New Candidates for Dust-forming Hot Stars

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Abstract

Circumstellar dust can easily form near evolved cool stars. Dust formation around evolved hot stars requires special conditions, such as very high matter densities or hydrogen deficiency. Only a few groups of hot and luminous stars producing new dust are currently known (Wolf-Rayet stars, B[e] supergiants, and LBVs). Studying unclassified B[e] stars, we have identified another distinct group of ∼20 intermediate- and low-luminosity ($\log L/L_\odot = 2.5$–5) hot stars with IRAS fluxes suggestive of a recent CS dust formation process. The dust formation mechanism in these objects is not clear. In order to investigate how common these stars are in the Milky Way, we searched for optical counterparts of IRAS sources with similar colors in the mid-infrared MSX catalog, near-infrared 2MASS catalog, and optical USNO–B1.0 catalog. As a result, we found ∼40 new candidates to our group. In this poster, we present a list of newly found objects and the results of initial photometric and spectroscopic observations. We also discuss the role of these objects in galactic dust production, and possible impacts of their study on understanding dust formation around hot stars.

Introduction

Circumstellar (CS) Dust:

- Found near stars of all spectral and luminosity types
- Proto-stellar in young stars
- Formed in situ around evolved stars

Dust Formation:

- Fairly well understood for cool stars (e.g., red supergiants and carbon stars)
- Still poorly understood in hot stars
  - Must occur far away from star (lower temperature)
  - Need heavy element abundances
  - Process inefficient (lower density)

Dust around Hot Stars:

- Wolf-Rayet (WR) Stars
- Luminous Blue Variables (LBV's)

  WR and LBV's:
    - evolved and very luminous
    - have extremely dense radiatively-driven winds
    - dust could form due to the presence of heavy elements and the self-shielding of parts of their winds from the UV radiation, which otherwise would destroy newly formed dust
- **B[e] Stars**

B[e] Stars

B[e] stars are a heterogeneous group including objects of mostly B spectral type that show forbidden emission lines in their optical spectra and large infrared (IR) excesses due to hot CS dust (65 galactic stars, Allen & Swings 1976).

Nearly 40 B[e] stars have been identified as members of other known stellar groups (e.g., Herbig Ae/Be stars, Proto-Planetary Nebulae, LBV's).

We have identified a distinct group of B[e] stars.

Their properties include:

- IRAS fluxes suggestive of recent CS dust formation (Fig. 1)
  - Hence: **B[e] stars with warm dust = "B[e]WD"**
- Neither pre-main-sequence nor post-AGB objects
- Wide range of luminosities
- Mostly close to main-sequence of HR diagram (Fig. 2)
- Suggestive that dust formation near hot stars more common than thought
- Strong emission-line spectra (Fig. 3)

IR Spectral Energy Distribution (SED) distinguishes the B[e]WD from other B[e] stars.

~20 B[e]WD objects identified to date (Miroshnichenko et al. 2002, Table 1)

Use IRAS data to separate them (~4500 sources found in the color region shown in Fig. 1)

~30 B[e]WD and ~10 RV Tau candidates found by cross-correlation with a subsample of ~1000 IRAS sources with the 2MASS and USNO–B1.0 catalogs (Table 2 and 3)

The candidates separated from cool stars and RV Tau stars with IR color-color diagrams (Fig. 4)

Below we report on initial observations of these candidates.

Observations

Initial observations were obtained in August-November 2003 and included broad-band optical photometry, low- and high-resolution optical spectroscopy, and low-resolution IR spectroscopy.

Photometry:

- 50-cm telescope of the Tien-Shan Observatory (Kazakhstan) with a single-element photometer in the BVR bands (Table 4)

Low-resolution spectroscopy:

- Optical region: 0.8 m telescope of the Dark Sky Observatory (Boone, NC) with the Gray-Miller spectrograph (spectral resolving power $R \sim 1\,300$, spectral region 3800–5600 Å)

- Near-IR region: 3 m Shane telescope of the Lick Observatory with the Aerospace Near-Infrared Imaging Spectrograph spectrograph ($R \sim 700$, region 0.8–2.5 μm, Rudy et al. 1999)

- Mid-IR region: 3 m NASA IRTF (Mauna Kea, HI) with the BASS spectrograph ($R \sim 100$, region 3–14 μm)

High-resolution spectroscopy:

- 6 m telescope of the Russian academy of Sciences (Nyzhnyj Arkhyz, Russia) with the échelle spectrometer NES ($R \sim 80\,000$, Panchuk et al. 1999)

- 3.6 m CFHT (Mauna Kea, Hawaii) with the high-resolution ($R \sim 100\,000$) Gecko échelle spectrograph, fiber-fed from the Cassegrain focus (Baudrand & Vitry 2000).

Results

• The photometric criteria used are good to separate B[e]WD from other types of dusty objects.

• 3 emission-line stars confirmed (IRAS00470+6429, IRAS06341+0159, and IRAS07080+0605) and 2 discovered (IRAS22061+4747 and IRAS06165+3158, Fig. 5–7)

• IR flux level detected by IRAS is confirmed for 2 sources (IRAS00470+6429 and IRAS03434+5818, Fig. 8)

Conclusions

• A new group of intermediate-luminosity stars with recently formed CS dust is found. With ∼30 new candidates, it becomes the largest group of dust-forming hot stars.

• The large fraction of B[e]WD candidates suggests that many more of them may be found among the remaining ∼80% of the initial sample.

• Evolved hot stars are considered to be significant contributors of gas to the IS medium (comparable to supernovae). Similarly, they could supply a large amount of dust. Extending and investigating the B[e]WD group may lead to a completely new view of CS dust formation and reveal the total scale of this process.

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Table 1: B[e] stars with warm dust

Name	IRAS	V	Sp.T.	D	log L/L$_\odot$	E^{tot}_{B-V}	Hα
AS 78	03549+5602	11.2–11.4	B2/4	2.5	3.9±0.1	0.90	115
CI Cam	04156+5552	9.0–11.6	B0/2+?	1.5	5.0±0.5	1.10	250[a]
HD 45677	06259−1301	6.9–8.8	B2	0.5	3.5±0.4	0.20	170
HD 50138	06491−0654	6.5–6.8	B5/8+?	0.3	2.9±0.2	0.15	60
AS 160	07370−2438	10.9	B1		4.0±0.1		250
Hen 140	08128−5000	10.1	B2/8	2.0	3.1±0.2	0.30	
Hen 298	09350−5314	11.4:	B				330
Hen 303	09369−5406	13.1:	B				
HD 85567	09489−6044	8.6	B2	1.5	4.0±0.3	0.40	31
CPD−57°2874	10136−5736	10.1	B3/5	2.5	5.7:	1.85	
CPD−52°9243	16031−5255	10.3	B3/4	4.9	5.7±0.3	1.75	57–83
HDE 327083	17117−4016	9.7	B1/2+F	5.0	5.0±0.4	1.80	36
Hen 1398	17213−3841	10.6	O9	3.3	5.3±0.2	1.10	
MWC 300	18267−0606	11.5–11.7	B1	15	5.1±0.1	1.20	140±10
MWC 623	19545+3058	10.5–10.9	B2+K2	2.4	3.7±0.4	1.40	122±5
AS 381	20047+3305	14.4	B1+K	4.0	4.9±0.2	2.20	≥85
MWC 342	20212+3920	10.2–10.9	B1/2	1.0	4.1±0.4	1.40	200±15
V669 Cep	22248+6058	12.0–12.4	B5+K	1.0	2.7±0.3	0.90	67–186
MWC 657	22407+6008	12.3–12.9	B1	2.0	3.7±0.3	1.60	180

D is the distance from the Sun in kpc (column 5); E^{tot}_{B-V} (column 7) is the overall reddening determined from the observed and intrinsic color-indices; the equivalent width of the Hα line is given in column 10.
[a] – measured during the quiescent state

Table 2: New B[e]WD candidates

IRAS	R.A. (2000)	Dec. (2000)	m_V	K	Comments
00470+6429	00:50:06.0	+64:45:35.0	12.0	7.00	A-type emission-line
02103+7621	02:15:25.9	+76:35:20.0	12.5	8.70	K+A, emission-line
03419+5429	03:45:47.0	+54:39:08.0	12.0	5.16	
03434+5818	03:47:30.6	+58:28:07.0	12.5	7.72	
05533+3022	05:56:34.8	+30:23:16.0	12.2	6.52	
06071+2925	06:10:17.4	+29:25:16.7	13.5	9.81	B/A-type emission-line
06341+0159	06:36:43.6	+01:57:04.0	12.1	9.12	emission-line
06364+0450	06:39:06.7	+04:47:45.0	11.5	6.79	
07080+0605	07:10:43.9	+06:00:08.0	12.5	7.00	AO, emission-line
07377−2523	07:39:48.5	-25:30:30.0	12.5	8.85	B-type emission-line
07439−3612	07:45:45.7	-36:19:25.7	14.0	8.25	
07474−2539	07:49:33.2	-25:46:42.0	12.5	6.93	
07481−3646	07:49:57.9	-36:54:30.0	13.5	6.90	
08307−3748	08:32:35.8	-37:59:01.5	9.7	7.81	B-type emission-line
08376−4003	08:39:29.3	-40:13:44.1	15.0	8.82	
08519−5255	08:53:27.9	-53:07:04.4	10.5	8.51	
09360−5705	09:37:33.9	-57:18:43.2	13.5	7.06	
09400−4733	09:41:51.9	-47:46:57.8	10.5	5.16	
15556−5444	15:59:32.1	-54:53:22.5	11.0	6.94	
17432−3355	17:46:34.4	-33:56:28.4	12.0	8.86	
17475−3101	17:50:48.5	-33:56:28.4	13.0	7.10	
18000−3359	18:03:19.9	-33:59:21.5	13.0	6.29	
19447+3007	19:46:41.1	+30:15:24.0	12.0	6.58	
19587+2257	20:00:54.6	+23:05:45.8	11.0	7.46	
20017+3227	20:03:43.8	+32:35:33.6	14.0	6.06	F-type
20134+2712	20:15:32.6	+27:22:12.2	13.0	8.47	
20422+4644	20:43:55.6	+46:55:22.1	12.0	6.80	AO
23361+6437	23:38:27.1	+64:54:38.9	13.5	8.34	

m_V are taken from our photometry or the USNO–B1.0 catalog, while K–band photometry from the 2MASS catalog.

Spectral classification is based on our low-resolution spectra

Table 3: New RV Tau star candidates

IRAS	R.A. (2000)	Dec. (2000)	m_V	K	Comments
02155+6410	02:19:22.8	+64:24:41.2	10.94	9.45	A3
06165+3158	06:19:50.9	+31:56:57.0	12.2	7.22	K-type, emission-line
07302−2442	07:32:19.6	-24:48:40.0	9.7	6.42	K-type
08152−3407	08:17:13.2	-34:17:15.1	10	7.68	
10046−5258	10:06:30.9	-53:12:56.2	10.5	7.45	
10054−5344	10:07:18.7	-54:00:00.1	12.04	9.00	
17050−2408	17:08:09.4	-24:13:05.8	10	9.03	
19420+3318	19:43:55.7	+33:25:23.0	10.5	4.86	
20299+3226	20:31:55.4	+32:37:02.0	12	10.24	
20299+3424	20:31:51.9	+34:34:31.0	13	8.21	
22022+4410	22:04:16.2	+44:24:46.4	10.49	8.02	F7
22061+4747	22:08:05.7	+48:02:09.7	10.05	7.78	G3, emis.Hα
23551+6054	23:57:38.4	+61:11:26.0	11.5	8.12	K1

m_V are taken from our photometry or the USNO–B1.0 catalog, while K–band photometry from the 2MASS catalog.

Spectral classification is based on our low-resolution spectra

Table 4: Photometric observations of the new B[e]WD and RV Tau candidates

IRAS	V	$W-B$	$B-V$	$V-R$
00470+6429	11.90	−	1.06	1.15
02155+6410	10.94	−0.02	0.60	0.50
03434+5818	13.1:	−	0.73	2.1:
05533+3022	12.19	−	1.83	1.9:
06165+3159	12.14	−	1.77	1.57
06341+0159	12.15	−	0.26	0.56
22022+4410	10.49	0.10	0.88	0.72
22061+4747	10.05	0.05	0.82	0.67

Typical observational errors 0.02 mag

Data obtained with uncertainties of $\geq$0.1 mag are marked with a colon

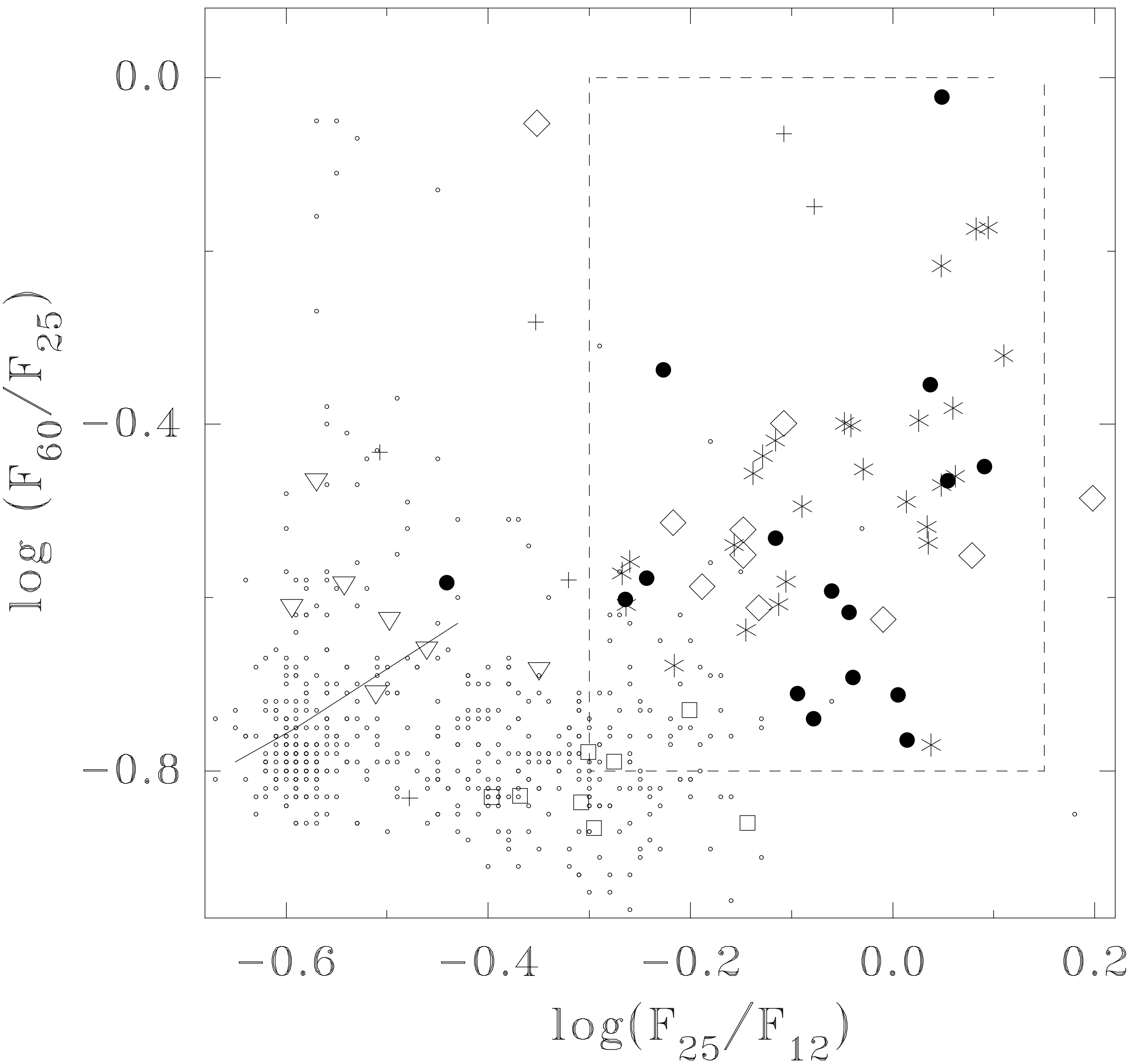

Figure 1: The IRAS color–color diagram for early-type stars associated with CS dust. B[e]WD are shown by filled circles; symbiotic binaries by pluses, carbon stars by open downward triangles, VV Cep binaries by open squares, M stars (including Miras) by small dots, and RV Tau stars by open diamonds. New B[e]WD and RV Tau candidates are shown by star symbols. The box marks the most probable location of B[e]WD.

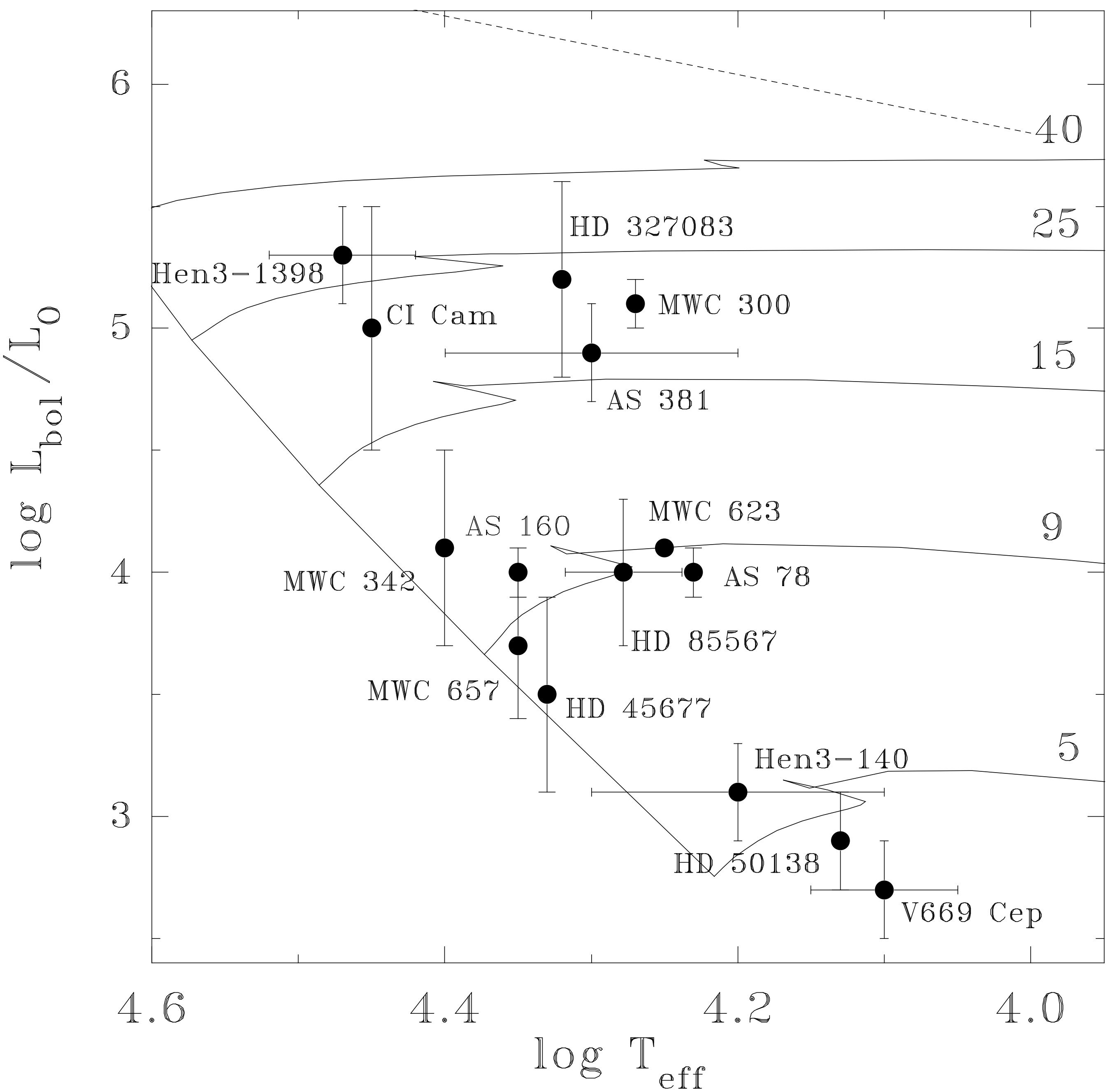

Figure 2: A Hertzsprung-Russell diagram for the B[e]WD. The solid lines show the zero-age main sequence and theoretical evolutionary tracks for single stars from Schaller et al. (1992) with the initial masses indicated by numbers in $M_{\odot}$. The dashed line shows the upper luminosity limit for stable configurations (Humphreys & Davidson 1979).

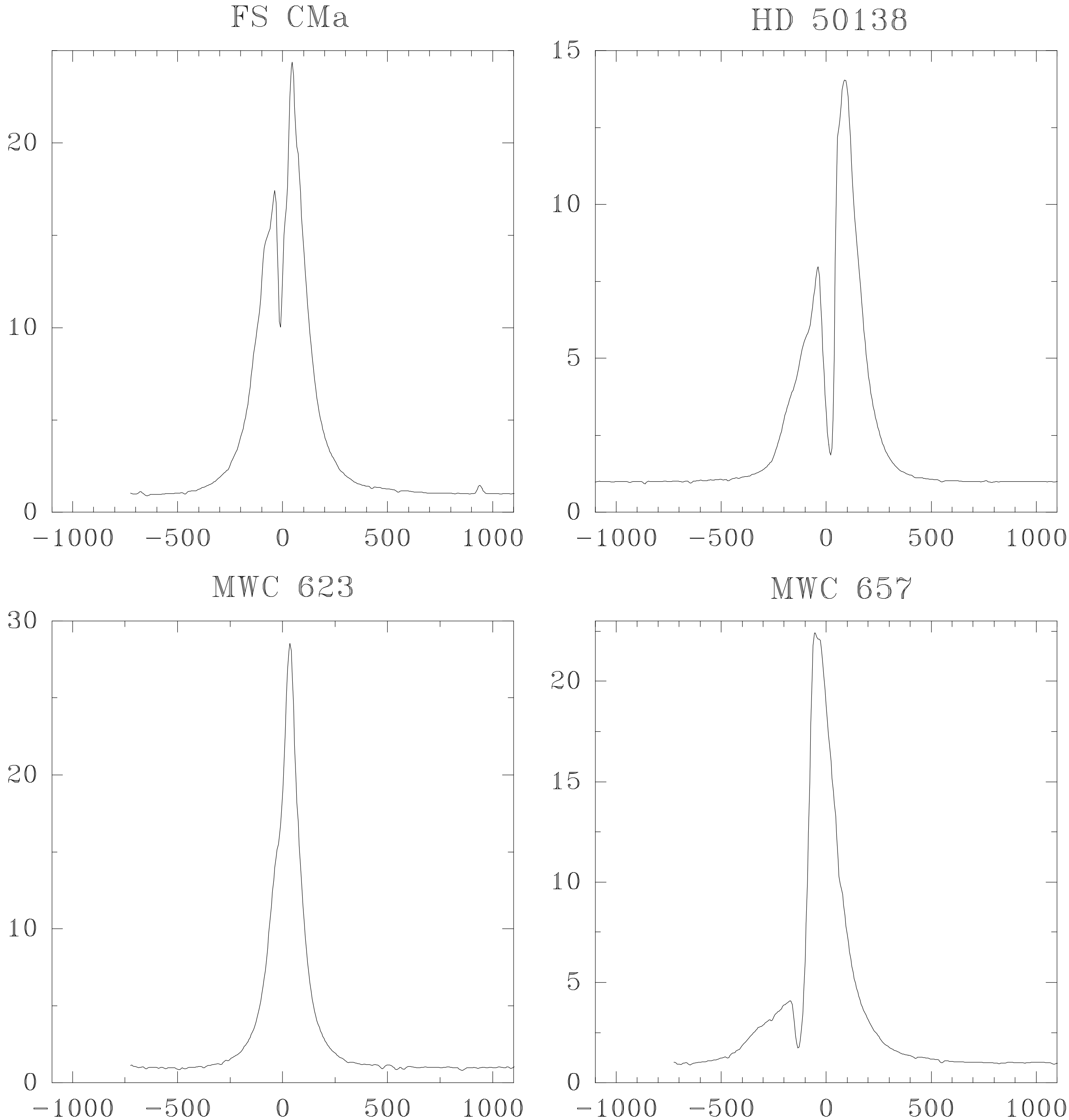

Figure 3: Hα profiles of a sample of B[e]WD. The intensities are normalized to the underlying continuum, and the radial velocity (V_r) is in km s^{-1}.

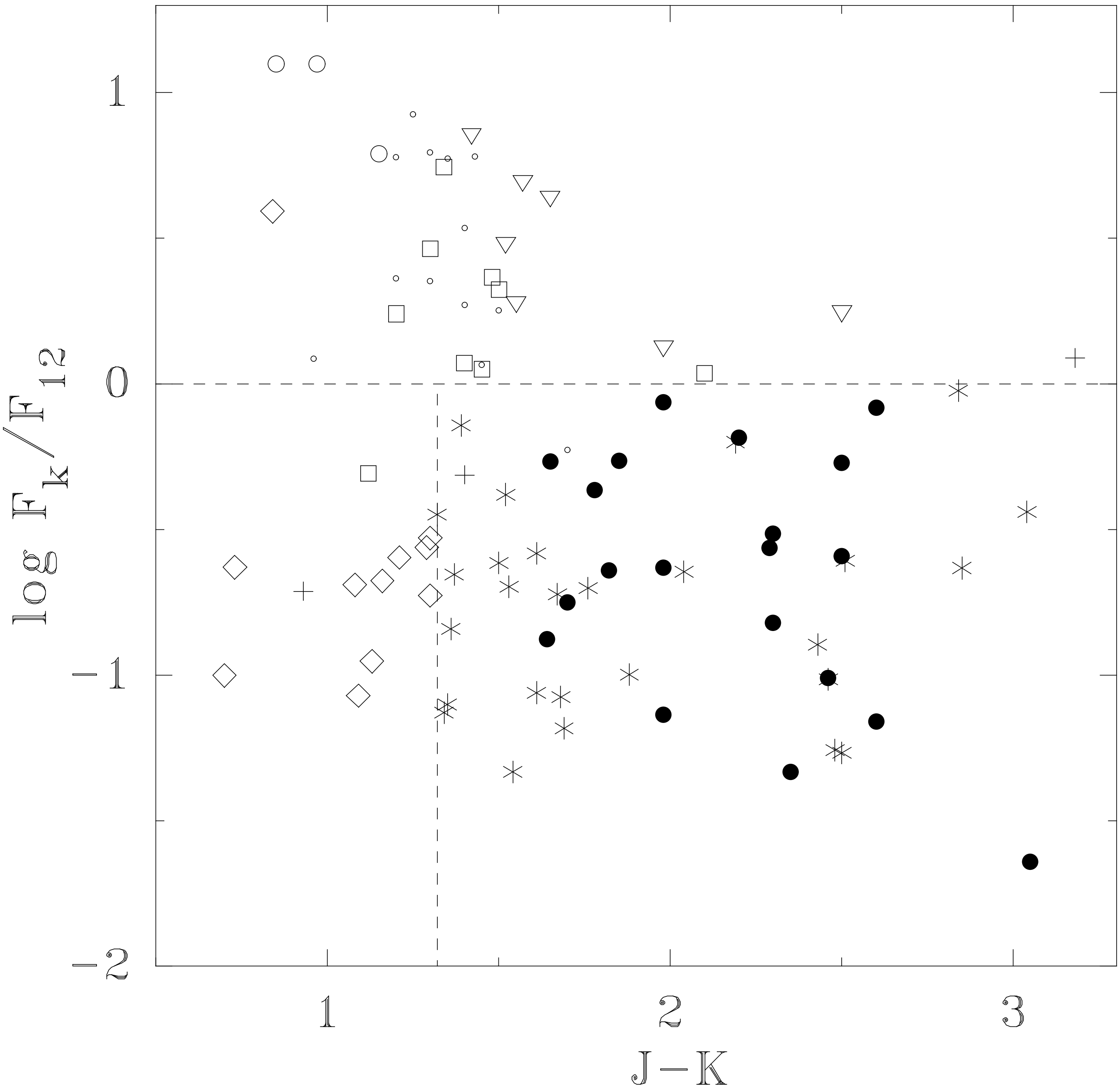

Figure 4: A color-color diagram which combines data from different catalogs and spectral regions. The symbols represent the same groups of objects as in Fig. 1. Star symbols represent only new B[e]WD candidates. Open circles represent normal K-type stars without CS dust. Most of the M-type stars seen in Fig. 1 are out of the range of this figure. They have larger F_K/F_{12} flux ratios. The dashed lines show empirical boundaries between cool and hot stars with CS dust.

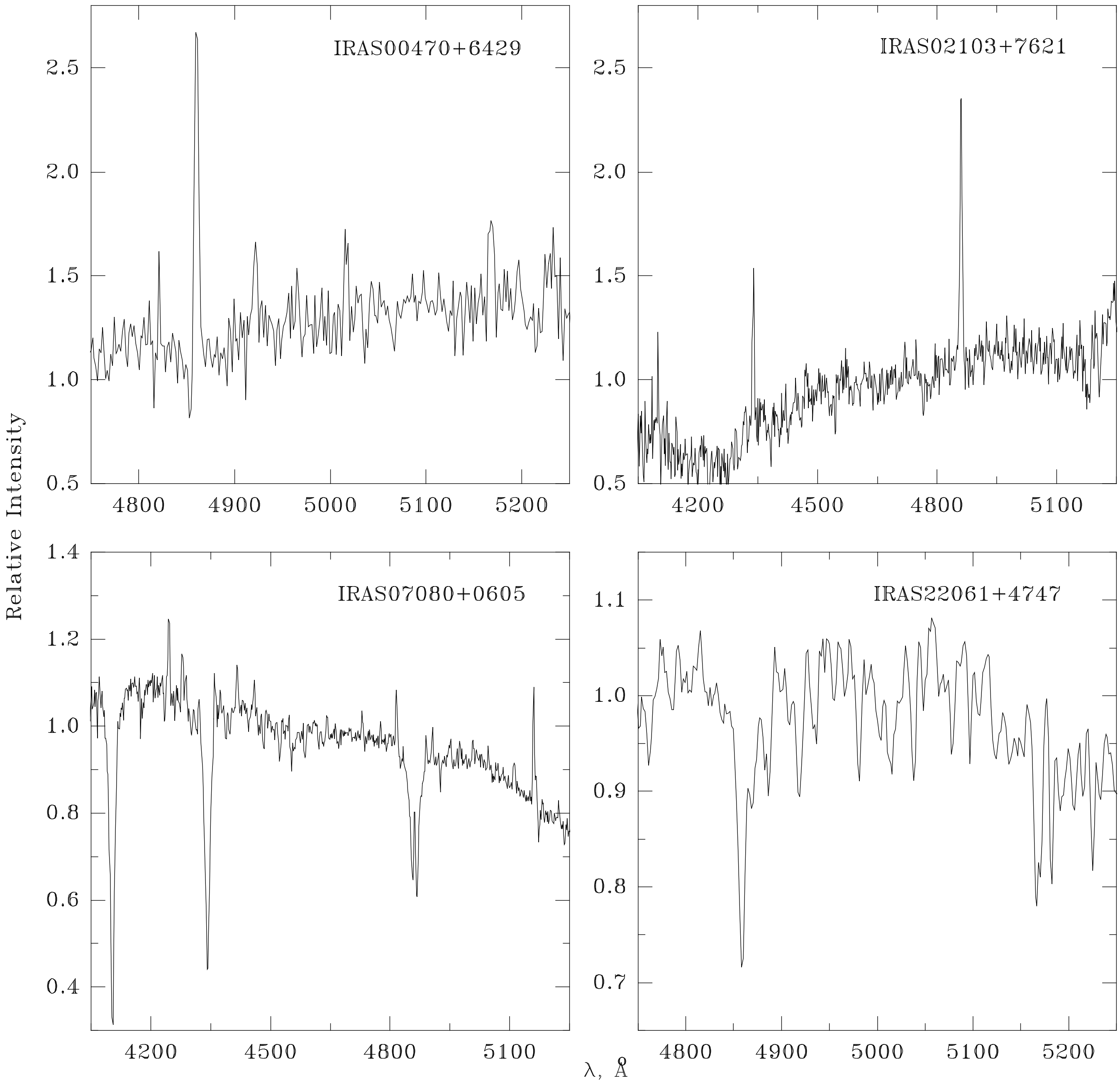

Figure 5: Dark Sky Observatory spectra of some new candidate B[e]WD. The intensities are normalized to those at 4500 Å.

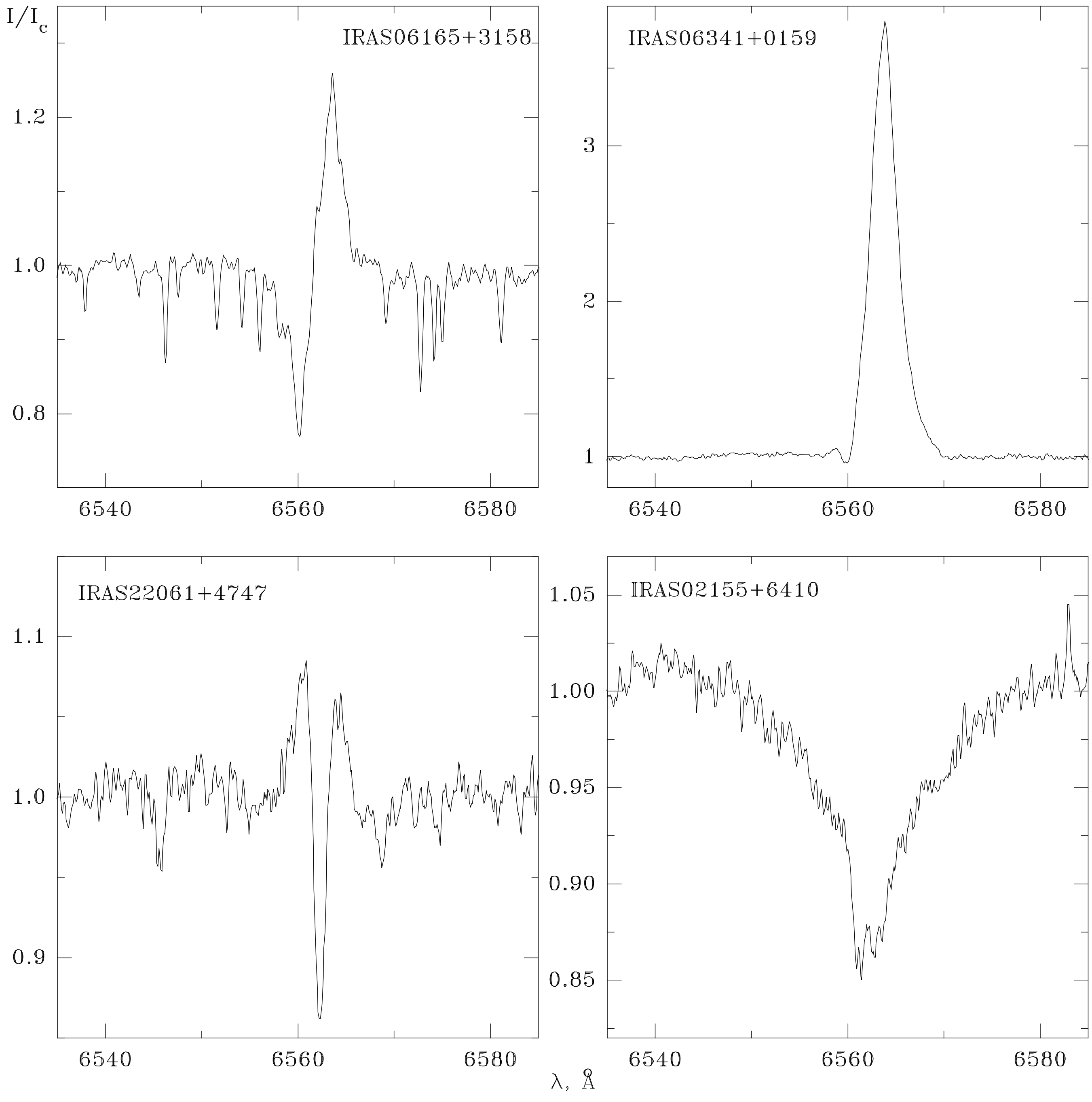

Figure 6: CFHT spectra of some new candidate B[e]WD in the Hα region. The intensities are normalized to the underlying continuum.

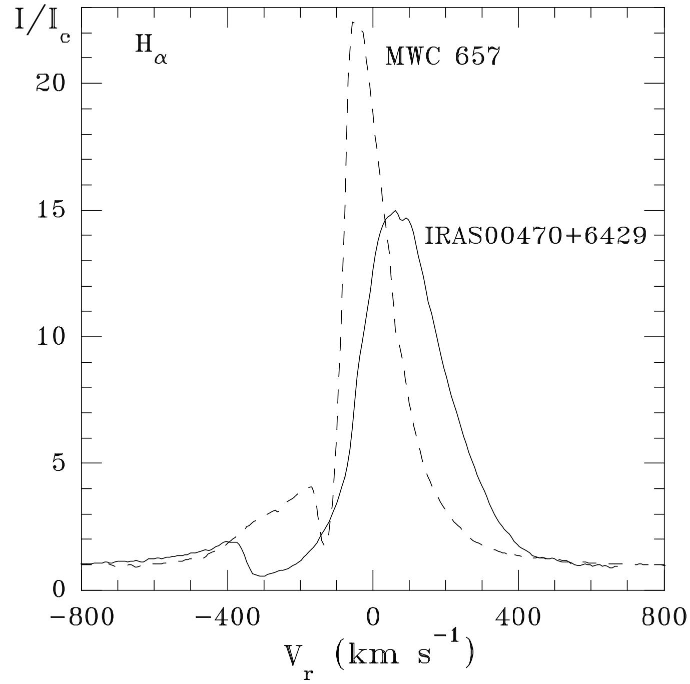

Figure 7: The Hα line profiles in the spectra of the B[e]WD MWC 657 (Miroshnichenko et al 2000) and a newly found B[e]WD candidate IRAS00470+6429 obtained at the 6-meter telescope of the Russian Academy of Sciences. The intensity is in units of the underlying continuum, and the radial velocity (V_r) is in km s^{-1}.

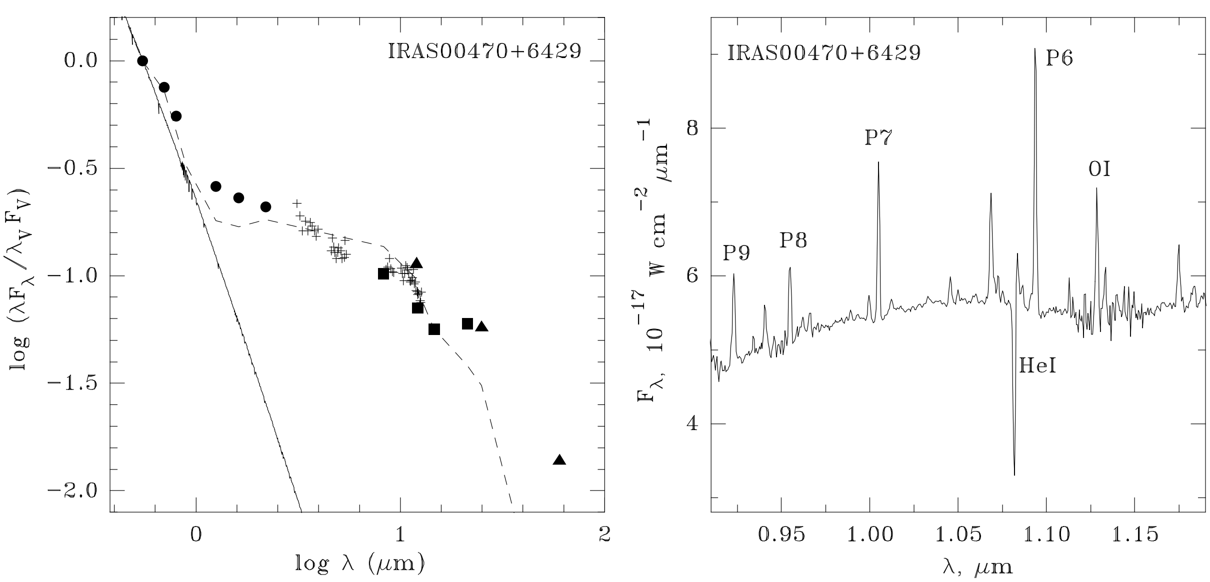

Figure 8: The SED (left panel) and near-IR spectrum (right panel) of IRAS 00470+6429. Our *BVR* and the 2MASS data are shown by filled circles, the MSX fluxes by filled squares, the IRAS fluxes by filled upward triangles, and the IRTF BASS data by crosses. The SED is corrected for IS extinction using the wavelength dependence of Savage & Mathis (1979). The solid line for T_{eff}=20000 K, $\log g$=3. The dereddened SED of MWC 657 is shown by the dashed line.