Assignment 7

Due: Thursday, April 28

Attempt 1 of the 2 questions.

These two questions are concerned with the s-process and involve applications of the neutron capture cross-sections. Data on these cross-sections should be taken from the KADONIS data-base (www.kadonis.org).

1. Neyskens et al. (2015, Nature, 517, 174) analyze spectra of cool stars enriched in s-process elements. The paper is titled `The temperature and chronology of heavy-element synthesis in low-mass stars'.

a: - Explain how these authors obtain the temperature of the s-process site and constrain the time elapsed since the start of the s-process. (Assume that the analysis of the high-resolution spectra provides the necessary elemental abundances.)

b: - The temperature determination is based on their Figure 1. This requires the measurement of the abundance ratio of Zr to Nb (equivalently Zr to ^{93}Zr) where Zr is the total abundance of all stable Zr isotopes.

The s-process flow can be approximated by the condition that $< \sigma N >$ is approximately constant. Introductions to the neutron capture process claim that a cross-section is approximately inversely proportional to velocity and, hence, the rate constant $< \sigma v >$ is approximately independent of temperature.

Using the KADONIS database attempt to reproduce the theoretical curve in Figure 1 and explain the origins of the decline of the Zr/Nb ratio with increasing temperature, i.e., the decline is related to the temperature dependence of the rate constant for which Zr isotope(s)? Possibly, Lugaro et al. (2014, ApJ, 780, 95) may be helpful.

2. Europium is one of a handful of heavy elements for which it is possible to measure isotopic ratios from stellar spectra. Aoki et al. (2003a, ApJ, 597, L67) measure the ^{151}Eu/^{153}Eu ratio in two s-process enhanced metal-poor stars. This ratio has also been measured in r-process enriched stars (Sneden et al. 2002, ApJ, 566, L25; Aoki et al. 2003b, ApJ, 586, 506) - see also Roederer et al. (2008, ApJ, 675, 723).

The s-process path and interference from the r-process is traced by Beer et al. (1984, ApJ, 278, 388) and also by Roederer et al.

a: - Explain why the branch at ^{151}Sm serves as `an excellent thermometer' for the s-process, why it cannot be effectively exploited using abundances established for the Standard Abundance Distribution (i.e., solar system material) but why stars like those chosen by Aoki et al. are fine candidates in this regard.

b: - Describe how Aoki et al. (2003a) measured the ^{151}Eu/^{153}Eu ratio for the two s-process enriched stars.

c: - Aoki et al. (2003a) predict the fractional abundance of ^{151}Eu as a function of neutron density and temperature (their Figure 2). Their coverage of these two parameters was based on their insistence that s-processing in AGB stars occurs primarily in the brief episode of convective He-burning in the He-shell, that is at high T and high neutron density. Almost certainly (they should have known this!), s-processing occurs primarily in the interpulse period, i.e., at low density and lower temperature. With respect to low neutron density, they write

``In contrast to the high neutron density conditions, ^{151}Sm -βdecay during the s-process is increasingly important with decreasing neutron density (N_n < ^{10}7 cm^{-3}). For the typical temperature ranges thought to apply in the s-process (1-30 keV), the neutron capture rate on ^{151}Eu is faster than that for ^{153} Eu [A]. Therefore, the nuclear flow passes through ^{151}Eu rather easily and creates ^{153}Gd via In low neutron density conditions, the electron capture on ^{153}Gd is comparable with, or faster than, the neutron capture [B]. This contributes to the production of ^{153}Eu and explains the decrease of fr(^{151}Eu) with decreasing neutron density the low (N_n < 107 cm-3) range [C]. This trend appears more clearly for the higher temperature case, because the effect of a higher neutron capture rate on ^{151}Eu relative to that on ^{153}Eu is large, while the branching factor decreases with temperature. [D]''

Provide quantitative justification for the above claims [A], [B], [C] and [D].