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Cool giants and supergiants as probes of the chemical evolution of the Milky Way

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Abstract. This short review is intended to be a snapshot of some recent observational facts and open questions regarding the study of chemical evolution in the innermost regions of the Milky Way, as traced by spectroscopy of cool giant and supergiant stars.

Keywords. stars: abundances, late-type, supergiants; Galaxy: abundances, disk, stellar content.

1. The context

Red giants and supergiants are luminous, cool stars, tracing the latest stages of stellar evolution for a wide range of masses, from about 1 to 40 Solar masses. Hence, they also trace stellar populations over a wide range of ages, from a few million years when massive stars evolve as red supergiants, to the oldest ages in the Universe when low mass stars evolve as red giants.

These luminous, evolved stars are observed in any galactic component and environment, hence they also probe stellar populations over the full range of metallicities and out to large distances, dominating the integrated stellar luminosity of their host galaxies.

Spectroscopic studies are crucial to constrain chemistry and kinematics of stellar populations. The coupling of chemical and kinematic information is fundamental to disentangle sub-structures and constrain formation and evolution scenarios in complex stellar systems as galaxies are, including the Milky Way.

Systematic ground-based spectroscopic studies at medium-high resolution of warm giants in the Milky Way, aimed at obtaining precise chemical abundances and abundance patterns, are routinely performed. These studies provide fundamental information on stellar nucleosynthesis and chemical enrichment. Observations at very high spectral resolution and signal-to-noise can also constrain stellar 3D structure, mixing processes, activity, magnetic fields, winds, and mass loss.

Quantitative spectroscopy and chemical abundance analysis of the coolest giant and supergiant stars is a quite recent field of investigation, on the learning curve, and it presents challenges over a wide parameter space.

Observationally, one would aim to get spectra at high spectral resolution and with wide spectral coverage for complete line diagnostics and comprehensive chemical tagging of large samples of stars, in order to characterize population properties. IR spectroscopy is often needed because of the intrinsic low temperatures of these stars and the likely high reddening of their environments, if for example located in the inner disk/bulge or in star-forming regions.

From the modeling point of view, spectral and chemical abundance analysis of cool giants and supergiants require state-of-the-art model atmospheres and molecular chemistry to properly account for blanketing and blending effects.

2. Chemical enrichment in the Galaxy center

In the last decade a number of massive spectroscopic surveys of the old populations in the Milky Way halo and outer bulge/disk have been performed using 4-8m class telescopes and multi-object spectrographs mostly working at optical wavelengths.

Radial velocities and chemical abundances for several ten thousands giant stars in the Galaxy field and star clusters have been obtained, providing fundamental information on the formation and chemical enrichment history of the various galactic components. A few other massive surveys are planned in the near-future by using the next generation of multi-object spectrographs with large multiplexing (e.g. VLT-MOONS and VISTA-4MOST), as follow-up of the GAIA mission, to provide a comprehensive 3D mapping of the stellar populations of the Milky Way.

Within the Galaxy however, the innermost regions towards the Galactic center remain poorly explored, mostly because the extinction is so severe that only observations at IR and radio wavelengths are possible. APOGEE and a few other small surveys at Keck, VLT and Gemini are making use of medium-high red and near IR spectroscopy to observe giant stars in the inner disk/bulge and to get chemical abundances of iron, CNO and some other alpha and light elements.

The old giant stars in the central few kpc from the Galactic center show a relatively broad iron distribution, with a peak at about solar [Fe/H] or a bimodal distribution with peaks at slightly (i.e. about a factor of two) below and above solar and a tail towards lower (Fe/H]<-0.5 dex) metallicities (see e.g. Origlia 2014 and reference therein for a recent review). For the same stellar populations some alpha-enhancement with respect to the solar-scaled value has been measured up to about solar metallicity, indicating that the bulk of the bulge population formed from a gas mainly enriched by type II supernovae on a short timescale and liekly at early epochs.

Some chemical abundances of younger and more massive red supergiants in the Galactic center and in the Scutum Arm young clusters, where extinction easily exceeds ten magnitudes at optical wavelenghts, have been also obtained. The Scutum Arm young clusters and associations (e.g. Davies *et al.* 2007, Negueruela *et al.* 2011) are especially interesting stellar systems to probe star-formation and young stellar populations in the inner disk. Indeed, they are quite massive (a few 10^4 $M_\odot$) and rich in red supergiants (a few tens each) to allow statistical significant population studies in a giant star-forming region where the activity is likely triggered by the interactions with the Galactic bar.

About half-solar iron abundances in the Scutum young clusters RSGC1, RSGC2 and RSGC3 (Davies *et al.* 2009b, Origlia *et al.* 2013, Origlia *et al.* 2015), and about solar iron abundance in the Galactic center (Ramirez *et al.* 2000, Cunha *et al.* 2007, Davies *et al.* 2009a, Ryde & Schultheis 2015) have been measured by using IR echelle spectrographs (e.g. Keck-NIRSPEC, Gemini-Phoenix, IRTF-CSHELL, VLT-CRIRES and more recently TNG-GIANO), mounted at 4-10m class telescopes. Some depletion of [C/Fe] and enhancement of [N/Fe], consistent with standard CN burning, and low $^{12}C/^{13}C$ isotopic abundance ratios have been also measured, indicating that some extra-mixing (e.g. rotationally induced) could be at work in the stellar interiors during the evolution of massive stars. For most of the other measured light and heavy metals, including alpha-elements, about solar-scaled [X/Fe] abundance ratios have been inferred, fully consistent with a thin-disk chemistry (Reddy *et al.* 2003), and significant chemical enrichment by type I supernovae over long timescales.

The about solar metallicity of the young red supergiants in the central few kpc of the Galaxy are intriguing, since abundance measurements in Cepheids (Genovali *et al.* 2013, Andrievsky *et al.* 2013) and open cluster giants (Magrini *et al.* 2009), as well as model predictions (Cescutti *et al.* 2007), suggest values well in excess of solar at larger (⩾4 kpc) Galactocentric distances.

The fact that the iron abundance of the stellar populations in the innermost disk and in the Galactic center do not seem to follow the positive gradient traced by the giant stars in the outer disk suggests a more complex chemical and likely dynamical evolution in that region. This is not surprising, given that the innermost region of the Galaxy include several sub-structures belonging to different components (i.e. inner bulge/bar/disk and spiral arms), with large fluctuations in stellar/gas density and star-formation rates. In such a complex physical and kinematic environment, also the chemical enrichment process is expected to have been more complex.

These first near IR spectroscopic studies of the chemical and kinematic properties of the young stellar populations in the inner Galaxy are fundamental in complementing the information derived from the older population of giant stars in the outer, less obscured regions and characterize the chemical enrichment across the entire disk of the Galaxy.

3. Future studies

Near IR spectroscopy of cool giant and supergiant stars has a huge potential in unveling the kinematic and chemical properties of obscured stellar populations, thus tracing the overall star-formation and chemical enrichment of their hosts.

The next generation of medium-high resolution spectrographs at the existing 8-10m class telescopes (e.g. VLT-MOONS, VLT-CRIRES+) and for the future extremely large telescopes (e.g. E-ELT HIRES) will offer a unique opportunity to perform a comprehensive chemical tagging of these luminous stellar populations in the Milky Way and in several other galaxies of the Local Group and beyond.

These studies are of fundamental importance to trace the formation and evolution history of the host galaxies, but also to probe stellar nucleosynthesis and chemical enrichment in very different environmental conditions.

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