Optolong L-eXtreme F2

by Jim Thompson, P.Eng
Test Report – December 22nd, 2021

Introduction:
The last couple of years has seen a lot of developments in equipment for the amateur astronomy field. One such development is the continued evolution of the multi-narrowband filter. Since their arrival a few years ago, these filters have become very popular amongst astrophotographers and electronically assisted astronomy (EAA) users. Fortunately for us filter manufacturers have noticed our interest in these filters, and are listening to our suggestions for ways to make the filters better. An example of this positive feedback in action is the new filter from Optolong called the L-eXtreme F2. The filter is Optolong's answer to the user community's desire to use their successful L-eXtreme filter with fast optics. The filter is designed with its pass bands pre-shifted up in wavelength so that when used on a RASA scope or an SCT with the Hyperstar system operating at f/2, the filter's pass bands shift back down to be well centered on the desired nebula emission wavelengths.

Optolong has generously sent me a prototype of this new filter so that I may evaluate it using my well established testing methods. This report summarizes the result of my testing.

Objective:
The deficiency in the performance of the L-eXtreme filter on f/2 optics is well documented in the reviews of other fellow amateur astronomers. I discuss the topic to a small extent in my test report on the L-eXtreme published in August 2020. The topic of narrowband filters and fast optics is discussed in more detail in another report I published in November of the same year.

http://karmalimbo.com/aro/reports/Test%20Report%20-%20Optolong%20L-eXtreme%20Filter_Aug2020.pdf

http://karmalimbo.com/aro/reports/Article%20-%20Narrowband%20Filters%20&%20Fast%20Optics_Nov2020_rev1.pdf

The objective of this test is to evaluate the performance of the new L-eXtreme F2 against the original L-eXtreme filter. The focus of the testing is to determine the relative impact of optics speed on the filters' performance. For the purposes of comparison I have included two additional multi-narrowband filters. The complete list of filters tested is as follows:

- Baader Planetarium UV/IR Cut (for reference in imaging)
- Optolong L-eNhance
- Optolong L-eXtreme
- Optolong L-eXtreme F2
- IDAS NBZ

I have included the IDAS NBZ in my comparison as this filter has already been demonstrated by my own testing to have a consistent high level of performance at optics speeds down to f/2. Filter performance is evaluated during this test based on the increase in contrast between the observed object and the background, which is a measurable quantity. It was evaluated quantitatively using the measured filter spectra combined with the spectra of several common deepsky objects, and qualitatively by visually comparing images captured using each filter and a one shot colour (OSC) camera.

Method:
Testing consisted of data collection in the following manner:

- Spectral transmissivity data, from near-UV to near-IR, measured using an Ocean Optics USB4000 spectrometer; and
- Image data, collected using a ZWO ASI-294MC Pro OSC camera, and one of two different telescopes: a William Optics FLT98 triplet apochromatic refractor with f-ratio f/6.3, and a Celestron C14 Edge HD with Starizona Hyperstar system giving an f-ratio of f/2.0.

The spectrometer data was collected in my basement workshop with the USB4000 and a broad spectrum light source. To collect the data I recorded two back-to-back scans from each filter and calculated the average. In the event that the data varied by more than 0.1% between back-to-back scans, I rejected the data set and repeated the whole measurement again. Filter spectrums were measured for a range of filter angles relative to the light path, from 0° (perpendicular) to 20° off-axis. Additional information about my spectrometer setup was provided in my IDAS Filter Test Report.

The image data was collected from my backyard in central Ottawa, Canada where the naked eye limiting magnitude (NELM) due to light pollution is +2.9 on average, which translates to Bortle 9+. I don't have a filter wheel, so to switch filter configurations I had to remove the camera from the telescope and swap the filter by unthreading it from the camera. Each time I changed filters I would refocus on a conveniently located bright star using a Bahtinov mask. Images with the various filters under test were collected on a single evening for a particular telescope to minimize the variation between images due to sky conditions. Two common Winter deepsky targets were used for all the images: the Orion Nebula (M42) and the neighbouring Running Man Nebula (NGC1977), and the Flame Nebula (NGC2024) with nearby Horsehead Nebula (B33). These objects were selected because they were well placed in the southern sky for the duration of the image captures. These two deepsky targets are a good proxy for many different types of objects, presenting a variety of emissions (i.e. O-III, H-alpha, reflection nebula, & dark nebula). Images with the C14 were captured on December 12th, and with the FLT98 on the following night. Transparency and seeing conditions were similar on the two nights, being average to below average. The waxing gibbous Moon was present at the time of image captures, but was 80 to 90° to the West of Orion during my testing.

Results – Spectrum Measurements:
Using the test method mentioned above the spectral transmissivity for each filter was measured for a range of filter angles relative to the light path. Figure 1 presents a plot of the resulting spectral transmissivity data for the case of the filter perpendicular to the light path. It is clear from the spectrum measurement that the L-eXtreme F2 filter has its pass bands pre-shifted up in wavelength, i.e. to the right.

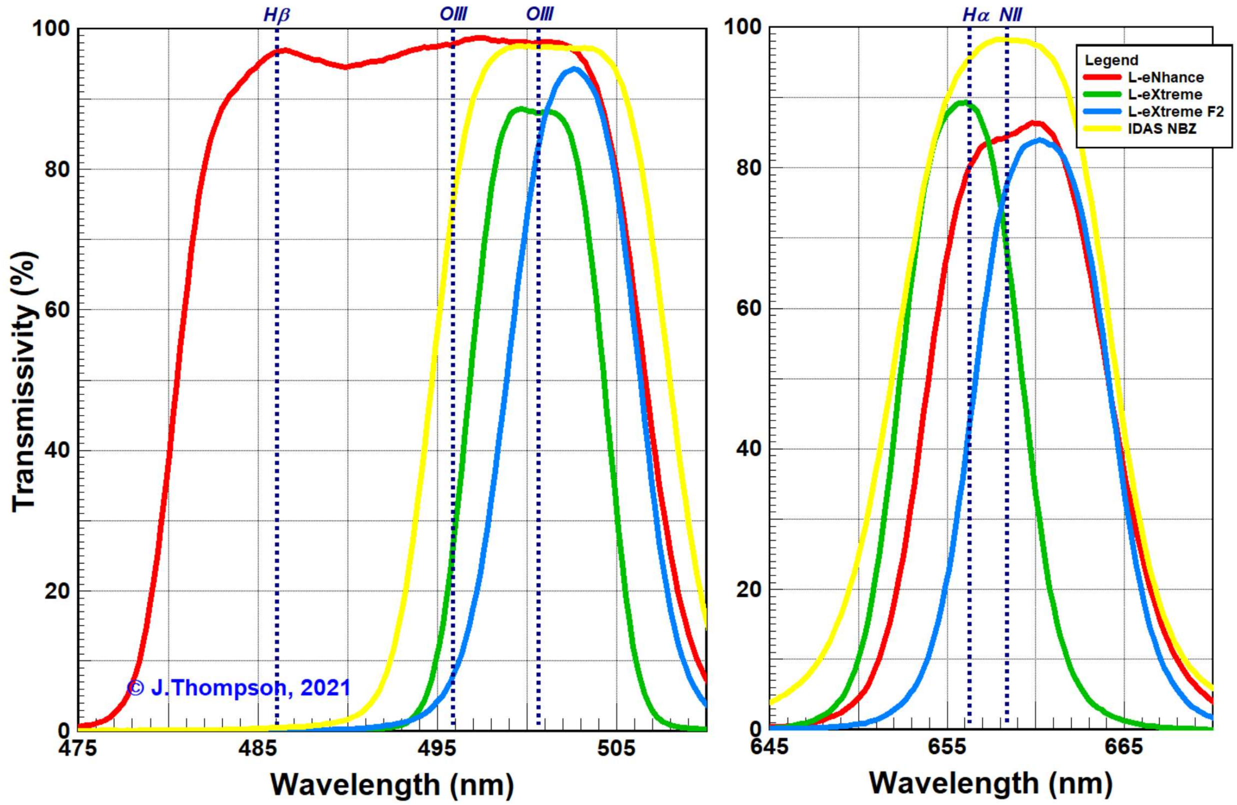


Figure 1 Measured Spectral Response of Tested Filters – Filter Perpendicular to Light Path

As mentioned, each filter had its spectrum measured for a range of angles. The impact of angle on each filter's transmission for some important nebula emission wavelengths is shown in Figure 2. Note how the response of the L-eXtreme filter drops off before angles corresponding to f/2, especially for Hα. The angle response for the L-eXtreme F2 is shifted to the right in comparison so that transmission at its best in the f/2 to f/3 range.

Figure 2 also has black vertical lines corresponding to different optics f-ratios. These lines are positioned at the angle values corresponding to light coming from the outer edge of the scope's aperture for the noted f-ratio. The net performance of a filter on any particular speed of optics is an area weighted average of the filter's performance, for light angles from perpendicular out to the angle at the outer edge of the aperture. Using the measured filter spectra at each angle I have calculated a net filter spectrum for each of the two telescopes I have selected for my testing, the f/6.3 refractor and f/2 C14 w/Hyperstar. The area averaging process is illustrated in Figure 3. Essentially the aperture of the scope is divided into donuts defined by the angles at which I have measured filter data. The percentage each donut is of the total primary optical area is the weighting applied to that particular spectrum. Figures 4 and 5 present the resulting net spectra for the two telescopes used in my testing. The shift in filter response between that shown in Figure 1 and for the f/6.3 telescope (Figure 4) is almost zero, but is significant for the f/2 scope (Figure 5). The effects of filter band shift are worse on the C14 due to the large central obstruction which results in a larger percentage of the light having to pass through the filter at an angle.

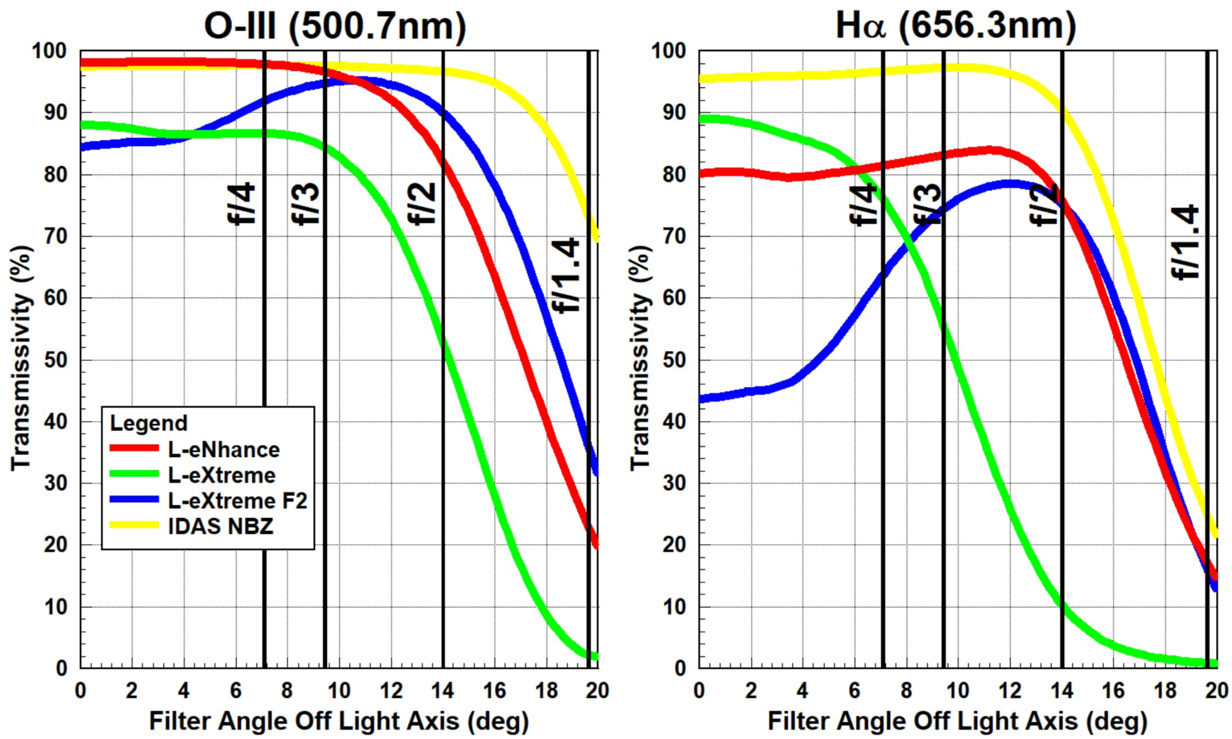


Figure 2 Measured Impact of Angle on Filter Response

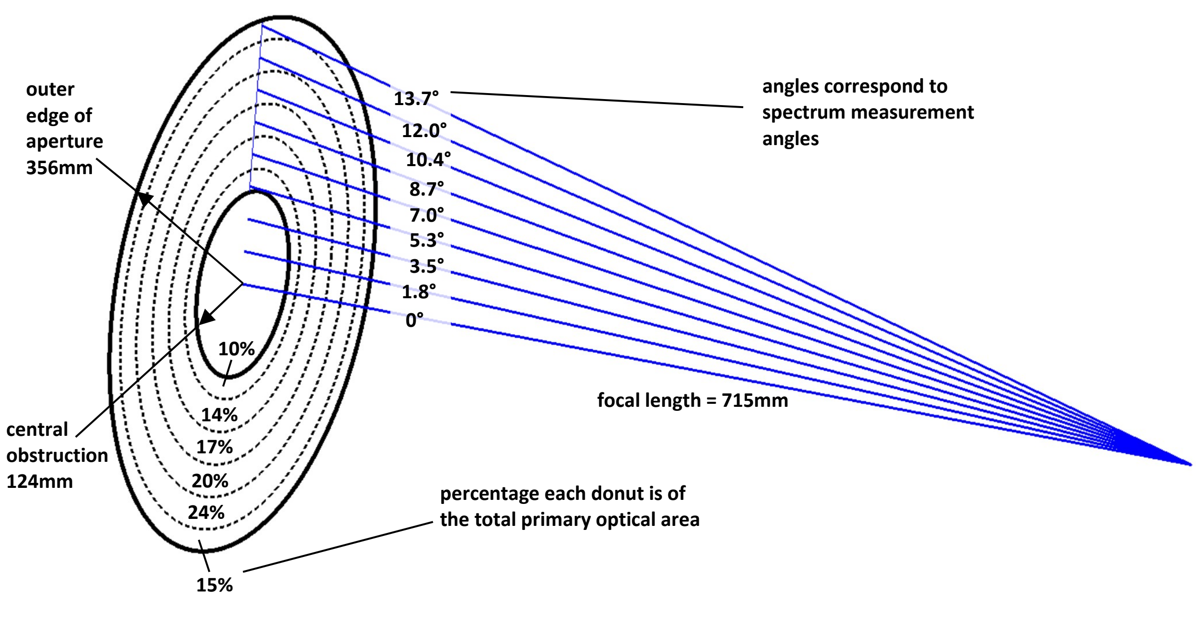


Figure 3 Illustration of Area Weighted Average Filter Response Calculation – C14 Hyperstar

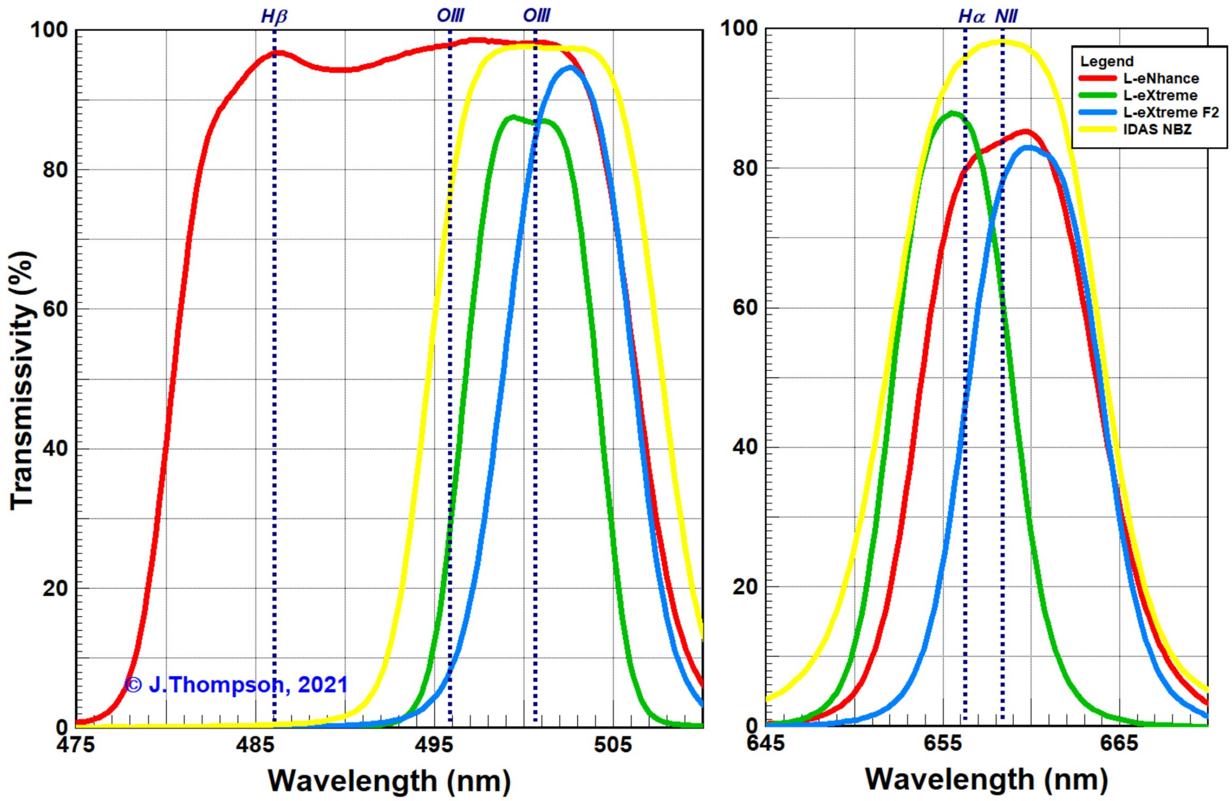


Figure 4 Net Spectral Response of Tested Filters – f/6.3 Refractor Area Weighted Average

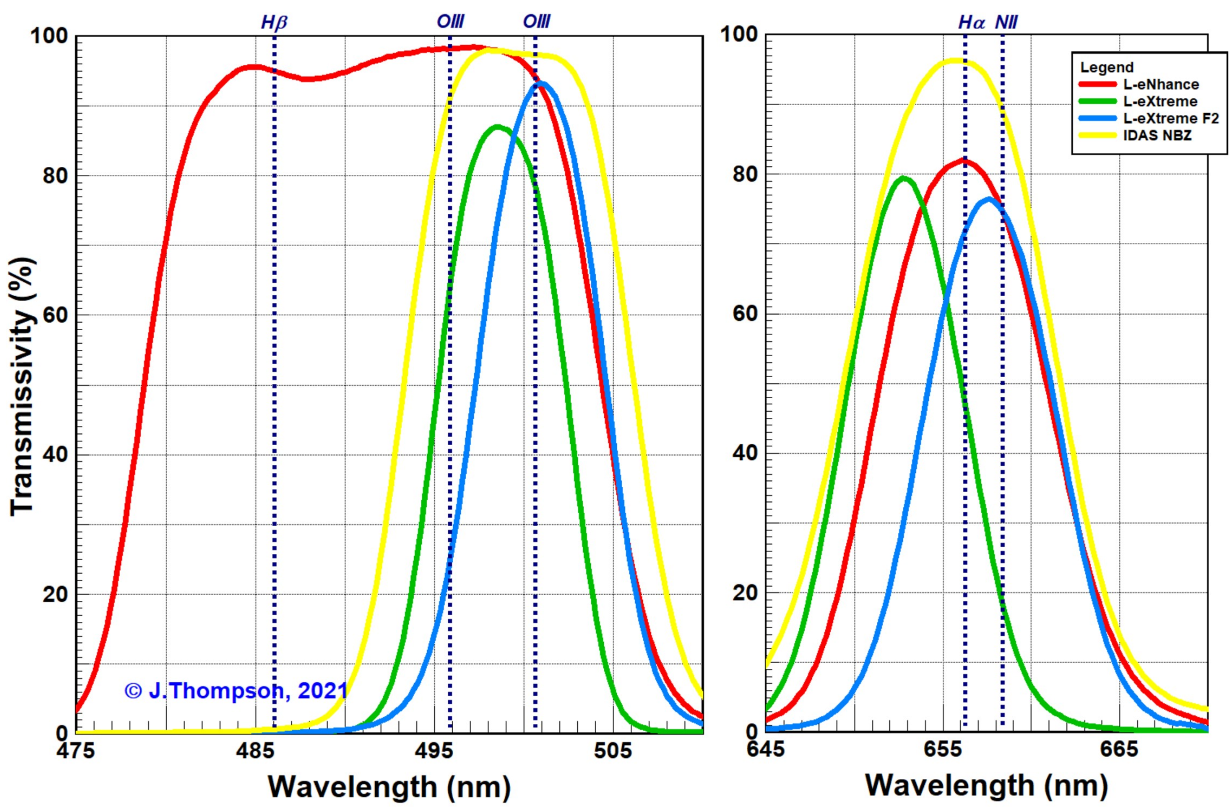


Figure 5 Net Spectral Response of Tested Filters – f/2 C14 w/Hyperstar Area Weighted Average

With the net filter spectra in hand, it is possible to extract overall performance related statistics for each filter, such as transmission values at key wavelengths of interest and pass band widths. These filter statistics are provided in Table 1, including a calculated value for percent Luminous Transmissivity (%LT), a single number that describes generally how much light is getting through the filter. The calculated value of %LT depends on the spectral response of the detector, which in this case is assumed to be a modern back illuminated colour CMOS sensor.

Filter	Scope Optics	%LT*	Hbeta/O-III Pass Band				Halpha Pass Band			
			FWHM	Hbeta (486.1)	O-IIIA (495.9)	O-IIIB (500.7)	FWHM	Halpha (656.3)	N-II (658.4)	S-II (672.4)
L-eNhance	f/∞	8.3%	25.5nm	96.8%	97.9%	98.1%	10.5nm	80.2%	84.5%	1.4%
	f/6.3**	8.3%	25.5nm	96.8%	97.9%	98.2%	10.3nm	79.8%	84.0%	1.3%
	f/2***	8.1%	25.2nm	95.0%	98.2%	93.9%	10.4nm	81.9%	74.3%	0.8%
L-eXtreme	f/∞	3.2%	7.4nm	0.2%	27.4%	88.1%	6.9nm	89.0%	67.1%	0%
	f/6.3	3.2%	7.3nm	0.1%	29.8%	86.8%	6.8nm	86.8%	59.9%	0%
	f/2	3.0%	7.2nm	0.1%	65.1%	77.6%	7.3nm	46.8%	17.9%	0%
L-eXtreme F2	f/∞	3.6%	7.2nm	0.1%	8.2%	84.4%	7.9nm	43.5%	78.1%	0.4%
	f/6.3	3.6%	7.1nm	0.1%	8.5%	85.5%	7.8nm	46.2%	78.5%	0.2%
	f/2	3.5%	7.2nm	0.2%	25.8%	93.0%	8.1nm	72.0%	74.4%	0.2%
NBZ	f/∞	6.0%	12.9nm	0.5%	76.2%	97.4%	12.3nm	95.4%	98.1%	3.7%
	f/6.3	6.0%	12.7nm	0.5%	77.4%	97.6%	12.1nm	95.8%	98.1%	3.3%
	f/2	5.9%	12.5nm	0.7%	91.5%	97.3%	12.1nm	96.0%	88.6%	2.5%

* calculated assuming spectral QE curve for IMX174C with no UV/IR blocking filter; ** FLT98 refractor; *** C14 w/Hyperstar

Table 1 Measured Filter Performance Summary

Knowing the measured spectral response of the sample filters also allowed me to predict the theoretical relative performance of each filter on different kinds of deepsky object, under different sky conditions. To do this I used the method I developed back in 2012 which uses the spectral response of the filter and sensor combined with the spectral emission from the deepsky object and background sky to estimate the apparent luminance observed. To help visualize the results of this analysis I have plotted the predicted % increase in contrast for each filter versus the filter's %LT. Figure 6 shows the resulting plot corresponding to filter performance when using a colour CMOS camera under heavily light polluted skies complete with local LED street lights (i.e. my backyard). Note that these are theoretical predictions of the increase in visible contrast between the object and the background. The absolute values of my predictions may not reflect what a user will experience with their own setup, but the predicted relative performance of one filter to another should be representative. In general the desired performance for a filter is high contrast increase with high %LT, so the higher and more to the right a filter's performance is in the plot the better. Note that solid filled data markers on the plot correspond to the filter used on a f/6.3 refractor, and the outline data markers correspond to the filters used on a f/2 C14 with Hyperstar.

Based on my predictions, the L-eNhance and NBZ filters deliver a consistent increase in contrast, one that does not change significantly down to an f-ratio of f/2. The two models of L-eXtreme filter however do deliver a contrast increase that varies significantly with f-ratio, especially on H-alpha dominant objects. In fact, if one were to use the L-eXtreme on an f/2 scope, or the L-eXtreme F2 on an f/6 scope, the resulting increase in contrast is predicted to be the same or worse than that of the L-eNhance and NBZ which have significantly wider pass bands.

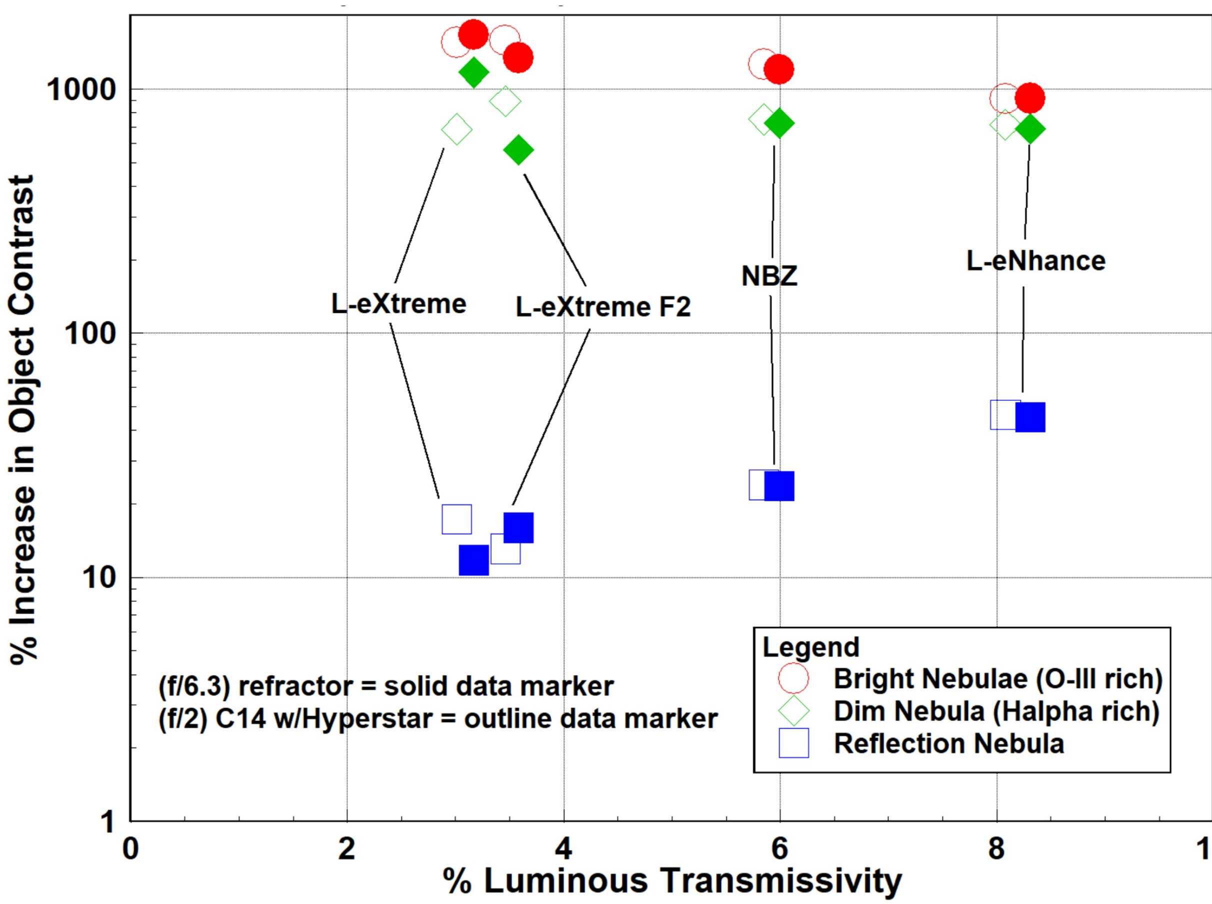


Figure 6 **Predicted Filter Performance: Back Illuminated Colour CMOS, LP w/LED (NELM+2.9)**

Results - Imaging:

As described above in the Method section, image data was captured with each filter using the same OSC camera on each telescope, with all images from a particular scope collected on the same night within a 90 minute time window. The camera colour channel gains were adjusted at the start of each imaging session to give a white balanced image with UV/IR cut filter on, and then left fixed for the duration of the data collection with each of the other filters. Data was collected by generating a live stack in Sharpcap of five minutes total duration, which was then saved as a 16bit FITS file. Camera settings were fixed for all images on a particular telescope, as defined below:

- FLT98: 300gain (53%), bin 2x2, WB(R) 80%, WB(B) 77%, TEC -10°C
- C14 w/Hyperstar: 250gain (44%), bin 1x1, (R) 83%, WB(B) 84%, TEC -10°C

The exception is exposure time per frame which was adjusted for each filter in order to achieve an image of generally the same level of overall exposure as the UV/IR cut filter reference image. This was determined qualitatively by observing the extent of image saturation around the core of M42. I did not use any calibration frames during my data collection, so no dark or flat frames have been applied. There was also no histogram adjustment made to the live stacks within

Sharpcap; black point and white point were left at their default positions, and the gamma slider was positioned in the middle.

Using the histograms from my raw captured images, combined with the sub-exposure times, I pulled out the impact of each filter on relative exposure for each colour channel. The results are summarized in Table 2. This information can be used to help astrophotographers determine how each filter will impact their exposure time relative to just a UV/IR cut filter.

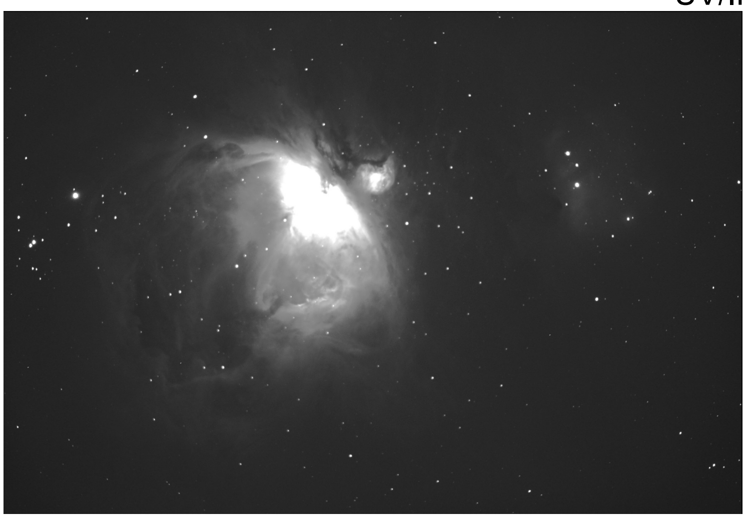
Filter	Scope Optics	Sub-Exposure Time [s]	Measured Exposure (Relative To UV/IR Cut Filter)			
			R	G	B	L
UV/IR Cut	f/6.3	10	-	-	-	-
	f/2	10	-	-	-	-
L-eNhance	f/6.3	25	7.8%	11.9%	14.1%	11.4%
	f/2	25	5.5%	9.8%	12.5%	9.4%
L-eXtreme	f/6.3	45	5.3%	5.0%	5.5%	5.2%
	f/2	45	3.7%	4.0%	4.1%	4.0%
L-eXtreme F2	f/6.3	45	4.9%	5.2%	5.3%	5.2%
	f/2	45	3.7%	4.3%	4.2%	4.1%
NBZ	f/6.3	30	8.7%	9.1%	9.3%	9.1%
	f/2	30	6.7%	7.4%	7.2%	7.2%

Table 2 Measured Relative Exposure By Colour Channel

For the visual comparison of the images I approached the task from two different directions. First I separated each colour channel out for comparison to each other. In this way the performance of the filter on different nebula emission wavelengths can be evaluated individually. I used AstroImageJ to save each image's colour channel as a 16-bit TIFF, and then used an image editor to apply the same amount of histogram stretching to each colour channel image. The resulting images are presented in Figures 7 to 12 for M42, and Figures 13 and 14 for just the red channel from the Flame Nebula.

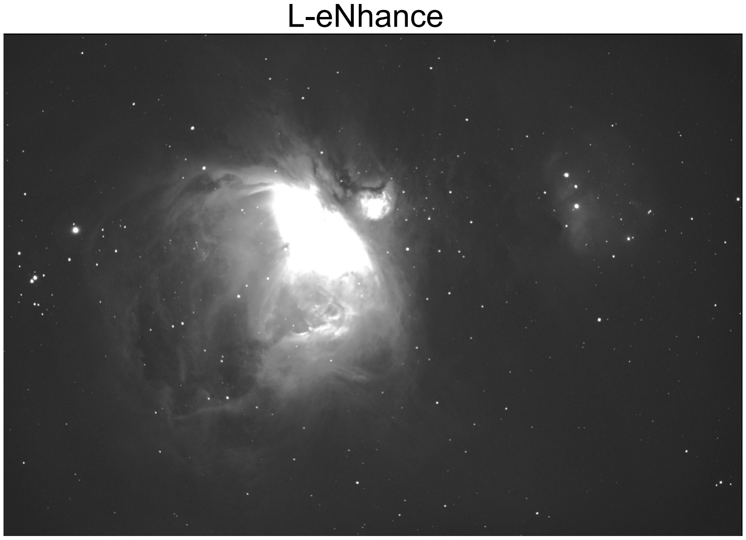
The second approach to visually comparing the images was to work with the full colour images. I first aligned the colour channel histograms for each image in Fitswork v4.47, a free FITS editing software. This was done by adjusting the black point on each colour channel's histogram until the histogram peaks were all aligned with each other. I then applied the same amount of luminance channel histogram stretching to each image. The resulting images are presented in Figures 15 to 18. Although a large number of images have been assembled for comparison in this test report, the results are all pretty consistent. The trend in contrast improvement predicted by my spectral analysis was reflected in the images that were recorded. The improvement in performance of the L-eXtreme F2 over the original L-eXtreme on f/2 optics is obvious, especially in regards to Hα emissions, i.e. red colour channel images.

UV/IR Cut

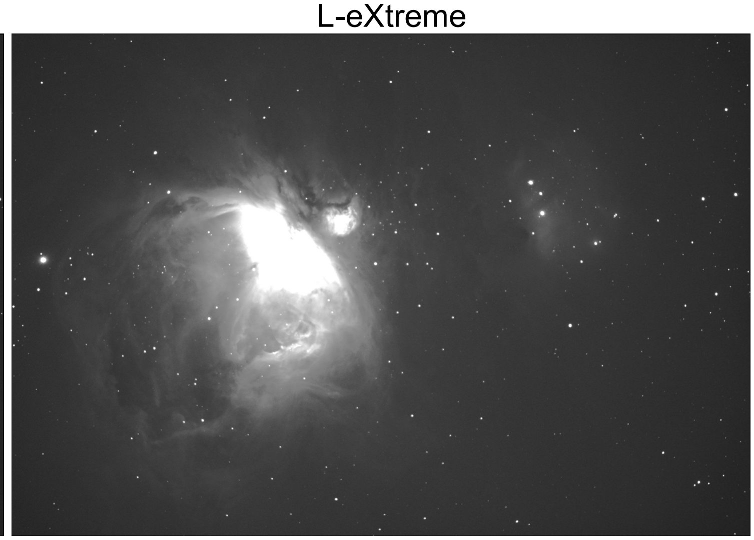


L-eNhance

L-eXtreme



L-eXtreme F2



NBZ

Figure 7 Image Comparison: M42, f/2, Red Channel

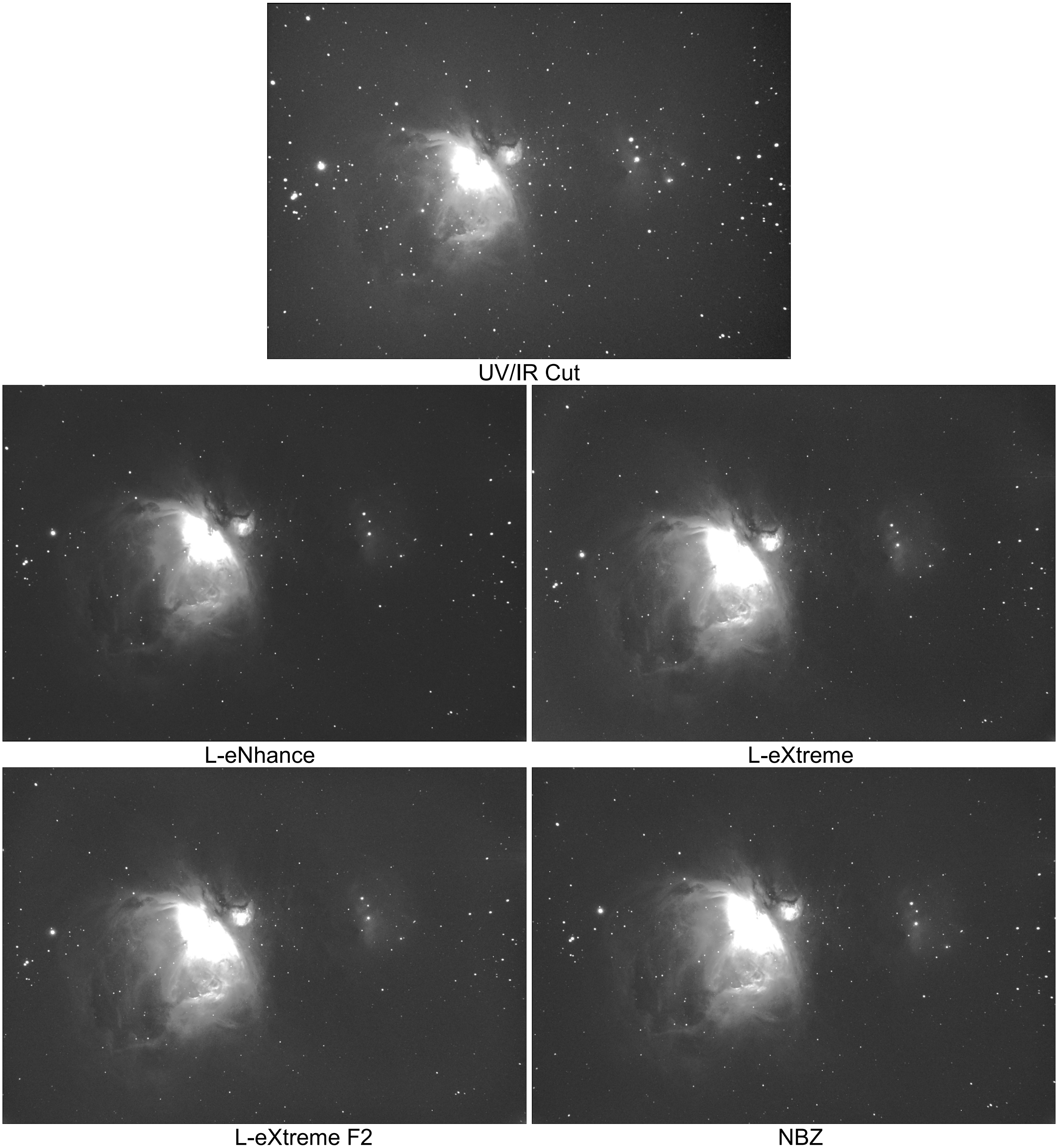


Figure 8 Image Comparison: M42, f/6.3, Red Channel

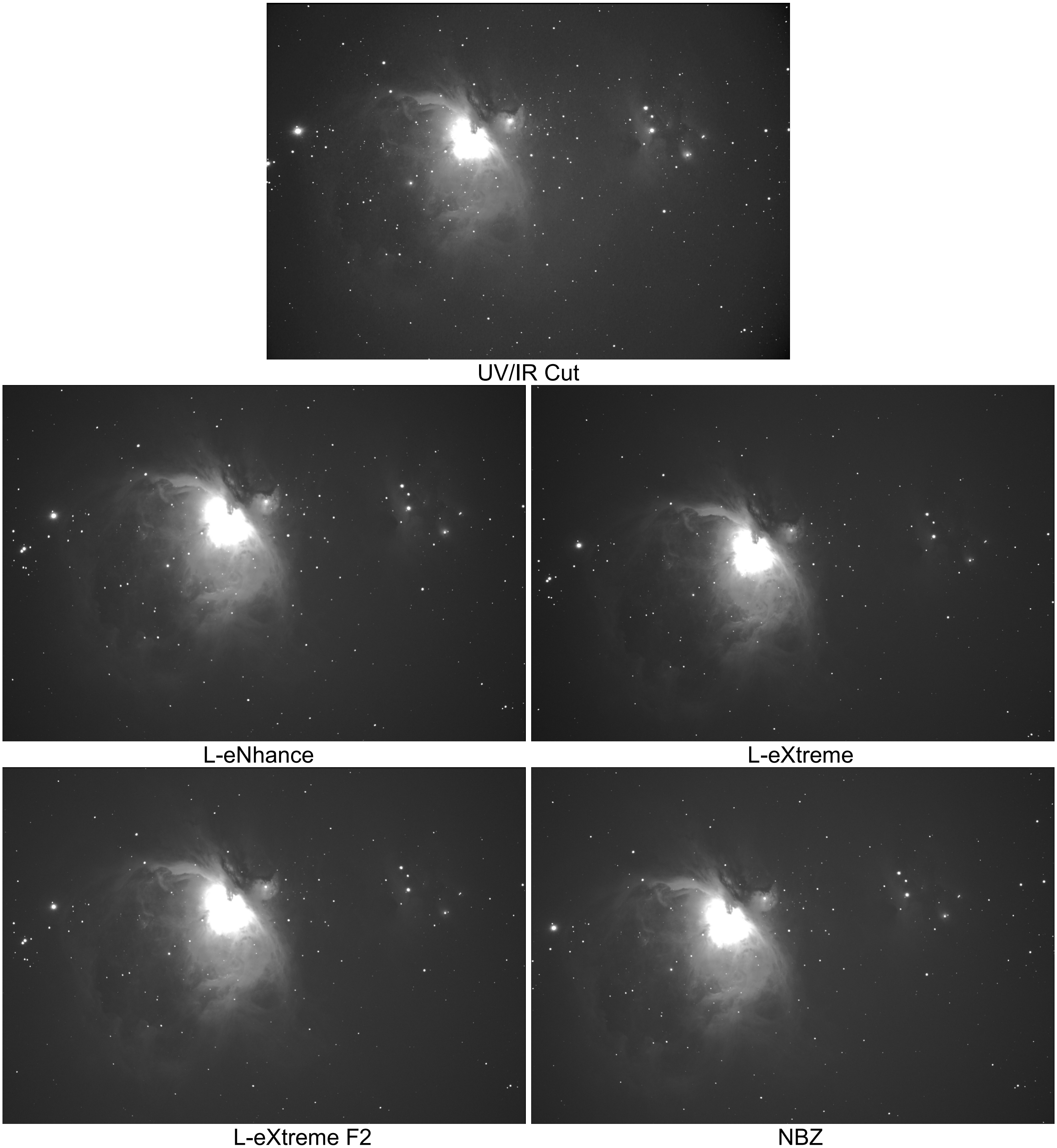


Figure 9 Image Comparison: M42, f/2, Green Channel

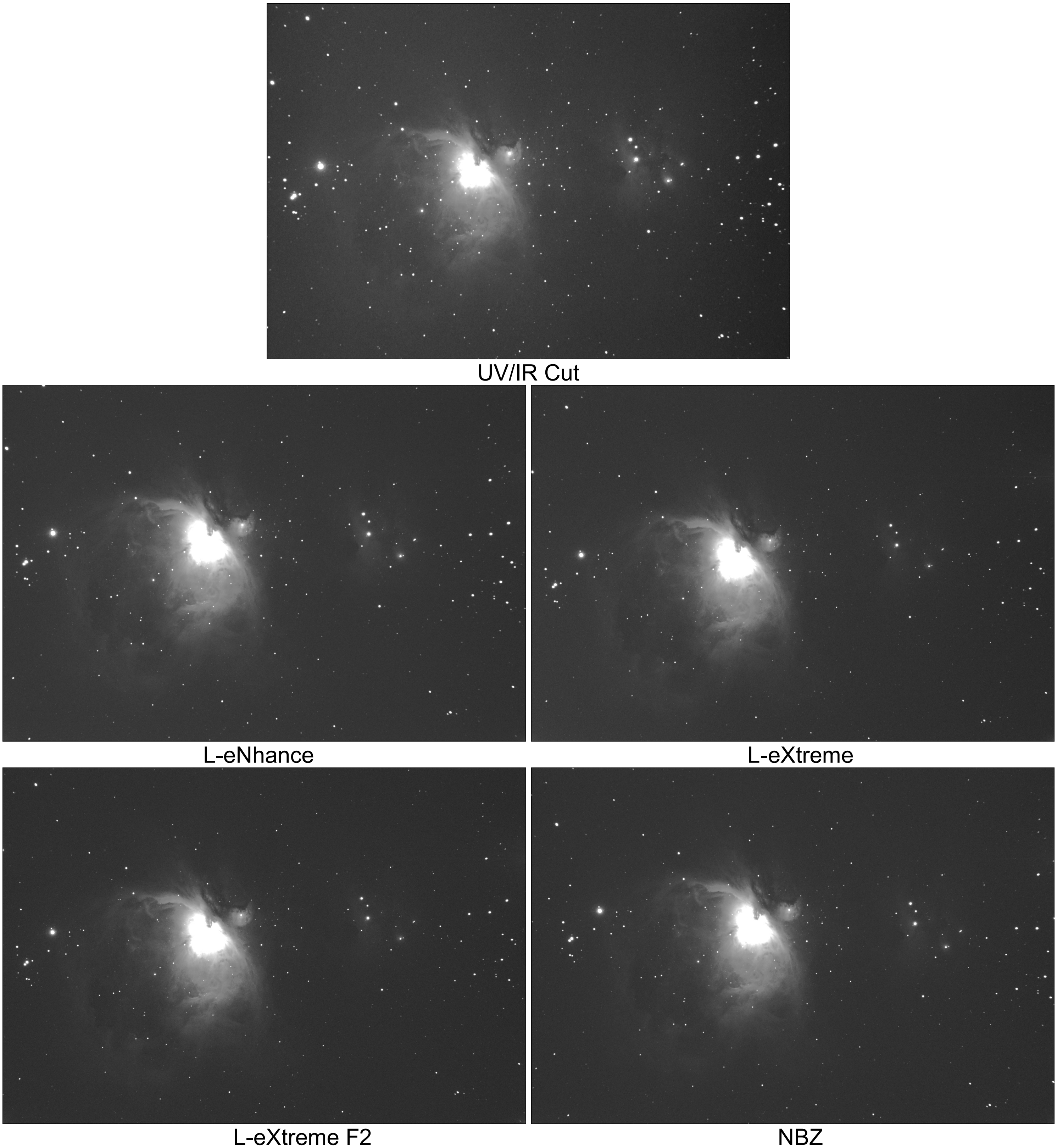


Figure 10 Image Comparison: M42, f/6.3, Green Channel

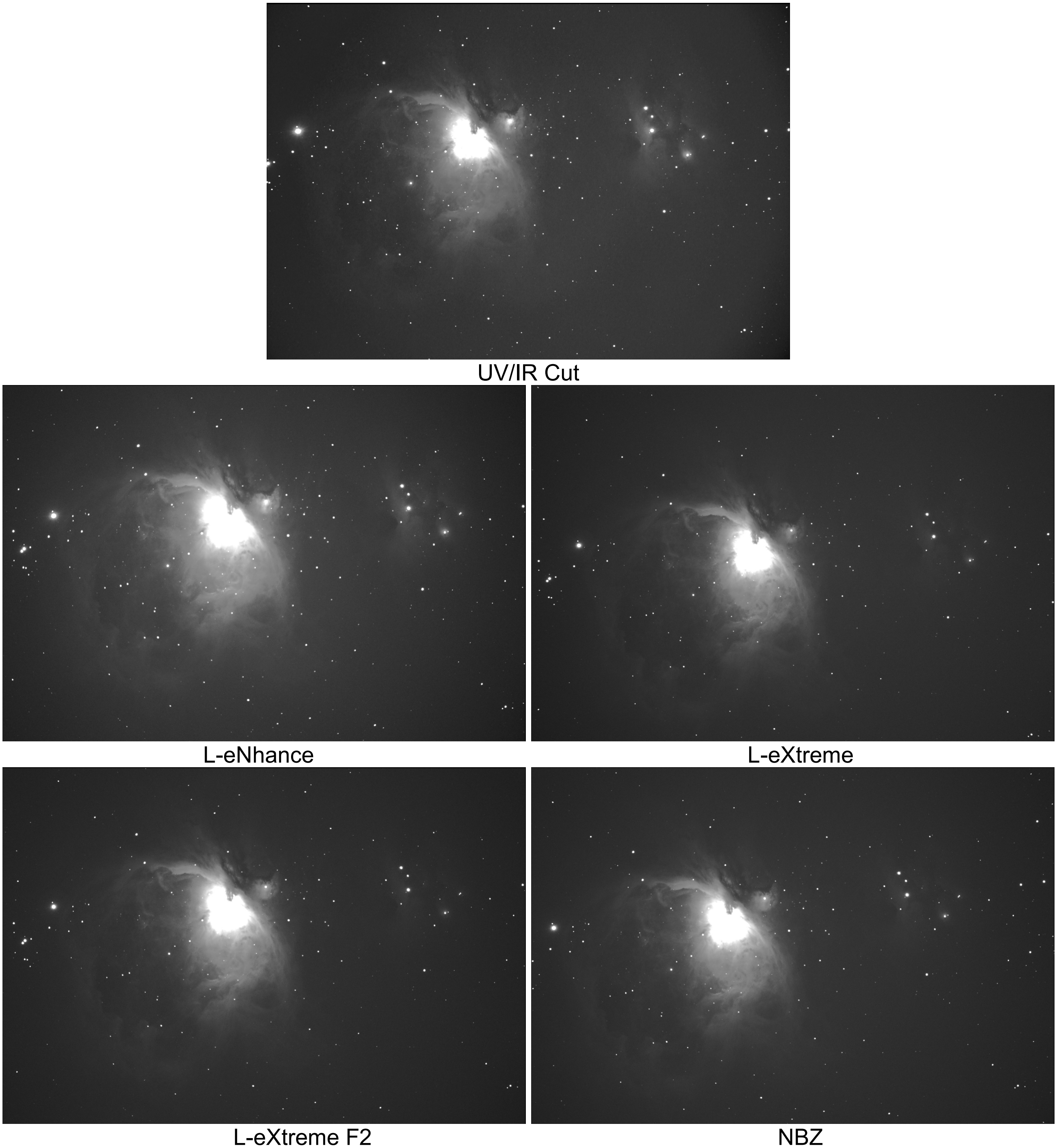


Figure 11 Image Comparison: M42, f/2, Blue Channel

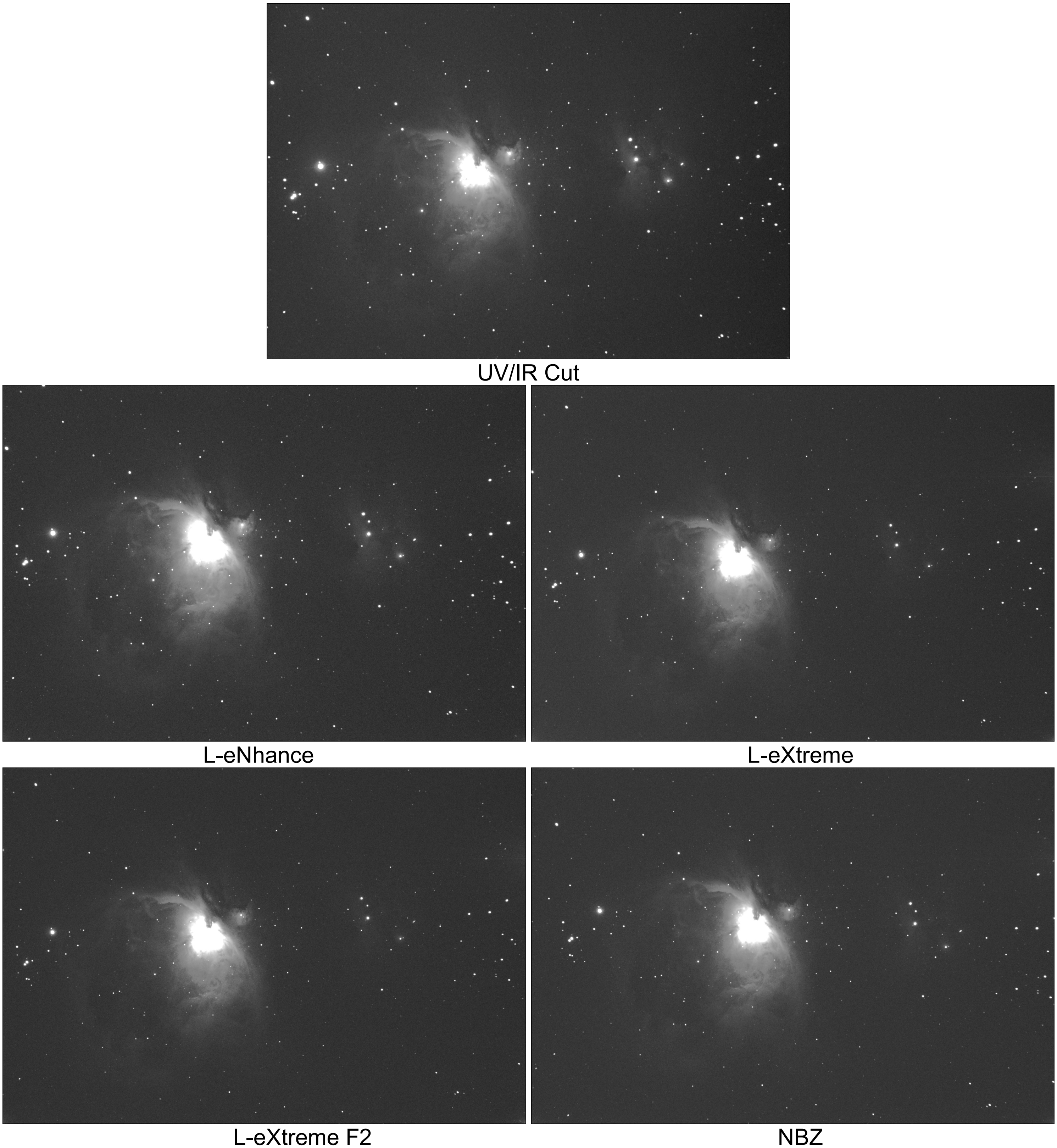


Figure 12 Image Comparison: M42, f/6.3, Blue Channel

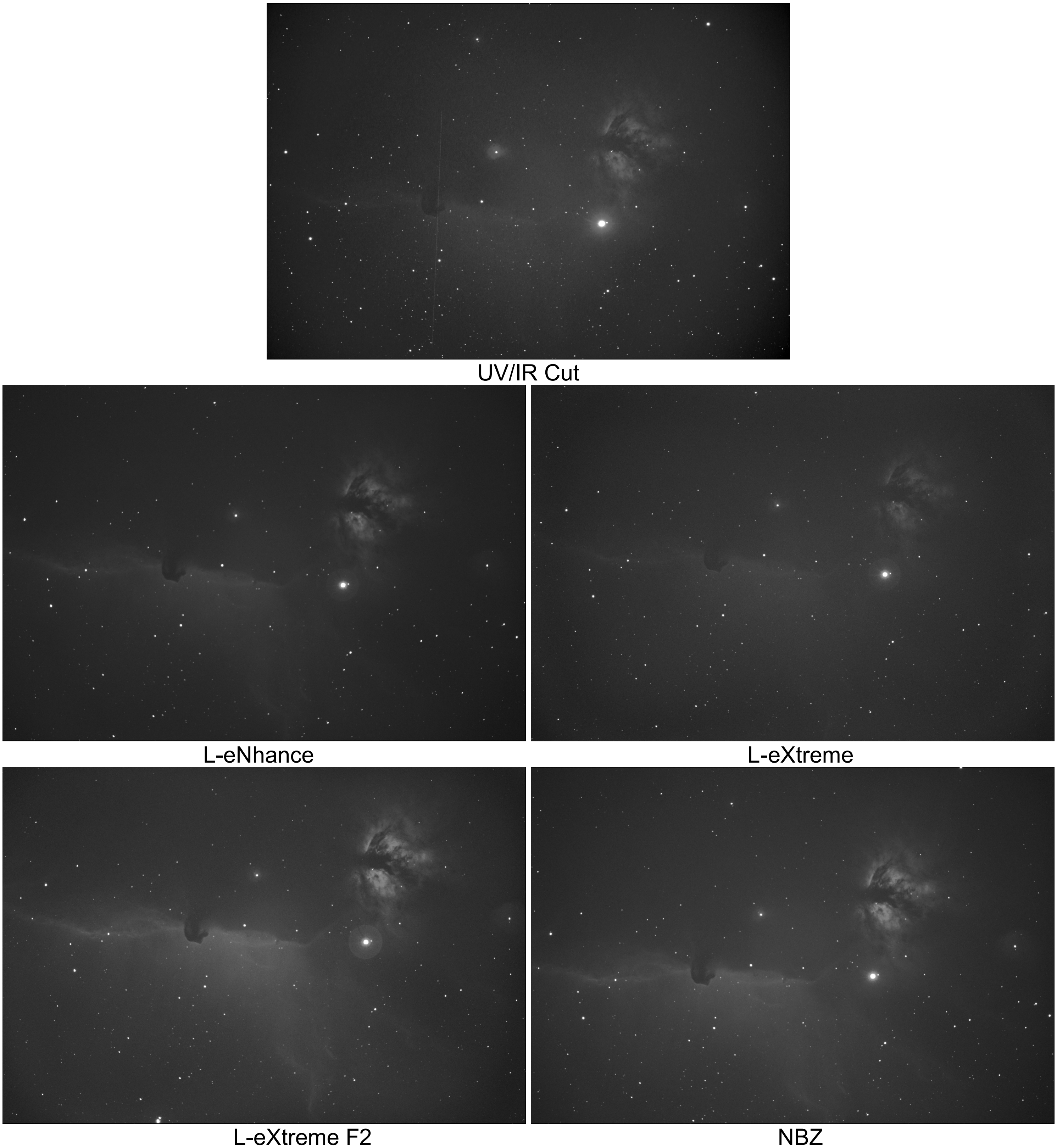


Figure 13 Image Comparison: Flame, f/2, Red Channel

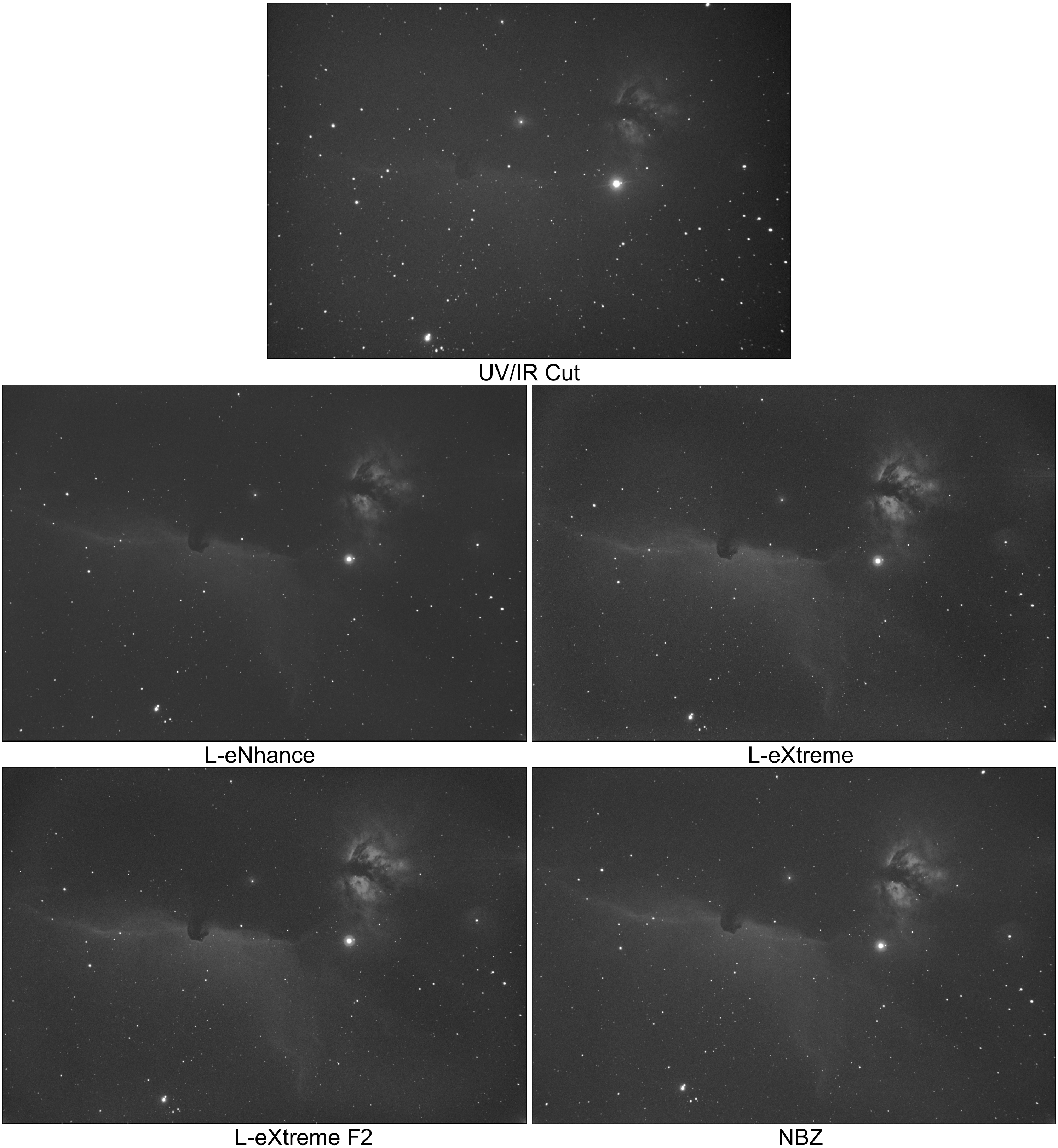


Figure 14 Image Comparison: Flame, f/6.3, Red Channel

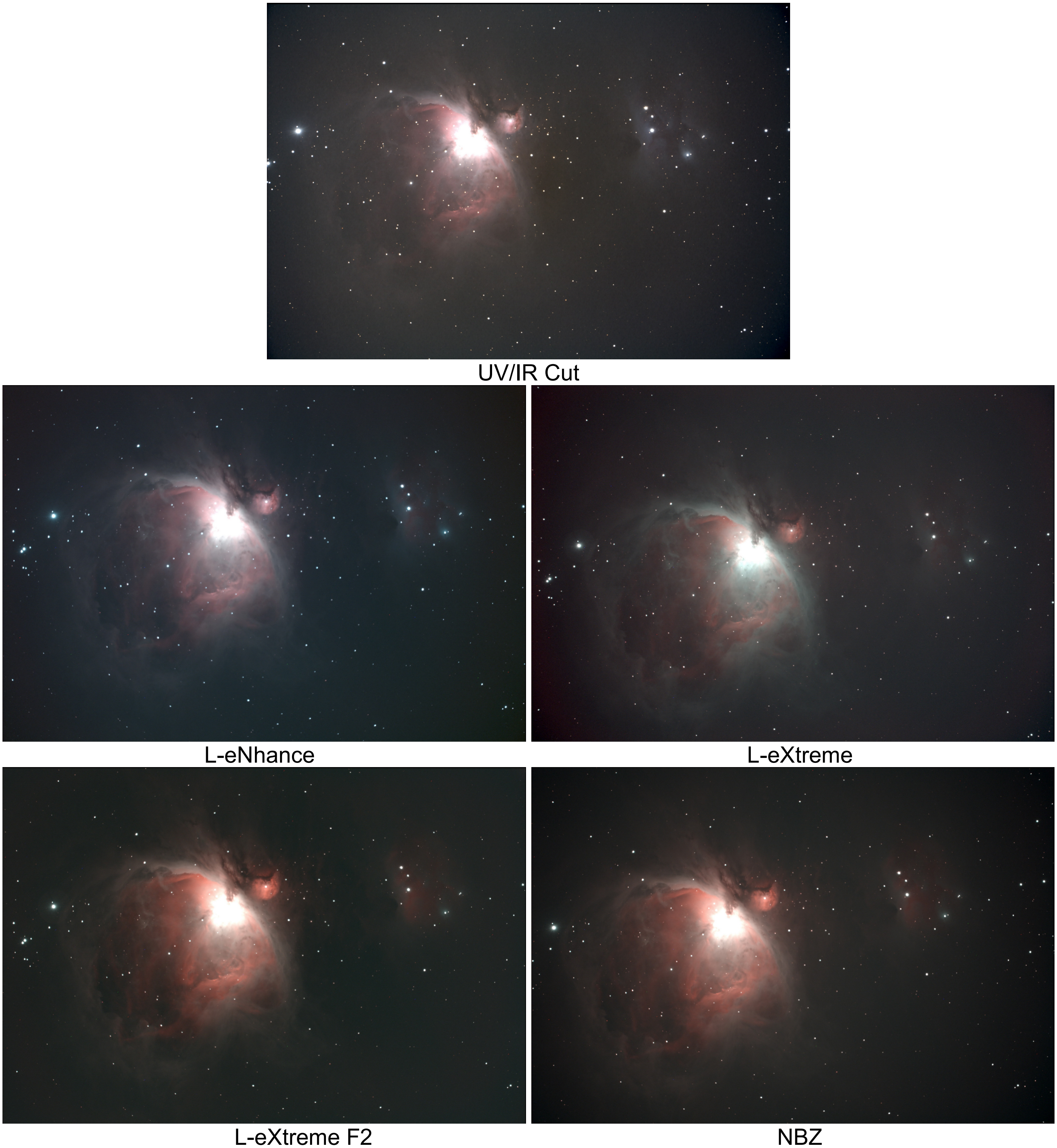


Figure 15 Image Comparison: M42, f/2, Full Colour

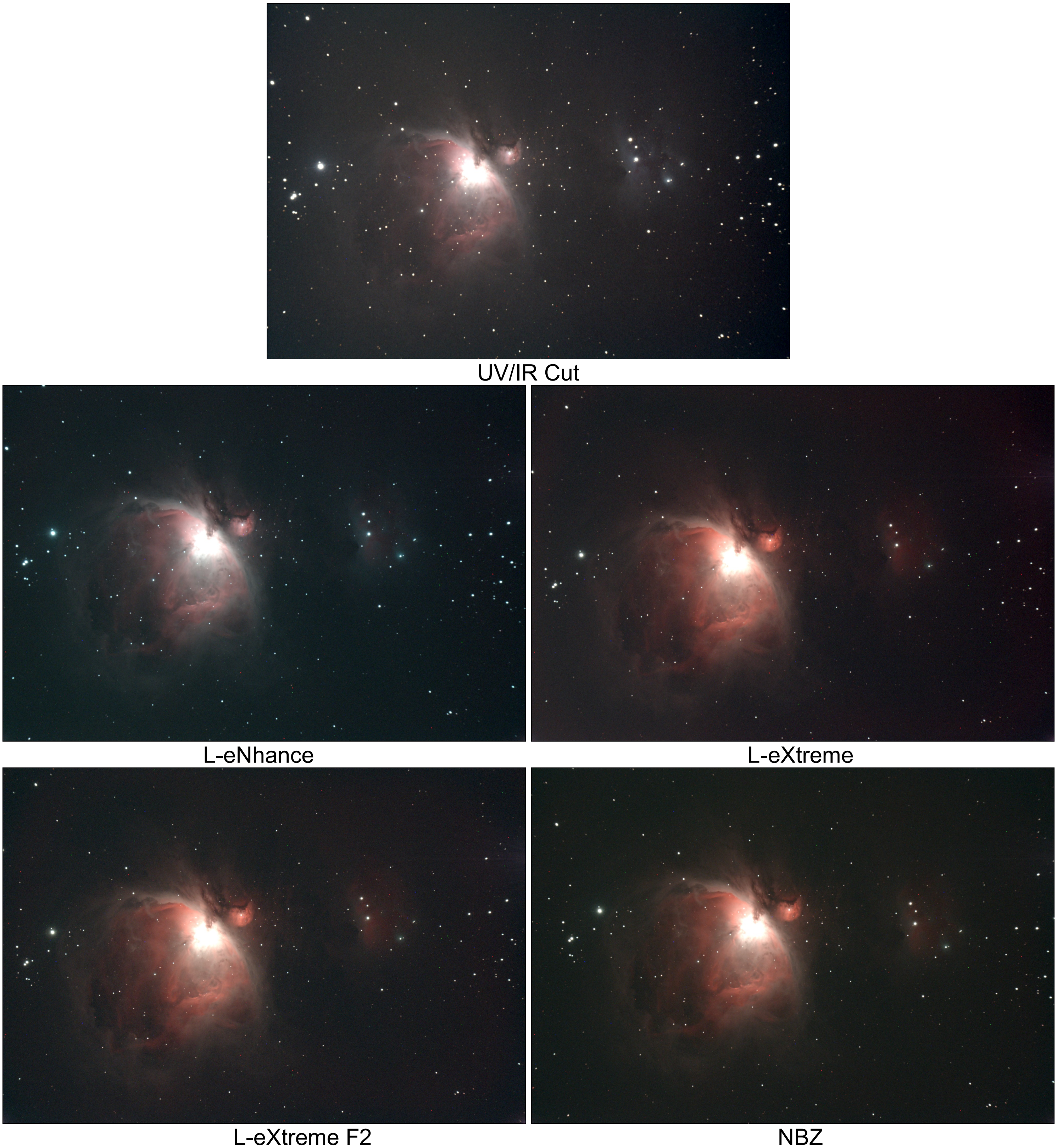


Figure 16 Image Comparison: M42, f/6.3, Full Colour

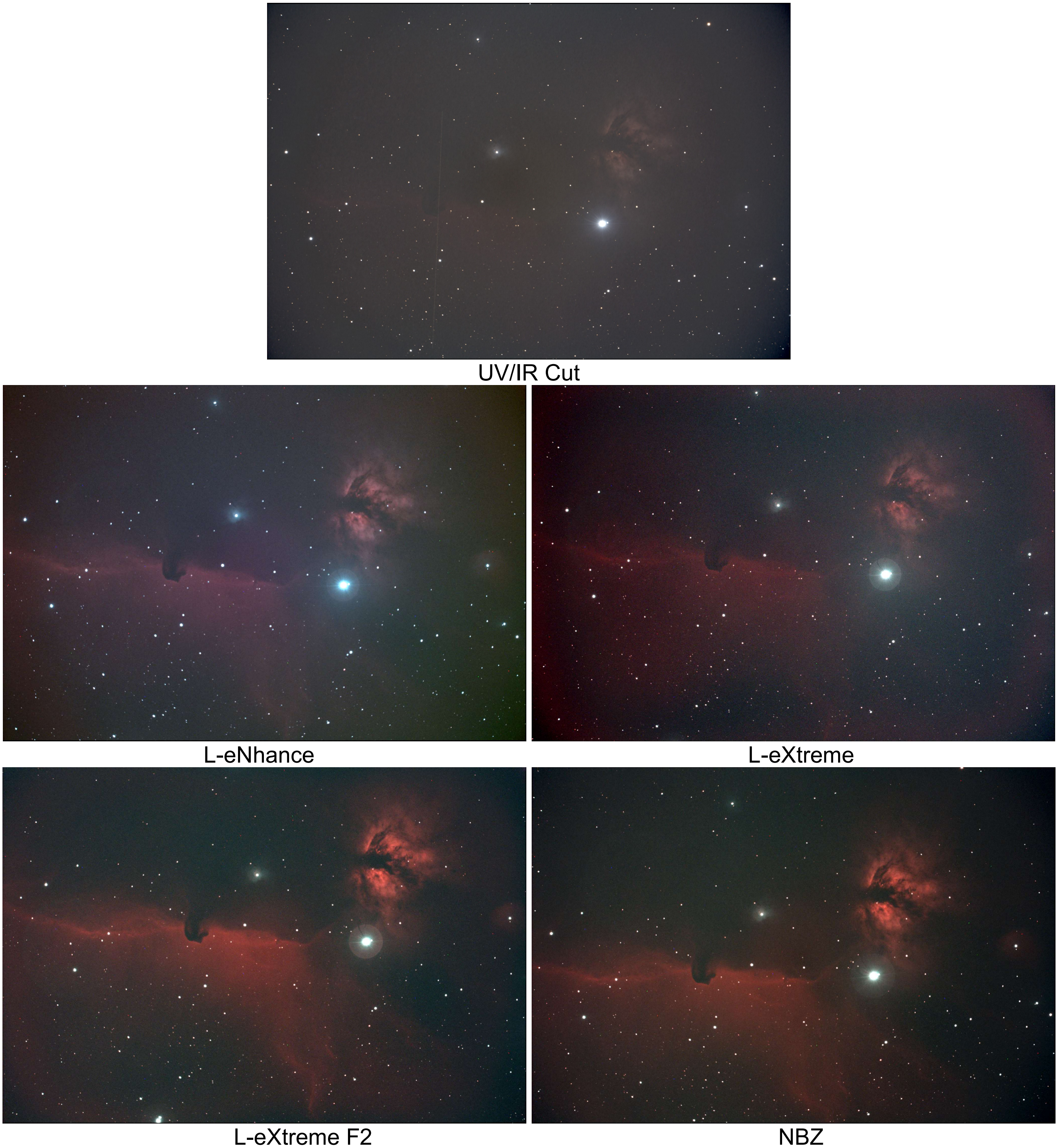
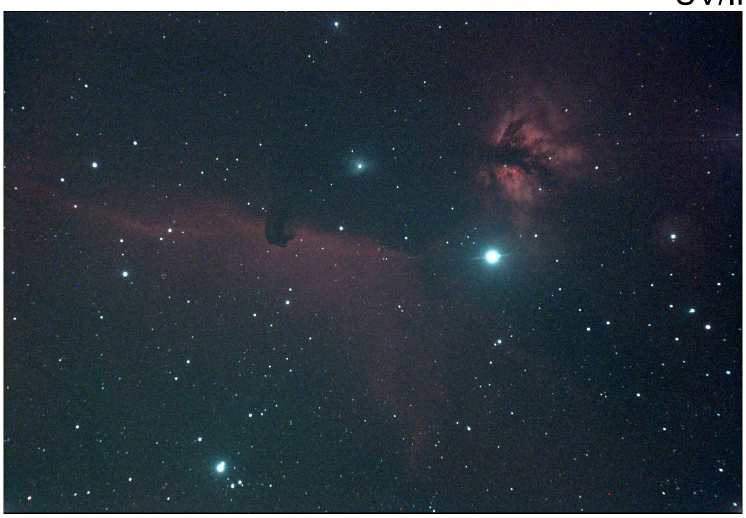
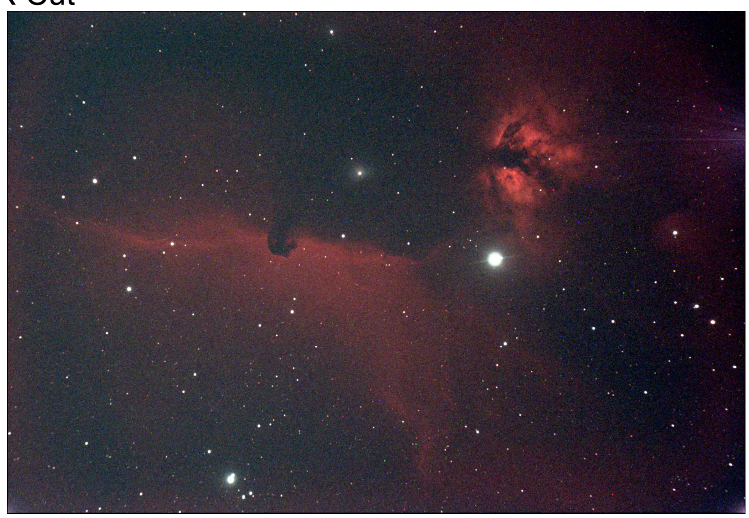


Figure 17 Image Comparison: Flame, f/2, Full Colour

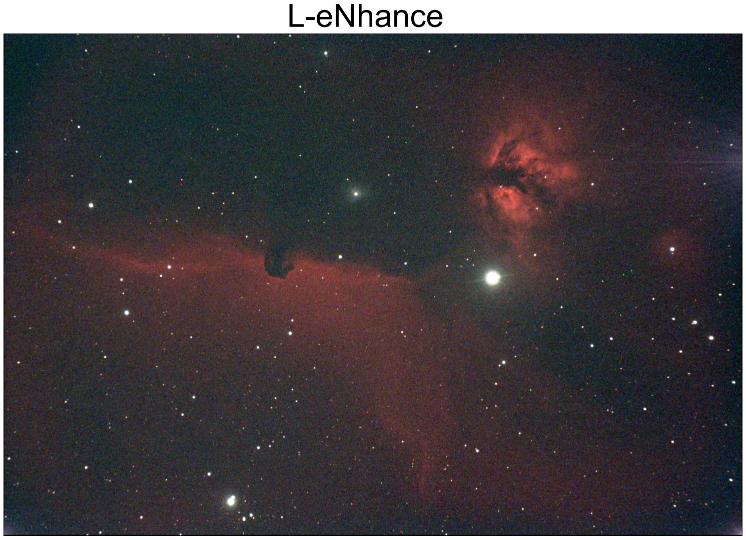
UV/IR Cut



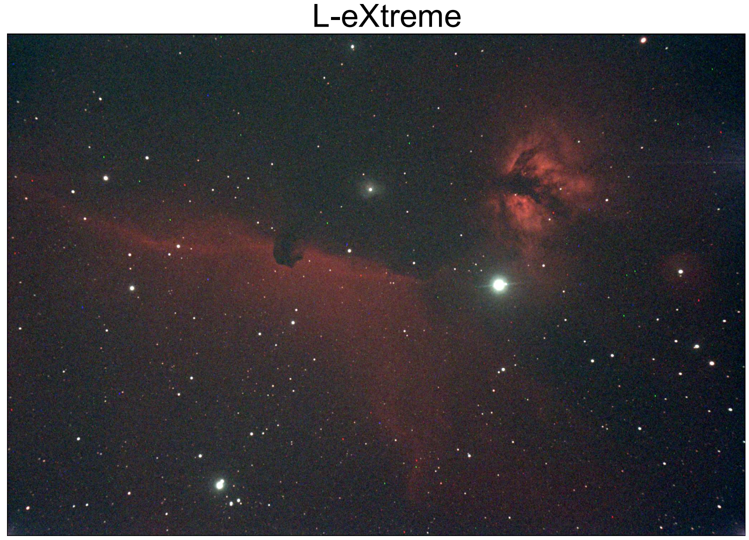
L-eNhance



L-eXtreme



L-eXtreme F2



NBZ

Figure 18 Image Comparison: Flame, f/6.3, Full Colour

There were a few other interesting observations I made from the collected images:

- All three Optolong filters showed a strong halo around bright stars when used with the Hyperstar system. This artefact was most prevalent in the images of the Flame Nebula which has the bright star Altnitak in the field of view. There is a halo in the images taken with the NBZ filter, but the visibility of the halo is much reduced – an advertised design feature of this IDAS filter. It is unclear from the images what the halo is due to: either a reflection from filter to the Hyperstar lens, or from filter to camera sensor window. It may be that my choice for the position of the filters relative to the camera has played a role. When testing on the Hyperstar system the filters were located as close to the camera as physically possible, about 5mm from the camera front face. When testing on the refractor the filters were significantly further from the camera, on the end of a 2” nosepiece. This may explain why there is little or no halos in the refractor images. Nonetheless, Optolong may want to research non-reflective coatings to reduce the appearance of halos around bright stars.
- All three Optolong filters showed an unsual non-uniformity around the outer edge of the image that was only visible after the image histogram was stretched. This non-uniformity was more prevalent when using the f/2 scope. I did not take the time to experiment with taking flat frames to see if the non-unformity could be calibrated away. Images taken with the NBZ filter showed no such non-uniformity. After some further investigation, I discovered that the non-uniformity I observed is a well known image calibration issue related to the IMX294 sensor in my camera. This problem is worse under light polluted skies, and is apparently more visible the narrower the band pass of filter being used. That is why it is more prevalent in the L-eXtreme images, and less so in the NBZ images.
- I had not expected it at the outset of the testing, but it makes sense to me now, that the L-eNhance provided clearly the best performance on reflection nebulae. The appearance of the reflection part of the Running Man nebula is most prevalent using this filter. Reflection nebulae are almost completely blocked from view when using the L-eXtreme or NBZ filters.
- I found the images collected using the IDAS NBZ filter to not be significantly different in terms of contrast from those captured using either of the L-eXtreme filters. This is despite the fact that the NBZ has wider pass bands than the L-eXtreme filters, 12nm versus 7nm respectively. The explanation for the high level of performance of the NBZ is the very high in-band transmissivity values the filter delivers; well over 95% (area average) for f-ratios down to f/2. There is thus another opportunity then to improve the performance of the L-eXtreme and L-eXtreme F2 filters: by pushing their in-band transmission rates up closer to 95%.

Conclusions:
Based on the results of the testing described above, I have made the following conclusions:

1. The L-eXtreme F2 performs as designed, delivering the same level of contrast improvement on emission nebulae as the original L-eXtreme but on optics operating at f/2.
2. The L-eNhance filter performed the best out of all the filters tested when looking at reflection nebulae.
3. There is an opportunity to improve the performance of Optolong filters through the addition of anti-reflective coatings to reduce halos around stars.
4. There is an opportunity to improve the performance of the L-eXtreme and L-eXtreme F2 filters by pushing their in-band transmission rates up closer to 95%.

Acknowledgements:
This test report would not be possible without the generous help I received from local astronomy club member André Paquette, who graciously loaned me his C14 with Hyperstar for use during this test.

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

Cheers!

Jim Thompson
top-jimmy@rogers.com