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eenens@astro.ugto.mx

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Contents of this newsletter

News

The proceedings of the Brussels conference 'The Influence of Binaries on Stellar Population Studies' (ed. D. Vanbeveren, dvbevere@vub.ac.be) are published and can be ordered via Kluwer Academic Publishers, Dordrecht. The proceedings were included in the conference fee and the participants will receive their copy by normal mail.

Accepted Papers

Partial Mixing of Material in the Radiative Envelope and Convective Core of a Rotating Main–Sequence Star with Mass $16M_{\odot}$.

E.I.Staritsin

Astronomical Observatory, Ural State University, Yekaterinburg, 620083 Russia

The evolution of a rotating main–sequence star with mass $16M_{\odot}$ is studied. The flow of material in the radiative envelope is turbulent. When the exchange of energy and chemical elements is taken into account, this turbulence transfers helium and momentum from the convective core to the radiative envelope. The helium content at the stellar surface is enhanced toward the end of the evolution on

the main sequence by 0.006–0.306, depending on the character of the star's initial rotation and the horizontal coefficient of the turbulent viscosity.

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2 μm Narrow–band Adaptive Optics Imaging in the Arches Cluster

R. D. Blum[1], D. Schaerer[2], A. Pasquali[3], M. Heydari-Malayeri[4], P. S. Conti[5], W. Schmutz[6]

[1] Cerro Tololo Interamerican Observatory, Casilla 603, La Serena, Chile

[2] Laboratoire d'Astrophysique, Observatoire Midi-Pyrénées, 14 Av. E. Belin F-31400, Toulouse, France [3] ESO/Space Telescope European Coordinating Facility, Karl-Schwarzschild-Strasse 2, D-85748 Garching bei M—nchen, Germany

[4] DEMIRM, Observatoire de Paris, 61 Avenue de l'Observatoire, F-75014 Paris, France

[5] JILA, University of Colorado, Campus Box 440, Boulder, CO, 80309, USA

[6] Physikalisch-Meteorologisches Observatorium, 7260 Davos, Switzerland

Canada–France–Hawaii-Telescope adaptive optics bonnette images through narrow–band filters in the $K-$band are presented for the Arches cluster. Continuum fluxes, line fluxes, and equivalent widths are derived from high angular resolution images, some near diffraction limited, for the well known massive stars in the Arches cluster. Images were obtained in the lines of He I 2.06 μm, H I Brγ (2.17 μm), and He II 2.19 μm as well as continuum positions at 2.03 μm, 2.14 μm, and 2.26 μm. In addition, fluxes are presented for H I Pα (1.87 μm) and a nearby continuum position (1.90 μm) from Hubble Space Telescope archival data. The 2 μm and Pα data reveal two new emission–line stars and three fainter candidate emission–line objects. Indications for a spectral change of one object between earlier observations in 1992/1993 and our data from 1999 are found. The ratio of He II 2.19 μm to Brγ emission exhibits a narrow distribution among the stars, suggesting a narrow evolutionary spread centered predominantly on spectral types O4 If or Wolf-Rayet stars of the WN7 sub–type. From the approximate spectral types of the identified emission–line stars and comparisons with evolutionary models we infer a cluster age between $\sim$ 2 and 4.5 Myr.

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Preprints from ftp://ftp.ctio.noao.edu/pub/blum/arches.ps.gz

High and intermediate-resolution spectroscopy of Be stars An atlas of Hγ, He I 4471 and Mg II 4481 lines

J. Chauville[1], J. Zorec[2], D. Ballereau[1], N. Morrell[3], L. Cidale[3] and A. Garcia[2]

[1] DASGAL, UMR 8633 du CNRS, Observatoire de Paris-Meudon, 92195 Meudon, France

[2] Institut d'Astrophysique de Paris, CNRS, 98$^{\rm bis}$ bd. Arago, F-75014 Paris, France (zorec@iap.fr)

[3] Facultad de Ciencias Astronómicas y Geofísicas, Universidad de La Plata, Paseo del Bosque S/N, 1900 La Plata, Argentina

We present an atlas of Hγ, He I λ 4471 and Mg II λ 4481 line profiles obtained in a 10 year observation period of 116 Be stars, which enabled many of them to be observed at quite different emission epochs. From the best fit of the observed He I λ 4471 line profiles with non-LTE, uniform ($T_{\rm eff}, \log g$) and full limb-darkened model line profiles, we determined the $V \sin i$ of the program stars. To account,

to some degree, for the line formation peculiarities related to the rapid rotation-induced non-uniform distributions of temperature and gravity on the stellar surface, the fit was achieved by considering $(T_{\rm eff}, \log g)$ as free parameters. This method produced $V \sin i$ estimations that correlate with the rotational velocities determined by Slettebak (1982) within a dispersion $\sigma \leq 30$ km s^{-1} and without any systematic deviation. They can be considered as given in the new Slettebak's et al. (1975) system. Only 13 program stars have discrepant $V \sin i$ values. In some objects, this discrepancy could be attributed to binary effects. Using the newly determined $V \sin i$ parameters, we found that the ratio of true rotational velocities $V/V_{\rm c}$ of the program Be stars has a very low dispersion around the mean value. Assuming then that all the stars are rigid rotators with the same ratio $V(\overline{\omega})/V_{\rm c}$, we looked for the value of $\overline{\omega}$ that better represents the distribution of $V \sin i/V_{\rm c}$ for randomly oriented rotational axes. We obtained $\overline{\omega} = 0.795$. This value enabled us to determine the probable inclination angle of the stellar rotation axis of the program stars. In the observed line profiles of Hγ, He I λ 4471, Mg II λ 4481 and Fe II λ 4351 we measured several parameters related to the absorption and/or emission components, such as: equivalent width, residual emission and/or absorption intensity, FWHM, emission peak separations, etc. The parameters related to the Hγ line emission profiles were used to investigate the structure of the nearby environment of the central star. From the characteristics of the correlations between these quantities and the inferred inclination angle, we concluded that in most of cases the Hγ line emission forming regions may not be strongly flattened. Using a simple representation of the radiation flux emitted by the star+envelope system, we derived first order estimates of physical parameters characterizing the Hγ line emission formation region. Thus, we obtained that the total extent of the Hγ region is $R_{\rm f} \simeq 2.5 \pm 1.0 R_*$ and that the density distribution in these layers can be mimicked with a power law $\rho \sim R^{-\alpha}$, where $\alpha = 2.5^{+2.2}_{-0.6}$. The same approach enabled us to estimate the optical depth of the Hγ line emission formation region. From its dependence with the aspect angle, we concluded that these regions are caracterized by a modest flattening and that the ρ(equator)/ρ(pole) density contrast of the circumstellar envelope near the star should be two orders of magnitude lower than predicted by models based on a priori disc-shaped circumstellar envelopes. We found that the separation between the emission peaks, $\Delta_{\rm p}$, and the full width at half maximum, $\Delta_{1/2}$, of the Hγ line emission are not only sensitive to kinematic effects, but to line optical depth as well. This finding agrees with previous theoretical predictions and confirms that Huang's (1972) relation overestimates the extent of the Hγ line emission formation region.

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Rotationally modulated X-ray emission from the single O star ζ Ophiuchi

L. M. Oskinova[1], D. Clarke[1] and A. M. T. Pollock[2]

[1] Department of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, Scotland, UK

[2] Computer & Science Co., Ltd., 34 Westwood Road, Sheffield S11 7EY, England, UK

Archived measurements by the X-ray Telescope on the ASCA satellite of the single runaway O9.5V star, ζ Ophiuchi, are analysed. The data set is unique as it covers just more than one full rotational period of the star. We report a clearly detected periodic X-ray flux variability in the ASCA passband (0.5 - 10 keV). The detected period $\sim 0^d77$ possibly indicates a connection with the recurrence time ($0^d875 \pm 0^d167$) of the discrete absorption components (DACs) in UV spectra of the star, thought to be due to the presence of large scale structures in the stellar wind modulated by rotation. We attribute the X-ray fluctuation with an uneven distribution of X-ray absorbing material. We also report that

an analysis of similar ASCA observations of O4Ief star ζ Puppis failed to confirm earlier reported variability of X-rays from this star based on ROSAT observations.

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The origin of the Local Bubble

Jesús Maíz-Apellániz[1]

[1] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, U.S.A.

The Sun is located in a low-density region of the interstellar medium partially filled with hot gas that is the likely result of several nearby supernova explosions within the last 10 Myr. Here we use astrometric data to show that part of the Scorpius-Centaurus OB association was located closer to the present position of the Sun $5-7$ Myr ago than today. Evolutionary synthesis models indicate that the association must have experienced ~ 20 supernova explosions in the last $10-12$ Myr, a prediction that is supported by the detection of four or five runaway stars escaping from it. The ~ 6 SNe produced by the Lower Centaurus Crux subgroup are likely responsible for the creation of the Local Bubble.

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A Near-Infrared Survey of Radio-Selected Ultra-Compact HII Regions

M.M. Hanson[1], **K.L. Luhman**[2] **and G.H. Rieke**[3]

[1]Department of Physics, The University of Cincinnati, Cincinnati, OH 45221. Email: hanson@physics.uc.edu

[2]Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138.

[3]Steward Observatory, The University of Arizona, 933 North Cherry Avenue, Tucson, AZ 85721.

A near-infrared (NIR) survey of 63 radio-selected, ultra-compact HII (UC HII) regions representing 47 different star forming sites has been completed. The survey was obtained using H-band imaging and moderate resolution, $R = 1200$, K-band spectroscopy, centered on the radio emission peak of the UC HII regions. The goal of this survey was to determine the fraction of radio-selected UC HII regions that can be studied with NIR observations and analysis.

Approximately 50% of the 63 radio-selected UC HII regions appear to be detected at NIR wavelengths in Brγ emission (10^7 ergs s^{-1} cm^{-2} sr^{-1}). For a few of these UC HII regions, the central ionizing sources are detected through high signal-to-noise NIR spectra of photospheric transitions. This preliminary survey suggests that perhaps 5 to 10% of UC HII regions showing NIR counterparts will have directly detectable central ionizing sources.

Using the ratio of HeI 2.11 to Brγ, the effective temperatures of the central ionizing stars in 25 UC HII regions have been estimated. While HeI is not always detected in UC HII regions, when it was found or a meaningful upper limit determined, the spectral type implied by the ratio of HeI 2.11 to Brγ closely matched similar estimates of spectral type derived from radio. Model predictions based on mid-infrared measurements appear to underestimate the temperature of the central ionizing stars for which we have directly detected spectral types.

The line ratios of H_2 2-1 S(1) and 1-0 S(0) relative to the 1-0 S(1) line in our sample of UC HII regions are generally indicative of dense photo-dissociation regions rather than shocks, similar to what is seen in the Orion Bar. This was true even for UC HII regions showing very weak Brγ emission. While Brγ was generally found to be spatially correlated with the radio emission, H_2 showed little correlation with the UC HII regions, typically lying $\sim 10''$ from the central radio emission.

A discussion of each UC HII region studied is included in an extensive Appendix.

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Preprints: `www.physics.uc.edu/~hanson/ABSTRACTS/hanson12.html`

Chemical Abundances of OB Stars with High Projected Rotational Velocities

S. Daflon[1], K. Cunha[1], K. Butler[2] and V. V. Smith[3]

[1] Observatório Nacional, Rua General José Cristino 77, CEP 20921-400, Rio de Janeiro BRAZIL

[2] Institut für Astronomie und Astrophysik der Universität München, Scheinerstrasse 1, D-81679 München, GERMANY

[3] Department of Physics, University of Texas at El Paso, El Paso, TX 79968-0515 USA

Elemental abundances of carbon, nitrogen, oxygen, magnesium, aluminum, and silicon are presented for a sample of twelve rapidly rotating OB star ($v \sin i > 60 \mathrm{kms}^{-1}$) members of the Cep OB2, Cyg OB3 and Cyg OB7 associations. The abundances are derived from spectrum synthesis, using both LTE and non-LTE calculations. As found in almost all previous studies of OB stars, the average abundances are slightly below solar, by about 0.1 to 0.3 dex. In the case of oxygen, even with the recently derived low solar abundances the OB stars are closer to, but still below, the solar value. Results for the 9 Cep OB2 members in this sample can be combined with results published previously for 8 Cep OB2 stars with low projected rotational velocities to yield the most complete set of abundances, to date, for this particular association. These abundances provide a clear picture of both the general chemical and individual stellar evolution that has occurred within this association. By placing the Cep OB2 stars studied in an HR diagram we identify the presence of two distinct age subgroups, with both subgroups having quite uniform chemical abundances. Two stars are found in the older subgroup that show significant N/O overabundances, with both stars being two of the most massive, the most evolved, and most rapidly rotating of the members studied in Cep OB2. These characteristics of increased N abundances being tied to high mass, rapid rotation, and an evolved phase are those predicted from models of rotating stars which undergo rotationally driven mixing.

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IUE Observations of Beta Cephei Stars. Paper 1: BW Vulpeculae

D. J. Stickland and C. Lloyd

Rutherford Appleton Laboratory, Didcot, OX11 0QX, UK

Archival high- and low-resolution IUE spectra of BW Vul have been measured for radial velocity and photometric variations. A velocity curve very similar to those recorded in the optical region was found, while model fitting to low-resolution spectra indicates an effective temperature cycle from 19500

to 25000 K. This range is confirmed on an amplitude *versus* frequency plot employing observations spanning 1050 Åto 22000 Åbut relying strongly on IUE data; non-resonant-line strength variations in the UV are concurrent. The broad picture for the pulsation cycle of BW Vul suggested by Furenlid et al. (*ApJ*, **319**, 264, 1987) is endorsed.

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The mass of the neutron star in Vela X-1

O. Barziv[1,2], L. Kaper[2], M.H. van Kerkwijk[3], J.H. Telting[4], J. van Paradijs[2,5]

[1] European Southern Observatory, Karl-Schwarzschild-Strasse 2, 85748 Garching, Germany

[2] Astronomical Institute "Anton Pannekoek", University of Amsterdam and Center for High-Energy Astrophysics, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands

[3] Astronomical Institute, Utrecht University, P. O. Box 80000, 3508 TA Utrecht, The Netherlands

[4] Isaac Newton Group of Telescopes, Netherlands Organisation for Scientific Research (NWO), Apartado 321, E-38700 Santa Cruz de La Palma, Spain

[5] Physics Department, University of Alabama, Huntsville, AL35899, USA

We measured the radial-velocity curve of HD 77581, the B-supergiant companion of the X-ray pulsar Vela X-1, using 183 high-resolution optical spectra obtained in a nine-month campaign. We derive radial-velocity amplitudes for different lines and wavelength regions, and find all are consistent with each other, as well as with values found in previous analyses. We show that one apparent exception, an anomalously low value derived from ultra-violet spectra obtained with the *International Ultraviolet Explorer*, was due to an error in the analysis procedures. We re-analyse all IUE spectra, and combine the resulting velocities with the ones derived from the new optical spectra presented here, as well as those derived from optical spectra published earlier. As in previous analyses, the radial velocities show strong deviations from those expected for a pure Keplerian orbit, with root-mean-square amplitudes of $\sim$7 km s^{-1} for strong lines of Si IV and N III near 4100 Å, and up to $\sim$20 km s^{-1} for weaker lines of N II and Al III near 5700 Å. The deviations likely are related to the pronounced line-profile variations seen in our spectra. Our hope was that the deviations would average out when a sufficient number of spectra were added together. It turns out, however, that systematic deviations as a function of orbital phase are present as well, at the 3 km s^{-1} level, with the largest deviations occurring near inferior conjunction of the neutron star and near the phase of maximum approaching velocity. While the former might be due to a photo-ionisation wake, for which we observe direct evidence in the profiles of Hδ and Hα, the latter has no straightforward explanation. As a result, our best estimate of the radial-velocity amplitude, $K_{\rm opt} = 21.7 \pm 1.6$ km s^{-1}, has an uncertainty not much reduced to that found in previous analyses, in which the influence of the systematic, phase-locked deviations had not been taken into account. Combining our velocity amplitude with the accurate orbital elements of the X-ray pulsar, we infer $M_{\rm ns} \sin^3 i = 1.78 \pm 0.15\ M_\odot$.

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On the wavelength drift of spectral features from structured hot star winds

W.-R. Hamann[1], J.C. Brown[2], A. Feldmeier[1] and L.M. Oskinova[2]

[1] Professur Astrophysik, Universität Potsdam, D-14469 Potsdam, Germany

[2] Department of Physics & Astronomy, University of Glasgow, Glasgow G12 8QQ, Scotland, UK

Spectral lines formed in stellar winds from OB stars are observed to exhibit profile variations. Discrete Absorption Components (DACs) show a remarkably slow wavelength drift with time. In a straightforward interpretation, this is in sharp contradiction to the steep velocity law predicted by the radiation-driven wind theory, and by semi-empirical profile fitting. In the present paper we re-discuss the interpretation of the drift rate. We show that the Co-rotating Interaction Region (CIR) model for the formation of DACs does not explain their slow drift rate as a consequence of rotation. On the contrary, the apparent acceleration of a spectral CIR feature is even higher than for the corresponding kinematical model without rotation. However, the observations can be understood by distinguishing between the velocity field of the matter flow, and the velocity law for the motion of the *patterns* in which the DAC features are formed. If the latter propagate upstream against the matter flow, the resulting wavelength drift mimics a much slower acceleration although the matter is moving fast. Additional to the DACs, a second type of recurrent structures is present in observed OB star spectra, the so-called modulations. In contrast to the DACs, these structures show a steep acceleration compatible with the theoretically predicted velocity law. We see only two possible consistent scenarios. Either, the wind is accelerated fast, and the modulations are formed in advected structures, while the DACs come from structures which are propagating upstream. Or, alternatively, steep and shallow velocity laws may co-exist at the same time in different spatial regions or directions of the wind.

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or on the web at `www.astro.physik.uni-potsdam.de`

Submitted Papers

The Outer Evolution of Instability-Generated Structure in Radiatively Driven Stellar Winds

M.C. Runacres[1] and S.P. Owocki[2]

[1] Royal Observatory of Belgium, Ringlaan 3, B-1180 Brussel, Belgium

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

We investigate stochastic structure in hot-star winds. The structure (i.e. inhomogeneities such as clumps and shocks) is generated by the instability of the line driving mechanism in the inner wind. It is self-excited in the sense that it persists even in the absence of explicit perturbations. The evolution of structure as it moves out with the flow is quantified by the radial dependence of statistical properties such as the clumping factor and the velocity dispersion. We find that structure evolves under the influence of two competing mechanisms. Dense clumps pressure-expand into the rarefied gas that separates them, but this expansion is counteracted by supersonic collisions among the clumps, which

tend to compress them further. Because of such ongoing collisions, clumps can survive over an extended region out of pressure equilibrium with the rarefied surrounding gas. Moreover, the line-driving force has little rôle in maintaining the structure beyond about 20-30 R_*, implying that the outer evolution can be simplified as a pure gasdynamical problem. In modelling the distant wind structure we find it is necessary to maintain a relatively fine constant grid spacing to resolve the often quite narrow dense clumps. We also find that variations in the heating and cooling, particularly the "floor" temperature to which shock-compressed gas is allowed to cool, can affect both the density and temperature variation. Finally, we find that increasing the value of the line-driving cut-off parameter $\kappa_{\max}$ can significantly enhance the level of flow structure. Overall, the results of our work suggest that structure initiated in the inner wind acceleration region can survive to substantial distances ($\sim 100R_*$), and thus can have an important influence on observational diagnostics (e.g. infrared and radio emission) formed in the outer wind.

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Preprints from Mark.Runacres@oma.be

The Spectral Components of SS 433

D. R. Gies[1], M. V. McSwain[1], R. L. Riddle[1], Z. Wang[1], P. J. Wiita[1], and D. W. Wingert[1]

[1] Center for High Angular Resolution Astronomy, Department of Physics and Astronomy, Georgia State University, Atlanta, GA 30303

We present results from new optical and UV spectroscopy of the unusual binary system SS 433, and we discuss the relationship of the particular spectral components we observe to the properties of the binary. These spectral components include:
(1) The continuum spectrum which we associate with flux from the super-Eddington accretion disk and the dense part of its wind. A FUV spectrum from HST/STIS made during the edge-on orientation of the disk places an upper limit on the temperature of an equivalent blackbody source ($T < 21,000$ K for $A_V = 7.8$) when combined with NUV and optical fluxes. The continuum source has a radius of approximately half the binary separation which may be larger than the Roche radius of the compact star.
(2) Hα moving components which are formed far from the binary orbital plane in the relativistic jets. We confirm that these emission features appear as "bullets" at a fixed wavelength and may last for a few days. We present a contemporary radial velocity curve for the precessional motion of the jets which includes the nodding motion caused by tidal interaction with the optical star.
(3) Hα and He 1 "stationary" emission lines which we suggest are formed in the disk wind in a volume larger than the dimensions of the binary. These lines vary on all time scales and sometimes appear as P Cygni lines. We suggest that their radial velocity curves (which show greatest redshift at inferior conjunction of the optical star) result from an evacuation of the disk wind surrounding the optical star (caused by physical blockage, heating, or colliding winds). We argue that the wake of this interaction region causes an extended eclipse of the X-ray source (as seen in RXTE/ASM light curves).
(4) A weak "stationary" emission feature we identify as a C 2 $\lambda\lambda$7231, 7236 blend that attains maximum radial velocity at the orbital quadrature of disk recession (like the velocity curve of He 2 λ4686). This is probably formed in outflow from the central region of the disk near the compact star.
(5) Absorption and emission features from outflowing clumps in the disk wind (seen most clearly in an episode of blue-shifted Na 1 emission).
(6) We found no clear evidence of the absorption line spectrum of the optical star, although we point out the presence of He 1 absorption features (blended with the stationary emission) with the expected

radial velocity trend at the orbital and precessional phases when the star might best be seen.
(7) A rich interstellar absorption spectrum of diffuse interstellar bands.
The results suggest that the binary is embedded in an expanding thick disk (detected in recent radio observations) which is fed by the wind from the super-Eddington accretion disk.

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Ion Runaway Instability in Low-Density, Line-Driven Stellar-Winds

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

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

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

We examine the linear instability of low-density, line-driven stellar-winds to runaway of the heavy minor ions when the drift speed of these ions relative to the bulk, passive-plasma of hydrogen and helium approaches or exceeds the plasma thermal speed. We first focus on the surprising results of recent steady-state, two-component models, which indicate that the limited Coulomb coupling associated with suprathermal ion drift leads not to an ion runaway, but instead to a relatively sharp shift of *both* the ion and passive fluids to a much *lower* outward acceleration. Drawing upon analogies with subsonic outflow in the solar wind, we provide a physical discussion of how this lower acceleration is the natural consequence of the weaker frictional coupling allowing the ion line-driving to maintain its steady-state balance against collisional drag with a comparitively shallow ion velocity gradient. However, we then carry out a time-dependent, linearized stability analysis of these two-component steady solutions, and thereby find that, as the ion drift increases from sub- to suprathermal speeds, a wave mode characterized by separation between the ion vs. passive-plasma goes from being strongly damped to being strongly amplified. Unlike the usual line-driven-flow instability of high-density, strongly-coupled flows, this ion separation instability occurs even in the long-wavelength, Sobolev limit, although with only modest spatial growth rate. At shorter wavelengths, the onset of instability occurs for ion drift speeds that are still somewhat below the plasma thermal speed, and moreover generally has a very large spatial growth. For all wavelengths, however, the *temporal* growth rate exceeds the already rapid growth of line-driven instability by a typical factor of ~ 100, corresponding to the mass density ratio between the bulk plasma and the driven minor ions. We further show that this ion-separation mode has an inward propagation speed that is strongly enhanced (at its maximum by a similar factor of ~ 100) over the usual "Abbott-wave" speed of a fully coupled, line-driven flow, implying that in the context of this separation mode, the entire domain of any steady-state solution can be considered as 'subcritical'. Finally we note that, despite the extremely rapid linear growth rate, further analyses and/or simulations will be needed to determine whether the nonlinear evolution of this instabilty should lead to true ion runaway, or instead perhaps might be limited by damping from two-stream plasma instabilities.

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In Proceedings

On the X-ray emission of η Carinae's outer ejecta

Kerstin Weis [1,*], Michael F. Corcoran[2] and Kris Davidson[1]

[1] Astronomy Department, University of Minnesota

[2] High Energy Astrophysics Science Archive Research Center

[*] Feodor-Lynen fellow of the Alexander-von-Humboldt foundation The extremely luminous and unstable star

η Carinae is surrounded by ejecta formed during the star's giant eruption around 1843. The optical nebula consists of an inner region, the bipolar Homunculus and the outer ejecta. The X-ray emission as detected in ROSAT and CHANDRA shows a hook shaped emission structure mainly at the position of the outer ejecta substantially larger than the Homunculus. We present results of a comparative study of the optical morphology, the kinematics and the X-ray emission of the outer ejecta around η Carinae. In general we find that the X-ray emission traces the shocks of faster moving knots in the outer ejecta. First results of CHANDRA/ACIS data will be presented, with spectra of selected areas in the outer ejecta giving insight to the conditions (temperature, present elements and degree of ionization) of the hot gas. The X-ray spectra will again be compared to the kinematics of the gas as known from our optical spectra.

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or on the web at `http://www.astro.umn.edu/~kweis/publications.html`,
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The ISM Towards the Be Star HD120991

Y. Frémat[1], J. Zorec[2], A.-M. Hubert[1], L.S. Cidale[3], R.D. Rohrmann[4], J.-M. Désert[2], R. Ferlet[2], A. Lecavalier[2] and A. Vidal-Madjar[2]

[1] Observatoire de Paris-Meudon, DASGAL/UMR 8633 du CNRS, 5 Place Jules Janssen, F–92195 Meudon CEDEX (France)

[2] Institut d'Astrophysique de Paris, CNRS, 98bis Boulevard Arago, F–75014 Paris (France)

[3] Facultad de Ciencias Astronómicas y Geofisicas, Universidad Nacional de La Plata, Paseo del Bosque S/N, 1900 La Plata (Argentina)

[4] Observatorio Astronómico, Universidad Nacional de Córdoba, Laprida 854, 5000 Córdoba (Argentina)

Far UV Spectra have been obtained by FUSE for the pole-on Be star HD120991 (B2 IIIe). At these wavelengths, interstellar molecular bands and interstellar atomic lines are prevailing. Their presence strongly affects the stellar line profiles and the photospheric + envelope energy distribution. In our contribution, we produce some of the results we obtained studying the interstellar medium (ISM) seen towards HD120991. Using the column densities determined from the analysis of the FUSE spectra, we estimate the distance to the star and discuss its position relative to the surrounding ISM.

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Fundamental parameters of Be stars seen equator-on

J. Zorec[1], Y. Frémat[2], A.-M. Hubert[2], M. Floquet[2]

[1] Institut d'Astrophysique de Paris, CNRS, 98bis Boulevard Arago, F–75014 Paris (France)

[2] Observatoire de Paris-Meudon, DASGAL/UMR 8633 du CNRS, 5 Place Jules Janssen, F–92195 Meudon CEDEX (France)

The geometrical deformation, as well as the non uniform surface gravity and temperature distributions induced by the fast rotation are taken into account to determine the stellar fundamental parameters of 10 Be stars seen nearly equator-on. For each star the angular velocity ratio $\Omega/\Omega_{\rm c}$ is determined, so that we can also obtain the stellar aspect angle, the "true" mass, the equatorial radius, the stellar age and the rotational frequency. The obtained rotational frequencies are on average a factor 0.7 smaller than the photometric ones. Stars lay in the first half of the main sequence evolutionary span, which suggests that their fast rotation is related to initial formation conditions, rather than to evolutionary effects. The average inclination found is $i = 68^o \pm 18^o$, even for the program strong Be-shell stars.

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VLT/ISAAC spectroscopy of young massive stars embedded in ultra-compact H II regions

L. Kaper[1], A. Bik[1], M.M. Hanson[2], F. Coméron[3]

[1] Astronomical Institute, University of Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands

[2] Dept. of Physics & Astronomy, University of Cincinnati, USA

[3] European Southern Observatory, Garching, Germany

Using ISAAC mounted at the *Very Large Telescope*, we have obtained medium-resolution K-band spectra of newly formed massive stars, which are deeply embedded in ultra-compact H II regions (UCHIIs). Candidate young massive stars were selected on the basis of their near-infrared luminosity and colour measured from narrow-band images obtained in a survey of 45 southern UCHIIs. This strategy turned out to be very successful: follow-up spectroscopy confirmed the OB-star nature of 36 embedded stars, among them O stars of very early spectral type. The K-band spectra of over a dozen stars do not show photospheric absorption lines, but include a strong and broad Brγ emission line. These stars might represent an early phase in the evolution of massive stars, when they are still surrounded by a circumstellar disk. Our ultimate goal is to better understand the formation process of the most massive stars.

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On some Uncertainties in Evolutionary Synthesis Models

M. Cerviño[1] and D. Valls–Gabaud[2]

[1] Max-Planck-Institut für extraterrestrische Physik, Giessenbachstrasse, D-85748 Garching bei München, Germany

[2] UMR CNRS 5572, Observatoire Midi-Pyrénées, 14, avenue Edouard Belin, 31400 Toulouse, France

Ranging from track interpolation techniques through model atmospheres to the stochastic nature of the IMF, there are many uncertainties which need to be taken into account when modelling HR diagrams or performing population synthesis, particularly if comparison with actual data is sought. In this paper, we highlight (1) the problem of discontinuities along evolutionary tracks of massive stars (M> 8 $M_\odot$), showing that inconsistencies appear in the computation of the corresponding isochrones, and (2) the sampling fluctuations produced by the stochastic nature of the IMF, presenting a statistical formalism to estimate the dispersion in any given observable of a stellar population due to sampling effects which bypasses the need of performing Monte Carlo simulations.

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The high interest of asteroseismology with EDDINGTON for massive stars

A. Maeder and G. Meynet

Geneva Observatory

Massive stars are an essential piece of our knowledge of the Universe, since they determine both the spectral and chemical evolution of galaxies. We emphasize that there are many evidences of stellar oscillations in massive stars, not only for β Cephei and SPB stars, but more generally for all OB type stars. These oscillations of short periods (days) are not only observed as fluctuations in the stellar winds, but there are indications of their photospheric origin. This shows the interest of the observation of O– and B–type stars by EDDINGTON.

We discuss a number of problems in star formation and evolution of massive stars, which demand a better knowledge of their internal structure, as will be possible with EDDINGTON. Particularly, observations of pre–MS stars may enable us to distinguish between the different existing theories for massive star formation. Also, the better knowledge of the internal μ–gradient and rotation appears as a key information influencing all the outputs of stellar evolution, such as age, tracks in the HR diagram, populations of blue and red supergiants, populations of WR stars, supernova progenitors and nucleosynthetic yields.

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