Viscous time lags between starburst and AGN activity

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1. Introduction

Motivated by, for instance, observed correlations between the mass of an AGN’s central black hole and the host galaxy’s velocity dispersion (MBH-σ correlation, e.g., Gebhardt et al., 2000) and between black hole mass and bulge mass (e.g., Kormendy and Richstone, 1995), there is an ongoing debate whether, and if so, how starbursts and AGN are connected to each other. Di Matteo et al. (2005), for instance, explain such correlations (div $v < 0$) as due to a thermal AGN feedback that expels enough gas from the galaxy to quench further star formation and AGN activity and explains the observed MBH-σ correlation. In their merger simulations starburst and AGN activity occur simultaneously, but recent observations show that AGN activity may be delayed with regard to star formation activity by time scales of 50-250 Myr (e.g., Wild et al., 2010). We explain this time lag by modelling the loss of angular momentum and the ensuing inflow of gas towards the centre of the newly forming galaxy before reaching the centre the gas must first lose its angular momentum, which it does firstly due to gravitational instabilities. Some 100 parsecs from the centre it forms an accretion disc and loses further angular momentum due to viscous torques. The gas finally reaches the black hole, leading to the activity of the galactic nucleus.

2. Numerical Methods

We simulate galaxy collisions using the TreeSPH code GADGET-2 (Springel, 2005). We include star formation, AGN evolution and AGN feedback as described as follows:

4. Results: SFR and BHAR

5. Results: MBH-σ correlation

3. Model Setup

We consider two gas rich disc galaxies that are on a parabolic collision course and then merge, forming a gas poor elliptical galaxy. Due to the merging process tidal forces and the collision and compression of the galaxies gas masses provoke enhanced star formation and therefore trigger a starburst. Moreover tidal forces cause the inflow of gas towards the centre of the newly forming galaxy. Before reaching the centre the gas has to lose its angular momentum, which it does firstly due to gravitational instabilities. Some 100 parsecs from the centre it forms an accretion disc and loses further angular momentum due to viscous torques. The gas finally reaches the black hole, leading to the activity of the galactic nucleus.

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Star formation

Star formation takes place in gas clouds whose density $\rho$ exceeds a critical density $\rho_{\text{crit}}$, and that are in a state of collapse (div $v < 0$). If these two criteria are fulfilled, the star formation rate $\dot{M}_s$ is calculated via a local star formation law (e.g., Katz, 1992):

$$\dot{M}_s = c_s \frac{\rho_{\text{free}}}{t_f}$$

where $c_s = 0.1$ is the star forming efficiency, $t_f = \sqrt{\text{SFR} / 2 \rho_0}$ the free-fall time and $\rho_{\text{free}}$ the mass of the gas cloud.

Modeling the AGN

The AGN is represented by an accretion disc particle (ADP, Power et al., 2011) that accretes gas particles if their distance to the ADP falls below the ADP’s accretion radius $R_{\text{acc}}$. We set $R_{\text{acc}} = 300$ pc where viscous processes start to play a dominant role for the accretion of material onto the black hole. The black hole growth rate is calculated via a subgrid model: The ADP contains a black hole and an accretion disc, the mass accreted by the ADP is added to the outer rim of the accretion disc, from which it is accreted towards the black hole. This accretion process is described by solving the equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

that describes the time dependent evolution of the surface density $\Sigma$ of a rotationally symmetric and geometrically thin accretion disc (see, e.g., Pringle, 1981). Here $s$ is the distance to the central black hole, $\omega$ is the angular frequency and $\nu$ is the viscosity of the gas, we use the turbulent $\nu$ viscosity prescription for selfgravitating accretion discs proposed by Duschl et al. (2000).

AGN feedback

Following Debahr et al. (2012) the AGN injects momentum and mass to the surrounding gas of the galaxy. Both the momentum flux $\mathbf{p}$ and the mass outflow $\dot{M}_s$ of the AGN are proportional to its luminosity

$$L = L_{\text{MBH}}$$

with accretion efficiency $\eta = 0.1$ and black hole accretion rate $\dot{M}_{\text{MBH}}$. Each timestep the total mass $M_{\text{MBH}}\Delta t$ and momentum $\mathbf{p}\Delta t$ made available by the AGN are calculated and equally distributed among the surrounding SPH particles.

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4. Results: SFR and BHAR

5. Results: MBH-σ correlation

6. Summary

With only one model setup we were able to reproduce three observational findings that have been identified in galaxies:

(i) The observed time lag between starburst and AGN activity is, in our work, principally caused by a viscous time lag the gas needs to flow through the accretion disc until it reaches the black hole.

(ii) Our results match the observed MBH-σ correlation. As, e.g., Di Matteo et al. (2005) have already shown, AGN feedback is responsible for this relation.

(iii) The large scatter of the MBH-σ correlation is, in our work, caused by the continuing evolution of the black hole mass after the merging event.

References

Price, D. J.: 2007, PASA 24, 159