THE HOT 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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From the Editor

We had many good meetings on hot massive stars during the summer. Unfortunately, the Brussels meeting overlapped with others. In order to avoid such clashes of dates, it is suggested to send a note to the chairman of the Working Group on Hot Massive Stars eenens@astro.ugto.mx before finalizing dates and details of planned meetings. At that stage, an announcement will not necessarily be published in the Newsletter, unless the organizers wish to do so.

A meeting on `Flows, Shocks and Lasers` will take place near Paris in November (see last page of this newsletter.)

A meeting in the tradition of the Boulder-Munich workshops, on a topic similar to the recent Joint Discussion on Massive Star Birth, is being planned in Boulder in July or August 2001 (Peter Conti and Paul Crowther.)

An IAU Symposium on a related topic is planned for 2003 or 2004 (Peter Conti and Ed Churchwell.)

Mart de Groot is sharing with us an interesting report with the highlights of the *P Cygni* colloquium. It would be nice to hear about the other meetings held during 2000.

Report

P CYGNI 2000; 400 years of progress

Mart de Groot[1]

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This successful International Workshop to celebrate the 400th anniversary of P Cygni's discovery and to review our current understanding of this enigmatic object was held in Armagh from 20 to 23 August, 2000. The 31 participants had lively discussions about P Cygni and a few other, somewhat similar, stars.

Photometric studies of P Cyg identified time-scales of 17 d (de Groot et al.), 100 d (Percy et al.), and 4 yr (de Groot et al.), and 7 yr (Markova), as well as weaker evidence for other time-scales. For some of these time-scales there is an indication of spectrum variations with the same frequency. Kolka and Markova reported on their extensive studies of the star's spectrum variations, identifying very-long-term variability (7 yr) in Hα emission intensity, long-term variability (2 yr) in absorption-line velocities, the presence of DAC, and a "swaying" variability of the velocity and strength of certain spectral lines.

Imaging (Chesneau et al., Meaburn et al.), optical and IR spectroscopy (Friedjung et al., Smith et al.), radio (Exter, Nugis) and polarimetric (Nordsieck et al.) observations all point to clumps of various sizes and distances from the photosphere, but it remains unclear whether and how clumps at small distances evolve into clumps at larger distances.

Theoretical approaches yielded important information about abundances (N up, C down, O, Mg, Si slightly down: Najarro), a possible scenario for P Cyg's evolution (Blue SG - Red SG - Yellow hypergiant - LBV - WR star or SN: de Jager), and strange-mode pulsations (Glatzel). Relevant and interesting results for η Car, R81, HR8752, and a few other stars were also presented.

The participants adopted a resolution that encourages colleagues to use the name "S Dor-type variables" for hot luminous stars that show photometric and/or spectroscopic variability; the use of the name LBV is discouraged (many so-called LBVs go through phases where they are no longer 'blue'): S Dor-type stars that have suffered larger outbursts should preferably be called *S Dor-type variables that have undergone an η Car-type outburst*. The Proceedings, edited by de Groot and Sterken, will appear in the Astron. Soc. Pacific Conference Series. Individuals who did not attend the Workshop but would like to obtain a copy of the Proceedings are invited to contact the editors. Abstracts of the talks are available from the Workshop's web site at *www.arm.ac.uk/∼mdg*.

Accepted Papers

Spectroscopy of HD 4004. Correlated profile variations?

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We present results of detailed analysis of spectral variability observed in the optical spectrum ($\lambda\lambda$ 4350-5700 Å) of HD 4004 (WR 1). Basing on data obtained during spectroscopic monitoring of this object in three nights in September 1994, and six nights in November 1995 we show that the

variations observed in He ii lines λ 4542, 4686, 4860 and 5411 are very similar and well correlated. We also show that the amount of variability in these lines is identical. We provide evidence, however, that the variations as observed in those He ii show also noticeable differences. The projected velocities of perturbations exposed on He ii emission line profiles do not scale with line width (FWHM). This means that the factor responsible for the observed profile variations is not coupled with the wind and its velocity law. Based on our results we argue for two-component (fast-slow) wind model of HD 4004.

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Preprints from aniedzi@astri.uni.torun.pl
or on the web at http://www.astri.uni.torun.pl/∼aniedzi/public_an.html

A Near-Infrared Stellar Census of Blue Compact Dwarf Galaxies: NICMOS Detection of Red Giant Stars in the Wolf-Rayet Galaxy Mrk 178

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We observed the Blue Compact Dwarf/Wolf-Rayet galaxy Mrk 178 with the NICMOS camera aboard HST. The galaxy is well resolved into individual stars in the near-IR; photometry in J and H yields color-magnitude diagrams containing 791 individual point sources. We discuss the stellar content, drawing particular attention to the intermediate age and/or old stars.

Mrk 178 is only the second Blue Compact Dwarf galaxy in which the red giant branch has been resolved, indicating stars with ages of at least 1-2 Gyr. This allows us to derive a distance of $\geq$4.2($\pm$0.5) Mpc. The near-IR color-magnitude diagram also exhibits an abundance of luminous, asymptotic giant branch stars. We find that this requires vigorous star formation several hundred Myr ago. Some candidate carbon stars are identified via their extreme near-IR color.

We argue that Mrk 178 is fundamentally an old galaxy, based on the NICMOS detection of red giants underlying the blue, starburst core, and its extended, faint halo of redder color.

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Preprints from http://xxx.lanl.gov/abs/astro-ph/0007417

Surface trapping and leakage of low-frequency g-modes in rotating early-type stars – I. Qualitative analysis

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A qualitative study of the surface trapping of low-frequency non-radial g-modes in rotating early-type stars is undertaken within the Cowling, adiabatic and traditional approximations. A dispersion relation describing the local character of waves in a rotating star is derived; this dispersion relation is

then used to construct propagation diagrams for a $7\,M_\odot$ stellar model, which show the location and extent of wave trapping zones inside the star. It is demonstrated that, at frequencies below a cut-off, waves cannot be fully trapped within the star, and will leak through the surface. Expressions for the cut-off frequency are derived in both the non-rotating and rotating cases; it is found from these expressions that the cut-off frequency increases with the rotation rate for all but prograde sectoral modes.

While waves below the cut-off cannot be reflected at the stellar surface, the presence of a sub-surface convective region in the stellar model, due to He II ionization, means that they can become partially trapped within the star. The energy leakage associated with such waves, which are assigned the moniker *virtual modes* due to their discrete eigenfrequencies, means that stability analyses which disregard their existence (by assuming perfect reflection at the stellar surface) may be in error.

The results are of possible relevance to the 53 Per and SPB classes of variable star, which exhibit pulsation frequencies of the same order of magnitude as the cut-off frequencies found for the stellar model. It is suggested that observations either of an upper limit on variability periods (corresponding to the cut-off), or of line-profile variations due to virtual modes, may permit asteroseismological studies of the outer layers of these systems. **Accepted by MNRAS**
Preprints from `rhdt@star.ucl.ac.uk`
or on the web at `http://www.star.ucl.ac.uk/~rhdt/publications/`

Surface trapping and leakage of low-frequency g-modes in rotating early-type stars – II. Global analysis

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A global analysis of the surface trapping of low-frequency non-radial g-modes in rotating early-type stars is undertaken within the Cowling, adiabatic and traditional approximations. The dimensionless pulsation equations governing these modes are reviewed, and the boundary conditions necessary for solution of the equations are considered; in particular, an outer mechanical boundary condition which does not enforce complete wave trapping at the stellar surface is derived, and discussed in detail. The pulsation equations are solved for a $7\,M_\odot$ model star over a range of rotation rates, using a numerical approach.

The results of the calculations confirm the findings of the preceding paper in the series: modes with eigenfrequencies below a cut-off cannot be fully trapped within the star, and exhibit leakage in the form of outwardly-propagating waves at the surface. The damping rates due to leakage are calculated for such 'virtual' modes, and found to be appreciably larger than typical growth rates associated with opacity-driven pulsation. Furthermore, it is demonstrated that the surface perturbations generated by virtual modes are significantly changed from those caused by fully-trapped modes; the latter result suggests differences in the line-profile variations exhibited by these two types of mode.

The findings are discussed in the context of the 53 Per, SPB and pulsating Be classes of variable star. Whilst wave leakage will probably not occur for overstable g-modes in the 53 Per and slowly-rotating SPB stars, the adoption of the new outer mechanical boundary condition may still affect the pulsational stability of these systems. Wave leakage for overstable modes remains a possibility in Be stars and the more rapidly-rotating SPB stars. **Accepted by MNRAS**
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The VIIth catalogue of galactic Wolf-Rayet stars

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The *VIIth* catalogue of galactic Population I Wolf-Rayet stars provides improved coordinates, spectral types and *bv* photometry of known WR stars and adds 71 new WR stars to the previous WR catalogue. This census of galactic WR stars reaches 227 stars, comprising 127 WN stars, 87 WC stars, 10 WN/WC stars and 3 WO stars. This includes 15 WNL and 11 WCL stars within 50 pc of the Galactic Center.

We compile and discuss WR spectral classification, variability, periodicity, binarity, terminal wind velocities, correlation with open clusters and OB associations, and correlation with H I bubbles, H II regions and ring nebulae. Intrinsic colours and absolute visual magnitudes per subtype are re-assessed for a re-determination of optical photometric distances and galactic distribution of WR stars.

In the solar neigbourhood we find projected on the galactic plane a surface density of 3.3 WR stars per kpc^2, with a WC/WN number ratio of 1.5, and a WR binary frequency (including probable binaries) of 39 %. The galactocentric distance ($R_{\rm WR}$) distribution per subtype shows $\overline{R_{\rm WR}}$ increasing with decreasing WR subtype, both for the WN and WC subtypes. This $\overline{R_{\rm WR}}$ distribution allows for the possibility of WNE $\rightarrow$ WCE and WNL $\rightarrow$ WCL subtype evolution.

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Preprints by anonymous ftp from
`ftp://saturn.sron.nl/pub/karelh/UPLOADS/7thWRCat.dir/7thWRCAT.ps`

Massive star populations and the IMF in metal-rich starbursts

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We present new spectroscopic observations of Mkn 309, a starburst galaxy with one of the largest WR populations known. A highly super solar metallicity of 12 + log(O/H) $\sim$ 9.3–9.4 is derived. Using additional objects from Guseva et al. (2000) we analyse a sample of five metal-rich ([O/H] > 0) WR galaxies with the main goal of constraining the basic properties of the massive star populations (IMF slope, $M_{\rm up}$) and the star formation history (age, burst duration) of these objects by quantitative comparisons with evolutionary synthesis models. The following main results are obtained:

- The observations are well explained by extended bursts of star formation with durations $\Delta t \sim$ 4–10 Myr seen at ages of 7–15 Myr or a superposition of several bursts with age differences of $\sim$ 4–10 Myr including a young ($\leq$ 5 Myr) burst. This naturally explains both the observed WR populations (including WN and WC stars) and the presence of red supergiants. The burst durations, somewhat longer compared to those derived in other WR galaxies using the same models (Schaerer et al. 1999a), are plausible in view of the physical sizes of the observed regions and the nature and morphology of our objects (nuclear starbursts), and pose no fundamental physical problem.
- The SEDs in the optical range are very well reproduced for all objects, provided the stellar light

suffers from a smaller extinction than that of the gas (derived from the Balmer decrement). This confirms earlier findings from studies combining UV–optical data of other starburst galaxies.

- All the considered observational constraints are compatible with a Salpeter IMF extending to masses $M_{\rm up} \geq 40\ M_\odot$. Adopting a conservative approach we derive a *lower limit* of $M_{\rm up} \geq 30\ M_\odot$ for the Salpeter IMF. ¿From more realistic assumptions on the metallicity and SF history we favour a lower limit $M_{\rm up} \geq 30$–$40\ M_\odot$, which is also in agreement with Hβ equivalent width measurements of metal-rich HII regions in spiral galaxies indicating an upper mass cut-off of at least $\sim 35 - 50\ M_\odot$. Steep IMF slopes ($\alpha \geq 3.3$) are very unlikely.

The uncertainties of our results are discussed. We compare our findings to other work on massive star populations and the IMF in similar environments. We stress the importance of direct analysis of stellar populations compared to other indirect methods based on properties of ionized gas to constrain the IMF in metal-rich starbursts.

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Preprints from `schaerer@ast.obs-mip.fr`
Also on the web at `http://webast.ast.obs-mip.fr/people/schaerer/`
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Colliding Stellar Winds: 'Asymmetric' Thermal Conduction

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We present the first results from modeling asymmetric thermal conduction in colliding stellar winds. This effect is important when even a weak magnetic field is present in wind-blown bubbles and planetary nebulae. Using a simplified model of this complicated physical situation, we demonstrate that asymmetric conduction may cause asymmetric structures even if the colliding winds were intially spherically symmetric. We also find that the interior of such hot bubbles becomes convective. The objects this model represents will show higher asymmetry if observed in X-rays than in the optical.

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Preprints by anonymous ftp to `super.colorado.edu`
`cd pub/Preprints ; get athc-ApJL.gz ; then one needs to gunzip the file`
`(gunzip athc-ApJL.gz)`

A New Look at Simple Inhomogeneous Chemical Evolution

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A rudimentary, one-zone, closed-box model for inhomogeneous chemical evolution is offered as an alternative reference than the Simple model in the limit of no mixing. The metallicity distribution functions (MDFs) of Galactic halo and bulge stars can be matched by varying a *single* evolutionary

parameter, nQ. Q is the filling factor of contaminating regions and n is the number of star-forming generations. Therefore, *Q and n have equivalent roles*, and combinations of n and Q yield systems with different metallicities at any given age. The model also revises interpretation of observed MDFs. Unevolved systems probe the parent distribution of metal production $f(z)$, for example, the high-metallicity tail of the halo distribution agrees with a power-law $f(z)$. The Galactic disk G-dwarf Problem also improves.

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Preprints from `oey@stsci.edu`
or on the web at `http://www.stsci.edu/~oey` and `astro-ph/0008302`

An X-ray Binary Model for the Galactic Center Source IRS 13E

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We present several models for IRS 13E, an infrared, mm and X-ray source in the Galactic Center. Our favoured interpretation is that of an early-type binary with strong colliding winds emission. This naturally explains the observed X-ray count rate and the strong IR emission lines, and has a distinct advantage over competeing hypotheses based upon a single star or BH system.

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or on the web at `http://ast.leeds.ac.uk/~robc/research.html`

Compact star clusters of the LMC H II region N11 C

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Based on imaging and spectroscopy obtained at the ESO NTT telescope and using an efficient image analysis algorithm, we study the core of the LMC OB association LH 13, particularly the two compact stellar clusters Sk–66°41 and HNT in the H II region N 11C. We resolve Sk–66°41 into 15 components and for the first time the HNT cluster into 70 stars, and derive photometry for the members. Moreover, from medium resolution spectroscopy we determine the spectral types for sixteen stars in N 11C. We compare the color-magnitude diagrams of the clusters with that of the field stars and discuss the cluster ages. With an age of ~ 100 Myr, the HNT cluster appears significantly older than the very young (≤ 5 Myr) Sk–66°41 starburst. We suggest that most of the 'field' O-stars in the core of N 11C have actually been ejected from Sk–66°41 through dynamical interactions in the compact cluster. The properties of the Sk–66°41 and HNT clusters suggest that we are viewing different star formation regions lying at different distances along the same line of sight.

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For preprints, contact `Mohammad.Heydari-Malayeri@obspm.fr`
Also available from astro-ph `http://arXiv.org/ps/astro-ph/0007414`

Stellar and circumstellar activity in the Be star EW Lac from the 1993 multi-site campaign

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A multi-site, multi-technique campaign on the Be star EW Lac was held for about 9 days in August-September 1993. We present results of the analysis of visual, high S/N spectroscopic data (He I 6678 Å and Hα). Search for short-term variability was carried out on He I 6678 (line profiles, radial velocity (RV), equivalent width (EW), full width at half-maximum (FWHM) on the absorption part of the line profile and on violet (V) and red (R) emission peaks) and on Hα emission line (line profiles, EW, V, R and V/R ratio). The presence of multi-periodicity is confirmed and we detected the frequencies found in 1989 by Floquet et al. (1992) during a 8-day mono-site campaign. Possible non-radial pulsation solutions for the main frequencies detected are $\ell \approx 2-3$, $|m| \approx 2-3$. We found evidence on the He I 6678 line of episodic matter outflows through the presence of relatively broad, variable absorption line-profile variations. At least one sharp absorption feature was also observed slowly crossing the stellar disc. It is attributed to a blob of matter temporarily orbiting the star. A brief account is given of broad-band polarimetric observations, performed over 6 nights. A correlation is found between the variation in intrinsic polarization level in the B-band and He I 6678 Å strength. Finally, we present a simple model that reproduces rather well the additional "pseudo-photosphere" contribution in 1993 as opposed to 1989.

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Preprints from `michele.floquet@obspm.fr`
or by anonymous ftp to ftp.obspm.fr/outgiong/floquet/ewlac93.ps.gz

Spectral variability of luminous early type stars. I. Pecular supergiant HD199478

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We have obtained time-series of high-quality $H\alpha$ spectra with high resolution in wavelength (R = $\lambda/\Delta\lambda$ of 15000 to 22000) and time (Δt =1d) of the late-type B supergiant HD199478. The spectra

were analysed in terms of line-profile variability (lpv) using contemporary techniques of time-series analysis, such as Temporal Variance Spectrum and the 2d- Discrete Fourier Transform. The $H\alpha$ profile is found to consist of a highly variable emission core (between -280 and +150km s^{-1}) superimposed on almost constant, extended ($\pm$1000km s^{-1}) emission wings. Due to the lack of strong line-emission the latter is attributed to electron-scattering in deep atmospheric layers.

The $H\alpha$ variability manifests itselfs by variations in velocity and intensity of blue– and red–shifted emission peaks, which result in drastic alterations in the shape of the profile from almost symmetric and unshifted, with respect to the stellar rest frame, emission through blue- or red-shifted asymmetric emission to double-peaked emission or a reverse P Cygni-type profile. Significant variations in total emissivity (i.e. EW) of the line are also established but these variations do not appear to be obviously linked to changes in the line-profile shape. The pattern of variability resembles that in Be-stars - though on a much shorter time scale - and suggests interpretation in terms of an axially symmetric and perturbed stellar wind. Since the time-scales of the V/R variations is found to be 3 to 5 times longer than the radial fundamental pulsation period but consistent with rotational period, rotational modulation as a possible cause for this variability is considered.

Besides variations in $H\alpha$ continuous changes in velocity (typical dispersion of $\sigma \sim$ 5km s^{-1}) and strength, i.e. EW, (up to 13% of the mean) of a sample of three absorption lines ($CII\lambda\lambda$6583, 6578 and $HeI\lambda$6678) were also established. The phenomenon observed is more likely connected to changes in velocity and temperature structures of the stellar photosphere. Pulsation instability as a possible cause of photospheric variability is suggested.

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Preprints from `rozhen@mbox.digsys.bg`

New Theoretical Mass-Loss Rates of O and B stars

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We have calculated mass-loss rates for a grid of wind models covering a wide range of stellar parameters and have derived a mass-loss recipe for two ranges of effective temperature at either side of the bi-stability jump around spectral type B1.

For a large sample of O stars, it is shown that there is now good agreement between these new theoretical mass-loss rates that take *multiple scattering* into account and observations.

Agreement between the observed and new theoretical wind momenta increases confidence in the possibility to derive distances to luminous stars in distant stellar systems using the Wind momentum Luminosity Relation.

For the winds of the B stars there is an inconsistency in the literature between various mass-loss rate determinations from observations by different methods. One group of $\dot{M}$ determinations of B stars *does* follow the new theoretical relation, while another group does not. The lack of agreement between the observed mass-loss rates derived by different methods may point to systematic errors in mass-loss determinations from observations for B stars.

We show that our theoretical mass-loss recipe is reliable and recommend it be used in evolutionary calculations.

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The Massive Wolf-Rayet Binary LSS 1964 (= WR 29)

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We present a radial velocity study of LSS 1964 (= WR 29) based on digital spectral images obtained with the 2.15-m telescope at CASLEO, San Juan, Argentina, between 1997 and 2000. We find this star to be a double-lined WN + O binary with a period of 3.16415 days. The WN component appears to be more massive than the O type component. NIV absorption at $\sim \lambda 5203$ Å is found to belong to the WN7 star.

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Preprints from rgamen@fcaglp.unlp.edu.ar
or on the web at http://lilen.fcaglp.unlp.edu.ar

Submitted Papers

A Search for High Velocity Be Stars

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We present an analysis of the kinematics of Be stars based on *Hipparcos* proper motions and published radial velocities. We find approximately 23 of the 344 stars in our sample have peculiar space motions greater than 40 km s^{-1}, and a similar number are found at large distances from the galactic plane ($|z| > 1200$ pc). We argue that these high velocity stars are either the result of a supernova that disrupted a binary or they were ejected by close encounters of binaries in young clusters. Be stars spun up by binary mass transfer will only appear as high velocity objects if there was significant mass loss during the supernova explosion of the initially more massive star, but the moderate peculiar velocities of Be X-ray binaries indicate that the progenitors lost most of their mass prior to the supernova (in accordance with model predictions). Whether all Be stars were spun up by binary mass transfer remains unknown, since the post-mass transfer companions are difficult to observe.

Submitted to ApJ
Preprints from gies@chara.gsu.edu

Detection of the Faint Companion in the Massive Binary HD 199579

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We present new radial velocity data for the massive binary HD 199579 (O6 V((f))) based upon spectra obtained from *IUE*, CFHT, KPNO, the David Dunlap Observatory, and the GSU Multiple-Telescope Telescope. We derive a revised period, $P = 48.5216 \pm 0.0015$ d, and improved orbital elements that agree with the earlier elements within their errors. We applied a Doppler tomography algorithm to the KPNO spectra to reconstruct the individual primary and secondary spectra in the red, yielding the first detection of the secondary's spectrum. The spectral features observed, implied mass ratio ($M_2/M_1 = 4 \pm 1$), and magnitude difference ($\triangle V = 2.5 \pm 0.3$) are all consistent with a secondary of type B1 V – B2 V. The maximum angular separation of the components is predicted to be ≈ 1.2 mas, and, thus, the binary is an important target for optical interferometry.

Submitted to ApJ

Preprints from `gies@chara.gsu.edu`

Radiation-driven winds of hot luminous stars XIII. A description of NLTE line blocking and blanketing towards realistic models for expanding atmospheres

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Spectral analysis of hot luminous stars requires adequate model atmospheres which take into account the effects of NLTE and radiation driven winds properly. Here we present significant improvements of our approach in constructing detailed atmospheric models and synthetic spectra for hot luminous stars. Moreover, as we regard our solution method in its present stage already as a standard procedure, we make our program package *WM-basic* available to the community (download is possible from the URL given below).

The most important model improvements towards a realistic description of stationary wind models concern:

- A sophisticated and consistent description of line blocking and blanketing. Our solution concept to this problem renders the *line blocking influence on the ionizing fluxes* emerging from the atmospheres of hot stars — mainly the spectral ranges of the EUV and the UV are affected — in identical quality as the *synthetic high resolution spectra* representing the observable region. In addition, the line blanketing effect has been properly accounted for in the energy balance.
- The atomic data archive which has been improved and enhanced considerably, providing the

basis for a detailed multilevel NLTE treatment of the metal ions (from C to Zn) and an adequate representation of line blocking and the radiative line acceleration.

- A revised inclusion of EUV and X-ray radiation produced by cooling zones which originate from the simulation of shock heated matter.

With this new tool we present not only an easy to use method for O-star diagnostics — via a comparison of observed and synthetic spectra physical constraints on the properties of stellar winds, stellar parameters, and abundances can be obtained — but also the astrophysically important information about the ionizing fluxes of hot stars can be determined automatically. Results pointing to this are discussed by means of a basic model grid calculated for O-stars with solar metallicity. To demonstrate the astrophysical potential of our new method further we provide a first detailed spectral diagnostic determination of the stellar parameters, the wind parameters and the abundances by an exemplary application to one of our grid-stars the O9.5Ia O-supergiant α Cam.

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In Proceedings

Long-Term UBV Observations of the Episodic Dust Maker WR 140

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We report on photoelectric UBV observations of the Wolf-Rayet binary star WR 140 obtained between October 1991 and June 2000. In 1993, close to periastron passage in the 7.94 yr orbit, the star underwent a shallow light minimum which lasted until 1997. This light attenuation is probably caused by the obscuration through circumstellar dust which has formed from shock-compressed material of the colliding winds of the Wolf-Rayet and O-type stellar components. The most recent observations, taken in June 2000 do not yet show any signs of light attenuation which is expected to occur in the course of the forthcoming periastron passage in early 2001.

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Preprints from `seggewis@astro.uni-bonn.de`

WSRT non-thermal radio emission studies of WR+OB colliding-wind binaries

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One and a half decades of monitoring the Wolf-Rayet objects WR 140 (WC7+O4-5), WR 146 (WC6+O8) and WR 147 (WN8(h)+B0.5V) with the WSRT at 6 cm and 21 cm have revealed variable non-thermal radiation in the three objects, indicative of colliding-wind effects and orbital modulation of the flux-densities. The 7.94 yr binary period of WR 140, discovered from infrared light-curves, is confirmed by the WSRT radio observations. WR 146 and WR 147 are binaries with estimated periods $P_1 \simeq 550$ yr and 1350 yr, respectively. Additional modulation of their radio light-curves shows periods of, respectively, $P_2 = 3.38$ and 7.9 yr. Therefore, WR 146 and WR 147 are possible triple stars.

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Preprints by anonymous ftp from `ftp://saturn.sron.nl/pub/karelh/UPLOADS/idlm.dir/hpaper.ps`

Theses

Intriguing Variability of WR 46 and of "dusty" Wolf-Rayet stars

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In part I of this thesis we discuss the intriguing variability of WR 46 (WN3p). Its photometric variability is presented and investigated in Chapter 2. The period analysis of all the data sets shows strong evidence for periodic variability of the brightness and colour. Only the analysis of the two most extended data sets in 1989 and 1991 results into unambiguous frequency determinations of 7.08 c d^{-1} and 7.34 cd^{-1}, respectively, on the basis of brightness and colour variations. Because the radial velocity varies on a time scale of the photometric double-wave period (Chapter 3) and the mean folded light curve shows indication of unequal depths and different colours for the two minima, it is suggested that the double-wave period is actually the main period. The difference between the double-wave period of $6^{\rm h}47^{\rm m}$ in 1989 and of $6^{\rm h}33^{\rm m}$ in 1991 is highly significant. An additional frequency of 4.34 cd^{-1} is identified in the flux variations of 1989, but not in the colour changes. Furthermore, our observations confirm the brightning over these same years as detected by the HIPPARCOS satellite. The combination of the brightening and the period decrease is intriguing.

In Chapter 3 we investigate the spectroscopic variability over several seasons of WR 46, observed simultaneously with the photometry. The object shows radial-velocity variation with a period equal to twice the photometric period, i.e. the double-wave period. The amplitude of the radial velocity can be very large up to 200 km s^{-1}. However, during several nights the radial-velocity is constant. The line

flux varies in concert with the photometry, showing a maximum at both radial-velocity minimum and maximum. The emission lines show phase delays consistent with a stratified outflowing atmosphere. These delays and the absence of hydrogen are inconsistent with the suggestion that WR 46 would be a type of cataclysmic variable and that its spectrum is formed in (the wind from) a disk. Hereby, we confirm the WR nature of the object. In addition, we note a few remarkable single events in the spectroscopic variation.

Chapter 4 discusses the interpretation behind the photometric and spectroscopic variability. We show that the variability can be understood as the rotation of an ellipsoidally distorted stellar wind. On the one hand, this distortion and the single-wave radial-velocity motion indicates that the object is a binary system. We discuss extensively the possibility that WR 46 is indeed a binary despite the large difference in periods in 1989 and 1991. Although this seems not truely impossible, it is not very satisfying. On the other hand, the large difference between the periods indicates that pulsation is driving the variability. Moreover, we note the possibility that certain pulsational modes may indeed induce an rotating density structure in the wind. However, the phasing of the radial-velocity- and line-flux curves is not consistent with the naive application of this suggestion. We conclude i) that from a theoretical point of view it is necessary to model the response of the WR atmosphere to various pulsational modes of the stellar core, and ii) that only a world-wide photometric and spectroscopic monitoring campaign might identify the mechanism behind the intriguing variability of WR 46.

Chapter 5 reports on the search for non-thermal radio-emission from the reported short-period photometric variable WR stars WR 46 and WR 50 using the Australian Telescope. However, the objects were not detected and the implied upperlimits to their radio-emision seem to be in agreement with the objects being thermal emitters. The thermal emission of WR 46 seems to be in line with a single WR star, possibly accompanied by a low-mass non-compact companion as suggested from the optical variability study. As to WR 50, we note that its variability is suspicious.

Part II of this thesis deals with optical and infrared photometric variability of WC stars, which was shown to be related to circumstellar dust. In Chapter 6 we present observations of WR 19 showing an infrared excess due to newly created dust similar to an event observed in 1987. On the basis of the archetype "dusty" colliding-wind binary WR 140, we suggest that these episodes of dust-formation of WR 19 are periodic ($P \simeq 10$yr) and are related to the binary nature of the object. In support of this thesis we identified absorption lines from a companion of spectral type O9.5-9.7.

In Chapter 7, we report a fading of WR 121 (WC 9) on a time scale of weeks, during which the star reddened comparably to interstellar reddening. In addition, we found a fading of WR 103 (WC9) in 1988 in the data set of the LTPV-project. Together with known curious "eclipses" in the literature, all these objects are known to have a IR luminous dust shell. We interprete the "eclipses" as obscurations by temporary condensing dust clouds in the line of sight. It appears possible to fit the light curves with a simple geometrical model, assuming the dust flow velocity to be equal to the terminal wind velocity. Using the colour changes during the obscuration and an estimate of the optical dust parameters, we derive the mean particle size. We discuss the results (dust-mass production rate and distance of condensation) in relation to the IR luminous dust in the distant shell. We speculate on the relation between the dust production of late-WC stars and R CrB stars.

Chapter 8 presents two new "eclipsing" dusty stars, WR 53 and WR 106. Furthermore, we show that at one of the times of eclipse predicted by the initial binary hypothesis, WR 103 did not show an eclipse. Subsequently, we discuss the suggestion in the literature that all "dusty" WR stars are colliding-wind binaries. In this view the persistent dust makers happen to have the right conditions at the collision throughout the whole orbit. However, we argue that this proposition is not very satisfying, because of statistical problems, the occurence of "eclipses" of most optically bright "dusty" stars, and the

compositional difference between WC9 stars that do show dust and those that do not. We conclude that at least some of the "dusty" WC9 stars produce dust particles on their own.

Thesis completed in Leiden under the supervision of Prof. Habing, van Genderen and van der Hucht. September 2000.

Preprints from `p.m.veen@minocw.nl and CC veen@strw.leidenuniv.nl`
or by anonymous ftp to `ftp.strw.leidenuniv.nl pub/veen/thesis`

Jobs

Postdoctoral Research Position
University of Pittsburgh

Email Inquiries: jdh@galah.phyast.pitt.edu

Attention: Dr. D. J. Hillier
University of Pittsburgh, Department of Physics and Astronomy, 3941 O'Hara Street, Pittsburgh, PA 15260, USA

Applications are invited for a postdoctoral research position at the University of Pittsburgh. The successful applicant will work with D. John Hillier on developing numerical techniques for multi-dimensional radiative transfer, and on developing a multi-dimensional code that can be used to analyze objects for which geometric effects are important. Initial application of the code will be to Be stars, however we anticipate applying the techniques and principles to other astrophysical objects (e.g, interacting binary stars, novae, supernovae, quasars).

Applicants must have a Ph.D. in Astronomy. Expertise in two or more of the following areas is highly desirable: radiative transfer, atomic physics, stellar winds, hydrodynamics. Expertise with Fortran (or C) programming is essential. The initial appointment, commencing immediately, will be for 1 year, with a likely extension for a further 2 years (subject to funding and performance).

To apply, send a curriculum vitae and bibliography to D.J. Hillier at the above address. Applicants should also send a brief description of their suitability for the position, and of their current and future research interests (2-3 pages maximum), and arrange for 3 letters of recommendation to be sent directly to the above address.

All materials are due 15-Oct-2000. This deadline has been extended by two weeks from that published in the Astronomy Job register.

Meetings

Hypersonic and Aerothermic Flows and Shocks, and Lasers
Plasma-radiation-surface interactions in Astrophysics, Applied Physics, Industry and Fundamental Physics

This is the second event of a series of three symposia devoted to physics and techniques in relation with matter processing throughout the stellar and galactic universe.

It will be held in the Observatoire de Paris (campus of Meudon) from 20 to 24 november 2000.

The aim is to gather people with usually different research fields or techniques, on the basis of a pluridisciplinary common field of interest focused of all aspects of matter- radiation interaction in physically similar problems arising in astrophysical systems or applied devices, for cross fertilization.

The topics concerned are shock waves as drivers of circumstellar matter and stellar wind interactions, as well as entry aerothermics for planes, shuttles or bodies in atmospheres or lasers used for shooting on targets.

Details concerning the topics, the scientific and local organization committees, the invited speakers and the provisionnal scientific programme, the social programme, the inscription and registration, the format of abstracts and other practical informations to attend the meeting can be found on the following web site:

http://www.obspm.fr/euroconferences

Note: The sponsoring of the conference allows partial funding, especially for young European research people, on request.

For other information contact
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