PhD name: Elena Lacchin
PhD Cycle: 35
Tutor: Dr. Francesco Calura

RESEARCH PROJECT: Hydrodynamic simulations of young globular clusters

It is already well-known that globular clusters (GC) host multiple stellar populations; from the analysis of the spectra of the hosted stars it appears that the chemical abundances of several light elements are significantly different within the same GC even though their iron composition is not. One of the most studied scenarios to account for the origin of multiple populations in GCs, is the asymptotic giant branch (AGB) one, where the first generation (FG) forms in a rapid starburst while second generation (SG) stars form from the ejecta of FG AGB stars plus a significant amount of 'pristine' gas, i.e. the gas with same chemical composition of FG stars.
During these two years I have been using a customized version of RAMSES (Teyssier, 2002), an hydrodynamic code based on the Adaptive Mesh Refinement technique, to model a realistic physical environment for a star forming GCs within the AGB scenario. Most of my work deals with the effects of stellar feedback from FG stars on SG ones, focusing on the chemistry, an ingredient still poorly included in GCs simulations. In particular, I've investigated the role of Type Ia supernovae (SNe), one of the physical processes which are generally assumed to cause the end of the star formation (SF) of the SG. Basing on the results obtained by d'Ercole et al. (2008), in fact, SNe Ia are expected to quench the SF almost immediately after the first explosions. However, their work has been performed in 1D, where centrally located SN bubbles reached very high filling factors.
During the last year I continued the project I started in my first year, aimed at studying, by means of 3D hydrodynamic simulations, the effects of Type Ia SN feedback on a massive (1e7Msun) star-forming GC, focusing on both the chemistry of SG stars and the duration of the SG formation. This work has led to a recently published paper where we concluded that, in a low gas density environment, the SN feedback lowers significantly the star formation rate (SFR) of SG stars and prevents the accretion of pristine gas (Lacchin et al. 2021). The AGB ejecta are therefore not diluted which leads to an unobserved spread in helium. Even assuming that Type Ia SNe begin exploding after the infall has started leads to a similar result. On the contrary, for high pristine gas densities, the SN feedback has a weak effect both on the SFR and on the helium spread. The iron one is instead heavily influenced by the SN explosions, for which we derive a value in agreement with Type II GCs (Milone et al. 2017), a sub-class of Galactic GCs characterized by a significant iron spread.
We are following-up on the previous work investigating the dependency of iron spread caused by Type Ia SNe on the cluster mass, studying clusters with an initial FG mass of 1e6Msun and 1e5Msun. Clusters of these masses are more compact, therefore higher resolutions are needed to characterize them. The set-up used in Lacchin+21 has already been extended to lower-mass clusters. At present, simulations are already running on remote HPCs.

Type Ia SNe, however, are not the only producers of iron, as also core collapse (CC) SNe do. Given the high mass of Type II clusters, they could have also retained part of the Fe-rich CC-SN ejecta then used to form new stars which would show higher iron abundances. To test this hypothesis I'm currently studying how the feedback of FG massive stars influenced the formation of new stars both from the energetic and the chemical point of view.
In this setup, every particle in the code is associated with a single star, which means that single stars are able to be formed but also that feedback from every star is modeled separately. Such particle treatment represents a step towards a more realistic modelization of feedback from individual stars, which is is still poorly used in literature, in favour of particles with IMF-averaged properties, which are known to lead to feedback underestimation.

Finally, I've started a project which aims at studying the effect of rotation, another fundamental ingredient in GC formation, on the dynamics and chemistry of SG stars. In the past years, an increasing number of GCs have been found to rotate. We are performing simulations varying the cluster mass, the velocity profile and the angle between the direction of the infall and the rotation axis. In these last two months I've tested the code and I'll soon start with high-resolution runs. What emerged so far from the preliminary tests is that rotation delays the SG SF and therefore SG stars are generally less helium enriched than in the case with no rotation.

WORKSHOPS, CONFERENCES & MEETINGS

- 7-11 January 2020 Sexten – "Chemical evolution of galaxies: the next 25 year" **Contributed talk** on: "Chemical evolution of ultrafaint dwarf galaxies: testing the IGIMF"
- December 3-4 2020 "Linking the Galactic and Extragalactic: stellar dynamics and stellar populations of the Milky Way and its siblings" (online)
- February 10-12 2021, "MW-Gaia Workshop: Galactic Centre and Inner Galaxy" (online)
- May 11-14 2021, "ISM 2021: Structure, characteristic scales, and star formation" (online)
- June 28 - July 2 2021, "European Astronomical Society 2021", Leiden (online). **Poster** on : "The effects of Type Ia supernova feedback on the second generation star formation in globular clusters"
- September 27-29 2021, "Ramses User Meeting 2021" (online). **Contributed talk** on: "The role of Type Ia supernova feedback on the second generation formation in globular clusters"

PhD SCHOOLS

- "Introduction To Parallel Computing with MPI and OpenMP", March 3-5 2021, HPC Cineca (online)
- "International Summer School on the Interstellar Medium of Galaxies, from the Epoch of Reionization to the Milky Way", July 12-23 2021 (online)

INTERNAL COURSES

- May, June, July 2020, "Neutrinos and Dark Matter in Astro- and Particle Physics"
- September 17-22 2020, "Gaia: Great Advances In Astrophysics"
- November 30 - December 2 2020, "The Interstellar Medium"
- April 19-23 2021, "Gamma Ray Bursts: from observations to physical properties"
- May 2021 , "Writing, talking and presenting Science"

ISA LECTURES

- 19/05/2020 - “Exploration of small bodies of the Solar System: focus on comets”
- 17/11/2020, "Organisational Learning and Adaptation to Address Complex Societal Challenges"
- 19/01/2021, "Extreme events: how to describe and predict them using mathematical theories”
- 28/09/2021, “How the brain controls pain”

RESEARCH PERIOD ABROAD

COMPETITIVE TELESCOPE/COMPUTER TIME ALLOCATIONS

- January 2020 - PI of the proposal: “Hydrodynamic simulations of Globular Clusters” at CINECA (Italy), **1M CPU/h** on MARCONI 100.
- July 2020 - PI of the proposal: “Hydrodynamic simulations of iron-complex clusters” at CINECA (Italy), **500k CPU/h** on GALILEO.
- July 2020 - CO-I of the proposal: “Hydrodynamic simulations of the young star cluster PW1 in the Magellanic Stream” at CINECA (Italy), **500k CPU/h** on GALILEO.
- January 2021 - PI of the proposal: “Hydrodynamic simulations of proto-globular clusters: the role of Type Ia SNe” at CINECA (Italy), **5.2M CPU/h** on MARCONI 100.

OTHER RELEVANT ACTIVITIES

PUBBLICATIONS

- Gjergo E., Palla M., Matteucci F., Lacchin E., Biviano A., Fan X., "On the origin of dust in galaxy clusters at low-to-intermediate redshift", 2020, MNRAS, 493, 2782
- Palla M., Calura F., Matteucci F., Fan X. L., Vincenzo F., Lacchin E., "The influence of a top- heavy integrated galactic IMF and dust on the chemical evolution of high-redshift starbursts", 2020, MNRAS, 494, 2355
- Lacchin E., Matteucci F., Vincenzo F., Palla M., "Chemical evolution of ultra-faint dwarf galaxies: testing the IGIMF", 2020, MNRAS, 495, 3276
- Lacchin E., Calura F., Vesperini E., “On the role of Type Ia supernovae in the second-generation star formation in globular clusters”, 2021, MNRAS, 506,5951