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COMMISSION 26: DOUBLE AND MULTIPLE STARS
(ETOILES DOUBLES ET MULTIPLES)

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1. INTRODUCTION: THE RISING INTEREST IN YOUNG BINARY STARS

This triennial report (1996-1999) reviews the subject from a somewhat personal angle, mostly related to binary star formation and young binary star populations - a subject whose time had come in the early 1990s and is now in full swing.

Many astronomers have searched for binary systems among main-sequence stars, and two large-scale surveys published in 1991 and 1992 have already become classics. Well before they became famous for finding extrasolar planets (see below), observing teams led by Michel Mayor (Geneva Observatory) and Geoffrey Marcy (San Francisco State Univ., now Univ. of Calif. at Berkeley) spent many years searching for low-mass stellar companions of nearby stars. The late Antoine Duquennoy and Mayor surveyed all solar-type dwarfs (spectral types F7 through G9) within 20 pc of the Sun, while Debra Fischer and Marcy studied stars with somewhat lower mass (M dwarfs) slightly nearer to the Sun.

In November 1993, three different surveys for binary systems among low-mass pre-Main Sequence stars (T Tauri stars) were published: Reipurth & Zinnecker (AA 278, 81), Leinert et al. (AA 278, 129), and Ghez et al. (AJ 106, 2005) which all suggested that binary stars are more common among young stars in T associations (such as Taurus-Auriga at 140 pc) than among the older nearby field stars. An excellent summary of the findings is provided in the review by Mathieu in ARAA 32, 465 (1994).

In the last 3 years these works have been extended in several directions which will be described in the next section.

2. SOME RECENT ACTIVITIES

2.1. Observational

The above works on young binaries were succeeded by a variety of efforts:

1. X-ray (ROSAT) selected T Tauri star samples have been probed for multiplicity (e.g. Brandner et al. AA 307, 121, 1996; Köhler & Leinert AA 331, 977, 1998; Brandner & Köhler ApJ 499, L79, 1999; Köhler et al. AA, in press, 2000) using direct imaging and speckle interferometry techniques. An X-ray (ROSAT all sky survey) selection bias in favour of binary detection has been discussed. The binary nature of young stars, if unrecognized, systematically affects (underestimates) the age determination of low-mass stars and the interpretation of the star formation history of OB associations (cf. Preibisch & Zinnecker, AJ 117, 2381, 1999).

2. Young clusters like the Trapezium Cluster (Petr et al. ApJ 500, 825, 1998; Simon et al. AJ 117, 1375, 1999) and the Pleiades cluster (Bouvier et al. AA 323, 139, 1997) have been studied using speckle interferometric and adaptive optics methods, respectively

(see also the Ph.D. works of Duchene at Grenoble (with Bouvier) and Patience at UCLA (with Ghez) on IC348, α Per, Pleiades, Praesepe, Hyades, and other clusters).

3. Speckle surveys of binary companions around more massive primary stars were conducted, in particular around young intermediate-mass Herbig Ae/Be stars (Leinert et al. AA 318, 472, 1997; Pirzkal et al. ApJ 481, 392, 1997) as well high-mass OB stars (both in the field, see Mason et al. AJ 115, 821, 1998) and in the Orion Nebula Cluster (Weigelt et al. AA 347, L15; Preibisch et al. NewA, in press, 2000)

2.2. Theoretical

1. There are many groups in the world which are carrying out binary star formation and early evolution calculations; these include Bate & Bonnell (Cambridge/UK; e.g. MNRAS 285, 33, 1997), Bodenheimer & Burkert (Santa Cruz/MPIA Heidelberg; e.g. MNRAS 280, 1190, 1996), Boss (Carnegie Institution; e.g. ApJ 501, 77, 1998), Tsuribe & Inutsuka (Kyoto/Tokyo, e.g. ApJ 523, L155, 1999), as well as Hanawa & Matsumoto (Nagoya, e.g. ApJ 521, 659, 1999), Klein (Berkeley; ApJ 495, 821, 1998), Whitworth (Cardiff/UK; MNRAS 300, 1189, 1998) to name the most active ones.

2. Early orbital evolution of young binary systems with circumbinary rings is studied by Artymowicz & Lubow (ApJ 467, L77, 1996) while Bate & Bonnell (MNRAS 285, 33, 1997) and Burkert & Bodenheimer (MNRAS 280, 1190, 1996) study the accretion from the circumbinary ring or disk onto the proto-primary and the proto-secondary.

3. Kroupa (MNRAS 298, 231, 1998) investigates the stellar dynamical evolution of the primordial binary population in a young bound cluster, starting with a 100% binary frequency and checking how many of them survive after many crossing times. Malkov & Zinnecker (MNRAS, in press, 2000) have carried out analytical calculations as well as Monte Carlo simulations to study the stellar mass function, assuming that all stars are born as binaries and are paired randomly.

2.3. Some conclusions

A major conclusion that emerged from the above studies was to realize that different environments produce different binary frequencies, in the sense that some T associations like Taurus produce an overabundance of solar-type binaries with respect to the field population, while similarly young clusters produce a more "normal" binary population. However, this does not necessarily imply that dense young clusters start out with fewer binaries, it may just mean that the original high binary frequency in these clusters is subject to modification (i.e. reduction, especially for the wider binaries) through dynamical binary-binary and binary-star interactions (see the simulations of the Trapezium Cluster by Kroupa et al. 1999, NewA 4, 495 and the observations by Scally et al MNRAS 306, 253, 1999). Whatever the reason for the similar cluster and field star binary fractions, it must be noted that this empirical fact is consistent with the hypothesis that most low-mass stars form in dispersing clusters or OB associations rather than in loose T associations.

Besides the environmental effect there appears to be a mass-dependent effect: the trend is that higher-mass young stars exhibit higher multiplicity than lower-mass young stars, but this conclusion is still somewhat tentative and remains to be confirmed.

The true underlying stellar mass function of single stars differs significantly from the stellar mass function of both primaries and secondaries, if binary formation can be described by a random pairing process. In particular, a turnover of the composite mass function, with the binary stars unresolved, can be spurious, the underlying single star IMF being a pure Salpeter-like power-law (without any characteristic mass).

3. SCIENTIFIC HIGHLIGHTS

3.1. Observations

Young Binary Disks and Protobinaries, Brown Dwarfs and Giant Planets

1. Circumbinary gas and dust disks around young binaries were discovered, using mm interferometry observations at IRAM/PdB, as well as adaptive optics observations, the text book example being GG Tau which shows a ring of gas and dust with a radius of about 300 AU (2") around a young binary with 40 AU (0.3") component separation (Dutrey et al. AA 348, 570, 1999; Roddier et al. 463, 326 1996). Another example is the UY Aur binary (Duvert et al. AA 332, 867, 1998; Close et al. ApJ 499, 883, 1998).

2. Circumstellar disks around the individual components of a very young dust-enshrouded binary, L1551-IRS5, with component separation of only 0.35" (first seen in 2.7 mm interferometry observations at BIMA (Looney et al. ApJ 484, L157, 1997)), were also discovered and resolved by 7mm continuum very long baseline measurements with the VLBA (Rodriguez et al. 1998, Nature 395, 355, 1998). Moreover, it seems as if there is a double jet emerging from this double star. This result, originally suggested by NICMOS/HST observations, has been confirmed by recent infrared images from the Japanese SUBARU telescope on Mauna Kea under exceptional seeing conditions.

3. Finally, the first cases of true protobinary stars were found, using the BIMA interferometer to image the continuum emission at 2.7mm (Mundy, priv. commun.); ongoing work at Owens Valley Radio Observatory (Launhardt et al. , Proc. Workshop "Science with the Atacama Millimeter Array", ed. Wootten, in press) promises a rich harvest among isolated dark globules, such as CB230 (L1177) where a rotating core broke up into two condensations 5000 AU apart.

4. New major progress came from imaging studies of brown dwarfs found by the DENIS and 2MASS near-infrared sky surveys. The first resolved binary brown dwarf, DENIS J1228.2-1547, was found (Martin et al. Science 283, 1718, 1999). The separation is small enough to witness orbital motion over the next few years and to determine accurate masses (cf. also the triple system GJ 2005 = LHS 1070, see Leinert et al. 1998 in Proc. Brown Dwarfs and Extrasolar Planets, eds. Rebolo et al. , ASP Conf. Series 134, p. 203). Success with binary brown dwarfs or L-dwarfs continues (Koerner et al. ApJ 526, L25, 1999).

5. The most dramatic and surprising highlight in the last few years was the detection of extrasolar planets by precise radial velocity monitoring (Doppler wobble method). In late 1995, Mayor and Queloz as well as Marcy and Butler both independently discovered a Jupiter-like planet in orbit around the solar-type star 51 Pegasi with a short period of 4.23 days. By 1999 the census of similar planets exceeds two dozens: giant planets are being discovered at the astonishing rate of about 1 planet per month (see the update on the internet under http://www.obspm.fr/encycl/encycl.html). An important issue is the distinction of planets in orbit as opposed to brown dwarfs (Mayor, Mazeh).

6. In late 1996, Cochran and Hatzes were even able to detect a planet in a 2 yr (1.7 AU) orbit around one of the components of a wide binary system (16 Cygni). This is particularly exciting, considering that so many young stars are born as binary systems. Whether these and other planets in binary systems remain stable or get ejected in the long run is an interesting question: perhaps there exists a free-floating population of giant and/or earth like planets in the Galactic disk (originally born in binary systems but ultimately ejected) which just perhaps may be detectable by gravitational microlensing observations towards Galactic bulge sources?!

3.2. Theory

1. The biggest breakthrough lately in the theory of binary formation was probably the 3D-SPH calculations of Mathew Bate (ApJ 508, L95, 1998) who succeeded in evolving embryonic protobinaries from first fragmentation to accretion of 100% of the matter.

2. On the more technical side, the importance of resolving the Jeans mass or Jeans length in fragmentation calculations has been realized, otherwise the calculations do not produce a correct result (e.g. Truelove et al. ApJ 489, L179; Whitworth MNRAS 296, 442, 1998).

3. Another important step forward seems to be the inclusion of magnetic fields in MHD fragmentation calculations, albeit only in the form of some magnetic pressure (Boss ApJ 483, 309 and ApJ 520, 744, 1997 and 1998, respectively).

4. Finally, we mention new work on the precession of circumstellar disks and wiggly jets in binary systems (Larwood et al. MNRAS 282, 597, 1996; Terquem et al. ApJ 512, L131, 1999), although other models without precession can generate S-shaped and C-shaped jets from binary systems (Fendt & Zinnecker AA 334, 750, 1998).

4. OVERALL PROGRESS

It is becoming increasingly clear that binary and multiple star formation is the rule rather than the exception. Almost all stages of binary star formation (from protobinaries to various pre-Main Sequence star binaries with and without disks up to Main Sequence systems) have been observed. However, the dominant binary formation process remains to be identified: fragmentation of a rotating protostellar clump is the favorite theory but filament or disk fragmentation are contenders. In very dense regions, where the massive stars tend to form, even tidal capture of protostars or pre-MS stars (failed mergers) may play a role (cf. Bonnell et al. MNRAS 298, 93, 1998). Therefore, it is premature to claim that there is a dominant unique process, valid for both close and wide binaries, and for all masses.

Despite much progress with some 3D numerical collapse calculations, a full 3D MHD simulation resulting in a binary system is not yet at hand. This is a formidable task, but probably within reach in the near future.

5. SYMPOSIA, COLLOQUIA, CONFERENCES

There was only one major meeting related to binary stars during the past 3 years, namely IAU Coll 170 "Precise Stellar Radial Velocities" proposed by IAU Comm. 30 and supported by our Comm. 26; The Proceedings of the meeting have been published (Eds. J.B. Hearnshaw & C.D. Scarfe, ASP Conf. Ser. Vol. 185).

An IAU Symposium (No. 200!) has been approved by the IAU Executive in June 1999 to be held in Potsdam, Germany, in April 2000. It was proposed by Comm. 26 and is entitled: 'The formation of binary stars', co-chaired by R.D. Mathieu and H. Zinnecker.

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President of the Commission