Band-Pass Filters For Visual & Video Astronomy

by

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Table of Contents

List of Figures

List of Tables

1.0 Introduction

Almost a year ago now I shared my astronomy filter research with the OAOG and Mallincam community. That personal project came about from my own selfish desire to know as much as I could about filters, both planetary (colour) and deep-sky (band-pass), so that I could make an informed purchase and later informed application of these filters. At the time I was devoted to observing visually, primarily from my backyard in Ottawa. Since that time I have been drawn into the world of video astronomy, and as a result I have been the proud owner of a Mallincam Xtreme since early January this year. With this recent shift in my observing methodology, some rework of my filter research was required.

2.0 Scope

A lot of technical data was compiled on band-pass type astronomical filters in my original research, but that data was compiled from the perspective of using the filters for visual observation only. Opening up the use of these filters to video astronomy as well results in some of the filters I ignored before now being of interest. Video astronomy also provides a very convenient method of comparing the performance of different filters not just using plots and % Luminous Transmissivity (%LT) numbers, but visually as well.

This whitepaper presents the revision I've made to my filter research specifically related to use with my Mallincam astrovideo camera. The following changes specifically are included:

- added 18 filters, mostly H-alpha which are not suitable for visual use but are suitable for video astronomy;
- calculated %LT for all filters based on spectral response of Sony CCD used in the Mallincam; and
- captured images using my Mallincam Xtreme of a fixed target (M42), using a range of band-pass filters, over a range of integration times.

The final task in my scope is an important one, as it provides some way of seeing firsthand how the use of a particular filter affects not only the view but technical issues like total integration time which in turn affects the importance of tracking accuracy (guided vs. unguided). The images collected are also useful for the visual observer since they give an idea what one can hope to achieve for contrast improvement, as will be discussed later.

3.0 Detector Spectral Response

In my filter research from a year ago I presented what is understood to be the sensitivity of the human eye to various wavelengths of light, both when light adapted (photopic) and dark adapted (scotopic). In order to consider the Mallincam or other video imaging device, a spectral sensitivity for this type of sensor was needed. The technical specification document for the Sony CCD sensor installed in the Mallincam has the spectral response of each of the four colour channels, CMYG. I took a straight average of these responses to get the average sensor response, as shown in Figure 1. The normalized average response is used later in the calculation of %LT. The spectral sensitivity of the Mallincam is compared to the human eye in Figure 2.

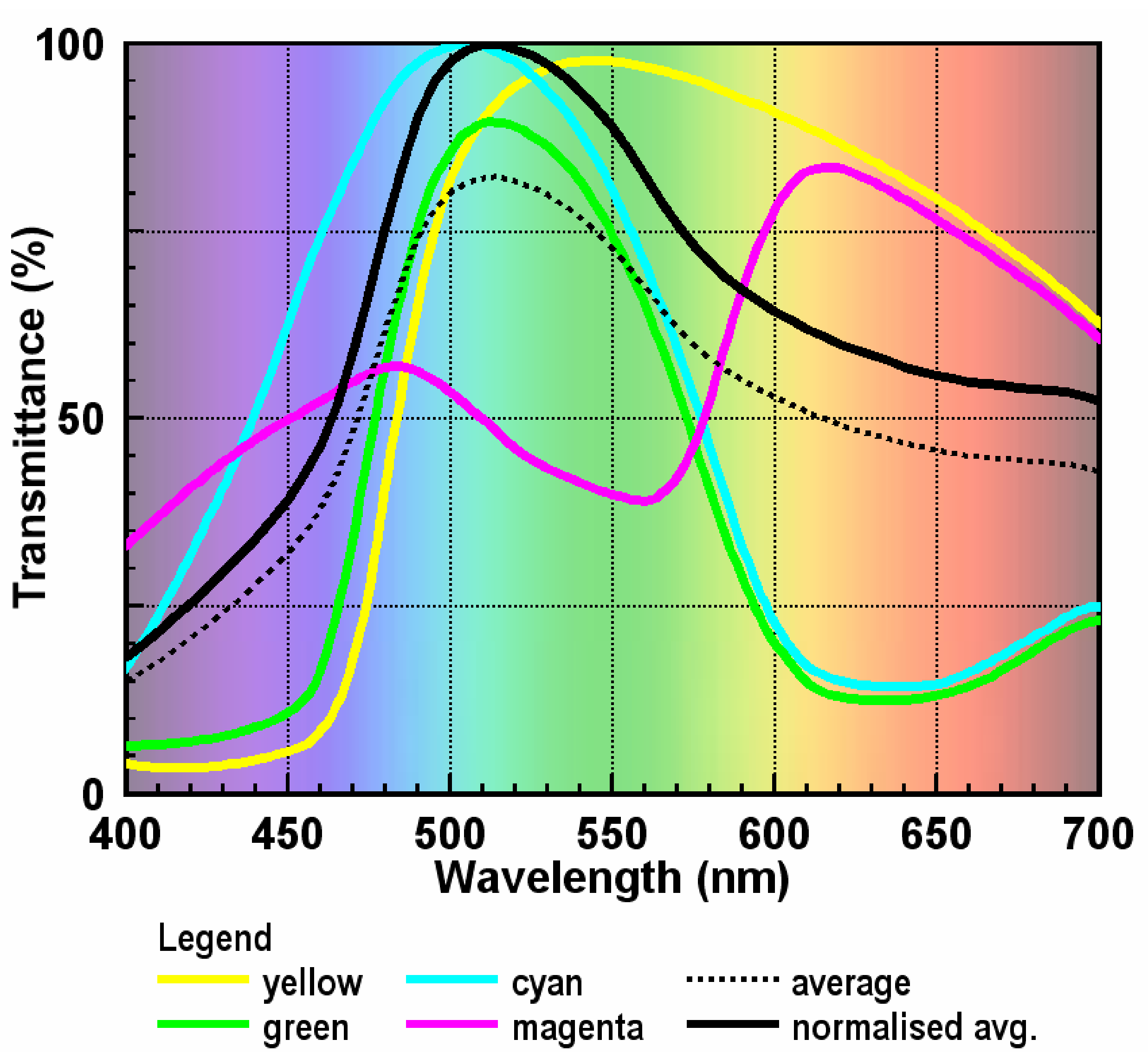

Figure 1 *Spectral Response Of The Sony ICX418AKL-A CCD*

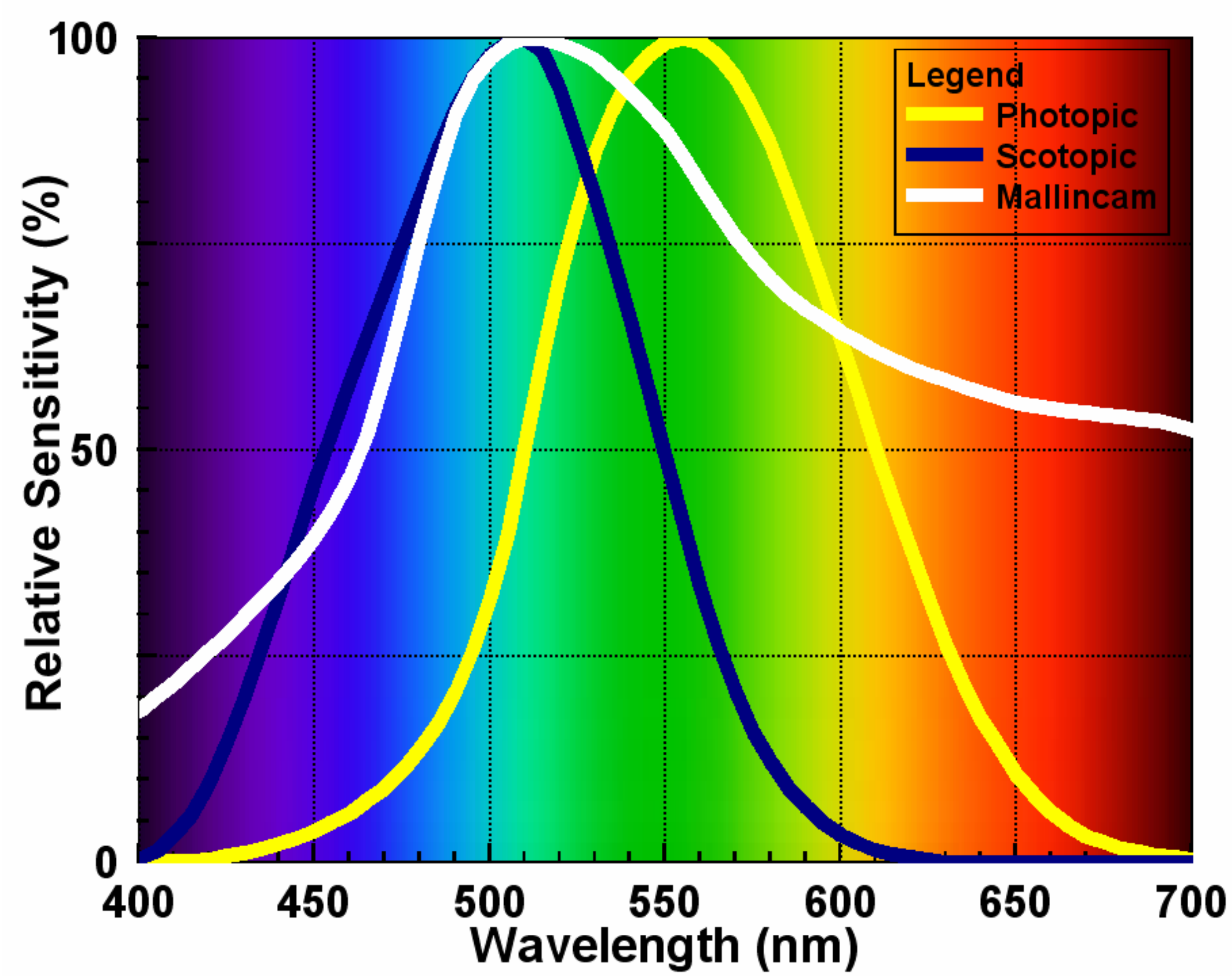

Figure 2 ***Relative Spectral Response - Human Eye vs. Mallincam***

The Mallincam, as well as many other (unfiltered) CCD devices, has a much higher sensitivity in the red end of the spectrum, but is otherwise very similar to the human eye.

4.0 Filter Manufacturers, Types, & Categories

Using band-pass filters with CCD devices opens up a range of wavelengths that the human eye is not normally sensitive to, from 600 to 700nm and even into the infrared (700+). In my initial research I completely ignored H-alpha type filters since they have no application in visual astronomy. They do have application to video astronomy however, so I have now added them to my already exhaustive list of filters. Eighteen filters in total have been added, 13 H-alpha filters plus a couple of miscellaneous ones: Astronomik OIII CCD, Astronomik H-beta CCD, Astronomik CLS CCD, Baader Planetarium Solar Continuum, and FLI OIII. This brings the total to 82 filters!

Appendix A contains a summary table of all 82 band-pass type filters. Appendix B contains the spectral transmissivity plots for these filters. The same filter categories defined in my first whitepaper are re-used again here, with the addition of the H-alpha filters. Table 1 below summarizes the 13 filter categories as well as the recommended use of each category of filter. Also listed in the table is the minimum recommended telescope aperture for each filter category when they are being used for visual astronomy. For those of you looking for a limit that is more filter specific, Figure 3 shows the relationship between filter % Scotopic Luminous Transmissivity (%SLT) found in Appendix A and telescope aperture. Table 1 also shows the amount by which one can expect the Mallincam integration time to increase for a fixed target when the particular category of filter is used. A more filter specific value of integration time increase can be calculated by simply taking the inverse of the % Mallincam Luminous Transmissivity (%MLT) which is also found in the table in Appendix A. For example a filter with %MLT = 50% would need an integration time that is approximately 2x longer than without a filter.

Category	Prerequisite	Application	Min. Aperture for Visual Use	MC Integration Time
O-III Group A	Allow both doubly ionized Oxygen wavelengths to pass	View & image emission/planetary nebulae & supernova remnants under heavy light pollution	5.5" (140mm)	4-14x
O-III Group B	Allow only one doubly ionized Oxygen wavelength to pass	Image emission/planetary nebulae & supernova remnants under heavy light pollution	not suitable	9-40x
H-beta Group A	Pass H-beta wavelength with >90% transmission	View & image faint emission nebulae, with or without light pollution	8" (203mm)	10-21x
H-beta Group B	Pass H-beta wavelength with <90% transmission	Image faint emission nebulae, with or without light pollution	not suitable	10-48x
H-alpha Group A	H-alpha pass band is >10nm wide	Image emission/planetary nebulae & supernova remnants under heavy light pollution	not suitable	5-40x
H-alpha Group B	H-alpha pass band is <10nm wide	Image emission/planetary nebulae & supernova remnants under heavy light pollution	not suitable	42-71x
Narrow Band	H-beta + O-III pass band is <35nm wide	View & image emission/planetary nebulae & supernova remnants under moderate-to-no light pollution	4.5" (114mm)	3-9x
Medium Band	H-beta + O-III pass band is >35 but <50nm wide	View & image emission/planetary nebulae & supernova remnants under moderate-to-no light pollution	3.5" (89mm)	3-5x
Wide Band	H-beta + O-III pass band is >50 but <70nm wide	View emission/planetary nebulae & supernova remnants under mild-to-no light pollution; image all deep-sky objects	2.5" (64mm)	2-4x
Extra Wide Band	H-beta + O-III pass band is >70nm wide	View or image all objects under mild-to-no light pollution	no limit	1.5-2x
Multi Band	More than two major pass bands in the visible range	View or image all objects under mild-to-no light pollution	no limit	1.7-1.9x
Special A	Filters esp. designed for planets or other special object viewing	Baader Solar for Sun; Lumicon comet for comets; Orion Mars for Mars; all others for contrast improvement while viewing Moon or planets	Lumicon comet 5.5", all others no limit	1.6-20x
Special B	Special filters for contrast enhancement based on Neodymium infused glass	Contrast improvement while viewing Moon or planets	no limit	1.4-1.9x

Table 1 Summary Of Band-Pass Filter Categories

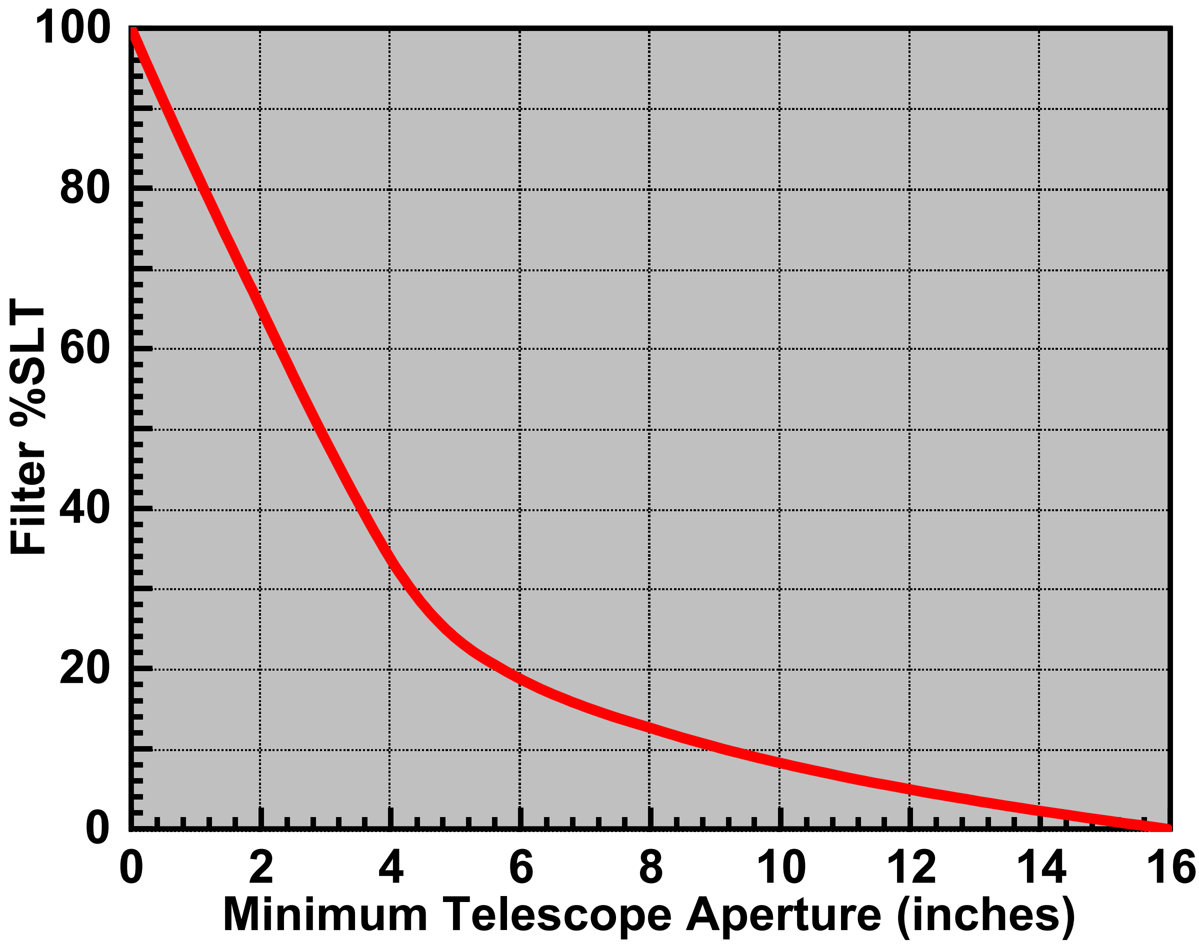

Figure 3 Minimum Recommended Telescope Aperture For Visual Observation

5.0 Visual Comparison Of Filters

Spectral transmissivity plots and %LT values are useful metrics for comparing different filters to each other. They are especially useful when deciding what filter to buy with a filter category. But how does one decide what filter category is best for their application? My suggested applications in Table 1 provide some guidance, but the real test for me is visually comparing the view that each filter produces. It has probably become obvious to everyone by now that I am a bit of a curious little monkey. In my fiddlings and experimental viewings I have compiled a fairly broad sampling of band-pass type filters:

- Baader Planetarium Moon & Skyglow
- Astro Hutech IDAS LPS-P2

- Orion Skyglow Broadband
- Baader Planetarium UHC-S
- Astronomik UHC
- Astronomik H-beta
- Astronomik OIII
- Lumicon #29 Dark Red + Baader Planetarium UV/IR Blocker

The last filter in my list was just for fun…boy was I pleasantly surprised by the results, as you will see later. Figures 4 and 5 show the spectral transmissivity curves for the eight filters.

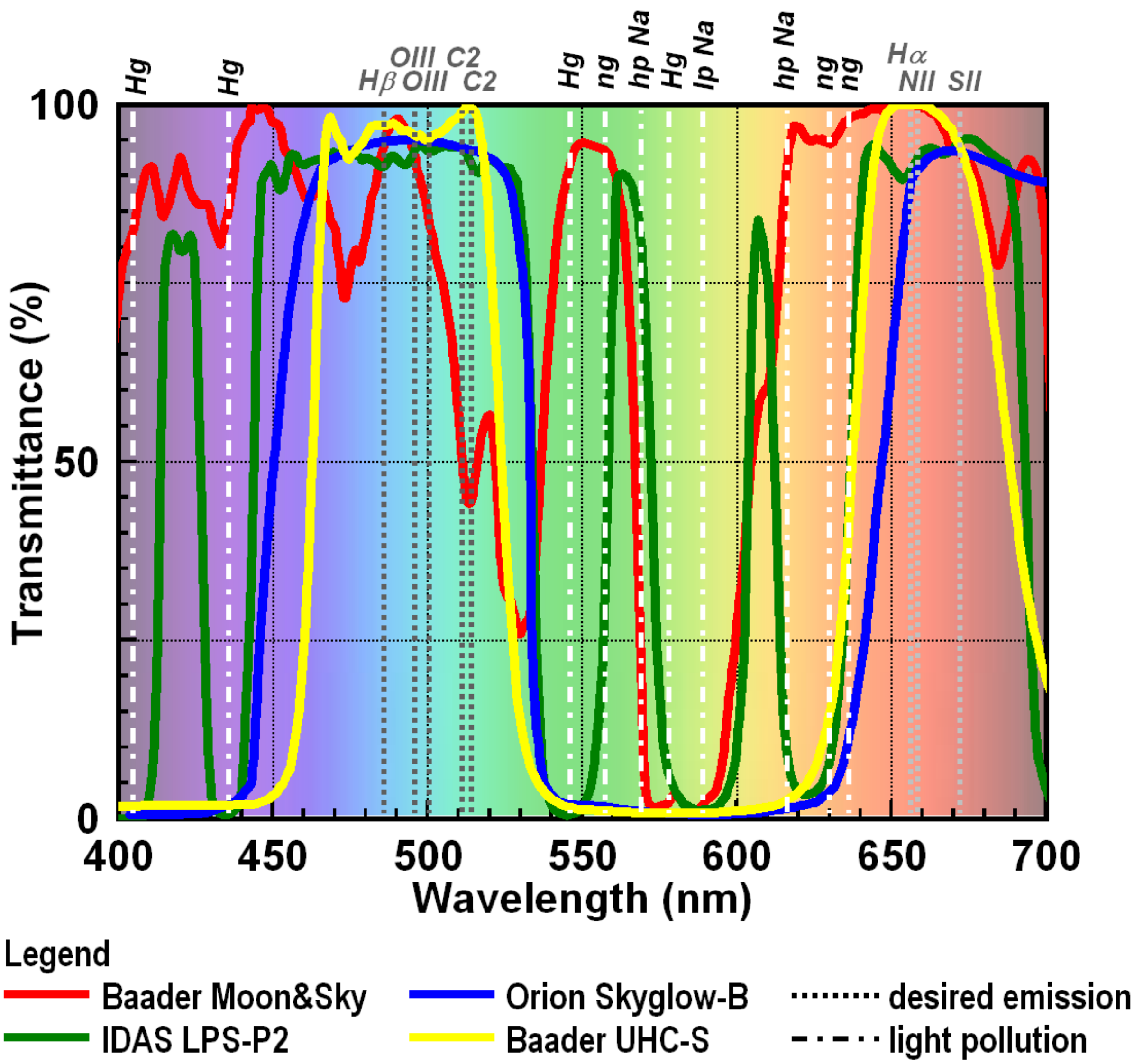

Figure 4 *Band-Pass Filters Used In Test - Part 1*

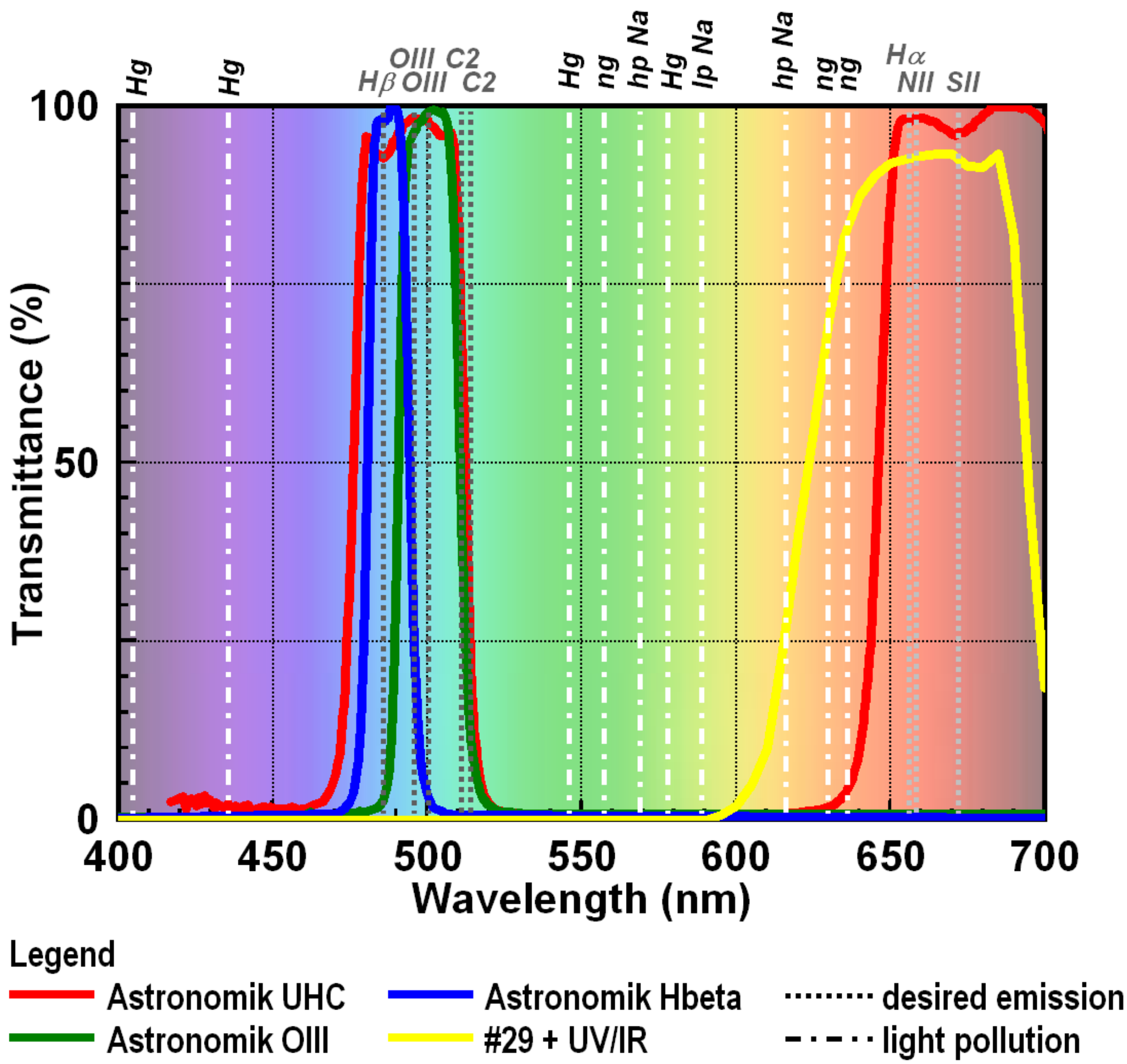

Figure 5 Band-Pass Filters Used In Test – Part 2

My images were collected in as consistent a manner possible, with the lovely M42 as the target. I used my Meade 8" LX10 telescope with Meade f/3.3 focal reducer on my Orion Atlas EQ/G mount, plus my Mallincam Xtreme astrovideo camera to collect the images. Each image was recorded at a fixed Hue (60), Saturation (75), Sharpness (2), AGC (5), and APC (8). Brightness was adjusted for each image to give a well balanced image with dark background, and Contrast was held mostly at 40 with some images varying up to 45 and 50. I recorded images at a fixed set of integration times: 2.1s (integration off), 4sec, 8sec, 12sec, 16sec, 24sec, 32sec, 48sec, 60sec, 75sec, 90sec. For each integration time I recorded images from three refreshes, which were then later hand stacked into one image for comparison purposes. No additional processing was performed on the per-integration time images. The images can be found in Appendix C. Note that the H-beta, OIII, and #29 Dark Red filters were recorded in B&W since the filters have such narrow wave bands they only let one colour through anyway, cyan, green, and red respectively. Many of the filters did not make it to 90sec integration as the view was totally over exposed and/or I ran out of brightness adjustment. In addition to the per-integration time images, I made multi-exposure hand stacks using 4 different integration times, selected to have as close to the same relative exposure between each filter tested. The results from this can be found below in Figure 6. I did use tone balancing on these multi-exposure stacks in order to give the sexiest image possible with the selected image data.

No Filter Baader Moon&Sky

IDAS LPS-P2 Orion Skyglow-B

Baader UHC-S

Astronomik UHC

Astronomik H-beta

Astronomik OIII

#29 Dark Red + UV/IR Blocker

6.0 Conclusions

In the end I was very happy with the results of my testing. Some of the filter images are slightly blurry, suggesting that I did not have the focus quite right on them, but all-in-all the images turned out nice. My conclusions on each of the filters tested are as follows:

None: The stacked image looks pretty good surprisingly, but there is an obvious hue to the background due to the light pollution. Integration times were as short as they can be, plus there are lots of stars, which is okay on the periphery, but in the trapezium area it results in the image being over exposed.

Baader M&S: Seems to provide a slight improvement over no filter. Hue due to light pollution seems to be mostly gone. Integration times still short.

LPS-P2: Provides nice colour balance and finer details in the nebula. Background is dark, and integration times are low. Stars still fairly bloated at longer integration times.

Orion Skyglow-B: More intense reds, but blues still visible. Contrast similar to slightly worse than LPS-P2. At longer integration times, stars had strange coma shape.

Baader UHC-S: Image very red, almost orange. Contrast similar to slightly less than Orion Skyglow-B.

Astro. UHC: The nicest colour image in my opinion. Very nice colour balance, and wispy blues much more refined. Finer contrast and detail in dark lanes, esp. in M43. Very nice dark background, and stars are small and round.

Astro. H-beta: Okay contrast, but very long integration time to get it. Seem to get the same from #29 but at shorter integration time.

Astro. OIII: Not very exciting, interesting how only the blues (OIII) regions are coming through and none of the H-alpha (red), but the resulting image is not very pleasing in my opinion. Very long integration times.

#29 + UV/IR: Wow, what a pleasant surprise! This very inexpensive, very wide band H-alpha filter produced what I feel are very impressive images. The best for contrast overall I think. I wonder what a proper H-alpha filter would do? Hmmmmm….

In my opinion, the LPS-P2 and Astronomik UHC gave the best detailed and colour balanced images. I am however curious now what a filter from the Narrow Band category would produce.

There is a definite trade off between higher contrast in the image and longer integration times. I was lucky to get a good polar alignment for these images and had good weather to leave my setup outside for 3 days so that I could get all the images. I had good tracking up to 90sec with no guiding during my tests, but most of the time (with having to setup and teardown every night) I can only get 30-40sec.

For the visual observers out there, I hope you can get some useful information out of this work as well. For example, if you equate integration time to the light gathering capacity of a telescope (roughly equal to aperture^2), you can get an idea what impact bigger apertures have on your ability to see detail. You can also visually see how the image gets more contrast but dimmer as a result of using each filter when you compare images of the same integration time.

One important behavior that bares mention is how band-pass filters respond in short focal length telescopes. The spectral transmissivity curve for these filters tends to shift back and forth with wavelength as the angle of the filter to the light beam is changed. In the case of short focal length scopes, the angle of the light passing through the middle of the filter is different enough from the light passing through the outer edge that there will be a visible difference in performance. This centre-to-edge variation is progressively more important as the filter's pass band gets narrower, and may become a serious issue with the narrowest filters (eg. H-beta, OIII, H-alpha, & Narrow Band). I don't have any observational data to know what the practical lower focal length limit is, so filter users should just be aware and keep their eyes open for this phenomenon, especially if they use small aperture fast focal ratio refractors or possibly even the Hyperstar lens system some have on their SCT. One way of mitigating this problem is to move the filter forward in the optical train, ahead of focal reducers, where the light rays are more parallel (ie. area of longer affective focal length).

I hope my little whitepaper is interesting and useful to someone out there. I am convinced that large improvements to the quality of the image can be achieved when combined with the proper telescope aperture (visual & video) or appropriate integration time (video only). This is definitely true for emission/planetary nebulae and super nova remnants. I assume the impact will be less so for clusters, galaxies, and reflection nebulae since they are broad spectrum targets (filter cuts emission from target along with cutting out light pollution). If you have any questions, feel free to contact me.

Cheers!

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Appendix A Band-Pass Filter Summary Table

Deep-Sky Filter Summary Table

#	Manufacturer	Model	Full Name	Manuf.'s Recommended Use	Contact	Category	% Luminous Transmissivity Photopic	Scotopic	Mallincam
1	1000 Oaks	LP-1	LP-1 Broadband	Slight to moderately light polluted areas	www.thousandoaksoptical.com	wide band	16.8	50.6	39.0
2		LP-2	LP-2 Narrowband	Heavily light polluted areas		narrow band	9.3	26.5	18.7
3		LP-3	LP-3 O-III	Diffuse & planetary nebulae		O-III A	4.5	11.8	10.9
4		LP-4	LP-4 H-beta	Horsehead, California, & other faint nebulae		H-beta A	4.2	10.8	10.4
5	Andover Corporation	O-III	O-III	Heavily light polluted areas, planetary nebulae	www.andovercorp.com	O-III A	4.4	14.2	7.2
6		3ch Nebula	3 Channel	Light polluted areas, planetary & emission nebulae		narrow band	12.5	32.9	30.9
7	Antares	ALP	Anti-Light Pollution, Broadband	block light pollution, improve view of emission nebulae	www.antaresoptical.com	wide band	26.0	59.6	46.6
8	Astrodon	H-alpha1	H-alpha 3nm	CCD imaging	www.astrodon.com	H-alpha B	0.4	0.0	1.4
9		H-alpha2	H-alpha 5nm	CCD imaging		H-alpha B	0.4	0.0	1.6
10	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	20.7
11		H-beta	IDAS H-beta	narrow-band nebular + Hbeta passband modifier filter		H-beta A	2.6	10.2	9.1
12		LPS-P1	IDAS Light Pollution Suppression v1	Light polluted areas, nebulae viewing, color balanced photography		multi band	46.3	73.5	56.0
13		LPS-P2	IDAS Light Pollution Suppression v2	Light polluted areas, nebulae viewing, color balanced photography		multi band	44.9	72.7	59.2
14		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	38.0
15		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	33.5
16	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	10.4
17		O-III CCD	O-III CCD	CCD imaging		O-III A	6.2	20.9	10.8
18		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	6.3
19		H-beta CCD	H-beta CCD	CCD imaging		H-beta A	2.8	11.8	6.2
20		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	33.0
21		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	38.2
22		CLS	"Clear Sky"?	budget filter for visual LPR, very good colour balance for photography (film or digital)		extra wide band	31.1	67.5	52.0
23		CLS CCD	"Clear Sky"? CCD	CCD imaging		extra wide band	24.3	65.8	47.6
24		H-alpha1	H-alpha 6nm	CCD imaging		H-alpha B	0.8	0.5	2.4
25		H-alpha2	H-alpha 13nm	CCD imaging		H-alpha A	1.9	0.5	5.9
26		O-III	O-III Visual Nebula	maximum contrast and image sharpness, emission & planetary nebulae		O-III B	2.0	6.5	3.3
27		H-beta	H-beta Narrowband CCD	maximum contrast and image sharpness		H-beta B	1.1	5.4	2.7

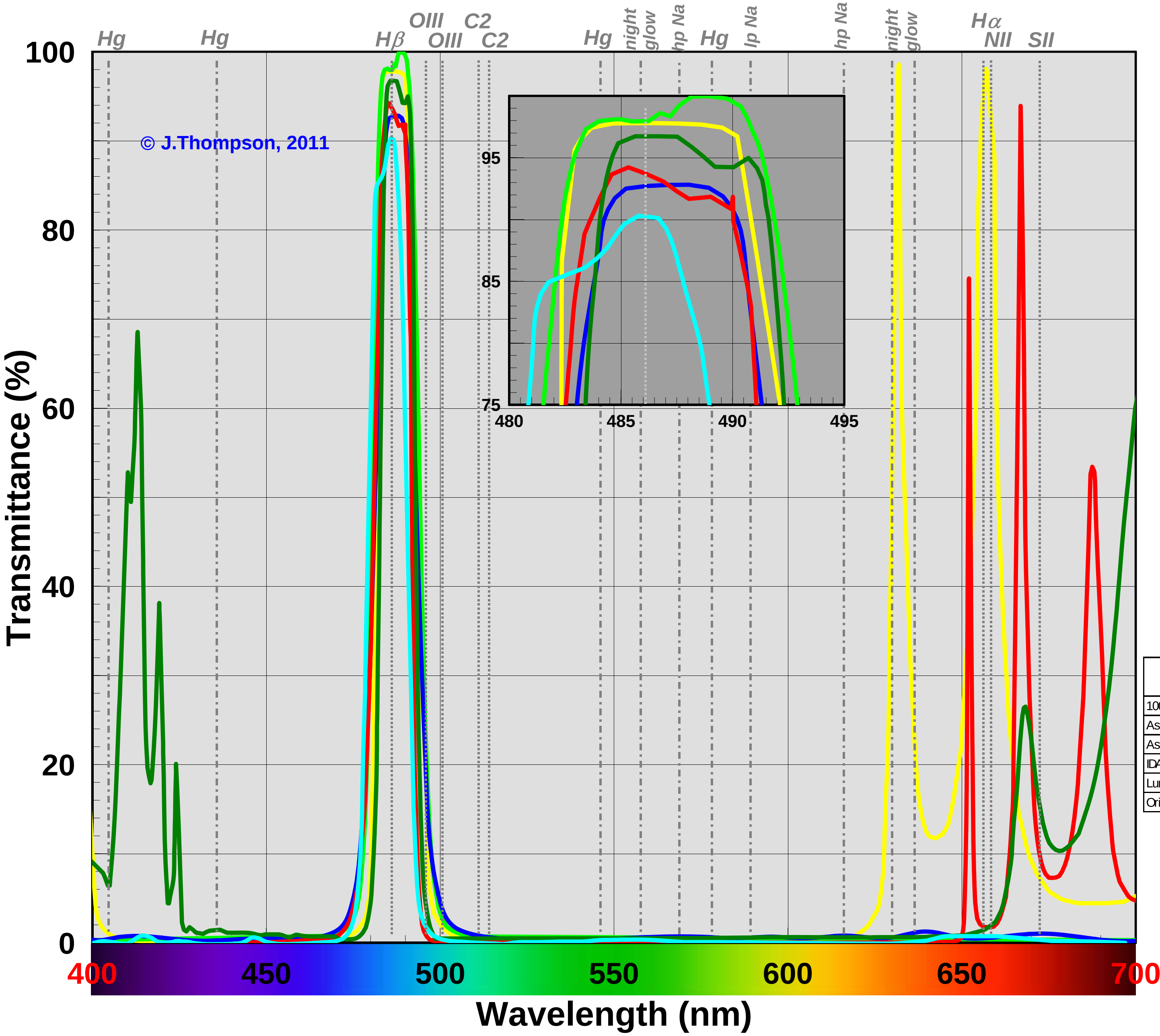
28		UHC-S	UHC-S Nebula	improved contrast over typical broadband filters without sacrificing stars like other UHC filters, great for smaller scopes, good for imaging			wide band	22.5	54.7	42.4
29		Moon&Sky	Moon & Sky Glow	neodymium infused glass, enchances both planetary & deep sky contrasts by reducing skyglow from LP & Moon, RGB intensifier			special B	55.3	72.3	70.7
30		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	56.0
31		Solar	Solar Continuum	enhance solar granulation & sunspot detail, boost contrast & reduce atmos. Turbulence, also good for star testing telescopes			special A	8.4	7.0	4.9
32	Baader	H-alpha1	H-alpha 7nm	CCD imaging			H-alpha B	0.5	0.0	2.2
33	Planetarium	H-alpha2	H-alpha 35nm	CCD imaging	www.baader-planetarium.com		H-alpha A	4.7	0.0	9.7
34	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	26.8
35		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			O-III B	1.5	4.8	2.5
36		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	2.1
37		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	12.9
38	Custom	H-alpha1	H-alpha 4nm	CCD imaging			H-alpha B	0.4	0.0	1.5
39	Scientific	H-alpha2	H-alpha 10nm	CCD imaging	www.customscientific.com		H-alpha A	0.6	0.0	2.5
40		O-III	High Performance O-III	maximum enhancement of emission and reflective nebula			O-III B	10.4	10.7	11.4
41		NPB	Narrow Pass Band Nebula	UHC type, small & fainter emission & planetary nebula, retains natural star colours			narrow band	12.3	22.6	25.7
42		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	34.5
43	DGM	GCE	Galaxy Contrast Enhancement	aids visual observation of galaxies & Milky Way dust clouds & dark lanes, general purpose LPR, most of visible spectrum passed	users.erols.com/dgmoptics/		extra wide band	33.4	67.7	62.8
44		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			O-III B	2.0	7.8	7.9

45		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	24.6
46	Denkmeier Optical	Planetary	Hi Def Planetary	very unique contrast enhancement filter, see brighter greens and reds, greatly improve contrast of Mars, Jupiter, & Saturn	www.denkmeier.com	special A	52.8	54.3	62.1
47		O-III	O-III 8nm	CCD imaging		O-III B	1.9	6.1	3.1
48	FLI	H-alpha	H-alpha 8nm	CCD imaging	www.flicamera.com	H-alpha B	0.6	0.0	2.1
49		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		O-III A	3.8	12.6	9.9
50		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	8.6
51		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	16.5
52		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	44.0
53		Comet	SWAN	enhances cyanogen wavelength in comet tails, narrow pass band allows OII and C2		special A	9.3	21.3	11.0
54		H-alpha	H-alpha Pass	CCD imaging		H-alpha A	3.2	0.0	17.4
55	Lumicon	#29	#29 Dark Red	planetary viewing	www.lumicon.com	H-alpha A	7.3	0.1	21.6
56		O-III	O-III	Diffuse & planetary nebulae		O-III A	6.7	16.7	23.7
57		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	25.2
58	Meade	Wide	Wideband Nebular	LPR, photography, enhances nebula mostly but does improve contrast on galaxies	www.meade.com	medium band	10.2	37.8	29.2
59		O-III	OIII Narrow CCD	precision interference filter, narrow band pass, best for CCD imaging		O-III B	1.7	5.6	2.8
60		H-beta	Hb Narrow	precision interference filter, narrow band pass, best for CCD imaging		H-beta B	4.1	6.8	10.5
61		Wide	Hb&OIII Nebula II	precision interference filter, relatively broad pass band allwos Hbeta & OIII wavelengths		wide band	20.2	49.4	25.5
62		Narrow	Hb&OIII Nebula	precision interference filter, narrow pass band allows Hbeta & OIII wavelengths		medium band	12.0	34.3	25.1
63		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	65.0
64	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	www.omegafilters.com	multi band	50.4	50.9	51.5

65		O-III	O-III	Diffuse & planetary nebulae		O-III B	3.2	9.7	4.9
66		Deepsky	Deepsky	blocks UV, violet, & sodium light completely		extra wide band	33.6	59.4	55.6
67	Optec Inc.	H-alpha	H-alpha	CCD imaging	www.optecinc.com/astronomy	H-alpha B	0.6	0.0	2.3
68		O-III	O-III	reveal more wondrous details when viewing nebulas, completely blocks all other visible wavelengths, for >8" aperture, visual use only		O-III A	4.2	13.8	7.2
69		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	4.7
70		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	13.6
71		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	47.6
72		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	60.2
73		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	53.7
74	Orion	H-alpha	H-alpha Narrow Band	CCD imaging	www.telescope.com	H-alpha B	0.5	0.0	1.8
75		NEB1	Nebula	-		medium band	17.7	41.1	23.3
76		CE1	Contrast Enchance	-		special A	60.9	50.1	60.4
77		PC1	Planetary Contrast	-		special A	40.7	35.9	36.5
78	Sirius Optics	NPC	Neodymium Planetary Contrast	-	out-of-business	special B	49.0	55.1	53.3
79		O-III	O-III	narrowband nebular filter for observing and imaging		O-III B	3.0	9.9	5.0
80	TS Optics	UHC	Ultra High Contrast	contrast boosting filter for deep sky observing	www.telescope-service.com	narrow band	5.9	22.2	11.2
81		O-III	Bandmate O-III	enhances planetary nebulae in larger scopes		O-III A	9.7	27.3	14.7
82	Televue Optics	Nebustar	Bandmate Nebustar	high-performance dielectric squarewave “UHC” type general purpose narrow-band filter, great for all nebulae types and instrument sizes	www.televue.com	medium band	14.9	42.5	22.1

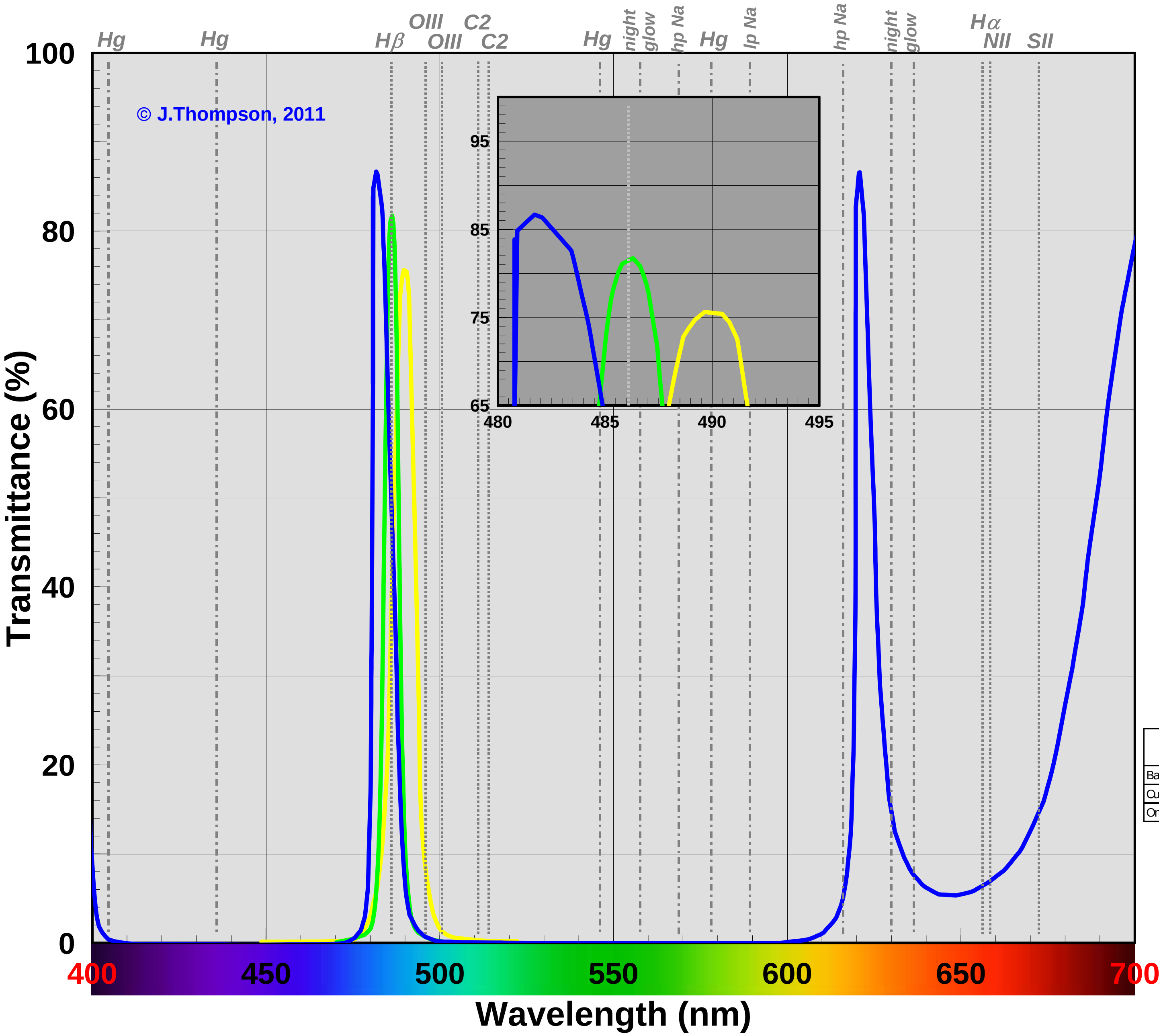
Appendix B Band-Pass Filter Spectral Transmissivities

H-beta Group A



Filter	% Transmittance		
	Photopic	Scotopic	MC
1000 Oaks LP4	4.2	10.8	10.4
Astronomik Hbeta	2.5	12.6	6.3
Astronomik Hbeta CCD	2.8	11.8	6.2
IDAS Hbeta	2.6	10.2	9.1
Lumicon Hbeta	2.4	10.1	8.6
Orion Hbeta	1.8	9.5	4.7

H-beta
Group B



Filter	%Transmittance		
	Photopic	Scotopic	MC
Baader Hbeta	1.1	5.4	2.7
Cust-Sci Hbeta	0.8	4.3	2.1
Omega Hbeta	4.1	6.8	10.5

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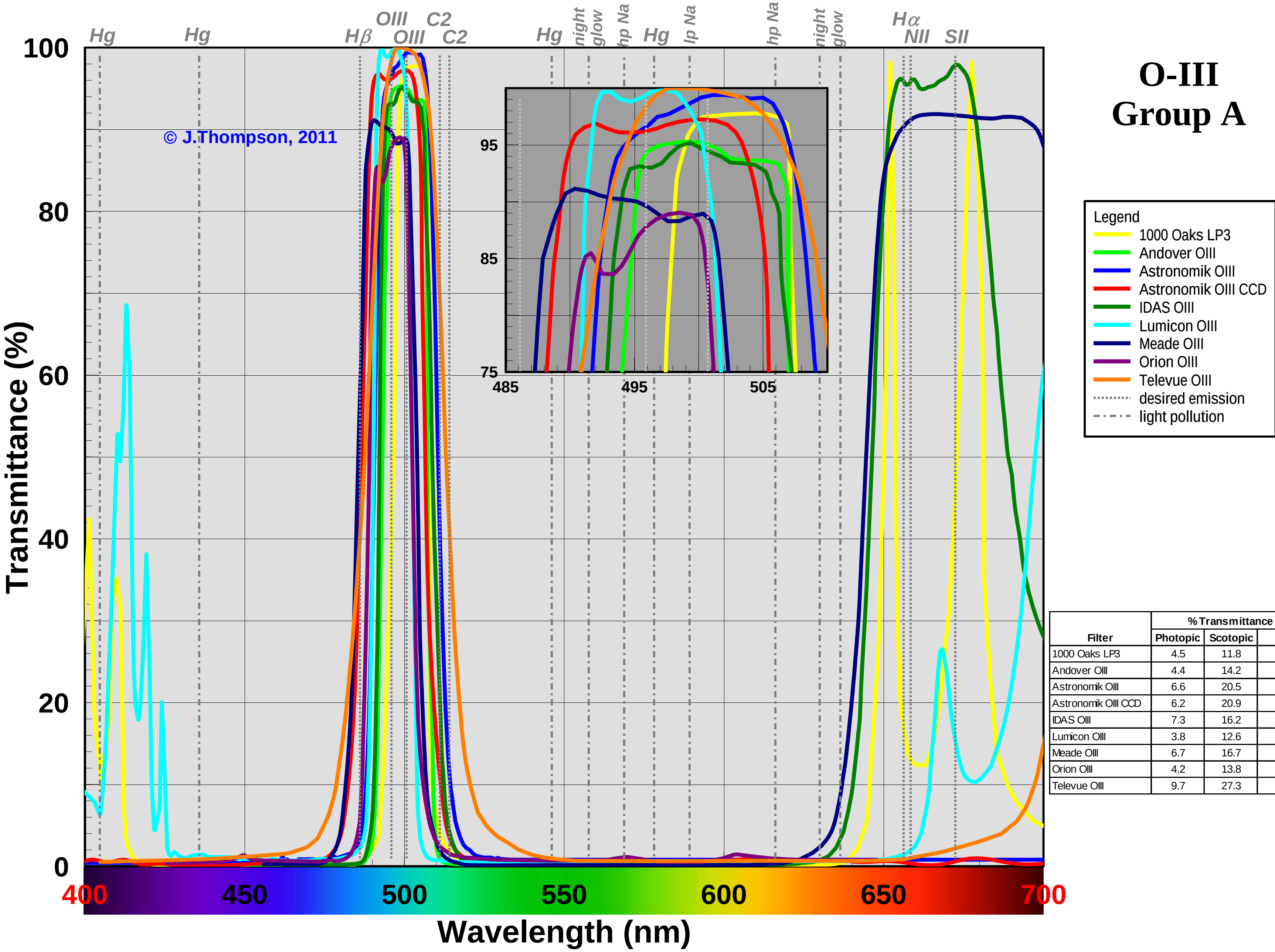
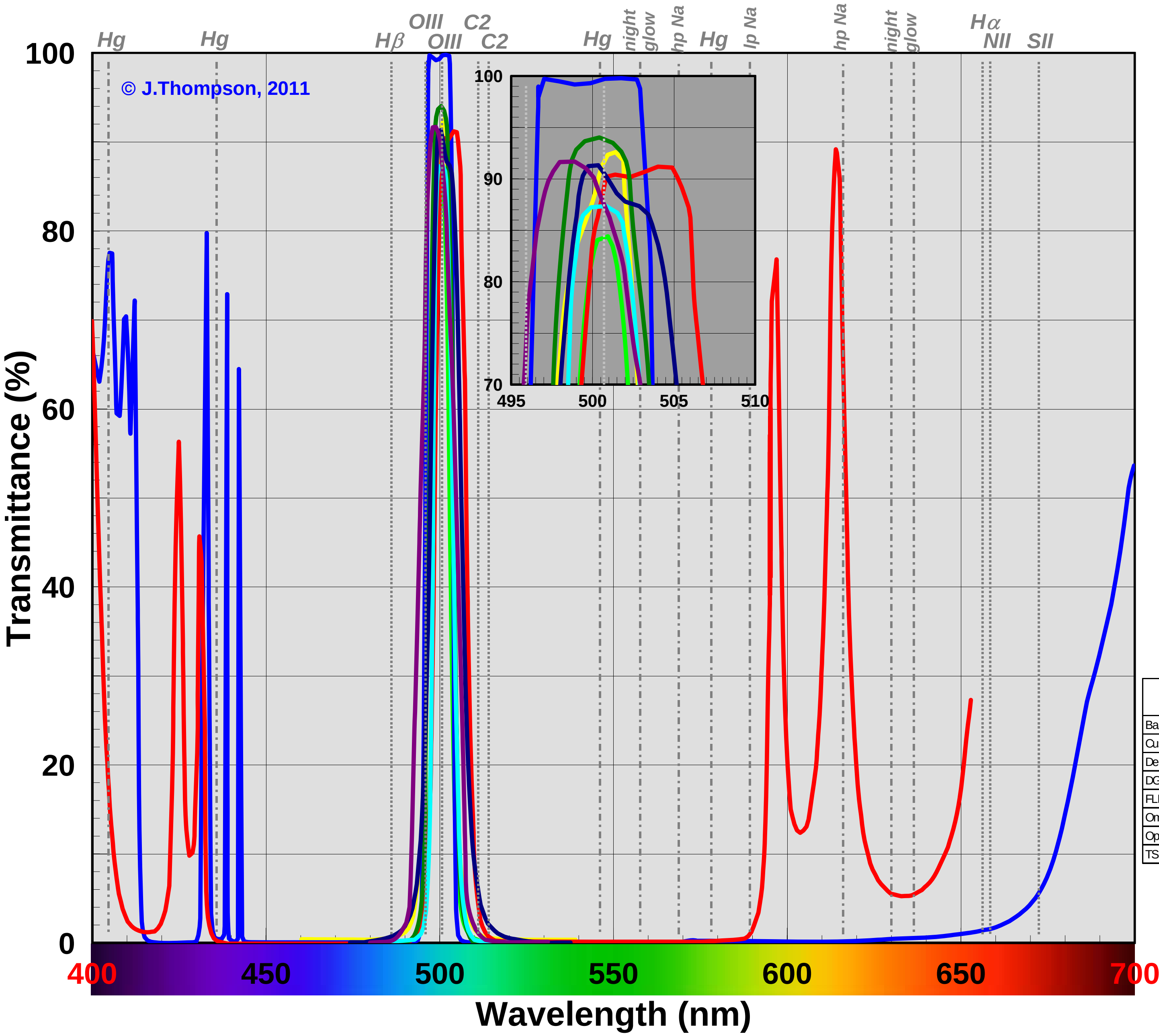
O-III
Group A



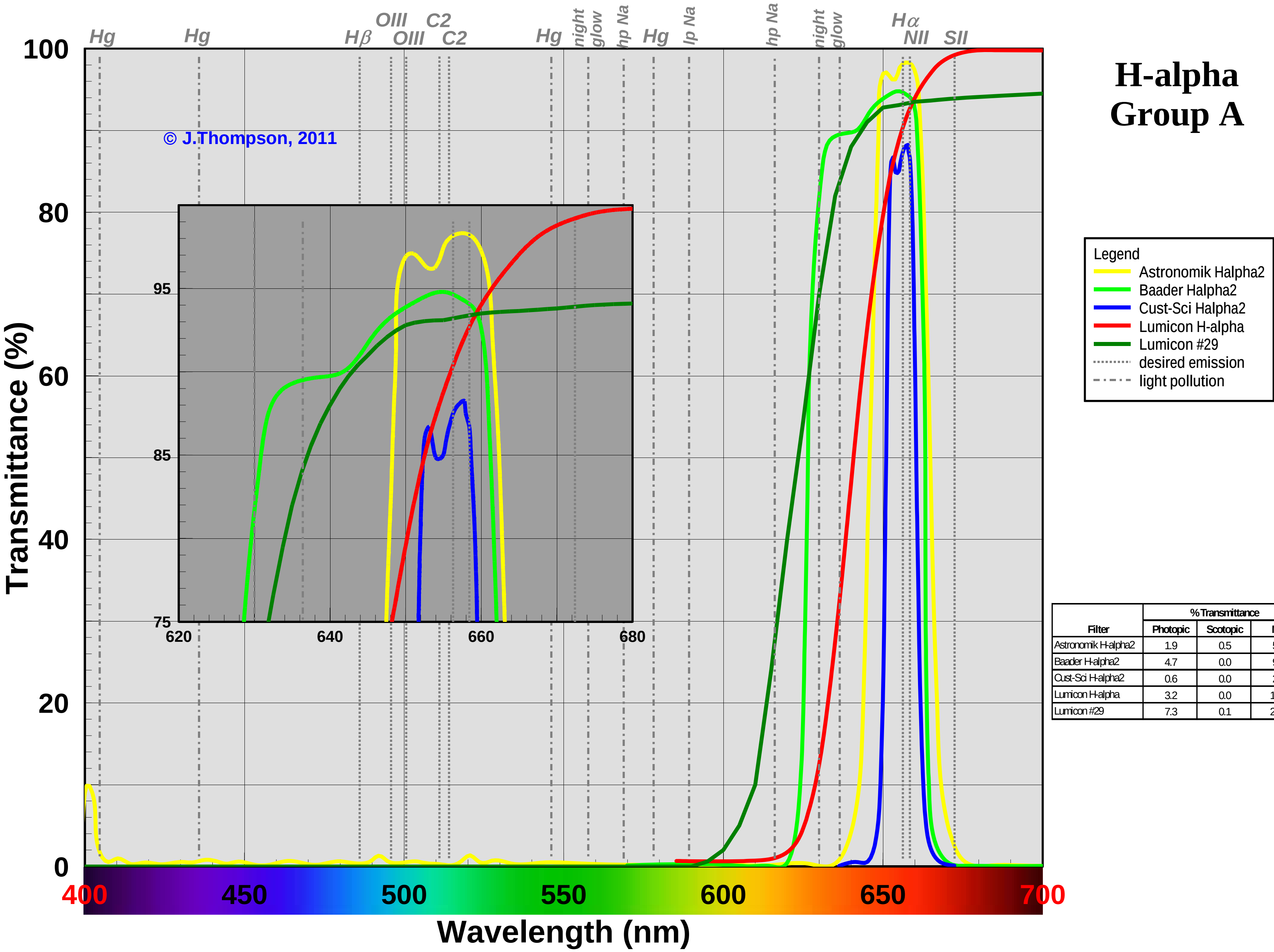
Filter	% Transmittance		
	Photopic	Scotopic	MC
1000 Oaks LP3	4.5	11.8	10.9
Andover OIII	4.4	14.2	7.2
Astronomik OIII	6.6	20.5	10.4
Astronomik OIII CCD	6.2	20.9	10.8
IDAS OIII	7.3	16.2	20.7
Lumicon OIII	3.8	12.6	9.9
Meade OIII	6.7	16.7	23.7
Orion OIII	4.2	13.8	7.2
Televue OIII	9.7	27.3	14.7

O-III
Group B

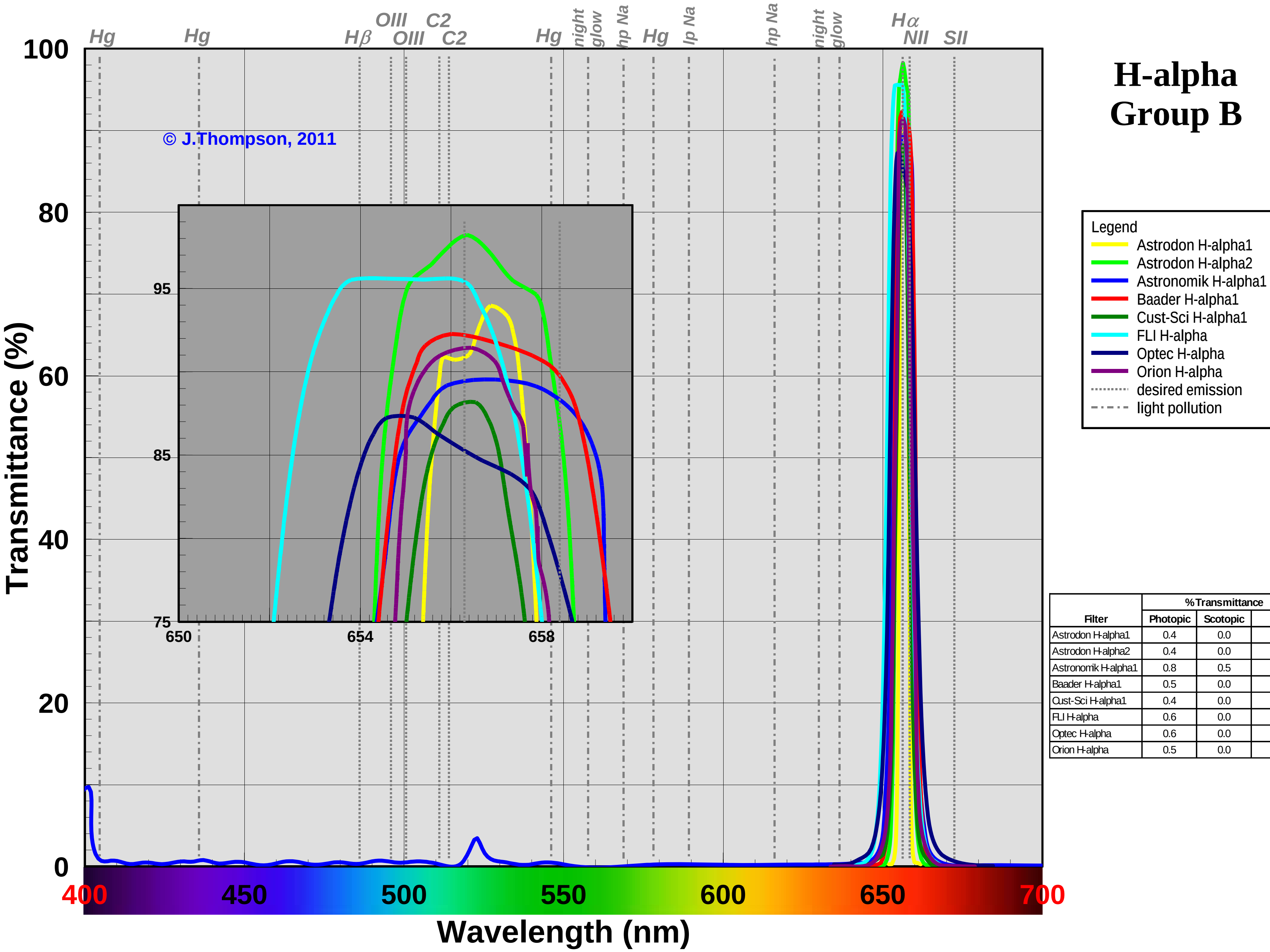


Filter	% Transmittance		
	Photopic	Scotopic	MC
Baader OIII	2.0	6.5	3.3
Cust-Sci OIII	1.5	4.8	2.5
Denkmeier OIII	10.4	10.7	11.4
DGM OIII	2.0	7.8	7.9
FLI OIII	1.9	6.1	3.1
Omega OIII	1.7	5.6	2.8
Optec OIII	3.2	9.7	4.9
TS OIII	3.0	9.9	5.0

H-alpha Group A



Filter	% Transmittance		
	Photopic	Scotopic	MC
Astronomik H-alpha2	1.9	0.5	5.9
Baader H-alpha2	4.7	0.0	9.7
Cust-Sci H-alpha2	0.6	0.0	2.5
Lumicon H-alpha	3.2	0.0	17.4
Lumicon #29	7.3	0.1	21.6



Filter	%Transmittance		
	Photopic	Scotopic	MC
Astrodon H-alpha1	0.4	0.0	1.4
Astrodon H-alpha2	0.4	0.0	1.6
Astronomik H-alpha1	0.8	0.5	2.4
Baader H-alpha1	0.5	0.0	2.2
Cust-Sci H-alpha1	0.4	0.0	1.5
FLI H-alpha	0.6	0.0	2.1
Optec H-alpha	0.6	0.0	2.3
Orion H-alpha	0.5	0.0	1.8

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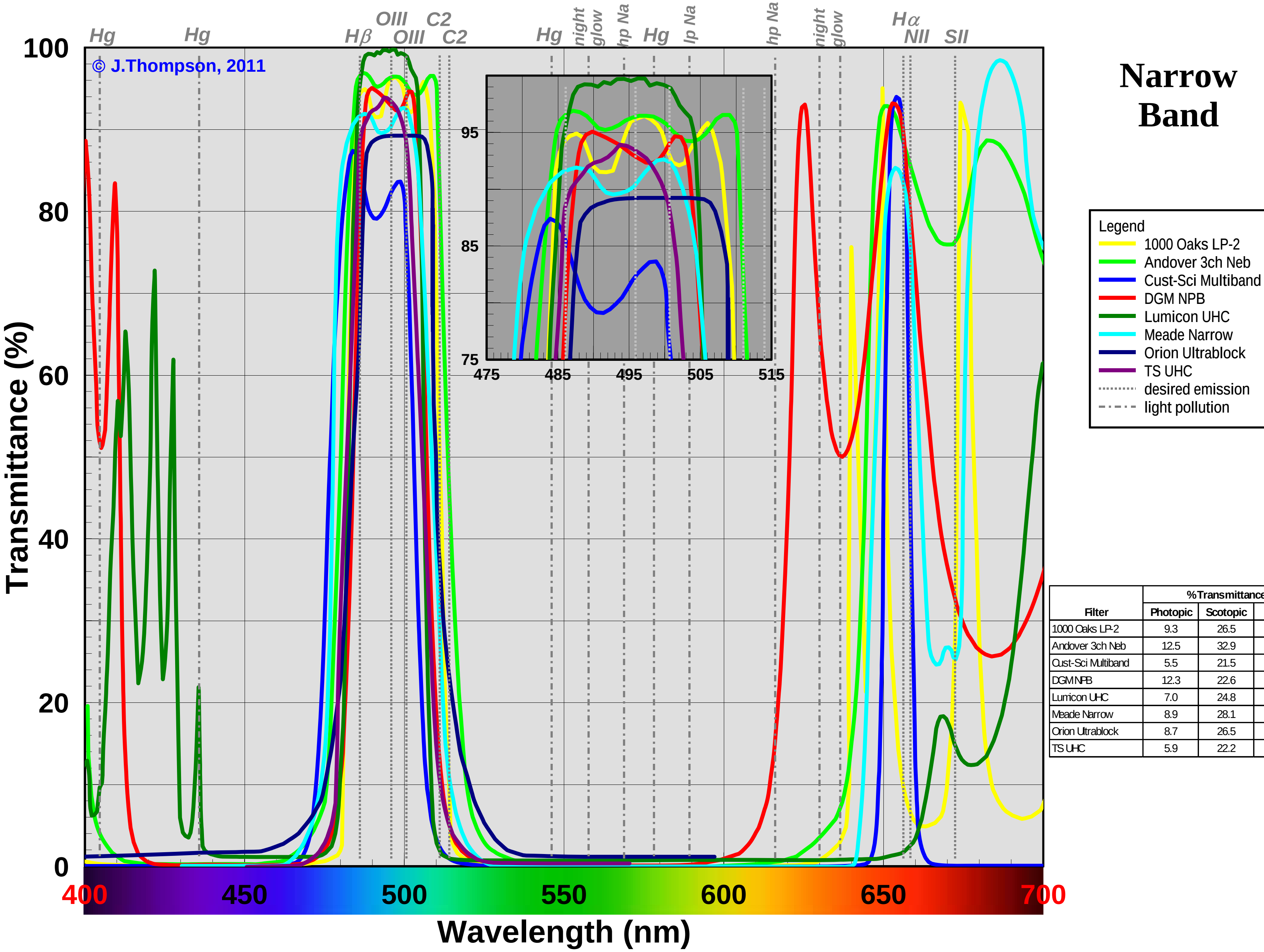
Narrow Band



Filter	%Transmittance		
	Photopic	Scotopic	MC
1000 Oaks LP-2	9.3	26.5	18.7
Andover 3ch Neb	12.5	32.9	30.9
Cust-Sci Multiband	5.5	21.5	12.9
DGM NPB	12.3	22.6	25.7
Lumicon UHC	7.0	24.8	16.5
Meade Narrow	8.9	28.1	25.2
Orion Ultrablock	8.7	26.5	13.6
TS UHC	5.9	22.2	11.2

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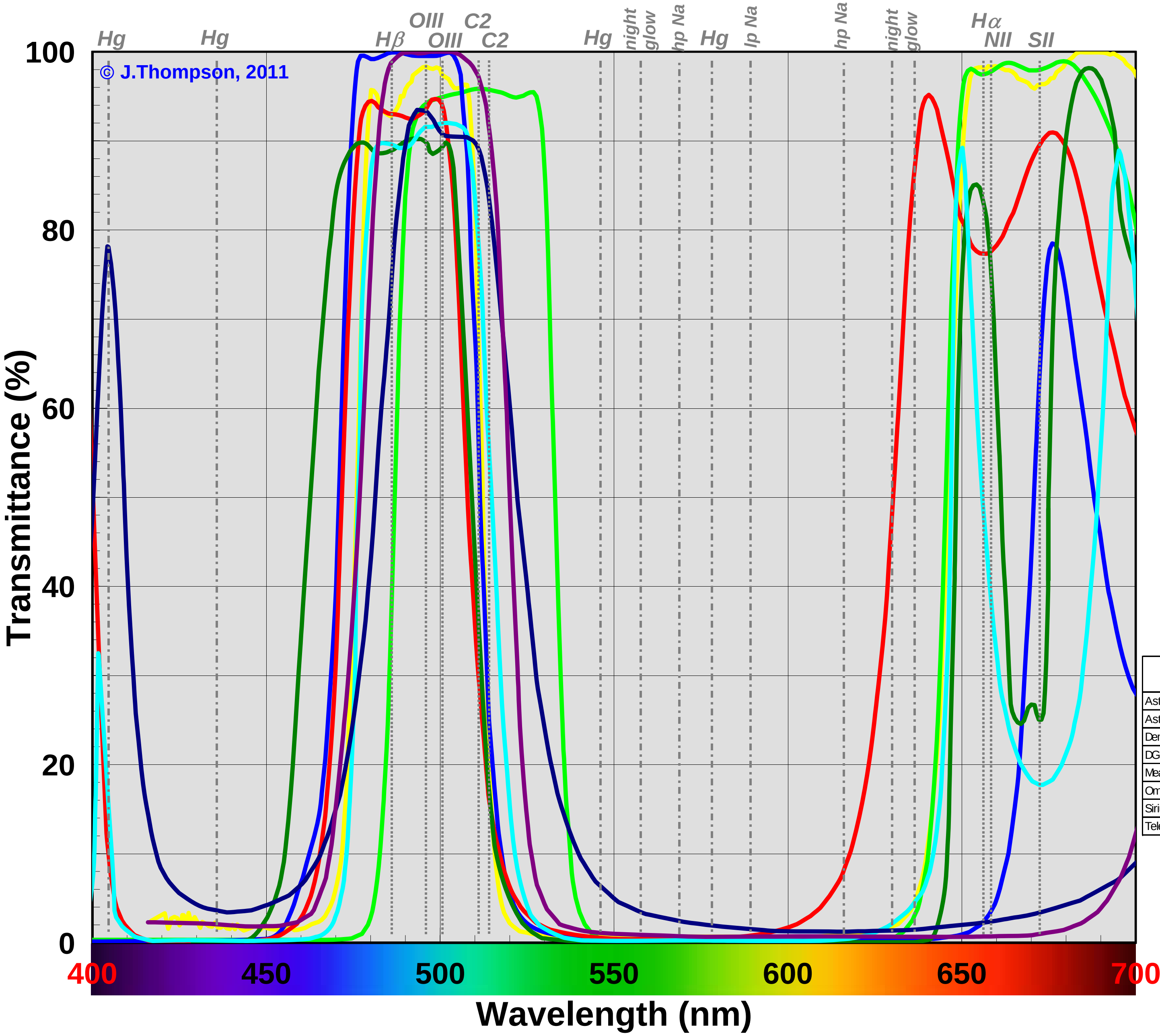
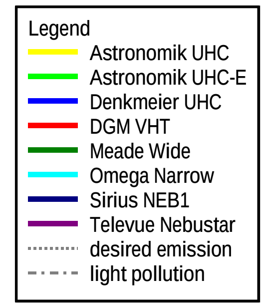
Medium Band





Filter	%Transmittance		
	Photopic	Scotopic	MC
Astronomik UHC	11.8	33.6	33.0
Astronomik UHC-E	23.9	42.5	38.2
Denkmeier UHC	10.7	38.8	34.5
DGM VHT	14.1	33.3	24.6
Meade Wide	10.2	37.8	29.2
Omega Narrow	12.0	34.3	25.1
Sirius NEB1	17.7	41.1	23.3
Televue Nebustar	14.9	42.5	22.1

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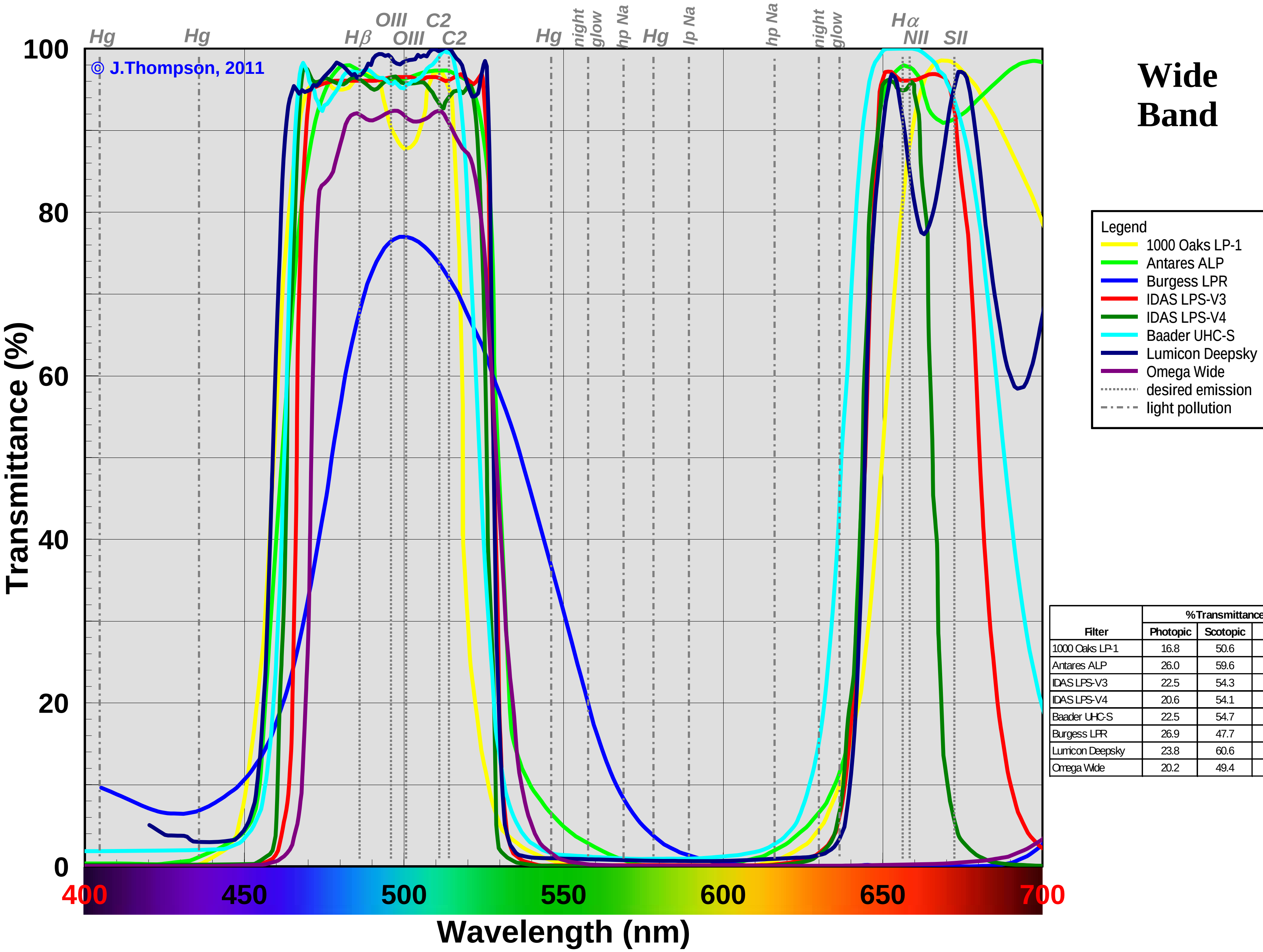
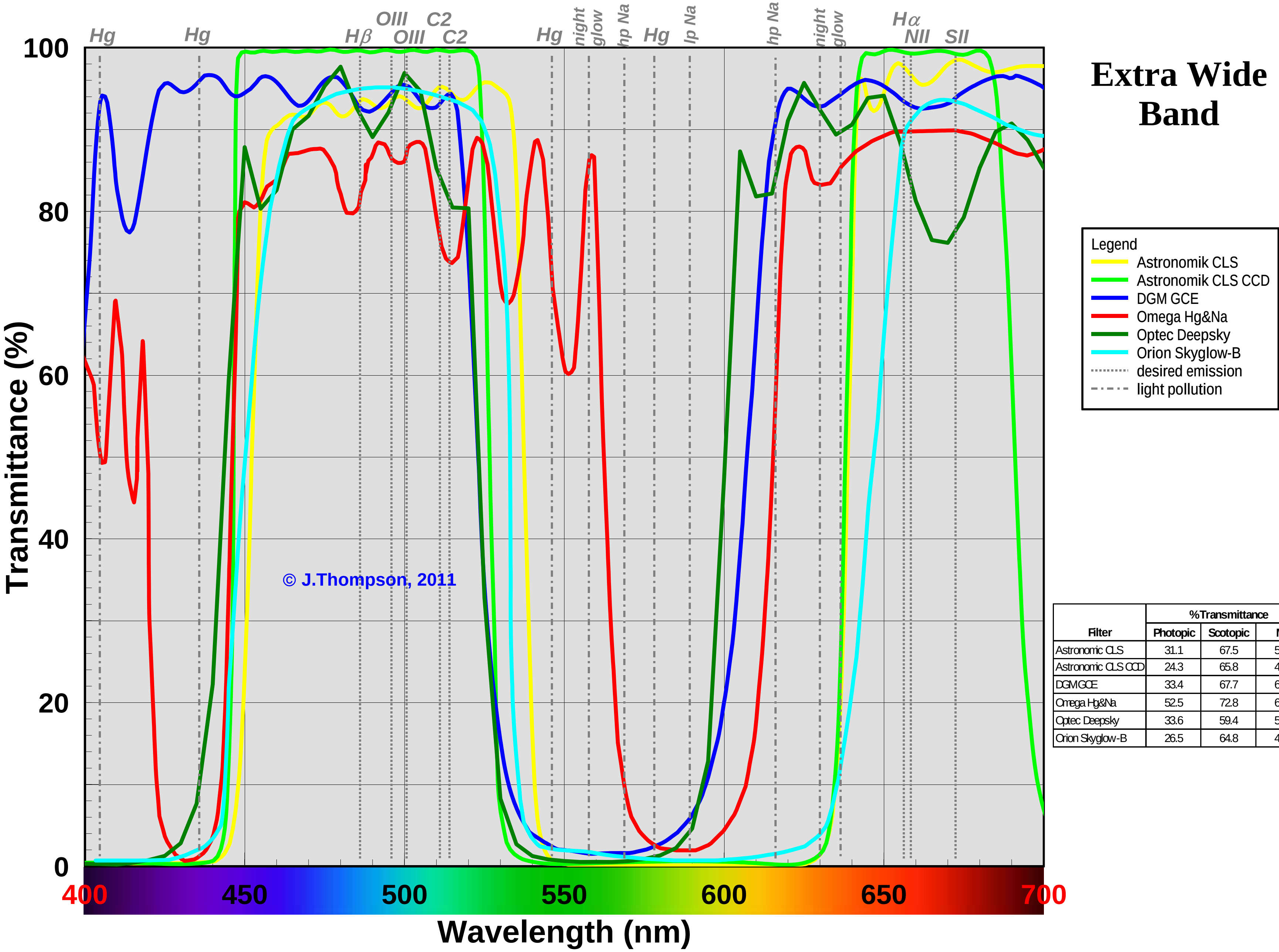
Wide Band

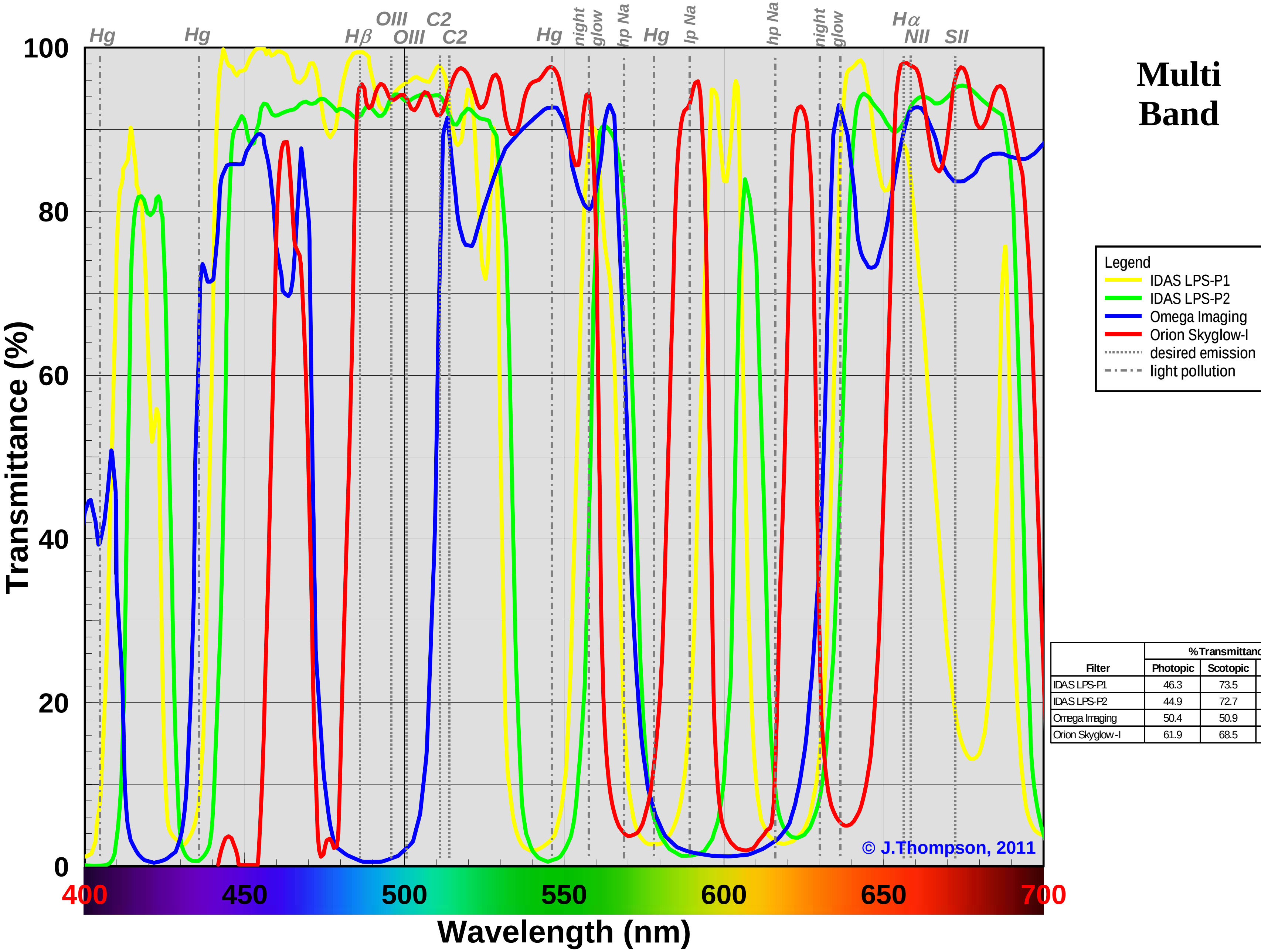


Filter	%Transmittance		
	Photopic	Scotopic	MC
1000 Oaks LP-1	16.8	50.6	39.0
Antares ALP	26.0	59.6	46.6
IDAS LPS-V3	22.5	54.3	38.0
IDAS LPS-V4	20.6	54.1	33.5
Baader UHC-S	22.5	54.7	42.4
Burgess LPR	26.9	47.7	26.8
Lumicon Deepsky	23.8	60.6	44.0
Omega Wide	20.2	49.4	25.5



Filter	%Transmittance		
	Photopic	Scotopic	MC
Astronomic CLS	31.1	67.5	52.0
Astronomic CLS CCD	24.3	65.8	47.6
DGM GCE	33.4	67.7	62.8
Omega Hg&Na	52.5	72.8	65.0
Optec Deepsky	33.6	59.4	55.6
Orion Skyglow-B	26.5	64.8	47.6

Multi Band



Filter	% Transmittance		
	Photopic	Scotopic	MC
IDAS LPS-P1	46.3	73.5	56.0
IDAS LPS-P2	44.9	72.7	59.2
Omega Imaging	50.4	50.9	51.5
Orion Skyglow-I	61.9	68.5	60.2

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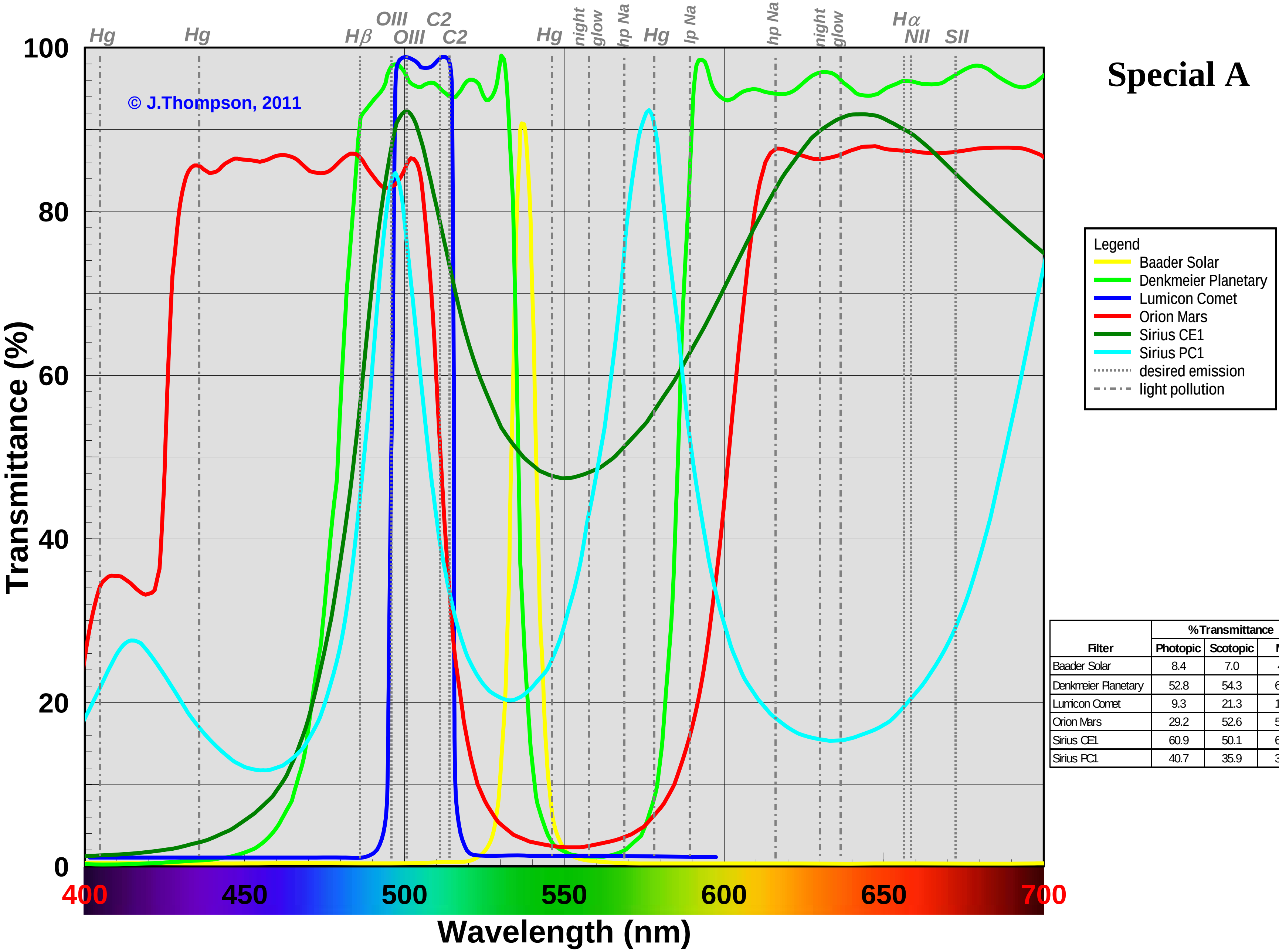
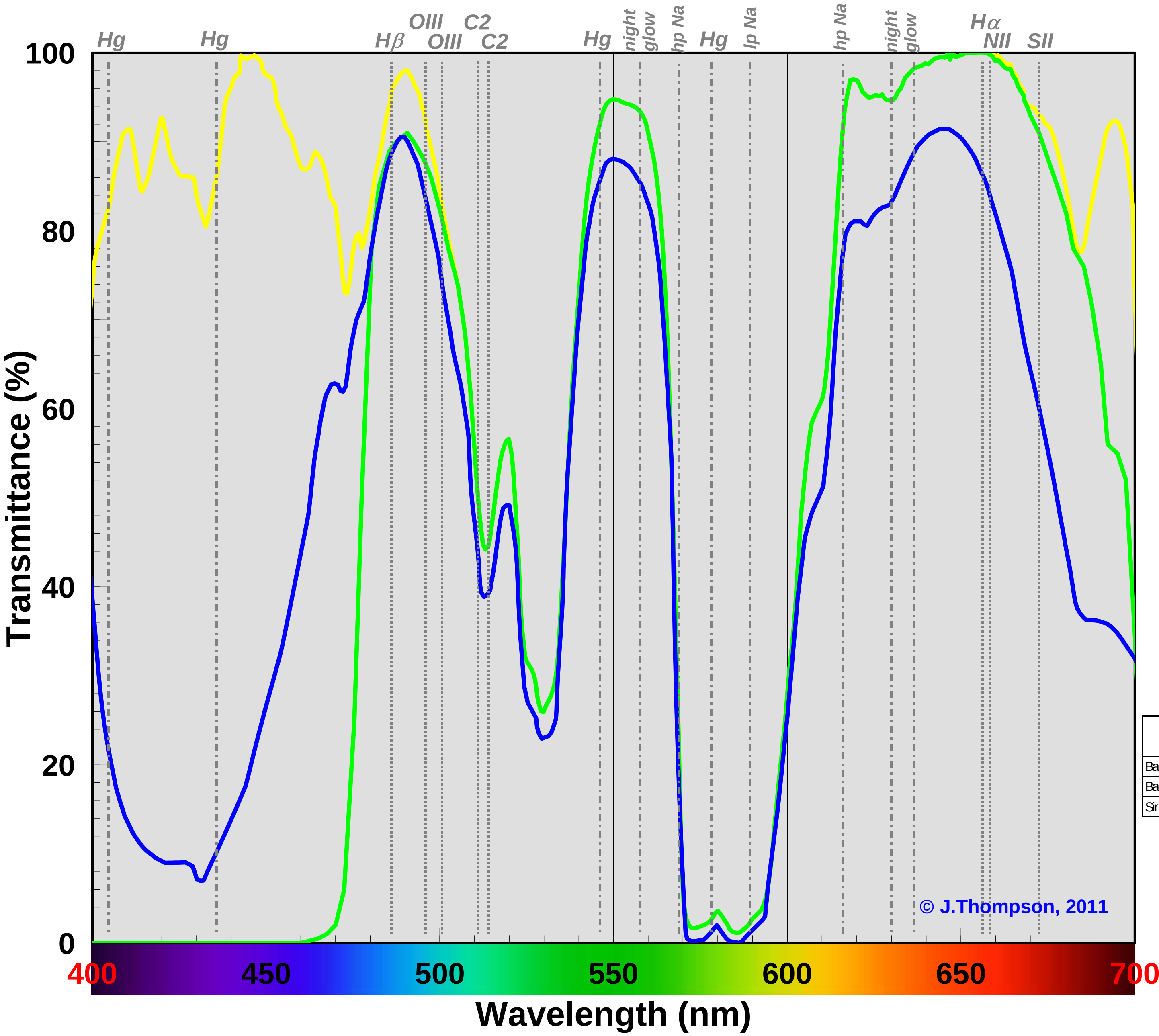


Filter	%Transmittance		
	Photopic	Scotopic	MC
Baader Solar	8.4	7.0	4.9
Denkmeier Planetary	52.8	54.3	62.1
Lumicon Comet	9.3	21.3	11.0
Orion Mars	29.2	52.6	53.7
Sirius CE1	60.9	50.1	60.4
Sirius PC1	40.7	35.9	36.5



Special B

Filter	%Transmittance		
	Photopic	Scotopic	MC
Baader Moon&Sky	55.3	72.3	70.7
Baader Contrast	53.1	48.9	56.0
Sirius NPC	49.0	55.1	53.3

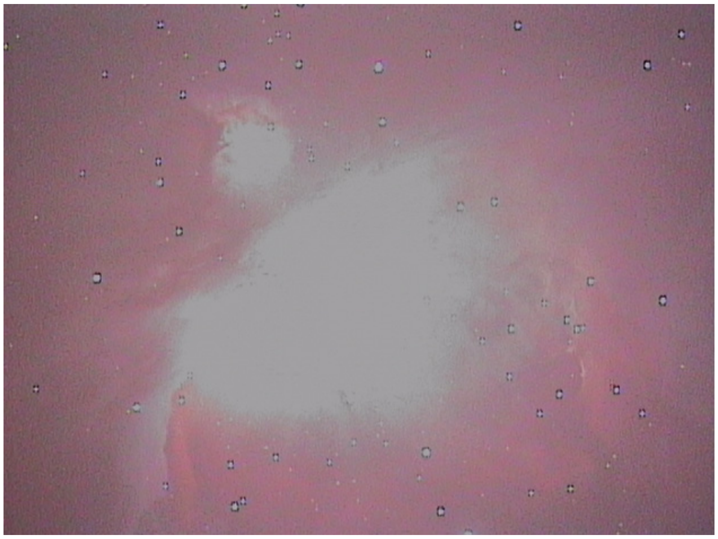
Appendix C Per-Integration Time Images

none-2sec-stack.tif

none-4sec-stack.tif

none-8sec-stack.tif

none-12sec-stack.tif



moonsky_2sec-stack.tif

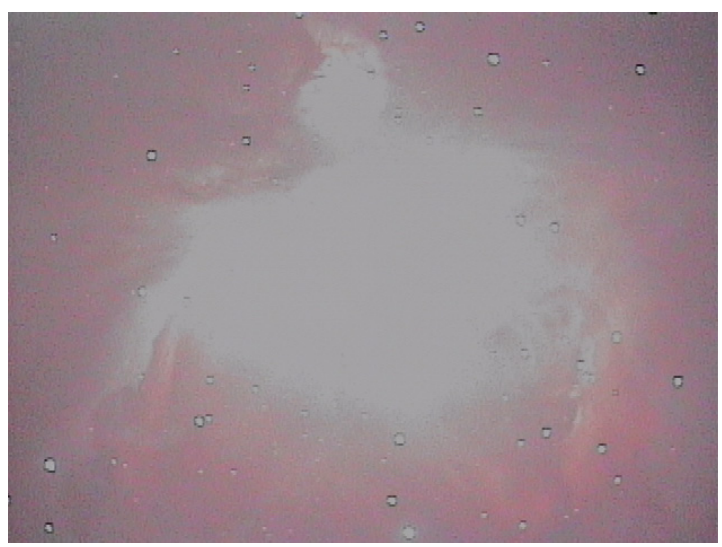
moonsky_4sec-stacked.tif

moonsky_8sec-stacked.tif

moonsky_12sec-stacked.tif

moonsky_16sec-stacked.tif

moonsky_24sec-stacked.tif



lps-2sec-stack.tif

lps-4sec-stack.tif

lps-8sec-stack.tif

lps-12sec-stack.tif

lps-16sec-stack.tif

lps-24sec-stack.tif

lps-32sec-stack.tif

orion-2sec-stack.tif

orion-4sec-stack.tif

orion-8sec-stack.tif

orion-12sec-stack.tif

orion-16sec-stack.tif

orion-24sec-stack.tif

orion-32sec-stack.tif

uhcs-2sec-stack.tif

uhcs-4sec-stack.tif

uhcs-8sec-stack.tif

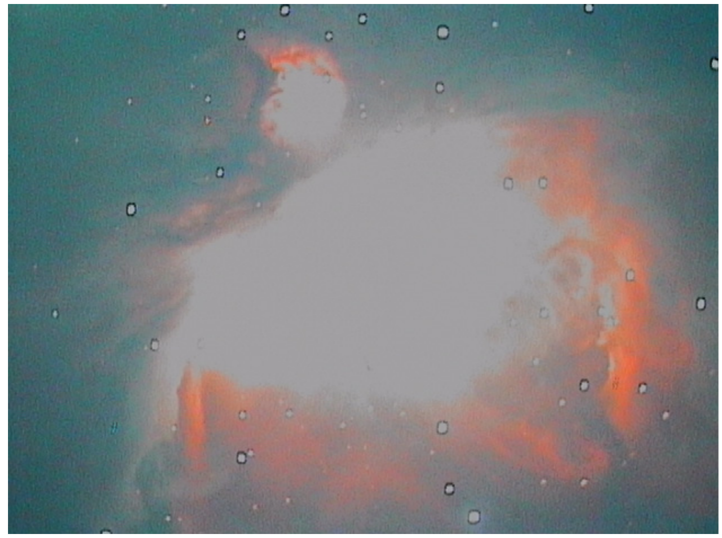
uhcs-12sec-stack.tif

uhcs-16sec-stack.tif

uhcs-24sec-stack.tif

uhcs-32sec-stack.tif

uhcs-48sec-stack.tif



auhc_2sec-stacked.tif

auhc_4sec-stacked.tif

auhc_8sec-stacked.tif

auhc_12sec-stacked.tif

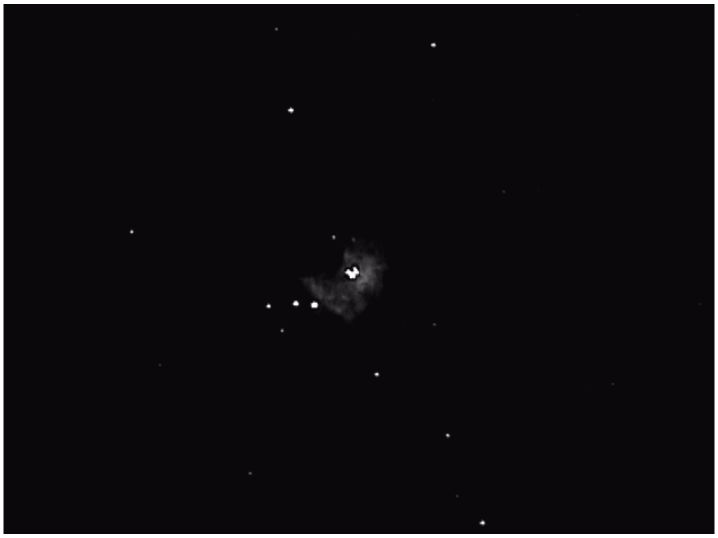
auhc_16sec-stacked.tif

auhc_24sec-stacked.tif

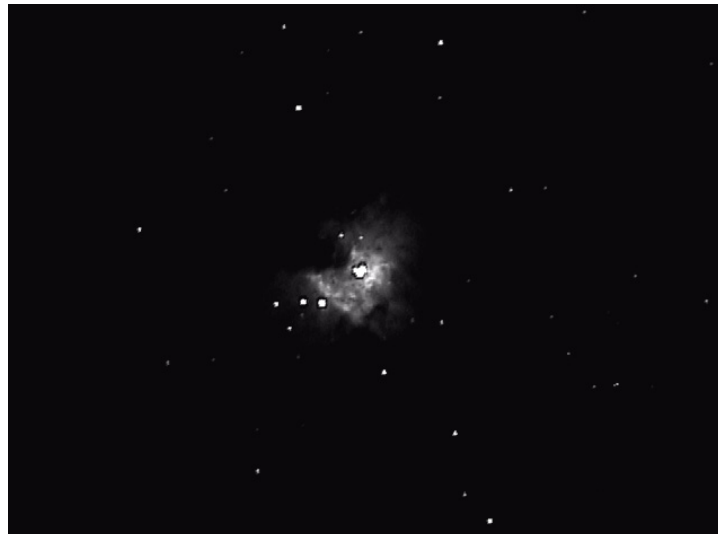
auhc_32sec-stacked.tif

auhc_48sec-stacked-badcoll.tif

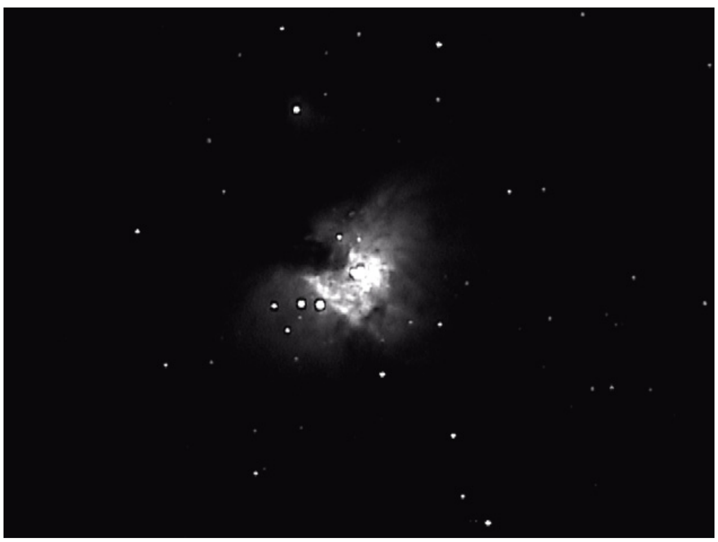
abeta_2sec-stacked.tif



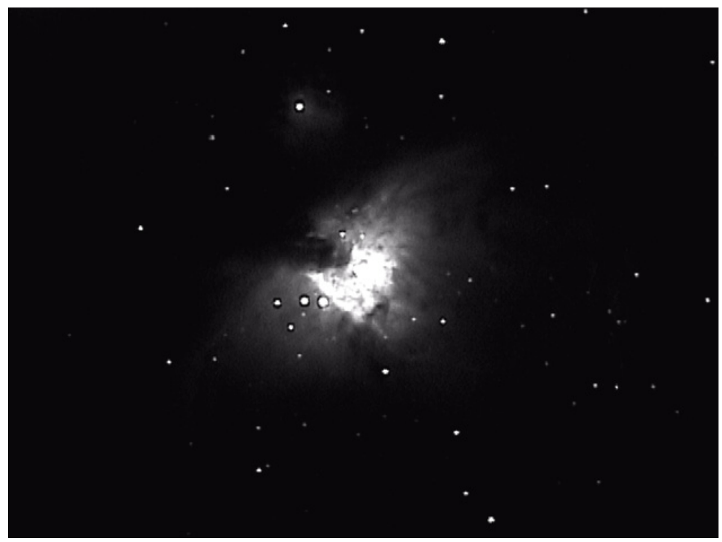
abeta_4sec3-stacked.tif



abeta_8sec-stacked.tif



abeta_12sec-stacked.tif

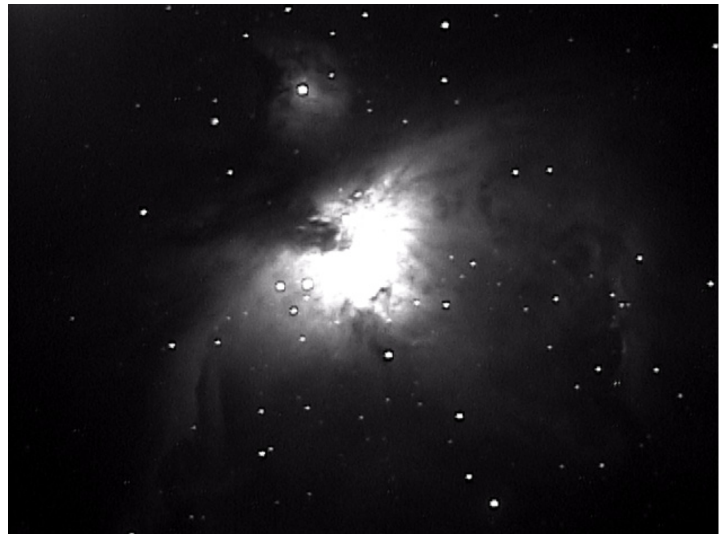


abeta_16sec-stacked.tif

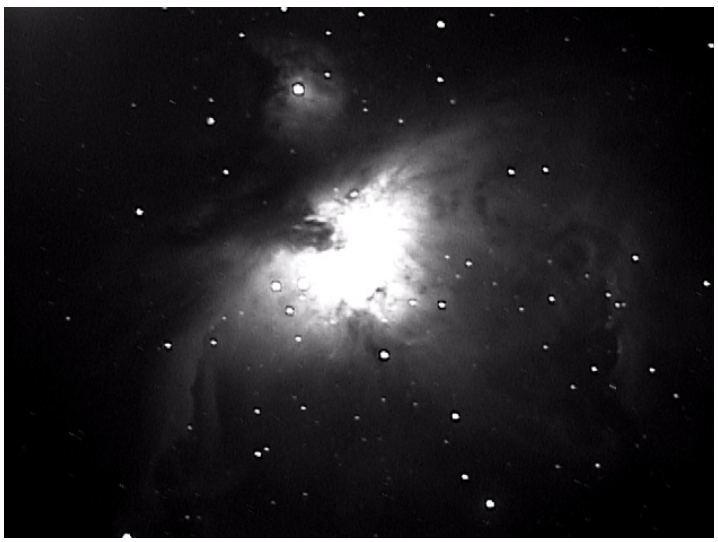
abeta_24sec-stacked.tif

abeta_32sec-stacked.tif

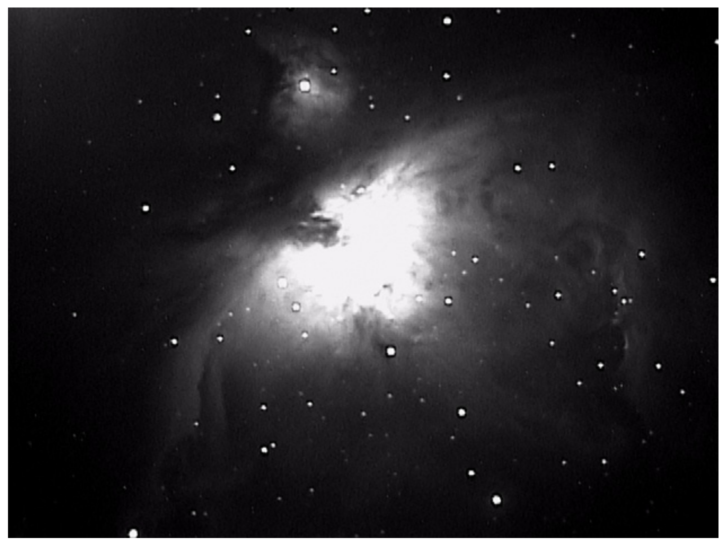
abeta_48sec-stacked.tif



abeta_60sec-stacked.tif



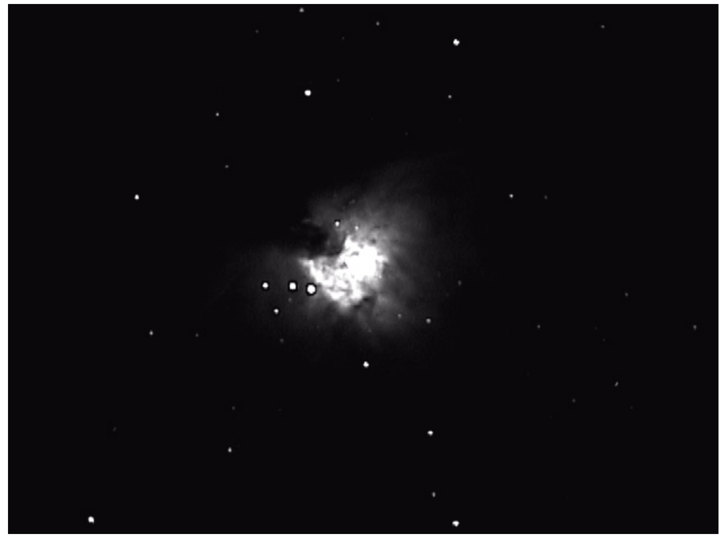
abeta_75sec-stacked.tif



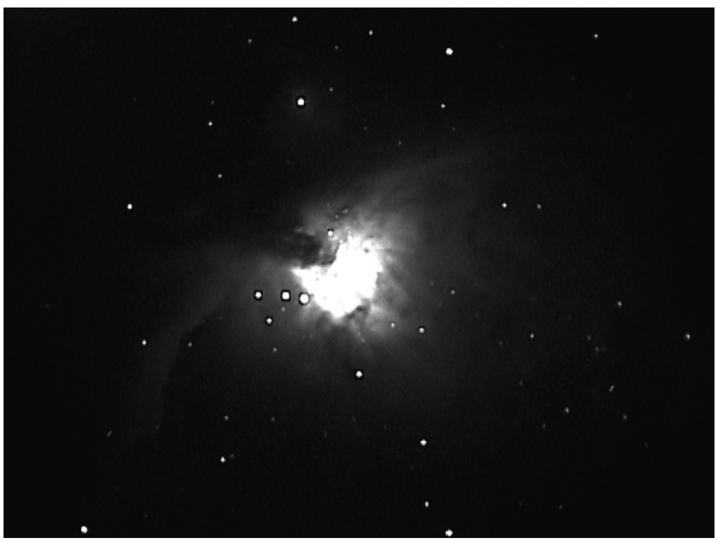
abeta_90sec-stacked.tif

o3-2sec-stack.tif

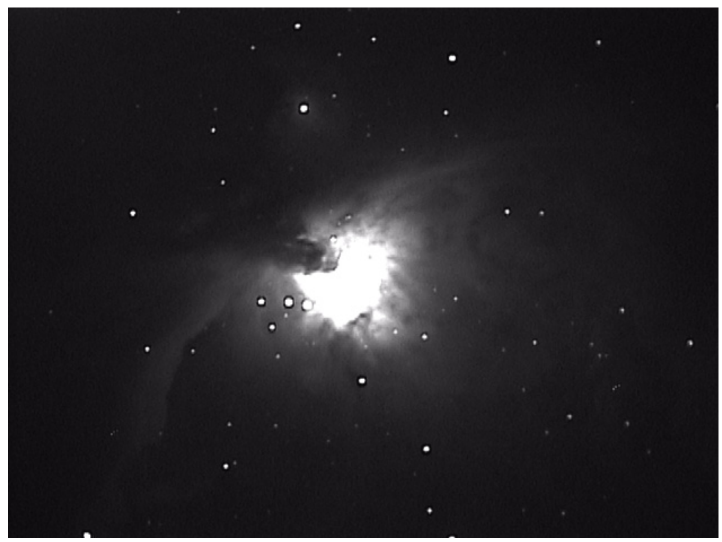
o3-4sec-stack.tif



o3-8sec-stack.tif

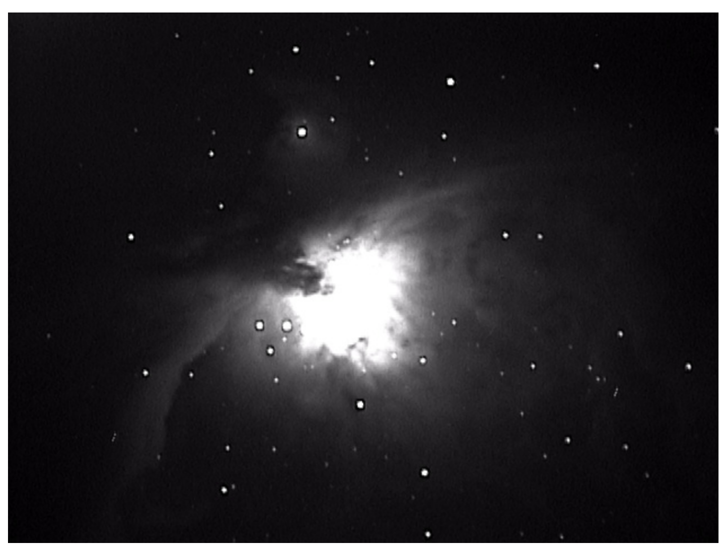


o3-12sec-stack.tif



o3-16sec-stack.tif

o3-24sec-stack.tif



o3-32sec-stack.tif

o3-48sec-stack.tif

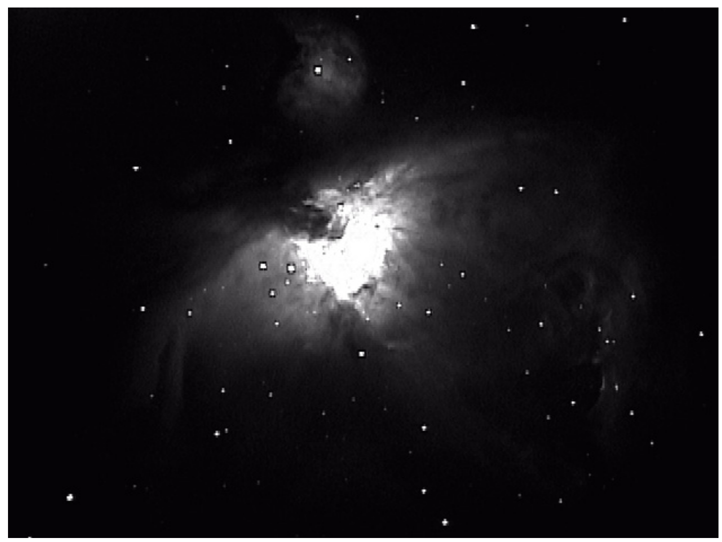
o3-60sec-stack.tif

red_2sec-stacked.tif

red_4sec-stacked.tif

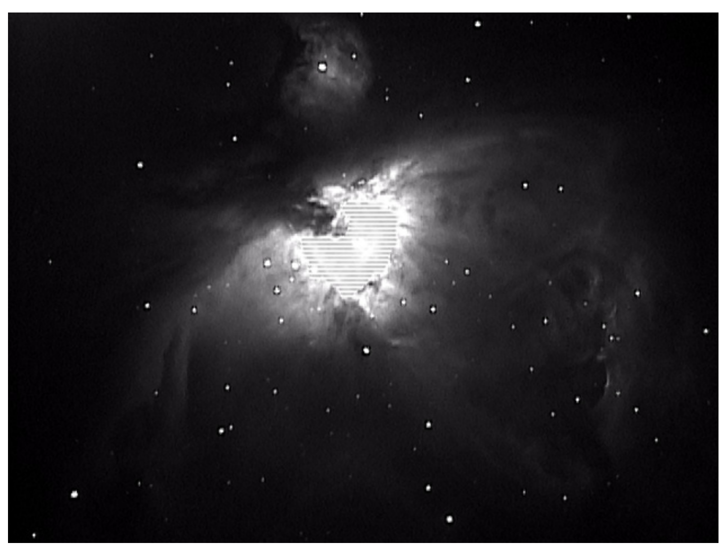
red_8sec-stacked.tif

red_12sec-stacked.tif

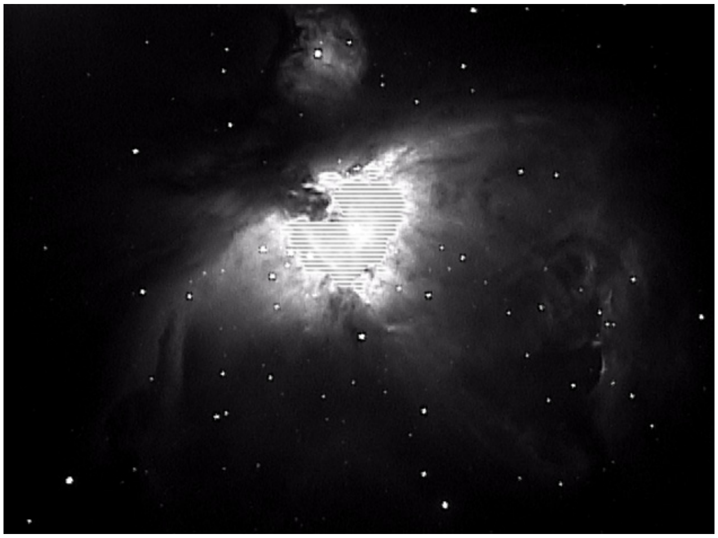


red_16sec-stacked.tif

red_24sec-stacked.tif



red_32sec-stacked.tif



red_48sec-stacked.tif

red_60sec-stacked.tif

red_75sec-stacked.tif

red_90sec-stacked.tif