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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No. 57 2000 December http://www.astro.ugto.mx/∼eenens/hot/
editor: Philippe Eenens http://www.star.ucl.ac.uk/∼hsn/index.html
eenens@astro.ugto.mx ftp://saturn.sron.nl/pub/karelh/UPLOADS/WRBIB/

Accepted Papers

The spectral variability of HD 192639 and its implications for the star's wind structure

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We report the analysis of an extensive set of spectroscopic data of the O(f) supergiant HD 192639. A Fourier analysis of our time-series reveals a recurrent variability with a 'period' of roughly 4.8 days which is most prominent in the absorption components of the He II λ 4686 and Hα P-Cygni profiles. The same periodicity is also detected in the blue wing of several absorption lines (e.g. Hβ). The variations of the absorption components correspond most probably to a cyclical modulation of the amount of stellar wind material along the line of sight towards the star. The 4.8-day period affects also the morphology of the double-peaked He II λ 4686 and Hα emission components, although these emission components display also variations on other (mainly longer) time scales.
The most likely explanation for the 4.8-day modulation is that this cycle reflects the stellar rotational period (or half this period). We find that the most important observational properties can be explained - at least qualitatively - by a corotating interaction region or a tilted confined corotating wind.

Accepted by Astronomy & Astrophysics
Preprints from `rauw@astro.ulg.ac.be`
or on the web at `http://vela.astro.ulg.ac.be/Preprints/P61/index.html`

Episodic dust formation by HD 192641 (WR 137) – II

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We present new infrared photometry of the WC7 type Wolf-Rayet star HD 192641 (WR 137) from 1985–1999. These data track the cooling of the dust cloud formed in the 1982–84 dust-formation episode from 1985 to 1991, the increase of the infrared flux from 1994.5 to a new dust-formation maximum in 1997 and its subsequent fading. From these and earlier data we derive a period of 4765±50 d. (13.05±0.15 y.) for the dust-formation episodes. Between dust-emission episodes, the infrared SED has the form of a power law, $\lambda F_\lambda \propto \lambda^{-1.86}$. The rising branch of the infrared light curve (1994 – 1997) differs in form from that of the episodic dust-maker WR 125. Time-dependent modelling shows that this difference can be attributed a different time dependence of dust formation in WR 137, which occurred approximately $\propto t^2$ until maximum, whereas that of WR 125 could be described by a step function, akin to a threshold effect. For an adopted distance of 1.6 kpc, the rate of dust formation was found to be 5.0×10^{-8} $M_\odot$ y^{-1} at maximum, accounting for a fraction $f_C \approx 1.5 \times 10^{-3}$ of the carbon flowing in the stellar wind. The fading branches of the light curves show evidence for secondary 'mini eruptions' in 1987, 1988 and 1990, behaviour very different from that of the prototypical episodic dust-maker HD 193793 (WR 140), and suggesting the presence in the WR 137 stellar wind of large-scale structures which are crossed by the wind-wind collision region.

Accepted by MNRAS
Preprints from `pmw@roe.ac.uk`
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Wolf-Rayet stars and cosmic gamma-ray bursts

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We analyze the observed properties of cosmic gamma-ray bursts, Wolf-Rayet (WR) stars and their CO-cores in the end of evolution. WR stars are deprived of their extended hydrogen envelopes, which makes it easier for the collapse energy to transform into observed gamma-ray emission. Presently, of ~ 90 well-localized gamma-ray bursts, 21 ones are optically identified and for 16 of them redshifts are measured ($z = 0.4 \div 4.5$). The observed energy of gamma-ray bursts spans over a wide range from 3×10^{51} to 2×10^{54} ergs. There is some evidence that this distribution $N(\Delta E)$ is bimodal if take into account GRB980425 associated with a peculiar type Ic supernova SN1998bw in a nearby galaxy ESO 184-G82 for which $\Delta E_\gamma \approx 10^{48}$ ergs. These characteristics of gamma-ray bursts are similar to the distribution of the final masses of CO-cores of WR stars which is also wide and homogeneous: $M_{CO} = (1-2)M_\odot \div (20-44)M_\odot$. A possible bimodality of the gamma-ray burst energy distribution ($E_1 = 10^{48}$ erg; $\Delta E_2 = 3 \times 10^{51} \div 2 \times 10^{54}$ erg) is in accord with the bimodal mass distribution of relativistic objects ($M_{NS} = (1.35 \pm 0.15)M_\odot$; $M_{BH} = (4 \div 15)M_\odot$). That the supernova SN1998bw is of the "peculiar Ic" type, atypical for WR collapses (type Ib/c), can be related to the rotation of the collapsing CO-core which can make the collapse longer and lead to the formation of a neutron star, the decrease of the gamma-ray burst energy, and the increase of the fraction of kinetic energy transported to the envelope. The expected collapse rate of CO-cores of most compact WR stars of type WO in the Galaxy is $\sim 10^{-5}$ per year, which is only by one and a half order of magnitude higher than the average gamma-ray burst rate in one galaxy ($\sim 10^{-6} - 10^{-7}$ per year). Two particular models that use WR stars as gamma-ray burst progenitors are considered: the hypernova model by Paczyński (1998) and the model of unstable CO-core collapse suggested by Gershtein (2000). In both models the allowance of a gamma-ray beaming or random outcome of the CO-core collapse due to some instabilities permits one to bring the rate of CO-core collapses in accordance with that of gamma-ray bursts. The conclusion is made that WR stars (most probably, of type WO) can be considered as progenitors of cosmic gamma-ray bursts. Two types of gamma-ray bursts are predicted in correspondence with the bimodal mass distribution of the relativistic objects. Three types of optical afterglows should appear depending on which CO-core is collapsing: of a single WR star, of a WR star in a WR+O or a hypothetic WR+(A-M) binary system. In addition, we briefly consider a model of gamma-ray bursts as a transient phenomenon occurring at early stages of galactic evolution ($z > 1$), when very massive ($M > 100 M_{\odot}$) low-metallicity stars could form. Such massive stars should also loose their hydrogen envelopes and become massive WR stars whose collapses could be accompanied by gamma-ray bursts. WR-galaxies can be most probable candidates for gamma-ray burst host galaxies.

Accepted by Astronomy Reports, 2001
Preprints from astro-ph/0012512

Self-Similar Evolution of Wind-Blown Bubbles with Mass-loading by Conductive Evaporation

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We present similarity solutions for adiabatic bubbles that are blown by winds having time dependent mechanical luminosities and that are each mass-loaded at a rate per unit volume proportional to $T^{5/2} r^{\lambda}$, where T is the temperature, r is the distance from the bubble center, and λ is a constant. In the limit of little mass loading a similarity solution found by Dyson (1973) for expansion into a smooth ambient medium is recovered. For solutions that give the mass of swept-up ambient gas to be less than the sums of the masses of the wind and the evaporated material, $\lambda \gtrsim 4$. The Mach number in a shocked mass-loaded wind shows a radial dependence that varies qualitatively from solution to solution. In some cases it is everywhere less than unity in the frame of the clumps being evaporated, while in others it is everywhere greater than unity. In some solutions the mass-loaded shocked wind undergoes one or two sonic transitions in the clump frame. Maximum possible values of the ratio of evaporated mass to stellar wind mass are found as a consequence of the evaporation rates dependence on temperature and the lowering of the temperature by mass-loading. Mass-loading tends to reduce the emissivity in the interior of the bubble relative to its limb, whilst simultaneously increasing the central temperature relative to the limb temperature.

Accepted by A&A
Preprints from jmp@ast.leeds.ac.uk
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High velocity structures in, and the X-ray emission from the LBV nebula around η Carinae

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The Luminous Blue Variable star η Carinae is one of the most massive stars known. It underwent a giant eruption in 1843 in which the Homunculus nebula was created. ROSAT and ASCA data indicate the existence of a hard and a soft X-ray component which appear to be spatially distinct: a softer diffuse shell of the nebula around η Carinae and a harder point-like source centered on the star η Car. Astonishingly the morphology of the X-ray emission is very different from the optical appearance of the nebula. We present a comparative analysis of optical morphology, the kinematics, and the diffuse soft X-ray structure of the nebula around η Carinae. Our kinematic analysis of the nebula shows extremely high expansion velocities. We find a strong correlation between the X-ray emission and the knots in the nebula and the largest velocities, i.e. the X-ray morphology of the nebula around η Carinae is determined by the interaction between material streaming away from η Car and the ambient medium.

In Press: Astronomy and Astrophysics

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Extended optical spectroscopic monitoring of wind structure in HD 152408

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New perspectives are provided on significant spatial structure and temporal variability in the near-star wind regions (i.e. $< 3R_\star$) of the massive luminous star HD 152408 (classified as O8:Iafpe or WN9ha). This study is primarily based on the analysis of high-quality échelle spectra secured during 21 nights between 1999 July to August, using the Landessternwarte-developed (fibre-fed) FEROS instrument on the ESO 1.52-m telescope. These extended time-series data, with a total simultaneous wavelength coverage of $\lambda\lambda 3600 - 9200$Å, were exploited to monitor absorption and emission fluctuations (of $\sim$ 5-10% of the line flux) in several He I and Balmer lines, together with more deep-seated (near-photosphere) disturbances in weaker metallic emission and absorption lines.

Organised *large-scale* wind structure in HD 152408 is principally betrayed by sequential episodes of discrete absorption and emission features, which migrate from near zero velocity to almost the wind terminal velocity. This evolution is extremely slow, however, typically spanning $\sim$ 4 days for an individual episode. We demonstrate that the blue-shifted absorption episodes in He I are very closely mirrored (in velocity and time) by *absorption* features (i.e. reduced not enhanced flux) in the blue wings of the mainly recombination formed broad Hα emission line. The implication is that there is detailed

balancing between ground state photoionization and recombination in the substantially optically thick Balmer lines. Surprisingly, the velocity behaviour of the red-ward and blue-ward migrating features is highly asymmetric, such that the mean acceleration of the former is less than 50% of the latter.

Fourier analysis reveals a modulation time-scale for the wind activity of $\sim$ 7.7 days, plus its harmonic at 3.9 days. The longer period is $\sim$ 28 times greater than the characteristic radial wind flow time of HD 152408. We also detect a $\sim$ 1.5 day periodic variation in the radial velocity of the weak C IV $\lambda\lambda$5801, 5812 absorption lines, which are the closest approximation to 'pure' photospheric lines in the optical spectrum of HD 152408.

The wind-formed optical lines of HD 152408 are also affected by fluctuations in the central peak emission, particularly evident in Hα where the equivalent width may vary by up to 20%. Data secured between 1995 and 1999 reveal, however, that the epoch-to-epoch mean profiles are remarkably similar. Non-LTE steady-state stellar atmosphere models are used to synthesis profiles to match representative Hα and He I λ5876 line profiles. Only a slow (tailored) velocity law (compared to β=1) provides a good match to the Hα emission peak and wings, but the models predict excess He I absorption. The observed extreme Hα emission variations can be reproduced by the synthetic profiles with an implied $\pm$10% variation in mass-loss rate.

The results on optical line profile variability in HD 152408 are discussed in the context of models for co-rotating interaction regions (CIRs) in the wind. Several constraints are provided that argue against simple velocity fields in such streams, including (i) the slow acceleration of features to high velocities, within $\sim$ 3R$_\star$, (ii) the strong asymmetry in projected acceleration of the approaching and receding stream material, (iii) Balmer line absorption effects in the approaching material, (iv) the rise of localised features from very low velocities, and (v) the stability of the large-scale CIRs against turbulent small-scale wind structure. We suggest that it may be worth exploring hydrodynamic simulations of CIRs that incorporate different velocity fields on the leading (faster accelerating; blue-ward absorption) and trailing (slower accelerating; red-ward emission) edges of the spiral structures.

Accepted by A&A

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The HMXRB System BD+37^o 1160/4U 0515+38

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We present new optical data on BD+37^o 1160, the optical counterpart of the X-ray source 1H0521+373 (= 4U0515+38). The analysis of the stellar spectrum confirms that it is a very high mass object (possibly, a B[e]) that probably experienced in the past several shell emission episodes. From the present optical data we find clear evidence of a new shell being ejected by the star. The hard spectrum of the X-ray source points to the presence of a compact companion on a very wide orbit.

Accepted by Advances in Space Research

Preprints from polcaro@saturn.ias.rm.cnr.it

A Search for the Cause of Cyclical Wind Variability in O Stars
Simultaneous UV and optical observations including magnetic field measurements of the O7.5III star ξ Persei

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We present the results of an extensive observing campaign on the O7.5 III star ξ Persei. The UV observations were obtained with the *International Ultraviolet Explorer*. ξ Per was monitored continuously in October 1994 during 10 days at ultraviolet and visual wavelengths. The ground-based optical observations include magnetic field measurements, Hα and He I λ6678 spectra, and were partially covered by photometry and polarimetry. We describe a method to automatically remove the variable contamination of telluric lines in the groundbased spectra. The aim of this campaign was to search for the origin of the cyclical wind variability in this star. We determined a very accurate period of 2.086(2) d in the resonance lines of Si IV and in the subordinate N IV and Hα line profiles. The epochs of maximum absorption in the UV resonance lines due to discrete absorption components (DACs) coincide in phase with the maxima in blue-shifted Hα absorption. This implies that the periodic variability originates close to the stellar surface. The phase−velocity relation shows a maximum at -1400 km s^{-1}. The general trend of these observations can be well explained by the corotating interaction region (CIR) model. In this model the wind is perturbed by one or more fixed patches on the stellar surface, which are most probably due to small magnetic field structures. Our magnetic field measurements gave, however, only a null-detection with a 1σ errorbar of 70 G in the longitudinal component. Some observations are more difficult to fit into this picture. The 2-day period is not detected in the photospheric/transition region line He I λ6678. The dynamic spectrum of this line shows a pattern indicating the presence of non-radial pulsation, consistent with the previously reported period of 3.5 h. The edge variability around -2300 km s^{-1} in the saturated wind lines of C IV and N V is nearly identical to the edge variability in the unsaturated Si IV line, supporting the view that this type of variability is also due to the moving DACs. A detailed analysis using Fourier reconstructions reveals that each DAC actually consists of 2 different components: a 'fast' and a 'slow' one which merge at higher velocities.

Accepted by Astronomy and Astrophysics
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A Representative Sample of Be Stars IV: Infrared Photometry and the Continuum Excess

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We present infrared (JHK) photometry of 52 isolated Be stars of spectral types O9–B9 and luminosity classes III–V. We describe a new method of reduction, enabling separation of interstellar reddening and circumstellar excess. Using this technique we find that the disc emission makes a maximum contribution to the optical $(B-V)$ colour of a few tenths of a magnitude. We find strong correlations between a range of emission lines (Hα, Brγ, Br11, and Br18) from the Be stars' discs, and the circumstellar continuum excesses. We also find that stellar rotation and disc excess are correlated.

All papers in this series and further information concerning the sample can be obtained from the web address below.

Accepted by Astronomy and Astrophysics
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The spatial distribution of O-B5 stars in the solar neighborhood as measured by *Hipparcos*

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We have developed a method to calculate the fundamental parameters of the vertical structure of the Galaxy in the solar neighborhood from trigonometric parallaxes alone. The method takes into account Lutz-Kelker-type biases in a self-consistent way and has been applied to a sample of O-B5 stars obtained from the Hipparcos catalog. We find that the Sun is located 24.2 ± 1.7 (random) $\pm$ 0.4 (systematic) pc above the galactic plane and that the disk O-B5 stellar population is distributed with a scale height of 34.2 ± 0.8 (random) $\pm$ 2.5 (systematic) pc and an integrated surface density of $(1.62 \pm 0.04$ (random) $\pm$ 0.14 (systematic)$) \cdot 10^{-3}$ stars pc-2. A halo component is also detected in the distribution and constitutes at least $\approx 5\%$ of the total O-B5 population. The O-B5 stellar population within ~ 100 pc of the Sun has an anomalous spatial distribution, with a less-than-average number density. This local disturbance is probably associated with the expansion of Gould's belt.

To appear in the May 2001 issue of the Astronomical Journal
Preprints from `jmaiz@stsci.edu`
or on the web at `http://arXiv.org/abs/astro-ph/0101310`

Submitted Papers

X-Ray Line Profiles from Parameterized Emission Within an Accelerating Stellar Wind

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Motivated by recent detections by the *XMM* and *Chandra* satellites of X-ray line emission from hot, luminous stars, we present synthetic line profiles for X-rays emitted within parameterized models of a hot-star wind. The X-ray line emission is taken to occur at a sharply defined co-moving-frame resonance wavelength, which is Doppler-shifted by a stellar wind outflow parameterized by a 'beta' velocity law, $v(r) = v_\infty(1 - R_*/r)^\beta$. Above some initial onset radius R_o for X-ray emission, the radial variation of the emission filling factor is assumed to decline as a power-law in radius, $f(r) \sim r^{-q}$. The computed emission profiles also account for continuum absorption within the wind, with the overall strength characterized by a cumulative optical depth τ_*. In terms of a wavelength shift from line-center scaled in units of the wind terminal speed v_∞, we present normalized X-ray line profiles for various combinations of the parameters β, τ_*, q and R_o, and including also the effect of instrumental broadening as characterized by a Gaussian with a parameterized width σ. We discuss the implications for interpreting observed hot-star X-ray spectra, with emphasis on signatures for discriminating between "coronal" and "wind-shock" scenarios. In particular, we note that in profiles observed so far the substantial amount of emission longward of line center will be difficult to reconcile with the expected attenuation by the wind and stellar core in either a wind-shock or coronal model.

Submitted to the Astrophysical Journal
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or in PDF format at: www.bartol.udel.edu/~owocki/preprints/xprofile.pdf

In Proceedings

Massive Stars in the Bulge of M51: a new mode of star formation?

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We have studied 30 bright point-like sources in the bulge of of M51 i.e. within 110 to 350 pc from

the nucleus, located in elongated "strings" which follow the general pattern of the dust lanes around the nucleus. The point sources, are probably individual massive stars (or very small groups of a few massive stars) rather than clusters because:
(a) the energy distributions of most object are best fitted with models of single stars.
(b) in the HR-diagram the sources follow the Humphreys-Davidson luminosity upper limit for single stars.
(c) the distribution of the sources in the HR-diagram shows a gap in the range of $20\,000 < T_{\rm eff} < 10\,000$ K, which agrees with the rapid crossing of the HR-diagram by stars, but not with the evolution of clusters.
We have derived upper limits to the total mass of low mass stars, i.e. $M_\star < 10\ M_\odot$, that could be "hiding" in the point sources. For the "bluest" sources the upper limit is only a few hundred $M_\odot$.

Theoretical predictions of star formation suggest that single massive stars might be formed in clouds in which H_2, [OI] 63 μm and [CII] 158 μm are the dominant coolants. This is expected to occur in regions of rather low optical depth, $A_V \leq 1$, with a hot source that can dissociate the CO molecules. These conditions may be met in the bulge of M51. This mode of star formation may show resemblance to that in the early Universe when the metallicity was very low.

Accepted for "Modes of Starformation", eds. Grebel and Brandner, 2001, PASP Conf Series
Preprints from `lamers@astro.uu.nl`

High-mass X-ray binaries and OB-runaway stars

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High-mass X-ray binaries (HMXBs) represent an important phase in the evolution of massive binary systems. HMXBs provide unique diagnostics to test massive-star evolution, to probe the physics of radiation-driven winds, to study the process of mass accretion, and to measure fundamental parameters of compact objects. As a consequence of the supernova explosion that produced the neutron star (or black hole) in these systems, HMXBs have high space velocities and thus are runaways. Alternatively, OB-runaway stars can be ejected from a cluster through dynamical interactions. Observations obtained with the *Hipparcos* satellite indicate that both scenarios are at work. Only for a minority of the OB runaways (and HMXBs) a wind bow shock has been detected. This might be explained by the varying local conditions of the interstellar medium.

Review paper in Proc. "Influence of binaries on stellar population studies", Brussels, August 2000, Eds. D. Vanbeveren, W. Van Rensbergen, Kluwer Acad. Pub.
Preprints from `lexk@astro.uva.nl`

The outer ejecta of η Carinae

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The nebula around η Carinae consists of an inner bipolar structure, historically called the *Homunculus*, and the outer ejecta consisting mainly of a variety of knots of different sizes. They reach out to distances of up to 30″ or 0.3 pc from η Car. With high-resolution long-slit observations we mapped the outer nebula in order to analyze the global expansion pattern and to model the three dimensional structure of the ejecta. We find very different expansion velocities for the knots of the outer ejecta. In some cases they reach up to values as high as $2000\,\mathrm{km\,s^{-1}}$. Typical expansion velocities lie at considerably lower values around $400-600\,\mathrm{km\,s^{-1}}$, i.e., they are comparable to the expansion velocities found in the Homunculus. Remarkably, the expansion of the outer ejecta reveals a bidirectional motion pattern, which is consistent with the bipolar structure of the inner nebula. A general overview of the morphology and kinematics of the outer ejecta is given and put into context with the structure and kinematics of the inner part of the nebula, the Homunculus.

To appear in 'Eta Carinae and other mysterious stars', ASP Conf. Series
Preprints from `kweis@ita.uni-heidelberg.de`
or on the web at `http://www.ita.uni-heidelberg.de/~kweis/publications.html`

LBV Nebulae: The Mass Lost from the Most Massive Stars

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The most massive stars, with initial masses above $\sim 50\,\mathrm{M_\odot}$, encounter a phase of extreme mass loss—sometimes accompanied by so-called giant eruptions—in which the stars' evolution is reversed from a redward to a blueward motion in the HRD. In this phase the stars are known as *Luminous Blue Variables* (LBVs). Neither the reason for the onset of the strong mass loss nor the cause for the giant eruptions is really understood, nor is their implications for the evolution of these most massive stars. I will present a study of the LBV nebulae which are formed in this phase as a consequence of the strong mass loss and draw conclusions from the morphology and kinematics of these nebulae on possible eruption mechanisms and stellar parameters of the LBV stars. The analysis contains a large collection of LBV nebulae which form an evolutionary sequence of LBV nebulae. A special concern will be the frequently observed bipolar nature of the LBV nebulae which seems to be a general feature and presents strong constraints on further models of the LBV phase and especially on the formation mechanism of the nebulae.

To appear in: Reviews in Modern Astronomy 14 (Schielicke R.E., ed.), Springer
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