Active OB stars: structure, evolution, mass Loss, and critical limits
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Discussion – Rapid rotation and mixing in active OB stars

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Abstract. The general discussion following Session 1: Rapid Rotation and Mixing in Active OB Stars is summarized. Topics that focus on observational and theoretical issues are included.

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1. Introduction

This is the first of six general discussion sessions that followed each of the sections of IAUS-272. We decided to divide the allotted time of 30 minutes equally between observational and theoretical topics. Geraldine Peters presided over the former and Georges Meynet chaired the latter.

2. Observational Topics

The nitrogen abundance as a marker of photospheric mixing of CNO-processed material from the interior of an OB star was mentioned throughout this session. Since the determination of the N abundance is a straightforward way to confront theory with observation, it is important to confirm the errors that exist in the abundance analyses for both the slowly-rotating and fast-rotating stars, especially the Be stars. Sources of error might include the choice of model atmospheres, input parameters, and the observations themselves. The opportunity today to obtain very high quality spectra of OB stars in our galaxy and the Magellanic Clouds is unprecedented. As I see it, the greatest challenge in interpreting the optical data is correcting for the flux from the disk. In the UV one is faced with coverage and blending issues, continuum placement, and in the case of the Be stars possible line emission from circumstellar material and sometimes pervasive shell spectra. Of course the abundances that are determined are only as good as the model atmospheres. How well do the models represent real stars? This is quite an important issue for rapidly-rotating OB stars. Perhaps the least certain input parameter is the microturbulence. It has been known for some time now that the value for $V_{\rm turb}$ determined from optical lines (e.g. O II) is larger than that found from the UV lines. For a typical B star with modest microturbulence the difference is $\sim$3 km s^{-1} (cf. Fig. 1). An error of the latter size produces an uncertainty of $\sim$0.1–0.4 dex in the abundance (Hunter *et al.* 2007) depending on which line in which star is being analyzed and the upper limit is approaching the theoretical predictions for the nitrogen enrichment in the photosphere.

Daniel Lennon, who spoke on behalf of the VLT-FLAMES Survey, reaffirmed that it is very difficult to determine nitrogen abundances in the Be stars, or any fast rotator, due to their broad lines. Very high S/N is needed and this presents problems. The error

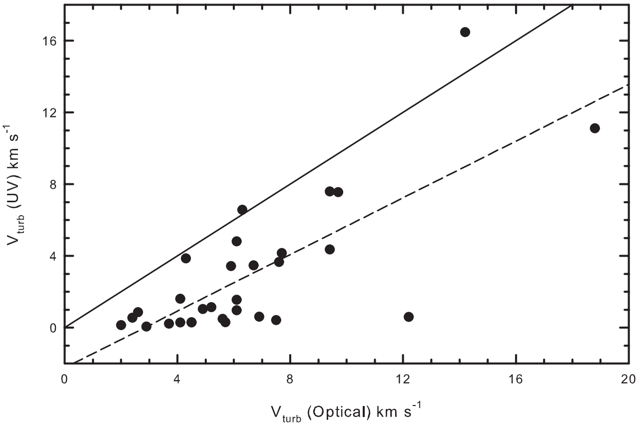

Figure 1. The microturbulence parameter determined for the same B star from optical (Gies & Lambert 1992) and UV(Proffitt & Quigley 2001) lines. The lower *dashed* line is a linear regression fit to the data, while the upper *solid* line represents a one-to-one correlation. The implied V_{turb} from the UV study is systematically smaller and suggests that V_{turb} may be depth-dependent.

bars for an analysis of an individual star will be large. But it helps to observe a large sample of stars, and this is where the VLT-FLAMES project is contributing. With a large sample one can simulate a population based upon what you know about the error bars and feed this into the simulation. This is the focus of Inès Brott's work. However if one looks at the parameter space and number of stars in each mass bin it is clear that some regions are sparsely populated. VLT-FLAMES II (The Tarantula Survey) will address this problem by gathering a larger sample of stars in the LMC. According to Lennon, the objective of the VLT-FLAMES Surveys is not to understand each individual star but to "understand all of the stars all of the time, not some of the stars some of the time – and this is a challenge". Peters commented that it is unfortunate that a new UV spacecraft is not forthcoming as many strong N II and N III lines are found in this spectral region. Lennon pointed out that HST/COS and HST/STIS are currently available and urged the audience to submit proposals.

The VLT-FLAMES group was then asked by Georges Meynet why there are systematic differences between the nitrogen abundances that they found and those determined by Norbert Przybilla and Kresimir Pavlovski. Lennon replied that their sample included a large number of intrinsically-slow rotators that tended to show large nitrogen abundances. There were too many stars with low values of *v*sin *i* for it to be an inclination effect. Many slow rotators showed a high N abundance, contrary to the predictions for simple rotational mixing. Improved NLTE calculations and further study are warranted. It was then pointed out that the calculations must not be that bad because the lowest N abundance is consistent with that of the baseline abundance for the LMC.

Norbert Przybilla recommended that the VLT-FLAMES group reinvestigate the N abundance from their FLAMES I database using N III. Peters pointed out that many good N III reside in the UV. Lennon then mentioned that there are good N III lines in the optical and that the VLT-FLAMES group is looking at both species in FLAMES II.

3. Theoretical Topics

The discussion was initiated by a question of Georges Meynet on mass loss: mass loss, in addition to be often clumpy in space also frequently presents some "clumpiness" in time. Indeed, mass loss, in many circumstances does not appear as a continuous flow but as shell ejections or outbursts. This seems to be the case for Be stars which eject matter in their equatorial disks in a discontinuous way. This is also the case for Luminous Blue Variables (LBV) which suffer very strong outbursts. Thus the question is what can be the physical cause of such behaviors? Can it be related to change of surface abundances?

Gloria Koenigsberger made the following addendum to that question: a handful of LBVs eruptions are apparently not conserving their bolometric luminosity. The bolometric luminosity increases. What can be the physical cause for these changes? This is a key question to answer for understanding these objects. Olivier Chesneau mentioned different works supporting the idea that the collective effects of non radial pulsations can play a role in stochastic mass ejections.

Stan Owocki emphasized the difference between baseline-type theories for wind mass loss and theories for shell ejections or eruptions. He noted that the CAK theory for line driven winds is very successful in explaining inferred mass loss of hot stars, and constitutes a good theoretical framework to study the effects of rotation, magnetic fields, pulsations, etc. However when stars approach critical limits, either the Eddington limit or a critical rotation limit, it becomes difficult to make firm predictions. Stan makes the analogy of water flowing over the edge of a fountain. When regular and not perturbed, this overflow is just at the steady rate set by the water source. But on a windy day the ripples and waves on the water surface lead to splashes and sprays, making the overflow quite variable and difficult to predict in detail. Analogously, when stars approach or reach a critical limit, small fluctuations can have dramatic effects, making the associated flows dynamical and variable, and hard or even impossible to predict. Nonetheless, when averaged over such fluctuations, the net outflow depends on whatever interior processes drive the star towards the critical limit, whether Eddington limit, critical rotation, or even Roche lobe overflow. If these interior driving processes are known and understood, then the averaged mass loss can be robustly predicted, since it is governed by the need to remove mass in order to evolve back from the critical limit and recover some more stable regime. For instance at critical rotation, mass loss will be governed by the necessity for the star to remove an excess of angular momentum. Near the Eddington limit, similar processes likely occur, though it is still not clear what causes the giant eruptions like the one of η Car. But again internal evolution probably plays a major role, and further study is needed to understand the nature of that.

Nathan Smith noted that in order to explain the giant LBV eruptions which may eject 15 $M_\odot$ with energies of the order of 10^{50} ergs, surface effects such as the reaching of some critical rotation or opacity limits may not be sufficient. Some processes occurring in deeper interior layers might need to be invoked for the larger eruptions.

Coming now to another point, Nathan Smith noted that the circumstellar nebula around LBVs offer a kind of archival record of what happened in the past, allowing one to trace back the history of mass ejection and changes in surface abundances. Determinations of the abundances in different parts of the nebula around η Car indicates that these shell eruptions can produce large and rather sudden changes in the surface abundances of a star, and may at least temporarily change its surface rotation rate after an eruption. Concerning η Car, he recalls that the N/O ratio has passed from solar value to values around 20 after the shell eruptions, producing a change of this ratio in an incredibly short interval of time of a few thousand years (Smith & Morse 2004). Thus he was wondering whether similar processes, although perhaps less extreme in amplitude compared to η Car, could also possibly be invoked to explain the puzzling positions of some stars in the Hunter diagram (N/H versus $\upsilon \sin i$ plane) as mentioned in the talk by Inès Brott, for instance those stars presenting strong surface enrichments and very low surface velocities.

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