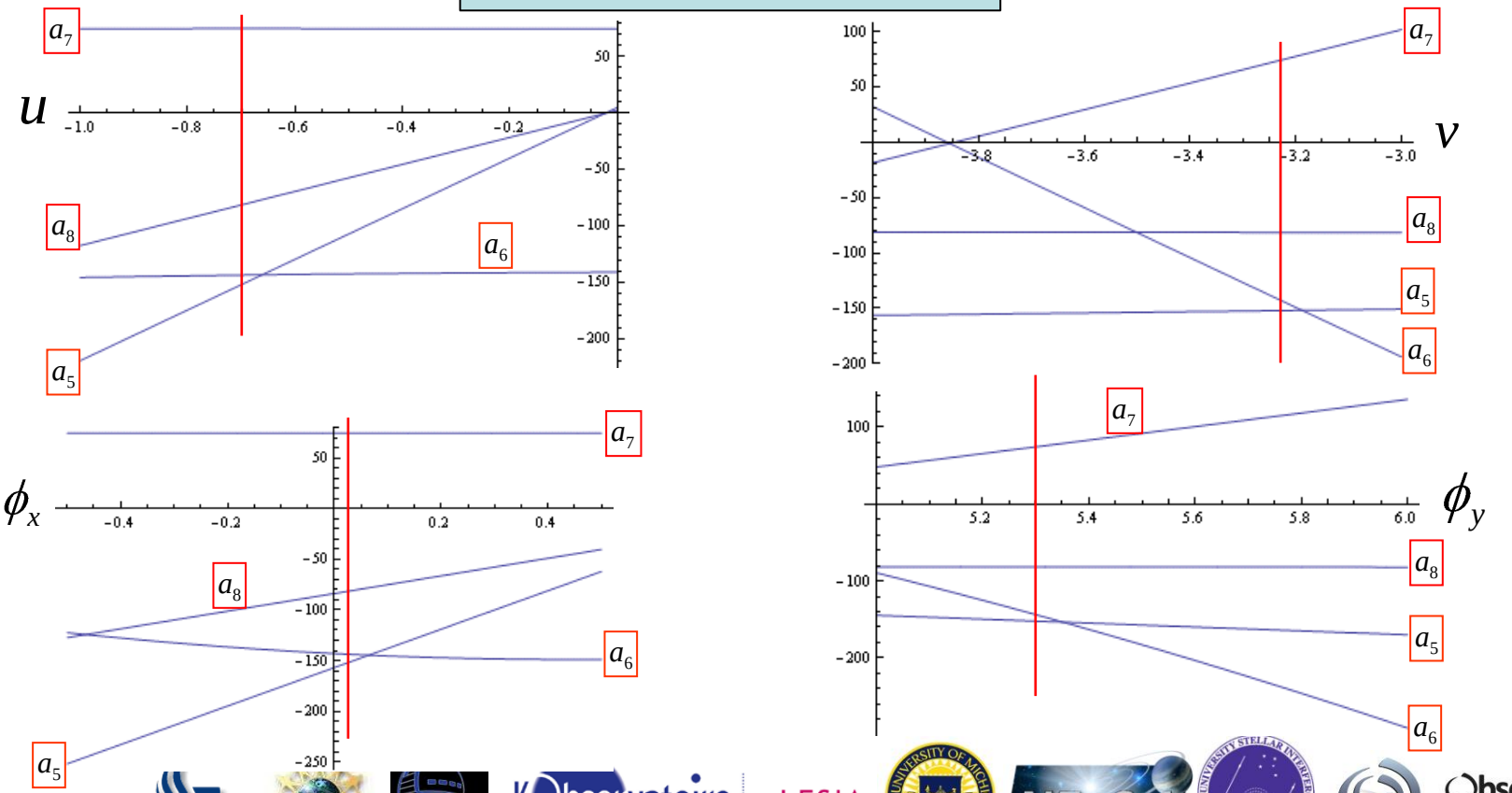
Target: $a_5 = -152nm$

$a_6 = -145nm$

$a_7 = 70nm$

$a_8 = -81nm$

Variation of Zernike coefficients



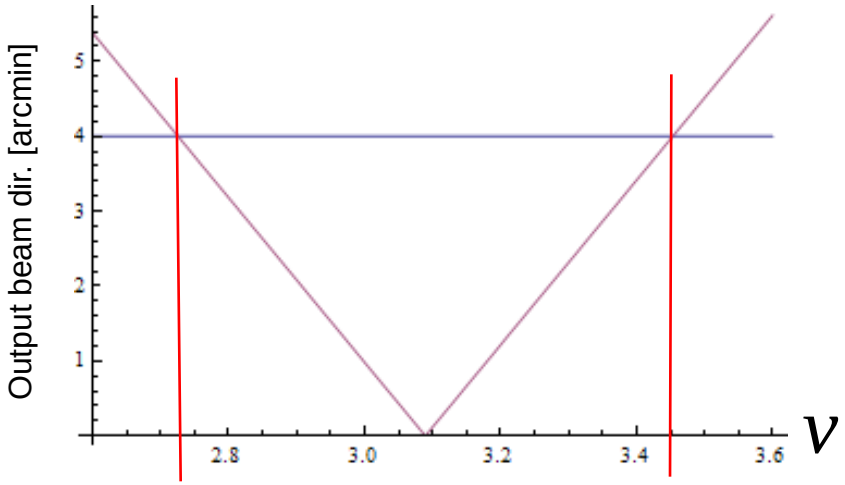
Error estimates:

Not done yet

- random error in a_i ~15%
  more measurements, S-H sensor

- the output beam direction is not (0,0,-1) ⇨ grid-point error ⇨

Biased solution



Solutions found

	α[arcmin]	β[arcmin]	***u*** *[mm]*	***v*** *[mm]*	***w*** *[mm]*	ϕ**x**[arcmin]	ϕ**y**[arcmin]
E1	36	8	-0.7	3.7	0.43	0.95	-4.1
E2	27±2	0.3±2	-0.2±0.4	3.1±0.4	0.065	-0.2±0.5	-2.5±0.5
W1	39	4	-0.7	-3.2	0.21	0.03	5.3

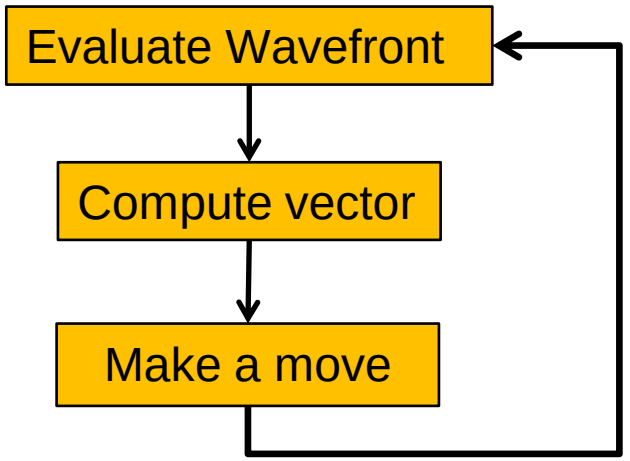
provides a way to estimate δ → More accurate placement of M1 target

Complications:

lateral adjustments of M2 (u, v) is difficult

pivot is not at vertex of M2 (α, β)

coupling among (u, v, α, β)



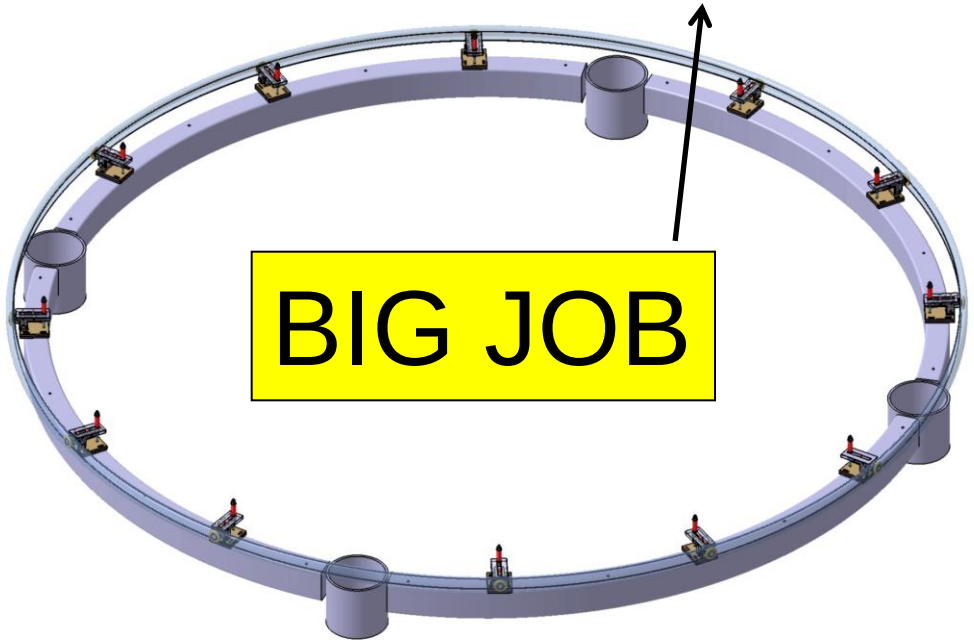
Hardware Updates

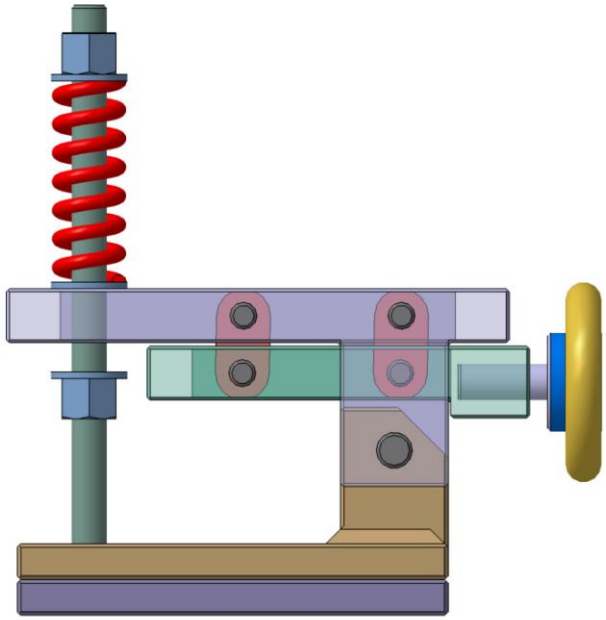
- Ovenized crystal oscillator in the clock
- Three domes have been retrofitted with the new dome wheels
- Differential Image Motion Monitor (DIMM) on S1
- New M3 mount (W1 & W2)
- Coude-box cover prototype
- AZ limit switch mounting
- Particulate Monitor on S2
- New alignment telescope mount
- Serial bus on the telescope
- RS-485 interface for the finder and acq. cameras
- RS-485 interface for temperature/humidity sensor

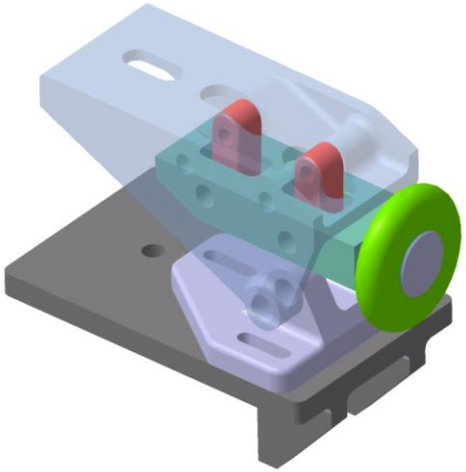
Dome Rollers

three domes done, three to go (Golden, Webster)

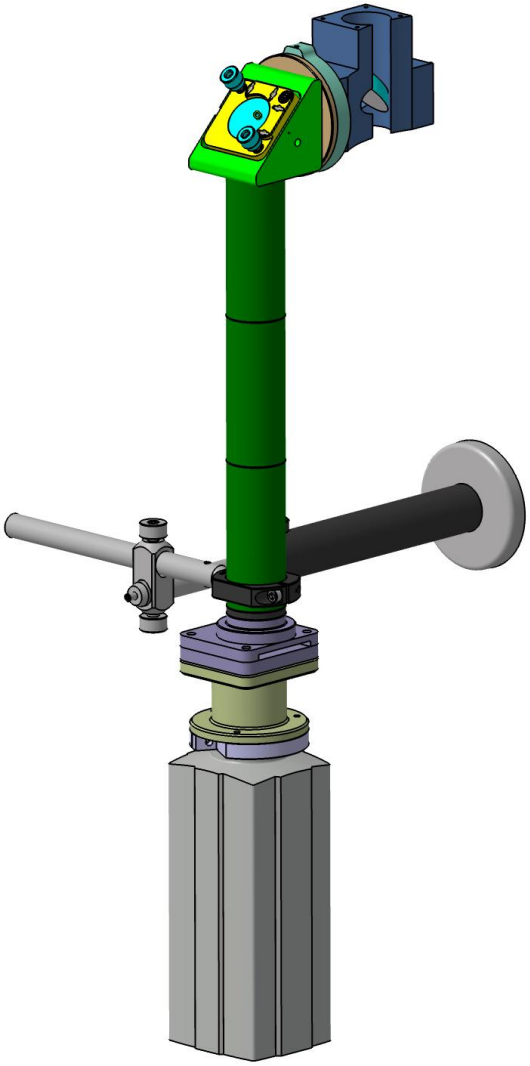
"floating" dome support equalizes load on the individual wheels, minimizes wear and load on the drive motor, quieter







DIMM Mounted on S1



Rotatable mirror in the acq. telescope

Needs motor for remote operation

fold-mirror

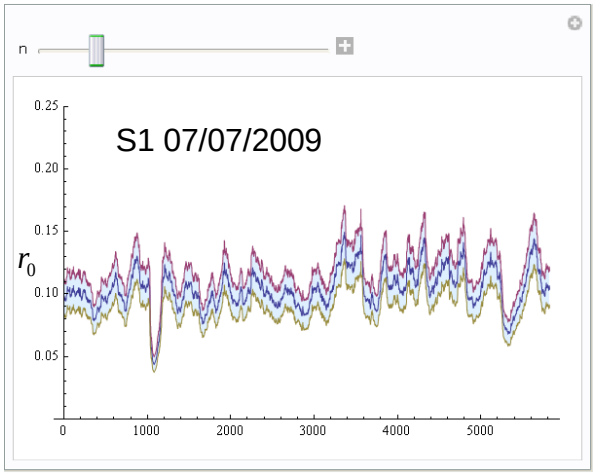
collimator

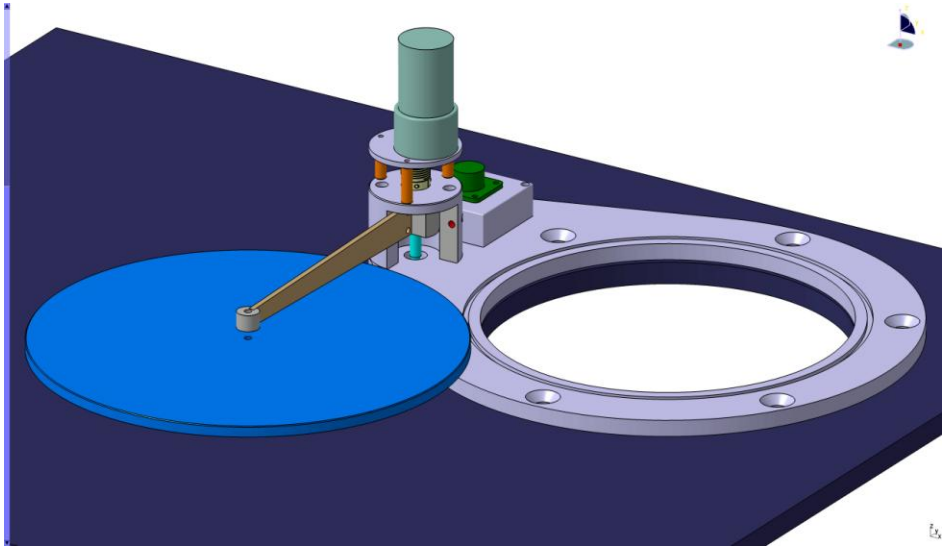
mask

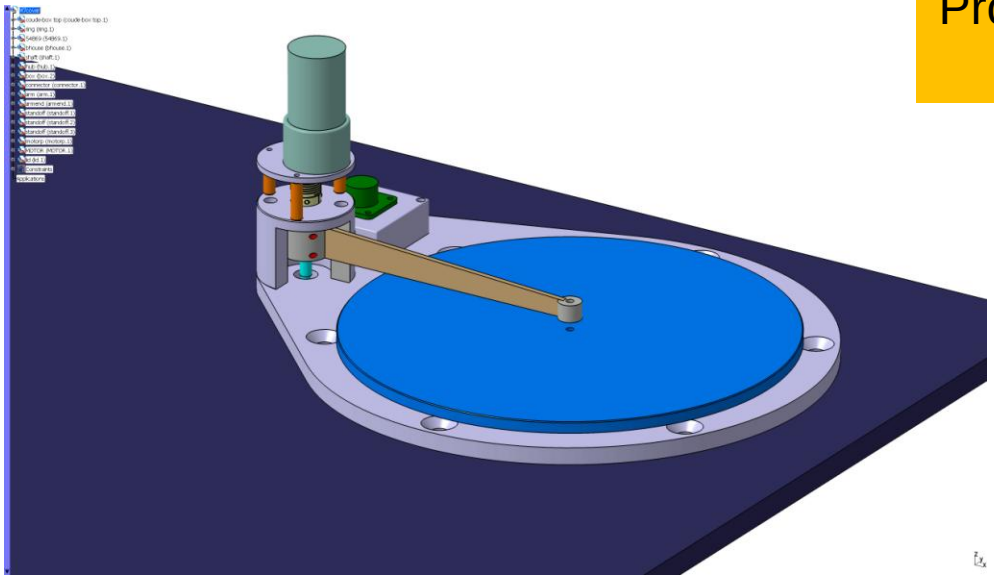
wedge prisms

camera lens

camera



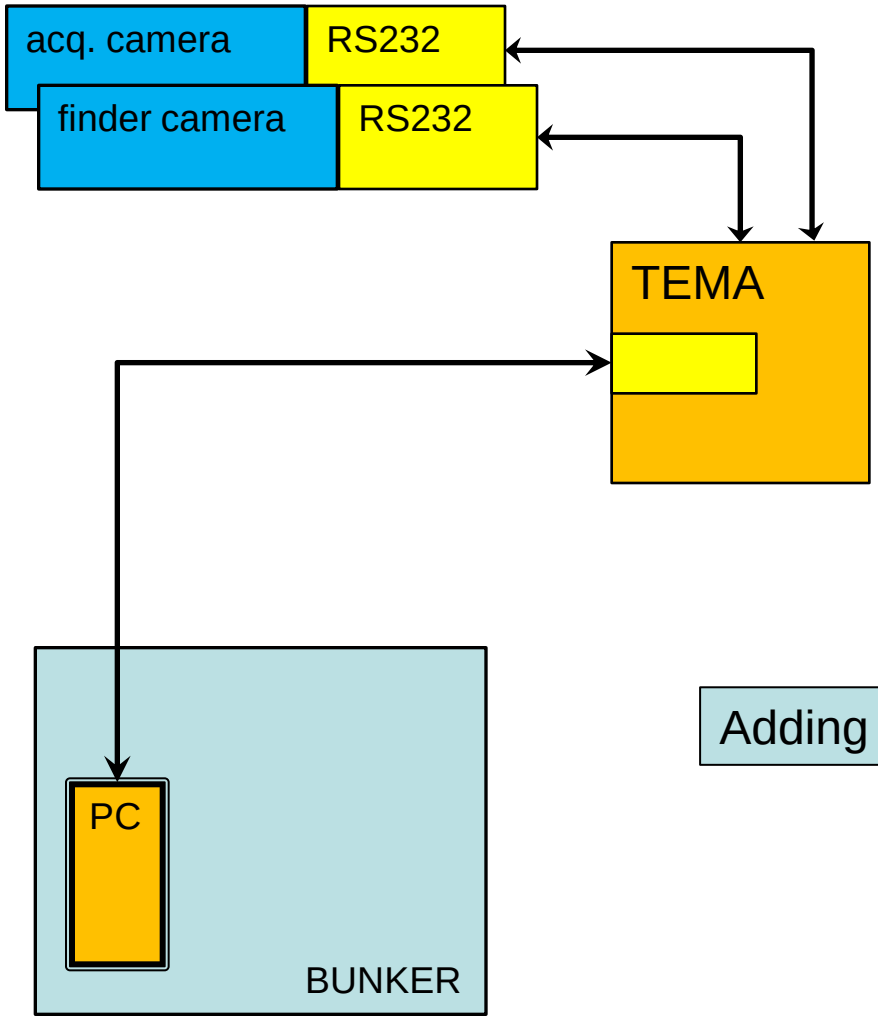


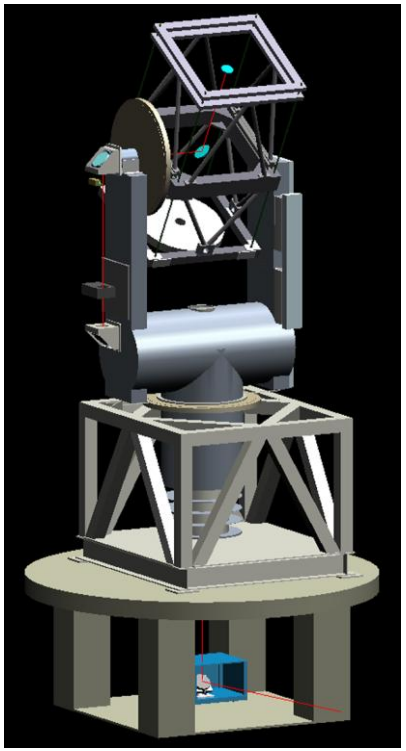


coude-box cover

Prototype has been built but not tested yet.

RS-485 Bus on the Telescope

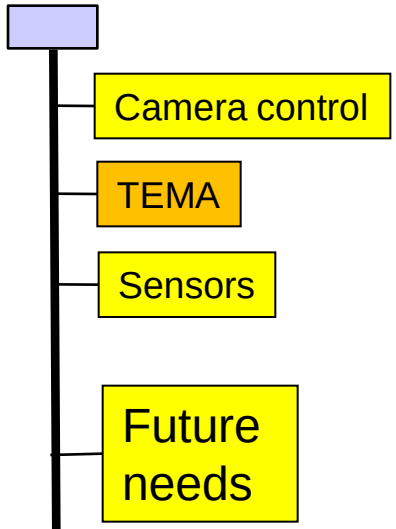


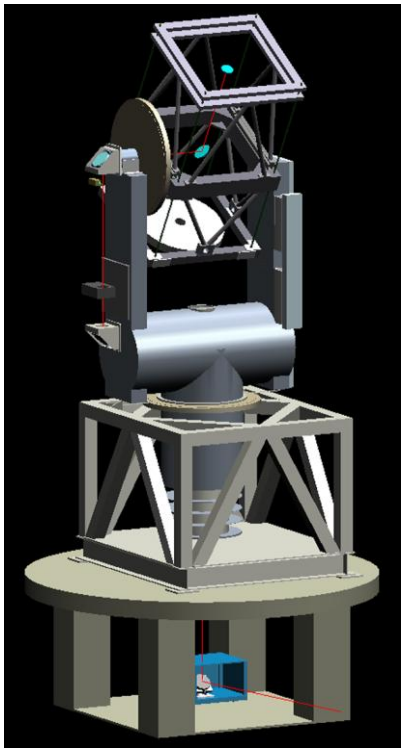


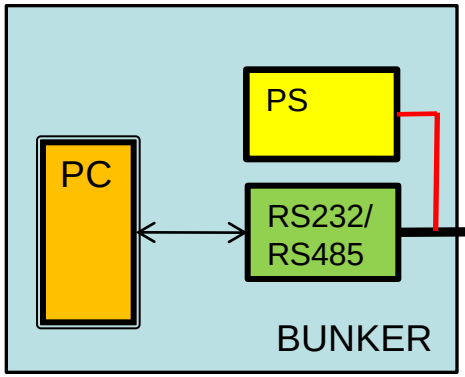
Adding serial ports to TEMA is not practical.

RS-485 Bus on the Telescope

Implementing a serial bus on the telescope and hooking up devices to the bus makes more sense.
Simpler cabling, expandable.







RS-485 bus,
Power