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BOOK REVIEWS

Binary and Multiple Stars as Tracers of Stellar Evolution*

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These proceedings comprise 62 papers, largely reflecting the substance of talks given at the Colloquium. No transcripts of the discussion from the floor are provided. There are four parts to the volume: I) Evolution of stars in the post–main sequence stage; II) Evolutionary trends in wide binary systems; III) Evolutionary processes in close binary systems: IV) Cataclysmic binaries and their role in stellar evolution. Each part opens with an introductory survey, and the volume closes with an index of subjects and individual stars.

Reviewing the course of evolution in the red giant stage, R. Kippenhahn (Max-Planck-Institute für Astrophysik, Garching) considers stars of low ($M \leq 1.4\ M_\odot$) and intermediate (1.4-$10\ M_\odot$) mass, with emphasis on a qualitative account of certain mixing effects and flash burning of elements, which manifest themselves in stellar evolutionary tracks. Detailed evolutionary calculations for intermediate-mass stars in the red giant stage indicate that a deep convection zone will develop, "dredging up" heavy elements after the core helium flash occurs. In principle the dredge-up mechanism might explain the existence of carbon stars, although quantitative difficulties arise. The giants in certain globular clusters differ in composition from field stars of the same type, suggesting the massive clusters contain an auxiliary source of chemical change in stellar surface layers, which may be accreting some material ejected by supernovae or other eruptive stars that belong to the cluster.

Low-mass stars, which lack core convection, undergo a curious behavior: after the helium in the core is ignited during the red giant stage, burning proceeds not at the very center but in a shell source, where maximum temperature is reached (the central temperature will be lower, due to neutrino cooling). As carbon accumulates in the shell source, convective mixing will occur from time to time because the presence of a heavy fluid layer (He + C) above a light layer (He) is an unstable situation. Evolutionary calculations for the stage following the giant branch show that the prolonged horizontal branch in globular clusters cannot merely reflect age differences among the member stars. The loops that a star describes in the H-R diagram after the red giant stage have a small span and can account only for the far right section of the horizontal branch. In order to explain the whole horizontal branch, especially its blue left-hand end, one has to suppose that when they are red giants at least some stars lose much of their initial mass by shedding from the envelope. The more intensive the mass loss, the farther the evolutionary tracks of these stars will shift blueward. Generally speaking, we have to guarantee as yet that models of the helium-flash stage represent the processes correctly. In fact, work done in the past few years indicates that we may still be in for some qualitative revisions in our ideas about the behavior of stars during this phase of their evolution.

A brief note by F. Meyer and E. Meyer-Hofmeister (MPI Garching) deals with the Hubble–Sandage variables, the brightest individual objects ($L \approx 10^5\ L_\odot$) observed in external galaxies. These blue, F-type variables display irregular light variations. It has just recently been shown that the Hubble–Sandage variables are binaries, comprising a main-sequence star of $\approx 15\ M_\odot$ and a companion, presumably a giant, overfilling its Roche lobe. Color simulations suggest that much of the luminosity comes from an accretion disk around the normal component. The accretion rate would be quite high ($\approx 3 \cdot 10^{-3}\ M_\odot/\mathrm{yr}$), and the central part of the disk should be subject to instability due to the radiation pressure. As a result the disk from time to time may rapidly, in a convective regime, turn into a spherical isentropic envelope surrounding the normal star or perhaps even both components. The process would operate on a time scale of 1-10 yr. Perhaps such an event caused the change in color index from $0^m.3$ to $1^m.5$ reported by Hubble and Sandage for the star Var A in M33.

G. Russo (Naples) points out that binary-system effects should play a major role in the evolution of Cepheids. The data suggest that about 25% of all Cepheids have blue companions, an estimate which can be much improved by satellite ultraviolet observations. Two notes by E. Antonello et al. (Milan) list visual and spectroscopic binaries that contain definite or suspected δ Scuti variables. Pulsational variability of stars in the lower part of the instability strip, evidently involving nonradial oscillation modes, might be induced by rapid rotation of the variable or by the tidal action of its companion. The axial rotation of the variable and its orbital motion in the binary system should then be asynchronous. Slow axial rotation or synchronous orbital motion would on the contrary inhibit development of pulsational variability, but could give rise to the Am star phenomenon. For example, in the Hyades 18 objects (excluding Am stars) are in the lower part of the instability strip: 7 variables and 11 stable stars. Six of the variables are spectroscopic binaries, but only three of the stable stars.

A. Giménez and J. M. García-Pelayo (Granada) have studied the stellar internal-structure parameter k_2 by analyzing the apsidal motion in close binary systems. They find that the evolution of k_2 is strongly correlated with the surface gravity of the star, in reasonable agreement with evolutionary calculations. In fact the past few years have seen considerable improvement in the fit between theoretical and empirical values of k_2. T. Panchatsaram and K. D. Abhyankar (Hyderabad) have investigated the secular and periodic variability in the orbital periods

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of 22 eclipsing binaries. In most cases the change in orbital period reflects exchange of material between the components or mass loss from the system, but in some instances effects from a third component are definitely present.

P. van de Kamp (Swarthmore) opens Part II with a concise review of progress in studies of visual binary stars. Much of what has been achieved stems from van de Kamp's own activity over the past half century. He points out that the components of a wide binary will often be in completely different evolutionary stages, so it is hard to accept a joint, simultaneous formation. In the solar neighborhood the stellar multiplicity coefficient is fully 1.3; that is, every 100 objects actually comprise 230 component stars. Among visual binaries whose orbits have been determined, 18% contain a third component while 6% have four to six components. Conceivably the sun might have a companion star; if so, it ought to exhibit a large parallax but a relatively small proper motion. Incidentally, in 1981 the D. Reidel Publishing Company brought out a monograph by van de Kamp, entitled "Stellar Paths."

Several of the papers deal with topics in ongoing star formation. V. Vanýsek (Prague) states that the spatial distribution of the small, dense clouds containing pointlike infrared sources often resembles clusters of OB stars such as the Trapezium. The separate cloudlets tend to be ≈ 0.1 pc apart, about the same as in Trapezium systems. Cloudlets also group together in the dense parts of molecular complexes, in company with OH and H_2O masers and compact H II regions (OMC 1 and 2, W3, and Mon R2 are examples). The infrared source in these cloudlets has a bolometric luminosity of order 10^4–10^5 $L_\odot$. This circumstance, as well as the presence of recombination lines and silicate-grain absorption at $\lambda = 10\ \mu$ suggests that such clouds may contain a young OB star or one that is just forming. At 6-cm wavelength the best-studied cloudlets measure 1-10 AU across, and contain 0.3-3 $M_\odot$ of gas. Thus along with the OB star the cooling and gravitational fragmentation of a cloudlet can only produce a low-mass star. Since a 1 $M_\odot$ star will take 500 times as long to reach the main sequence as the OB star, one would expect many main-sequence OB stars to have a low-luminosity pre–main sequence companion, such as a T Tauri or YY Orionis star.

H. Zinnecker (MPI Garching) puts forward an interesting hypothesis: assuming that the excess angular momentum of protostars is transferred to the interstellar medium by its magnetic field, and regarding the interstellar field strength as rising toward the galactic center, Zinnecker predicts that the proportion of double and multiple stars should diminish toward the galactic center and increase toward the periphery of the Galaxy. Thus the dark halos of galaxies might contain a great many binary systems of very low mass.

E. I. Popova et al. (Astronomical Council, Moscow) have been studying the correlation between the major semiaxis a of the orbits of spectroscopic binaries and the mass M_1 of the primary component. Extensive material has been used: observations of 333 systems with both spectra visible. The authors confirm a result first reported by M. A. Svechnikov: there are hardly any systems with $a \lesssim 10\ R_\odot$ and $M_1 \gtrsim 1.5\ M_\odot$. To interpret this fact in a general way, they suggest that during the Hayashi accretion stage a $\approx 2\ M_\odot$ star will have a radius of $\approx 30\ R_\odot$, so two such stars cannot develop close together. Binaries with $M_1 < 1.5\ M_\odot$ may intensively lose angular momentum, because these low-mass stars will possess strong chromospheric activity and thereby a heavily magnetized stellar wind. Hence only systems of this kind can develop into near-contact binaries as they envolve toward the main sequence.

In his review to open Part III, M. J. Plavec (University of California, Los Angeles) describes the major advances in studying hot binary-system components that have been made possible by the IUE and Copernicus satellites, with their ultraviolet telescopes. These facilities have brought us closer to resolving the enigma of the peculiarities posed by the eclipsing system ε Aurigae: the spectrum of a hot secondary component surrounded by an accretion disk has been detected, and it is thought to be responsible for eclipsing the primary F0 Ia supergiant. While recent work has led to some understanding and to a genetic arrangement for many types of binary and nonstable stars, several celebrated objects (ε Aur, β Lyrae, and above all SS 433) still seem to be altogether unique, or at any rate extreme representatives of their class.

One classic problem for close binary systems is to study the accretion disks around relativistic components. Analytic solutions of this problem generally treat the inner part of the disk, which may be considered azimuthally symmetric. Now G. Hensler (Göttingen) describes a three-dimensional numerical method for simulating the accretion process in a close binary. In the magnetohydrodynamic approximation this technique enables one to investigate the spatial structure of the accretion disk, including the hot spot and the strongly distorted outer part of the disk where the accreting gas is changing over from linear to circular motion. Such a numerical approach does have its limitations, for it neglects the self-gravitation of the disk; it is therefore applied to systems having a disk of small mass, $\approx 10^{-10}\ M_\odot$. To study massive disks ($\approx 0.5\ M_\odot$), R. E. Wilson (Gainesville) has developed an analytic method which he has applied to model the disk in the β Lyr system. The simulation fits the observations quite well.

N. P. Red'kina and G. P. Chernova (Dushanbe) report near-synchronous photoelectric photometry and polarimetry of T Tau and RY Tau. In T Tau the polarization varies cyclically with a $5^h.18$ period; presumably it results from free-electron scattering in the star's gaseous envelope. The polarization variability of RY Tau exhibits two modes; perhaps the star is indeed double. F. van't Veer (Paris) argues that in the old open cluster NGC 188 (its H-R diagram indicates an age of $5 \cdot 10^9$ yr) successive bursts of star formation have occurred $(1\text{-}2) \cdot 10^9$ yr apart. The last of these era evidently produced the four W Ursae Majoris stars observed in this cluster—contact binaries completely atypical of old star clusters.

The origin of the W UMa stars is discussed by T. Rahunen and O. Vilhu (Helsinki). In principle, contact binaries can form in either of two ways: a) a rapidly rotating protostar may split in two at the close of its contraction phase; b) angular-momentum loss may bring the

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components of a detached or semidetached pair together. Of the several mechanisms of momentum loss, the one most often envisaged is magnetic braking. This idea would fit in with the correlation between rotational velocity and chromospheric activity recently established for single stars. In solar-type stars the surface rotational velocity diminishes with age ($v_{\mathrm{rot}} \propto t^{-1/2}$), as does the Ca^+ emission. Presumably these two parameters become correlated as follows: the rotation is braked by magnetized stellar wind whose intensity is related to the strength of the dynamo effect in the star's outer convection zone, and the dynamo effect itself weakens as the rotation slows down. In close binaries, tidal friction will tend to synchronize the spin and orbital motions of the components. Hence the loss of spin angular momentum by the mechanism described above will serve not to retard but to accelerate the rotation, for the orbital angular momentum will act as a "reservoir" to increase the spin angular momentum. As a result the momentum loss rate in close binaries, rather than diminishing with time as in single stars, will increase to the point where the stars may coalesce during their lifetime. As a rule the components should coalesce when the more massive star becomes a giant. Very likely we are observing the final step of this process in the rapidly rotating giants of the FK Comae Berenices class. Comparison of the nuclear and thermal (Kelvin–Helmholtz) time scales for main-sequence stars [$\tau_{\mathrm{nuc}} \approx 10^{10}\ (M/M_\odot)^{-3.5}$ yr, $\tau_{\mathrm{th}} \approx 3 \cdot 10^7\ (M/M_\odot)^{-3.5}$ yr] indicates that W UMa stars cannot have a very small mass ratio ($q \geqslant 0.2$). In fact, the observations tell us that the components are of comparable mass. Rahunen and Vilhu have worked out a numerical model for a close binary system ($1\ M_\odot + 0.6\ M_\odot$) which experiences a cyclic ($6 \cdot 10^6$ yr period) mass exchange between the components.

Upon processing the IUE satellite ultraviolet spectra of the W UMa system, S. M. Ruciński (Warsaw), J. E. Pringle (Cambridge, England), and the late J. A. J. Whelan found that the more massive component is also the more chromospherically active. With the same satellite Y. Kondo (Goddard Space Flight Center) and G. E. McCluskey (Lehigh University) obtained spectra of the eclipsing binary R Arae. This system displays unique ultraviolet flux variations in between eclipses, suggesting it is in a rare evolutionary phase. The components of the Si IV and Mg II resonance absorption lines are Doppler-shifted by ≈ -500 km sec, representing evidence of mass loss from the system.

Several of the papers at the Colloquium concerned white dwarfs. V. Weidemann (Kiel) has evaluated the mass of white dwarfs that belong to close binary systems (cataclysmic variables) or are nuclei of planetary nebulae. His average value, $0.7\ M_\odot$, can be understood if these stars undergo strong mass loss during their binary evolution. W.-Y. Law and H. Ritter (MPI Garching) outline a scenario for white dwarf evolution in a close binary system. Unlike single white dwarfs, whose mass spectrum peaks sharply near $0.6\ M_\odot$, white dwarfs in binaries are distributed almost uniformly with respect to mass from about 0.3 to $1.3\ M_\odot$. These authors believe that white dwarfs with $M \leqslant 0.8\ M_\odot$ may develop when a low-mass binary component loses angular momentum during the phase when the components are moving within a common envelope. White dwarfs with $M \geqslant 1\ M_\odot$ may result from the evolution of a massive star which leaves behind a carbon–oxygen core whose mass is close to the Chandrasekhar limit.

The most thorough analysis of supernovae exploding in close binary systems is that given by J.-P. De Cuyper (Brussels). In a sense his investigation culminates the research on this subject: it includes such effects as the eccentricity of the initial orbit, the asymmetric ejection of the supernova envelope, and the interaction of the envelope with the secondary component. The only simplification here is the premise that the shell is ejected instantaneously. De Cuyper compares the results of his calculations against the parameters of binary systems containing presupernovae (Wolf-Rayet + OB binaries) as well as the distribution of pulsars and high-velocity (runaway) OB stars.

Two articles in the volume deal with a unique galactic object, the source SS 433. R. Ruffini (Rome) reviews the observed properties of this x-ray and radio source and discusses some proposed models. A detailed account is given of Ruffini's own model of a relativistic disk around a low-mass black hole. G. W. Collins and G. H. Newsom (Ohio State University) draw attention to the secular changes in the parameters of their kinematic model of SS 433. They consider that not only is the period of the precessing source variable, but also the angle of the precession cone. Collins and Newsom explain the kinematic parameters of the source and their variability by a model in which the rotation axis of a normal, magnetized massive star is precessing due to the tidal action of the companion star.

On the whole the Colloquium proceedings leave a very good impression. The book fully reflects the current status of evolutionary studies for double and multiple stellar systems. New theoretical methods and models are set forth, as well as much fresh observational material. Particularly impressive are the satellite ultraviolet and x-ray observations, which have disclosed hot components in binary systems and the stellar coronae that play so large a role in the dynamical evolution of rotating stars. But lest astronomers flatter themselves too much with their success in learning about binary stars, Zdeněk Kopal (Manchester), co-editor of the proceedings, addresses his concluding remarks to the unsolved problems posed by the binaries in the spherical subsystem of our Galaxy and the evolutionary paradox of Sirius, among other matters. Kopal's remarks may serve as a good outline for future research programs.

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