VARIATIONS OF THE EARTH'S ALBEDO DEDUCED FROM THE ASHEN LIGHT OF THE MOON

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Abstract. An analysis of 1210 visual brightness estimations of the Moon's ashen light is presented, performed by a working group of amateur astronomers from June 1972 to December 1973. In the Moon phase interval $0.1 \leqslant T_b \leqslant 0.7$ the brightness expressed in a semi-empirical scale, S_G, is found to be linearly related to the phase. Monthly deviations from the mean brightness show well defined winter maxima (January) and summer minima (July). Within the referenced period the brightness of the ashen light tends to increase, whereas the solar magnetic activity decreased. In addition, minor correlations and, respectively, anti-correlations are found at stratospheric temperature and, respectively density. On account of the nature of the ashen light its variations are regarded as fluctuations of the Earth's albedo.

1. Introduction

From photoelectric investigations Lockwood and Thompson (1979) derived a well-defined anti-correlation between the albedos of both Neptune and Saturn's satellite Titan on the one side, and the solar activity on the other side. Their observations cover the years from 1972 to 1976. Lockwood and Thompson suggest that changes of the solar activity apparently induce slow structural and chemical changes in planetary atmospheres.

Variations of the ashen light may be used to investigate changes of the Earth's albedo which is the reason for the ashen light. Changes may be due to ice, vegetation, atmospheric conditions or, less established, the solar activity. The estimated brightness of the ashen light observed from a distinct place on the Earth's surface in addition depends on:

(1) the geometry of the Earth-Moon-Sun system (as, e.g., the angles and distances)

(2) the distribution of bright terrae and dark maria on the dark side of the Moon: The ashen light appears brighter on waning Moon when mainly the high-albedo terrae reflect the Earthshine. After New Moon (waxing Moon) the dark maria on the east part of the disc (IAU convention) will cause a smaller albedo.

(3) the distribution of continents and seas on the bright side of the Earth faced to the Moon

(4) straylight from the directly illuminated area of the Moon which is strongest near full moon

(5) straylight from the atmospheric twilight close to new Moon

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(6) the elevation of the Moon
(7) the transparency of the atmosphere
(8) the observer and the instrument used.

With this paper we report visual estimates of the brightness of the ashen light in order to study changes of the Earth's albedo.

2. Observations

From June 1972 to December 1973 the Volkssternwarte Gummersbach (FRG) organized an observing program to perform a systematic monitoring of the Moon. Nearly 200 amateur astronomers from the FRG and neighbouring countries contributed observations (see Hilbrecht and Küveler, 1984). One of the main purposes was to estimate visually the brightness of the ashen light using a semiempirical scale (Küveler, 1972) given in Table I.

This 'Gummersbach scale' (S_G) represents a contrast graduation reflecting the photometric brightness of the ashen light since physiologically a higher photon flux refers to a higher contrast of lunar features.

The observations were performed with small (2 to 6 inch) telescopes. The frequency of observations is shown in Figure 1. The total number of reports amounts to 1210 (498 in 1972 and 722 in 1973).

TABLE I

The Gummersbach scale for visual estimations of the brightness of the ashen light

S_G	Definition of S_G
0	The ashen light is invisible.
1	The ashen light is visible with difficulties.
2	The ashen light is visible but the contrast to the celestial background is low.
3	No details within the ashen light can be observed but the contrast to the background is good.
4	The maria can be seen in low contrast to terra regions within the ashen light.
5	The maria are well visible, Aristarchus appears as a low contrast feature.
6	The boundaries of maria are marked sharply and details within are recognizable.
7	Same as 6, but bright craters are visible extra-ordinarily well.

3. Reductions

From all estimates performed under good transparency conditions daily means of the uncorrected (S_G) values were calculated and plotted in Figure 2 as a function of the area T_b of the directly illuminated part of the Moon. For $0 \leqslant T_b \leqslant 0.1$ and $0.7 \leqslant T_b \leqslant 1$ straylight problems become significant (see Introduction, item 4 and 5). Thus, we exclude

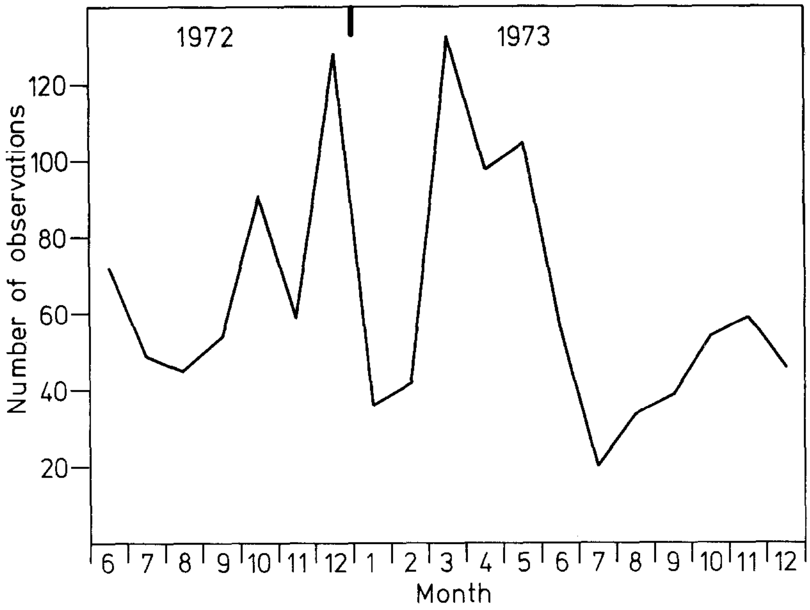

Fig. 1. Monthly numbers of monitoring observations.

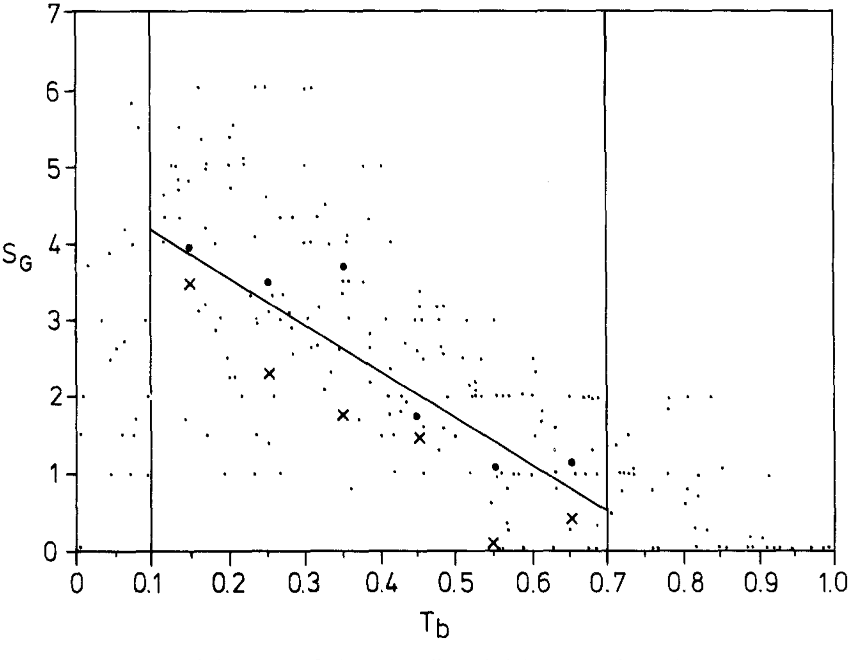

Fig. 2. Daily means of brightness of the ashen light (•) in units of the Gummersbach scale (S_G) from new Moon ($T_b = 0$) to full Moon ($T_b = 1$). Circles (●) for the mean brightness ($\Delta T_b = 0.1$) of the ashen light at waning Moon, crosses (X) at waxing Moon. The straight line is the regression curve according to Equation (1) valid for the interval $0.1 \leqslant T_b \leqslant 0.7$.

these intervals from further reductions. In the interval $0.1 \leqslant T_b \leqslant 0.7$ the relation seems to be linear, similar to the photometric curve published by Danjon (1964).

The asymmetric distribution of lunar features (see Introduction, item 2) requires the distinction between observations during waxing and waning Moon. As seen in Figure 2 values averaged over $T_b = 0.1$ intervals always are significantly higher for waning Moon. After correction of all data for the actual difference of their T_b-interval the linear part can be described by the equation

$$S = -6.1T_b + 4.8. \tag{1}$$

The corrected mean observations S_G^{corr} then are compared to the fitted curve

$$\Delta S = S_G^{\text{corr}} - S(T_b). \tag{2}$$

Negative ΔS values refer to a higher-than-average brightness. Most of the effects (1)–(5) mentioned in the Introduction have monthly periods. In order to avoid systematical errors monthly means of ΔS are computed. In addition, this leads to a considerable diminution of the influences of the effects (6)–(8).

4. Results

Figure 3 shows the variation of both, ΔS and the monthly mean of the solar sunspot number R_i, for the referenced period as given in Table II. It is seen that ΔS generally tends to negative values, i.e. to a larger brightness of the ashen light. Superposed seasonal

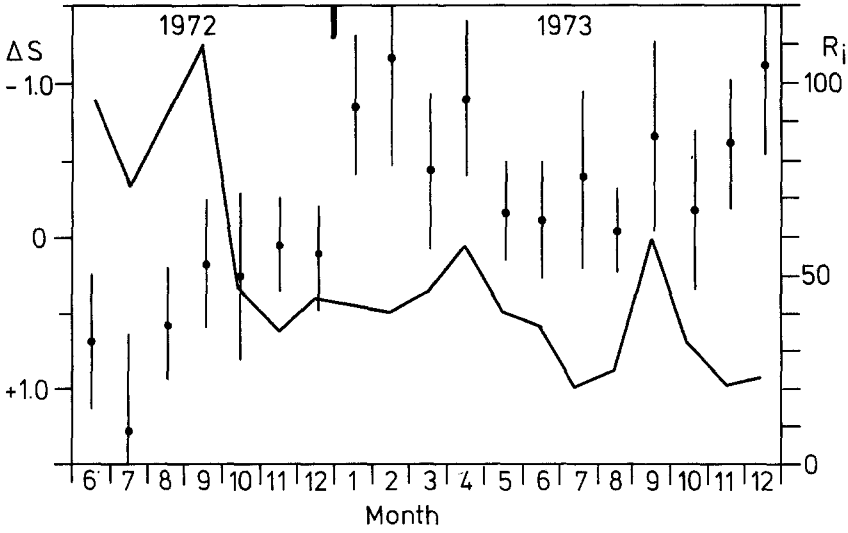

Fig. 3. Monthly means of the brightness of the ashen light. Negative ΔS values refer to higher brightnesses. The solid curve shows the solar activity represented by the monthly means of the Zürich solar sunspot number (R_i).

TABLE II

Monthly means of ΔS and Zürich Sunspot Number (R_i) from June 1972 to December 1973. Negative S_G-values refer to a higher than mean brightness of the ashen light. See Figure 3 for graphical display.

1972	ΔS	R_i
June	0.65 ± 0.91	96.0
July	1.25 ± 1.33	73.0
August	0.56 ± 0.76	94.0
September	0.15 ± 0.85	111.6
October	0.24 ± 1.13	46.6
November	0.02 ± 0.63	35.7
December	0.06 ± 0.73	44.2
1973		
January	− 0.87 ± 0.87	42.2
February	− 1.19 ± 1.46	40.9
March	− 0.45 ± 1.09	45.9
April	− 0.91 ± 0.99	58.2
May	− 0.17 ± 0.67	41.5
June	− 0.09 ± 0.78	37.6
July	− 0.41 ± 1.16	20.4
August	− 0.02 ± 0.56	25.6
September	− 0.67 ± 1.26	60.8
October	− 0.20 ± 1.09	33.0
November	− 0.63 ± 0.86	22.1
December	− 1.15 ± 1.17	24.2

variations clearly exist with winter maxima and summer minima. Whereas the general ΔS trend is positive, the solar activity decreases during the period investigated. Considering ΔS and R_i exclusively in the interval 02/1973 to 10/1973 one might get the impression of a positive correlation. In this period the seasonal variations are more pronounced than the small general trend to higher brightness of the ashen light. For those months (6 to 12) covered by the data in both years all ΔS are smaller in 1973 than in 1972 (see Table II).

In order to give an idea of possible physical processes linking the relation between ΔS and R_i in Table III the correlation coefficients for linear regressions between all parameters ΔS, R_i, stratospheric temperature and density at an altitude of 35 km are shown (see Discussion).

5. Discussion

The most evident effect seen from the data is the seasonal brightness variation of the ashen light with two winter maxima (see Figure 3). The effect is much larger than expected from the varying Earth-Sun distance which yield maximum brightness fluctuations of about ± 3%. From satellite measurements Baumgartner *et al.* (1976) found

TABLE III

Correlation coefficients $r_{x,y}$ between brightness variation of the ashen light ΔS, monthly mean of Zürich sunspot number R_i, temperature T_{35} and density D_{35} at a height of 35 km (data from the Institut für Meteorologie der Freien Universität Berlin).

Parameters compared	$r_{x,y}$
$\Delta S, R_i$	− 0.29
$\Delta S, T_{35}$	0.11
$\Delta S, D_{35}$	− 0.30
R_i, T_{35}	− 0.16
R_i, D_{35}	0.19

seasonal variations near ± 20% showing maxima in January and minima in July. This is in very good agreement with the ΔS fluctuations presented here.

The correlation between the brightness of the ashen light (regarded as an indicator of the Earth's albedo) and the monthly mean of the sunspot number (taken as an indicator for the solar activity) is moderately negative ($r_{x,y} \approx -0.3$). During the same solar cycle Lockwood and Thompson (1979) also found a negative correlation from two solar objects (Neptune and Titan) with different atmospheres from that of the Earth. The correlations obtained by these authors appear much more significant than ours. This, however, may be due to the longer period of approximately 6 yrs covered by their measurements.

Short period fluctuations of the solar activity are neither seen in the brightness variations of the ashen light nor in the measurements by Lockwood and Thompson taken in sufficiently short intervals. Possibly the high energy solar radiation affects atmospherical processes with timescales longer than one or two months.

For the sunspot cycle 1958–1970 Schwentek (1971) found density (D_{35}) and temperature (T_{35}) of the stratosphere at a height of 35 km to be significantly correlated to the solar activity represented by the Zürich sunspot number (R_i). We tried to reproduce his results by monthly means of D_{35} and T_{35}.

As Schwentek did we used daily measurements from the Institut für Meteorologie der Freien Universität Berlin. All correlation coefficients (Table III) are very small except for moderately negative correlations of ΔS, R_i and S, D_{35} ($r_{x,y} \approx -0.30$). A long time variation of the stratospheric density might be the causal link between solar activity and the Earth's albedo.

The present data suffer from the short interval covered with respect to the solar cycle. Nevertheless, the variations of the Earth's albedo deduced from the observation of the Moon's ashen light and the correlation with the solar activity seems to be of some importance. The present method is simple, inexpensive and appears to be capable of reproducing satellite-based data. More extended observational periods are required.

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