Galaxy Evolution and Feedback across Different Environments
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Feedback from central massive black holes in galaxies using cosmological simulations

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Abstract. Gas accretion onto central supermassive black holes of active galaxies and resulting energy feedback, is an important component of galaxy evolution, whose details are still unknown especially at early cosmic epochs. We investigate BH growth and feedback in quasar-host galaxies at $z \geqslant 6$ by performing cosmological hydrodynamical simulations. We simulate the $2R_{200}$ region around a $2 \times 10^{12} M_{\odot}$ halo at $z = 6$, inside a (500 Mpc)^3 comoving volume, using the zoom-in technique. We find that BHs accrete gas at the Eddington rate over $z = 9-6$. At $z = 6$, our most-massive BH has grown to $M_{\rm BH} = 4 \times 10^9 M_{\odot}$. Star-formation is quenched over $z = 8-6$.

Keywords. galaxies: nuclei, quasars: supermassive black holes, cosmology: simulations

1. Introduction

Active galactic nuclei (AGN) emit enormous amounts of energy powered by the accretion of gas onto their central supermassive black holes (SMBHs) (Rees 1984). SMBHs of mass $\geqslant 10^9 M_{\odot}$ are observed to be in place in luminous quasars by $z \sim 6$, when the Universe was less than 1 Gyr old (Wu *et al.* 2015). It is difficult to understand how these early SMBHs formed over such short timescales (Matsumoto *et al.* 2015).

AGN feedback should operate mostly in the negative form quenching star formation (Schawinski *et al.* 2006). In the host galaxy of the quasar SDSS J1148+5251 at $z = 6.4$, Maiolino *et al.* (2012) detected broad wings of the [CII] line tracing a massive outflow with velocities up to ± 1300 km/s. The physical mechanisms by which quasar outflows affect their host galaxies remain as open questions.

We performed zoomed-in cosmological hydrodynamical simulations of quasar-host galaxies at $z \geqslant 6$ and study their outflows. Details of this work is in Barai *et al.* (2018).

2. Numerical method

The initial conditions are generated using the MUSIC† software (Hahn & Abel 2011). We use the code GADGET-3 (Springel 2005) to perform our zoom-in simulations. First, a dark-matter (DM) only low-resolution simulation is carried out of a (500 Mpc)^3 comoving volume, using 256^3 DM particles, from $z = 100$ up to $z = 6$. We select the most-massive halo at $z = 6$ to zoom-in, which has a total mass $M_{\rm halo} = 4.4 \times 10^{12} M_{\odot}$, and a virial radius $R_{200} \simeq 511$ kpc comoving. We execute a series of four simulations, all incorporating metal cooling, chemical enrichment, SF and SN feedback. The first run has no AGN included, while the latter three explore different AGN feedback models.

† MUSIC - Multi-scale Initial Conditions for Cosmological Simulations: https://bitbucket.org/ohahn/music

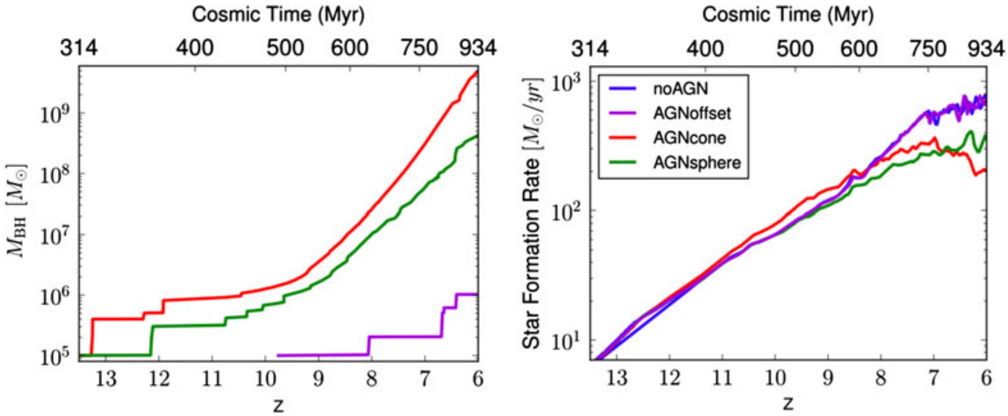

Figure 1. Left panel: BH mass growth with redshift of the most-massive SMBH in each run. Right panel: Sum total star formation rate (in $M_\odot yr^{-1}$) as a function of redshift. The different colours discriminate the various runs: *AGNoffset* - violet, *AGNcone* - red, *AGNsphere* - green.

3. Results and Discussion

3.1. *Black hole growth*

The redshift evolution of the most-massive SMBH mass in the three AGN runs is plotted in Fig. 1 - left panel. Each BH starts as a seed of $M_{\rm BH} = 10^5 M_\odot$, at $z \sim 14$ in the runs *AGNcone* and *AGNsphere* ($z \sim 10$ in *AGNoffset*). The dominant mode of BH growth occurs over $z = 9-6$ in runs *AGNcone* and *AGNsphere*, corresponding to Eddington-limited gas accretion where Eddington ratio = 1. The BH has grown to $M_{\rm BH} = 4 \times 10^9 M_\odot$ at $z = 6$ in run *AGNcone* (red curve). The BH grows 10 times more massive at $z = 6$ in the *AGNcone* case than in the *AGNsphere* run. This is because more gas can inflow along the perpendicular direction to the bi-cone, and accrete onto the BH.

3.2. *Star formation*

The star formation rate (total in the simulation box) versus redshift of the four simulations is displayed in Fig. 1 - right panel. The SFR rises with time in all the runs initially, and continues to increase in the *noAGN* case without a BH. The SFR in run *AGNoffset* is almost similar to that in the run *noAGN*, because the BHs are too small there to generate enough feedback. The models suppress SF substantially from $z \sim 8$ onwards, when the BHs have grown massive and generate larger feedback energy. Thus, we find that BHs need to grow to $M_{\rm BH} > 10^7 M_\odot$ in order to suppress star-formation. BH feedback causes a reduction of SFR up to 4 times at $z = 6$: from $800 M_\odot$/yr in the *noAGN* run, to $200 M_\odot$/yr in run *AGNcone*, and $350 M_\odot$/yr in run *AGNsphere*.

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