# 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 ($M_{BH}$-$\sigma$ 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 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 $M_{BH}$-$\sigma$ 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 mass towards the central black hole in the framework of an accretion disc scenario. Thus the time lag between starburst and AGN activity consists of a dynamical lag the gas needs to reach the accretion disc and a subsequent viscous lag the gas needs to flow through the accretion disc until it reaches the black hole.

## 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:

### Star formation

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

$$\dot{M}_* = c_* \frac{M_{gas}}{t_*}$$

where $c_* = 0.1$ is the star forming efficiency, $t_* = \sqrt{3\pi/32G\rho}$ the free-fall time and $M_{gas}$ 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 $R_{acc}$. We set $R_{acc} = 200$ 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 where it is accreted towards the black hole. This accretion process is described by solving the equation

$$\frac{\partial \Sigma}{\partial t} + \frac{1}{s}\frac{\partial}{\partial s}\left[\frac{\frac{\partial}{\partial s}\left(\nu \Sigma s^3 \frac{\partial \omega}{\partial s}\right)}{\frac{\partial}{\partial s}\left(s^2 \omega\right)}\right] = 0$$

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 $\beta$-viscosity prescription for selfgravitating accretion discs proposed by Duschl et al. (2000).

### AGN feedback

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

$$L = \eta c^2 \dot{M}_{BH}$$

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

## 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 first 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.

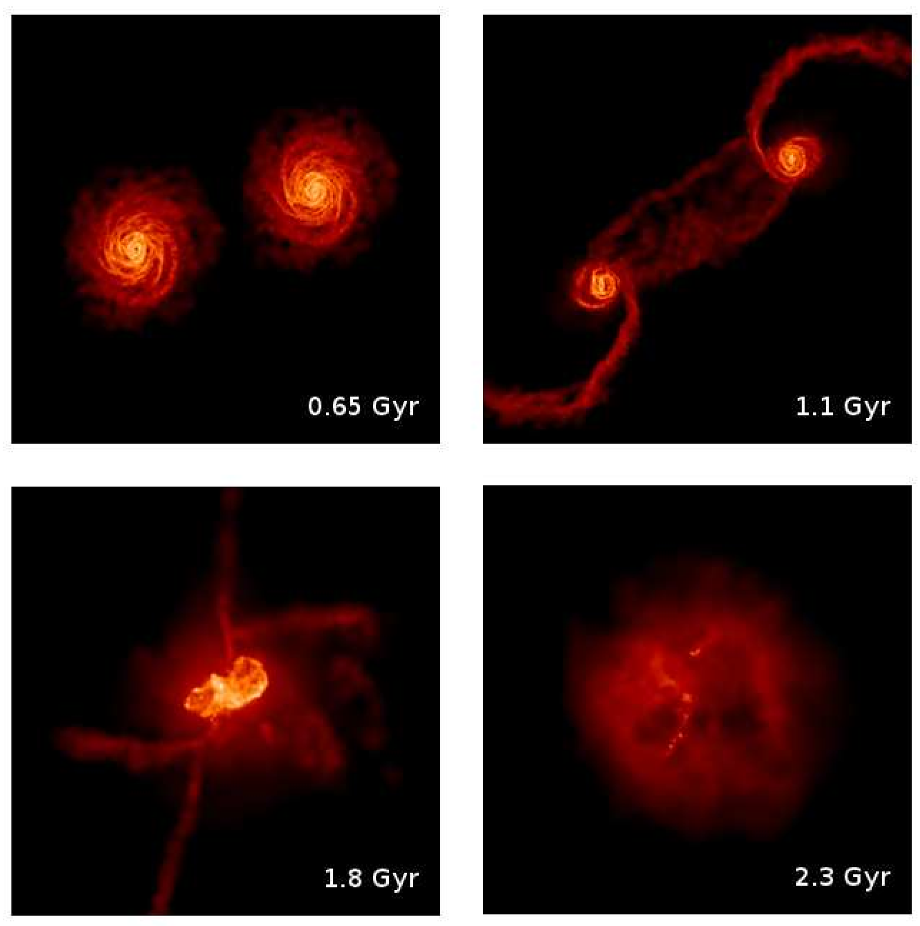


**Figure 1:** The time evolution of the merger event brings the galaxies to their first passage $\sim 0.7$ Gyr after the start of the simulation, they finally merge at 1.8 Gyr and form a gas-poor elliptical galaxy.

## 4. Results: SFR and BHAR

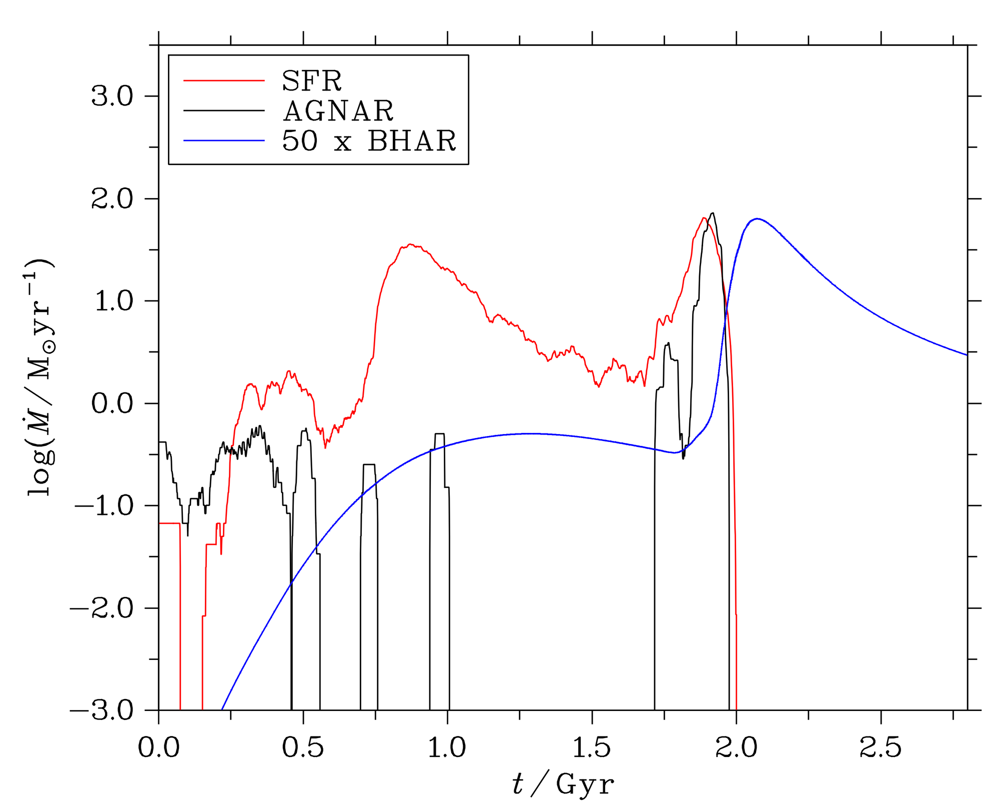


**Figure 2:** Star formation rate (SFR), accretion rate of the AGN (AGNAR) and black hole accretion rate (BHAR) as functions of time. The two merging galaxies have approx. the mass and the size of the Milky Way.

The merging event drives huge amounts of gas towards the centre of the new forming merged galaxy where it causes a starburst with a lifetime of $200 - 300$ Myr and feeds the AGN.
After being devoured by the AGN the gas flows through the accretion disc on a viscous timescale that corresponds to a time lag of approx. $200$ Myr between the starburst and the peak of the BHAR, resulting in a time lag between starburst and AGN activity that is in agreement with observations (e.g., Wild et al., 2010).
Fig. 2 shows that AGN feedback quenches the SFR and the AGNAR, but until the onset of AGN activity huge amounts of mass are inserted into the accretion disc. Thus the BHAR is not quenched by the AGN feedback, the AGN continues evolving for some time after the galaxies have merged.

## 5. Results: $M_{BH}$-$\sigma$ correlation

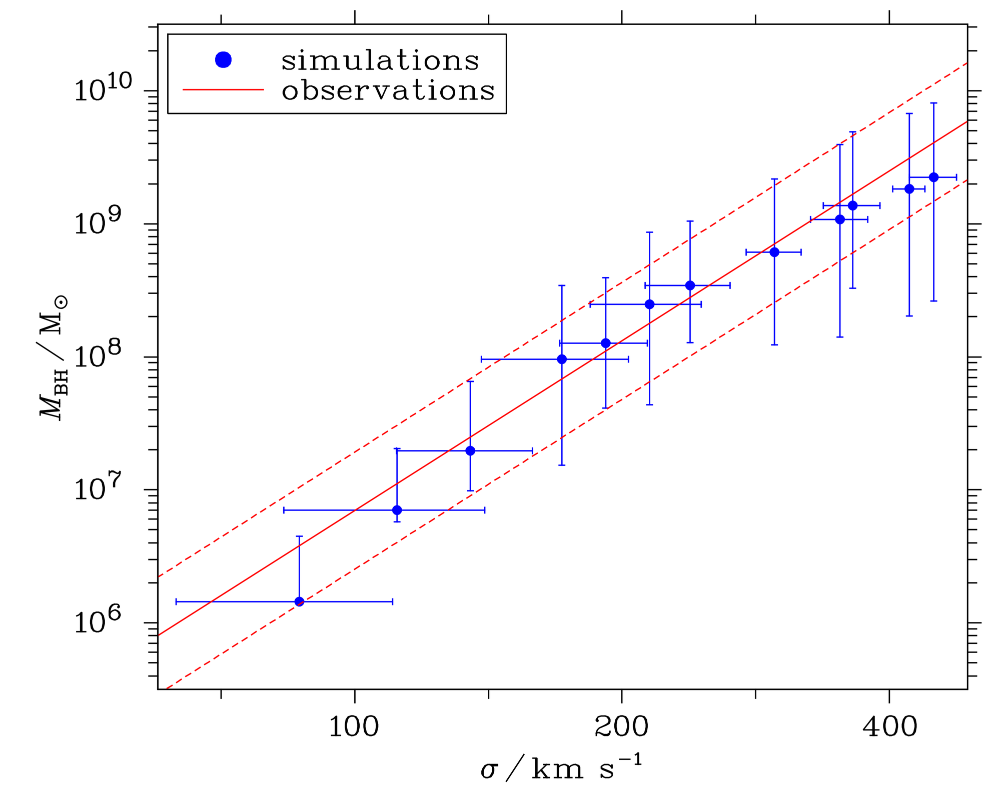


**Figure 3:** Black hole mass $M_{BH}$ as function of the galaxy's stellar velocity dispersion $\sigma$. Blue dots: black hole mass at the time the black hole accretion rate (BHAR) reaches its maximum value. Horizontal bars: error of $\sigma$. Vertical bars: range of black hole mass from the time of the end of the starburst to the time the BHAR decreases to $5\,\%$ of its maximum value. Solid line: observed $M_{BH}$-$\sigma$ correlation with intrinsic scatter (dashed lines) according to Gültekin et al. (2009).

To check the agreement of our model with the $M_{BH}$-$\sigma$ correlation we repeat the calculations for different initial galaxy masses. Fig. 3 shows the mass of the black hole at the time the BHAR reaches its maximum value as function of the stellar velocity disperion of the resulting elliptical galaxy. The results are consistent with the observed correlation.
As the black hole continues growing after the galaxies have merged we additionally plot the range of black hole masses as described in Fig. 3. Our results suggest that this continuing evolution of the black hole mass may contribute to the large scatter of the observed $M_{BH}$-$\sigma$ 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 AGN's accretion disc until it reaches the central black hole.
(ii) Our results match the observed $M_{BH}$-$\sigma$ 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 $M_{BH}$-$\sigma$ correlation is, in our work, caused by the continuing evolution of the black hole mass after the merging event.

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