THE $\mathrm{H}\,\mathrm{O}^{\mathrm{T}}$ STAR NEWSLETTER

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

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Contents of this newsletter

News

Call for observations: WR 137

Peredur Williams

Royal Observatory Edinburgh

Recent (1996) infrared photometry of WR 137 (HD 192641, WC7 +?) confirms last year's observations that this system is brightening owing to the formation of circumstellar dust, as last occurred in 1983–84 (e.g. Williams *et al.*, MNRAS, 215, 23P, 1985). The observations suggest a recurrence time (or period) of ~ 12.6 years and that dust formation will reach a maximum in late 1996 or early 1997. If dust formation is caused by wind interaction or collision effects, the current (ground-based) observing season will be the best time to look for evidence of such effects, which may be at their maximum in the next few months. For a detailed description of the optical spectrum, see Underhill (ApJ 398, 636, 1992) and references therein.

Further information from `pmw@roe.ac.uk`

Accepted Papers

New masses for the O-type binary DH Cep, and the temperatures of O-stars

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Spectroscopic observations, secured in 1973 and 1991, are analysed together with data from Sturm & Simon (1993) and Penny et al. (1996) to yield a new determination of the masses of the O+O-type binary system DH Cep. The masses are $32.7 \pm 1.7\,M_\odot$ for the O5.5V primary and $29.6 \pm 1.6\,M_\odot$ for the O6.5V secondary. Analysis of the light curves from Lines et al.(1986), coupled with temperature and flux ratios from Sturm & Simon, results in revised absolute parameters with final masses increased by 10% relative to those determined by Sturm & Simon. These revised parameters are in excellent accord with the evolutionary models of Schaller et al. (1992), at an age of 1.5 Myr.

In the context of those evolutionary models, and the work of Schönberner & Harmanec (1995) on lower-mass binaries, we discuss the properties of 6 O to B0 detached binaries including DH Cep. The masses and radii for the components of these systems are all in remarkable agreement with the Schaller et al. models of solar composition. The O star temperatures need to be reduced by an average ~ 1000 K to achieve agreement in $T_{\rm eff}$ with the models, but this averaged value may hide the need for substantial reductions (~ 2500 K) around O8. We note also some discrepancies between derived visual absolute magnitudes, and the M_v–spectral type relationship for O stars compiled by Schmidt-Kaler (1982).

Accepted by A&A *For preprints, contact* `rwh@st-and.ac.uk` *or use* `http://star-www.st-and.ac.uk/astronomy/preprints.html`

Spectroscopy of Dwarf O Stars in the Region 6250 to 7150 Å

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We present moderate-resolution spectra of normal dwarf O stars taken over the commonly ignored spectral range from 6250 to 7150 Å. Numerous, strong, telluric absorption features, particularly the prominent O_2 feature beyond 6850 Å, have made the study of stellar photospheres over this spectral region very difficult in the past. In this study, we use a method for removing the atmospheric absorption features during the reduction process. With our cleaned spectra, we have been successful in identifying the He II 6891 Å line in O dwarf stars that has until now been too heavily contaminated by telluric features to be clearly detected.

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The distinction between O Iafpe and WNLha stars – A spectral analysis of HD 151804, HD 152408 and HDE 313846

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From detailed atmospheric analysis of the Galactic late O supergiants, HD 151804 (O8 Iaf) and HD 152408 (O8: Iafpe) and the morphologically related Wolf-Rayet star, HDE 313846 (WR108; WN9ha) we conclude that little distinguishes the overall structure and composition of the stellar atmosphere of HD 152408 from HDE 313846, such that HD 152408 could be considered to be a W-R star equivalent to HDE 313846.

Our quantitative spectroscopic analysis uses ultraviolet (*IUE*), optical (AAT, Mt. Stromlo) and infrared (UKIRT, CTIO) spectroscopy and is based on model atmospheres obtained with the iterative scheme of Hillier (1990). Stellar properties for all three stars are quite similar: $\log L_*/L_\odot \approx 5.8$, $R_*/R_\odot \approx 35$, $-4.9 \leq \log \dot{M}/M_\odot \mathrm{yr}^{-1} \leq -4.5$, $955 \leq v_\infty \leq 1445\,\mathrm{km\,s^{-1}}$. Spectroscopic mass-loss rates are in excellent agreement with radio methods and are more representative of late WN (WNL) stars than O-type supergiants.

From this comparison we find that the O and WNL spectral classifications are distinguished principally by surface mass flux ($\dot{M}/4\pi R_*^2$), with stellar temperature and surface helium content secondary effects.

Since surface chemical abundances do not necessarily define the core energy production mechanism – a commonly used distinction between O and WR types – we argue that caution is required when comparing observed O:WNL ratios with theoretical predictions and inferring stellar evolution in various galaxies.

The increasing helium content of the programme stars – O8 Iaf (y=N(He)/[N(H)+N(He)]=0.20), O8: Iafpe (y=0.40) and WN9ha (y=0.45) – is strongly indicative that a direct evolutionary connection from O8 If⇒WN9ha may exist without passage through an intermediate Luminous Blue Variable phase, contrary to current evolutionary theory and suggestive that an additional mixing process (e.g. rotation) brings processed material to the surface. The high helium content of HD 151804 confirms previous findings that Of stars are helium enriched by core processed material.

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Dynamic Processes in Be Star Atmospheres. IV. Common Attributes of Line Profile "Dimples"

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"Dimples" are transient central absorption features flanked by weak emissions commonly seen in the He I λ6678 line profile of the mild B2e star λ Eri. Smith and Polidan have found that these features

can be reproduced with a model in which line photons are scattered within an optically thick (in the line) slab elevated over the surface of a rapidly rotating star. We have undertaken a series of simultaneous He I multi-line observations of this star at the McMath, McDonald, Lick, David Dunlap, and Ritter observatories to search for dimples in weak blue He I lines when they appear in λ6678. Four dimples were found during 15 hours of multi-observatory monitorings. In three cases a dimple was observed in a weak blue line of the same absorption series as λ6678. In the fourth instance, a dimple was observed only in λ5876 and λ5015 lines which, like λ6678, are strong and have weak wings. A joint IUE/optical campaign demonstrated that the He II λ1640 line shows weak emission just as new dimples appear in the λ6678 line.

Our observations confirm a previous report that dimples appear in the λ6678 line of four other Be stars. We also find that the resonance C IV double weakens when dimples appear, a result similar to that found for λ Eri. Our data also disclosed that "migrating subfeatures" similar to those found in γ Cas are present in the λ6678 line of the B5 star HR 1011. These features appear to be a more vigorous form of dimple activity than observed in λ Eri and other mild Be stars. These findings lend strong support to the slab model for the dimple phenomenon. They also suggest that this activity is endemic to the class of mild Be stars. The appearance of dimples in the weak blue He I lines suggests slab masses of at least 6×10^{-13} $M_\odot$ for most dimples.

The greatest enigma that characterizes classical Be stars is their highly variable and episodic mass loss histories. Our estimates of dimple-slab masses are high enough that this problem may be removed if the magnetic paradigm for Be activity is correct. In this picture exospheric flares trigger explosive ablations of plasma from the upper photosphere. The evaporated mass is trapped by overlying closed magnetic field loops where it cools, taking on characteristics of prominence-like structures. If the loops were opened for any reason, this mass would be free to escape from the star at a rate consistent with mass loss rates during active Be episodes. Then the essential difference between Be stars in active and inactive phases would be understood not as a difference in their mass release rates but rather in the prevailing geometries of their surface fields.

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Exact, Algebraic Solutions of the Thin Shell Two-Wind Interaction Problem

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We have developed a formalism based on considerations of linear and angular momentum conservation for solving axisymmetric, steady, "thin shell" problems, which is applicable to problems of interactions of non-accelerated flows. This formalism yields a system of algebraic equations that can be solved to obtain the shape of the thin shell, its mass surface density, and the velocity along the shell. We first use this approach to obtain the solution (obtained with a somewhat different approach by Wilkin 1996) to the problem of an isotropic stellar wind interacting with a plane-parallel stream. Secondly, we find an exact (implicit) and approximate (explicit) analytic solution to the problem of the interaction of two isotropic stellar winds.

Our solution of the two-wind problem is a step forward from previous, numerical solutions based on a ram pressure balance argument, as it is analytic, and furthermore includes centrifugal effects. This

solution has clear applications to problems of interacting winds in binary stars, as well as in young stellar objects.

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Preprints available from www site http://astro.berkeley.edu/wilkin/franksworld.html

The Wolf-Rayet counterpart of Cygnus X-3

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We present orbital-phase resolved I and K-band spectroscopy of Cygnus X-3. All spectra show emission lines characteristic of Wolf-Rayet stars of the WN subclass. On time scales longer than about one day, the line strengths show large changes, both in flux and in equivalent width. In addition, the line ratios change, corresponding to a variation in spectral subtype of WN6/7 to WN4/5. We confirm the finding that at times when the emission lines are weak, they shift in wavelength as a function of orbital phase, with maximum blueshift coinciding with infrared and X-ray minimum, and maximum redshift half an orbit later. Furthermore, we confirm the prediction – made on the basis of previous observations – that at times when the emission lines are strong, no clear wavelength shifts are observed. We describe a simplified, but detailed model for the system, in which the companion of the X-ray source is a Wolf-Rayet star whose wind is at times ionised by the X-ray source, except for the part in the star's shadow. With this model, the observed spectral variations can be reproduced with only a small number of free parameters. We discuss and verify the ramifications of this model, and find that, in general, the observed properties can be understood. We conclude that Cyg X-3 is a Wolf-Rayet/X-ray binary.

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or on the web at `http://astro.caltech.edu/~mhvk/preprints.html`

VLA Observations of Massive Stars at 7-mm

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Early-type stars possess ionized winds that produce detectable free-free emission in the radio. Measurement of this thermal radiation was expected to provide a way to determine the stellar mass loss rate. However, the observations have shown that these stars often have time-variable, strong non-thermal emission that contaminates the cm free-free radiation arising from the stellar wind. At higher frequencies one expects to observe uncontaminated thermal emission. We present multifrequency radio continuum observations of a sample of eight O stars and WR stars and propose that 7-mm radio

observations are a more reliable method to derive mass loss rates for massive stars. We also discuss how the 7-mm observations improve our knowledge of the characteristics of individual stars.

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Stellar evolution with rotation I. The computational method and the inhibiting effect of the μ-gradient

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We study the effects of rotation on the structure and evolution of massive stars. The method of Kippenhahn & Thomas (1970) to incorporate the hydrostatic effects of rotation in one dimensional stellar evolutionary codes is strictly valid only in case the angular velocity distribution has a cylindrical symmetry. We demonstrate how this method can be applied (cf. Appendix) in the case where the angular velocity is constant on isobars ("shellular rotation law", cf. Zahn 1992). We also investigate the structural effects of rotation on the stellar atmosphere. The effects of rotational mixing are considered with the theory of Zahn (1992, asymptotic regime) for the circulation and turbulence in rotating stars. The subsequent developments brought to the Richardson criterion by Maeder (1995a) and Maeder and Meynet (1996) to account for thermal effects on the shear instability are also applied.

Evolutionary tracks are calculated for initial masses of 9, 20, 40 and 60$M_\odot$ with account of the above hydrostatic and mixing effects. The main results are the following ones:

1) The hydrostatic effects alone are quite modest: when the initial angular velocity (Ω) increases from 0 to 90% of the surface critical velocity ($\Omega_{\rm crit}$), the lifetimes of massive star models (40 to 60$M_\odot$) are increased by 1 to 2%. The evolutionary tracks are shifted towards lower luminosities, making them appear as the ones resulting from slightly lower initial mass stars, typically 0.5 to 2.5 $M_\odot$ smaller.

2) Surprisingly we find that the $\mu-$gradients, when non zero, are always strong enough to inhibit mixing. Indeed, the effects of μ-gradients are quite difficult to overcome and this tends to make the rotationally induced mixing inoperant when the Richardson criterion is applied.

3) We suggest that different mixing criteria and/or diffusion coefficients must be searched for and applied if one wants to reproduce the observations by Herrero et al. (1992). Indeed these authors show that above a certain rotational velocity, quite efficient mixing processes are active and able to modify the surface abundances in helium during a fraction of the main sequence lifetime.

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Submitted Papers

Be star surveys with CCD photometry. II. NGC 1818 and its neighbouring cluster in the LMC

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As part of an ongoing photometric survey of young Magellanic Cloud clusters we identified Be stars in NGC 1818 and a nearby smaller cluster in the Large Magellanic Cloud. The neighbouring cluster does not appear to contain any evolved stars, and its sparsely populated main sequence does not extend to stars as massive as in NGC 1818. Both clusters are younger than the surrounding field population, but the current data do not allow to conclude whether NGC 1818 is a binary cluster or not. The small cluster is more heavily reddened than NGC 1818 indicating the presence of differential reddening, leftover gas and dust from the star formation process, or a larger distance. NGC 1818 does not seem to be significantly affected by differential reddening.

We find both clusters to be rich in Be stars. The field only contains very few Be stars as one would expect for a predominantly older population. NGC 1818 contains almost as many Be stars as the slightly younger SMC cluster NGC 330, while NGC 2004, a young LMC cluster, has a lower Be star content.

Comparing Be star fractions of the Magellanic Cloud clusters NGC 1818, NGC 330, and NGC 2004 to young Galactic open clusters, we show that the Be phenomenon is strongly peaked toward early-type B stars (and thus clusters in an age range of a few 10^7 years). Total numbers of Be stars are higher in the Magellanic Cloud clusters, while Be star fractions are similar in Galactic and Magellanic clusters of comparable age.

Possible constraints on Be star theories from Be stars and Be star fractions in stellar aggregates of given age and metallicity are discussed. The location of Be stars in the colour-magnitude diagrams of young clusters suggests that Be stars are in the evolutionary state of main-sequence stars.

Submitted to A & A *Preprints from* `grebel@astro.uni-wuerzburg.de`

Revised Spectral Types for 64 B-supergiants in the Small Magellanic Cloud: Metallicity Effects

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The problem of the classification of metal poor stars, such as occur in the Small Magellanic Cloud (SMC), is discussed with reference to the applicability of the MK system in such an environment. An alternative method is presented here and applied to B-type supergiants in the SMC. A local reference

system is first devised and then a transformation to MK spectral types is determined by comparing the *trends* of metal line strengths in these two systems. For the determination of the luminosity class, we emphasize the need to use the hydrogen Balmer line strengths independently of metal line-strength considerations. This method is used to determine new spectral types for 64 supergiants in the SMC, 75% of the sample requiring classifications different from previous findings. These new types result in much improved line strength – spectral type correlations for He, C, N, O, Mg and Si. Corresponding changes in the distribution of these stars in the Hertzsprung-Russell diagram of the SMC reveal more clearly than before the existence of a ridge which may be the SMC analogue of a similar feature found for the LMC by Fitzpatrick & Garmany ([**?**]). The group of very luminous supergiants lying above this ridge includes the LBV AV415 (R40), a property which this object has in common with LBVs in the Large Magellanic Cloud. Also, for the first time, clear examples of BN/BC supergiants are found in the SMC.

Submitted to A & A *Preprints from* djl@usm.uni-muenchen.de

In Proceedings

Population of massive stars in the new Wolf-Rayet galaxy Mrk 712

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We derive the population of massive stars in the IRAS barred spiral galaxy Mrk 712 from spectrophotometric observations. We report the discovery of a large number of Wolf-Rayet stars ($\sim$ 450) in a giant H II region 4.5″ South of the nucleus. The ratio of WNL to O-type stars, estimated from the luminosity of the He IIλ4686 line, is about 0.2. By comparison with starburst and stellar evolution models, we find that this high value is only compatible with a very young starburst episode (3 – 4 Myr) and a nearly flat initial mass function.

To appear in: *From Stars to Galaxies: The Impact of Stellar Physics on Galaxy Evolution*, eds. C. Leitherer, U. Fritze-von Alvensleben, & J. Huchra, ASP Conf. Series Vol. 98, page 439.
Preprints from contini@obs-mip.fr

Comparison of the dense molecular gas in the LINER galaxy NGC 6764 and in the Wolf-Rayet galaxy NGC 5430

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We compare the dense molecular gas content in two barred spiral galaxies, NGC 6764 (classified LINER) and NGC 5430 (a Wolf-Rayet galaxy). We find a significant difference in the proportion of dense molecular gas between the two galaxies. CS(3→2) is detected in NGC 6764 but not in NGC

5430, even though the intensities of ^{12}CO(2→1) and HCN(1→0) are higher in the latter galaxy. The non detection in NGC 5430 indicates that the CS abundance in that galaxy is unusually low, or that HCN is subthermally excited. To complement these observations, we discuss the ionization source in the nucleus of the LINER galaxy NGC 6764.

To appear in: *The Physics of LINERs in View of Recent Observations*, eds. M. Eracleous & C. Leitherer, ASP Conf. Series, in press. *Preprints from* `contini@obs-mip.fr`

Thesis

Stellar Content and Evolution of OB Associations

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One of the basic goals in astronomy is to understand the star formation process. Basic questions include: How do individual stars or multiple systems form? How do global properties of the stellar population arise during the star formation process? Much of the theoretical work on star formation has gone into answering the first question, and has led to fairly detailed knowledge of the formation of individual stars. However, there are no detailed theories on the origin of the *global* properties of the stellar population, such as the initial mass function.

To understand the origin of these global properties detailed studies of young stellar groups are required. Close to the Sun one finds a number of such groups, the nearby OB associations. Detailed studies thereof require a good knowledge of the membership. However, up to now the most reliable membership determinations (based on proper motions) for OB associations are limited to spectral types earlier than B5.

To remedy this problem the SPECTER consortium, formed at Leiden in 1982, proposed the observation by HIPPARCOS of over 10 000 candidate members of OB associations within 1 kpc from the Sun. HIPPARCOS gathered accurate positions, proper motions and parallaxes. The expected accuracy of the proper motions and parallaxes are $\sim$ 1.2 milli-arcsecond/year and $\sim$ 1.5 milli-arcsecond, respectively. The HIPPARCOS results will be available by early 1996.

In anticipation thereof, ground based studies have been carried out, which are intended to complement the proper motion and parallax data. Walraven photometry was collected for $\sim$ 5500 candidate members in the associations Sco OB2, Ori OB1, Mon OB1, CMa OB1 and Sct OB2. A Key Programme was started at ESO, in collaboration with Antwerp and Brussels, to gather accurate radial velocities for the early type stars in Sco OB2. Combined with the HIPPARCOS proper motions the full space motions of the stars in Sco OB2 can be obtained. Furthermore, these data also allow a precise determination of rotational velocities, and repeated observations will lead to detection of binarity.

The combined data from the SPECTER project will lead to a much improved knowledge of the stellar content and internal kinematics of nearby OB associations. This leads to valuable information on the initial mass function, the local star formation rate and efficiency, the velocity distribution of young stars as a function of mass and position in the association, differential age effects between subgroups in an association, and the characteristics of the binary population. Ultimately this will lead to better constraints on star formation theories.

The aim of this thesis is to further investigate nearby OB associations by ground-based observations, to carry out a first analysis of the data from the ESO Key Programme on Sco OB2, and to prepare

for the release of HIPPARCOS data.

Chapters 2 and 3 of the thesis concern the Orion OB1 association. This association is located near the Orion molecular cloud complex, which is the nearest site of high-mass star formation. In chapter 2 Walraven photometry is presented of established and probable members of Orion OB1. The physical parameters of the stars are derived. These are used to determine the distance to the association, the ages of the subgroups, the depth of the molecular clouds along the line of sight, and the IMF. Using the derived IMF and the ages, it is shown that the early-type stars in Orion OB1 are probably responsible for the existence of the Orion-Eridanus bubble in the interstellar medium.

This bubble is investigated in detail in chapter 3. Data on neutral hydrogen from the Leiden/Dwingeloo survey are combined with infrared (IRAS), CO (taken from the literature), and X-ray data (from the HEAO1 mission). The neutral-hydrogen maps for the Orion-Eridanus region allow identification of the H I filaments and arcs delineating the Bubble and a derivation of the expansion velocity of the surrounding shell. The X-ray data are shown to anti-correlate in a detailed way with kinematically narrow features in H I. Comparison of IRAS 100 μm data with the H I data shows that the H I shell emission is optically thin, which justifies a derivation of its mass by direct conversion of the H I emission to column densities. Using a model that takes the density stratification of the Galactic H I layer into account, it is shown that the stellar winds and supernovae from Orion OB1 can account for the size as well as for the expansion velocity of the H I shell.

In chapter 4 attention is turned to the Key Programme on radial velocities in Sco OB2. Observations for this programme were carried out with the CASPEC and ECHELEC echelle spectrographs at ESO, La Silla. The data reduction procedure for ECHELEC spectra is described in detail. It is shown that the accuracy of the reduced spectra is mostly set by intrinsic instrumental imperfections. The differential wavelength calibration of the spectra is better than 0.25 $\mathrm{km\,s^{-1}}$.

A first analysis of the ECHELEC spectra is presented in chapter 5. Precise rotational velocities are derived for a sample of 156 stars that are established or probable members of Sco OB2. Three different techniques are employed to derive the value of $v \sin i$. In increasing order of expected $v \sin i$ these are: 1) converting the widths of spectral lines directly to $v \sin i$, 2) comparing artificially broadened spectra of low $v \sin i$ stars to the target spectrum, 3) comparing the He II λ4026 line profile to theoretical models. The sample is extended with literature data for 47 established members of Sco OB2. Analysis of the $v \sin i$ distributions shows that there are no significant differences between the subgroups of Sco OB2. It is shown that members of the binary population of Sco OB2 on the whole rotate more slowly than the single stars. The effects of rotation on colours in the Walraven photometric system are investigated. It is shown that positions of B7–B9 single dwarfs above the main sequence are a consequence of rotation.

Chapter 6 focuses on the preparation for the release of HIPPARCOS data. N-body models of OB associations are employed to investigate the reliability of so-called kinematic ages. These are the ages derived from proper motions, based on the model of linear expansion. It is shown that the tracing back of proper motions in time always leads to underestimated ages. If the proper motion in a certain direction is plotted vs. the corresponding coordinate to derive an expansion coefficient, the ages can be overestimated as well as underestimated, depending on the chosen coordinate direction and the magnitude of the effects of virtual expansion caused by radial motion. The conclusion is that the longstanding discrepancy between the kinematic and nuclear ages for OB associations can be attributed to underestimates of the kinematic age.

Ph.D. Thesis completed at Leiden University, January 17 1996, under the direction of P.T. de Zeeuw. *For copies, contact* `brown@strw.LeidenUniv.nl`