Modelling Light Pollution for Highways Agency Environmental Policy

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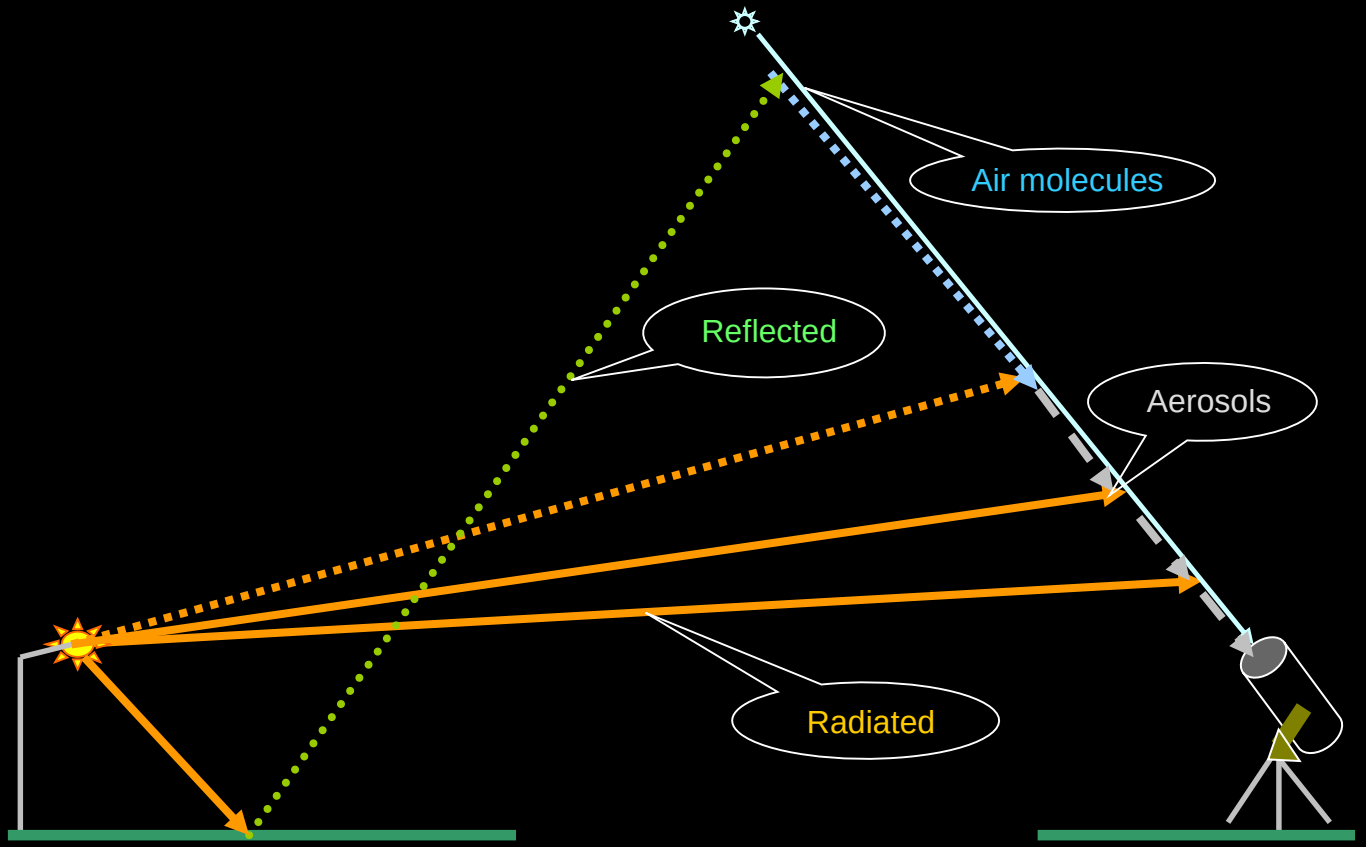
Outline

- Modelling method
- Dark Sky Survey of the Malvern Hill Area of Outstanding Natural Beauty
- 2014 Highways Agency Environmental Impact Policy
- Modeling Environmental Impact of Navigation and Aviation Warning Lights on Proposed Large Offshore Windfarm

Modeling Method

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

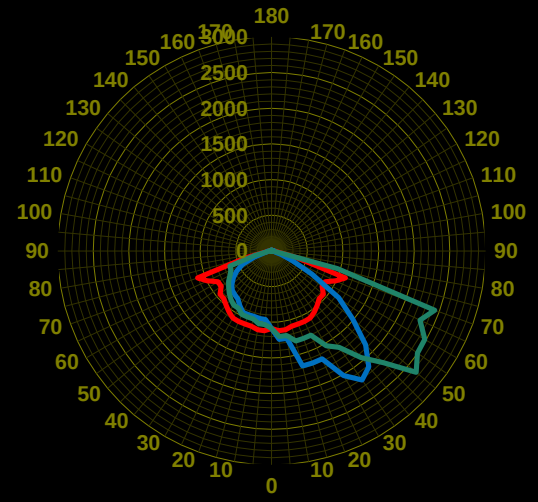


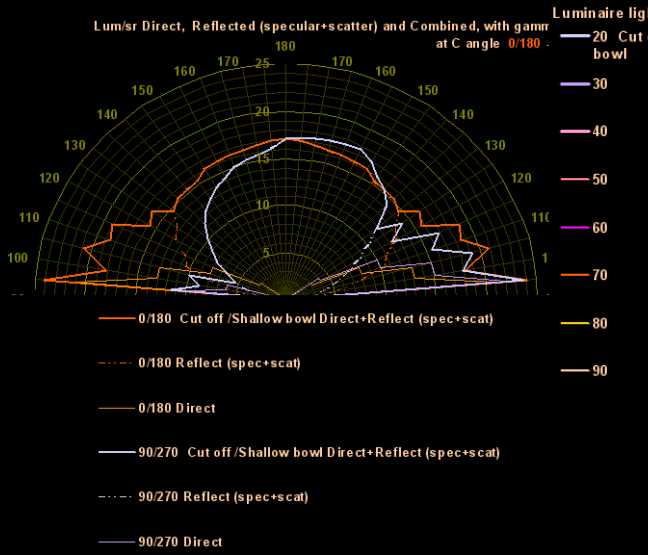
Ground Reflection

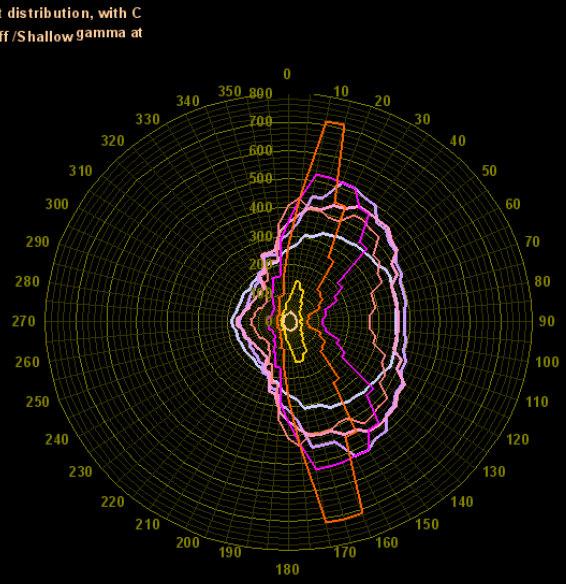
DIRECT

IMPACT OF GROUND REFLECTION

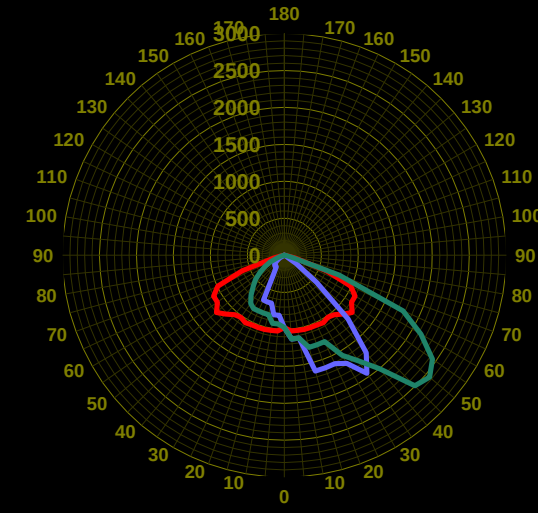
CUT-OFF PCB SON

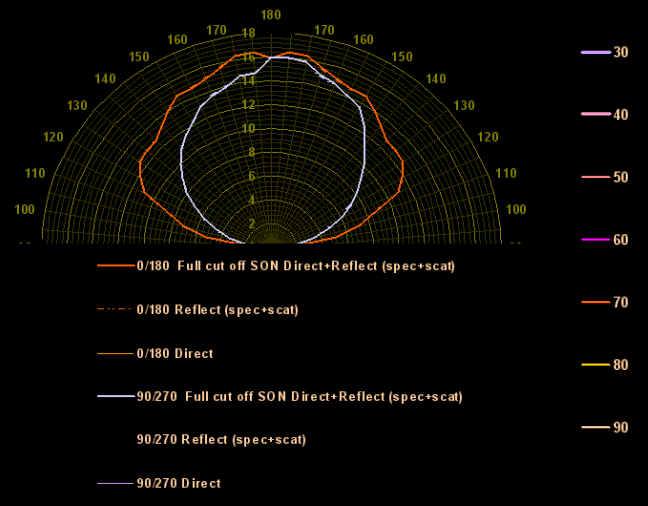


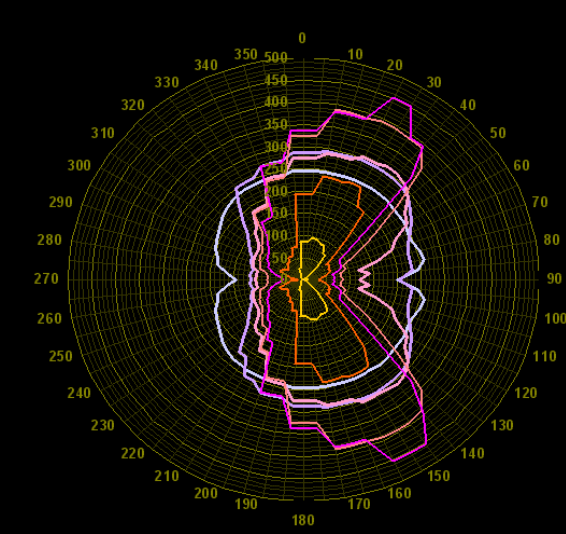




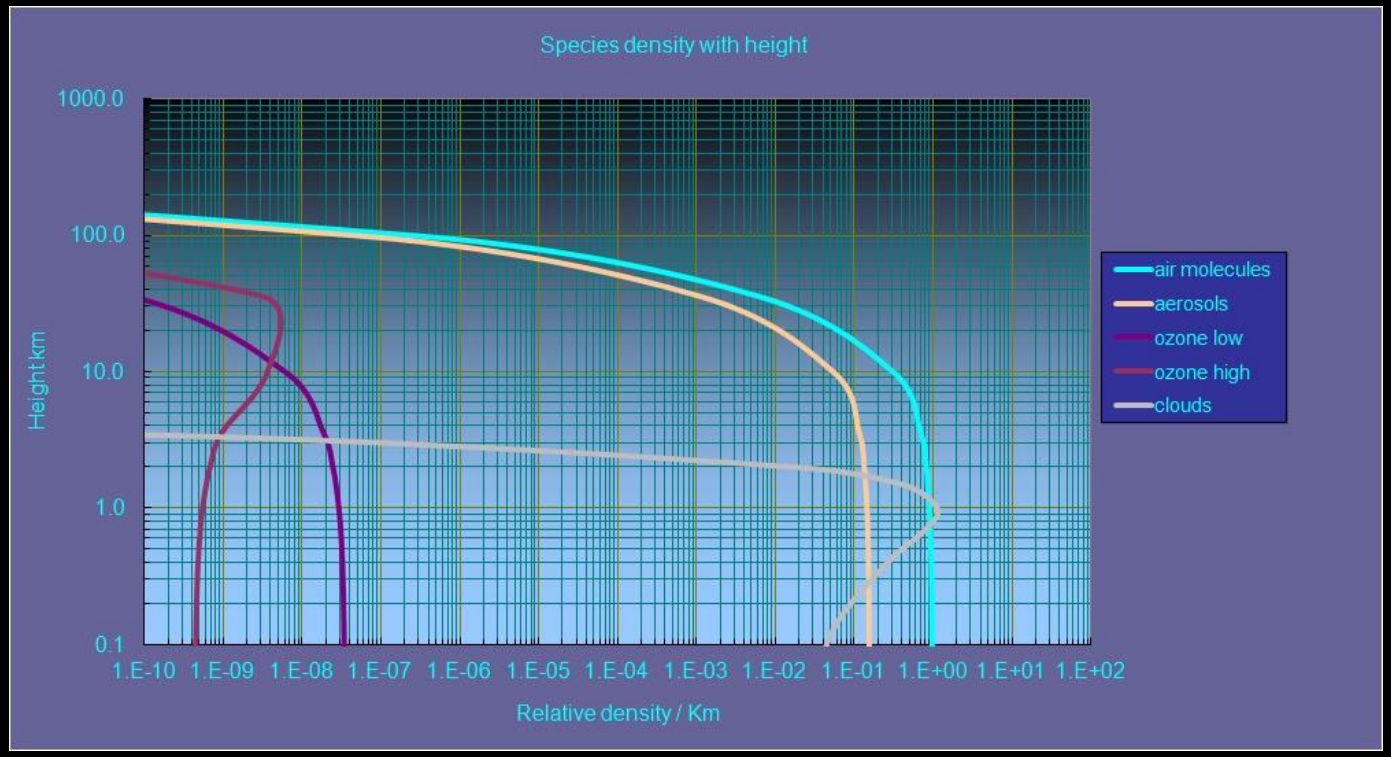
FULL CUT-OFF FGL SON







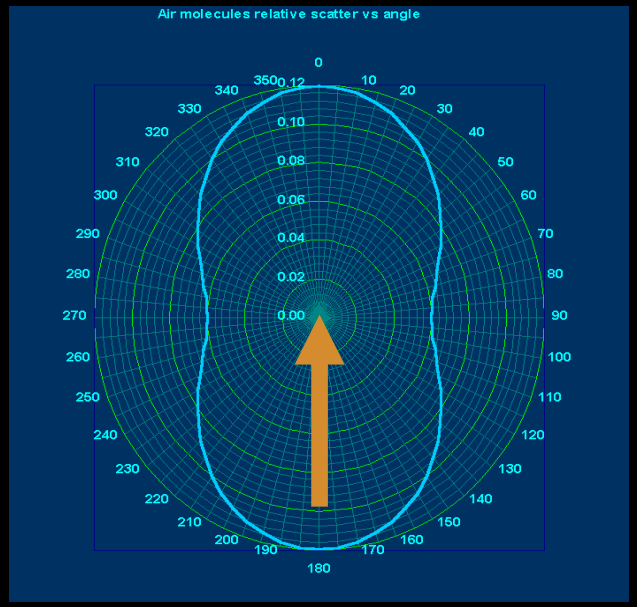
Atmospheric Component Densities

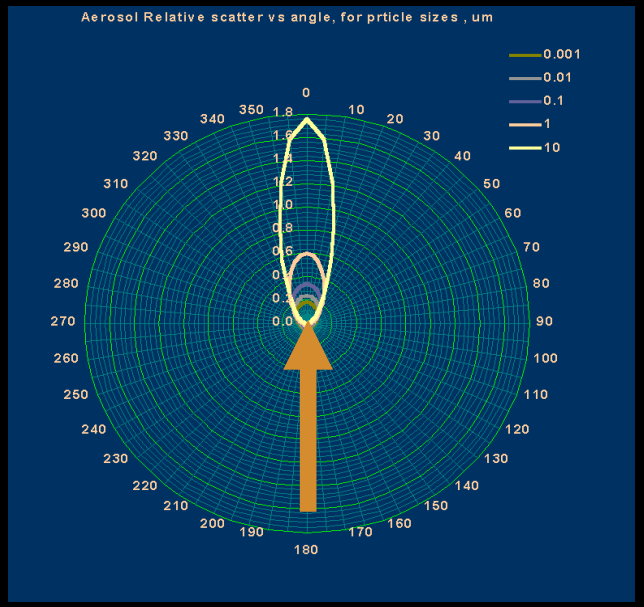


- Water droplets forming clouds are dominant in the lower atmosphere up to a few kilometers. Dust and ice based Aerosols continue higher, falling exponentially with molecular density.
- By 10 km, the atmospheric density is only a third of that in the ground.
- The model takes this scaling of molecular 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 λ^4 (blue biased).

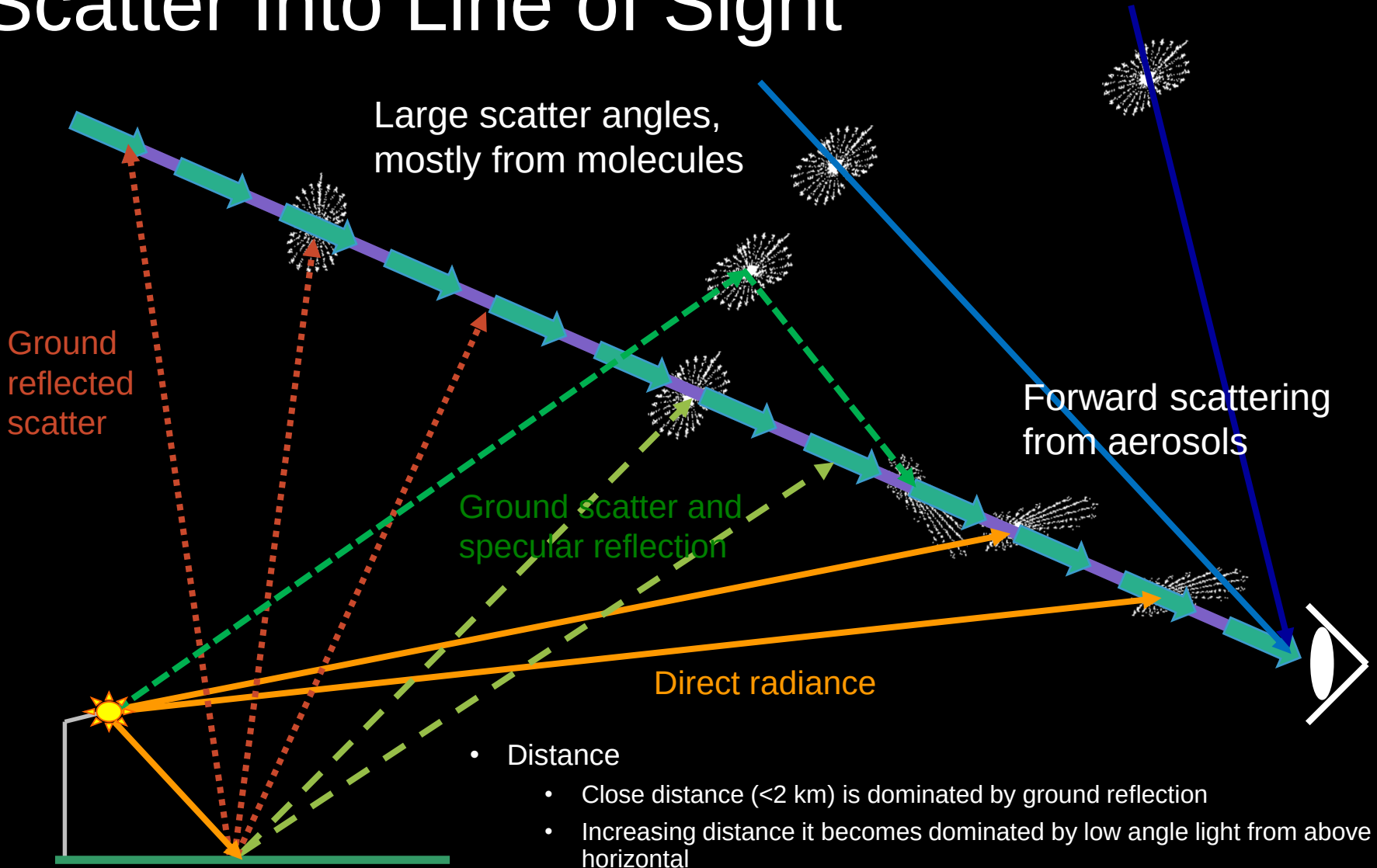
$$P(\psi) = (3/(16\pi)(1+\cos^2 \vartheta)$$

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.

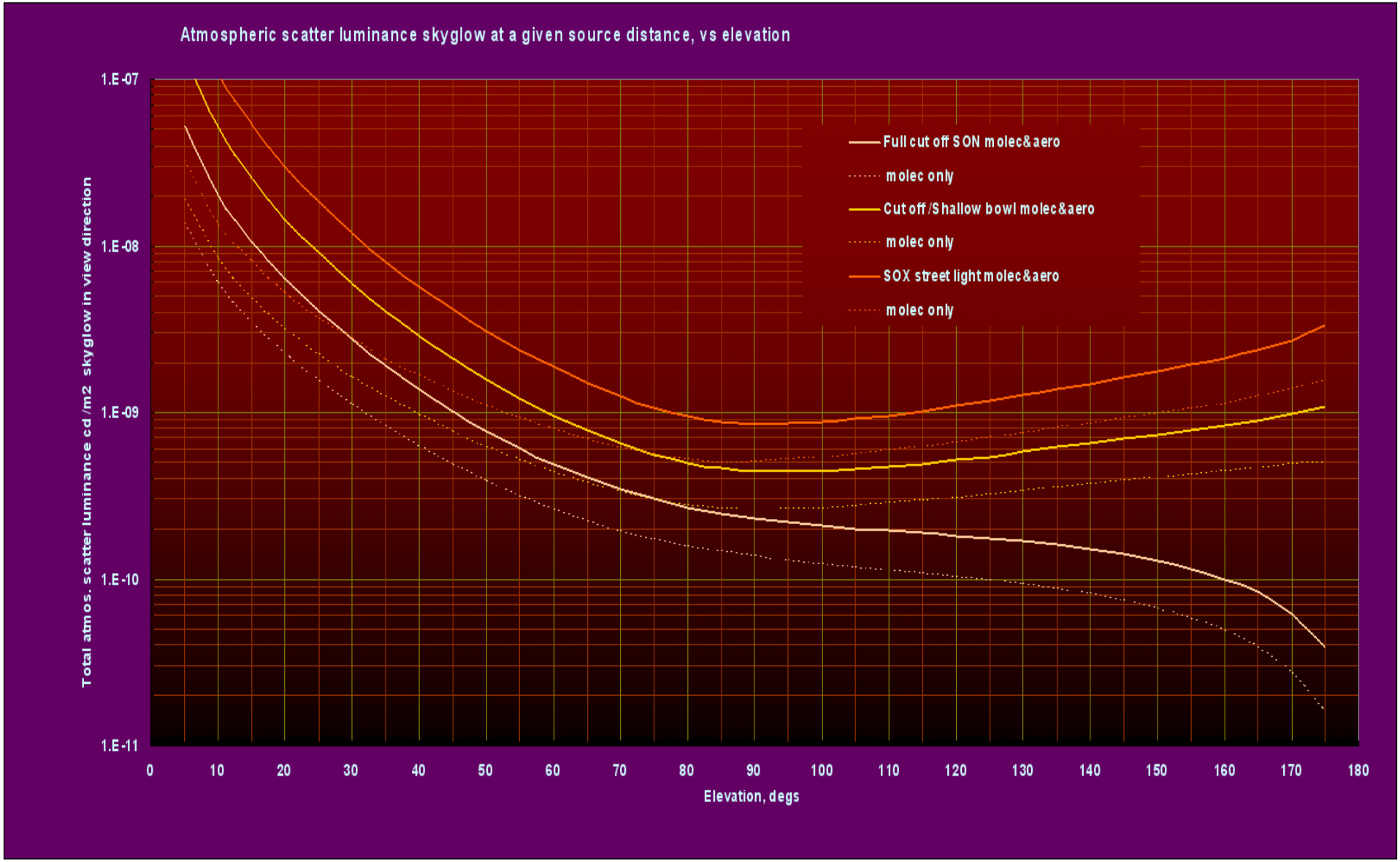
$$P(\vartheta) = (1-g^2)\left[\frac{1}{(1+g^2)-2g\mu)^{3/2}} + f\,\frac{(3\mu^2-1)/2}{(1+g^2)^{3/2}}\right]$$

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

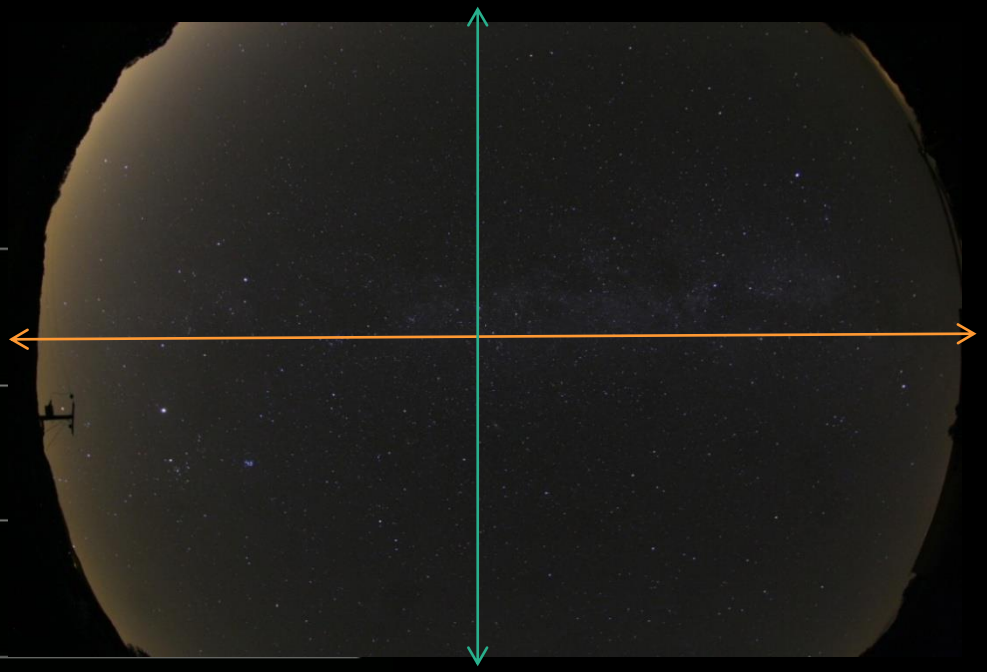
Scatter Into Line of Sight

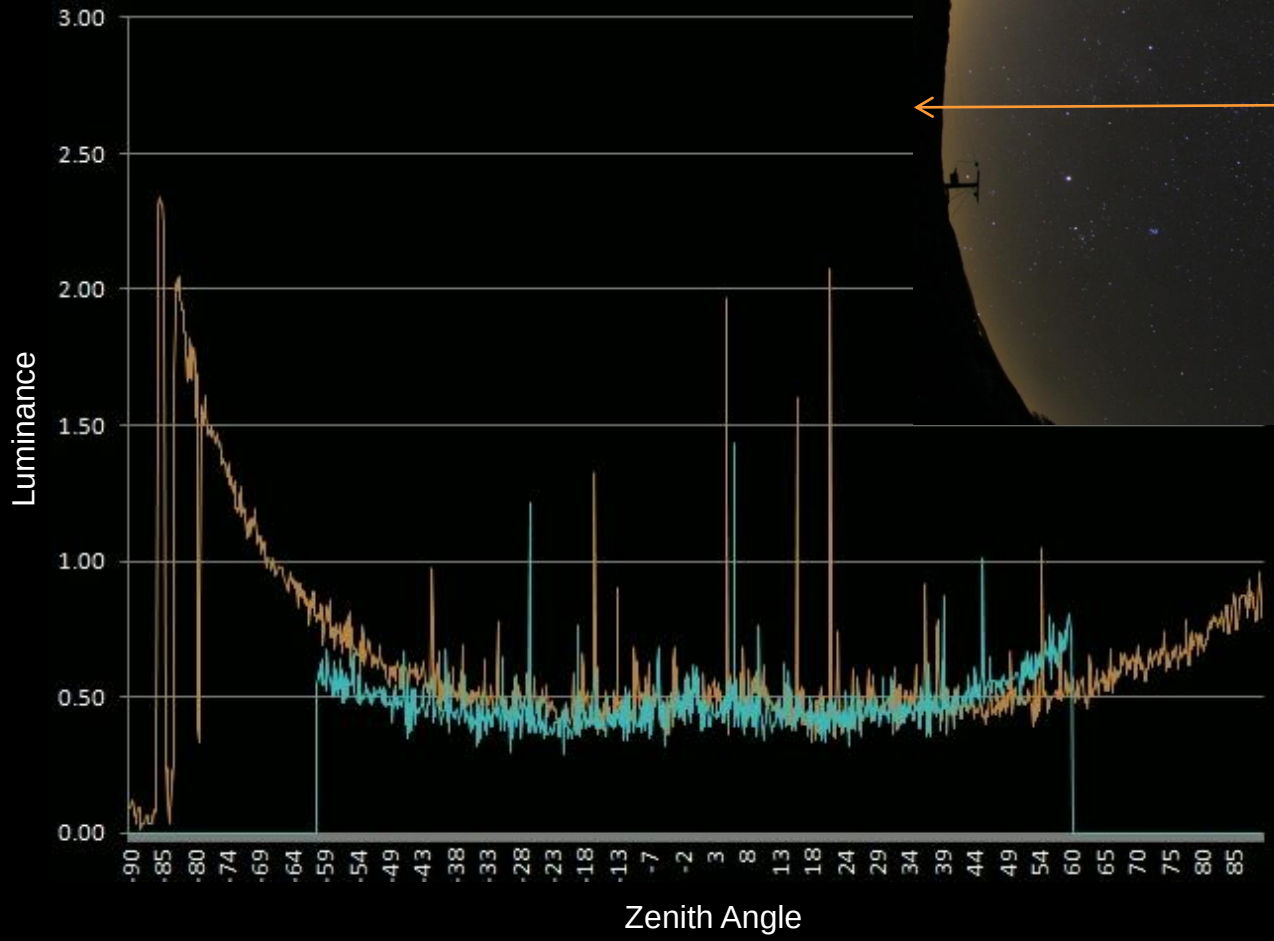


Dark Sky Survey of the Malvern Hill Area of Outstanding Natural Beauty

- The **Milky Way** surface luminance was calculated to be about **0.1 mcd/m^2**
- 1000 SOX luminaires at 40° elevation at 10km is **> 0.1 mcd/m^2**
- **Exceeds** the Milky Way surface brightness and that of other nebulae
- For FCOs it is more than **5 times lower**, and far more so in the opposite direction, making the Milky Way visible.

Dark Sky Survey of the Malvern Hill Area of Outstanding Natural Beauty





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.

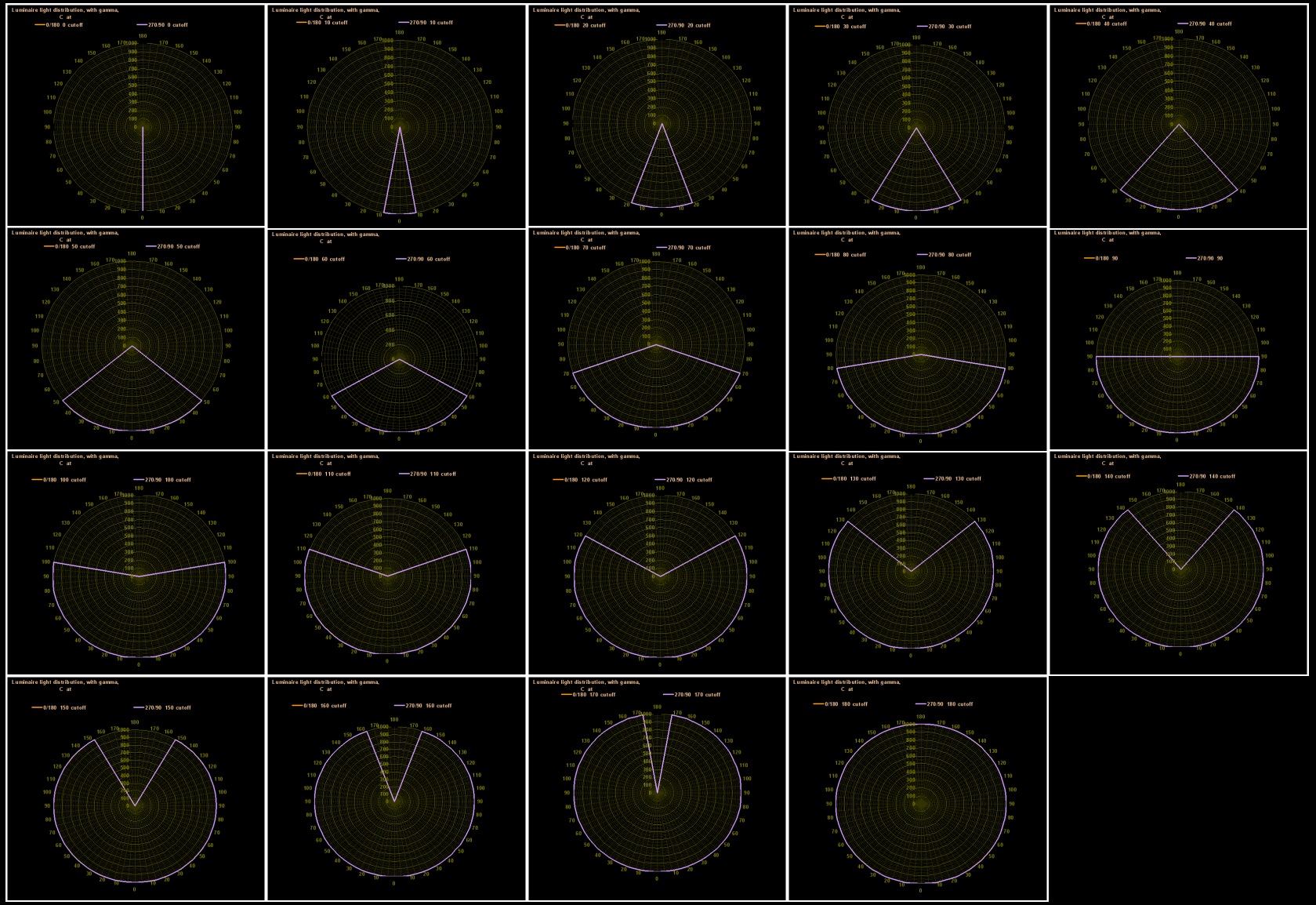
2014 Highways Agency Environmental Impact Policy

- Modelling of a Globelight stepped gamma cutoff contribution to skyglow to show **effect of changing cut off angle on skyglow**.

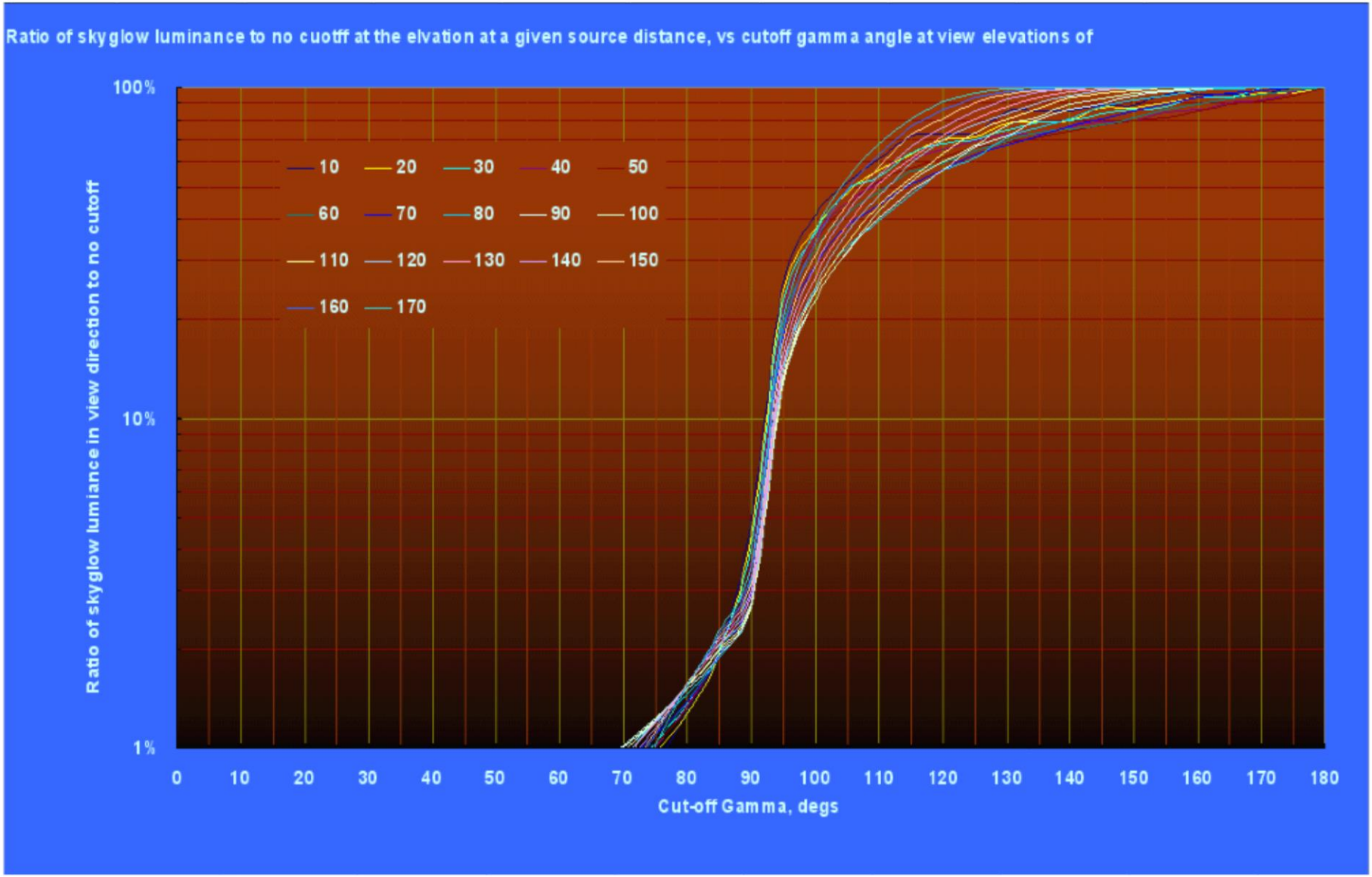
- **Exponential impact** from 70deg through 90deg gamma.

- Providing a **weighting factor** scaling metric with high gamma cutoff angles for the light pollution section of the HA environmental impact assessment policy.

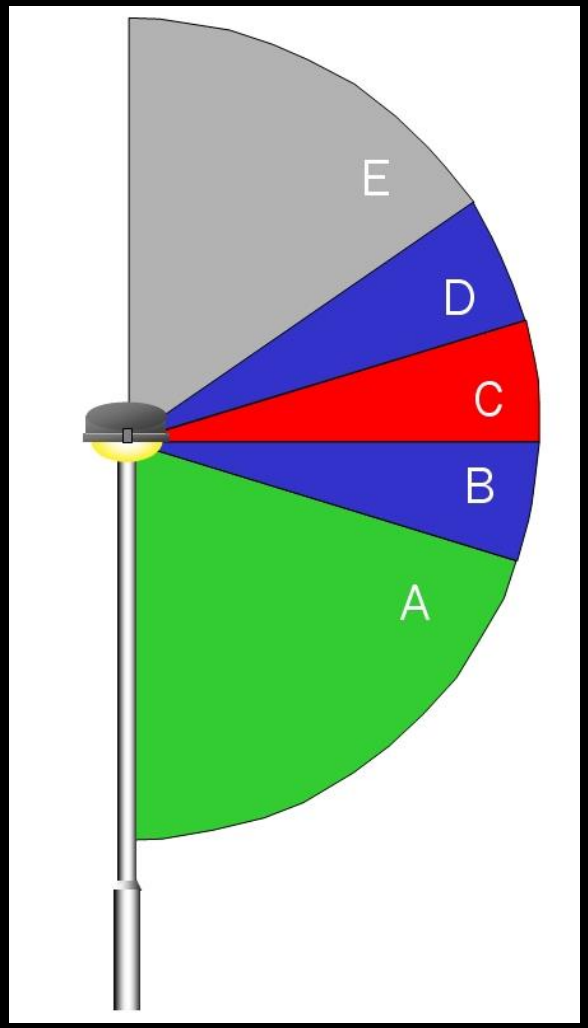
Stepped Gamma Plots



Stepped Gamma Plots



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.

Luminaire Output

Gamma Angle	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

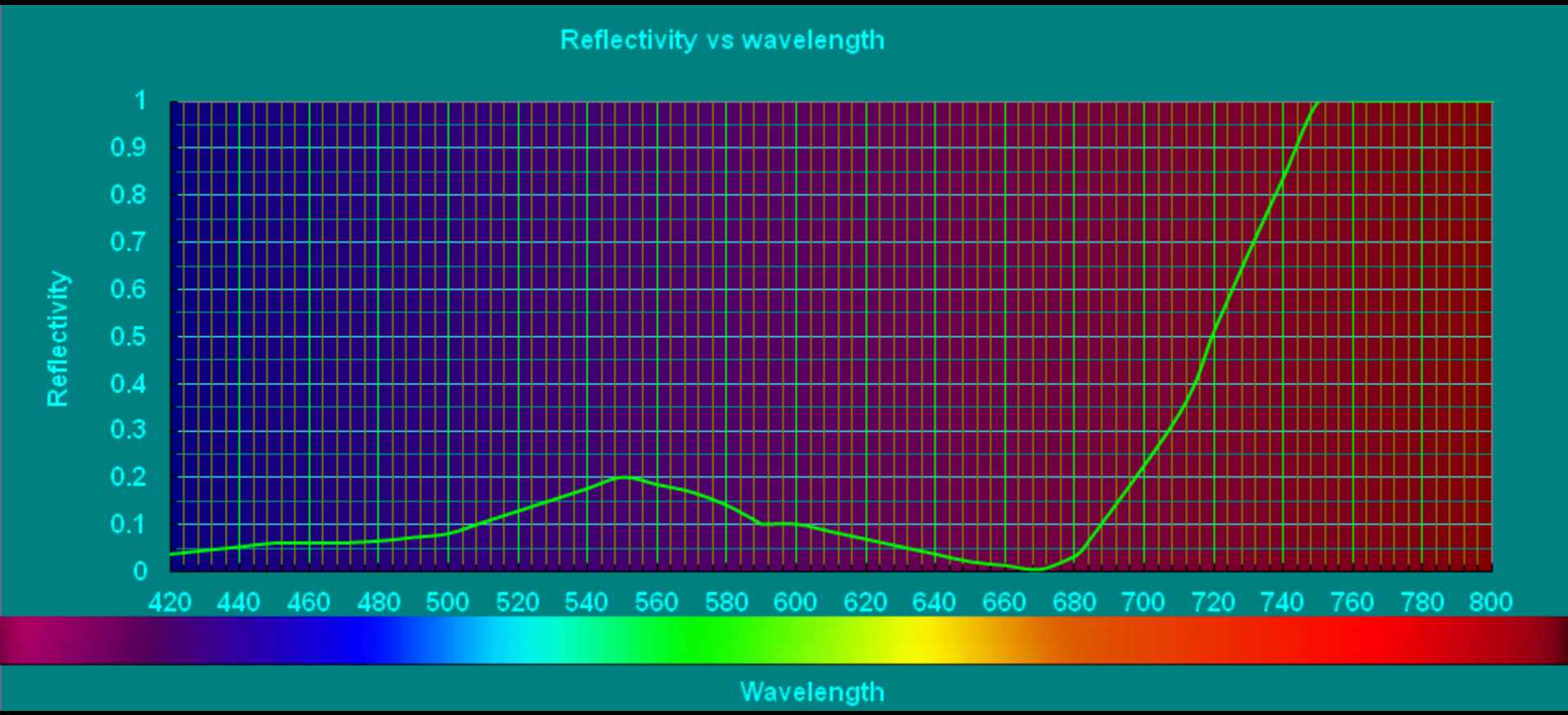
- Due to the highly directional properties of LEDs, the **weighting factor** scaling metric from 70 to 90 gamma cutoff angles (and beyond) will be effective in limiting skyglow from LED class G4 to similar to current G6 SON (full horizontal cut off) as currently used.

- Curved and tilted base-plates to spread the light reduce this, and will not pass this criterion, as used in classes G1 to G3

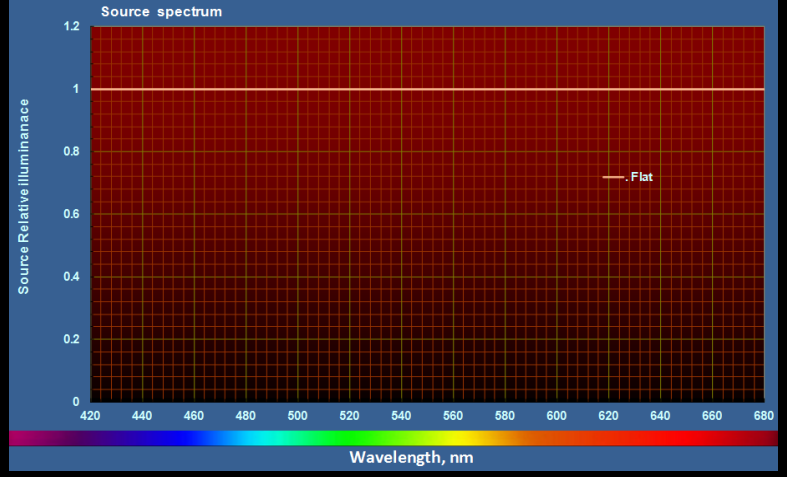
- Class G1 to G3 LEDs are being rolled out on Council controlled roads countrywide, often replacing LPS SOX, which have a large upward light ratio. Modeling of this for Herefordshire in underway.

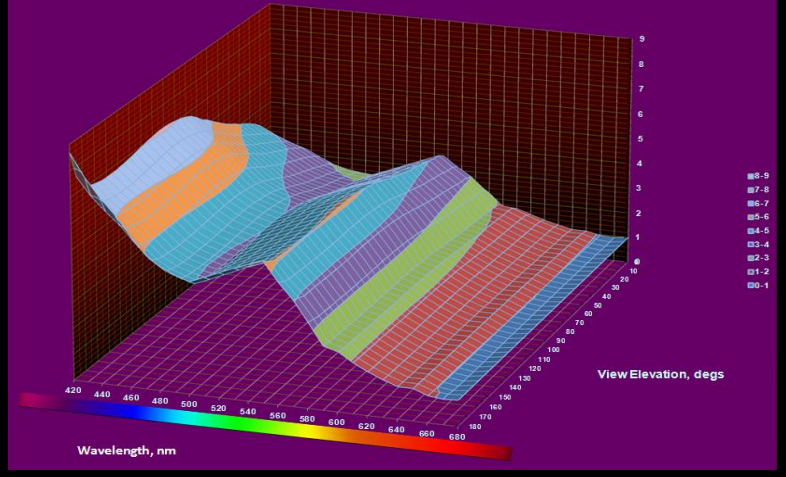
- The HA is requesting limiting colour temperature. Modeling of this shows the significant potential problem to astronomy.

Grass Reflectance

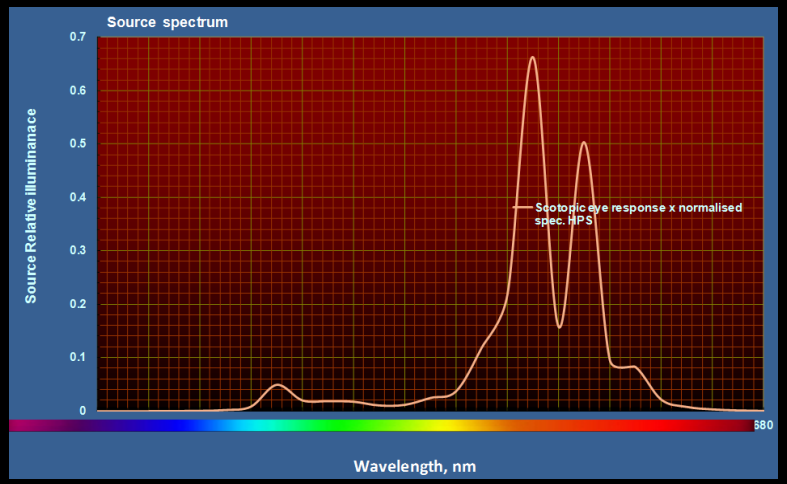


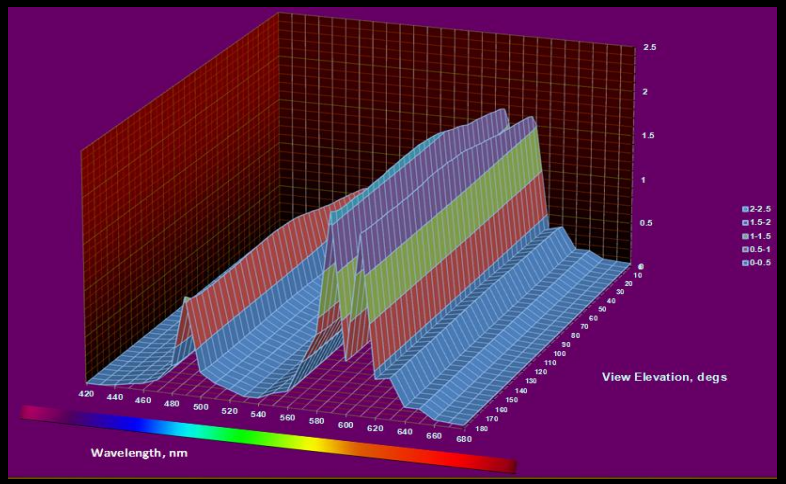
FLAT SPECTRUM



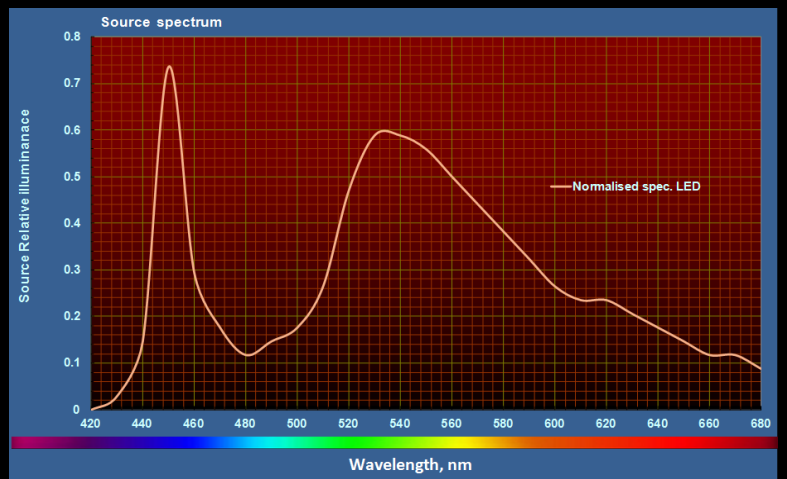


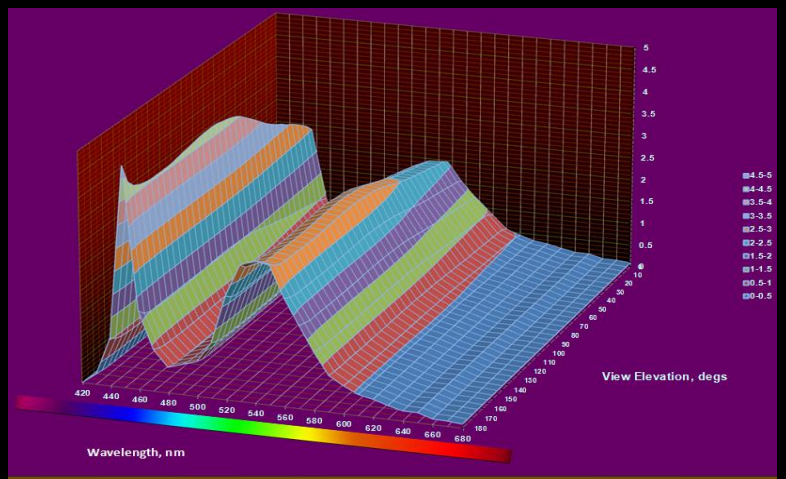
HPS





LED

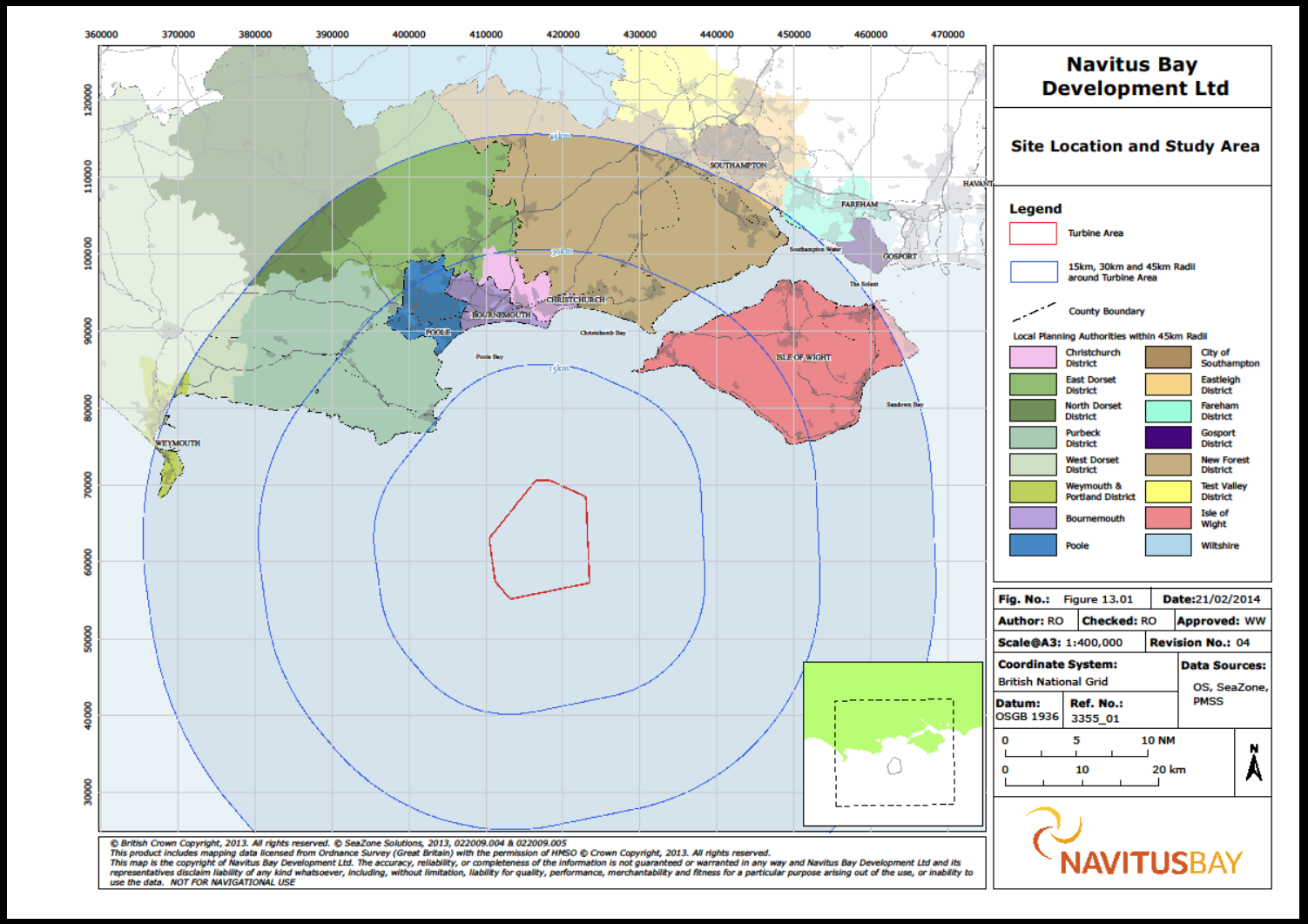




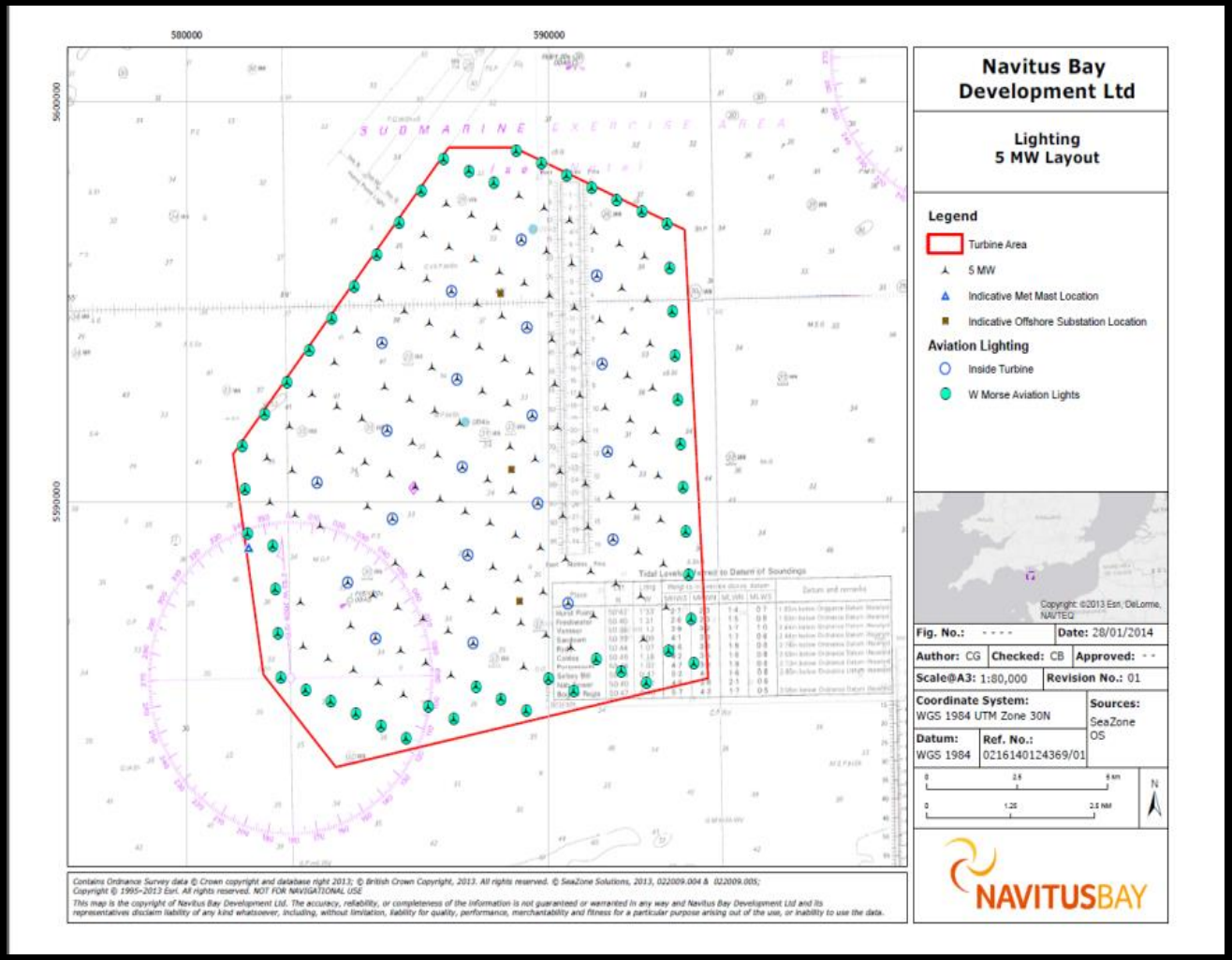
Summary

- The increasing use of blue rich LED lighting should be discouraged.
- The potential Photopic / Scotopic ratio light intensity reduction compensation is not sufficient.
- Atmospheric highly blue bias Rayleigh scattering and reflection off green vegetation increases skyglow at the Zenith by **up to 5x** that from HPS luminaires for the same ground brightness. A potential astronomical disaster.
- Much lower colour temperature, 3000K, is recommended by the International Dark Sky Association.

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

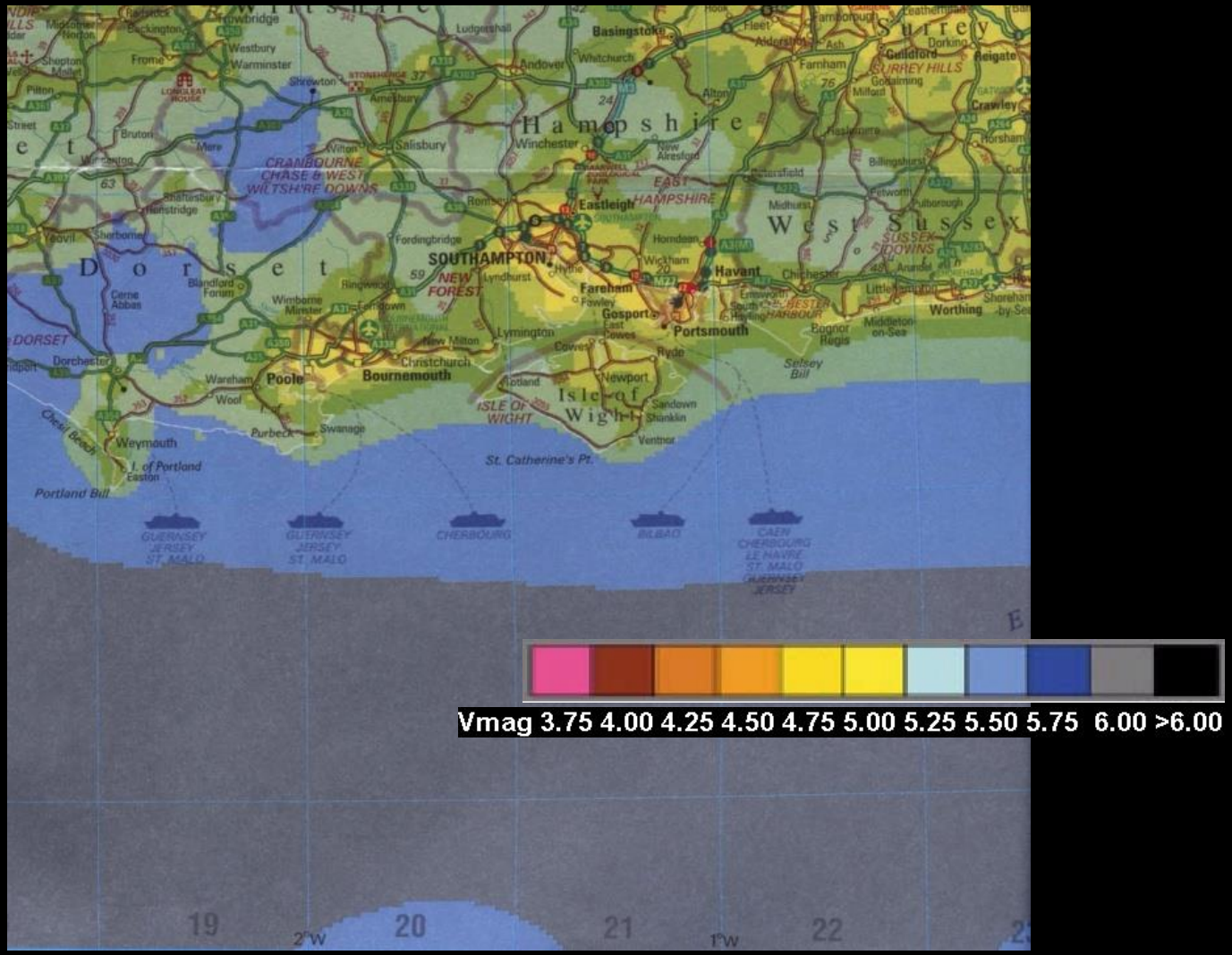


Windfarm Array Map



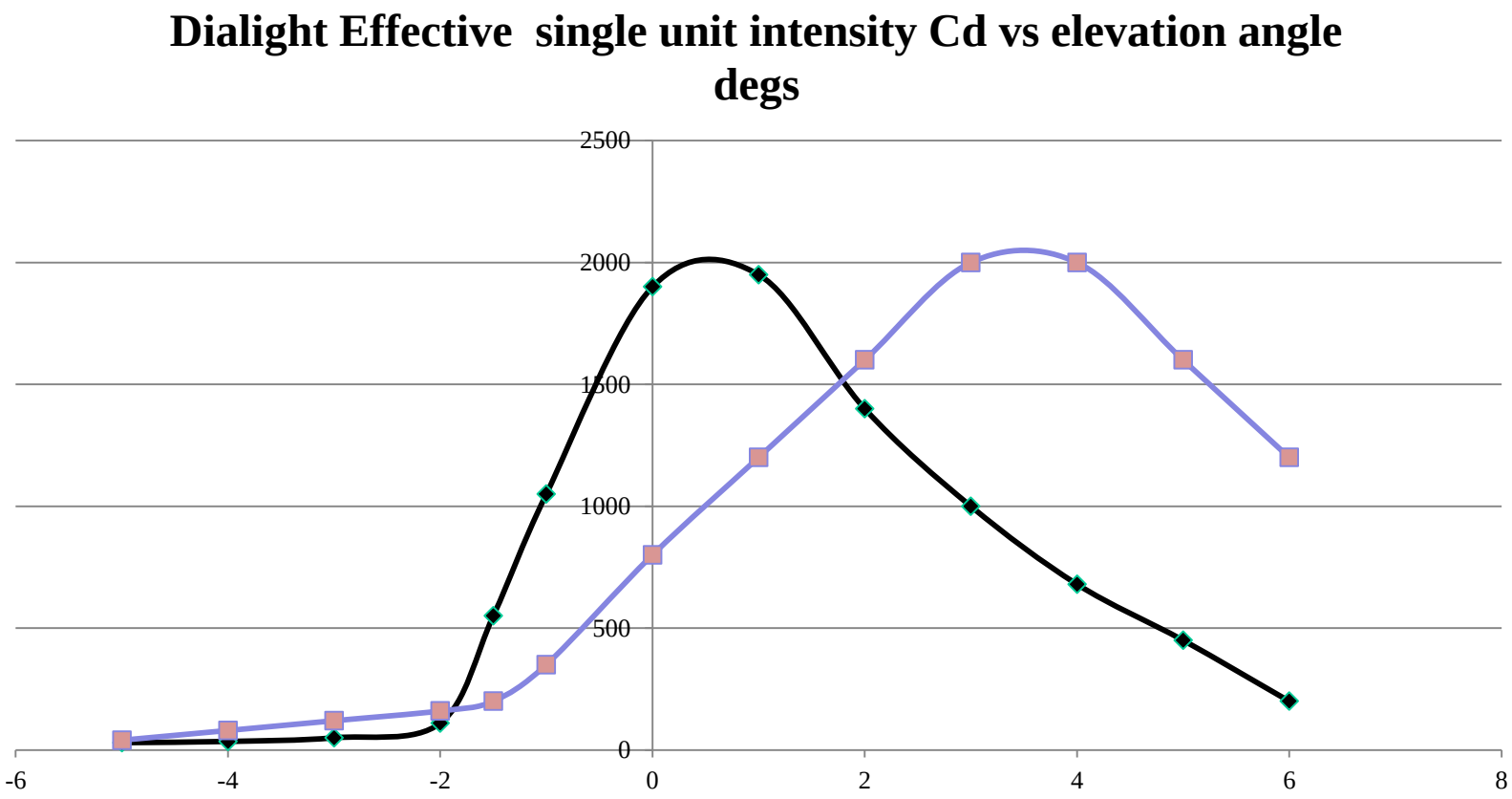
- 194 x5 MW wind turbine installations, covering roughly 12.5 km x 12.5 km off the Isle of Wight, directly south of Poole and Bournemouth, in the English Channel.
- 71 Vigilant directional 4 degree upwards tilted circular azimuthal red Warning lights and 30 low level mast base omnidirectional broad band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

Dark Skies Map



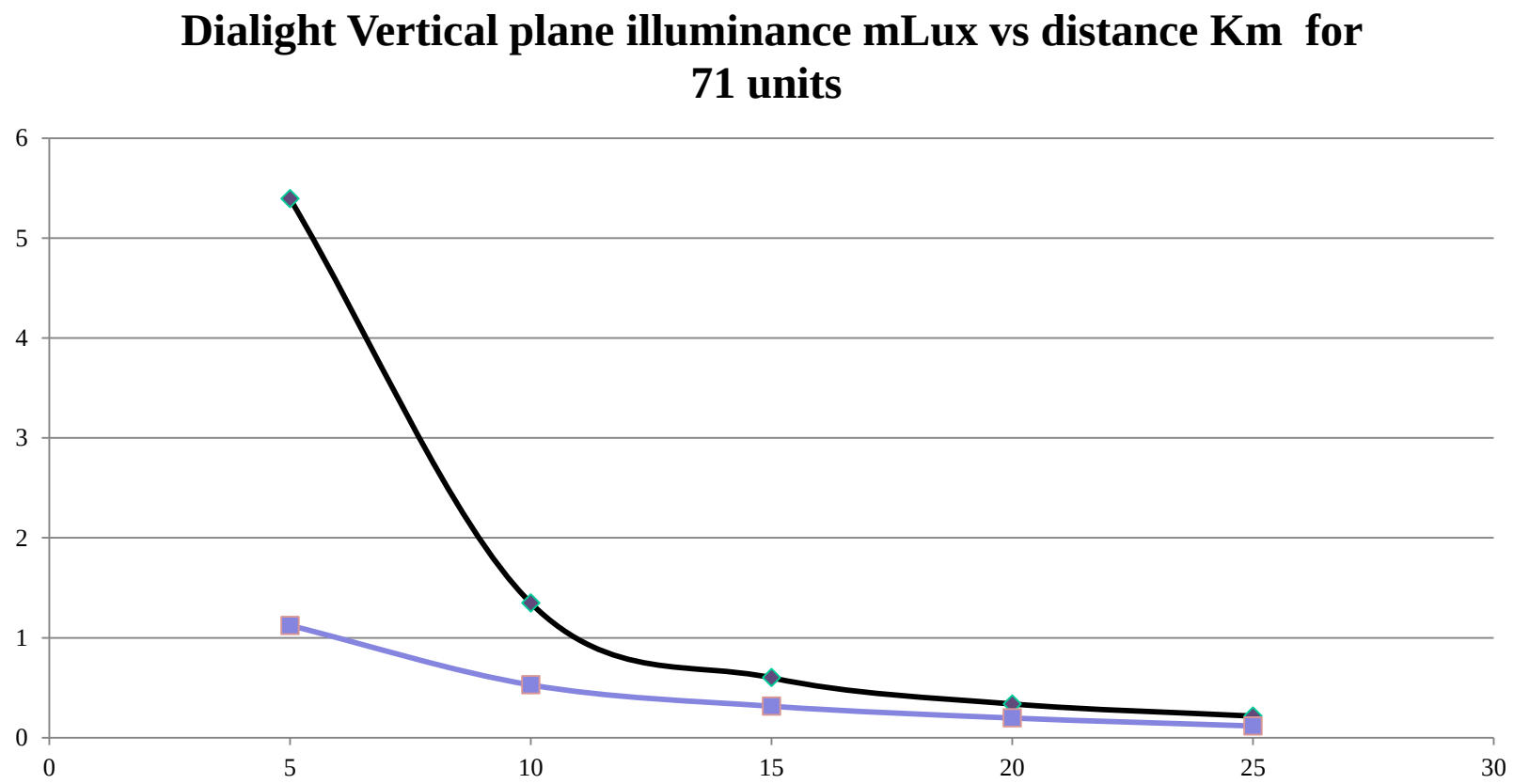
- Star visibility limits in the UK superimposed on a road map. A collaboration between CfDS, P. Cinzano - (ISTIL Dipartimento di Astronomia Padova, Italy), and Philips – Maps.

Dialight Vigilant Warning Lights



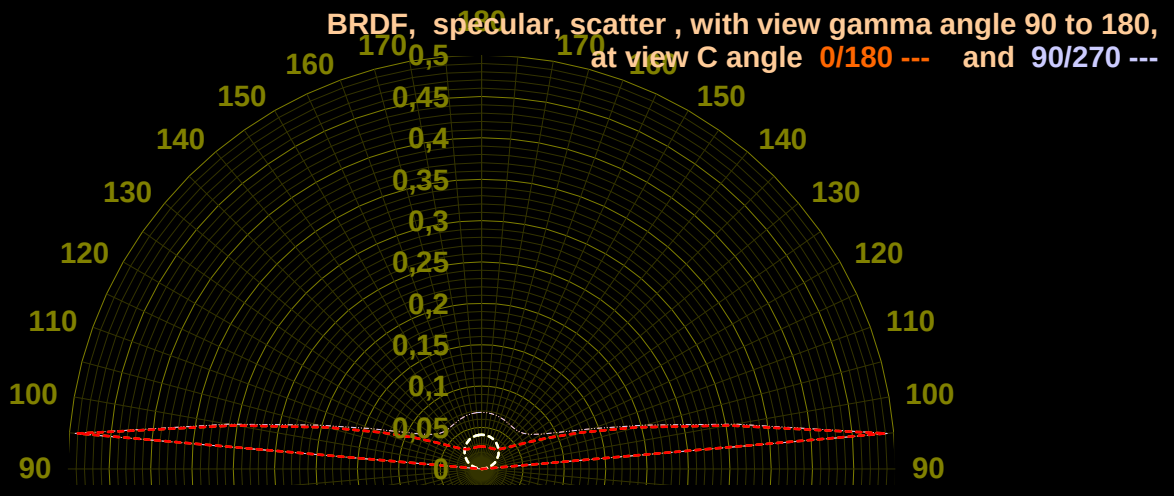
- This shows the elevation angle distribution intensity in candelas for Dialight Vigilant non-tilted (black) and Dialight VIgilant adjusted to CAA guidance (tilted 4°) (blue).

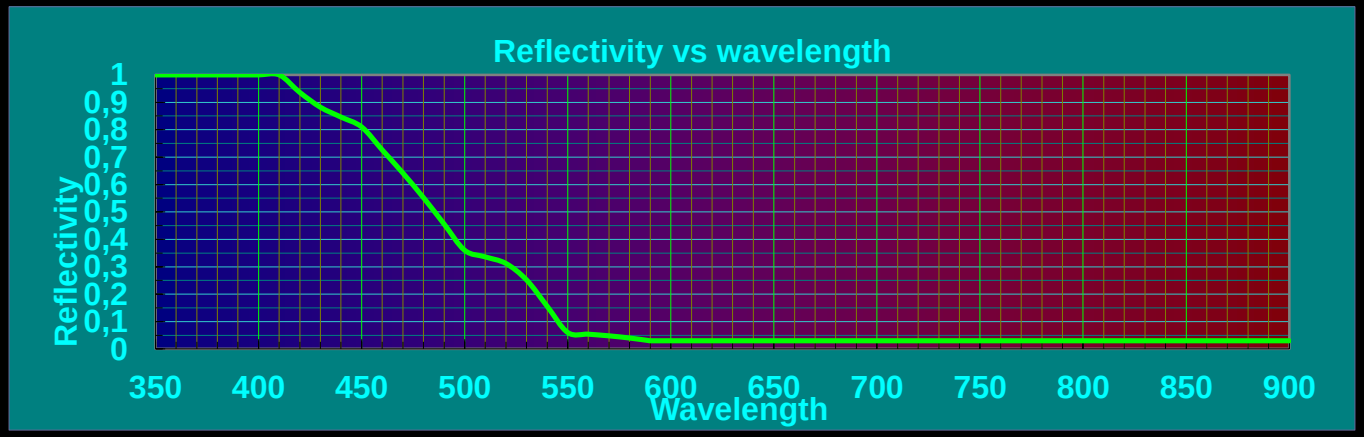
Dialight Vigilant Warning Lights



- 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





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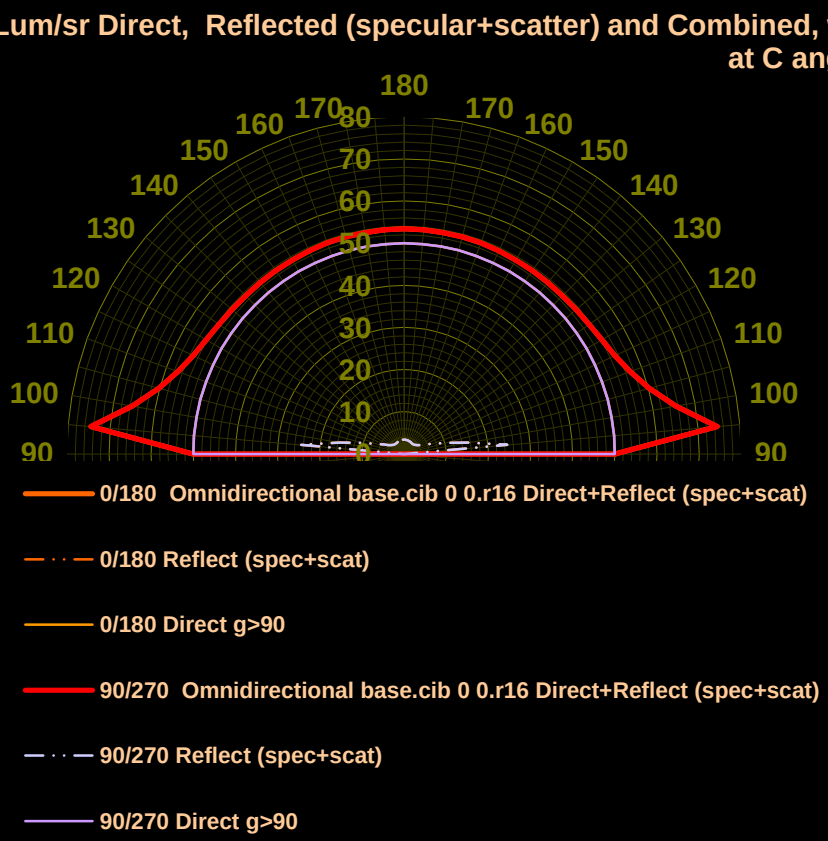

Summary

- 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 low-level base warning lights will **not be visible** from the coast due to the Earth curvature and waves.

- The effect of sky glow from the small number of **low-level omnidirectional lights** at the base of some of the towers is **not significant**.

- 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. Sky glow towards the **zenith** is mostly from Rayleigh scattering by air molecules and very blue biased. That will be dominated by English towns and those on the French coast.

Modelling Light Pollution for Highways Agency Environmental Policy

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