# 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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## Accepted Papers

### The stellar content of the compact H II region Sh2-88B


**L. Deharveng[1], D. Nadeau[2], A. Zavagno[1] and J. Caplan[1]**

[1] Observatoire de Marseille, 2 Place Le Verrier, 13248 Marseille Cedex 4, France

[2] Observatoire du Mont Mégantic et Département de Physique, Université de Montréal, C.P. 6128, Succ. Centre-ville, Montréal, QC, Canada H3C 3J7



We present a photometric study of the compact H II region Sh2-88B and its associated stellar cluster. The positions and *JHK* magnitudes are obtained for 125 stars over an $80'' \times 80''$ field centered on the region.

The region has two components, called Sh2-88B1 and Sh2-88B2. B1 is a compact cometary H II region associated with a cluster containing several massive stars. The dominant exciting star, at the center of the cometary structure, has an ionizing radiation flux corresponding to a spectral type in the range O8.5V–O9.5V. It is highly reddened, with a visual extinction in the 30–42 mag range, and exhibits a near-IR excess. B1 has a simple morphology, with the ionized and neutral gas clearly separated. Its unidentified infrared band (UIB) emission, observed by ISOCAM in the 5–8.5 $\mu$m passband, comes from the photodissociation region at the periphery of the ionized gas. B2 is an ultracompact H II region whose exciting star, probably of spectral type later than B0.5V, is not detected; this indicates a visual extinction greater than 60 mag. A very steep and regular increase of the extinction from west to east is observed over the whole of Sh2-88B.



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*Preprints from* `deharveng@observatoire.cnrs-mrs.fr`

# A new orbital solution for the massive binary system HD 93403

**G. Rauw, H. Sana, E. Gosset, J.-M. Vreux, E. Jehin, G. Parmentier**

Institut d'Astrophysique et de Géophysique, Université de Liège, 5, Avenue de Cointe, B-4000 Liège, Belgium

We present a spectroscopic analysis of the early-type massive binary system HD 93403. Using high resolution optical spectra, we clearly separate the primary and secondary components. For the first time, we are able to provide an orbital solution for both stars. Our new orbital parameters show discrepancies with the previous solution published by Thackeray & Emerson (1969). We further discuss several spectral features of HD 93403. We finally derive qualitative constraints on the inclination of the system and we discuss its evolutionary status and the position of both components in the Hertzsprung-Russell diagram.

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# Exospheric Models for the X-ray Emission from Single Wolf-Rayet Stars

**R. Ignace[1], L. Oskinova[2], and C. Foullon**

[1] Physics and Astronomy, University of Iowa

[2] Physics and Astronomy, University of Glasgow

[3] Mathematical Institute, University of St. Andrews

We review existing *Rosat* detections of single Galactic Wolf-Rayet (WR) stars and develop wind models to interpret the X-ray emission. The *Rosat* data, consisting of bandpass detections from the Rosat All-Sky Survey (RASS) and some pointed observations, exhibit no correlations of the WR X-ray luminosity ($L_X$) with any star or wind parameters of interest (e.g., Bolometric luminosity, mass loss rate, or wind kinetic energy), although the dispersion in the measurements is quite large. The lack of correlation between X-ray luminosity and wind parameters among the WR stars is unlike their progenitors the O stars, which show trends with such parameters. In this paper we seek to (a) test by how much the X-ray properties of the WR stars differ from the O stars and (b) place limits on the temperature $T_X$ and filling factor $f_X$ of the X-ray emitting gas in the WR winds. Adopting empirically derived relationships for $T_X$ and $f_X$ from O star winds, the predicted X-ray emission from WR stars is much smaller than observed with *Rosat*. Abandonning the $T_X$ relation from O stars, we maximise the cooling from a single temperature hot gas to derive lower limits for the filling factors in WR winds. Although these filling factors are consistently found to be an order of magnitude greater than those for O stars, we find that data are consistent (albeit the data is noisy) with a trend of $f_X \propto (\dot{M}/v_\infty)^{-1}$ in WR stars as is also the case for O stars.

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## The Hanle Effect as a Diagnostic of Magnetic Fields in Stellar Envelopes III. Including the Finite Star Depolarization Effect

**R. Ignace**

Physics and Astronomy, University of Iowa

The Hanle effect is a relatively new magnetic diagnostic in stellar astrophysics. Although a substantial literature exists for applications of the Hanle effect in solar studies, the Hanle effect is only a fledgling subject in stellar astrophysics, with previous work focussing on simplistic cases to isolate the magnetic effects on polarized resonance scattering line profiles. In particular, applications to stars have treated the star as as a point source of illumination. This paper carries the work forward by considering the consequences of finite stellar size for the line polarization. An approach based on intensity moments is derived. For optically thin line scattering and a star that is uniformly bright, the effect of finite star illumination is shown to produce the familiar finite star depolarization factor found by Cassinelli, Nordsieck, & Murison (1987) for Thomson scattering by free electrons. An illustrative case is examined to show how the depolarization factor and magnetic field distribution affect the spatial sensitivity of the Hanle effect as a magnetic diagnostic.

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## The Puzzle of HD 104994 (=WR 46)

**S.V. Marchenko[1], J. Arias[2], R. Barbá[2], L. Balona[3], A.F.J. Moffat[1], V.S. Niemela[2], M.M. Shara[4] and C. Sterken[5]**

[1] Département de Physique, Université de Montréal, C.P. 6128, Succursale Centre-Ville, Montréal, QC H3C 3J7, Canada, and Observatoire du Mont Mégantic

[2] Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de la Plata, Paseo del Bosque S/N, B1900FWA La Plata, Argentina

[3] South African Astronomical Observatory, PO Box 9, Observatory 7935, Cape, South Africa

[4] Department of Astrophysics, Division of Physical Sciences, American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024-5192

[5] University of Brussels, Pleinlaan 2, 1050 Brussels, Belgium

Intense coordinated spectroscopic and photometric monitoring of the suspected Wolf-Rayet binary WR 46 in 1999 reveals clear periodic variations, $\mathrm{P} = 0.329 \pm 0.013\,\mathrm{d}$, in the radial velocities of the emission lines of highest ionization potential, O VI and N V, found deepest in the WR wind and thus least likely to be perturbed by a companion. These are accompanied by coherent variability in the profiles of lines with lower ionization/excitation potential and in the continuum flux. Most probably originating from orbital motion of the WR component of the binary, this periodic radial velocity signal disappears from time to time, thus creating a puzzle yet to be solved. We show that the entangled patterns of the line profile variability are mainly governed by transitions between high and low states of the system's continuum flux.

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*Preprints from* sergey@astro.umontreal.ca

# A search for interstellar bubbles surrounding massive stars in Per OB1

**Cristina Cappa[1] and Uwe Herbstmeier[2]**

[1] Instituto Argentino de Radioastronomía, CC 5, 1894 Villa Elisa, Argentina and Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Paseo del Bosque s/n, 1900 La Plata, Argentina
[2] Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany
and Radioastronomisches Institut der Universität Bonn, Auf dem Hügel 71, D-53121 Bonn, Germany

We have examined the interstellar medium in the vicinity of massive stars belonging to the Per OB1 association based on neutral hydrogen 21-cm observations obtained with the 100-m radiotelescope at Effelsberg (HPBW = 8.4 arcmin) and complementary data from the Leiden-Dwingeloo HI Survey (HPBW = 36 arcmin).

The higher angular resolution HI observations allowed to discover probable wind blown bubbles related to four massive stars in the association, namely, HD 14442 [O5n(f)p], HD 14947 [O5If+], HD 13022 [O9.5II-III((n))] and HD 13338 [O9.5V], while the detection of a wind blown bubble associated with HD 16691 [O5If+] is less conclusive. A clear HI shell coincident in position with two B1III stars (HD 15233 and Hilt 311) was also detected. Some of these features have also infrared and/or molecular counterparts. The energetics of the structures related to each massive star is analyzed. The new HI interstellar bubbles appear to be similar to the ones found surrounding Wolf-Rayet stars and other Of stars.

The large scale maps obtained using the lower angular resolution HI data show that most of the early type stars belonging to Per OB1 are placed in a region of low HI emission. The association could have blown a HI shell of about 350 × 550 pc in size. This large HI shell has an infrared counterpart.

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# Stellar Evolution with Rotation V: Changes in all the Outputs of Massive Star Models

**Georges Meynet and André Maeder**

Geneva Observatory, University of Geneva, CH–1290 Sauverny, Switzerland

Grids of models for rotating stars are constructed in the range of 9 to 120 $M_\odot$ at solar metallicity. The following effects of rotation are included: shellular rotation, new structure equations for non–conservative case, surface distorsions, increase of mass loss with rotation, meridional circulation and interaction with horizontal turbulence, shear instability and coupling with thermal effects, advection and diffusion of angular momentum treated in the non–stationary regime, transport and diffusion of the chemical elements.

Globally we find that for massive stars the effects of rotation have an importance comparable to those of mass loss. Due to meridional circulation the internal rotation law $\Omega(r)$ rapidly converges, in 1–2 % of the MS lifetime, towards a near equilibrium profile which then slowly evolves during the MS phase. The circulation shows two main cells. In the deep interior, circulation rises along the polar axis and goes down at the equator, while due to the Gratton–Öpik term it is the inverse in outer layers. This external inverse circulation grows in depth as evolution proceeds. We emphasize that a stationary approximation and a diffusive treatment of meridional circulation would be unappropriate. After the

MS phase, the effects of core contraction and envelope expansion dominate the evolution of the angular momentum.

The surface velocities decrease very much during the MS evolution of the most massive stars, due to their high mass loss, which also removes a lot of angular momentum. This produces some convergence of the velocities, but not necessarily towards the break–up velocities. However, stars with masses below ∼12 $M_\odot$ with initially high rotation may easily reach the break–up velocities near the end of the MS phase, which may explain the occurence of Be–stars. Some other interesting properties of the rotational velocities are pointed out.

For an average rotation, the tracks in the HR diagram are modified like a moderate overshoot would do. In general, an average rotation may increase the MS lifetime up to about 30 %; for the helium–burning phase the effects are smaller and amount to at most 10 %. From plots of the isochrones, we find that rotation may increase the age estimate by about 25 % in general. However, for stars with M $\gtrsim$40 $M_\odot$ and fast rotation, a bluewards "homogeneous–like" track, with important He– and N–enrichments, may occur drastically affecting the age estimates for the youngest clusters. Rotation also introduces a large scatter in the mass–luminosity relation: at the same $\log g_{\rm eff}$ and $\log T_{\rm eff}$, differences of masses by 30 % may easily occur, thus explaining what still remains of the alleged mass discrepancy.

Rotation also brings significant surface He– and N–enhancements, they are higher for higher masses and rotation. While it is not difficult to explain very fast rotators with He– and N–excesses, the present models also well account for the many OB stars exhibiting surface enrichments and moderate or low rotation, (cf. Herrero et al. 1992, 2000). These stars likely result from initially fast rotators, which experienced mixing and lost a lot of angular momentum due to enhanced mass loss. The comparison of the N–excesses for B– and A–type supergiants supports the conclusion by Venn (1995, 1999), that these enrichments mostly result from mixing during the MS phase, which is also in agreement with the results of Lyubimkov (1996).

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## Stellar evolution with rotation VI: The Eddington and Ω–limits, the rotational mass loss for OB and LBV stars

**André Maeder and Georges Meynet**

Geneva Observatory, University of Geneva, CH–1290 Sauverny, Switzerland

Several properties of massive stars with large effects of rotation and radiation are studied. For stars with shellular rotation, i.e. stars with a constant angular velocity Ω on horizontal surfaces (cf. Zahn 1992), we show that the equation of stellar surface has no significant departures with respect to the Roche model; high radiation pressure does not modify this property. Also, we note that contrarily to some current expressions, the correct Eddington factors Γ in a rotating star explicitely depend on rotation. As a consequence, the maximum possible stellar luminosity is reduced by rotation.

We show that there are 2 roots for the equation giving the rotational velocities at break–up: 1) The usual solution, which is shown to apply when the Eddington ratio Γ of the star is smaller than formally 0.639. 2) Above this value of Γ, there is a second root, inferior to the first one, for the break–up velocity. This second solution tends to zero, when Γ tends towards 1. This second root results from the interplay of radiation and rotation, and in particular from the reduction by rotation

of the effective mass in the local Eddington factor. The analysis made here should hopefully clarify a recent debate between Langer (1997,1998) and Glatzel (1998).

The expression for the global mass loss–rates is a function of both $\Omega$ and $\Gamma$, and this may give raise to extreme mass loss–rates ($\Omega\Gamma$–limit). In particular, for O–type stars, LBV stars, supergiants and Wolf–Rayet stars, even slow rotation may dramatically enhance the mass loss rates. Numerical examples in the range of 9 to 120 $M_\odot$ at various $T_{\rm eff}$ are given.

Mass loss from rotating stars is anisotropic. Polar ejection is favoured by the higher $T_{\rm eff}$ at the polar caps ($g_{\rm eff}$–effect), while the ejection of an equatorial ring is favoured by the opacity effect ($\kappa$–effect), if the opacity grows fastly for decreasing $T_{\rm eff}$.

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*Preprints from* Andre.Maeder@obs.unige.ch
*or on the web at* http://xxx.sissa.it/abs/astro-ph/0006405

## Coordinated Monitoring of the Eccentric O-star Binary Iota Orionis: The X-ray Analysis

**Julian M. Pittard[1,2], Ian R. Stevens[1], Michael F. Corcoran[3], Ken G. Gayley[4], Sergey V. Marchenko[5], Gregor Rauw[1,6]**

[1]School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

[2]School of Physics and Astronomy, University of Leeds, Woodhouse Lane, Leeds LS2 9JT, UK

[3]Universities Space Research Association/Laboratory for High Energy Astrophysics, GSFC, Greenbelt, MD 20771, USA

[4]University of Iowa, Iowa City, IA 52245, USA

[5]Départment de physique, Université de Montréal, C.P. 6128, Succursale Centre-Ville, Montréal, Québec, H3C 3J7, Canada

[6]Institut d'Astrophysique & Géophysique, Université de Liège, 5, Avenue de Cointe, B-4000 Liège, Belgium

We analyse two *ASCA* observations of the highly eccentric O9 III + B1 III binary Iota Orionis obtained at periastron and apastron. Based on the assumption of a strong colliding winds shock between the stellar components, we expected to see significant variation in the X-ray emission between these phases. The observations proved otherwise: the X-ray luminosities and spectral distributions were remarkably similar. The only noteworthy feature in the X-ray data was the hint of a proximity effect during periastron passage. Although this 'flare' is of relatively low significance it is supported by the notable proximity effects seen in the optical (Marchenko *et al.* 2000) and the phasing of the X-ray and optical events is in very good agreement. However, other interpretations are also possible.

In view of the degradation of the SIS instrument and source contamination in the GIS data we discuss the accuracy of these results, and also analyse archival *ROSAT* observations. We investigate why we do not see a clear colliding winds signature. A simple model shows that the wind attenuation to the expected position of the shock apex is negligible throughout the orbit, which poses the puzzling question of why the expected $1/D$ variation (*ie.* a factor of 7.5) in the intrinsic luminosity is not seen in the data. Two scenarios are proposed: either the colliding winds emission is unexpectedly weak such that intrinsic shocks in the winds dominate the emission, or, alternatively, that the emission observed *is* colliding winds emission but in a more complex form than we would naively expect. Complex hydrodynamical models are then analyzed. Despite strongly phase-variable emission from the models, *both* were consistent with the observations. We find that if the mass-loss rates of the stars are low then intrinsic wind shocks could dominate the emission. However, when we assume higher mass-loss rates of the stars, we find that the observed emission could also be consistent with a purely colliding winds

origin. A summary of the strengths and weaknesses of each interpretation is presented. To distinguish between the different models X-ray observations with improved phase coverage will be necessary.

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## Confidence levels of evolutionary synthesis models

**M. Cerviño[1,2] V. Luridiana[3] and F.J. Castander[1]**

[1] LAT-OMP (Toulouse, France)

[2] CESR (Toulouse, France)

[3] UNAM (Mexico)

The stochastic nature of the IMF in young stellar clusters implies that clusters of the same mass and age do not present the same unique values of their observed parameters. Instead they follow a distribution. We address the study of such distributions, parameterised in terms of their confidence limits, in evolutionary synthesis models. These confidence limits can be understood as the inherent uncertainties of the synthesis models. Here we concentrate on some parameters such as EW(H$\beta$) in emission. For instance, we show that for a cluster where $10^5$ Mo have been transformed into stars, the dispersion of EW(H$\beta$) is about 18% within the 90% confidence levels at ages between 3.5 and 5 Myrs.

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*Preprints from* `mcervino@obs-mip.fr`

*or on the web at* `http://arXiv.org/abs/astro-ph/0006441`

## Cygnus OB2 – a young globular cluster in the Milky Way

**J. Knödlseder[1,2]**

[1]INTEGRAL Science Data Centre, Chemin d'Ecogia 16, CH-1290 Versoix, Switzerland

[2]Centre d'Etude Spatiale des Rayonnements, CNRS/UPS, B.P. 4346, F-31028 Toulouse Cedex 4, France

The morphology and stellar content of the Cygnus OB2 association has been determined using 2MASS infrared observations in the $J$, $H$, and $K$ bands. The analysis reveals a spherically symmetric association of $\sim$ 2deg in diameter with a half light radius of $13'$, corresponding to $R_h = 6.4$ pc at an assumed distance of 1.7 kpc. The interstellar extinction for member stars ranges from $A_V \approx 5^{\rm m}$ to $20^{\rm m}$, which led to a considerable underestimation of the association size and richness in former optical studies. ¿From the infrared colour-magnitude diagram, the number of OB member stars is estimated to $2600 \pm 400$, while the number of O stars amounts to $120 \pm 20$. This is the largest number of O stars ever found in a galactic massive star association. The slope of the initial mass function has been determined from the colour-magnitude diagram to $\Gamma = -1.6 \pm 0.1$. The total mass of Cyg OB2 is estimated to $(4 - 10) \times 10^4$ $M_\odot$, where the primary uncertainty comes from the unknown lower mass cut-off. Using the radial density profile of the association, the central mass density is determined to $\rho_0 = 40 - 150$ $M_\odot{\rm pc}^{-3}$.

Considering the mass, density, and size of Cyg OB2 it seems untenable to classify this object still as OB association. Cygnus OB2 more closely resembles a young globular cluster like those observed in the Large Magellanic Cloud or in extragalactic star forming regions. It is therefore suggested to

re-classify Cygnus OB2 as young globular cluster – an idea which goes back to Reddish et al. (1966). Cygnus OB2 would then be the first object of this class in the Milky Way.

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## $Fe^{+}$ column density and line opacities of the UV2 multiplet of Fe II in laboratory and peculiar stellar sources

**Roberto F. Viotti[1], Nissan Spector[1,2], Giovanni Battista Baratta[3] and Corinne Rossi[4]**

[1] Istituto di Astrofisica Spaziale, CNR, Area di Ricerca Tor Vergata, 00133 Roma, Italy

[2] On leave of absence from Soreq Research Center, Yavne 81800, Israel

[3] Osservatorio Astronomico di Roma, Via del Parco Mellini 84, 00136 Roma, Italy

[4] Dipartimento di Fisica, Università La Sapienza, Piazza Aldo Moro, 2, 00185 Roma, Italy

The Self-Absorption Curve method has been applied to the UV2 multiplet $a^6D - z^6F^o$ of Fe II observed in the laboratory and in emission–line stars. For the laboratory observations line opacities of this multiplet were obtained using various sets of atomic data. The best fit is obtained using data by Bergeson et al. (1996), which provide line opacities that are in remarkable agreement with results by Kastner (1999a), derived using independent methods. A value of $7.3\times10^{12}$ cm$^{-2}$ for the $Fe^{+}$ column density is derived for the laboratory source, and lower limits of $2.1\times10^{15}$ and $\sim2\times10^{17}$ cm$^{-2}$ are obtained for the peculiar stars KQ Pup and RR Tel, respectively.

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# Submitted Papers

## Wind Inhomogeneities in Wolf-Rayet Stars. IV. Using Clumps to Probe the Wind Structure in the WC8 Star HD 192103

**Sébastien Lépine[1], Matthew J. Dalton[2], Anthony F. J. Moffat[3], Sergey V. Marchenko[3], Nicole St-Louis[3], Paul A. Crowther[2], Linda J. Smith[2], Allan J. Willis[2], Igor I. Antokhin[4], and Gaghik H. Tovmassian[5]**

[1] Department of Astrophysics, American Museum of Natural History, Central Park West at 79th street, New York, NY 10024

[2] Department of Physics and Astronomy, University College London, Gower Street, London, WC1E 6BT, UK

[3] Département de Physique, Université de Montréal, C.P. 6128, Succursale Centre-Ville, Montréal, QC H3C 3J7, Canada

[4] Moscow State University, Sternberg State Astronomical Institute, Universitetskij Prospect 13, 119899, Moscow, RussiaInstitute Two and Address

[5] Instituto de Astronomía, Apartado Postal 877, C.P. 22860, Ensenada, México

We present the most intensive, high-quality spectroscopic monitoring of optical Wolf-Rayet emission lines ever obtained. The Wolf-Rayet star HD192103 (=WR135; subtype WC8) was observed in the

5650 − 5840Å regime alternately from both the William-Herschel Telescope and the Canada-France-Hawaii Telescope. The final data consist of a series of 197 spectra spread over 64 hours, each with a resolving power $\lambda/\Delta\lambda \simeq 20000$ and a signal-to-noise ratio in the continuum $\simeq 450$ per 3-pixel resolution element. We clearly and unambiguously identify stochastic, structured patterns of intrinsic variability at the 1-2 % level of the line flux in the broad CIII λ5696 emission line. The λ5801/12 doublet emission is also found to be variable at the 0.2-0.5% level of the line flux. We find a correlation between the variability patterns found in CIII and CIV, which suggests a significant overlap in the emission volumes of these transitions, although CIV is known to arise somewhat closer to the star. We attempt to reproduce the observed line-profile variation patterns using a simple phenomenological model, which assumes the wind to be fully clumped. With a minimal set of assumptions, we are able to reproduce both the shape and the variability in the CIIIλ5696 emission profile. We show that the variability pattern provides constraints on the radial extent of WR135's wind where CIII is produced, as well as on the local wind acceleration rate. However, our simple clump model does not reproduce the lower variability in the CIV doublet unless we assume the CIV emission to occur in a much larger volume than CIII, implying that significant CIV emission occurs farther out in the wind that CIII. We suggest that while some CIV emission might occur farther out, possibly because of re-ionisation from shocks, a more likely explanation is that wind clumping significantly increases with distance to the star, leading to larger variability levels in CIII, formed farther out than most of CIV. Alternatively, optical depth effects and/or local ionisation gradients within clumps could conspire to attenuate clumping effects in the CIV emission line while enhancing them in the CIII line.

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## WSRT 1.4 and 5 GHz light-curves for WR 147 (AS 431, WN8(h)+B0.5V)

**Diah Y.A. Setia Gunawan[1,2], A. Ger de Bruyn[3,1], Karel A. van der Hucht[2], and Peredur M. Williams[4]**

[1] Kapteyn Astronomical Institute, P.O. Box No. 800, NL-9700 AV Groningen, The Netherlands.

[2] Space Research Organization Netherlands, Sorbonnelaan 2, NL-3584 CA Utrecht, The Netherlands.

[3] Netherlands Foundation for Research in Astrophysics, P.O. Box No. 2, NL-7990 AA Dwingeloo, The Netherlands.

[4] Institute for Astronomy, University of Edinburgh, Royal Observatory, Blackford Hill, Edinburgh EH9 3HJ, U.K.

The Wolf-Rayet (WR) binary WR 147 was monitored with the Westerbork Synthesis Radio Telescope (WSRT) at 1.4 and 5 GHz (21 and 6 cm) from 1988 till 1997. The system is not resolved by the WSRT, thus we observed the total flux density of the system.

The spectral index of the time-averaged total 5-1.4 GHz flux densities is $\alpha_{5-1.4\mathrm{GHz}} \approx 0.23 \pm 0.04$. The departure from the value expected for an optically thick thermal source with expanding envelope of $\alpha = 0.6$, has been attributed in related studies to extra emission from a bow-shaped source to the north of the thermal source. The spectral energy distribution, after the contribution of the southern thermal source is subtracted, can be fitted by a free-free absorbed synchrotron-emission model. The non-thermal emission is synchrotron emission originating in the region where the winds of the binary components collide with relativistic particles accelerated by the shock mixing with thermal particles.

The 1.4-GHz flux density varied between ∼ 20 mJy and ∼ 30 mJy. We attribute the irregular, stochastic variations with a typical time-scale of ∼weeks to inhomogeneities in the wind. The flux density *increase* results when the inhomogeneities in the wind/clumps enter the wind collision region,

fueling the synchrotron production. The typical time-scale of the flux density *decrease* is shorter than the time against synchrotron loss ($\sim 10^3$ yr) or the Inverse-Compton life-time ($\approx 4.5$ yr). Therefore, we suggest that the flux-density *decrease* is dominated by free-free absorption of the synchrotron emission by clumps in the line-of-sight.
There is a hint of a sinusoidal variation of 8 yr period, confirmation of which requires further monitoring.

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*or on the web at* `http://www.astro.rug.nl/~diah; click on` '*publications*'

## Digital Spectroscopy of O3-O5 and ON/OC Supergiants in Cygnus

**Nolan R. Walborn[1] and Ian D. Howarth[2]**

[1] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA

[2] Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, UK

High signal-to-noise, optical digital classification spectrograms of three northern very early-O supergiants and four late-O supergiants with CNO anomalies are illustrated and discussed. Several of these exceptional objects either are the prototypes of their classes, originally discovered photographically, or are unique representatives of them in the Northern Hemisphere. The full blue-violet and yellow-red spectrum of the extreme ON supergiant BD $+36°4063$, discovered by Mathys with limited wavelength coverage, is shown for the first time. Extensive line identifications are provided, and the high quality of these data reveals numerous new absorption and emission features corresponding either to the high ionization in the case of the very early objects, or to the chemical abundance anomalies in the later ones. These data provide standards for digital classification of related objects in the north, and guidance for subsequent astrophysical analyses with higher spectral resolution.

**Submitted to PASP**
*Preprints from* `walborn@stsci.edu`

## The X-ray Lightcurve of $\eta$ Car: Refinement of the Orbit and Evidence for Phase Dependent Mass Loss

**M. F. Corcoran[1,2], K. Ishibashi[3], J. H. Swank[2], R. Petre[2]**

[1] Universities Space Research Association, 7501 Forbes Blvd, Ste 206, Seabrook, MD 20706

[2] Laboratory for High Energy Astrophysics, Goddard Space Flight Center, Greenbelt MD 20771

[3] National Research Council, Laboratory For Astronomy and Space Physics, Goddard Space Flight Center, Greenbelt, MD 20771

We solve the observed X-ray lightcurve of the extremely luminous and massive star $\eta$ Carinae with a colliding wind emission model to refine the ground-based orbital elements. The sharp decline to X-ray minimum at the end of 1997 fixes the date of the last periastron passage at $1997.95 \pm 0.05$, not 1998.13 as derived from ground-based radial velocities. This helps resolve a discrepancy between the ground-based radial velocities and spatially-resolved velocity measures obtained by STIS. The X-ray data are consistent with a mass function $f(M) \approx 1.5$, lower than the value $f(M) \approx 7.5$ previously reported, so that the masses of the two stars are $\sim 80M_\odot$ and $30M_\odot$. In addition the X-ray data

suggest that the mass loss rate from $\eta$ Carinae is generally less than $3 \times 10^{-4}$ $M_\odot$ $yr^{-1}$. We could not match the duration of the X-ray minimum with any standard colliding wind model in which the wind is spherically symmetric and the mass loss rate is constant. However we show that we can match the variations around X-ray minimum if we include an increase of a factor of $\sim$ 20 in the mass loss rate from $\eta$ Carinae for approximately 80 days following periastron. If real, this excess in $\dot{M}$ would be the first evidence of tidally enhanced mass flow off the primary when the two stars are close, and it is likely that the X-ray spectra measured by *ASCA* and *RXTE* near the X-ray minimum are significantly contaminated by unresolved hard emission ($E \geq 2$ keV) from some other nearby source, perhaps associated with fast shocks near the homunculus or scattering of the colliding wind emission by circumstellar dust. Based on the X-ray fluxes the distance to $\eta$ Carinae is 2300 pc, with an uncertainty of about 10%.

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## The X-ray Spectral Evolution of $\eta$ Car as Seen by *ASCA*

**M. F. Corcoran[1,2], A. C. Fredericks[3], R. Petre[2], J. H. Swank[2], and S. A. Drake[1,2]**

[1] Universities Space Research Association, 7501 Forbes Blvd, Ste 206, Seabrook, MD 20706

[2] Laboratory for High Energy Astrophysics, Goddard Space Flight Center, Greenbelt MD 20771

[3]Boeing/RTS 535 Lipoa Pkwy. Ste. 200 Kihei, HI 96753

Using data from the *ASCA* X-ray observatory, we examine the variations in the X-ray spectrum of the supermassive star $\eta$ Car with an unprecedented combination of spatial and spectral resolution. We include data taken during the recent X-ray eclipse in 1997–1998, after recovery from the eclipse, and during and after an X-ray flare. We show that the eclipse variation in the X-ray spectrum is apparently confined to a decrease in the emission measure of the source. We compare our results with a simple colliding wind binary model and find that the observed spectral variations are only consistent with the binary model if there is significant high-temperature emission far from the star and/or a substantial change in the temperature distribution of the hot plasma. If contamination in the 2–10 keV band is important, the observed eclipse spectrum requires an absorbing column in excess of $10^{24}$ $cm^{-2}$ for consistency with the binary model, which may indicate an increase in $\dot{M}$ from $\eta$ Carinae near the time of periastron passage. The flare spectra are consistent with the variability seen in nearly simultaneous *RXTE* observations and thus confirm that $\eta$ Carinae itself is the source of the flare emission. The variation in the spectrum during the flare seems confined to a change in the source emission measure. By comparing 2 observations obtained at the same phase in different X-ray cycles, we find that the current X-ray brightness of the source is slightly higher than the brightness of the source during the last cycle, perhaps indicative of a long-term increase in $\dot{M}$, not associated with the X-ray cycle.

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# Physical parameters of erupting Luminous Blue variables: NGC 2363-V1 caught in the act

**L. Drissen[1], P. A. Crowther[2], L. J. Smith[2], C. Robert[1], J.-R. Roy[1] and D. J. Hillier[3]**

[1] Département de physique, Université Laval, Québec (Québec)

[2] Department of Physics and Astronomy, University College London, London, UK

[3] Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, USA

A quantitative study of the Luminous Blue Variable NGC 2363-V1 in the Magellanic galaxy NGC 2366 (D = 3.44 Mpc) is presented, based on ultraviolet and optical *Hubble Space Telescope* STIS spectroscopy. Contemporary WFPC2 and William Herschel Telescope imaging reveals a modest V-band brightness increase of ∼0.2 mag/year between 1996 January–1997 November, reaching V=17.4 mag, corresponding to $M_V$=−10.4 mag. Subsequently, V1 underwent a similar decrease in V-band brightness, together with a UV brightening of 0.35 mag from 1997 November to 1999 November.

The optical spectrum of V1 is dominated by H emission lines, with Fe II, He I and Na I also detected. In the ultraviolet, a forest of Fe II absorption features and numerous absorption lines typical of mid-B supergiants (such as Si II, Si III, Si IV, C III) are observed. ¿From a spectral analysis with the non-LTE, line-blanketed code of Hillier & Miller (1998), we derive stellar parameters of $T_*$=11kK, $R_*$=420$R_\odot$, $\log(L/L_\odot)$=6.35 during 1997 November, and $T_*$=13kK, $R_*$=315$R_\odot$, $\log(L/L_\odot)$=6.4 for 1999 July. The wind properties of V1 are also exceptional, with $\dot{M} \sim 4.4 \times 10^{-4} M_\odot yr^{-1}$ and $v_\infty$ ∼300 km s$^{-1}$, allowing for a clumped wind (filling factor = 0.3), and assuming H/He∼4 by number.

The presence of Fe II lines in the UV and optical spectrum of V1 permits an estimate of the heavy elemental abundance of NGC 2363 from our spectral synthesis. Although some deficiencies remain, allowance for charge exchange reactions in our calculations supports a SMC-like metallicity, that has previously been determined for NGC 2363 from nebular oxygen diagnostics.

Considering a variety of possible progenitor stars, V1 has definitely undergone a giant eruption, with a substantial increase in stellar luminosity, radius, and almost certainly mass-loss rate, such that its stellar radius increased at an average rate of ≈4 km s$^{-1}$ during Oct 1992–Feb 1995. The stellar properties of V1 are compared to other LBVs, including $\eta$ Car and HD 5980 during its brief eruption in September 1994, the latter newly analyzed here. The mass-loss rate of the HD 5980 eruptor compares closely with V1, but its bolometric luminosity was a factor ∼6 times larger.

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In Proceedings

# Empirical Lower Mass Limit for Black-hole Formation in a Massive Binary

**Lex Kaper[1] and Anatol Cherepashchuk[2]**

[1] Astronomical Institute, University of Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands

[2] Sternberg State Astronomical Institute, Moscow State University, 119899, Universitetskij pr., 13, Moscow, Russia

Observations of massive binaries provide important constraints on the evolutionary fate of massive stars. Although stellar evolution in a binary system is different from single-star evolution, practically the only way to derive information on the progenitor masses of neutron stars and black holes is by studying massive binaries and their descendants. Wolf-Rayet binaries show a rather continuous mass distribution, while there might be a gap between the neutron-star and black-hole masses. Wray 977 (GX301-2) hosts the most massive OB star with X-ray pulsar companion, and sets an empirical lower mass limit for black-hole formation in a massive binary. HD153919 is the OB supergiant with earliest spectral type, and potentially the most massive OB star in a high-mass X-ray binary, but the nature of the X-ray source (4U1700-37) is not clear. Although it might be a low-mass black hole, new observations suggest it is a neutron star.

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