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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editor: Philippe Eenens http://www.astro.ugto.mx/∼eenens/hot/
eenens@carina.astro.ugto.mx http://www.star.ucl.ac.uk/∼hsn/index.html

Contents of this newsletter

Four years of hot star publications

Completeness? Not without your help!

The *Hot Star Newsletter* (HSN) is celebrating its fourth anniversary. Indeed its creation was announced during the 163rd IAU symposium at Elba. In 39 issues and more than 400 pages, the HSN has distributed abstracts of 457 refereed papers and 110 non-refereed papers to over 400 subscribers (astronomers and postgraduate students). This reflects the productivity of the *hot massive star* community. We are grateful to all the contributors, without whom the HSN would not be possible.

A comparison with the bibliography of Wolf-Rayet stars shows that a number of papers are not announced in the newsletter. We would like the HSN to be as complete as possible, as advances in research should build on previous results. You can help in two ways. Firstly, by remembering to send abstracts of your own recent papers. Secondly, by notifying us if you see a paper which has not been announced in the newsletter. Each time you learn from another source about a paper related to hot massive stars, you should be surprised: *How come I have not seen the abstract in the HSN?* The reflex then should be to send a short e-mail to the editor, with the name of the first author and the title. This would not only remedy the absence of an abstract in the HSN, but most likely also the absence of an author in the distribution list. We would all benefit from this kind of help, as this would increase the efficiency of our research.

The scope of the HSN

Two streams of research converge in the HSN:
– *hot stars:* stars with radiative winds, single and binaries;
– *massive stars:* their distribution in galaxies and their evolution.
The HSN thus welcomes abstracts on topics such as: Wolf-Rayet stars, LBVs, OB stars, Be/X stars, perhaps winds from other supergiants, etc. It is unclear whether to include planetary nebulae and hot subdwarfs (OB). The following fall clearly outside the scope of the HSN: AGB winds, Ap stars, pre-main sequence stars and supernovae.

Other services

There certainly are other ways in which the HSN could contribute to strengthen our field of research. We already have announcements of meetings, jobs and campaigns. We are open to suggestions. Perhaps you would like to use the HSN to ask for information and data? To make quick announcements? For more flexibility, such requests and announcements could be sent to the distribution list between regular issues. The HSN is a tool for the *hot massive star* community. Use it! Let us know how to make it more useful!

A complement to the HSN is the Wolf-Rayet bibliography. We thank Karel van de Hucht, who has just provided us with a recent update (see our web pages). Who would like to compile a bibliography of O stars?

Accepted Papers

Inference of steady stellar wind $v(r)$ laws from optically thin emission lines III. Inversion of total line intensity distributions

R. Ignace[1], J.C. Brown[1], J.E. Milne[1], and J.P. Cassinelli[2]

[1] Dept of Physics and Astronomy, Univ of Glasgow, Glasgow, UK

[2] Dept of Astronomy, Univ Wisconsin, Madison, WI, USA

The variation with wavelength for a sequence of total intensities of stellar wind lines is considered as a basis for deriving the wind velocity law $v(r)$. In particular, we focus on the case where the continuum formation in the wind is dominated by the free-free opacity so that the inner radius increases with wavelength, as is realized in some massive winds like those of the Wolf-Rayet stars. The line emission in the wind occurs exterior to the continuum photosphere, hence lines observed at different wavelengths probe different regions of the wind acceleration. A major consequence of these physical conditions is the opportunity to infer $v(r)$, even if non-monotonic. Numerical examples are given to test the method, in which smooth and non-smooth monotonic $v(r)$, non-monotonic $v(r)$, and the effects of noise are addressed. In the absence of noise, the inversion of the simulated data for radius $r(\lambda)$ and expansion velocity $v(\lambda)$ is excellent. Even with noise at the 15% level, the recovery for $r(\lambda)$ remains reasonably robust, though the results for $v(\lambda)$ are more strongly affected. Although more sophisticated techniques are required to infer $v(\lambda)$ from noisy data, the simpler considerations presented here provide a basic

theoretical framework for applying the inversion and indicate the potential of the method for deriving the wind flow structure.

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For preprints, contact rico@astro.gla.ac.uk
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Long-term visual spectrophotometric behaviour of Be stars

A. Moujtahid,[1], J. Zorec[2], A.M. Hubert[1], A. Garcia[2] and D.G. Burki[3]

[1] Observatoire de Paris-Meudon, DASGAL, F-92195 Meudon Principal Cedex, France

[2] Institut d'Astrophysique de Paris, C.N.R.S. - 98^{bis}, bd. Arago, F-75014 Paris, France

[3] Observatoire de Genève, CH-1290 Sauverny, Switzerland

The long-term spectrophotometric variations of 49 Be stars are studied using the U and V magnitudes of the UBV system, the total Balmer discontinuity D and the visible gradient $\Phi_{\rm rb}$. BCD spectrophotometric and photometric data in five different photometric systems, obtained in most cases since 1950 and reduced to the BCD system, were used. The (U, D), (V, D), $(\Phi_{\rm rb}, D)$ and $(\Phi_{\rm rb}, V)$ correlations obtained differ from star to star and they can be single or double-valued. They differ clearly for Be phases or Be-shell phases. Be stars with small $V \sin i$ showing the "spectrophotometric shell behaviour": $D > D_*$, were found. This finding implies either that strongly flattened models of circumstellar envelopes are in doubt for these stars, or that not all Be stars are rapid rotators. Comparison of observed variations with those predicted for model Be stars with spherical circumstellar envelopes of variable densities and dimensions implies that spectrophotometric patterns of Be phases are due to circumstellar envelopes in low opacity regimes, while those of spectrophotometric shell phases are due to circumstellar envelopes in high opacity regimes. In a given star, the envelope regions responsible for the observed variations of D and $\Phi_{\rm rb}$ in spectrophotometric shell phases seem to be smaller and denser than those producing the observed variations of these parameters in spectrophotometric Be phases. The high positive RV found in strong shell phases might favor the formation of compact circumstellar layers near the star.

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Preprints from Ali.Moujtahid@obspm.fr

Spectrum formation in clumped stellar winds: consequences for the analyses of Wolf-Rayet spectra

W.-R. Hamann and L. Koesterke

Lehrstuhl Astrophysik, Universität Potsdam, Am Neuen Palais 10, D-14469 Potsdam, Germany

Inhomogeneous Wolf-Rayet type stellar winds are modeled in a first-order approximation, assuming that small-scale clumps are distributed with a constant volume filling factor within an interclump space which is void. Model calculations as well as analytical considerations show that the main spectral features, i.e. the strength of the emission lines, are approximately invariant if the enhanced density in the clump medium is compensated by a suitable scaling of the mass-loss rate. Hence, to

the first order the mass-loss rate is the only empirical parameter which is affected by the application of clumped models for spectral analyses.

In clumpy atmospheres the electron-scattering line wings become weaker than in homogeneous models. This effect can be used to determine the degree of clumping empirically. We select Wolf-Rayet stars of different spectral subclasses and compare their spectra with adequate models, varying the clumpiness. In all cases, the homogeneous model can be definitely ruled out because it predicts electron scattering wings that are significantly stronger than observed. If the clumps fill 1/4 of the volume, the line wings are in reasonable agreement, while for a filling factor of 1/16 the wings are possibly too shallow, but still compatible with the observation within the error margin. Adopting a filling factor of 1/4 (i.e. the density in the clumps is enhanced by a factor of four, compared to a smooth model with same mass-loss rate) as a typical value, the empirical mass-loss rates become smaller by a factor of two than obtained with homogeneous models.

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The relative frequency of type II and $I_{b,c}$ supernovae and the birth rate of double compact star binaries.

E. De Donder and D. Vanbeveren

Astrophysical Institute, Vrije Universiteit Brussel, Pleinlaan 2,B 1050 Brussels, Belgium

Using a population number synthesis code, we estimate the relative rates of different type (II and $I_{b,c}$) of supernovae for regions of constant star formation. We combine a large set of massive single star and massive close binary evolutionary computations and allow for black hole formation. If a neutron star forms, the binary system is followed through a supernova explosion where we account for asymmetries needed to explain the observed space velocity distribution of a large sample of pulsars. We also predict the theoretical formation rate and period distribution at birth of double compact star binaries. Finally we give the distribution of the binary parameters of the progenitors of the double neutron star systems.

Our calculations reveal that the number ratio ($II/I_{b,c}$) strongly depends on the massive binary formation rate, on the binary mass ratio and period distribution. As consequence when average relative rates, obtained from observed supernova events in a sample of different galaxies, are used to predict the relative rates in a particular galaxy, this is meaningful only if the massive binary formation rate, the binary mass ratio and period distribution are the same in all these galaxies.

Interestingly, the observed average number ratio from 2461 galaxies of different types can be reproduced assuming an average (cosmological) massive binary formation rate of ∼40-50% which may differ by a factor two from the massive binary formation rate in one particular galaxy.

The theoretically predicted formation rate of close double neutron star systems in the galaxy, (10^{-6}-10^{-5})/year, is in agreement with the observed values. Taking 40 $M_\odot$ as limiting mass for black hole formation in binaries, we find that double black hole systems form at a very high rate.

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Evolved Massive Stars in the Local Group II. A New Survey for Wolf-Rayet Stars in M 33 and Its Implications for Massive Star Evolution: Evidence of the "Conti Scenario" in Action

P. Massey[1] **and O. Johnson**[2]

[1] KPNO/NOAO, P. O. 26732, Tucson, AZ 85726-6732

[2] CFA, 60 Garden Street, Cambridge, MA

We expect the evolution of massive stars to be strongly influenced by mass-loss, and hence be sensitive to metallicity. It should be possible to test this "Conti scenario" be comparing the populations of evolved massive stars among the Local Group galaxies, but such investigations have been hampered by incompletness. In Paper I we presented results of a new survey for red supergiants (RSGs) in selected regions of the Local Group galaxies M 33, M 31, and NGC 6822. In the present paper, we survey eight fields in M 33 for Wolf-Rayet stars (WRs), using interference filter imaging with a CCD to select candidates. Followup spectroscopy is used to confirm 22 newly found WR stars, all of WN type. We establish that our survey would readily detect WRs as weak-lined as any known, and we conclude that our survey is essentially complete. This survey confirms suspicions that the previous photographic surveys were only 50% complete for WN-type WRs and allows us to combine the data with equally complete samples on other Local Group galaxies. We find that the relative number of WC and WN type WRs correlates extremely well with metallicity, varying by a factor of 3 with galactocentric distance within the plane of M 33, and continuing the trend to lower and higher metallicity galaxies. The WC/WN ratio within 3 kpc of the sun is slightly above this trend, and we argue that WN stars are underrepresented in this sample. The WC/WN ratio is anomalously high in IC 10, given its low metallicity, and we demonstrate that this is not due to selection effects, but is likely due to IC 10's current status as a starburst system. We examine the spectral properties of WC stars within these galaxies, confirming the previously reported trends that the spectral lines are stronger and broader in regions of lower metallicity. We suggest that the different WC spectral subclasses do not primarily indicate different physical properties for these stars, but rather are simply a reflection of the effect that the initial metal abundances has had on the stellar wind structure. Finally, we compare the luminous RSGs with WRs in these galaxies. We find that there is a very strong correlation of the relative numbers of RSGs and WRs with metallicity, in the sense predicted by Maeder, Lequeux, & Azzopardi: at lower metallicities the fraction of luminous ($M_{bol} < -7$) RSGs is higher, with a factor of 6 change within the disk of M 33 (Δlog (O/H)=0.35 dex), and a factor of ~ 10 change from M 31 (or the inner portions of M 33) to NGC 6822 (Δlog (O/H)=0.5 dex). This is easily explained by the Conti scenario in terms of massive stars spending proportionately less of their He-burning lifetimes as RSGs rather than WRs at higher metallicites and hence higher mass-loss rates. Finally, we note that the presence of luminous RSGs and WRs stars is extremely well correlated for the OB associations in M 31 and M 33: where one finds one, one finds the other. To the extent that an association is strictly coeval, this argues that some stars of $15\mathcal{M}_{\odot}$ and above indeed do go through both a RSG and WR stage. The presence of WR stars of both WN and WC type in the same associations as luminous RSGs further suggests that some WCs, at least, have gone through the RSG phase. We include an appendix providing a complete catalog of confirmed WR stars in Local Group galaxies beyond the Magellanic Clouds.

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or on the web at `ftp://tofu.tuc.noao.edu/pub/wrpre.ps`

WCFIELDS: A Magnetic Rotating Stellar Wind Model from Wind Compression Theory

R. Ignace[1], J.P. Cassinelli[2], and J.E. Bjorkman[3]

[1] Physics and Astronomy, Univ of Glasgow

[2] Astronomy, Univ of Wisconsin

[3] Physics and Astronomy, Univ of Toledo

A stellar wind model for a magnetic rotating star is presented. We use the semi-analytic Wind Compression model that predicts the 2-dimensional geometry of outflows from rotating stars and consider the addition of a magnetic field. In the limit of weak magnetic fields, such that the fields are unimportant in accelerating the flow, the Wind Compression model can be used to predict the magnetic field distribution throughout the wind, which is shown to follow the mass flux distribution. A compression of field lines near the equator results as the flow of material from higher latitudes brings magnetic flux toward that region. As examples, Wind Compression models with magnetic fields ("WCField" models) are computed for both a Wolf-Rayet star and a Red Supergiant star. In both cases an order of magnitude enhancement of the equatorial magnetic field can result within a few stellar radii for stellar rotation rates around 20% of critical. Such enhancements could have consequences for explaining (1) non-thermal emission observed from some Wolf-Rayet winds and (2) the ring structures observed in the ejecta of SN1987a.

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or by anonymous ftp to `info.astro.gla.ac.uk /pub/rico/wcfields.ps`

The Pistol Star

Donald F. Figer[1], Francisco Najarro[2,5], Mark Morris[1], Ian S. McLean[1], Thomas R. Geballe[3], Andrea M. Ghez[1], & Norbert Langer[4]

[1] University of California, Los Angeles, Division of Astronomy

[2] Institut für Astronomie und Astrophysik der Universität München, Scheinerstr. 1, D-81679 München, Germany

[3] Joint Astronomy Centre, 660 N A'ohoku Place, University Park, Hilo, HI 96720

[4] Institut für Theoretische Physik und Astrophysik, Am Neuen Palais 10, D-14469 Potsdam, Germany

[5] CSIC, Instituto de Estructura de la Materia, Dpto. Fisica Molecular Serrano 121, 28006 Madrid, Spain

We present new near-infrared data and an analysis which indicates that the "Pistol Star" is one of the most luminous stars known, adding another test point for massive star formation and stellar evolution theories. We estimate an extinction of $A_K = 3.2 \pm 0.5$ using the near-infrared colors of the star and surrounding stars in the young Quintuplet cluster. Using our wind/atmosphere code, we find two families of models which fit the spectral energy distribution and detailed line profiles. The lower luminosity models give $L = 10^{6.6 \pm 0.2}$ $L_\odot$ and $T_{eff} = 10^{4.15 \pm 0.01}$ K, while the higher luminosity models give $L = 10^{7.2 \pm 0.2}$ $L_\odot$ and $T_{eff} = 10^{4.33 \pm 0.01}$ K; the error in luminosity assumes an uncertainty of ± 0.5 in A_K, while the error in T_{eff} is constrained by detailed line modeling. The models also reveal a helium enriched surface. As previously existing stellar evolution models do not extend to such high luminosities, we employ new evolutionary tracks for very massive stars to determine the initial mass and age of the Pistol Star, and estimate $M_{initial} = 200-250$ $M_\odot$ and an age of 1.7−2.1 Myrs. The inferred luminosity and temperature place the star in a sparsely populated zone in the HR diagram where "Luminous Blue Variables" (LBVs) are often found. This is consistent with our evolutionary

models which predict that the star is in an unstable evolutionary stage. We interpret the star and its surrounding nebula as an LBV which has recently ejected large amounts of material. Our K-band speckle imaging data reveal the star to be single down to a projected separation of 110 AU.

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or by anonymous ftp to `ftp://quintup.astro.ucla.edu/pistol/`
or on the web at `http://www.astro.ucla.edu/ figer`

Submitted Papers

Small carbon clusters and silicon species in carbon-rich Wolf-Rayet stars

Isabelle Cherchneff[1], Yoann H. Le Teuff[1], Peredur M. Williams[2] and Xander Tielens[3]

[1] Deparment of Physics, UMIST, PO Box 88, Manchester M60 1QD, UK

[2] Royal Observatory, Blackford Hill, Edinburgh EH9 3HJ, UK

[3] Kapteyn Institute, University of Groningen, PO Box 800, NL–9700 Groningen, The Netherlands

The formation of small carbon chains and molecular precursors to silicon carbide grains is investigated in the hot, hostile environment of carbon-rich Wolf-Rayet (WC) winds. We consider only WC stars which produce dust on a continuous basis and use a chemical kinetic approach to test the possibility of nucleating dust precursors in the outflow. Because WC stars have lost all their hydrogen in the WN phase, the chemical processes used in the model involve a pure helium, carbon, oxygen, silicon and sulphur chemistry which resembles that encountered in graphite or metal vaporization experiments in the laboratory. We derive abundances for small linear carbon clusters up to C_6 and silicon-bearing species for various wind parameters and conclude that high-density regions in the form of clumps or discs are of paramount importance to the formation of dust in WC stars.

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Preprints from `imc@europa.phy.umist.ac.uk`

A 2.3 Day Periodic Variability in the Apparently Single Wolf-Rayet Star WR 134: Collapsed Companion or Rotational Modulation?

Thierry Morel[1], Sergey V. Marchenko[1], Philippe R. J. Eenens[2], Anthony F. J. Moffat[1], Gloria Koenigsberger[3], Igor I. Antokhin[4], Thomas Eversberg[1], Gaghik H. Tovmassian[5], Grant M. Hill[6], Octavio Cardona[7], and Nicole St-Louis[1]

[1] Département de Physique, Université de Montréal, Canada.

[2] Departamento de Astronomía, Universidad de Guanajuato, México.

[3] Instituto de Astronomía, UNAM, México.

[4] Sternberg Astronomical Institute, Moscow, Russia.

[5] Instituto de Astronomía, Ensenada, México.

[6] McDonald Observatory, Fort Davis, USA.

[7] Instituto Nacional de Astrofísica, Optica y Electrónica, Puebla, México.

The apparently single WN 6 type star WR 134 (HD 191765) is distinctive among the Wolf-Rayet star

population by its strong, presumably cyclical ($\mathcal{P} \approx 2.3$ day), spectral variations. A true periodicity — which is still very much debated — would render WR 134 a prime candidate for harboring either a collapsed companion or a rotating, large-scale, inhomogeneous outflow.

We have carried out an intensive campaign of spectroscopic and photometric monitoring of WR 134 from 1989 to 1997 in an attempt to reveal the true nature of this object. This unprecendentedly large data set allows us to confirm unambiguously the existence of a coherent 2.25 ± 0.05 day periodicity in the line-profile changes of He II λ4686, although the global pattern of variability is different from one epoch to another. This period is only marginally detected in the photometric data set.

Assuming the 2.25 day periodic variability to be be induced by orbital motion of a collapsed companion, we develop a simple model aiming to investigate (i) the effect of this strongly ionizing, accreting companion on the Wolf-Rayet wind, and (ii) the expected emergent X-ray luminosity. We argue that the calculated and observed X-ray fluxes can only be matched if the accretion on the collapsed star is significantly inhibited. Additionally, we performed simulations of line-profile variations caused by the orbital revolution of a localized, strongly ionized wind cavity surrounding the X-ray source. A reasonable fit is achieved between the observed and modeled phase-dependent line profiles of He II λ4686. However, the derived size of the photoionized zone substantially exceeds our expectations, given the observed low-level X-ray flux.

Alternatively, we explore rotational modulation of a persistent, largely anisotropic outflow as the origin of the observed cyclical variability. Although qualitative, this hypothesis leads to greater consistency with the observations.

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Preprints from `morel@astro.umontreal.ca`
or by anonymous ftp to `132.204.60.20; cd incoming/morel/WR134`

The optical counterparts to Be/X-ray binaries in the Magellanic Clouds

J.B.Stevens[1], M.J.Coe[1] and D.A.H.Buckley[2]

[1] Dept. of Physics and Astronomy, University of Southampton, Highfield,

[2] South African Astronomical Observatory, P.O. Box 9, Observatory, 7935, South Africa

The fields of 8 X-ray sources in the Magellanic Clouds believed to be Be/X-ray binaries have been searched for possible Be star counterparts. BVR and Hα CCD imaging was employed to identify early type emission stars through colour indices and Hα fluxes. Follow up Hα spectroscopy of 5 sources confirms the presence of Hα emission in each case. Based on the positional coincidence of emission line objects with the X-ray sources, we identify Be star counterparts to the ROSAT sources RX J0032.9-7348, RX J0049.1-7250, RX J0054.9-7226 and RX J0101.0-7206, and to the recently discovered ASCA source AX J0051-722. We confirm the Be star nature of the counterparts to the EXOSAT source EXO0531.1-6609, and the HEAO1 source H0544-665. In the field of the ROSAT source RX J0051.8-7231 we find three possible counterparts, each showing evidence for Hα emission.

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Periods, period changes and the nature of the microvariations of Luminous Blue Variables

H.J.G.L.M. Lamers[1,2], M.V. Bastiaanse[1], C. Aerts[3] and H.W.W. Spoon[4]

[1] Astronomical Institute, University of Utrecht, Princetonplein 5, NL 3584 CC, Utrecht, The Netherlands,

[2] SRON Laboratory for Space Research, Sorbonnelaan 5, NL 3584 CA, Utrecht, The Netherlands,

[3] Instituut voor Sterrenkunde, Katholieke Universiteit Leuven, Celestijnenlaan 200 B, B-3001 Heverlee, Belgium,

[4] Max Planck Institut fur Extraterrestische Physik, Giessenbachstrasse, D-85740, Garching, Germany

We present period determinations of the microvariability of the six luminous blue variables AG Car, HR Car, 164 G Sco, S Dor, R 127, and R 71. In total, we were able to determine 22 periods in these stars, ranging from 18 days up to 195 days. All stars have period changes by up to a factor 4 within time scales of a few hundred days. For all stars the amplitude of the pulsations in V increases with increasing periods. The slope of the correlation between the amplitude and the period decreases with increasing luminosity.

The values of the pulsation constant Q were determined. HR Car, 164 G Sco, R 71 and R 127 have Q-values in the range of 0.07 to 0.18 days. This is about a factor two larger than those of most other B-type supergiants, possibly because the LBVs have a higher L/M ratio as they have lost more mass. The most common value for the pulsational constant of LBVs is $Q = 0.07 \pm 0.01$ days, but Q can increase temporarily by as much as a factor four. This is not related to a particular phase in the light curve. The long periods might be due to a beat of two frequencies.

For the two stars R 71 and R 127, which showed significant changes in M_V, and hence in radius during the course of the observations, the pulsational period increased with increasing radius. The Q-values of R 71 and R 127 increase when the stars get brighter and their radii increase. This is probably due the changes in the density structure of the stars as their outer envelope expands.

We compare the observed variations with those predicted for strange modes by Kiriakidis et al. (1993). The periods of the observed microvariations are orders of magnitudes longer than predicted for strange modes. A comparison with the variations of slowly pulsating B-stars (SPBs) suggests that the microvarions of LBVs are due to g-mode pulsations. A first attempt for mode identification, based on a simple linear pulsation model by means of the multicolour Strömgren data, shows that none of the variations can be explained by means of a radial pulsation. The amplitude-wavelength relations suggest g-modes of low ℓ.

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Long-term spectroscopy of η Carinae I. The high and low excitation phases

A. Damineli[1], O. Stahl[2], A. Kaufer[2], B. Wolf[2], G. Quast[3] and D.F. Lopes[4]

[1] JILA University of Colorado and National Inst. for Standards and Technology, Boulder, CO 80309-0440, USA

[2] Landessternwarte, Königstuhl, D-69117 Heidelberg, Federal Republic of Germany

[3] Laboratório Nacional de Astrofísica/CNPq , R. Estados Unidos 154, Caixa Postal 21, 37500-000 Itajubá, Brazil

[4] Observatório Nacional, R. General José Cristino 77, 20921-440 Rio de Janeiro, Brazil

Quantitative measurements of line parameters in the spectrum of η Carinae are presented for both the broad and narrow line components. A total of 655 spectral features were measured in the spectral range

3850 Å to 11000 Å, giving a comprehensive view of the behavior of atomic transitions ranging from a few to tens of electron volts. The spectrum on the phase of maximum intensity in the high excitation lines (1995) is compared with that on minimum intensity (June 1992), showing that at this phase the high excitation lines disappear but the broad components of low excitation lines strengthens. We reject a number of previous line identifications and propose several new ones, including Fe II, [Fe II], [Fe III], [N II], and the near-infrared Ca II triplet. Some lines commonly used to diagnose density, temperature, chemical composition, and reddening were found to be blended, urging a revision of the results based on previous data. The existence of double-peaked lines, suggested in previous papers, is ruled out. In the case of hydrogen lines, the apparent double-peaks are shown to be real absorption components. The velocity field in the inner 2 arcsec around the central star shows additional components previously unknown. The phases of high and low excitation in η Carinae are discussed in light of a recently proposed binary system. We derived a temperature $T \sim 16000$ K for the primary star, what suggests that it's close to enter in the core He-burning evolutionary stage.

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or by anonymous ftp to ftp.lsw.uni-heidelberg.de - incoming/akaufer/etaCar/etaprep.ps.gz
or on the web at http://casa.colorado.edu/∼damineli/PAPERS/ETACAR/etaprep.ps.gz

General Interest

A reliable transformation of Hipparcos H_p magnitudes into Johnson V and B magnitudes

Petr Harmanec

Astronomical Institute, Academy of Sciences, 251 65 Ondřejov, Bohemia - Czech Republic

A comparison of accurate UBV magnitudes, derived from numerous observations at Hvar and Skalnaté Pleso, and of the mean Hipparcos H_p magnitudes for a number of constant stars showed a very good mutual correspondence of these two data sets. Simple transformation formulæ are presented which allow calculating Johnson V and B magnitudes from the H_p magnitude and known $B-V$ and $U-B$ colours. For constant stars with well-known values of both colours the accuracy of the transformation is clearly better than $0\overset{\mathrm{m}}{.}01$. At the same time, the transformation is not critically sensitive to the exact values of $B-V$ and $U-B$. It is applicable over a wide range of colours ($B-V$ between $-0\overset{\mathrm{m}}{.}25$ and $2\overset{\mathrm{m}}{.}0$) and works well also for reddened stars. However, since it was defined for stars brighter than about $8\overset{\mathrm{m}}{.}0$ and for reddenings smaller than about $1\overset{\mathrm{m}}{.}0$, its application outside these limits should be made with some caution and further tested. Since the $B-V$ and $U-B$ colours are known for the majority of brighter stars and since there are many classes of variable stars which do change colours only very mildly during their light changes (like the majority of Be stars) or for which the instantaneous colours can be predicted or estimated from existing optical observations, the transformations presented here may turn out to be very useful for many researchers who need to combine Hipparcos and optical photometry into one homogeneous data set.

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Meetings

A one-day discussion on the enigmatic SMC system HD 5980

Upon suggestion from Gloria Koenigsberger and Tony Moffat, a one-day mini-workshop on HD5980 is planned for the day preceding IAU symposium 193 in Puerto Vallarta, Mexico, i.e. on Monday November 2nd. We would like to know how many would be interested, in order to make the necessary arrangements.

The only thing we ask you for the moment is to send us a short e-mail if you are interested:
eenens@carina.astro.ugto.mx

It is recommended that you arrive the evening before to take advantage of this and to plan for the next day over dinner. There will be no set agenda, but be prepared to present your point of view (with a few viewgraphs) and to discuss openly. Someone among those interested will be asked to introduce HD 5980. There will be no publication from this – just a lot of fun debating, discussing, talking.

Another one-day discussion: the Xmega campaign

Mike Corcoran proposes to organize another mini-workshop about the observations obtained within the XMEGA campaign, and future plans. Interested people should contact him:
corcoran@barnegat.gsfc.nasa.gov