Asociación Argentina de Astronomía
Boletín de artículos científicos

Unveiling the origin of the bulge of M81 with spectroscopic observations and the TNG50 simulation

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Resumen / Presentamos los aspectos principales de un estudio en proceso acerca del origen del bulbo de la galaxia espiral cercana M81 combinando datos espectrales, obtenidos a partir de observaciones de Gemini/GMOS-N, y las simulaciones cosmológicas hidrodinámicas TNG50-1 de la colaboración IllustrisTNG. El bulbo de M81 es clasificado en la literatura como un bulbo clásico. Este tipo de bulbo es comúnmente asociado a un origen por fusiones galácticas. Sin embargo, la historia de fusiones tranquilas revelada por el halo estelar de M81 pone restricciones fuertes a este escenario. Colocamos cuatro ranuras largas que cubren la región central de M81 con una disposición tal que nos permitirá estudiar los perfiles radiales de edad, abundancias químicas y momentos de la distribución de velocidades en la línea de la visual (e.g., velocidad media, dispersión de velocidades) a diferentes latitudes galácticas. Definimos análogos a M81 en la simulación a partir de la relación entre la masa del bulbo y la masa del halo estelar acretado y encontramos tres galaxias simuladas que se muestran cerca de M81 en dicho diagrama. Los tres análogos de M81 muestran una fracción baja de estrellas acretadas dentro del bulbo definido a partir de consideraciones cinemáticas, indicando que las fusiones pueden no ser el mecanismo principal de construcción del bulbo de M81.

Abstract / We present the main remarks of an ongoing study about the origin of the bulge of the nearby spiral galaxy M81 combining spectral data, obtained using Gemini/GMOS-N observations, and the cosmological hydrodynamical simulation TNG50-1 of the IllustrisTNG collaboration. The bulge of M81 is classified in the literature as a classical bulge. This type of bulge is commonly linked to a merger origin. However, the quiet merger history revealed by the stellar halo of M81 puts strong constraints on this scenario. We placed four long-slits to cover the central region of M81 with such a disposition that will allow us to study radial profiles of ages, chemical abundances and the moments of the line-of-sight velocity distribution (e.g., mean velocity, velocity dispersion) at different galactic latitudes. We define M81 analogues in the simulation by means of a bulge mass - accreted stellar halo mass relation and find three simulated galaxies that lie close to M81 in such diagram. The three M81 analogues show low to negligible fractions of accreted stellar particles in their kinematically selected bulge, implying that mergers may not be the main mechanism for the build-up of M81's classical bulge.

Keywords / galaxies: individual (M81) — galaxies: bulges — methods: numerical — methods: observational

1. Introduction

Bulges of Milky Way (MW) mass galaxies in the local Universe show a wide range in their properties, suggesting diverse physical origins (Bell et al., 2017, B17 from now on). Thus, they represent an ideal laboratory to test bulge formation mechanisms in models in the context of the Λ-cold dark matter paradigm (Peebles, 2020, and references therein). Historically, bulges have been classified into two classes: classical bulges and pseudobulges (Kormendy & Kennicutt, 2004). Centrally concentrated classical bulges are usually considered to be the result of merger activity. However, it has been shown in the last years that the link between the formation of bulges in MW-sized galaxies and mergers is not trivial (B17, Gargiulo et al., 2019, 2022). B17 selected a sample of MW-mass galaxies with stellar masses in the range $3 - 12 \times 10^{10} M_{\odot}$ and studied whether there was a relation between the merger history of these galaxies, through the properties of their stellar haloes, and the bulge growth. They found that the bulge mass is not correlated with the accreted stellar halo mass for their sample of MW-mass galaxies, as it would be expected if mergers contribute proportionally to the formation of stellar haloes and bulges. A striking case that stands out in the sample of B17 is the galaxy M81. This particular galaxy has a bulge mass that is very large in relation to its stellar halo mass and its bulge is usually classified as classical. However, the quiet merger history revealed by the stellar halo of M81 (Smercina et al., 2020) puts strong constraints on the merger scenario as the main mechanism for growing its bulge. What drives the bulge mass growth in this galaxy? Here, we present preliminary results of a study about the origin of the bulge of the nearby spiral galaxy M81 combining spectral data, obtained using Gemini/GMOS-N observations, and the state-of-the-art cosmological magneto-hydrodynamical simulation TNG50-1.

Presentación mural

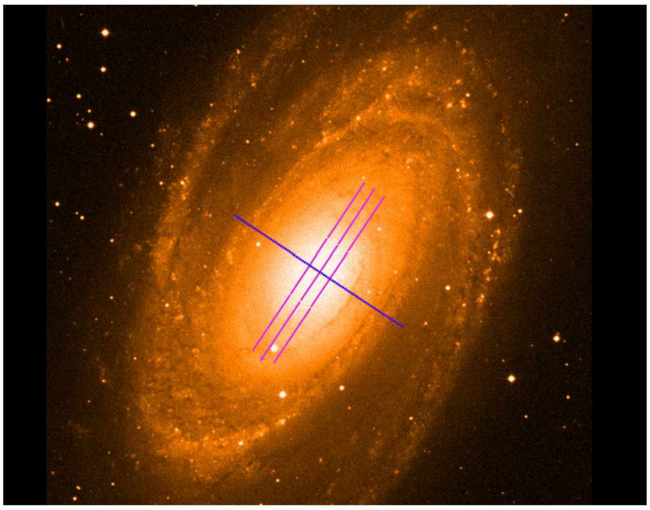

Figura 1: Image of the nearby galaxy M81. Three long-slits were placed parallel to the major axis of the galaxy and one along the minor axis as shown with pink lines and a blue line, respectively.

2. Methodology

2.1. Observational set-up

Spectroscopic observations of the nearby galaxy M81 were obtained using Gemini/GMOS-N in long-slit mode. In Fig. 1 we show a DSS image of M81 with the positions of the four observed long-slits. Pink lines indicate the positions of three long-slits placed parallel to the major axis of the brightness distribution, and a blue line indicates the position of a fourth long-slit placed along to the minor axis of the brightness distribution. Currently, spectral data are being reduced and we expect to obtain age and abundance gradients (Fe/H, O/Fe, Mg/Fe), together with line-of-sight velocity moments, in order to compare with the properties of M81 simulated analogues.

2.2. The parent sample of MW/M31-like galaxies from TNG50-1

The illustrisTNG50 simulation (Nelson et al., 2019; Pillepich et al., 2019) is the highest resolution run of the IllustrisTNG project (Pillepich et al., 2018; Nelson et al., 2018; Naiman et al., 2018; Springel et al., 2018; Marinacci et al., 2018). We select M81 analogues from a sample of 287 MW/M31-mass galaxies from the TNG50-1 simulation defined by Gargiulo et al. (2022, G22 from now on). With a gas-cell resolution of $\sim 8.5 \times 10^4\,\mathrm{M}_\odot$ and a periodic volume of $L_{\rm box} \sim 50$ cMpc, it represents an excellent opportunity to select a large sample of dynamically well-resolved MW/M31-mass galaxies in a variety of environments. The MW/M31-like galaxies were selected according two criteria: they must have a stellar mass that lie in the range $[10^{10.5} - 10^{11.2}]\,\mathrm{M}_\odot$ and have a disk morphology (see Sec. 2.2 in G22). M81 analogues used in this work fall within this definition, but are selected with a more stringent criterium from a bulge mass - accreted stellar halo mass diagram (see Sec. 3; Bell et al., 2017; Gargiulo et al., 2019, and Gargiulo et al. 2022, in prep.). The idea behind this is to constrain the merger history of M81 analogues through the total accreted mass of their stellar haloes, while selecting simulated galaxies with similar bulge masses.

2.3. Photometric decomposition of simulated galaxies

We model the photometric bulge and disc of the MW/M31-like galaxies in our sample by a 2-component decomposition of their surface brightness profiles (SBP). The sum of a Sérsic function, that accounts for the bulge of the galaxy, and an exponential function, for the disc, is fitted to the SBP up to the optical radius of the simulated galaxies. In this work, we use the fitted parameters from G22 and refer the reader to the aforementioned article for more details about the fitting procedure and description of the resulting values of the parameters. Bulge masses are obtained in an equivalent manner than observed values. The bulge-to-total ratio (B/T) is derived by integrating the Sérsic component of the surface brightness profile of the galaxy and dividing the result by the integral of the summed fitted function to the whole SBP, up to the optical radius. Later on, we use the color dependent mass-to-light ratios from Bell et al. (2003) to obtain the stellar mass of the galaxy by means of the B-V color and K magnitude, and estimate the final bulge mass by multiplying it by B/T.

2.4. Kinematic bulge and accreted halo

In order to discriminate between the galactic bulge and halo components from the discs, from a kinematic point of view, we perform a kinematic decomposition based on the circularity of stellar particles. The circularity is defined as $\epsilon = J_z/J(E)$ (Abadi et al., 2003), where J_z is the angular momentum component perpendicular to the disk plane of a stellar particle with orbital energy E, and $J(E)$ is the maximum possible angular momentum for the given E, which corresponds to a circular orbit. Stellar particles with $\epsilon > 0.7$ are considered disk particles. The remaining particles belong to the stellar halo or the kinematically selected bulge. If a stellar particle lies outside a spherical region of $2 \times R_{\rm eff}$ of the Sérsic component from the photometric decomposition (See Sec. 2.3), it belongs to the stellar halo. If they lie inside that region, the stellar particles with low circularity belong to the kinematic bulge. For the kinematically selected stellar halo and bulge, we further identify the *accreted* stellar particles (i.e., formed bound to satellite galaxies) and those formed in-situ (inside the virial radius of the host and not bound to any satellite galaxy). The accreted mass of the stellar haloes is defined as the sum of all the accreted stellar particles in the stellar halo region. It was shown that the accreted halo mass of simulated MW-like galaxies is correlated with the number and mass of the progenitors involved in its formation (Monachesi et al., 2019). Thus, the accreted stellar halo mass is assumed to be a good predictor of the galaxy's assembly history.

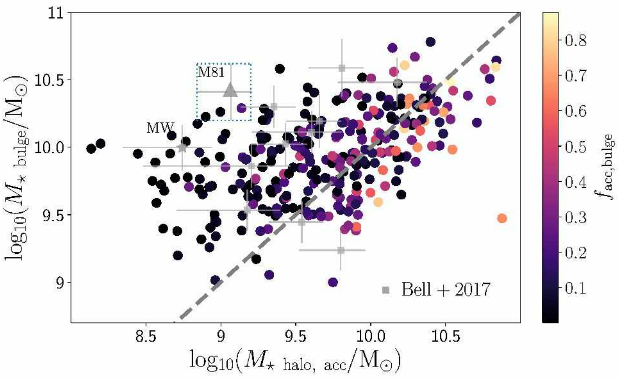

Figura 2: Bulge mass as a function of accreted stellar halo mass for the whole sample of MW/M31 galaxies, in circles. Grey symbols with error bars indicate the observational estimates from Bell et al. (2017). M81 analogues lie inside the dotted line box. The dashed grey line indicate the 1:1 correlation. Galaxies in this diagram show a large scatter, as in observations, indicating that other processes are involved in the build-up of photometric bulges, besides mergers. The color-coding represents the fraction of accreted stars in the kinematically selected bulge. Galaxies laying close to the 1:1 correlation show larger accreted fractions in the kinematically selected bulge. M81 analogues show low to negligible fractions of accreted stellar particles in their kinematic bulge. This figure is based on Gargiulo et al. 2022, in prep.

3. The possible non-merger origin of M81's classical bulge

We show in Fig. 2 the bulge mass - stellar halo mass diagram for our sample of 287 MW/M31-like simulated galaxies, together with the observed values and errors from Bell et al. (2017), in grey squares. We highlight the observed estimate of M81 with a larger triangle and the observed value of the MW with a star, for reference. Bulge masses in this figure were computed mimicking the procedure to obtain the observed bulge masses, as described in Sec. 2.3. In dotted lines we show the box enclosing the observed range (considering errors) in accreted stellar halo mass and bulge mass of M81. Only three galaxies from our sample lie inside this range and are considered, therefore, M81-analogues. The symbols are color-coded according to the fraction of accreted stars in the kinematically selected bulge (see Sec. 2.4). We caution that this fraction of accreted stellar particles does not represent the fraction of accreted particles inside the photometric bulge, since both definitions are independent. However, combining both definitions allow us to gain useful insight on the formation mechanisms of bulges. Galaxies lying near the 1:1 correlation in this diagram, depicted by a dashed grey line, present higher accreted fractions, hinting towards a significant contribution from mergers to the origin of their bulges. The three M81 analogues inside the dotted-line box show low fractions of accreted stars. Two of them present negligible fractions below the ten percent, and only one of them has an accreted fraction $f_{\mathrm{acc}} = 0.23$. This implies that accretions may have not been the main driver for the build-up of the massive classical bulge of M81. Other mechanisms such as bars (G22), radial migration due to spiral arms (Sellwood & Binney, 2002) and gas compaction (Dekel & Burkert, 2014) are being investigated as possible main contributors to the build-up of M81 analogues in the simulation. This might help to explain, in turn, the complex history behind the formation of the bulge of M81. Finally, another aspect that could also help to constrain and disentangle the contributions of different channels involved in the formation of the inner region of M81 is the existence of a massive black hole with a low luminosity active galactic nucleus in its centre(Ho, 1999) .

4. Summary

We select M81 analogues from the state-of-the-art TNG50-1 simulation according to their position in the bulge mass - accreted stellar halo mass diagram (Bell et al., 2017; Gargiulo et al., 2019, Gargiulo et al. 2022, in prep.) in order to constrain the assembly history of simulated galaxies. The fraction of accreted stellar particles formed in satellites in the kinematically selected bulges of M81 analogues are negligible or low, compared to galaxies that build their bulge mainly by mergers (Gargiulo et al. 2022, in prep). Other mechanisms driven by secular evolution like bars and strong spiral arms arise as possible main contributors to the formation of the classical bulge of M81. The comparison of spectroscopic observations with simulated data can shed some light to our understanding of a possible non-merger scenario for the formation of the classical bulge of M81.

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