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Nuclear Physics A 758 (2005) 288c–291c

NUCLEAR  
PHYSICS A

## How to reconcile the C and s-process abundances in the metal-poor star V453 Oph ?

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In this poster we present a detailed chemical analysis of the RV Tauri star of low intrinsic metallicity, V453 Oph ( $[\text{Fe}/\text{H}] = -2.2$ ), which shows a mild but clear s-process surface overabundance. This result is strengthened by a relative analysis to the RV Tauri star DS Aqr of similar metal deficiency ( $[\text{Fe}/\text{H}] = -1.6$ ), but without such s-process enrichment. A remarkable result is that the s-process enrichment of V453 Oph is *not* accompanied by a measurable C enhancement. To explain the surface abundances observed in V453 Oph, two nucleosynthesis models are considered. The first model assumes the partial mixing of protons during the radiative interpulse phase while the second scenario is based on the possible production of s-process elements within the flash-driven convective pulse only. Both models can give a satisfactory explanation for the s-process enrichment of V453 Oph, but not the simultaneous low C-abundance observed.

### 1. Introduction

RV Tauri stars are rare supergiants which occupy the high luminosity end of the pop. II Cepheid instability strip. They are identified on the basis of their characteristic light curves, which show alternating deep and shallow minima with periods between 30 and 150 days. Their post-AGB nature is established on the basis of their far-IR excess due to circumstellar dust, which is thought to be a relic of the dusty mass loss at the end of the AGB. The genuine high luminosity nature of this RV Tauri class was established by the detection of some members in Globular Clusters and the LMC.

Post-AGB objects are very useful in constraining the AGB chemical evolutionary models, because the absence of strong molecular veiling allows detection of atomic transitions from CNO up to the heavy s-process elements beyond the Ba-peak.

### 2. Observations and reduction

High resolution spectra of V453 Oph and DS Aqr were acquired with the spectrograph FEROS, mounted on the 1.5 m telescope at La Silla. These spectra in combination with the latest KURUCZ model atmospheres were employed to derive accurate abundances for

Table 1

The model parameters of V453 Oph and DS Aqr as determined using the Fe lines. The derived CNO abundances for both objects are also given.

starname	$T_{\text{eff}}$	$\log(g)$	$\zeta_t$	[Fe/H]	[C/Fe]	[N/Fe]	[O/Fe]
V453 Oph	6250	1.5	3.0	$-2.23 \pm 0.12$	-0.26	0.74	0.99
DS Aqr	5750	0.5	3.5	$-1.62 \pm 0.12$	-0.15	0.32	0.64

both objects. The parameters for the model atmospheres were determined using spectroscopic criteria only (using the Fe lines). The resulting model parameters are shown in Table 1. The huge number of Fe lines (136 and 316 for V453 Oph and DS Aqr respectively) ensures an accurate determination of these values.

### 3. Abundance analysis

For both objects we performed a very detailed chemical abundance analysis. All lines in the spectra showing a clear and symmetric profile were measured and subsequently identified on the basis of wavelength. For each of these lines, the most recent atomic data was researched in the literature. To eliminate possible biasing in the atomic data, a strict relative analysis between both objects was performed using exactly the same lines for both objects. Because of the very similar atmospheric parameters, these relative abundances are less sensitive to possible systematic errors in general.

The result of the absolute abundance analysis (i.e. for each object independently) reveals that V453 Oph is mildly enriched in s-process elements while DS Aqr is not. Therefore, the relative abundance analysis of V453 Oph – DS Aqr, depicted in Fig. 1, gives extremely accurate s-process enrichment values. Some of the s-process lines used in the analysis are shown in the left panel of Fig. 2. Although V453 Oph is s-process enriched, the C abundance as derived from a spectrum synthesis (shown in the right panel of Fig. 2), is very similar to DS Aqr (see Table 1).

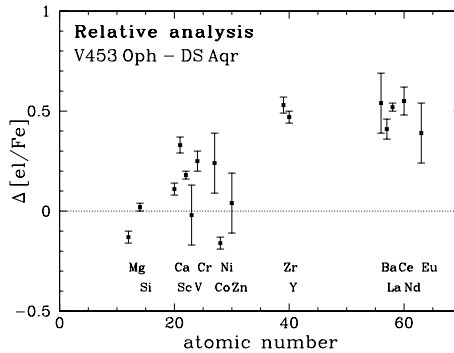


Figure 1. The abundance results as determined from the relative abundance analysis.

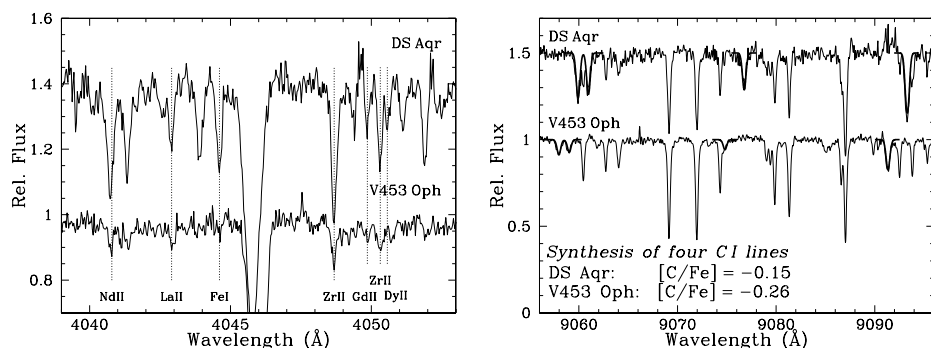


Figure 2. *Left panel:* Velocity corrected spectra of both objects showing some of the employed s-process lines. *Right panel:* Non-velocity corrected spectra with the spectrum synthesis of four CI lines shown using a thicker line.

#### 4. AGB nucleosynthesis

In general, two different scenarios are invoked to explain the s-process enrichment: in the less massive objects, the  $^{13}\text{C}(\alpha, n)^{16}\text{O}$  reaction, which takes place under radiative conditions, is nowadays believed to be the major neutron source [1]. For hot AGB stars, however, another s-process scenario is also invoked. It concerns the production of s-elements under convective conditions by the  $^{22}\text{Ne}(\alpha, n)^{25}\text{Mg}$  neutron source. Both scenarios were explored in order to explain the s-enrichment of V453 Oph without a C enhancement. In the following, these scenarios are referred to as radiative and convective s-process models.

The most favoured s-process model is associated with the partial mixing of protons (PMP) into the radiative C-rich layers at the time of the third dredge-up (3DUP). S-process calculations were performed using this PMP model for an  $1.5M_{\odot}$   $Z=0.0001$  AGB model star. The model has been evolved selfconsistently up to the 49th interpulse-pulse sequence. However, no 3DUP is found to take place, so that only a mild s-process develops in the convective pulse through the  $^{22}\text{Ne}(\alpha, n)^{25}\text{Mg}$  neutron source. At the end of the 49th pulse, protons are artificially injected into the C-rich layers to simulate the PMP scenario (as described in [2]). An efficient s-process develops in the radiative zone and after the 50th pulse, a 3DUP is assumed. The left panel of Fig. 3 compares the observed abundances with the radiative s-process model predictions. Clearly, the abundance distribution agrees well with the observations. However, the overabundance obtained for C ( $[\text{C}/\text{Fe}] = 1.5$ ) is incompatible with the observed value ( $[\text{C}/\text{Fe}] = -0.26$ ).

In the convective model, the s-process originates exclusively from the neutron irradiation due to the  $^{22}\text{Ne}(\alpha, n)^{25}\text{Mg}$  source, requiring temperatures of about  $3.5 \cdot 10^8 \text{K}$ . In the  $1.5M_{\odot}$   $Z=0.0001$  model star, the maximum temperature at the bottom of the thermal pulse amounts to about  $3.3 \cdot 10^8 \text{K}$ . To allow an s-process to develop in the pulse, the  $^{22}\text{Ne}(\alpha, n)^{25}\text{Mg}$  reaction rate has been increased by a factor of 10 with respect to the NACRE recommended rate. This value is well within the uncertainties still affecting this

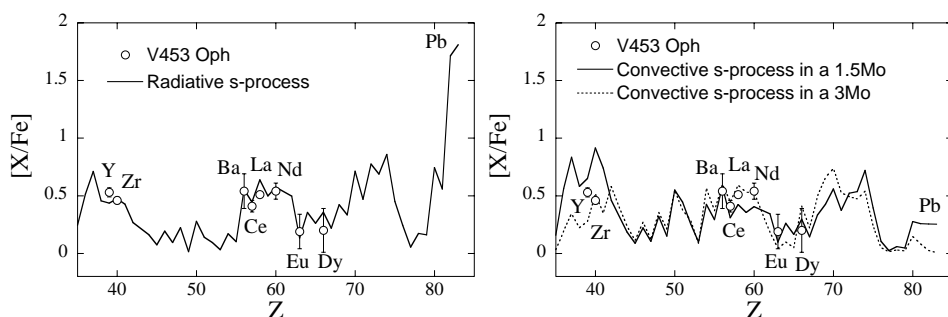


Figure 3. Comparison of the observed relative surface abundances with the radiative (*left panel*) and convective (*right panel*) s-process models.

rate [3]. With this increased rate, the full sequence of the 50 pulse-interpulse in the  $1.5M_{\odot}$   $Z=0.0001$  model star have been calculated ending with a parametrized dredge-up. The resulting elemental abundance distribution is shown in the right panel of Fig. 3 to reproduce the observations satisfactorily. However, the C prediction ( $[C/Fe] = 1.2$ ) is again not compatible with the observations.

The only model that does provide a compatible C abundance with observations is a  $3M_{\odot}$   $Z=0.0001$  model star. In this case, temperatures as high as  $3.7 \cdot 10^8$  K are encountered and a significant s-process takes place. The resulting surface enrichment obtained assuming a dredge-up at the end of the 18th computed pulse is given in Fig. 3 and is again in good agreement with the observations. Even the predicted C abundance ( $[C/Fe] = 0.1$ ) is in agreement with the observations. Therefore this seems the only model able to reproduce simultaneously the s-process enrichment and the low C abundance. However, a  $3M_{\odot}$  star with the very low metallicity of V453 Oph is very unlikely from evolutionary viewpoint.

## 5. Conclusion

This paper reports upon the abundance analysis of a very particular s-process enriched object: V453 Oph. The abundances derived for this object are of particular nucleosynthesis interest, since for the first time, the s-process enrichment is not accompanied by a simultaneous C-enrichment. This observation provides us with clear proof that our knowledge about the AGB nucleosynthesis is still unsatisfactory because no current model can fully reproduce the specific history of this object.

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