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

Kepler stars in Gaia-Enceladus debris

2. Abstract

The Galactic halo is composed by both stars formed in-situ and by stars accreted from satellites. Thanks to the exquisite data from *Gaia* DR2 and from APOGEE survey, the remnants of a big accretion event has been kinematically identified in a group of counter-rotating stars. The event appears to have occurred ∼10 Gyr ago, from a satellite of the size of the Small Magellanic Cloud, named Gaia-Enceladus. In the APOKASC catalogue (APOGEE+*Kepler*) we identified 4 stars that have an high probability to belong to the Gaia-Enceladus debris. Our preliminary analysis suggests that their age, computed using asteroseismology, cover a wide range of values (7-13 Gyrs). This spread is not in agreement with the range associated to Gaia-Enceladus population, and might indicate that not all these counter-rotating metal-poor stars belong to the accreted satellite. Unfortunately, our characterization of these stars is limited, due to the large uncertainties associated to APOGEE spectra (metallicity). With this proposal we aim to complete the chemical profile of the stars up to Europium. The precise and complete chemical profile, combined with the high-quality asteroseismic data, will reveal the origin of those stars.

3a. Number of requested hours per telescope and instrument

TNG					REM	
DOLORES	DOLOR.+MOS	NICS	HARPS-N	GIANO-B	ROSS	REMIR
			10.5			

3b. Observing modes

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

4a. Preferred months

first choice: apr-may-june 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

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7. Co-investigators (name and institution)

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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.

Not applicable.

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.

The Kepler targets in the proposal does not belong to the GTO and GAPS protected targets.

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

A) Scientific rationale In recent times, thanks to spectroscopic, photometric surveys, and precise astrometric data, the Galactic halo is revealing an unexpected complexity, being composed by streams, shells, clumps, debris, and correlated substructures. This gives us a further indication that a significant fraction of halo stars may come from accreted satellites. To reconstruct the history the Milky Way halo stars, three powerful diagnostics are available for tracing back their origins: kinematics, chemical-tagging, and age determination. The kinematics of stars, via the analysis of their orbits, can give hints on non-local formations, including accretion from satellites (e.g. high energetic orbit, retrograde motion, Villalobos & Helmi 2008). The chemical-tagging, or the analysis of elemental abundances of the stars, relies on the fact that their atmospheres enshrine the characteristics of the interstellar medium (ISM) of their birth-sites (Freeman & Bland-Hawthorn, 2002). In order to complete the picture on the nature and origin of the halo we need information on the stellar ages. This is also fundamental to reconstruct the chemical enrichment history of the interstellar medium (Miglio et al. 2017). Deriving ages for field stars is however a challenging task, and so far was possible only using nucleo-cosmo-chronology (reaching a precision of ≈30%, from [U/Th] abundances ratio, with very high signal-to-noise and high-resolution spectra). On the other hand, thanks to asteroseismology it is possible to obtain precise stellar masses, and, therefore, ages with precision better than 30% (Davies & Miglio, 2016). This techniques were already applied to metal-poor halo stars both in stellar clusters and field (Miglio et al. 2016, Valentini et al. 2018).
Recently, Helmi et al. 2018, by combining astrometry (from *Gaia* Second Data Release, hereafter GDR2, Gaia collaboration et al. 2018) and chemical abundances (APOGEE survey, Abolfathi et al. 2018), proposed that the numerous, counter-rotating stars in the inner halo, were the relics of one single accretion event occurred ≈10 Gyr ago, involving a satellite galaxy with the size of the Small Magellanic Cloud (Fig. 1). This substructure has been called the Gaia-Enceladus stream.

Question: Can all the counter-rotating metal-poor population be attributed to Gaia-Enceladus?

B) Scientific aim With this proposal we aim at observing 4 giants, that have been identified (kinematically and chemically) as good candidates to the Gaia-Enceladus debris, for which we also have high-quality oscillation spectra (from *Kepler*) and APOGEE spectroscopy. However APOGEE spectra can provide abundances only for α-elements and Fe-Peak (since they are centered in the H band), with no useful or well known lines of heavy elements. The abundances of heavy elements, coming from two types of n-capture processes, are indeed able to characterize the primordial chemical enrichment and, eventually, the different origin for our stars: r-process from core-collapse supernovae of massive stars and neutron-star mergers, and the contribution of fast rotating massive stars to the early enrichment in s-process elements. The HARPS spectra will complete the chemical pattern of the stars, providing key information about their n-capture element content and therefore about their birthplace star formation and nucleosyntesis. We will focus on n-capture elements:*i)* s-(slow), spinstars and AGB stars (Sr and Ba); and *ii)* r-(rapid), from neutron-star mergers and core-collapse supernovae (Eu).
Target selection. We performed a kinematic selection from APOKASC catalogue v.4.3.4 (following Helmi et al. 2018 criteria), based on GDR2 proper motions, distances derived using asteroseismology and radial velocity from GDR2 and APOGEE. Selected stars (>80% probability) in the velocity plane are showed in Fig. 1.
Stellar ages. We used PARAM (Rodrigues et al. 2017) to derive stellar mass, radius and age for the target stars. We used the atmospheric parameters from APOGEE-DR14, seismic parameters from APOKASC catalogue v4.3.4. The radii obtained with PARAM were used for constructing the temperature-luminosity diagram in Fig. 2. We selected stars located below the clump, to avoid age uncertainties due to not-precise approximation for mass-loss. Ages of the proposed targets span from 7 to 13 Gyrs, with an error of 40%, ascribable mainly to the high uncertainty on the effective temperature, that we aim to reduce. If confirmed by our project, the population of metal-poor counter rotating stars in the Halo is not mono-aged, but has a scatter and therefore Enceladus might not account for the entire retrograde metal-poor population.
Analysis of HARPS-N spectra. We aim at measuring more precise $T_{\rm eff}$, log(g) and abundances by using, iteratively, the very precise seismic log(g), as successfully performed in Valentini et al. 2013, 2016, 2017, 2018. We investigated the feasibility of obtaining element abundances with an error of 0.1 dex by degrading Arcturus Hinkle spectrum at HARPS-N resolving power and at different signal-to-noise ratio (SNR) realizations. A SNR of 50 at 4,000 Å will grant our analysis, as showed in Fig. 3. As indicators of rapid (r) and slow (s) neutron-capture process elements, we aim at measuring Eu (at 4435, 4522, 6437, 6645 Å), Ba (at 4554, 4934, 5853, 6141 Å) and Sr (4215 Å). If measurable, 12C/13C abundances ratio will provide insightful information on the evolutionary phase of the star than can pin down age error (Rodrigues et al. 2017). In addition 12C/13C, when corrected for stellar evolutionary effects, will provide information about the mixing of the birth-site ISM (Choplin et al. 2018).
Results We will proceed as following: a) we will derive atmospheric parameters using seismic log(g) and test the agreement with APOGEE; b) we will construct an homogeneous set of abundances for each star (alpha elements, Fe-peak, and n-capture elements as Eu, Sr and Ba); c) we will recompute ages with the newly determined $T_{\rm eff}$ and log(g); and finally d) we will combine ages, chemical pattern, and kinematics.

The proposed targets are the only targets available with seismic parameters that have an high probability to belong to the Gaia-Enceladus debris. This represents an unique possibility for investigating the origins of the counter-rotating stars in the Halo using kinematics, precise chemical abundances covering different production channels and using precise stellar ages.

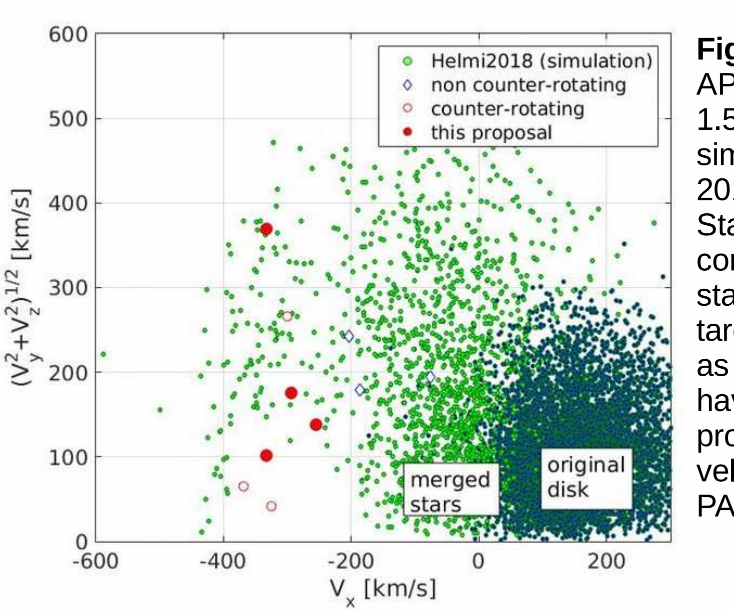

Fig.1: Velocity distribution of APOKASC metal poor stars ([Fe/H]<-1.50 dex) overimposed to the simulation results as in Helmi et al. 2018 (dark and pale green points). Stars that satisfy Helmi et al. 2018 conditions for being Gaia-Enceladus stars are plotted as red circles. Stars targeted with this proposal are plotted as filled red circles. Galactic velocities have been computing using Gaia-DR2 proper motions, APOGEE-DR14 radial velocities and seismic distances from PARAM.

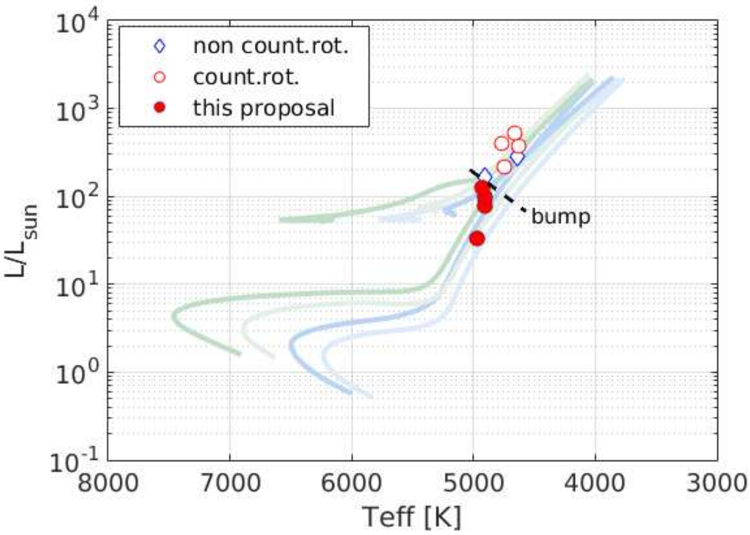

Fig.2: Temperature-luminosity diagram of the APOKASC metal poor stars. Temperatures come from APOGEE-DR14 catalogue, luminosities has been computed from the seismic radii obtained with PARAM (using seismic parameters). Tracks are obtained from MESA, for two masses, and for two metallicities (pale and dark). Stars targeted for this proposals (red filled circles) are the stars laying below the bump, for avoiding biases in ages due to an incorrect mass-loss assumption.

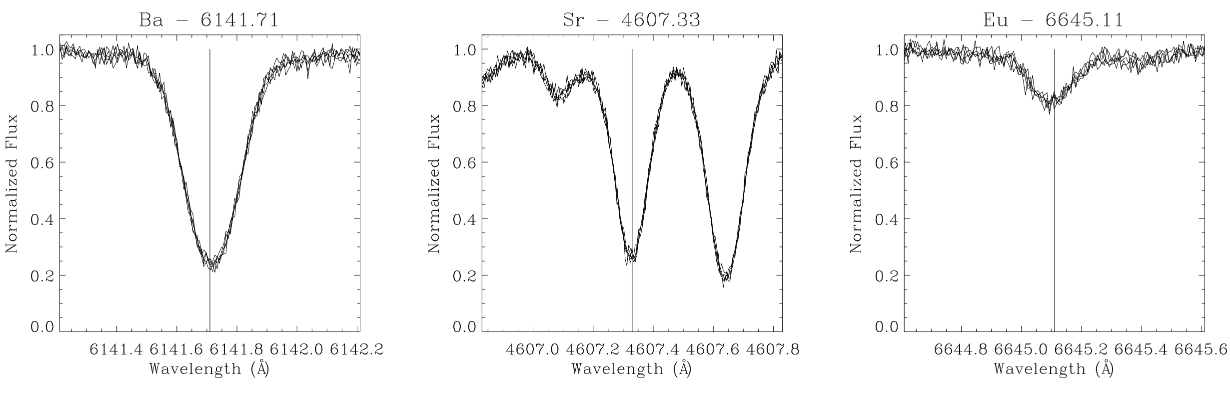

Fig.3: Line detectability at SNR 50 for Ba, Sr and Eu lines at HERMES-N resolution power. Arcturus Hinkle atlas (Hinkle et al. 2000) has been used as template. For the sake of visibility in the figure, five different realizations of the same SNR are overimposed. Since our targets are faint (V~12 mag), we tested the SNR limits that grant the abundaces measurements. SNR 50 at 4500 Å grants the feasibility of our project (error on the abundances of ~0.1 dex).

References:

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Bergemann, M., & Gehren, T. 2008, A&A, 492, 823
Cayrel, R., Hill, V., Beers, T. C., et al. 2001, Nature, 409, 691
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Miglio, A., Chaplin, W. J., Brogaard, K., et al. 2016, MNRAS, 461, 760
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Valentini, M., Chiappini, C., Bossini, D., et al. 2018, A&A, submitted (arXiv:1808.08569)
Valentini, M., Chiappini, C., Davies, G. R., et al. 2017, A&A, 600, A66
Valentini, M., Chiappini, C., Miglio, A., et al. 2016, Astronomische Nachrichten, 337, 970
Valentini, M., Morel, T., et al. 2013, European Physical Journal Web of Conferences, 43, 03006
Villalobos, Á., & Helmi, A., 2008, MNRAS, 391, 1806

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
4143467	287.549455	39.288364	J2000	V12.8	5x1800s	
9339711	290.74864	45.81358	J2000	V12.3	5x1800s	
7191496	289.031884	42.775551	J2000	V12.1	5x1800s	
9335536	288.797962	45.80545	J2000	V13.3	6x1800s	

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

Our targets are observable only from the northern hemisphere and our science case requires the measurement of elements form lines visible in the range 4,00-6500 Åand with an accuracy feasible only at high resolution for red giants (a spectral interval not accessible by APOGEE, centered in the H band). HARPS-N is the perfect instrument for completing our program.
We request classical fiber spectroscopy mode, in the objAB set-up: fiber A on target and fiber B on sky. This will allow a correct sky subtraction. This set-up needs also the standard calibrations to be taken at the beginning of the night.
Exposure times were calculated ensuring a SNR of 50 at 4500 Å. This SNR is the minimum value that allows a successful measurement of the elements necessary for our case (Eu, Ba, Sr), as shown if Fig. 3. To the exposure times we added 220s overheads per target (following HARPS-N USER MANUAL v 2.4).
We used the latest version of the HARPS-N exposure time calculator, setting an airmass of 1.2", seeing of 1 arcsecond and a star of spectral type K0, as our targets are.

13. Requested instrument(s) setup

Id	Instrument	Binning	Filter(s)	Slit	Grism	Time	Additional Information
1	HARPS-N	1x1	none			9.5hr	

14a. Moonlight constraints

Max. # of days from new moon [7]

14b. Scheduling constraints, special requirements and other remarks
(please include justification of constraints in 14a)

The proposed targets are faint, so scattered moonlight contamination could hamper our measurements. Therefore we ask for our observations to be performed at max of 7 days from the new moon and a maximum angular distance of 20 deg from the moon (F. Patat et al. 2004 - ESO Messenger).

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