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THE Be STAR SPECTRA (BeSS) DATABASE

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ABSTRACT

Be stars vary on many timescales, from hours to decades. A long time base of observations to analyze certain phenomena in these stars is therefore necessary. Collecting all existing and future Be star spectra into one database has thus emerged as an important tool for the Be star community. Moreover, for statistical studies, it is useful to have centralized information on all known Be stars via an up-to-date catalog. These two goals are what the Be Star Spectra (BeSS, http://basebe.obspm.fr) database proposes to achieve. The database contains an as-complete-as-possible catalog of known Be stars with stellar parameters, as well as spectra of Be stars from all origins (any wavelength, any epoch, any resolution, etc.). It currently contains over 54,000 spectra of more than 600 different Be stars among the ∼2000 Be stars in the catalog. A user can access and query this database to retrieve information on Be stars or spectra. Registered members can also upload spectra to enrich the database. Spectra obtained by professional as well as amateur astronomers are individually validated in terms of format and science before being included in BeSS. In this paper, we present the database itself as well as examples of the use of BeSS data in terms of statistics and the study of individual stars.

Key words: astronomical databases: miscellaneous – catalogs – circumstellar matter – stars: emission-line, Be – techniques: spectroscopic

Online-only material: color figures

1. INTRODUCTION

Be stars are non-supergiant B stars that have displayed Balmer line emission at least once. This property applies to about 20% (Zorec & Briot 1997) of all B-type stars in the field of our Galaxy and can concern an even larger fraction of B stars in other environments. Some late O and early A stars also show such emission and are considered extensions of Be stars. The phases of emission in the optical and infrared lines of hydrogen and several ions, called the Be phenomenon, reflect changes in the structure of the circumstellar envelope created by episodic ejections of mass. The origin of this phenomenon is still unexplained, although at least in some cases non-radial pulsations have been reported to be closely correlated to outbursts (e.g., Huat et al. 2009). See Porter & Rivinius (2003) for a complete review of Be stars and the proceedings of the recent IAU Symposium 272 (Neiner et al. 2011) for the latest discussion on this topic.

Be stars are variable on all timescales. Although their short-term variations can be easily studied by observing Be stars during a few days or weeks, the study of longer term phenomena requires the collection of data over several years or decades. In particular it is interesting to follow the evolution of the Hα emission of Be stars, not only the total emission but also the individual violet (V) and red (R) peaks, to learn about the structure of the disks around Be stars. The use of archives is the only way to obtain the necessary observations. This can, however, become a tremendous task when data are spread over the world or on the internet (e.g., the spectroscopic Be star atlas of C. Buil[5]), available in different formats, and when little information exists about the various data sets. This is why it seemed important to put all available spectra of Be stars in one place, in one unique format, together with all relevant information for the analysis. With this aim, we created the "Be Star Spectra" (BeSS) database, accessible at http://basebe.obspm.fr and via the Virtual Observatory (VO, see the Appendix). It contains a catalog of all known Be stars with some of their stellar parameters (see Section 2) and aims at collecting all available Be star spectra obtained by professional as well as amateur astronomers (see Section 3). Statistical information on Be stars can be extracted from the database, as can results for individual stars (see examples in Section 4).

[5] http://astrosurf.com/buil/us/becat.htm

2. THE CATALOG OF Be STARS IN BeSS

2.1. Content of the Catalog

Catalogs of Be stars have been compiled over the years (e.g., Jaschek & Egret 1982). However, whereas new Be stars are regularly discovered, no recent catalog exists. Therefore it was necessary to establish a list of all known (∼2000) Be stars, in order to know which spectra can or cannot be accepted in BeSS. Only classical Be stars and main-sequence B[e] stars have been considered. In particular, Herbig Ae/Be stars have been excluded so far. An extension of BeSS to Herbig objects is, however, planned in the future. For cases in which authors disagree in the literature about the classical or Herbig Be nature of a star, we examined the available optical spectra and IR data to perform our selection of stars.

This list of Be stars is based on the catalog published by Jaschek & Egret (1982). We added to this list most stars labeled as Be stars in the Simbad database (CDS, http://simbad.u-strasbg.fr) that were not referenced in Jaschek & Egret (1982). However, according to the literature and available

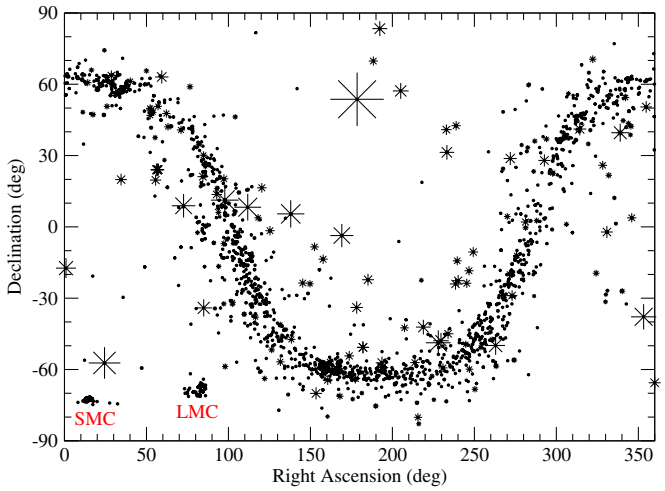

Figure 1. Distribution of all known Be stars in the sky (and thus in BeSS). The symbol size is inversely proportional to the distance (if known).
(A color version of this figure is available in the online journal.)

spectra, certain stars labeled as Be stars in Simbad are actually not Be stars and those have therefore been dismissed. In addition, Be stars listed in Halbedel (1996) that were not labeled as Be stars in Simbad, and Be stars recently discovered by various authors, e.g., by Neiner et al. (2005) and Martayan et al. (2006), have also been added. The BeSS catalog is updated regularly, as Be stars are discovered/confirmed/dismissed in the literature. The full list of Be stars with their coordinates, V magnitudes, and a reference paper stating that they are Be stars is provided in BeSS. Figure 1 shows the distribution of all Be stars in the sky. Be stars are present all along the Galactic plane as well as in the Large and Small Magellanic Clouds (LMC and SMC).

Moreover, it appeared important to put at the disposal of the community and maintain a more complete catalog of these Be stars with additional information on their stellar parameters. Therefore, for each Be star in the list, stellar parameters are being collected from the Simbad database and from the literature, when available. These parameters are FK5 coordinates, magnitude, spectral type, effective temperature, surface gravity, v sin i, inclination angle, distance, and radial velocity. The corresponding error bars and references are also indicated. In addition, information about the membership of Be stars to a cluster or galaxy, if available, is also given. This full catalog with stellar parameters is available online on the BeSS Web site and will be continuously updated. In particular, any newly discovered Be star can be reported to BeSS so that the catalog remains up to date.

Table 1
Main Contributors for Spectra Currently in BeSS

Instrument	Number of Spectra
Elodie@OHP193	31153
Amateurs	17140
IUE	2601
Musicos@TBL	2240
Feros@ESO	1069
SARG@TNG	117
Giraffe@VLT	69

For more than ∼600 (at the time of writing) among the ∼2000 Be stars in the catalog, spectra are also available in BeSS (see Section 3 and Table 1).

2.2. *Querying BeSS for Be Stars*

A user can query the database to obtain a list of Be stars. This is particularly useful to prepare an observing run or to study the population of Be stars in a certain region of the sky.

The basic name used for each star in BeSS is the first existing one out of common name (e.g., Achernar), Greek constellation name (e.g., γ Cas), other constellation name (e.g., 66 Oph), variable name (e.g., V518 Car), HD number (e.g., HD 24479), or other names recognized by Simbad. In fact, BeSS recognizes any star name that is also recognized by Simbad. Indeed, when a name is not known by BeSS itself, BeSS queries Simbad to identify the star.

Since the catalog also contains stellar parameters of Be stars, a query can also be performed by parameters, e.g., to obtain Be stars brighter than $V = 5$ or Be stars with $v \sin i \geqslant 300$ km s^{-1}. Combining several criteria on parameters is also possible. See Figure 2 and an example of a result in Figure 3. The catalog can thus be used to perform statistical studies on the parameters of Be stars.

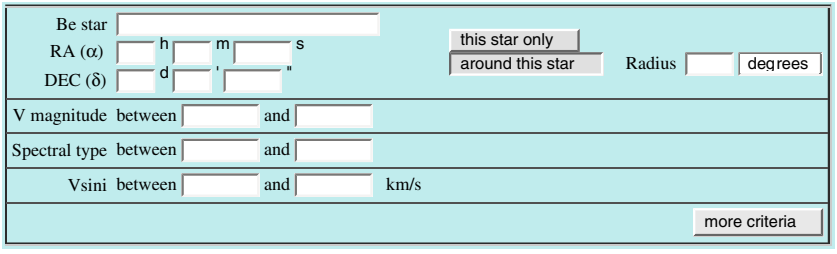

Figure 2. Screenshot of the Be stars query page of BeSS. The database can be queried by different parameters.
(A color version of this figure is available in the online journal.)

#	Be star	RA (h m s)	DEC (deg m s)	V	Type	vsini (km/s)	Nb of spectra in BeSS
1	HD 55806	07 14 38.46	02 54 06.92	9.1	B9		36
2	bet CMi	07 27 09.04	08 17 21.54	2.886	B8Ve	230	139

Figure 3. Screenshot of a page of results from a Be stars query to BeSS.
(A color version of this figure is available in the online journal.)

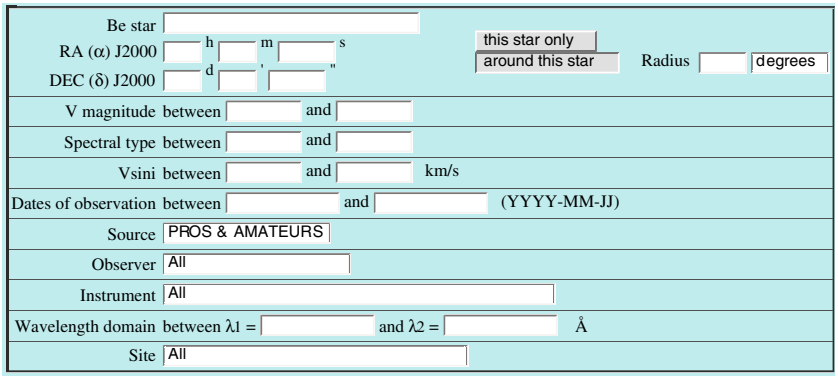

Figure 4. Screenshot of the spectra query page of BeSS. The database can be queried by different parameters.
(A color version of this figure is available in the online journal.)

#	Be star	RA (h m s)	DEC (deg m s)	Instrument	Site	Observers	Date	mid-HJD (d)	Plot	Download 1 by 1	Download many
1	64 Ser	18 57 16.59	02 32 07.25	T62AQ1-F15-Lh3-1200	AQ-St Veran	Cochard	2006-09-11	2453990.425	plot	spec_3	
2	64 Ser	18 57 16.59	02 32 07.25	JR C9.25 LhiresIII#26-1200 ST7	Atalaia	Ribeiro	2007-03-11	2454170.683	plot	spec_2439	
3	64 Ser	18 57 16.59	02 32 07.25	Feros@ESO1.52	ESO-LASILLA	Neiner GAUDI de Batz	2001-07-07	2452097.740	plot	echelle_1to38_2_272	
											Download

Figure 5. Screenshot of a page of results from a spectra query to BeSS. Spectra obtained by professionals are indicated in dark blue, those from amateurs in dark green. Some fields are links (underlined blue) to description records.
(A color version of this figure is available in the online journal.)

3. SPECTRA IN THE BeSS DATABASE

The BeSS database is meant to contain spectra of Be stars at any wavelength. However, it currently contains mainly spectra obtained in the visible domain, since they are the most abundant in the various available archives. These spectra have been obtained both by professional astronomers and by amateurs. Note, however, that spectra in BeSS obtained by amateurs follow the same format and scientific validity checks as professional ones and are therefore of similar quality to those obtained by professionals.

The BeSS database has been initially filled with Be star spectra available in various other spectral databases, such as the Elodie archive (http://atlas.obs-hp.fr/elodie; Moultaka et al. 2004) of the OHP (Observatoire de Haute-Provence), the GAUDI database (http://sdc.laeff.inta.es/gaudi/; Solano et al. 2005) of the ground-based preparatory work of the *CoRoT* satellite which includes data from Elodie, SARG, and Feros, and the INES database (http://sdc.laeff.inta.es/ines; Wamsteker et al. 2000) of the *IUE* satellite. Some additional spectra have already been added by individual PIs and the database currently contains over 54,000 spectra concerning 626 different Be stars among the 2027 known Be stars in the catalog. The list of spectra is summarized in Table 1. Anyone in possession of Be star spectra is encouraged to upload these spectra to BeSS to enrich the database.

3.1. Querying BeSS for Spectra

A user can query the database to obtain Be star spectra. A query can be performed through usual stellar parameters as for the query for Be stars (see above). However, spectra can also be queried by spectral parameters: observation dates, instrument, observation site, etc. (or a combination of both stellar and spectral parameters). See Figure 4 and an example of a result in Figure 5.

When a query is performed, BeSS provides the list of spectra corresponding to the selected criteria. The user also obtains additional information about the resulting spectra: some information is given by default (dates of observation, instrument, etc.) and some are given only if they have been specified in the query. The user can then download the spectra, either file by file or by selecting several files on a page and downloading one single archive. See Figure 5 for an example. Users can also have a quick look at the spectra without downloading them. In addition, the user can retrieve information about the instrument, site, and authors of the spectra, as well as about the stars, by clicking in the result table to check their description records. Note that the *authors* indicated for each spectrum in the database can be the observers as well as people who performed the data reduction, the PI of the observing program, or even a database from which the spectrum was retrieved.

If spectra are used for scientific publications, the authors are requested to include the following sentence in their paper: "This work has made use of the BeSS database, operated at LESIA, Observatoire de Meudon, France: http://basebe.obspm.fr." Moreover, if it appears to the user that a significant fraction of the observations is provided by a specific observer/author or that the contribution of this observer/author is essential to the results exposed in a paper, the user is encouraged to invite this person as a coauthor of that publication. It is sufficient to thank observers that provided less spectra in the publication.

3.2. Uploading Spectra in BeSS

To upload spectra in BeSS, it is sufficient to fill in a form on the BeSS Web site (see Figure 6, top panel) and to upload one first spectrum of a Be star. The format of this spectrum (see below) will be automatically checked at upload and its scientific content will be checked by the administrators. The same criteria are used to accept/reject each spectrum and will enforce the integrity of the database.

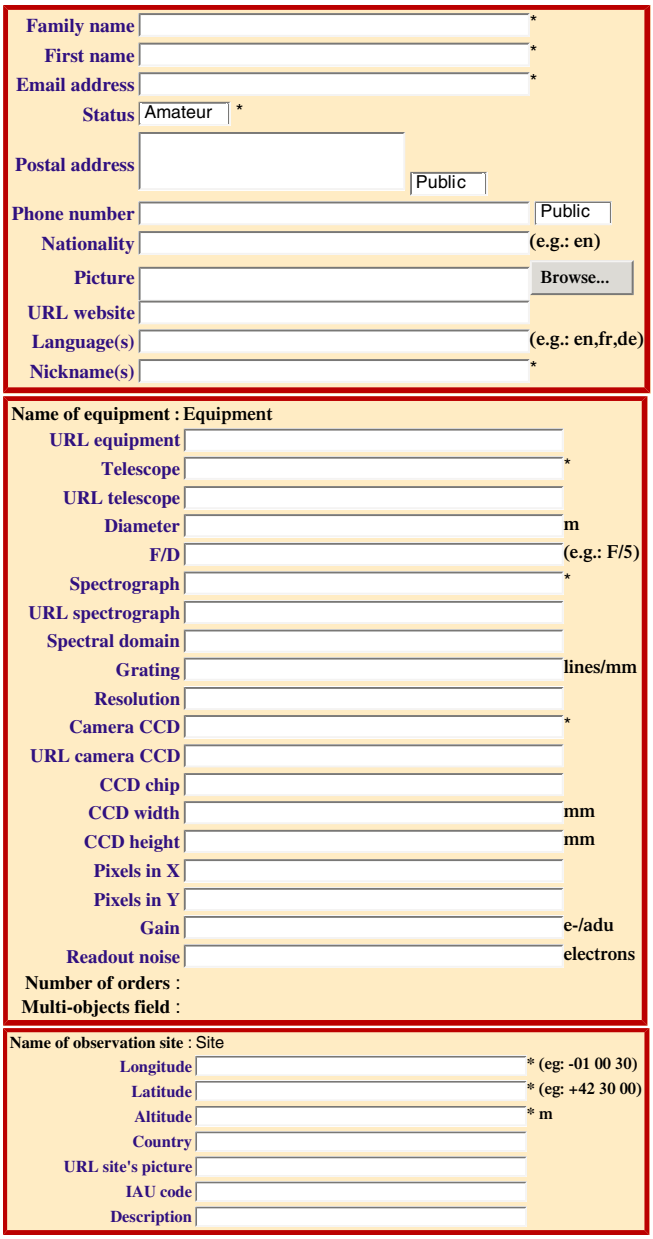

Figure 6. Screenshot of the forms to be filled regarding the author(s) of the spectrum, instrument, and observation site when spectra are uploaded and if this information is not yet registered in BeSS.

(A color version of this figure is available in the online journal.)

Once the first spectrum uploaded by a user has been validated by the administrators of BeSS, the user will receive by email a login and password for BeSS. From then on, the user will be able to upload the remainder of his or her Be star spectra. However, each spectrum will continue to be automatically checked at upload and manually scientifically checked by the administrators. The automatic checks concern the format of the FITS files as well as the plausibility of the values given in the keywords (e.g., whether the star was indeed visible from the specified telescope at the time when it is claimed to have been observed). The science check concerns the wavelength calibration, flat fielding, adequacy between the values given in the keywords and visible in the spectrum, e.g., whether the spectrum is normalized or not, corrected for telluric lines or not, etc. We also check that the spectrum indeed resembles other spectra of that Be star (if any exist) and, if another spectrum of

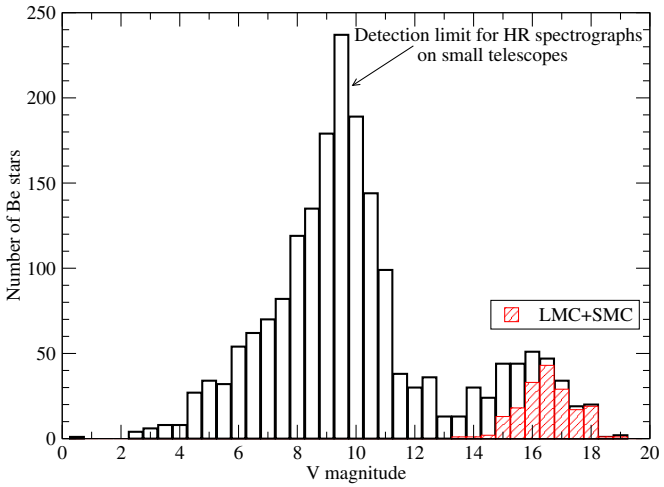

Figure 7. Distribution of V magnitude of all Be stars in the sky and thus available in BeSS (black bars). The Be stars from the Large and Small Magellanic Clouds are superimposed in hashed red bars.

(A color version of this figure is available in the online journal.)

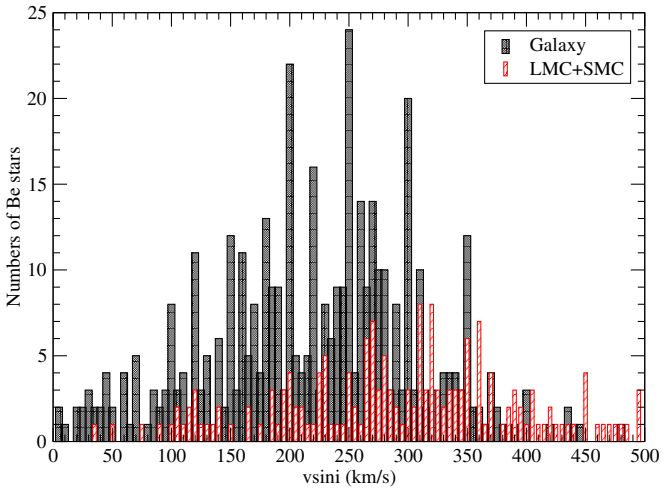

Figure 8. Distribution of projected rotational velocity ($v \sin i$) in km s^{-1} of Be stars in the Galaxy (filled gray bars) and in the Magellanic Clouds (hashed red bars) in the BeSS catalog.

(A color version of this figure is available in the online journal.)

that star exists at almost the same time, we check that the Hα emission is similar. The uploaded spectra will only appear in the database after validation by the administrators, i.e., within approximately one week.

The spectra uploaded in BeSS must follow the BeSS format specifications, i.e., they must be SIMPLE FITS spectra (see http://fits.gsfc.nasa.gov/standard21b.html) with a header including at least a few mandatory keywords. The list of these mandatory keywords and the corresponding descriptions is given in Table 2. Optional keywords can also be used. On the Web site of BeSS, users will find a page to check their spectra beforehand if they are uncertain of their format (in the Tools menu), as well as view a document fully describing this format (on the Home page).

Moreover, while uploading spectra, the user will be asked for details concerning the instrument (telescope, spectrograph, camera) used to obtain the spectra, the observation site, and the author(s) of the spectra, if these details are not yet registered in BeSS. See Figure 6. In this way, users retrieving spectra from BeSS will have all useful information to fully exploit the data.

Table 2
List of Mandatory FITS Keywords in a BeSS Spectrum

Keyword	Keyword Type	Description	Allowed Value and Units
SIMPLE	basic standard	Primary header logical constant	T
BITPIX	basic standard	Number of bits per data value	8,16,32,−32 or −64
NAXIS	basic standard	Number of axis	1
NAXIS1	basic standard	Size of the axis	[1:500000] in pixels
CRVAL1	astro standard	Wavelength of the first pixel	[1:40000]
CDELT1	astro standard	Wavelength step	[10^{-4}:30]
CRPIX1	astro standard	First pixel coordinate	
CTYPE1	astro standard	Type of units	Wavelength
CUNIT1	astro standard	Wavelength unit	Å or nm
OBJNAME[a]	astro standard	Name of the star	Any name recognized by Simbad
RA[a]	astro standard	Right ascension of the star	[0:+360] in degrees
DEC[a]	astro standard	Declination of the star	[−90:+90] in degrees
EQUINOX[a]	astro standard	Equinox of coordinates	2000
RADECSYS[a]	astro standard	System of coordinates	FK5
DATE-OBS[b]	astro standard	ISO date of the beginning of the observation	YYYY-MM-DDTHH:MM:SS.ssssss
DATE-END[b]	astro standard	ISO date of the end of the observation	YYYY-MM-DDTHH:MM:SS.ssssss
MID-HJD[c]	astro standard	Heliocentric Julian Date at mid-exposure	in days
EXPTIME[b]	astro standard	Exposure time	in seconds
BSS_VHEL	astro BeSS	Applied heliocentric velocity correction	[−200:200] in km s^{-1}
OBSERVER	astro standard	Name(s) of the author(s) of the spectrum	List separated by commas
BSS_TELL[d]	astro BeSS	Spectral correction from telluric lines	Description of the applied correction
BSS_COSM[d]	astro BeSS	Spectral correction from cosmics	Description of the applied correction
BSS_NORM	astro BeSS	Normalization to the continuum	Description of the applied normalization
BSS_INST[e]	astro BeSS	Name given to the equipment	
TELESCOP[e]	astro standard	Name of the telescope	
DETNAM[e]	astro standard	Name of the camera	
INSTRUME[e]	astro standard	Name of the spectrograph	
BSS_ORD[f]	astro BeSS	Number of echelle orders	$\geqslant 2$
BSS_FLD[g]	astro BeSS	Diameter of the field for multi-objects instruments	in degrees
BSS_FRA[g]	astro BeSS	Right ascension of the multi-object field center	[0:+360] in degrees
BSS_FDEC[g]	astro BeSS	Declination of the multi-object field center	[−90:+90] in degrees
BSS_SITE[c]	astro BeSS	Name given to the observation site	
BSS_LAT [c]	astro BeSS	Latitude of the observation site	[−90:+90] in degrees
BSS_LONG[c]	astro BeSS	Longitude of the observation site	[0:+360] in degrees
BSS_ELEV[c]	astro BeSS	Elevation of the observation site	[−200:5500] in meters
BSS_SAT[c]	astro BeSS	Name given to the satellite	

Notes. Column 2 indicates whether the keyword is a basic standard FITS keyword, a standard astronomical FITS keyword, or a keyword created especially for BeSS.
[a] Either OBJNAME or (RA, DEC (EQUINOX or RADECSYS)) has to be present.
[b] Two of the three keywords DATE-OBS, DATE-END, and EXPTIME have to be present.
[c] Either BSS_SITE or (BSS_LAT, BSS_LONG, BSS_ELEV) or (BSS_SAT, MID-HJD) has to be present.
[d] BSS_TELL and BSS_COSM are mandatory only if a correction has been applied.
[e] Either BSS_INST or (TELESCOP, DETNAM, INSTRUME) has to be present.
[f] BSS_ORD is mandatory only for echelle spectra.
[g] BSS_FLD, BSS_FRA, and BSS_FDEC are mandatory only for multi-object instruments.

4. EXAMPLE OF THE USE OF BeSS DATA

We present a few examples below of the use of the BeSS catalog and BeSS spectra. Of course, many more results can be extracted by the community thanks to data mining in BeSS.

4.1. Be Star Statistics

Figure 7 shows the distribution in V magnitude of all known Be stars, i.e., of the whole BeSS catalog. The distribution peaks at $V = 9.5$ and $V = 16$. The first peak corresponds to the limiting magnitude for currently available small telescopes equipped with high-resolution (>10,000) spectrographs, i.e., it corresponds to the observational limit of the type of instruments used for most of the studies of Be stars. The second peak is due to Be stars detected with larger telescopes or very low resolution surveys, in particular those detected in the Magellanic Clouds thanks to GIRAFFE/FLAMES surveys (e.g., Martayan et al. 2006).

Figure 8 shows the distribution of projected rotational velocity (v sin i) in km s^{-1} for stars in the Galaxy and in the Magellanic Clouds for which $v \sin i$ is known from the literature and included in BeSS. The distribution of v sin i for the stars from the Magellanic Clouds peaks at a higher value than the one for the Be stars from our Galaxy. Indeed, Martayan et al. (2007) found that the distributions of initial rotational velocities at the zero-age main sequence (ZAMS) for Be stars in the SMC, LMC, and in our Galaxy are mass- and metallicity-dependent.

Figure 9 shows the distribution of spectral type classification for stars in the Galaxy and in the Magellanic Clouds for which the spectral type is known from the literature and included in

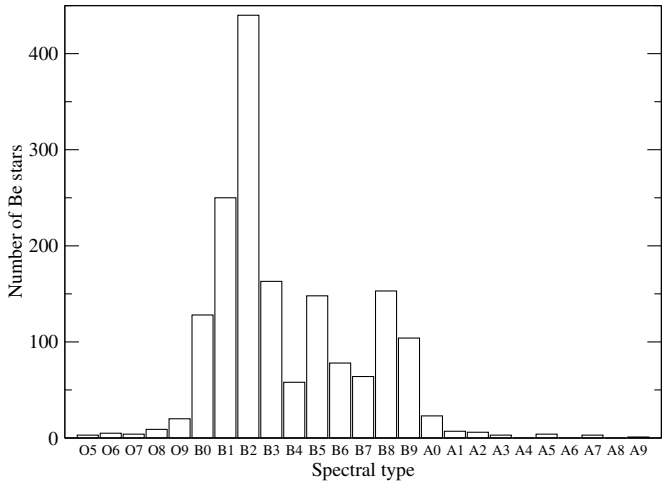

Figure 9. Distribution of spectral type of Be stars available in BeSS.

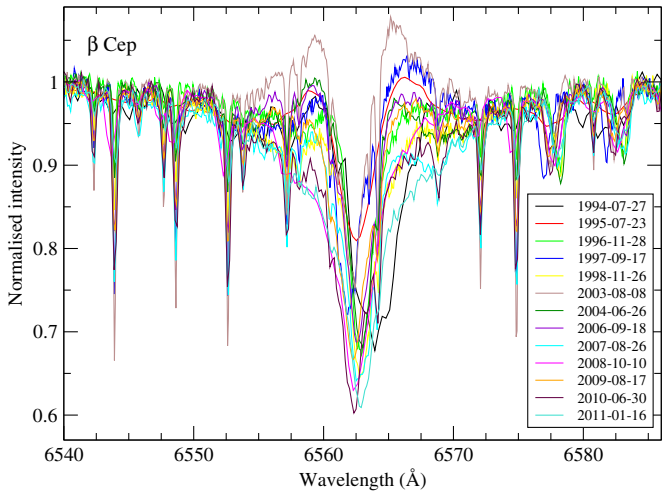

Figure 10. Example of 15 Hα spectra of β Cep obtained between 1994 and 2011 among the 7161 spectra available in BeSS. The BeSS observers for these spectra were C. Buil, V. Desnoux, P. Ehrenfreud, T. Garrel, J. Guarro, H. Henrichs, C. Neiner, O. Thizy, and S. Ubaud.

(A color version of this figure is available in the online journal.)

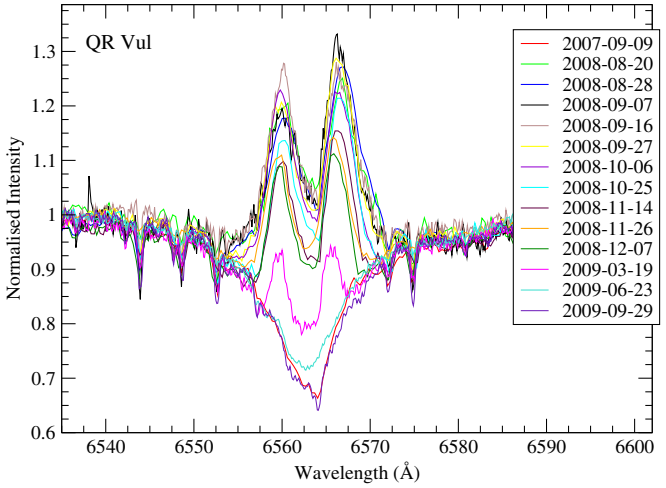

Figure 11. Observations of QR Vul at Hα before, during, and after the outburst which occurred in 2008 and was detected thanks to BeSS. The BeSS observers for these spectra were C. Buil, V. Desnoux, J. Guarro, M. Pujol, and O. Thizy.

(A color version of this figure is available in the online journal.)

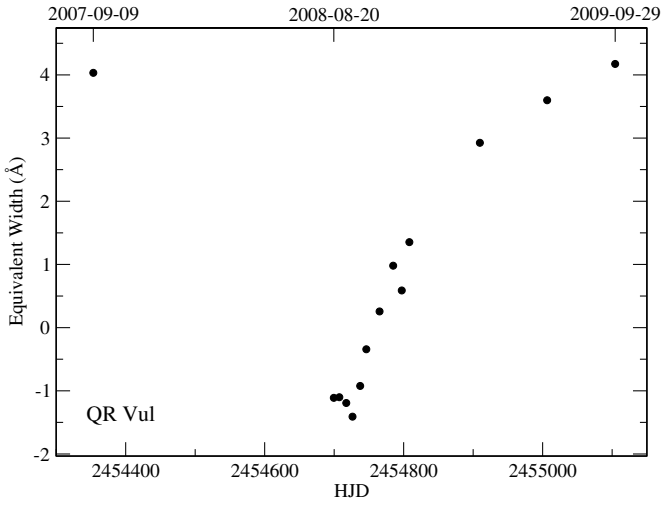

Figure 12. Equivalent width variations with time in QR Vul for the spectra shown in Figure 11.

BeSS. The distribution of spectral type peaks at B1–B2. This is well known for stars in our Galaxy (see, e.g., Zorec & Briot 1997 for a review of various studies) as well as for stars in clusters (e.g., Fabregat 2003).

4.2. Study of Individual Stars

At the time of writing, BeSS contains spectra for 626 Be stars. The number of spectra per star currently ranges from 1 to 7161, the highest number of spectra being available for the star β Cep. Examples of 15 of these spectra of β Cep obtained between 1994 and 2011 are shown in Figure 10. The long-term variation of the emission in the spectra is clearly visible. Note that it is the companion of β Cep, which is a Be star, and is not the primary star (Schnerr et al. 2006).

The data collected in BeSS also allow the detection and study of outbursts. Six outbursts have been detected so far thanks to BeSS in Be stars QR Vul, HD 22780, λ Cyg, λ Eri, HD 37149, and HD 34959. For example, the outburst of QR Vul was detected in 2008 August. Some spectra from BeSS obtained before, during, and after the outburst are shown in Figure 11. The variation of equivalent width for these spectra is shown in Figure 12. The outburst was detected close to its maximum of emission at Hα in 2008 August. It took the star about a year to come back to its usual photospheric profile.

5. CONCLUSIONS

The BeSS database is a new tool useful for Be star research. It contains a catalog of Be stars with their parameters as well as the available spectra. Information on Be stars and spectra can be queried and retrieved through the interactive front end at http://basebe.obspm.fr or via the VO. BeSS is a two-way database: data can be retrieved and spectra can also be uploaded. It thus allows the whole community to share data on Be stars.

This database is particularly useful for the study of long-term phenomena in Be stars, since it contains spectra obtained over several decades. This will allow us to obtain results on variations over long timescales and on the recurrence of outbursts. Moreover, it is useful for the study of statistical properties of Be stars since it also contains data on all known Be stars.

We thank the β-testers of BeSS, namely, C. Buil, S. Dearden, O. Garde, and O. Thizy for their useful feedback, as well as the many observers who already contributed to BeSS. We also thank D. Baade for valuable discussions about the database and this paper. This research has made use of the Simbad database maintained at CDS, Strasbourg, France, and of the BeSS database, operated at LESIA, Observatoire de Paris-Meudon, France: http://basebe.obspm.fr.

Facilities: OHP:1.93m (Elodie), *IUE*, TBL (Musicos), ESO:Kueyen (Feros), Max Planck:2.2m (Feros), TNG (SARG), VLT:1.52m (Giraffe)

APPENDIX

THE STRUCTURE OF THE BeSS DATABASE

BeSS has been developed under PostgreSQL and is hosted on a Linux Debian server at LESIA (Observatoire de Paris-Meudon, France). A duplicate of the database tables and data is created every 24 hr on a separate disk. This copy of the database is the one visible online, so that BeSS is available to its users 24/24 hr even while maintenance is performed on the original version. Updates made to BeSS, including uploads of spectra (see Section 3.2), therefore appear online only at duplication time, i.e., within 24 hr.

The front-end Web sites are written in PHP and HTML (without JavaScript) to allow full compatibility with any Web browser and operating system. The Web sites are currently available in English, French, and German, and more languages will be added in the future.

BeSS is compatible with the VO (see, e.g., Padovani & Dolensky 2005; Walton et al. 2006) and can thus also be queried from the VO. However, a VO query is currently only defined (by the standards of VO), in addition to selecting criteria on stellar and spectral parameters, either by a cone search around certain coordinates or by a name search using names directly defined in BeSS (no name resolver; see Dolensky & Tody 2004 and http://www.ivoa.net/Documents/latest/SSA.html). Therefore, the name query is currently much less flexible via VO than through BeSS directly. Users are thus encouraged to use the direct URL http://basebe.obspm.fr. The VO interface of BeSS will remain compatible with the latest version of the VO protocols as the VO evolves. Eventually resolving names in BeSS will also be possible via VO.

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