Measuring Backyard Light Pollution

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Test Report – November 8th, 2021

Introduction:

I have spent a lot of time over the past ten years researching light pollution (LP) filters, especially how they work relative to each other. To be able to predict how filters will perform on different types of deep-sky object, I have had to make some assumptions regarding the nature of LP. Specifically, I have made assumptions regarding the spectral make-up of LP based on the information I was able to find online. I have not had an opportunity to confirm by measurement that my assumed LP spectrum aligns with what I am actually seeing in my backyard, until now. This article presents the results of my attempt to measure the spectrum of the LP in the central Ottawa night sky.

Sources of LP:

There are a number of sources that contribute to LP, but broadly speaking these sources can be organised into two categories: man-made, and naturally occurring. The spectrum of man-made LP varies widely depending on the technology used to generate the light. Incandescent lighting, which includes halogen bulbs, has a broad spectrum (see Figure 1a). Its use however has been in a steady decline for the past 15 years due to more energy efficient technologies such as compact fluorescent and LED. Mercury and Sodium vapour lighting (Figures 1b and 1c respectively) has been used for many years in outdoor applications because it is more reliable and cost efficient than incandescent lighting. Although it too is being gradually phased out by LED lighting, there are still a large number of these lights in use today. Metal halide lights (Figure 1d) are less common but can still be found in applications requiring high intensity lighting such as outdoor sports venues. Fluorescent lighting (Figure 1e) is not that common for outdoor use because of its relatively low brightness. It is most commonly found in illuminated signage. Finally LED lighting (Figure 1f) is the new technology on the block. It has been gradually replacing all the other lighting technologies over the past five years due to its low cost and low energy consumption.

As one can see from the spectrums in Figure 1, all of these man-made light sources are either: broad band emitters, emitting light over a wide portion of the spectrum; narrow band emitters, emitting light at a combination of discrete wavelengths; or a combination of both. Broad band light sources are much more difficult to block using filters since some of their emissions overlap with the emissions of the deep-sky objects we are trying to see. Narrow band light sources provide us an opportunity to customize our LP filters so that they block only the LP and not the light from the deep-sky object. At the moment, at least in my neighbourhood, man-made LP is a combination of broad band and narrow band light sources, so filters are effective at improving the view of deep-sky objects, at least to some extent.

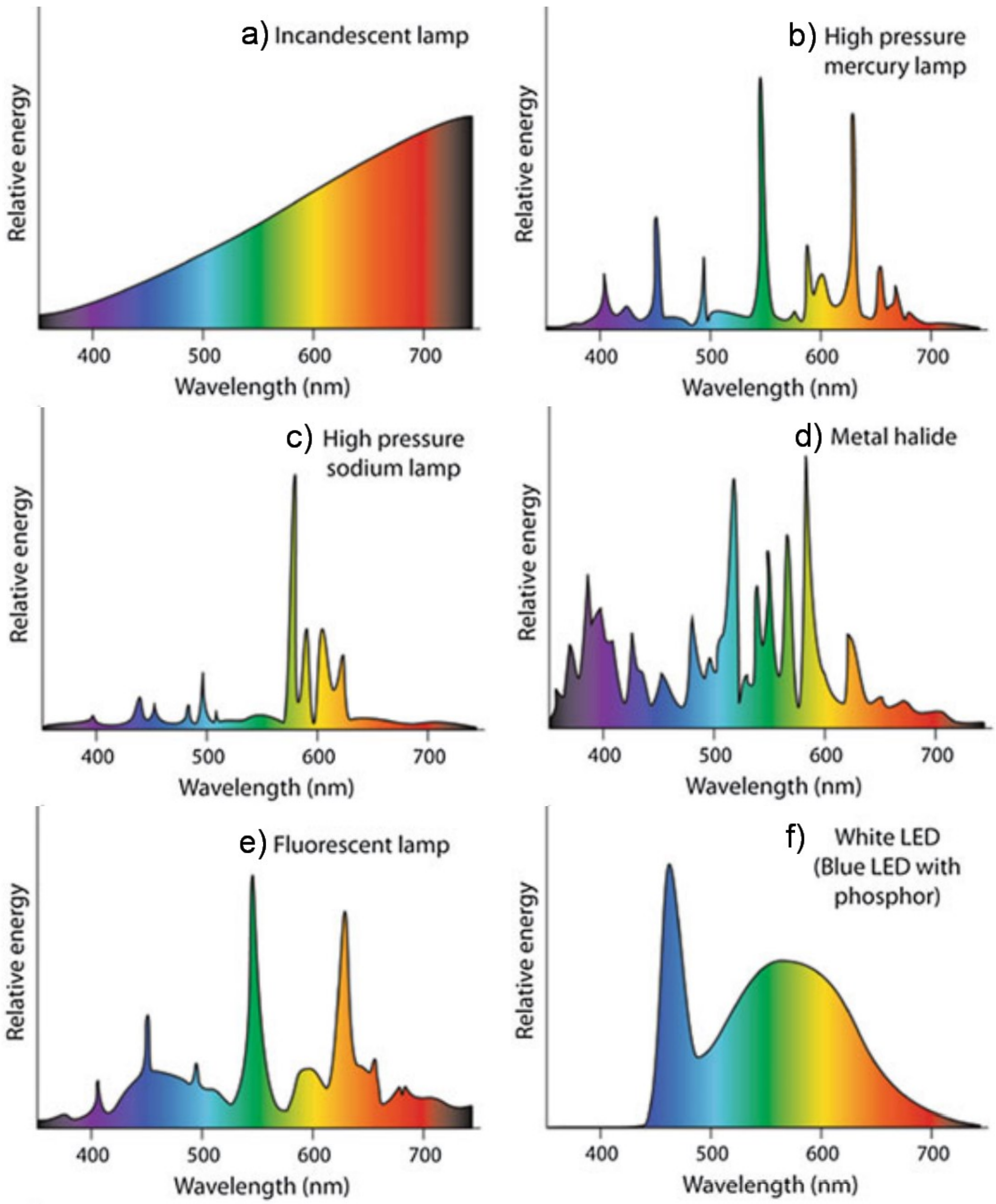

Figure 1 Typical Spectra for Different Man-Made Lighting Technologies[1]

We humans are not the only source for LP. There are also a number of naturally occurring sources, the two most notable being: sky glow, and the Moon. Sky glow is a phenomenon whereby molecules in our upper atmosphere that have been energized by the Sun's UV radiation during the day release that energy at night in the form of a faint glow. This glow is at discrete wavelengths depending on which element is doing the emitting. The Moon for all intents and purposes is a big mirror. It is reflecting the Sun's broad spectrum back at us. Figure 2 illustrates the appearance of each natural LP source's typical spectrum.

[1] Figures from: S. Dutta Gupta (ed.), Light Emitting Diodes for Agriculture, DOI 10.1007/978-981-10-5807-3_1

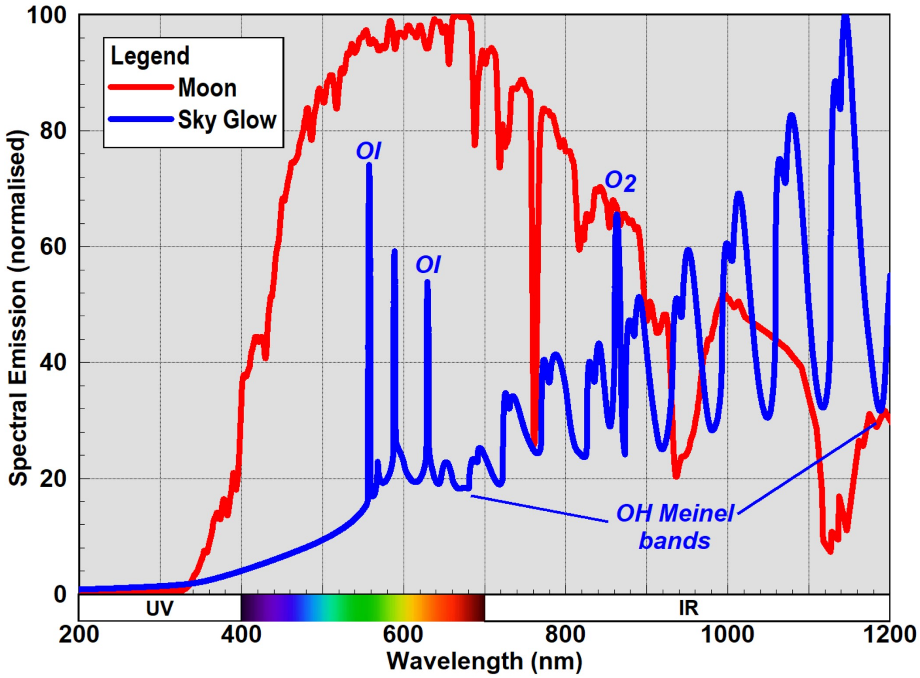

Figure 2 Typical Spectra for Naturally Occurring LP

Modeling My Backyard LP:

Each of the individual sources of LP illustrated in Figures 1 and 2 are combined in some manner to create the net LP spectrum for my location. Since I have no way of determining how much of each LP source is present in my skies, I turned to the internet to see if anyone has directly measured the spectrum of an urban sky before so that I could at least have an idea of what to expect. Luckily I was able to find a number of research papers on the topic. From these papers I constructed what can be considered a "typical" urban sky spectrum, consisting of a man-made component and a natural component. In order to set the relative brightness of my LP spectrum I calculated the area under the assumed spectrum curve to give me a single number representing the total luminance coming from the sky. This number was compared to the same calculation for a reference spectrum, that from the star Vega, which has a visual magnitude of zero. Knowing the actual relative magnitude of these two sources, I was able to figure out how much to scale the LP curve by to get the correct overall relative brightness. For example: to get the spectrum for a sky with naked eye limiting magnitude (NELM) of +4, I found the scaling factor needed to make the area under its spectrum equal a number four magnitudes dimmer than the area under the Vega curve, a factor of 0.025 times. I repeated this process to create spectra for a number of different LP levels. For the case of a dark +7 magnitude sky I assumed there was no man-made component, just natural, and that the area under the natural LP curve was seven magnitudes dimmer than Vega, or a factor of 0.0016 times. Figure 3 presents the LP spectra that resulted from this exercise. I had to plot the spectra using a logarithmic scale in order to capture the large range in relative sky brightness between a dark sky and a heavily light polluted sky. Fairly recently I added the spectrum for a +2.9 magnitude sky by adding a component of LED lighting to the spectrum for a +3.5 magnitude sky. This was done to reflect the recent installation of LED street lights in my neighbourhood.

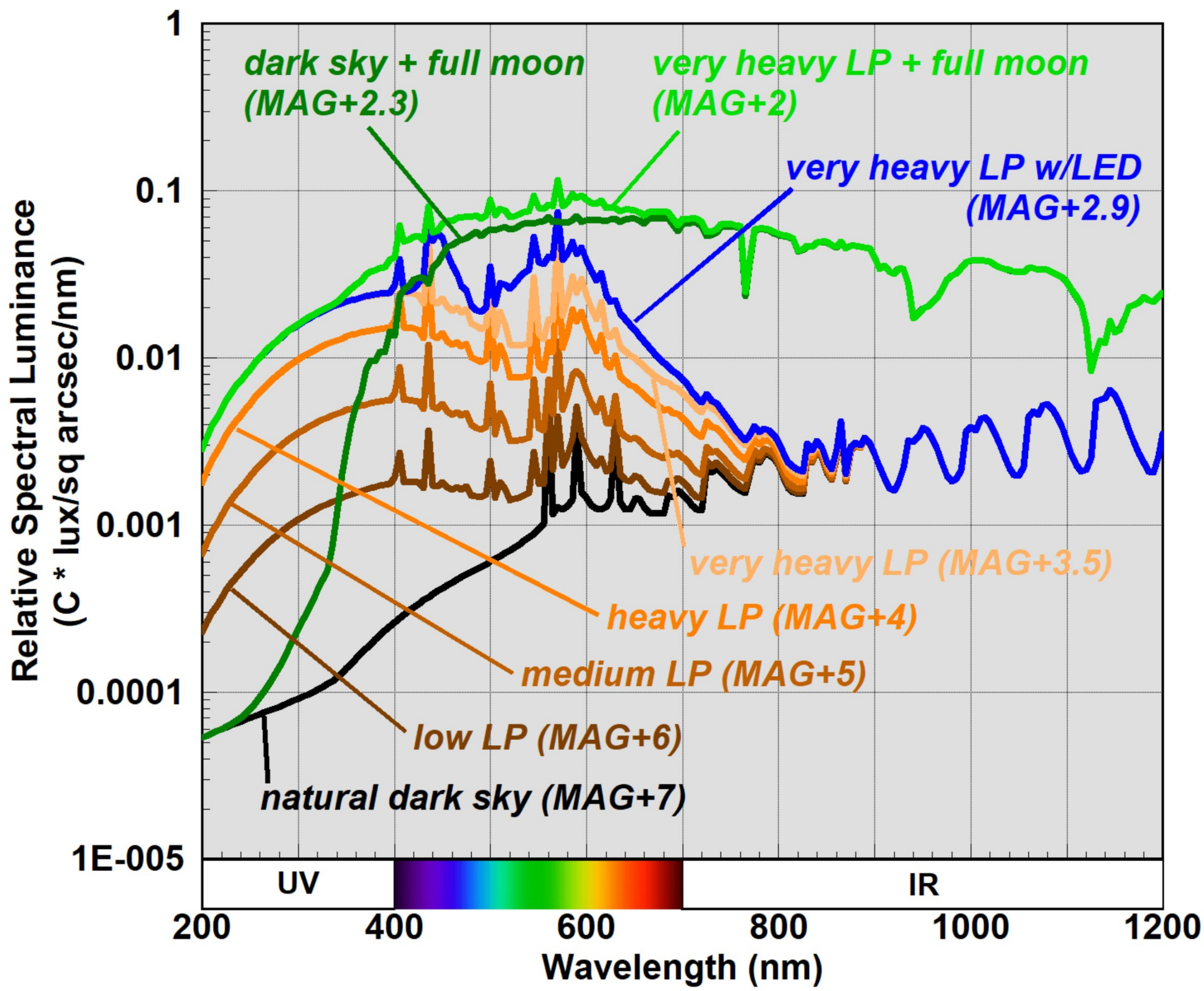

Figure 3 My Fabricated Sky Spectra for Various Levels of LP

Measuring My Backyard LP

Measuring the brightness of one's sky is relatively easy if you have a sky quality meter (SQM) such as those sold by Canadian company Unihedron. I own one of their SQM-LE models (shown in Figure 4), and have used it many times to monitor my urban skies. An SQM provides a measurement of the sky brightness, in magnitudes per square arc second, which can also be converted into a NELM value. This device is handy for quickly and reliably determining how bright my sky is, but it does not tell me anything about the spectrum of my LP. Measuring the spectrum of the night sky is a difficult task since the light source we are trying to measure is faint, much fainter than the laboratory reference light that bench top spectrometers are normally used with. I have tried many combinations of lenses and telescopes to try and get a reading using my Ocean Insight USB4000 spectrometer, but the signal is simply too low. As I am not about to purchase a million dollar professional observatory grade spectrometer, I decided to try a more rudimentary approach using an astro-video camera and a bucket full of filters.

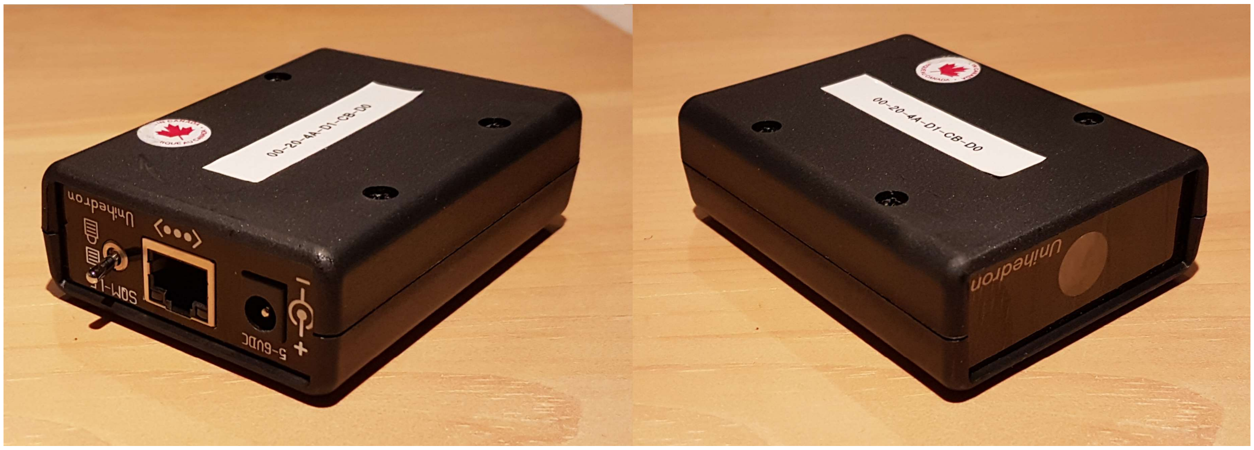

Figure 4 Images of Unihedron SQM-LE

My keen interest in optical filters of all sorts means I have accumulated quite a library of different filter types, so much so that I have band pass filters covering pretty much all of the visual and near infrared band. This provided an opportunity for me to turn a typical camera used for electronically assisted astronomy (EAA) into a very sensitive spectrometer. I selected eleven filters or filter combinations in total:

1. Meade #47 (indigo) + Mallincam IR Cut
2. Hoya B390 (blue) + Meade #8 (light yellow) + Mallincam IR Cut
3. Astronomik Hβ (visual, cyan) + Mallincam IR Cut
4. Astronomik O-III (visual, green) + Mallincam IR Cut
5. Baader Planetarium Solar Continuum (dark green) + Baader Planetarium UV/IR Cut
6. Semrock 572 (yellow) + Mallincam IR Cut
7. Semrock 607 (dark yellow) + Mallincam IR Cut
8. Omega Optics 650BP10 (red)
9. IDAS NB-3 (dark red) + Omega Optics XMV660 (red)
10. Astronomik ProPlanet 642 (NIR) + generic 680nm high pass
11. ZWO 850nm IR high pass

I confirmed the spectra of these filter combinations with my USB4000 spectrometer, the resulting curves are shown in Figure 5. Using these measured spectra combined with the spectral response of the sensor in the camera I used for my measurement, a ZWO ASI290MM (monochrome), I calculated the fraction of the incoming light the camera theoretically sees through each filter combo. The sky LP measurement was completed by putting the camera onto my 98mm refractor and aiming it towards the south at a 45° elevation. With camera binning at 1x1, gain at 38%, and an exposure time of 60 seconds, I captured a single 16-bit frame with each filter combo. I also captured a frame with no filter at the start and finish of the test to act as my reference, and I captured a dark frame to use as my zero offset. All data was captured on the same evening, October 7th, 2021, between 11pm and midnight. Conditions on that evening were typical for my backyard in central Ottawa: clear with below average transparency. Using the freeware image analysis software AstroImageJ I extracted the average pixel intensity value from each of my captured images. Those values were then used to calculate the measured fraction of light getting through each filter to the camera according to the formula:

$$\text{Luminance Fraction} = (L_{filter\_n} - L_{darkframe}) / (L_{reference} - L_{darkframe})$$

, where 'L' is the 16-bit average pixel luminance values coming from AstroImageJ. The measured fraction was then compared with the theoretical fraction that I calculated from the measured filter spectra in order to determine the relative intensity of the LP in each filter's pass band.

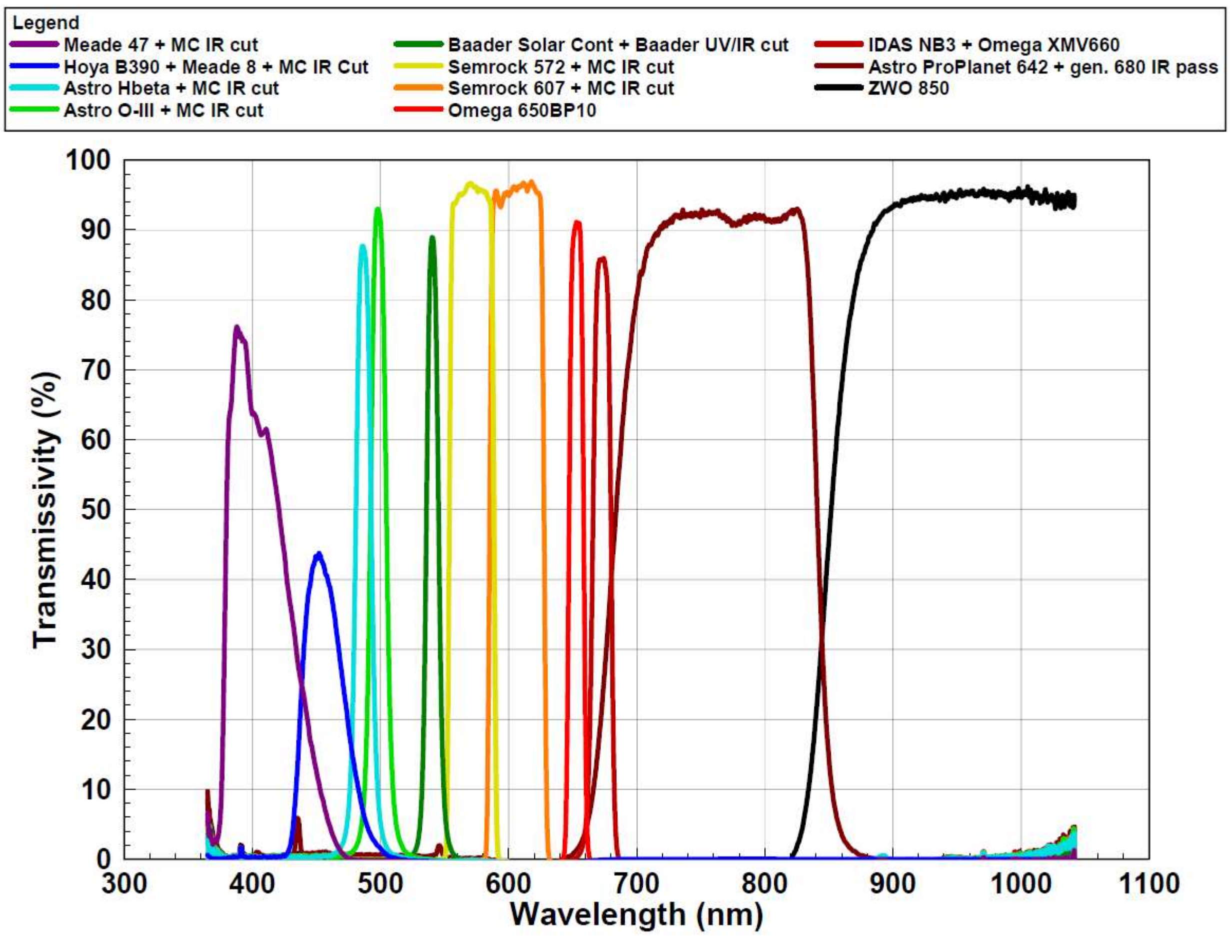

Figure 5 Measured Spectra for Selected Filter Combinations

The result of this calculation was a measure of how bright the LP is in each filter pass band, but only in a relative sense. To determine in absolute terms what the emission spectrum from the sky is in physical units (e.g. mags/sqr arcsec) would require me to also have a calibrated light source, which I don't have. So instead I plotted my measured spectrum together with my fabricated spectrum for the +2.9 magnitude sky, and scaled the measured spectrum uniformly to achieve what appeared to be the best match (i.e. resulted in the largest number of measured points aligning with the fabricated spectrum). The result is presented in Figure 6.

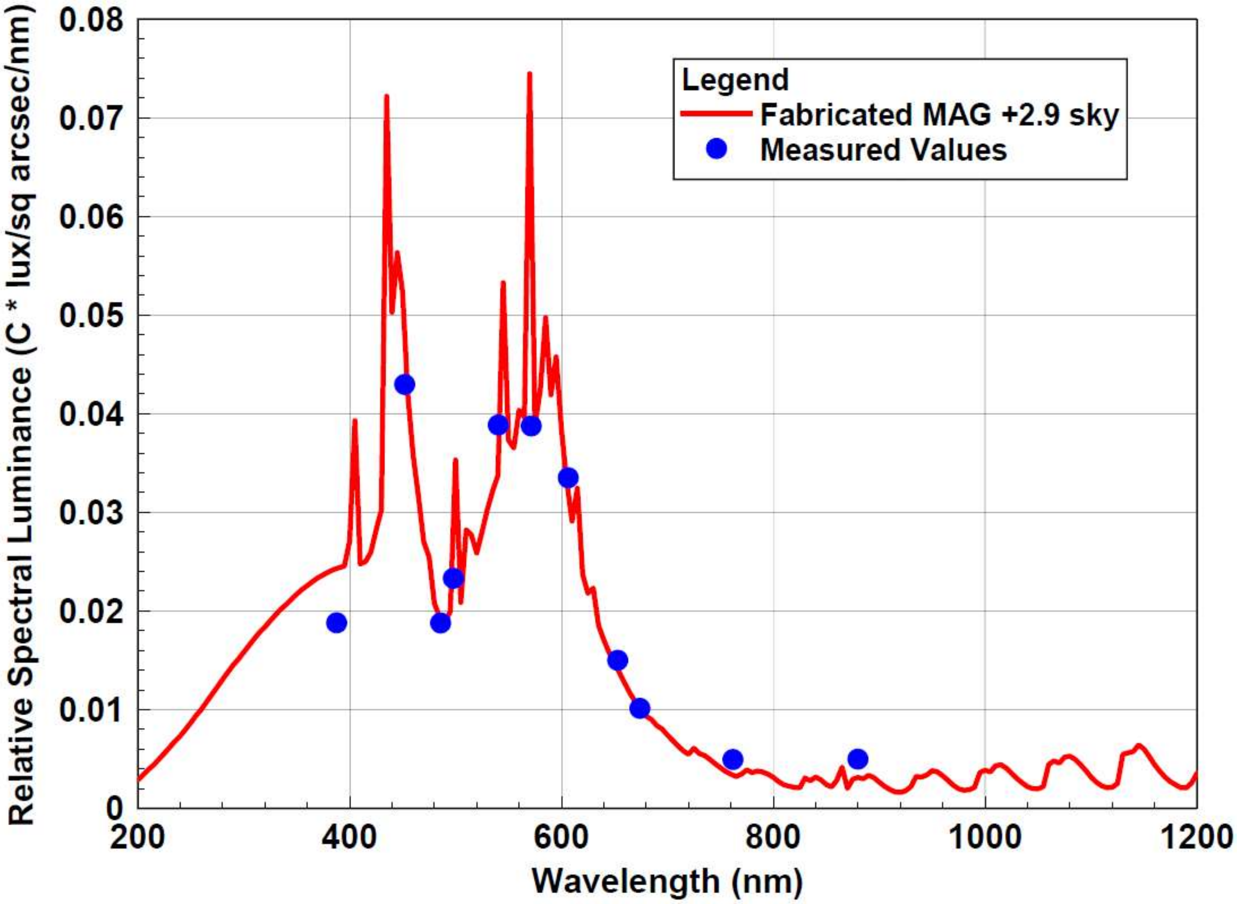

Figure 6 Measured Backyard LP Spectrum vs Fabricated

To be honest I was shocked to see how well my measurements aligned with my fabricated LP spectrum. It appears that my model is a little low in intensity at the infrared end of the spectrum, and quite a bit too high in the UV end of the spectrum, but otherwise the other data points line up very well. The data point at 572nm appears to have missed the large spike assumed to exist due to high pressure Sodium vapour lighting, but I believe this is due to the width of the filter band pass I was using. That data point, as well as the one at 607nm are effectively averages over a 35 to 40nm wide band.

I am very pleased with the outcome of my measurement. Achieving a good alignment with my assumed LP spectrum adds to the confidence I have in my filter performance prediction method. I have collected numerous observations over the years that support my method's prediction of filter performance. This latest measurement just adds to that growing collection of validation data.

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

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