THE HOT STAR NEWSLETTER

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From the editor

Karel van der Hucht communicates:

ASCII versions of the main catalogue tables of the paper "The VIIth Catalogue of Galactic Wolf-Rayet Stars" (van der Hucht, K.A. 2001, New Astronomy Reviews 45, 135) are now available in ftp://saturn.sron.nl/pub/karelh/UPLOADS/VIIWRCAT.dir

Accepted Papers

The Stellar Content of Obscured Galactic Giant H II Regions III.: W31

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We present near infrared (J, H, and K) photometry and moderate resolution ($\lambda/\Delta\lambda = 3000$) $K-$band spectroscopy of the embedded stellar cluster in the giant H II region W31. Four of the brightest five cluster members are early O–type stars based on their spectra. We derive a spectro–photometric

distance for W31 of 3.4 ± 0.3 kpc using these new spectral types and infrared photometry. The brightest cluster source at K is a red object which lies in the region of the $J-H$ vs. $H-K$ color–color plot inhabited by stars with excess emission in the $K-$band. This point source has an H plus $K-$band spectrum which shows no photospheric features, which we interpret as being the result of veiling by local dust emission. Strong Brackett series emission and permitted Fe II emission are detected in this source; the latter feature is suggestive of a dense inflow or outflow. The near infrared position of this red source is consistent with the position of a 5 GHz thermal radio source seen in previous high angular resolution VLA images. We also identify several other $K-$band sources containing excess emission with compact radio sources. These objects may represent stars in the W31 cluster still embedded in their birth cocoons.

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A Near-Infrared Stellar Census of Blue Compact Dwarf Galaxies: The Wolf-Rayet Galaxy I Zw 36

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We report the results of near-IR imaging in J and H, of I Zw 36 ($\approx Z_\odot/14$) with the Hubble Space Telescope. Whereas imaging with the pre-COSTAR Faint Object Camera (FOC) previously resolved hot and massive stars in the near-UV, the NICMOS data furnish a census of the cool, intermediate- and low-mass stars. There clearly was star formation in I Zw 36 prior to the activity which earned it its Blue Compact Dwarf/Wolf-Rayet galaxy classification. The detection of luminous, asymptotic giant branch stars requires that stars formed vigorously several hundred Myr ago. The well-populated red giant branch indicates stars with ages of at least 1-2 Gyr (and possibly older than 10 Gyr). We use the tip-of-the-red-giant-branch method to derive a distance of $\geq$5.8 Mpc. This is the third in a series of papers on near-IR—resolved Blue Compact Dwarf galaxies. We notice that the color-magnitude diagrams of VII Zw 403, Mrk 178, and I Zw 36 do not exhibit the gaps expected from an episodic mode of star formation. Using simulated color-magnitude diagrams we demonstrate for I Zw 36 that star formation did not stop for more than a few 10^8 yrs over the past 10^9 yrs, and discuss the implications of this result.

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HST study of the LMC compact star forming region N83B

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High resolution imaging with the *Hubble Space Telescope* uncovers the so far hidden stellar content and the nebular features of the high excitation compact H II region N83B in the Large Magellanic Cloud (LMC). We discover that the H II region is powered by the most recent massive starburst in the OB association LH 5 and the burst has created about 20 blue stars spread over $\sim 30''$ on the sky (7.5 pc). Globally N83B displays a turbulent environment typical of newborn massive star formation sites. It contains an impressive ridge, likely created by a shock and a cavity with an estimated age of only $\sim$ 30,000 yr, sculpted in the ionized gas by the powerful winds of massive stars. The observations bring to light two compact H II blobs, N83B-1 and N83B-2, and a small arc-nebula, N83B-3, lying inside the larger H II region. N83B-1, only $\sim 2''.8$ (0.7 pc) across, is the brightest and most excited part of N83B. It harbors the presumably hottest star of the burst and is also strongly affected by dust with an extinction of $A_V = 2.5$ mag. The second blob, N83B-2, is even more compact, with a size of only $\sim 1''$ (0.3 pc). All three features are formed in the border zone between the molecular cloud and the ionized gas possibly in a sequential process triggered by the ionization front of an older H II region. Our *HST* imaging presents an interesting and rare opportunity to observe details in the morphology of the star formation in very small spatial scales in the LMC which are in agreement with the concept of the fractal structure of molecular star forming clouds. A scenario which supports hierarchical massive star formation in the LMC OB association LH 5 is presented.

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Also available from the URL http://wwwusr.obspm.fr/∼heydari/projects/N83 and *http://fr.arXiv.org/abs/astro-ph/0103414*

Optical spectroscopy of X-MEGA targets I. CPD -59° 2635: A New Double-Lined O type Binary in the Carina Nebula

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Optical spectroscopy of CPD -59° 2635, one of the O-type stars in the open cluster Trumpler 16 in the Carina Nebula, reveals this star to be a double-lined binary system. We have obtained the first radial velocity orbit for this system, consisting of a circular solution with a period of 2.2999 days and semi amplitudes of 208 and 273 km s^{-1}. This results in minimum masses of 15 and 11 $M_\odot$ for the binary components of CPD -59° 2635, which we classified as O8V and O9.5V, though spectral type variations of the order of 1 subclass, that we identify as the *Struve-Sahade effect*, seem to be present in both components. From ROSAT HRI observations of CPD -59° 2635, we determine a luminosity ratio $\log(L_x/L_{bol}) \approx -7$, which is similar to that observed for other O-type stars in the Carina Nebula region. No evidence of light variations is present in the available optical or X-rays data sets.

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Optical spectroscopy of X-Mega targets in the Carina Nebula. II. The massive double-lined O-type binary HD 93205

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A new high-quality set of orbital parameters for the O-type spectroscopic binary HD 93205 has been obtained combining échelle and coudé CCD observations. The radial velocity orbits derived from the He II λ4686 Å (primary component) and He I λ4471 Å (secondary component) absorption lines yield semiamplitudes of 133 ± 2 and 314 ± 2 km s^{-1} for each binary component, resulting in minimum masses of 31 and 13 $M_\odot$ ($q = 0.42$). We also confirm for the binary components the spectral classification of O3 V + O8 V previously assigned. Assuming for the O8 V component a "normal" mass of 22 – 25 $M_\odot$ we would derive for the primary O3 V a mass of "only" 52 – 60 $M_\odot$ and an inclination of about 55° for the orbital plane. We have also determined for the first time a period of apsidal motion for this system, namely 185 ± 16 years using all available radial velocity data-sets of HD 93205 (from 1975 to 1999). Phase-locked variations of the X-ray emission of HD 93205 consisting of a rise of the observed X-ray flux near periastron passage, are also discussed.

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Wind Circulation in Selected Rotating Magnetic Early-B Type Stars

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The rotating magnetic B stars are a class of variables consisting of He-strong and some β Cep stars which have oblique dipolar magnetic fields. Such stars develop co-rotating, torus-shaped clouds by channeling wind particles from their magnetic poles to circumstellar regions centered around the plane of their magnetic equators. The rotation of the cloud-star complex permits the study of absorptions from the cloud as it occults the star. In this paper we describe a quantitative analysis of archival *IUE* data to map the properties of these clouds over four stars (HD 184927, σ Ori E, β Cep, and HR 6684). By computing spectral synthesis models for these stars, we find that only β Cep has a solar-like metallicity. Our analysis also shows that the metal composition across the surfaces of all these stars is at least approximately homogeneous.

Using the Hubeny code *CIRCUS*, we demonstrate that the periodic variations of broad-band ultraviolet continuum fluxes can be explained fully by the absorptions of the co-rotating cloud. We show next that among selected lines, those arising from low-excitation states are selectively affected by cloud absorption and turbulence. Our analysis also quantifies the cloud temperatures and column densities required to match the absorptions of a number of weak to moderate strength resonance lines. These temperatures increase with the ionization potential of the parent ions of these various lines, a result which is consistent with radiative equilibrium models in which temperature increases with proximity to the star's surface. Although these attributes appear stable from one epoch to another, dynamic processes are nonetheless at work. Both the strengths and widths of resonance lines at occultation phases indicate the presence of a turbulence in the cloud which increases inwards.

The spectroscopic hallmark of this stellar class is the presence of strong C IV and N V resonance line absorptions at occultation phases and of redshifted emissions of these lines at magnetic pole-on phases. The emissions have characteristics which seem most compatible with their generation by high-energy shocks at the wind-cloud interface, as predicted recently by Babel.

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Chemical Abundances of OB Stars in Five OB Associations

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We present LTE abundances of magnesium, aluminum, sulfur and iron, and non-LTE abundances of carbon, nitrogen, oxygen, and silicon for a sample of 15 slowly-rotating B stars belonging to five OB associations: Cyg OB3, Cyg OB7, Lac OB1, Vul OB1 and Cep OB3. These OB associations lie on the Galactic plane and are situated within 3 kpc of the Sun. Of the 8 elements sampled, non-LTE abundances for C, N, O, and Si, as well as LTE abundances for Al and Fe, generally show subsolar abundances, with typical underabundances of $\sim$ 0.2-0.4 dex. The LTE abundances for Mg and S tend to fall closer to solar values in the five associations. Whether the somewhat larger abundances derived for Mg and S, relative to the other 6 elements studied, are significantly different will require further work, while the modest, but persistent, underabundances (relative to solar) found for the other elements confirm a number of previous studies of young disk OB stars lying relatively near to the Sun. The five associations studied here do not span a significant range of Galactocentric distances, however, their derived abundances agree with what would be expected based upon previous studies which have mapped abundance versus Galactocentric distance and measured abundance gradients in the Milky Way disk.

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Spectrum Variability of the A-Type Supergiant Star HD 223960

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HD 223960, an A0 Ia-type supergiant in the Cas OB5 association, is unusual among Galactic supergiants of its class in having an Hα profile with double-peaked emission entirely above the continuum. We analyzed twelve high-resolution échelle spectra obtained in 1993–1995 and in 1999 with the 1-m telescope of Ritter Observatory. The radial velocities of photospheric Si, C, He, Ne, and S lines were found to be constant to within ± 2 km s^{-1}, but the data suggest variability in the equivalent widths of Si 2 $\lambda\lambda$ 6347, 6371 and several other photospheric lines. The radial velocities and equivalent widths and, especially, the ratio V/R of the Hα components vary. The present data do not indicate a binary explanation for the double-peaked emission feature. Alternative explanations are considered, but none is completely satisfactory. The available evidence is consistent with the star having a weak, fast wind.

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Formation of Contact in Massive Close Binaries

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We present evolutionary calculations for 74 close binaries systems with initial primary masses in the range 12...25 $M_\odot$, and initial secondary masses between 6 and 24 $M_\odot$. The initial periods were chosen such that mass overflow starts during the core hydrogen burning phase of the primary (Case A), or shortly thereafter (Case B). We use a newly developed binary code with up-to-date physics input. Of particular relevance is the use of OPAL opacities, and the time-dependent treatment of semiconvective

and thermohaline mixing. We assume conservative evolution for contact-free systems, i.e., no mass or angular momentum loss from those system except due to stellar winds.

We investigate the borderline between contact-free evolution and contact, as a function of the initial system parameters. The fraction of the parameter space where binaries may evolve while avoiding contact — which we found already small for the least massive systems considered — becomes even smaller for larger initial primary masses. At the upper end of the considered mass range, no contact-free Case B systems exist. While for primary masses of $16\,M_\odot$ and higher the Case A systems dominate the contact-free range, at primary masses of $12\,M_\odot$ contact-free systems are more frequent for Case B. We identify the drop of the exponent x in the main sequence mass-luminosity relation of the form $L \propto M^x$ as the main cause for this behaviour.

For systems which evolve into contact, we find that this can occur for distinctively different reasons. While Case A systems are prone to contact due to reverse mass transfer during or after the primary's main sequence phase, all systems obtain contact for initial mass ratios below ~ 0.65, with a merger as the likely outcome. We also investigate the effect of the treatment of convection, and found it relevant for contact and supernova order in Case A systems, particularly for the highest considered masses.

For Case B systems we find contact for initial periods above ~ 10 d. However, in that case (and for not too large periods) contact occurs only after the mass ratio has been reversed, due to the increased fraction of the donor's convective envelope. As most of the mass transfer occurs conservatively before contact is established, this *delayed contact* is estimated to yield to the ejection of only a fraction of the donor star's envelope. Our models yield the value of β, i.e., the fraction of the primaries envelope which is accreted by the secondary.

We derive the observable properties of our systems after the major mass transfer event, where the mass gainer is a main sequence or supergiant O or early B type star, and the mass loser is a helium star. We point out that the assumption of conservative evolution for contact-free systems could be tested by finding helium star companions to O stars. Those are also predicted by non-conservative models, but with different periods and mass ratios. We describe strategies for increasing the probability to find helium star companions in observational search programs.

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What is the real nature of HD 108?

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Since the beginning of the past century, the nature of HD 108 has been a subject of intense debate. One after another, astronomers explored its variability and attributed it either to binarity, or to changes in the stellar wind of a single star. In this article, we analyse a 30 years long campaign of spectroscopic observations of this star with special emphasis on the last 15 years during which photographic plates have been replaced by CCD detectors. Our investigation of the radial velocities of HD 108 yields no significant short- or long-term period and does not confirm the published periodicities either. Though the radial velocity of HD 108 appears clearly variable, the variations cannot be explained by the orbital motion in a spectroscopic binary. However, our data reveal spectacular changes in the H I Balmer lines and some He I profiles over the years. These lines continuously evolved from P Cygni profiles

to 'pure' absorption lines. A similar behaviour was already observed in the past, suggesting that these changes are recurrent. HD 108 seems to share several characteristics of Oe stars and we discuss different hypotheses for the origin of the observed long-term variations. As we are now in a transition period, a continuous monitoring of HD 108 should be considered for the next few years.

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Detection and study of the compact HII region N26A-B in the SMC

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This paper presents new imagery and spectrophotometric results for the N26 HII region in the Small Magellanic Cloud. The observations using monochromatic images and low-resolution spectra (3700-10000 $\AA$) reveal a compact and complex nebula composed of two cores A and B where A in the region of Hβ is brighter than B by a factor $\sim$ 5 and distance of 2". The core A of FWHM $\sim$ 2".1 or 0.6 pc presents a high excitation [O III] $\lambda\lambda 5007 + 4959/H\beta$ up to $\sim$ 8 and a high reddening E(B-V) $\leq$ 0.6, while the core B is less excited but has a higher reddening $\geq$ 0.8. Each core contains one exciting source; the brighter one should be responsible for the high excitation of A. The apparent spectral type of the two cores ranges from O7 to O9 V and the gas electron density and temperature were derived from the absorption and emission-line intensities. The total mass of the ionized gas is evaluated at 13 M$\odot$. The chemical abundances of He, O, N, Ne, S, and Ar were computed. These abundances seem consistent with average abundances for SMC HII regions, except N that appears slightly overabundant. N26A-B is comparable to the objects previously observed in the LMC and SMC that we have called "blobs".

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On the Nature of the Central Source in Eta Carinae

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Long-slit spectroscopic observations of Eta Carinae and its Homunculus have recently been obtained using STIS on the HST. We have extracted the spectrum of the central source using a $0.1''$ by $0.13''$ aperture. As expected, the spectrum is very different from ground-based spectra obtained under normal seeing conditions (i.e., $1''$) — the HST observed spectrum exhibits primarily broad permitted emission lines ($v_{\rm FWHM} \approx 500\,{\rm km\,s^{-1}}$) while ground-based spectra show strong narrow ($v_{\rm FWHM} \approx 40\,{\rm km\,s^{-1}}$) permitted and forbidden lines (primarily [Fe ii], Fe ii, and H i) superimposed on a broad emission line spectrum.

In the optical, the spectrum shows strong H i, He i, and Fe ii emission lines, many exhibiting P Cygni absorption components. Emission features due to N i Si ii, Na i, Mg ii, Ca ii, and Al ii can also be

identified. Only a few weak broad lines of [Fe ii] are seen. The spectrum is qualitatively similar to a much less luminous object, the extreme P Cygni star HDE 316285.

We have performed a detailed analysis of the spectrum using the non-LTE line blanketed wind code of Hillier and Miller. Despite the complexity of Eta Carinae, we are able to obtain a good fit to the optical emission line spectrum using a model with a mass-loss rate of $10^{-3}\,M_\odot\,\mathrm{yr}^{-1}$. The weakness of the electron scattering wings indicates that the wind is clumped, with a volume filling factor of approximately 0.1.

Due to the parameter range, and the extremely dense wind associated with the central star, our best fit model is not unique. As is the case for HDE 316285, there is a strong coupling between the derived mass-loss rate and the derived N(H)/N(He) abundance ratio. In addition, the wind is so dense that the star's surface cannot be observed. Consequently, the effective temperature of the underlying star is not well determined.

Because of the rich emission-line spectrum we are able to place limits on many abundances: Mass fractions of species such as Fe and Mg (and perhaps Ca, Si, and Al) are solar to within a factor of 2. In accord with standard evolutionary scenarios, Na is slightly enhanced, the N mass fraction is at least a factor of 10 over solar, while C and O show substantial depletions.

The adopted luminosity of $5 \times 10^6\,L_\odot$ is based on the observed IR flux and an assumed distance of 2.3 kpc. Thus, based on the Eddington limit, the minimum mass of the system is approximately $120(L/5 \times 10^6\,L_\odot)\,M_\odot$ (for N(H)/N(He)=5). While Eta Carinae may be a binary, recent evidence suggests that the purported secondary star has a mass less than $30\,M_\odot$. Thus the primary star is currently more massive than $90\,M_\odot$, and the initial mass of the star should conservatively have been in excess of $150(L/5 \times 10^6)\,M_\odot$.

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In Proceedings

Emission-Line Spectra of B[e] Supergiants and S Dor Variables

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Two relatively homogeneous groups of emission-line stars in the upper left part of the HRD are the B[e] supergiants and the S Dor variables. The properties of both groups of objects, with emphasis on peculiar properties of their emission-line spectra, are reviewed.

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Zeeman Detection of Magnetic Fields in Hot Stars

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No confirmed detection of a surface magnetic field exists for any nondegenerate star earlier than about spectral type B2. On the other hand, the existence of intense fields in main sequence A and B type stars, along with the cyclic variability commonly observed in the winds and envelopes of many O and Be stars, provide strong indications that magnetic fields are indeed present in hot stars. In this paper I discuss the observational and theoretical bases for suspecting that many hot stars host surface magnetic fields of order 10-1000 G. I describe the difficulties involved in using conventional Zeeman magnetic diagnostic techniques to detect such fields, and review the various attempts to date. I conclude by describing the recent "success stories" of β Cep and θ^1 Ori C, and describe possible future strategies and the outlook for exploitation of large telescopes.

In the proceedings of Magnetic Fields Across the H-R Diagram
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The observed galactic Wolf-Rayet star distribution in relation with metallicity

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The recent *VIIth Catalogue of Galactic Wolf-Rayet Stars* (van der Hucht, K.A. 2001, *New Astron. Revs.* **45**, 135) lists 227 Population I WR stars, comprising 127 WN, 87 WC, 10 WN/WC and 3 WO stars. Additional discoveries bring the census to 234 WR stars, including 22 WNL and 11 WCL stars within 50 pc of the Galactic Center.

A re-determination of the optical photometric distances and the galactic distribution of WR stars shows in the solar neighbourhood a projected surface density of 2.7 WR stars per kpc^2, a $N_{\rm WC}/N_{\rm WN}$ number ratio of 1.3, and a WR binary frequency of 40 %.

The galactocentric distance ($R_{\rm WR}$) distribution per subtype shows $\overline{R_{\rm WN}}$ and $\overline{R_{\rm WN}}$ decreasing with later WN and WC subtypes. The observed trend is more indicative of WNE → WCE and WNL → WCL subtype evolution, rather than of WNL → WNE and WCL → WCE subtype evolution.

Compared with other Local Group galaxies and in relation with metallicity, the Milky Way has within 3 kpc from the Sun a number ratio $N_{\rm WC}/N_{\rm WN} = 1.3$, which is a factor of ~ 2 above the expected trend. This could mean that some 30 galactic WN stars in the $d < 3$ kpc volume are still hiding.

To appear in: D. Vanbeveren (ed.), The Influence of Binaries on Stellar Population Studies, Proc. Int. Conf., Brussels, Belgium, 21-25 Augustus 2000 (Dordrecht: Kluwer).
Preprints on the web at: `ftp://saturn.sron.nl/pub/karelh/UPLOADS/papers.dir`

Active dust formation by Population I Wolf-Rayet stars

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We review studies of heated dust formation around Wolf-Rayet stars, observed in the near-IR with groundbased $JHKL'M$ photometry and in the IR with *ISO*-SWS spectroscopy. Episodes of fresh dust formation with intervals of the order of ten years has been discovered for three WC+O colliding wind binaries, episodic and variable persistent dust formation has been found for four other WC+O candidate binaries, and persistent dust formation is known for 19 WC8-9 stars. Of the last two categories two stars have been imaged in the near-IR, showing pinwheels in the sky with rotation periods of the order of 1-2 yr. This suggests that perhaps all dusty WC stars are binaries.

Dust formation is the least understood of all phenomena associated with colliding stellar winds in WC+OB binaries, including non-thermal radio emission and variable X-ray and $\gamma-$ray emission. While the latter two phenomena are associated with the apex of the wind-wind collision cones, dust formation occurs in the wake of the collision cones, at distances of a few hundred stellar radii away from these hot evolved massive binaries. After formation, the dust is being carried away by the WC stellar winds and cools gradually to interstellar temperatures. The cooling dust radiation emission affects the wavelength regions where *FIRST* will observe.

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Massive Single and Binary Star Models: A Comparison

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We compare the predictions of recent single and binary star models with respect to several observable features. First, we find that rotationally induced mixing and accretion from a close binary component may lead to almost identical surface abundance patterns — with the boron to nitrogen ratio as a marked exception. We then compare the formation of Wolf-Rayet and helium stars in isolation and binary systems and relate them to Type Ib and Type Ic supernovae. We furthermore discuss the influence of a binary companion on the critical initial masses for the white dwarf–neutron star and neutron star–black hole transitions. E.g., assuming an upper initial mass limit for the formation of white dwarfs of $8M_\odot$ in single stars, we argue that this limit may be as high as $16M_\odot$ in binary systems. Finally, we discuss trends for the spins of compact objects emerging from the most recent single star and binary models.

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The Blue-to-Red Supergiant Ratio of Galaxies

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Modern color-magnitude diagrams (CMDs) of nearby galaxies are now of such high quality that they can be used to adress long-standing disagreements between observation and stellar-evolution theory. There is one piece of good news for theory: modern CMDs now exhibit a clear separation between the main sequence (MS) and blue, core-He-burning (BHeB) stars. This is the previously "missing" blue gap. Photometric data can thus be used to furnish a BHeB count without substantial MS (+BSG) contamination. However, supergiant counts based on even these modern CMDs struggle with small number statistics, and various other complications such as the potentially severe contamination of red supergiant (RSG) counts by asymptotic-giant-branch (AGB) stars. We provide luminosity functions for BHeB and RHeB stars for two extremely metal-poor dwarf galaxies using HST photometry. We find that the B/R frequency for massive stars determined from these CMDs is as low as that previously derived with photometry and spectroscopy for SMC supergiants by Humphreys (1983). This supports the idea that the B/R frequency at low metallicity is small. We also comment on evolutionary scenarios for Wolf-Rayet (WR) stars using the approach of Massey (1998).

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Theses

Radiation-driven wind models of massive stars

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Mass loss from OB stars is pivotal for the evolution of both massive stars and starburst galaxies. An accurate description of mass loss as a function of stellar parameters is therefore needed. In principle mass-loss rates can be derived from observations of UV P Cyg lines, Optical H α emission, IR and Radio free-free excess. Although the UV and IR method are sensitive mass-loss indicators, they unfortunately cannot (yet) be used for accurate derivations of OB mass-loss rates, due to their dependence on the details of model atmosphere calculations.

On the other hand, mass-loss determinations from Hα emission and the radio regime are pretty much model-independent. Although the winds of O stars may be clumpy rather than smooth, the good agreement between the Hα and radio rates for O stars shows that these two methods are consistent. Radiation-driven wind theory however has – up to recently – shown a *systematic* discrepancy with both of these observed data sets. Since this discrepancy becomes more severe at larger wind density, it is suggested that ”multiple-scattering” may be needed for a quantitative parametrization of O star winds. In this thesis, the effects of multiple scattering are therefore investigated, and a large grid of wind models is calculated.

First, the bi-stability jump is investigated, and it is shown that the steep decrease in the ratio between the terminal wind velocity over the escape velocity around spectral type B1 is accompanied by a jump in the mass-loss rate of a factor of five. This results from a strong increase in the line force due to iron recombination around this temperature. Possible consequences of the bi-stability jump for B[e] supergiants and LBV stars are also studied in the thesis.

Secondly, the mass-loss predictions are extended to stars with different masses, luminosities and metallicities. Subsequently, additional bi-stability jumps are discovered, as the winds of different metallicities are found to be driven by different ionic species! The resulting mass-loss “recipe” has been compared with the most reliable observed mass-loss rates up to date, and it is shown that multiple scatterings resolve the reported systematic discrepancy between observations and radiation-driven wind theory. Note that the additional agreement between observed and theoretical wind moments shows that this agreement is *not* an artifact of the adopted stellar mass (evolutionary vs. spectroscopic) as wind momenta are known to be almost independent of mass. We therefore recommend our mass-loss recipe be used in evolutionary calculations of massive stars and starburst galaxies.

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