Single vs binary hot subdwarfs: towards a 200-pc volume-limited complete sample

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Abstract *From current statistics, based on mag-limited samples, ~35% of sdO/B hot subdwarfs are in close binaries with M-dwarf/WD companions, ~30% are in wide binaries with F/G/K MS stars, ~35% are apparently singles. However, without a companion it is hard to explain the huge mass loss near the RGB tip needed to form an sdB star. The presence of a substellar companion, difficult to detect, is a possibility. The goal of this project is to shed light on the formation mechanisms of single sdO/B stars by searching for binary signatures on a small but* ***complete*** *200-pc volume-limited sample using different data/methods: TESS light curves, Gaia spectra, SEDs, and precise RVs from Harps/Harps-N spectra.*

Introduction, selection of the targets, data/methods

The target list was extracted from the catalog of **Culpan+2022 (A&A 662, A40)**, based on Gaia EDR3, which was complete up to about 250 pc as we can see from Fig.1. As a first step we considered the sample within 200 pc (20 stars) and later we added one missing star from the more recent 500-pc volume-limited sample by **Dawson+2024 (A&A 686, A25)**. These 21 stars are listed in Table 1. We can see that 2 are in tight binaries with a WD, 1 is in a tight binary with an M-dwarf, and 3 have MS companions in larger orbits. Among the remaining 15 stars, 3 show tiny periodic variations in their TESS light curves, and one shows irregular photometric variations. The objective of this project is to verify how many of these stars are truly single, moving down as much as possible the detection limit of a faint, low-mass companion. The HARPS and HARPS-N instruments are ideal to obtain a homogeneous set of high-resolution spectra in both hemispheres, from which accurate radial velocities (RVs) can be derived. Using the cross correlation function (CCF) on 100-200 metal absorption lines (up to 500 in one case), we can reach typical errors of 100-200 m/s (Fig.2).

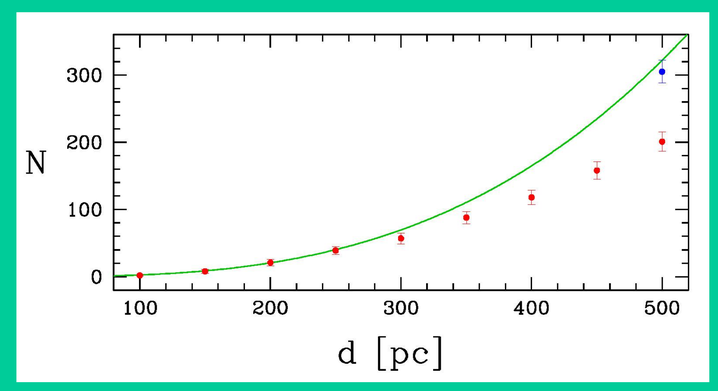


Fig.1. Local space density of sdO/B subdwarfs. We see that the **Culpan+2022** catalog (red dots) is complete up to ~250 pc assuming a local space density of 6.15×10^{-7} pc^{-3}, as determined by **Dawson+2024** (the blue dot is the number of hot subdwarfs within 500 pc obtained by these authors).

Name	SC	G mag	Teff	log g	d (pc)	# spectra	SN^
HD188112	sdB+WD	10.17	21500	5.66	72		
HD149382	sdB	8.89	34200	5.89	76	21	103.6
BD+284211	sdO	10.45	81300	6.52	112	(4*)	
BD+254655	sdO	9.65	39500	5.8	116	8+(2*)	62.6
CD-2314565	sdB+WD	9.80	27200	5.3	139		
PG1234+253	sdB	10.46	34500	5.83	142	5	104.6
BD+75325	He-sdO	9.49	52000	5.50	145	4	62.8
EC20089-6511	sdB	11.31			170	(13*)	
PG0342+026	sdBV	10.93	26000	5.59	171	4	71.3
BD+102357	sdO+A3/5	8.81			171		
PG0044+097	sdBV	10.26	24650	5.38	172	11	101.9
HW Vir	sdB+dM	10.59	28500	5.63	173		
HD127493	He-sdO	9.96	42100	5.61	176	4	77.8
HD185510	sdB+K	7.80	25000	6.0	179		
CD-38222	sdB	10.31	26300	5.31	183	(8*)	
EC03591-3232	sdB	11.15	28000	5.55	184	(3*)	
BD+393226	He-sdO	10.13	44700	5.5	189	1+(2*)	128.7
UVO0512-08	sdB	11.18	38400	5.77	191	3+(2*)	65.0
TYC4406-285-1	sdB	11.22	25600	5.67	193		
BD+341543	sdB+F	10.05	25400	5.54	194		
PG1758+364	sdB	11.30	34600	5.79	194	7+(1*)	70.0

Table 1. List of sdO/B subdwarfs within 200 pc. From col.7 we see that we have spectra or we should soon have spectra (*=scheduled) for all single stars except TYC4406-285-1. ^The SN in col.8 is the mean signal-to-noise ratio at 470 nm.

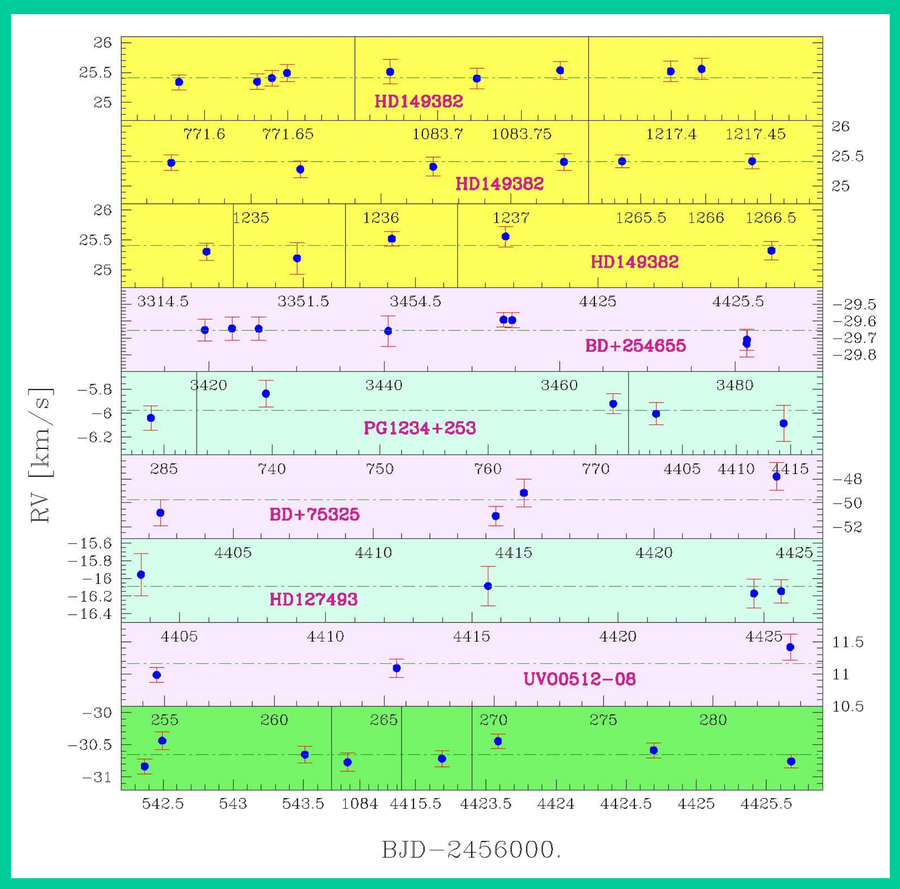


Fig.2. Radial velocities obtained from Harps-N spectra using the CCF method with 4 masks, corresponding to 4 different models: 25000 K He-poor, 35000 K He-poor, 38000 K He-rich, 50000 K, He-rich. The masks were built from 4 line lists kindly provided by Matti Dorsch.

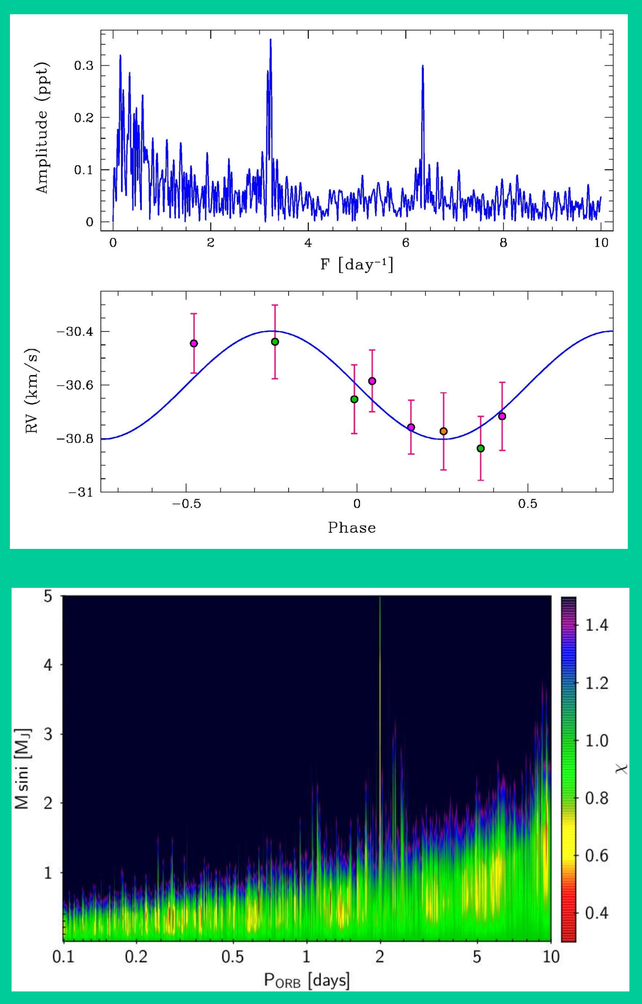
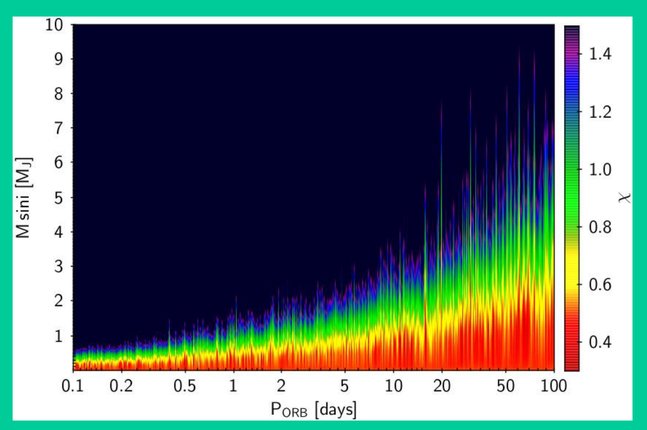


Fig.3. **Upper panel**: TESS Fourier spectrum of one of the targets showing periodic photometric variations (**top**) and phase diagram of the RV measurements folded onto the main photometric period at 0.315 d (**bottom**). These RV measurements are not yet sufficient to confirm the presence of a low-mass companion (they are compatible with constant RVs) and more data will be needed. **Lower panel**: comparison between RV data and synthetic RV curves computed for different orbital periods and companion masses (and optimizing the phases), assuming circular orbits. The color-coded quantity χ is defined as follows: $\chi = (\Sigma_{i=1,n} | RV_i - RVsynth_i | / \sigma_i) /n$, where σ_i are the RV errors. In practice, the regions compatible with the presence of a companion are those in red or yellow. Near 0.3 d, the companion must have a minimum mass lower than 1 M_J.



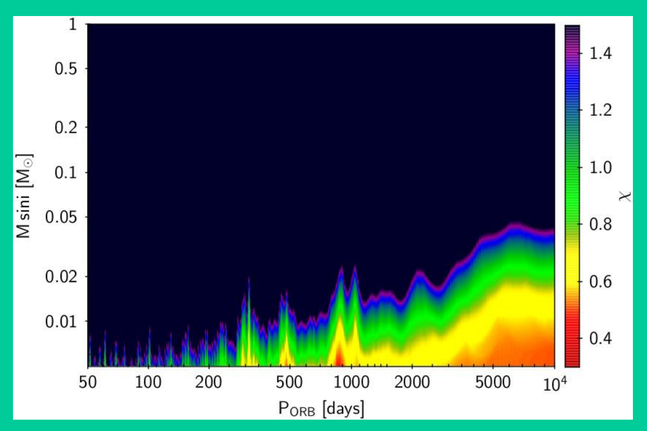


Fig.4. Same as Fig.3 (lower panel) for HD149382, the star with the largest RV coverage. **Top**: we can exclude a companion in tight orbit down to 1 Jupiter mass with an orbital period up to ~10 d. **Bottom**: thanks to the 10-years RV coverage on this star, it's possible to exclude also more massive companions in wider orbits.

Preliminary results and short discussion

At least 6 out of 15 apparently single sdO/B stars within 200 pc do not show TESS photometric variations nor RV variations within measurement limits. Three stars show short-period variations in their TESS light curves, presumably due to a companion, which may or may not be confirmed by ongoing RV measurements (an example is given in Fig.3). One star shows irregular photometric variations in its TESS light curve and it should be observed soon with HARPS@3.6m. Two stars (PG0342+026 and PG0044+097) are known g-mode pulsators (**Sahoo+2020, MNRAS 495, 2844**; **Silvotti+2020, MNRAS 489, 4791**) and for this reason their RV data are not shown in Fig.2. These 2 articles report some limits on the presence of a companion, however the RV variations caused by g-mode pulsations make it more difficult to set reliable strong limits. Finally, 3 stars do not have yet RV measurements: one has only 1 spectrum but should be reobserved this summer with HARPS-N@TNG, another should be observed this autumn with HARPS@3.6m, the third does not yet have scheduled observations. A few stars show a weak flux excess near 400 nm in their Gaia BP/RP XP spectrum that might be due to a WD companion but further analyses (and additional RV data) are needed to confirm this finding.