Revista Mexicana de Astronomía y Astrofísica Serie de Conferencias, 60, 196-197, (2026)

OPEN ACCESS https://doi.org/10.22201/ia.14052059p.2026.60.175

"XVII LARIM", Montevideo, Uruguay, November 27 - December 1, 2023.Volume Editors: Gonzalo Tancredi, Cecilia Mateu & Juan José Downes

The co-evolution between galaxies and dark matter halos (Invited contribution)

Aldo Rodriguez-Puebla[1]

[1] *Universidad Nacional Autónoma de México, Instituto de Astronomía, AP 70-264, CDMX 04510, México.*

Keywords: *galaxies: evolution, galaxies: haloes, methods: statistical*

Abstract

In this proceeding we present the star formation history, SFH, of galaxies over cosmic time, ranging from dwarfs to massive ellipticals, using the semi-empirical modeling based on the new model EMPIRE. Progenitors of massive galaxies reveal distinct growth stages, with evidence suggesting that cold streams played a key role in sustaining star formation, SF, at higher redshifts, while virial shock heating became more prominent at lower redshifts.

Resumen

En estas memorias presentamos la historia de formación estelar SFH, de galaxias en una escala de tiempo cósmico, desde galaxias enanas hasta elípticas masivas, usando modelado semi-empírico basado en el nuevo modelo EMPIRE. Los progenitores de galaxias masivas revelan diferentes etapas de desarrollo, con la evidencia sugiriendo que las corrientes frías juegan un rol clave en el sustento de la formación estelar (SF) a alto corrimiento al rojo, mientras el calentamiento virial por choques se vuelve más prominente a corrimientos al rojo bajos.

Corresponding author: apuebla@astro.unam.mx

1. Introduction

The current cosmological model suggests that dark matter halos serve as the gravitational framework for galaxy formation, shaped by hierarchical structure formation and local astrophysical processes. This interdependence implies that the growth and assembly of halos may influence galaxy properties. Through the semi-empirical modeling, we can use observational data on galaxy demographics, including the galaxy stellar mass function and star formation rates (SFRs), along with dark matter assembly histories from N−body simulations (Rodríguez-Puebla et al., 2017). This approach enables us to explore the intricate relationship between halos and galaxies, specifically unraveling the SFH of galaxies over time. By adopting this framework, we gain a direct and interpretable cosmological understanding of galaxy formation and evolution, providing insights into the main mechanisms driving galaxy formation.

In this proceeding, we present the empirical SFH of galaxies as a function of their dark matter halos, utilizing the new semi-empirical model EMPIRE (Rodríguez-Puebla et al. in prep.)

2. The co-evolution between galaxies and dark matter halos

Figure 1 presents SFHs ranging from dwarf galaxies, with stellar masses M_*=10^8M$_\odot$, to giant ellipticals at the centers of large clusters, M_*∼7×10^{11}M$_\odot$. The thick white lines depict the average growth history of central galaxies in dark matter halos with peak[1] masses at z=0 of $M_{\rm peak}$ = $10^{10.5}$, 10^{11}, 10^{12}, 10^{13} and $M_{\rm peak}$=10^{14}M$_\odot$ utilizing merger trees from the SmallMultidark-Planck (SMDP) simulation (see Klypin et al. (2016) for details).

Galaxies, ranging from dwarfs to intermediate masses, $M_* = 10^8 - 10^{10}$M$_\odot$, have been forming stars at a roughly constant rate, approximately 0.1 M$_\odot$/yr for the smallest dwarfs, $M_* < 10^9 M_\odot$, ∼ 0.5 M$_\odot$/yr for small galaxies $M_* \sim 5\times10^9 M_\odot$ and ∼ 5 M$_\odot$/yr for the intermediate ones $M_* \sim 10^{10} M_\odot$. Milky Way (MW)-sized galaxies exhibit a

[1] refers to the largest mass ever achieved by a dark matter halo during its history.

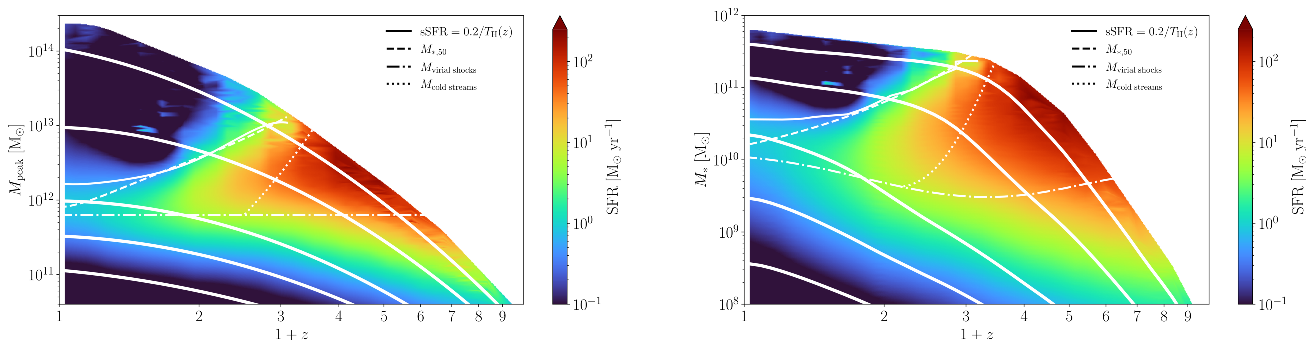

Figure 1. Star formation histories as a function of M_{peak} (left panel) and M_* (right panel) for progenitors at $z = 0$ with masses $M_{\text{peak}} = 10^{11}, 10^{11.5}, 10^{12}, 10^{13}$ and $10^{14}\mathrm{M}_{\odot}$. The solid line indicates the threshold when the sSFR= $0.2/T_{\text{H(z)}}$ where T_{H} is the Hubble time at z, the dashed line indicates when 50% of galaxies are actively forming stars, and the dot-dashed and dotted lines represent the mass limits for coldstreams and shock-heated gas, respectively. The star formation histories of central galaxies in the most massive halos reached their peak below the cold stream mass limit, eventually undergoing quenching.

more complex SFH compared to dwarfs and intermediates. The SFH of MW-sized galaxies increased by a factor of ~ 20 between $z \sim 3.5$ and ~ 1 reaching a maximum of around $10\ \mathrm{M}_{\odot}/\mathrm{yr}$ before declining. In contrast, more massive galaxies, on average, have undergone elevated periods of star formation. The progenitors of giant ellipticals reached an average of $\sim 200\ \mathrm{M}_{\odot}/\mathrm{yr}$ between $z \sim 3-4$, followed by a rapid decline.

The formation process of massive galaxies with $M_* > 10^{11}\ \mathrm{M}_{\odot}$ ($M_{\text{peak}} \sim 10^{13}\ \mathrm{M}_{\odot}$) is complex and involves distinct stages. Initially, when their halos had masses below $M_{\text{peak}} \sim 6 \times 10^{11}\ \mathrm{M}_{\odot}$ (approximately $M_* \sim 0.2 - 0.4 \times 10^9\ \mathrm{M}_{\odot}$ for all z) gas accretion was highly efficient due to the short cooling time compared to the dark matter's dynamical time. During this phase, gas freely fell into the galaxy, leading to an elevated period of star formation and causing galaxies to grow by approximately two orders of magnitude from $z \sim 6-8$ to $\sim 3-5$.

As halos reached masses around $M_{\text{peak}} \sim 6{\times}10^{11}\ \mathrm{M}_{\odot}$ the incorporated gas was heated by virial shocks, resulting in longer cooling times. The gas temperature rose to levels where baryonic cooling efficiency decreased, limiting cold gas from forming stars. If the cooling time was shorter than the halo's dynamical time, the gas fell (within a cooling radius) and settled in the galaxy (White & Frenk, 1991). Alternatively, if the cooling time was longer, the gas was unable to radiate thermal energy, forming a (quasi-) hydrostatically balanced atmosphere (halo quenching, Dekel & Birnboim (2006)). Surprisingly, the empirical evidence that is deduced from Fig. 1 shows that galaxies continued to exhibit elevated periods of star formation even as most of the progenitors of today's massive galaxies crossed the halo mass quenching transition (dot-dashed line).

It is worth noting that at intermediate redshifts, $z \sim 2-4$, hot halos could be penetrated by cold streams (Kereš et al., 2005), supplying sufficient gas to sustain star formation in massive halos between $z \sim 2-5$. This gas supply facilitated not only mass growth but also an increase in central density, contributing to the growth of supermassive black holes (SMBHs), coinciding with the peak epoch of high SMBH accretion (Kormendy & Ho 2013). As cold streams became less efficient and halo quenching took over (the region above the dotted line in Figure 1), the star formation history (SFH) experienced a strong suppression by $\sim 2-3$ orders of magnitude, below $z \sim 1-2$. Specifically, the sSFR dropped below $0.2/T_{\text{H(z)}}$ where T_{H} is the Hubble time at z, leading these galaxies to become part of the population of quiescent galaxies (solid and dashed lines). Despite the suppression of SF, galaxies were still able to grow by a factor of $\sim 2-3$ through galaxy mergers since $z \sim 2$.

3. Conclusion

In this work, we explored the complex interplay between galaxies and their halos, shedding light on the SFH of galaxies over cosmic time using the semi-empirical model EMPIRE. The presented SFHs in Figure 1 unveil the varied evolutionary trajectories of galaxies, spanning from dwarfs to massive ellipticals. Particularly noteworthy are the discernible growth stages observed in the progenitors of massive galaxies. The data aligns with the notion that, at higher redshifts, cold streams played a key role in sustaining star formation in massive galaxies, while virial shock heating might become more prominent at lower redshifts.

References

Dekel, A., & Birnboim, Y. 2006, MNRAS, 368, 2, doi: 10.1111/j.1365-2966.2006.10145.x

Kereš, D., Katz, N., Weinberg, D. H., & Davé, R. 2005, MNRAS, 363, 2, doi: 10.1111/j.1365-2966.2005.09451.x

Klypin, A., Yepes, G., Gottlöber, S., Prada, F., & Heß, S. 2016, MNRAS, 457, 4340, doi: 10.1093/mnras/stw248

Rodríguez-Puebla, A., Primack, J. R., Avila-Reese, V., & Faber, S. M. 2017, MNRAS, 470, 651, doi: 10.1093/mnras/stx1172

White, S. D. M., & Frenk, C. S. 1991, ApJ, 379, 52, doi: 10.1086/170483

“XVII LARIM”, Montevideo, Uruguay, November 27 - December 1, 2023.Volume Editors: Gonzalo Tancredi, Cecilia Mateu & Juan José Downes