Francesco Ferraro

Bulge fossil fragments

Uncovering the origins of the galactic bulge

The Milky Way is home to around 150 globular clusters, but some of them could be just fakes!

- Astronomers today still don’t entirely agree on the origins of galactic bulges.
- A team of researchers, led by Francesco R Ferraro at the University of Bologna, Italy, has discovered a possible solution in two star clusters close to the Milky Way’s centre.
- The ages and chemical composition of each cluster’s stars show that they are likely to be the remnants of primordial stellar structures.
- Termed ‘Bulge Fossil Fragments’, they provide evidence that these ancient structures merged together to form the galactic bulge.

The centres of most galaxies are home to vast, tightly packed distributions of stars called ‘galactic bulges’, which often outshine the entirety of their host galaxies. Yet, despite being such prominent features, the history of their formation and evolution is, to date, a topic of heated debate among astronomers.

In most galaxies, bulges are made up of ancient stars, which were likely formed early on in the galaxy’s history. According to some astronomers, this suggests that they formed through mergers between primordial stellar structures, such as small galaxies embedded in the dark matter halos or the fragments of unstable galactic disks. So far, however, no evidence for these theories has been found in the Milky Way.

Answers in globular clusters?

Through their research, Francesco R Ferraro of the University of Bologna, Italy, and team propose that answers to this mystery could lie with spherical, ancient clumps of stars named ‘globular clusters’. ‘These are aggregates made of up to one million stars with essentially the same age and the same iron abundance’, explains Ferraro. The Milky Way is home to around 150 globular clusters, but some of them could be just fakes.

In fact, if bulges are formed through the merging of ancient stellar structures, not all of this material would have necessarily coalesced into a single bulge; instead, some of it may have been left behind, and formed some remnant stellar system that could still be present close to the galactic centre with the appearance of a globular cluster.

If this scenario is correct, astronomers predict that, at odds with globular clusters, these remnants should harbour stars with different ages and iron abundances because they formed from vastly larger fragments that had a gravitational pull strong enough to retain the iron-rich gas and dust ejected by past supernovae, allowing new stars to form several billions of years later.

For more than 40 years, two stellar systems orbiting the Galactic bulge, named Terzan 5 and Liller 1, have been catalogued as genuine globular clusters.

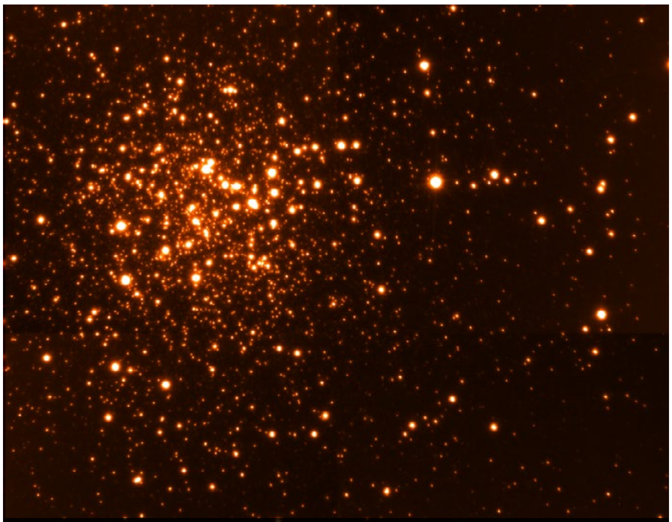
Galactic archaeology: obtaining evidence

Two stellar systems orbiting the galactic bulge, named Terzan 5 and Liller 1, have managed to capture the team’s attention. For more than 40 years, these objects have been catalogued as genuine globular clusters. To determine the stellar makeup of the two clusters in closer detail, Ferraro’s team examined photometric and spectroscopic observations made using both ground-based telescopes and the Hubble Space Telescope.

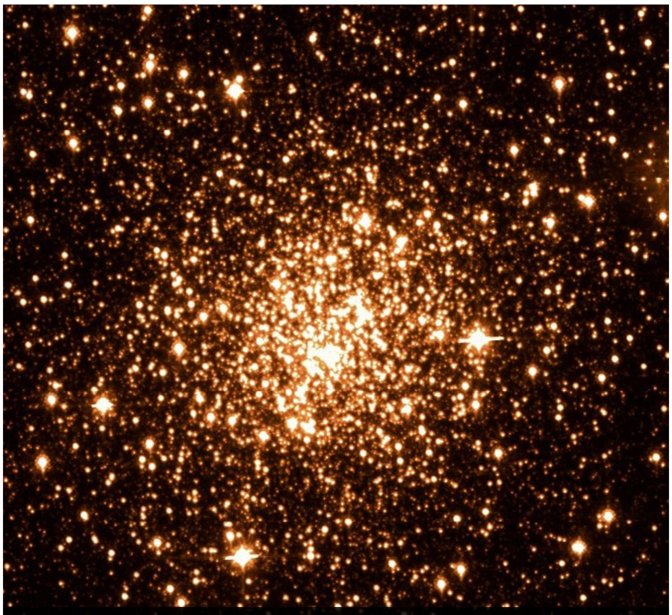
They found that each cluster hosts groups of stars with starkly differing chemical compositions which change as the stars age. ‘This suggests that Terzan 5 and Liller 1 are the remnants of much more massive objects that, at odds with genuine globular clusters, experienced at least two bursts of star formation with a time delay of several billion years', Ferraro explains.

Indeed, the observations provide strong evidence that the two structures aren't true globular clusters after all, but the fossil fragments of giant stellar clumps, which merged together around 12 billion years ago to form the Milky Way's galactic bulge.

For Ferraro, his team's investigation bears some striking resemblance to one very different field of research. 'Like archaeologists seeking for the vestiges of ancient civilisations, we now have to dig deeper into



The extraordinary image of Terzan 5 acquired in the near-infrared with the Multi-conjugate Adaptive optics Demonstrator (MAD) at the Very Large Telescope (VLT) facility of the European Southern Observatory (ESO).



The first optical image ever obtained for Liller 1 with the Hubble Space Telescope.

the bulge of our galaxy searching for similar fossil remains', he says. Tapping into the history of the formation of the Milky Way written in these fossil remains, the team aims to read this story and redesign the scenario for the formation of the bulge.

Bulge Fossil Fragments

To highlight their distinction from regular globular clusters, Ferraro's team coined the term 'Bulge Fossil Fragments' to describe Terzan 5, Liller 1, and any similar structures they predict will be found close to the centres of other galaxies. Building on this theory, they identified four key properties, which they predict will be shared by all of these structures.

Personal response

Why have the origins of galactic bulges been difficult to identify so far?

Because they are the most obscured regions of galaxies, where star light is largely absorbed by thick clouds of interstellar dust. For instance, because of these clouds, in our galaxy, the visible light coming from those stars can be up to 10,000 times fainter than the light emitted! Only the infrared light is able to efficiently pass through those clouds. This is why, for both Liller 1 and Terzan 5, in combination with the Hubble images, we used near-infrared images acquired with ground-based (8m diameter mirror) telescopes, equipped with instrumentation able to compensate for the distortion that the Earth's atmosphere causes on stellar images.

In this case, the similitude with archaeology is even more evident: archaeologists must dig through the dust piling up on top of the remains from past civilisations; in a similar way, we need to perforate the thick clouds of interstellar dust to reach the light coming from these extraordinary cosmic relics and finally read the story of the primordial Milky Way. The data acquired was really extraordinary! Thanks to an almost perfect correction from atmospheric distortions, they have an angular resolution comparable to that of the images acquired from space (where no degradative effects from the Earth's atmosphere are present). Once combined with Hubble Space Telescope images, they allowed us to efficiently exclude the galactic field intruders and finally have a clear picture of the stellar populations belonging to Terzan 5 and Liller 1.

Can you explain in more detail how you identified different generations of stars from your observations?

The presence of different generations of stars in these two systems has been identified by measuring the age of the observed stellar populations. This is feasible by keeping in mind the following points: (1) when a stellar population forms, it is initially made of both massive and low-mass stars; (2) the high-mass stars are very bright and very hot, while the luminosity and surface temperature are progressively smaller for decreasing stellar mass. This draws a well-defined sequence (named 'main sequence') in a diagram plotting the stellar luminosity as a function of the surface temperature; (3) after birth, every star spends most of its life along the main sequence, burning hydrogen in their core and shining with a fixed luminosity and surface temperature, and then it rapidly becomes colder; (4) this evolution is maximally fast for high-mass stars, and becomes slower and slower for decreasing stellar mass.

The combination of these four points implies that when a population is young, its main sequence is very extended, comprising both very bright (high-mass) stars and faint (low-mass) objects. On the other hand, as it gets older and older, the main sequence progressively shortens because the brightest and hottest stars have left the main sequence (they become bloated and cold stars, called 'giants', or they even died).

Thus, just like a candle, the main sequence shortens as a function of time, providing a sort of 'clock' to measure the age of stellar populations. For a young population, we expect a main sequence extended in luminosity (like a recently lighted candle)

Firstly, these systems are indistinguishable from genuine globular clusters in their appearance. Secondly, they have metallicity and abundance patterns compatible with those observed in the bulge field stars. Thirdly, Bulge Fossil Fragments host populations of older stars, formed early in the history of the galaxy. Finally, they must also contain stellar populations several billions of years younger than these original stars – enabled by the cluster's capacity for multiple generations of star formation.

Altogether, Ferraro and the research team hope their discoveries could help bring an end to the longstanding debate surrounding the origins of galactic bulges. In turn, their findings could help to deepen our understanding of the formation and evolution of our galaxy, and many others with a similar history.

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Ferraro's team examined photometric and spectroscopic observations of Terzan 5 and Liller 1 made using both ground-based telescopes and the Hubble Space Telescope.

whereas for an old population, we expect a sequence poorly extended in luminosity (like a consumed candle). Indeed, the luminosity of the brightest point along the main sequence is the clock-hand of this cosmic chronometer indicating the age of the population.

In genuine globular clusters, only one (consumed) main sequence is observed (meaning that all stars have the same old age). Conversely, in Terzan 5 and Liller 1, we detected two distinct main sequences with two different brightest points, witnessing the presence of two generations of stars with different ages, with the brightest main sequence corresponding to the youngest population.

The two generations discovered in each system also differed in their iron abundance. This is measured through spectroscopy, a technique that splits the star light into its constituent wavelengths (or frequencies) and allows us to determine the abundance of a given chemical element by measuring how much light is missing at a specific frequency. We found that by observing the youngest generation, the amount of missing light is larger than that measured for the older population. This indicates that the former is more iron-rich than the latter.

Do you predict that Bulge Fossil Fragments may be common in other galaxies?

Indeed, one of the observational pieces of evidence that inspired our work was that in very distant star-forming galaxies, we really see these primordial structures on the verge of merging to form bulges. In fact, ultra deep observations with the Hubble Space Telescopes distinguished giant clumps of stars and gas in star forming galaxies that, for this reason, were named 'clumpy' galaxies. Of course, we expect that the vast majority of these primordial fragments dissolve to form the bulge, but simulations show that a few of them could survive the total disruption and still be present in the inner regions of the host galaxy. Thus, we expect that as in the Milky Way, a few of them survived the bulge formation and still wait to be discovered to tell us the primordial history of that galaxy!

Details

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Bio

Francesco R Ferraro is full professor at University of Bologna, Italy. He has led many observational programmes aimed at investigating stellar populations in star clusters. He was awarded an ERC Advanced Grant in 2010 for the project Cosmic-Lab. He received the International Prize 'L. Tartufari' for Astronomy in 2018 from the Accademia Nazionale dei Lincei.

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