LIGHTING AND ASTRONOMY

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We will discuss the impact of direct and scattered light from cities on observatory sites, how "skyglow" affects astronomy observations, how it is measured, and how far it reaches. This will include examples from specific observatories around the world. Data from all-sky cameras and powerful, but simple handheld Sky Quality Meters (SQMs) at two sister observatories in North and South America will be included. The SQMs are used as part of the GLOBE at Night citizen science program[1]. While both the astronomy and lighting professions have significant expertise in measuring light, our terminology, methods, and needs differ. The presentation will offer background on astronomy observations that is relevant to the lighting community.

All light is not created equal. When considering the effects of artificial light escaping from an urban environment, the angle at which the light is propagating is very important. When a town is seen from the vantage point of a distant observatory, there are some important considerations:

1. The atmosphere is relatively thin, with thickness (air density) decreasing exponentially. Every 4km in altitude corresponds to a decrease by a factor 0.6 in density and pressure. This means that light that is reflected from the ground going nearly straight up has a relatively good chance (about 85%) of leaving the Earth's atmosphere without scattering and contributing to skyglow.

2. Light that is emitted in nearly horizontal directions can propagate for enormous distances (up to 300 km) through the atmosphere. Because it passes through so much air, it has a nearly 100% likelihood of scattering, and therefore contributing to skyglow. Furthermore, it can produce skyglow at great distances from the light source.

3. Light that is reflected from the ground has a reasonable chance of being intercepted by adjacent low structures and vegetation. However, because of the sizes of structures and vegetation types near the world's major observatories, light that is emitted horizontally directly from light fixtures is mostly unobstructed, and therefore produces skyglow.

For the case of La Serena, located about 90 km from Cerro Tololo observatory in Chile, any light that reflects off the ground from a fully shielded fixture has to first find its way "around" obstructions, propagating upwards. If we look from the observatory over La Serena at an angle of 30 degrees from horizontal, the air that the telescope beam passes through over La Serena is 45 km above the Earth, and so has an atmospheric pressure of about 0.003 atm - there is essentially no air there, and so the reflected light from La Serena cannot scatter into the telescope. The only way for this light to enter the telescope is for it to scatter twice - once at lower altitude, changing the direction, then a second time closer to Cerro Tololo. This situation should be contrasted to the case of a partially shielded fixture that can emit light directly in the direction of the observatory. Light from such a partially shielded fixture only has to scatter once to enter the telescope. The likelihood of

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[1] The goal of GLOBE at Night is to raise public awareness on the issues surrounding light pollution by involving everyone (in particular, families and students) in naked-eye and SQMbased measurements of sky brightness worldwide.

scattering for green light in one thickness of atmosphere is approximately 15%. The difference in impact on observatories between double scattering (required for fully shielded fixtures) compared to single scattering (partially shielded fixtures) is therefore approximately 1/0.15, or a factor of approximately 6. Physical shielding by low-level structures and vegetation further increase this factor.

Not only professional observatories, but many national parks, wilderness areas, rural communities, and other locations that are away from cities around the world are affected at significant distances by skyglow from cities. Simple models have been developed that equate upwards light to skyglow - these can give a reasonable prediction for skyglow above the city or source of light. However, this approach cannot properly predict skyglow at a distance from the city, because the angular dependence of the emitted light is critically important. More robust modeling that includes the angular distribution of light has recently been developed and applied to the case of Flagstaff, Arizona.

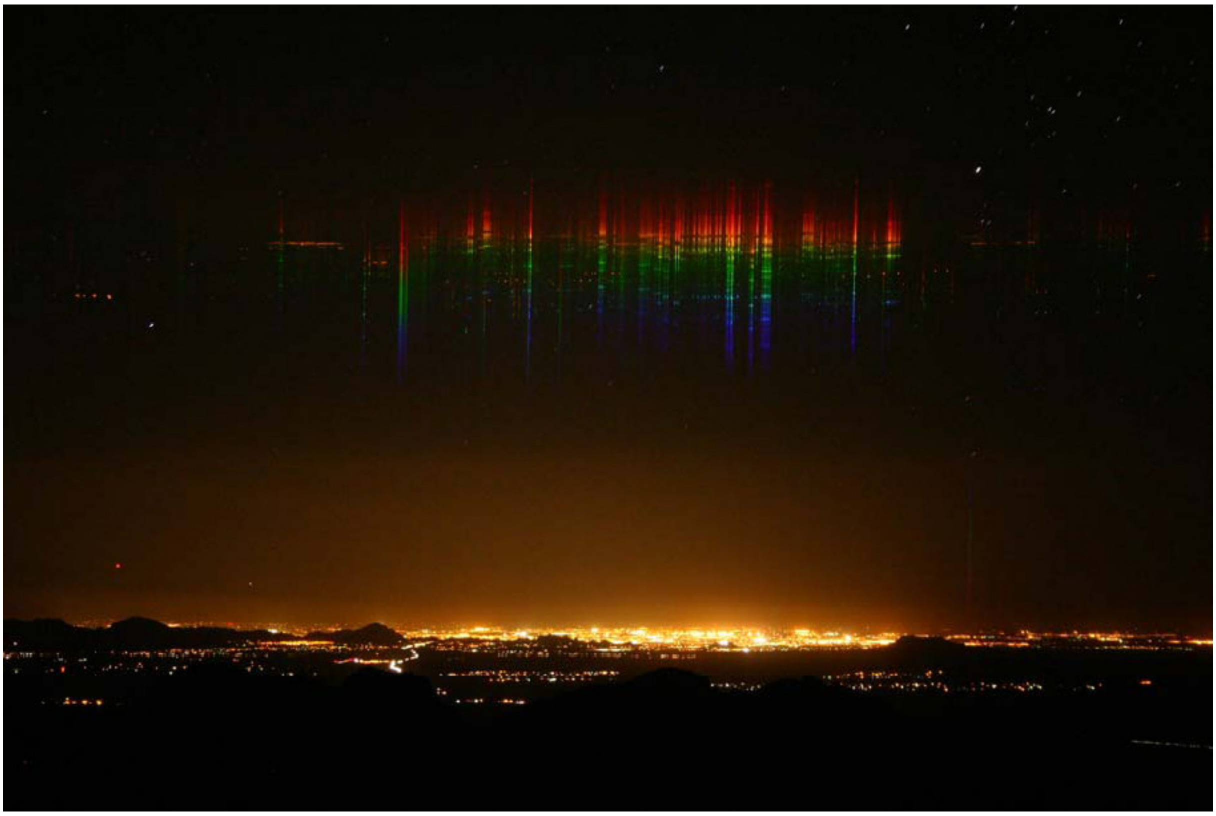

Figure 1. Spectrum of the lights of Tucson seen from afar