HABILITATION SUMMARY

1. Name: **Rodolfo Henrique Silva Smiljanic**
2. List of all scientific degrees (including name, place, date of obtaining, and title):
   (a) Doctor of Science in astronomy; University of São Paulo, São Paulo, Brazil; 08.12.2008; thesis title: "*Light elements: tracers of mixing and of the formation of the Galaxy*"; supervisor dr. Beatriz Barbuy.
   (b) Master of Science in astronomy; University of São Paulo, São Paulo, Brazil; 08.03.2005; thesis title: "*CNO in intermediate-mass stars*"; supervisor dr. Beatriz Barbuy.
3. Employment
   (a) Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences, since 2012:
   tenure-track, 2015–
   post-doc, 2012–2015
   (b) European Southern Observatory, Garching bei München, Germany:
   fellow, 2009–2012
   (c) University of São Paulo, São Paulo, Brazil:
   post-doc, January to September 2009
4. Habilitation achievement:
   (a) title

   Impact of accurate atmospheric parameters and chemical abundances on the understanding of stellar mixing processes

   (b) authors, title, year of publishing, journal name, volume and page of publications
   - **Praca P1: Smiljanic, R.**, *On the sodium overabundance of red giants in open clusters: The Hyades case* (2012), Monthly Notices of the Royal Astronomical Society, 442, 1562.
   - **Praca P2: Smiljanic, R.**, Korn, A., Bergemann, M., Frasca, A., Magrini, L., Masseron, T. i in., *Gaia-ESO Survey: the analysis of high-resolution UVES spectra of FGK-type stars* (2014), Astronomy & Astrophysics, 570, A122.
   - **Praca P3:** Dutra Ferreira, L., Pasquini, L., **Smiljanic, R.**, Porto de Mello, G. F., Steffen, M., *Consistent metallicity scale for cool dwarfs and giants: A benchmark test using the Hyades* (2016), Astronomy & Astrophysics, 585, A75.
   - **Praca P4: Smiljanic, R.**, Romano, D., Bragaglia, A., Donati, P., Magrini, L., Friel, E. i in. *The Gaia-ESO Survey: Sodium and aluminium abundances in giants and dwarfs. Implications for stellar and Galactic chemical evolution* (2016), Astronomy & Astrophysics, 589, A115.
   - **Praca P5: Smiljanic, R.**, Franciosini, E., Randich, S., Magrini, L., Bragaglia, A., Pasquini, L., Vallenari, A. i in., *The Gaia-ESO Survey: Inhibited extra mixing in two giants of the open cluster Trumpler 20?* (2016), Astronomy & Astrophysics, 591, A62.

   (c) presentation of research goals, results and resulting publications

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1 Introduction

In many stages of the evolution of low- and intermediate-mass stars, internal material processed by nuclear reactions can be mixed to the stellar surface. The first dredge-up, at the bottom of the red-giant branch (RGB), is a well known example of such events. This dredge-up results in the increase of the photospheric abundances of ^{13}C and ^{14}N and the decrease of Li and ^{12}C.

In the standard model of stellar evolution, convection is the only mechanism responsible for the mixing of the stellar material. However, it has been known for a long time that such standard models fail to explain many of the surface abundance changes observed in stars.

"Extra mixing" is needed to explain additional mixing events observed in different evolutionary stages and/or to explain changes in the efficiency of convective mixing. Observations requiring extra mixing to be explained include: the spread of surface Li abundances in cool main sequence stars, of the same mass, in open clusters (e.g., Bouvier et al. 2016) and the decrease in the ^{12}C/^{13}C ratio in giants after the luminosity bump (e.g., Smiljanic et al. 2009). This is a non-exhaustive list of physical processes causing extra-mixing events in stars:

- **Rotation-induced mixing:** Rotation affects both the transport of angular momentum and chemical elements inside a star. "Rotation-induced mixing" actually includes a series of different effects such as meridional circulation, large scale flow of material because of variations in gravity between pole and equator, and shear instabilities, which appear in the interface of regions having different rotational properties (see, e.g., Pinsonneault 1997).

- **Internal gravity waves:** These are waves that propagate and dissipate in radiative regions and are generated by the turbulent motions of the stellar convective zones (and should not to be confused with gravitational waves). They can be effective as an additional mechanism transporting angular momentum inside a star which in turn affects the transport of chemicals (e.g., Rogers & McElwaine 2017).

- **Thermohaline mixing:** Thermohaline mixing is an instability appearing in otherwise stable regions where the mean molecular weight decreases with depth. One such region is the top part of the H-burning layer of red giants, where the reaction ^{3}He (^{3}He,2p) ^{4}He transforms two ^{3}He atoms into two protons and one ^{4}He.

  One of the effects of thermohaline mixing would be to decrease the surface isotopic ratio of ^{12}C/^{13}C, potentially solving a more than 40-years old problem in the chemical composition of red giants. However, there is an active debate in the literature about the efficiency of thermohaline mixing (e.g., Garaud & Brummell 2015)

- **Magnetic buoyancy:** Magnetic fields could play a role in stellar mixing through the buoyancy of light magnetised bubbles or tubes. This could be important if there is a dynamo operating at the base of the convection zone in RGB and asymptotic-giant branch (AGB) stars. Magnetic buoyancy is an alternative to thermohaline mixing to explain the extra-mixing observed in giants (Palmerini et al. 2011).

All these physical mechanisms have been tested in stellar evolution models. However, their treatment is often approximate and with many free parameters. Limited attempts have been made to understand how these multiple processes affect each other (Maeder et al. 2013). Usually they are treated independently, but complex interactions might suppress or enhance some effects.

Moreover, recently, studies of the internal rotation of red giants have become possible with asteroseismic observations. These new observations suggest the need for including an additional efficient, but yet unknown, mechanism to transport angular momentum in stellar radiative zones of evolved star (e.g., Eggenberger et al. 2017).

Observational results, therefore, still play a key role in providing constraints regarding the efficiency of all these mixing processes.

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1.1 Accurate chemical abundances

Precision is related to the random errors of the analysis, to the stability of multiple measurements of the same quantity. Accuracy is related to systematic errors of the analysis, to how close to the true value a measurement really is.

High precision in the determination of stellar abundances is obtained in the careful differential analysis of high-quality data of very similar stars. In the comparison between similar stars, the systematic errors cancel out.

Accuracy is much harder to obtain. The usual methods of spectroscopic analysis introduce different systematic errors in different regions of the parameter space (e.g., warm dwarfs against cool giants). Moreover, approximations valid in a certain regime might break down in another.

However, when studying stellar evolution, the goal is exactly to compare abundances among very different stars. We want to trace variations of the chemical abundances with respect to stellar mass and metallicity in stars covering a range of evolutionary stages (pre-main sequence, main sequence, RGB and AGB). It is also needed to study different chemical elements, as they can trace mixing processes taking places at different depths of the star. This adds the complication that systematic errors can vary among the elements.

The first step needed to achieve accurate abundances is the careful and accurate determination of atmospheric parameters. Ways to ensure the accuracy of the atmospheric parameters include: giving preference to those estimates that are fundamental, i.e., based on measurements and not on modelling (e.g., angular diameters for the effective temperature, $T_{\rm eff}$, and distances for the logarithm of the surface gravity, log g); checking the position of stars members of clusters against the expected evolutionary path in the HR diagram; and using the fact that all stars in a cluster have the same initial chemical composition.

The second is the careful control of sources of systematic errors. These can be controlled by the use of high-quality atomic data of the spectral lines, the detailed understanding of the blending properties of the lines (i.e., if other atomic or molecular lines can affect the observed line of your element of interest), and the use of modern computations of non-local thermodynamic equilibrium (non-LTE) and three-dimensional granulation effects (3D-effects).

2 Habilitation achievement

Although stellar evolution theory is successful in the general description of the life of stars, there are physical processes that remain poorly understood. A correct and detailed description of stellar evolution is fundamental for the comprehension of stellar systems, be them clusters or galaxies, and of the processes involved in the formation of planetary systems. Thus, improved understanding of stellar evolution has a broad impact on both Galactic and extragalactic science.

The importance of the topic is what drives my continued interest in the field of observational aspects of stellar evolution. The five publications chosen for the habilitation achievement highlight my contribution to the field. They stress my efforts in obtaining accurate stellar parameters and abundances, and their impact in providing robust constraints for models of the internal physics of low- and intermediate-mass stars.

2.1 P1. Sodium abundances in the giants of the Hyades

Publication P1 (Smiljanic 2012) can be understood as a proof of concept. In this publication, I solved a long standing problem with the Na abundances in the red giants of the Hyades open cluster. Many authors before me had obtained Na abundances that were too high and difficult to understand. This culminated with the statement of Schuler et al. (2009) that their Na abundances were "too large to be explained by any known self-enrichment scenario", i.e., that perhaps a new and so far unknown internal mixing process was acting in these stars.

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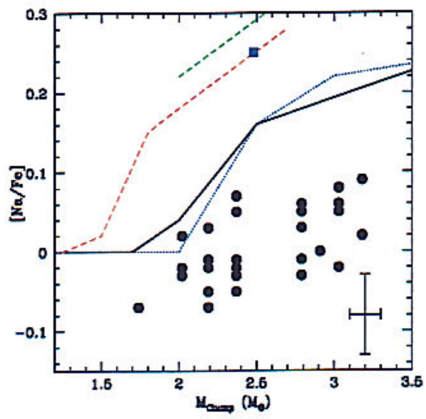

Figure 1: Sodium abundances, [Na/Fe], as a function of the stellar mass. The circles are giants from Smiljanic et al. (2009) and the blue square is the mean abundance of the Hyades. The lines are the models from Charbonnel & Lagarde (2010) for the standard case (solid line), for a model with thermohaline mixing only (blue dotted line) and for models with rotation-induced mixing (red and green dashed lines).

Very high Na abundances require deeper mixing than is possible in the models. The deep mixing would additionally change the surface abundance of oxygen, which was not observed. Understanding the changes in the surface abundance of Na impacts in the understanding of the maximum depth reached by the convective zone during the first dredge-up, as production of Na requires very high temperatures only found in the deep stellar interior.

From the moment I became aware of the results from Schuler et al. (2009), I started suspecting of accuracy problems. Issues with the zero point of their results could be precluding a robust comparison with the models.

Further motivation for an independent reanalysis of the abundances came from the possibility of using fundamental values of T_{eff} and log g obtained independently from spectroscopy. This was possible thanks to interferometric measurements of the angular diameter of the giants (Boyajian et al. 2009), which help to constraint T_{eff}, and the use of Hipparcos parallaxes to help constraining log g (de Bruijne et al. 2001). The detailed procedure is given in P1 and is not repeated here.

The accuracy of these T_{eff} and log g values, mostly based on direct measurements, are much better that those estimated from the complex modelling of stellar atmospheres and spectroscopic data. While relying on well constrained parameters is important for the abundance determination, the abundances themselves can not be directly measured, they can only be inferred from the modelling of the spectra.

For that, I carefully selected the needed atomic data and thoroughly inspected the available Na spectral lines to exclude from the analysis further sources of uncertainties. I estimated the Na abundance from the best Na lines and using spectrum synthesis. With this technique, it is possible to model and take into account any eventual contribution of surrounding spectral features. The resulting Na abundance is shown in Fig. 1 in comparison with stellar evolution models. The agreement with models including rotation-induced mixing is excellent.

As I stated in the conclusions of P1, in spite of previous claims to the contrary, the careful and accurate analysis that was performed showed that the Na overabundances in the giants of the Hyades can be well explained by the effects of known evolutionary mixing processes. This success stimulated my continued work towards obtaining accurate atmospheric parameters and abundances for new samples of stars. It became clear for me that this was the only way to obtain meaningful and robust abundances for the comparison with stellar evolution models.

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2.2 P3. Consistency between dwarfs and giants

Although chronologically publication P3 (Dutra-Ferreira et al. 2016) appeared after P2 (Smiljanic et al. 2014), the project itself started earlier, as a natural continuation of P1. Therefore, I discuss publication P3 first.

Once an accurate analysis of the giants in the Hyades became possible, the next step was to devise a procedure that could guarantee consistent results for both dwarfs and giants. In other words, a method of analysis that minimises systematic effects among different types of stars.

The Hyades were again an excellent test case for that. All the stars in the cluster were formed with the same initial chemical composition, so that the abundance of elements not affected by stellar evolution (like iron) should be the same in dwarfs and giants. It is important to stress that the Hyades is young ($\sim$ 650 Myr) and thus effects related to atomic diffusion are not important, as they had no time to develop (see, e.g., Önehag et al. 2014).

It is well known that problems can appear when comparing abundances of dwarfs and giants. For example, Alves-Brito et al. (2010) showed that previous claims of chemical differences between bulge and thick disk stars were the result of systematic errors in the comparison between abundances of dwarfs and giants.

Further motivation for this project came from the work of a collaborator, dr Luca Pasquini from ESO, on the topic of planet-host stars. Main-sequence FGK-type stars that host giant planets tend to be more metal rich then those stars without giant planets (Gonzalez 1997; Fischer & Valenti 2005). This observation supports the core accretion scenario of planet formation, where the metallicity of the material is important to enable the formation of planets (Pollack et al. 1996). However, Pasquini et al. (2007) showed that giant stars with planets do not tend to have higher metallicities, casting doubts about the trend seen in dwarfs.

This project was lead by a PhD student that worked under the co-supervision of myself and dr Luca Pasquini. My role was to instruct her on the use of the analysis codes, the development of the methodology, and to guide her on the interpretation of the results.

We tested two methods to determine the atmospheric parameters. The first method was independent from spectroscopy. For the giants, it used the same approach as in P1. For the dwarfs, the $T_{\rm eff}$ was determined with photometry and the InfraRed Flux Method (IRFM) and log g using the same method as for the giants.

One of the main novelties of the paper was the introduction of microturbulence (ξ) calibration based on 3D model atmospheres. Microturbulence is a parameter introduced because classical 1D model atmospheres do not describe properly the velocity fields of stellar photospheres. We used 3D hydrodynamic models from the CIFIST grid (Ludwig et al. 2009) computed with the CO^{5}BOLD code (Freytag et al. 2012). The calibration was obtained by matching the equivalent width of the 3D-generated lines with the profile derived from the 1D models.

The second method of analysis was the usual spectroscopic one, where all parameters are determined using lines of neutral and ionised iron. But in this case, we tested two different line lists. One line list was chosen with the aim of minimising non-LTE effects in the iron abundances (based on Mashonkina et al. 2011). The other line list was carefully chosen to be well suited for the analysis of giants, i.e., with transitions free of blends and with accurate atomic data.

The results of our analysis showed that with a careful determination of atmospheric parameters and using a well-selected line list, it was possible to analyse both giants and dwarfs and obtain consistent metallicities with a value of [Fe/H] = +0.18. This result is very important as it shows how to guarantee accuracy across different types of stars.

As discussed in P3, the results using the first method (constraints independent of spectroscopy) seemed more robust. Nevertheless, using the second method, the line list chosen to be optimal for giants provided results in excellent agreement with the first method. Therefore, we also recommended that a simultaneous spectroscopic analysis of giants an dwarfs needs to use a line list that has been optimised for giants.

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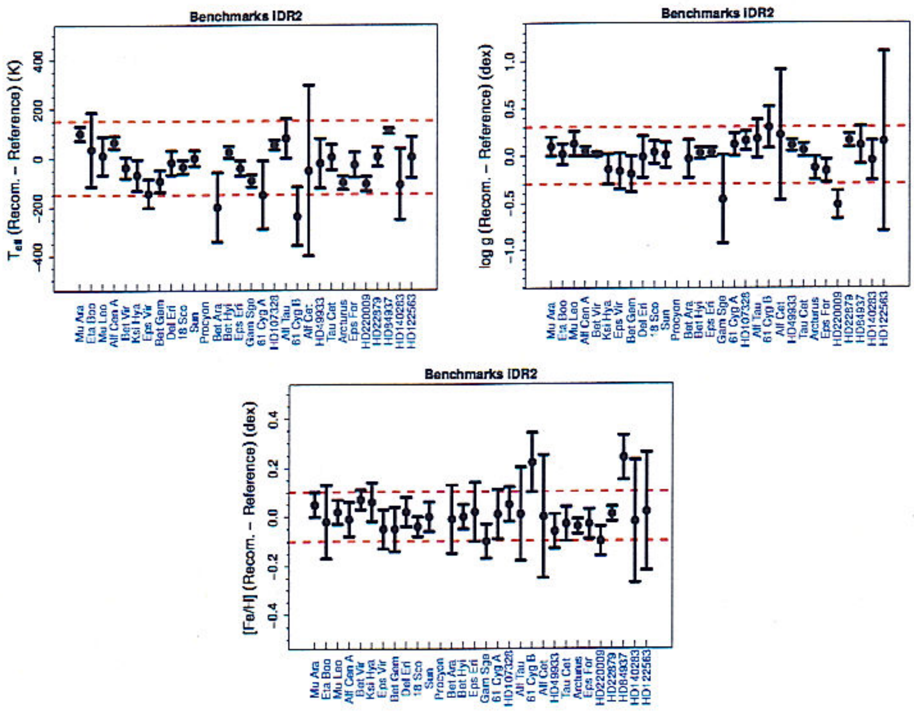

Figure 2: Difference between the *Gaia*-ESO recommended values of $T_{\rm eff}$, log g, and [Fe/H] and the reference values of the *Gaia* benchmark stars. The stars are sorted in order of decreasing [Fe/H] (left to right). The dashed red lines indicate ±150 K in $T_{\rm eff}$, ±0.30 dex in log g, and ±0.10 dex in [Fe/H].

2.3 P2. Accuracy in the *Gaia*-ESO Survey

The *Gaia*-ESO Survey brings the need for accuracy to whole different level. Stars of very different types are observed in the survey, from metal-poor to metal-rich stars, from pre-main sequence to giant stars, and all spectral types between M and O. It is our ambition that the results for all these type of stars are put in the same scale and can thus be directly compared.

Since the beginning of the survey, I am co-coordinator of Working Group 11 (WG 11), dealing with the analysis of high-resolution UVES spectra of FGK-type stars. The coordination is shared with dr Andreas Korn, from the Uppsala University, Sweden. Early on, we adopted a series of common "tools" to be used across the whole survey, to minimise sources of systematic errors. These "tools" include a common line list with recommendations regarding the quality of the atomic data, a common set of model atmospheres for the spectroscopic analysis, a common library of synthetic spectrum, and a microturbulence calibration.

Moreover, we use a series of references objects to compare the results obtained in the survey. These reference objects include stars in open an globular clusters, stars with asteroseismic constraints in log g, and the so-called *Gaia* benchmark stars (see Pancino et al. 2017, for a complete description of the calibration strategy). The benchmark stars are well-known bright stars with parameters ($T_{\rm eff}$ and log g) that are independent of spectroscopy (Heiter et al. 2015) and with carefully determined reference metallicities (Jofré et al. 2014). These stars are the main reference defining the accuracy of the *Gaia*-ESO atmospheric parameter scale. This is a considerable improvement with respect to using the Sun as the only reference as the *Gaia* benchmark stars are distributed across the parameter space.

My main responsibility was what we call "homogenisation". To compare results of the analysis of FGK-type stars coming from different analysis pipelines and build the final recommended set of results that is tied to the fundamental scale defined by the *Gaia* benchmark stars.

To achieve homogeneity here means to ensure that the final results reproduce well the "real" parameters of the reference stars. I designed and implemented the method used to judge the performance of each pipeline, by defining weights according to how well each analysis can reproduce the reference parameters of the benchmark stars. In the particular case of this publication, different weights are assigned in three different regions of the parameter space: 1) metal-rich dwarfs (stars with [Fe/H] > -1.00 and log $g > 3.5$); 2) metal-rich giants (stars with [Fe/H] > -1.00 and log $g \leq 3.5$); and 3) metal-poor stars (stars with [Fe/H] ≤ -1.00).

Weighted-medians are then computed for each atmospheric parameter of each star and adopted as the recommended best value of the atmospheric parameters. Medians are used as they are robust against outliers, minimising the influence of low-quality results. The weights help to select the best values in each region of the parameter space and to force the scale to reproduce the real parameters of the benchmark stars (Fig. 2). This figure showcases that with the procedure that I implemented, good accuracy in the atmospheric parameters was obtained in a large part of the parameter space. The results become uncertain only for cool stars ($T_{\rm eff} <$ 4200 K), as seen for HD220009, Bet Ara, 61 Cyg B, Alf Cet, and Gam Sge in the figure.

For the abundances, weighted medians were also computed. In this case, the abundances were combined on a line-by-line basis (i.e., combining separately the abundance of a given line obtained by each pipeline). The same weights defined for the atmospheric parameters were used.

The Sun is the only fundamental reference for abundances. In the Survey, solar spectra are analysed and processed in the same way as all other stellar spectra. We also include in the sample some famous solar twins or solar analogues, i.e., stars that have very similar atmospheric parameters and abundances as the Sun: α Centauri A (Porto de Mello et al. 2008), star 18 Scorpii (Porto de Mello & da Silva 1997) and star 1194 of the M 67 open cluster (Önehag et al. 2011). For the Sun and the solar twins, the abundances obtained using the method described above agree with the expected ones usually within $\pm$ 0.10.

2.4 P4. Sodium and aluminium abundances and stellar mass

The *Gaia*-ESO Survey provided the opportunity to determine accurate Na abundances in red giants belonging to open clusters with a range of ages, and thus, for stars with different masses. In P1, it was demonstrated that the Na abundances of the Hyades (at $\sim$ 2.5 M$_\odot$) agreed with the model expectations. It remained to be shown if the trend of increasing Na with increasing stellar mass predicted by the models was observed.

In addition, we could study the abundances of aluminium. Low-mass stars are not expected to have high enough temperatures in their interiors to activate the MgAl cycle and produce Al. However, the observational picture of Na and Al abundances in giants was very confusing.

Approximately 65% of giants in open clusters (stars with about solar metallicity and a wide range of masses) were reported to have enhanced Na and/or Al abundances (e.g., Jacobson et al. 2007; Pancino et al. 2010). However, no clear trend with stellar mass had emerged, different authors would disagree about the abundances in the same cluster, and some of the reported overabundances were very high, as was the case for the Hyades before P1. Clearly, a systematic and careful investigation of the issue was in order.

Abundances of Na and Al provide two important tests for evolutionary models. The first, whether the dependence of the depth reached by the convective zone with stellar mass during the first dredge-up was correct. The second, whether the models were correctly predicting the core temperatures of low-mass stars.

Our results for six open clusters with ages from 300 Myr to 4.5 Gyr (masses between 1.1 and 3.2 M$_\odot$) are shown in Fig. 3. In the case of Na, the abundances were corrected for non-LTE effects and 3D effects were found to be negligible. With the exception of NGC 2243 ([Na/Fe] $= +0.10$ and mass of $\sim$ 1.2 M$_\odot$), the agreement between observations and models is excellent.

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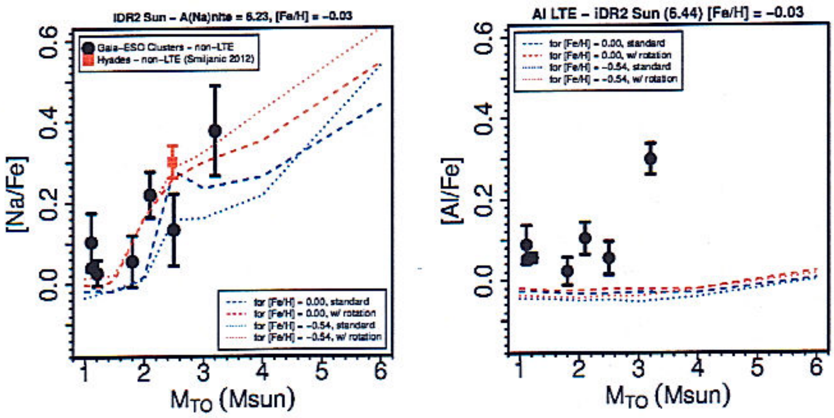

Figure 3: Mean cluster abundance of Na (left) and Al (right), from giants only, after the selection of members and best-quality values, as a function of the estimated stellar mass (from Smiljanic et al. 2016b).

NGC 2243 is the most metal-poor cluster of the sample, [Fe/H] = -0.44, and thus some Na enrichment caused by the Galactic chemical evolution can not be excluded.

In the case of Al, Fig. 3 shows abundances in LTE, with most clusters having [Al/Fe] $\sim$ +0.06. Detailed non-LTE corrections for Al are not available, but preliminary calculations seem to indicate a correction of the order of ~ -0.05 (T. Nordlander, private communication). This would bring the abundances into agreement, expect for NGC 6705 with 3.2 $M_\odot$ and [Al/Fe] = +0.30. NGC 6705, however, likely suffered a peculiar enrichment that might have cause overabundances of Al and of α-elements like Mg (Magrini et al. 2014, 2015). We, therefore, concluded that the surface Al abundances are not affected by evolutionary mixing processes.

In addition, we performed a critical review of literature results, correcting the published Na abundances to agree with the *Gaia*-ESO ones. This was possible for giants in open clusters and for giants with asteroseismic determinations of mass. In both cases, the same correlation between Na abundances and stellar mass emerged. This gave extra support to our conclusions. Evolutionary mixing processes are the origin of the observed Na enhancements in giants with M > 2 $M_\odot$ as predicted by models that take into account rotation-induced mixing.

I am particularly proud of these results, as they extend the work started with P1 and further confirm my thoughts at the time, that accurate abundances were missing and very necessary for robust comparisons with stellar models.

2.5 P5. Inhibition of extra-mixing processes

In publication P5 (Smiljanic et al. 2016a), I turned my attention to Trumpler 20 (of about 1.7 Gyr), an interesting open cluster where I thought accurate results of atmospheric parameters and abundances were needed. A noticeable feature in the colour-magnitude diagram (CMD) of Trumpler 20 is its extended red clump region (Fig. 4), larger than predicted by stellar evolution models (see Donati et al. 2014, and references therein). This could be caused by the presence of two distinct red clumps. The fainter clump made of stars massive enough to start core He-burning in non-degenerate conditions and the brighter clump made of lower-mass stars that have been through the He-core flash (as discussed in Girardi 1999). The alternative view was that those stars were still at the first ascension of the red giant branch, before the clump stage.

My first motivation to look at Trumpler 20 was to investigate if the abundances of elements affected by evolutionary mixing (Li, C, N, and O) could help in clarifying the evolutionary stage of the supposed red clump stars. Stars at the clump have all completed the first dredge-up and thus have distinct abundances when compared to first ascent giants. Looking at the abundances

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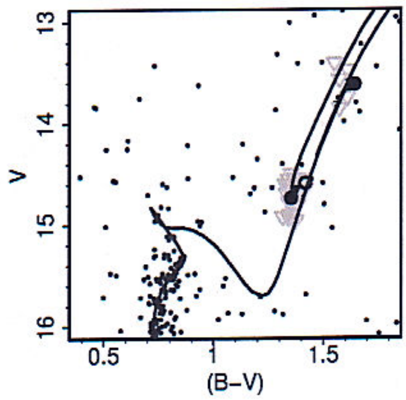

Figure 4: Color magnitude diagram of Trumpler 20. The two Li-rich giants (see text) are shown as filled circles, other giants with Li detections as open circles, giants with Li upper limits as gray triangles, and the remaining stars in the field as dots.

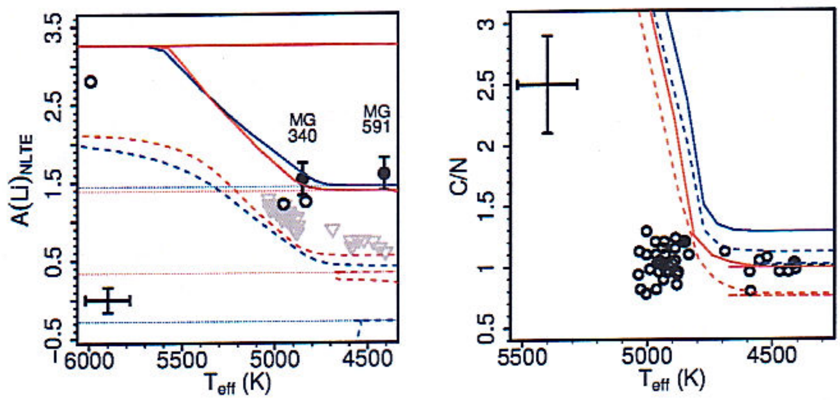

Figure 5: *Left:* Li abundance as a function of $T_{\rm eff}$. *Right:* C/N ratio as a function of $T_{\rm eff}$. Solid lines are the predictions of standard models and dashed lines of models with rotation-induced mixing and thermohaline mixing (Lagarde et al. 2012). Lines in blue and red are for solar metallicity stars of 1.5 $M_\odot$ and 2.0 $M_\odot$, respectively. The two Li-rich giants are shown as full circles.

is when I discovered the presence of two Li-rich giants in the cluster (left panel of Fig. 5).

After the first dredge-up, the surface Li abundance of giants should decrease as material from the interior, where Li was destroyed, is brought to the upper layers. In solar metallicity giants, the Li abundance should decrease from A(Li) $\sim$ 3.2 dex to under 1.5 dex.

Lithium-rich giants are defined as those that, after the first dredge-up, have A(Li) $\geq$ 1.50 dex. About 1–2% of known red giants are found to be Li-rich (e.g., Casey et al. 2016). The process that creates Li-rich giants is still not understood. Their evolutionary stage is also not well established. Some works find these stars to be preferentially located at the red clump and at the luminosity bump (Charbonnel & Balachandran 2000; Kumar et al. 2011). Others find these stars throughout the whole RGB (Monaco et al. 2011; Martell & Shetrone 2013).

The observed C and N abundances of the giants are compared to models in the right panel of Fig. 5. According to the models, first ascent giants with $T_{\rm eff} \sim 5000$ K have the C/N > 3, as they have not completed the first-dredge up. All our stars have C/N $\sim$ 1 instead, i.e., they are all after the first dredge-up. The conclusion is that all the giants with $T_{\rm eff} \sim 5000$ K are at the red clump, answering the question that motivated me to look at Trumpler 20 in the first place.

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We then moved on to investigate the Li-rich giants. From the CMD in Fig. 4, the two Li-rich giants are in different evolutionary stages, one at the bump the other at the red clump. Because of the large surface convective layers in giants, the Li enrichment is likely short lived. Thus, Li-rich giants created at the bump should not remain Li-rich during the evolution to the clump. Most likely, the Li enrichment happened at the current evolutionary stages of the stars.

To explain the giants with self Li enrichment would require a process acting in two different evolutionary stages. Moreover, their similar Li abundances is a puzzling coincidence. Lithium-rich giants with Li abundances above the current level of the interstellar medium (A(Li) $\sim$ 3.0) indeed require local Li production to be explained. The Trumpler 20 stars, however, have A(Li) $\sim$ 1.5. They would now be either in the middle of their Li enrichment or in the middle of the subsequent Li depletion. But it seems an odd coincidence to observe both stars with exactly the same Li enrichment, despite the different evolutionary stages.

We thus advanced a new scenario that could explain at the same time both stars, with their different evolutionary stages, and their Li abundances. The hypothesis is that their higher Li abundance, when compared to other cluster stars, is the result of the inhibition of extra-mixing processes. Standard evolutionary models, that do not include extra-mixing predict surface abundances of A(Li) $\sim$ 1.5. All other giants in the cluster have Li abundances below that, implying that extra mixing has been activated. But in stars where extra mixing failed to be activated, the surface Li abundance would remain at the level predicted by standard models.

The possibility of extra-mixing inhibition had been proposed before (e.g., Charbonnel & Zahn 2007). The idea is that extra mixing could be avoided by giants that are descendant from magnetic Ap-type main-sequence stars. The interaction between internal mixing processes and fossil magnetic fields would be behind the inhibition. Interestingly, the mass range of magnetic Ap stars (1.5 to 3.6 $M_\odot$) is consistent with the mass of the giants in Trumpler 20 ($\sim$ 1.8 $M_\odot$). Moreover, between 1.7 to 3.5% of A-type stars are found to be of the magnetic Ap-type (Power et al. 2007). This is also consistent with finding two such stars in a sample of 40 that were observed in Trumpler 20 (a fraction of 5%).

3 Summary

In the series of papers presented in this habilitation achievement, I have worked to establish methods to determine accurate sets of atmospheric parameters and abundances in low and intermediate-mass stars (P1, P2 and P3). I then used these accurate abundances to investigate internal mixing processes in these stars (P1, P4 and P5). In particular, publication P2 made in the context of the *Gaia*-ESO Survey has now become my most cited paper, having attracted so far more than 80 citations. Besides being a fundamental paper for those using the *Gaia*-ESO results, P2 is now an important reference when the accuracy of spectroscopic results is discussed in the context of other large surveys and spectroscopic analyses.

In many previous cases, systematic uncertainties in chemical abundances were precluding robust conclusions about details of the internal evolution of stars. Publications P1 and P4 are the the first to clearly demonstrate that Na and Al abundances in red giants agree very well with the predictions of models including rotation-induced mixing. Before P1 and P4, the observational picture was very confusing and no firm conclusion was possible.

Publication P5 described the discovery of two Li-rich giants in the open cluster Trumpler 20. In P5, we also used C and N abundances to confirm the evolutionary stage of stars thought to be red clump giants. Motivated by our accurate abundances, we proposed a scenario where magnetic activity inhibits extra mixing to explain the Li-rich giants in this cluster.

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4 Short description of other projects and activities

In addition to the papers highlighted above, I have contributed in a smaller fraction to other *Gaia*-ESO publications that discussed internal evolutionary processes in giants (Tautvaišienė et al. 2015; Overbeek et al. 2017; Tang et al. 2017) and in dwarfs (Jackson et al. 2016). I have also participated in publications on this topic independently from the survey (Smiljanic et al. 2011; Pasquini et al. 2014; Drazdauskas et al. 2016).

Moreover, since May 2015, I am the principal investigator of a three-years NCN/OPUS grant in the field of Galactic archaeology. The project is entitled "A detailed view of the distinct halo stellar components with large spectroscopic surveys". The goal is to compile a large sample of halo stars by combining results from different large spectroscopic surveys. This sample will be used to study the distribution of chemical abundances, kinematic parameters, and orbits in these objects, to understand their origins and build a comprehensive picture of how the Galactic halo was assembled. This grant project marks the widening of my research goals towards different aspects of stellar properties. Preliminary results of this project have already been presented in conferences (Smiljanic & Gaia-ESO Survey Consortium 2017; Smiljanic & de Souza 2017).

In addition, I recently lead a successful application for funding to ESO to be able to organise a scientific conference in Poland. The conference "A Revolution in Stellar Physics with *Gaia* and Large Surveys" will take place between 3 and 7 of September 2018, in Warsaw. I am the chair of both Scientific Organising Committee (SOC) and Local Organising Committee (LOC). We plan to receive up to 150 in this conference.

I am member of the scientific consortium of two instrumentation projects. The first is CUBES, the Cassegrain U-band Brazilian ESO Spectrograph. This is a new near-UV medium-resolution (R $\sim$ 20 000) spectrograph proposed for the VLT. I have contributed to the elaboration of the Science Case Document. The second is Arago, a new concept for a medium-size space telescope equipped with a high-resolution spectropolarimeter working in the UV and visible wavelengths. It was proposed to ESA for a future M mission.

In 2015, I was awarded the prestigious three-years stipend for outstanding young scientists by the Ministry of Science and Higher Education. I often act as referee for A&A and MNRAS, and have also refereed for ApJ and PASJ in the past. I am an external referee of observational proposals for OPTICON (Optical Infrared Co-ordination Network for astronomy) since 2013. I have recently been invited by ESO to serve in the OPC (Observing Programmes Committee) as a panel member for proposals submitted in category D, Stellar Evolution, starting in May 2018.

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Warsaw, October 20, 2017

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