Background of Airglow [OI] 5577Å and Two-Colour Photometry

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Abstract

Some informations for colour of the background of the airglow [OI] 5577Å line were obtained empirically, which is a continuous spectrum composed of the integrated star light, the zodiacal light and the airglow continuum.

A relation between the intensity of the airglow continuum and the one of the 5577Å line was found, which is not linear, but the former varies with a power of 0.78 for the latter and this suggests that the two-body collision process of [OI] atoms is possible as the origin of the airglow continuum near 5250Å.

These informations were utilized into the explicit formulation of the method of the two-colour photometry.

An information was found on the spatial distribution of the zodiacal light extending to higher ecliptic latitude.

For the calibration of the photometer, an improved method was expressed in connection with the two-colour photometry.

§1. Introduction

In the measurement of the absolute intensity of the airglow emission line, it is well known that the basic problems are classified into three groups:

(a) the calibration of the photometer;

(b) the subtraction of the background which is the continuous spectrum composed of the integrated star light, the zodiacal light[(1)] and the airglow continuum;

(c) corrections for the extinction and scattering by the earth's lower atmosphere.

The two-colour photometry after Roach and Barbier [1] can be an effective method of the subtraction of the background only if its spectrum can be estimated.

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(1) In this report, the term of "zodiacal light" is used in the sence of the reflected solar light by the interplanetary matter, which is of course intensified near the ecliptic but can not be neglected even in the higher ecliptic latitude.

This paper is aimed to give some informations of such the background, that is, mean spectra in 5000Å region of the integrated star and the zodiacal light, or actually the flux ratio at the special two wavelengths near 5000Å.

As the airglow continuum, a relation between its intensity and the one of the airglow [OI] 5577Å green line will be given. These informations are all utilized in the estimation of the part due to only the emission line in the actually observed night sky photo-currents.

For the calibration of the photometer, there is an improved method by combining the observations of some selected stars, with the relative sensitivity obtained by the direct projection of the monochromatic light into the photometer itself, which has been originally presented by Hikosaka and us [2]. Somewhat detailed treatments of this method will be described in this paper specially in connection with the two-colour photometry.

The actual observations for these purposes were made by Japanese IGY photometer for the airglow 5577Å line by Huruhata et al. [3], and data were taken from those at Niigata airglow station (37°42′N, 138°49′E) during Jul. 1957 and May 1958.

§2. Basic Equations of the Two-Colour Photometry

When the airglow [OI] 5577Å green line intensity is G' in Rayleigh units, the photometer receives

$$G' \cdot 10^6 \frac{1}{4\pi(57.3)^2} \text{ photons per cm.}^2 \text{ sec. deg.}^2,$$

if there were no atmospheric extinctions, as the Rayleigh unit is defined by 4π brightness of the sky (emitting photons per cm.^{2} sec. steradian) $\times 10^{-6}$.

The sensitivity of the photometer, that is the photocurrent mm. produced per unit photon per cm.^{2} sec. Å, is the product of the following factors of the optical system:

(a) the area of objective,
(b) the transmission of filters,
(c) the local sensitivity of photocathode,
(d) the flux loss, if exists, due to geometry.

Especially saying of the filter, in the case of an interference type, it must be considered the shifting of its transmission wavelength by an oblique incidence.

Therefore the overall sensitivity of the photometer, t_1, is a function $(\lambda, \theta, \varphi)$, where λ is wavelength, θ is the vertical angular distance of the incidence from the optical axis and φ is the horizontal as same as θ. Thus the photocurrent by the 55577Å green line, G_0 mm., is given by

$$G_o = G' \frac{10^6}{41250} \iint t_1(5577,\ \theta,\ \varphi) d\theta d\varphi,$$

or by using the effective field, Ω deg.^{2}, defined as

$$\Omega = \frac{\iint t_1(5577,\ \theta,\ \varphi) d\theta d\varphi}{t_1(5577,\ 0,\ 0)},$$

more simply

$$Go = G' \frac{10^6}{41250} t_1(5577)\Omega, \qquad (2.1)$$

where $t_1(5577)$ represents the sensitivity in the case of the optical axis being directed to an object, that is $t_1(5577, 0, 0)$. If we get Go due to the airglow line observationally, whose intensity G' can be derived by eq.(2.1) in Rayleigh units.

By the method of two-colour photometry, in which the photometer has two changeable filters, the one named the green line filter has peak transmission near 5577Å and the other named the control filter has a peak at, say 5250Å, and both of them have about several ten Å as halfwidths, the green line current Go is obtained by using the following notations:

I_1; the observed current mm. by the green line filter,

I_2; the observed current mm. by the control filter. Both I_1 and I_2 have been corrected for the earth's lower atmospheric extinction.

$t_1(\lambda)$; the overall sensitivity of the photometer with the green line filter represented by mm. per unit photon per cm.^{2} sec. Å deg.^{2},

$t_2(\lambda)$; the overall sensitivity with the control filter in the same sense as $t_1(\lambda)$,

G; the brightness of the sky due to the airglow green line in units of photons per cm.^{2} sec. deg.^{2}, so that G is connected with G', which is the brightness in Rayleigh units, by the equation

$$G = \frac{41250}{10^6} G'$$

$Gc(\lambda)$; the brightness of the sky due to the airglow continuum in photons per cm.^{2} sec. deg.^{2} Å,

$A(\lambda)$; the astronomical content of the night sky brightness which is the sum of the integrated star light $S(\lambda)$ and the zodiacal light $Z(\lambda)$ in units as same as $G_c(\lambda)$.

When the photometer is exposed to the sky by alternating its two filters, the observed photocurrent I_1, I_2 are expressed as

$$I_1 = \int_0^\infty \left\{A(\lambda) + G_c(\lambda)\right\} t_1(\lambda) d\lambda + G t_1(5577), \qquad (2.2)$$

$$I_2=\int_0^\infty\left\{A(\lambda)+G_c(\lambda)\right\}t_2(\lambda)d\lambda+Gt_2(5577), \tag{2.3}$$

where of course $Gt_2(5577)$ is a correction term in the I_2 current through the control filter. Introducing the following symbols to simplify eqs. (2.2), (2.3), that is

$$\int_0^\infty t_1(\lambda)d\lambda/\int_0^\infty t_2(\lambda)d\lambda=t,$$
$$t_1(5577)/t_2(5577)=1/p,$$
$$\int_0^\infty A(\lambda)t_1(\lambda)d\lambda/\int_0^\infty A(\lambda)t_2(\lambda)d\lambda=ta,$$
$$\int_0^\infty G_c(\lambda)t_1(\lambda)d\lambda/\int_0^\infty G_c(\lambda)t_2(\lambda)d\lambda=t_c,$$
$$Gt_1(5577)=G_o,$$
$$\int_0^\infty A(\lambda)t_2(\lambda)d\lambda=A_o,$$
$$\int_0^\infty G_c(\lambda)t_2(\lambda)d\lambda=G_c,$$

thus we get

$$I_1=t(aA_o+cG_c)+G_o, \tag{2.4}$$

$$I_2=A_o+G_c+pG_o. \tag{2.5}$$

Here, if we divide the astronomical light $A(\lambda)$ into two parts of the star light $S(\lambda)$ and the zodiacal light $Z(\lambda)$, eqs. (2.4) and (2.5) may be expressed in the next equations by using same symbols, ts, tz and S_o, Z_o as ta and A_o, respectively,

$$I_1=t(sS_o+zZ_o+cG_c)+G_o, \tag{2.6}$$

$$I_2=S_o+Z_o+G_c+pG_o, \tag{2.7}$$

where pG_o represents the contamination of the green line intensity in I_2.

The instrumental constants, which are sensitivities $t_1(\lambda)$, $t_2(\lambda)$ and sensitivity ratio of two filters t and p appeared in these basic equations, will be measured by the method of §3. Since two filters have maxima near 5577Å and 5250Å in our case, constants a or s, z and c in eqs. (2.4), (2.6) represent flux ratios between 5577Å and 5250Å for the above mentioned four continuous light sources. From §4, it will be discussed how these constants may be determined as possible as empirically. For the airglow continuum G_c, a relation between its intensity and the one of the green line intensity G_o will be found in §5. By doing so, if we observe two photo-currents I_1 and I_2, we can get the content of the green line G_o and the one of the astronomical light A_o or S_o+Z_o from eqs.(2.4), (2.5) or (2.6), (2.7). Here we note that I_1 and I_2 have to been corrected for the atmospheric extinction. For these actual treatments the method of Ashburn's function [4] is used.

§3. Characters of the Optical System

Overall sensitivities $t_{1,2}(\lambda, \theta, \varphi)$ of the whole optical system of the photometer as described in §2, where signs 1, 2 denote sensitivities with the green line filter and the control filter respectively, may be expressed in eq. (3.1) by using two new terms, relative sensitivities, $t'_{1,2}(\lambda, \theta, \varphi)$ and a conversion factor, α, that is

$$t_{1,2}(\lambda, \theta, \varphi)=\alpha t'_{1,2}(\lambda, \theta, \varphi) \tag{3.1}$$

or in the case of $\theta=\varphi=0$ more simply

$$t_{1,2}(\lambda)=\alpha t'_{1,2}(\lambda), \tag{3.2}$$

where α is photocurrent mm. per unit photon per. cm.^{2} sec. Å deg.^{2}, and $t'_{1,2}(\lambda, \theta, \varphi)$ and α can be measured by the following way.

3.1. dependences of relative sensitivities $t'_{1,2}(\lambda\ \theta\ \varphi)$ on θ, φ and the effective field of the photometer.

We point the photometer to a distant small light source and read the photocurrent $i(\lambda, \theta, \varphi)$, leting its image systematically cross the photocathode.

Mapping out these readings, the effective field Ω is determined in deg.^{2} as

$$\Omega=\frac{\iint i(\lambda, \theta, \varphi)d\theta d\varphi}{i(\lambda, o, o)}, \tag{3.3}$$

then from eqs. (3.1), (3.2) and (3.3),

$$\iint t_{1,2}(\lambda, \theta, \varphi)d\theta d\varphi=\alpha t'_{1,2}(\lambda, o, o)\Omega,$$

and more simply

$$=\alpha t'_{1,2}(\lambda)\Omega, \tag{3.4}$$

in our case

$$\Omega=2.92 \text{ deg.}^2. \tag{3.5}$$

3.2. dependences of overall sensitivities $t_{1,2}(\lambda)$ of the optical system on wave-length.

Dependences of the relative overall sensitivities $t'_{1,2}(\lambda)$ of the optical system on wavelength λ is possible to be measured in laboratory under the following cautions.

(a) The colour temperature of an incandescent lamp which is a light source of the monochrometer should be examined elaborately by a standard lamp.

(b) The light beam coming from the monochrometer has to cover fully the objective of the photometer.

(c) The light through the objective has to cover the field stop of the photometer and illuminate the same position and area on the filter and the photocathode as the case of the actual airglow observation. Such a condition may be reached by using a ground glass set in front of the objective.

Thus obtained final curves of the relative overall sensitivities $t'_1(\lambda)$ and $t'_2(\lambda)$ in arbitrary units are illustrated in Fig. 3.1, and some characters of them are given in Table 3. 1.

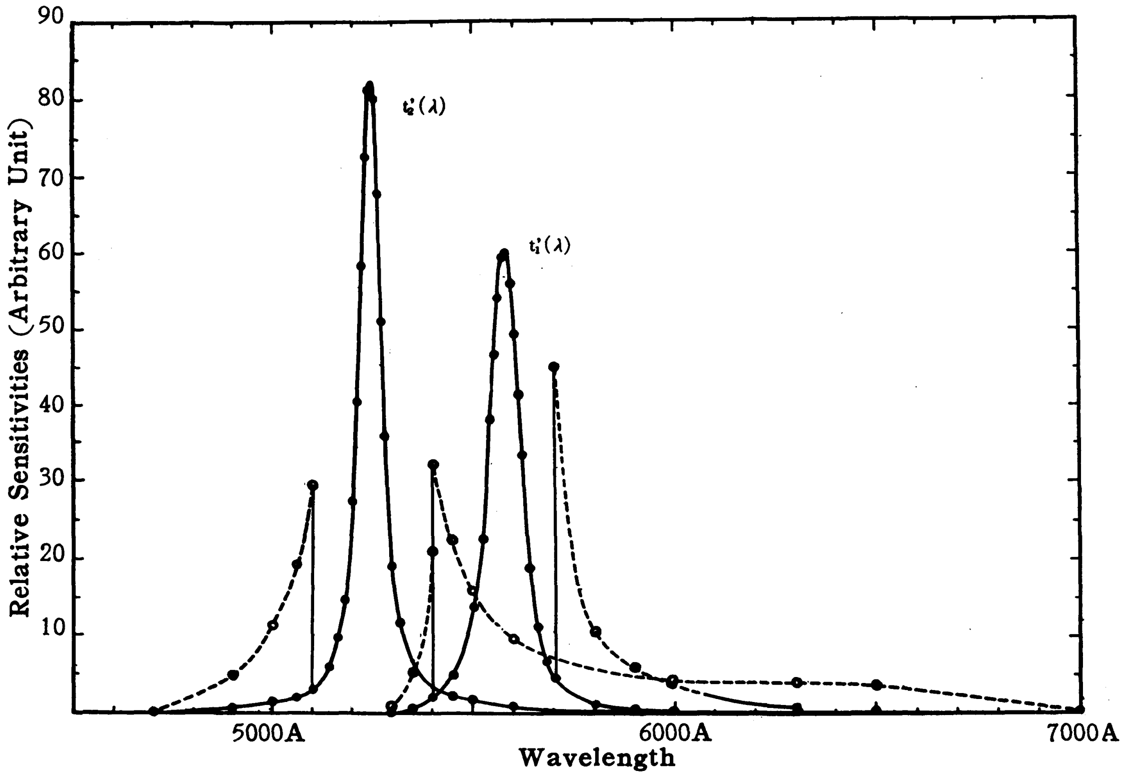

Fig. 3.1 Relative Sensitivities of the Photometer using the GreenLin e or the Control Filter, $t'_1(\lambda)$, $t'_2(\lambda)$ in Arbitrary Unit.

For the small regions of values of $t'_1(\lambda)$ and $t'_2(\lambda)$, the ordinate scale has been used in 10 times.

Table 3.1 Some Characters of the Photometer using the Green Line or the Control Interference Filter

Used Filter	P. Wave.	H. W.	E. W.	$t'_{1,2}(5577)$
Green Line	**5580 Å**	**94 Å**	**119 Å**	**59.7**
Control	**5245 Å**	**66 Å**	**99 Å**	**1.05**

P. Wave. = Peak Wavelength.
H. W. = Half Width.
E. W. = Effective Width.

Effective widths W_1, W_2 are defined as eq. (3.6), where $t'_{1,2}(\lambda)$ are the relative sensitivities in arbitrary units.

In Table 3. 1, the effective widths of the whole optical system, W_1 and W_2, were defined as as

$$\left.\begin{aligned} W_1 &= \frac{\int_0^\infty t'_1(\lambda)d\lambda}{t'_1(5577)} = 119\text{A} \\ W_2 &= \frac{\int_0^\infty t'_2(\lambda)d\lambda}{t'_2(5245)} = 99\text{A}. \end{aligned}\right\} \quad (3.6)$$

From Fig. 3.1, the ratio of two sensitivities is given by

$$t = \int_0^\infty t'_1(\lambda)d\lambda \Big/ \int_0^\infty t'_2(\lambda)d\lambda$$

in our case $\qquad = 0.88. \qquad (3.8)$

In the two-colour photometry, since the value of t is definitely important, it will be tested again by the way of **3.4** of this section.

3.3 the conversion factor, α

In order to get the value of conversion factor α, which is the current per unit photon per cm.^{2} sec. Å deg.^{2} of the incidence to the photometer, we observe some standard stars, whose magnitudes and colour temperatures are known.

If $F(m, \text{T}, \lambda)$ is the flux of any star, photons per cm.^{2} sec. Å, having vis. mag. m and col. temp. T, the current through the green line filter due to the star being $m=1$ and $\text{T}=\text{T}_0=6400°\text{K}$(G type) after the correction for the extinction, j_o, is

$$j_o = \int_0^\infty F(1, \text{T}_0, \lambda) t_1(\lambda) d\lambda,$$

where $t_1(\lambda)$ is the sensitivity in this case.

Therefore by eqs. (3.2) and (3.6)

$$\begin{aligned} j_o &= \int_0^\infty F(1, \text{T}_0, \lambda)\alpha t'_1(\lambda)d\lambda \\ &= \alpha F(1, T_o, 5577) t'_1(5577)\text{W}_1. \end{aligned} \qquad (3.8)$$

In this equation, since $F(1, \text{T}_0, 5577)$ is known and $t'_1(5577)$ and W_1 may be measured by the way of **3.2** of this section, then if we can get j_o observationally, the value of conversion factor α will be given by eq. (3.8), that is

$$\alpha = \frac{j_o}{F(1, \text{T}_0, 5577) t'_1(5577)\text{W}_1}$$

Thus from eqs. (3.2) and (3.8),

$$t_1(5577) = \frac{j_o}{F(1, \text{T}_0, 5577)\text{W}_1}, \qquad (3.9)$$

and the brightness of the green line in Rayleigh units, G' is from eq. (2.1) as a result,

$$G' = G_o \frac{41250}{10^6} \frac{\text{W}_1}{\Omega} \frac{F(1, \text{T}_0, 5577)}{j_o}. \qquad (3.10)$$

Now j_o in eq. (3.10) will be derived from i_o, which is the same quantity as j_o but through the *control* filter, that is

$$i_o=\int_0^\infty F(1,\ T_0,\ \lambda)t_2(\lambda)d\lambda,$$

if we correct for the magnitude, colour temp., the photometer sensitivity and the extinction. The reason for such the employing the *control* filter is that the subtraction of the background of the fixed star is more easy in this case. For these purposes some standard stars to be observed have been selected as summarized in Table 3.2. In this table the last column r represents the adjusting coefficient to

Table 3.2 The Standard Stars Selected for the Calibration of the Photometer and their Adjusting Coefficients

Star	Sp.	m	C	T°K	r
ηUMa	B3(V)	1.83	−0.27	20500	1.99
αAnd	B8p(III)	2.12	−0.21	17000	2.61
βOri	B8(Ib)	0.14	−0.17	15400	0.422
αLyr	A0(V)	0.05	−0.13	13600	0.390
αCMa	A1(V)	−1.43	−0.15	14500	0.100
αPsA	A3(V)	1.13	−0.06	11900	1.12
αOph	A5(III)	2.09	+0.03	10300	2.60
αCMi	F5(IV)	0.35	+0.31	7400	0.540
αUMi	F8(Ib)	2.1	+0.43	6700	2.72
αAur	G1(III)	0.13	+0.74	5400	0.458
βCet	G8(III)	2.10	+0.89	5000	2.85
αUMa	G7(III)	1.84	+1.0	4700	2.33
αBoo	K0(III)	0.03	+1.21	4200	0.457

Sp. = Spectral Type,
m = Visual Magnitude,
C = Colour Index,
T = Colour Temperature, all the above values are taken from "Astrophysical Quantities" by Allen, C. W., The Athlone Press, Univ. London (1955).
r = Adjusting Coefficient to i_0 of the star (m=1.0, T=T_0=6400°K), i_0 is discussed in 3.3.

the photocurrent due to the star being $m=1$ and $T=T_0$ from the one being any m and T.

Then

$$j_o=i_o\frac{\int_0^\infty F(1,\ T_0,\ \lambda)t'_1(\lambda)d\lambda}{\int_0^\infty F(1,\ T_0,\ \lambda)t'_2(\lambda)d\lambda}$$

or

$$=i_0\frac{F(1,\ T_0,\ 5577)}{F(1,\ T_0,\ 5250)}t \qquad (3.11)$$

An example to get such i_o observationally is illustrated in Table 3.3 and Fig. 3.2, in which $i(Z)$ is the photocurrent of a star through the control filter at zenith distance Z and log $ri(Z)$ are plotted against their air masses belonging to Z.

Table 3.3 An Example of Star Observations Prepared for Fig. 3.2.

Aug. 1–2, 1957

Observed Star	J. S. T.	$i(Z)$	Z	a. m.	r	log $ri(Z)$
αLyr	01 : 16	101.5	40.0	1.21	0.390	1.600
	02 : 50	89.0	58.9	1.80	〃	1.540
αAur	01 : 15	56.5	73.0	3.15	0.458	1.413
	02 : 42	76.0	60.0	1.85	〃	1.540
αPsA	01 : 10	27.0	68.4	2.51	1.12	1.481
	02 : 47	26.5	68.1	2.48	〃	1.473
αAnd	01 : 19	17.0	24.0	1.02	2.56	1.638

Aug. 2–3, 1957

Observed Star	J. S. T.	$i(Z)$	Z	a. m.	r	log $ri(Z)$
αLyr	23 : 52	99.3	27.0	1.04	0.390	1.588
	01 : 49	90.6	43.9	1.29	〃	1.549
	02 : 56	78.7	60.8	1.90	〃	1.487
αAur	01 : 53	66.5	66.9	2.36	0.458	1.483
	02 : 54	71.0	57.9	1.74	〃	1.512
αAnd	23 : 14	13.7	49.0	1.41	2.56	1.545
	23 : 56	15.0	42.0	1.25	〃	1.584
	01 : 58	15.8	17.0	0.97	〃	1.606
αPsA	23 : 58	18.4	73.0	3.15	1.12	1.314
	01 : 56	25.6	67.5	2.42	〃	1.458
αUMa	23 : 47	11.5	71.5	2.91	1.98	1.358

$i(Z)$ = Observed photocurrent mm. through the control filter at zenith distance Z in deg.,
a. m. = Air mass for Z.

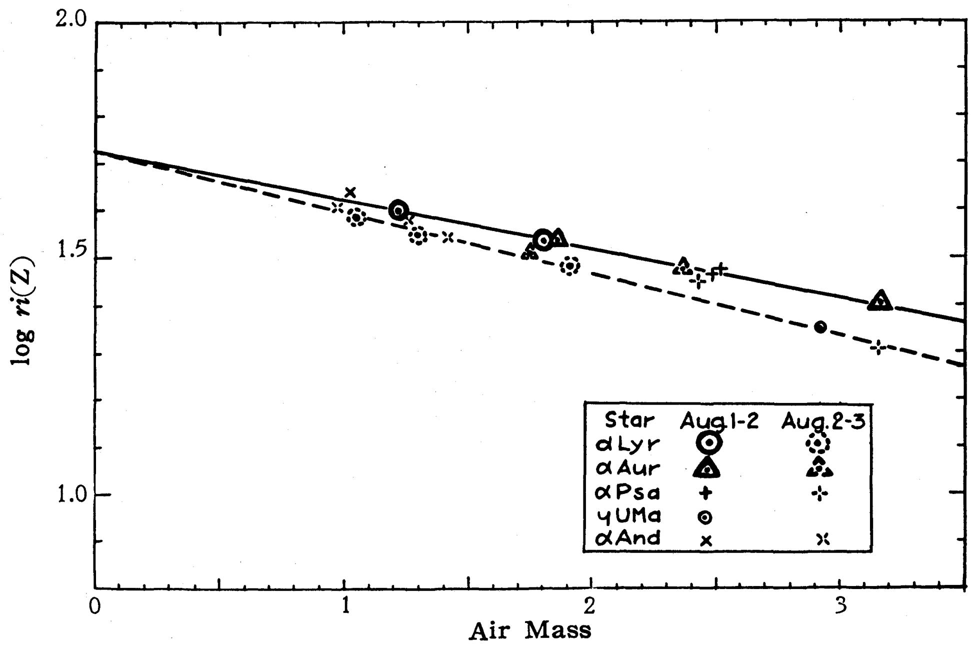

Fig. 3.2 An Example of Star Observations.

From this figure, we take

$$\log i_0 = 1.728$$

by the mean straight line of log $ri(Z)$ and so that

$$i_o = 53.5 \text{ mm.} \tag{3.12}$$

from eq. (3.11) $\therefore\ j_o = 53.5 \times 0.954 \times 0.90$

$$= 46.0 \text{ mm.}, \tag{3.13}$$

where we take a value of 0.90 for the sensitivity ratio t, in stead of 0.88 of eq. (3.7) because of being described in 3.4.

3.4 a method of crossing stars having known colour temperatures to determine the value of sensitivity ratio, t.

If we observe the star having known col. temp. by exchanging two filters and correct for the atmospheric extinction, the relative sensitivity as defined by eq. (3.7), t, can be directly obtained. Our results are summasized in Table 3.4, in which Jupiter, α Aur and α Boo are selected as the star having known col. temp.. For the difference of the atmospheric extinctions at two wavelengths 5250Å and 5577Å, we utilize an empirical relation being measured beforehand by us, which will be presented in our next paper.

Table 3.4 Results of the Sensitivity Ratio t obtained by the Various Observations

Observed Star	Data	$i(5577)/i(5250)$	Z	k^*	t
Jupiter	Mar. 21–22	0.965	51.7	1.28	0.939
〃	Mar. 23–24	0.956	54.6	0.40	0.940
〃	〃	0.954	55.0	0.40	0.937
〃	〃	0.956	55.4	0.40	0.939
〃	Mar. 24–25	0.935	57.4	0.95	0.899
〃	〃	0.927	57.1	0.95	0.893
〃	Apr. 16–17	0.925	49.0	0.33	0.921
〃	Apr. 19–20	0.914	45 4	0.20	0.929
〃	〃	0 907	45.4	0.20	0.921
αAur	Mar. 20–21	0.942	34.0	0.31	0.899
〃	〃	0.997	55.5	0.41	0.927
〃	Mar. 21–22	1.003	40.5	1.28	0.937
〃	Mar. 24–25	0.920	47.0	0.44	0.865
〃	〃	0.970	57.2	0.57	0.893
〃	Apr. 15–16	0.915	54.0	0.19	0.878
〃	Apr. 16–17	0.950	71.0	0.33	0.855
αBoo	Mar. 20–21	1.010	50.3	0.34	0.886
〃	Mar. 24–25	1.010	43.0	0.44	0.885
〃	〃	1.090	18.0	0.44	0.968
〃	Apr. 15–16	1.020	52.3	0.19	0.910
〃	〃	1.006	18.0	0.23	0.906
〃	〃	1.030	33.3	0.98	0.901
Laboratory meas. 3.2 in § 3					0.88
Adopted Mean Value					0.90

$i(5577)/i(5250)$ = the ratio between the observed photocurrent of the green line filter $i(5577)$ and that of the control $i(5250)$ at zenith distance Z.
t = the sensitivity ratio obtained after the correction for the lower atomspheric extinction and the colour of star.
Z = zenith distance in deg.
k^* = observed extinction coefficient for 5250Å.

3.5. summary

As a result, if we make use of above obtained some constants being needed for the green line brightness G' in Rayleigh as eq. (2.1) or (3.10),

$$G'=G_0\frac{41250}{10^6}\frac{W_1}{\Omega}\frac{F(1,\ T_0,\ 5577)}{j_0}$$
$$=G_0\frac{41250}{10^6}\frac{119}{2.92}\frac{472}{46.0}$$
$$=G_0\times 17.4 \text{ Rayleigh,} \qquad (3.14)$$

where a value of 472 is taken from Roach [5] as $F(1,\ T_0,\ 5577)$ photons per cm.^{2} sec. Å.

The photocurrent due to the green line only, G_0, may be given by basic eqs. (2.4) and (2.5) from data of I_1 and I_2 by exchanging two filters as described in §2.

§4. Mean Colour of the Integrated Star Light

A value of s defined as

$$s=\frac{\int_0^\infty S(\lambda)t_1(\lambda)\,d\lambda}{\int_0^\infty S(\lambda)t_2(\lambda)\,d\lambda}\ \frac{\int_0^\infty t_2(\lambda)d\lambda}{\int_0^\infty t_1(\lambda)d\lambda}$$

represents a colour index of the integrated star light in a sense since it is the flux ratio between two maximum sensitive wavelengths of filters, for example 5577Å and 5250Å in our case. Such a value of s can be obtained purely empirically by the following way.

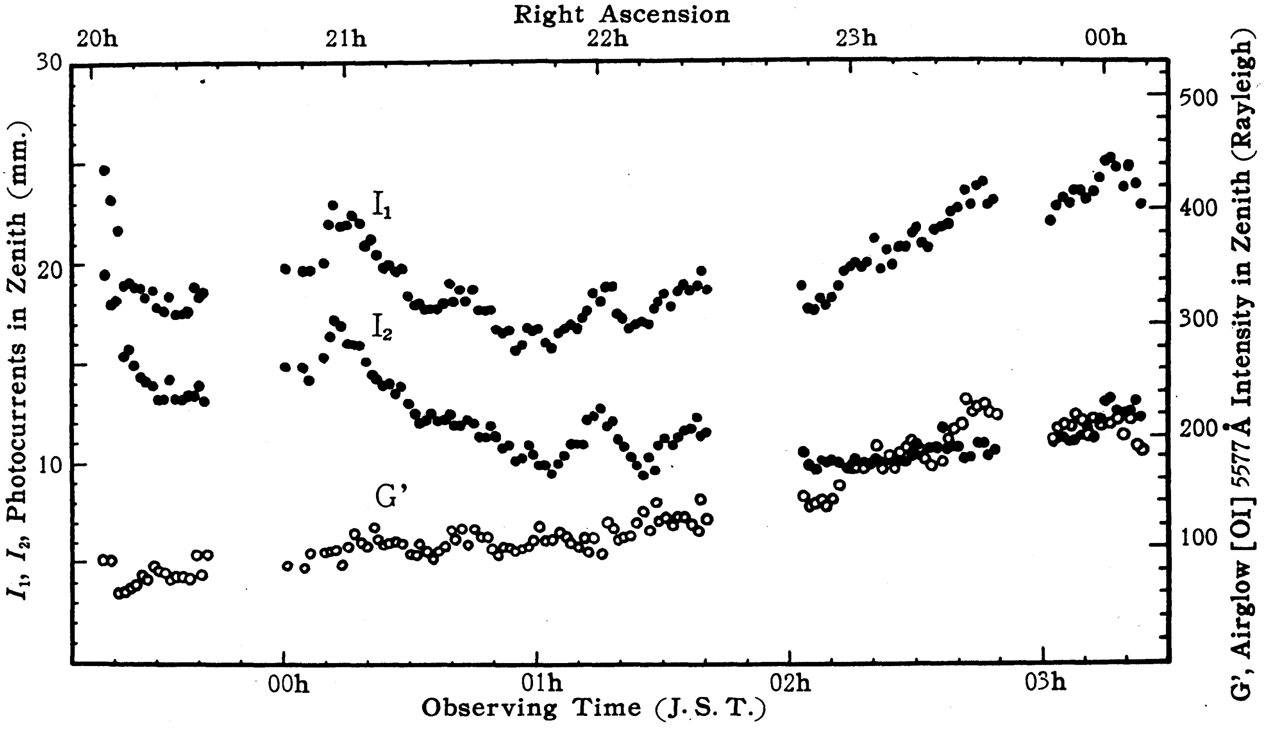

Fig. 4.1 An Example of Zenith Photocurrents I_1 and I_2 when the Milky Way is near the Zenith, Aug. 2–3, 1957.

Above I_1 and I_2 are corrected for the atmospheric extinction and the G' is the green line intensity obtained by the equation (8.3) in Rayleigh units.

Fig. 4.1 shows an example Aug. 2-3, 1957 of the simultaneously observed I_1 and I_2 when the integrated star light, S_0, is the major part, that is

(a) the airglow intensity G_0 is seasonally as possible as small,

(b) the zodiacal intensity is almost constant, in our case all the data of I_1, I_2 have been taken from those zenith at middle night,

(c) the Milky Way is in zenith.

Thus I_1 and I_2 are almost subjected to S_0, therefore the gradient $\triangle I_1/\triangle I_2$ represents ts directly.

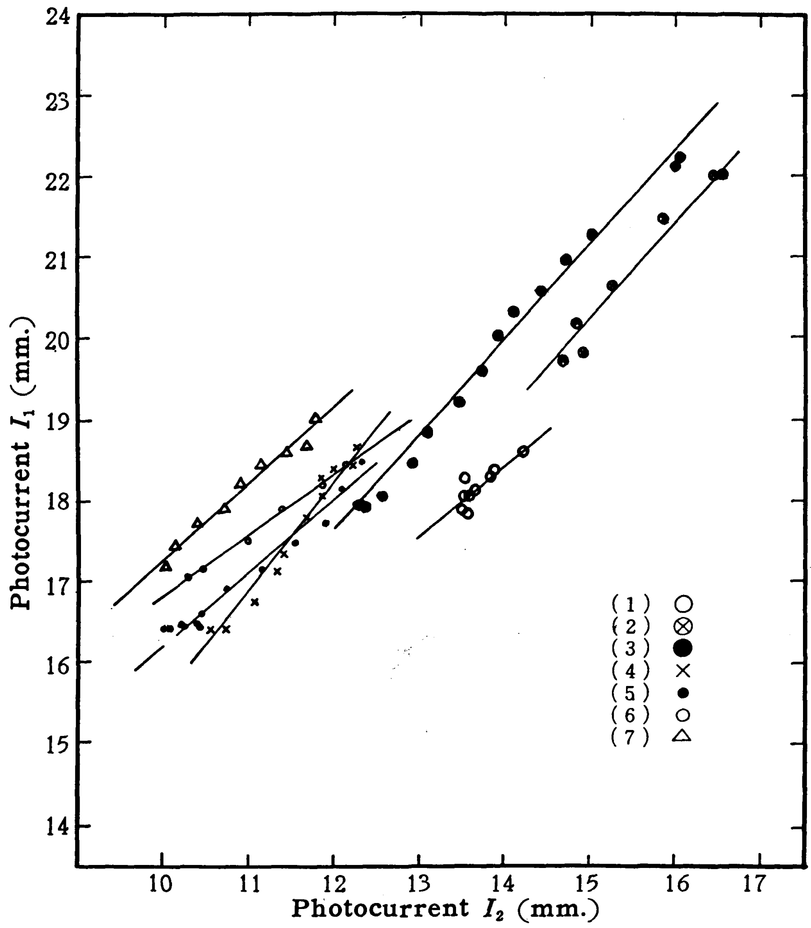

Fig. 4.2 I_1 against I_2 near the Milky Way of Aug. 2-3 from Fig. 4.1. Numbers (1), (2), (3), (4), (5), (6), (7) are shown in Table 4.1.

Fig. 4.2 shows an example of I_1 against I_2 of Aug. 2-3, 1957. The splitting to some parallel lines as appeared in Fig. 4.2 is clearly due to the variation of the airglow G_0, and the gradients themselves can not probably free from this effect, although these data are limited to those of very small G_0. But in principle we can employ such a method in order to determine experimentally the mean colour index, say s. Some diagrams for Aug. 1-2 and Aug. 21-22, 1957, as Fig. 4.2, have been drawn and these results are summarized in Table 4.1.

Table 4.1 Ratio $\triangle I_1/\triangle I_2=ts$ near the Milky Way.

Date	J. S. T.	R. A.	*ts*
Aug. 2–3 (1)	23:28 – 23:40	20:13 – 20:25	0.82
〃 (2)	00:01 – 00:19	20:46 – 21:04	1.15
〃 (3)	00:20 – 00:36	21:05 – 21:21	1.16
〃 (4)	00:40 – 00:57	21:25 – 21:42	1.20
〃 (5)	00:58 – 01:16	21:44 – 22:00	0.89
〃 (6)	01:17 – 01:24	22:02 – 22:09	0.75
〃 (7)	01:25 – 01:37	22:10 – 22:22	0.93
Aug. 1–2 (1)	22:13 – 23:05	18:54 – 19:46	0.91
〃 (2)	23:06 – 23:35	19:47 – 20:16	1.00
〃 (3)	00:01 – 00:40	20:42 – 21:21	0.92
〃 (4)	00:41 – 00:57	21:22 – 21:38	1.00
Aug. 21–22 (1)	20:50 – 21:14	18:50 – 19:14	0.70
〃 (2)	21:25 – 22:19	19:25 – 20:19	1.04

R. A. = Right Ascension.
From this table, we get Mean $ts = 0.95$

We get as the mean value of s in this table

$$ts=0.95$$

$$\therefore\ s=1.06 \qquad (4.1)$$

and the colour corresponding to this value of is s is G type just as we expected.

§5. Airglow Continuum

In Fig. 5.1 we plot I_2, the observed currents through the control filter, against I_1, those through the green line filter, when the same celestial point (e.g. 00:50 Right Ascension, 37°42′ Declination) comes to the zenith. As the contribution to

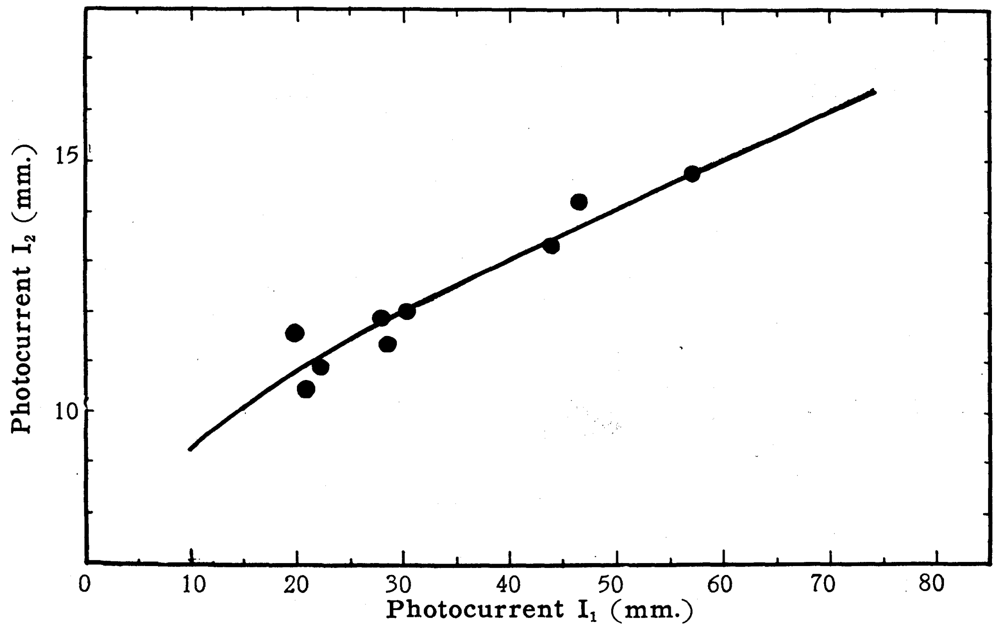

Fig. 5.1 I_2 against I_1, which are observed in zenith when the same celestial point (R. A. = 00:50, Dec. = 37°42′) comes there.

I_1 and I_2 from the stars is constant in this case and the one of the zodiacal light is also nearly so, as we have selected the celestial points sufficiently far from the sun, the variation of the green line current I_1 must solely due to the one of the green line G_o plus the continuum tcG_c, and the variation of the control current I_2 predominantly to G_c plus pG_o. From Fig. 5.1, then, a relation between the continuum G_c and the green line G_o may be suggested as follows,

$$G_c = KG_o^n \quad (5.1)$$

where K and n are constants.

These constarts K and n may be determined by the method of least squares, by plotting as possible as many such curves as shown in Fig. 5.1, e.g., twenty-two, which have been obtained from the same numbers of groups at the same definite celestial points (shown in Table 6.1 of §6). Our results are $K=0.27$ and $n=0.78$, after correcting the green line contamination pG_o in the control photocurrent I_2. Therefore eq. (5.1) is, both G_c and G_o in mm.,

$$G_c = 0.27G_o^{0.78}, \quad (5.3)$$

or expressing G_c in Rayleigh per Å and G_o in Rayleigh,

$$G_c = 0.0046G_o^{0.78}, \quad (5.4)$$

and approximately at the usual green line intensity (5.3) and (5.4) become

$$G_c = 0.140G_o \text{ in mm. units,}$$

or

$$G_c = 0.00128G_o \text{ in Rayleigh units,} \quad (5.5)$$

and in these formulations the flux ratio c of the airglow continuum between 5577Å and 5250Å has been assumed to be 1.

Now, by determniing K and n, that is, G_c being expressed by G_o, the astronomical ligh, A_o and taA_o, belonging to the above twenty-two celestial points may be obtained by the method of least squares using more than two groups of I_1 and I_2, see eqs. (2.4) and (2.5).

In Table 6.1 of §6 we summarize such estimated A_o, the astronomical light contained in the current I_2 and taA_o, the one in the current I_1, where A_o are observationally more precise than taA_o.

In Fig. 5.2, we plott $I_2 - A_o$ against $I_1 - taA_o$, where a curve shows a relation between the continuum G_c and the green line G_o using eq. (5.3) without a correction for pG_o in I_2 for a comparision.

Although the relation, $G_c \propto G_o^{0.78}$, differs apparently from the one of Barbier [6], in which a perfectly linear relation between G_c and G_o has been given, this discrepancy is not serious within not strong green line intensity. According to our

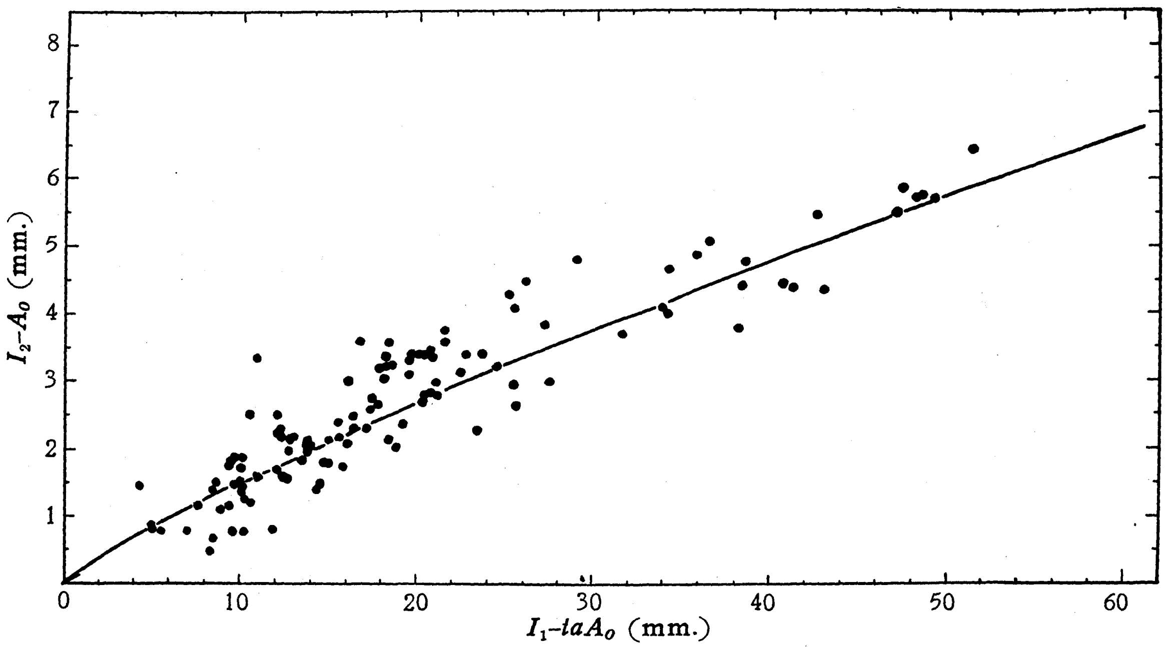

Fig. 5.2 Relation between the Airglow Continuum in 5250Å and Green Line.
The experimental formula of the mean curve is the equation (5.3) without a correction for pG_O in $I-A_O$, for a comparison.

result, however, as the origion of the airglow continuum a possibility of the two-body collision of [OI] atoms may be suggested, because if G_c is owing to a perfect two-body collision, such a relation is to be

$$G_c \propto G_O^{\frac{2}{3}}$$

as the green line intensity G_o is considered that originated from the three-body process of [OI] atoms.

§6. Astronomical Light, its Intensity and Colour

All taA_o and A_o, which are the sum of the star light and the zodiacal light, obtained in the former section of the twenty-two celestial points in the constant declination 37°42′ are summarized in Table 6.1.

In 6th column the stellar unit with the symbol S^{10}/deg.^{2} are used for convenience which is defined as the number of 10th vis. mag. G_2 stars per deg.^{2}, and S_o of 7th column in the same unit are taken from Roach's diagram [7]. Such twenty-two A_o are illustrated against the Right Ascension in Fig. 6.1 and against the galactic latitude in Fig. 6.2, wherein all the points are classified into three groups for the

Table 6.1 Astronomical Light of the Twenty-Two Points at the Constant Declination 37°42′

No.	R. A.	taA_o	A_o	ta	$[A_o]$	S_o	$[A_o]$-S_o	G. L.	E. L.
1	00:55	10.0	9.2	1.09	232	86	146	−24.0	29.0
2	01:50	12.0	9.9	1.21	249	79	170	−22.0	24.5
3	02:20	13.5	10.5	1.29	265	77	188	−19.5	22.5
4	03:05	11.5	10.5	1.10	265	98	167	−16.0	19.5
5	04:25	11.5	10.9	1.06	274	145	129	− 6.0	15.8
6	05:20	14.0	12.6	1.11	318	170	148	3.0	14.5
7	06:15	11.0	10.9	1.01	274	95	179	12.0	14.3
8	07:10	10.0	9.9	1.01	249	70	179	22.0	15.0
9	08:50	9.5	9.5	1.00	240	37	203	42.0	19.3
10	09:30	9.0	8.8	1.02	222	35	187	49.5	21.5
11	10:35	7.5	7.9	0.95	200	34	166	61.5	26.5
12	11:25	8.0	7.5	1.07	189	33	156	70.5	31.0
13	12:55	7.5	7.4	1.01	187	35	152	80.0	39.5
14	13:55	7.0	6.7	1.04	169	38	131	71.0	45.5
15	14:35	7.0	7.1	0.99	180	39	141	64.0	49.5
16	15:35	7.0	7.4	0.95	187	52	135	52.0	54.5
17	16:45	7.0	7.9	0.89	200	74	126	39.0	59.1
18	17:20	8.0	8.0	1.00	202	92	110	32.0	60.5
19	20:18	13.0	12.8	1.01	324	230	94	0.0	54.8
20	21:45	10.0	10.1	0.99	255	200	55	−12.5	47.4
21	22:48	10.8	9.3	1.16	234	125	109	−19.0	41.0
22	23:50	9.5	9.1	1.04	229	95	134	−23.0	35.4

R. A. = Right Ascension.
taA_o = Photocurrent for the astronomical light of 5577 Å in mm.
A_o = Photocurrent for the Astronomical light of 5250 Å in mm.
$[A_o]$ = The astronomical light of 5250A in $S^{10}/deg.^2$
So = The star light given by Roach [9] in $S^{10}/deg.^2$
G. L. = Galactic Latitude in deg..
E. L. = Ecliptic Latitude in deg..

From this table, we get mean ta = 1.04.

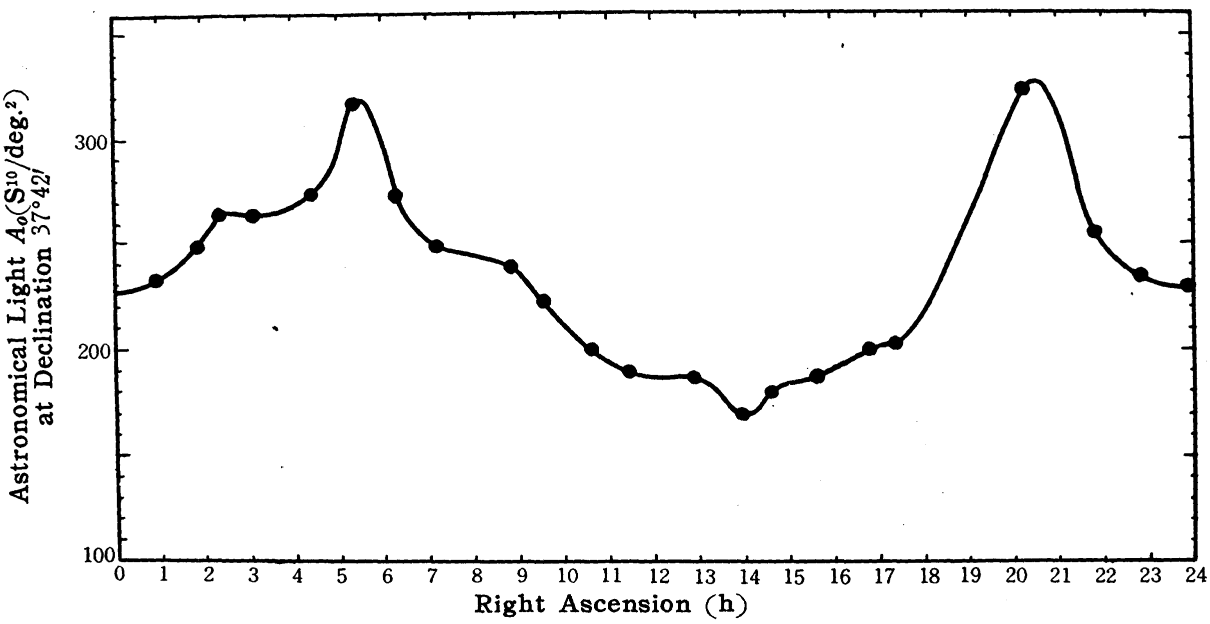

Fig. 6.1 Mean Astronomical Light in 5250 Å against Right Ascension at the Constant Declination 37°42′.

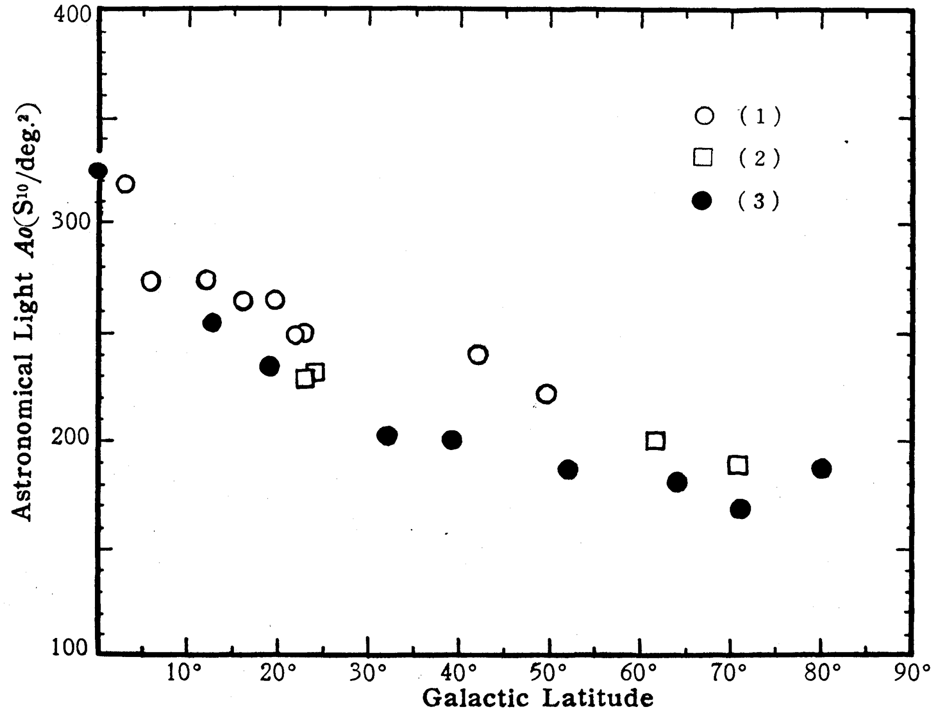

Fig. 6.2 Astronomical Light A_0 against Galactic Latitude.

All the twenty-two points are classified into three groups for ecliptic latitude as follows, (1)=14.3°~25.0°, (2)=25.1°~35.0°, and (3)=35.1°~61.5°.

ecliptic latitude: (1) 14°.3~25°.0, (2) 25°.1~35°.0, (3) 35°.1~61°.1.

The mean astronomical light in zenith at any night, which is actually averaged during two hours after sunset and two hours before sunrise, can be calulated from

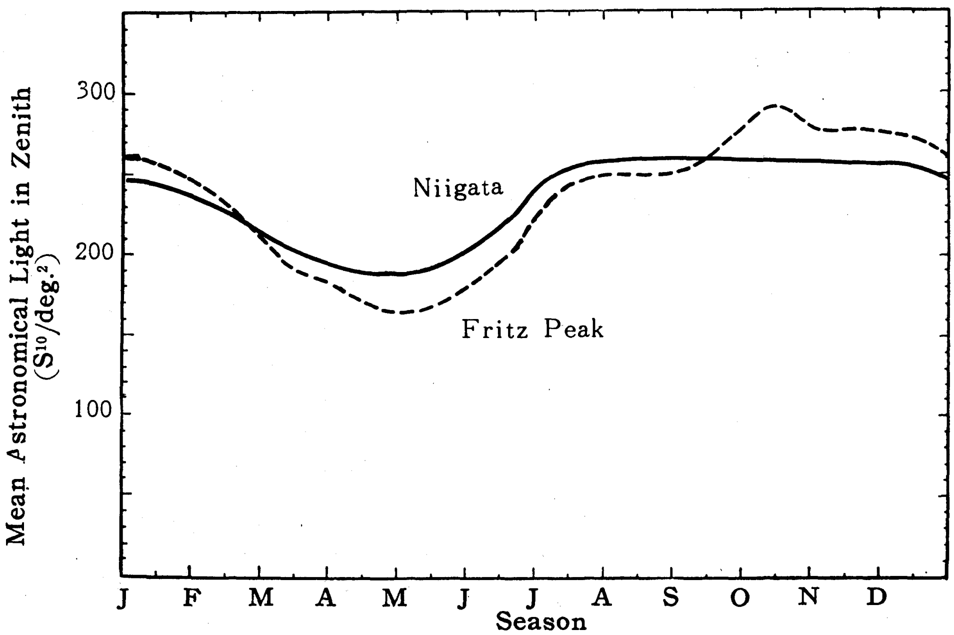

Fig. 6.3 Mean Astronomical Light in Zenith, at Niigata and Fritz Peak.

Fig. 6.1, and is illustrated in Fig. 6.3 seasonally.

This result is to be compared to Roach's data [8], which gives the mean star light plus zodiacal light in zenith at Fritz Peak (39° 54′ N, 105° 20′ W) averaged from end of evening twilight to beginning of morning twilight. These two results are well fitted to each other.

The mean value of a is obtained by Table 6.1 since $t=0.90$ in our case,

$$\therefore\ a=1.1, \qquad (6.1)$$

and this result suggests a fact that the astronomical light, which is star light plus zodiacal light, has the colour of nearly K type star in its mean. Of course this value of a has been derived from data of very small wavelength separation and by filters with considerably narrow band widths too, and still more might be affected by the scattering of the earth's atmosphere. Just a value of a which obtained by the above method, however, may be used in the two-colour photometry.

Next, a value of 1.1 is seemed to be closed to a result of Roach and Meinel's report [9], where the mean astronomical light is 275 $S^{10}/\text{deg.}^2$ for 5300Å and 304 $S^{10}/\text{deg.}^2$ for 5577Å, although their data are limited to three nights, so that the ratio between them become to 1.1.

§7. Zodiacal Light

Fig. 7.1 shows the zodiacal lights Z_o, which are A_o-S_o in Table 6.1, plotted against the ecliptic latitude. Here it

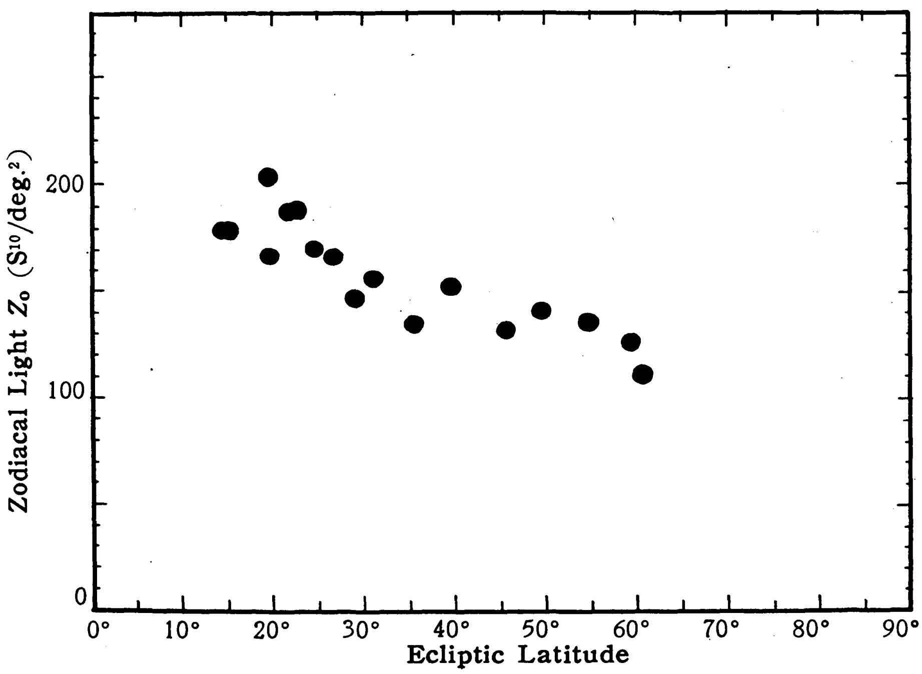

Fig. 7.1 Zodiacal Light, averaged in 120°~180° of elongation, against the ecliptic latitude.

should be noticed that original data used to illustrate such the diagram have been taken from those in the zenith sky at midnight, that is, in 120°~180° of elongations, therefore every point in Fig 7.1 is such as the mean value in 120°~180° of the elongation.

Next, if we use values of a and s and assume mean intensities of the star light and the zodiacal light, we can find the mean of z from Table 6.1, which is defined as the flux ratio between 5577Å and 5250Å of the zodiacal light, that is $z=1.2$, for the instrumental constant $t=0.90$ in our case. Although this value of z is not so precise, this result may show that the zodiacal light extending to higher ecliptic latitude has a colour of the K type star.

§8. Summary-Absolute Brightness of the Airglow Emission Line and the Astronomical Light

This paper is especially devoted to the study of the background of the airglow green line, which is the continuous spectrum composed of the integrated star light, the zodiacal light and the airglow continuum.

Its total intensity is considerably weak and has the order of 1 Rayleigh per Å at 5250Å, whereas the green line has the mean intensity of two, three or occasionally several hundreds of Rayleigh, but if we use such as the interference filter having a transmission bandwidth of about 100Å or so, the influnce from backgrounds is very serious.

Two-colour photometry, which is an effective method of the subtraction of backgrounds, becomes to more complete one if we know precisely colours of these continous light sources. In this paper we wanted to establish more explicitly basic equations of the two-colour photometry and estimate colours of the integrated star light and the zodiacal light or the astronomical light, which are expressed in symbols s, z or a. Furthermore we found a relation between the airglow continuum and the green line intensity. An information of the spatial distribution of the zodiacal light extending to higher ecliptic latitude was given.

The method, originally presented by Hikosaka and us, of getting Rayleigh values from the mm.-redings of the photometer, was given specially in connection with the two-colour photometry.

For the absolute brightness of the airglow green line and the astronomical light, we can get G_0 and A_0 from eqs. (2.4), (2.5) and (5.3) as follows

$$G_0=\frac{I_1-taI_2-0.27t(c-a)G_0^{0.78}}{1-p}. \qquad (8.1)$$

In this equation a term of $0.27t(c-a)\ G_0^{0.78}$ may be neglected in the case of usual green line intensity and p is also small in our case, therefore eq. (8.1) becomes

$$G_o = I_1 - taI_2 \text{ in mm.,} \qquad (8.2)$$

and the absolute brightness of the green line G' is from eqs. (3.14) and (8.2)

$$G' = 17.4\ (I_1 - taI_2) \qquad (8.3)$$
$$= 17.4(I_1 - I_2) \text{ in Rayleigh,}$$

for $a=1.1$ from eq. (6.1) and $t=0.90$ in our case.
Thus obtained G' in the case of Aug. 2-3, 1957, have been illustrated together in Fig. 4.1.

The astronomical light A_o can also be obtained from eqs. (2.4) and (2.5). From eq. (5.5)

$$G_c = 0.140G_o,$$

therefore

$$A_o = \frac{(0.14ct+1)I_2 - 0.14I_1}{(0.14ct+1) - 0.14ta}, \qquad (8.5)$$

or putting $a=1.1$, $c=1.0$, $t=0.90$,

$$A_o = \frac{8.0I_2 - I_1}{7.0} \text{ in mm.,} \qquad (8.5)$$

so that

$$A_o = 3.61(8.0I_2 - I_1) \text{ in } S^{10}/\text{deg.}^2. \qquad (8.6)$$

The author wishes to express his sincere thanks to Prof. T. Hikosaka of Niigata Univ. for his full directions in this study, and to Mr. K. Yano for his collaboration in observations and for many valuable discussions.

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