The B[e] Phenomenon: Forty Years of Studies
ASP Conference Series, Vol. 508
A. Miroshnichenko, S. Zharikov, D. Korčáková, and M. Wolf, eds.

A Search for New Objects with the B[e] Phenomenon

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Abstract. Recent all-sky photometric surveys at optical and infrared wavelengths obtained with a high positional accuracy (e.g., *UCAC4, 2MASS, WISE*) allowed to conduct reliable searches for all kinds of objects with circumstellar envelopes. Using our previous experience in identifying hot stars surrounded by circumstellar dust, we continued searching for more candidates to these types of object, mostly aiming at finding those with the B[e] phenomenon. In this talk we discuss our search strategies, present photometric criteria for separating the objects of interest, and show spectral energy distributions of some newly found candidates.

1. Introduction

IR-excesses in the Spectral Energy Distributions (SED) of hot stars were discovered over 40 years ago (Geisel 1970). However massive searches for such objects became possible only after the *IRAS* mission in 1983). First positional cross-identifications between the IR and optical sources were done for bright stars. For instance, Patten & Willson (1991) found that ~20% of the Bright Star Catalog ($V \leq 6.5$ mag, Hoffleit & Jaschek 1991) stars have IR excesses. Nevertheless, many misidentifications occurred due to a poor astrometric accuracy of the IR coordinates (typically $10'' - 20''$) and the occasional presence of faint cool stars near brighter hot stars. Oudmaijer et al. (1992) cross-identified the *SAO* catalog of optical positions ($V \simeq 11$ mag, Whipple 1966) and the *IRAS* catalog, found more hot stars with IR excesses, and ended up with a fewer misidentifications for the same above reason. There has been a number of other searches with various goals. Some of them were aiming at revealing any kind of IR excess, others targeted stars at certain evolutionary stages. We just mention a more recent one by Clarke et al. (2005) that used Tycho–2 (*BV*, Høg et al. 2000) and MSX ($8 - 21\mu$m, Egan et al. 2003) with a higher positional accuracy in both spectral regions and found ~1000 new objects undetected by *IRAS*.

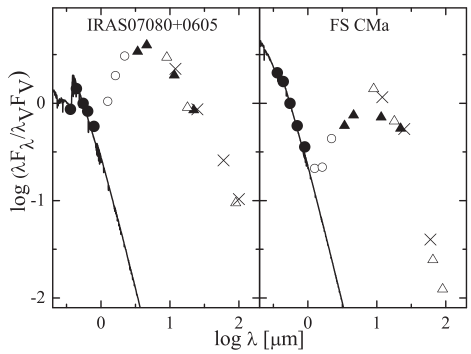

Figure 1. SEDs of two FS CMa type objects. Fluxes normalized to those in the V–band versus wavelength are shown in the logarithmic scale. Symbols: filled circles – *UBVRI* photometry, open circles – *JHK* data from 2MASS, filled triangles – *WISE* data, open triangles – *AKARI* data, crosses – *IRAS* data. Solid lines show synthetic SEDs from Kurucz (1998) for the following parameters: $T_{\rm eff}$ = 12000 K, $\log g$ = 4.0 for IRAS 07080+0605 and $T_{\rm eff}$ = 19000 K, $\log g$ = 3.0 for FS CMa. Correction for the total (interstellar and circumstellar) extinction has been applied.

2. Our Searches

Our main goal has been to find objects with the B[e] phenomenon. It manifests itself through both spectroscopic (forbidden lines) and photometric (IR excess) features. Massive spectroscopic searches are more difficult than photometric ones because of the following. Although large regions of the sky can be covered at low resolution and fainter objects can be detected, it is easy to miss typically weak forbidden lines. Spectroscopic search at a high-resolution require larger telescopes and/or target brighter objects. Photometric searches require a good astrometric accuracy at both optical and IR wavelengths. At the same time, they do not provide spectral information. Therefore, photometric searches need to be accompanied by follow-up spectroscopy of selected candidates. Before 2007 we were searching for new objects with IR excesses using catalogs of emission-line stars (e.g., Kohoutek & Wehmeyer 1999) positionally cross-correlated with *IRAS*. We were specifically looking for FS CMa objects, whose properties include strong emission-line spectra, early B- to early A- spectral type dominating the optical spectrum, and IR excesses with the flux declines towards longer wavelengths at $\lambda > 10\mu$m. The declining IR flux was the main criterion for selecting the source from the *IRAS* Point Source Catalog. As a result, we found 10 B[e] objects and 10 non-B[e] objects (Miroshnichenko et al. 2007). However, objects of other types show up in our searches (e.g., young stars, very cool stars with little reddening). Introduction of the NOMAD catalog (a combination of USNO–B1.0 and 2MASS, Zacharias et al. 2005) allowed for easier searches due to a very good astrometric accuracy (< 1″). However, this catalog contains optical photometry in non-standard filters which for many stars was taken non-simultaneously. Therefore it was hard to set strict criteria for optical data. Nevertheless, our analysis of IR properties of known FS CMa objects (see Fig. 1) resulted in establishing several photometric criteria to search for hot stars with circumstellar dust, avoiding classical Be stars and objects with only cold dust (e.g., planetary nebulae). These criteria were as follows: m_{blue} - m_{vis} $\leq$ 1 mag, $m_{vis} - K \geq 2$ mag, $J - K \geq 1.4$ mag, and $H - K \geq 0.7$ mag.

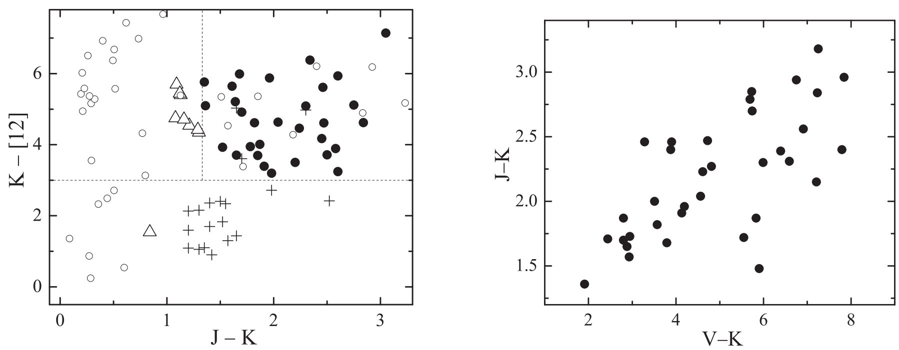

Figure 2. *Left:* IR color-color diagram showing positions of FS CMa type objects and candidates and Galactic B[e] supergiants (filled circles) compared to those of RV Tau stars (open triangles), cool evolved stars (carbon, Miras – crosses), and hot post–AGB candidate objects (open circles, Szczerba et al. 2007). *Right:* Optical-IR color-color diagram for FS CMa type objects.

With the above criteria we were first selecting objects, whose photometry satisfied the IR color-indices. At the next stage, the first two criteria were applied. Finally, selected objects were observed spectroscopically to search for the presence of emission lines including forbidden. Some results of our searches were presented by Miroshnichenko et al. (2011), who found 16 candidates in the Milky Way and 10 candidates in the Large Magellanic Clouds. Eighteen objects with the B[e] phenomenon have been confirmed by spectroscopy (see Miroshnichenko, Rossi, Polcaro, et al., this meeting). Nearly a dozen emission-line stars with no forbidden lines have been found as well. Some types of cool stars with dusty envelopes can be separated from B[e] objects (see Fig. 2). At the same time, post-AGB objects of B–F type may still have hot dust in their environments and mix with those of our interest. In most cases, the ultimate separation between them becomes obvious after taking spectra. The FS CMa type objects and massive B[e] supergiants typically exhibit much stronger emission-line spectra than post-AGB stars. Figure 3 shows SEDs of several objects found in our search. Three of them (MWC 482, AD Tau, and MWC 1051) show a declining IR flux between $\lambda \sim 10\mu$m and $\lambda \sim 20\mu$m and most likely belong to the FS CMa or B[e] supergiant group. Theses two groups differ by mass and luminosity of the underlying stars. Accurate luminosity determination becomes possible upon analysis of high-resolution spectra, derivation of kinematic distances, and examining regions around the objects. The fourth object, MWC 485, shows nearly a flat IR SED and is probably a young stellar object. Spectra of all four objects show the presence of Balmer and forbidden oxygen emission lines, while their optical color-indices imply an early spectral type. Analysis of our data collection for these objects is in progress. We continue the search using the *UCAC–4* catalog (Zacharias et al. 2013) that contains 5–color (*BVgri*) optical photometry and the 2MASS *JHK*-data. More accurate and better calibrated optical photometric data from *UCAC–4* will allow us to search for more reddened hot stars, which we have not been sampling earlier. After initial selection, SEDs will be assembled by adding data

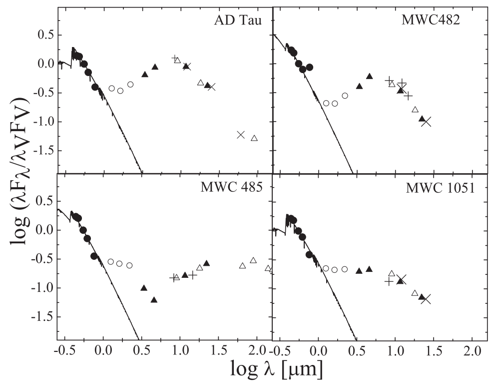

Figure 3. SEDs of recently found objects with the B[e] phenomenon. Symbols are the same as in Feg. 1. Solid lines show synthetic SEDs from Kurucz (1998) for the following parameters: T_{eff} = 12000 K, log g = 4.0 for AD Tau and MWC 1051; T_{eff} = 19000 K, log g = 3.0 for MWC 482; and T_{eff} = 16000 K, log g = 3.0 for MWC 485. Approximate correction for the total extinction was applied based on *BV* photometric data from *UCAC–4* and our T_{eff} estimates.

from various IR surveys, such as *MSX*, *WISE* (Cutri et al. 2012), and *AKARI* (Ishihara et al. 2010) and follow up spectroscopy will be carried out.

Acknowledgments. A. S. M. acknowledges support from the College of Arts and Sciences Advancement Council and the Department of Physics and Astronomy of the University of North Carolina at Greensboro. A. K. and K. K. thank the conference organizing committees for supporting their travel. This study was supported by Ministry of Education and Science of the Republic of Kazakhstan (program 0263/PSF).

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