CONCLUDING REMARKS

VIRGINIA TRIMBLE
Astronomy Program and Physics Department
Univ. of Maryland Univ. of California
College Park MD 20742 Irvine CA 92717 USA

1. THE PAST

In one sense our subject is an old one, dating back more than two centuries to the work of John Michell on statistics of visual star pairs. In another sense, it is both young and rapidly growing. The first meeting devoted exclusively to binary systems took place in 1966 in Uccle, Belgium, followed by the first IAU Joint Discussion on the subject in 1967 and IAU Colloquia 6 and 18 in 1969 and 1972. From this average of less that one meeting with published proceedings per year, our gatherings have proliferated to about five per year in the mid 80's. I am inclined to suspect that the topic of formation and evolution of binary stars is now too broad to fit into any one meeting, room, day, or mind.

Over these 21 years, both the subject and its practitioners have evolved a good deal. The 1969 Elsinore colloquium, for instance, had 21 official participants, 12 of whom are still publishing in binary star astronomy. Topics of extensive discussion there included activity in old novae, models for Beta Lyrae, evidence for mass loss (including the first rocket UV data), definition of RS CVn stars by Popper, data on masses of Algols, and the first persuasive models for Algol formation via conservative mass transfer from Kippenhahn & Weigert, Paczyński, and Plaveç et al.

Some years down stream, the 1983 NATO workshop on interacting binaries had 115 participants, at least 98 of whom published something on the subject in 1986-87. Much of the discussion focussed on departures from conservative mass transfer, including common envelope binaries, the loss or transfer of angular momentum during mass loss and transfer, and the nature and persistence of contact. Other hot topics were the physics of outbursts in RNe and DNe, statistical issues (both the distribution of P, a, e, q, etc. and the question of which objects and phenomena really are systematically associated with binaries), and formation mechanisms. Many of these are clearly still with us, A. Underhill's remarks having reminded us that there is not yet full concensus on the importance of binaricity even among Wolf-Rayet stars, though explaining WRs was one of the early triumphs of conservative mass transfer.

Somehow in the same time frame, the present author has evolved from gate-crasher, through contributed papers and invited reviews, to concluding remarks, and expects shortly to be asked to give after dinner talks.

D. McNally (ed.), Highlights of Astronomy, Vol. 8, 177–180.

2. THE PRESENT

2.1 Observations

The full importance of results presented at this JD will become obvious only some years in the future. From the perspective of a few hours' hindsight, however, two major and several minor observational points and about four theoretical areas seem noteworthy. First, 1988 is the year in which pre-main-sequence binaries finally became common enough to look at statistically. M. Simon's lunar occultation sample (6 of 29 stars double with $\Delta\theta = 0.01$-$0\overset{''}{.}5$ and $\Delta m = 1$-2), R. Mathieu's pre-MS spectroscopic systems (10 orbits, some separations less than T Tau accretion disc sizes), and R. de la Reza's isolated binary T Tau collectively lead to the impression that pre-MS binaries are about as common at various separations as MS binaries, apart from a shortage of short-period true T Tau's. This deficit can be blamed both on the difficulty in getting good photospheric velocities for the stars and on the transience of the phase: inevitably two stars separated by about their own disc sizes will spiral together and expel the discs. Mathieu noted that better pre-MS evolutionary tracks are needed to confirm coevality (or lack of it) in his pairs.

A second observational highlight is the proliferation of pairs with mass ratios less than 0.1. D. Latham introduced us to several such systems, including his own HD 114762, where the companions are arguably in the brown dwarf mass range. The 0.05 $M_\odot$ secondary of AA Dor was probably still less massive on the main sequence, according to B. Paczyński. Zuckerman's IR companions to WDs (10 of 100 searched) are presumably also BDs or late M's. B. Campbell's 9 systems (of 18 late MS stars studied) are, on the other hand, in the planetary range, with companion masses of 1-10 Jupiters, and no brown dwarfs. If this is the tip of the planetary iceberg, then half or more of pop I late MS stars have solar systems. Given the difference in parent populations, I do not see any real contradiction between Campbell's and Latham's results. Self-evidently, then, we do not yet have the data to decide whether two discrete physical processes are needed to produce low-mass-ratio binaries and planetary systems respectively, but I would bet the answer is yes.

Other neat new things on the observational front, and the people who remarked upon them, include (a) the filling-in of the gap in period and separation by radial velocity spectrometer and speckle techniques (D Latham), (b) the circularization of 4^d orbits within 10^6 yr (R. Mathieu) (c) the non-coplanarity of multiple systems (K.D. Borne), (d) the proliferation of main sequence pairs with good enough data to confirm that the components share both composition and birthdays (J. Andersen), (e) the remarkable present faintness of the novae of 1437 and 1670 near $M_V = +10$ (M. Shara), and (f) the high mass of the white dwarf member of the CV (EXO 033319-2554.2) that trespasses on the period gap (J.P. Lasota). Finally, preprints and rumors (noted by M. Shara and R. Webbink) abound with, at last, a few short-period double degenerates, one at Steward Observatory and two at Bologna, the latter in company with two WDs that have close M dwarf companions, within a sample of 20 WDs.

2.2. Theory

Recent theoretical advances divide naturally into four areas: formation from dense gas, formation from pre-existing stars, early system evolution, and later system evolution. Formation ab initio might occur by either fission or fragmentation of a rotating gas cloud, the former being a quasi-equilibrium process, the latter a dynamical collapse one. In summary, fission (R.W. Durisen, N.R. Lebovitz) is out, and fragmentation (A.P. Boss, S.M. Miyama, J. Tohline) is in. Even with differential rotation, quasi-equilibrium processes spin off only low-mass arms and discs, not comparable components (though the residual central tri-axial bars still need to be followed through further contraction and may yet prove interesting). Fragmentation, on the other hand, systematically leaves two (or more) comparable lumps over a well-defined range of initial rotation energy, thermal energy, and degree of central concentration (not too much!). Calculations cannot yet predict how many systems of each separation, mass ratio, etc. should form, but it does seem possible to produce the full known range of properties, and heirarchical processes can occur.

Pre-existing stars can give rise to binaries through disruption of triples (J. Anosova, on film) and via capture and exchange in dense environments like cluster cores (F. Verbunt). Verbunt noted that tidal capture and exchange of a neutron star for an MS component in an existing binary are competing contributors of low mass X-ray systems in globular clusters and that the spun-up NS can be liberated by a second exchange as well as by evaporating its companion.

A number of interesting points about early system evolution defy logical ordering. They include (a) the necessary shrinkage of pre-MS orbits to get the closest MS systems (R. Mathieu), (b) the use of circularization time as an age criterion (D. Latham), including the implication that pre-MS circularization must reach 4^d period systems in 10^6 yr, even though MS calculations get only to $2^d\!.4$ in that time (R. Mathieu), (c) the explanation of asynchronous MS rotators as overshooting when the stars contract after pre-MS synchronization (C. Zwaan), (d) the fact that $q \sim 1$ small-a systems can fill their Roche lobes and retract more than once while still MS stars (because mass transfer increases the size of the recipient's convective core and so raises central hydrogen content, decreasing radius, J.-P. de Grève), (e) the undetectability of convective overshoot effects on structure of main sequence O binaries, despite its later importance (J. Andersen), and (f) the possible effects of magnetic fields in the formation of binary Wolf-Rayets (B. Hidayat).

Leading to later evolutionary phases come R.E. Taam's important simulations of the common envelope phase. He finds that ejection is largely equatorial, occurs in 1-10 yr, and has efficiency of only 0.3-0.6. The systems need to be followed further to decide whether M_2 accretes or ablates and whether some pairs will merge before ejection is complete.

Before the JD began, I was inclined to think that the second mass transfer phase (CVs, X-ray binaries, etc.) was now about as well understood as the first phase was at the time of IAU Symp. 73 (1975). This illusion persisted through M. Shara's discussion of hibernating novae, J.P. Lasota's explanation of the AM Her period spike (and the associated spike in B values (because higher ones evolve catastrophically fast), P.C. Joss's confession that the shortest-period CVs and LMXRBs push very hard on scenarios both for formation and for driving adequate mass transfer, and J. Krolik's revelation that the group whose scheme for forming isolated msec pulsars predicted systems like 1957+20 are no longer sure their evaporation mechanism works very well. Illusion shattered over B. Paczyński's conclusions that magnetic winds turn off in close systems (from the absence of W UMa progenitors in NGC 188), that hibernation may conflict with observed numbers of related systems, that the CV period gap is not understood, and that CVs may simply evolve through a short P range and then die. Finally, attempts to model type I supernova progenitors as RG + WD common envelope systems (I. Hachisu), which turn out to be unacceptably bright, or as double degenerates, which will explode if mass transfer is strongly super-Eddington (R. Webbink) but which don't seem to exist, lead one to the conclusion that what we need is a class of SNI progenitors with no detectable properties at all.

3. THE FUTURE

There is a sense in which binary star evolution is a solved problem: if we are told the values of M_1, M_2 and a and that $e = 0$ at $t = 0$ and are given rules for rates of mass loss from the system, angular momentum loss from the system, and angular momentum transfer between orbit and components, all as a function of time, then there exist calculations that can predict the future state of the system and what it should look like. Approaching from the other side, we seem to find that most kinds of systems we see, from RS CVn stars to millisecond pulsars, can be modeled somewhere in one or more of the scenarios.

But there is a catch. There is clearly underlying physics that determines all these things: initial masses and separations from the processes of star formation; circularization from tidal and perhaps magnetic interactions; loss of mass and angular momentum from single-star winds, common envelope processes, and probably other things we have not thought of yet; exchange of angular momentum via tides, accretion, magnetic fields, etc. This underlying physics largely eludes us, its products being represented by adjustable parameters in the calculations. Admittedly, our present understanding of single star evolution shares many of these problems.

At the end of the 1983 workshop, I bid the participants au revoir or the equivalent in 11 languages, predicting that we would all gather again in 1987. We are a year late (but Serbo-Croatian, Danish, Russian, and Turkish -- Allahaismarladik -- have been added to the list), which suggests 1992±1 for the next stock-taking. By then we can reasonably expect that fragmentation calculations will be predicting statistics of main sequence systems, that common envelope simulations will indicate which systems eject and which merge, that the samples of pre-main-sequence and low-mass-ratio binaries will have expanded further still, and, if we are very lucky, that someone will finally have found a type I supernova progenitor.