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# THE MASSIVE STAR NEWSLETTER

formely known as *the hot star newsletter*

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## Contents of this newsletter



## Accepted Papers

### Modeling Ultraviolet Wind Line Variability in Massive Hot Stars

**A. Lobel & R. Blomme**

Royal Observatory of Belgium

We model the detailed time-evolution of Discrete Absorption Components (DACs) observed in P Cygni profiles of the Si IV $\lambda$1400 resonance doublet lines of the fast-rotating supergiant HD 64760 (B0.5 Ib). We adopt the common assumption that the DACs are caused by Co-rotating Interaction Regions (CIRs) in the stellar wind. We perform 3D radiative transfer calculations with hydrodynamic models of the stellar wind that incorporate these large-scale density- and velocity-structures. We develop the 3D transfer code WIND3D to investigate the physical properties of CIRs with detailed fits to the DAC shape and morphology.

The CIRs are caused by irregularities on the stellar surface that change the radiative force in the stellar wind. In our hydrodynamic model we approximate these irregularities by circular symmetric spots on the stellar surface. We use the ZEUS3D code to model the stellar wind and the CIRs, limited to the equatorial plane. We compute a large grid of hydrodynamic models and dynamic spectra for the different spot parameters (brightness, opening angle and velocity). We demonstrate important

effects of these input parameters on the structured wind models that determine the detailed DAC evolution.

We constrain the properties of large-scale wind structures with detailed fits to DACs observed in HD 64760. A model with two spots of unequal brightness and size on opposite sides of the equator, with opening angles of 20° ±5° and 30° ±5° diameter, and that are 20±5% and 8±5% brighter than the stellar surface, respectively, provides the best fit to the observed DACs. The recurrence time of the DACs compared to the estimated rotational period corresponds to spot velocities that are 5 times slower than the rotational velocity.

The mass-loss rate of the structured wind model for HD 64760 does not exceed the rate of the spherically symmetric smooth wind model by more than 1%. The fact that DACs are observed in a large number of hot stars constrains the clumping that can be present in their winds, as substantial amounts of clumping would tend to destroy the CIRs.

**Reference: ApJ, 667 Main Journal (in press).**
*Comments:* 23 pages, 16 color figures, & 1 animation. More information about research of the paper at http://alobel.freeshell.org/hotstars.html

*On the web at:* `http://arxiv.org/abs/0712.3804`

*Preprints from:* `alobel@sdf.lonestar.org`

## Chandra monitoring of the very massive binary WR20a and the young massive cluster Westerlund 2

**Y. Naze, G. Rauw, and J. Manfroid**

Institute of Astrophysics & Geophysics, University of Liege, Belgium

Context: Westerlund 2 is a young, massive, obscured stellar cluster of our Galaxy. It harbors the most massive star with well determined parameters, WR20a ($82{+}83 M_\odot$), a dozen very early O-type stars (O3-7), and a wealth of PMS stars. Although of importance, this cluster is still not well known.

Aims: The high-energy properties of this cluster, especially those of its early-type stars are examined in details. The variability of the X-ray sources is investigated.

Methods: A monitoring of the field was performed using three Chandra observations. This dataset probes daily as well as monthly to yearly timescales and provides the deepest X-ray view of the cluster to date.

Results: The two Wolf-Rayet stars WR20a (WN6ha+WN6ha) and WR20b (WN6ha) were analyzed in detail. They are both very luminous and display very hard spectra, but WR20b does not seem to vary. On the contrary, WR20a, a known eclipsing, colliding-wind binary, brightens in the X-ray domain during the eclipses, i.e. when the collision is seen face-on. This can be explained by the properties of the wind-wind collision zone, whose high density leads to a large absorbing column ($2 \times 10^{24}$ cm$^{-2}$).

All twelve O-type stars previously classified spectroscopically, two eclipsing binaries previously identified and nine newly identified O-type star candidates are detected in the high energy domain; ten of them could be analyzed spectroscopically. Four are overluminous, but the others present typical $L_X/L_{BOL}$ ratios, suggesting that several O-type objects are actually binaries. Variability at the $\sim 2\sigma$ level was detected for a majority of the sources, of unknown origin for the putatively single objects.

Faint, soft, diffuse emission pervades the entire field-of-view but no clear structure can be identified, even at the position of a blister proposed to be at the origin of the TeV source HESS J1023-575. Finally, the X-ray properties of PMS objects were also investigated, in particular the brightest flaring ones. They provided an additional argument in favor of a large distance (∼8kpc) for the cluster.

**Reference: Astronomy & Astrophysics**

*Comments:* Images of the cluster will soon be added on the Chandra public webpage http://chandra.harvard.edu/

*On the web at:* `http://arxiv.org/abs/0801.0647`

*Preprints from:* `naze@astro.ulg.ac.be`

## Spectropolarimetry of the Massive post-Red Supergiants IRC +10420 and HD 179821

**M. Patel[1,2], R.D. Oudmaijer[1], J.S. Vink[3,4], J.E. Bjorkman[5], B. Davies[1,6], M.A.T. Groenewegen[7], A.S. Miroshnichenko[8], J.C. Mottram[1]**

1 - University of Leeds; 2 - Imperial College London; 3 - Armagh Observatory; 4 - Keele University; 5 - Ritter Observatory; 6 - Rochester Institute of Technology; 7 - Instituut voor Sterrenkunde; 8 - University of North Carolina at Greensboro

We present medium resolution spectropolarimetry and long term photo-polarimetry of two massive post-red supergiants, IRC +10420 and HD 179821. The data provide new information on their circumstellar material as well as their evolution. In IRC +10420, the polarization of the H alpha line is different to that of the continuum, which indicates that the electron-scattering region is not spherically symmetric. The observed long term changes in the polarimetry can be associated with an axi-symmetric structure, along the short axis of the extended reflection nebulosity. Long term photometry reveals that the star increased in temperature until the mid-nineties, after which the photospheric flux in the optical levelled off. As the photometric changes are mostly probed in the red, they do not trace high stellar temperatures sensitively. And so, it is not obvious whether the star has halted its increase in temperature or not. For HD 179821 we find no polarization effects across any absorption or emission lines, but observe very large polarization changes of order 5% over 15 years. During the same period, the optical photometry displayed modest variability at the 0.2 magnitude level. This is unexpected, because large polarization changes are generally accompanied by strong photometric changes. Several explanations for this puzzling fact are discussed. Most of which, involving asymmetries in the circumstellar material, seem to fail as there is no evidence for the presence of hot, dusty material close to the star. A caveat is that the sparsely available near-infrared photometry could have missed periods of strong polarization activity. Alternatively, the variations can be explained by the presence of a non-radially pulsating photosphere. Changes in the photometry hint at an increase in temperature corresponding to a change through two spectral subclasses over the past ten years.

**Reference: MNRAS, accepted**

*Preprints from:* `m.patel06@imperial.ac.uk`

## Biases on initial mass function determinations. II. Real multiple systems and chance superpositions

**J. Maíz Apellániz**

IAA-CSIC

When calculating stellar initial mass functions (IMFs) for young clusters, one has to take into account that most massive stars are born in multiple systems and that most IMFs are derived from data that cannot resolve such systems. It is also common to measure IMFs for clusters that are located at distances where multiple chance superpositions between members are expected to happen. In this article I model the consequences of both of those phenomena, real multiple systems and chance superpositions, on the observed color-magnitude diagrams and the IMFs derived from them. Using numerical experiments I quantify their influence on the IMF slope for massive stars and on the generation of systems with apparent masses above the stellar upper mass limit. The results in this paper can be used to correct for the biases induced by real and chance-alignment multiple systems when the effects are small and to identify when they are so large that most information about the IMF in the observed color-magnitude diagram is lost. Real multiple systems affect the observed or apparent massive-star MF slope little but can create a significant population of apparently ultramassive stars. Chance superpositions produce only small biases when the number of superimposed stars is low but, once a certain number threshold is reached, they can affect both the observed slope and the apparent stellar upper mass limit. In the second part of the paper, I apply the experiments to two well known massive young clusters in the Local Group, NGC 3603 and R136. In both cases I show that the observed population of stars with masses above 120 solar masses can be explained by the effects of unresolved objects, mostly real multiple systems for NGC 3603 and a combination of real and chance-alignment multiple systems for R136. Therefore, the case for the reality of a stellar upper mass limit at solar or near-solar metallicities is strengthened, with a possible value even lower than 150 solar masses. An IMF slope somewhat flatter than Salpeter or Kroupa with gamma between -1.6 and -2.0 is derived for the central region of NGC 3603, with a significant contribution to the uncertainty arising from the imprecise knowledge of the distance to the cluster. The IMF at the very center of R136 cannot be measured with the currently available data but the situation could change with new Hubble Space Telescope (HST) observations.

**Reference: Accepted for publication in ApJ**

*Comments:* arXiv version has low-quality figures due to their size limitations.
See http://dae45.iaa.csic.es:8080/∼jmaiz/research/papers/IMF_II.pdf for a full-quality version.

*On the web at:* `http://arxiv.org/abs/0801.3772`

*Preprints from:* `jmaiz@iaa.es`

## The massive binary HD 152218 revisited: a new colliding wind system in NGC 6231

**H. Sana, Y. Nazé, B. O'Donnell, G. Rauw, E.Gosset**

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We present the results of an optical and X-ray monitoring campaign on the short-period massive SB2 binary HD 152218. Combining our HiRes spectroscopic data with previous observations, we unveil

the contradictions between the published orbital solutions. In particular, we solve the aliasing on the period and derive a value close to 5.604 d. Our eccentricity e = 0.259 +/- 0.006 is slightly lower than previously admitted. We show that HD 152218 is probably undergoing a relatively rapid apsidal motion of about 3deg/yr and we confirm the O9IV + O9.7V classification. We derive minimal masses of 15.82 +/- 0.26 $M_\odot$ and 12.00 +/- 0.19 $M_\odot$ and constrain the radius of the components to R1 = 10.3 +/- 1.3 $R_\odot$ and R2 = 7.8 +/- 1.7 $R_\odot$. We also report the results of an XMM-Newton monitoring of the HD 152218 X-ray emission throughout its orbital motion. The averaged X-ray spectrum is relatively soft and it is well reproduced by a 2-T optically thin thermal plasma model with component temperatures about 0.3 and 0.7 keV. The system presents an increase of its X-ray flux by about 30% near apastron compared to periastron, which is interpreted as the signature of an ongoing wind-wind interaction process occurring within the wind acceleration region.

**Reference: New Astronomy, 13, 202**

*On the web at:* http://arxiv.org/abs/0801.3753

*Preprints from:* hsana@eso.org

## LMC origin of the hyper-velocity star HE0437-5439. Beyond the supermassive black hole paradigm

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3 - Centre for Astrophysics Research, University of Hertfordshire, College Lane, Hatfield AL10 9AB, UK

Context: Hyper-velocity stars move so fast that only a supermassive black hole (SMBH) seems to be capable to accelerate them. Hence the Galactic centre (GC) is their only suggested place of origin. Edelmann et al. (2005) found the early B-type star HE0437-5439 to be too short-lived to have reached its current position in the Galactic halo if ejected from the GC, except if being a blue straggler star. Its proximity to the Large Magellanic Cloud (LMC) suggested an origin from this galaxy.

Aims: The chemical signatures of stars at the GC are significantly different from those in the LMC. Hence, an accurate measurement of the abundance pattern of HE0437-5439 will yield a new tight constraint on the place of birth of this hyper-velocity star.

Methods: High-resolution spectra obtained with UVES on the VLT are analysed using state-of-the-art non-LTE modelling techniques.

Results: We measured abundances of individual elements to very high accuracy in HE0437-5439 as well as in two reference stars, from the LMC and the solar neighbourhood, respectively. The abundance pattern is not consistent at all with that observed in stars near the GC, ruling out an origin from the GC. However, there is a high degree of consistency with the LMC abundance pattern. Our abundance results cannot rule out an origin in the outskirts of the Galactic disk. However, we find the life time of HE0437-5439 to be more than three times shorter than the time of flight to the edge of the disk, rendering a Galactic origin unlikely.

Conclusions: Only one SMBH is known to be present in Galaxy and none in the LMC. Hence the exclusion of an GC origin challenges the SMBH paradigm. We conclude that there must be other

mechanism(s) to accelerate stars to hyper-velocity speed than the SMBH. We draw attention to dynamical ejection from dense massive clusters, that has recently been proposed by Gvaramadze et al. (2008).

**Reference: Astronomy & Astrophysics**

*On the web at:* `http://www.sternwarte.uni-erlangen.de/~ai32/hvs.pdf`

*Preprints from:* `przybilla@sternwarte.uni-erlangen.de`

## Nitrogen enrichment, boron depletion and magnetic fields in slowly-rotating B-type dwarfs

**T. Morel (1,2), S. Hubrig (3) and M. Briquet (1)**

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Evolutionary models for massive stars, accounting for rotational mixing effects, do not predict any core-processed material at the surface of B dwarfs with low rotational velocities. Contrary to theoretical expectations, we present a detailed and fully-homogeneous, NLTE abundance analysis of 20 early B-type dwarfs and (sub)giants that reveals the existence of a population of nitrogen-rich and boron-depleted, yet intrinsically slowly-rotating objects. The low-rotation rate of several of these stars is firmly established, either from the occurrence of phase-locked UV wind line-profile variations, which can be ascribed to rotational modulation, or from theoretical modelling in the pulsating variables. The observational data presently available suggest a higher incidence of chemical peculiarities in stars with a (weak) detected magnetic field. This opens the possibility that magnetic phenomena are important in altering the photospheric abundances of early B dwarfs, even for surface field strengths at the one hundred Gauss level. However, further spectropolarimetric observations are needed to assess the validity of this hypothesis.

**Reference: Accepted by A&A.**

*Comments:* 11 pages, 4 figures (some in colour).

*On the web at:* `http://www.ster.kuleuven.be/~thierry/preprints.html`

*Preprints from:* `morel@astro.ulg.ac.be`

## On the importance of the wind emission to the optical continuum of OB supergiants

**M. Kraus (1), J. Kubat (1), J. Krticka (2)**

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Context: Thermal wind emission in the form of free-free and free-bound emission is known to show up in the infrared and radio continuum of hot and massive stars. For OB supergiants with moderate mass loss rates and a wind velocity distribution with $\beta \simeq 0.8 \ldots 1.0$, no influence of the wind to the optical continuum, i.e. for $\lambda \lesssim 1.0, \mu$m, is expected. Investigations of stellar and wind parameters of

OB supergiants over the last few years suggest, however, that for many objects $\beta$ is much higher than 1.0, reaching values up to 3.5.

Aims: We investigate the influence of the free-free and free-bound emission on the emerging radiation, especially at optical wavelengths, from OB supergiants having wind velocity distributions with $\beta \geq 1.0$.

Methods: For the case of a spherically symmetric, isothermal wind in local thermodynamical equilibrium (LTE) we calculate the free-free and free-bound processes and the emerging wind and total continuum spectra. We localize the generation region of the optical wind continuum and especially focus on the influence of a $\beta$-type wind velocity distribution with $\beta > 1$ on the formation of the wind continuum at optical wavelengths.

Results: The optical wind continuum is found to be generated within about $2, R_*$ which is exactly the wind region where $\beta$ strongly influences the density distribution. We find that for $\beta > 1$, the continuum of a typical OB supergiant can indeed be contaminated with thermal wind emission, *even at optical wavelengths.* The strong increase in the optical wind emission is dominantly produced by free-bound processes.

**Reference: Astronomy & Astrophysics**

*On the web at:* http://arxiv.org/pdf/0801.4273

*Preprints from:* kraus@sunstel.asu.cas.cz

## Chandra X-ray Grating Spectrometry of Eta Carinae near X-ray Minimum: I. Variability of the Sulfur and Silicon Emission Lines

**D.B. Henley[1], M.F. Corcoran[2,3], J.M. Pittard[4], I. R. Stevens[5], K. Hamaguchi[2,3], T.R. Gull[6]**

1- Department of Physics and Astronomy, University of Georgia, Athens, GA 30602; 2 - NASA Goddard Space Flight Center, CRESST, Astrophysics Science Division, Code 662, Greenbelt, MD 20771; 3 - Universities Space Research Association, 10211 Wincopin Circle, Columbia, MD 21044; 4 - School of Physics and Astronomy, University of Leeds, Woodhouse Lane, Leeds, LS2 9JT, U.K.; 5- School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham, B15 2TT, U.K.; 6 - Astrophysics Science Division, Code 667, Goddard Space Flight Center, Greenbelt, MD 20771

We report on variations in important X-ray emission lines in a series of Chandra grating spectra of the supermassive colliding wind binary star Eta Carinae, including key phases around the X-ray minimum/periastron passage in 2003.5. The X-rays arise from the collision of the slow, dense wind of Eta Car with the fast, low-density wind of an otherwise hidden companion star. The X-ray emission lines provide the only direct measure of the flow dynamics of the companion's wind along the wind-wind collision zone. We concentrate here on the silicon and sulfur lines, which are the strongest and best resolved lines in the X-ray spectra. Most of the line profiles can be adequately fit with symmetric Gaussians with little significant skewness. Both the silicon and sulfur lines show significant velocity shifts and correlated increases in line widths through the observations. The R = forbidden-to-intercombination ratio from the Si XIII and S XV triplets is near or above the low-density limit in all observations, suggesting that the line-forming region is > 1.6 stellar radii from the companion star. We show that simple geometrical models cannot simultaneously fit both the observed centroid variations and changes in line width as a function of phase. We show that the observed profiles can be

fitted with synthetic profiles with a reasonable model of the emissivity along the wind-wind collision boundary. We use this analysis to help constrain the line formation region as a function of orbital phase, and the orbital geometry.

**Reference: The Astrophysical Journal**

*On the web at:* `http://arxiv.org/abs/0801.4779`

*Preprints from:* `dbh@physast.uga.edu`

## A downward revision to the distance of the 1806-20 cluster and associated magnetar from Gemini near-Infrared spectroscopy

**J. L. Bibby(1), P. A. Crowther(1), J. P. Furness(1), J. S. Clark(2)**

1: Sheffield; 2: Open University

We present H- and K-band spectroscopy of OB and Wolf-Rayet (WR) members of the Milky Way cluster 1806-20 (G10.0-0.3), to obtain a revised cluster distance of relevance to the 2004 giant flare from the SGR 1806-20 magnetar. From GNIRS spectroscopy obtained with Gemini South, four candidate OB stars are confirmed as late O/early B supergiants, while we support previous mid WN and late WC classifications for two WR stars. Based upon an absolute Ks-band magnitude calibration for B supergiants and WR stars, and near-IR photometry from NIRI at Gemini North plus archival VLT/ISAAC datasets, we obtain a cluster distance modulus of 14.7+/-0.35 mag. The known stellar content of the 1806-20 cluster suggests an age of 3-5 Myr, from which theoretical isochrone fits infer a distance modulus of 14.7+/-0.7 mag. Together, our results favour a distance modulus of 14.7+/-0.4 mag ($8.7^{+1.8}_{-1.5}$ kpc) to the 1806-20 cluster, which is significantly lower than the nominal 15 kpc distance to the magnetar. For our preferred distance, the peak luminosity of the December 2004 giant flare is reduced by a factor of three to $7 \times 10^{46}$ erg/s, such that the contamination of BATSE short gamma ray bursts (GRB's) from giant flares of extragalactic magnetars is reduced to a few percent. We infer a magnetar progenitor mass of $\sim 48^{+20}_{-8}$ $M_{\odot}$, in close agreement with that obtained recently for the magnetar in Westerlund 1.

**Reference: MNRAS Letters**

*On the web at:* `http://arXiv.org/abs/0802.0815`

*Preprints from:* `Paul.Crowther@sheffield.ac.uk`

## The massive star binary fraction in young open clusters I. NGC 6231 revisited

**H. Sana, E. Gosset, Y. Naze, G. Rauw, N. Linder**

European Southern Observatory, Chile    Liege University, Belgium

We present the results of a long-term high-resolution spectroscopy campaign on the O-type stars in NGC 6231. We revise the spectral classification and multiplicity of these objects and we constrain the fundamental properties of the O-star population. Almost three quarters of the O-type stars in the

cluster are members of a binary system. The minimum binary fraction is 0.63, with half the O-type binaries having an orbital period of the order of a few days. The eccentricities of all the short-period binaries are revised downward, and henceforth match a normal period-eccentricity distribution. The mass-ratio distribution shows a large preference for O+OB binaries, ruling out the possibility that, in NGC 6231, the companion of an O-type star is randomly drawn from a standard IMF. Obtained from a complete and homogeneous population of O-type stars, our conclusions provide interesting observational constraints to be confronted with the formation and early-evolution theories of O stars.

**Reference: Accepted by MNRAS**

*On the web at:* `http://arxiv.org/abs/0707.2847`

*Preprints from:* `hsana@eso.org`

## Kinematics of massive stars in the Small Magellanic Cloud

**Christopher J. Evans (1), Ian D. Howarth (2)**

(1) UK Astronomy Technology Centre, Edinburgh; (2) University College London

We present radial velocities for 2045 stars in the Small Magellanic Cloud (SMC), obtained from the 2dF survey by Evans et al. (2004). The great majority of these stars are of OBA type, tracing the dynamics of the young stellar population. Dividing the sample into ad hoc 'bar' and 'wing' samples (north and south, respectively, of the line: $\delta = -77°50' + [4\alpha]'$, where $\alpha$ is in minutes of time) we find that the velocities in the SMC bar show a gradient of 26.3 +/- 1.6 km/s/deg at a position angle of 126 +/- 4 deg. The derived gradient in the bar is robust to the adopted line of demarcation between the two samples. The largest redshifts are found in the SMC wing, in which the velocity distribution appears distinct from that in the bar, most likely a consequence of the interaction between the Magellanic Clouds that is predicted to have occurred 0.2 Gyr ago. The mean velocity for all stars in the sample is +172.0 +/- 0.2 km/s (redshifted by ~20 km/s when compared to published results for older populations), with a velocity dispersion of 30 km/s.

**Reference: MNRAS**

*On the web at:* `http://www.roe.ac.uk/~cje/2df_rv.pdf`

*Preprints from:* `cje@roe.ac.uk`

## On the role of the WNH phase in the evolution of very massive stars: Enabling the LBV instability with feedback

**Nathan Smith and Peter S. Conti**

UC Berkeley, U. Colorado

We propose the new designation "WNH" for luminous Wolf-Rayet (WR) stars of the nitrogen sequence with hydrogen in their spectra. These have been commonly referred to as WNL stars (WN7h, for example), but this new shorthand avoids confusion because there are late-type WN stars without hydrogen and early-type WN stars with hydrogen. Clearly differentiating WNH stars from H-poor/H-free WN stars is critical when discussing them as potential progenitors of Type Ib/c supernovae and

gamma ray bursts — the massive WNH stars are *not* likely Type Ib/c supernova progenitors, and are distinct from core-He burning WR stars in several respects. We show that the stellar masses of WNH stars are systematically higher than for *bona fide* H-poor WR stars (both WN and WC), with little overlap. Also, the hydrogen mass fractions of the most luminous WNH stars are higher than those of luminous blue variables (LBVs). These two trends favor the interpretation that the most luminous WNH stars are still core-H burning, preceding the LBV phase (at lower luminosities the WNH stars are less clearly distinguished from LBVs). While on the main sequence, a star's mass is reduced due to winds and its luminosity slowly rises, so the star increases its Eddington factor, which in turn strongly increases the mass-loss rate, pushing it even closer to the Eddington limit. Accounting for this feedback from mass loss, we show that observed masses and mass-loss rates of WNH stars are a natural and expected outcome for very luminous stars approaching the end of core-H burning (ages $sim2$ Myr). Feedback from the strong WNH wind itself plays a similar role, enabling the eruptive instability seen subsequently as an LBV. Altogether, for initial masses above 40–60 $M_{\odot}$, we find a strong and self-consistent case that luminous WNH stars are pre-LBVs rather than post-LBVs. The steady march toward increased mass-loss rates from feedback also provides a natural explanation for the continuity in observed spectral traits from O3 V to O3 If* to WNH noted previously.

**Reference: 2008, ApJ, v. 679, in press**

*On the web at:* http://lanl.arxiv.org/abs/0802.1742

*Preprints from:* nathans@astro.berkeley.edu

## Chandra spectroscopy of the hot star $\beta$ Crucis and the discovery of a pre-main-sequence companion

**David H. Cohen (1), Michael A. Kuhn (1,2), Marc Gagné (3), Eric L. N. Jensen (1), Nathan A. Miller (4)**

(1) Swarthmore College; (2) currently at Penn State; (3) West Chester University; (4) University of Wisconsin, Eau Claire

In order to test the O star wind-shock scenario for X-ray production in less luminous stars with weaker winds, we made a pointed 74 ks observation of the nearby early B giant, $\beta$ Cru (B0.5 III), with the Chandra High Energy Transmission Grating Spectrometer. We find that the X-ray spectrum is quite soft, with a dominant thermal component near 3 million K, and that the emission lines are resolved but quite narrow, with half-widths of 150 km/s. The forbidden-to-intercombination line ratios of Ne IX and Mg XI indicate that the hot plasma is distributed in the wind, rather than confined near the photosphere. It is difficult to understand the X-ray data in the context of the standard wind-shock paradigm for OB stars, primarily because of the narrow lines, but also because of the high X-ray production efficiency. A scenario in which the bulk of the outer wind is shock heated is broadly consistent with the data, but not very well motivated theoretically. It is possible that magnetic channeling could explain the X-ray properties, although no field has been detected on $\beta$ Cru. We detected periodic variability in the hard ($h\nu > 1$ keV) X-rays, modulated on the known optical period of 4.58 hours, which is the period of the primary $\beta$ Cep pulsation mode for this star. We also have detected, for the first time, an apparent companion to $\beta$ Cru at a projected separation of 4 arcsec. This companion was likely never seen in optical images because of the presumed very high contrast between it and $\beta$ Cru in the optical. However, the brightness contrast in the X-ray is

only 3:1, which is consistent with the companion being an X-ray active low-mass pre-main-sequence star. The companion's X-ray spectrum is relatively hard and variable, as would be expected from a post T Tauri star. The age of the $\beta$ Cru system (between 8 and 10 Myr) is consistent with this interpretation which, if correct, would add $\beta$ Cru to the roster of Lindroos binaries – B stars with low-mass pre-main-sequence companions.

**Reference: MNRAS, in press**

*Comments:* 19 pages, 15 figures, some in color

*On the web at:* `http://astro.swarthmore.edu/~cohen/papers/bcru_mnras2008.pdf`

*Preprints from:* `cohen@astro.swarthmore.edu`

## Proceedings

## The Physical Properties of Red Supergiants: Comparing Theory and Observations

**Philip Massey (1), Emily M. Levesque (2), Bertrand Plez, (3), and K. A. G. Olsen (4)**

(1) Lowell Observatory; (2) Institute for Astronomy, University of Hawaii; (3) GRAAL, Universite Montpellier II; (4) Gemini Science Center, NOAO

Red supergiants (RSGs) are an evolved stage in the life of intermediate massive stars (less than 25 solar masses). For many years, their location in the H-R diagram was at variance with the evolutionary models. Using the MARCS stellar atmospheres, we have determined new effective temperatures and bolometric luminosities for RSGs in the Milky Way, LMC, and SMC, and our work has resulted in much better agreement with the evolutionary models. We have also found evidence of significant visual extinction due to circumstellar dust. Although in the Milky Way the RSGs contribute only a small fraction ($< 1\%$) of the dust to the interstellar medium (ISM), in starburst galaxies or galaxies at large look-back times, we expect that RSGs may be the main dust source. We are in the process of extending this work now to RSGs of higher and lower metallicities using the galaxies M31 and WLM.

**Reference: Invited review, Massive Stars as Cosmic Engines, IAU Symp 250, ed. F. Bresolin, P. A. Crowther, & J. Puls (Cambridge Univ. Press)**

*On the web at:* `http://www.lowell.edu/users/massey/IAU250RSG.pdf.gz`

*Preprints from:* `Phil.Massey@lowell.edu`

## Luminous Blue Variables & Mass Loss near the Eddington Limit

**Stanley P. Owocki[1], Allard Jan van Marle[1]**

1-Bartol Research Institute, Department of Physics & Astronomy, University of Delaware

During the course of their evolution, massive stars lose a substantial fraction of their initial mass, both through steady winds and through relatively brief eruptions during their Luminous Blue Variable

(LBV) phase. This talk reviews the dynamical driving of this mass loss, contrasting the line-driving of steady winds to the potential role of continuum driving for eruptions during LBV episodes when the star exceeds the Eddington limit. A key theme is to emphasize the inherent limits that self-shadowing places on line-driven mass loss rates, whereas continuum driving can in principle drive mass up to the "photon-tiring" limit, for which the energy to lift the wind becomes equal to the stellar luminosity. We review how the "porosity" of a highly clumped atmosphere can regulate continuum-driven mass loss, but also discuss recent time-dependent simulations of how base mass flux that exceeds the tiring limit can lead to flow stagnation and a complex, time-dependent combination of inflow and outflow regions. A general result is thus that porosity-mediated continuum driving in super-Eddington phases can explain the large, near tiring-limit mass loss inferred for LBV giant eruptions.

**Reference: Invited review, Massive Stars as Cosmic Engines, IAU Symp 250, ed. F. Bresolin, P. A. Crowther, & J. Puls (Cambridge Univ. Press)**

*On the web at:* `http://www.bartol.udel.edu/~owocki/preprints/IAUS250-Owocki-Dec07.pdf`

*Preprints from:* `owocki@bartol.udel.edu`

## Physical and wind properties of OB-stars

**Joachim Puls**

Universitaetssternwarte Muenchen, Scheinerstr. 1, D-81679 Muenchen, Germany

In this review, the physical and wind properties of OB-stars are discussed, with particular emphasis on metallicity dependence and recent results from the FLAMES survey of massive stars. We summarize the relation between spectral type and Teff, discuss the status quo of the "mass-discrepancy", refer to the problem of "macro-turbulence" and comment on the distribution of rotational velocities. Observational constraints on the efficiency of rotational mixing are presented, and magnetic field measurements summarized. Wind properties are reviewed, and problems related to weak winds and wind-clumping highlighted.

**Reference: Proc. IAU Symp. 250 "Massive Stars as Cosmic Engines", F. Bresolin, P. Crowther & J. Puls (eds.), Cambridge: Cambridge University Press**

*On the web at:* `http://www.usm.uni-muenchen.de/people/puls/papers/puls_hawaii.pdf`

*Preprints from:* `uh101aw@usm.uni-muenchen.de`

## IMF biases created by binning and unresolved systems

**J. Maíz Apellániz**

IAA-CSIC

I discuss two of the possible sources of biases in the determination of the IMF: binning and the existence of unresolved components. The first source is important for clusters with a small number of stars detected in a given mass bin while the second one is relevant for all clusters located beyond the immediate solar neighborhood. For both cases I will present results of numerical simulations and I

will discuss strategies to correct for their effects. I also present a brief description of a third unrelated bias source.

**Reference: To appear in "Young massive clusters, initial conditions and environments"**

*On the web at:* http://arxiv.org/abs/0801.3778

*Preprints from:* jmaiz@iaa.es

## X-rays from magnetically channeled winds of OB stars

**David H. Cohen**

Swarthmore College, Department of Physics and Astronomy

OB stars with strong radiation-driven stellar winds and large-scale magnetic fields generate strong and hard X-ray emission via the Magnetically Channeled Wind Shock (MCWS) mechanism. In this brief paper, I describe four separate X-ray diagnostics of the MCWS mechanism in OB stars, with applications to the prototype young O star, theta-1 Ori C.

**Reference: To appear as part of an article on the specialist session on magnetic massive stars held prior to IAU Symposium 250, "Massive Stars as Cosmic Engines," Kauai, HI, December 2007; eds. Bresolin, Crowther, & Puls, Cambridge University Press, 2008.**

*Comments:* 2 pages; 1 figure (color, but looks fine in b/w)

*On the web at:*
http://astro.swarthmore.edu/~cohen/papers/cohen_magneticOstars_kauai2007.pdf

*Preprints from:* cohen@astro.swarthmore.edu

## X-ray emission from O stars

**David H. Cohen**

Swarthmore College, Department of Physics and Astronomy

Young O stars are strong, hard, and variable X-ray sources, properties which strongly affect their circumstellar and galactic environments. After ~1 Myr, these stars settle down to become steady sources of soft X-rays. I use high-resolution X-ray spectroscopy and MHD modeling to show that young O stars like theta-1 Ori C are well explained by the magnetically channeled wind shock scenario. After their magnetic fields dissipate, older O stars produce X-rays via shock heating in their unstable stellar winds. Here too I use X-ray spectroscopy and numerical modeling to confirm this scenario. In addition to elucidating the nature and cause of the O star X-ray emission, modeling of the high-resolution X-ray spectra of O supergiants provides strong evidence that mass-loss rates of these O stars have been overestimated.

**Reference: To appear in IAU Symposium 250, "Massive Stars as Cosmic Engines," Kauai, HI, December 2007; eds. Bresolin, Crowther, & Puls, Cambridge University Press, 2008.**

*Comments:* This version of the paper includes the post-talk Q&A transcript as well as one extra figure. Many of the figures are in color. A b/w version without the extra figure is also available: http://astro.swarthmore.edu/∼cohen/papers/cohen_OstarXrays_bw_kauai2007.pdf

*On the web at:*
`http://astro.swarthmore.edu/∼cohen/papers/cohen_OstarXrays_color_kauai2007.pdf`

*Preprints from:* `cohen@astro.swarthmore.edu`

## X-ray spectroscopy of early-type stars: The present and the future

**G. Rauw (1), Y. Naze (2), and L.M. Oskinova (3)**

(1) Institute of Astrophysics & Geophysics, University of Liege, Belgium (2) Astrophysics, University of Potsdam, Germany

XMM-Newton and Chandra have boosted our knowledge about the X-ray emission of early-type stars (spectral type OB and Wolf-Rayet). However, there are still a number of open questions that need to be addressed in order to fully understand the X-ray spectra of these objects. Many of these issues require high-resolution spectroscopy or monitoring of a sample of massive stars. Given the moderate X-ray brightness of these targets, rather long exposure times are needed to achieve these goals. In this contribution, we review our current knowledge in this field and present some hot topics that could ideally be addressed with XMM-Newton over the next decade.

**Reference: Astronomische Nachrichten/AN 329, 222**
*Comments:* Proceedings of the conference "XMM-Newton: The Next Decade" held in Villafranca del Castillo (Spain), 4-6 June 2007

*Preprints from:* `rauw@astro.ulg.ac.be`

## Stellar Evolution at Low Metallicity

**Raphael Hirschi[1], Cristina Chiappini[2,3], Georges Meynet[2], André Maeder[2], & Sylvia Ekström[2]**

[1]Keele University, UK [2]Observatoire de Genève, CH [3]Osservatorio Astronomico di Trieste, Italia

Massive stars played a key role in the early evolution of the Universe. They formed with the first halos and started the re-ionisation. It is therefore very important to understand their evolution. In this review, we first recall the effect of metallicity (Z) on the evolution of massive stars. We then describe the strong impact of rotation induced mixing and mass loss at very low $Z$. The strong mixing leads to a significant production of primary N14, C13 and Ne22. Mass loss during the red supergiant stage allows the production of Wolf-Rayet stars, type Ib,c supernovae and possibly gamma-ray bursts (GRBs) down to almost $Z = 0$ for stars more massive than 60 $M_{\odot}$. Galactic chemical evolution models calculated with models of rotating stars better reproduce the early evolution of N/O, C/O and C12/C13. Finally, the impact of magnetic fields is discussed in the context of GRBs.

**Reference: "Massive Stars as Cosmic Engines" Conference proceedings, F. Bresolin, P.A. Crowther, J. Puls Eds**
*Comments:* 12 pages, 7 figures

*On the web at:* `http://arxiv.org/abs/0802.1675`

*Preprints from:* `r.hirschi@epsam.keele.ac.uk`

## Symposium Summary

**Claus Leitherer**

STScI

I summarize the highlights of the conference. First I provide a brief history of the beach symposia series our massive star community has been organizing. Then I use most of my allocated space discussing what I believe are the main answered and open questions in the field. Finally I conclude with a perspective of the future of massive star research.

**Reference: IAU Symp. 250, Massive Stars as Cosmic Engines, Kauai (HI), 12/2007, ed. F. Bresolin, P. Crowther, & J. Puls**

*Status:* Conference proceedings

*On the web at:* `http://xxx.lanl.gov/abs/0801.4010`

*Preprints from:* `leitherer@stsci.edu`

# Thesis

## A new class of X-ray emitters: the $\gamma$Cas-like sources

**Raimundo LOPES DE OLIVEIRA**

Universidade de São Paulo, Brazil and Université Louis Pasteur Strasbourg I, France

$\gamma$ Cassiopeiae (B0.5 Ve; $\gamma$ Cas) has long stood out as having unique X-ray properties among massive stars and Be/X-ray systems. Their properties include hard-thermal X-ray emission ($k$T $\sim$ 12 keV) of moderate luminosity ($\sim 10^{32-33}$ erg,s$^{-1}$, at 0.2–12 keV) and a light curve that displays marked variability on long and short time scales. In contrast, "normal" O-B-Be stars are usually soft ($k$T $\sim$ 0.5 keV) and modest X-ray emitters, while all well-known Be/X-ray systems (all of them are Be + neutron star binaries) are non-thermal and more intense X-ray emitters. In spite of several multi-wavelength observing campaigns, since its discovery as prototype of Be stars in the end of 19 century, the true nature of the X-ray emission of $\gamma$ Cas remains elusive. Two exciting interpretations have been proposed in the recent literature and raise a number of interesting astrophysical issues, and these are that the X-rays are emitted from: (i) the interaction between a single-Be star with unusually strong magnetic activity and its decretion disk; and (ii) a binary system with an accreting white dwarf. In the first case, $\gamma$ Cas would be a progenitor to the magnetars, while the Be + WD binary case would be predicted by evolutionary models of massive binary systems, though they are still not identified as such. One of the obstacles in advancing the understanding of the X-rays of $\gamma$ Cas is the fact that the proposed models are restricted to one only object: $\gamma$ Cas itself. This work intends to fill such gap.

Our efforts were concentrated on two pillars of inquiry: the investigation of the X-rays of $\gamma$ Cas itself, and the search for and study of new $\gamma$ Cas analogs. We confirm the main properties already known in the literature of $\gamma$ Cas, but a number of peculiarities were also observed for the first time. For example, the local photoelectric absorption of $\gamma$ Cas is variable and apparently non-correlated with the intensity of the Fe fluorescence line at 6.4 keV. Also, we detect strong and recurrent variations in its energy distribution in the form of flare-like events in the X-ray colours. On the other hand, we present 6 B0.5e-B1e stars with common X-ray and optical properties quite similar to those of the so far unique star $\gamma$ Cas and we point out the emergence of a new class of X-ray emitters: the $\gamma$ Cas-like sources. Apart the fact that all stars occupy a narrow band of spectral type, all of them have large or dense circumstellar disks. Other members of the class are: HD 161103, SAO 49725, SS 397, HD 119682, HD 110432 and USNO 0750-13549725. The last three stars are blue stragglers in open clusters of $\sim$ 45–60 millions of years (NGC 5281, NGC 4609 and NGC 6649, respectively). Therefore, an evolved status may be a prerequisite to the source being a peculiar X-ray emitter like $\gamma$ Cas. Other 41 candidates to members of this class were identified from an extensive investigation of the 2XMMp catalogue.

The massive stars in five young open clusters ($\sim$ 10–25 millions of years) especially rich in Be stars ($>$ 135) and in two other old open clusters ($\sim$ 95 and 300 millions of years) containing $>$ 11 Be stars were investigated. We paid particular attention to the massive stars, with the aim of constraining evolutionary processes that might lead to the Be phenomenon and to search for low X-ray luminosity massive accreting binaries and $\gamma$ Cas-like systems. There is no clear evidence of the presence of these systems in following clusters we have examined so far: NGC 7419, NGC 3766, NGC 663, NGC 884, NGC 869, NGC 3114 and IC 4725. The only exceptions are the well-known Be/X RX,J0146.9+6121 in NGC 663, and perhaps for MWC 39 in NGC 884, which is most likely a neutron star accreting wind matter originating from its main sequence B star companion.

The nature of the X-ray emission of the new class of $\gamma$ Cas-like objects is discussed in light of the models proposed for $\gamma$ Cas, on the basis of the derived properties and frequency of these objects in open clusters. Finally, we discuss the implications of the results in the context of the Be phenomenom.

(This work was based on X-ray observations carried out by XMM-*Newton* satelite and available informations in the literature, and for some targets also on optical and infrared spectroscopy from several Earth-based telescopes.)

**Reference: PhD Thesis (30 November 2007). Universidade de S ao Paulo (IAG), Brazil and Université Louis Pasteur Strasbourg I (Observatoire Astronomique), France.**
*Comments:* Advisor: Christian Motch; Co-Advisor: Eduardo Janot-Pacheco.

*Preprints from:* rlopes@astro.iag.usp.br

## Evolution and Pulsations of Massive Stars on the Main Sequence and Close to it

## 7-11 July, 2008
## Liège (Belgium)

The main idea of this colloquium is first to close in on the problems raised by "non standard" physics, second, to focus on the effects of these often missing physical processes on stellar evolution and third, to analyse what asteroseismology can do to bring a new light on these processes and their modelling. The targets are massive stars (O, B, WR) for which new and exciting results are now coming from asteroseismic interpretations of observed modes.

*Weblink:* `http://www.ago.ulg.ac.be/APub/Colloques/Liac38/`

*Email contact:* `liac2008@misc.ulg.ac.be`

## Astrophysical Shocks: Space Observations vs. Modeling

## 13-20 July 2008
## 37th COSPAR Scientific Assembly Montreal, Canada

Scientific Event E13

Shock waves play a prominent role in cosmological structure formation, clusters of galaxies, radio jets, gamma-ray bursts, supernova remnants, shocks in the heliosphere, etc., making understanding shock processes a high priority. Our event will address current and forthcoming multi-wavelength observations of thermal and nonthermal shock emission in radio, IR (Spitzer, Herschel), optical (HST, VLT), X-ray (Chandra, XMM-Newton, Swift), and gamma-ray (INTEGRAL, HESS and GLAST) bands. Recent high resolution observations and modeling of clusters of galaxies, AGNs, gamma-ray bursts, and supernova remnants suggest that strongly nonlinear processes in shocks can produce large amplifications of the ambient magnetic field and efficiently accelerate particles. On the other hand, physical conditions in the partially ionized ambient medium are crucial for understanding both the the collisional and collisionless shock processes and are still poorly understood. We plan to bring together approximately 120 experts in shock observations and modeling to provide a broad, multi-disciplinary view of astrophysical shocks, and to encourage new observational programs and new theoretical concepts for interpreting observations. IAU is co-sponsoring the event.

Please register by 17 February, 2008, if you would like to propose a talk.

*Weblink:* `http://www.cospar-assembly.org/`

*Email contact:* `jmp@ast.leeds.ac.uk`