Francesco's Legacy - Star formation in space and time

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Star formation through cosmic space and time as traced by Milky Way progenitors

Abstract

In this work the close relation between cosmic star formation and the properties of galaxies is investigated in terms of feedback processes acting through cosmic space and time. Stars not only shape the chemical composition of the galactic ISM by enriching the surrounding gas with metals but the transfer of their ionizing radiation also changes the temperature and ionization status of the interstellar and intergalactic medium. Successive generations of galaxies evolve in redshift regulated by chemical and radiative feedback processes acting between cosmic environments.
By adopting the recent semi-analytical model of galaxy formation GAMESH [1,5] we explore how chemical and radiative feedback act through cosmic times and connect the current generation of galaxies with their candidate progenitors as suggested by a series of recent observations.

GAMESH: Star formation along galaxy evolution

The galaxy formation run has been performed with GAMESH [1,5] interfacing a dark matter simulation of an isolated Milky Way (MW)-like halo and its Local Group (LG), with a customized version of the data-constrained, semi-analytic model GAMETE [2,3] and the latest version of the radiative transfer code CRASH [4].

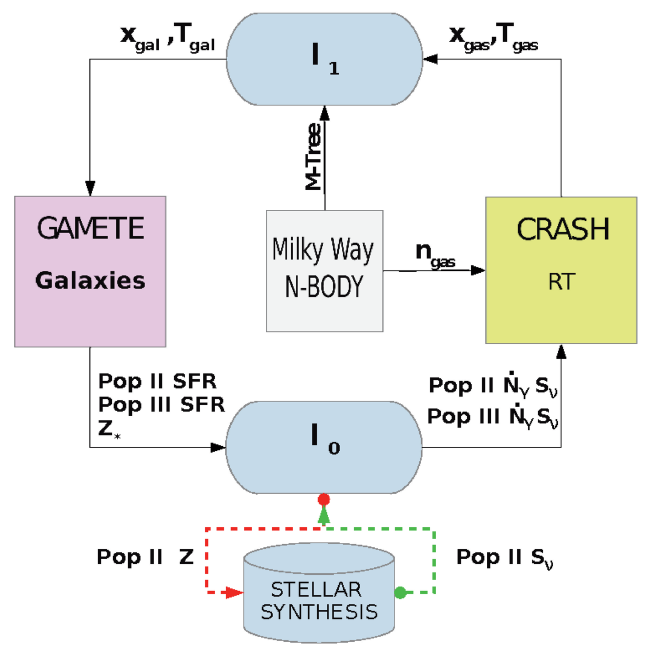

Figure 1: GAMESH pipeline logic at fixed redshift z_i. The quantities x_{gal}, T_{gal}, x_{gas} and T_{gas} refer to the ionisation fractions and temperatures of the gas in the grid cells containing galaxies and in the simulated domain, respectively. The gas number density projected into the grid used by CRASH is indicated as n_{gas} and the global set of information provided by the N-body merger tree as M-Tree. The quantities used by interactor I_0 are the star formation rates (SFR) and the metallicity of the stars Z_*.

The GAMESH pipeline is then capable to:

- **compute the baryonic evolution of the dark matter halos by accounting for different chemical and radiative feedback schemes.**
- **ensure that the MW galaxy has the observed values of stellar, gas and metal mass: M_*, M_{gas}, M_Z at z=0 by calibrating the star formation efficiency on MW observations.**

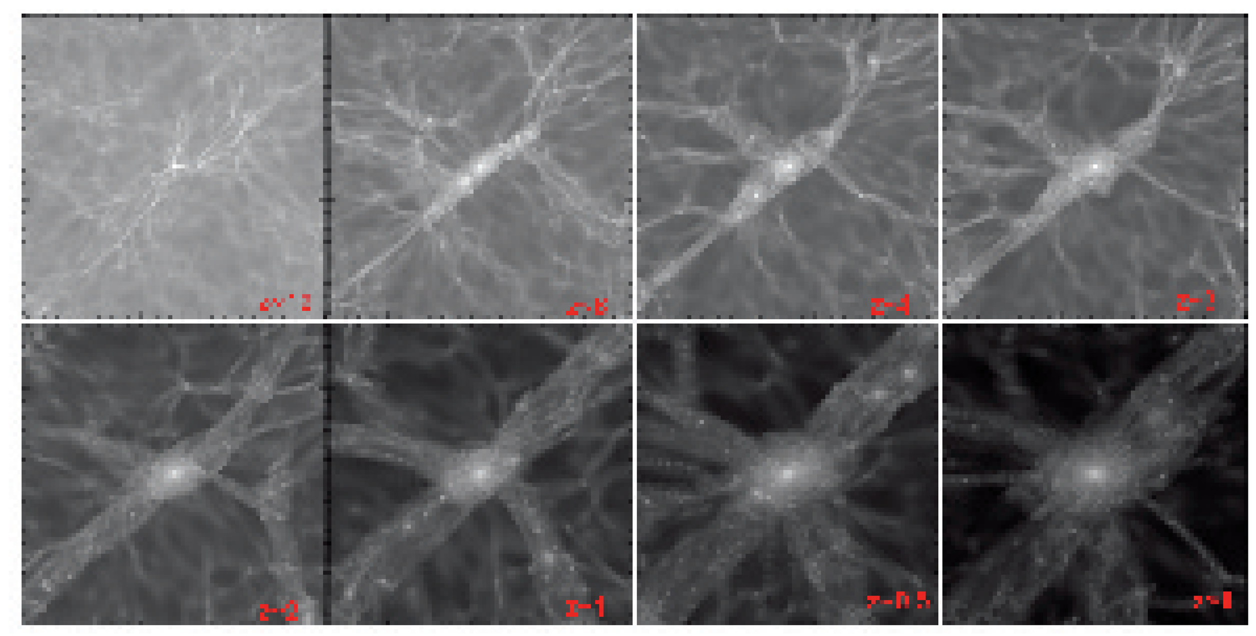

Figure 2: Slice cuts of the LG evolution at various redshits. The panels show the DM density map obtaining by projecting the DM mass in each cell of the spatial grid. The total volume is 4 cMpc comoving mapped on a grid of 512 cells/side, for a spatial resolution of r = 7.8 ckpc.

-> The stellar populations of the Milky Way galaxy can be described with a great level of accuracy

-> The stellar population histories of the MW and its companion galaxies can be explored in detail

Results: Local Group properties

Properties of simulated galaxies surrounding the MW have been verified to satisfy a large number of observational constrains: the observed galaxy main sequence, the mass-metallicity and the fundamental plane of metallicity relations in 0 < z < 4. GAMESH also accounts for the correct stellar mass evolution of candidate MW progenitors in 0 < z < 2.5.

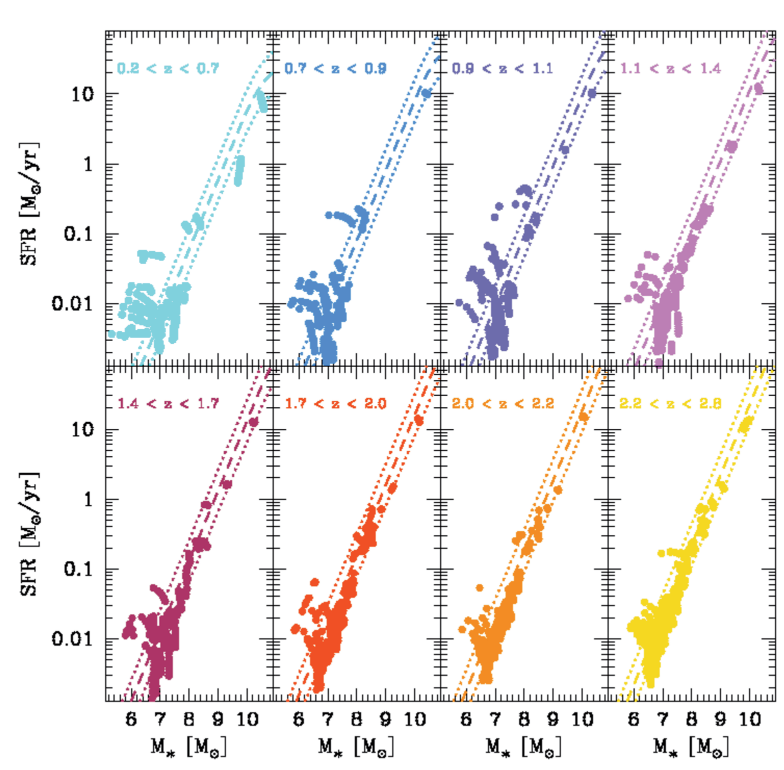

Figure 3: the SFR as function of M_* of all MW progenitors in different z bins. Points represent the simulated systems, while the dashed line shows the analytic fit to the galaxy main sequence at the central redshift of the bin [8]. Dotted lines are a factor of 2 above/below the fit.

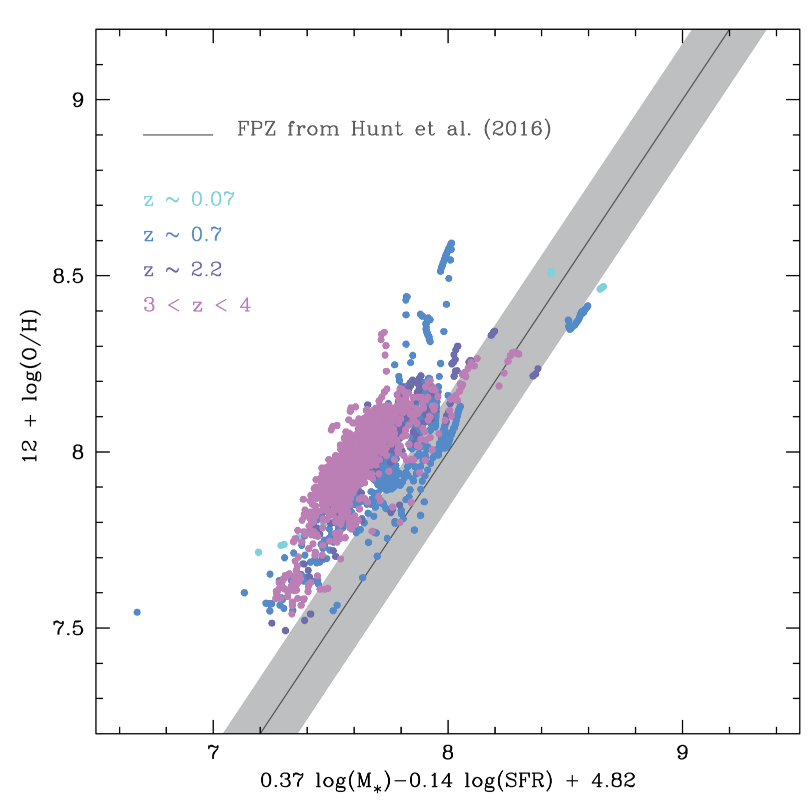

Figure 4: distribution of the MW progenitors relative to the Fundamental Plane of metallicity [7]. All the simulated systems at z = 0.07, 0.7, 2.2 and at 3< z < 4 are shown with data points. Dashed lines with shaded regions show the observed fits.

Conclusions:

- The most massive galaxies among the MW progenitors lie within a factor of 2 of the galaxy main sequence from z = 2.5 to z = 0.
- The predicted SFRs show an increasing scatter towards low stellar mass systems due to the rising importance of feedback effects.
- Agreement found with the distribution of the simulated galaxies with the observed FPZ [7] at 0 < z < 4.

Since these scaling relations are believed to originate from the interplay between gas accretion, star formation and supernova-driven outflows, we conclude that the description of these physical processes obtained by GAMESH leads to results consistent with observations.

Results: star formation rates

GAMESH can study the evolution of galaxy populations and their stellar content by following the standard classification of DM haloes in mini- and Lya cooling haloes.
Within each family it follows, in particular, their SFR, M_* , M_Z along the redshift.

At all but the highest redshifts, the SFR of the MW is dominated by a multiplicity of galaxies in Lya cooling haloes, hosting Pop II stars. These systems are progressively accreted by the major branch of the MW merger tree, which provides the dominant contribution to the SFR at z < 1. The cumulative contribution of star-forming minihaloes in the LG is comparable to the SFR along the MW merger tree at z > 6, indicating that these systems provide an important source of ionizing photons.

Due to efficient metal enrichment, Pop III stars are confined to form in the smallest minihaloes at z > 16, and their formation rate is larger in the LG than along the MW merger tree. This suggests that traces of Pop III star formation are not confined to the MW and its satellites but may be found in external galaxies of the LG, although their detection may be challenging even for the next generation of telescopes.

We find that a large number of minihaloes having old stellar populations are dragged into the MW or can survive in the local Universe. However, due to the effect of radiative feedback, minihaloes collapsing at z < 6 remain instead dark because they never experienced star formation.

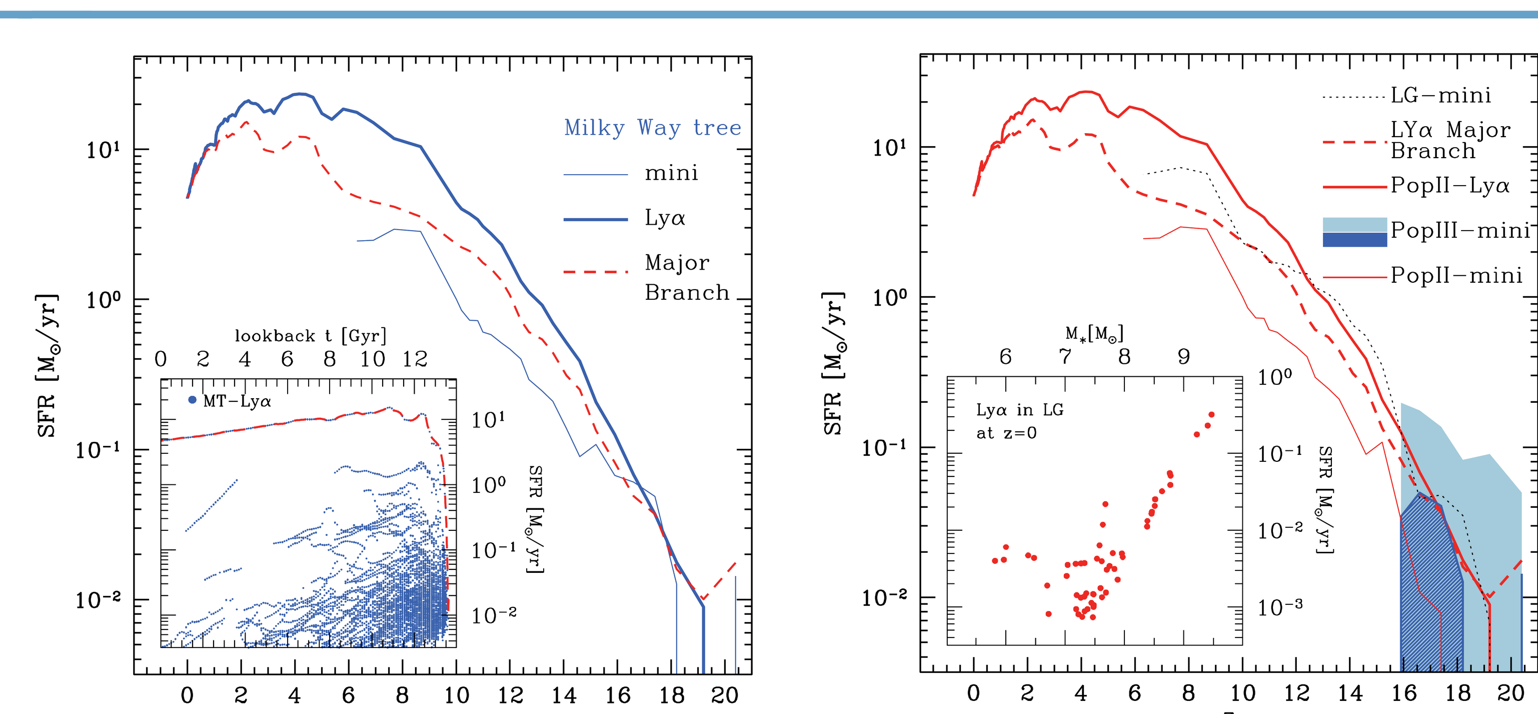

Figure 5: redshift evolution of the total SFR of galaxies hosted in minihaloes and Lya cooling haloes along the merger tree of the MW and in the LG. Left-hand panel: SFR of minihaloes and Lya cooling haloes belonging to the MW merger tree (solid thin and thick blue lines, respectively). The dashed red line shows the SFR along the major branch of the MW (the most massive halo at each redshift). The panel inset shows the SFR along the major branch (red dashed line) as function of the lookback time t (Gyr) and the SFR of all the Lya cooling haloes as blue points. Right-hand panel: SFR of Pop II stars along the MW merger tree and hosted in minihaloes (solid thin red line) and in Lya cooling haloes (solid thick red line). The dotted black line indicates the Pop II SFR history in all the minihaloes of the LG. Pop III SFRs along the MW merger tree and in the LG are indicated by shaded areas (blue and cyan, respectively). For comparison, we also show the SFR along the MW MB (red dashed line). The panel inset shows the SFR versus stellar mass of all galaxies hosted by Lya cooling haloes in the LG at z= 0.

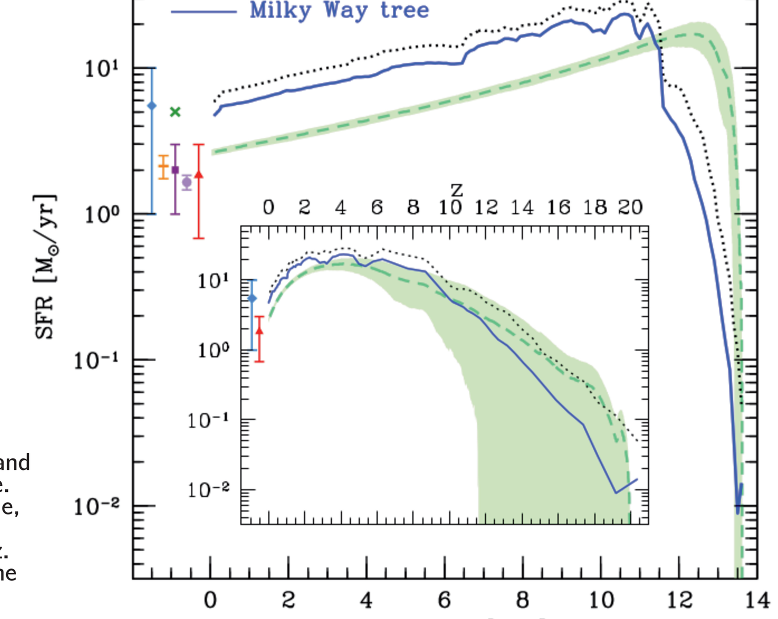

Figure 6: total SFR in the MW merger tree (solid blue line) and in the LG (dotted black line) as function of the lookback time. The average SFR found in [6] is shown with dashed green line, with the shaded region showing the 1σ dispersion. In the enclosed panel the same quantities are shown as function of z. Data points with error bars, when available, are taken from the literature [5].

References

[1] Graziani L., Salvadori S., Schneider R. et al., 2015, MNRAS, 449, 3137

[2] Salvadori S., Schneider R., Ferrara A., 2007, MNRAS, 381, 647

[3] Salvadori S., Ferrara A., Schneider R., et al.,, 2010a, MNRAS, 401, L5

[4] Graziani L., Maselli A., Ciardi B., 2013, MNRAS, 431, 722

[5] Graziani, L., de Bennassuti, M., Schneider R. et al., 2017, MNRAS, 469, 1101-1116

[6] de Bennassuti M., Schneider R., et al., 2014, MNRAS, 445, 3039

[7] Hunt L., Dayal P., Magrini L., Ferrara A., 2016a, MNRAS, 463, 2002

[8] Schreiber C., et al., 2015, AAP, 575, A74