Active OB stars: structure, evolution, mass loss, and critical limits
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Concluding Remarks

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Abstract. Highlights of this outstanding meeting are emphasized, as well as important open questions for future research.

Keywords. stars: early-type, stars: rotation, stars: magnetic fields, stars: mass loss, stars: interiors, stars: oscillations (including pulsations)

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1. Introduction

I remember many years ago at an IAU symposium on QSO in Geneva, Lo Woltjer addressing a speech to the assembly started in this way: my dear colleagues, I am very impressed how little progress has been made over the last 30 years ! Frankly the same cannot be said here. Recent observations in interferometry, asteroseismology, polarimetry and high resolution spectroscopy have brought many new results. In the long tradition of the meetings on massive stars, this one particularly brightens by its new emerging lines on stellar physics and evolution. The global order of the various sessions is respected here, but some topics treated in different sessions have been grouped at one place. These conclusions are not a summary of the various talks, but only the emphasis of some points which appeared, at least to me, as particularly interesting. I often add a few personal comments. I sincerely apologize to those who may consider that I have not well reported on their results, any selection of a limited number of results is evidently disputable. Only the name of the speaker delivering the talk is mentioned; for the full references, please refer to the original contributions in these proceedings.

2. Rapid rotation and mixing in active OB stars

On the theoretical side, many instabilities and transport processes occur in rotating stars as recalled by Jean-Paul Zahn. Among the critical points, there is the horizontal turbulence which is poorly known. It enforces shellular rotation (depending on radius), it also influences shear mixing and meridional circulation, the problem is that the diffusion coefficient associated to horizontal turbulence is uncertain. In this respect and as also stated by Zahn, I want to emphasize that the transport of angular momentum by meridional circulation is not a diffusion process, as often implicitly assumed by many authors. If one does that, even the sign of the effect may be wrong.

The main future developments concern the interaction of rotation with the magnetic field, in particular the two following problems. 1) Is there a dynamo in rotating radiative zones ? Zahn expresses doubts on the closing of the Tayler-Spruit dynamo, however other closing mechanisms have not yet been worked out. The question is a major one, since the field made by such a dynamo may impose rigid body rotation in radiative zones, thus completely modifying the transport of angular momentum and chemical elements. 2) The other question is whether a magnetic field really kills the meridional circulation. Zahn suggests it is the case for fields above 600 G, but the question may still need further investigations. Zahn also emphasizes that convective cores may operate a dynamo, but whether the resulting field may appear to the surface is not known.

Regarding the treatment of convective zones, Adrian Potter discusses the effects of the two different assumptions: 1) Ω = constant and 2) angular momentum constant. The differences are relatively small for the evolution in the HRD, but large for the internal rotation and this may have consequences for the further evolutionary stages. Massive stars have small surface convective zones, as shown by Matteo Cantiello. These zones may play a significant role for microturbulence, wind clumping, magnetic braking and nonradial pulsations. I note the mass in this zone is lost in a few months according to current mass loss rates, thus the processes must be regarded as dynamical.

The observations of rotational mixing are still controversial according to the presentations by Ines Brott and Norbert Langer (see also the posters by Peters and by Dunstall *et al.*). The comparison of theory and observations as usual in Science may either result in the collapse of the theory or to its improvement and reinforcement. For now, it is to early to conclude. However, as shown by Norbert Przybilla the data by Hunter *et al.* (2008) show for the N/C vs. O/N ratio, which is a model independent test, a very scattered diagram instead of a well defined slope of 4 as predicted by the nuclear reactions and demonstrated from high precision spectroscopy. Incidentally, we note that the argument that the scatter is due to uncertainties in C does not hold, since the sum of C+N+O should be constant. Also Maeder *et al.* (2009) have shown that, if stars in a limited domain of masses and ages are considered, the correlation of the N-enrichments with $v \sin i$ is much better than the one found by Hunter *et al.* Awaiting more results from high resolution spectroscopy to solve the debate, we emphasize that 1) the effects of gravity darkening should be accounted in all parameter determinations and 2) the enrichments N/C are a multivariate function

$$\Delta \log(N/H) = f(v \sin i, M, age, multiplicity, Z, magnetic\ field)\ . \qquad (2.1)$$

Thus, to properly test the dependence on $v \sin i$, the other variables should be kept as constant as possible.

The interferometric observations globally confirm the Roche model for rotating stars, although some small deviations near the break-up limit may exist as shown by Ming Zhao. The remarkable fact is that the coefficient β of the gravity darkening relation $T_{\rm eff} \sim g^{\beta}$ can now be estimated. Instead of $\beta = 0.25$ in blue stars, lower values are observed in Regulus (B8V, $\beta = 0.178$) and Alderamin (A7V, $\beta = 0.22$), for convective envelopes the lower value $\beta = 0.08$ (Lucy 1967) is supported. In case of fast rotating stars, one may have a variable β over the stellar surface.

Be stars are a crossroad in this meeting. The initial rotation velocities and masses leading to them in the course of MS evolution have been modeled by Sylvia Ekström. She also emphasizes the role of the mechanical mass loss from these stars. This kind of mass loss may play a role in many situations particularly at the lower metallicities and in the first stellar generations. The observation properties have been reviewed by Christophe Martayan, who points out the effects of the line saturation, which leads to an underestimate of the rotation velocities, and the veiling effect from the circumstellar disk. The number frequencies and the pulsation properties change with metallicity Z. Globally the magnetic fields of Be stars are weak, typically lower than 150 G (see also poster by Ruslan Yudin). This is rather expected, otherwise the rotation of these stars would have been slowed down. Interestingly enough, in the higher mass range of Be stars, the Be phenomenon occurs mostly during the early MS phase, while in the lower mass range Be stars tend to concentrate near the end of the MS phase.

The origin of the Be phenomenon has been commented, particularly by Stan Owocki. It is clearly a combination of a long term secular effect and of short term instabilities, for example pulsation. The secular evolution brings the star close enough to the critical break-up velocity, so that the additional velocity field due to an instability may allow some mass ejection.

3. Winds and magnetic fields of active OB stars

The session starts by a useful "survival kit" on magnetic fields by Véronique Petit. Low resolution observations only provide the global longitudinal field, while the high resolution together with the multi-line technique gives the structure and field intensity. For the solar-type stars the magnetic fields are ubiquitous, spatially complex, weak on the average and due to a dynamo. The fields of hot stars are rare, possibly strong, organized and showing no correlation with stellar properties. In the mass range of 1.6 to 5 $M_{\odot}$, only 2% of the stars show magnetic fields with intensities larger than about 300 G. This limit may be the result of dissipation for weaker fields (poster by Kholtygin). Among OB stars, the frequency of magnetic stars seems to show some differences in clusters. There are 3 over 9 in Orion cluster and 1 over 26 in NGC 2244. The technique of Doppler imaging, as shown by Oleg Kochukhov, also allows one to make a detailed mapping of the field and of the abundance peculiarities over stellar surfaces. I note that one may wonder about the origin of the large differences in the magnetic field of massive stars. What comes from the field of the interstellar medium, what comes from the dynamo in convective regions at the pre-MS stage?

Gregg Wade, pointing out that the magnetic field in astrophysics is like sex in psychiatry, reports on the beautiful MiMeS collaboration, which has received 640 hours of observations on the CFHT (see many posters). The objectives of this collaboration focus on the origin of the fossil fields, the magnetic braking, the interaction with winds and the impact on stellar evolution. Two magnetic stars are particularly remarkable. As reported by Mary Oksala, σ Ori E (B2Vp) has a polar field of 9.6 kG with $v \sin i = 150$ km s^{-1}. HR 7355 (B2Vpn), as reported by Thomas Rivinius and Oksala, has a variable field which reaches 3.2 kG, it has $v \sin i = 310$ km s^{-1}. In these two cases, the wind is magnetically dominated and the ejected particles form structures which corotate with the star. In HR 7355, metals seem to accumulate at the poles. Another similar star, HR 5907, has been detected.

There was unfortunately no remark on the relation between magnetic fields and chemical N–enrichments, except the poster by Thierry Morel. Indeed, it is known from the work by Henrichs *et al.* (2003a) and Henrichs *et al.* (2003b) that some stars with strong magnetic fields and often low rotation velocities show strong nitrogen enrichments by 1 to 2 dex. These interesting observations are recalled in Table 1 below. These observations, although scarce, suggest that there is some mixing effect related to the presence of a magnetic field. What is the mechanism responsible for this mixing? A possibility is that it is due to the meridional circulation, which is not necessarily killed by the magnetic field. Models by Maeder & Meynet (2005) show that the meridional circulation may be enhanced by the fact that a magnetic star rotates near solid body rotation, i.e. out of equilibrium for meridional circulation. This may be the case for moderate fields, while for very large fields circulation may be inhibited. Another possible source of mixing could be a magnetic instability able to make a sufficient transport of the elements. However, such an instability has not yet been identified.

Table 1.

Name	Sp	$v \sin i$	Polar field Bp	$\Delta logN$
β Cep	B1IVe	27 km s^{-1}	360 G $\pm$ 40	1.2
V2052 Oph	B1V	63 km s^{-1}	250 G $\pm$190	1.3
ζ Cas	B2IV	17 km s^{-1}	340 G $\pm$ 90	2.6
ω Ori	B2IVe	172 km s^{-1}	530 G $\pm$200	1.8

On the theoretical side, concerning the fields at stellar surfaces Richard Townsend shows both analytical developments and numerical simulations of magnetospheres and X–ray emissions. He points out two key parameters for magnetospheres:

$$\eta = \frac{B^2 R^2}{\dot{M} v_\infty} \quad \text{and} \quad t_{\text{spindown}} = \frac{2}{3}\, k\, \eta^{-1/2} t_{\text{M}-\text{loss}}\,. \tag{3.1}$$

The parameter η describes the ratio of the magnetic and wind momenta. A ratio larger than 1 implies the existence of a magnetosphere. For example, in the case of σOri E, the magnetosphere would extend up to 30 stellar radii. The spindown of the star is characterized by the spindown timescale t_{spindown}, where k is a constant and $t_{\text{M}-\text{loss}}$ is the characteristic time of the mass loss of the order of $M/\dot{M}$. It seems to me that the spindown by magnetic fields should soon also be accounted for in evolutionary models. It could account for some slow rotating stars with enhanced mixing.

Stéphane Mathis studies the magnetic effects in stellar interiors. He examines the initial conditions for fossil fields and derives the condition for the stability of such fields. He shows that the ratio of magnetic to gravitational energy must not be too large otherwise instabilities develop. When applied to the complex field structures of magnetic hot stars, these conditions generally indicate stability. Mathis also examines the possibility of a dynamo operating in a radiative zone. He suggests following the paper by Zahn, Brun & Mathis (2007) that the Pitts and Tayler instability exists, however he claims that the dynamo proposed by Spruit does not work. Nevertheless, a loop closing the dynamo may be possible. If it works, as emphasized above, this will be a major effect in stellar evolution, since it will deeply affect the internal rotation and the transport processes.

The winds of OB stars

There are many structures in the winds, as shown by Alex Fullerton. Among the various components, there are the narrow and discrete absorption components (NACS and DACS), which are essentially the same and visible on the left of the big absorption components. They are ubiquitous and persistent for some time. There are also the periodic optical depth modulations (PAMS, "they smile to you"), as well as corotating interacting regions (CIRs) and spiral structures. These result from the interaction of the fast wind with a slower wind component. In addition to the porosity due to the various inhomogeneities, there is also the "vorosity" due to inhomogeneities in the velocity distribution. The important point is that for different mass loss estimates, the dependence in density is different

$$\textit{radio \& } H_\alpha \textit{ determinations} \quad \textit{depend on } \varrho^2 \tag{3.2}$$
$$\textit{UV determinations} \quad \textit{depend on } \varrho\,. \tag{3.3}$$

The presence of clumping leads to large overestimates, up to an order of a magnitude, of the mass loss rates based on radio and H_α observations. Small scale density fluctuations make large effects, while large scales make small effects. On the whole, I think this means that the mass loss rates are still rather uncertain.

As shown by David Cohen in Session 4, the X-ray spectroscopy provides a clumping–independent mean to determine the mass loss rates of O–type stars. The X–rays are formed by shocks in the wind, the plasma reaches temperatures of the order of 10^6 K. With respect to the observer, the more distant part of the shock (contributing to the red side of the lines) is absorbed with respect to the closer part (blue side). The optical depth $\tau = \kappa \dot{M}/(4\pi R v_\infty)$ of this absorption is sensitive to the mass loss rates. The mass loss rates determined in this way are typically a factor of 3 to 5 smaller than the values from radio and H_α determinations.

4. Populations of OB stars in galaxies

Norbert Langer comments on the difficulty to define the end of the MS phase, which seems to extend much outside the formal MS band predicted by evolutionary models. Incidentally, this effect was also found in a study of 23 clusters with ages smaller than $2 \cdot 10^7$ yr in the Galaxy, the LMC and SMC (Meylan & Maeder 1982). They found that 40% of the stars are observed out of the MS band instead of about 8% predicted. Everything is like if the MS band reaches the early types A, thus both studies agree. The relative excesses of A, F, G, K and M stars my increase with decreasing metallicities. Extended mixing and/or binaries may contribute to such an effect, as well as atmospheric effects, however it is clear that no simulations properly reproduce the observations. Langer also discusses the fast decrease of rotation velocities near $\log T_{\rm eff} = 4.3$ as well as the uncertainties concerning the N–enrichments in relation with the $v \sin i$ as nentioned in Sect. 1. He also examine what are the progenitors of GRBs and shows that the number ratio of GRB/SN increases with decreasing Z. Galactic stars are not expected to produce GRBs, because of a too low angular momentum in final stages.

Thibaut Decressin establishes the relation between the chemical properties of stars in globular clusters and the properties of the massive stars in the early stellar generations. Most of the globular clusters show signs of a second stellar generation in the form of a double MS band in the HR diagram. He shows that the abundance anomalies, such as the oxygen–sodium anticorrelation, result from wind enrichment by an earlier generation of fast rotating massive stars, which experienced mechanical ejections as discussed above by Ekström. Dynamical models indicate that following supernova explosions most of the remaining gas is ejected as well as a fraction of the stars of the first generation.

Chris Evans reviews the results on OB stars in nearby galaxies from multi–object spectrographs on large telescopes. Most properties show a strong dependence on metallicity Z, a point which was also nicely emphasized in the introductory talk by Dietrich Baade. An important fact is that the lower Z, the lower the mass loss rates due to the smaller atmospheric and wind opacities. Among other facts, the SMC stars at a given spectral type are hotter. There are more Be stars and the $v \sin i$ are generally larger at lower Z, despite a significant scatter. In this respect, I note that there may be two effects responsible for this property: 1) the effects of the lower mass loss at lower Z and 2) the possibility of faster initial rotations at lower metallicities (Maeder, Grebel & Mermilliod 1999). The binary fraction varies from cluster to cluster (see also Sana, this meeting), but no trend has been identified yet with Z. Evans also comments on recent claims about the existence of very massive stars up to 320 $M_\odot$. As this is is not the first time that such claims are made, some concerns may be expressed whether the announcement will survive further observations. Finally, Evans points out the major interest of I Zw 18, a well known irregular galaxy with a metallicity equal to 1/30 of solar. This is a great step

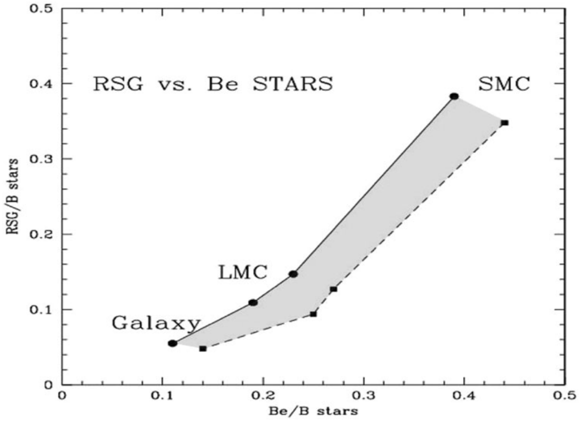

Figure 1. The relation between the ratio of red to blue supergiants and the ratio of Be to all B stars (normal+Be). Two different limits in the definition of RSG are shown. Data collected by the author from the WEBDA cluster data basis and from Maeder, Grebel & Mermilliod (1999).

toward the very low metallicities of the distant Universe. Photometric data have recently been obtained from the HST for a part of this galaxy (Jamet *et al.* 2010).

Indeed, several of the dependences on Z, particularly those concerning number ratios such as the number ratio of WR to O–stars, are the result from the lower mass loss rates at lower Z and/or from the differences in the rotation velocities at the end of the MS phase. Probably not all the possible dependences have been found yet. For example, I note that the ratio of red to blue supergiants is increasing with decreasing metallicities and faster rotations. This in turn implies that there is is a positive relation between the number ratio RSG/BSG of red to blue supergiants and the relative frequency of Be stars among all B stars. I show such a relation in Fig. 1.

Alceste Bonanos reports on an infrared survey of about 5000 stars from Spitzer SAGE. This allows her to study the IR properties of Oe, Be, B[e], LBV, RSG, WR and OH/IR stars. She finds evidences of transition from Be to B stars and vice versa, as well as signatures of dust around the B[e] stars. The survey also provides several interesting statistical informations on the number frequencies. Anatoly Miroshnichenko studies the B[e] stars in the Galaxy and Magellanic Clouds and examines the possible origin of these stars. Is it just some range of masses and rotation velocities which lead to them or is it the effects of binary merging? Dominik Bomans and Kerstin Weis observe the LBV in external galaxies, these are (with the WR stars) the stars which can be identified at the largest distances. From the new LBV discovered, they conclude that the LBV phenomenon is not restricted to high metallicities. Weis emphasizes that at least 50% of the LBV show bipolar nebulae (75% in the Milky way). LBV cover a large range of luminosities. She wonders why not all LBV show bipolar nebulae and whether it is related to their rotation.

5. Circumstellar environment of active OB stars

The observations of circumstellar (CS) discs with various techniques, in particular interferometry, are reviewd by Philippe Stee, by Alex Carciofi and by Christopher Tycner. Properties and processes at the origin of the CS disc of Be stars are reviewed by Stee, who states that each Be star is a special case. Some discs are permanent, some are dissipating. Clearly the ratio Ω/Ω_c of the angular velocity to the critical value is a leading parameter, but there may be other ones, like the beating of nonradial pulsations. Binarity influences the disc properties, for example by making truncations and deformations. Carciofi particularly emphasizes that most disc properties are consistent with the model of viscous decretion disc: the size at various λ, the thin opening angle, the small deviations from a Keplerian disc, the long term variations in the integral light and colors, etc. He also comments on the viscous properties, as well as on the deviations from a steady state viscous disc model. Tycner describes the careful iterations between the long-baseline interferometry and the models necessary to obtain consistent disc models, he provides nice examples with P Cygni and some Be stars.

Rigel (B8Ia) and Deneb (A2Iae) were monitored in the IR by AMBER/VLTI and by VEGA/CHARA as reported by Olivier Chesnau. It is particularly interesting that in the near IR, the stellar diameters are essentially independent of the mass loss rates. His pioneer observations also show the presence of clear signs of activity in these supergiants.

The case of the Herbig Ae/Be stars is presented by Evelyne Alecian. These pre-MS stars show accretion discs. They extend from 0.3 to 1000 AU and may contain PAH as well as various molecules. Generally the discs are less massive around Be stars than around Ae stars, a fact which may be due to higher photoevaporation in the former. Many evidences of planet formation are also present. Noticeably 5% of the Ae/Be stars show signatures of magnetic fields, this fraction is the same as that among the MS stars of the corresponding mass range. The magnetic fields are compatible with flux conservation between these two evolutionary stages.

Be stars generally have IR excesses due to the free–free emission of the ionized gas. In JHK color-color diagram, as shown by Chien–De Lee, a group of Be stars with large excesses behave differently and this is the signature of thermal emission from dust in these stars. Dust seems to form in Be stars near the end of the MS phase.

6. Periodic variations and asteroseismology of OB stars

New data from MOST, CoRoT and Kepler have brought many new facts concerning massive stars, as reported by Peter de Cat. The β Cephei stars (low order p– and g–modes with periods of 2 to 12 h) and Slowly Pulsating B stars (SPB with high–order g–modes and periods of 0.3 to 5 days) are privileged objectives for asteroseismic observations. The observations of V836 Cen, a β Cep star, support an overshooting distance $d_{\rm over}$ equal to 0.10 of the pressure scale height H_P and a core angular velocity 4 times larger than the surface velocity Ω_S. For ν Eri, a SPB star, these values are respectively 0.31 H_P and 3 times Ω_S. Evidences of pulsations are also found in Be and SPBe stars, which both have high rotations. In μ Cen (B2IV–Ve), the outburst coincides with a mode–enhancement, indicating that pulsations may stimulate the ejection (in addition to effects of secular evolution as mentioned above). The variability of the B1Ve star HD 51193 extensively observed by CoRoT, Harps and Sophie is further discussed by Juan Gutierrez–Soto. On the whole I think asteroseismology allows us to make giant steps forward in the study of massive star properties.

In a enlightening discussion of theoretical aspects, Marc–Antoine Dupret shows that low degree g–modes from the core can reach the surface and give information not only on the overshooting, but also on semiconvection and rotational mixing. Indeed current overshooting models predict abrupt transition of the internal distribution of the mean molecular weight μ, while rotation mixing predicts smooth transitions in the distribution of μ. As he reports, Miglio *et al.* (2008) show that in MS models the periods of high-order gravity modes are accurately described by a uniform period spacing superposed to an oscillatory component. The periodicity and amplitude of such a component are related, respectively, to the location and sharpness of the μ–gradient. Observations indicate that there is nos sharp variations of μ above the core, in agreement with models of rotational mixing. Dupret also shows that the great rotational distortion of Be stars demands that 2D models are used to discuss the oscillations. Interestingly enough, new families of instability modes appear in this case. Finally, Dupret calls our attention that due the lower opacities for stars in the LMC and SMC, SPB and β Cep stars should not occur in these galaxies according too the models. The fact they are observed is challenging, particularly regarding the opacities.

The upper part of the HR diagram deserves a particular attention as pointed out by Hideyuki Saio, who shows that above some luminosity limit the strange modes are active. Also, in stars with a convective zone due to the Fe–opacity peak, low degree g–modes may appear at the surface. To what extent do they contribute to turbulence? In the case of LBV, the microvariations are consistent with oscillatory convective and strange modes. The question arises evidently how this is influenced by the boundary conditions, since running waves may form in the wind. The WR stars with their very high L/M ratio are likely to show strange mode pulsations, as reported by André–Nicolas Chené. He reviews the results from MOST, which has observed 6 WR stars. These stars show multimode oscillations mainly in the continuum. A period of 9.8 h has been found by Lefevre *et al.* (2005) for WR123 and two other WR stars show periods of a few days. In addition, some variations may also be due to a corotating interacting region (CIR) in about 20 % of the WR stars, as estimated by Chené.

The interesting case of binaries

Binaries are the sites of many interesting physical processes, in the interior, at the surface as well as in the colliding winds. The review of the observations by Hugues Sana is presented by Chris Evans. According to the domain of the parameter space, different observational techniques are required: radial velocities, interferometry, speckle, adaptative optics and imaging. The fraction of binaries among massive stars varies a lot from cluster to cluster. On the average a fraction of 45 % is found in nearby rich clusters, about 50% have periods smaller than 1000 days and separation smaller than 10 AU. From the statistics given, I note that it would be interesting in relation with models to try to estimate which fraction of all stars experiences binary mass transfer of type A, B or C, as well as synchronisation, tidal mixing, etc.

The evolutionary models of binaries are reviewed by Walter van Rensbergen, who presents a catalog with 561 models of binaries covering a wide range of initial parameters, thus leading to different evolutionary scenarios. Some new physical effects are now accounted for in the models, the spinning up of the gainer as well as the hot spots on its surface due the impacting mass coming from the donor. The rotational energy added to the radiative energy of the hot spots may produce matter ejection from the system (liberal era). A critical parameter in this evolution is the mass fraction called β accreted by the gainer. Van Rensbergen applies his models to the Algol systems issuing from a binary with a B–type primary. The period distribution is well represented, while the models give less Algols (17%) with large mass ratios (0.45-1) than observed (45 %).

7. Normal and active OB stars as extreme conditions test beds

A review of some interesting problems concerning the photospheres and the winds of massive OB stars is given by Joachim Puls. A question concerns the origin of the clumps and the possible role of convection and pulsations. The interest of the B– and A–type supergiants as possible sites of strange modes is underlined. Concerning the $\Omega\Gamma$–limit, he mentions that, while the so-called $g_{\rm eff}$ effect due to gravity darkening is observed in the anisotropic winds, it is not (yet?) the case for the κ–effect, i.e. a jump in the mass loss rates over the stellar surface due to a bistability (a discontinuity in the opacity due to a difference in ionization state). The case of γ Ara would also be interesting to examine, since in principle the $\Omega\Gamma$–limit would predict an enhanced mass loss rate for this star. Finally, Puls emphasizes the problem of the wind momentum of stars with $\log L/L_{\odot} \leqslant 5.5$, which is much lower than predicted and is still a challenging question.

Maria-Fernanda Nieva reports on the results of high precision spectroscopy applied to a well selected sample of 276 B–stars. A non-LTE technique is applied to the treatment of line formation. A very careful checking of all possible systematic effects in the data is performed. It is really quite remarkable how the whole spectrum is well reproduced by a single set of parameters. The method allows her to obtain accurate spectroscopic distances, evolutionary masses, M/L ratios, $T_{\rm eff}$, $\log g$ and chemical compositions. The sample is applied to the discussion of the metal content of the solar neighborhood, as well as to the origin of the chemical mixing.

The extreme case of the LBV

The properties of LBV have been reviewed by Nathan Smith and Jose Groh with different interesting approaches. Both show that the LBV lie between two lines in the HR diagram (Smith *et al.* 2004), which join together at the luminosity level of about a 20 $M_{\odot}$ star. Smith points out that lifetime of the LBV phase is much longer than previously assumed, since the many dormant LBV were not accounted for in previous studies. He proposes a lifetime $t_{\rm LBV} = (2-5)\cdot 10^5$ yr instead of $(2-3)\cdot 10^4$ yr. The very interesting consequence is that this may make the LBV phase the evolutionary stage where occurs most of the mass loss necessary to form WR stars. Thus, it may alleviate or even solve the problem set by the new low mass loss rates which make the formation of WR stars difficult. Interestingly enough, Smith defines a timescale $t_{\rm rad} = t_{\rm erup} \cdot L_{\rm erup}/L_{\rm star}$, this is the timescale for energy supply, i.e. it says how long the star has to store the energy necessary to feed the outburst. For η Carinae, it is of the order of 75 yr.

As mentioned by Groh, the fact that some supernovae (like SN 2008S) might originate from an LBV is an interesting problem, since stellar models do not generally predict SN explosions as LBV. He shows that on the LBV minimum line, i.e. the limiting line on the blue side of the HR diagram, some LBV such as HR Carinae and AG Carinae are about at the critical rotation, while they are much below the critical value (e.g. $\Omega_S/\Omega_C = 0.4$ for AG Car) when they are on the red side of the LBV domain. Thus, rotation certainly is an important effect for at least a part of the LBV. Indeed, Groh suggests that there are two groups of LBV: the fast rotating, highly variable stars with an S Dor cycle and the slow rotating ones with much less variability like P Cygni.

High energies from OB stars

The high energy emissions of OB stars are reviewed by Guillaume Dubus and by Stan Owocki. Dubus examines the interactions in some binaries between the relativistic wind of a pulsar and the wind of an OB star. The wind collision generates a non thermal emission with most of its energy above 1 MeV. Some interesting cases occur when a pulsar moves through the disc of a Be star. Owocki focus on the interesting γ–ray source LS5039, wich consists of an O6.5V star and a compact companion, which may be a black hole. He make 3D SPH simulations of the accretion of the O–star wind on the compact companion and shows that the high–enery observations are correctly described by a Bondi-Hoyle accretion. This new scheme by Owocki offers a valuable alternative to the usual pulsar wind shock model. Interestingly also, some wind properties such the as porosity have an effect of the high energy emissions and might perhaps be tested in this way.

At the end, warm thanks and intense applauses are addressed to Coralie Neiner for this most excellent meeting, both for the outstanding scientific program and for the excellent organization she has conducted throughout with the help of motivated collaborators, to whom we also express our gratitude. This meeting will remain as great step in our understanding of massive stars.

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