THE HOT STAR NEWSLETTER

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An electronic publication dedicated to A, B, O, Of, LBV and Wolf-Rayet stars and related phenomena in galaxies

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Commentary

An outlook on Wolf-Rayet stars in actively star-forming galaxies

I have been asked by the Editor to summarize recent progress on studies of massive star populations in starburst galaxies, highlighting some of the latest concerns and "current trends" in this field, and discussing a few subjects hopefully of interest to the hot star community and other fields directly or indirectly concerned by studies of massive stars. In this format and as such the text given below is of course not a review of the field, but may rather reflect a personal view with all its incompleteness, weaknesses etc. I hope some readers will nevertheless find these lines useful and maybe even stimulating!

Since the first detection of Wolf-Rayet (WR) features in an emission-line galaxy in 1976 a large number of objects showing direct signatures of WR stars in their integrated spectrum have been detected, first in systematic searches ([8]) and later mostly serendipitously: from the compilation of Peter Conti listing 31 galaxies ([2]), the number of objects outside the Local Group harbouring populations of WR stars has now grown to more than 120 ([17]) – in a short time WR galaxies (not to speak of their WR content) will outnumber the WR stars in the Local Group!

The term WR "galaxy" should be used with caution, since it simply designates objects where a broad emission line (usually He II λ4686) from WR stars is observed in the spectrum. Indeed WR galaxies are found among a large variety of types from blue compact dwarf galaxies (BCDs), irregulars, spirals, to IRAS galaxies, Seyfert 2, LINER, and possibly also in central cluster galaxies in cooling flows. Obviously the absolute scales of the concerned regions also vary greatly: they reach from extragalactic H II regions and super star clusters to nuclear starbursts which harbour from few individual to $\sim 10^5$ WR stars.

Why bother about WR galaxies ? As *bona fide* young star forming regions containing massive stars beyond doubt, these objects deserve a special interest for studies of early phases of starburst activity. In particular, "simple" WR galaxies can serve as templates for young starforming galaxies in the early universe, which are now being discovered in great number with 10m-class telescopes (cf. [10, 11]) and which show great resemblance with these "local exotica". Increasingly, direct stellar signatures including those of WR stars are also found in spectra of active galaxies such as Seyfert 2 and LINER. Certainly the spectacular "show case" Mrk 477 ([5]) has triggered and revided a wealth of new studies on the relation between starbursts and AGN, whose results can be expected in the near future.

As objects showing direct traces of the most massive stars, WR galaxies can ideally be used to determine important properties such as the upper end and the slope of the IMF, the age and duration of the star forming events etc. in young starbursts. Conversely there is also a great potential in using observations of so-called super star clusters (SSCs) to constrain stellar evolution models in different environments, e.g. at extremely low metallicities, inaccessible in the Local Group. SSCs, which have drawn a lot of attention in the last few years especially as possible progenitors of Globular Clusters, are rich compact clusters frequently found in starbursting galaxies. Indeed, if the stellar content of SSCs consists of a nearly coeval population and provided some assumption on the IMF, their integrated spectra can directly be used to constrain the stellar properties and evolutionary tracks. The recent observations ([6, 9]) revealing WR stars of WN and WC type in I Zw 18, the most metal-poor galaxy known to date, are a striking example (see [3]). Many more objects await future analysis. In particular such studies allow to probe indirectly the variation of mass loss with metallicity. They could also provide some insight into different evolutionary scenarios of high mass stars including the role of close binary systems for the formation of WR stars, which is being explored with some recent synthesis models ([21, 1]).

Roberto Terlevich & Jorge Melnick ([20]), in their original WARMER model for starbursts in AGN were the first to point out that starbursts with important WR populations may show peculiar nebular emission line spectra. Although their model is not advocated for this purpose anymore and improvements in modeling WR star atmospheres have led to more moderate effects ([18]), remanences from these peculiarities are found again in a different context. E.g. hot WR stars may explain the appearance of high excitation H II regions ([16]) and also contribute to peculiar excitation conditions found by infrared (ISO) observations of starbursts ([12]). This illustrates that WR stars may have a non-negligible impact on the ionization state of the ISM in young starbursts.

WR galaxies are also of concern for studies of the chemical evolution and outflows from galaxies. Given the important production and ejection of processed elements from massive stars, regions with WR stars could be "self-polluted" to detectable levels ([15],[4]). Detailed recent investigations show, however, that this simple scenario does not seem to hold ([7]). The mixing processes governing between the ejecta and the ISM indicate a more complex picture requiring the inclusion of the different ISM phases and probably hydrodynamic phenomena at large scales. E.g. outflows and galactic winds, increasingly observed in starbursts from the optical to X-rays (e.g. [13, 14, 19]), could be an observable manifestation of these processes with potentially profound implications for their chemical and dynamical evolution. In this respect WR galaxies can play the role of laboratories to study the interaction between massive stars, SNae, and the ISM.

These examples should suffice to illustrate some aspects involved in studies about WR galaxies. As young starbursts theses objects are not only templates for studies of distant star forming galaxies but also cornerstones for the understanding of star formation in the local universe and in active galaxies. Nearby objects also serve as ideal laboratories for detailed studies on the evolution of massive stars and their interaction with the ISM. Many of these subjects (and certainly much more!) will be discussed in the forthcoming IAU Symposium 193 on "WR phenomena in massive stars and starburst galaxies" this November. We look forward to an interesting meeting and to many more years of fascinating and challenging work.

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References

[1] Cerviño M., 1998, PhD thesis, Univ.Complutense, Madrid, Spain

[2] Conti P., 1991, ApJ 377, 115

[3] de Mello D., et al., 1998, ApJ, in press (astro-ph/9805342)

[4] Esteban C., Peimbert, M., 1995, A&A 300, 78

[5] Heckman T., et al, 1997, ApJ

[6] Izotov Y.I., et al., 1997, ApJ 487, L37

[7] Kobulnicky H.A., Skillmann E.D., 1998, ApJ 497, 601

[8] Kunth D., Joubert M., 1985, A&A 142, 411

[9] Legrand F., et al., 1997, A&A 326, L17

[10] Leitherer C., et al., 1996, ApJ 465, 717

[11] Lowenthal J.D., et al., ApJ 481, 673

[12] Lutz D., et al., 1998, A&A 335, L75

[13] Martin C., 1998, ApJ, in press (STScI preprint 1243)

[14] Méndez D.I., Esteban C., 1997, ApJ 488, 652

[15] Pagel B., et al., 1992, MNRAS 255, 325

[16] Schaerer D., 1996, ApJ 467, L17

[17] Schaerer D., Contini C., 1998, A&A, in preparation

[18] Schmutz et al., 1992, PASP 104, 1164

[19] Stevens I.R., Strickland D.K., 1998, MNRAS 294, 523

[20] Terlevich R., Melnick J., 1985, MNRAS 213, 841

[21] Vanbeveren D., et al., 1997, A&A 317, 487

Accepted Papers

Microturbulence in O supergiants

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We investigate the rôle of classical microturbulence in the non-LTE He I/He II line-formation problem for luminous O-type stars. We find that the shapes and strengths of certain saturated He I lines, in particular the triplets $\lambda\lambda$4471, 4713 and the singlet λ4921, are sensitive to microturbulent velocities in excess of $5\,\mathrm{km\,s^{-1}}$. Weaker lines, including most of the He I singlets, are effectively independent of this parameter, as are the Fowler series He II lines $\lambda\lambda$4199, 4541, 5411. We show that this behaviour is due to interaction between direct line-broadening effects in the radiative transfer and indirect changes in the atmospheric structure and the populations of absorbing states. Using an analysis of high-resolution, high signal-to-noise observations of the O9.7-supergiant HD 152003 as an illustrative example, we show how the introduction of microturbulence in non-LTE models allows consistent fits to be obtained to *all* blue-region He I lines – including the strong triplets $\lambda\lambda$4026, 4713, 4471 – at an assumed solar helium abundance, thereby offering a resolution to the problem of the 'generalized dilution effect' described by Voels et al. We argue that by extension this result may also have implications for the so-called 'helium discrepancy' identified in OB-type stars by Herrero et al.

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Quantitative Near-Infrared Spectroscopy of Of and WNL stars

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From new high signal-to-noise 1–2.2μm spectroscopy of nine extreme early-type stars – including O Iaf, O Iafpe and WN9 types – we determine stellar parameters from detailed atmospheric analysis and evaluate results from near-IR analogues of well-known spectral diagnostics in the optical. We conclude that accurate stellar parameters can be measured from near-IR spectroscopy alone, an analysis technique important to studies of luminous stars in the Galactic Center and other galaxies.

Derived stellar parameters – mass-loss rates, luminosities, surface abundances, temperatures – show good agreement between optical and near-IR analyses, providing IR data are of sufficient spectral resolution (R>2000) and signal-to-noise ratio (S/N>30). Wind velocities derived from He I 1.0830μm are consistent with those from ultraviolet P Cygni near-IR diagnostics, a difference not significant in determining the stellar properties of these objects; which set of spectral lines provides the more accurate physical parameters – optical or IR – cannot at present be ascertained. The strength of He I 2.0581μm is very sensitive to the extreme ultraviolet energy distribution where line blanketing by heavy elements plays an important role; this line should not on its own be considered a reliable temperature diagnostic.

The three peculiar, extreme emission line stars – the O Iafpe stars, HD 152386, HD 152408 and HDE 313846 – are more similar in both morphological and physical characteristics to WNL-type Wolf-Rayet stars than normal O Iaf supergiants and should be classified as W-R. Their classification should be WN9ha, where they remain a unique sub-group.

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or on the web at http://www.star.ucl.ac.uk/~pac/publications.html

Numerical Solution of the Expanding Stellar Atmosphere Problem

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In this paper we discuss numerical methods and algorithms for the solution of NLTE stellar atmosphere problems involving expanding atmospheres, e.g., found in novae, supernovae and stellar winds. We show how a scheme of nested iterations can be used to reduce the high dimension of the problem to a number of problems with smaller dimensions. As examples of these sub-problems, we discuss the numerical solution of the radiative transfer equation for relativistically expanding media with spherical symmetry, the solution of the multi-level non-LTE statistical equilibrium problem for extremely large model atoms, and our temperature correction procedure. Although modern iteration schemes are very efficient, parallel algorithms are essential in making large scale calculations feasible, therefore we discuss some parallelization schemes that we have developed.

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One-micron spectroscopy of normal OB stars

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We have obtained spectra of seventy normal OB stars in the near-IR I (1-μm) band. The strongest features are those due to lines of the hydrogen Paschen series and neutral and ionized helium which are, for the most part, in absorption. The information content in this spectral range is only sufficient for a rough classification of hot stars into 'early O', 'late O' and 'B' types. Curiously, the leading He I triplet line, He I $\lambda 1.0830\mu$m, is usually not detectable, although in a few stars it is in emission; its behaviour generally correlates with the leading to be present in emission only in stars with extremes of mass loss or wind extension.

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Constraints on the Radial Velocity Curve of HDE 245770 = A 0535+26

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We present new radial velocity measurements from *IUE* high dispersion spectra of HDE 245770, the Be companion of the X-ray transient binary system, A 0535+26. We formally derive the semiamplitude of the star's binary motion by fitting the UV and published radial velocity measurements with the other orbital parameters fixed according to the neutron star orbit from CGRO/BATSE results. The observational errors are still too large to claim detection of the Be star orbital motion, but we use limits on the semiamplitude ($K_1 < 10.6$ km s^{-1}), a classification based on UV criteria (O9.5 III-Ve), and the derived projected rotational velocity ($V \sin i = 250 \pm 15$ km s^{-1}) to re-assess the system masses.

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The Wolf-Rayet Binary WR 141 (WN5o+O5V-III) Revisited

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We combine all previously published radial velocity measurements of the spectroscopic binary WR 141 with new CCD data from 1988-1989 and 1992, complemented by polarimetric broadband measurements from 1989. This enables us to refine the orbital elements ($P = 21.6895$ d, $e = 0.018$, K_{WR}=118 km s^{-1}, K_O=(163-194) km s^{-1}), estimate the masses of the components ($M_{WR} = (36-54)\,M_\odot$, $M_O = (26-33)\,M_\odot$ for orbital inclination $i = 68^o$) and restore the spectrum of the O star via a specifically designed decomposition algorithm. Along with pronounced erratic variations, the spectral lines of the WR component demonstrate systematic phase-locked variability induced by the radiation field of the hot, luminous O companion.

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An optical and near-IR spectroscopic study of the extreme P Cygni-type supergiant HDE 316285

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A detailed study of the Galactic P Cygni-type supergiant HDE 316285, based on high quality optical (AAT, MSO, CTIO) and near-IR (UKIRT, CFHT, CTIO) spectroscopy, is presented. As has been noted previously, its spectrum is dominated by H, He I, and Fe II P Cygni profiles. Emission lines due to N I, N II, [N II], O I, Na I, Mg II, Al II, Ca II, Si II, Si III, Fe II and [Fe II] can also be readily identified. Many of the metal lines are produced by continuum fluorescence. The rich N spectrum, the paucity of the O spectrum (only 2 O lines can be identified), and the apparent absence of emission due to C, strongly suggest that the atmosphere of the star is contaminated by CNO processed material. A comparison of the spectrum of HDE 316285 with P Cygni and He 3-519 is presented.

From a spectral analysis using the non-LTE atmosphere code of Hillier, and assuming a distance of 1.85 kpc, our preferred model for HDE 316285 has the following parameters: $T_* = 15\,\mathrm{kK}$, $\log L_*/L_\odot = 5.44$, $\dot{M} = 2.4 \times 10^{-4}\,M_\odot\,\mathrm{yr}^{-1}$, $v_\infty = 410\,\mathrm{km\,s}^{-1}$, $E_{\mathrm{B-V}}$=1.81 mag, and H/He$\sim$1.5 by number. Due to the low degree of He ionization the derived H/He abundance ratio and mass-loss rate are strongly coupled. Models with H/He=10 to 0.5 are equally capable of explaining the H and He I spectrum provided the mass-loss rate is scaled according to the approximate formula $\dot{M} = 9.1 + 26.3(\mathrm{He/H} - 0.1) \times 10^{-5} M_\odot\,\mathrm{yr}^{-1}$. Preliminary work, however, indicates that a solar H/He ratio can be ruled out on the basis of line strengths of other species — particularly N, Mg, Al.

The stellar wind from HDE 316285 is more extreme than P Cygni with an performance number (= ratio of wind momentum to radiative momentum) 30 times greater. The low H/He abundance ratio and high N/He abundance ratio confirms that HDE 316285 is evolved.

Although we find no evidence in the literature for photometric variability, we find strong evidence for significant spectral variability. Because of the spectral variability, and because the stellar properties and chemical content of HDE 316285 are similar to known luminous blue variables (LBVs), we suggest that it is a LBV. Support for this contention comes from the detection by McGregor et al. of a cold circumstellar dust shell associated with HDE 316285. However HDE 316285, like P Cygni, could currently be in a relatively quiescent phase of its LBV life, exhibiting significant spectral variations but not undergoing major photometric outbursts similar to AG Car.

The mass loss of HDE 316285 is prodigious. In less than 10^5 years it will lose over $20\,M_\odot$. Even if HDE 316285 is not an LBV, it is obviously in an evolutionary phase of short duration.

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HST-WFPC2/Hα Imagery of the Nebula M1-67: A Clumpy LBV Wind Imprinting Itself on the Nebular Structure?

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With HST-WFPC2 we have obtained a deep, Hα image of the relatively young ejection-type nebula M1-67 around the runaway population-I Wolf-Rayet star WR124 (WN8). This image shows a wealth of complex detail, some of which have never been seen before in such a nebula. In particular, large arcs of nebulosity extend around the central star yet with no overall global shell structure to the nebula and no clear bipolar signature as claimed by Sirianni et al.(1998). In addition, numerous bright, resolved knots of emission, each $\lesssim 10^{-4}$ M$_\odot$, occur in the inner part of the nebula, often surrounded by what appear to be their own local "wind" diffuse bubbles. Is this the first direct evidence of spatially resolved hot clumps being ejected from a hot central star?

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Infrared line-profile variability in Wolf-Rayet binary systems

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We present phase-resolved spectroscopy of the He I 1.0830μm line in six Wolf-Rayet systems (WR 113=CV Ser; WR 136=HD 192163; WR 139=V444 Cyg; WR 141=HD 193928; WR 153=GP Cep; and WR 155=CQ Cep). Five of these systems are known WR+O binaries, with periods ranging from 1.6 days to nearly 30 days; WR 136 is only suspected of binarity. We find that the He I 1.0830μm line profile varies systematically with orbital phase, in a qualitatively similar manner for all systems (except WR 136).

We interpret this variability as being a consequence of wind–wind interaction (i.e., colliding winds), and present results from simple models which include the effects of binary rotation and emission from the interaction region in a schematic manner. We find that the model qualitatively explains many (though not all) characteristics of the observed variability, with the shock emission an important feature; we thereby demonstrate that variability in the He I 1.0830μm line is a sensitive indicator of wind dynamics in these colliding-wind systems.

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A second dust episode of the Wolf-Rayet system WR 19 : another long-period WC+O colliding-wind binary

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We present observations of WR 19 showing an infrared excess due to newly created dust similar to an event observed in 1988. We suggest that these episodes of dust-formation are periodic ($P \sim 10$yr) and related to the binary nature of the object, comparable to the colliding-wind binary WR 140. In support of this thesis we identified absorption lines from a companion of spectral type O9.5-9.7. We propose monitoring the object to determine orbital parameters, non-thermal radio emission and the accurate shape of the infrared light-curve.

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An improved classification of B[e]-type stars

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We review the classification criteria for the B[e]-type stars (B type stars with forbidden emission lines in their optical spectrum) and we express these in terms of physical characteristics of the stars and the circumstellar (CS) matter. We show on the basis of observations that these criteria can be met in different kinds of stars of different mass and different evolutionary stages. We propose that the name "B[e] phenomenon" is more appropriate than the name "B[e] stars". We propose the definition of five classes of stars which show the B[e] phenomenon:

(a) B[e] supergiants or "sgB[e] stars"

(b) pre-main sequence B[e]-type stars or "HAeB[e] stars"

(c) compact planetary nebulae B[e]-type stars or "cPNB[e] stars"

(d) symbiotic B[e]-type stars or "SymB[e] stars"

(e) unclassified B[e]-type stars or "unclB[e] stars"

The primary and secondary classification criteria for each of these groups are defined. We also present lists of objects for each group, except for the SymB[e] stars.

It is possible that some stars satisfy the criteria for more than one of the classes sgB[e], HAeB[e], cPNB[e] and SymB[e]. In that case the evolutionary phase of the star is unclear and the star should be assigned to class unclB[e].

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Populations of WC and WN stars in Wolf-Rayet galaxies

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We report the detection of WC stars in five Wolf-Rayet (W-R) galaxies: He 2-10, NGC 3049, NGC 3125, NGC 5253 and Tol 89. The faint broad C IV λ5808 line requires sufficiently high S/N ($\geq$ 40) to be detected explaining the non-detection of this WC feature in previous observations. From the measurement of W-R emission lines (N III λ4640 + C III λ4650, He II λ4686, and C IV λ5808), we conclude that all W-R regions contain a mixed population of WNL, and early WC stars. The exception is the high-metallicity region NGC 3049 where late WC stars prevail.

A spatial offset between the multiple peaks of the nebular emission and the stellar light in He 2-10 and Tol 89 is observed. These nebular emission structures are likely due to the existence of bubbles and loops, owing to the injection of mechanical energy in the ISM through the W-R winds and/or supernovae. Due to age differences and likely smaller energy deposition the structures around the W-R regions are possibly smaller than the ones predominantly energized by SNe. The spatial distribution of W-R stars closely follows the stellar continuum with no significant distinction between WNs and WCs distributions.

From the luminosity of the W-R signatures we have estimated the absolute number of W-R stars of the different subtypes. The WC/WN number ratios have typical values between 0.2 – 0.4, and show no clear trend with metallicity. For low-metallicity objects ($Z \sim 1/5 Z_{\odot}$), these values are larger than the observed WC/WN ratios in Local Group objects, but are compatible with expectations for star forming events with short duration if stellar evolution models with high mass loss are used.

We derive ages for the starburst regions in the range of 3 to 6 Myr and confirm that the burst duration must not exceed $\sim$ 2–4 Myr to account for the high population of W-R stars observed in starburst regions, even if emission line stars similar to those observed in R136 and NGC 3603 are common in starbursts. Within the uncertainties the majority of the observed quantities is reasonably reproduced by models with a Salpeter IMF. Although some W-R lines in few regions are stronger than predicted by the models no clear case requiring a significantly flatter IMF is found. IMF slopes much steeper than Salpeter may, however, not be compatible with our data.
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Paper also available on the web at `http://www.obs-mip.fr/omp/astro/people/schaerer/`

Submitted Papers

Refined orbital parameters of HD193928

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Based on 123 high-resolution CCD spectra carried out in 40 nights and previously published data a refined period P=21.6878 ± 0.0001 and a new orbit solution for the Wolf-Rayet star HD193928 were obtained. In the light of the newly derived mass function of the system, the probable spectral class and minimum mass of the companion are briefly discussed.

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Some Characteristics of Current Star Formation in the 30 Doradus Nebula Revealed by HST/NICMOS

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The extensive "second generation" of star formation within the 30 Doradus Nebula, evidently triggered by the R136 central cluster around its periphery, has been imaged with HST/NICMOS. Many new IR sources, including multiple systems, clusters, and nebular structures, are found in these images. Six of the NICMOS fields are described here, in comparison with the WFPC2 images of the same fields. Knots 1-3 of Walborn & Blades (early O stars embedded in dense nebular knots) are all found to be compact multiple systems. Knot 1 is shown to reside at the top of a massive dust pillar oriented directly toward R136, whose summit has just been removed, exposing the newborn stellar system. Knots 1 and 3 are also near the brightest IR sources in the region, while parsec-scale jet structures are discovered in association with Knots 2 and 3. The Knot 2 structures consist of detached, nonstellar IR sources aligned on either side of the stellar system, which are interpreted as impact points of a highly collimated, possibly rotating bipolar jet on the surrounding dark clouds; the H_2O maser found by Whiteoak et al. is also in this field. These outflows from young massive stars in 30 Dor are the

first extragalactic examples of the phenomenon. In the field of the pillars south of R136, recently discussed in comparison with the M16 pillars by Scowen et al., a new luminous stellar IR source has been discovered. These results establish the 30 Doradus Nebula as a prime region in which to investigate the formation and very early evolution of massive stars and multiple systems. The theme of triggered formation within the heads of extensive dust pillars oriented toward R136 is strong. In addition, these results provide further insights into the global structure and evolution of 30 Doradus, which are significant in view of its status as the best resolved extragalactic starburst.

Submitted to: Astronomical Journal
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or on the web at `http://www.stsci.edu/~rbarba/publications.html#preprints`

Molecular Gas Associated with the Ejecta Ring Nebula Around the Wolf-Rayet Star WR16

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The environments of stars have the potential of providing important clues to their evolution. The history of a changing stellar output, in the form of winds and ejecta, is written in the environments of Wolf-Rayet stars. These show that Wolf-Rayet stars are evolved massive stars that are likely to have gone through several stages of mass-loss in the forms of both fast and slow winds. At present the evolutionary path of massive stars to the Wolf-Rayet stage is not well understood. As part of a program to probe the evolution of massive stars through their environments, we have begun a study of the neutral gas around Wolf-Rayet stars. Our intent is to determine information on the mass-loss and kinematics of ejected material from Wolf-Rayet stars. In this paper we shown the WN8 star WR 16 to be almost completely surrounded by a cocoon of molecular gas. Optical spectra of associated ionized gas suggest that the whole cocoon is likely to be made of nitrogen-rich, processed material probably ejected in a red supergiant phase. Some tentative evidence is also given for fast-moving components that may have come from an eruption of the star in a prior phase as a luminous blue variable. The total molecular gas mass is estimated to be in the range 4 to 78 $M_\odot$, depending on the degree of enrichment of heavy elements and the uncertain distance to the star.

Submitted to ASTROPHYSICAL JOURNAL
Preprints from `tm9991r@acad.drake.edu`

Observational Constraints on the Efficiency of Acceleration in the Optically Thin Parts of Wolf-Rayet Winds

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Wolf-Rayet stars have such strong winds that their inner regions are optically thick, preventing us

from seeing the hydrostatic stellar cores. One might expect considerable acceleration of the wind to occur in the optically thick part. However, we show *empirically* that at least 50%, and in some cases up to 100%, of the wind's acceleration occurs in the optically *thin* part of the WR wind.

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Preprints from `sergey@astro.umontreal.ca`

In Proceedings

Co-rotating Interaction Regions in Hot-Star Wind Models with Line-Driven Instability

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I review simulations of Co-rotating Interaction Regions (CIRs) in line-driven stellar winds. Previous CIR models have been based on a local, Sobolev treatment of the line-force, which effectively suppresses the strong, small-scale instability intrinsic to line-driving. Here I describe a new "3-ray-aligned-grid" method for computing the nonlocal, smooth-source-function line-force in 2D models that do include this line-driven instability. Preliminary results indicate that key overall features of large-scale CIRs can be quite similar in both Sobolev and non-Sobolev treatments, *if* the level of instability-generated wind structure is not too great. However, in certain models wherein the unstable self-excitation of wind variability penetrates back to the wind base, the stochastic, small-scale structure can become so dominant that it effectively disrupts any large-scale, CIR pattern.

To appear in: Proceedings of IAU Colloquium 169 on "Variable and Non-spherical Stellar Winds in Luminous Hot Stars", B. Wolf, A. W. Fullerton, & O. Stahl, eds., Springer Lecture Notes in Physics
Preprints from `owocki@bartol.udel.edu`
or by anonymous ftp to `ftp.bartol.udel.edu/owocki/heidelberg.uue`

The Pistol Star and Massive Stars in the Galactic Center

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A significant portion of the massive stars in the Galaxy are located within 50 pc of the Galactic Center. The stars have a variety of ages between 1 and 10 Myr, giving rise to Wolf-Rayet and red supergiant types. Most of these stars reside in three massive clusters: the Central Cluster, Quintuplet Cluster, and Arches Cluster. The clusters have similar masses, $\approx 10^4$ $M_\odot$, but the first two are substantially older (3-5 Myr) than the last (1-2 Myr). This spread in age, with most other parameters being equal, gives us a unique opportunity to test models which predict massive star evolution. We discuss the content in these clusters, with a particular emphasis on how well they fit into our current

understanding of stellar evolution. In particular, we discuss the Pistol Star, one of the most luminous, and, therefore, initially most massive, stars in the Galactic Center. Its evolutionary status places the star in the unstable Luminous Blue Variable stage, providing an extraordinary opportunity to test stellar evolution models for massive stars near their Eddington limits. We find a lower luminosity limit of $10^{6.6}$ $L_\odot$, $T_{\rm eff} \approx 10^{4.15}$ K, and a helium-enriched surface, consistent with the star's advanced evolutionary status. Our evolutionary tracks suggest an initial mass of ~ 200 $M_\odot$ and age of 1.7−2.1 Myrs. We interpret the star and its surrounding nebula as an LBV which has recently ejected large amounts of material. We expect that many of the massive stars in the Galactic Center will soon progress through an LBV stage and eventually become supernovae at a rate of ≈ 1 per 20,000 years for the next several Myr.

To appear in Unsolved Problems in Stellar Evolution
Preprints from `figer@astro.ucla.edu`
or by anonymous ftp to `quintup.astro.ucla.edu/stsci/stsci15.ps`
or on the web at `http://www.astro.ucla.edu/~figer/intro.html`

HST/STIS witnesses a major LBV eruption

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HST/STIS spectroscopy of V1 – a recently discovered LBV in the extragalactic giant H II region NGC 2363 – is analysed using a sophisticated non-LTE, line blanketed atmospheric code. Complementary photometry reveals that V1 has brightened by ≥4 mag since 1992, such that $M_{\rm V}$=−10.6 mag in 1997 November. At this epoch the stellar properties of V1 are remarkable – its luminosity is $\log(L/L_\odot)\approx 6.6$, with a wind velocity of ∼325 km s^{-1} and a mass-loss rate of $\dot{M}/(M_\odot{\rm yr}^{-1})\approx 10^{-3}$. Our analysis confirms that V1 is currently undergoing an extremely rare giant eruption. We investigate whether the heavy element content of NGC 2363 – as derived from our spectroscopy of V1 – is as depleted as the known H II region oxygen abundance.

To appear in *Proc. 'Unsolved Problems in Stellar Evolution', STScI Symposium series 12, (M. Livio, ed.), Cambridge University Press*
Preprints from `pac@star.ucl.ac.uk`
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or on the web at `http://www.star.ucl.ac.uk/~pac/publications.html`

Massive Star Evolution in Different Environments

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We review the properties of massive star evolution in different environments, where the major environmental factor is metallicity. Comparisons between evolutionary models and observations of massive OB, WR stars and related objects are presented. We also review several observations asking for future improvements of stellar models and theoretical developments in this respect. We summarize evolutionary scenarios for the most massive stars and try to clarify recent questions regarding their evolutionary status as core-H or core-He burning objects.

Another environmental effect, which might affect stellar evolution is a cluster environment with a high stellar density. As test cases of massive star evolution in dense clusters we summarize recent work on the densest known resolved young clusters: R136, NGC 3603, and the three Galactic Center (GC) star clusters – the central cluster, Quintuplet and the "Arches" cluster. For the central cluster we present new comparisons between stellar parameters of emission line stars derived by Najarro et al (1994, 1997), and appropriate evolutionary models. From their parameters we argue that most of these stars can be regarded as WNL stars, and do hence not necessarily represent a peculiar class. We suggest that some apparent differences with well known WR stars can be understood in terms of their core burning stage and/or other changes due to a high metallicity. Based on our present knowledge we conclude that in young clusters with central stellar densities up to $\rho_c \sim 10^{5-6}\, M_\odot \mathrm{pc}^{-3}$ no compelling evidence for a secondary effect influencing the evolution of massive stars has yet been found.

Invited review to appear in "Active Galactic Nuclei, Dense Stellar Systems and Galactic Environments", Eds. A.C. Baker, S. Lamb, J.J. Perry, ASP Conf. Series, 1998. (Revised and extended 1998, original version August 1996)
Preprints from schaerer@obs-mip.fr
or on the web at http://www.obs-mip.fr/omp/astro/people/schaerer/Preprints.html

Colliding Winds in Binary Star Systems

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In this short review, we discuss the astronomical relevance of colliding winds in different binary star systems together with the governing physical processes.

In a first part, colliding winds in hot star binaries are discussed. Shocks confine the spirally shaped interaction zone of the two winds. The broken symmetry in the outflow from the system can e.g. be observed in a highly asymmetric X-ray light curve. When the cooling time for shocked matter is short compared to the dynamical time scale, high density shells are formed, contributing to the emission in the optical and ultraviolet. In this radiative case, the interaction zone of the two winds gets dynamically unstable. In close systems or when one wind dominates the other, radiative forces become dynamically important. Finally, a possible connection between wind collision and non-thermal radio and X-rays emission as observed in many hot star systems is discussed.

In a second part, colliding wind models of evolved low mass binaries are presented, with special attention to symbiotics. In this case, the mass distribution and the velocity field of the circumstellar matter is completely determined by the wind-wind-interaction, even up to scales typically for PNe. High-density shells are formed, spiraling outward. While at the same time nearly evacuated regions are present on the orbital scale. The shocks are strong enough to explain the observed X-ray emission. Finally, computed emission line profiles and their variation over one orbit of the binary are presented.

The line profiles mirror the asymmetry of the wind and it seems possible to derive basic parameters of colliding winds on grounds of the analysis of line profile variations.

Conference Proceedings, appears in Astrophysics and Space Science
Preprints from walder@astro.phys.etzh.ch
or by anonymous ftp to saturn.ethz.ch (./pub/walder/odile_collwind.ps.gz)
or on the web at
http://www.astro.phys.ethz.ch/papers//walder/walder_p.html

The Formation of Knots and Filaments in Shocks

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[2] Seminar für Angewandte Mathematik, ETHZ Zürich, Switzerland

We review the stability properties of colliding hypersonic flows, present new results of high-resolution numerical simulations of such collisions, and discuss some implications for selected astrophysical objects like PNe, SNR, wind-bubbles, and binaries. We find that the interaction zone of colliding hypersonic flows is generally in a supersonically turbulent state and substructures like *knots, filaments, flyers, and pillars* are formed.

We briefly review analytical and numerical investigations of different thin shell instabilities in the isothermal regime. We discuss aspects of the long-term evolution of these instabilities and the possible transition to supersonic turbulence of the flow in the interaction zone. Considering next the case of resolved cooling layers, their thermal instability is briefly sketched. In its catastrophic form, this instability has a particularly large impact on the interaction zone as strong pressure waves can drive Rayleigh-Taylor spikes and excite turbulence.

New results of high-resolution numerical simulations of two extreme cases with resolved cooling layers are presented. In the asymmetric case (e.g. present in energy driven nebulae), where only one shock is radiative while the other is adiabatic, fingers and pillars aligned with the flow are forming. The fingers eventually break off and knots, floating away from the interaction zone, are formed. In the symmetric case (e.g. a model for momentum driven nebulae), where both shocks are radiative, filaments with strongly enhanced densities are formed. The filaments are arbitrarily oriented in space and embedded in gas of much lower density. The interaction zone is highly variable in time and sporadically pillars of high density mass are ejected.

Finally, we discuss the impact of the such collision on the strength of X-ray emission, the width and the profile of emission lines in the optical and UV and their contribution to the presence of substructure in a variety of astrophysical objects.

Conference Proceedings, appears in Astrophysics and Space Science
Preprints from walder@astro.phys.etzh.ch
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or on the web at
http://www.astro.phys.ethz.ch/papers//walder/walder_p.html

Job Offers

Postdoctoral position in: "Studies of the Wolf-Rayet Phenomenon in Stars and Starburst Galaxies"

at University College London

Applications are invited for a post-doctoral research assistant (PDRA) to work in the Wolf-Rayet group in the Department of Physics and Astronomy, UCL. This position is funded by PPARC Research Grants, will be available for 3 years, with a commencement date on 1 January 1999 (possibly earlier by mutual agreement).

UCL is a major research centre for the study of Wolf-Rayet and related hot, luminous stars. The successful candidate will ideally have observational or theoretical experience in this area, and will be expected to participate in on-going programmes on the WR phenomenon in stars and galaxies and on related massive stars including (i) far-UV spectroscopic studies with the FUSE satellite of OB and WR stars in the Galaxy and Magellanic Clouds; (ii) quantitative studies of WR stars in Local Group galaxies and WR galaxies. Our group conducts extensive programmes with current space (ISO and HST) and ground-based (LPO, UKIRT, AAT) facilities, which will be extended in the near future with FUSE and Gemini.

Candidates should have a PhD in Astronomy or Astrophysics. The salary will be on the RA1A scale, commencing at £17,570 (+ £2,134 London weighting) per annum. Applications, to include a full curriculum vitae and outline of previous research experience, should be sent by **31 October 1998** to:

Professor Allan J. Willis,
Department of Physics and Astronomy,
University College London,
Gower Street,
London WC1E 6BT, UK.

Applicants should also arrange for 2 letters of reference to be sent to Professor Willis by the closing date. Informal enquiries about the position can be made to Dr Paul Crowther (pac@star.ucl.ac.uk).

University College London is an equal opportunity employer.

Meetings

Announcement of an international workshop "Thermal and Ionization Aspects of Flows from Hot Stars: Observations and Theory"

We are organizing an international workshop on the thermal and ionization structure of flows from hot stars. This topic has rarely been discussed at the conferences and symposia about stellar winds. Yet it is crucial for understanding the mechanisms and processes in the winds of hot stars. Moreover the thermal and ionization structure of winds provides the diagnostic methods for the study of the winds by means of optical and UV spectroscopy, X-rays, IR-mm- and radio fluxes.

During the last years an increasing numbers of X-ray observations and high resolution and high S/N UV spectra of HST have been obtained. In the near future the FUSE observations of spectra between 900 and 1200 A will provide a wealth of new information about the ionization of winds from hot stars. At the same time there has been a significant progress in numerical modelling of shocked winds and in the theory of colliding winds. Therefore it is time to have a workshop to discuss the present status, the expected progress, and the problems of the observations and theory of the thermal and ionization structure observations.

THERMAL AND IONIZATION ASPECTS OF FLOWS FROM HOT STARS: OBSERVATIONS AND THEORY

Tartu (Estonia)

August 23 through 27 1999

Scientific Organizing Committee: Cassinelli (USA), Cherepashchuk (Russia), Hillier (USA) Kudritzki (Germany), Lamers (chair, Netherlands), Nussbaumer (Switzerland), Sapar (Estonia), Stahl (Germany)

Local Organizing Committee: Nugis (chair), Ergma (co-chair), Annuk, Kolka, Ruusalepp

The program will include the following sessions:

- A: Single stars
  Observations of ionization and thermal structure of OB-stars, WR-stars, LBV's, B-stars with weak winds
  Theory of thermal and ionization structure of smooth winds
  Theory of thermal and ionization structure of shocked winds

- B: Binaries
  Observations of the ionization and thermal structure of Symbiotic stars and interacting WR/OB binaries
  Theory of thermal and ionization structure of winds of Symbiotic stars
  Theory of thermal and ionization structure of colliding winds

- C: Spectral modelling and Diagnostics
  Spectral modelling and diagnostics of structured winds and colliding winds

The proceedings will be published in the conference series of the Astronomical Society of the Pacific: (editors: Lamers and Sapar).

The workshop is limited to about 70 participants. Interested participants should contact: Dr Tiit Nugis (nugis@aai.ee) with a short description of their interest and their work related to the topic of the workshop.

Information can be found on Web page:
http://www.aai.ee/workshop/Tartu_workshop.html
http://www.aai.ee/workshop/Tartu_workshop.html