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Heavy element abundances in giant branch stars in 47 Tuc

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Abstract. Analysis of the light (Y and Zr) and heavy (La and Nd) s-process elemental abundances in five AGB and two RGB stars in 47 Tucanae shows light-s and heavy-s enhancements of [X/Fe]$\sim$ +0.6±0.1 and $\sim$ +0.4±0.1 respectively. An [Fe/H] of -0.6±0.1 was determined for the seven stars analysed. The abundance results are significantly more internally consistent than previous studies of giant branch stars in this cluster. There is no difference in the s-process element abundances between the RGB and AGB stars, which indicates that these enhancements are intrinsic to the cluster and have not been produced by dredge-up of processed material in these stars on the AGB. The small samples in this and in the previous studies of giant branch stars in 47 Tuc, provide a strong case for a larger sample of RGB and AGB stars to be analysed. An observational programme with the Robert Stobie Spectrograph (formerly known as the Prime Focus Imaging Spectrograph) on the Southern African Large Telescope (SALT) are proposed in the near future.

Key words. Stars: abundances – Stars: atmospheres – Galaxy: globular clusters –

1. Introduction

The Asymptotic Giant Branch (AGB) phase is a very short stage of stellar evolution. However, the s-process nucleosynthesis that occurs during this phase is of great consequence in the understanding of element formation and recycling in the cosmos. Nucleosynthesis is also an important tracer of temperature and mixing in stars and, consequently, understanding the nucleosynthesis that occurs during this phase is a vital tool in astrophysics (Busso et al. 1999).

AGB nucleosynthesis is dependent on a number of factors: stellar mass and composition and the mass loss rate during the later stages of their evolution. Significant uncertainty exists at present concerning the efficiency of the third dredge-up phenomenon. Details of the ^{13}C pocket, both its formation and the resulting abundance profile, are still not known. Much evidence exists to support the idea that a spread in ^{13}C pockets is required to match the observed s-process abundances in stars (Lattanzio & Karakas 2001).

Globular clusters provide an excellent environment for studying stellar evolution. It is assumed that all the stars in any given cluster are of similar age and at the same distance. Therefore, a colour-magnitude diagram provides the phase of evolution of any partic-

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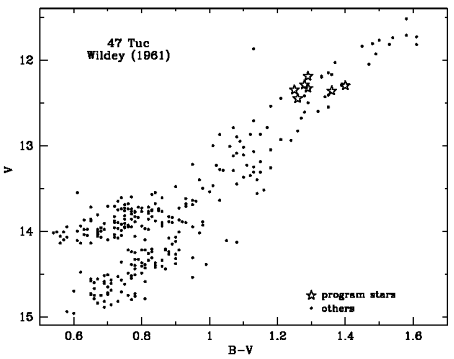

Fig. 1. Colour-magnitude diagram for 47 Tuc, with the poistion of the seven analysed stars shown. The V and B-V values are from Wildey (1961).

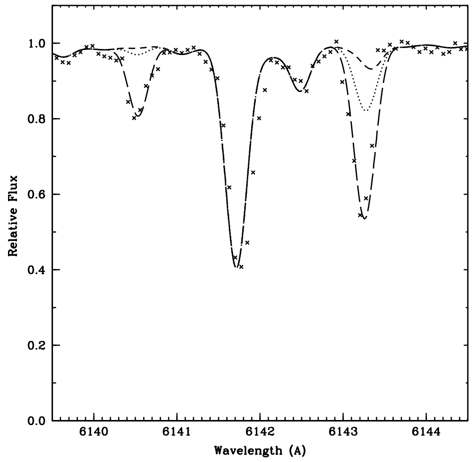

Fig. 2. Sample spectrum synthesis in one of the ZrI line regions for the RGB star W66 compared to the high resolution data from AAT UCLES shown as crosses. The various syntheses correspond to no Zr (short dash); best fit to the observations, [Zr/Fe]=+0.6 (long dash); the BW92 Zr abundance value, [Zr/Fe]=-0.4.

ular star and a clear distinction between Red Giant Branch (RGB) and AGB stars. It is assumed that all stars will show similar abundance characteristics. However, the globular cluster M15 has been shown to have a real star-to-star variation in the abundances of elements made by neutron capture (Cohen et al. (2005) and references therein). Three previous studies of the metal-rich cluster 47 Tucanae (Brown & Wallerstein (1992), hereafter BW92, James et al. (2004) and Alves-Brito et al. (2005)) involved an extensive element abundance analysis of RGB stars. One key result from all this previous work was the large range in light s- and heavy s- process element abundances.

The stars that were observed and analysed in this study are shown in Fig. 1. This indicates that five of the stars (W139, W164, 347, 364, 384) appear to be on the AGB but two stars (W66 and W68) fall on the RGB. All seven stars were observed using the 3.9m Anglo-Australian Telescope and UCLES during 2004 August. Spectra were obtained from 4400 to 6900Å and the spectral resolution was about 40,000. The data were reduced at the University of Canterbury using the FIGARO software. The reduced exposures for one star were co-added to produce overall signal-to-noise ratios in the final spectrum of greater than 40.

2. Abundance determinations

In this research the atmospheric parameters (T_{eff}, log g, [Fe/H] and microturbulent velocity) and the abundances of the light and heavy s-process species were determined using the spectral analysis program MOOG (Sneden 1973). Fig. 2 shows a sample spectrum synthesis. This figure shows that there is a real difference between the abundances determined by BW92 and in this study. The abundances for the seven giant branch stars are given in Table 1, where there is no statistical difference between the abundances determined for the AGB and RGB stars.

The abundances determined in this study need to be interpreted by considering single star AGB evolution, binary star evolution, as well as the possibility that these abundances are a result of stellar processing in a previous generation of stars, producing s-process abundances with a star-to-star spread.

Table 1. Mean abundances and uncertainties for the whole sample of RGB and AGB stars in 47 Tuc.

Species	Abundance	σ
$[Fe/H]$		
Fe I	−0.58	±0.06
Fe II	−0.61	±0.10
$[species/Fe]$		
Na I	+0.65	±0.23
Y I	+0.63	±0.20
Y II	+0.62	±0.18
Zr I	+0.67	±0.15
Zr II	+0.58	±0.16
La II	+0.35	±0.19
Nd II	+0.39	±0.13
Eu II	+0.14	±0.12
ls/Fe	0.62	±0.10
hs/Fe	0.37	±0.14
hs/ls	−0.25	±0.11

Of the possible scenarios proposed to explain these enhancements, the most likely seems to be the possibility of a genuine spread in element abundances in individual stars in 47 Tuc. Any star-to-star scatter would be explained by primordial processes, which would remove the need to reassess the assumptions made in low-mass AGB modelling. These results and their interpretation are discussed in more detail in Wylie et al. (2006).

3. SALT programme

A large sample survey of stars at various evolutionary phases and an extensive abundance analysis of a range of key nucleosynthetic indicators would help to confirm whether the abundances determined in this study are indicative of the cluster as a whole.

We propose to use the Robert Stobie Spectrograph (RSS), formerly known as the Prime Focus Imaging Spectrograph, on the Southern African Large Telescope (SALT) to address this question (Buckley et al. 2004). The RSS has a multi-object spectroscopy mode (see Fig. 3) which will enable up to 100 stars to be observed simultaneously at a resolving power up to 8,000 (see Fig. 4). It is clear that with signal to noise ratio spectra of ~50-80, s-process abundances with uncertainties less than ~0.3dex should be able to be determined. This should be sufficient precision to be able to provide additional support for the current small sample study.

Fig. 3. Sample RSS slitmask superimposed on a star field.

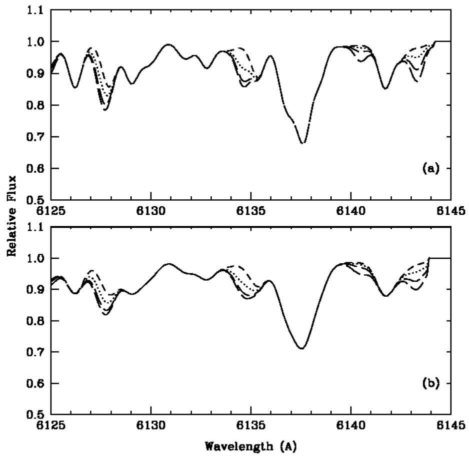

Fig. 4. Synthetic spectra in the Zr 6140Å region at resolving powers of (a) 8,000 and (b) 6,000, indicative of observations that will be obtained with the Robert Stobie Spectrograph on SALT. The short dashed line corresponds to no Zr and the other symbols are solar Zr/Fe and [Zr/Fe]=+0.5 and +1.0.

We would observe samples of RGB and AGB stars as well as Horizontal Branch and upper Main Sequence stars as part of this programme. This would be undertaken as part of the University of Canterbury's 4% shareholding in SALT.

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