THE HOT STAR NEWSLETTER

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

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From the editor

Easier access to the *HOT* WWW site

Have you experienced that the internet link to Mexico is sometimes a bit slow? There is now an alternative. Thanks to Sergio Paoli, the WWW site for the Hot Star Newsletter is mirrored somewhere in California. You can access it at the URL

http://webhead.com/∼sergio/hot/

Unfortunately, the hyper-text version of the newsletter is not yet available.

Meetings

Our next WR meeting is announced for 1996 July. All details at the end of this newsletter. Information on the forthcoming IAU Symposium will be given in a later issue.

Articles wanted

Would you like to write for the Newsletter a short article on a *hot* topic? Not the kind of paper accepted by ApJ, but a short contribution emphazising remaining problems, open questions and perspectives for future work. These articles we hope will provide food for thought and stimulate more interaction. This new section of the newsletter will start with the next issue. I would appreciate your suggestions.

Contents of this newsletter

Accepted Papers

The fading of radiatively driven winds in B stars

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In the theory of radiation-driven winds by Castor et al. (1975) (hereafter CAK), the radiative acceleration has no formal dependence on the outwards velocity in the wind and the detailed shadowing by photospheric lines is not included in the computation of radiative accelerations (or force multipliers). In this paper, we compute radiative accelerations taking this effect into account and show that the detailed shadowing by photospheric lines has large consequences on the wind of main sequence B stars.

Using these computations, we reconsider the onset and the existence of winds in B stars. In particular, a criterion based on the sonic point of the wind permits to define three zones in the HR diagram where (i) only negligible radiatively driven winds are possible, (ii) only inhomogeneous winds can exist and (iii) where homogeneous winds can be present. These zones are very different from the ones found by Abbott (1979). They are in very good agreement with the locus of chemically peculiar stars, and in particular with He-weak, ^{3}He and He-rich stars.

We also incorporate the effect of detailed photospheric shadowing in computations of wind models for stars in which homogeneous wind solutions may exist. The main difference from the CAK theory is found in main sequence B stars, typically for stars with $T_{\rm eff} \simeq 20000 - 23000$ K and $\log g \simeq 3.7 - 4.0$. This gravity is within a factor of 0.25-1.0 of the gravity for which only inhomogeneous wind are possible. For these objects, the mass loss rate is found to be lower than predicted by CAK theory by at least a factor of 4 . We also obtain an anticorrelation between the mass loss rate and the ratio u_∞/u_{esc} with values of u_∞/u_{esc}, which in some cases exceed 4.

Accepted by A & A *For preprints, contact* babel@astrophysik.uni-kiel.de

The infrared and radio continuum of early-type stars

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The infrared and radio continuum fluxes of 18 well-observed early-type stars are studied by comparing observations with theoretical models. The observations are taken from the literature. All available observations are included. The theoretical NLTE models for photosphere and stellar wind include free-free and free-bound emission as well as electron scattering. The good quality of the model is shown by the agreement of the theoretical and observed fluxes for most stars. For four stars (α Cam, δ Ori A, κ Ori and ζ Pup) the observations suggest the presence of an additional emission mechanism (inhomogeneous and/or anisotropic outflow).

Accepted by A & A *Preprints* are available from the anonymous ftp-server ftp.vub.ac.be directory /pub/papers - file iradio.ps.Z

The H I distribution in the environment of the WR star HD 50896

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The neutral matter distribution from the interstellar medium located in the vicinity of the galactic Wolf-Rayet (WR) star HD 50896 has been examined by means of HI 21-cm line observations obtained with both low (HPBW≃34 arcmin) and intermediate (HPBW≃9 arcmin) angular resolution. The most interesting discovery is a huge ovoidal HI minimum spanning the velocity range +1.5 km s^{-1} to +10.0 km s^{-1}, created, very likely, by the joint action of the progenitor of HD 50896 and the WR itself. Inside this cavity, two minima are clearly discernible. The WR star is offset with respect to either the geometrical center of the main HI void or the inner HI minima. A physical link between S308, the ring nebula associated with HD 50896, and one of the HI minima is suggested by our data. Based on the radial velocity of the HI cavity, a kinematical distance of ∼1 kpc for HD 50896 is derived.

The dual HI-minimum geometry observed inside the main HI cavity, a feature also seen in the HI distribution of the ISM located close to other galactic WR stars, may be a consequence of the interaction process itself. The ovoidal shape of the main cavity can not be explained within the framework of the standard interstellar bubble theory. Elongated bubbles may result when the the large scale galactic magnetic field is taken into account.

Accepted by MNRAS *For preprints, contact* arnal@fcaglp.fcaglp.unlp.edu.ar

R 4 in the SMC: a spectroscopic binary with a B[e]/LBV-type component

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During the past twelve years we observed several spectra of the B[e] star R4 in the SMC with CASPEC at ESO, La Silla. We also obtained $UBV(RI)$ and JHK photometry during various occasions at La Silla. Further photometry was available in the literature. Brightness variations typical for LBVs of about 0.7^{m} in V were found. The optical spectra are dominated by strong emission lines of hydrogen and of Fe II and [Fe II]. Also numerous absorption features of different ions, ranging from Mg I to Si IV, were found. The radial velocity measurements clearly showed that R4 is a spectroscopic binary with an early B component showing absorption features of Si III, Si IV, He I, O II and N II, and an early A-type component with absorption lines mainly of Ti II and Cr II. The emission lines are associated with the B star which therefore is called B[e] component. Likewise the observed IR excess,a defining property of B[e] stars, is ascribed to this component. By extrapolating the radial velocity curves we determined an orbital period of about 21 yrs, spectroscopic masses of $M \sin^3 i \approx 13$ M$_\odot$ for both, the B[e] and the A component, respectively, and their separation $a = 23$ a.u. Using ATLAS8 models we estimated for the A star $T_{\mathrm{eff}} \approx 9500$ K from the strength of Ti II, Cr II, Mg I and from an upper limit for Fe I absorption lines, and $M_{\mathrm{bol}} \approx -5.6$. For the B[e] component we calculated the Si III/Si IV ionization equilibrium and the spectral energy distribution using ATLAS8 model atmospheres. This yielded $T_{\mathrm{eff}} = 27\,000$ K, $\log g = 3.2$, $R = 14$ R$_\odot$ and $M_{\mathrm{bol}} = -7.7$. From evolutionary tracks a ZAMS mass of 10 M$_\odot$ was estimated for the A star which is close to the spectroscopic mass. This leads to

$\sin^3 i \approx 1$. The ZAMS mass of the B[e] component is about 20 $M_\odot$, i.e. nearly twice the present mass. Therefore this component has obviously lost a large fraction of its mass during previous evolutionary phases. With our observations we could for the first time determine directly the mass of a B[e] giant. The low present mass and the evolutionary timescales of both binary components show that the B[e] giant is in an advanced evolutionary stage, most likely in the post-red supergiant phase.

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Variability in the optical wind lines of HD 151804 (O8 Iaf)

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High S/N (∼200), high spectral resolution (∼25 km s^{-1}) optical time series spectroscopy of the extreme O8 supergiant HD 151804 is presented. These data were collected over ∼5 nights in 1992 July in a coordinated campaign between Australia (Mount Stromlo Observatory) and Chile (Cerro Tololo Inter-American Observatory). Variability in the strong wind of HD 151804 is principally monitored via the He I λ5876 P Cygni and the Hα emission profiles, both of which are sensitive diagnostics of density structures in the wind close to the star.

Systematic changes are present in the He I profiles, which take the form of: (i) blueward migrating optical depth enhancements, which travel from ∼0.14 of the terminal velocity (v_∞) to ∼0.5 v_∞ in about 24 hours; and (ii) blueward and redward motion of up to 50 km s^{-1} of the low-velocity emission portion of the He I profile. Fluctuations are also evident in the blue emission wing of Hα between −200 km s^{-1} and −750 km s^{-1}, which are in sympathy with the systematic changes in He I absorption. These results indicate that the inner stellar wind of HD 151804, i.e., between 1.0 and 2.0 stellar radii, is unstable and affected by coherent, evolving structures. Constraints on global mass-flux variations and localised column density enhancements based on steady-state stellar atmosphere modelling are presented.

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

Submitted Papers

Hα Line Formation in Hot Star Winds – The Impact of Rotation

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We investigate the influence of stellar rotation on the Hα line formation in O-star winds. The 2-D wind model used is based on the kinematical approach by Bjorkman & Cassinelli (1993, BC), adapted to the parameter space considered in this paper. We discuss only those cases where the rotational rates are well below those that would induce an onset of disk formation.

The influence of gravity darkening on the line formation is shown to be negligible, as long as appropriate *averaged* photospheric parameters (which then are a function of the rotational rate) are used. The distortion of the stellar radius from sphericity can likewise be neglected in most cases.

Our investigations show that the Hα line formation is strongly affected by two processes which we call the *resonance zone* and the ρ^2*-effect*. The former process diminishes the emission near the line core and enhances the emission in both wings due to a twist in the resonance zones induced by differential rotation. The latter process leads to an increase in the overall emission due to the density contrast between the polar and the equatorial zones caused by the deflection of material towards the equator in the BC-model.

We compare the line profiles from our 2-D models with those resulting from the conventional 1-D approach, as a function of absolute or projected rotational velocity, and inclination angle and mass-loss rate.

It is shown that in *all* cases independent of inclination angle and rotational rate, the 1-D method – for a given mass-loss rate – yields the largest (conventionally defined) equivalent width. This in turn means that all mass-loss rates presently derived from Hα are *overestimated*. The maximum error introduced by this simplified approach is of the order $50 \ldots 70\,\%$ for typical O-Supergiants and occurs for stars with *small* $v \sin i$ and observed nearly pole on.

Moreover, our theoretical line *shapes* show a number of features actually found in the observations of rapidly rotating stars.

Finally, the distinct influence of the rotational rate and inclination angle which both, *independently* modify the profiles in a typical way may provide us with a method for the determination of $\sin i$ from Hα line fits (in connection with the analysis of other spectral regions) in future investigations.

Submitted to A & A *For preprints, contact* uh101bv@hpmail.lrz-muenchen.de

Multi-frequency observations of the Wolf-Rayet star WR146: another colliding-wind binary?

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We present the first high spatial resolution radio observations of the Wolf-Rayet star WR146, obtained at 1.6 and 5 GHz with the MERLIN array. The 5-GHz observations resolve the source into two components separated by 116 ± 14 milli-arcseconds (mas). The weaker (southern) source is identified as thermal emission arising from the stellar wind of the WR star and the stronger (northern) source, which is resolved with a diameter of 38 mas and a brightness temperature $T_b \sim 10^6$ K, as non-thermal emission. New infrared and millimetre photometry of WR146 are consistent with a stellar-wind origin for the southern radio component and allow us to estimate the distance to the WR star to be 1.2 ± 0.3 kpc. We also present a high-resolution blue spectrum of WR146, which shows evidence for absorption lines attributable to a luminous O9.5–B0 main-sequence companion to the WC6 star.

In these respects, WR146 is similar to the other Wolf-Rayet stars (WR125 and WR140) known to be non-thermal emitters. We suggest that the non-thermal emission arises from the interaction of the WR wind and that of its newly detected luminous companion. The observed size of the non-thermal radio emitting region is consistent with that expected from colliding wind theory. We estimate that the non-thermal emission is essentially unabsorbed by the stellar wind of the WR star, providing an unprecedented opportunity for studying colliding winds.

Submitted to MNRAS *For preprints, contact* smd@drao.nrc.ca

Theses

2–μm Spectroscopy of Young Massive Stars in M17

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I have obtained high-quality 2 μm spectra of more than 30 stars in the direction of the very young, heavily extinguished Galactic star-forming region M17. I have identified seven stars as O type from their spectral lines of H I, He I, He II, and N III using a 2 μm spectral classification system of 130 optically visible massive stars that I developed. Two of these O stars are behind more than 15 magnitudes of visible extinction and provide unprecedented opportunities for absorption studies of dark interstellar clouds at optical and near-infrared wavelengths. The O stars found are able to provide the number of Lyman continuum photons required to explain radio continuum observations of the region. A set of stellar objects, all but one with strong excess emission in the infrared, show completely different spectral characteristics from known main-sequence stars. Three are completely featureless throughout the 2 μm window, four (possibly five) show molecular CO in emission. Extrapolating from the number of early-O stars found in the M17 region and assuming a normal stellar mass function, photometric surveys of the field suggest the number of late-O and B stars found may be below the number expected. The peculiar stellar objects I found may be massive, young stellar objects, possibly the "missing" late-O and B stars, still shrouded by circumstellar material. Because the early-O stars in the field are already free of their circumstellar material, the most massive stars must have a very short accretion phase. Either the majority of their mass comes from the proto-stellar collapse phase or the current models used for forming intermediate- and low-mass stars cannot be extrapolated to the most massive stars.

This PhD thesis was completed in October, 1995, at the University of Colorado, Boulder under the direction of Peter S. Conti.

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The Stellar Population at the Galactic Center and the Mass Distribution in the Inner Galaxy

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Near infrared (1.25 μm − 2.2 μm) imaging and spectroscopy are used to investigate the massive stellar population at the Galactic center and the mass distribution in the inner Galaxy. **Caution:** Part of this thesis involves studies of cool stars. Some Hot Star readers may wish to skip the first section.

The Mass Distribution in the Inner Galaxy

Radial velocities are presented for approximately 40 M giant stars in each of four optically obscured, off-axis fields toward the Galactic bulge at projected radii between 150 pc and 300 pc from the Galactic center. These velocities are used to compute mean radial velocities and radial velocity dispersions along an axis which is 55° from the major axis of the Galaxy.

The M giant kinematics were used to investigate the mass distribution in the inner Galaxy at projected radii between 150 pc and 300 pc where the large extinction due to dust had precluded studies at optical wavelengths. These kinematics were compared to the axisymmetric dynamical model of Kent (1992, ApJ, 387, 381) and the non-axisymmetric bar model of Zhao (1994, Ph.D. Dissertation, Columbia University). Both models are generally consistent with the observations; the bar model may provide a marginally better match.

The velocity dispersion in the innermost field is 153 km s^{-1} ± 17 km s^{-1}, 1 to 2 σ ($\sim 15 - 30$ km s^{-1}) higher than either Kent's or Zhao's model prediction and higher than observed anywhere else in the inner Galaxy. This means that we have yet to observe a decrease in the velocity dispersion toward smaller radii as we might expect if the bulge and Galactic center populations are to join smoothly together.

A simple dynamical model of the Galactic bulge is developed using the tensor virial theorem. The model is based, in part, on the mean kinematics described above and a new spatial density distribution based on the near infrared surface brightness distribution of the stellar population within $\sim 10°$ of the Galactic center (GC) as observed by the Cosmic Background Explorer (Dwek et al. 1995, ApJ, 445, 716). The new density distribution is highly triaxial (bar shaped) and taken to rotate with a pattern speed of 81 km $s^{-1}kpc^{-1}$. The model predicts a bulge mass of 2.8×10^{10} $M_\odot$, significantly larger than previous estimates. This value is most dependent on the adopted pattern speed and the angle which the bar major axis makes with our line of sight ($\sim 20°$, Dwek et al. 1995). Smaller pattern speeds and/or angles would lead to similar mass estimates as previous bar models.

The Population of Massive Stars at the Galactic Center

R ($\equiv \lambda/\Delta\lambda$) $\approx$ 570 resolution K band (2.2μm) spectra are also presented for the He I emission-line sources at the Galactic center (GC); an H band (1.65μm) spectrum is also presented for the most prominent He I star, the AF star. These are compared to similar spectra for nine galactic and Large Magellanic Cloud (LMC) early type mass losing stars, including Ofpe/WN9, WN, and LBV stars. While the GC and comparison star spectra show some morphological similarities, larger He I equivalent widths are found in the AF source and two galactic early type mass losing stars than in any of the LMC stars. Several of the GC He I sources are found to have higher He I velocity widths than any of the galactic or LMC early type mass losing stars. The velocity width difference may be due to differences in the GC and LMC environments in which the otherwise similar stars formed, e.g.

the metallicity may be significantly higher at the GC. The He I equivalent width difference may be due to differences in evolutionary states between the stars.

The GC He I sources are not likely to be normal OB giant/supergiants, early type WC, or WN7-8 stars based on a comparison of the present work to published spectra of these types. The value of the bolometric correction, $BC_K = M_{bol} - M_K$, is estimated for the GC sources as a function of effective temperature from published data on LBV, WN9, and Ofpe/WN9 stars, and combined with limits on the effective temperature to place the GC sources in the Hertzsprung–Russell diagram. The effect of the He I stars on the GC environment through ionizing radiation and mass loss were estimated. These estimates suggest that the He I stars could provide much of the bolometric radiation observed through re-radiation by dust in the far infrared and the ionizing radiation implied by the observed nebular excitation in the GC. The mass loss, as estimated from these spectra, appears insufficient to supply the excitation by shock heating of molecular material observed previously in the GC.

The investigation of the GC massive stellar population includes the discovery of a Wolf-Rayet star located at 0.5 pc projected radius from the center of the Galaxy. This is the first such object to be discovered near the GC; its discovery has strong implications for the character and extent of recent star formation in the region.

The He I stars probably represent recent ($\lesssim 10^7$ yr) star formation at the GC. One possibility is that a burst of star formation occurred within this time, of which the He I stars are the most luminous tracers. The discovery of a Wolf-Rayet star at the GC strongly enhances this possibility. For the first time, we now begin to see a wide range of evolutionary states of massive stars in the GC including the He I stars and an M2 supergiant. This would be expected for a burst of star formation involving a range of masses. The Wolf-Rayet star mentioned above was classified as a WC9 star based on its K band spectrum and its existence points to star formation at epochs even earlier than 10^7 yr ago.

Thesis completed June 5, 1995, at the Ohio State University, under the direction of Prof. Kris Sellgren

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Meetings

33rd Liège International Astrophysical Colloquium
Wolf-Rayet Stars in the Framework of Stellar Evolution
Liège, Belgium, July 1-3, 1996
Chairman : P.S. Conti.
Contact: Jean-Marie Vreux (vreux@astro.ulg.ac.be)

Twenty years ago, during the 20th Liege Colloquium, Peter Conti set out what is now known as the "Conti scenario" for the formation of single Wolf-Rayet stars. To celebrate the 20th anniversary of the publication of this historical talk in the "Mémoire de la Société Royale des Sciences de Liège", our Institute has decided to devote the next Liège International Astrophysical Colloquium to the favorite objects of Peter Conti, i.e the Wolf-Rayet stars.