PhD name: Alice Minelli
PhD Cycle: XXXIV
Tutor: Prof. Alessio Mucciarelli - DIFA

RESEARCH PROJECT:
The chemical composition of the Milky Way satellites: Magellanic Clouds and Sagittarius dwarf galaxy

Astrophysical context

This PhD project aims to investigate the chemical composition of the stellar populations in the closest satellites of the Milky Way (MW), namely the Large and Small Magellanic Cloud (LMC and SMC, respectively) and the remnant of the Sagittarius (Sgr) dwarf spheroidal galaxy.

The galaxies populating the Local Group are an excellent laboratory for near-field cosmology because they provide us the possibility to investigate a large variety of stellar systems in terms of morphology, mass, metallicity and star-formation histories.

LMC, SMC and Sgr are the closest MW satellites and their proximity allows us to resolve their individual stars both with spectroscopy and photometry, studying in details the characteristics of their stellar populations. Also, they are examples of interacting galaxies: LMC and SMC are in an early stage of a minor merger event, and Sgr is a Galactic satellite that is being disrupted by the tidal field of the Milky Way.

Despite their importance and proximity, the chemical composition of these galaxies is still poorly known and a complete picture of their chemical enrichment history is still lacking.

Comparison between the abundances of LMC/Sgr and MW stars

This work concerns the homogeneous comparison between the chemical composition of LMC, Sgr, and the MW. I analysed high-resolution (R~45,000) spectra acquired with UVES@VLT of 30 LMC, 14 Sgr and 14 MW red giant stars in order to highlight similarities and differences in the chemistry of these galaxies. In particular, I derived in a homogeneous way the chemical abundances of 22 species belonging to the main groups of elements.

The main results are: (1) LMC and Sgr stars show very similar abundance ratios for almost all the measured elements, pointing out that the two galaxies have experienced similar chemical enrichment histories, and supporting the hypothesis that the progenitor of Sgr was a galaxy with a mass and star formation rate similar to those of the LMC; (2) the only differences between LMC and Sgr are related to the neutron capture elements Ba and La, where the Sgr stars are more enriched in both the abundance ratios with respect to the LMC, suggesting a significant contribution from metal-poor, low-mass AGB stars; (3) the comparison between LMC/Sgr and MW samples reveals that the former galaxies have different chemical abundances with respect to the MW stars for almost all the species. In particular, the lower [alpha/Fe] and iron-peak abundance ratios measured in LMC and Sgr suggest a lower SFR and a smaller contribution by massive stars in comparison to the MW; (4) the most evident differences between LMC/Sgr and MW have been found for V and Zn, with abundance ratios lower than those of the MW stars by 0.5-0.7 dex.

These results have been published in Minelli et al. (2021a, ApJ, 910, 114. doi:10.3847/1538-4357/abe3f9)

Chemical abundances of SMC stars

The chemical composition of the SMC is still poorly investigated with respect to that of the LMC. I focused my attention on the chemistry of both clusters and field SMC RGB stars observed with FLAMES@VLT.

Regarding the globular clusters (GCs), I analysed UVES spectra of stars belonging to three GCs with different ages, ~11, ~6 and ~1 Gyr, hence covering the entire range of ages of the SMC clusters system and allowing to properly investigate the SMC chemical evolution. The metallicity of the galaxy remains nearly constant around –1.2 dex until 6 Gyr ago, pointing out a slow SFR in the early ages. Later, the metallicity increases reaching a value of ~–0.6 dex in the following 4 Gyr, probably as a result of the first encounter between the LMC and SMC happened 4 Gyr ago. Also, we found that all the three GCs are solar-scaled concerning the [alfa/Fe] ratios. We measured also the light elements (O, Na, Mg, Al) abundances and we found that all the GCs exhibit a homogeneous content of these elements, in contrast with the MW clusters.

A paper as a first author about the chemical composition of these three clusters is in preparation.

For field stars, I completed the chemical analysis of a sample of ~200 SMC giants spectra observed with GIRAFFE, by deriving abundances of Cu and neutron capture elements. This sample allows us to compare the chemical composition of field stars with the GCs ones, showing always a good agreement between field and cluster stars.
In addition, in this sample, metal-poor SMC stars ([Fe/H]~ – 2.5 dex) have been detected for the first time, allowing to study early chemical enrichment.
These results are presented in Mucciarelli, Minelli et al. submitted.

LMC old globular clusters
LMC has a large (~15) population of old GCs that are useful tools to investigate the early chemical enrichment history of this galaxy. We analysed UVES@VLT and MIKE@Magellan spectra of stars in 11 old LMC GCs. Among these clusters we identified a cluster (namely NGC 2005) that exhibits a clearly different chemistry with respect to the other GCs. This suggests that this cluster originated in a galaxy with a less efficient star formation compared to the LMC, and probably a mass comparable to those of the dwarf spheroial galaxies observed in the Local Group. The result demonstrates that the process of galaxy formation through building block merging occurred also in our closest satellite. This finding opens a new way to investigate the assembly history of galaxies beyond the MW via the chemical tagging of their GC systems.
Within this project, I contributed with the complete chemical analysis of the control sample of MW clusters. The result has been published in Mucciarelli, Massari, Minelli et al. 2021, Nature Astronomy. doi:10.1038/s41550-021-01493-y

Search for accreted globular clusters in the Milky Way
As demonstrated in Minelli et al (2021a), the largest abundance differences between metal-rich LMC/Sgr and MW stars are measured for the iron-peak elements Sc, V and Zn. Therefore, these abundances could be used to identify, among the stars in the Galactic disk, those stars accreted from galaxies that have experienced a chemical enrichment history similar to those of LMC and Sgr.
Therefore I homogeneously analysed UVES@VLT spectra of giant stars belonging to four MW GCs, selected with similar metallicities but different origin according to the dynamics: two of the GCs, namely NGC 5927 and NGC 6496, are clearly identified as born in-situ MW clusters through an analysis of their orbital properties, whereas the origin of the other two, namely NGC 6388 and NGC 6441, is more uncertain. We found that while the alpha-elements Si and Ca have similar abundance ratios for all the four GCs, and Ti and neutron capture elements (La, Ba and Eu) only show a marginal discrepancy, a stark difference is found for the abundances of Sc, V and Zn. In particular, NGC 6388 and NGC 6441 have similar abundance ratios for these iron-peak elements, but they are significantly lower (by~0.5 dex) than those measured in NGC 5927 and NGC 6496, which are in agreement with the MW abundances. These findings suggest that NGC6388 and NGC6441 formed in a different environment (with a chemical composition similar to those of LMC and Sgr) with respect to the other two clusters.
These results are discussed in Minelli et al 2021b ApJL, 918, L32. doi:10.3847/2041-8213/ac2156.

The chemical composition of Sgr
I'm analysing a sample of about 450 FLAMES@VLT spectra of RGB stars belonging to the main body of Sgr. These stars were selected according to the Gaia eDR2 proper motions, in order to avoid the contamination by foreground MW stars affecting the blue/metal-poor side of the RGB of Sgr, and to select a clean sample of high-probability members over the whole metallicity range spanned by Sgr RGBs. The stars are located outside of the nuclear region where the metal poor GC M54 lies.
Therefore this sample allows us to derive for the first time an un-biased Metallicity Distribution Function of Sgr and to obtain a complete view of its main abundance patterns.
This work has been done during my period abroad at the Observatoire de Paris (Meudon), under the supervision of Piercarlo Bonifacio. A paper as a first author is in preparation.

WORKSHOPS, CONFERENCES & MEETINGS

27-31 May 2019 - Bologna, Italy
IAUS 351: Star Clusters: from the Milky Way to the Early Universe (MODEST 19)
Poster : “Chemical and Kinematic study of Large Magellanic Cloud RGB stars”
LOC

9-13 September 2019 - Munich, Germany
ESO workshop: A synoptic view of the Magellanic Clouds: VMC, Gaia and beyond
Contributed Talk : “A spectroscopic high-resolution comparison between LMC and Sagittarius dwarf galaxy”

14 - 16 October 2019 - Bologna, Italy
Workshop INAF: “tinkering, coding e gaming per la didattica dell’astrofisica”

29 June – 03 July 2020 - online
EAS 2020: European Astronomical Society Annual Meeting 2020
sessions: “The Magellanic Clouds in the 2020s: a spectroscopic perspective”
“Gaia: The (two) billion star galaxy census: The promise of (E)DR3 and ground-based synergies”

7 - 8 September 2020 - online
Workshop ESO: “La Silla Paranal Observatory User Workshop”

6 July 2021 – online
Hypatia Colloquium series 2021
Contributed Talk : “Unveiling the chemical composition of the Small Magellanic Cloud”

4 – 18 September 2021 - online
ONSCI – Officina di Narrazione della Scienza”

18 – 22 October 2021 - online
HRMOS science workshop
Contributed Talk : “A new tool for chemical tagging based on iron-peak elements”

8 April 2021
Online talk for the group of dwarf galaxies and galatic halo of the Leibniz-Institut für Astrophysik Potsdam (AIP): “An homogeneous comparison between the chemical composition of the Large Magellanic Cloud and the Sagittarius dwarf galaxy”

PhD SCHOOLS

June-July 2020, online school - “Neutrinos and Dark Matter in Astro and Particle Physics”

INTERNAL COURSES

17 - 25 June 2019 Bologna, Italy – “Statistics for Astrophysics”

17-22 September 2020, Bologna, Italy – “ Gaia: Great Advances In Astrophysics”

30 November – 2 December 2020, Bologna, Italy – “The interstellar medium”

19-23 April 2021, Bologna, Italy – "Gamma Ray Bursts: from observations to physical properties"

5 - 14 May 2021, Bologna, Italy – "Writing, talking and presenting science"

Academic year 2020-2021 - "Weekly PhD Seminars"
Talk: "Throughout the information from the stellar abundances"

ISA LECTURES

13/11/2018 - "A heart attack: can we re-wire the heart?" by Damia Mawad

07/05/2019 - "You have to be cool to go to Mars" by Steven John Swoap

19/11/2019 - "Rigour and aesthetics: Japanese traditional mathematics" by E. Delucchi

16/07/2020 - "Crossing the Borders of Chemistry and Biology for targeting the Corona Virus Proteases" by T. Bottcher

19/01/2021 - "Extreme events: how to describe and predict them using mathematical theories" by Sandro Valenti

28/09/2021 - "How the Brain controls pain" by Mary Heinricher

COMPETITIVE TELESCOPE TIME ALLOCATIONS

"The first un-biased Metallicity Distribution of Sagittarius dSph: a Gaia-selected sample" PI: Bellazzini, FLAMES@VLT, Run ID:105.20AH.001, hours:8, priority:A

RESEARCH PERIOD ABROAD

September – November 2021 - Observatoire de Paris, France
working with Prof. Piercarlo Bonifacio

OTHER RELEVANT ACTIVITIES

21-26 January 2020 – Observations with spectrograph BFOSC@Loiano
program: "A pilot project to explore the potential use of the Cassini telescope for Galactic Archeology" PI: Mucciarelli

26 February 2019 - Alma Orienta
14 May 2020 - Alma Orienta
2 March 2021 - Alma Orienta

PUBLICATIONS

"An homogeneous comparison between the chemical composition of the Large Magellanic Cloud and the Sagittarius dwarf galaxy", A. Minelli et al. 2021, ApJ

"A New Set of Chisels for Galactic Archeology: Sc, V, and Zn as Taggers of Accreted Globular Clusters", A. Minelli et al. 2021, ApJL

"A relic from a past merger event in the Large Magellanic Cloud", A. Mucciarelli; D. Massari; A. Minelli, et al. 2021, Nature Astronomy

"Chemical analysis of three SMC globular clusters of different age",
A. Minelli et al., in preparation

"The chemical double helix of the Small Magellanic Cloud: a high-resolution chemical analysis of 200 red giant star" ,
A. Mucciarelli, A. Minelli et al., submitted

"The first un-biased Metallicity Distribution of Sagittarius dSph",
A. Minelli et al., in preparation