Understanding Astronomical Filters

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1. Thank you to your president Chuck Real for inviting me to present this evening. It is my pleasure to share what I have learned about filters with the amateur community. First let me give you a quick overview of my background. <>
2. I graduated in '96 with a Masters degree in Aerospace Engineering, specializing in propulsion & aerodynamics. <> Since I graduated I have been working for a defense contractor called Davis Engineering. We design and build infrared suppression systems for ships and aircraft. <> I live in central Ottawa, Canada with my wife and two kids. The skies from my backyard are a nice milky Bortle 9+. <> I grew up keenly interested in astronomy, but did not pursue it actively through my 20's and 30's … there was simply too many other things demanding my time. Around 2009 my kids started showing an interest in astronomy, which in turn reinvigorated my interest in the hobby. <> Over the past 10 years my interests have focused on astronomical filters, inspired largely by my badly light polluted skies and my unwillingness to accept the general lack of useful information on filters. My plan this evening is to share much of what I have learned about filters through <> research, analysis, and testing. <>
3. My astronomical filter presentation tonight has been organized into three parts. The bulk of the talk will be taken up by discussing <> What Are They, and <> How to Use Them. Then at the end I will present <> a brief summary of some of latest filter research I have been working on. <>
4. So without further ado, lets get started with Part 1 – What Are They? <>
5. Here we see a lovely image of a mountain valley, rich in detail and contrast. Unfortunately, more often than not, <> something gets in the way of us capturing the view we want. This is where a filter comes in. There purpose is to <> block light we don't want to see. By doing this we can <> improve the contrast and sharpness of our view, <> emphasize specific features in the scene, or <> help enhance faint details. <>
6. To give you an idea what I mean consider this view of the planet Mars. This is what it looks like to the Hubble Space Telescope. From our vantage point here on Earth <> the view is not quite as nice. Our atmosphere hides details from view. We can however add a colour filter to improve the view. <> For example adding a red filter will darken greens and blues, increasing contrast. Similarly using a <> green filter can enhance the visibility of other parts of the planet's surface. The same is true of <> a blue filter, which can enhance the view of clouds and polar ice caps. <>
7. Another example of what filters can do applies to deepsky objects. This is an image of the Flame and Horsehead nebulae taken from my backyard with no filter. Although the objects are visible, contrast and detail are poor. Now add <> a light pollution filter, and you can see a marked improvement in the scene's contrast and detail. <>

8. There are essentially two types of filters. The first type <> are most commonly referred to as planetary filters, which are in essence <> colour filters, commonly identified using the Wratten numbering system. These filters are all <> absorption type, they block light by absorbing it. <> The other type of filter goes by several names including: deepsky, <> nebula, or <> light pollution. Regardless of the name, these are all <> Interference type filters, they block light by reflecting it. I will explain more what I mean in a moment, for first lets take a moment to talk about special filters <>
9. There are filters on the market that combine both absorption and interference for very specific applications such as: <> planetary observing, <> chromatic aberration correction, <> solar observing, <> and UV/IR blocking. Although these are also very useful filters to the amateur astronomer, <> let's ignore them for now. <>
10. Getting back to how filters work, consider this graphical representation of an absorption type filter. These filters consist of <> dye infused glass or a coloured gel that is sandwiched between two thin layers of glass. <> Molecules in the die are designed to absorb some wavelengths but not others. <> The result is a filter than can selectively block light but in a rather imprecise way, in broad bands with gently sloping cut-offs. By the way, if you were wondering where Wratten numbers come from, Frederick Wratten was a British inventor and co-founder of the first photography company. He devised a standard catalog of filters for use with terrestrial photography. <> He and his partner C.E.K. Mees sold their company to Eastman Kodak in 1912. Kodak still manufactures Wratten filters to this day. <>
11. Interference filters are rather different than absorption filters. They are made by adding <> 10's to 100's of thin alternating layers on a glass substrate. <> Each layer is made from a material with a different refractive index. <> At each boundary between layers, light partly reflects and partly refracts. <> By choosing the thickness of these layers it is possible to have all the reflections of undesired wavelengths out of phase with each other so they cancel out , allowing only the desired wavelengths through. <> Interference filters made more than 10 years ago tended to sandwich the layers between clear glass just like colour filters because the refractory materials used were relatively soft. Now the materials used are harder than the glass substrate and do not need to be protected. <>
12. For the next couple of slides I will describe some commonly used terminology, the first being the idea of a spectrum. <> A spectrum is a quantitative visual way of presenting how well a filter transmits light at different wavelengths. The example spectrum shown here is the typical format for presenting filter spectra, with wavelength on the horizontal axis and percent transmission on the vertical axis. <> It allows for easy comparison between filters, <> and provides information on how the filter will perform in different situations. <>
13. The next term to discuss is Luminous Transmissivity. %LT is essentially <> a measure of generally how dark a filter is, on average what percentage of light is getting through. <> It is calculated based on the specific sensor the filter is to be used with, so a filter will have a different %LT if used with the human eye or a camera. <> For whatever reason, it seems that the value of %LT that you sometimes find quoted on manufacturer's websites is the value for daytime human eye use. For those interested, the actual calculation of %LT <> is

simply an average where the filter transmissivity at each wavelength is weighted by the sensor sensitivity at the same wavelength. <>

14. The next item I'd like to go over is some basic filter nomenclature. <> This filter spectrum plot is for something called a Low-Pass filter. All the light at wavelengths below the cut-off are passed, and all those above are blocked. <> The opposite of this filter is a High-Pass, where all wavelengths above the cut-off are passed and those below are blocked. If we combine these two spectrums together <> we get a Band Pass filter, in this case a wide band pass. This spectrum type is defined by its center wavelength, and its band width, also referred to as its Full Width Half Maximum. The FWHM is literally the wavelength width from one side of the band to the other, with the cut-off wavelengths placed where the transmission value is ½ the band's maximum. Band pass filters can come in any width, from wide <> to narrow. It is also possible to have more than one pass band. <> This for example is a multi-narrowband spectrum which I will discuss more later. The idea of multiple bands can be taken to the extreme <> with filters that have so many pass bands they are sometimes referred to as comb or notch filters due to the shape of their spectrum. I refer to these filters simply as multi-band pass. <>
15. Now that we have some filter lingo under our belt, let's look at some actual filter spectra, starting with absorption type filters. <> Blue and green filters all tend to be wide band pass filters. <> Yellows, oranges, reds, and infrareds are all high pass filters. <> Pinks and purples are a combination of band pass and high pass that block green. Browns are high pass filters with additional green and blue. <> All of these filters have gentle cut-offs and relatively low peak transmissivity values typical of absorption type filters. Colour filters with steep cut-offs and high transmission are available <> but they are all a combination of absorption and interference types. <>
16. Most of the interference type filters made for astronomy are for use with deepsky objects. They are designed <> to selectively pass desired emission wavelengths from nebulae, namely: Hbeta, O-III, Halpha, N2 and S2. The thing that distinguishes one filter from another <> is the extent to which it blocks light pollution. In an attempt to make some sense of things, I have created my own deepsky filter categories. Probably the most common category <> is Broadband. These filters have a single large pass band around Hbeta and O3, and are meant for visual use. They therefore do not necessarily pass Halpha. I have, based on band width further sub-divided the category into Extra-Wide, Wide, Medium, and Narrow. The next major category is <> Narrowband. These filters have a single narrow pass band around one of the nebulae emission bands of interest. Halpha, N2 and S2 filters are only for imaging as our eyes cannot see these wavelengths when dark adapted. Narrowband filters in the 10 to 20 nm wide range are typical of visual applications, and less than 10nm wide are meant for imaging. The next major category is <> Multi-Band. As discussed earlier these filters pass multiple bands, and tend to block specific wavelengths known to predominately contain light pollution. Overall their ability to block LP is moderate to poor, but they do very well at providing a nicely colour balanced view. They are less effective around modern LED lighting due to their passing a lot of the blue part of the

spectrum. The final deepsky filter category is a relatively new one that I call <> Multi-Narrowband. These filters have narrow pass bands around more than one nebula emission. They are often referred to as dual, tri, or quad band filters depending on how many bands they pass. They are designed to maximize the amount of LP blocked, and have recently become very popular with astrophotographers who use one shot colour cameras. <>

17. This concludes Part I of my presentation. If there are any questions on the material covered so far, I am happy to answer them. Otherwise we can proceed on to Part 2. <>
18. Lets open the discussion on how to use filters by starting with solar system observing. Recall that these filters are <> used to darken some features but not others. This is accomplished <> primarily using absorption type filters. What filter to use is <> unfortunately very subjective. <> There is a lot of trial and error required, and in the end it comes down to <> personal preference. <>
19. If you like you can read astronomy books or find online resources that will tell you the best filter to use for observing the planets. <> The end result will be a list as long as your arm of the filters you simply must have in your kit. The alternative is to take the advice of a poor shmuck who actually took the time to test all of these combinations for himself … ah-hem! <>
20. Personally I have found most filters do very little in improve the view. The list of filters that actually do something significant to the view is short. <> On Mars or Jupiter a magenta filter like a Wratten #47 or #30 does a good job of enhancing contrast. <> A red filter on the Moon or Mars also works well to sharpen the image and improve contrast. <> A light tan or orange filter like a Wratten #81 or #85 is also beneficial in enhancing details in the bands on Jupiter and Saturn. If you often observe a nearly full Moon or Venus, <> you may also want to use a variable polarizer or neutral density filter to cut the brightness. <> If you are lazy like me and just want one all-purpose filter for planetary observing, you may want to consider <> a special type filter called a Moon & Skyglow or more generically a neodymium filter. <> One final thing to remember is that filters block light, so your view will be darker. <> Dark filters, those with a low value of %LT, may require a large scope to use effectively. <>
21. For those of you who are imaging solar system objects, contrast, colour, etc can all be controlled after the fact during post processing, <> so a colour filter is not needed. <> The main concern is Seeing, the unsteadiness in the view resulting from turbulence in our planet's atmosphere. <> At a minimum you should use a UV/IR cut filter to sharpen your view, or <> try filters passing red or infrared only as seeing has less of an impact at long wavelengths. <> Again, a good all-purpose filter for imaging exists, <> the Moon & Skyglow I mentioned earlier does a good job of cutting UV/IR, and enhancing contrast. <>
22. Moving on to deepsky observing, let's review again what sort of benefits can be realized when using a filter. <> This is a sketch I made of M42 from my backyard in Ottawa using a 4" refractor. Without a filter all I could make out was a smudge of nebulosity around the trapezium stars. <> Adding a medium broadband filter improved the contrast and allowed a bit more of the features around the perimeter to be visible. <> Moving to a narrowband O-

III filter resulted in a large improvement in the amount of faint structure that I could see. <> Finally, the multi-narrowband gave the best view, with subtle differences in the brightness of the features now visible. <>

23. The impact of different filters can also be visualized using imagery. <> This is an image of the North American nebula captured from my backyard, also using a 4” refractor. With no filter it is difficult to make out the nebula amongst all of the many Milky Way stars. <> Adding progressively narrower filters, from Wide Broadband <> to Medium Broadband brings out more and more detail in the nebula. You will also notice that the stars are becoming progressively fainter. <> Adding a UV/IR cut filter to the Medium Broadband filter further increases the image contrast. Further improvement in contrast is achieved by moving to progressively narrower band passes, first <> a Multi-Narrowband filter, and finally <> a Narrowband Halpha. Note that all 6 images have the same total exposure time of 5 minutes. <>
24. So, how does one choose what deepsky filter to use? Well, <> like planetary filters we want to increase contrast, and <> interference type filters are the most capable of delivering accurate high transmission pass bands around our wavelengths of interest. <> The best filter to use depends on a number of things including: <> the nature of your light pollution, <> the type of deepsky object you are trying to observe, <> the size and type of optics you are using, <> and in the case of imaging or EAA the tracking capability of your mount. The next couple of slides discuss these factors in more detail, starting with …<> light pollution.
25. Light pollution is <> all the light entering our telescope from sources located between us and the deepsky object. The most obvious source of light pollution <> comes from man-made outdoor lighting, some of which illuminates our view directly, and <> some illuminates the sky by scattering off dust and moisture in the atmosphere. There is also a naturally occurring component of light pollution generally referred to as <> sky glow. This light is emitted by atoms in the Earth’s upper atmosphere that were energized by the Sun’s UV rays during the day. The final naturally occurring source of light pollution is of course <> the Moon. It acts like a big mirror, reflecting the Sun’s rays back at us, thus giving it a broad light spectrum. As suggested by the component spectra shown on this slide, light pollution consists of both broadband and narrowband emissions. To understand the implications of this on our filter choices we next have to look at the spectra of deepsky objects. <>
26. Deepsky objects can be grouped into two categories based on the nature of the light they give off. The first category is <> broad spectrum objects. This includes galaxies, star clusters, and reflection nebulae … basically anything that we can see because of light emitted from stars. The fact that these objects have broad spectrums makes them <> very difficult to pick out from light pollution using a filter. The second category of objects are <> narrow band emitters. These objects include HII regions, planetary nebulae and super nova remnants, any object that we can see because of light given off by excited gases like Hydrogen or Oxygen. Because these objects emit at very specific wavelengths, <> they are much easier to separate from light pollution using a filter. <>

27. The last thing to consider before choosing your deepsky filter is telescope aperture. <> Recall that filters block light, resulting in a darker view. <> This means that the %LT of a filter will limit the aperture of scope you will be able to use it with visually. <> This plot provides a general recommendation for how dim a filter you can use with different sized scopes. <> At the top I have marked off the ranges of %LT that are common for the different categories of deepsky filter. So for example if you wanted to use a typical Medium Broadband filter with a 4" refractor, you'd probably be okay. Trying to use a narrowband filter with a 4" refractor though is probably pushing your luck. For imaging or EAA <> there is no such limit on scope size because you can simply compensate with more exposure time. This does however mean that you will need progressively better mount tracking the narrower the filter is you want to use. There is one final thing to note in regards to aperture, <> the impact of a filter on broad spectrum objects is much worse than for narrow band objects. <>
28. At last we have come to where the rubber hits the road: what is the best deepsky filter to use? If you are observing or imaging a narrowband object, the best filter to use is <> the narrowest band pass filter your aperture or mount tracking will handle, regardless of how much light pollution you have, be it Bortle 2 or Bortle 9. Adding an IR cut filter can also help to improve contrast if using a camera. If you are observing broad spectrum objects from a dark sky, <> don't use any filters for visual observing. If imaging, an IR cut filter can help contrast but the improvement is small. If visually observing broad spectrum objects from a light polluted location, <> I'm afraid there isn't a filter that can help. If using a camera however, a wide to medium broadband filter that passes infrared works best. Even better contrast can be achieved using an infrared high pass filter, although long exposure times will result. I have one additional thing to note about <> trying to image in infrared using a refractor. <> Most ED doublets and APO triplets are okay, but achromats do not do well focusing IR light along with the visible spectrum, resulting in fuzzy bloated stars. <> The same is true of many camera lenses. For these types of optics you can see a large improvement in your images by using an IR cut filter. <>
29. Besides the beneficial effects mentioned already, filters have a number of other effects on your observing or imaging. The first thing to note is that <> filters change the scene's white balance. <> Broadband filters add a magenta hue, O3 a green hue, Hbeta cyan, Halpha red, and IR pass a brownish red colour. <> Some filters are better than others for white balance, for example Multi-band filters give a good colour balanced image. For those of you who are imaging, <> post processing may or may not be able to completely correct for the hue added to the scene by the filter. Another effect to note is that <> filters will change your focus slightly because of refraction, enough that if you change from one filter to another there is a good chance you will need to refocus. That is why many users like to purchase all their filters from the same manufacturer, so the glass is the same thickness, permitting filter changes without refocusing. Finally <> filters add two more surfaces in your optical train to have <> reflections off of although anti-reflective coatings can help. Filter surfaces can also collect <> dirt dust or dew, so yet another thing to keep clean. <>

30. The final aspect of astronomical filters to talk about is cost. <> It is tempting to save money and go with a cheaper option, but quality really does suffer. Cheap filters are prone to: <> reflections, delamination, poor machining, optical distortion, poor optical transmission, and various other issues. <> There are a lot of filter manufacturers available, perhaps too many. I put them into 5 groups ranging from <> premium filters all the way down to filter brands that you should avoid. Astronomik and IDAS are two of my favourites in the high quality category; and amongst the Good Value manufacturers I have had good success with Optolong. <>
31. That brings us to the end of Part II. I would be happy to answer any questions the audience may have on this material. Otherwise we can move along to the third and final part of my talk. In part three I have brought some slides talking about three major areas of research I have been working on over the past year. <>
32. The first area of research is the ongoing race for the best Multi-narrowband filter. <> These filters have become very popular with one shot colour imagers. <> This has motivated filter OEM's to work on developing the "ultimate" filter. They have worked to produce filters with <> progressively narrower bands in order increase contrast to the max. <> Presently there are 15 different models of multi-narrowband filter available commercially. I have plotted them here in terms of the width of their O-III and Halpha bands. The dot colour denotes the cost of each filter. Although I have test many of these filters over the years, most recently I did a comparison between the top four performers: <> the IDAS NBZ, Optolong L-eXtreme, Antlia ALP-T, and Radian Triad Ultra. I made both bench-top spectrometer measurements of these four filters, and deepsky object image comparisons. My testing resulting in plots such as this <> that shows not only how each filter performs relative to the other, but how that performance changes with optics f-ratio. My findings were that the ALP-T was the best all-round performer, and that the Radian Triad Ultra on average did not perform significantly different than the much less expensive L-eXtreme. <>
33. The topic of narrowband filters and fast optics is second main area of research over the past year. If you can recall from earlier, <> an interference type filter's band pass is defined by the thickness of its layers. Thus, if you <> change the thickness of the layers, you change the filter's pass band. Well it so happens that <> if light is directed through the filter on an angle, you effectively increase the thickness of all the layers. It also is the case that <> the faster your optics, the steeper the light cone it produces, in other words light passes through the filter at more of an angle. The net result of trying to use narrowband filters on fast optics is <> the center wavelength of the filter shifts down, <> the peak transmission is reduced, <> and the band width increases. <>
34. The graph shown on the left is of an actual 3nm wide Halpha filter that I measured with my benchtop spectrometer. You can see how the pass band shifts down and left as the angle of the light passing through the filter is increased. In terms of what this does to how your scope works, <> it is as if you added an aperture mask. <> This plot on the right shows what I mean. These curves are my prediction of the effective aperture that results from using an Halpha filter of varying band width on scopes of different f-ratios. Refractors down to a

speed of f/3 do not appear to be affected too much by narrowband filters as narrow as 7nm. A scope as fast as f/4 is probably fine to use filters as narrow as 5nm, and an f/5 scope as narrow as 4nm before one would notice any degradation in scope performance. Scopes as fast as f/2 are severely impacted by narrowband filters, especially scopes with central obstructions such as RASA or SCT's with Hyperstar. Fortunately filter OEM's have the backs of fast scope owners as there is a growing selection of <> pre-shifted filters available for use with fast optics. The center wavelengths of these filters are positioned slightly to the right of the desired nebula emission so that when the band shifts down on fast optics, the pass band is properly centered where you want it. <>

35. The final area of filter research I have been working on lately is evaluating narrowband imaging filters, sulfur – oxygen – hydrogen or SHO. <> This research was triggered simultaneously by Optolong sending me a set of their 3nm SHO filters to test, and a friend of mine asking me to evaluate the Chroma 3nm Halpha he just bought. In trying to measure the spectrum of these very narrow filters I learned that <> I had to upgrade my spectrometer to have a better resolution. It took some time and delicate surgery on my spectrometer, but I am now able to measure filters to a resolution of 0.5nm. <> This is a plot of some of my measurement results using the newly upgraded equipment. The next step is the test these filters in the field, <> which I started doing just this past Monday night using IC1318 in Cygnus as my target. <> So far the Halpha filter results are looking very interesting, showing a clear trend in SNR with filter luminous transmissivity. Stay tuned for more on this topic. <>
36. Well that is it. Thank you everyone for tuning in tonight. If anyone is interested in reading my various test reports, including the recent material I covered tonight, you can access it from my website: karmalimbo.com/aro. If there are any final questions, I would be happy to answer them.