Detailed Look At Focal Reducers
by Jim Thompson, P.Eng
Test Report – Sep. 13th, 2013

Objectives:
I have used focal reducers (FR) with all of my various telescopes at one time or another. The reason for doing so was to: "speed up" my optics to reduce exposure time, increase my field of view to be able to better frame particular deep sky objects, or both. Up until now I have simply tried each FR I have and picked the one giving the nicest image to use. My own thoughts about focal reducers have been re-opened by my recent purchase of a VRC10. The construction of the focuser allows for some added flexibility in how the FR's are used, so I decided to have a closer look.

I have a number of FR's from various sources in my gear. Each one has different strengths and weaknesses. I felt the best way to determine which FR or FR combination was best to use with my VRC10 was to systematically test them. The two main input parameters to my test were: FR type and FR distance to CCD. These two inputs produced two measureable outputs: focal reduction factor, and change in focus position. These two outputs are important as I want to know how fast an f-ratio I can get to plus whether or not I can achieve focus. Two additional subjective outputs from my test were the extent of vignetting and coma, which is important to how usable the resulting FR configuration is.

Methodology:
The method was simple: take screen captures of the same deep sky object using each FR configuration, and later measure the distance in pixels between common stars and compare. During the testing I also measured the location of the focus plane by keeping track of all the various adapters and focuser settings in the optical path. The object I used for all my tests was the rich open cluster M11. This object provided lots of stars to confirm the presence (or not) of vignetting and coma, and allowed easy comparison of distances between stars. In some of the later tests I also recorded screen captures of NGC7635 (Bubble Nebula) for the purpose of making visual comparisons. In my main body of testing I tested nine different basic FR configurations:

1. Meade telecompressor 07051
2. Meade f/6.3 focal reducer and field flattener
3. Meade f/3.3 focal reducer and field flattener
4. Mallincam MFR5
5. Mallincam MFR5 with 5mm spacer between elements
6. long half only of Mallincam MFR5
7. short half only of Mallincam MFR5 (= MFR6)
8. Mallincam MFR 2" 0.5x
9. Mallincam MFR 2" – RC 0.75x

Figure 1 shows a picture of the 6 basic FR's used in my testing. Each of the nine FR configurations listed above were tested at different FR-to-CCD distances in order to capture the trends in the output parameters. To do this I had to use a combination of different adapters and extension rings, and on occasion a little aluminum duct tape to hold it all together. All testing was performed using my VRC10 and Mallincam Xtreme (classic), from my backyard in downtown Ottawa, Canada. The main body of testing was performed on two nights (Aug. 1^{st} and 15^{th}, 2013), with some additional testing performed on Aug. 18^{th} , 20^{th}, and 23^{rd}, 2013.

Figure 1 Image of the Six Focal Reducers Tested

Basic FR Results:

Table 1 summarizes all my measurements. The table includes all the inputs and outputs from my tests including my observation of vignetting and coma. My vignetting/coma observations were scored from 0 to 3 based on the following:

0	=	none observed
1	=	hint observed
2	=	clearly observed by not obtrusive
3	=	very apparent and affects viewing

Test #	FR	focus distance [mm]	delta focus distance [mm]	FR-to-CCD distance [mm]	ref. star distance [pixels]	f/ratio [non]	reduct. factor [non]	vignette score [non]	coma score [non]
0	nothing	221.6	0	0	264.61	8	1	0	0
1	MFR2" on 2" c-thread adapter	172.9	-48.7	45.3	126.46	3.82	0.478	0	1
2	MFR2" on 2" c-thread adapter + 5mm	154	-67.6	50.3	113.27	3.42	0.428	0	2
3	MFR2" on 2" c-thread adapter + 10mm	128.3	-93.3	55.3	99.58	3.01	0.376	1	3
4	MFR2"-RC	198.9	-22.7	75.5	204.50	6.18	0.773	0	0
5	MFR2"-RC + pull out 6.1mm	194.5	-27.1	81.6	200.82	6.07	0.759	0	0
6	MFR2"-RC + pull out 10.2mm	188.8	-32.8	85.7	198.31	6.00	0.749	0	0
7	MFR2"-RC + pull out 16.6mm	183.7	-37.9	92.1	194.61	5.88	0.735	0	0
8	MFR2"-RC + pull out 24.1mm	179.5	-42.1	99.6	189.93	5.74	0.718	0	0
9	MFR5	195.6	-26	28.5	132.51	4.01	0.501	0	0
10	MFR5 + 5mm spacer in front	176.1	-45.5	33.5	108.29	3.27	0.409	2	0
11	MFR5 + 10mm spacer in front	141.1	-80.5	38.5	82.19	2.48	0.311	3	1
12	MFR5 + 5mm between	183.6	-38	31	120.42	3.64	0.455	1	0
13	MFR5 + 5mm between + 5mm in front	160.6	-61	36	96.65	2.92	0.365	2	2
14	MFR5 + 5mm between + 10mm in front	117.1	-104.5	41	73.40	2.22	0.277	3	3
15	short half MFR5 (=MFR6)	221	-0.6	14.5	223.33	6.75	0.844	0	0
16	short half MFR5 + 5mm in front	218.5	-3.1	19.5	207.94	6.29	0.786	0	0
17	short half MFR5 + 10mm in front	215	-6.6	24.5	191.94	5.80	0.725	0	0
18	short half MFR5 + 15mm in front	209.5	-12.1	29.5	175.24	5.30	0.662	0	0
19	short half MFR5 + 19.5mm in front	202.5	-19.1	34	160.51	4.85	0.607	0	1
20	long half MFR5	209.6	-12	32.5	180.66	5.46	0.683	0	0
21	long half MFR5 + 5mm in front	203.1	-18.5	37.5	168.79	5.10	0.638	0	0
22	long half MFR5 + 10mm in front	195.1	-26.5	42.5	155.26	4.69	0.587	0	0
23	long half MFR5 + 15mm in front	183.6	-38	47.5	141.74	4.29	0.536	1	0
24	Meade Telecompressor 07051	184.6	-37	56.5	152.82	4.62	0.578	0	0
25	Meade Telecompressor pullout 8mm	162.6	-59	64.5	135.91	4.11	0.514	0	0
26	Meade Telecompressor pullout 18mm	127.6	-94	74.5	116.36	3.52	0.440	1	1
27	meade f/3.3 spacing #1 (5.8, min)	182.8	-38.8	43.9	132.92	4.02	0.502	0	0
28	meade f/3.3 spacing #2 (8.5)	175	-46.6	46.6	125.07	3.78	0.473	0	1
29	meade f/3.3 spacing #3 (11.7)	162.7	-58.9	49.8	116.37	3.52	0.440	0	1
30	meade f/3.3 spacing #4 (12.3, max)	159.3	-62.3	50.4	114.00	3.45	0.431	0	2
31	meade f/3.3 spacing #5 (taped in focuser)	139.6	-82	61.5	97.42	2.95	0.368	0	2
32	meade f/3.3 + new adapt + 2 filters tween	132.2	-89.4	75.9	88.19	2.67	0.333	0	2
33	meade f/6.3 spacing #1 (5.2, min)	212.7	-8.9	43.3	205.25	6.21	0.776	0	0
34	meade f/6.3 spacing #2 (7.7)	208.7	-12.9	45.8	201.97	6.11	0.763	0	0
35	meade f/6.3 spacing #3 (13.3)	198.7	-22.9	51.4	194.93	5.89	0.737	0	0
36	meade f/6.3 spacing #4 (30.1)	162.2	-59.4	68.2	173.63	5.25	0.656	0	0
37	meade f/6.3 spacing #5 (34.5, max)	152.2	-69.4	72.6	167.73	5.07	0.634	0	0

Table 1 Summary of FR Measurements

To better understand what was going on I plotted up the outputs in graph form. Figure 2 shows the relationship between FR-to-CCD distance and focal reduction factor. I was surprised to see that this relationship is very clearly linear. This means that we can pretty confidently predict what focal reduction we are going to get if we know the FR-to-CCD distance. Note that in the case of a FR with two lens elements (eg. MFR5), the FR-to-CCD distance is measured to the point midway between the two lenses. Another interesting observation is that the MFR5 and MFR5 with 5mm spacer between appear to perform like basically the same FR. Adding the 5mm spacer in between the elements of the MFR5 simply increases the FR-to-CCD distance by 2.5mm. Finally the Meade f/3.3 FR showed very strange performance in that it behaved linearly like the other reducers up to a FR-to-CCD spacing of about 50mm, after which the reducer behaved non-linearly…I have no explanation for this.

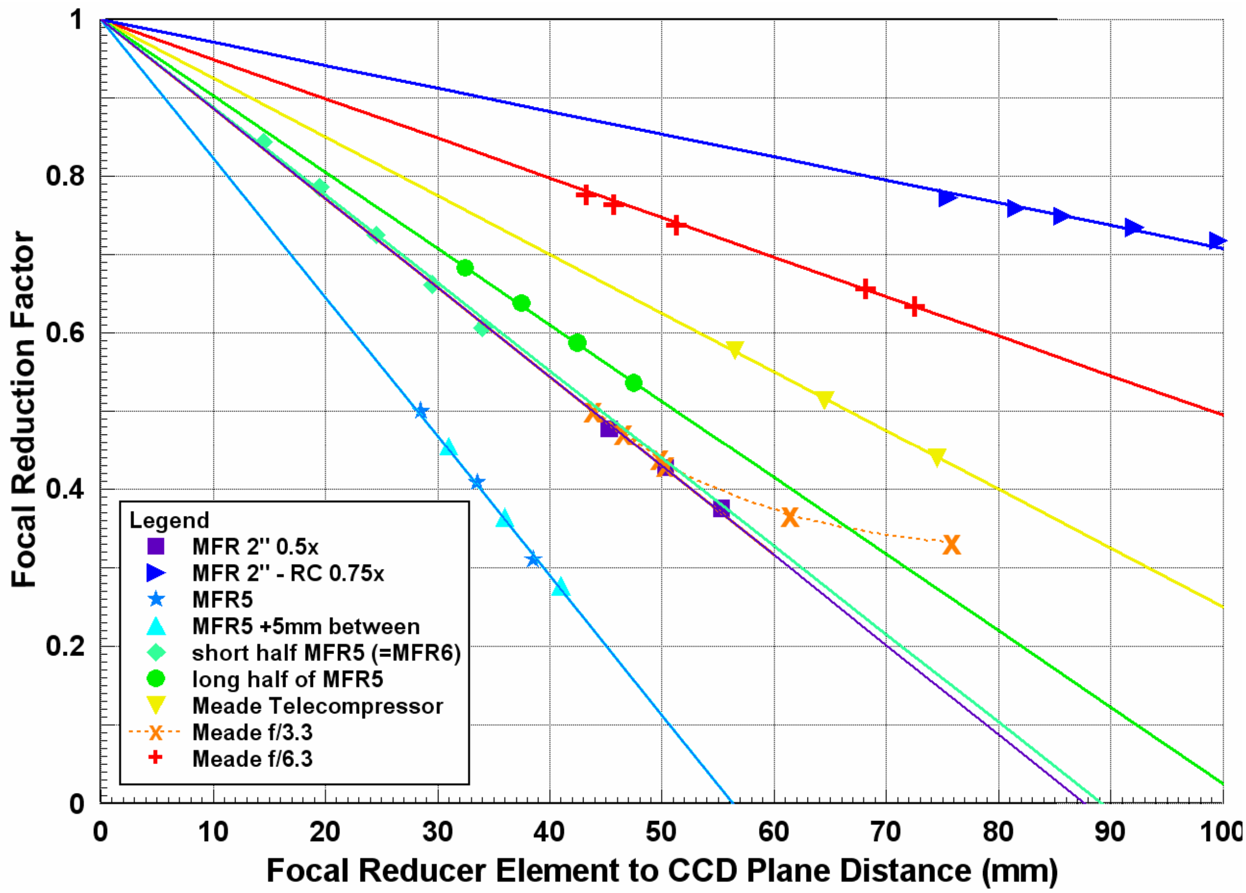

Figure 2 Measured Focal Reduction Factor vs. FR-to-CCD Distance

The next graph I plotted up was the change in focus distance versus FR-to-CCD distance, as shown in Figure 3. My value of focus distance change is relative to the focus distance when I was using the scope at its native f/ratio (no focal reducers), which I measured to be 221.6mm from the back of the optical tube where the focuser attaches out to the plane of the CCD. The trend in the measured data seems to be a cubic, ie. the amount by which you have to adjust your focus inwards increases with the FR-to-CCD distance to the power of 3. Thus very quickly as you increase the distance between FR and camera, you will run out of focus travel on your telescope. The available amount of in focus travel is one of the major factors affecting how low a focal ratio you can get your scope to. The curves in Figure 3 are specific to the telescope I used, but I believe a rough estimate could be made for other telescopes by multiplying the change in focus position value by the ratio of the telescope focal lengths. For example on my WO Zenithstar 66 that has a focal length of 388mm, I would scale the change in focus position numbers in Figure 3 by approximately (388/2000=) 0.2. This is of course an educated guess, and as of yet has not been confirmed by me.

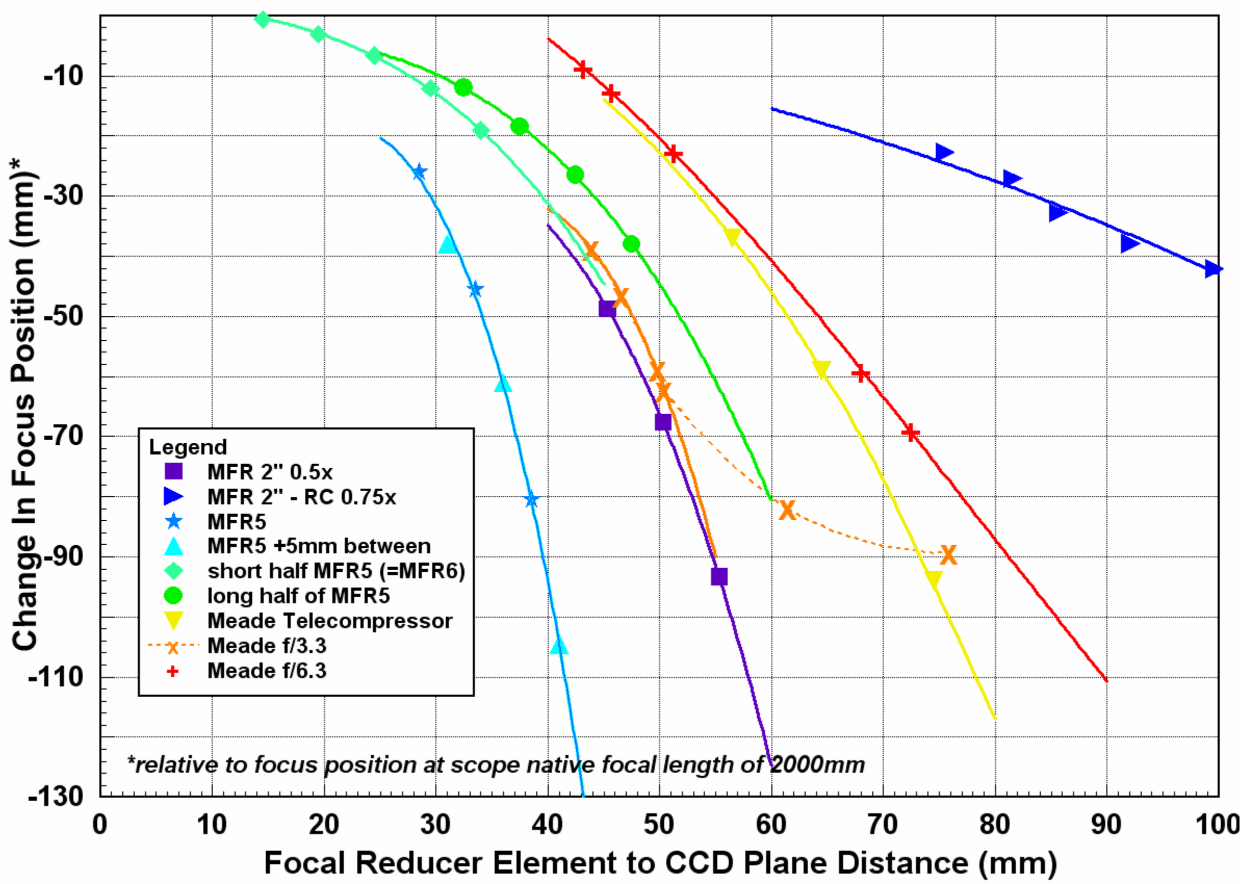

Figure 3 *Measured Focus Position Change vs. FR-to-CCD Distance*

The last plot I made from the measurements (Figure 4) was to compare the focal reduction factor to the focus position change. This plot gives an indication of the "reduction efficiency" of the focal reducer (I just made that term up!), or in other words which focal reducer can give the most reduction with the least amount of focus distance change. This plot seems to better identify the differences between the different focal reducer configurations as they all lie on unique curves, which again appear to be cubics. The basic MFR5 appears to have the highest "reduction efficiency", being able to provide focal reduction factors down in the 0.3x range when adding spacers in front (between camera and FR). What this graph does not show however is the extent of vignetting and coma when using this FR in this fast configuration. Referring back to Table 1, the vignetting was very strong for this configuration making it unusable in my opinion. The issue I believe is the diameter of the MFR5. When trying to use it at really fast reduction factors, the light cone is simply too big for a 1.25" FR. This is confirmed by the lack of vignetting observed on all the other large diameter FR's that I tested. So what do I do now…well, what if it was possible to combine the reduction efficiency of the MFR5 with the larger diameter of the other FR's? Enter the compound focal reducer.

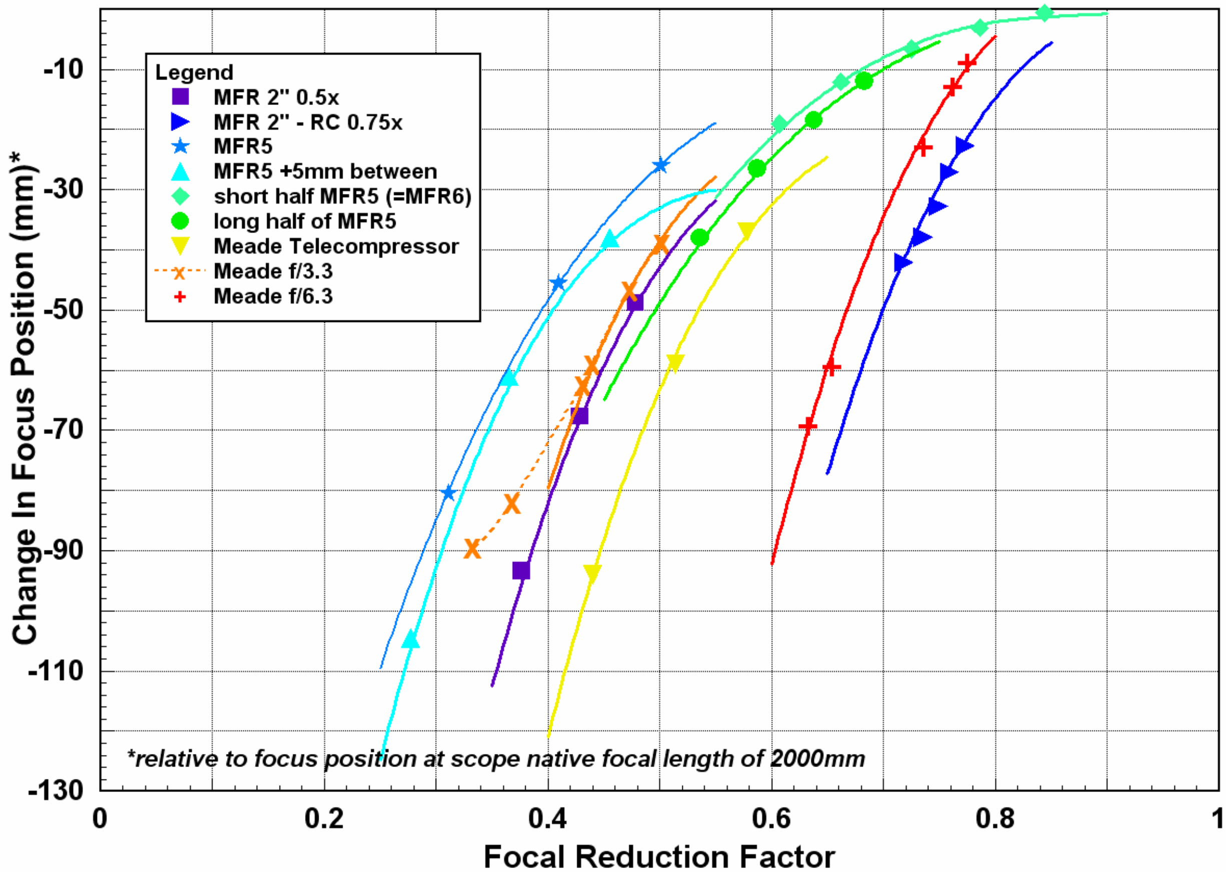

Figure 4 Simple FR Measured Focus Position Change vs. Focal Reduction Factor

Compound FR Results:

The MFR5 is essentially a compound FR. It uses two lens elements at a fixed spacing to achieve more focal reduction than would be achieved using just a single lens. This is a novel design which makes the MFR5 very flexible, but also gives it high reduction efficiency. My next batch of testing continued with this idea of combining lens elements to get increased reduction. I tested 7 compound FR configurations:

1. longer half of MFR5 plus Meade telecompressor;
2. shorter half of MFR5 plus Meade telecompressor;
3. longer half of MFR5 plus Meade f/6.3 FR;
4. Meade telecompressor plus Meade f/6.3 FR;
5. longer half of MFR5 plus MFR2" – RC;
6. shorter half of MFR5 plus MFR2" – RC; and
7. entire MFR5 plus MFR2" - RC.

I'm sure there are other combinations I could have tried, but I had to end the testing some time! I varied the distance between the lens elements and between the stack and camera. There was less flexibility in my spacings for these tests as I chose to limit myself to a combination of spacers that made sense for everyday use, so spacers of readily available fixed sizes. Figures 5 through 12 show an image of the different compound FR configurations tested. In some cases I varied the number of spacers between, but for the most part the images represent exactly what was tested. My goal was to narrow in on a practical solution that I would intend to use regularly afterwards, so I purchased a couple of adapters from AgenaAstro to help with the connections. Specifically I purchased two different versions of an SCT-to-2" thread adapter (see Figure 13) that allowed me to connect the Meade FR's to my optical train. I also extensively used a C-thread to 2" camera nosepiece that Rock was kind enough to give me to try out a couple years ago. Knowing that in all likelihood my focus position change would be large, I configured the compound FR's so that they were essentially inside the focuser draw tube. Luckily the 3"-to-2" adapter on the VRC10's focuser screws off easily, making this FR configuration easy to work with. The advantage of this is that I am able to get the camera as close to the scope as possible and thus be able to accept the larger focus position changes associated with lower reduction factors. In the pictures below, everything to the left of the 2" diameter barrel section was outside the focuser draw tube, and everything to the right was inside. Figure 14 gives some views of what one of the compound FR's looks like with the 3"-to-2" adapter.

A general observation I made was that I was picking up internal reflections from the light pollution filters when they were on the outside of the assembly (right most end in photos). A sharper image with no reflections could be achieved with the filters somewhere in between the components of the assembly. I also found putting the filters on the end (towards telescope) resulted in a small amount of vignetting.

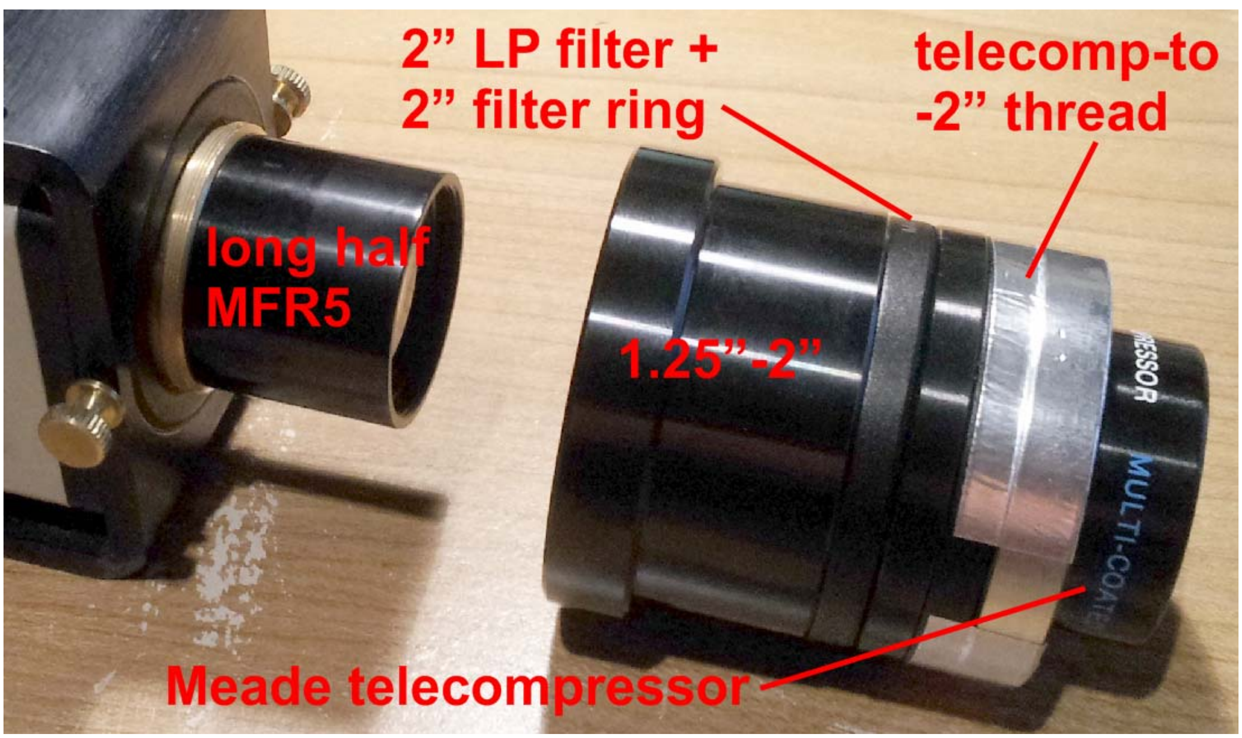

Figure 5 Compound FR #1 – Long Half MFR5 + Meade Telecompressor

Figure 6 Compound FR #2 – Short Half MFR5 + Meade Telecompressor

Figure 7 Compound FR #3a – Long Half MFR5 + Meade f/6.3 FR, filters first

Figure 8 Compound FR #3b – Long Half MFR5 + Meade f/6.3 FR, filters between

Figure 9 Compound FR #4 – Meade Telecompressor + Meade f/6.3 FR

Figure 10 Compound FR #5 – Long Half MFR5 + MFR2"- RC

Figure 11 Compound FR #6 – Short Half MFR5 + MFR2"- RC

Figure 12 Compound FR #7 – Whole MFR5 + MFR2"- RC

Figure 13 SCT-to-2" Adapters Used In Tests

Figure 14 Example Compound FR Assembly

Table 2 summarizes the measurements I made using these seven different compound FR configurations. Using the compound method it was relatively easy to get the reduction factor down in the 0.3x to 0.4x range. What was harder was finding a combination that gave a nice flat image with no vignetting and no coma. In playing around with spacers it seems that adjusting the space between the half of the MFR5 and the camera had a very strong impact on the overall reduction, but also had an impact on vignetting. The smallest amount of vignetting was achieved with the MFR5 component closest to the camera, then adjusting the focal reduction factor by changing the spacing between FR's.

Test #	FR	focus distance [mm]	delta focus distance [mm]	FR-to-CCD distance [mm]	ref. star distance [pixels]	f/ratio [non]	reduct. factor [non]	vignette score [non]	coma score [non]
	Compound Focal Reducer Point Tests (Aug. 18th, 2013)								
38	long half MFR5 + Meade telecomp (23.5 tween)	125.6	-96	44.3	82.38	2.49	0.311	3	2
39	long half MFR5 + Meade telecomp (18.2 tween)	142.6	-79	41.65	89.07	2.69	0.337	3	2
40	long half MFR5 + Meade f/6.3 (41 between)	172.6	-49	53	114.28	3.46	0.432	0	1
41	long half MFR5 + Meade f/6.3 (64 between)	129.1	-92.5	64.5	96.05	2.90	0.363	1	2
42	5mm+long half MFR5 + Meade f/6.3 (41 tween)	145.6	-76	69.5	97.31	2.94	0.368	1	2
43	5+longhalfMFR5+M f/6.3 pull out 10 (51 tween)	124.1	-97.5	74.5	89.63	2.71	0.339	2	2
44	telecomp + m f/6.3 (50 tween)	155.4	-66.2	50	117.89	3.56	0.446	0	1
	Final Compound Focal Reducer Tests (Aug. 20th, 2013)								
45	long half MFR5 + M f/6.3, Woadapt, 10mmtween	142.6	-79	65.45	101.79	3.08	0.385	0	1
46	17mm tween	124.1	-97.5	68.95	93.30	2.82	0.353	0	2
47	22mm tween	113.1	-108.5	71.45	91.59	2.77	0.346	0	3
48	final (2filters+empty ring, 19.2mm tween)	119.6	-102	70.05	92.31	2.79	0.349	0	2
	Additional Compound Focal Reducer Tests (Aug. 23rd, 2013)								
49	short half MFR5 + Meade telecomp (40 tween)	112	-109.6	39.6	96.83	2.93	0.366	1	0
50	long half MFR5 + MFR2"-RC (20 tween)	183.3	-38.3	51.3	137.24	4.15	0.519	0	0
51	short half MFR5 + MFR2"-RC (40 tween)	194.7	-26.9	48	171.21	5.18	0.647	0	0
52	whole MFR5 + MFR2"-RC	157.3	-64.3	48.3	98.47	2.98	0.372	0	2
53	long half MFR5 + M f/6.3, Woadapt, 2filters tween	137	-84.6	61.35	98.99	2.99	0.374	0	2
54	long half MFR5 + MFR2-RC + 3 filters tween + 5mm in front	142	-79.6	60	121.20	3.66	0.458	0	0

Table 2 Summary of Compound FR Measurements

For comparison I have plotted the compound FR results against those of the regular FR results in order to compare their relative reduction efficiency (Figure 15). The figure plots the regular FR results as curves, and the compound FR results as points. The number beside each compound FR data point is the corresponding test # found in Table 2. As you can see from the number of cases I tested, there is pretty much an infinite number of spacings and lens element combinations that are possible. Although my aim was to see how low an f/ratio I was able to achieve, really my aim was to get something around f/3.0 (reduction factor 0.375) that had very little vignetting and coma.

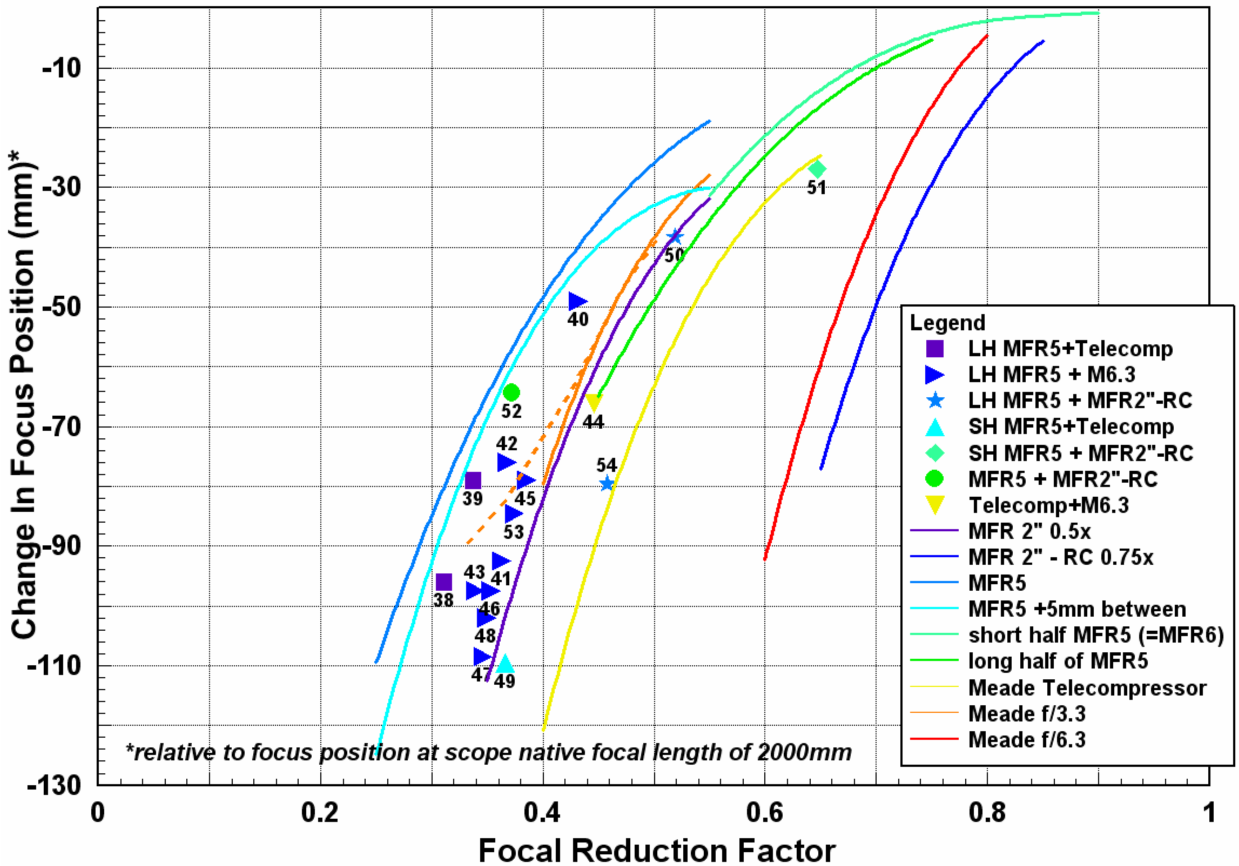

Figure 15 *Compound FR Measured Focus Position Change vs. Focal Reduction Factor*

To try and help the down select process I observed the Bubble Nebula with the configurations that I felt had the most promise, all at around f/2.9 to f/3.0. Single frame image captures for the different configurations can be found below in Figure 16. Included in the short list was the regular (non-compound) Meade f/3.3 FR which I tested again but this time with the SCT-to-2" adapter that I didn't yet have for the initial testing (see Figure 17). I had trouble adjusting the spacing on this FR to get it around f/2.9 and in the end settled for f/2.7 for the comparison. I also included the longer half MFR5 + MFR2"-RC with focal ratio f/4.2 because it produced a very nice flat sharp image to use for comparison.

LH MFR5 + MFR2”-RC (f/4.15)

Meade f/3.3 (f/2.67)

LH MFR5 + Meade f/6.3 (f/2.99)

SH MFR5 + Meade telecompressor (f/2.93)

Whole MFR5 + MFR2”-RC (f/2.98)

Figure 16 Compound FR Bubble Nebula Screen Captures

Figure 17 Final Tested Meade f/3.3 FR Configuration

From the images in Figure 16 there is not a clear winner in my opinion. The SH MFR5+telecomp gave a very sharp image with little coma but quite a significant amount of vignetting. The LH MFR5+Meade f/6.3 and the MFR5+MFR2"-RC both gave little or no vignetting but very similar levels of coma. The straight Meade f/3.3 FR is the strangest of them all as in my earlier tests at slower f/ratios it produced a worse image (more coma) than the image I recorded at f/2.67. It is almost as if there is a sweet spot for this FR…perhaps there is a sweet spot for all the FR's and I just haven't found them yet?

It has been at least 2 pages since my last graph, so here's another one (Figure 18). This one plots the observed image quality versus reduction factor for all 54 of my test cases (Tables 1 and 2). The image quality value is simply the sum of my vignetting plus coma scoring in the tables above. The test # for each data point is noted on each graphed point.

When I'm live observing I am not super picky about the image quality, so I am content with a FR configuration that has a quality score of 2 or less (0 being perfect). If I was really trying to get some nice captures, maybe for stacking later, then perhaps I'd limit myself to using FR configurations with a quality of 1 or better. Based on this type of requirement I can use Figure 18 to pick the best FR configuration to use to achieve whatever focal reduction factor I want.

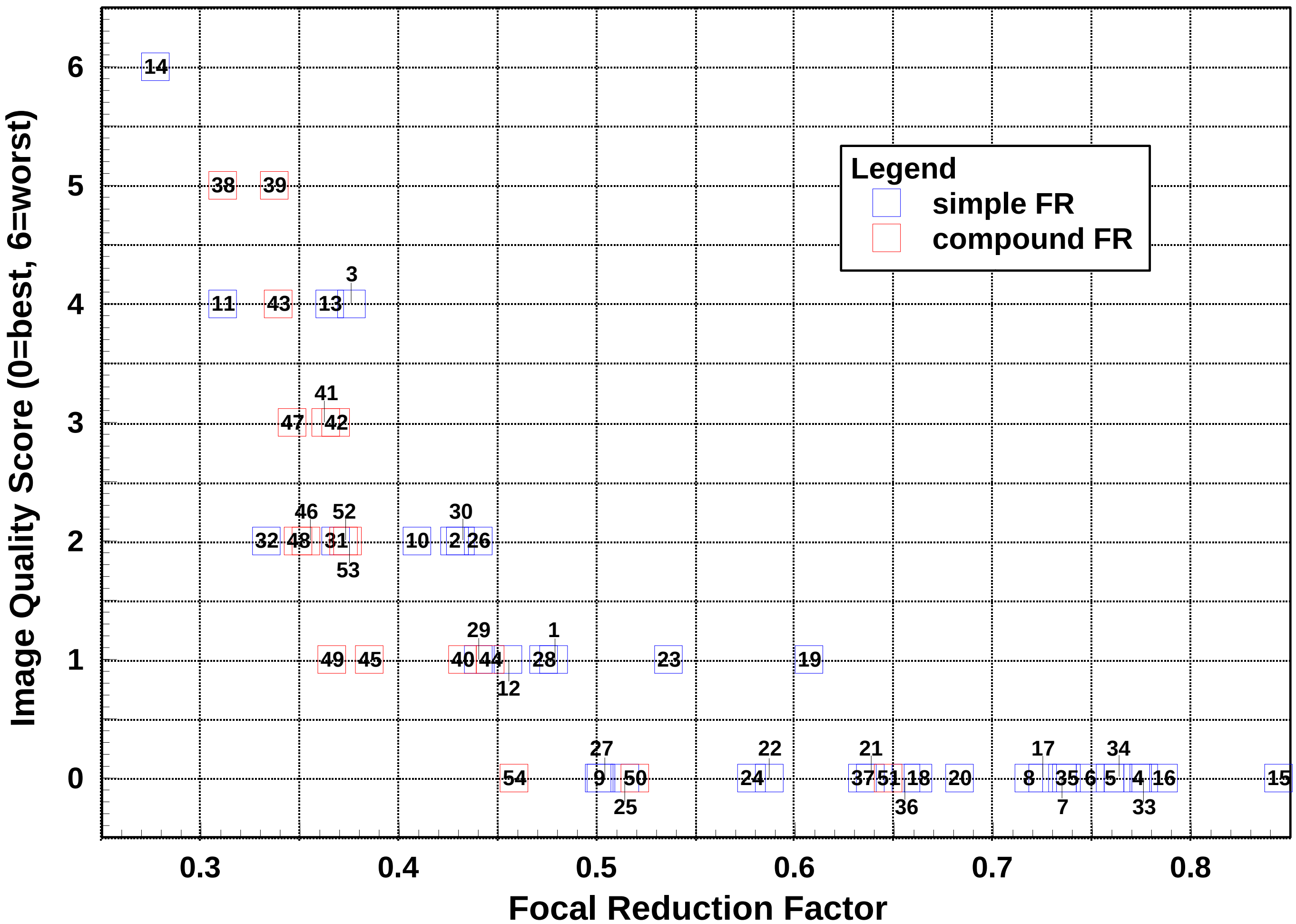

Figure 18 Observed Image Quality vs. Focal Reduction Factor

Conclusions:

I am glad I did this test as I learned a lot about how FR's work. I believe that the measurements of focal reduction factor and change in focus distance can be applied to other telescopes as is discussed above. My observation of image quality however is probably closely related to the specific telescope used for the test. I encourage others to try some of the FR configurations I tested on their own telescopes to see how their results compare with mine.

There is one important general observation that I made during my testing. The image quality, or more specifically the amount of coma, depends heavily on how well the camera and FR are aligned with the axis of the telescope. If the camera-FR is off center or not parallel with the telescope axis, you will see increasing amounts of coma. Notice in the Bubble Nebula images above how the extent of the coma is not uniform all the way around the image; the coma is distributed more in one or two corners than the others. This suggests to me that something in my optical path is not aligned properly. The long length of some of the compound FR's I tested probably exacerbated this problem as a slight angling off axis would result in the free end being well off center. Using the 2” nosepiece on the camera seems to reduce the amount of misalignment. The fact that the short half MFR5 + Meade telecompressor and the Meade f/3.3 both were shorter assemblies and both used a 2” nosepiece may have contributed to them having less coma than the other compound FR’s tested.

I intend to follow-up on a couple of items as a result of this report:

1. Do more observations with the Meade f/3.3 FR to see if the odd behavior I present in this report is correct or simply out to lunch;
2. Push the long half MFR5 + MFR2”-RC compound FR more to see how low a reduction factor I can get and yet keep the nice sharp image I have been getting so far with it.
3. Experiment with shims or other methods to snug up areas of potential misalignment in the optical train. I have already tried a little Vaseline on the tapered seat of the focuser to help it seat more squarely with the telescope, and it seems to have helped.

I hope my work is useful to the amateur astronomy community. If you have any questions, please feel free to contact me at: karmalimbo@yahoo.ca

Cheers,

Jim Thompson
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