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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Special Issue

1996 Liège Colloquium

This special issue presents abstracts of some of the papers presented at the 33rd Liège International Astrophysical Colloquium on "WR Stars in the Framework of Stellar Evolution" (held in July 1996).

The editors of the Colloquium Proceedings kindly communicated that the book will be available as early as December, as promised. Therefore readers interested in the full articles are invited to contact the proceedings' editors at

vreux@astro.ulg.ac.be

Contents of this newsletter

Invited Reviews

Past and present classification of hot massive stars

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Abstract. Thirty years of spectral classification of O-type stars, Wolf-Rayet stars and Ofpe/WN9 stars are reviewed, covering optical, ultraviolet and infrared wavelength ranges. Pioneering work by Walborn in the early 70-s demonstrated a close morphological relationship between the earliest Of-type spectra and the WN spectra of stars in Carina OB1. Half a decade later, Conti proposed that those spectral similarities indicate an evolutionary sequence from Of-type to WN-type stars. Inspiration from this Conti scenario is found throughout the literature.

"Wolf-Rayet Stars in the Framework of Stellar Evolution", 33$^{\mathbf{rd}}$ Liège Int. Astroph. Coll.

The Conti scenario for forming WR stars: past, present and future

André Maeder

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A short historical review of the mass loss scenario for forming WR stars is presented. The various successes of this scenario are presented. These are mainly:

— The M–L–T_{eff} – R – $\dot{M}$ relations (Schaerer and Maeder 1992)
— The filiation sequences
— The surface chemistry
— The WR lifetimes and number statistics in galaxies

Furthermore, the remaining problems in massive and WR star evolution are also examined. These are the mass loss rates, particularly in the supergiant stages, the binary evolution, and the internal mixing.

The problem of rotational mixing is discussed. Current theories predict that the μ–gradients built by nuclear evolution are preventing any significant mixing. A new solution for the diffusion by shear instabilities is proposed. It produces substantial mixing in massive rotating star models. The first main evolutionary consequences are examined.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33$^{\mathbf{rd}}$ Liège Int. Astroph. Coll.

Observed properties of Wolf-Rayet and related stars at Optical to X-ray wavelengths

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We review observational characteristics of Wolf-Rayet (WR) and related objects (O-stars, Luminous Blue Variables) at short wavelengths (optical, ultraviolet and X-rays) yielding information on their mass-loss and chemical properties and hence evolutionary status. Studies of these stellar groups provide important tests of both stellar wind theory and stellar evolution models incorporating mass-loss effects.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33$^{\rm rd}$ Liège Int. Astroph. Coll.

Wolf-Rayet Stars at Long Wavelengths — Inferences from Infrared and Radio Observations.

P. M. Williams

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While the radiative spectral energy distributions of Wolf-Rayet and O type stars peak in the ultraviolet and visible, their long-wavelength tails carry valuable information about their mass loss and wind structure. Developments in the study of infrared, millimetre and radio emission from hot stellar winds are reviewed, including the spectra of free-free emission from stellar winds and determination of mass-loss rates. The non-thermal radio sources associated with OB and WR stars are described and discussed in terms of their constraints on stellar wind structures. The incidence of heated dust in the winds of WC type WR stars is discussed, with emphasis on the handful of stars which condense dust episodically. The conditions required for the formation of dust in stellar winds demands the presence of significant density inhomogeneities such as clumps, disks or wind-collision wakes. The value of long-term observations in the study of both infrared emission by circumstellar dust and non-thermal radio emission is illustrated with the case of the variable source in the colliding-wind WC7+O binary system WR 140.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33$^{\rm rd}$ Liège Int. Astroph. Coll.

Spectral and Photometric Variability

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Intensive high quality spectral and photometric observations of WR stars variability obtained in last years provided several insights into the nature of these intriguing objects.

It was recognized that spectral variability in WR+O binaries could be understood in terms of selective atmospheric eclipses and wind-wind interaction. Although rather simplified, recent modelling made it possible not only to qualitatively explain the variations but also to derive the important constrains on the parameters of the winds and stars themselves.

Photometric variability of nearly all formerly suspected WR+c candidates is probably caused by other reasons. In some cases, strong evidences are found that rotation is one of the likely sources of the variability (HD50896, HD191765).

The first possible example of non-radial pulsations among WR stars was found (WR66); however, there is no any observational sign for the radial pulsations predicted by the modern evolutionary scenarios.

There exist "single" WR stars (primarily WN8s?) which exhibit large amplitude quasi-periodic photometric variability. It is likely that the true periodicity for these objects exist being however buried in large stochastic variations. Their cause is unlikely to be explained by inhomogeneous nature of WR winds and remains unknown.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33rd Liège Int. Astroph. Coll.

Asymmetries and Inhomogeneities in Wolf-Rayet Winds

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Are the winds of single WR stars spherically symmetric? On *large scales*, the answer is probably 'yes' in most instances, with global asymmetries such as DACs or CIRs being detected only in a few (nevertheless quite remarkable) cases. This is in contrast to O-type winds, where the effects of rotation and related DAC/CIR activity appear to be generally more prevalent or simply more obvious.

On *small scales*, the answer must be qualified. In 'snapshot' mode, the response is clearly negative, with virtually all WR winds being pervaded by outwardly propagating density inhomogeneities. Integrated over time, however, these inhomogeneities tend to smear out to yield something that apparently corresponds closely to spherical symmetry (except in the few cases of large-scale asymmetry noted above). The small-scale inhomogeneities appear to be stochastic and obey power scaling-laws. They may be the result of turbulent shocks in a supersonic, compressible medium, driven by radiative instabilities. In contrast, the large-scale structures require a different driver, e.g. NRP or localized magnetic fields, at or near the surface of the underlying (rotating) star.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33rd Liège Int. Astroph. Coll.

Numbers and Distribution of Wolf-Rayet Stars in Local Group Galaxies: Clues to Massive Star Evolution

Philip Massey

See HSN 21

Ring Nebulae as Probes of the Evolutionary Links between Wolf-Rayet Stars and their Precursors

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The past lives of Wolf-Rayet stars are contained in the circumstellar structures created by the interaction of their progenitor winds and ejecta with the interstellar medium. By careful analyses of the ring nebulae associated with WR stars it is possible to reconstruct their past evolution and assess whether they are descended from Red Supergiants or Luminous Blue Variables. I review recent hydrodynamical calculations by García-Segura et al. (1996a,b) which follow the evolution of the circumstellar medium around a 60 and a 35 $M_{\odot}$ star with intermediate LBV and RSG phases before the WR stage. I then compare the resulting theoretical predictions with the observed chemical compositions, masses and morphologies of 4 WR (NGC 6888, S 308, RCW 58 and M1–67) and 2 LBV (AG Car and HR Car) ring nebulae. It is found that the nebulae are composed of material which has undergone mild CNO-processing rather than material which has reached CNO-equilibrium abundances as predicted for LBV and post-LBV WR nebulae. Moreover, the nitrogen and helium enrichments and oxygen depletions are identical, implying that the nebulae were ejected at the same point in the evolution of the central stars, and have undergone no further chemical modification. Comparison of the observed abundance pattern with the abundances of the inner ring of SN 1987A (thought to be composed of RSG ejecta; Panagia et al. 1997, in prep.) and evolutionary model predictions (Meynet et al. 1994) for RSG surface abundances shows excellent agreement. It is therefore proposed that the WR nebulae and the AG Car nebula are the H-rich envelopes of RSGs. The problem of a RSG phase for AG Car is discussed and it is found that the LBV model of Stothers & Chin (1993, 1996), where the major episode of mass-loss occurs during a single ejection event in a brief yellow or red supergiant phase, is capable of explaining the observed abundance pattern for the AG Car nebula.

"WR Stars in the Framework of Stellar Evolution", 33rd Liège International Astrophysical Colloquium, 1996.

Evolutionary Implications for "Transitions" Stars from Ground-Based and ISO-SWS Spectra

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In this paper we highlight the use of infrared spectroscopy for studying aspects of massive star evolution in the possible "transition" stages, and in the WN to WC stages. The objects include several WN and WC Wolf-Rayet stars and the related OIf, Of/WN, Be B[e], and Luminous Blue Variable objects. The data come from recent ground-based K-band (2.0 - 2.4 μm) observations, and from new data obtained with the *Short Wavelength Spectrometer* (2.4 - 45.2 μm) aboard the *Infrared Space Observatory.* We discuss the evolutionary aspects of spectral and physical morphology among the transition stars (including the possible B[e]–LBV–Of/WN link), and predicted versus measured chemical abundances at the later stages.

Spectral Analyses with the Standard Model. Part II: Wolf-Rayet Stars

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The quantitative analysis of Wolf-Rayet type spectra requires non-LTE models for expanding atmospheres which became available in the last decade. Idealizing assumptions of the so-called standard model are spherical symmetry, homogeneity and stationarity. Synthetic spectra calculated under these assumptions are in general agreement with observation. However, specific observational facts (spectrum variability, X-ray emission) indicate that the standard assumptions are violated to some degree.

The standard model has been extensively applied to analyze the "classical", massive Wolf-Rayet stars of Population I. The galactic WN class has been studied comprehensively on the basis of helium-hydrogen models. The recent inclusion of their nitrogen lines by means of corresponding models confirms the results for WNL (i.e. late subtype WN) stars, while for part of the WNE (early subtype) stars a revision of the temperature scale is to be expected.

Some work remains to be done with the WC stars, which require models with carbon for their analysis. Only WC stars of intermediate subtype have been studied so far in the Pop. I domain. WC-type spectra are also shown by a considerable fraction of central stars of planetary nebulae. Recent spectral analyses of these low-mass stars, covering an extreme range of different subtypes, confirm the good experiences made with the standard model.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33$^{\rm rd}$ Liège Int. Astroph. Coll.

Wind Compression Effects in WR Winds, and the Hanle Effect as a Magnetic Field Diagnostic

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The effects of rotation and magnetic fields on the winds from Wolf-Rayet (WR) stars are discussed. The basic ideas of wind compression models for rotating stars are described and applied to WR stars and Red Supergiant (RSG) stars, although emphasis is given to the WR star models. In the case of the WR stars, highly compressed disks do not appear to be needed, and the milder effects associated with Wind Compressed Zone models seem to be sufficient to explain polarization and other evidence for wind asymmetries. In these models there is a strong wind in all directions from the WR star, but if the star has even moderate rotation, a significant density enhancement in the equatorial region relative to the polar regions may result. Magnetic fields might also be amplified by the wind compression. We present a discussion of the Hanle effect as a new and potentially powerful diagnostic of magnetic fields in winds. The effect leads to a modification of the linear polarization across resonance line profiles. The magnitude of the effect depends on the ratio of the field strength B to the A-value of the resonance line. By observing the Hanle effect in several lines with different A-values, it should be possible to estimate the strength and geometry of the field from the distribution of line polarizations.

WR Stars in the Framework of Stellar Evolution; 33rd Liege Int. Astroph. Coll.

What We Really Know, What We Don't Know

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I address with two different approaches the systematic uncertainties of standard spectroscopic analyses of Wolf-Rayet spectra. I first discuss in detail the loss of photons from the He II λ303 line radiation field. A theoretical calculation of the photon loss yields a loss factor of 10^{-4} for a model of a WN5 star. Then I investigate by how much the predictions of atmosphere models including photon loss differ from the results of the standard models. I find for a few examples that analyses with photon loss lead to 50% to 200% larger luminosities. Based on this inside view of model calculation I argue that the luminosities as known today underestimate the correct value by about a factor of two. Luminosities of Wolf-Rayet stars can also be estimated from their mass, using a theoretical mass - luminosity relation. A comparison of the luminosities inferred from the masses with luminosities derived by standard model analyses also indicates a factor of two deficiency of the model results. Thus, two independent methods yield the same conclusion: the standard model analyses underestimate the Wolf-Rayet luminosities.

WR Stars in the Framework of Stellar Evolution; 33$^{\rm rd}$ Liège Int. Astroph. Coll., J.-M. Vreux (ed.)

Massive Stars in Wolf-Rayet Galaxies

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Wolf-Rayet galaxies are a subset of starburst/H II galaxies whose integrated optical spectra exhibit broad emission features of C III/IV 4650, He II 4686 and C IV 5808 due to the presence of large numbers of Wolf-Rayet stars. I review the observed and inferred properties of these galaxies, with particular emphasis on the determination of the hot star populations within them. The results are compared with theoretical predictions and used to place constraints on the parameters characterizing the starburst episodes. I show that the large Wolf-Rayet to O star number ratios derived from optical spectra, in addition to the detection of numerous, compact, UV-bright knots seen in recent HST images of the star-forming regions in these galaxies, provide convincing evidence that massive star formation in these objects has occurred in relatively recent, short-lived bursts against a background of spatially extended and more quiescent continuous star formation.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33$^{\rm rd}$ Liège Int. Astroph. Coll.

Concluding Remarks

Peter S. Conti [1] [2]

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Several topics discussed during the Colloquium are examined: the confrontation of the predictions of single star evolution with the observations; the role of red supergiants in the production of W-R stars; the function of close binaries and the related topic of secondary accretion; W-R stars in starburst and

more distant galaxies. I shall also touch on the earliest stages of massive star birth with respect to W-R spectra and note in passing that a recent paper in the literature can be taken to imply that W-R stars do *not* end their lives as supernovae.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33rd Liège Int. Astroph. Coll.

Posters

Ionization Stratification in WN Winds

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We performed measurements of the emission line widths on ultraviolet, optical, and infrared spectra of 10 Wolf-Rayet stars belonging to the WN subtype. Our goal is to investigate whether or not ionization stratification exists in all Wolf-Rayet stars which have a "momentum problem". Ionization stratification can be observed via the dependence of line width on ionization potential. Our multi-wavelength approach allows us to obtain line widths of blend-free lines while at the same time covering a wide range of ionization potentials. Assuming a linear relation, we model the data with least-squares fits, and we give the slopes and errors. We find a high probability for the existence of a correlation between the strength of the ionization stratification as measured by these slopes and the wind performance numbers. This is the expected behavior if a stratified ionization structure plays a role in extracting a sufficiently large momentum from the radiation field to accelerate Wolf-Rayet winds.

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A search for companions to dust-making Wolf-Rayet stars

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A spectroscopic search for companions to WC type Wolf-Rayet stars making circumstellar dust reveals the presence of absorption lines attributable to companions in the blue spectra of the WC4 episodic dust-maker WR 19 and the persistent dust-makers WR 104 (Ve 2–45) and WR 119.

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On the Infrared Spectral Morphology of Wolf-Rayet WN Subtypes

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We present new infrared spectra of Wolf-Rayet stars of the nitrogen sequence between 1.5 and 2.4 μm. We provide line identifications. We suggest line ratio criteria to assign WN subtypes from the near-infrared spectra alone. We discuss the morphological diversity of spectra of the same subtypes.

WR Populations in Starbursts: WN and WC Subtypes and the Role of Binaries

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We present the first results of a new set of population synthesis models, which utilize the latest stellar evolutionary tracks, recent non-LTE atmosphere models which include stellar winds, and observed line strengths in WR spectra to predict the relative strengths of various WN and WC/WO emission features in the spectra of starburst galaxies. Our results will be used to derive accurate numbers of WN and WC stars in starburst galaxies. We also analyze the frequency and the WN and WC content of WR-rich galaxies in low metallicity samples; the theoretical predictions are found to be in good agreement with the observed frequencies. We also discuss the possible role of massive close binaries in starburst regions. If the starburst regions are formed in relatively instantaneous bursts we argue that, given their young age as derived from emission lines equivalent widths, *(1)* in the majority of the observed WR galaxies massive close binaries have not contributed significantly to the WR population, and *(2)* nebular He II 4686 emission is very unlikely due to massive X-ray binaries.

To appear in "WR stars in the Framework of Stellar Evolution", 33rd Liège Int. Astroph. Coll.

Multiple Rings Around Wolf-Rayet Stars: Implications for Evolution.

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Optical and IRAS survey results are presented which provide evidence for multiple, concentric rings of material around galactic Wolf-Rayet stars. Such rings are consistent with an evolution from progenitor O stars, through a heavy mass-loss phase, before becoming Wolf-Rayet stars. Study of multiple ring nebulae around Wolf-Rayet stars therefore have the potential to provide valuable information on the evolution of the central stars. Here we illustrate how size and dynamical information obtained from both optical and IRAS data are able to provide timescales for the three main evolutionary phases, while IRAS data may also be

used to provide total mass-loss estimates. Estimated timescales for the three main phases of evolution are consistent with theoretical models of Wolf-Rayet evolution and inferred mass-loss rates are in agreement with those observed in Luminous Blue Variables, the probable precursors of Wolf-Rayet stars. Our results are being used to observationally determine the timescale and mass-loss parameters for all galactic Wolf-Rayet stars.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33$^{\rm rd}$ Liège Int. Astroph. Coll.

Wolf-Rayet stars: major contributors to the galactic ^{19}F ?

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Meynet & Arnould (1993a) have suggested that Wolf-Rayet (WR) stars could significantly contaminate the Galaxy with ^{19}F. This question is revisited more quantitatively on grounds of detailed evolutionary sequences for stars with initial masses from 25 to 120 $M_\odot$ and for three metallicities ($Z = 0.008$, 0.02 and 0.04). The ^{19}F abundance in the WR winds of 60 $M_\odot$ model stars is found to be about 10 to 70 times higher than its initial value, depending on the metallicity. This prediction is used in conjunction with a very simple model for the chemical evolution of the Galaxy to predict that WR stars could be significant (dominant ?) contributors to the solar system fluorine content.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33$^{\rm rd}$ Liège Int. Astroph. Coll.

On the Nature of OIafpe Stars

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Our spectroscopic analysis of the two OIafpe stars, HD 152408 and HD 152386, and the morphologically related stars, HD 151804 (O8 Iaf), HDE 313846 (WN9ha), NS4 (WN9h) and HD 177230 (WN8o) indicates that the astrophysical discrimination between Of and WNL is the surface mass flux ($\dot{\rm M}/4\pi R_*^2$), with stellar temperature and surface helium abundance secondary effects. Above a surface mass flux of $\sim 10^{-8.8}$ $M_\odot {\rm yr}^{-1} R_\odot^{-2}$ stars are classified as Wolf-Rayet. From detailed studies we conclude that (the three known) OIafpe stars should be re-classified as WN9ha stars, and we suggest a direct evolutionary sequence between O Iaf and WNLha stars, without observational evidence for an intermediate LBV phase.

From new, high-resolution CTIO/IRS line profiles we find that given sufficient spectral resolution (R≥1 000) over a suitable range in wavelength, the near-IR is a excellent region for quantatitive studies. We find good agreement between wind velocities derived from He I 1.0830μm and the usual ultraviolet P Cyg profiles. Overall our model analyses indicate good consistency between stellar parameters (mass-loss rates, luminosities, surface abundances) based on either near-IR or optical diagnostics, a question of importance to investigating stars obscured by interstellar dust (e.g. in the Galactic Center) or in crowded regions where IR spectroscopy and low-order adaptive optics provides spatial discrimination (e.g. stars in Local Group galaxies).

Wolf-Rayet Stars in Very Young Starburst Galaxies

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Preliminary results from spectrophotometric observations of galaxies with very young starbursts are presented. Starburst galaxies with an age of the burst in the range between 3 and 6 Myr have been observed and new detections of Wolf-Rayet galaxies are reported. We discuss the origin of high excitation nebular lines observed in these galaxies and their possible link with the population of Wolf-Rayet stars. **"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33rd Liège Int. Astroph. Coll.**

Wolf-Rayet Stars in NGC 300

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The Sc galaxy NGC 300, a member of the Sculptor Group, has been surveyed for WR stars using both the slitless spectroscopy method and the on-line/off-line technique particularly well suited in crowded regions. Observations were carried out with the NTT equipped with the ESO MultiMode Instrument (EMMI). The WR nature of some of the candidates identified in the field and in a few associations was confirmed by slit spectroscopy using the MOS mode of EMMI. The total number of WR stars known at the present time in NGC 300 is 32.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33rd Liège Int. Astroph. Coll.

Blobs Also in O Star Winds

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We present ultra-high signal-to-noise observations of the HeII 4686 Å line in the O4I(n)f supergiant ζ Puppis obtained during two nights at the 3.6m Canada-France-Hawaii Telescope in December 1995. Analysis of the 51 Reticon spectra reveals time-variable fine-structures in the line. Similar features are well established in the strong winds of Wolf-Rayet stars, where they are explained by outward moving inhomogeneities (e.g., blobs, shocks) in the winds. Using a standard 'β' velocity law, we obtain a $\beta \approx 1.3$ as a fair approximation to account for the kinematics of these structures in ζ Pup. In addition to the small-scale variations we also find a global line variation between the two nights, which is comparable to that seen previously in the Hα line of ζ Pup.

Do We Really Need the WO Spectral Type?

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The WO spectral type, as a third spectral class of the WR stars separated from the "historical" WN and WC ones, was introduced by Barlow and Hummer (1982) to group 2 galactic (Sand 4 and Sand 5) and 2 MC stars (Sand 1 and Sand 2) of the well known Sanduleak (1971) list of 5 Pop I WR stars whose spectrum is dominated by the O VI 381.1–383.4 nm doublet. This choice was made following the introduction by Smith and Aller (1968) of a separate "O VI sequence" for the Nuclei of Planetary Nebulae displaying this feature. The WO spectral type has been so far applied to massive Pop I WR, since the current models (e.g. Hamman, 1992) foresee for $M > 40 M_\odot$ stars in their final evolutionary stage a spectrum deprived of helium and dominated by the O lines. Our recent works on Sand 4 (Polcaro et al. 1992) and Sand 5 (Polcaro et al. 1996) have clearly disclosed the presence of He II in their spectra. In addition, a 10 year–long monitoring of the spectrum of Sand 5 suggests that at least one of the lines used by Kingsburgh and Barlow (1995) for their subclassification of the WO stars is variable in time.

From the analysis of the four Sanduleak's WO stars spectra, we conclude that in many respects the WO stars behave like extreme WCs, with wind velocities systematically faster than in the earlier WC stars. The line width seems to be independent on the parent galaxy (MW or MC), though this point needs to be verified on the basis of systematic high resolution observations. On the other hand, the line equivalent widths appear to be more sensitive to the parent galaxy. A possible interpretation puts the WO stars in a very late phase of He shell burning. Therefore He burning, even if still present, is unstable. Several hints point towards identifying the WO stars as those stars that, in the evolutionary models, have come to the end of He burning in a shell. The presence of three such stars in our galaxy (WR30a, Sand 5, Sand 4), though, implies probably that the end of this phase is less sharp than what the current models foresee. This transition would occur through instability stages (variability of the 465 nm line) with "hot" and "cold" phases of the kind that are observed for LBV stars.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33^rd Liège Int. Astroph. Coll.

Wolf-Rayet Emission Lines Varying All Together: The Case of the WC9 Star HD164270

Sébastien Lépine

[1] Département de Physique, Université de Montréal, and Obervatoire du Mont-Mégantic, Québec, Canada The analysis of spectral data from the WC9 star HD164270 (a.k.a. WR103) in the spectral domain 5200Å-5900Å, reveals that every detectable emission line is variable, and that variations appear to be very similar (i.e. synchronous) in all the lines. The variability consists of moving, narrow features (subpeaks) on the top of the lines, similar to those described first by Moffat *et al.* (1988), and studied by Robert (1992).

Cross-correlation techniques are used to compare this subpeak component in different lines. This yields several remarkable findings: 1-The subpeak pattern is very similar in all the lines. 2- Subpeaks are detected even in lines of weak intensity. 3- The subpeak component can be used to resolve line blends. 4- Not all lines correlate equally well with each other, suggesting that subpeaks appear at slightly different times in different lines

These findings corroborate the view that subpeaks are the signature of local, outward propagating overdensities in the stellar wind. Thus, they appear at different times in different lines depending on the depth in the wind at which each line is formed. This provides further evidence for an ionisation stratification of the wind.

"Wolf-Rayet Stars in the Framework of Stellar Evolution"; 33rd Liège Int. Astroph. Coll.

The "Photosphere-Wind Connection" in Wolf-Rayet Stars: Simultaneous Photometry and Spectroscopy of EZ CMa

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In an attempt to reveal the driving mechanism for the 3.77-day periodicity associated with the Wolf-Rayet star EZ CMa (compact companion or rotational modulation of a structured wind), we have monitored this object in optical spectroscopy and narrow-band photometry for 20 consecutive nights in January 1995, simultaneously with the *IUE* Mega project. Arguments are presented against a compact companion as the origin of the observed periodic variability. Instead, we propose that the atypical level of variability intrinsic to this object results from the rotation of its structured wind. The existence of large-scale structures in the wind of EZ CMa is most likely triggered by a spatial (azimuthal) dependence in the physical conditions at the base of the outflow. A local or large-scale magnetic field could cause this inhomogeneity.

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The All-Variable WN8 Stars: the Stellar Core as Driver

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As a continuation of our all-sky survey of the 'enigmatic' variable WN8 stars, we have carried out coordinated multi-site spectroscopic and photometric observations of three WN8 stars in 1995. These include WR123, WR124 and WR156. Combining the data with previously obtained simultaneous spectroscopy and photometry of another WN8 star, WR40, we confirm the lead of the stellar core in restructuring the whole wind. This emerges as a *statistical* trend: the higher the level of the ∼continuum (i.e. ∼core) light variations, the higher the variability of the P Cygni edges of the optical emission lines. However, a direct time correspondence between the light and profile variations might have a different form for each individual star.

WR 134 Revisited: the Persistent 37-Day Periodicity

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We report the results of intense 6-year photometric monitoring of the variable WN6 star WR134. Broadband photometry from the Automatic Photometric Telescope (Arizona) in 1990-1995 is supplemented by intense two-site photometry (México and Crimea) in 1995. We confirm our previous finding of the long-term 37-day periodicity. An additional low-amplitude modulation emerges from the dataset at P=614 days.

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The erratic 21 cm light-curve of WR146 (HM 19-3, WC6+OB)*

*Based on observations made with the Westerbork Synthesis Radio Telescope

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The Wolf-Rayet star WR146 (WC6+OB) is among the brightest WR stars observable at radio wavelengths. We have been monitoring this star with the Westerbork Synthesis Radio Telescope (*WSRT*) at 6 cm and 21 cm since 1989, mostly during *filler* time. At 21 cm we find the flux density varying with an amplitude of ~ 15 mJy around an average $S_{21} \approx 67$ mJy level on time-scales of about a month to about two years. The average spectral index $\alpha_{6-21cm} \approx -0.7$ clearly points to a domination by non-thermal radiation, which we associate with colliding winds in this binary system. Those variations, well above the typical 0.5 mJy observational uncertainty, may be due to inhomogeneities and/or turbulence in the OB and/or WR star winds or due to modulation by a third companion.

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Does the "Conti Scenario" Accurately Describe the Evolutionary Relationship between O, Of, and Wolf-Rayet Stars?

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The meaning of the "Conti Scenario" in terms of the physical state and composition of O, Of, and Wolf-Rayet atmospheres is reviewed. This review discusses the results of the models proposed by Bhatia

and Underhill in 1986, 1988, and 1990 as well as the results found by others using what is called by some "The Standard Model". I conclude that there are no reasons based on physics which imply the truth of the "Conti Scenario". That scenario is based on a suggestion made by B. Paczyński at IAU Symposium No. 49 on Wolf-Rayet and High-Temperature Stars" held in Buenos Aires in 1971.

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The Distance to HD 193576 (V444 CYG)

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[1] Tartu Astrophysical Observatory, EE2444 Tõravere, Estonia The eclipsing binary system V444 Cyg (WN 5

+ O 6V) is usually regarded to be a member of the open cluster Berkeley 86 having the distance $d = 1.59 \pm 0.15$ kpc according to Forbes et al.: 1992, AJ 103, 916. The comparison of the parameters of Be 86 and V444 Cyg forces us to conclude that V444 Cyg is not a member of Be 86. We derived the distance to V444 Cyg from the value of the radius of the O 6V component obtained via the polarimetric eclipse analysis by St-Louis et al.: 1993, ApJ 410, 342 ($R_{\rm O} = 8.5 \pm 1 R_\odot$). The new distance to V444 Cyg is found to be 1.15 ± 0.13 kpc. The mass loss rate of the WN 5 component of V444 Cyg as derived from the observed value of the radio flux at 4.9 GHz is $0.95{\times}10^{-5}$ M$_\odot$ y^{-1} which is in accord with the estimates obtained from the period change rate (dynamical method) and from the polarimetric studies.

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Clumping in the Winds of Late Type WN Stars

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[1] Tartu Astrophysical Observatory, EE2444 Tõravere, Estonia In some recent studies (Leitherer et al.: 1995,

ApJ 450, 289) it has been concluded that either the role of clumping in the winds of late type WN stars (WN 7 – 9) is negligibly small in the forming of line and continuum fluxes or that the clumping parameters must be constants over the huge wind areas. The last possibility is regarded to be less probable. Theoretical support for almost smooth wind structure in some WNL winds comes also from the modeling study of Crowther et al.: 1995, A&A 293, 427. Such conclusions have been drawn from the smallness of the difference between the observed long basis spectral index $\alpha_{\rm IR-radio}$ and the prediction of the smooth wind model.

We found that the role of clumping in the winds of late type WN stars (WNL) is important in forming the IR, mm and line fluxes (most of the total flux is due to the contribution of clumps) and that interactions in the wind (impacts of clumps) give origin to the extra ionized zone in the outer wind region. The extent of the extra ionized zone seems to vary in the WNL winds. Big variations in radio fluxes as observed in WR 89 (Abbott et al.: 1986, ApJ 303, 239; Leitherer et al.: 1995, ApJ 450, 289) and suspectedly in WR 22 and WR 24 having unexpected spectral indexes ($\alpha_{\rm 3.5cm-6.25cm} = 0.14 \pm 0.26$ and $\alpha_{\rm 3.5cm-6.25cm} = 1.85 \pm 0.80$) point to such kind of variations. The comparatively small values of spectral indexes $\alpha_{\rm IR-radio}$ in some WNL stars can be explained by the interacting clumped wind model with the extra ionized zone extending up to infinity.

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A coupled hydrodynamic-ionisation model for the clumpy Wolf-Rayet ring nebula RCW 58

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We present a time-dependent hydrodynamic model for the Wolf-Rayet ring nebula RCW 58 that includes a self-consistent treatment of the nonequilibrium evolution of the ionisation state of the gas. We investigate the feasibility that hydrodynamic ablation from embedded dense clumps in the nebula is responsible for the high-velocity ultraviolet absorption features observed towards the central star. It is found that the observed correlation between the velocity of these features and the ionisation potential of the absorbing ion can be qualitatively reproduced by such a model. The calculated velocity range depends strongly on the adopted wind velocity.

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Evolution of Very Massive Stars

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As shown by several authors in recent years, the details of massive star evolution are still rather uncertain. The problems are mainly related to uncertainties in input physics, in particular mass loss rates and different convective phenomena.

New computations that are presented follow the evolution up to Ne-burning and include modern input physics and a large nuclear network. The complex internal structures arising during the LBV stage and again during late stages are discussed. Abundances throughout the stars during the WR stage are presented.

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