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TECHNICAL REPORT

Green Laser Pointers for Visual Astronomy: How Much Power Is Enough?

Salvador Bará*, Marisol Robles†, Isabel Tejelo‡, Ramón I. Marzoa†, and Héctor González§

ABSTRACT

Purpose. Green laser pointers with output powers in the tens to hundreds of milliwatt (mW) range, clearly exceeding the limiting 5 mW of American National Standards Institute class 3a (International Electrotechnical Commission class 3R), are now easily available in the global market. They are increasingly being used in public sky observations and other nighttime outreach activities by educators and science communicators in countries where their use is not well regulated, despite the fact that such high power levels may represent a potential threat to visual health. The purpose of this study was to determine the output power reasonably required to perform satisfactorily this kind of activities.

Methods. Twenty-three observers were asked to vary continuously the output power of a green laser source (wavelength 532 nm) until clearly seeing the laser beam propagating skyward through the atmosphere in a heavily light-polluted urban setting. Measurements were conducted with observers of a wide range of ages (9 to 56 years), refractions (spherical equivalents −8.50 to +1.50 diopters), and previous expertise in using lasers as pointing devices outdoors (from no experience to professional astronomers). Two measurement runs were made in different nights under different meteorological conditions.

Results. The output power chosen by observers in the first run (11 observers) averaged to 1.84 mW (±0.68 mW, 1 SD). The second run (17 observers) averaged to 2.91 mW (±1.54 mW). The global average was 2.38 mW (±1.30 mW). Only one observer scored 5.6 mW, just above the class 3a limit. The power chosen by the remaining 22 observers ranged from 1.37 to 3.53 mW.

Conclusions. Green laser pointers with output powers below 5 mW (laser classes American National Standards Institute 3a or International Electrotechnical Commission 3R) appear to be sufficient for use in educational nighttime outdoors activities, providing enough bright beams at reasonable safety levels.

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Key Words: laser pointer, power output, laser safety, retinal damage

The potential risks for ocular health[1–8] and air traffic safety[9–13] of the widespread use of laser pointers have been a matter of concern in the last years. Based on the recommendations from the main laser safety standards,[14,15] several countries adopted regulations limiting the use of handheld laser pointers by the general public to devices with maximum output power of 5 mW.[16] More restrictive regulations do also exist,[17] motivated in some cases by repeated incidents of reported laser misuse.[18]

Although visible laser beams in the 1- to 5-mW power range may represent a certain level of ocular risk in case of intrabeam viewing for extended periods of time (overriding the blink reflex and the natural aversion response of the eye), this risk appears to be relatively low, and it is considered to be reasonably manageable in normal foreseeable conditions of use. Hence, visible laser pointers with power up to 5 mW (corresponding to laser class 3a in the American National Standards Institute Z136.1 standard[15] or class 3R in the International Electrotechnical Commission-60825 standard[14]) are generally deemed to be acceptable tools for some workplace applications if the user has adequate training.[17]

Most laser pointers available in the 1990s were class 3a devices based on simple diode lasers emitting in the red end of the visible spectrum, with typical wavelengths in the 650- to 670-nm range.[19] Clinical reports on the effects of intentional eye exposure to these kind of pointers described transient central or pericentral scotomata and ophthalmoscopically detectable retinal pigment epithelial disturbances.[20–22] Although the visual symptoms generally

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*PhD
†MSc
‡BSc
§MSc, OD
Área de Óptica, Dept. Física Aplicada, Optics and Optometry School, Universidade de Santiago de Compostela, Galiza, Spain (SB, MR, IT, HG), and Departamento de Astrofísica, Universidad de La Laguna, Tenerife, Spain (RIM).

did not last for long periods of time and the patient's vision gradually returned to normal values, the retinal signs tended to be more persistent.

Class 3a green laser pointers (GLPs) were introduced later in the consumer markets. Most of them are DPSS-FD lasers, the acronym standing for "diode-pumped, solid state, frequency doubled." These green laser devices are relatively more complex than the classical red ones, because they generally use a high-power infrared laser diode (wavelength 808 nm) to pump a neodymium-based solid state laser emitting at 1064 nm, which is subsequently frequency doubled using a nonlinear medium to get the final 532-nm green beam. Because the efficiency of these wavelength conversion processes is far from 100%, good quality infrared filters shall be located at the exit apertures to allow the visible beam to propagate undistortedly, while blocking the unwanted residual infrared radiation.

Everything else being equal, a green laser beam poses an increased level of ocular risk in comparison with a red one, because it propagates with less angular spreading, and its energy is more efficiently absorbed at the retina. Some clinical studies have shown clear signs of retinal pigment epithelial damage caused by class 3a green laser beams after relatively short exposures, although not accompanied with visual symptoms.[8] However, all in all, class 3a GLPs appear to be reasonably safe devices for educational applications if they are correctly built and are used with proper caution, and the small number of relevant incidents reported so far is but reassuring.

However, the laser market evolved at a fast pace. Nowadays, GLPs of exceedingly higher powers—up to about 700 mW—are easily available through the Web at amazingly low prices. They can be bought also at local retailers in countries where their use is still not well regulated or the regulations are not sufficiently enforced. GLP of this kind are increasingly being used, among others, by educators and amateur and professional astronomers in public outreach activities, e.g., to show the locations of the constellations and stars in the night sky. Powers between 20 and 100 mW are not unusual. As a matter of fact, some amateur astronomy magazines routinely announce 200-mW GLP devices for use as finders in small and midsized telescopes. Our experience in public astronomy activities suggests that the use of such powerful GLP should be discouraged if only in purely educational grounds, because they become a major factor of distraction: many attendees just disregard the sky once the conspicuous laser beam is on. However, besides these educational reasons, a handheld laser pointer of a few hundred milliwatts is not something to be taken lightly.

As a general rule, in public activities, it seems advisable to use the minimum power sufficient to accomplish the intended task. Probably, the most demanding application is using the laser pointer to generate a clearly visible beam of light propagating skyward through the atmosphere, to use it as a pointing tool in naked-eye stargazing. This application requires that the fraction of laser radiation scattered by the atmosphere in the direction of the observer be intense enough as to be clearly perceived against the brightness of the night sky background. In urban settings, this power is expected to be higher than in dark sky sites, because the urban night sky luminance is strongly dominated by the effects of the light pollution associated with inefficient outdoor lighting systems.

In this study, we present an estimate of the output power reasonably required to use GLP as sky-pointing devices from light-polluted urban sites, based on the choices made by 23 observers with different levels of expertise in stargazing, astronomy outreach activities, and laser technology. This estimate, albeit provisional, may be of interest for eye care practitioners providing professional advice regarding the convenience and risks of using GLP. It may be also a useful reference for educators and scientists seeking the proper laser device for educational outdoors applications.

A 45-mW DPSS-FD green laser module (model SDL-532-020F; Shanghai Dream Laser Technology, Shanghai) was used as a light source. It provides a Gaussian beam (TEM_{00}) with divergence smaller than 1.2 mrad. An infrared blocking filter (IR-Blocker; Astronomik, Hamburg, Germany) located immediately behind the laser head was used to filter the unwanted residual wavelengths (808 and 1064 nm) while allowing the visible 532-nm green beam to propagate almost without attenuation. The exit beam power was controlled with the help of two linear polarizers: rotating the first, we set the maximum attainable power level, taking advantage of the fact that the laser beam leaving the laser head is itself partly polarized, whereas rotating the second one, the observers could vary in a continuous way the exit power, from nearly zero (crossed polarizers) to the maximum (parallel polarizers). The whole setup (laser head, filter, and polarizers) was attached to an altazimuthal mount on a stable tripod.

The beam power was monitored with a PM300E Optical Power and Energy Meter equipped with a S121B silicon power meter head (both from Thorlabs, Newton, NJ). Power data readings were fed to a portable PC through a USB connection.

The measurements were made at a location near the Optics and Optometry School building in the South Campus of Universidade de Santiago de Compostela. The night sky quality at this urban setting is heavily affected by light pollution because of the lighting system of the town (100 000 inhabitants) and by the luminaires installed in the campus, still in process of refitting to reduce the stray light levels. Because most educational activities involving the use of laser pointers are developed in urban locations affected by skyglow and glare due to light pollution, this situation was considered fit to carrying out our measurements.

A total of 23 different observers were asked to collaborate in this experiment, spanning a wide range of ages (9 to 56 years), refractions (spherical equivalents -8.50 to $+1.50$ diopters), and previous experience in using lasers as pointing devices outdoors (from no experience to advanced astronomers and MSc in laser technology). All observers had their refraction corrected to within 0.75 D of their current best correction. Two measurement runs were performed in different nights under different meteorological conditions, with 11 and 17 observers, respectively (5 of them participated in both runs).

After sunset, the laser setup was located outdoors and allowed to stabilize. The beam was directed toward the WNW horizon, where the effects of light pollution were smallest (although still relevant), and at a 30-degree elevation angle. The observers were located at about one arm's length from the laser unit, in such a way that they could easily vary the exit power by rotating the last polarizer. Participants were instructed to increase the output power from zero until seeing comfortably the green laser beam propagating skywards through the atmosphere, being sufficiently bright as to be deemed useful as a pointing tool to show sky objects. Each participant performed this operation twice, without feedback from other observers and unaware of the actual power levels measured by the detector. After setting the chosen beam brightness, data streams were fed to the PC taking samples every second or half-second, monitoring the output power for about 2 min to assess possible midterm laser source power drifts and to average noise. Meteorological data were subsequently downloaded from the 10-minute resolution daily records of the nearby MeteoGalicia Santiago-EOAS weather station, located 100 m away form the measurement place, which are available at the MeteoGalicia web site.[23]

The first measurement run was carried out in December 2008, with the collaboration of 11 observers aged 9 to 56 years. The sky was overcast by a low altitude cloud layer, which noticeably reflected back the upward emission of sodium and mercury vapor street lamps. Relative humidity was 82% and visibility 20 km. The output power chosen by the observers to see comfortably the green laser beam against the cloud background averaged to 1.84 mW (±0.68 mW, 1 SD), with minimum and maximum values of 1.42 and 2.43 mW, respectively. Two measurement series were taken for each observer. Data for individual observers are plotted in Fig. 1 (circles). The points and the error bars represent the averages and the SDs, respectively, of the combined data of the two series for each observer. Most of the uncertainties come from random electrical noise at the detector, because the averages of the two series for each observer are generally very close to each other.

The second measurement run was carried out in March 2009, this time with the participation of 17 observers (aged 13 to 48

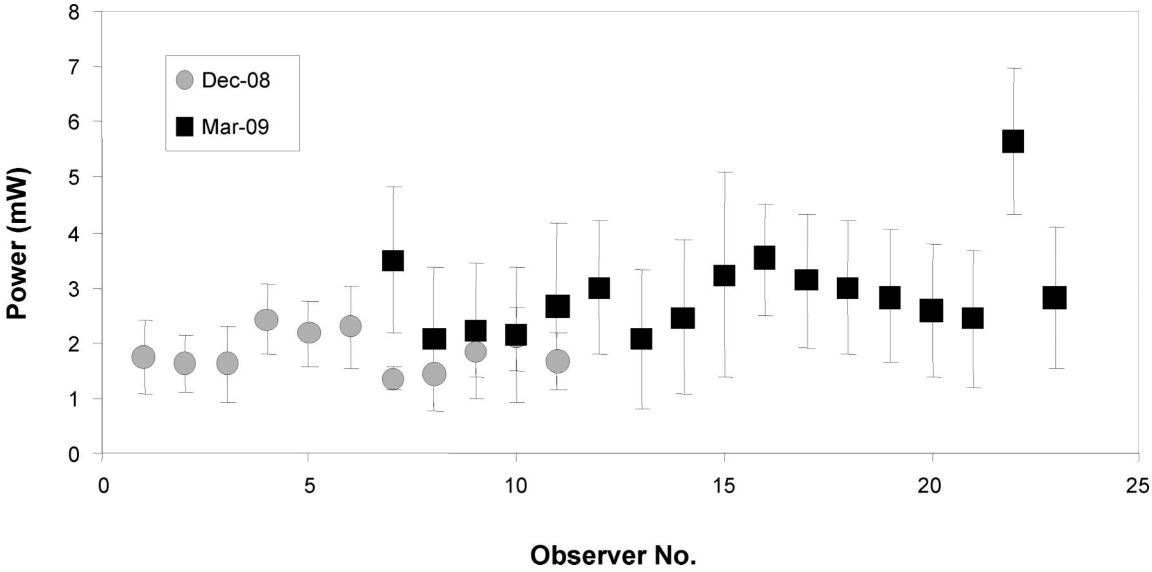

FIGURE 1.

Output power (mW) required to see comfortably the beam of a GLP (532 nm) propagating through the atmosphere against the night sky background. Each point represents the average of the power readings for each observer; error bars represent 1 SD of the data.

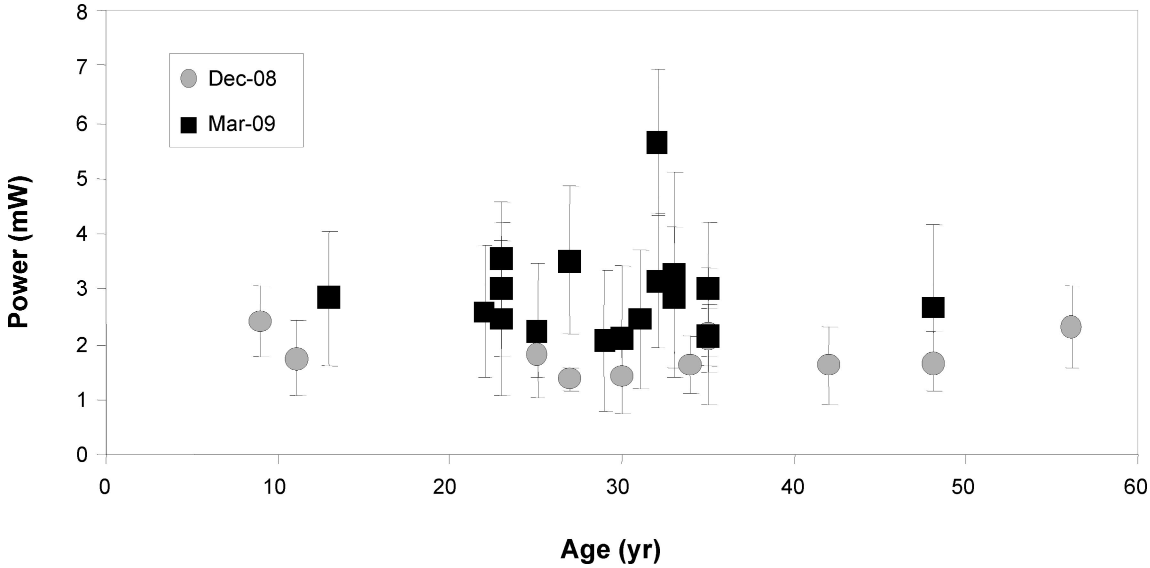

FIGURE 2.

Output power (mW) required to see comfortably the beam of a GLP (532 nm) propagating through the atmosphere against the night sky background vs. observers' age. Each point represents the average of the power readings for each observer; error bars represent 1 SD of the data.

years), 5 of whom also took part in the first one. The night sky was clear, and stars were visible down to a limiting magnitude +3.5 because of the light pollution level at the observing site. Relative humidity was 48% and visibility >20 km. The power chosen by the observers averaged this time to 2.91 mW (±1.54 mW), with 2.07 and 5.64 mW extreme values. Excepting for one observer scoring 5.64 mW, the remaining choices were smaller than 3.54 mW. As in the previous run, two measurement series were taken for each observer, and the global averages and SDs of their pooled data are represented in Fig. 1 (square dots). The global average of the two measurement runs (December 2008 and March 2009) was 2.38 mW (±1.30 mW).

We found no noticeable dependence of the power on the observers' age (Fig. 2). Searching for biases, the data were also grouped according to the previous experience of the observers with lasers in three broad classes: astronomers acquainted with the use of GLP as a pointing device outdoors; laser technologists used to work with weak laser beams in research laboratory environments; and general public, with no previous expertise in lasers. Although the observers labeled as general public tended to choose slightly higher powers than the other two groups, the differences were not found to be statistically significant ($p > 0.05$) within the precision provided by the measurement system.

The perceived brightness of a laser beam propagating skyward through the atmosphere is the result of a multiple set of factors. The laser wavelength, power, and beam divergence are key parameters to describe, at a first approximation, the direct propagation of the beam energy through the atmosphere. The directional distribution of the power scattered off the beam by each atmospheric volume element depends on the air constituents at the molecular level (Rayleigh scattering) and on the size and concentration of the different kinds of aerosols (Mie scattering), the latter strongly dependent in turn on the current weather conditions at the measurement site. The irradiance at the retina depends on the relative locations of the source, scattering volume, and observer, as well as on intrinsic eye parameters (e.g., the pupil size and the transmittance of the ocular media at the wavelengths under study). The laser power required to ensure a successful perception of the beam against the night sky background will additionally depend on the luminance contrast threshold. Ambient factors at the observing site are also relevant: glare due to direct eye illumination from ill-shielded neighboring street lamps is a major contributing factor to decrease contrast, principally in overlit urban places, as is the one from where our measurements were taken.

The aim of this work was not to make a detailed study of the dependence of the GLP beam visibility on all these factors but rather to get an order-of-magnitude estimate of the laser output power reasonably required to use GLP as pointing devices in nighttime astronomy outdoor educational activities under normal operating conditions. Hence, the experimental settings tried to approach as much as possible the prevalent conditions in such kind of activities, which are very often carried out in places strongly affected by light pollution and usually involve people with very different age and training level. The source-to-observer distance, in our experiments approximately 1 m, corresponds well to those situations in which the GLP is used as a pointing device working with small groups of people, located around and close to the pointer bearer.

The difference between the output power chosen by the observers in the first (1.84 ± 0.68 mW) and second runs (2.91 ± 1.54 mW) can be mostly attributed to the different weather conditions in each test. The five observers who participated in both test consistently scored higher powers at the second one (Fig. 1, observers 7 to 11). Taking into account that the conditions of the second run (clear skies with limiting stellar magnitude of +3.5) are typical of nighttime astronomy observations from light-polluted urban settings, the power data corresponding to this run may be taken as a reasonably useful beam power estimate.

In summary, GLPs emitting at 532 nm with output powers below 5 mW (laser classes American National Standards Institute 3a or International Electrotechnical Commission 3R) appear to be fully adequate for use in educational nighttime outdoor activities, providing enough bright beams at reasonable safety levels. The use for these particular applications of overpowered GLP devices should be clearly discouraged in our opinion.

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Salvador Bará
Area de Optica, Dept Fisica Aplicada
EUOO, Optics and Optometry School
Universidade de Santiago de Compostela
Campus Sur, 15782 Santiago de Compostela
Galiza, Spain
e-mail: salva.bara@usc.es