Viscous time lags between starburst and AGN activity

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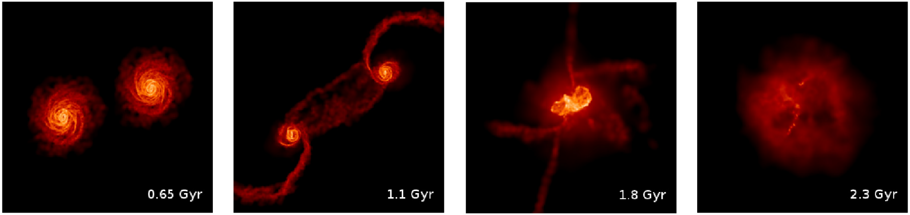
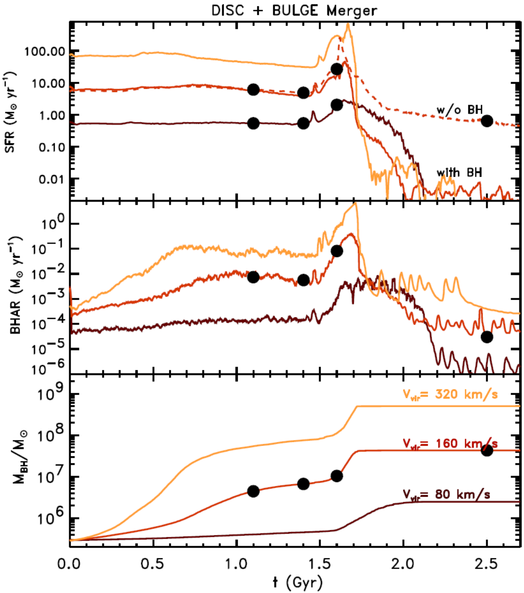
Starbursts and active nuclei in galaxies

General picture:

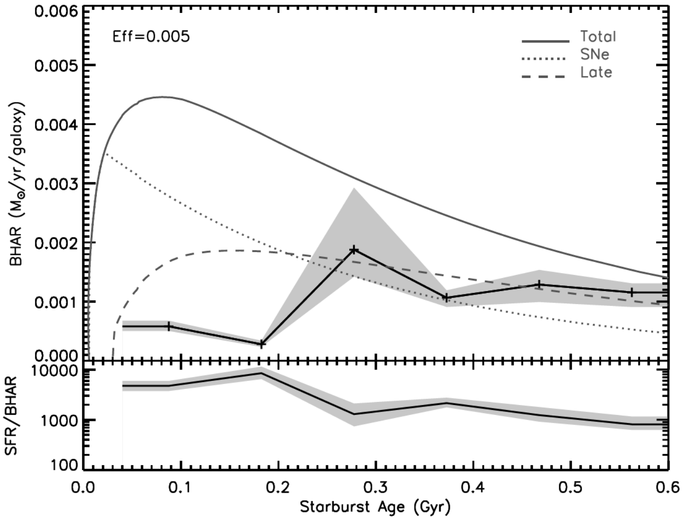
- two disk galaxies undergo a merger event ...
- ... that generates a burst of star formation
- tidal forces cause inflow of gas to the centre of the newly forming galaxy $\Rightarrow$ AGN activity
- feedback of the BH expels gas from the galaxy and quenches further SF and BH growth
- remnant: gas-poor, elliptical galaxy
(with $M_{\mathrm{BH}} \sim \sigma^4$, e.g. Gebhardt et al. 2000, Gueltekin et al. 2009)



Di Matteo et al. 2005: SPH-simulations of mergers



Wild et al. 2010: Observations of SF, BH accretion



Computational Methods

Merger simulations with

GADGET-2: TreeSPH code developed by Springel 2005

Essential extensions:

- star formation
- subgrid model for the AGN (BH + accretion disk)
- AGN-feedback

Star Formation

according to Scannapieco et al. 2005

- From observations (e.g. Kennicutt '89): SF almost completely suppressed at densities below a threshold density

$$\rho_i > \rho_{\text{crit}}$$

- SF only occurs for convergent flows

$$\nabla \cdot \vec{v}_i < 0$$

- apply local star formation law (e.g. Silk '87)

$$\frac{dM_*}{dt} \sim \frac{M_{gas}}{t_*}$$

BH accretion

- AGN (= BH + accretion disk) is represented by sink particle (accretion disk particle method, Power et al. '11)
- interacts with its environment only via gravitation (and AGN-feedback)
- swallows everything within $R_{\rm acc}$ (200 pc for reference model)
- accreted material is added to the outer rim of the accretion disk

Evolution of accretion disk (e.g. Pringle '81):

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

solve for Σ $\Rightarrow$ get $\dot{M}_{\rm BH}$

AGN-feedback

according to Debuhr et al. 2011, 2012

$$L_{\mathrm{AGN}} = \eta c^2 \dot{M}_{\mathrm{BH}}$$

Momentum per unit time: $\dot{p} = (\tau + \tau_{\mathrm{w}}) \frac{L}{c}$

Mass flow of the wind: $\dot{M}_{\mathrm{w}} = \tau_{\mathrm{w}} \frac{L}{c v_{\mathrm{w}}}$

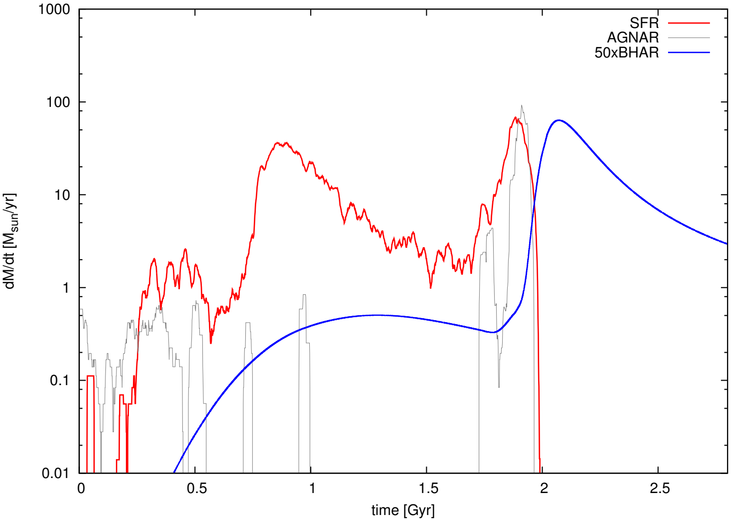
Total momentum $\dot{\vec{p}} \Delta t$ and total mass $\dot{M}_{\mathrm{w}} \Delta t$ are distributed among the surrounding gas particles.

Galaxy Model

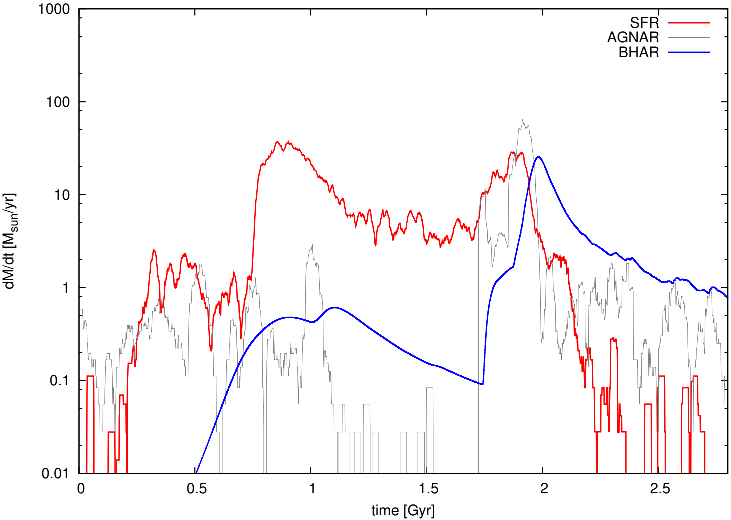
- $M_{\text{gal}} = 1.36 \cdot 10^{12}\, M_\odot \qquad (v_{\text{vir}} = 160\,\text{km}\,\text{s}^{-1})$
- 4.1 % exponential disk (30 % gas), $R_S = 3.8\,\text{kpc}$
- 1.4 % spherical bulge
- rest: spherical DM halo

- parabolic collision course
- each galaxy: 80 000 Particles
- one galaxy contains AGN-particle

Results: with AGN-feedback

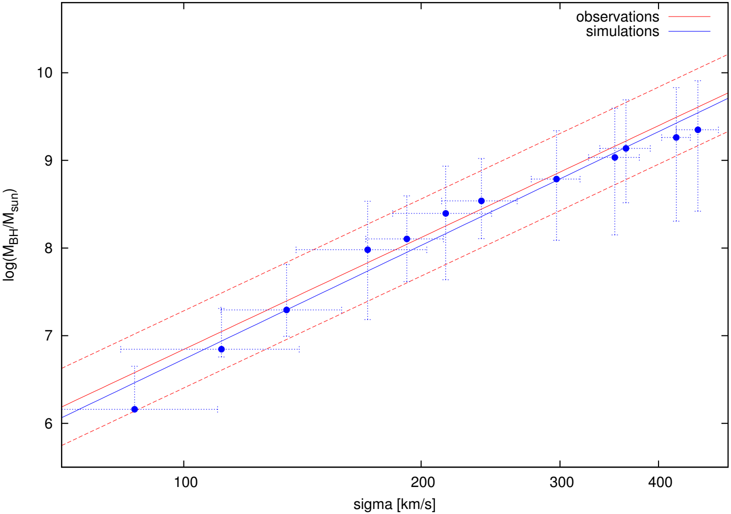


Results: without AGN-feedback



Results: $M_{\mathrm{BH}} - \sigma$ correlation

observations from Gültekin et al. 2009



Conclusions

- time delay of order 200 Myr - in agreement with observations
- simulations correspond to observed $M_{\mathrm{BH}} - \sigma$ correlation
- continuing growth of the black hole may contribute to the large observed scatter