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Notes

Isotope Ratio of Europium in Procyon

Ken-ichi Kato

Osaka Electric-Science Museum, Shinmachi, Nishi-ku, Osaka 550

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Abstract

The Eu II line at 4129.7 Å in the spectrum of Procyon (α CMi, F5 IV–V) is analyzed by the method of spectrum synthesis to derive the isotope ratio of europium. It is found that the observed profile is well reproduced by the computed profile when we take the isotope ratio of $\varepsilon(Eu^{153})/\varepsilon(Eu^{151})=(35\pm15)/(65\pm15)$. This is in fairly good agreement with the solar value obtained from the same line in the solar spectrum.

Key words: Abundances of elements; Stellar atmospheres; Procyon.

Europium, an element of lanthanide rare-earths, has two isotopes of mass numbers 151 and 153. The solar-system isotope ratio of $\varepsilon(Eu^{153})/\varepsilon(Eu^{151})=52.1/47.9$ {in the logarithmic scale, $\log[\varepsilon(Eu^{153})/\varepsilon(Eu^{151})]=+0.04$} is reported by Anders and Ebihara (1982). For the Sun, Hauge (1972) derived the logarithmic isotope ratio of -0.04 ± 0.10 from an analysis of six Eu II lines. He also pointed out that the two strong Eu II lines at 4129.7 Å and at 4205.1 Å give inconsistent logarithmic isotope ratios; they are -0.25 for the former and $+0.30$ for the latter.

Elemental abundances of the lanthanides in Procyon have been investigated by Griffin (1971), Kato and Sadakane (1982), Leushin and Sokolov (1980), and Steffen (1985). Recently a more detailed analysis has been made by Kato and Sadakane (1986) for 13 lanthanides using the method of spectrum synthesis. These studies show that the abundance of Eu in Procyon is solar. However its isotopic composition has not yet been explored for this star. It is of particular interest to investigate the isotope ratios of atomic species in stars of different ages from the viewpoint of the chemical evolution of our Galaxy.

In this study the isotope ratio of europium in Procyon is investigated by comparing the synthetic spectrum of the Eu II line at 4129.7 Å with the intensity tracings in the *Procyon Atlas* (Griffin and Griffin 1979). The line at 4129.7 Å is selected in this analysis for the following reasons:

(1) It is one of the three strongest lines of singly ionized europium (Meggers et al. 1975) and its widened contour can be clearly seen. The other strong lines at 4205.1 Å and at 3819.7 Å are excluded, because they are found to be blended (Moore

et al. 1966). The inconsistent solar isotope ratio derived from the line at 4205.1 Å by Hauge (1972) is probably due to the effect of blending.

(2) The line is already studied in detail for the Sun so that we can compare the result of Procyon with that of the Sun.

(3) It is apparently free from the effect of blending. Kurucz and Peytremann (1975) list the following two lines in the region around 4129.7 Å: 4129.684 Å (Ar I, $\log gf = -1.28$, $\chi = 19.8$ eV) and 4129.817 Å (Co I, $\log gf = -3.97$, $\chi = 3.81$ eV). An LTE computation of equivalent widths for these lines shows that they are extremely weak ($W_\lambda < 0.1$ mÅ) in the spectra of normal F-type stars.

(4) No other blend-free and strong lines suitable for our purpose can be found in the lists of Hauge (1970, 1972).

Both isotopes of Eu^{151} and Eu^{153} have six components split by the effect of nuclear spin, where the energy difference of Eu^{151} due to the splitting is larger than that of Eu^{153}. Thus Eu^{153} contributes only to the central part of the line at 4129.7 Å, while Eu^{151} determines its overall contour. Therefore, we can expect to estimate the contribution of each isotope to the profile from the comparison between computed and observed profiles. Synthetic spectra around the Eu II line at 4129.7 Å are calculated for various isotopic compositions by using the line-blanketed model atmosphere of Kurucz (1979) for the solar composition. Six split components with an intensity ratio of 7: 6: 5: 4: 3: 2 are adopted for both isotopes, and their wavelength spacings are treated as in Hauge (1972). The atmospheric parameters for Procyon are the same as in the previous analysis (Kato and Sadakane 1982): ($T_{\rm eff}$, $\log g$, $\xi_{\rm t}$)=(6650 K, 4.0, 1.8 km s^{-1}). We adopt the Gaussian-type line broadening of $\exp[-(v/\xi)^2]$, where $\xi = 5.0$ km s^{-1} is chosen. In this analysis it is assumed that the line broadenings due to rotation, macroturbulence, and instrumental profile can be approximated by this single parameter, because it is extremely difficult to separate these broadening effects into individual components. However it is important to keep in mind a rather large instrumental profile of the Mt. Wilson coudé spectrograph (Griffin 1969; Ruland et al. 1980; Steffen 1985), from which the original spectrograms of the *Procyon Atlas* (Griffin and Griffin 1979) were obtained.

The equivalent width of this line is measured to be 48 mÅ, and the corresponding $\log gf\varepsilon$ is 0.71 (Kato and Sadakane 1986) on the scale of $\log \varepsilon(\mathrm{H}) = 12.00$. When we adopt the $\log gf$ value of $+0.204$ (Biémont et al. 1982), the resultant abundance is found to be 0.51. This is in good agreement with the solar value of 0.48 derived from the 4129.7 Å line by Biémont et al. (1982). It is also consistent with the meteoritic abundance of 0.55 (Anders and Ebihara 1982).

Figure 1 shows the dependency of the contour of the line at 4129.7 Å on the isotopic composition. A best fit with the observed spectrum is obtained in a range of $\varepsilon(Eu^{153})/\varepsilon(Eu^{151})$ between 50/50 and 20/80; on the logarithmic scale the isotope ratio becomes -0.30 ± 0.30. The relatively large uncertainty, which arises from the difficulty in the fitting procedure, is mainly due to the quality of the observational data. As can be seen from figure 1, it is very hard to determine exactly the isotope ratio from a comparison of the computed spectrum with the *Procyon Atlas* (Griffin and Griffin 1979). To reduce the error limit in the result, high signal-to-noise spectroscopic data and a complete list of absorption lines are necessary.

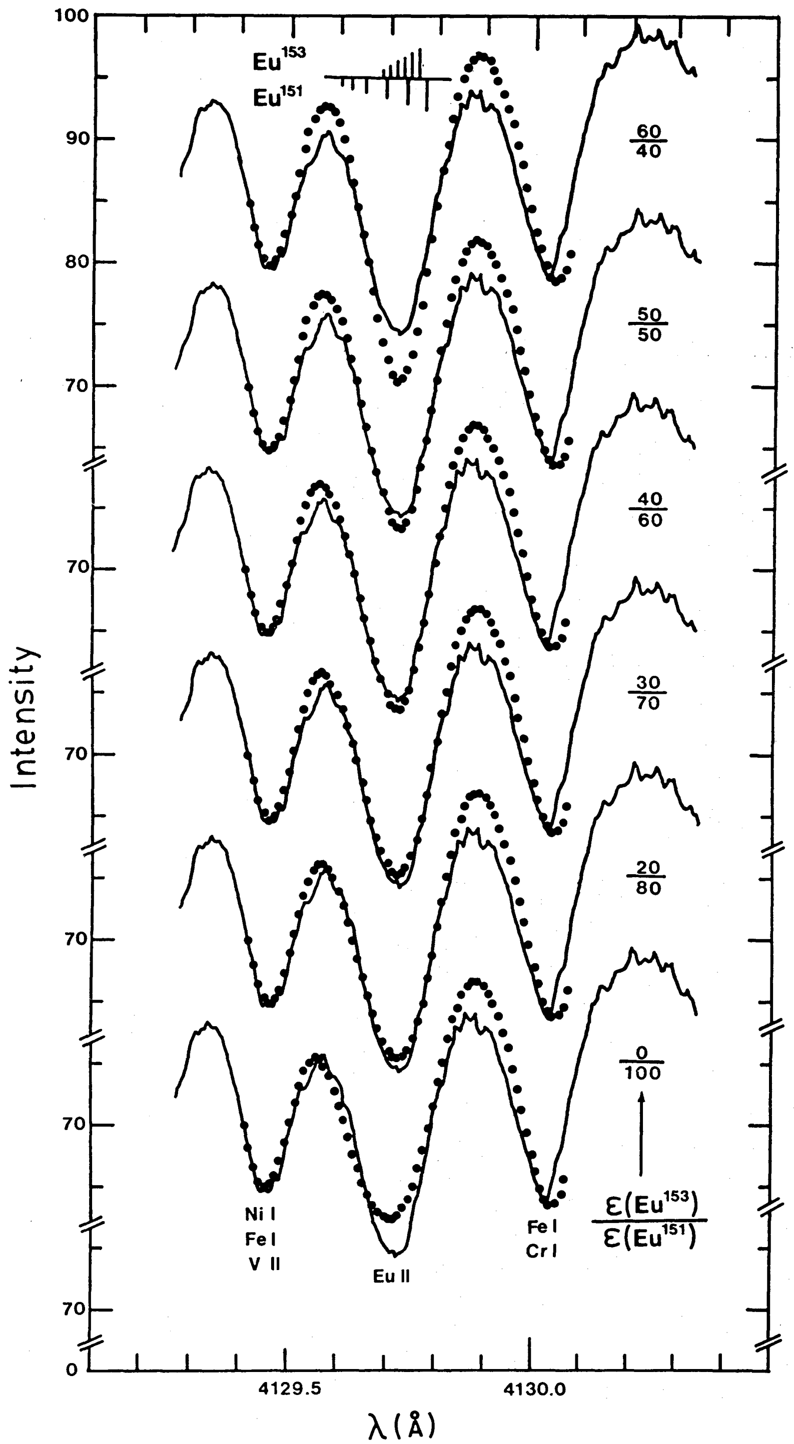

Fig. 1. Procyon's spectrum around the Eu II line at 4129.7 Å (full line) and the computed profiles (dot) for different isotope ratios. The split lines of both isotopes are also indicated.

The isotope ratio determined here shows a good agreement with the solar value of -0.25 for the 4129.7 Å line (Hauge 1972), but seems to deviate from the logarithmic terrestrial ratio of $+0.04$ (Anders and Ebihara 1982). The uncertainty in our analysis is unfortunately too large to conclude that the isotope ratio in Procyon is really different from the terrestrial value. In addition we should be careful about the effect of blending lines, because the result is sensitive to the presence of weak lines. According to Hauge (1972), the isotope ratio becomes −0.03 when two hypothetical lines are introduced at 4129.645 Å and at 4129.773 Å. He estimated equivalent widths of both lines to be about 5 mÅ. If such unknown lines with similar strengths are also present in the spectrum of Procyon, we can explain the profile around 4129.7 Å by adopting the terrestrial isotope ratio.

The main result of the present analysis is that the isotope ratio of europium in Procyon is determined for the first time, and it is found to be identical to the solar value. In this study the analysis is limited to the line at 4129.7 Å. More accurate observations for many lines are desirable to establish the isotopic compositions of europium and other rare-earth elements in Procyon.

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