COMMISSION 26 : DOUBLE AND MULTIPLE STARS

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Introduction

The observational study of double and multiple stars is traditionally seen as comprised of several specialized subfields, each defined by particular observational selection effects. Improvements in increased precision and accuracy, higher resolution, higher signal-to-noise ratios, greater sensitivity *etc.*), are leading the study of double stars to a truly coherent field. Significant advances in ground-based spectroscopy and interferometry provide a framework from which we can prepare for the future. The contributions to be made from space are currently in a state of uncertainty as we await results from the Hubble Space Telescope and Hipparcos.

This report has been prepared by the commission president solely from contributions from members of Commission 26 and therefore can only represent highlights of the activities surrounding double and multiple stars. If there is a theme to this report it is that we are presently in a state of transition from classical and standard methods to a situation in which the mysteries of almost any given system can be thoroughly unveiled through the applications of many complementary observational tools. The primary new tool will be long-baseline optical interferometry, a method capable of resolving all but the closest binaries. The combination of high spatial resolution interferometry with high precision spectroscopy will revolutionize double star astronomy.

Visual and Photographic Measures and Orbital Analyses

Several individuals and groups report continuing programs of visual micrometry. P. Couteau of the Observatoire de la Côte d'Azur, using 50 cm and 74 cm refractors at Nice and the 2 m telescope at Pic du Midi, has discovered 156 new binaries and compiled 1800 measures of COU stars and other close visual and interferometric pairs. Nearly 2600 systems have been discovered to date by Couteau, and a *Catalogue de 2550 Couples COU* has been compiled. Couteau has written a history of double star astronomy through the present time entitled *Ces Astronomes Fous du Ciel.* Orbital analysis is concentrating on systems of particular interest to stellar evolution through the location of the components on the HR diagram to determine ages. Methods of determining the orbital constant a^3/P^2 without the remaining elements have been developed for statistical applications. Also using the 50 cm Nice refractor, P. Muller has made 1,612 micrometer measures and has completed his polar survey in the zone ($+52° \leq \delta \leq +79°$). 3,300 of the original sample of 37,000 stars remain to be examined at the highest declinations. 700 pairs have been discovered and 60 more are expected.

In Spain, J.A. Docobo, J.F. Ling, J.M. Costa, and C. Prieto of the Observatorio Astronomico "Ramón María Aller" of the Universidade de Santiago de Compostela collaborate with A.C. Elipe, A.J. Abad and V. Lanchares of the Universidade de Zaragoza. Visual observations have been carried out at the Observatoire de la Côte d'Azur (through a cooperation with P. Couteau) as well as at the 1.2 m Calar Alto telescope. Spanish facilities include the 38 cm refractor of the Fabra Observatory (Barcelona) and the 12 cm refractor and 35.6 cm reflector at Santiago de Compostela. Photographic observations of multiple stars have been conducted with the 40 cm double astrograph at the Yebes Astronomical Center (Guadalajara). Orbits have been calculated for 15 systems using an analytical method developed by Docobo. Theoretical activities have included new methods for solving visual edge-on orbits and orbits of spectroscopic/interferometric binaries from combined data, and for applying hierarchical relative coordinates to the analysis of subsystems of many-body problems. A stroboscopic method has been appled to multiple star systems.

M. Scardia, of the Osservatorio Astronomico di Brera (Italy), began in 1986 a systematic program at ESO with the GPO 38 cm refractor. During 7 observing sessions for a total of 184 nights, Scardia obtained 1840 measures of pairs with $\rho \geq 0''.18$. Scardia has now produced 2898 measures since 1982 using instruments at Merate, Collurania, La Silla, and Nice and has contributed to the CCDM through

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measurement of photographic plates containing known and unknown pairs. He has continued the calculation of new and improved orbits.

N. Wieth-Knudsen (Frederiksberg, Denmark) has developed a method of orbit determination from a short arc using the coefficients of power series in time. He continues to make measurements with a Muller-type micrometer and has translated into Danish, papers encouraging amateur astronomers to carry out visual micrometer observations. Amateur activities of the Société Astronomique de France (Commission des Etoiles Doubles) are reported by J. Dommanget to include original measurements and the indentification of relatively close pairs on finding charts.

J. Dommanget, coordinator of the Double Star Working Group of the Hipparcos Input Catalogue Consortium, reports considerable activities as a by-product of Hipparcos preparation. The Observatoire Royal de Belgique continues an astrographic program with the GPO refractor at ESO by L. Louys, J. Doyle, and A. Koeckelenbergh realizing 470 plates since 1987. R. Perdomo of the Observatorio Astronomico, La Plata, has measured 2000 components on some 160 plates previously taken with the GPO refractor. J.P. Anosova and V.V. Orlov of the Leningrad State University, have organized an astrographic program of some tens of triple systems reduced in collaboration with colleagues at Belgrade. F. Schmeidler, Universitäts Sternwarte München, has conducted a program of micrometric observations of triple and quadruple systems. D. Sinachopoulos, Universitäts Sternwarte Bonn and Observatoire Royal de Belgique, made 200 CCD measurements of double stars with W. Seggewiss (Bonn) at the 123 cm telescope at Calar Alto. He also obtained photometric data for 120 double stars at the 50 cm Danish telescope of ESO. Th. Pauwels, P. Lampens and J. Cuypers, of the Observatoire Royal de Belgique, measured the positions of the components of 71 systems on old plates taken at the Zeiss Double Astrograph. Under the leadership of A.N. Argue, University of Cambridge, a program of CCD observations with the 1 m Kapteyn telescope on La Palma has yielded some 2000 measurements. P. Lampens, Observatoire Royal de Belgique, in addition to an interest in CCD observations of binary stars, initiated a *Catalogue of Variable Components of Double and Multiple Stars* presently containing 400 systems from the CCDM. J. Dommanget and D. Sinachopoulos have investigated the optical nature of catalogued systems on the basis of statistical and other criteria to separate physical from optical pairs. Similarly, Brosche (Bonn) compiled average positions (and, if significant, relative motions) for about 2,000 wide visual pairs to form a data base for the discrimination between optical and physical pairs.

C.E. Worley of the U.S. Naval Observatory (Washington) has continued his long-term micrometric program with the 26-inch refractor in Washington. Since 1987, he has made 3,195 measurements and has published a series of 10,004 measures. Worley has continued the very extensive effort in maintaining the *Washington Double Star Catalog* (WDS) which now contains 428,619 measures of 76,945 pairs. Of these measures, 179,068 were entered at Lick in the original *Index Catalog* and 249,551 have since been added at Washington. The effort to include early observations continues, as does that concerning the improvement of spectral types, magnitudes, *etc.* Worley has supplied many thousands of lines of data to numerous astronomers taking advantage of the resource provided by the WDS.

Hipparcos and HST

The primary concern of the Double Star Working Group of the Hipparcos Input Catalogue Consortium (INCA) has continued to be the compilation of the *Catalogue of the Components of Double and Multiple Stars* (CCDM). The working group includes: J.P. Anosova (Leningrad), A.N. Argue (Cambridge), P. Bacchus (Lille), P. Brosche (Bonn), J. Dommanget (Uccle - Working Group Coordinator), A. Jorissen (Uccle), L. Louys (Uccle), E. Oblak (Besançon), V.V. Orlov (Leningrad), O. Nys (Uccle), R. Pannunzio (Torino), R. Perdomo (La Plata), M. Scardia (Brera-Milano), F. Schmeidler (München), D. Sinachopoulos (Bonn and Uccle), and G. Soulie (Bordeaux).

Till mid-1987, the main objective has been the completion of the CCDM by DM, AGK2/3, and SAO identifications and the correction of catalogue errors. The principal aim was then directed toward the completion of accurate astrometric data using first a new *Catalogue des Données Astrométriques* compiled at the Astronomische Rechen-Institut (Heidelberg), with additional material from many lists of positions compiled by members of the Working Group, especially by A. Jorissen, L. Louys, and M. Scardia. The CCDM now contains 31,870 positions for 62,237 systems. A systematic measurement by M. Rousseau (Bordeaux) of all stars of the INCA data base from ESO Schmidt survey plates has yielded some 12,300 systems of which 9,700 are new. These will be introduced into the next version of the CCDM. The data needed for the Hipparcos mission have been brought together in a list from the CCDM containing 18,165 double stars, 2,469 triple stars, 639 quadruple stars, and 249 systems with $n \geq 4$. At the time of this writing, Hipparcos appears to be capable of achieving its nominal mission.

It is too soon after the launch of HST to determine its ultimate astrometric performance. O.G. Franz, Lowell Observatory (Flagstaff) reports that detailed plans have been formulated and extensive software developed for the HST fine guidance sensors' analysis of double stars, but the final performance assessment remains to be made.

Interferometric Programs

High resolution interferometric observations are being carried out by several groups with large aperture telescopes. While speckle interferometry is making extensive contributions, the actual number of speckle groups observing double stars has diminished. A major step toward improving this situation is the U.S. Naval Observatory's construction of a speckle camera system as a major new component of the long-term program of C.E. Worley. The USNO camera will be first used in late 1990.

Infrared speckle programs, while not primarily dedicated to double star applications, are yielding important results for duplicity of pre-main sequence stars. H. Zinnecker of the Universität Wurzburg, with astronomers in the US and Germany, has used fast slit scans and 2-D IR arrays for speckle resolution of several PMS systems including obtaining IR photometric values for the individual components. Several previously known systems and the newly resolved objects XZ Tau and MWC 863 have been observed.

Three interferometry groups are in the USSR. At the Sternberg Astronomical Institute (Moscow), the phase grating interferometer developed and used originally by A. Tokovinin has been used on a 1 m telescope by R.M. Ismailov. Y.Y. Balega has continued speckle observations with the 6 m telescope of the Special Astrophysical Observatory (Zelenchukskaya) providing resolutions down to $0''.020$. About 150 new measurements of 80 objects were made between 1987.3 and 1989.8 with special attention to close pairs discovered by speckle observers. Orbits have been prepared for ten such objects. Balega has initiated a new effort on late-type nearby dwarfs. A speckle program, using a new camera system at the AZT-11 reflector, was initiated by V.D. Bakhtin, V.V. Konichek, D.P. Kobaladze, and G.N. Salukvadze of the Abastumani Astrophysical Observatory.

The speckle interferometry group of the Center for High Angular Resolution Astronomy (CHARA) at Georgia State University (Atlanta) continued to use the Kitt Peak 4 m telescope for double star observations. The CHARA program was extended to the southern hemisphere in 1988 with the initiation a continuing series of observing runs at the CTIO 4 m. This group included H.A. McAlister, W.I. Hartkopf, W.G. Bagnuolo, D.J. Barry, E.G. Dombrowski, W.S. Tsay, B.D. Mason, and A. Al-Shukri. O.G. Franz of the Lowell Observatory has collaborated extensively in the CHARA activities. A *Second Catalog of Interferometric Measurements of Binary Stars* was published and contains 8,976 measurements of 1,588 systems as well as 280 binaries first resolved by (primarily speckle) interferometry. CHARA is developing methods for accurately extracting differential magnitudes from speckle data. This so-called *speckle photometry* has been applied to several systems including Hyades binaries and Capella. CHARA has proposed the construction of a 7-telescope optical array with limiting resolution of 0.2 milliarcsec. The array would be capable of resolving the majority of the spectroscopic binaries.

The potential for long-baseline arrays has been shown by the resolution of the 107-day spectroscopic binary β Ari by X. Pan and his collaborators using the Mark III Stellar Interferometer on Mt. Wilson. That instrument has a maximum baseline of 32 m to give a limiting resolution of $\sim$2 milliarcsec, an order of magnitude gain over speckle methods at 4 m telescopes. The Sydney University Stellar Interferometer, a project being carried out under the direction of J. Davis, is under construction and will provide a factor of 20 gain in resolution over the Mark III instrument. The 1990's will show a remarkable productivity in double star astronomy from the SUSI array and other projects proposed or planned for optical and infrared interferometry.

Spectroscopic Observations of Potentially Resolvable Systems

High precision radial velocity programs are providing overlap into the realm of the visual binaries, especially in the case of speckle binaries. F.C. Fekel of Vanderbilt University (Nashville) has continued spectroscopic observations of double and multiple stars. Approximately 30 systems, nearly all of which have been resolved by speckle interferometry, are being observed with a CCD detector and the KPNO coudé feed telescope. The orbital periods range from about one year to 80 years, and data have been obtained for most of the systems for 10 to 14 years.

A. Tokovinin (Moscow) began a survey of nearby dwarf stars with a radial velocity spectrometer in 1986 and has published the first results including the orbit of Gliese 171.2. A collaboration with A.

Kiselev (Pulkova) is aimed at radial velocities of wide pairs for the computation of long-period orbits from short observed arcs.

In Canada, A. Batten of the Dominion Astrophysical Observatory (DAO, Victoria) continues observing several binaries, including an investigation of Lick plates in an attempt to improve the orbital period of 70 Oph. Victoria observations of δ Sge, which has occasionally been resolvable by speckle interferometry, are being analyzed by Batten to understand this difficult system which shows evidence of a third close component. C. Scarfe, of the University of Victoria, continued to obtain radial-velocity observations of visual binary and multiple systems with the DAO coudé spectrograph mostly using the photoelectric radial-velocity scanner. Photographic spectra of a few systems are still obtained where higher accuracy is essential. Observations of many IAU standard radial-velocity stars, both to check the spectrograph's stability and to confirm (or refute) the constancy of those stars' radial velocities have also been obtained with A. Batten and M. Fletcher. With D. Barlow, Scarfe has continued to develop programs to solve for the elements of systems of interest, including simultaneous solutions for both long and short-period orbits in triple systems and solutions of radial velocity and visual (speckle) data simultaneously. Recently studied systems include ζ Her, ϵ Hya, HR 5472, HR 6469, HD 53299 and HD 202908.

The radial velocity program of the Harvard-Smithsonian Center for Astrophysics (CfA) utilizes digital speedometers routinely on the 1.5 m Oak Ridge telescope and occasionally on the 1.5-m telescope at the Whipple Observatory on Mt. Hopkins. The programs of primary relevance here are carried out by D.W. Latham and R.P. Stefanik (CfA) and T. Mazeh of the Wise Observatory (Tel Aviv University). One emphasis of this very productive program has been the detection of low-mass companions to low-luminosity stars. They conclude that sub-stellar companions may be rare compared to stellar companions, but that brown dwarf candidates may exist.

Miscellaneous Activities

Statistical properties of double and multiple stars continue to be of great interest due to their relevance to star formation and stellar evolution. V. Trimble of the Universities of Maryland and California (Irvine) has investigated the distributions of mass ratios with special consideration given to selection processes in assembling a statistical sample. For spectroscopic binaries as defined by R. Griffin's radial velocity spectrometer program, Trimble found a power law distribution with a slope less than that generally found for initial mass functions. Mass loss from K III primaries would be required to account for the difference. From common proper motion pairs compared with visual binaries, Trimble concluded that the CPM mass ratio distribution is consistent with a random subset drawn from the normal IMF while visual binaries are more difficult to interpret and may indicate a slight preference for mass ratios near unity.

A. Poveda and C. Allen (Universidad Nacional Autonoma de Mexico) have continued their analysis of the distribution of separations of binaries in the vicinity of the sun as a function of age. Based on material contained in the Gliese catalog and its extensions, for a quasi-complete sample of stars closer than 12.5 pc, it has been found that 90% of the binaries younger than the sun have separations up to about 4,000 AU. For older binaries, such a percentage extends to only about 1,000 AU. This effect is interpreted as a proof of the effect of dissociation with time.

W. Gliese of the Astronomisches Rechen-Institut (Heidelberg) continues his long-standing interest in the multiplicity characteristics of the nearby stars. The *Third Catalogue of Nearby Stars* (within 25 pc of the sun) contains about 5,000 objects (single stars and individual components of systems) of which ~50% of the stars within 5 pc are members of binary or multiple systems. This fraction decreases to 28% for the catalog as a whole implying that selection effects tend to prefer the nearest stars in duplicity detection.

W. van Altena, D. Hoffleit, and J.T. Lee of Yale University (New Haven) have been trying to improve cross identifications in the new Yale Parallax Catalogue (YPC) with the WDS. Van Altena and Lee have examined the mass-luminosity relation for Sun-like stars using data from the YPC and found no significant difference from the previous calibration of W.D. Heintz. Following that work, van Altena began an investigation of the possible existence of a "Lutz-Kelker" systematic error in the calibration of double star masses. This effect does exist and differs from the distance calibration correction only in the numerical value of the constant.

With thanks to those who have contributed to this report,

H.A. McAlister, Commission 26 President