Active OB stars: structure, evolution, mass loss and critical limits
Proceedings IAU Symposium No. 272, 2010
C. Neiner, G. Wade, G. Meynet & G. Peters, eds.

DOI: 00.0000/X000000000000000X

The B[e] phenomenon in the Milky Way and Magellanic Clouds

Anatoly Miroshnichenko[1], **Nadine Manset**[2], **Francesco Polcaro**[3], **Corinne Rossi**[4], **Sergey Zharikov**[5]

[1]Dept. of Physics & Astronomy, University of North Carolina at Greensboro, P.O. Box 26170, Greensboro, NC 27402–6170, USA
email: a_mirosh@uncg.edu
[2]CFHT Corporation, 65–1238 Mamalahoa Highway, Kamuela, HI 96743
[3] Istituto di Astrofisica Spaziale e Fisica Cosmica, INAF, Via del Fosso del Cavaliere 100, 00133, Roma, Italy
[4] Universitá La Sapienza Roma - Pza A Moro 5, I–00162 Roma, Italy
[5] Instituto de Astronomía, Universidad Nacional Autónoma de México, Apartado Postal 877, 22800, Ensenada, BC, Mexico

Abstract. Discovered over 30 years ago, the B[e] phenomenon has not yet revealed all its puzzles. New objects that exhibit it are being discovered in the Milky Way, and properties of known objects are being constrained. We review recent findings about objects of this class and their subgroups as well as discuss new results from studies of the objects with yet unknown nature. In the Magellanic Clouds, the population of such objects has been restricted to supergiants. We present new candidates with apparently lower luminosities found in the LMC.

Keywords. stars: early-type; infrared: stars; (stars:) circumstellar matter

1. Introduction

The B[e] phenomenon was observationally defined by Allen & Swings (1976) on the basis of optical spectroscopic and near-infrared photometric data. It refers to the simultaneous presence of forbidden line emission (e.g., [O I], [Fe II], [N II], and sometimes [O III] lines) in addition to permitted line emission (e.g., Balmer and Fe II lines) and large IR excesses in the spectra of B-type stars. These observational features make it different from the Be phenomenon. The presence of forbidden lines indicates that the gaseous component of the circumstellar (CS) envelopes is more extended than in Be stars. The large IR excess is a manifestation of CS dust which is not present in Be stars. Also, the B[e] phenomenon occurs in a wider variety of objects than the Be phenomenon (see Miroshnichenko 2006 for a recent review).

Allen & Swings have already noticed the variety of objects with the B[e] phenomenon. Some twenty years later Lamers et al. (1998) summarized available data and concluded that the B[e] phenomenon occurs in four stellar groups with well-understood nature and evolutionary status (Herbig Ae/Be stars, symbiotic binaries, supergiants, and compact Planetary Nebulae). At the same time, nearly half of the original list of 65 objects with the B[e] phenomenon remained unclassified. A few of them were well-studied (e.g., FS CMa = HD 45677 and V742 Mon = HD 50138), but their derived properties did not allow to fit them within any of the above groups. Other unclassified objects have not been studied enough to classify them until recently.

A few years ago Miroshnichenko (2007) and Miroshnichenko et al. (2007) analyzed both historic and their own data on the unclassified objects and concluded that most of them can be separated into a new group. The group was called FS CMa type objects after the prototype object with the B[e] phenomenon (Swings 2006). These authors also showed that FS CMa objects are neither pre-main-sequence Herbig Ae/Be stars nor symbiotic binaries, their luminosity range (log $L/L_{\odot} \sim 2.5$–4.5) is below that of supergiants, and they are unlikely to be at the post-AGB evolutionary stage. The main observational features of this group are described in the other paper by Miroshnichenko et al. in these proceedings. One of these features is a very strong emission-line spectrum which is hard to explain by the evolutionary mass loss from a single star of the described luminosity range (Vink, de Koter, & Lamers 2001). Therefore, it was suggested that FS CMa objects are binary systems observed after a rapid mass-exchange phase (Miroshnichenko 2007). No direct mass transfer seems to be currently observed in any of these objects.

Currently, only a few objects with the B[e] phenomenon can be called unclassified due to insufficient data. All Herbig Ae/Be stars, not only seven from the original list, exhibit the B[e] phenomenon. Therefore, the original list of 65 objects has been expanded significantly. Among the variety of objects with the B[e] phenomenon, only supergiants and FS CMa type objects seem to form dust while having a B-type star in their content. Here we will concentrate on the expansion of the list of objects which belong to the FS CMa group in the Milky Way and the Large Magellanic Cloud (LMC).

2. Finding new candidates.

Another feature of the FS CMa group is a sharp decrease of the IR flux at $\lambda > 10\mu$m. It allowed Miroshnichenko et al. (2007) to expand the group by finding nine IRAS sources (whose fluxes were accurately measured in three IRAS photometric bands at 12, 25, and 60 μm) with such a flux behavior that positionally coincide with early-type emission-line stars. However, this procedure only works for relatively bright IR sources, because the sensitivity of IRAS decreases with wavelength. Also, the lowest-mass post-AGB objects, RV Tau type stars, turned out to have IRAS colors within the same range.

Nevertheless, a new photometric criterion for FS CMa objects was established in the same paper. It was found that the observed $J - K$ color-indices of FS CMa objects exceed ~1.3 mag, while RV Tau stars show bluer colors. We decided to use this criterion in combination with not very large optical colors and search for new candidates with the B[e] phenomenon in a catalog of emission-line stars by Kohoutek & Wehmeyer (1997), which we cross-correlated with the NOMAD catalog by Zacharias et al. (2005).

As a result, we found sixteen new candidates. Five of them, randomly picked, were observed and the presence of forbidden lines was found in all of them. Additionally, a very faint object with the B[e] phenomenon ($V \sim 17$ mag) was accidentally found. It turned out to positionally coincide with the 2MASS source 03094640+6418429. Fragments of our spectra of some of these objects are shown in Fig. 1. They are most likely FS CMa objects, because luminosity sensitive absorption lines (e.g., Si III 5739 Å, Miroshnichenko et al. 2004) typical for supergiants, were not found in their spectra. Other newly discovered and spectroscopically confirmed objects with the B[e] phenomenon include IRAS 02110+6212 = VES 723, IRAS 21263+4927, IRAS 20090+3809, and MWC 485.

We continue searching the NOMAD catalog and have already found another dozen of new candidates. The photometric search is not exhaustive, because we only look for objects with not very different magnitudes in the blue and red band. Redder objects may be just very cool stars. Nevertheless, currently the number of FS CMa objects and candidates approaches 70.

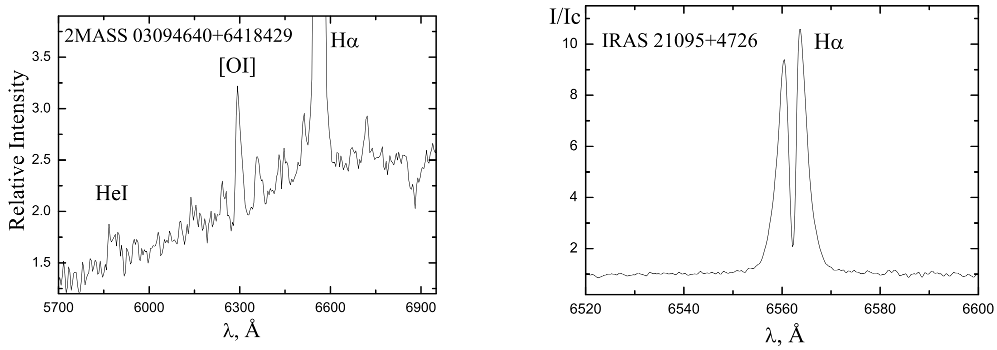

Figure 1. Left panel: Low-resolution spectrum of 2MASS 03094640+6418429 obtained at the 1.82-m telescope of the Padova Observatory ($R \sim 1500$). Right panel: High-resolution spectrum of IRAS 21095+4726 obtained at the 2.12-m telescope of the San Pedro Martir Observatory ($R \sim 15000$).

3. New candidates in the Large Magellanic Cloud.

The first object (R 126) with the B[e] phenomenon in the Magellanic Clouds was reported by Zickgraf et al. (1985). Another seven were added by Zickgraf et al. (1986) and four more by Gummersbach, Zickgraf, & Wolf (1995). All these objects are located beyond the main-sequence. Ten of them are supergiants with luminosities $\log L/L_{\odot} = 4.7 - 6.1$, while the remaining two (Hen S59 and Hen S137) are late B-type stars with a luminosity of $\log L/L_{\odot} \sim 4$.

It is easier to separate supergiants from less luminous stars in the Clouds with their low interstellar extinction than in the Milky Way. All the supergiants with the B[e] phenomenon in the LMC have optical brightnesses of $V = 11 - 13$ mag objects, while Hen S59 and Hen S137 have $V \sim 14$ mag. In an attempt to find more candidates to the list of objects with the B[e] phenomenon in the LMC, we positionally cross-correlated a catalog of optical photometry by Zaritsky et al. (2004) and the 2MASS catalog (Cutri et al. 2003).

Table 1. Candidates for objects with the B[e] phenomenon in LMC

Name	**R.A.**	**Dec.**	V	K	$J-K$
ARDB 54	4:54:43.5	−70:21:27.8	12.77	11.55	1.15
0218-0100858	5:45:29.5	−68:11:45.7	14.02	11.48	1.62
0203-0138943	5:41:43.7	−69:37:38.3	14.11	11.14	2.00
0181-0125572	5:27:47.6	−71:48:52.6	14.24	11.77	1.72
BE74 540	5:12:09.1	−71:06:49.7	14.27	12.11	1.61
BE74 580	5:24:17.4	−71:31:50.0	14.56	12.24	1.55
0225-0105286	5:24:57.9	−67:24:57.9	14.67	12.51	1.40
LHA120-N 148B	5:31:42.2	−68:34:53.9	15.42	13.41	1.50
AL 190	5:26:30.7	−67:40:36.5	15.69	12.48	2.12

Comments:
The objects names are from Bohanan & Epps (1974) - BE74, Henize (1956) - LHA120, Andrews & Lindsay (1964) - AL, Ardeberg et al. (1972) - ARDB, and the rest is from the USNO–B1.0 survey (Monet et al. 2003). The coordinates are given for the epoch 2000.0.

In total, we found nearly 100 positionally close objects that have slightly reddened colors of B-type stars and large IR color-indices, but for only nine of them the optical-IR position offset does not exceed 1 arcminute. These objects are listed in Table 1. One of these objects, ARDB 54, is a supergiant (see right panel of Fig. 2). All the others have $V = 14.0 - 15.7$ mag and represent lower luminosity objects.

A near-IR color-color diagram for the recognized objects with the B[e] phenomenon in the Magellanic Clouds and the objects from Table 1 is shown in the left panel of Fig. 2. If forbidden line emission is found in their spectra, then they probably belong to the FS CMa group. We plan to obtain both photometric and spectroscopic observations of these objects in the nearest future.

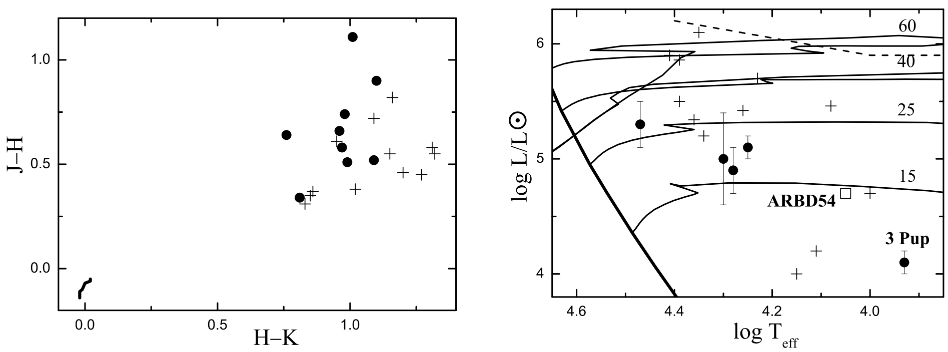

Figure 2. Left panel: A $(J-H) \sim (H-K)$ diagram for the known Clouds objects with the B[e] phenomenon (pluses) and the objects from Table 1 (circles). The solid line in the lower left corner represents intrinsic colors of B-type supergiants (Wegner 1994). Right panel: A Hertzsprung-Russell diagram for supergiants with the B[e] phenomenon and well-constrained luminosities in the Milky Way (circles) and in the Clouds (pluses). The newly found candidate ARDB 54 is shown by an open square. The solid lines are the zero-age main-sequence and evolutionary tracks for single stars (Schaller et al. 1992) labeled with initial masses in solar units. The dashed line is shows the Humphreys-Davidson stability limit.

4. Conclusions.

Using our photometric criteria for separation of objects with the B[e] phenomenon, we found nearly 20 new candidates in the Milky Way and eight in the LMC. One new supergiant candidate is also found in LMC. The presence of the B[e] phenomenon in five Galactic objects was confirmed. Thus, we expanded the Galactic FS CMa group to nearly 50 members and 20 candidates. The number of objects with the B[e] phenomenon in the LMC may be doubled, if its presence in the spectra of the reported candidates is confirmed.

Acknowledgements. This research has made use of the SIMBAD database operated at CDS, Strasbourg, France, and of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

References

Allen, D.A. & Swings, J.-P. 1976, *A&A*, 47, 293
Andrews, A.D., & Lindsey, E.M. 1964, *Irish Astronomy*, 6, 241
Ardeberg, A., Brunet, J.P., Maurice, E., & Prevot, L. 1972, *A&AS*, 6, 249
Bohannan, B., & Epps, H.W. 1974, *A&AS*, 18, 47

Cutri, R.M., et al. 2003, *CDS/ADC Collection of Electronic Catalogues*, 2246
Gummersbach, C.A., Zickgraf, F.-J., & Wolf, B. 1995, *A&A*, 302, 409
Henize, K.G. 1956, *ApJS*, 2, 315
Kohoutek, L., & Wehmeyer, R. 1997, *Astron. Abh. Hamburg. Sternw.*, 11, 1
Lamers, H.J.G.L.M. et al. 1998, *A&A*, 340, 117
Miroshnichenko, A.S., et al. 2004, *A&A*, 417, 731
Miroshnichenko, A.S. 2006, In Stars with the B[e] Phenomenon, eds. M. Kraus & A.S. Miroshnichenko, *ASP Conf. Ser.*, 355, 13
Miroshnichenko, A.S. 2007, *ApJ*, 667, 497
Miroshnichenko, A.S., et al. 2007, *ApJ*, 671, 828
Monet, D.G., et al. 2003, *AJ*, 125, 984
Schaller, D.J., et al. 1992, *A&AS*, 92, 625
Swings, J.-P. 2006, In Stars with the B[e] Phenomenon, eds. M. Kraus & A.S. Miroshnichenko, *ASP Conf. Ser.*, 355, 3
Vink, J.S., de Koter, A., & Lamers, H.J.G.L.M., 2001, *A&A*, 369, 574
Wegner, W. 1994, *MNRAS*, 270, 229
Zacharias N., Monet D.G., Levine S.E., Urban S.E., Gaume R., & Wycoff G.L. 2005, *AAS*, 205, 48.15
Zaritsky, D., Harris, J., Thompson, I.B., & Grebel, E. 2004, *AJ*, 128, 1606
Zickgraf, F.-J., Wolf, B., Stahl, O., Leitherer, C., & Klare, G. 1985, *A&A*, 143, 421
Zickgraf, F.-J., Wolf, B., Leitherer, C., Appenzeller, I., & Stahl, O., 1986, *A&A*, 163, 119