Narrowband Filters & Fast Optics
(A match made in heaven, or is it?)

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Introduction:

I have been researching and experimenting with astronomical filters for more than ten years now. My interest in filters began with a simple question: "What filter should I buy?" At the time I was just getting back into amateur astronomy, and my location in the center of a large city (by Canadian standards!) meant I needed a light pollution filter in my kit. Since then my curiosity has led deeper and deeper into the ever growing and often confusing market of astronomical filters. Through all my explorations a common truth has come to light: when observing an emission-type nebula, the narrower your filter pass band width the better. This is all well and good, but to realise this truth in practice one has to gather a lot of light, either by using a really large aperture when observing visually, or by using fast optics if using a camera. Conveniently there are several options commercially available today for very fast optics, Starizona's Hyperstar system and Celestron's Rowe-Ackermann Schmidt Astrograph (RASA) being two very popular options. Both of these optical systems provide f-ratios (focal length divided by aperture) in the *f*/2 range, which should make quick work of a narrowband filter right? Well, I'm afraid there is more to this story.

A filter's pass band width is often referred to as its "Full Width Half Maximum" or FWHM for short, and is measured in nanometers. All astronomical filters with FWHM values smaller than 70nm are interference filters; many extremely thin alternating layers of refractory material applied to a glass substrate, working together to block unwanted wavelengths through destructive interference (Google "wave properties of light" for more information). The wavelengths that are passed by an interference filter are dependant on the thickness of the many layers that were applied. Anything that changes the thickness of these layers will change the filter's pass band. For example light passing through the filter at an angle will effectively increase the thickness of the layers, thus causing a shift in the pass band. This is an unfortunate property of interference filters since the angle at which light passes through a filter increases as your optics' f-ratio goes down. Perhaps putting that 3nm wide filter together with your RASA wasn't such a great idea after all? That is what I discuss in the remainder of this article, the effectiveness of using a narrowband filter with fast optics.

Method:

I discovered early in my filter research that trying to use visual or imaging based observations as the basis for comparing the performance of filters is very challenging. There is no way to remove the uncertainty associated with your seeing conditions, which are constantly changing throughout the evening. A reasonable comparison of a hand full of filters in an evening may be do-able, but not 10 or 20 filters. As a result I developed ways of evaluating filters that do not depend on observations of real life targets. Although I still do collect live observations from time to time, most of my comparisons are done by analysis. The starting point of that analysis is acquiring a good quality, high resolution spectral response for the filter in question. With that piece of information it is possible to predict how the filter will behave in different scenarios.

For the analysis presented in this article, I generated a series of generic narrowband filter response curves based on my knowledge of the range of filters that are available commercially. I also added a couple of extremely narrowband filters that are not available commercially, but I thought would be interesting to add to the analysis. I chose to use H-alpha as my nebula emission band of interest since it is the most commonly used narrowband filter. Figure 1 presents the spectral transmissivity curves for my generic H-alpha filters.

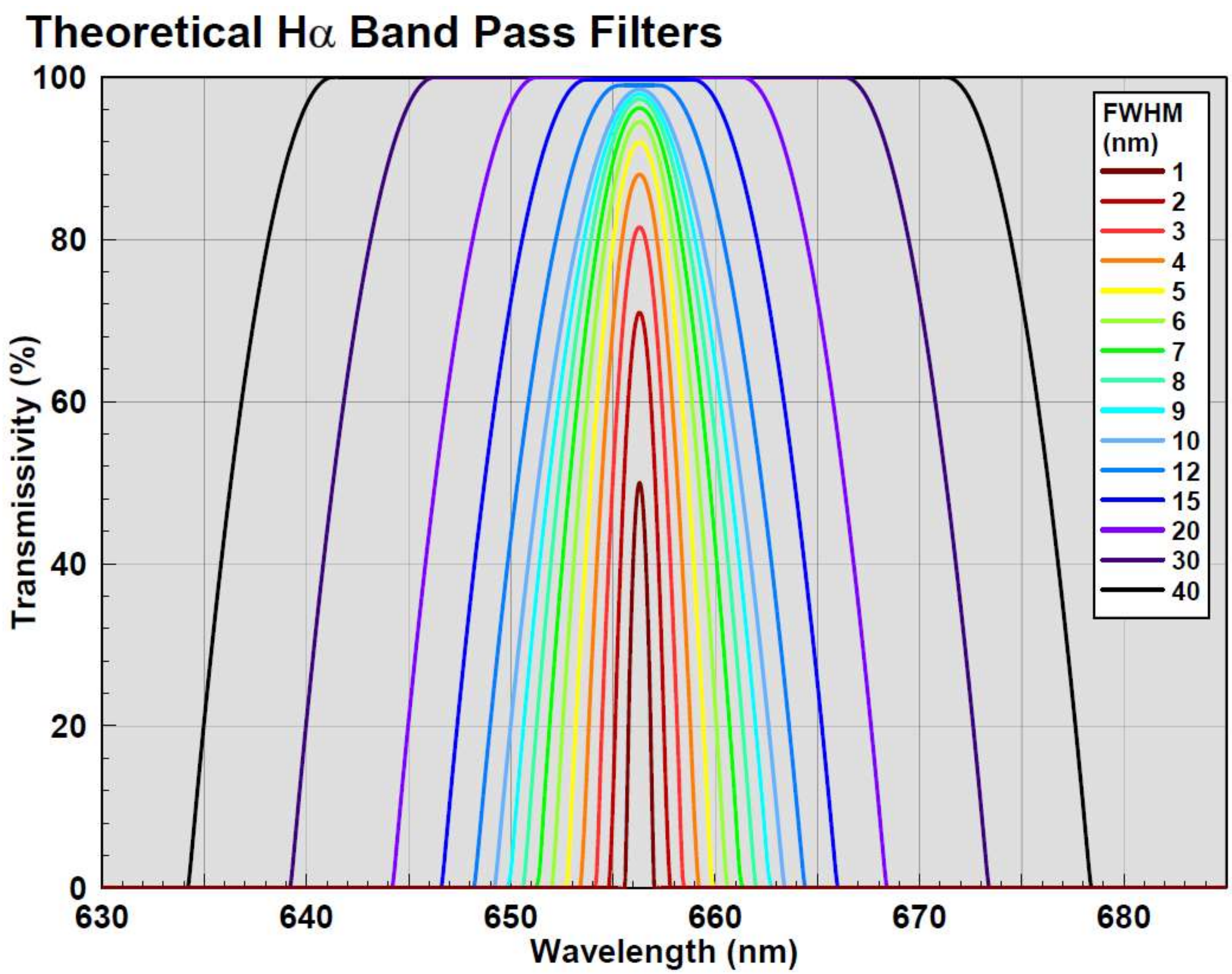

Figure 1 Spectral Response of Generic H-alpha Narrowband Filters

To understand how my generic filters would behave at different f-ratios, I did an experiment with an actual narrowband filter. Using a spectrometer I measured how the H-alpha pass band of an OPT Radian Triad filter changes with the angle of the light passing through the filter. Details of this measurement are presented in a test report that you can find on my website (http://karmalimbo.com/aro/reports/). Figure 2 plots the transmissivity data collected during the measurement. As you can see in the figure, a very clear change in filter properties with angle was observed. The variation in FWHM, peak transmissivity, and center wavelength (CWL) with angle from this measured data was applied to my generic filter spectrums, and the resulting shifted spectrums used to predict how each filter will behave on a fast f-ratio telescope. I chose an *ƒ*/2 8" RASA as my "test" scope, plus a 4" *ƒ*/4 refractor for comparison purposes as it has the same focal length (and thus same field of view) as the 8" RASA.

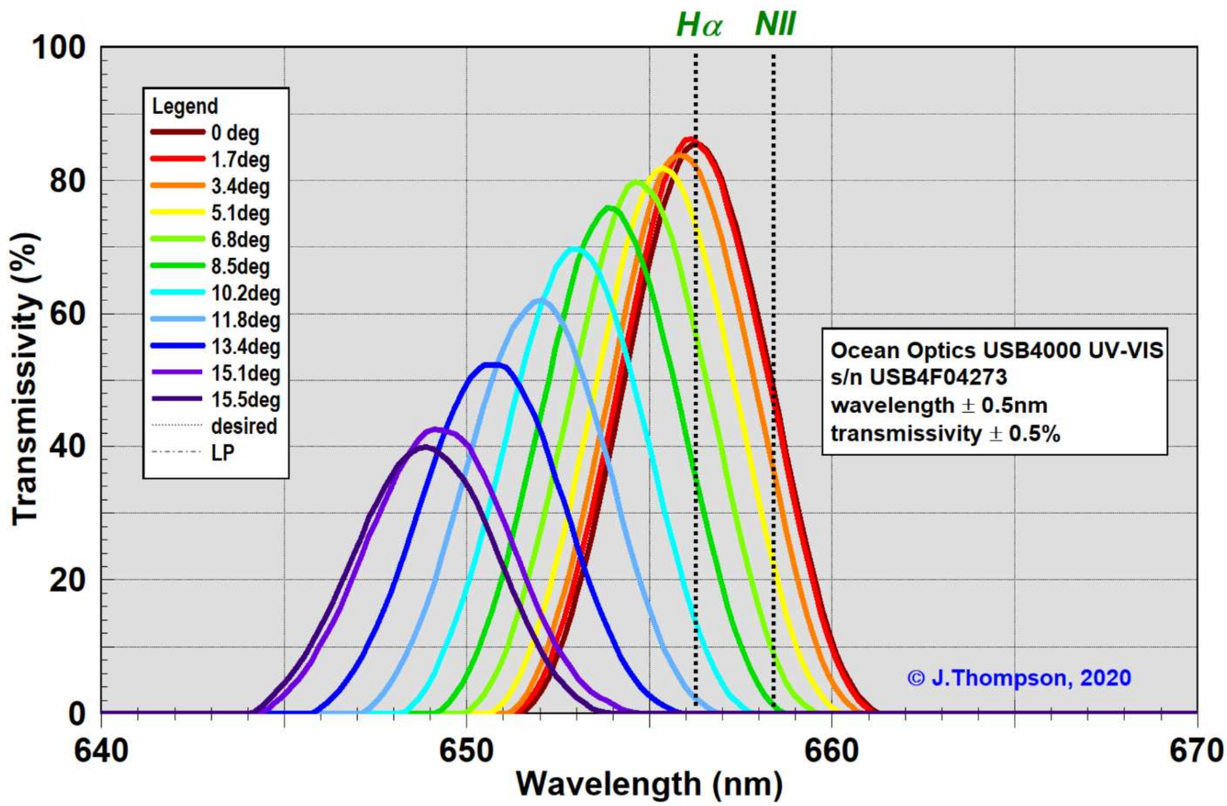

Figure 2 Measured Spectral Response of Radian Triad Filter vs Angle – H-alpha Band

In addition to predicting how filter performance varies with f-ratio, I also wanted to have an idea of how the FWHM of my generic filters affected the increase in contrast one should expect to see when using the filters. To predict the contrast increase of each filter I used the method I developed back in 2012. The method uses spectrums for: the background sky emission including light pollution, the emission from the deepsky object being observed, the response of the sensor whether it be human eye or a camera, and the response of the filter. These spectral curves are all combined numerically to work out the object contrast with the sky, with and without the filter. For the analysis presented in this article I assumed the sensor is a modern monochrome CMOS, and the target being observed is the faint emission nebula NGC7000 (North American Nebula). For the background sky emission I assumed I was observing from my urban backyard, with local LED street lights, to give a naked eye limiting magnitude (NELM) of +2.9.

Results:

My prediction of the contrast increase resulting from using each filter is presented in Figure 3. Contrast in my calculation is defined as a ratio: (luminance object) / (luminance sky). The increase in contrast that is shown in Figure 3 is the factor by which this ratio gets multiplied, to go from no-filter to with-filter. A value >1 means adding the filter increased contrast, and a value <1 means the contrast was worse with the filter. The x-axis in Figure 3 is the luminous transmissivity (LT) of each filter, essentially a calculation of the area under each of the curves in Figure 1. The number tells us generally how much light is getting through the filter as a whole, the calculation of which is based on the sensor you are using.

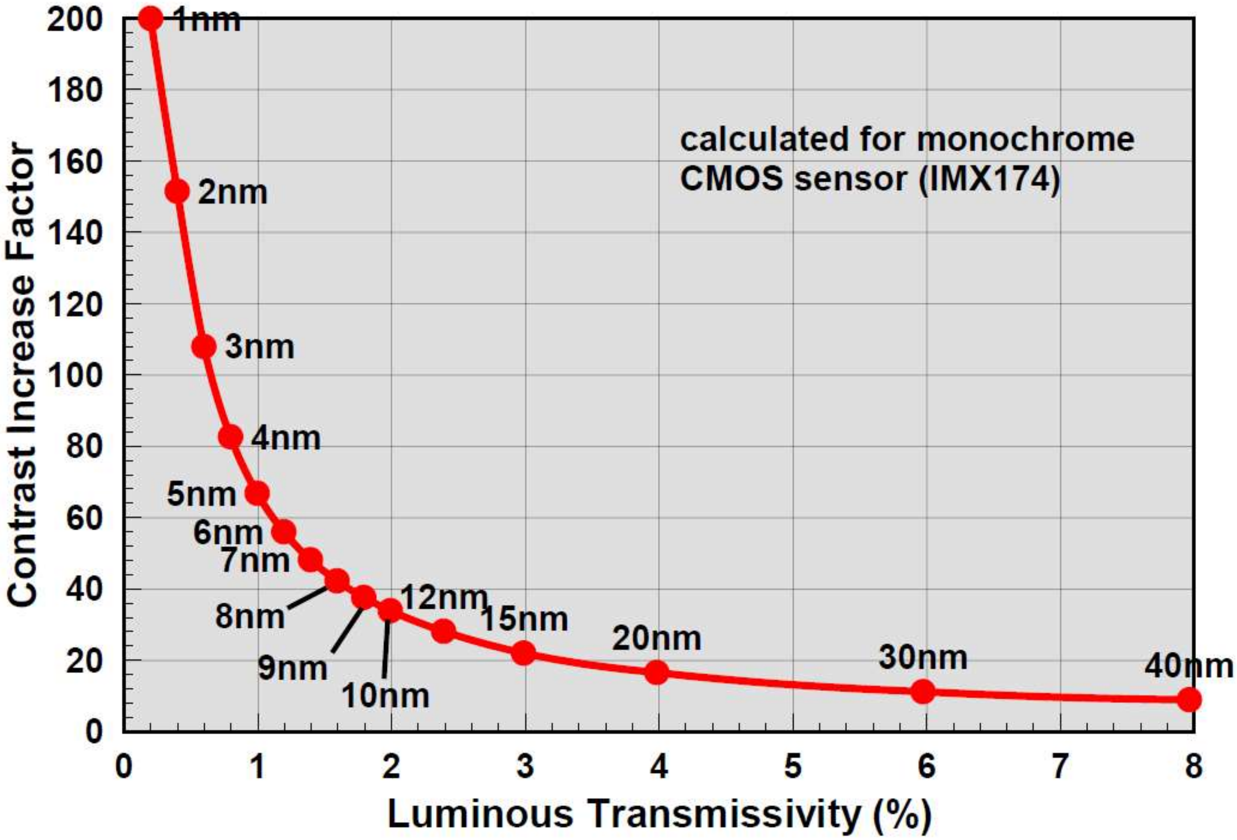

Figure 3 Predicted Generic H-alpha Filter Contrast Increase vs Luminous Transmissivity

The predicted relationship between contrast increase and %LT is very clearly hyperbolic in shape, and is described by the equation $y = C/x$, where 'C' is a constant which for this analysis has a value of ~64. This result is consistent with the observation noted at the top of this article; the narrower your pass band, the better the contrast. In very rough terms Figure 3 also tells us the relative exposure time between different band width filters. For example using a 10nm filter should require about twice as much exposure as using a 20nm filter, but you should get about twice the contrast. Using this graph to estimate relative exposure time does not however include the impact of f-ratio on filter performance. That is what I will show next.

The first step in predicting the impact of scope optical speed on filter performance is to calculate how the transmission rate of H-alpha shifts with angle for each of my generic filters. As I mentioned earlier, I applied the angle sensitivity measured from the Radian Triad filter to my generic H-alpha filters. The results of this calculation are presented in Figure 4. Included on the graph are markers at the angles corresponding to the light cone for $f/2$, $f/3$, and $f/4$.

The second and final step is to use the H-alpha transmission predictions to work out effectively how much light from the telescope is getting through the filter. Light from the center of the telescope's optics passes through the filter at an angle near zero, so the filter transmits H-alpha light the most efficiently. Light from the edge of the optics passes through the filter at an angle that is defined by the system's f-ratio. For a $f/2$ scope that means that the amount of H-alpha light getting through is greatly reduced, and is in fact zero for filters narrower than 4nm. By dividing the telescope's aperture into concentric slices, reading the filter transmissivity for each slice off of Figure 4, and adding up the results, I am able to calculate what the overall impact of the filter is on the amount of light getting through to the sensor.

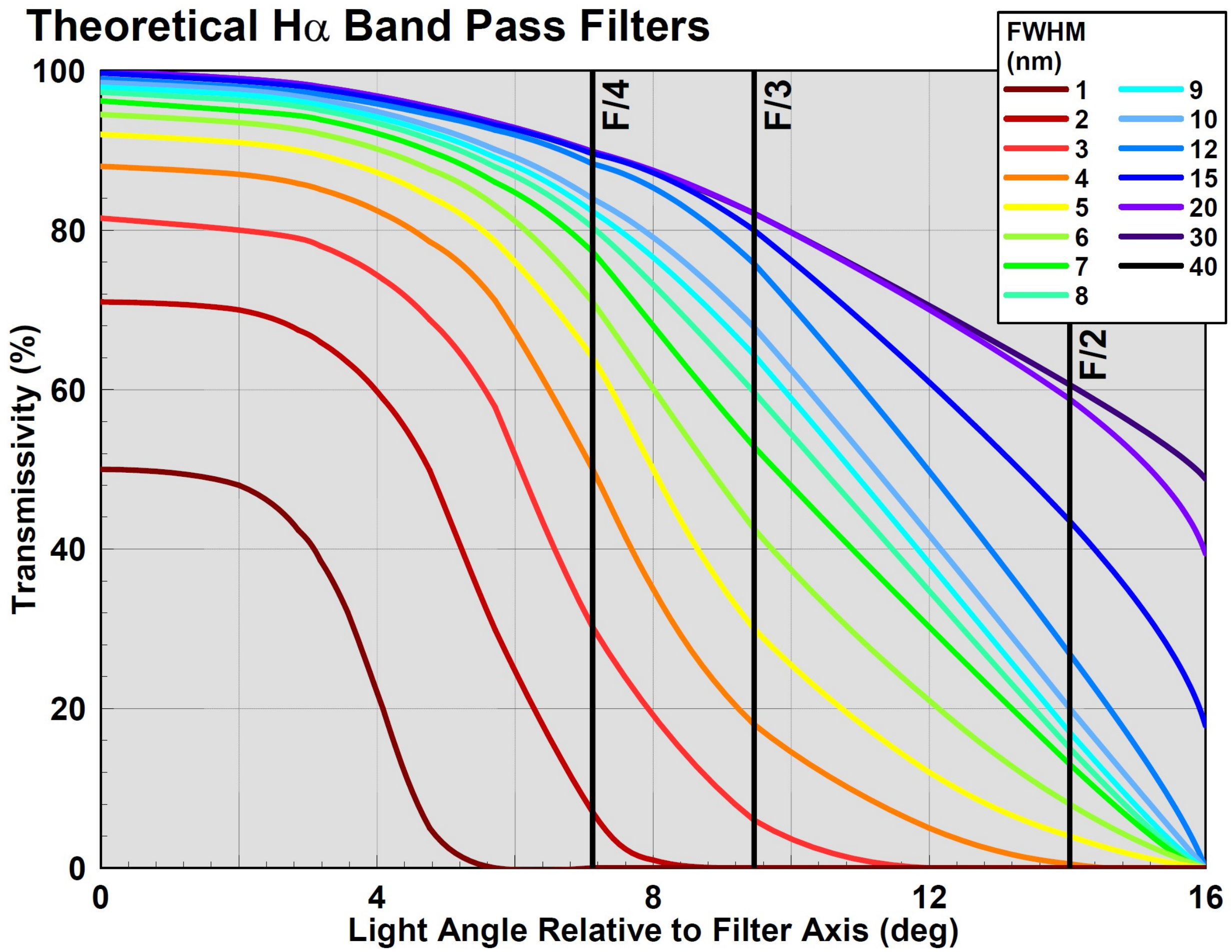

Figure 4 Predicted Generic Filter H-alpha Transmission vs Angle

The result of this calculation is shown in Figure 5. I have plotted the amount of light getting through to the sensor in terms of an effective aperture. Adding a narrowband filter decreases the effective aperture of the scope, and the amount the aperture decreases by depends on how wide the filter's pass band is. In essence, adding the narrowband filter has the same effect as adding an aperture mask to the telescope. The predictions shown in Figure 5 suggest that the effective aperture of the RASA scope starts to reduce rapidly for filters with FWHM less than 20nm, and for a filter with band width as small as 1nm there is absolutely zero light getting through. The refractor is predicted to be much less sensitive to filter band width, showing little effect until the filter FWHM is below ~7-10nm, and still having effectively more than a third of its aperture when using a filter as narrow as 1nm. The sensitivity of the RASA scope to filter band width is much larger than that of the refractor due to its central obstruction forcing a larger percentage of the gathered light to pass through the filter at an angle. The implication of these results is that if you intend to use band pass filters narrower than 6.5nm, you will get much better performance using them with refractors.

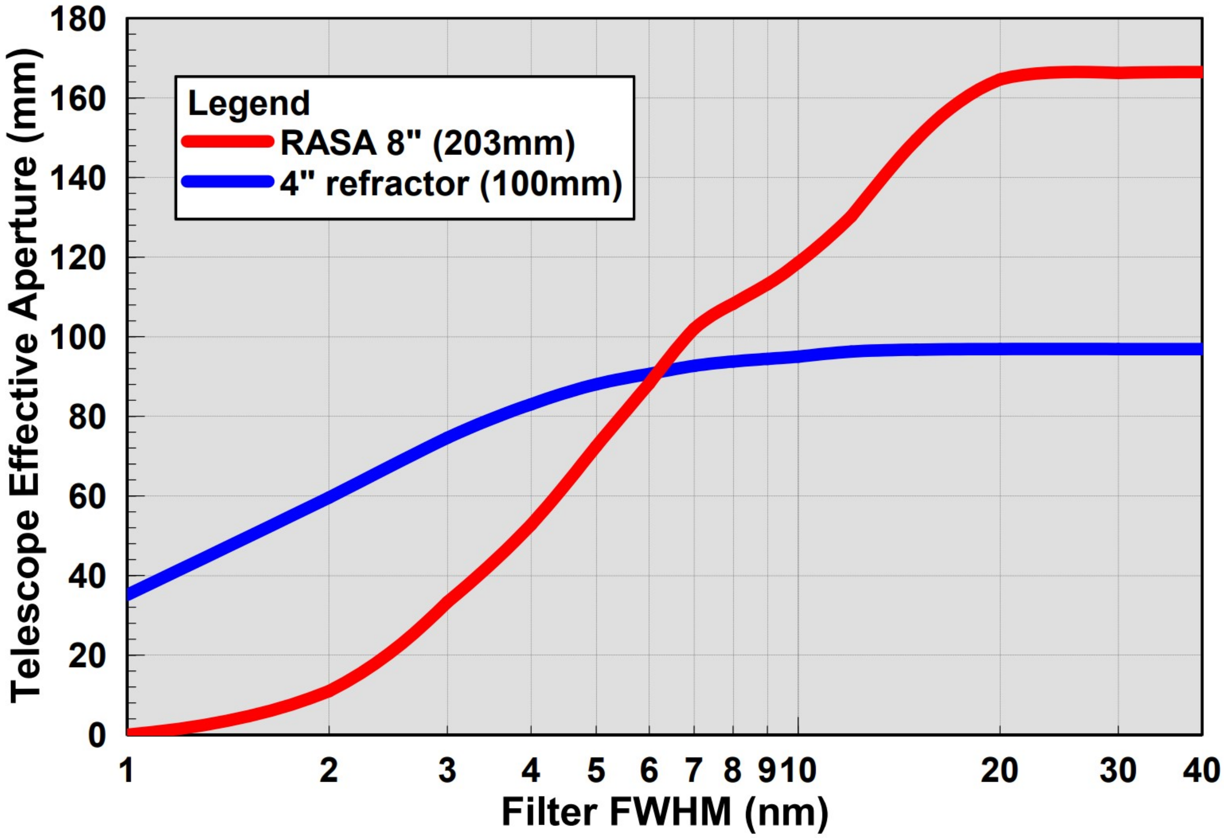

Figure 5 **Predicted Scope Effective Aperture vs Filter FWHM**

Conclusions:

In this test report I have presented an analytical method for predicting the effectiveness of narrowband filters on a $f/2$ telescope. The results of this analysis suggest that $f/2$ scopes such as the RASA are very sensitive to narrow band filters, with the scope responding to these filters as if an aperture mask was added. In contrast, refractors are predicted to be much less sensitive to filter band width, and are therefore a better choice of optics if using filters with FWHM values less than 6.5nm. Despite the impact of using a narrow band filter on your telescope's effective aperture, these filters are shown by observation and by analysis to provide a large increase in contrast on emission type nebulae. Figure 6 brings these two aspects together on one plot: contrast increase, and effective aperture. The effective aperture in the figure has been plotted instead as an f-ratio. Figure 6 summarizes the cost-benefit of using narrow band filters.

One aspect of filter design that I have not discussed in this paper is the idea of placing the filter CWL off-band by design. In my analysis I assumed each filter's CWL was perfectly aligned on H-alpha. As a result, any filter angle off perpendicular will result in a reduction in the transmission of H-Alpha. It is possible however to preferentially move the CWL of the filter up in wavelength so that as the pass band shifts with angle, your desired emission stays in the filter's pass band longer. This is exactly what Astro Hutech has done with their new IDAS-NBX filter. That will be the topic of a future report, so stay tuned!

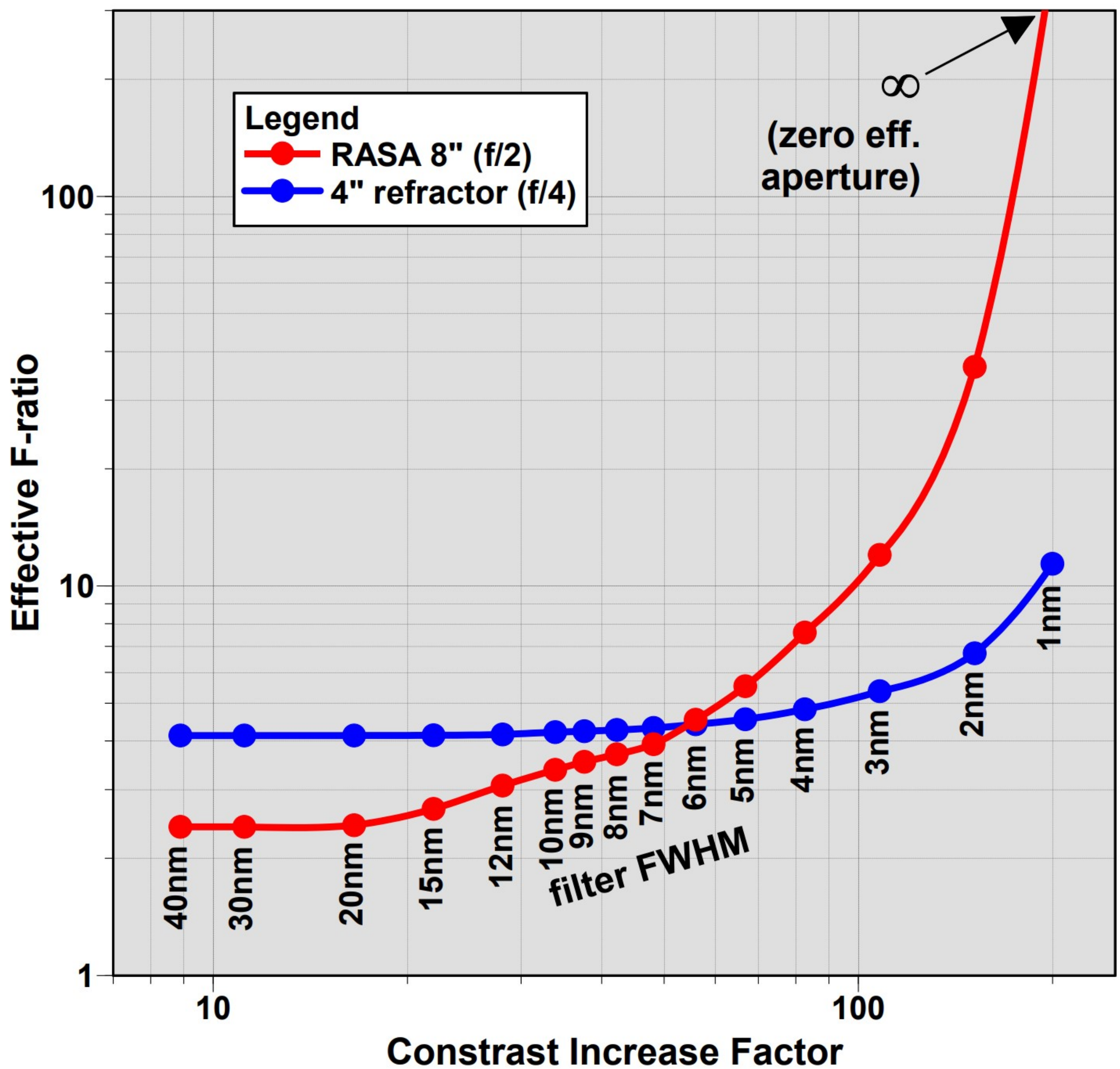

Figure 6 Predicted Scope Effective F-ratio vs Filter Contrast Increase