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A search for *s*-process elements in extremely metal-poor halo planetary nebulae

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Abstract. We have performed deep high-dispersion spectroscopy to examine enhancement of *s*-process elements in the exremely metal-poor ([Ar/H]∼–2.1) halo planetary nebulae H4-1 and BoBn1 using the 8.2-m Subaru telescope/High-Dispersion Spectrograph (HDS). We have detected several emission lines of *s*-process elements in H4-1 and BoBn1, and we have found that the enhancement of heavy *s*-process elements in these objects is comparable with that in *s*-process enhanced CEMP stars with [Fe/H]>–2.5. The C- and N-rich abundances of H4-1 and BoBn1 might be explained by binary evolution models. We have detected 5 fluorine lines in BoBn1. The re-estimated F abundance using these lines is [F/H]=+1.4±0.1.

Keywords. (ISM:) planetary nebulae: individual (H4-1, BoBn1), stars: evolution

1. Introduction

Currently, over 1,000 objects are regarded as planetary nebulae (PNe) in our Galaxy, while 14 of them have been identified as halo members from their location and kinematics. Of them, 5 objects are known as C- and N-rich ([C,N/O]>0) halo PNe with [Ar/H]<–1.7. K648 (in M15), H4-1, and BoBn1 are C- and N-rich halo PNe with [Ar/H]∼–2.1. The progenitors of halo PNe are thought to be ∼0.8 $M_\odot$ stars. These C- and N-rich halo PNe, however, show signatures that they have evolved from massive progenitors.

For example, these halo PNe can become N-rich, but not C-rich, if they have evolved from single ∼0.8 $M_\odot$ stars. To become C-rich PNe, the third dredge-up must take place in the late AGB phase. However, the third dredge-up takes place in stars with initial masses >1.2–1.5 $M_\odot$. Also, current stellar evolutionary models predict that the post-AGB evolution of a star with an initial mass ∼0.8 $M_\odot$ proceeds too slowly for a visible PN to be formed. Unless these issues are resolved, we will not be able to take full advantage of halo PNe as a proof of low-mass star evolution and the Galactic chemical evolution.

How these progenitor stars became C and N-rich halo PNe? To answer this key question, we have been observing these halo PNe using the 8.2-m Subaru telescope/High-Dispersion Spectrograph (HDS) and collecting archival data and carefully analyzing spectra of these objects. Our recent research reveals that [C/Fe] and [N/Fe] abundances of K648, H4-1, and BoBn1 are compatible with those of carbon-enhanced metal poor (CEMP) stars (Otsuka *et al.* 2008a). Interestingly, BoBn1 is the most fluorine rich among

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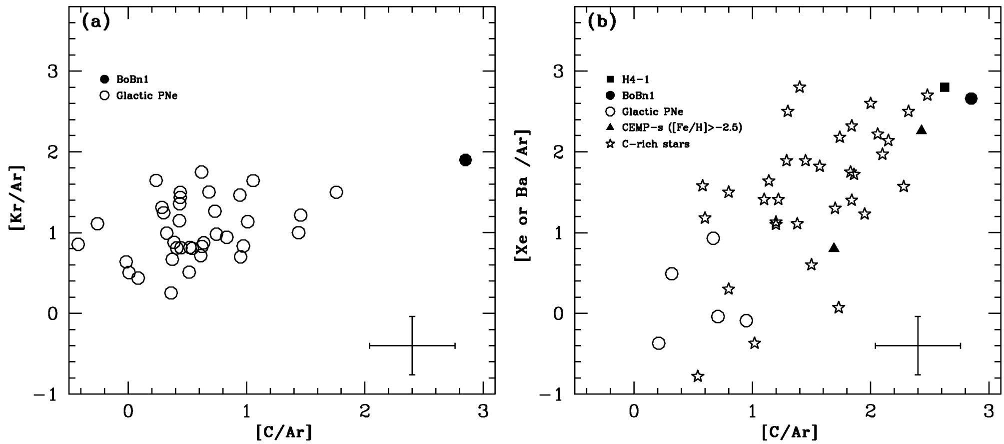

Figure 1. (*left panel*) [Kr/Ar]-[C/Ar] diagram. Galactic PNe: the data of 37 objects taken from Sterling & Dinerstein (2008). (*right panel*) [Xe or Ba/Ar]-[C/Ar] diagram. Galactic PNe: taken from Sharpee *et al.* (2007). CEMP-*s* and C-rich AGB: taken from the SAGA data base (Suda *et al.* 2008).

F-detected PNe, and its F-abundance is comparable with the *s*-process enhanced CEMP star (CEMP-*s*) HE1305+0132 (Otsuka *et al.* 2008b). These C-, N-rich halo PNe might share their origins with CEMP-*s* stars. If these halo PNe had evolved from binary stars such as CEMP-*s* stars, *s*-process element might be enhanced as well as C and N. To examine enhancement of *s*-process elements and verify our hypothesis, we have performed deep HDS spectroscopy for H4-1 and BoBn1. In this paper, we present our recent results of chemical abundance analysis of these objects.

2. Observations & results

We have secured the spatially ($<0\farcs6$ seeing) and spectrally ($R>33{,}000$) highest-resolution spectra with high S/N (>40 at the nebular continuum), and detected >300 emission lines for each object. We solved level populations for a multi-level (2–30 levels) atomic model using our codes and estimated >14 elemental abundances. The remarkable findings are as follows: (1) In H4-1 and BoBn1, several emission lines of *s*-process elements such as krypton (Kr, $Z = 36$), rubidium (Rb, $Z = 37$), xenon (Xe, $Z = 54$), and barium (Ba, $Z = 56$) are detected. The detections of these elements are for the first time. (2) H4-1 and BoBn1 are *s*-process element rich PNe (Fig. 1). The [Kr, Xe, Ba/Ar]-[C/Ar] diagrams indicate that C-rich objects are also *s*-process element rich. This is consistent with nucleosynthesis theory for low-intermediate mass stars. The enhancement of heavy *s*-process elements in H4-1 and BoBn1 is comparable with that in CEMP-*s* stars. The C- and N-rich abundances of these PNe might be explained by binary evolution models. (3) In BoBn1, 5 fluorine lines are detected. The re-estimated F abundance using these lines is $[F/H] = +1.4 \pm 0.1$.

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