INAF – TIME ALLOCATION COMMITTEE

Application for observing time **Category: D**

Period AOT39 (April 2019 – September 2019) **Submit using: www.tng.iac.es/submit.html**

1. Title

Factory of lithium in AGB stars

2. Abstract

As one of the most important metal sources, asymptotic giant branch (AGB) stars play a critical role in the Galactic chemical evolution. Lithium is also produced by AGB stars through hot bottom burning (HBB) mechanism. Despite many advances in past decades, the total contribution of Li from AGB stars to Galactic chemical enrichment remains unsettled. Detailed measurements of element abundances that are affected by the HBB nucleosynthesis are therefore the key to constrain the HBB mechanism during AGB phases and their detailed contribution to chemical enrichment. These include several elements including lithium, carbon, nitrogen, oxygen, neon, sodium, magnesium, and aluminium. We aim to combine efforts from optical, near-infrared, and sub-mm observations, towards a small but representative sample of oxygen-rich and carbon-rich AGB stars, to measure these element abundances. Here we propose for observations with mode GIARPS to simultaneously obtain optical (HARPS-N) and near-infrared (GIANO-B) spectra for our sample. A related proposal for sub-mm observations will be submitted to ALMA in the next cycle.

3a. Number of requested hours per telescope and instrument

TNG					REM	
DOLORES	DOLOR.+MOS	NICS	HARPS-N	GIANO-B	ROSS	REMIR
			5.8			

3b. Observing modes

TNG:		Visitor	X	Service		ToO
REM:		Rapid Response		Queuing		ToO

4a. Preferred months

first choice: second choice:

4b. Other scheduling constraints (use also box 14)

5a. Past and future of the project

a) Hours already awarded to the project:

b) Hours foreseen to complete the project:
(not including this request)

6. Principal investigator

Name X. Fu

Institute INAF-OAS

Address via Gobetti 93/2, 40129 Bologna, Italy

e-mail xiaoting.fu@inaf.it

Phone +39 051 6357-332

7. Co-investigators (name and institution)

P. Marigo, B. Aringer, Y. Chen — University of Padova
A. Bragaglia, D. Romano — INAF-OAS
A. Mucciarelli — University of Bologna
Z. Zhang — University of Edinburgh
S. Ramstedt — Uppsala University

8. Status of the project

Telescope	Instrument	Date	Hours	Notes

Description

Publications

9a. If this proposal is a part of a PhD thesis, write here the name of the student, the thesis title and briefly describe the relevance of these observations for the thesis goals.

9b. Is this, or a similar application submitted to other time allocation committees (e.g. ESO, TNG-CAT, ITP)? If yes, please specify which and explain if and why the proposals should be considered complementary.

10. Description of the programme (max. 3 pages, including references, tables, and figures.)

A) Scientific rationale

Lithium in most warm, metal-poor, main sequence stars shows a constant abundance plateau and the upper envelope of the lithium vs. metallicity distribution increases as we approach solar metallicity. The sources of the Li enrichment include asymptotic giant branch (AGB) stars, low-mass red giants, novae, core-collapse supernovae, and Galactic cosmic rays. However, relative contributions among these origin sources are unsettled, which is referred as *the Galactic Lithium problem*. Furthermore, different Li enrichment histories in the Galactic thick and thin discs have been found (see e.g. Fu et al., 2018, based on Gaia-ESO survey data). Li is also the first element that shows a decline in absolute abundance as metallicity increases, which is found in field stars with super-solar metallicities. **A very-well constrained AGB model will help to elucidate the Li contribution from AGB stars, and will shed light on these problems.**

Li is synthesised in AGB stars via the Cameron-Fowler beryllium transport mechanism (Cameron & Fowler 1971) during the so-called hot bottom burning (HBB). HBB takes place during the AGB phase (Sackmann & Boothroyd 1992) of intermediate-mass stars (M $\geq$ 4 $M_\odot$), when the bottom of the convective envelope becomes hot enough for the activation of hydrogen burning via the CNO cycle, as well as NeNa and MgAl chains. As AGB stars lose mass, the burning products, brought to the surface by convection, are ejected in the interstellar medium (ISM). In addition to the Li-production, HBB also modifies the abundance of C, N, O, Na, Ne, Mg, Al, and their isotopes. Figure 1 shows the abundance evolution for several elemental isotopes in the envelope a few and molecular species at the photosphere during the entire TP-AGB phase for a TP-AGB model computed with the `COLIBRI` code (Marigo et al., 2013). The nucleosynthesis of HBB left its signatures in the prominent chemical anti-correlations (C-N, O-Na, Mg-Al) currently detected in Globular Cluster stars (e.g. Carretta et al. 2009). Its products, ^{22}Ne and ^{13}C, are neutron sources which dominate the following slow neutron-capture process (s-process) nucleosynthesis (García-Hernández et al. 2013).

The production of Li in HBB models depends on stellar mass and metallicity, mostly when the star is O-rich (i.e. C/O<1, see e.g. Marigo et al., 2013). Indeed, Garcíia-Hernández et a. (2013) observe four Galactic O-rich AGB stars and find that the high Li over-abundances are accompanied by weak or no s-process elements (i.e. Rb and Zr). This may indicate that the third dredge-up is either little efficient or that it becomes efficient at later stages during the thermally-pulsing asymptotic giant branch (TP-AGB) phase.

However, several C-rich (C/O>1) AGB stars are reported with large Li abundance in our Galaxy (Abia et al., 1991), as well as in the Small and Large Magellanic Clouds (Smith et al., 1995). Abia et al. (1993) conclude that the contribution of C-rich AGB stars to the Galactic Li enrichment can reach 30%. The contribution, having said that, is sensitive to the mass loss and Li synthesis in the AGB modelling. For instance, Romano et al. (2001) and Travaglio et al. (2001) reach opposite conclusions, because of the adoption of different yield sets and different assumptions about the underlying stellar physics (e.g. mixing process, mass-loss rate) in their chemical evolution models. Ventura et al. (1999) perform the modelling of the Li production in TP-AGB stars and argue that there is a peculiar evolutionary stage with a narrow range of stellar mass that can actually produce large Li abundance in the C-rich phase. Since the luminosity range at this stage is very small, they also suggest that the Li-rich C-rich AGB stars could be an independent distance indicator.

The Magellanic Clouds used to be the best objects to check TP-AGB models because they have reasonably known distances. Now the Gaia parallax measurements (Gaia Collaboration, 2018) of the Galactic AGB stars, though not quite precise because of the convection-related variability, improves the distance accuracy of these stars. we can set a better constraint in modelling TP-AGB stars in our own Galaxy, by comparing with the detailed elemental and molecular abundances from observations.

B) Scientific aim

We plan to study the HBB nucleosynthesis, especially the Li production, in TP-AGB stars, with synergy between multiple gas phases. Ultimately, we will use **high resolution optical, infrared spectra, together with sub-mm observations**, to measure the detailed element abundances in a small sample of representative Galactic TP-AGB stars covering a range of physical properties. The resonance line of neutral ^{7}Li atom at 6708 Å, the lines of heavier elements Na, Mg, Al, and s-process elements (Zr, Ba, Y, La, Ce) can be measured with HARPS-N, and the detailed CNO abundance will be obtained with GIANO-B. Because of their low temperature, many molecules, including lithium hydride (LiH), are formed in the photospheres and in circumstellar envelopes of AGB stars. We will propose ALMA observations in the next cycle to measure the LiH abundances and fully exploit the archival databases (e.g. APEX, ALMA, SMA, etc.) to obtain other molecular species (e.g. ^{12}CO, ^{13}CO, SiO, HCN, CS, etc.) for the same targets. With information from multiple gas phases, we can also better constrain the mass loss of these AGB stars.

To properly sample most stages of TP-AGB phases, we select both O-rich and C-rich AGB stars from the AGB catalogue (Suh & Hong 2017) and the `DEATHSTAR` project catalogue in Uppsala University. From a total of 3828 O-rich and 1168 C-rich AGB stars, we select those *i.* that could be observed with both TNG and ALMA; *ii.* that have Gaia parallaxes; *iii.* that have relatively strong sub-mm continuum emission (for future abundance measurement via absorption lines), based on ALMA archival data; and *iv.* that are brighter than V=12 mag. In the end, we conclude with 8 O-rich and 6 C-rich AGB stars in our sample (see the list of targets in box 11).

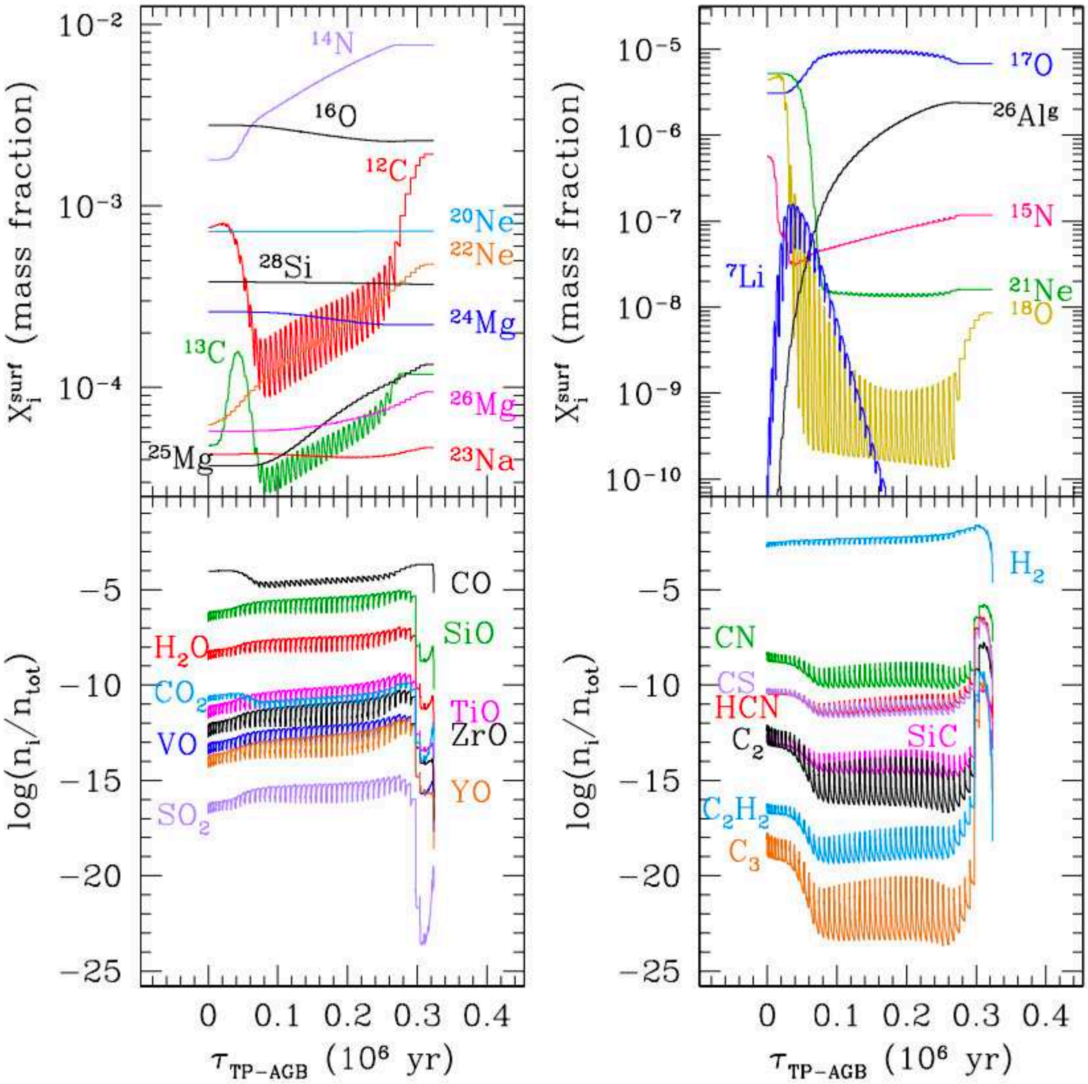
We will calibrate the TP-AGB model `COLIBRI` using abundances measured from multiple gas phases, with synergy between TNG/GIARPS and ALMA data. The AGB yields from the calibrated models will be adopted in updated chemical evolution models for Li by Romano et al., (2001) to study the Galactic lithium evolution.

Our team has extensive experience in spectroscopic observations and abundance analysis (X. Fu, A. Bragaglia, A. Mucciarelli), AGB star modelling (P. Marigo, B. Aringer, Y. Chen), Galactic chemical evolution (D. Romano), and AGB star observations (S. Ramstedt, Z. Zhang).

References

Abia, C., Boffin, H. M. J., Isern, J., & Rebolo, R. 1991, A&A, 245, L1
Cameron, A. G. W., & Fowler, W. A. 1971, ApJ, 164, 111
Carretta, E., Bragaglia, A., Gratton, R. G., et al., 2009, A&A, 505, 117
Chiavassa, A., Freytag. B., Schultheis. M. 2018 A&A, 617 1
Fu, X., D. Romano, D., Bragaglia, A., et al., 2018, A&A, 610, 38
Gaia Collaboration, Brown, Vallenari, et al. 2018, A&A, 616, 1
Marigo, P., Bressan, A., Nanni, A., et al., 2013, MNRAS, 434, 488
Sackmann, I. J., & Boothroyd, A. I. 1992, ApJ, 392, L71
Romano, D., Matteucci, F., Ventura, P., & DAntona, F. 2001, A&A, 374, 646
Suh, Kyung-Won, & Hong, Jinju, 2017, Journal of the Korean Astronomical Society, 50, 131
Travaglio, C., Randich, S., Galli, D., et al. 2001, ApJ, 559, 909
Ventura, P.; D'Antona, F.; Mazzitelli, I., ApJ, 524, 111

Figure1: Theoretical abundance predictions for several elemental isotopes in the convective envelope (upper panels) and molecular species at the photosphere (lower panels) during the entire TP-AGB phase from `COLIBRI` AGB model (M_i=5 $M_\odot$, Z_i=0.008).



11. List of targets (note that the absence of a proper object list and information may weaken the proposal)

Name	α	δ	Epoch	Mag.	Time	Additional Information
UY Cet	00:27:06.4	-06:36:16.8	J2000	9.32	2100s	O-rich AGB
R Leo	09:47:33.4	+11:25:43.8	J2000	7.53	300s	O-rich AGB
BK Vir	12:30:21.0	+04:24:59.1	J2000	7.28	300s	O-rich AGB
RT Vir	13:02:37.9	+05:11:08.3	J2000	7.41	300s	O-rich AGB
SW Vir	13:14:04.3	-02:48:25.1	J2000	6.85	300s	O-rich AGB
RR Aql	19:57:36.0	-01:53:11.3	J2000	7.80	600s	O-rich AGB
EP Aqr	21:46:31.8	-02:12:45.9	J2000	6.78	300s	O-rich AGB
R Crt	11 00 33.8	-18 19 29.5	J2000	9.80	2400s	O-rich AGB
W Ori	05:05:23.7	+01:10:39.4	J2000	6.10	180s	C-rich AGB
HD 56126	07:16:10.2	+09:59:47.9	J2000	8.32	1800s	C-rich AGB
SS Vir	12:25:14.3	+00:46:10.9	J2000	6.60	300s	C-rich AGB
V Aql	19:04:24.1	-05:41:05.4	J2000	6.90	300s	C-rich AGB
19 Psc	23:46:23.5	+03:29:12.5	J2000	5.02	180s	C-rich AGB
RV Aqr	21:05:51.7	-00:12:42.1	J2000	11.5	7200s	C-rich AGB

12. Observational strategy and justification of requested time, including overheads.

We propose to observe with GIARPS mode, with the observation time driven by HARPS settings. We used the HARPS-N ETC tool NSTS and computed the exposure time for each target (see table below). Since most of our sample stars are bright, we don't have special constraints on the moon light.
By selecting bright night (14 days from new moon), seeing=1.2", we find that in order to achieve an average S/N $\geq$ 100 per pixel we need to integrate for 4.6 hours (science time) for the 14 targets in total. Adding overheads (about 70 mins, considering 5 min per star), the total time we requested is 5 hours 46 mins.
We summarize the exposure time (science time) in the table above (section 11) and the desired S/N for each target in the table below.

target	spectra type	S/N
UY Cet	M7	125
R Leo	M7-9e	110
BK Vir	M7-III	120
RT Vir	M8III	115
SW Vir	M7III	150
RR Aql	M7.5e	130
EP Aqr	M7-III	150
R Crt	M7	120
W Ori	C-N5	165
HD 56126	F0	110
SS Vir	C-N4.5	135
V Aql	C-N5	120
19 Psc	C-N6	210
RV Aqr	C6	80

13. Requested instrument(s) setup

Id	Instrument	Binning	Filter(s)	Slit	Grism	Time	Additional Information
1	HARPS-N					5.8 hr	
2	GIANO					5.8 hr	
3	GIARPS					5.8 hr	total science time= 4.6 hr

14a. Moonlight constraints

Max. # of days from new moon $\boxed{14}$

14b. Scheduling constraints, special requirements and other remarks

(please include justification of constraints in 14a)

15. Observational background of the applicants

Name of the observer(s) at TNG:

Experience of the observer(s) with the requested TNG instrument(s)

Experience of the observer(s) with other telescopes/instruments