Galaxy mergers with varying mass ratios: The M_{BH}-σ plane

Peter Johansson
University Observatory, Munich

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Johansson, Naab, Burkert, 2008, ApJ, in preparation

The role of AGN feedback

- 1) Observed relic supermassive black holes - quasars.
- 2) Observed ULIRGs, merging galaxies with intense starburst and/or AGN activity.
- 3) The observed M_{BH}-σ relation. The coeval growth of black holes and galaxy bulges.

- Simplified feedback energetics: SN/AGN- energy coupling/location
  - Supernova II feedback:

$$\text{Salpeter IMF} \Rightarrow 1\text{SN}/125\text{M}_\odot \text{ of } 10^{51}\text{ergs} \rightarrow \text{E}_{\text{SNII}} \sim 5 \cdot 10^{48}\text{erg}/\text{M}_\odot$$

$$\Rightarrow (\Delta E)_{\text{FB,SNII}} \sim 2.8 \cdot 10^{-6} m_\star c^2$$

  - AGN feedback:

$$m_{BH}/m_\star = 10^{-3}, \quad \Delta E_{\text{rad}}/m_{BH}c^2 = 10^{-1}, \quad \Delta E_{\text{BH}}/\Delta E_{\text{rad}} = 5 \cdot 10^{-2}$$

$$\Rightarrow (\Delta E)_{\text{FB,AGN}} \sim 5 \cdot 10^{-6} m_\star c^2$$

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BH feedback model

- The Schwarzschild radius of a SMBH with M~10^7 M_{sun} is R_S~10^{-6} pc. Numerical Galaxy simulations at best resolve details down ~10 pc -> effective subresolution model.

- Use the Tree-SPH GADGET-2 code (Springel et al. 2005) with cooling +SF+SN feedback+BH feedback based on a Bondi-Hoyle accretion model (Bondi 1952):

$$r_B = \frac{GM_{\rm BH}}{c_\infty^2} = 50{\rm pc}\left(\frac{\rm M_{BH}}{10^7 {\rm M}_\odot}\right)\left(\frac{\rm c_\infty}{30{\rm km/s}}\right)^{-2}$$

$$\dot{M}_B = \frac{4\pi\alpha G^2 M_{\rm BH}^2 \rho}{(c_s^2+v^2)^{3/2}} \qquad \alpha\sim100$$

$$\dot{M}_{\rm Edd} = \frac{4\pi G M_{\rm BH} m_{\rm p}}{\epsilon_r \sigma_T c}$$

$$\dot{M}_{\rm BH} = \min(\dot{\rm M}_{\rm Edd}, \dot{\rm M}_{\rm B})$$

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BH feedback model energetics

- The radiative efficiency $\varepsilon_r \sim 0.1$ (Sunyaev&Shakura 1973) and the thermal coupling $\varepsilon_f \sim 0.05$ resulting in a total BH feedback energy efficiency of = 0.5%.

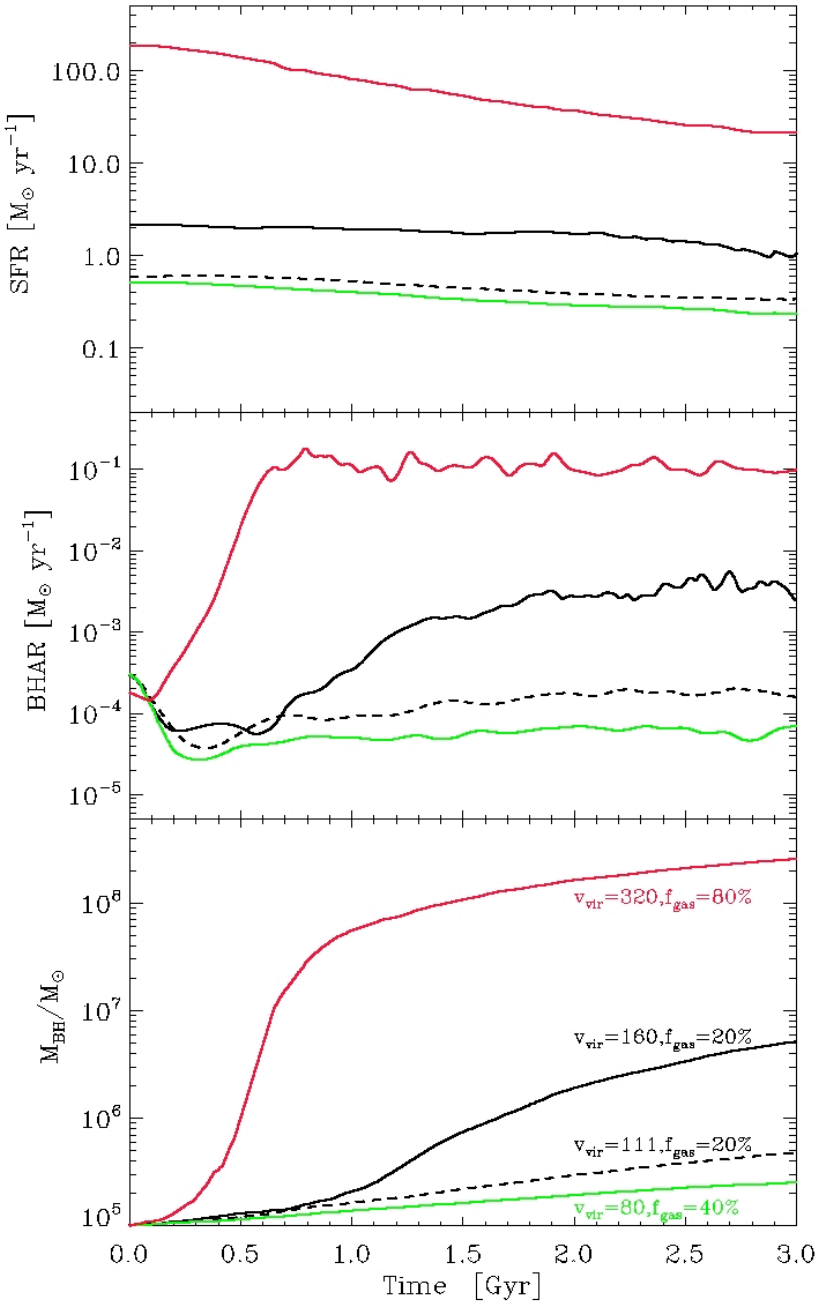
$$\epsilon_r = \frac{L_r}{\dot{M}_{\rm BH} c^2} = 0.1$$

$$\dot{E}_{\rm feed} = \epsilon_f L_r = \epsilon_f \epsilon_r \dot{M}_{\rm BH} c^2, \epsilon_f \sim 0.05$$

- The SPH kernel is used to calculate the average gas density, temperature as well as the gas bulk velocity relative to the BH.
- The BH mass grows stochastically by absorption of gas particles, include also smooth internal black hole mass, which is used to determine the accretion rate.
- BHs will merge instantly if they come within a smoothing length and if their relative velocity is smaller than the local soundspeed.
- FB energy distributed weighted within the SPH kernel.

Model setup and BHs in isolated disk galaxies

- Using the Springel (2000) method based on Hernquist (1993) we setup disk galaxies with NFW DM profiles+bulges&discs with f_{gas}=20%-80%.
- The BH is initially at rest in the centre of each model galaxy with a seed mass of 10^5 M_{sun}.
- We simulate a sample of isolated galaxies, 1:1 and 3:1 mergers, dry E-E and mixed E-Sp mergers.



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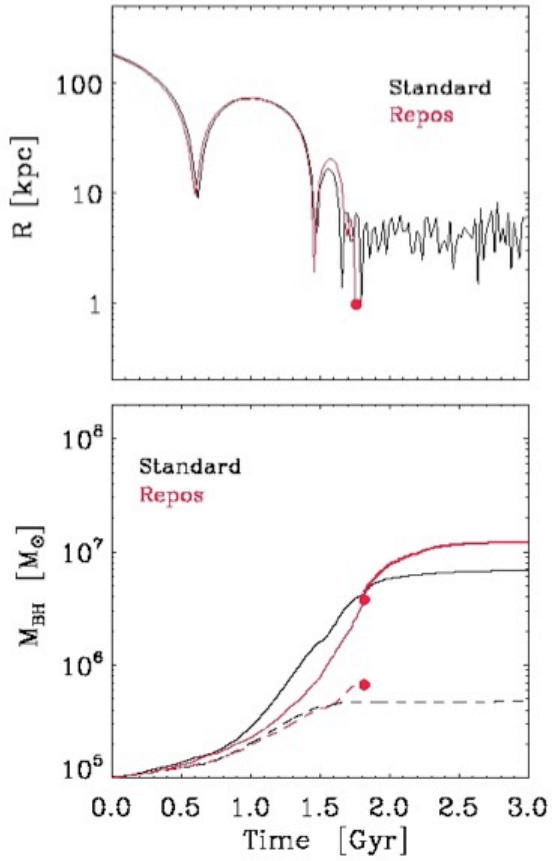
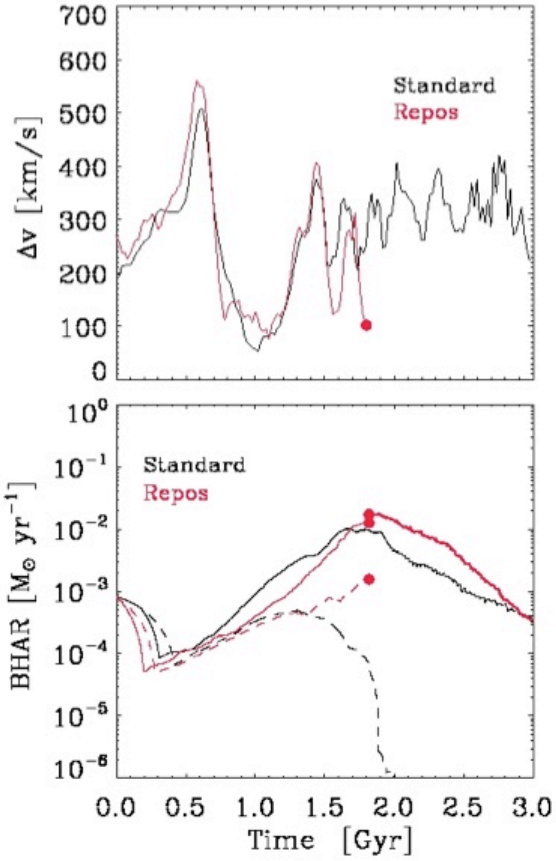
Numerical techniques ensuring BH merging

- The momentum is conserved in BH mergers.
- For unequal-mass mergers 'repositioning' of the BHs at the position of the minimum of the potential is required.
- The standard prescription is adequate for equal-mass mergers.





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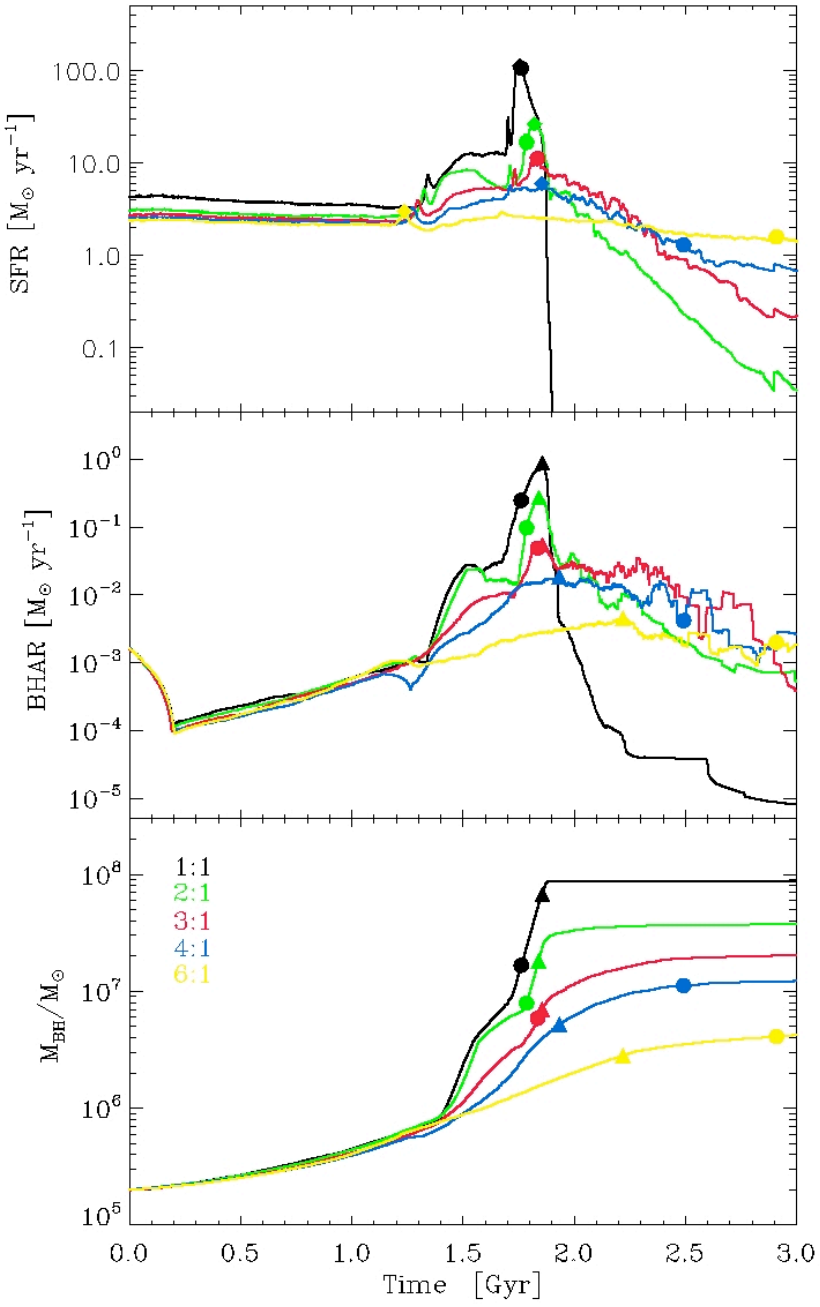
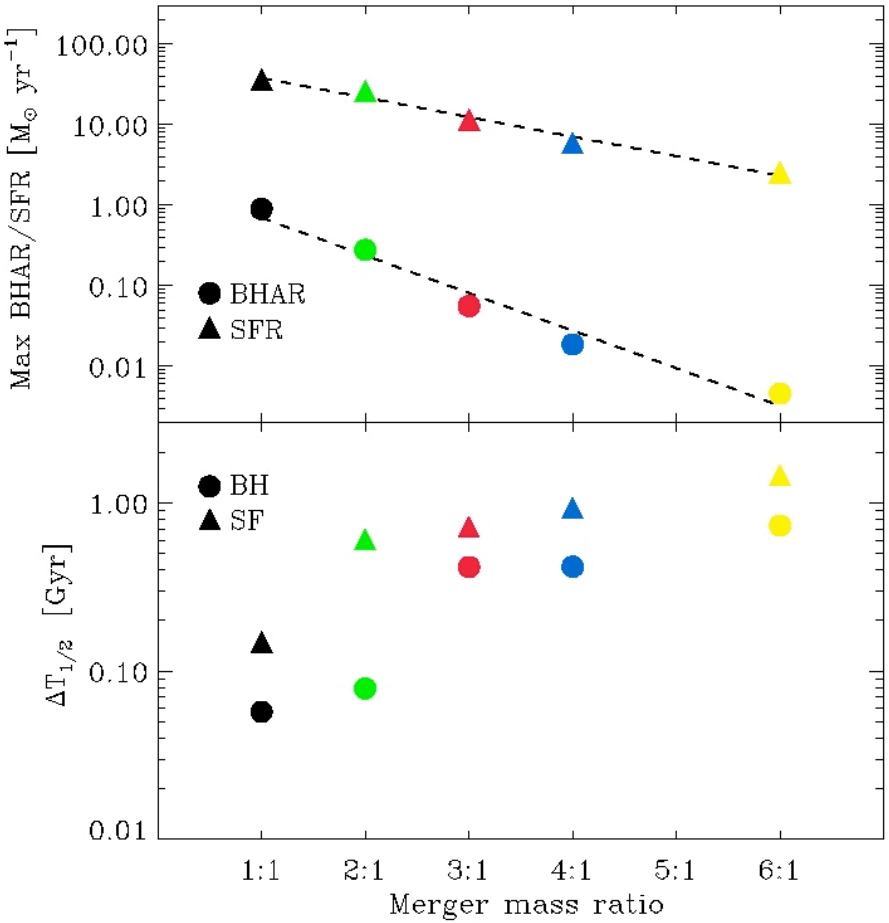
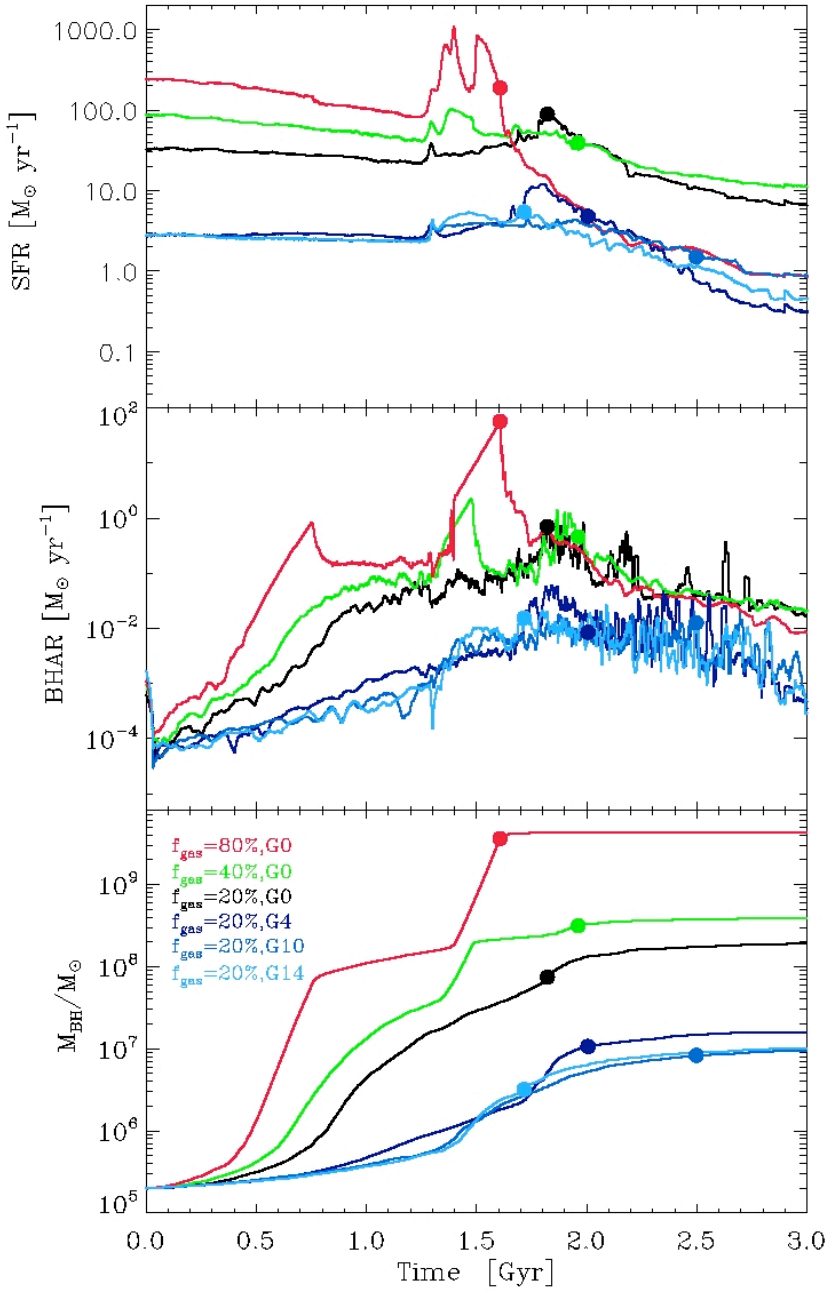
The BH accretion and SF histories

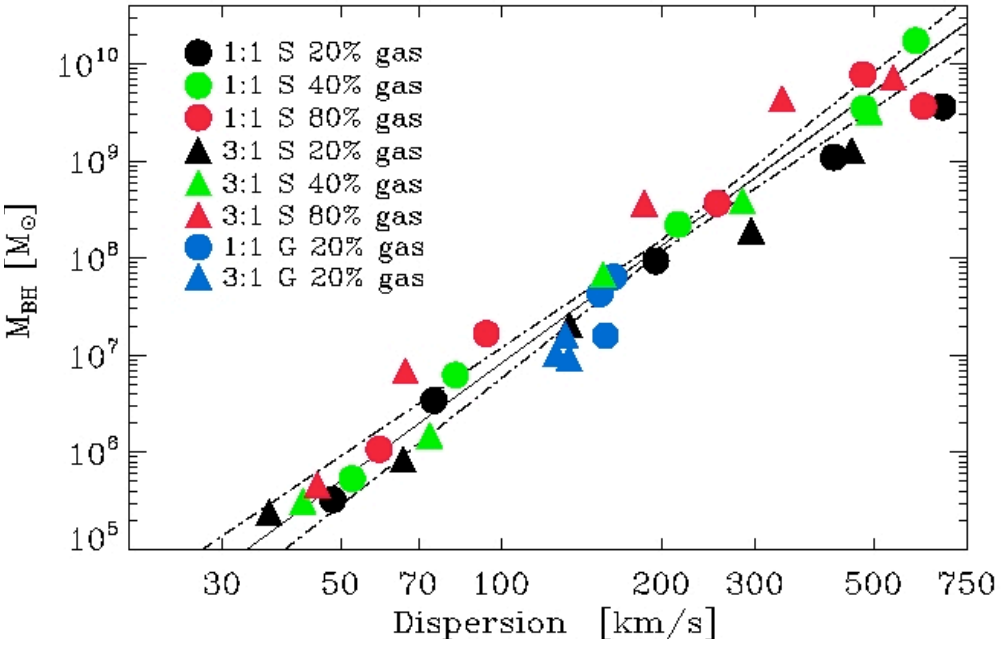


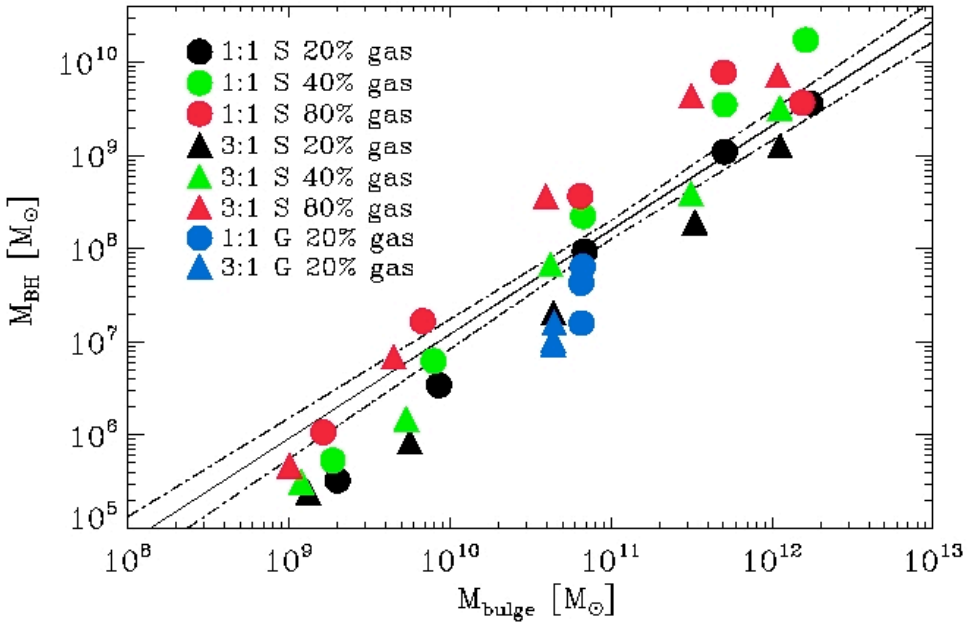


- Systematic variations in final BH mass, peak SF&BH accretion values.

The M_{BH}-σ relation for 3:1 and 1:1 mergers







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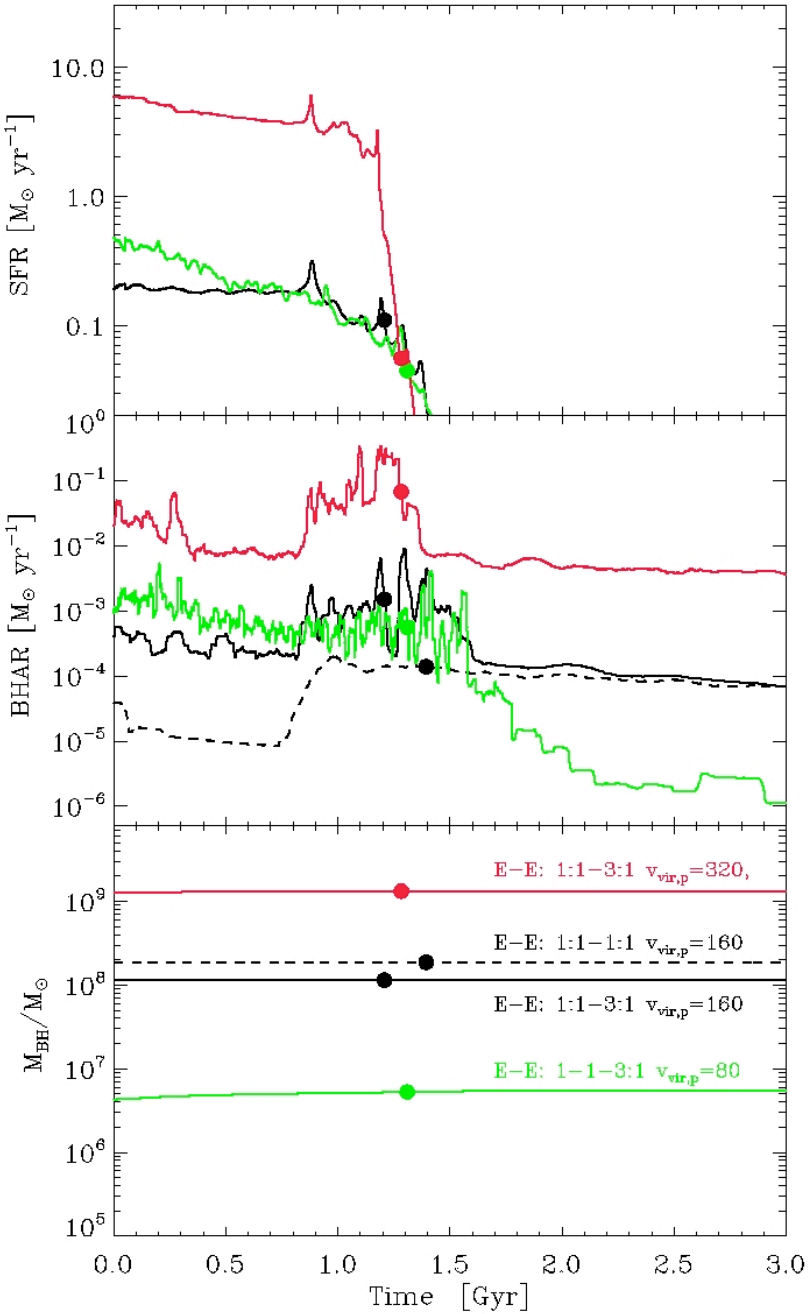
The M_{BH}-σ relation for dry E-E mergers



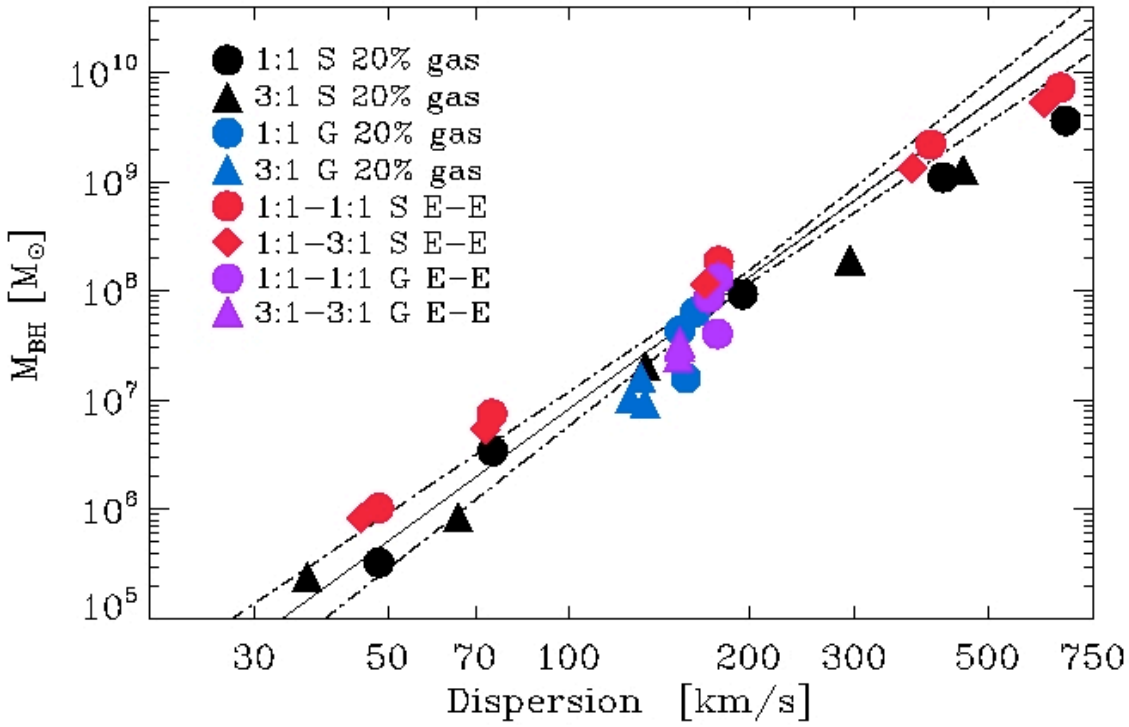


TABLE 4
BEST FIT $M_{BH} - \sigma$ RELATION FOR 3:1 AND 1:1 MERGERS

Sample	N	α	β	$\Delta_{\log M_{BH}}$
Tot sample	36	8.06	3.77	0.31
3:1 sample	18	8.07	3.81	0.35
1:1 sample	18	8.06	3.73	0.27
G0-20% gas sample	10	7.84	3.48	0.15
G0-40% gas sample	10	8.13	3.98	0.16
G0-80% gas sample	10	8.33	3.71	0.34
Obs sample[a]	31	8.13 ± 0.06	4.02 ± 0.32	0.25-0.3

[a]From Tremaine et al. (2002).

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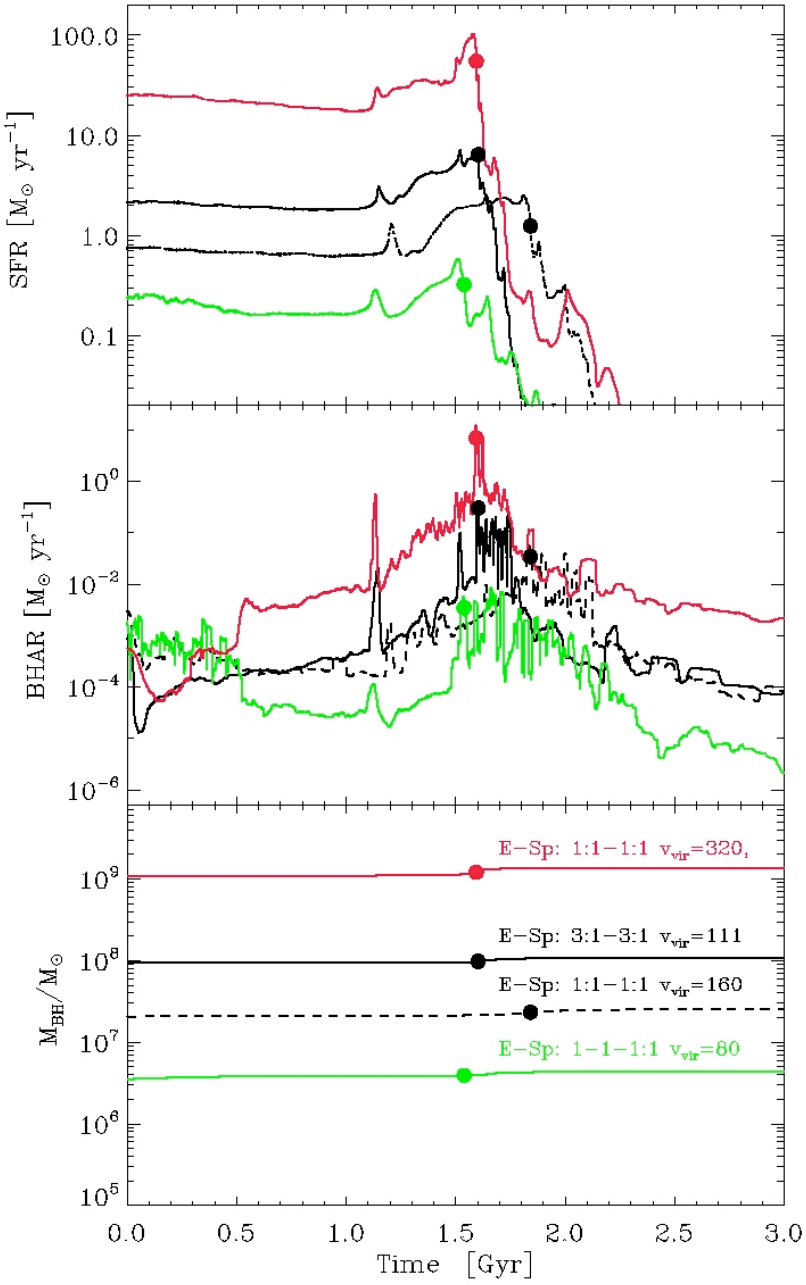
The M_{BH}-σ relation for mixed E-Sp mergers



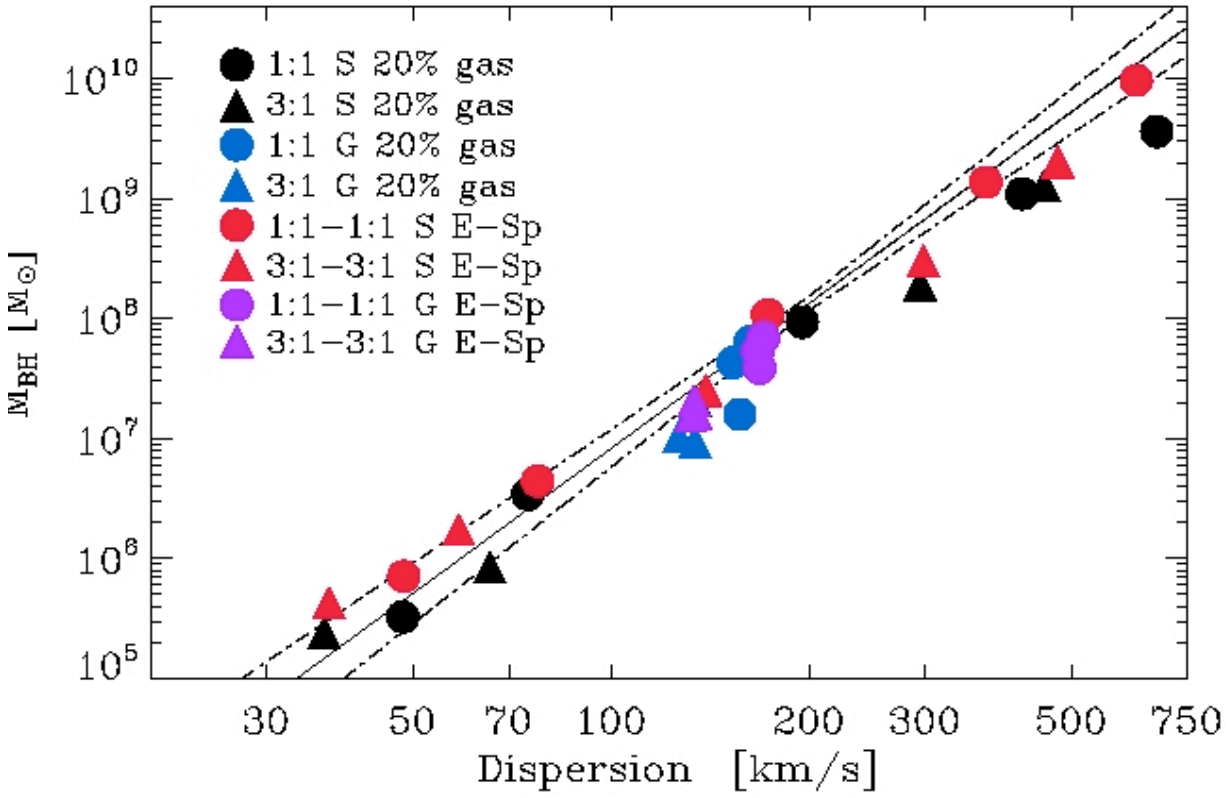


TABLE 6
BEST FIT $M_{BH} - \sigma$ RELATION FOR E-E AND E-SP MERGERS

Sample	N	α	β	$\Delta_{\log M_{BH}}$
Progenitor sample	16	7.83	3.50	0.18
E-E Remerger sample	16	8.13	3.39	0.20
E-Sp Mixed sample	16	8.03	3.52	0.15

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Conclusions/Summary

- The simple BH accretion/feedback model works remarkably well in reproducing the observed M_{BH}-σ relation for equal, unequal, E-E dry and mixed mergers.
- The relation is the result of large-scale gas flows to the center of the galaxy and the self-regulation of M_{BH} due to feedback energy.
- The global properties of the galaxy are insensitive to the details of the BH feedback model, but what about the detailed properties? Surface density profiles, kinematics, orbits...
- Potential model improvements: Include spin of the BH, more physical accretion model, quasar mode vs. radio mode, jets....

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