Applications of the Photo-Electric Cell in Astronomy

Jakob Kunz

University of Illinois, Urbana, Illinois

Since about thirty years ago the photo-electric cell has been used as a photometer in astronomy and has led to important results in various fields. At first the cell was used for the study of eclipsing double stars, and the intensity of light of the corona of the sun in the case of total eclipses; in recent years the absorption of light in the milky way system has been determined by the cell which seems to be called upon to measure also the light from the most distant nebulae, which are from 400 to 800 million light years away from us. The cell may be used in the measurements which are planned for the decision as to whether our universe expands or not. The 100 inch and the 200 inch telescope will be used for this purpose.

We shall begin with the eclipsing binary stars. The Arabs already knew that the star Algol changes its intensity of light considerably in about three days. But exact measurements were only recently made by means of the photoelectric cell by Joel Stebbins, to whom we owe most of the photoelectric results in astronomy. The three stars Algol, IH Cassiopeiae and λ Tauri give very characteristic light curves as function of time-curves which in connection with spectroscopic investigation and with the knowledge of the distance allow us to determine the mechanical system of the double stars. Over 100 eclipsing binaries are known. The preponderant type of close double stars with components of the same order of size and of equal or unequal brightness, consists of bodies whose distance between centers is approximately 5 times their average radius, whose period of revolution is about 4 days and whose mean density is 1/20 that of the sun. Algol has a total light about 100 times that of the sun, its companion has a surface intensity 10 times that of the sun; the light is yellower than that of the primary star. There are other variable stars whose light variation is not due to eclipses but to the ellipsoidal shape of the components, for instance, π^5 Orionis and b Persei.

It is fairly difficult to find constant stars to be used as standards of comparison. The sun also is a variable star, for a single sun spot is enough to change the total light. The variation of this light is probably easier to measure indirectly than directly by the use of the light reflected from Saturn or Uranus. The photo-electric cell measures not only the intensity of light from point sources, but also the light of luminous surfaces, like the light of the corona of the sun, or of a comet or of a nebula or star cluster or of the zodiacal light.

ABSORPTION OF LIGHT IN THE MILKY WAY SYSTEM

Trumpler, an astronomer of the Lick Observatory, had found that there is an absorbing layer in the middle of the milky way system. This was confirmed by Stebbins at the Mt. Wilson Observatory by means of a photo-electric cell attached to the 60 inch and to the 100 inch telescopes. There are two distinct phenomena of absorption of light in the sky. Light is scattered by gases and vapors; the Rayleigh scattering, which explains the blue color of the sky and the red lights at sunset. Then there is ordinary absorption and obstruction of light by dust and larger solid particles. We consider at first space reddening by the light scattered by a gaseous layer in the center of the milky way. Trumpler had observed this effect by means of open clusters, Stebbins observes it by means of globular clusters and by B stars; in this central zone of the milky way E. P. Hubble found no extra galactic nebulae, while the nebulae are most numerous near the galactic pole.

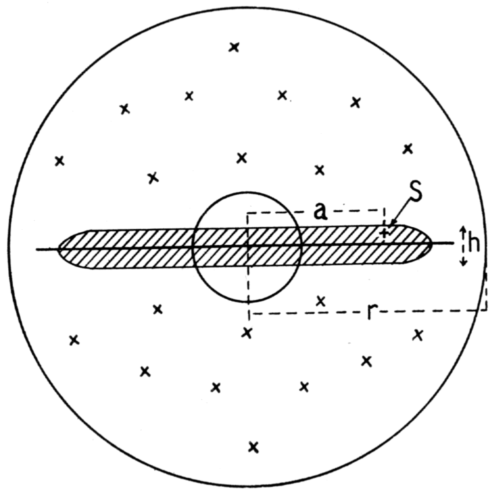

Fig. 1.—SKETCH OF THE MILKY WAY SYSTEM.

h = 1800 light years.
a = 32000 light years.
r = 4000 light years.
s = sun.

The color of a star is measured by its color index. The photographic plate is more sensitive to blue and violet rays than the human eye. The photographic magnitude of a star minus the visual magnitude is the color index. For the class AO stars, on the average the color index is by definition zero, while for blue stars the color index is negative, positive for red stars. Now in galactic latitude between +5° and —17° Stebbins and C. M. Huffer found strong reddening of B stars, outside this zone practically no reddening. The strongest reddening occurs where there are many stars. Each B star was measured through two filters, which with the cell used have effective sensitivities at wave length 4200Å and 4700Å, giving a difference in color index of 0.74 mag. between AO and KO stars.

By the results of the measurements of Stebbins it is possible to estimate the dark material in our galactic system, with the assumption that the absorption and reddening is of the same order as in the atmosphere, where light per cm^2 passes through 1000 gr. If r is the radius of the galaxy, then the total scattering by the dark layer in a direction at right angles to the plane of the milky way is due to a mass $\pi r^2.1000$. One light year is 9.5×10^{12} km, and the radius of the milky way is 40,000 light years, hence the radius r of the galaxy is

$$r = 9.5 \times 10^{12}\ 4.10^4 \times 10^5 \text{ cm.}$$
$$r = 3.8 \times 10^{22} \text{ cm and}$$

$\pi r^2 = 4.5 \times 10^{45}$, and the scattering or dark mass is $m = 4.5 \times 10^{45} \times 1000 = 4.5 \times 10^{48}$ gr. But the mass of the sum is $ms = 2.10^{33}$ gr., hence the dark mass of the milky way is equivalent to $\dfrac{4.5 \times 10^{48}}{2 \times 10^{33}} = 2.2 \times 10^{15}$

suns. This estimate may be reduced to perhaps 2×10^{11} suns, while the number of stars in the milky way is about 3×10^{10}. Near its median plane the galactic system is filled with a layer of dark material which reddens all stars at sufficient distances and blots out everything behind it. The average density of matter in the galactic system is $d = M/V$, where

$$M = 2 \times 10^{33} \times 2.10^{11} = 4.10^{44} \text{ gr. and}$$
$$V = 4\pi/3 \; r^3 = 4 \times 10^{68} \text{ cm}^3 \text{, hence}$$

$d = 10^{-24}$ gr/cm^3, while the mass of a hydrogen atom is 1.66×10^{-24} gr. Another result of this absorption of light or space reddening is a change in the dimensions of the milky way. The distance of a cepheid variable star can be determined by the fluctuation of its light intensity. For transparent

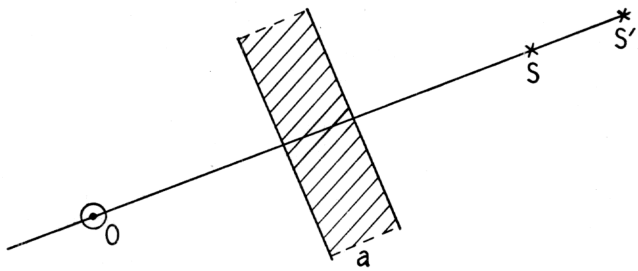

Fig. 2.

space the inferred distance between the observer O and the star would be OS', but with an absorbing layer a between the observer and the star, the true distance will be OS; that is, the absorbing layer makes the distance smaller, in the same way the large diameter of the disc of the milky way shrinks from about 100,000 to about 80 or 60,000 light years, so that our galactic system approaches the dimensions of the nearest galactic system outside our own, i.e., the Andromeda nebula, whose dimensions on the contrary by photoelectric measurements have been increased. Our milky way system may be just another galaxy.

ABSORPTION WITHOUT REDDENING

This effect seems to be harder to measure than the reddening. But non-selective absorption is found in the case of extra-galactic nebulae in regions where the counted number of nebulae indicate heavy absorption, but where the colors of the nebulae are not very much affected. Moreover faint stars in the dark areas of our milky way would be much redder than they are found to be.

NEW PROBLEMS

Cosmic relativity leads to the idea of an expanding universe. And the astronomers find that the distant nebulae recede from us with a velocity which increases with increasing distance; this conclusion is drawn from the red shifts of the spectral lines and from Doppler's principle. E. Hubble has recently concluded that this leads to a closed model of a radius of about 500 million light years,—a large fraction of which can be observed with existing telescopes, and which is packed with matter to the very "threshold of perception." But the red shifts may not be velocity shifts. This question may be decided by the 200″ telescope and the photo-electric cell which is more sensitive than the photographic plate. One of the problems related to astronomical investigations is a more sensitive and constant photo-electric cell. Research is going on in this connection and results will be published in a future communication.