The metallicity scale of dwarf and giant stars

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Abstract. Differences between metallicity measurements of dwarfs and giants belonging to the same open clusters, as envisaged, would have tremendous implications, among other things, on the planet formation theory and on the stellar populations in the Milky Way. They also have a high importance on their own right, as they may indicate either that there are important processes presently not taken into account in modelling the atmosphere of evolved stars, or that the composition of the stars changes when they leave the main sequence. However, they have not yet been evaluated based on solid and conclusive data. We review literature data, employing different models and line lists, in order to investigate the extent, the origin, and the nature of the aforementioned differences.

1. Introduction
Based on abundance measurements from stars in open clusters at different evolutionary stages, several authors suggested that a difference between dwarfs and giants may arise in the analysis. Some of the authors [1] also state that the differences depend on the particular method used, pointing to systematic errors in the analysis rather than to true abundance differences responsible for this result. This, if confirmed, is not only relevant for its own sake, as it urges for the improvement of stellar atmosphere models, but also has tremendous implications for several fields of astrophysics, since various important studies rely on the comparison of metallicities between dwarf and giants, which, if our hypothesis is confirmed, may lead to spurious results.

2. Implications on the planet formation
Pasquini et al. [2] noticed that the metallicity distribution of planet host giant stars is comparable to that of the overall giant population, while it has long been recognized that planet host dwarfs tend to be much more metal rich than main sequence stars without detected planets. This result was later confirmed [3]. Two classes of scenarios have been invoked to explain the higher metal content of planet host dwarfs: the pollution scenario and the higher probability of metal rich discs forming planets. In the former, planet host dwarfs accrete discs whose composition had been previously modified by the planet formation process, thus accumulating metals only in their convective envelopes. When the stars evolve off the main sequence, the deepening of the convective layer washes out the metal enhancement by mixing enriched and unprocessed material, thus bringing the observed abundance closer to the original one. On the contrary, if planet host stars are intrinsically more metal rich, we expect no accumulation of metals in the external layers, and when the star evolves off the main sequence, the observed chemical abundance is expected to remain unaltered. That is why the result of Pasquini et
al. [2] is decisive in favoring the pollution scenario, provided that a direct comparison between abundance measurements in dwarfs and giants is possible and does not lead to spurious results.

3. Implications on the Galactic chemical evolution

Taylor and Croxall [4] noticed that the distribution of metallicity of giant stars in the solar neighborhood is narrower than that of the dwarfs in the same volume of space. Later surveys [3, 5] confirmed that the metallicity distribution of giants lacks the metal-rich tail, for $[\text{Fe/H}] > 0.2$ dex, on the contrary to that of dwarfs stars.

Again, we should ask ourselves whether we are facing an important piece of evidence shedding light on the chemical evolution of the Galaxy, or an artifact created by the comparison of different classes of objects.

As a matter of fact, the comparison of different classes of objects already lead to conclusions that had to be revised later on. Early studies claimed that the Galactic bulge is metal-poor. This would have important theoretical consequences, because a lack of metal-poor G-dwarfs in the solar neighborhood is a major discrepancy between observations and predictions of closed-box models, i.e. models that do not include the inflow or outflow of gas. Such a phenomenon, commonly referred to as the G-dwarf problem, would then be absent or less severe in the bulge. However, later on it has become widely accepted that the metallicity distributions of bulge stars and solar neighborhood stars are very similar, and this through studies employing rich samples of giants in both populations [6,7,8], or dwarfs. The study of bulge dwarfs with high-resolution spectroscopy is only possible by exploiting the micro-lensing effect [9].

Another important probe of the Galactic chemical evolution is the metallicity gradient of the Galactic disc, which is best measured through chemical analysis of open-cluster members. Most of the chemical analyses in open clusters are based on giants, especially the older ones, which are typically distant. The BOCCE project was undertaken to study the properties of a sample of mostly old Galactic open clusters [10]. It targeted red clump stars. It is of crucial importance to know how to use the results of this kind of survey, in order to understand whether the chemical composition that we measure in giants truly reflects that of the molecular cloud out of which the open cluster formed. Observations in open clusters are the only tool that allows us to directly investigate the differences between giants and dwarfs. The state of the art and the foreseeable developments about data in open clusters is the topic of the next Section.

4. State of the art of the observations in open clusters

The advent of the 8-meter class telescopes boosted chemical composition analyses of stars in open clusters through high-resolution spectroscopy. Several single studies and coordinated efforts have been dedicated to this effort. To the best of my knowledge, the most updated compilation is given in [11].

In Santos et al. [1] data about 6 clusters with observations of both evolved and unevolved stars were examined. Systematic differences in iron content were found between dwarf and giants, which depended on both the metallicity of the cluster and the list of spectral lines used to determine the chemical abundances. When the list of Sousa et al. [12] was used, the iron abundances in metal rich giants were overestimated with respect to dwarfs, while the opposite occurs for metal-poor giants. The results obtained by employing the line list of Hekker & Melendez [13], on the contrary, lead to an underestimation of the metallicity in giants with respect to dwarfs, of which the degree was proportional to the metallicity itself. Thus, it is important in this type of analysis to analyze the data in a strictly homogeneous way, because one of the effects to detect and correct for is the dependence of the results on the approach adopted.

Carrera & Pancino [11] have recently published results of chemical abundances from high-resolution spectroscopy of evolved stars in 4 open clusters: Berkeley 32, Praesepe, Hyades
and NGC 752. For Praesepe and Hyades, abundance measurements from dwarf stars are also available in the literature. These clusters are rich and close, therefore they are well studied down to their main sequence.

As far as the Hyades are concerned, all the studies except one [14], provide [Fe/H] between 0.11 and 0.14 dex, independent on whether they use giants [11] or dwarfs [15, 16, 17, 18]. Therefore, Hyades data do not point to any difference in the metallicity scale between dwarf and giants. However, a homogeneous analysis of stars of both types in this cluster is still not available.

Contrary to the Hyades, iron abundance measurements in Praesepe stars show a remarkably large range of values, from solar up to 0.27±0.1 dex in [19]. The latter value is based on 7 dwarfs studied with high-resolution and large signal-to-noise ratio spectra. Carrera & Pancino [11] measure for Praesepe [Fe/H]=0.16 ±0.05 based on 3 giants. The difference between dwarfs in Praesepe measured by Pace et al. and giants measured by Carrera & Pancino, are just what we expected on the basis of the trend in differences found by Santos et al. when using the line list of [12]. We note, however, that such a trend depends on the particular line list used for determining the abundance. As a matter of fact, An et al. [19] also analyzed a sample of main sequence stars in Praesepe using high-quality spectra, and their metallicity is slightly lower than that of Carrera & Pancino. Even lower metallicities are found by other authors who analyzed dwarfs in Praesepe with [Fe/H]=0.04±0.04 dex [21].

Clearly, the dependences of the results on the used method has to be properly understood before drawing conclusions about the differences between dwarfs and giants, and this has to be done by analyzing homogeneously available data, and by testing different models and line lists.

4.1. Abundances of aluminum and sodium
Overabundances of aluminum and sodium in open cluster giants, were found by several authors. In the following clusters overabundances of both elements were found: IC4756, NGC6939, and NGC7142 [22], NGC6475 [23], Collinder261 [24], Berkeley17 [25], Saurer1, and Berkeley29 [26]. In some other clusters, enhancements were found only in sodium: IC4651 [27], M67 [28], NGC7789 [29], NGC1817, NGC1883, NGC2141, and NGC2158 [30]. In some of the aforementioned references silicon enhancements were also measured. These overabundances are either directly attributed to the difference between giants and dwarfs, or to a large abundance ratio: [Na-Al/Fe]>0.1 dex. Heavier neutron-capture elements are believed to remain unchanged during the normal course of stellar evolution, therefore they have been used to check that the molecular clouds out of which open clusters were formed were homogeneous [31]. On the contrary, the overabundances of sodium and aluminum could be the result of deep mixing with layers that underwent the NeNa cycle of hydrogen burning, as suggested, for instance, by [29]. They therefore deserve close attention, but a thorough test must be performed in order to check whether some non-LTE effect stronger in giants than in dwarfs is affecting our analysis.

5. Conclusions
It is of fundamental importance to carry out chemical abundance measurements of both dwarfs and evolved stars for as many open clusters as possible. It would guarantee the accurate knowledge of the chemical gradient in the Galactic disc, and, at the same time, would finally answer the question whether the metallicity scales of giants and dwarfs are different. The Gaia-ESO survey will provide a wealth of precious data.

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