THE COLORS OF THE SKY GLOW

PIERANTONIO CINZANO, RUGGERO STAGNI
Dipartimento di Astronomia, Università di Padova, vicolo dell'Osservatorio 5,
I-35122 Padova, Italy
email: cinzano@pd.astro.it, stagni@pd.astro.it

ABSTRACT. We present preliminary results on the behaviour of the B-V color index with the distance from polluting sources. Predictions obtained with models of light pollution propagation are compared with available measurements of color index in Italy.

1. Introduction

The colors of sky glow depends mainly on (1) how light of different wavelength propagates through the atmosphere, (2) the emission curve of the polluting sources, (3) the relative intensity of artificial and natural sky brightness and (4) the color of this last. Garstang (1993) studied with detailed models the changes with time of the colors of the sky connected with relative changes of the color of the light emitted by polluting cities due to the evolution of lighting technology.

In this paper we study the relation between the color index $B-V$ and the distance from a polluting source. In section 2 we present a comparison between predicted $B-V$ color index and available measurement in Italy and we discuss the results. In section 3 we shortly outline our preliminary conclusions.

2. Models, Observations and Results

We computed the $B-V$ color index of the artificial sky glow for increasing distances from a source with detailed models for light pollution propagation developed by Garstang (1986, 1987, 1988, 1989a, 1989b, 1989c, 1991a, 1991b, 1991c, 1992, 1993, 1999) and recently applied in Italy by Cinzano (1999a, 1999b, 1999c). For a description of the modelling technique the readers is referred to the cited papers and, in particular, to Cinzano (1999a). The models allow the determination of the illuminance produced by a city on each infinitesimal volume of atmosphere along the line-of-sight of the observer taking in account extinction along light paths and both direct light and light scattered once from aerosols and molecules. The models take also in account the height o.s.l. of the observer and the polluting city, the aerosol content of the atmosphere and the ratio between upward emissions of the source in B band and in V band. An integration of the light scattered toward the observer by particles and molecules in the infinitesimal volumes along the line-of-sight allow us to obtain the sky brightness.

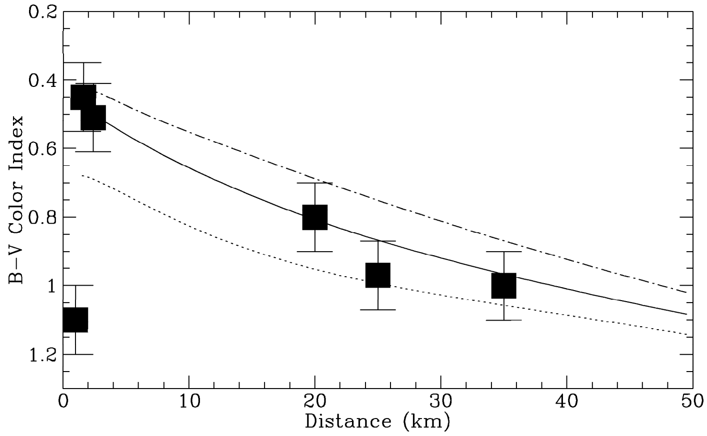

Fig. 1. $B-V$ color index and models predictions. Solid line is a model for an height of 1.000 m o.s.l. of the observer and zero height o.s.l. of the source computed for standard clean atmosphere. Dotted line and dashed line are models for zero height o.s.l. of both the observer and the source computed respectively for standard clean atmosphere and very clean atmosphere.

In figure 1 we show the measurements of $B-V$ color index near zenith in some Italian observatories collected from literature together with prediction of our model. Solid line is a model computed for an height of 1.000 m o.s.l. of the observer, zero height o.s.l. of the source and standard clean atmosphere as defined by Garstang (1986). For comparison, dotted line and dashed line are models computed for zero height o.s.l. of both the observer and the source, and respectively for standard clean atmosphere and very clean atmosphere. Models assume a V/B photon ratio of 2.3 at the source. This parameter does not affect the shape of the curves but shifts them along the vertical axis and it was chosen to optimize the fit of the first model (solid line) to observations. Measurements are done respectively at "G. Ruggieri" Observatory inside Padova (Favero et al. 1999), Collurania Astronomical Observatory (Piersimoni et al. 1999), Asiago Astrophysical Observatory (Cinzano 1999d), Mount Ekar Observatory (Cinzano 1999d), Bologna University Observatory in Loiano(Zitelli 1999) and Catania Observatory Stellar Station in Serra La Nave (Catanzaro et al. 1999). Measurements are *under the atmosphere*, i.e. catalogue magnitudes of the standard stars used in calibration have been corrected for the extinction of the light along its path to the telescope. The contribution of natural sky brightness to the measured color indexes, unknown, was not subtracted. Only for dark sites, where the artificial brightness is not prominent, the color index depends on the relative strength of the artificial and the natural sky brightness ($B-V\approx 1.1$ in dependence of direction of observation and airglow contribution) and is higher than the color index of the artificial brightness. Distances are average distances from the main polluting cities or areas. Errorbars are an estimate of the incertitude in the extinction.

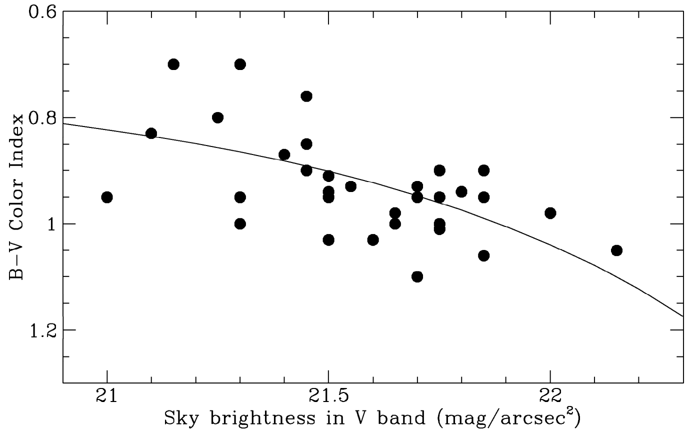

Fig. 2. Measurements of $B-V$ color index at Crimean Astrophysical Observatory and predictions as discussed in the text.

3. Conclusions

Measurements and models show that sky becomes redder as the observer move away from the sources. The redder color with increasing distance is produced by the stronger extinction of B wavelengths due at the λ^{-1} dependence of aerosol scattering and λ^{-4} dependence of Rayleigh scattering from molecules. The redder color index measured at "G.Ruggieri" Observatory inside Padova (the square at the lower left in figure 1) is likely produced by the greater aerosol content and by the greater V/B photon ratio at the source due at the great number of high pressure sodium lamps.

Our results might explain the correlation found by Lyutyi and Sharov (1982) at Crimean Astrophysical Observatory between sky brightness in V band and $B-V$ color index. If the artificial brightness from the nearby cities, increasing in mean of 0.03 mag per year from 1965 to 1980 (as shown in fig. 4 of the cited paper), change in dependence of the atmospheric conditions near the cities, then likely the color index varies in the range between its natural value and the artificial one. In this case the color index is:

$$B-V = 0.52 - 2.5log_{10}\frac{10^{\frac{0.52-(B-V)_a}{2.5}}\left(10^{\frac{41.44-V}{2.5}} - 10^{\frac{41.44-V_0}{2.5}}\right) + 10^{\frac{41.96-B_0}{2.5}}}{10^{\frac{41.44-V}{2.5}}} \qquad (1)$$

where B_0 is the natural sky brightness in B band, V_0 is the natural sky brightness in V band and $(B-V)_a$ is the color index of artificial sky brightness. The numeric coefficients are computed from Garstang (1989) conversion formulae from magnitudes ($mag/arcsec^2$) to photon counts ($ph\ cm^{-1}\ s^{-1}\ sr^{-1}$). The fit of this equation to Lyutyi and Sharov (1982) measurements *under the atmosphere* (from their table I) is showed in figure 2 for $V_0 = 22.15$, $B_0 = 23.25$ and $(B-V)_a = 0.7$.

Acknowledgements

We are indebted to Roy Garstang of JILA-University of Colorado for his friendly kindness in reading and refereeing this research note, for his helpful suggestions and for interesting discussions.

References

Catanzaro, G., Catalano, F.A. 1999,in this volume.
Cinzano, P. 1999a, in this volume.
Cinzano, P. 1999b, in this volume.
Cinzano, P. 1999c, in this volume.
Cinzano, P. 1999d, in this volume.
Favero, G., Federici, A., Blanco, A.R., Stagni, R. 1999, in this volume.
Garstang, R.H. 1984, Publ. Astron. Soc. Pacific, 96,788.
Garstang, R.H. 1986, Publ. Astron. Soc. Pacific, 98, 364-375.
Garstang, R.H. 1987, in Identification, optimization and protection of optical observatory sites, eds. R.L. Millis, O.G. Franz, H.D. Ables & C.C. Dahn (Flagstaff: Lowell Observatory), p. 199-202.
Garstang, R.H. 1988, The Observatory, 108, 159-161.
Garstang, R.H. 1989a, Publ. Astron. Soc. Pacific, 101, 306-329.
Garstang, R.H. 1989b, Ann. Rev. Astron. Astrophys., 27, 19-40.
Garstang, R.H. 1989c, Bull. of American Astron. Soc., 21, 2, 759-760.
Garstang, R.H. 1991a, in Light Pollution, Radio Interference and Space Debris, IAU Coll. 112, ed. D.L. Crawford, Astron. Soc. of Pacific Conf. Series 17, p. 56-69.
Garstang, R.H. 1991b, Publ. Astron. Soc. Pacific, 103, 1109-1116.
Garstang, R.H. 1991c, The Observatory, 111, 239-243.
Garstang, R.H. 1992, Bull. of American Astron. Soc., 24, 740.
Garstang, R.H. 1993, Bull. of American Astron. Soc., 25, 1306.
Garstang, R.H. 1999, in this volume.
Lyutyi, V.M., Sharov, A.S. 1982, Soviet Astron., 26(1), 105-109.
Piersimoni, A., Di Paolantonio, A., Brocato, E. 1999, in this volume.
Zitelli, V. 1999, in this volume.