Wolf-Rayet Stars
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World-wide amateur observations - A viable future of massive star research

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For some years now, spectroscopic measurements of massive stars in the amateur domain have been fulfilling professional requirements. Various groups in the northern and southern hemispheres have been established, running successful professional-amateur (ProAm) collaborative campaigns, e.g., on WR, O and B type stars. Today high quality data (echelle and long-slit) are regularly delivered and corresponding results published. Night-to-night long-term observations over months to years open a new opportunity for massive-star research. We introduce recent and ongoing sample campaigns (e.g. ϵ Aur, WR 134, ζ Pup), show respective results and highlight the vast amount of data collected in various data bases. Ultimately it is in the time-dependent domain where amateurs can shine most.

1 World-wide amateur communities

For some years now spectroscopic observations of massive stars have become well established in the world-wide amateur community. Besides many small teams, this community is still concentrated in the German *VdS Section Spectroscopy* (VdS Spectroscopy) and the French *Astronomical Ring for Access to Spectroscopy* (ARAS). A third presently upcoming group is the *Southern Astrospectroscopy Email Ring* (SASER) in the southern hemisphere (see section 3). Smaller groups and single observers can be found in Canada, China, Denmark, Spain, UK, USA, etc. Websites and internet forums bring these amateurs and professionals together. Data are regularly delivered to respective databases (e.g. the database *Be Star Spectra* (BeSS) presently contains more than 100.000 professional and amateur Be star spectra). Annual conferences with typically 50 participants take place in France and Germany. Observations are performed with standard long-slit spectrographs, as well as Echelles, which can be commercially designed or self-made.

2 Specific amateur domains

Some specific measurements cannot be easily performed with professional telescopes and manpower. These include, e.g., repeated observations for times longer than a month or so. In addition, long-term campaigns of several months can usually not be performed with professional telescopes. Either the necessary small-size instruments do not exist/are not available or observing proposals compete with other programs.

2.1 Monitoring

Long-term monitoring of spectral quantities/indicators is probably an exclusive amateur domain. In contrast to professional observations amateurs can monitor targets for many years delivering solid and uniform information about certain stellar behaviour. Figure 1 shows a 10 year amateur monitoring of the bright Be star δ Scorpii with dramatic changes in EW of the Hα disk emission line.

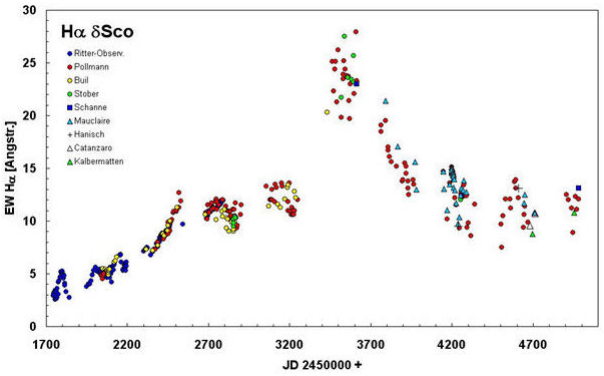

Fig. 1: Amateur Hα observations of the Be star δ Sco for about 10 years. The first observations were performed by professional astronomers, indicating line-strength variability between 3 and 5 Å (blue dots). Amateur observations over 10 years revealed a global long-term variability between 3 and 28 Å (Pollmann et al.).

2.2 Long-term campaigns

Up until now, numerous ProAm long-term campaigns have been performed. Examples are the outburst of the symbiotic star V407 Cyg in 2010, δ Sco periastron passage in 2011, the Algol type eclipsing system AZ Cas in 2012 – 2014 and the erupting Nova

Delphini in 2013. All observations were performed with very small telescopes (∼ 30cm) at private backyard observatories. Two examples:

2.2.1 ϵ Aurigae eclipse campaign 2009–2011

ϵ Aur is the longest-period eclipsing binary known (∼27.1 years). Amateurs and professionals separately measured the 18 month eclipse of the primary F0 star by a dust disk around a B type secondary. Professional observations with the CHARA interferometer (Fig. 2, top) delivered direct imaging of this event. However, no information about the disk structure could be obtained. Amateur equivalent width measurements of neutral Potassium at 7699 Å, however, revealed a line-strength variability which suggests a structured disk (Fig. 2, bottom).

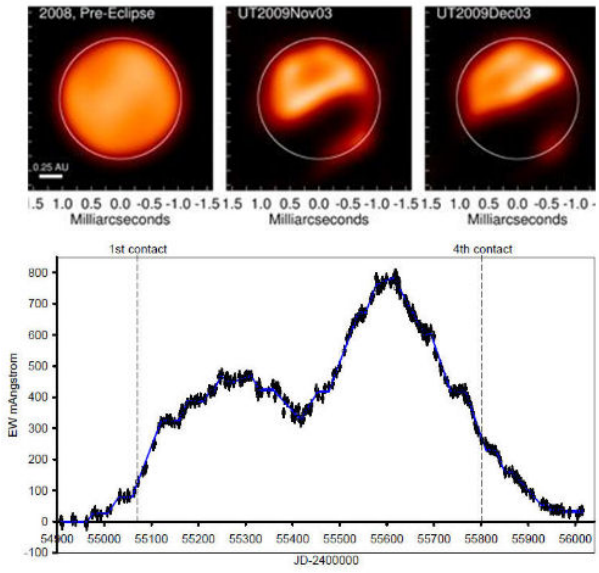

Fig. 2: Observations of the eclipse of ϵ Aur. Top: Observation with the CHARA interferometer. A dust disk obscures the F0 primary (Kloppenborg et al. 2010). Bottom: Excess K I 7699 absorption observed with a 20cm telescope and an off-the-shelf spectrograph (Leadbeater et al. 2012).

2.2.2 Teide WR campaigns

Because IAC-Tenerife generously offers specific amateur access, the professional Teide Observatory is a logical choice for ProAm campaigns together with European amateurs. Besides a ProAm campaign on the Be star δ Sco in 2011 (Miroshnichenko et al. 2013) two campaigns have been performed on WR stars, both in a joint international campaign at world-wide telescopes. These two campaigns also included ground- and space-based X-ray, optical and IR facilities. They monitored the periastron passage of WR 140 and tried to detect periodicities in the winds of WR 134, WR 135 and WR 137. The former delivered accurate ephemerides for the orbit as well as the stellar parameters for the WR star, its O companion and the wind shock-cone (Fahed et al. 2011). The latter confirmed Corotating Interaction Regions (CIR) in the wind of WR 134 including estimation of a typical half-life for the CIR pattern of about 18 stellar rotation periods (Aldoretta et al. 2015). Such long campaigns deliver additional target opportunities. In our case we filled respective time-windows with observations of some B (Morel et al. 2011) and Oe type stars (Rauw et al. 2015).

3 Amateur data quality

It is often believed that amateur spectroscopists deliver data of inferior quality. However, the corresponding instrumentation is only a scaled-down version of that used at larger telescopes. Professional and amateur data (exposure times, signal-to-noise-ratio, spectral resolving power) differ only because of smaller telescopes. Considering 30 cm amateur telescopes, the typical performance for a 7mag star observed at R ∼10.000 is S/N ∼100 for an integration time of ∼30 min.

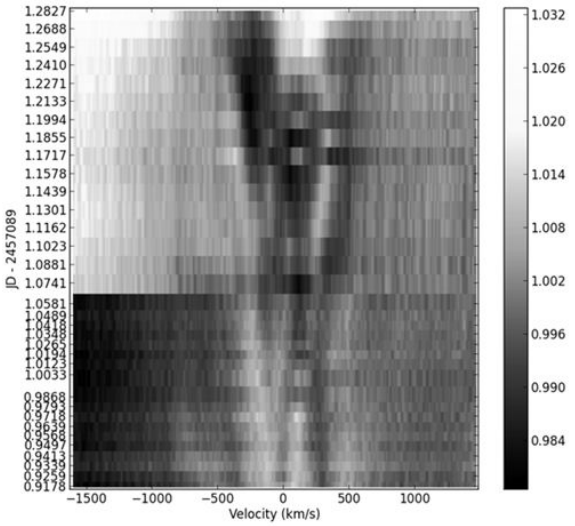

Fig. 3: Amateur He II 4686 observations of ζ Pup from central Melbourne (lower part) and central Perth (upper part). Greyscales of nightly residuals from the mean rectified spectrum are plotted in time vs. radial velocity. Both observations have been performed with 28cm telescopes and off-the-shelf spectrographs.

As an example, during a campaign investigating the long-term behavior of the He II 4686 central reversal of ζ Pup in late 2014 through 2015 May about

700 high-resolution spectra have been obtained by SASER amateurs alone (beside hundreds of other spectra of γ Vel and η Car). For comparison with professional work grey-scale plots of the low-contrast wind clumping residuals in the He II line have been computed. Figure 3 shows two consecutive plots from data obtained in central Melbourne and central Perth. For comparison with professional results we refer to figs. 2 and 3 in (Eversberg et al. 1998) obtained with a 3.6m telescope at Mauna Kea.

4 A Pro-Am campaign recipe

Compared to professional observation campaigns ProAm collaborations require additional care. Amateur spectroscopists often have a relatively high level of expertise, sometimes even holding a scientific degree. They are normally familiar with the basic data reduction procedures (e.g., bias subtraction, flat-fielding, continuum rectification). However, the majority are not familiar with target physics and the details of spectroscopic analysis. Hence, according to our experience a basic guideline for building up a ProAm campaign is required.

→ Besides an announcement among the respective communities a dedicated campaign webpage with background information ensures continuously updated information about the goals, physics and campaign management.
→ It is mandatory to talk to the amateurs, since they may not have the necessary knowledge. Amateurs in both hemispheres have already established discussion forums. Scientists in charge should also use them.

For amateur observations at professional sites additional action is required:

→ The professional prime investigator (PI) should be responsible for the science case including professional support observations. The amateur campaign management should be responsible for organizing all issues with respect to the core observation site.
→ The PI should write the telescope proposal.
→ It is mandatory that all involved professionals offer permanent support.

A specific issue concerns financial resources. Amateurs are willing to contribute their time and money to such a campaign (transportation, accommodation and other resources). But from experience, additional financial resources are often necessary. For the two 4-month WR campaigns on Tenerife we needed about 4000 Euro to cover unexpected costs (e.g., Echelle guiding unit, unexpectedly higher equipment transportation costs, other unforeseen events). One should also take care of the corresponding spectrograph equipment. Normally such instruments can be contributed from the amateur side. But it is highly recommended to organize this central part maybe even before setting the campaign kick-off. Specific care should be invested in explaining the different campaign roles so that every team member remains informed. Especially for volunteer observers the responsibilities during the campaign and the general framework at the observatory (e.g., what is possible and what is not) should be well discussed.

5 Summary and prospects

Amateur spectroscopic observations of massive stars have reached the professional domain. This is clearly the result of modern engineering and corresponding low prices in the "Golden Age of Astronomy". Considering the present situation in astronomy it seems obvious that skilled amateurs equipped with modern instrumentation, can successfully contribute with their knowledge and enthusiasm to professional spectroscopic campaigns, either at their home observatories or at professional sites. Apart from the size, self-designed and off-the-shelf amateur instrumentation fullfils all professional requirements (today, off-the-shelf spectrographs are often in operation at small professional telescopes). For specific goals where long-term observations or quick reaction are required (e.g., binary interactions, long period phenomena, novae) amateurs can often deliver better conditions than professional facilities. The only obstacle for performing continuous observations like those at professional sites is the local weather and the fact that amateur astronomer usually have to work in their daily job. This however can be circumnavigated by joint campaigns, as shown above. It is up to the professional community to uncover this valuable treasure.

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Michael Corcoran: Can you address the issue of quality control?

Thomas Eversberg: A very important point! I normally recommend to reduce the data by one single person for consistent reduction. BUT: Some amateurs are very skilled in reduction. When working with a new group you will quickly realize their capabilities and skills. Maybe you then can leave this work in their hand just taking the reduced material. In any case, if the data are taken for a thesis, reduction should be performed by the student, anyway. In general: Data quality can certainly be imprived by respective advise and discussions. You need to talk!