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Accepted Papers

The Massive Wolf-Rayet Binary SMC WR7

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We present a study of optical spectra of the Wolf–Rayet star AzV 336a (= SMC WR7) in the Small Magellanic Cloud. Our study is based on data obtained at several Observatories between 1988 and 2001. We find SMC WR7 to be a double lined WN+O6 spectroscopic binary with an orbital period of 19.56 days. The radial velocities of the He absorption lines of the O6 component and the strong HeII emission at λ4686Å of the WN component describe antiphased orbital motions. However, they show a small phase shift of $\sim$ 1 day. We discuss possible explanations for this phase shift. The amplitude of the radial velocity variations of He II emission is twice that of the absorption lines. The binary components have fairly high minimum masses, $\sim$ 18 $\dot{M}$ and 34 $\dot{M}$ for the WN and O6 components, respectively.

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Non-radial pulsation, rotation and outburst in the Be star ω Orionis from the MuSiCoS 1998 campaign

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ω Ori (HD 37490, HR 1934) is a Be star known to have presented variations. In order to investigate the nature and origin of its short-term and mid-term variability, a study is performed of several spectral lines (Hα, Hδ, HeI 4471, 4713, 4921, 5876, 6678, CII 4267, 6578, 6583, MgII 4481, SiIII 4553 and SiII 6347), based on 249 high signal-to-noise high-resolution spectra taken with 8 telescopes over 22 consecutive nights during the MuSiCoS (Multi SIte COntinuous Spectroscopy) campaign in November-December 1998. The stellar parameters are revisited and the projected rotational velocity ($v\sin i = 179$ km s^{-1}) is redetermined using several methods. With the MuSiCoS 98 dataset, a time series analysis of line-profile variations (LPVs) is performed using the Restricted Local Cleanest (RLC) algorithm and a least squares method. The behaviour of the velocity of the centroid of the lines, the equivalent widths and the apparent $v\sin i$ for several lines, as well as Violet and Red components of photospheric lines affected by emission (red HeI lines, SiII 6347, CII 6578, 6583) are analyzed. The non-radial pulsation (NRP) model is examined using phase diagrams and the Fourier-Doppler Imaging (FDI) method. The LPVs are consistent with a NRP mode with $l = 2$ or 3, $|m| = 2$ with frequency 1.03 c d^{-1}. It is shown that an emission line outburst occurred in the middle of the campaign. Two scenarios are proposed to explain the behaviour of a dense cloud, temporarily orbiting around the star with a frequency 0.46 c d^{-1}, in relation to the outburst.

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The massive double-lined O-type binary HD 165052.

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We present a new optical spectroscopic study of the O-type binary HD 165052 based on high- and intermediate-resolution CCD observations. We re-investigated the spectral classification of the binary components, obtaining spectral types of O6.5 V and O7.5 V for the primary and secondary, respectively, finding that both stars display weak C III λ5696 emission in their spectra. We also determined a radial-velocity orbit for HD 165052 with a period of 2.95510 $\pm$ 0.00001 d, and semiamplitudes of 94.8 and 104.7 $\pm$ 0.5 km s^{-1}, resulting in a mass ratio $Q = 0.9$. From a comparison with previous radial-velocity determinations, we found evidence of apsidal motion in the system. Several signatures of wind-wind collision, such as phase-locked variability of the X-ray flux and the Struve-Sahade effect, are also considered. It was also found that the reddening in the region should be normal, in contrast with previous determinations.

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Stellar evolution with rotation VIII: Models at $Z = 10^{-5}$ and CNO yields for early galactic evolution

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We calculate a grid of star models with and without the effects of axial rotation for stars in the mass range between 2 and 60 M$_\odot$ for the metallicity $Z = 10^{-5}$. Star models with initial masses superior or equal to 9 M$_\odot$ were computed up to the end of the carbon–burning phase. Star models with masses between 2 and 7 M$_\odot$ were evolved beyond the end of the He–burning phase through a few thermal pulses during the AGB phase. Compared to models at $Z = 0.02$, the low Z models show faster rotating cores and stronger internal Ω–gradients, which favour an important mixing of the chemical elements. The enhancement of N/C at the surface may reach 2 to 3 orders of magnitude for fast rotating stars. Surface enrichments may make the evolved stars less metal poor than they were initially. In very low Z models, primary nitrogen is produced during the He–burning phase by rotational diffusion of ^{12}C into the H–burning shell. A large fraction of the primary ^{14}N escapes further destruction and enters the envelope of AGB stars, being ejected during the TP–AGB phase and the formation of a planetary nebula. The intermediate mass stars of very low Z are the main producers of primary ^{14}N, but massive stars also contribute to this production; no significant primary nitrogen is made in models at metallicity Z=0.004 or above. We calculate the chemical yields in He, C, N, O and heavy elements and discuss the chemical evolution of the CNO elements at very low Z. Remarkably, the C/O vs O/H diagram is mainly sensitive to the interval of stellar masses, while the N/O vs O/H diagram is mainly sensitive to the average rotation of the stars contributing to the element synthesis. The presently available observations in these diagrams seem to favour contributions either from stars down to about 2 M$_\odot$ with normal rotation velocities or from stars above 8 M$_\odot$ but with very fast rotation.

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Optical Spectroscopy of X-Mega targets - IV. CPD -59° 2636: a new O-type multiple system in the Carina Nebula

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High resolution optical spectroscopy of CPD -59° 2636, one of the O-type stars in the open cluster Trumpler 16 in the Carina Nebula, reveals this object to be a multiple system displaying triple lines which we label as components A, B and C of spectral types O7 V, O8 V and O9 V, respectively. From our radial velocity measurements we find that the components A and B form a close binary with a period of 3.6294 days, and we obtain the first circular radial velocity orbit for this system with semi-amplitudes of 184 and 192 km.s^{-1}, leading to minimum masses of 10.1 and 9.7 M$_{\odot}$. We find that the component C is a single lined binary with a period of 5.034 days and semiamplitude of 48 km.s^{-1}. We also analyze the X-ray radiation from CPD -59° 2636 finding no appreciable overluminosity nor phase related X-ray flux variations.

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The Star Formation History and Mass Function of the Double Cluster h and Chi Persei

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The h and χ Per "double cluster" is examined using wide-field ($0.98° \times 0.98°$) CCD UBV imaging supplemented by optical spectra of several hundred of the brightest stars. Restricting our analysis to near the cluster nuclei, we find identical reddenings ($E(B-V) = 0.56 \pm 0.1$), distance moduli (11.85 ± 0.05), and ages (12.8 ± 1.0 Myr) for the two clusters. In addition, we find an IMF slope for each of the cluster nuclei that is quite normal for high-mass stars, $\Gamma = -1.3 \pm 0.2$, indistinguishable from a Salpeter value. We derive total masses of 3700 $\mathcal{M}_{\odot}$ for h Per and 2800 $\mathcal{M}_{\odot}$ for χ Per. There is evidence of mild mass segregation within the cluster cores. Our data are consistent with the stars having formed at a single epoch; claims to the contrary are very likely due to the inclusion of the substantial population of early-type stars located at similar distances in the Perseus spiral arm, in addition to contamination by G and K giants at various distances. We discuss the uniqueness of the double cluster, citing other examples of such structures in the literature, but concluding that near unity mass ratio between the two cores is unusual. We fail to settle the long-standing controversy

regarding whether or not the double cluster is the core of the Per OB1 association, and argue that this may be unanswerable with current techniques. We also emphasize the need for further work on the pre-main sequence population of this nearby and highly interesting region.

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Properties of galactic B[e] supergiants. I. CI Cam.

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We present a study of the high-resolution (R=60000) optical spectrum of the B[e] sup ergiant CI Cam obtained 4 years after its all-wavelength outburst. The profiles of most of the emission lines show a triple-peaked structure, an effect previously not observed. The Na I D-lines clearly have 2 interstellar absorption components, suggesting that the system is most probably located within the Perseus arm at a distance of $\leq$3 kpc. Uncertainties of the distance toward the object, its luminosity, and physical parameters of the circumstellar disk are discussed.

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V669 Cep: A new binary system with a B[e] star.

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We present the results of optical and near-IR spectroscopic and broadband multicolour photometric observations of the emission-line object V669 Cep. We find evidence that it contains a hot, low

luminosity, B4–B6 star and a cool companion (most likely late-ty pe giant). Significant variations of the Hα line strength are detected on a timescale of months. The emission-line spectrum and strong IR-excess indicate a large amount of circumstellar gas and dust in the system. The spectral energy distribution in the near-IR region and the absence of late-type star features in the optical spectrum indicates that the cool star is heavily obscured by circumstellar dust, while the hot star is much less affected by reddening. The system is located at 1–1.5 kpc from t he Sun in the local spiral arm. We suggest that V669 Cep is an evolved and probably mass exchanging, binary system, a member of the group of Be stars with warm dust.

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Further Insights into the Structure of 30 Doradus from the Hubble Space Telescope Instruments

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New observations with the HST Wide Field Planetary Camera 2, combined with prior archival data, provide nearly complete coverage of the inner 30 Doradus Nebula in both nebular lines and continuum at 0.″1 resolution. The developing wind-blown cavity surrounding the massive first-generation, central cluster and its interface with the remanent molecular clouds, the site of second-generation, triggered star formation, are imaged in their entirety. Dithered Planetary Camera observations with 0.″03 resolution of Knots 1–3 reveal further structural details of the large dust pillars oriented toward the central cluster and the newborn, massive multiple systems of the second generation in those fields. The new data also provide the first WFPC2 coverage of the fields of two interesting, luminous infrared sources observed in our previous Near Infrared Camera and Multi-Object Spectrometer program; comparisons of the high-resolution optical and IR images are illuminating. In addition, we have obtained Space Telescope Imaging Spectrograph optical, long-slit observations of seven O-type multiple systems in the region, including those in Knots 1–3 and four representatives of the older generation. The spatially resolved spectrograms and classifications of the close pairs, with separations ranging from 0.″09 to 1.″18, are presented, as well as WFPC2 photometry of the individual components and the compact clusters of fainter stars associated with them. These new observations, and planned further analysis of them, offer significant new information about the intricate structure and evolution of the two-stage starburst in 30 Doradus.

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New Challenges for Wind Shock Models: The Chandra Spectrum of the Hot Star δ Ori

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The Chandra spectrum of δ Ori A shows emission lines from hydrogen- and helium-like states of Si, Mg, Ne, and O, along with N VII Lyman-α and lines from ions in the range Fe 17-Fe 21. In contrast to the broad lines seen in ζ Pup and ζ Ori (850 ± 40 km s^{-1} and 1000 ± 240 km s^{-1} HWHM, respectively), these lines are broadened to only 430 ± 60 km s^{-1} HWHM. This is much lower than the measured wind terminal velocity of 2000 km/s. The forbidden, intercombination, and resonance (*fir*) lines from He-like ions indicate that the majority of the X-ray line emission does not originate at the base of the wind, in agreement with the standard wind shock models for these objects. However, in that model the X-ray emission is distributed throughout an expanding, X-ray absorbing wind, and it is therefore surprising that the emission lines appear relatively narrow, unshifted, and symmetric. We compare the observed line profiles to recent detailed models for X-ray line profile generation in hot stars, but none of them offer a fully satisfactory explanation for the observed line profiles.

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Gamma-ray line emission from OB associations and young open clusters. II. The Cygnus region

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Gamma-ray and microwave observations of the Cygnus region reveal an intense signal of 1.809 MeV line emission, attributed to radioactive decay of ^{26}Al, that is closely correlated with 53 GHz free-free emission, originating from the ionised interstellar medium. We modelled both emissions using a multi-wavelength evolutionary synthesis code for massive star associations that we applied to the known massive star populations in Cygnus. For all OB associations and young open clusters in the field, we determined the population age, distance, and richness as well as the uncertainties in all these quantities from published photometric and spectroscopic data. We propagate the population uncertainties in model uncertainties by means of a Bayesian method. The young globular cluster Cyg OB2 turns out to be the dominant ^{26}Al nucleosynthesis and ionisation source in Cygnus. Our model reproduces the ionising luminosity of the Cygnus region very well, yet it underestimates ^{26}Al production by about a factor of 2. We attribute this underestimation to shortcomings of current nucleosynthesis models, and suggest the inclusion of stellar rotation as possible mechanism to enhance ^{26}Al production. We also modelled ^{60}Fe nucleosynthesis in the Cygnus region, yet the small number of recent supernova events suggests only little ^{60}Fe production. Consequently, a detection of the 1.137 MeV and 1.332 MeV decay lines of ^{60}Fe by the upcoming *INTEGRAL* observatory from Cygnus is not expected.

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Multi-wavelength study of the nebula associated with the galactic LBV candidate HD 168625

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We present high resolution HST imaging of the nebula associated with the galactic LBV candidate HD 168625, together with ISO imaging and AAT echelle spectroscopy. The overall nebular morphology is elliptical with the major axis at PA $\simeq 120^{\rm deg}$. The dimensions of the nebula are $12''$ x $16''.7$ at H_α and $15''.5$ x $23''.5$ at 4 μm. In the HST Hα image, the nebula is resolved into a complex structure of filaments and arcs of different brightness. The asymmetry is lost in the HST continuum image where the nebula appears more diffuse and richer in filaments and clumps with the shape of cometary tails. At 11.3 μm the nebular emission peaks in two diametrically opposite lobes, placed on the nebula boundaries and along its major axis. A very faint loop is also visible at optical wavelengths, north and south of the shell. We suggest that the nebula is an ellipsoid with projected sizes of $14''$ and $9''$ (0.19 pc $\times$ 0.12 pc) along the RA and DEC directions, respectively. This ellipsoid is expanding at 19 km s^{-1} and is dynamically as old as $\simeq$ 4800 yrs; it probably interacts with the stellar wind and the loop so that PAH emission is detected from its caps, i.e. the lobes seen in the ISO images. The chemistry of the loop suggests that it is composed of un-processed material, probably from the local interstellar medium swept by the stellar wind.

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Characteristics of new star cluster candidates in the Cygnus area

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The morphology and stellar content of 22 clusters in the Cygnus area has been determined using 2MASS infrared observations in the J and K bands. 7 of them are well known objects and our results are in good agreement with previous works. 12 objects are recently discovered cluster candidates (Dutra & Bica 2001) and 3 are new cluster candidates. Adopting distance estimates from the literature or from considering cluster counterparts, we derive a consistent set of parameters suitable for analysis and comparisons: center coordinates, radius, stellar population, IMF slope and mass range. We find a mean IMF slope of $\Gamma = -1.30$ for known clusters and $\Gamma = -1.40$ for the others. Infrared data having better completeness, we derive larger stellar contents and cluster masses than previous works. An important fraction of the cluster stellar population in Cygnus is hidden in very obscured areas. A clear tendency to mass segregation appears for most of the clusters. Some of the new clusters seem to be quite massive, probably hosting very massive stars at the center. They are privileged targets for more detailed investigations using infrared spectroscopy.

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Evolutionary synthesis models of starburst IV. Soft X-ray emission

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In this work we investigate the evolution of the X-ray emission of a cluster of single young massive stars with different metallicities. We have considered the X-ray contribution originated by the diffuse gas heated by the mechanical energy released by stellar winds and SN explosions as well as the X-ray contribution from SN remnants. The resulting ionizing spectrum (i.e. $\lambda < 912$ Å), has been used to compute the expected intensity of the nebular He ii λ4686 Å. The observational ratio He ii/Hβ could be reproduced by the models assuming that a fraction of the mechanical energy produced by the star-formation episode is reprocessed by interaction with the ISM as soft X-ray radiation, contributing to the He ionization. However, the discreteness of the stellar populations affects the ionizing flux and may be responsible for the observed dispersion of the ratio. We have finally used the synthesis models to estimate the contribution of circumnuclear star-forming regions to the multiwavelength energy distribution in Active Galactic Nuclei and find that the UV to soft X-ray continuum in many Seyfert 2 galaxies seems to be dominated by star-formation processes.

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Model results on the web at `http://www.laeff.esa.es/users/mcs/SED`

The quadruple Wolf-Rayet system GP Cep: spectral types, masses, mass-loss rate and colliding winds

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We have re-evaluated the orbital elements for each pair of the quadruple (WR+O) + (O+O) stellar system GP Cep and propose new spectral types WN6o/WCE + O3–6, B0:I + B1:V–III. It is shown that there is only one WR star in GP Cep, contrary to a previous claim. A rate of change $\dot{P} = 1.3 \pm 0.2$ s yr^{-1} is determined for the WR+O pair, which leads to a new period of 6.6887 d and to a WR mass-loss rate of (0.8–3.0)$\times 10^{-5}$M$_\odot$ yr^{-1}. Masses for this pair are estimated to be $M_{\rm WR} \gtrsim 6$ M$_\odot$ and $M_{\rm O} \gtrsim 21$ M$_\odot$. The effects of wind-wind collision in the WR+O pair are studied. It is shown that even after allowing for dilution by the OB components of the quadruple system, these effects are not as strong as in the binary V444 Cygni (WN5+O6, $P = 4.212$ d). In GP Cep, the phase-dependent, relatively weak excess-emission does not originate in the arms of the bow shock cone. It rather emerges from the extra heated portion of the WR wind facing the hot O-companion. The trailing bow-shock arm is clearly seen, however, as an enhanced He 1 absorption component near quadrature at phase ~ 0.73. An anomalous blueshifted He 1 absorption is present at phase ~ 0.9, as is also seen in V444 Cyg, in the WC8+O9I/O8III binary γVelorum and in the LBV type binary R81 (B2.5Iab:e). A 3.5d orbit for the eclipsing B-star pair is confirmed.

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Rotational velocities of A-type stars II. Measurement of $v\ sini$ in the northern hemisphere

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This work is the second part of the set of measurements of $v \sin i$ for A-type stars, begun by Royer et al. (2002). Spectra of 249 B8 to F2-type stars brighter than $V = 7$ have been collected at Observatoire de Haute-Provence (OHP). Fourier transforms of several line profiles in the range 4200–4600 Å are used to derive $v \sin i$ from the frequency of the first zero. Statistical analysis of the sample indicates that measurement error mainly depends on $v \sin i$ and this relative error of the rotational velocity is found to be about 5 % on average.
The systematic shift with respect to standard values from Slettebak et al. (1975), previously found in the first paper, is here confirmed. Comparisons with data from the literature agree with our findings: $v \sin i$ values from Slettebak et al. are underestimated and the relation between both scales follows a linear law $v \sin i_{\rm new} = 1.03\, v \sin i_{\rm old} + 7.7$.
Finally, these data are combined with those from the previous paper (Royer et al. 2002), together with the catalogue of Abt & Morrell (1995). The resulting sample includes some 2150 stars with homogenized rotational velocities.

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Further variability of the compact radio nebula of P Cygni

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Skinner et al. (1997) presented 2 high resolution 6 cm (5 GHz) images of the B-supergiant star P Cygni. These show the observed morphology and flux densities to have changed over the intervening month. Following on from this, we present a series of 7 high resolution 6 cm images (including re-reductions of the 2 from Skinner et al.). These confirm that radio emission from the inner 400 mas of the wind is inhomogenous, consisting usually of several separated bright spots, and that the total and peak flux densities and the observed morphology vary over all time-scales sampled. We suggest that recombination in cooling clumps of gas which will decrease the radio emission, followed by the appearance of other ionized clumps could explain such rapid changes, but detailed models must await further observations.

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In Proceedings

Modifying the Rosseland Mean when the Mean-Free Path Varies

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When dealing with highly optically thick atmospheres, even in the presence of considerable scattering, it is customary and convenient to assume that the zeroth-order moment of the radiation field completely thermalizes. This in turn implies that the frequency-dependent flux is inversely proportional to the local frequency-dependent opacity, resulting in the well-known Rosseland mean as the flux-weighted average. The necessary logic is that the energy density determines the energy flux, but this is actually only true on scales large compared to the thermalization length. On smaller scales, the reverse is true: conserving flux determines the energy density, and thus the energy density will not be locally thermalized whenever the mean-free-path varies on scales smaller than the thermalization length. This has important ramifications for the Rosseland mean in the presence of opacity inhomogeneities, such as from ionization gradients in static atmospheres, line distributions in supersonic flows, and clumping.

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Effects of Nongray Opacity on Radiatively Driven Wolf-Rayet Winds

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Wolf-Rayet winds are characterized by their large momentum fluxes, and simulations of radiation driving have been increasingly successful in modeling these winds. Simple analytic approaches that help understand the most critical processes for copious momentum deposition already exist in the effectively gray approximation, but these have not been extended to more realistic nongray opacities. With this in mind, we have developed a simplified theory for describing the interaction of the stellar flux with nongray wind opacity. We replace the detailed line list with a set of statistical parameters that are sensitive not only to the strength but also the wavelength distribution of lines, incorporating as a free parameter the rate of photon frequency redistribution. We label the resulting flux-weighted opacity the statistical Sobolev- Rosseland (SSR) mean, and explore how changing these various statistical parameters affects the flux/opacity interaction.

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Jobs

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