Night Sky Brightness

Even when moonless, the night sky is far from black and dark. You would think that all those stars out there, those galaxies you may catch a glimpse of, are what causes this, but in truth, they hardly effect the brightness of the sky. The major brightness contributors to the night sky (after the moon) are zodiacal light, airglow and scattered starlight.

Airglow:

A glowing luminosity which originates from earths own atmosphere, airglow occurs all across the atmosphere and its brightness seems to be globally uniform. The brightest region is a 10km thick section, roughly 100km up in the atmosphere. Different regions in the atmosphere have different colours of glow. This glow is caused by chemiluminescence. Chemiluminescence light emission is caused by chemical reactions, usually between oxygen, nitrogen, sodium and hydroxyl atoms and molecules, between 100 and 300km up in the atmosphere. During the day, solar radiation energy breaks electrons away from the atoms, but at night the resultant ions combine, and this is what generates the glow, as this combining reaction is accompanied by an emission of light.
The colours, atoms that cause them, their rough wavelength and rough height of where they occur in the atmosphere:
Green : oxygen and nitrogen, 558nm, 90-100km up. **Yellow:** sodium, 589nm, 5km band somewhere between 85 – 105km up. **Red:** ozone and hydrogen, roughly 640 nm and up, between 105 – 300km high. Airglow contributes significantly more light to the night sky than starlight, and is the brightest contributor.
Relevant Links:
http://www.albany.edu/faculty/rgk/atm101/airglow.htm
http://www.universetoday.com/112237/how-to-see-airglow-the-green-sheen-of-night/

Zodiacal Light:

Zodiacal light is an astronomical source of light. It appears as a diffuse white glow and is very faint. Obscured by any kind of ambient light, it is usually seen as a small triangular shape extending up from the horizon. This source of brightness is caused by the reflection and scattering of sun light from tiny dust particles which are concentrated roughly along the ecliptic plane. It is known as zodiacal light as it is best seen in the region known as the zodiac, this region extends to 8 degrees above and below the ecliptic plane. This is considered the second strongest source of night sky brightness.
Relevant Links:
http://www.encyclopedia.com/topic/zodiacal_light.aspx
http://en.wikipedia.org/wiki/Sky_brightness
http://earthsky.org/astronomy-essentials/everything-you-need-to-know-zodiacal-light-or-false-dusk

Scattered Starlight:

Another astronomical source of brightness, scattered starlight is one of the lowest contributors to the brightness of the night sky. Air scatters starlight and the diffuse light of the galaxy when it reaches the atmosphere. Stars up to magnitude 16 can contribute to the diffuse scattered starlight. This has very little effect on the brightness of the night sky.

A measured base of brightness, at which the night sky can hardly get darker, with no man-made light pollution and no moon, has a brightness level of roughly 22 mag. per square arcsecond.

The different contributors to night sky brightness and their effect (suspect V- band):

Light source	Surface brightness [S_{10}]	Percentage
Air glow	145	65
Zodiacal light	60	27
Scattered starlight	15	7

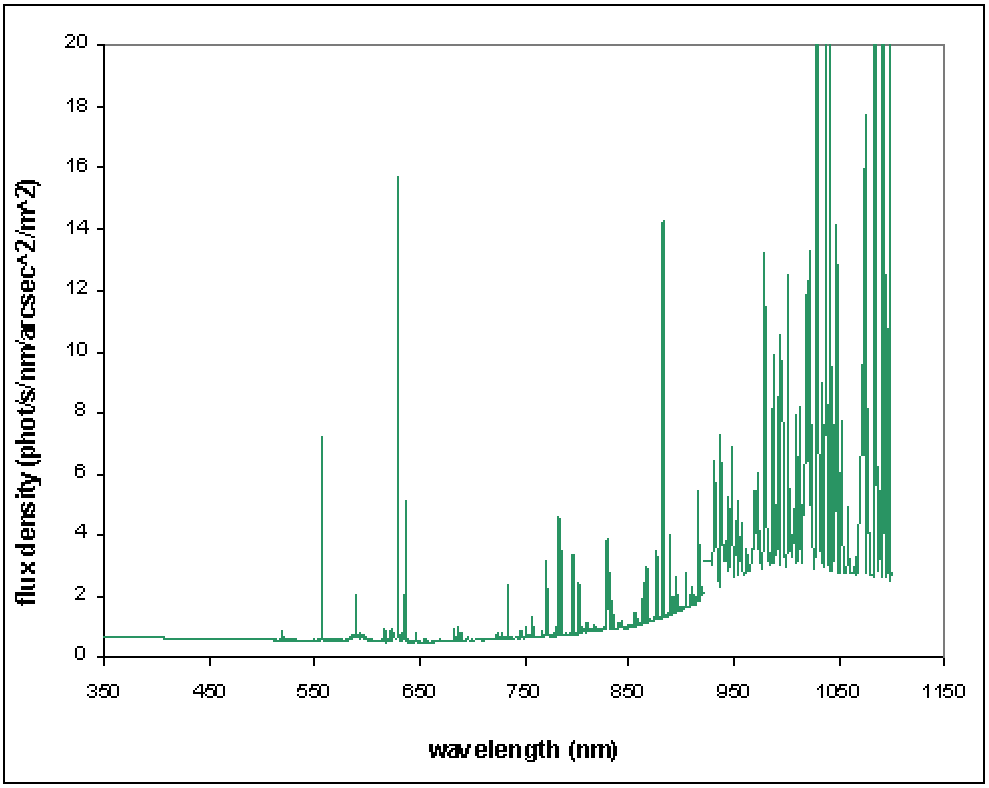
(The S_{10} unit is defined as the surface brightness of a star whose V-magnitude is 10 and whose light is smeared over one square degree, or 27.78 mag arcsec^{-2})

“The **colour** of the sky changes with lunar phase. Adopted values are shown in the table below (taken from ESO, by scaling V for inferred equivalent lunar phase, and from Walker, NOAO Newsletter No. 10). The conversion between the sky background category and the number of nights from new moon indicates the constraints that are applied to schedule **classical** observations and do not necessarily correspond to conventional definitions of dark, grey and bright time.”

Sky Background Category	Approx Nights From New Moon (+/-)	Sky Brightness (mag/arcsec2)			
		V-band	U-band	B-band	R-band
20%-ile ('darkest')	=< 3	21.3	V + 0.0	V + 0.8	V - 0.9
50%-ile ('dark')	=< 7	20.7	V - 1.5	V + 0.2	V - 0.8
80%-ile ('grey')	=< 11	19.5	V - 2..2	V - 0.0	V - 0.4
any ('bright')	=< 14	18.0	V - 3.0	V - 0.5	V - 0.1

“The broad-band sky brightnesses given in the table above have been used to scaled a model **optical sky spectrum** . These spectra are used in the Integration Time Calculators. The sky spectrum is patched to the near Testing of brightness – ESO Skycalc

-IR sky spectrum at a wavelength of 920nm. An example is shown below (for 50%, 'dark' conditions) and the data file is available.”

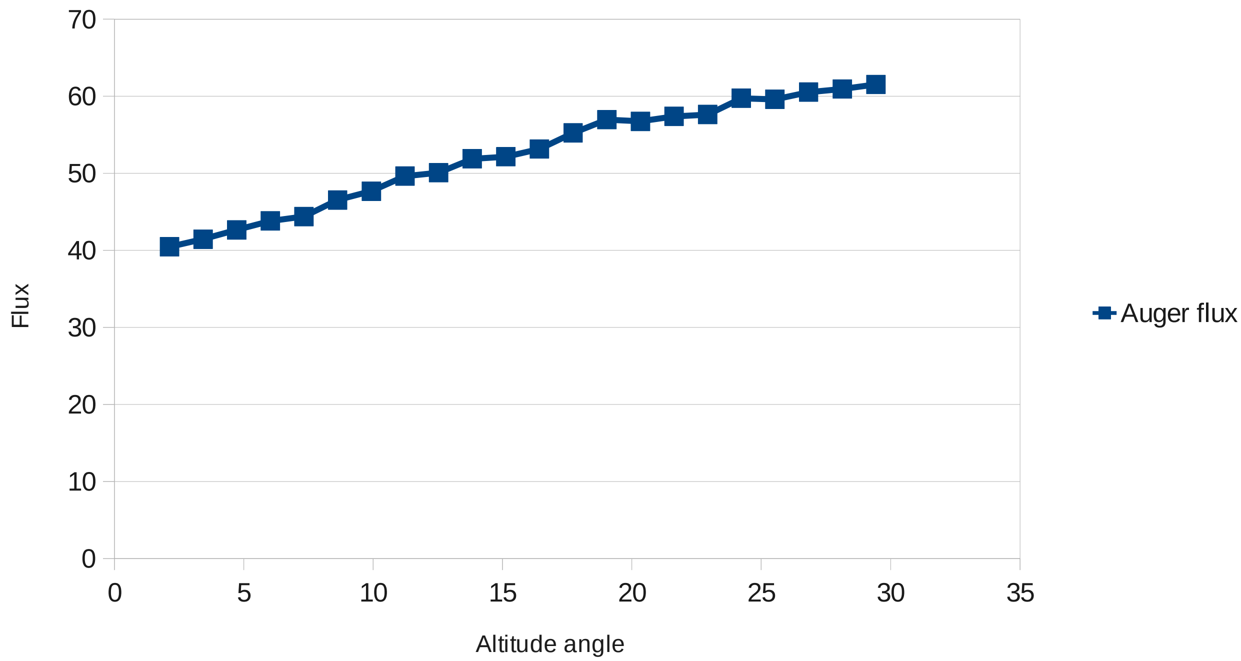


http://www.gemini.edu/sciops/telescopes-and-sites/observing-condition-constraints/optical-sky-backgroundTesting of brightness – ESO Skycalc

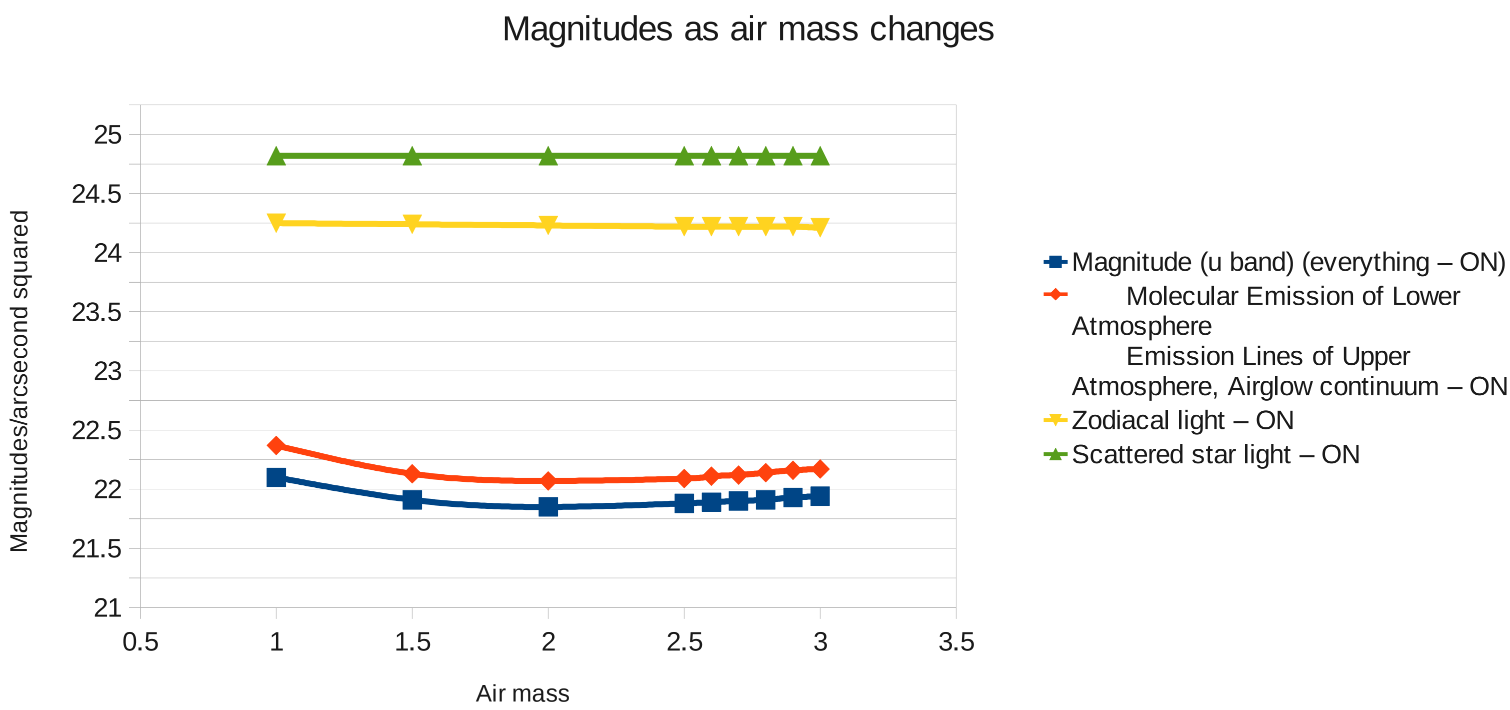
<u>Testing of brightness – ESO Skycalc</u>

Using the skycalc, the brightness of the night sky can be measured using a model made at Cerro Paranal, and by toggling features such as a moon, zodiacal light, airglow etc. The following results are the brightness levels within the U – band, without a moon, testing what effects the night sky brightness. (Zodiacal light target angles are (135, 90)
ESO Skycalc: https://www.eso.org/observing/etc/bin/simu/skycalc

The data from Auger:

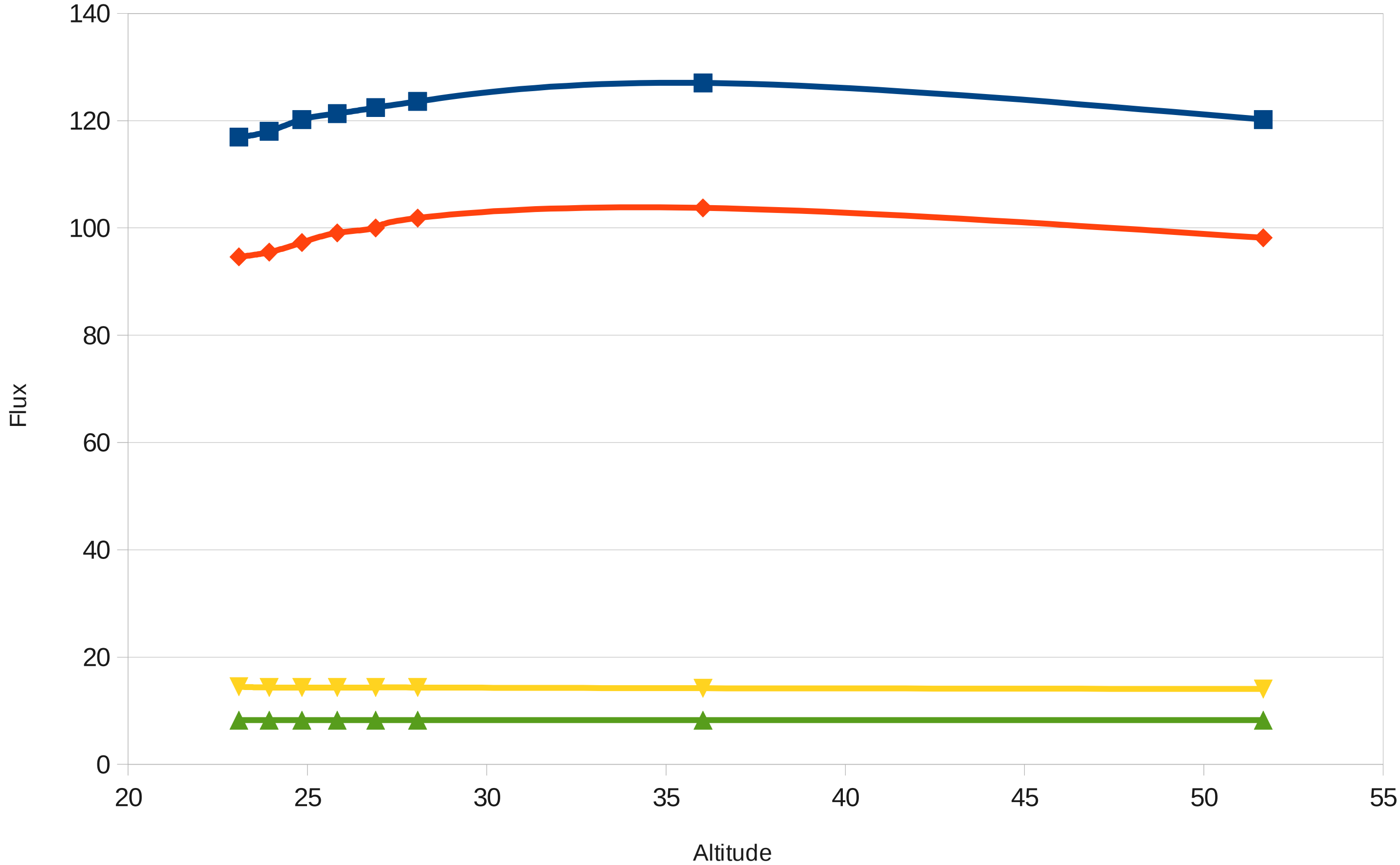


Skycalc ESO brightness measured in magnitude per arcsec^2 as a function of air masses:

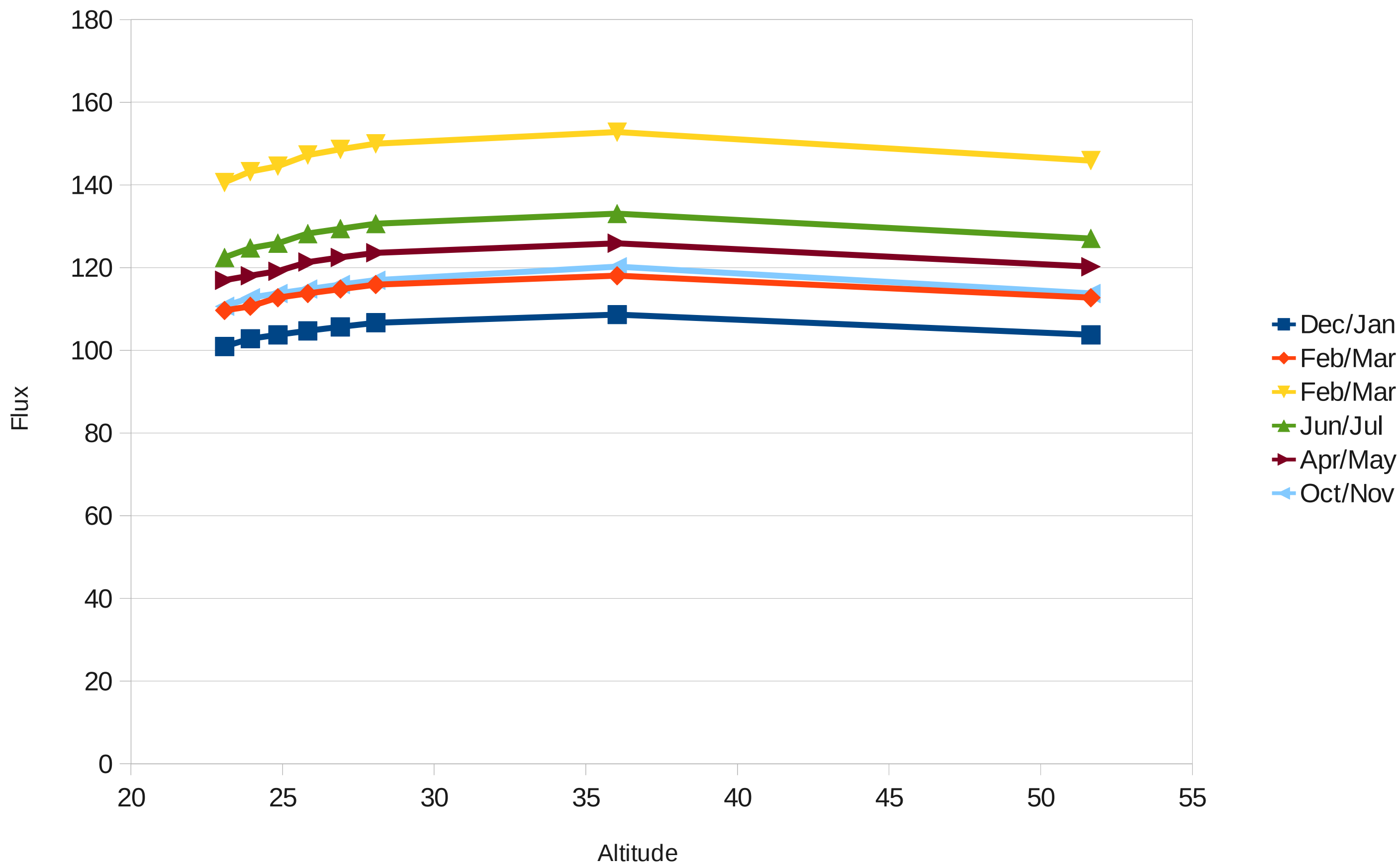


In this, the magnitude of each brightness component is measured. Airglow seems to have the most impact. The total magnitude is also present, in which all of the sources of light are contributing.

The same graph, measured in flux as a function of altitude angle:



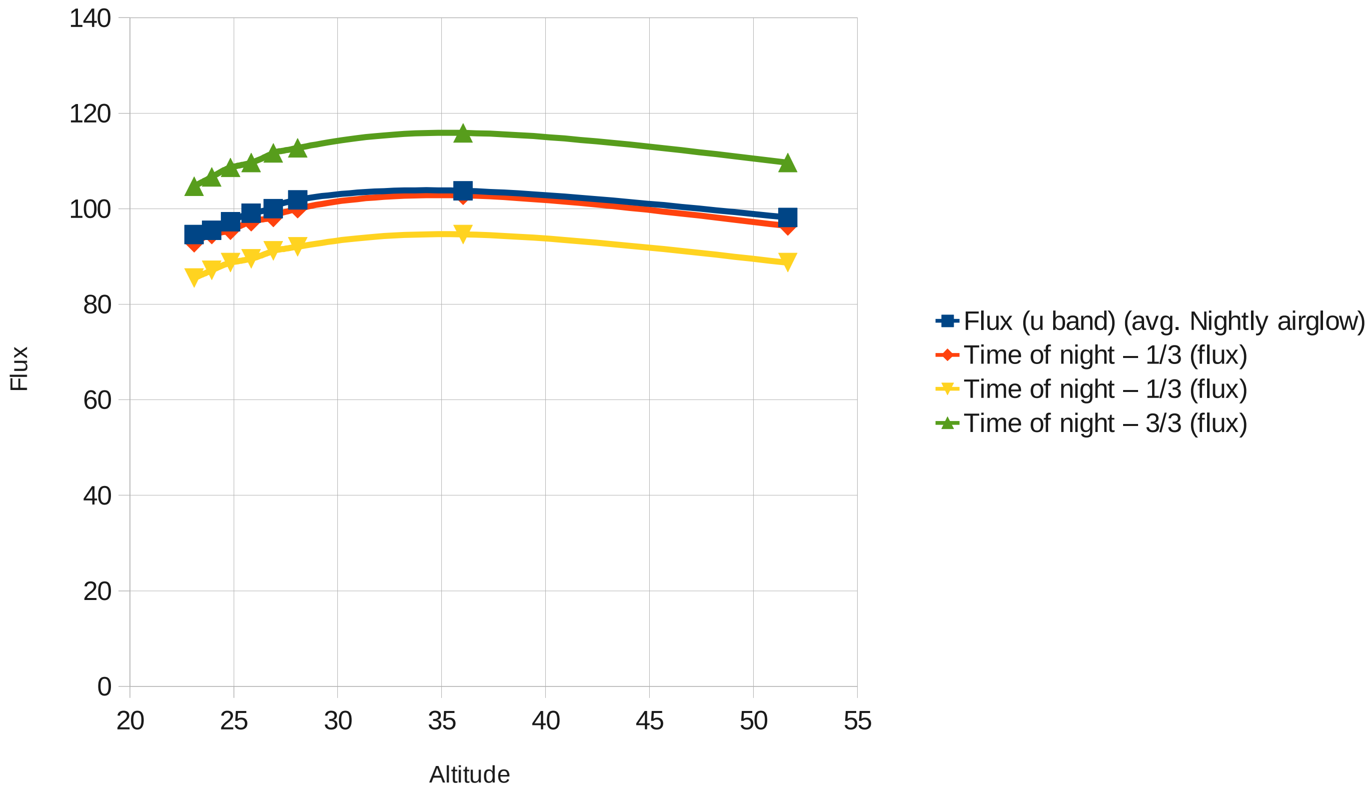
The seasonal effects on brightness, measured in flux as a function of altitude angle:



February/March are the brightest months in this area, with December/January being the dimmest. Contrary to our hypothesis, season had no effect on zodiacal light.

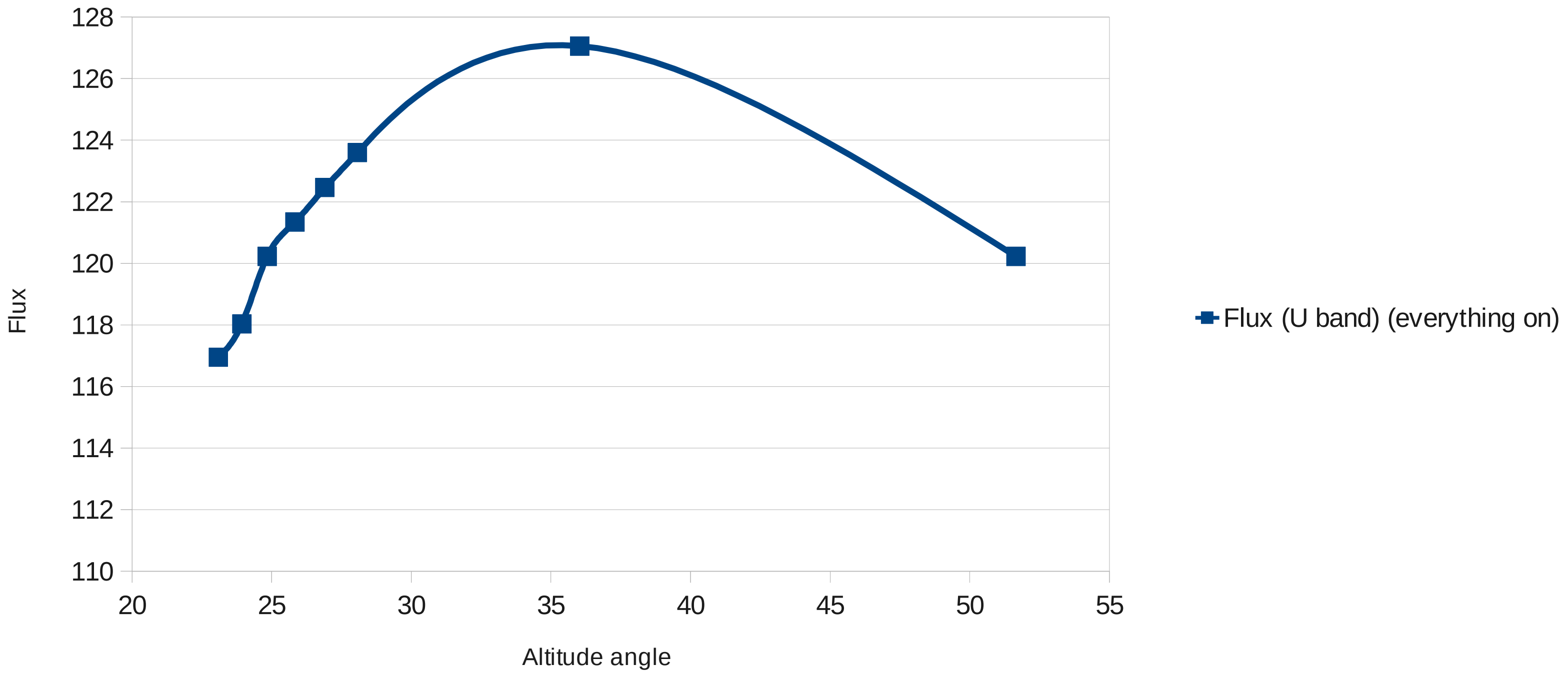
Water vapor's effect on brightness is non-existent in the U- band

The effect of the time of night on air glow, measured in flux as a function of altitude angle:



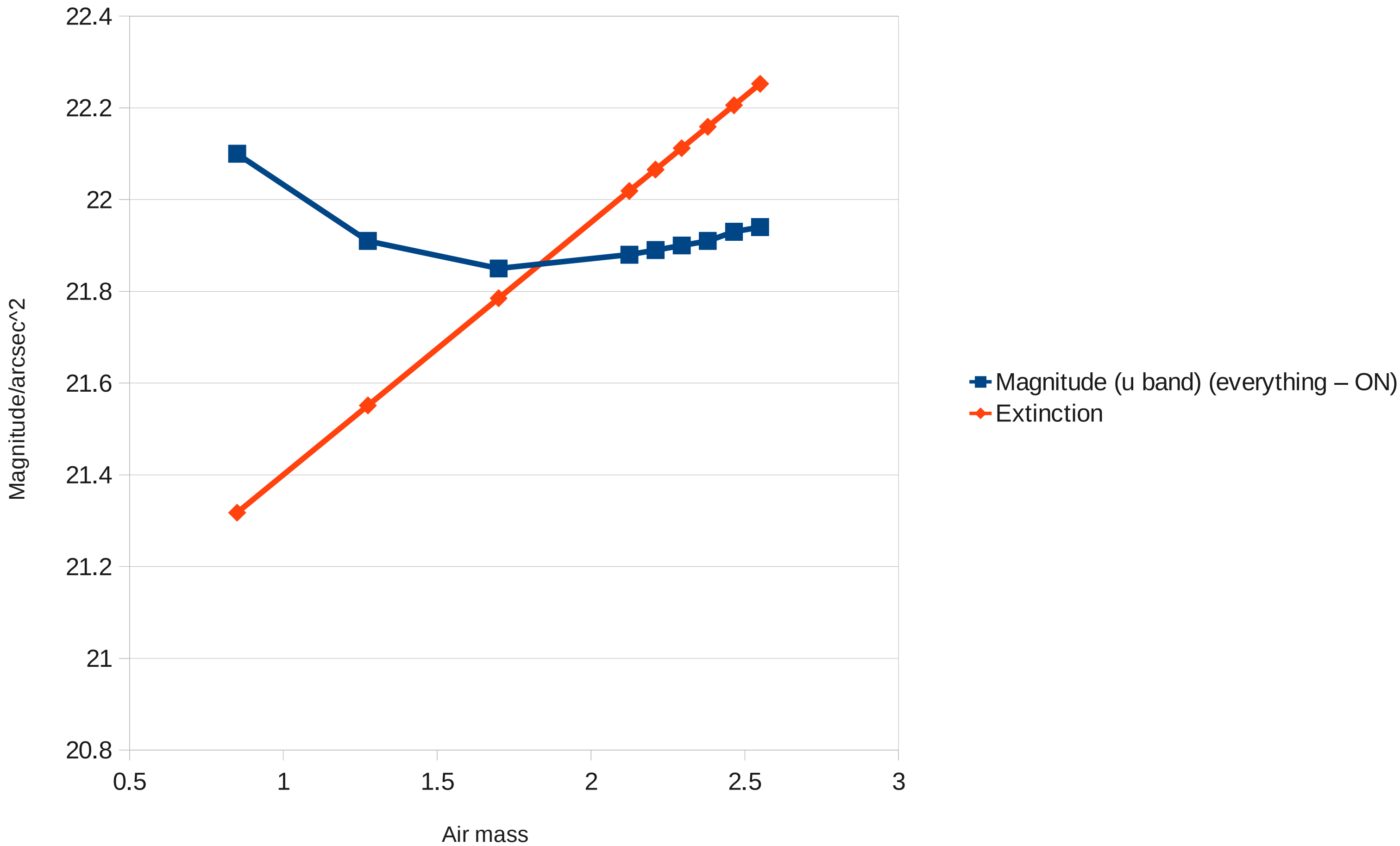
(yellow is 2/3)
The time of night changes the brightness of air glow, with air glow being strongest in the last third of the night and weakest in the second. This fits with the current knowledge of it, as the amount of excited particles combining decreases over time, so there is less reaction in the 2nd, but more in the 3rd where the suns energy is possibly contributing to the reactions again.

Fitting the flux from the model to the altitude angles at Auger:



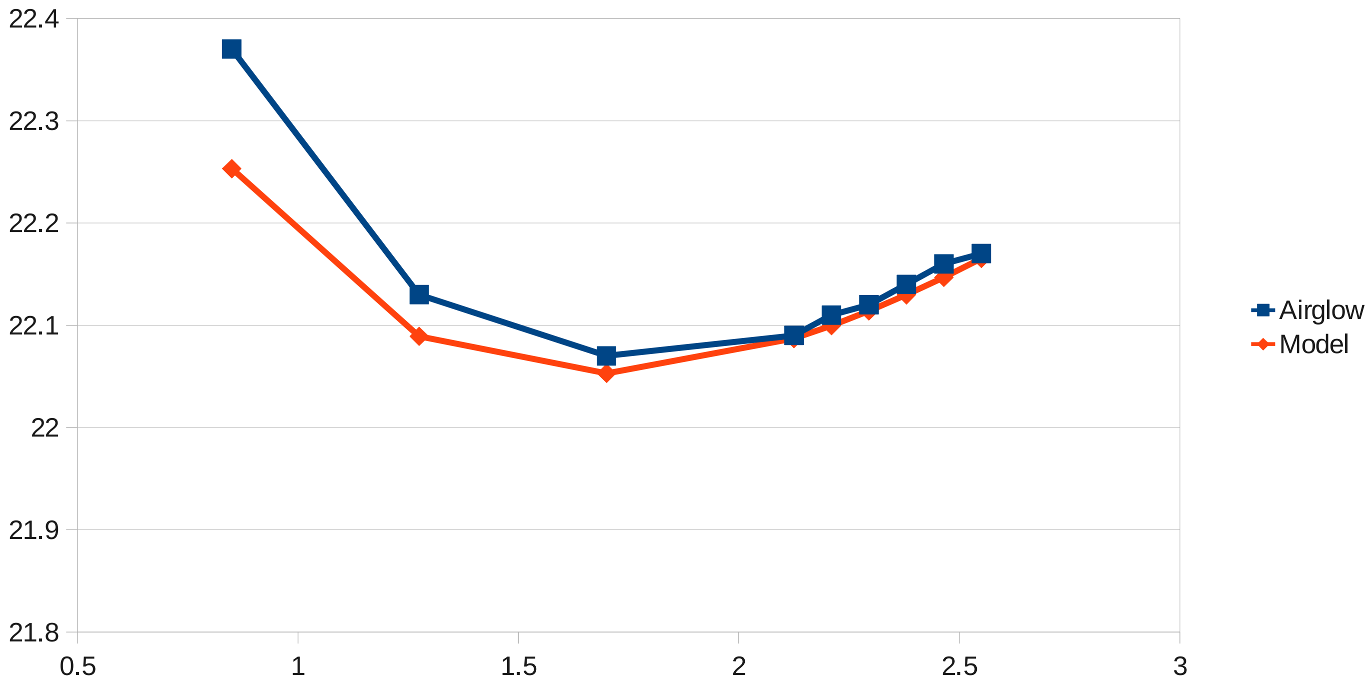
By roughly calculating what an air mass at Cerro Paranal is as an air mass at Auger, the altitude angles at Auger can be found. These altitudes angles are then fitted to the flux found using the model. This is the flux found using the model, as a function of the altitude angles at Auger.

Extinction rate and data found, shown as magnitude per arcsec^2 as a function of air mass:



Using the previous graph – the flux from the model on the altitude angles of Auger, the flux was converted to magnitudes per arcsec^2 and the altitude angles to air masses, so an extinction factor could be plotted next to it. It would be expected that the end of the light would be following the line of extinction, but it does not dim as fast as it should as the air mass increases. This might be due to the fact that though you look through more air and therefore attenuation is increased when you look toward the horizon, you are also theoretically looking through more airglow, this is potentially slowing the dimming of the light.

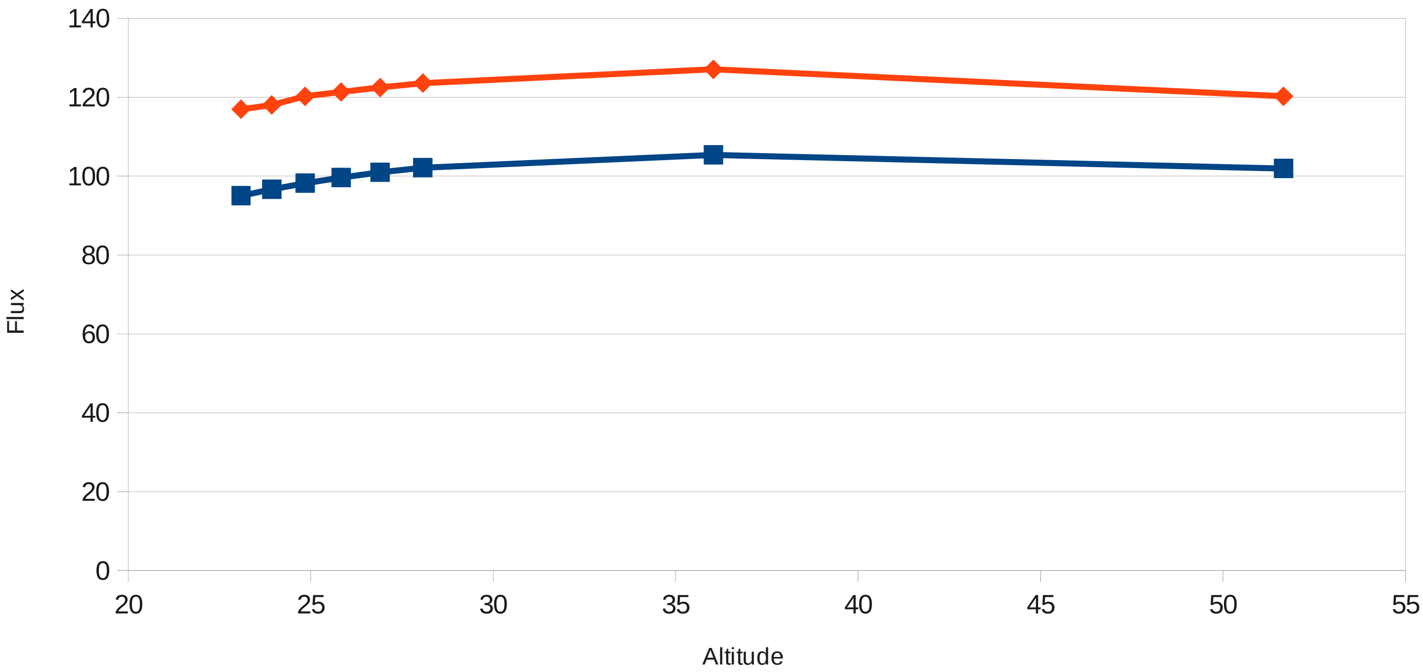
Airglow (flux) over different air masses, with a model of what airglow production might be had it caused the deviation in the last graph:



Devising a model of how airglow is increasingly produced as air mass increases, but factoring in extinction also increasing as air mass increases, we fitted this to the data gained on airglow changing as air mass was increased. This model was remarkably close to the results given by the Skycalc. Due to that fact and the idea that we had developed that airglow was the major light contributor and had caused the extinction deviations, we could use this model to possibly extrapolate the total ESO results to further altitude angles that Auger used, but the Skycalc could not calculate and see whether the original Auger data fit with the Skycalc data.

Model equation:
M (airglow produced) = -2.5*LOG10((1.35*10^-9)*airmass)+0.65*(airmass-1)
where 0.65 = extinction co-efficient
and (1.35*10^-9)*airmass represents the source contribution of airglow

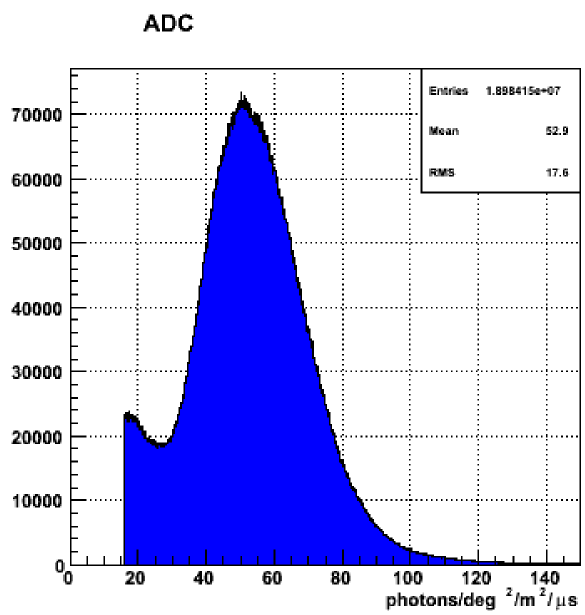
Our airglow model compared to the total ESO data

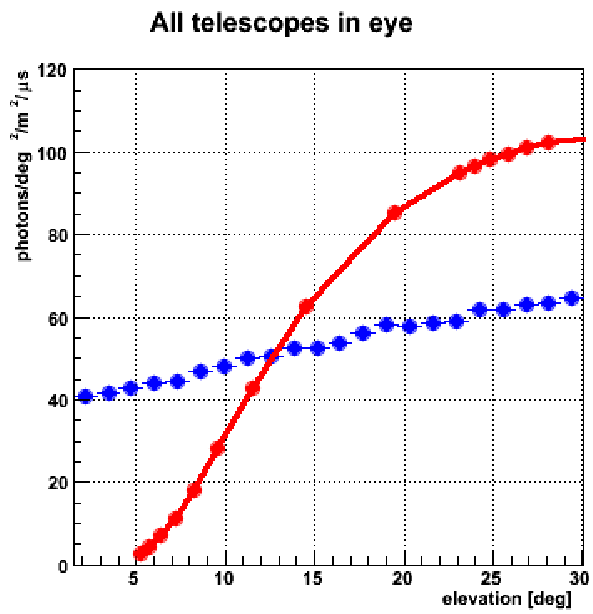


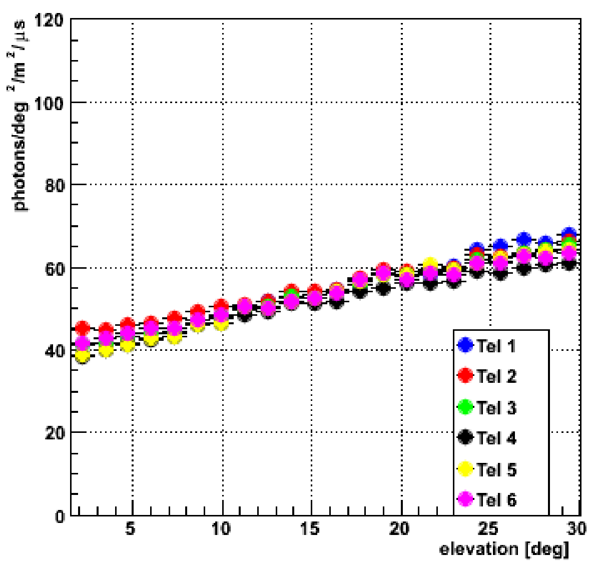
Our Model For Airglow = Blue
ESO Data For Total Background Light= Orange

Our model is 20 % lower than the total ESO curve. This is understood as we have neglected the contributions of zodiacal light and scattered starlight. However the shapes are very similar. Our model can extrapolate to smaller altitude angles.

Our extrapolated model, compared to Auger results from January 2013:



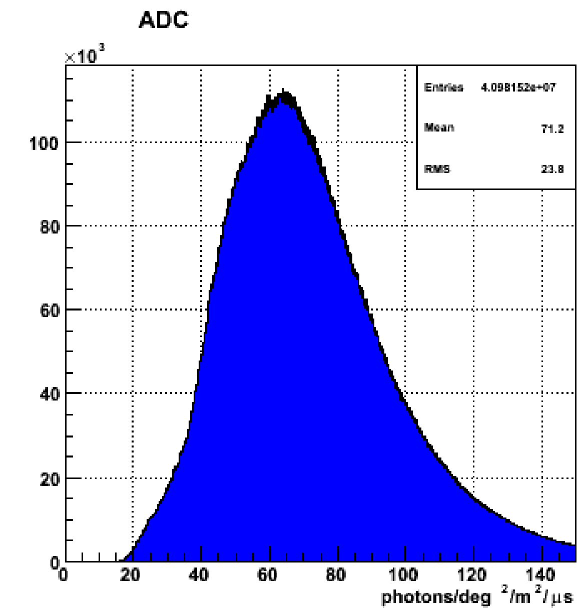


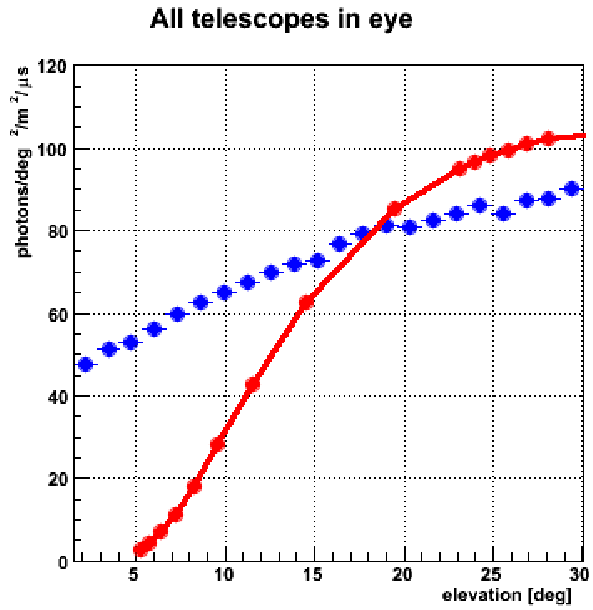


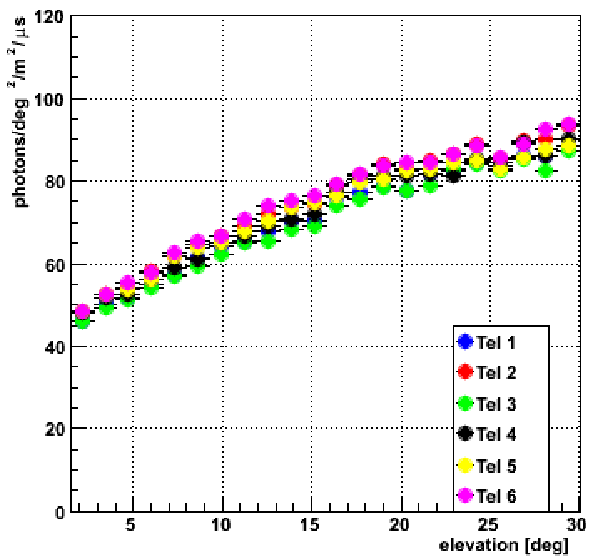
Our extrapolated model is in red, the Auger data in blue

This is the average data taken from the Auger telescope of Coihueco in the first month of 2013. Our extrapolated model is much steeper than it.

Our extrapolated model, compared to Auger results from April 2013:



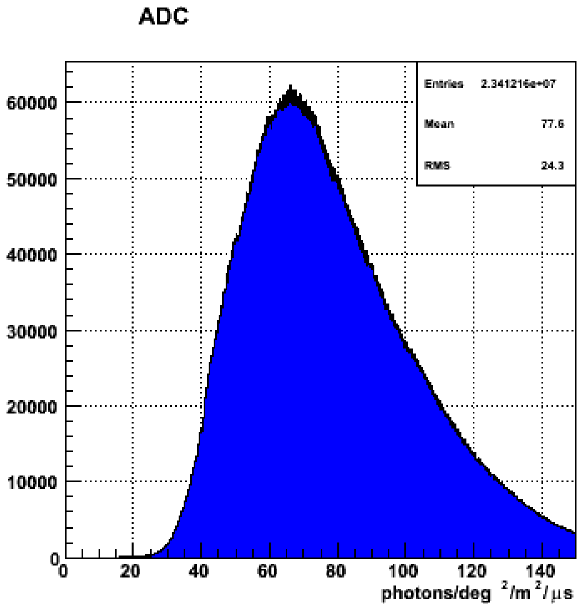


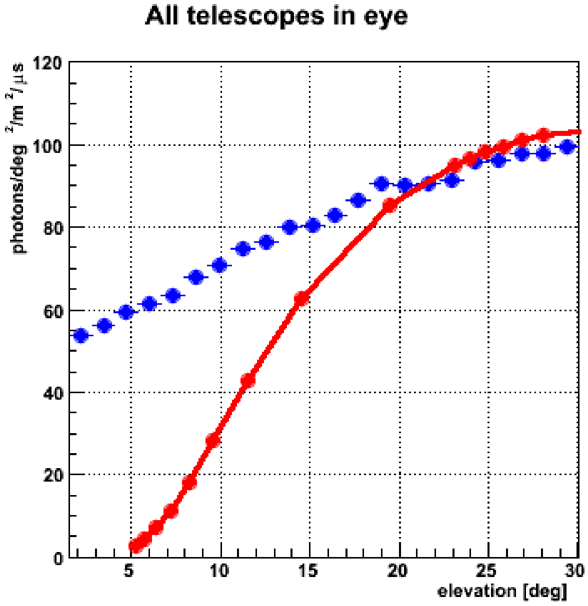


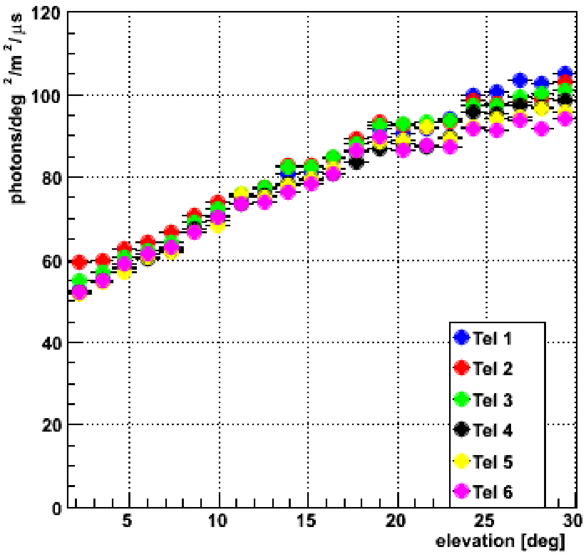
Our extrapolated model is in red, the Auger data in blue

In the month of April, the data recorded at Auger from the Los Morados telescope is a lot closer to our model, yet still not as steep, as it conserves flux as the elevation decreases, whereas our model loses flux very quickly. It should also be of note that, as mentioned earlier, April is one of the brightest nights for the night sky, which would explain why this is higher than January.

Our extrapolated model, compared to Auger results from December 2013:





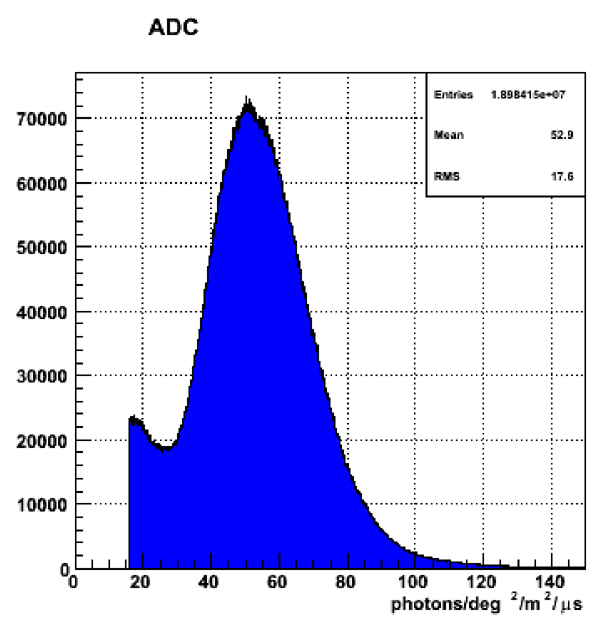


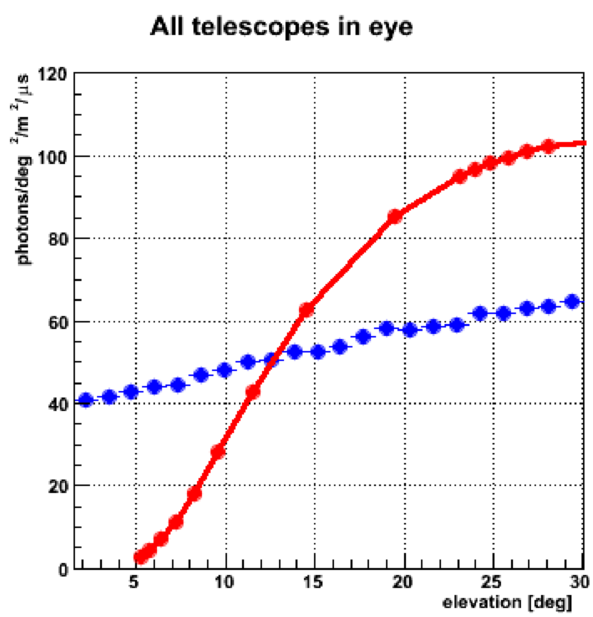
Our extrapolated model is in red, the Auger data in blue

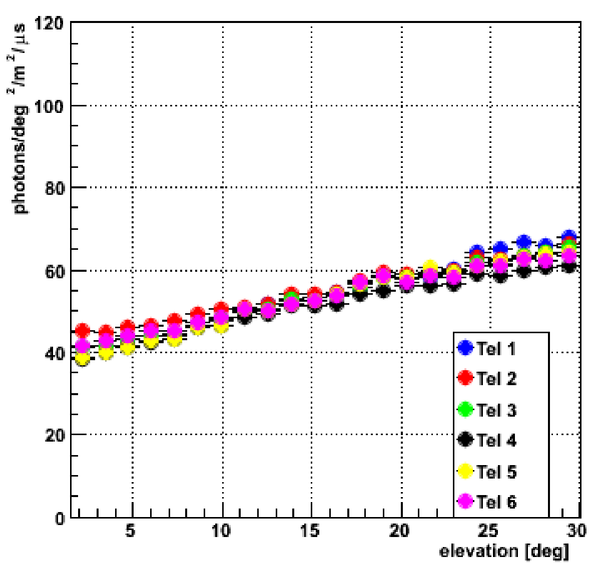
This data was taken in December by Coihueco, which according to the skycalc has the lowest brightness of the months, yet this data is as high as that from April. This data fits with or model at higher elevations, but yet again, the model is a lot steeper than this data.

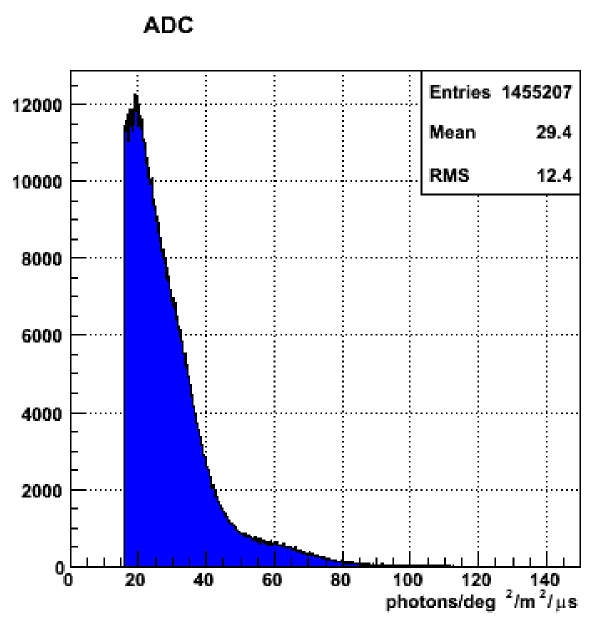
Data from a single day :

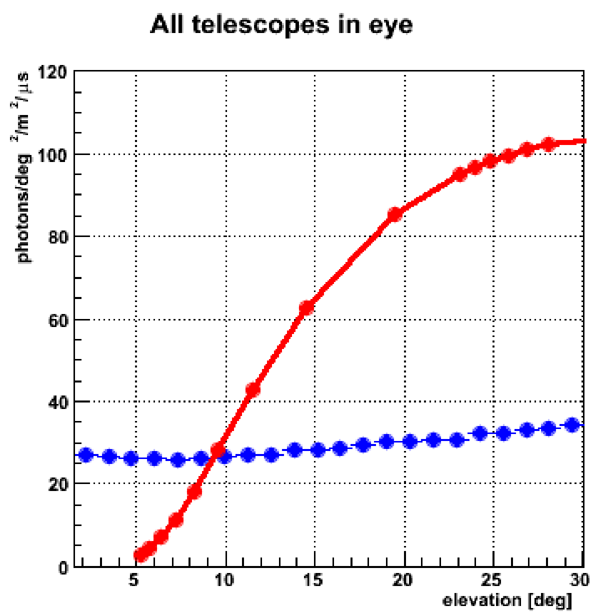
Here again is the average data from January of 2013, which is a lot higher than the data on the next page which is taken from a single day in January. This random error was most likely caused by cloud cover on that day, which would have blocked the light and created a dimmer result. Things like cloud cover aren't tested by the skycalc and could possibly be affecting the overall results.

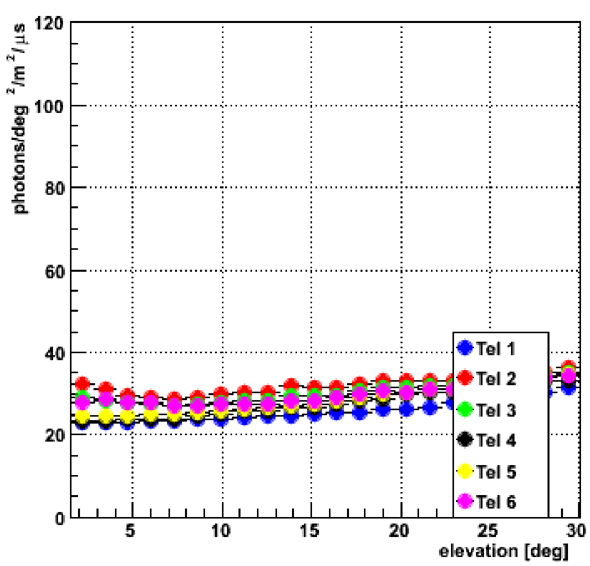







ADC
Entries 1455207
Mean 29.4
RMS 12.4
photons/deg ^{2}/m ^{2}/ μs


All telescopes in eye
photons/deg ^{2}/m ^{2}/ μs
elevation [deg]


photons/deg ^{2}/m ^{2}/ μs
Tel 1
Tel 2
Tel 3
Tel 4
Tel 5
Tel 6
elevation [deg]