THE GROWTH OF LIGHT POLLUTION IN NORTH-EASTERN ITALY FROM 1960 TO 1995

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ABSTRACT. I studied the growth rate of light pollution in the Veneto plain (Italy) analyzing archive measurements of sky brightness obtained in V, B and R bands at the Ekar Astronomical Observatory and at the Asiago Astronomical Observatory in the period 1960-1995. The light pollution in the last 35 years has increased exponentially. Assuming a constant annual increase from 1960 to 1995, the mean annual increase results of 10 percent per year. In the period 1990-1996 at the Observatory sites the strong increase of the artificial sky brightness was hidden by the decrease of the natural sky brightness due to the decrease of airglow emission produced by the sun activity going to its minimum but in the next 5 years the artificial sky brightness and the increasing airglow emission will sum producing a rapid growth of the sky brightness.

1. Introduction

The most worrying feature of light pollution is that it is rapidly growing because of its dependence on the increase of external night lighting. Nor does this tendency to increase spare astronomical sites of world interest (Garstang 1991). Monitoring of sky glow shows that an efficient limitation requires the best decoupling between the two growth rates (e.g. Hoag et al. 1973). In Italy so far no systematic measurement of sky brightness growth or upward flux growth in large areas has been carried on.

I studied the growth rate of light pollution in the Veneto plain (Italy) in the period 1960-1995 analyzing archive measurements of sky brightness obtained in V, B and R bands at two Observatory sites where the artificial sky brightness near the zenith on clear nights is due mostly to light pollution coming from more than 1200 sources in the nearby plain. I disentangled the contribution from airglow variations due to the solar activity cycle. In section 2 I describe and discuss the measurement analysis and in section 3 I present the results. My conclusions are in section 4.

2. Sky brightness measurements and their analysis

I collected the archive photometric measurements of sky brightness in B, V and R bands near the zenith at Mount Ekar Astronomical Observatory (thereafter site E) and Asiago Astrophysical Observatory (thereafter site A) obtained by many authors in the period 1960 - 1995 (see tab. 1). I corrected the measurements for the extinction of the standard stars in order to take them “under the atmosphere” (Kalinowski et al. 1975), assuming a mean extinction at one air mass of 0.25 mag in V, 0.5 mag in B and 0.1 mag in R. Then I computed in the two sites the growth curve of the ratio

$$(b_{tot} - b_0)/b_0 = (10^{-0.4(m_{tot}-m_0)}) - 1 \tag{1}$$

where m_0 is the natural sky brightness in the same photometric band. I assumed, quite conservatively, that near the zenith and for mean solar activity the natural sky brightness is 21.60 mag in V band, 22.40 mag in B band and 20.5 mag in R band. In a first approximation the ratio $(b_{tot} - b_0)/b_0$ corresponds to the ratio b_{art}/b_0 between the artificial sky brightness b_{art} and the average natural sky brightness b_0 or between the artificial sky photon radiance and the average natural sky photon radiance in that photometric band. In the case of measurements in V band it also correspond to the ratio between the artificial sky luminance and the average natural sky luminance.

Among the main error sources in the ratio b_{art}/b_0 there are the variations in the natural sky brightness m_0 depending on the solar cycle phase and due to the airglow emission. So I corrected the measurement of $(b_{tot} - b_0)/b_0$ assuming that the natural sky brightness increases or decreases depending on the solar cycle phase (Walker 1988; Cannon 1987 in Krisciunas et al. 1987) with:

$$\Delta m = -2.5 log_{10} \frac{b_{nat}}{b_0} = -0.5 \cos 2\pi \left(\frac{t - 1957.5}{11.} \right) \tag{2}$$

With this espression I corrected the eq.(1) obtaining:

$$b_{art}/b_0 \approx b_{tot}/b_0 - b_{nat}/b_0 = (10^{-0.4(m_{tot}-m_0)}) - 10^{0.2 \cos 2\pi \left(\frac{t-1957.5}{11.} \right)} \tag{3}$$

Other sources of errors for the ratio b_{art}/b_0 came from the difficulties in making an accurate estimate of the extinction and the impossibility of taking into account the changes in zodiacal light, galactic light and integrated stars light contributions, depending on the celestial coordinates of the observation point, and the decay of the airglow contribution connected to the number of hours past twilight. Nevertheless these contributions are little for the considered measurements given the high value of the artificial brightness. I computed the errorbars on the ratio b_{art}/b_0 produced by an error of ± 0.2 mag in Δm. This might be a good estimate of the incertitude in both the estinction correction and the natural sky brightness value.

3. Results for the period 1960-1995

Figure 1 shows the ratio b_{art}/b_0 between the artificial sky brightness and the natural reference brightness in V band(circles), B band (squares) and R band(triangles) obtained with eq.(1) for site A (filled symbols) and site E (open symbols). Figure 1 shows an exponential increase of the artificial sky brightness in the last 35 years. Results for B, V and R band measurements are quite similar. Scatter of values for b_{art}/b_0 arises because, as explained, the natural sky brightness oscillates around the assumed reference value m_0 because of the dependence of the airglow emission in the high atmosphere on

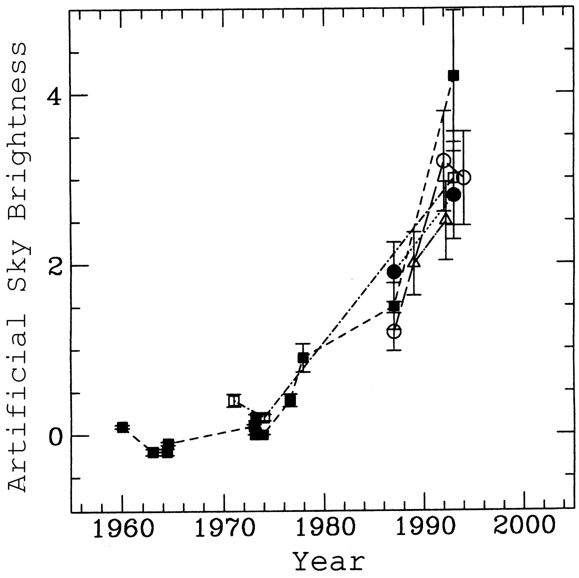

Fig. 1. The ratio between the artificial sky brightness and the natural reference brightness in V band (circles), B band (squares) and R band (triangles) for site A (filled symbols) and for site E (open symbols).

the solar activity cycle. I stress that I chose the reference natural sky brightness very conservatively so it is possible that in periods of mean solar activity it may even be lower than 0.2-0.4 mag, so the ratio between artificial brightness and natural brightness might be greater than the ratio b_{art}/b_0 even of 20-45%.

I also computed the ratio b_{art}/b_0 between the artificial sky brightness and the natural reference sky brightness in the same band corrected for the solar activity cycle with the eq. (3). Differences in the growth of the ratio b_{art}/b_0 with time between photometric bands are little so it also expresses the ratio between the artificial sky luminance and the natural reference sky luminance. Figure 2 shows its behaviour. The increase with time is well expressed by:

$$\frac{b_{art}}{b_0} = \left(\frac{b_{art}}{b_0}\right)_{t_0} (1 + x/100)^{t-t_0} \tag{4}$$

where $t_0 = 1955$, $(\frac{b_{art}}{b_0})_{t_0} \approx 0.075$ and $x \approx 10$ (dotted curve). This implies that the artificial sky luminance increases with a quite constant annual growth rate which amounts to about 10 percent per year. Given that the sources of the artificial sky luminance at the two Observatories are mainly located on the nearby plain (see Cinzano 1999) and they are a large number (more than 1200 towns inside a radius of 120 km), the annual increase is almost independent from the site and is likely roughly the same in all the venetian plain.

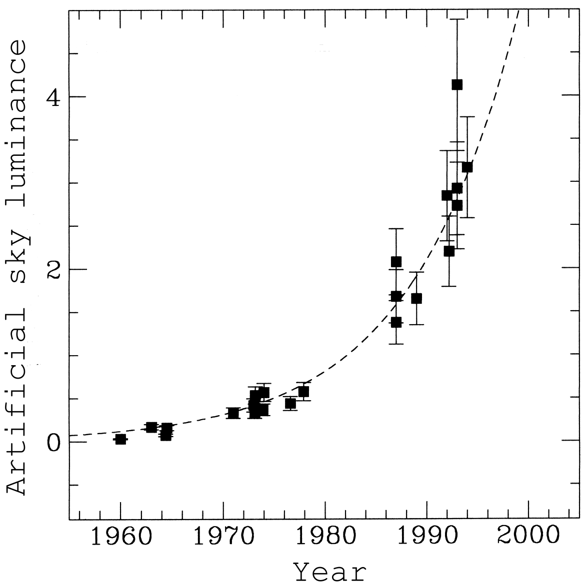

Fig. 2. The ratio between the artificial sky luminance and the natural reference luminance in both sites corrected for the solar activity.

An increase of 10 percent yearly is plausible. An analysis of the increase of compsumption of energy for external public lighting shows an annual growth rate of the order of 4.6 - 5 percent per year. Usually new fixtures use more efficient lamps than the average of the installed light park. The average efficiency in cities' lighting park increased from about 15 lm/w in the '60 to about 60-70 lm/w around 1995, which means an average annual growth rate of another 5 percent per year. Even if depending on local economic conditions, this result seems in agreement with the growth of light pollution measured in other countries. Walker (1973) presented photometric evidence that the night sky brightness in V and B bands in direction of San Jose had increased by about 5 percent per year between 1948 and 1972 and 6.2 percent per year between 1965 and 1978 (Walker 1991). Hoag et al. (1973) showed that the sky over Tucson brightened by 10-15 percent per year before the ordinance of 1972. Pike reported qualitative estimates by many observers in Southern Ontario suggesting an increase of 7 - 10 percent per year. Satellite measurements of upward emission from some cities in Japan (Isobe 1993; Isobe & Hamamura 1999) give a growth rate of about 12% per year.

In order to check the effects of solar activity on the measurements, I also plotted in figure 3 all the measurements of sky brightness in $mag/arcsec^2$, reduced to the V band from b_{art}/b_0, together with the prediction obtained from eq.(4) (continuum curve) and the prediction corrected for the effects of the solar activity on the airglow (dotted curve)

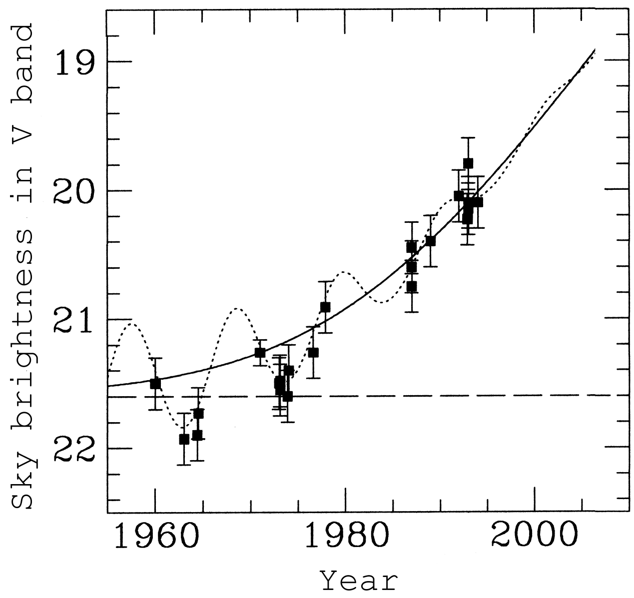

Fig. 3. All the measurements reduced to the V band (in $mag/arcsec^2$), together with the prediction obtained from (4) (continuum curve) and the prediction corrected for the effects of the solar activity (dotted curve).

assuming that the natural sky brightness depends on the solar phase by eq.(2):

$$m_{tot} = -2.5 log_{10} \left(\frac{b_{art}}{b_0} + \frac{b_{nat}}{b_0} \right) + m_0 \tag{5}$$

The corrected prediction fits quite well the measurements. Note that the decrease in the natural sky brightness in the period 1990-1995, connected to the decrease of solar activity, hid in our measurements the strong increase in artificial sky brightness. In the next 6 years the two effects will sum producing a rapid increase of the sky brightness that will be measured at the two sites.

4. Conclusions

I studied the growth rate of light pollution in the Veneto plain (Italy) in the period 1960-1995 analyzing archive measurements of sky brightness obtained in V, B and R bands at two Observatory sites where the artificial sky brightness near the zenith on clear nights is due mostly to light pollution coming from more than 1200 sources in the plain. My conclusions are:

1. The light pollution from Veneto plain increases about 10 percent per year.
2. Differences on results for B, V and R bands are under measurement incertitudes, due to natural sky brightness subtraction.

3. The effects of solar activity on the measurements are non negligible. The prediction corrected assuming that the natural sky brightness depends on the solar phase with a simple cosine law fits quite well the measurements.
4. The decrease of the natural sky brightness in the period 1990-1995, connected to the decrease of solar activity, hid in our measurements the strong increase of the artificial sky brightness. In the next 6 years the two effects will sum producing a rapid increase of the sky brightness that will be measured at the two sites.

Levels of sky brightness measured at the two sites are a lower limit to the levels inside the plain. So we can conclude that after about '80 the finest details of the Milky Way were surely invisible from the plain. Today it is likely that the Milky Way cannot be observed other than near the zenith from everywhere in the plain, if it is visible at all.

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TABLE I

Sky brightness measurements.

Year	Band	m_{obs}	m_{corr}	$\frac{b_{tot}}{b_0}$	$\frac{b_{art}}{b_0}$	m^*_{tot}	Site	Sources
1960	B	21.8	22.30	1.10	0.1	21.50	A	Capaccioli, priv. comm.
1963	B	22.13	22.63	0.81	-0.2	21.93	A	Bertola (1966)
1964.4	B	22.20	22.70	0.76	-0.2	21.90	A	Bertola (1966)
1964.5	B	22.03	22.53	0.89	-0.1	21.73	A	Bertola & Benacchio (1967)
1971	B	model	-	1.37	0.4	21.26	E	Bertiau et al. (1973)
1973	B	21.8	22.30	1.10	0.1	21.50	A	Capaccioli (1974)
1973.1	B	21.85	22.35	1.05	0.0	21.55	A	Barbon & Capaccioli (1976)
1973.15	B	21.78	22.28	1.17	0.2	21.48	A	Barbon & Capaccioli (1975)
1973.9	B	21.90	22.40	1.00	0.0	21.60	A	Barbon & Capaccioli (1975)
1974	B	21.7	22.20	1.20	0.2	21.40	E	Capaccioli, priv. comm.
1976.6	B	21.56	22.06	1.37	0.4	21.26	A	Barbon et al. (1978)
1977.9	B	21.21	21.71	1.89	0.9	20.91	A	Barbon et al. (1982)
1987	V	20.5	20.75	2.19	1.2	20.75	E	Stagni in Bianchini et al. (1993)
1987	V	20.2	20.45	2.88	1.9	20.45	A	Stagni in Bianchini et al. (1993)
1987	B	20.9	21.40	2.51	1.5	20.60	A	Stagni in Bianchini et al. (1993)
1989	R	19.2	19.30	3.02	2.0	20.40	E	Cinzano, priv. comm.
1992	V	19.8	20.05	4.17	3.2	20.05	E	Falomo et al. (1993)
1992.9	R	19.03	19.13	3.53	2.5	20.23	E	Fasano, priv. comm.
1993	V	19.9	20.15	3.80	2.8	20.15	A	Stagni in Bianchini et al. (1993)
1993	B	20.4	20.90	3.98	3.0	20.10	E	Ortolani, priv. comm.
1993	B	20.1	20.60	5.25	4.2	19.80	A	Stagni in Bianchini et al. (1993)
1994	V	19.85	20.10	3.98	3.0	20.10	E	Ortolani, priv. comm.

In the table was included also a theoretical prediction for b_{art}/b_0 computed from b_{art}/b_{nat} corrected by b_{nat}/b_0.

References

Barbon, R. & Capaccioli M. 1976, A&A, 51, 25.

Barbon, R. & Capaccioli M. 1975, A&A, 42, 103.
Barbon, R. & Capaccioli M. 1975, A&A, 42, 221.
Barbon, R. et al. 1978, A&A, 51, 25.
Barbon, R. et al. 1982, A&A, 115, 388.
Bertiau, F.C.S.J., de Graeve, E.S.J. & Treanor, P.J.S.J. 1973, Vatican Observatory Publ., 1, 4, 159-179.
Bertola, F. 1966, MSAIt, 37, 3.
Bertola, F. & Benacchio L. 1967, MSAIt, 38, 1.
Bianchini, A., Bortoletto, F., Munari, U., Ortolani, S., Salvadori, L., Ragazzoni, R. 1993, Internal Report, University of Padova.
Cinzano, P. 1999, in this volume.
Falomo, R., Cremonese, G., Munari, U., Ortolani, S. 1993, Relazione GEK, Internal Report, Astronom. Obs. Padova-Asiago.
Garstang, R.H. 1989a, Ann. Rev. Astron. Astrophys., 27, 19-40.
Garstang, R.H. 1989b, Bull. of American Astron. Soc., 21, 2, 759-760.
Hoag, A.A., Schoening, W.E. & Coucke, M. 1973, Publ. Astron. Soc. Pacific, 85, 503-507.
Isobe, S. 1993, Measurement of energy loss through world light distribution at night, preprint.
Isobe, S. & Hamamura, S. 1998, in Preserving the Astronomical Windows, IAU JD5, Astron. Soc. of Pacific Conference Series 139, p. 191-199.
Kalinowski, J.K., Roosen, R.G. & Brandt, J.C. 1975, The night sky brightness at McDonald Observatory, Publ. Astron. Soc. Pacific, 87, 869-876.
Krisciunas, K. et al. 1987, Atmospheric extintion and night-sky brightness at Mauna Kea, Publ. Astron. Soc. Pacific, 99, 887.
Pike, R. 1976, J. Royal Astron. Soc. Canada, 70, 116-126.
Walker, M.F. 1973, Publ. Astron. Soc. Pacific, 85, 508-519.
Walker, M.F. 1988, Publ. Astron. Soc. Pacific, 100, 496.
Walker, M.F. 1991, in Light Pollution, Radio Interference and Space Debris, IAU Coll. 112, ed. D.L. Crawford, Astron. Soc. of Pacific Conference Series 17, p. 52-55.