Stars with the B[e] Phenomenon
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Michaela Kraus and Anatoly S. Miroshnichenko

A Grandfather's Question : Why Have these Stars Been Called B[e]s ?

Jean-Pierre Swings

Institute of Astrophysics and Geophysics, University of Liège, Allée du 6 Août, 17, 4000 Liège, Belgium

Abstract. A short historical review is presented, from before the Mount Wilson Catalog to the 1996 introductory report by P. Conti. The main properties of these peculiar stars, and in particular of its galactic prototype HD 45677[1], as well as some considerations on similarities with other types of objects, is also given.

1. The Early Days : HD 45677 from 1898 to the 1960's

The historical milestones to be remembered are the following:

1898:

Mrs. W.P. Fleming discovers hydrogen emission lines in very low dispersion spectra of HD 45677 (Fleming 1898)

1923:

Paul Merrill finds "unusual bright lines in the spectrum of HD 45677", these lines appearing also in the spectra of XX Oph (now called "Merrill's star"), AG Peg and η Car (Merrill 1925).

1928:

The "unusual" lines mentioned above are identified by Merrill as being due to [FeII]; in addition, on the basis of the continuous spectrum and of some absorption lines, he allocates a spectral type B2 to HD 45677 (Merrill 1928).

1930's and 1940's:

HD 45677 appears as MWC 142 in the catalogs of emission line objects of Merrill & Burwell (1933, 1943, 1949, 1950).

1940 and 1943:

Pol Swings and Otto Struve include HD 45677 in their systematic spectroscopic investigation of "peculiar objects" and observe some variability of the Balmer line profiles (the V/R ratio) in the spectra of this star (Swings & Struve 1940, 1943).

[1] HD 45677 = BD-12°1500 = MWC 142 = FS CMa

1952:

Merrill states that HD 45677 is not a "normal" star with an envelope; rather it is "*intermediate between a Be star and a planetary nebula*". It is thus a star with an extremely extended and bright outer atmosphere.

1950's and 1960's:

These were two decades of quasi-blackout concerning peculiar Be stars; Burnichon and collaborators nevertheless refined the spectral classification of HD 45677 on the basis of low dispersion spectra, particularly around the Balmer discontinuity, with the result that it is a B2 IVe star, with some uncertainty on the luminosity class (Burnichon et al. 1967).

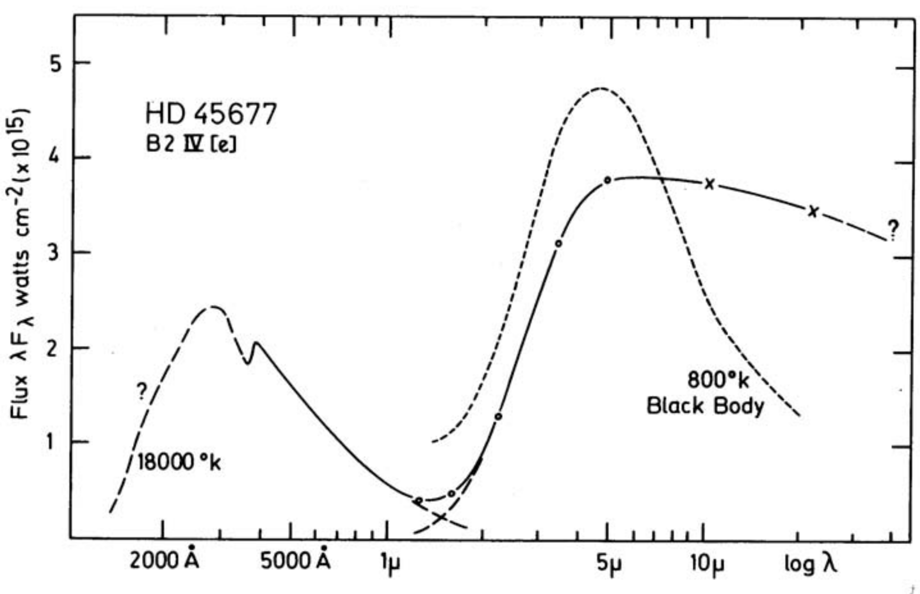

Figure 1. Energy distribution of HD 45677. Wavelength is plotted logarithmically on the abscissa, and flux linearly on the ordinate: on such a graph the area under a segment of the curve represents the energy radiated in that wavelength interval. An 800°K black-body, shifted by 10^{-15} W cm^{-2}, is shown for comparison (figure from Swings 1977).

2. The 1970's

1970-1971:

Prominent near infrared continuous emission around HD 45677 was found by Low et al. (1970), who attributed this to a 580°K companion to the star; one of their co-authors (Geisel 1970) in a later paper, however, linked the excess IR radiation to mass loss from the star, which was a more likely explanation. Indeed, the presence of a companion, which must have a mass comparable to that of the primary star, should be manifested by periodic variations in radial velocity:

however, as shown by J.P. Swings (no longer P!) and D. Allen (1971), the radial velocitites of stellar and shell lines in the spectrum of HD 45677 had shown no periodic variations over the previous 48 years. The broad energy distribution in the infrared implies a range of blackbody temperatures, the hottest being around 800°K (see Fig.1).

These points together with the evidence for mass loss and the intrinsic reddening of the star, lead Swings & Allen (1971), in their paper entitled "The infrared object HD 45677", to conclude that the IR excess is due to reradiation in a dust shell surrounding HD 45677, and not to the presence of a cool companion. This was in fact confirmed by Savage et al. (1978) who, on the basis of ultraviolet spectrophotometric data from the ANS satellite, showed that an approximate equality exists between the missing UV and visible radiation and the excess IR radiation: there thus exists a conversion of visible and especially UV radiation into infrared radiation by circumstellar dust absorption and reemission (cfr. Fig. 2 of Savage et al. 1978).

From 1971 Onwards:

1. A few words about the variability of HD 45677

   The last, and short, sentence of the abstract of "The Infrared object HD 45677" (Swings & Allen 1971) was: "The star has been found to vary"; and in fact it seems that HD 45677 has faded in the visible by approximately one magnitude since 1969. Between 1899 and 1969, however, the amplitude of variation in photographic magnitudes (684 photographic sky patrol plates examined from the Harvard College Observatory archives) had always been smaller than about 0.3 mag., without any trend towards periodicity (Swings & Swings 1972). In 1976, Feinstein et al. (1976) gave a historical review of the changes in magnitudes of HD 45677 from 1899 to 1972 and presented UBV and uvby data gathered during the years 1973-75: these data show night-to-night variations of some photometric indices that can reach 0.10 mag, as well as smaller variations during the course of several individual nights. Since rapid variations occuring essentially in the complex P Cygni profiles of the Balmer lines from night to night (or even shorter) were reported (see e.g. Swings 1973), correlations between line-profile and photometric variations were searched for by Swings et al. (1980). This search was based on two sets of homogeneous simultaneous and spectrographic observations of HD 45677 in 1977 (6 nights of UBV data; 38 spectra) and in 1979 (7 nights of uvby data; 30 spectra). It appeared that photometric data and some spectral features are well correlated (or anti-correlated) at certain epochs, but not at all at others. Because of these conflicting results, no explanation of the behaviour of the extended complex atmosphere surrounding this peculiar object could be proposed. It nevertheless seems plausible that the largest photometric variations are due to the presence of moving patches of the dust surrounding HD 45677 that do cross our line of sight to the central object. More recent photometric observations of HD 45677 can be found, e.g., in de Winter et al. (1996).

2. Peculiar Be stars with IR excess:
Correlations and similarities between objects...

From their extensive spectroscopic survey of Be stars with infrared excesses, Allen & Swings (1976) came up with two conclusions :

a. the presence of circumstellar dust radiating at 2-3 μ is more common in lower- temperature emission-line stars;
b. dust radiating at 2-3 μ occurs preferentially in denser circumstellar envelopes.

In other words, there definitely exists a (strong) correlation between the presence of [OI], [SII] and [FeII] emission lines in the spectra of the Be type objects[2] and the existence of a strong infrared excess (characterized by H(1.6 μ) - K(2.2 μ) $\geq$ 1.0 and K - L(3.5 μ) $\geq$ 1.0. Examples of such objects, actually showing similarities, are plotted in the now "canonical" H-K vs K-L color diagram (see Fig.2, from Swings 1977).

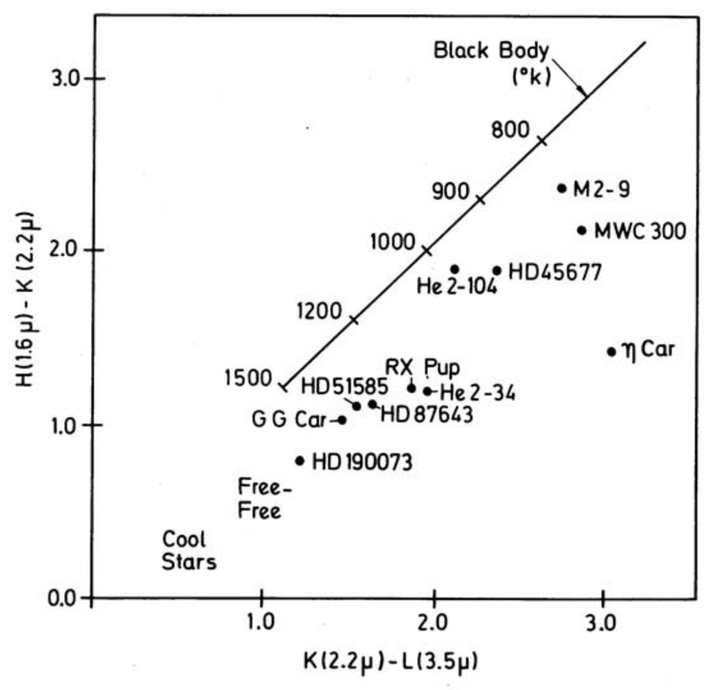

Figure 2. Near infrared colors (see text) of a few peculiar emission-line objects. Temperatures of "idealized" dust shells are indicated along a "blackbody" line. The locations of normal cool stars and of stars whose IR continuum is due to free-free emission are indicated for comparison (figure from Swings 1977).

[2]and/or of [OIII] λ 4363 Å in the case of dense (proto-) planetary nebulae (such as M 2–9).

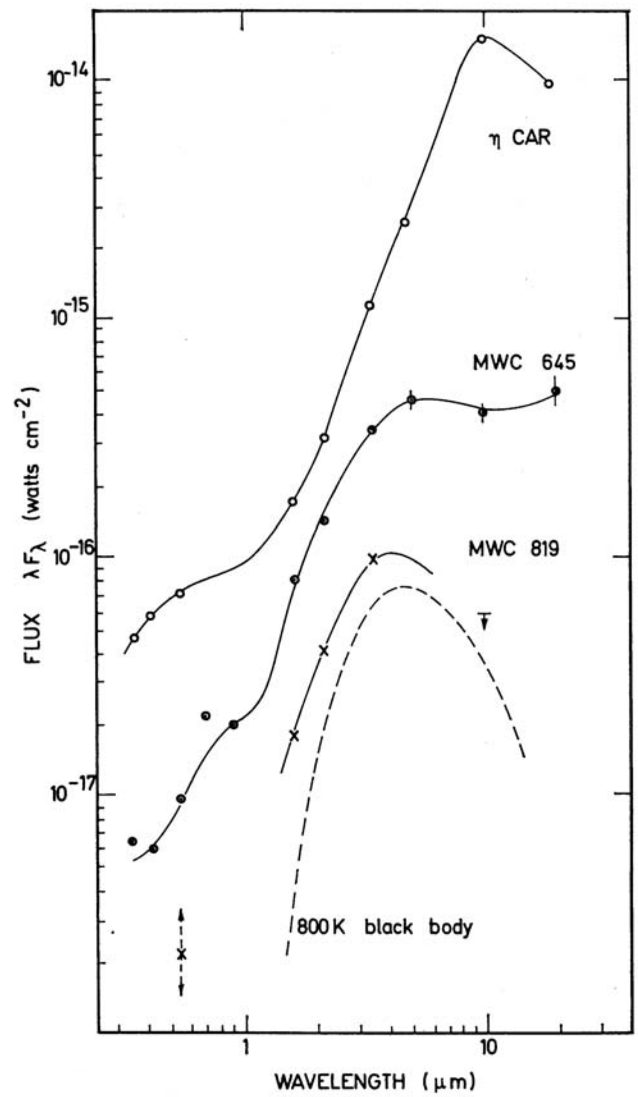

Figure 3. Energy distributions of MWC 645, MWC 819, and η Car (the latter divided by 100), objects definitely exhibiting similarities to HD 45677, GG Carinae, etc. (from Swings & Allen 1973).

Other similarities between infrared excesses are displayed in Figure 3 (from Swings & Allen 1973): it is interesting to note that several spectral features do also exhibit similarities among these objects.
As far as polarization in peculiar emission-line objects is concerned, Barbier & Swings (1982) reported on measurements of a few peculiar Bes[3]

[3]for information, for HD 45677: p(U) $\simeq$ 1.2 ($\pm$ 0.1) %, p(B) $\simeq$ 1.5 ($\pm$ 0.1) %, p(V) $\simeq$ 1.2 ($\pm$ 0.1) % with an angle around 172° in all cases

and related stars, and on their unsuccessful search for correlating the observational data with characteristics of the objects or of their surrounding dust shells.

3. A Physical "Model" for HD 45677 ?

It is a difficult and doubtful matter to construct a physical model that takes into account the spectroscopic properties of HD 45677. Swings (1973) nevertheless attempted to define the zones around this peculiar Be star where there exists preferential absoprtion or emission of the various observed elements.

- At the surface of the stellar photosphere: wide absorptions of H and HeI, rotational velocity v sin i $\sim$ 200 km/s.
- Near the surface: a variable equatorial disk where the emission in Mg II λ 4481 originates (velocity shift between emissions: $\sim$ 200 km/s; central wide absorption: v'sin i $\simeq$ 120 - 150 km/s).
- Further "out": regions causing the complex structure of the Balmer lines: continuous outflow of material (P Cygni profiles) and rapid motions (pulsations, random excursions) of "clouds" of great dimensions (variations in the structure of H_γ and H_δ).
- Around 10 R_*: equatorial ring with on the inside Mn II and Cr II (rotational velocity $\sim$ 25 km/s), and on the outside FeII ($v_{rot} \simeq$ 15 km/s) with its double emission lines.
- Outer region, beyond $\sim$ 10R_* extension of the ring into a disk or a torus (with $T_e \sim 4500°$K, $N_e \simeq 10^8$ cm^{-3}) in which the emissions of [O I], [S II], [Fe II], [Ni II], [Cr II] originate[4].
- A "dust shell", responsible for the strong infrared excess. As pointed out by Swings & Allen (1971): "The 5 μ flux from HD 45677 is equal to that from a 640° K sphere of diameter 32 A.U.[4] at 1 kpc and is therefore consistent with that from an almost optically thick dust shell heated only by the underlying star". The zones mentioned above are drawn schematically in Fig. 4 in a representation where they would be seen "pole-on".

Such a model is obviously quite "ad hoc" and was meant to be a stimulus for quantitative refinement and/or further work, taking into account the characteristics of more than one object, such as was done later, e.g., by Zickgraf et al. (1996) and references therein, and by several participants to this workshop.

4. And (Almost) Finally... the Origin of the B[e] Terminology: Why and When ?

Where and when did the term B[e] star originate ? When P. Conti "volunteered" to talk about them at an LBV meeting in 1996 he (now comes a long quotation

[4]for comparison: the [Fe II]-rich asymmetric nebula around α Sco B extends between a few hundred AUs and 2000 AUs (Swings & Preston 1978)

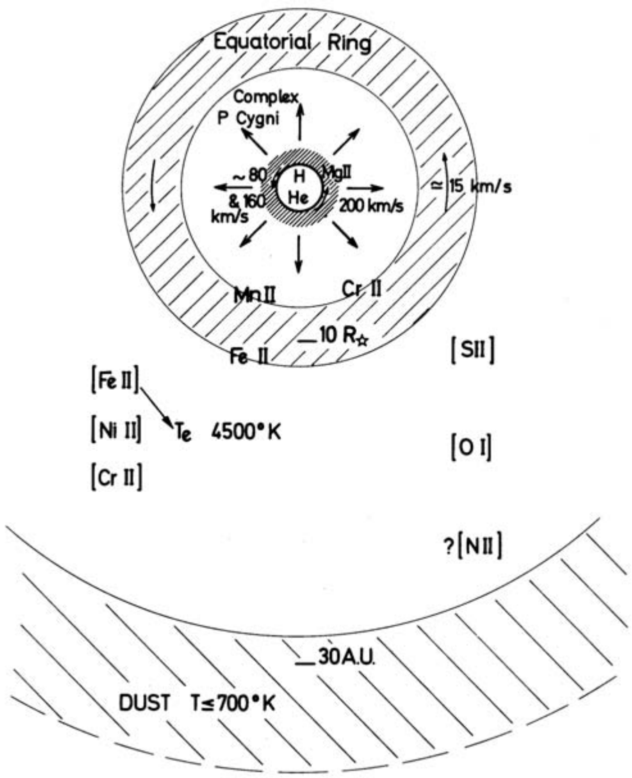

Figure 4. A model ? "Pole-on" projection of the suspected zones around the B2 IV[e] star HD 45677 in which the various absorptions and emissions are believed to take place preferentially (see text; figure from J.P. Swings 1976).

from Conti 1997): "thought the term probably went back to Struve and Pol Swings in the 40s. While recently in Liège, I asked Jean-Pierre Swings to seek out the origin for me, which I will now share with you. Curiously, this terminology only goes back to the IAU Symposium on Be stars held at the Red Jacket Beach Motor Inn on Cape Code. In those proceedings you will find both a paper by J.P. Swings (1976) and a detailed remark by me (!) in the general discussion proposing the use of the term B[e] for those Be stars with forbidden emission lines in the optical region. I suspect what actually happened was that at one of the numerous informal discussions we had during that meeting (and I seem to recollect a lot of bar time), both Jean-Pierre and I thought to distinguish those stars with forbidden lines from their more prevalent cousins, the "classical" Be stars; J.P. Swings (1973) had made a detailed investigation of HD 45677, the defining B[e] star, and discovered its "infra-red" excess.

The *initial* definition of a B[e] star thus includes the following conditions: 1) A B[e] star is first of all a Be-type star, having in addition to its absorption line spectrum (often weak and difficult to see) recombination emission lines of H and HeI, and narrow permitted emission lines of other elements. 2) In addition, forbidden lines in the optical, of such species as [FeII], [SII], [OI], etc, are observed.

3) Subsequently, it was found that B[e] stars have a strong IR excess (e.g., Allen & Swings 1976), due to associated dust. 4) Furthermore, at least some B[e] stars appear to have broad stellar wind lines, and many are quite luminous."

So, in a nutshell, B[e] stars are Be stars with forbidden (low excitation) emission lines plus strong infrared excess(es) due to (fairly) hot (nearby) dust.

5. What About the Present and the Future ?

As far as planned or future researches on B[e] stars are concerned, one can easily think of at least four areas:

- high angular resolution observations: using adaptive optics and/or interferometric techniques, a search for disks/rings around B[e] objects would most probably lead to interesting results. Ground-based as well as space observations have e.g. already revealed reflection nebulae or asymmetries around some of these objects. However the 10^{-2} - 10^{-3} arc sec resolution that is becoming available should be taken advantage of while observing B[e] stars, especially in the near infrared;

- high spectral resolution observations in order to obtain much higher quality data on the profiles and relative intensities of the various emission lines: this should lead to more realistic physical models for several B[e] stars;

- polarimetry and spectro-polarimetry should tell us much more about the dust distribution around B[e] stars: this technique is also becoming of common use, even for fairly faint objects;

- as a challenge to Conti's (1997) statement that "B[e]s will not become LBVs (nor vice-versa)", thus that possibly this type of objects could evolve towards Wolf-Rayet stars with very asymmetric winds (Conti 1997), there is plenty of room for studies on connections and/or links between B[e]s and other types of objects, be them LBVs, WRs, or protoplanetary nebulae such as M 2–9, as proposed in the latter case, on several occasions, by the Allen-Swings team in the 1970's!

Acknowledgments. I am grateful to the organizers of this workshop for having thought of inviting me, although I have been inactive in the B[e]-field for quite some time, in particular to Michaela Kraus and Anatoly Miroshnichenko... for their insistance! I further wish to congratulate Michaela and her colleagues for the excellent organization of this very enjoyable Vlieland Workshop... which made me feel younger by almost three decades. Thanks.

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