THE HOT STAR NEWSLETTER

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and related phenomena in galaxies

ed. Philippe Eenens

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Discussion Forum

This month you will find the abstracts of 16 accepted papers and of 15 recently submitted papers.

Is it correct to assume that the silent majority *also* agrees with the idea to form a Working Group on Hot Luminous Stars and with the suggested voting procedure for the commitee? In such a case, you may soon receive a formal invitation to send your list of ten candidates.

The Standard Star Newsletter No 18 appeared recently, the first electronic issue. Besides abstracts and reports, it contains interesting discussions on early-type (and other) standards for polarimetry, radial velocity and MK classification. The editor is Chris *corbally@as.arizona.edu*

Accepted

On ionization structure of HII regions in stellar envelopes with an outward density decrease

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In the framework of spherical pure hydrogen models of stellar envelopes photoionized by photospheric (or chromospheric) radiation we study a dependence of their ionization structure on an outward density decrease. To avoid the problem of radiative transfer we make use of the two classical approximations of optically thin (A) and thick (B) HII regions. We show that all density decreases can be classified, by means of some simple criterion, as slow and fast ones. For slow density decrease the radius of HII region can be estimated in the way which gives a straightforward generalization of Strömgren radius to inhomogeneous envelopes. But for fast density decrease this generalization can be failed, and a radius of HII region crucially depends on ionization parameter p near some critical value p_l. Namely, it grows sharply when p increases up to p_l and it becomes very large (essentially infinite), in comparison with the inner radius r_0, for $p > p_l$. It means that in the case of the fast density decrease an HII region is essentially a threshold phenomenon: there is no significant HII region when $p < p_l - \Delta p$ while an envelope is almost completely ionized when $p > p_l$, the value of Δp being much smaller than p_l. It is

shown also that for sufficiently fast density decrease and p in the vicinity of p_l there is a possibility of a nonmonotonious distribution of ionization degree throughout an envelope.

We present analytical and numerical results for the power law density distribution $n(r) = n_0(r_0/r)^k$ in which case the slow and fast decreases correspond to $k < 3/2$ and $k > 3/2$. The case of a stationary flow with the Lamers velocity law is also briefly discussed and numerical estimates are given in the context of Catala and Kunasz (1987) models of an outflowing envelope around Herbig Ae/Be star AB Aur.

Accepted by A & A *For preprints, contact* stas@aispbu.spb.su

Speckle masking observations of HD 97950 with 75 mas resolution: Evolution of the stellar core of the starburst cluster NGC 3603

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We present diffraction-limited speckle masking observations of the central object HD 97950 in the giant H II region and starburst cluster NGC 3603. In the reconstructed images 28 stellar components with V magnitudes in the range from 11.40 to 15.85 were detected in the 6.3" $\times$ 6.3" ($\sim$0.2 pc$\times$0.2 pc) field of view. Four different filters were used for the selection of distinct spectral regions comprising Hα emission, the main Wolf-Rayet and Of-type emission lines, and two continuum bands. The angular resolutions of the four reconstructed images are 0.080" (RG 695 filter), 0.075" (658 nm), 0.079" (545 nm), and 0.174" (471 nm). Two WN stars and two further stars with mild WN-type characteristics were found. A colour-magnitude diagram has been constructed. Isochrone fits taken from the new grids of stellar models from Schaller et al. (1992), yield a cluster age of about 3.2 Myr which is in accordance with the time-scale of Wolf-Rayet star evolution and places NGC 3603 in the Carina nebula phase of young stellar aggregates. The initial mass function IMF of HD 97950 has a fairly steep slope of x = 1.59, in contrast to other Local Group giant H II regions and to starburst galaxies. HD 97950 has, compared to the cores of extragalactic H II regions, a similar, but high number ratio of WN to OB-type stars, indicating an instantaneous burst of star formation. HD 97950 hosts OB-type stars with a total mass of about 1000 $M_\odot$, corresponding to a mass density of $\sim 10^5\, M_\odot\, \mathrm{pc}^{-3}$. Thus, HD 97950 is even more compact than R 136a, the core of the giant H II region 30 Dor in the LMC.

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Speckle masking observations of R64, the dense stellar core of the OB association LH9 in the LMC

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We present speckle masking observations of R64 (= HD 32228; O9.5II: + WC5), the central object of the OB association LH9 in the Large Magellanic Cloud. Two sets of speckle interferograms were taken to select the Johnson V spectral band and the strong Wolf-Rayet emission lines between 450 and 490

nm. In the 6.4" $\times$ 6.4" field of view 25 stellar components were detected in R64 with V magnitudes in the range 12.5 to 17.1 and down to a resolution of 0.12". The brightest star in the visual component B is the only Wolf-Rayet star in R64. The colour-magnitude diagram of LH9, completed with the components of R64, serves for the discussion of the evolutionary state of the association. There is evidence that the outer regions of LH9 are its youngest parts with an upper age of about 5 Myr, in accordance with estimates by Walborn & Parker (1992). The WC5 star in the centre is most likely the product of mass exchange in a massive close binary system with an age in excess of 5 Myr. The mass density in R64 is about 250 $M_{\odot}\mathrm{pc}^{-3}$ for stars more massive than 5 $M_{\odot}$.

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The O5-7 + WN Binary System HDE 320102

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By means of spectrographic observations obtained at CTIO, Chile, we have determined that HDE 320102 is an O6+WN binary system, with an orbital period of 12.595 days. We present an analysis of the orbital elements of this system based on radial velocities of the absorption lines of the O6 component, and of the HeII λ4686 Å and NV $\lambda\lambda$4603–19 Å emissions of the WN component.

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Simultaneous millimetre and radio observations of Cygnus X-3 in a quiescent radio state

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Observations of Cygnus X-3 at 2.0 and 1.1 mm with the JCMT, partially simultaneous with radio flux measurements at 2 cm and 18 cm, are presented. These are the first known observations of Cyg X-3 at millimetre wavelengths whilst the source was in a quiet radio state. The observed millimetre fluxes are several times greater than those expected for the synchrotron tail of emission extrapolated from the radio, and the 2-mm flux exceeds that at 1.1 mm, suggesting a peak in the region of a few mm. The observations are interpreted using an extension of the model of Marti, Paredes & Estalella to repeated short injections of relativistic electrons in a region in the Cyg X-3 stellar wind which is optically thin to millimetre-wave photons, but optically thick at centimetre wavelengths. Centimetre-wavelength emission is not observed until the ejecta have travelled further out in the wind. A MERLIN radio map at 18 cm reveals the same elliptical asymmetry in the scattering medium around Cyg X-3 as found by Wilkinson, Narayan & Spencer.

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Wind-wind interaction in the close Wolf-Rayet binary CQ CEP (WN6 + O9 II-Ib)

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A large collection of blue & yellow CCD spectra of the short-period eclipsing binary CQ Cep allows us to improve the double-line (SB2) orbit of Kartasheva & Snezhko (1985) and reclassify the system as WN6 + O9 II-Ib. With orbital inclination $i = 78^o - 65^o$, the masses and radii are: $M_O = 18 - 23M_\odot$, $M_{WR} = 15 - 19M_\odot$, $R_O \leq 10R_\odot$, $2R_\odot \leq R_{WR} \leq 10R_\odot$. For its spectral type, the O-star mass and radius are smaller than values deduced from evolutionary models, but agree with recent determinations of other O stars in binaries. The WR star is shown to contain a small amount of hydrogen in its wind.

Because of the rapid orbit revolution compared to the wind velocities, the wind interaction zone is tightly wrapped around the system. We construct a phenomenological model which explains the numerous phase-dependent spectral variations.

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High-speed narrow-band photometry of the Wolf-Rayet star HD197406 (WN7)

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Short-time low amplitude variability was detected in HD197406 wich has been claimed to be a WR + BH binary (WR148). High-time resolution observations were obtained with 0.1 and 0.25 s integration time. They were obtained with two-star photometer in two narrow-band filters centered on the continuum with $\lambda = 4270$Å and on the $H_\beta + HeII$ λ4859Å + in part of NV λ4945Å emission lines. An energetic test for detecting of flickering and a pre-filtering technique for estimating of low amplitude variations developed by one of the authors were used. The high-frequency flickering was detected in both filters. The powers of variable component are of the order of 3 per cent in the emission lines and of 0.5 per cent in the continuum. Short-term flares of the flickering were found in both filters at the more than 3 sigma contidence level. The brightness changes were found in both filters on a time scale of about half an hour with amplitudes of 0.03 mag. Flare events were found in the filter centered on the lines only on a time scale of 100 - 200 s. Amplitudes of flares in the range of 0.04 - 0.07 mag.

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The hot emission line objects in IRAS 17380–3031 and 18405–0448

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Near-infrared spectroscopy of two IRAS sources, 17380–3031 and 18405–0448, whose LRS spectra suggested the presence of carbonaceous dust confirms that the former is a late-type Wolf Rayet (WC8–9) star and shows that the latter is not. Together with new red spectroscopy, our data for IRAS 18405–0448 show H I (Hα and Pa6–16), O I excited by the Lyβ fluorescence mechanism, Fe II, [S III] and [O II]. This shows that IRAS 18405–0448 is similar to luminous emission-line objects like LkHα 101 or η Car. The reddening from the continuum and Paschen decrement was found to be $E(B-V) = 5.5\pm0.5$ and that from the O I lines $E(B-V) \geq 4.5$. It is suggested that this extinction is mostly circumstellar and that the corresponding absorption in the "silicates" feature can account for the IRAS LRS spectral shape. New photometry of IRAS 17380–3031 indicates variability in the dust luminosity on a time-scale $\sim 1.4y$ possibly caused by variation in the dust condensation rate.

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The WO stars. II. Long slit spectroscopy of the G2.4+1.4 nebula around Sand 4

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We have investigated the association of the massive, evolved WO star Sand 4 (WR 102) with the peculiar diffuse nebula G2.4+1.4 in which it is embedded. Long slit spectra at four different positions were used to study many regions of the nebula and to derive their physical parameters.

From the Hα/Hβ ratio a mean E_{B-V}=1.25 is derived, with regions of enhanced reddening around Sand 4, and, possibly, at the NE knot of the nebula. We find that the electron density varies from less than 100 to 900 cm^{-2}. The ionization largely changes from one region to another, reaching a maximum at the bright arc north of Sand 4. Regions of strong He II λ468.6 emission are found to the east and 40 arcsec west of Sand 4. Some of the knots of which the nebula is composed appear overabundant in He, with He/H up to >0.2. Two regions of the nebula present a marked nitrogen anomaly.

We suggest that some regions of the nebula, to the NE and to the west might be the shock front which should have been generated from enhanced mass loss during a previous LBV phase of the star, which is presently forming a partially hidden ring–like structure. The variable helium and nitrogen enrichment of the nebula is tentatively linked with the evolutionary history of Sand 4, in the framework of the present–day evolutionary models of very high mass stars. We also suggest that the successive mass loss phases of the central star are associated with an evolutionary path in the He/H, N^+/S^+ diagram.

The final fate of Sand 4 should be a type Ib supernova, embedded in a ring-like nebular structure, such as that observed in the Kepler SNR.

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An Eight Year Study of the Radio Emission from the Wolf-Rayet Binary HD 193793 = WR 140

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HD 193793 = WR 140 is a WR+O binary system with a 7.9 year, highly elliptical ($e = 0.85$) orbit. It shows variable, nonthermal radio emission over its orbital period that is explained as synchrotron radiation from relativistic electrons accelerated in the shock between the WR and O winds. Although we now know of quite a few WR+O star binary systems, only HD 193793 is well studied across the entire electromagnetic spectrum; hence it affords us the best opportunity to test various models for the system against a wealth of observational data. HD 193793 is an ideal laboratory for studying the properties of hot star winds and the physics of particle acceleration by strong shocks in those winds.

In this paper we present the results of 8 years of monitoring the radio flux density from HD 193793 with the VLA. This database is unique both in terms of its dense coverage of an entire binary cycle and because it extends the radio coverage to 2 cm wavelength, a shorter wavelength than previously available. With this data we are able to simultaneously solve for the time-dependent attenuation in the system and the intrinsic radio luminosity. The standard model of spherically symmetric colliding winds faces severe difficulties in explaining the observations. We conclude that the radio data are most readily interpreted if we adopt a new model of the system in which the WR star wind is strongly equatorially enhanced, so that most of the mass loss is confined to a plane. This model for the WR wind also provides a natural explanation for the sudden formation of dust that causes an infrared outburst just after periastron.

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Manuscript available on WWW at http://sundog.stsci.edu/rick/wr140preprint.ps.Z

Tomographic Separation of Composite Spectra. III. UV Detection of the Hot Companion of Phi Persei

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We have used archival *IUE* high dispersion UV spectra of the Be binary ϕ Per and published spectroscopic radial velocity curves to reconstruct the individual primary and secondary spectra using Doppler tomography. The primary's spectrum has rotationally broadened photospheric lines (consistent with a spectral type B0.5 III-Ve) and narrow "shell" lines formed in its circumstellar disk. The recovered secondary spectrum (which contributes only $\approx 12\%$ of the UV flux) has a very different appearance, with strong emission in C IV $\lambda 1550$ and many narrow, weak absorption lines (mainly Fe V) similar

to those found in the spectra of hot O-type subdwarfs (in particular the sdO6 star HD 49798). These results strongly support Poeckert's (1981) model in which the secondary is the stripped-down core of a once massive star. Such objects could be the progenitors of unusual supernovae.

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A detailed study of a very late WN star in M33

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We present the first quantitative analysis of a M33 Wolf-Rayet star, the Ofpe/WN9 candidate MCA1-B (Willis et al. 1992). From new higher resolution observations analysed with the Wolf-Rayet standard model, we reclassify MCA1-B as WN9 and find its stellar parameters (T_*=29kK, $T_{\rm eff}$=19kK, log $L/L_\odot$=5.8, log $\dot{M}/M_\odot$yr=−4.0, v_∞=420 km s^{-1}) to be very similar to the LMC WN9 stars (Crowther et al. 1995a), and R84 in particular. Chemical abundances (H/He=2.6, N/He=0.003, C/N<0.1) are also comparable to R84 indicating a similar evolutionary status (probable dormant LBV) and metallicity (Z∼0.008) consistent with its location in the outer regions of M33.

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Identification of Emission-Line Stars in 30 Doradus using HST Observations

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Using broadband (F439W) and narrowband (F469N) *Hubble Space Telescope* archive images of the R 136 central cluster of 30 Doradus, we have identified candidate Wolf-Rayet stars from the strength of their He II λ4686 emission lines. The number ratio of Wolf-Rayet to O stars found in our data is 0.11 ± 0.03. Our results are more consistent with an instantaneous burst with an age of about 3×10^6 yr than with a continuous star formation scenario. However, even in the starburst scenario, evolutionary model predictions for low-metallicity stellar evolution agree with our observations only if we also assume enhanced mass loss and/or a relatively flat slope ($\Gamma > -1.35$) for the initial mass function with an upper mass limit greater than $80\mathcal{M}_\odot$.

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An IRAS-Based Search for New Dusty WCL Stars

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I have examined all InfraRed Astronomy Satellite (IRAS) data relevant to the 173 galactic Wolf-Rayet

(WR) stars in an updated catalog, including the 13 stars newly discovered by Shara *et al.* (1991). Using the WR coordinates in these lists, I have examined the IRAS Point Source Catalog (PSC), the Faint Source Catalog, Faint Source Reject Catalog, and generated 1-dimensional spatial profiles ("ADDSCAN"s), and 2-dimensional full-resolution images ("FRESCO"s). The goal was to assemble the best set of observed IRAS color indices for different WR types, in particular for known dusty WCL objects. These color indices define zones in the IRAS color-color ([12]–[25],[25]–[60]) plane. By searching the PSC for otherwise unassociated sources that satisfy these colors, I have identified potential new WR candidates, perhaps too faint to have been recognized in previous optical searches. I have extracted these candidates' IRAS Low Resolution Spectrometer (LRS) data and compared the spectra with the highly characteristic LRS shape for known dusty WCL stars. The 13 surviving candidates must now be examined by optical spectroscopy. This work represents a much more rigorous and exhaustive version of the LRS study that identified IRAS 17380-3031 (WR98a) as the first new WR (WC9) star discovered by IRAS (Cohen *et al.* 1991). This search should have detected dusty WCL stars to a distance of 7.0 kpc from the Sun, for $|l| > 30°$, and to 2.9 kpc even in the innermost Galaxy. For free-free dominated WRs the corresponding distances are 2.5 and 1.0 kpc, respectively.

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Fundamental parameters of Wolf-Rayet stars V. The nature of the WN/C star WR8

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A detailed study has been carried out on the Galactic WN/C star WR8 (HD 62910), based on ultra-violet, optical and infrared spectroscopy. Our standard model analysis allows a determination of its stellar parameters and chemical abundances of hydrogen, helium, carbon, nitrogen and oxygen. We find that the WN and WC spectral features are consistent with formation in the same stellar wind and derive stellar parameters of T_*=48kK ($T_{\rm eff}$=32kK), $\log(L/L_\odot)$=5.1, $\log(\dot{M}/M_\odot{\rm yr}^{-1})$=−4.2, v_∞=1590 km s^{-1}. The chemistry of WR8 (H/He≃0, C/He≃0.02, C/N≃3, C/O≃4 by number) is indeed found to be intermediate between normal WN and WC stars, and explains the peculiar WC line spectrum of WR8. In common with previous WN analyses (e.g. Crowther et al. 1995d) all high and low excitation features cannot be simultaneously reproduced at present, which we attribute to the neglect of line blanketing.

We also determine physical parameters and C/He ratios for two other WN/C stars, WR145 (MR111) in the Galaxy and Brey 29 (HDE 269485) in the LMC. The physical properties of these stars are found to be very similar to WR8, with C/N ratios also estimated to be of order unity. Overall, our results confirm that mixing does take place at the boundary of the convective He core in Wolf-Rayet stars, with an estimated timescale of $\simeq 10^4$ years and are in excellent agreement with the theoretical predictions of Langer (1991, 1994, private communication) in which slow mixing is produced through semi-convection.

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The dynamical evolution of circumstellar gas around massive stars I. The impact of the time sequence O star → LBV → WR star

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We show that computation of the behavior of circumstellar gas provides a powerful tool for the investigation of stellar mass loss history. Our computations allow us to add a new dimension to the Hertzsprung-Russell diagram by including the existence and size of circumstellar nebulae as an additional diagnostic of stellar evolution. As a first example, we follow the dynamics of the interaction of a 60 $M_\odot$ star (Langer et al. 1994) with its circumstellar medium over its entire lifetime. We use an implicit hydrodynamic code for massive stellar evolution to provide the inner boundary conditions for an explicit hydrodynamic code to model the circumstellar gas dynamics. The final supernova phase is not included. Our computations predict short-lived ($\tau \simeq 10^4$ yr) observable nebulae during the luminous blue variable (LBV) stage and the onset of the Wolf-Rayet stage.

Small scale features of ring nebulae can also give insight into the preceding stellar wind evolution. We find that variations in the stellar wind drive an instability that produces radial filaments in ring nebulae. The filaments maintain an almost steady angular spacing, but grow radially. This may explain the short angular spacing and comet-like tails of clumps observed in ring nebulae surrounding massive stars such as RCW 58 or AG Carinae. This instability may also explain the clumps observed in several planetary nebulae such as the Helix nebula and NGC 2392. Furthermore, the double shell structure found in our computations resembles that observed in η Carinae. Finally, we predict a fragmented circumstellar nebula around the LBV P Cygni.

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Submitted

Light curve solution of the earliest known star in a binary, HD 93205 (O3V+O8V)

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We present the results of an extensive photometric study of the O3 V+O8 V binary HD 93205 ($P \simeq 6^d.08, e = 0.49$). The primary O3 V star has by far the earliest known spectral type of a normal

star in a close binary. Some 186 individual differential observations, each of precision ∼0.003 mag, were obtained over a contiguous interval of ∼ 3 months in a narrow, visual continuum bandpass. The amplitude of photometric variability is very low, about $0^m.02$, with most of the light changes occuring near periastron passage.

Analysis of the light variations with a state–of–the–art binary model in an eccentric orbit leads to the conclusion that the system does not exhibit eclipses. Rather, the light variations are due to orbital revolution of tidally distorted stars. However, there is a very small, but real systematic decreasing trend in the light curve of the system ∼ centered on apastron passage, i.e. between orbital phases 0.3 and 0.95, which cannot be accounted for with present models. A non–uniform brightness distribution on the surface of the star(s), whose origin remains a mystery, may be responsible for this effect. Nevertheless, *assuming* that the model is adequate in the vicinity of periastron, when most of the light changes occur, one can estimate the range of possible values for the orbital inclination angle, e.g. at the 5% significance level: $78\,\mathrm{deg} \;\geq\; i \;\geq\; 30\,\mathrm{deg}$, which leads to the masses $M_{\rm O3} \simeq 42 - 312\ R_\odot$ and $M_{\rm O8} \simeq 16 - 120\ R_\odot$. The best fit value, $i = 60\,\mathrm{deg}$, leads to $M_{\rm O3} = 60\ M_\odot$ and $M_{\rm O8} = 23\ M_\odot$. The latter value is compatible with the reliable masses of the two O8 V stars (22 $M_\odot$) in the detached eclipsing binary system EM Car. This would imply that the most massive main sequence stars may have masses close to $50 - 60\ M_\odot$, rather than $100 - 120\ M_\odot$, as claimed elsewhere in the literature.

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Polarimetric versus photometric variability and the density of WR star wind inhomogeneities

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Intensive broad band observations of WR stars by Moffat et al. reveal photometric and polarimetric fluctuations on timescales of hours, similar to the timescale of variation of narrow spectral features on emission lines. These are attributed to localised density enhancements (blobs) in the general wind. The r.m.s. fluctuations in the two observing modes are found to be in the ratio $R = \sigma_{\rm pol}/\sigma_{\rm phot} \simeq 0.05$ whereas if both were due to electron scattering of starlight in single optically thin blobs the ratio should be around unity.

It has been suggested that the smallness of R may be attributed to cancellation of the polarisation contributions of significant numbers, N, of blobs emitted in different directions. We prove that this explanation of the small σ ratio is untenable, by calculating the expected values of $\sigma_{\rm pol}$ and $\sigma_{\rm phot}$ due to random fluctuations in N and in blob positions. This is done analytically in a simplified case and numerically in the general case. No value of N can yield the observed R.

We conclude that the discrepancy must result from a substantial photometric contribution from broad band light emitted in the blobs and/or substantial reduction in the polarisation by multiple scattering in the blobs. Either explanation demands that the blobs be very dense, with $n_e \gtrsim 5 \times 10^{13}\mathrm{cm}^{-3}$, when the blobs are at distances of around 10^{12} cm.

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Terminal velocities and the bistability of stellar winds

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The terminal velocity of the stellar winds of 73 stars of spectral types O through F has been measured from the spectra in the new *Atlas of Ultaviolet P Cygni profiles* by Snow *et al.* (1994). The ratio v_∞/v_{esc} decreases from 2.58 ± 0.20 in O-stars to 0.72 ± 0.15 in A and F stars. There is a clear discontinuity in this ratio near $T_{\rm eff} \simeq 21\ 000$ K at spectral type B1, when the ratio drops by almost a factor two from $v_\infty/v_{esc} \simeq$2.6 at the high temperature side to $v_\infty/v_{esc} \simeq$1.3 at the low temperature side, and possibly a smaller discontinuity near $T_{\rm eff} \simeq 10\ 000$ K. The discontinuity near 21 000 K is due to the change in the nature of the lines that produce the radiation pressure. At $T_{\rm eff} \gtrsim 21\ 000\ K$ the radiation pressure is due to high ionization lines which are largely optically thick, whereas at $T_{\rm eff} \lesssim 21\ 000\ K$ the radiation pressure is due to very large numbers of low ionization lines, which are more optically thin. Near $T_{\rm eff} \simeq 21\ 000\ K$ the winds can exist in two states: winds with high mass loss rates and low velocities, and winds with low mass loss rates and high velocities. This is the *bi-stability* of stellar winds for stars with $T_{\rm eff} \simeq 21\ 000\ K$. We present evidence that the bi-stability may also produce a jump in the mass loss rates of the stars near $T_{\rm eff} \simeq 21000K$ with the higher mass loss rates at the low temperature side of the jump. We discuss the possible role of bi-stability in the formation of disks around B[e]-supergiants.

The observed values of v_∞ are used to derive empirical values of the force multiplier parameter α of the radiation-driven wind theory for all stars. The mean relations between α and log($T_{\rm eff}$) are given These allow a very accurate prediction of the terminal velocity of the wind of any early type star, if the stellar parameters are known.

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Detection of a stellar wind from Sirius A. III. HST-GHRS observations of Sirius A.

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Observations of Sirius A with the GHRS instrument on board the Hubble Space Telescope revealed the presence of absorption features in the blue wings of the strong Mg II and H I resonance lines in the velocity range from -20 km.s^{-1} to -80 km.s^{-1}. These features are probably due to the stellar wind of Sirius rather than to blends of photospheric lines because: 1) the absorption features in the lines of Mg II h and k and in Lyman-α are at the same velocity, 2) the two features of the Mg II lines have about the same asymmetric shape, 3) the depths of the two Mg II h and k features have a ratio of about 1/2 which is the doublet ratio, 4) the blue wing of the h and k features agrees approximately with the expected variation of the optical depth of a line formed in a wind of low mass loss rate. A similar feature seems to be present in the C II resonance lines.

The mass loss rate derived from the Mg II lines is between 2 10^{-13} and 1.5 $10^{-12} M_\odot.yr^{-1}$ depending on the assumed ionization fraction of Mg II. This mass loss rate is a factor 10^{-2} smaller than the upper

limit derived from the Hα line. The mass loss rate agrees with the requirements for interpreting the chemically peculiar A stars by means of diffusion and mass loss.

The mass loss rate of Sirius predicted by the radiation driven wind theory is 1.0 $10^{-12} M_{\odot}.yr^{-1}$ with an uncertainty of a factor 3, and the predicted terminal velocity of the wind is $v_{\infty} \simeq 1300$ km s^{-1} . The approximate agreement between the observed and predicted mass loss rate suggests that the wind of Sirius A might be radiation driven.

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The ionization in the winds of O stars and the determination of mass-loss rates from UV lines

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The empirical ionization fractions of C IV, N V, Si IV, and the empirical ionization plus excitation fractions of C III*[†] and N IV* in the winds of O stars have been derived. This was done by combining the results of the line fitting of UV resonance lines and subordinate lines of these ions by means of the SEI method with the mass-loss rates derived from radio measurements and from Hα. We describe the dependence of these empirical ionization fractions on the effective temperature of the stars and on the mean density in the wind.

The ionization fraction and excitation fraction of C III* and N IV*, derived from the lines at 1176 Å and 1718 Å, respectively, are remarkably constant with $T_{\rm eff}$ and mean wind density. This makes these lines ideally suited for mass-loss determinations from O stars. An accuracy of about $\delta \log \dot{M} \simeq 0.16$ can be reached. The N V line can also be used, but the resulting accuracy of $\dot{M}$ is considerably worse. The C IV lines are not useful for mass-loss determinations of O stars because the lines are usually saturated, and for unsaturated lines the optical depth of the P Cygni profiles appears to be almost independent of $\dot{M}$. We did not find a reliable expression for the ionization fraction of Si IV because of the small number of stars with reliable optical depth of the Si IV resonance lines in our sample.

We describe a simple and accurate method to derive mass-loss rates from line fits of the UV wind lines of N V, N IV* and C III*.

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B[e] phenomenon extending to lower luminosities in the Magellanic Clouds

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An analysis of the four recently discovered B[e] stars Hen S 35, S 59, S 93, and S 137 in the Large Magellanic Cloud has been carried out using low-resolution IUE spectra, ESO 3.6-m CASPEC spectra, and ESO 0.5-m and 1-m *UBV* and *JHK* photometry, respectively. LTE model atmospheres have been

[†]Superscript asterisks indicate ions with subordinate lines.

fitted to the observed continuum energy distributions in order to derive the stellar parameters. The results are $T_{\rm eff} = 22\,000$ K, $R = 28$ R$_\odot$, and $\log L/L_\odot = 5.2$ for Hen S 35, $T_{\rm eff} = 14\,000$ K, $R = 16$ R$_\odot$, and $\log L/L_\odot = 4.0$ for Hen S 59, and $T_{\rm eff} = 13\,000$ K, $R = 26$ R$_\odot$, and $\log L/L_\odot = 4.2$ for Hen S 137.

The presence of absorption lines in the optical spectrum of the B9[e] Ib star Hen S 93 allowed an additional LTE line analysis for this star using Balmer, He I, Si II, Mg II, and Fe II lines to derive $T_{\rm eff} = 10\,000$ K, $R = 73$ R$_\odot$, $\log L/L_\odot = 4.7$, $\log g = 1.75$, $\xi = 10$ km s^{-1}, $v \sin i = 65$ km s^{-1}, and $M \gtrsim 14$ M$_\odot$.

Our investigation shows that the class of B[e] stars in the Magellanic Clouds extends to luminosities of about $\log L/L_\odot = 4$, i.e. much lower than those of the previously studied B[e] supergiants. This result reinforces the importance of axial symmetry in large regions of the Hertzsprung-Russell diagram.

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Identification of the Ionizing Sources of M17

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We have obtained high-quality 2-μm (K-band) spectra of 25 stars in the direction of the heavily extincted, Galactic star-forming region M17. Interloping cool field giants are a potential source of confusion, but K-band spectra combined with normal JHK colors can identify and distinguish these stars via their strong CO absorption features at $\lambda \geq 2.29\mu$m. Among the other sources, we have identified five stars as O type from their absorption lines of HI, HeI, HeII, and NIII by using a K-band classification system that we have developed (Hanson & Conti 1994). The remaining stellar objects, all but one with strong NIR excesses, show completely different spectral characteristics from known main-sequence stars. A few are completely featureless throughout the K band, and five show strong CO bands in emission. We have also found two candidate FU Orionis-like objects (CO bands in absorption combined with extreme NIR excesses). We suggest that our stellar objects are relatively massive YSOs, still shrouded by circumstellar material.

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The Initial Mass Function and Massive Star Evolution in the OB Associations of the Northern Milky Way

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We investigate the massive star content of Milky Way clusters and OB associations in order to answer three questions: (1) How coeval is star formation? (2) How constant is the IMF? (3) What is the progenator mass of Wolf-Rayet stars? Our sample includes NGC 6823/Vul OB1, NGC 6871/Cyg OB3, Berkeley 86/Cyg OB1, NGC 6913/Cyg OB1, NGC 7235, NGC 7380/Cep OB1, Cep OB5, IC 1805/

Cas OB6, NGC 1893/Aug OB2, and NGC 2244/Mon OB2. Large-field CCD imaging and multiobject, fiber spectroscopy has resulted in UBV photometry for >10,000 stars and new spectral types for ≈200 stars. These data are used to redetermine distances and reddenings for these regions, and to help exclude probable non-members in constructing the H-R diagrams. We reanalyze comparable data previously published on Cyg OB2, Tr 14/16, and NGC 6611, and use all of these to paint a picture of star-formation and to measure the initial mass-functions. We find:
(1) Most of the massive stars are born during a period $\Delta\tau$ <3 Myr in each association. Some star formation has clearly proceeded this event, as evidenced by the occasional presence of evolved ($\tau \approx$10 Myr) $15\mathcal{M}_\odot$ stars despite a typical age $\tau \approx$2 Myr for the more massive population. However, all these regions also show evidence of 5-10 $\mathcal{M}_\odot$ pre-main-sequence stars (τ <1 Myr), demonstrating that *some* star formation at lower masses does continue for at least 1 Myr after the formation of high mass stars.
(2) There is no statistically significant difference in IMF slopes among these clusters, and the average value is found to be $\Gamma = -1.1 \pm 0.1$ for stars with masses $> 7\mathcal{M}_\odot$. A comparison with similarly studied OB associations in the Magellanic Clouds reveals no difference in IMF slope, and hence we conclude that *star formation of massive stars in clusters proceeds independently of metallicity, at least between z=0.02 and z=0.002.* The masses of the highest mass stars are approximately equal in the Milky Way, LMC, and SMC associations, contrary to the expectation that this value should vary by a factor of 3 over this metallicity range. We conclude that radiation pressure on grains must not limit the mass of the highest mass star that can form, in accord with the suggestion of Wolfire & Cassinelli that the mere existence of massive stars suggests that shocks or other mechanisms have disrupted grains in star-forming events.
(3) The four Wolf-Rayet stars in our sample have come from stars more massive than $40\mathcal{M}_\odot$; one WC star and one late-type WN star each appear to have come from very massive (≈100 $\mathcal{M}_\odot$) progenitors.

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Wind Variability of B Supergiants: I. The Rapid Rotator HD 64760 (B0.5 Ib)

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We present the results of a 6 day time series of observations of the rapidly rotating B0.5 Ib star HD 64760 obtained in March of 1993. We point out several reasons why such intermediate luminosity B supergiants are ideal targets for wind variability studies and then present our results which show: 1) Continuous wind activity throughout the 6 day run with the wind never in steady state for more than a few hours. 2) Wind variability very near v = 0 km s^{-1} in the resonance lines from the lower ionization stages (Al III and C II). 3) A distinct correlation between variability in the Si III $\lambda\lambda$ 1300 triplets, the strong C III λ1247 singlet, and the onset of extremely strong wind activity, suggesting a connection between photospheric and wind activity. 4) Long temporal coherence in the behavior of the strong absorption events. 5) Evidence for large scale spatial coherence, implied by a whole scale, simultaneous weakening in the wind absorption over a wide range in velocities. 6) Ionization variability in the wind accompanying the largest changes in the absorption strengths of the wind lines.

In addition, modeling of the wind lines provides the following information about the state the wind in HD 64760. 1) The number of structures on the portion of a constant velocity surface occulting the

stellar disk at a particular time must be quite small, while the number on the entire constant velocity surface throughout the wind must be large. 2) The escape probability at low velocity is overestimated by a normal $\beta \sim 1$ velocity law, perhaps due to the presence of low velocity shocks deep in the wind or a shallow velocity gradient at low velocity. 3) Estimates of the ionization structure in the wind indicate that the ionization ratios are not those expected from thermal equilibrium wind models or from an extrapolation of previous O star results. The large observed $q(\text{N V})/q(\text{Si IV})$ ratio is almost certainly due to distributed X-rays, but the level of ionization predicted by distributed X-ray wind models is inconsistent with the predicted mass loss rate. Thus, it is impossible to reconcile the observed ionization ratios and the predicted mass loss rate within the framework of the available models.

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Excess Radiation In The Visual Energy Distribution of Wolf-Rayet Stars

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The near-infrared, optical and UV energy distribution of nitrogen rich Wolf-Rayet stars (WR stars of type WN) in the LMC and in the Galaxy is compared with models for the winds of WR stars. The energy distribution is approximately a power law, $F_\lambda \sim \lambda^{-\alpha}$ with a spectral index $\alpha = 2.8 \pm 0.4$. Simple model calculations with a ρ^2-dependent opacity show how the spectral index is expected to depend on the radius of the star, the mass loss rate, and the temperature and density profiles of the wind. A comparison between these predictions and the observed values of α shows that there is a gradual transition between strong-lined and weak-lined WN stars.

We have compared the empirical values of α with those from published non-LTE models of the "Kiel group". We adopted the stellar parameters that were derived by the "Kiel group" on the basis of their study of the Helium lines. According to these models the strong- and weak-lined WN stars in the Galaxy exhibit distinctly different measures of atmospheric extension such that for the strong-lined stars the continuum is formed over a more extended region in the wind than for the weak-lined stars. Therefore these models predict a bimodal distribution of the values of α with smaller values of $\alpha \simeq 2.7$, i.e. corresponding to flatter energy distributions, for the strong-lined stars and larger values of $\alpha \simeq 3.1$, corresponding to steeper energy distributions, for the weak-lined stars.

The observed values of α do not show this distinction between strong- and weak-lined stars. This discrepancy indicates that the present non-LTE models for weak-lined WN stars do not properly describe their winds: the continuum radiation of these stars is formed over a more extended region of their wind than predicted. This is supported by a recent analyses of several Galactic late-type WN stars by Crowther et al. (1994a,b,c), who show that weak-lined WN stars (in particular WN8 stars) often do in fact have denser winds than predicted by the models.

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The nuclear cluster of the Milky Way: star formation and velocity dispersion in the central 0.5 parsec

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We report the first results of an extensive new study of the composition, dynamics and evolution of the Galactic center stellar cluster. Previous proposals are now confirmed more quantitatively that the central parsec is powered by a cluster of hot, massive stars of which the IRS16/IRS13 complex is the central core. The members of this cluster that are most prominent at 2μm are two dozen HeI/HI emission line stars. They are very luminous ($10^{6\pm0.5}\,L_\odot$) helium rich, blue supergiants/Wolf-Rayet stars (T_{eff} ~20,000 to 30,000 K) with ZAMS masses up to 120 $M_\odot$. In addition to about a dozen WN9/Ofpe stars we have also identified one WN9 star, four WC9/Of stars and at least one B[e] star. We conclude that the most likely scenario for the formation of the massive stars is a small star formation burst between 3 and 7×10^6 years ago that may have been the result of substantial prior gas influx into the central few parsecs. In this scenario the Galactic center is presently in a short-lived, post-main sequence 'wind phase'. In addition, there is evidence for another star formation event about 10^8 years ago, as well as for recently formed massive stars that may have been transported into the central core along with orbiting gas streamers. The radial velocity dispersion of 35 early and late type stars with distances of $1''$ to $12''$ from SgrA* is 153±18 km/s. Our new results strongly favor the existence of a central dark mass of $\sim 3 \times 10^6$ $M_\odot$ (density $\leq 10^{8.5}\,M_\odot$ pc^{-3}, M/L$\geq$10 $M_\odot/L_\odot$) within 0.14 pc of the dynamic center.

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A Study of the Spectra of Seven Of Stars I. Radial Velocities

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Seven Of stars, namely HD 17603 O7.5 If, HD 34656 O7 II(f), HD 188001 9 Sge O7.5 Iaf, HD 190864 O6.5 III(f), HD 192639 O7 Ib(f), HD 193514 O7 Ib(f), and HD 210839 λ Cep O6 I(n)fp, have been observed at 30 Å mm^{-1} in the blue-violet, yellow-green, and red regions. The above are Walborn spectral types. All the spectrograms were measured for radial velocity; radial-velocity results are presented in Tables 2–9.

Each star is discussed separately in Sections 3.1–3.7; the results are summarized in Section 4. The spectrum of each star has been classified using the ratio $W' = W_\lambda(\mathrm{HeI}\lambda4471)/W_\lambda(\mathrm{HeII}\lambda4541)$ to determine the spectral type; the Stark effect broadening of the lines of the Pickering series of He II has been used to determine the luminosity class. The question of appropriate luminosity and spectral type criteria is discussed in Sections 3.10 and 3.11. The generally accepted luminosity criteria for stars of types O8 and earlier are found to be ambiguous, while the traditional criterion for spectral type among the O stars is found to be sensitive to factors in addition to the effective temperature of the star.

New spectral types are recommended for the program stars. They are: HD 17603 O8 Ifv, HD 34656 O7.5 III((f)), HD 188001 9 Sge O8 If, HD 190864 O7 III((f)), HD 192639 O8 Ifv, HD 193514 O7.5 I(f), and HD 210839 λ Cep O6.5 IIIfp. The letter v is introduced in two cases to indicate that the Of subtype has been observed to change from f to (f). It is suggested that the peculiar character of the spectrum of λ Cephei indicates the presence of a disk; the Stark broadening of the He II lines of this star clearly indicate that λ Cephei is a giant rather than a supergiant. The profiles of Hα and He II λ4686 indicate that the physical state/degree of ionization of the winds of HD 17603, HD 188001 9 Sge, HD 192639, and HD 210839 λ Cep change. The time scale of the changes has been observed to be hours for λ Cephei, a few days for HD 192639, and months or years for HD 188001 9 Sge and HD 17603. These changes in the physical state of the wind occur with no detected change in the luminosity of the star or of its spectral type.

The star HD 188001 9 Sge is confirmed to be a SB1 with a period of 78.74 day and small range. The stars HD 190864 and HD 192639 would benefit from intense observation over 10–14 days to determine whether or not they are SB1s of small range. In some of the stars, see the notes on each star, the sharp emission lines are displaced relative to lines formed in the photosphere. The weak sharp emisssion lines appear to be formed close to the photosphere and to rotate with the photosphere. Four new emission lines are seen near 6720 Å. Some support is adduced for the model for O stars described by Underhill in 1984.

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A Study of the Spectra of Seven Of Stars II. Line Profiles and Equivalent Widths

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Seven Of stars (HD 17603, HD 34656, HD 188001 9 Sge, HD 190864, HD 192639, HD 193514, and HD 210839 λ Cep) have been observed in the blue-violet, yellow-green, and red spectral regions chiefly at 30 Å mm^{-1}. The equivalent widths and $FWHM$ measures of the prominent absorption and emission lines in these spectra are presented here and this new information is used with information presented in Paper I (Underhill 1995) to study what the spectra of stars of types O8–O6 imply.

It was noted in Paper I that the character of the profiles of Hα and He II λ4686, both being lines formed in the winds from the stars, have been observed to vary. The other absorption and emission lines of H, He I, He II, C III, C IV, N III, and Si IV have not been observed to change by an amount in excess of five percent. It is argued that the photosphere and line-emitting plasma of the program stars are more constant in behaviour than the winds of the program stars are. An index measuring the amount of Stark broadening of the He II lines is derived and it is argued that this index can be used as a criterion of the density in the photosphere of an O star. This index correlates fairly well with the luminosity classes assigned by Walborn from inspection of the spectra of the stars.

The appearance of N III $\lambda\lambda$4634, 4641 emission lines in all O spectral types bearing an Of tag of any description is noted to mean that heated plasma is present in the line-forming regions of some, but not all, main-sequence, giant, and supergiant O stars. It is suggested that the heating may be a result of the transformation of mechanical energy to heat in the presence of small magnetic fields on the surfaces of Of stars. A specific agent must be invoked to explain why only *some* stars in each spectral type–luminosity class box show selected weak sharp emission lines.

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Wolf-Rayet Bubbles. I. Analytic Solutions

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Stellar wind bubble dynamics are sensitive to the stellar wind velocity and mass-loss history. Observations of ring nebulae can thus strongly constrain theories of stellar winds and massive stellar evolution. Furthermore, ring nebulae are often observed around Wolf-Rayet stars likely to soon become supernovas, so their influence on the circumstellar medium is vital to understanding young supernova remnants such as Cas A. To interpret the observations, the connection between the input wind and the observed gas distribution must be described. This is our goal in this series of papers.

In this paper, we present analytic solutions for the dynamics of bubbles expanding into media with power law density distributions such as r^{-2}. We apply the solutions to Wolf-Rayet bubbles expanding into red supergiant winds. A semi-analytic method is used to model aspherical bubbles resulting from non-spherical red supergiant winds. Applying this method we find, for the case of steady winds, that bubbles expand at nearly constant velocity in each direction, keeping their shapes. We can then make the approximation that the bubbles have constant eccentricity ellipsoidal shapes to derive a fully analytic dynamical model. From this we derive solutions for the diffuse X-ray luminosities from steady winds, using the assumption of classical conductive evaporation. Useful relationships between observables are also given.

The solutions are compared to observations of the Wolf-Rayet ring nebula NGC 6888. We find that with either the assumption of energy conservation or momentum conservation, the dynamics of this nebula cannot be explained if the reported wind kinetic energy of the central star WR 136 is used. The nebular kinematics require an order of magnitude less effective mechanical luminosity from WR 136, demanding either a lower mass-loss rate, a lower wind velocity, or both.

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Wolf-Rayet Bubbles. II. Gas Dynamical Simulations

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We perform two-dimensional gas dynamical simulations to model the growth of a stellar wind bubble around a Wolf-Rayet (WR) star, taking into account the prior main sequence and red supergiant phases. Following the three-wind model we have proposed in García-Segura and Mac Low (paper I), we take the main sequence, red supergiant, and Wolf-Rayet winds to each be constant in time. We consider the possibilities that the main sequence bubble either cools or remains hot and pressurized. We

simulate the history of a realistic bubble using qualitative simulations. We then perform a numerical resolution study to get a quantitative description of the swept-up, unstable shell.

We find that the Vishniac instability dominates the behavior of the ring nebula while the Wolf-Rayet wind sweeps up the red supergiant wind. Clumps form with column densities at least a factor of two higher than the unperturbed shell, while the column density in the rest of the shell decreases by two orders of magnitude. As a result, external neutral shells probably cannot exist around Wolf-Rayet ring nebulae. The only place neutral material could exist would be within dense, self-shielding clumps. When the Wolf-Rayet wind finishes sweeping up the red supergiant wind, it breaks out into the surrounding low density, main sequence bubble, becoming Rayleigh-Taylor unstable. At breakout, we find a 12° wavelength to be dominant in the clumpy shell. The shapes and dynamics of the individual blowouts suggest that observed Wolf-Rayet ring nebulae such as NGC 6888 lie within main sequence bubbles that have already cooled. No more than 90% of the swept-up gas lies in visible clumps. Before blowout, clumps travel up to 40% slower than the interclump shell, and contain less than 65% of the shell kinetic energy expected from analytic models. At this time, the observable clumps carry less than 18% of the total wind kinetic energy.

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News

HD 5980 (and AG Car)

R. Barba and V. Niemela, Observatorio Astronomico, La Plata, communicate: "Spectral observations (360-700 nm) obtained between Oct. 24 and 27 with the REOSC echelle spectrograph + CCD attached to the 2.15-m telescope at CASLEO Observatory, San Juan, show that the brightest Wolf-Rayet eclipsing binary star in the SMC, HD 5980 (R.A. = 0h58m.62, Decl. = -72 deg 17'.9, equinox 1975.0; Azzopardi and Vigneau 1982, A.Ap.Suppl. 50, 291), has brightened considerably and completely changed its spectrum, which is now similar to eta Car-type variables, with strong P-Cyg lines of He I and H Balmer, as well as Fe III and N II lines. From flux-calibrated spectra we estimate that the continuum V brightened by about 1 mag with respect to previous observations obtained with the same telescope in Jan. and June, when it was at V = 11.0, already 0.8 mag brighter than published values (cf. Azzopardi and Vigneau 1982, ibid.). HD 5980 appears to be currently undergoing an eta Car-type outburst." **IAU Circular No. 6099 (1994 November 2)**

F. M. Bateson, Variable Star Section, Royal Astronomical Society of New Zealand, reports (via A. Gilmore): "HD 5980 (cf. IAUC 6099) has been monitored by A. F. Jones, Nelson, since 1958. He first detected an increase in brightness of 1 mag on 1994 July 18.7 UT (VSS Circular M94/7, RASNZ)." **IAU Circular No. 6102 (1994 November 9)**

> The light curves for HD5980 and AG Car, covering several years, have been published by Frank M. Bateson in the Bulletin No 19 of the Variable stars section of the RAS New Zealand. *(Kindly communicated by Virpi Niemela)*
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> Frank's address is P.O.Box 3093, Greerton, Tauranga, N.Z. *(Kindly communicated by John Hearnshaw)*

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