恒星的运动和宇宙的结构

Stellar Movements and the Structure of the Universe

[英]A.S. 爱丁顿

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BY

A. S. EDDINGTON

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Stellar Movements and the Structure of the Universe

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PREFACE

THE purpose of this monograph is to give an account of the present state of our knowledge of the structure of the sidereal universe. This branch of astronomy has become especially prominent during the last ten years; and many new facts have recently been brought to light. There is every reason to hope that the next few years will be equally fruitful; and it may seem hazardous at the present stage to attempt a general discussion of our knowledge. Yet perhaps at a time like the present, when investigations are being actively prosecuted, a survey of the advance made may be especially helpful.

The knowledge that progress will inevitably lead to a readjustment of ideas must instil a writer with caution; but I believe that excessive caution is not to be desired. There can be no harm in building hypotheses, and weaving explanations which seem best fitted to our present partial knowledge. These are not idle speculations if they help us, even temporarily, to grasp the relations of scattered facts, and to organise our knowledge.

No attempt has been made to treat the subject historically. I have preferred to describe the results of investigations founded on the most recent data rather than early pioneer researches. One inevitable result I particularly regret; many of the workers who have prepared the way for recent progress receive but scanty mention. Sir W. Herschel, Kobold, Seeliger, Newcomb and others would have figured far more prominently in a historical account. But it was outside my purpose to describe the steps by which knowledge has advanced; it is the present situation that is here surveyed.

So far as practicable I have endeavoured to write for the general scientific reader. It was impossible, without too great a sacrifice, to avoid mathematical arguments altogether; but the greater part of the mathematical analysis has been segregated into two chapters (VII and X). Its occasional intrusion into the remaining chapters will, it is hoped, not interfere with the readable character of the book.

I am indebted to Prof. G. E. Hale for permission to reproduce the two photographs of nebulæ (Plate 4), taken by Mr. G. W. Ritchey at the Mount Wilson Observatory, and to the Astronomer Royal, Dr. F. W. Dyson, for the three remaining plates taken from the Franklin-Adams Chart of the Sky. This represents but a small part of my obligation to Dr. Dyson; at one time and another nearly all the subjects treated in this book have been discussed between us, and I make no attempt to discriminate the ideas which I owe to him. There are many other astronomers from whose conversation, consciously or unconsciously, I have drawn material for this work.

I have to thank Mr. P. J. Melotte of the Royal Observatory, Greenwich, who kindly prepared the three Franklin-Adams photographs for reproduction.

Dr. S. Chapman, Chief Assistant at the Royal Observatory, Greenwich, has kindly read the proof-sheets, and I am grateful to him for his careful scrutiny and advice.

I also desire to record my great indebtedness to the Editor of this series of monographs, Prof. R. A. Gregory, for many valuable suggestions and for his assistance in passing this work through the press.

A. S. EDDINGTON.

THE OBSERVATORY, CAMBRIDGE.
April, 1914.

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CHAPTER I

THE DATA OF OBSERVATION

It is estimated that the number of stars which could be revealed by the most powerful telescopes now in use amounts to some hundreds of millions. One of the principal aims of stellar astronomy is to ascertain the relations and associations which exist among this multitude of individuals, and to study the nature and organisation of the great system which they constitute. This study is as yet in its infancy; and, when we consider the magnitude of the problem, we shall scarcely expect that progress towards a full understanding of the nature of the sidereal universe will be rapid. But active research in this branch of astronomy, especially during the last ten years, has led to many results, which appear to be well established. It has become possible to form an idea of the general distribution of the stars through space, and the general character of their motions. Though gaps remain in our knowledge, and some of the most vital questions are as yet without an answer, investigation along many different lines has elicited striking facts that may well be set down. It is our task in the following pages to coordinate these results, and review the advance that has been made.

Until recent years the study of the bodies of the solar system formed by far the largest division of astronomy; but with that branch of the subject we have nothing to do here. From our point of view the whole solar system is only a unit among myriads of similar units. The system of the stars is on a scale a million-fold greater than that of the planets; and stellar distances exceed a million times the distances of the comparatively well-known bodies which circulate round the Sun. Further, although we have taken the stars for our subject, not all branches of stellar astronomy fall within the scope of this book. It is to the relations between the stars—to the stars as a society—that attention is here directed. We are not concerned with the individual peculiarities of stars, except in so far as they assist in a broad classification according to brightness, stage of development, and other properties. Accordingly, it is not proposed to enter here into the more detailed study of the physical characters of stars; and the many interesting phenomena of Variable Stars and Novæ, of binary systems, of stellar chemistry and temperatures are foreign to our present aim.

The principal astronomical observations, on which the whole superstructure of fact or hypothesis must be based, may be briefly enumerated. The data about a star which are useful for our investigations are:—

1. Apparent position in the sky.
2. Magnitude.
3. Type of spectrum, or Colour.
4. Parallax.
5. Proper motion.
6. Radial velocity.

In addition, it is possible in some rather rare cases to find the mass or density of a star. This is a matter of importance, for presumably one star can only influence another by means of its gravitational attraction, which depends on the masses.

This nearly exhausts the list of characteristics which are useful in investigating the general problems of stellar distribution.* It is only in the rarest cases that the complete knowledge of a star, indicated under the foregoing six heads, is obtainable; and the indirect nature of most of the processes of investigation that are adopted is due to the necessity of making as much use as possible of the very partial knowledge that we do possess.

The observations enumerated already will now be considered in order. The apparent position in the sky needs no comment; it can always be stated with all the accuracy requisite.

Magnitude.—The magnitude of a star is a measure of its *apparent* brightness; unless the distance is known, we are not in a position to calculate the intrinsic or absolute brightness. Magnitudes of stars are measured on a logarithmic scale. Starting from a sixth magnitude star, which represents an arbitrary standard of brightness of traditional origin, but now fixed with sufficient precision, a star of magnitude 5 is one from which we receive 2·512 times more light. Similarly, each step of one magnitude downwards or upwards represents an increase or decrease of light in the ratio 1 : 2·512.† The number is so chosen that a difference of five magnitudes corresponds to a light ratio of $100 = (2{\cdot}512)^5$. The general formula is

$$\log_{10} \frac{L_1}{L_2} = -0{\cdot}4\,(m_1 - m_2),$$

where

L_1, L_2 are the intensities of the light from two stars
m_1, m_2 are their magnitudes.

Magnitude classifications are of two kinds: photometric (or visual), and photographic; for it is often found that of

* We should perhaps add that the separations and periods of binary stars are also likely to prove useful data.

† It is necessary to warn the reader that there are magnitude systems still in common use—that of the Bonn Durchmusterung, that used by many double-star observers, and even the magnitudes of Boss's Preliminary General Catalogue (1910)—which do not conform to this scale.

two stars the one which appears the brighter to the eye leaves a fainter image on a photographic plate. Neither of the two systems has been defined very rigorously; for, when stars are of different colours, a certain amount of personality exists in judging equality of light by the eye, and, if a photographic plate is used, differences may arise depending on the colour-sensitiveness of the particular kind of plate, or on the chromatic correction of the telescope object-glass. As the accuracy of magnitude-determinations improves, it will probably become necessary to adopt more precise definitions of the visual and photographic scales; but at present there appears to be no serious want of uniformity from this cause. But the distinction between the photometric and photographic magnitudes is very important, and the differences are large. The bluer the colour of a star, the greater is its relative effect on the photographic plate. A blue star and a red star of the same visual brightness may differ photographically by as much as two magnitudes.

The use of a logarithmic scale for measuring brightness possesses many advantages; but it is liable to give a misleading impression of the real significance of the numbers thus employed. It is not always realised how very rough are the usual measures of stellar brightness. If the magnitude of an individual star is not more than $0^{m}\cdot 1$ in error, we are generally well satisfied; yet this means an error of nearly 10 per cent. in the light-intensity. Interpreted in that way it seems a rather poor result. An important part of stellar investigation is concerned with counts of the number of stars within certain limits of magnitude. As the number of stars increases about three-fold for each successive step of one magnitude, it is clear that all such work will depend very vitally on the absence of systematic error in the adopted scale of magnitudes; an error of two- or three-tenths of a magnitude would affect the figures profoundly. The establishment of an accurate magnitude-system, with sequences of standard stars, has been a matter of great difficulty, and it is not certain that even now a sufficiently definitive system has been reached. The stars which come under notice range over more than twenty magnitudes, corresponding to a light ratio of 100,000,000 to 1. To sub-divide such a range without serious cumulative error would be a task of great difficulty in any kind of physical measurement.

The extensive researches of the Harvard Observatory, covering both hemispheres of the sky, are the main basis of modern standard magnitudes. The Harvard sequence of standard stars in the neighbourhood of the North Pole, extending by convenient steps as far as magnitude 21, at the limit reached with the 60-inch reflector of the Mount Wilson Observatory, now provides a suitable scale from which differential measures can be made. The absolute scale of the Harvard sequence of photographic magnitudes has been independently tested by F. H. Seares, at Mount Wilson, and S. Chapman and P. J. Melotte, at Greenwich. Both agree that from the tenth to the fifteenth magnitudes the scale is sensibly correct. But according to Seares a correction is needed between the second and ninth magnitudes, $1^{m}\cdot00$ on the Harvard scale being equivalent to $1^{m}\cdot07$ absolute. If this result is correct, the error introduced into statistical discussions must be quite appreciable.

For statistical purposes there are now available determinations of the magnitudes of the stars in bulk made at Harvard, Potsdam, Göttingen, Greenwich and Yerkes Observatories. The revised Harvard photometry gives the visual magnitudes of all stars down to about $6^{m}\cdot5$; the Potsdam magnitudes, also visual, carry us in a more limited part of the sky as far as magnitude $7^{m}\cdot5$. The Göttingen determinations, which are absolute determinations, independent of but agreeing very fairly with the Harvard sequences, provide photographic magnitudes over a large zone of the sky for stars brighter than $7^m{\cdot}5$. The Yerkes investigation gives visual and photographic magnitudes of the stars within 17° of the North Pole down to $7^m{\cdot}5$. A series of investigations at Greenwich, based on the Harvard sequences, provides statistics for the fainter stars extending as far as magnitude 17, and is a specially valuable source for the study of the remoter parts of the stellar system.

So far we have been considering the apparent brightness of stars and not their intrinsic brightness. The latter quantity can be calculated when the distance of the star is known. We shall measure the absolute luminosity in terms of the Sun as unit. The brightness of the Sun has been measured in stellar magnitudes and may be taken to be $-26^m{\cdot}1$, that is to say it is 26·1 magnitudes brighter than a star of zero magnitude.* From this the luminosity L of a star, the magnitude of which is m, and parallax is ϖ'', is given by

$$\log_{10} L = 0{\cdot}2 - 0{\cdot}4 \times m - 2 \log_{10} \varpi.$$

The absolute magnitudes of stars differ nearly as widely as their apparent magnitudes. The feeblest star known is the companion to Groombridge 34, which is eight magnitudes fainter than the Sun. Estimates of the luminosities of the brightest stars are usually very uncertain; but, to take only results which have been definitely ascertained, the Cepheid Variables are *on an average* seven magnitudes brighter than the Sun. Probably this luminosity is exceeded by many of the Orion type stars. There is thus a range of at least fifteen magnitudes in the intrinsic brightness, or a light ratio of 1,000,000 to 1.

* The most recent researches give a value −26·5 (Ceraski, *Annals of the Observatory of Moscow*, 1911). It is best, however, to regard the unit of luminosity as a conventional unit, roughly representing the Sun, and defined by the formula, rather than to keep changing the measures of stellar luminosity every time a better determination of the Sun's stellar magnitude is made.

Type of Spectrum.—For the type of spectrum various systems of classification have been used by astrophysicists, but that of the Draper Catalogue of Harvard Observatory is the most extensively employed in work on stellar distribution. This is largely due to the very complete classification of the brighter stars that has been made on this system. The classes in the supposed order of evolution are denoted by the letters :—

O, B, A, F, G, K, M, N.

A continuous gradation is recognised from O to M, and a more minute sub-division is obtained by supposing the transition from one class to the next to be divided into tenths. Thus B5A, usually abbreviated to B5, indicates a type midway between B and A; G2 denotes a type between G and K, but more closely allied to the former. It is usual to class as Type A all stars from A0 to A9; but presumably it would be preferable to group together the stars from B6 to A5, and this principle has occasionally been adopted.

For our purposes it is not generally necessary to consider what physical peculiarities in the stars are represented by these letters, as the knowledge is not necessary for discussing the relations of motion and distribution. All that we require is a means of dividing the stars according to the stage of evolution they have attained, and of grouping the stars with certain common characteristics. It may, however, be of interest to describe briefly the principles which govern the classification, and to indicate the leading types of spectrum.

Tracing an imaginary star, as it passes through the successive stages of evolution from the earliest to the latest, the changes in its spectrum are supposed to pursue the following course. At first the spectrum consists wholly of diffuse bright bands on a faint continuous background. The bands become fewer and narrower, and faint