The complex structure of the SiIV λλ 1393.755, 1402.73 Å regions of 42 BeV stars

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Introduction

The ultraviolet resonance lines of SiIV (λλ 1393.755, 1402.77 Å) arise from the transition $3s^2S$-$3p^2P^0$. This doublet is usually an intense feature in the spectra of early type stars and provides us with a useful tool for the study of the stellar atmosphere's structure. Thus, it has been studied by many researchers. The profile of the resonance lines seem to depend on the spectral subtype and the luminosity class, (Snow 1977), so it has been proposed that the doublet may be a significant tool for the spectral classification (Walborn & Nichols-Bohlin 1987; Prinja 1990). It has been observed that the lines present decreasing strength from the earliest to the latest spectral subtypes. Panek & Savage (1976) and Henize et al. (1976, 1981) observed that they disappear in the spectra of Be stars later than B3. However, Marlborough (1982), Marlborough & Peters (1982) and Slettebak (1994) observed the doublet may be observed in stars as cool as B8. Many researchers have studied the existence of Satellite Absorption Components (SACs or DACs), which accompany the SiIV resonance lines in the spectra of Be stars and which are of circumstellar or interstellar origin (Underhill 1974, 1975; Snow 1977; Lamers & Snow 1978; Gathier et al. 1981; Lamers et al. 1982; Marlborough 1977, 1982; Snow et al. 1979; Henrichs et al. 1983; Hack et al. 1983; Codina et al. 1984; Hubeny et al. 1985, 1986; Danezis 1984, 1986; Danezis et al. 1991; Sahade et al. 1984; Sahade & Brandi 1985; Hutsemekers 1985; Aydin et al. 1988; Doazan et al. 1988; Bruhweiler et al. 1989; Sapar & Sapar 1992; Ferero 1998, Lyratzi et al. 2003). Finally, the SiIV doublet is an indicator of mass-loss effects in B stars, especially when asymmetries appear in both of the resonance lines (Snow & Marlborough 1976; Snow & Morton 1976; Lamers & Snow 1978; Henrichs et al. 1983).

Besides, Kondo et al. (1981) studied the binary system U Cephei. They observed shallow and broad absorption lines of SiIV in the star's spectra from which they calculated a rotation velocity of about 300 km/s, which led them to associate the lines with the photosphere of the B star. They reported variations of the total absorption, perhaps due to hot regions on the B star and gas streaming effects. By comparing with the far-UV spectra of B stars, they found that the SiIV and CIV doublet lines are too strong for a B7 star, while they are comparable to a B0-1 star. They suggested that "the SiIV and CIV lines arise from the region above the conventional photosphere, where the infalling matter from the gas stream gives rise to a pseudophotosphere, whose temperature is higher than that of the photosphere observed from the ground. This pseudophotosphere may exist primarily along the equatorial, region of the BV star". They mentioned that the resonance lines of SiIV and CIV show effects of gas streaming and, possibly, hot regions on the B star, which are due to the hot gas stream of low density leaving the G star and orbiting about 270º around the B star, before escaping from the system. Finally, they suggested that "the absence of emission indicates that the total volume occupied by the gas stream having significant densities is smaller than the volume of the B star".

Also, Codina et al. (1984) studied the UV spectra of the B0.5 IIIe star HD 110432, and observed "broad absorption photospheric lines, narrow absorption lines of high ionized species displaced to the short wavelengths, indicating velocities of about -1350 km/s and very narrow absorption lines of interstellar origin". They calculated a rotation velocity of about 360±40 km/s. As the resonance doublets of SiIV and CIV are asymmetric with extended blue wings, they probably indicate a tenuous expanding envelope. For the narrow absorption lines (SACs) of high ionized species such as SiIV, CIV and NV, they proposed that "they could originate in matter ejected occasionally by the star due to some kind of photospheric activity. In this line of thought, such an ejection is probably a localized phenomenon not associated with the whole surface of the star (blob)". Concerning the "blobs", they proposed that the gas inside them is probably hot, not necessarily in ionization equilibrium and that the ionization is caused by collisional processes.

Sapar & Sapar (1992) studied the UV spectra of η CMa and found that the SiIV resonance lines show changes in their profiles, suggesting the presence of some shell condensations moving with time-dependent radial velocities. They observed "blue-shifted satellite components belonging to expanding shell condensations", with radial velocities -360 km/s, -180 km/s, -110 km/s and -30 km/s. They proposed accelerating expansion of the shell, as they calculated greater radial velocities for the shell components than those from earlier observations by Underhill (1974, 1975). They attributed the presence of strong unshifted resonance line components of SiIV to a hot circumstellar gas cloud. They concluded to such behavior being the result of "an extended expanding envelope having dense shells which move away from the star and have different velocities".

In this paper we present a statistical study of the UV SiIV resonance lines λλ 1393.755, 1402.73 Å in the spectra of 42 BeV stars. Our study is based on the model proposed by Danezis et al. (2003) and our purpose is to extract the limits of the values of the apparent rotation and radial velocities (Vrot, Vexp) and to check whether there exists a common physical structure for the atmospherical regions which create the Satellite Absorption Components (SACs) or the SiIV resonance lines in the spectra of all the BeV stars. It is essential to perform such a study in a great number of stars, in order to accept that the proposed model gives satisfactory results and is able to describe the structure of these atmospherical regions.

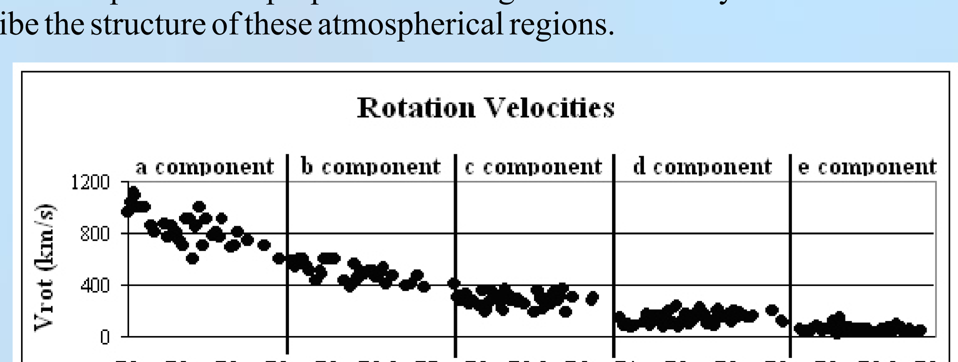


Diagram 1: Apparent rotation velocities of all the SACs as a function of the spectral subtype. Five levels of rotation velocity are presented with the mean values of 830 km/s, 492 km/s, 285km/s, 137 km/s and 51 km/s. The observed dispersion may be due to the different values axis inclination of the regions where the SACs are created.

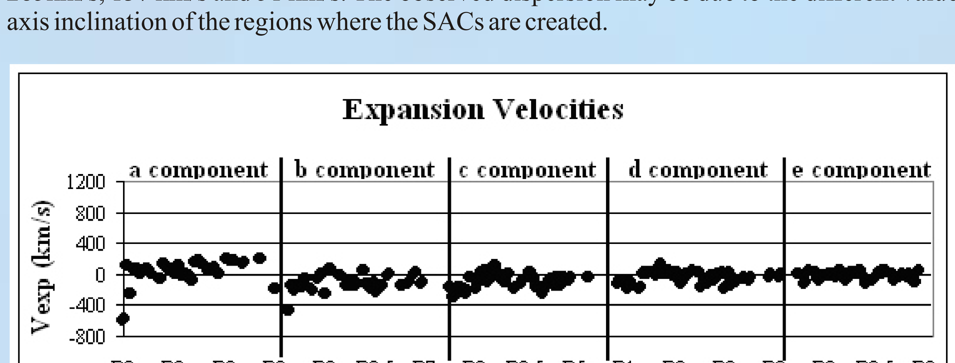


Diagram 2: Apparent expansion/contraction velocities of all the SACs as a function of the spectral subtype. The values of the expansion/contraction velocity of all the SACs lie in the range between -306 km/s and +194 km/s.

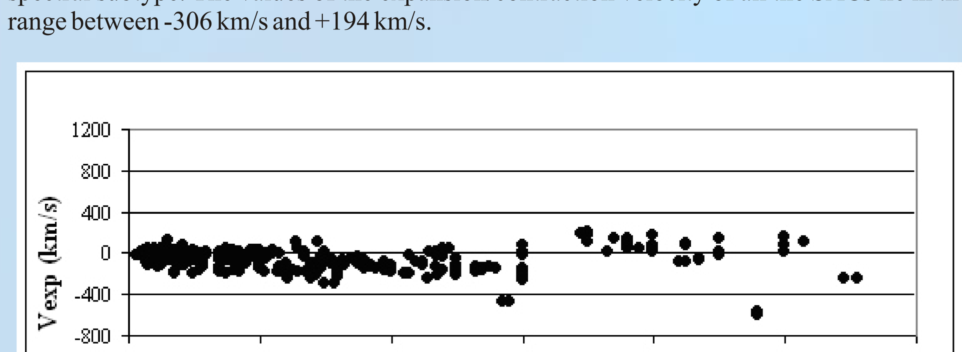


Diagram 3: Apparent expansion/contraction radial velocities of all the SACs as a function of the respective apparent rotation velocities. For the smaller values of the rotation velocity (12 - 560 km/s) the values of the expansion/contraction velocity lie in a small range between -306 and +118 km/s. As the rotation velocity increases (570 and 1110 km/s) the expansion/contraction velocity presents greater dispersion and lies between -608 and +192 km/s.

Method of spectral analysis

In order to study the physical structure and the existence of SACs phenomena in the regions where these lines are created we used the model proposed by Danezis et al. (2002b, 2003a). This model presupposes the existence of independent density layers of matter in these regions. With this method we can calculate the apparent rotation (V_{rot}) and expansion/contraction radial velocities (V_{exp}) of these density regions, as well as their ξ value, which is an expression of the optical depth. The final function which reproduces the complex line profile is:

$$I \quad I_{0} \;{}_{i}\; \exp \quad L_{i}\;{}_{i} \qquad {}_{j}\; S_{e}\, 1 \quad \exp \quad L_{ej}\;{}_{eej} \quad \exp \quad L_{g}\;{}_{g}$$

L_i, L_e, L_g: are the distribution functions of the absorption coefficients $k_{\lambda i}$, $k_{\lambda e}$, $k_{\lambda g}$ respectively. Each L depends on the values of the apparent rotation velocity as well as of the apparent expansion/contraction radial velocity of the density shell, which forms the spectral line (V_{rot}, V_{exp}) and

ξ: is an expression of the optical depth.

Observational Data

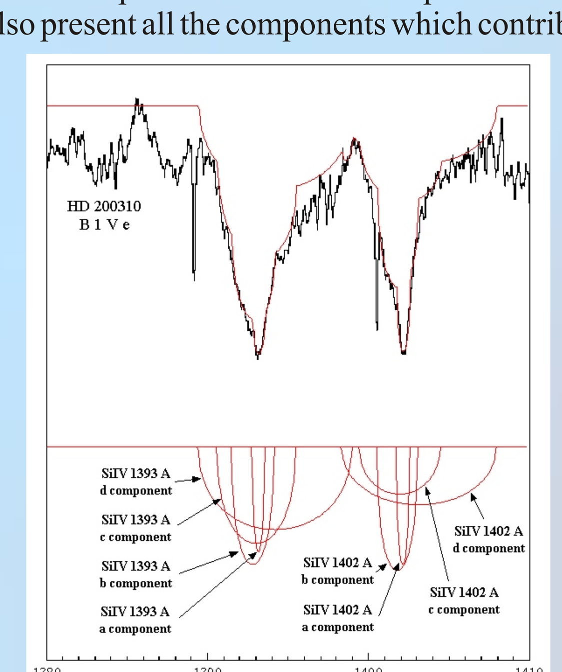
The data we used are the SiIV resonance lines of 42 BeV stars. The stars' spectrograms have been taken with IUE satellite with the Short Wavelength range Prime camera (SWP) at high resolution (0.1 to 0.3 Å). The spectral types of the studied stars have been taken by the SIMBAD database (Centre de Donnees Astronomiques de Strasbourg (CDS), Strasbourg, France). Our data are presented in the following Table.

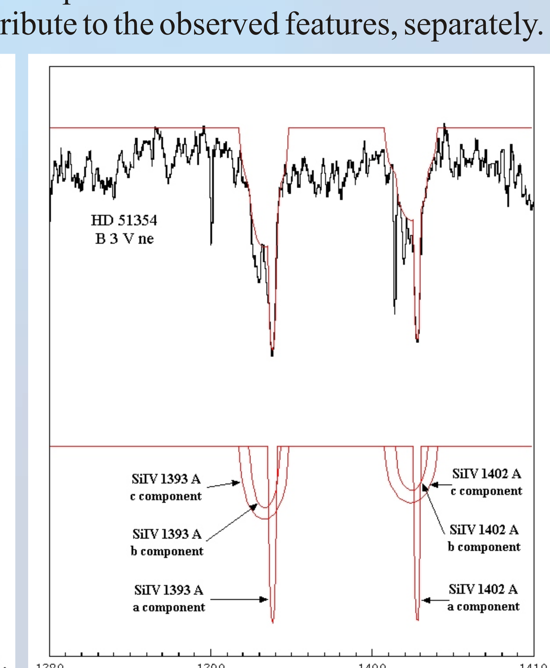
Table

Star	Spectral Type	Camera	Star	Spectral Type	Camera
HD 206773	B0 V : pe	Swp 18753	HD 32343	B2.5 V e	Swp 06932
HD 200310	B1 V e	Swp 10853	HD 37967	B2.5 V e	Swp 21491
HD 212571	B1 V e	Swp 07009	HD 65875	B2.5 V e	Swp 06544
HD 35439	B1 V pe	Swp 07716	HD 187811	B2.5 V e	Swp 19937
HD 44458	B1 V pe	Swp 18306	HD 191610	B2.5 V e	Swp 08600
HD 200120	B1.5 V nne	Swp 09458	HD 208682	B2.5 V e	Swp 19935
HD 30076	B2 V e	Swp 20844	HD 20336	B2.5 V ne	Swp 19934
HD 32991	B2 V e	Swp 14840	HD 60855	B2/B3 V	Swp 21915
HD 50083	B2 V e	Swp 15958	HD 51354	B3 ne	Swp 16547
HD 58050	B2 V e	Swp 16536	HD 25940	B3 V e	Swp 07011
HD 164284	B2 V e	Swp 08614	HD 45725	B3 V e	Swp 28106
HD 41335	B2 V ne	Swp 08604	HD 183362	B3 V e	Swp 31218
HD 52721	B2 V ne	Swp 25377	HD 208057	B3 V e	Swp 05909
HD 58343	B2 V ne	Swp 08605	HD 205637	B3 V : p	Swp 07008
HD 148184	B2 V ne	Swp 07753	HD 217543	B3 V pe	Swp 31186
HD 194335	B2 V ne	Swp 19938	HD 22192	B5 V e	Swp 08593
HD 202904	B2 V ne	Swp 08601	HD 138749	B6 V nne	Swp 09124
HD 65079	B2 V ne&	Swp 53980	HD 192044	B7 V e	Swp 28251
HD 28497	B2 V : ne	Swp 08594	HD 22780	B7 V ne	Swp 20846
HD 45995	B2 V nne	Swp 09936	HD 18552	B8 V ne	Swp 55906
HD 10516	B2 V pe	Swp 08592	HD 199218	B8 V nne	Swp 30071

Figures

The best fit is not just the graphical composition of some components (line profiles). The reproduced feature is the result of the final function of the model. In these figures we present the fitted SiIV resonance lines of the BeV stars HD 200310 and HD 31354. The black line presents the observed spectral line's profile and the red one the model's fit. We also present all the components which contribute to the observed features, separately.





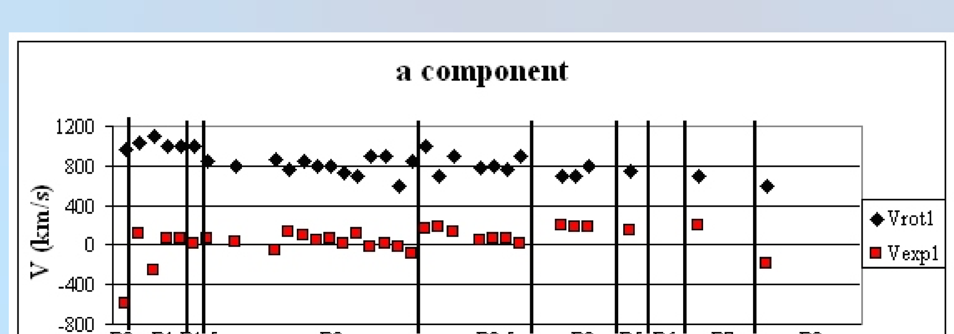


Diagram 4: Apparent rotation and expansion/contraction radial velocities of the first SAC as a function of the spectral subtype. The first SAC's rotation and expansion/contraction velocities present a uniform fluctuation around the values of 830 km/s and +31 km/s respectively.

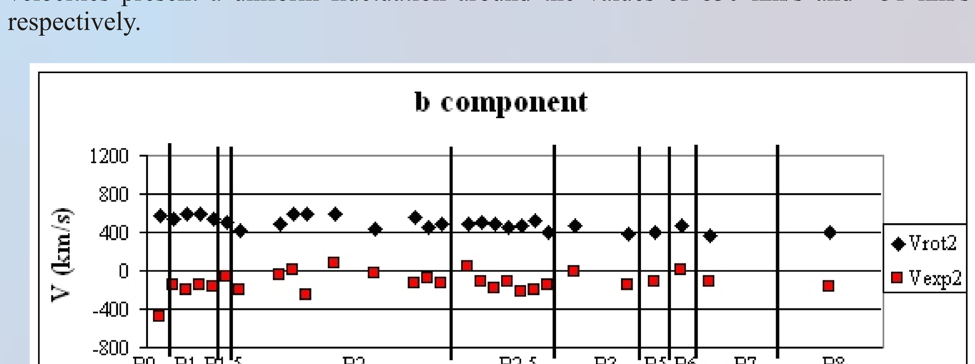


Diagram 5: Apparent rotation and expansion/contraction radial velocities of the second SAC as a function of the spectral subtype. A uniform fluctuation is also presented in the second SAC's rotation and expansion/contraction velocities around the values of 492 km/s and -131 km/s respectively.

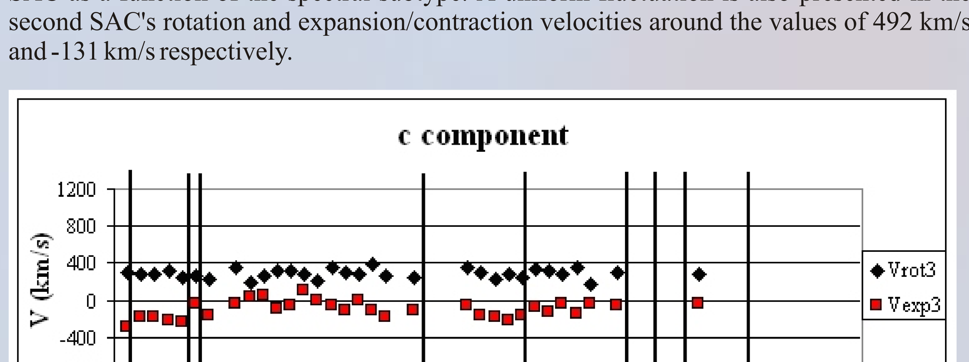


Diagram 6: Apparent rotation and expansion/contraction velocities radial of the third SAC as a function of the spectral subtype. The third SAC's rotation and expansion/contraction velocities fluctuate around the values of 285 km/s and -105 km/s respectively.

Conclusions

We applied the method described above, on the SiIV resonance lines in 42 BeV stellar spectra and we calculated the apparent rotation and radial velocities, in order to extract some general physical lows for the SiIV region of BeV stars. Some interesting results inferred from the investigations are the following:

1. The proposed rotation model gives satisfactory results for the regions where the SiIV λλ 1393.755, 1402.73 Å resonance lines are created.

2. The absorption atmospherical regions where the SiIV resonance lines are created are formed of five independent density layers of matter, which rotate and move radially with different apparent velocities and which do not appear, though, to all the 42 BeV stars we studied. These regions present five apparent rotation velocity groups of 51 km/ s, 137 km/s, 285 km/s, 492 km/s, 830 km/s. The apparent expansion/contraction radial velocities of these regions are about -25 km/s, -54 km/s, -105 km/s, -131 km/s and+31 km/s, respectively. These calculated values lead us to accept that the SiIV resonance lines of the BeV stellar spectra present Satellite Absorption Components.

3. We observe that the apparent rotation velocities of the five density regions present a uniform fluctuation with the spectral subtype, which we could not accept as accidental. We detected that there exists a relation among the parameters V_{rot} and V_{exp}.

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References

Aydin, C., Brandi, E., Engin, S., Ferrer, O. E., Hack, M., Sagade, J., Solivella, G. & Yilmaz, N.: 1988, A&A, 193, 202
Bruhweiler, F. C., Grady, C. A. & Chiu, W. A.: 1989, ApJ, 340, 1038
Codina, S. J., de Freitas Pacheco, J. A., Lopes, D. F. & Gilra, D.: 1984, A&AS, 57, 239
Danezis, E.: 1984, The nature of Be stars, PhD Thesis, University of Athens.
Danezis, E.: 1986, IAU, Colloq. No 92, Physics of Be Stars, Cambridge University Press.
Danezis, E., Theodossiou, E. & Laskarides, P.G.: 1991, Ap&SS, 179, 111-139
Danezis, E., Nikolaidis, D., Lyratzi, V., Stathopoulou, M., Theodossiou, E., Kosionidis, A., Drakopoulos, C., Christou G. & Koutsouris, P.: 2003, Ap&SS, 284, 1119
Doazan, V., Thomas, R. N. & Bourdonneau, B.: 1988, A&A, 205L, 11
Ferrero, R. F.: 1998, LNP, 506, 99
Gathier, R., Lamers, H. J. G. L. M. & Snow, T. P.: 1981, ApJ, 247, 173
Hack, M., Sahade, J., de Jager, C. & Kondo, Y.: 1983, A&A, 126, 115
Henize, K. G., Wray, J. D., Parsons, S. B. & Benedict, G. F.: 1976, IAUS, 70, 191
Henize, K. G., Wray, J. D. & Parsons, S. B.: 1981, AJ, 86, 1658
Henrichs, H. F., Hammerschlag-Hensberge, G., Howarth, I. D. & Barr, P.: 1983, ApJ, 268, 807
Hubeny, I., Stefl, S. & Harmanec, P.:1985, BAICz, 36, 214
Hubeny, I., Harmanec, P. & Stefl, S.:1986, BAICz, 37, 370
Hutsemekers, D.: 1985, A& AS, 60, 373-388
Kondo, Y., McCluskey, G. E. & Harvel, C. A.: 1981, ApJ, 247, 202
Lamers, H. J. G. L. M. & Snow, T. P.: 1978, ApJ, 219, 504
Lamers, H. J. G. L. M., Gathier, R. & Snow, T. P.: 1982, ApJ, 258, 186
Lyratzi, Å., Danezis, E., Stathopoulou, M., Theodossiou, E., Nikolaidis, D., Antoniou, A., Drakopoulos, C., Soulikias, A. & Koutroumanou, M.: "SACs phenomena in SiIV regions of 42 BeV stars". JENAM 2003, August 25 - 31, 2003 Budapest, Hungary
Marlborough, J. M.: 1977, ApJ, 216, 446
Marlborough, J. M.: 1982, IAUS, 98, 361
Marlborough, J. M. & Peters, G. J.: 1982, IAUS, 98, 387
Panek, R. J. & Savage, B. D.: 1976, ApJ, 206, 167
Prinja, R. K.: 1990, MNRAS, 246, 392
Sahade, J., Brandi, E. & Fontela, J.M.: 1984, A&AS, 56, 17
Sahade, J. & Brandi, E.: 1985, Rev. Mex., 10, 229
Sapar, L. & Sapar, A.:1992, BaltA, 1, 37
Slettebak, A.: 1994, ApJS, 94, 163
Snow, T. P. & Marlborough, J. M.: 1976, ApJ, 230L, 87
Snow, T. P. & Morton, D. C.: 1976, ApJS, 32, 429
Snow, T. P.: 1977, ApJ, 217, 760
Snow, T. P., Peters, G. J. & Mathieu, R. D.: 1979, ApJS, 39, 359
Underhill, A. B.: 1974, ApJS, 27, 359
Underhill, A. B.: 1975, ApJ, 199, 691
Walborn, N. R. & Nichols-Bohlin, J.: 1987, PASP, 99, 40

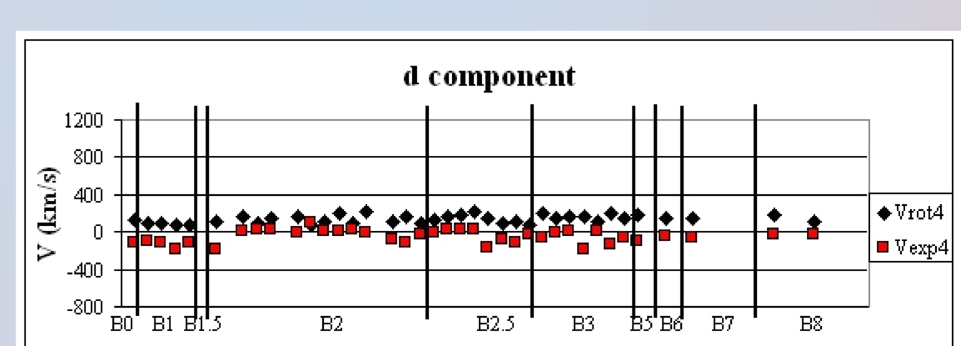

Diagram 7: Apparent rotation and expansion/contraction radial velocities of the forth SAC as a function of the spectral subtype. The forth SAC's rotation and expansion/contraction velocities fluctuate around the values of 137 km/s and -54 km/s respectively.

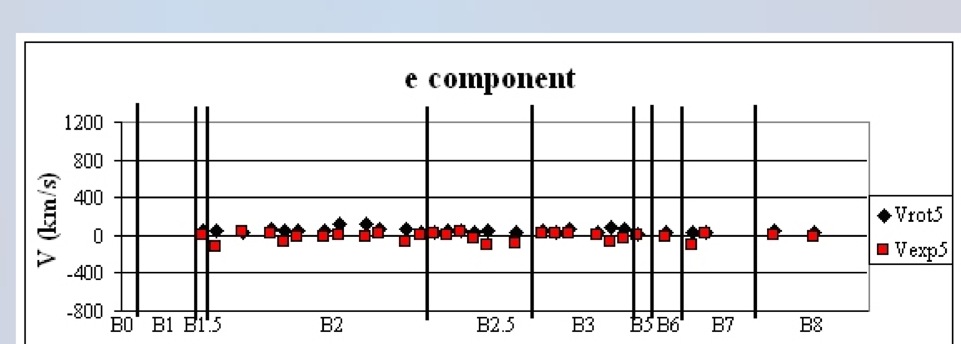

Diagram 8: Apparent rotation and expansion/contraction radial velocities of the fifth SAC as a function of the spectral subtype. The fifth SAC's rotation and expansion/contraction velocities fluctuate around the values of 51 km/s and -25 km/s respectively.

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