LIGHT POLLUTION IN LAZIO
A measure by high-school students

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Keywords: Light pollution; hands-on high-school activity; naked-eye star visibility.

Abstract: Light pollution is one of the most evident, though overlooked, source of environment pollution characterizing the industrial and post-industrial society. It is due to a bad illumination of the towns and results from two main reasons:
a) a deep ignorance, at a general level, of how the vision process works;
b) a built-in fear of darkenss, so that the amount of emitted light is believed to be by itself good.
The net result of these facts is an ever increasing consumption of electric power which is used to badly illuminate our streets, buildings, and the sky over them.
To increase the awareness of the light pollution, in the International Year of Astronomy, we made a didactic project involving some 15 High Schools in The Lazio Region: the students made naked-eye observations of the faintest star visible from their house in selected Constellations and put their data in a common database using a dedicated web site. Finally a map of the stars visibility was drawn and compared with a similar map derived from DMSP satellite data.

1 INTRODUCTION

Among the several kinds of pollution which characterize our post-industrial society, light pollution is apparently the less harmful. Surely it is not as dangerous for the health as the engine exaust gases or the very small dust particles (PM10, PM2.5), however its effects on the every day life are evident.

Since the second half of the XIX century, street illumination started to be a must for the major world cities, firstly by gas lamps and then by electric lamps. By now there is no small group of houses in the civilized world which does not show its presence in the night, from sunset to sunrise, even if nobody needs to know it.

From the psicological point of view, this has produced the end of the darkness in the experience of everyday life, but has also cut off the vision of the starry sky, which was quite common to everybody up to just one century ago. All our cosmology, and religions, have been conditionated by this every night experience.

Technically speaking, light pollution is an increase of the natural level of light during the night, due to human activity. From the practical point of view we define light pollution any light emission which goes outside the area which is the real target of the emission.

The main point to keep in mind, when we are dealing with illumination tasks, is that the light must fall on the object to be seen in order to be useful: any light which reaches directly the observer eye without illuminating the target is harmful for the vision, not useful. From this point of view the worst illumination system, unfortunately still much used today, is the simple glass sphere including a lamp in its center: nearly 50% of the light produced by the lamp goes above the horizon directly into the sky (or clouds) and is completele wasted for human vision. The reason why it is still used is that it is very similar to a candle (or a torch) and is the cheapest to build. But, in a few years of use, the cost of the electric energy wasted overcomes the initial save of money.

Another point to keep in mind is the danger of dazzling; the surface brightness of the lamp is necessarily much larger than that of the ground illuminated by it, so that, if the eye sees simultaneously the ground and the lamp is forced to adapt itself to the lamp brightness and does not see well the dimmer ground. The proper way to overcome this danger, and produce a clear vision of the ground, is to shield the lamp so that it cannot be seen directly by the observer.

2 HOW TO REDUCE LIGHT POLLUTION

The main guidelines to follow to reduce light pollution are:

- Illuminate only IF necessary
- Illuminate only WHEN necessary
- Illuminate only HOW MUCH necessary
- use only cut-off systems

An example of bad illumination is given in Fig.1, right: the garden ball-fixture is much brighter than the street and grass. Similar lamps, in the buildings at distance, also pick up the attention of the eye. In Fig.1 left, the same place have been illuminated with a semi-cutoff fixture: the attention of the eye is now on the street and grass, while the lamp is much less evident and does not disturb the eye.

A glaring lamp diminishes safety on the street, because divertes the eye form the road: the aim is to see the road, not the lamps above it!

A large collection of documentation on this topic may be found in the home page of the Italian organization Cielo Buio (1997), an affiliated society of the International Dark Sky Association (IDA, 1988)

3 SIDE EFFECTS

- Chemical pollution: the excess of light produced is useless, and therefore a waste. Given that the electric power is largely still produced by fossil fuels (in Italy 84%, ENEL GRTN 2003) this waste produces an increase of CO_2 in atmosphere, and therefore also a chemical pollution. It is also a waste of money.

Figure 1: Left: Night illumination of a garden with a semi-cutoff fixture; the eye is not dazzled by the lamp.
Right: the same garden with a simple ball fixture; the eye is strongly dazzled by the lamp.

- Biological alterations: animal species living in urban areas, adapted to the night life, loose their adaptive advantage with respect with daytime species; this may lead to their reduction and eventually to their extinction. Vegetal species can continue the photosynthesis also during night-time with variations of their biological balance. This topic is still largely to explore in details.
- Effects on the night-rest of humans: the light coming inside the house during the night may hamper the sleep for many people. Keeping the windows closed to keep off the street lights may be uncomfortable in summer times, and then induce a larger use of air conditioning, which in turn means a larger waste of electric power.
- Psycological effects: With the night illumination of the towns, the direct experience of the night darkness has become very rare. The new generations are therefore lacking the experience of the direct vision of the starry sky, which was on the contrary a common experience of all mankind up to just a century ago. The effects of this lack of experience on the general perception of the world, and of the man within it, are still largely to be defined.

4 How much is Light Pollution expensive

The ENEL forecast in Italy for energy consumption for illumination in 2010 is 38 TWh (38×10^9 KWh). A reduction of 20%, corresponding to the minimum achieveble substituting present bad fixtures with cutoff ones, corresponds to 8×10^9 KWh. In terms of saved fossil fuel it is 16 millions tons of oil. At domestic fare (0.11 Euro/KWh) it means 900 millions Euro.

This is comparable to one year budget of our University (1.1×10^9 Euro, 2008). For comparison, our Government decided last year, as a strong support for the whole public University system, an additional bonus to the overall budget of just 4×10^8 Euro.

To renew the street illumination plants is indeed expensive, but in any case it must be gradually done to replace damaged or obsolete items, and the lifetime of a street illumination plant is of several tens of years. In a few years, the energy saving given by a modern cutoff system counterbalances the larger expenses of renewal and grants a money saving for a long time.

5 Light Pollution and the International Year of Astronomy

The year 2009 has been declared by the International Astronomical Union as International Year of Astronomy, to remember the 400th anniversary of the first astronomical use of the telescope by Galileo Galilei. In this occasion the Physics Department of the University La Sapienza has carried on a project of sensibilization of students belonging to 15 high schools in the Rome Province to the matters of light pollution and energy saving (Nesci 2009a).

The technique used was the naked eye observation of a few selected Constellations and the recording of the faintest star visible from a list of preselected ones. It is well known that the star visibility depends on the

brightness of the sky, so that fainter stars become visible when the sky is darker. When adapted to darkness, our eye is able to detect stars as faint as a writing-desk lamp put at 100 km distance.

The apparent brightness of stars is measured in magnitudes, which is a logarithmic measure of brightness: a difference of 5 magnitudes corresponds to a flux ratio of 100, so that a difference of 1 magnitude corresponds to a flux ratio 2.5. The most luminous stars have smaller values (even negative) of magnitude: e.g. the Sun is -26.5, the full Moon -12.5, Venus -4, Sirius -1.6, the Polar star +2. With the naked eye, in very good conditions, it is possible to see stars up to magnitude +6, but this number becomes smaller and smaller as the sky brightness increases.

The determination of the limiting magnitude of the visible stars can therefore be taken as a good indicator of the sky brightness. To have a feeling of how the number of stars changes with sky brightness, we report in Table 1 the number of stars brighter than a given magnitude and the corresponding sky brightness (in magnitudes/square arc seconds) necessary to detect such stars by naked eye. The detection of the Milky Way requires a limiting magnitude greater than 5.

Table 1: Number of stars visible by naked eye at different sky brightness.

Mag.	N.stars	sky bright. mag/arcsec^{-2}
1	5	14.9
2	22	15.9
3	82	17.0
4	250	18.0
5	800	19.0
6	2500	20.0

6 Objectives of the project

The project was aimed at making the students acquainted with the night sky by actual observations, make them to partecipare to a real data collection, give them an opportunity of collaboration between different schools and to get actual experience of the light pollution problem. To this aim a web page was set up (Nesci 2009b), hosted on a computer of the Department of Physics, which performed the following functions:

- description of the project and how-to instructions;
- registration of the students;
- keep a Forum for communications between students;
- hold the database of all the observations, freely accessible to all the partecipants;
- keep a Google-map with the positions of all active observers.

Each student had to register in the web site, putting the geographcal coodinates of his observing position, and observe several times during the winter 2008/09 a few Constellations (Cassiopeia, Taurus, Orion, Gemini) to pick up the faintest visible star from a given list. Then she/he had to put the records of his observations in the common database through the web interface. The final aim was to produce a map of the naked eye visibility of the stars in the Rome Province, to be compared with that computed by Cinzano (2001). This last map is shown in Fig. 2 (left), while the distribution of the observers is shown at right.

The map by Cinzano was computed on the basis of data from the Defense Meteorological Satellite Program (DMSP) and a model of the light diffusion in the atmosphere, with a resolution of about 5 km. To compare the students results with the Cinzano's map we had to average the data on a comparable scale. A critical point was how to choose among the values reported by the observers on different nights. We decided to get the best result from each observer, without taking into account observers with only one observation. Then we grouped the observers in homogeneous areas and took as representative the median of the observations in that area. The dispersion of the data in a given area was also computed as an indicator of the homogeneity.

The final results are collected in Table 2. Column 1 is the area, column 2 the observed limiting magnitude, column 3 its dispersion, column 4 the magnitude espected from Cinzano's map, column 5 the number of observers in that area.

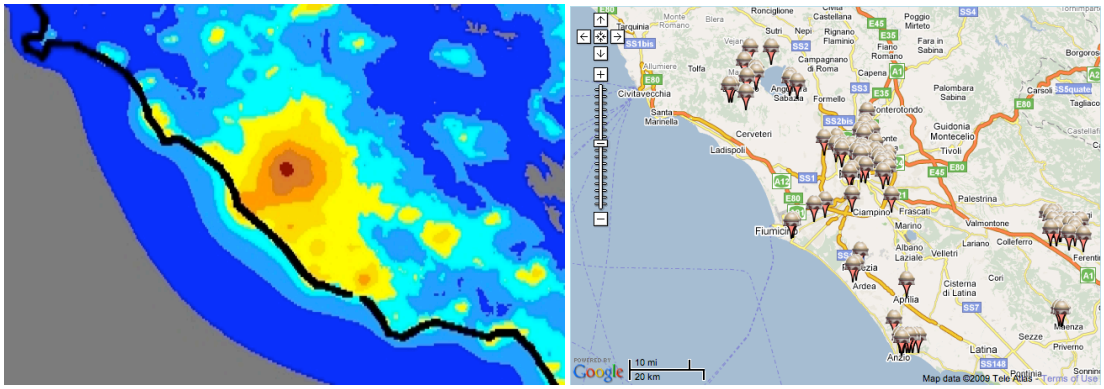

Figure 2: Left. Star visibility according to Cinzano 2001; color coding in magnitude is as follows: red=3.75-4.00; Marron=4.00-4.25; Orange=4.25-4.50; Dark Yellow=4.50-4.75;Gold=4.75-5.00;Light blue=5.00-5.25; blue=5.25-5.50; dark blue=5.50-5.75
Right. Map of the observers positions.

Table 2: Limiting magnitudes observed in the monitored areas.

Area	observ.	disp.	Expected	number
Bracciano	5.27	0.84	5.00-5.25	13
Roma North	3.68	0.74	4.25-4.50	7
Roma East	3.68	1.01	4.25-4.50	12
Roma Cent	3.77	1.64	3.75-4.25	13
Roma West	3.96	1.25	4.25-4.50	7
Roma South	4.00	0.58	4.25-4.50	4
Pomezia-Aprilia	5.38	0.24	4.75-5.00	9
Anzio-Nettuno	3.51	0.35	4.50-4.75	7
Anagni	3.65	0.85	4.75-5.00	18
Roccagorga	5.43	0.50	5.25-5.50	3

A scatter plot between observed and measured magnitudes is shown in Fig.3. Th agreement between expected and observed data is fair in the darker areas, while is bad in the towns. The slope of the linear fit is therefore markedly smaller than one: the easiest interpretation is that the adaptation of the eye to darkness is practically impossible in a light polluted environment, so that the prediction of the star visibility based only on the light diffusion model is optimistic.

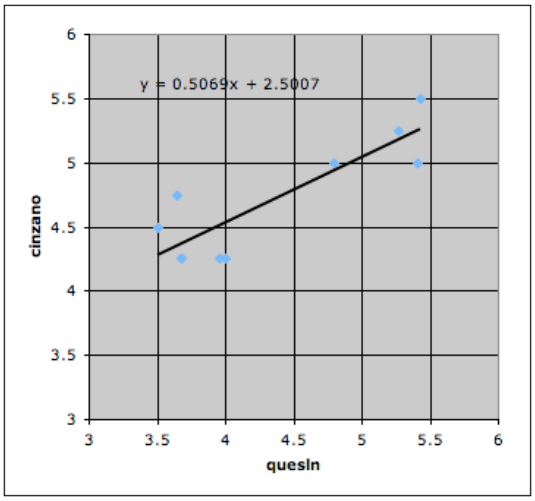

Figure 3: Comparison of the limiting magnitude derived in the present work with that of the Cinzano map. The slope of the fit is definitely flatter (0.5) then the expected value of 1.

7 Conclusions

A strong dispersion of the data among observers within the same area is present, even at small geographycal distance. The agreement with the map computed by Cinzano (2001) is good as far as the general layout is considered: the slope of the fit between observed and expected value is however substantially less than one, pointing to the existence of some systematic effect, probably an incomplete adaptation of the eye to darkness. The star visibility is poor also in small towns (Anzio, Anagni), slightly better than expected in some country areas.

The teachers participating to the project have been much satisfied of its didactic validity and asked to repeat it in the future. The students which carried on the project up to the end (about one third of those initally registered) have also been very happy to participate.

8 References

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