Planetary Nebulae in our Galaxy and Beyond
Proceedings IAU Symposium No. 234, 2006
M. J. Barlow & R. H. Méndez, eds.
© 2006 International Astronomical Union
DOI: 00.0000/X000000000000000X

Abundances of *s*-process elements in planetary nebulae: Br, Kr & Xe

Y. Zhang[1,2], R. Williams[2], E. Pellegrini[3], K. Cavagnolo[3], J. A. Baldwin[3], B. Sharpee[4], M. Phillips[5] and X.-W. Liu[1]

[1]Department of Astronomy, Peking University, Beijing 100871, P. R. China
[2]Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA
[3]Department of Physics & Astronomy, Michigan State University, East Lansing, MI 48824, USA
[4]SRI International, 333 Ravenswood Ave. Menlo Park, CA 94025, USA
[5]Las Campanas Observatory, Carnegie Observatories, Casilla 601, La Serena, Chile

Abstract. We identify emission lines of post-iron peak elements in very high signal-to-noise spectra of a sample of planetary nebulae. Analysis of lines from ions of Kr and Xe reveals enhancements in most of the PNe, in agreement with the theories of *s*-process in AGB star. Surprisingly, we did not detect lines from Br even though *s*-process calculations indicate that it should be produced with Kr at detectable levels.

Keywords. ISM: abundances, planetary nebulae: general, nucleosynthesis

arXiv:astro-ph/0605181v1 6 May 2006

1. Introduction

As remnants of AGB stars, planetary nebulae (PNe) represent material that has undergone nuclear processing in their precursors via the *s*-process. The analysis of nebular emission provides essential information for stellar models. However, detection of emission lines from *s*-elements has been hampered by their weakness and by uncertainties in the atomic data. A pioneer attack on the problem was made by Pequignot & Baluteau (1994), who identified a number of post-Fe emission lines in NGC 7027. Dinerstein and collaborators studied *s*-process elements in PNe by searching for their IR emission (Dinerstein 2001; Sterling & Dinerstein 2004, this volume) and far-UV absorption (Sterling et al. 2002, 2003). As part of an on-going program to detect weak lines in PNe, we have obtained a number of high resolution spectra of very high S/N's.

2. Observations and Analysis

Our current sample of objects consists of four PNe (IC 2501, IC 4191, NGC 2440, and NGC 7027). The spectra were obtained with the KPNO 4m using the Cassegrain echelle spectrograph and the LCO 6.5m with the MIKE echelle spectrograph at a resolving power of about 25,000. Fig. 1 shows the quality of our spectra. The deep spectra enable us to detect extremely faint lines with a flux of $\sim 10^{-6}$ the intensity of Hβ. For comparison, we also searched for Kr and Xe in two H II regions, the Orion Nebula (Baldwin et al. 2000) and NGC 3576 (García-Rojas et al. 2004).

We have detected krypton and xenon emission lines, [Kr III] λ6827, [Kr IV] $\lambda\lambda$5868, 5346, [Kr V] λ6256, [Xe III] λ5846, [Xe IV] $\lambda\lambda$5709, 7535, and [Xe V] λ7077. However, we failed to detect Br lines, [Br III] λ6133 and [Br IV] λ7368, even though the current *s*-process calculations indicate that Br should be produced along with Kr at detectable levels. The reason remains unknown.

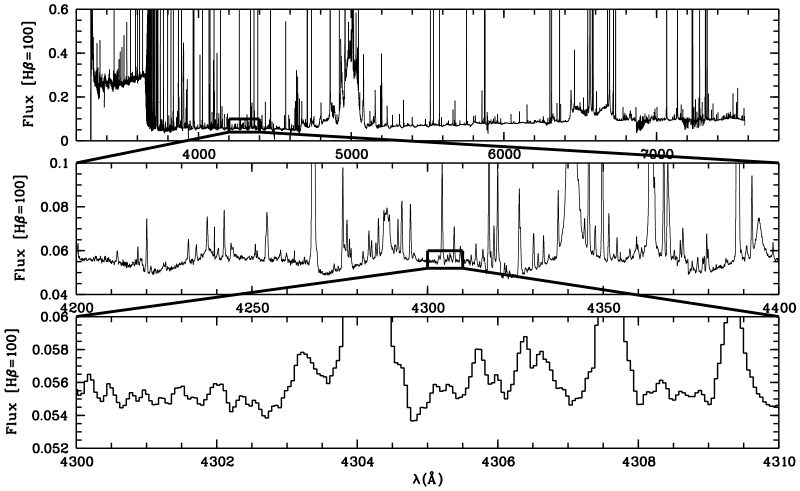

Figure 1. Spectrum of IC 2501 illustrating the quility of our spectra.

Table 1. Abundances of Br, Kr, and Xe.

	PNe					H II regions	
Abundance	IC 418	IC 2501	IC 4191	NGC 2440	NGC 7027	Orion	NGC 3576
[Br/Ar]	< -0.8	< -1.2	< -0.5	< -1.0	< 0.3	...	...
[Kr/Ar]	0.76	0.04	0.38	0.15	1.04	-0.08	< -0.69
[Xe/Ar]	0.91	0.01	0.51	0.33	0.87	< 0.58	...

Using the current available atomic data, we have determined Kr and Xe abudances. We converted ionic ratios to elemental values by making use of the similarity in ionization potentials of the noble gases, from which it follows that $(\mathrm{Kr, Xe})/\mathrm{Ar} = [(\mathrm{Kr}^{+2}, \mathrm{Xe}^{+2}) + (\mathrm{Kr}^{+3}, \mathrm{Xe}^{+3})]/(\mathrm{Ar}^{+2} + \mathrm{Ar}^{+3})$ and $[(\mathrm{Kr}^{+2}, \mathrm{Xe}^{+2}) + (\mathrm{Kr}^{+3}, \mathrm{Xe}^{+3}) + (\mathrm{Kr}^{+4}, \mathrm{Xe}^{+4})]/(\mathrm{Ar}^{+2} + \mathrm{Ar}^{+3} + \mathrm{Ar}^{+4})$ for low- and high-excitation PNe, respectively. The upper limits for the Br abundances were estimated. These results, relative to the solar values, are given in Table 1. It is evident that Kr and Xe are both enhanced by similar factors of up to 10 in the five PNe, but not in the two H II regions which represent unprocessed ISM gas.

References

Baldwin, J. A., Verner, E. M., Verner, D. A., Ferland, G. J., Martin, P. G., Korista, K. T., & Rubin, R. H. 2000, *ApJS*, 129, 229

Dinerstein, H. L. 2001, *ApJ*, 550, L223

García-Rojas, J., Esteban, C., Peimert, M. et al. 2004, *ApJS*, 153, 501

Péquignot, D., & Baluteau, J. P. 1994, *A&A*, 283, 593

Sterling, N. C. & Dinerstein, H. L. 2003, Rev.Mex.Ast. & Ap.Ser.Conf. 18, p. 133

Sterling, N. C. & Dinerstein, H. L. 2004, in ASP Conf. Ser. 313, Asymmetric Planetary Nebulae III, eds. M. Meixner, J. Kastner, B. Balick, & N. Soker (San Francisco: ASP), p. 410

Sterling, N. C., Dinerstein, H. L., & Bowers, C. W. 2002, *ApJ*, 578, L55