The Astrophysical Journal Supplement Series, 156:237–243, 2005 February


# THE IDENTIFICATION OF NEW Be STARS IN GAUDI[1]

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*Received 2004 June 16; accepted 2004 September 30*

## ABSTRACT

The Ground-based Asteroseismology Uniform Database Interface (GAUDI) is the result of the preparatory work performed for the *COROT* satellite. In the data available in GAUDI we discovered 17 B-type stars that show emission in their Balmer lines and were not known to display such emission before, including at least 16 non-supergiant ones. We thus reclassify those stars as Be stars. These 17 new Be stars increase the number of Be stars in the field of view of *COROT* by ~25%, which is important for the target selection of the mission. Moreover, ~70% of the discovered Be stars are of late subtypes. Be stars have been mostly found among early subtypes until now, but this could be due to an observational bias. Finally, one of the discovered stars is either a slowly rotating shell Be star or a Herbig Be star with a low $v \sin i$, which makes this star especially interesting.

*Subject headings:* stars: activity — stars: emission-line, Be

*Online material:* color figures

## 1. INTRODUCTION: Be STARS

Be stars are nonsupergiant B stars that show or have shown emission, at least once, in at least one Balmer line (Collins 1987). Late Oe and early Ae stars seem to represent extensions of the Be phenomenon to higher and lower temperatures, respectively. The emission is due to the presence of a circumstellar disk, fed by episodic ejections of material from the star. However, how these ejections can occur and how the material can reach a stable orbit to form the circumstellar disk is still not understood.

Be stars represent about 20% of all B-type stars in our galaxy. However, there seems to be a strong dependence of the proportion of Be stars compared to B stars as a function of spectral type (Zorec & Briot 1997). Indeed, the Be phenomenon is mostly observed around the subtypes B0–B2 (see Fig. 1 of Balona 2000).

Be stars often rotate fast ($v \sin i \sim 250$–$300$ km s$^{-1}$) and are then called *classical* Be stars. Their high rotation rate (typically 80% of the critical velocity, Chauville et al. 2001) probably plays an important role in the Be phenomenon but is, however, always lower than the critical velocity at which the centrifugal force balances the gravity at the stellar equator. Thus, rotation by itself cannot explain the ejections of material. Moreover, some examples of Be stars do rotate slowly (e.g., $\beta$ Cep with $v \sin i = 27$ km s$^{-1}$ and $i = 60°$, Donati et al. 2001).

Be stars exhibit variability at all timescales, related to stellar winds, rotation, pulsations, magnetic fields, and the presence of the circumstellar disk and clouds (see the review by Porter & Rivinius 2003). These phenomena could be at the origin of the Be phenomenon. For example, the beating of nonradial pulsations or the presence of a magnetic field are often considered as the potential source of extra angular momentum needed to bring the photospheric material to supercritical velocity and eject it from the star.

Be stars are potential secondary targets (Neiner et al. 2003a) in the asteroseismology program of the *COROT*[2] (*Convection, Rotation and planetary Transits*) mission (Baglin & The *COROT* Team 1998). *COROT* will allow us to detect pulsations in Be stars, especially multiperiodicity and beating periods in early Be stars and low-amplitude pulsations in late Be stars. It will also allow us to study the effect of the recently discovered magnetic fields in these stars (Henrichs et al. 2000; Neiner et al. 2003b), by studying the magnetic splitting of the pulsation frequencies, if a magnetic field is present in the targets, as well as the rotational modulation.

In this paper we present observations obtained in the framework of the ground-based preparation of *COROT* (§ 2) and report on 16 newly discovered Be stars and one possible supergiant in § 3. In § 4 we discuss individual properties of these stars, followed by conclusions in § 5.

## 2. SEARCH FOR Be STARS IN GAUDI OBSERVATIONS

In preparation for the *COROT* satellite observations, an ambitious ground-based observing program was performed. For

[1] Based on GAUDI, the data archive and access system of the ground-based asteroseismology programme of the *COROT* mission. The GAUDI system is maintained at LAEFF (http://ines.laeff.esa.es/corot/). LAEFF is part of the Space Science Division of INTA.

[2] http://www.astrsp-mrs.fr/projets/corot.

TABLE 1
JOURNAL OF OBSERVATIONS RETRIEVED FROM GAUDI

| HD (1) | Obs. Date (2) | $T_{exp}$ (s) (3) | Instrument (4) | S Type (5) | G Type (6) | $V$ (7) | *Hipparcos* (8) | Remarks (9) |
|---|---|---|---|---|---|---|---|---|
| 14191............. | 2001 Jul 08 | 1500 | Elodie | A1 Vn | B9 IV | 5.58 | C | |
| 30677............. | 2003 Jan 25 | 2700 | Elodie | B1 II–IIIn | B0 III | 6.84 | C | |
| 38856............. | 2000 Dec 15 | 2400 | Elodie | B8 | B5 V | 7.25 | C | |
| 43264............. | 2001 Nov 27 | 3300 | Elodie | B9 | B9 II–III | 7.51 | D | |
| 43913............. | 2002 Feb 20 | 600 | Sarg | A0 | | 7.88 | D | |
| 44783............. | 2000 Dec 18 | 1500 | Elodie | B8 Vn | B9 III | 6.23 | | |
| 46484............. | 2003 Jan 26 | 3600 | Elodie | B1 V | B0 IV | 7.65 | C | Cluster |
| 47160............. | 2002 Jan 28 | 300 | Feros | B9 | B8 IV | 7.10 | D | |
| 49567............. | 2002 Apr 01 | 1500 | Elodie | B3 II–III | B2.5 III | 6.15 | U2 | Variable |
| 50581............. | 2003 Jan 23 | 2700 | Elodie | A0 | A0 IV | 7.54 | C | Binary |
| | 2003 Jan 27 | 3600 | Elodie | | | | | |
| 51506............. | 2003 Jan 24 | 3600 | Elodie | B5 | B3 IV | 7.68 | | |
| | 2003 Jan 24 | 3600 | Elodie | | | | | |
| 166917........... | 2002 Aug 14 | 720 | Elodie | B9 | B7.5 III | 6.69 | C | |
| 170009........... | 2000 Jun 07 | 2400 | Elodie | B8 | B8.5 III | 8.00 | C | |
| 174512........... | 2001 Jul 05 | 700 | Feros | B8 | | 8.0 | U2 | Binary |
| | 2001 Jul 08 | 2400 | Elodie | | | | | |
| 176630........... | 2001 Jul 06 | 600 | Feros | B4 IV | B3 III | 7.7 | U2 | |
| 184767........... | 2002 Jul 07 | 350 | Feros | A2 | | 7.18 | C | Binary |
| 194244........... | 1999 Dec 20 | 3600 | Elodie | B9 V | B9 III | 6.14 | C | Variable |

NOTE.—For each star, the observation date, exposure time and instrument used are given in cols. (2)–(4). The spectral type given in SIMBAD and GAUDI are quoted in cols. (5) and (6). The $V$ magnitude from SIMBAD is given in col. (7). When the star has been observed by *Hipparcos*, the variability comment is given in col. (8) (C = constant, D = duplicity, U2 = unsolved variable). Remarks retrieved from SIMBAD are displayed in col. (9).

each star with a magnitude between 5.5 and 8 located in the observing cones of the *COROT* satellite, at least one spectrum was obtained. The data were mainly obtained with three high-resolution échelle spectrographs: Elodie at the 2 m telescope of the Observatoire de Haute-Provence (OHP, France), FEROS at the 1.5 m and 2.2 m telescopes of ESO (La Silla, Chile), and SARG at the 3.6 m Telescopio Nazionale Galileo (TNG, La Palma, Spain). Additional observations were also obtained at the 1.9 m telescope at SAAO (South Africa) with the Giraffe spectrograph, with the Coralie spectrograph on 1.2 m Swiss telescope in La Silla (Chile), and with the Coudé spectrograph on the 2 m telescope of the Tautenburg observatory (Germany). The data of this preparatory work obtained with the main three instruments are available via GAUDI, together with information derived from the data such as temperature and gravity (Solano et al. 2005), and are those used in this paper.

We searched for Be stars in the data available in GAUDI. We first selected all the data showing emission in H$\alpha$, by visual inspection of the normalized spectra. We then excluded the stars for which the spectral type was outside the range O6–A4 and those which were obviously not Be stars (e.g., Wolf-Rayet stars or obvious supergiants). Thanks to a literature search, we rejected the stars that were already known to be Be stars. Finally, a more detailed study of the remaining candidates was performed to precise the strength of the Be character of the stars, e.g., by checking the H$\beta$ and H$\gamma$ lines. In Table 1 we present the journal of observations of the 17 newly discovered Be stars.

Note that HD 14191, HD 30677, and HD 38856 are not in the observable regions of *COROT* but are in GAUDI because these targets belonged to old scenarii of the *COROT* mission.

When a weak H$\alpha$ emission has been detected in the GAUDI spectrum of a star, additional observations were obtained with the Aurélie spectrograph on the 1.52 m telescope of OHP (France) on January 2–11 of 2004 to confirm/infirm the Be star character of the star. This is the case for the stars HD 30677 and HD 46484. This spectrograph has been used with a resolution of 20000 at H$\alpha$ and the average signal-to-noise ratio of our observations is ∼150 at the continuum level. The data have been reduced with IRAF.[3]

## 3. 17 NEW Be STARS

### 3.1. *Global Description*

Figure 1 shows the H$\alpha$, H$\beta$, and H$\gamma$ profiles of the 17 studied stars. Emission is observed in H$\alpha$ for the 17 stars but is usually absent from H$\gamma$, except when the emission in H$\alpha$ is very strong, such as for HD 38856 or HD 51506. The emission in the H$\alpha$ line is often a double emission peak, as regularly observed in Be stars. This emission is often weak and can only be detected with high resolution spectrographs such as those used for GAUDI.

Table 1 summarizes the information given by SIMBAD[4] and the *Hipparcos* catalog (Perryman et al. 1997) for the 17 emission-line stars. Most of the stars have been observed by *Hipparcos* but found constant (C), only three of them are found to be variable (U2), and three others are found to be in a multiple system (D). For the three stars flagged as U2 in *Hipparcos*, a periodicity search has been performed (see § 4). Most of the 17 stars are classified as B-type stars in SIMBAD, except four objects classified as early A-type stars. Ae stars are often regarded as an extension of Be stars toward cooler stars, but some of them could be late Be stars with a wrong spectral classification.

[3] IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy (AURA), Inc., under cooperative agreement with the National Science Foundation.

[4] http://simbad.u-strasbg.fr.

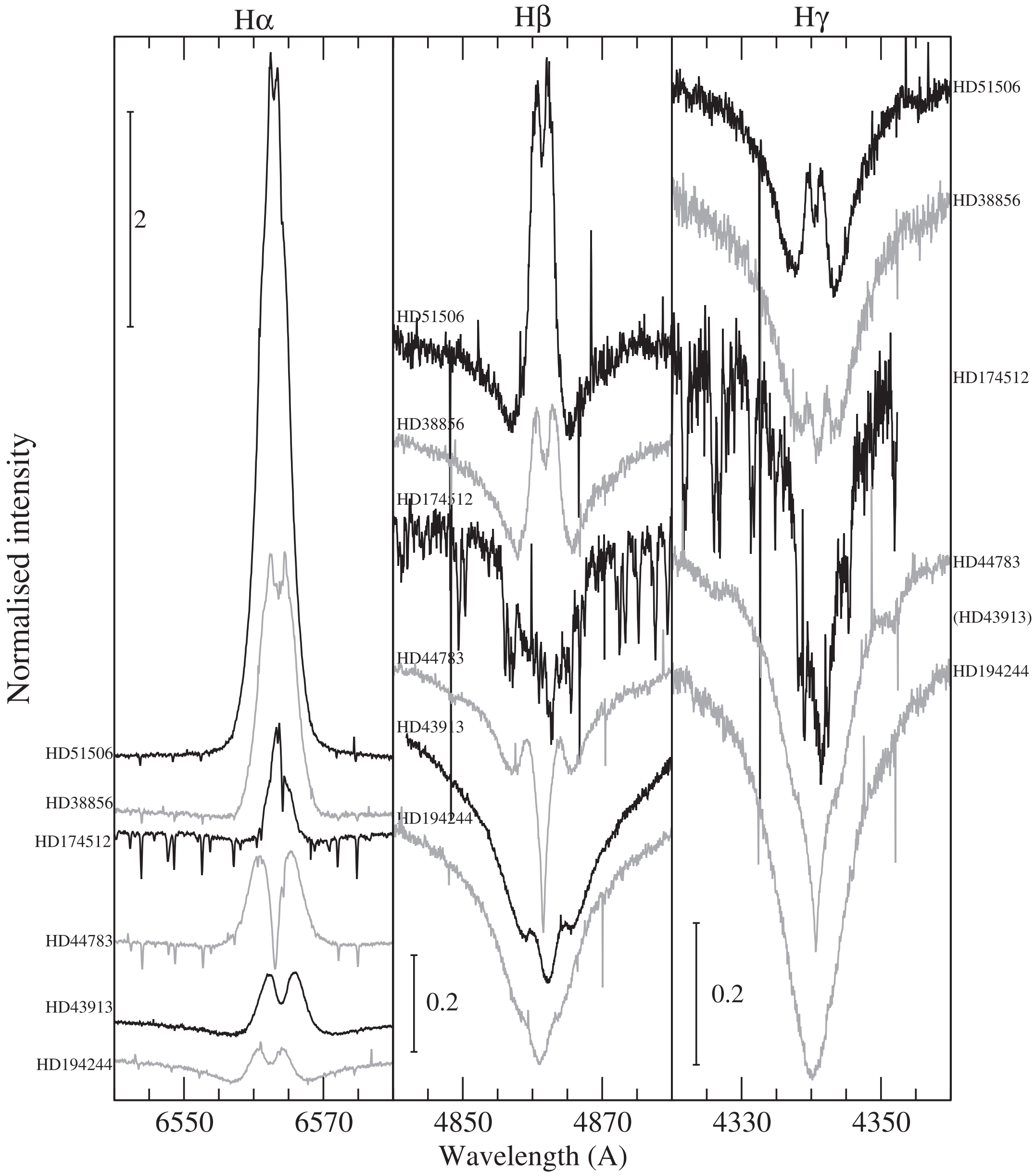


Fig. 1.—Hα, Hβ, and Hγ normalized profiles of the new emission-line stars. The spectra have been shifted in intensity to make the plot readable. The stars are displayed in the same order in each column panel. There is no spectrum of the Hγ line of HD 43913 since the SARG spectrograph does not cover this wavelength. HD 43264 might be a supergiant, the other stars are Be stars. [*See the electronic edition of the Journal for a color version of this figure.*]

Indeed, the classification of these stars is not straightforward because of their fast rotational velocity. Note, however, that the spectral types derived in GAUDI (Y. Frémat et al. 2005, in preparation) are not very different from those found in SIMBAD, in most of the cases (see Table 1).

### 3.2. *Proportion of Early Versus Late Be Stars*

About 70% of the discovered Be stars in this paper are late subtypes. Statistically, however, the frequency of known Be stars is higher for early subtypes (34% for B1 stars) than for late subtypes (8% for B9 stars) (Zorec & Briot 1997). Zorec (2000) estimates that many Be stars later than B7 are "missing" and that about 150 Be stars of late subtypes up to magnitude $V = 7$ still have to be detected.

The discovery of mainly late Be stars in the homogeneous sample of stars of GAUDI confirms this prediction. The fact that late Be stars are missing in the literature is probably due to a bias in the observations, since early Be stars usually have stronger emission (e.g., Briot 1971) and are thus easier to detect, in particular with photometry or low resolution spectroscopy.

### 3.3. $v \sin i$ *Determination*

As the stars are fainter than $V = 5.5$, not much is known about their stellar parameters. In particular no $v \sin i$ value is given in the literature for most of the stars (see Table 2). Therefore, for each star, we determine the $v \sin i$ value by applying a Fourier transform analysis to the line profiles (Gray 1976). Using this method, the estimate of $v \sin i$ is not significantly affected by asymmetry or emission in the line wings (Jankov et al. 2000). Different lines have been used depending on the spectral type of the star, e.g., Mg II for late-types and Si III for early-types. We used a limb darkening coefficient of 0.4, typical for B-type stars (Claret 2000).

The results of the $v \sin i$ determination are reported in Table 2. The error bar is about $\pm 20$ km s$^{-1}$. For the few stars for which a $v \sin i$ value is available in the literature, our results are

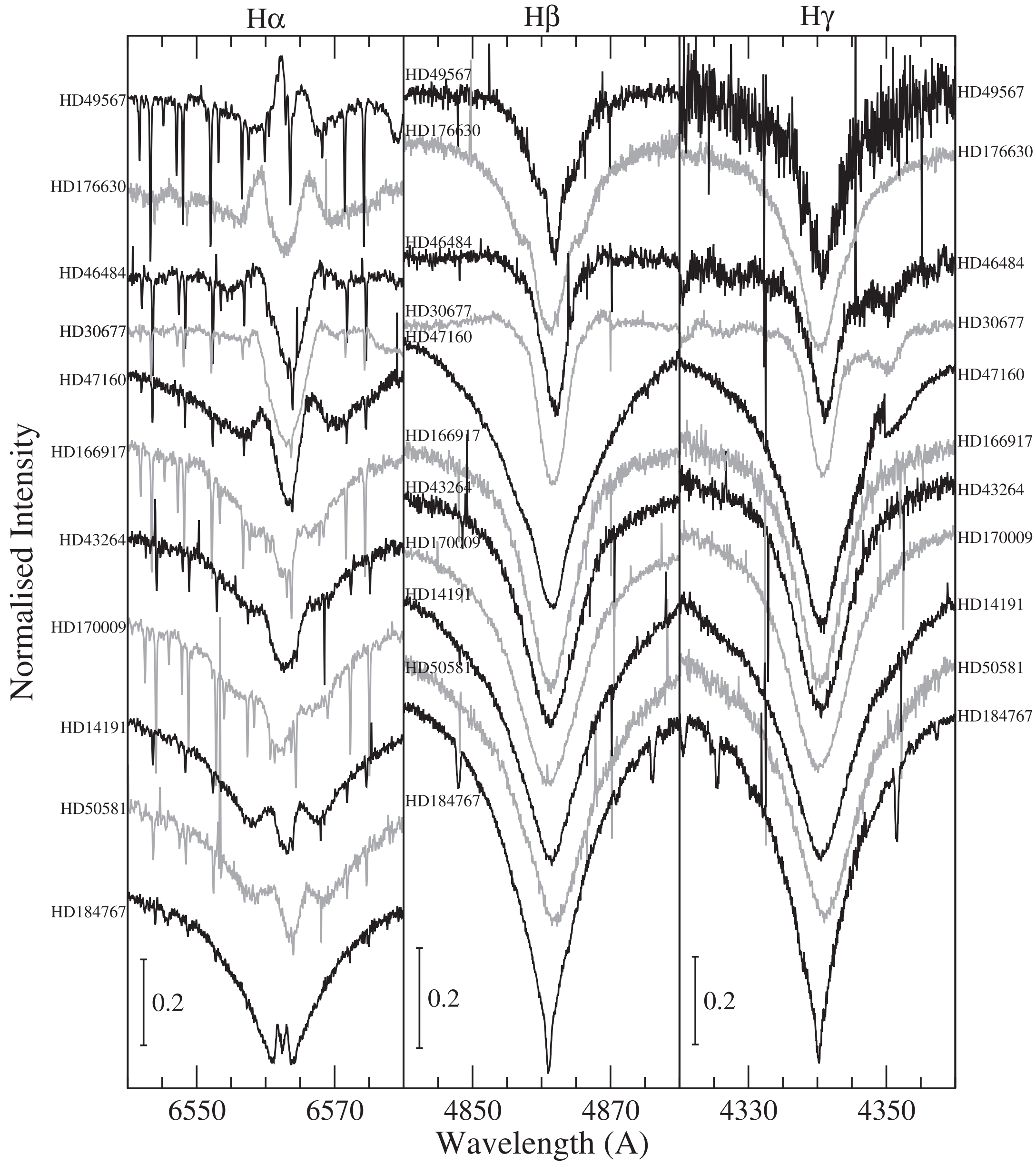


Fig. 1.—*Continued*

consistent with those. For HD 43913 and HD 174512 no $v \sin i$ value could be determined, respectively because the spectral domain covered by SARG does not contain any suitable line and because all the lines are blended.

Note that stellar parameters of all the Be stars of GAUDI, including the 17 stars of this paper, are currently being accurately determined, using stellar atmosphere models, in the framework of a preparatory study for the observations of Be stars with the *COROT* satellite (working group led by A.-M. Hubert) and will appear in a forthcoming paper (Y. Frémat et al. 2005, in preparation).

## 4. DESCRIPTION OF EACH Be STAR

*HD 14191*.—The star shows a H$\alpha$ profile with wide absorption wings and two emission peaks at $I/I_C = 0.76$.

*HD 30677*.—This star has a very weak asymmetrical double-peaked emission on the wings of H$\alpha$, with $I_V/I_C = 1.005$ for the violet ($V$) peak and $I_R/I_C = 1.03$ for the red ($R$) peak. An additional spectrum obtained with the Aurélie spectrograph on 2004 January 4 confirmed the weak H$\alpha$ emissions on each side of the absorption line. Moreover, the He i 4921 Å line and Si iii triplet lines at 4553, 4568 and 4575 Å show an asymmetrical profile, indicative of possible pulsations (Fig. 2).

*HD 38856*.—This star shows a strong emission, visible from H$\alpha$ ($I/I_C = 3.4$) to H$\beta$ ($I/I_C = 1.04$) down to H$\gamma$ ($I/I_C = 0.69$).

*HD 43264*.—The star shows a H$\alpha$ profile with absorption wings and two emission peaks at $I_V/I_C = 0.82$ and $I_R/I_C = 0.83$. Note that this star could be a supergiant according to the spectral classification in GAUDI (see Table 1) and thus possibly not a Be star. However, the large $v \sin i$ is unusual for a supergiant and the fact that the star is a binary could lead to a wrong spectral classification.

*HD 43913*.—This star shows a double-peaked emission at H$\alpha$ ($I_V/I_C = 1.41$ and $I_R/I_C = 1.43$) and a weak double-peaked emission at H$\beta$ ($I_V/I_C = 0.62$ and $I_R/I_C = 0.63$). H$\gamma$ is outside the wavelength range of the SARG spectrograph.

TABLE 2

$v \sin i$ Values (in km s$^{-1}$) Determined with a Fourier Transform Analysis from Different Lines Depending on the Spectral Type

| HD | Literature | Mg II λ4481 | Si III λ4568 | He I λ4471 | He I λ4388 |
|---|---|---|---|---|---|
| 14191 | 186 (1) | 178 | | | |
| 30677 | | | 151 | | |
| 38856 | | 183 | | 176 | |
| 43264 | | 276 | | | |
| 44783 | 230 (2) | 242 | | | |
| 46484 | | | 69 | | |
| 47160 | | 130 | | 123 | |
| 49567 | 75 (2) | 87 | | 73 | |
| 50581 | | 194 | | | |
| 51506 | | | | | 165 |
| 166917 | | 172 | | 138 | |
| 170009 | | 205 | | | |
| 176630 | | | | 122 | 183 |
| 184767 | | 21 | | | |
| 194244 | 222 (1) | 217 | | | |

Notes.—The error bar is about ±20 km s$^{-1}$. No $v \sin i$ value could be determined for HD 43913 and HD 174512 (see § 3.3).

References.—(1) Royer et al. 2002; (2) Abt et al. 2002.

*HD 44783*.—The star is a Be-shell star, with an emission at H$\alpha$ at $I_V/I_C = 1.77$ and $I_R/I_C = 1.82$, also visible at H$\beta$ ($I/I_C = 0.82$) and H$\gamma$ ($I/I_C = 0.63$).

*HD 46484*.—This star shows emission on the wings of the H$\alpha$ line at $I/I_C = 1.01$. Additional observations obtained with the Aurélie spectrograph on 2004 January 2–11 show variable profiles for the He I 4471 Å and Mg II 4481 Å lines but no emission anymore in H$\alpha$ (Fig. 3). The circumstellar disk has thus disappeared within 1 year.

*HD 47160*.—This star shows a H$\alpha$ profile with absorption wings and two emission peaks at $I_V/I_C = 0.88$ and $I_R/I_C = 0.91$.

*HD 49567*.—The H$\alpha$ line of this star has an asymmetrical double peak with $V > R$ ($I_V/I_C = 1.1$ and $I_R/I_C = 1.02$), still slightly visible in H$\beta$ ($I/I_C = 0.79$). In the *Hipparcos* data, one can see that an outburst occurred around HJD 2,448,356 (Fig. 4). We remove the four points obtained during the outburst and those with large error bars and search for periodicity in the remaining points. We find a frequency at $f = 0.39$ cycles day$^{-1}$ ($P = 2.56$ days; Fig. 5), compatible with $f = 0.40$ cycles day$^{-1}$ found by Koen & Eyer (2002).

*HD 50581*.—This star shows a double-peaked emission in H$\alpha$ ($I/I_C = 0.77$) but no emission in H$\gamma$.

*HD 51506*.—The star has a very strong emission in H$\alpha$ with $I_V/I_C = 7.5$ and $I_R/I_C = 7.2$, visible down to H$\beta$ ($I/I_C = 1.5$) and H$\gamma$ ($I/I_C = 0.86$). The H$\alpha$ line has a quadruple emission profile (the fainter peaks being around $I/I_C = 5.7$), which can be attributed either to a disk that is optically thick in the direction perpendicular to the disk plane for a star with an inclination angle around 30°–40° (Hummel 2000) or to a disk composed of two rings. The Fe II lines also show a double-peaked emission profile.

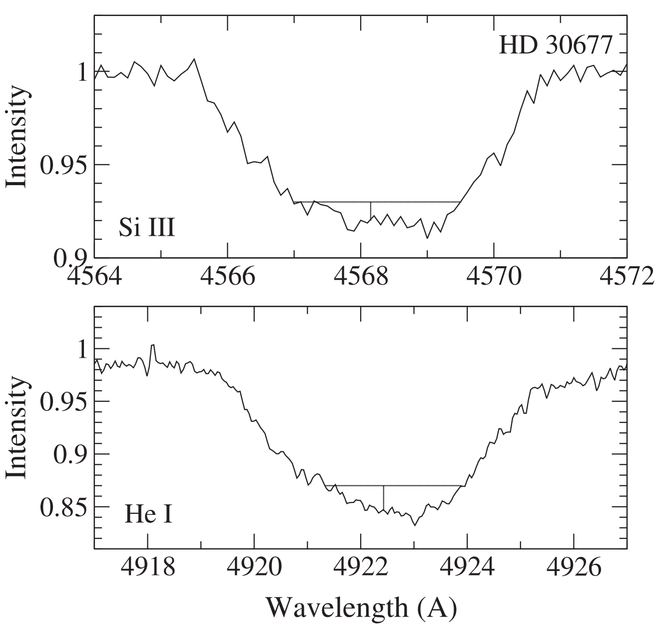


Fig. 2.—Si III 4568 Å and He I 4921 Å line profiles of the star HD 30677 show an asymmetrical profile, indicative of possible pulsations. A vertical dashed line at the center of the profiles and a horizontal dashed line at an arbitrary intensity value have been overplotted to emphasize the asymmetry.

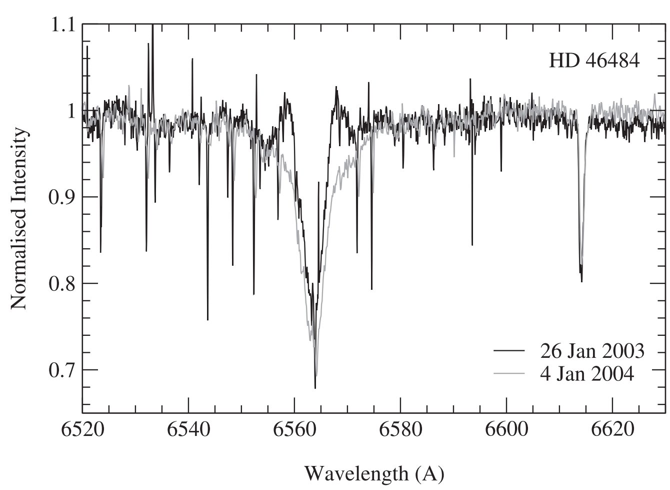


Fig. 3.—H$\alpha$ profile of HD 46484 observed in January of 2003 and 2004. The emission disappeared within 1 year. [*See the electronic edition of the Journal for a color version of this figure.*]

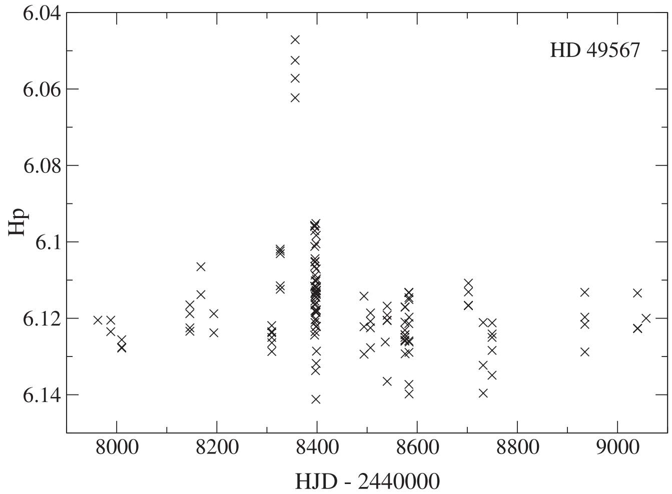


FIG. 4.—*Hipparcos* data for HD 49567. An outburst is observed around HJD 2448356. The error bars on the *Hipparcos* magnitude are less than 0.01.

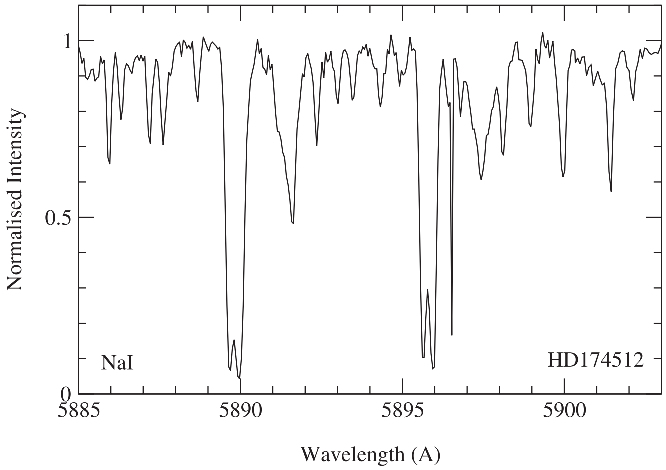


FIG. 6.—Na I 5890 and 5896 Å lines of the star HD 174512, which show an interstellar component and a blueshifted circumstellar component.

*HD 166917*.—This star has a weak double-peaked emission in H$\alpha$ with $I/I_C = 0.8$ but no emission is detectable in H$\beta$ or H$\gamma$.

*HD 170009*.—The star shows a weak emission in H$\alpha$ ($I/I_C = 0.8$) but no emission in H$\beta$ or H$\gamma$. The profiles are very similar to HD 166917.

*HD 174512*.—This star shows an emission peak in H$\alpha$ with $I/I_C = 2.01$. From the *Hipparcos* photometry, we find a possible period of variations with $f = 0.82$ c d$^{-1}$ ($P = 1.22$ days; Fig. 5). This star is also a binary and metal lines such as Ti II and Cr II from a cold companion are observed in the spectrum. Moreover, the Ca II 3933 and 3968 Å and Na I 5890 and 5896 Å lines (Fig. 6) show an interstellar component and a blueshifted ($\sim$14 km s$^{-1}$) circumstellar component, similar to what is sometimes observed in shell Be stars (e.g., 48 Lib; Hanuschik & Vrancken 1996) and Herbig Ae/Be stars (Catala et al. 1986). Although no $v \sin i$ could be determined with the Fourier method (§ 3.3), the line width corresponds to a low projected rotational velocity with $v \sin i \sim 20$ km s$^{-1}$. If HD 174512 is a shell Be star, i.e., it is observed equator-on, it has an inclination angle close to 90°, and thus it is an intrinsically slow rotator. If HD 174512 is a Herbig Be star rather than a shell Be star, and thus has an accretion disk rather than an excretion disk, it would be the second example of Herbig Ae/Be stars with a low $v \sin i$ after HD 104237. However, other common features of Herbig stars (e.g., presence of the IR Ca II triplet, emission in the Fe II 5018 Å line) are not present in the spectra. Intrinsically slowly rotating Be stars and Herbig Be stars with a low $v \sin i$ are both rare cases and this star is thus in any case a very interesting object that deserves further investigations.

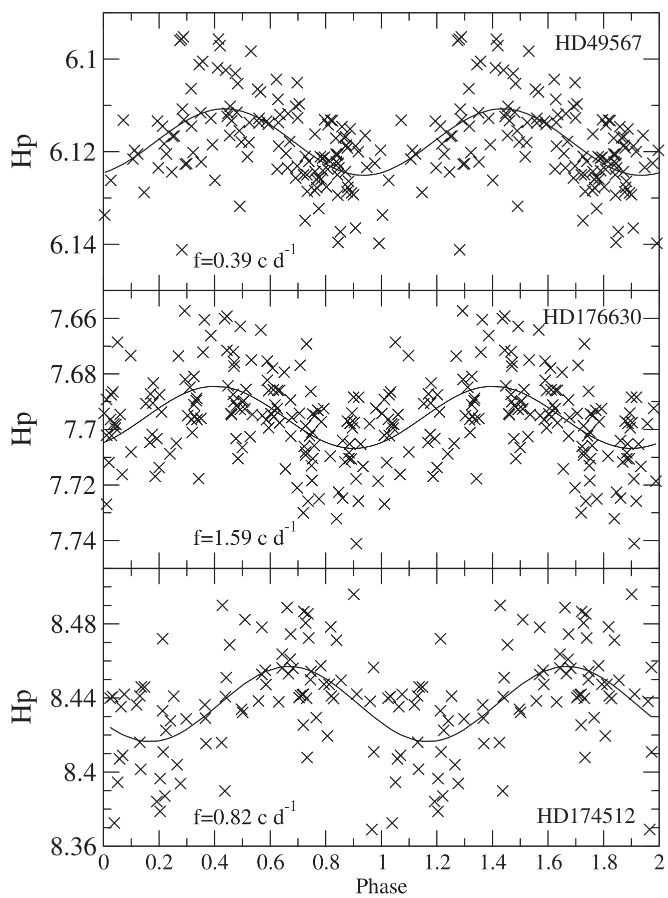


FIG. 5.—*Hipparcos* data for HD 49567, HD 176630, and HD 174512 folded in phase with $f = 0.39$, 1.59, and 0.82 cycles day$^{-1}$ respectively. The *Hipparcos* magnitude Hp is close to the *V* magnitude.

*HD 176630*.—This star shows emission in H$\alpha$ ($I_V/I_C = 1.04$ and $I_R/I_C = 1.02$) and a faint double-peaked emission in H$\beta$ ($I/I_C \sim 0.72$). The He I lines at 4921 and 5876 Å seem to be asymmetrical, possibly indicative of the presence of pulsations. In the *Hipparcos* data, we find a periodic variation with $f =$ 1.59 cycles day$^{-1}$ ($P = 0.63$ days, Fig. 5).

*HD 184767*.—The star shows a weak double-peaked narrow emission in H$\alpha$ ($I/I_C = 0.65$) and no emission in H$\beta$ or H$\gamma$.

*HD 194244*.—This star shows a H$\alpha$ profile with absorption wings and a double-peaked emission at $I_V/I_C = 1.14$ and $I_R/I_C = 1.08$, also visible but weak in H$\beta$ ($I/I_C \sim 0.57$).

## 5. CONCLUSION

Thanks to the ground-based preparatory work of *COROT* and its database GAUDI, we discovered 17 B-type stars with a magnitude between 5.5 and 8 that show emission at least in the H$\alpha$ line. We thus reclassify those stars as Be stars. One of them (HD 43264), however, might be a supergiant.

These newly discovered Be stars can be selected as Be targets for the asteroseismology program of the *COROT* mission. They increase the number of Be stars in the field of view of *COROT* by $\sim$25%, which is important for the target selection of the mission.

Moreover, ∼70% of the discovered Be stars are of late subtypes. Be stars have been mostly found among early subtypes until now and late subtypes are lacking, but this is probably due to an observational bias.

Finally, one of the discovered Be star (HD 174512) is either a slowly rotating shell Be star or a Herbig Be star with a low $v \sin i$, which makes this star especially interesting.

We are grateful to the ground-based asteroseismology working group of *COROT* and all the contributors of GAUDI, in particular W. Weiss (Univ. Vienna, Austria), V. Tsymbal and D. Lyashko (Tavrian National Univ., Ukraine) for releasing the SARG spectrum before the end of the GAUDI proprietary time. This research has made use of the SIMBAD database maintained at CDS, Strasbourg, France.

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