Massive Stars in Interacting Binaries
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The Enigmatic B[e] Star Hen 2-90 – an Interacting Binary?

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Abstract. We present the enigmatic galactic unclassified B[e] star Hen 2-90. Its optical spectrum is discussed and analysed in terms of the forbidden emission lines coming from a non-spherical wind. The evolutionary phase of Hen 2-90 is discussed. We raise the question whether an interacting binary nature seems to be a possible solution to account for all observed characteristics.

1. Introduction

Stars with the B[e] phenomenon have besides their spectral type several characteristics in common: strong Balmer emission lines, many permitted and forbidden emission lines of low ionized metals, e.g. [FeII] and [OI], and a strong near- or mid-infrared excess due to hot circumstellar dust.

The group of stars showing the B[e] phenomenon is heterogeneous and has been divided by Lamers et al. (1998) into subgroups according to their evolutionary phase. These subgroups contain supergiants, Herbig stars, symbiotic objects and compact planetary nebulae. The biggest group, however, are the unclassified B[e] stars whose evolutionary phase is not or not unambiguously known.

Here, we present the enigmatic object Hen 2-90, a galactic unclassified B[e] star. It has first been classified as a compact planetary nebula, e.g. by Henize (1967); Schwarz et al. (1992); Costa et al. (1993); Lamers et al. (1998). Later on, a bipolar jet-like structure was resolved with HST (Sahai & Nyman 2000) with several perfectly aligned knots extending up to $\sim 10''$ on both sides of the star. Such a structure reminds more of a young stellar object or a symbiotic object than of a compact planetary nebula. Further observations with HST (Sahai et al. 2002) revealed even a bipolar high-ionized wind, a low-ionized wind at intermediate latitudes as well as a high-density circumstellar disk.

2. The Nature of Hen 2-90

Due to the different classifications found in the literature, we wanted to test their reliability. In this section we therefore discuss the different possible classifications in terms of the characteristics of Hen 2-90 found from already existing observations and from our own set of observations.

2.1. Non-Spherical Mass Loss in a Compact Planetary Nebula?

The circumstellar material on the HST image of Hen 2-90 (Sahai et al. 2002) shows a latitude dependence of the ionization structure turning from high-ionization in polar directions to low-ionization in equatorial directions. Such a behaviour might be explained with a latitude dependent mass flux and surface temperature distribution as a result of a rapidly rotating underlying star (Kraus et al. 2005). We took optical spectra[1] centered on the star with a slit width

Table 1. Observed and modelled forbidden-line luminosities for a stellar distance of 2 kpc. Column 5 gives the ratio of observed over modelled line luminosity, column 6 the wind part(s) in which the line is produced: polar (p), intermediate (i) or disk wind (d).

Ion	λ (Å)	$L_\lambda^{\rm obs}$	$L_\lambda^{\rm model}$	ratio	region
O III	4959	3.58×10^{34}	3.91×10^{34}	0.92	p,i
O III	5007	1.13×10^{35}	1.13×10^{35}	1.00	p,i
O III	4363	9.71×10^{33}	2.90×10^{34}	0.33	p,i
O II	7319	7.23×10^{33}	7.70×10^{33}	0.94	i
O II	7330	6.18×10^{33}	6.17×10^{33}	1.00	i
O I	6300	4.98×10^{32}	4.86×10^{32}	1.02	d
O I	6364	1.49×10^{32}	1.60×10^{32}	0.93	d
O I	5577	1.12×10^{32}	2.33×10^{32}	0.48	d
S III	6312	2.95×10^{33}	2.98×10^{33}	0.99	i
S II	6731	2.13×10^{32}	2.20×10^{32}	0.97	i,d
S II	6716	9.05×10^{31}	1.05×10^{32}	0.86	i,d
S II	4076	3.43×10^{32}	1.18×10^{32}	2.90	i,d
S II	4068	1.15×10^{33}	4.57×10^{32}	2.52	i,d
N II	5755	4.56×10^{33}	4.57×10^{33}	1.00	i
N II	6548	4.84×10^{33}	6.15×10^{33}	0.79	i
N II	6584	2.08×10^{34}	1.81×10^{34}	1.15	i
Cl III	5538	1.74×10^{32}	1.74×10^{32}	1.00	p,i
Cl III	5517	1.10×10^{32}	4.23×10^{31}	2.60	p,i
Cl II	6153	3.88×10^{31}	3.82×10^{31}	1.01	i
Ar III	7136	7.37×10^{33}	6.88×10^{33}	1.07	p,i
Ar III	7753	1.49×10^{33}	1.68×10^{33}	0.89	p,i
Ar III	5193	1.16×10^{32}	6.44×10^{32}	0.18	p,i

[1]Based on observations with the 1.52m telescope at the European Southern Observatory (La Silla, Chile), under the agreement with the Observatório Nacional-MCT (Brasil)

that just covers the non-spherical ionization structure visible in the HST image of Sahai et al. (2002).

The spectrum shows strong [O I] emission which is an indication for the presence of a huge amount of neutral hydrogen material close to the star because H and O have the same ionization potential. According to the HST image, this neutral material can only be located in the equatorial disk. As Kraus & Lamers (2003) showed in the case of B[e] supergiants, equatorial disks around hot stars can indeed be neutral even close to the hot stellar surface, simply due to the high equatorial mass fluxes that result in effective shielding of the disk material from the ionizing stellar continuum photons.

Besides the O lines, the optical spectrum of Hen 2-90 also contains many more forbidden emission lines that can be related to the different wind regions (see Table 1). We performed a detailed analysis of these forbidden emission lines and found mass fluxes that increase from the pole to the equator by about a factor of 8 while the surface temperature drops by about a factor 3 (for more details see Kraus et al. 2005). These facts seem to be consistent with a rotating central star model. However, to fit the observed line luminosities, we had to adopt the elemental abundances. We found that S, Ar, Cl and He have about solar abundances, while O seems to be depleted (0.3 solar). We did not identify any C line which speaks in favour of C being depleted, too. These abundances are in agreement with Hen 2-90 being an evolved single star. The puzzling thing, however, is the fact, that N also seems to be depleted (0.5 solar) which cannot be explained by standard stellar evolution. We conclude that our simple picture of a rotating single star undergoing non-spherical mass loss cannot be the full story.

2.2. The Jet and Knots of Hen 2-90

The strange abundances found from our modeling and the fact that Hen 2-90 has a jet-like structure with perfectly aligned knots which are ejected regularly might help to come closer to the real nature of this puzzling and in a sense unique object. In Table 2 we listed all objects known to possess jets and knots and the identification of their source of jet and knot formation.

From this table we can draw two major conclusions: (1) except for young stellar objects, all jet systems are binaries, and (2) the jet and knot appearence is always linked to some kind of accretion. In the following sections, we therefore

Table 2. Objects showing jets and knots (after Livio 1999).

Object	Physical system
Young stellar objects	*Accreting* young star
Massive X-ray binaries	*Accreting* neutron star or black hole
Black hole X-ray transients	*Accreting* black hole
Low mass X-ray binaries	*Accreting* neutron star
Supersoft X-ray sources	*Accreting* white dwarf
Symbiotic stars	*Accreting* white dwarf
Hen 2-90	*Accreting* ?????

want to discuss whether the characteristics of Hen 2-90 fit into one of the classes of objects listed in Table 2.

2.3. Hen 2-90 – a Young Stellar Object?

The perfectly aligned knots on both sides of the star remind one of a Herbig object, i.e. a young stellar object (YSO). There are, however, a few points that speak against the identification of Hen 2-90 as a YSO:

- Hen 2-90 is not located in a star-forming region,
- its IRAS colors are much hotter than those of a YSO, separating Hen 2-90 in a color-color diagram from the regions covered by YSOs, OH/IR stars, HII regions, and ultracompact HII regions, and
- the depletion in C and O found from our modeling speak more in favour of an evolved object rather than a YSO.

To us it seems therefore clear that Hen 2-90 cannot be a YSO. If it belongs to one of the categories defined in Table 2, Hen 2-90 must be a binary.

2.4. An X-ray Binary?

Most of the binaries in Table 2 are X–ray sources. Chu et al. (2003) studied the X–ray emission from planetary nebulae and wind-blown bubbles and super-bubbles. Hen 2-90 was on their list of Chandra observations, but could not be detected in the 0.1–10 keV range. As far as we know, this was the only investigation of Hen 2-90 in X–rays. Observations e.g. in the hard X-ray band are certainly needed to quantify whether Hen 2-90 is an X–ray source.

2.5. A Symbiotic Object?

A symbiotic object is a binary consisting of a hot component, normally a white dwarf, and a cool component, normally a giant star. The optical spectrum of a symbiotic is a combination of these two individual spectra and therefore contains characteristics of both the hot and the cool components. The major characteristics of symbiotic objects are:

- strong HeII emission from the hot component and
- TiO absorption bands arising in the atmosphere of the cool giant.

Our optical spectrum shows indication neither for HeII emission, nor for TiO absorption bands. These features might be hidden within the circumstellar disk-like material, but the clear absence of any emission line coming from ions with an ionization potential larger than 40 eV speaks more in favour of these ions not existing, which means that the ionizing source in Hen 2-90 cannot be too hot, which is consistent with the fact that the effective temperature has been found to be of order 50 000 K (Kaler & Jacoby 1991). We therefore exclude Hen 2-90 being a symbiotic object.

3. Conclusions

We presented the unclassified B[e] star Hen 2-90 and discussed the possible nature of this fascinating object. It shows a jet-like structure with several perfectly aligned knots on both sides of the star that seem to be ejected regularly (every 40 years). This jet structure is perpendicular to the disk-like structure seen with HST. This disk seems to be neutral in hydrogen since strong [OI] emission has been observed that can only come from this disk. During the analysis of the forbidden emission lines it turned out that C, O **and** N need to be depleted to reproduce the observed line luminosities. This fact is not consistent with any known stellar-evolution scenario of single stars. In addition, a kind of accretion mechanism is certainly necessary to create the observed knots. From our comparison with other well-known systems having jets and knots we could exclude the YSO and the symbiotic nature of Hen 2-90. We cannot exclude Hen 2-90 being an X–ray binary since only observations with Chandra in the soft X–ray bands have to date been performed. But it seems to be clear that some kind of interaction has been or is still going on in this system. We want to finish our contribution by raising questions open for further discussions and investigations:

1. No wiggling of the knots around the jet axis – hint for a close binary?
2. The period of knot ejection of about 40 years – if it is due to binary interaction must it then be an extremely eccentric system?
3. The disk like structure seen on the HST image – an outflowing disk or the remnant of an earlier common envelope phase?
4. The variety of line profiles – hint for a complex velocity and density structure of the circumstellar matter due to ongoing mass transfer, accretion and ejection?

Only further observations (e.g. in the hard X–ray bands) will help to understand and disentangle the real nature of the enigmatic object Hen 2-90.

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Discussion

Norbert Langer: Just on the discussion on whether it's a young object or an evolved object, you said carbon, nitrogen *and* oxygen are depleted.

Michaela Kraus: Yes.

Norbert Langer: I don't see that this is evidence for it being a young or an evolved object, because CNO processing would enhance nitrogen, of course.

Michaela Kraus: Yes, what we find is really strange. We don't see any carbon lines in the spectrum. And we also have an ISO spectrum where we only see oxygen-rich dust. So, our conclusion is that there is no carbon or carbon is very depleted. Then from modelling the ionisation structure of the oxygen and nitrogen regions from the forbidden lines, we found that we have to reduce the oxygen abundance compared to, for example, sulphur, argon and chlorine abundances, which we took as solar. But then oxygen must be depleted by a factor of at least three. And what we also find is that the nitrogen has to be depleted by a factor of two. We don't understand that at all.

Philipp Podsiadlowski: There is another object which is more extreme than this in some respects; it's SS433. It has a jet but it also has a disk-like structure. There is a lot of mass outflowing in the equatorial plane; in fact, it's probably the dominant outflow.

Michaela Kraus: But SS433 is a known binary. Here we don't know.

Gloria Koenigsberger: Yes, but SS433's jets have huge velocities. Have you any way of estimating their velocity, if you assume that these things occur every 40 years?

Michaela Kraus: Yes, the maximum velocity of the knots is about 400 km/sec. It's not really large.

Peredur Williams: Do you have a history of observations of this to see if there are any spectroscopic or photometric changes which show the same periodicity as the ejection of the knots?

Michaela Kraus: Yes, the knots have been observed. A new knot has just been found which was ejected 10 years ago. Propagation of the knots is also seen.

Peredur Williams: Is there a photometric history so you could look for correlations of other behaviour?

Michaela Kraus: No.

Doug Gies: Do you have any information about the location of the object? Is it a disk population-I object, population II object out of the disk? Is the distance from us known?

Michaela Kraus: It's a southern object. It's in the disk, as far as I know, at about 2 kpc.

Michaela Kraus