Multi-Narrowband Astronomical Filter Testing

By Jim Thompson

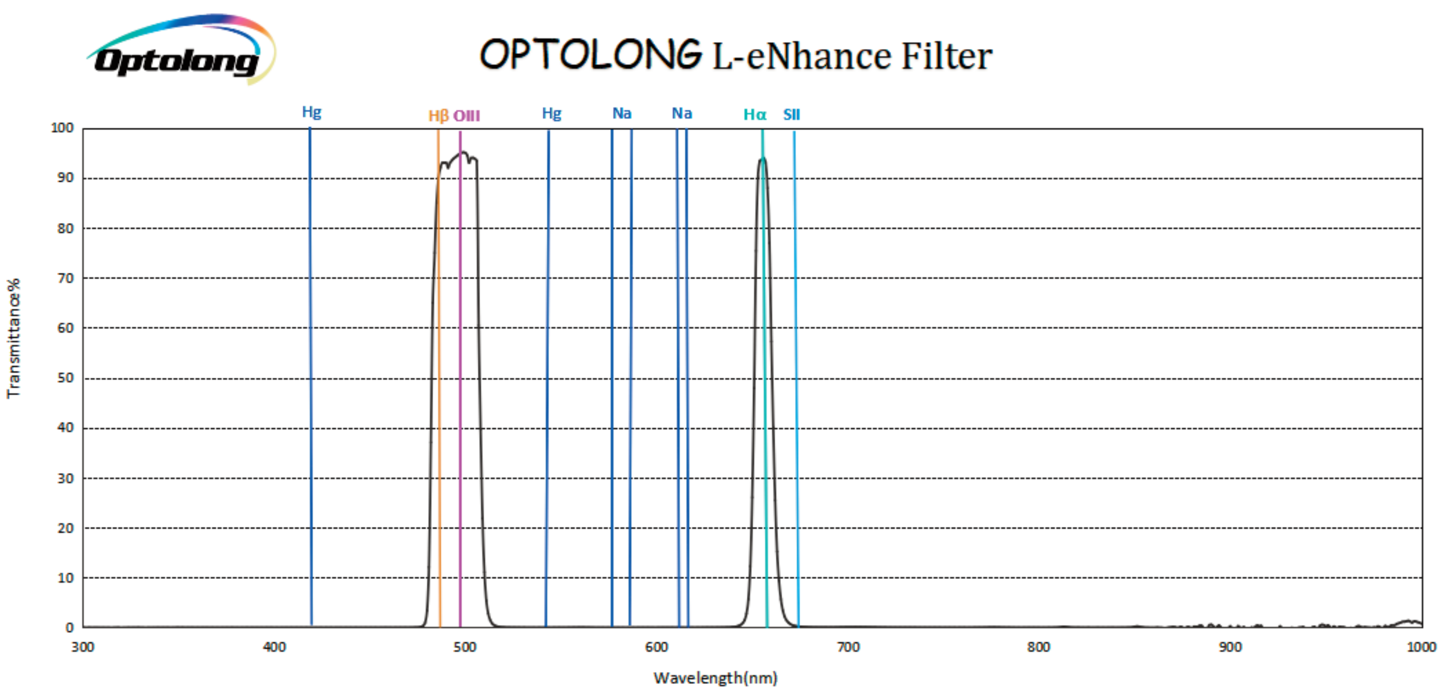

Figure 1

This article is a condensed version of a test report published in February 2020. A copy of the original report is available from the author upon request at top-jimmy@rogers.com.

Introduction:

Of all the things that can impact our personal enjoyment of astronomy, besides the weather, light pollution is perhaps the most prevalent. Every year the night-time background light levels around populated areas continue to grow.

However, light pollution (LP) filters are working hard to claw back some of what we have lost. Commercially available for decades, the performance of these filters continues to improve, and their costs have come down considerably in recent years.

I have invested significant time and money into evaluating LP filters, through both testing and analysis. From all my research of LP filters it has become clear that the narrower the pass band of a filter, the better it is for light pollution rejection. This reality has culminated in the creation of what is perhaps the penultimate LP filter: the multi-narrowband filter. More commonly referred to as duo-band, tri-band, or quad-band,

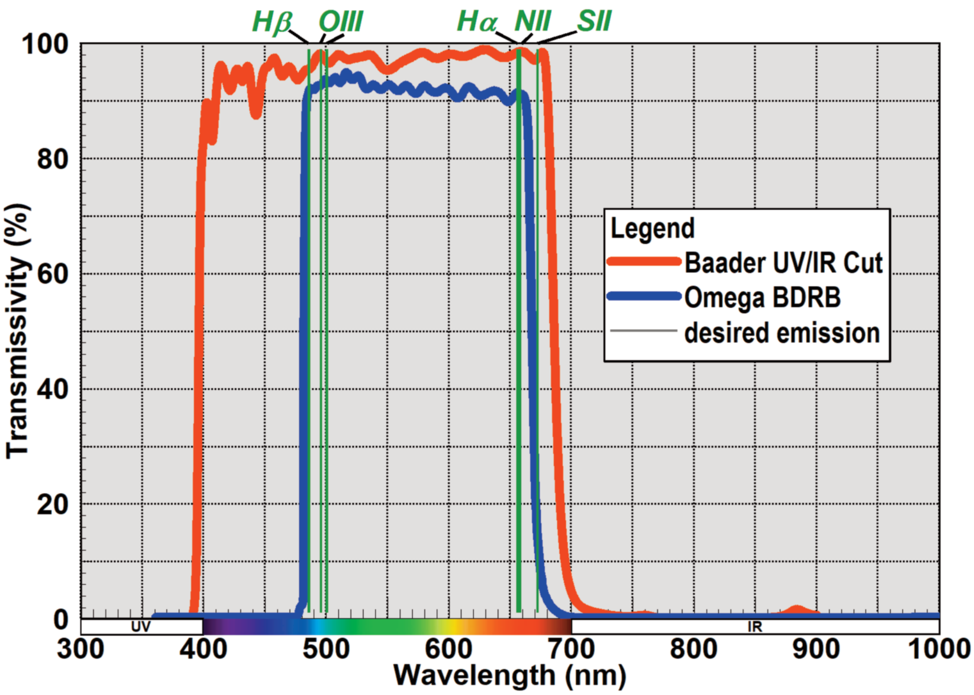

Figure 2

these filters are designed to very precisely pass some combination of the main wavelengths of light associated with emission nebulae (Hβ, O-III, Hα, N-II, and S-II) while blocking everything else. **Figure 1** shows the spectral response of an example of this relatively new filter type.

Background:

I have a keen interest in multi-narrowband filters because I believe I may have played a role in their development. My involvement with multi-narrowband filters starts back in March 2011 when I placed an order for a custom-built UV/IR blocking filter from Omega Optical, a filter manufacturer located in Vermont, USA.

The filter I had them build for me was narrower than a normal UV/IR cut, with cut-off wavelengths carefully selected to block light below Hβ and above Hα. My plan was to stack this custom filter with a commercially available LP filter, in my case a Meade brand O-III filter, to achieve the end result of a dual narrowband filter.

After working through some trial and error with Omega, they delivered what I now call the Blue and Deep Red Blocker (BDRB) later that year. The spectral re-

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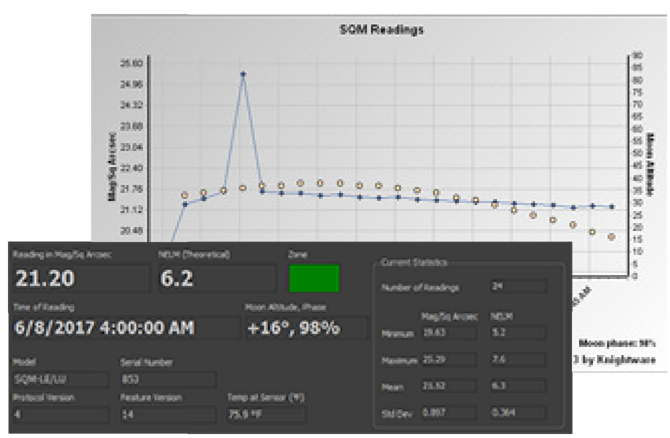
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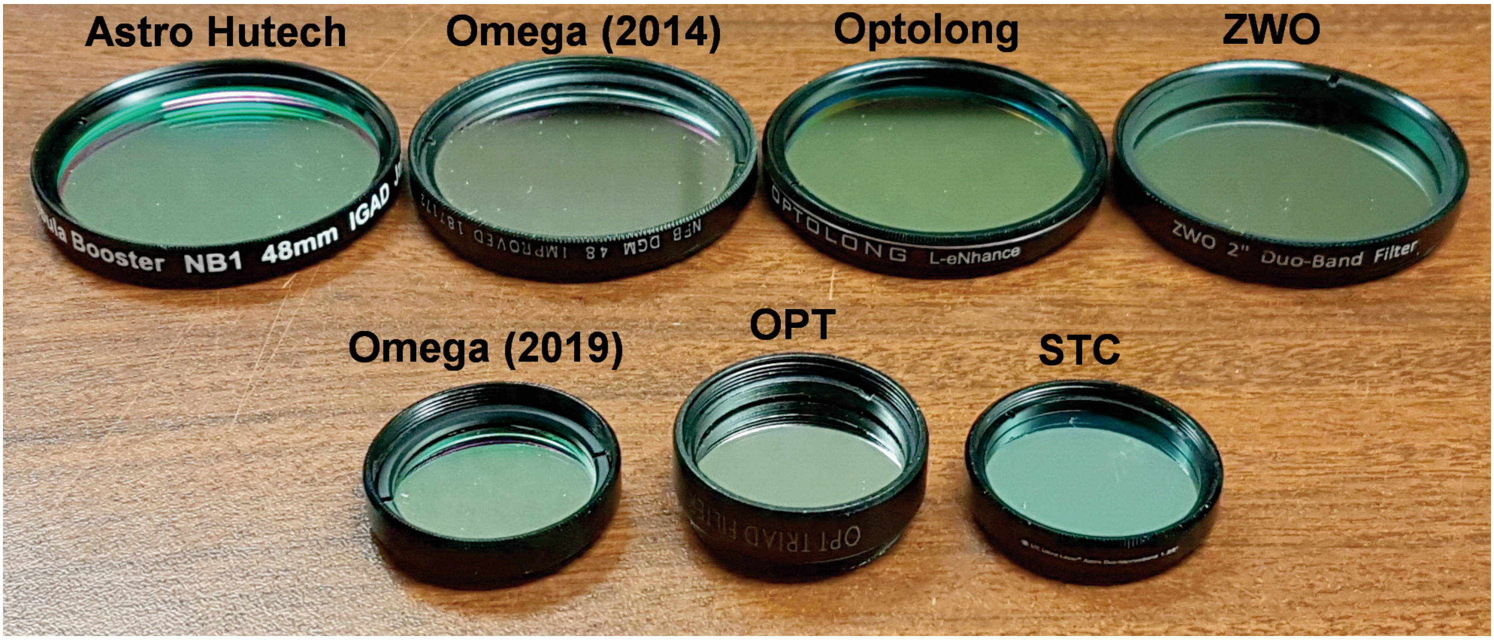

Figure 3

sponse of the BDRB is compared to a typical UV/IR cut filter in **Figure 2**.

I tested the BDRB filter extensively over the course of the next year, using a one-shot colour astrovideo camera (Mallincam Xtreme) for all of my observations. My test results confirmed what theory suggested: the narrower the band pass, the better the image contrast.

I was so excited by the positive results of my testing that I shared a summary report with Omega Optical in August 2012. This story might have ended there except that in November 2014, while casually browsing the Omega Optical store on eBay, I noticed that Omega had a new filter for sale: the Hydrogen & Oxygen Nebula LPF Improved NPB DGM.

This filter was the first multi-narrowband filter available commercially, and was essentially an improved version of what I presented to Omega back in 2012. I contacted Omega immediately after my discovery, and expressed my concerns over them having used my idea to generate a new product. As a show of good faith Omega sent me a free 2” sample of the new filter, which I proceeded to test and author a test report on. A copy of the test report is available upon request.

At this point the story goes fairly quiet. Omega sold small quantities of the Improved NPB DGM filter over the following years, sufficient numbers though to keep the item in their online inventory. It wasn’t until September 2017 that the tale picks up again, this time with the announcement by Oceanside Photo & Telescope (OPT) of a new filter they had developed called the Radian Triad filter.

OPT focused on promoting the Triad as a high-performance filter that allowed for multi-narrowband imaging using a one-shot colour (OSC) camera. It took about a year, but eventually OPT’s idea for marketing this filter to OSC imagers paid off. There are now many users of multi-narrowband filters, and versions of the filter type are available from several different original equipment manufacturers (OEMs).

If you were to ask each of the different OEMs where the idea for their multi-narrowband filter came from, I am sure they’d say they came up with it themselves. Nonetheless I can’t help but think that it was my interaction with Omega Optical that started the ball rolling.

Objective:

There are now at least six different OEMs selling various versions of the multi-narrowband filter. The retail prices of these offerings vary widely, which made me pose the question: “Which of these filters provides the best value?”

That is the objective of the testing summarized in this article, to test samples of the available multi-narrowband filters and compare them to each other in terms of performance and cost. The filters under test are summarized in Table 1, along with their retail price. In addition to the seven filters listed in Table 1, I also tested two other multi-narrowband filter configurations to use as benchmarks:

- Astronomik UHC + Baader UV/IR cut
- Meade O-III + Omega BDRB

The UHC stacked with a UV/IR cut is a filter combination that many amateurs can easily achieve using their existing gear. The Meade O-III plus Omega BDRB is the original filter combination that started it all (maybe).

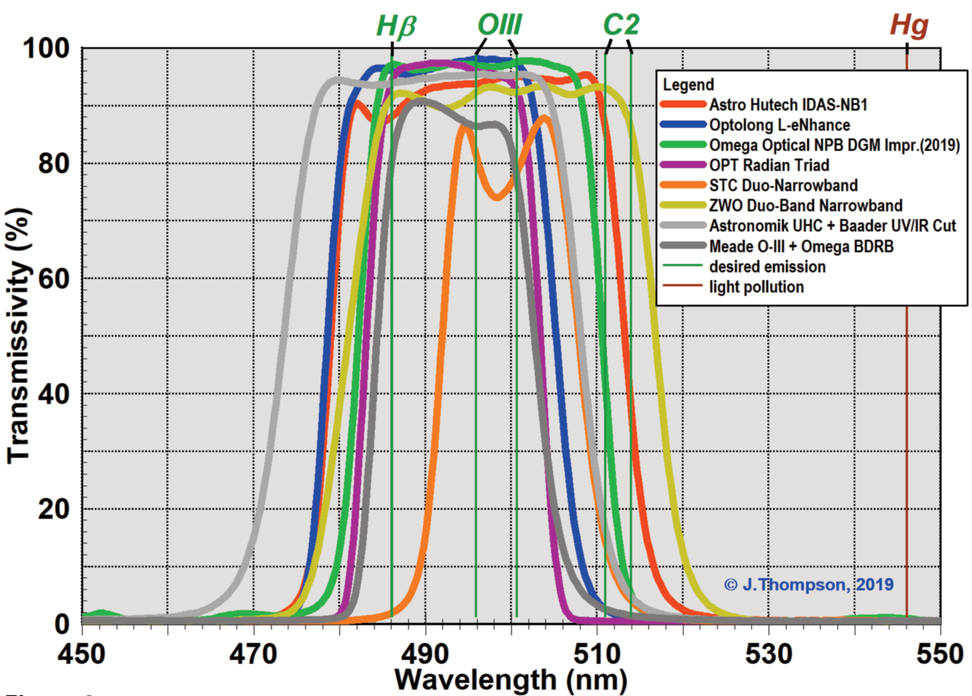

Figure 4

Method

The testing began with a thorough visual inspection, followed by data collection in the following forms:

- Spectral transmissivity data, from near-UV to near-IR, measured using an Ocean Optics USB4000 spectrometer; and
- Image data, collected using a William Optics FLT98 triplet apochromatic refractor, and one of two cameras: ZWO ASI-294MC Pro (OSC), or Mallincam Skyraider DS432M-TEC (monochrome).

The spectrometer data was collected in my basement workshop with the USB4000 and a broad-spectrum light source. The image data was collected from my backyard in central Ottawa where the naked eye limiting magnitude (NELM) due to light pollution is +2.9 on average, which translates to Bortle 9+. Images with each camera were collected on different evenings in early October. The ZWO brand filter was released after these images were collected, so images with that filter were collected in late February 2020 of a different target.

Results - Visual Inspection:

Figure 3 presents the appearance of the seven sample filters relative to each other. Additional photographs are avail-

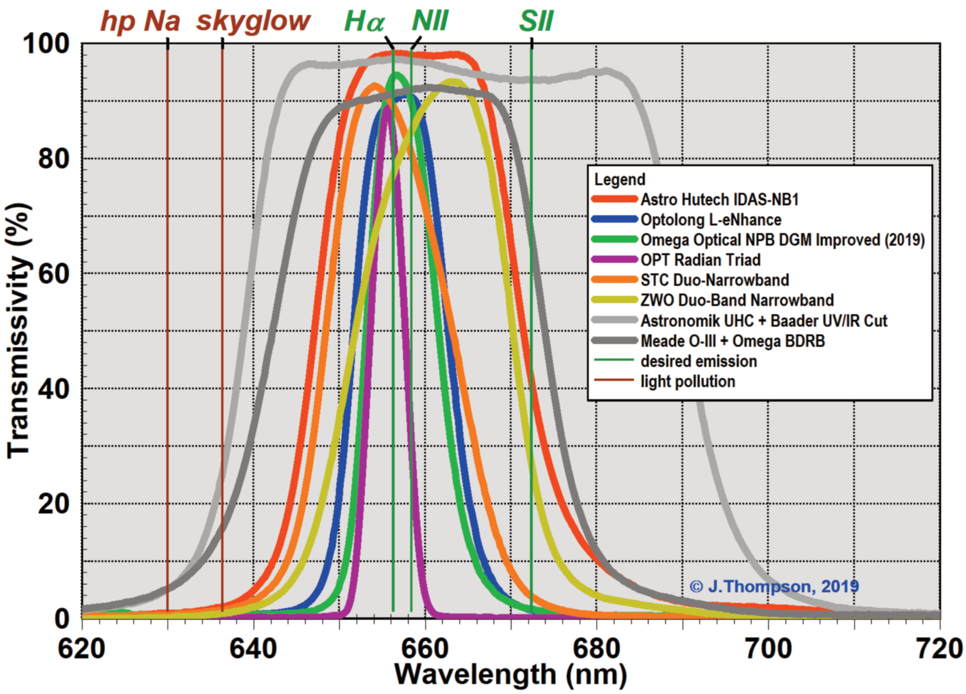

Figure 5

able in the original test report. The first thing I noticed was that the extent of the packaging varies considerably between the different filters.

Both of my samples from Omega arrived in a fabric envelope that was taped to my receipt, shipped inside a simple padded mailer. In contrast the OPT and STC filters came inside plastic cases that were in turn packaged inside decorative boxes, packed inside protective outer boxes for shipping. The other samples were in between, with the filter contained in a plastic case shipped in a small cardboard box.

The next thing I noted was the differences in the filter cell designs. Both Optolong and STC use much lower profile cells, reportedly to save weight and reduce vignetting, but more likely to reduce manufacturing costs. While switching between filters during my testing I found the shorter cells harder to handle, with the STC filter being the hardest to handle (I dropped it on the ground once when swapping it with another filter).

Another thing I noted was that the thickness of the retaining ring varied between the different filter brands, to the point where in the case of the Optolong and ZWO brand filters, the retaining ring thickness results in no female threads showing. This is a bit of a nuisance since it means you can't screw anything on the scope side of the filter.

Based on visual inspection it appears that all of the filters use physical vapour deposition (PVD) coatings. This is good as it means that all of the filters should be reasonably durable and easy to maintain.

I disassembled all the sample filters to see if the glass media had darkened edges, a feature that helps to reduce scattering of light within the glass media, improving contrast. I found the following filters had darkened edges: ZWO, Optolong, OPT, and STC; and the following did not:

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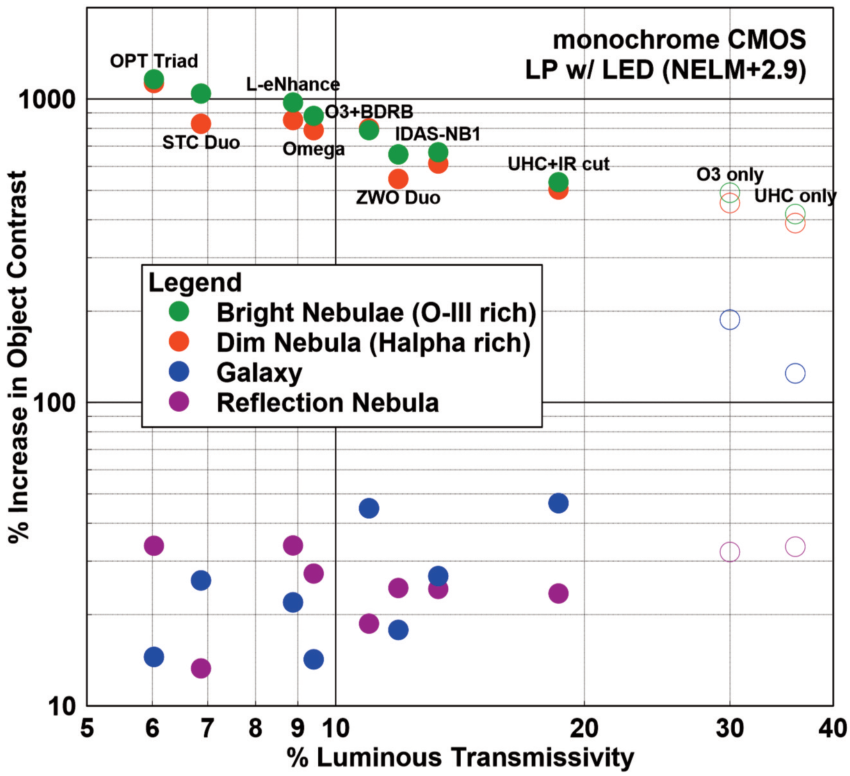

Figure 6

Omega, and Astro Hutech.

Regarding general quality however I was surprised to find that the OPT filter arrived with dirt on the glass, and with the glass loose in its cell. I found out later, when I disassembled the filter, that part of the reason for the looseness was that the filter glass is cut about 1mm too small in diameter and so is able to move in the cell unless it is pressed down tightly by the retaining ring. All the other filter samples, even the frugally packaged Omega ones, arrived clean and tight in their cells.

In addition to the observations noted above, the STC brand filter presented some additional curious features. The silk-screened labelling on the side of the filter cell is so small (<1mm tall) I found it impossible to read without a magnifying glass! I also discovered when I disassembled the filter that they used extremely thin glass, on the order of 0.5mm thick. Knowing this fact I am worried this filter will be very easy to break … I was evidently very lucky the filter fell onto the grass when I dropped it. All the other filters use glass thicknesses that are more typical, between 1 and 3mm.

Figure 7

Results – Spectrometer Measurements:

For me, one of the big questions to be answered by this test was: "Does the filter deliver what the manufacturer says it does?" In my many investigations of astronomical filters I have found numerous occurrences of marketing material not being entirely accurate.

The individual spectral transmissivity measurement plots for each filter can be found in the original test report. Based on my spectrometer measurements, it would appear that all of the filter performances are well characterised by their corresponding marketing material, with the exception of the OPT and STC filters.

The spectral response plot provided by OPT for the Triad filter shows in-band responses that are essentially at 100%, but that is very clearly not the case as I measure peak responses well below 90%. Similarly the STC Duo-Narrowband filter marketing material shows a single peak at >90% transmissivity centered on the O-III pass band, but in reality the filter has a double peak in that pass band, with a transmissivity closer to 80%.

The other big question that can be answered by the spectrometer measurements is: "How do the performances of the filters compare with each other?" **Figures 4 and 5** present a comparison of spectral transmissivity between all the filters measured, for the bands around O-III and Hα respectively. The principle performance characteristics for each filter have been calculated from the measured data and are summarized in Table 2.

Of the multi-narrowband filters tested, the Astro Hutech and ZWO versions have wider pass bands than the other filters so they are not expected to provide as good an increase in contrast as the others. I should note that Astro Hutech also has an NB2 and NB3 model filter with narrower pass bands that are expected to provide higher contrast levels similar to the other filters in this test.

The OPT Triad, having the narrowest pass bands, is expected to deliver the best

Figure 8

increase in contrast, however the narrowness and band position around Hα suggests that this filter is also more sensitive to focal ratio than the others. This is something that I will discuss in more detail later in this article. The Omega and Optolong filters, although not as narrow as the OPT Triad, are expected to be very good performers as well. The STC filter is hard to judge by looking at the spectral response plots, but I suspect it will provide performance similar to the Omega and Optolong brand filters.

Knowing the measured spectral response of the sample filters also allowed me to predict the 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. If interested in learning more about this method, please contact the author.

To help visualize the results of this analysis I plotted the predicted % increase in contrast for each filter versus the filter's % Luminous Transmissivity (%LT). %LT is a measure of how much light gets through the filter in the wave band being observed, which varies depending on whether the observer is a human or a camera. **Figure 6** shows a sample of the resulting plot, specifically the plot corresponding to filter performance when using a monochrome CMOS camera under heavily light polluted skies complete with local LED streetlights. Plots for the other cases, CMOS under a dark sky and the comparable two plots for a human observer, can be found in the full test report.

For emission type nebulae, there is an obvious trend to the data: as the pass band gets narrower (i.e. %LT is lower), the contrast increase gets larger. For broadband targets like galaxies and reflection nebulae there does not seem to be any sort of trend with %LT; if anything the contrast increase goes down with decreasing %LT. The average expected increase in contrast is also significantly less for broadband targets than for emission nebulae. For comparison I have included in the plot the case of the Astronomik

Figure 9

UHC and Meade O-III filters without an IR blocking filter added since previous studies have shown these filters to be good performers on galaxies when observed with a camera.

In terms of how each multi-narrowband filter is predicted to perform relative to the others, the results are consistent with what was surmised from looking at the measured spectral response data alone. The OPT Triad filter is predicted to provide the best increase in contrast compared with no filter. The ZWO and IDAS NB1 are predicted to improve contrast the least, and the other three are predicted to have similar reasonably good performance. Another interesting observation from the predicted performance plots is that when used visually on faint nebulae, i.e. those that emit mostly Hα and Hβ only, the STC Duo-Narrowband filter performs much more poorly than the other multi-narrowband offerings. This is because the STC filter passes virtually no Hβ, but the other brands do.

Results – Imaging:

Figure 7 and 8 are examples of the monochrome and colour images respectively that were collected using the different multi-narrowband filters. The rest of the collected images can be found in the original test report. The target used for all the images was the Eastern Veil nebula (NGC6992) as it has prominent emissions from both O-III and Hα, and it was well placed overhead at the time the images were captured.

Looking first at the monochrome images, my initial impression was that all the filters tested provided a similar large increase in contrast versus no filter. Looking more closely at each image there are subtle differences in the extent of faint nebulosity that is visible. These subtle differences are consistent with the measured spectral response data. For example, the clearest presentation of faint nebulosity is provided when using the OPT Triad filter, followed closely behind by the Optolong, Omega, and STC brand filters. The IDAS filter showed a good increase in contrast, but not quite as good as the other filters. Based on the other observations made during my testing, I would expect an image captured of this target using the

ZWO filter to be very similar to that captured with the IDAS filter.

Next let's consider the colour images. When capturing these images, the camera white balance (WB) settings were left at default so that the full effect of the filter on WB can be seen clearly. The most obvious observation is that all of the multi-narrowband filters impart a strong green cast to the image. This is to be expected on a OSC camera since the typical Bayer matrix on the sensor has two green pixels for every red or blue pixel, and most of the light passed by the filter is centered around the green part of the spectrum. Further investigation of the WB issue is provided by examining each image's histogram, which can be found in the full test report. There are a couple of implications resulting from the WB disparity:

1. The effective exposure on each colour channel is not the same. Table 3 summarizes the effective exposure of the RED and BLUE channels relative to GREEN for each filter, as measured from the histogram data.
2. Achieving the desired WB on the deepsky object and the background sky/stars simultaneously is difficult. **Figure 9** shows the processed version of Figure 8, where a LEVELS tool has been used to individually adjust each colour channel's histogram so that their peaks and widths roughly align with each other.
3. The relative prominence of each emission type varies significantly as a result of the WB process. Some filters emphasize O-III more than Halpha, some emphasize Halpha more, and some provide more of a balance between the two.

The WB has a very large impact on the end result, and so requires a significant amount of attention from the user of multi-narrowband filters if they expect to get results they are satisfied with. For the astrophotographer who is using a normal image processing workflow, the WB is perhaps an issue they are already used to dealing with. For users who are applying the filter to a camera for "live" observing (Electronically Assisted Astronomy), it is more of a challenge to achieve the desired WB as the software tools available are not as elaborate as for image post processing.

My recommendation is that if your software of choice has the function, use the LEVELS tool on each channel individually so you can set the black point and white point on each colour channel separately. For the visual observer, the WB issue is not really an issue at all since humans can't see colour very well when their eyes are dark adapted. Stars will however have a very obvious blue-green colour when using a multi-narrowband filter visually.

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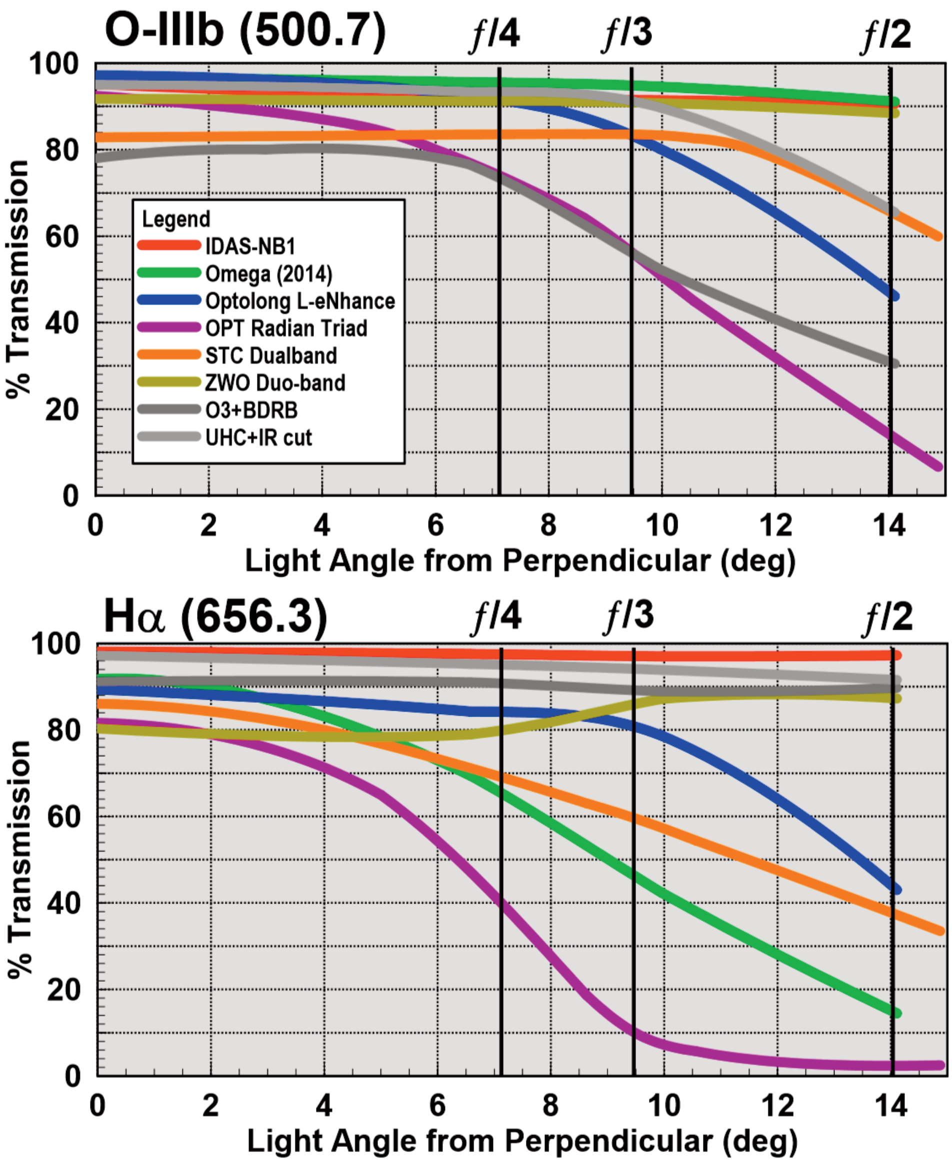

Figure 10

Results - Angle Sensitivity

The narrowness of a filter's pass bands will have an impact on how it performs on fast f-ratio telescopes. This is because the faster the f-ratio of your optics, the bigger the angle off of perpendicular the light passing through the filter will be. Making the light pass through the filter at an angle effectively increases the thickness of the many layers that make up the filter, thus changing its optical properties. Typically, as the angle increases, the pass bands shift to the left and peak transmissivity goes down.

To quantify this effect, I re-measured the spectrum of each filter using my spectrometer, but with one end of the filter propped up using a series of spacer blocks. The results of this measurement are presented in Figure 10, which shows how each filter's transmission of O-III and Hα varies with angle. Included in the plot are lines denoting the angle corresponding to optics with f-ratios of 4, 3, and 2.

The results presented in Figure 10 are rather interesting as they highlight the fact that there is more involved in picking the best filter than just which one has the narrowest pass bands. The optics with which the filter will be used plays a role in how effective the filters are. The two filters I identified earlier as producing the lowest increase in contrast, the IDAS NB-1 and ZWO Duo-Band, are also the two filters providing the least sensitivity to f-ratio. Conversely the filter identified as providing the largest improvement in contrast, the OPT Radian Triad, is also the one with the largest sensitivity to f-ratio. Based on my measurements, my recommendations are that the Optolong and STC filters are probably okay for use with f/3 or slower systems, the Omega filter down to f/4, and the OPT will work best on systems slower than f/5.

Conclusions:

This test report summarizes what is probably the most thorough testing and analysis I've ever done on any sort of filter. My extra effort stems from a heightened interest in the multi-narrowband class of filters, with which I share a personal history.

In addition to the observations noted in this article, I have come to the following conclusion: Based on quality and performance the Astro Hutech, Omega, Optolong, and ZWO brand filters provide the better value for money. The Omega brand filter is the cheapest available option, and it delivers very good performance. I would like to say it is my favourite of the filters tested, also because of the history we share, but to be honest I think the Optolong brand filter has a small edge over the Omega filter due to its better f-ratio sensitivity. ATT