Subdwarf B stars in HW Vir systems

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Abstract

Subdwarf B stars (sdB) dominate the populations of faint blue stars and are found in both the old disk (field sdBs) and halo populations (globular cluster members) of our own Galaxy. Considerable evidence has accumulated that these stars are sufficiently common to be the most likely source for the "UV upturn phenomenon" observed in elliptical galaxies and galaxy bulges. The origin of sdB stars however remains largely a puzzle, but evidence is accumulating that close binary evolution is fundamental to the problem. Recently, pulsations in sdB stars, driven by the κ-mechanism due to an opacity bump caused by iron, have been predicted. Pulsations in sdB stars have subsequently been discovered. With interferometric methods, we expect to detect close companions and learn about their nature to derive further insight in the evolution of sdB stars, and to derive constraints for the asteroseismological analysis.

What are sdB stars?

Introduction: Spectroscopic analysis

Subdwarf B stars represent a fairly uniform class of faint blue stars. They are evolved objects populating the blue extension of the horizontal branch (HB). Normal HB stars correspond to the stage of stable helium core burning with simultaneous hydrogen burning in a shell. In contrast to these, extreme HB (EHB) stars can be identified with models burning helium in their cores but with hydrogen layers too thin to sustain nuclear burning (Heber 1986). The mass of the helium burning core is centered around 0.5 $M_\odot$ for all HB stars since at that core mass the critical temperature for helium burning is being reached, so the parameter which determines the position on the HB (or its blue extension, the EHB) is a different one, namely the mass of the remaining hydrogen layer. SdB stars appear so blue because with a very thin hydrogen layer, the hot core is located closer to the surface. In the limit of a vanishing hydrogen layer, the EHB meets the helium main sequence at 0.5 $M_\odot$.

The left plot below, taken from Dorman et al. (1993), depicts the region in an astrophysical Hertzsprung-Russel diagram occupied by these exotic yet abundant objects. Since the EHB evolutionary stage is a very long-lived one (10^8 yr), diffusion processes can be held responsible for the mostly subsolar abundances observed in the hydrogen dominated sdB atmospheres. Upon closer inspection, however, it seems that only the interplay of mass loss, diffusion, and the particular age of the object can explain the large variety of photospheric metal abundance ratios. While the future evolution of an sdB star can be predicted by model calculations as leading more or less directly to the white dwarf graveyard, thus avoiding a second giant phase, the question of how they have formed in the first place is still an issue very much under investigation.

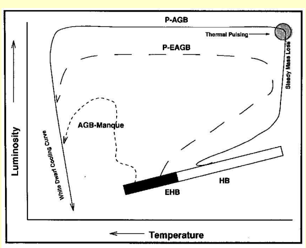
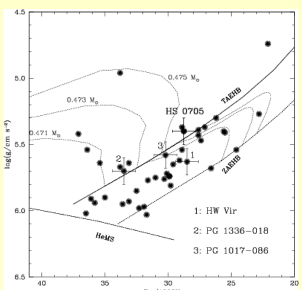


FIG. 1.—Schematic representation of the different types of post-HB evolutionary sequences described in the text. "EHB" stars have envelope masses that are too small to reach the end stages of normal AGB evolution. Also marked are the places in the H-R diagram where other physical processes are important.



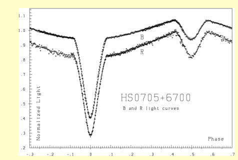
Astroseismology with EC 14026 stars

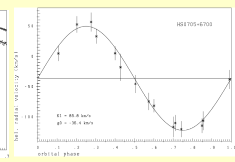
An important step towards a deeper understanding of sdB stars was made possible when a fraction of them were discovered to be variable, on timescales of minutes with amplitudes of typically a few mmag. Named after the prototype EC 14026, photometric monitoring campaigns have so far turnd up more than 28 objects of this new class of variables (see Charpinet 2001 for a review including a compilation of known pulsators). The most recent addition is HS0702+6743, depicted with its siblings in the above plot to the right (Dreizler et al. 2002). While the fact that even within the so-called sdBV instability strip most of the sdB's are stable (within the observational limits) adds to the mystery, there has nevertheless been considerable progress: Both the theoretical modelling of the driving mechanisms as well as the combined observational and theoretical task of mode identification for the observed pulsations recently have started to yield convincing results. Mode identification, i.e. the determination of which observed frequency corresponds to what kind of geometrical variation, or eigenmode dynamics, is crucial to astroseismological analysis and has proved to be rather non-trivial for sdB's. Once successfully applied however, astroseismology yields precise results for stellar parameters such as the luminosity, mass, inner structure and chemical composition, rotation or magnetic fields of an object. The just emerging application of spectrophotometric monitoring to sdBV's and its exploitation by astroseismology will certainly push our understanding a lot further in the near future.

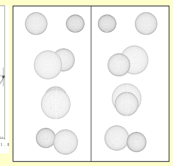
Why do sdB stars exist?

Evolution scenarios and HW Vir systems

The main question to be answered is how the progenitor of an sdB star got rid of most of its hydrogen envelope, which, according to standard evolution theory, should not easily happen. More precisely formulated, it is unclear how the progenitor star manages to remove all but a tiny fraction of the hydrogen envelope at exactly the same time as the helium core has attained the mass of 0.5 $M_\odot$, which is required for the helium flash.







Single star evolution with enhanced mass loss has been proposed as a possible explanation. A competing scenario evoques binary evolution. It is supported by the finding that many sdB's do indeed reside in binary and often even close binary systems. Yet though evidence is accumulating in favour of this idea, there will remain considerable doubts about the validity of this approach as long as this cannot be shown for all of the objects. Binarity alone is not all that is needed to explain the formation of sdB stars; the additional requirement of a past common envelope ejection seems to be essential and is certainly harder to prove. Possible pairs that would fit into this picture are the combinations [sdB + cool main sequence star] and [sdB and white dwarf star].

Photometric, radial velocity and infrared excess surveys have tried to get answers about the existence and nature of companions to sdB's. A particularly noteworthy kind of system are the HW Vir variables which consist of a cool main sequence star orbiting an sdB in a plane oriented in such a way that eclipses can be witnessed from earth. They permit to extract a wealth of information about its components. As an example, some observational riches are displayed above for HS0705+6700: the eclipse lightcurve (left) and a radial velocity curve (middle), which together with spectral information (not shown) make it possible to build a detailed model such as is shown on the right (Drechsel et al. 2001). Two more such systems are known so far; their parameters are compiled in the table below.

	HW Vir	PG 1336−018	HS 0705+6700
Author	Wood et al. (1993)	Kilkenny et al. (1998)	Drechsel et al. (2001)
data	UBVR	UVR	BR
P	2^h48^m	2^h25^m	2^h18^m
$q = M_2/M_1$	~ 0.3	0.3	0.278
i	80°.6	81°	84°.4
K_1	87.9 kms^{-1}	78 kms^{-1}	85.8 kms^{-1}
T_1	~ 33 000 K	33 000 K	29 600 K
T_2	~ 3700 K	~ 3000 K	2900 K
$\log g_1$	5.64	5.7	5.40
M_1	0.54 $M_\odot$	~ 0.50 $M_\odot$	0.483 $M_\odot$
M_2	0.18 $M_\odot$	0.17 $M_\odot$	0.134 $M_\odot$
R_1	0.183 $R_\odot$	0.165 $R_\odot$	0.230 $R_\odot$
R_2	0.188 $R_\odot$	0.175 $R_\odot$	0.186 $R_\odot$
a	0.89 $R_\odot$	0.79 $R_\odot$	0.81 $R_\odot$

Binarity and opportunities with the VLTI

To settle the question whether all sdB's reside in close binary systems, interferometric results with VLTI will be of great value. The search technique can be calibrated against and will complement the accurate results from either astroseismology or eclipsing binary analysis; then it can be extended to constrain possible companions to sdB's which neither show pulsations or eclipses, and in particluar test for companions to those sdB's which do not show any signs of binarity so far.

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