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A search for new hot subdwarfs stars by means of Virtual Observatory tools.

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Abstract

We present here a selection strategy to find new, uncatalogued hot subdwarfs making use of Virtual Observatory (VO) tools. We used large area catalogues (GALEX, SDSS, Super-Cosmos, 2MASS) to retrieve photometric and astrometric information of stellar objects. To these objects, we applied colour and proper motion filters, together with an effective temperature cut-off, aimed at separating hot subdwarfs from other blue objects such as white dwarfs, cataclysmic variables or main sequence OB stars.
As a result, we obtained 437 new, uncatalogued hot subdwarf candidates, which represents an increase of 17% in the census of known hot subdwarfs. Visual inspection of the 68 candidates with SDSS specrum showed that 65 can be classified as hot subdwarfs: 5 sdOs, 25 sdOBs and 35 sdBs. This success rate above 95 per cent proves the robustness and efficiency of our methodology.
Taking advantage of the VOSA capabilities, we built the Spectral Energy Distribution (SED) of our candidates. 45 per cent of the SEDs showed infrared excesses, a signature of their probable binary nature. The stellar companions of the binary systems so detected are expected to be late-type main sequence stars.
A more detailed description of the methodology, the analysis and results can be found at [13]

1 Introduction

Hot subdwarf (hot sd) stars are core-helium burning stars at the end of the horizontal branch or even beyond that stage. The origin of these faint, blue objects is still a matter of controversy. With effective temperatures exceeding 19000 K and logg ≥ 5, hot sds are objects that have lost most of their H envelope in previous evolutionary stages, leading to a $\sim 0.5\mathrm{M}_{\odot}$ star. They are unable to follow canonical evolution through the Asymptotic Giant Branch (AGB) proceeding, instead, directly towards the white dwarf cooling track.

Circumstances that lead to the removal of all but a tiny fraction of the hydrogen envelope, at about the same time as the core has achieved the mass required for the He flash ($\sim 0.5\mathrm{M}_{\odot}$), are still a matter of debate. Theoretical evolution scenarios proposed so far include enhancement of the mass loss efficiency near the red giant branch (RGB) tip ([4]) or mass transfer through binary interaction ([9]).

Hot sds are divided in two main classes, sdBs and sdOs, according to composition. SdB spectra are dominated by the Balmer series, while sdOs are hotter objects caracterized by the presence of He II 4686Å and the Pickering series. Additionally, a variety of He I lines may appear in both classes, and some sdOs show metallic C or N lines. More complex classification schemes have been recently proposed in [3].

Increasing the number of hot sds is important for a robust statistical confrontation with theoretical evolutionary scenarios. It may also lead to the discovery of interesting objects that are still scarce, such as pulsating sdBs or sdOs ([8]), or hot sds as central stars of planetary nebulae ([1]). Taking advantage of large photometric surveys available in astronomical archives and Virtual Observatory tools, we have used the selection workflow described in [11] to discover new hot subdwarf candidates.

2 Methodology

The methodology described in [11] is applied here to the region in common between 2MASS (PSC) and SDSS (DR7) (11663 deg^2 approximately). It consists of the following steps:

- Crossmatching: The surveys employed in this work were 2MASS (PSC), SDSS (DR7), GALEX GR6/GR7, and SuperCosmos. We retained sources with counterparts in all the surveys within a maximum distance of 5 arcsec. Sources must also be classified as point objects by SDSS (cl=6).

- Photometric and kinematic filtering: We required GALEX sources to have measured magnitudes in both filters (FUV > 0, NUV > 0) and to be brighter than 5σ of the magnitude limit (FUV < 19.9, NUV < 20.8). To distinguish sds candidates from other blue objects we applied the following cuts:

$$-4 < (FUV_0 - Ks_0) < 0.5 \tag{1}$$

$$-2 < (FUV_0 - NUV_0) < 0.2 \tag{2}$$

$$19 < H(NUV_0) < 27 \tag{3}$$

  where the 0 subscript stands for Galactic extinction corrected magnitudes, and H(NUV_0) for the reduced proper motion of the NUV filter.

- Removal of known candidates: We crossmatched our list with published and well-established catalogues of spectroscopically confirmed subdwarfs, white dwarfs, cataclysmic variables and OB stars to remove known candidates.
- Effective temperature filtering: Using VOSA[1] ([2]) we estimated the effective temperature of our candidates by fitting the observed spectral energy distribution (SED) to the TLUSTY collection of theoretical models. Objects with $T_{eff} > 19000$ K or below this temperature but with a bad fit (a potential signature of the possible presence of a cool companion) were kept.
- Source image checking: Finally, using Aladin, the SDSS images and catalogue data, we visually inspected our pre-candidate list of targets to discard instrumental features, bad crossmatches or contamination from nearby, bright sources. In fact, we found some cases with a clear mismatch between GALEX, SDSS and 2MASS sources. These pathological cases are mostly due to the different spectral coverage and limiting magnitude of the surveys.

3 Results

After crossmatching the photometric surveys and applying the selection filters previously mentioned, we ended up with a list of 437 objects not previously found in the literature. Astrometric, photometric and physical parameter information of these objects as well as links to the SED fitting diagrams and the SDSS spectrum (when available) can be accessed using the SVO hot subdwarf archive, a research resource specifically created for this work (see Section 6).

3.1 Binary sample

An important issue regarding hot subdwarfs is to know the binary fraction of these objects, as it can help to discriminate among the competing theories proposed to explain the dramatic mass loss they suffer during the red giant phase.

Regarding sdBs, the binary fraction is estimated around 40 per cent or higher, depending on the nature of the samples and the method used to detect the stellar companion (see, [7] for a review). The sdO binary fraction is more controversial, with different studies reaching opposite conclusions: [10] found only one out of 23 radial velocity (RV) variable sdO, while [6] and [5] found a similar distribution of RV variations between sdBs and sdOs.

A combination of optical and infrared photometry is commonly used to find late-type companions such as F, G or K types, because the hot subdwarf will shine in the blue, while the companion will have brighter red colours. [14] found a 40 per cent of binary systems in a magnitude-limited sample of hot subdwarfs using 2MASS infrared filters and optical photometry.

[1]http://svo2.cab.inta-csic.es/theory/vosa/

In our list of 437 hot subdwarf candidates, 20 of them have no infrared photometric data available. For the other 417, we consider as binary candidates those with excess in the infrared as detected by VOSA from the SED fitting. There are 189 of them, making a total fraction of 45 per cent. This fraction could be overestimated, as some of the flux excesses may be apparent, due to inaccurate photometric measures or bad SED fittings. The possible spectral type of the companion star was estimated analyzing the excess of hot sds with main sequence companions catalogued in [12]. We have selected all subdwarfs classified as sds+F, sds+G or sds+K of this catalogue and identified from which band the excess is detected in VOSA. A more rigorous check of all possible binary candidates, using a two-component fit, is presently being addressed and will be presented in a future work.

4 Spectral classification

Only 68 stars of our list of subdwarf candidates (16 per cent) had SDSS spectrum. We performed a visual inspection of each object's whole spectrum. One spectrum was too noisy to allow identification. The rest were identified as one white dwarf, one probable cataclysmic variable and 65 subdwarfs: 5 sdOs (8 per cent), 25 sdOBs (38 per cent) and 35 proper sdBs (54 per cent). These results demonstrate the outstanding effectiveness of our selection procedure (95.6 per cent) within this subset.

We also inspected the presence of characteristic lines of cooler main sequence stars to identify binary candidates. In particular, we looked for the Mg I triplet (5172, 5183, 5167Å), the G band (4300Å), and the Ca II K line (3933Å). The Na I doublet (5889-5895Å) can also be an indicator, although it may be overlapped with a near He II line. We found 23 probable binary systems: 22 binary sdBs (including sdOBs) and 1 binary sdOs. The binary fraction for sdBs obtained by visual inspection of the spectrum was 37 per cent, somehow lower than the photometric fraction. Besides the possible overestimation of the photometric fraction, as argued in the previous section, the relatively low signal-to-noise ratio of some SDSS spectra may be obscuring the binary nature of some candidates, hiding the cold companion lines. We point out that all the spectrum-detected binary systems are also binary candidates from the photometric excess point of view.

5 Future work

A lot of work remains to be done after the selection procedure developed here. Regarding the list of hot subdwarf candidates, a deeper analysis of the binary sample is presently under study. On the other hand, seventeen of our candidates show apparent ultraviolet excess which makes them good candidates for very hot objects. The hotter sdOs are measured to have up to 100000 K. These objects are scarce between subdwarfs, and some of them have been proved to have planetary nebulae [1]), a signal of a probable post AGB origin. Photometric and spectroscopic accurate data would be needed to reach further conclusions about the origin of these stars.

A detailed line spectral analysis of the hot subdwarf candidates, to be performed using advanced/accurate NLTE atmospheric models, would yield more reliable values for the star effective temperatures, helium abundances and surface gravities.

Regarding the search of new hot subdwarf candidates, different approaches could be used. One of those would imply applying our selection procedure to new releases of some of the surveys already considered (e.g. SDSS, GALEX) or using new catalogues, both in the optical (e.g. Pan-Starrs, or J-PAS in the near future) and in the infrared (UKIDSS, VISTA). Another possibility would be employing other catalogues containing astrometric information. At this moment, our routine discards any source without proper motion data in the SuperCosmos survey. This fact could be modified making the routine look for proper motion information in other catalogues, like UCAC4 or PPMXL. In particular, it would be interesting to explore the possibilities of the data that GAIA will provide regarding this point.

Finally, attention must be paid to forthcoming missions such as CHEOPS or PLATO, as they are expected to have an impact on ultra-high precision photometry and stellar astroseismology for bright targets, covering large fractions of the sky and widening, then, the possible detection of new pulsating hot sds.

6 The hot subdwarf archive

In order to help the astronomical community on using the catalogue of subdwarfs identified in this paper we have developed an archive system that can be accessed from a Web page[2] or through a Virtual Observatory ConeSearch.

The archive web system implements a very simple search interface that permits queries by coordinates/radius as well as by other criteria of interest (object identifier, Teff, quality flag or excess). A selection of the astrometric, photometric and physical parameters to be displayed in the table of results can also be done assigning a type of verbosity: minimum, medium or maximum. The default search radius is set to 5 arcsec. The user can also select the maximum number of sources to return (with values ranging from 10 to unlimited)

The result of the query is a HTML table with all the sources found in the archive fulfilling the search criteria. Detailed information on the output fields can be obtained placing the mouse over the name of the column. The archive implements the SAMP (Simple Application Messaging Protocol). SAMP allows applications to communicate with each other in a seamless and transparent way for the user. This way, the results of a query can be easily transferred to other VO application, such as Topcat (Fig. 1).

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[2]http://svo2.cab.inta-csic.es/vocats/hsa/

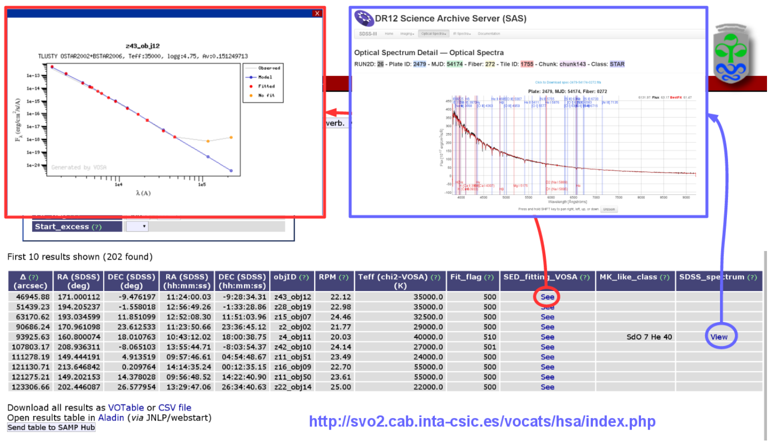

Figure 1: Result from a query in the SVO hot subdwarf archive. The SED and SDSS spectrum visualisation capabilities as well as the possibility of sending the information to VO tools like TOPCAT is shown.

References

[1] Aller A., Miranda L. F., Olguín L., Vázquez R., Guillén P. F., Oreiro R., Ulla A., Solano E., 2015, MNRAS, 446, 317

[2] Bayo A., Rodrigo C., Barrado y Navascués D., Solano E., Gutiérrez R., Morales-Calderón M., Allard F., 2008, A&A, 492, 277

[3] Drilling J. S., Jeffery C. S., Heber U., Moehler S., Napiwotzki R., 2013, A&A, 551, A31

[4] D'Cruz N., Rood R., O?Connell R., Dorman B., Dickens R., 1996, in Bulletin of the American Astronomical Society, Vol. 28, American Astronomical Society Meeting Abstracts, p. 1390

[5] Geier S. et al., 2011, A&A, 530, A28

[6] Green E. M., Fontaine G., Hyde E. A., For B.-Q., Chayer P., 2008, in Astronomical Society of the Pacific Conference Series, Vol. 392, Hot Subdwarf Stars and Related Objects, Heber U., Jeffery C. S., Napiwotzki R., eds., p. 75

[7] Heber U., 2009, ARA&A, 47, 211

[8] Kilkenny D., 2002, in Astronomical Society of the Pacific Conference Series, Vol. 259, IAU Colloq. 185: Radial and Nonradial Pulsationsn as Probes of Stellar Physics, Aerts C., Bedding T. R., Christensen-Dalsgaard J., eds., p. 356

[9] Mengel J. G., Norris J., Gross P. G., 1976, ApJ, 204, 488

[10] Napiwotzki R., Karl C. A., Lisker T., Heber U., Christlieb N., Reimers D., Nelemans G., Homeier D., 2004, Ap&SS, 291, 321

[11] Oreiro R., Rodríguez-López C., Solano E., Ulla A., Østensen R., García-Torres M., 2011, A&A, 530, A2

[12] Østensen R. H., 2006, Baltic Astronomy, 15, 85

[13] Pérez-Fernández, E., Ulla, A., Solano, E., Oreiro, R., Rodrigo, C. 2016, MNRAS, 457, 3396

[14] Stark M. A., Wade R. A., 2003, AJ, 126, 1455