Visual Astronomy Filter Research

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1.0 The Great Filter Filibuster

There are many books and websites out there that will describe the virtues of using filters to enhance your telescope viewing experience. In my attempt to understand what filters are best to have in my own accessory case and why, I have had to glean small bits of information from many different places. Most sources compare a couple filters to each other, and only a very small number of sources site real measured data instead of qualitative observations. No single website or book compares all the available filters to each other, and tries to explain why one is better than the other. In this web-paper I have attempted to collect and present information about astronomical filters from a purely technical point-of-view. I'm an engineer by trade, so I am more comfortable making comparisons and choices based on real data, which is what I've tried to do here.

Figure 1 An assortment of planetary (colour) filters

Filters improve what we see by removing what we don't want to see from the image. For example a light pollution filter improves the view of faint deep-sky objects by removing the wavelengths of light from city lights, or the contrast of Mars' blue and red features are improved by using a filter that blocks green light, etc. Regardless of the filter type, they all work by blocking some combination of wavelengths of light. So by knowing what wavelengths of light are being blocked by a filter and by how much, we can determine how affective it might be for a specific application. But where does one get this kind of information?

Figure 2 An example of deep-sky (band-pass) filters

The filter property that I am talking about is its spectral response. It is a measure of the percentage of light passed by the filter at each wavelength of light. I have been hunting high and low to gather the spectral responses of as many filters as I can. Most data I have found on the internet, some I got directly from the manufacturer, and some I have figured out myself by experiment. I have grouped my research into two broad filter categories:

1. planetary (colour) filters; and
2. deep-sky (band-pass) filters.

My interest in filters is strictly in relation to visual astronomy, so let's begin with a look at the human eye.

2.0 The Human Eye

The human eye is a wonderful thing. Without it there wouldn't be much point to all this filter research I've been doing! Anyhoo, it is important to understand how the human eye responds to different wavelengths, and under different conditions. The retina, the part of our eye that converts light into nerve impulses, is covered in two types of receptors: the colour sensitive cones, and the non-colour sensing but more sensitive rods. Figure 3 below shows a plot of rod and cone density vs. position on the retina. Cones are located in a very narrow area at our central focus, and the rods are located over a broad region on either side of the central focus. It is easy to see from Figure 3 why the "averted vision" method of seeing faint objects works; it lines the object up with the area of peak rod density.

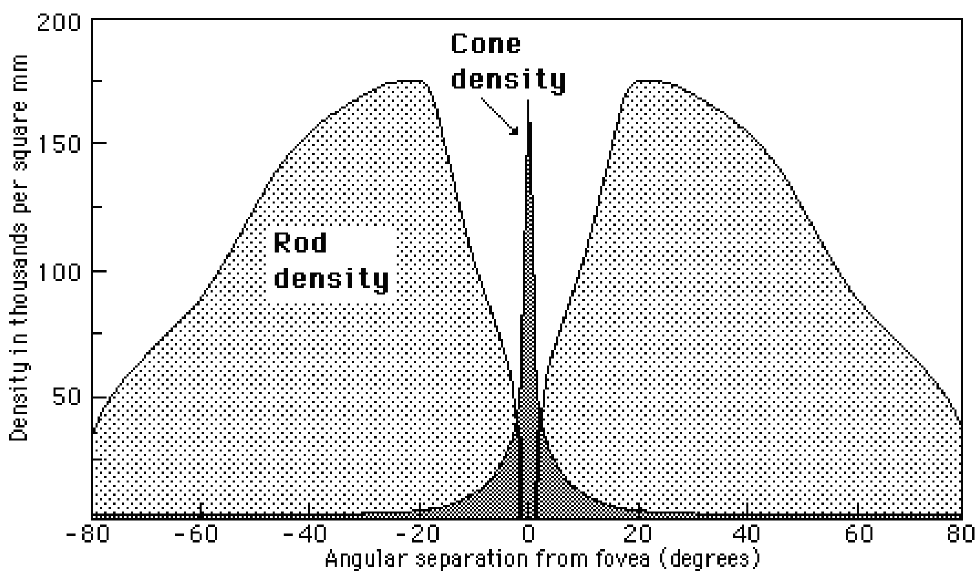


Figure 3 Human Eye Rod & Cone Density Distribution

One fascinating feature of the eye is its ability to change what receptors it uses under different lighting conditions. In bright light our eyes capture visual data using its cone receptors, while in low light our eyes use the more sensitive rod receptors. As it happens, the sensitivity of the rods and cones to different wavelengths of light is different. As a result of this, our ability to perceive different colours (wavelengths of light) changes depending on whether our eyes are light adapted (photopic) or dark adapted (scotopic). Figure 4 is a plot of the spectral sensitivity of the human eye under these two conditions. This is an important point since the state of our eyes' light adaptation will affect how the filters I discuss later will work. The plot also includes vertical lines marking some key emission wavelengths; these will be explained later in the chapter on "Using Deepsky Filters". PDF or XLS versions of this data are available upon request.

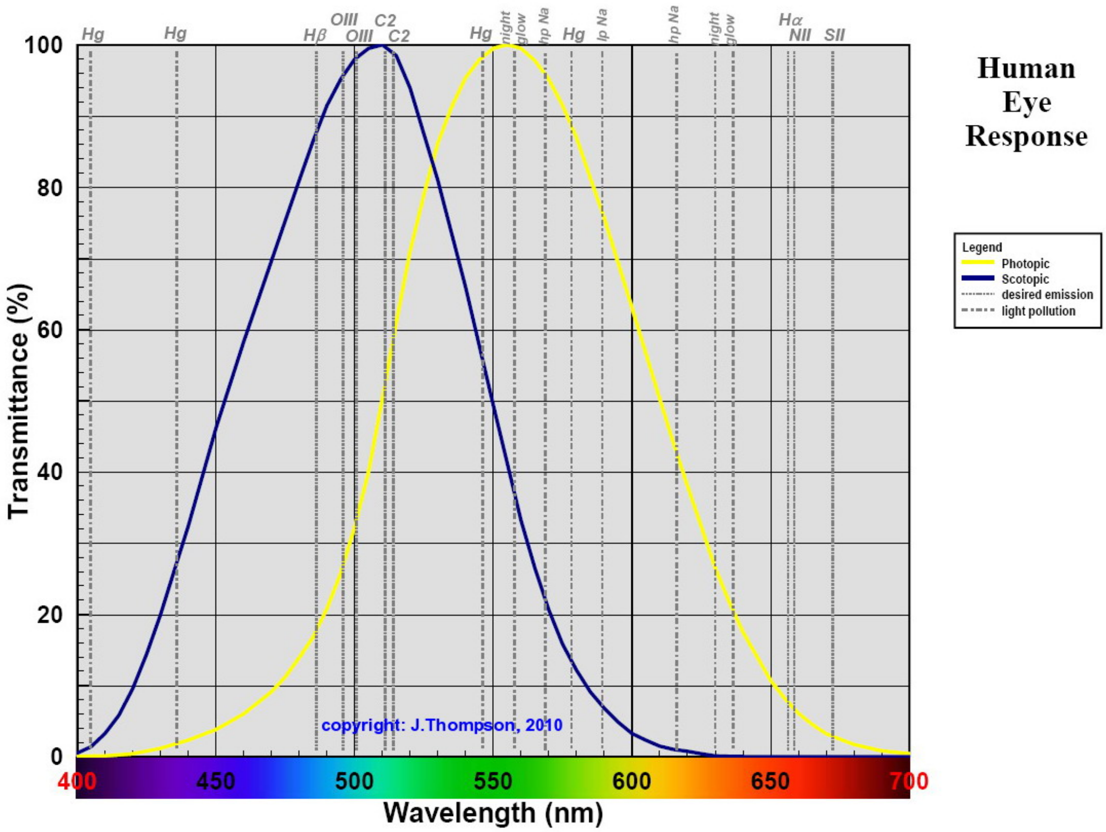


Figure 4 Human Eye Spectral Sensitivity

It is interesting to note from Figure 4 that when light adapted our eyes are at peak sensitivity for the wavelengths of ionized Mercury (Hg) and Sodium (Na), not surprising then that these lamps are so popular - thus the light pollution! Also, our dark adapted eyes are at peak sensitivity for Hydrogen Beta (Hβ) and doubly ionized Oxygen (O-III) which are common wavelengths emitted by nebulae, and Acetyl (C2) which are common emission wavelengths for comet tails - how convenient!

To help boil down and compare the spectral response data for the various filters there is a useful parameter called the Luminous Transmissivity. This fancy term is simply the average % of light passed by the filter across the range of visible wavelengths, from 400 to 700 nm. The average is calculated by multiplying the filter's % transmission at each wavelength by the corresponding human eye spectral sensitivity, summing up and dividing by the number of wavelength samples (I had to figure this calculation out for myself). From what I can tell, the % transmission values quoted by manufacturers are always that corresponding to the light adapted eye. In the research I present later, I have calculated both the photopic and scotopic transmissivity, since in all likelihood I will be using these filters in the dark…duh!

Now the nitty gritty, Planetary Filters.

3.0 Planetary (Colour) Filter Research

Probably the least explained but most common accessory in everyone's case is colour filters. They are lauded by many for their ability to improve the contrast of certain features on the moon and the planets…but why? Why does one filter work better than another? Do I need 3 shades of red? Why are there no pinks? What's the difference between violet and indigo?

Figure 5 The Available Spectrum of Colour Astronomy Filters

I'm a curious chap, and used to answering questions by first gathering all the data I can. So, working within the theme of my research I decided to put together a database of spectral response curves for commonly available colour filters. The problem of course was that nobody has that data. None of the manufacturers I researched have spectral response data for standard colour filters. Lucky for us colour filters for astronomy find their origin in terrestrial film photography. Some time ago Kodak established a colour filter standard called the Wratten #. The filter numbers we are used to seeing in astronomy are in fact these Wratten #'s from the original Kodak system. So, where does one find spectral data for Kodak Wratten filters? There was apparently a photography book published by Kodak that is out of print now, but I instead found the data in the "CRC Handbook of Chemistry & Physics, 1st Student Edition" which just happens to be sitting on my shelf at work. The data tables in the book also included the % transmissivity (photopic), a parameter that filter manufacturers do quote. You can download a PDF of the Wratten filter tables from the "Reference" chapter.

I used the Kodak spectral response data to calculate my own % transmissivities, and compared that to the values quoted by different filter manufacturers. I noticed a lot of discrepancies: some filters obviously quoting other filters' transmissivities (eg. green quoting transmissivity for dark green), other filters being just completely out-to-lunch. The out-to-lunch filters made me wonder; was the Wratten data not applicable to these filters, or was the manufacturer's quoted transmissivity data wrong? The only way to know for sure was to have measured data from a reputable source, me.

Figure 6 Main Components of My Make-Shift Spectrum Analyser

Yes, I did perhaps buy more filters than I will ever use, but I wanted to cover as many of the available colour filters as possible. I purchased one of every available planetary filter colour I could find, from various sources; whatever was the easiest and cheapest source. Some are Hirsch, some Meade, and some Lumicon brands. I have also purchased a number of other common photographic filters that are not available for astronomy but that I thought looked interesting. There is a large number of other Wratten and Colour Compensating filter colours out there, but they are not easily attainable in glass (by "attainable" I mean can be found easily for sale AND sell for a relatively low cost <$15). A visual comparison of the available filter colours can be found in the "References" chapter.

Next I purchased an accurate but reasonably cheap light meter off Ebay. Finally (the kicker) I purchased a series of laser pointers to finish off my half-assed spectrometer, 6 laser pointers in all: purple (405 nm), blue (473 nm), green (532 nm), yellow (589 nm), red (635 nm), and red (650 nm). With the laser pointers plus a normal white light source I was able to measure the photopic transmissivity of each filter plus the response of the filter at each of the six laser wavelengths. I later discovered/realised that my "white" light source, a "daylight" compact fluorescent, was not really equivalent to white. I apparently require a specially calibrated lighting standard to measure the photopic transmissivity. Oh well. At least I was able to use the laser data to give me the basic shape of the response curve that I could then use with the Kodak data to come up with the final best guess at the actual spectral response of each colour filter. The basic laser measurement consisted of putting the light sensor inside a box with a 1cm square hole cut in it. Each laser was in turn secured to a support overtop of the box, aiming directly at the light sensor through the hole in the box. I used the peak-hold feature of the light meter to give me the peak Lux value for a 10 second period, with and without the filter in place. I found that the laser pointer output varied up and down over time, so I made a without filter measurement for every with filter measurement. Instead of using batteries in the laser, I hooked it up to an external 3VDC supply with a microswitch, allowing me to switch the laser on and off without changing its aim at the sensor. Filters were centred over the 1cm square hole in the box during a reading.

Figure 7 My Spectrum Analyser in Action

The results of my measurements, and subsequent curve fitting are shown in the plots below. I added some additional curves out of the Kodak data just for interest sake. I have also added a couple of special filters available for planetary observing: the Orion Mars filter, the Baader Planetarium Fringe Killer, and the Denkmeier Optical Planetary filter (which I think is similar to the Televue Bandmate Mars-A). Additional information on these special filters is covered in the Deep-Sky chapters under the category "Special". There are two graphs on each plot, the upper one shows the spectral responses as specified by Kodak, and the lower one is as I measured it. In some cases there is a big difference between spec and measured, mostly for the astronomy filters. The photography filters were all a pretty good match to the Kodak spec. I have reasonably high confidence in my laser data since I repeated about 25% of my measurement points because I thought they looked incorrect, and for all but a couple got the same measured value. PDF or XLS versions of this data are available upon request.

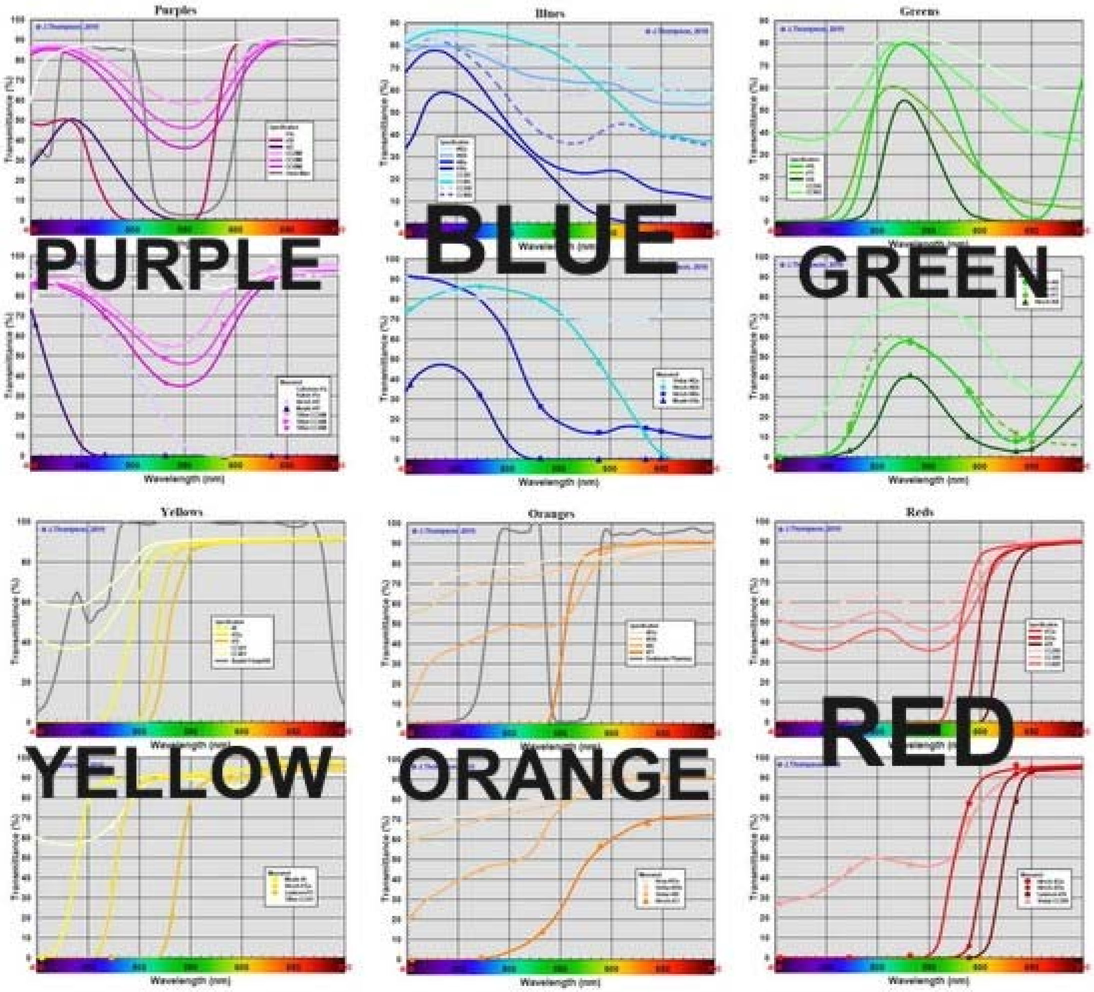


Figure 8 Colour Filter Spectral Response Curves

With the spectral response of each colour filter determined, I was able to calculate the photopic and scotopic transmissivity of each filter. I have summarized this data in Table 1 below, which is also available as a PDF or XLS.

			Specification		My Measured			
Colour Group	**Colour**	**Wratten #**	**Photopic %Trans**	**Scotopic %Trans**	**Photopic %Trans**	**Scotopic %Trans**	**Manuf. Of Tested Filter**	**Notes**
purples	lt pink	1a	86.0	85.7	88.4	90.6	Celestron	different from spec
	lt pink	1a	86.0	85.7	87.1	85.9	Kakon	ok match to spec
	dk magenta	30	28.9	10.2	-	-	-	-
	dk violet	47	2.9	17.6	17.0	39.5	Hirsch	colour actually lt violet
	dk violet	47	2.9	17.6	0.1	1.9	Meade	very different from spec
	lt magenta	cc20m	67.5	70.7	68.5	67.8	Tiffen	good match to spec
	lt magenta	cc30m	58.6	62.7	59.3	62.2	Tiffen	good match to spec

	magenta	cc40m	50.6	55.3	50.4	54.8	Tiffen	good match to spec
	Orion Mars	-	29.2	52.6	-	-	-	colour is dk magenta
blues	lt blue	82a	72.5	76.6	71.8	76.6	Vivitar	ok match to spec
	lt blue	82b	64.3	70.6	61.7	81.1	Hirsch	colour actually cyan
	blue	80a	27.8	46.0	24.6	54.4	Hirsch	different from spec
	dk blue	38a	16.4	37.8	1.9	14.9	Meade	very different from spec
	lt cyan	cc20c	78.5	85.4	-	-	-	-
	cyan	cc40c	69.7	81.7	-	-	-	-
	lt blue	cc20b	62.2	70.6	-	-	-	-
	blue	cc40b	42.5	56.5	-	-	-	-
greens	green	56	52.1	45.4	40.4	35.6	Meade	different from spec
	yellow-green	11	39.6	38.8	67.8	62.0	Hirsch	colour actually lt green
	yellow-green	11	39.6	38.8	42.3	39.4	Kodak	good match to spec
	dk green	58	23.3	22.4	22.1	19.4	Hirsch	different from spec
	lt green	cc20g	77.6	75.6	-	-	-	-
	green	cc40g	67.3	64.0	-	-	-	-
yellows	lt yellow	8	83.7	52.9	91.7	85.6	Meade	different from spec
	yellow	12a	75.3	31.1	86.3	65.2	Hirsch	different from spec
	dk yellow	15	67.6	22.1	75.7	15.9	Lumicon	ok match to spec
	lt yellow	cc20y	89.4	79.9	88.2	78.9	Tiffen	good match to spec
	yellow	cc40y	87.9	71.4	-	-	-	-
	Baader Fringe Killer	-	98.4	88.3	-	-	-	colour is lt yellow
oranges	lt brown	81a	82.2	78.5	81.4	76.8	Hoya	good match to spec
	lt brown	81b	77.1	72.2	82.5	73.3	Vivitar	ok match to spec
	lt orange	85	63.5	47.3	73.6	53.0	Vivitar	different from spec
	orange	21	47.5	7.7	34.5	9.2	Hirsch	very different from spec
	Denkmeier Planetary	-	52.8	54.3	-	-	-	colour is brown
reds	lt red	23a	27.3	1.8	33.7	3.0	Hirsch	ok match to spec
	red	25a	15.8	0.4	14.4	0.4	Hirsch	good match to spec
	dk red	29	7.1	0.1	7.2	0.1	Lumicon	good match to spec
	lt red	cc20r	65.9	61.0	-	-	-	-
	lt red	cc30r	56.7	50.7	56.7	45.5	Vivitar	ok match to spec
	red	cc40r	48.2	41.2	-	-	-	-

Table 1 Summary of Colour Filter Transmissivities

So now that I have this data, what do I do next? Back to the internet.

4.0 Using Planetary (Colour) Filters

With the response curves and transmissivity values I have calculated, I now have a better understanding of what exactly all these different filters are doing. The blue filters remove greens and reds, the green filters remove blue and red, etc. One obvious question, and one that luckily many other amateur astronomers have already figured out is: what are all these colour filters good for? The simple answer is to increase the contrast between different features when viewing planets through your telescope. I have come across a number of tables summarizing the application of different colour filters for different planetary features. The most comprehensive I've found is from the Filter page on the Lumicon website (www.lumicon.com). I have repeated the tables below; one organised by filter colour, and the other organised by planetary feature. From my own experience I know it takes a lot of time and patience to assess whether a filter does anything to improve the view of a planet, so my deepest thanks go to the people who contributed to this list!

#82A Light Blue Moon: Low-Contrast Features Mars: Low-Contrast Features Jupiter: Low-Contrast Features Saturn: Low-Contrast Features	#80A Blue Moon: Feature Contrast Jupiter: Belts Jupiter: Rilles Jupiter: Festoons Jupiter: Great Red Spot Saturn: Belts Saturn: Polar Regions	#38A Dark Blue Venus: Clouds Mars: Dust Storms Jupiter: Belts Jupiter: Great Red Spot Jupiter: Disc Saturn: Belts
#47 Violet Venus: Clouds Mars: Polar Caps Saturn: Rings	#56 Light Green Moon: Detail Mars: Dust Storms Mars: Polar Caps Jupiter: Belts Jupiter: Atmosphere Jupiter: Red/Blue/Light Contrast	#58 Green Venus: Clouds Mars: Polar Caps Jupiter: Red/Blue/Light Contrast Saturn: Belts Saturn: Polar Regions
#11 Yellow-Green Mars: Maria Jupiter: Clouds Jupiter: Red/Blue Contrast Saturn: Clouds Saturn: Cassini Division Saturn: Red/Blue Contrast	#8 Light Yellow Moon: Feature Contrast Mars: Maria Jupiter: Belts Jupiter: Orange-Red Zonal Uranus: Dusky Detail Neptune: Dusky Detail	#12 Yellow Moon: Feature Contrast Mars: Blue-Green Areas Jupiter: Red-Orange Features Saturn: Clouds Saturn: Red-Orange Features
#15 Dark Yellow Moon: Feature Contrast Mars: Clouds Mars: Polar Caps Jupiter: Belts Saturn: Belts Uranus: Dusky Detail Neptune: Dusky Detail	#21 Orange Mars: Maria Jupiter: Belts Jupiter: Polar Regions Saturn: Belts Saturn: Polar Regions	#23A Light Red Mercury: Planet/Sky Contrast Mars: Maria Mars: Blue-Green Areas Jupiter: Belts Jupiter: Polar Regions Saturn: Belts Saturn: Polar Regions
#25 Red Mercury: Features Venus: Planet/Sky Contrast	#29 Dark Red Mercury: Features Venus: Planet/Sky Contrast	Rotating Polarizing Filter Moon: Glare Reduction or Variable Transmission

Venus: Terminator Mars: Maria Mars: Polar Caps Jupiter: Belts Jupiter: Galilean Moon Transits Saturn: Clouds	Venus: Terminator Mars: Maria Mars: Polar Caps Jupiter: Belts Jupiter: Galilean Moon Transits Saturn: Clouds	

Table 2 Application of Planetary Filters - Organised by Colour

Object	Features	Recommended Filter
Mercury	Planet/Sky Contrast	#23A Light Red
	Features	#25 Red #29 Deep Red
Venus	Clouds	#38A Deep Blue #47 Violet #58 Green
	Planet/Sky Contrast	#25 Red #29 Deep Red
	Terminator	#25 Red #29 Deep Red
Moon	Detail	#56 Light Green
	Feature Contrast	#8 Light Yellow #12 Yellow #15 Deep Yellow #80A Blue
	Low Contrast Features	#82A Light Blue
	Glare Reduction	ND13 Neutral Density
Mars	Clouds	#15 Deep Yellow
	Maria	#8 Light Yellow #15 Deep Yellow #11 Yellow-Green #21 Orange #23A Light Red #25 Red #29 Deep Red
	Blue-Green Areas	#12 Yellow #23A Light Red
	Dust Storms	#38A Deep Blue #56 Light Green
	Polar Caps	#15 Deep Yellow #25 Red #29 Deep Red #47 Violet #56 Light Green #58 Green

		Deep Sky Filter
	Low Contrast Features	#82A Light Blue
Jupiter	Clouds	#11 Yellow-Green
	Belts	#8 Light Yellow #15 Deep Yellow #21 Orange #23A Light Red #25 Red #29 Deep Red #38A Deep Blue #56 Light Green #80A Blue
	Rilles	#80A Blue
	Festoons	#80A Blue
	Atmosphere	#56 Light Green
	Red-Orange Features	#12 Yellow
	Orange-Red Zonal	#8 Light Yellow
	Red/Blue Contrast	#11 Yellow-Green
	Blue/Light Contrast	#25 Red
	Great Red Spot	#38A Deep Blue #80A Blue
	Galilean Moon Transits	#25 Red #29 Deep Red
	Red/Blue/Light Contrast	#56 Light Green #58 Green
	Polar Regions	#21 Orange #23A Light Red
	Disc	#38A Deep Blue
	Low Contrast Features	#82A Light Blue
Saturn	Clouds	#11 Yellow-Green #12 Yellow #25 Red #29 Deep Red
	Belts	#15 Deep Yellow #21 Orange #23A Light Red #38A Deep Blue #58 Green #80A Blue
	Polar regions	#21 Orange #23A Light Red #58 Green

		#80A Blue
	Rings	#47 Violet
	Cassini Division	#11 Yellow-Green
	Red/Blue Contrast	#11 Yellow-Green
	Red/Orange Features	#12 Yellow
	Low Contrast Features	#82A Light Blue
Uranus	Dusky detail	#8 Light Yellow #15 Deep Yellow
Neptune	Dusky detail	#8 Light Yellow #15 Deep Yellow
Double Stars	Bright Primary	ND13 Neutral Density

Table 3 Application of Planetary Filters - Organised by Viewed Object

One aspect of using colour filters that is not often discussed is the fact that they attenuate the amount of light getting to your eye. This is clearly evident by the % transmissivity values in my Table 1. People don't tend to be too concerned about the level of attenuation colour filters impose since the objects they are looking at are bright, namely planets. However the effectiveness of a colour filter at increasing some particular detail on a planet will be affected by the aperture of your telescope. A smaller aperture will not reveal the same enhancement that a large aperture would. Figure 9 summarises the recommended minimum aperture size when using colour filters for planetary work, based on scotopic % transmissivity. You can also calculate the minimum aperture using the simple relation: Aperture = 0.02*(%Scotopic - 100)^2.

Figure 9 Minimum Recommended Aperture Size for Colour Filters

In addition to improving the view of planets, colour filters can improve the view of other objects as well. The moon is a good candidate for contrast enhancement through the use of colour filters. In my experience though, the improvements observed are more due to the attenuation of the moon's brightness than actual filtering out of different colours. I talk a bit more on the moon below. Another use of colour filters is as a poor man's (or woman's) violet fringe killer. As can be seen in my plots from the previous page, a yellow filter is not that different from a minus-violet filter that one would use to cut the violet-blue fringe that is seen around bright objects on achromatic refractors. Hey, the spectral response curves don't lie, try it some time. Another reasonably common use of colour filters is for viewing the sun. In particular an interesting band to look at the sun in is Hydrogen Alpha ($H\alpha$), which can be achieved cheaply using a dark red (#29) filter on the eyepiece end in conjunction with a solar filter on the objective end. You can do the same trick to isolate $H\alpha$ emissions from nebulae (without the solar filter of course!), but if you recall the graph of eye spectral sensitivity, you can't actually see these emissions. They are useful for imaging only. If anyone else has a non-planetary use for colour filters, I'd be happy to add it to the list!

There are some other filters out there that are not technically colour filters, but that are intended for enhancing the views of planets. Some examples include the Baader Planetarium Moon & Skyglow filter, the Orion Mars filter and the Televue Bandmate Mars-A filter. These special filters use the fancy coating technology developed for deep-sky filters to make filters that improve contrast when viewing the moon and planets. I present more data on these filters in my Deep-Sky Filter chapters, under the category "Special".

Figure 10 Some Common Photography Filters Not In Your Accessory Case

While I was researching the various filters sold for astronomy, I wondered why there were some filter colours missing. The list of Wratten filters is very long, plus there is a whole other family of commonly used photography filters called "Colour Compensating" that introduce colours like cyan and magenta. Is there a good reason why these filters are not used for astronomy? Have I uncovered the biggest conspiracy in amateur astronomy history? I needed more data! That is why I purchased some common photography filters on top of the usual astronomy ones. I assessed their spectral response and transmissivity, and did my own visual comparison tests on the objects that were readily available this past April/May: Moon, Venus, Mars, Saturn, and Jupiter. The viewing of Venus was very poor due to its location low on the evening horizon, views of Mars were frustratingly bad-good-bad-good, and of course views of Jupiter (morning) and Saturn (evening) were nice. My observations are summarized below in Table 4. I evaluated my new Orion Mars filter at the same time for comparison, the results being in Table 4 as well. In the table I have listed what the commonly observed effect of each filter is as well as what I have been able to observe through my 8" SCT. Entries with a "n/o" mean that I have not yet had an opportunity to view that object with the filter in question.

Wratten/ Name	Colour	Reported Affect On…					My Observed Affect On…				
		Moon	Venus	Mars	Jupiter	Saturn	Moon	Venus	Mars	Jupiter	Saturn
#47H	light violet	none reported	improve view of atmosphere	improve view of polar ice caps & clouds	none reported	improve contrast on rings & surface detail	slightly improve all details, large boost to light feat. like ejecta, violet hue	n/o	improvement to contrast between light & dark regions	improved contrast, fine details in zones, very little colour cast	improved contrast of n.hemisphere dark bands
#82B	light blue	improve contrast	slightly improve surface markings	improve contrast	improve contrast	improve contrast	similar to #47H but more contrast, neutralise orange colour of moon when low in east	n/o	view not improved	view not improved	view not improved
#11H	light green	improve contrast	none reported	improve view of polar ice caps & dust storms	improve contrast between red & blue features	none reported	improve contrast of light features	n/o	view not improved	improved contrast dark to light, but darkens view	surface detail less visible!
#8	light yellow	improve view of features	slightly improve low contrast surface features	slightly improve contrast between light and dark regions	improve view of red & orange features	improve view of red & orange features	very small improve	n/o	view not improved	view not improved	minor improvement in surface detail contrast, almost no change in colour or view
#21	orange	none reported	none reported	improve maria regions & edge details	polar regions, belt contrast, red spot	polar regions, slightly surface details	n/o	n/o	improved detail around polar cap	n/o	very dark, no improvement observed
#23A	light red	none reported	daytime contrast with sky	improve maria regions & edge details	polar regions, belt contrast, red spot	polar regions, slightly surface details	improve contrast but dark, loose detail in dark areas	n/o	improved detail around polar cap	small increase in contrast	view not improved
Variable Polarizer	neutral	improve contrast, glare reduction	none reported	improve contrast, glare reduction	improve contrast, glare reduction	improve contrast, glare reduction	reduced glare, improved contrast, wash out dark areas	reduced glare, some dark features visible	view not improved	n/o	view not improved

Orion Mars	magenta	none reported	none reported	dramatically improve views, improve contrast & detail of all regions at same time	some improve in contrast between light & dark belts	none reported	reduced glare, improved contrast, very dark and very pink (not pleasing)	no improvement observed	large increase in contrast between all regions: light, dark, and polar caps, but view was dark and very pink, no bluish clouds	n/o	improved contrast of n.hemisphere dark bands, dark and purple colour
Baader Moon&Sky	neutral	improve contrast & features	none reported	improve contrast & features but leave natural colour	improve contrast & features	improve contrast & features	reduced glare, improved contrast mostly to light areas, minor colour cast but practically neutral, still quite bright	n/o	very dramatic increase in contrast & detail visible, clearly see light & dark regions, polar caps, & bluish clouds near pole, natural colour & nice bright view	large increase in contrast & visibility of fine detail & shading, very nice colour	all around increase in contrast
#81B	light brown	not known					reduced glare, improved contrast, pleasing tan colour	slight reduced glare, brought surface details just into visible threshold	improvement to contrast between light & dark regions, and edge of polar cap	improved contrast between belts & zones	increase contrast of surface features, nice natural colour
#85	light orange	not known					reduced glare, improved contrast, more orange and darker than 81B	similar improve to 81B, but darker view	improvement to contrast between light & dark regions, and edge of polar cap, but more than 81b	improved contrast between belts & zones	increase contrast of surface features more than 81B, but more orangish colour
CC20M	light magenta	not known					reduced glare, improved contrast of light and dark features, slight pink colour not distracting	view not improved	similar view to Moon&Sky but with a bit more contrast, natural colour, clearly see polar cap & light/dark regions, hard to see bluish clouds	surprising improved contrast in belts & zones, like 47H & Moon & Sky, pleasing colour	small increase in contrast

CC30M	light magenta	not known	reduced glare, improved contrast of light and dark features, slight pink colour not distracting	n/o	similar view to Moon&Sky but with a bit more contrast, a bit more pinkish colour, clearly see polar cap & light/dark regions, hard to see bluish clouds	almost same as CC20M	small increase in contrast
CC40M	magenta	not known	reduced glare, improved contrast of light and dark features, pink colour starting to get distracting	view not improved	view midway between Moon&Sky and Orion Mars, pinkish colour, clearly see polar cap & light/dark regions, not see bluish clouds	like CC30M but darker so harder to see details in zones	small increase in contrast

Table 4 Summary of My Observations With Colour Filters

Well, needless to say I am very pleased with myself! I have discovered some potentially useful new filter colours for use in astronomy. But are they really new? There are many web and book references to using a Wratten #30 or #34 for Mars observation, but I was not able to find anyone who sells these magenta coloured filters. Some people also like the Orion Mars filter (included on the "violets" plot) or even broadband light pollution filters (you'll see them later) for viewing Mars, both of which are a dark magenta colour. So if magenta filters are so great for viewing Mars, and I have personally confirmed that the reports are true, why then is a Wratten #30 not a standard filter in everyone's collection? Why can I not buy it anywhere, even if I wanted to?...hmmmmm. There is also the Televue Bandmate Mars-A filter which boasts letting green and red through but not other wavelengths. The images of this filter look an aweful lot like a #85 to me, and is probably something like the Denkmeier Optical Planetary filter shown with the orange curves. The Wratten #85 is readily available for photographic work, and I even found a 48mm (2") one pretty easily on Ebay. So why is there no 28mm (1.25") version of this filter or the #81 which I found worked well with all the planets?...double hmmmmm.

In my using of colour filters I found that I prefer filters that improve contrast but do not darken the view too much. That is why I've only included the lighter of the standard colour filters in my Table 4. I also prefer filters that leave the least amount of colour-cast to the particular viewing object. This is obviously a personal choice, and perhaps with a different telescope or different viewing conditions, I may change this position. For now though I have decided to add a magenta (CC30M), light brown (#81b) and light orange (#85) filter to my active list of filters. I've also added light yellow (CC20Y), light red (CC30R), a real light blue (#82a), and a real yellow-green (#11) for use in future observational tests. To make this happen I used a diamond Dremel cutting disk to trim the camera sized filter glasses down to fit 1.25" filter housings. I purchased empty filter housings off Ebay from the seller **bjomejag**. The end result can be seen below in Figure 11.

Figure 11   My New Filter Colours Join The Family

Okay, so we've got planets taken care of, but what about DEEEEEEP SPAAAAAACE?

5.0 Deep-Sky (Band Pass) Filter Research

Deep-sky filters are potentially far more useful than colour filters, at least that is if you plan to observe anything other than the moon and planets. This is doubly true if you observe primarily in an urban setting. Researching and buying colour filters is relatively easy since they are inexpensive, and even though there are several manufacturers, they all make the same standard set of Wratten colours. Deep-sky filters on the other hand are in a very muddled and confusing market due to the myriad of options that are available. The names and descriptions used to describe the available filters are kind-of standardized but not enough to make a clear decision on what filter is best for what. The only way to really understand the strengths and weaknesses of a filter is to look at its spectral response curve…here we go again!

Opposite to what I found for colour filters, pretty much every deep-sky filter maker publishes a spectral response curve of some sort. Most people do not find these curves all that useful since they do not always show things like desirable wavelengths for nebulae viewing or undesirable wavelengths for avoiding light pollution. Also, the big thing (for me anyway) is that there is no place one can go to compare response curves from one filter to the other.

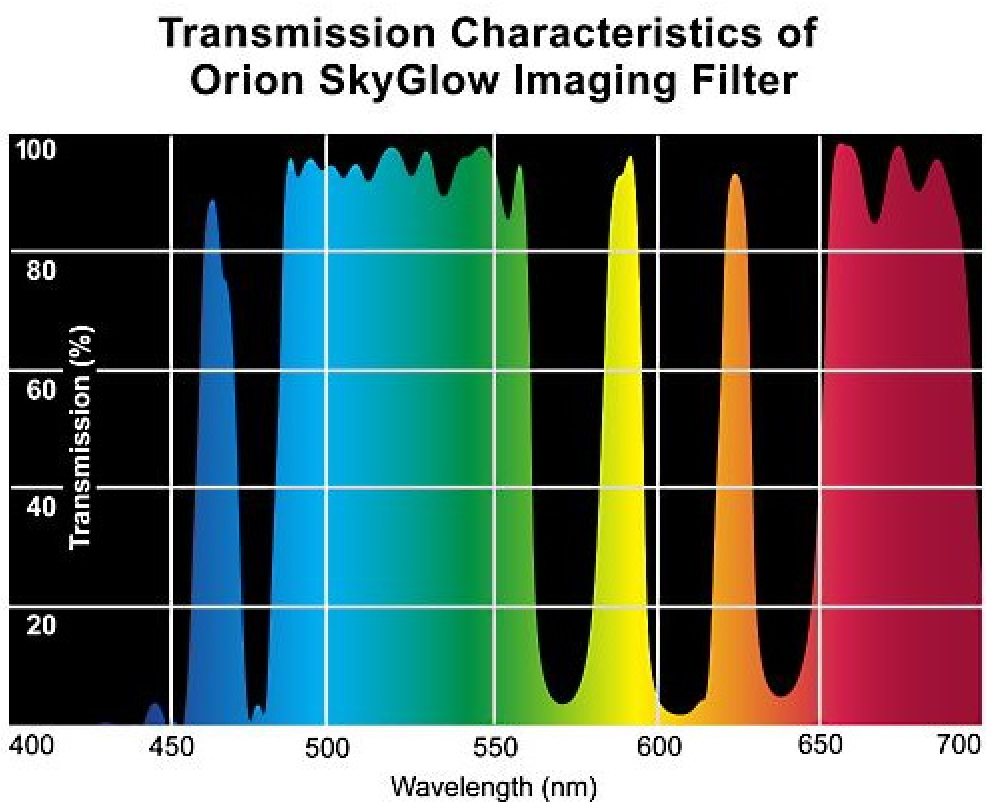


Figure 12 Example Manufacturer Supplied Spectral Response Curve

My interest in these filters came originally from a desire to make an informed purchase since these filters tend to be rather expensive. I wanted to make sure that I was: getting good bang for my buck, and getting the correct performing filter for what I wanted to use it for. To do that I needed to compare the available filters to each other directly using the published spectral response data. So I painstakingly collected spectral response curves for every filter I could find, converted them to x-y data by methodically tracing each image by hand in a drafting software, then re-plotting the curves together in logical groups. Since my interest is in visual observation, I have limited my research to filters that are marketed for visual use or that could be used as such. In the end I was very surprised at how many different types of filters I found; 18 different manufacturers, and 64 different filters. Included in my research are the following filters and filter manufacturers (note filter names are abbreviated below, see summary table for full filter names):

- 1000 Oaks (LP-1, LP-2, LP-3, LP-4)
- Andover Corporation (O-III, 3ch Nebula)
- Antares (ALP)
- Astro Hutech (O-III, H-beta, LPS-P1, LPS-P2, LPS-V3, LPS-V4)
- Astronomik (O-III, H-beta, UHC, UHC-E, CLS)
- Baader Planetarium (O-III, H-beta, UHC-S, Moon&Sky, Contrast)
- Burgess Optical (LPR)
- Custom Scientific (O-III, H-beta, Multiband)
- DGM (O-III, NPB, VHT, GCE)
- Denkmeier Optical (O-III, UHC, Planetary)
- Lumicon (O-III, H-beta, UHC, Deepsky)
- Meade (O-III, Narrow, Wide)
- Omega Optical (O-III, H-beta, Wide, Narrow, Hg&Na, Imaging)
- Optec Inc. (O-III, Deepsky)
- Orion (O-III, H-beta, Ultrablock, Skyglow-B, Skyglow-I, Mars)
- Sirius Optics (NEB1, CE1, PC1, NPC)
- TS Optics (O-III, UHC)
- Televue Optics (O-III, Nebustar)

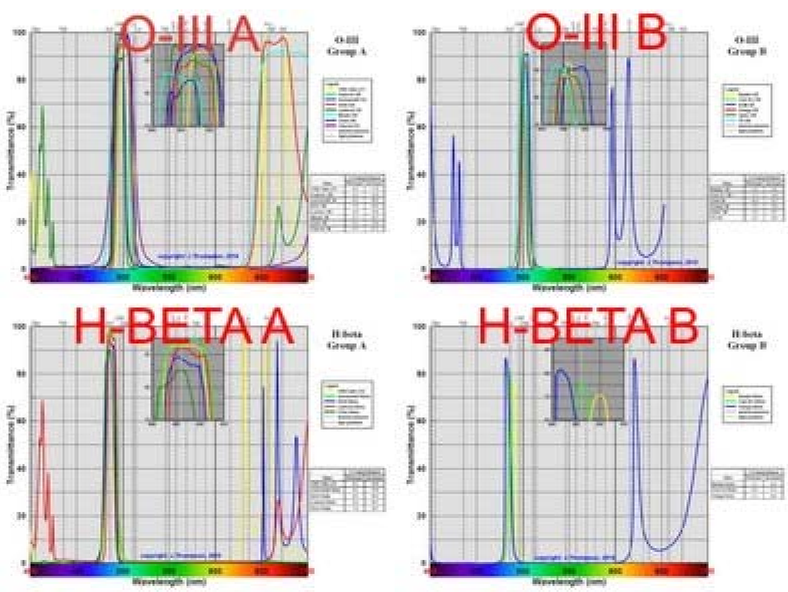
I know for a fact that there are other filters out there, but I have not included them because I was not able to find spectral response data for them. Specifically I was not able to find data for Antares (O-III & Narrowband Nebular) and Televue (Mars-A & Mars-B). There are likely others I am not even aware of. Also, the curves I have for Sirius Optics are provided from Island Eyepiece out in BC who were very helpful, as the company Sirius Optics itself is no longer in business. Finally Celestron brand filters, from what I have been able to determine, are made by Baader Planetarium and are therefore assumed to be equivalent in performance. Manufacturer provided spectral response data suggests that this assumption is correct.

I have summarized all the basic info on the filters and filter manufacturers in a master table that you may download if you like (.XLS is available upon request). The table includes my calculation of photopic and scotopic transmissivity (see "Human Eye" chapter for more on my methodology), as well as my own categorization for each of the filters. My logic for grouping the filters into 11 categories is explained in the table below.

Category	Prerequisite
O-III Group A	Allow both doubly ionized Oxygen wavelengths to pass
O-III Group B	Allow only one doubly ionized Oxygen wavelength to pass
H-beta Group A	Pass H-beta wavelength with >90% transmission
H-beta Group B	Pass H-beta wavelength with <90% transmission
Narrow Band	H-beta + O-III pass band is <35nm wide
Medium Band	H-beta + O-III pass band is >35 but <50nm wide
Wide Band	H-beta + O-III pass band is >50 but <70nm wide
Extra Wide Band	H-beta + O-III pass band is >70nm wide
Multi Band	More than two major pass bands in the visible range
Special A	Filters especially designed for planets or other special object viewing
Special B	Special filters for contrast enhancement based on Neodymium infused glass

Table 5 Deep-Sky Filter Category Definitions

I'll talk in the next chapter about what each category of filter is probably best used for. For now let's have a look at how these filters compare. Below are spectral response plots for each of the 11 categories described above. The similarities and differences between the various filters are more easily viewed now using these plots. I apologize in advance if there are inaccuracies in my data. My method of re-digitizing image files has weaknesses, but this was the only way to get the data in a usable form. PDF or XLS versions of this data are available upon request.



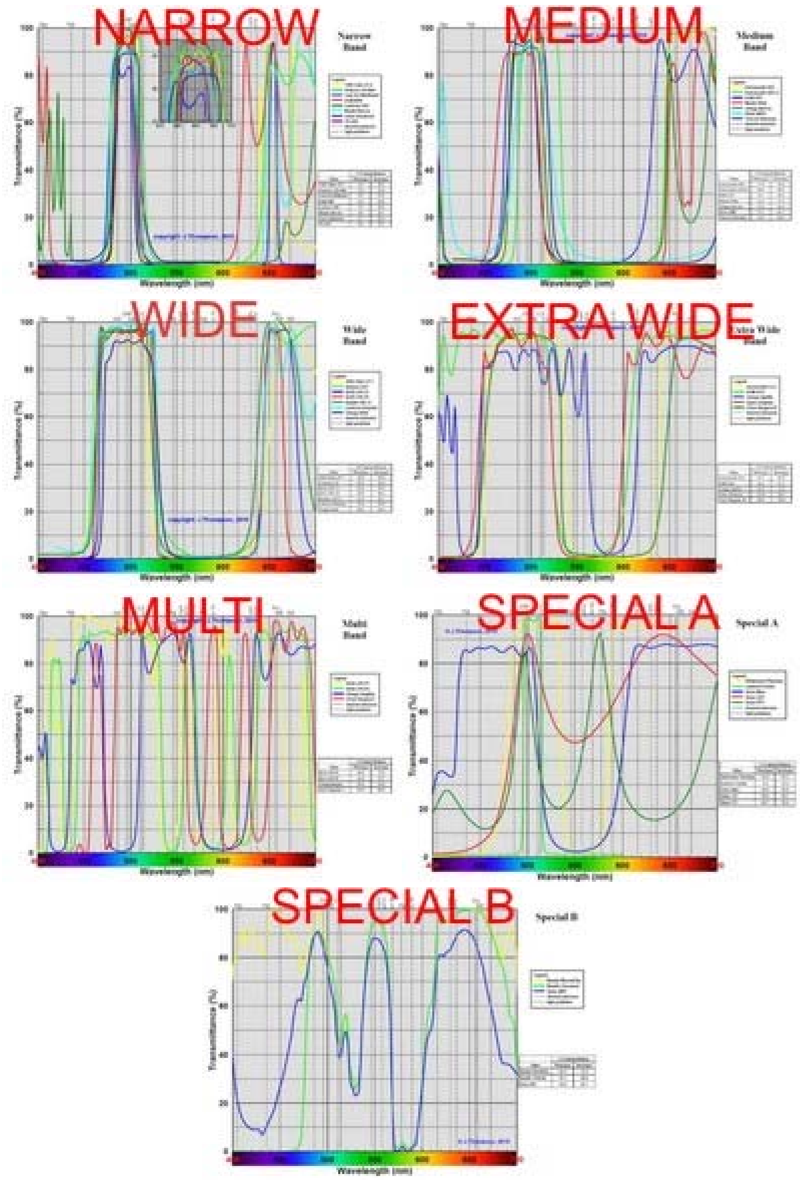


Figure 13 Deep-Sky Filter Spectral Response Comparison Plots

Well all this spectral data is nice but...zoooey! how am I going to pick a filter now? I have so many choices, what do I really want or need?

6.0 Using Deep-Sky (Band Pass) Filters

Before you can decide what deep-sky filter is best, and how best to use it, you have to ask yourself a number of questions:

1. What kinds of objects do you want to look at?
2. What kind of telescope do you use?
3. Where do you do your observing?
4. How much are you willing to pay?

The answer to these four questions will help you decide what filter or filters are best for you. I had to answer the same questions before I purchased my deep-sky filters. I'll share my answers and the filter choices I made with you a little later. Right now let's look at some of the additional information that I used to help me make my decision.

Type of Objects:

The type of objects you want to observe will have an impact on what filter is best for the task. The wavelengths at which an object emits light has an obvious link to how the view of that object is affected by the different filters. The nature of the light that we see through our telescope is that it has either been emitted or reflected from the object we are viewing. The most obvious source of light that we see is star light. Star light, and the light from objects that are visible due to reflected star light (eg. moons, planets, asteriods, reflection nebulae, star clusters, galaxies) tends to have a broad spectrum with no obviously dominant wavelength. Light can also be emitted directly from clouds of ionized gas such as from emission nebulae, planetary nebulae, and supernova remnants. Light emitted from these sources is at discrete and very specific wavelengths due to the way the light is generated (Google "quantum theory of light" to learn how this works). This is perhaps a good opportunity to finally explain the vertical dashed lines on my spectral response graphs. Table 6 below summarises the list of emission wavelengths that are desirable and undesirable from the astronomer's perspective. The vertical lines in my graphs correspond to these desirable and undesirable wavelengths.

Deep-sky filters take advantage of the fact that the desirable and undesirable wavelengths do not coincide with each other, allowing for a filter to be made that allows all of the desirable but none of the undesirable wavelengths through to your eye. The result is darkening of everything in your eyepiece view except the desirable emission wavelengths. This works great for emission nebulae, planetary nebulae, and supernova remnants, but what about everything else? Some manufacturers and users have stated that certain types of deep-sky filter can enhance the visibility of deep-sky objects like galaxies and clusters too. I have no experience myself to say whether or not this is true. Based on my research plus my own limited experience, I have prepared a table that lists the recommended applications for each of my 11 filter categories.

Desirable			Undesirable		
Moniker	**Origin**	**Wavelength**	**Moniker**	**Origin**	**Wavelength**
H-beta	Hydrogen in nebulae	486.1	Hg	Mercury in man-made lighting	404.7
O-III	Oxygen in nebulae	495.9	Hg	Mercury in man-made lighting	435.8
O-III	Oxygen in nebulae	500.7	Hg	Mercury in man-made lighting	546.1
C2	Acetyl (a carbon based molecule) in comet tails	511.0	nightglow	natural glow from Oxygen in upper atmosphere	557.7
C2	Acetyl (a carbon based molecule) in comet tails	514.0	hp Na	Sodium in high-pressure man-made lighting	568.8
H-alpha	Hydrogen in nebulae or our sun	656.3	Hg	Mercury in man-made lighting	578.2
N-II	Nitrogen in nebulae	658.4	lp Na	Sodium in low-pressure man-made lighting	589.3
S-II	Sulphur in nebulae	672.4	hp Na	Sodium in high-pressure man-made lighting	616.0
			nightglow	natural glow from Oxygen in upper atmosphere	630.0
			nightglow	natural glow from Oxygen in upper atmosphere	636.4

Table 6 Summary of Desirable & Undesirable Wavelengths for Astronomy

Category	Application
O-III Group A	Viewing of emission nebulae, planetary nebulae, & supernova remnants under heavy light pollution
O-III Group B	Imaging of emission nebulae, planetary nebulae, & supernova remnants
H-beta Group A	Viewing of faint emission nebulae, with or without light pollution
H-beta Group B	Imaging of faint emission nebulae
Narrow Band	Viewing & imaging of emission nebulae, planetary nebulae, & supernova remnants under moderate-to-no light pollution
Medium Band	Viewing & imaging of emission nebulae, planetary nebulae, & supernova remnants under moderate-to-no light pollution
Wide Band	Viewing of emission nebulae, planetary nebulae, & supernova remnants under mild-to-no light pollution; imaging of all deep-sky objects
Extra Wide Band	Viewing or imaging of all objects under mild-to-no light pollution
Multi Band	Viewing or imaging of all objects under mild-to-no light pollution
Special A	Lumicon Comet for comets; Orion Mars for Mars; all others for contrast improvement while viewing moon or planets
Special B	Contrast improvement while viewing moon or planets

Table 7 Deep-Sky Filter Application By Filter Category

You will note in Table 7 that I don't recommend the use of O-III Group B and H-beta Group B for visual use. The bandwidths and %transmissivities for these filters are very small, making them best suited to CCD imaging applications. Clearly the most common application of deep-sky filters is the observation of emission-type objects. The Lumicon website has a very useful list of common nebulae and the filter they recommend for viewing from their catalog, which I have repeated below in Table 8 but with my filter categories substituted.

Nebula	Name	Best Filter	Nebula	Name	Best Filter
M1	Crab nebula	Narrow / Medium	NGC7000	North America Nebula	O-III Group A
M8	Lagoon Nebula	Narrow / Medium	NGC7008		O-III Group A
M16	Eagle Nebula	Narrow / Medium	NGC7009	Saturn Nebula	none
M17	Swan Nebula	O-III Group A	NGC7023		Wide / Extra Wide
M20	Trifid Nebula	Narrow / Medium	NGC7026		O-III Group A
M27	Dumbbell Nebula	Narrow / Medium	NGC7027		O-III Group A
M42	Orion Nebula	Narrow / Medium	NGC7048		O-III Group A
M43	Orion Nebula	H-Beta Group A	NGC7129-7133		Narrow / Medium
M57	Ring Nebula	Narrow / Medium	NGC7139		O-III Group A
M76	Little Dumbbell Nebula	Narrow / Medium	NGC7293	Helix Nebula	O-III Group A
M97	Owl Nebula	O-III Group A	NGC7538		Narrow / Medium
NGC40		Narrow / Medium	NGC7635	Bubble nebula	O-III Group A
NGC246	Skull Nebula	O-III Group A	NGC7662	Blue Snowball	none
NGC281	Pac-Man Nebula	Narrow / Medium	NGC7822		Narrow / Medium
NGC604	in M33	O-III Group A	IC405	Flaming Star Nebula	Wide / Extra Wide
NGC896/IC1795		Narrow / Medium	IC410		O-III Group A
NGC1360		O-III Group A	IC417		H-Beta Group A
NGC1491		Narrow / Medium	IC434/B33	Horsehead Nebula	H-Beta Group A
NGC1499	California Nebula	H-Beta Group A	IC1318		H-Beta Group A
NGC1514	Crystal Ball Nebula	O-III Group A	IC1396		Narrow / Medium
NGC1999		none	IC1848		Narrow / Medium
NGC2022		O-III Group A	IC2177	Seagull Nebula	H-Beta Group A
NGC2024	Flame Nebula	Narrow / Medium	IC4628		Narrow / Medium
NGC2174		Narrow / Medium	IC5067-70	Pelican nebula	Narrow / Medium
NGC2327		H-Beta Group A	IC5076	inNGC6991	H-Beta Group A
NGC2237-2239	Rosette Nebula	Narrow / Medium	IC5146	Cocoon Nebula	H-Beta Group A
NGC2264	Cone Nebula	Narrow / Medium	PK64+5.1	Campbell's Hydrogen Star	H-Beta Group A
NGC2359	Thor's Helmet	O-III Group A	PK164+31.1	Headphone Nebula	Narrow / Medium
NGC2371-2		O-III Group A	PK205+14.1	Medusa Nebula	O-III Group A
NGC2392	Eskimo Nebula	O-III Group A	Sh2-13		Narrow / Medium

NGC2436		Narrow / Medium	Sh2-54		Narrow / Medium
NGC2438	in M46	O-III Group A	Sh2-84		Narrow / Medium
NGC2440		Narrow / Medium	Sh2-101		Narrow / Medium
NGC3242	Ghost of Jupiter	Narrow / Medium	Sh2-112		O-III Group A
NGC4361		Narrow / Medium	Sh2-132		O-III Group A
NGC6210		O-III Group A	Sh2-142		O-III Group A
NGC6302	The Bug Nebula	O-III Group A	Sh2-155		Wide / Extra Wide
NGC6334		Narrow / Medium	Sh2-157		Narrow / Medium
NGC6357		O-III Group A	Sh2-170		Narrow / Medium
NGC6445		Narrow / Medium	Sh2-171		Narrow / Medium
NGC6543	CatsEye Nebula	O-III Group A	Sh2-235		H-Beta Group A
NGC6559		Narrow / Medium	Sh2-254-5-6-7-8	inIC2162	H-Beta Group A
NGC6781		O-III Group A	Sh2-261		Narrow / Medium
NGC6804		O-III Group A	Sh2-276	Barnard's Loop	H-Beta Group A
NGC6888	Crescent Nebula	O-III Group A	Sh2-311	in NGC2467	Narrow / Medium
NGC6905	Blue Flash Nebula	Narrow / Medium	vdB93(Gum-1)	near IC2177	H-Beta Group A
NGC6960-6995	The Veil Nebula	O-III Group A			

Table 8 Recommended Filter For Use With Particular Nebulae

Type of Telescope:

The type of telescope you use can also affect how useful the different deep-sky filters are to you. The primary parameter of concern is aperture. Deep-sky filters can attenuate a large percentage of the light coming through your telescope, making some limited to use only on larger aperture telescopes. Table 9 below summarizes the recommended minimum telescope apertures for the 11 filter categories. I used the aperture recommendations from various filter manufacturers (primarily Astronomik) to come up with my own relationship between scotopic %transmissivity and telescope aperture.

Now don't assume if you use a filter on an aperture smaller than recommended above that you won't see any improvement in your view, because you will. The recommended apertures are just what is needed to get the best performance out of your filter. Another way to look at the issue of pairing a filter to a telescope is to consider the exit pupil size. The exit pupil size is calculated by dividing your eyepiece focal length by your telescope's focal ratio. For example: a 26mm eyepiece on an f/10 telescope would have an exit pupil diameter of 2.6mm. Lumicon has a table on their filter webpage recommending exit pupil size ranges for their various filters. I have reproduced that table below.

Category	Scotopic % Transmissivity	Minimum Aperture
O-III Group A	12-27	5.5"(140mm)
O-III Group B	5-11	10" (254mm)
H-beta Group A	10-13	8" (203mm)
H-beta Group B	4-7	11.5" (292mm)
Narrow Band	22-33	4.5" (114mm)
Medium Band	33-43	3.5" (89mm)
Wide Band	50-61	2.5" (64mm)
Extra Wide Band	59-73	no limit
Multi Band	51-74	no limit
Special A	21-54	Lumicon Comet 5.5", all others no limit
Special B	49-72	no limit

Table 9 Minimum Recommended Aperture By Filter Category

Filter Type	**Deep Sky** (wide band)	**UHC** (narrow band)	**O-III** (Group A)	**H-Beta** (Group A)
Bandpass	90nm	22-26nm	10-12nm	8-10nm
Optimum Exit Pupil (Light-polluted sky)	0.5-2mm	1-4mm	2-5mm	3-7mm
Optimum Exit Pupil (Dark sky)	1-4mm	2-6mm	3-7mm	4-7mm

Table 10 Recommended Exit Pupil Size For Lumicon Filters

Other than having sufficient aperture, and picking the right focal length eyepiece, there really is no limit that I can find on what type of telescope you can use deep-sky filters on. Well, actually I guess there is one thing: band pass filters can have poorer performance on low focal ratio telescopes. I believe that this is generally true of all telescope accessories, and has something to do with the fact that light from the outer edge of the objective is passing through the filter at a significantly different angle than from the the center of the objective. Testing by others (see the work done by Christian Buil) shows that a filter's pass band wavelengths shift with the angle of the filter relative to the incident light. This effect is used constructively in the fancy (ie. expensive) tunable H-alpha filters used for Sun observing. The result for deep-sky filters on low focal ratio telescopes is a non-uniform view over the filter area. Some web reviews I've found suggest that this effect is worsened when using lower quality filters.

Observing Location:

Ahh if only we had a time machine, that we could jump into and go back 100 years or so for our evening's observing session. Back then you'd only have to go a short wagon ride to get to where the light pollution was basically zero. The sad reality is that the majority of amateur astronomers are forced to do their observing from urban or sub-urban environs. Sure we may get to go on the odd road trip to a dark sky sight, but if any of us plan on observing with any regularity we will have to learn to accept our light polluted backyards for what they are. To give you an idea of what we astronomers are having to deal with, I have put together a composite map of the Southeastern Ontario region where I live and do my observing. The map overlays satellite light pollution data over the Google map for the region so you can see clearly what cities are generating the light pollution. I live in the white blob second from the right.

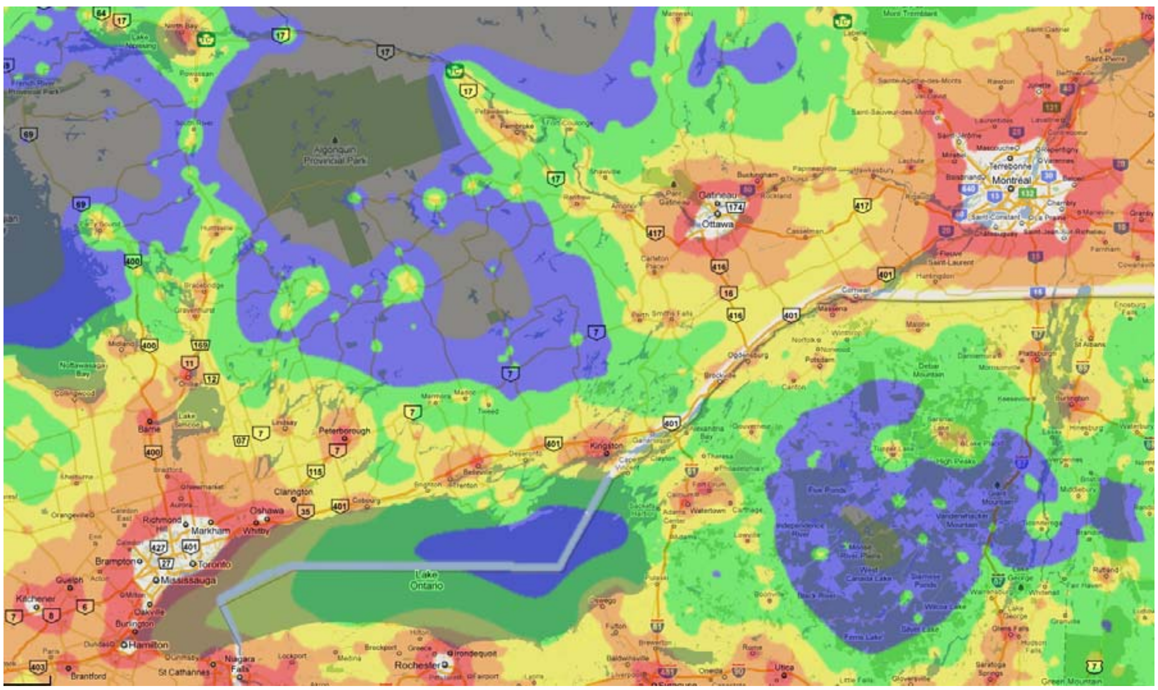


Figure 14 Light Pollution Map for Eastern Ontario, Canada

With this reality in mind it is easy to understand why there is such a large variety of deep-sky filters available to choose from. So if you are like me, and you live in a large city where light pollution is high, you probably should consider an appropriate deep-sky filter if you want to have any hope of seeing nebulae from your backyard. If you live further outside a large city, the light pollution rejection capability of the filter you choose maybe doesn't need to be so much. If you are a lucky bum, and you live or can observe regularly from a dark sky sight, then you may not need a deepsky filter at all. For you dark-sky bums, you may want to at least consider that deep-sky filters can also improve your view of faint nebulae by reducing the brightness of other neigbouring objects like stars.

Price:

The one thing I did not include in my research is price. There are simply too many different suppliers out there for me to compile a list of price along with each filter's performance. That work you'll have to do for yourself. One piece of advice though is that in general, it seems that you get what you pay for; expensive filters tend to be the better performers. So what is a good performer? It is any filter with the following attributes:

- has a transmittance as close to 100% as possible at all the desired wavelengths;
- has a transmittance as close to 0% as possible at all the undesired wavelengths; and
- transition from undesired to desired wavelengths is very steep, essentially a step change from 0% to 100%.

There are a few other signs of good quality filters to look for such as: optically polished glass, anti-reflection coatings on both sides, and hard protective coatings for anti-scratch. Also, companies that provide you with a print-out of YOUR filter's factory measured spectral response is always a good sign of a quality manufacturer.

My Choice:

The answers to the initial four questions for me are:

1. I am just getting back into astronomy, and not knowing yet what I can and can't see from my backyard, I want to explore everything that I can. Therefore I want to have filters that can enhance all the different types of deep-sky objects.
2. I have an f/10 8" SCT and an f/5 80mm achromat. That way I can view small dim objects or planets as well as large nebulae or star fields.
3. I do my observing primarily from my backyard, in the middle of a fairly large urban center. I do on a few occasions observe at my in-laws out in the country.
4. I am willing to pay a premium in order to get a high quality, high performance filter. I don't have a giant telescope nor a dark sky observing site, so I want to maximise the performance of the filters I choose.

It is my nature to explore, experiment, optimise...the engineer's curse! The choice that best meets my needs is a selection of high performance filters, from wide to narrow. This provides me with the largest flexibility, and the freedom to experiment and learn for myself what filters work the best on different objects for my circumstances. Figure 15 is an image of the filters I selected: Astro Hutech IDAS LPS-P2 (Multi Band, 72.7% trans), Baader Planetarium UHC-S (Wide Band, 54.7% trans), Astronomik UHC (Medium Band, 33.6% trans), Astronomik O-III (O-III A, 20.5% trans), and Astronomik H-beta (H-beta A, 12.6% trans).

Figure 15 My Deep-Sky Filter Choices

Well, that's it. I've said all I wanted to say, researched all I wanted to research, and tabularised all I wanted to tabularise. It is now time to get outside and do some observing! Thank you for listening. If you have any questions about my background material, please check out my "References" page, or contact me at jimmythepuker2@yahoo.ca. Cheers!

7.0 References

A big thank you to everyone that has helped me on this pet project. Without your contributions my research could not have been as thorough or enlightening!

Thank You's:

- Special thanks to Brian and Joanne at Island Eyepiece & Telescope Ltd. for providing me the data they had on Sirius Optics brand filters, and for providing a source for Lumicon colour filters, plus the help with all my other questions.
- Thanks to Ted Ishikawa at Astro Hutech for providing me data on their IDAS line of filters, and to Mia Ishikawa for her fast & courteous online purchasing support.
- Many thanks to Manish and Sarah at Agena Astro for their great support with Baader Planetarium brand filters as well as lots of other bits and pieces.
- Thank you to Vivien Zhao at Changchun New Industries Optoelectronics Tech Co. Ltd. in China for her help in making an otherwise impossible purchase of rare wavelength laser pointers possible (and affordable!).
- Finally, thanks to Adirondack Astronomy for their quick and dependable supply of Astronomik brand filters and Lumicon brand filter changers.

Filter Data Sources:

- The images of deep-sky filter spectral responses I used in my analysis were found by me from all over the internet. Some on manufacturer websites, some on reseller websites, and some buried in papers that were available online. I have packaged all the source images together into a single downloadable archive for reference. <deepsky filter source images.zip>
- The Kodak Wratten and Colour Compensating filter spectral response data was published in older editions of the CRC Handbook of Chemistry and Physics (which is what I have), but is no longer in current editions. I did happen to find a scanned in copy of this section of the book online in case anyone is interested. <transmission of wratten filters.pdf>
- http://www.astrosurf.com/buil/filters/curves.htm : A great site containing deep-sky filter spectral response data as measured by a third party with a spectrometer. Note that Christian Buil's measured response of Meade brand filters showed a much lower response than quoted by the manufacturer, but I have chosen to use the manufacturer's data in my analysis. His other plots match fairly well with the responses reported by the manufacturer.
- I have tried to very carefully and consistently take pictures of the spectrum of colour filters I have used in my research so that people can visually compare my filters to what they are using. The resulting images are below.

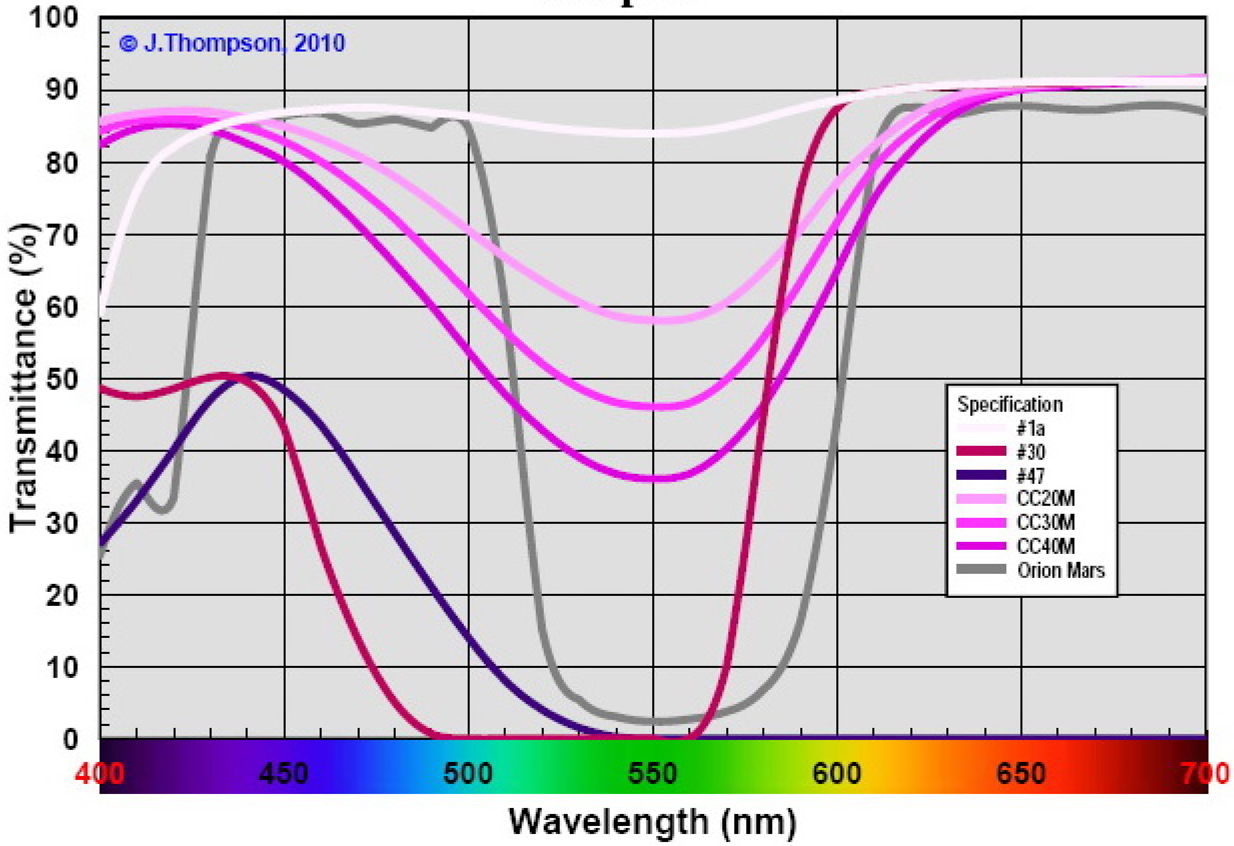

No. 1A
No.47H Violet
Filter No.47
CC20M
CC40M
82A
No.82B Light
No.11 Light
Filter No.56
No.80A Blue
Filter No.38A
11
No.58 Green
CC20Y
Filter No.8
81A
81B
No.12A Light Yellow
No. 15 Yellow
85
No.21
CC30R
No.23A Light
No.25A Red
No. 29 Deep

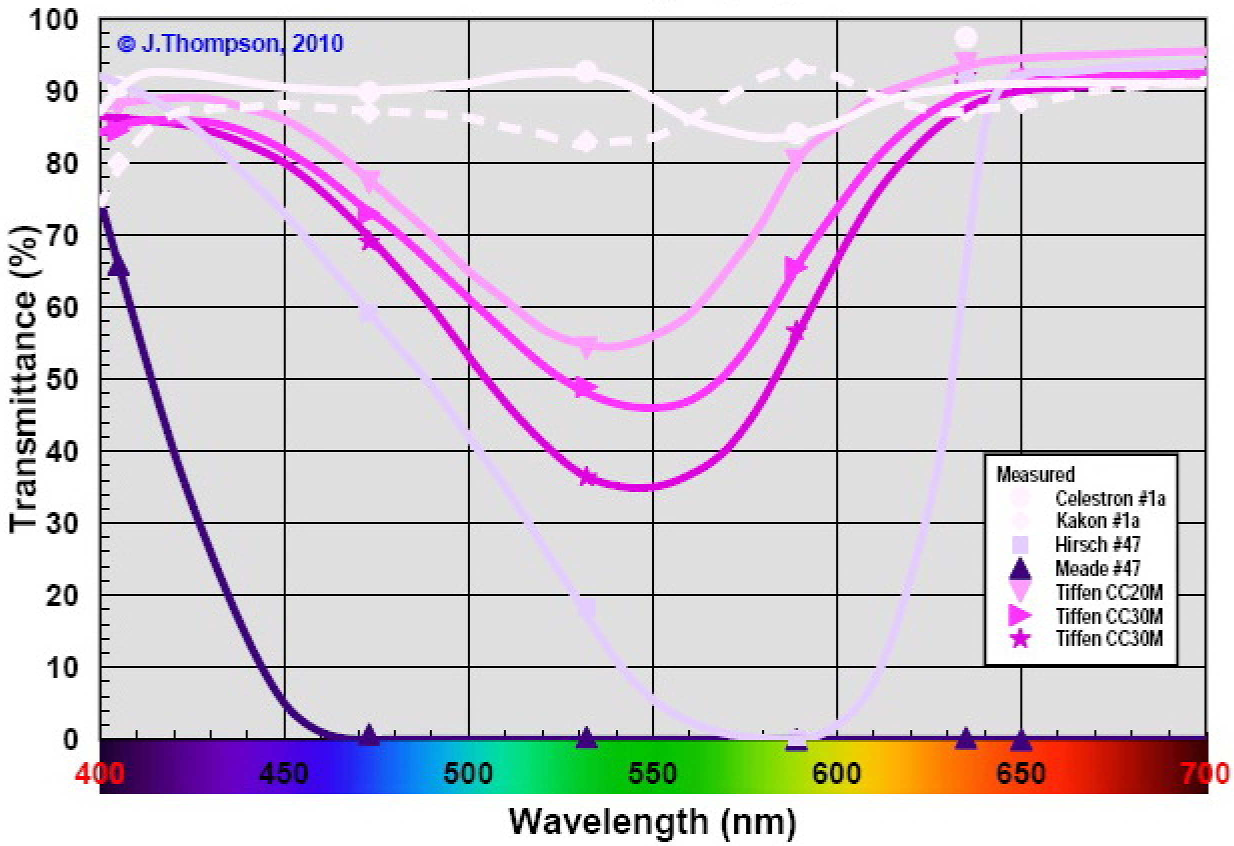
Miscellaneous Filter Info Links:

- http://alpo-astronomy.org/mars/articles/FILTERS1.HTM : Observing the Planets with Color Filters
- http://jeff.medkeff.com/astro/observing/colorfilter/index.htm : How and Why to use Color Filters
- http://www.astro-tom.com/technical_data/filters.htm : General discussion about filters
- http://sciastro.net/members/portia.php/2009/01/31/g-the-use-of-filters : Astronomy for Everyone site discussion about the use of filters
- http://www.lumicon.com/astronomy-accessories.php?cid=1&cn=Filters : the Lumicon filter page, with lots of background info on picking and using deep-sky filters
- http://www.brayebrookobservatory.org/BrayObsWebSite/HOMEPAGE/forum/colourfilters/html/colourfilters.html : Colour Filters by Rodger W. Gordon & Chris Lord
- http://pages.sbcglobal.net/raycash/filters.htm : Filter Performance Comparisons for Some Common Nebulae
- http://home.freeuk.com/m.gavin/grism2.htm : Testing deepsky / OIII filters via a simple spectroscope
- An Excel spreadsheet summarizing a lot of different nebular filters, including price and some other data. Compiled by the people at the Cloudynights.com website. <198673-Nebula Filters.xls>

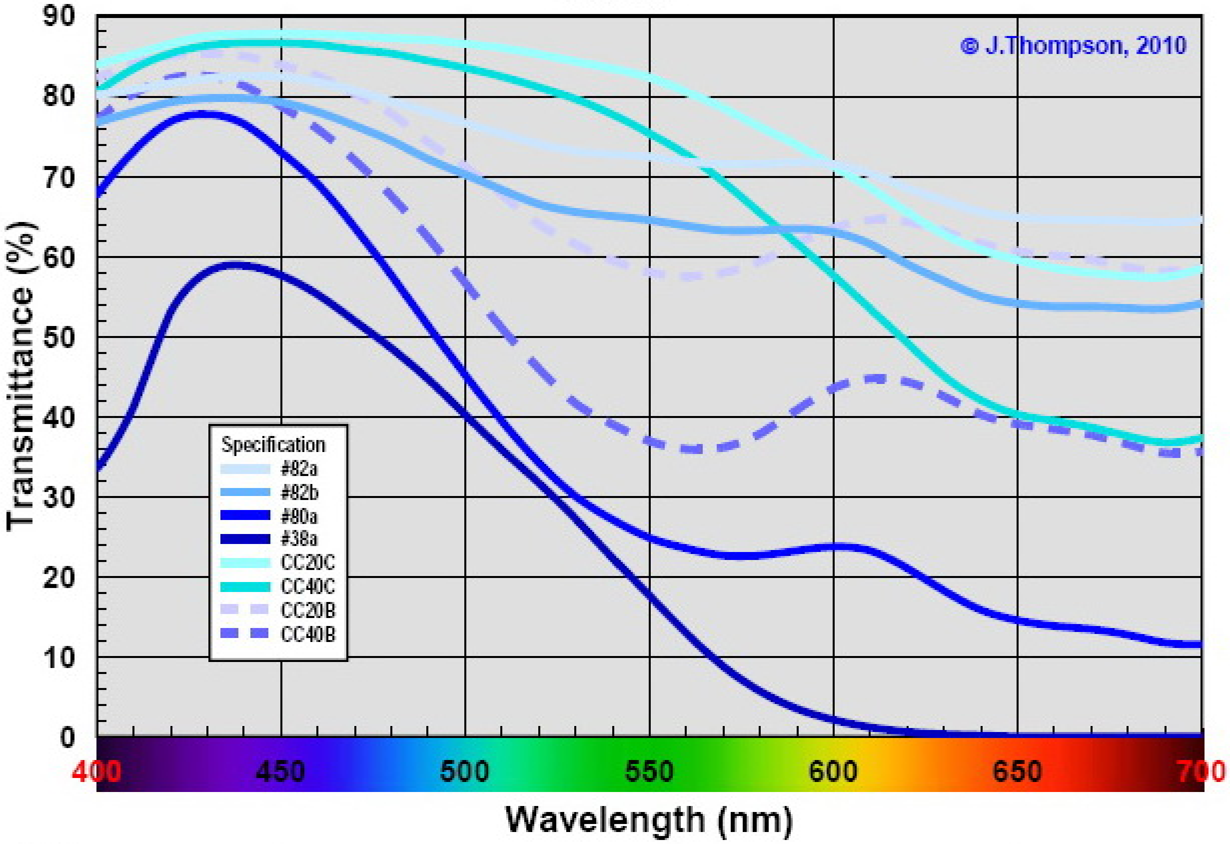
Appendix A – Colour Filter Plots

Purples

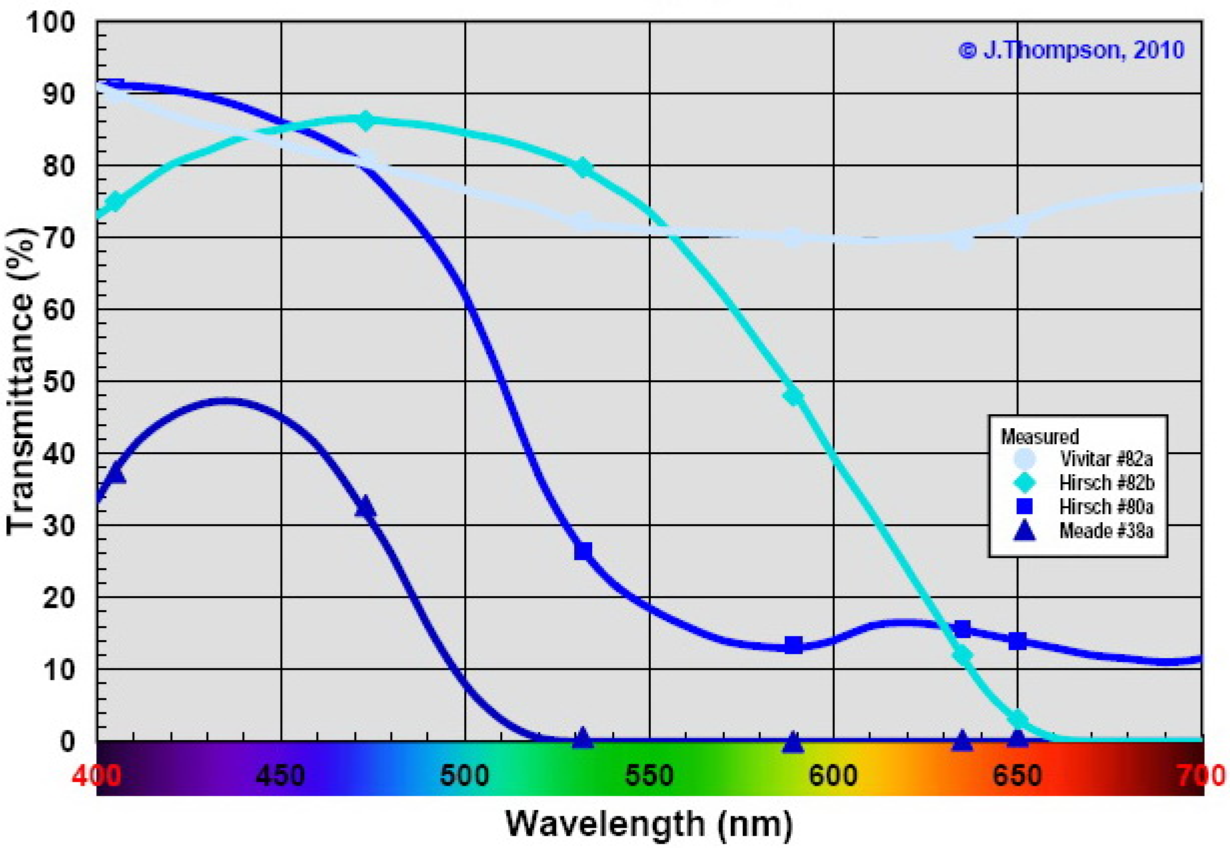

© J.Thompson, 2010
Transmittance (%)
Wavelength (nm)
Specification
#1a
#30
#47
CC20M
CC30M
CC40M
Orion Mars


© J.Thompson, 2010
Transmittance (%)
Wavelength (nm)
Measured
Celestron #1a
Kakon #1a
Hirsch #47
Meade #47
Tiffen CC20M
Tiffen CC30M
Tiffen CC30M

Blues

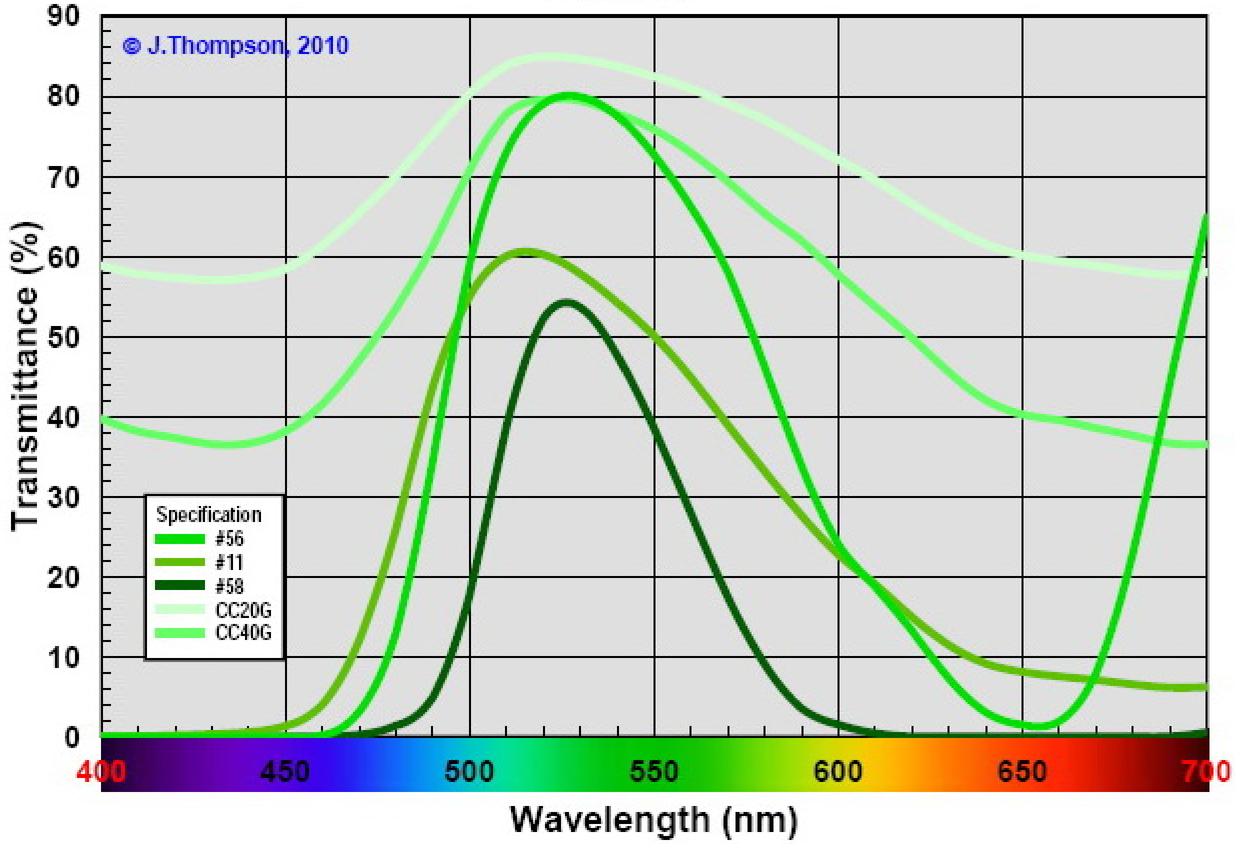


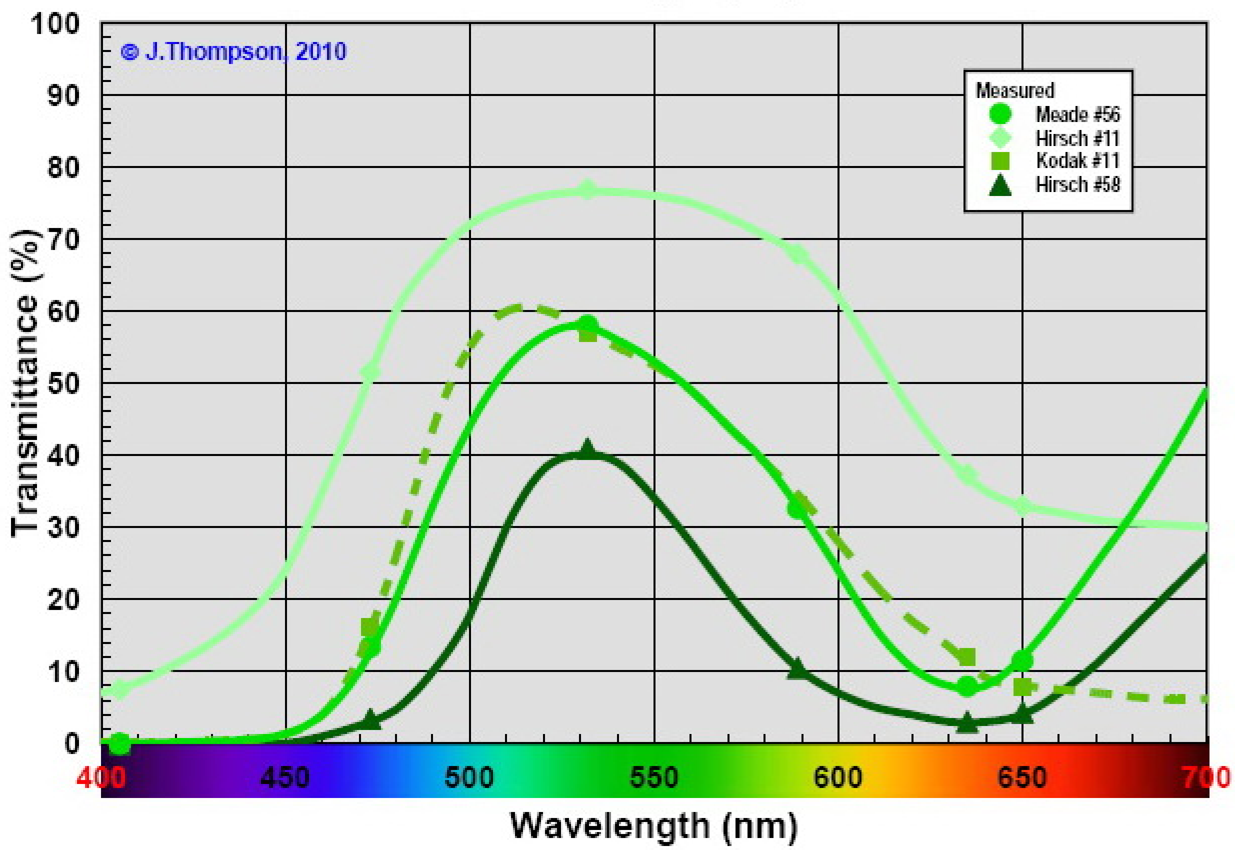
© J.Thompson, 2010
Specification
#82a
#82b
#80a
#38a
CC20C
CC40C
CC20B
CC40B
Transmittance (%)
Wavelength (nm)
400
450
500
550
600
650
700



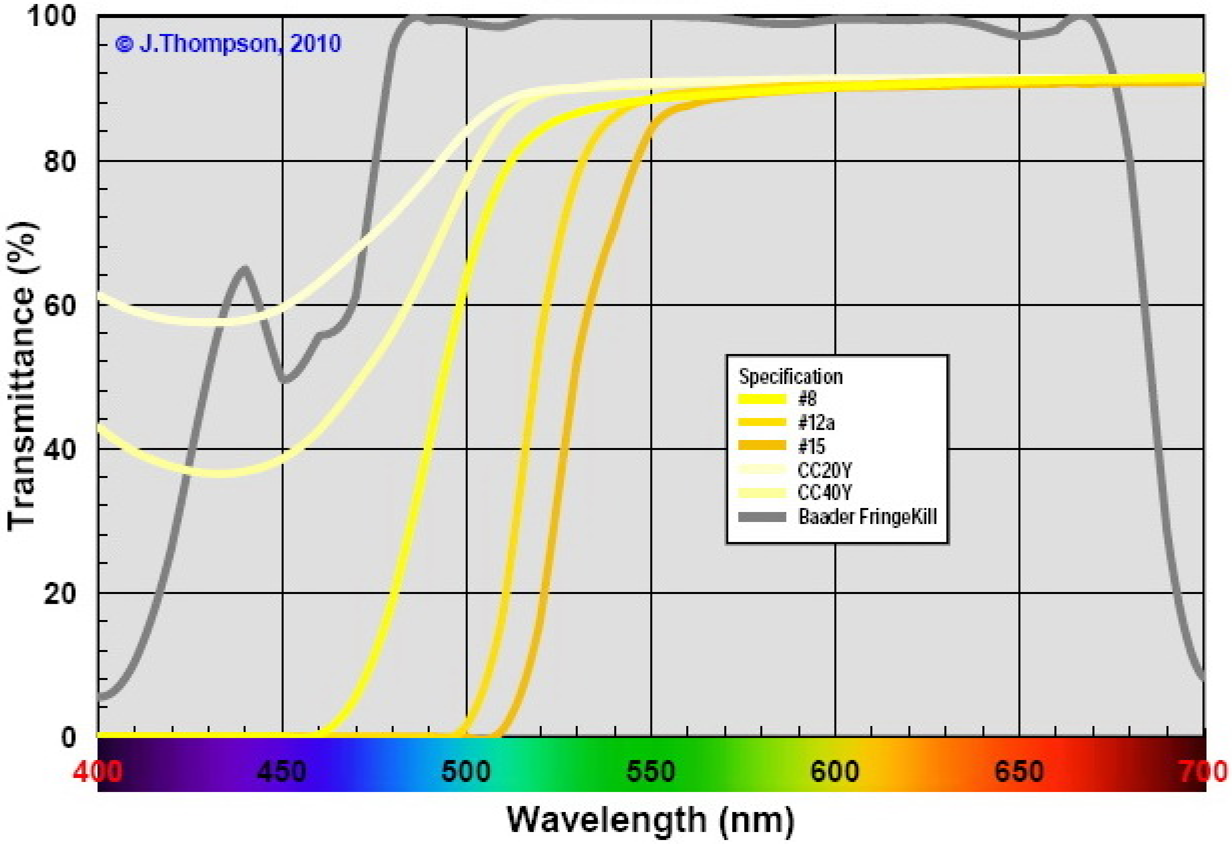
© J.Thompson, 2010
Measured
Vivitar #82a
Hirsch #82b
Hirsch #80a
Meade #38a
Transmittance (%)
Wavelength (nm)
400
450
500
550
600
650
700

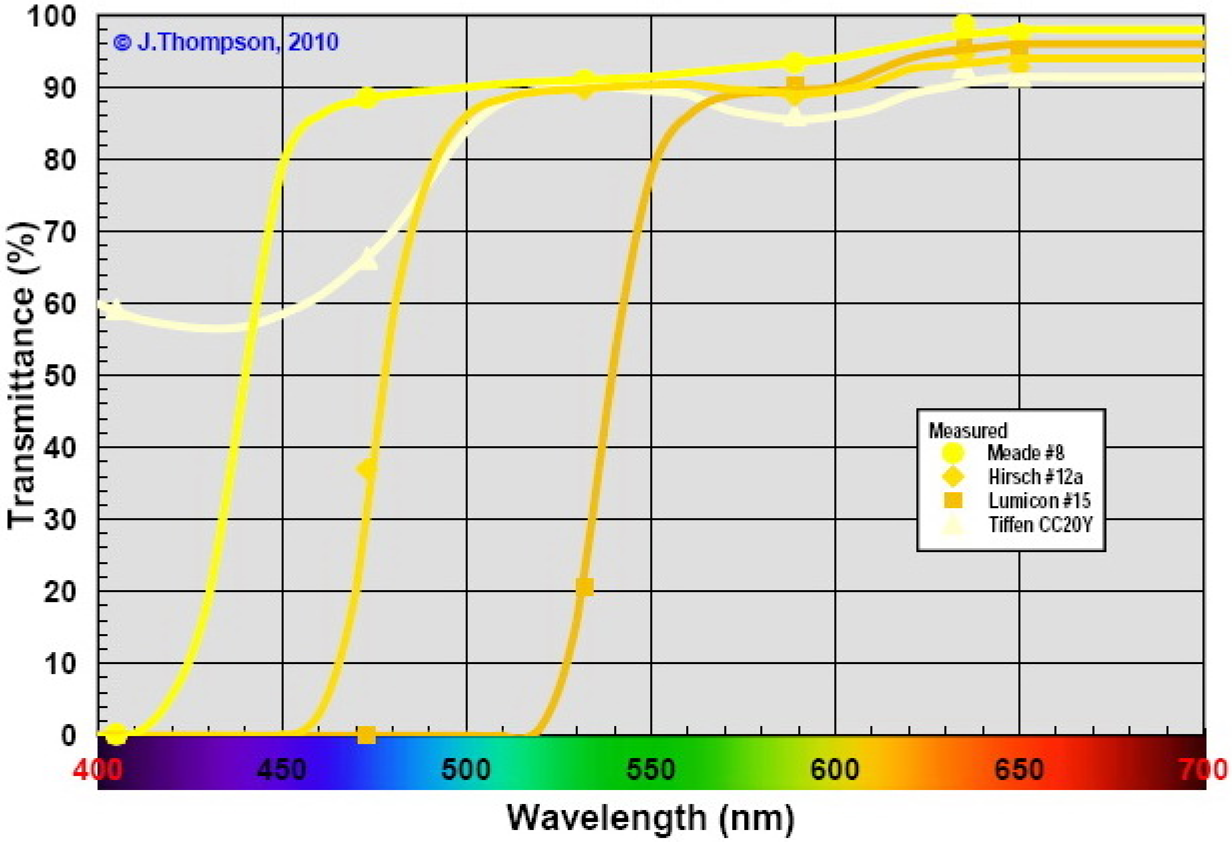
Greens


© J.Thompson, 2010
Transmittance (%)
Wavelength (nm)
Specification
#56
#11
#58
CC20G
CC40G
0
10
20
30
40
50
60
70
80
90
400
450
500
550
600
650
700

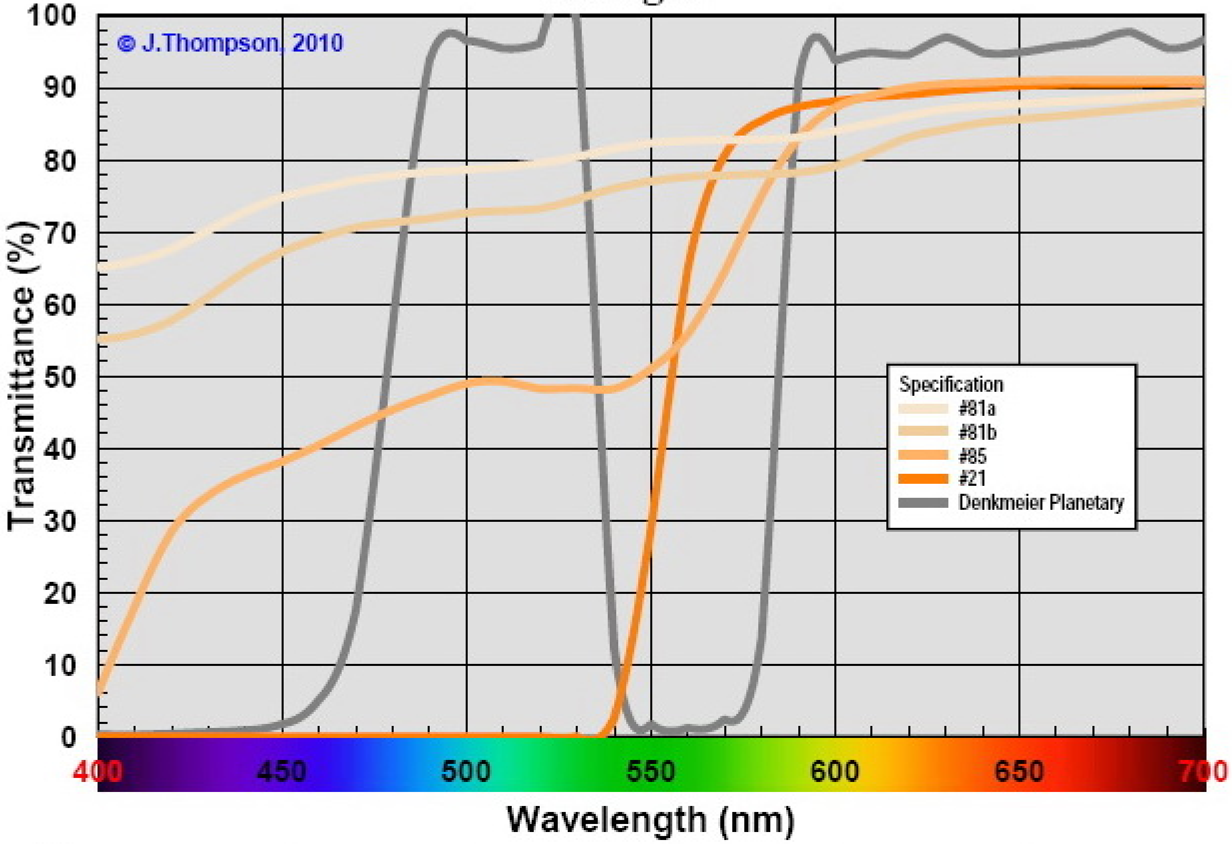

© J.Thompson, 2010
Measured
Meade #56
Hirsch #11
Kodak #11
Hirsch #58
Transmittance (%)
Wavelength (nm)
0
10
20
30
40
50
60
70
80
90
100
400
450
500
550
600
650
700

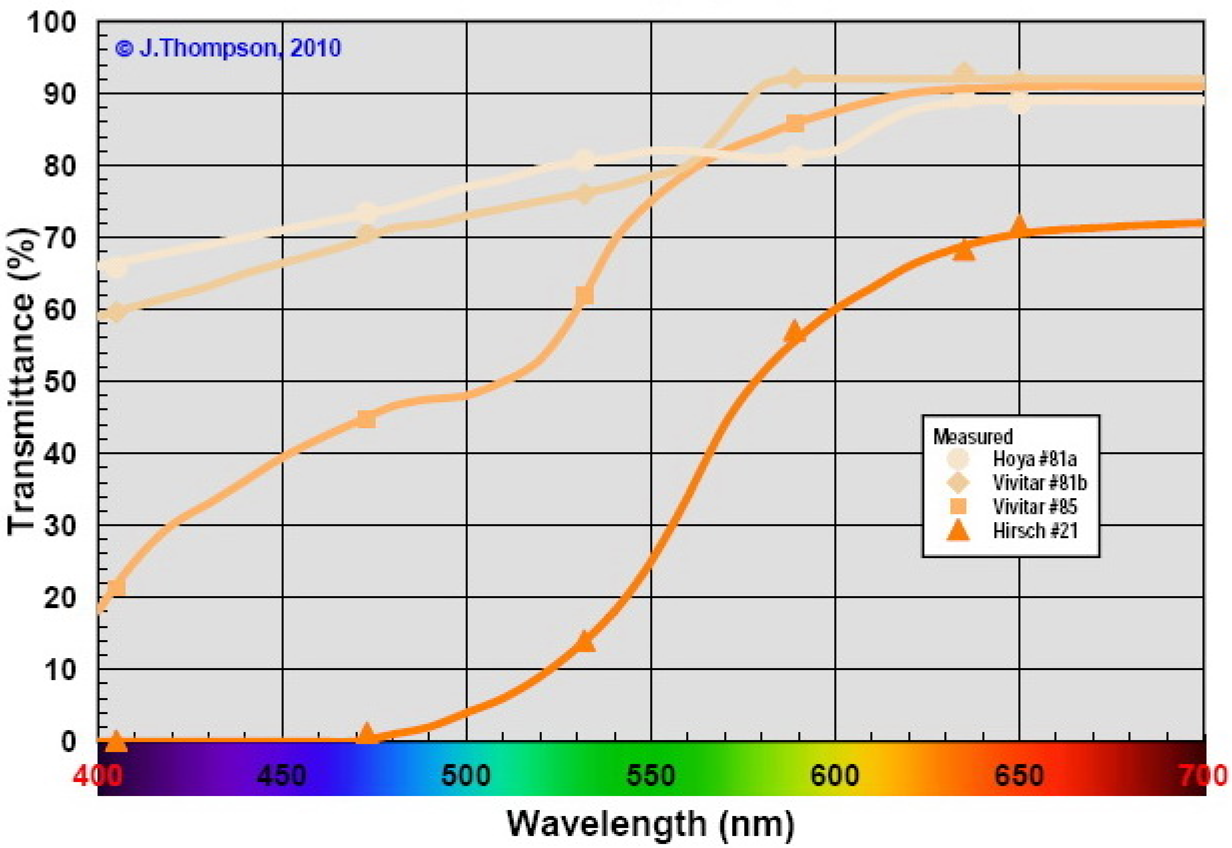
Yellows


© J.Thompson, 2010
Transmittance (%)
Wavelength (nm)
100
80
60
40
20
0
400
450
500
550
600
650
700
Specification
#8
#12a
#15
CC20Y
CC40Y
Baader FringeKill

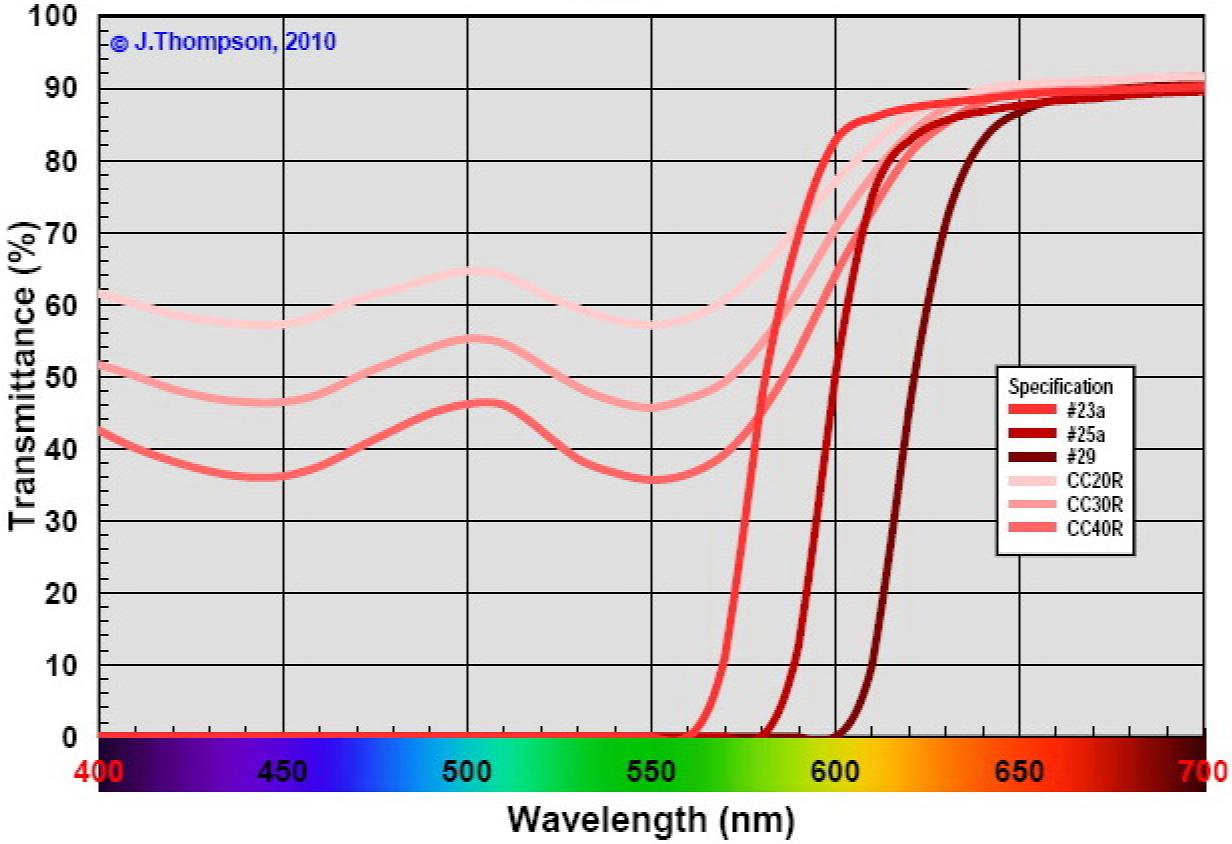

© J.Thompson, 2010
Transmittance (%)
Wavelength (nm)
100
90
80
70
60
50
40
30
20
10
0
400
450
500
550
600
650
700
Measured
Meade #8
Hirsch #12a
Lumicon #15
Tiffen CC20Y

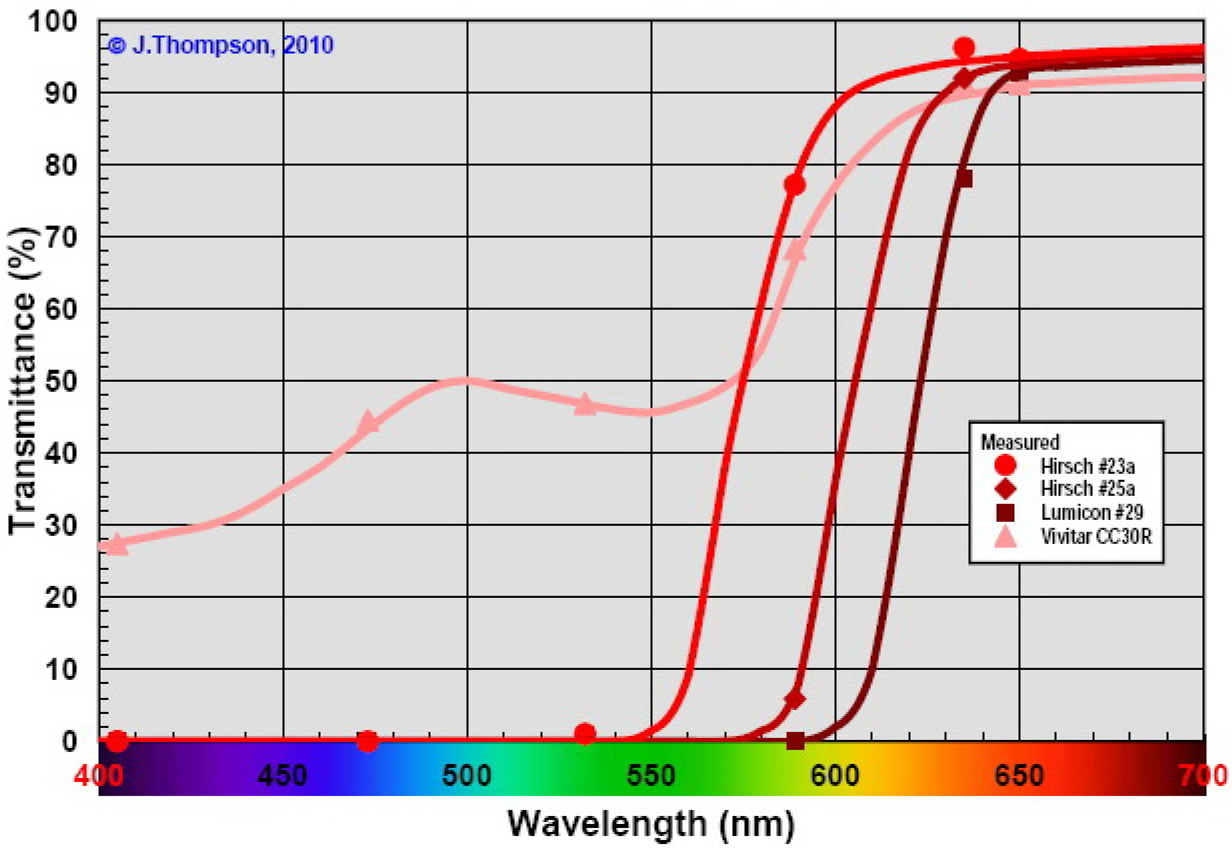
Oranges


© J.Thompson, 2010
Transmittance (%)
100
90
80
70
60
50
40
30
20
10
0
400
450
500
550
600
650
700
Wavelength (nm)
Specification
#81a
#81b
#85
#21
Denkmeier Planetary


© J.Thompson, 2010
Transmittance (%)
100
90
80
70
60
50
40
30
20
10
0
400
450
500
550
600
650
700
Wavelength (nm)
Measured
Hoya #81a
Vivitar #81b
Vivitar #85
Hirsch #21

Reds


© J.Thompson, 2010
Transmittance (%)
Wavelength (nm)
0
10
20
30
40
50
60
70
80
90
100
400
450
500
550
600
650
700
Specification
#23a
#25a
#29
CC20R
CC30R
CC40R


© J.Thompson, 2010
Transmittance (%)
Wavelength (nm)
0
10
20
30
40
50
60
70
80
90
100
400
450
500
550
600
650
700
Measured
Hirsch #23a
Hirsch #25a
Lumicon #29
Vivitar CC30R

Appendix B – Deepsky Filter Plots

Deep-Sky Filter Summary Table

#	Manufacturer	Model	Full Name	Manuf.'s Recommended Use	Contact	My Classification	Weighted % Transmissivity	
							Photopic	Scotopic
1	1000 Oaks	LP-1	LP-1 Broadband	Slight to moderately light polluted areas	www.thousandoaksoptical.com	wide band	16.8	50.6
2	1000 Oaks	LP-2	LP-2 Narrowband	Heavily light polluted areas		narrow band	9.3	26.5
3	1000 Oaks	LP-3	LP-3 O-III	Diffuse & planetary nebulae		O-III A	4.5	11.8
4	1000 Oaks	LP-4	LP-4 H-beta	Horsehead, California, & other faint nebulae		H-beta A	4.2	10.8
5	Andover Corporation	O-III	O-III	Heavily light polluted areas, planetary nebulae	www.andovercorp.com	O-III A	4.4	14.2
6	Andover Corporation	3ch Nebula	3 Channel Narrowband Nebula	Light polluted areas, planetary & emission nebulae		narrow band	12.5	32.9
7	Antares	ALP	Anti-Light Pollution, Broadband	block light pollution, improve view of emission nebulae	www.antaresoptical.com	wide band	26.0	59.6
8	Astro Hutech	O-III	IDAS O-III	narrow-band nebular + O-III passband modifier filter	www.sciencecenter.net/hutech/	O-III A	7.3	16.2
9	Astro Hutech	H-beta	IDAS H-beta	narrow-band nebular + Hbeta passband modifier filter		H-beta A	2.6	10.2
10	Astro Hutech	LPS-P1	IDAS Light Pollution Suppression v1	Light polluted areas, nebulae viewing, color balanced photography		multi band	46.3	73.5
11	Astro Hutech	LPS-P2	IDAS Light Pollution Suppression v2	Light polluted areas, nebulae viewing, color balanced photography		multi band	44.9	72.7
12	Astro Hutech	LPS-V3	IDAS LPS v3, Narrow-Band Nebular	Provide maximum contrast between key emission lines and light polluted sky		wide band	22.5	54.3
13	Astro Hutech	LPS-V4	IDAS LPS v4, Narrow-Band Nebular	Provide maximum contrast between key emission lines and light polluted sky		wide band	20.6	54.1
14	Astronomik	O-III	O-III	f3 to f15 & >6" aperture, substantial contrast gain on emission & planetary nebulae & supernova remnants	www.astronomik.com	O-III A	6.6	20.5
15	Astronomik	H-beta	H-beta	f4.5 to f6 optimal, f3.5 to f15 possible, >8" aperture, dim hydrogen emission nebulae		H-beta A	2.5	12.6
16	Astronomik	UHC	Ultra High Contrast	LPR, better views of deep-sky-objects, f4 to f15 & >4" aperture, CCD and DSLR photography		medium band	11.8	33.6

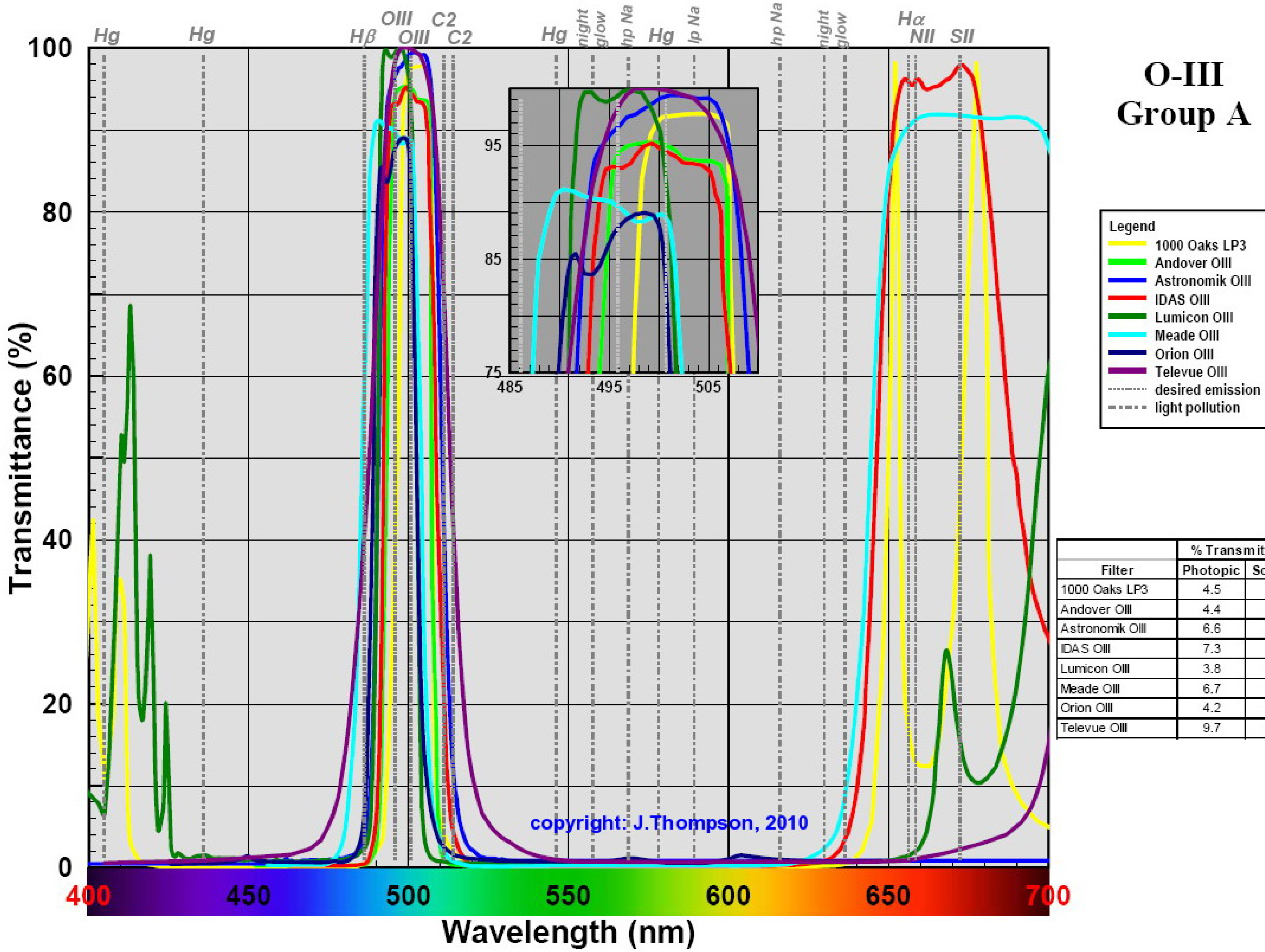
17	Astronomik	UHC-E	Ultra High Contrast - Economy	increase contrast between target and night sky, well suited for smaller telescopes <5", comets, jupiter's clouds, double stars, LPR for photography		medium band	23.9	42.5
18	Astronomik	CLS	"Clear Sky"?	budget filter for visual LPR, very good colour balance for photography (film or digital)		extra wide band	31.1	67.5
19	Baader Planetarium	O-III	O-III Visual Nebula	maximum contrast and image sharpness, emission & planetary nebulae	www.baader-planetarium.com	O-III B	2.0	6.5
20	Baader Planetarium	H-beta	H-beta Narrowband CCD	maximum contrast and image sharpness		H-beta B	1.1	5.4
21	Baader Planetarium	UHC-S	UHC-S Nebula	improved contrast over typical broadband filters without sacrificing stars like other UHC filters, great for smaller scopes, good for imaging		wide band	22.5	54.7
22	Baader Planetarium	Moon&Sky	Moon & Sky Glow	neodymium infused glass, enchances both planetary & deep sky contrasts by reducing skyglow from LP & Moon, RGB intensifier		special B	55.3	72.3
23	Baader Planetarium	Contrast	Contrast Booster	neodymium infused glass + minus violet filter, boosts lunar & planetary contrast, cuts skyglow, totally eliminates de-focused blue halo in achromats, natural colour balance, great for Mars		special B	53.1	48.9
24	Burgess Optical	LPR	Broadband Nebula - Light Pollution Reduction	a fine light pollution filter that passes a very high percentage of light originating from stellar sources, blocks light at wavelengths typically found in outdoor lighting	www.burgessoptical.com	wide band	26.9	47.7
25	Custom Scientific	O-III	Narrowband O-III	one of most commonly used filters by researchers and serious amateurs, useful for capturing high resolution images with high light pollution	www.customscientific.com	O-III B	1.5	4.8
26	Custom Scientific	H-beta	Narrowband H-beta	one of most commonly used filters by researchers and serious amateurs, useful for capturing high resolution images with high light pollution		H-beta B	0.8	4.3
27	Custom Scientific	Multiband	Multiband H-beta / O-III / H-alpha	one of most commonly used filters by researchers and serious amateurs, useful for capturing high resolution images with high light pollution		narrow band	5.5	21.5
28	DGM	O-III	High Performance O-III	maximum enhancement of emission and reflective nebula	users.erols.com/dgmoptics/	O-III B	10.4	10.7

29	DGM	NPB	Narrow Pass Band Nebula	UHC type, small & fainter emission & planetary nebula, retains natural star colours		narrow band	12.3	22.6
30	DGM	VHT	Very High Throughput Nebula	smaller scopes (4-6"), compromise between UHC and broadband, enhance view of emissioni & reflective nebula with minimum star dimming		medium band	14.1	33.3
31	DGM	GCE	Galaxy Contrast Enhancement	aids visual observation of galaxies & Milky Way dust clouds & dark lanes, general purpose LPR, most of visible spectrum passed		extra wide band	33.4	67.7
32	Denkmeier Optical	O-III	Hi Def O-III	the square transmission curves mean only photons in the desired emission bandpasses of the observed object are viewed, red halos around stars will not be present, a more natural and contrasty view results	www.denkmeier.com	O-III B	2.0	7.8
33	Denkmeier Optical	UHC	Hi Def Ultra High Contrast	the square transmission curves mean only photons in the desired emission bandpasses of the observed object are viewed, red halos around stars will not be present, a more natural and contrasty view results		medium band	10.7	38.8
34	Denkmeier Optical	Planetary	Hi Def Planetary	very unique contrast enhancement filter, see brighter greens and reds, greatly improve contrast of Mars, Jupiter, & Saturn		special A	52.8	54.3
35	Lumicon	O-III	O-III	narrow band pass, near-photographic views of Veil, Ring, Dumbbell, Orion, use on diffuse/planetary/faint nebulae, optimum exit pupil L2-5mm/D3-7mm	www.lumicon.com	O-III A	3.8	12.6
36	Lumicon	H-beta	H-beta	extremely faint nebulae like California, Cocoon & Horsehead, used best under clear skies & large aperture, optimum exit pupil L3-7mm/D4-7mm		H-beta A	2.4	10.1
37	Lumicon	UHC	Ultra High Contrast	superb views of Orion, Lagoon, Swan and other extended nebulae, best all-around dark-sky nebualr filter, optimum exit pupil L1-4mm/D2-6mm		narrow band	7.0	24.8
38	Lumicon	Deepsky	Deepsky	LPR, imaging of all types of deepsky objects, high contrast views of Martian polar caps, optimum exit pupil L0.5-2mm/D1-4mm		wide band	23.8	60.6
39	Lumicon	Comet	SWAN	enhances cyanogen wavelength in comet tails, narrow pass band allows OII and C2		special A	9.3	21.3
40	Meade	O-III	O-III	Diffuse & planetary nebulae	www.meade.com	O-III A	6.7	16.7

41	Meade	Narrow	Narrowband Nebular	striking contrast between nebula and background, best with >25mm ep , not intended for photography, useful on fewer objects but those objects are greatly enhanced		narrow band	8.9	28.1
42	Meade	Wide	Wideband Nebular	LPR, photography, enhances nebula mostly but does improve contrast on galaxies		medium band	10.2	37.8
43	Omega Optical	O-III	OIII Narrow CCD	precision interference filter, narrow band pass, best for CCD imaging	www.omegafilters.com	O-III B	1.7	5.6
44	Omega Optical	H-beta	Hb Narrow	precision interference filter, narrow band pass, best for CCD imaging		H-beta B	4.1	6.8
45	Omega Optical	Wide	Hb&OIII Nebula II	precision interference filter, relatively broad pass band allwos Hbeta & OIII wavelengths		wide band	20.2	49.4
46	Omega Optical	Narrow	Hb&OIII Nebula	precision interference filter, narrow pass band allows Hbeta & OIII wavelengths		medium band	12.0	34.3
47	Omega Optical	Hg&Na	Hg&Na Skylight Reject	multi band interference filter, cuts out prominent light pollution wavelengths but maintains high overall transmission		extra wide band	52.5	72.8
48	Omega Optical	Imaging	Colour Enhancing LPF	enhances recording of colour images, especially on bright objects like moon and planets, reduces light pollution, removes cyan and yellow that mute Hue		multi band	50.4	50.9
49	Optec Inc.	O-III	O-III	Diffuse & planetary nebulae	www.optecinc.com/astronomy	O-III B	3.2	9.7
50	Optec Inc.	Deepsky	Deepsky	blocks UV, violet, & sodium light completely		extra wide band	33.6	59.4
51	Orion	O-III	O-III	reveal more wondrous details when viewing nebulas, completely blocks all other visible wavelengths, for >8" aperture, visual use only	www.telescope.com	O-III A	4.2	13.8
52	Orion	H-beta	H-beta	visually capture elusuve faint nebulas, perhaps only way to see Horsehead, California, & Cocoon, best with a moderate to large aperture scope & clear dark skys		H-beta A	1.8	9.5
53	Orion	Ultrablock	Ultrablock	for deep-sky observers at highly light polluted sites, enhances the sky presence of a significant number of fainter deep-sky objects		narrow band	8.7	26.5
54	Orion	Skyglow-B	Skyglow Broadband	enhances deep-sky observing in moderately light polluted skies, improves the view of nebulas, galaxies, & clusters		extra wide band	26.5	64.8
55	Orion	Skyglow-I	Skyglow Imaging	deep-sky CCD or DSLR imaging from light polluted skies, enhances all types of deep-sky objects (galaxies, nebulas, clusters), preserves neutral colour balance		multi band	61.9	68.5

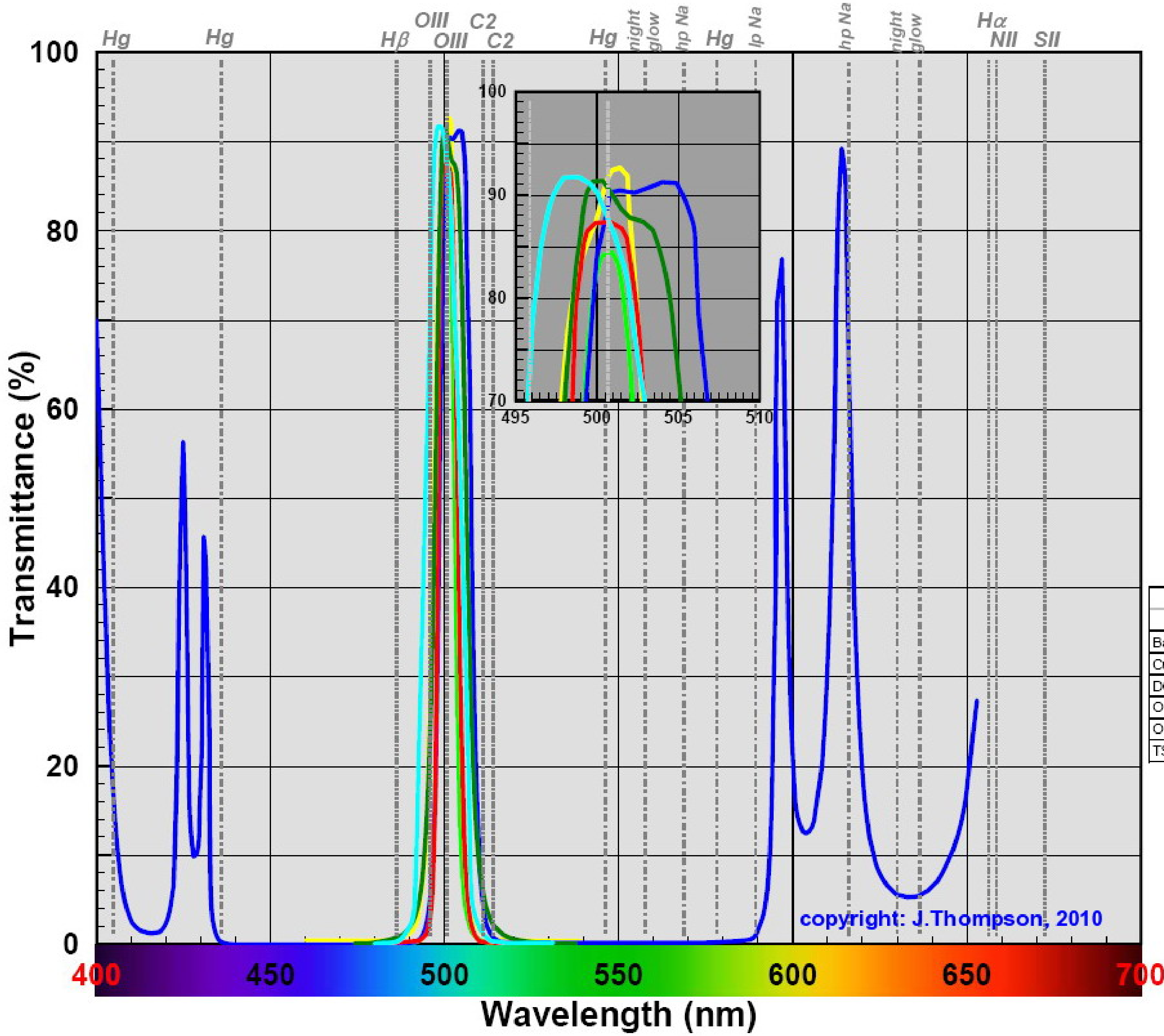
56	Orion	Mars	Mars	high performance visual filter for improving views of Mars, improves view of polar ice caps, subtle mare shadings, cloud activity, dramatic improvements even in smaller telescopes		special A	29.2	52.6
57	Sirius Optics	NEB1	Nebula	-	out-of-business	medium band	17.7	41.1
58	Sirius Optics	CE1	Contrast Enchance	-		special A	60.9	50.1
59	Sirius Optics	PC1	Planetary Contrast	-		special A	40.7	35.9
60	Sirius Optics	NPC	Neodymium Planetary Contrast	-		special B	49.0	55.1
61	TS Optics	O-III	O-III	narrowband nebular filter for observing and imaging	www.telescope-service.com	O-III B	3.0	9.9
62	TS Optics	UHC	Ultra High Contrast	contrast boosting filter for deep sky observing		narrow band	5.9	22.2
63	Televue Optics	O-III	Bandmate O-III	enhances planetary nebulae in larger scopes	www.televue.com	O-III A	9.7	27.3
64	Televue Optics	Nebustar	Bandmate Nebustar	high-performance dielectric squarewave “UHC” type general purpose narrow-band filter, great for all nebulae types and instrument sizes		medium band	14.9	42.5

O-III Group A



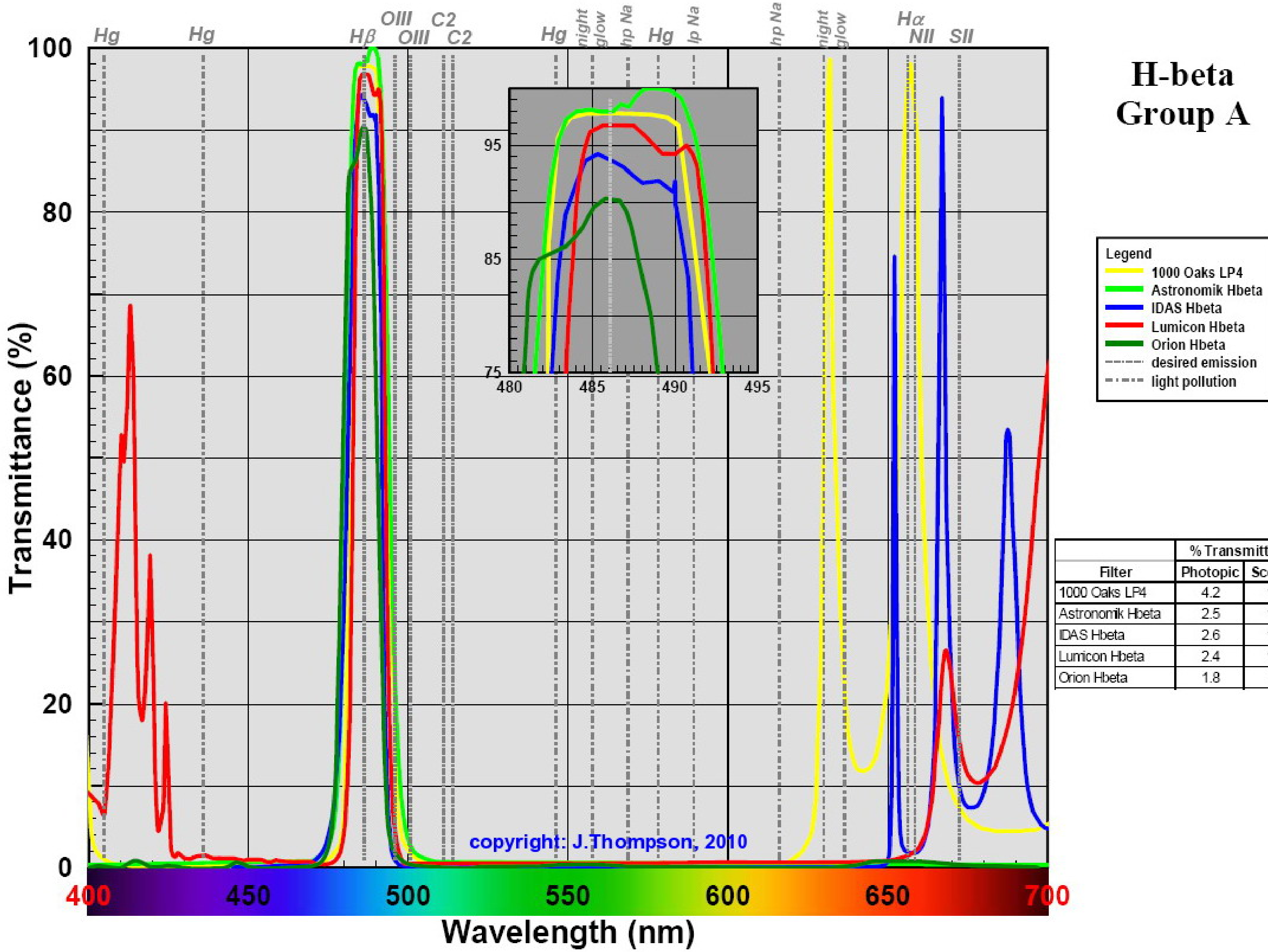
Filter	% Transmittance	
	Photopic	Scotopic
1000 Oaks LP3	4.5	11.8
Andover OIII	4.4	14.2
Astronomik OIII	6.6	20.5
IDAS OIII	7.3	16.2
Lumicon OIII	3.8	12.6
Meade OIII	6.7	16.7
Orion OIII	4.2	13.8
Televue OIII	9.7	27.3

O-III
Group B

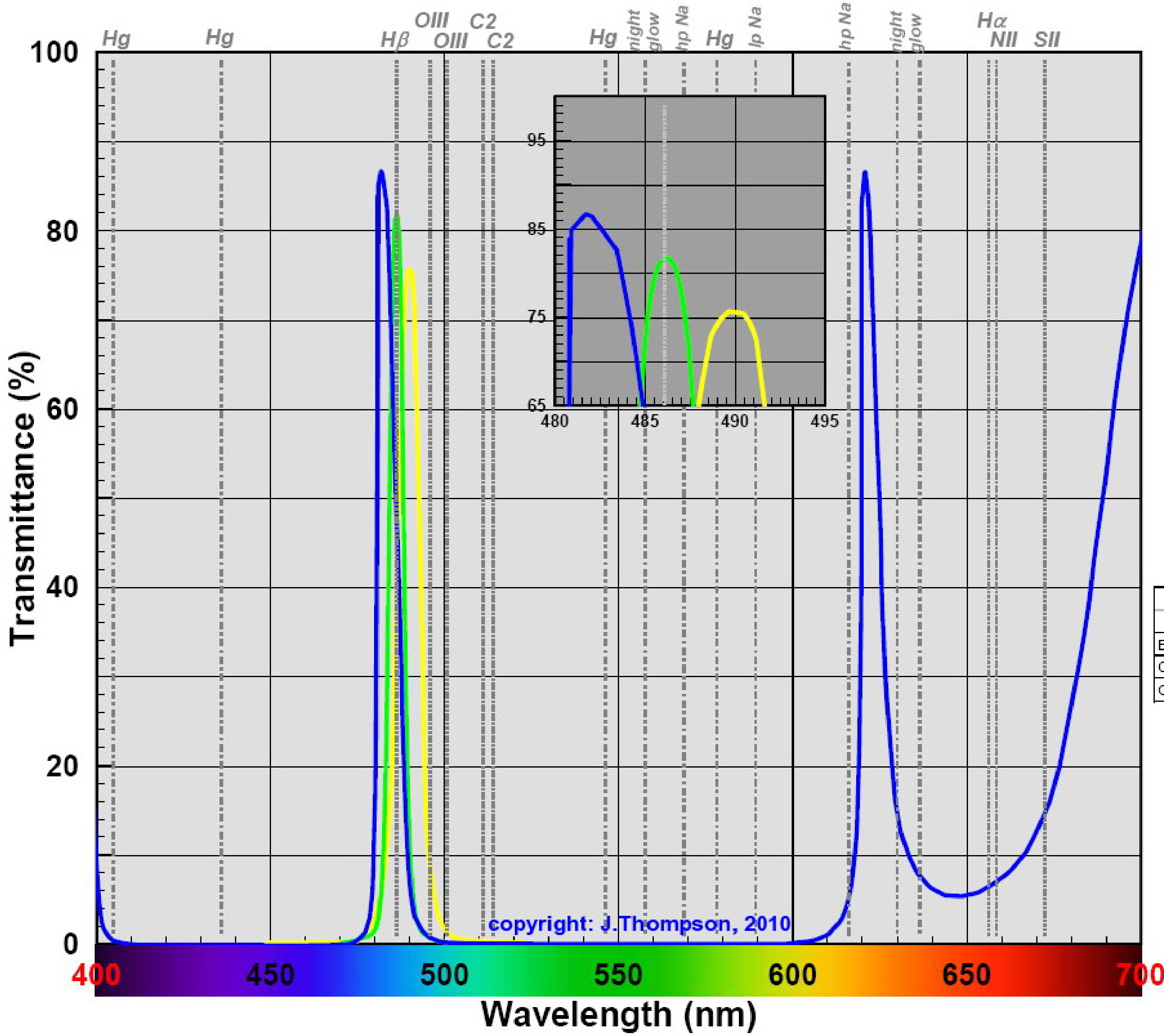


Filter	% Transmittance	
	Photopic	Scotopic
Baader OIII	2.0	6.5
Cust-Sci OIII	1.5	4.9
DGM OIII	10.4	10.7
Omega OIII	1.8	5.6
Optec OIII	3.2	9.7
TS OIII	3.0	9.9

H-beta
Group A



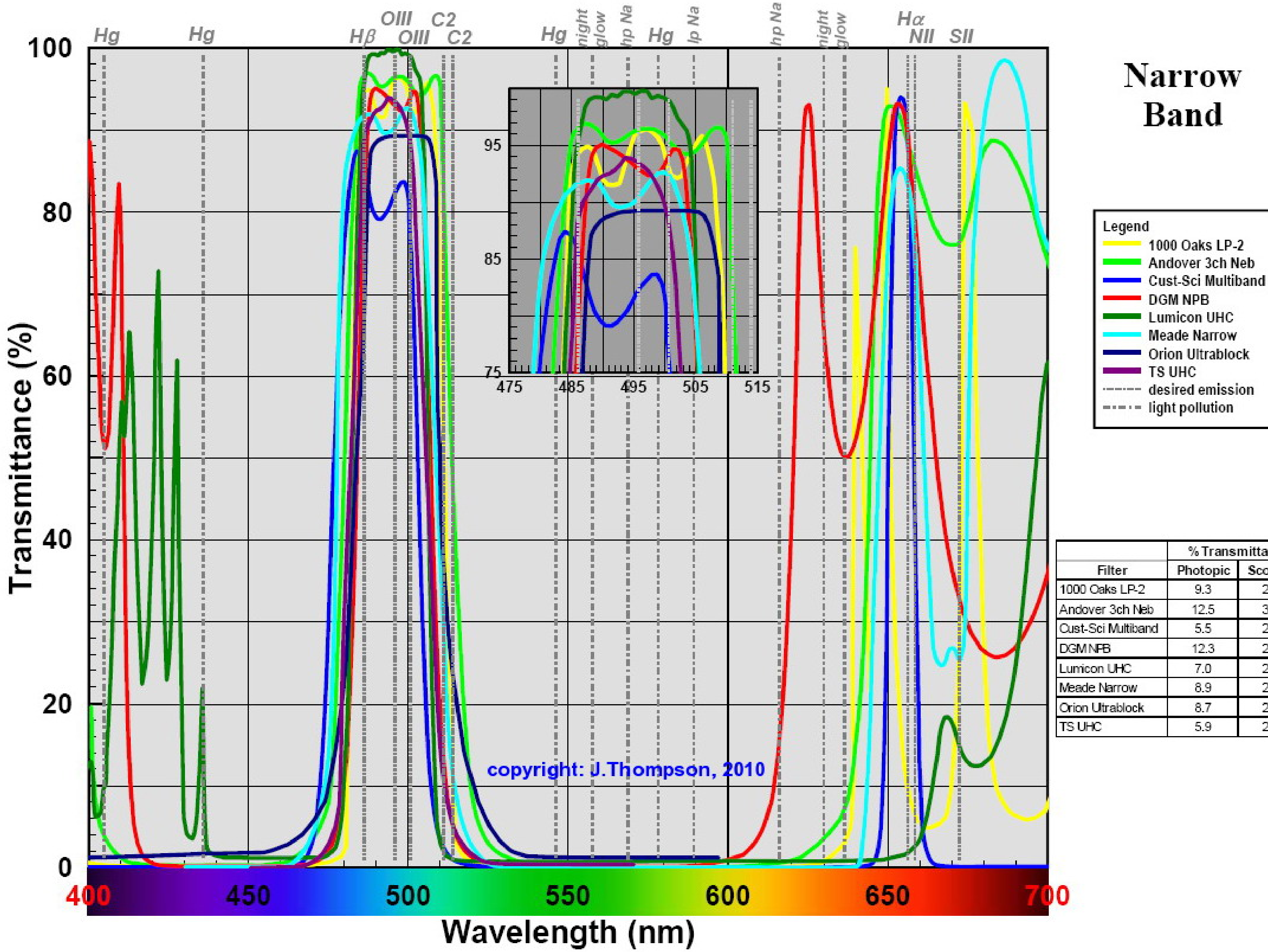
Filter	% Transmittance	
	Photopic	Scotopic
1000 Oaks LP4	4.2	10.8
Astronomik Hbeta	2.5	12.6
IDAS Hbeta	2.6	10.2
Lumicon Hbeta	2.4	10.1
Orion Hbeta	1.8	9.5



H-beta Group B

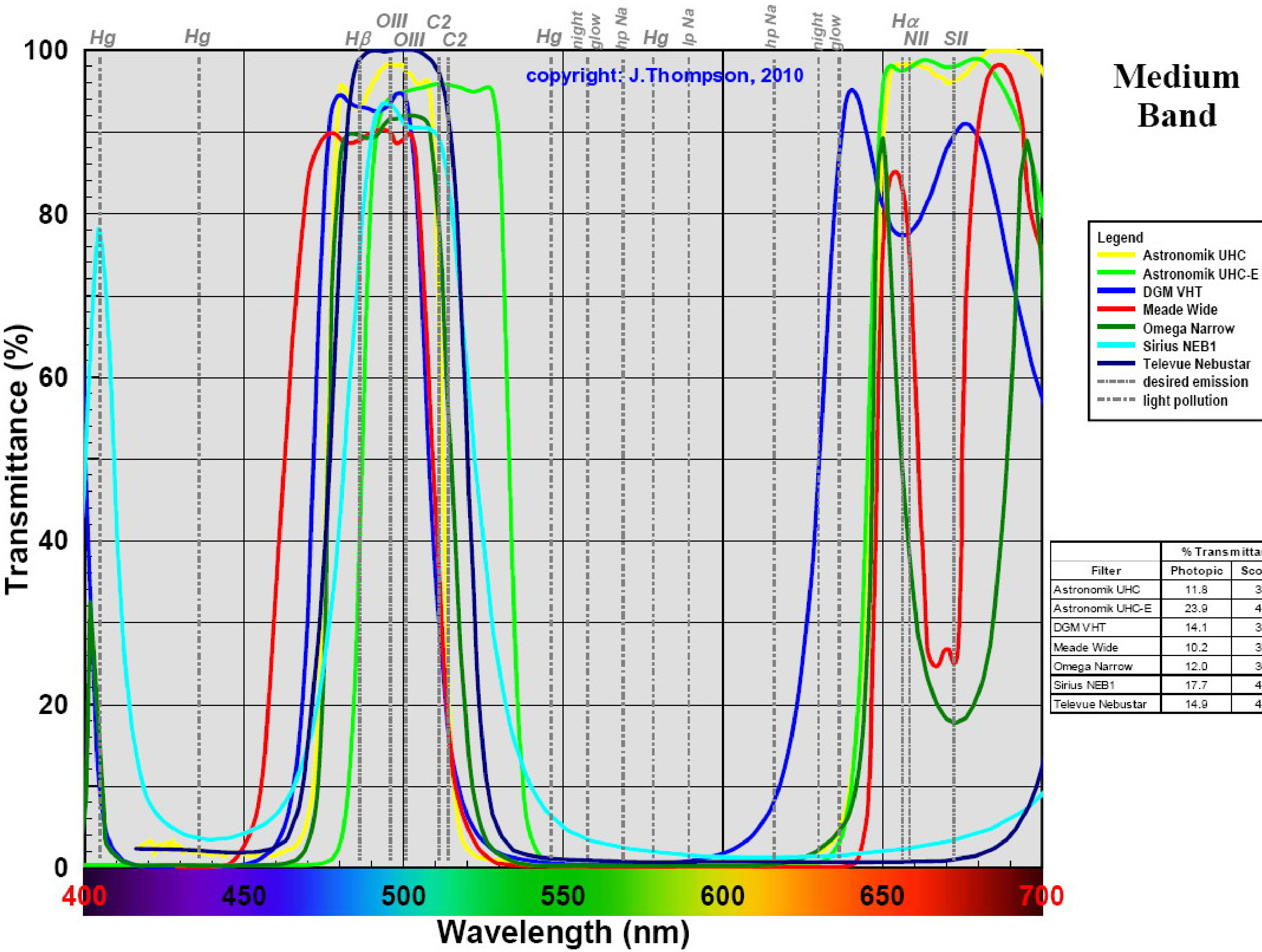
Filter	% Transmittance	
	Photopic	Scotopic
Baader Hbeta	1.1	5.4
Cust-Sci Hbeta	0.8	4.3
Omega Hbeta	4.1	6.8

Narrow Band

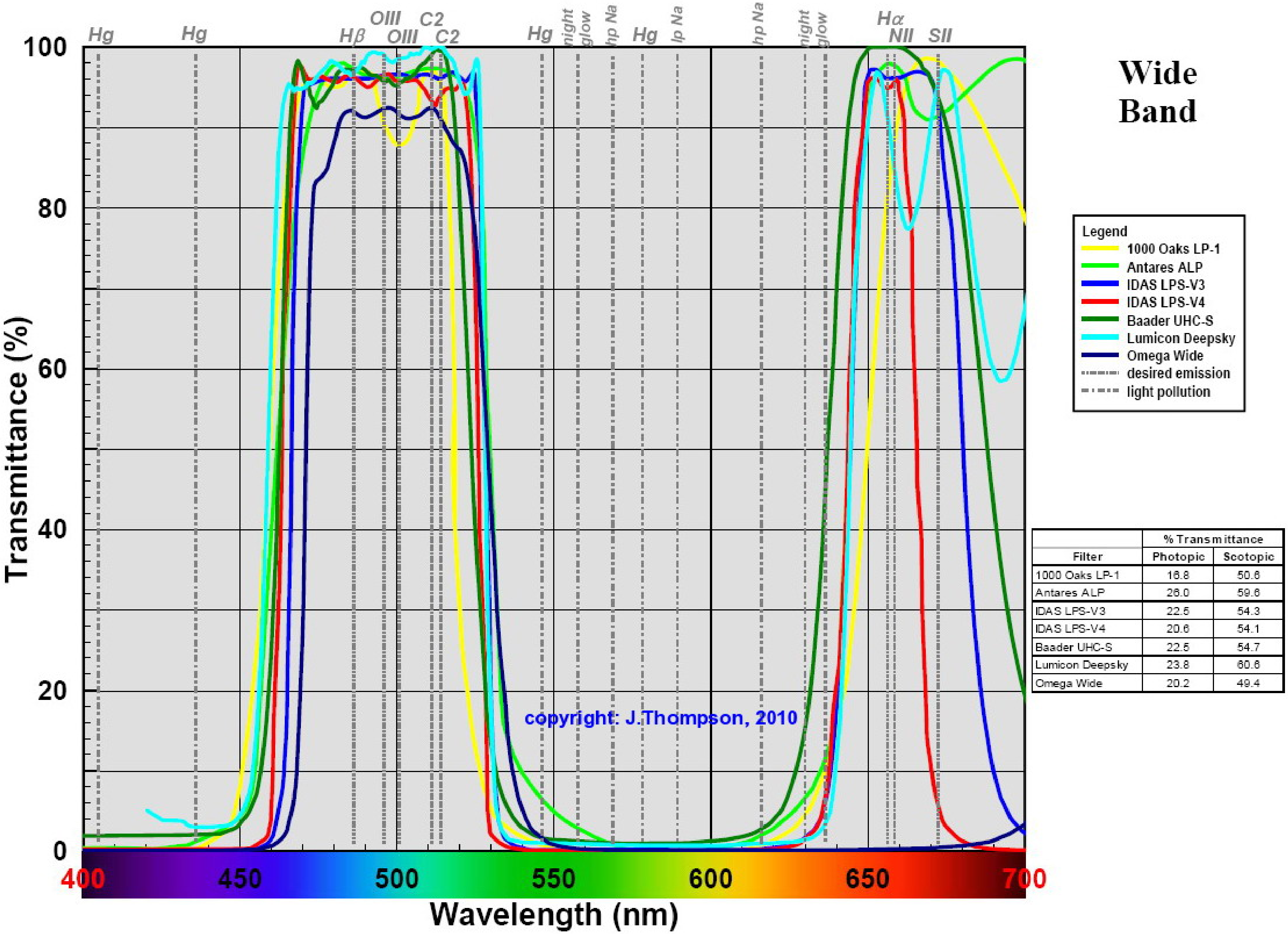


Filter	% Transmittance	
	Photopic	Scotopic
1000 Oaks LP-2	9.3	26.5
Andover 3ch Neb	12.5	32.9
Cust-Sci Multiband	5.5	21.5
DGM NPB	12.3	22.6
Lumicon UHC	7.0	24.8
Meade Narrow	8.9	28.1
Orion Ultrablock	8.7	26.5
TS UHC	5.9	22.2

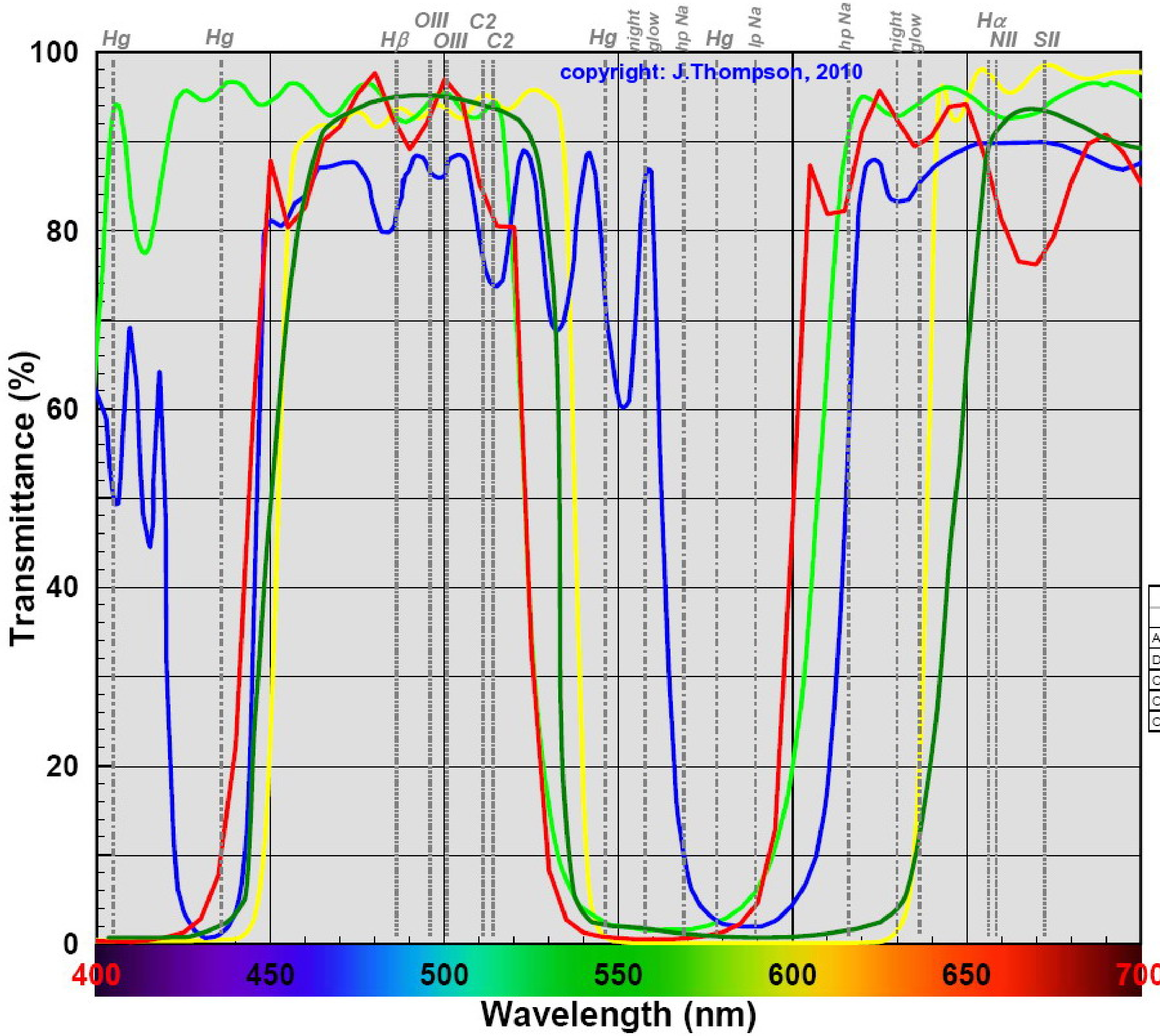
Medium Band



Filter	% Transmittance	
	Photopic	Scotopic
Astronomik UHC	11.8	33.6
Astronomik UHC-E	23.9	42.5
DGM VHT	14.1	33.3
Meade Wide	10.2	37.8
Omega Narrow	12.0	34.3
Sirius NEB1	17.7	41.1
Televue Nebustar	14.9	42.5



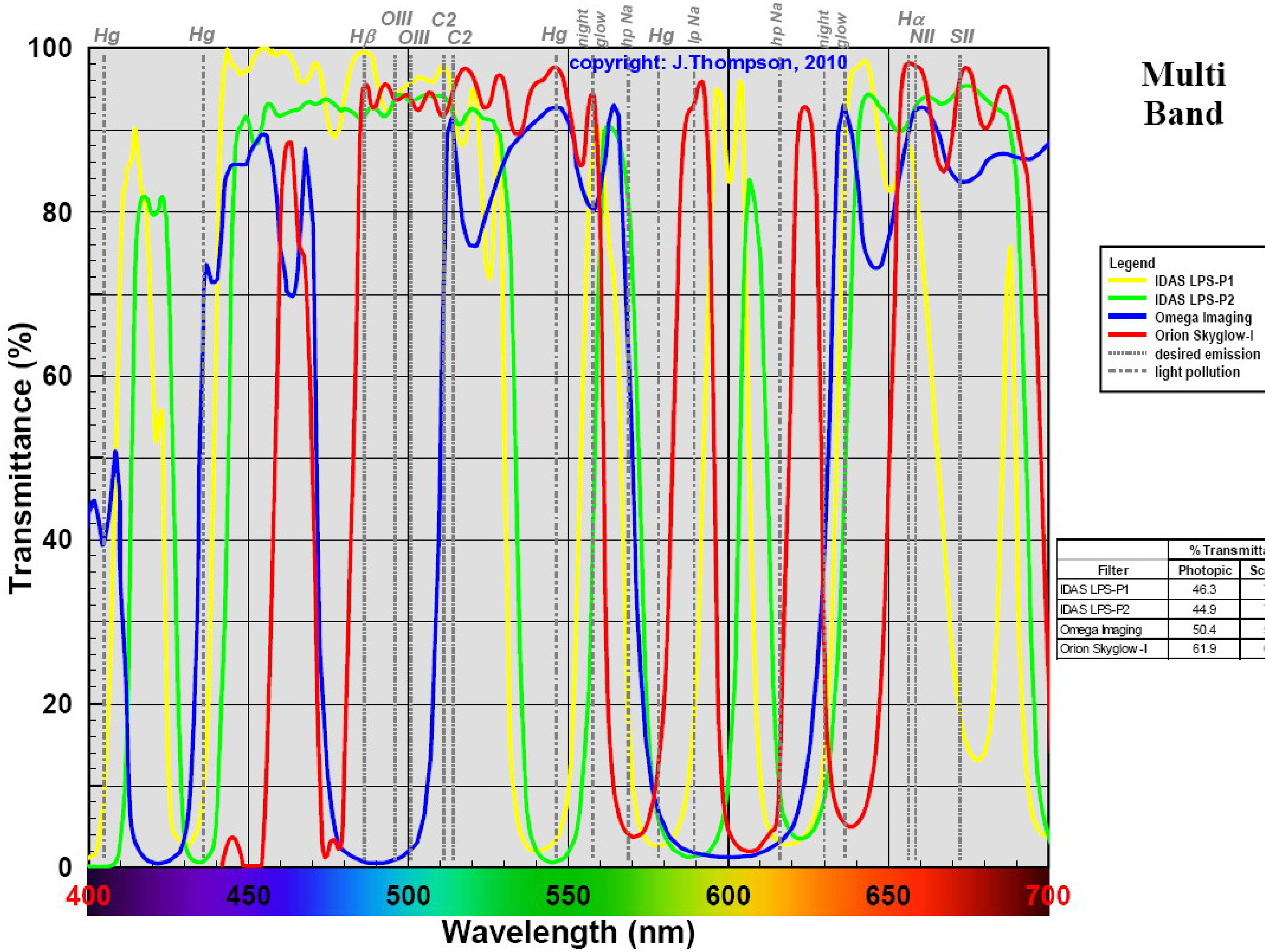
	% Transmittance	
Filter	Photopic	Scotopic
1000 Oaks LP-1	16.8	50.6
Antares ALP	26.0	59.6
IDAS LPS-V3	22.5	54.3
IDAS LPS-V4	20.6	54.1
Baader UHC-S	22.5	54.7
Lumicon Deepsky	23.8	60.6
Omega Wide	20.2	49.4



Extra Wide Band

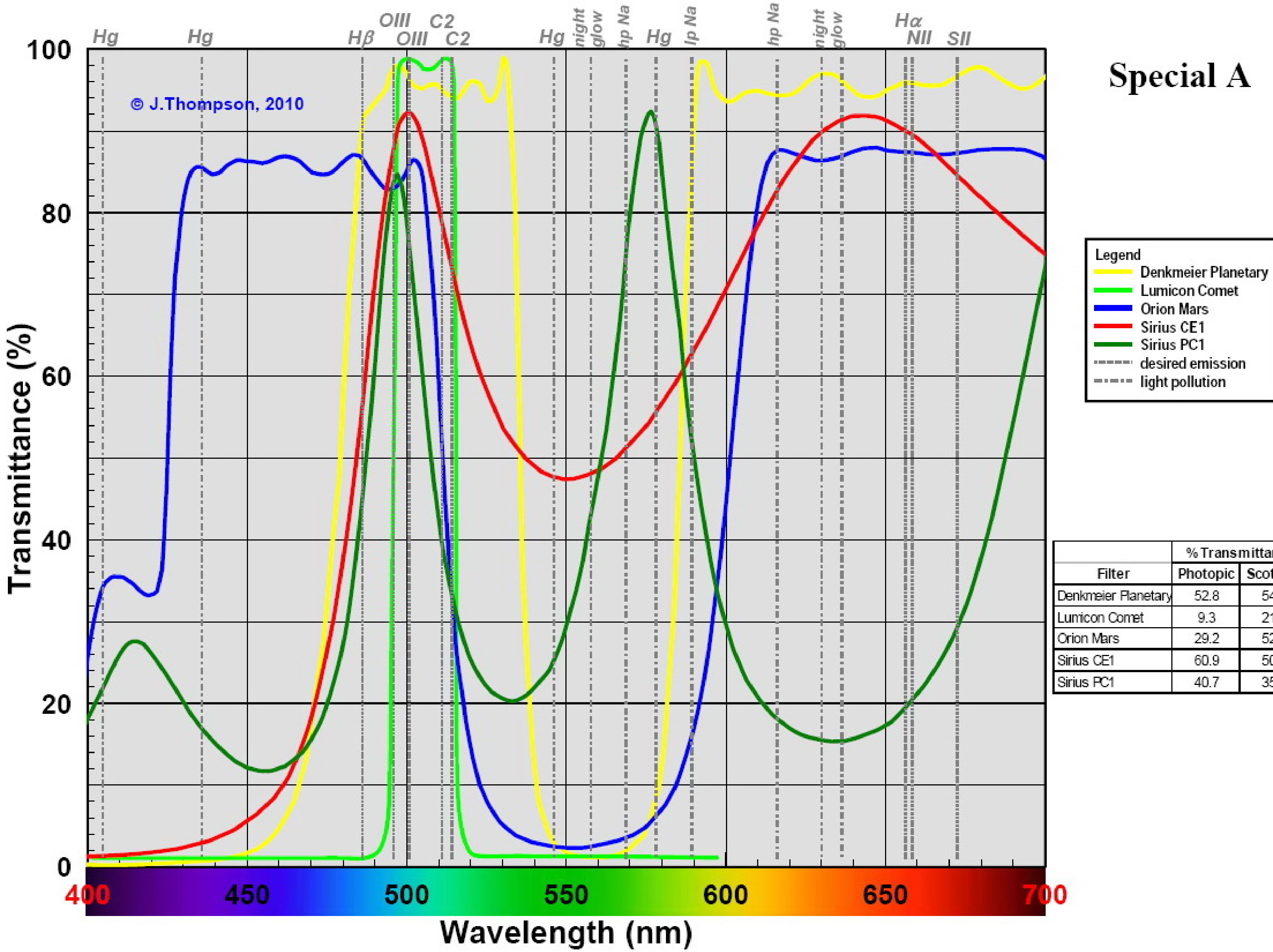
Filter	% Transmittance	
	Photopic	Scotopic
Astronomic CLS	31.1	67.5
DGM GCE	33.4	67.7
Omega Hg&Na	52.5	72.8
Optec Deepsky	33.6	59.4
Orion Skyglow -B	26.5	64.8

Multi Band



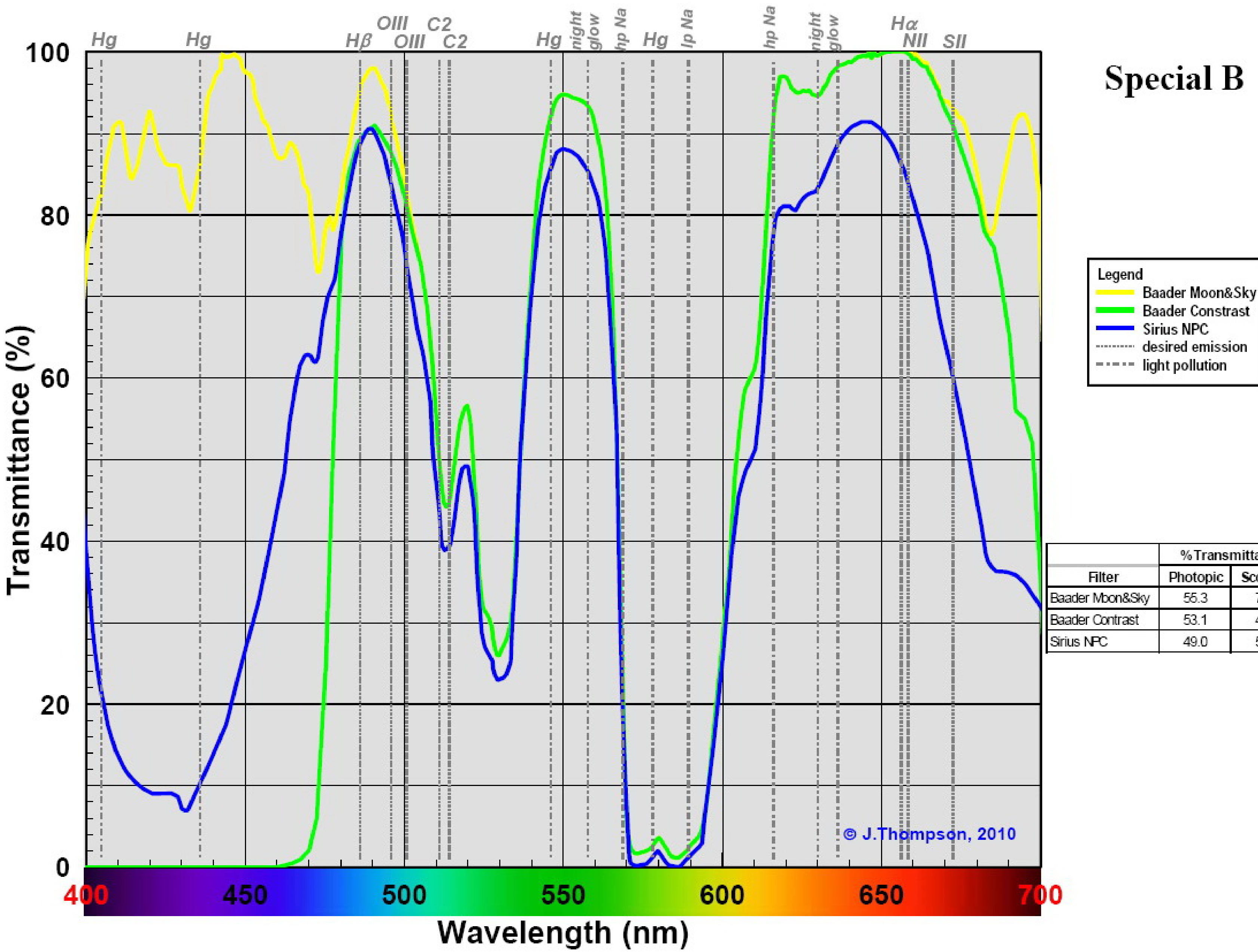
Filter	% Transmittance	
	Photopic	Scotopic
IDAS LPS-P1	46.3	73.5
IDAS LPS-P2	44.9	72.7
Omega Imaging	50.4	50.9
Orion Skyglow-I	61.9	68.5

Special A



Filter	% Transmittance	
	Photopic	Scotopic
Denkmeier Planetary	52.8	54.3
Lumicon Comet	9.3	21.3
Orion Mars	29.2	52.6
Sirius CE1	60.9	50.1
Sirius PC1	40.7	35.9

Special B



	%Transmittance	
Filter	Photopic	Scotopic
Baader Moon&Sky	55.3	72.3
Baader Contrast	53.1	48.9
Sirius NPC	49.0	55.1