**Medium Size Sensor Focal Reducer Testing**
by Jim Thompson, P.Eng
Test Report – May 19th, 2016

**Introduction:**
The latest cameras that are coming on to the video astronomy market have sensors with higher resolutions and correspondingly larger physical sizes. This increase in sensor size has put pressure on focal reducer retailers to come up with something that provides fast focal ratios with minimal coma and vignetting. Among the available 2" diameter focal reducers Mallincam has a number of designs available for purchase, and the two Meade SCT based focal reducers are still available in various forms (ie. used, or Antares/Celestron versions). This report summarizes the results of testing using a large variety of different focal reducers with a medium-sized sensor camera.

**Objectives:**
The objective of this test is to observe the quality of image produced by each FR as tested in various possible configurations, and to evaluate the reduction factor that results. The objective is to produce as low a focal ratio as possible with a minimum of image defects.

**Methodology:**
This testing was performed outdoors in my backyard in central Ottawa, Canada. I used a 10" Ritchey-Chretien telescope (f/8) on an Orion Atlas EQ/G mount to observe a single deepsky object, M13 the great globular cluster in the constellation Hercules. A variety of extension tubes and focuser spacer rings had to be used to achieve focus with the various FR configurations. The camera used was the Mallincam SkyRaider DS2.3+ . This camera was used due to its medium sized sensor (IMX302LQJ, 13.4mm diagonal) and HD resolution. The camera was used with its accompanying MallinSky software, with single frames of 5 to 10sec exposure collected for the analysis. In a few cases an LP filter was used but in most cases no filter was used. In all cases the scope was re-focused on a nearby bright star (Arcturus) after FR configuration changes using a Bahtinov mask.

All the FR configurations tested were based on a number of basic optical elements (see Figure 1):

- MC 2" 0.5x
- MC 2" 0.75x
- MC 1.25" MFR5
- Meade f/6.3 SCT (made in Japan)
- Meade f/3.3 SCT (made in Japan)
- generic 98mm focal length achromat, 2" diameter

The two 2" FR elements sold by MC are made by OEM Guan Sheng Optical (GSO), the MFR5 is made by Mallincam, I do not know the OEM of the two Meade FR's but they are both "made in Japan", and the generic achromat was purchased from Surplus Shed in the US. These basic FR elements were either used singly with various spacers, or combined as will be described below. The focal reducer configurations tested were all attached directly to the camera's T-thread via a T-to-2" adapter. The T-to-2" adapter used adds approximately 5mm to the spacing between camera sensor and FR. The two Meade focal reducers were connected to the camera via a 2"-to-SCT adapter which was also approximately 5mm long.

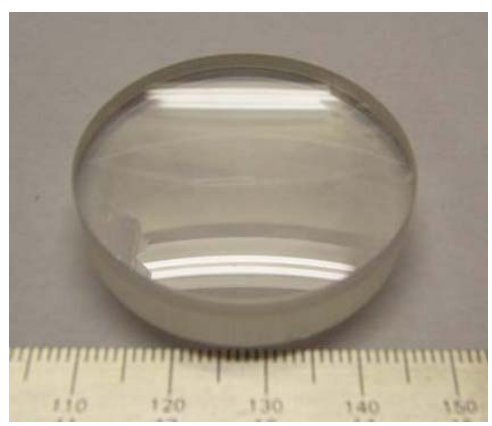

MC 2" 0.5x

MC 2" 0.75x


MC 1.25" MFR5


Meade f/6.3 SCT


Meade f/3.3 SCT




Generic 98mm f.l. achromat

**Figure 1 Optical Elements Used In Testing**

Data was gathered by capturing an image of the star pattern for each FR configuration, including an image taken with no FR for reference. These captures were then later used to determine reduction factor and to quantitatively assess coma and vignetting in the image. All image analysis was performed using a basic image editing software tool. Also recorded during the testing was the distance from the back of the telescope to the front face of the camera, referred to in this report as the "focus distance". Data was gathered over the course of three evenings: April 23rd, April 26th, and May 1st, 2016.

**Results:**

The images captured for each FR configuration can be found at the end of this report in Appendix A. An example image is shown below in Figure 2, that of the telescope at its native f-ratio (no focal reducer). The reference length used in all the images to determine reduction factor is shown in the figure.

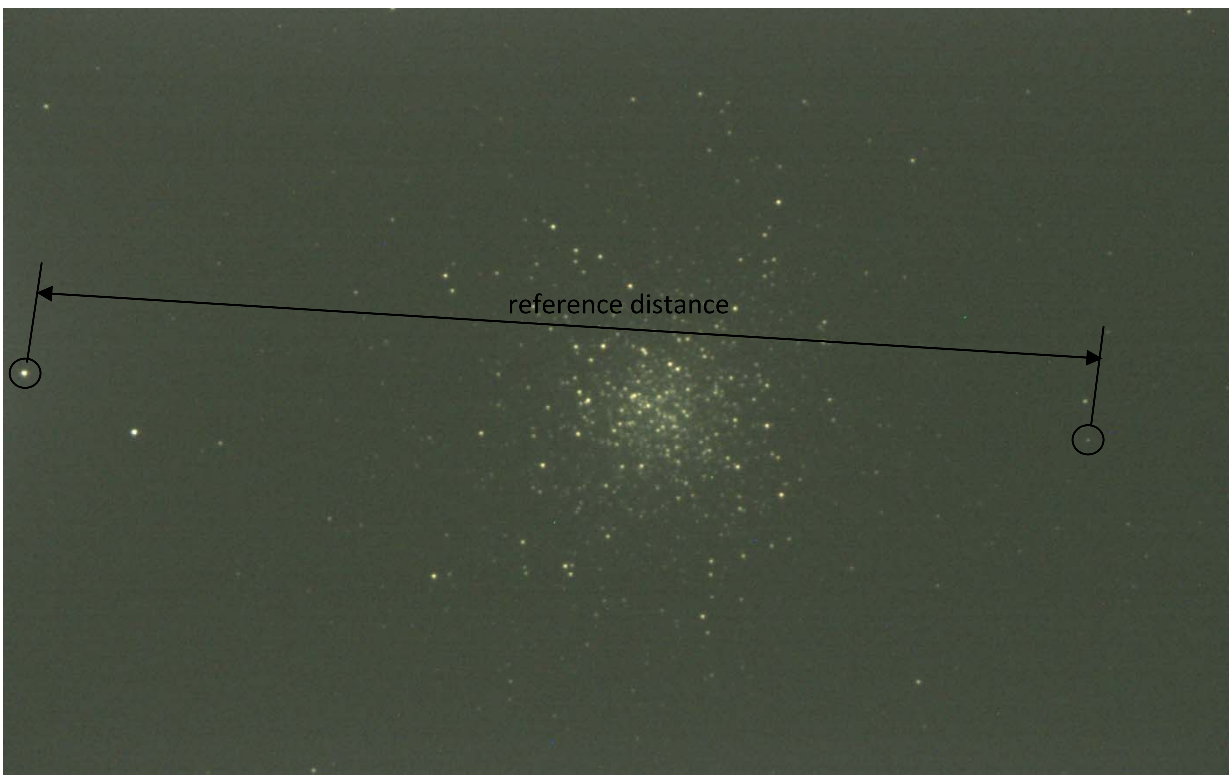



**Figure 2 M13 Through VRC10 at Native f/8 (no FR)**

The focal reduction factor that resulted from each FR configuration has been summarized in Table 1 below. Included in the table is a measurement of the percentage of the frame by area that was observed to be coma free and vignetting free. To help interpret the results I have also provided two graphs: one showing % of frame that is coma free versus reduction factor, and one showing the relative clear field of view (FOV) versus reduction factor. The relative clear field of view is evaluated by taking the measured diameter of the coma free area in pixels and dividing it by the reference length in pixels. Thus a larger value of relative clear FOV for the same focal reduction is desirable. Note that the text colour for each FR configuration listed in Table 1 corresponds to the colour of those same points on the two graphs. Also, the number inside each data marker on the plot corresponds to the test point number in Table 1.

**Table 1 FR Testing Result Summary**

| test point | date | config | reduct. factor | fratio | focal length | % coma free | % vign. free | focus distance (mm) | relative clear FOV |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 23-Apr-16 | native scope (VRC10 no FR) | 1.000 | 8.00 | 2000 | 100 | 100 | 110 | 1.35 |
| 2 | | whole mfr5 | 0.427 | 3.42 | 855 | 14 | 35 | 82 | 0.90 |
| 3 | | long half mfr5 (mfr8) | 0.649 | 5.19 | 1298 | 90 | 88 | 94 | 1.72 |
| 4 | | 5mm+0.75x | 0.847 | 6.77 | 1693 | 100 | 100 | 110 | 1.60 |
| 5 | | 36mm+0.75x | 0.790 | 6.32 | 1580 | 100 | 100 | 101 | 1.71 |
| 6 | | 5mm+0.75x+0.75x | 0.647 | 5.17 | 1294 | 100 | 100 | 89 | 2.09 |
| 7 | | 36mm+0.75x+0.75x | 0.539 | 4.31 | 1077 | 77 | 100 | 31 | 1.80 |
| 8 | | 36mm+15mm+0.75x+0.75x | - | - | - | - | - | no focus | - |
| 9 | | 5mm+0.50x | 0.698 | 5.58 | 1395 | 87 | 100 | 104 | 1.55 |
| 10 | | 20mm+0.50x | 0.522 | 4.18 | 1044 | 45 | 100 | 85 | 1.32 |
| 11 | | 36mm+0.50x | 0.378 | 3.03 | 757 | 17 | 74 | 26 | 1.10 |
| 12 | | 5mm+0.5x+0.75x | 0.558 | 4.46 | 1116 | 87 | 100 | 83 | 1.93 |
| 13 | | 20mm+0.5x+0.75x | 0.373 | 2.98 | 746 | 26 | 100 | 34 | 1.38 |
| 14 | | 5mm+0.5x+15mm + 0.75x | 0.536 | 4.29 | 1073 | 80 | 100 | 87 | 1.86 |
| 15 | | 5mm+filter (7mm)+0.5x+15mm+0.75x | 0.457 | 3.66 | 914 | 55 | 100 | 65 | 1.71 |
| 16 | | 20mm + Meade0.33x | 0.455 | 3.64 | 910 | 48 | 100 | 74 | 1.57 |
| 17 | | 36mm + Meade0.33x | - | - | - | - | - | no focus | - |
| 18 | 26-Apr-16 | 5mm+0.50x | 0.697 | 5.58 | 1395 | 99 | 100 | 104 | 1.81 |
| 19 | | 20mm+0.50x | 0.523 | 4.19 | 1046 | 48 | 100 | 73 | 1.37 |
| 20 | | 36mm+0.50x | 0.378 | 3.02 | 755 | 20 | 74 | 26 | 1.20 |
| 21 | | 5mm+0.75x | 0.845 | 6.76 | 1691 | 100 | 100 | 109 | 1.60 |
| 22 | | 20mm+0.75x | 0.815 | 6.52 | 1630 | 100 | 100 | 105 | 1.66 |
| 23 | | 36mm+0.75x | 0.790 | 6.32 | 1580 | 100 | 100 | 100 | 1.71 |
| 24 | | 51mm+0.75x | 0.759 | 6.07 | 1518 | 100 | 100 | 91 | 1.78 |
| 25 | | 81mm+0.75x | 0.706 | 5.64 | 1411 | 100 | 100 | 65 | 1.92 |
| 26 | | longhalf mfr5 + 30mm+0.75x | 0.499 | 3.99 | 997 | 49 | 78 | 80 | 1.45 |
| 27 | | longhalf mfr5 + 45mm+0.75x | 0.480 | 3.84 | 960 | 39 | 72 | 67 | 1.34 |
| 28 | | longhalf mfr5 + 57mm+0.75x | 0.465 | 3.72 | 931 | 35 | 63 | 57 | 1.30 |
| 29 | 30-Apr-16 | 5mm + 98mm f.l. achromat | 0.727 | 5.82 | 1454 | 96 | 100 | 106 | 1.66 |
| 30 | | 20mm+98mm f.l. achromat | 0.571 | 4.57 | 1142 | 87 | 100 | 82 | 1.88 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 31 | | 35mm+98mm f.l. achromat | 0.415 | 3.32 | 830 | 20 | 89 | 39 | 1.10 |
| 32 | | 5mm+98mm f.l. achromat + 0.75x | 0.585 | 4.68 | 1170 | 87 | 100 | 82 | 1.84 |
| 33 | | 20mm+98mm f.l. achromat + 0.75x | 0.416 | 3.33 | 833 | 25 | 100 | 49 | 1.21 |
| 34 | | 5mm+98mm f.l. achromat+15mm+0.75x | 0.562 | 4.50 | 1125 | 72 | 100 | 91 | 1.65 |
| 35 | | 5mm+98mm f.l. achromat+30mm+0.75x | 0.540 | 4.32 | 1080 | 66 | 100 | 78 | 1.61 |
| 36 | | 5mm+98mm f.l. achromat+30mm+filter (7mm)+0.75x | 0.532 | 4.26 | 1065 | 56 | 100 | 73 | 1.47 |
| 37 | | 5mm + 0.5x + 5mm + Meade0.63x | 0.499 | 4.00 | 999 | 76 | 100 | 98 | 1.92 |
| 38 | | 35mm + filter (5mm) + 5mm + Meade0.63x | 0.663 | 5.30 | 1326 | 100 | 100 | 91 | 2.04 |
| 39 | | 35mm + filter (5mm) + 0.75x + 0.75x | 0.519 | 4.15 | 1038 | 65 | 100 | 15 | 1.66 |

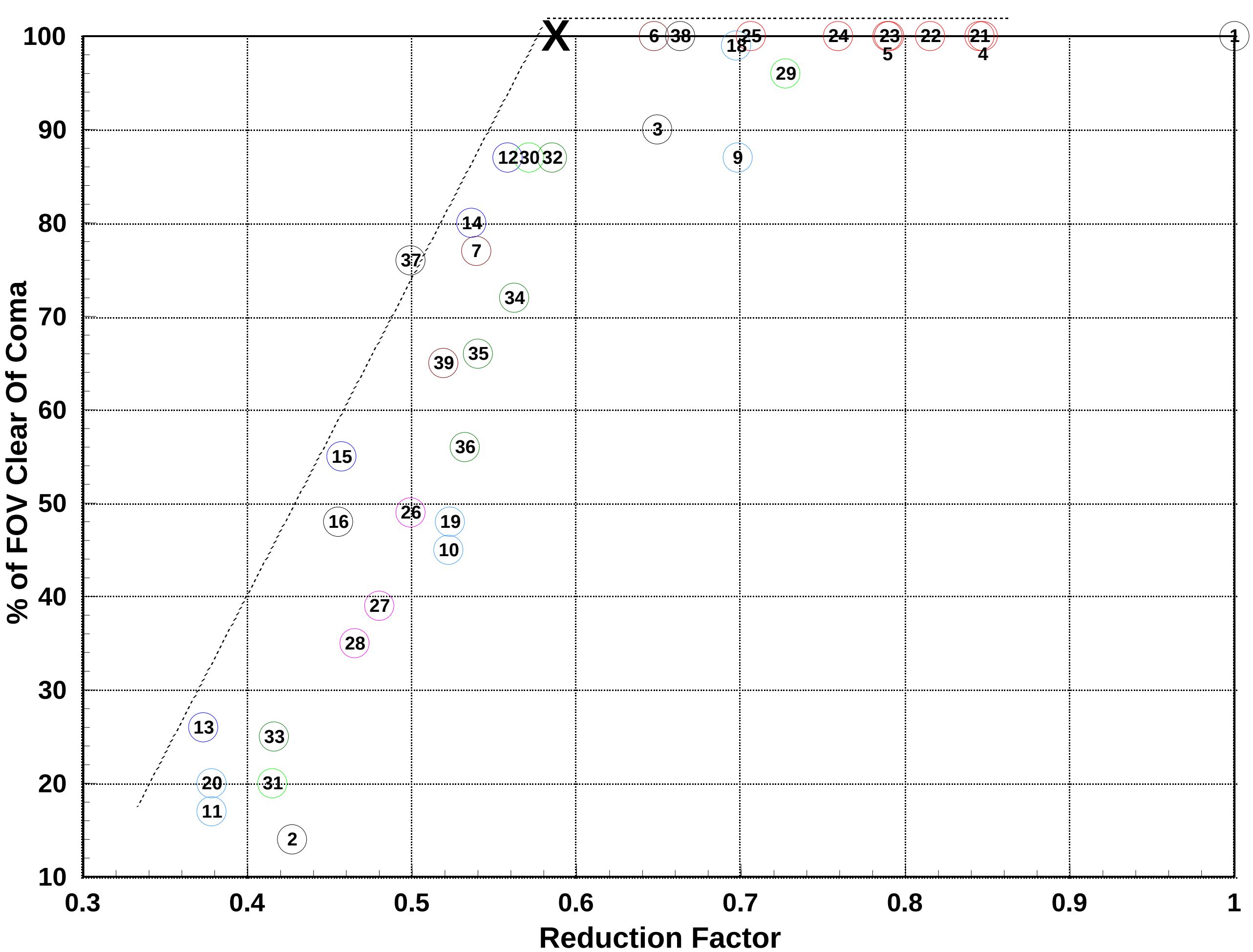



**Figure 3 Observed % of FOV Clear of Coma vs. Reduction Factor**

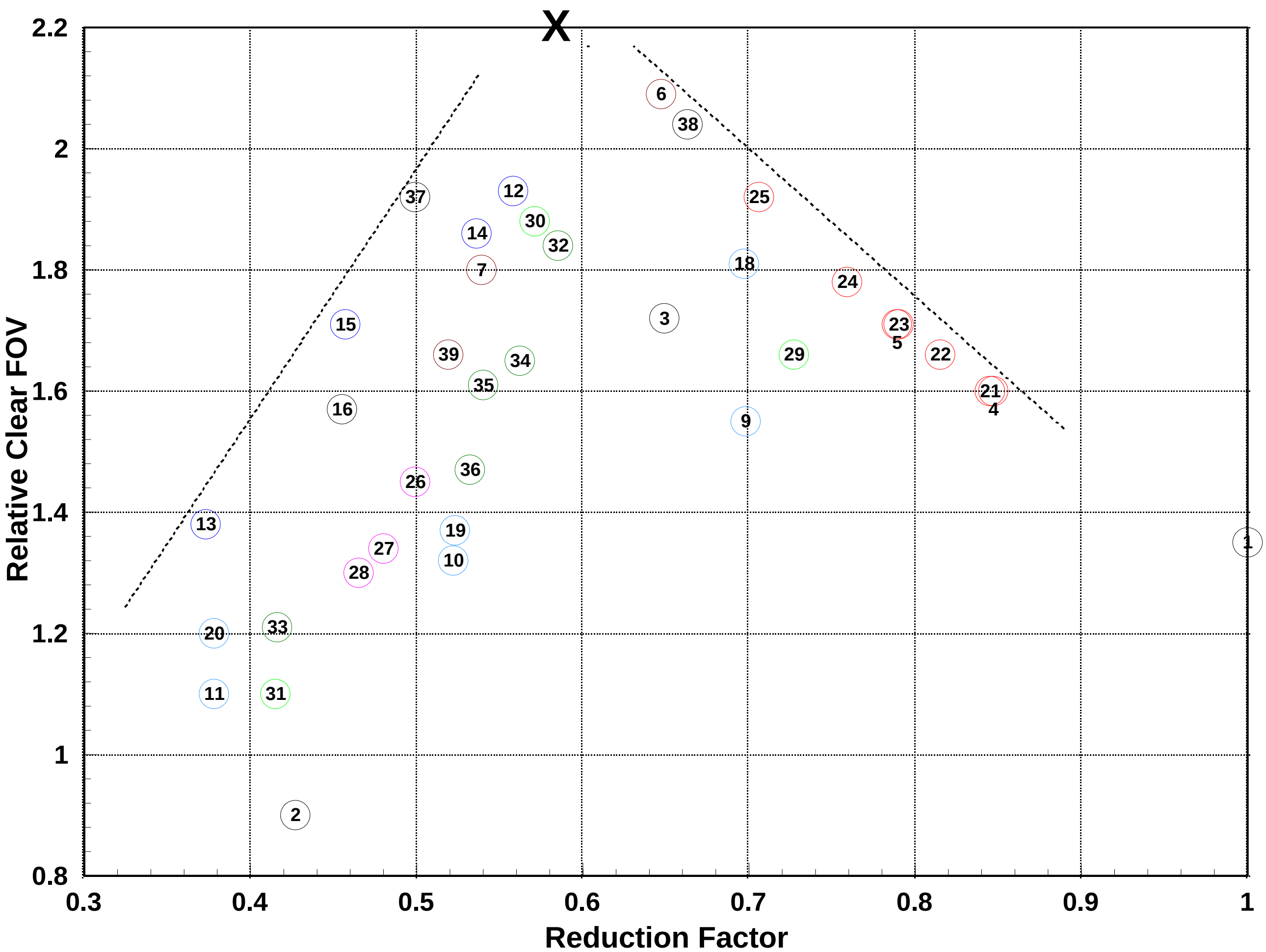



**Figure 4 Relative Clear FOV vs. Reduction Factor**

I find the two graphs useful as they make it more clear what is achievable. For example Figure 3 shows that from all the configurations tested the lowest reduction factor that is likely to be found and have a 100% coma free frame is around 0.58x to 0.62x (marked with 'x' on plot). Figure 4 makes it quite clear that there is an optimum FR configuration, one that gives the largest visible defect free field of view. This optimum clear FOV point seems to correspond to the minimum focal ratio with 100% coma free, around 0.58x. From the FR configurations tested, the ones that appear to be most likely to achieve this optimum design point, with the correct combination of spacers, are the double stacked MC 0.75x focal reducers, and the Meade f/6.3 focal reducer. If some small amount of coma is acceptable (<20%), then a focal ratio closer to 0.5x is achievable with the two aforementioned FR's or using the MC 0.5x + MC 0.75x combination.

**Conclusions:**

1. For a camera with sensor of this size (13.4mm), it appears unlikely that a focal reducer configuration can be found that will deliver a coma and vignetting free view below a reduction factor of 0.58x.
2. Depending on how particular a user is about the extent of coma in their frame, it is possible to get down to a reduction factor of 0.5x without too much coma (<20% by area).
3. Presumably the idea of an optimum reduction factor exists for every sensor size. The smaller the sensor, the smaller the reduction factor that can be achieved without image defects. For example when I recently used the Meade f/3.3 focal reducer with a camera that has a 6.46mm sensor, I was able to get to a reduction factor of 0.36x with 81% coma free; thus the optimum for this sensor is somewhere in the area of 0.40 to 0.42x.
4. The issue of coma and vignetting is exacerbated by sensors with an HD format, ie. 16:10 aspect ratio. For the same diagonal size, the HD sensor is wider than the SD one, making the effect of coma and vignetting more evident. From the standpoint of efficient use of coma free FOV, a square sensor would be best.
5. Follow-on testing will likely involve the double stacked MC 0.75x FR and Meade f/6.3 FR, fine tuning spacers to get to the theoretical optimum reduction point. Follow-on testing will also likely involve a different telescope, probably a refractor, to determine if the % coma free versus reduction factor is similar for different telescopes.

If you have any questions about my testing, please feel free to contact me.

Best Regards,

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Appendix A - Images Captured During Testing