THE HOT STAR NEWSLETTER

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

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From the editor

The Hot Star Newsletter is now sent to over 300 individual subscribers and ten libraries. I am told that this service is highly appreciated and that the exchange of *hot* preprints through electronic means reaches a peak near the newsletter mailing date.

Please do not forget to share any interesting news. The usefulness of this newsletter depends on your timely contributions.

The Be Star Newsletter issue 30 has just appeared. It contains, among other interesting contributions, a summary of the UV polarimetric observations of hot stars obtained with WUPPE on board *Astro*. The newsletter is available by ftp (1428949 bytes) from chara.gsu.edu dir BeNews or on the WWW at URL
http://www.chara.gsu.edu/BeNews/intro.html

Contents of this newsletter

Accepted Papers

A new deep infrared finder chart for the Cygnus X-3 field

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We present a new deep K-band infrared finder chart for the Cygnus X-3 field, revealing the presence of at least ten previously undetected infrared objects within a few arc seconds of the source. Although these newly-discovered objects have in all likelihood not affected previous infrared spectroscopy or photometry of Cyg X-3, knowledge of their locations is an important consideration for future deep infrared spectroscopy of the source.

Accepted by A & A *For preprints, contact* r.p.fender @ open.ac.uk

Absorption Line Profile Variations Among the O Stars. I. The Incidence of Variability

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We have conducted a spectroscopic survey of a magnitude-limited sample of O stars to search for intrinsic absorption line profile variations, particularly those attributable to nonradial pulsations. Our final sample consists of 30 stars that cover the full range of luminosity classes for spectral types between O4 and O9.7. For these objects, we obtained high resolution, high signal-to-noise ratio spectroscopic time series of the C IV $\lambda\lambda$5801, 5812 doublet and the He I λ5876 triplet. These time series typically consist of 20 spectra per object, and sample time scales ranging from a few hours to $\sim$1 week. We developed a new technique, Temporal Variance Spectrum analysis, to detect line profile variations in these data in an objective, statistically rigorous manner.

As the primary result of this survey, we report the detection of statistically significant line profile variations in at least one of the absorption lines for 77% (23/30) of our sample. The incidence and amplitude of variability increase with increasing stellar radius and luminosity, so that all the supergiants in our sample exhibit line profile variations and, conversely, the non-variable stars are mostly dwarfs. We found no statistically significant line profile variability for dwarfs earlier than O7.

The observed distribution of line-profile variables in the HR diagram agrees approximately with the predicted domain of strange-mode oscillations, even though many of the variations in the spectra of supergiants must, in the first instance, arise in the stellar wind. We discuss ways of reconciling these two, apparently contradictory, aspects of the observed activity in terms of mechanisms that causally link variations in the stellar photosphere to the formation of structure in the stellar wind, especially

the strong line-driven instability. Although the true nature of the widespread line-profile variability remains an open issue, it seems likely that pulsation is responsible for much of the observed activity.

Accepted by ApJS. *For preprints, contact:* alex@usm.uni-muenchen.de. Preprints are also available on the WWW at http://www.usm.uni-muenchen.de:8001/people/fullerton/preprints.html.

Long- and short-term variability in O-star winds I. Time series of UV spectra for 10 bright O stars

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An atlas of time series of ultraviolet spectra is presented for 10 bright O stars. The spectra were obtained with the *International Ultraviolet Explorer* during seven observing campaigns lasting several days over a period of 6 years. The UV P Cygni lines in 9 out of the 10 studied stars exhibit a characteristic pattern of variability in the form of discrete absorption components (DACs) migrating through the absorption troughs on a timescale of a day to a week. This pattern is significantly different for each star, but remains relatively constant during the time span of our observations for a given star. A quantitative evaluation of the statistical significance of the variability is given.

The winds of a number of stars appear to vary over the full range of wind velocities: from 0 km s^{-1} up to velocities exceeding the terminal velocity v_∞ of the wind as measured by the asymptotic velocity reached by DACs. The amplitude of variability reaches a maximum at about 0.75 v_∞ in the unsaturated resonance lines of stars showing DACs. In saturated resonance lines we find distinct changes in the steep blue edge. This edge variability is also found, although with smaller amplitude, in unsaturated resonance lines. The subordinate line of N IV at 1718 Å in ξ Per shows weak absorption enhancements at low velocities in the blue-shifted absorption that are clearly associated with the DACs in the UV resonance lines.

We interpret these three manifestations of variation as reflecting a single phenomenon. The DACs are the most conspicuous form of the variability. The changes at the edge can often be interpreted as DACs, but superposed on a saturated underlying wind profile; in many cases, however, at the same time two or more absorption events in different stages of their evolution can be identified in the unsaturated profiles, hampering a detailed interpretation of the edge variability. The low velocity absorption enhancements in the subordinate lines are the precursors of DACs when they are formed close to the star.

The constancy of the pattern of variability over the years and the (quasi-)periodic recurrence of DACs strongly suggest that rotation of the star is an essential ingredient for controlling wind variability. The observation of low-velocity variations in subordinate lines, which are supposedly formed at the base of the stellar wind, indicate an origin of wind variability close to or at the photosphere of the star.

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Combined stellar structure and atmosphere models for massive stars: Wolf-Rayet models with spherically outflowing envelopes

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We present a simple analytical method to describe the structure of a spherically expanding envelope with strong mass outflow. The structure is consistently connected to the hydrostatic stellar interior and provides an adequate description of the outer boundary conditions for stellar models with large mass loss rates.

We apply our treatment to evolutionary models of Wolf–Rayet (WR) stars in order to study the possible influence of the stellar winds on the interior, and to determine more reliable radii of WR stars. Independently of the wind parameters (wind density, opacity, velocity law) the interior structure and evolution of WR stars is found to be unaffected by the outer layers.

On the other hand, the stellar parameters (radii, effective temperatures) may well depend on the wind structure. For hydrogen rich WR stars (WNL) we find the existence of a temperature domain in the HR–diagram, where a transient concentration of stars on their blueward track is predicted in case of a strong backwarming from the wind.

For WNE and WC/WO stars with strong mass loss rates we also derive subphotospheric radii corresponding to Rosseland optical depths of $\sim$ 10–20. The dependence of the subphotospheric radii on the adopted envelope structure is discussed. With respect to wind–free stellar models the subphotospheric radii are increased by up to a factor of $\sim$ 4 for the most luminous WNE or WC stars. These radii and the corresponding effective temperatures should roughly be comparable with the stellar parameters ("core" radii and temperatures) of non–LTE atmosphere models of WR stars. Comparisons using the newly derived subphotospheric radii yields a better agreement with observations.

The stellar parameters obtained with the new treatment allow a better assignment of theoretical spectra to evolutionary tracks of evolved WR stars (WNE, WC). This also provides the base for future studies of the spectral evolution of post main-sequence massive stars and their descendants.

We also point out the possible importance of the iron opacity peak for the acceleration of WR winds in the optically thick part, which may be essential for the understanding of the dynamics of WR winds.

Accepted for publication in A&A *For preprints, contact* schaerer@scsun.unige.ch. Preprints are also available by anonymous ftp from obsftp.unige.ch directory pub/Preprints (file costar_wr.ps), or by WWW at http://obswww.unige.ch/Preprints

The Hopkins Ultraviolet Telescope Far-UV Spectral Atlas of Wolf-Rayet Stars

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During the 1995 March 16-day Astro-2 mission of the Astro space shuttle observatory, we obtained far-UV spectra of the four WN stars WR 6 (WN5), WR 134 (WN6), WR 24 (WN7+a) and WR 40 (WN8) with the Hopkins Ultraviolet Telescope. These data, extending from 820 to 1840 Å at a resolution of $\sim$3 Å, form the basis for the first systematic exploration of Wolf-Rayet star spectra from 1150 Å to the Lyman limit. We identify the prominent emission lines in this spectral region and discuss their

changes along the WN sequence. The spectrum of HD 5980, a former WN3+WN4.5 SMC binary recently recognized as a Luminous Blue Variable, is classified WN6/WN8 in the UV using the WN sequence. A previously unpublished spectrum of WR 48 (WC6+O9.5I), obtained with the Hopkins Ultraviolet Telescope during the 1990 December Astro-1 mission, allows for a comparison of the WN sequence with one WC spectrum.

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Evidence for Wind Attenuation and a Multi-Temperature Plasma in the Combined *EUVE* and *ROSAT* Observations of ϵ Canis Majoris (B2 II)

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We use both *EUVE* and *ROSAT* data sets to test three general pictures – coronal, wind shock, and external – for the production of the observed high energy emission from the B giant, ϵ CMa (B2 II). Because of the very low interstellar opacity along its line of sight, ϵ CMa is the only early-type star that has strong emission lines detected with the *EUVE* spectrometers. The line spectrum provides the first solid observational evidence that the emission is thermal. Theoretical EUV spectra based upon two-temperature model fits to the *ROSAT* data predict too much flux, especially in the iron line complex near 175 Å. We use progressively more complex models until we are able to achieve a fit to the combined data sets. We find that both a temperature distribution in the emitting plasma and some attenuation of the EUV and soft X-ray emission by the ionized stellar wind must be included in the models. The model fitting indicates that only 13 to 21 percent of the emission line complex near 175 Å escapes the wind. This amount is consistent with the wind shock model, in which the emitting material is distributed throughout the stellar wind. It is much more absorption than is predicted by the external source model, where all of the emitting material is at radii beyond the cold stellar wind. And it is significantly less absorption than is expected in the coronal model, given what is known about the star's mass loss rate. The derived temperature distribution and wind filling factor of hot gas are also qualitatively consistent with our numerical simulations of wind shocks. We conclude that although the observed flux from ϵ CMa in the interval 54 eV $< E <$ 100 eV is approximately the same as that above 100 eV, because of wind attenuation the total generated radiation in the EUV band between 54 eV and 100 eV is 5 times greater than that in the X-ray region.

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or http://www.astro.wisc.edu/prints/prints.html.

ROSAT X–ray Observations of the WR Star HD 50896 (WN5)

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We present an analysis of 8 X–ray observations of HD 50896 obtained in our Guest Observer programmes with the XRT+PSPC on the *ROSAT* satellite, covering the energy range [0.1–2.5 keV]. Our first observation, obtained in AO2, covered an integration time of 7 ksec on 29 March 1992. This was followed by a further 7 PSPC observations, during AO3, at roughly daily intervals during 20–26 September 1992. The total PSPC count rates show evidence for variability at the $\leq$ 30% level on timescales of $\leq$ 1 day, together with larger ($\times$ 1.7) epoch–changes. We find no evidence for significant variations on very short timescales ($\leq$ 1-hour) previously reported from *Einstein* X–ray data. No 'phase–dependent' modulation is apparent in the PSPC total count rates, or spectral fits, within the $3^{d}.766$ optical period of the source. Single component spectral fitting (blackbody emission + photo-electric absorption) to the derived mean PSPC spectrum yields kT = 0.28 kev, and log N(H) = 20.6. The latter is very close to the line-of-sight interstellar hydrogen column to HD 50896 of log $N(H)_{ism}$ = 20.7, implying that the observed X—ray emission from the source has undergone negligible absorption in the WN5 wind. With an adopted distance of 1.8 kpc, the mean X-ray luminosity in the PSPC energy range is 3.1×10^{32} erg s^{-1}, whilst the overall observed variations span the range $[2.2–3.8] \times 10^{32}$ erg s^{-1}. Adopting a mass loss rate of 5×10^{-5} $M_{\odot}yr^{-1}$, and a wind terminal velocity of v_{∞} = 2000 km s^{-1}, we estimate the 0.28 keV X–ray emergent emission has a characteristic radius of $\geq$ 1000 $R_{\odot}$. A re–analysis of archival *Einstein* IPC X–ray [0.2–4 kev] observations of HD 50896 at three different epochs confirms substantial variability ($L_x \sim [3–9] \times 10^{32}$ erg s^{-1}), but shows no significant changes in spectral shape, for which kT $\sim$ 0.4 keV is derived – compatible with that deduced from our *ROSAT* data. We conclude that the observed PSPC and previous IPC X–ray emission from HD 50896 originates *via* mechanisms intrinsic to the WR wind, probably in shocked gas produced by radiatively–induced instabilities of the kind being predicted theoretically by Owocki and co-workers.

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Spectroscopic Binary Orbits from Ultraviolet Radial Velocities. Paper 18: TU Muscae

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The orbital elements of the O8-type binary TU Mus have been determined from measurements on high-resolution IUE spectra. The velocity amplitudes are shown to be significantly smaller than found in earlier measurements on optical spectra, and with the adoption of $i = 76$, masses of 17.2 and 10.8 $M_{\odot}$ are recovered. As with LY Aur, the secondary appears to be overluminous for its mass and the system may be evolved.

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Ultraviolet Observations of the Eruption in the Small Magellanic Cloud Wolf-Rayet System HD 5980

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We present results of IUE observations (1200–3200) of the erupting system HD 5980 obtained in 1994

November and December. The 1994 spectrum presents emission lines from ions such as N III, Si IIIII and Al III which were absent in 1991. There is a systematic tendency towards higher degrees of ionization over the 44 days covered by the present observations. At the start of the observations on HJD 2449674 the UV continuum flux at 1850 A is a factor of ~ 2 larger than in 1991, declining by 30% in 18 days, followed by a tendency to once again increase. FES magnitudes indicate a rapid decline in visual brightness after maximum in the eruption. Wind speeds as high as ~ 1700 km s^{-1} are measured although the P Cygni absorption components are highly peculiar, containing several emission-like "bumps", the most prominent of which lies at 920 km s^{-1}. We conclude that the eruption occurred in the primary star of the 19.3 day orbital pair, the one classified as WN4 by Breysacher et al. and which now is displaying an LBV-type event. The phenomena in HD 5980 provide evidence supporting evolutionary scenarios in which pulsationally unstable, H-rich WN stars precede the LBV phase.

To appear in ApJ Letters 452:L107 (1995 October 20)
For preprints, contact gloria@astroscu.unam.mx
Paper available at URL http://www.aas.org/ApJ/v452n2/5220/sc0.html

An Extension of the Case-Hamburg OB Star Surveys

John S. Drilling and Louis E. Bergeron

We have extended the Case-Hamburg OB star surveys to $b = \pm 30$ degrees for $\ell = \pm 60$ degrees using the Curtis Schmidt telescope and 4 degree objective prism at the Cerro Tololo Inter-American Observatory. A catalog of 234 OB stars and other objects with peculiar spectra is presented along with finding charts for those objects too faint to be included on the BD or CD charts.

To appear in PASP 107, 846 (September 1995)

Photometric and Spectroscopic Distances for OB Stars: A Comparison

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Reddenings, absolute magnitudes, and distances (D) based on both UBV-β photometry and MK-system spectral classifications are computed and compared for 287 stars of spectral types 04–B2.5. While overall agreement is very good, $D_{UBV-\beta}/D_{MK} = 1.06 \pm 0.39$ (s.d.), significant trends in photometric vs. spectroscopic absolute magnitudes and distances as a function of both absolute magnitude and photometric vs. spectroscopic luminosity classification are evident. Prescriptions as to whether one is likely to over- or under-estimate photometric as compared to spectroscopic distances in given circumstances are developed. Almost all of the standard deviation in $D_{UBV-\beta}/D_{MK}$ is attributable to differences in inferred absolute magnitudes.

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Submitted Papers

Infrared Spectra of Massive Stars in Transition: OIf, Of/WN, B[e], and Luminous Blue Variable Stars

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We compare the spectra of several Of supergiant, Ofpe/WN9, late-type WN, B[e], and luminous blue variable (LBV) stars at 2 μm and (for the Ofpe/WN9 and LBV objects) 1.6 μm. These objects are "transitional" in their optical spectral classification. In the near-infrared at least one example from each class of objects is readily associated with another type through overlapping spectral morphology. This has important consequences on the classification of hot, luminous objects. For example, we find that a 2 μm spectrum of the B[e] object GG Carinae is nearly *identical* to the well-known LBV AG Carinae (which had been optically classified as Ofpe/WN9 or WN11 in a higher-temperature, lower-brightness state). Our new 2 μm spectra also include HD 5980, a WN binary recently observed to undergo an LBV-like outburst in short-term brightness and spectroscopic variations. The erupting component of HD 5980 fits the 2 μm morphology of the LBV He 3-519 and the WN8 star WR 123 (both hydrogen deficient). The overlapping infrared spectral morphology reinforces the notion that the objects in this study are interrelated in their evolution. We propose that "transitional" massive stars with hydrogen present at their surfaces (including the least-extreme WN types) are not yet in the stage of core-helium burning, but rather a previous phase in which the stellar atmosphere/wind is sometimes dynamically unstable.

Submitted to Astrophysical Journal *For preprints, contact* P.Morris@sron.ruu.nl

Observed constraints for radii of Wolf-Rayet stars in very close binaries. A challenge for the "standard model" of WR stars

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Stars in binaries cannot be larger than the space available for them. We apply this simple principle to Wolf-Rayet binaries in which the constraints are most severe, i.e. systems with the shortest periods and smallest separations. In particular, analysis of the short-period systems CQ Cep and V444 Cyg leads to observed upper limits for the WR radii that are smaller than the core radii predicted by the so-called "standard model" for WR stars. It is suggested that the standard model tends to systematically underestimate the core temperatures and consequently overestimate the core radii of WR stars in many cases. Correcting for this may place most, if not all, hydrostatic cores of WR stars closer to the He-ZAMS in the H-R diagramme, as expected for such hot, He-rich stars.

Submitted to A& A *For preprints, contact* sergey@astro.umontreal.ca.
Preprints are also available by anonymous ftp from astro.umontreal.ca *directory* incoming/sergey/radii

Some Puzzling Facts About Massive Star Evolution

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Massive stars, thanks to their great luminosities, can be viewed very far in the universe and therefore give us the chance to explore quite different astrophysical environments, from the solar vicinity up to blue compact dwarf galaxies, passing through the centre of the Milky Way. In this paper, we shall review some puzzling facts concerning the massive stars: Why does there seem to be a lack of massive stars near the ZAMS in the Herztsprung-Russel diagram ? How to explain the Humphreys-Davidson limit, the absence of the "Blue Herzsprung Gap", the presence of the "ledge" ? How can we account for the distribution of the supergiants in the red and in the blue ? Can we reproduce their surface abundances ? Can we explain the statistics of Wolf-Rayet stars observed in different galaxies ? We explore some tentative answers to these challenging questions and present the effects on the outputs of the stellar models of different assumptions regarding the mass loss rates and the mixing processes. We shall end by commenting on some future promising lines of research.

Review for "Stellar Evolution: What Should Be Done"
32$^{\text{nd}}$ Liège Int. Astroph. Coll. 1995, eds. A. Noels, M. Gabriel, N. Grevesse & P. Demarque (Liège: Institut d'Astrophysique). *For preprints, contact* Meynet@scsun.unige.ch