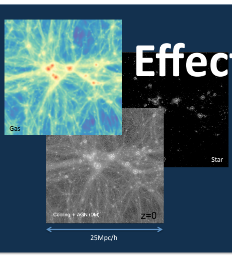

Effect of AGN-Jet Feedback on Star Formation Histories in AMR Cosmological Simulations

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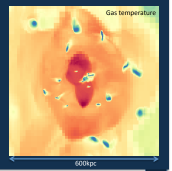


ABSTRACT

Observational evidence that galaxy and super-massive black hole formation and evolution are tightly coupled has become overwhelming. Theoretical arguments can easily be made as to why AGN feedback should regulate star formation. However, it is yet unclear how, to what extent, and when in the life of a galaxy such an interplay occurs. We present preliminary results of the first attempt to shed light on this complex issue using AMR cosmological simulations. We find that intermittent, sub-relativistic AGN jets efficiently suppress the cooling and star formation at low redshift (z<1), reasonably reproducing the recent star formation histories and optical colours. However, our model still produces slightly more massive galaxies than the observed, implying that star formation at high redshift is not suppressed enough.

1. Simulations

- AMR code : RAMSES (Teyssier 02)
- Physical box size: $(25 Mpc/h)^3$
- Resolution: 256^3 (DM particle), $m_{*min}=4 \times 10^6 M_{sun}$, L_{min}~1kpc
- Halo finding: MSM AdaptaHop (Tweed et al. 09)
- Physical ingredients

We have included radiative cooling, star formation, UV background heating, black holes (BHs) and AGN jets. We link the AGN energy release with the BH growth. BHs accrete gas at the 'boosted' Bondi-Hoyle-Lyttleton rate (Booth & Schaye 09) and a fraction of the BH accretion energy is returned in the form of sub-relativistic jets with the same momentum profile as in Omma et al. (2001). The jet axis fluctuates as it is aligned with the angular momentum of its host galaxy (Dubois et al. 2010, submitted).

Table 1. Summary of physical ingredients

Model	Cooling	SF	BH & AGN Jet	Supernova
Run-Cool	Y	Y	N	N
Run-AGN	Y	Y	Y	N

2. Effect of Jets

Episodic, sub-relativistic jets have a mechanical and/or thermal impact depending on the physical properties of the surrounding gas. For instance, they can blow dense gas out of a region with radius r_{cool} and mix this gas with high entropy gas. However this process also create strong shocks which can heat the gas to high temperatures.

Nevertheless, not all the jets are effective at suppressing star formation. Fig. 1 plots a serious of quantities averaged within the main galaxy virial radius as a function redshift for two galaxies: Galaxy A $_{(left)}$ and B $_{(right)}$. Even when major merger occurs (see violet dashed vertical lines at z~1.5 for Galaxy A and z~0.2 for Galaxy B), leading to a jump in accretion rate (eta_{Edd}) and therefore the BH mass (M_{BH} plot), the subsequent AGN feedback cannot entirely quench the star formation (circled orange region in dM_star/dt for Galaxy A). If, on the other hand, a galaxy has much less dense gas pre-merger (shaded green region in M_dense plot for Galaxy B), star formation is suppressed much more efficiently (circled orange region in dM_star/dt for Galaxy B) after a significant merger. Note that Galaxy B had its quantity of dense gas reduced prior to the significant merger by a series of minor mergers (see peaks in BH accretion rate plot eta_Edd and the high outflow of hot gas dM_out/dt prior to the significant merger for Galaxy B).

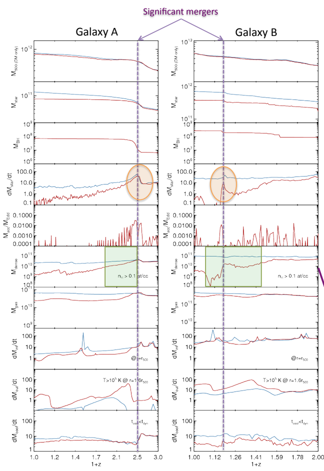


Figure 1 Physical properties of two galaxies as a function of redshift. Blue (*Run-Cool*), Red (*Run-AGN*)

After the major merger, star formation in Galaxy A is gradually suppressed by a series of encounters and mergers (reflected in the peaks in the accretion plot eta_Edd and the high dM_out/dt)

3. Recent SF, Colours, and BH accretion

- Figs 2-3 show the importance of AGN feedback in reproducing the physical properties of galaxies. As pointed out by many authors, galaxies are predicted to be blue and actively star-forming in model without AGN jets (i.e. *Run-Cool*). This implies gravitational heating by infalling satellites is unable to offset the cooling at low redshift.

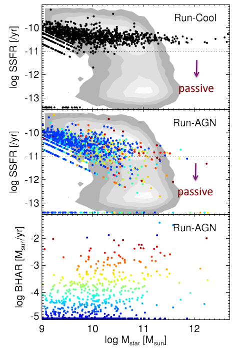


Figure 2 Specific star formation rates (SSFR) and black hole accretion rates (BHAR) at z=0 of galaxies with (middle and bottom panels) and without (top panel) AGN jets. Observational estimates of SSFR are shown as gray shading (Salim et al. 2007).

Most galaxies showing suppressed recent star formation relative to *Run-Cool* are likely to have AGN activity, but since the jets are sub-relativistic, star formation could either linger or be suppressed even if there is very little current accretion onto black holes (blue points).

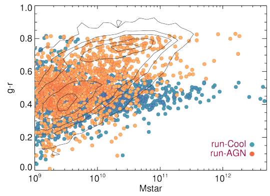


Figure 3 (g-r) colours of *Run-Cool* (green points) and *Run-AGN* (orange points) runs. Contours indicate the observed (g-r) colour distribution from SDSS (Yang et al. 2007). Run with AGN jets show good agreement with observation.

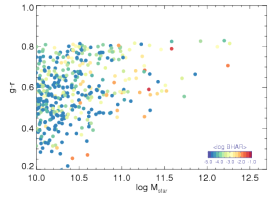


Figure 4 Black hole accretion activity and (g-r) colour. Massive galaxies in green valley (0.5 < g-r < 0.7) show high BHAR in general

4. AGN Jets at high redshifts

Massive galaxies (M_{star}~$10^{11}M_{sun}$) at high redshift are believed to be fed by cold accretion and numerous merging events. Moreover since gas discs are much denser at high redshift, momentum injection is likely to be less effective than at low redshift despite the fact that black holes are probably more massive for a given stellar mass (i.e. Di Matteo et al. 2008)

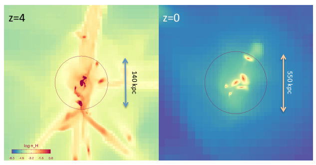


Figure 5 Gas density map of two central galaxies with similar stellar mass (~$10^{11}M_{sun}$). Circles denote r_{500} of each cluster. Dense filaments can be seen at high redshift (left). The colour table is the same for both figures.

5. Evolution of galaxy stellar mass

At high redshift (z>2) there is no significant difference in stellar mass between mass between *Run-Cool* and *Run-AGN*

At z<2 star formation is suppressed in massive galaxies. However, since most (30-50%) of the stars that constitute z=0 galaxies formed at redshift z>2, the feedback only suppresses the growth of stellar component by a factor of a few at z=0.

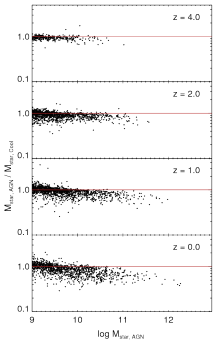
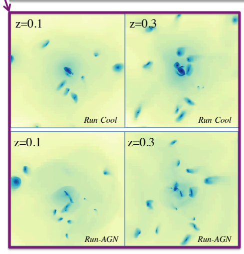


Figure 6 Evolution of galaxy stellar mass for *Run-Cool* versus *Run-AGN*.



Gas density map of Galaxy B

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