DISENTANGLING ARTIFICIAL SKY BRIGHTNESS FROM SINGLE SOURCES IN DIFFUSELY URBANIZED AREAS

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ABSTRACT. The impact of single sources on the sky brightness of a site can be evaluated by computing the artificial sky brightness distribution which they produce with detailed models for light pollution propagation. The upward emission function of sources can be constrained with the condition that the sum of all contributions, including the natural sky brightness, fits the observed sky brightness in one or more sites of the country. Here I present some applications in Italy of Garstang models. Due to the fast growth with time of total upward flux of cities in Italy, the calibration of models resulted in a function of time.

1. Introduction

Light Pollution is characterized by additivity and propagation at large distances. In diffusely populated countries the artificial sky brightness in a site is the sum of the contributions of a large number of sources (e.g. cities) and the contribution of each source is mostly indistiguishable. This missing information is important in order to understand what are the sources producing the stronger impact on the site's sky and to undertake appropriate actions in order to limit their pollution.

Experimental observations cannot give help. An exam of the sky brightness distribution could sometimes be misleading. When in the country there are many well spread-out sources, their contributions add and smooth together so that apparent gradients of the sky brightness are noticeable only for nearby sources and at low altitude in the sky. Nevertheless the absolute value of the artificial sky brightness near the zenith could be mainly produced by many far sources. Spectroscopical measurements, on the other hand, could disentangle single sources only if their lighting park is very different from that of other sources.

A way to evaluate the impact of single sources on the sky brightness of a site is to compute their contribution to the artificial sky brightness distribution with a propagation model for light pollution applied to the sources on the basis of their known geographical positions and altitudes. Free functions and parameters can be constrained with the condition that the sum of all the contributions, including the natural sky brightness, fits the observed sky brightness distribution in the site or in several sites. With this aim, I constructed models for the propagation of light pollution based on the modelling technique introduced and developed by Garstang (1986, 1987, 1988, 1989a, 1989b, 1989c, 1991a, 1991b, 1991c, 1992, 1993, 1999). With them, it is possible to evaluate the sky brightness distribution on the sky of a site of given altitude above sea level produced by a set of sources of given geographic positions, altitude and upward emission. In each point of the sky, it is possible to predict both the value of sky brightness and its gradient, and analyze the distribution of the artificial sky brightness contribution produced by each source.

The outline of the modelling technique is presented and discussed in section 2. In section 3 a preliminary calibration is discussed and the average upward flux by italian cities is estimated. The results for sky brightness distribution in some italian sites are presented, discussed and compared with available observations in section 4. Contributions from some single sources are also presented. Section 5 draws the conclusions.

2. Description of the modelling technique

The models are based on the modelling technique introduced and developed by Garstang (1986, 1987, 1988, 1989a, 1989b, 1989c, 1991a, 1991b, 1991c, 1992, 1993, 1999). Here I will only illustrate the main steps. The reader is referred to the cited papers for a discussion of the details (see also Cinzano 1999a). Given that the aim of this work is to model the sky brightness in a site not far from areas strongly urbanized and not in an isolated astronomical site as Garstang (1991b), I neglected the curvature of the Earth. In the applications of this paper a big fraction of artificial sky brightness is produced inside the first 50 km from the site (see Cinzano 1999a) where the effects of the curvature of the Earth, increasing with distance, reach 2 percent (Garstang 1989). The computation of the sky brightness is done in a grid of 19×74 points equispaced in zenith distance and in azimuth. For each infinitesimal volume of atmosphere along the line-of-sight, the direct illuminance produced by each source and the illuminance due at light scattered once from molecules and aerosols are computed, this last estimed with the approach of Treanor (1973) as extended by Garstang (1984, 1986). The total flux that molecules and aerosols in the infinitesimal volume scatter toward the observer is computed from the illuminance, and, with an integration, the artificial sky brightness of the sky in that direction is obtained. Extinction along light paths are included. The model assumes Rayleigh scattering by molecules and Mie scattering by aerosols.

The same atmospheric model as Garstang (1996, 1991) was assumed, with the density of molecules and aerosols decreasing exponentially with the height. The angular scattering function of aerosols was studied by many authors measuring daily skylight scattering (e.g. Volz 1987) or searchlight beam brightness (e.g. Hulburt 1941). The average scattering function of aerosols adopted is the representation of Garstang (1991) of the function measured by McClatchey et al. (1978).

The sources of upward light are cities and towns in the country. Their geographical positions and altitudes at 1991 were obtained from Istituto Italiano di Statistica (ISTAT). In order to became simple, I assumed that the lighting habits are similar in all the cities of the considered territory. This is likely because I considered areas of not more than 120 km around each site. I considered as point sources the cities when the line of sight did not approach them more than 12 times their radius and I used in the other cases a seven points approximation (Abramowitz and Stegun 1964). I neglected the presence of mountains which might shield the light emitted from the sources to a fraction of the atmospheric particles along the line-of-sight of the observer. Given the vertical extent of the atmosphere in respect to the highness of the mountains, the shielding is not negligible only when the source is very near the mountain and both are quite far from the site (Garstang 1989, see also Cinzano 1999a). I neglected the effects of the Ozone layer and the presence of volcanic dust studied by Garstang (1991b, 1991c) (see also sec. 3).

The computation of the natural sky brightness in each direction follow the Garstang (1986) approach. It assumes that the light coming from the higher atmosphere has a distribution based on the analysis of Roach and Meinel (1955) and reaches the observer either directly or by scattering from atmospheric aerosols and by Rayleigh scattering from atmospheric molecules. The computation is done for conditions of minimum solar activity in order to neglect the effects of solar activity on the airglow natural emission (Walker 1988).

Sky brightness expressed in magnitudes is obtained from sky luminance expressed in cd/m^2 or from photon radiance in $ph\ cm^{-2}s^{-1}sr^{-1}$ with formulae in Garstang (1986, 1989a).

Free parameters and functions of the models are:

1. The aerosol content of the atmosphere.
2. The normalized average city emission function giving the relative intensity in each direction of the total upward light emission of cities both coming directly from its lighting fixtures and from reflections from lighted surfaces.
3. The total upward flux emitted by each city.

Other parameters as the scale radius of vertical distribution of aerosols and molecules, their scattering sections,the altitude of the van Rhijn layer for airglow emission and the natural sky brightness in the higher atmosphere, are likely not much variable. To account for presence of sporadic denser aerosol layers at various heights or at ground level as Garstang (1991b) is beyond the scope of this paper.

2.1. Aerosol content of the atmosphere

The propagation of light pollution depends on aerosol content. The atmospheric content of aerosols is variable in dependence of atmospheric conditions and it is expressed in models by the atmospheric clarity K, a parameter introduced by Garstang (1986) which is essentially a measure of the aerosol-to-molecule ratio at ground level. Atmospheric clarity in fact is not a free parameter because it is related to the vertical extinction (Garstang 1988, eq.1) at the site and to the horizontal daylight visibility (Garstang 1991, eq.7). These quantities can constrain the atmospheric clarity in a specific night. Nevertheless, in this paper computations were done for standard clear atmosphere (K=1 in Garstang 1996) in order to obtain standard results without the necessity to determine what are the mean atmospheric conditions for each site. An increase of aerosol content usually produces a decrease of sky brightness in sites outside the cities boundaries due to the increase of extinction along light paths. On the contrary, it produces an increase

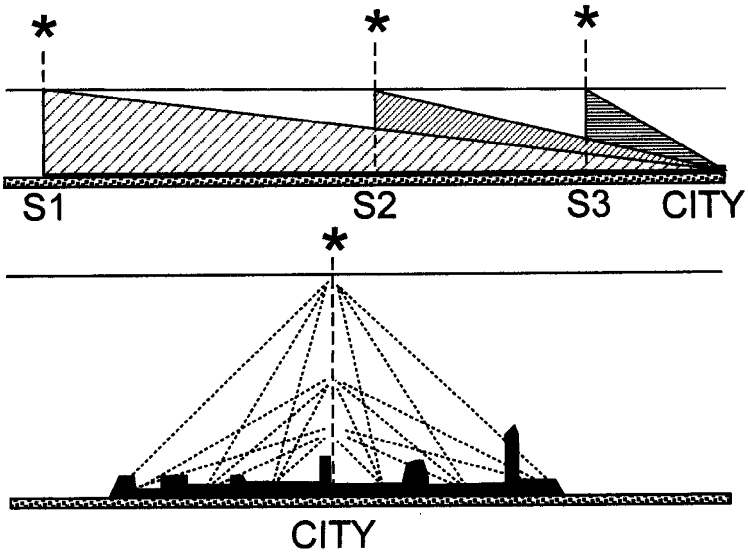

Fig. 1. Range of elevation angles involved in illumination of particles along the line-of-sight of an observer looking at the zenith and (above) far from the source more than scale height of atmosphere, or (below) inside a source.

of sky brightness inside city boundaries due to the increased scattering (e.g. Garstang 1986, fig.3, for Denver).

2.2. Normalized average city emission function

The normalized average emission function of cities is the sum of the direct emission from fixtures and the reflected emission from lighted surfaces, normalized to its integral and is not well known. In future it will be possible to obtain it directly by integrating upward emission from all lighting fixtures and all lighted surfaces on the basis of lighting engineering measurements and models as soon as they will be available. Actually, this function can be constrained comparing predictions of models and measurements. A comparison with measurements at different distances from an isolated city would be useful because for geometrical reasons light emitted at lower angles above the horizon propagates far contributing to the artificial brightness at far sites and light emitted at higher angles above the horizon contributes mainly to sky brightness at lower distances, wherever the emission near the zenith contributes only to the sky brightness near the city center as shown in figure 1.

In Italy, where isolated cities are rare, a first constraint is that the predictions of the zenith artificial brightness as a function of distance cannot be too much different from the Treanor Law which was tested in Italy by Bertiau et al. (1973). The presence of many cities at different distances around a site (e.g. more than 2000 inside 120

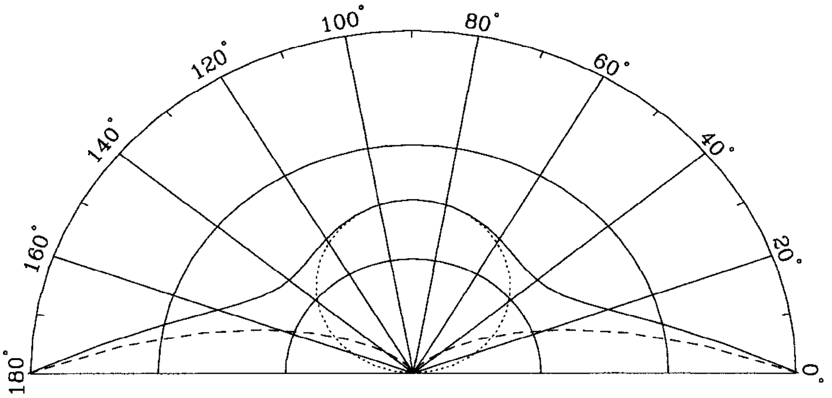

Fig. 2. Normalized average city emission function from Garstang (1986).

km from Brera-Milan Observatory in Merate) (a) smooths very much the shape of the normalized average emission function so that it can be considered in first approximation axisimmetric; (b) smooths very much the effects of changes in the shape of the function, so in order to better constrain it, measurements of sky brightness in many sites are needed and in different configurations (sites inside cities, sites near cities, sites far from main cities, etc.).

Given the limited number of measurement in Italy so far, I started adopting the normalized average city emission function from Garstang (1986) which worked well with his many comparisons of models to observational data. This function is semi-empirical in the sense that the author assumed it be produced by the sum of direct emission from fixtures at high zenith distances and Lambertian emission from lighted horizontal surfaces at higher zenith angles. Nevertheless, upward flux can be emitted at all zenith angles both from fixtures and vertical or horizontal surfaces, so I considered Garstang's parameters G and F only as shape parameters without any meaning of fraction of direct and reflected light. Here I used always G=0.15, F=0.15. I plan to constrain the average city emission function in subsequent works as soon as more observations will be available. Comparison of effects of different normalized average city emission functions are presented by Cinzano (1999a).

2.3. Total upward flux emitted by each city

The total upward flux is the integral of the city emission function of each city. I assumed that the upward light emission of each source be function of its population in agreement with results of satellite measurements of upward fluxes in Italy by Falchi and Cinzano (1999): $u \propto qf(P)$ where q is a scale parameter. The population of cities at 1995 was provided from Istituto Italiano di Statistica (ISTAT). At short distances from a city differences between geographic positions of the city and the position of its light emission baricenter can be source of errors as well as the limits of the adopted seven-points approximation. I plan to use directly satellite data as soon as they will be available. The functional form giving the total upward flux in function of population of the city is discussed in section 3.

3. Calibration of models and upward flux from Italian cities.

The calibration of the artificial sky brightness predicted by the models depends on the parameter q. The upward emissions of cities are rapidly increasing with the time as shown for the Veneto plain in Cinzano (1999b). If, in first approximation, geographical gradients of the growth ratio of upward emission can be assumed negligible (this is under study by Falchi and Cinzano), the scale parameter q depends only on time. I obtained a preliminary calibration for V band comparing the ratio $q(t)$ between measured and predicted artificial sky luminances in some italian observatory sites in different epochs. I selected sky brightness measurements in V band in periods near minimum solar activity, I converted them into luminances with formulae in Garstang (1986) and I subtracted the natural sky luminances obtained by the model, except for a measurement obtained in 1990 which was corrected subtracting an estimated natural sky luminance for mean solar activity of 300 cd/m^2.

Figure 3 shows the ratios versus the year of measurement for the adopted calibration. In left panel are shown ratios for models with $f(P) = P$ and in right panel are shown ratios for models with $f(P) = P^{0.8}$ (see Falchi & Cinzano 1999). The measurements refers, in sequence, to Mount Ekar Observatory (Cinzano 1999b), "G.Ruggieri" Observatory in Padova (Favero et al. 1999), Bologna University Observatory in Loiano(Zitelli 1999), Brera-Milan Astronomical Observatory in Merate (Poretti & Scardia 1999), Mount Ekar Observatory (Cinzano 1999b), Catania Observatory - Stellar Station in Serra La Nave (Catanzaro and Catalano 1999), Collurania Astronomical Observatory in Teramo (Piersimoni et al. 1999) and "G. Ruggieri" Observatory in Padova (Favero et al. 1999).

The little number of measurements does not allow to distinguish between the two functional forms of $f(P)$ suggested by Falchi & Cinzano (1999). Models with $f(P) = P^{0.8}$ (right panel) show a better agreement together than models with $f(P) = P$ (left panel) but sky luminance at "G.Ruggieri" Observatory (triangles) and Collurania Astronomical Observatory (dot) is mainly produced by one city and a lower emission from two cities does not require necessarily a $f(P) = P^{0.8}$ functional form to be explained, given the scatter between a city and another. Sites where sky luminance is determined by a big number of sources as Mount Ekar Observatory or Bologna University Observatory in Loiano (squares) are much less sensitive to scatter in upward emission of cities.

The figures show that the upperflux is rapidly growing. For comparison the dashed curves show an exponential increase from 1982 to 1998 with an yearly increase of 9 percent. This growth rate fits quite well and is in good agreement with growth rates in Cinzano (1999b). The figure shows that the standard output of models refers to 1990. At that epoch the total upward city emission required by the models with $f(P) = P$ to fit observations with the Garstang city emission function was 277 lm per head. The

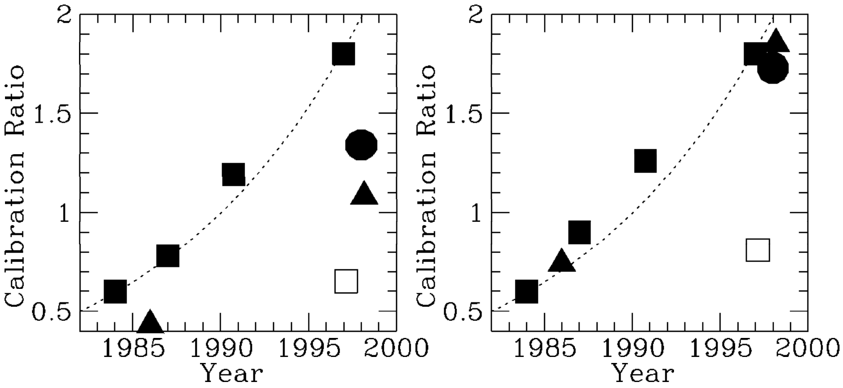

Fig. 3. Time dipendence of the scale parameter q.

scale parameter $q(t)$ that I adopted for models is:

$$q(t) = (1 + x)^{(t-t_0)} \tag{1}$$

with $x = 0.09$, $t_0 = 1990.0$. More measurements are needed in order to confirm these results.

In this calibration I assumed that all observations are done in clean atmospheric conditions. The upward flux required by the models might be lower if the air clarity would be higher than the typical clear air at sea level, an unlikely event in the climate of Pianura Padana. If the clarity is lower as for the model with K=2, the upward flux per inhabitant requested by the models would be higher. In future work when more sky brightness measurements will be available together with the extinction in the same night, I plan to recalibrate more accurately the models taking in account aerosol content of each nights. The calibration assumes the absence of geographical gradients in upward emission as the satellite measurements by Falchi and Cinzano (1999) seems to show. The prediction of artificial sky luminance for Catania Observatory Stellar Station in Serra La Nave (open symbol) is clearly overestimated in respect to the measurement. This is probably due to the presence of volcanic dust or other kind of aerosol layers. The quite high extinction at the 1725 m of height o. s. l. of the observatory, $k_\nu = 0.2422$ (Catanzaro and Catalano 1999), confirms the presence of an high aerosol content. This value of k_ν at 1725 m requires a clarity parameter approximately double than e.g. at the 1350 m of Mount Ekar Observatory. If this behaviour, under study, is produced by a layer of volcanic dust or other aerosols, its extinction of the light from the city of Catania might explain the quite dark sky measured at the observatory (see e.g. Garstang 1991b).

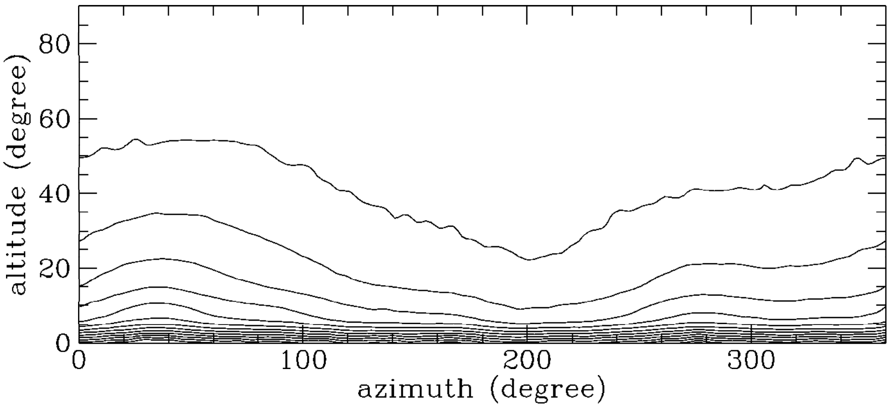

Fig. 4. Sky brightness distribution at Brera Milan Observatory in Merate. Isophotes show respectively a sky brightness increase of 4.0, 4.5, 5.0, 5.5 etc. over the natural level in 1990.

4. Results

With the models described above I computed the sky brightness distribution in V band for some Italian Observatory sites and the contributions of some single sources. In few cases it was possible to compare predicted sky brightness with observations. In other cases only measurements near the zenith were available and they were used to calibrate the models in section 2. All models presented here assume $f(P) = P$ except for "Guido Ruggieri" Observatory which required a lower emission from Padova.

Figure 4 presents the model predictions of the sky brightness distribution at the Brera-Milan Astronomical Observatory in Merate (long. $-9°25'42"$, lat. $45°41'58"$ alt. $330m$ o.s.l.). Isophotes shows the brightness increases over the natural sky value obtained taking in account 2171 towns inside 120 km from the observatory. The origin of the azimuth is South and it increase toward West.

The comparison between the total sky brightness predicted by the model along the meridian toward South for some zenith distances and the available photometric measurements in clean nights (Poretti & Scardia 1999) give:

z (degrees)	0	10	20	30	40	50
ΔV_{obs} (V mag/arcsec^2)	0.00	-0.08	-0.19	-0.4	-0.6	-0.9
ΔV_{calc} (V mag/arcsec^2)	0.00	-0.05	-0.14	-0.3	-0.5	-0.8

Between measured zenith sky brightness and predicted zenith sky brightness for September 1990 there is a difference of -0.11 mag. Measurement could not be corrected for solar activity, crepuscular decay of airglow emission, galactic longitude and latitude, zodiacal light contribution. Nevertheless, the corrections would be in this case very little given the amount of the artificial sky brightness. I tested the effect of an increase of aerosol content in the atmosphere computing the total brightness for K=2: the relative sky brightness distribution resulted poorly sensitive to the value of K whereas the brightness values

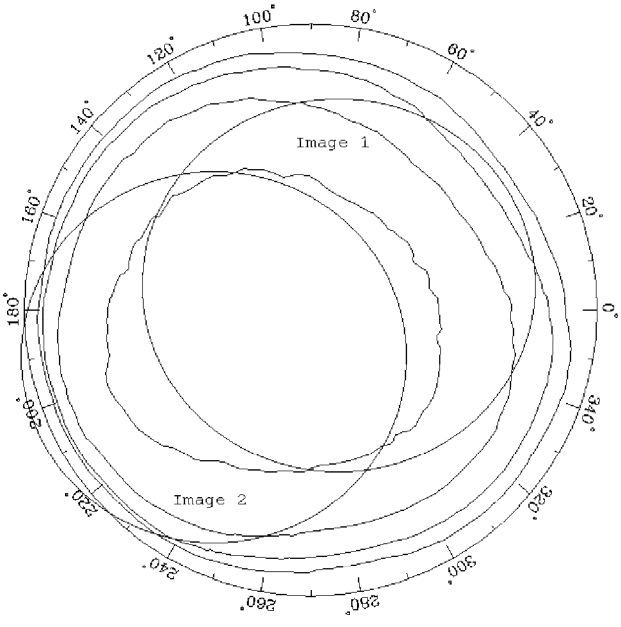

Fig. 5. Predicted isophotes of sky brightness at Brera-Milan Observatory in Merate. In the figure are shown indicatively the field covered by the image of figure fig. 6 (image 1) and by the image in Poretti & Scardia (1999) (image 2).

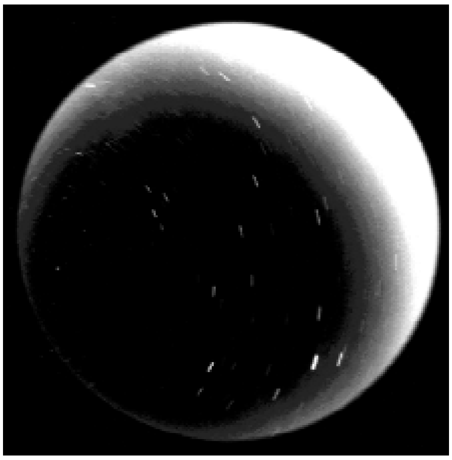

Fig. 6. Fish-eye image of the sky at Brera-Milan Observatory in Merate kindly provided by E. Poretti & M. Scardia. The field of view is shown in figure 5 (image 1).

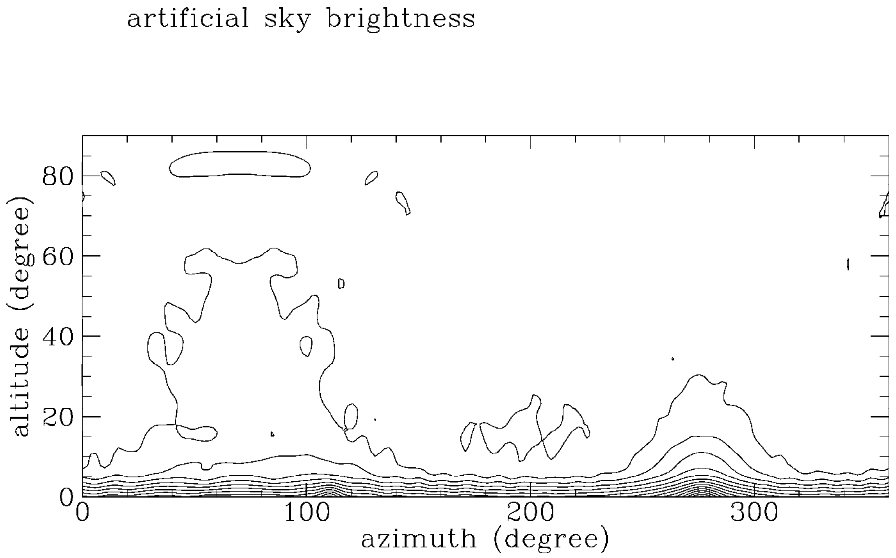

Fig. 7. Contribution to the sky brightness distribution produced by the cities of Merate, Como and Bergamo (from left to right). Isophotes show respectively a sky brightness increase of 2.5, 3.0, 3.5 etc. over the natural level in 1990.

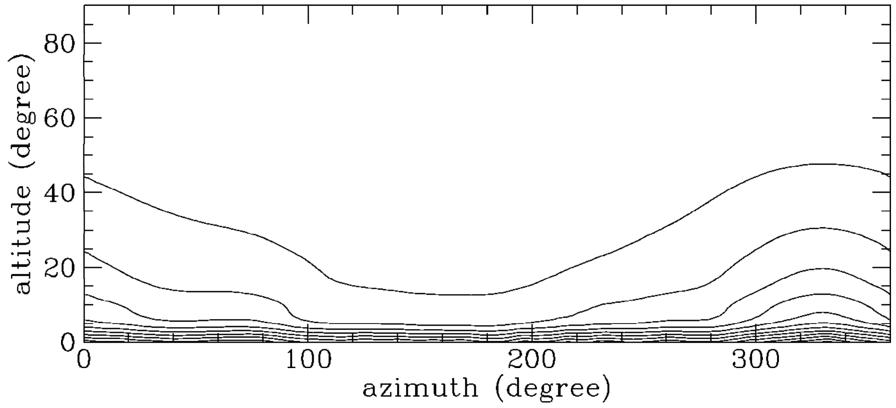

Fig. 8. Sky brightness distribution at Catania Astronomical Observatory in Serra La Nave. Isophotes show respectively a sky brightness increase of 2.0, 2.5, 3.0, 3.5 etc. over the natural level in 1990.

decrease as expected due at the increase of extinction of the light from far sources.

Figure 5 shows predicted isophotes of sky brightness at Brera-Milan Observatory in projection. In the figure are shown indicatively the fields of view covered by the fish eye images of figure 6 (image 1) and in Poretti & Scardia (1999) in this book (image 2), useful for comparison. For details on these images see the cited paper. When comparing the images and the figure 5, the orientation must be checked from field stars positions. I also present in figure 7 the contribution to the sky brightness distribution produced by the cities of Merate, Como and Bergamo alone.

Figure 8 presents the model predictions of the sky brightness distribution at the Catania Astronomical Observatory Stellar Station in Serra La Nave (long. $-14°58'24"$, lat. $37°41'30"$ alt. $1735m$ o.s.l.), taking in account the 362 towns inside 120 km from the site. The predictions reproduce very well the sky brightness distribution measured by Catanzaro and Catalano (1999) as shown by a comparison with the figure 2 of the cited paper in this book. The origin of azimuth in figure 8 is South whereas in the figure of Catanzaro and Catalano (1999) the origin is North. The effect of the high aerosol content (see sec. 3) seems to be more effective on the absolute values of sky brightness than on its distribution on the sky. The contribution of Catania city alone at the zenith of the observatory is the 17% percent of the total artificial brightness in this model (K=1). Even if this is the main source, the main pollution is produced by the sum of the contributions from many other towns like Adrano (7%), Paternó (6%), Biancavilla (6%), Belpasso (4%), Acireale (4%), etc.

I computed the sky brightness distributions for Mount Ekar Observatory (long. $-11°34'18"$, lat. $45°50'36"$ alt. $1350m$ o.s.l.) and Bologna Observatory in Loiano (long. $-11°20'0"$, lat. $44°15'23"$ alt. $714m$ o.s.l.) shown respectively in figure 9 and 11. The contribution to sky brightness distribution from some sources in their surrounding territory are shown in figures 10 and 12. The contribution of Bologna to the artificial zenith sky brightness of Bologna Astronomical Observatory in Loiano is 18%. Its contribution at 45° of zenith distance towards the city was $341\mu cd/m^2$ in 1990, twice the natural sky brightness. The contribution of Loiano town has to be considered quite uncertain due to the extreme proximity to the observatory which can be sensitive to the limits of the seven point approximation used to describe the city and to the difference between the geographical position and the position of the baricenter of the light emission of the city. Contribution at the zenith sky brightness of Mount Ekar Observatory from some cities in the surrounding land are listed in table I. The table shows that the sky glow at the observatory is produced by the sum of many little contributions. I counted 1819 cities and towns in a radius of 150 km around the observatory. Note that the contributions from Asiago, the area of Thiene, the area of Piovene, the area of Schio, the area of Zugliano, the city of Bassano, the city of Vicenza and the Province of Padova are of the same order of magnitude.

In diffusely and strongly urbanized areas where cities and towns are distributed sparsely on the territory, the sky brightness can be decomposed in two components: a background component slowly changing when moving the observation site in the country and produced by the total contribution of sources which smooth together and a vicinal component strongly floating which has maxima when the observation site is near or inside a source city and with minimum when it is at a distance from nearby cities.

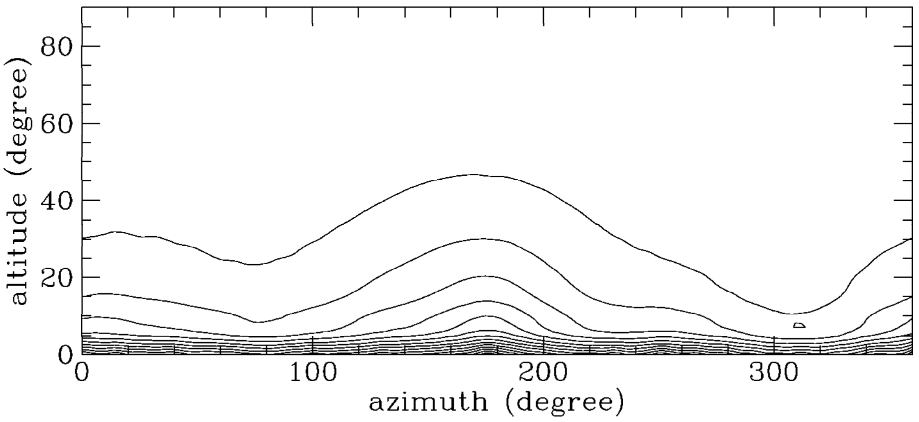

Fig. 9. Sky brightness distribution at Bologna Astronomical Observatory in Loiano. Isophotes show respectively a sky brightness increase of 2.0, 2.5, 3.0, 3.5, 4.0 etc. over the natural level in 1990.

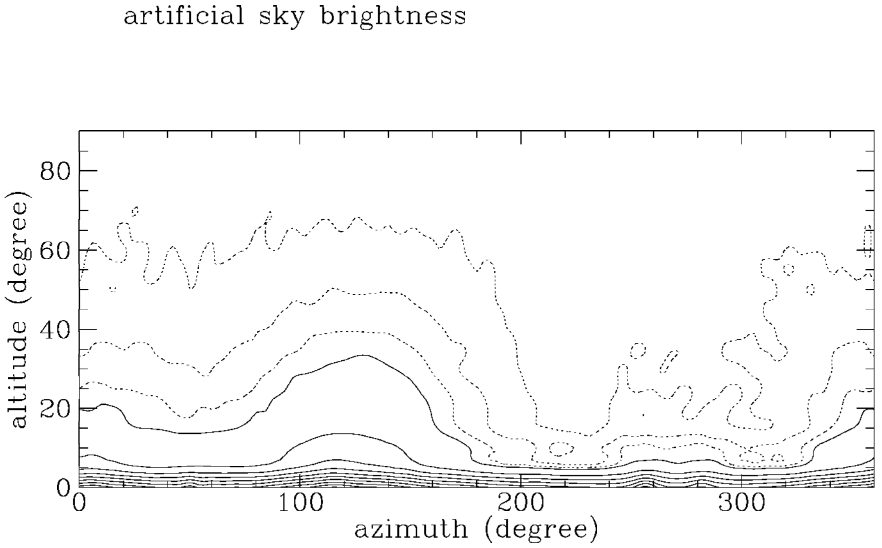

Fig. 10. Contribution to the sky brightness distribution at Bologna Astronomical Observatory in Loiano produced by the cities of Monghidoro (~ 0°), Monzino and Loiano (~ 100 – 140°), Ravenna, Rimini e Riccione (~ 250 – 270°). Isophotes show respectively a sky brightness increase of 0.7, 0.8, 0.9 (dotted lines), 1.0, 1.5, 2.0 etc. (solid lines) over the natural level in 1990.

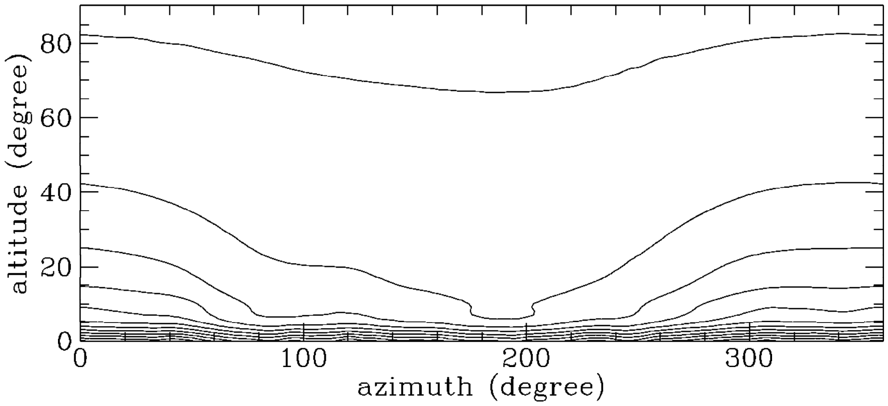

Fig. 11. Sky brightness distribution at Mount Ekar Observatory. Isophotes show respectively a sky brightness increase of 1.5, 2.0, 2.5, 3.0, 3.5, etc. over the natural level in 1990.

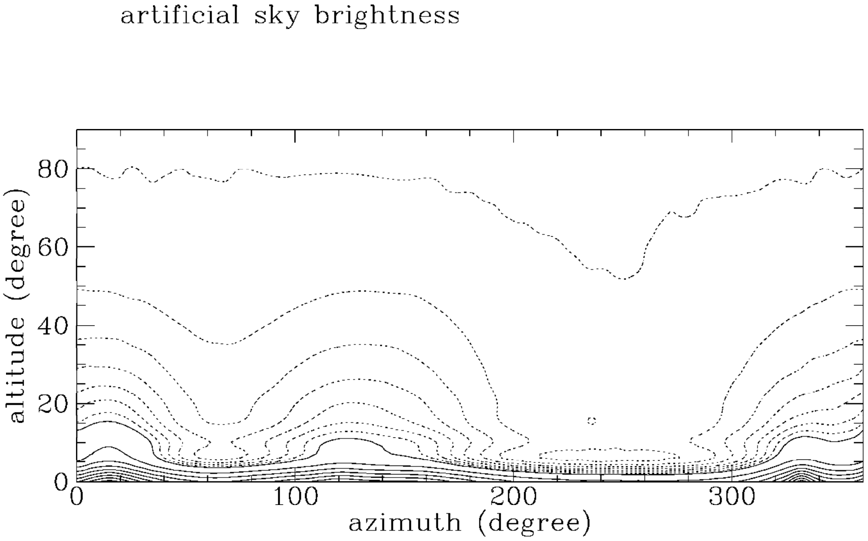

Fig. 12. Contribution to the sky brightness distribution at Mount Ekar Observatory produced by the cities of Thiene (~ 8°), Asiago (~ 120°), Gallio (~ 160°), Padova (~ 330°). Isophotes show respectively a sky brightness increase of 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 etc. over the natural level in 1990.

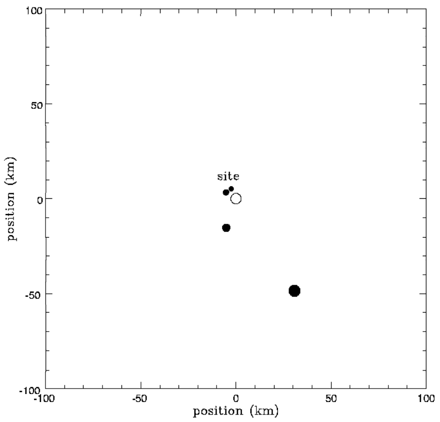

Fig. 13. Map of the sources of previous figure.

TABLE I
Artificial sky brightness contributions at Mount Ekar Observatory from some cities.

Source	p inhab.	d km	b %	Source	p inhab.	d km	b %
Asiago	6652	5.2	4.6	Area of Zugliano	14115	13	3.4
Gallio	2340	4.6	1.6	Zugliano	5677		1.2
Roana	3747	8.8	1.6	Lugo	3696		1.0
Rotzo	604	13	0.1	Fara Vic.	3732		0.9
Conco	2250	6.8	1.5	Salcedo	1010		0.3
Lusiana	2881	7.6	1.7	Marostica	12610	14	2.2
Arsiero	3313	18	0.4	Breganze	7500	16	1.1
Area of Piovene	17165	14	3.7	Bassano	39289	17	5.1
Piovene	7340		1.4	Vicenza	107786	34	3.0
Carré	2950		0.6	Padova	212731	55	1.3
Chiuppano	2422		0.6	Cittadella	18324	28	0.7
Cogollo	3212		0.7	Grisignano	4099	55	0.5
Calvene	1241		0.4	Treviso	81195	56	0.5
Area of Thiene	34250	18	4.3	Castelfranco	30079	34	0.7
Thiene	20476		2.7	Mestre-Venezia	298915	70	0.7
Zané	5548		0.8	Trento	103181	56	1.3
Marano	8226		0.8	Belluno	35375	66	0.2
Area of Schio	41631	23	3.5	Verona	254145	64	1.5
Schio	36601		2.9				
Santorso	5030		0.6				

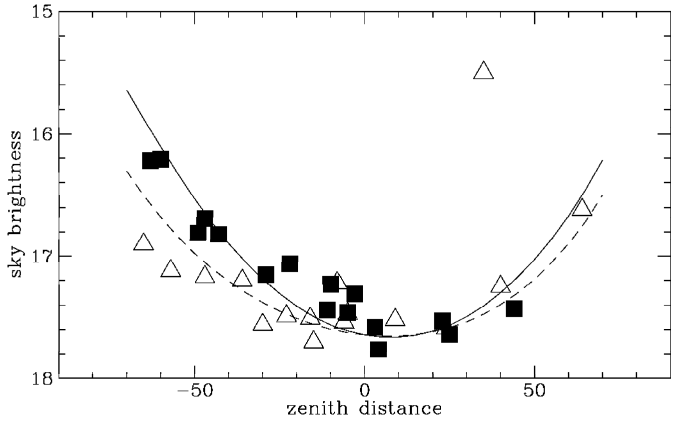

Fig. 14. Model predictions and sky brightness measurements at "G. Ruggieri" Observatory in Padova (Favero et al. 1999). Solid squares are measurements with azimuth ±45° from the meridian, open triangles are measurements with azimuth ±45° from the West-to-East circle. Solid line is the model prediction along the meridian and dashed line is the prediction along the West-to-East circle. Zenith distance is negative toward Padova city center.

When map of light pollution in a large territory are computed as done by Bertiau et al (1973) or Falchi and Cinzano (1999), the mean contribution in each considered grid point is calculated neglecting the effects of the casual presence of a source near the observation site. All sources are assumed to be at a minimum given distance. It is interesting to check how big could be the fluctuations gived by the casual presence of a source near the site. This is also interesting in order to determine what could be the minimum and maximum sky brightness that on a clear night could be found in a given area of the territory. The background component constitutes a lower limit, the higher being given by the sum of the background and the maximum fluctuation. Moreover, it is interesting to check inside cities what fraction of sky brightness is produced by the city itself and what fraction by the background. At last, it would be interesting to determine what is the population level at which the local brightness produced by the city became comparable to the background brightness.

These questions can be answered with the models applied in this paper. As an example I computed the sky brightness at a site inside the city of Padova, the "G. Ruggieri" Observatory (long. $-11°53'20"$, lat. $45°25'10"$ alt. $20m$ o.s.l.) both including and excluding the contribution of the city. This model assume $f(P) = P^{0.8}$ in order to fit observations of Favero et al. (1999) as discussed in sec. 3. The good agreement of predicted sky brightness distribution with measurements obtained by Favero et al. (1999) is shown in figure 14. In order to obtain the better fit, the predictions needed to be increased by 0.15 mag. Figure 15 and figure 16 show the sky brightness distribution at the site with and without the city. I found that 74 percent of artificial brightness at the zenith of the site is coming from Padova and 26 percent from the background. Note

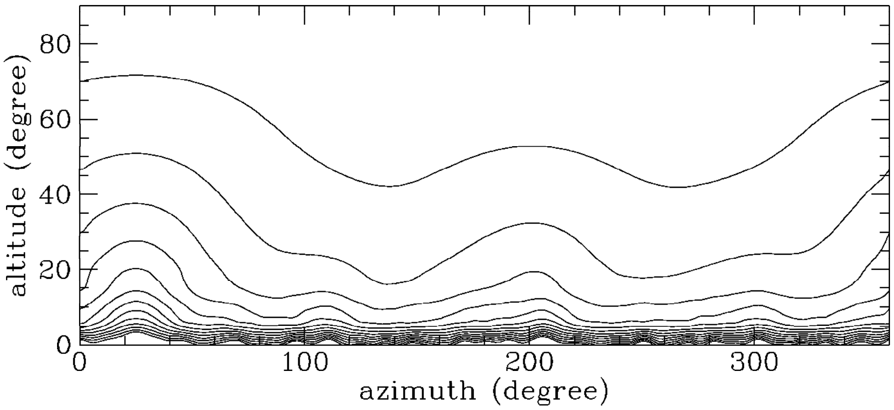

Fig. 15. Sky brightness distribution at "G. Ruggieri" Observatory in Padova. Isophotes shows respectively a sky brightness increase of 4.0, 4.5, 5.0, 5.5 etc. over the natural level in 1990. At low altitudes the 7-point approximation for Padova show its limits.

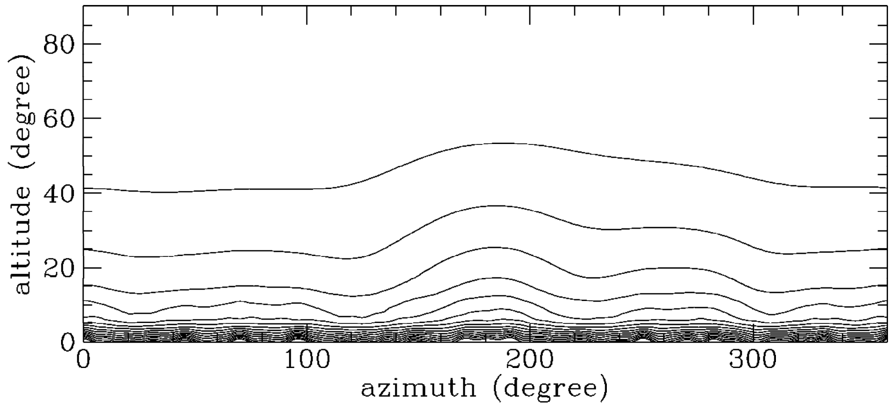

Fig. 16. Contribution to the sky brightness distribution produced at "G. Ruggieri" Observatory in Padova by all the cities excluding Padova. Isophotes show respectively a sky brightness increase of 3.0, 3.5, 4.0, 4.5, 5.0 etc. over the natural level in 1990.

that the contribution of the surrounding country is not negligible even in a site inside a city of 210000 inhabitants like Padova.

5. Conclusions

The impact of single sources on the sky brightness of a site was evaluated by computing the artificial sky brightness distribution which they produce with detailed models for light pollution propagation. The upward emission of cities in function of their population and the time was constrained with the condition that the sum of all contributions, including the natural sky brightness, fits the available measurements in some sites. The conclusions are:

1. Detailed models are usefull for disentangle contribution of single sources in diffusely urbanized areas.
2. Models well predict the sky brightness distribution in the studied sites showing that Garstang modelling technique works well in Italy too.
3. The preliminary calibration requires that the total upward flux from cities increases at about 9 percent per year in Italy, in good agreement with Cinzano (1999b), with an average total upward emission of 277 lm per head in 1990 (for models with $f(P) = P$).
4. Given the little number of available measurements it isn't possible to distinguish between the two functional forms of the total upward city flux versus city population pointed out by Falchi and Cinzano (1999).

More work is still necessary to better constrain average city emission function and the total upward flux calibration.

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