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LIGHT VARIATIONS OF THE SEYFERT GALAXY NGC 4151. III.

LONG TERM PHOTOGRAPHIC B VARIATIONS AND INFRARED K DATA

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Abstract

Examination of Harvard patrol plates taken during the years 1932 through 1952, and of Steward Observatory plates taken between the years 1956 and 1968 indicates irregular changes of the photographic magnitude of the Seyfert galaxy NGC 4151 within the range $10^{m}.7$ - $12^{m}.7$ with one recorded outburst of $9^{m}.9$ and one low of $13^{m}.2$. A possibility of the presence of a cycle of about 5 years in the light variations of this object is not incompatible with the photographic data. Measurements in the infrared at 2.2 microns performed since 1967 do not exclude a possibility of variations in brightness of the order of one magnitude, but more sensitive observations are needed to definitely establish the variations.

I. Long Term Optical Variability

Light variations of the Seyfert galaxy NGC 4151 were detected by Fitch, Pacholczyk and Weymann (1967) (Paper I). Further photometry of this object was done by Pacholczyk and Weymann (1968) (Paper II), Barnes (1968), and Zaitseva and Lyutyi (1969). Paper II also contains some preliminary data from photographic photometry of NGC 4151 between 1932 and 1952.

Long term optical variability of the nucleus of the Seyfert galaxy NGC 4151 was investigated using Harvard Observatory patrol plates and Steward Observatory plates taken in the years 1932-1952, and 1956-68, respectively. Harvard RH series plates were obtained with the 75 mm Ross-Fecker refractor of focal length 21 inches at Oak Ridge. Steward Observatory plates were taken with the 36-inch reflector between 1956 and 1961, and with the 21-inch reflector in 1968. The plates were measured with the iris photometers of Harvard and Steward Observatories. RH plates with exposures of 1 1/2 hours or more were used; the image of NGC 4151 was well above the plate limit and consisted of a stellar-like nucleus. Seven nearby standard stars were used, five of which have colors comparable to those of the nucleus of NGC 4151. No significant corrections to the measured blue magnitudes of NGC 4151 are necessary on account of differential extinction and chromatic effects of lens aberration. Two stars were treated as variable objects to provide a check on the accuracy of the photometry; one comparison star with (photoelectric) B magnitude 10.46 ± 0.02 has colors similar to those of NGC 4151: B-V = 0.59, U-B = 0.00, while the other is fainter (B = 12.20 ± 0.02) and has different colors: B-V = 1.06, U-B = + 0.81.

Figure 1 summarizes the results of the photographic photometry. The standard deviation of a single observation of NGC 4151 from the mean value is 0.6 mag for an observation on the Harvard plates and 0.3 mag during the period covered by the Steward plates. This deviation is significantly larger than the error of a single measurement: the standard deviation of a single measurement of any of the two comparison stars is 0.2 mag (Harvard plates) and 0.1 mag (Steward plates). The photometry is therefore indicative of variations of brightness of the nucleus of NGC 4151. Another estimate of the magnitude of errors involved was provided by the comparison of 1968 Steward photographic data with the photoelectric observations of Zaitseva and Lyutyi (1969), which were done in the same period of time. Figure 2 illustrates both sequences of data, in B and U systems. It is evident that blue photographic magnitudes are systematically larger by about 0.3 mag than the photoelectric magnitudes. This is due to the difference in the size of the diaphragm used by Zaitseva and Lyutyi (1969) (27")

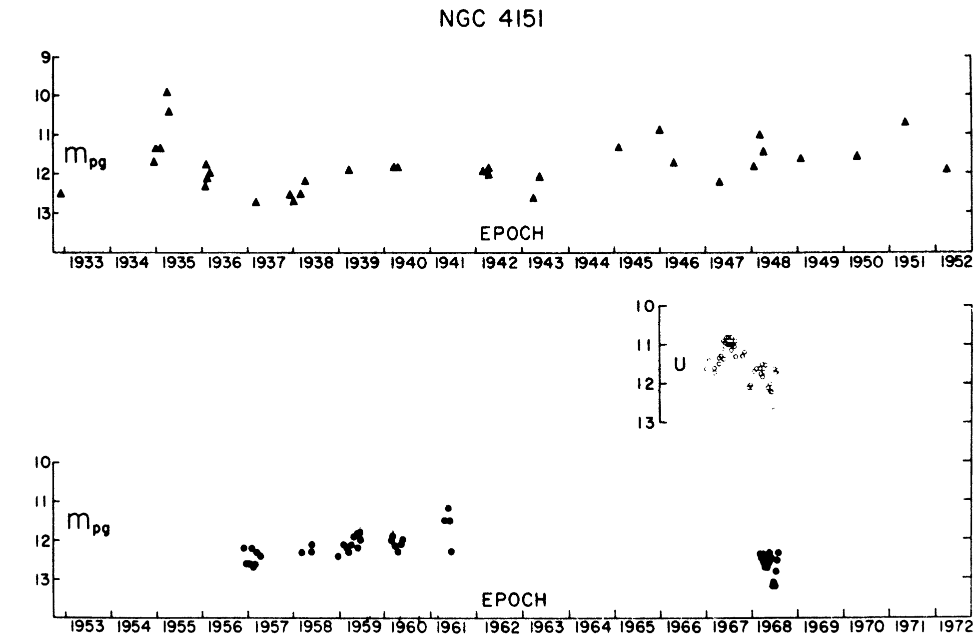

Fig. 1. Photographic photometry of the Seyfert galaxy NGC 4151. Harvard and Steward plates data are represented by triangles and dots, respectively. For comparison, the photoelectric ultraviolet magnitudes, taken from Papers I and II, from Barnes (1968) and from Zaitseva and Lyutyi (1969), are plotted on a separate scale as open circles.

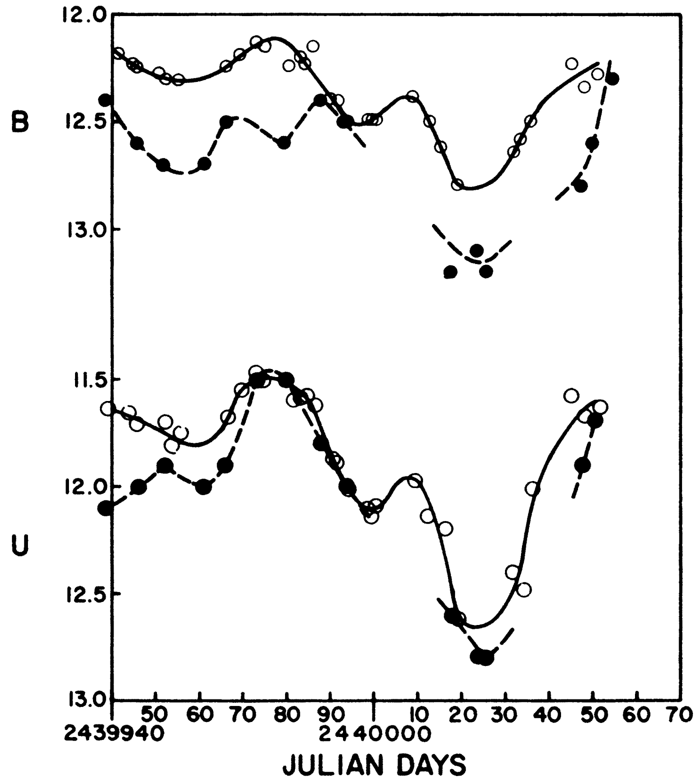

Fig. 2. Comparison between the Steward photographic measurements of NGC 4151 (dots) and photoelectric measurements by Zaitseva and Lyutyi (1969) (open circles). Upper curves refer to blue magnitudes, lower to ultraviolet magnitudes.

and the size of the iris diaphragm of the photometer, which was on the average somewhat larger than the size of the image of the nucleus of the galaxy. Since the distribution of brightness in the ultraviolet of NGC 4151 is more concentrated toward the center than it is in the blue (Dibai, Zaitseva and Lyutyi 1969), the difference in photoelectric and photographic U magnitudes should be smaller. This is indeed the case; from Fig. 2 we can see that this difference is of the order of 0.1 mag or less.

Photographic observations of the Seyfert galaxy NGC 4151, summarized in Fig. 1, indicate changes of brightness within the range $10^{m}.7$ - $12^{m}.7$ with one recorded outburst of $9^{m}.9$ and one low of $13^{m}.2$. Although the plates used for determination of the two high points in 1935 are of rather poor quality, the increase in brightness of the object seems to be real. Observations do not exclude a possibility of the presence of a 5.1 year cycle in the variations of brightness, with minima observed in 1932, 1937, 1942, 1947, 1952, 1957 and 1968. Indeed, the average magnitude of NGC 4151 during half-cycles around the minima is 12.34 ± 0.05 while the magnitude during half-cycles between the minima is 11.64 ± 0.12.

II. Observations in the Infrared

Infrared observations of NGC 4151 were carried out since 1967 at 2.2 μ (in the K photometric system) with the 60-inch telescope at the Catalina observing station of the Lunar and Planetary Laboratory of the University of Arizona. The PbS photometer (Johnson 1965) was equipped with a 15" diaphragm. Because of the particular structure of the photometer the sky readings were made at a distance of 22" from the object measured. Figure 3 summarizes the observations. Each point represents an average of twenty values of differences between "star" and "sky" readings, performed with an integration time of 15 seconds. Figure 4 shows standard deviations of a single observation

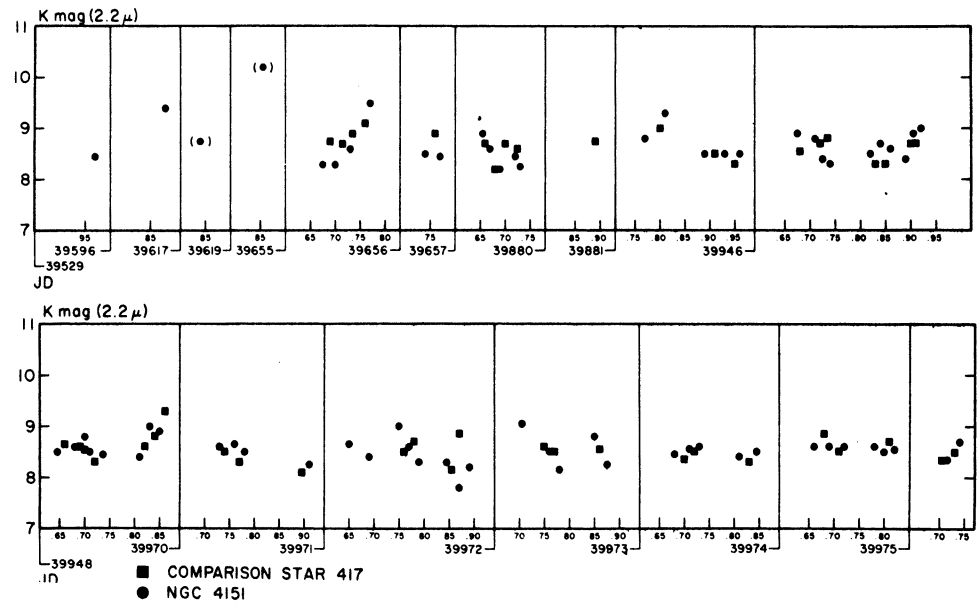

Fig. 3. Observations of the Seyfert galaxy NGC 4151 at 2.2 microns. Time is expressed in Julian days and their fractions. Points in parentheses refer to measurements of low weight.

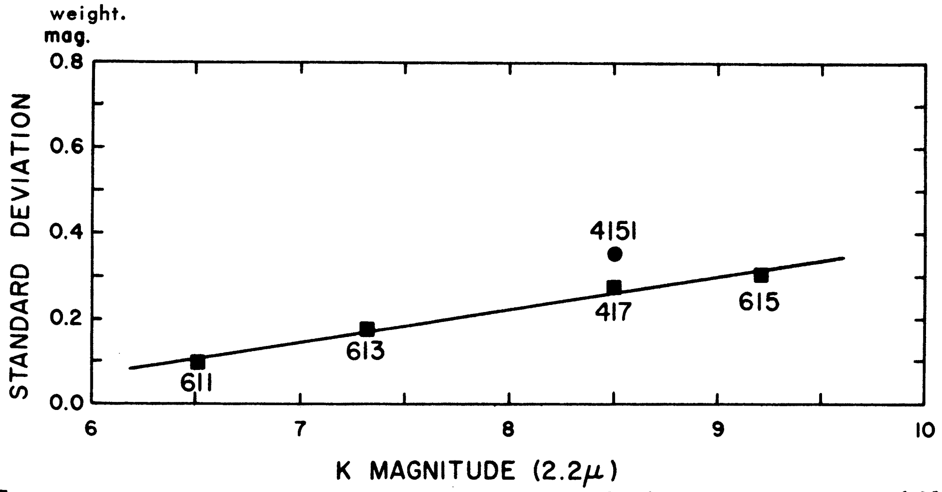

Fig. 4. Standard deviation from a mean value of a single observation consisting of 20 differences between measurements of "star" and of "sky," each measurement employing an integration time of 15 seconds. Squares represent observations of comparison stars of various magnitudes at 2.2μ. Dots refer to measurements of the Seyfert galaxy NGC 4151 (total number of observations is 67).

(corresponding to one point in Fig. 3) from the mean value for NGC 4151 and for several comparison stars of various magnitude. The scatter of the measured values for comparison stars around the mean value, illustrated by standard deviations plotted in Fig. 4, is indicative of the magnitude of the errors involved. The scatter for NGC 4151 is somewhat higher than if it were solely due to photometric errors. The most important effects contributing to the difference in standard deviations of measured magnitudes of NGC 4151 and of the comparison star are the effects of differential extinction and centering errors. Figure 5 represents the atmospheric transmission around 2.2 μ ; the

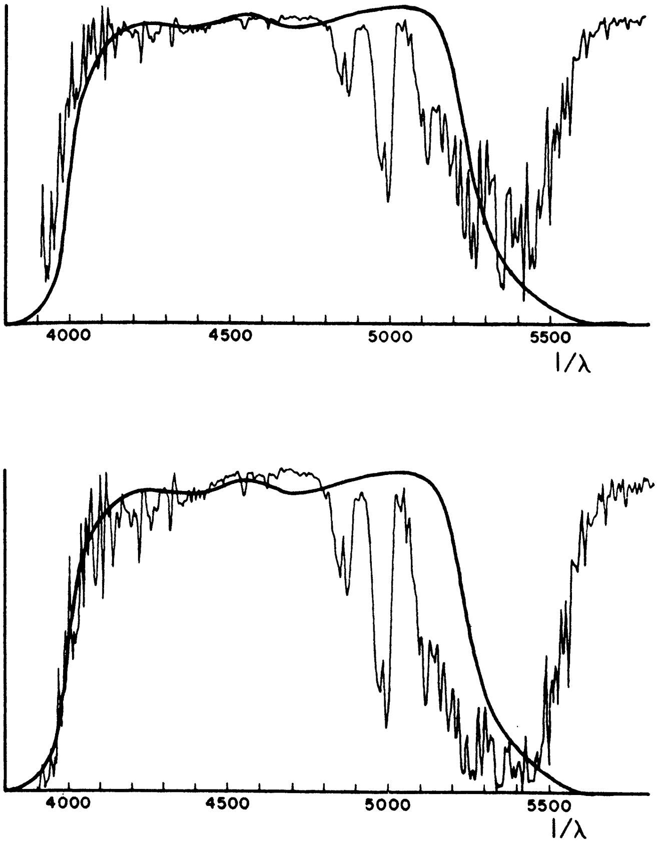

Fig. 5. The transmission of the atmosphere between the Catalina Observatory ground level and a surface at the height of 41,500' (fine curve), for directions corresponding to 1.2 air masses (upper figure) and 1.9 air masses (lower figure). Solid curve is the photometer response function in the 2.2 μ band (K system) superimposed on the atmospheric transmission data.

transmission curves were obtained by Johnson et al (1968) by comparing the spectra of the Moon taken with a 12-inch telescope in a jet aircraft at an altitude of 41,500 with those taken from the ground at the Catalina station through air masses of 1.2 and 1.9. It can be seen from Fig. 5 that the short wavelength side of the K band is more affected by the air mass involved than the long wavelength side. Therefore the effect of extinction on the measurement of an object with a small value of the color index J-K (like the comparison star 417, J-K = 0.8) will be different than that of an object with a large J-K (like NGC 4151, J-K = 1.3). Figure 6 shows the extinction curves determined on

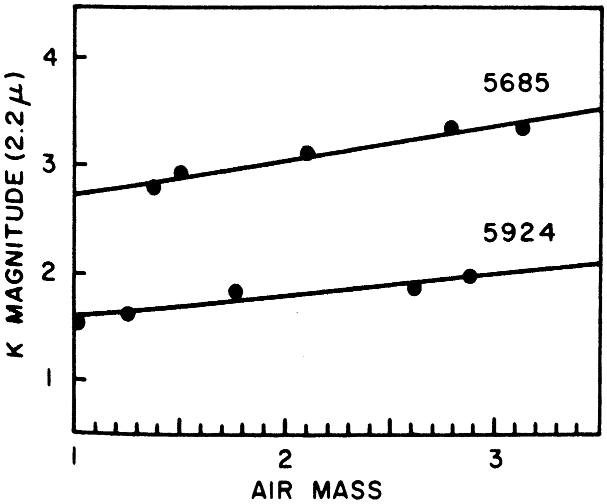

Fig. 6. Atmospheric extinction curves in the 2.2 μ band, determined on a relatively damp night with some cirrus clouds from observations of a red star 5924 (K5 III, V-K = 3.94, J-K = 1.02) and a blue star 5685 (B8 V, V-K = - 0.23, J-K = - 0.05). The difference in slope of the two lines (differential extinction) is 0.07.

a photometrically poor night with high extinction for a blue star (J-K = -0.05) and for a red star (J-K = 1.02). The difference in extinction coefficients from measurements of those two stars is 0.07. Since all the observations were made through air masses smaller than 2, differential extinction can produce an error of the order of $0^{m}.05$.

Figure 7 represents the results of infrared area-scanning of the inner regions of NGC 4151, obtained by D.J. Taylor on May 1, 1970. The system response was limited to a region between I and J bands (Fig. 8). The scanner's diaphragm had dimensions 0.74" x 10.36"; scans were made at position angles of 0^{o}, 225^{o}, 270^{o}, and 315^{o}. Assuming that the distribution of brightness at 2.2 μ is similar to that on Fig. 7 (observations of longer wavelength by Kleinmann and Low (1970) indicate no effect of beam size when diaphragms ranging from $4''.5$ to 35" were used) we can conclude that the effect of centering of the object in the diaphragm of the photometer on measurements of K magnitudes is insignificant.

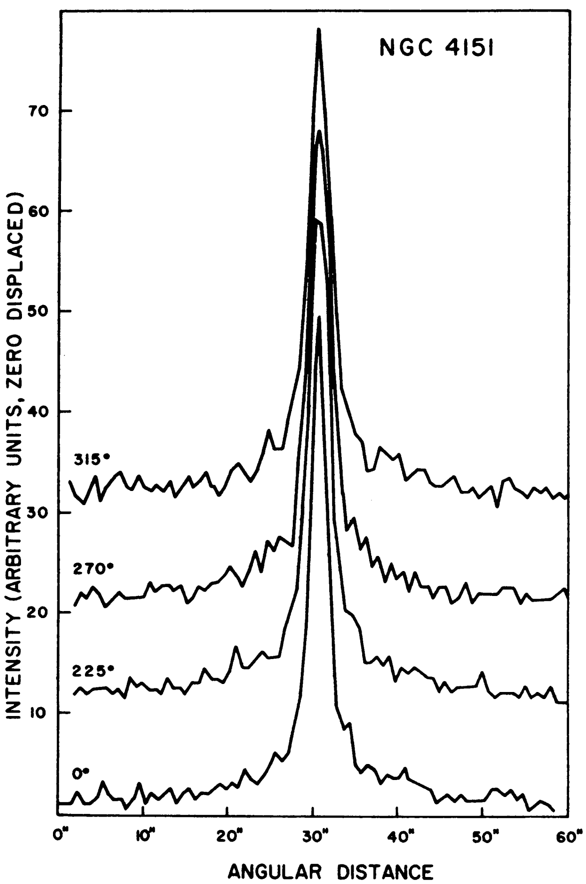

Fig. 7. Area scans of NGC 4151 with a 0.74" x 10.36" diaphragm, made at position angles of 0°, 225°, 270° and 315°. Except for the first, each scan is displaced relative to the preceding one by 10 units on the intensity scale. Sky readings near NGC 4151 averaged 2.3 units. Spectral response of the area scanner is given in Fig. 8.

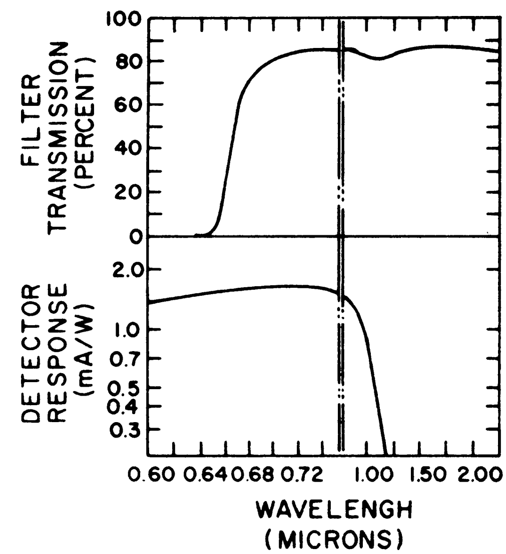

Fig. 8. Spectral response of the area scanner used for measurements represented in Fig. 7.

The infrared observations discussed above are not incompatible with a possible variability of the infrared flux of NGC 4151 at 2.2 μ with an amplitude similiar to that of NGC 1068 (Pacholczyk 1970); it is however clear that observations with more sensitive instrumentation are needed to definitely establish the variability of NGC 4151. The new infrared photometer of the Steward Observatory together with the 90-inch telescope will provide such an opportunity.

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