Comparison Testing the Latest Multi-Target Filters

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Test Report – May 5th, 2023

Introduction:
Use of an optical filter to help reduce the impact of light pollution is a well established technique in the amateur astronomy community. The solution to the light pollution problem is easy when your target is an emission-type nebula – simply use one of the many commercially available narrowband or multi-narrowband filters. Finding a filter solution to help with imaging broadband emitting targets like galaxies or reflection nebula is much more difficult. Finding one filter well suited to imaging all object types combined would be like finding the proverbial "golden goose", assuming that it is even physically possible for such a filter to exist. It so happens that a couple of filter OEMs are attempting to find such a multi-target capable filter, the evaluation of which is the objective of this latest test report.

Objective:
The objective of this test is to evaluate the performance of two new filters: the Antlia Triband RGB Ultra, and the IDAS Galaxy & Nebula Booster (GNB). These two new filters are compared to other already existing filters, and evaluated for their ability to improve contrast and SNR on all target types including: emission nebulae, galaxies, reflection nebulae, and comets. The list of filters considered in this test report is as follows (cost quoted for 2" version):

Physically Tested Filters
- Astronomik IR Cut, $99.95USD
- Optolong Nighsky Halpha, $119.00USD
- Astronomik UHC, $199.95USD
- IDAS LPS-D2, $189.00USD
- **Antlia Triband RGB Ultra, $179.00USD**
- **IDAS GNB, $269.00USD**
- IDAS NB-1, $199.00USD
- IDAS NBZ, $299.00USD

The above list is of the filters that I have procured a sample of and thus was able to collect physical data on. I also considered some additional filters but only from an analytical standpoint as I don't have a sample to test:

Analytically Tested Filters
- Optolong L-Pro, $199.00USD
- IDAS "Dusk 'til Dawn" (DTD), ~$240USD
- Hypothetical Ideal #1
- Hypothetical Ideal #2

I have a sample L-Pro but only in 1.25" format, so not suitable for my 2" imaging setup. The IDAS DTD is a brand new filter not available in Canada yet at the time of this writing. The two hypothetical filters are my attempt to combine filter traits to find the ideal multi-target filter.

Ideal #1 is similar to an NBZ filter but with a third pass band added with center wavelength (CWL) 390nm and full width half maximum (FWHM) 20nm. Ideal #2 is the same as Ideal #1 but with a pass band added in the near-infrared part of the spectrum same as the GNB.

Filter performance was evaluated during this test based on the increase in contrast between the observed object and the background, which is a measurable quantity. It was evaluated quantitatively using the measured filter spectra combined with the spectra of several common deepsky objects, and by direct measurement from images captured using each filter and a back-illuminated CMOS camera. The spectrum and image data was also used to evaluate the signal-to-noise ratio (SNR) achieved using each filter.

Method:
Testing consisted of data collection from the following sources:

- Spectral transmissivity data, from near-UV to near-IR, measured using an Ocean Optics USB4000 spectrometer; and
- Image data collected using a variety of cameras and optics, as summarized below:
  - Jan. 10th: ZWO ASI533MC Pro one-shot colour (OSC) camera + William Optics ZS66 ED doublet refractor, native f/5.9
  - Feb. 24th (nebulae): ZWO ASI533MC Pro OSC camera + William Optics ZS66 ED doublet refractor, native f/5.9
  - Feb. 24th (galaxies): ZWO ASI533MC Pro OSC camera + William Optics FLT98 triplet apochromatic refractor, native f/6.3
  - Mar. 28th: ZWO ASI183MM Pro monochrome camera + Mallincam VRC-10" Ritchey-Chretien + Astrophysics 0.67x focal reducer, effective f/6.5
  - Apr. 7th: Mallincam DS432M-TEC monochrome camera + Mallincam VRC-10" Ritchey-Chretien, native f/8

The spectrometer data was collected in my basement workshop with the USB4000 and a broad spectrum light source. Filter spectrums were measured for a range of filter angles relative to the light path, from 0° (perpendicular) to 20° off-axis. The spectrometer was recently upgraded, replacing the entrance slit and diffraction grating, to give a wavelength resolution of 0.5nm.

For the purposes of predicting the relative performance of each filter, a reference spectrum was established for the typical observing objects: bright O-III rich emission nebulae, faint H-α rich emission nebulae, galaxies, reflection nebulae, and comets. The normalized emission spectra used in the analysis are plotted in Figure 1. Reference data used to produce these spectra was found in publicly available resources online, the source object in each case being as follows:

- O-III rich nebulae: M27
- H-α rich nebulae: NGC7000
- galaxies: M51
- reflection nebulae: M45
- comet: combination of 8 different comets from various sources

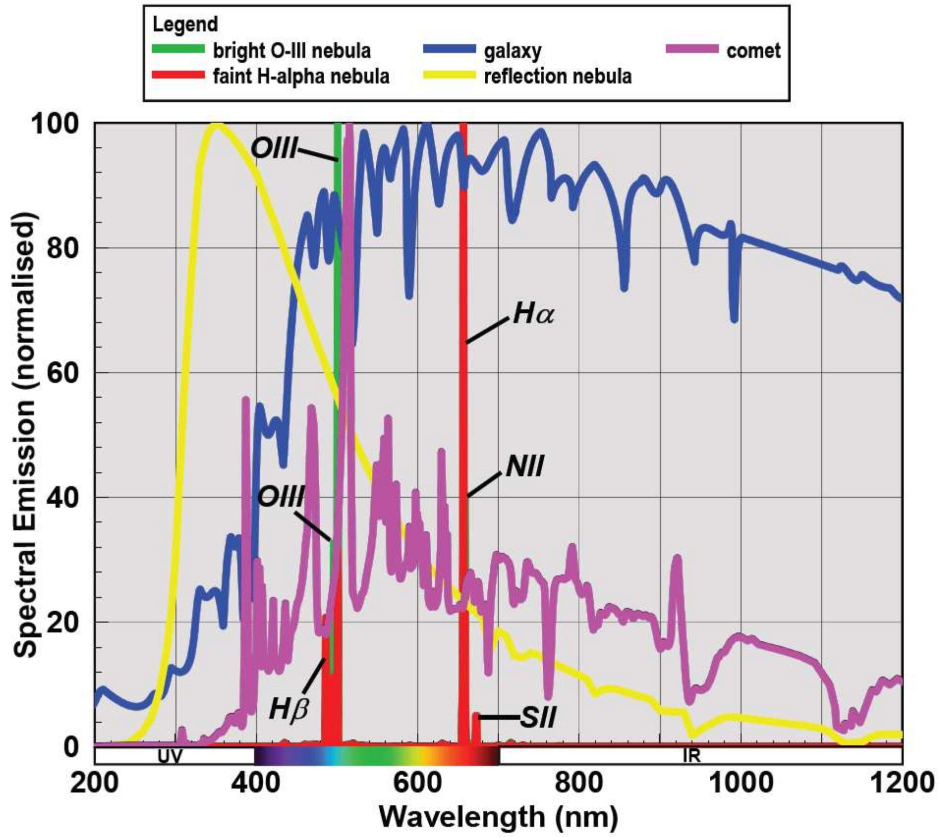


Figure 1 Normalized Emission Spectra for Typical Observing Targets

The image data was collected from my backyard in central Ottawa, Canada where the naked eye limiting magnitude (NELM) due to light pollution is +2.9 on average (Bortle 9+). I switched filter configurations using a ZWO 2" filter drawer. Each time I changed filters I refocused on a conveniently located bright star using a Bahtinov mask. Images with the various filters under test were collected with the scopes and cameras listed above. Images of four different deepsky objects were captured, each on a different evening as follows:

1. M42 & Running Man Nebulae, January 10th
2. Flame & Horsehead Nebulae, February 24th
3. Leo Triplet (M65, M66, NGC3628), February 24th
4. Whirlpool Galaxy (M51), March 28th and April 7th

For all the imaging sessions I used sub-exposure times that varied according to the narrowness of the filter pass bands so that the overall image exposure (brightness) as captured was roughly the same. The exception was the imaging session held on April 7th, for which I used a constant sub-exposure time of 30s for all filters except "no-filter" and the UV/IR Cut filter for which I had to use 10s sub-exposures due to the brightness of the background. All images captured were live stacks of 5 minutes total duration except on April 7th which were 10 minutes total. All images with the ZWO cameras were captured using Sharpcap in 16-bit FITS format, while images from the Mallincam camera were captured using MallincamSky.

Results – Spectrum Measurements:
Using the test method mentioned above the spectral transmissivity for each filter was measured for a range of filter angles relative to the light path. Figures 2 and 3 present plots of the measured spectra for the two main filters being evaluated, the RGB Ultra and GNB respectively, for the case of the filter perpendicular to the light path. Each filter has three distinct pass bands. They both have in common pass bands around O-III and Halpha, but differ for the third pass band. The RGB Ultra has its third band centered in the blue part of the spectrum, and the GNB has its third band centered in the near-infrared. Both filter OEMs suggest that their third pass band provides for improved performance on broadband objects such as galaxies. The validity of this assertion is the objective of this test effort.

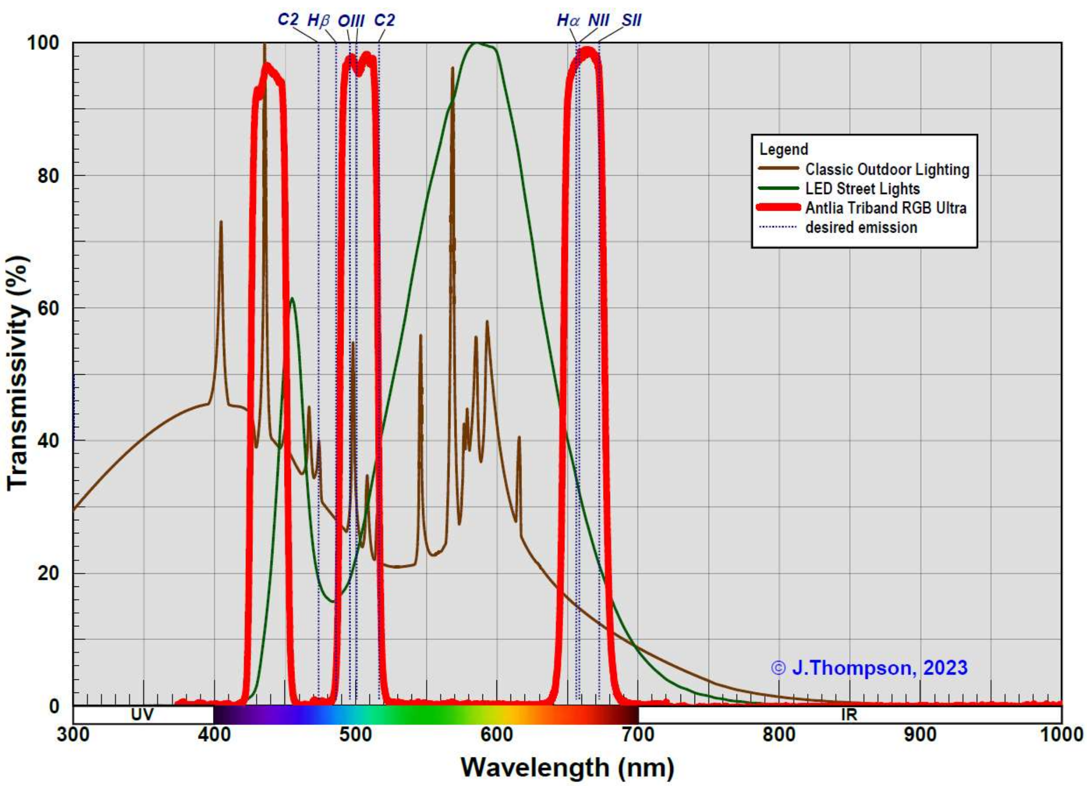


Figure 2 Measured Spectral Response of Antlia Triband RGB Ultra – Filter Perpendicular to Light Path

I don't have a sample of the new IDAS DTD filter, so I have digitised a graph of this filter's spectrum that I acquired from the IDAS website. The result is plotted in Figure 4. The remaining filters considered in this test for comparison have also all had their spectra measured using my setup. Plots of their measured spectra are provided in Figure 5. As mentioned above, there were also two made up filters considered in this test. These filters are my best guess at realizable filters that in theory should have the overall best performance on all object types. The assumed spectra for these two filters are presented in Figure 6.

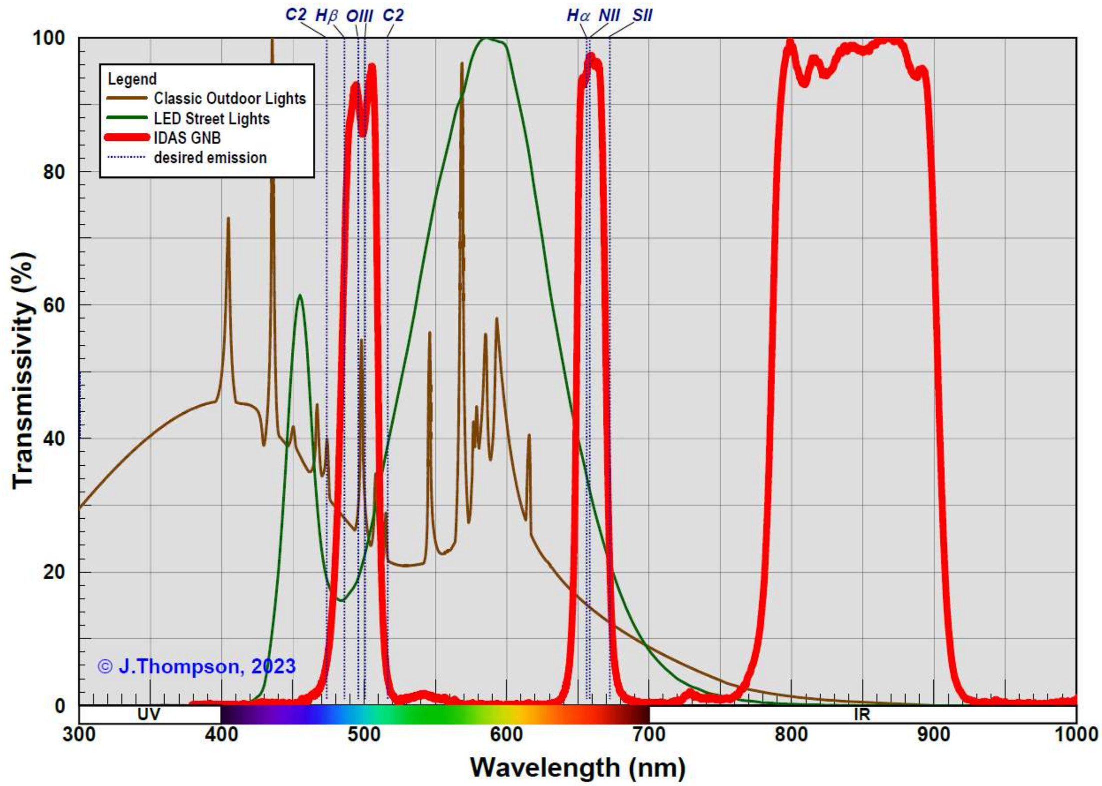


Figure 3 Measured Spectral Response of IDAS GNB – Filter Perpendicular to Light Path

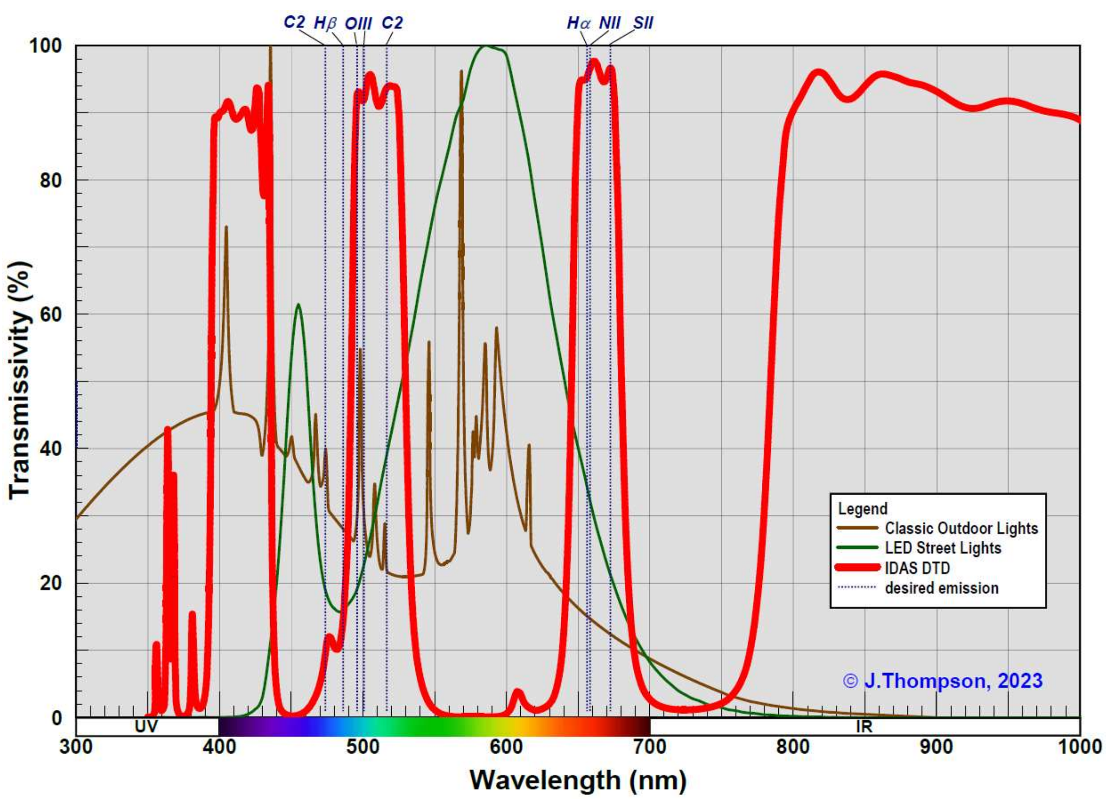


Figure 4 OEM Advertised Spectral Response of IDAS DTD – Filter Perpendicular to Light Path

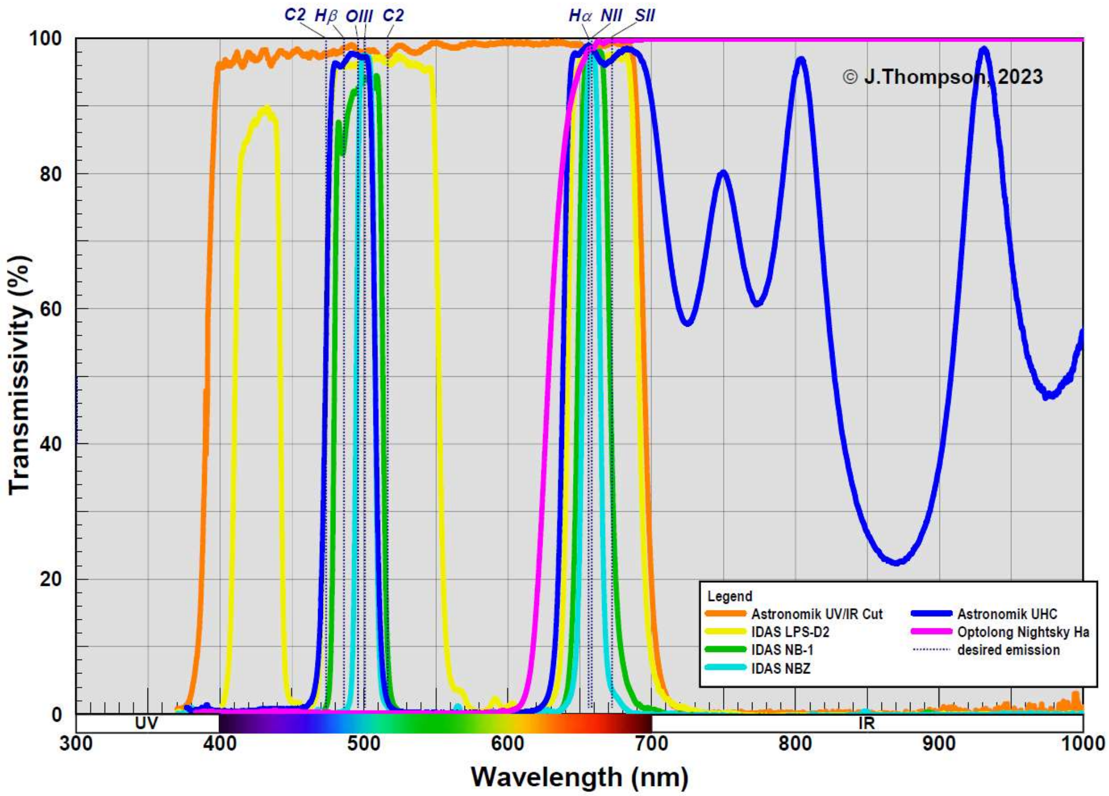


Figure 5 Measured Spectral Response of Other Filters Under Test – Filter Perpendicular to Light Path

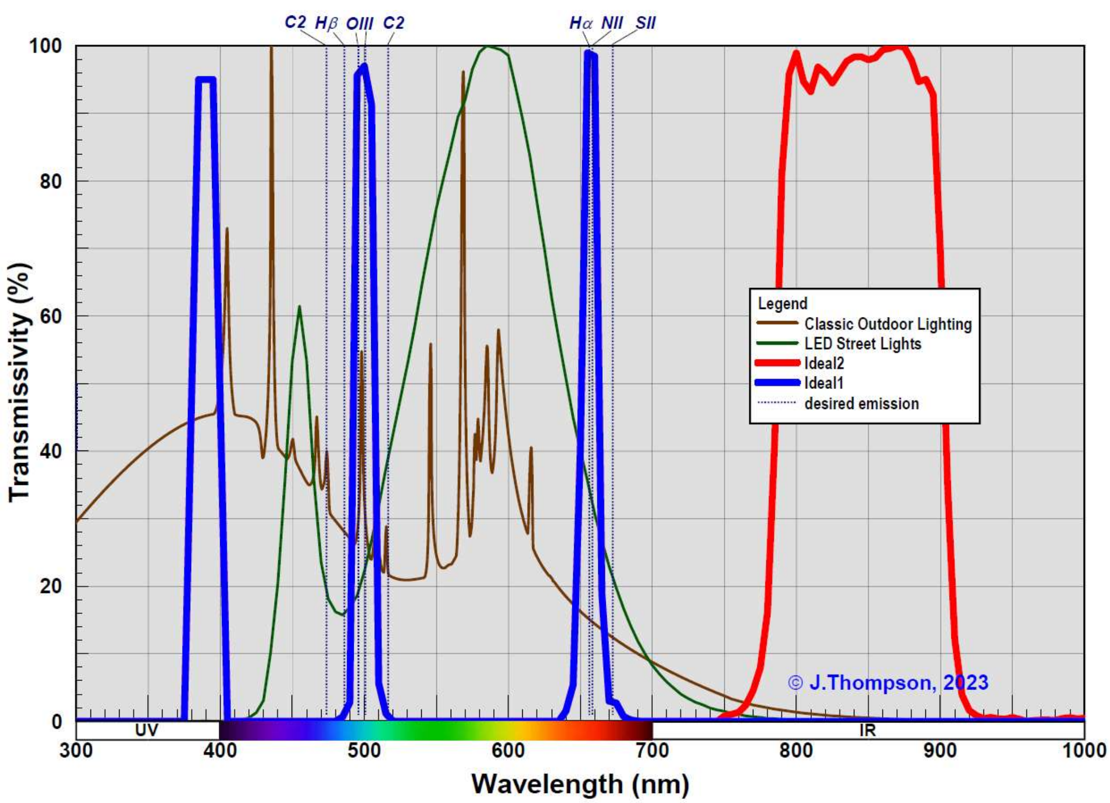


Figure 6 Fabricated Spectral Response of "Ideal"Filters – Filter Perpendicular to Light Path

Although the impact of angle on each filter's respective emission band transmission was measured, the results are not presented in this report. All the filters under test have relatively wide pass bands and are therefore not strongly sensitive to f-ratio.

With the filter spectra in hand, it was possible to extract overall performance related statistics for each filter, such as transmission values at key wavelengths of interest. The six emission wavelengths of interest for emission nebulae are included in Table 1 below (H-β, O-IIIa & b, H-α, N-II, S-II), as well as some key wavelengths associated with comets (CH, Swan C2 bands). An average transmission value for the near-infrared part of the spectrum is also included in the table. The filter statistics are provided in Table 1, including a calculated value for percent Luminous Transmissivity (%LT), a single number that describes generally how much light is getting through the filter. The calculated value of %LT depends on the spectral response of the detector, which in this case is assumed to be a modern back illuminated CMOS sensor.

Filter	%LT*	CH (387)	C2 (471.5)	Hbeta (486.1)	O-IIIA (495.9)	O-IIIB (500.7)	C2 (516.5)	C2 (563.5)	Halpha (656.3)	N-II (658.4)	S-II (672.4)	NIR (avg 700-1000)
No Filter	100	100	100	100	100	100	100	100	100	100	100	100
Astronomik IR Cut	65.2	19	97	98	98	98	97	99	99	98	99	0
Optolong Nightsky Hα	37.9	0	0	0	0	0	0	0	98	99	99	99
Optolong L-Pro	36.7	4	93	96	96	95	93	69	93	92	96	0
Astronomik UHC	36.0	1	29	96	97	97	2	0	99	98	97	59
IDAS DTD**	35.5	2	6	14	92	92	94	0	95	97	97	59
IDAS LPS-D2	33.3	0	25	96	96	96	96	4	97	98	98	0
IDAS GNB	19.5	0	4	67	91	87	4	0	95	97	21	37
Ideal #2**	17.7	95	0	1	96	97	1	0	99	98	3	37
Antlia Triband RGB Ultra	17.5	0	1	5	97	96	38	0	97	98	96	0
IDAS NB-1	12.3	0	0	84	93	94	9	0	98	98	39	0
Ideal #1**	8.9	95	0	1	96	97	1	0	99	98	3	0
IDAS NBZ	6.5	0	0	0	76	97	1	0	95	98	4	0

* calculated assuming spectral QE curve for IMX174M with no UV/IR blocking filter

** data from source other than my spectrometer

Table 1 Measured Filter Performance Summary (%)

Knowing the measured spectral response of the sample filters also allowed me to predict the theoretical relative performance of each filter when imaging different types of object. To do this I used the method I developed back in 2012 which applies the spectral response of the filter and sensor combined with the spectral emission from the object (Figure 1) and background light polluted sky to estimate the apparent luminance observed. To help visualize the results of this analysis I have plotted the predicted % increase in contrast (vs. no filter) for each filter versus the filter's %LT. Figure 7 shows the resulting plot corresponding to filter performance when using a CMOS camera to image a faint H-α rich nebula under a range of sky darkness levels, from a NELM of +2.9 (Bortle 9+) down to +6. Note that these are theoretical predictions of the increase in visible contrast between the object and the background. The absolute values of my predictions may not reflect what a user will experience with their own setup, but the predicted relative performance of one filter to another should be representative. In general, the desired performance for a filter is high contrast increase and high %LT, so the higher and more to the right a filter's performance is in the plot the better. Similar plots of predicted contrast increase for the other object types can be found in Appendix A.

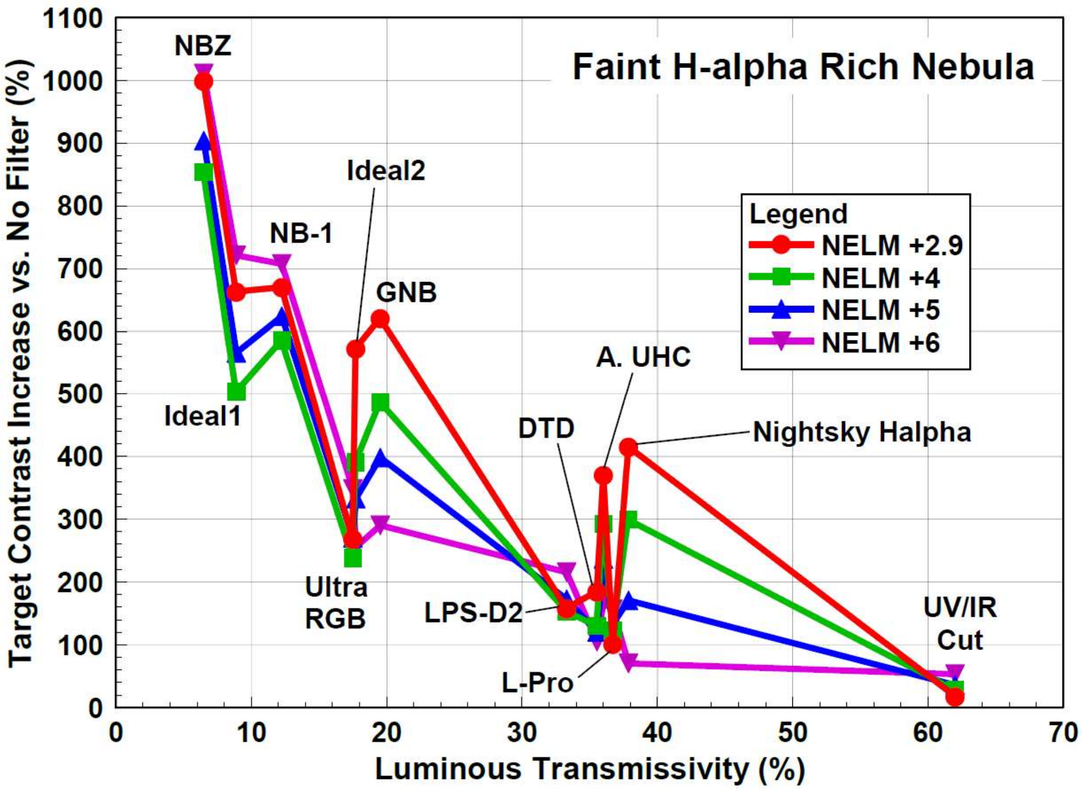


Figure 7 Predicted Contrast Increase: Back Illuminated CMOS, H-α Rich Nebula

Some general observations can be made from the contrast increase prediction plots, including:

- All of the filters considered in the analysis produce an improvement in object contrast when the object is an emission-type nebula (O-III or H-α rich). The narrower the pass bands, the larger the contrast increase.
- On broad spectrum objects (galaxies, reflection nebulae, comets) the increase in contrast realizable from applying a filter is much smaller than for an emission nebula; on the order of 1/10 the contrast increase. In some cases use of a filter results in a loss of contrast versus no filter.
- The extent to which a filter affects object contrast can in some cases vary dramatically depending on the level of light pollution. On broad spectrum objects, it is arguable that there is no significant improvement in contrast to be achieved when man-made light pollution levels are low (i.e. under dark skies).

It is also possible to predict image SNR using my analysis method. To perform the calculation I have made a simplifying assumption: that the camera is ideal and therefore there is no dark current or read noise. As a result the only noise considered in the calculation is shot noise.

Figure 8 is a plot of the predicted SNR when imaging a faint H-α rich nebula under a range of sky darkness levels, like presented above for contrast increase. For the calculation it is assumed that the same exposure time has been used for each filter. The SNR values have been normalized so that the predicted value with no filter equals 1.0. Thus, if a filter's SNR prediction is greater than one the filter has resulted in a net increase in image SNR, and if less than one the filter caused a net reduction in SNR versus no filter. Similar plots for the other object types can be found in Appendix A.

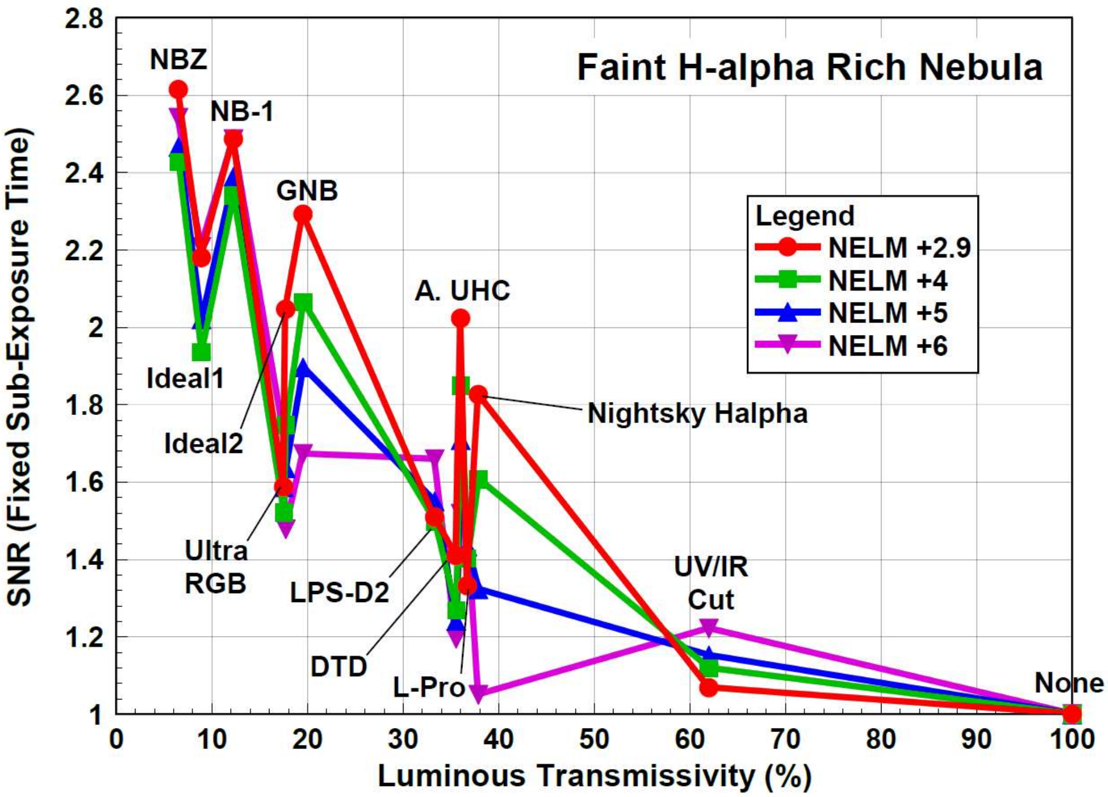


Figure 8 Predicted Image SNR: Back Illuminated CMOS, H-α Rich Nebula, Fixed Sub-Exposure Time

Some general observations can be made from the fixed exposure SNR prediction plots, including:

- All of the filters considered in the analysis produce an improvement in image SNR when the object is an emission-type nebula (O-III or H-α rich). The narrower the pass bands and larger the in-band transmission, the larger the SNR increase. The exception was the Nightsky Halpha filter on O-III rich nebulae, for which an SNR worse than no filter was predicted.
- In all cases, on broad spectrum objects (galaxies, reflection nebulae, comets), there is a reduction in SNR predicted versus no filter. The exception is for the Nightsky Halpha filter which is predicted to result in an increase in SNR when imaging galaxies. The reduced SNR means that to achieve the final result of better contrast on broad spectrum objects, more sub-exposures will be required when using filters than if no filter was used. The reason for the SNR reduction is that filters tend to reduce a broad band object's signal as much as it reduces the background signal.

- The extent to which a filter affects SNR can in some cases vary dramatically depending on the level of light pollution.

One of the benefits of using a filter to increase contrast is that the background is darker for the same sub-exposure time. To take full advantage of the beneficial impact a filter might have on contrast and SNR it is recommended that the user increase their sub-exposure time so that the same background brightness is achieved as when there was no filter, checking of course for over exposure of the target object. Worded another way, you should increase sub-exposure time so that you continue to use all of the available camera dynamic range. Using the same calculation methods, I have replotted the SNR predictions but weighted assuming each filter's sub-exposure time has been varied according to their %LT; lower %LT equals longer sub-exposure. Figure 9 is a plot of the result when imaging a faint H-α rich nebula under a range of sky darkness levels, again normalized so that the no-filter case has an SNR of 1.0. Similar plots for the other object types can be found in Appendix A.

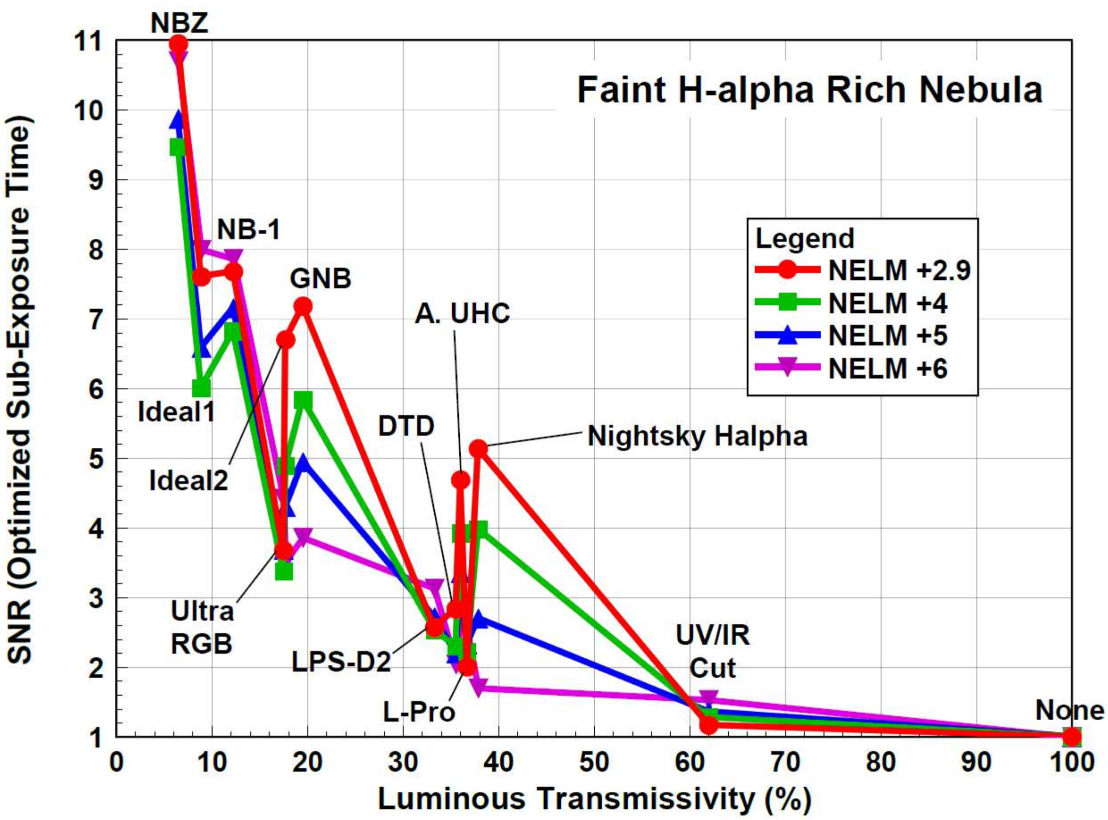


Figure 9 Predicted Image SNR: Back Illuminated CMOS, H-α Rich Nebula, Vary Sub-Exposure Time According to %LT

Some general observations can be made from the optimized sub-exposure SNR prediction plots, including:

- All of the filters considered in the analysis produce an improvement in image SNR when the object is an emission-type nebula (O-III or H-α rich) and optimized sub-exposure times are used. The narrower the pass bands and larger the in-band transmission, the larger the SNR increase. This is true regardless of the light pollution level.

- On galaxies and comets, a significant increase in SNR over no filter is predicted to occur under light polluted conditions when a filter that passes IR is used. Filters that do not pass IR are predicted to result in SNR values worse than no filter or to produce no significant difference in SNR.
- On broadband objects the SNR increase possible through the use of a filter is predicted to be significantly smaller than for an emission-type nebula.
- On reflection nebulae, the magnitude of improvement in SNR that is achievable by use of a filter is very small if not negligible. Filters with pass bands in the 390 to 420nm range may provide the best SNR gain when under heavily light polluted conditions. For skies better than NELM +4 (Bortle 7-8), one is better off using no filter.
- The extent to which a filter affects SNR can in some cases vary dramatically depending on the level of light pollution. The performance of some filters vary so much that they can be one of the best under light polluted conditions but one of the worst under dark sky conditions.

After flipping through the many plots in Appendix A, I think the reader would agree that it is very difficult to make a decision regarding which filter is the all-round best for use on multiple object types. In an attempt to simplify the visualization of the results I have compiled a summary table of predicted values (contrast increase & SNR) and coloured the table cells according to the ranking for each object type; green for best and red for worst. The result can be found below in Table 2.

For a filter to earn the title of "best multi-target filter" it should present as an all-green column in Table 2. As you can see from my results, such a filter does not exist. The filter characteristics required for good performance on emission-type nebulae are counter to that required for good performance on reflection nebulae or galaxies, not to mention the fact that the characteristics required for good performance change depending on the extent of the light pollution. If we focus on just observing from sites with high levels of light pollution, it is possible to use the results in Table 2 to make some filter recommendations: for the %LT range of 30-40% the best multi-target filter is the Astronomik UHC; for %LT 15-30% the best is the IDAS GNB; and for %LT below 15% the best is the IDAS NB-1. If I had to choose a single best all-round filter from the list of tested filters, I would pick the IDAS GNB. The Antlia Triband RGB Ultra is not predicted to provide a significant benefit on object contrast nor SNR when in light polluted conditions. It is predicted to actually perform best when under dark skies! In my opinion, instead of calling it a light pollution filter it fits better in the "colour correction" category along with filters like the Optolong L-Pro and IDAS LPS-D2.

One filter for which I am a little surprised by its predicted performance is the IDAS DTD. My first impression upon looking at the filter's spectrum was that it should perform as good or better on galaxies than the GNB. Apparently the larger amount of light passed by the filter in the visual band more than offsets the higher transmission of IR, resulting in a net reduction in performance on galaxies compared to the GNB. The DTD is also advertised as a good filter for comets due to its transmission of a major diatomic carbon emission line, one of the so-called "Swan bands". My analysis however suggests that it is not as good as other existing filters that pass IR. After some further investigation I came to the conclusion that Swan band filters

Performance Parameter	Object	NELM	No Filter	Astro. IR cut	Optolong Nightsky	Optolong L-Pro	Astro. UHC	IDAS DTD	IDAS LPS-D2	IDAS GNB	Ideal 2	Ultra RGB	IDAS NB-1	Ideal 1	IDAS NBZ
Luminous Transmissivity (%)			100.00	65.21	37.87	36.72	36.02	35.54	33.30	19.53	17.72	17.50	12.25	8.90	6.49
% Contrast Increase vs. No Filter	Bright O-III Nebula	MAG+2.9		13.69	140.63	110.88	410.86	254.64	174.97	747.27	864.03	387.60	774.00	994.53	1476.61
		MAG+4		23.69	86.74	133.87	327.71	187.18	171.42	590.22	604.55	348.53	678.31	766.26	1269.20
		MAG+5		31.18	26.76	145.36	266.62	175.49	191.55	486.11	521.19	390.95	722.24	855.81	1341.15
		MAG+6		47.56	-20.21	169.65	190.55	156.37	237.41	359.19	410.50	493.88	817.12	1079.20	1494.73
	Faint Halpha Nebula	MAG+2.9		14.19	414.20	100.60	369.32	183.83	157.12	619.88	571.35	267.88	669.41	662.23	998.33
		MAG+4		24.23	299.05	122.47	292.93	129.84	153.80	486.44	390.64	238.40	585.17	503.26	853.84
		MAG+5		31.75	170.87	133.40	236.80	120.49	172.62	397.99	332.59	270.40	623.85	565.62	903.96
		MAG+6		48.20	70.50	156.51	166.92	105.19	215.51	290.15	255.51	348.06	707.38	721.19	1010.95
	Galaxy	MAG+2.9		-21.17	243.51	-11.77	116.24	43.80	-0.48	112.10	90.53	-6.06	27.47	-3.74	25.58
		MAG+4		-14.24	166.59	-2.16	81.05	16.45	-1.77	72.78	39.24	-13.58	13.52	-23.82	9.05
		MAG+5		-9.04	80.96	2.65	55.18	11.71	5.52	46.72	22.77	-5.41	19.92	-15.94	14.79
		MAG+6		2.32	13.90	12.81	22.99	3.96	22.11	14.95	0.89	14.42	33.76	3.70	27.02
	Reflection Nebula	MAG+2.9		-13.40	11.74	-4.44	27.64	33.84	12.48	30.75	53.70	15.28	26.53	49.65	17.04
		MAG+4		-5.79	-13.28	5.98	6.87	8.38	11.02	6.51	12.33	6.04	12.67	18.44	1.64
		MAG+5		-0.08	-41.14	11.19	-8.40	3.97	19.26	-9.55	-0.96	16.07	19.03	30.68	6.98
		MAG+6		12.39	-62.95	22.19	-27.40	-3.24	38.02	-29.14	-18.61	40.41	32.77	61.22	18.39
	Comet	MAG+2.9		-13.66	175.03	1.84	85.40	48.58	11.03	101.25	83.49	17.63	50.14	15.14	36.35
		MAG+4		-6.07	113.44	12.94	55.23	20.32	9.59	63.95	34.10	8.21	33.70	-8.87	18.41
		MAG+5		-0.38	44.88	18.49	33.05	15.42	17.72	39.22	18.23	18.44	41.25	0.55	24.63
		MAG+6		12.06	-8.80	30.21	5.45	7.41	36.24	9.07	-2.83	43.27	57.54	24.05	37.91
Fixed Sub-Exposure Time SNR	Bright O-III Nebula	MAG+2.9	1.00	1.06	0.85	1.39	2.17	1.75	1.60	2.63	2.85	2.08	2.75	3.03	3.57
		MAG+4	1.00	1.10	0.75	1.46	1.96	1.56	1.58	2.32	2.39	1.96	2.52	2.62	3.17
		MAG+5	1.00	1.13	0.62	1.47	1.78	1.50	1.60	2.06	2.15	1.97	2.42	2.53	2.91
		MAG+6	1.00	1.18	0.50	1.49	1.55	1.42	1.64	1.76	1.87	1.98	2.27	2.41	2.58
	Faint Halpha Nebula	MAG+2.9	1.00	1.06	1.83	1.33	2.02	1.41	1.51	2.29	2.05	1.59	2.49	2.18	2.61
		MAG+4	1.00	1.11	1.61	1.40	1.85	1.27	1.50	2.07	1.75	1.52	2.34	1.94	2.43
		MAG+5	1.00	1.14	1.32	1.43	1.71	1.24	1.55	1.90	1.64	1.59	2.39	2.02	2.47
		MAG+6	1.00	1.21	1.05	1.50	1.52	1.19	1.66	1.67	1.48	1.73	2.49	2.21	2.54
	Galaxy	MAG+2.9	1.00	0.73	1.21	0.59	0.93	0.71	0.58	0.67	0.58	0.41	0.41	0.28	0.30
		MAG+4	1.00	0.77	1.06	0.62	0.85	0.64	0.58	0.61	0.50	0.39	0.39	0.25	0.28
		MAG+5	1.00	0.79	0.88	0.63	0.78	0.63	0.60	0.56	0.47	0.41	0.40	0.26	0.29
		MAG+6	1.00	0.83	0.70	0.66	0.70	0.61	0.64	0.50	0.42	0.45	0.42	0.29	0.30
	Reflection Nebula	MAG+2.9	1.00	0.81	0.40	0.63	0.55	0.66	0.66	0.42	0.47	0.50	0.41	0.43	0.28
		MAG+4	1.00	0.84	0.35	0.67	0.50	0.60	0.66	0.38	0.40	0.48	0.39	0.38	0.26
		MAG+5	1.00	0.86	0.29	0.68	0.47	0.59	0.68	0.35	0.38	0.50	0.40	0.40	0.27
		MAG+6	1.00	0.92	0.23	0.71	0.42	0.57	0.73	0.31	0.34	0.55	0.42	0.44	0.28
	Comet	MAG+2.9	1.00	0.81	0.87	0.68	0.75	0.71	0.65	0.60	0.53	0.50	0.47	0.33	0.32
		MAG+4	1.00	0.84	0.74	0.70	0.68	0.65	0.64	0.53	0.46	0.48	0.44	0.30	0.30
		MAG+5	1.00	0.86	0.64	0.70	0.63	0.63	0.64	0.49	0.43	0.49	0.43	0.31	0.29
		MAG+6	1.00	0.88	0.58	0.70	0.59	0.61	0.65	0.46	0.41	0.49	0.42	0.32	0.29
Optimized Sub-Exposure Time SNR	Bright O-III Nebula	MAG+2.9	1.00	1.14	2.39	2.10	5.03	3.51	2.73	8.24	9.34	4.81	8.49	10.55	14.95
		MAG+4	1.00	1.23	1.85	2.31	4.16	2.83	2.67	6.57	6.69	4.35	7.35	8.13	12.37
		MAG+5	1.00	1.30	1.26	2.39	3.49	2.66	2.81	5.37	5.66	4.57	7.25	8.26	11.65
		MAG+6	1.00	1.45	0.80	2.54	2.71	2.42	3.10	4.06	4.45	5.06	7.19	8.72	10.87
	Faint Halpha Nebula	MAG+2.9	1.00	1.14	5.13	2.01	4.69	2.84	2.57	7.18	6.70	3.68	7.68	7.60	10.94
		MAG+4	1.00	1.24	3.98	2.22	3.92	2.30	2.53	5.84	4.89	3.38	6.82	6.01	9.47
		MAG+5	1.00	1.32	2.70	2.33	3.35	2.20	2.72	4.94	4.30	3.69	7.15	6.59	9.87
		MAG+6	1.00	1.48	1.70	2.55	2.65	2.04	3.13	3.86	3.52	4.42	7.86	7.99	10.70
	Galaxy	MAG+2.9	1.00	0.79	3.41	0.88	2.15	1.44	1.00	2.11	1.90	0.94	1.27	0.96	1.25
		MAG+4	1.00	0.86	2.63	0.98	1.80	1.16	0.98	1.72	1.39	0.87	1.13	0.76	1.09
		MAG+5	1.00	0.91	1.79	1.03	1.54	1.11	1.05	1.46	1.22	0.95	1.20	0.84	1.15
		MAG+6	1.00	1.02	1.13	1.12	1.22	1.04	1.21	1.14	1.01	1.14	1.32	1.04	1.26
	Reflection Nebula	MAG+2.9	1.00	0.87	1.12	0.96	1.28	1.34	1.12	1.31	1.54	1.15	1.26	1.50	1.17
		MAG+4	1.00	0.94	0.87	1.06	1.07	1.08	1.11	1.06	1.12	1.06	1.13	1.18	1.02
		MAG+5	1.00	1.00	0.59	1.11	0.92	1.04	1.19	0.91	0.99	1.16	1.19	1.30	1.07
		MAG+6	1.00	1.12	0.37	1.22	0.73	0.97	1.37	0.71	0.82	1.39	1.32	1.59	1.18
	Comet	MAG+2.9	1.00	0.87	2.44	1.02	1.74	1.43	1.10	1.87	1.73	1.16	1.45	1.14	1.33
		MAG+4	1.00	0.95	1.84	1.11	1.44	1.17	1.08	1.50	1.28	1.07	1.27	0.92	1.15
		MAG+5	1.00	1.00	1.31	1.13	1.23	1.11	1.13	1.27	1.13	1.13	1.29	1.00	1.18
		MAG+6	1.00	1.08	0.94	1.19	1.04	1.05	1.22	1.06	0.98	1.26	1.34	1.15	1.23

Table 2 Predicted Filter Performance Summary – Contrast Increase & SNR

designed for observing comets are meant for visual use, or for imaging with a camera that has no IR response such as an unmodified DSLR. When the imaging system can sense IR, better contrast on comets can be achieved by focusing on the comet's IR emission instead of the Swan bands. This is at least what I predict using my analysis method. I have not had an opportunity to try imaging a comet under light polluted conditions to confirm that this is true in practice.

My two educated guesses at ideal filters did not perform as well as I had hoped. The Ideal #1 performs very well on all types of nebulae, including reflection nebulae for which it is the best performer of the filters analysed. It does not however perform well on galaxies nor comets since it does not pass IR. The Ideal #2 filter that has the IR pass band added performs better on galaxies and comets than Ideal #1, but not as well as the GNB.

Results - Imaging:
All image collection on a particular night was done within a two-hour time window. This process was repeated five times, each on a different deepsky target and/or evening as described above. Imaging results from the five sessions are provided below. The images presented are of the final stacks. All the images had their histograms adjusted in exactly the same way using Fitswork v4.47, a free FITS editing software, so that they provide as fair a visual comparison as possible.

Images from the first imaging session are shown in Figures 10 and 11. I did not yet have a sample of the GNB filter, which is why there is no image shown for that filter. The images from the first target on the second imaging session are shown in Figures 12 to 14, and the second target in Figures 15 and 16. Images from the third imaging session can be found in Figures 17 and 18, and finally images from the last imaging session are shown in Figures 19 and 20. In general, the differences visible between filters on the same target are very subtle, at least for the broad band emitting targets. The differences are more pronounced for the emission-type nebula targets. Only after close examination is it possible to identify features that are more prominent in one filter's image than another's. To be able to extract more quantitative observations it was required to do some image analysis using software tools.

Using the captured image data I was able to directly measure the contrast increase delivered by each filter, putting a number to what was already observed qualitatively from the images in Figures 10 through 20. This was accomplished by using AstroImageJ to measure the average luminance from two common areas in the images: a dark background area, and a uniformly illuminated area of the deepsky object. The particular areas used are illustrated in Figure 21 (red box for target, blue box for background), with these same areas used for all the images from the various filters. Measurements of luminance average and standard deviation were taken from the original unedited FITS files in each colour channel. Contrast increase was calculated from the measured luminance values using the following equations:

Measured Contrast = [measured object luminance – measured background luminance] ÷ measured background luminance

% Contrast Increase = [contrast w/filter – contrast w/out filter] ÷ contrast w/out filter x 100

Astro. IR Cut (200 x 1.5s)

IDAS LPS-D2 (125 x 2.5s)

Antlia Triband RGB Ultra (85 x 4s)

IDAS NB-1 (60 x 5s)

Figure 10 Jan. 10th Imaging Results – M42 + Running Man, Part 1

IDAS NBZ (30 x 10s)

Figure 11 Jan. 10th Imaging Results – M42 + Running Man, Part 2

No Filter (150 x 2s)

Astro. UV/IR Cut (100 x 3s)

Optolong Nightsky Halpha (59 x 5.3s)

Astro. UHC (55 x 5.5s)

Figure 12 Feb. 24th Imaging Results A – Flame + Horsehead, Part 1

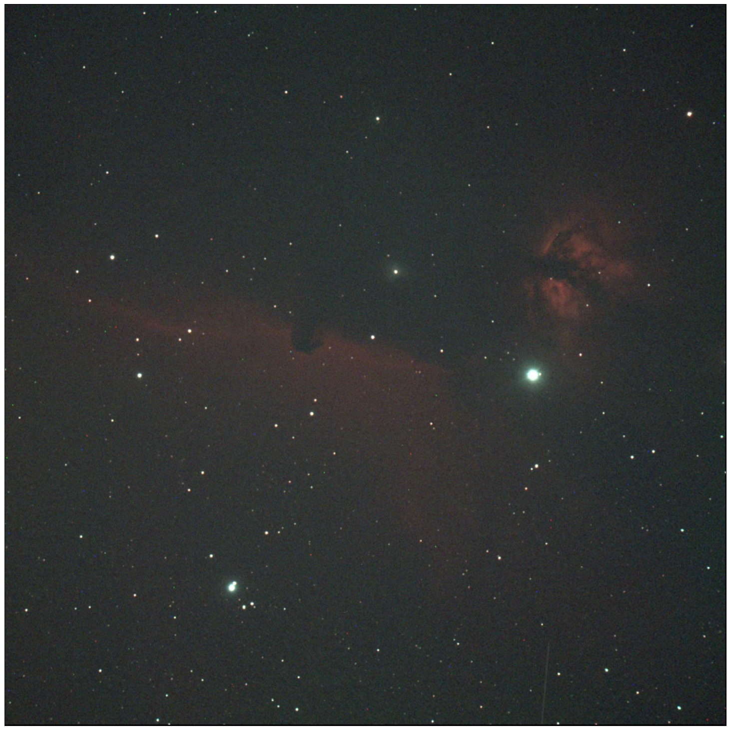
IDAS LPS-D2 (50 x 6s)

Antlia Triband RGB Ultra (60 x 5s)

IDAS GNB (30 x 10s)

IDAS NB-1 (19 x 16.3s)

Figure 13 Feb. 24th Imaging Results A – Flame + Horsehead, Part 2



IDAS NBZ (10 x 30s)

Figure 14 Feb. 24th Imaging Results A – Flame + Horsehead, Part 3

No Filter (150 x 2s)

Astro. UV/IR Cut (100 x 3s)

Optolong Nightsky Halpha (61 x 5.3s)

Astro. UHC (58 x 5.5s)

IDAS LPS-D2 (56 x 6s)

Antlia Triband RGB Ultra (31 x 10s)

Figure 15 Feb. 24th Imaging Results B – Leo Trio, Part 1

IDAS GNB (30 x 10s)

IDAS NB-1 (21 x 16.3s)

IDAS NBZ (12 x 30s)

Figure 16 Feb. 24th Imaging Results B – Leo Trio, Part 2

No Filter (150 x 2s)

Astro. UV/IR Cut (100 x 3s)

Optolong Nightsky Halpha (58 x 5.3s)

Astro. UHC (56 x 5.5s)

IDAS LPS-D2 (52 x 6s)

Antlia Triband RGB Ultra (30 x 10s)

Figure 17 Mar. 28th Imaging Results – M51, Part 1

IDAS GNB (30 x 10s)

IDAS NB-1 (19 x 16.3s)

IDAS NBZ (10 x 30s)

Figure 18 Mar. 28th Imaging Results – M51, Part 2

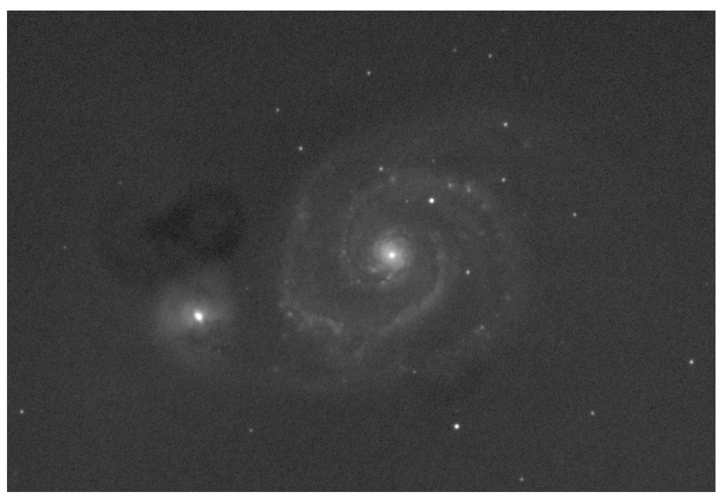
No Filter (60 x 10s)

Astro. UV/IR Cut (60 x 10s)

Optolong Nightsky Halpha (20 x 30s)

Astro. UHC (20 x 30s)

IDAS LPS-D2 (20 x 30s)



Antlia Triband RGB Ultra (20 x 30s)

Figure 19 Apr. 7th Imaging Results – M51, Part 1

IDAS GNB (20 x 30s)

IDAS NB-1 (20 x 30s)

IDAS NBZ (20 x 30s)

Figure 20 Apr. 7th Imaging Results – M51, Part 2

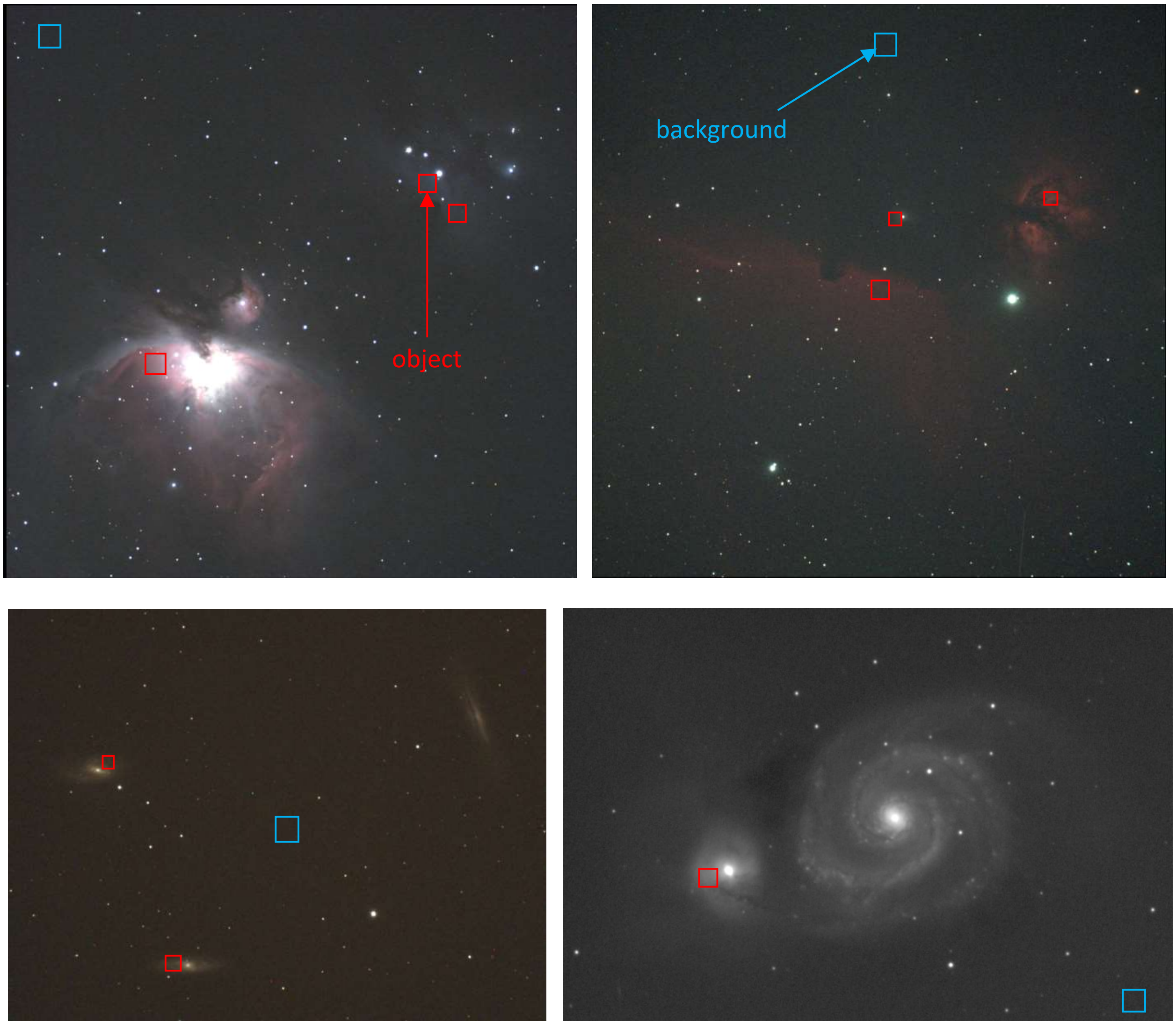


Figure 21 Areas Used for Image Analyses

The resulting contrast increase measurements are plotted in Figure 22, along with the corresponding prediction for each filter. The absolute value of the measurements vary significantly when compared to each other and to the predicted values. This variation is due to the target brightness and observing conditions not being the same between points. Despite these differences, the trend in relative performance from one filter to the other matches the prediction very well.

The measurements of luminance from the images also allowed me to evaluate signal-to-noise ratio (SNR). When I extracted the average luminance values from each image in AstroImageJ, I also recorded the standard deviation (σ). This allowed me to calculate the SNR achieved by each filter using the following equation:

SNR = (measured object luminance – measured background luminance) ÷ measured object σ

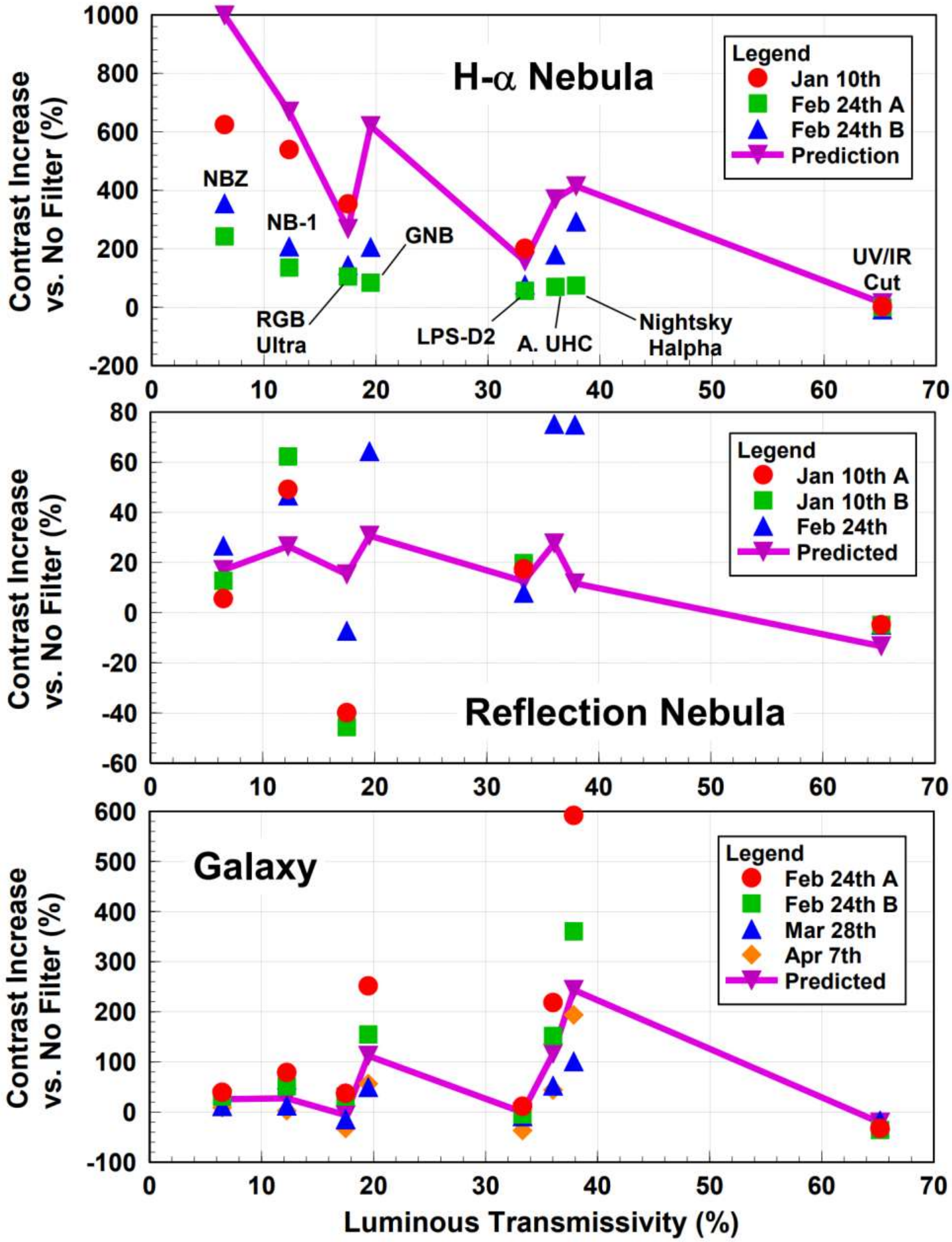


Figure 22 Measured Object Contrast Increase vs. Predicted

The results have been normalized so that the "no-filter" case has a value of 1.0. Thus, values of SNR greater than 1 indicate that adding the filter increased SNR, the same convention as used in the previous section. The resulting plots are provided in Figure 23, for the case of the same exposure time for all filters. As with the contrast increase measurement, the measured SNR shows a significant amount of scatter due to the variation in observing conditions and target brightness. For the H-α rich nebula and galaxy images, the trend in the measured SNR values matches the prediction very well. For the reflection nebula images however, the alignment between measured and predicted values is not as good, with the measured SNR values being consistently higher than what was predicted. However, the measured trend does still align reasonably well with the predicted trend.

Finally, the measurement of luminance from the images allowed me to calculate the impact of each filter on exposure time. Table 3 summarizes the relative exposures (i.e. overall image brightness) in each colour channel relative to the no-filter case, averaged from the various imaging sessions. Also shown in the table is the %LT of each filter, as calculated from my spectrometer data. For the most part there is good alignment between the relative Luminance (L) exposure and the calculated value of %LT. The exception seems to be all of the filters tested that pass a significant amount of IR, which had measured relative exposures on the order of ½ the corresponding %LT value. This discrepancy between measurements and predictions is a side-effect of my local night time sky having significantly less infrared emission than visible light, a characteristic that is already accounted for in my filter performance predictions. The calculation of %LT however assumes equal luminance at all wavelengths, from 200 to 1200nm.

Filter	Relative Exposure				%LT
	R	G	B	L	
No Filter	100	100	100	100	100
Astronomik IR Cut	82.8±1.9	88.8±0.4	86.5±0.5	86.7±5.0	65.2
Optolong Nightsky H-α	30.7±3.2	6.2±1.9	4.8±2.0	14.0±2.6	37.9
Astronomik UHC	18.1±2.6	13.7±1.9	13.8±1.9	16.3±2.1	36.0
IDAS LPS-D2	13.9±0.9	41.7±2.1	38.0±2.1	34.4±3.2	33.3
IDAS GNB	8.8±1.9	11.1±2.0	10.2±2.0	10.5±1.2	19.5
Antlia Triband RGB Ultra	8.5±0.9	13.3±1.3	38.8±3.1	19.2±2.1	17.5
IDAS NB-1	6.2±0.7	11.9±1.2	9.8±0.9	8.8±2.2	12.3
IDAS NBZ	4.1±0.5	5.9±0.7	4.6±0.5	5.0±0.6	6.5

Table 3 Measured Image Relative Exposure (%)

Another observation to note from the measured relative exposure values in Table 3 is the disparity for some filters between colour channels. Most notable are: the Nightsky H-α, LPS-D2, and RGB Ultra. These filters were found to have relative exposure values that varied widely between colour channels. This filter property makes it more difficult to select a sub-exposure time that properly exposes the fainter channels without overexposing the brighter channels. It also makes white balancing images captured with those filters more difficult.

In light of the good alignment between my measured and predicted values of contrast increase, SNR, and exposure time, the filter recommendations drawn from predictions in the previous section are still valid.

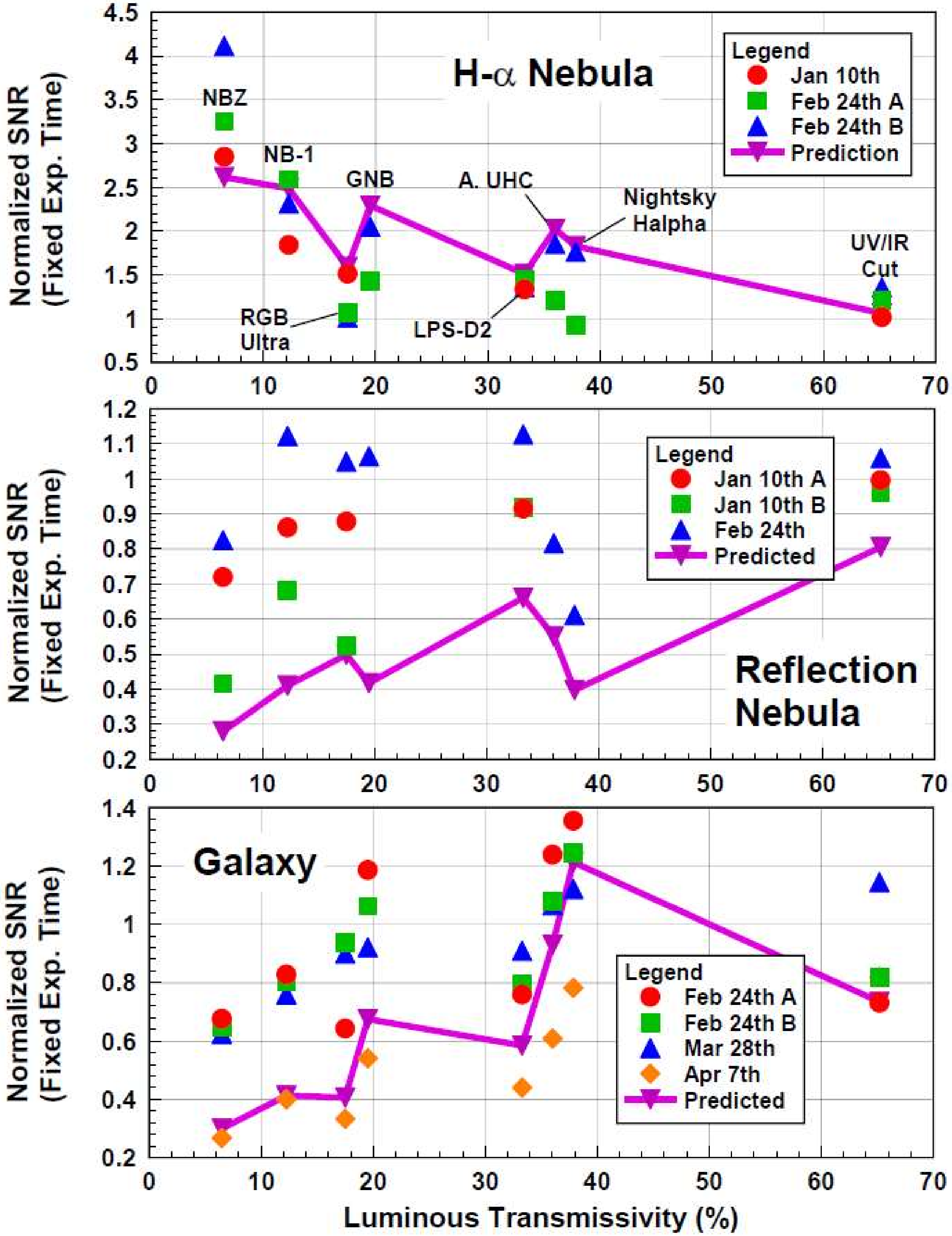


Figure 23 Measured Object SNR vs. Predicted, Fixed Exposure Time

Conclusions:
Based on the results of the testing described above, I have made the following conclusions:

1. Amateur astronomers desire a filter that can improve their view of all types of objects, from emission nebulae to galaxies to comets. The filter characteristics required to produce good performance on one type of object are not the same, and often counter to, those required for another object type. This reality makes it impossible to design a filter that has excellent performance on all object types. The best that can be achieved is one of three outcomes: 1) a filter that is excellent on one object type but poor on the other types, 2) a filter that has equally mediocre performance on all object types, and 3) a filter that is a compromise somewhere between 1) and 2) with good performance on some object types and mediocre performance on others.
2. The beneficial impact that a filter can have on object contrast and SNR varies significantly in magnitude depending on the object type. On emission-type nebulae filters have the potential to produce a very large impact, but on broadband emitters like galaxies or comets the potential impact is on the order of 1/10th as large. Reflection nebulae are the object type that is the least affected by adding a filter, with the beneficial impact being on the order of 1/50th of what can be achieved on emission-type nebulae; arguably an insignificant impact.
3. My analysis predicts that filters passing infrared work the best on comets when imaging from a light polluted location. Imaging data needs to be collected before this behaviour can be confirmed.
4. The Antlia Triband RGB Ultra filter did not demonstrate performance (i.e. contrast increase & SNR) that was significantly better than any of the other existing filters considered in this test. The filter was also difficult to white balance due to the large disparity in relative exposure between colour channels.
5. Based on the results of the testing summarized in this report, the filter that delivers the best compromise in performance on all object types is the IDAS GNB.

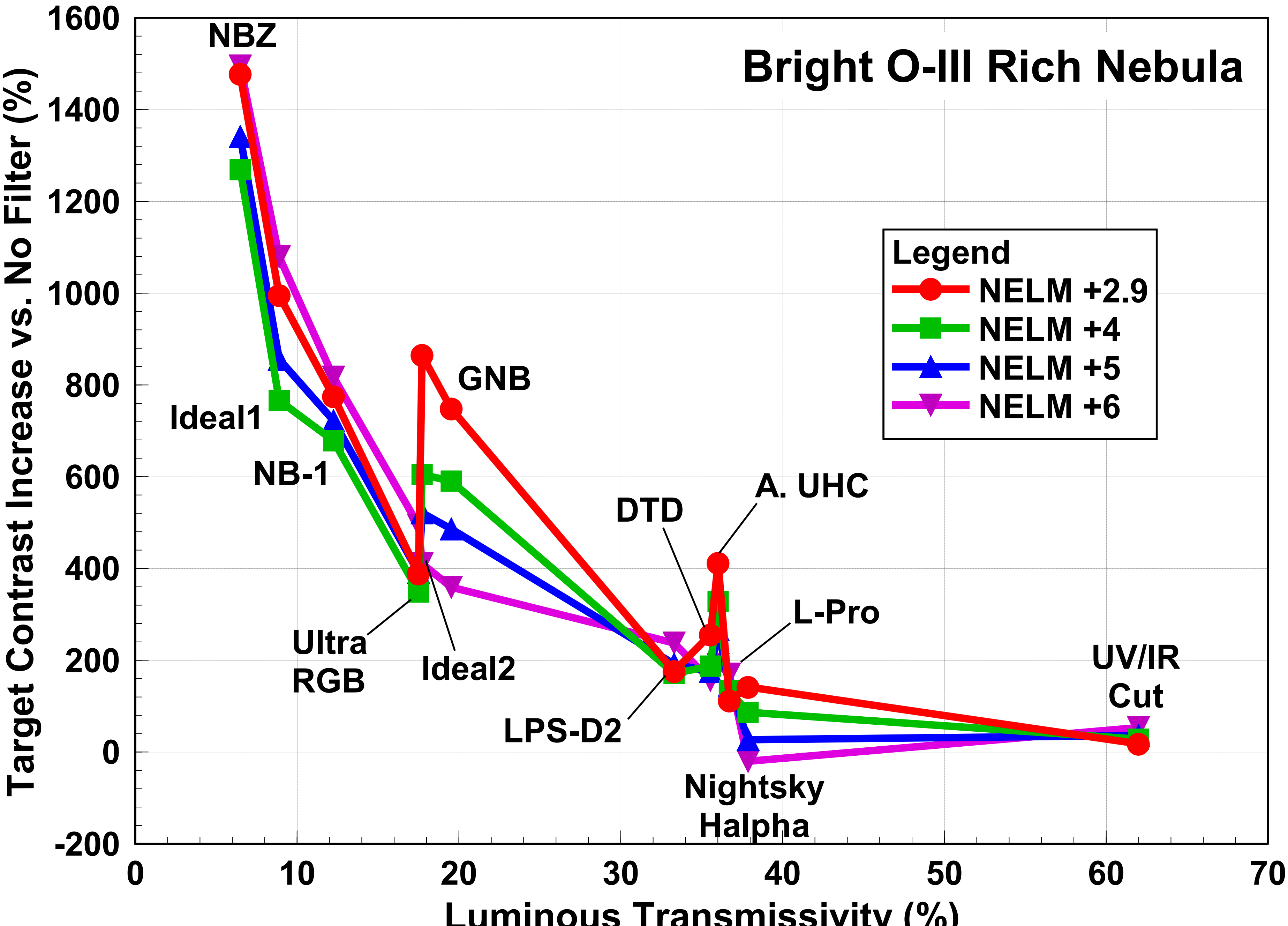
If you have any questions, please feel free to contact me.

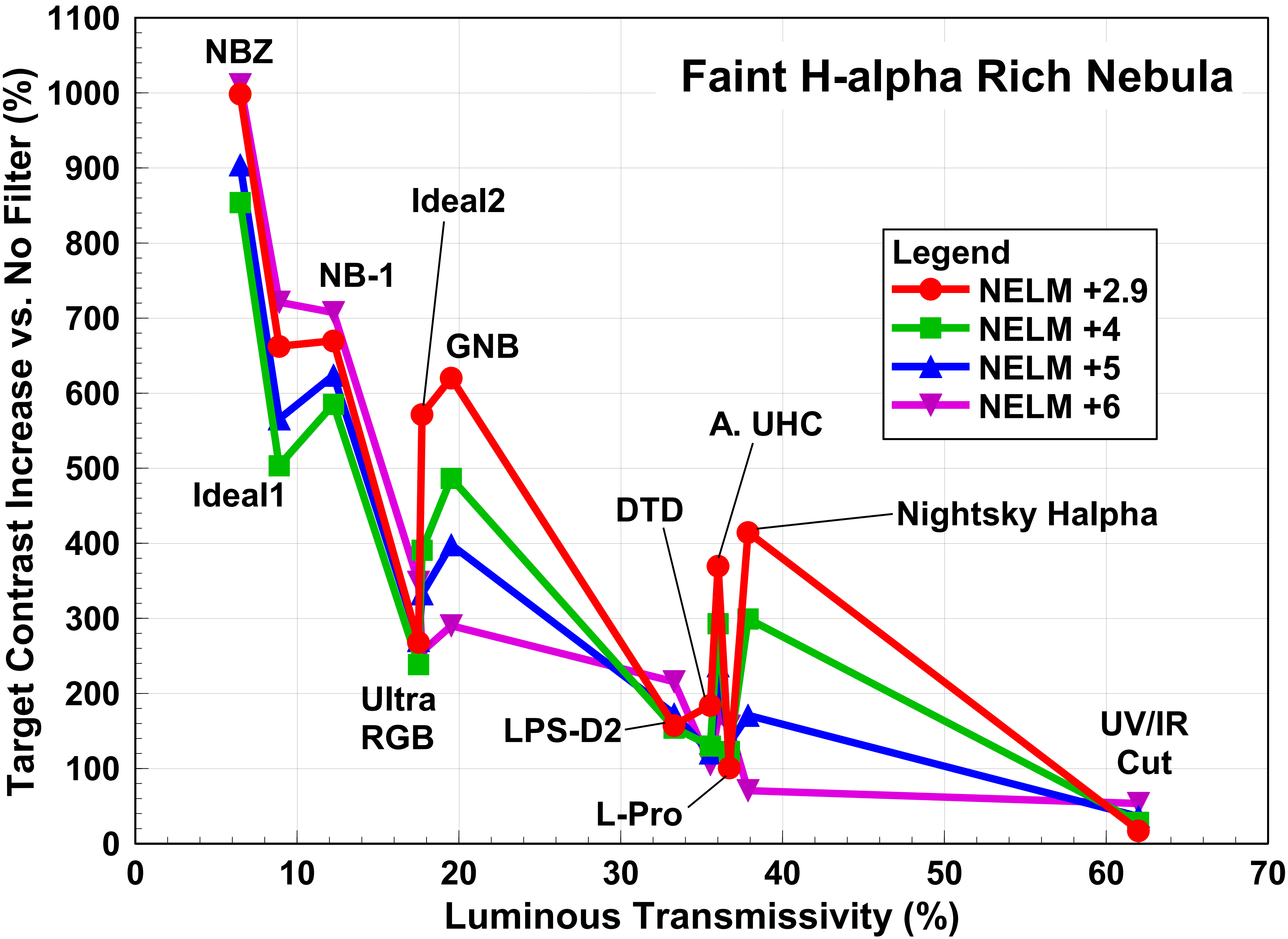
Cheers!

Jim Thompson
(top-jimmy@rogers.com)

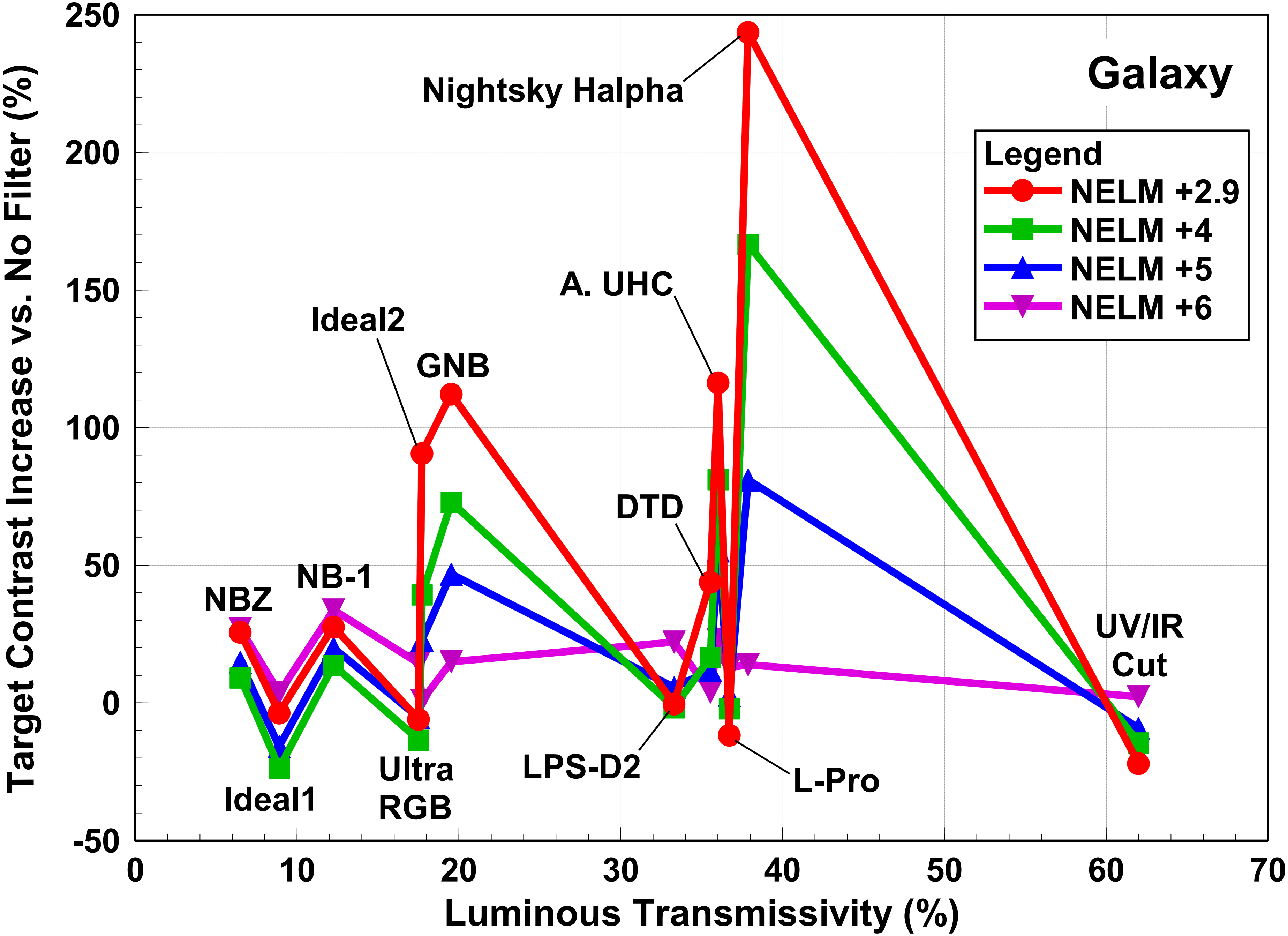
Appendix A

Predicted Performance Comparison Plots

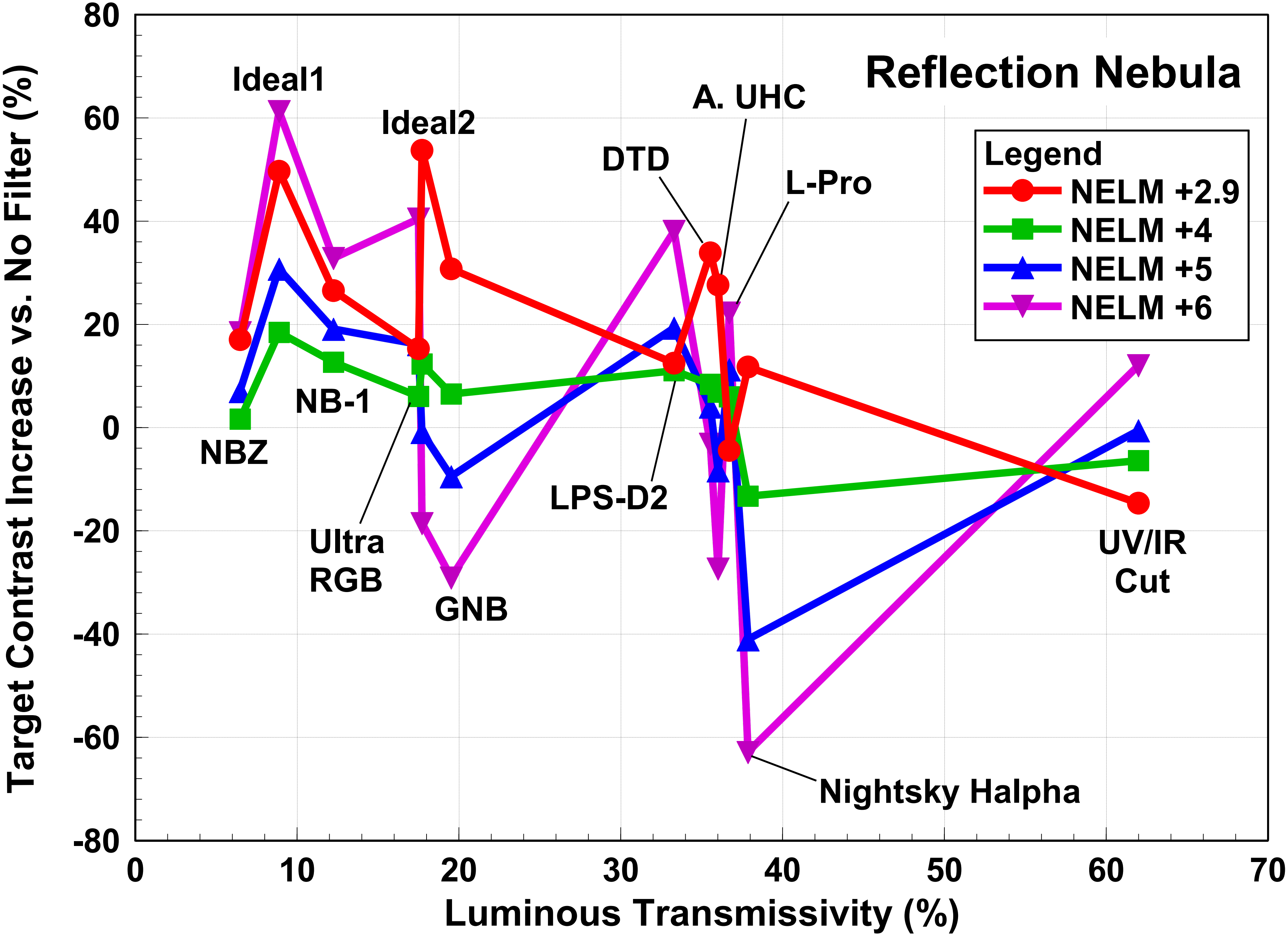

Bright O-III Rich Nebula
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
NBZ
Ideal1
NB-1
Ultra RGB
Ideal2
GNB
DTD
A. UHC
L-Pro
LPS-D2
Nightsky Halpha
UV/IR Cut
Target Contrast Increase vs. No Filter (%)
Luminous Transmissivity (%)
1600
1400
1200
1000
800
600
400
200
0
-200
0
10
20
30
40
50
60
70

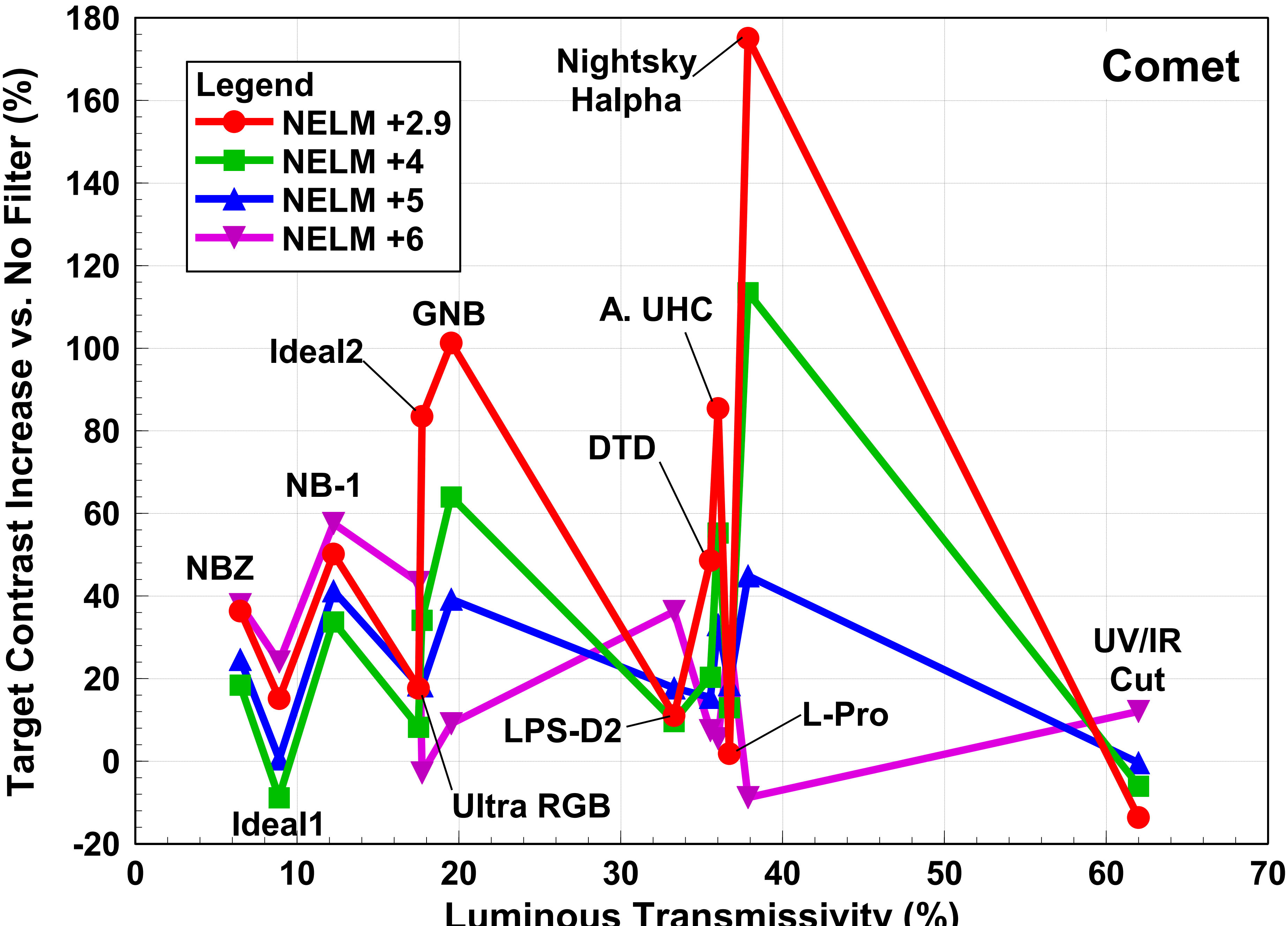


Faint H-alpha Rich Nebula
Target Contrast Increase vs. No Filter (%)
Luminous Transmissivity (%)
0
100
200
300
400
500
600
700
800
900
1000
1100
0
10
20
30
40
50
60
70
NBZ
Ideal1
NB-1
Ideal2
GNB
Ultra RGB
LPS-D2
DTD
A. UHC
L-Pro
Nightsky Halpha
UV/IR Cut
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6

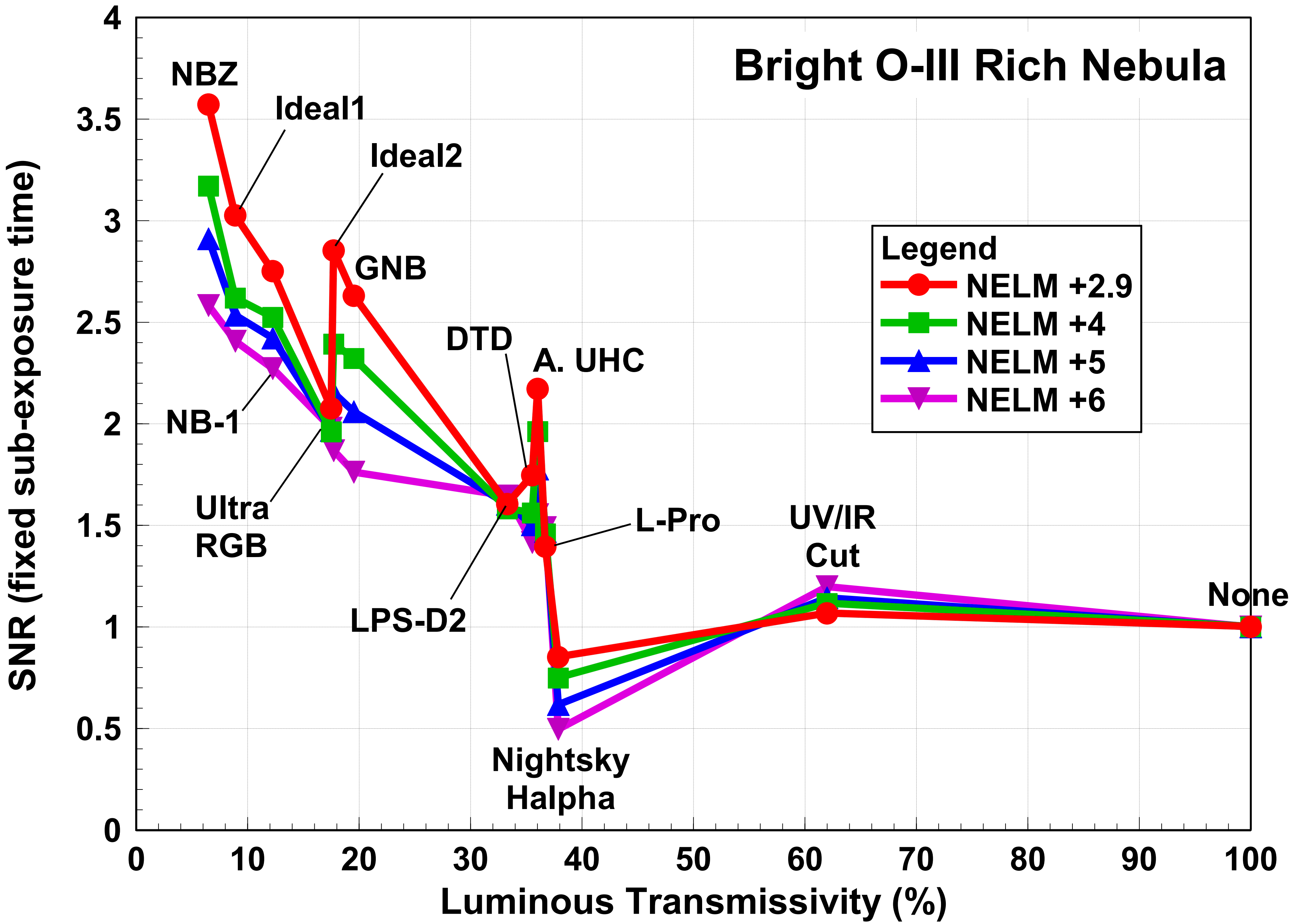


Galaxy
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
Nightsky Halpha
A. UHC
Ideal2
GNB
DTD
NB-1
NBZ
Ideal1
Ultra RGB
LPS-D2
L-Pro
UV/IR Cut
Target Contrast Increase vs. No Filter (%)
Luminous Transmissivity (%)
250
200
150
100
50
0
-50
0
10
20
30
40
50
60
70

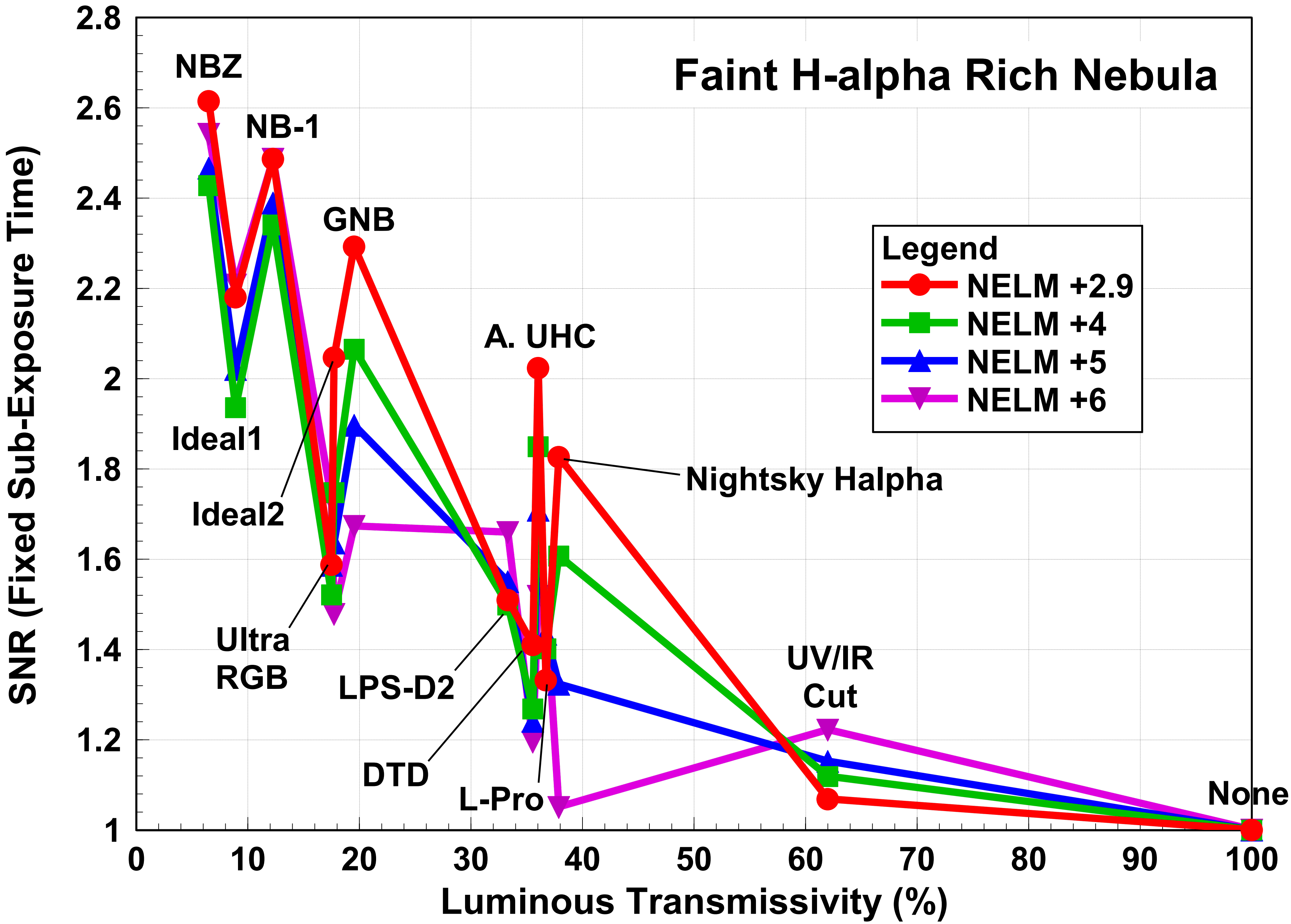

Reflection Nebula
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
Ideal1
Ideal2
DTD
A. UHC
L-Pro
NB-1
NBZ
Ultra
RGB
GNB
LPS-D2
UV/IR
Cut
Nightsky Halpha
Target Contrast Increase vs. No Filter (%)
Luminous Transmissivity (%)
80
60
40
20
0
-20
-40
-60
-80
0
10
20
30
40
50
60
70

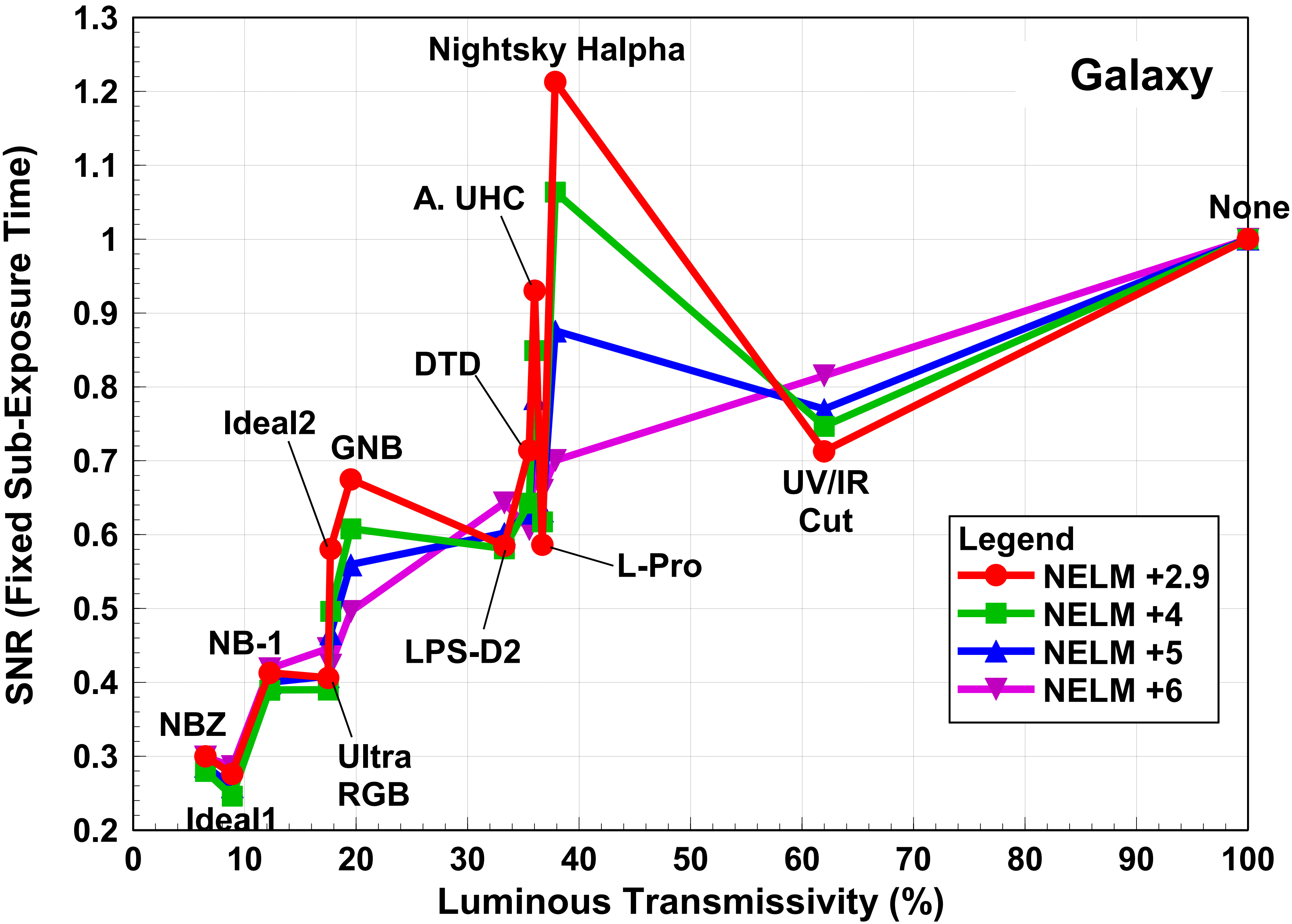


Comet
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
Nightsky Halpha
GNB
Ideal2
A. UHC
DTD
NB-1
NBZ
UV/IR Cut
L-Pro
LPS-D2
Ultra RGB
Ideal1
Target Contrast Increase vs. No Filter (%)
Luminous Transmissivity (%)
180
160
140
120
100
80
60
40
20
0
-20
0
10
20
30
40
50
60
70

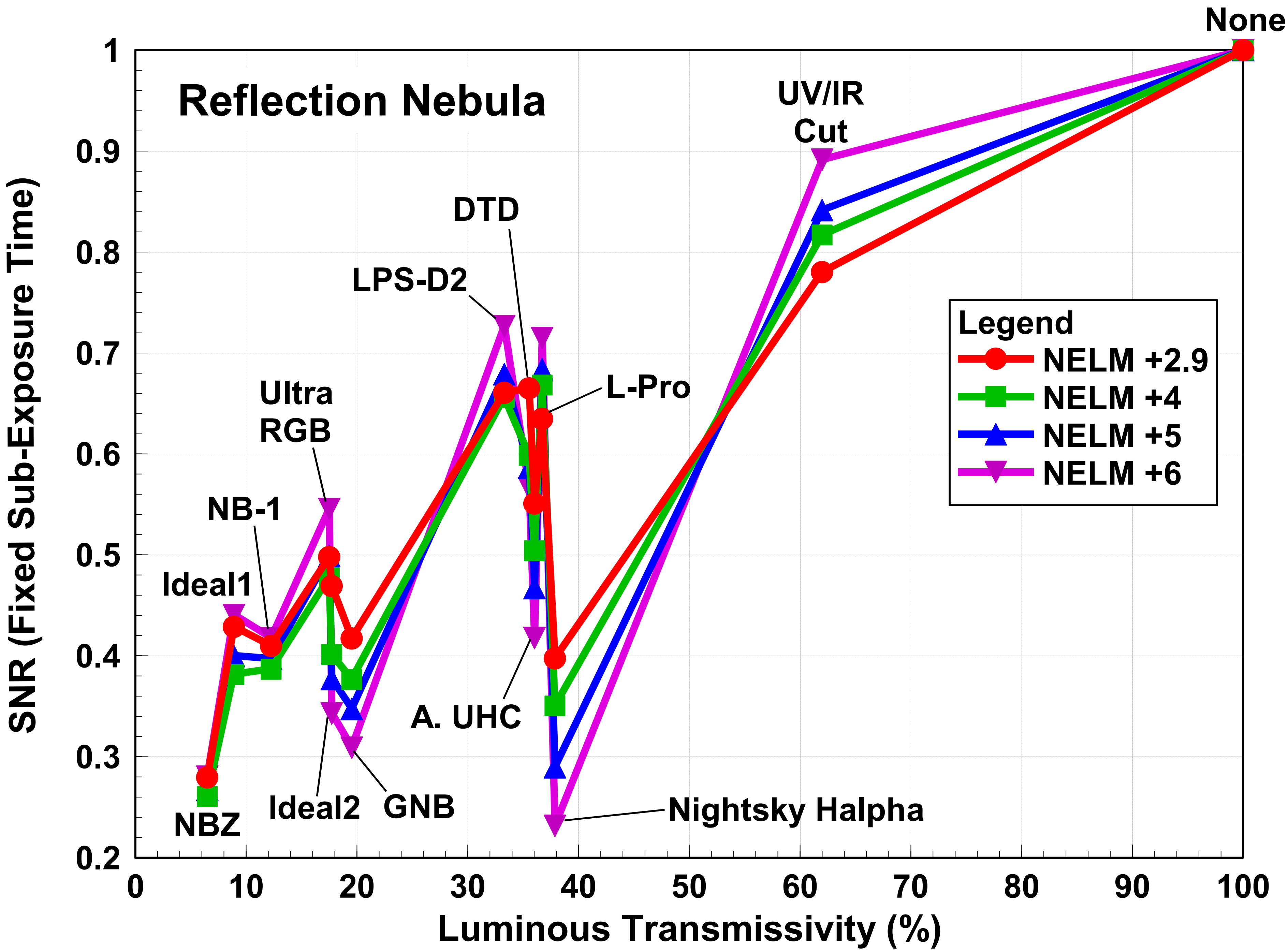


Bright O-III Rich Nebula
SNR (fixed sub-exposure time)
Luminous Transmissivity (%)
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
NBZ
Ideal1
Ideal2
GNB
NB-1
Ultra RGB
LPS-D2
DTD
A. UHC
L-Pro
Nightsky Halpha
UV/IR Cut
None
0
0.5
1
1.5
2
2.5
3
3.5
4
0
10
20
30
40
50
60
70
80
90
100

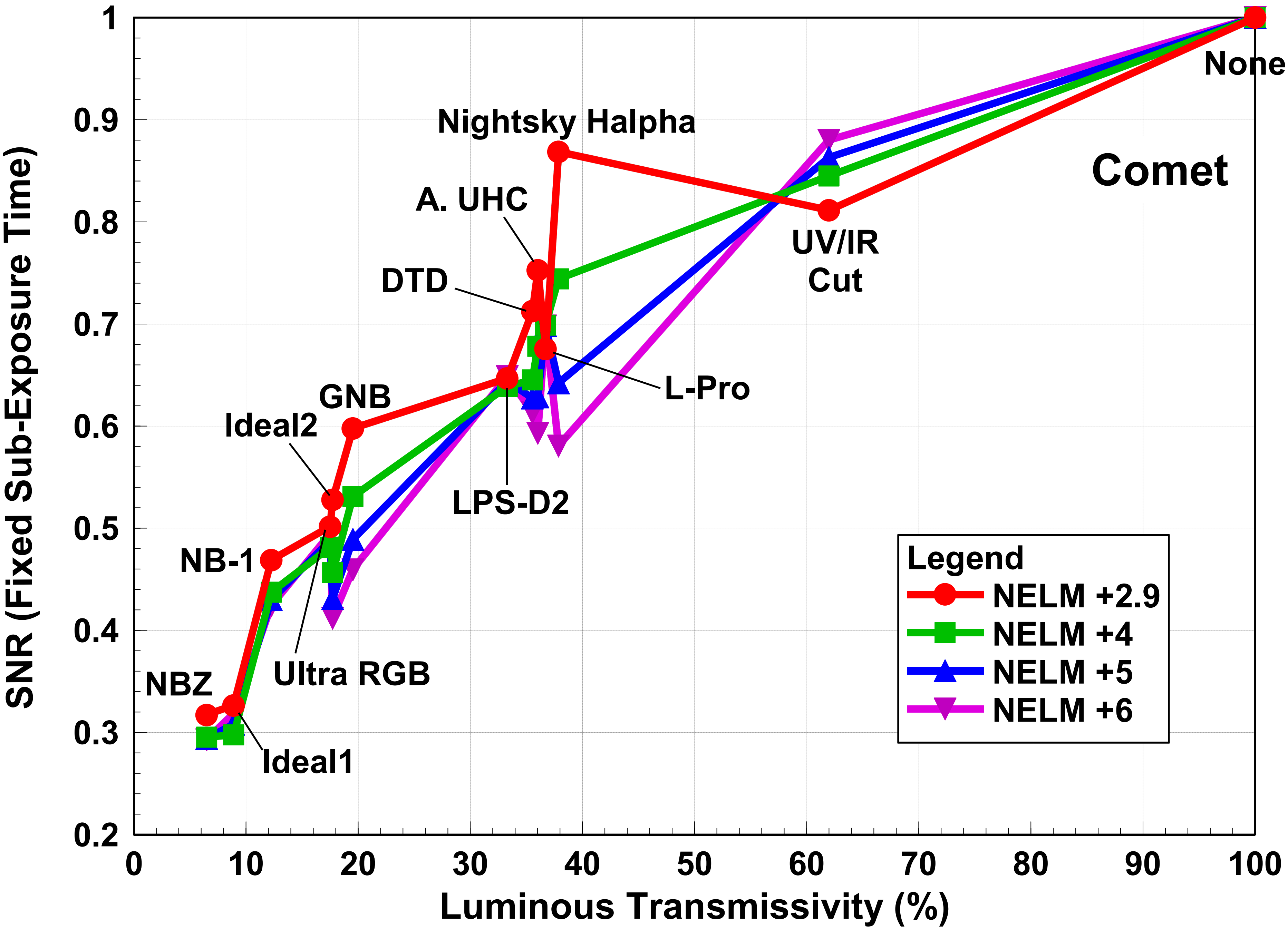

Faint H-alpha Rich Nebula
SNR (Fixed Sub-Exposure Time)
Luminous Transmissivity (%)
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
NBZ
NB-1
GNB
A. UHC
Ideal1
Ideal2
Ultra RGB
LPS-D2
DTD
L-Pro
Nightsky Halpha
UV/IR Cut
None
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
10
20
30
40
50
60
70
80
90
100



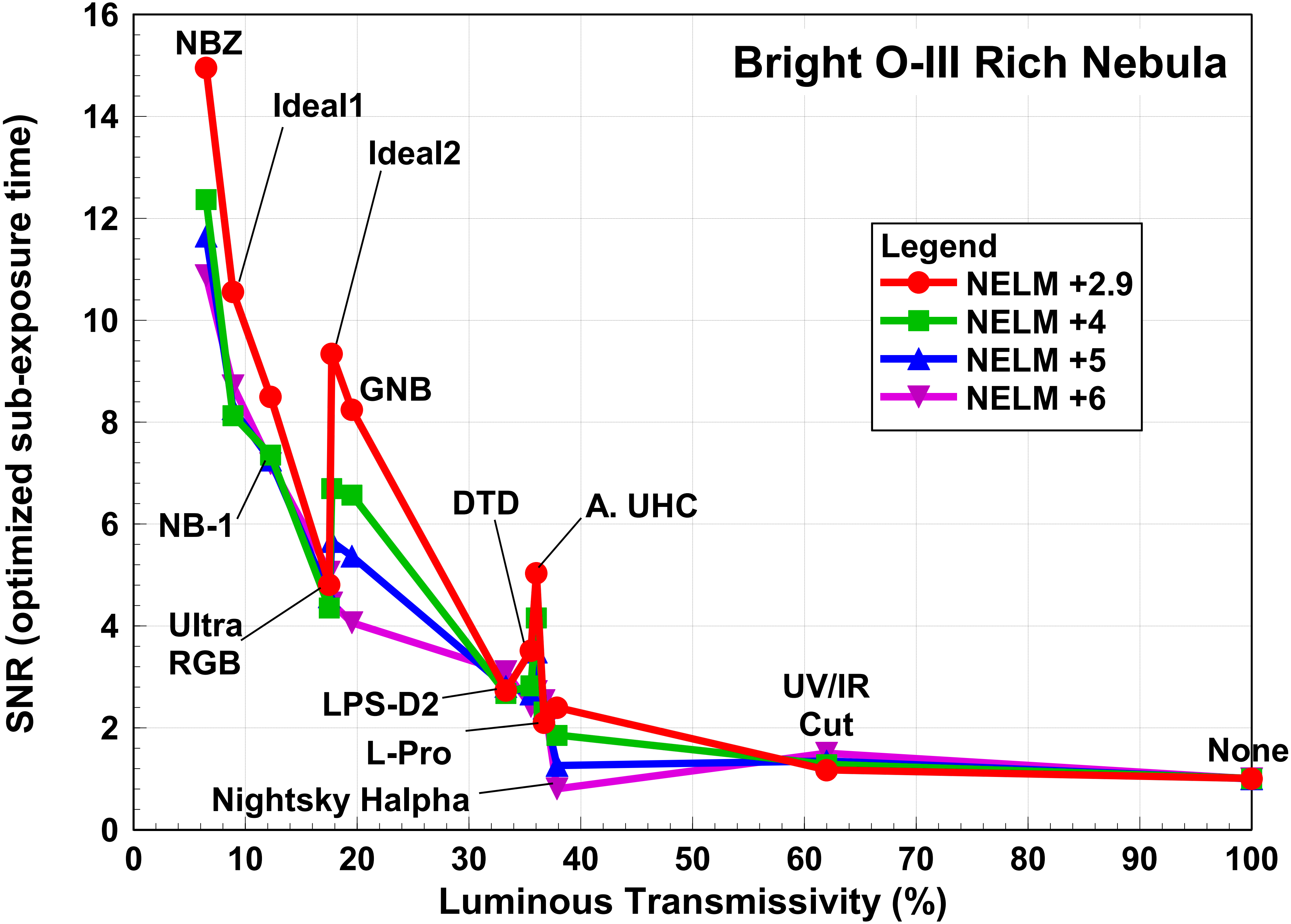
Galaxy
Nightsky Halpha
A. UHC
None
DTD
Ideal2
GNB
UV/IR
Cut
L-Pro
LPS-D2
NB-1
NBZ
Ultra
RGB
Ideal1
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
SNR (Fixed Sub-Exposure Time)
Luminous Transmissivity (%)
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
10
20
30
40
50
60
70
80
90
100



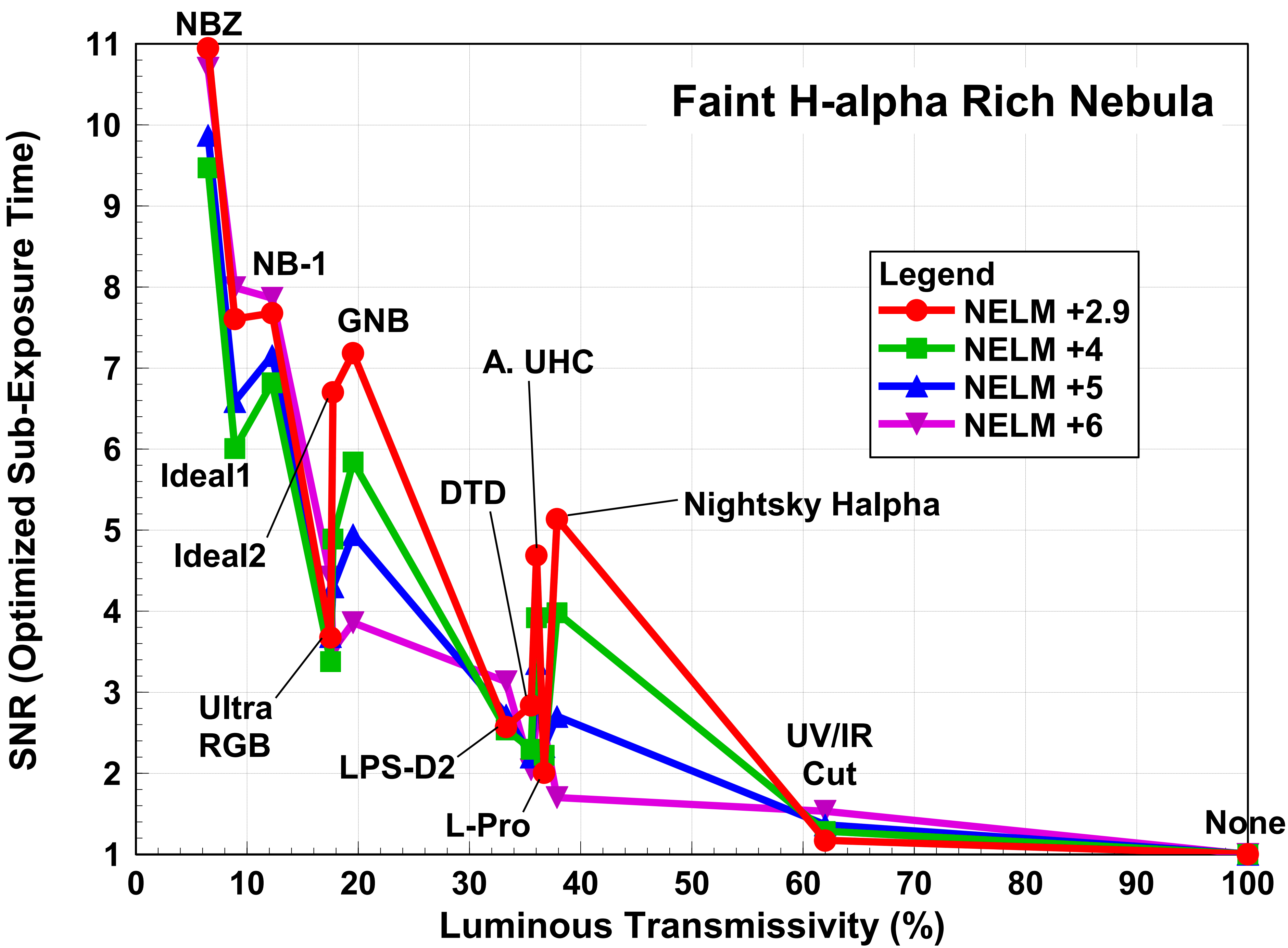
Reflection Nebula
None
UV/IR
Cut
DTD
LPS-D2
L-Pro
Ultra
RGB
NB-1
Ideal1
A. UHC
Ideal2
GNB
NBZ
Nightsky Halpha
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
SNR (Fixed Sub-Exposure Time)
Luminous Transmissivity (%)
0
10
20
30
40
50
60
70
80
90
100
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

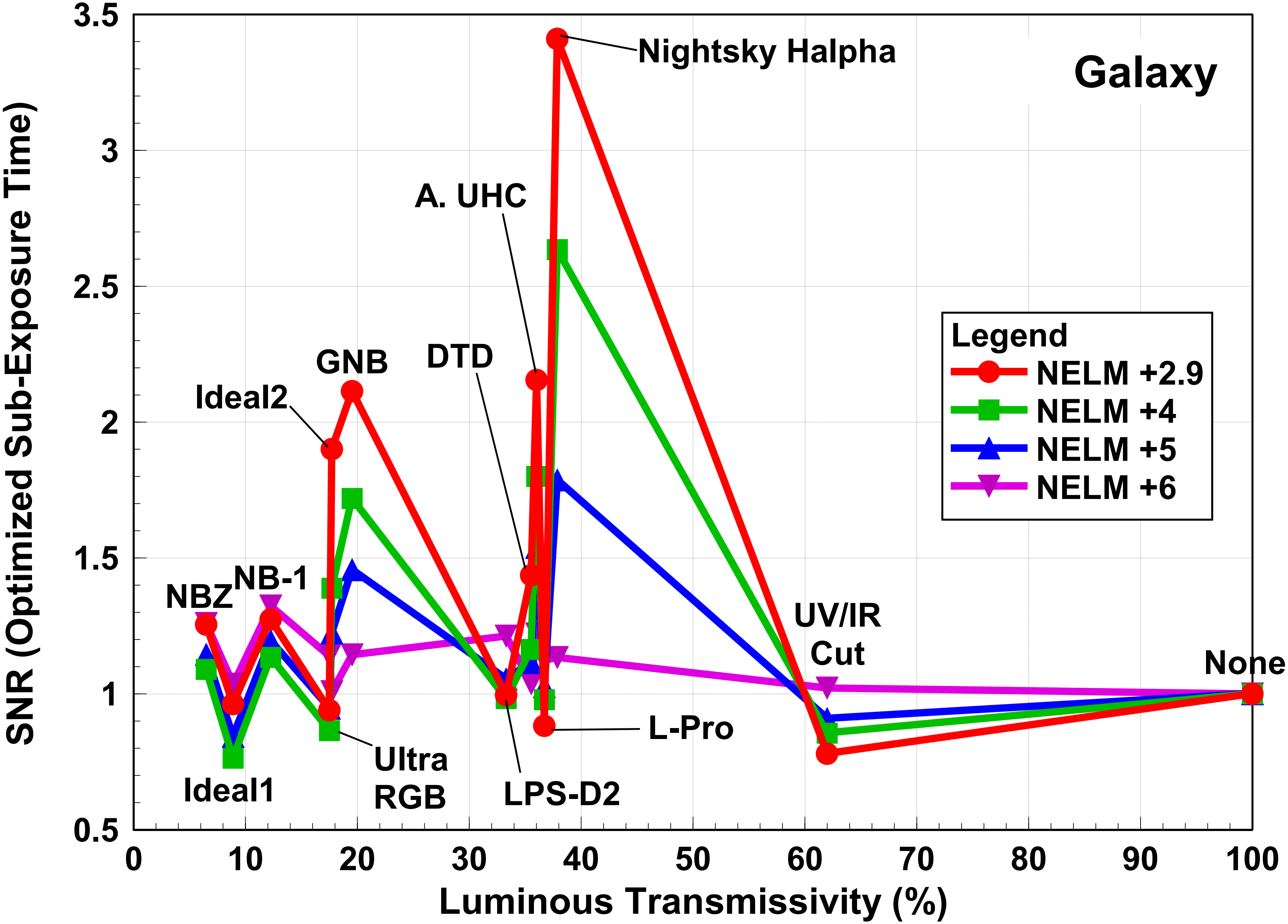


SNR (Fixed Sub-Exposure Time)
Luminous Transmissivity (%)
Comet
None
Nightsky Halpha
A. UHC
DTD
UV/IR
Cut
L-Pro
GNB
Ideal2
LPS-D2
NB-1
Ultra RGB
NBZ
Ideal1
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6

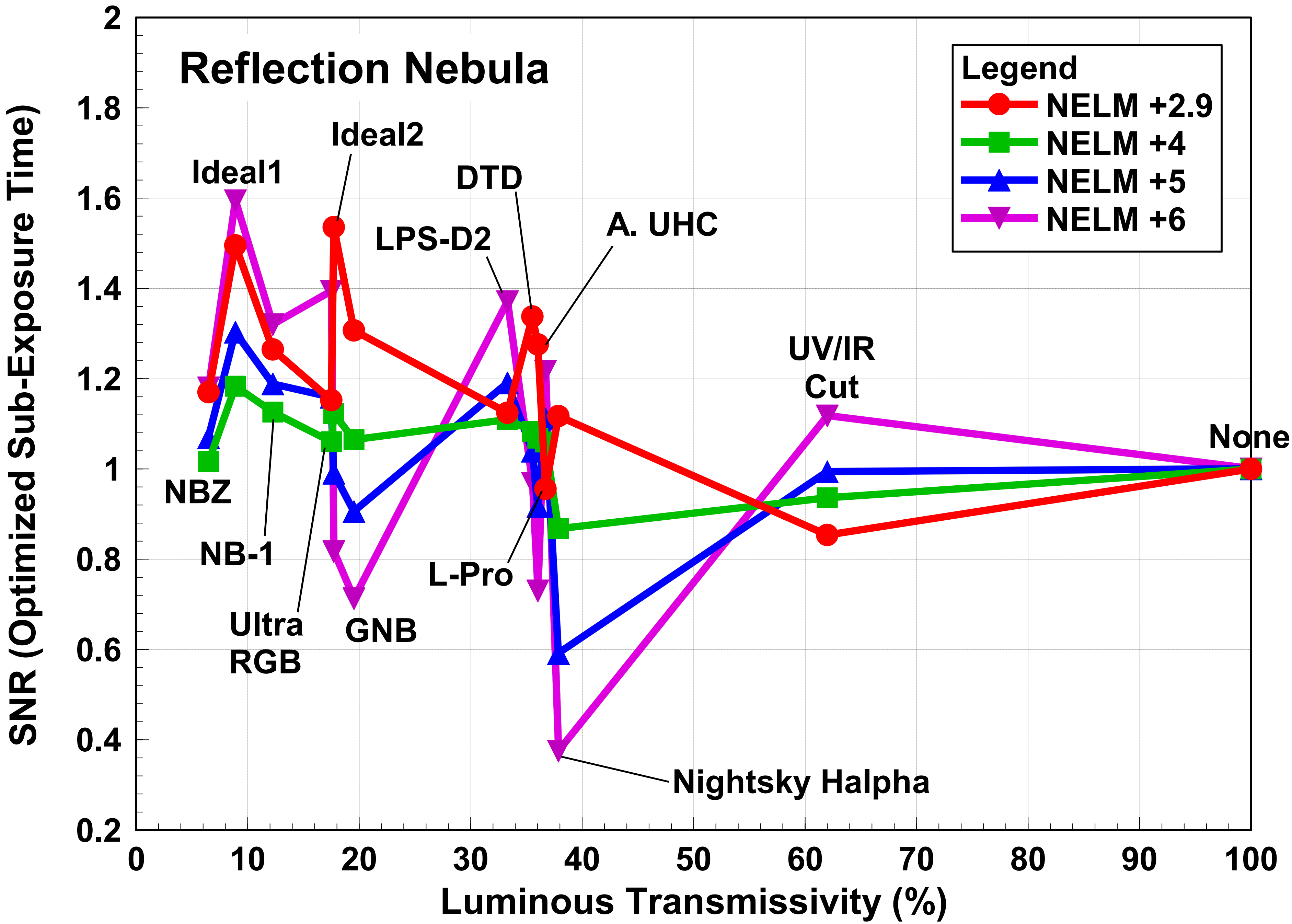


Bright O-III Rich Nebula
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
NBZ
Ideal1
Ideal2
GNB
NB-1
Ultra RGB
DTD
A. UHC
LPS-D2
L-Pro
Nightsky Halpha
UV/IR Cut
None
SNR (optimized sub-exposure time)
Luminous Transmissivity (%)
0
2
4
6
8
10
12
14
16
0
10
20
30
40
50
60
70
80
90
100

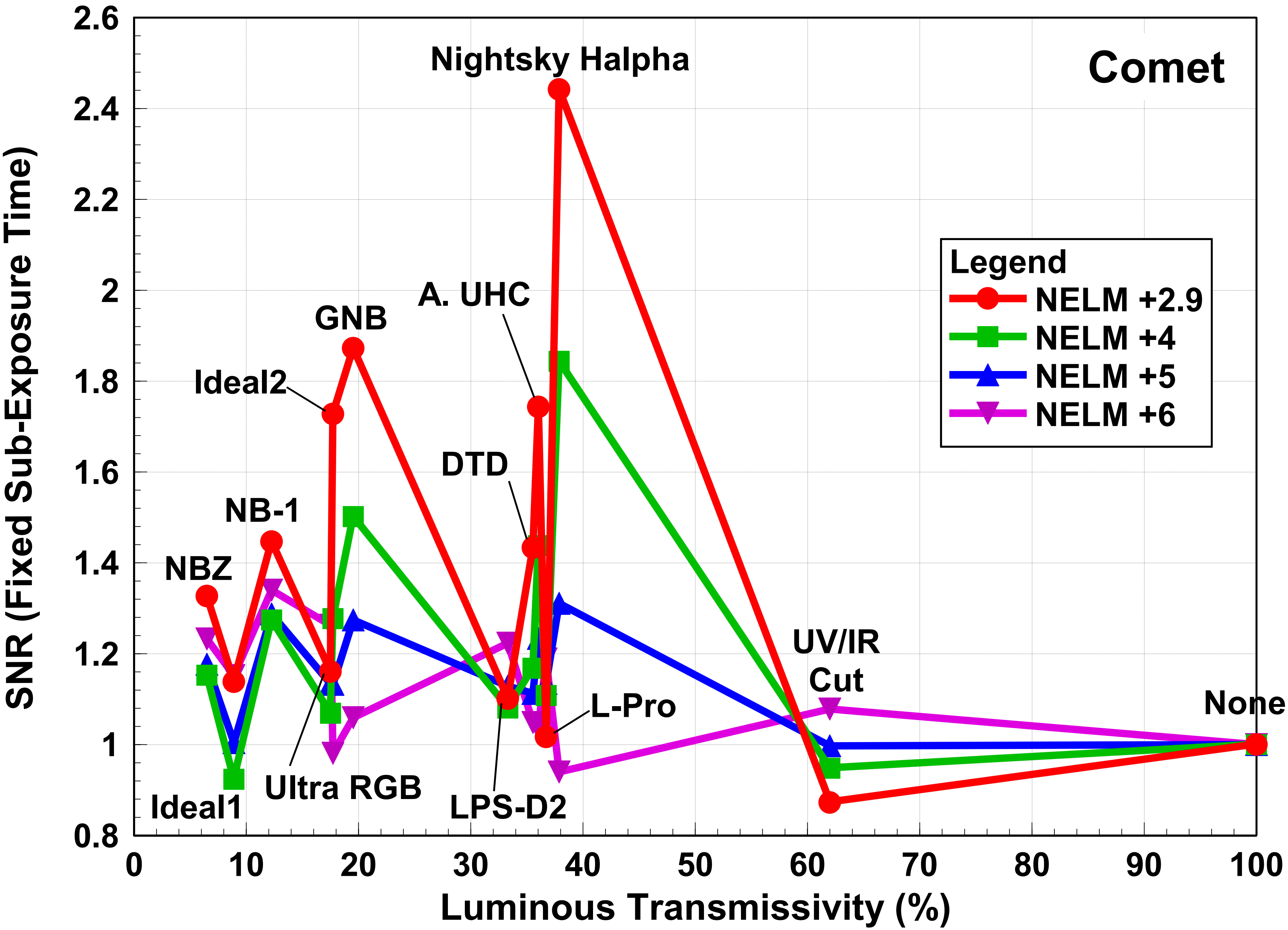

Faint H-alpha Rich Nebula
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
NBZ
NB-1
GNB
A. UHC
DTD
Nightsky Halpha
Ideal1
Ideal2
Ultra RGB
LPS-D2
L-Pro
UV/IR Cut
None
SNR (Optimized Sub-Exposure Time)
Luminous Transmissivity (%)
1
2
3
4
5
6
7
8
9
10
11
0
10
20
30
40
50
60
70
80
90
100



Galaxy
Nightsky Halpha
A. UHC
GNB
DTD
Ideal2
NBZ
NB-1
Ideal1
Ultra
RGB
LPS-D2
L-Pro
UV/IR
Cut
None
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
SNR (Optimized Sub-Exposure Time)
Luminous Transmissivity (%)
0.5
1
1.5
2
2.5
3
3.5
0
10
20
30
40
50
60
70
80
90
100



Reflection Nebula
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
Ideal1
Ideal2
DTD
A. UHC
LPS-D2
UV/IR
Cut
None
NBZ
NB-1
Ultra
RGB
GNB
L-Pro
Nightsky Halpha
SNR (Optimized Sub-Exposure Time)
Luminous Transmissivity (%)
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
10
20
30
40
50
60
70
80
90
100


Comet
Nightsky Halpha
A. UHC
GNB
Ideal2
DTD
NB-1
NBZ
UV/IR
Cut
None
L-Pro
Ultra RGB
LPS-D2
Ideal1
Legend
NELM +2.9
NELM +4
NELM +5
NELM +6
SNR (Fixed Sub-Exposure Time)
Luminous Transmissivity (%)
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
0
10
20
30
40
50
60
70
80
90
100