# The thickness of the beamsplitter and image quality when using the NCU

**wht-naomi-74**
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NCUbeamsplitter.doc
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There are 5 light paths to consider when using the NCU. Details of the geometric image quality for each of these paths are given in sections 1.1 to 1.5. The actual image quality will obviously depend on the seeing (for stellar images) and the form factor errors of the optical components (all images). In choosing the thickness of the beamsplitter the image quality for NCU on-axis sources as seen by the OMC needs to be balanced against the image quality of the stellar images seen through the beamsplitter and the stellar and NCU images seen by the acquisition camera. In the case of stellar images seen through the beamsplitter the amount by which the focus of the WFS and the science camera needs to move also has to be considered; for a 2mm thick beamsplitter the focus shift is 1.4mm while for a 6mm beamsplitter it is 4mm. For t=2 mm the unfocussed wavefront error is 1.18?m, with refocussing this reduces to 0.6?m. For t=6mm with refocusing there is a residual wavefront error of ~1.8 ?m. However the maximum focus shift of INGRID is ?0.52 mm at the NAOMI f/16 output which means that, if images before and after correction are to be observed, some of the wavefront error will need to be removed by the DM - ~1?m for t=2mm.

Another constraint on the thickness of the beamsplitter is the maximum thickness (6mm) of the compensator plate that can be fitted in front of the acquisition camera. (See sections 1.3. and 1.4.). This limits t(beamsplitter) to be <4mm.

The stellar and NCU images as seen by the acquisition camera are shown in Figures 10-13. These show that for a 2 mm beamsplitter the images are <<0.25 arcsec and for a 6mm beamsplitter are <<0.5 arcsec.

We have requested quotations for beamsplitters 2mm and 6mm thick. When we have the quotes we will discuss the achievable flatness, especially spherical and cylindrical bowing and at scales ~1 sub-aperture, with the manufacturers before choosing the thickness of the beamsplitter.

### *1.1. From the telescope to the Nasmyth focal plane* without *the beamsplitter in place.*

This is used as a reference to compare with the other stellar paths. The spot diagrams[1] show the images for this path at the corners and centres of the short edges of the fov of the acquisition camera.

[1] all spot diagrams and encircled energy plots are for 0.5-1 ?m

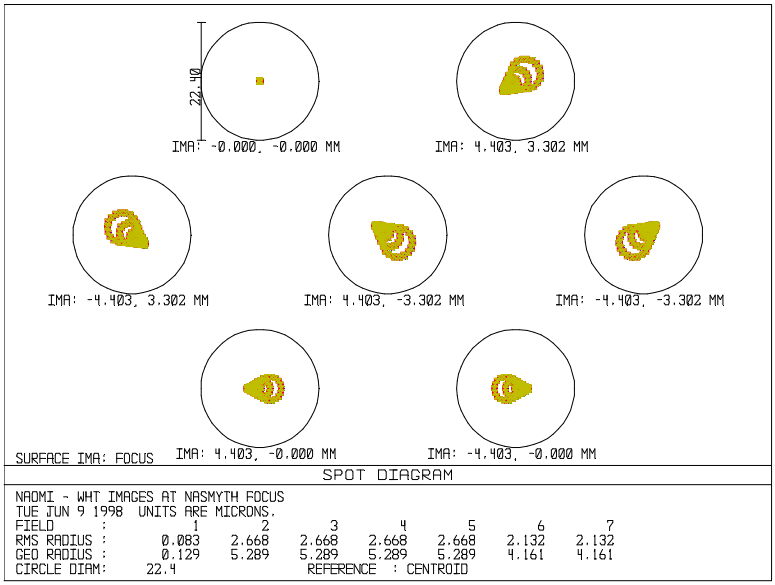


**Figure 1**

*WHT images at Nasmyth focal plane*
*The circle is 0.1 arcsec diameter.*

### *1.2. From the telescope to the Nasmyth focal plane with the beamsplitter in place.*

This path is used when, for example, the images before and after correction are being monitored. The image quality for 3 cases are shown.

#### 1.2.1. Beamsplitter thickness 2mm. No refocussing

The spot diagrams are the images at the Nasmyth focus with a 2mm thick fused silica beamsplitter inserted in the telescope beam. As can be seen the images have a total extent of 0.5 arcsec and from the encircled energy plot the FWHM for the on-axis image is ˜ 60? m or 0.27arcsec. The Zemax wavefront analysis is in Table 1 column 2.

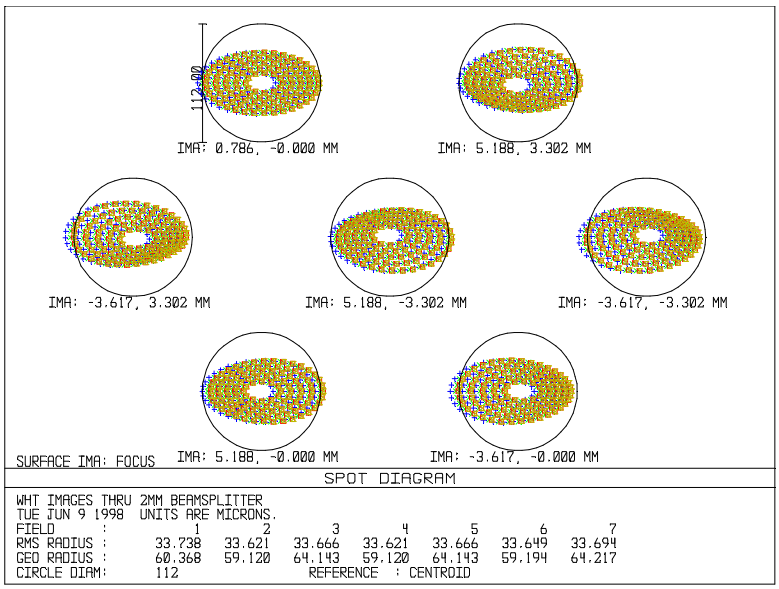

**Figure 2** WHT images through 2mm beamsplitter *The circle is 0.5 arcsec diameter*

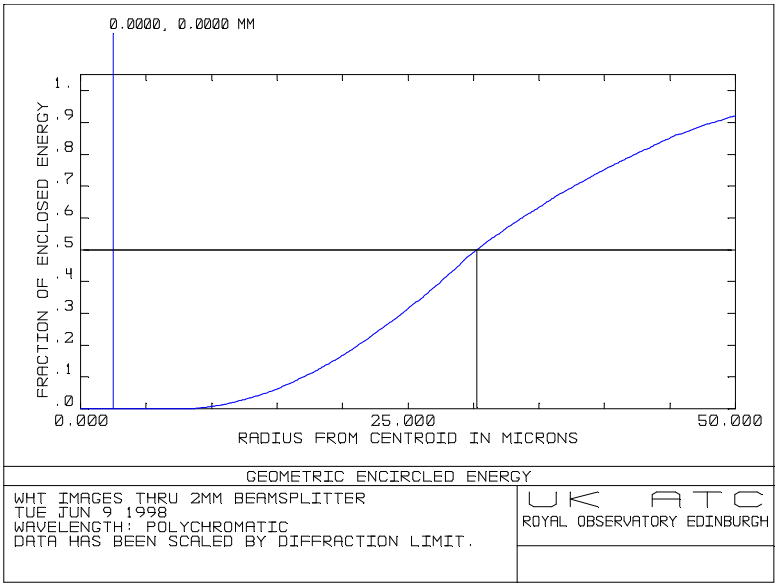


**Figure 3**

| Zernike number | a) t=2mm unfocussed | b) t=2mm refocussed | c) t=6mm refocussed | Noll representation |
|---|---|---|---|---|
| | Waves (?=1 ?m) | | | |
| Z 2 | 0.010661 | 0.010659 | 0.031980 | ?4 r cos? |
| Z 3 | 0.000000 | 0.000000 | 0.000000 | ?4 r sin? |
| Z 4 | -0.269721 | 0.004116 | -0.046868 | ?3 ($2r^2 - 1$) |
| Z 5 | 0.000000 | 0.000000 | 0.000000 | ?6 $r^2$ sin? |
| Z 6 | -0.115837 | -0.115820 | -0.347471 | ?6 $r^2$ cos? |
| Z 7 | -0.000000 | -0.000000 | -0.000000 | ?8 ($3r^3 - 2r$) sin? |
| Z 8 | 0.003768 | 0.003767 | 0.011303 | ?8 ($3r^3 - 2r$) cos? |
| Peak to Valley | 1.184600 | 0.601395 | 1.804246 | |

**Table 1** *Wavefront aberrations for stellar images seen through the NCU beamsplitter***.**

*The cases tabulated are a) a 2mm beamsplitter no refocussing of the WFS/science camera b) a 2mm beam splitter with WFS/science camera refocussed and c) a 2mm beam splitter with WFS/science camera refocussed*

### 1.2.2. Beamsplitter thickness 2mm. Refocussed camera and WFS

If the focus is corrected (focussing the science camera and WFS rather than the telescope so that the best focus is maintained on the acquisition camera) the spot diagrams (Fig 4), encircled energy (Fig 5) are as below and Zernike coefficients are given in Table 2, column 3. The shift in focus position is 0.9 mm at the Nasmyth focal plane ~1.4 mm at the WFS and science ports.

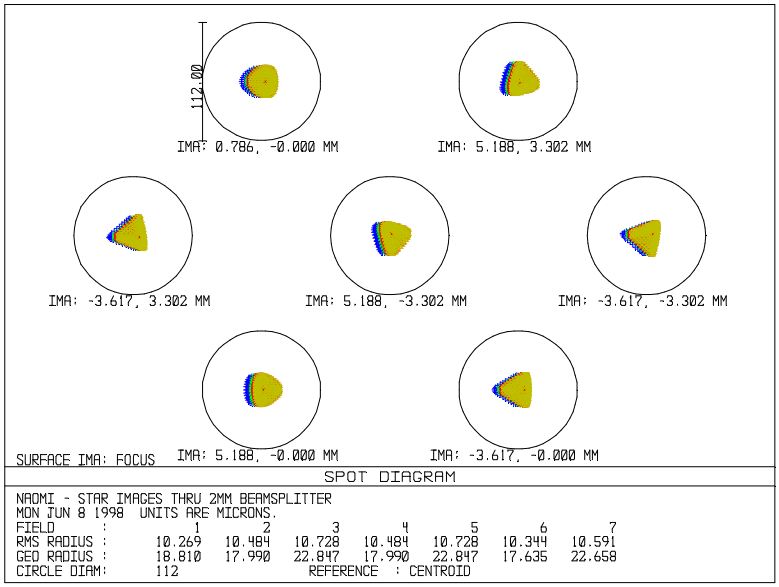


**Figure 4**

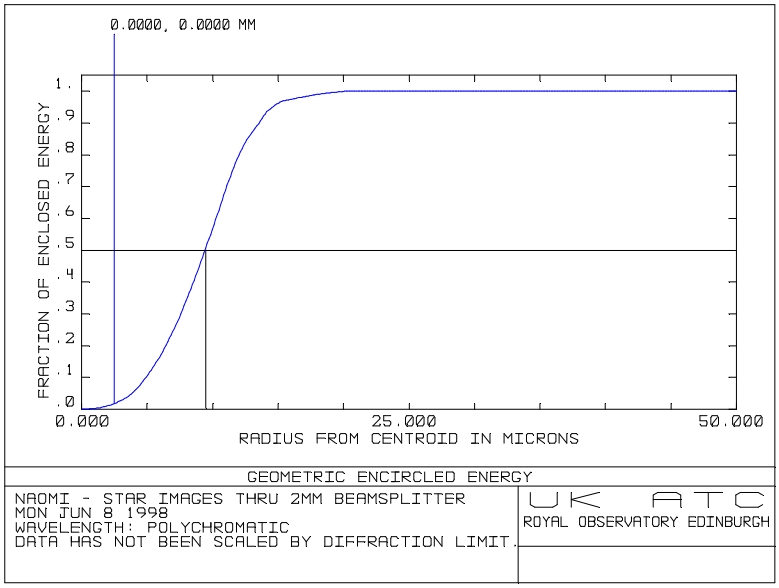


**Figure 5**

### 1.2.3. Beamsplitter thickness 6mm. Refocussed camera and WFS

If a 6mm beamsplitter is used the shift of focus at the Nasmyth focal plane is 2.5 mm or 3.75 mm at the WFS and the science port. With this defocus removed the spots (Fig 6), encircled energy (Fig 7) and wavefront aberrations (Table 1 column 4) are as shown.

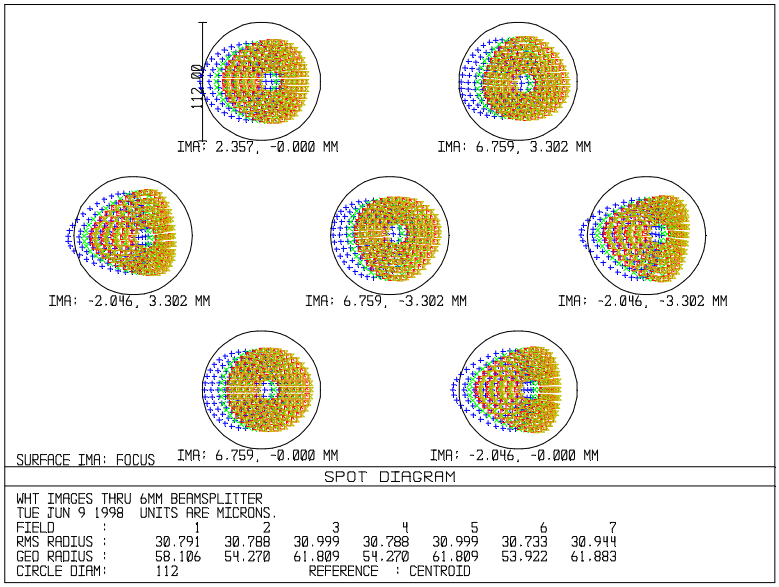


**Figure 6** *WHT images at Nasmyth focus through 6mm beamsplitter, science camera refocussed. Circle is 0.5 arcsec*

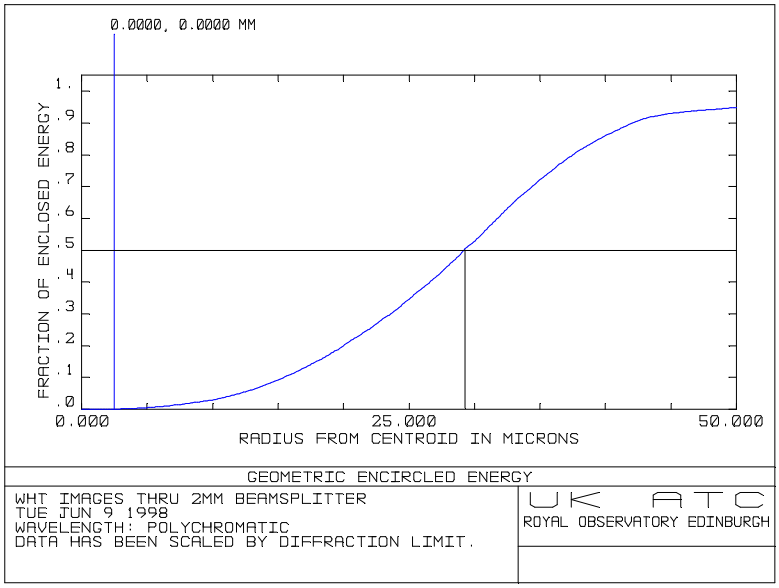


**Figure 7**

### *1.3. From the telescope to the acquisition camera.*

Used for acquisition and for monitoring the 'before' images. See Figure 8 The light passes through the beamsplitter, is partially reflected by the ~50/50 coating repasses the beamsplitter and emerges at 90$^{o}$ to the input. The light then passes through a compensator plate before the image is relayed to the acquisition camera CCD. The Zemax model was set up so that the positions, with respect to the incoming beam and the beamsplitter, of the acquisition camera focal plane and the compensation plate are the same for both the light from the telescope and the light from the NCU (See section 1.3)

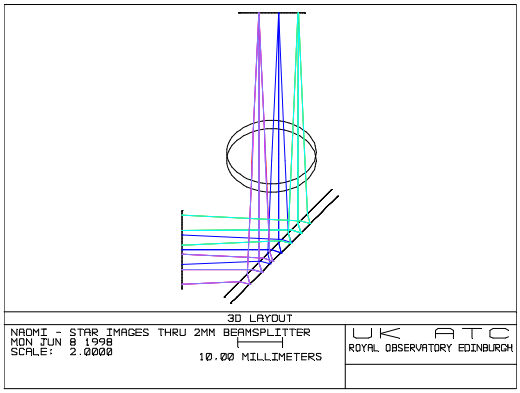


**Figure 8** *Telescope to Acquisition camera*

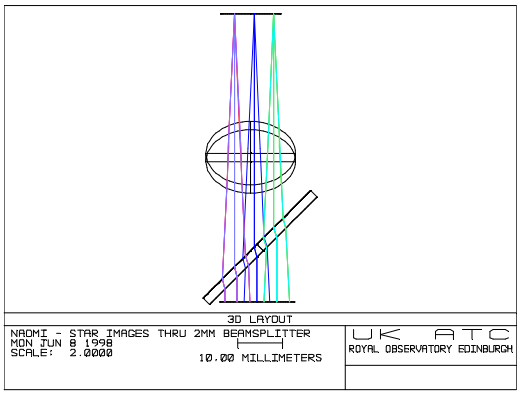


**Figure 9** *NCU to acquisition camera*

Light from the telescope passes twice through the beamsplitter in this configuration but only once for the light from the NCU (Figure 9). The optimum thicknesses for the compensating plate are 2? and 1? the thickness of the beamsplitter for each of these modes respectively. The compensator plate cannot be changed between the two modes (in fact both can be used simultaneously) so a compromise of 1.5?beamsplitter thickness is used. The spot diagrams for the telescope to acquisition camera mode are shown in Figures 10 for a beamsplitter with t=2 mm and in Figures 11 for t=6mm.

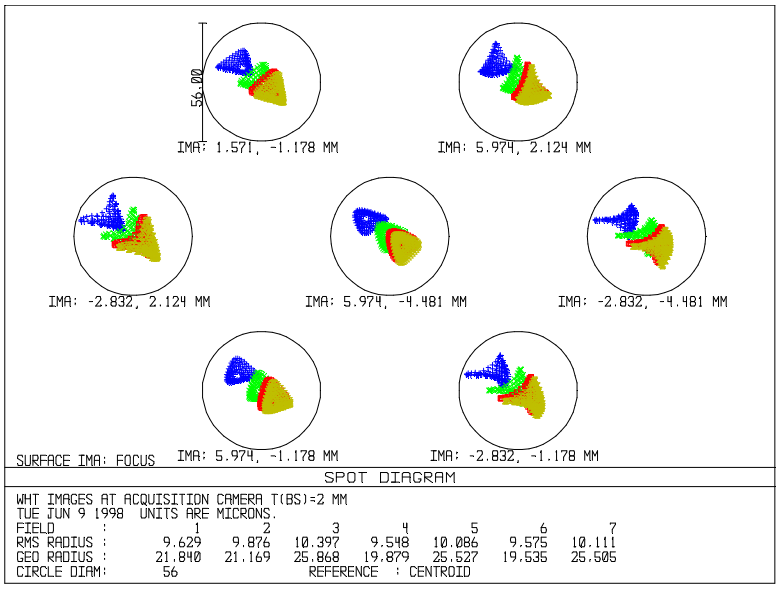


**Figure 10** *WHT images at acquisition camera, 2mm Beamsplitter. Circle is 0.25 arcsec*

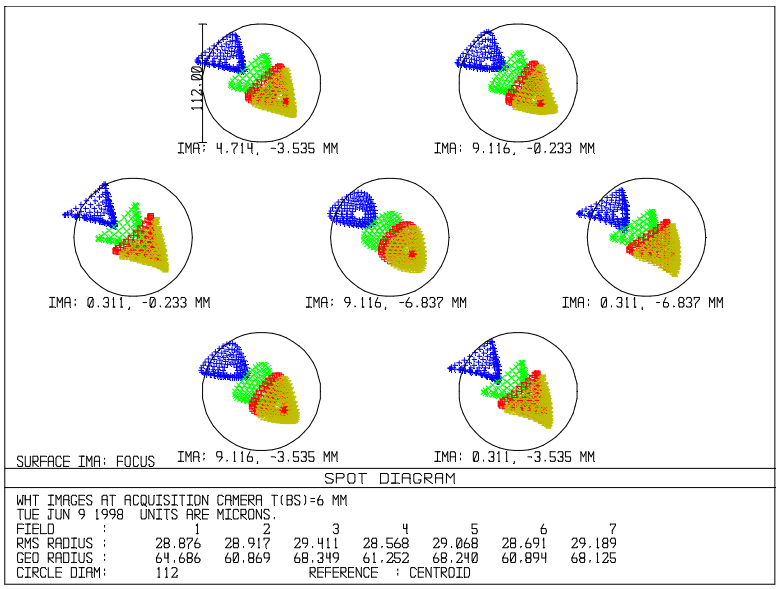


**Figure 11** *WHT images at acquisition camera*

*6mm Beamsplitter. Circle is 0.5 arcsec*

### *1.4. From the Offner relay to the acquisition camera*

The spot diagrams for the light path shown in Figure 9 are given in Figures 12 and 13 for beamsplitter thicknesses of 2mm and 6mm respectively.

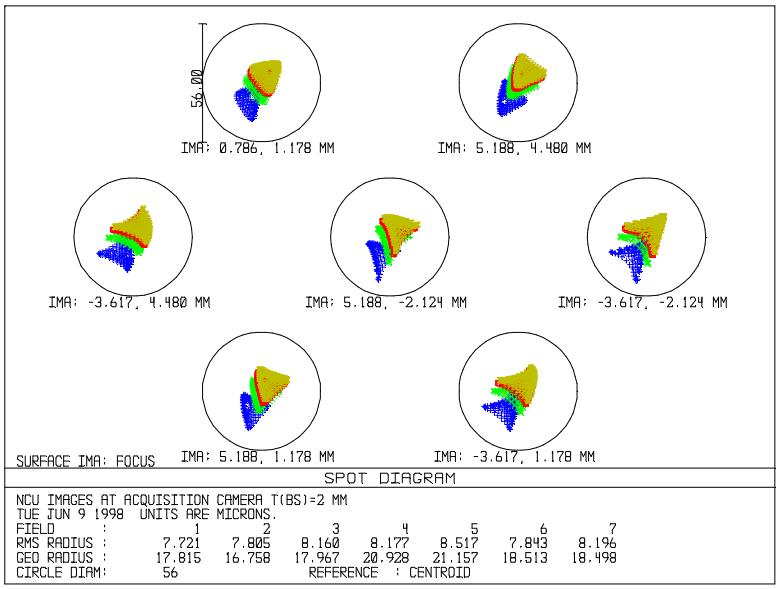


**Figure 12** *NCU to acquisition camera*

*2mm beamsplitter. Circle is 0.25 arcsec diameter*

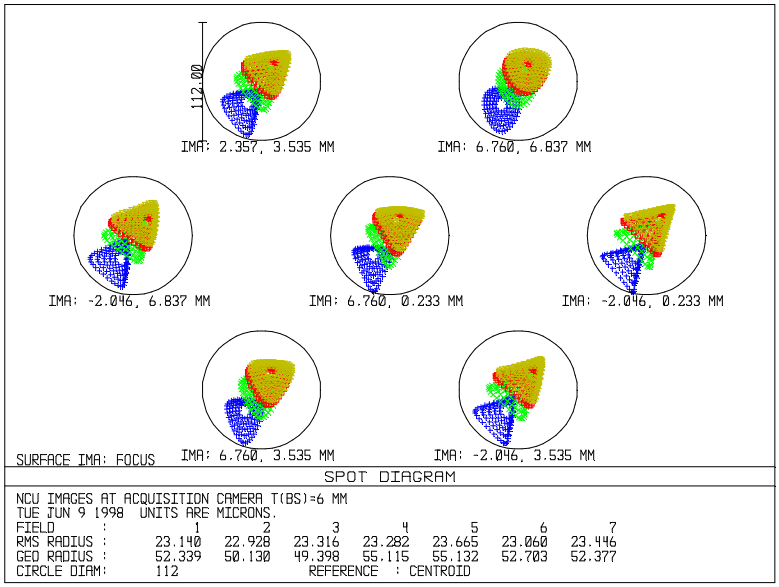


**Figure 13** *NCU to acquisition camera*

*6mm beamsplitter. Circle is 0.5 arcsec diameter*

### *1.5. From the Offner relay to the Nasmyth focal plane*

The image quality for this light path is not affected directly by the thickness of the beamsplitter, the geometric spot sizes are diffraction limited at 2?m over the science field of 40?40 arcsec, see NCU CDR document page 12. The image quality will however be affected by the flatness of the beamsplitter. Price quotes for 2mm and 6mm thick beamsplitters have been put out tender. We will discuss the achievable flattness, especially spherical and cylindrical bowing and at scales ~1 sub-aperture, with the manufacturers.