PhD name: Chiara Crociati

PhD Cycle: 36

Tutor: Prof. Francesco Ferraro

Co-Tutor: Barbara Lanzoni, Cristina Pallanca

RESEARCH PROJECT: *Searching for Fossil Fragments into the Galactic Bulge*

Nowadays, a satisfactory description of the processes that let the formation of galaxy bulges is still lacking. The observational proofs gathered so far for the Milky Way spheroid suggest, on the one hand, that it formed through secular dynamical processes (as corroborated by its shape and stellar kinematics), on the other hand, that it experienced a fast and early formation (as suggested by its stellar population properties). Among the proposed scenarios, the "merging picture" (e.g., Immeli+04 A&A,413,547; Elmegreen+08, ApJ, 688,67; Bournaud+09, ApJL, 694, 158) suggests that the formation of bulges occurs through the merging of primordial giant clumps of gas and stars, generated by early disk instabilities. This is indeed consistent with the observations of such massive sub-structures in the so-called "chain and clumpy galaxies" at high redshift (e.g., Elmegreen+09, ApJ, 692,12). The model also suggests that, while the majority of these clumps coalesces to generate the bulge, a few of them may survive the total disruption and be observable under the false identity of massive globular clusters (GCs), hosting multiple populations of stars with different iron abundances and different ages (Bournaud 2016, ASSL, 355). These are indeed the striking characteristics identified a few years ago in Terzan 5 (Ferraro+09, Nature, 462,483; +16,ApJ,828,75; Massari+14, ApJ,795,22; Origlia+11, ApJ,726,L20): although it appears as a massive GC in the Galactic Bulge, this system hosts two main stellar populations with ages of 12 and 4.5 Gyr, with an iron abundance difference as large as ~1 dex, and with an [α/Fe]-[Fe/H] pattern (which is the "chemical DNA" of a stellar population) perfectly consistent with that of the Bulge and incompatible with those of the Halo and the Local Group dwarf galaxies. All these evidences strongly suggest that Terzan 5 formed and evolved in deep connection with the Galactic Bulge, making it a strong candidate remnant of one of the massive clumps predicted within the merging picture. Being unique, however, Terzan 5 could have been just bizarre.

My PhD project is aimed at searching for other systems with properties similar to Terzan 5 that might still be hidden in the core of the Milky Way, with the final goal to shed new light on the formation processes of our Bulge and galaxy bulges in general. Within this context, during the last year I worked on an unprecedented characterization of Liller 1, another stellar system with the appearance of a massive GC in the Bulge direction. I took care of the challenging photometric analyses of both HST and ground-based adaptive-optics corrected images for the high density central region of such a severely extincted system. This has been the first laborious, but mandatory step for the determination of the high-resolution differential reddening map of the system (Pallanca et al., 2021, ApJ, 917,92), and the relative proper motions of individual stars that finally allowed us to discover the presence of two distinct stellar populations with remarkably different ages: ~12 and 1-2 Gyr, respectively. The results of this work deserved publication on Nature Astronomy (Ferraro et al., 2021, Nat. Astr., 5, 311).

I was then in charge of the delicate task to generate artificial star catalogs needed for the determination of the star formation history of the system. The preliminary results indicate that Liller 1 suffered two major bursts of star formation: a first, prolonged event occurred ~13 Gyr ago and formed 80% of the total stellar mass, while the most recent one occurred ~1 Gyr ago. The paper presenting these results is currently in preparation (Dalessandro, Crociati, et al., 2021).

The properties observed so far in Liller 1 and Terzan 5 suggest that we are likely in the presence of a new class of stellar systems (that we named "Bulge Fossil Fragments") that could have contributed to form our Bulge. To confirm this intriguing possibility, I'm currently working on the complete characterization of these systems. A crucial step is the determination of the chemical abundances of the two stellar populations discovered in Liller 1. To this aim, and in addition to determine the internal kinematics of the system, I just started to work on MUSE spectra, learning how to analyze IFU data cubes. I also contributed to draft an ESO proposal specifically dedicated to CRIRES and additional MUSE observations of Liller1, which is currently under submittion. In wider terms, during the first year of PhD, I also learned how to efficiently handle Gaia catalogs and utilize interface tools for planning observational proposals (such as the Astronomer Proposal Tool for HST and JWST), other than

extending and strengthening my knowledge about the Galactic Bulge and the assembly history of the Milky Way.

WORKSHOPS, CONFERENCES & MEETINGS

10 / 12 February 2021 Online – Milky Way Gaia Workshop "Galactic Centre and Inner Galaxy"

5 / 8 July 2021 Online – MAVIS online science workshop

5 / 7 October 2021 Online – "Star clusters: the Gaia revolution"
(I will attend this workshop soon)

PhD SCHOOLS

21 / 23 September 2021 Online – WG2 PhD school
"Stellar spectroscopy and astrophysical parameterisation from Gaia to large spectroscopic surveys"

INTERNAL COURSES

30 November – 2 December Online - "The interstellar medium"

19 / 23 April Online - "Gamma-Ray bursts : from observations to physical properties"

5 / 7 - 10 / 14 May Bologna, Italy - "Writing, talking and presenting science"

ISA LECTURES

6 July 2021 - "How positive pedagogy can address mental health and wellbeing of students?" - Lecture by Dr. Priyank Shukla, Ulster University (UK)

28 September 2021 - "How brain controls the pain" - Lecture by Mary Heinricher, Oregon Health and Science University (USA)

RESEARCH PERIOD ABROAD
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COMPETITIVE TELESCOPE/COMPUTER TIME ALLOCATIONS
Co-I in the ESO-VLT P109 proposal (submitted): "Fossil Fragnments & parsec scale Dark Matter halos: redesigning the assembling hisrtory of the Galactic Bulge"

PI: F. R. Ferraro, 20 h

Co-I in the ESO-VLT P109 proposal (submitted): "The crash signal: measuring the age of globular clusters to date a past merger event"

PI: D. Massari, 2 h

OTHER RELEVANT ACTIVITIES

Volunteer during the event "Alma Orienta" for the Master course in Astrophysics.

PUBBLICATIONS

Ferraro, F. R., Pallanca, C., Lanzoni, B., Crociati, C. et al. *A new class of fossil fragments from the hierarchical assembly of the Galactic bulge*, 2021, Nature Astronomy, 5, 311, doi: 10.1038/s41550-020-01267-y

Pallanca, C., Ferraro, F. R., Lanzoni, B., Crociati, C., et al. *High-resolution extinction map in the direction of the strongly obscured bulge fossil fragment Liller 1*, 2021, ApJ, 917, 92, doi: 10.3847/1538-4357/ac0889

Dalessandro, E., Crociati, C., et al. , *Star Formation History of the complex bulge stellar cluster Liller 1*, 2021, in prep.

Crociati, C., et al., *The age-metallicity relation of Terzan 5: a new outlook on its complex nature*, 2021, in prep.