CRIRES Science Verification Proposal

The C/O and $^{12}C/^{13}C$ ratios and the third dredge-up in bulge AGB stars

Investigators	Institute	EMAIL
PI S. Uttenthaler	ESO/Garching	suttenth@eso.org
CO-I 1 H. U. Käufl	ESO/Garching	hukaufl@eso.org
CO-I 2 T. Lebzelter	IfA, Vienna, Austria	lebzelter@astro.univie.ac.at
CO-I 3 J. Hron	IfA, Vienna, Austria	hron@astro.univie.ac.at

Abstract:

During the Asymptotic Giant Branch (AGB) phase of stellar evolution, the slow neutron capture process, H and He burning as well as complex mixing events (in particular the so called 3^{rd} dredge-up, 3DUP) influence the surface abundances of many elements and isotopes. In a recent work (Uttenthaler et al., 2006, submitted to A&A) we investigated the occurrence of the radioactive 3DUP indicator Technetium (Tc) in the atmospheres of bright bulge AGB stars using UVES spectra. A number of stars was identified to show absorption lines of this element, giving evidence for very recent s-process activity and 3DUP mixing. As another indicator for 3DUP, the C/O and the $^{12}C/^{13}C$ isotopic ratios are proposed since 12C, the main product of He burning, is mixed to the surface during 3DUP. We herewith apply for 180 min of CRIRES SV time to determine, by comparison with existing state-of-the-art model spectra, the C/O and $^{12}C/^{13}C$ ratios in bulge AGB stars identified to show Tc lines, as well as of stars without Tc of comparable luminosity. Via a correlation with the occurrence of Tc the usability of $^{12}C/^{13}C$ as dredge-up indicator will be investigated. The important question of the affiliation of bulge AGB variables to the generic bulge population will be addressed using the O abundance and the C/O ratio.

Scientific Case:

In the late stages of their evolution, low and intermediate mass stars evolve onto the Asymptotic Giant Branch (AGB). Strong mass loss and pronounced variability are characteristic for stars on the AGB. In their interior, recurrent thermal instabilities of the helium burning shell (so called thermal pulses, TP) cause complex nucleosynthesis and convective mixing events. This results in the dredge-up of freshly processed material from regions close to the C-O core to the stellar surface, named the 3^{rd} dredge-up (3DUP, see Busso et al. 1999, ARA&A 37, 1, for a review). The most noticeable influence of 3DUP on surface abundances is that on ^{12}C, the product of He burning, and on heavy elements produced via the slow neutron capture (s-) process. One of the elements synthesized in the s-process is Technetium (Tc) which has only unstable isotopes with life times short compared to the life time of the AGB star progenitor (^{99}Tc, $\tau_{1/2} \simeq 2.1 \times 10^5$ yrs).

We conducted a study to investigate the luminosity at which 3DUP sets in by searching for absorption lines of Tc in UVES spectra of a sample of bulge AGB variables (Uttenthaler et al., submitted to A&A). Among a sample of 27 variables, four were found to show absorption lines of Tc. Theoretical model prediction for the onset of 3DUP thus were confirmed.

Naively, one would expect a close correlation between the occurrence of Tc and the C/O as well as the ^{12}C/^{13}C ratio, since Tc and ^{12}C are both dredged to the surface in the same mixing events. However, there are a number of scenarios which can potentially lead to a weakening of this correlation. (i) Due to the short life time of Tc it can decay below the detection limit if 3DUP does not occur for several thermal pulses ("rare" dredge-up mechanism, see Busso et al. 1990, ASP Conference Series 11, 464) or if dredge-up stopped due to the eroded envelope. ^{12}C/^{13}C is conserved due to its stability against radioactive decay. (ii) Extra mixing mechanisms may increase the ^{13}C abundance earlier on the AGB, thus requiring more 3DUP events to reach a certain ^{12}C/^{13}C value. (iii) Tc might not have been detected in some of the AGB stars due to a blending of Tc lines with other metal lines, or simply due to a too low SNR of the optical spectra for a definite line detection (AGB stars are generally bright in the IR, but faint in the optical/blue spectral region where the Tc lines are located). As there are substantial uncertainties in the modelling of 3DUP, all of these scenarios are conceivable and must be quantified to establish the usefulness of $^{12}C/^{13}C$ as 3DUP indicator.

We herewith apply for 180 min of CRIRES SV time to determine the strength of the correlation between the occurrence of Tc and the $^{12}C/^{13}C$ ratio. The information derived from this study will be used for future investigations of 3DUP in more metal poor environments (LMC/SMC). Knowledge of the metallicity dependence of 3DUP is of particular high importance, not only for the study of AGB stars themselves, but also for the understanding of the chemical evolution of galaxies at earlier epochs of the universe.

Also, the abundance of O and the C/O ratio in the proposed targets is of high interest. Several studies on the bulge AGB population point towards a younger age of these objects (van Loon et al. 2003, MNRAS 338, 857; Groenewegen & Blommaert 2005, A&A 443, 143; Uttenthaler et al. 2006, submitted to A&A) compared to the generic bulge population (Zoccali et al. 2003, A&A 399, 931). Recently, Zoccali et al. (2006, A&A 457, L1–L4) found an O abundance in bulge K giants that supports the early and fast formation of the bulge. Measurement of the O abundance (and the C/O ratio) in the proposed targets will thus provide further hints on the age of the bulge AGB population and its questionable affiliation to the generic bulge population.

By using existing state-of-the-art MARCS model atmospheres and spectral synthesis codes, the $^{12}C/^{13}C$ ratio will be readily derived. This will lead to prompt publication. Determination of the C and O abundances (to give C/O) will require more care. They have a strong impact on the atmospheric structure itself. Thus new model atmospheres may have to be generated for a reliable abundance determination.

The project is well suited for SV. It pushes the limits of the instruments in the sense that moderately high SNR is required even for bright objects where the SNR is not photon noise limited. Also, the AO will be challenged by these very red objects. The data set acquired can be exploited for prompt publication on a topic that is of wide scientific interest. Also, the project uses the core modes of the instrument that have been commissioned already.

Required observing time

Target	RA	DEC	Wavelength Band	Magnitude	DIT	NDIT
M794	18 24 28.0	-32 30 51	1618-1658	H=6.65	60	2
M794	18 24 28.0	-32 30 51	1623-1663	H=6.65	60	2
M794	18 24 28.0	-32 30 51	2348-2401	K=6.10	60	2
M794	18 24 28.0	-32 30 51	2355-2407	K=6.10	60	2
M1313	18 37 35.5	-34 12 27	1618-1658	H=7.50	60	2
M1313	18 37 35.5	-34 12 27	1623-1663	H=7.50	60	2
M1313	18 37 35.5	-34 12 27	2348-2401	K=6.81	60	2
M1313	18 37 35.5	-34 12 27	2355-2407	K=6.81	60	2
M1347	18 38 45.7	-34 33 28	1618-1658	H=6.57	60	2
M1347	18 38 45.7	-34 33 28	1623-1663	H=6.57	60	2
M1347	18 38 45.7	-34 33 28	2348-2401	K=6.01	60	2
M1347	18 38 45.7	-34 33 28	2355-2407	K=6.01	60	2
S942	18 28 09.0	-36 31 26	1618-1658	H=7.07	60	2
S942	18 28 09.0	-36 31 26	1623-1663	H=7.07	60	2
S942	18 28 09.0	-36 31 26	2348-2401	K=6.59	60	2
S942	18 28 09.0	-36 31 26	2355-2407	K=6.59	60	2

The overhead for telescope preset, target acquisition, change of wavelength setting, etc., is estimated to amount to 10min per object. With a DIT of 60s, NDIT=2 and one AB nodding cycle per wavelength setting the time on target is estimated to about 36min. According to the current ETC a SNR of 80 - 100 per resolution element will thus be reached, which is sufficient to derive the described science goals. Including two standard star observations (with NDIT=1) the total time required amounts to 180min.