Multiplicity of massive stars

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Summary. We review the multiplicity of massive stars by compiling the abstracts of the most relevant papers in the field. We start by discussing the massive stars in the Orion Trapezium Cluster and in other Galactic young clusters and OB associations, and end with the R136 cluster in the LMC. The multiplicity of field O-stars and runaway OB stars is also reviewed. The results of both visual and spectroscopic surveys are presented, as well as data for eclipsing systems. Among the latter, we find the most massive known binary system WR20a, with two $\sim 80\,\mathrm{M}_\odot$ components in a 3 day orbit. Some 80 % of the wide visual binaries in stellar associations are in fact hierarchical triple systems, where typically the more massive of the binary components is itself a spectroscopic or even eclipsing binary pair. The multiplicity (number of companions) of massive star primaries is significantly higher than for low-mass solar-type primaries or for young low-mass T Tauri stars. There is also a striking preponderance of very close nearly equal mass binary systems (the origin of which has recently been explained in an accretion scenario). Finally, we offer a new idea as to the origin of massive Trapezium systems, frequently found in the centers of dense young clusters.

1 The origin of the Orion Trapezium system

Let us begin by discussing the origin of the massive stars in the center of the Orion Nebula Cluster, i.e. the well-known Trapezium system Θ^1 Ori. Numerical SPH simulations of supersonic gravo-turbulent fragmentation of a protocluster cloud ($1000\,\mathrm{M}_\odot$) suggest that a collapsing cloud develops a few subclusters (star+gas systems) which subsequently merge into a single cluster entity. Each subcluster carries one most massive star (likely multiple), thus the merging of subclusters results in a central Trapezium-type system, as observed in the core of the Orion Nebula cluster (see Fig. 1).

Figure 1 shows the stellar cluster forming through hierarchical fragmentation of a turbulent molecular cloud. Each panel shows a region of 1 parsec per side. The logarithm of the column density is plotted from a minimum of 0.025 (black) to a maximum of $250\,\mathrm{g\,cm^{-2}}$ (white). Stars are indicated by the white dots. The four panels A−D capture the evolution of the $1000\,\mathrm{M}_\odot$ system at times of 1.0, 1.4, 1.8 and 2.4 initial free-fall times, where the free-fall time for the cloud is $\mathrm{t}_{ff} = 2 \times 10^5$ years. The turbulence causes shocks to form in the molecular cloud, dissipating kinetic energy and producing fila-

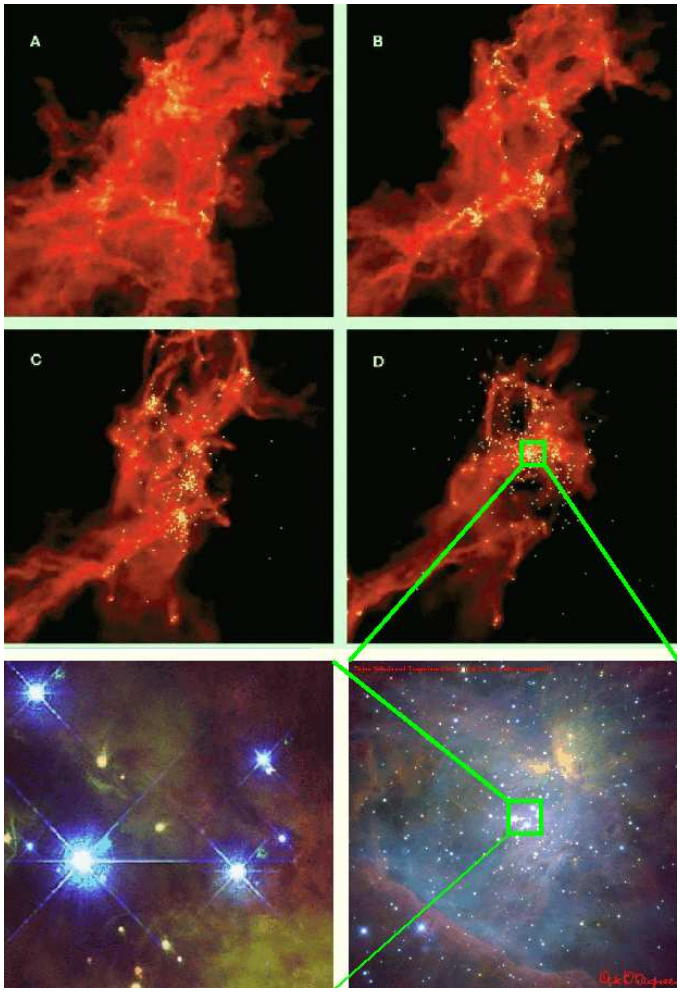

Fig. 1. Panels A, B, C, D: SPH simulations of star cluster formation by Bonnell, Bate, & Vine (2003); bottom right: Orion Trapezium cluster IRTF infrared JKL image (courtesy McCaughrean & Rayner); bottom left: Orion Trapezium system HST/WFPC2 nb-optical image (Bally et al. 1998)

mentary structures which fragment to form dense cores and individual stars (panel A). The stars sink towards local potential minima and hence form subclusters (panel B). These subclusters evolve by accreting more stars and gas, ejecting stars, and by merging with other subclusters (panel C). There is one massive star per subcluster. The final state of the simulation is a single, centrally condensed cluster with little substructure but with 4 massive stars, one from each subcluster (Trapezium-system) (panel D). The cluster contains more than 400 stars and has a gas fraction of approximately 16%.

2 Relevant papers

"Binary Stars in the Orion Trapezium Cluster Core"

M. G. Petr, V. Coudé Du Foresto et al. 1998

Abstract. We have obtained high angular resolution (0.13" FWHM) near-infrared images of the central $\sim$ 40" $\times$ 40" of the Trapezium cluster, using a speckle holography technique that we describe in detail. A search for close binary systems was made in K_s (2.16 μm) and H (1.65 μm) mosaic images. We show that the massive Trapezium star Θ^1 Ori A has a nearby companion separated by $\sim$0.2" ($\sim$90 AU). The location of this companion is coincident, within the positional uncertainties, with a nonthermal and variable VLA radio source, which was previously associated with Θ^1 Ori A itself. We give H photometry for 32 stars, K_s photometry for 43 stars, and present a color-magnitude diagram for the Trapezium core.

"Bispectrum speckle interferometry of the Orion Trapezium stars: detection of a close (33 mas) companion of Θ^1 Ori C"

G. Weigelt, Y. Balega et al. 1999

Abstract. We present bispectrum speckle interferometry observations with the SAO 6 m telescope of the four brightest stars in the Orion Trapezium. Diffraction-limited images with an unprecedented resolution λ / D of 57 mas and 76 mas were obtained in the H- and K-band, respectively. The H and K images of Θ^1 Ori C (the star responsible for the proplyds) show for the first time that Θ^1 Ori C is a close binary with a separation of only $\sim$33 mas (H-band observation). The sub-arcsecond companions of Θ^1 Ori A and Θ^1 Ori B reported by Petr et al. (1998) are confirmed. We use the magnitudes and colors of the companions to derive information about their stellar properties from the HR-diagram. In addition we briefly discuss the multiplicity of the Trapezium stars. Considering both, the visual and the spectroscopic companions of the 4 Trapezium stars, there are at least 7 companions, i.e. at least 1.75 companions per primary on average. This number is clearly higher than that found for the low-mass stars in the Orion Nebula cluster as well as in the field population. This suggests that a different mechanism is at work in the formation of high-mass multiple systems in the dense Trapezium cluster than for low-mass stars.

"Multiplicity of the massive stars in the Orion Nebula cluster"

T. Preibisch, Y. Balega et al. 1999

Abstract. We present bispectrum speckle interferometry observations of 13

bright Orion Nebula cluster member stars of spectral type O or B. Diffraction-limited images with a resolution λ / D of 75 mas in the K′-band were obtained with the SAO 6 m telescope. In our speckle images we find 8 visual companions in total. Using the flux ratios of the resolved systems to estimate the masses of the companions, we find that the systems generally have mass ratios below 1 / 2. The distribution of mass ratios seems to be consistent with a companion mass function similar to the field IMF. Considering both, the visual and the spectroscopic companions of the 13 target stars, the total number of companions is at least 14. Extrapolation with correction for the unresolved systems suggests that there are at least 1.5 companions per primary star on average. This number is clearly higher than the mean number of ~ 0.5 companions per primary star found for the low-mass stars in the Orion Nebula cluster as well as in the field population. This suggests that a different mechanism is at work in the formation of high-mass multiple systems in the dense Orion Nebula cluster than for low-mass stars (see also IAU-Symp. 200, p. 69).

"Orbital motion of the massive multiple stars in the Orion Trapezium"

D. Schertl, Y. Y. Balega et al. 2003

Abstract. We present bispectrum speckle interferometry of the multiple Orion Trapezium stars Θ^1 Ori A, Θ^1 Ori B, and Θ^1 Ori C obtained with the SAO 6 m telescope in Russia over a period of 5.5 years (epochs 1995-2001). Our diffraction-limited images have a resolution λ / D of 42 mas (J-band), 57 mas (H-band) and 76 mas (K-band). We clearly detect motion of the companions relative to their primary stars in the systems Θ^1 Ori A1-2 (mean separation $\rho \sim 220$ mas, change in position angle $\Delta \mathrm{PA} = 6$), Θ^1 Ori B2-3 ($\rho \sim 205$ mas, $\Delta \mathrm{PA} = 8$), and Θ^1 Ori C1-2 ($\rho \sim 37$ mas, $\Delta \mathrm{PA} = 18$); Fig. 2. In our K-band image of Θ^1 Ori B we resolve a fourth visual component, confirming its discovery by Simon et al. . We determine the J, H, and K magnitudes of the system components and estimate the stellar masses of the companions in the HR-diagram. The companions Θ^1 Ori C2 and Θ^1 Ori B2 show clear evidence of near-infrared excess in the color-color diagram. The companions Θ^1 Ori A2 and Θ^1 Ori B3 show much stronger extinction than their primary stars, providing evidence of the presence of circumstellar material around the companions.

"The Origin of Runaway Stars"

R. Hoogerwerf, J. H. J. de Bruijne, & P. T. de Zeeuw 2000

Abstract. Milliarcsecond astrometry provided by Hipparcos and by radio observations makes it possible to retrace the orbits of some of the nearest

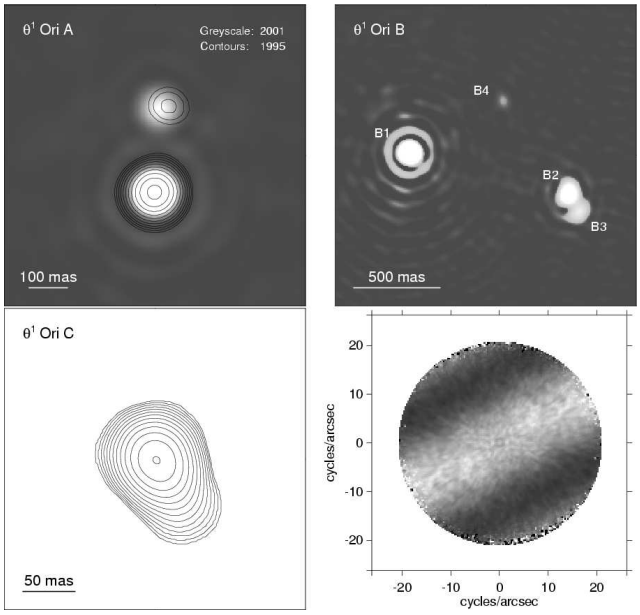

Fig. 2. Upper left: bispectrum speckle K-band images of Θ^1Ori A. The greyscale image was reconstructed from the 2001 data, the contour image from the 1995 data. The orbital motion of the companion can be easily seen. Upper right: bispectrum speckle K-band image of Θ^1Ori B (2001 data). The faint fourth component is seen near the center of the upper half of the image. Note that Θ^1Ori B1 (BM Ori) is itself an eclipsing spectroscopic binary (Popper & Plavec 1976). Lower left: contour representation of our J-band bispectrum speckle image of Θ^1Ori C (2001 data). Lower right: reconstructed power spectrum of Θ^1Ori C (J band, 2001 data) (Schertl, Balega et al. 2003).

runaway stars and pulsars to determine their site of origin. The orbits of the runaways AE Aurigae and μ Columbae and of the eccentric binary ι Orionis intersected each other ~ 2.5 Myr ago in the nascent Trapezium cluster, confirming that these runaways were formed in a binary-binary encounter. The path of the runaway star ξ Ophiuchi intersected that of the nearby pulsar PSR J1932+1059, ~ 1 Myr ago, in the young stellar group Upper Scorpius. We propose that this neutron star is the remnant of a supernova that occurred in a binary system that also contained ξ Oph and deduce that the pulsar received a kick velocity of $\sim 350\,\mathrm{km\,s^{-1}}$ in the explosion. These two cases provide the first specific kinematic evidence that both mechanisms proposed for the production of runaway stars, the dynamical ejection scenario and the binary-supernova scenario, operate in nature.

"Hubble Space Telescope NICMOS Imaging of W3 IRS 5: A Trapezium in the Making?"

S. T. Megeath, T. L. Wilson, & M. R. Corbin 2005

Abstract. We present Hubble Space Telescope NICMOS imaging of W3 IRS 5, a binary high-mass protostar. In addition to the two protostars, NICMOS images taken in the F222M and F160W filters show three new 2.22 μm sources with very red colors; these sources fall within a region 5600 AU in diameter and are coincident with an $\sim 100\,M_\odot$, dense molecular clump. Two additional point sources are found within 0.4" (800 AU) of one of the high-mass protostars; these may be stellar companions or unresolved emission knots from an outflow. We propose that these sources constitute a nascent Trapezium system in the center of the W3 IRS 5 cluster containing as many as five proto-OB stars. This would be the first identification of a Trapezium still deeply embedded in its natal gas.

"High-mass binaries in the very young open cluster NGC 6231. Implication for cluster and star formation"

B. Garcia & J. C. Mermilliod 2001

Abstract. New radial-velocity observations of 37 O- and B stars in the very young open cluster NGC 6231 confirm the high frequency of short-period spectroscopic binaries on the upper main sequence. Among the 14 O-type stars, covering all luminosity classes from dwarfs to supergiants, 8 are definitively double-lined systems and all periods but one are shorter than 7 days. Several additional binaries have been detected among the early B-type stars. NGC 6231 is an exceptional cluster to constrain the scenarios of cluster- and binary-star formation over a large range of stellar masses. We discuss the evidences, based on NGC 6231 and 21 other clusters, with a total of 120 O-type stars, for a clear dichotomy in the multiplicity rate and structure of very young open clusters containing O-type stars in function of the number of massive stars (for other cluster data, see IAU-Symp. 200, p. 191).

"Binary systems and stellar mergers in massive star formation"

I. A. Bonnell & M. R. Bate 2005

Abstract. We present a model for the formation of high-mass close binary systems in the context of forming massive stars through gas accretion in the centres of stellar clusters. A low-mass wide binary evolves under mass accretion towards a high-mass close binary, attaining system masses of the order of $30-50\,M_\odot$ at separations of the order of 1 AU. The resulting high frequency of binary systems with two massive components is in agreement with

observations. These systems are typically highly eccentric and may evolve to have periastron separations less than their stellar radii. Mergers of these binary systems are therefore likely and can lead to the formation of the most massive stars, circumventing the problem of radiation pressure stopping the accretion. The stellar density required to induce binary mergers is $\approx 10^6$ stars pc^{-3}, or ≈ 0.01 that required for direct stellar collisions.

"The binary population in OB associations"

A. G. A. Brown 2001

Abstract. The OB associations in the solar vicinity contain a large fraction of all the bright O and B stars. Many studies of their multiplicity exist in the literature. As a first step, multiplicity data on the 3 subgroups of the nearby Sco OB2 association has been compiled (see Fig. 3).

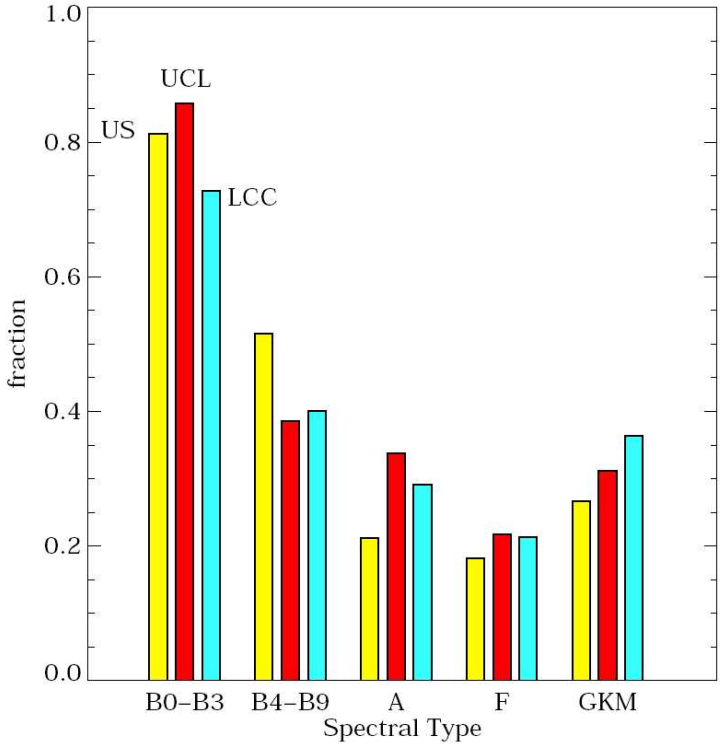

Fig. 3. The fraction of multiple systems vs. spectral type for the Hipparcos members of each of the 3 subgroups of Sco OB2 association. The fraction is incomplete beyond spectral type B9.

"The kinematical and binary properties of association and field O stars"

D. R. Gies 1987

Abstract. A catalog of 195 Galactic O-type stars brighter than $V = 8.0$ mag has been compiled to compare the velocity distribution and binary frequency among cluster and association, field, and runaway stars. Both the field stars and runaway stars have a larger dispersion in peculiar radial velocity, a more positive mean peculiar radial velocity, and a wider z-distribution than stars found in clusters and associations, which is consistent with the ejection of field and runaway stars from their birthplaces in associations. Visual binaries are common among stars in clusters and associations, but their incidence is a factor of 2 lower among field stars, and they are absent in the runaway stars. Similarly, there is a deficiency of spectroscopic binaries among field stars, and especially the runaway stars, relative to the numbers found in clusters and associations. Many of these properties can be understood in terms of ejection through close gravitational interactions with binary stars during an early high number density epoch in the evolution of clusters.

"ICCD speckle observations of binary stars. XIX - an astrometric/spectroscopic survey of O stars"

B. D. Mason, D. R. Gies et al. 1998

Abstract. We present the results of a speckle interferometric survey made with the CHARA speckle camera and 4 m class telescopes of Galactic O-type stars with $V < 8$ mag. We can detect with the speckle camera binaries in the angular separation range $0.035 - 1.5$ arcsec with $\Delta m < 3$ mag, and we have discovered 15 binaries among 227 O-type systems. We combined our results on visual binaries with measurements of wider pairs from the Washington Double Star Catalog and fainter pairs from the Hipparcos Catalog, and we made a literature survey of the spectroscopic binaries among the sample. We then investigated the overall binary frequency of the sample and the orbital characteristics of the known binaries. Binaries are common among O stars in clusters and associations but less so among field and especially runaway stars. There are many triple systems among the speckle binaries, and we discuss their possible role in the ejection of stars from clusters. The period distribution of the binaries is bimodal in $\log P$, but we suggest that binaries with periods of years and decades may eventually be found to fill the gap. The mass ratio distribution of the visual binaries increases toward lower mass ratios, but low mass ratio companions are rare among close, spectroscopic binaries. We present distributions of the eccentricity and longitude of periastron for spectroscopic binaries with elliptical orbits, and we find strong evidence of a bias in the longitude of periastron distribution.

"The O-type Binary 15 Monocerotis Nears Periastron"

D. R. Gies, B. D. Mason et al. 1997

Abstract. We present new radial velocity measurements for the massive binary 15 Monocerotis which indicate that the system is now very close to periastron (1996.9) in its 24 yr orbit. The velocity separation in the coming year may be large enough to permit an accurate estimate of mass ratio. We also present our first astrometric measurement of 15 Mon made with the Hubble Space Telescope Fine Guidance Sensors (FGS). The FGS transfer functions are consistent with an advanced orbital position close to periastron, and we present preliminary orbital elements for the combined spectroscopic and astrometric orbit. (PS. Derived component masses are 35 and 24 $M_\odot$)

"The origin of massive O-type field stars"

W. J. de Wit, L. Testi et al. 2005

Abstract. In two papers we try to confirm that all Galactic high-mass stars are formed in a cluster environment, by excluding that O-type stars found in the Galactic field actually formed there. In de Wit et al. (2004) we presented deep K-band imaging of 5 arcmin fields centred on 43 massive O-type field stars that revealed that the large majority of these objects are single objects. In this contribution we explore the possibility that the field O stars are dynamically ejected from young clusters, by investigating their peculiar space velocity distribution, their distance from the Galactic plane, and their spatial vicinity to known young stellar clusters. We (re-)identify 22 field O-type stars as candidate runaway OB-stars. The statistics show that 4 ± 2 % of all O-type stars with $V < 8$ mag can be considered as formed outside a cluster environment. Most are spectroscopically single objects, some are visual binaries. The derived percentage for O-type stars that form isolated in the field based on our statistical analyses is in agreement with what is expected from calculations adopting a universal cluster richness distribution with power index of $\beta = 1.7$, assuming that the cluster richness distribution is continuous down to the smallest clusters containing one single star.

"Resolving OB Systems in the Carina Nebula with the Hubble Space Telescope Fine Guidance Sensor"

E. P. Nelan, N. R. Walborn et al. 2004

Abstract. We observed 23 OB stars in the Carina Nebula (NGC 3372) with the Hubble Space Telescope's Fine Guidance Sensor 1r (FGS1r) in its high angular resolution mode. Five of these OB stars are newly resolved binaries with projected separations ranging from 0.015" to 0.352" (37 to 880 AU at a

distance of 2.5 kpc), and V-band magnitude differences ranging from 0.9 to 2.8. The most important astrophysical result is the unexpected resolution of the prototype O2 If* star HD 93129A as a 55 milliarcsecond (mas) double with a $\Delta\,\mathrm{m}_V$ of 0.9. This object has served as a spectroscopic benchmark for the analysis of the most massive hot stars and their winds on the prior assumption that it is a single star. This discovery supports the interpretation of recent radio and X-ray observations as evidence of colliding-wind phenomena in HD 93129A. Another interesting result is the determination of an upper limit of about 35 AU for the projected separation of the binary pairs in the hierarchical double spectroscopic binary HD 93206. The high incidence of resolved binaries provides motivation for a more thorough, statistically meaningful study of multiplicity among the most massive stars in the young ionizing clusters of the nebula to obtain a complete sample of the long-period systems that have evaded spectroscopic detection. However, considering that the nine spectroscopic binaries with accurate orbits in the Carina Nebula have orbital dimensions ≤ 1 AU, which at a distance of 2.5 kpc subtends an angle of only 0.4 mas, well below the $\simeq 10$ mas angular resolution of FGS1r, there remains a significant range of orbital periods and separations over which it is very difficult to detect multiplicity in the nebula with currently available instruments.

"V 3903 Sagittarii: a massive main-sequence (O7V+O9V) detached eclipsing binary"

L. P. R. Vaz, N. C. S. Cunha et al. 1997

Abstract. We present for the first time an analysis based on *uvby* light curves, Hβ indices and on new spectroscopic data of the massive detached double-lined O-type eclipsing binary V 3903 Sgr. The *uvby* light curves are analysed with the WINK (initial solutions) and the Wilson-Devinney (WD, final solution) programs. Both codes were used in their extended versions, with stellar atmospheres and taking into account the geometric distortions and photometric effects caused by proximity of the components.

We conclude that V 3903 Sgr is one of the rare O-type detached systems where both components are still on the initial phases of the main sequence, with an age of either 1.6×10^6 yrs or 2.5×10^6 yrs (depending on the evolutionary model adopted) at a distance of ~ 1500 pc, the same as for the Lagoon Nebula (Messier8) complex, of which the system is probably a member. We determine the absolute dimensions: $\mathrm{M}_A = 27.27 \pm 0.55$, $\mathrm{R}_A = 8.088 \pm 0.086$, $\mathrm{M}_B = 19.01 \pm 0.44$ and $\mathrm{R}_B = 6.125 \pm 0.060$ (solar units). There is no evidence of mass transfer and the system is detached. The orbit is circular, and both components show synchronous rotation, despite their early evolutionary stage. The absolute dimensions determined should be representative for normal single stars.

"WR 20a is an eclipsing binary: accurate determination of parameters for an extremely massive Wolf-Rayet system"

A. Z. Bonanos, K. Z. Stanek et al. 2004

Abstract. We present a high-precision I-band light curve for the Wolf-Rayet binary WR 20a, obtained as a subproject of the Optical Gravitational Lensing Experiment. Rauw et al. have recently presented spectroscopy for this system, strongly suggesting extremely large minimum masses of 70.7 ± 4.0 and $68.8 \pm 3.8\,M_\odot$ for the component stars of the system, with the exact values depending strongly on the period of the system. We detect deep eclipses of about 0.4 mag in the light curve of WR 20a, confirming and refining the suspected period of $P = 3.686$ days and deriving an inclination angle of $i = 74.5\,d \pm 2.0\,d$. Using these photometric data and the radial velocity data of Rauw et al., we derive the masses for the two components of WR 20a to be 83.0 ± 5.0 and $82.0 \pm 5.0\,M_\odot$. Therefore, WR 20a is confirmed to consist of two extremely massive stars and to be the most massive binary known with an accurate mass determination. (PS. WR20a is actually a hydrogen-burning binary system)

"Speckle masking observation of the central object in the giant H II region NGC 3603"

K.-H. Hofmann & G. Weigelt 1986

Abstract. The first reconstruction of a true diffraction-limited image of the central object HD 97950 AB in NGC 3603 is reported. The image has been reconstructed by a four-dimensional version of speckle masking (triple correlation processing). Speckle masking is a solution of the phase problem in speckle interferometry. The reconstructed image shows that HD 97950 AB consists of 4 stars (V-magnitudes 11.7, 11.7, 11.7, and 12.2; separations relative to Al: 0.78, 0.37 and 0.34 arcsec).

"R136a in the 30 Doradus nebula resolved by holographic speckle interferometry"

G. Weigelt & G. Baier 1985

Abstract. Digital speckle interferometry observations of R136, the luminous central object in the 30 Doradus nebula have been performed. It was possible to reconstruct a diffraction-limited true image of R136a by using R136b and R136c as the deconvolution keys (holographic speckle interferometry). The reconstructed image shows for the first time that R136a is a dense star cluster consisting of 8 stars within a diameter of 1 arcsec (at wavelength approximately 710 nm). The dominating objects are three stars of almost identical magnitudes with separations of 0.10 and 0.48 arcsec. The reconstructed image has a resolution of 0.09 arcsec.

"The ionising cluster of 30 Doradus. IV. Stellar kinematics"

G. Bosch, F. Selman et al. 2001

Abstract. On the basis of multislit spectroscopy of 180 stars in the ionising cluster of 30 Doradus we present reliable radial velocities for 55 stars. We calculate a radial velocity dispersion of $\sim 35\,\mathrm{km\,s^{-1}}$ for the cluster and we analyse the possible influence of spectroscopic binaries in this rather large velocity dispersion. We use numerical simulations to show that the observations are consistent with the hypothesis that all the stars in the cluster are binaries, and the total mass of the cluster is $\sim 5 \times 10^5\,\mathrm{M_\odot}$. A simple test shows only marginal evidence for dynamical mass segregation which if present is most likely not due to dynamical relaxation.

"Orbits of Four Very Massive Binaries in the R136 Cluster"

P. Massey, L. R. Penny, & J. Vukovich 2002

Abstract. We present radial velocity and photometry for four early-type, massive, double-lined spectroscopic binaries in the R136 cluster. Three of these systems are eclipsing, allowing orbital inclinations to be determined. One of these systems, R136-38 (O3 V + O6 V), has one of the highest masses ever measured for the primary, $57\,\mathrm{M_\odot}$. Comparison of our masses with those derived from standard evolutionary tracks shows excellent agreement. We also identify five other light variables in the R136 cluster that are worthy of follow-up study. (PS. R145 ...)

"Forty eclipsing binaries in the Small Magellanic Cloud: fundamental parameters and Cloud distance"

R. W. Hilditch, I. D. Howarth, & T. J. Harries 2005

Abstract. We have conducted a programme to determine the fundamental parameters of a substantial number of eclipsing binaries of spectral types O and B in the Small Magellanic Cloud (SMC). New spectroscopic data, obtained with the two-degree-field (2dF) multi-object spectrograph on the 3.9-m Anglo-Australian Telescope, have been used in conjunction with photometry from the Optical Gravitational Lens Experiment (OGLE-II) data base of SMC eclipsing binaries. Previously we reported results for 10 systems; in this second and concluding paper we present spectral types, masses, radii, temperatures, surface gravities and luminosities for the components of a further 40 binaries. The uncertainties are typically $\pm\,10\,\%$ on masses, $\pm\,4\,\%$ on radii and $\pm\,0.07$ on $\log \mathrm{L}$. The full sample of 50 OB-type eclipsing systems is the largest single set of fundamental parameters determined for high-mass binaries in any galaxy. We find that 21 of the systems studied are in detached

configurations, 28 are in semidetached post-mass-transfer states, and one is a contact binary.

The overall properties of the detached systems are consistent with theoretical models for the evolution of single stars with SMC metal abundances ($Z \simeq 0.004$); in particular, observed and evolutionary masses are in excellent agreement. Although there are no directly applicable published models, the overall properties of the semidetached systems are consistent with them being in the slow phase of mass transfer in case A. About 40 % of these semidetached systems show photometric evidence of orbital-phase-dependent absorption by a gas stream falling from the inner Lagrangian point on the secondary star towards the primary star. This sample demonstrates that case-A mass transfer is a common occurrence amongst high-mass binaries with initial orbital periods $P \leq 5\,d$, and that this slow phase has a comparable duration to the detached phase preceding it.

Each system provides a primary distance indicator. We find a mean distance modulus to the SMC of $18.91 \pm 0.03 \pm 0.1$ (internal and external uncertainties; $D = 60.6 \pm 1.0 \pm 2.8\,kpc$). This value represents one of the most precise available determinations of the distance to the SMC.

"High intrinsic binarity rate for massive stars: Multi-epoch radial velocity survey of O-stars in ultracompact HII regions"

D. Apai, A. Bik et al. 2006

Abstract. We present here the first multi-epoch radial velocity study of very young massive stars using near-infrared spectra obtained by the ISAAC/VLT instrument aiming to measure their intrinsic binarity rate. Our 28 targets are associated to known ultracompact HII regions ensuring that dynamic evolution of the clusters did not influence the binarity rate. We identify two stars with about 90 km/s velocity differences between the two epochs proving the presence of close massive binaries. In addition, we show that the radial velocity dispersion of the full sample is about 35 km/s, significantly larger than our accuracy (~ 25 km/s). Simple Monte Carlo models are used to test different binarity fractions and mass ratios and we conclude that "a substantial number" of the young massive stars are formed as binaries. Implications to previously proposed formation scenarios are discussed.

Final note

A summary table of masses and other parameters of massive binary systems is provided by Gies (2001), while Zinnecker (2003) reviews the formation of massive binaries (see also Zinnecker & Bate 2002).

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