# THE MASSIVE STAR NEWSLETTER

formely known as *the hot star newsletter*

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No. 90 2005 Octobre–December http://www.astroscu.unam.mx/massive_stars

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## Contents of this newsletter



## News

### Proceedings of the JENAM 2005 Workshop on "Massive Stars and High-Energy Emission in OB Associations" held in Liège (Belgium) on July 4 - 5, 2005

**G. Rauw[1], Y. Nazé[1], R. Blomme[2] and E. Gosset[1]**

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In the framework of the Joint European and National Astronomy Meeting (JENAM) held in Liège (Belgium) from July 4 – 7, 2005, one of the mini-symposia was focused on "Massive Stars and High-Energy Emission in OB Associations". This workshop addressed recent developments in several hot topics related to massive star research. Recent analyses of the fundamental parameters of these important objects, of their interactions within binary systems as well as with their surroundings (including the feedback of massive stars on the formation of other stars) were presented. Special emphasis was put on the studies of OB associations and young open clusters with current high-energy space observatories (XMM-Newton, Chandra and INTEGRAL) which provide not only information on the massive stars, but also on pre-main sequence stars. The papers presented during this workshop include

- *X-ray and gamma-ray emission from single and binary early-type stars* (I.R. Stevens)
- *X-ray survey of Wolf-Rayet stars in the Magellanic Clouds* (M.A. Guerrero & Y.-H. Chu)
- *Parameters of massive stars in the Milky Way and nearby galaxies* (A. Herrero & F. Najarro)
- *The peculiar Of?p stars HD 108 and HD 191612* (Y. Nazé et al.)
- *A new paradigm for the X-rays from O-stars* (A.M.T. Pollock & A.J.J. Raassen)
- *CN status of a sample of galactic OB supergiants* (M. Sarta Dekovic & D. Kotnik-Karuza)

- *Observations of non-thermal radio emission in O-type stars* (R. Blomme)
- *Radio emission from colliding-wind binaries: observations and models* (S.M. Dougherty et al.)
- *The XMM-Newton view of Plaskett's star and its surroundings* (N. Linder & G. Rauw)
- *Non-thermal X-ray and $\gamma$-ray emission from the colliding-wind binary WR 140* (J.M. Pittard & S.M. Dougherty)
- *Can single O-stars produce non-thermal radio emission? Or are they binaries?* (S. Van Loo)
- *Are WC9 Wolf-Rayet stars in colliding-wind binaries?* (P.M. Williams et al.)
- *X-ray analysis of the close binary system FO 15* (J.F. Albacete Colombo & G. Micela)
- *Evidence for phase-locked X-ray variations from the CWB Cyg OB2 #8a* (M. De Becker & G. Rauw)
- *Preliminary results of an observational campaign aiming at the study of the binary system LSS 3074* (E. Gosset et al.)
- *The colliding winds of WR 146: seeing the works* (E.P. O'Connor et al.)
- *On the multiplicity of the non-thermal radio emitters 9 Sgr and HD 168112* (G. Rauw et al.)
- *CPD−41° 7742: an unusual wind interaction* (H. Sana et al.)
- *Energetic processes and non-thermal emission of star forming complexes* (A.M. Bykov)
- *X-raying the super star clusters in the Galactic center* (L.M. Oskinova)
- *XMM-Newton observations of the Cyg OB2 association* (G. Rauw et al.)
- *The young open cluster NGC 6231: five years of investigations* (H. Sana et al.)
- *A spectroscopic investigation of the young open cluster IC 1805* (M. De Becker & G. Rauw)
- *A survey for $\gamma$-ray emission from OB associations with INTEGRAL: some preliminary results* (J.-C. Leyder & G. Rauw)

The proceedings of the workshop are now available on the web at the URL

http://www.astro.ulg.ac.be/RPub/Colloques/JENAM/proceedings/proceedings.html

We would like to take this opportunity to thank all the participants in the workshop.

## Accepted Papers

# Reduced Wolf-Rayet Line Luminosities at Low Metallicity

**Paul A Crowther, L J Hadfield**

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New NTT/EMMI spectrophotometry of single WN2-5 stars in the Magellanic Clouds are presented, from which HeII 4686 line luminosities have been derived, and compared with observations of other Magellanic Cloud WR stars. SMC WN3-4 stars possess line luminosities which are a factor of 4 times lower than LMC counterparts, incorporating several binary SMC WN3-4 stars. Similar results are found for WN5-6 stars, despite reduced statistics, incorporating observations of single LMC WN5-9 stars. CIV 5808 line luminosities of carbon sequence WR stars in the SMC and IC1613 (both WO subtypes) are a factor of 3 lower than LMC WC stars from Mt Stromlo/DBS spectrophotometry, although similar results are also obtained for the sole LMC WO star. We demonstrate how reduced line luminosities at low metallicity follow naturally if WR winds are Z-dependent, as recent results suggest. We apply mass loss-Z scalings to atmospheric non-LTE models of Milky Way and LMC WR stars to predict the wind signatures of WR stars in the metal-poor star forming WR galaxy IZw18. WN HeII 4686 line luminosities are 7-20 times lower than in Z-rich counterparts of identical bolometric luminosity, whilst WC CIV 5808 line luminosities are 3-6 times lower. Significant $He^+$ Lyman continuum fluxes are predicted for Z-poor early-type WR stars. Consequently, our results

suggest the need for larger population of WR stars in IZw18 than is presently assumed, particularly for WN stars, potentially posing a severe challenge to evolutionary models at very low Z. Finally, reduced wind strengths from WR stars at low Z impacts upon the immediate circumstellar environment of long duration GRB afterglows, particularly since the host galaxies of high-redshift GRBs tend to be Z-poor.

Reference: Accepted for A&A

Weblink: astro-ph/0512183

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## $\alpha$ Eri: Rotational Distortion, Stellar and Circumstellar Activity

**M.M.F. Vinicius[1] J. Zorec[2] N.V. Leister[1] R.S. Levenhagen[1]**

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We explore the geometrical distortion and the stellar and circumstellar activity of $\alpha$ Eri (HD 10144), the brightest Be star in the sky. We present a thorough discussion of the fundamental parameters of the object for an independent determination of its rotational distortion. We used stellar atmosphere models and evolutionary tracks calculated for fast rotating early-type stars. If the star is a rigid rotator, its angular velocity rate is $\Omega/\Omega_c \simeq 0.8$, so that its rotational distortion is smaller than the one inferred from recent interferometric measurements. We then discuss the stellar surface activity using high resolution and high S/N spectroscopic observations of He I and Mg II lines, which concern a period of H$\alpha$ line emission decline. The variations in the He I lines are interpreted as due to non-radial pulsations. Time series analysis of variations was performed with the CLEANEST algorithm, which enabled us to detect the following frequencies: 0.49, 0.76, 1.27 and 1.72 c/d and pulsation degrees $\ell \sim (3-4)$ for $\nu = 0.76$ c/d; $\ell \sim (2-3)$ for $\nu = 1.27$ c/d and $\ell \sim (3-4)$ for $\nu = 1.72$ c/d. The study of the absolute deviation of the He I $\lambda$6678 Å spectral line revealed mass ejection between 1997 and 1998. We conclude that the lowest frequency found, $\nu = 0.49$ c/d, is due to the circumstellar environment, which is present even at epochs of low emission in the wings of He I $\lambda$6678 Å and Mg II $\lambda$4481 Å line profiles, as well as during nearly normal aspects of the H$\alpha$ line. This suggests that there may be matter around the star affecting some spectral regions, even though the object displays a B-normal like phase. The long-term changes of the H$\alpha$ line emission in $\alpha$ Eri are studied. We pay much attention to the H$\alpha$ line emission at the epoch of interferometric observations. The H$\alpha$ line emission is modeled and interpreted in terms of varying structures of the circumstellar disc. We conclude that during the epoch of interferometric measurements there was enough circumstellar matter near the star to produce $\lambda 2.2\mu$m flux excess, which could account for the overestimated stellar equatorial angular diameter. From the study of the latest B[e] phase transition of $\alpha$ Eri we concluded that the H$\alpha$ line emission formation regions underwent changes so that: a) the low H$\alpha$ emission phases are characterized by extended emission zones in the circumstellar disc and a steep outward matter density decline; b) during the strong H$\alpha$ emission phases the emitting regions are less extended and have a constant density distribution. The long-term variations of the H$\alpha$ line in $\alpha$ Eri seem to have a 14-15 year cyclic B[e] phase transition. The disc formation time scales, interpreted as the periods during which the H$\alpha$ line emission increases from zero to its maximum, agree with the viscous decretion model. On the other hand, the time required for the disc dissipation ranges from 6 to 12 years which questions the viscous disc model.

Reference: Astronomy and Astrophysics

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## Collisionless Damping of Fast MHD Waves in Magneto-rotational Winds

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We propose collisionless damping of fast MHD waves as an important mechanism for the heating and acceleration of winds from rotating stars. Stellar rotation causes magnetic field lines anchored at the surface to form a spiral pattern and magneto-rotational winds can be driven. If the structure is a magnetically dominated, fast MHD waves generated at the surface can propagate almost radially outward and cross the field lines. The propagating waves undergo collisionless damping owing to interactions with particles surfing on magnetic mirrors that are formed by the waves themselves. The energy damping rate is especially effective where the angle between the wave propagation and the field lines becomes moderately large ($\sim 20$ to $80^{\circ}$). The angle tends naturally to increase into this range because the field in magneto-rotational winds develops an increasingly large azimuthal component. The dissipation of the wave energy produces heating and acceleration of the outflow. We show using specified wind structures that this damping process can be important in both solar-type stars and massive stars that have moderately large rotation rates. This mechanism can play a role in coronae of young solar-type stars which are rapidly rotating and show X-ray luminosities much larger than the sun. The mechanism could also be important for producing the extended X-ray emitting regions inferred to exist in massive stars of spectral type middle B and later.

Reference: ApJ, in press

Weblink: http://arxiv.org/abs/astro-ph/0505013

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## On the He II Emission In Eta Carinae and the Origin of Its Spectroscopic Events

**J. C. Martin, K. Davidson, R. M. Humphreys, D. J. Hillier, K. Ishibashi**

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We describe and analyze Hubble Space Telescope (HST) observations of transient emission near 4680 Å in Eta Car, reported earlier by Steiner & Damineli (2004). If, as seems probable, this is He II $\lambda$4687, then it is a unique clue to Eta Car's 5.5-year cycle. According to our analysis, several aspects of this feature support a mass-ejection model of the observed spectroscopic events, and not an eclipse model. The He II emission appeared in early 2003, grew to a brief maximum during the 2003.5 spectroscopic event, and then abruptly disappeared. It did not appear in any other HST spectra before or after the event. The peak brightness was larger than previously reported, and is difficult to explain even

if one allows for an uncertainty factor of order 3. The stellar wind must provide a temporary larger-than-normal energy supply, and we describe a special form of radiative amplification that may also be needed. These characteristics are consistent with a class of mass-ejection or wind-disturbance scenarios, which have implications for the physical structure and stability of Eta Car.

Reference: Astrophysical Journal

Weblink: http://arxiv.org/abs/astro-ph/0504151

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## Nonlocal Radiative Coupling in Non Monotonic Stellar Winds

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There is strong observational evidence of shocks and clumping in radiation-driven stellar winds from hot, luminous stars. The resulting non monotonic velocity law allows for radiative coupling between distant locations, which is so far not accounted for in hydrodynamic wind simulations. In the present paper, we determine the Sobolev source function and radiative line force in the presence of radiative coupling in spherically symmetric flows, extending the geometry-free formalism of Rybicki and Hummer (1978) to the case of three-point coupling, which can result from, e.g., corotating interaction regions, wind shocks, or mass overloading. For a simple model of an overloaded wind, we find that, surprisingly, the flow decelerates at all radii above a certain height when nonlocal radiative coupling is accounted for. We discuss whether radiation-driven winds might in general not be able to re-accelerate after a non monotonicity has occurred in the velocity law.

Reference: A&A, in press

Weblink: http://de.arxiv.org/pdf/astro-ph/0510806

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## The Early Star Generations: the Dominant Effect of Rotation on the CNO Yields

**Georges Meynet, Sylvia Ekstrom, Andre Maeder**

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We examine the role of rotation on the evolution and chemical yields of very metal–poor stars. The models include the same physics, which was applied successfully at the solar $Z$ and for the SMC, in particular, shear diffusion, meridional circulation, horizontal turbulence, and rotationally enhanced mass loss. Models of very low $Z$ experience a much stronger internal mixing in all phases than at solar $Z$. Also, rotating models at very low $Z$, contrary to the usual considerations, show a large mass loss, which mainly results from the efficient mixing of the products of the $3\alpha$ reaction into the H–burning shell. This mixing allows convective dredge–up to enrich the stellar surface in heavy elements during the red supergiant phase, which in turn favours a large loss of mass by stellar winds, especially as rotation also increases the duration of this phase. On the whole, the low $Z$ stars may lose about half of their mass. Massive stars initially rotating at half of their critical velocity are likely to avoid the pair–instability supernova. The chemical composition of the rotationally enhanced winds of very low $Z$ stars show large CNO enhancements by factors of $10^3$ to $10^7$, together with large excesses of $^{13}$C

and $^{17}O$ and moderate amounts of Na and Al. The excesses of primary N are particularly striking. When these ejecta from the rotationally enhanced winds are diluted with the supernova ejecta from the corresponding CO cores, we find [C/Fe], [N/Fe],[O/Fe abundance ratios that are very similar to those observed in the C–rich, extremely metal–poor stars (CEMP). We show that rotating AGB stars and rotating massive stars have about the same effects on the CNO enhancements. Abundances of s-process elements and the 12C/$^{13}$C ratio could help us to distinguish between contributions from AGB and massive stars.

Reference: Astronomy and Astrophysics

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## The Massive Eclipsing LMC Wolf-Rayet Binary BAT99-129 1. Orbital Parameters, Hydrogen Content and Spectroscopic Characteristics

**C. Foellmi (1), A.F.J. Moffat (2), S.V. Marchenko (3)**

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BAT99-129 in the LMC is one among a handful of extra-galactic eclipsing Wolf-Rayet binaries known. We present blue, medium-resolution, phase-dependent NTT-EMMI spectra of this system that allow us to separate the spectra of the two components of the binary and to obtain a reliable orbital solution for both stars. We assign an O5V spectral type to the companion, and WN3(h)a to the Wolf-Rayet component. We discuss the spectroscopic characteristics of the system: luminosity ratio, radii, rotation velocities. We find a possible oversynchronous rotation velocity for the O star. Surprisingly, the extracted Wolf-Rayet spectrum clearly shows the presence of blueshifted absorption lines, similar to what has been found in all single hot WN stars in the SMC and some in the LMC. We also discuss the presence of such intrinsic lines in the context of hydrogen in SMC and LMC Wolf-Rayet stars, WR+O binary evolution and GRB progenitors. Altogether, BAT99 129 is the extragalactic counterpart of the well-known Galactic WR binary V444 Cygni.

Reference: Accepted by A&A

Weblink: http://arxiv.org/abs/astro-ph/0510528

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## Multi-Periodic Photospheric Pulsations and Connected Wind Structures in HD64760

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We report on the results of an extended optical spectroscopic monitoring campaign on the early-type B supergiant HD64760 (B0.5Ib) designed to probe the deep-seated origin of spatial wind structure in massive stars. This new study is based on high-resolution echelle spectra obtained with the FEROS instrument at ESO La Silla. 279 spectra were collected over 10 nights between February 14 and 24, 2003. From the period analysis of the line-profile variability of the photospheric lines we identify three closely spaced periods around 4.810hrs and a splitting of +/-3%. The velocity - phase diagrams of the line-profile variations for the distinct periods reveal characteristic prograde non-radial pulsation patterns of high order corresponding to pulsation modes with l and m in the range 6-10. A detailed modeling of the multi-periodic non-radial pulsations with the BRUCE and KYLIE pulsation-model codes favors either three modes with l=-m and l=8,6,8 or m=-6 and l=8,6,10 with the second case maintaining the closely spaced periods in the co-rotating frame. The pulsation models predict photometric variations of 0.012-0.020mag consistent with the non-detection of any of the spectroscopic periods by photometry. The three pulsation modes have periods clearly shorter than the characteristic pulsation time scale and show small horizontal velocity fields and hence are identified as p-modes. The beating of the three pulsation modes leads to a retrograde beat pattern with two regions of constructive interference diametrically opposite on the stellar surface and a beat period of 162.8hrs (6.8days). This beat pattern is directly observed in the spectroscopic time series of the photospheric lines. The wind-sensitive lines display features of enhanced emission, which appear to follow the maxima of the photospheric beat pattern. The pulsation models predict for the two regions normalized flux amplitudes of A=+0.33,-0.28, sufficiently large to raise spiral co-rotating interaction regions. We further investigate the observed Halpha wind-profile variations with a simple rotating wind model with wind-density modulations to simulate the effect of possible streak lines originating from the localized surface spots created by the NRP beat pattern. It is found that such a simple scenario can explain the time scales and some but not all characteristics of the observed Halpha line-profile variations.

Reference: Accepted for A&A on October 17, 2005.

Weblink: http://arxiv.org/abs/astro-ph/0510511

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## The Discordance of Mass-Loss Estimates for Galactic O-Type Stars

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We have determined accurate values of the product of the mass-loss rate and the ion fraction of $P^{4+}$, Mdot q($P^{4+}$), for a sample of 40 Galactic O-type stars by fitting stellar-wind profiles to observations of the P V resonance doublet obtained with FUSE, ORFEUS/BEFS, and Copernicus. When $P^{4+}$ is the dominant ion in the wind, Mdot q($P^{4+}$) approximates the mass-loss rate to within a factor of 2. Theory predicts that $P^{4+}$ is the dominant ion in the winds of O7-O9.7 stars, though an empirical estimator suggests that the range from O4-O7 may be more appropriate. However, we find that the mass-loss rates obtained from P V wind profiles are systematically smaller than those obtained from fits to Halpha emission profiles or radio free-free emission by median factors of about 130 (if $P^{4+}$ is dominant between O7 and O9.7) or about 20 (if $P^{4+}$ is dominant between O4 and O7). These discordant measurements can be reconciled if the winds of O stars in the relevant temperature range are strongly clumped on small spatial scales. We use a simplified two-component model to investigate the volume filling factors of the denser regions. This clumping implies that mass-loss rates determined from "density squared" diagnostics have been systematically over-estimated by factors of 10 or more, at least for a subset of O stars. Reductions in the mass-loss rates of this size have important implications for the evolution of massive stars and quantitative estimates of the feedback that hot-star winds provide to their interstellar environments.

Reference: ApJ, in press

Weblink: http://arxiv.org/abs/astro-ph/0510252

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## Radio Emission Models of Colliding-Wind Binary Systems - Inclusion of IC Cooling

**J.M. Pittard[1], S.M. Dougherty[2], R.F. Coker[3], E. O'Connor[4], N.J. Bolingbroke[5]**

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Radio emission models of colliding wind binaries (CWBs) have been discussed by Dougherty et al. (2003). We extend these models by considering the temporal and spatial evolution of the energy distribution of relativistic electrons as they advect downstream from their shock acceleration site. The energy spectrum evolves significantly due to the strength of inverse-Compton (IC) cooling in these systems, and a full numerical evaluation of the synchrotron emission and absorption coefficients is made. We have demonstrated that the geometry of the WCR and the streamlines of the flow within it lead to a spatially dependent break frequency in the synchrotron emission. We therefore do not observe a single, sharp break in the synchrotron spectrum integrated over the WCR, but rather a steepening of the synchrotron spectrum towards higher frequencies. We also observe that emission from the wind-collision region (WCR) may appear brightest near the shocks, since the impact of IC cooling on the non-thermal electron distribution is greatest near the contact discontinuity (CD), and demonstrate that the impact of IC cooling on the observed radio emission increases significantly with decreasing binary separation. We study how the synchrotron emission changes in response to departures from equipartition, and investigate how the thermal flux from the WCR varies with binary separation. Since the emission from the WCR is optically thin, we see a substantial fraction of this emission at certain viewing angles, and we show that the thermal emission from a CWB can mimic a thermal plus non-thermal composite spectrum if the thermal emission from the WCR becomes comparable to that from the unshocked winds. We demonstrate that the observed synchrotron emission depends upon the viewing angle and the wind-momentum ratio, and find that the observed synchrotron emission decreases as the viewing angle moves through the WCR from the WR shock to the O shock. We obtain a number of insights relevant to models of closer systems such as WR140. Finally, we apply our new models to the very wide system WR147. The acceleration of non-thermal electrons appears to be very efficient in our models of WR147, and we suggest that the shock structure may be modified by feedback from the accelerated particles.

Reference: Accepted for A&A

Weblink: http://arxiv.org/abs/astro-ph/0510283

Comments: 21 pages, 16 figures

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# In Proceedings

## New Photometric Observations of sigma Ori E

**Mary Oksala & Rich Townsend**

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We present new UBVRI observations of the magnetic Bp star sigma Ori E. The basic features of the star's lightcurve have not changed since the previous monitoring by Hesser et al. (1977), indicating that the star's magnetosphere has remained stable over the past three decades. Interestingly, we find a rotation period that is slightly longer than in the Hesser et al. (1977) analysis, suggesting possible spindown of the star.

Reference: To appear in "Active OB Stars: Laboratories for Stellar & Circumstellar Physics", ASP Conf. Ser. 2005, S. Stefl, S. P. Owocki & A. Okazaki, eds.

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## sigma Ori E: The Archetypal Rigidly Rotating Magnetosphere

**Rich Townsend**

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I review the basic concepts of the Rigidly Rotating Magnetosphere model for the circumstellar plasma distribution around the helium-strong star sigma Ori E. I demonstrate that the model can furnish a good fit to the photometric, spectroscopic and magneticv ariability exhibited by this star, and argue that the variability of other helium-strong stars may be amenable to a similar interpretation.

Reference: To appear in "Active OB Stars: Laboratories for Stellar & Circumstellar Physics", ASP Conf. Ser. 2005, S. Stefl, S. P. Owocki & A. Okazaki, eds.

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## Kappa-Mechanism Excitation of Retrograde Mixed Modes in B-Type Stars

**Rich Townsend**

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The stability of retrograde mixed modes in rotating B-type stars is investigated. It is found that these modes are susceptible to kappa-mechanism excitation, due to the iron opacity bump at log T   5.3. The findings are discussed in the context of the pulsation of SPB and Be stars.

Reference: To appear in "Active OB Stars: Laboratories for Stellar & Circumstellar Physics", ASP Conf. Ser. 2005, S. Stefl, S. P. Owocki & A. Okazaki, eds.

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## Outflowing Disk Winds in B[e] Supergiants

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The effects of rapid rotation and bi–stability upon the density contrast between the equatorial and polar directions of a B[e] supergiant are investigated. Based on a new slow solution for different high rotational radiation–driven winds and the fact that bi–stability allows a change in the line–force parameters $(\alpha, k, \delta)$, the equatorial densities are about $10^2$ - $10^3$ times higher than the polar ones. These values are in qualitative agreement with the observations. This calculation also permits to obtain the aperture angle of the disk.

Reference: To appear in "Stars with the B[e] Phenomenon", ASP Conf. Ser. 2005, Michaela Kraus & Anatoly S. Miroshnichenko, eds.

Weblink: astro-ph/0510695

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## X-ray Observations of Binary and Single Wolf-Rayet Stars with XMM-Newton and Chandra

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We present an overview ofrecent X-ray observations of Wolf-Rayet (WR) stars with XMM-Newton and Chandra. A new XMM spectrum of the nearby WN8 + OB binary WR 147 shows hard heavily absorbed emission, including the Fe K-alpha line complex, characteristic of colliding wind shock sources. In contrast, sensitive observations of four of the closest known single WC (carbon-rich) WR stars have yielded only non-detections. These results tentatively suggest that single WC stars are X-ray quiet. The presence of a companion may thus be an essential factor in elevating the X-ray emission of WC + OB stars to detectable levels.

Reference: To appear in: Close Binaries in the 21st Century - New Opportunities and Challenges (eds. A. Gimenez, E. Guinan, P. Niarchos, S. Rucinski), Astrophys. and Space Sci. special issue, 2006.

Weblink: astro-ph/0511137 (after 7 Nov. 2005)

Comments: 4 pages, 2 figures, 1 table

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## Massive Star Feedback - From the First Stars to the Present

**Jorick S. Vink**

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The amount of mass loss is of fundamental importance to the lives and deaths of very massive stars, their input of chemical elements and momentum into the interstellar and intergalactic media, as well as their emitted ionizing radiation. I review mass-loss predictions for hot massive stars as a function of metal content for groups of OB stars, Luminous Blue Variables, and Wolf-Rayet stars. Although it is found that the predicted mass-loss rates drop steeply with decreasing metal content (Mdot   $Z^{0.7-0.85}$), I highlight two pieces of physics that are often overlooked in cosmologocal studies: (i) mass-loss predictions for massive stars approaching the Eddington limit, and for (ii) stars that have enriched their own atmospheres with primary elements such as carbon. Both of these effects may significantly boost the mass-loss rates of the first stars – relevant for the reionization of the Universe, and a potential pre-enrichment of the intergalactic medium – prior to the first supernova explosions.

Reference: Vink, 2006, in: "Stellar Evolution at Low Metallicity: Mass-Loss, Explosions, Cosmology", eds: H. Lamers, N. Langer, T. Nugis), ASP Conf Series

Comments: Invited Review in Tartu workshop, Aug 2005.

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## O Star X-ray Line Profiles Explained by Radiation Transfer in Inhomogeneous Stellar Wind

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It is commonly adopted that X-rays from O stars are produced deep inside the stellar wind, and transported outwards through the bulk of the expanding matter which attenuates the radiation and affects the shape of emission line profiles. The ability of Chandra and XMM-Newton to resolve these lines spectroscopically provided a stringent test for the theory of X-ray production. It turned out that none of the existing models was able to reproduce the observations consistently. The major caveat of these models was the underlying assumption of a smooth stellar wind. Motivated by the various observational evidence that the stellar winds are in fact structured, we present a 2-D model of a stochastic, inhomogeneous wind. The X-ray radiative transfer is derived for such media. It is shown that profiles from a clumped wind differ drastically from those predicted by conventional homogeneous models. We review the up-to-date observations of X-ray line profiles from stellar winds and present line fits obtained from the inhomogeneous wind model. The necessity to account for inhomogeneities in calculating the X-ray transport in massive star winds, including for HMXB is highlighted.

Reference: "The X-ray Universe 2005", ESA, El Escorial, Madrid, Spain, 26 - 30 September 2005

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## A Simple Nozzle Analysis of Slow-Acceleration Solutions in 1-D Models of Rotating Line-Driven Stellar Winds

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For a star rotating at more than about 75% of the critical rate, one-dimensional (1-D) models for the equatorial regions of a line-driven stellar wind show a sudden shift to a slow-acceleration solution, implying a slower, denser equatorial outflow that might be associated with the dense disks inferred for sgB[e] stars. To clarify the nature of this solution shift, I present here a simple analysis of the 1-D flow equations based on a nozzle analogy for the terms that constrain the local mass flux. At low rotation rates the nozzle minimum (or "throat") occurs near the stellar surface, allowing a near-surface transition to a steeply accelerating, supercritical flow solution. But for rotations above about 75% of the critical rate, this *local*, inner nozzle minimum exceeds the *global* minimum approached asymptotically at large radii, implying that near-surface supercritical solutions would now have an overloaded mass loss rate. Maintaining a monotonically positive acceleration is then only possible if the flow is kept subcritical out to large radii, where the nozzle function approaches its *absolute* minimum. For fixed line-driving parameters, the associated enhancements in equatorial density are typically a factor 5-30 relative to the polar (or nonrotating) wind. However, when gravity darkening and 2-D flow effects are accounted for, it still seems unlikely that rotationally modified equatorial wind outflows could account for the very large densities inferred for the disks around supergiant B[e] stars.

Reference: To appear in "Stars with the B[e] Phenomenon", ASP Conf. Ser. 2005, Michaela Kraus & Anatoly S. Miroshnichenko, eds.

Weblink: http://www.bartol.udel.edu/∼owocki/preprints/vlieland-rotnoz.pdf

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# Jobs

## Graduate Student Research Assistantships at STScI in Massive Star LTSA Project, Space Telescope Science Institute

**Don Figer** (STScI)

The Space Telescope Science Institute (STScI) invites applications from advanced graduate students to pursue PhD thesis research with Dr. Don Figer. A stipend of approximately $22,000 per year (depending on qualifications) is provided by STScI. Some support for tuition is also available if required. This position is for the 2005 academic year, with a likely opportunity for an extension up to three years. IDL experience is required.

As part of a 5-year funded NASA Long Term Space Astrophysics project, we seek an energetic graduate student to identify and characterize the most massive stars in the Galaxy. The following is the abstract for this project.

Until the Spitzer Space Telescope, there was no wide area survey that could identify massive stars at all distances in the Galaxy. Indeed, the sample of known O-stars is woefully incomplete, as it has largely been generated using optical observations that suffer from the absorption produced by dust in the disk. We are now at the cusp of a revolution in massive star research that Spitzer will trigger, and we propose to capitalize on that opportunity by performing the first survey of massive stars covering the majority of the Galactic volume. We will find and measure the physical properties of the most massive stars in the Galaxy using HST, Spitzer, Chandra, SOFIA, and ground-based observatories, using a survey technique that probes the majority of the Galaxy. This program addresses fundamental questions whose answers are basic requirements for studying many of the most important topics in Astrophysics: the formation and evolution of the most massive stars, the effects of massive stars on lower mass protostellar/protoplanetary systems, gamma-ray burst (GRB) progenitors, nature of the first stars in the Universe, chemical enrichment of the interstellar medium, Galactic gas dynamics, star formation in starbursts and merging galaxies (particularly in the early Universe). The results of our program will influence the science programs for future NASA projects, i.e. JWST, SOFIA, SIM, TPF-C, and TPC-I.

Applicants must have a Bachelor's degree (or equivalent), must have completed all required graduate course work, and must have been admitted to the PhD program at their home universities. Enquiries about this program may be directed to Dr. Don Figer (410-338-4377, figer@stsci.edu).

Applications should include three copies each of the following material: a signed cover letter, a curriculum vitae, a statement of research interests, and a letter from the official advisor or departmental chairperson giving permission to work at STScI. These should be sent by regular mail to Human Resources, Space Telescope Science Institute, 3700 San Martin Drive, Baltimore MD, 21218. Applicants should also arrange for their academic transcripts and three letters of recommendation to be sent to the same address.

Applications and letters of reference received before December 1, 2005 will receive full consideration. The Space Telescope Science Institute is an affirmative action, equal opportunity employer. Women and members of minority groups are strongly encouraged to apply.

Attention: Christine Rueter - Reg 479

Weblink: http://members.aas.org/JobReg/JobdetailPage.cfm?JID=22139

Email: figer@stsci.edu

## Post Doc at STScI in Massive Star LTSA Project
## Space Telescope Science Institute

**Don Figer** (STScI)

The Space Telescope Science Institute (STScI) invites applications from postdoctoral researchers to pursue research with Dr. Don Figer. This position is for 1 year with possible extension to 3 years.

As part of a 5-year funded NASA Long Term Space Astrophysics project, we seek an energetic postdoctoral scholar to identify and characterize the most massive stars in the Galaxy. The following is the abstract for this project.

Until the Spitzer Space Telescope, there was no wide area survey that could identify massive stars at all distances in the Galaxy. Indeed, the sample of known O-stars is woefully incomplete, as it has largely been generated using optical observations that suffer from the absorption produced by dust in the disk. We are now at the cusp of a revolution in massive star research that Spitzer will trigger, and we propose to capitalize on that opportunity by performing the first survey of massive stars covering the majority of the Galactic volume. We will find and measure the physical properties of the most massive stars in the Galaxy using HST, Spitzer, Chandra, SOFIA, and ground-based observatories, using a survey technique that probes the majority of the Galaxy. This program addresses fundamental questions whose answers are basic requirements for studying many of the most important topics in Astrophysics: the formation and evolution of the most massive stars, the effects of massive stars on lower mass protostellar/protoplanetary systems, gamma-ray burst (GRB) progenitors, nature of the first stars in the Universe, chemical enrichment of the interstellar medium, Galactic gas dynamics, star formation in starbursts and merging galaxies (particularly in the early Universe). The results of our program will influence the science programs for future NASA projects, i.e. JWST, SOFIA, SIM, TPF-C, and TPC-I.

Applicants must have a PhD. Enquiries about this program may be directed to Dr. Don Figer (410-338-4377, figer@stsci.edu).

Applications should include three copies each of the following material: a signed cover letter, a curriculum vitae, and a statement of research interests. Applicants should also arrange for their academic transcripts and three letters of recommendation to be sent to the same address.

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