A Method of Measuring of the Atmospheric UV Extinction Change Using the Stellar Photometry

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Abstract

A method is proposed for measuring the solar ultraviolet flux increase due to the formation of ozone hole. The concept of the new method is based on that of the stellar UBV photometry which is most fundamental in the modern astronomical observations.

1. Introduction

One of the most serious problem of environmental pollution is the decay of ozone layer and the appearance of the ozone hole because of the recent enormous production of Chloro-fluoro-carbons. As a result, the solar ultraviolet flux increases and is thought to be very dangerous for almost all the species of the creature on the earth. It is reported that in the southern hemisphere, the increase of the UV flux have hurt the animals. Here in the northern hemisphere, the increase of the UV is also possible. From the medical point of view, it is quite important to detect the temporal change of the atmospheric extinction of UV flux. To calculate the value of the atmospheric extinction of the electromagnetic wave from the celestial objects is an important part of the astronomical photometry because even the visible light from the stars is affected by the atmosphere of the earth. In order to obtain the true brightness (magnitude) of the stars, modern astronomy had established the instruments, methods and the photometric systems. One of the most convenient system is so-called Johnson's UBV system invented by Johnson and Morgan (1951, 1953). This photometric system uses three different type of wide band filters named U (ultraviolet), B (blue) and V (visual or yellow). Fortunately, the U filter covers the range of the wavelength concerned with the extinction by the ozone layer. On the other hand, in the field of the astronomical photometry, we use different types of detectors. Historically, apart from the visual observation, the oldest detector has been a photograph. But the photographic photometry is not so precise as the photoelectric photometry, which was invented and developed mainly Stebbins (1910). Moreover the photomultiplier tube is sensitive at the ultraviolet region of the wavelength. On the contrary, the charge coupled device (CCD), which is widely used today because of its dual characteristics of photograph and photomultiplier, is quite insensitive at UV region. The purpose of this paper is to show that the photoelectric photometry by making use of the combination of the Johnson's UBV system and photomultiplier tube is effective for detecting the increasement of solar UV flux. In section 2, we give a summary of the stellar photometry, according to the standard text book by Henden and Kaichuck (1989). In section 3, the above mentioned UBV system and related concepts of this system are introduced that are necessary for our method of UV extinction detection. In section 4, our method of measurement of an atmospheric ultraviolet extinction is shown. In the final section, several problems including different methods are discussed.

2. Outline of the Stellar Photometry

For the purpose of measuring the change of UV flux, the best way is to use the photoelectric photometry with photomultiplier. In practice, a star is not measured in flux units. Because the detector of photometry produces an electrical output, we can get a measurement as current or counts per second. In the astronomical photometry, an electrical output is directly proportional to the stellar flux. Symbolically,

$$F_\lambda = kd_\lambda \tag{1}$$

where d_λ is the practical measurement, subscript λ denotes the observed wavelength, and k is the constant of proportionality. While, in general,

$$m_1 - m_2 = -2.5 \log \frac{F_1}{F_2} \tag{2}$$

where, F_1, F_2 and m_1, m_2 refer to the fluxes and magnitudes of two stars respectively. This relationship is often referred to as a *Pogson scale*, which is one of the most basic relationship of astronomy. By equation (1), equation (2) can be rewritten as following equation, provided that star 2 is a reference star of magnitude zero and star 1 is the unknown.

$$m_\lambda = q_\lambda - 2.5 \log d_\lambda \tag{3}$$

This relates the actual measurement, d_λ, to the instrumental zero point constant q_λ, and to the instrumental magnitude, m_λ.

The *color index* of a star is defined as the magnitude difference between two different spectral region. A color index c_λ is defined as

$$c_\lambda = m_{\lambda 1} - m_{\lambda 2} = q_{\lambda 12} - 2.5 \log \frac{d_{\lambda 2}}{d_{\lambda 1}} \tag{4}$$

where, the subscripts 1 and 2 express those two region, and zero point constants have been collected into a single term.

The earth's atmosphere has some complex behavior. The most important behavior is that the amount of light loss depends on the height of the star above the horizon. Because of this effect, we need the atmonpheric extinction correction. That is, the measured magnitudes and color indices are corrected to a location above the earth's atmosphere. A measured magnitude, m_λ is corrected to the magnitude that would be measured above the earth's atmospher, $m_{\lambda 0}$, by the following equation.

$$m_{\lambda 0} = m_{\lambda} - (k'_{\lambda} + k''_{\lambda} c)X \tag{5}$$

Where, k'_{λ} is called the *principal extinction coefficient* and k''_{λ} is the *second-order extinction coefficient*. Still more, c is the observed color index. X is referred to the *air mass*, and express the path length of the light. When the zenith distance, z, is less than 60°, X is defined by the following equation approximately.

$$X = \sec z$$

A measured color index, c is corrected to a color index as seen from above the earth's atmosphere, c_0 by the following equation.

$$c_0 = c - k'_c X - k''_c X c \tag{6}$$

Where, the subscript c is a reminder that the value of the coefficient depends on the two wavelength region measured. The extinction coefficient k'_{λ}, k''_{λ}, k'_c and k''_c are determined observationally.

As a last step, we need the transforming to a standard system. In order for observers at different observatories to be able to compare observational data with others, it must be transformed from the instrumental system to a standerd system. Here, only the results are stated. $m_{\lambda 0}$ which is defined on the equation (5) can be transformed to a standardized magnitude M_{λ} by

$$M_{\lambda} = m_{\lambda 0} + \beta_{\lambda} C + \gamma_{\lambda} \tag{7}$$

where, C is the standard color index of the star. β_{λ} and γ_{λ} are the color coefficient and zero point constant, respectively, of the instrument. C is expressed by following equation.

$$C = \delta c_0 + \gamma_c \tag{8}$$

Where, c_0 is the observed color index, δ is a color coefficient and γ_c is a zero point constant. These coefficients and constants are determined for each photometer system by the observation of standard stars.

3. UBV Photometric System and Two-color Diagram

In early 1950's H. L. Johnson and W. W. Morgan established the UBV system. The UBV system was developed around the RCA 1P21 photomultiplier and three broad-band filters. These filters give a visual magnitude (V), a blue magnitude (B), and an ultraviolet magnitude (U) which should be measured with a reflecting telescope. The B magnitude is approximately equal to the photographic magnitude. U, B, V filters centered around 5500 Å, 4300 Å, 3500 Å, respectively. The transmission function of the filters are shown in Fig. 1.

The UBV standard stars are non-variable stars (hopefully), and were measured by Johnson's original photometer without any transformation. That is to say, the UBV

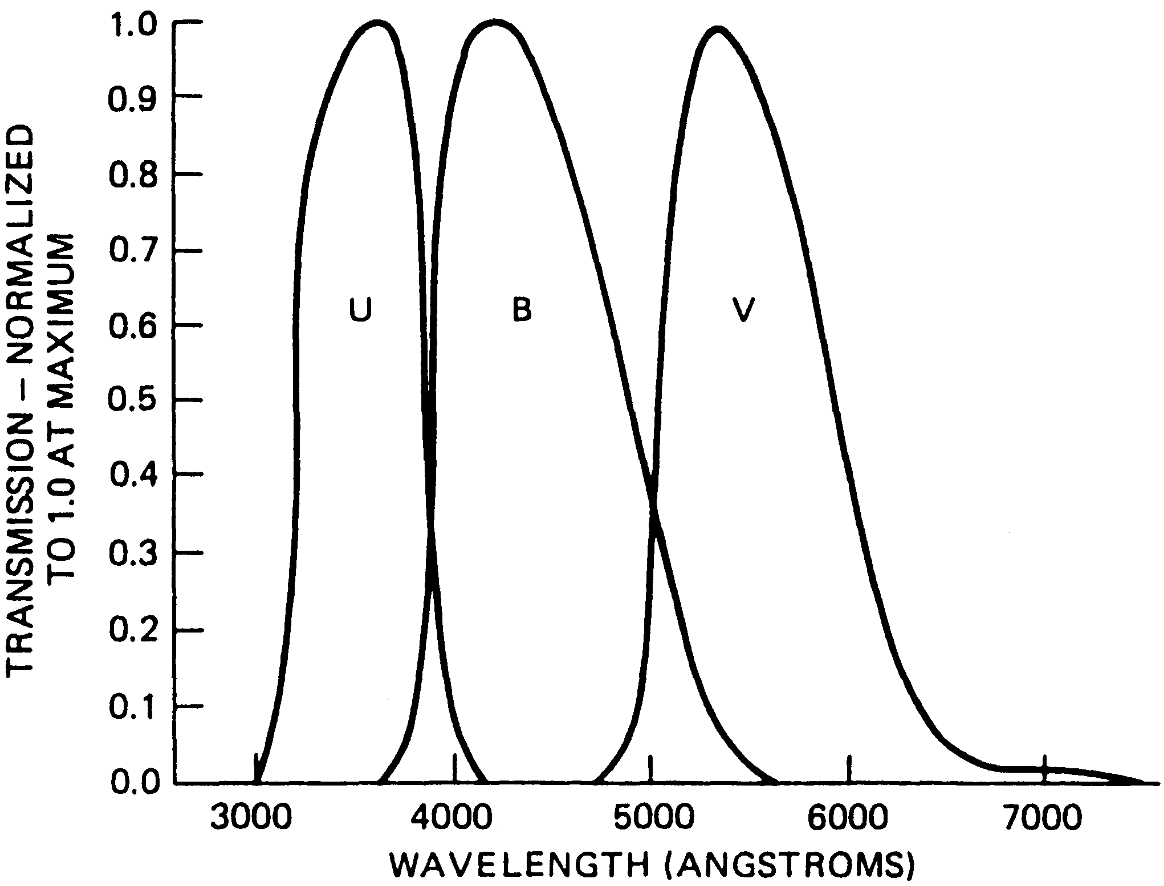

Fig. 1 Normalized transmission function of the U, B, and V filters of the UBV system.

system is instrumental system of Johnson's photometer. The system was originally defined 10 primary standard stars. But the number of primary standards is an insufficient to calibrate photometer which is at every part of the world. So there is the more extensive list of secondary standards that is established by Johnson and Morgan.

An observer can take instrumental measurements of program stars and transform them to the standard UBV system, by the observation of standard stars. In section 2, the transformation equation has been presented in a general form. It is customary to change the symbols used in equations in section 2 to indicate the use of the UBV system. Equation (3) is replaced by

$$\begin{aligned} v &= -2.5 \log d_v \\ b &= -2.5 \log d_b \\ u &= -2.5 \log d_u \end{aligned} \tag{9}$$

where, v, b, u and d_v, d_b, d_u refer to the instrumental magnitude and measurement through the V, B and U filters, respectively. Equation (5), (6) and (8) become

$$\begin{aligned} v_0 &= v - k'_v X \\ (b-v)_0 &= (b-v)(1-k''_{bv}X) - k'_{bv}X \\ (u-b)_0 &= (u-b) - k_{ub} \end{aligned} \tag{10}$$

where, the subscript 0 denotes the value as seen from above the earth's atmosphere. In the UBV system, k''_{ub} is defined to be zero and experience has shown that k''_{v} is very small. Equation (7) and (8) become

$$\begin{aligned} V &= v_0 + \varepsilon(B-V) + \xi_v \\ (B-V) &= \mu(b-v)_0 + \xi_{bv} \\ (U-B) &= \psi(u-b)_0 + \xi_{ub} \end{aligned} \tag{11}$$

where, ε, μ, ψ are the transformation coefficient and ξ_v, ξ_{bv}, ξ_{ub} are the zero-point constants.

Fig. 3 shows a relationship of $(U-B)$ versus $(B-V)$, for Johnson's standard stars of luminosity class V main-sequence stars. This is referred to an a *two-color diagram*. Note that the $(U-B)$ color gets smaller as you move upwards in the plot: the star is becoming brighter in U than in B. (Magnitudes are larger if a star is fainter.) Blackbodies of various temperatures follow a nearly linear relation. On the other hand, stars deviate significantly from blackbody. There is a large difference between ideal blackbody and actual stars, as a result of the absorption lines in stellar spectra.

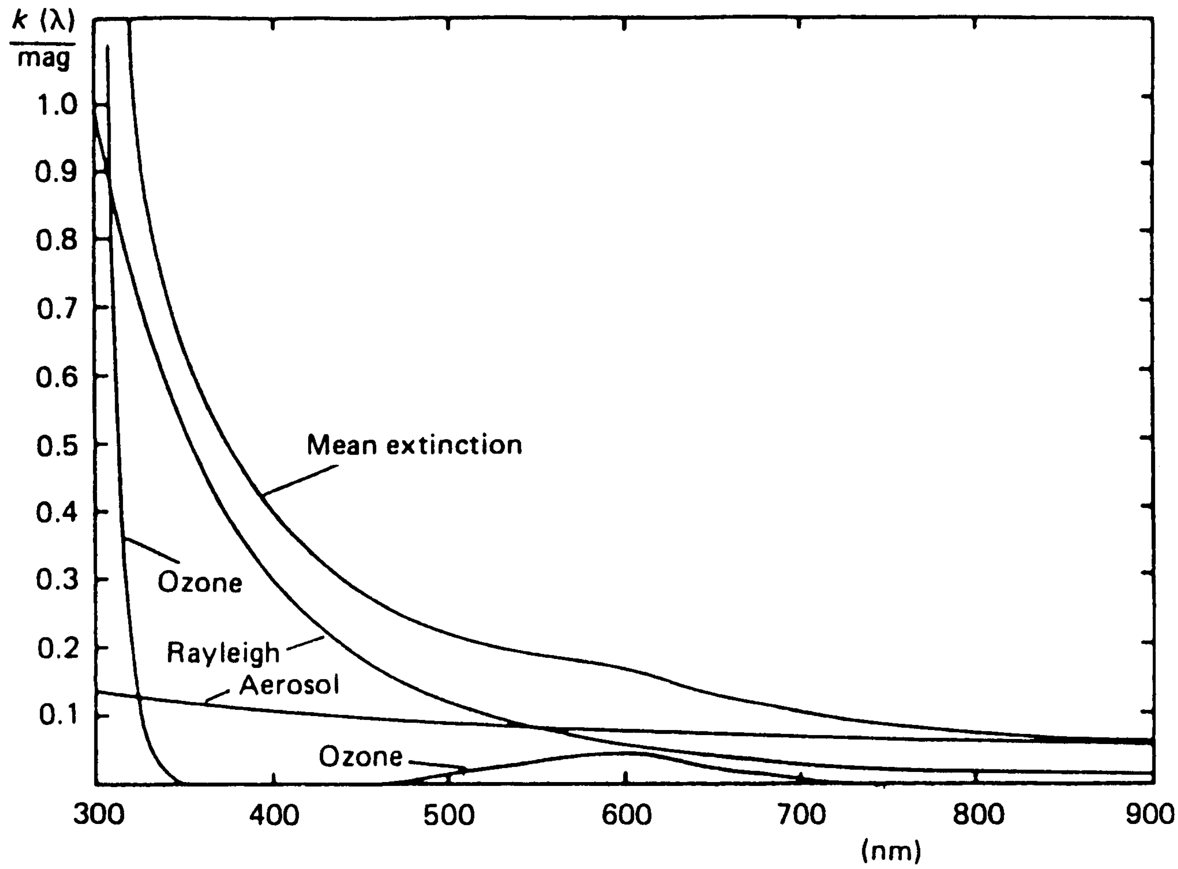

Fig. 2 The mean vertical extinction in magnitudes at Flagstaff, Arizona, for 1976 May-June obtained by Tug et al. (1977). The assumed contributions of ozone, aerosols, and Rayleigh scattering to the extinction are shown separately.

4. A method of measuring the atmospheric UV extinction

As is shown in the previous sections, the UBV photometry is to obtain the unknown brightness/magnitude of the stars by observations of Johnson's standard stars and the determination of the transformation coefficients. Our method of detecting the atmospheric ultraviolet extinction change is an application of this absolute stellar photometry. Before going to the detail of our method, we must exhibit the range of the wavelength of UV extinction by ozone. In Fig. 1, we can see the range of this extinction is effective at the wavelength shorter than 330nm. On the contrary, the Johnson's U filter has the range of bandpass is longer than 300nm. It is the only one that extends to the range of UV extinction by ozone so far. The basic concept of our method is that the magnitudes of the standard stars whose intrinsic brightness is known change because of the change of UV extinction by the Earth atmosphere. As a result, U magnitude of the standard stars varies but other B and V do not change. So the obtained 2-color diagram will be different from the original one. In the stellar astronomy, we use the same for finding the effect of reddening by the interstellar dust.

Our method has the following steps:

(1) To observe as many standard stars at one photometric night.

(2) At least one of the standard star is observed at that night at different time (different height or zenith distance).

(3) To calculate the extinction coefficients of that night using Eq. (10) with the least square analysis for this single star.

(4) To calculate the transformation coefficients of our system by making use of Eq. (11) with the least square analysis for the observed standard stars.

(5) To observe the standard stars that was observed at the first night.

(6) To calculate the UBV magnitudes of these stars by using the Eq. (11) with the transformation coefficients obtained by the step (4).

(7) To draw the two-color diagram ($B-V$ vs. $U-B$) and compare with that of the previous (the first) observation.

At first sight the extinction seems to be expressed in terms of the extinction coefficient, the value k changes with the weather of the night of observation. In the other words, the coefficient depends strongly upon H_2O or vapour. Instead we have chosen the above mentioned steps for the method of detecting UV flux change. Our assumption is that the transformation coefficients does not change but intrinsic UV brightness of the Johnson's standard stars change with time. As a result we can expect the change of the 2-color diagram of the observed Johnsos's UBV standard stars. In Fig. 3, we show the initial two-color diagram of the standard stars with spectral class V (main sequence stars). This is an initial state of the atmospheric UV extinction, which has a possibility of change of the shape if the environmental pollution proceeds in the future.

5. Discussion

As was mentioned in the previous section, the basic idea of the detection of the

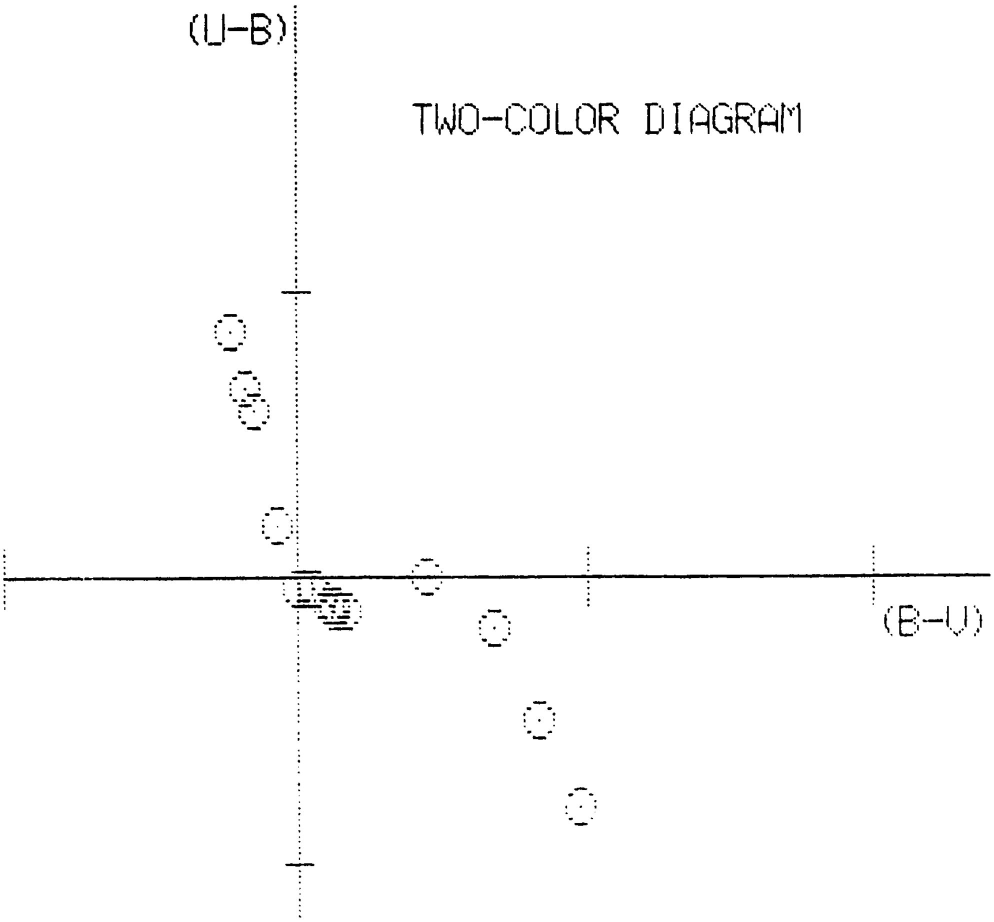

Fig. 3 A relationship of (U−B) versus (B−V), for Johnsons standard stars of luminosity class V main-sequence stars.

increase of solar UV flux is that the atmospheric extinction of UV is diminuated due to destruction of the ozone layer. As a result, we expect that the U magnitude of the standard stars changes. We take this effect as the change of the intrinsic U magnitude. However we assume that transformation coefficients do not change at all. In the conventional stellar photometry, such an assumption is not always correct. We usually calibrate by observing the standard stars to get the revised value of the transformation coefficients. Actually the change of the value of the coefficients is small enough to detect the extinction change if we keep our instruments fresh and clean. Even though something wrong happens on our instruments, it will cause the change of the transformation coefficients not only k_{uv} but also other coefficients k_v and k_{bv}. To check the change of the transformation coefficients due to fadeness, usage of two or more different types of the photoelectric photometer is desirable.

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