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2017 May 22

Attn: Executive Director, Resource Assessments

Department of Planning and Environment

GPO Box 39

Sydney NSW 2001

**This is a submission to the Narrabri Gas EIS.**

I object to this project and believe it should be rejected.

I wish to submit my objection to the Santos EIS in their proposed use of unshielded flare stacks. There are two main reasons behind my objection

1. The flares will significantly contribute to light pollution, affecting the dark skies of Siding Spring Observatory and the Warrumbungle Dark Sky Park and thus affect the professional, amateur and tourism aspects of astronomy in the region.
2. There are unconsidered consequences of open flares that could result in a bushfire. Also, the existence of a flare could influence the early detection of a bushfire.

Should the project go ahead, it would be essential for flares to be enclosed as a minimum requirement. The ideal would be full retention of gas without flaring. This would minimise all light pollution and bushfire concerns.

My background is as an observational astronomer with around 40 years of experience, the latter 30 being at Siding Spring Observatory. Now retired, I am conducting various scientific programs in the study of meteor showers and continuing my search for comets. With 82 comets bearing my name, I have almost three times as many discoveries as the next most successful comet hunter in history.

Given this background, I was concerned at the lack of understanding of the issue of light pollution and lack of any quantitative data in the EIS. The EIS should be rejected and resubmitted with these issues properly addressed.

Below I outline my analysis of the likely impacts of this project covering

- Light pollution
- Baseline data of existing flares
- Visual aspects of flare light pollution
- Flare stacks and bushfire
- Flares and wildlife

**Light Pollution**

In response to my earlier concerns about light pollution, Santos indicated that they would address the issue in their EIS (ref 1), but no data is presented by Santos about the effect of the flares on sky brightness. In the EIS (ref. 2, p82), there is reference to "sensitive receptors" with no definition as to what they are and there appears to be a misunderstanding (Ref. 2, Appendix C) that light pollution refers only to direct line of sight and not atmospheric scattering. To counter this lack of baseline data, I purchased several sky brightness meters from Unihedron (ref 3) and started sky brightness monitoring and conducted what I believe would be a minimum requirement for any EIS dealing with light pollution.

In Appendix 1, the basics of light pollution are discussed with the demonstration that cloud or haze amplifies the effects of light pollution. All cloud or haze affects the limiting magnitude of the stars by absorbing light. In the presence of light pollution, the cloud is illuminated thus increasing the brightness of the background sky, making the stars even less visible. Thus, even if local light pollution has a minor effect in completely clear skies, the presence of water/dust haze or cloud magnifies the effects of light pollution.

**Baseline data of existing flares**

During 2017 April and May, attempts were made to measure the sky brightness near the existing three flares in the Pilliga (Tintsfield, Bibblewindi and Dewhurst). This required a clear night, free from moonlight and at a time when the Milky Way was not overhead, as it would contaminate the measures. Very few opportunities met these criteria.

Bibblewindi and Dewhurst were measured on April 27 giving overhead sky brightness readings of 20.80 and 20.60 mag/arcsec$^2$ just outside their enclosures. On April 30, the Tintsfield flare was measured at 20.76. Measures of the Bibblewindi flare on May 21 gave 20.86 mag/ arcsec$^2$. The consistency of these can be taken as a base measure for extrapolating the overall effects of the proposed flares.

Measuring the overhead sky brightness at points along Kiandool Lane on which the Tintsfield flare is located, allows an estimate of the range over which the flare is detectable (Fig 1).

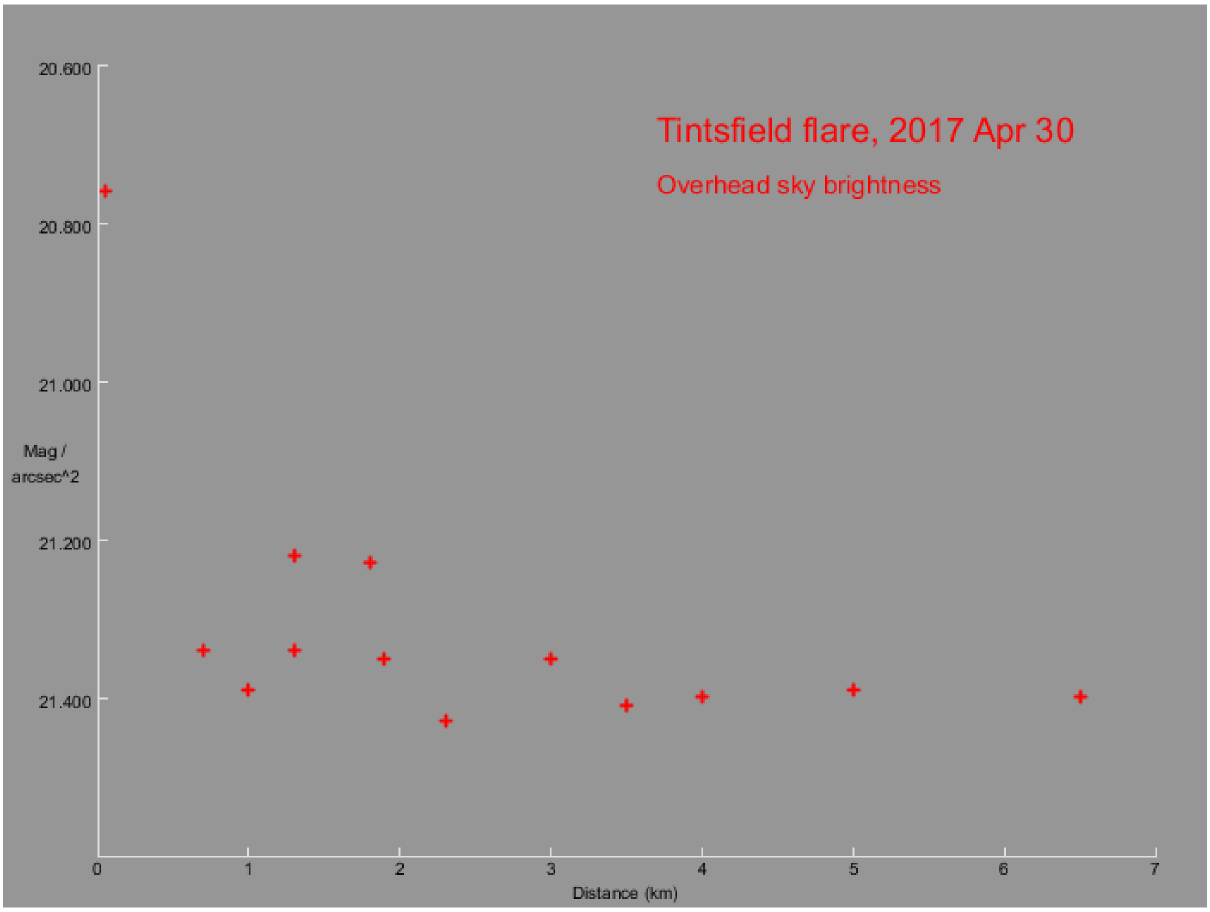



Figure 1. Overhead sky brightness near the Tintsfield flare.

These measures were taken using a less accurate hand-held version of the Unihedron sky brightness metres and need to be repeated with the higher accuracy ones, but it appears the overhead sky displays a detectable effect out to 2km from the flare. The next opportunity to make measures was on May 15, but the flare was not burning. Measures on that night, with the higher accuracy meter, indicate the sky brightness along Kiandool Lane is uniform to a level much less than the scatter beyond 2km. Thus, no other light sources are having an influence on the profile of this plot.

Future measures were planned using the higher accuracy meters, allowing a more reliable assessment of the brightness profile with distance. An opportunity arose on the night before this submission. On the night of May 21, measures were made at the Bibblewindi flare. After an inch or rain in the previous three days, the sky was wonderfully clear, but the humidity eventually resulted in cloud formation, terminating the measures. Measures were made at each location over a couple of minutes using two meters. Each point is an average of four measures with a scatter of around 0.02 mag/ arcsec$^2$. The data is shown in Fig. 2 and indicate a detectable increase in overhead sky brightness out to 4km from the flare.

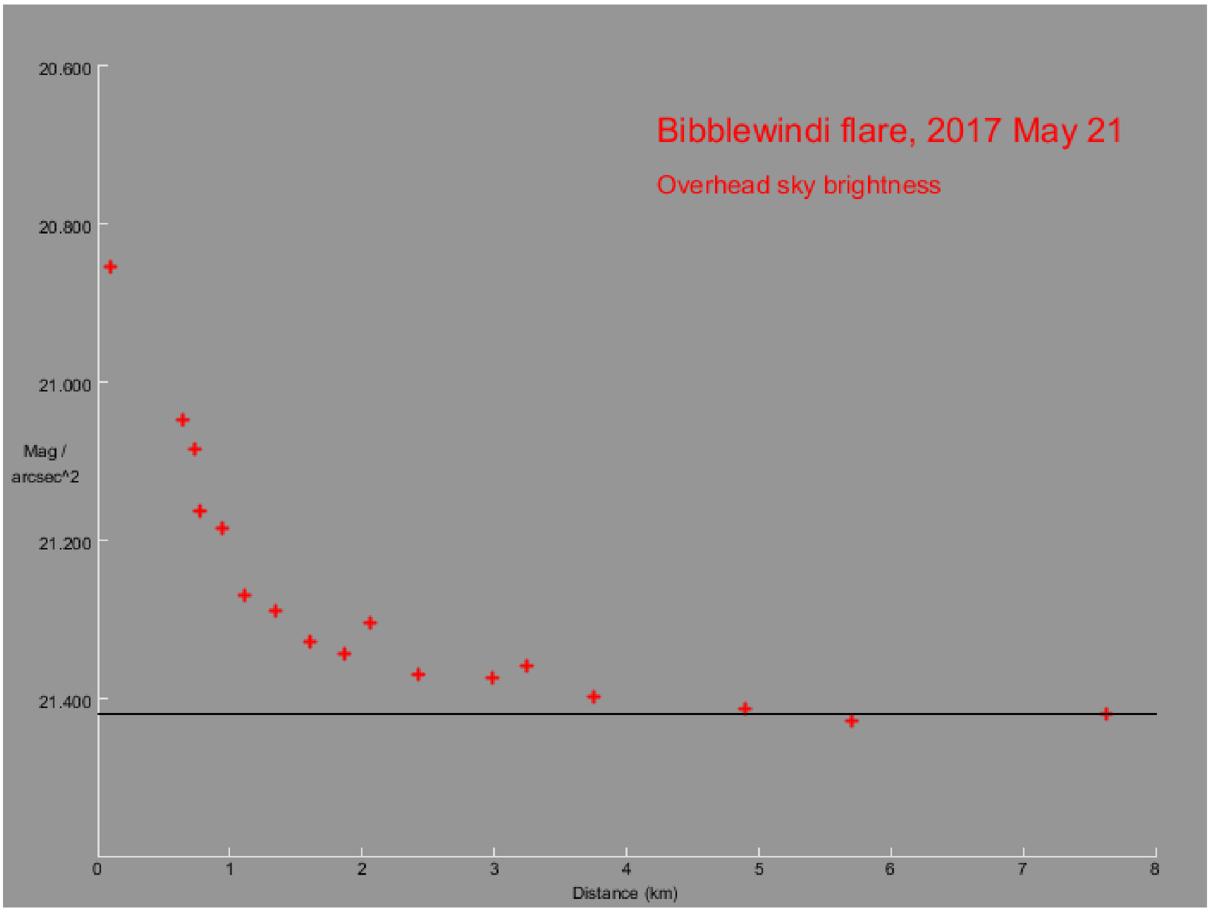



Figure 2. Overhead sky brightness near the Bibblewindi flare.

All three exploratory flares had flame heights of ~5m. If flare brightness is a function of the flare volume, then a 30m flare will be $(30/5)^3$ = ~200 times brighter. Brightness will fall off with distance according to the inverse square law, so the increased range that the flare would have an influence overhead will be a factor of $(30/5)^{1.5}$ = ~15. In other words, a 30m flare would be detectable overhead to a distance of 30km. However, the effect would be rather greater than this, as the flare is atop a much higher stack thus also contributing direct illumination, not just sky reflection. Sightings of such large flares have been made from Siding Spring Observatory confirming such direct visibility.

All the above measures were of the overhead sky brightness in a clear sky, but visual observations from over 5km distance from the Tintsfield flare at the same time as the above measures clearly displayed the influence of the flare on sky brightness at lower angles. It was these measures I wished to make on May 15 when the flare was not alight. If this is confirmed, it would imply that a single large flare would have a detectable influence lower down in the sky out to 100km from the flare, and beyond. These estimates are conservative, as the Bibblewindi data obtained on May 21 suggest these distances could be doubled.

Light pollution is a cumulative effect. The effect of the several proposed flares are likely to have a detectable influence on the sky brightness at Siding Spring Observatory, and increasingly more so closer to the project area where other telescopes and astronomy tourism businesses are located. Add to this any Santos infrastructure lighting in the project area and the situation is made worse. This is a *best-case scenario* of the influence flares would have in a clear sky. As demonstrated in appendix 1, haze or cloud magnifies the effects of light pollution. To protect the sky brightness at Siding Spring Observatory, it would be imperative to have all flares enclosed.

Further data gathering and analysis will be presented in ref 11.

## Visual aspects of flare light pollution

After a long wait for clear moonless skies, 2017 May 21 gave an excellent opportunity. Recent rain had cleared the air of dust, but the humidity was high. The photographs below were taken at various distances from the Bibblewindi flare on that evening. To clearly indicate the effect of the flare, pairs of photos were taken different azimuths to highlight the impact on the sky. This light pollution is clearly due to the flare, as out past 3km the flicker of the flame is evident in the sky glow.

This amount of light pollution ruins a huge dark area in this region. Astronomical tourism would suffer if the aesthetics of the sky are damaged in this way. These concerns, as well as a review of the science, are covered in *The End of Night* (ref. 5). There is no doubting from this book, and from my personal experience, that astronomy tourism is heavily influenced by light pollution free skies.

1.71km from Bibblewindi flare (junction Garlands Rd and X Line Rd)

2.06km from Bibblewindi flare (junction Boundary Rd and X Line Rd)

3.27km from Bibblewindi flare (junction Nickel Rd and X Line Rd)

3.39km from Bibblewindi flare (junction Bohena Creek Rd and X Line Rd)

5.70km from Bibblewindi flare (junction Blue Nobby Rd and X Line Rd)

After this, some cloud started to form, but a final pair of photos were taken beside the Newell Hwy, when no vehicles were within several kms. These dramatically show the effect of poor sky conditions magnifying the effect of light pollution.

7.65km from Bibblewindi flare (junction Newell Hwy and X Line Rd)

Photos were taken on a Canon 5D Mk I, ISO 800, 60s exposure with an 8mm f/2.8 lens. No processing of the images has been made.

**Flare Stacks and Bushfire**

DUST DEVILS

Fires are known to have been caused from flare stacks when solid or liquid contaminants come through the system. There appears to have been no consideration of the effect of dust devils in lifting flammable material through a flare and potentially starting a bushfire. This is a low probability, but high consequence threat. The EPA regulations that allow gas flaring during a total fire ban are quite inadequate in this regard (ref. 10).

For the past thirty years, I have had a keen interest in dust devils and tornadoes and had a significant library on the topic. As an amateur, my contributions have been limited, but I appear to have been the first person to note in the scientific literature some unusual animal behaviour related to dust devils (ref. 7) which was subsequently confirmed. I have documented several tornadoes in the Coonabarabran vicinity for the Bureau of Meteorology storm spotter network. One significant tornado in the southern Pilliga is discussed at (ref. 8). There is an underappreciation in Australia of the occurrence of tornadoes (ref. 9), with the press treating tornadoes (often significant tornadoes) as “mini tornadoes”. All such events, had they occurred in the USA, would have been treated as simply “tornadoes”. This Australian mindset has potential consequences if dust devils and tornadoes are ignored as irrelevant.

Dust devils are causes by a vortex being induced in rising ground-heated air. Studies have shown that dark soil increases the likelihood of dust devil formation through increased ground heating by sunlight. The existence of an already existing column of rising air from a flame must surely increase the likelihood of dust devil formation. Fire devils are a common sight in bushfires. Having the surrounding ground a light colour could act to limit dust devil formation, but this would increase the reflected light from both the infrastructure lighting and the gas flare, exacerbating light pollution. The solution to these concerns would be to enclose the flare.

HUMAN BEHAVIOUR AND BUSHFIRES

Regarding human behaviour, there are two very real effects that could have significant consequences: mistaking a flare for a bushfire, or much worse, mistaking a bushfire for a flare. Weather conditions like fog or low cloud can produce unusual effects that would dramatically change the appearance of the light pollution from a flare. Variations in flare activity (on/off), flare intensity, and weather conditions, make flare visibility unpredictable and thus a dangerous presence in a forest. Having been caught out by the 2013 Wambelong bushfire, my partner and I lost everything by having to evacuate immediately as there was only a single escape route. There are limited roads throughout the Pilliga. Any loss of time through mistaking a bushfire for light pollution from a flare could be fatal. Having flares in a forest with public access is unacceptable.

**Flares and Wildlife**

The lighting of infrastructure can be minimised with appropriate shielding and wattage, but the omnidirectional effect of a flare will disrupt wildlife over a large area. There are well known effects of light pollution of humans and wildlife but in a forest where there is little human presence, the effect is mostly on the wildlife with consequences to feeding, sleep, predation and breeding. There is an ecosystem in the forest that will be disrupted, no matter what that ecosystem is. (Ref. 6)


Ref. 1: https://www.theguardian.com/science/2014/oct/21/siding-spring-observatory-threat-coal-seam-gas-light-pollution Also covered independently by The Northern Daily Leader of Tamworth.

Ref. 2: https://majorprojects.affinitylive.com/public/983a679b1da9a99bcfcd355d122edff4/Appendix%20Q%20Landscape%20and%20visual%20impact%20assessment.pdf

Ref. 3: http://www.unihedron.com The detectors are called SQM (Sky Quality Meters).

Ref. 4: The International Dark Sky Association, http://www.darksky.org

Ref. 5: *The End of Night – Searching for natural darkness in an age of artificial light*. Paul Bogart, Little, Brown and Company, 2013.

Ref. 6: *The Ecological Consequences of Artificial Night Lighting*. Eds. Catherine Rich and Travis Longcore, Island Press, 2006.

Ref. 7: "On Galahs and vortices", R. H. McNaught and G. J. Garradd, EMU Vol 92, pp 248-249, 1992. http://www.publish.csiro.au/mu/pdf/MU9920248

Ref. 8: http://www.australiasevereweather.com/storm_news/2005/docs/200501-04.htm

http://narrabriweather.net/events/20Jan2005.html

Ref. 9: http://www.bom.gov.au/nsw/sevwx/tornadofact.shtml

Ref. 10: NSW EPA fact sheet on gas flaring http://www.epa.nsw.gov.au/resources/epa/2564-gas-flaring-fact-sheet.pdf

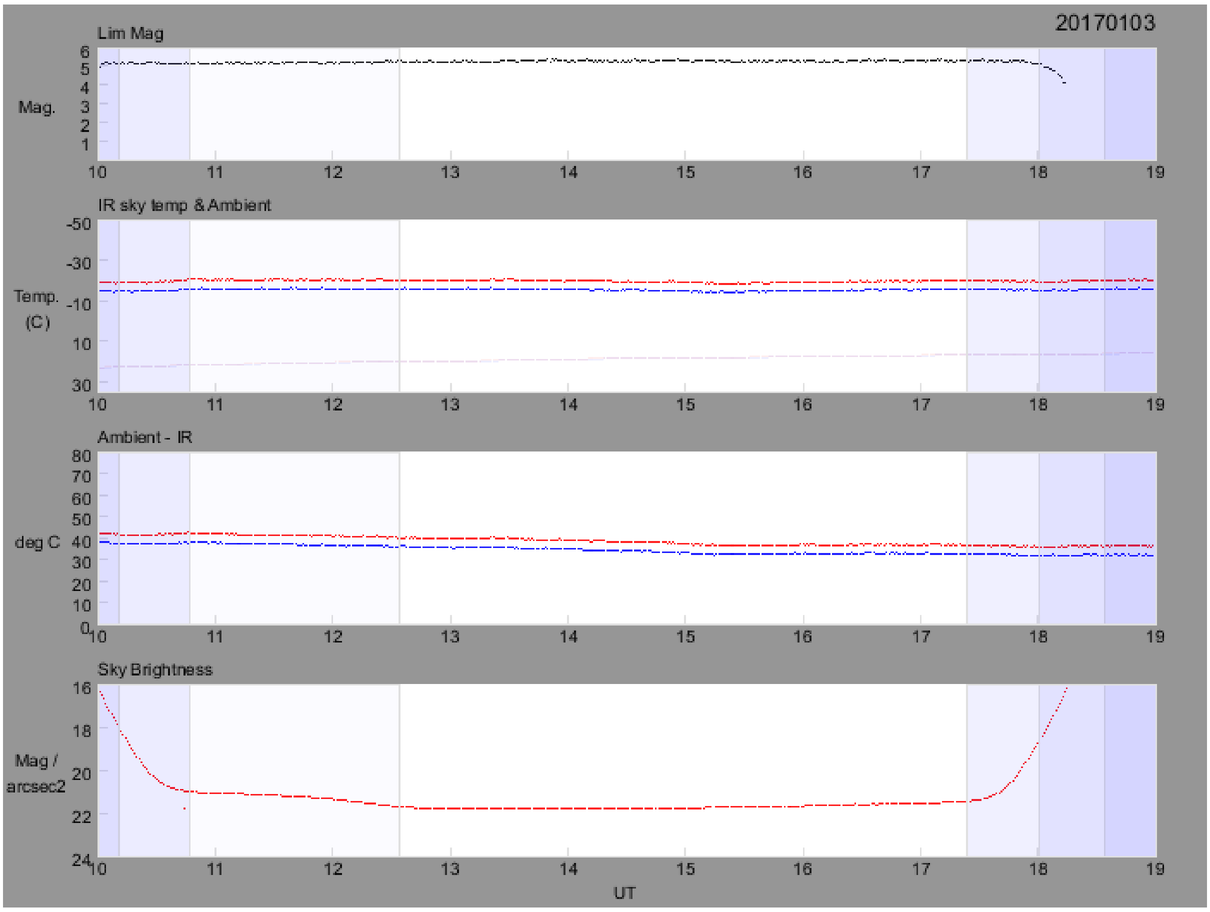
Ref. 11: http://www.map.id.au/skybrightness

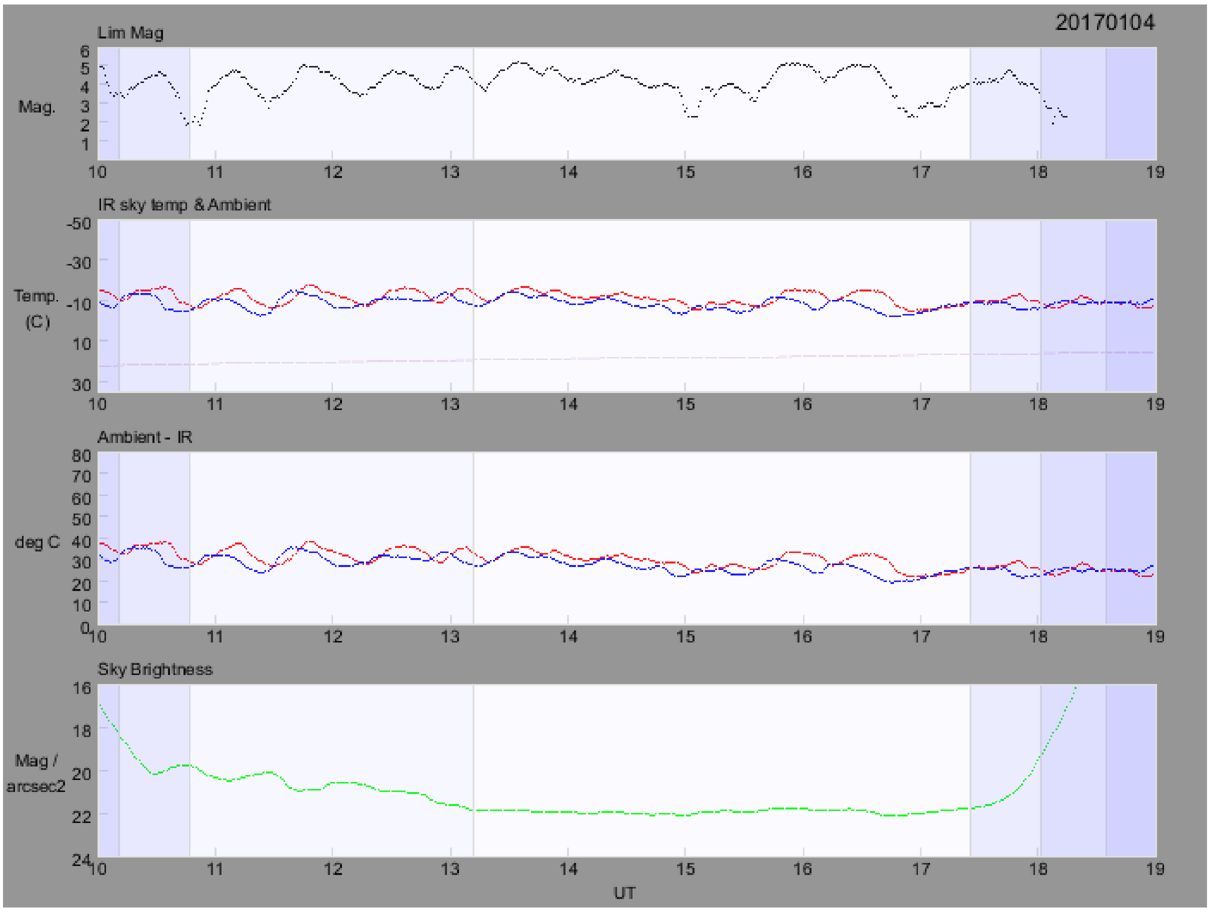
**Appendix 1**

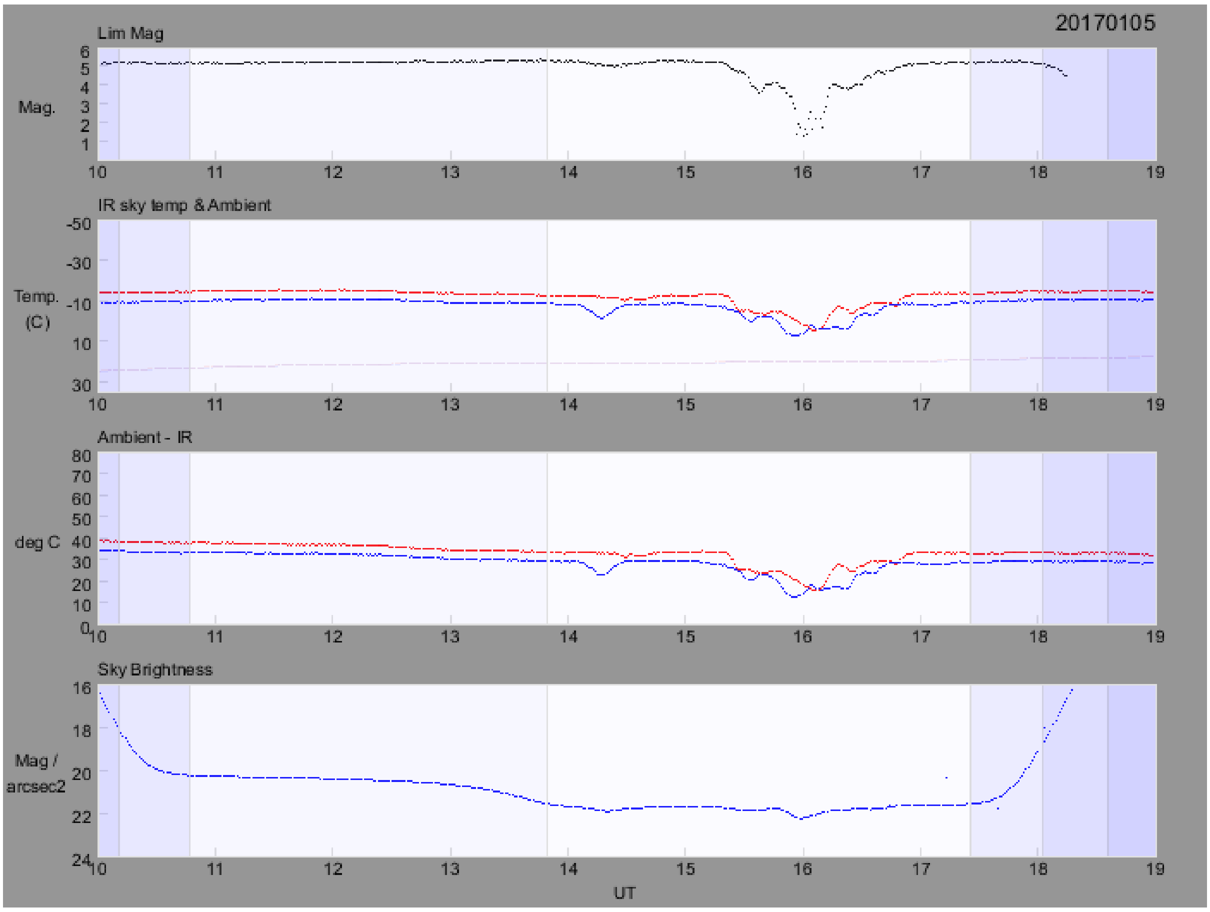
Sky brightness has numerous sources, many natural and many man-made. The most dramatic contributions are sunlight (twilight), moonlight and man-made light pollution. In addition, there are significant modifiers to the effect of light sources through the presence of cloud, or haze due to water or dust. In general, these modifiers magnify the consequences of light pollution. Light pollution has is its minimum impact in a clear sky, so measurements were planned to assess this *minimum impact* during a clear moonless night outside astronomical twilight (sun below 18 degrees below the horizon) with the moon below the horizon and Milky Way not in the direction being measured. The Milky Way is obvious to the naked eye, and thus is a significant contributor to the sky brightness in its direction.

For the past six months, I have been monitoring the sky brightness from my property on the Timor Road, half way between Coonabarabran and Siding Spring Observatory. The equipment comprises a video camera to monitor the faintest stars visible (limiting magnitude), a pair of IR detectors (wavelengths 5-14microns) which essentially measure the sky temperature and is most influenced by water vapour in the atmosphere, and a Unihedron sky brightness meter which measures in the visual waveband with the output in magnitudes per square arcsecond. The video camera is not intensified, so does not directly detect the dark sky background other than around nautical twilight, but the limiting star brightness allows a comparison with the IR detectors for the presence of cloud. All detectors point at the celestial south pole which means stars and Milky Way do not move into and out of the field of view during the night. Any changes in the measured values outside twilight and moonlight are due to the non-astronomical effects of cloud and man-made light pollution. There are no major sources of man-made light pollution within 150km in this direction.

Below are examples of measurements obtained on a totally clear night (2017 Jan 3), mostly clear night (2017 Jan 5) and for a night with significant periods of cloud (2017 Jan 4). These allow a clear comparison of the effect of cloud/haze on a light affected sky (moon present) and a dark sky (no moon).


20170103
Lim Mag
Mag.
6
5
4
3
2
1
10
11
12
13
14
15
16
17
18
19
IR sky temp & Ambient
Temp. (C)
-50
-30
-10
10
30
Ambient - IR
deg C
80
70
60
50
40
30
20
10
0
Sky Brightness
Mag / arcsec2
16
18
20
22
24
UT

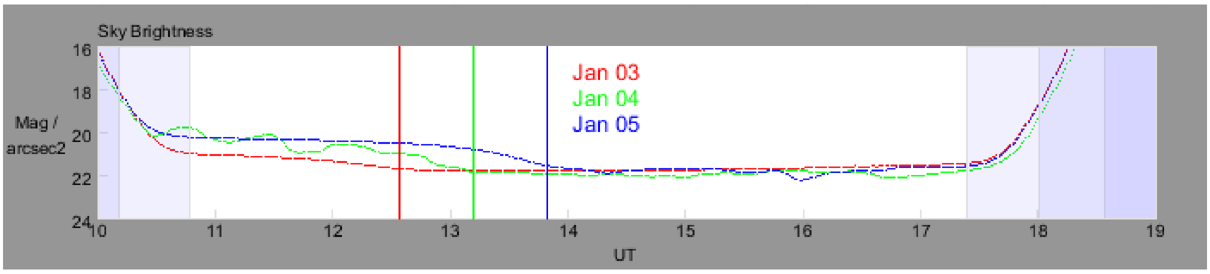

20170104
Lim Mag
Mag.
6
5
4
3
2
1
10
11
12
13
14
15
16
17
18
19
IR sky temp & Ambient
Temp. (C)
-50
-30
-10
10
30
Ambient - IR
deg C
80
70
60
50
40
30
20
10
0
Sky Brightness
Mag / arcsec2
16
18
20
22
24
UT




On each night, there are plots of four different quantities

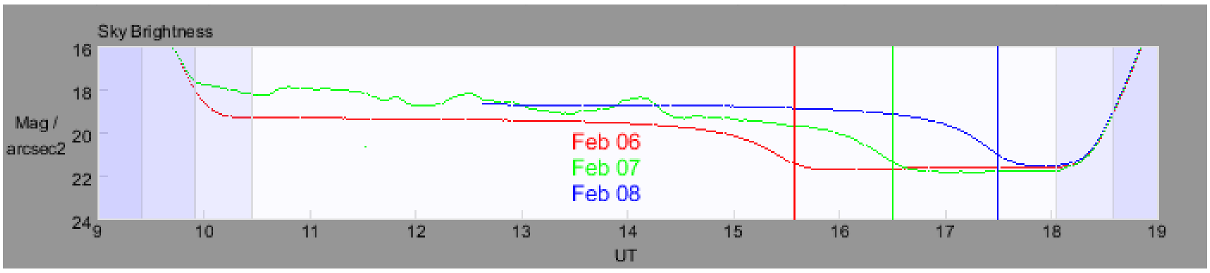
- The top plot is the limiting magnitude from the video camera
- 2nd top is the sky temperature from two IR sensors, the red and blue channels covering the left and right halves of the video camera. The offset between the channels is due to a scale error between the two (cheap) detectors. The grey plot is of the ambient temperature.
- 2nd bottom shows the difference between the ambient and the sky temperatures. This quantity drops to zero in fog or rain.
- The bottom plot is the sky brightness in the visual waveband from the Unihedron sky brightness meter. The meter has a FWHM of 20 degrees of sky.

Over these three nights, nautical and astronomical twilights end at 10:11 and 10:47 UT (Universal Time) and astronomical twilight and nautical twilight start at 17:25 and 18:01 UT. Thus between 10:47 and 17:25 UT the (overhead) sky is unaffected by the sun. The moon is visible in the evening, setting at 12:34, 13:12 and 13:50UT respectively over the three nights, brightening as it moves from new to full. Over these three dates, the evening moonlit sky brightens and allows the comparison of cloud during moonlit and moonless skies. During the moonlit period, the cloud affected sky brightens, whereas after moonset, cloud obscures the natural sky brightness, making it darker. This is clearly shown in the comparison diagram below.



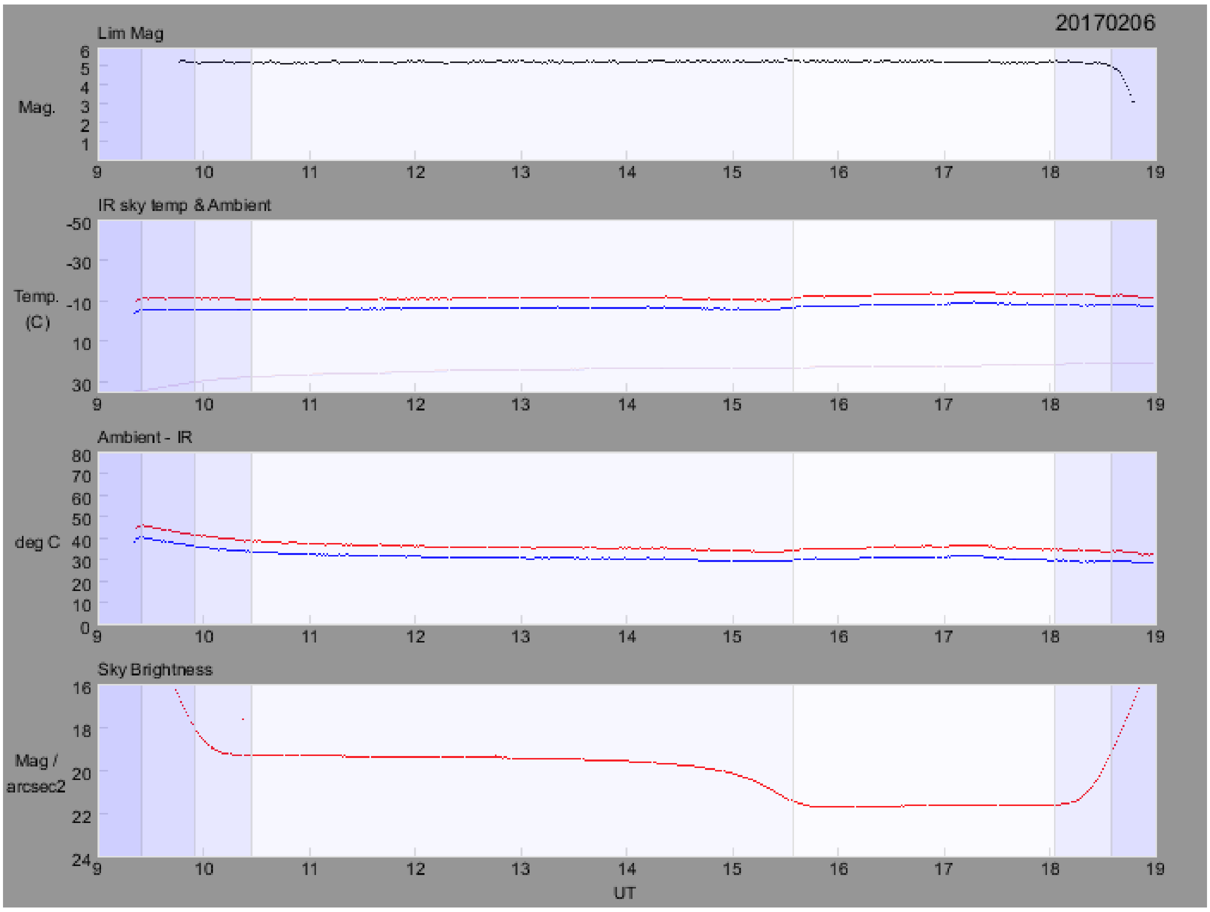

The coloured vertical lines give the time of Moonrise on the three nights. Due to the Earth's orbit and orientation, the twilight times differ from night to night. Evening twilight is the same over the three nights, but is getting later by 1minute/day in the morning. Thus, the data after 17:24UT is plotted 1 minute earlier on Jan. 04 and 2 minutes earlier on Jan 05, allowing a direct comparison during twilights. The data for the two mostly clear nights (Jan. 03 and 05) fall extremely close to each other, except before moonset (Moon is much brighter on Jan. 05, mag -10.0, than on Jan. 03, mag -8.9) and when cloud affects Jan. 05 around 16:00 UT. On Jan. 04, the Moon is a crescent, 6.2 days past new moon and of mag -9.5. The cloud on that night increases the sky brightness when illuminated by moonlight, but lessens the sky brightness when the moon has set and there is no other illuminating source of the cloud like man-made lighting. Note that during morning twilight, the effect of cloud is still to darken the sky: the brightening twilight sky is in the high atmosphere above the cloud, the cloud itself not being lit by the sun till very close to sunrise.

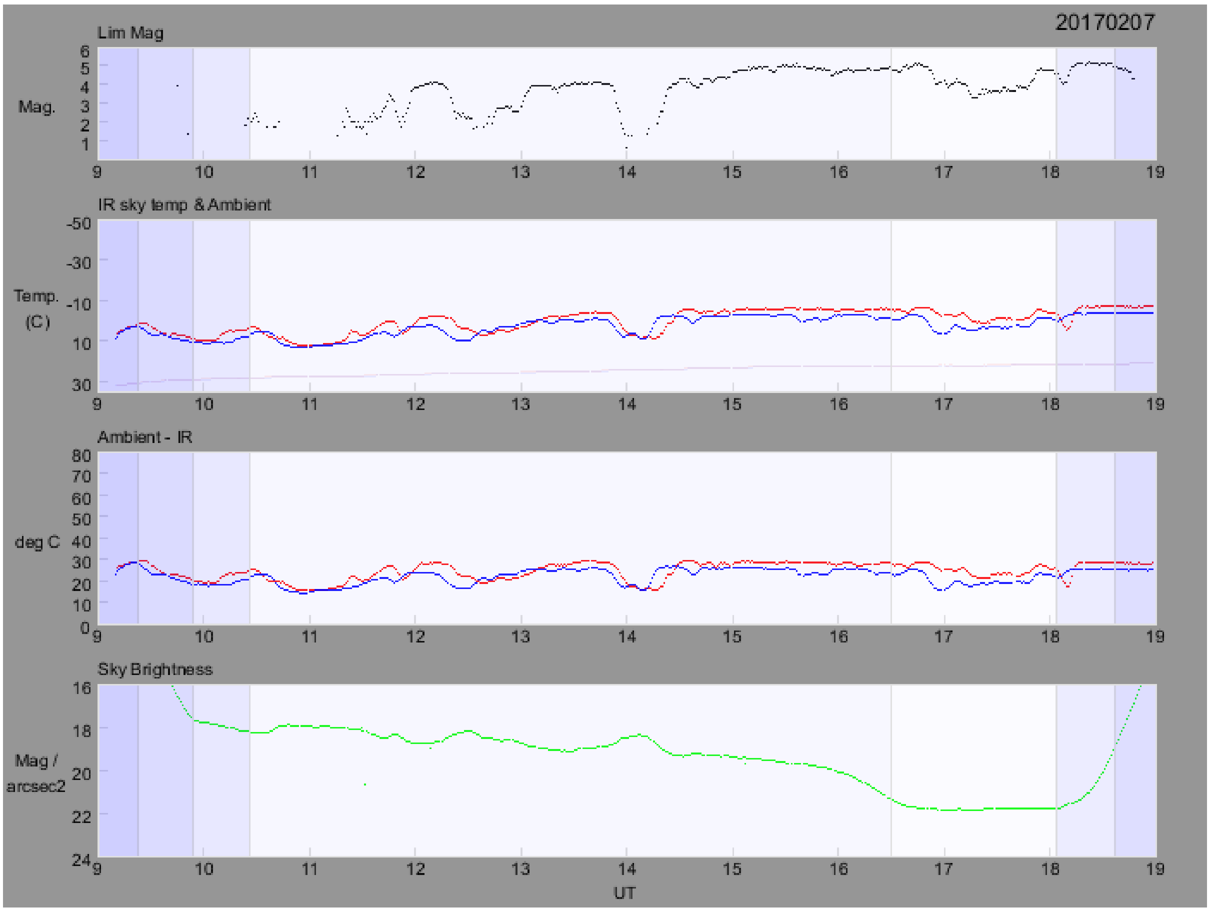
Another example is given below for data obtained over 2017 Feb. 06, 07 and 08, showing the same pattern of effects.

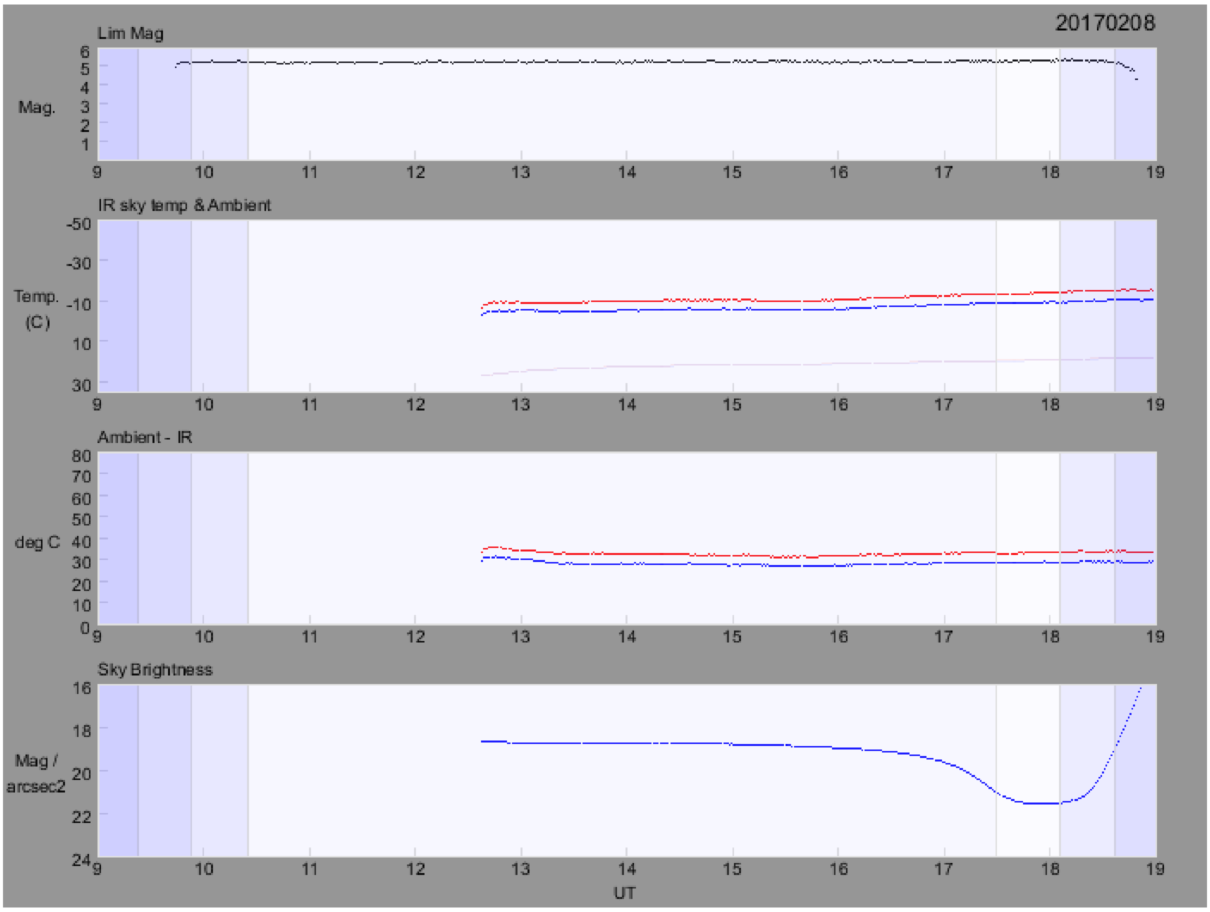



The coloured vertical lines give the time of Moonrise on the three nights. Evening astronomical twilight arrives earlier by 1minute/day and morning astronomical twilight, later by 1minute/day over these three days. Thus, the data before 10:30UT is plotted 1 min later, on Feb. 07 and 2 min later, on Feb. 08. For morning twilight, after 18:06UT data is plotted 1 minute earlier on Feb. 07 and 2 minutes earlier on Feb. 08, allowing a direct comparison of the data during twilight as well as night.

Below are the nightly plots for the second comparison of how light (in this case moonlight) affects sky brightness. On Feb. 08, the IR and sky brightness monitors were not switched on until 12:35UT.


20170206
Lim Mag
Mag.
IR sky temp & Ambient
Temp. (C)
Ambient - IR
deg C
Sky Brightness
Mag / arcsec2
UT


20170207
Lim Mag
Mag.
IR sky temp & Ambient
Temp. (C)
Ambient - IR
deg C
Sky Brightness
Mag / arcsec2
UT




**Sky Brightness Meter Accuracy**

Unihedron quotes an accuracy of its SQM-LU (computer connected) and SQM-LU-DL (internal data logging) thus: “Each SQM-LU is factory-calibrated. The absolute precision of each meter is believed to be +/-10% (+/-0.10 mag/arcsec$^2$). The difference in zero-point between each calibrated meter is typically +/-10% (+/-0.10 mag/arcsec$^2$).”

Comparison of my three meters show small (~0.05 mag/arcsec$^2$) zero-point differences, but the relative accuracy is ~0.02 mag/arcsec$^2$. The hand-held narrow-field model (same field size as the above two models) is less accurate at ~+/-20%.

A 10% increase in sky brightness equates to drop of 0.10 mag/arcsec$^2$.