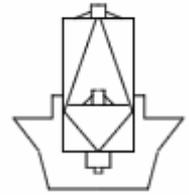




Analysis v2.doc



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Kottamia 74 inch Telescope

Preliminary Image Analysis

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Introduction

This brief report presents the image data from several test periods and attempts to identify the cause of the poor image quality. An optical analysis and corresponding Zeemax synthesis is used to compare with the actual telescope images to indicate the degree aberration present in the optical system assuming it is all attributed to the support of the primary mirror. With this information a simple finite element analysis (FEA) is undertaken to examine what primary mirror support malfunction may be responsible.

Initial findings

There are two tests which reveal the significant causes of the poor images from the 74 inch telescope; a focus run test from observations of 6th May 2008 and the in-focus and the extra-focal images from tests on 10th/11th September 2008.

Focus Run

The diary entry for the observations on 6th May 2008 is shown below. The appropriate frames are _009 to _015.

Extracts of a particular star from this sequence of images are shown on the following page and ordered so as to progress through focus.

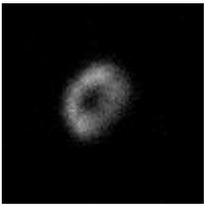
It is immediately obvious from this test that a significant degree of astigmatism is present as the images are elongated close to focus and the elongation changes by 90° either side of focus. The brightness of the out-of-focus images is not uniform and the in-focus image is not circular. This indicates that coma is most likely to also be present.

It usually possible to obtain an estimate of the degree of astigmatism by comparing the length and width of the image close to focus but additional coma can undermine this. Extra-focal images further away from focus can provide a clearer indication and a better estimate.

20080506 Tuseday

				Filter	
	20080506_001	bais			
78517	20080506_002	1 sec	bright star	without	
	_003	5 sec	bright star	without	
	_004	5 sec	bright star	without	
	_005	60 sec	NGC3646	without	
	_006	60 sec	NGC3646	without	
	_007	60 sec	NGC3646	without	
	_008	300sec	NGC3646	without	
I-band:					
78517	_009	300sec	NGC3646	I	needs focusing
-500	_010	60 sec	NGC3646	I	wrong direction
+1000	_011	60sec	NGC3646	I	Improving
+500	_012	60sec	NGC3646	I	Improving
+500	_013	60sec	NGC3646	I	Improving
+500	_014	60sec	NGC3646	I	Improving
+500	_015	60sec	NGC3646	I	Reversed

Focus run images ordered from furthest out to just through focus.



20080506_010 focus 78517 - 500



20080506_009 focus 78517



20080506_011 focus 78517 + 500



20080506_012 focus 78517 + 1000



20080506_013 focus 78517 + 1500



20080506_014 focus 78517 + 2000



20080506_015 focus 78517 + 2500

Best focus is at 80517

In-focus and Extra-Focal Images

These images were obtained during tests on 10th/11th September

In-focus images

Two images are shown below. They are of short duration and so are unlikely to include tracking errors or wind disturbance (unless an optical component or the camera was vibrating).

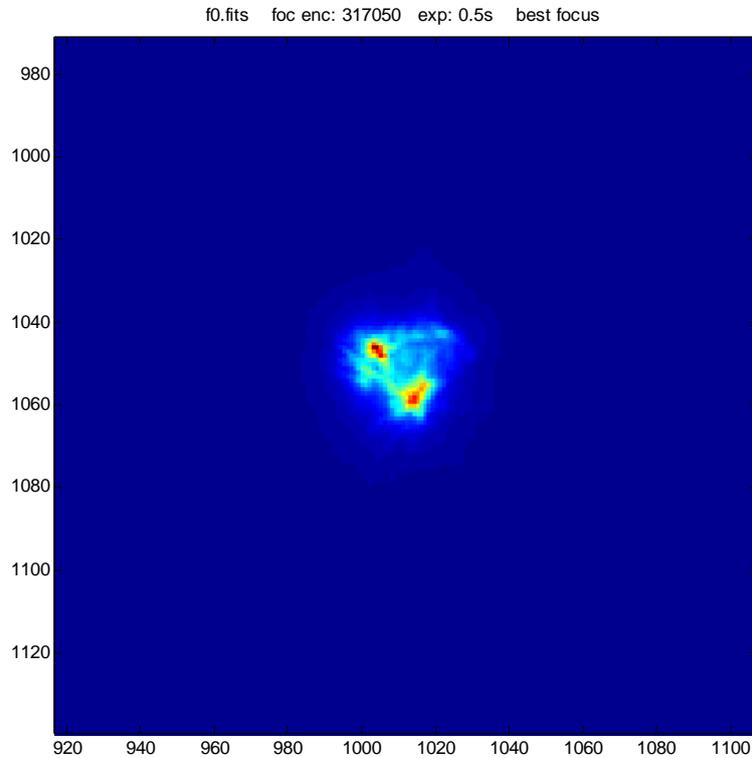


Figure 1 Zoomed view of best focus image showing the image core doubled in the NW direction

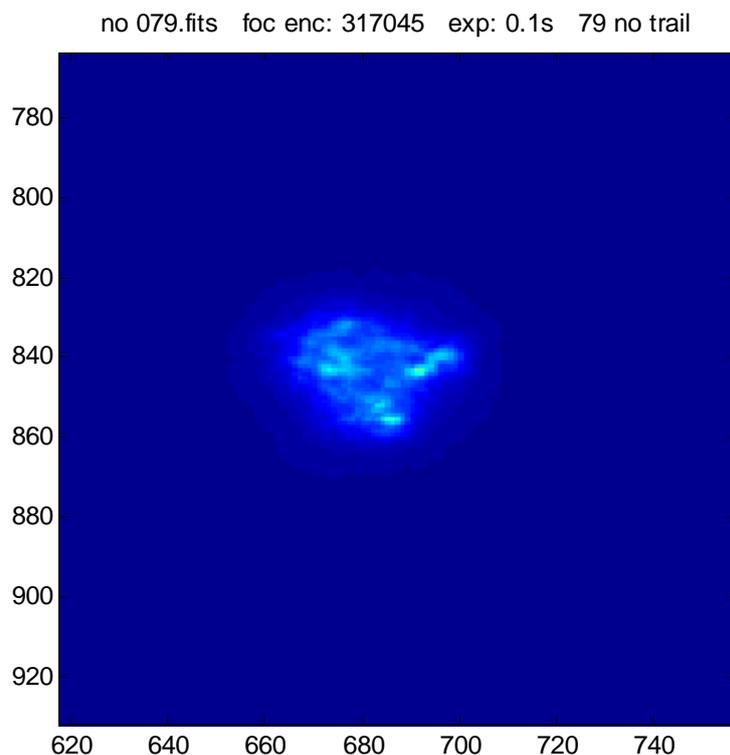


Figure 2 Nominal focus zoomed view showing three image cores (NW and NE)

These images reveal that the circle of least confusion is not just the result of astigmatism. They may indicate some trefoil but additional coma is much more likely.

Extra-Focal images

The first pair of images taken at 40,000 units either side of focus show the elongation due to astigmatism and significant non-uniform illumination due to coma. The second pair of images at approximately 140,000 units either side of focus indicate, through the displacement of the central obstruction, that coma is present due to misalignment of some component. The fact that the central obstruction is sharply defined indicates that there is little spherical aberration.

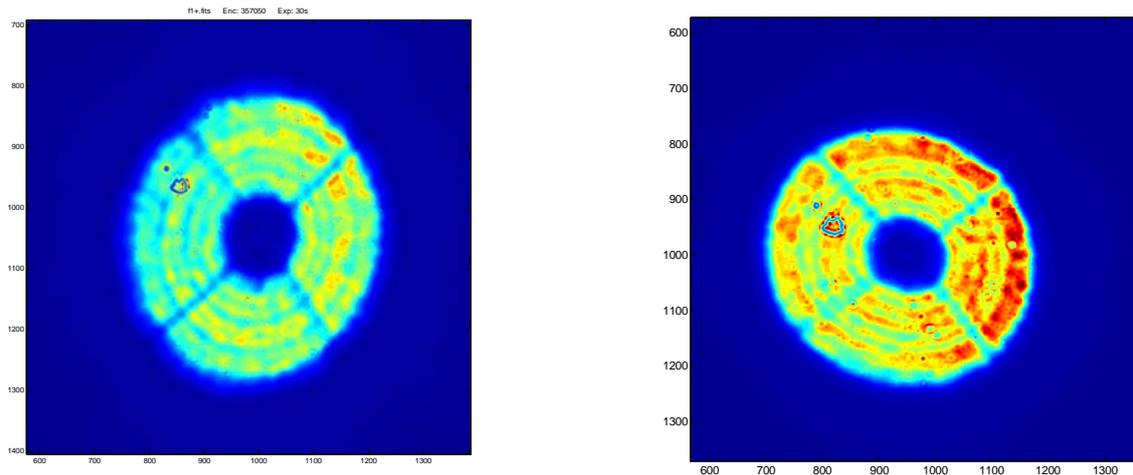


Figure 3 Focus +40,000 units zoomed (left) and Focus -40,000 units zoomed (right)

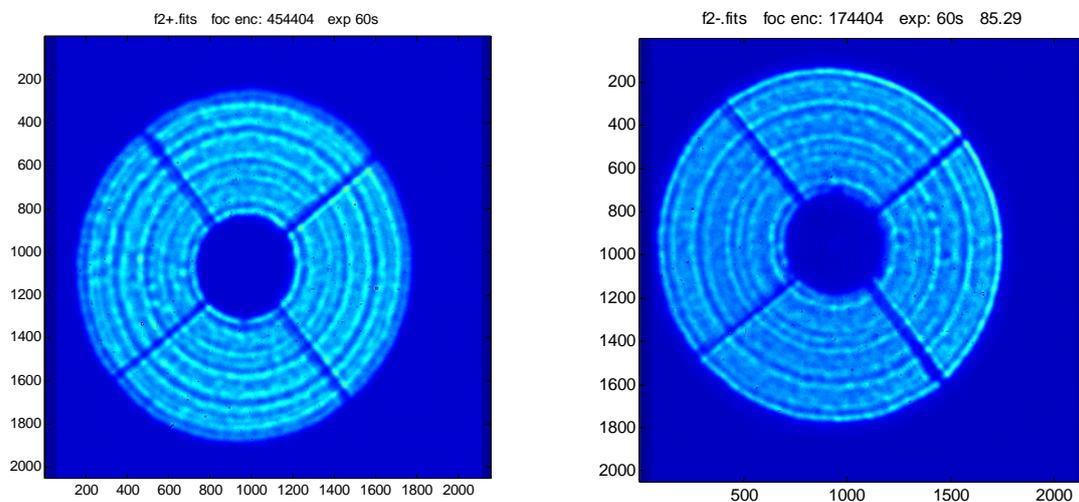


Figure 4 Focus +137350 units (left) and Focus -142,646 units (right)

Observations have been obtained 10-11 Sept. 2008, at Cassegrain focus

File name	Focus Encoder	Exp(sec)	Rem
f0.fits	317050	0.5	best focus
f1+.fits	357050	30	
f2+.fits	454404	60	
f1_.fita	277050	60	
f2_.fits	174404	60	85.29

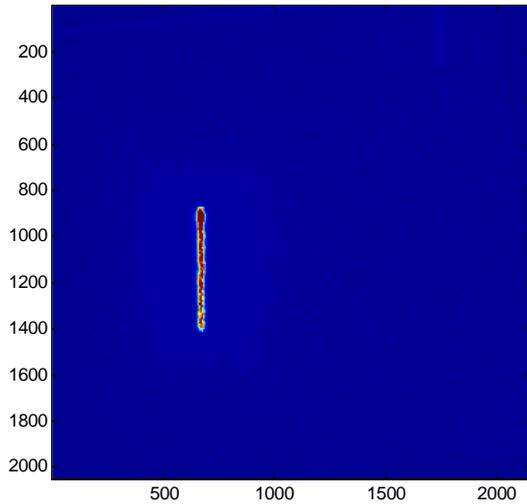
Confirmation of HA and DEC directions

The two images indicating the directions of W and N reveal a non-orthogonality – I don't have an explanation for this.

Start trailing

trailwest_078.fits	317045	10	79 trailing towards West
no_079.fits	317045	0.1	79 no trail
trailnorth_080.fits	317045	10	79 trailing towards North

trailnorth 080.fits foc enc: 317045 exp: 10s 79 trailing towards North



trailwest 078.fits foc enc: 317045 exp: 10s 79 trailing towards West

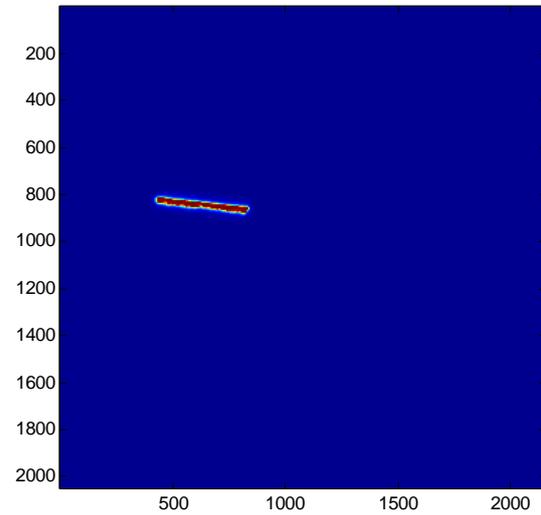
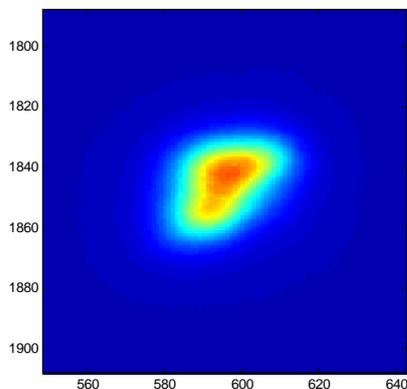


Figure 5 Telescope trailed N (image moves S) left and Telescope trailed W (image moves E) right.

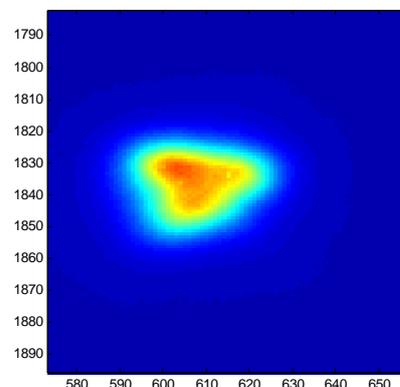
Further in-focus/near focus observations

This sequence is from observations on 10-11/9/2008. The first image is probably just one side of focus and the following three are just the other side of focus.

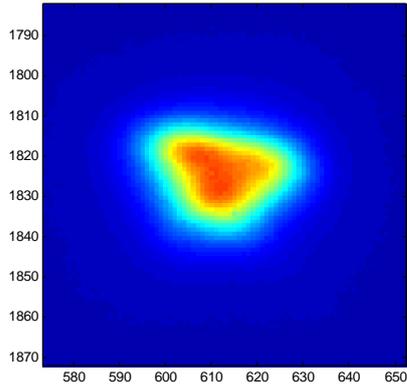
File name	Focus	Exp(sec)	Rem
080910_col_V_037.FITS	318000	120	M29
080910_col_V_038.FITS	317108	120	M29
080910_col_V_039.FITS	317068	120	M29
080910_col_V_040.FITS	317068	40	M29



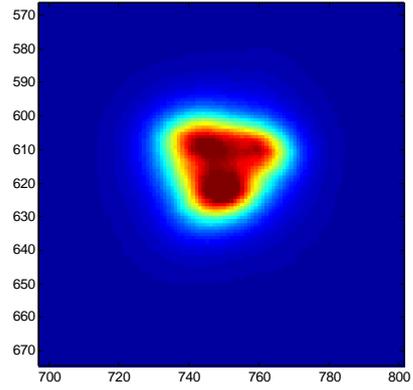
080910_col_V_037.FITS 318000 120s



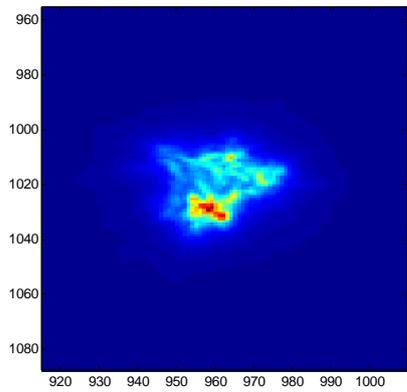
080910_col_V_038.FITS 317108 120s



080910_col_V_039.FITS 317068 120s



080910_col_V_040.FITS 317068 40s



080910_col_V_065.FITS 317050 0.1s Best focus

The last image above is best focus later in the night.

Initial analysis of image quality

(Analysis provided by Dr S Worswick)

1. This is only a representative analysis and some basic assumptions have been made.
2. F/18 Cassegrain telescope. Primary mirror f/4.84, radius of curvature 18288 mm, clear aperture 1888 mm. Secondary mirror placed to produce f/18 focus 1 m behind pole of primary. This may a bit short but can be corrected with further mechanical information. Image scale 165 μm per arcsecond.
3. Image sizes in Figure 3 of this report are around 450 pixels in diameter. Assume 15 μm pixel size gives image diameter ~ 6.75 mm so at f/18 gives focus throw $\sim \pm 120$ mm.
4. Different levels of coma and astigmatism can be introduced by using a Zernike phase surface within the ZEMAX program. Orientations may not be correct but an approximate relative power in the 2 aberrations can be estimated.
5. A combination of astigmatism and coma can give a triangular image. There follow 3 images taken at focus, 120 mm before and 120 mm after focus obtained by refocusing the telescope. Sign convention: The before focus image is obtained by pushing the in focus image down from the primary that is decreasing the primary, secondary separation. The aberration distribution has been convolved with a Gaussian seeing disc of 1 arcsec FWHM.

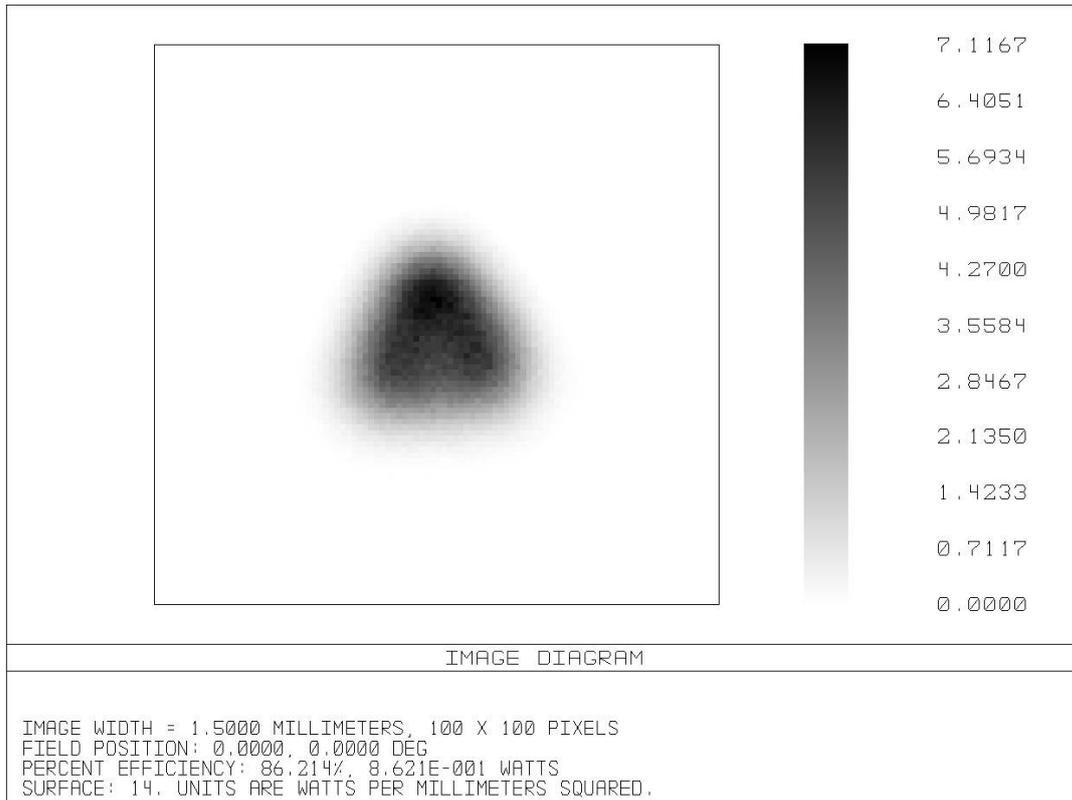


Figure 6 Image at focus

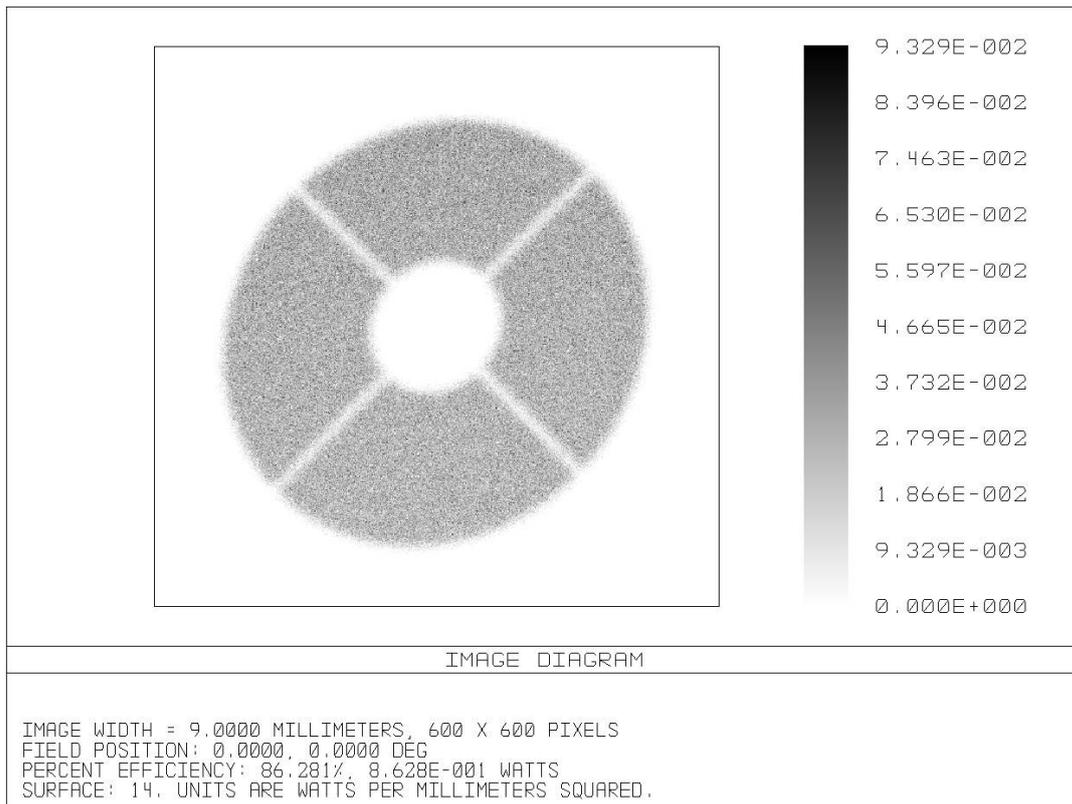


Figure 7 Image 120 mm before focus

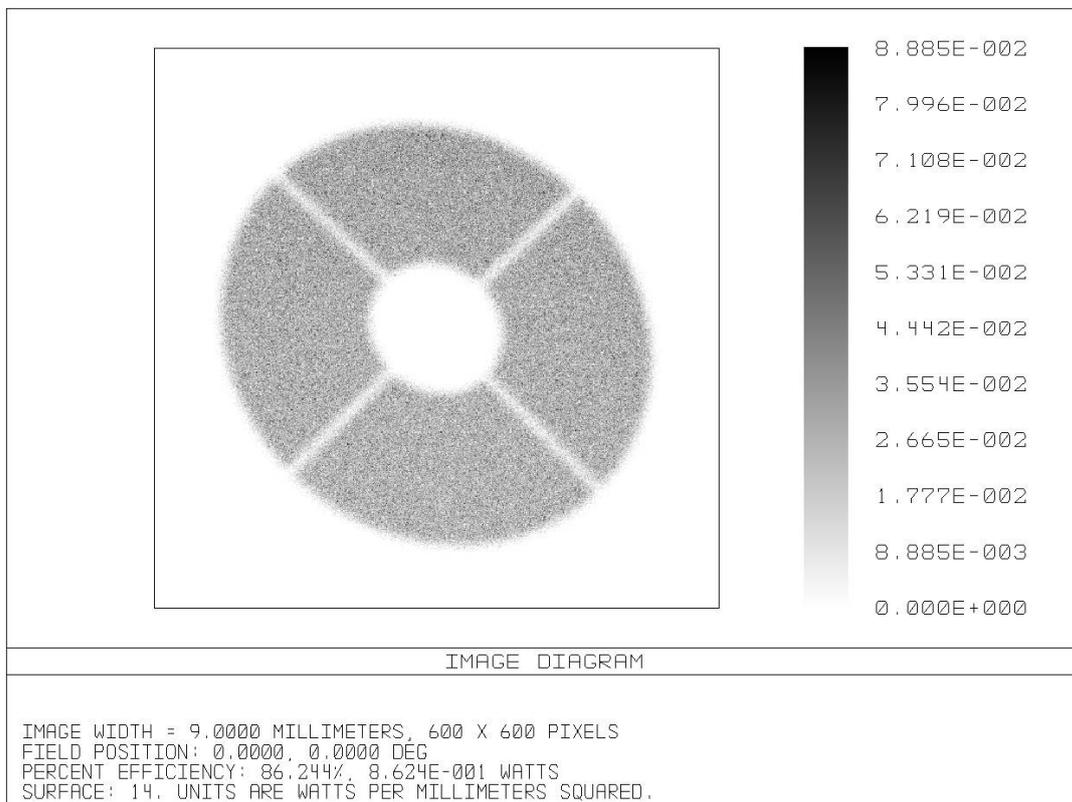


Figure 8 Image 120 mm after focus

Mirror Support Analysis

In this analysis the layout and approximate dimensions of the mirror and support system are modelled in an FEA program. Although the settings of the axial supports are not revealed by the Ziess documentation a reasonable approximation is obtained by optimising the support forces to minimise the deflections of the mirror in the analysis.

The support forces are optimised so that the out ring of axial supports and the reaction forces on the fixed supports are reasonable close. When the mirror deflections are within reasonable bounds (around ± 25 nm) the model is ready for various loads to be applied. The analyses which follow compute the deflections associated with the complete removal of support from various axial supports.

Note that it is possible for axial supports to stick in a way which decrease or increases the support force. It is possible that an axial support may get stuck to the extent that it behaves like a fixed support, effectively changing the fixed support points to a non symmetric distribution and introducing the possibility that the mirror may become bi-stable, depending on flexure of the mirror cell. This case could give rise to a substantial coma term.

Mirror support layout

The layout of the mirror support and parameters of the primary mirror are



Figure 9 Kottamia 74" primary mirror cell (N.B. North is to the right)

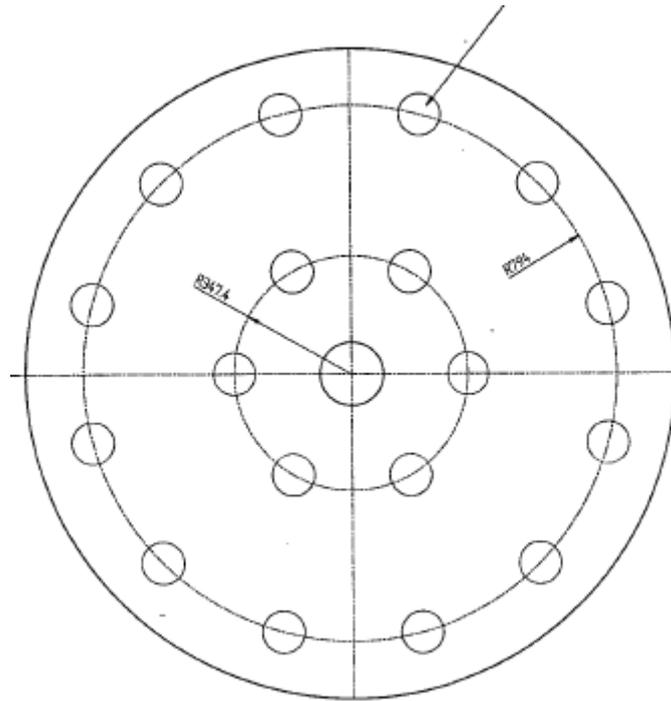


Figure 10 Mirror axial support layout

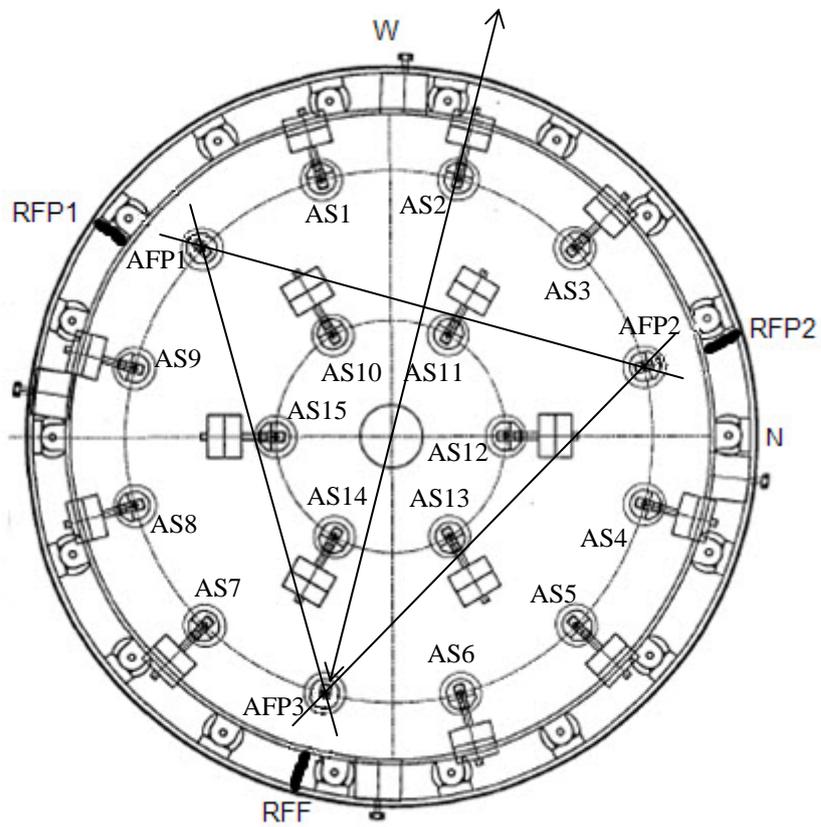
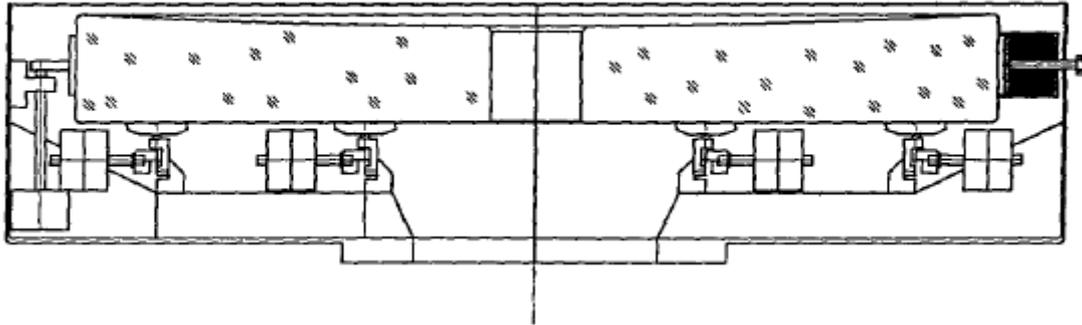


Figure 11 Mirror support layout details



Technical parameters:

Primary mirror:

Diameter	1930mm
Diameter of center hole	188 mm
Thickness on the edge	230 mm
Optical aperture	1880 mm
Radius of curvature	5883 mm
Material	ZERODUR
Thermal expansion coefficient	0±0.10 x 10E-6 /K

?

Secondary mirror:

Diameter	496.8 mm
Thickness in center	80.1 mm
Optical aperture	483 mm
Radius of curvature	7380 mm
Conical constant	k= -3.012377
Material	ZERODUR
Thermal expansion coefficient	0±0.10 x 10E-6 /K

Optical system

Focal ratio	f/18
Focal length	33984 mm
Distance M1 M2 vertex	6989.9 mm
Distance M1 vertex -focal plane	1000 mm

Primary mirror Support

Number of axial supports	18
Number of radial support	16
Distance focal plane- instrument rotator flange	417.5 mm
Maxmal load onto Instrument rotator flange	400 kg with 1000 mm distance to center of gravity

Mirror Support Analysis

An approximately optimised mirror support for a 1900 mm diameter mirror of edge thickness 230mm and a central hole diameter of 200mm gives a peak to valley deformation of 40nm. This uses 840N loads on the nine outer ring free supports and 880N on the inner ring of six free supports.

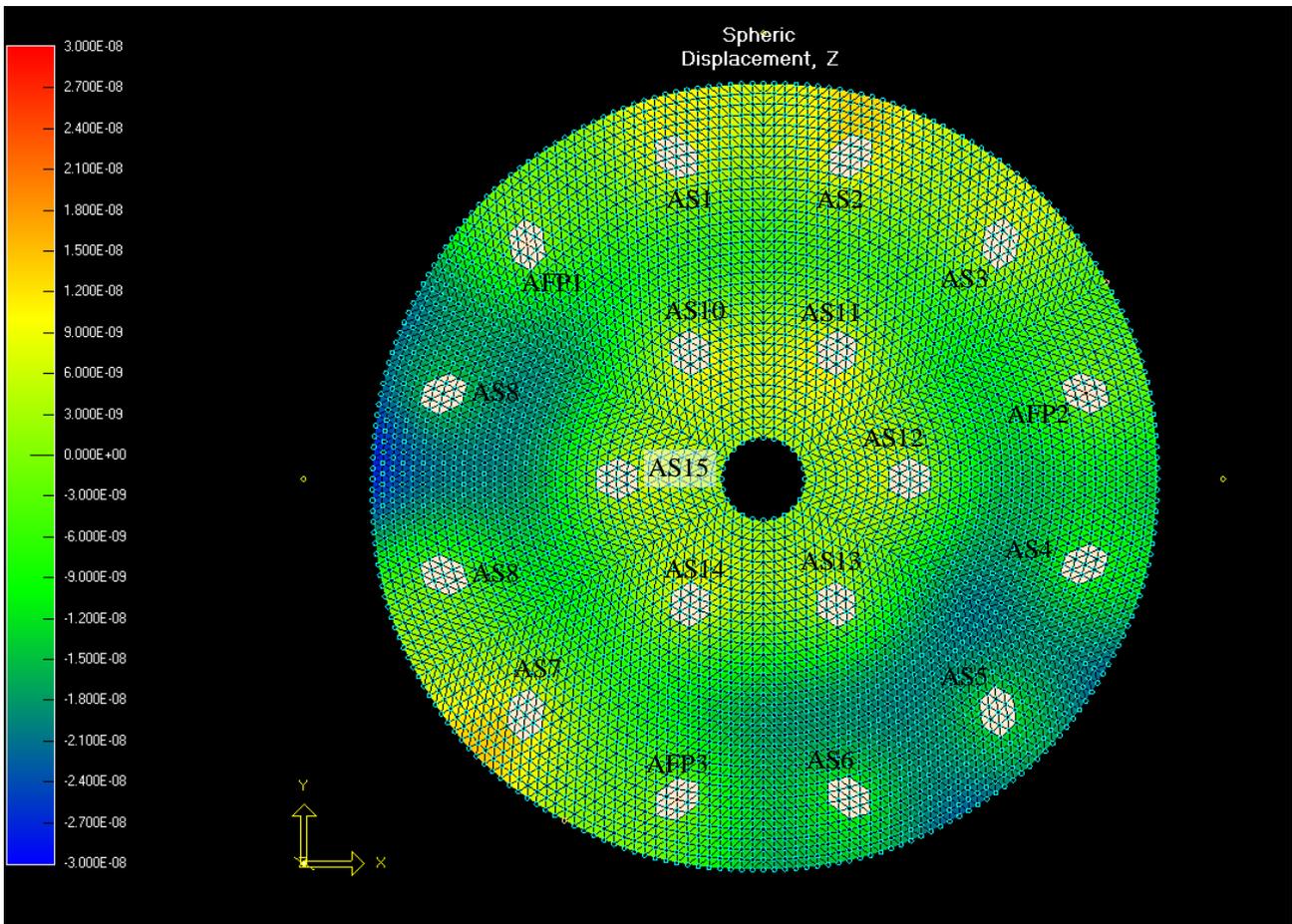


Figure 12 Optimised mirror support model

Reaction forces at the fixed supports are shown below. The differences are due to modeling/solution asymmetries.

The reaction forces at the defining supports (axial fixed pads) are:

AFP1	8.561E+02 N
AFP2	8.398E+02 N
AFP3	8.244E+02 N

Total 2520 N

This is a reasonable estimate for the Kottamia 74 inch support system but may not be the same as the forces determined by Zeiss because the mirror weight is estimated and the support positions are approximated to the nearest 25mm.

Note that loss of a axial support will increase the load on the three defining supports by about 840N to 880N i.e. to a total of 3360N to 3400N depending on the support position.

The following three cases consider the complete loss of support from a free axial support unit.

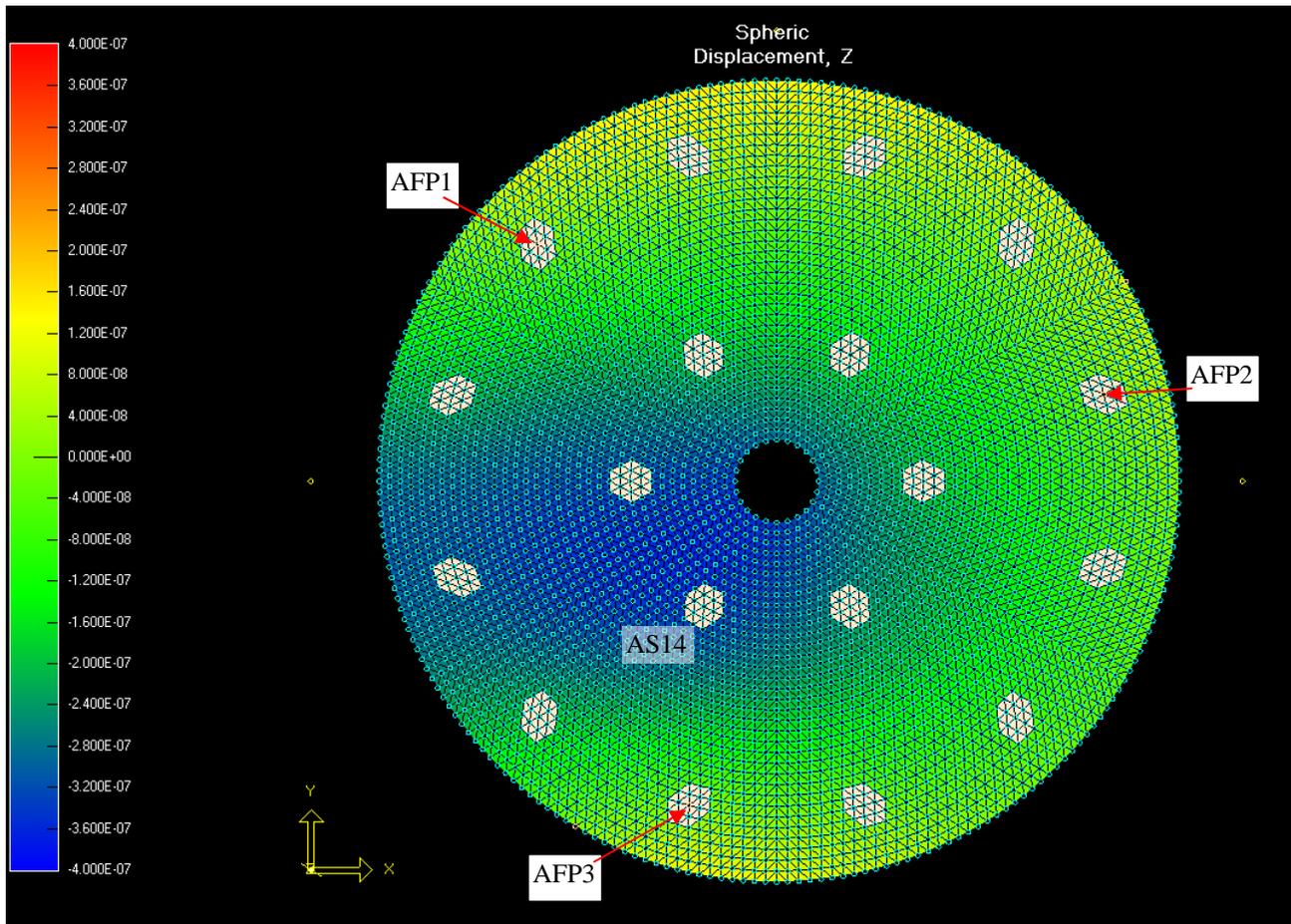


Figure 13 Complete loss of support from an inner axial support unit

Loss of an inner support (e.g. AS14) causes a peak to valley error of about 0.8 μm with a N/S fold in the mirror.

The reaction forces at the defining supports (axial fixed pads) are:

AFP1	1.083E+03 N
AFP2	9.517E+02 N
AFP3	1.366E+03 N

Total 3401 N

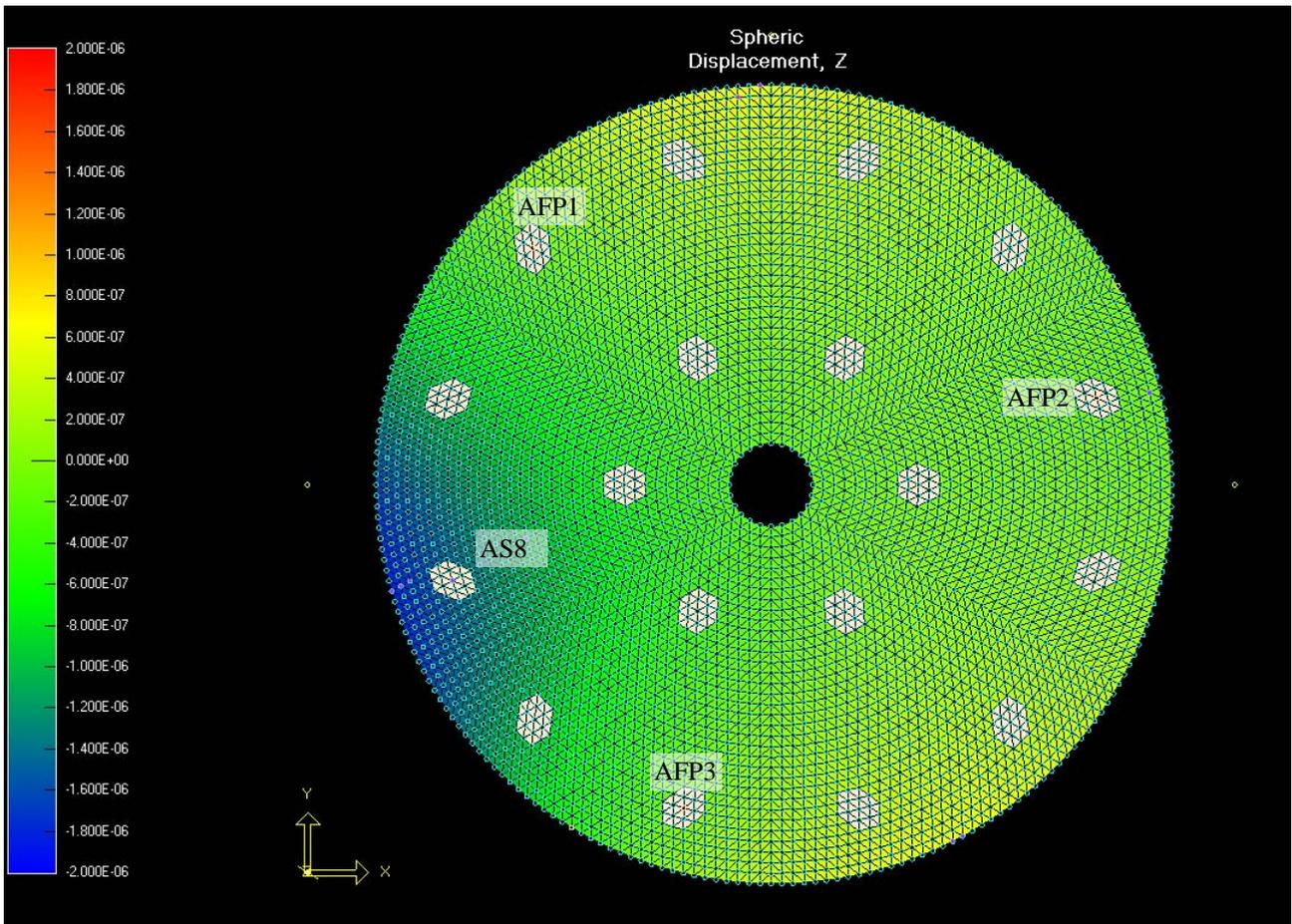


Figure 14 Complete loss of support from an outer axial support unit (case 1)

Loss of an outer support (e.g. AS8) which is between defining supports but adjacent to an inner support causes a peak to valley error of about 2.4 μm with a N/S fold in the mirror and the main fold peak to valley of about 1.6 μm .

The reaction forces at the defining supports (axial fixed pads) are:

AFP1	1.400E+03 N
AFP2	5.601E+02 N
AFP3	1.400E+03 N

Total 3360 N

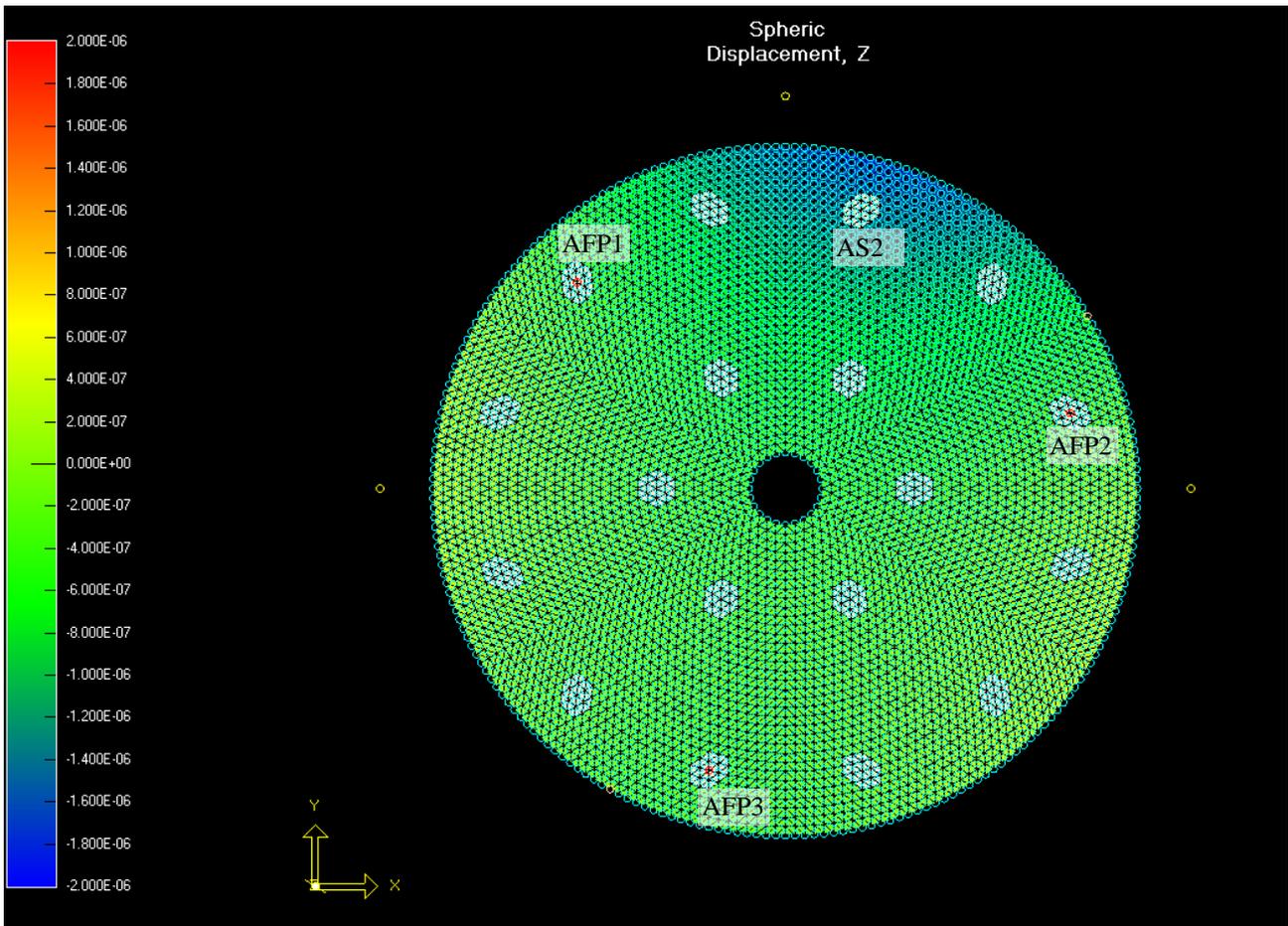


Figure 15 Complete loss of support from an outer axial support unit (case 2)

Similarly, loss of an outer support (e.g. AS2) causes a peak to valley error of about 2.4 μm with a WNW fold in the mirror with the main fold peak to valley of about 1.2 μm .

The reaction forces at the defining supports (axial fixed pads) are:

AFP1	1.416E+03 N
AFP2	1.400E+03 N
AFP3	5.444E+02 N

Total 3360 N

These last three cases illustrate that the magnitude of astigmatism present in the telescopes image could easily be explained by a loss of support from one of the free support units. They do not explain the presence of coma but that may be due to a fixed collimation error rather than a faulty primary support.

Conclusions and Recommendations

The astigmatism in the Kottamia 74 inch optical image could be produced by something like a peak-to-valley distortion of 2.5 μm in the primary mirror. Such a distortion is likely to be due to a fault in the primary support system. That the primary is responsible can be confirmed if the astigmatism is present at both the Cassegrain and Newtonian foci. It should also be confirmed if the astigmatism reduces with increased zenith distance because the axial support forces become less relevant as the load transfers to the radial supports.

The degree of astigmatism could be explained by a failure of one of the free axial supports. Such a failure may be caused by a failure of or a high level of friction the pivot bearing which transfers the load of the counterweight to the mirror support pad. It is also possible that a piece of material could get wedged between the counterweight mechanism and the mirror cell, preventing the counterweight from applying the load through to the mirror.

The astigmatism could also be caused by a free axial support which is stuck in such a way as to apply excess load to the mirror or even to lift the mirror away from the nearest defining (fixed) axial support. This would lead to a similar level of astigmatism because one of the fixed supports would in that case not be supporting the mirror.

It is possible to introduce astigmatism if the mirror is over-supported or under supported but it would also be accompanied by trefoil. The in-focus images may contain some trefoil but it is probable that coma is the major cause of the three sided appearance.

Another way to confirm these conclusions would be to analyse the Hartmann data at least to the level of trefoil. This could be done but it would take some time to set up the analysis and also to centroid the spots because of the dust-doughnuts and other artefacts in the images.

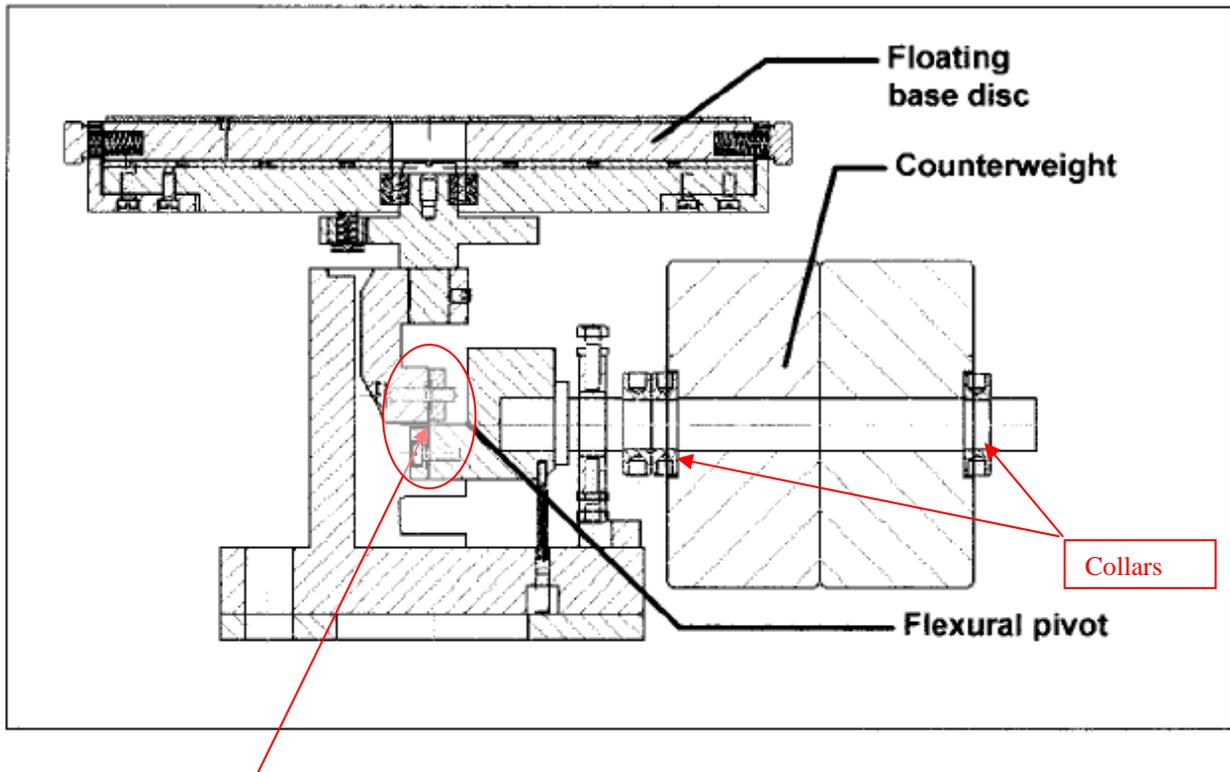
Recommendation 1

Check to see if astigmatism reduces at high zenith distance ($> 60^\circ$). This can be done by taking a series of images through focus and assessing the elongation of the image or taking an image either side of focus and measuring the major and minor axes.

Recommendation 2

If astigmatic images are present at both Cassegrain and Newtonian foci, then remove the mirror from the primary mirror cell and inspect the axial and radial support system. This inspection should include the following actions:

- Before removing the mirror, check that the mirror seems central and that the radial flexible support is forcing the mirror against the two radial fixed supports. Then check that the radial support links connect to the mirror properly and that there is just a small amount of movement at the counterbalance arm for each radial support.
- After removing the mirror check to see that each axial support counterweight mechanism is free to move by lifting the counterweight up and down. Check that the flexure pivot is undamaged (see picture on next page).
- Check that no objects are caught in the mechanism.
- Check what load can be applied to the support pad to make the counterweight move. (This might be done by adding weights until the mechanism moves and then measuring the total weight. You should need between 80kg and 90kg).
- Check that the fixed axial supports are stable (note that the top of the support is a floating disc and so will be able to move laterally).
- Check that the radial supports also move freely.
- Check that the mirror cannot touch any other part of the cell when it is replaced.



Check that the thin plate connecting the counterweight arm and the vertical support is undamaged and that the counterweight moves freely between its limits, moving the support up/down.

If a flexure is broken or damaged then a new one will have to be obtained from Zeiss.

Also ensure that the collars which position the counterweights are secure. If a collar has become loose and the weights are out of position then reposition them so that they are the same distance from the pivot as the weights in the other supports of the same ring.