MW-Gaia STSM

CNO abundances of open clusters studied with Gaia and high resolution spectroscopy

Juan Carbajo Hijarrubia, PhD student at the Universitat de Barcelona enjoyed a two weeks stay (12-25/01/2020) at the Vilnius University thanks to a GP1 STSM grant to collaborate with Prof. Grazina Tautvaisiene.

Juan Carbajo thesis "Chemical evolution of the Galactic disk from star clusters" developed in the framework of the Open Clusters Chemical Abundances from Spanish Observatories survey (OCCASO). The aim of the Ph.D. thesis is to study the dynamics and abundances of Open Clusters (OCs) in order to investigate the formation and evolution of the Galactic disc.

This research project is carried out in the Gaia team at Barcelona University. The team is involved in the Gaia space mission of the European Space Agency since 1998. Gaia is a unique instrument that takes a giant step in the precision of measurements and in the understanding of the formation and evolutionary history of our Galaxy, as demonstrated by the data published up to now. Most of the stars are born in OCs and, therefore, their study is a fundamental piece to understand the evolution of the Galaxy.

Although Gaia provides very precise distances and movements of the stars, its capabilities to determine radial velocities and precise chemical compositions are limited. The Barcelona Gaia team participates in spectroscopic projects to obtain complementary information from the ground such as Gaia-ESO Survey, OCCASO, and the future WEAVE and 4MOST.

The OCCASO project (Casamiquela et al. 2016) is framed in this context, and its main objective is to derive detailed chemical abundances for OCs in the Northern hemisphere. Large ground-based spectroscopic surveys are mainly sampling the Southern hemisphere OCs (Gaia-ESO survey, GALAH), or do not have a specific program for homogeneously sample OCs (APOGEE). OCCASO aims to complement these surveys. For each of the studied clusters at least 6 Red Clump stars have been observed with a signal-to-noise ratio (SNR) ~70. The spectrographs used in the survey are CAFE@CAHA, FIES@NOT and HERMES@Mercator, all of them with resolutions R > 65,000. This resolution combined with the high signal-to-noise ratio of the observations allows the determination of detailed abundances. The team had already performed an abundance analysis of 10 species (Fe, Ni, Cr, V, Sc, Si, Ca, Ti, Mg, O) for red giant stars in 18 OCCASO clusters. (Casamiquela et al. 2019) and had completed data for 37 OCs thanks to the discoveries based on Gaia DR2 (new members of known OCs and new OCs detected). This conforms a homogeneous sample regarding the instrument features, method, line list and solar abundances from confirmed member stars.

One of the goals of the PhD thesis is to determine the CNO abundances in the OCCASO sample. Since the group led by Gražina Tautvaisiene at the Vilnius University holds the needed expertise for the determination of such elements, this visit has played a crucial role in the development of the PhD. The STSM allowed establishing a collaboration between the two groups (Barcelona & Vilnius) on this and other projects related to the characterization of OCs in the Gaia era.

The stay has allowed Juan Carbajo to learn more about the physics of the atmospheres of red giants, mainly those effects concerning CNO lines like the molecular equilibrium, and also about how these physical processes affect the stellar spectra in the case of the molecular bands used for CNO abundance determination.

The OCCASO spectra has been reviewed to confirm that their characteristics are adequate to perform the analysis, in terms of covered spectral range, signal to noise ratio (SNR), and spectrum normalization. OCCASO spectra cover well the regions usually measured by the Vilnius team. The spectrum SNR is sufficient to perform these studies. Regarding normalization, it is necessary to perform a local renormalization in the C_2 region Swan band at 5135 Å.

One of the most important parts of the stay has been acquiring knowledge about the methodology used by the Vilnius team to determine abundances of CNO elements. They have used the differential synthetic spectrum method for that. The abundance of carbon has been derived using the C_2 Swan band heads (0,1) at 5135 and 5635.5 Å. The nitrogen abundances and carbon isotope ratios have been determined studying wavelength range 7940-8130 Å. Oxygen abundances have been determined from line [O I] to 6300 Å (Tautvaišienė et al. 2015). They have also used the region around of 8004 Å to determine the carbon 12C/13C ratio. The relative abundance between these two carbon isotopes depends on the evolutionary state of the star. The different dragged-off processes that occur in stars causing element mixing of their different shells are not fully understood yet. Therefore, the analysis of carbon isotopes in the high-quality OCCASO survey sample can provide new information about these processes.

From the point of view of the determination of chemical gradients in the Milky Way, it is especially interested to know the evolutionary state of the stars under study. It is necessary to be able to separate variations in abundance due to the evolutionary state, from those due to the position occupied by the cluster in the Galaxy and the age at which it formed. The CNO elemental determination and carbon isotope ratio provide complementary information to the Gaia photometry in the evolutionary state determination.

We have started the development of a new code designed to fit interactively the OCCASO spectra with synthetic spectra. The program is a new implementation of the methodology developed by Vilnius team in a new environment. The program uses iSpec, a Python tool for the treatment and analysis of stellar spectra. The goal of the program is to apply the iSpec multiple capabilities to the analysis of CNO elements. The radiative transfer code used to generate the synthetic spectra is Turbospectrum and the line list used is VALT.

Main achievements

During the stay, one of the main results have been the development of the first version of the python code described in previous section. This new implementation of CNO analysis take all the advantages of iSpec tools. It is a program capable of doing the most essential tasks, such as spectrum normalization, as well as the more advanced tools dedicated to spectral synthesis. The development started during the stay aims to become an automatic pipeline dedicated to the CNO analysis that can be a useful tool for both teams.

This first analysis has allowed the collaboration to evaluate the possibilities that OCCASO data has for CNO analysis regarding the data quality. How to perform the analysis so that work can be continued in both universities has been established.

This short visit has allowed the start of the collaboration and to take the first steps towards our final goal, which is the determination of CNO abundances and carbon isotope ratio for the complete OCCASO sample: 245 stars have been observed in the OCCASO survey belonging to 37 open clusters.

This visit has also allowed each team to know better the other's scientific goals and to be able to prepare new projects based on our common interests. One of the future collaborations, that we have started to prepare, is to observe some open clusters of common interest using the telescope and instrumentation available in Moletai observatory (Lithuania).

As a result of the STSM with the Institute of Theoretical Physics and Astronomy in Lithuania, a collaboration on the study of the Galactic radial gradients and age variation of 21 chemical elements measured in open clusters is underway. This work is under referee review. In addition, the publication of the chemical abundances of CNO elements in these same objects is in preparation.