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

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Accepted Papers

X-ray emission from Ap-Bp stars: a magnetically confined wind-shock model for IQ Aur

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We present the results of a *ROSAT*-PSPC pointed observation on the hot A0p star IQ Aur (HD 34452). The X-ray luminosity obtained is $L_X = 4.0 \times 10^{29}$ erg s^{-1} ($\log L_X/L_{\rm Bol} \simeq -6.9$) and the plasma temperature is $T_X = 0.29$ keV. Since A and B stars have no known magnetic activity, the only possibility is to invoke a wind origin for this emission. On IQ Aur, the expected mass loss rate driven by stellar radiation is small, around 10^{-10}- 10^{-11} $\mathrm{M}_\odot \mathrm{yr}^{-1}$ with $v_\infty = 800$ km s^{-1}, so that the kinetic energy flux of the wind is not much larger than the observed X-ray emission. This implies that the X-ray emission from IQ Aur must arise from a very efficient process. These constraints, together with the large observed magnetic field of IQ Aur, lead us to propose that the confinement of the wind by the magnetic field leads to a collision from the wind components of the two hemispheres in the closed magnetosphere, leading to a strong shock. In this model the magnetic field confines the wind and also affects the mass loss rate.

We propose a self-consistent approach for the X-ray emission of IQ Aur, using radiatively driven wind models based on the stellar parameters of IQ Aur and including the effect of magnetic confinement of the wind. We also model the whole postshock region. We show that our shock model is able to

satisfy the constraints on the observed X-ray luminosity and temperature. The model also leads to the formation of a disk at the magnetic equator corotating up to $r \lesssim 4R_*$. We show that ambipolar diffusion of hydrogen in the disk or current sheet formation due to equipartition between the disk and the magnetic field might play a significant role in emptying the magnetosphere.

We discuss the interplay between mass loss and particle diffusion. Our computations suggest that the onset of a wind on IQ Aur is very recent, so that the abundance anomalies at the stellar surface have not yet been removed by the outflow, or that the wind exhibits transient phases due to the mutual feedback between the wind and abundance anomalies.

Finally, we point out that our wind-shock model provides a very convenient framework to explain the radio emission of Ap-Bp stars. It has been shown that the emission mechanism is optically thick gyrosynchrotron, but instead of (or in addition to) the previously invoked acceleration by magnetic reconnection in current sheets, we propose that the electrons are accelerated by second-order Fermi acceleration mechanism ("stochastic" acceleration) often invoked for the acceleration of solar flare flare particles. We show that electrons accelerated by the wind shock easily reach the required energies for radio emission in the GHz band throughout the magnetosphere.

Given the success of our model in explaining IQ Aur, we think that it has a fairly general application to magnetic Ap-Bp stars. The wind-shock model also provides a unified explanation for both the X-rays and the radio emission from these stars.

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Starbursts in barred spiral galaxies. II. Molecular and optical study of three Wolf-Rayet galaxies

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We have searched for dense molecular gas in three barred spiral galaxies with young starbursts, NGC 3049, 5430 and 6764, which are known Wolf-Rayet galaxies. We detected HCN in the latter two, and CS was marginally detected in NGC 6764.

The dense molecular gas contents of the three galaxies are compared to those of other galaxies and to other indicators of star formation. The HCN luminosities (relative to the CO and far infrared ones) in these galaxies with very young starbursts are consistent with those observed in galaxies with older starbursts and in normal galaxies, and so are our upper limits to the CS intensities (relative to CO).

The starburst ages evaluated from our spectrophotometric observations are in the range 3.4 to 6.0 Myr. A circum-nuclear ring is apparent on our images of NGC 5430, the galaxy with the oldest central starburst; this galaxy also has the widest molecular lines. The central star formation rates derived from the Hα luminosity are consistent with those expected from the global FIR luminosities, and are correlated with the HCN luminosities.

Finally, an independent estimate of the H_2 column density is obtained by optical spectrophotometry; it leads to a H_2 column density to CO intensity ratio which is about 2 to 3 times lower than the standard value, because the CO intensities of the three galaxies are higher than average, relative to their far infrared fluxes.

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The Bipolar HR Carinae Nebula: Dynamics and Chemical Abundances

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We present the results of a new set of medium resolution spectroscopic observations and high resolution coronographic images of the nebula around the galactic Luminous Blue Variable (LBV) HR Carinae. The observations were carried out at the ESO/NTT (La Silla) in May 1995 and January 1996. The nebular morphology and kinematics confirm that the nebula around HR Carinae is truly bipolar, and very reminiscent of the η Carinae nebula. The previously identified *"filaments"* outline the edges of two symmetrical expanding bubbles, originating from the star and located respectively in the NW and SE quadrants. The small compact inner nebula, a few arcseconds in size, previously detected, represents the *"waist"* of the bipolar distribution. The orientation in the images and the kinematical study have allowed us to define the true orientation of the bubbles, whose major axis lies at an angle of $\simeq 50^o$ with the plane of the sky, at an inclination of approximately 30^o on the line of sight. The maximum projected expansion velocity is of the order of $\simeq$ 100 km/s. In the light of these new kinematical data, we revise the dynamical timescale to a younger age of $\simeq$ 5000 yrs.

The nebula around HR Carinae is relatively young and fast. Spectroscopically, the nebula is of low excitation with [OIII] absent, and [NII] fairly strong. [NiII] λ6667 is detected, but only in the inner regions ($\leq 5''$). We find that the electron density increases from 400 cm^{-3} in the outer regions to $> 10^4$ cm^{-3} in the innermost regions. An analysis of the chemical abundances in different regions of the nebula finds that N is overabundant, indicating that the nebula is composed of CNO processed stellar material. We find that the filamentary HII region, seen to the NW of HR Carinae, is at the same distance and is composed of material with typical HII region abundances, and has a morphology that suggests it has been shaped by the wind of HR Carinae.

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Ultraviolet Photometry of Stars in the Compact Cluster R136 in the Large Magellanic Cloud

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We present ultraviolet photometry of stars in the Large Magellanic Cloud star cluster R136. The data were obtained with the refurbished Wide Field/Planetary Camera on the *Hubble Space Telescope*

through an ultraviolet filter centered at 1750 Å (F170W). These data, combined with optical observations presented previously, are used to explore the hot, luminous stellar population within the cluster. The first question we wanted to address was whether the ultraviolet could place better constraints on differential reddening and the degree of coevality within the cluster than optical photometry alone. The stellar sequence in the color magnitude diagram using the F170W−F555W color is broader than it was in the optical and is broader than would be expected from photometric uncertainties. Although there could be a modest age spread among the massive stars, a large part of the intrinsic spread in the color-magnitude diagram is likely to be due to reddening differences. There is also some evidence that stars in the outer parts of the cluster are affected by a larger range in reddening than those in the smaller region of the cluster core. The second question we addressed is whether ultraviolet photometry in combination with optical photometry can distinguish the most massive stars more readily than is possible with the optical colors. The F170W−F555W color is better at separating B supergiants, of which there is only one in R136, from comparably bright O and Wolf-Rayet stars. However, spectral classifications of the stars within R136 will be necessary to properly identify stellar types of the rest of the stars and to disentangle age and reddening effects.

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The influence of clumping on the infrared and radio continuum of early-type stars

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Time-dependent hydrodynamical models predict that the stellar winds of early-type stars are clumped, due to the sweeping up of material into dense shells. In this paper we investigate whether these shells can explain the long wavelength (≥ 10 μm) continuum fluxes of O and early B stars. We had previously found that, for some stars, smooth wind models failed to explain the infrared and millimetre fluxes.

To calculate the continuum flux, we model the clumping by a single shell. This single shell can represent the joint effect of a number of shells and we discuss how multiple shells can be combined into a single shell. The shell strength parameter is introduced, which combines density contrast and width of the shell. From the 12, 25 and 60 μm IRAS observations of ζ Pup, we derive a shell strength and position. We find that the clumping is less extreme than predicted by the hydrodynamical models. This means that the strength of the shells is less than the models predict, that there are not as many of them or that they do not fill a complete solid angle.

Considering such *partial* (i.e. filling a solid angle of $< 4\pi$) shells is a natural way to make the time-dependent hydrodynamical models agree with the observations. That *complete* shells are found in the hydrodynamical models is solely a consequence of present computational limitations. When we introduce partial shells in our model for ζ Pup, we find that the IRAS observations can be explained if each shell is limited to a solid angle of $\sim 4\pi/3$.

The shells dissipate as they move away from the star, but reach the radio formation region before they damp out completely, thereby influencing the radio fluxes of the stars. In this case, applying a *smooth* wind model to the radio observations of an O or early B star could lead to an overestimate of the mass loss rate. In the case of ζ Pup this error turns out to be negligible.

While clumping can explain the observed infrared continuum fluxes of O and early B stars, it cannot

be excluded that other phenomena also contribute. Co-rotating interaction regions especially will influence the infrared flux formed in the wind.

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Preprints from Ronny.Blomme@oma.be
or by anonymous ftp to ftp://ftpserver.oma.be/pub/astro/ronny/clumping

X-ray properties of bright OB-type stars detected in the ROSAT all-sky survey

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The ROSAT all-sky survey has been used to study the X-ray properties for all OB-type stars listed in the Yale Bright Star Catalogue. Here we present a detailed astrophysical discussion of our analysis of the X-ray properties of our complete sample of OB-type stars; a compilation of the X-ray data is provided in an accompanying paper[a] (Berghöfer, Schmitt & Cassinelli 1996, A&AS, 118, 481).

We demonstrate that the "canonical" relation between X-ray and total luminosity of $L_x/L_{Bol} \approx 10^{-7}$ valid for O-type stars extends among the early B-type stars down to a spectral type B1–B1.5; for stars of luminosity classes I and II the spectral type B1 defines a dividing line for early-type star X-ray emission.

We discuss the X-ray properties of X-ray detected B2-B9 stars (LC III–V) in the context of possible companions.

We also compare our results to the results obtained from *Einstein Observatory* data and ROSAT pointed observations. We show for our sample of stars that X-ray variability is generally not common for O-type stars as well as early B-type stars.

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[a] Note that the X-ray fluxes and X-ray luminosities reported in Table 2 and 3 are not corrected for interstellar absorption, an erratum providing a correction function is in press. Please get a new copy of the revised catalogue paper and/or the erratum from my WWW page.

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or on the web at http://www.rosat.mpe-garching.mpg.de/∼thb/public.html

MWC 297, B1.5Ve: a zero-age main sequence star in the Aquila Rift

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Moderate resolution optical spectra of the significantly reddened Herbig Be star, MWC 297, are

presented. The data are of sufficient quality that it has been possible to obtain a spectral type for this star by comparing heavy element absorption features with those present in early-B field stars of known spectral type. The best fit is to B1.5V, with an uncertainty of half a sub-type. It is estimated that $v \sin i$ for MWC 297 is about 350 ± 50 km s^{-1}, suggesting that the star's rotation axis is almost in the plane of the sky. The reddening towards this object is reviewed and is derived afresh from spectra at wavelengths spanning the B–R optical bands. Using $A_v \simeq 8$ and the absolute magnitude corresponding to B1.5V, it is argued that the distance to MWC 297 is 250 ± 50 pc rather than $\sim$500 pc as has recently been quoted in the literature. At this distance the star can be located very plausibly in the Aquila Rift.

We go on to present a MERLIN 5GHz radio map of the source which shows it to be markedly elongated in an almost N–S direction (to a dimension of 125 AU at 250 pc). Existing data on the optical linear polarization of MWC 297 suggest a complicated picture that leaves open the question of whether the radio axis might trace an ionized electron-scattering equatorial disk. We also present and briefly discuss high resolution Brα and He I 1.083 μm line profiles obtained within a week of the optical spectra. The He I profile is very complex, but confirms that MWC 297 is an outflow source. It is noted that the H I emission lines are undoubtedly highly variable although the timescales for this are not yet clear.

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Ionization structure of the shells surrounding Herbig Ae/Be stars

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The ionization balance of the circumstellar gas around Herbig Ae/Be stars is studied. The model used is based on the results obtained by Catala & Kunasz (1987) for the wind formation region of the typical Herbig Ae/Be star AB Aur. Large brightness variations of some stars are assumed to be due to their obscuration by clumps in the shells, and the gas ionization in the clumps is also considered.

It is shown that the source of ionization of gas is the radiation of the stellar photosphere and chromosphere, and the main processes that determine the ionization structure of the shells are photoionization, photorecombination and dielectronic recombination. The column density of Na I and Ca II, the central optical thickness and the equivalent width of the circumstellar Ca II K and Na I D_2 absorption lines are estimated and their dependence on the model parameters is examined. It is found that the clumps are the places where sufficiently strong variable lines may originate. The equivalent width of the lines are mainly determined by the gas to dust ratio and the element depletion in the clumps. The lines could be observed with the current large telescopes and give information on the nature of the clumps being probably the places of planet formation. The model is used to interpret two episodes of the spectral line variations observed for AB Aur and HR 5999.

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In Proceedings

Radiation pressure in LBV winds

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I investigate the radiation pressure in atmosphere models of AG Car. I find sufficient radiation force to accelerate its wind but there is a deficiency of force around the critical point. In order to increase the radiation force at low velocities I introduced modifications of the model calculations. Clumping, a possible explanation, is found not to be significant. The clumping factor is determined to be 1, i.e. the wind is not clumped. However, turbulence is a likely to play a role at low velocities. With a simple treatment of turbulence the critical point equations can be solved and a hydrodynamic wind solution is obtained that reproduces the observed Hα profiles.

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or by anonymous ftp to `saturn.ethz.ch` *in* `pub/astro2/schmutz` *file* `kona-agcar.ps`

The Eddington limit in rotating massive stars

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The concept of the Eddington limit for the stability of massive stars is investigated. We show that it does not apply in the stellar interior, where convection and density inversions can prevent instability. We show that, due to the fact that all stars rotate, the Eddington limit can also not be a valid stability criterion at the stellar surface, but it should be replace by the appropriate condition for critical rotation, the Ω-limit. We show that a significant number of OB stars is expected to approach the Ω-limit during their evolution. We conclude that rotation — besides mass and metallicity — must be considered as a third independent initial parameter for the evolution of massive stars.

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The Physics of Stellar Winds Near the Eddington Limit

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We review the physics of stellar winds for stars near or exceeding the Eddington limit. We first emphasize that a superEddington condition need not generally lead to sustained mass loss, but instead

can induce convection, a pressure inversion, or a stagnated outflow, all of which should have a net general effect of extending the stellar envelope. Next, we derive simple analytic flow solutions to illustrate the role of "photon tiring" or unsustained driving in the deceleration and stagnation of an initial outflow. We then summarize how a continuum force near the Eddington limit can substantially enhance the mass loss in a line-driven outflow. Finally, we discuss the latitudinal variation of such line-driven mass loss in stars rotating near the critical, 'Omega' limit, noting in particular that the expected equatorial gravity darkening of the stellar radiation field can lead naturally to a prolate, bipolar wind outflow similar to that observed for η Car and other LBVs.
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The effective temperatures of hot stars

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We review the effective temperature scale of hot ($\geq$10kK) stars, including results from direct, continuum and ionization equilibrium techniques. We discuss the impact of recent developments in theoretical model atmospheres for OB subdwarfs, dwarfs and supergiants, white dwarfs and Wolf Rayet stars and present a revised $T_{\rm eff}$ scale for OB stars. Direct techniques coupled with Kurucz model atmospheres allow Strömgren photometry to be used as a sensitive $T_{\rm eff}$ indicator for normal stars with $T_{\rm eff}\leq$25kK. Reliable $T_{\rm eff}$ determinations for hotter, low surface gravity and H-deficient stars require sophisticated ionization equilibrium techniques, generally considering non-LTE and line-blanketing effects.

To appear in *Proc. IAU Symposium 189, Fundamental Stellar properties: the Interaction between Observation and Theory,* **T. Bedding, A. Booth, J. Davis (eds.)**
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Theses

Spectropolarimetry: A new Window for Stellar Physics

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I present a short review (as part of a pre-doctoral exam report) about the use of spectropolarimetry for hot stars (OB, Be, WR and Bp/Ap). After an historical overview and the description of possible sources for polarized light, some examples of observations in spectropolarimetric mode (linear as well

as circular) of these stars are considered. Also a brief introduction into theoretical aspects for linearly and circularly polarized light is presented. In addition, a description of polarized light via Stokes' parameters and use of Mueller calculus for retarders and polarizers are given. Finally, I introduce the new William – Wehlau – Spectropolarimeter which is able to measure linearly and quasi-simultaneously circularly polarized light.

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Editor's note: A nice review of 43 pages!