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

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

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Discussion Forum

This newsletter could serve as a forum for informal exchanges and discussions. Please do not hesitate to share news, suggestions and opinions. A few topics are offered here for your consideration:

- What are the opinions among the Hot Star community about the **creation of a Working Group** on hot luminous stars (similar to, *e.g.,* the Working Group on Active B Stars)? This idea has been suggested by Dr Peter Conti. There is presently a trend, in the IAU executive committee, to give an increasing role to such specialized Working Groups, as they seem to provide a very efficient tool for complementing the work of the Commissions. In particular, this Working Group would help prepare Symposia, promote exchange between researchers in the field as well as provide communication with groups having affined interests.

- So far, the only abstracts published in this newsletter were those of papers already accepted for publication. Since we aim at a fast communication between researchers working in the same field, it seems useful to publish abstracts as soon as the papers are *submitted*, since most papers undergo only minor changes between submission and acceptance. **Abstracts of submitted papers are now welcome** for inclusion in this newsletter, however with one condition: the authors should be willing to circulate drafts at the same time.

- There is some talk about our **next IAU Symposium** in May 1997. The title could be *Wolf-Rayet phenomena in stars and starbursts*. One of the suggested locations is Hawaii. There is however some concern about prices, especially just before an IAU Assembly in Japan. From the INAOE comes the offer to organize the symposium in Puerto Vallarta or Huatulco, both on the Pacific coast of Mexico. Any comment welcome.

- Two **meetings** and a summer school are announced at the end of this newsletter. Please keep us inform about other meetings of possible interest to the Hot Star community.

Abstracts: Theory

Wolf-Rayet population syntheses for starburst galaxies

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We present new evolutionary population synthesis models based on the most recent grids of stellar models computed at the Geneva Observatory. We study the effects on the massive star populations born in a starburst, of the star formation rate (SFR), of the initial mass function (IMF), of the age, of the metallicity (Z) and of a change of the mass loss rates by stellar winds ($\dot{M}$).

We obtain that the more intense and shorter is the burst of star formation, the higher are the ratios of WR to O-type stars reached after the burst. The same trend is expected when the IMF's slope becomes flatter, the upper mass cut off, the metallicity, and/or the mass loss rates increase.

At a given age and metallicity, the way the WR are distributed among the different WR subtypes depends sensitively on the rate of mass loss experienced by the stars. For metallicities Z=0.004 and Z=0.008, we have that only the high $\dot{M}$ models do predict the existence of a long WC-dominated phase. Moreover, only the high $\dot{M}$ models might account for the presence of a significant number of WC stars at very low metallicity (Z= 0.001).

We estimate the percentage of young starbursts, (*i.e.* with O and/or WR stars), whose massive star population is dominated by O-type stars, Wolf-Rayet, WNL, WNE and WC stars respectively. We find that the fraction of starbursts with a WNL-dominated population varies between 6 and 33 % depending on the metallicity.

We study the supernova rates expected in recent and powerful star formation regions and find that the maximum rate occurs when the most massive stars explode. One obtains that for the most powerful starburst region observed by Vacca & Conti (1992, NGC 1614), one can expect, at the maximum, a supernova rate of about 12 supernovae per century.

The present evolutionary population synthesis models can account for the very high ratios of WNL to O-type stars observed in some starburst galaxies. If the presence of a significant WC star population is confirmed in the low metallic starburst regions He 2-10 A and NGC 4214, this will be an indication that the mass loss rates experienced by the stars, at least during the pre-WR phases, are higher than previously thought, in agreement with the conclusions of Maeder & Meynet (1994).

Accepted by A & A *For preprints, contact* meynet@scsun.unige.ch

Time-dependent structure and energy transfer in hot star winds

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We present time-dependent hydrodynamical models of radiation driven hot star winds, which are subject to a strong instability intrinsic to the radiative line force. The calculations are done using a newly developed radiation hydrodynamics code applying the Smooth Source Function method (Owocki 1991) to calculate the radiative acceleration. Assuming spherical symmetry, the wind consists of a sequence of narrow, dense shells, where each shell is bounded by a pair of reverse and forward shocks,

in good agreement with comparable models by Owocki (1992). We find frequent encounters of two shells with subsequent merging of the shells into one. For *small* periodic base perturbations, the wind structure is also periodic, without a stochastic component. For *large* base perturbations, on the other hand, a continuous spectrum of wave frequencies is excited in the wind. Furthermore, our models show the shock decay to set in from about 5 stellar radii on.

The major theme of this paper is the *energy transfer* in the wind. Time-dependent supergiant wind models up to now simply assume radiative cooling to be efficient, and hence the shocks to be isothermal. To test this assumption and to calculate the X-ray emission, the energy equation is included in the simulations. A severe numerical shortcoming is then encountered, whereby all radiative cooling zones collapse and the shocks become isothermal again. We propose a new method to hinder this defect. Simulations of dense winds then prove radiative cooling to indeed be efficient *up to* 5 to 7 R_*. Shock temperatures are between 10^6 to 10^7 K, depending on the base perturbation. Beyond these radii, however, the cooling zones of strong shocks become broad and thereby alter the wind structure drastically: all reverse shocks disappear, leaving regions of previously heated gas. This gas cools as it advects to larger radii. Since, moreover, shell-shell collisions only occur up to 6 to 7 R_*, the wind can be divided into two regions: an *inner, active* one with frequent shocks and shell-shell collisions; and an *outer, quiescent* region with "old" hot material, and with no further shell collisions.

Accepted by A & A *For preprints, contact* feldmeier@usm.uni-muenchen.de

Spectral analyses of the Galactic Wolf-Rayet stars: hydrogen-helium abundances and improved stellar parameters for the WN class

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Almost all known Galactic single WN stars have been analyzed applying non-LTE models for spherically expanding atmospheres. While in a previous study we performed "coarse" spectral analyses based essentially on helium-line *equivalent widths* compared to a grid of models, we now present improved results from 25 detailed "fine" analyses, i.e. from fitting the *line profiles* with individual model calculations. The non-LTE models applied now account for a helium-hydrogen composition, and corresponding abundances are determined for each star.

53% of the studied Galactic WN stars (33 out of 62) are hydrogen-free, populating a luminosity range from $10^{4.6}$ to $10^{5.7}\,L_\odot$. The occurrence of hydrogen is restricted to those WN stars with lowest stellar temperatures (30 ... 35 kK, with few exceptions), comprising most stars of late subtype (WNL) and part of the weak-lined early-type WN stars (WNE-w). But all WN stars are definitely hydrogen-deficient, compared to the solar value. Most WN stars showing hydrogen exhibit mass fractions $\beta_{\rm H}$ between 10% and 30%. They cover the whole luminosity range of the the hydrogen-free WN stars, but extend also to higher values: a group of ten WNL stars with hydrogen is brighter than $10^{5.7}\,L_\odot$, i.e. brighter than any hydrogen-free WN star. Only three WN stars are found with hydrogen mass fractions as small as $\approx 5\%$. A small group of four WN7 stars with high luminosities ($> 10^{5.6}\,L_\odot$) has outstandingly high hydrogen mass fractions (40 ... 53%).

The gradual switching from the high mass-loss rates of the hydrogen-free WN stars to the much lower mass-loss rates of typical OB stars is found to be correlated with the hydrogen abundance.

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Preprints available from anonymous ftp-server 134.245.66.1 alias saturn.astrophysik.uni-kiel.de (Name: *anonymous*, password: your e-mail address); PostScript File: pub/WRHamann/WN-hydro.ps (423 kB)

Evolution of WR ring nebulae generated by moving massive stars - I. The paradigm of G2.4+1.4

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We present a two dimensional numerical simulation of the interaction between the stellar wind blown by a Wolf-Rayet star and the local interstellar medium (ISM) through which the star is moving. Modifications of the surrounding medium due to the previous action of the main sequence stellar wind and RSG wind are also considered. It is shown that the proposed scenario can naturally account for the morphology and photometric properties of the nebula G2.4+1.4 without any particular assumption on the unperturbed local medium.

Accepted by MNRAS *For preprints, contact* brighenti@astbo3.bo.astro.it

Spectral analyses of 25 Galactic Wolf-Rayet stars of the carbon sequence

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We present a grid of helium-carbon models for Wolf-Rayet (WR) stars of the carbon sequence (WC) with $\beta_{\rm C} = 0.2$ (carbon mass fraction), thus extending our previously released grid with $\beta_{\rm C} = 0.6$ to a different chemical composition. The WR model atmospheres are based on the so-called standard assumptions. The calculations account for non-LTE radiation transfer in spherically expanding atmospheres. Helium and carbon are represented by detailed model atoms, especially concerning the ions C III and C IV.

Using the model grids 25 Galactic WC stars of intermediate subtype (WC 5 to WC 8) are analyzed. Subsequently we perform fine analyses by calculating several individual models for each of the program stars. Temperatures, radii, mass-loss rates and terminal velocities are determined together with the carbon to helium ratio.

The analyzed WC stars are found to form two groups, which can be distinguished by the strength of their emission lines. Stars with weak lines (WC-w) have effective temperatures close to 50 kK and their winds are relatively thin, forming the continuous spectrum in regions with small expansion velocities. WC stars with strong lines (WC-s) have higher effective temperatures (60 to 100 kK, referring to the core radius) and thick winds. Thus there is a strong analogy to the distribution of the early-type WN stars (WNE-w and WNE-s, respectively). For the WC stars we determine luminosities between $10^{4.7}$ and $10^{5.5}\,L_\odot$ and mass-loss rates from $10^{-4.8}$ to $10^{-3.9}\,M_\odot\,{\rm yr}^{-1}$. The carbon mass fraction varies from 0.2 to 0.6. No correlation is found between the carbon abundance and any of the stellar parameters (e.g. temperature, luminosity) or the spectral subtype.

The evolution of WR stars is discussed by comparing the results of our analyses with evolutionary tracks.

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Abstracts: Observations

ASCA Solid State Imaging Spectrometer Observations of O Stars

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We report *ASCA* Solid State Imaging Spectrometer (SIS) X-ray observations of the O stars δ Ori and λ Ori. The energy resolution of the SIS allows us to resolve features in the O star X-ray spectra which are not apparent in spectra obtained by X-ray spectrometers with lower energy resolution. SIS spectra from both stars show evidence of line emission, suggesting the thermal nature of the X-ray source. However the observed line strengths are different for the two stars. The observed stellar X-ray spectra are not well described by isothermal models although absorbed thermal emission models with 2 or more temperatures can provide an adequate fit to the data. For both stars we present evidence of absorbing columns significantly larger than the known ISM columns, indicative of absorption by a circumstellar medium, presumably the stellar winds. In addition, the λ Ori spectrum shows the presence of emission at energies > 3 keV which is not seen in the δ Ori spectrum.

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The stellar wind of an O8.5 I(f) star in M 31

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We rediscuss the UV spectrum of OB 78#231, an O8.5 I(f) star in the Andromeda galaxy M 31, which

has been obtained with the Faint Object Spectrograph on the Hubble Space Telescope by Hutchings et al. (1992). The spectrum has been reextracted with better knowledge of background, calibration, and scattered light. The empirical analysis of the stellar wind lines results in a terminal velocity and mass loss rate similar to those typically found in comparable galactic objects. Furthermore, a comparison with an FOS spectrum of an O7 supergiant in the Small Magellanic Cloud and IUE spectra of galactic objects implies a metallicity close to galactic counterparts. These results are confirmed quantitatively by spectrum synthesis calculations using a theoretical description of O-star winds.

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EUVE Spectroscopy of ϵ Canis Majoris (B2 II) from 70 Å to 730 Å

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We present spectra of the brightest stellar source of extreme ultraviolet (EUV) radiation longward of 400 Å, the B2 II star, ϵ CMa. These data were taken with the three spectrometers aboard the NASA Extreme Ultraviolet Explorer satellite (*EUVE*) during the first cycle of pointed observations. We report on our initial studies of the continuum and line spectrum of the stellar photosphere in the 320 to 730 Å region, and on the wind emission lines observed in the 170 - 375 Å region. This is the first EUV spectrum of an early-type star, and thus makes ϵ CMa the most comprehensively observed B star from the X-ray to infrared regimes.

The radiation in both the H Lyman continuum and He^o continuum (shortward of 504 Å) is found to be significantly greater than predicted by both LTE and non-LTE model atmospheres. Since ϵ CMa also exhibits a mid-infrared excess, this points to the outer layers being warmer than the models predict. The anomalously large Lyman continuum flux, combined with the very low column density measured in the direction towards this star implies that it is the dominant source of hydrogen ionization of the local interstellar medium in the immediate vicinity of the sun. All of the lines predicted to be strong from model atmospheres are present and several wind absorption features are also identified. We have detected emission lines from highly ionized iron, ranging from Fe^{+8} to Fe^{+15}, which arise in the X-ray producing region. The lines are consistent with the *ROSAT* PSPC observations if a multi-temperature emission model is used, and the assumption is made that there is significant absorption beyond that of the neutral phase of the ISM. The EUV spectrum shows strong He II Lyman α emission at 304 Å. This line cannot be formed in the upper regions of the photosphere, but rather is due to the recombination of He^{++}, which is itself produced by the X-ray and EUV ($\lambda < 228$ Å) radiation present in the outer atmosphere. The spectrum also shows strong O III 374 Å line emission produced by the Bowen fluorescence mechanism, which has not previously been observed in the spectra of hot stars.

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Multiple Rings Around Wolf-Rayet Stars and Wolf-Rayet Evolution

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We present optical narrow-band imaging of multiple rings existing around galactic Wolf-Rayet stars. The existence of multiple rings of material around Wolf-Rayet stars clearly illustrates the various phases of evolution that massive stars go through. The objects presented here show evidence of a three stage evolution. O stars produce an outer ring with the cavity being partially filled by ejecta from a red supergiant or luminous blue variable phase. A wind from the Wolf-Rayet star then passes into the ejecta materials. A simple model is presented for this three stage evolution. Using observations of the size and dynamics of the rings allows estimates of timescales for each stage of the massive star evolution. These are consistent with recent theoretical evolutionary models. Mass estimates for the ejecta, from the model presented, are consistent with previous ring nebula mass estimates from IRAS data, showing a number of ring nebulae to have large masses, most of which must in be in the form of neutral material. Finally, we illustrate how further observations will allow the determination of many of the parameters of the evolution of massive stars, such as total mass loss, average mass loss rates, stellar abundances and total time spent in each evolutionary phase.

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γ Cir : A young visual binary with pre-main-sequence component(s) ?

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An analysis of the evolutionary stage of the bright, close visual pair γ Cir is given. From the observed spectral types and apparent visual magnitudes of the components and the comparison with stellar evolutionary computations we deduce that the members of this system, discovered in 1835, cannot both be evolving rightward in the Hertzprung-Russell diagram: at least the F8 component is a pre-main sequence object.

On the other hand, a re-analysis of all available astrometric data shows that the observations can be fitted either by rectilinear or elliptical motion. Very accurate data collected during several more years would be needed to distinguish between both.

However, should the binary nature be confirmed in the future, then - according to considerations based on stellar evolution - γ Cir appears to be a pre-main sequence binary system.

Accepted by A & A *For preprints, contact* jpdgreve@vnet3.vub.ac.be

Meetings

From stars to galaxies — the impact of stellar physics on galaxy evolution

Dates: October 9 – 13, 1995

Location: Porto Elounda Mare, Crete (Greece)

Contact: Claus Leitherer (STScI; Chair of the LOC)
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Rationale: The rationale behind this meeting is to bring together specialists working in the areas of stellar astrophysics and galaxy evolution in order to stimulate this rapidly expanding field. The meeting covers theoretical and observational ingredients in population synthesis models at infrared, optical, and ultraviolet wavelengths. Particular emphasis will be on different stellar evolution models, stellar library spectra, model atmospheres, and photoionization models. A central issue of the meeting will be the intercomparison of different approaches (population synthesis vs. evolutionary synthesis, star/cluster vs. isochrone spectra). Applications to nearby early- and late-type galaxies and to galaxies at high redshift will be discussed.

The interplay between massive star formation, the ISM and galaxy evolution

Dates: 3–8 July, 1995

Location: Institut d'Astrophysique de Paris

Contact: Daniel Kunth, Chairman of the LOC
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Rationale: This conference has for aim to discuss in depth the interaction between massive star formation and the interstellar medium (ISM), and how that interaction affects star formation processes and the evolution of galaxies. Stars are thought to be made from the collapse of gaseous molecular clouds in the interstellar medium of galaxies. The massive stars, once formed, interact in turn strongly with the ISM via supernovae explosions and stellar winds. These processes probably rule the star formation efficiency and might alter strongly the evolution of galaxies through the formation of bubbles in the gas and the triggering of galactic winds. The approach of the proposed meeting is original in that it attempts to integrate the massive stars, their interaction with the ISM, and the photometric, chemical and dynamical evolution of galaxies into one single coherent picture. Conferences have been held before separately on each of these topics, but no attempt has been made to link intimately the small scale phenomena to global processes.

Latin-American school of astronomy on interacting binary stars

Dates: July 3–27, 1995

Location: INAOE, Tonantzintla, Mexico

Contact: Philippe Eenens, Chairman of the LOC
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Attendance: Open to graduate students and young post-docs in astronomy, particularly (but not exclusively) coming from Iberoamerican and Caribbean countries. (The lectures will be given in English.)