Stellar parameters of Be stars observed with X-shooter*

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ABSTRACT

Aims. The X-shooter archive of several thousand telluric star spectra was skimmed for Be and Be-shell stars to derive the stellar fundamental parameters and statistical properties, in particular for the less investigated late type Be stars, and the extension of the Be phenomenon into early A stars.

Methods. An adapted version of the BCD method is used, utilizing the Balmer discontinuity parameters to determine effective temperature and surface gravity. This method is optimally suited for late B stars. The projected rotational velocity was obtained by profile fitting to the Mg i lines of the targets, and the spectra were inspected visually for the presence of peculiar features such as the infrared Ca ii triplet or the presence of a double Balmer discontinuity. The Balmer line equivalent widths were measured, but due to uncertainties in determining the photospheric contribution are useful only in a subsample of Be stars for determining the pure emission contribution.

Results. A total of 78 Be stars, mostly late type ones, were identified in the X-shooter telluric standard star archive, out of which 48 had not been reported before. The general trend of late type Be stars having more tenuous disks and being less variable than early type ones is confirmed. The relatively large number (48) of relatively bright (V > 8.5) additional Be stars casts some doubt on the statistics of late type Be stars; they are more common than currently thought: The Be/B star fraction may not strongly depend on spectral subtype.

Key words. Circumstellar Matter – Stars: emission-line, Be – Stars: activity

1. Introduction

Be stars are non-supergiant B stars that show or have shown Hα emission, as defined by Jaschek et al. (1981). Emission does not only occur in the first members of the Balmer line series, but can affect the continuum and line profiles of other species as well, most often singly ionized metals, such as Fe ii. It is generally agreed that, in classical Be stars, this emission is due to the presence of a gaseous Keplerian disk, concentrated in the equatorial plane. This disk is a decretion disk, i.e., the source of the disk material is the central star, generated by the equatorial flow of stellar material. One of the key factors in creating the disk is supposed to be the very high rotational velocity. In fact, Be stars are known to have higher rotational velocities than normal B-type stars (Catanzaro 2013). For a complete review on the topic, see Porter & Rivinius (2003) and Rivinius et al. (2013).

Classical Be stars are known to vary both in brightness and spectral line appearance, with a large range of time scales from years to minutes (Okazaki 1997; Floquet et al. 2002; Kogure & Leung 2007). While long-term variations are associated with formation and dissipation of the disk (Okazaki 1997), the origin of short-term variability is usually attributed to pulsations within the B star photosphere (Baade 2000; Huat et al. 2009). Photometric studies show that earlier type Be stars are more likely to be variable (e.g. Hubert & Floquet 1998). Chojnowski et al. (2015) have demonstrated that Be stars can often be found among stars observed for the purpose of removing telluric absorption in the near-infrared domain, because main sequence B stars are among the preferred objects for this task. Inspired by this example, we decided to search for Be stars in a similarly extensive database of telluric standard star observations, namely the one taken at the VLT with the X-shooter instrument.

2. Observations and Data reduction

All spectra have been acquired with the VLT/X-shooter instruments. Most data were taken as telluric standard stars for other observations, from the commissioning of X-shooter in 2007 un-
X-shooter is a multi-wavelength medium-resolution spectrograph mounted at the Cassegrain focus of UT2 of the Very Large Telescope (VLT) at ESO Paranal that has a mirror diameter of 8.2 m. X-shooter’s three arms are named UVB, covering 300–550 nm, VIS, covering 550–1010 nm, and NIR, covering 1000–2500 nm. The resolution depends on the chosen slit-width and ranges from $R = 1890$ to $9760$ in the UVB, $3180$ to $18110$ in the VIS, and $3900$ to $11490$ in NIR arm, respectively (Vernet et al. 2011).

To select the Be stars and other possibly interesting objects from this huge archival sample, first the raw frames in the VIS arm were obtained. A window, containing only the spectral order with the $H\beta$ line, was cut from the entire raw frame. From the inter-order space in that window the local background, effectively the sum of bias + dark + scattered light, was estimated and subtracted. The result was integrated into a 1D-spectrum, divided by a generic blaze shape obtained from flat field frames, and then divided by the counts in the continuum. This procedure yields an approximately normalized $H\beta$ line profile in the units of pixel vs. flux (i.e., without any wavelength calibration) that is sufficient to judge upon the line shape for the presence of emission and other features of interest.

The resulting more than 10 000 profiles of 1334 stars were inspected visually for emission or any other curious appearance, such as binarity or strong profile shape distortions. 1093 stars were found to be spectroscopically normal BA main sequence objects, and 16 of later spectral type. Of the remaining objects, 89 were spectroscopic binaries of type SB2 (as seen in $H\alpha$) and 48 were found to be supergiants with winds, or otherwise not quite as expected for a single main-sequence star. The procedure yielded a number of emission line stars for further inspection, of which two are known as Herbig Be stars (Hip 56379 and Hip 85755), and four are mass-transferring binaries of various types (Hip 33237, Hip 45311, Hip 88615, and Hip 93502). This leaves 78 Be stars identified from the X-shooter data. In addition, among the un-suspicious stars four could be identified using the SIMBAD database as currently inactive Be stars and hence were added to the sample (Hip 15188, Hip 25950, Hip 108022, and Hip 108975), bringing the number to a total of 82 Be stars. We note that not all stars could be used for every analysis below, so the number of Be stars used for some results might be lower.

The spectra of the Be star sample, identified in the above way, were reduced with the REFLEX workflow for X-shooter (Freudling et al. 2013). The ESO Recipe Flexible Execution Workbench is a workflow environment to run ESO VLT pipelines. It provides an easy and interactive way to reduce VLT science data. The steps executed by the ESO X-shooter pipeline (v.2.6.0) include bias subtraction, flat-fielding, wavelength and flux calibration, and order merging.

For the flux calibration the master response calibration provided by the ESO archive was used, except for UVB data obtained between 2009 and beginning of 2012. Using the master calibration on these spectra produces an obviously spurious dip in the region immediately bluewards of the Balmer discontinuity. This is most likely due to the use of two flatfield lamps in the very blue, where their flux ratio was not entirely stable. To avoid the problem, spectra taken in these years were flux calibrated with a flux standard taken in the same night or not more than a few nights before or after, that was reduced with the same pipeline. It provides an easy and interactive way to reduce VLT science data. The steps executed by the ESO X-shooter pipeline (v.2.6.0) include bias subtraction, flat-fielding, wavelength and flux calibration, and order merging.

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Spectra that had obvious faults, like bad flux calibration, too little flux, or were overexposed in the relevant parts of the continuum, were discarded from the following analysis. This left ten Be stars without suitable data to determine stellar parameters.

For each spectrum, a flux calibrated version and a normalized version, using a global spline fit to continuum regions, were produced for analysis.

In Fig. 1 an overview of the data of the Be star Hip 11116 is shown. Similar plots for the remaining 77 identified Be stars are presented in Appendix C.
3. Analysis methods

3.1. Fundamental parameters via the BCD method

The primary goal of this work was to obtain fundamental parameters of Be stars. In addition the line broadening \(v\sin i\) and Balmer emission equivalent widths were obtained.

3.1.1. Measuring the Balmer discontinuity

Stellar parameters were determined with a procedure akin to the BCD method (Named after the main contributors to the method, Barbier, Chalonge, and Divan. See App. A of Zorec et al. 2009 for a description, as well as the references in that work for the history of the method). The BCD method uses the height \((D_\odot)\) for a description, as well as the references in that work for the BCD method (Named after the main contributors to the method, Barbier, Chalonge, and Divan). See App. A of Zorec et al. 2009, for five X-shooter instrumental resolutions in the UVB, which was defined by hand by selection the points with the highest flux between the two. Next, the midpoints between the Balmer lines, which are local flux maxima, are used for a 4th order polynomial fit to estimate an upper envelope of the flux curve. The wavelength at which this upper envelope intersects the midpoint between the Balmer and Paschen continuum is taken to measure \(\lambda_1\). We note that this position is not independent of the spectral resolution, in particular for lower resolutions as used in the original BCD system.

The principle of measurement is illustrated in Fig. 2. For the non-Be star HD 130163, the results and fit for the two most discrepant observations, in terms of slopes of the Balmer and Paschen continua, are compared. For the strong Be-shell star Hip 25007 the procedure in case of a clear double Balmer discontinuity is illustrated.

3.1.2. Model grid

To determine stellar parameters the measurements will be compared against a model grid, rather than an existing calibration of the BCD method, also since calibrations exist only for low resolution (much lower than the lowest available for X-shooter data). We use the B4 model, which in terms of physics is identical to the B4 model described in Sect. 3 of Rivinius et al. (2013b), but has been updated computationally to make use of GPU parallel computing. The model creates a surface grid of a rotating star based on the Roche model, then assigns each point a local value of \(T\) and \(g\) using the Roche model and von Zeipel relations, here using a traditional value of \(\beta = 0.25\). The computationally new code then interpolates these pre-computed intensity spectra, which take into account the aspect of the line of sight. Finally, the numerically updated part integrates the surface grid over the visible surface, a task GPUs were explicitly designed for, into the observed spectrum. This is done first for input spectra including all spectral lines, and then for an input grid of spectra with continuum emission only. The resulting spectra can then either be normalized traditionally, i.e., in the same way as the observations, or “perfectly”, with the computed continuum spectrum.

The set of stellar parameters for the input grid is based on Table 6 of Zorec et al. (2009), i.e., computing models based on their parameters for B0 to A1, and for LC’s V to III. Note that any sufficiently dense and even sampling of the \(D_\odot\)–\(\lambda_1\)-plane would have produced the same numerical results for the determined parameters, except it would not have been possible to give an estimate of spectral types. This grid of models was produced for five X-shooter instrumental resolutions in the UVB, which depend on slit-width, as mentioned in section 2.

For the spectrophotometric slit of 5\(^{\prime}\) the resolution is effectively governed by the seeing, for which a somewhat worse than typical value for Paranal observatory of 1.0\(^{\prime}\) is assumed. The BCD parameters were measured in the model spectra in the same way as in the observed data.
Fig. 2: For HD 130163 in the two upper panels the spectra with the most discrepant calibration of the UV flux slope. The steps to determine \( D_\star \) are indicated in red: selection of continuum points to fit the slopes and the difference between the two fits at 3700 Å as the value of \( D_\star \). In blue for \( \lambda_1 \): the midpoints between the continuum fits in red, the upper envelope of the BD. The intersection of this envelope with the midpoints to determine \( \lambda_1 \). For Hip25007, the lower panel, a clear double BD is present, and the Balmer continuum must be determined by choosing *bona fide* continuum points manually.

To obtain the stellar parameters, the three models forming a triangle that encloses the observed value in the \( D_\star-\lambda_1 \)-plane were chosen, and the barycentric coordinates of the observational \((D_\star, \lambda_1)\) pair in this triangle were computed (see Fig. [3]). With these coordinates, the physical parameters were interpolated. The spectral type is assigned as the one of the most nearby grid point. We note that this is not a spectral classification scheme, which would have to rely on actual standard stars, but is rather meant as an indication only. In a few cases where stars are outside the grid limits, but still close (see Fig. [4]), extrapolation was used instead of the barycentric interpolation.

As Be stars are typically fast rotators, the grid was computed for two values of \( \omega = \Omega/\Omega_\text{crit} \), a slow rotation grid with \( \omega = 0.25 \) and a fast one with \( \omega = 0.85 \). The former was computed for only one value of \( v \sin i = 20 \, \text{kms}^{-1} \), a total of 5 \( \times \) 51 models, the latter for inclinations from a pole-on value of \( v \sin i = 10 \, \text{kms}^{-1} \) to the equator on case in steps of 10 \( \, \text{kms}^{-1} \), a total of 5 \( \times \) 651 models. For the fast rotation grid, at low temperatures and low surface gravities, the equatorial parameters were outside the grid of input spectra, and no model spectra were produced for these parameters. The full grids will be published in CDS as Tables 6 to 15.

Most program stars are of late type and some are at the very edge of the \( D_\star-\lambda_1 \)-range covered by the models at \( \omega = 0.85 \). We investigate the influence of rapid rotation on the parameter determination first for a number of test stars only.

### 3.1.3. Test cases

Three non-Be stars with a large number of observations with the different slit widths were selected from the archive for the purpose of assessing stability and reliability of the method. These are Hip72362 (HD 130163, A0V, \( V = 6.9 \, \text{mag} \)), Hip98926 (HD 190285, A0V, \( V = 7.2 \, \text{mag} \)), and Hip01115 (HD 955, B3/5V, \( V = 7.4 \, \text{mag} \)).

In addition, program stars with ten or more observations were analyzed in a thorough way similar to the three test stars, before applying the method to the bulk of objects with fewer observations. All stars used for tests are given in Table 1.

An absolute flux calibration is not very reliable across the different slit widths, so only the relative flux calibration is assessed. For this, all spectra were normalized to the mean flux in the interval from 404 to 406 nm. The spectra have a large individual scatter, but the averages for the different slit widths are indistinguishable. This indicates that, at the resolutions offered by X-shooter, the differences in resolution does not have much influence for the method employed.

In particular, there is no systematic difference between the observation with the \( 5\prime\prime \) slit, which does not suffer from any slit-loss, vs. the ones with smaller slit-widths. This is confirmed by measurements in the model grid, in which the differences between the resolutions turned out well to be below the scatter of the measurements and other systematic errors discussed here (see also Fig. [3]). The last two columns of Table 1 give the mean and standard deviation of the measured BCD parameters. Both height and position of the Balmer discontinuity \( D_\star \) and \( \lambda_1 \) can be very well measured in X-shooter data. An imperfect flux calibration turns out not to be a problem, since, even if not perfect, it is reasonably stable across the region of interest. In a sense the fitting procedure can be regarded as self-calibrating, and only strong slopes, curvatures, or discontinuities in the flux calibration around 370 nm would have a strongly detrimental effect on the derived parameters.

In the next step, and for the non-Be stars only, we investigate how well the \( D_\star \) and \( \lambda_1 \) values translate into physical parameters. As Table 2 shows, there are systematic effects between the slow rotation and the high rotation model grids. The same BCD parameters analyzed with the slow rotation grid will give systematically higher effective temperatures, well outside the statistical scatter. For the effective gravity, the effect is less severe, giving lower lower log \( g \) for slow rotation, but still within the limit of the statistical error, by which the 3σ limit is meant, traditionally
employed in astronomy vs. the more conservative $5 \sigma$ limit often found in other fields of physics.

In turn, the differences of the BCD measurements with high rotation, but different inclinations, is negligible. In this context, it does not matter that we do not know the actual rotation of the non-Be test stars. It only matters that we do know it for the Be stars, namely that they are rapid rotators, much closer to 85\% than to 25\%. It follows that the Be stars must be analyzed with the 85\% grid to avoid the identified systematic errors. However, we do not need to know the inclination, or even $v \sin i$ of the Be star with high precision, since this choice does not have a strong effect on the determined BCD parameters.

Combining the errors listed in Tables 1 and 2, one can estimate a typical error of about 50 K and 0.03 in log g for a late type B stars, for which the BCD method has the highest power of distinction (since the BD parameters change steeply at this spectral type), and about 400 K and 0.05 in log g for a mid type B star. Since for most targets only one or two spectra are available, we use these numbers as the typical accuracy.

### 3.2. Projected rotational velocity

When available, $v \sin i$ was taken from the literature; otherwise for each observed spectrum the rotational parameter $v \sin i$ was fitted using synthetic spectra to the Mg i 4481 Å line, which is reasonably strong across the entire range of spectral types investigated in this work, mostly B5 to B9 with a few earlier ones only.

For the fit the line profiles were computed with two different sets of underlying model atmospheres. For effective temperatures below 15 000 K ATLAS9 LTE model atmospheres (Kurucz 1993) were used. Above that temperature TLUSTY NLTE atmospheres (Lanz & Hubeny 2007) were used. As values for $T_{\text{eff}}$ and log g the ones obtained by the BCD method were used.

The results of $v \sin i$ for each star are given in Table 3 and Appendix B. Shows the observed and fitted line profiles for each star.

### 3.3. Disk variability and other observations of interest

Often Be stars show variability in their emission equivalent width (EW) and in the line profiles (Catanzaro 2013). This was checked visually in the spectra, as shown in Appendix C, and flagged in Table 3. The goal to measure the Balmer decrement, i.e., the ratio of emission strength, however, was not achieved with acceptable accuracy. This is because the emission in general is often weak, and the Balmer decrement is steep for late-type Be stars. This is seen in the total H$\beta$ EWs in Table 3 none of which is negative, i.e. all are still dominated by the photospheric absorption. The values for H$\beta$ after subtracting the model photospheric EW are dominated by the systematic errors arising from the stellar parameters and the resulting D34 Balmer decrement does not allow to draw any reliable conclusion.

Some stars show the infrared Ca\textsc{i} triplet in emission. It has been speculated that this is connected to binarity, in particular accretion onto a secondary (Polidan 1976), Koubsk\`{y} et al. (2012) reject this, but accede that the presence of this line must be due to some not further specified peculiarity in the circumstellar environment. The stars for which a clear or possible Ca\textsc{i} triplet emission is observed are also flagged in Table 3.

![Fig. 3: The BCD plane and interpolation for one star. Shown are all $(D_*, A_1)$ points for all computed $v \sin i$ in the models for $R = 3300$ (red) and $R = 9100$ (blue). The chosen sub-grid to analyze this observation ($R = 5100$ for 1” slit width, $v \sin i = 150 \text{ km s}^{-1}$), is shown in black, and the surrounding triangle is indicated by dashed lines, together with the barycentric coordinates to obtain the weighted parameter values by solid lines. The nearest grid point, used to associate a spectral type, is for a B7 III star.](image-url)

### 4. Results

In this section the overall results concerning the sample are reported, for notes and observations on individual stars see Appendix A.

#### 4.1. Incidence of Be stars

To assess the impact of this work on the statistics of Be stars, the selection biases of the sample need to be known and discussed. In fact, the target list is indeed heavily biased towards later type B stars, which is due to the selection policy for telluric standard stars at the VLT. Unless explicitly specified otherwise by the PI of the observations, late type B and early type A main sequence stars are preferred. Consequently, the distribution among the luminosity classes V to III is less biased, even though a bias favouring non-giant stars still exists, as not all observers are familiar with the broader definition of main sequence among B stars vs. solar type telluric stars. Another bias is that Be stars are known to be unsuited as telluric standards, hence there is a bias against known Be stars. Two of those biases can be well seen from Table 5 in that there generally fewer early type stars, and almost no Be stars among them, even if the observed Be star incidence is highest among the early type B stars (Zorec & Briot 1997).

Some care is needed to interpret Table 5, however. The spectral types for the non-Be stars were taken from SIMBAD, i.e., they are collected from a large number of quite inhomogeneous sources. For instance, the original definition of the MK spectral classification scheme did not include standard stars for all subtypes, in particular B4, B6, and B7 were missing and not classified in that scheme at all, while already quite early the intermediate type of B0.5 was included (see, e.g., Table 1 in Ardeberg 1979). The system has evolved since, and more intermediate subtype as well as standard stars for the missing integer subtypes have been proposed. Nevertheless, the first line of our Table 5 shows a lack of B4, B6, and B7 for exactly this reason. Also,
Table 1: Objects, their derived spectral types, and the number of observations at each slit width to test the method and obtain the statistical scatter and the mean measured \( D_s \) and \( \lambda_1 \) values.

| Star       | Sp Type | N of observations/slit | \( D_s \) | \( \lambda_{1-3700} \) |
|------------|---------|------------------------|----------|------------------|
|            |         | 0.5''                  | 0.8''    | 1.0''            | 1.3''            | 1.6''            | 5.0''            |
| HD 130163  | A1V     | —                      | —        | 38               | 5                | 6                | 1                | 0.545 ± 0.006   | 63.65 ± 0.97   |
| HD 190285  | A1V     | 14                     | 8        | 15               | 1                | 5                | —                | 0.565 ± 0.013   | 68.16 ± 1.1    |
| Hip 1115   | B3IV    | 2                      | 2        | 2                | 5                | 2                | 0.253 ± 0.006   | 45.65 ± 2.0     |
| Hip 32474  | A0IIIe  | 1                      | 7        | 7                | 2                | —                | —                | 0.522 ± 0.01    | 44.525 ± 3.5   |
| Hip 39483  | B4IIIe  | —                      | 3        | 5                | 1                | 1                | —                | 0.281 ± 0.008   | 34.44 ± 1.0    |
| Hip 52977  | B4IIIe  | 7                      | 5        | 8                | 1                | —                | 0.263 ± 0.017   | 34.44 ± 3.04    |
| Hip 71974  | A0IIIe  | 5                      | 5        | 1                | 2                | —                | —                | 0.522 ± 0.007   | 47.89 ± 1.1    |
| Hip 85138  | B7IIIe  | 6                      | 4        | —                | 3                | —                | —                | 0.393 ± 0.011   | 34.44 ± 2.4    |
| Hip 85195  | B9IIIe  | 5                      | 16       | 3                | 6                | —                | 0.479 ± 0.007   | 38.92 ± 1.1     |
| Hip 88374  | B9IVe   | 1                      | 2        | 10               | 2                | 2                | 2                | 0.443 ± 0.006   | 44.52 ± 2.07   |
| Hip 89486  | A0IIIe  | 4                      | 6        | —                | 4                | —                | —                | 0.512 ± 0.01    | 41.16 ± 0.88   |
| Hip 94986  | B4IIIe  | 8                      | 5        | 7                | 1                | 5                | —                | 0.278 ± 0.02    | 36.68 ± 3.52   |
| Hip 104508 | B7IIIe  | 6                      | 14       | 1                | —                | 1                | —                | 0.431 ± 0.014   | 36.68 ± 2.95   |

Table 2: Stellar parameter for the non-Be stars from Table 1, derived under different assumptions for the stellar rotation.

| Star       | \( \omega = 0.25, \sin i = 20 \text{km s}^{-1} \) | \( \omega = 0.85, \sin i = 20 \text{km s}^{-1} \) | \( \omega = 0.85, \max\text{converging or measured } v \sin i \) |
|------------|---------------------------------------------|---------------------------------------------|---------------------------------------------|
|            | \( T_{\text{eff}} \) \( \log g_{\text{pole}} \) | \( T_{\text{eff}} \) \( \log g_{\text{pole}} \) | \( v \sin i \) \( T_{\text{eff}} \) \( \log g_{\text{pole}} \) |
|            | [K]                                         | [K]                                         | [km s\(^{-1}\)] [K]                         |
| HD 130163  | 9763 ± 64                                   | 3.76 ± 0.03                                | 9481 ± 63                                   | 3.89 ± 0.03      | 120                        | 9592 ± 54       | 3.86 ± 0.03     |
| HD 190285  | outside of grid                             | outside of grid                             | outside of grid                             |                         | 130                        | 9358 ± 32       | 3.94 ± 0.02     |
| Hip 1115   | 15296 ± 324                                 | 3.78 ± 0.05                                | 14970 ± 349                                 | 3.91 ± 0.05      | 150                        | 15119 ± 358    | 3.92 ± 0.05     |

for the purpose of the Table, all intermediate classifications have been rounded to the next earlier integer sub-type.

Photometric or spectrophotometric classification systems, like BCD, on the other hand, define B0 to B9 much more linearly, and also without intermediate types. Therefore, in order to avoid systematic effects arising due to these inconsistencies as much as possible, the sample is grouped into early, mid, and late type stars, which we define as B0–B2, B3–B6, and B7–A1. Then there are 3 Be stars out of 99 early B stars, 21 out of 313 mid B stars, and 56 out of 681 late ones.

This lack of early type Be stars in the sample is due to known Be stars being avoided. The detection probability for an earlier type Be star is much higher, as discussed by, e.g., Zorec et al. (2007). The reason for this bias can be seen from Appendix C. Almost all newly discovered Be stars have quite weak H\( \alpha \) emission, and often no H\( \beta \) at all. Since the traditional spectral classification wavelength range does not include either, but only H\( \gamma \) and bluer Balmer lines, the Be nature is easily missed for stars with steep Balmer decrement.

Fig. 3 of Zorec et al. (2007) suggests that the statistics of Be stars is sufficiently complete for spectral types as late as about B6, but becomes increasingly incomplete for B8 and later sub-types. Updating the numbers of Zorec et al. (2007) with our findings does not entirely restore the suggested trend in their Fig. 3, but given that our search was not designed to achieve completeness, it certainly strengthens the suggestion of Zorec et al. (2007), that the probability of a B star to become a Be during its life star does not (strongly) depend on spectral subtype.

4.2. Stellar parameters

The values of \( D_s \) and \( \lambda_1 \) measured by the method described above, as well as the stellar parameters \( T_{\text{eff}} \) and \( \log g \) obtained from them, are given in Table 3 and plotted in the upper panel of Fig. 4. Comparing this to Fig. 1 of Zorec et al. (2005) the values of \( \lambda_1 \) show a systematic offset. This is because of the much higher resolution of X-shooter data vs. nominal BCD method data. At the nominal resolution for the BCD method, the value of \( \lambda_1 \) is strongly affected by the convolution of the stellar spectrum with the instrumental resolution. This is why the original BCD method puts strong emphasis on using spectra at a given resolution of \( \Delta \lambda = 8 \AA \) at the BD, and the published BCD calibrations cannot be used for X-shooter data. On the other hand, the X-shooter instrumental resolution is so high that its contribution to the BCD parameters is negligible, and our mapping of \( T_{\text{eff}} \) and \( \log g \) onto \( D_s \) and \( \lambda_1 \) is valid for all medium to high resolution data.

Table 5 also confirms the finding of Zorec et al. (2005) that among the later type Be stars the higher luminosity classes are more common, i.e., later-type Be stars are more likely found in the second half of their main sequence life. This is in agreement with the idea of the Be phase being a consequence of rotational evolution during the main sequence (e.g., Granada et al. 2013). In that hypothesis a Be star with moderate rotation at the ZAMS will, due to the internal evolution and angular momentum transport from core to surface, at some point approach critical rotation at the surface as the star ages. To prevent the surface rotation to go above the critical threshold, angular momentum must be
Table 3: Program stars with the number of valid observations, whether Hα variability, a single or double BD, and the Ca II IR triplet is observed, the measured $D_\alpha$ and $\lambda_1$ (mean values in case of more than one observation) and stellar parameters. For the double BD and Ca II flags “Y” and “N” are clear statements, “-” means uncertain, and “—” mean no suitable spectra were available. Newly identified Be stars are marked in bold face. In case of Hα variability, “—” means that all spectra, even if more than one, were taken in the same night.

| Star  | # of obs. U/V/N | Sp Type | Hα var? | Double BD? | IR Ca II emiss.? | $D_\alpha$ [dex] | $\lambda_1$ -3700 Å | $T_{eff}$ [K] | log $g_{pol}$ [dex] | $v \sin i$ [km s$^{-1}$] |
|-------|-----------------|---------|---------|-----------|-----------------|-----------------|---------------------|-------------|-----------------|------------------|
| Hip 11116 | 4/4/4 | B3III | N | N | N | 0.35 | 29.97 | 11994 | 3.47 | 190 |
| Hip 15188 | 1/1/1 | B3: | — | — | — | — | — | — | — | — |
| Hip 23161 | 2/2/2 | B7III | — | N | N | 0.335 | 29.97 | 12272 | 3.45 | 150 |
| Hip 24475 | 3/4/3 | B9II | Y | N | N | 0.44 | 25.50 | 10643 | 3.29 | 220 |
| Hip 25007 | 6/6/6 | B3IV | Y | Y | N | 0.183 | 38.30 | 18089 | 3.63 | — |
| Hip 25690 | 4/4/4 | A0IV | — | N | N | 0.525 | 50.14 | 9691 | 3.70 | 90 |
| Hip 25950 | 1/2/0 | B7: | N | — | N | — | — | — | — | — |
| Hip 26368 | 2/2/2 | A1III | N | N | Y | 0.535 | 45.65 | 9550 | 3.57 | 190 |
| Hip 26964 | 2/2/1 | B4V | — | Y | N | 0.262 | 50.2 | 15220 | 4.00 | 200 |
| Hip 28561 | 3/3/3 | B8IV | Y | Y | Y | 0.399 | 40.4 | 11554 | 3.73 | 70 |
| Hip 29635 | 8/8/9 | B8IV | N | N | Y | 0.395 | 41.16 | 11409 | 3.75 | 160 |
| Hip 31362 | 1/1/1 | B8IV | — | N | N | 0.443 | 38.92 | 10769 | 3.64 | 270 |
| Hip 32474 | 10/14/16 | A0III | Y | N | N | 0.524 | 44.52 | 9733 | 3.60 | 120 |
| Hip 33509 | 1/1/1 | B4V | — | Y | N | 0.226 | 45.65 | 15747 | 3.92 | 160 |
| Hip 34144 | 1/1/1 | B8II | — | Y | N | 0.4 | 27.73 | 11204 | 3.38 | 200 |
| Hip 36009 | 1/1/1 | B4V | — | N | N | 0.23 | 50.14 | 16435 | 4.00 | 40 |
| Hip 37007 | 6/6/6 | B7IV | N | N | Y | 0.34 | 36.68 | 12245 | 3.70 | 230 |
| Hip 39183 | 2/2/2 | A0III | Y | N | N | 0.481 | 25.50 | 10167 | 3.22 | 190 |
| Hip 39483 | 10/11/11 | B6IV | Y | N | N | 0.28 | 34.44 | 13583 | 3.60 | 130 |
| Hip 39595 | 1/1/1 | B9IV | — | N | Y | 0.455 | 38.92 | 10592 | 3.63 | 240 |
| Hip 41085 | 1/1/1 | B3IV | — | Y | N | 0.245 | 41.16 | 14860 | 3.84 | 250 |
| Hip 41268 | 2/2/2 | B8III | Y | Y | N | 0.384 | 29.97 | 11460 | 3.45 | 240 |
| Hip 42060 | 1/1/1 | B7V | — | N | N | 0.35 | 45.65 | 12235 | 3.95 | 250 |
| Hip 43073 | 1/1/1 | B9IV | — | N | N | 0.466 | 38.92 | 10413 | 3.62 | 250 |
| Hip 43114 | 1/1/0 | B5IV: | — | N | N | — | — | — | — | — |
| Hip 44423 | 2/3/3 | B7IV | N | N | N | 0.362 | 38.92 | 11909 | 3.74 | 160 |
| Hip 46329 | 2/2/2 | B5IV | Y | N | N | 0.25 | 45.65 | 14763 | 3.95 | 160 |
| Hip 47868 | 1/1/1 | B0III: | — | N | N | 0.067 | 23.70 | — | — | — |
| Hip 47962 | 1/3/3 | A0IV | N | N | N | 0.517 | 45.65 | 9786 | 3.65 | 220 |
| Hip 48882 | 4/6/6 | B5IV | Y | Y | Y | 0.26 | 51.26 | 15396 | 4.01 | — |
| Hip 48943 | 2/5/2 | B5IV | Y | Y | Y | 0.284 | 43.95 | 14077 | 3.81 | 190 |
| Hip 51444 | 1/2/2 | B5III | Y | N | N | 0.23 | 25.50 | 14795 | 3.30 | 250 |
| Hip 51491 | 3/3/4 | B9III | Y | N | Y | 0.475 | 38.92 | 10341 | 3.60 | 230 |
| Hip 51546 | 2/2/2 | A0V: | — | N | N | — | — | — | — | 210 |
| Hip 52977 | 21/21/21 | B6III | Y | N | N | 0.26 | 34.44 | 14076 | 3.57 | 200 |
| Hip 56393 | 1/1/1 | A1IV | — | N | N | 0.56 | 52.39 | 9200 | 3.62 | 270 |
| Hip 57861 | 4/6/6 | B6IV | Y | N | N | 0.29 | 38.92 | 13390 | 3.76 | 270 |
| Hip 59970 | 2/2/2 | A1IV-III | — | N | N | 0.574 | 48.45 | — | — | — |
| Hip 64501 | 2/2/2 | B8IV | — | N | N | 0.39 | 38.92 | 11512 | 3.77 | — |
| Hip 64867 | 5/6/6 | A0III | N | N | N | 0.524 | 36.68 | 9708 | 3.43 | 170 |
| Hip 66339 | 1/1/1 | B3V | — | Y | N | 0.222 | 52.7 | 17493 | 4.00 | 210 |
| Hip 66351 | 2/2/2 | B9III | — | N | N | 0.469 | 37.80 | 10404 | 3.57 | 140 |

transported away. The means of this transport then is the circumstellar decration disk (Krüicka et al., 2011).

4.3. Disk properties as a function of spectral type

Although it was not possible to determine the Balmer decrement for our sample stars (see Table 4 for measurements of the equivalent widths), already this provides information: Because the emission is weak and the Balmer decrement too steep, the disks found by X-shooter are too tenuous to allow a reliable measurement of the Balmer decrement. This is in agreement with Vieira et al. (2017), who found that late type Be stars have less dense disks than early type ones. As mentioned above, there is also a general agreement that late type Be stars show less variability than early-type ones. This is again confirmed by the numbers shown in Table 5 where in the early and mid-type Be stars 2/3 are found to be variable, but only about 1/3 among the late subtypes.
We clearly detect the IR Ca\,\textsc{ii} triplet in emission in 13 stars. This is in agreement with the reported about 20\% of Be stars showing this feature (e.g., Koubský et al. 2012). In absorption and possibly emission the IR Ca\,\textsc{ii} triplet is seen in another 8 stars.

There is no obvious correlation of the presence of the IR Ca\,\textsc{ii} triplet, in either emission or absorption, with spectral type of the Be star. Although our sample (heavily biased towards later type Be stars) does not include stars with Ca\,\textsc{ii} triplet emission earlier than B5, a literature search does reveal such stars (Polidan & Peters 1976; Polidan 1976; Briot 1981, but is reported to be present by Koubský et al. 2012) to be anti-correlated with the Balmer emission for the same star.

This suggests that, while the formation region is the same as for the other lines, i.e., the disk around the Be star, the excitation process is not originating in the same source as for the other spectral lines formed in the disk. Koubský et al. (2012) investigate the correlation of the Ca\,\textsc{ii} triplet with binarity and conclude that binarity is not the responsible mechanism, but suggest some other, not further specified peculiarity of the circumstellar disk.

4.4. The IR Ca\,\textsc{ii} triplet

The emission strength of the Ca\,\textsc{ii} triplet can vary without similar changes taking place in O18446 or the Balmer lines. It can even be transient without a major change in the Balmer line emission properties, e.g., the Ca\,\textsc{ii} triplet was not detected in γCas by Briot (1981), but is reported to be present by Koubský et al. (2012) to be anti-correlated with the Balmer emission for the same star.

For Young Stellar Objects the common presence of the Ca\,\textsc{ii} triplet in emission is suspected to be linked to either magnetic processes or accretion (e.g., Kwan & Fischer 2011; Moto'oka & Itoh 2013), or a combination of both. In cataclysmic vari-
Table 4: Equivalent widths of Hα and Hβ for the program stars with clearly measurable emission.

| Star      | \( T_{\text{eff}} \) [K] | Hα (tot) | Hα (phot) | Hα (emi) | Hβ (tot) | Hβ (phot) | Hβ (emi) |
|-----------|----------------|----------|---------|---------|---------|---------|---------|
| Hip 11116 | 12240          | -7.94    | 4.20    | -12.15  | 5.23    | 7.24    | -2.00   |
| Hip 26368 | 9874           | 5.39     | 6.83    | -1.435  | 10.8    | 12.1    | -1.28   |
| Hip 29635 | 11822          | -1.69    | 5.39    | -7.085  | 7.68    | 9.55    | -1.78   |
| Hip 33509 | 17064          | -16.4    | 3.57    | -20.06  | 6.06    | 7.57    | -1.50   |
| Hip 37007 | 15093          | -5.95    | 4.35    | -1.435  | 10.8    | 12.1    | -1.28   |
| Hip 39183 | 11231          | 4.44     | 5.94    | -1.493  | 8.39    | 10.5    | -2.12   |
| Hip 39595 | 12234          | -1.65    | 5.68    | -7.337  | 9.12    | 10.1    | -1.03   |
| Hip 46329 | 14599          | -8.91    | 4.27    | -13.18  | 5.28    | 6.85    | -1.56   |
| Hip 51491 | 11697          | 0.43     | 5.94    | -5.503  | 9.07    | 10.1    | -1.09   |
| Hip 80577 | 11697          | -6.90    | 3.93    | -10.83  | 5.13    | 6.75    | -1.61   |
| Hip 87032 | 11936          | -6.37    | 6.70    | -13.07  | 7.89    | 11.1    | -3.22   |
| Hip 90096 | 11453          | 4.44     | 5.94    | -1.493  | 8.39    | 10.5    | -2.12   |
| Hip 90509 | 12234          | -1.65    | 5.68    | -7.337  | 9.12    | 10.1    | -1.03   |
| Hip 91975 | 11231          | 0.65     | 5.39    | -7.085  | 7.76    | 9.55    | -1.78   |
| Hip 92038 | 15139          | -14.4    | 3.80    | -18.23  | 3.80    | 5.98    | -2.18   |
| Hip 94770 | 12721          | -2.43    | 5.12    | -7.561  | 7.70    | 9.55    | -1.78   |
| Hip 94859 | 15311          | -2.25    | 4.26    | -6.523  | 6.80    | 8.12    | -1.31   |
| Hip 95109 | 11847          | 1.64     | 5.48    | -3.830  | 8.56    | 9.55    | -1.74   |
| Hip 96453 | 14338          | 2.81     | 4.52    | -1.706  | 5.51    | 5.77    | -0.25   |
| Hip 99457 | 23061          | -1.37    | 2.51    | -3.889  | 2.73    | 3.71    | -0.97   |

Table 5: Statistics of Be stars observed with X-shooter

| Bin name | early | mid | late |
|----------|-------|-----|------|
| Sp. type | B0    | B1  | B2   |
|          | B3    | B4  | B5   | B6   |
| # of all stars | 4    | 10  | 85   | 99   |
| # of Be stars | 1    | 1   | 1    | 3    |
| # of new Be stars | 0   | 0   | 0    | 0    |
| LC V     | 0    | 0   | 1    | 1    |
| LC IV    | 0    | 0   | 0    | 1    |
| LC III   | 0    | 0   | 0    | 1    |
| Ca ii emi/abs | 0  | 0   | 0    | 0    |
| Variability detectable? | 0   | 1   | 1    | 2    |
| Hα variable | 0  | 1   | 0    | 1    |

ables, the formation of the triplet is more specifically traced to external UV irradiation of an optically thin gas (Ivanova et al. 2004). If we combine that with the current understanding of Be stars, which do not show any trace of large scale magnetic fields, this leaves UV photons formed in accretion shocks as the most promising mechanism to power the Ca ii triplet. The self-re-accretion from the viscous disk is probably not sufficient, as otherwise almost all Be stars should have Ca ii emission.

This leaves binarity. As Koubský et al. (2012) point out, several known binaries do not show Ca ii in their data. However, plain binarity is not sufficient, the companion must also accrete to form the UV flux to excite Ca ii. Hence binarity remains a possible hypothesis to explain the infrared Ca ii triplet emission.

5. Conclusions

Searching the X-shooter database of telluric standards, 78 Be stars were detected in emission, of which 48 had not been reported before. The sample is strongly biased towards later-type Be stars. In some sense, this is an advantage, because later type Be stars, owing to their lack of variability and often less dense disks, are less well studied than earlier type ones. In particular, we could confirm, or at least strengthen, a number of findings and hypotheses:

- The Galactic Be star fraction drops less steep towards the later spectral (sub-)types than previously known numbers suggest. It may even be constant, as proposed by Zorec et al. (2005).
- Late type Be stars show less variability of their disks than early type ones.
- Late type Be stars have less dense disks than early type ones.
- Be stars are more likely to be closer to the TAMS than to the ZAMS.
- The presence of the IR Ca ii in emission may be linked to accretion onto a companion, but the emission itself originates from the Be disk proper.

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Some of these points either clearly are, or may well be, linked to stellar evolution and its timescales. For instance the lower density of disks around later subtype Be stars could be a natural consequence of their slower evolution, if indeed the disk is the means by which the star stays below critical rotation: The amount of angular momentum to lose over a given time is simply less. The same might explain the lower variability of the later subtypes.

In summary, while late type Be stars are less well investigated than the earlier ones, it might actually be this lack of "interesting" behavior in them that will enable new insights on the origin and evolution of Be stars.

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Appendix A: Notes on individual Be stars

For each of the identified Be stars, in the following observations of interest are noted, together with literature values of parameters and stellar rotation, where available, and whether the star is a known or newly identified Be star.

- Hip 11116 (HD 14850). [Buscombe (1970)] report emission in Hβ. The analysis by Levenhagen & Leister (2006) gives spectral type B8 V, and $T_{\text{eff}} = 13500 \pm 550 \, \text{K}$, log $g = 3.60 \pm 0.10$, $v \sin i = 150 \pm 20 \, \text{km}\,\text{s}^{-1}$. The parameters determined by the BCD method in this work are within their 3σ errors, but not vice versa.

- Hip 15188 is listed as a B3 Ve star with $v \sin i \approx 130 \, \text{km}\,\text{s}^{-1}$ in the SIMBAD database. The spectral appearance is in agreement with the early type, but the Be star seems inactive at the moment, i.e., there is no trace of circumstellar line emission.

- Hip 23161 (HD 31764, HR 1600). Tolbert (1964) classified the star as a variable in a binary system. They identified the components as as B8-III and B6-7IV, suggesting a period of $P = 230 \, \text{yr}$. In our spectra no companion is obvious, nor would any detectable radial velocity change be expected for such a long period, but it is a newly identified weak Be star.

- Hip 25007 (AN Col, HD 35165, HR 1772), has been listed as B5IVnpe by [Hiltner et al. (1969)], and as B5 IVnpe by [Mennickent & Vogt (1988)]. This star is a strong shell star showing a clear double Balmer discontinuity, which, if not taken into account, leads to a later spectral type classification. Consequently, we derive B3 IVe-sh as spectral type, in agreement with Levenhagen & Leister (2006) who gave $T_{\text{eff}} = 21500 \pm 500 \, \text{K}$ and log $g = 3.77 \pm 0.10 \, \text{dex}$, with a high $v \sin i = 350 \pm 23 \, \text{km}\,\text{s}^{-1}$. Its spectral variability seems to be due to a long-term V/R cycle type behavior.

- Hip 25690 (HD 37027) is a newly identified weak late-type Be star.

- Hip 25950 (HD 36408, HR 1847) is a very narrow lined star that shows no trace of emission in the X-shooter data. The data is unsuitable for BCD parameter determination. It is a well separated double star, and Harrington & Kuhn (2009) classified one component as B7 IIIe. The star observed by X-shooter was possibly the other, non-Be component, judging from the spectra shown by Harrington & Kuhn (2009). As this is not certain, however, it is kept in this list.

- Hip 26368 (HD 37935, HR 1960), spectral type B9.5 V according to [Carrier et al. (2002)].

- Hip 26964, (V731 Tau, HD 37967, HR 1961), a spectral type of B2.5 Ve as reported in [Bhatt et al. (1984), Goraya & Tur (1988)]. They classified the star as B3 V, $T_{\text{eff}} = 21000 \, \text{K}$, log $g = 4.0$, while Frémat et al. (2005) determine $T_{\text{eff}} = 16543 \pm 264 \, \text{K}$ and log $g = 3.850 \pm 0.041$ and $v \sin i = 210 \pm 10 \, \text{km}\,\text{s}^{-1}$. The discrepancy is probably due to its double BD, filled in by emission, as we conclude the same values as Frémat et al. (2005), i.e., a stronger BD when taking into account the doubling. The Balmer emission lines have a very narrow, single peaked appearance, supporting a pole-on star designation, even if the $v \sin i$ seems quite high for that.

- Hip 28561 (HD 44533) is a newly discovered late type Be star.
– Hip 47962 (HD 84929) is a newly discovered late type Be star.
– Hip 48582 (HD 85834) is flagged as an emission line star in SIMBAD. Since this was communicated by C. Martayan on the basis of the same X-shooter data used here, we consider it as a new discovery for the purpose of assessing the statistical impact on the Be star frequency. The star shows strong $V/R$ variability in Hα. The observed change takes place in 23 days, making it very likely that the star is either a binary, in which case the secondary affects the disk, or a hierarchical triple, in which case the variability is due to the linear superposition of the RV curve of the components Ba+BB. We note that the star has strong IR Ca α triplet in emission. The spectrum shows also a small double BD.

– Hip 48943 (OY Hya, HD 86612, HR 3946) is a well known Be star of spectral type B4Ve (Hiltner et al. 1969). $v \sin i = 229 \text{ km s}^{-1}$ is given by Zorec et al. (1983), also Briot (1986) determine $v \sin i = 230 \text{ km s}^{-1}$. The star has a pronounced double BD character. Some of the Hα spectra are overexposed, cross-checking with Hβ reveals that the apparent variability is purely due to that. However, in the Paschen regime the variability of the Paschen lines blended with the IR Ca α triplet is far stronger than that of the non-blended lines. Most likely the IR Ca triplet is in emission, and variably so.

– Hip 51444 (LX Vel, HD 91188) is a known emission line star. It is a photometrically variable, for which Balona (1990) report as the most likely frequency $f = 0.684 \text{ d}^{-1}$. In the X-shooter spectra the circumstellar emission is clearly variable, and the strength of the central absorption in Hα and its variability in the Paschen lines suggest a shell nature of the star.

– Hip 51491 (HD 91120, HR 4123) is a well known Be shell star. It shows the IR Ca α triplet in emission, but it is interesting to note that while Hα does vary in the three available VIS spectra, the Ca α triplet remains constant.

– Hip 51546 (HD 91373) is a newly discovered late type Be star. No reliable stellar parameters can be given due to over exposure of the UVB continuum.

– Hip 52977 (HD 94097) is a newly discovered mid to late type Be star. It shows some low level of variability in Hα and possibly Mg ii 4481.

– Hip 56393 (HD 100528) is a newly discovered late type Be star. The Paschen line profiles blended with the IR Ca α triplet look suspiciously different from the other Paschen lines, but not enough so for a conclusive statement.

– Hip 57861 (HD 103077) is a newly discovered mid to late type Be star. It showed clear emission line variability in the X-shooter spectra, and as well He i 4471 and Mg ii 4481 are variable in their line profiles.

– Hip 59970 (HD 106965) is a newly discovered late type Be star. Physical parameters cannot be given since the BCD values are outside our grid. This could be because the star might have a weak double BD, or BDs merging into each other without being clearly separated, which we could not unambiguously identify. Indeed, it seems to be a shell star, and it should also be noted that the He i 4471 line is surprisingly strong for its spectral type (i.e., height of BD). The IR Ca α triplet is certainly present in absorption, whether there is also an emission component is uncertain, but possible.

– Hip 64501 (HD 114531) is a newly discovered late type Be star.

– Hip 64867 (HD 115415) is a newly discovered late type Be star.

– Hip 66339 (HD 118246, GP Vir) is a known mid type Be shell star. Its spectral type was given as B3e, with $v \sin i$ of 270 km s$^{-1}$ by Halbedel (1996), while Slettebak et al. (1997) classified it as B5IVe, and determine a $v \sin i$ of above 350 km s$^{-1}$. It shows a clear double BD, favoring the earlier spectral type, i.e., B3 V.

– Hip 66351 (HD 117872) is a newly discovered late type Be star.

– Hip 68100 (HD 120845) is a newly discovered mid to late type low inclination, near to pole-on Be star, with $v \sin i = 100 \text{ km s}^{-1}$.

– Hip 69429 (HD 124176) is a newly discovered late type Be star.

– Hip 71668 (CK Cir HD 128293) is a known Be star. The spectral types published range from B5Ve, with $v \sin i = 216 \text{ km s}^{-1}$ (Balona 1975) to B2IVe (Jaschek & Jaschek 1992). The X-shooter spectrum favors the earlier type when looking at the He/Mg balance.

– Hip 71974 (HD 129433, HR 5484, 4Lib) is a newly discovered late type Be star.

– Hip 78375 (HD 143513) is a newly discovered late type Be shell star. The situation is very similar to Hip 59970: Physical parameters cannot be given since the BCD values are outside our grid. This could be because the star has a double BD which we failed to identify. The IR Ca α triplet is certainly present in absorption, whether there is also an emission component is uncertain, but possible.

– Hip 80577 (HD 147747) is a newly discovered late type Be star, seen at low inclination, with $v \sin i = 100 \text{ km s}^{-1}$.

– Hip 80820 (HD 148382) is a newly discovered late type Be star. The Hα emission is slightly variable.

– Hip 81321 (HD 149595) is a newly discovered, very weak late type Be star. No UVB spectrum is available, but the Hα profile is clearly indicating a Be star.

– Hip 82874 (HD 152541) is a known but little studied late type Be star.

– Hip 83278 (HD 153608) is a newly discovered late type Be star.

– Hip 84184, is a newly discovered late type strong Be shell star. The strength of the shell changed considerably in the X-shooter spectra over about two years, showing a double BD only when the stronger shell is present.

– Hip 85138 (HD 156709) is a newly discovered late type Be star. The Hα emission is slightly variable.

– Hip 85195 (HD 157546, HR 6473) is a newly discovered late type Be star. The Hα emission is slightly variable.

– Hip 85566 (HD 158419) is a newly discovered late type Be star. However, it was reported by Kuchner et al. (2016) as a disk candidate based on its infrared excess, indicating cold dust. It might, therefore, rather be a Herbig Ae star or a β Pictoris type object. The IR Ca α triplet is in absorption, but might have an emission component as well.

– Hip 87032 (HD 161734) was classified as an emission line star by Gray & Corbally (2002). As the flux calibration of the Balmer continuum is obviously wrong, we do not give BCD parameters. The IR Ca α triplet is in emission.

– Hip 87698 (HD 162888) is a newly discovered weak, but obvious late type Be star.

– Hip 88172 (V974 Her, HD 164447, HR 6720) is a known Be star.

– Hip 88374 (HD 164716, HR 6732) is a newly discovered late type Be star. The Hα emission is clearly variable.

– Hip 89486 (HD 167230) is a newly discovered late type Be star. The Hα emission is clearly variable.
– Hip 89500 (HD 167095) is a newly discovered very weak late type Be star. The only indication for a Be nature is a slight filled in absorption flank of Hα. Since this is however not present in another spectrum, this is a good indication for a variable amount of circumstellar material, i.e., a Be star. Computing the difference spectra reveals the usual double peak emission signature.

– Hip 90096 (HD 169033, HR 6881) [Merrill & Burwell (1943)] classified as B8 Vε, as did Jaschek et al. (1980), who also gave \( \nu \sin i = 220 \text{km s}^{-1} \).

– Hip 90509 (HD 165338) is a newly discovered late type Be star. The IR Ca\textsc{ii} triplet is in absorption, but might have an emission component as well.

– Hip 91460 (HD 172054) is a newly discovered late type Be star.

– Hip 91975 (4 Aql, HD 173370, HR 7040) is a well known Be star. Irvine (1975) observed weak emission in Hα, with a strong central reversal. The IR Ca\textsc{ii} triplet is in absorption, but might have an emission component as well.

– Hip 92038 (HD 173375) is a newly discovered late type Be star. The emission strongly increased during the observations with X-shooter over about three years, to the point at which a double BD became apparent. The IR Ca\textsc{ii} triplet is in emission as well, but its strength decreased, i.e., behaved in opposite to the Balmer emission.

– Hip 93993 (HD 178075, HR 7246) is a newly discovered late type Be star. It shows an extreme pole-on appearance \( \nu \sin i = 10 \text{km s}^{-1} \), with only Hα in emission. The IR Ca\textsc{ii} triplet is very weakly present in absorption, which is probably photospheric and typical for the late spectral type.

– Hip 94770 (HD 179419) is a known (but largely ignored) late type Be star, given as B8 Vε by [Andersen & Nordstrom (1983)]. The change in the Hα is due to slight over exposure in one of the two spectra and not real. The IR Ca\textsc{ii} triplet is in emission.

– Hip 94859 (HD 180699) is a newly discovered late type Be star. The IR Ca\textsc{ii} triplet is in absorption, emission might possibly be present as well.

– Hip 94986 (HD 180885, HR 7316) is a newly discovered low inclination early type Be star. It is variable in Hα, and the emission is not always present. Pulsational variability is clearly seen in Mg\textsc{ii} 4481.

– Hip 95109 (HD 181751) is a newly discovered late type Be star. The spectral type was given as B8 by [Stagg (1983)].

– Hip 96453 (HD 184597) is a newly discovered mid type Be star. It shows clear signs of an outburst in one of the two spectra acquired in the VIS arm of X-shooter.

– Hip 99457 (BE Cap, HD 191639, HR 7709) is a known early type Be star by Merrill & Burwell (1943) as MWC 650. No recent study has found Balmer emission in this star, and also in the X-shooter spectra there is no evidence for emission.

– Hip 100859 (VV PsA) is a known late type Be shell star discovered by [Henize (1976)], who found Hα to be a very sharp, moderate to weak emission line and Hβ to be in absorption, from 1949-1952 objective prism plates. It shows both a double BD and the IR Ca\textsc{ii} triplet is in emission.

– Hip 108975 (UU PsA, HD 209522, HR 8408) has been reported as early type Be star by [Merrill & Burwell (1943)] as MWC 650. No recent study has found Balmer emission in this star, and also in the X-shooter spectra there is no evidence for emission.
Appendix B: Projected rotational velocity fits

Fig. B.1: Best fit models for projected rotational velocities for the program Be stars, for Mg II 4481 Å. Solid lines mark observed and dotted ones theoretical profiles.
Fig. B.1: Continued
Fig. B.1: Continued
Fig. B.1: Continued
Appendix C: Spectral appearance of the identified Be stars

In this Appendix excerpts of the spectra of the identified Be stars are shown, except for Hip 11116, which is shown in Fig. 1. In some cases noisy or otherwise unsuitable spectra were excluded from the plots.

In the upper row, from left to right, profiles of Hβ, Hα, the Fe ii 5169, and the He i 4471 and Mg ii 4481 lines are shown. These illustrated the presence and variability of Balmer emission as well as the Balmer decrement, the presence of circumstellar emission or shell absorption in Fe ii, and the balance of He vs. Mg may serve as a sanity check on the obtained effective temperatures and spectral types.

In the lower row, the Balmer discontinuity is shown and the higher lines of the Paschen series, that include the O i 8446 and Ca ii triplet lines.

![Fig. C.1: Spectrum overview plot for Hip 15188. No usable UVB spectrum is available for this star.](image1)

![Fig. C.2: Spectrum overview plot for Hip 23161](image2)
Fig. C.6: Spectrum overview plot for Hip 25950

Fig. C.7: Spectrum overview plot for Hip 26368

Fig. C.8: Spectrum overview plot for Hip 26964
Fig. C.12: Spectrum overview plot for Hip 32474

Fig. C.13: Spectrum overview plot for Hip 33509

Fig. C.14: Spectrum overview plot for Hip 34144
Fig. C.24: Spectrum overview plot for Hip 43114

Fig. C.25: Spectrum overview plot for Hip 44423

Fig. C.26: Spectrum overview plot for Hip 46329
Fig. C.36: Spectrum overview plot for Hip 59970

Fig. C.37: Spectrum overview plot for Hip 64501

Fig. C.38: Spectrum overview plot for Hip 64867
Fig. C.42: Spectrum overview plot for Hip 69429

Fig. C.43: Spectrum overview plot for Hip 71668

Fig. C.44: Spectrum overview plot for Hip 71974
Fig. C.45: Spectrum overview plot for Hip 78375

Fig. C.46: Spectrum overview plot for Hip 80577

Fig. C.47: Spectrum overview plot for Hip 80820
Fig. C.48: Spectrum overview plot for Hip 82874

Fig. C.49: Spectrum overview plot for Hip 83278

Fig. C.50: Spectrum overview plot for Hip 84184
Fig. C.51: Spectrum overview plot for Hip 85138

Fig. C.52: Spectrum overview plot for Hip 85195

Fig. C.53: Spectrum overview plot for Hip 85566
Fig. C.54: Spectrum overview plot for Hip 87032

Fig. C.55: Spectrum overview plot for Hip 87698

Fig. C.56: Spectrum overview plot for Hip 88172
Fig. C.57: Spectrum overview plot for Hip 88374

Fig. C.58: Spectrum overview plot for Hip 89486

Fig. C.59: Spectrum overview plot for Hip 89500
Fig. C.60: Spectrum overview plot for Hip 90096

Fig. C.61: Spectrum overview plot for Hip 90509

Fig. C.62: Spectrum overview plot for Hip 91460
Fig. C.66: Spectrum overview plot for Hip 94770

Fig. C.67: Spectrum overview plot for Hip 94859

Fig. C.68: Spectrum overview plot for Hip 94986
Fig. C.72: Spectrum overview plot for Hip 100664

Fig. C.73: Spectrum overview plot for Hip 104508

Fig. C.74: Spectrum overview plot for Hip 108022
Fig. C.75: Spectrum overview plot for Hip 108402

Fig. C.76: Spectrum overview plot for Hip 108597

Fig. C.77: Spectrum overview plot for Hip 108975