To date I have written six magazine articles, two research papers, and five test reports all on the topic of astronomical filters. The objective of all my work has been to figure out what filters work best, both for visual and video observing. The culmination of all my research and testing is a method I have developed to predict the performance of any filter based solely on its published spectral response. I am very pleased with the outcome of my prediction method, however the end result has been the generation of a large amount of data that is too cumbersome for Joe Astronomer to wade through. My huge spreadsheet of filter performance numbers needs to be boiled down simply to: "use THIS filter, and not THAT one". In this article I try to do just that.

Specifically what this article will do is explain how to choose the best light pollution filter for your particular telescope setup. My analysis has shown that image contrast improves as the narrowness of the LP filter increases. Thus the only limit on the choice of filter is the aperture of your scope for visual observing, or the length of time you can integrate for when video observing. I assume in this article that the filter is being selected to deal with high levels of light pollution. More moderate levels of light pollution would allow for a less narrow filter to be used. Towards the end of this article I also provide some recommendations regarding IR Cut and IR Pass filters.

Visual Observing

Pretty much all commercially available LP filters are made for visual observing. Even so, some filters perform far better than others. The main parameter affecting the selection of an LP filter is your aperture. Since filters block a portion of the light coming in, you will need a progressively larger aperture to be able to affectively use a narrower filter. Based on recommendations from filter manufacturers plus some of my own testing, I have established a relationship between filter luminous transmissivity (%LT) and telescope aperture. Recall that %LT is the average "darkness" of the filter weighted by the observer's spectral sensitivity, in this case the dark adapted human eye.
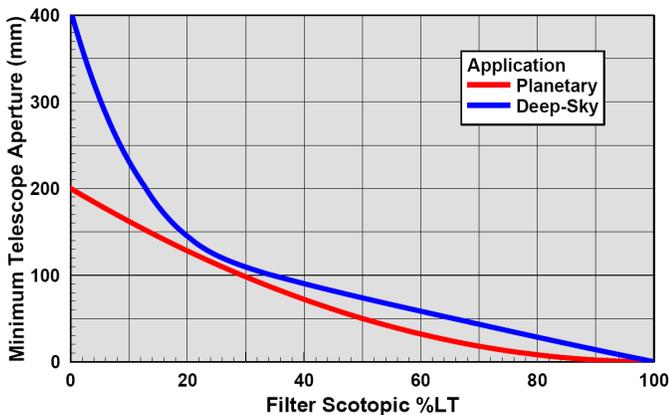
Figure 1. Minimum Telescope Aperture vs. Filter %LT (scotopic human eye): *The relative "darkness" or luminous transmissivity of a filter limits what aperture scope it can be used on.*

To assist in the filter selection process I have created a grading system. A letter grade has been assigned to represent each filter's performance relative to what is typical for a filter of the same %LT. My grading system is as follows:

A+	performance >20% better than average
A	performance 0-20% better than average
B	performance 0-20% below average
C	performance >20% below average
D	view is worse with filter than no-filter

Using my filter performance prediction method, I have graded all 100+ filters I have in my database on the basis of performance. Based on that grading I have made a table summarizing the best performing filters over the range of available %LT. From this list a filter can be selected that matches with the lowest %LT your telescope can handle. For example: if you use a 4" refractor, your optimum %LT is around 35%. The best performing filter for you is probably an Astronomik UHC or Andover 3-channel Nebular for both bright and dim nebulae. Note that although LP filters are predicted to improve the view of galaxies, the amount by which they do so is very small. There is no filter available that will significantly improve the view of galaxies when observing visually.

LT Range	Filter	%LT	Grade		
			Bright Nebulae	Dim Nebulae	Galaxies
0-10%	Custom Scientific Hbeta	4.25	C	A+	B
	Custom Scientific O-III	4.85	A	C	D
	Baader Solar Continuum	7.04	D	D	A+
10-20%	1000 Oaks LP4	10.76	C	A	A+
	Lumicon O-III	12.57	A	C	D
	Astronomik Hbeta	12.63	C	A	A+
	Meade O-III	16.64	A	C	D
20-30%	Lumicon UHC	24.78	A	B	D
	1000 Oaks LP2	26.54	A	A	C
	Antares Narrow	29.06	A	A	A
30-40%	Andover 3ch Nebula	32.88	A	A	A
	Astronomik UHC	33.6	A	A	A
	Denkmeier UHC	38.76	A	A	B
40-50%	Televue Nebustar	42.49	A	A	A
	Astronomik UHC-E	42.52	A	C	A+
	Omega Wide	49.52	B	A	A+
50-60%	Arcturus Broad	50.74	A	B	A+
	Denkmeier Planetary	54.27	A	B	A+
	IDAS LPS-V3	54.84	A	A	B
	Antares ALP	59.58	A	A	B
60+%	Lumicon Deepsky	60.54	A	A	C
	Astronomik CLS	67.52	A	A	A
	Orion Skyglow Imaging	68.51	A	B	A+
	IDAS LPS-P1	73.54	A+	A+	C

Table 1. Top Performing Deep-Sky Filters - Visual Use: *The table above lists the best performing filters (by prediction) in each %LT range for use with visual observing.*

Video Observing

Even though pretty much all commercially available LP filters are made for visual observation, many of them are well suited for use in video astronomy. Video astronomy is less limited by aperture than it is by maximum exposure time, which is determined by the ability of the mount to track the target effectively. Thus, to be able to use a filter with a low %LT, you will need to have a mount that can provide very steady tracking. In the extreme case, when using the narrowest of filters, mount guiding will be essential. Based on my own testing I have established an estimate of how much longer you will need to integrate for per frame relative to no filter based on the filter's %LT. For video astronomy the %LT is calculated using the Sony ICX418AKL CCD as the sensor instead of the human eye.

To be able to pick a filter that is a good match to your setup, you will need to know roughly how long you are able to track for, as well as how long typically you are able to integrate on a typical DSO. For my location in a "white" zone for light pollution (sky brightness ~18 mags/sq arcsec, limiting mag +3.5), I normally can get to between 8 and 12 seconds of integration (AGC=4) with my Mallincam when not using any filters. This assumes my Gamma is already at 1.0 and video Brightness adjustment is at zero. An integration time any longer results in the image background being too washed out/over exposed. In many of my past tests I have compared the relative amount of time required to get to this same "Brightness=0" condition using a number of different filters. Figure 2 below presents a summary of the results. I have fit a simple curve through the scattering of points, the equations for which are:

Band-Pass Filters: $(100 / \%LT)^{1.32}$
Red/IR High-Pass Filters: $(100/ \%LT)^{1.96}$
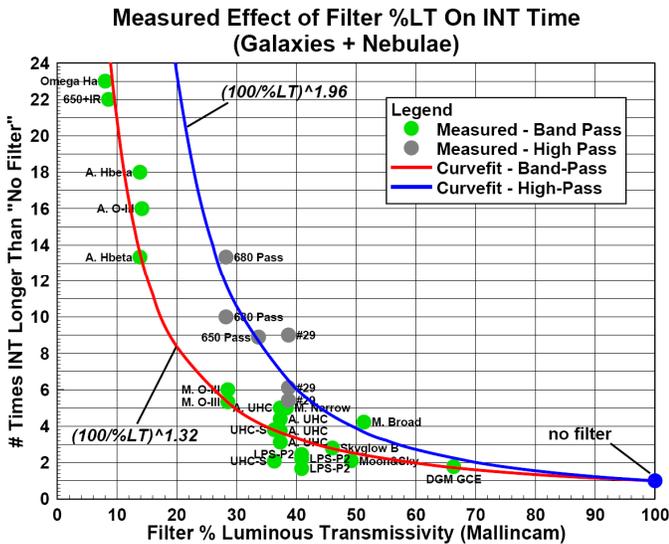
Figure 2. Measured Effect of %LT On Integration Time (ICX418AKL): *Based on my test results, an estimate of integration time vs. %LT has been made.*

I have used my filter performance prediction method again to come up with a grading of all the deep-sky filters in my database when used with an astro-video camera. From this I have generated a table of top performers by %LT range, much like I did above for visual observing. The filters in my table below have been colour coded as well, the colour representing the shade of monochrome the filter produces. Filters giving full colour images are listed in black.

LT Range	Filter	%LT	Grade		
			Bright Nebulae	Dim Nebulae	Galaxies
0-2%	any Halpha <10nm wide	0.9 - 2.0	A+	A+	A*
2-5%	FLI O-III 8nm	2.13	A+	C	D
	Baader O-III	2.27	A+	C	D
	Orion Hbeta	3.28	C	A	D
	Astronomik Halpha 13nm	4.16	A+	A+	C*
5-10%	Baader Halpha 35nm	6.73	C	A+	C*
	Astronomik O-III CCD	7.42	A+	C	D
	Omega Halpha	8.04	C	A+	A*
	Baader Solar Continuum	9.45	D	D	A+*
10-20%	Astronomik Hbeta	13.84	C	C	A+*
	Astronomik O-III	14.17	A	C	C*
	IDAS O-III	14.23	A+	A	C*
20-30%	1000 Oaks LP3	21.43	A	C	A+
	Custom Scientific Multiband	22.17	A	A+	A
	1000 Oaks LP4	24.06	C	A+	A+
	Meade O-III	28.55	A+	A	A+
30-40%	Arcturus Narrow	36.34	A	A	A
	Astronomik UHC	37.32	A	A	A
	Meade Narrowband	38.34	A+	A+	A+
	Lumicon Halpha Pass	38.75	C	A+	A+
40-50%	Arcturus Broad	41.65	A	B	B
	1000 Oaks LP1	43.04	B	C	B
	Antares ALP	45.39	B	B	C
	Lumicon Deepsky	49.22	A	B	B
50-60%	Meade Wideband	51.3	A	A	A
	Astronomik CLS	56.45	A	A	A
60+%	Denkmeier Planetary	61.45	A	A	B
	Optec Deepsky	62.48	A+	A+	A
	DGM GCE	66.32	A+	A+	B
	Can-Tele Moon&Sky	66.45	A	A	C

Table 2. Top Performing Deep-Sky Filters – Video Use: *The table above lists the best performing filters (by prediction) in each %LT range for use with video observing. Colour text denotes monochrome filters.*

I do have a word of caution about the Meade brand filters listed in Table 2. My results are based on the manufacturer supplied spectral plots that came with my version of these filters. Historically Meade LP filters have varied widely in their performance due to quality control issues and changing filter suppliers over time. A good way to tell if you have a good performing version of a Meade filter is to hold it up to a bright light at arm's length and look through the filter. It

should appear cyan, blue, or green depending on whether it is the Broadband, Narrowband, or O-III filter respectively. Now if you rotate the filter relative to your eye you should see the colour change. Your filter hopefully will change to magenta by the time you've rotated it by 30 to 45°, confirming that the filter is passing both O-III and H-alpha (which you want). If the filter changes colour to blue and not magenta when you rotate it, then the filter is not passing any H-alpha (which you don't want).

I also want to point out that although at %LT values below 20% the best filter for improving contrast in galaxies appears to be Halpha, my grading scheme hides the fact that in absolute terms the best contrast overall on galaxies is achieved by a filter in the 20 to 40% LT range. This does not include IR Pass filters, which perform better than any deep-sky filter on galaxies, as will be discussed later.

Infrared Filters
In all cases, whether you are considering an IR Cut filter or an IR Pass filter, they are only useful for video observing. The human eye can't see that far into red end of the spectrum, so these filters would serve no purpose in visual observing. That being said, CCD detectors commonly used in astro-video cameras CAN see infrared, up to wavelengths around 1000 to 1200nm. This makes IR Cut and Pass filters worth considering in video astronomy.

IR Cut filters normally block both UV and IR, which is beneficial for a number of reasons:

- in refracting type telescopes and lenses the removal of UV & IR light improves overall image focus and sharpness since optics are normally not designed to focus these wavelengths to the same point in space like they are for the visible spectrum;
- removing IR from the image helps reduce the relative brightness of stars, decreasing the amount by which they are bloated in size by the video camera sensor; and
- a component of light pollution exists in the UV and IR bands, so adding the cut filter helps to remove this light pollution and increase overall image contrast.

By far the most important benefit is the first one; removing unfocused UV & IR. If you use an achromatic telescope or lens, you probably should consider using an IR Cut filter. If you are using a reflecting telescope or an APO refractor, you will see a benefit from using an IR Cut filter, but only because of the later two reasons listed above, which have a small impact. If you are viewing primarily emission nebulae an IR Cut filter is maybe worth it, but if you plan to view galaxies the last two benefits listed above will not outweigh the penalty an IR Cut imposes on galaxy brightness.

The IR Cut filters that are available commercially all have slightly different pass bands, but in the end can be chosen simply by their %LT. A summary of available IR Cut filters has been provided in Table 3, including their %LT values as calculated for the ICX418AKL CCD.

Filter	%LT
IDAS UV/IR Cut	66.92
Baader Planetarium UV/IR Cut	65.19
OPT UV/IR Cut	64.74
Orion IR Cut	64.20
Astronomik IR Cut	63.20
Mallincam IR Cut	62.59
B+W 486 UV/IR Cut	58.90
Omega BDRB (580WB185)	47.17
CM500S IR Cut (standard in digital cameras)	46.78

Table 3. Summary of Available IR Cut Filters

IR Pass filters are useful in video astronomy, but they have very specific uses. They are high pass filters, blocking all wavelengths below infrared including both UV and the entire visual band. For this type of filter to be useful, you need to be observing something that has a lot of emission in the infrared band, which includes:

- the Moon;
- planets;
- star clusters (open or globular); and
- galaxies.

Another interesting area that I have only started to explore is using IR Pass filters on nebulae in order to see what lies behind the glowing clouds of gas.

Selecting an IR Pass filter is similar to selecting an LP filter. Whether you are using them for solar system targets or DSO's, you need to understand how they impact the integration time versus no filter. Figure 2 presents a few measured points of how the IR Pass filter %LT affects integration time as well as a curve fit. Table 4 below summarizes the %LT for a list of IR Pass filters, as well as the predicted %improvement in image contrast when viewing galaxies compared with no filter.

Filter	%LT	contrast improvement on galaxies
Lumicon Halpha Pass	38.75	193%
Wratten #29 Dark Red	38.68	155%
generic IR650	33.67	214%
Baader IR-Pass	31.12	247%
generic IR680	28.23	268%
Wratten #89B	21.54	324%
generic IR720	21.52	335%
generic IR760	15.74	389%
generic IR850	6.37	385%
Wratten #87C	6.06	387%
generic IR950	1.37	314%
generic IR1000	0.50	259%

Table 4. Summary of Available IR Pass Filters

For more information on my filter performance prediction method, filter performance grades, or other questions and comments please contact me at: karmalimbo@yahoo.ca, or by going to my website: http://www.karmalimbo.com/aro.