Albus 1: A very bright white dwarf candidate

José Antonio Caballero[1,2]

Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany

caballero@mpia.de

Enrique Solano[2]

Laboratorio de Astrofísica Espacial y Física Fundamental, INSA, P.O. Box 50727, E-28080 Madrid, Spain

esm@laeff.inta.es

ABSTRACT

We have serendipitously discovered a previously-unknown, bright source (B_T = 11.75±0.07 mag) with a very blue $V_T - K_\mathrm{s}$ color, to which we have named Albus 1. A photometric and astrometric study using Virtual Observatory tools has shown that it possesses an appreciable proper motion and magnitudes and colors very similar to those of the well known white dwarf G 191–B2B. We consider Albus 1 as a DA-type white dwarf located at about 40 pc. If confirmed its nature, Albus 1 would be the sixth brightest isolated white dwarf in the sky, which would make it an excellent spectrophotometric standard.

Subject headings: white dwarfs – subdwarfs – solar neighbourhood

1. Introduction

The three classical white dwarfs were, at the beginning of the twentieth century, o^2 Eri B, Sirius B, and the van Maanen's star. Although o^2 Eri B had been discovered by Herschel (1785) and Sirius B had been predicted by Bessel (1844), it was not until the 1920s when other great astronomers noticed their oddness (Luyten 1922) and popularized the term "white dwarf" (Eddington 1924). The extreme physical conditions by which the white dwarfs are

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[1]Alexander von Humboldt Fellow at the MPIA.

[2]Members of the Spanish Virtual Observatory Thematic Network.

supported against gravitational collapse could not be understood until the Quantum Mechanic was properly developed. Since the 1930s, the number of known white dwarfs has exponentially increased, from 18 in 1939 (Schatzman 1958) and over a hundred in 1950 (Luyten 1950) to a few thousands at present (McCook & Sion 1999; Eisenstein et al. 2006). See Liebert (1980), Koester (2002) and Hansen & Liebert (2003) for extensive reviews of the general properties of white dwarfs.

The vast majority of the known white dwarfs are very faint, with typical magnitudes in the optical from $V = 15$ to 20 mag, or even fainter. Only a few very bright white dwarfs ($V < 12$ mag), including the three classical white dwarfs and Procyon B, are known. Many of them, especially those that are not in double degenerate systems, are extensively used as spectrophotometric stars (see, e.g., the recent catalogue by Landolt & Uomoto 2007). Except for rare exceptions, as the very hot dwarfs and cataclysmic variables found in the *ROSAT* all-sky survey of extreme-ultraviolet sources by Pounds et al. (1993), all the very bright white dwarfs were discovered during photometric and astrometric surveys before the early 70s (e.g. Kuiper 1941; Luyten 1949; Thackeray 1961; Eggen & Greenstein 1965; Giclas, Burnham & Thomas 1965; Schwartz 1972). Afterwards, and in particular with the advent of the Sloan Digital Sky Survey, the detection of new white dwarfs and blue subdwarfs has been biased towards magnitudes fainter than $V = 12$ mag. Because of that, the photometry-based discovery of a very bright white dwarf candidate 35 years later would be outstanding. If confirmed, it would yield doubts on the real knowledge that we have of the solar neighbourhood and on the completeness of previous and current surveys for white dwarfs.

In this work we present Albus 1, a previously-unknown very bright ($V_T = 11.80 \pm 0.14$ mag) white dwarf candidate[1]. Its finding chart is provided in Fig. 1. Albus 1 was serendipitously discovered during an optical-near infrared photometric study by Caballero & Solano (2007), devoted to characterize the young stars and brown dwarfs surrounding Alnilam (ϵ Ori) and Mintaka (δ Ori). As part of this study, they made a correlation between the Tycho-2 (Høg et al. 2000) and the 2MASS (Cutri et al. 2003) catalogues in ten 45 arcmin-radius comparison fields at the same galactic latitude of the brightest stars of the young Ori OB 1 b Association (the Orion Belt; $b \sim -17.5$ deg). The total investigated area was only 17.7 deg^2 ($\sim$0.04 % of the whole sky). Albus 1 has a $V_T - K_s$ color that clearly deviates from those of the other 1275 investigated sources (see Fig. 2). In particular, while the bluest remaining sources have $V_T - K_s \gtrsim -0.3$ mag, Albus 1 has a color $V_T - K_s = -0.95 \pm 0.14$ mag. The Tycho-2 $B_T V_T$ and 2MASS JHK_s photometry shows that the object is extremely blue at

[1] *Albus* is the Latin term for “white”.

all the wavelenghts from 0.4 to 2.2 μm. Given the extreme blueing of Albus 1, we decided to investigate it in detail.

2. Analysis

In this work we have taken advantage of the tools offered by the Virtual Observatory (VO; `http://www.ivoa.net`), which is an international, community-based initiative to provide seamless access to the data available from astronomical archive and services. The VO also aims to provide state-of-the-art tools for the efficient analysis of this huge amount of information. In particular, we have used Aladin (`http://aladin.u-strasbg.fr/aladin.gml`), a VO-compliant interactive sky atlas developed by CDS that allows the user to visualize and analyze astronomical images, spectra and catalogues available from the VO services.

Albus 1 has an appreciable Tycho-2 proper motion of 19 $\mathrm{mas\,a^{-1}}$. Since the comparison fields are relatively close to the antapex (the point the Sun is moving away from), the foreground objects in this region have not very large proper motions except for some very nearby stars with large tangential velocities. Indeed, the proper motion of Albus 1 is in the percentile 23 % of the investigated sources (i.e. 77 % of the investigated Tycho-2 stars have $\mu < 19\,\mathrm{mas\,a^{-1}}$). This makes Albus 1 to be a nearby Galactic object.

Apart from the coordinates, proper motion and $B_T V_T$ magnitudes from Tycho-2 and the JHK_s magnitudes from 2MASS, taken from Caballero & Solano (2007), we have also collected additional photometric and astrometric data from other catalogues: SuperCOSMOS Science Archive (Hambly et al. 2001), USNO-B1 (Monet et al. 2003), NOMAD1 (Zacharias et al. 2005) and DENIS (DENIS Consortium 2005). They nicely match between them and Tycho-2 and 2MASS, except for the fact that for very blue objects the Tycho-2 B_T and photographic B_J photometry are not comparable. To avoid superfluous, repetitive information in Table 1, we provide only the Tycho-2 and 2MASS information and the RI_N photometric data from USNO-B1.

The search with Aladin concluded that there is no radio (NRAO VLA), mid-infrared (*IRAS*), ultraviolet (*EUVE*), X-ray (*ROSAT*) source, or object discussed in the literature (SIMBAD) at less than 4 arcmin to Albus 1. Neither spectroscopic information exists nor photometry in the Johnson passbands has been obtained yet.

3. Results

To ascertain the real nature of Albus 1, we must compare its photometry with that of other very blue objects. There is a limited number of Galactic objects with $V_T - K_s$ colors as blue as those of Albus 1: white dwarfs, hot subdwarfs, and early-type main sequence, blue horizontal branch and Population II stars. Fig. 3 compares the optical-near infrared colors of Albus 1 with those of dwarf and giant stars in the direction to Alnilam and Mintaka. Our blue source is even bluer than the late O- and early B-type stars. Besides, such luminous stars are located at long heliocentric distances ($d \gtrsim 0.4$ kpc), which implies very low proper motions, in contrast with what we have measured for Albus 1. Population II stars are common in the bulge near the centre of the Galaxy and in the Galactic halo. Some of the latters cross the Solar neighbourhood, but only a few of them display extremely blue colors (see, e.g., the recent photometric study of horizontal-branch and metal-poor candidates by Beers et al. 2007). Therefore, Albus 1 is an early-type hot subdwarf or a white dwarf.

The extreme blueing of Albus 1 prevents from transforming the $B_T V_T$ magnitudes to Johnson BV magnitudes using standard relations and, therefore, to compare its colors with other white dwarfs tabulated in exhaustive works such as in Bergeron, Leggett & Ruiz (2001). A new comparison may come, instead, from the available Tycho-2 and 2MASS data. In Table 2 we have compiled the basic data of the brightest white dwarfs and blue subdwarfs identified in the Tycho-2 catalogue. We used the white dwarf lists by McCook & Sion (1999) and Holberg, Oswalt & Sion (2002), and looked for the Tycho-2 counterparts of the white dwarfs brighter than $V = 13.0$ mag. Fainter objects were not considered due to their poor photometric accuracy. This list surpasses the sample of white dwarf observed by the *Hipparcos* satellite in Vauclair et al. (1997). There are three evident absences: Sirius B, o^2 Eri B, and Procyon B (the three brightest known white dwarfs), which are too close to other bright stars and were, thus, not identified by Tycho-2. Among the tabulated objects, there is only one hot subdwarf with blue colors, GJ 3435, which indicates its rarity.

Data in Table 2 is represented in Fig. 3. Albus 1 is located in the color-color diagram very close to the well known white dwarfs G 191–B2B (DA1) and GJ 433.1 (DA3), at $V_T - J \sim -0.8$ mag, $J - K_s \sim -0.2$ mag. The resemblance between the spectral energy distributions of Albus 1 and G 191–B2B ("the best studied of all hot white dwarfs"; Barstow et al. 2003), shown in Fig. 4, is evident. Both of them have the same K_s magnitude within the error bars (Albus 1: $K_s = 12.76 \pm 0.03$ mag; G 191–B2B: $K_s = 12.76 \pm 0.02$ mag), but G 191–B2B is 0.40 ± 0.11 mag brighter in B_T. It leads to tentatively classify Albus 1 as an early DA white dwarf slightly cooler than G 191–B2B and, therefore, slightly closer to the Sun. The stellar common proper-motion companion of G 191–B2B has an accurate parallax determination by *Hipparcos* at $d = 46 \pm 4$ pc. Hence, Albus 1 could be located at about 40 pc, which would explain its appreciable proper-motion. The probability of Albus 1 being a more distant blue subdwarf is smaller (see Table 2). From the blue $J - K_{\rm s}$ color in Fig. 3, it is deduced, besides, that Albus 1 has no main sequence close companion or forms part of a cataclysmic variable system.

As shown by Salim & Gould (2002), an optical-infrared reduced proper motion digram (e.g. $V + 5 \log \mu$ vs. $V - J$) can be used to classify stars even if no parallax information is available. In particular, white dwarfs and subdwarf stars are easily distinguished from main sequence stars as they are several magnitudes dimmer at the same color. The position of Albus 1 in the reduced proper motion diagram in fig. 4 in Gould & Morgan (2003; $V_T + 5 \log \mu = 3.2 \pm 0.6$ mag, $V_T - J = -0.76 \pm 0.14$ mag) agrees with this requirement.

4. Conclusions

Of the 30 white dwarfs and blue subdwarfs listed in Table 2, only thirteen have Tycho-2 V_T magnitudes brighter than 12.0 mag. Albus 1, with $V_T = 11.80 \pm 0.14$ mag, is included in this group. Accounting for the three brightest known white dwarfs not in the Table, and discarding the close binary systems BL Psc AB, V841 Ara AB, V3885 Sgr AB, and BD+28 4211 AB, whose spectral energy distributions are affected by the main sequence close companions, then Albus 1 is the 12th brightest white dwarf yet known. Since six of the white dwarfs brighter than it are in multiple systems (the binary status of GJ 127.1 AB claimed by Gill & Kaptein 1896 is, however, not confirmed), then Albus 1 would be the sixth brightest isolated white dwarf, after the long-time known Feige 34, L 145–141, BD–07 3632, and HD 340611 (Luyten 1949; Eggen & Greenstein 1965) and the very hot white dwarf and extreme ultraviolet source RE J2214–49 (Holberg et al. 1993).

Albus 1, although located in the southern hemisphere, is visible from the most important northern observatories. This fact, together with its brightness, makes our blue source an appropiate candidate spectrophotometric standard provided that its white dwarf or hot subdwarf nature is spectroscopically confirmed. Our serendipitous detection has also shown that the $V_T - K_{\rm s}$ color is a good and simple discriminator to look for very blue, relatively bright objects. A search for new very bright white dwarf candidates using Tycho-2 and 2MASS is currently ongoing.

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Table 1. Basic data of Albus 1.

		Unit	Ref.[a]
Name	Albus 1		1
WD number	WD 0604–203		1
α (J2000)	06 06 13.39		2
δ (J2000)	–20 21 07.3		2
$\mu_\alpha \cos\delta$	+7±3	$\mathrm{mas\,a^{-1}}$	2
μ_δ	–18±3	$\mathrm{mas\,a^{-1}}$	2
B_T	11.75±0.07	mag	2
V_T	11.80±0.14	mag	2
R	11.84	mag	3
I_N	11.90	mag	3
J	12.56±0.02	mag	4
H	12.66±0.03	mag	4
K_s	12.76±0.03	mag	4
Sp. type	DA?		1
d	∼40?	pc	1

[a]References: 1, this work; 2, Tycho-2 catalogue; 3, USNO-B1; 4, 2MASS catalogue.

Table 2. The brightest white dwarfs and hot subdwarfs in the Tycho-2 catalogue.

WD number	Alternative name	Sp. type	V_T (mag)	J (mag)	K_s (mag)
WD 0041+092	BL Psc AB	DA2+K0IV	10.18±0.04	8.45±0.03	7.80±0.03
WD 0046+051	van Maanen's star	DZ7	12.559±0.018	11.69±0.02	11.50±0.02
WD 0148+467	GJ 3121	DA3.5	12.552±0.010	12.77±0.02	12.85±0.03
WD 0227+050	GJ 100.1, Feige 22	DA2.5	12.848±0.019	13.28±0.03	13.42±0.02
WD 0232+035	FS Cet AB, Feige 24	DA+M1V	12.6±0.2	11.26±0.03	10.557±0.019
WD 0310–688	GJ 127.1 A[a]	DA3	11.15±0.07	11.76±0.02	11.86±0.02
WD 0426+588	GJ 169.1 B[b]	DQ7	12.13±0.18	6.62±0.02	5.72±0.02
WD 0501+527	G 191–B2B	DA1	11.65±0.17	12.54±0.02	12.76±0.02
WD 0604–203	**Albus 1**	**DA?**	**11.80±0.14**	**12.56±0.02**	**12.76±0.03**
WD 0621–376	RE J0623–374	DA1	12.3±0.2	12.85±0.03	13.09±0.03
WD 0644+375	GJ 246, He 3	DA2.5	12.2±0.2	12.7±0.3	12.8±0.3
WD 0713+584	GJ 3435, GD 294	sdB	12.03±0.16	11.77±0.02	11.721±0.018
WD 1036+433	GJ 398.2, Feige 34	DA0:	11.10±0.07	11.64±0.02	11.540±0.019
WD 1134+300	GJ 433.1	DA3	12.14±0.19	12.99±0.02	13.18±0.03
WD 1142–645	GJ 440, L 145–141	DQ6	11.34±0.09	11.19±0.02	11.10±0.03
WD 1314+293	HZ 43 AB[c]	DA1+M3.5Ve	12.667±0.009	10.373±0.019	9.56±0.02
WD 1327-083	BD–07 3632[d]	DA4	11.77±0.18	12.62±0.04	12.74±0.05
WD 1337+705	G 238–44	DA3	12.839±0.010	13.25±0.02	13.45±0.04
WD 1620–391	HD 147513 B[e]	DA2	11.00±0.08	11.58±0.02	11.77±0.02
WD 1634–573	V841 Ara AB[f]	DOZ1+K0V	11.26±0.07	7.12±0.02	6.57±0.03
WD 1647+591	DN Dra, G 226–29[g]	DAV4.7	12.00±0.16	12.42±0.02	12.52±0.03
WD 1917–077	GJ 754.1 A[h]	DBQA5	13.1±0.3	12.35±0.03	12.42±0.03
WD 1944–421	V3885 Sgr AB[i]	DB:p+M:V	10.33±0.05	9.96±0.03	9.62±0.02
WD 2007–303	GJ 2147	DA4	12.9±0.3	12.58±0.02	12.70±0.03
WD 2032+248	HD 340611	DA2.5	11.55±0.10	12.04±0.03	12.19±0.03
WD 2039–202	GJ 7991.1	DA2.5	13.1±0.3	12.82±0.03	13.00±0.03
WD 2117+539	V2151 Cyg	DA3.5	12.7±0.3	12.68±0.02	12.85±0.04
WD 2148+286	BD+28 4211 AB[j]	sdO:p+G:	10.53±0.05	11.28±0.03	11.56±0.03
WD 2149+021	GJ 838.4	DA3	13.2±0.4	13.20±0.02	13.39±0.04
WD 2211–495	RE J2214–49	DA.76	11.52±0.08	12.44±0.03	12.64±0.03

[a]The status of the hypothetical companion GJ 127.1 B is unknown.

[b]The 2MASS pipeline did not identify the white dwarf, which is visible in JHK at ∼8.0 arcsec from GJ 169.1 A.

[c]Neither Tycho-2 nor 2MASS resolved the HZ 43 AB system (L 1409–4 AB), whose components are separated by 2.23±0.03 arcsec (McAlister et al. 1996).

[d]Common proper motion companion of the low-mass star GJ 514.1 (LHS 353; M4.5V).

[e]Common proper motion companion of the exoplanet-harbour star HD 147513 (G5V; Desidera & Barbieri 2007).

[f]2MASS did not resolve the V841 Ara AB system (HD 149499 AB), whose components are separated by 1.320 arcsec (Tycho-2).

[g]ZZ Ceti-type pulsating white dwarf.

[h]Common proper motion companion of the low-mass star GJ 754.1 B (L 923–22; M3.5V).

[i]UX UMa nova-like cataclysmic variable in which the secondary is a $\sim 0.5\,M_\odot$ red dwarf that fills its Roche lobe (orbital period: $P \approx 0.207\,\mathrm{d}$; Ribeiro & Diaz 2007).

[j]The binary status of BD+28 4211 has not been confirmed.

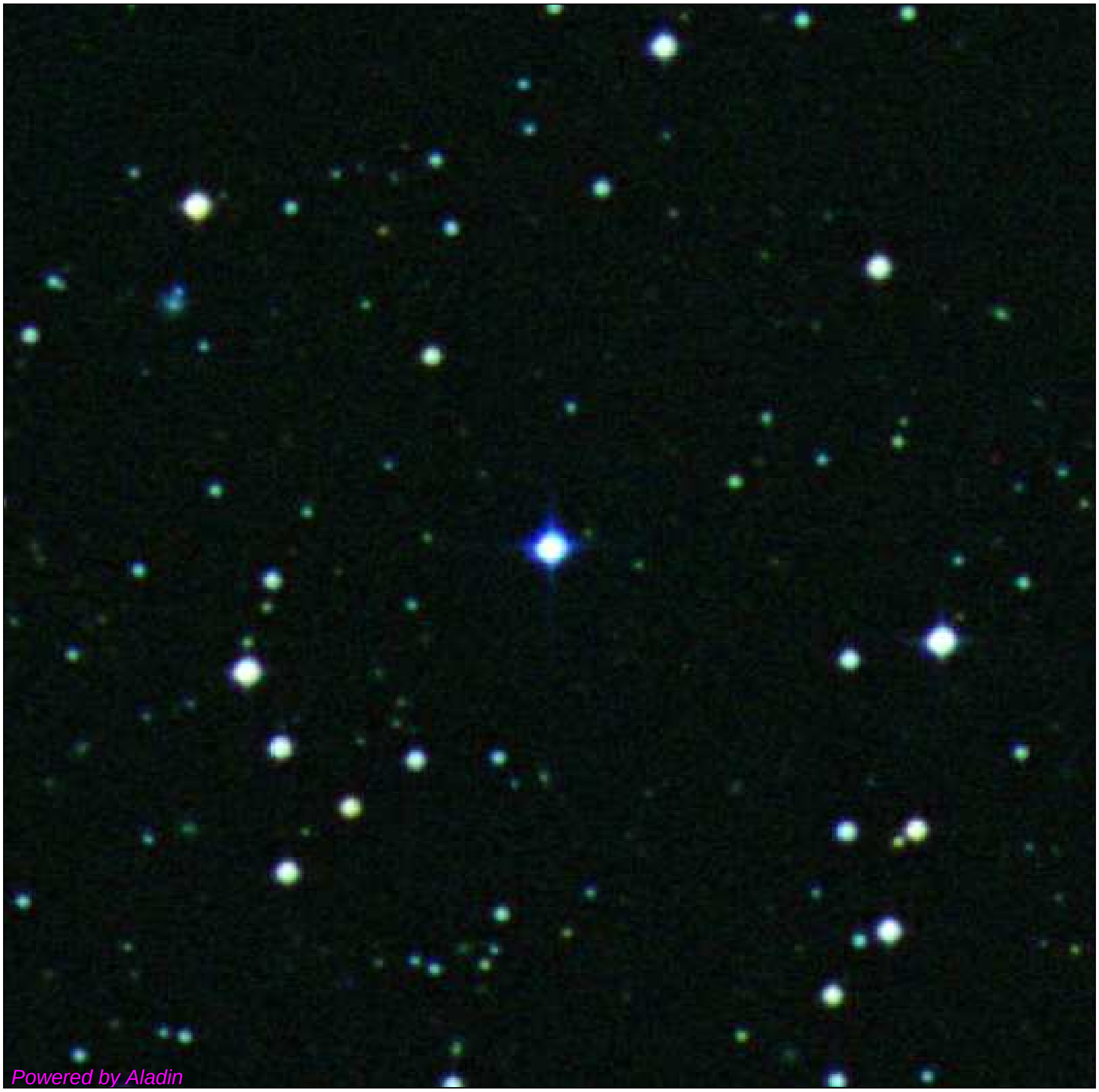

Fig. 1.— False-color composite image, $5.6 \times 5.6\,\mathrm{arcmin}^2$ wide, centred on Albus 1. Blue is for B_J, green for R, and red is for I_N (DSS1 and DSS2 photographic plates from ESO and MAMA). North is up, east is left.

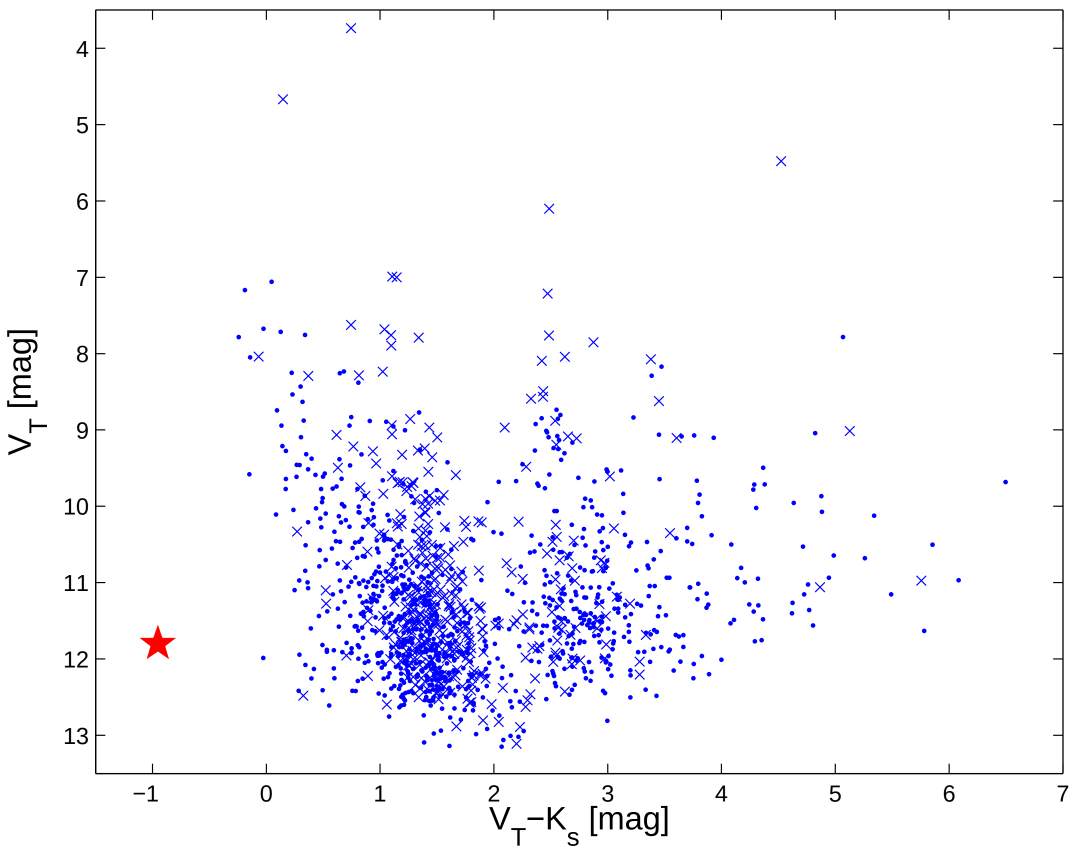

Fig. 2.— V_T vs. $V_T - K_{\rm s}$ color-magnitude diagram from the data in Caballero & Solano (2007). Tycho-2/2MASS sources with proper motions larger and smaller than $15\,{\rm mas\,a}^{-1}$ are shown with crosses and dots, respectively. Albus 1 is highlighted with a big filled (red) star.

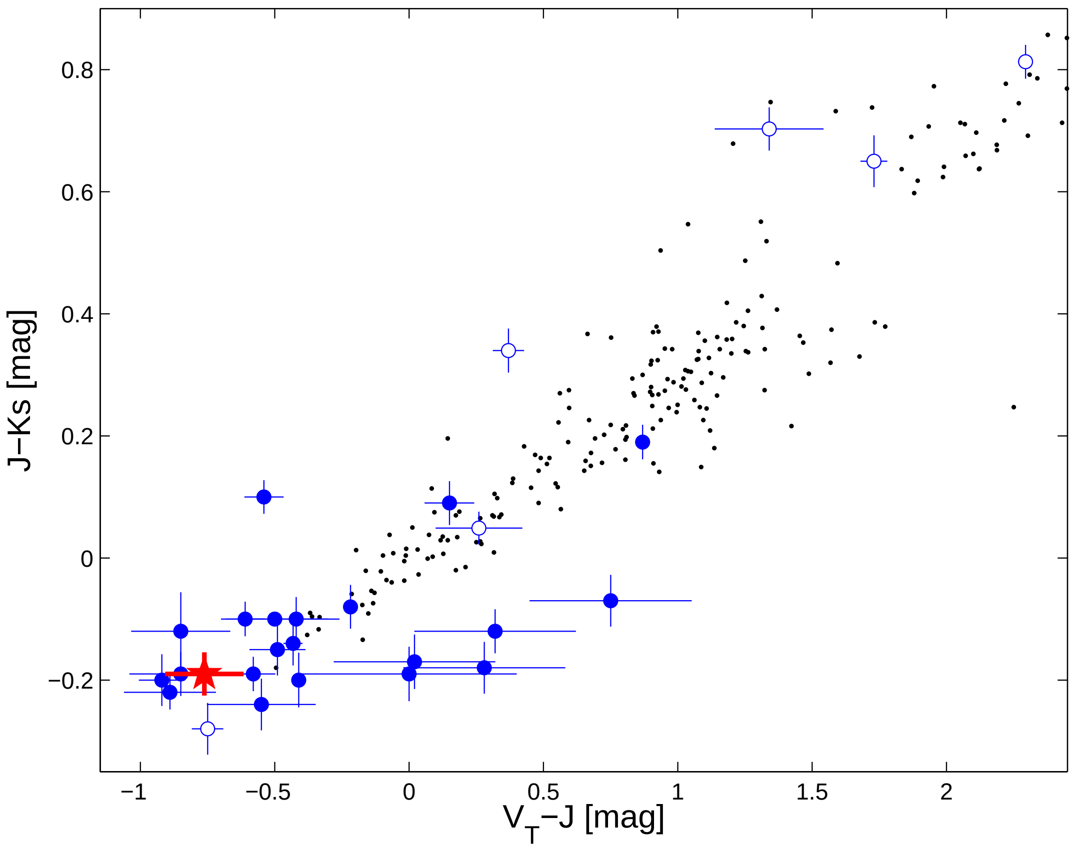

Fig. 3.— $V_T - J$ vs. $J - K_s$ color-color diagram of the white dwarfs and blue subdwarfs listed in Table 2. Code: (red) filled star, Albus 1; (blue) filled circles, single white dwarfs; (blue) open circles, white dwarfs in unresolved systems or hot subdwarfs. GJ 169.1 B and V841 Ara, that were resolved by Tycho-2 but not by 2MASS, are not shown; (black) dots, a sample of dwarf and giant stars covering the whole spectral type range from late O to early M, taken from Caballero & Solano (2007).

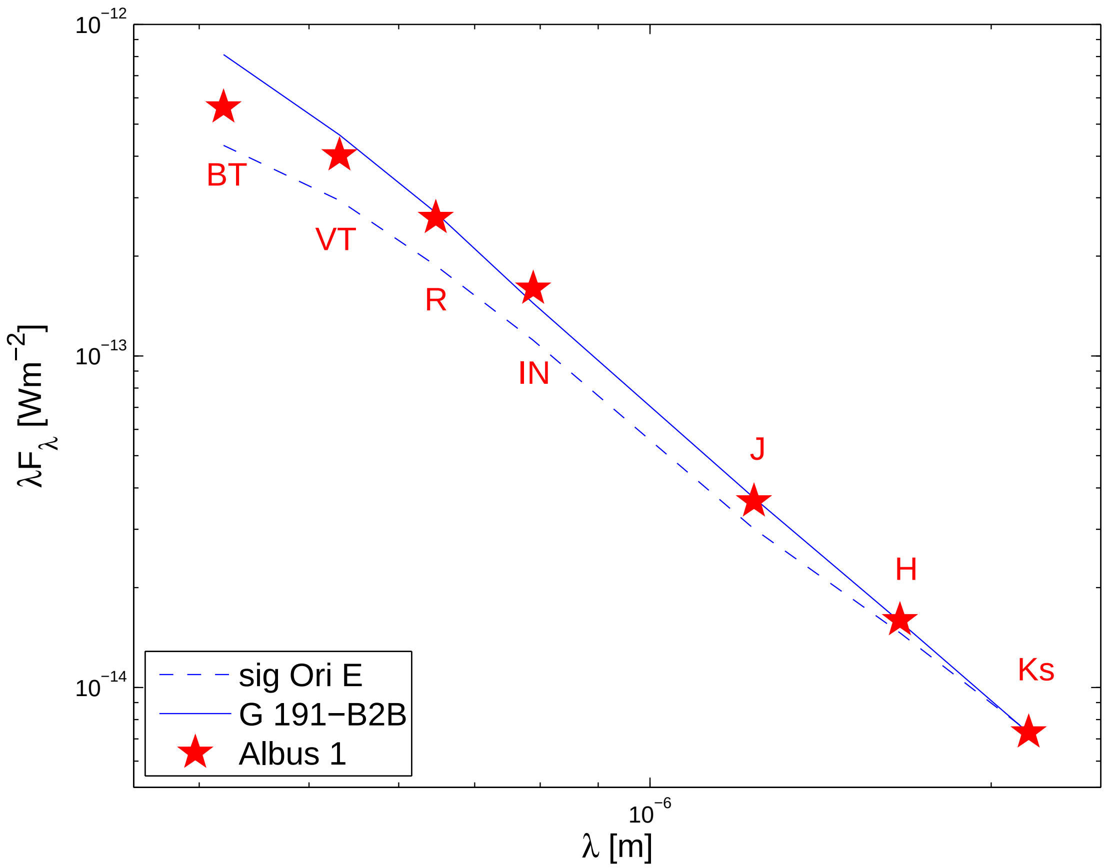

Fig. 4.— Spectral energy distributions of Albus 1, the DA1 white dwarf G 191–B2B, and the B2Vp star σ Ori E (shifted to an heliocentric distance of 0.5 kpc). The seven passbands ($B_T V_T R I_N J H K_\mathrm{s}$) are indicated.