Modelling Light Pollution for Highways Agency Environmental Policy, AONB Dark sky study, Impact of LED lighting, and a Sea based Windfarm proposal.

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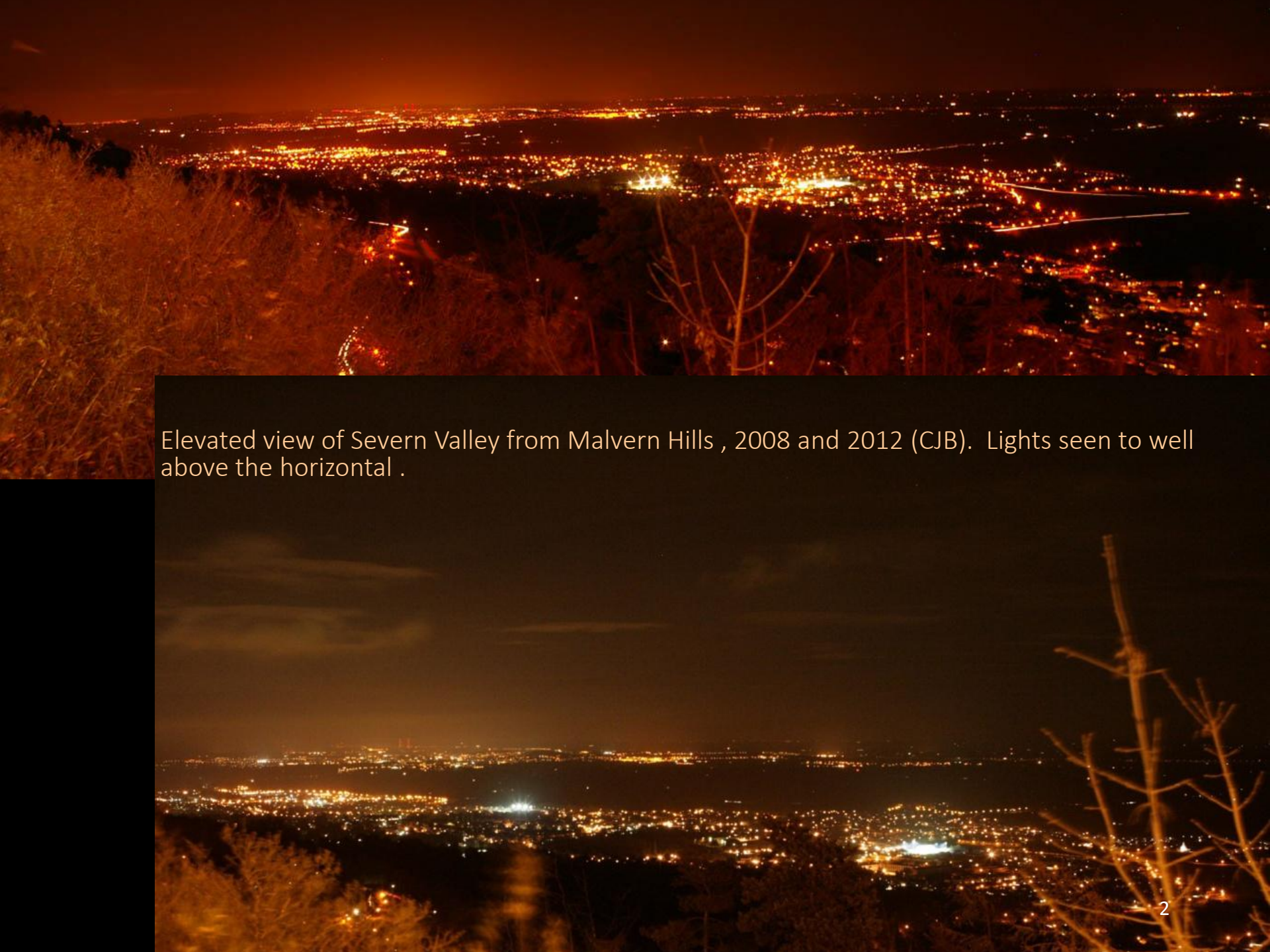
IAU General Assembly Meeting, Honolulu, Hawaii.

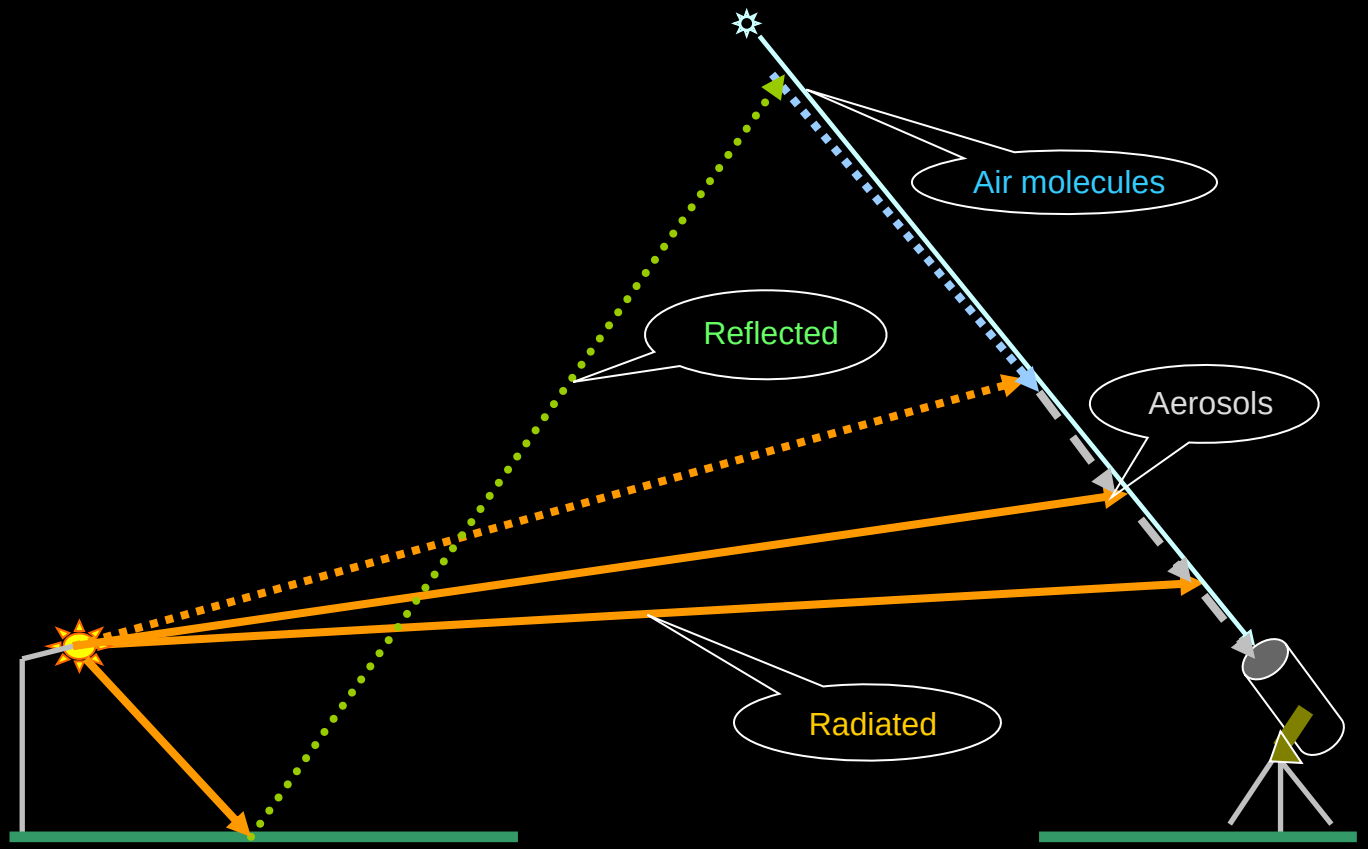
Week 2, 2015 Aug 10- Aug 14



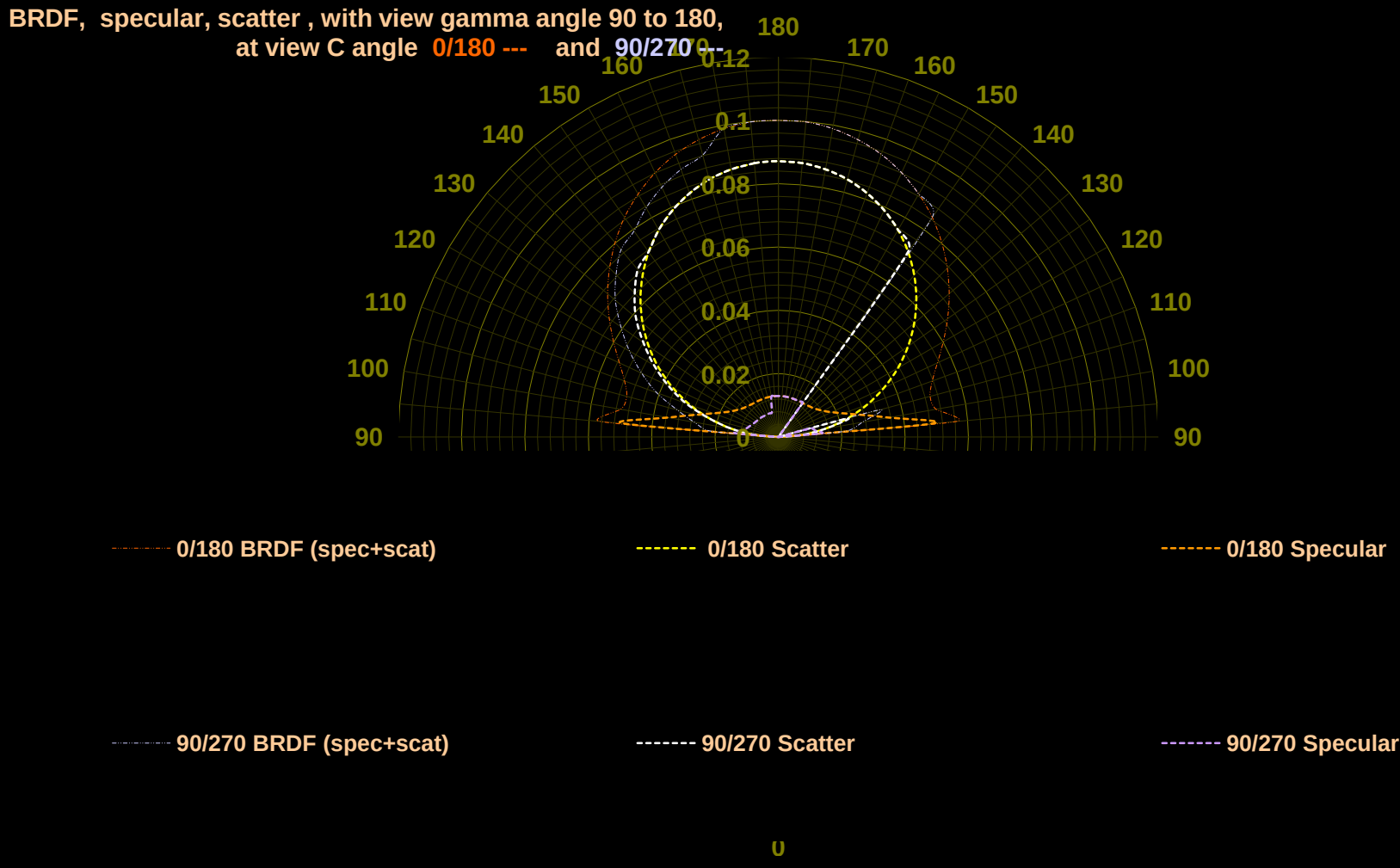
Elevated view of Severn Valley from Malvern Hills , 2008 and 2012 (CJB). Lights seen to well above the horizontal .

Modeling Method

- Luminaire specific photometry with ray trace ground types reflectance and scattering, and atmospheric scattering view-path sky luminance modelling



Bi-Reflectance Distribution Function (BRDF) from road and verges has a Lambertian scatter and specular component.

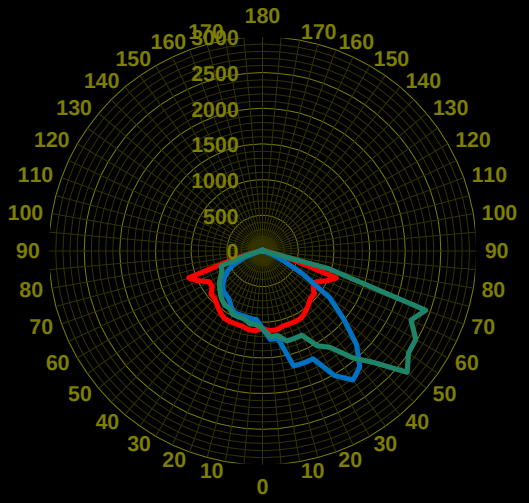


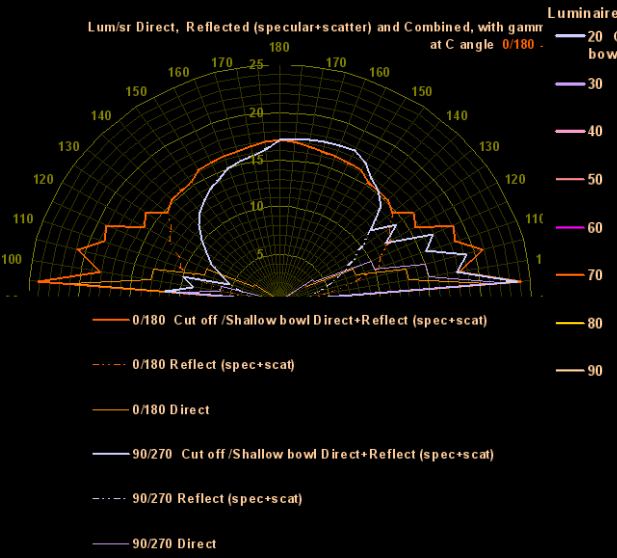
Ground Reflection

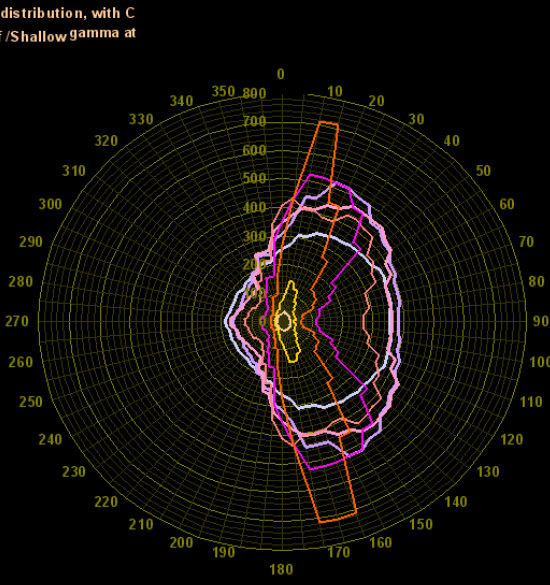
DIRECT

IMPACT OF GROUND REFLECTION

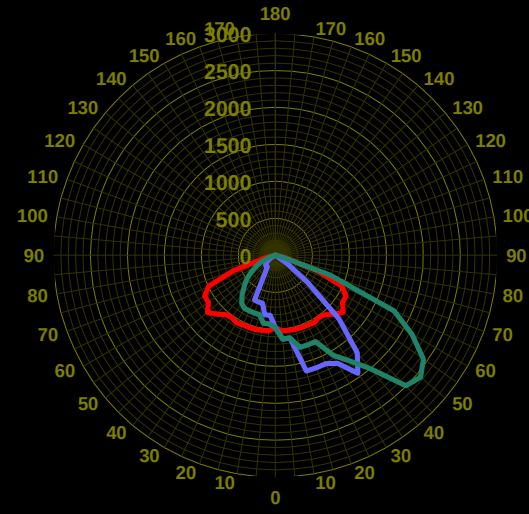
CUT-OFF PCB SON

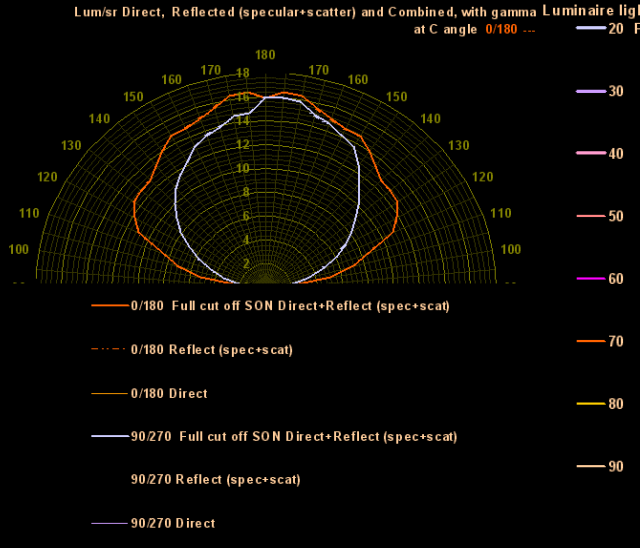


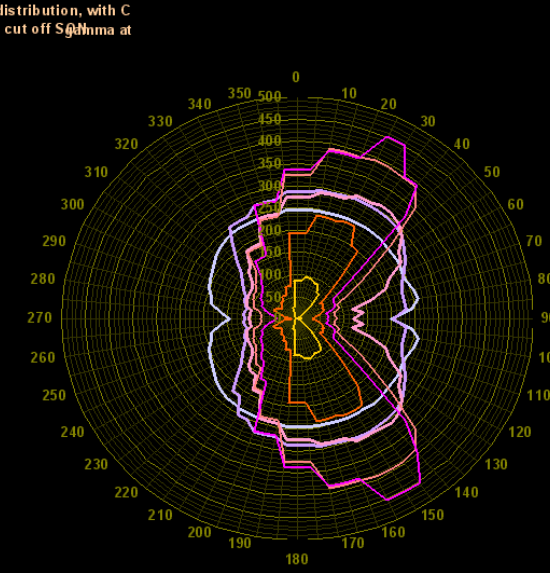




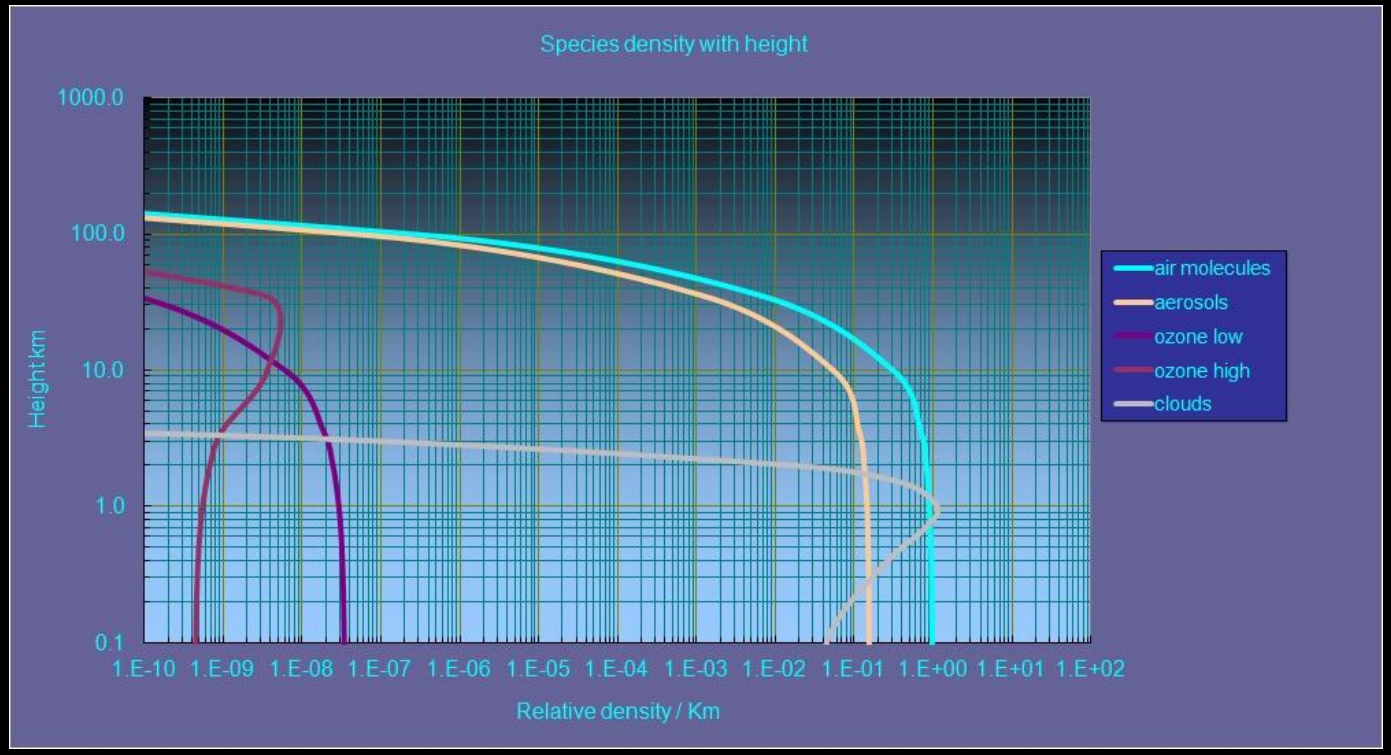
FULL CUT-OFF FGL SON







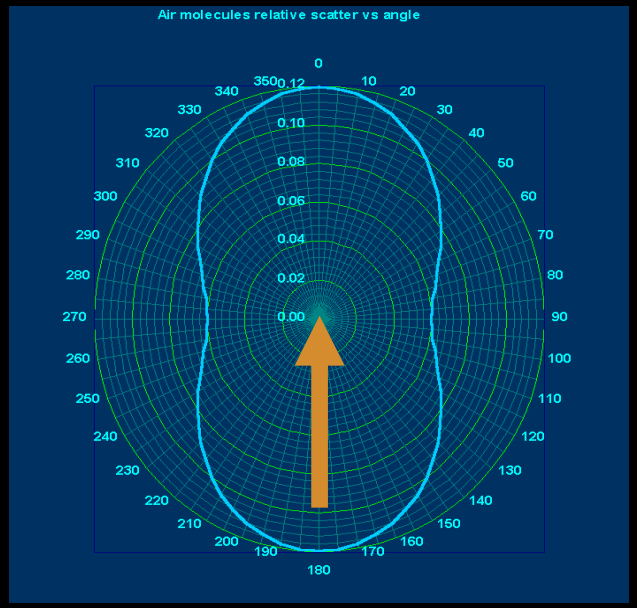
Atmospheric Component Densities

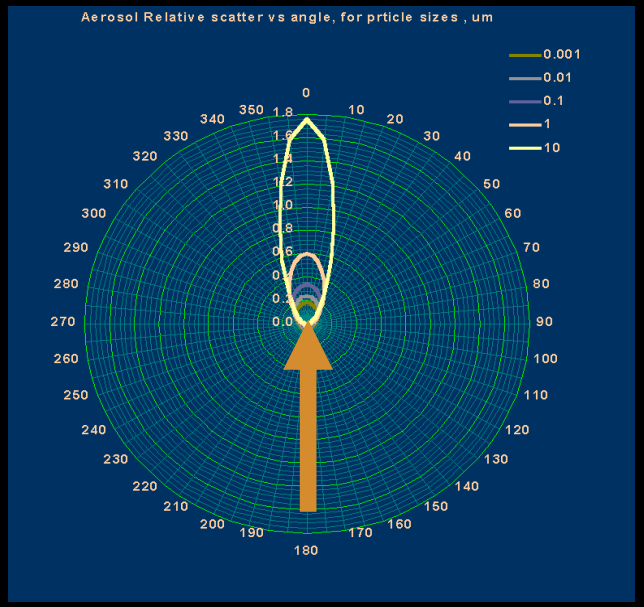


- Water droplets forming clouds are dominant in the lower atmosphere up to a few kilometers. Dust and ice based Aerosols continue higher, falling exponentially with molecular density.
- By 10 km, the atmospheric density is only a third of that near the ground.
- The model takes this scaling of molecular and aerosol scattering densities along the view path.

Scatter Probability

- Light from below is scattered in the direction of the grid angles. The distance from the centre curve gives the probability of scatter in that direction. The probability over all angles is set at 1, (100%), and must be multiplied by the scattering density.





Rayleigh Scattering

- Equal probability forwards and backwards, 50% of that sideways.
- Intensity varies as $1/\lambda^4$ (blue biased).

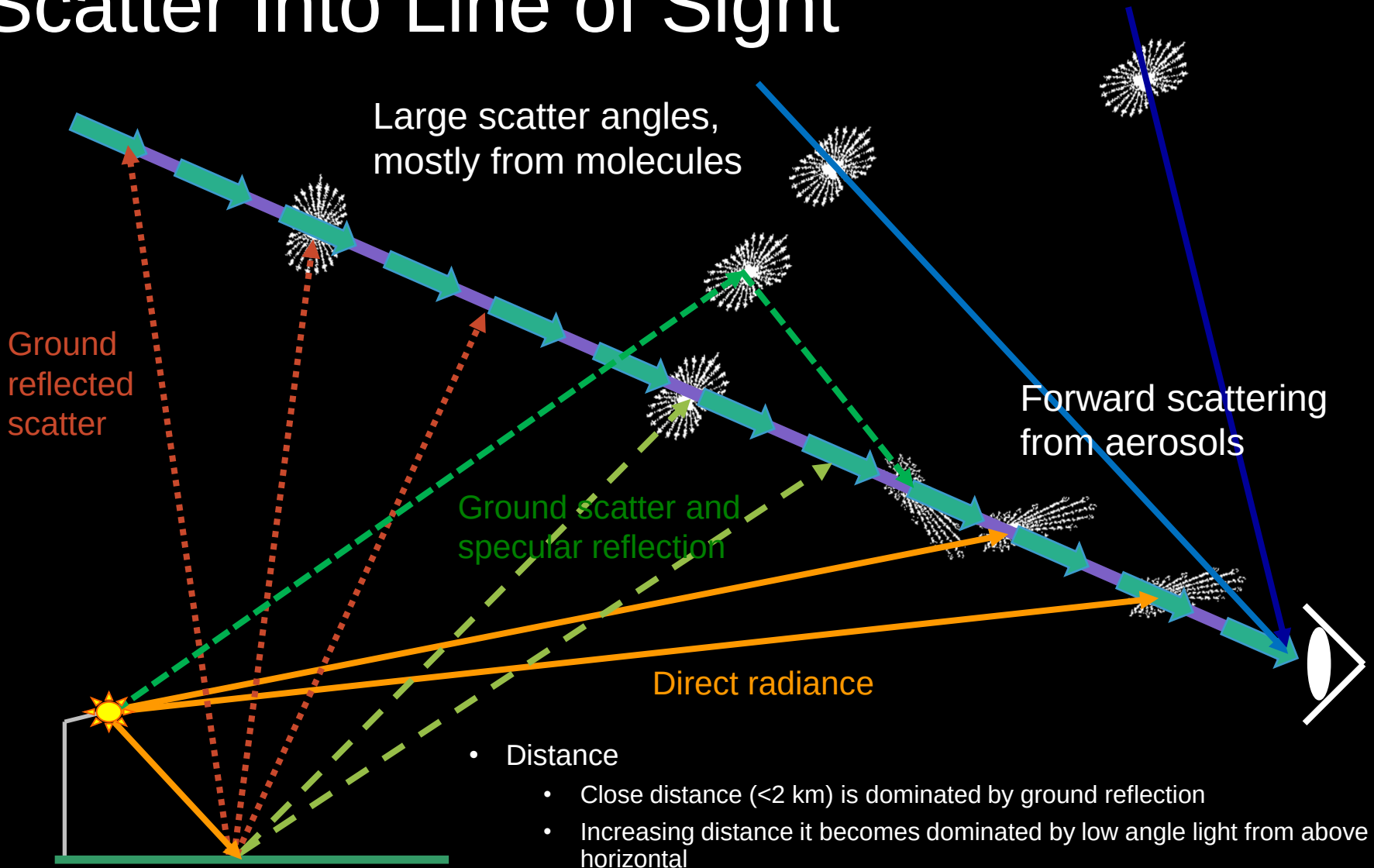
$$P(\psi) = (3/(16\pi)(1+\cos^2\vartheta)$$

Mie Scattering

- Heye-Greenstein function with added back scatter.
- Forward scatter is very peaked, increasing with particle size.
- Practically no sideways and minimal back scatter.
- No wavelength dependence.

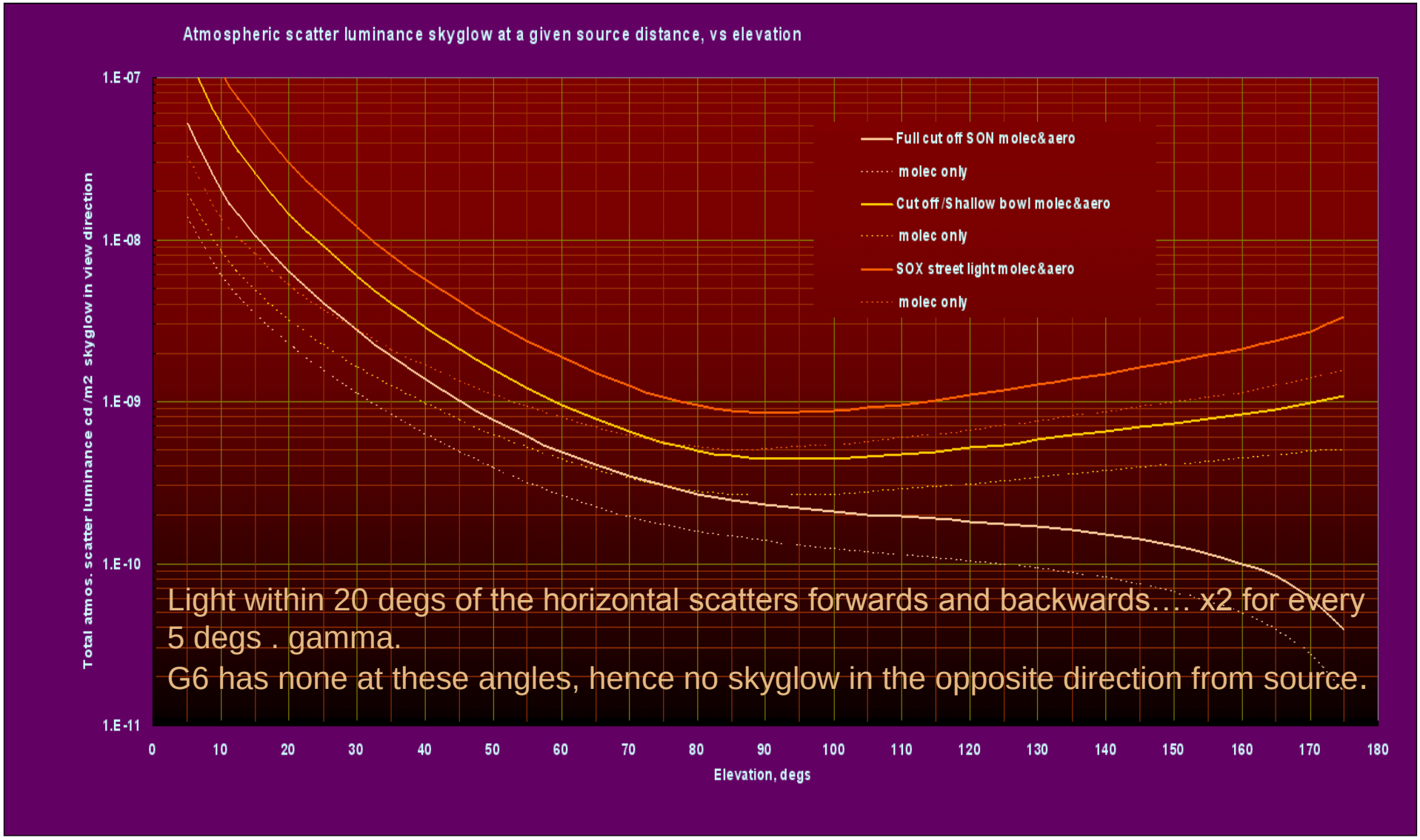
$$P(\vartheta) = (1-g^2)\left[\frac{1}{(1+g^2)-2g\mu)^{3/2}} + f\frac{(3\mu^2-1)/2}{(1+g^2)^{3/2}}\right]$$

Scatter Into Line of Sight



- Distance
  - Close distance (<2 km) is dominated by ground reflection
  - Increasing distance it becomes dominated by low angle light from above the horizontal
- Angle
  - Low angles is from aerosols
  - High angles it is mostly by air molecules, maximally in the blue

Scatter Into Line of Sight from Luniaires for view elevation angles 0 = toward, 90 = zenith, 180 =away from source. : LPS SOX (deep orange), Shallow bowl HP SON (orange), and Flat Glass SON - G6 (pink). For same ground illumination.
10 Km distance. Good. Visibility. (reduced aerosols=dotted).



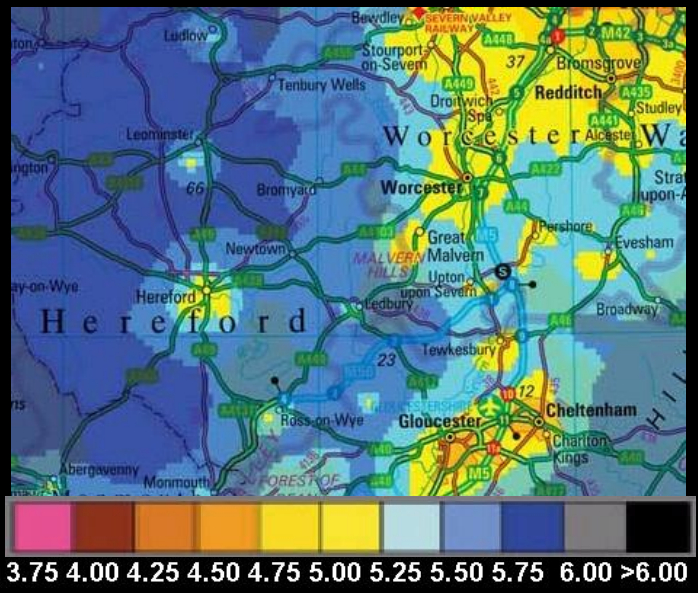
- A Dark Sky Survey of the Malvern Hills Area of Outstanding Natural Beauty.

- 2012 Sept –Dec. Zenith measurements using the Unihedron SQM, and all sky images where practical, over many rural locations within AONB, and Malvern commons.
- Comparison to modelling.

Dark sky areas of

Worcestershire and Herefordshire

(P. Cinzano / F Falchi ISTIL- Dipartimento di Astronomia Padova, Italy), Philips – Maps publication for CfDS, 2004 September



Images: Canon 20Da,

8mm F/3.5 180 deg Fisheye lens. 30 sec ISO 800.

Image profile calibration:

Calibration from vertical reading of SQM. Any offset corrected and converted from Mag/arcsec^2 to cd/m2

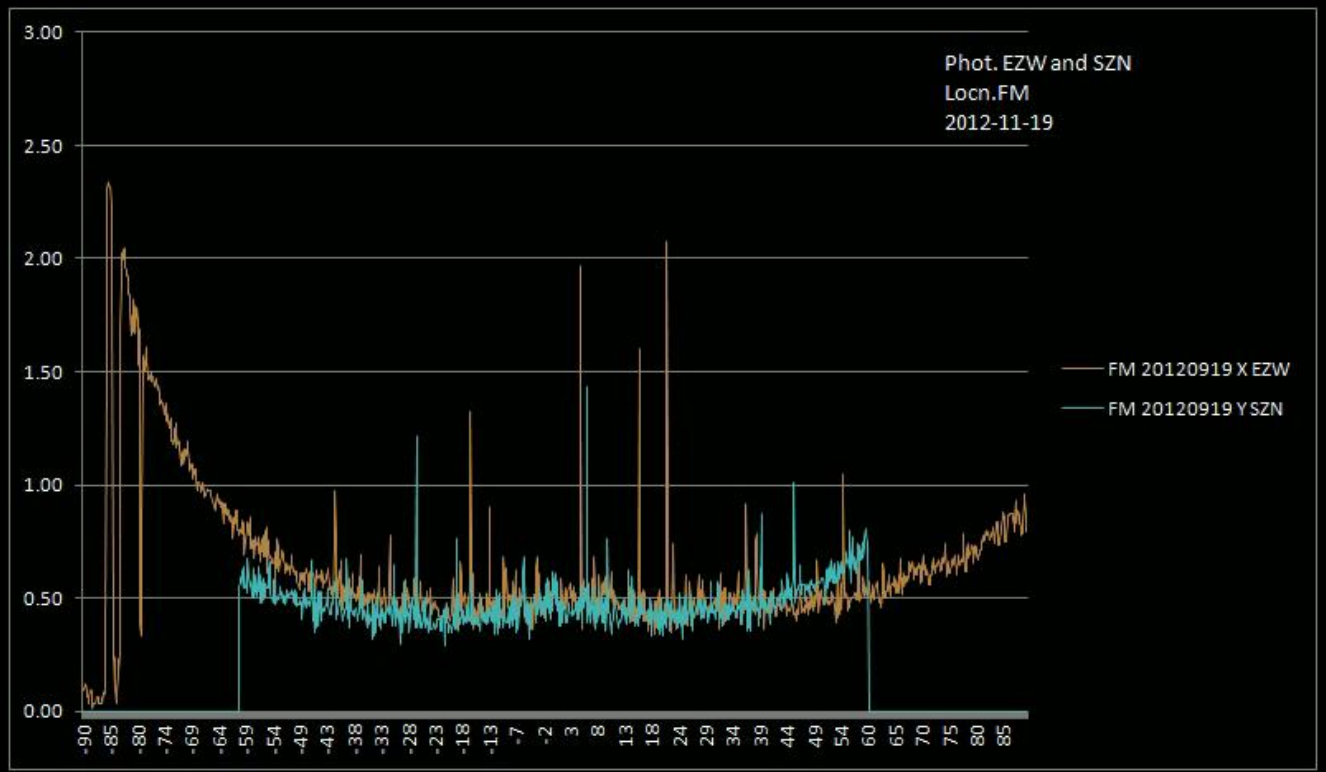
Lens vignetting was measured and applied as a correction to all E-W and N-S profile plots.. amounted to X 2 correction at the edge compared to the centre.

Skyglow,

Mathon

Rural, 5 Km West of Malvern hills, which shield the Severn Valley

2012-09-13



Sky photometry,

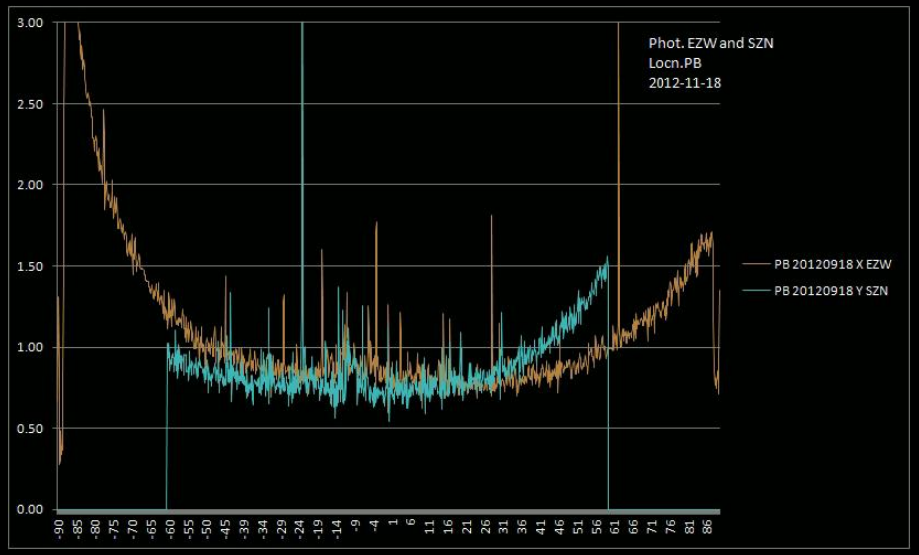
East through Zenith to West (tan), and

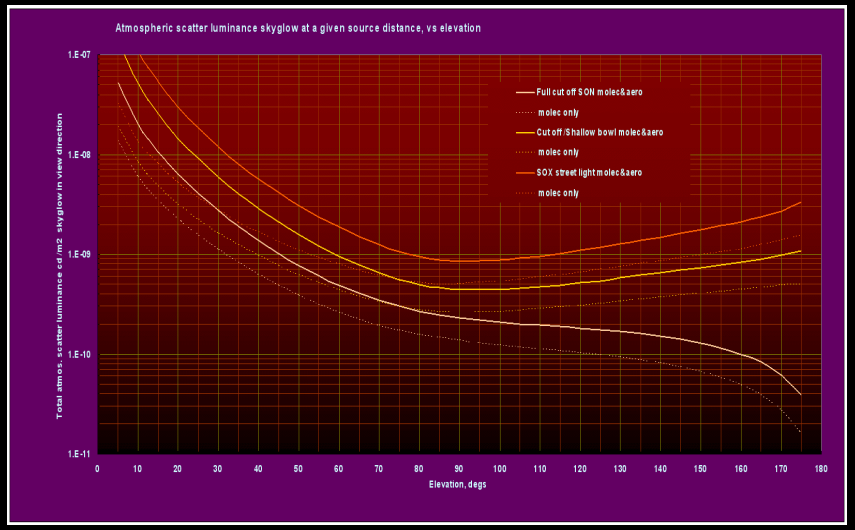
South through zenith to North (green).

(m.cd/m2 vs Zenith angle)

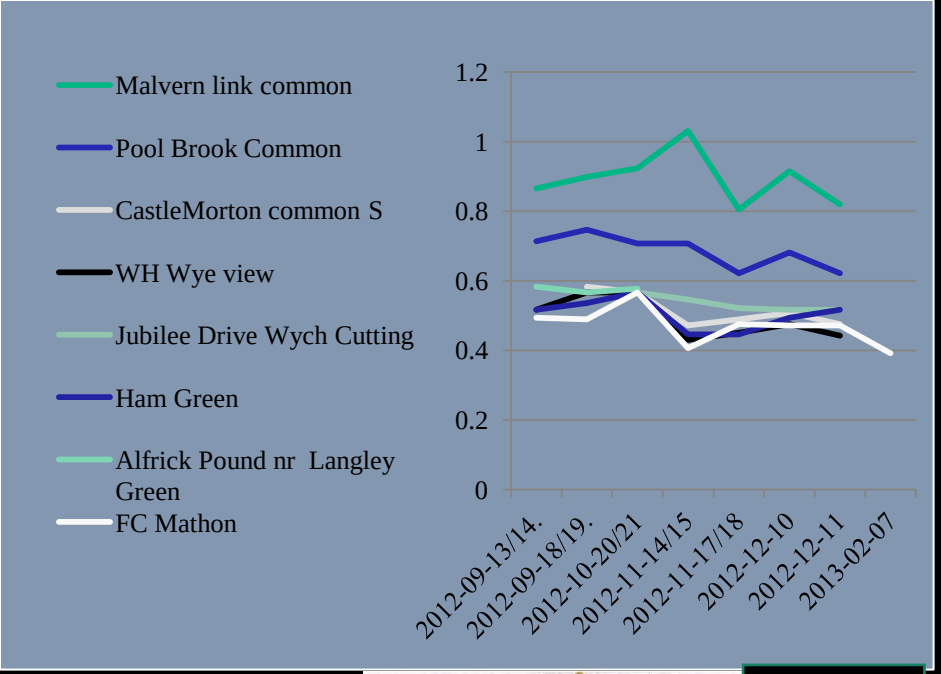
Plots Corrected for lens vignetting.

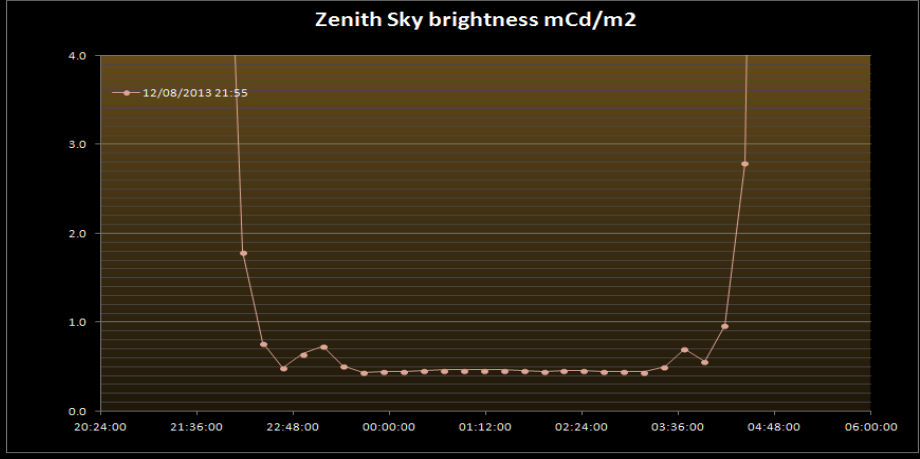
The Milky Way adds to zenith readings. Rise to East from all Severn Valley lights, not just Malvern

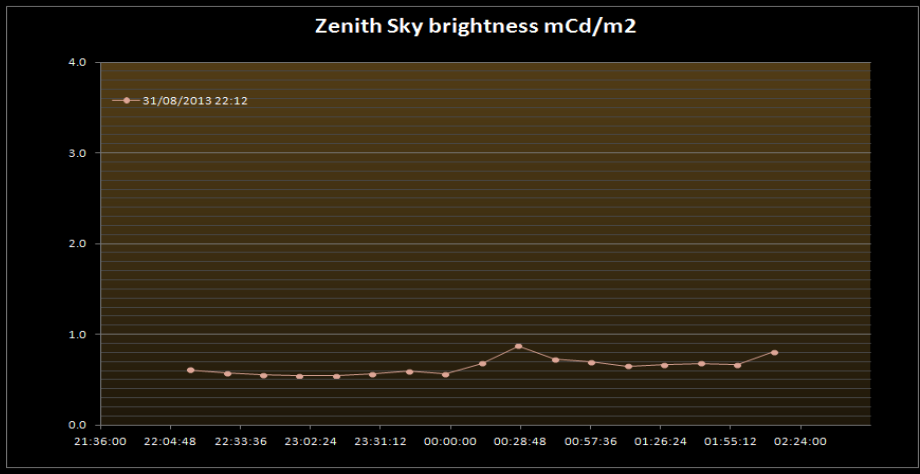


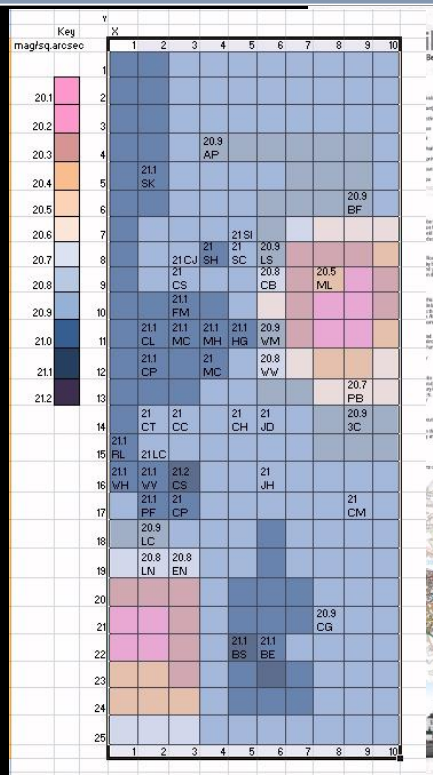


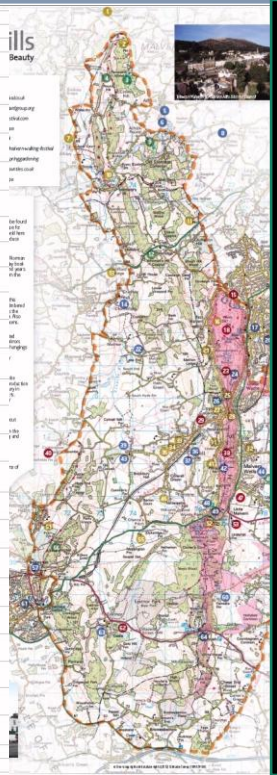
The Milky Way surface luminance was calculated to be about 0.1 m.cd/m^2. For 1000 SOX luminaires at >1E-8 cd/m^2 each at 40 degs. Elevation at 10km is > 0.1 m.cd/m^2 which exceeds the Milky Way surface brightness and that of other nebulae; while for FCOs it is more than 5 times lower, and far more so in the opposite direction, making the Milky Way visible.











From dusk to dawn plot of zenith sky brightness, Mathon, 2013 August 12-13. Blips are clouds. And Aug 31 showing variation. Now has optional automatic monitoring .

Summary MH AONB dark sky study.

Skylow to the horizon is six times that of the zenith, caused by streetlights with components towards and above the horizontal, **from the whole Severn valley area.**

The effect of local towns dominates low elevation light pollution for up to 30 km away from them. (mostly from aerosol forward scattering of light just above the horizontal). This can be controlled with better downward directed lighting.

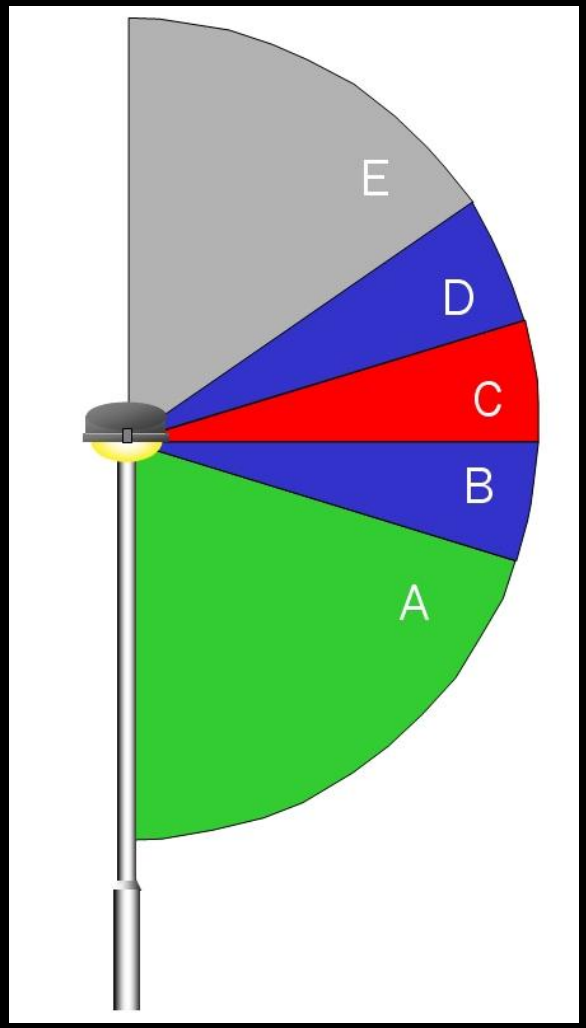
The zenith sky brightness is the same everywhere outside of the towns, as it is set by all major cities up to 100km. This is from Molecular scattering at higher altitude and is far more so in the blue-white.

The lowest aerosol content hence darkest skies in dark of the moon periods are February to March, when conditions are icy or dry rather than misty .

2014 Highways Agency Environmental Impact Policy

- The new industry-setting standard is to be **applied to all** proposed motorway lighting schemes.
- This will include energy costs, maintenance costs, safety, social impact on local communities, and **light pollution**.
- Each category is assessed and points deducted for not meeting the **highest standard**.
- Although light pollution is only one of many categories, a failure to score high in one is a **failure overall**, and so such a proposed project would not be funded.
- The aim is to achieve the same standard as lighting direction control, without specifying specific class designs. This is to allow **new technology** and some flexibility including installation of **LED lighting**.
- Lighting within **30° below to 20° above the horizontal** will get a heavy bias weighting against.

Luminaire Output



E 180-100° Critical area for skyglow from within urban areas but proportionally less impact to rural areas.

D 100-95° Significant contributor to skyglow, especially in rural areas where it is most aerosol dependent. Less likely to be obstructed.

C 99-90° Critical zone for skyglow and obtrusion seen at 10s of km (in rural areas) where it is strongly dependent on aerosol scattering.

B 90-70° Significant contributor to skyglow seen at a distance through reflection but reflected light more likely to be obstructed by buildings, trees and topography.

A 70-0° Ideal light distribution.

2014 Highways Agency Environmental Impact Policy

- Modelling of a Globelight stepped gamma cutoff contribution to skyglow to show **effect of changing cut off angle on skyglow**.
- **Exponential impact** from 70deg through 90deg gamma.
- Providing a **weighting factor** scaling metric with high gamma cutoff angles for the light pollution section of the HA environmental impact assessment policy.

Gamma angle degs, Weighting

70 to <75, x 0.01

75 to <80, x 0.02

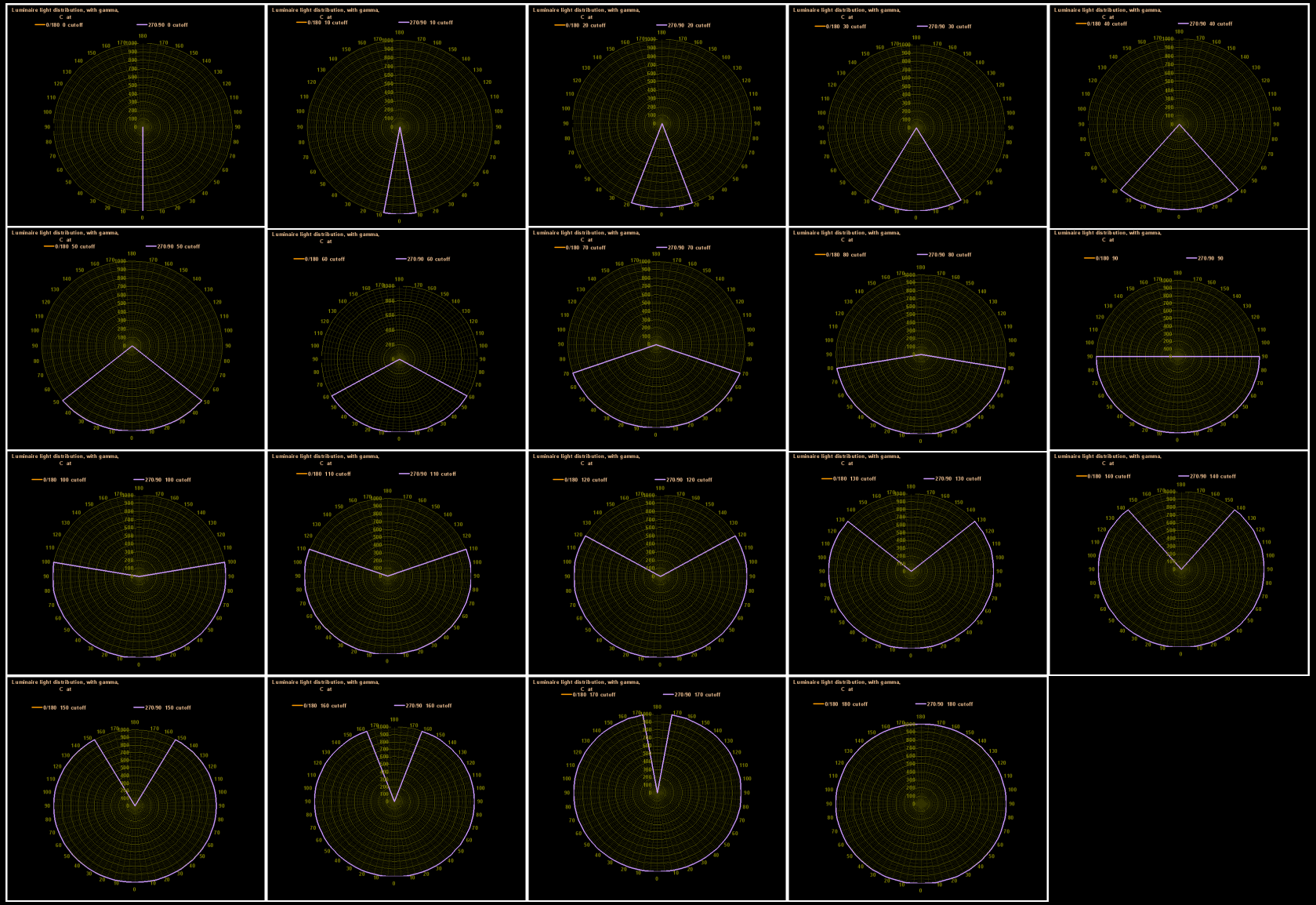
80 to <85, x 0.04

85 to <90, x 0.12

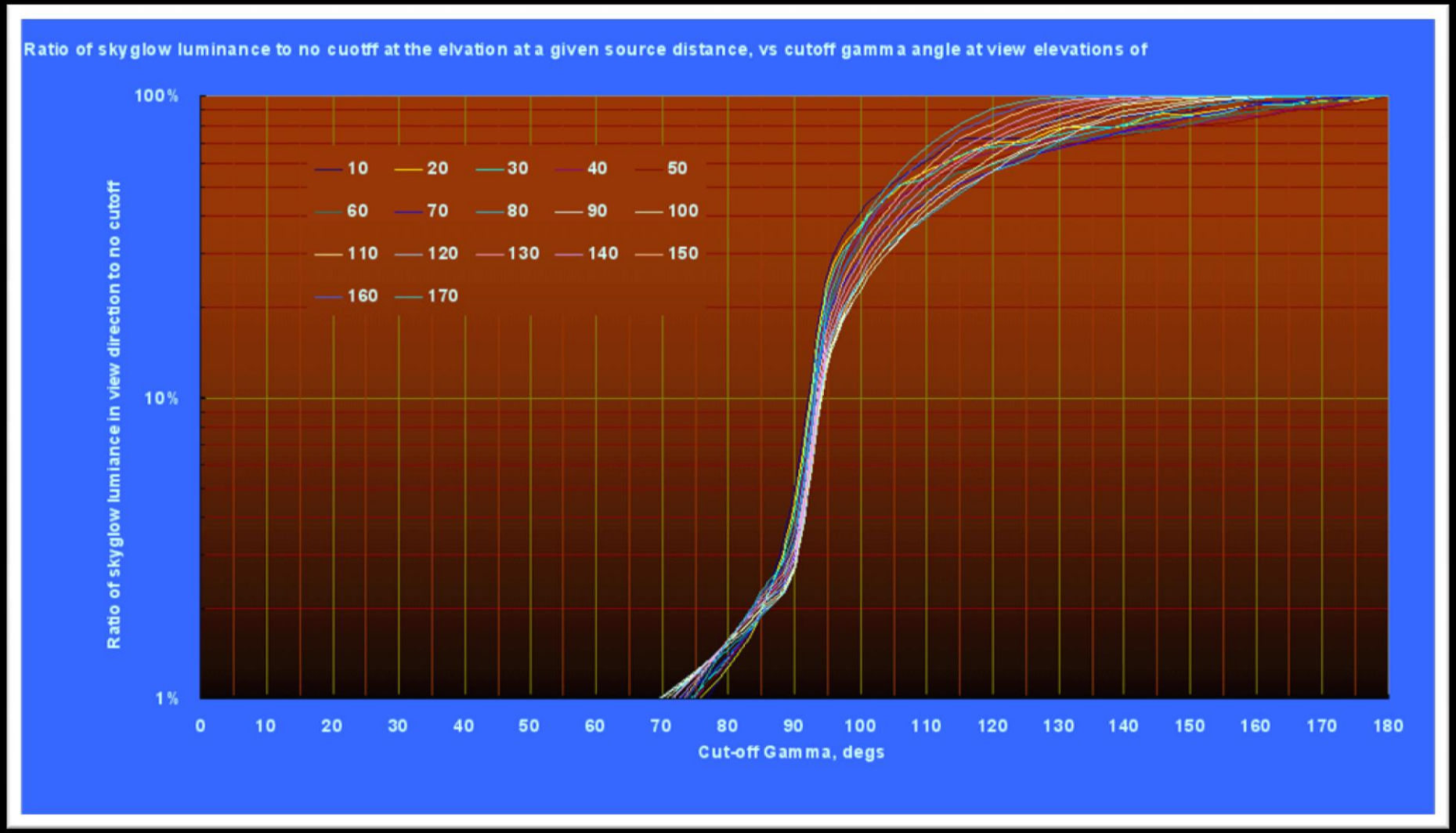
90 to <95, x 1.00

95 to <100, x 0.80 etc.

Stepped Gamma Plots

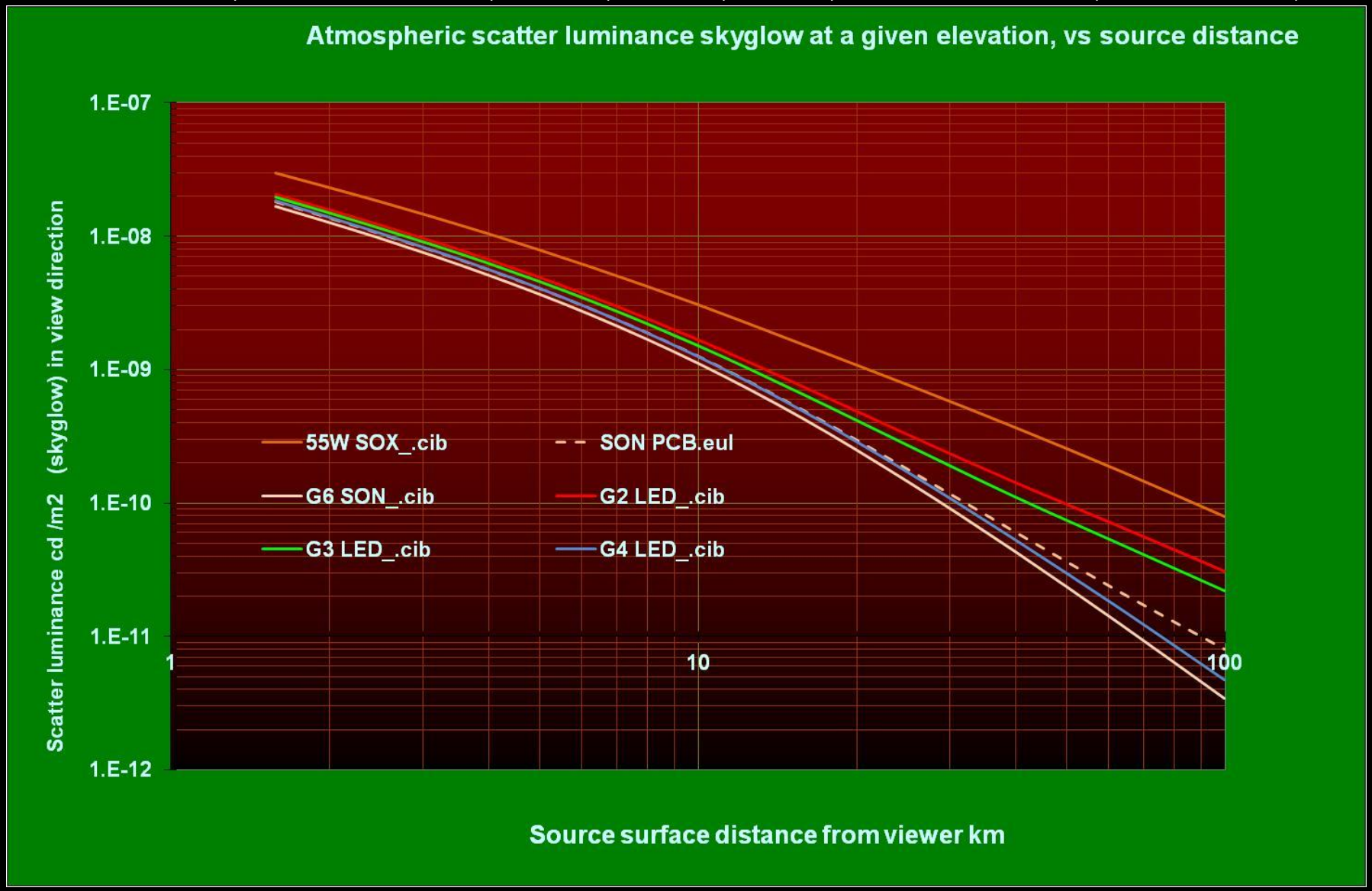


Stepped Gamma Plots Skyglow : Log %, normalised for all view elevations, for cut off gamma angle, 0 – 180. Exponential invcrease above 70 to 100 degs gamma.



Skyglow scatter into line of sight vs. Distance (Km) at view elevation 45 degs.,

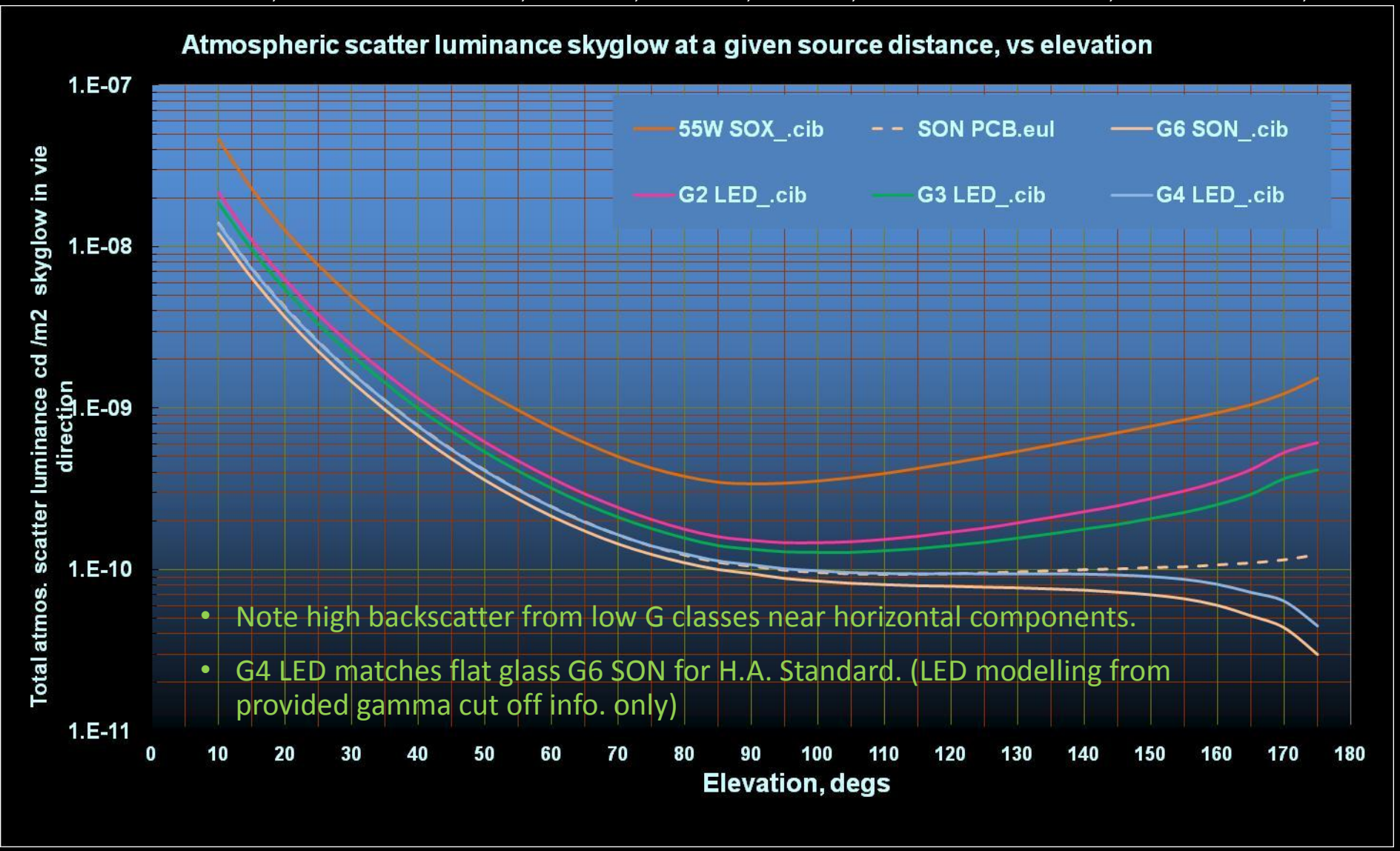
Cases : 55W SOX,SON Shallow bowls, G6 SON, G2 LED, G3 LED, G4 LED CCT 6000 K,G4 LED 4500 K, 3000 K



Skyglow scatter into line of sight vs. view elevation,

(0=towards source, 90 = Zenith, 180 = opposite direction) ; all at 10km.

Cases : 55W SOX,SON Shallow bowls, G6 SON, G2 LED, G3 LED, G4 LED CCT 6000 K,G4 LED 4500 K, 3000 K



Highway Agency Light pollution gamma angle weighting table criteria within proposed Environmental impact policy for all HA new schemes.

Gamma	70	80	90		70	80	90	
				Weighting	0.01	0.04	1	SCORE (lower the better)
Class	Cd/klm	Cd/klm	Cd/klm		Weighted	Weighted	Weighted	Totals
G5 MAX	350	100	10		3.5	4	10	17.5
G6 MAX	350	100	0		3.5	4	0	7.5
G6 SON	301	16	0		3.01	0.64	0	3.65
G4 LED	446	89	0		4.46	3.56	0	8.02

2014 Highways Agency Environmental Impact Policy

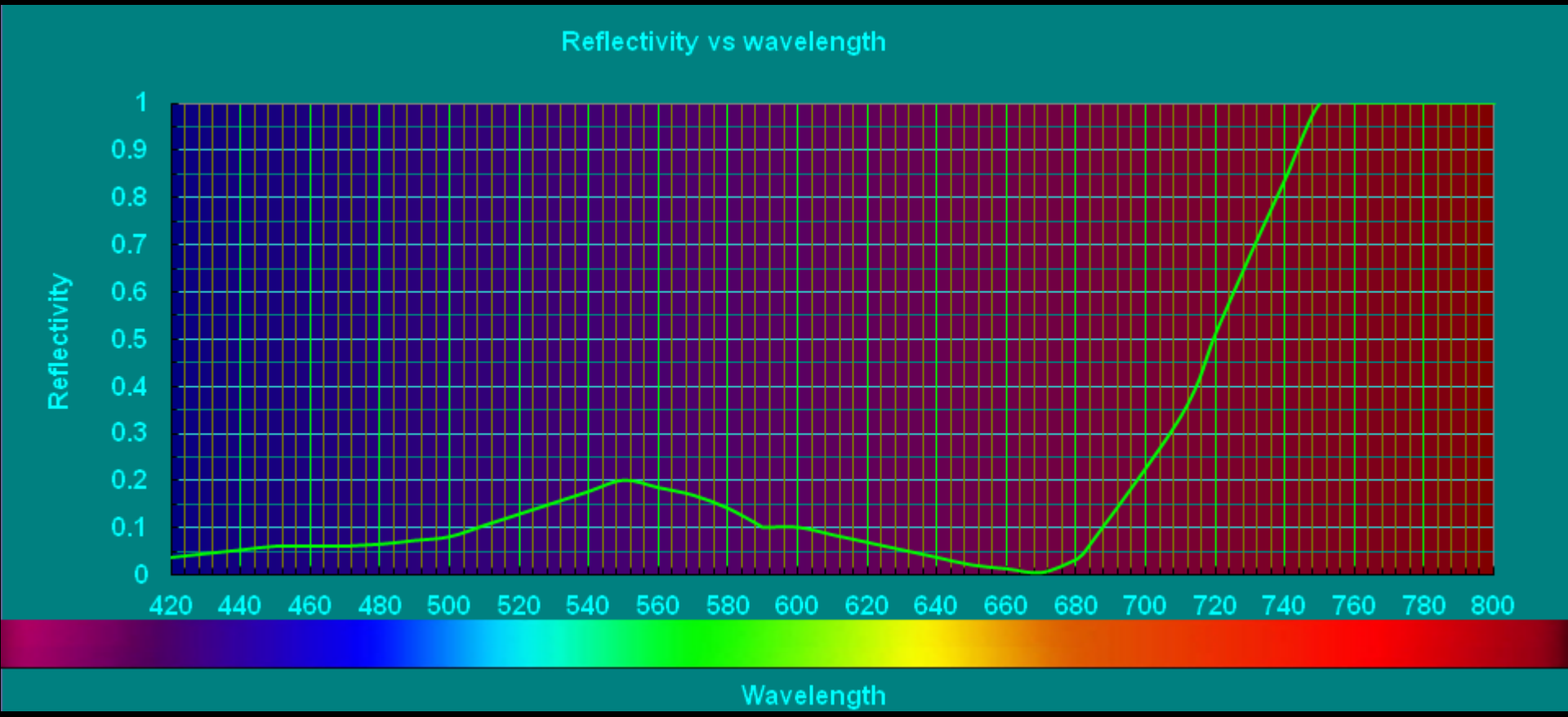
- Due to the highly directional properties of LEDs, the to be adopted **weighting factor** scaling metric from 70 to 90 gamma cutoff angles (and beyond) will be effective in limiting skyglow from LED class G4 to similar to current G6 SON (full horizontal cut off) as currently used.
- G1 to G3, will not pass this criterion. They use curved and tilted base-plates to spread the light distribution. This increases the light to the sky where it effects skyglow most, also in the opposite direction to the source, through backward atmospheric particle scattering.

- Class G1 to G3 LEDs are being rolled out on Council controlled roads countrywide, often replacing LPS SOX, which have a large upward light ratio. Modelling of this for Herefordshire in underway.

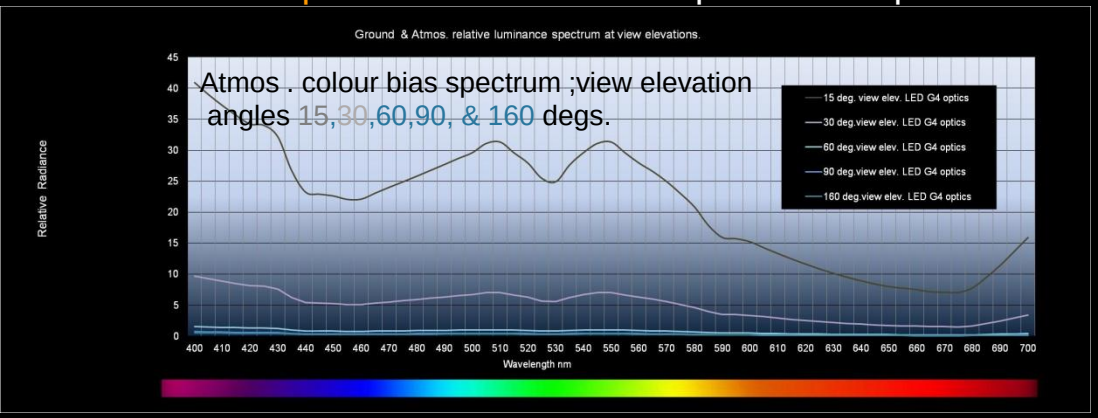
- The HA is requesting limiting colour temperature , but insufficiently, bearing in mind the high blue content often used. Modelling of this shows the significant potential problem to astronomy.

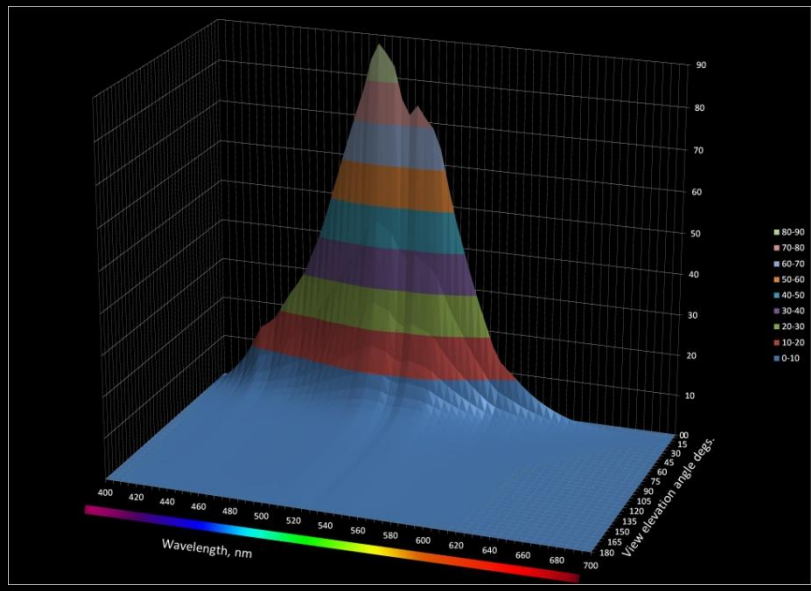
Effect of blue rich LED lighting on the night sky

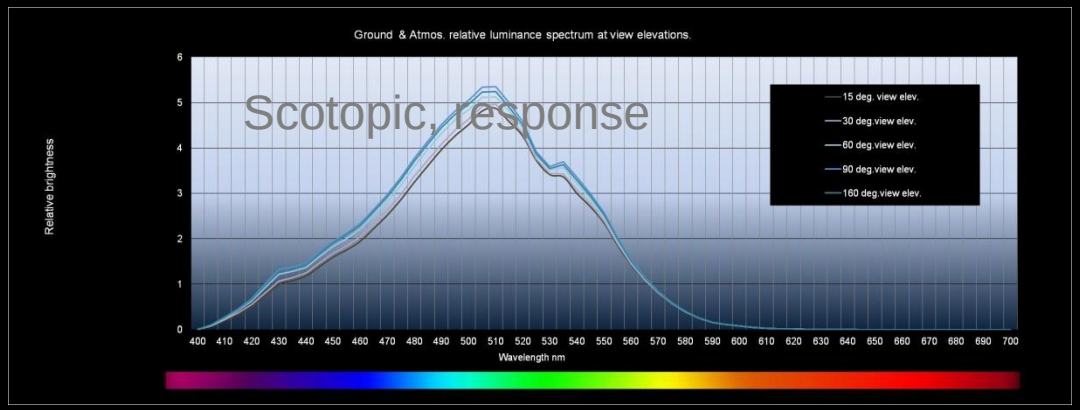
Spectral Green Bias ground off-road scatter and reflection from grass and vegetation. Photosynthesis absorption in the red, high reflectivity in near infrared.

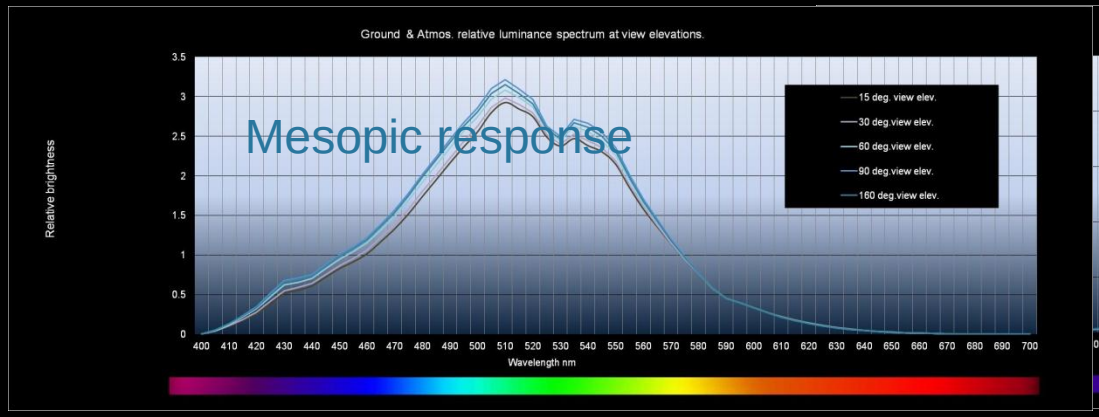


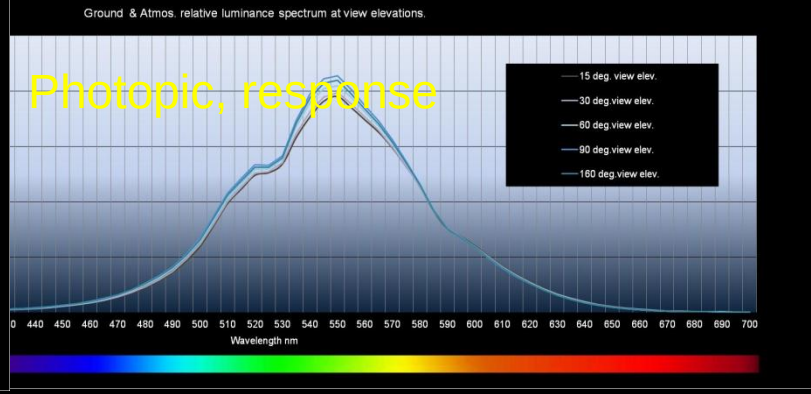
Night Sky relative spectral radiance inc. road and grass verge reflections, for view elevation angles 15,30,60,90, & 160 degs. Luminance wrt 590nm for Scotopic, Mesopic and Photopic, response. No luminaire spectral source. Surface plot axes.. spectrum and view elevation angle. G4 optics angular limitation.

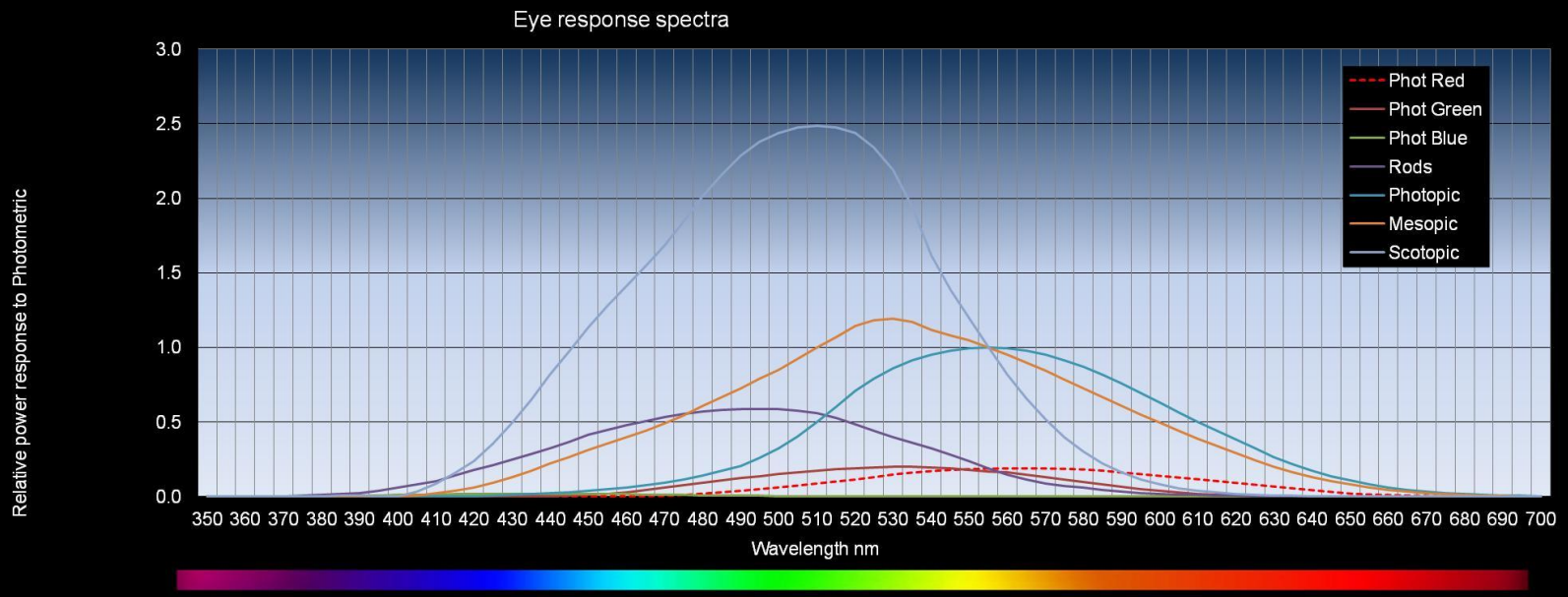




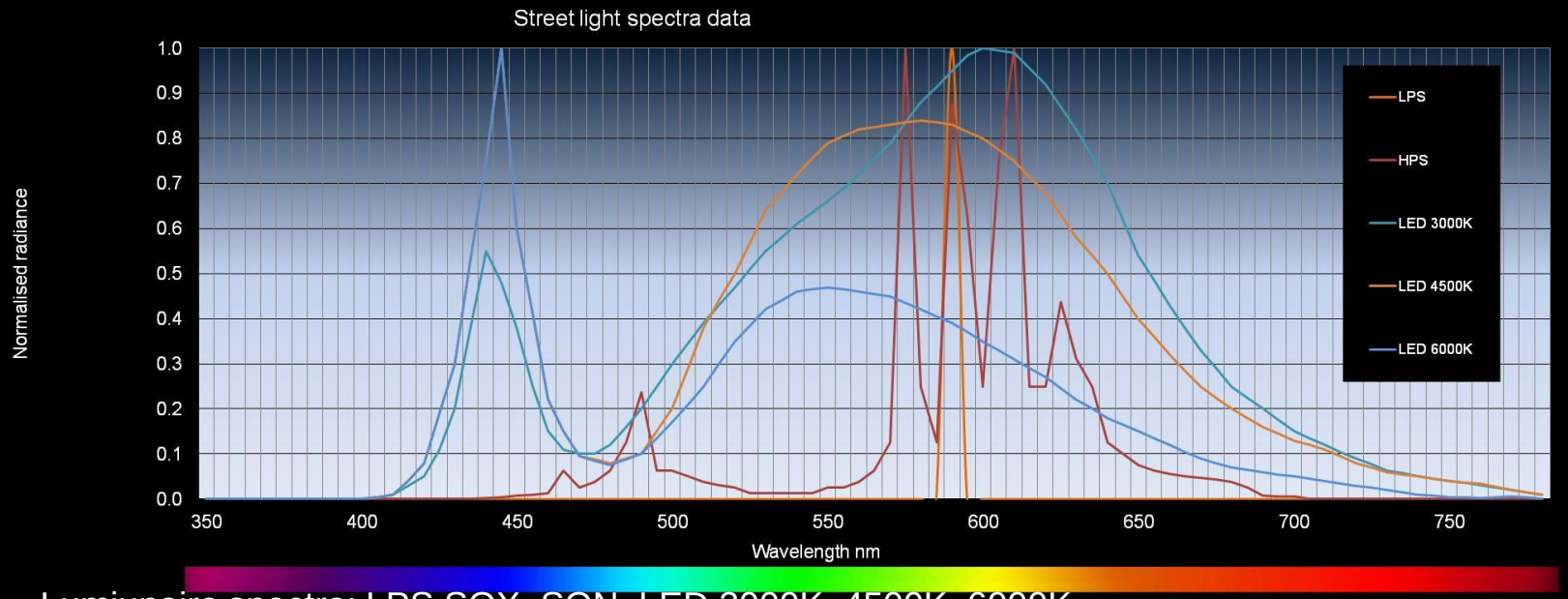




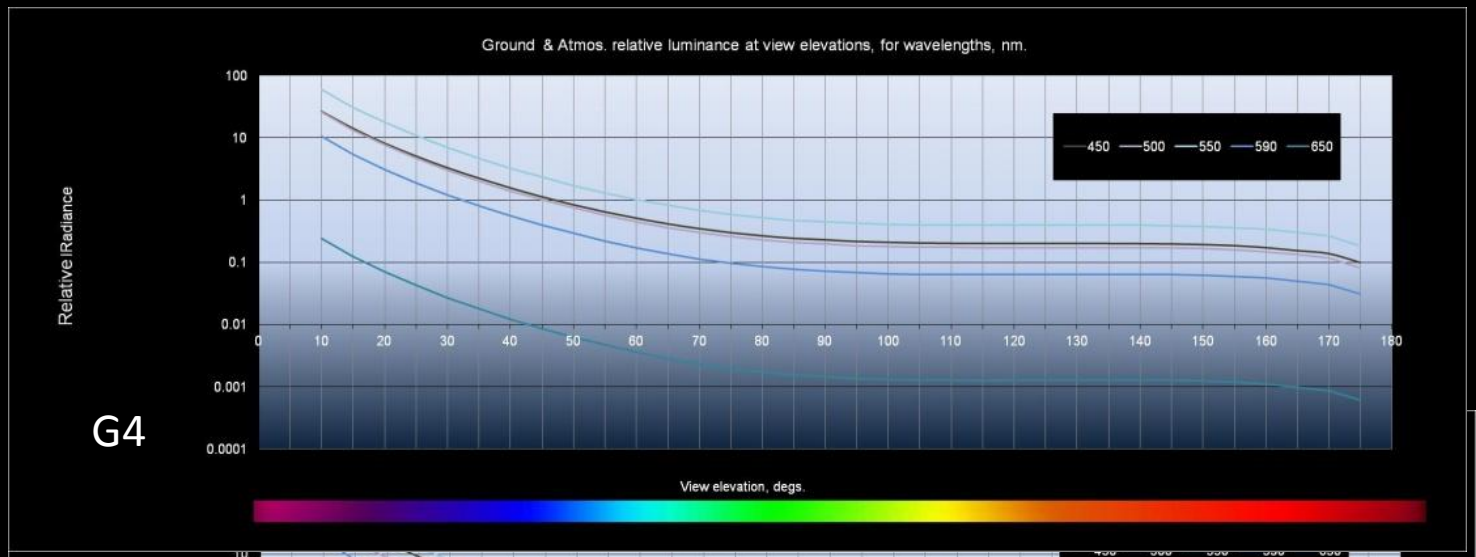




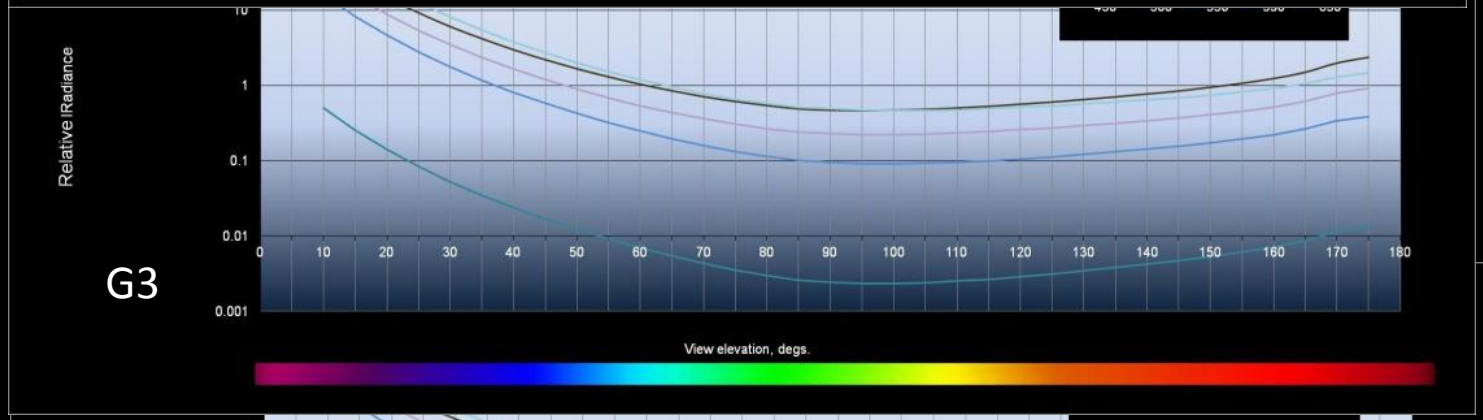
Eye relative Scotopic, Mesopic and Photopic, spectral response.



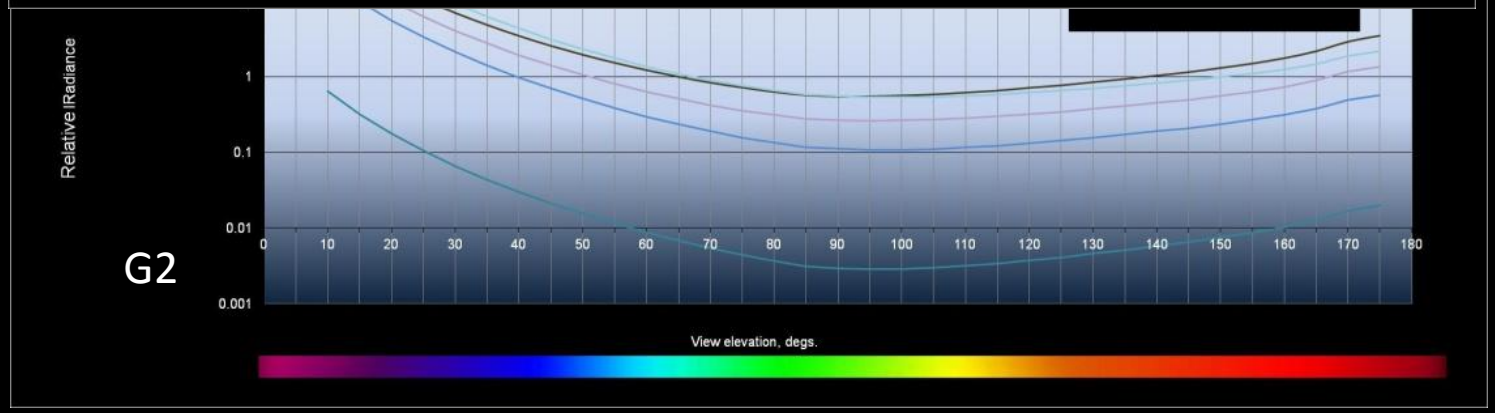
Lumiunaire spectra: LPS SOX, SON, LED 3000K, 4500K, 6000K.



G4



G3

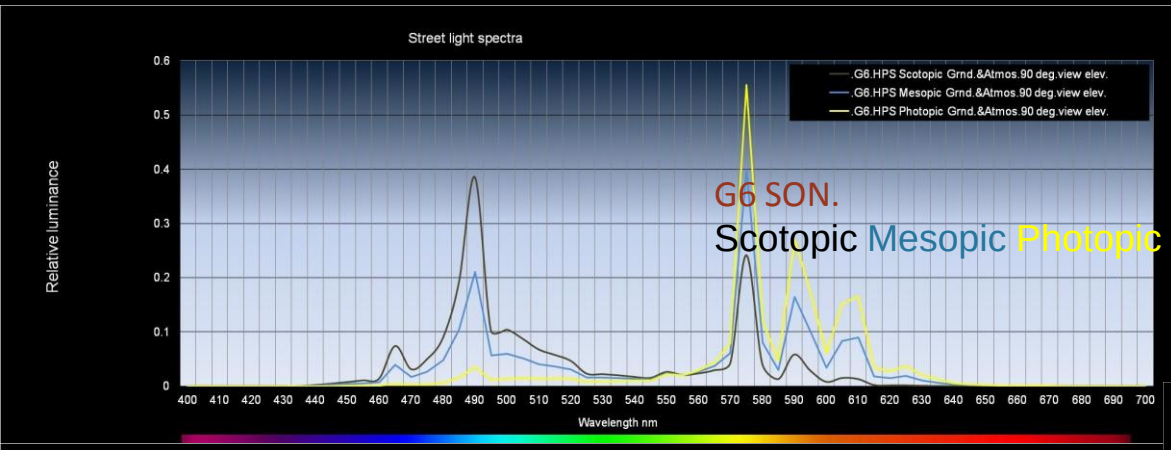


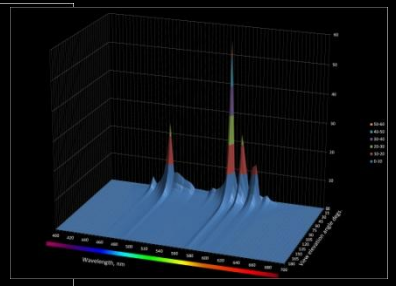
G2

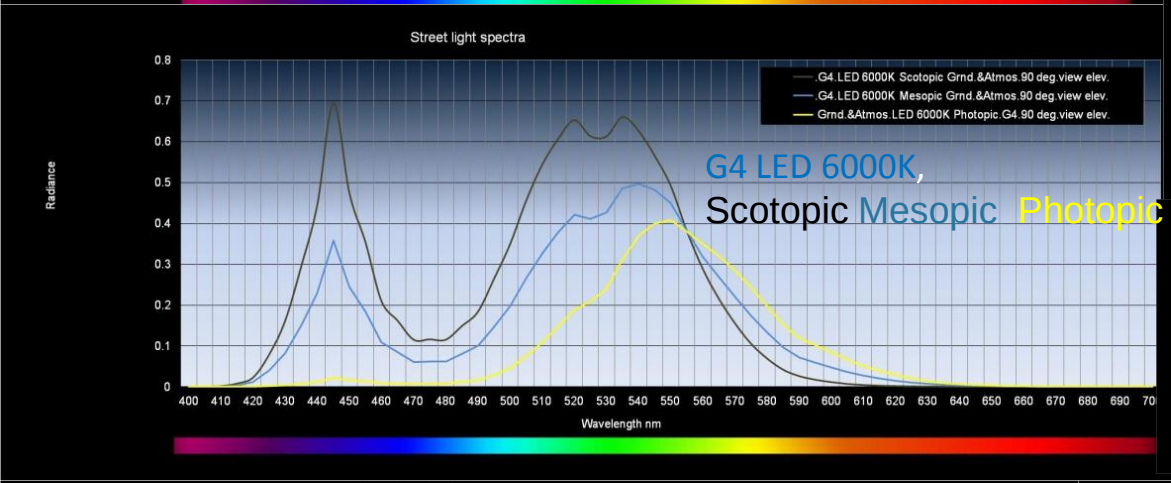
Night Sky Mesopic luminance. G4, G3 and G2 LEDs. CCT 6000K. Axes: View elevation towards through zenith to away, for wavelengths of

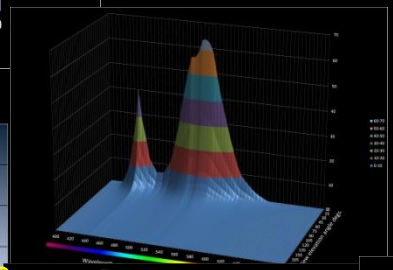
450,500,550,590, 650 nm.

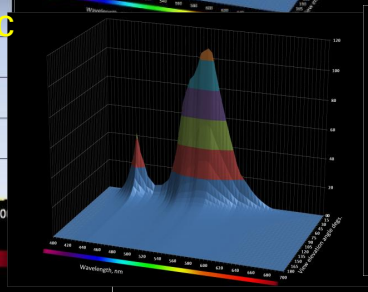
Zenith relative Skyglow luminance spectral response from SON, LED CCT 6000K, 4500K and 3000K

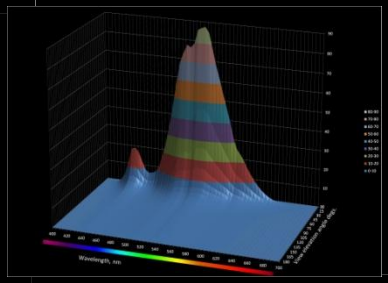




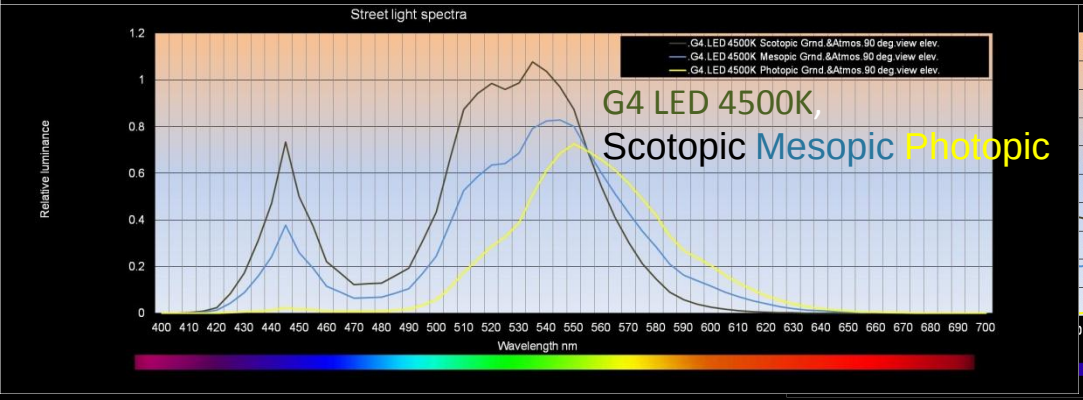


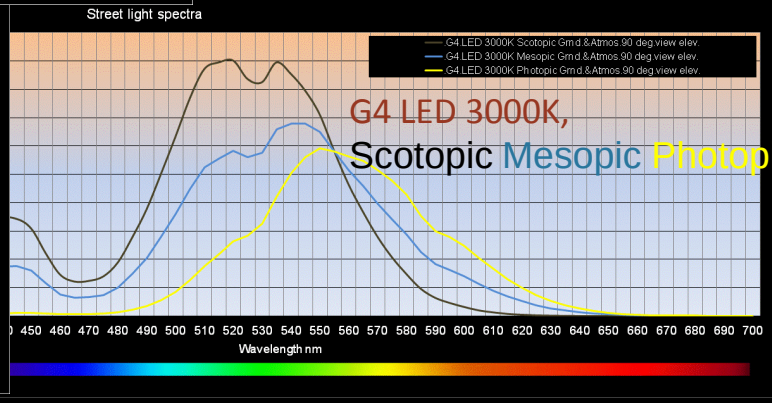




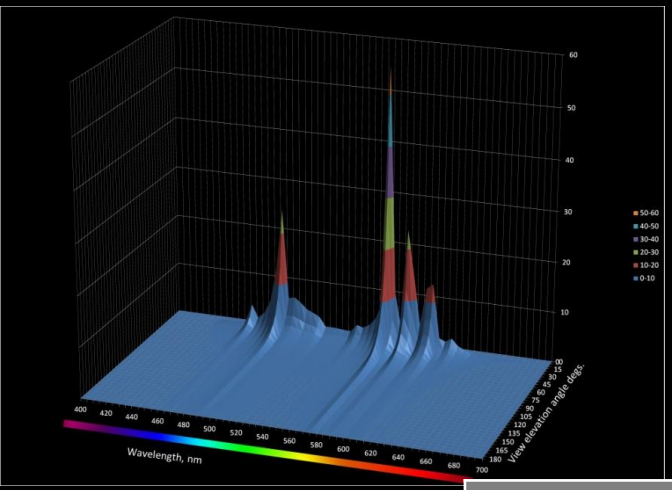


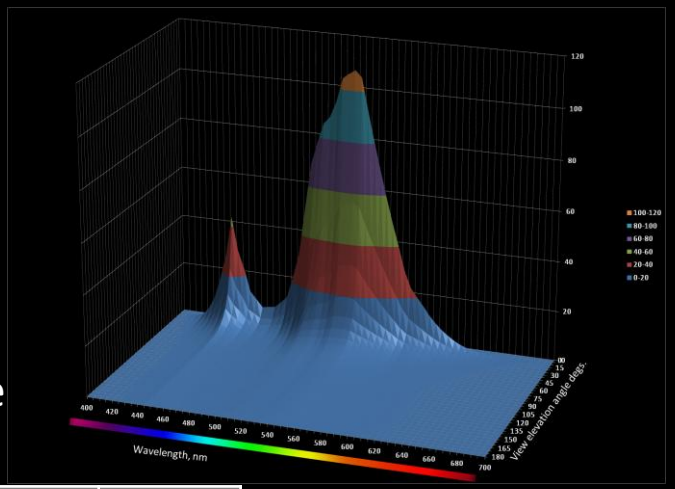
Mesopic response surface curves: Spectrum vs. View elevation angle.





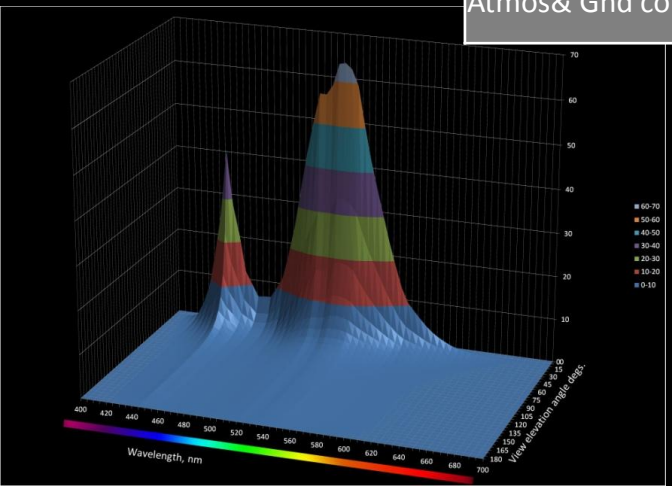
Skyglow from Mesopic eye response for G6 HP SON, G4 LED 6000K, 4500K, and 3000K luminaires. Axes: View elevation towards through zenith to away, and spectrum. Table of Skyglow integrated S/P for SON and LED at CCTs.

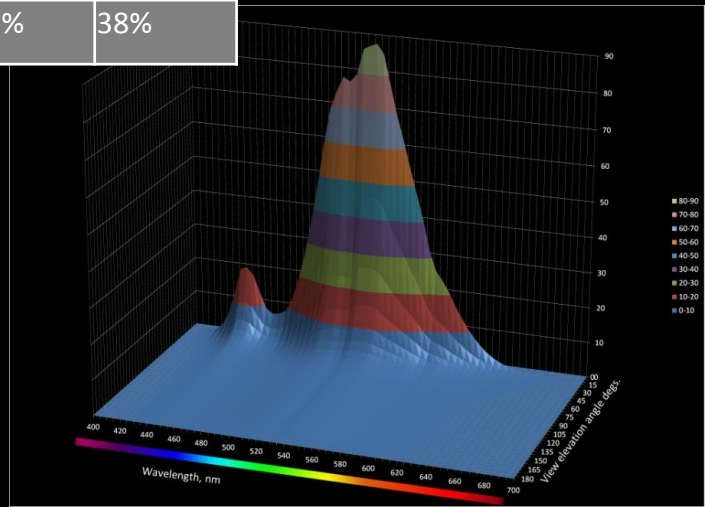




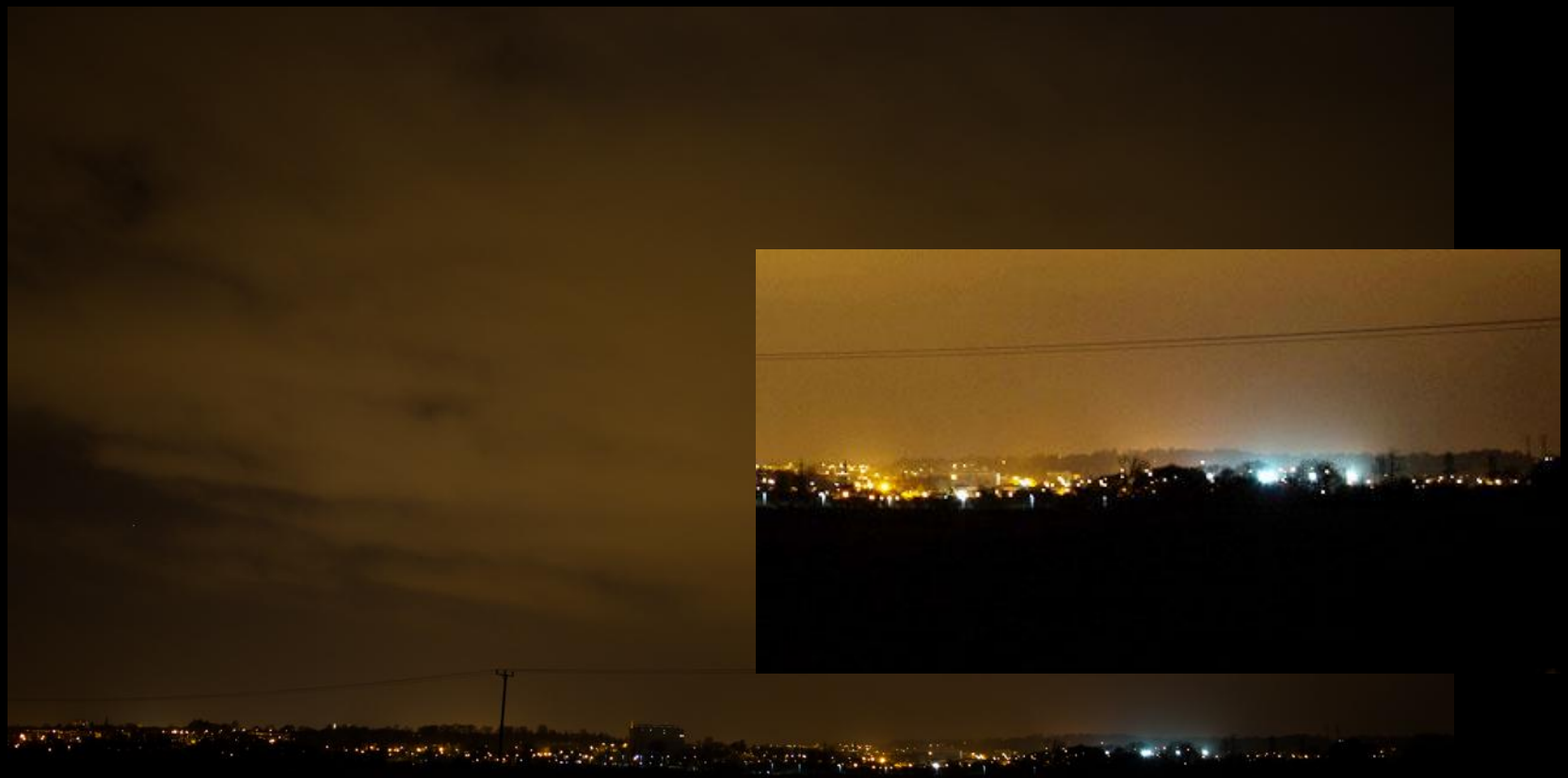
Summary table showing Ground and Atmospheric contribution to Luminaire S/P ratios.

	G6 SON	G4 LED 3000K	G4 LED 4500K	G4 LED 6000K	G3 LED 6000K
Luminaire Scotopic / Photopic	0.7	1.3	1.4	1.9	1.9
With Ground&Atmos S/P	1.0	1.7	1.8	2.2	2.6
Atmos& Gnd contrib. S/P	48%	23%	22%	17%	38%





G4 class blue rich LEDs replacing LPS in Norfolk, 2015.



Trowse Bypass, Norfolk (David Hook / c. Steve Lansdell). G4 LEDs invisible except on right where misaligned from horizontal and showing forward scattering.
All orange older lights are further away.

Summary

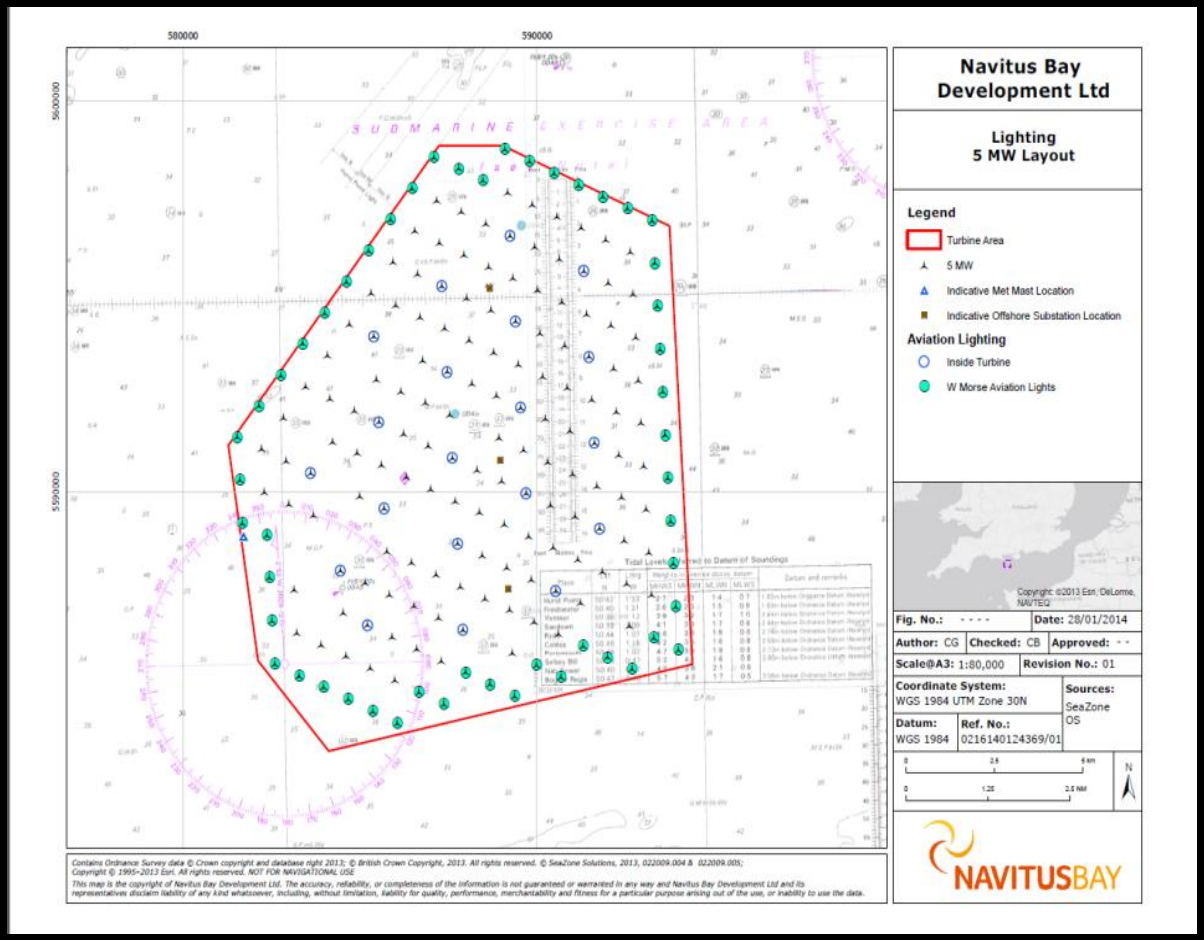
- The increasing use of blue rich LED lighting should be discouraged. Class G2 and G2 LEDs have significant skyglow compared with G4, equiv, to G6 SON.

- Atmospheric highly blue bias Rayleigh scattering and reflection off green vegetation greatly increases skyglow at the Zenith by from HPS luminaires for the same ground brightness.
- This is of great concern to the astronomical community, for 6000K LEDs.
- This seems so for classes below G4, as will be commonly used.

- Dimming by x2 does compensate, and more so by using lower colour temperature, where possible.

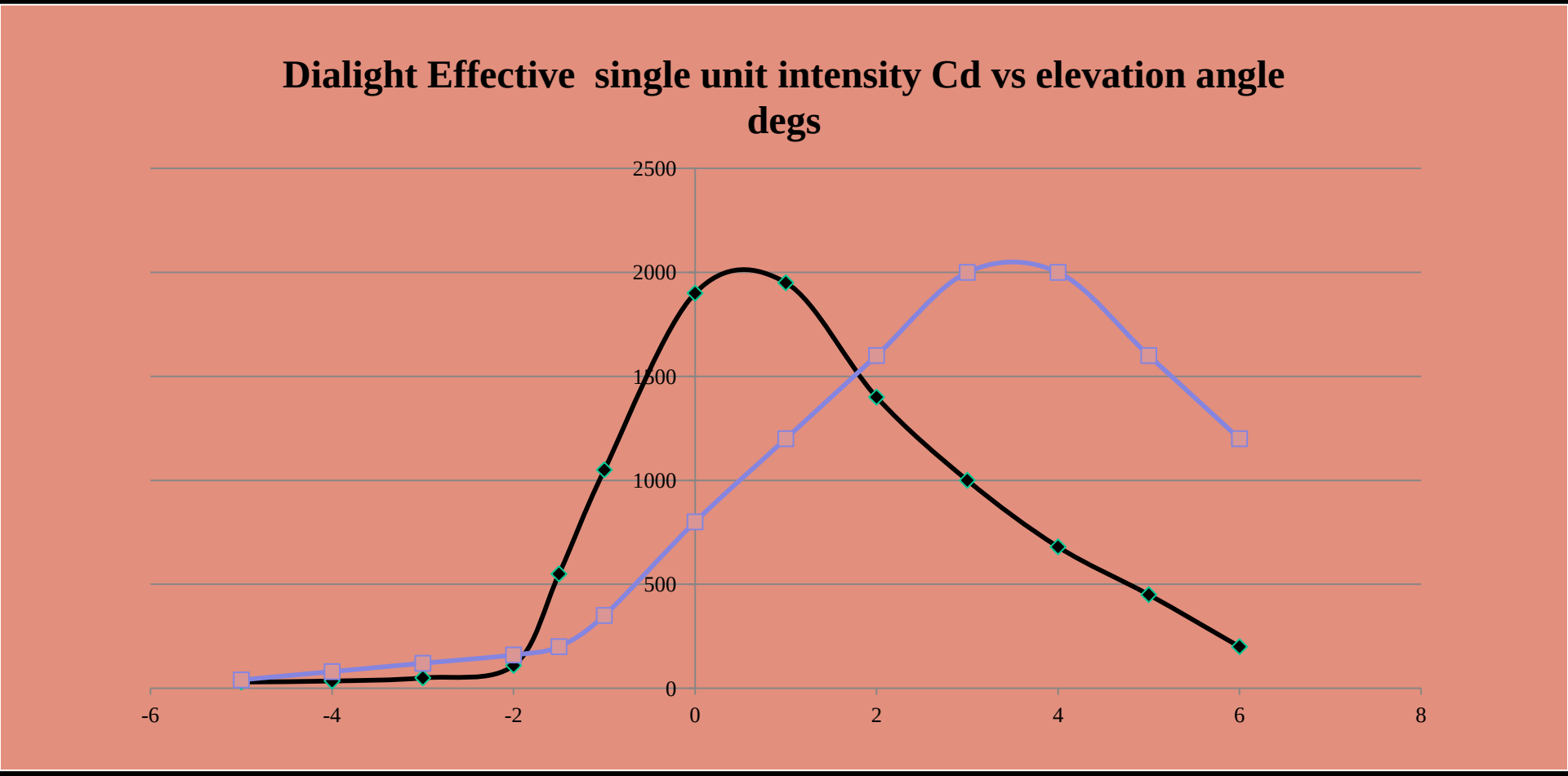
- A colour temperature of 3000K, is recommended by the International Dark Sky Association.
- Pending better LED class photometry info., atmospheric contribution enhancement to integrated S/P calculated as 20% for high CCT to 50% for lower CCTs; depending on angular distribution and ground scatter from vegetation, which moderates the atmospheric contribution.
- The more typical Mesopic region of some colour response to the night sky, due to existing low elevation light pollution, is less effected, and an improvement on existing SOX.

Modelling Environmental Impact of Navigation and Aviation Warning Lights on Proposed Large Offshore Windfarm.



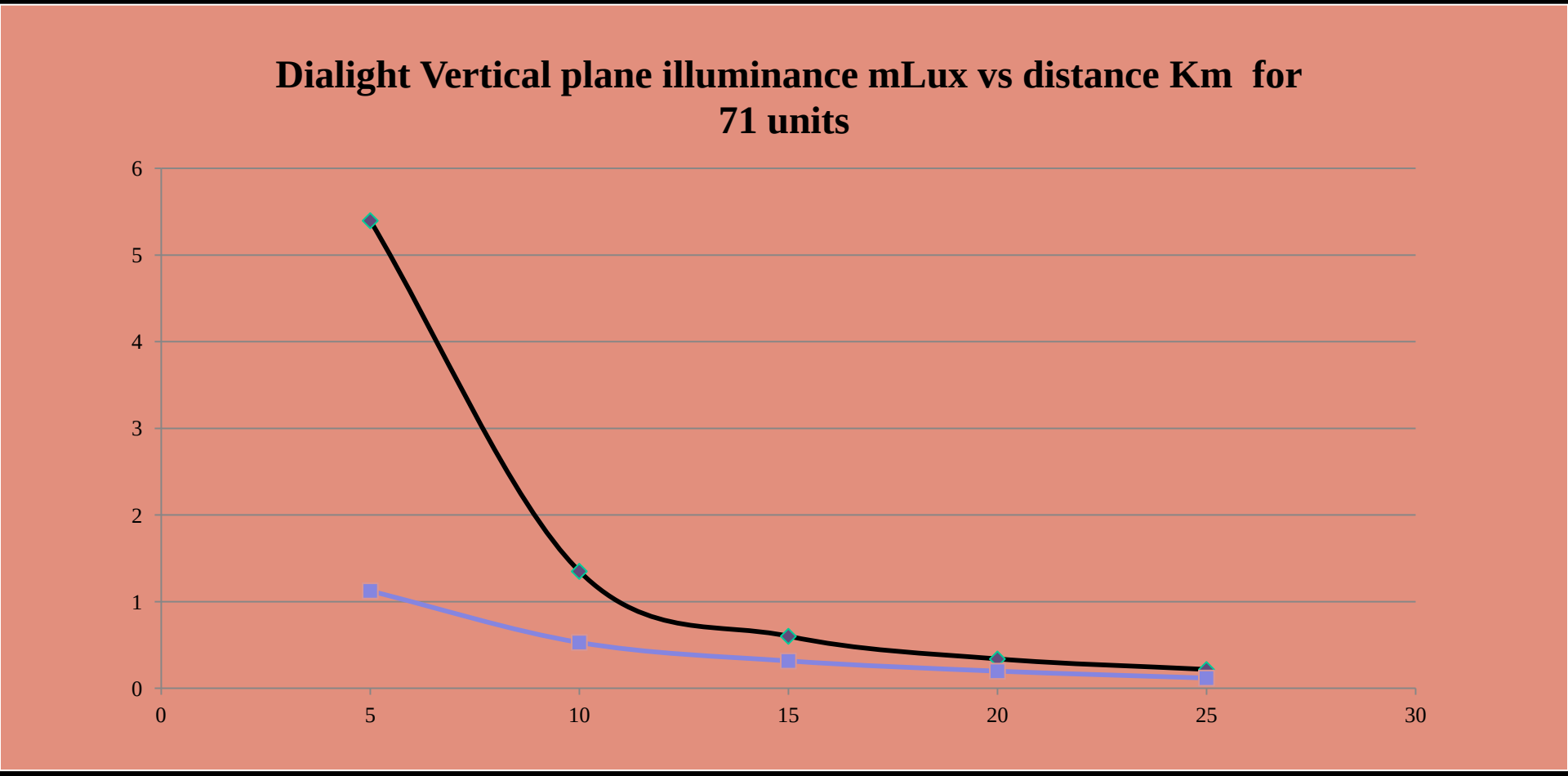
- 194 x5 MW wind turbine installations, covering roughly 12.5 km x 12.5 km off the Isle of Wight, directly south of Poole and Bournemouth, in the English Channel.
- 71 Vigilant directional 4 degree upwards tilted circular azimuthal red Warning lights and 30 low level mast base omnidirectional broad band lights

Dialight Vigilant Warning Lights



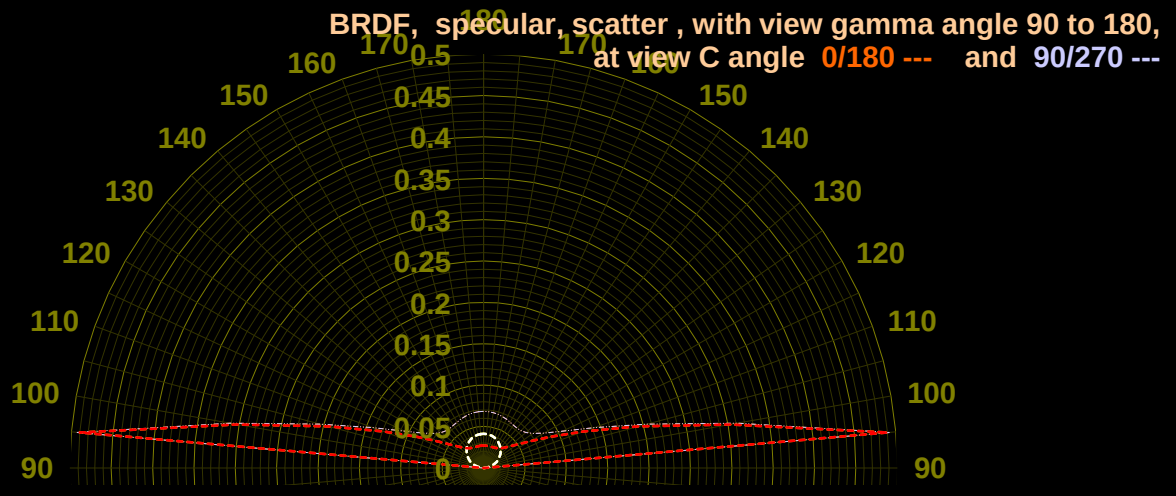
- This shows the elevation angle distribution intensity in candelas for Dialight Vigilant non-tilted (black) and Dialight VIgilant adjusted to CAA guidance (tilted 4°) (blue).

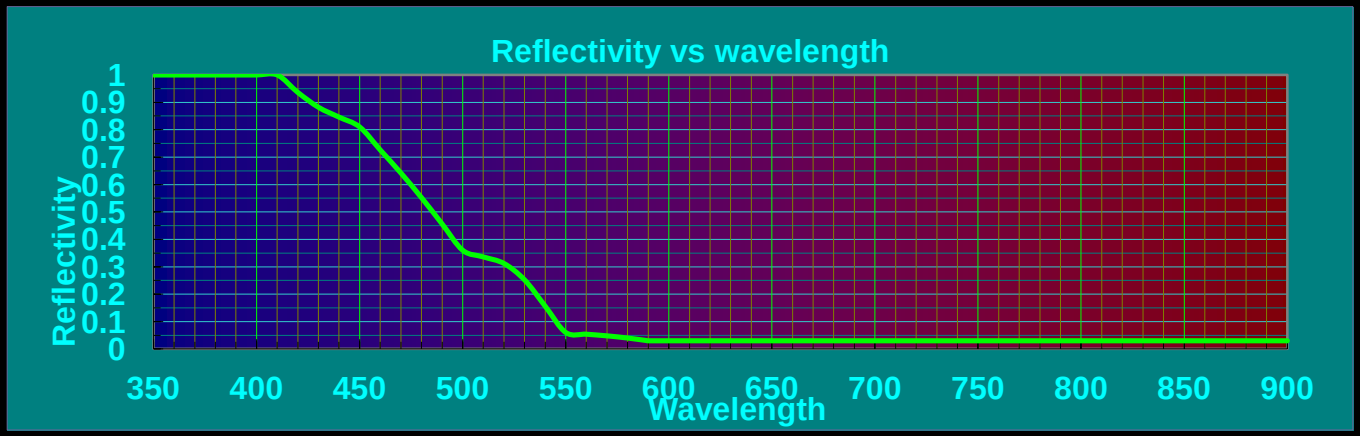
Dialight Vigilant Warning Lights



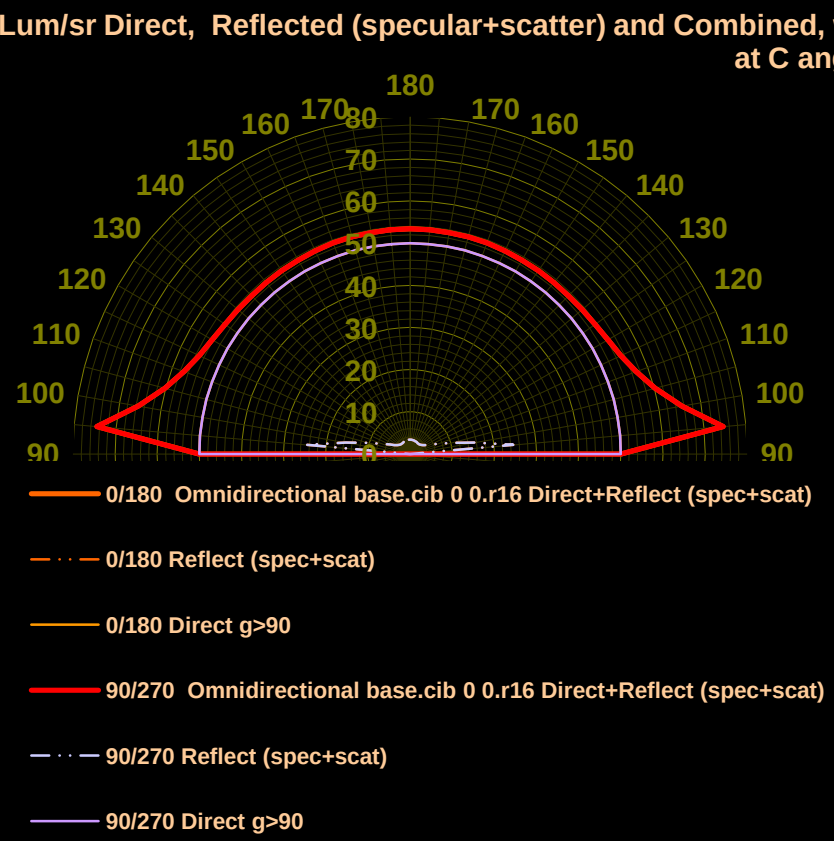
- Horizontal plane illuminance millilux of 71 Dialight units, for non-tilted, (black) and 4° tilted cases (blue). Each one will be perceived brighter then a bright star but dimmer than Jupiter.

BRDF of Warning Light over Sea





BRDF of Warning Lights over Sea



Summary

- The individual red tilted a aviation and navigation warning lights 15 km from landfall **will be visible** from the coast on the horizon at night. The brightness will be brighter than a bright Star, but dimmer than Jupiter.

- The **angular distribution** is quite different from that caused by normal road lighting in a landscape environment. The reflectivity off the sea is also very low angle.

- The **skyglow** from the navigation lights is limited to **near the horizon**, and on a clear night will be still less than those from that from external lighting in France.
- This is due to their directionality, and being deep red, where scattering is low.

Summary

End

Thank you!