Narrowband H-α Filter Comparison Test

by Jim Thompson, P.Eng
Test Report – August 10th, 2022

Introduction:

H-α filters have been used by astrophotographers for many years for the purpose of capturing high contrast images of emission nebulae. The filters are very effective at blocking everything except the light coming from the exited hydrogen gas of the nebula. With these filters being so popular it is no surprise that there is a wide variety of brands and models available to buy commercially. It is also no surprise that these filters vary widely in cost, from the $100 to $200 range all the way up to $1300. So, what exactly does a $1300 filter give you that a $200 filter can't? In theory the more expensive the filter, the narrower the width of the filter's pass band, and thus the larger the increase in contrast the filter can provide. The purpose of this test report is to determine whether or not this theory is born out in practice.

Objective:

The objective of this test report is to evaluate the performance of a selection of H-α filters, ranging in bandwidth from >100nm down to 3nm. Use of the term bandwidth in this report refers specifically to the filter's full width half maximum (FWHM), the wavelength range over which the filter's transmissivity is more than 50% of it's maximum. The list of filter configurations considered in this test report is as follows (costs are for 2" version):

- No Filter (for reference)
- Baader Planetarium UV/IR Cut (for reference)
- Optolong Night Sky H-alpha – hi-pass, $119USD
- Omega Optical XMV660/40 – FWHM 40nm, $180USD
- Omega Optical 650BP10 – FWHM 10nm, $220USD
- Optolong H-α 7nm – FWHM 7nm, $259USD
- IDAS H-α 6.8nm – FWHM 6.8nm, $379USD
- Optolong H-α 3nm – FWHM 3nm, $439USD (currently on sale $351USD)
- Chroma H-α 3nm – FWHM 3nm, $1300USD

I have acquired a sample of all the filters in this list. If theory is born out in the test results, there should be an observable improvement in deepsky object contrast as I move down the list of filters since they have progressively narrower pass bands. You will note that there is also an increase in filter cost as the pass bands get narrower. Whether or not the increase in performance is worth the increase in cost is yet to be determined. For example: is the performance of the Chroma 3nm three times better than the Optolong 3nm? … we shall see. 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 by direct measurement from images captured using each filter and a monochrome camera. The image data is also used to evaluate the signal-to-noise ratio (SNR) achieved using each filter.

Method:
Testing consisted of data collection from the following sources:

- Spectral transmissivity data, from near-UV to near-IR, measured using an Ocean Optics USB4000 spectrometer; and
- Image data, collected using various combinations of the following cameras and telescopes: a ZWO ASI183MM Pro or Mallincam DS432M-TEC monochrome camera, and a William Optics FLT98 triplet or Askar FMA230 quad apochromatic refractor.

The spectrometer data was collected in my basement workshop with the USB4000 and a broad spectrum light source. Filter spectrums were measured for a range of filter angles relative to the light path, from 0° (perpendicular) to 20° off-axis. The spectrometer was recently upgraded, replacing the entrance slit and diffraction grating, to give a wavelength resolution of 0.5nm.

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 switched filter configurations using a ZWO 2" filter drawer. Each time I changed filters I refocused on a conveniently located bright star using a Bahtinov mask. Images with the various filters under test were collected with the scopes at their native focal ratios: f/6.3 for the FLT98, and f/4.5 for the FMA230. Four duplicate sets of test images were captured of the same deepsky object, captured on four separate evenings in June 2022: the 12th, 16th, 24th, and 28th. The target object was the extensive emission nebula IC1318 in Cygnus, what I affectionately call the "Oriental Dragon" nebula. This object was selected because it was well placed high in the sky for the duration of the image captures, and presents a challenging object to observe from an urban location. The Moon had an impact on my first two imaging nights as they were two days on either side of the Full Moon. The later two imaging dates were near the new Moon and so were not impacted.

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. All the filters have their pass bands well positioned around 656nm, apart from two exceptions. It is evident from the measured spectra that the Omega 650BP10 filter is not optimized for Halpha as its center wavelength (CWL) is at 653nm and not 656nm. Similarly, my sample of the Optolong 7nm filter is also not properly centered on 656nm, being shifted significantly off-band to the right. My sample of the Optolong 7nm filter is several years old now, so it may not be completely representative of the product being produced today.

The impact of angle on each filter's transmission of H-α at 656.3nm is shown in Figure 2. As expected, filters with wide pass bands were less sensitive to angle than filters with narrow pass bands, with the most sensitive filters to angle being the two 3nm samples. The Omega 650BP10 has almost the same sensitivity to angle as the 3nm filters because of its CWL being shifted to the left of 656nm.

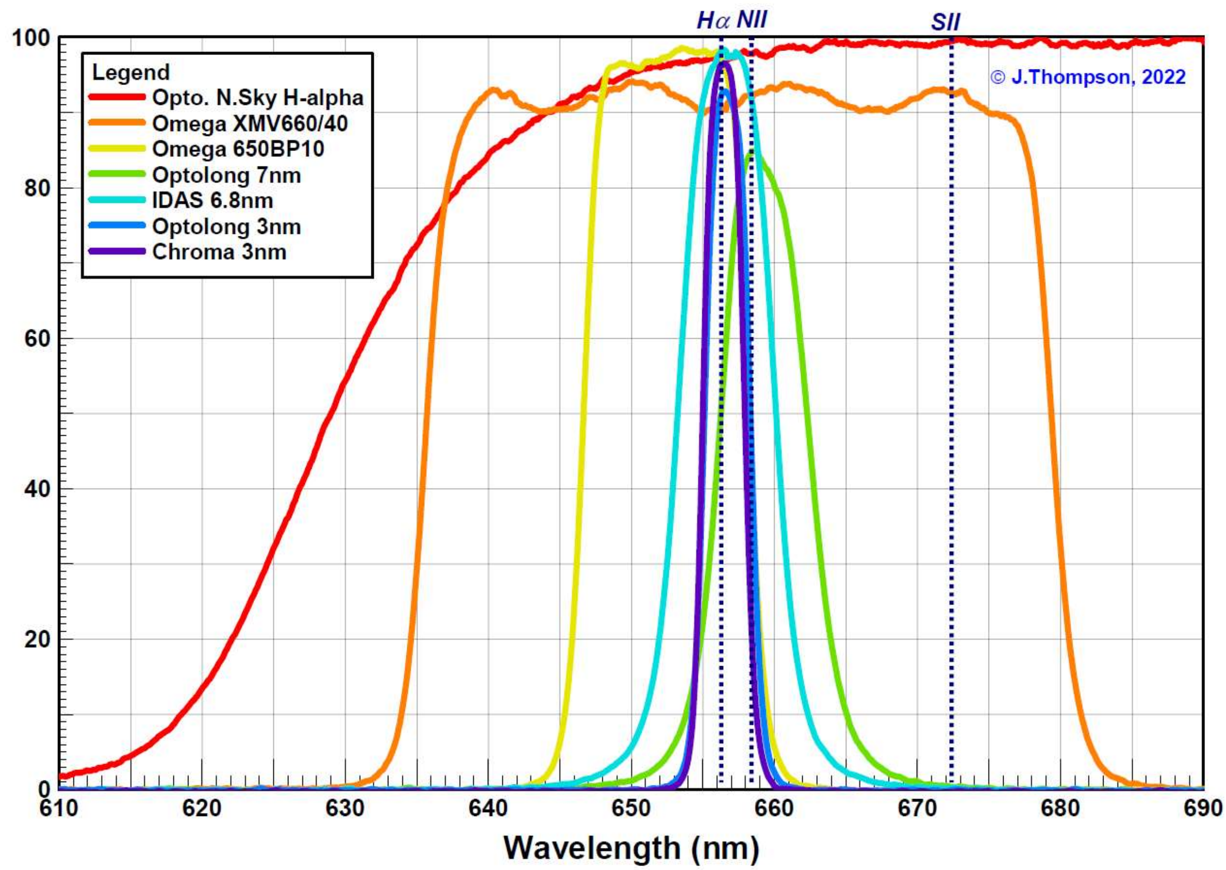


Figure 1 Measured Spectral Response of Tested Filters – Filter Perpendicular to Light Path

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 a selection of telescope f-ratios. The area averaging process is illustrated in Figure 3. Essentially the aperture of the scope is divided into rings defined by the angles at which I have measured filter data. The percentage each ring is of the total primary optical area is the weighting applied to that particular spectrum in the average. Figures 4 through 7 present the resulting net spectra for the different speeds of telescope. 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 very significant for the f/2 scope (Figure 7). The effects of filter band shift are worse on the Hyperstar scope due to the large central obstruction which results in a larger percentage of the light having to pass through the filter at an angle.

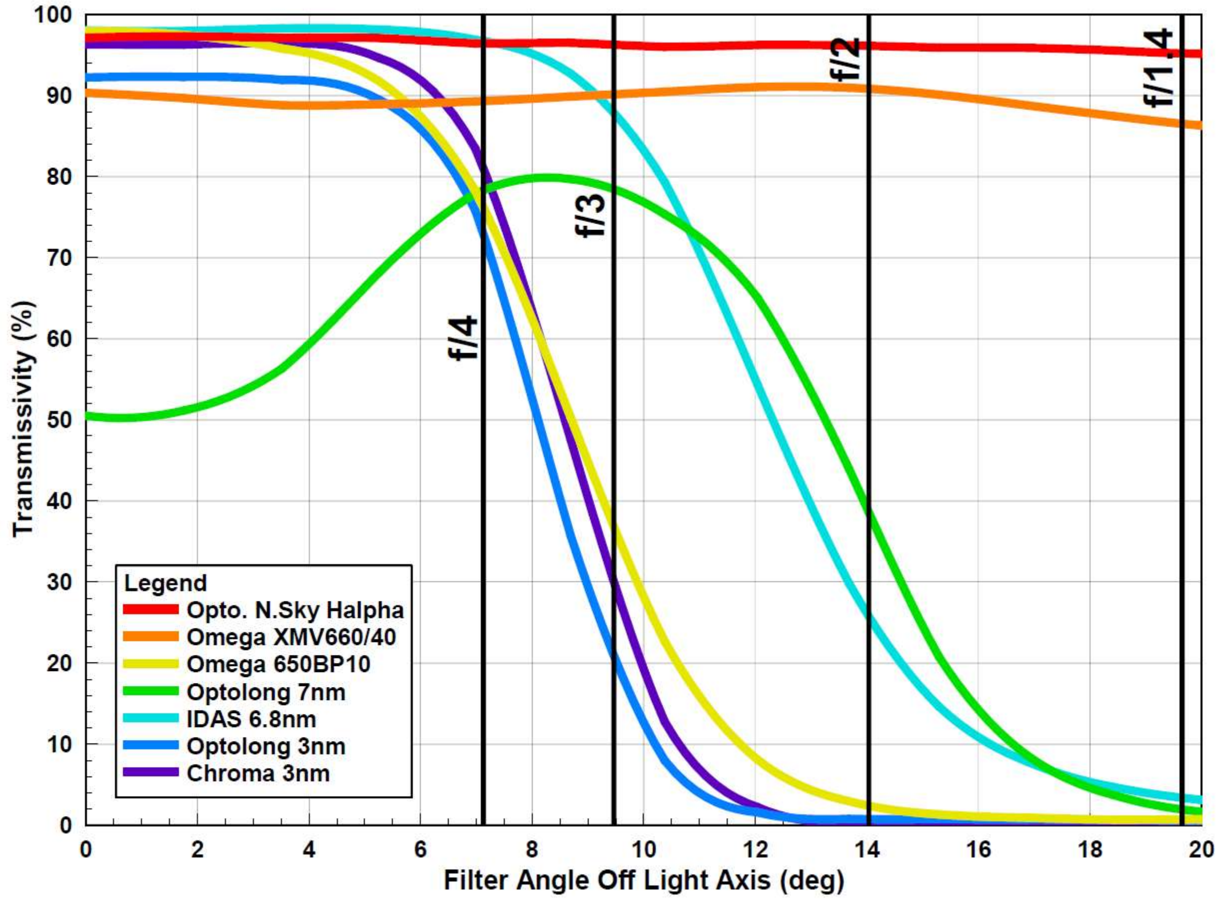


Figure 2 Measured Impact of Angle on Filter Response

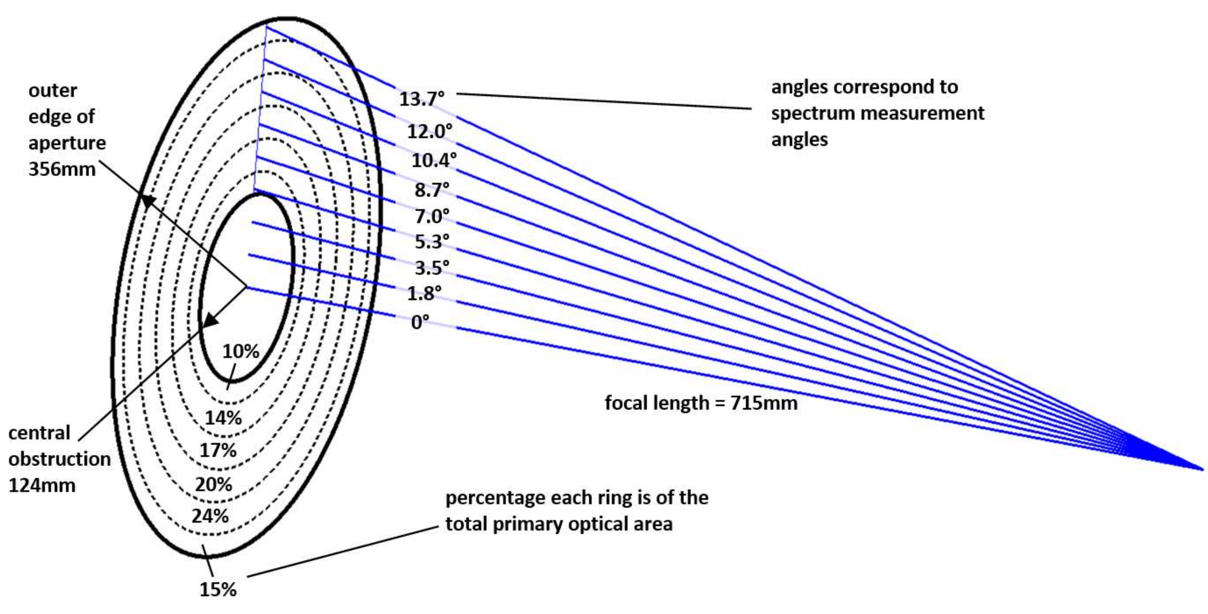


Figure 3 Illustration of Area Weighted Average Filter Response Calculation – C14 Hyperstar

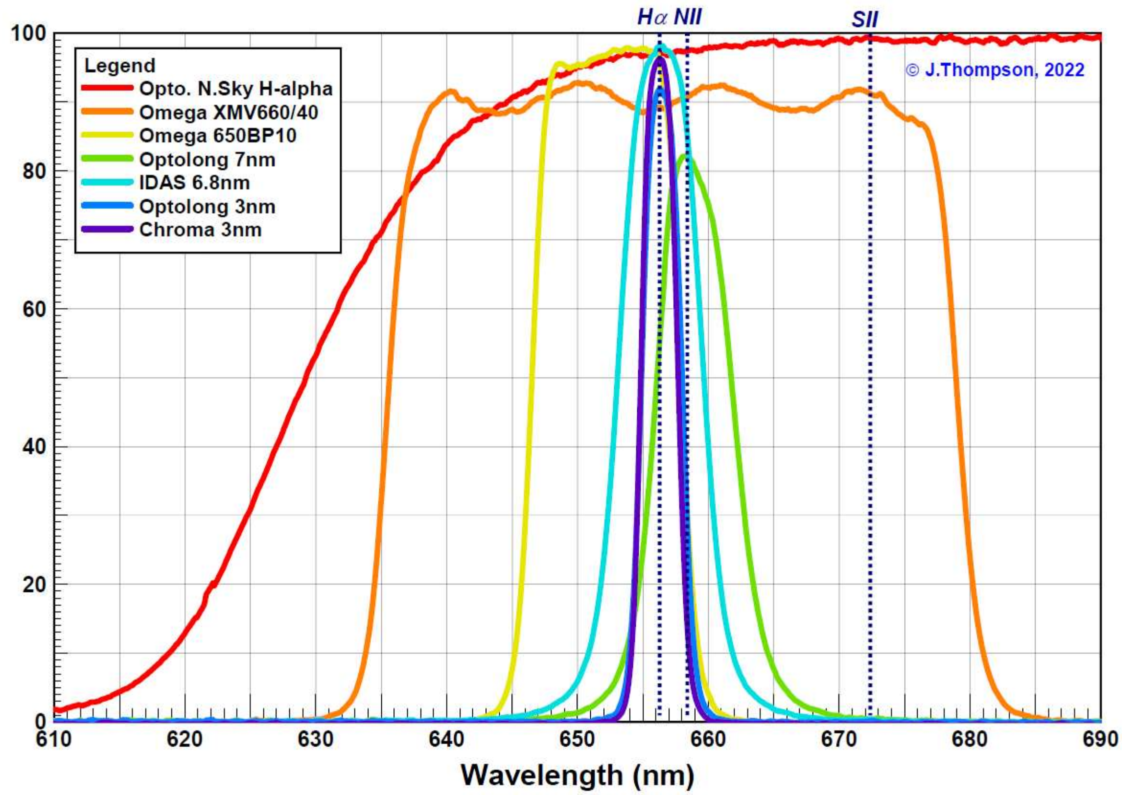


Figure 4 Net Spectral Response of Tested Filters – f/6.3 Refractor Area Weighted Average

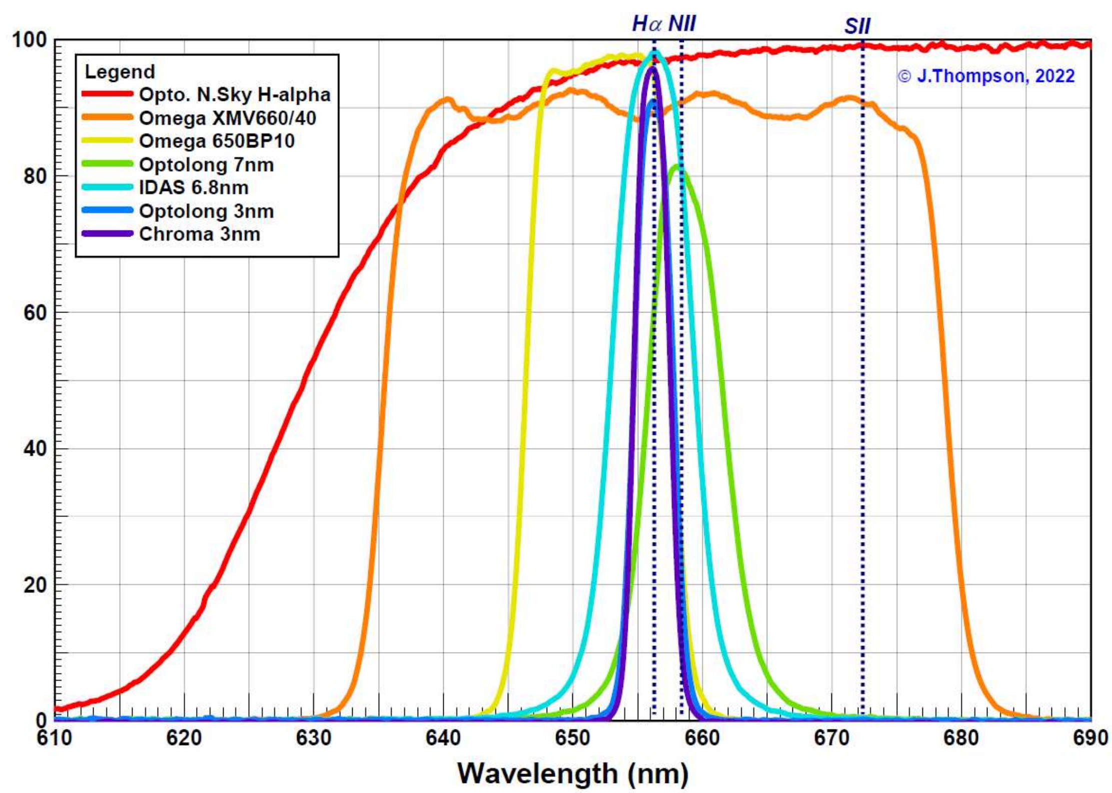


Figure 5 Net Spectral Response of Tested Filters – f/4.9 Refractor Area Weighted Average

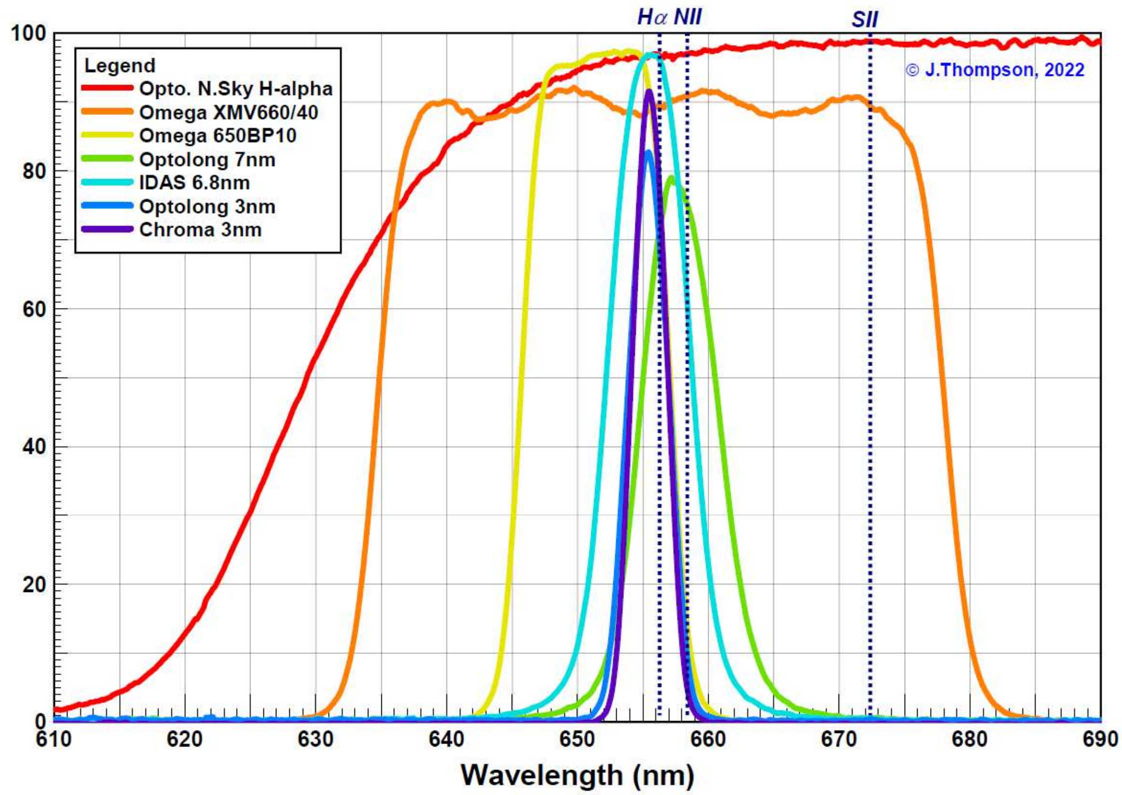


Figure 6 Net Spectral Response of Tested Filters – f/3.0 Refractor Area Weighted Average

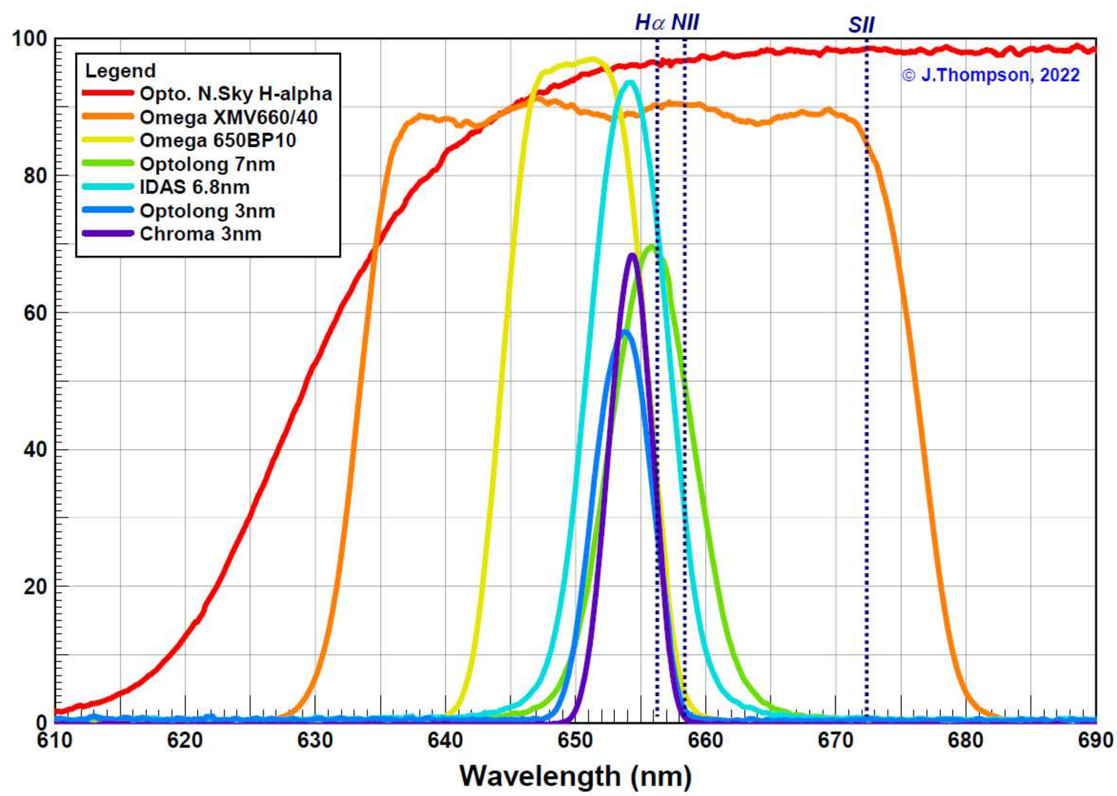


Figure 7 Net Spectral Response of Tested Filters – f/2 C14 w/Hyperstar Area Weighted Average

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 monochrome CMOS sensor. I have included transmission measurements in the table for a range of telescope f-ratios, from f/∞ (perfectly parallel & perpendicular light) down to f/2.

Filter	Scope Optics	%LT*	Halpha Pass Band			
			FWHM	Halpha (656.3)	N-II (658.4)	S-II (672.4)
Optolong Night Sky H-alpha	f/∞	38.0%	n/a (high pass filter)	97.1%	97.8%	99.5%
	f/6.3**			97.2%	97.4%	99.3%
	f/4.9**			97.1%	97.4%	99.2%
	f/3.0**			96.7%	97.0%	98.8%
	f/2***			96.3%	96.7%	98.6%
Omega XMV660/40	f/∞	7.97%	43.6nm	90.3%	92.1%	92.5%
	f/6.3			89.1%	90.7%	91.1%
	f/4.9			89.0%	90.7%	90.7%
	f/3.0			89.4%	90.8%	89.4%
	f/2			90.2%	90.2%	84.6%
Omega 650BP10	f/∞	2.32%	11.3nm	98.0%	42.1%	0.0%
	f/6.3			96.1%	30.6%	0.0%
	f/4.9			94.4%	25.2%	0.0%
	f/3.0			76.0%	13.7%	0.0%
	f/2			35.7%	4.4%	0.0%
Optolong 7nm	f/∞	1.17%	6.4nm	50.5%	84.8%	0.0%
	f/6.3			55.3%	82.1%	0.0%
	f/4.9			60.4%	81.0%	0.0%
	f/3.0			71.5%	75.2%	0.0%
	f/2			68.6%	49.6%	0.0%
IDAS 6.8nm	f/∞	1.43%	6.7nm	98.0%	91.9%	0.0%
	f/6.3			98.2%	85.3%	0.0%
	f/4.9			98.1%	80.9%	0.0%
	f/3.0			96.1%	61.1%	0.0%
	f/2			72.6%	30.9%	0.0%
Optolong 3nm	f/∞	0.63%	3.1nm	92.2%	45.8%	0.0%
	f/6.3			91.9%	28.8%	0.0%
	f/4.9			90.9%	21.4%	0.0%
	f/3.0			69.3%	9.6%	0.0%
	f/2			27.8%	2.0%	0.0%
Chroma 3nm	f/∞	0.59%	2.7nm	96.3%	21.9%	0.0%
	f/6.3			96.2%	13.9%	0.0%
	f/4.9			95.6%	10.5%	0.0%
	f/3.0			77.0%	4.8%	0.0%
	f/2			32.5%	0.9%	0.0%

* calculated assuming spectral QE curve for IMX174M with no UV/IR blocking filter; ** 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 when observing or imaging a faint emission nebula. 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 light polluted 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 8 shows the resulting plot corresponding to filter performance when using a monochrome 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 and high %LT, so the higher and more to the right a filter's performance is in the plot the better. Each filter's performance is plotted as a short line to show how the performance is predicted to change depending on the f-ratio of the telescope you are using the filter with. Slow f-ratio optics are at the right-most end of the line, f/3 is roughly in the middle of the line, and f/2 is at the left-most end of the line. I have plotted predicted filter performance assuming the target is a typical faint Hα rich nebula (eg. NGC7000).

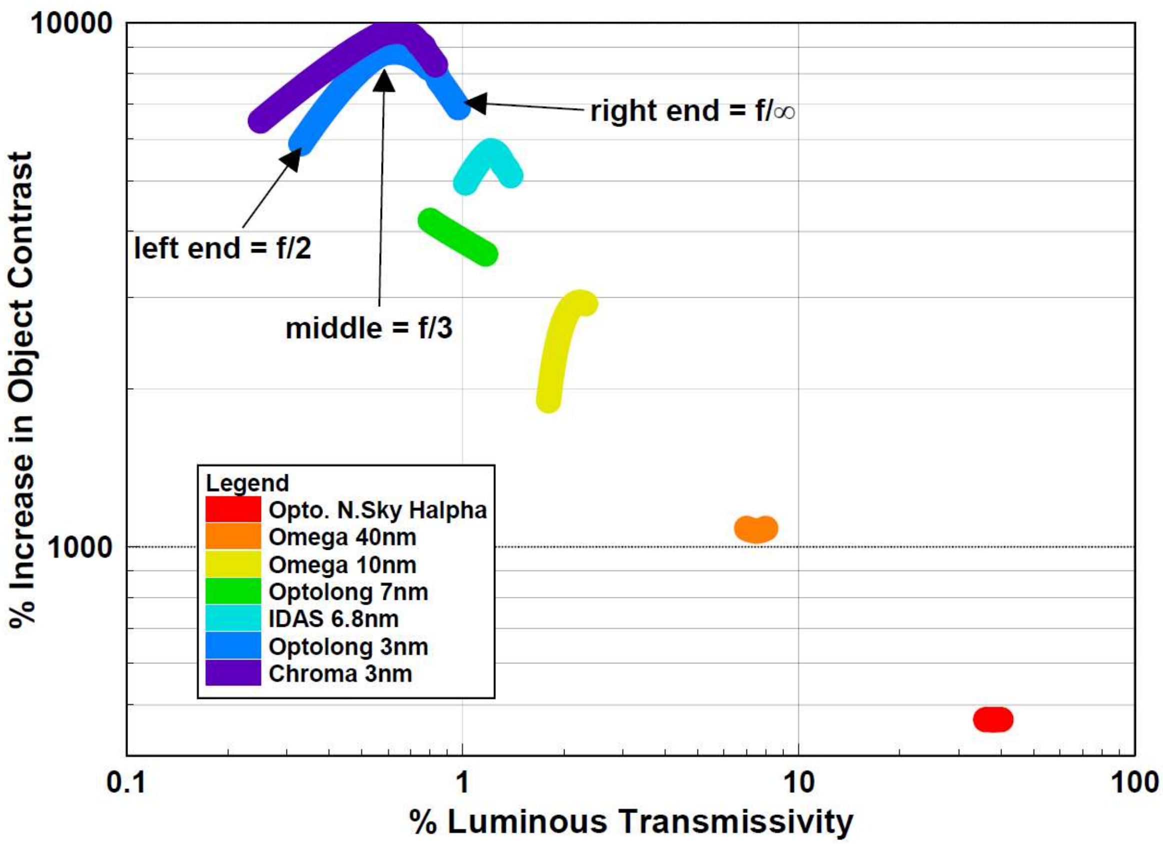


Figure 8 Predicted Filter Performance: Back Illuminated Monochrome CMOS, LP w/LED (NELM+2.9)

As expected, the predictions suggest that the narrower the filter's pass band (and thus lower %LT), the larger the contrast increase. The wider filters (Night Sky H-alpha & XMV660) are predicted to deliver a consistent increase in contrast, one that does not change significantly down to an f-ratio of f/2. The two 3nm filters deliver a contrast increase that varies widely with f-ratio, but in general are predicted to always deliver higher performance than the other filters tested. The drawback is that if you try to use the 3nm filters on fast optics, your exposure time will have to increase significantly to compensate for the much reduced %LT. The trade-off between contrast increase and exposure time is evident from Figure 8. For example: when used at f/6.3 the Chroma 3nm filter is predicted to provide a contrast increase 1.7x that of the IDAS 6.8nm (8877% vs. 5276%), at the cost of 1.8x the exposure (%LT of 0.77 vs. 1.35).

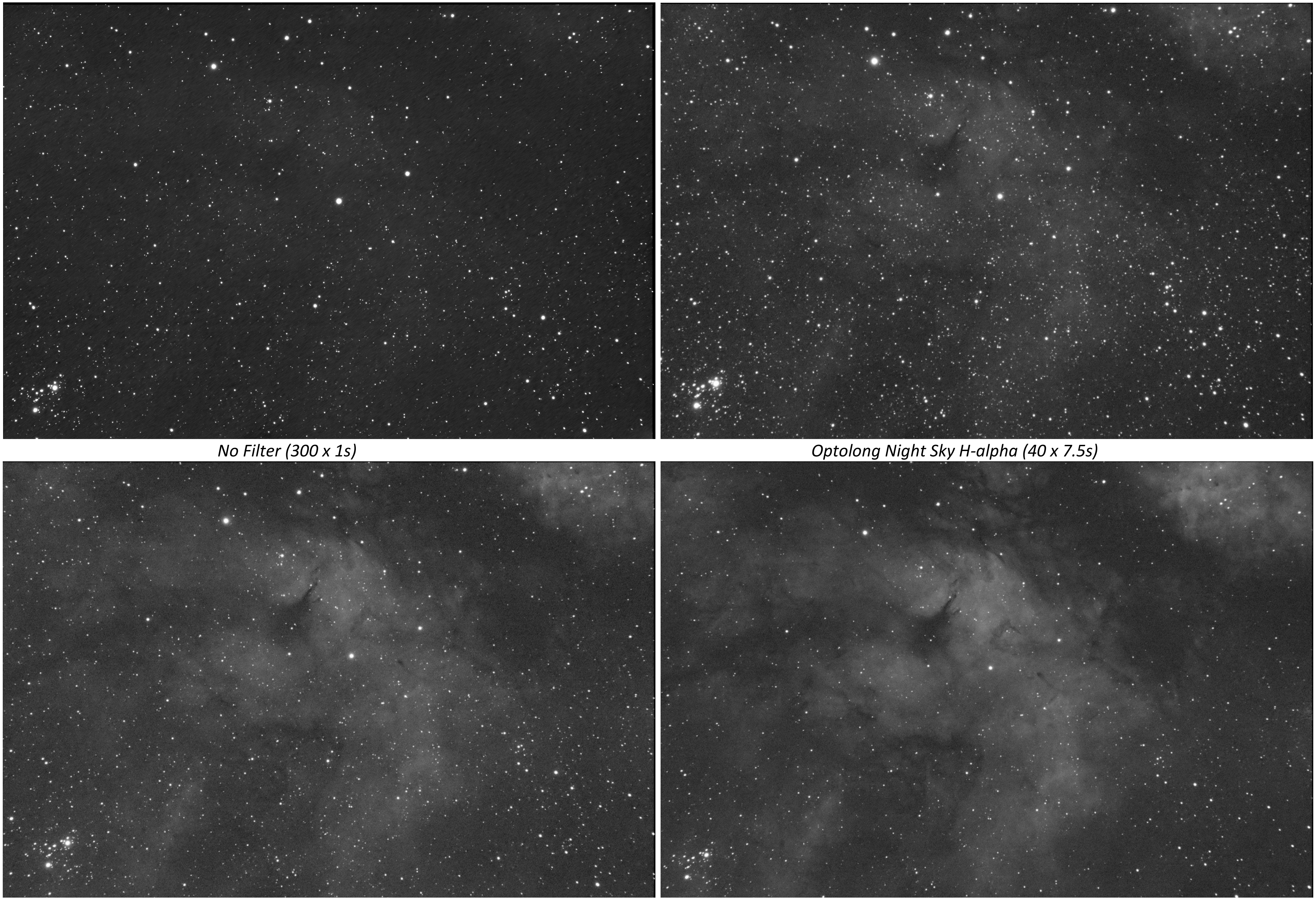
Results - Imaging:
As described above in the Method section, image data was captured with each filter using the same scope + camera configuration, with all images collected on the same night within a two-hour time window. This process was repeated four times using a variety of camera and scope combinations. Specifically, details for the four imaging sessions were as follows:

1. June 12th: DS432M TEC + FLT98 @ f/6.3; 12% gain, min gamma, bin 1x1, 20sec subs, 10 minute stacks; transparency poor, thin intermittent clouds, 2 days before full Moon.
2. June 16th: ASI183MM Pro + FLT98 @ f/6.3; 80% gain, bin 2x2, histogram at default, 30sec subs, 6 minute stacks; transparency average, 2 days after full Moon.
3. June 24th: ASI183MM Pro + FLT98 @ f/6.3; 80% gain, bin 2x2, histogram at default, sub-exposures varied with filter %LT to achieve same overall frame exposure, 5 minute stacks; transparency & seeing average, 4 days before new Moon.
4. June 28th: DS432M TEC + FMA230 @ f/4.5; 12% gain, default gamma, bin 1x1, sub-exposures varied with filter %LT to achieve same overall frame exposure, 10 minute stacks; transparency & seeing above average, new Moon.

Data was collected with the ZWO camera by generating a live stack in Sharpcap, which was then saved as a 16bit FITS file. With the Mallincam camera sub-exposures were saved to a folder and then stacked later using Deep Sky Stacker. For the first two imaging sessions I used fixed sub-exposure times of 20 or 30 seconds for all filters except when the frame was over exposed, at which point the sub-exposure time was reduced but the total stack time was kept constant. For the later two imaging sessions the sub-exposure time was adjusted for each filter in order to achieve an image of generally the same level of overall exposure as the no-filter reference image. This was determined qualitatively by adjusting exposure until the histogram peak had roughly the same luminance value.

Imaging results from the later two sessions are provided below in Figure 9 and 10 for the June 24th session, and Figure 11 and 12 for the June 28th session. The images presented are of the final stacks, 5 minute total duration in Figures 9/10 and 10 minute total duration in Figures 11/12. All the images had their histograms adjusted in exactly the same way using Fitswork v4.47, a free FITS editing software, so that they provide as fair a visual comparison as possible. Note that I don't have any image data from June 28th using the Chroma 3nm filter as I had returned the filter to its owner before the test occurred. Image data was collected however on the prior three dates using the Chroma filter.

The first thing to note from the presented images is that there is a very obvious change in the extent to which the nebulosity of IC1318 is visible, that extent being more so the narrower the pass band of the filter being used. The contrast increase that was observed is consistent with the predictions made from the spectrometer data. The two 3nm filters deliver the greatest amount of contrast increase, and that increase is significant compared with the 7nm filters. Another observation to note is that the Optolong 3nm filter performs effectively the same as the Chroma.



No Filter (300 x 1s)

Optolong Night Sky H-alpha (40 x 7.5s)

Omega XMV660/40 (15 x 20s)

Omega 650BP10 (8 x 40s)

Figure 9 June 24th Imaging Results – Batch 1

Optolong 7nm (4 x 75s)

IDAS 6.8nm (4 x 75s)

Optolong 3nm (3 x 120s)

Chroma 3nm (3 x 120s)

Figure 10 June 24th Imaging Results – Batch 2

No Filter (600 x 1s)

Optolong Night Sky H-alpha (60 x 10s)

Omega XMV660/40 (20 x 30s)

Omega 650BP10 (8 x 75s)

Figure 11 June 28th Imaging Results – Batch 1

Optolong 7nm (5 x 120s)

IDAS 6.8nm (5 x 120s)

Optolong 3nm (3 x 180s)

No Image Available

(filter returned to owner prior to test)

Chroma 3nm (n.a.)

Figure 12 June 28th Imaging Results – Batch 2

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. The results are summarized in Table 2. The table also includes the %LT value calculated from the measured spectra for comparison. Curiously the relative exposure measured from the images is consistently ½ of the calculated %LT values. I have no explanation for this; in past testing using colour cameras these two values have aligned very well. Regardless of this discrepancy, the information in Table 2 can be used to help astrophotographers determine how each filter will impact their exposure time relative to no filter.

Filter	June 24th		June 28th		Avg of Test Days	2 x Avg	%LT
	Sub-Exp. Time [s]	Mean Lum. Relative to No-Filter	Sub-Exp. Time [s]	Mean Lum. Relative to No-Filter			
Optolong Night Sky H-alpha	7.5	8.6%	10	12.3%	10.5%	20.9%	38.0%
Omega XMV660/40	20	3.4%	30	5.3%	4.3%	8.7%	8.0%
Omega 650BP10	40	0.91%	75	1.6%	1.3%	2.5%	2.3%
Optolong 7nm	75	0.41%	120	0.68%	0.54%	1.1%	1.2%
IDAS 6.8nm	75	0.56%	120	0.93%	0.75%	1.5%	1.4%
Optolong 3nm	120	0.28%	180	0.43%	0.35%	0.70%	0.63%
Chroma 3nm	120	0.26%	-	0.40% *	0.33%	0.65%	0.59%

***** estimated from June 24th data

Table 2 Measured Relative Image Exposure

Using the captured image data I was also able to directly measure the contrast increase delivered by each filter, putting a number to what was already observed qualitatively from the images in Figures 9 to 12. This was accomplished by using AstroImageJ to measure the average luminance from two common areas in the images: a dark background area, and a bright nebulous area. The particular areas used are illustrated in Figure 13, with these same areas used for all the images from all four imaging sessions. Measurements of average luminance were taken from both the raw stacked images as well as a single sub-exposure. Contrast increase was calculated from the measured luminance values using the following equations:

Measured Contrast = [measured nebula luminance – measured background luminance] ÷ measured background luminance

% Contrast Increase = [contrast w/filter – contrast w/out filter] ÷ contrast w/out filter x 100

The resulting contrast increase measurements are plotted in Figure 14. The amount of contrast increase varied widely from one night to another, an indication of the variance in observing conditions that were encountered during my testing. Especially note the results from the June 12th imaging session; the detrimental impact of the nearly full Moon and thin clouds on the image contrast that was achieved is very evident. Conversely the very good observing conditions on the 28th is evidenced by contrast numbers better than any of the previous test nights.

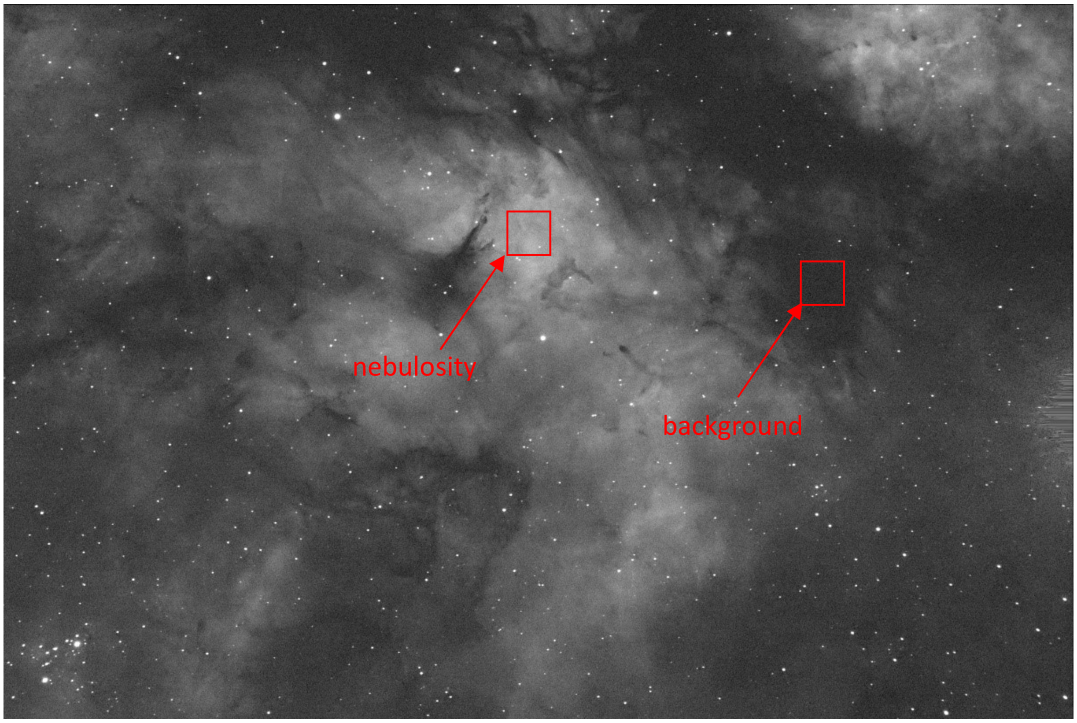


Figure 13 Areas Used for Image Analyses

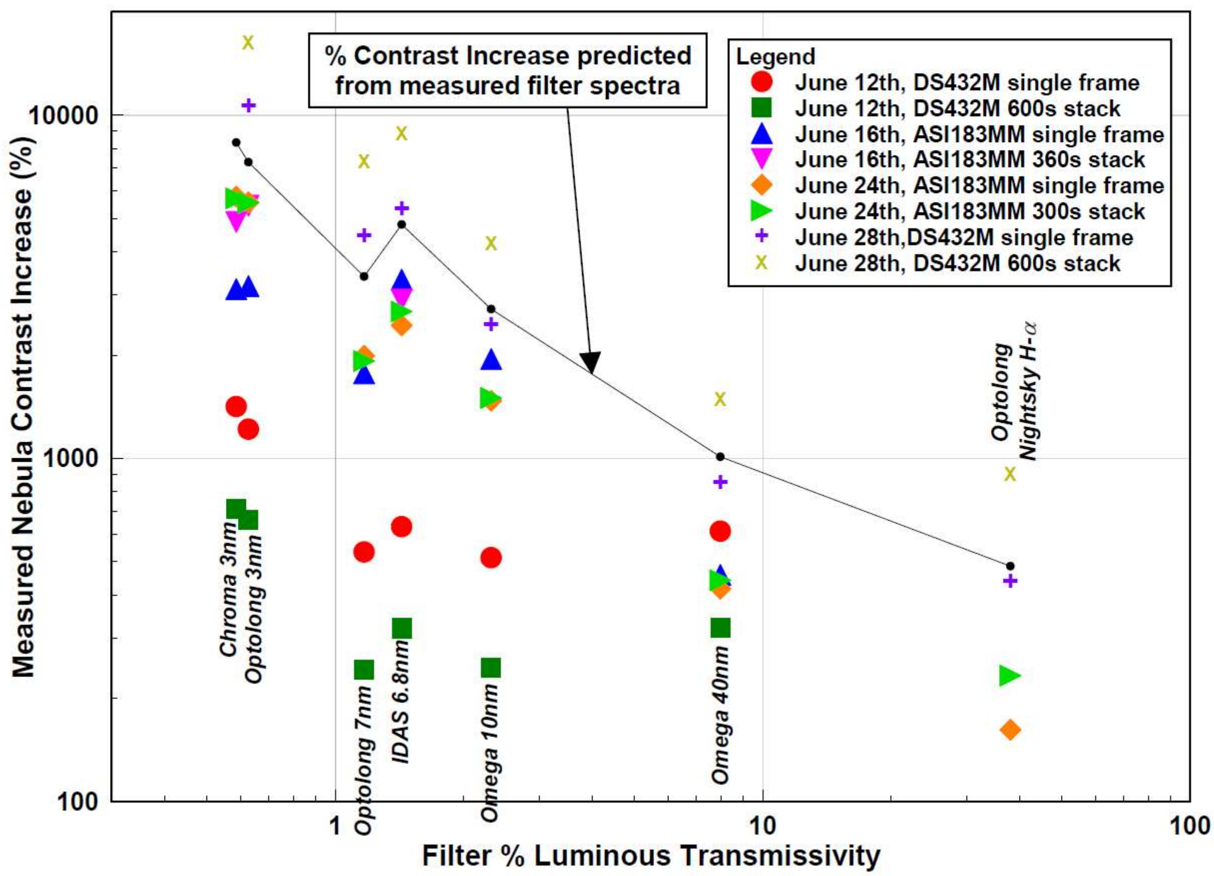


Figure 14 Measured Nebula Contrast Increase

Included in Figure 14 is a black curve representing the predicted contrast increase that was calculated using the measured filter spectra. The magnitude of the prediction differs from the image measurements because of the variability in observing conditions, but the predictions otherwise capture the trend in relative filter performance very well. As predicted, the two 3nm filters delivered the largest increase in contrast. Within the error of my measurements and the variability due to observing conditions, the two 3nm filters appear to perform the same. The IDAS 6.8nm filter also made a strong showing, delivering a contrast increase 40% lower than the two 3nm filters but still significantly higher than all the other filters tested.

The measurements of luminance from the images also allowed me to evaluate signal-to-noise ratio (SNR). When I extracted the average luminance values from each image in AstroImageJ, I also recorded the standard deviation (σ). This allowed me to calculate the SNR achieved by each filter using the following equation:

SNR = (measured nebula luminance – measured background luminance) ÷ measured nebula σ

As with the measured contrast increase values, the measured SNR values varied widely depending on the imaging session conditions as well as the number of frames stacked. To be able to better compare the results I normalized the measured values in an attempt to collapse them to a single curve. The result is shown in Figure 15 plotted versus %LT.

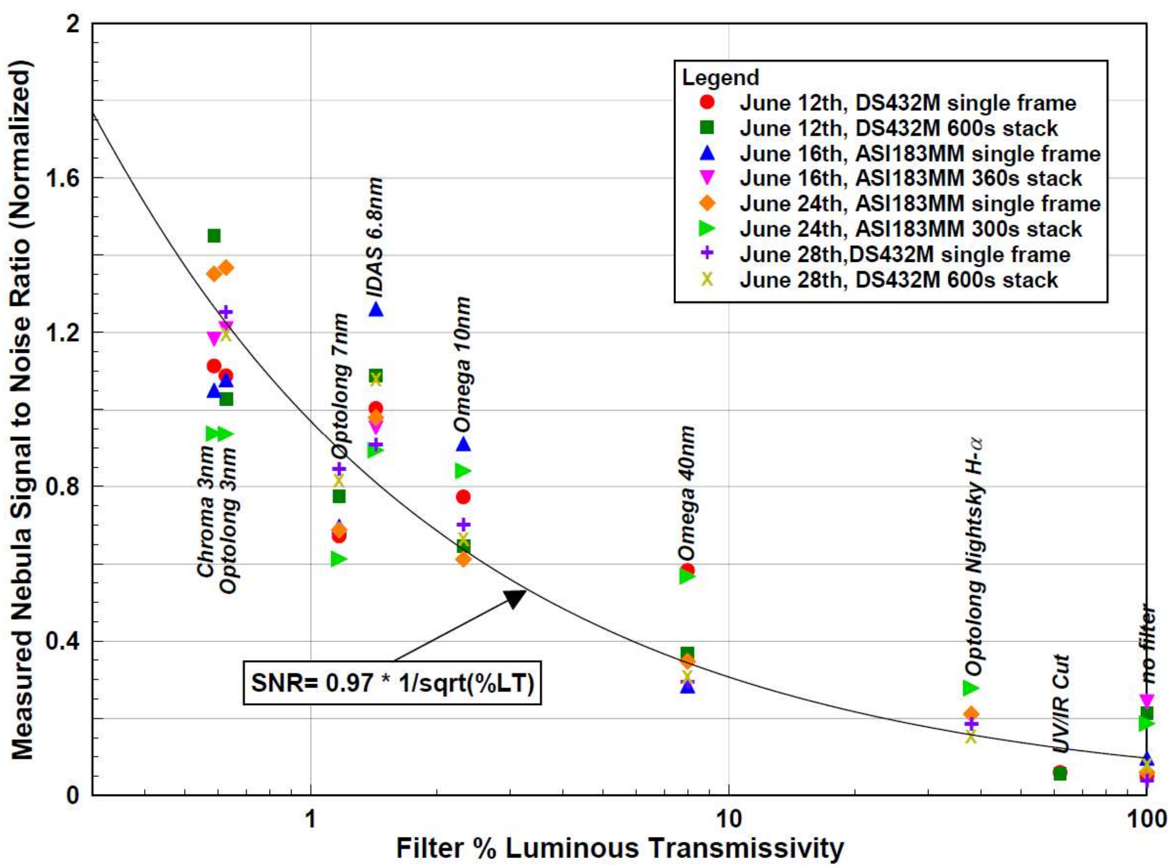


Figure 15 Measured Nebula Signal-to-Noise Ratio

An interesting observation to come from plotting the measured SNR values versus %LT is that they appear to follow an exponential curve, with SNR increasing as %LT decreases. The fact that I measured increasing SNR corresponding to narrower filter pass bands is not a surprise, but the simple exponential nature of this relationship is new information to me. This finding allows me to evaluate not only the tested filters relative to each other, but also the filters relative to others with the same band width. For example: the measured SNR values from the IDAS 6.8nm filter images are all well above the exponential curve shown in Figure 15, indicating that this filter is delivering superior performance to what would be expected of a filter with this bandwidth. Similarly, the SNR values for the Optolong 7nm filter are all below the curve, indicating that this filter performs below what would be expected of a filter with its bandwidth. Also, interesting to note from Figure 15 is the fact that within the error of my measurements, the two 3nm filters deliver the same SNR.

Out of curiosity I have assembled a final figure, one that evaluates the cost-benefit of each of the filters tested. Figure 16 presents a plot of SNR per $USD versus %LT.

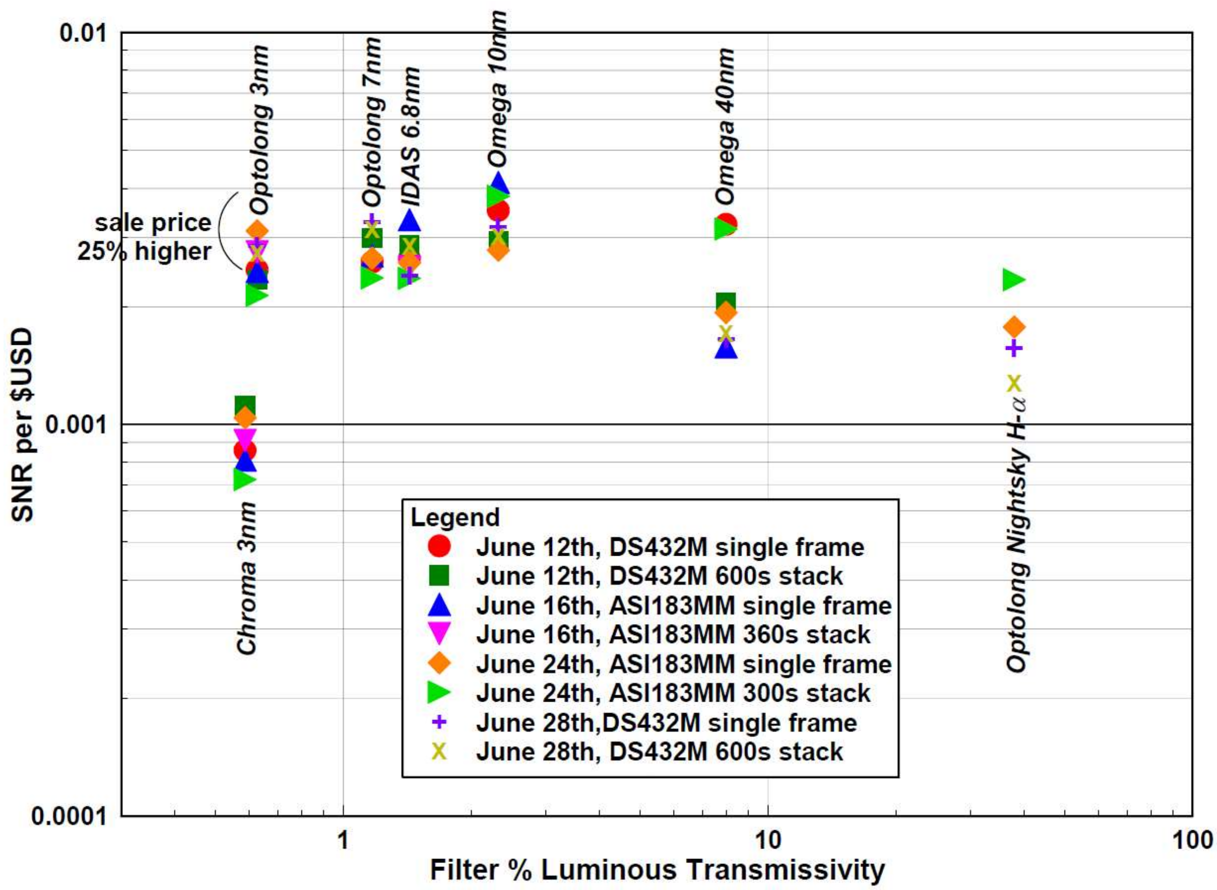


Figure 16 Filter Signal-to-Noise Ratio per $USD

Most of the filters fall within the same range of SNR/USD, around a value of 0.003. This suggests that all of these filters are competitively priced based on their measured performance. The exceptions are:

- the Chroma 3nm which, with the recent release of the Optolong 3nm filter, is no longer competitively priced, having an SNR/USD score low by a factor of 3; and
- the Optolong Night Sky H-alpha, which does not produce a large enough improvement in SNR on emission nebulae to make its price competitive with the other H-alpha filters.

It should be noted that the Night Sky H-alpha filter has other uses such as imaging galaxies or other objects in the near-infrared band for which it does very well, making it a good value overall but not on emission nebulae alone. Two other things to note from Figure 16 are that:

- the Optolong 3nm filter is already competitive at its regular price, making the current sale price of $351USD a good deal (SNR/USD ~0.004); and
- the Optolong 7nm filter, despite its performing below what would be expected of a 7nm wide filter, is still competitively priced. I expect then that other samples of the Optolong 7nm filter that have their pass band better centered on 656nm would be an even better value.

Conclusions:

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

1. A very clear improvement in nebula contrast with decreasing filter bandwidth was observed, both in the spectrum-based analysis and in the imaging results. The 3nm wide filters delivered a significantly higher contrast than the other filters tested.
2. The performance differences between the Chroma 3nm filter and the Optolong 3nm filter are predicted to be relatively small based on the spectrum-based analysis, and were observed to be effectively zero in the imaging results.
3. The IDAS 6.8nm filter was observed to be a strong performer, both by the spectrum-based analysis and by the imaging results, second only to the 3nm filters.
4. The good agreement observed between predicted nebula contrast increase and that measured from the image data is an additional validation of my spectrum-based analysis method for evaluating filter performance.
5. Based on the data generated by this test a typical cost-performance target for competitively priced H-α filters is in the range of 0.003 SNR per $USD. All the filters tested were within this range except for the Chroma 3nm (not competitively priced) and the Optolong Night Sky H-alpha (meant for other applications).

I have one closing comment: it is evident from this test report that Optolong is capable of delivering high performance/high value filters, but they are also capable of delivering filters that do not meet customer expectations. It is in the best interest of all filter manufacturers to deliver their filters with actual measured batch spectrum data, a practice first introduced by IDAS. Supplying this kind of information with every filter would go a long way towards building customer confidence. If you have any questions, please feel free to contact me.

Cheers!

Jim Thompson (top-jimmy@rogers.com)