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 ∼ 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 characteristics of Hen 2-90 found from already existing observations and found 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. 2004). We took optical spectra centered on the star with a slit.

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

1Based on observations with the 1.52m telescope at the European Southern Observatory (La Silla, Chile), under the agreement with the Observatório Nacional-MCT (Brasil)
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The spectrum shows strong [O I] emission which is an indication for the presence of a huge amount of hydrogen neutral 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 much more forbidden emission lines that can be related with 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. 2004). 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 also N 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 coming 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 of the young stellar objects, all jet systems are binaries, and (2) the jet and knot appearance 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 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 component. The major characteristics of symbiotic objects are:

- strong Heii emission from the hot component
- 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 ionization potential larger than 40 eV speaks more in favour of that these ions do not exist, 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.
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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 [O\textsc{i}] 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 excentric 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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