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and related phenomena in galaxies

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Accepted Papers

Non-LTE line-formation for neutral and singly ionized carbon

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A comprehensive model atom for non-LTE line-formation calculations for neutral and singly-ionized carbon is presented. Highly accurate radiative and collisional atomic data are incorporated, recently determined for astrophysical and fusion research using the R-matrix method in the close-coupling approximation. As a test and first application of the model, carbon abundances are determined on the basis of line-blanketed LTE model atmospheres for five stars, the main sequence object Vega (A0 V) and the supergiants η Leo (A0 Ib), HD 111613 (A2 Iabe), HD 92207 (A0 Iae) and β Ori (B8 Iae), using high S/N and high-resolution spectra at visual and near-IR wavelengths. The computed non-LTE line profiles fit the observations well for a single carbon abundance in each object. For two supergiants, η Leo and HD 111613, lines of both species are simultaneously present in the spectra, giving consistent C I and C II abundances (within the error bars). However, the uncertainties of the abundances are large, on the order of $\sim$0.3 dex (statistical+systematical error), thus the ionization equilibrium of C I/II is of restricted use for the determination of stellar parameters. All supergiants within our sample show a depletion of carbon on the order of 0.2–0.5 dex, indicating the mixing of CN-cycled material into the atmospheric layers, with the sum of the CNO abundances remaining close to solar. This finding is in accordance with recent stellar evolution models accounting for mass-loss and rotation. For Vega, an underabundance of carbon by 0.3 dex is found, in excellent agreement with the similar underabundance of other light elements. The dependence of the non-LTE effects on the atmospheric parameters is discussed and the influence of systematic errors is estimated. Special emphasis is given to the supergiants where a strong radiation field at low particle densities favours deviations from LTE . Non-LTE effects systematically strengthen the C I/II lines. For the C I lines in the infrared, a strong sensitivity to modifications in the photoionization and collisional excitation data is found. An increasing discrepancy between our model predictions and the observations for the C II doublet $\lambda\lambda$ 6578-82 is perceived with rising luminosity, while the other C II doublet and quartet lines remain consistent. Furthermore, the influence of microturbulence on the statistical-equilibrium calculations is investigated.

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Non-LTE line-formation for N I/II: abundances and stellar parameters

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A comprehensive model atom for non-LTE line formation calculations for neutral and singly-ionized nitrogen is presented. Highly accurate radiative and collisional atomic data are incorporated, recently determined for astrophysical and fusion research using the *R*-matrix method in the close-coupling approximation. As a test and first application of the model, nitrogen abundances are determined on the basis of line-blanketed LTE model atmospheres for five stars, the main sequence object Vega (A0 V) and the supergiants η Leo (A0 Ib), HD 111613 (A2 Iabe), HD 92207 (A0 Iae) and β Ori (B8 Iae), using high S/N and high-resolution spectra at visual and near-IR wavelengths. The computed non-LTE line profiles fit the observations excellently for a given nitrogen abundance in each object. Moreover, the ionization equilibrium of N I/II proves to be a sensitive temperature indicator for late B-type and early A-type supergiants – even at low metallicities – due to the apparent nitrogen overabundance in these objects. All supergiants within our sample show an enrichment of nitrogen of the order of ~0.3-0.6 dex, indicating the mixing of CN-cycled material into atmospheric layers, with the sum of the CNO abundances staying close to solar. This finding is in accordance with recent stellar evolution models accounting for mass-loss and rotation. For Vega, an underabundance of nitrogen by 0.25 dex is found, in good agreement with the similar underabundance of other light elements. The dependence of the non-LTE effects on the atmospheric parameters is discussed with special emphasis on the supergiants where a strong radiation field at low particle densities favours deviations from LTE. Non-LTE effects systematically strengthen the N I/II lines. For some N I lines in supergiants non-LTE abundance corrections in excess of 1 dex are found and they react sensitively to modifications of the collisional excitation data. The influence of microturbulence on the statistical-equilibrium calculations is also investigated: the line-strengths of the strong N I features show some sensitivity due to modifications of the line-formation depths and the departure coefficients, while the – in this parameter range – weak N II lines remain unaffected.

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Expanding atmospheres in non-LTE : Radiation Transfer using Short Characteristics

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We present our technique for solving the equations of radiation transfer in spherically expanding atmospheres. To ensure an efficient treatment of the Thomson scattering, the mean intensity J is derived by solving the moment equations in turn with the angle-dependent transfer equation. The latter provide the Eddington factors. Two different methods for the solution of the angle dependent equation are compared. Thereby the integration along short characteristics turned out to be superior in our context over the classical differencing scheme. The method is the basis of a non-LTE code suitable for the atmospheres of hot stars with high mass-loss.

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Ongoing massive star formation in the bulge of M51

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We present a study of $HST-WFPC2$ observations of the inner kpc of the interacting galaxy M51 in six bands from 2550 Å to 8140 Å. The images show an oval shaped area (which we call "bulge") of about 11×16 arcsec or 450×650 pc around the nucleus that is dominated by a smooth "yellow/reddish" background population with overimposed dust lanes. These dust lanes are the inner extensions of the spiral arms. The extinction properties, derived in four fields in and outside dust lanes, is similar to the Galactic extinction law. The reddish stellar population has an intrinsic color of $(B-V)_0 \simeq 1.0$ suggesting an age in excess of 5 Gyrs.

We found 30 bright point-like sources in the bulge of of M51 i.e. within 110 to 350 pc from the nucleus. The point sources have $21.4 < V < 24.3$, many of which are blue with $B-V < 0$ and are bright in the UV with $19.8 < m_{2550} < 22.0$. These objects appear to be located in elongated "strings" which follow the general pattern of the dust lanes around the nucleus. The spectral energy distributions of

the point-like sources are compared with those predicted for models of clusters or single stars. There are three reasons to conclude that most of these point sources are isolated massive stars (or very small groups of a few isolated massive stars) rather than clusters:
(a) The energy distributions of most objects are best fitted with models of single stars of M_V between -6.1 and -9.1, temperatures between 4000 and 50000 K, and with $4.2 < \log L/L_\odot < 7.2$, and $12 < M_* < 200\ M_\odot$.
(b) In the HR diagram the sources follow the Humphreys-Davidson luminosity upper limit for massive 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 HRD by stars, but not of clusters.
We have derived upper limits to the total mass of lower mass stars ($M_* < 10\ M_\odot$), that could be "hiding" within the point sources. For the "bluest" sources the upper limit is only a few hundred $M_\odot$.

We conclude that the formation of massive stars outside clusters (or in very low mass clusters) is occurring in the bulge of M51.

The estimated star formation rate in the bulge of M51 is 1 to 2×10^{-3} ($M_\odot\,{\rm yr}^{-1}$), depending on the adopted IMF. With the observed total amount of gas in the bulge, $\sim 4 \times 10^5 M_\odot$, and the observed normal gas to dust ratio of ~ 150, this star formation rate could be sustained for about 2 to 4×10^8 years. This suggests that the ongoing massive star formation in the bulge of M51 is fed/triggered by the interaction with its companion about 4×10^8 years ago. The star formation in the bulge of M51 ia compared with tat in bulges of other spirals.

Theoretical predictions of star formation suggest that isolated 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 are met in the bulge of M51, where the extinction is low and where CO can be destroyed by the radiation from the bright nuclear starburst cluster in the center. The mode of formation of massive stars in the bulge of M51 may resemble the star formation in the early Universe, when the CO and dust contents were low due to the low metallicity.

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A *UBVR* CCD Surey of the Magellanic Clouds

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We present photometry and a preliminary interpretation of a *UBVR* survey of the Large and Small Magellanic Clouds, which covers 14.5 deg^2 and 7.2 deg^2, respectively. This study is aimed at obtaining well-calibrated data on the brighter, massive stars, complementing recent, deeper CCD surveys. Our catalog contains 179,655 LMC and 84,995 SMC stars brighter than $V \sim 18.0$, and is photometrically complete to $U \sim B \sim V \sim 15.7$, and $R \sim 15.2$, although stars in crowded regions are selectively missed. We provide tentative cross-reference between our catalog stars and the stars with existing spectroscopy. Our photometry agrees well with the photoelectric work in V and $B–V$, and agrees well for $U–B$ for the bluest stars, but we find a large discrepancy (0.3 mag) in the $U–B$ color at $U–B\sim 0.0$. Examination of the colors of stars with known spectral types suggests that the problem *may* lie with the photoelectric data. We discuss the population of stars seen towards the two Clouds, identifying the features in the color-magnitude diagram, and using existing spectroscopy to help construct H-R diagrams. We derive improved values for the blue to red star ratios in the two Clouds, emphasizing

the uncertainties involved in this before additional spectroscopy. We compare the relative number of RSGs and Wolf-Rayet stars in the LMC and SMC with that of other galaxies in the Local Group, demonstrating a very strong, tight trend with metallicity, with the ratio changing by a factor of 160 from the SMC to M31. We also reinvestigate the initial mass function of the massive stars found outside of the OB associations. With the newer data, we find that the IMF slope of this field population is very steep, with $\Gamma \sim -4 \pm 0.5$, in agreement with our earlier work. This is in sharp contrast to the IMF slope found for the massive stars with OB associations ($\Gamma \sim -1.3$). Although much more spectroscopy is needed to make this result firm, incompleteness can no longer be invoked as an explanation.

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On the properties of massive Population III stars and metal-free stellar populations

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We present realistic models for massive Population III stars and stellar populations based on non-LTE model atmospheres, recent stellar evolution tracks and up-to-date evolutionary synthesis models, with the aim to study their spectral properties, including their dependence on age, star formation history, and IMF.

A comparison of plane parallel non-LTE model atmospheres and comoving frame calculations shows that even in the presence of some putative weak mass loss, the ionising spectra of metal-free populations differ little or negligibly from those obtained using plane parallel non-LTE models. As already discussed by Tumlinson & Shull (2000), the main salient property of Pop III stars is their increased ionising flux, especially in the He^+ continuum (> 54 eV).

The main result obtained for *individual Pop III stars* is the following: Due to their redward evolution off the zero age main sequence (ZAMS) the spectral hardness measured by the He^+/H ionising flux is decreased by a factor ~ 2 when averaged over their lifetime. If such stars would suffer strong mass loss, their spectral appearance could, however, remain similar to that of their ZAMS position.

The main results regarding *integrated stellar populations* are:

- For young bursts and the case of a constant SFR, nebular continuous emission — neglected in previous studies — dominates the spectrum redward of Lyman-α if the escape fraction of ionising photons out of the considered region is small or negligible. In consequence predicted emission line equivalent widths are considerably smaller than found in earlier studies, whereas the detection of the continuum is eased. Nebular line and continuous emission strongly affect the broad band photometric properties of Pop III objects.

- Due to the redward stellar evolution and short lifetimes of the most massive stars, the hardness of the ionising spectrum decreases rapidly, leading to the disappearance of the characteristic He II recombination lines after ~ 3 Myr in instantaneous bursts.

- He II λ1640, Hα (and other) line luminosities usable as indicators of the star formation rate are given for the case of a constant SFR. For obvious reasons such indicators depend strongly on the IMF.

- Due to an increased photon production and reduced metal yields, the relative efficiency of ionising photon energy to heavy element rest mass production, η, of metal-poor and metal-free populations is increased by factors of $\sim$ 4 to 18 with respect to solar metallicity and for "standard" IMFs.

- The lowest values of $\eta \sim 1.6 - 2.2$ % are obtained for IMFs exclusively populated with high mass stars ($M_{low} > 50$ $M_\odot$). If correct, the yields dominated by pair creation SNae then predict large overabundances of O/C and Si/C compared to solar abundance ratios.

Detailed results are given in tabular form and as fit formulae for easy implementation in other calculations. The predicted spectra will be used to study the detectability of Pop III galaxies and to derive optimal search strategies for such objects.

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The origin of primary nitrogen in galaxies

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We investigate the role of stellar axial rotation on the nitrogen nucleosynthesis at low metallicities Z. For this purpose, we have calculated models with initial masses between 2 and 60 $M_\odot$ at Z=0.00001 from the zero age sequence to the phase of thermal pulses for models below or equal to 7 $M_\odot$, and up to the end of central C–burning for the more massive stars. The models include all the main physical effects of rotation. We show that intermediate mass stars with rotation naturally reproduce the occurrence and amount of primary nitrogen in the early star generations in the Universe. We identify two reasons why rotating models at low Z produce primary ^{14}N: 1) Since the stars lose less angular momentum, they rotate faster. Simultaneously, they are more compact, thus differential rotation and shear mixing are stronger. 2) The H–burning shell has a much higher temperature and is thus closer to the core, which favours mixing between the two.

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Calculation of the Masses of the Binary Star HD 93205 by Application of the Theory of the Apsidal Motion

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We present a method to calculate masses for components of both eclipsing and non-eclipsing binary systems as long as their apsidal motion rates are available. The method is based on the fact that the equation that gives the rate of apsidal motion is a supplementary equation that allows the computation of the masses of the components, if the radii and the internal structure constants of them can be

obtained from theoretical models. For this reason the use of this equation makes the method presented here *model dependent*.

We apply this method to calculate the mass of the components of the *non-eclipsing* massive binary system HD 93205 (O3 V+O8 V), which is suspected to be a very young system. To this end, we computed a grid of evolutionary models covering the mass range of interest, and taking the mass of the primary (M_1) as the only independent variable, we solve the equation of apsidal motion for M_1 as a function of the age of the system. The mass of the primary we find ranges from $M_1 = 60 \pm 19 M_\odot$ for ZAMS models, which sets an upper limit for M_1, down to $M_1 = 40 \pm 9 M_\odot$ for an age of 2 Myr. Accordingly, the upper limit derived for the mass of the secondary ($M_2 = QM_1$) is $M_2 = 25 M_\odot$ is in very good agreement with the masses derived for other O8 V stars occurring in eclipsing binaries.

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Rotational velocities of A-type stars I. Measurement of $v \sin i$ in the southern hemisphere

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Within the scope of a Key Programme determining fundamental parameters of stars observed by HIPPARCOS, spectra of 525 B8 to F2-type stars brighter than $V = 8$ have been collected at ESO. Fourier transforms of several line profiles in the range 4200–4500 Å are used to derive $v \sin i$ from the frequency of the first zero. Statistical analysis of the sample indicates that measurement error is a function of vsini and this relative error of the rotational velocity is found to be about 6% on average. The results obtained are compared with data from the literature. There is a systematic shift from standard values from Slettebak et al. (1975), which are 10 to 12% lower than our findings. Comparisons with other independent $v \sin i$ values tend to prove that those from Slettebak et al. are underestimated. This effect is attributed to the presence of binaries in the standard sample of Slettebak et al., and to the model atmosphere they used.

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The H I Environment of Three Superbubbles in the Large Magellanic Cloud

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The ambient interstellar environment of wind- and supernova-driven superbubbles strongly affects their evolution, but its properties are rarely well-determined. We have therefore obtained H I aperture

synthesis imaging of the environment around three similar, optically-selected superbubble nebulae in the Large Magellanic Cloud. The resulting H I maps show that the ambient gas distribution around these superbubbles differ to an extreme: DEM L25 shows no neutral shell component, but is nestled within an H I hole; DEM L50 shows a massive neutral shell component, but is otherwise within an H I void; and DEM L301 shows no correspondence at all between the optical nebula and H I distribution. There is also poor correspondence between the H I and optical kinematics. These results strongly caution against inferring properties of the ambient neutral environment of individual superbubbles without direct observations. Finally, all three objects show some evidence of shock activity.

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The enigmatic WR 46: a binary or a pulsator in disguise. I. The photometry

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We discuss the observational history of the Wolf-Rayet object WR 46 (WN3p), including a re-investigation of the original discovery plates from early this century. We find that the reported presence of N III lines is a mis-interpretation of N V lines and conclude that the object did not change its spectral type since the first recording one century ago. We performed photometric monitoring in the period 1986 – 1999, and confirm that the object shows cyclical variability on a time scale of hours. The shape of the light curves varies from purely sinusoidal to irregular, and from an amplitude of nearly 0.1 mag to constancy. In addition, night-to-night variability of the mean brightness causes folded light curves to display a large scatter. We investigate the frequency behaviour of the photometric data. From the periodograms of our two large data sets, in 1989 and in 1991, we identify frequencies of significantly different values 7.08 cd^{-1} and 7.34 cd^{-1}, respectively. Moreover, the 1989 data show strong evidence for an additional frequency $f_{\rm x}$ = 4.34 cd^{-1}. The periodograms of our eight smaller data sets show more ambiguous behaviour. We discuss whether these latter data show evidence for multi-frequency behaviour, or whether they can be reconciled with a single clock with a changing clock-rate. As pointed out by van Genderen et al. (1991), if the data are folded using twice the single-wave period, the light curves appear ellipsoidal with unequal minima. Although the difference in depth of the minima is hardly significant, it does occur in both large data sets. Moreover, the simultaneously obtained radial velocity measurements are in better agreement with the double-wave than the single-wave period (Paper II). Finally, Marchenko et al. (2000) observed WR 46 to have a single-wave period of the same order as the double-wave period identified here. The periodograms of the $(V–W)$ colour index show that the colour changes are controlled by single-wave frequencies, or their sub-harmonics (double-wave periods), but not by $f_{\rm x}$. The colour variation of WR 46 is peculiar in the sense that the object is red when bright and blue when faint. Although the spectrum of WR 46 has been suggested to originate from a stellar disc, this peculiar colour behaviour is in line with its WR nature, which is also confirmed by its spectral variability (Marchenko et al. 2000; Paper II). In addition, our seasonal photometric averages of WR 46 show a rise from 1989 to 1991 of 0.12 mag, confirming the brightening detected by the *Hipparcos*-satellite (Marchenko et al. 1998). Eventually, WR 46 brightened by about 0.25 mag and subsequently declined on a time scale of years. Such a rise is unique among the WR stars in the *Hipparcos*-survey, and has not been found anywhere else. We investigate the changes to the double-wave behaviour and mean colour-index coinciding with the period change and brightening. Interpretation of the object as either a multi-frequency non-radial WR pulsator, or a WR binary with possible large orbital decay is deferred to Paper III.

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The enigmatic WR46: a binary or a pulsator in disguise. II: The Spectroscopy

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We present spectroscopic monitoring of the Wolf-Rayet star WR 46 between 1989 and 1998, which has been obtained simultaneously with multicolour photometry (Veen et al. 2002a: Paper I). The spectroscopic monitoring data show that the radiative fluxes of the optical emission lines (O VI 3811/34, O VI 5290, N V 4944, N V 4604/20, He II 4686, He II 4859, He II 5411, He II 6560) vary in concert with the photometric single-wave (sw) frequency $f_{\rm sw}$ (Paper I), and also the difference of that period between 1989 and 1991. The line-flux variability does not provide obvious support for a short second period (Paper I). The radial-velocity variations show a remarkable behaviour: usually, they display a coherent single-wave on the time scale of the double-wave period, while during some nights the radial velocity appears surprisingly to stay constant (see also Marchenko et al. 2000). These so-called stand-stills may be related to the observed time-delay effects.

A time-delay effect manifests itself in several phenomena. Firstly, the line flux shows small, but persistent time-delays for lines originating from lower optical depths, the outer-wind lines (N V 4604/20 and He II). Secondly, the radial-velocity variations display much larger time-delays than the line fluxes and their behaviour appears less consistent. *Assuming* that the double-wave period controls the radial velocity, the stand-still is once observed to start when the radial motion is in anti-phase with the presumed orbital motion. Thirdly, the outer-wind lines are observed to enter a stand-still much later than the inner-wind lines. Fourthly, the radial-velocity variations of the peaks of the emission lines precede the radial-velocity variations of the wings of those lines.

In addition to line-flux- and radial-velocity variability, the He II 4686 emission line shows pronounced line-profile changes on a time scale of hours. Our monitoring is not sufficient to study this in detail. Furthermore, we discern a flaring behaviour, i.e., an emission bump appeared on the blue wing of two He II-lines (around -1700 km s^{-1}) lasting less than 5 minutes. Finally, the line fluxes follow the observed brightenings, also on a time scale of years.

We conclude that the short-term cyclic variability confirms the WR nature as established from the WR standard model analysis by Crowther et al. (1995). The various time-delay effects are consistent with the formation of the spectrum in a stratified stellar wind. The outer layers trail the inner ones. The variability is inconsistent with the formation of the spectrum in a stellar disc as proposed by Niemela et al. (1995) and Steiner & Diaz (1998). The long-term cyclic variability of the brightness and line fluxes is related to an increase of the mass-loss-rate, and, possibly, to the period changes. The interpretation of the nature of the variability is deferred to Veen et al. (2002: Paper III).

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The enigmatic WR 46: a binary or a pulsator in disguise. III. Interpretation

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Photometric and spectroscopic monitoring campaigns of WR 46 (WN3p), as presented in Veen et al. (2002a,b: hereafter Papers I and II, respectively), yield the following. The light- *and* colour variations reveal a dominant single-wave period of $P_{\rm sw}^{89} = 0.1412$ d in 1989, and $P_{\rm sw}^{91} = 0.1363$ d in 1991. Because of a small difference in the minima, this periodicity may be a double-wave phenomenon ($P_{\rm dw}$). The line fluxes vary in concert with the magnitudes. The significant difference of the periods can be either due to the occurence of two distinct periods, or due to a gradual change of the periodicity. A gradual brightening of the system of 0.12 mag appeared to accompany the period change. In addition, the *light* variations in 1989 show strong evidence for an additional period $P_{\rm x} = 0.2304$ d. Generally, the radial velocities show a cyclic variability on a time scale of the photometric double-wave. However, often they do not vary at all. The observed variability confirms the Population I WR nature of the light source, as noted independently by Marchenko et al. (2000)

In the present paper, we first show how the photometric double-wave variability can be interpreted as a rotating ellipsoidal density distribution in the stellar wind. Subsequently, we discuss what mechanisms could drive such a configuration. First, stellar rotation of a single star is discarded as a likely cause. Second, the obvious interpretation of the double-wave photometry, i.e., a close binary system, is investigated. However unlikely, we discuss how the observed period change might be reconciled within a model of a strongly interacting binary. Third, an interpretation as a non-radial multi-mode pulsator is investigated. The observed period change and the multi-frequency behaviour do support this interpretation. We propose that the pulsational mode $l = 1$ and $|m| = 1$ may mimic a “binary” light- and radial-velocity curve. However, the phasing of the radial velocity and the light curve may be inconsistent. The possibility $l = 2$ and $|m| = 0$ is also discussed. Finally, we propose observations as to how the enigma of the variability of WR 46 may be solved.

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Photometric modeling of Slowly-Pulsating B Stars

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The photometric characteristics of slowly-pulsating B stars are investigated using a numerical approach. Stability calculations are performed for a set of stellar models representative of the mid-B type, using a nonradial nonadiabatic pulsation code. The results from these calculations are used to synthesize photometry, in several common systems, for unstable modes of harmonic degrees $\ell = 1 \ldots 4$.

Focusing on the Geneva system for illustrative purposes, a variety of techniques are employed to analyze and visualize the synthetic data, including the use of multicolour-amplitudes (Heynderickx 1994) and amplitude-phase (Stamford & Watson 1981) diagnostic diagrams. One outstanding aspect of the analysis is the discovery, for the $\ell = 2 \ldots 4$ modes, of 'inter-term cancellation' (ITC) — the process of destructive interference between the flux variations originating from surface temperature perturbations and those arising from radius perturbations.

The ITC can be severe enough that a mode may be excited to a significant amplitude, and yet exhibit levels of photometric variability which fall below typical observational detection thresholds. Furthermore, it can affect not only the light variations in a given photometric passband, but also the variations of the bolometric flux. However, the cancellation is dependent on wavelength, and will not occur to the same degree in more than one passband. Therefore, simultaneous observation in a multitude of passbands represents the best approach to ensuring that no modes are overlooked during searches for variability in B-type stars.

A consequence of ITC is that ratios between the variability amplitude, in differing passbands, become very sensitive towards mode-to-mode changes in the pulsation. This increased sensitivity will tend to complicate any attempts at identifying the harmonic degrees of the modes responsible for observed variability. However, the cancellation also introduces significant phase differences between the light variations in each passband, especially for the $\ell = 3$ and $\ell = 4$ modes. On the grounds that correspondingly large phase differences are not seen in observational data, it is argued that the variability seen in slowly-pulsating B stars can tentatively be attributed to $\ell = 1$ and $\ell = 2$ modes.

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Submitted Papers

Radio and submillimetre observations of ϵ Ori

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In common with other early-type stars, ϵ Ori (B0 Ia) shows evidence for structure in its stellar wind. Variations in optical and ultraviolet line profiles reveal the presence of *large-scale* structure in the inner wind. The detection of X-rays and the existence of black troughs in saturated ultraviolet lines are indicative of *small-scale* structure. The geometric extent of both types of structure is poorly known. In principle, large-scale structure can be detected directly from very high spatial resolution observations that resolve the stellar wind. A simpler technique is to look for the presence of additional flux compared to that expected from a smooth wind. The run of this excess flux as a function of wavelength indicates how fast structure decays in the wind. If there is variability in the excess flux, it shows us that the structure must be large-scale.
Such variability is suggested by two previous 6 cm radio observations of ϵ Ori: Abbott et al. (1980) found 1.6 ± 0.5 mJy, while Scuderi et al. (1998) measured only 0.60 ± 0.06 mJy. This could indicate that the large-scale structure persists beyond $\sim 50\ R_*$. To further investigate this variability, we used the Very Large Array (VLA) to monitor ϵ Ori over a 5-day period in February 1999. We supplemented our data with observations from the VLA archive. In an attempt to resolve the stellar wind, we

also obtained a series of high spatial resolution observations with the Multi-Element Radio Linked Interferometer Network (MERLIN) during January–March 1999. From this combined material we find no evidence for variability and we conclude that the Abbott et al. (1980) flux determination is in error.

The data do show substantial excess flux at millimetre wavelengths, compared to a smooth wind. This excess is confirmed by a submillimetre observation which we obtained with the James Clerk Maxwell Telescope (JCMT). The behaviour of ϵ Ori is therefore similar to what had been found previously for α Cam, δ Ori A, κ Ori and ζ Pup. While the present data do not allow very strong constraints, they show that considerable structure must persist up to at least $\sim 10\ R_*$ in the wind of ϵ Ori.

The combined radio fluxes are used to derive a mass-loss rate of $\log \dot{M}(M_\odot/\mathrm{yr}) = -5.73 \pm 0.04$. This value is in good agreement with the Hα mass-loss rate. The good agreement between Hα and radio mass-loss rates for hot stars in general remains puzzling, as it implies that the same amount of structure is present in very different formation regions.

Submitted to A&A

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In Proceedings

Helium-star mass loss and its implications for black hole formation and supernova progenitors

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Recently the observationally derived stellar-wind mass-loss rates for Wolf-Rayet stars, or massive naked helium stars, have been revised downwards by a substantial amount. We present evolutionary calculations of helium stars incorporating such revised mass-loss rates, as well as mass transfer to a close compact binary companion. Our models reach final masses well in excess of $10\,\mathrm{M}_\odot$, consistent with the observed masses of black holes in X-ray binaries. This resolves the discrepancy found with previously assumed high mass-loss rates between the final masses of stars which spend most of their helium-burning lifetime as W-R stars ($\sim 3\,\mathrm{M}_\odot$) and the minimum observed black-hole masses ($6\,\mathrm{M}_\odot$). Our calculations also suggest that there are two distinct classes of progenitors for Type Ic supernovae: one with very large initial masses ($\gtrsim 35\,\mathrm{M}_\odot$), which are still massive when they explode and leave black-hole remnants; and one with moderate initial masses ($\sim 12 - 20\,\mathrm{M}_\odot$) undergoing binary interaction, which end up with small pre-explosion masses and leave neutron-star remnants.

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Jobs

Postdoctoral and PhD positions on: Massive star forming regions and starburst galaxies

Postdoctoral position

The Geneva Observatory in Geneva, Switzerland, announces the availability of a research position at the postdoctoral level, open to applicants of all nationalities.

The succesfull candidate will work on a project aimed at studying the stellar populations and the interstellar medium of massive star forming regions from the local Universe to high redshift, involving both multi-wavelength observations and theoretical modeling. The successfull applicant will in particular have access to ground-based observational data covering the optical to mid-IR (including ESO/VLT data), and state-of-the-art modeling tools. He/she will mostly work in collaboration with Prof. Daniel Schaerer in Geneva.

The Geneva Observatory carries out observational, interpretative and theoretical research in fields including stellar evolution, stellar physics, galaxy evolution and dynamics, high energy astrophysics, and extra-solar planets.

The initial appointment will be for one to two years starting in fall 2002 (1 october 2002 or later). It is renewable.

Qualified candidates are encouraged to send their application including a CV, description of research experience and interests, and contact information of three references preferably via email to Daniel Schaerer (schaerer@ast.obs-mip.fr), Laboratoire d'Astrophysique, 14, Av. E. Belin, F-31400 Toulouse, France.

All applications received by January 4, 2002 will receive full consideration. Informal enquiries with Daniel Schaerer (schaerer@ast.obs-mip.fr) are welcome.

PhD student position

One or two PhD student positions at the Geneva Observatory are open on topics related to "Massive Star Forming Regions from the local Universe to high redshift", i.e. objects ranging from giant HII regions and starburst galaxies to the first galaxies (so-called Population III objects). The student will work with Prof. D. Schaerer and collaborators of the group. Observational and/or theoretical subjects are proposed.

Start of PhD: fall 2002 (1 october 2002 or later)

For more details on these positions, detailed topics, and other information, contact Daniel Schaerer (schaerer@ast.obs-mip.fr).

Contact `schaerer@ast.obs-mip.fr`
Related information also available from the URL
`http://webast.ast.obs-mip.fr/people/schaerer/`