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The Magellanic Clouds and their star clusters (Invited contribution)

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Abstract

The Large and Small Magellanic Clouds (LMC and SMC) are the two most massive satellite galaxies surrounding the Milky Way. They are likely in their first infall to our Galaxy and have just passed pericentre. Their orbit has been dragging a 200 degrees-long gas trailing stream and also a leading gas structure. The LMC-SMC pair has been interacting to each other with multiple encounters throughout their lives, which heavily impacted their structure, triggered star formation and boosted star cluster dissolution. The chemical evolution of these two galaxies is much less efficient than expected, and they are different in various regions of the SMC for example. Understanding this complex history requires a lot of precise chemical and kinematic information as a function of time and space combined to sophisticated chemo-dynamical models. The star clusters are excellent fossils because we can measure their 3D position, 3D velocities, age, metallicity, internal structure, and they trace the different regions of the LMC and SMC, as well as covering a large age range. In this talk, I briefly reviewed the topic and presented the VISCACHA survey that I lead involving astronomers from a handful of Latin America countries.

Resumen

La Grande y la Pequeña Nube de Magallanes (LMC y SMC, por sus siglas en inglés) son las dos galaxias satélites más masivas que rodean a la Vía Láctea. Es probable que estén experimentando su primera caída hacia nuestra galaxia y acaban de pasar el pericentro. Su órbita ha arrastrado un flujo de gas de 200 grados de longitud y también una estructura de gas líder. El par LMC-SMC ha interactuado entre sí con múltiples encuentros a lo largo de sus vidas, lo que ha afectado significativamente su estructura, ha desencadenado la formación de estrellas y ha impulsado la disolución de cúmulos estelares. La evolución química de estas dos galaxias es mucho menos eficiente de lo esperado y difieren en varias regiones, como en el caso de la SMC. Comprender esta historia compleja requiere una gran cantidad de información química y cinemática precisa en función del tiempo y el espacio, combinada con modelos químico-dinámicos sofisticados. Los cúmulos estelares son excelentes fósiles porque podemos medir su posición tridimensional, velocidades tridimensionales, edad, metalicidad, estructura interna y rastrean las diferentes regiones de la LMC y SMC, abarcando también un amplio rango de edades. En esta charla, revisé brevemente el tema, presenté el proyecto VISCACHA que lidero, en la que participan astrónomos de varios países de América Latina.

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1. Introduction

The Large and the Small Magellanic Clouds (LMC, SMC), or Tapi'i Hugua and Coxi Hugua in their tupi-guarani denominations[1], respectively, are two irregular galaxies that are Milky Way satellites. They have been studied systematically for decades and the most popular paradigm was that these two galaxies have been orbiting our Galaxy possibly since early times, and for the past 2 or 3 orbits they synchronized and became a pair orbiting the Milky Way with a period of about $\sim$ 2 Gyr (see e.g. Diaz & Bekki, 2012). A change of paradigm happened with the updated *HST*-based proper motions for the LMC and SMC (Kallivayalil et al., 2006b,a). They were adopted by

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the then PhD student Gurtina Besla in what is today her most cited paper (Besla et al., 2007). She proposed that the LMC and SMC have been a pair of galaxies that are most likely in their first infall into the Milky Way. A third big complement to the change of paradigm was the astrometric information from *Gaia* revealing that the LMC brought not only the SMC but a whole system of smaller dwarf galaxies forming a Magellanic System falling into the Milky Way (Sales et al., 2017; Kallivayalil et al., 2018). The LMC, SMC, and the other satellites of the Magellanic Clouds might have been interacting among them and leaving marks, the most famous being the Magellanic Bridge (e.g. Zivick et al., 2018). Among many purposes, the VISCACHA (VIsible Soar photometry of star Clusters in tApii and Coxi HuguA) survey team (Maia et al., 2019; Dias et al., 2020) has been using the star cluster systems of the LMC and SMC, observed in detail to help constraining the internal structure, kinematics, and chemistry of the Magellanic Clouds and searching for signatures of past interactions. The VISCACHA survey has been collecting images with the 4m SOAR telescope, improved by ground-layer adaptive optics system SAM imager (Tokovinin et al., 2016).

2. The effects of galaxies mergers

We highlight the results from two recent VISCACHA papers where the systematic observations of star clusters are used to trace back the chemo-dynamical evolution of the Magellanic Clouds and provide independent constraints for future models. The age-metallicity relation (AMR) of the SMC clusters (Fig.1) is known to display an intrinsic metallicity dispersion (e.g. Parisi et al., 2022). Dias et al. (2014) proposed a framework to help understand the complex chemical evolution history of the SMC by splitting the sky regions (see e.g. Dias et al., 2022).

Oliveira et al. (2023) studied star clusters along the Wing/Bridge, which is the main branch of the Magellanic Bridge. They found that the AMR does not show dispersion, but rather it reveals two metallicity dips related to the formation of the Magellanic Stream and Magellanic Bridge itself (see Fig. 1). Saroon et al. (2023) analyzed clusters in the opposite side, the West Halo region, and found that these clusters are systematically more metal-poor than those from the bridge, and they also show less dispersion in the AMR. Moreover, they revealed a clear metallicity dip and ran some chemical evolution models to conclude that it can only be explained by a major merger. Given the recent results showing that the LMC has multiple smaller satellites, it is not unlikely that a major merger could have been the origin of what we know today as the SMC.

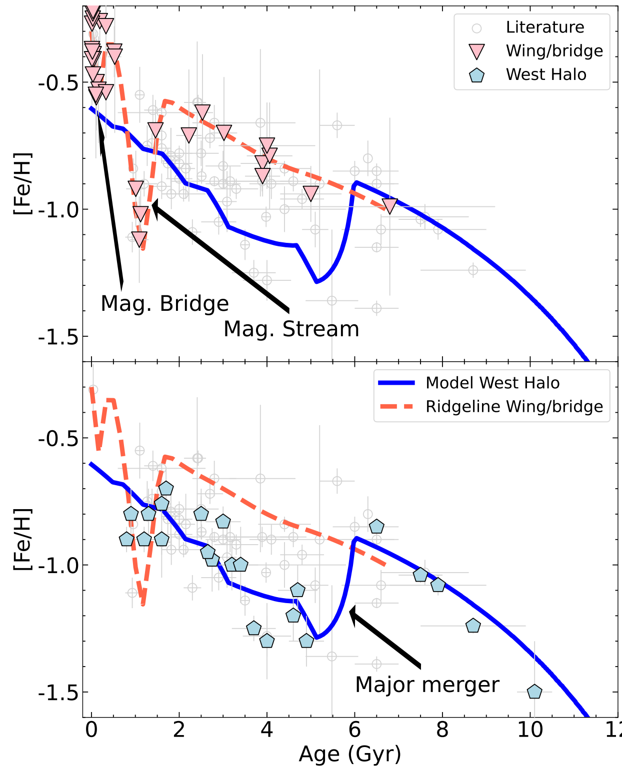

Figure 1. The age-metallicity relation for SMC clusters. Literature data shows a high metallicity dispersion. The SMC West Halo clusters can be described by a single chemical evolution model with a metallicity dip produced by a major merger around 6 Gyr ago. The SMC Wing/Bridge clusters are systematically more metal-rich than the West Halo group, and their evolution shows two metallicity dips at the formation time of the Magellanic Stream ∼ 1.5 Gyr ago and the Magellanic Bridge ∼ 200 Myr ago.

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