THE HOT STAR NEWSLETTER

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

No. 4 editor: Philippe Eenens
12 December 1994 eenens@tonali.inaoep.mx

# Abstracts: theory

## Effects of accretion onto massive main sequence stars

**H. Braun[1] and N.Langer[1]**

[1]Max-Planck-Institut für Astrophysik, Karl-Schwarzschildt-Str. 1, 85740 Garching, Germany

We investigate the effect of mass accretion onto massive main sequence stars on their internal structure and evolution. Adopted accretion rates and accretion time scales are in the range applying to massive Case B binary systems. For the first time, we incorporate the influence of molecular weight gradients on convection in this context. In contrast to earlier studies, we find that the so called “rejuvenation” of the mass accreting star does not always take place. Rather, stellar models with a chemical structure unlike that of single stars may be obtained. We investigate which physical parameters determine whether rejuvenation occurs, namely the fraction of the core hydrogen burning time spent until the onset of accretion, the amount of matter accreted, the initial mass of the accreting star, and the efficiency of convection in regions of stabilizing mean molecular weight gradients.

Further on, the evolution of accretion stars until central carbon ignition is investigated. We find that the main result of non-rejuvenation is a much smaller helium core mass and accordingly longer core helium burning times compared to single stars. This may lead to blue supergiant positions adjacent to the main sequence band in the HR diagram, and to blue supergiant pre-supernova configurations. Possible relations to the observed distribution of luminous stars in the HR diagram of the LMC and to the progenitor of supernova 1987 A are discussed.

**Accepted by A&A.** *For preprints, contact* hartl@mpa-garching.mpg.de

## On the Richardson criterion for shear instabilities in rotating stars

**André Maeder[1]**

[1] Observatoire de Genève, CH-1290 Sauverny, Switzerland

We examine the onset of instabilities and mixing in shear layers, taking into account the radiative heat losses and $\mu$–gradients. A new and consistent expression of the Richardson criterion is given. In the two limiting cases of adiabatic shears and shears with extreme heat losses we recover the classical expressions. Numerical estimates show that real stellar cases lie in–between these two extreme cases.

The turbulent viscosity and diffusion coefficients due to vertical shears are derived. The $\mu$–gradient necessary for stability depends on both the shear and the Peclet number. Interestingly enough, in a semiconvective zone we find an increased difficulty to inhibit shear instabilities by $\mu$–gradient. Thus, due to its small timescale, mixing by shear instabilities could dominate over semiconvective mixing in rotating stars. Finally, a simple expression for the temperature gradient in shear layers is given.

**Accepted by A & A** *For preprints, contact* maeder@scsun.unige.ch

## Abstracts: observations

# Proof of a fast wind in the symbiotic nova AG Pegasi

**Harry Nussbaumer[1], Werner Schmutz[1] and Manfred Vogel[1]**

[1] Institute of Astronomy, ETH-Zentrum, CH-8092 Zürich, Switzerland

Hubble Space Telescope observations of the symbiotic nova AG Peg reveal a P Cygni profile in N V $\lambda$1240. This proves that the hot compact object in the binary system loses material through a fast wind. High resolution spectra allow to discern three different emission regions: the wind from the hot compact star, a nebular emission region of relatively high density located in the extended atmosphere of the red giant, and a region of lower density most probably associated with the location where the fast wind from the hot star collides with the wind from the red giant.

**Accepted by Astron.Astrophys.** *For preprints, contact* nussbaum@astro.phys.ethz.ch

# Ultraviolet and optical spectroscopy of a B supergiant star in M31

**Luciana Bianchi[1,2], Henny J.G.L.M. Lamers[3] J.B. Hutchings[4], Philip Massey[5] Rolf Kudritzki[6,7], Artemio Herrero[8], and Danny J. Lennon[6]**

[1] Space Telescope Science Institute, 3700 San Martin dr.,Baltimore MD21218, USA

[2] Osservatorio Astronomico, I-10025 Pino Torinese (TO), Italy

[3] SRON Laboratory for Space Research and Astronomical Institute at Utrecht, Sorbonnelaan 2, NL-3584 CA Utrecht, Netherlands

[4] Dominion Astrophysical Observatory, 5071 W.Saanich Rd., Victoria, BC V8X 4M6, Canada

[5] Kitt Peak National Observatory, NOAO, P.O. Box 26732, Tucson, AZ85726-6732,

[6] Institut für Astronomie und Astrophysik Uni.München, Scheinerstr.1, D-W-8000 München 80, Germany

[7] Max Plank Institut für Astrophysik, Karl-Schwartzschild str. 1, D-85748 Garching bei München, Germany

[8] Instituto de Astrofísica de Canarias ,E-38200 La Laguna, Tenerife, Spain

We present and discuss the UV spectrum of the supergiant star in NGC206-277 in M31, obtained with the Faint Object Spectrograph (FOS) on *Hubble Space Telescope.* Customised extraction of the data was used to properly correct for the background light in the FOS. An optical blue spectrum taken at KPNO is also shown. From the optical and UV line spectra we classify the star B1.5Ia. We fit the continuum far-UV flux distribution, deriving $T_{eff}$=20000 K, and with this temperature we find log g=2.5 by comparing the $H_\gamma$ line and He I lines with predictions from NLTE models. We analyse the stellar UV wind line profiles with the SEI method and derive a terminal velocity of $v_\infty \simeq 700$ km/s.

We fit the H$\alpha$ emission line obtained at the WHT with a newly developed (by H.J.G.L.M.L.) code similar to the SEI method for UV lines, and derive $\dot{M}$=1.3 ± 0.5 10 $^{-6}$ $M_\odot$ yr$^{-1}$. We also compare the UV lines with those of Galactic stars of the same type and we find that the P Cygni profiles of the M31 star have slightly weaker and narrower absorptions, and no emission component.

We correct our previously published mass-loss estimate for an O star (NGC206-231) in the same association. The correct value is $\dot{M} \approx 10^{-6}$ $M_\odot$ yr$^{-1}$, assuming solar abundances.

**Accepted by A & A** *For preprints, contact* Bianchi@stsci.edu

## Combined spectrometric, photometric and polarimetric diagnostics for 'blobs' in WR star winds

**J.C. Brown[1], L.L. Richardson[1], I. Antokhin[2], C. Robert[3], A.F.J. Moffat[4] and N. St-Louis[4]**

[1] Dept. of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, Scotland.

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

[3] Space Telescope Science Institute, 3700 San Martin Dve., Baltimore MD 21218, USA.

[4] Dépt. de Physique, Université de Montréal, CP 6128, Succ. A, Montréal PQ H3C 3JC, and Observatoire de Mont Mégantic, Canada.

The quantitative interpretation of photometric, spectrometric and polarimetric data on transient features in WR stars is discussed and the diagnostic potential of detailed simultaneous coverage in all three modes emphasised. Our main conclusions/suggestions are :-

(i) Narrow emission line features are due to localised density enhancements in the mean near spherical wind structure;

(ii) Broad-band photo-/polari-metric transients are due to both scattering of starlight and emission in the blobs;

(iii) The amplitude of a polarisation transient is an indicator of the mass of a single blob, combined with the narrow feature width or the narrow feature luminosity. This allows blob density estimation;

(iv) The dense blobs cannot form *in* the visible part of the wind since redistribution of electrons in a localised blob would not result in a continuum polarimetric transient – rather they must form inside the effective photosphere;

(v) Star-blobs distance indicators include, for a single blob, the ratio of polarimetric to photometric transient feature amplitudes and the rate of change of polarisation;

(vi) When many blobs are present, if blob broad-band emission is significant, or if there is multiple scattering in the blobs, the polarimetric/photometric variation amplitude is reduced (as observed). This makes blob distance determination more difficult;

(vii) Narrow feature widths variation with feature shift is an indicator of blob velocity structure. If this is attributed to the general wind velocity gradient then the feature width ratio is only compatible with statistical observations of bullet acceleration/velocity trajectories for winds with substantial initial speed (at the effective photospheric surface). If the wind speed is low at the effective photosphere, explanation of the feature width variation requires either significant electron scattering optical depth within radially elongated blobs or strong differential motion within the blobs.

**Accepted by A&A** *For preprints, contact* john@astro.gla.ac.uk

# Observations and analyses of the S vi $\lambda$ 1975, $\lambda$ 1993 Å lines in the IUE ultraviolet spectra of WN stars

**T.Nugis [1] and A.J.Willis [2]**

[1] Tartu Astrophysical Observatory, EE 2444, Tõravere, Estonia

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

From a detailed study of high resolution *IUE* ultraviolet spectra we identify strong emission lines near $\sim \lambda$1990 Å as the S vi ($4p^2P^o$–$4d^2D$) transitions at $\lambda$ 1975.21 Å , $\lambda$ 1992.56, 1993.24Å in HD 187282 (WN4), HD 50896 (WN5), HD 191765 (WN6) and HD 192163 (WN6). These S vi emissions may also be weakly present in HD 151932 (WN7). Additional S vi (4s $^2$S–4p $^2$P$^o$) $\lambda$2587, $\lambda$2618 emission features are also evident in the WNE spectra. Theoretical S vi line intensities are calculated using empirical nLTE model atmosphere codes adopting both spherically–symmetric, homogeneous and clumped wind structures. The observed S vi line strengths compared to the model predictions yield an estimated abundance ratio of S/He$\sim$[2–3]$\times 10^{-4}$ by number. Within the observational and modelling uncertainties, this value is consistent with an intial near–solar abundance ratio, slightly modified by helium enhancement *via* CNO-burning, although a S-overabundance of $\times$2–3 cannot be ruled out.

**Accepted by: A & A** *For preprints, contact* ajw@star.ucl.ac.uk

# ROSAT observations of $\gamma$ Velorum (WC8+O9I) – Paper I: The discovery of colliding–wind X–ray emission

**Allan J. Willis[1], Hans Schild[2], & Ian R. Stevens[3]**

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

[2] Institute of Astronomy, ETH–Zentrum, CH–8092 Zurich, Switzerland

[3] School of Physics & Space Research, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

We present an analysis of 13 X-ray (0.1–2.5 keV) observations of $\gamma$ Velorum obtained with the XRT+PSPC on the *ROSAT* satellite. The first set of 10 observations were obtained in our Guest Observer AO2 programme, with 9 at roughly 8–day intervals in the $78^d.5$ binary period, providing nearly complete phase coverage. Of these, the last two (secured at phases .48 and .53) show respectively, a factor of 2 and 4 increase in X-ray emission, compared to the (relatively) constant flux at other phases. The increase in flux at phase .5 in our AO2 data is due to an additional, harder component superimposed on the (largely unvarying) soft X–ray flux reflecting 'low–state' emission. Rough spectral fitting suggests that this additional harder component has kT $\geq$ 2 keV and $L_x \geq 10^{32}$ erg $s^{-1}$, but these cannot be fully constrained within the limited energy range of the PSPC. Three further PSPC observations, secured in a Target of Opportunity programme during AO3, confirm that the increase in X-ray emission at $\phi \sim .5$ is cycle/phase repeatable. We conclude that this is due to emission produced in the wind collision, observed through a cavity in the WC8 wind around the O–star. The derived, well-defined light curve of this colliding–wind X–ray emission is asymmetric, due to orbital motion effects, with a half–opening angle of $\sim 25^o$. Spectral fitting to the 'low–state' PSPC data yields: log $N_H$ = 20.2 $\pm$0.2 and kT = 0.19 keV ($\equiv$ T = 2.2x$10^6$ K). The derived $N_H$ is consistent with purely ISM absorption, for which log $N_H$ =19.9 $\pm$ 0.1 is derived from IUE Lyman–$\alpha$ data. Adopting a distance of 0.5 kpc, yields a mean 'low–state' X–ray luminosity of 2.5 $\times 10^{31}$ erg $s^{-1}$. We consider this low–state X–ray emission arises in shocked material in the WC8 wind caused by radiatively–driven instabilities. The *ROSAT* observations show that $\gamma$ Velorum is located in a cluster of (at least) 6 resolved sources within the central 3'x5'of the FOV. The total PSPC flux of these other sources is comparable to the 'low–state' PSPC flux for $\gamma$ Velorum alone. These cluster sources were

not resolved in previous *Einstein* IPC X–ray data, and they clearly contributed to previous estimates of the luminosity and spectrum assigned to $\gamma$ Velorum in the 0.4–4.5 keV range. We have calculated state-of-the-art hydrodynamical models of colliding winds in the $\gamma$ Velorum system. These models predict copious X–ray emission with kT$\sim$3–5 keV, consistent with, but not constrained by the soft *ROSAT* data available. Our modelling shows: (a) a pronounced cavity and high temperatures shocked region does form around the O–star, (b) the predicted half–opening angle is $\sim$ 20–30$^o$, (c) at *ROSAT* energies, wind–collision X–ray emission should only be seen around phase .5, with a luminosity $\sim 10^{33}$ erg s$^{-1}$ (strongly dependent on the presumed O–star wind velocity at the interface region). Within current uncertainties in the binary system parameters we conclude that our model results are fully compatible with the observed X–ray light curve. Further, harder X–ray observations of the colliding wind emission we have discovered in $\gamma$ Velorum are needed to quantify its spectrum, luminosity and absorption, and provide important tests and constraints on the complex theory of the colliding wind phenomenon. We have recently been awarded time on the ASCA satellite to secure these data.

**Accepted by A & A** *For preprints, contact* ajw@star.ucl.ac.uk

## Massive stars in the field and associations of the Magellanic Clouds: the upper mass limit, the initial mass function, and a critical test of main-sequence stellar evolutionary theory

**Philip Massey[1], Cornelia C. Lang[2], Kathleen Degioia-Eastwood[2] and Catharine D. Garmany[3]**

[1] Kitt Peak National Observatory, National Optical Astronomy Observatories, P.O. Box 26732, Tucson, AZ 85726-6732

[2] Department of Physics and Astronomy, Northern Arizona University, P.O. 6010, Flagstaff, AZ 86011-6010

[3] Joint Institute for Laboratory Astrophysics, Campus Box 440, University of Colorado Boulder, CO 80309-0440

We investigate the massive star population of the Magellanic Clouds with an emphasis on the field population, which we define as stars located further from any OB association than massive stars are likely to travel during their short lifetimes. The field stars must have been born as part of more modest star-forming events than those that have populated the large OB associations found throughout the Clouds. We use new and existing data to answer the following questions: Does the field produce stars as massive as those found in associations? Is the initial mass function (IMF) of these field massive stars the same as those of large OB complexes? How well do the Geneva low-metallicity evolutionary models reproduce what is seen in the field population, with its mixed ages?

To address these issues we begin by updating existing catalogs of LMC and SMC members with our own new spectral types and derive H-R diagrams (HRDs) of 1584 LMC and 512 SMC stars. We use new photometry and spectroscopy of selected regions in order to determine the incompleteness corrections of the catalogs as a function of mass and find that we can reliably correct the number of stars in our HRDs down to 25 $\mathcal{M}_\odot$. Using these data we derive distance moduli for the Clouds via spectroscopic parallax, finding values of $18.4 \pm 0.1$ and $19.1 \pm 0.3$ for the LMC and SMC. The average reddening of the field stars is small: $E(B-V) = 0.13$ (LMC) and 0.09 (SMC), with little spread.

We find that the field *does* produce stars as massive as any found in associations, with stars as massive as 85 $\mathcal{M}_\odot$ present in the HRD even when safeguards against the inclusion of runaway stars are included. However, such massive stars are much less likely to be produced in the field (relative to lower mass stars) than in large OB complexes: the slope of the IMF of the field stars is very steep, $\Gamma = -4.1 \pm 0.2$ (LMC) and $\Gamma = -3.7 \pm 0.5$ (SMC). These may be compared with $\Gamma = -1.3 \pm 0.3$, which we rederive for the Magellanic Cloud associations. (We compare our association IMFs with the somewhat different results recently derived by Hill et al. and demonstrate that the latter suffer

from systematic effects due to the lack of spectroscopy.) Our reanalysis of the Garmany et al. data reveals that the Galactic field population has a similarly steep slope, with $\Gamma = -3.4 \pm 1.3$, compared to $\Gamma = -1.5 \pm 0.2$ for the entire Galactic sample. We do not see any difference in the IMFs of associations in the Milky Way, LMC, and SMC.

We find that the low metallicity evolutionary tracks and isochrones do an excellent job of reproducing the distribution of stars in the HRD at higher masses, and in particular match the width of the main-sequence well. There may or may not be an absence of massive stars with ages <2 Myr in the Magellanic Clouds, as others have found for Galactic stars; our reddening data renders unlikely the suggestion that such an absence (if real) would be due to the length of time it takes for a massive star to emerge. There is an increasing discrepancy between the theoretical ZAMS and the blue edge of the main-sequence at lower luminosities; this may reflect a metallicity dependence for the intrinsic colors of stars of early B and later beyond that predicted by model atmospheres, or it may be that the low metallicity ZAMS is misplaced to higher temperatures. Finally, we use the relative number of *field* main-sequence and Wolf-Rayet stars to provide a selection-free determination of what mass progenitors become WR stars in the Magellanic Clouds. Our data suggest that stars with initial masses $> 30\mathcal{M}_\odot$ evolve to a WR phase in the LMC; while the statistics are considerably less certain for the SMC, they are consistent with this limit being modestly higher there, possibly 50 $\mathcal{M}_\odot$, in qualitative agreement with modern evolutionary calculations.

**Accepted by ApJ** *For preprints, contact* massey@noao.edu

## The physics of massive OB stars in different parent galaxies. I. Ultraviolet and optical spectral morphology in the Magellanic Clouds

**Nolan R. Walborn[1], Daniel J. Lennon[2], Stephan M. Haser[2], Rolf-Peter Kudritzki[2], and Stephen A. Voels[3]**

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

[2]Institute for Astronomy and Astrophysics, Munich University, Scheinerstrasse 1, D-81679 Munich, Germany

[3]Astrophysics Data Facility, Code 631, Goddard Space Flight Center, Greenbelt, Maryland 20771, USA

HST/FOS and ESO 3.6m/CASPEC observations have been made of 18 stars ranging in spectral type from O3 through B0.5 Ia, half of them in each of the Large and Small Magellanic Clouds, in order to investigate massive stellar winds and evolution as a function of metallicity. The spectroscopic data are initially presented and described here in an atlas format. The relative weakness of the stellar-wind features in the SMC early O V spectra, due to their metal deficiency, is remarkable. Because of their unsaturated profiles, discrete absorption components can be detected in many of them, which is generally not possible in LMC and Galactic counterparts at such early types, or even in SMC giants and supergiants. On the other hand, an O3 III spectrum in the SMC has a weak C IV but strong N V wind profile, possibly indicating the presence of processed material. Wind terminal velocities are also given and intercompared between similar spectral types in the two galaxies. In general, the terminal velocities of the SMC stars are smaller, in qualitative agreement with the predictions of radiation-driven wind theory. Further analyses in progress will provide atmospheric and wind parameters for these stars, which will be relevant to evolutionary models and the interpretation of composite starburst spectra.

**Accepted by PASP** *For preprints, contact* walborn@stsci.edu

## Resolution of massive compact clusters in the 30 Doradus periphery with HST

**Nolan R. Walborn[1], John W. MacKenty[1], Abhijit Saha[1], Richard L. White[1], and Joel Wm. Parker[2]**

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

[2]Hughes STX Corporation, Code 681, Goddard Space Flight Center, Greenbelt, Maryland 20771

HST WF/PC I *UBV* images of three massive, compact multiple systems within the SNR 30 Dor B/NGC 2060 and 30 Dor C/NGC 2044 are discussed and illustrated. In two cases, WN+OB objects have been resolved into additional components to those previously known from ground-based observations, substantially reducing the luminosities of the WN stars and rendering them currently unidentified; in the third case, the components of a B+K composite-spectrum object have been clearly identified. The results are of significance for evolutionary interpretations of these massive stars and for determinations of the upper IMF in extragalactic systems.

**Accepted by Ap. J. Letters** *For preprints, contact* walborn@stsci.edu

## Spectroscopic observations of PU Vulpeculae in the 3210 - 10950 Å range during the nebular phase

**Yvette Andrillat [1] and Leo Houziaux [2]**

[1] Laboratoire d'Astronomie, Universite de Montpellier II, France

[2] Département d'Astrophysique , Université de Mons-Hainaut

Spectroscopic observations of PU Vulpeculae have been carried out at the Observatoire de Haute-Provence from 1989 June to 1992 September during a decline of brightness from 10.1 to 11.2 in visual magnitude. A spectral type M6III may be proposed for the cool component from the TiO bands intensities, while the hot surrounding gas is responsible for about 280 emission lines (many of which belong to Fe+ and Fe++ ions) undergoing variations in intensity. Analysis of the [OIII] lines reveals a kinetic temperature of about 12000K and a lower limit for the electron density of 6.7 x $10^7$ $cm^{-3}$ in October 1991, decreasing by a factor of $\sim$ 2-3 by 1992 September. Helium may be slightly overabundant (by a factor of $\sim$ 2) with respect to the solar value.

**Accepted by MNRAS** *For preprints, contact* U2141LH@vm1.ulg.ac.be