DOUBLE STAR ASTRONOMY*

DOUBLE star astronomy has always played a major part in the development of astrophysics. Its importance lies in the data it provides in formulating a consistent theory of stellar evolution. The ultimate problem of the study of binary stars is to gain an understanding of the cosmic processes which led to their formation, or which may control their astronomical future. As early as 1902, A. W. Roberts in the pioneer days of double star astronomy wrote : "the study of Algol variables should bring us to the very threshold of the question of stellar evolution, and to the heart of not a few of the greatest cosmical problems". The evolution of stars constitutes a process so slow when measured in terms of human time-scales that no changes arising from it can become perceptible within the brief period of a few centuries over which the subject has been studied. Hence the only method of testing theories of stellar evolution that have been propounded from time to time is to compare the theoretical deductions with the observed *statistical* properties of different types of stellar populations. The success of such tests will naturally depend on the range of information that can be gathered from observations of the various stellar types. In this context double star astronomy plays a unique role in that there is no other branch of practical astronomy which can supply such a wealth of data as can be obtained from detailed studies of close binary systems, especially of the eclipsing type. Close binaries are not a rare phenomenon either. At least seven eclipsing variables are known within 30 parsecs from the Sun, and as this volume contains some 3,000 stars, eclipsing binaries constitute about 0·2%, and the total number of binaries for all values of celestial inclinations may be in the neighbourhood of 1%, that is, in our galactic system as a whole the number of close binaries may be estimated as of the order of 10^9.

As a result of systematic work on the orbital and other characteristics of close binary systems in the galaxy many unexpected and exciting results have emerged. One such is Kuiper's deduction that the solar system is a degenerate double star in which the second mass did not condense into a single star but was spread out, and formed planets and comets. Another recent advance is the finding of Struve that close binaries interact not only dynamically but also *physically* and that there is frequently an interchange of matter from one star to its companion. These results together with the fact which recent studies have fairly well established, namely, that many of the very close binaries are evolving, so to say, right before our eyes, have made the study of close binary systems a subject of paramount importance in contemporary stellar astronomy. Visual binaries are sometimes separated by hundreds—often thousands—of astronomical units (AU, distance of Sun from the earth), so that several generations of astronomers are needed to observe even a small part of their orbital motion, but close binaries may make thousands of revolutions in a comparatively short time. For example, the binary star UX *Ursæ Majoris* completes one revolution in 4 hours 43 minutes, the shortest known period among binaries. The great significance of many short-period systems is that they give evidence of physical change taking place during the microscopically short lifetime of an astronomer, and there is some chance of his studying at least a small portion of the life-history of this type of stars. Such stars may truly be said as the astronomers' *drosophilæ*.

The term binary star was first used by Sir William Herschel in 1802, to designate a *real double star* which is "the union of two stars that are formed together in one system by the laws of attraction". It is to be distinguished from what is popularly referred to as "double star" to describe a close pair of stars which are really different in distance and age, having no physical connection, and owe the proximity of their projections on the celestial sphere only to the laws of chance. Double star systems vary widely both as regards their period, and the separation of the components. Their periods range from a few hours to about 10^7 years. As regards separation, there are pairs in which the components are almost in contact (contact binaries), and those in which the separation is of the order of 44,000 AU.

Binary systems are of two types : (*i*) wide (or visual) binaries which are resolvable through a telescope, and (*ii*) close binaries, which although they are not resolvable by telescopes, may yet be identified as binaries either (*a*) by the periodic variation of intensity (eclipsing binaries), or (*b*) by observing spectroscopically the Doppler shift due to varia-

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* *Close Binary Systems*. By Zdenek Kopal. International Astrophysical Series, Vol. V. (Published by Chapman and Hall, Ltd.), 1959. Pp. xvi + 558. Price 105 *sh*.

tion in their radial velocity (spectroscopic binaries). Both eclipsing and spectroscopic binaries belong to the same physical group and differ in their observable manifestations only by an accident of orientation of their orbits in space.

Wide binaries are of limited interest from the point of view of getting information; for apart from their mutual attraction which makes them to revolve in closed orbits around their common centre of gravity, the components do not influence each other in any other way, but behave, and probably also evolve, like single stars in space. The distance between wide binaries are very large compared to their stellar diameters. With increasing proximity, however, there will be mutual dynamical interaction between the two, and distortions and perturbations of significance will arise from tidal actions and axial rotations. The shape of the individual components will depart from a sphere, and provided that the free oscillations of the components are sufficiently short in comparison with the period of the orbit, the appropriate distortion of both will be governed by the equilibrium theory of tides, *i.e.*, the component stars will be distorted ellipsoids.

In interpreting the observed changes in the brightness of close binary systems, the effects of the distortion will have to be taken into account. Since the components of the eclipsing binaries are distorted ellipsoids with their longest axes constantly in the direction of the radius-vector, their apparent area—and, therefore, the light—as seen from the earth should vary continuously in the course of a revolution (*ellipticity effect*). It will also happen that part of the radiation of each component will fall on the other where it will be absorbed and re-emitted in all directions. This produces the *reflection effect*. These effects in the intensity of the light from close binaries will be in addition to, and independent of the light changes which arise from eclipses. The theoretical distribution of brightness over their apparent discs as seen by a distant observer can be deduced from the laws of limb-darkening and gravity-darkening as shown by Chandrasekhar. It may be noted that the limb-darkening tends to make brightest those parts of the visible surface which are nearest to the observer, the gravity-darkening those which are nearest to the star centre. The theory of the determination of the orbital elements of close binary systems from the properties of the photometric light curves, developed by Russell and Shapely, has enabled astronomers to estimate the sizes and shapes of component stars, as well as their luminosities and separations. Because many factors influence the shape of the light curve, complete analysis is often difficult.

It is in this particular field of investigation that Prof. Kopal, the author of the book under review, has made many significant contributions, and so the book is authoritative on the subject. It gives first-hand knowledge of the methods by which photometric and spectroscopic observations of close binary systems can be analysed to yield all possible information about their components. After the first introductory chapter, Chapter II deals with the general dynamics of close binary systems. Chapter III discusses the geometrical analysis of the Roche model or the centrally condensed model in which the components of the system are represented, for gravitational purposes, by two mass points. The importance of this model and the significance of what is shown as the Roche limit, in the author's theory of the evolution of binary systems, have been brought out clearly in a later chapter. Chapters IV and V contain a systematic development of the theoretical light-, and radial velocity-curves exhibited by distorted rotating components of close binary systems, between minima, as well as within eclipses. Chandrasekhar's elegant proof of von Zeipel's theorem relating to radiation flux in distorted stars is included here.

The most important chapter in the whole book is Chapter VI which covers nearly a third of the book. It deals with the determination of the elements of eclipsing binary systems from an analysis of their observed light changes. As mentioned already, the author himself is noted for his many contributions in this branch of the subject and, in fact, the contents of this chapter are largely a consolidated account of these contributions in what is known as Kopal's iterative methods, as opposed to the well-known direct method developed by Russell and Shapely. The concluding Chapter VII is on physical properties of close binary systems, and in the last section of this chapter the author, taking stock of all the known facts of binary systems, explains what they reveal concerning the origin and evolution of binary stars.

The origin of close binary systems is no doubt to be sought in the same general processes which lead to the formation of stars. The accepted theory is that the stars originate by a gravitational collapse of cosmic gas-clouds containing enough mass to give birth to hundreds or thousands of individual stars at the same time. Close binaries were formed simultaneously with single stars as by-products of essentially the same formative process. It is also evident that the chemical composition of the two components in each pair was initially the same at the time of formation. Their masses, however, were different and this has made all the difference in their subsequent evolution. The story of this evolution containing new ideas is told in the last chapter of the book.

This volume amply fulfils the main purpose of the International Astrophysical Series, which is to provide an authoritative account of the subjects in a manner to assist their teaching and advancement.

UNITED STATES' SUCCESS IN MANNED SPACE FLIGHT

A NOTABLE success in space flight was achieved by United States when on May 5, 1961, it sent a man into space and recovered him safely. The astronaut was 37-year old Commander Alan Shepard of the United States Navy. The space capsule in which Shepard rode was 6 ft. × 9 ft., a little bigger than a telephone booth, and weighed about one ton. It was blasted into the sky in the 66 ft. Redstone rocket from the missile base at Cape Canaveral, Florida, at 9·34 a.m. (14·34 GMT) on Friday, May 5, 1961. The capsule soared in a vast ballistic arc over the Atlantic and plummetted into the sea inside a ring of recovery ships just fifteen minutes later. Shepard climbed out of the capsule unaided and was winched to safety by a marine helicopter which landed both astronaut and capsule on the deck of the recovery ship, the aircraft carrier Lake Champlain stationed 290 miles downrange from the site of launching. The historic flight was the climax of two and a half years' work and 400 million dollars expenditure. It closely followed Russia's success in the first manned space flight just 23 days previously when on April 12, Major Gagarin orbited the earth once round in his 108-minutes flight in the space ship Vostok (*see Curr. Sci.*, April 1961).

The essential details of the US space flight have been reported as follows: The weather this morning was fine and Shepard was driven out to the launching pad in a van. His aluminised space suit gleamed in the glare of the arc lights as he squeezed through the tiny hatch of the capsule and wriggled on to the specially contoured couch. Shepard was sealed in the capsule at 6-10 a.m. (11·10 GMT). At blast-off, flame leaped from the base of the rocket and it began to lift into the air with a shattering roar, ponderously at first, then with gathering speed. Shepard was forced deep into his form-fitting couch by the fierce gravitational pull as the rocket vanished into the clouds and accelerated to a speed of over 4,000 miles per hour in a few seconds. Shepard's voice crackled into the tense control room. His first words were—"what a beautiful view". From then on, he reported continuously to the control room on how he felt and the behaviour of the rocket. He spent much of the flight with his eyes shut, reading the instruments by touch, as he fought the massive strain of 11 G.—eleven times the force of gravity. Subsequently Shepard reported: "I am now experiencing six G's-, five G's-, four G's-.

The capsule separated from the rocket when it was 90 miles up, and Shepard took over manual control of the capsule and performed basic manœuvres in different directions. He performed a roll successfully. He reported he had fired the retro-rockets to slow down the capsule before it plunged into the Atlantic. After being weightless for several minutes, Shepard prepared for the critical re-entry into the earth's atmosphere. He talked to recovery ships. Moments later slowed by the retro-rockets, the capsule decelerated further as Shepard opened his secondary parachute. Then the great red and white main parachute opened and watchers on the recovery ships saw the capsule for the first time as it drifted down to the Atlantic. A landing bag beneath the capsule inflated to cushion the fall when the capsule hit the sea 80 miles north-west of Grand Bahama island and three miles from the aircraft carrier Lake Champlain. Shepard climbed out of the capsule as a marine helicopter swooped down on him. Three minutes later he was aboard the helicopter, which also winched up the capsule.

An official announcement by the National Aeronautics and Space Administration (NASA) said: "The Project Mercury spacecraft carrying astronaut Alan Shepard on the nation's first manned flight landed on the Atlantic Ocean about 302 statute miles from here at 9-49 a.m. E.S.T. The altitude was about 115 miles, the speed about 5,100 miles per hour. The sub-orbital flight required 15 minutes. Preliminary data show the pilot performed satisfactorily during flight." The blast-off time was officially announced as 9 hours 34 minutes and 13 seconds a.m.
