THE HOT STAR NEWSLETTER

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

ed. Philippe Eenens
eenens@tonali.inaoep.mx
http://www.inaoep.mx/∼eenens/hot.html

No. 12
August 1995

Contents of this newsletter

Accepted Papers

Sodium Enrichment in A-F Type Supergiants

Mounib F. El Eid[1] and Arthur E. Champagne[2]

[1] Dept. of Physics, American University of Beirut (AUB), Beirut, Lebanon

[2] University of the North Carolina at Chapel Hill, N.C. 27599-3255, and Triangle Universities Nuclear Laboratory, Duke Univ., Durham, NC, USA

We have investigated the sodium (^{23}Na) nucleosynthesis in stars of masses $M = 5$ to $19\,M_\odot$ having solar–like initial chemical composition. The values obtained for the Na–excess after the first dredge–up phase are in close agreement with recent observations suggesting a moderate Na–excess in F–type supergiants. We also found a positive correlation between the overabundance factors [N/H] and [Na/H] which seems to indicate that Na–enrichment originates from the Ne–Na cycle operating simultaneously with the CNO tri-cycle in these stars. We emphasize that our results were obtained on the basis of standard physical assumptions in the stellar model calculations, but with up–dated reaction rates for the reactions involved in the Ne–Na cycle which are presented in this work.

Accepted by ApJ (To appear: September 1995) *For preprints, contact* meid@gwdg.de (meid@layla.aub.ac.lb starting October 1995)

Effect of Convective Mixing on the Red–Blue Loops in the H–R Diagram

Mounib F. El Eid[1]

[1] Dept. of Physics, American University of Beirut (AUB), Beirut, Lebanon

Evolutionary calculations are presented for stars in the mass range $1.5\,M_\odot$ to $20\,M_\odot$ with solar–like initial chemical composition. The stellar models were evolved beyond the core He-burning phase with the primary aim to investigate the influence of convective mixing on the properties of the red–blue loops in the H–R diagram. We performed various test computations based on the Schwarzschild criterion and the Ledoux criterion for convection. We also studied the effects of semiconvective mixing and core overshooting on the properties of the blue loops. We found that semiconvective mixing promotes the formation of the loops, but core overshooting strongly inhibits their extensions. We investigated the correlation between the extension of the loops and the efficiency of the hydrogen–shell burning, which crucially depends on the shape of the hydrogen profile created in a model star at the beginning of core helium burning. In the mass range up to $M \approx 13\,M_\odot$, similar loops are obtained with the Schwarzschild criterion, or with the Ledoux criterion if combined with efficient semiconvective mixing. Above this mass, the loops disappear abruptly when the Schwarzschild criterion is used. However, they are recovered if semiconvective mixing is included with the Ledoux criterion. Our investigations show, in agreement with previous works quoted in the text, that the properties of blue loops of stars of masses above $11\,M_\odot$ are very sensitive to the treatment of mixing in the semiconvective layers, where hydrogen shell–burning occurs. We present a set of evolutionary sequences which exhibit extended blue loops up to a stellar mass of $19\,M_\odot$.

Accepted by MNRAS (To appear: August 15, 1995) *For preprints, contact* meid@gwdg.de (meid@layla.aub.ac.lb starting October 1995)

X-rays from Mass-Loaded Supernova Remnants in the Large Magellanic Cloud

S. J. Arthur and W. J. Henney

Instituto de Astronomía, UNAM, Apdo. Postal 70-264, 04510 México D. F., México

E-mail: jane@astroscu.unam.mx, will@astroscu.unam.mx

Observations of HII complexes surrounding OB associations in the Large Magellanic Cloud have revealed x-ray luminosities that cannot be explained by stellar winds alone, nor by supernova remnants (SNR) evolving inside stellar wind bubbles. In neither case would there be enough matter inside the bubbles to produce the observed flux. We propose a model in which a SNR evolves inside an extremely diffuse stellar wind bubble (formed by the OB association stars), but the density in the SNR is augmented through hydrodynamic ablation of cool, dense clumps by the post blast wave SNR flow. We present hydrodynamic calculations, including a non-equilibrium treatment of the ionization and cooling, of the evolution of such mass-loaded SNRs. We show that the models naturally explain many of the properties of the observed diffuse x-rays. In particular, we find close quantitative agreement between one of our models and observed parameters of N51D.

Accepted by ApJ (February 1st issue) *For preprints, contact* jane@astroscu.unam.mx

Interstellar ultraviolet extinction towards the nitrogen sequence Wolf-Rayet stars.

Andrzej Niedzielski

[1] Institute of Astronomy Nicolaus Copernicus University, ul. Chopina 12/18, 87-100 Toruń, Poland

With the archive IUE spectra of WR stars gathered in Niedzielski & Rochowicz (1994) we obtain the UV extinction curve for WN stars. By use of the two-color diagram method we can reach the goal almost independently, assuming only similar $(b\text{-}v)_0$ for all single galactic WN stars, what is discussed on the basis of latest results.

The resulting extinction curve differs strongly shortwards the 2200 bump from that of Seaton (1979) and is virtually identical to that of Krełowski & Papaj (1992).

Assuming the power law shape of WN continua we obtain a new value of $(b\text{-}v)_0$=-0.22 for single WN stars and present E_{b-v} for 34 galactic WN stars.

Accepted by Acta Astronomica *For preprints, contact* aniedzi@astri.uni.torun.pl also available via anonymous ftp as /pub/hide/aniedzi/iueext.ps.Z from: ftp.astri.uni.torun.pl

Submitted Papers

The Wolf-Rayet Star HD 197406, with its Strongly Ionizing, Close Companion

Sergey .V. Marchenko[1,2], Anthony F.J. Moffat[1], Robert Lamontagne[1], and Gaghik H. Tovmassian[3]

[1] Département de physique, Université de Montréal, C.P. 6128, Succursale Centre-Ville, Montréal, Québec, H3C 3J7, Canada, and Observatoire du mont Mégantic. E-mail: sergey,moffat,lamont@astro.umontreal.ca

[2] On leave from Main Astronomical Observatory of the Ukrainian Academy of Sciences, Goloseevo, 252127 Kiev, Ukraine

[3] Inst. de Astronomía, Apartado Postal 877, C.P. 22860, Ensenada, México. E-mail: gag@bufadora.astrosen.unam.mx

High quality, phase-dependent CCD spectra are presented for the first time for this unusual population I, runaway WN7 single-line binary system. Besides confirming a previous orbit based on the nearly invariable NIV 4058 emission line, these spectroscopic data show phase-dependent line-profile variations, especially in HeII. The low mass-function, but normal orbital inclination, implies that the companion is either a normal B2-4 V-III star or a relativistic object. In either case, the phase-dependent line variations lead to the suggestion of an ionized cavity near the companion, that is created probably from X-rays generated via impact of the W-R wind on the windless B-star, or accretion on the relativistic companion. This is borne out in the light curve, based on new data combined with all previously published data, that shows a broad minimum when the W-R component is closest to the observer: Compared to all other light curves known for W-R + OB systems, HD 197406's light curve requires the secondary light to arise in an extended region, presumably the hot cavity. Some preference is shown for the scenario involving a relativistic companion, from timing arguments of the orbiting ionized cavity. Despite the strong local ionization, HD 197406 remains only a weak observed X-ray source.

Submitted to ApJ *For preprints, contact* sergey@astro.umontreal.ca

Combined stellar structure and atmosphere models for massive stars I. Interior evolution and wind properties on the main sequence

D. Schaerer[1], A. de Koter[2], W. Schmutz[3] and A. Maeder[1]

[1] Geneva Observatory, CH-1290 Sauverny, Switzerland

[2] Universities Space Research Association, Code 681, GSCF, Greenbelt, MD 20771, USA

[3] Institut für Astronomie, ETH Zentrum, CH-8092 Zürich, Switzerland

We present the first "combined stellar structure and atmosphere models" (*CoStar*) for massive stars, which consistently treat the entire mass loosing star from the center out to the asymptotic wind velocity. The models use up-to-date input physics and state-of-the-art techniques to model both the stellar interior and the spherically expanding non–LTE atmosphere including line blanketing. Our models thus yield consistent predictions regarding not only the basic stellar parameters, including abundances, but also theoretical spectra along evolutionary tracks. On the same ground they allow us to study the influence of stellar winds on evolutionary models.

In this first paper, we present our method and investigate the wind properties and the interior evolution on the main sequence (MS) at solar metallicity.

The wind momentum and energy deposition associated with the MS evolution is given and the adopted wind properties are discussed. From our atmosphere calculations, which include the effect of multiple scattering and line overlap, we also derive theoretical estimates of mass loss driven by radiation pressure. These values are compared with the predictions from recent wind models of the Munich group (Pauldrach et al. 1990, 1994, Puls etal. 1995). We find an overall agreement with most of their results. In addition, our models are better in reproducing the strong wind momentum rates observed in supergiants than those of Puls et al.

A comparison between boundary conditions given by the conventional plane parallel and the new spherically expanding atmosphere approach is made. For the MS evolution the evolutionary tracks and the interior evolution are found to be basically unchanged by the new treatment of the outer layers. However, for stars close to the Eddington limit, a small uncertainty in the behaviour of the deep atmosphere is found which might marginally affect the evolution. Given the small spherical extension of the continuum forming layers in the considered evolutionary phases, the predicted stellar parameters differ negligibly from those obtained using plane parallel atmospheres.

Submitted to A&A *For preprints, contact* schaerer@scsun.unige.ch. Preprints are also available by anonymous ftp from obsftp.unige.ch directory pub/Preprints (filename costar_ms_1.ps), or by WWW at http://obswww.unige.ch/Preprints

Combined stellar structure and atmosphere models for massive stars II. Spectral evolution on the main sequence

D. Schaerer[1], A. de Koter[2], W. Schmutz[3] and A. Maeder[1]

[1] Geneva Observatory, CH-1290 Sauverny, Switzerland

[2] Universities Space Research Association, Code 681, GSCF, Greenbelt, MD 20771, USA

[3] Institut für Astronomie, ETH Zentrum, CH-8092 Zürich, Switzerland

In Schaerer et al. (1995, Paper I) we have presented the first "combined stellar structure and atmosphere models" (*CoStar*) for massive stars, which consistently treat the entire mass loosing star from the center out to the outer region of the stellar wind. The models use up-to-date input physics and state-of-the-art techniques to model both the stellar interior and the spherically expanding non–LTE atmosphere. The atmosphere models include line blanketing for all elements from hydrogen to zinc.

The present publication covers the spectral evolution corresponding to the main sequence interior evolution discussed in Paper I. The *CoStar* results presented in this paper comprise: *(a)* flux distributions, from the EUV to the far IR, and the ionizing fluxes in the hydrogen and helium continua, *(b)* absolute optical and infrared UBVRIJHKLMN photometric magnitudes and UV colors, *(c)* detailed line blanketed UV spectra, and *(d)* non–LTE hydrogen and helium line spectra in the optical and IR, including theoretical K band spectra. These results may, e.g., be used for population synthesis models intended to study the massive star content in young starforming regions.

We compare our results with other predictions from LTE and non–LTE plane parallel models and point out the improvements and the importance of using adequate atmosphere models including stellar winds for massive stars. Particular emphasis is given to comparisons of the UV spectral evolution with observations, including continuum indices and several metal line signatures of P-Cygni lines and broad absorption features. Good agreement is found for most UV features. In particular, we are able to reproduce the strong observed Fe III 1920 Å feature in late O and early B giants and supergiants. This feature is found to depend sensitively on temperature and may be used to derive effective temperatures for these stars.

We also derive a simple formula to determine mass loss rates from the equivalent width of hydrogen recombination lines (Hα, Pα and Bα) for OB stars showing net emission in one or more of these lines.

Submitted to A&A *For preprints, contact* schaerer@scsun.unige.ch. Preprints are also available by anonymous ftp from obsftp.unige.ch directory pub/Preprints (filename costar_ms_2.ps), or by WWW at http://obswww.unige.ch/Preprints

Optical time-series spectroscopy of the O4 supergiant ζ Puppis

Andy H.N. Reid & Ian D. Howarth

Department of Physics & Astronomy, University College London, Gower Street, London, WC1E 6BT, United Kingdom

We present time-resolved echelle spectroscopy of the O4 I(n)f supergiant ζ Puppis. Variations are observed in all absorption-line profiles, with typical peak-to-peak amplitudes of ~2% of the continuum intensity (~4% in He II λ5411Å). All observed absorption lines (He I, He II, N IV, and C IV) show the same gross characteristics, with 'bumps' and 'dips' moving blue-to-red through the profiles, with no detectable line-to-line velocity shifts in the variability pattern ($<$ 15 km s^{-1}) although there are differences in the relative amplitudes across the lines. The time dependence of the variability is investigated by using 2-D CLEAN power-spectrum analysis. Significant power is found at a period of ~8.54 hr; the underlying signal is marginally consistent with sectorial, prograde non-radial pulsations with $\ell = m = -2$, although this does not account for all the observed variability. The blue emission wing of Hα was included in the echellograms, and, in contrast to the absorption lines, shows features moving red-to-blue, periods of 8.5 hr (the absorption-line period) and 19.6 hr (the recurrence time of 'discrete absorption features' observed in UV P-Cygni resonance lines). This provides the first direct evidence for a dynamical response of a radiation-driven wind to basal velocity fields.

The Effect of Multiple Scattering on the Polarization from Axisymmetric Circumstellar Envelopes I. Pure Thomson Scattering Envelopes

Kenneth Wood, J.E. Bjorkman, Barbara A. Whitney, Arthur D. Code

Department of Astronomy, University of Wisconsin 475 North Charter Street, Madison, WI 53706

We investigate, via a Monte Carlo computer code, the effect of multiple Thomson scattering on the continuum polarization arising from axisymmetric circumstellar envelopes such as equatorial disks, ellipsoidal envelopes, and polar jets or plumes. Previous single scattering models that incorporate attenuation by electron scattering find that the polarization is reduced below the single scattering without attenuation results. Furthermore, it is often assumed that multiple scattering will only further reduce the polarization. However, we find instead that multiple scattering in the envelope increases the polarization above this "single scattering plus attenuation" approximation. This increase in the polarization occurs because multiple scattering arises predominantly within the optically thick disk or plume. Thus the orientation of the scattering planes for these multiply scattered photons is biased toward a common direction (e.g., the plane of the disk). For equatorial disk geometries, multiple scatterings reduce the component of the electric vector parallel to this plane, leaving a net increased polarization that is perpendicular to the disk. In the case of polar jets, multiple scattering occurs preferentially along the optically thick jet axis, leaving the photons unpolarized until they scatter out of the jet. Those that are scattered into the observer's direction all possess similar polarization position angles, so there is little polarimetric cancellation, yielding an increase in the polarization.

In the abscence of any absorptive opacity, which would reduce the number of multiple scatterings, we find that multiple scattering produces high levels of polarization (of order 3–4% or more) in circumstellar disks. This result in is contrast to previous investigations that used the single scattering plus attenuation approximation, which predicted maximum polarization levels of about 2% for circumstellar disk geometries.

We have also investigated the polarization when the central star is either a finite sphere or a point source of radiation. Single scattering calculations include a geometrical "depolarization factor" that accounts for the finite solid angle subtended by the star and corrects the point source approximation. This depolarization factor results in a reduced single scattering polarization level for the finite source compared to the point source. However, when multiple scattering is included we find that, for large circumstellar optical depths, a finite source yields larger levels of polarization than a point source. This higher polarization occurs because more photons enter the disk from a finite star than from the more highly attenuated point source. These additional photons are multiply scattered, raising the polarization for a finite star above that for a point source star.

Submitted to ApJ *For preprints, contact* kenny@madraf.astro.wisc.edu

The Effect of Multiple Scattering on the Polarization from Axisymmetric Circumstellar Envelopes II. Thomson Scattering in the Presence of Absorptive Opacity Sources

Kenneth Wood, J.E. Bjorkman, Barbara A. Whitney, Arthur D. Code

Department of Astronomy, University of Wisconsin 475 North Charter Street, Madison, WI 53706

We investigate the effect on the polarization of multiple Thomson scattered stellar radiation in axisymmetric circumstellar envelopes that contain sources of continuous absorptive opacity and emission.

Our previous investigations of pure electron scattering envelopes have shown that multiple scattering increases the polarization level above that predicted by single scattering plus attenuation approximations. However, the inclusion of sources of absorptive opacity within the envelope lowers the albedo reducing the number of multiply scattered photons. Consequently for envelopes possessing a large absorptive opacity, the net polarization approaches the single scattering plus attenuation levels (which may be positive or negative, depending on the geometry and degree of polarimetric cancellation). Lowering the albedo further (by increasing the absorptive opacity) removes photons that have been singly scattered so that the polarization decreases below that predicted by the single scattering plus attenuation approximation. As the albedo approaches zero, few photons are scattered within the envelope (all are absorbed) and the only radiation reaching the observer is unscattered (i.e., unpolarized) stellar radiation, hence the polarization approaches zero.

A consequence of this behaviour is that when the albedo changes rapidly with wavelength, as occurs across ionization edges (e.g., across the Balmer jump), much larger changes in the polarization occur than predicted by single scattering plus attenuation approximations. This occurs because, just shortward of the jump, the absorptive opacity is large (effective albedo is small) and the polarization approaches the single scattering plus attenuation level (since many multiply scattered photons have been absorbed). However, just longward of the jump, where the absorptive opacity is small (effective albedo is close to unity), multiple scattering is dominant and the polarization is larger than the single scattering plus attenuation prediction. For this reason we find that the combined effects of multiple scattering plus absorptive opacity gives much larger polarization jumps than previous predictions — in some instances the polarization jump is doubled. In addition, the slope of the polarized continuum is steeper than that derived from single scattering plus attenuation calculations. Finally, for geometrically thick equatorial disk- like geometries, a position angle flip of 90° occurs shortward of the Balmer jump. This is due to the large hydrogen opacity which absorbs the multiply scattered photons in the equatorial disk. Thus, the polarization is dominated by singly scattered photons from the polar regions, producing a net negative polarization.

Submitted to ApJ*For preprints, contact* kenny@madraf.astro.wisc.edu

Nonlocal Escape-Integral Approximations for the Line-Force in Structured Line-Driven Stellar Winds

S. P. Owocki[1] and J. Puls[2]

[1] Bartol Research Institute, University of Delaware, Newark, DE 19716 USA

[2] Institut für Astronomie und Astrophysik der Universität München, Scheinerstraße 1, 81679 München, Germany

We develop a nonlocal, integral escape-probability formalism for approximating both the direct and diffuse line-force in a structured, radiatively driven stellar wind. Our approach represents a direct generalization of the local Sobolev escape-probability methods commonly applied in smooth, steady wind models. It naturally incorporates previous nonlocal force methods based on pure-absorption or Smooth Source Function (SSF) approximations for the line transport. However, it also leads to the development of a new “Escape-Integral Source Function” (EISF) method which, for the first time, takes account of the dynamical effects of gradients in the perturbed source function. Perturbation analyses, formulated here in terms of the perturbed escape probability, demonstrate how key aspects of the linear wind instability, including line-drag and phase-propagation reversals, are incorporated in the various nonlocal force approximations. The methods here thus provide the basis for further,

more complete simulations of the nonlinear wind structure resulting from this strong line-driven flow instability.

Submitted to the Astrophysical Journal, *For preprints, contact* owocki@bartol.udel.edu

ASCA Observation of Cygnus OB2 Association

Shunji Kitamoto[1] and Koji Mukai[2]

[1] 1-1, Machikaneyama-cho, Toyonaka, Osaka, 560, JAPAN

[2] NASA/Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A.

ASCA observed Cyg OB2 association on April 29, 1993. Four OB stars (5, 8a, 9, and 12) were clearly detected. In the X-ray spectra of three stars (8a, 5 and 12), at least two emission lines from SiXIII, and SXV were identified. The spectra of three stars, 5, 9, and 12, can be simulated by single thin thermal spectra with temperatures of 1.26 ± 0.12 keV, 2.46 ± 0.68 keV, and 0.90 ± 0.05 keV, respectively. However, the spectrum of 8a, which is the statistically best one, requires two component thin thermal spectra with temperature of 0.62 ± 0.04 keV and 1.47 ± 0.10 keV. The emission measure of the four observed stars are $\sim 10^{56\sim57}$ cm^{-3}, and their photoelectric absorption column densities are $(1 \sim 2)\times 10^{22}$ H atoms cm^{-2}. Apparent low metal abundances are suggested in all four stars and it is explained by an enrichment of light elements such as C, N and O.

Submitted to Publ. Astron. Soc. Japan *For preprints, contact* kitamto@ess.sec.osaka-u.ac.jp

Reviews

The Effect of Multiple Scattering on the Polarization and IR Excess of Be Stars: Constraints on the Disk Geometry

Kenneth Wood, J.E. Bjorkman, Barbara A. Whitney, Arthur D. Code

Department of Astronomy, University of Wisconsin 475 North Charter Street, Madison, WI 53706

We present results of a Monte Carlo calculation of the the polarization arising from multiple Thomson scattering in circumstellar disks. We find that multiple scattering in the disk *increases* the polarization levels above that predicted by "single scattering plus attenuation" approximations. This increase arises because multiple scattering occurs predominantly within the optically thick disk where multiply scattered photons are biased toward scattering in the equatorial plane. Multiple scatterings reduce the component of the electrc vector in this plane, leaving a net *increased* polarization. Previous single scattering approximations claimed that equatorial disks were unable to exceed the maximum polarization levels observed in Be stars. However, we find that multiple scattering within the disk can easily exceed the maximum observed polarization levels, ruling out the possibility of having disks with intermediate opening angles.

In particular, we have investigated the continuum polarization of the Be star ζ Tau and find that either a geometrically thin disk or a geometrically thick disk is required to match the optical polarization and 12μm flux excess. However, the thin disk polarization exhibits a 90° position angle flip in the IR, while the thick disk does not. We suggest that IR polarimetry may provide information to discriminate between the thick and thin disk solutions for Be circumstellar geometries.

To appear in "Polarimetry of the ISM" ed. W. Roberge & D. Whittet *For preprints, contact* kenny@madraf.astro.wisc.edu