Filters and Galaxies for EAA – Rev. 1

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Test Report – May 28th, 2021

Introduction:

The first time I tried a filter on a galaxy was back in August 2011. It was not so much a coordinated test but more of a casual "let's try it and see what happens" kind of thing. Even then it was evident to me that there was merit in using a filter in conjunction with a camera when observing galaxies under light polluted skies. My position on the topic was solidified in the Spring of 2012 when I started to generate the first results from my newly developed method for predicting the performance of filters on different kinds of observing targets. My predictions confirmed what I had observed during my testing, that a filter which passes infrared can be effective at improving the contrast of a galaxy, with the largest contrast increase coming from using an infrared high-pass filter (see Figure 1).

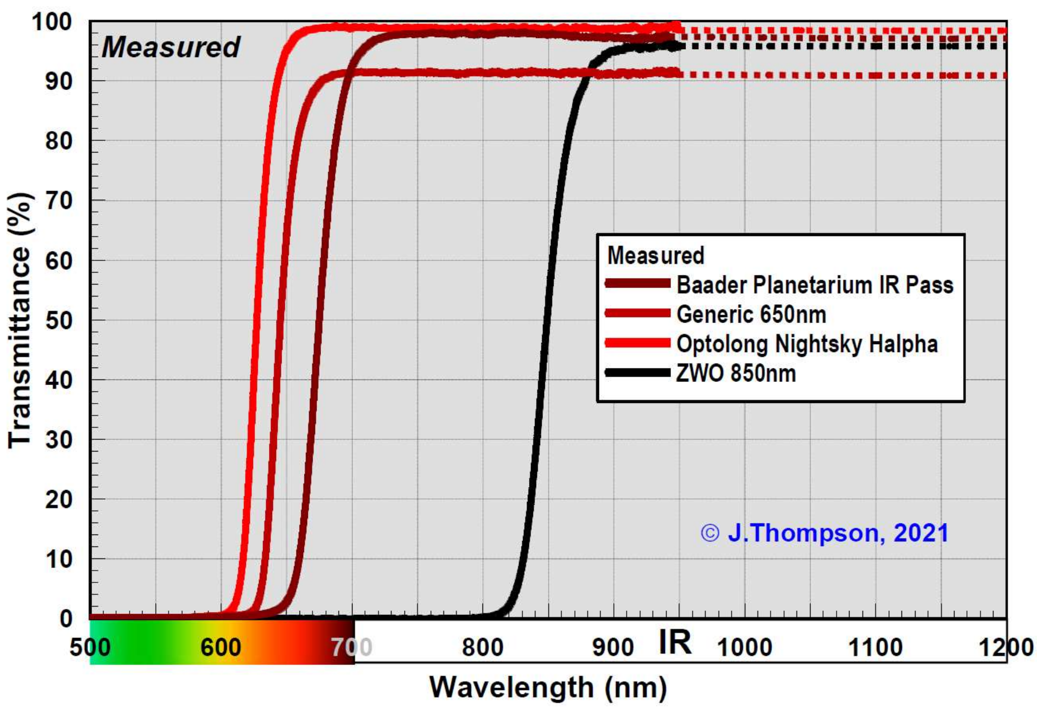

Figure 1 Spectral Response of Some Example Infrared High-Pass Filters

The major drawback of using filters on galaxies that I identified back in 2012 was that the camera exposure time had go way up. Back then my main camera for observing was a colour Mallincam Xtreme, a CCD-based analog astro-video camera which was the state-of-the-art at the time. Even with this very sensitive camera, the additional exposure time required when using an infrared high-pass filter on a galaxy was not practical for me. As a result I did not consider using such a filter as part of my normal observing setup, instead I used a milder more general purpose filter, the Astronomik UHC. The technology in cameras used for Electronically Assisted Astronomy (EAA) has evolved a lot since 2012, and the combination of very low read noise back illuminated CMOS sensors with live stacking has made possible many aspects of EAA that we would not have thought possible even five years ago. This fact has encouraged me to re-examine the question of what filters work best on galaxies, and how practical are these filters to use with today's equipment. My answer to these questions is what is described in this test report.

Objective:
The objective of this test is to compare, both by analysis and test, the performance of different commercially available light pollution filters on galaxies when used with a modern EAA camera. Specifically the filters to be tested are:

- Astronomik UHC *(passes IR)*
- Astronomik ProPlanet 642 *(passes IR)*
- Baader Planetarium IR Pass *(passes IR)*
- IDAS EAO1
- IDAS LPS-D2
- IDAS LPS-P2
- IDAS NBX
- Lumicon Deepsky *(passes IR)*
- Meade O-III *(passes IR)*
- Optolong Nightsky Halpha *(passes IR)*

The measured spectrums of the two IR high-pass filters being tested were already presented above in Figure 1. Figures 2 and 3 present the measured spectra for the remaining eight filters. Based on my past testing and analysis, I predicted that filters which pass infrared light (noted in italics above) would show an increase in contrast, and the others would not.

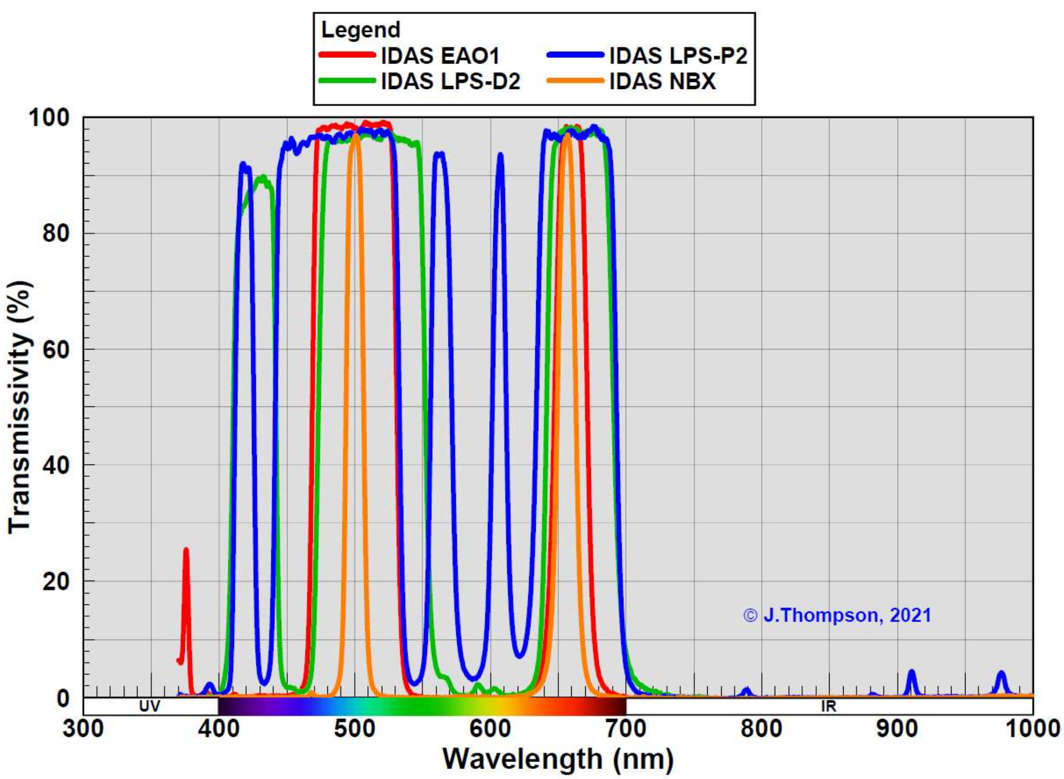

Figure 2 Spectral Response of IDAS Brand Filters Under Test

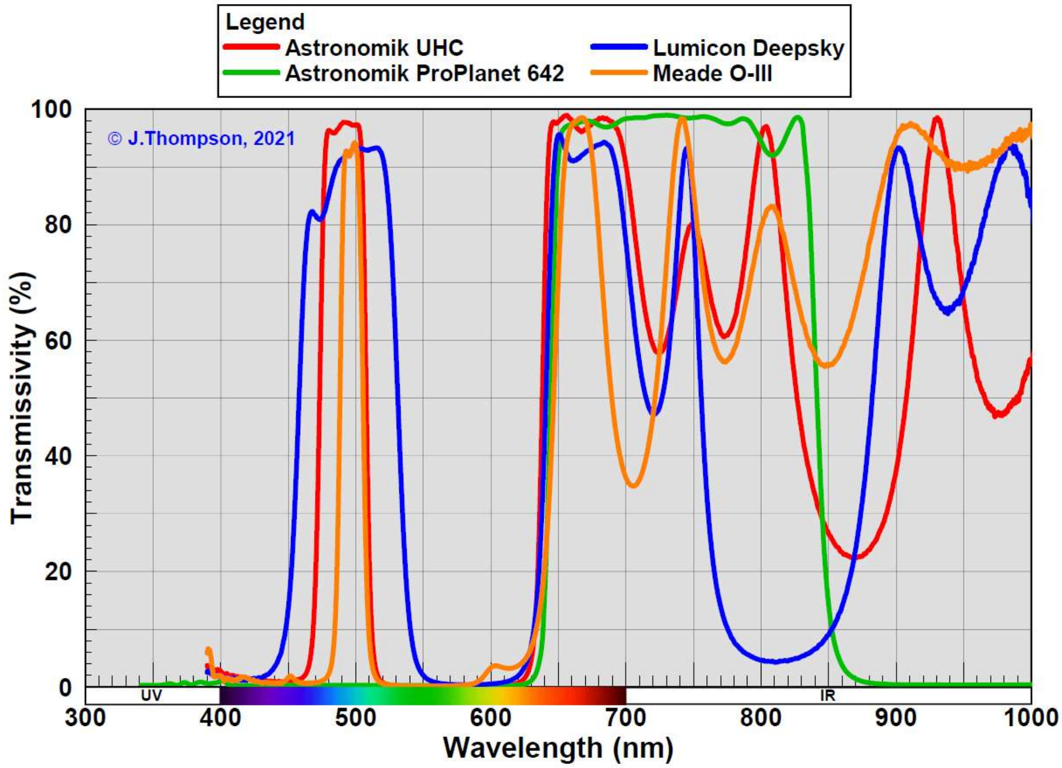

Figure 3 Spectral Response of Other Brand Filters Under Test

The EAA camera used to collect the image data is a Mallincam Skyraider DS432M-TEC. This thermoelectrically cooled monochrome camera is in my opinion the most sensitive currently available commercially.

Method:
The data used for my comparison was collected from two sources:

- Spectral transmissivity data, from near-UV to near-IR, measured using an Ocean Optics USB4000 spectrometer; and
- Image data, collected using a 10" Mallincam RC telescope at native f/8, and the DS432M-TEC camera mentioned above.

The spectrometer data was collected in my basement workshop with the USB4000 and a broad spectrum light source. To collect the data I recorded two back-to-back scans from each filter and calculated the average. In the event that the data varied by more than 0.1% between back-to-back scans, I rejected the data set and repeated the whole measurement again.

The image data was collected from my backyard in central Ottawa where the naked eye limiting magnitude (NELM) due to light pollution is +2.9 on average, which translates to Bortle 9+. I don't have a filter wheel, so to switch filter configurations I had to remove the camera from the focuser, and swap the filter manually. Each time I changed filters I would refocus on a conveniently located bright star using a Bahtinov mask. Images from all eleven filter configurations were collected on the same night, March 19th, 2021. Images are all live stacks of 15 x 20 second frames to give a total exposure time of 5 minutes. The exception is the "no filter" case, for which I had to use 30 x 10 second sub-exposures to get my 5 minutes as the images were too over exposed using 20 second exposures. The same deepsky target was used for all filters: M66, a fairly bright spiral galaxy in the constellation Leo.

Results – Predicted Performance:
The measured spectrum for each filter was used as input into my filter performance prediction method. By knowing the spectral response of the filter and camera, as well as the spectral emission from the deepsky object plus light polluted sky, it is possible to calculate the magnitude of the total light being received by the camera sensor with and without a filter. This information can then be used to calculate performance metrics such as signal-to-noise ratio (SNR) or percent change in contrast. Figure 4 presents a summary of my calculations, in this case SNR for each filter plotted against percent luminous transmissivity (%LT), a measure of generally how much light is getting through the filter as perceived by the camera. There are two distinct groups of points on the graph: filters that don't pass IR (in blue), and filters that pass IR (in dark red and green). Based on my calculations all the filters that don't pass IR are predicted to provide little if any increase in SNR over no filter. Filters that pass IR are predicted to provide a significant improvement in SNR, the extent varying with the particulars of the filter. Interestingly, the %LT for all the filters that pass IR is around the same, ranging from 28 to 38%. This would suggest that the impact of this group of filters on camera exposure time should be roughly the same.

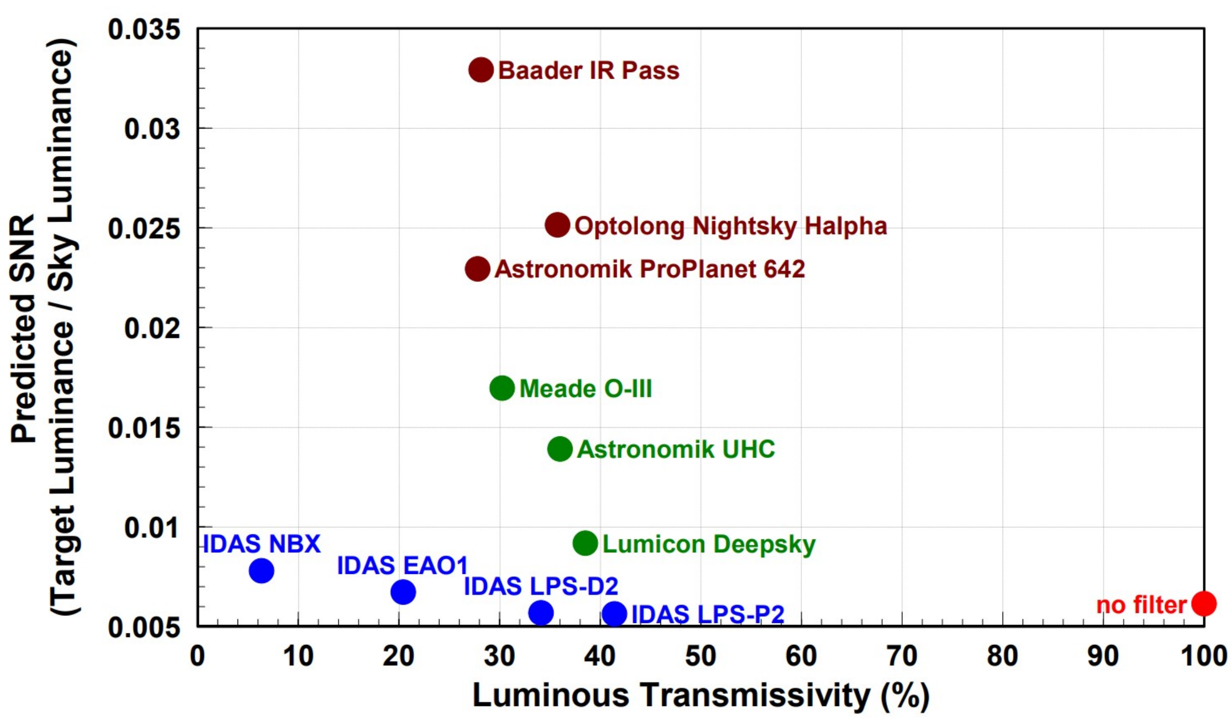

Figure 4 Predicted Impact of Filter on Galaxy SNR

The change in SNR between each filter and the no-filter case is in the grand scheme of things rather small, which is the reality of using a filter to observe galaxies. The improvement in contrast will never be as dramatic as when you use a filter to observe an emission nebula. That said, there are significant differences in the predicted performances of each filter. The question now is: can the prediction be confirmed in practice?

Results – Imaging:
Figure 6 presents the images of M66 that were captured using each filter configuration. Shown is a crop from each captured image focusing on the galaxy itself. All the images have had the same histogram stretching applied: 10% clipping of both the black point and white point, and no gamma adjustment. As suggested by the predictions, the improvement observed by adding a filter is subtle, with the increase in contrast being largest for the filters passing IR. There are some notable differences between my predictions and observations. The first is that my predictions suggest that the EAO1 and NBX filters provide a small amount of improvement over no filter, but my observations suggest the contrast is worse using these two filters. Another difference is that the Baader Planetarium IR Pass filter is predicted to provide the largest increase in contrast but it was the Optolong Nightsky Halpha that was observed to perform overall the best. To have a closer look at how well my predictions align with my observations, I measured the galaxy's SNR directly from each image and compared them to my predicted values. The measured SNR for the galaxy was calculated by sampling the image luminance value in three specific areas around the image as illustrated in Figure 5 using AstroImageJ. The measured SNR value was calculated using the following formulae:

$$SNR1_{measured} = (\text{Peak Luminance1} - \text{Average Luminance3}) \div (\text{Average Luminance3})$$

$$SNR2_{measured} = (\text{Peak Luminance2} - \text{Average Luminance3}) \div (\text{Average Luminance3})$$

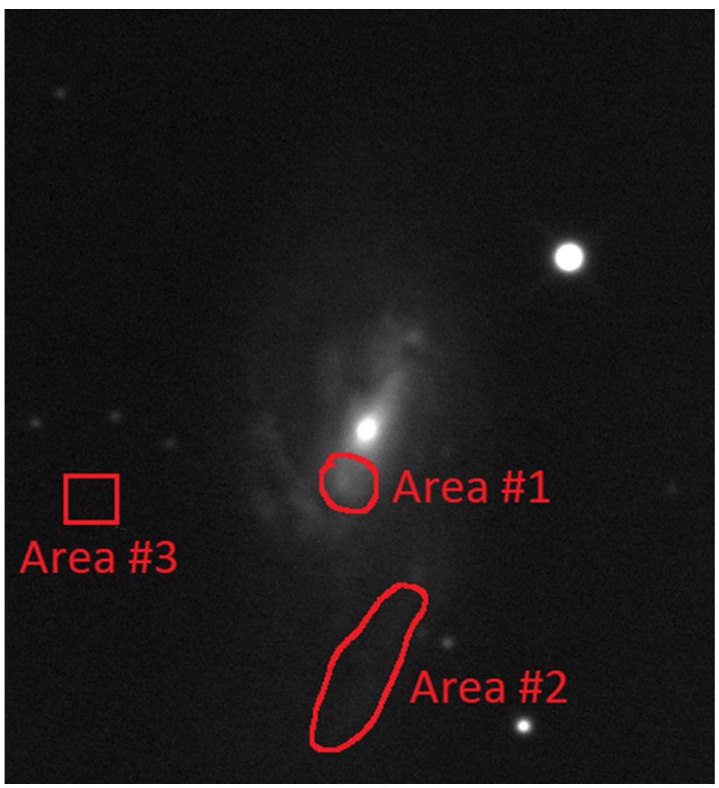

Figure 5 SNR Measurement Sample Areas

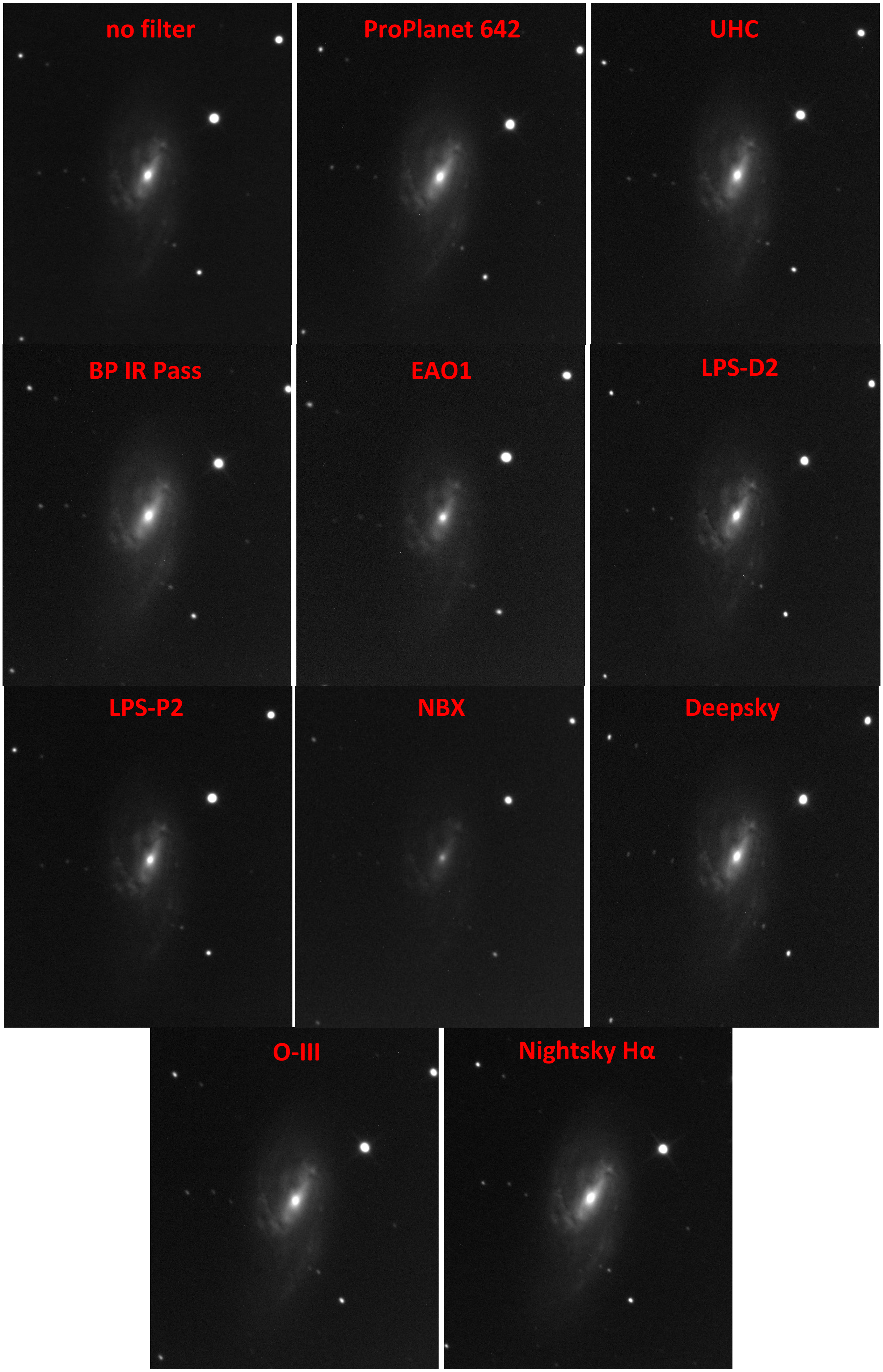

Figure 6 Image Comparison Between All Filters Tested

The measured SNR results for the two areas considered (Area #1 = bright bar portion, Area #2 = faint spiral arm portion) are presented in Figure 7, plotted against the corresponding predicted SNR values for each filter. I have also added a best fit line for each set of points. The tendency of the plotted points to follow the lines is a good sign; it means that there is a positive correlation between my predictions and what was observed. Filters predicted to perform better than others were observed to be such in reality. Even though there is some scatter in the points, the correlation is good in my opinion. If I had used longer total exposure times to get the image random noise down, there would be less scatter in the plot. Based on these results I am satisfied that my predictions are validated by observation.

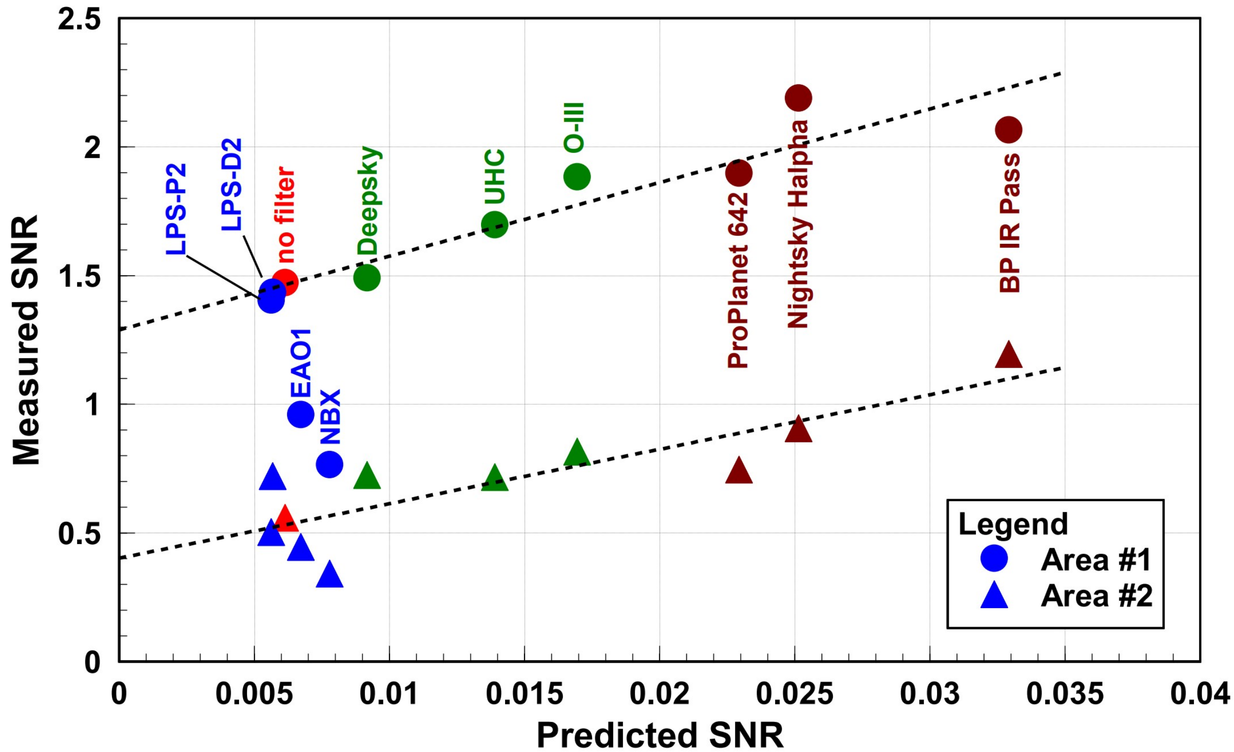

Figure 7 Correlation Between Measured & Predicted SNR

Impact of Sky Darkness:

Now having a level of confidence in my prediction method, I am able to determine how the performance of the tested filters changes depending on the extent of the light pollution. My measurements were made from my backyard that has a NELM of around +2.9. One would expect that there is a level of sky darkness at which using a LP filter has no benefit because there simply isn't any light pollution. I have predicted the SNR for observing a galaxy with the list of filters above, for the sky darkness levels summarized in Table 1 below. Using my model for each of these sky darkness levels I predicted the performance of the list of filters discussed above. I have also added a few other filters, a UV/IR cut and some IR pass filters, to the list in order to better understand the extent to which these filters are able to affect the SNR. A list of the filters considered is provided in Table 2. Also included in the table is the calculated %LT which will become relevant to the discussion, as you will see later.

Description	NELM	Bortle
Urban full Moon	+2.0	9
Rural full Moon	+2.3	9
Large city center, man-made lights incl. LED	+2.9	9
Large city, man-made lights (no LED)	+3.5	9
Sub-urban, man-made lights	+4.0	8
Rural w/nearby city, some man-made light	+5.0	6
Dark rural, very little LP	+6.0	4
Very dark sky, only natural skyglow for LP	+7.0	2

Table 1 Sky Darkness Levels Considered In Analysis

FILTER	%LT*
No Filter	100.0
IDAS EAO1	20.4
IDAS LPS-D2	34.1
IDAS LPS-P2	41.4
IDAS NBX	6.4
Lumicon Deepsky	38.5
Astronomik UHC	36.0
Meade O-III	30.3
Baader UV/IR cut	62.0
Astronomik ProPlanet 642	27.8
Baader IR Pass	28.2
Optolong Nightsky Halpha	38.2
ZWO 850	6.3
Generic IR Pass 760nm	13.9

* calculated for IMX174M sensor

Table 2 Filters Considered In Sky Darkness Analysis

The results of my calculations are presented in Figures 8 to 10. I have divided the filters into three groups to make the results easier to read. The results are more complicated that I was expecting. As the amount of man-made light reduces moving from Bortle 9 to Bortle 2, the filter that provides the best contrast increase varies continuously. In heavy light pollution the best filter is an IR Pass with a cut-off wavelength in the 750 to 850nm range. As the LP level decreases, so does the cut-off wavelength giving the best contrast. With little to no LP the best choice is a filter that blocks IR entirely as well as naturally occurring LP. Band pass filters with response in the IR band like the Astronomik UHC are a compromise between these two extremes of IR passing and IR blocking filters.

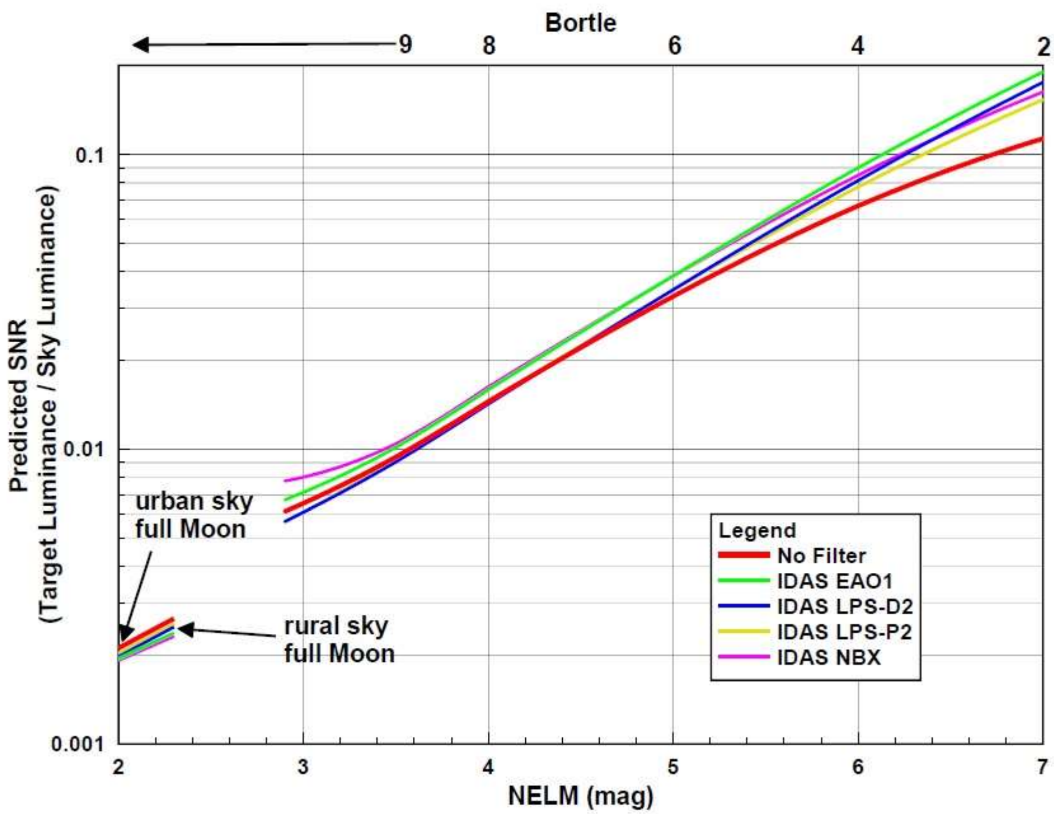

Figure 8 Predicted Filter Performance For Varying Sky Darkness – IDAS

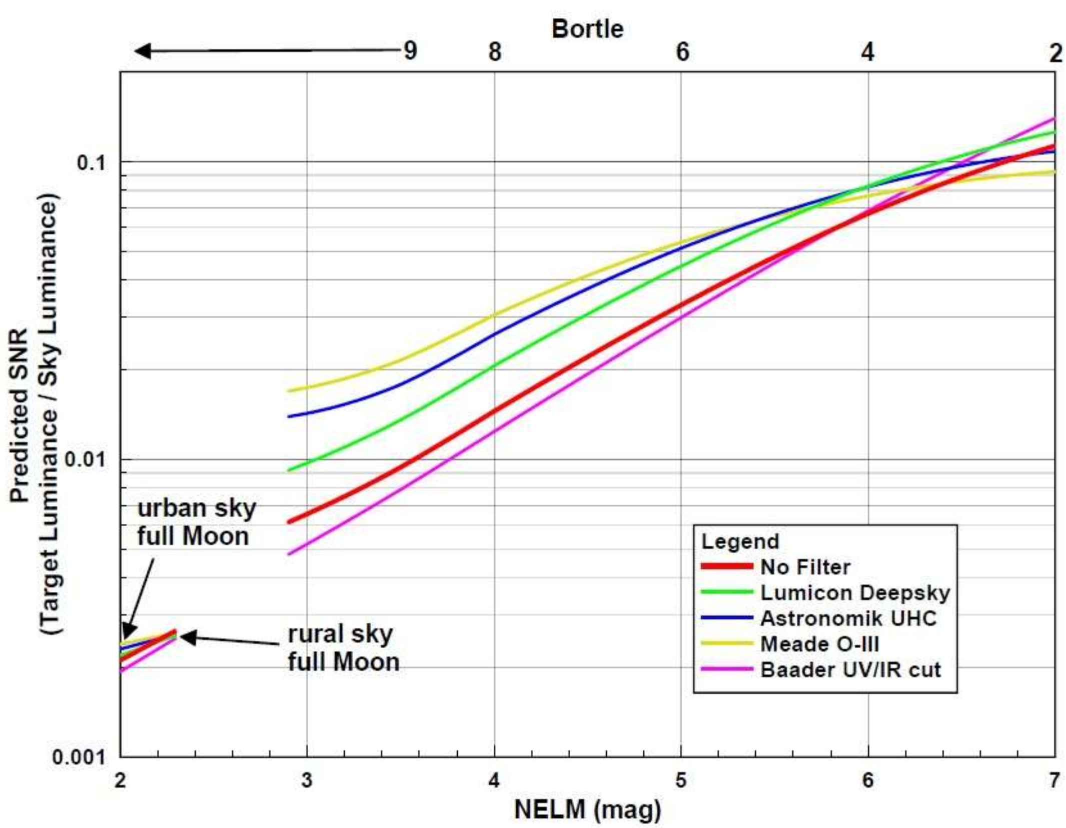

Figure 9 Predicted Filter Performance For Varying Sky Darkness – Other Bandpass

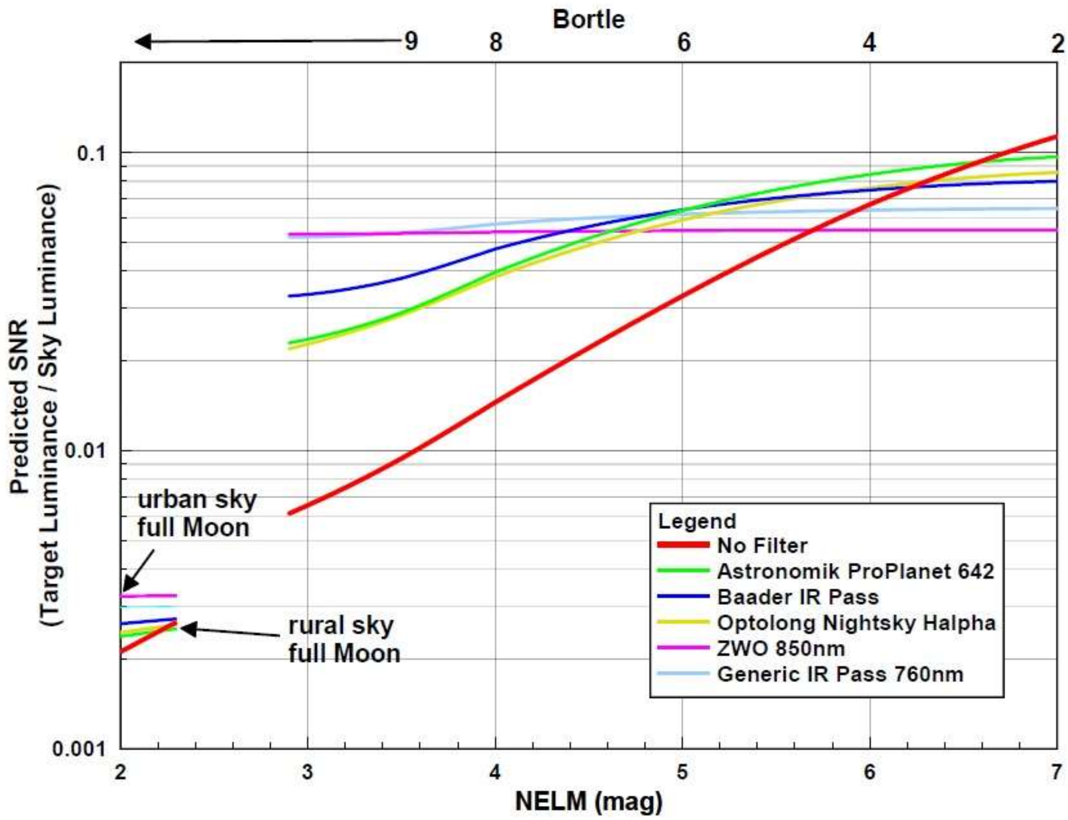

Figure 10 Predicted Filter Performance For Varying Sky Darkness – IR Pass

Conclusions:
The test results presented in this report confirm the following regarding the use of an optical filter with a modern EAA camera when observing a galaxy under light polluted skies:

1. Filters that pass infrared tend to increase the galaxy's SNR, but filters that block infrared tend to reduce SNR;
2. IR high pass filters provide the largest increase in SNR, with the Optolong Nightsky Halpha and Baader Planetarium IR Pass being two good performing commercially available examples; and
3. The filter performance predictions made using my method correlate well with observations.

Using my prediction method under different sky darkness levels, some additional conclusions can be made:

4. Under heavy light pollution, the best increase in contrast is achieved using an IR pass filter with cut-off wavelength around 750 to 850nm.
5. Under dark skies a filter blocking IR can in theory improve the contrast of galaxies, but the improvement is probably too small to see.
6. LP band pass filters that also pass IR are a good general purpose filter on galaxies and nebulae over a range of sky conditions from Bortle 4 to 9.

Before anyone runs out and buys the ZWO 850 or a generic 760nm High Pass filter, it is important to note how these filters affect exposure time. Table 2 lists the %LT I have calculated for each of the filters considered. When I did my testing I used sub-exposures of 20sec and that seemed to work okay for most of the filters, which have a %LT in the 30 to 40% range. The generic 760nm filter has a %LT of 14%, roughly half of what the filters in my test have. This would imply I would need to use sub-exposures twice as long, so 40sec which is probably still manageable. The ZWO 850 has a %LT of 6%, implying I'd need around 6x the exposure or around 120sec for my sub-exposures. That is starting to get too long for a sub-exposure in my opinion. The relative exposure requirements may be one reason why I was seeing the Optolong Nightsky Halpha performing better than the other filters tested. This may also address why the Baader IR Pass, IDAS EAO1 and NBX did not give test results consistent with my predictions. Perhaps another test is required, this time varying the sub-exposure length corresponding to each filter's %LT.

By the way, if you happen to already own a Lumicon Nightsky Halpha filter, the Optolong one is essentially an exact copy of it. Finally, I have applied some additional histogram stretching and noise reduction to three of the images from Figure 6: no filter, UHC, and Nightsky Halpha. The resulting images are presented in Figure 11. The improvement in contrast is still subtle but significant. Since this test I make it a habit now to use the Optolong filter for all my galaxy observing.

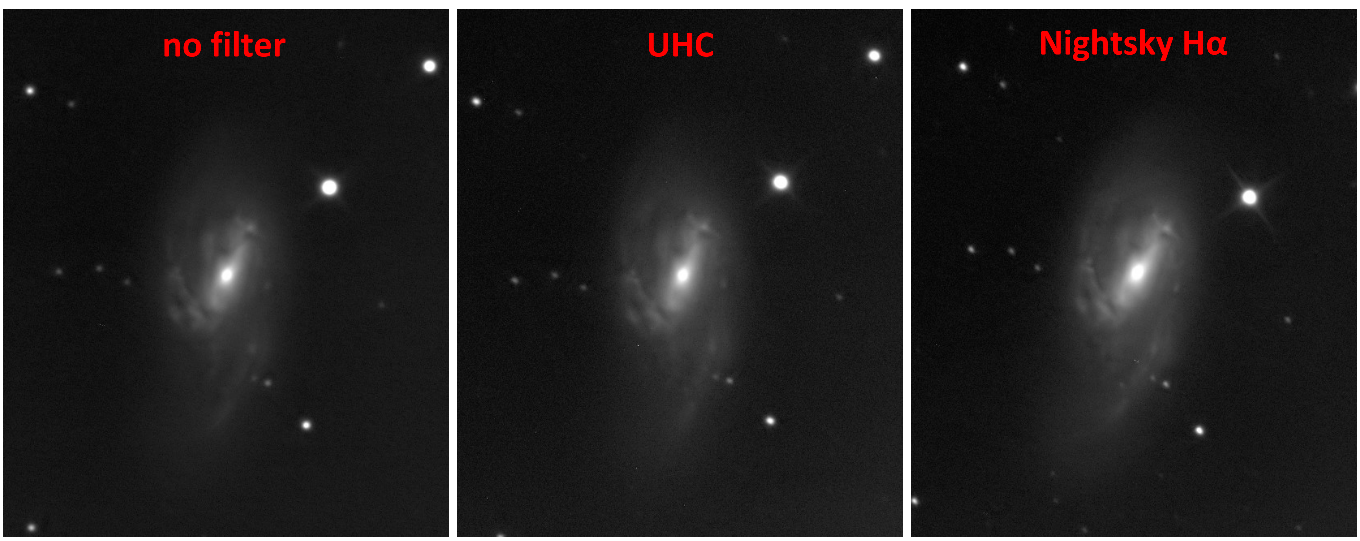

Figure 11 Image Comparison Between No-Filter, Astro' UHC, & Opto' Nightsky (more aggressive histogram stretch + noise reduction)

P.S. For one-shot colour (OSC) camera users, please note that using an IR high pass filter will result in a reddish-brown monochrome coloured image. If you want to try an IR high pass filter with your OSC camera, you may want to adjust your saturation down to get a more pleasing image.

Cheers!

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