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Simulations of disc galaxies: the effect of AGN feedback

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Abstract. With this project we carried out an extensive set of cosmological hydrodynamical simulations for the formation of disk galaxies using the Gadget-3 TreePM/SPH code. This set of simulations includes an advanced sub-resolution model for the description of a multi-phase interstellar medium and the ensuing star formation process. It was designed to study the effect of feedback resulting from gas accretion onto Super-Massive Black Holes hosted at the center of galaxies on the resulting history of star formation and morphology of such disk galaxies.

1. Introduction

The role of AGN (active galactic nucleus) feedback is key in controlling the star formation and the gas cooling processes in the Universe, and in regulating the formation and evolution of galaxies. The effect of the energy and momentum released during gas accretion onto super-massive black holes (SMBHs) on the forming galaxy and its surrounding medium across cosmic time is complex, as it involves phenomena still not thoroughly understood, yet challenging. Our work is aimed at investigating the impact of AGN feedback on the interstellar medium (ISM) and on the present-day properties of late-type galaxies, using cosmological hydrodynamical simulations.

2. Simulations: code and initial conditions

Our simulations adopt zoomed-in initial conditions leading to the formation of a halo of $\sim 2 \cdot 10^{12} M_{\odot}$ at redshift $z = 0$ and an improved version of the GADGET-3 code (non-public evolution of GADGET-2, Springel 2005). We use the sub-resolution model MUPPI (Murante et al., 2010, 2015; Valentini et al. 2017) for star formation, stellar feedback, and to describe several processes occurring below the resolution limit of our simulations. Our sub-resolution model describes a multiphase interstellar ISM, and accounts for the presence of a hot and a cold phase in pressure equilibrium, plus a possible stellar component. We exploit this feature of the model in order to study the coupling AGN feedback energy to different phases of the ISM over cosmic time.

3. Preliminary results

We benefitted of the assigned resources to carry out first a set of lower-resolution preparatory simulations to explore the parameter space of our AGN feedback model. These simulations allowed us to constrain the free parameters of our model, determining what we now

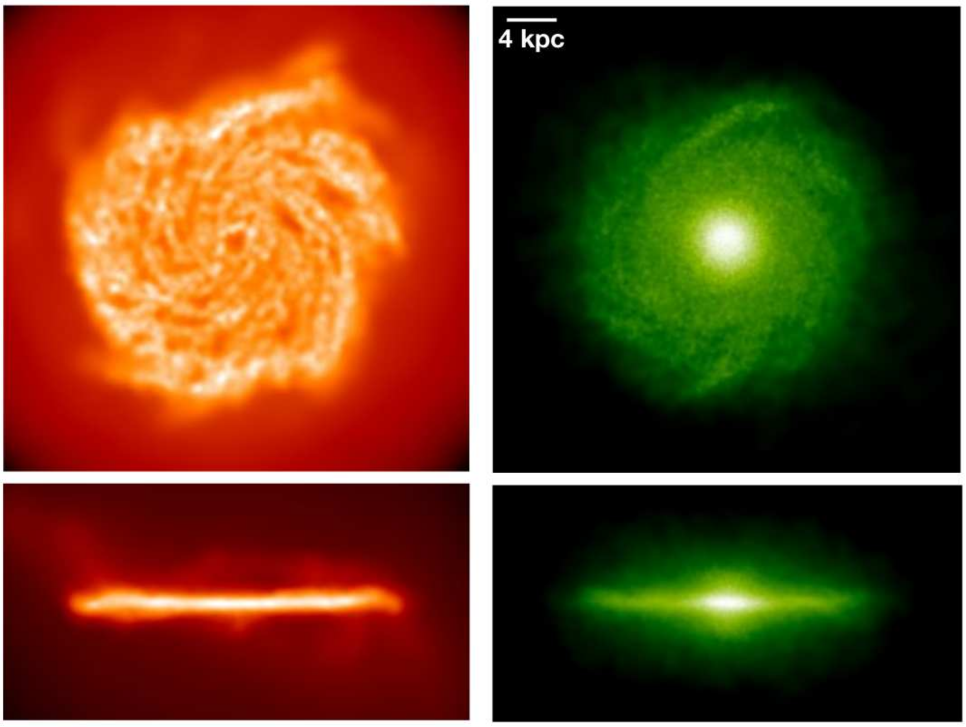

Fig. 1. Face on (upper panels) and edge on (lower panels) views for the gas density (left) and stellar density (right) for the cosmological simulation of a disk galaxy (see text).

consider optimal values for BH seed mass, radiative and feedback efficiencies. Once we calibrated these parameters, we ran a few higher-resolution simulations to address our goal. We investigated three possible scenarios:

(i) AGN feedback energy coupled thermally and isotropically to the hot ($T > 10^5 K$) and diffuse medium only;
(ii) feedback energy coupled to the diffuse ISM and to the cold component of the multiphase ISM;
(iii) the possibility to use feedback energy supplied to the multiphase ISM to both increase the temperature of the hot phase and make evaporate the cold gas phase.

Here, we show the results for one simulation where the third scenario is implemented. Figure 1 introduces one of the galaxy that we simulated including the AGN feedback. The top panels show face-on projected maps of gas (left) and stellar (right) density at redshift $z = 0$, while the bottom panels depict the edge-on corresponding views. As for the morphology, the galaxy has a limited bulge and a dominant disc, with a clear spiral pattern both in the gaseous and in the stellar components. Figure 2 shows the star formation history for two galaxies that we have simulated. The black curve describes the evolution of the star formation rate for the reference simulation where no AGN feedback is considered. The green curve refers to the galaxy (shown in Figure 1) where the presence of a central massive BH is accounted for. We see that the two galaxies experience a comparable star formation history at early epochs ($z \gtrsim 3$), when the bulge forms. Then the BH growth produces a feedback energy that is injected in the ISM and that pressurises it, pro-

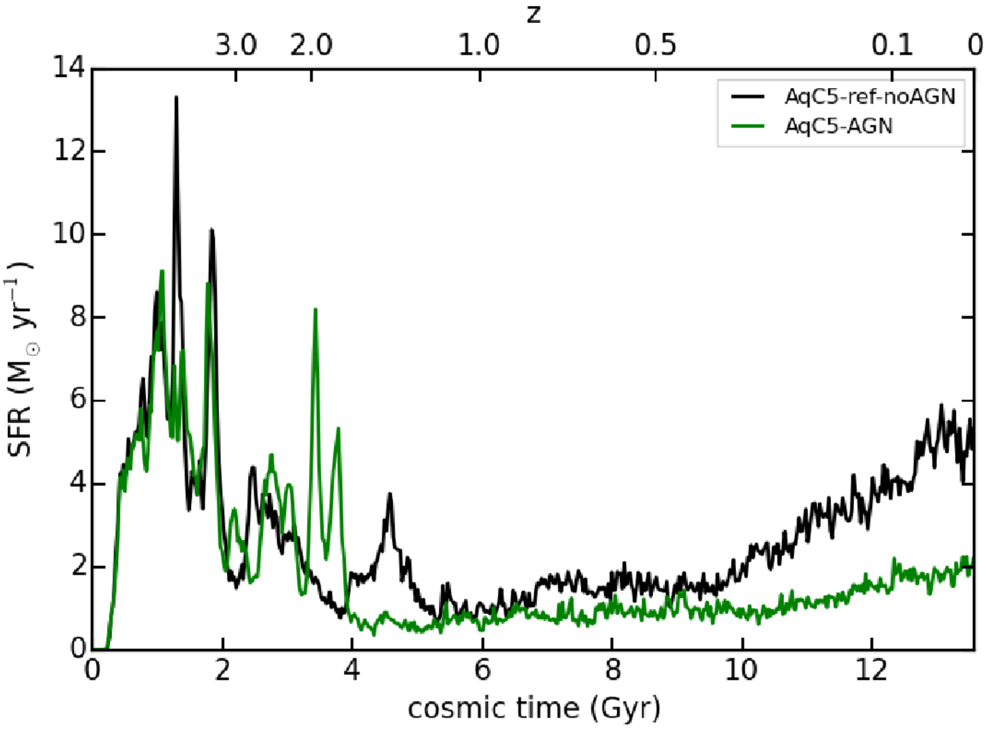

Fig. 2. History of star formation rate for the simulations of the same disk galaxy shown in Fig. 1, carried out by including (green line) and excluding (black line) the effect of feedback from AGN.

ducing a star formation burst at $z \sim 2$. From $z \sim 2$ onwards, when the BH has grown as massive as $M_{BH} \sim 10^6 M_\odot$, AGN feedback suppresses star formation in the galaxy significantly. These preliminary results suggest that the role of AGN feedback is twofold in our galaxies: it is positive as the feedback energy overpressurises the gas and enhances star formation, but also negative, resulting in a reduction or even quenching of the star formation. These findings favour a scenario where the BH feedback can reach a self-regulation. Galaxy stellar mass for the two simulations are: $1.85 \cdot 10^{10} M_\odot$ and $2.72 \cdot 10^{10} M_\odot$ for the galaxy with and without AGN feedback, respectively.

4. This project in perspective

This study has certainly paved the way to our current and future work. It has been preparatory for our ongoing research as it allowed us to calibrate a set of parameters that we are now adopting in simulations, and to outline preliminary trends that have then deserved further investigation. Also, two other computational proposals that have been accepted and that involve the PI and the collaborators have benefitted from this project:

- February 2018 *Simulating a high resolution disc galaxy with MUPPI and AGN feedback* (PI: G. Murante) at CINECA (Italy), 2000 K CPU hours awarded on the Marconi A1 cluster.

- July 2017 *Impact of AGN feedback on the formation and evolution of spiral and elliptical galaxies* (PI: A. Bressan) at CINECA (Italy), 600 K CPU hours awarded on the Marconi A2 cluster.

5. MoU CINECA-INAF with respect to generic calls: advantages

The main advantages of the time assignment through the INAF-CINECA MoU can be summarised in the following points.

- Higher flexibility in the way call are opened, proposals are prepared and computing time allocated. This is quite important for the development of HPC projects, especially those requiring a preparation phase, with intensive tests and small- size production runs, in view of larger allocations for intensive production.
- Evaluation by a panel made by experts on numerical astrophysics, also including a technical evaluation by a support person who is specifically expert on the HPC needs of the INAF community.
- Contributing to foster the growth of a HPC community within INAF, that is characterized by specific needs in terms of code development, testing and porting, and in terms of access to HPC facilities.

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