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Photoelectro-Photometric Survey of Night Sky Conditions in the Vicinity of Iowa City[1]

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Abstract. During the summer 1962, a systematic survey of night sky conditions in the vicinity of Iowa City was carried out for the purpose of selecting the best site for the proposed research observatory of the State University of Iowa. A photoelectric photometer was attached to the Newtonian focus of a 11-inch reflector whose equatorial mounting was modified to a horizontal system. The equipment was carried by a truck and observations were made at six different sites, ranging in distance from eight to twenty-three miles in all directions from the city. In order to eliminate random errors due to variations in sky conditions from night to night, measurements of scattered city lights and the atmospheric extinctions were taken on at least two different sites during the same night and were repeated for six or seven different moonless nights at each site. As a result, it was concluded that the region about twelve miles south-southwest of the city is least affected by the artificial city light.

The State University of Iowa is planning to build a research observatory in which to house a 24-inch reflector of first class quality as a major equipment. In the original proposal made during the spring of 1961, a site within the newly developed Lake Macbride Campus was chosen as a possible location for the observatory. The selection was based mainly on the general attractiveness of the site and various advantages and conveniences obtainable through the use of water, electric power, sewage facilities, and other accommodations being planned in the University recreation area. We later felt, however, some uneasiness about the astronomical suitability of the site due to a considerable amount of scattered city light and dust in Cedar Rapids and Iowa City. Since the proposed observatory is planned primarily for photometric observations, it is important to choose a site where the night sky, especially in the direction due south, is least affected by artificial lights and smog and its fluctuation from time to time. Thus, a systematic and quantitative photometric survey of night sky brightness and atmospheric extinction was conducted at the Macbride site and at other potential sites for comparison, during the summer months in 1962.

In this paper, we discuss the method of observation and

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analysis of scattered city lights, from which it was concluded that the Macbride site is decisively inferior to a number of other, apparently practical, sites near Iowa City for photometric observations with a large optical telescope. The results of the extinction problems are discussed in a separate report.[1]

Observational Equipment

The entire system of equipment used for observation is shown in Figure 1. It consists of a 11-inch Newtonian reflector of f/3.3, a RCA-6199 photomultiplier mounted directly behind the eyepiece at the Newtonian focus, (A), an Offner curvi-linear amplifier-recorder, (B), and a power supply, (C). They were carried by a Navy-surplus truck from site to site for observations, as shown in the figure.

Figure 1. A: Photomultiplier; B: Amplifier-Recorder Unit; C: Power Supply; D: Azimuth Setting-Circle; E: Altitude Setting-Circle.

Telescope-Mount

The 11-inch portable reflector was originally mounted equatorially on a bowl-shaped base, (D), which is supported along the direction of polar axis by three solid legs. The hour angle reading is marked around the edge of the bowl, (D), and the declination circle (E), is directly attached on the side of the telescope frame. It had an electrically controlled sidereal drive which has not been used in the present observations.

The mounting of the telescope in Fig. 1 shows a horizontal system modified from the original equatorial mount. The modification can be readily done by changing the original tripod to a simple set of three vertical legs to support the bowl, (D), horizontally. The alteration was first made for the purpose of using the telescope for satellite-tracking observations. As we planned the project reported in this paper, the three legs were made only a few inches long so that the telescope can be moved in the truck as shown in Fig. 1.

The setting circles for hour angle (D) and declination (E), therefore, give direct readings for the azimuth and the altitude. With such a system of the horizontal mount, the manual operation to point the telescope in any desired direction needed in the present work can be most efficiently performed.

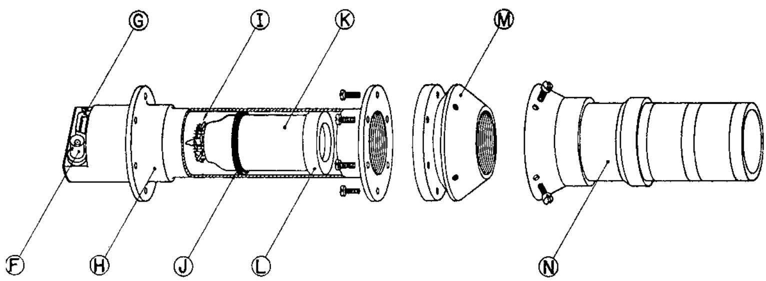

Figure 2. F:Coaxial Cable Receptacle; G: Multiple Conector Socket for High Voltage Input; H: Tail-Adapter of the Tube-Holder; I: Resistor Network; J: Rubber Electrical Tape; K: RCA 6199 Photomultiplier; L: Teflon Holder; M: Adapter to Eyepiece; N: Eyepiece.

Photoelectric-Photometer

The entire part of the photometer used in this work was constructed from surplus equipment in our space-physics laboratory and the electronic shop. An adapter (M) is elected to attach the phototube near the Ramsden circle of the eyepiece (N) with the eye relief of about 4 cm (see Fig. 2).

The RCA-6199 tube (K) is a head-on type, 10 stage photomultiplier which has a spectral response over the range from about $\lambda\lambda$3000A to 6500A with maximum sensitivity at approximately λ4400A[(2)]. It is equipped with dynode resistors of 560,000 ohms each. The high voltage is obtained from two transistorized power supplies connected in series, and the voltage regulation is accomplished by a regulator tube which maintains an output of 860 volts. These high voltage power supplies are driven by a 6 volt dc input taken from a Hewlett-Packard Model 721A, 0-30 volt, transistor power supply (C). Thus the portability of the complete system is maintained by the use of a dc to ac power converter which converts from 6 volts dc to 120 volts, 60 cycles ac, that is used to operate the recorder and to isolate the photomultiplier circuit from the truck electrical system. The power converter is a Heathkit MP-10 which provides about 120 watts. It is necessary to operate the truck engine continuously to maintain the battery charge.

The resistor network (I) out of convenience and simplicity is mounted on the base of the photomultiplier (K). The tube itself is mounted in a surplus magnesium shell designed specifically for head-on type photomultipliers to be flown in satellites. The signal is returned through a 20-foot coaxial cable to the recorder. The high voltage is also delivered to the resistor divider network by means of an equally long cable. The use of such long cables allows the telescope to be moved a reasonable distance from the truck for observations.

The tube is held in the shell by means of a Teflon washer (L) at a head and rubber electrical tape (J) wrapped about the base. The face of the tube is mounted 1.22 inches from the end of the shell to place it at the focal plane of the optical system. Diaphragms of various diameter or color-filters may be placed in front of the tube by means of the threaded interior of the shell. The opening of the Teflon washer itself is 1 inch in diameter, and the angular diameter of the field covered without additional diaphragm is found to be slightly more than one degree.

The recorder (B) used is an Offner Electronics two-channel pen recorder of which only one channel is used. At the same time, one of the indicating needles is replaced by a needle of about twice the original length in order to increase the amplitude of the recording. The output from the photomultiplier is fed directly into the recorder input terminal, and the input impedance of the recorder provides the voltage drop which is thereby recorded by the pen. The dark current level sets an arbitrary zero of the reading pen at each instant of observation.

The linearity of response of the complete circuit has been tested in the optics laboratory, using a radioactive source (Sr^{90}) called "Isolite" made by the U. S. Radium Corporation, as a light source. It radiates a self-collimated bundle of light whose spectral response covers the range between $\lambda\lambda$4000A and 6500A with a maximum at about λ5200A. By changing the distance between the source and the phototube placed on an optical bench, we found that the intensity measured in the recorder follows exactly the inverse square law. More detailed discussion of this experiment is given in the separate report[(1)].

Selection of Observing Sites

As we mentioned before, the purpose of the present work is to compare the night sky conditions at various potential sites in order to select the best location for photometric observations. The initial selection of the observing sites was made on the basis of (1) a relatively high point within fifteen miles from Iowa City in any direction, and (2) a site where a good road access can be obtainable. In fact, the plan for the new observatory was initiated to improve a difficulty due to the isolation and the long distance experienced with the present country observatory which is located about twenty-four miles west along the county road A. It has often been difficult to reach the site during the winter months.

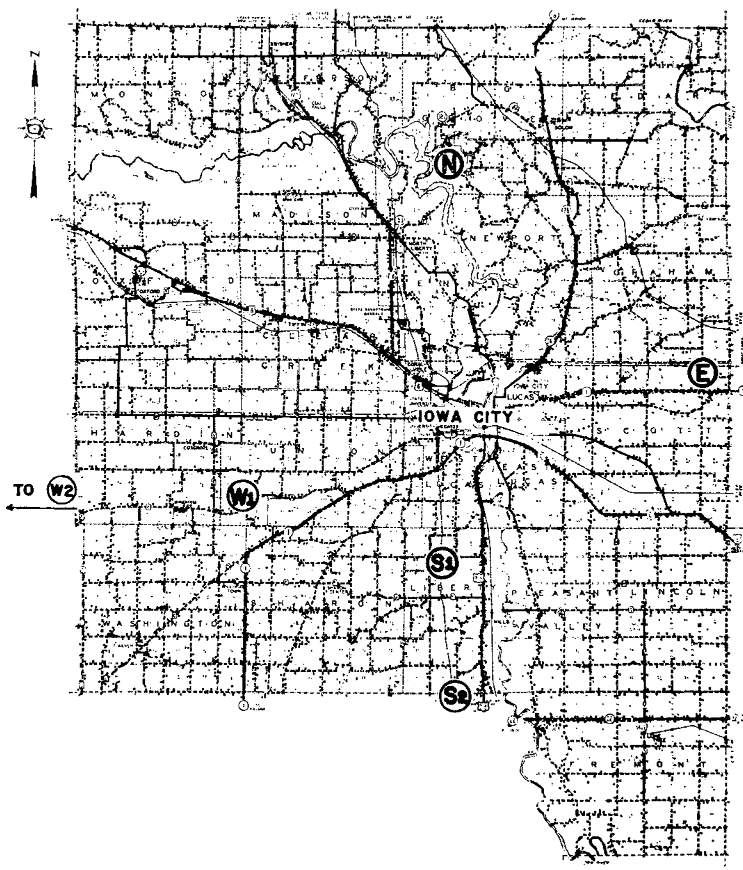

Figure 3. Sites elected for observations.

After some preliminary survey of possible sites in all directions, we chose the following locations for systematic observations (see Fig. 3):

Site N: About 15 miles north of Iowa City on U. S. Highway 261, and is within the newly developed Lake Macbride Field Campus of the State University of Iowa.

Site E: About 10 miles east of the city on State Highway 1. The preliminary survey has shown that a point beyond 10 miles east becomes too close to West Branch.

Site S1: About 8 miles south on U. S. Highway 218.

Site S2: About 12 miles south on U. S. Highway 218. This point was chosen as one of the highest points in the direction south.

Site W1: About 12 miles west on county road A toward the present country observatory where the 12-inch Newtonian-Cassegrain reflector is now located.

Site W2: The country observatory site. About 24 miles west on county road A.
The last site, W2, was later added to compare to the other locations nearer the city area, and only two night observations were made.

Method of Observations

In order to eliminate the effect due to the variation of sky conditions from night to night, we first attempted to take measurements at as many sites as possible during the same moonless night, so that the data at different sites can be directly compared. As a result of the determination of extinction coefficient discussed in the separate report, however, it was found that the sky conditions vary not only from night to night, but also from time to time during the same night(1). At the same time, we found from the preliminary survey that the zenith region above 45 degree altitude is practically free from city lights at all sites chosen for observations. Instead of the direct comparison that we first planned, therefore, we decided to express the brightness below 40 degree altitude in terms of a mean reading at 45 degrees for each observation. The normalized intensity values will then give direct comparisons between two different sites observed at different times.

As a routine program of measurement to be used for the final analysis, we thus decided to carry out systematic recordings of sky brightness at every 5 degrees in altitude and 7.5 degrees in azimuth, scanning the entire sky below 45 degree altitude line at each site.

It was also determined that the diaphragm, which was 1 inch in diameter, would be best suited for the measurements of sky light and the smallest diaphragm, 1/3 inch diameter, would be more appropriate for observation of stars used for determining extinction coefficients(1). With the largest diaphragm, the area of approximately one degree in angular diameter is covered by the photometer. Only a star brighter than about magnitude 2 has been found to distort our readings, and the random fluctuations due to the stars in the field are not detected except for the region of the Milky Way.

At least two observers are needed to carry out the measurements: one to operate the telescope, and the other to work with the recorder inside the truck. The telescope was placed on a platform with rollers, and with the use of a ramp, two persons could easily place it into or could bring it out of the truck at an observing site. The truck was left in a direction opposite from the city with respect to the telescope so that the unobservable portion of the sky occulted by the truck be considered free from the artificial light. The zero-point of the altitude reading was set by placing the telescope-platform exactly in a horizontal plane by means of a level, and the setting of the azimuth circle was done simply by pointing the telescope to the celestial North Pole. Through this procedure, it was not difficult to keep the pointing accuracy within several degrees, which was sufficient for our purpose.

The measurements were first carried out along the complete circle on the constant altitude of 5 degrees, and were then shifted by 5 degrees above this. The manual operation of the horizontal mount is simple, and the dark current recording between each measurement is done simply by covering the eyepiece with the hand while moving the telescope, so that an azimuthal scan for a given altitude can be completed within 3 minutes of time Thus, by repeating the azimuthal scanning at every 5 degrees until the 45 degree line is reached, data are yielded for the entire sky in terms of 432 recordings, within less than forty minutes. Figure 4 shows some of the sample recordings made in this manner. The level line between the sky readings gives the dark current and the height from this line to the top of the reading gives the direct intensity of the sky light. The higher peaks recorded at around the azimuth 30 degrees from the south point marked as "star" are due to the effect of the Milky Way. Generally, such an accidental inclusion of bright stars in the direction of measurements is easily detected.

Routine observations were carried out during the moonless hours of every clear night during the months of June and July. Due to the shorter period of night time, observations could not be commenced before 9:30 p.m. and the photometer began to detect sunlight as early as 3:00 a.m. A complete scanning at one site took about forty minutes. With the time spent loading and unloading, or setting up the telescope, about one hour was needed at one site. Much time was spent traveling between sites. When measurements were made at sites N and S2, for example, a distance of thirty miles had to be traveled, crossing the city area. Thus, at most, observations could be made at four different sites in the same night, and usually only three sites were visited during one new moon night. The order of observing sites was

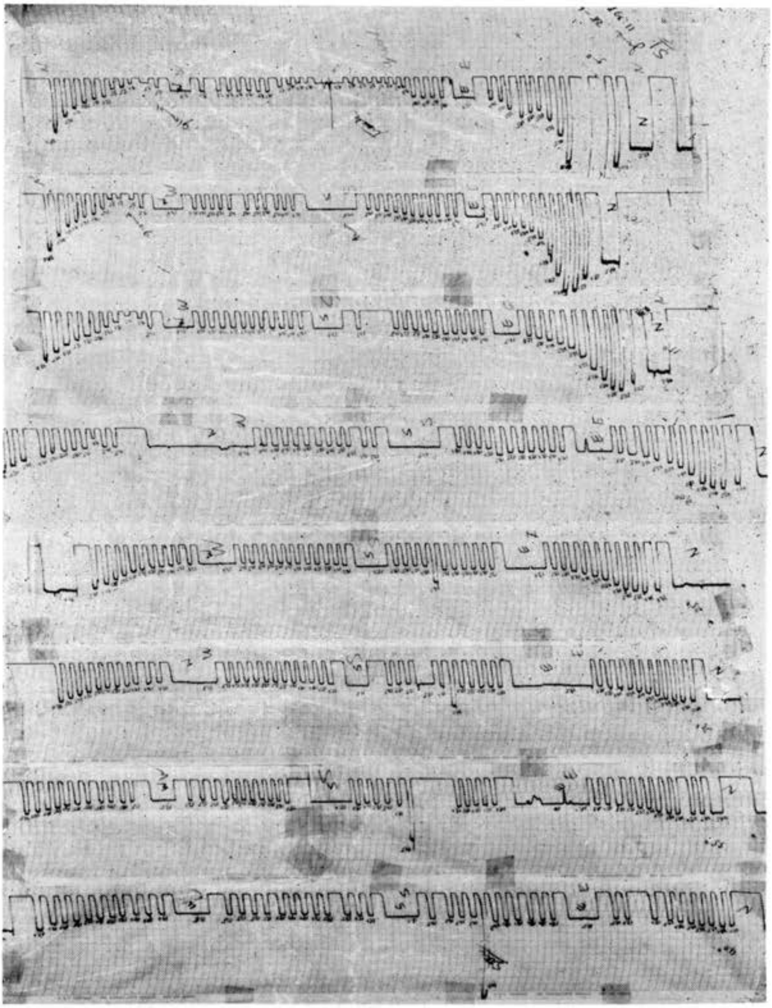

Figure 4. Example of recordings taken at Site S1. A set of azimuthal scan at each altitude is shown in each row, with a step of 5 degree altitude. The top row is for altitude 40° and the iowest for 5°.

changed from night to night, so that the same site could be visited at different hours during the course of the entire schedule. Fortunately, weather conditions during the scheduled period were unusually good, and we could use most of the new or nearly new moon nights on our schedule. Clear moon nights during the same period were used for determination of atmospheric extinctions[1]. Thus a total of thirty-one observations were successfully carried out over twelve different nights under the well-prepared schedule.

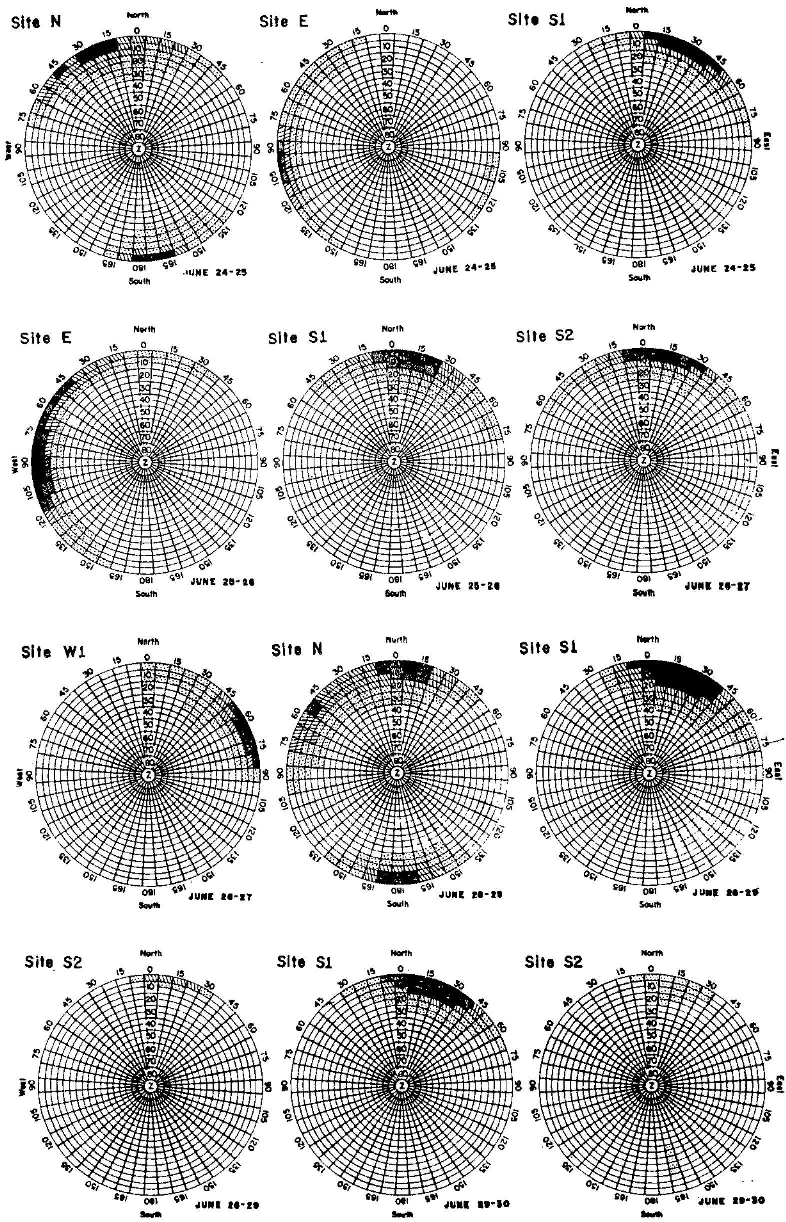

Figure 5. Final analysis of observations, I.

Method of Analysis

Among the thirty-one observations completed, only four observations were excluded in the final analysis. The data taken during these four times did not show consistent concentration of

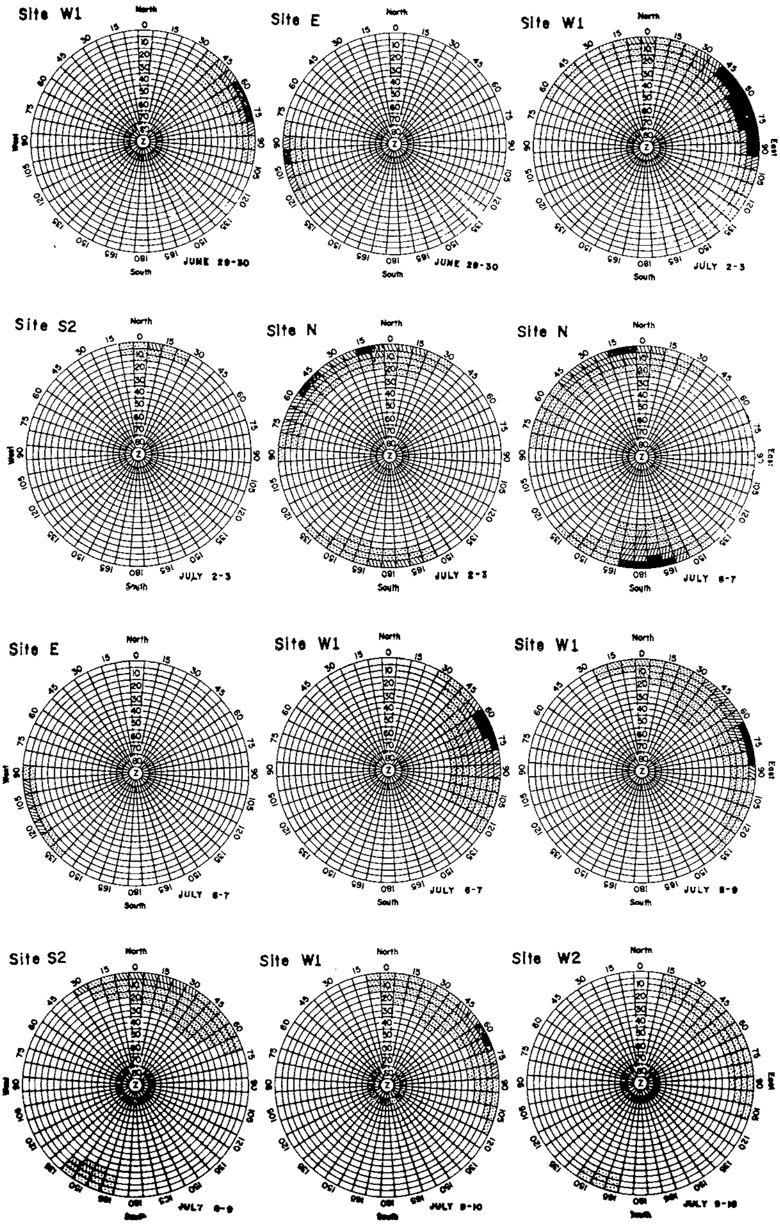

Figure 6. Final analysis of observations, II.

city light toward the horizon or in the direction toward any city area. Such inconsistent fluctuations in the measurements compared to the other twenty-seven observations appear to be due to undetectable thin clouds scattered over the sky.

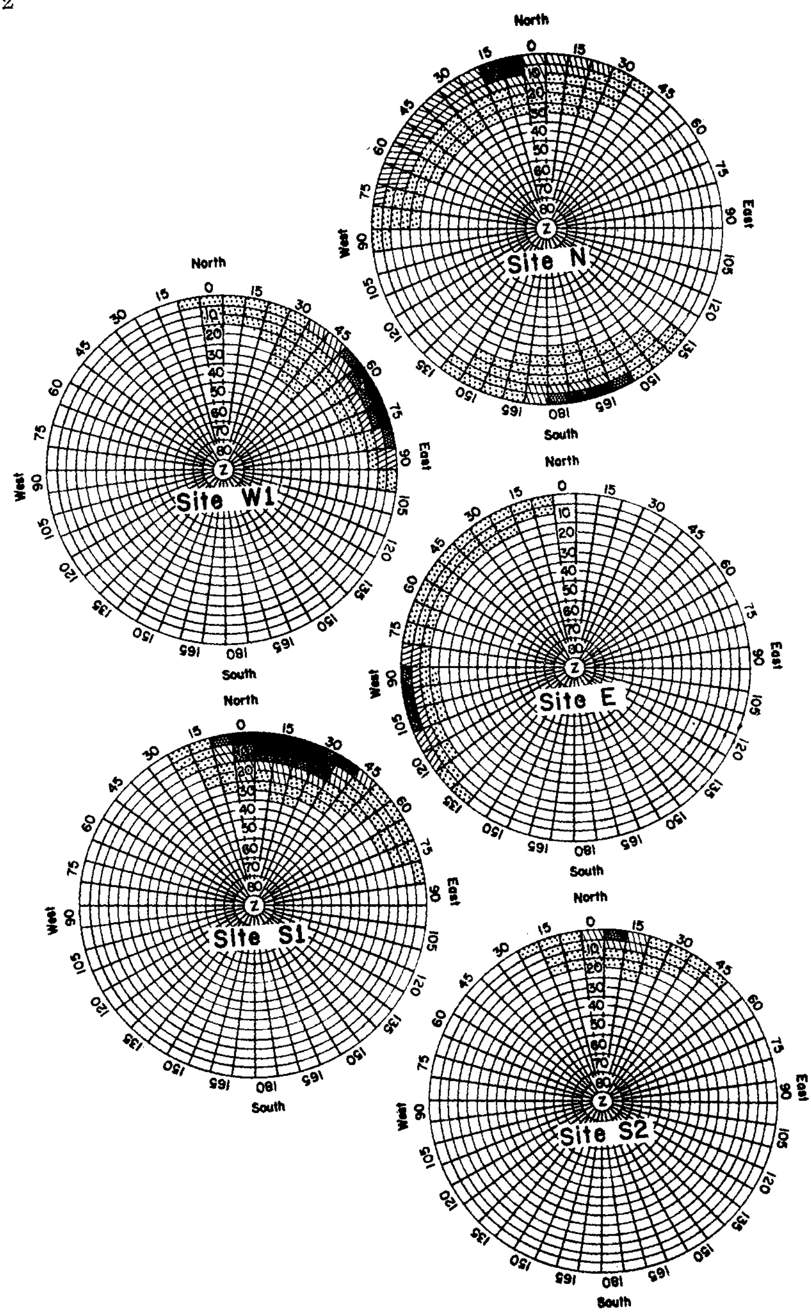

Figure 7. Sky brightness aeraged for each site.

The direct brightness readings of 432 points for each observation taken from the tracings, such as shown in Fig. 4, were first written into a circle representing the hemisphere with the zenith of the place of observation at the center. As is shown in Figs. 5 and 6, the hemisphere circle is divided into cells of 5° x 7.5°. Each number on an arbitrary scale, therefore, should be directly proportional to the brightness in the direction corresponding to the position of the cell. However, the absolute values of the readings depend on the zero point and scaling adjustment of the photometer-recorder system, in addition to the variation of sky conditions from observation to observation. In order to make direct comparison between two observations, therefore, the numbers are normalized in the following way.

First, take a mean value of forty-eight readings along the same 45 degree altitude line, and divide this mean value into other 384 reading numbers below the 40 degree altitude line. Such a normalization procedure is based on the assumption that the region of the sky above the 40 degree altitude is completely free from the artificial city light, as we have pointed out before. Further, the effect due to a possible difference in extinction or scattering by dust particles in the zenith region is assumed to be negligible, so that the numbers thus normalized yield direct comparison between different observations. As it will be seen later, the fact that the effect of city light is very clearly and consistently shown in the final result appears to indicate the correctness of these assumptions.

The final results of the analysis of twenty-four observations are shown in Figs. 5 and 6. The data circles are arranged in the order of the date and the time of observation if more than one observation is shown in the same date.

In these illustrations, the normalized brightness numbers are shown in five different shadings. Each step between the shades is taken to be equal to the difference of 0.3 in the stellar magnitude scale; that is, as the shading becomes darker by one step, the sky brightness increases by 32 percent. Hence, the difference in mean brightness between the unshaded area and the darkest shaded area corresponds to the difference of 1.2 magnitude or the ratio of the mean intensities between the two extreme regions of the sky is about a factor of three. In converging the normalized sky brightness number to this scale, we adopted the following scheme. In the increasing order of the normalized brightness, which is denoted by ε,

(a)	$\varepsilon < 1.15$	(d)	$2.00 < \varepsilon < 2.63$
(b)	$1.16 < \varepsilon < 1.51$	(e)	$\varepsilon > 2.64$
(c)	$1.52 < \varepsilon < 1.99$		

Some of the readings which are clearly disturbed by very bright stars or the Milky Way region such as seen in Fig. 4, are smoothed out in the final plottings. Such smoothing was necessary only for a few cells per one set of observations. For the cells around the lowest altitude, unevenness in the ground level and some high land objects sometimes gave too low readings, so that extrapolated values were used in the final plotting.

Results and Conclusions

The five hemispheric circles in Fig 7 show the similar plotting of mean values obtained for the five different sites; namely, a simple mean of the normalized brightness numbers obtained on different nights is taken for each direction or cell for the same site. Such a mean value in each cell of the hemisphere is plotted following the same classification scheme as in Figs. 5 and 6.

The effects of city light are clearly and consistently seen in these diagrams. The lights from the Cedar Rapids and Iowa City areas are seen separately in the northern and southern directions from Site N.

In order to indicate the comparison between different sites numerically, we introduce the following number which we call the *sky bright coefficient*, Ω. First, assign the five intergers, (a) 0, (b) 1, (c) 2, (d) 3, and (e) 4, for each cell in the hemisphere according to the increasing step of the shade. Then counting the number of cells in each shade, n_b, n_c, n_d, and n_e, we define the following value as Ω:

$$\Omega = 1 + \frac{1}{432}(n_b + 2n_c + 3n_d + 4n_e)$$

where $n_a + n_b + n_c + n_d + n_e = 432$.

Thus we obtain the following values for Ω at each site:

Ω (N) = 1.484
Ω (S1) = 1.290
Ω (E) = 1.155
Ω (S2) = 1.090
Ω (W1) =1.220
Ω (W2) = 1.131

The last figure given for the site W2 was obtained from the only observation completed at this site, which is shown in the last circle in Fig. 6. It is, therefore, less reliable than the other five. Also the assumption of the constancy of the normalization factor might not be true at this large distance.

The large number in the Site N was due greatly to the contribution of the Cedar Rapids city light, although the point is closer to Iowa City than to Cedar Rapids. In fact, the relative contribution of the northern sky (Cedar Rapids) to that in the south (Iowa City) as seen in the site N in Fig. 7 is found to be 28 to 13. Or, in terms of Ω, it gives Ω(N-north) = 1.331 and Ω(N-south) = 1.153. It is interesting to note than Ω(N-south), Ω(E), and Ω(W1) are about the same, whereas Ω(S2) is about a factor of 2 smaller. Since the distances from the city to these points are approximately equal, such a small value in Site S2 was a rather unexpected result that could not have been clearly noticed in naked-eye observations. Probably the most important factor making Ω(S2) smaller than the others is due to the fact that the elevation of the Site S2 is the highest in the area covered by this survey. Actually, the Site S2 was added to the observing sites after our routine schedule of observations began and the preliminary analysis of the Site S1 data indicated the favorable results in the direction south.

From the results obtained in this work, we conclude that the point about twelve miles south of Iowa City is far superior in sky darkness to any other site. As a matter of general rule, the direction south of a large city as an observatory site is always more favorable than other directions, because of the fact that in astronomical observations the southern sky is far more important than the northern sky. Due to the diurnal rotation of the sky, the region below the north celestial pole (41 degrees in altitude as viewed from Iowa City) can often be ignored, whereas to the south, the entire sky down to the horizon has to be observed in order to cover the maximum possible area.

In conclusion, it is our pleasant duty to express our sincere thanks to Dr. James Van Allen for suggesting this project and for his continuous encouragement throughout the course of this work. We also wish to thank Dr. Brian J. O'Brien and James B. Gardner for their kind assistance in designing the photometer. Finally, our particular thanks go to Harry D. Owens, Donovan M. Haxton, Jr., Jerry C. Woolums, and Richard W. Rinderknecht for their participation in the earlier stages of the observational work reported here as a part of their undergraduate laboratory course work.

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