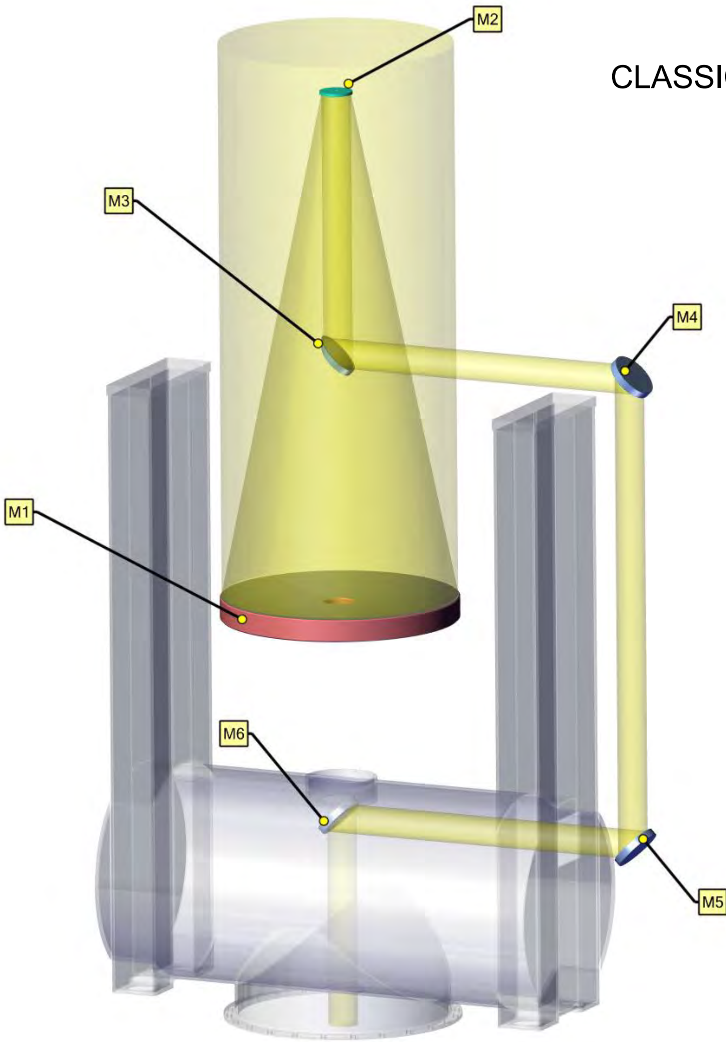
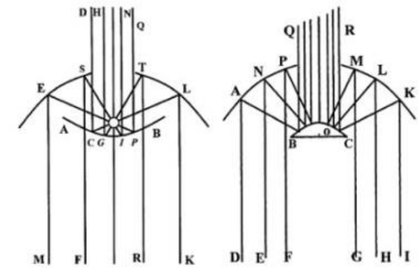
CHARA Telescope Alignment Issues

Laszlo Sturmann
CHARA

CHARA TELESCOPES



CLASSICAL TWO MIRROR TELESCOPE
(MERSENNE 1636)



M1:	D = 1m F = 2.5 m CONCAVE PARABOLOID

M2:	D = 0.14 m F = - 0.312 m CONVEX PARABOLOID

M1 AND M2 CONFOCAL

1:8 BEAM COMPRESSION

M3,M4,M5,M6… FLATS

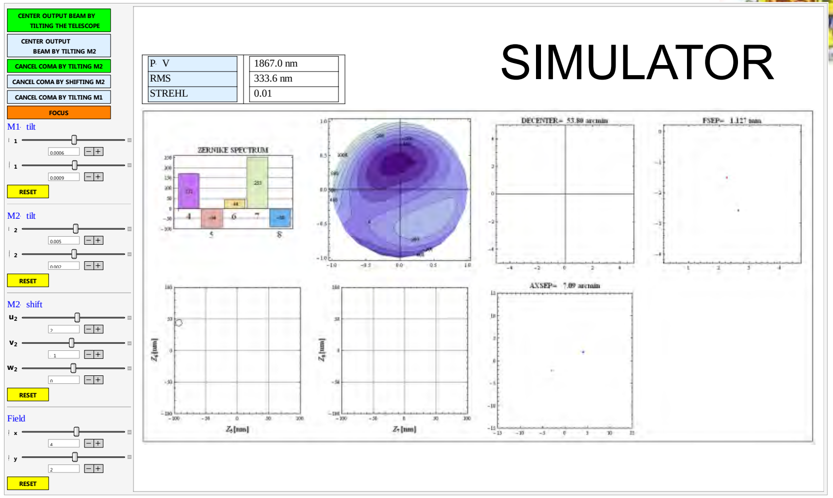
OUTPUT BEAM ∅ 0.125 m

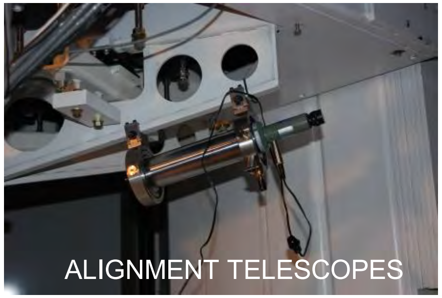
The beam-quality delivered by the telescope is limited by:

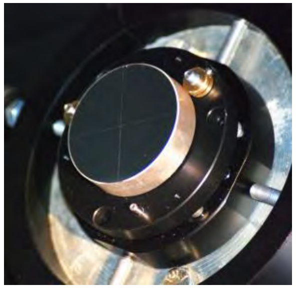
1. quality of the optics,
2. quality of the mounts,
3. optical alignment,
4. other (seeing, vibrations, etc.)

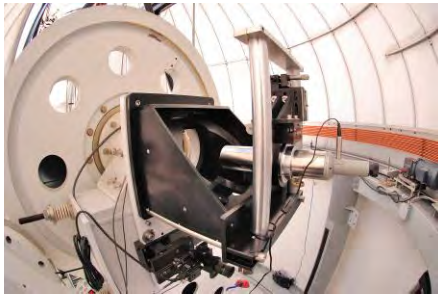
We have been focusing on optical alignment over the years

- better understanding from computer modeling
- built/acquired better instruments







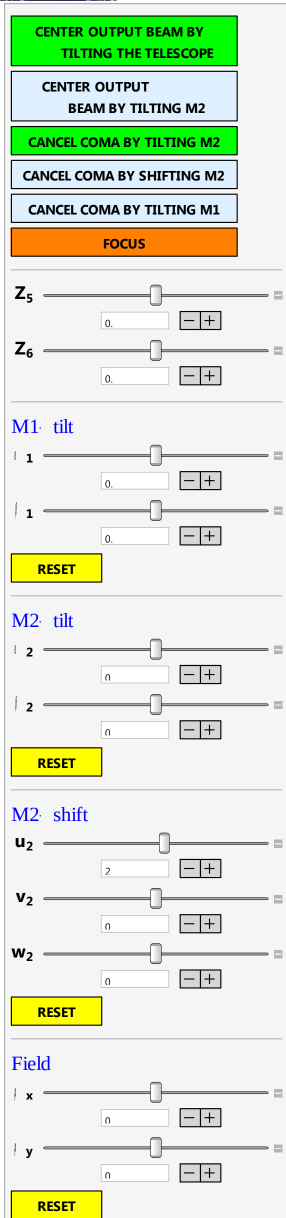


improved beam quality from the telescopes

BUT

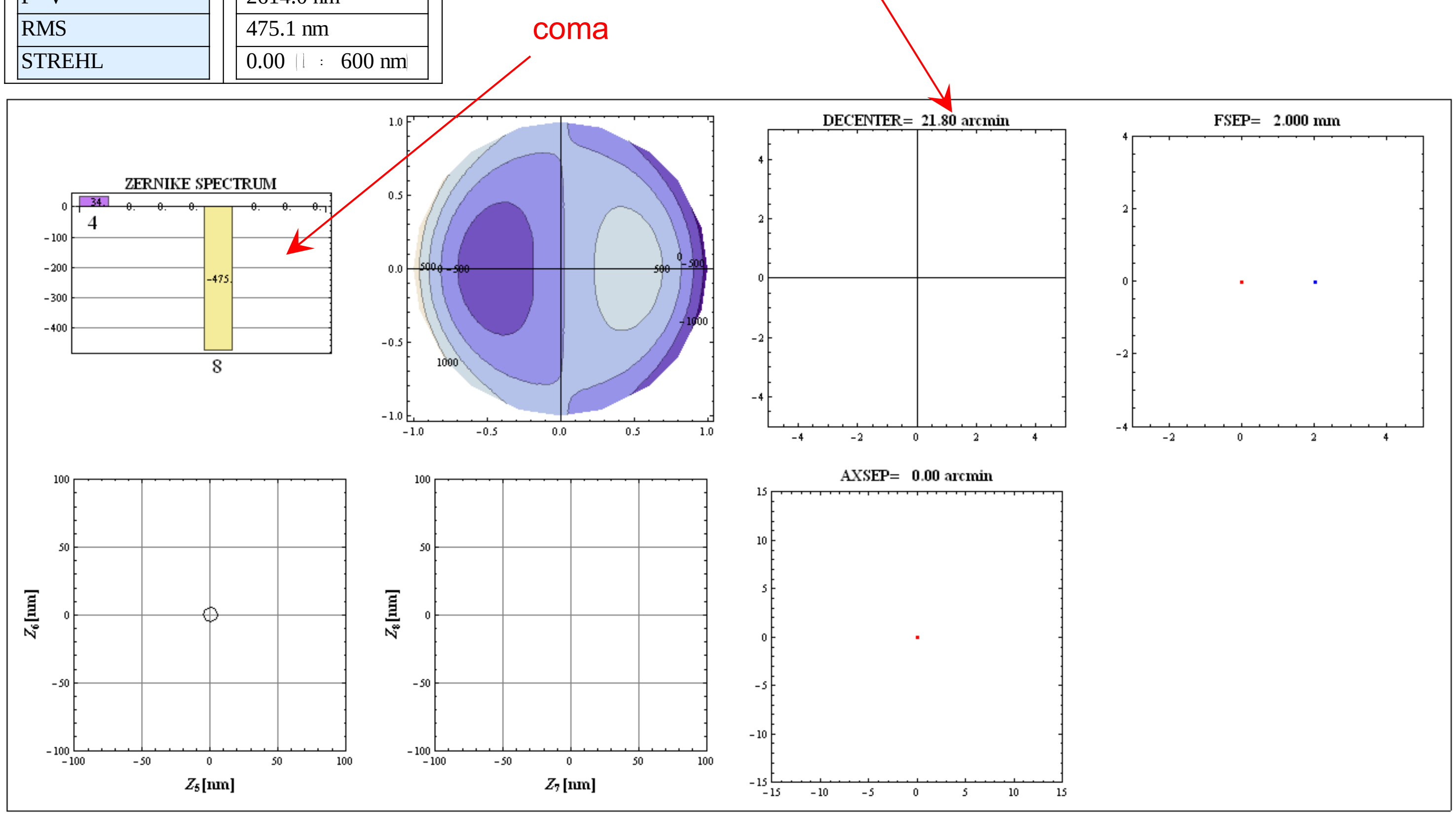
ASTIGMATISM REMAINED

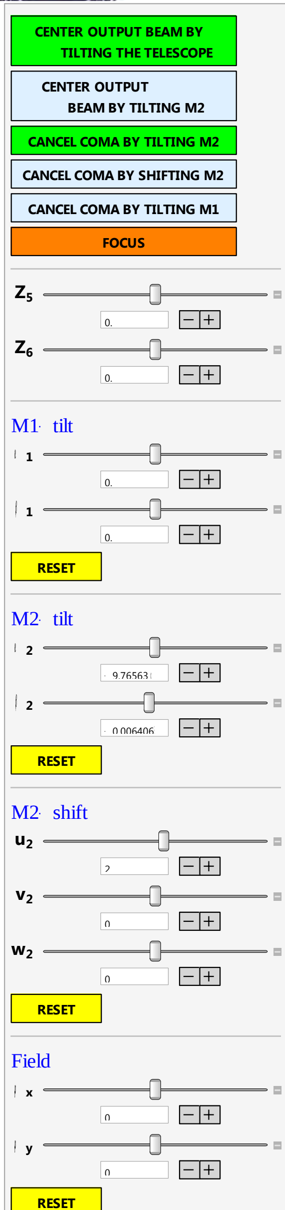
It is easy to make the telescope astigmatic by destroying its rotational symmetry



If M2 is decentered by 2 mm, the primary aberration is coma. The output beam direction is also off.

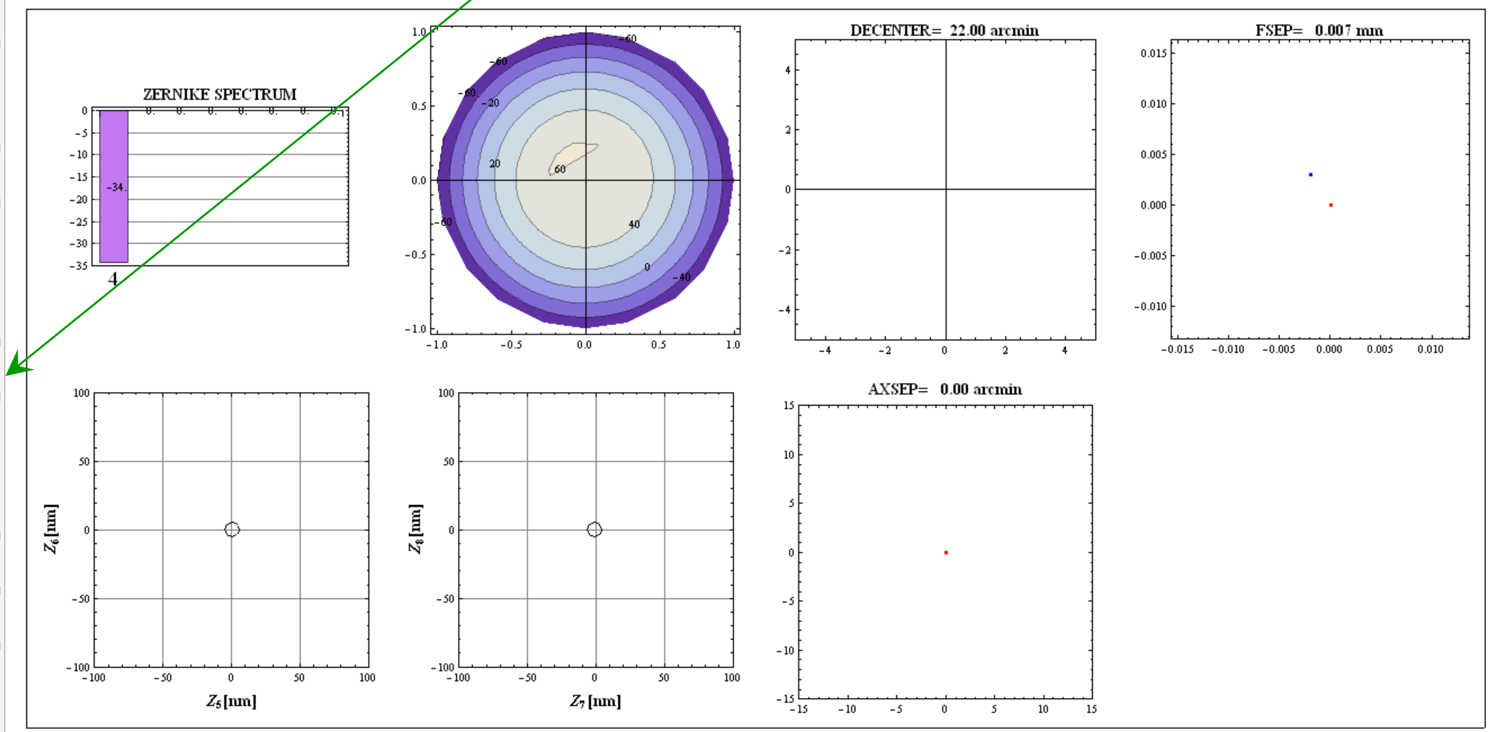
P V	2614.0 nm
RMS	475.1 nm
STREHL	0.00 600 nm





Coma can be eliminated by tilting M2, only defocus remains and the output beam direction is still off.

P V	122.4 nm
RMS	34.4 nm
STREHL	0.88 600 nm



CENTER OUTPUT BEAM BY TILTING THE TELESCOPE

CENTER OUTPUT BEAM BY TILTING M2

CANCEL COMA BY TILTING M2

CANCEL COMA BY SHIFTING M2

CANCEL COMA BY TILTING M1

FOCUS

Z_5 0.

Z_6 0.

M1 tilt

1: 0.

1: 0.

RESET

Out[3]=

M2 tilt

2: 9.76563

2: 0.006406

RESET

M2 shift

u_2 2

v_2 0

w_2 0.000757813

RESET

Field

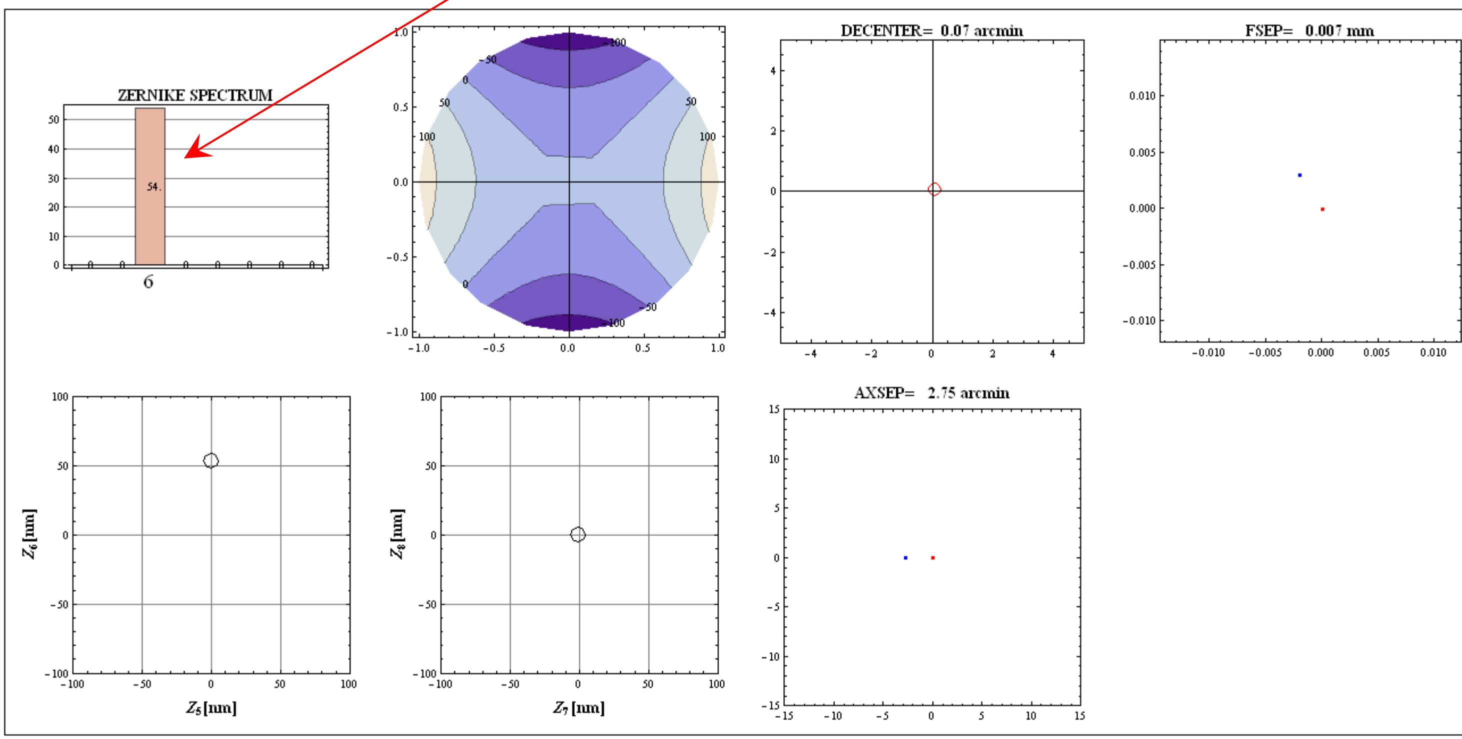
x: 2.75

y: 0.015625

RESET

Output beam direction is restored by re-pointing the telescope. The dominant aberration becomes astigmatism.

P-V	259.2 nm
RMS	53.5 nm
STREHL	0.73 (λ = 600 nm)



Apart from alignment issues, astigmatism can be present in the beam because

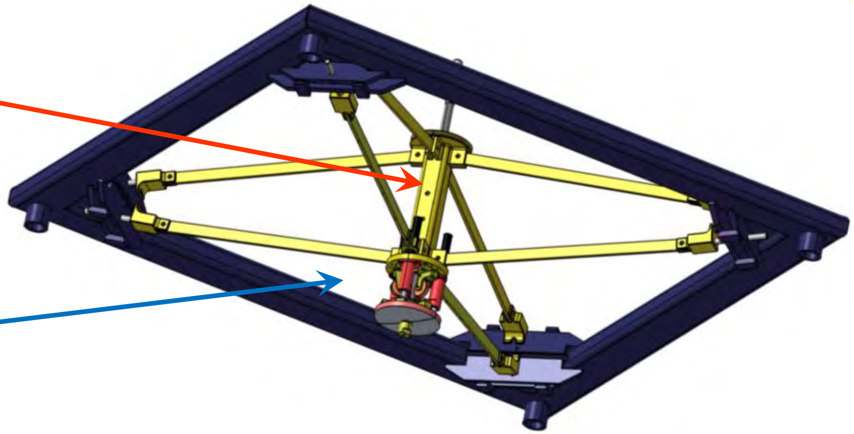
- the mirrors are astigmatic,
- mounts are stressing the mirrors,
- the wavefront sensor optics are astigmatic

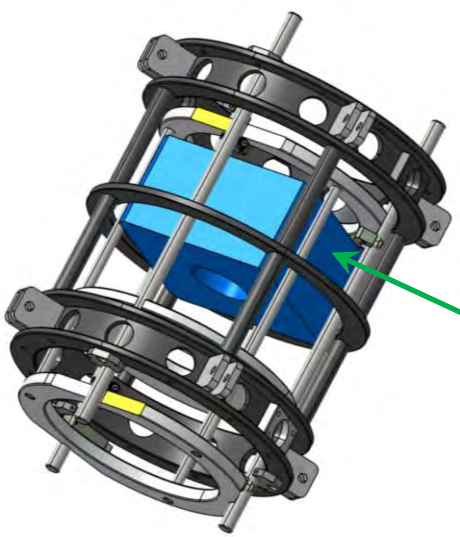
TESTING THE W1 PRIMARY *in situ*

M1 is a fast (F/2.5) paraboloid sensitive to coma.
For example, tangential coma would be 9 arcsecs 5 arcmin off-axis, easy to detect.
This can be used to find the axis of M1.

The expected off-axis aberration in the prime-focal plane is 3-d order coma, defocus and NOT MUCH ELSE

The primary focal plane is inaccessible without removing the M2 support.

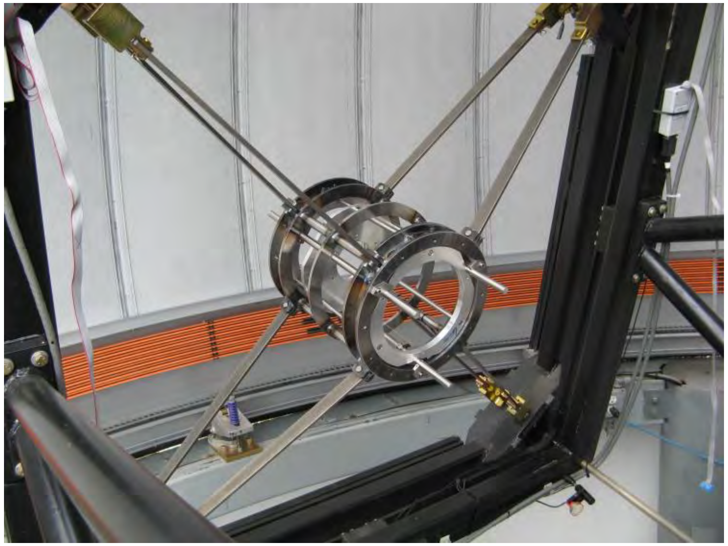


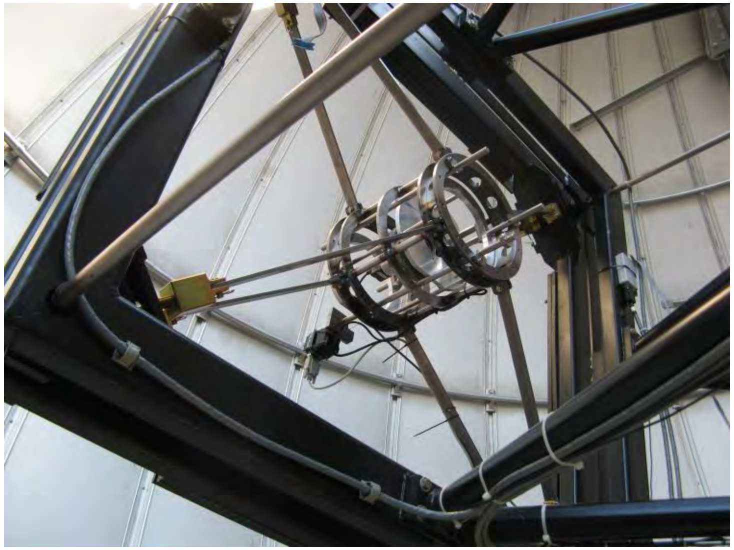


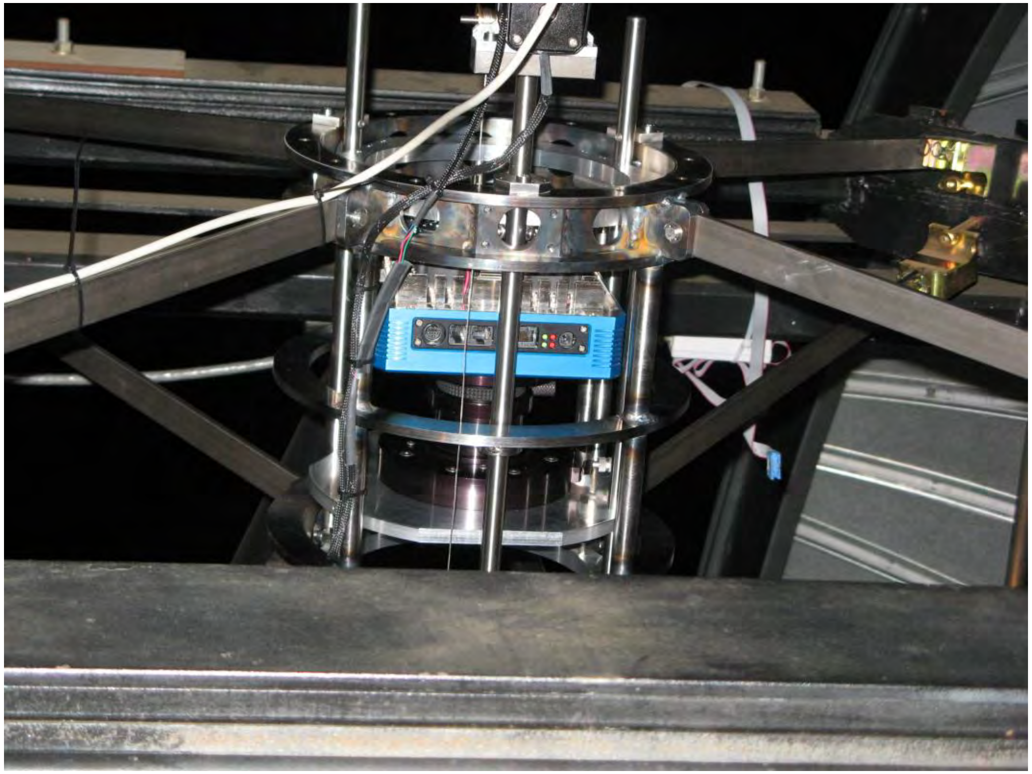
CCD CAMERA
1k x 1k $(13\ \mu m\ x\ 13\ \mu m)\ 18\ arcmin^2$

universal prime focus cage was built to hold a CCD camera or WFS

Prototype prime-focus cage





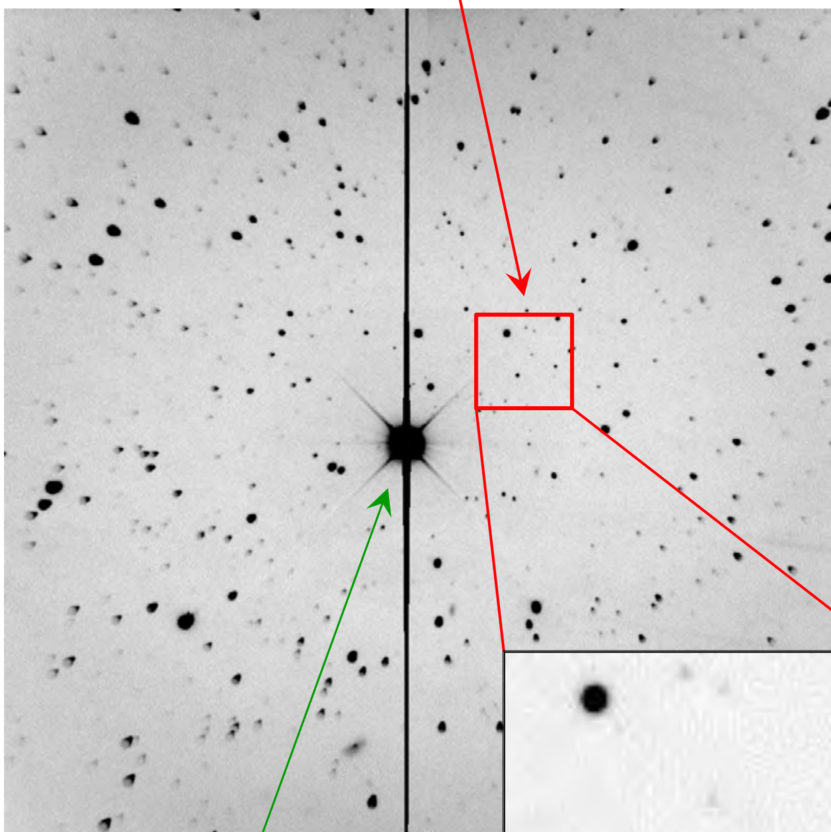


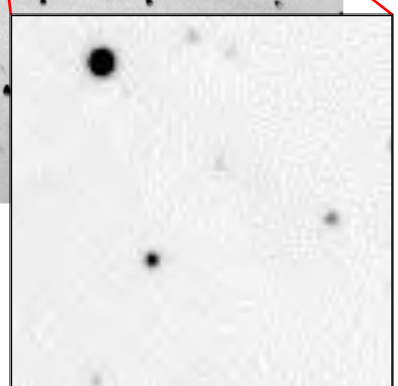
AXIS OF M1 POINTS HERE

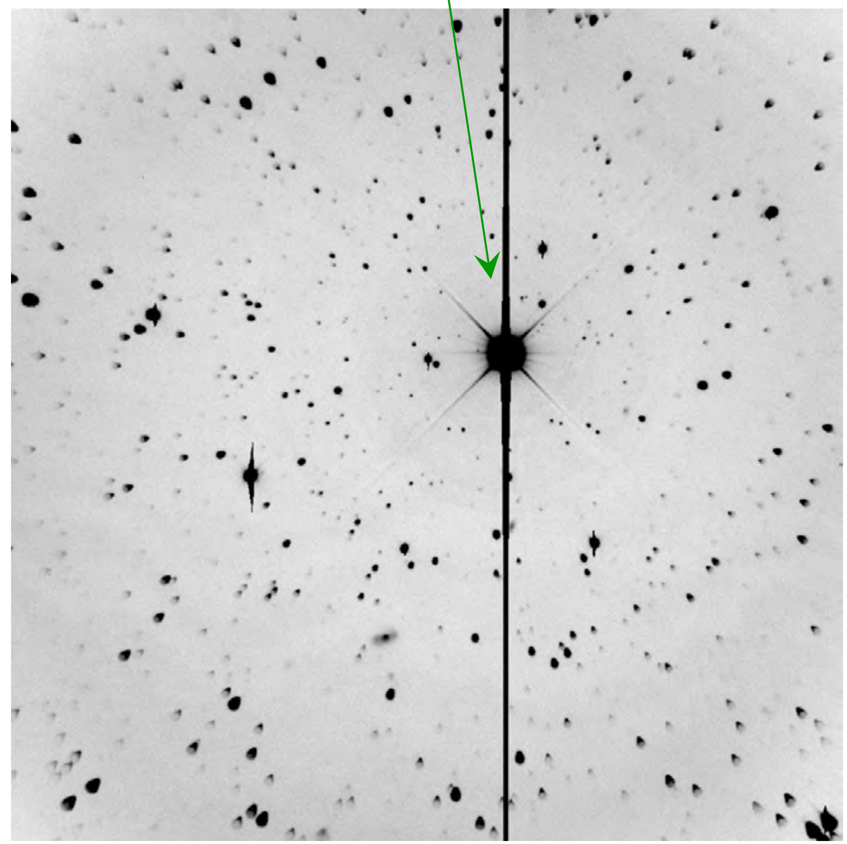
SMALL COMA

OPTICAL-AXIS OF THE CCD CAMERA

11 CMi



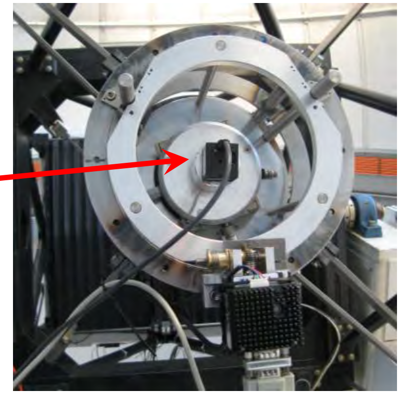




Telescope was pointing here

M1 was tilted until the star landed on the CCD where the optical axis of the telescope intersected the CCD.
The CCD apparently was not centered precisely in the camera head by the manufacturer, hence the offset.

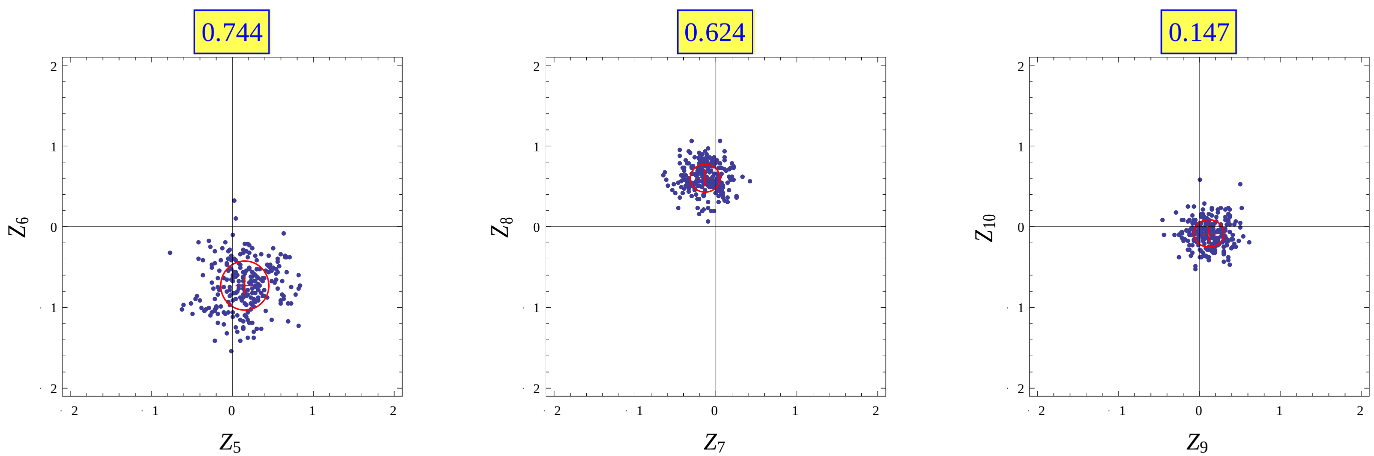
S-H wavefront sensor in prime-focus



Measurements showed astigmatism which cannot be related to the optical alignment of the telescope since M2 was not involved. However, the WFS optics could still be astigmatic.

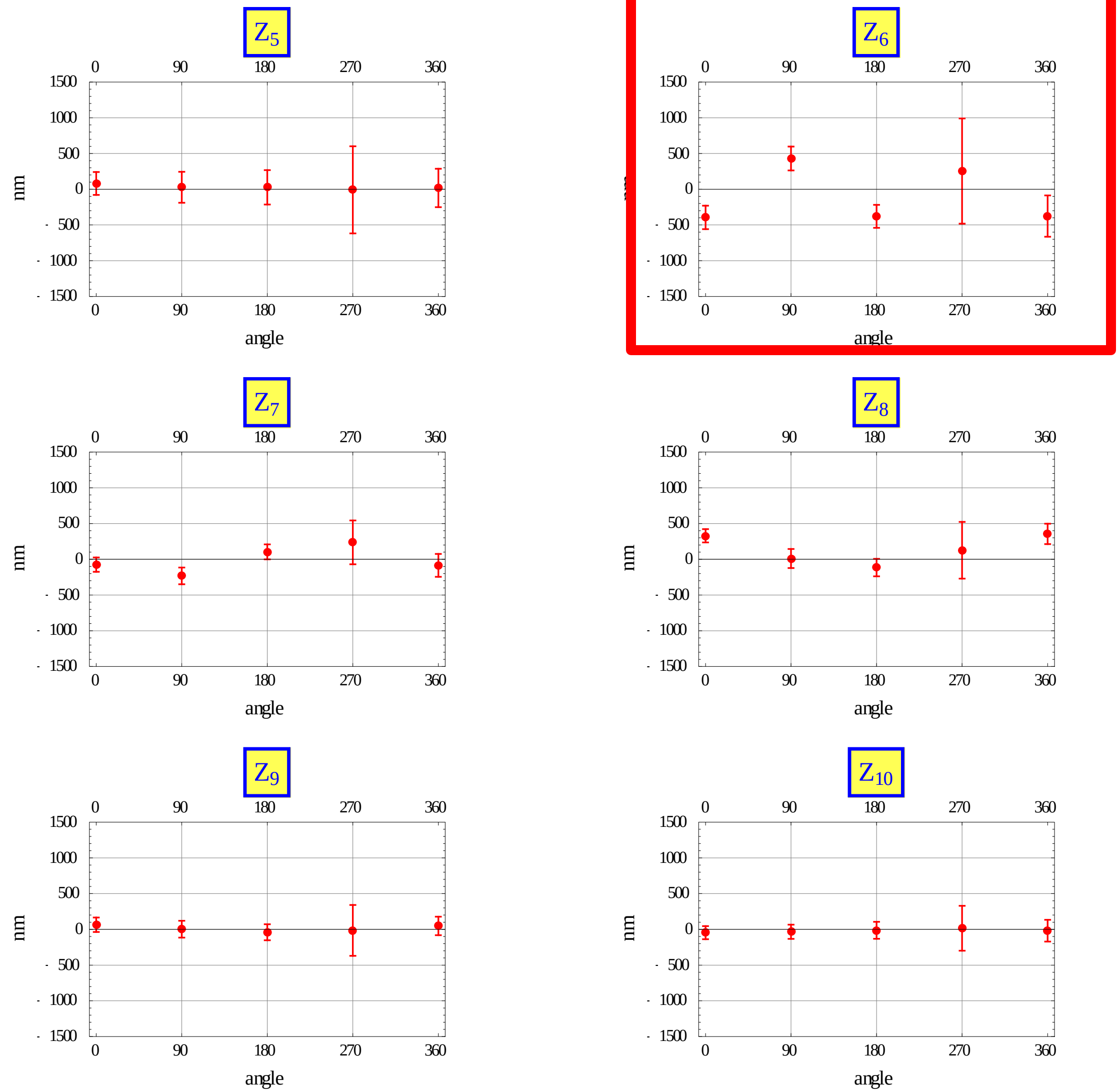
	MEAN wave	RMS wave
Z_4 DEFOCUS	0.	0.
Z_5 ASTIGM	0.15	0.297
Z_6 ASTIGM	-0.729	0.304
Z_7 COMA	-0.138	0.185
Z_8 COMA	0.609	0.172
Z_9 TREFOIL	0.119	0.186
Z_{10} TREFOIL	-0.0856	0.17
Z_{11} SPHE	-0.426	0.0852

IS THE WFS ASTIGMATIC?



WFS was rotated in 90° increments.

M1 & Rotating WFS



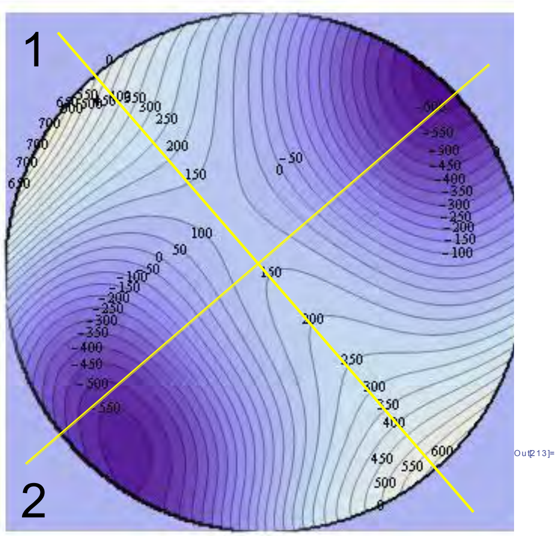
The means represent aberrations due to the WFS itself because the WFS optics rotates with the WFS camera.

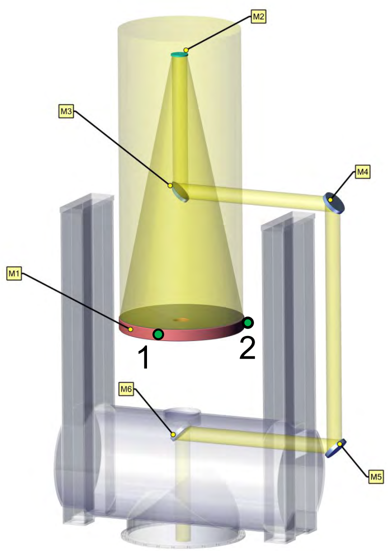
The variation in Z_6 shows that the beam from M1 itself is astigmatic. The astigmatism doesn't show up in Z_5 due to the 90° sampling.

M1 HAS ≈1 WAVE (540 nm) ASTIGMATISM

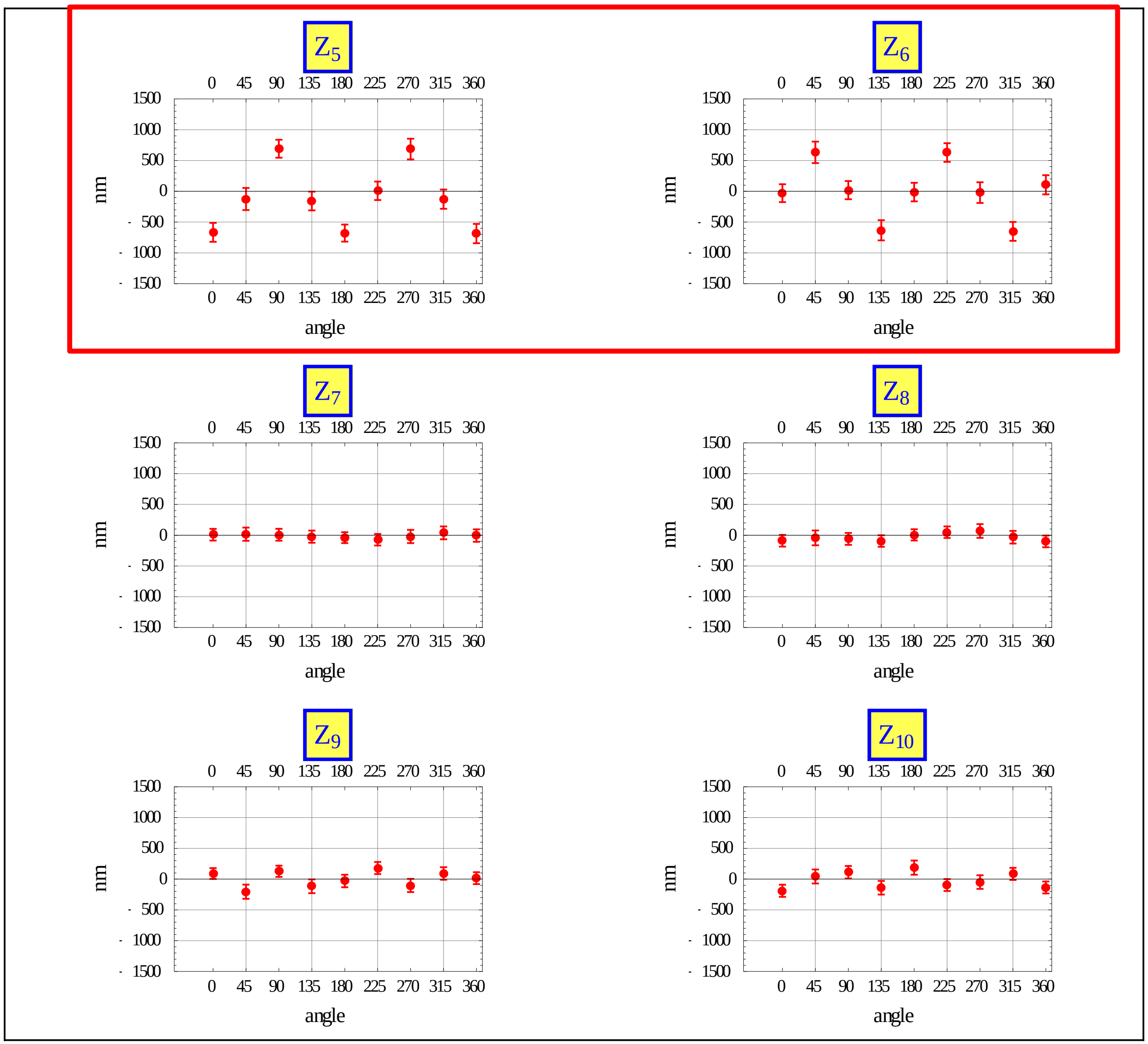
MORE THAN EXPECTED

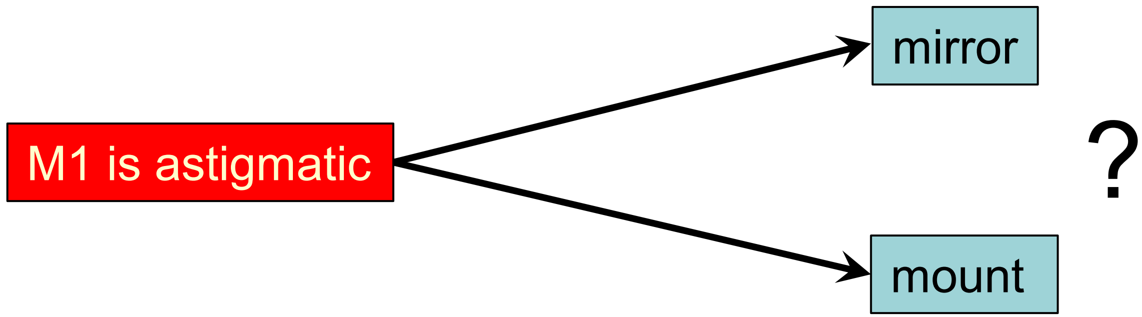
AFTER INSTALLING M3 THE WFS CAMERA WAS ROTATED IN 45° INCREMENTS





M1 & M2 Rotating WFS





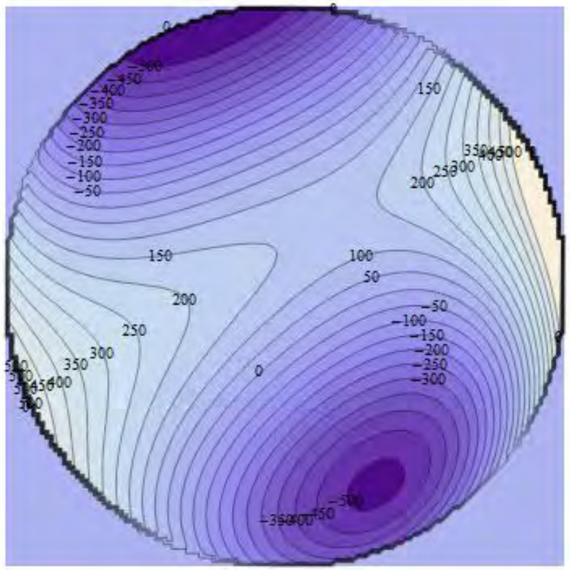
The beam quality can be greatly improved by introducing astigmatism with the opposite sign by intentionally misaligning the telescope.

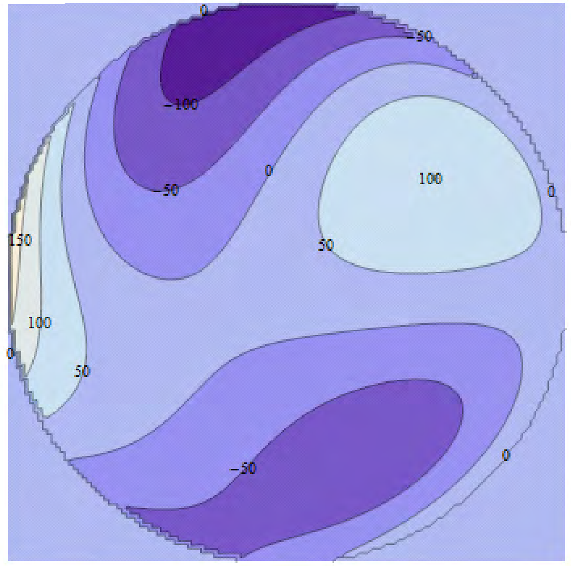
However, the pupil will not be symmetric and there will be beam shear (vignetting) but, RMS < 50 nm seems achievable (see 2011).

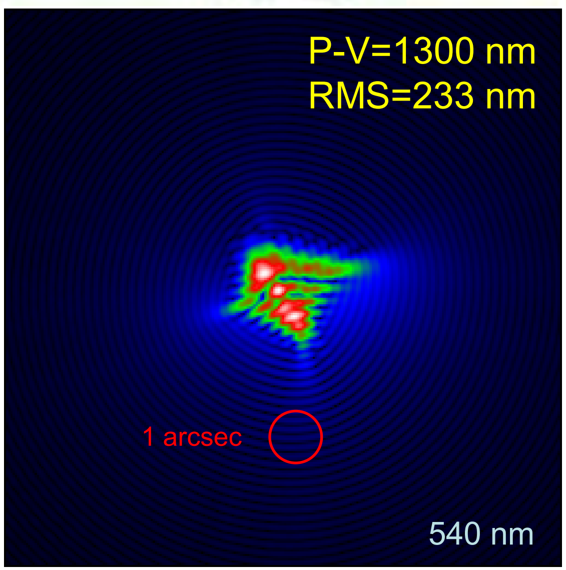
W1

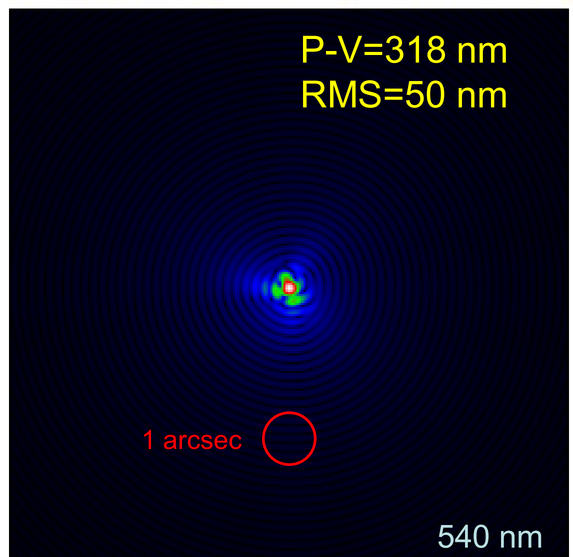
BEFORE 02-03-2011

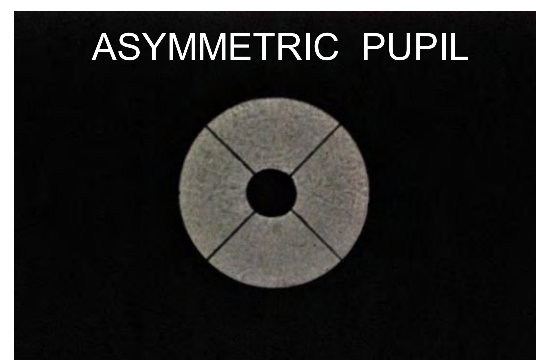
AFTER 02-12-2011







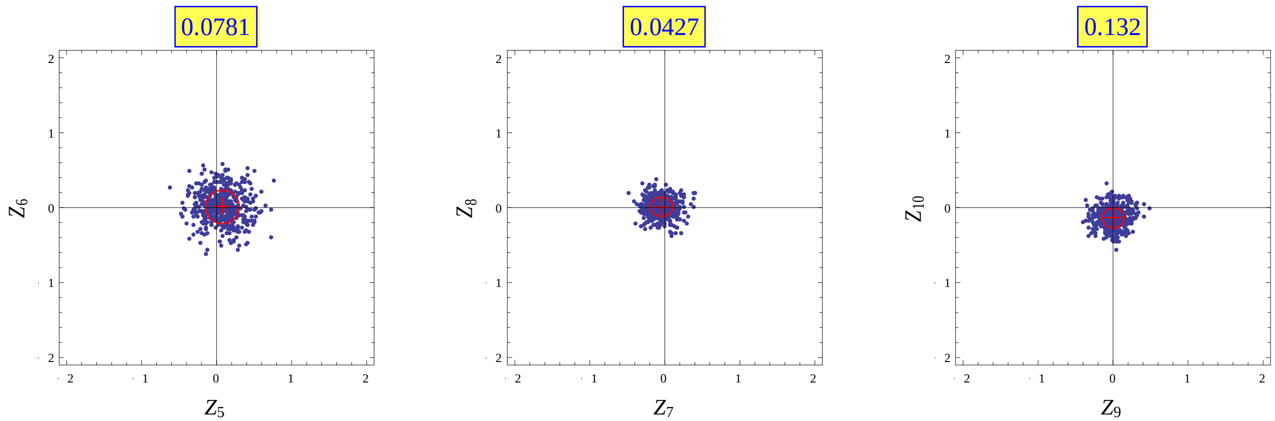




W1 02/2011

2.1

	MEAN wave	RMS wave
Z_4 DEFOCUS	-0.00705	1.75
Z_5 ASTIGM	0.0759	0.224
Z_6 ASTIGM	0.0181	0.225
Z_7 COMA	-0.0426	0.147
Z_8 COMA	0.00251	0.128
Z_9 TREFOIL	0.00961	0.145
Z_{10} TREFOIL	-0.132	0.135
Z_{11} SPHE	0.188	0.0749



Further improvement only by
Adaptive Optics

PROTOTYPE ON S2
SUMMER 2013

Conclusion:

- Astigmatism in the W1 beam is due to M1 itself.
- It can be fixed by laterally shifting the beam on M2 but the pupil will be asymmetric, there will be beam shear and possibly vignetting.