Optics of the Mees telescope, finder, cameras and eyepieces

Expanded from an ancient Mathcad document on the occasion of designing mounting hardware for the new SBIG STX-16803 camera and Shelyak LHIRES III spectrometer.

Updated 27 October 2013 DMW

Reference:C:\Program Files (x86)\Mathcad\Mathcad 14\template\Dan's constants and formulas 1.xmcd

1. **Mees 24" telescope prescription**

Primary mirror

$D_p := 24\cdot in$ $f_p := 84\cdot in$ $r_p := f_p\cdot 2$ $\varepsilon_p := 1$

Secondary mirror

$D_s := 6.55\cdot in$ $f_{2s} := (62.69 + 19.5)\cdot in$ $f_{1s} := 21.31\cdot in$

$c_s := \frac{f_{2s} + f_{1s}}{2}$ $a_s := \frac{f_{2s} - f_{1s}}{2}$ $b_s := \sqrt{c_s^{\,2} - a_s^{\,2}}$

$r_s := \frac{b_s^{\,2}}{a_s}$ $\varepsilon_s := \frac{c_s}{a_s}$

$r_s = 146.148\,cm$

$\varepsilon_s = 1.7$

Check:

$f_s := \frac{f_{1s}\cdot f_{2s}}{f_{2s} - f_{1s}}$ $\frac{f_s}{in} = 28.769$

Boller and Chivens says it's 28.78 in.

Interapex distance: $z_s := f_{2s} - 19.5\cdot in$

Petzval sum: $\kappa := \frac{1}{f_p} + \frac{1}{f_{1s}} + \frac{1}{f_{2s}}$ $\frac{1}{\kappa} = 35.776\,cm$

Effective focal length and plate scale at classical Cassegrain focus:

$f_e := f_p\cdot\frac{f_{2s}}{f_{1s}}$ $\frac{f_e}{in} = 323.977$

$PS_m := \frac{1}{f_e}\cdot rad$ $PS_m\cdot\frac{mm}{arcsec} = 25.066$

$\frac{f_e}{D_p} = 13.499$ Boller and Chivens says 13.5.

Radius of unvignetted FOV: $UFOV_m := 12 \cdot arcmin$

Defocus at edge of FOV:

$L := \frac{UFOV_m}{PS_m} = 2.872\,cm$ $\Delta z := \frac{1}{\kappa} \cdot \left(1 - \sqrt{1 - \kappa^2 L^2}\right) = 0.116\,cm$

In terms that RayTrace and Zemax and OSLO like:

$D_p = 60.96\,cm$ $r_p = 426.72\,cm$ $\varepsilon_p = 1$ $z_s = 159.233\,cm$

$D_s = 16.637\,cm$ $r_s = 146.148\,cm$ $f_{2s} = 208.763\,cm$ $\varepsilon_s = 1.7$

2. 6" finder telescope (refractor, achromat doublet objective)

$D_f := 6 \cdot in$ $f_f := 10 \cdot D_f$ $PS_f := \frac{1}{f_f} \cdot rad$

Radius of unvignetted FOV, degrees (field stop at eyepiece):

$UFOV_f := \frac{1.1 \cdot in}{2} \cdot PS_f$ $\frac{UFOV_f}{arcmin} = 31.513$

3. 8" Meade portable telescope (Schmidt-Newtonian)

$D_M := 8 \cdot in$ $f_M := D_M \cdot 4$ $PS_M := \frac{1}{f_M} \cdot rad$

Radius of unvignetted FOV, degrees (field stop at eyepiece):

$UFOV_M := \frac{1.1 \cdot in}{2} \cdot PS_M$ $\frac{UFOV_M}{arcmin} = 59.086$

For calculations:

$$f := \begin{pmatrix} f_e \\ f_f \\ f_M \end{pmatrix} \qquad D := \begin{pmatrix} D_p \\ D_f \\ D_M \end{pmatrix} \qquad PS := \begin{pmatrix} PS_m \\ PS_f \\ PS_M \end{pmatrix} \qquad i := 0 .. 2$$

$$UFOV := \begin{pmatrix} UFOV_m \\ UFOV_f \\ UFOV_M \end{pmatrix}$$

Eyepieces commonly in use:

Main telescope	Finder	Meade
55 mm Ploessl	40 mm Kellner	40 mm Ploessl
41 mm Panoptic	26 mm Kellner	20 mm Ploessl
6.3 mm Erfle	13 mm Nagler	9.7 mm Ploessl

$$f_{Eye} := \begin{pmatrix} 55 & 40 & 40 \\ 41 & 26 & 20 \\ 6.3 & 13 & 9.7 \end{pmatrix} \cdot mm \qquad j := 0 .. 2$$

Angular magnification, exit-pupil diameter and location (very crudely)

$$m_{Eye_{j,i}} := \frac{f_i}{f_{Eye_{j,i}}} \qquad m_{Eye} = \begin{pmatrix} 149.619 & 38.1 & 20.32 \\ 200.708 & 58.615 & 40.64 \\ 1.306 \times 10^3 & 117.231 & 83.794 \end{pmatrix}$$

$$D_{Eye_{j,i}} := D_i \cdot \frac{f_{Eye_{j,i}}}{f_i} \qquad \frac{D_{Eye}}{mm} = \begin{pmatrix} 4.074 & 4 & 10 \\ 3.037 & 2.6 & 5 \\ 0.467 & 1.3 & 2.425 \end{pmatrix}$$

$$z_{Eye_{j,i}} := \frac{f_{Eye_{j,i}}}{f_i} \cdot \left(f_{Eye_{j,i}} + f_i \right) \qquad \frac{z_{Eye}}{mm} = \begin{pmatrix} 55.368 & 41.05 & 41.969 \\ 41.204 & 26.444 & 20.492 \\ 6.305 & 13.111 & 9.816 \end{pmatrix}$$

And apparent FOV:

$$AFOV_{j,i} := UFOV_i \cdot m_{Eye_{j,i}} \qquad \frac{AFOV}{deg} = \begin{pmatrix} 29.924 & 20.011 & 20.011 \\ 40.142 & 30.785 & 40.021 \\ 261.239 & 61.571 & 82.518 \end{pmatrix}$$

261 degrees? This is why the Erfle isn't any good -- nor would the Nagler be, at the cass focus. But the Nagler (max 82-degree apparent field) would be great on the other two telescopes. Maybe we should get a 22-mm Nagler next time we have $525.

Cameras and CCDs in common use:

ST-i	KAI-0340	648x486
ST-7MEI	KAF-0401E	765x510
ST-9XE	KAF-0261E	512x512
STX-16803	KAF-16803	4096x4096

All the KAF CCDs are full frame.

Active-area and pixel dimensions:

$$\Delta x := \begin{pmatrix} 4.8 \\ 6.9 \\ 10.2 \\ 36.8 \end{pmatrix} \cdot mm \qquad \Delta y := \begin{pmatrix} 3.6 \\ 4.6 \\ 10.2 \\ 36.8 \end{pmatrix} \cdot mm \qquad \delta x := \begin{pmatrix} 7.4 \\ 9.0 \\ 20.0 \\ 9.0 \end{pmatrix} \cdot \mu m \qquad k := 0 .. 3$$

The autoguider CCD in the STX-16803 is the same as that in the ST-i. The one in the other two cameras is a TI TC-237, which is very similar to the KAI-0340 (657x495, 4.9x3.7 mm, 7.4 µm pixels) except for larger read noise ($12e^-$ vs $8.6e^-$) and smaller well depth ($20ke^-$ vs. $25ke^-$), and the fact that it's a frame transfer CCD rather than interline.

Fields of view (width or diameter):

$$\Delta\theta_{X_{k,i}} := if\left(PS_i \cdot \Delta x_k \le 2 \cdot UFOV_i, PS_i \cdot \Delta x_k, 2 \cdot UFOV_i\right)$$

$$\Delta\theta_{Y_{k,i}} := if\left(PS_i \cdot \Delta y_k \le 2 \cdot UFOV_i, PS_i \cdot \Delta y_k, 2 \cdot UFOV_i\right)$$

$$\delta\theta_{k,i} := PS_i \cdot \delta x_k$$

Summary

Key:

	24-inch	6-inch	8-inch
ST-i			
ST-7MEI			
ST-9XE			
STX-16803			

Field of view on the sky, arcminutes:

$$\frac{\Delta\theta_X}{\text{arcmin}} = \begin{pmatrix} 2.005 & 10.828 & 20.302 \\ 2.883 & 15.565 & 29.184 \\ 4.261 & 23.009 & 43.141 \\ 15.374 & 63.025 & 118.173 \end{pmatrix} \qquad \frac{\Delta\theta_Y}{\text{arcmin}} = \begin{pmatrix} 1.504 & 8.121 & 15.226 \\ 1.922 & 10.376 & 19.456 \\ 4.261 & 23.009 & 43.141 \\ 15.374 & 63.025 & 118.173 \end{pmatrix}$$

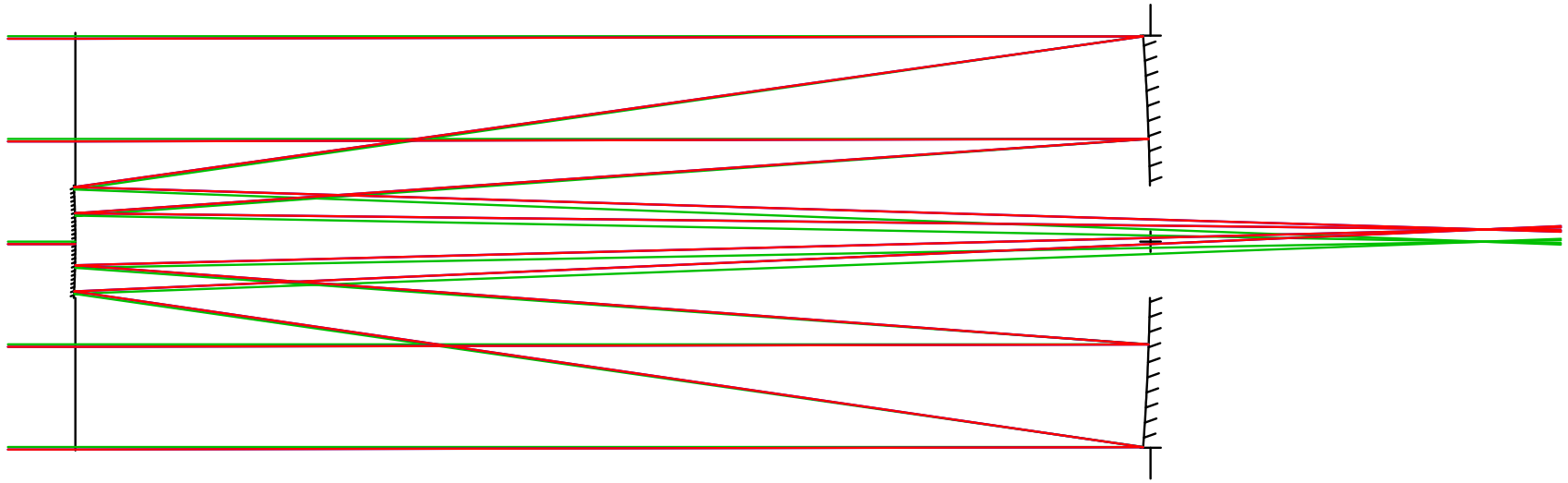
Pixel size, arcseconds:

$$\frac{\delta\theta}{\text{arcsec}} = \begin{pmatrix} 0.185 & 1.002 & 1.878 \\ 0.226 & 1.218 & 2.284 \\ 0.501 & 2.707 & 5.075 \\ 0.226 & 1.218 & 2.284 \end{pmatrix}$$

Mees 24-in cassegrain telescope
FOCAL LENGTH = 8229 NA = 0.03694

UNITS: MM
DES: OSLO

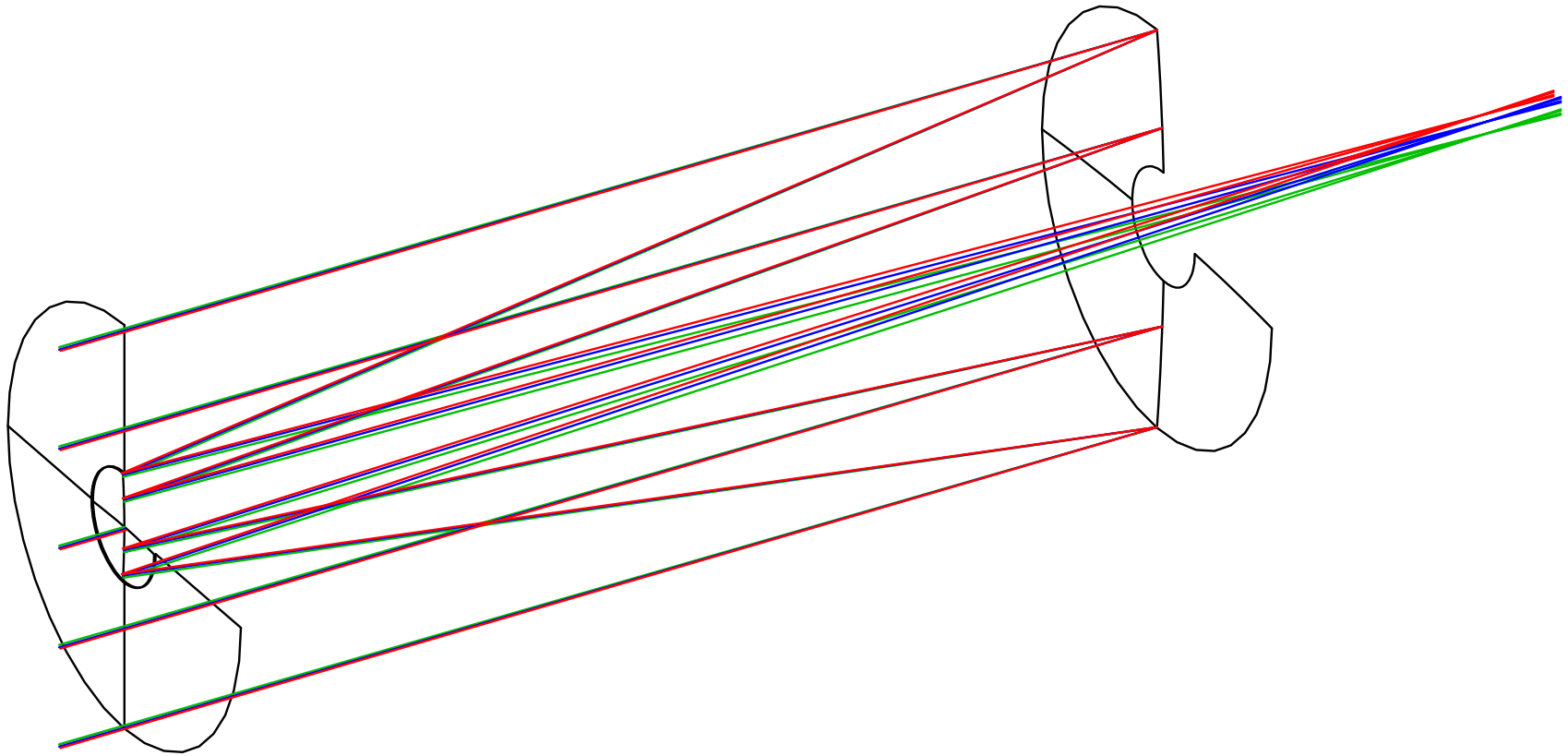
256

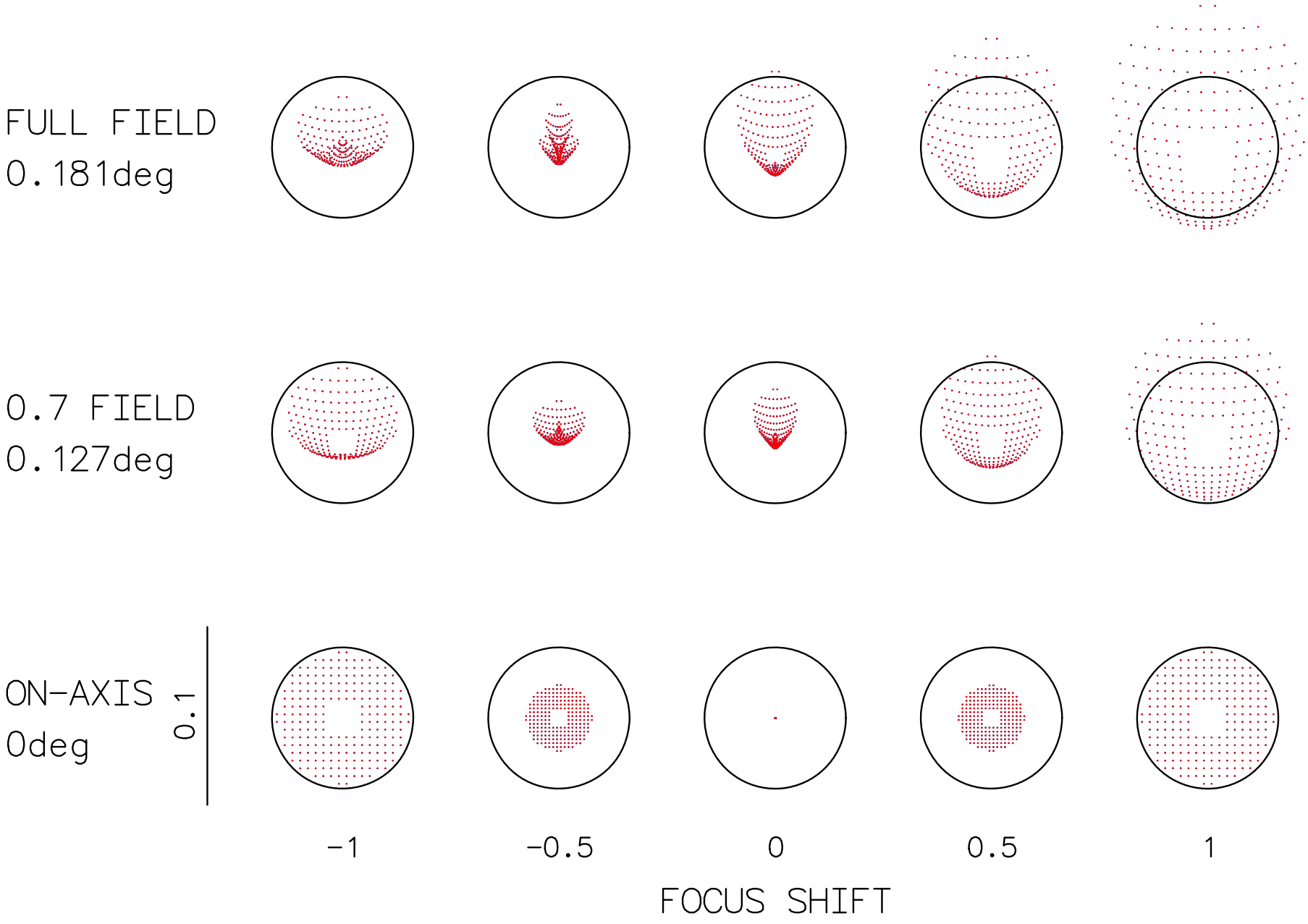


Mees 24-in cassegrain telescope
FOCAL LENGTH = 8229 NA = 0.03694

UNITS: MM
DES: OSLO

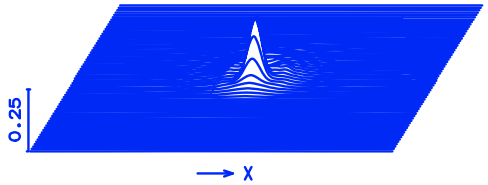
229

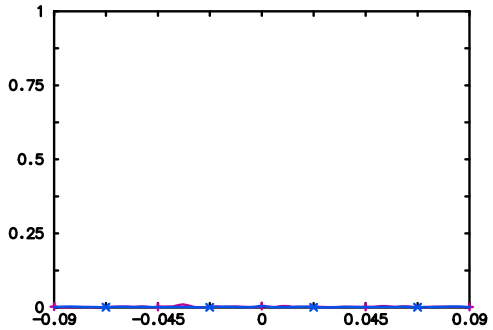




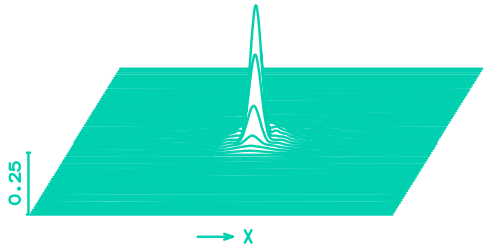
SPOT SIZE & FOCUS SHIFT: UNITS = mm WAVELENGTHS (μm) WV1: 2.4 WV2: 0.43 WV3: 0.7	Mees 24-in cassegrain telescope SPOT DIAGRAM ANALYSIS	OSLO 24 Nov 13 10:08 PM

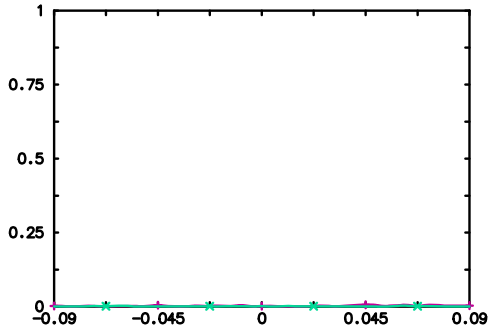
FULL FIELD = 0.181deg



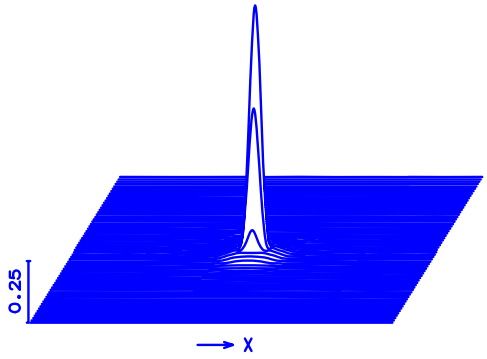


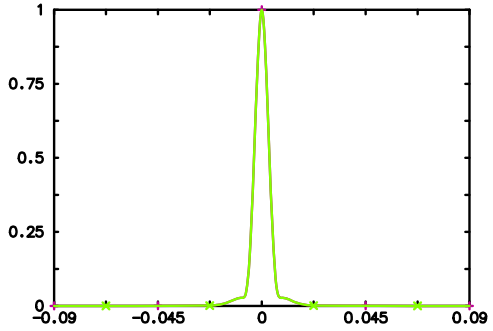
0.7 FIELD = 0.127deg

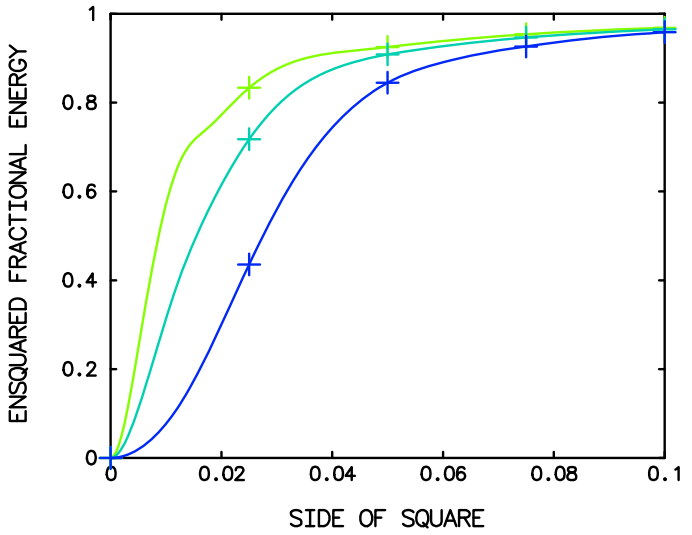




ON-AXIS = 0deg







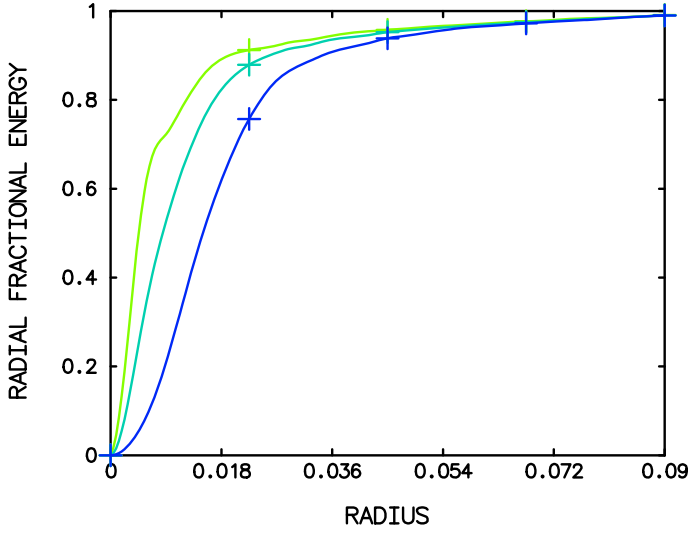


IMAGE PATCH SIZE: 0.1805 mm
Polychromatic
WV1: 0.54 WV2: 0.43 WV3: 0.7

Mees 24-in cassegrain telescope
POINT SPREAD FUNCTIONS

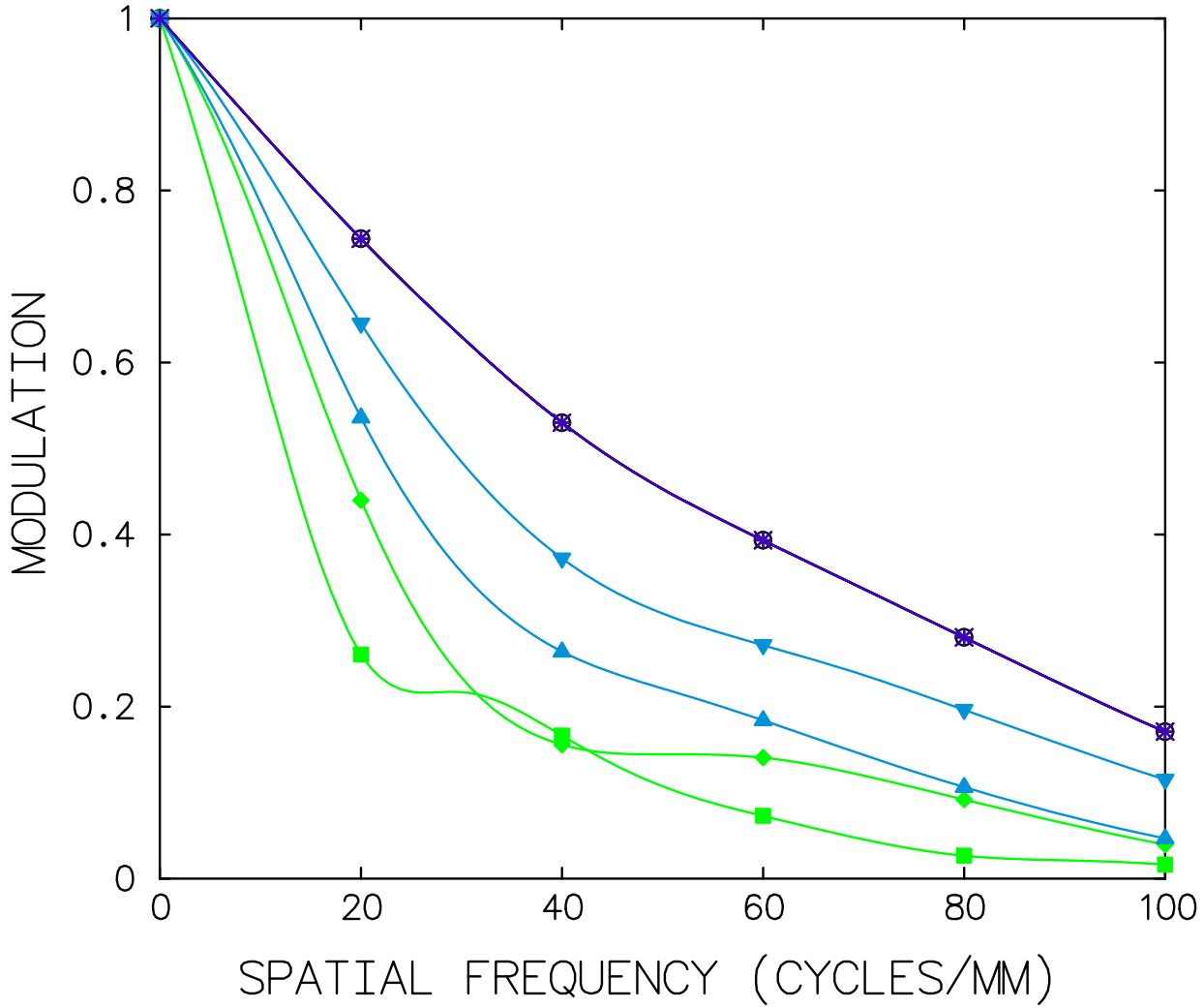
OSLO
24 Nov 13
10:20 PM

FIELD POINTS

ON-AXIS T+ S×
0.1267deg T▲ S▼
0.181deg T■ S◆
Ideal ○

WAVELENGTHS

#	λ(μm)	Weight
1	0.54	1
2	0.43	1
3	0.7	1



MTF TYPE
DIFFRACTION

Mees 24-in cassegrain telescope
MODULATION TRANSFER FUNCTIONS

OSLO
24 Nov 13
10:25 PM

FIELD POINTS

ON-AXIS T+ S×

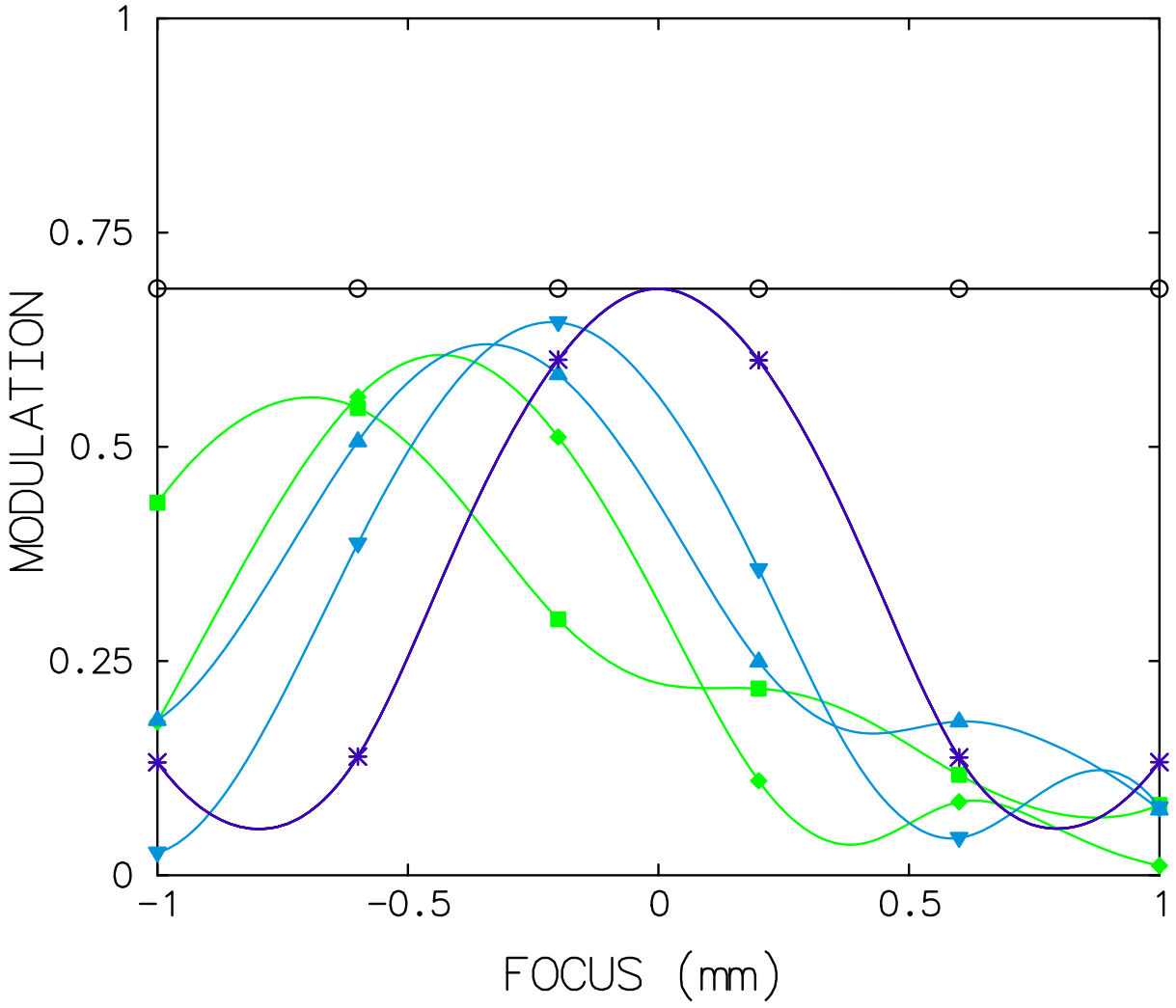
0.1267deg T▲ S▼

0.181deg T■ S◆

Ideal ○

WAVELENGTHS

#	λ(μm)	Weight
1	0.54	1
2	0.43	1
3	0.7	1



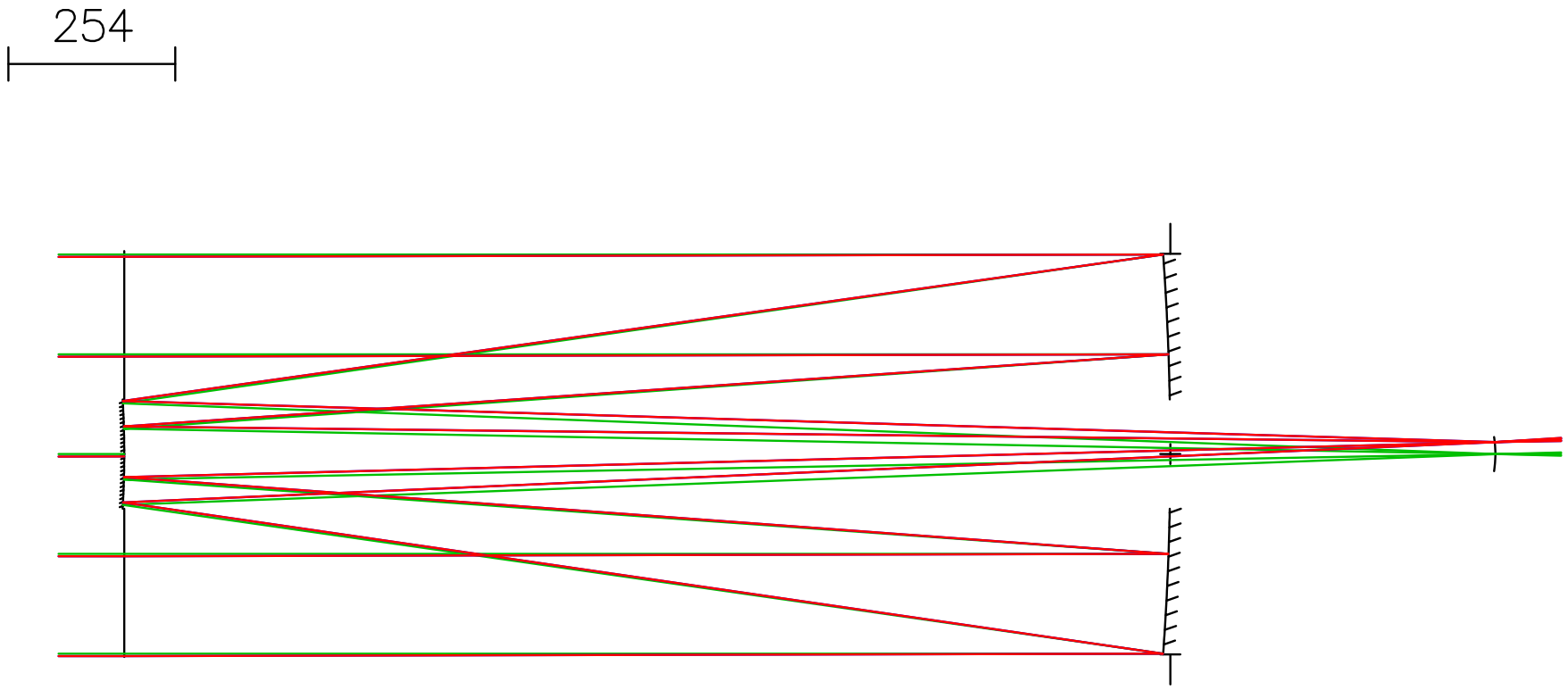
MTF TYPE
DIFFRACTION

Mees 24-in cassegrain telescope
POLYCHR. MTF AT 25 CYCLES/MM

OSLO
24 Nov 13
10:27 PM

Mees with field flattener
FOCAL LENGTH = 1.259e+04 NA = 0.0369

UNITS: MM
DES: OSLO



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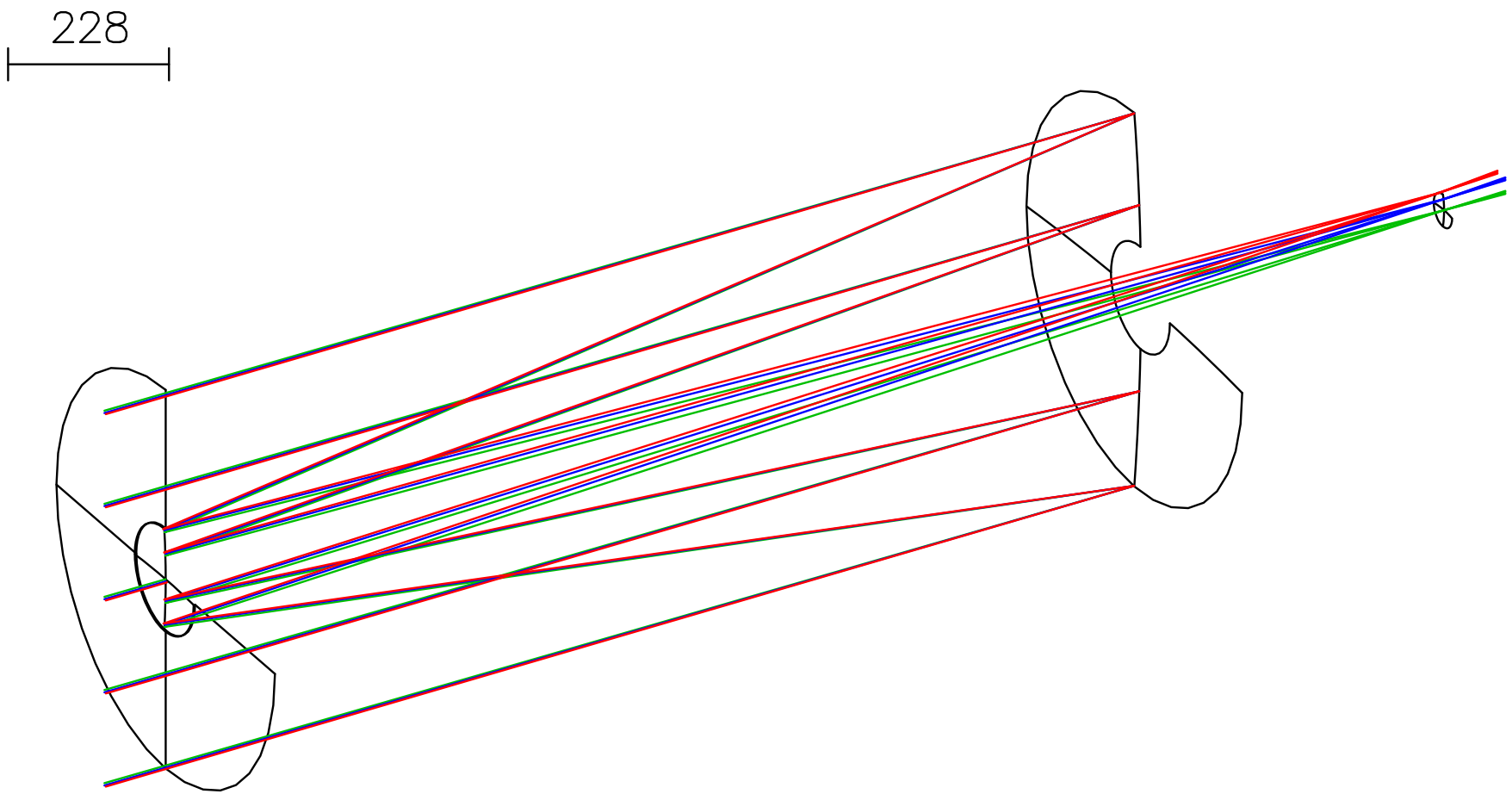
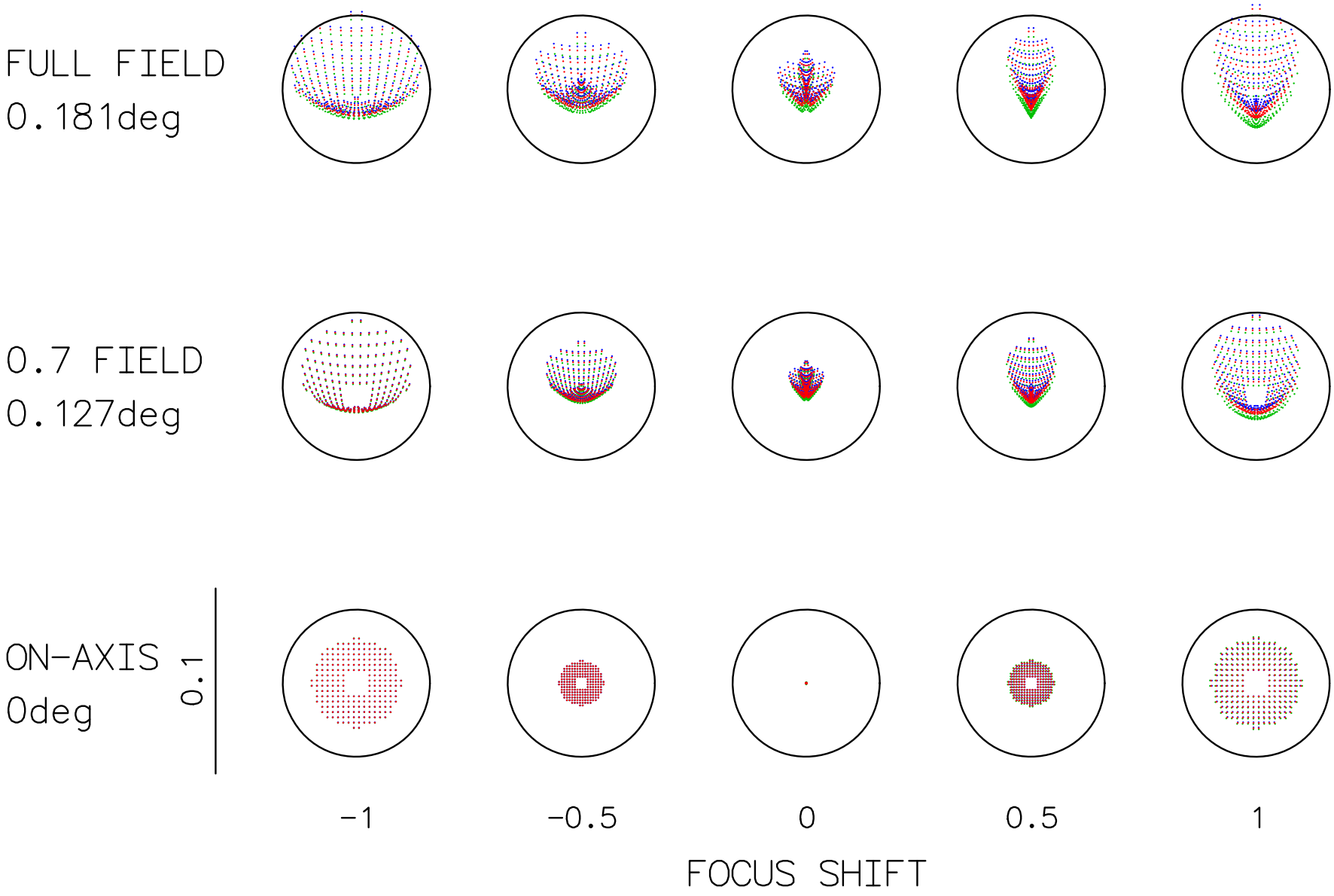
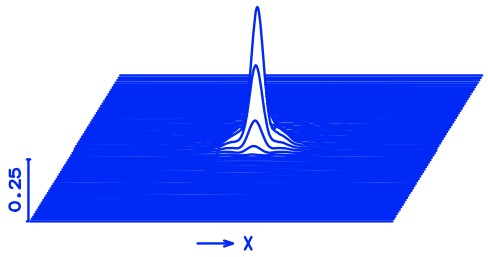
UNITS: MM
DES: OSLO

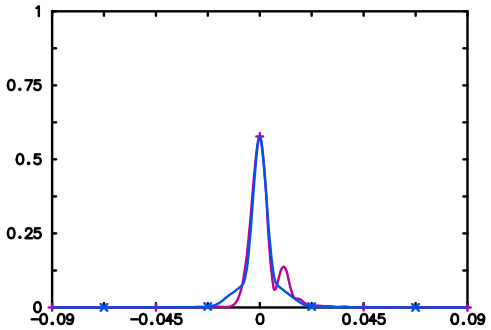




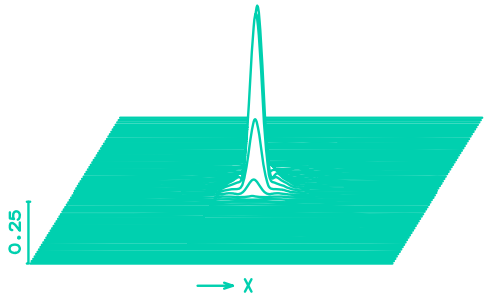
SPOT SIZE & FOCUS SHIFT: UNITS = mm WAVELENGTHS (μm) WV1: 2.4 WV2: 0.43 WV3: 0.7	Mees with field flattener SPOT DIAGRAM ANALYSIS	OSLO 24 Nov 13 10:36 PM

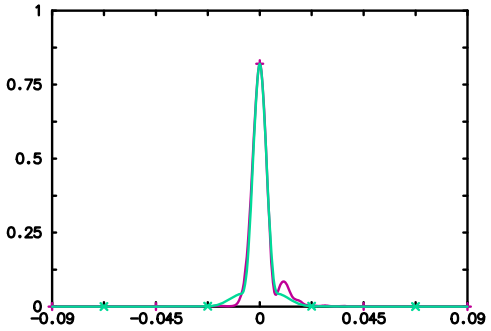
FULL FIELD = 0.181deg



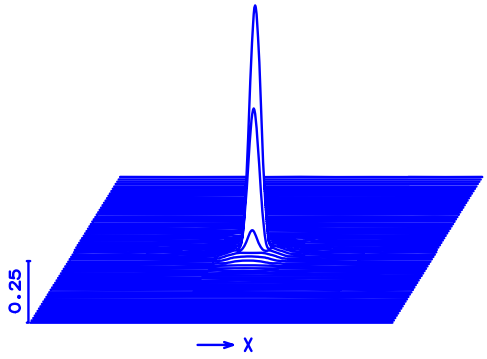


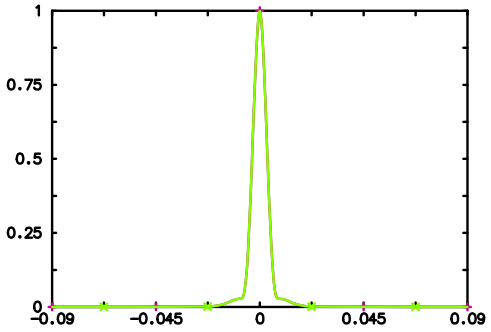
0.7 FIELD = 0.127deg

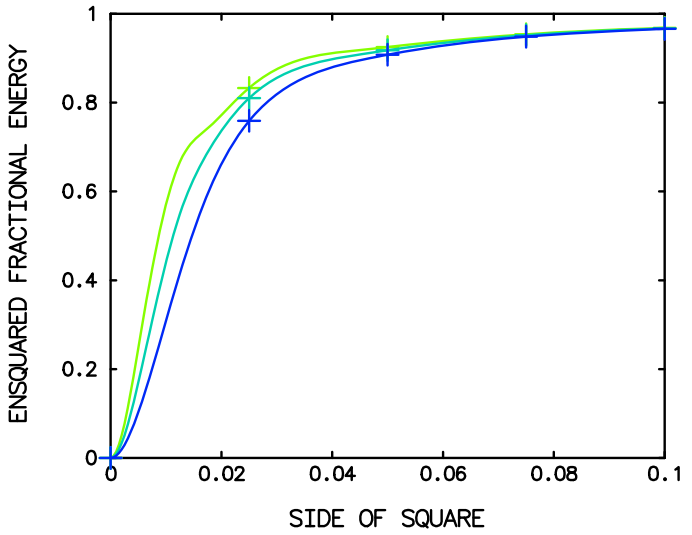




ON-AXIS = 0deg







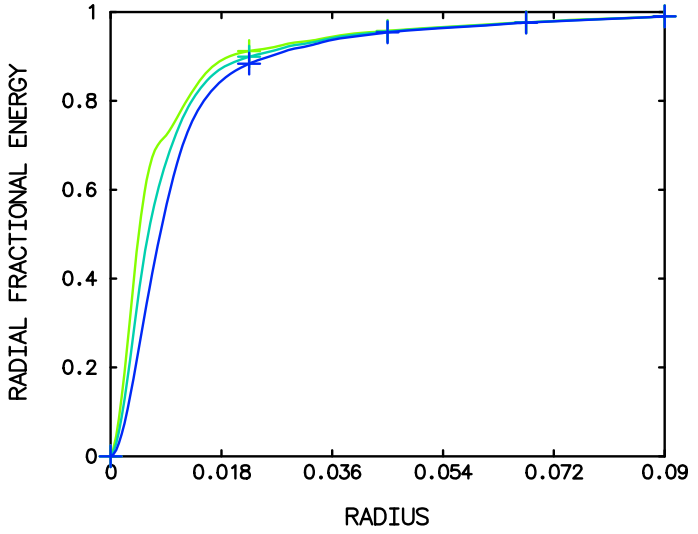


IMAGE PATCH SIZE: 0.1807 mm
Polychromatic
WV1: 0.54 WV2: 0.43 WV3: 0.7

Mees with field flattener
POINT SPREAD FUNCTIONS

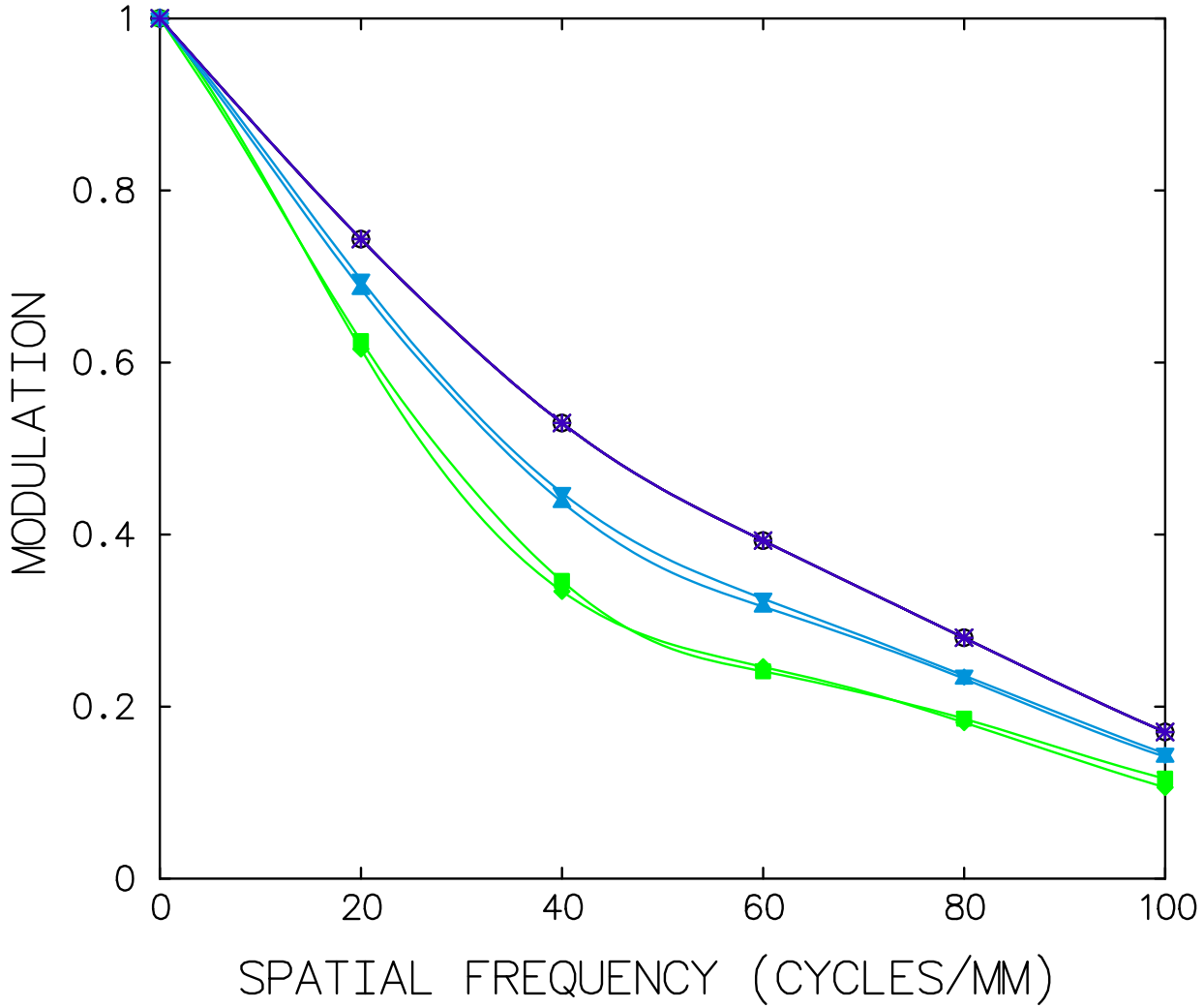
OSLO
24 Nov 13
10:38 PM

FIELD POINTS

ON-AXIS	T+	S×
0.1267deg	T▲	S▼
0.181deg	T■	S◆
Ideal		○

WAVELENGTHS

#	λ(μm)	Weight
1	0.54	1
2	0.43	1
3	0.7	1



MTF TYPE
DIFFRACTION

Mees with field flattener
MODULATION TRANSFER FUNCTIONS

OSLO
24 Nov 13
10:39 PM

FIELD POINTS

ON-AXIS T+ S×

0.1267deg T▲ S▼

0.181deg T■ S◆

Ideal ○

WAVELENGTHS

#	λ(μm)	Weight
1	0.54	1
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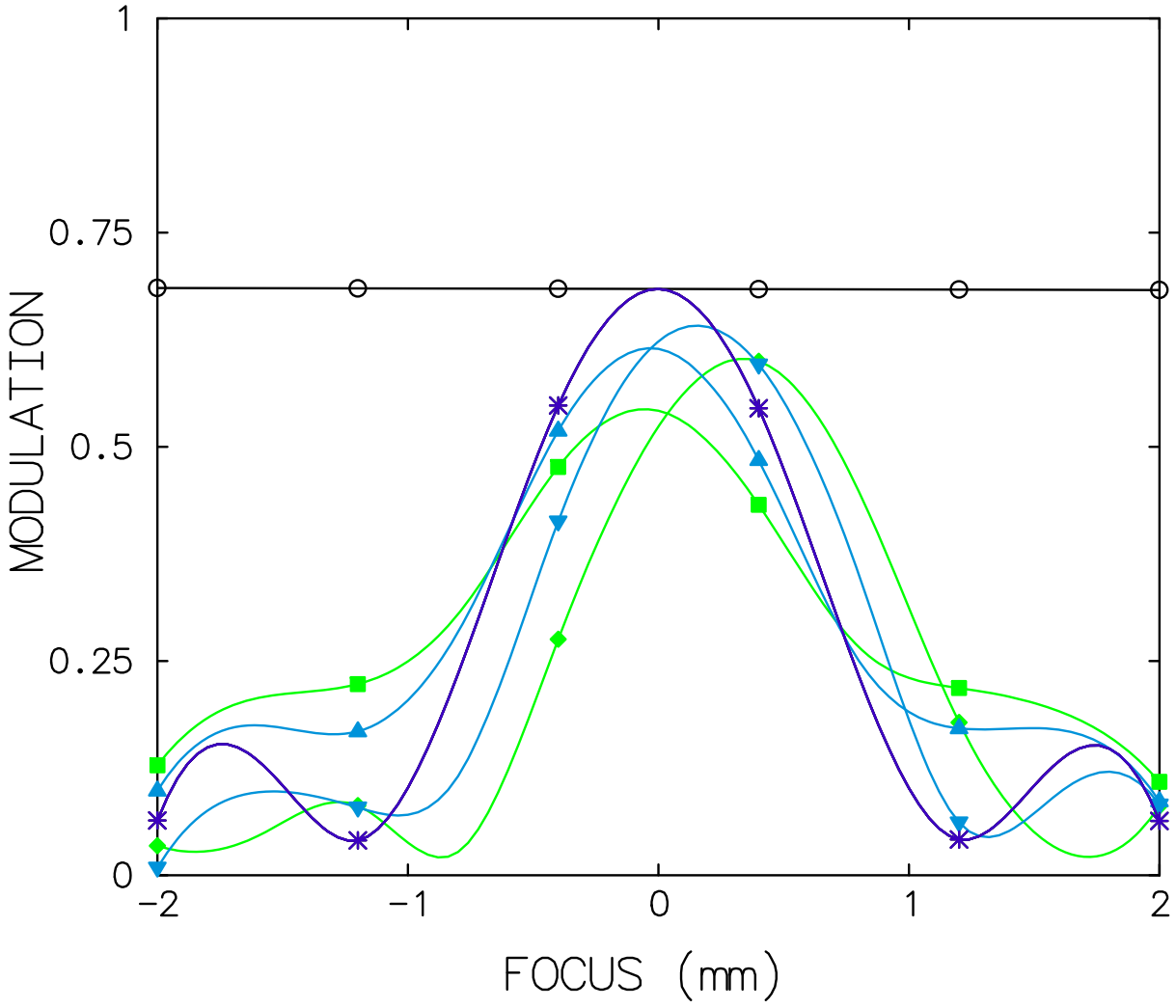
3	0.7	1



MTF TYPE
DIFFRACTION

Mees with field flattener
POLYCHR. MTF AT 25 CYCLES/MM

OSLO
24 Nov 13
10:40 PM