CAS-CONICYT Postdoctoral Program 2018

1) Research subject title and an abstract (<1000 words,)

Title:

"*The Nature and Astrophysical Site(s) of unexplained Nitrogen-rich stars throughout the Milky Way*"

Abstract:

The recent discoveries of the most ubiquitous abundance patterns in the Milky Way have reinvigorated the study of unusual abundances of some light elements challenging our understanding about the rare nucleosynthetic pathways in galactic globular cluster environments as well in field stars, and at the same time have open a new frontier in Galactic archaeology. Using high-resolution (R~ 22,000) APOGEE (DR 12, 13 and 14) spectra in the near-infrared as well as LAMOST DR3 spectra, we have discovered a handful of unexplained outliers (field giant stars) in the halo-disk interface (e.g., $-1.7 < [Fe/H] < -0.7$ dex) that show enhanced Al and N accompanied by decreased C abundances, atypical Mg underabundances and unexplained CH features, indicating an unique chemical pattern among Milky Way stars and whose origin is not known. A speculative scenario suggests that most of our Mg-deficiency signatures could have an extragalactic origin and former *second-generation* stars of dissolved "extragalactic" globular clusters or exotic binary systems are other of the several scenarios proposed so far. We possess high-resolution (R~ 48,000) spectroscopic spectra from FEROS/ESO spectrograph never covered in spectroscopy studies before, which we will use to begin this project. We aims at measure the abundances of heavy neutron-capture elements for the first time (e.g., s-process elements like Zr, Tc, Y, Nb, and La; not accessible with APOGEE data), which will offer clues about rare astrophysical events or nucleosynthetic pathways present in such stars. This will be a major step forward to understanding the formation and evolution of our own Galaxy.

2) Project proposer, his/her collaborator and host institutions in Chile and/or China

Principal Investigator (PI):
Dr. Baitian Tang (Sun Yat-sen University, China)
Co-Is:
Dr. Mauro Barbieri (Universidad de Atacama, Chile)

3) A brief Scientific Justification, Chile-China connection, and any other relevant information

The assumption that abundance anomalies are present only in light elements (namely C, N, O, Na, Al, and Mg) within globular cluster populations (e.g., Carretta et al. 2009, 2012, Mészáros et al. 2015, Tang et al. 2017, Schiavon et al. 2017b) and not in the field population (e.g., Gratton et al. 2000, Martell et al. 2011, Lardo et al. 2017) has been challenged by the recent discoveries of field stars with globular cluster like abundance patterns (e.g., Ramírez et al. 2012, Majewski et al. 2012, Carretta et al. 2013, Fernández-Trincado 2016, 2017, Schiavon et al. 2017a, Recio-Blanco et al. 2017) and particularly by the discovery of an unique population of wandering metal-rich ([Fe/H]> -1.0 dex) giant stars with unusual Mg under-abundances (see Fernández-Trincado et al. 2017), accompanied by light-element abundance variations (namely typified by large N and Al overabundances with low Carbon abundance ratios) similar to observed in the so-called second-generation stars (see Mészáros et al. 2015, Pancino et al. 2017, for instance), but not seen in Galactic globular cluster stellar populations at similar metallicity.

To date, only a handful of chemically anomalous giant stars in the Galactic field (toward the bulge, disk, and halo) have been found to exhibit interesting variations in their heavy (neutron-rich) element abundance patterns (e.g., Ce, Nd, Nb, Y, Zr, La: Hasselquist et al. 2016, Pereira et al. 2017, Cunha et al. 2017) together with significant inhomogeneities in their light-element abundances, strikingly similar to those observed in the "second-generation" population of globular clusters (Lind et al. 2015, Fernández-Trincado 2016, Schiavon et al. 2017a). Often, these stars have been hypothesised to be associated with debris and/or signals of disruption of globular clusters (e.g., Fernández-Trincado et al. 2013, 2015a, 2015b, 2016a). Following this line of investigation, Fernández-Trincado et al. (2017) and Fernandez-Trincado et al. (2018, in preparation) have recently discovered a new ***SG-like stellar population*** across of the main components (bulge, disk, and halo) of the Milky Way, with atypically low Mg abundances; i.e., with respect to those seen in the SG stars of Galactic globular clusters at similar metallicities. Based on the unique stars Mg-deficiency and their orbital properties, the authors speculate that most of these atypical stars may have an extragalactic origin. For example, they could be former members of dissolved extragalactic globular clusters (e.g., Mucciarelli et al. 2012) and/or the result of exotic binary systems; former members of a dwarf galaxy (with intrinsically lower Mg) polluted by a massive AGB star.

Fernández-Trincado et al. (2017) and more recently Fernandez-Trincado et al. (2018, submitted) studied the chemical composition of red giant field stars using near-infrared (~1,5-1,7 microns) high-resolution (~22,500) APOGEE spectra (along the different data releases: DR12, 13 and 14), and found evidence for the basic SG-like chemical pattern of depletion in C and O together with N and Al enrichment (see Figure 1). We note that the Na abundances from our APOGEE spectra are not reliable because they rely on the Na I lines at 1,63738 and 1,63888 microns, which are too weak in the typical Teff, log g, and metallicity range of our sample stars. Unfortunately, only two heavy elements, Nd and Ce, are actually accesible with APOGEE (see e.g., Hasselquist et al.

2016; Cunha et al. 2017). Similarly to the Na case, Nd can be only measured in one star, while the Ce abundances have been estimated from a few lines weakly blended by telluric features (Fernández-Trincado et al. 2019, in preparation).

FEROS (Fiber-Fed Extended Range Optical Spectrograph, Kaufer et al. 1999) on the ESO 2.2-m telescope at La Silla (Chile) have been well suited to collect additional elements not contained in the APOGEE data base (see Pereira et al. 2017, for instance), especially those typified by heavy neutron-rich (e.g., the r-process and s-process) elements (e.g., Y, Zr, Nb, Nd, La, Ce, Tc), with the goal of add tightly constraints of the astrophysical sources that led to the unusual abundance patterns. The same spectra obtained in a different epoch than APOGEE ones will be well suited to provide radial velocity "variability" which will give us additional clues to establish the number of such objects formed through the binary channel, or result from low-level radial velocity (RV) variations known to exist in low-gravity red giants (e.g., Pereira et al. 2017), as well as determine more precisely other light-elements such as Oxigen and Sodium which will allows us to confirm the SG-GC-like nature. The constraints placed with FEROS/ESO spectra will bring us closer to the understanding of their origin.

While astronomers found an increasing number of *N-rich* stars using The Sloan Digital Sky Survey (SDSS), The Large Sky Area Multi-Object Fibre Spectroscopic Telescope (LAMOST) Galactic spectroscopic survey has not been explored in this regard. Recently, we identified a group of *CN-strong* metal-poor field stars from LAMOST DR3. We use the CN3839 and CN4142 spectral indices to select CN-strong stars out of the normal metal-poor field stars, and we further separated the CH-strong stars out of the sample using CH4300 spectral indices.

We mainly focus on the CH-normal stars, since CH-strong stars are mostly carbon-enhanced, which is the topic of a different research field. Chemical abundances we derived showed that the N-enhancement should be raised by additional astrophysical process besides extra-mixing during the RGB phase. Therefore, an unknown astrophysics process is present in these CN-strong CH-normal stars. We also examined the kinematics of these CH-normal stars to discuss their origins. We derived distances using Gaia DR2 and spectrophotometric approach, respectively. The Toomre diagram is a strong diagnostic tool to differentiate the origin of these stars.

In the following papers of this series, we will increase our sample size by applying our selection technique to later LAMOST data releases, e.g., DR5. Large sample size is crucial for statistical discussion of the classification and origin of the CH-normal stars. Another improvement is related to the C, N abundance derivation from the low-resolution LAMOST spectra. We will improve the C, N abundance derivation by introducing the template fitting method given by Briley et al. (2004).

Finally, this is a 100% made in Chile-China project, with most of the collaborators currently working, or having very recently worked, in a variety of Chilean and China universities. We anticipate that a large number of both Chilean and China as well as international researchers will benefit from the data collected FEROS/EROS and LAMOST studies on this new field.

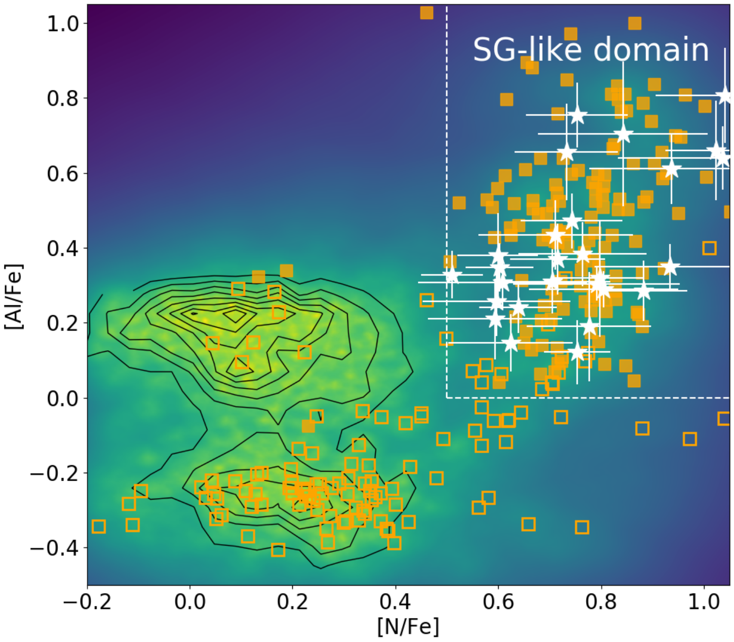

Figure 1: APOGEE DR14 distribution of the ~6,000 giant stars in the [N/Fe] vs [Al/Fe] plane. Shown with star symbols are stars selected as chemically anomalous. The same field sample is compared to APOGEE data for Globular Clusters within a smaller range of metallicities. First-generation (orange open squares) globular clusters are a good match to the [N/Fe] vs [Al/Fe] relation halo field stars, as expected, with Second-generation (orange filled squares) stars spanning larger values of [N/Fe], thus occupying the same locus as the N-rich stars (white symbols) reported in this work (e.g., *Fernández-Trincado et al. 2018b, submitted to MNRAS*).

4) Implementation details including expected project duration (two years or three years, with a maximum of 2 years in Chile and the rest time in China)

The present project is guaranteed with 8 nights of observation (Proposals 2018A and 2018B submitted to the Chilean Time Allocation Committee (CNTAC) —P.I: José G. Fernández-Trincado) in the The Fiber-fed Extended Range Optical (FEROS/ESO) Spectrograph installed at the MPG/ESO 2.2-metre telescope located at ESO's La Silla. We have submitted a new extended proposal (CNTAC 2019A— P.I: José G. Fernández-Trincado) in FEROS/ESO spectrograph aims to study the chemical composition of newly identified anomalous giant stars using APOGEE/ DR14 data in order to complete the full statistical census of such peculiar stars across the Milky Way. To begin this project we already possess high-resolution spectra from FEROS/ESO spectrograph for 75% of our sample, which will be analyzed and processed by the Postdoc Fellow as well as follow new observations for the rest of the sample by middle 2019.

Furthermore, we need more high-resolution spectra of the CH-normal stars that we found in LAMOST data. Recently we are granted 3 nights to use the high-resolution spectragraph (HRS) in NAOC 2.16 m telescope. We will observe 11 bright CH-normal stars in our sample to derive detailed chemical abundances. Our nights are scheduled on Dec. 2018, Feb. 2019, and Apr. 2019. Chemical abundances from high-resolution optical spectra are important indicators of their origins. We will compare O, Na, Mg, and Al abundances to find out if the CH-normal stars match the GC SG star chemical pattern. The result will verify/disprove their possible GC origin. We will also derive neutron capture elements to estimate their AGB contribution, which may be related to binary activities.

Work Plan: Project duration = 3 years (2 years in Chile and rest time in China).

In the present section we sketch a expected work plan for each year of the proposed project.

- **Year 1:** The Postdoc Fellow will be analysis the data collected with the MPI 2.2m FEROS/ESO spectrograph, aimed at studying the presence/absence of ”s-/r”-process abundances (Ce II, Nd II, Y II, Zr I, La II) in giant stars selected from the APOGEE-2 survey (APOGEE H bands spectrum does not provide information about these chemical species, which give useful clues on the composite nature of the giants, AGB phase, etc), in order to place constraints on the pollution scenarios that could have formed the chemically anomalous giant stars recently discovered in Fernández-Trincado et al. (2016) and Fernández-Trincado et al. (2017). We anticipate at least two papers: one describing the first constraints reached with this data, and a second paper presenting new chemistry discoveries from the APOGEE-2S spectroscopic follow-up programs using public data release by 2019.

- **Year 2:** The Postdoc Fellow will work in the first and global dynamical picture of these stars combining Gaia DR2 (parallax, proper motions) data with radial velocity information from FEROS/ESO + APOGEE data, adopting the new dynamical software called “GravPot16” (P.I: José G. Fernández-Trincado), a state-of-the art orbital integration model with an (as far as possible) realistic gravitational potential, which consider a realist boxy bar and Spiral Arms perturbations. We anticipate at least one paper describing the first dynamical picture of such stars across the Milky Way.

- **Year 3:** The Postdoc Fellow will combine all the techniques from the Year 1 and Year 2 to conduct the largest search for such stars using complementary spectroscopic survey’s like LAMOST DR5 and near future survey’s like WEAVE, 4MOST and other, in order to put more constraints on the origin of these atypical stars, as well as reach a satisfactory explanation for stars with unusual elemental abundances signatures and offer insight into the rare astrophysical events or nucleosynthetic pathways of such stars. All the possible results from this project, whether or not they turn out to be a positive or negative detection of significant variations in neutron-capture elements will provide strong constraints on the origin of this new group of giant stars and will therefore be published. The postdoc will reduce the high-resolution spectra from HRS of NAOC 2.16m telescope, and continue to observe CN-strong CH-normal stars found in LAMOST DR5 using Chinese 2-meter class telescopes. The postdoc is also expected to write papers about this topic.

All the possible results from this project, whether or not they turn out to be a positive or negative detection of significant variations in neutron-capture elements will provide strong constraints on the origin of this new family of giant stars and will therefore be published.

5) CV(s) of the project's leader(s) and list of their publications relevant to the proposal

5.1) CV(s) of the project's leader(s):

The corresponding files have been submitted in separate files.

5.2) Publications relevant to the proposal:

1. Briley, M. M.; Harbeck, D.; Smith, G. H.; et al. 2004, AJ, 127, 1588
2. Fernández-Trincado et al. 2018b, submitted to MNRAS
3. Fernández-Trincado et al. 2018a, submitted to A&A (2018arXiv180107136F)
4. Fernández-Trincado, J. G.; Zamora, O.; García-Hernández, D. A.; et al., 2017, ApJ Letters, 846, L2
5. Fernández-Trincado, J. G.; Robin, A. C.; Moreno, E.; et al., 2016, ApJ, 833, 132
6. Fernández-Trincado, J. G.; Robin, A. C.; Reyle, C.; et al., 2016, MNRAS, 461, 1404
7. Fernández-Trincado, J. G.; Robin, A. C.; Vieira, K.; et al., 2015, A&A, 583, A76
8. Fernández-Trincado, J. G.; Vivas A. K.; Mateu, C. E.; et al., 2015, A&A, 574, A15
9. Fernández-Trincado, J. G.; Vivas A. K.; Mateu, C. E.; et al., 2013, MnSAI, 84, 265
10. Schiavon, R. P.; Johnson, J. A.; Frinchaboy, P. M.; et al., 2017b, MNRAS, 466, 1010
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23. Caffau, E., Bonifacio, P., Faraggiana, R., et al. 2005, A&A, 441, 533
24. Desidera, S., Gratton, R. G., Scuderi, S., et al. 2004, A&A, 420, 683

25. Gratton, R. G., Carretta, E., Desidera, S., et al. 2003, A&A, 406, 131
26. Gratton, R. G., Carretta, E., Claudi, R., Lucatello, S., & Barbieri, M. 2003, A&A, 404, 187