COMPARING H-α FILTERS – FROM WIDE TO NARROW

By Jim Thompson, P.Eng

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 a 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. This article is an excerpt from a test report I wrote that determined whether or not this theory is born out in practice.

Method

The objective of my testing was 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 article 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 filters considered in my testing is as follows (costs are for 2" version at the time of the writing of this article):

- 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
- Chroma H-α 3nm – FWHM 3nm, $1300USD

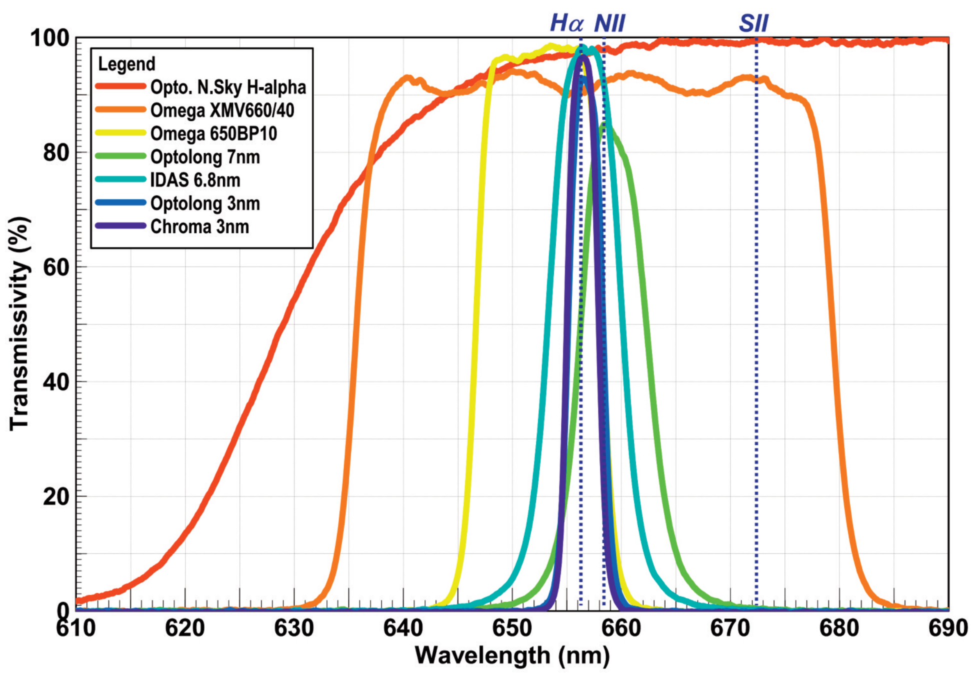

Figure 1: Measured Filter Spectral Response – Filter Perpendicular to Light Path

Filter performance is evaluated during this test based on the increase in contrast between the observed object and the

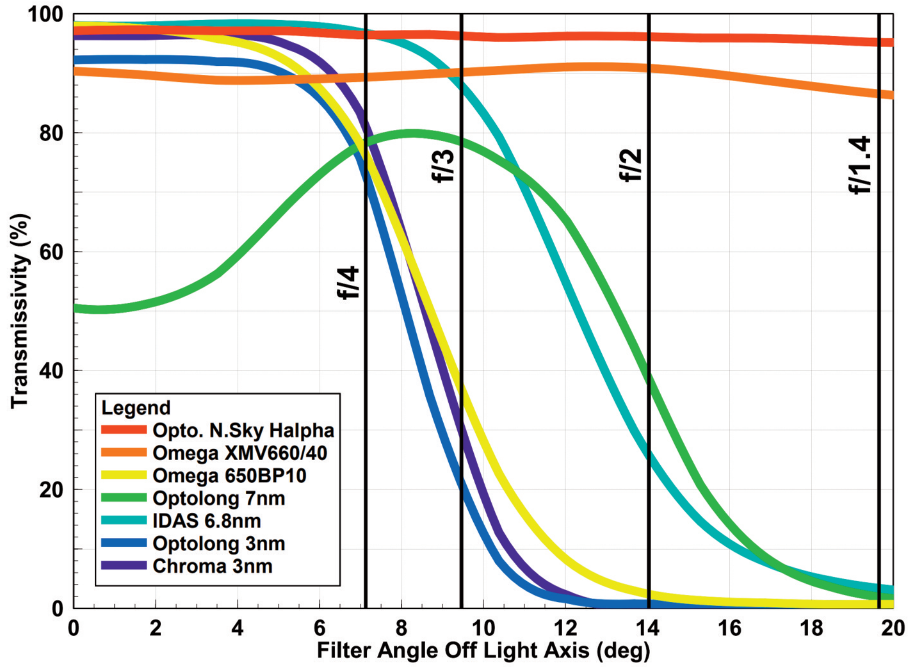

Figure 2: Measured Impact of Angle on Filter Response

background, which is a measurable quantity. It was evaluated analytically using the measured filter spectra combined with the spectra of a typical emission nebula (NGC7000), 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.

Testing consisted of data collection from the following sources:

- Spectral transmissivity data: From near-UV to near-IR, measured using an Ocean Insight USB4000 spectrometer (0.5nm resolution) at a range of filter angles relative to the light path from 0° (perpendicular) to 20° off-axis.
- Image data: Collected using various combinations of the following cameras and telescopes: a ZWO ASI183MM Pro or Mallincam DS432M-TEC mono chrome camera, and a William Optics FLT98 triplet (f/6.3) or Askar FMA230 quad (f/4.5) apochromatic refractor.

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+. Four duplicate sets of test images were captured of the same deepsky object during the month of June 2022. The target object was the extensive emission nebula IC1318 in Cygnus, what I affectionately call the "Oriental Dragon" nebula. The object 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.

Results – Spectrum Measurements

Using my bench-top spectrometer setup I measured the spectral transmissivity of each filter for a range of filter angles relative to the light path. **Figure 1** presents a plot of the resulting spectrum 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: the Omega 650BP10 that has a center wavelength (CWL) shifted off-band 2nm left, and the Optolong 7nm filter which is shifted 2nm off-band right. Note that my sample of the Optolong 7nm filter is more than four years old now, so it may not be representative of the product being produced today.

The impact of angle on each filter's transmission of H-α is shown in **Figure 2**. As expected, filters with wide pass bands are 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 fil-

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 (>200nm)	97.1%	97.8%	99.5%
	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/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/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/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/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/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/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%

Figure 3: Measured Filter Performance Summary

ters because of its CWL being shifted off-band to the left. The IDAS 6.8nm is less sensitive to angle than filters of similar bandwidth because it is designed to have its pass band pre-shifted up in wavelength, effectively extending the range of focal ratios that the filter can be used with.

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 all light angles from perpendicular out to the angle at the outer edge of the aperture.

I have calculated the net filter performance for several f-ratios, allowing me to extract overall performance related statistics for each filter, such as peak transmission and FWHM. These filter statistics are provided in **Figure 3**, including a calculated value for percent Luminous Transmissivity (%LT), a single number that describes generally how much light is getting through the filter assuming the detector is a modern CMOS sensor.

Knowing the filter spectral responses also allowed me to predict the theoretical relative performance of each filter when 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 deep-sky 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 4** shows the resulting plot corresponding to filter performance when using a back illuminated (BI) monochrome CMOS camera under heavily light polluted skies complete with local LED streetlights (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.

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, and f/2 is at the left-most end. I have plotted predicted filter performance assuming the target is a typical faint Hα rich nebula (eg.

NGC7000).

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 of trying to use the 3nm filters on fast optics is that 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 4. 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).

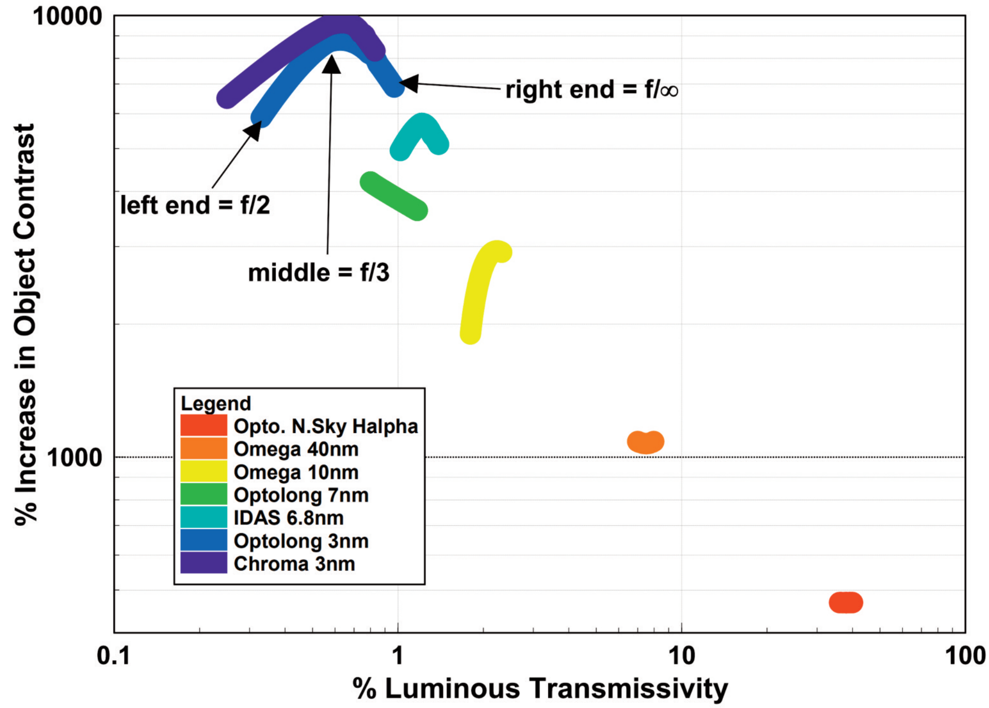

Figure 4: Predicted Filter Performance: Monochrome BI CMOS, LP w/LED (NELM+2.9)

Results - Imaging

As described 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.

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 the same 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 in **Figures 5 and 6** for the June 24th session (ASI183MM Pro + FLT98 @ f/6.3), and **Figure 7** for the June 28th session (DS432M-TEC + FMA230 @ f/4.5). The images presented are of the final stacks, 5 minute total duration in Figures 5 and 6 and 10 minute total duration in Figure 7. All the images had their histograms adjusted in exactly the same way using Fitswork v4.47 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.

Using the captured image data, I was 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 5 to 7. This was accomplished by using As-

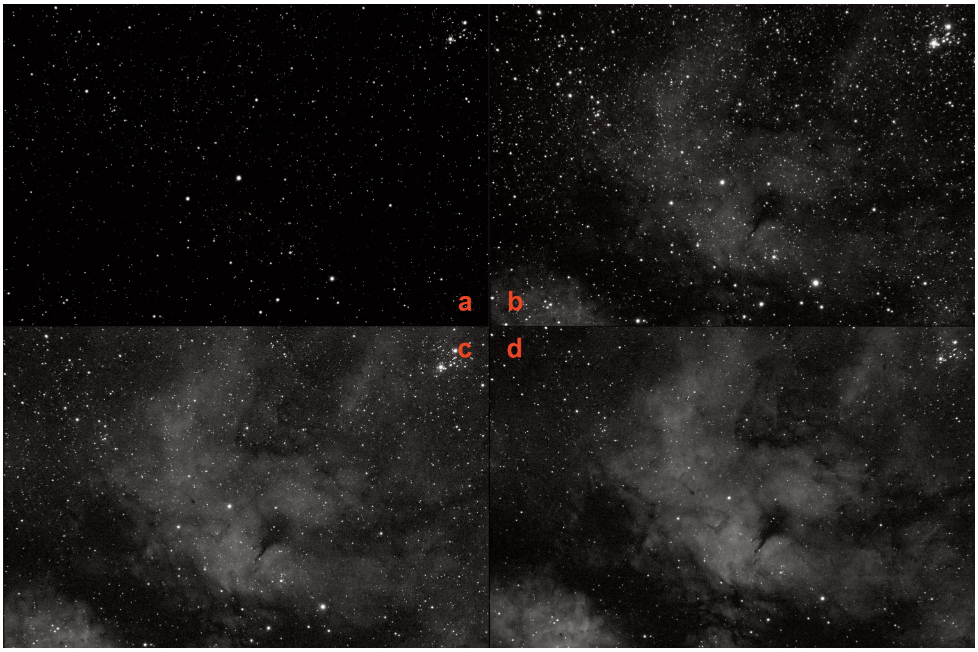

Figure 5: June 24th Imaging Results – Batch 1 (a. No Filter 300x1s, b. Night Sky H-α 40x7.5s, c. XMV660/40 15x20s, d. 650BP10 8x40s)

troImageJ to measure the average luminance from two common areas in the images: a dark background area and a bright nebulous area. 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 and are plotted in **Figure 8**.

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. Clearly the conditions on June 12th were not as good as on June 28th, an observation that is consistent with notes from each imaging session (12th had thin cloud and a nearly full Moon, 28th had no Moon and clear skies).

Included in Figure 8 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.

The two 3nm filters delivered the largest increase in contrast, but 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. 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 9** plotted versus %LT.

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. 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 above the curve shown in Figure 9, 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 Opto-

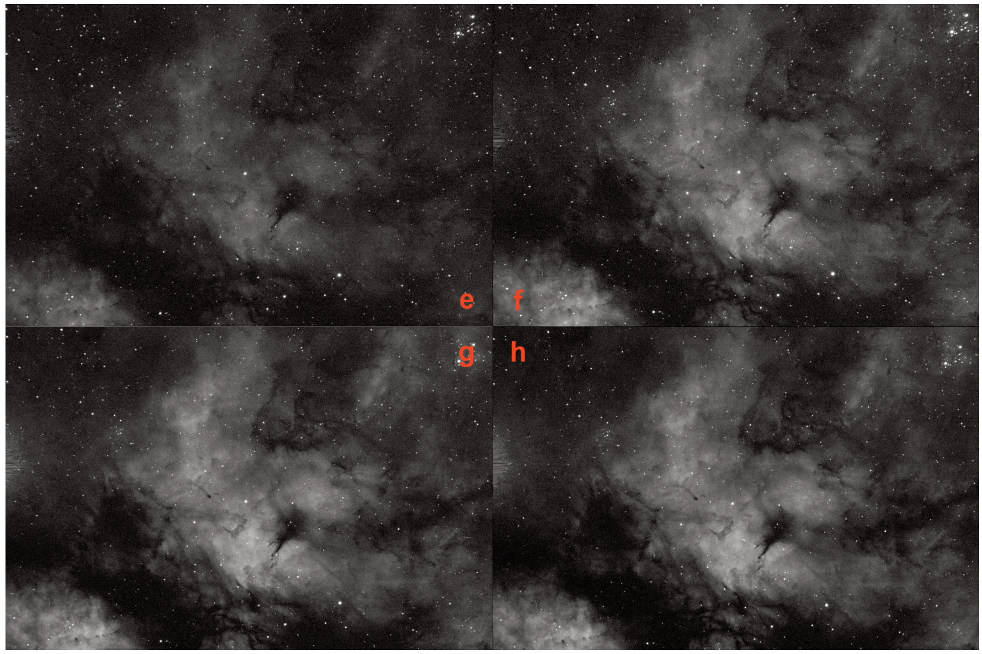

Figure 6: June 24th Imaging Results – Batch 2 (e. Optolong 7nm 4x75s, f. IDAS 6.8nm 4x75s, g. Optolong 3nm 3x120s, h. Chroma 3nm 3x120s)

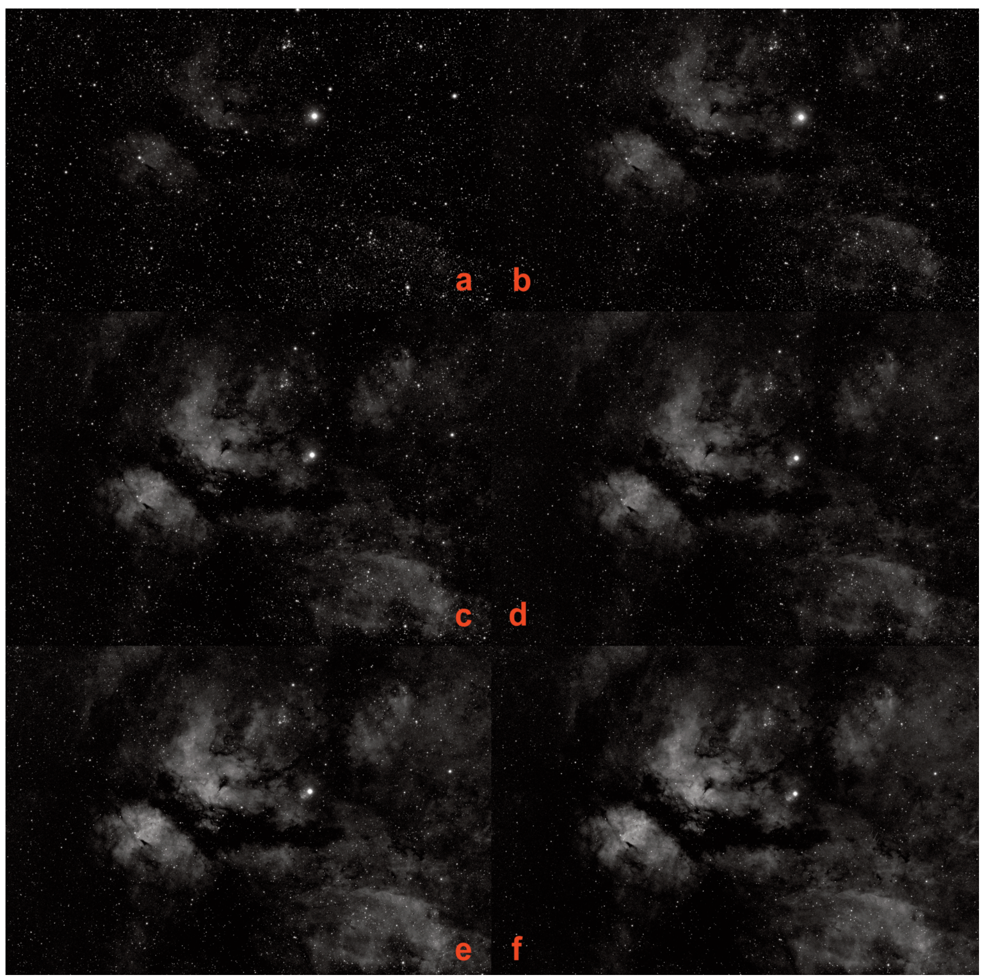

Figure 7: June 28th Imaging Results (a. Night Sky H-α 60x10s, b. XMV660/40 20x30s, c. 650BP10 8x750, d. Optolong 7nm 5x120s, e. IDAS 6.8nm 5x120s, f. Optolong 3nm 3x180s)

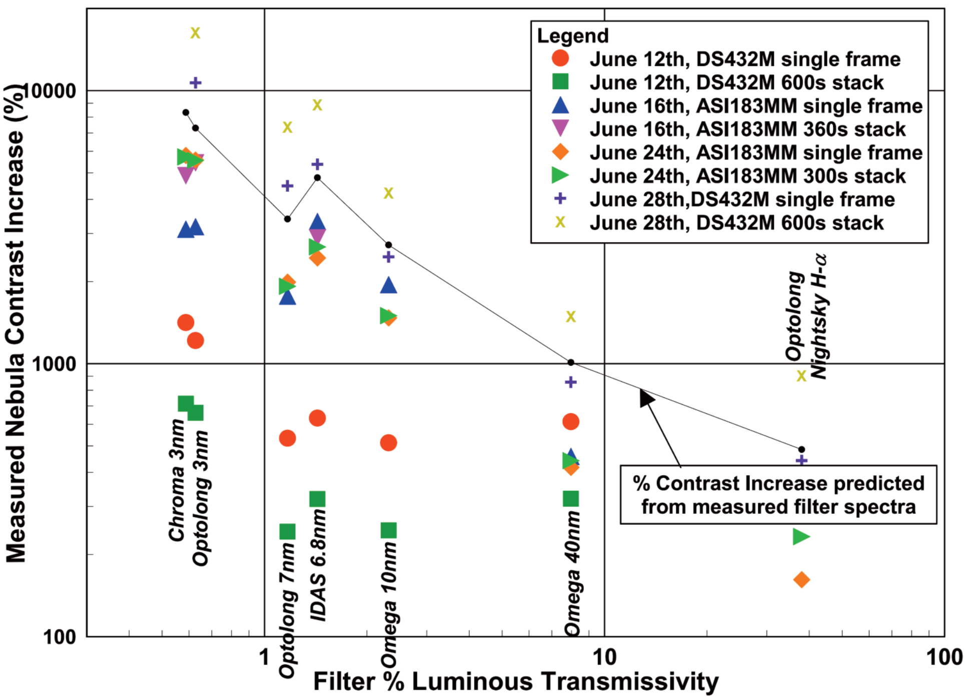

Figure 8: Measured Nebula Contrast Increase

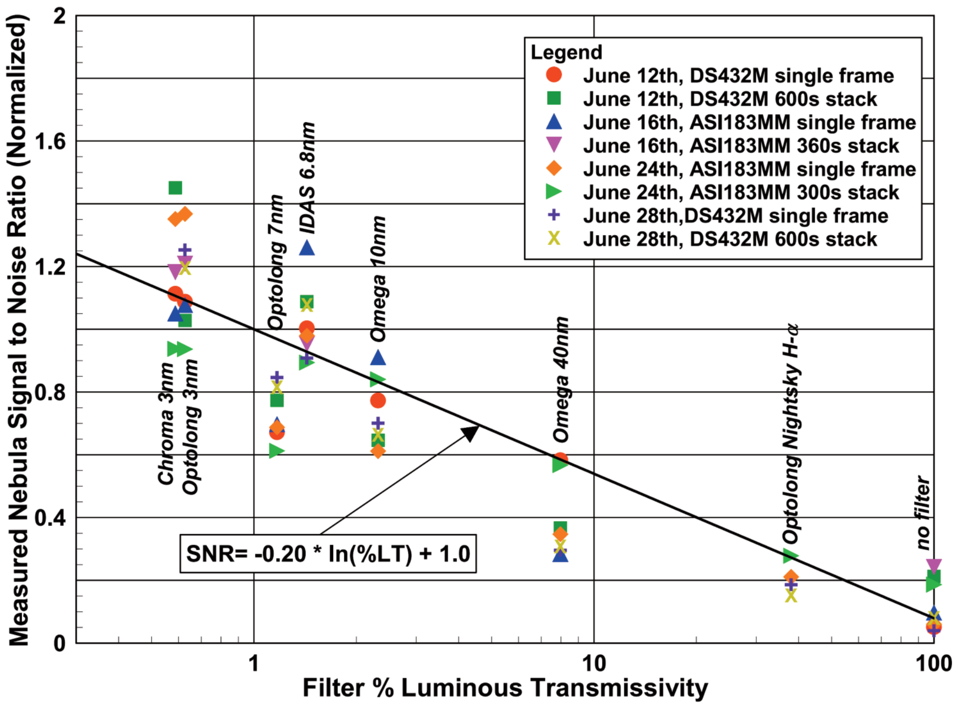

Figure 9: Measured Nebula Signal-to-Noise Ratio

long 7nm filter are all below the curve, indicating that this filter performed below what would be expected of a filter with its bandwidth. Also, interesting to note from Figure 9 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 10 presents a plot of $USD per unit SNR versus %LT. Most of the filters fall within the same range of USD/SNR, around a value of $360 at the time of writing this article.

This suggests that all of these filters are competitively priced based on their measured performance. The exceptions, that is the filters that are not competively priced based on their performance, are: the Chroma 3nm which is the most expensive filter tested, and the Optolong Nightsky H-α. It should be noted that the Night Sky H-α 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. Another interesting observation is that 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 here, 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. Based on the data generated by this test a typical cost-performance target for competitively priced H-α filters is in the range of $360USD per unit SNR. All the filters tested were within this range except for the Chroma 3nm and Optolong Night Sky H-α.

I have one closing comment: it is evident from this test report that 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. ATT

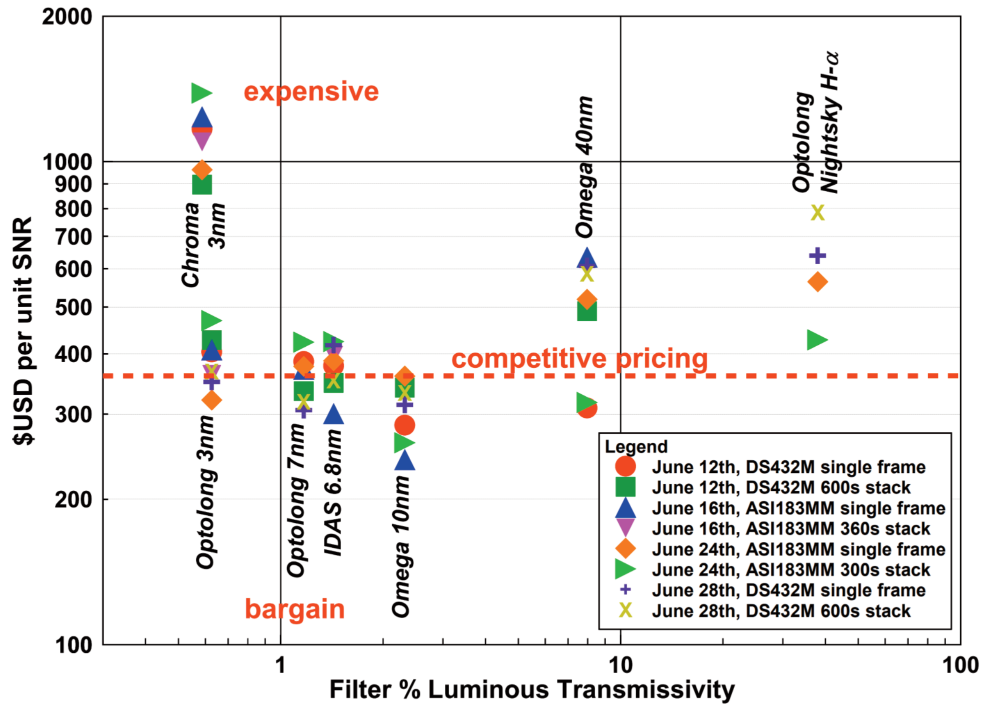

Figure 10: Filter $USD per unit Signal-to-Noise Ratio