MEASUREMENTS OF THE NIGHT SKY BRIGHTNESS AT THE CATANIA ASTROPHYSICAL OBSERVATORY

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ABSTRACT. We report on measurements of the night sky brightness at the *"M. G. Fracastoro"* stellar station of the Catania Astrophysical Observatory during 3 moonless nights in February 1998. Measurements were performed in the broad band UBV filters. We compare our observed night sky zenith brightness to measurements from other sites and we also discuss the long term variations from 1980 up to now. Futhermore, we try to correlate the brightness variations both with the solar activity and with the mount Etna volcanic activity.

1. Introduction

To describe the quality of an astronomical site one of the most important parameters to take into account is the brightness of the night sky, which is due to both natural and artificial components. Among the natural components, some are extraterrestrial in origin and thus indipendent from the place on the Earth's surface in which the measurements have been done: zodiacal light, unresolved starlight, diffuse galactic light and extragalactic background light. Other natural components have their origin in the Earth's atmosphere: the airglow emission and the scattered light, for example, depend on the site and the time of the observations.

The artificial component is added to these natural components and contributes to total night sky brightness. This component is mainly due to the artificial illumination that reachs the sky.

There have been many studies of the night sky brightness at particular observatories, see for examples references in Table II. Some studies of light pollution have been made over wider geographical areas, for examples California and Arizona (Walker 1973), Southern Ontario (Berry 1976) and Italy (Bertiau et al. 1973). Berry (1976) has demonstrated an important relationship between the city center zenith sky brightness and the population of the city. Walker (1977) by using the results of his observations derived luminosity - population, brightness-distance and population-distance relationships.
Despite all these observational results, there have been few attempts to construct models to explain the observations, see for example the work performed by Berry (1976) and

Bertiau et al. (1973), who used the empirical law derived by Treanor (1973) to reproduce the zenith luminosity. An important step toward in the modelling of the night sky brightness was given by Garstang (1986, 1989). This author derived a model that, taking into account the main features of the physical situation, provided a good theoretical representation of the observed data.

With the aim of analyzing the actual situation of light pollution at the Catania Astrophysical Observatory, we have performed photometric observations during three moonless nights in February 1998. Moreover to study the long term variations we have examined a number of data collected at our site during last 20 year. The observational techniques and reduction procedures are described in Sect. 2. In Sect. 3 we report on the long term sky brightness variations and in Sect. 4 and 5 respectively, their correlation with solar and mount Etna volcanic activity. Finally, in Sect. 6 we present our summary and conclusions.

2. Observations and data reductions

The observations were carried out at the *"M. G. Fracastoro"* stellar station of the Catania Astrophysical Observatory located at $\lambda = 14° : 58.4'$ W, $\phi = 37° : 41.5'$ at the height of 1735 m on mount Etna in the south of Italy. We used the 91 cm cassegrain telescope equipped with a single channel photometer with an EMI 9893QA/350 photomultiplier, which, cooled to -15 C, produces a dark current of 1 count/s, negligible in comparison with the sky signals, which were at least several hundred counts/s. The selected diaphram gives on the focal plane an image having a diameter of 2 mm corresponding to 28.92 arc sec on the sky.

The observing technique was to get photometry of some selected points in such a way to cover as uniformly as possible the sky and avoiding in the selected area the presence of stars brighter than 20^{th} magnitude. This choice has been done to avoid the influence of the unresolved starlight. The selected points in the sky are shown in Fig. 1. The sky brightness at each point were calibrated and atmospheric extinction coefficients were determined by observing a set of standard stars extracted from the list of Landolt (1983). The measured extincion coefficients are given in Table I.

The maps shown in Fig. 2 have been realized by means of an interpolating procedure created in the IDL environment. These maps describe the trend of the night brightness expressed in mag/□". Azimuth coordinates are measured from the north point eastwards.

According to the maps, it is evident the great contribute of the artificial illumination produced in the city of Catania located close to the south. Despite the patchy structure

TABLE I
Measured extincion coefficients

	U	B	V
k(λ)	0.89 ± 0.13	0.58 ± 0.10	0.28 ± 0.10

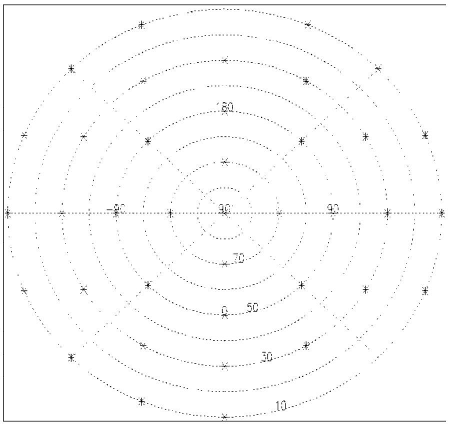

Fig. 1. Selected positions observed to realize the maps. Missing positions were not observed due to the presence of obstacles on the horizon (essentially the tops of some trees near the dome).

of the light distribution over the sky it is however possible to find out a spherical cap centered at the zenith and with a radius of about 20°, in which the brightness is essentially constant. The values of the sky magnitude in that cap have been compared with the ones measured in other important astronomical sites. The results are shown in Tab. II. As we can see, the zenith night sky brightness in our site is at least 1 magnitude brighter than at other astronomical observatories. The measured V magnitude is in good agreement with the theoretical one calculated by Cinzano (1998) for our site. Developing Garstang (1986,1989) models with $K = 1$, this author found 20.44 mag/□" for an epoch near solar minimum. K is a parameter related to the aereosol content in the Earth's atmosphere. According to Garstang (1986), $K = 1$ is the typical value for clear air at sea level.

TABLE II

Comparison of zenith sky brightness at different sites in units of mag/□". The given solar 10.7 cm flux value is in unit of 10^4 Jy.

Site	I_U	I_B	I_V	Solar flux	Reference
Catania	21.37	21.13	20.80	95	This work
ESO - La Silla	–	22.85	21.80	165	Mattila et al. (1996)
Calar Alto	–	22.51	21.79	65	Leinert et al. (1995)
CASLEO	22.10	23.30	22.70	–	Clariá & Bica (1990)
San Benito Mt.	–	23.08	22.07	77	Walker (1988)

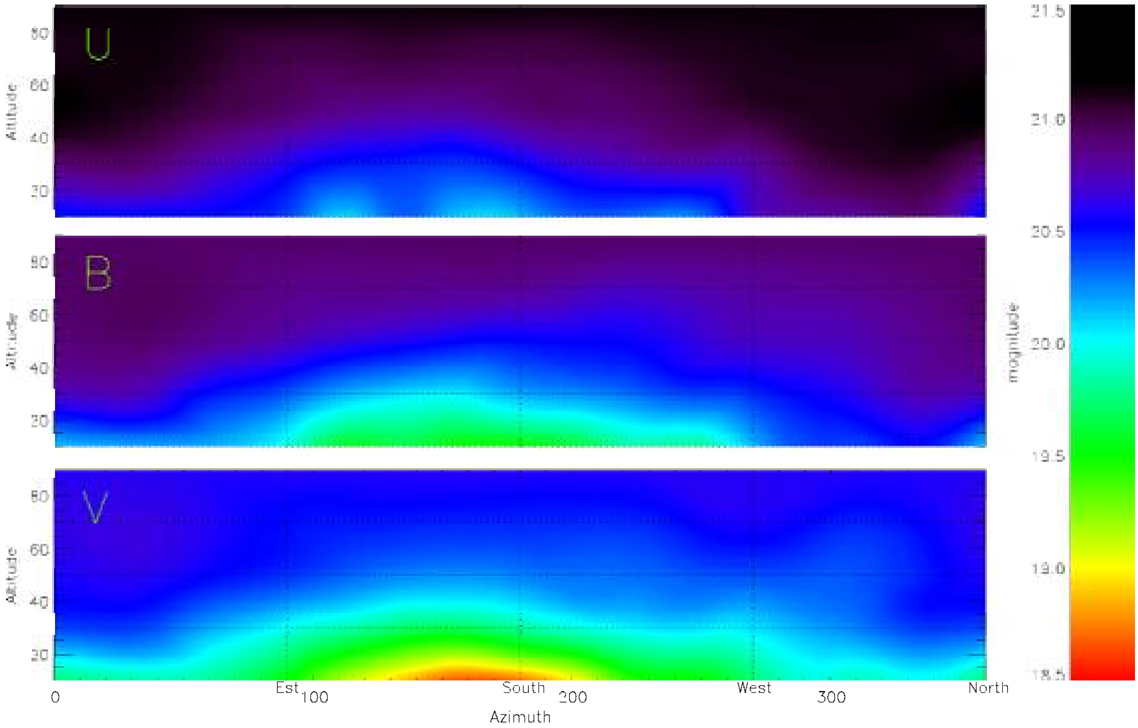

Fig. 2. UBV maps of night sky brightness at the Catania Astrophysical Observatory. The origin of azimuth coordinates is at the North point.

3. Long term variations

In the attempt to study the long term variations of the night sky brightness, we have analyzed a number of photometric observations collected at the Catania Astrophysical Observatory during the period from 1980 up to now (Catalano et al., 1998).
The selection criteria were:

- used strumentation as uniform as possible (telescope + photometer + filters + diaphram)
- position in the sky of the observed point inside a spherical cap extending up to $z = 20°$. In fact, as we can see in Fig. 2 inside that zone the brightness is pratically costant
- the photometric observations have been performed during periods without Etna's eruptions, in such a way to avoid problems with the interactions between volcanic dust and light
- and finally, the photometric observations have been carried out in moonless nights.

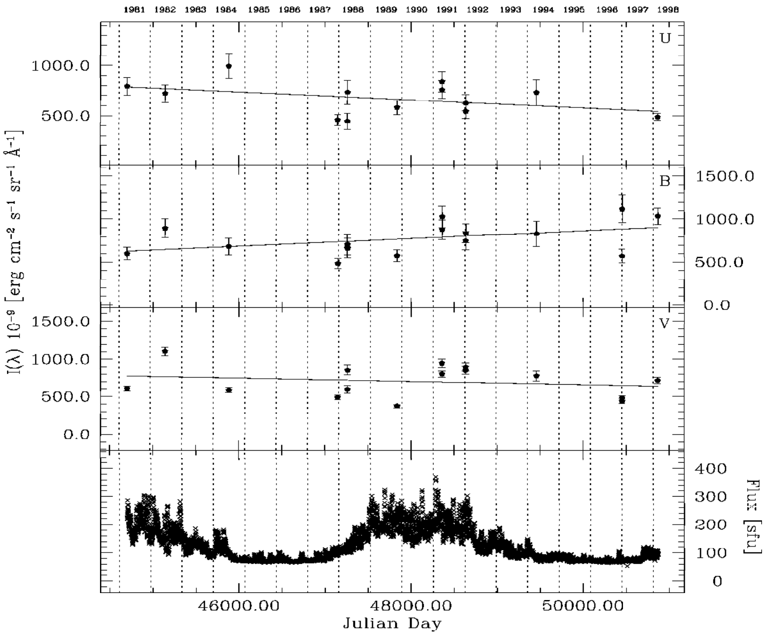

Fig. 3. Long term variations of the night sky brightness as measured during the period 1980 - 1998. The first panel represent the solar activity cycle monitored by means of the 10.7 cm flux (DRAO).

In Fig. 3 we plot the night sky brightness versus julian day for the period 1980 - 1998. To express the magnitudes in energetic units (erg · $\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathrm{\AA}^{-1}$), we first used the formula given in Leinert et al. (1995) to transform the mag/□″ in S_{10} units[1]

$$I(mag/\Box'') \;=\; -2.5\log I(S_{10}) \;+\; 27.78 \tag{1}$$

then according to Leinert et al. (1998), we used the following conversion factors:

$$1\,S_{10} \;=\; \begin{cases} U: & 1.37\cdot 10^{-9} erg\cdot cm^{-2}s^{-1}sr^{-1}\mathring{A}^{-1} \\ B: & 2.17\cdot 10^{-9} erg\cdot cm^{-2}s^{-1}sr^{-1}\mathring{A}^{-1} \\ V: & 1.18\cdot 10^{-9} erg\cdot cm^{-2}s^{-1}sr^{-1}\mathring{A}^{-1} \end{cases} \tag{2}$$

As shown by the fit lines, the data seem to vary in time but in different ways in the three filters, in the sense that in the U and V bands the fluxes show a slight decrease while the flux increases in the B bands. We would like to point out that, since the component of the natural sky brightness measured at the zenith is almost constant, the total brightness can be used without any loss of generality.

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[1] 1 S_{10} unit is the brightness equivalent to the flux of a star of magnitude 10 distribuited over one squared degree. It refers to A0 stars, which essentially have the same magnitude in all wavelength bands.

4. Correlation of the night sky brightness with solar activity

A correlation between the intensity of the 5557 Å OI airglow line with sunspot numbers has been already reported by Rayleigh (1928) and Rayleigh & Jones (1935). A similar correlation has been later on found for other emission lines of OII, Na, D and OH (Rosenberg & Zimmerman 1967, Walker 1988). For the period 1976 - 1987 Walker (1988) found in his mesaurements a clear evidence of correlation with the solar cycle, in the sense that the night sky brightness increased with the solar activity. Walker argued this result to be the demonstration of the validity of this kind of correlation not only for the strong lines but also for the airglow emission. A similar result has been obtained by Leinert et al. (1995), who, from photometric data carried out at the *Calar Alto Observatory* in Spain, concluded that sky night brigthness is correlated with solar activity.

In order to better investigate the correlations between the night sky brightness and the solar activity, we have plotten each night measurement against the solar 10.7 cm flux. The daily flux was measured in Ottawa (Army Research Office) at 17:00 UT until June 1991, when the program was moved to the Dominion Radio Astronomical Observatory in Penticton (Canada). The daily time of the measurements was changed to 19:30 UT for one year, then was changed to 20:00 UT as it continues today. The solar fluxes are expressed in sfu[2] and are the "observed values", i.e. not corrected to a 1 AU solar distance.

Our results are shown in Fig. 4, in which we can individuate a slight correlation between sky brightness and solar flux, but also in this case we have different slopes for the three filters. U and V bands show an encrease with solar flux while B band shows an opposite behaviour. In order to study this correlations in more detail we have calculated the correlation coefficients r and the related probability P(r,N), where N is the number of data points. The correlation coefficients, the probability and the least squares fit parameters found are shown in Tab. III.

TABLE III

Correlation of the night sky brightness with solar activity. The correlation coefficients r, the probability and the least squares fit parameters for the linear relation ($I_{sky} = a \cdot f_{sfu} + b$) are given for each colour.

Filter	a	b	r	P(r,N)
U	0.73	595.73	0.06	0.50
B	−0.80	904.35	0.24	0.68
V	0.14	641.75	0.23	0.67

In astronomical sites in which the level of light pollution is low, the observed variations due to the effect of solar activity on the airglow emission are usually about 0.4 mag for the B band and 0.5 mag for the V band (Walker 1988, Leinert et al. 1995). Thus, the poor correlation between night sky brightness and solar activity that we observed

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[2] $1\ \mathrm{sfu} = 10^{-22}\ \mathrm{W\ m^{-2}\ Hz^{-1}} = 10^{4}\ \mathrm{Jy}$

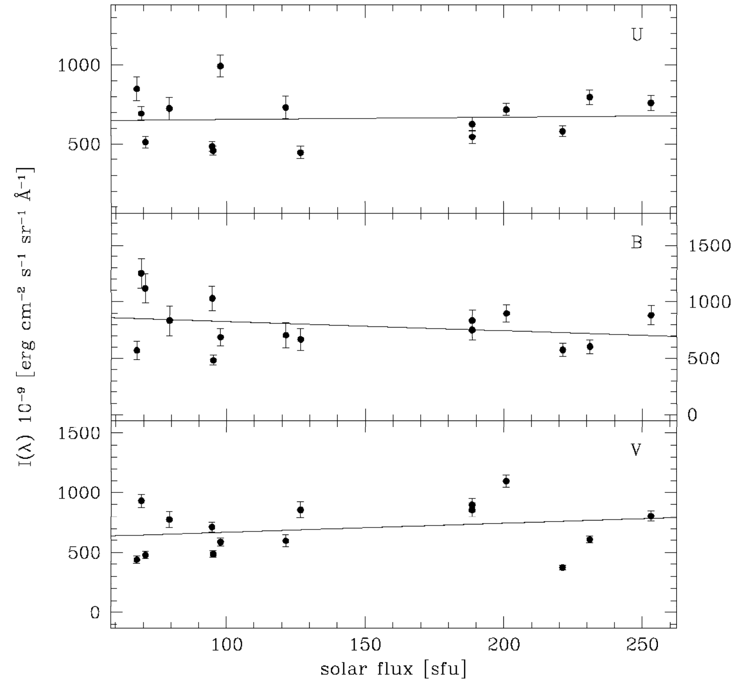

Fig. 4. The night sky brightness versus the solar 10.7 cm flux expressed in sfu units

might be related to high level of the artificial illumination, which contributes to mask the variations due to solar cycle.

5. Correlation of the night sky brightness with mount Etna volcanic activity

It has been known for many years that volcanic dust in the high atmosphere affects astronomical observations. Many studies were made on the effects of volcanic ash when a violent eruption in the Andes on 1932 April 10 left a cloud of volcanic material in the stratosphere over the Commonwealth Solar Observatory on Mount Stromlo in Australia. During that day a decrease in the intensity of the total solar radiation was observed (Rimmer, 1937).

Volcanic dust affects photometric measurements. For example, the eruption of Mount Agung in Bali, of March 1963 formed a cloud that passed over Australia and Chile which produced an excess extinction of 0.38 mag in the B band and 0.30 mag in the V band over the normal ones (Hogg, 1963). Moreno & Stock (1964) reported that the visual extinction at the Cerro Tololo Inter-American Observatory in Chile started to increase in late April 1963 from its normal value of about 0.12 mag, reached a maximum of 0.42

mag in September 1963, and subsequently decreased gradually. The maximum excess extinction due to the cloud was thus 0.30 mag. By September 1964 the excess extinction had fallen to 0.07 mag (Moreno et al., 1965). Futhermore they found that the volcanic extinction was gray.

More recently, Livingston & Lockwood (1983) studied the effect of the stratospheric cloud coming from the eruption of the volcano El Chichón, Mexico. They measured the increase in extinction and found that it was remarkably gray over the visible spectrum, but not in the infrared, where it was much less.

Theoretical works on the interaction between volcanic dust and light were performed by Garstang (1991 a,b). According to his models, Garstang (1991b) calculated the refractive index and the particle distribution function for ash particles from the El Chichón volcano. His results show that extinction and scattering are nearly grey in the visual region, that is, that the absorption has a modest dependence on wavelenght.

In the attempt to investigate the effect of the mount Etna eruptions on the night sky illumination, we have plotted the night sky brightness measured near the zenith versus the ash column produced during volcanic explosions (Coltelli, 1998). The ash column is the height at which volcanic dusts have been ejected, expressed in km above sea level, and it is a good indicator of volcanic activity.

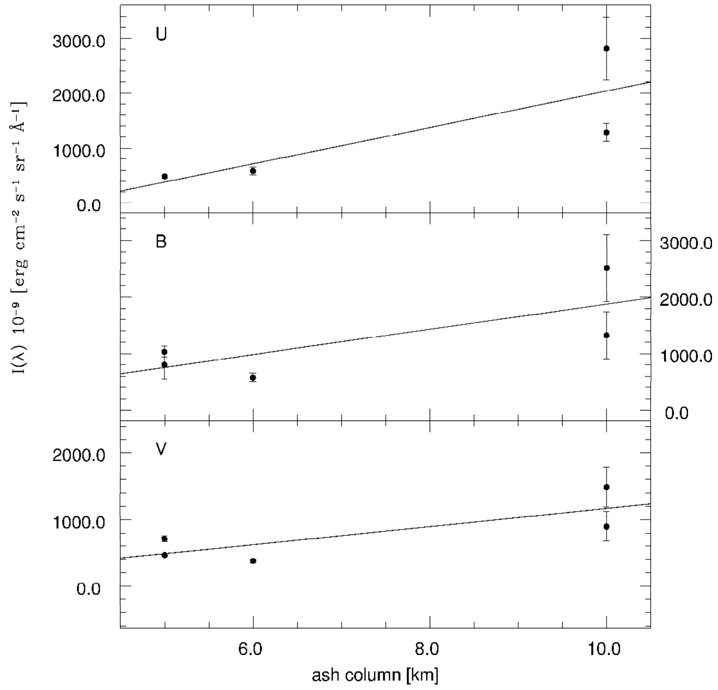

Fig. 5. The night sky brightness versus the ash column expressed in km above sea level

As can be seen from Fig. 5, a correlation between these two quantities might exist. To stress this point, we have calculated the quantities shown in Tab. IV; by means of the correlation coefficient, we estimated the probability and for all filters we obtained $P(r,N) \geq 0.9$. Nevertheless, because we were not able to get the actual extinction factors for the three bands, we used the mean ones. So, it is possible that these effects mimic an increase of the extinction which appears as a real increase due to the presence of the dust in the atmosphere. Hence, further work is still necessary to understand the real effects of dust on the light pollution.

TABLE IV

Correlation of the night sky brightness with mount Etna volcanic activity. The correlation coefficients r and the least squares fit parameters for the linear relation ($I_{sky} = a \cdot ash\ column + b$) are given for each colour.

Filter	a	b	r
U	330.80	−1273.66	0.91
B	223.43	−367.57	0.77
V	135.79	−192.48	0.78

6. Conclusions

We have performed broad band photometry of night sky brightness during three moonless nights in February 1998 at the *"M. G. Fracastoro"* stellar station of the Catania Astrophysical Observatory with an observing technique that allows to map the luminosity of the sky. We also have investigated about the long term variations and about the correlations of the night sky brightness both with the solar activity and with the mount Etna volcanic activity.

Our main conclusion are the following:

1. there is a spherical cap centered at the zenith and with a radius of about 20° in which the sky brightness is almost constant;
2. the zenith sky brightness at our site is at least 1 magnitude brighter than at other observatories;
3. our V band measurament is in good agreement with theoretical calculation performed by Cinzano (1998) for our site;
4. during the last 20 years the long term variations show different type of variation in the three band;
5. the night sky brightness is slightly correlated with the solar activity cycle measured by means of 10.7 cm flux;
6. the night sky brightness seems to show a strong correlation with the mount Etna activity monitored by using the ash column ejected in the atmosphere during the eruptions.

We will continue our observations both to better understand the previous points and also to check the presence of seasonal variations.

Acknowledgements

We wish to express our sincere gratitude to drs. S. Catalano, E. Marilli and A. Frasca for putting at our disposal their unpublished data of sky brightness measurements. We also thank dr. P. Cinzano for its comments useful to improve our paper.

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