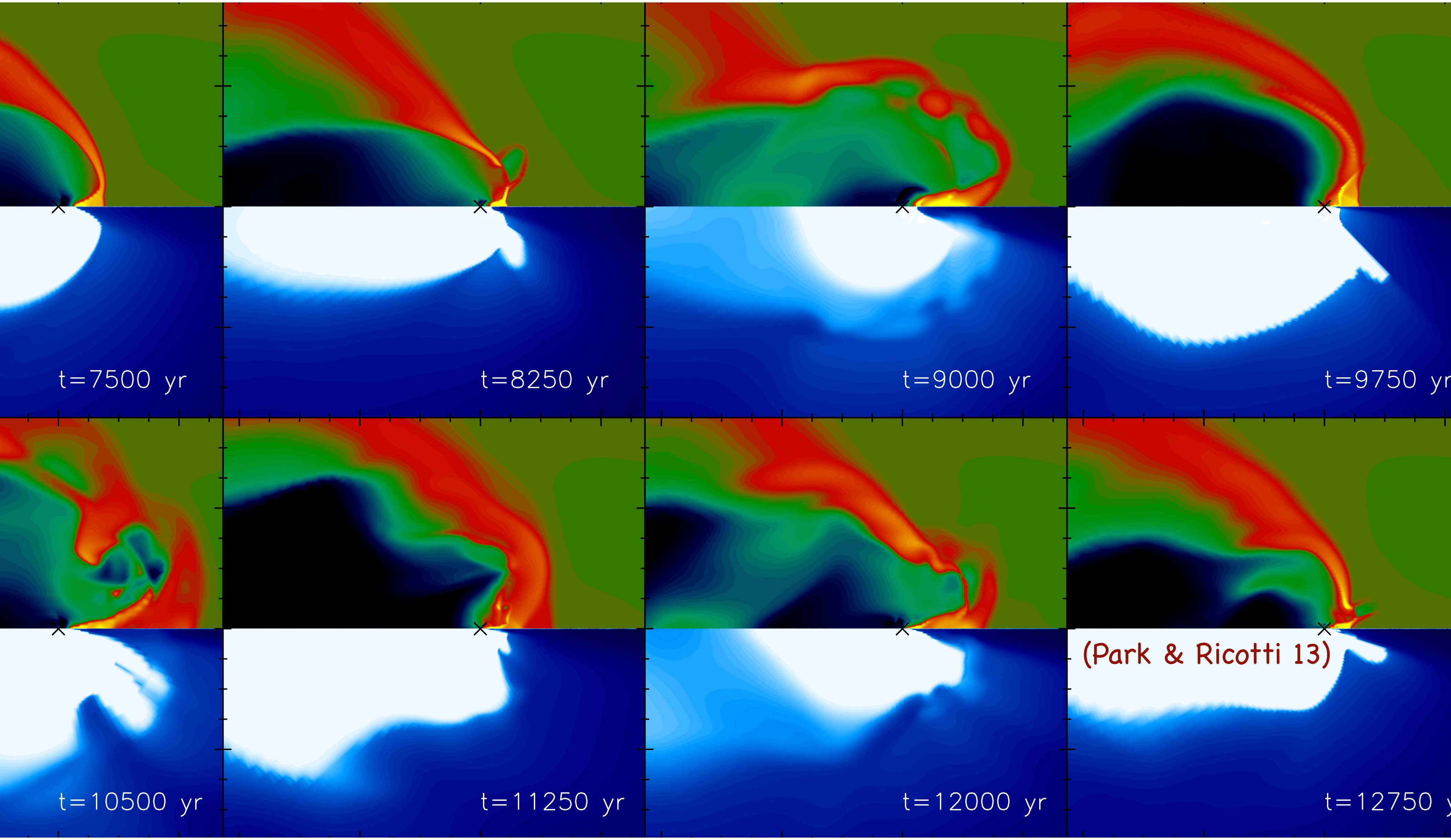
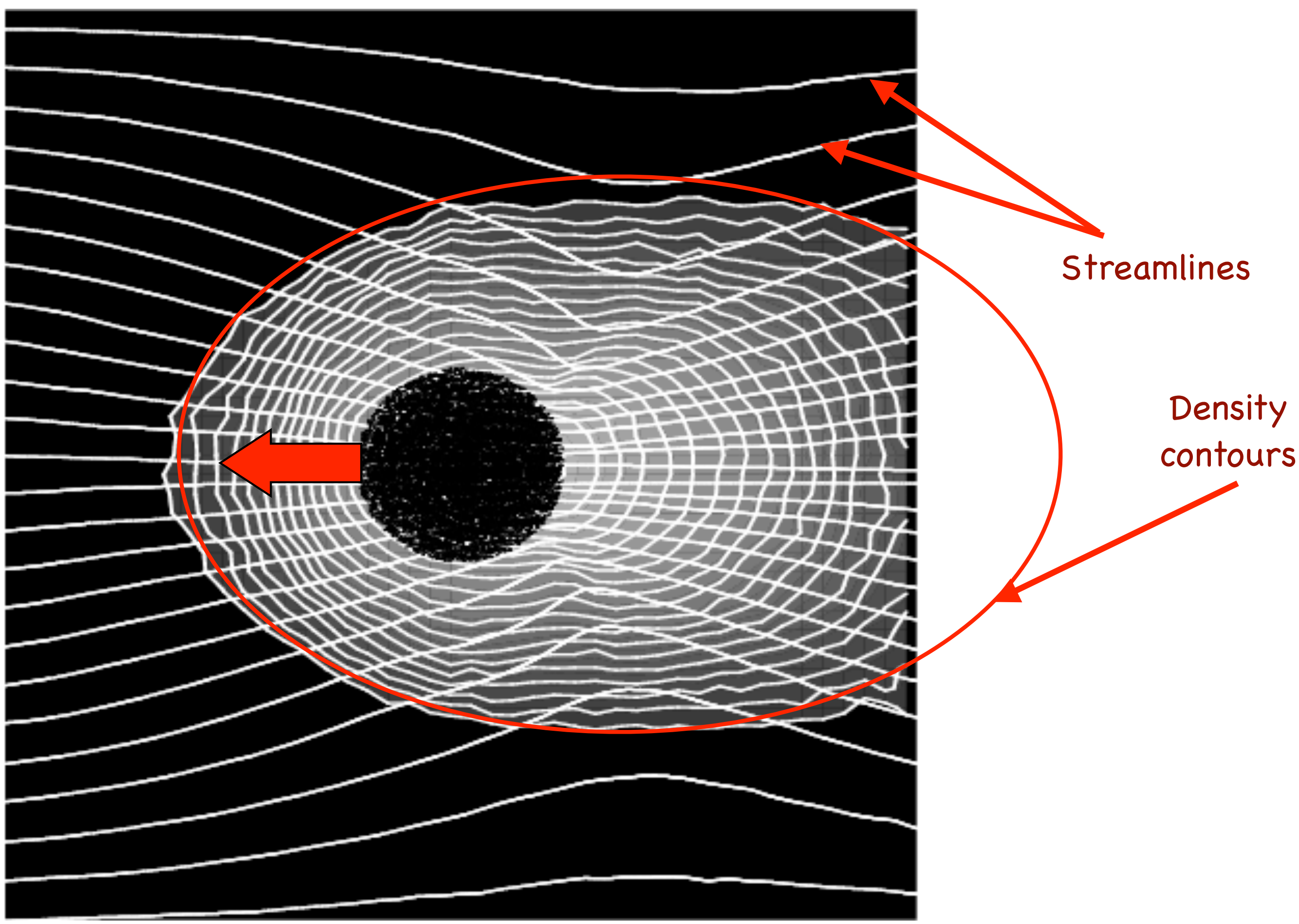


Gaseous Dynamical Friction in Presence of BH Radiative Feedback

Cole Miller and Tamara Bogdanović

MBHs transported by dynamical friction

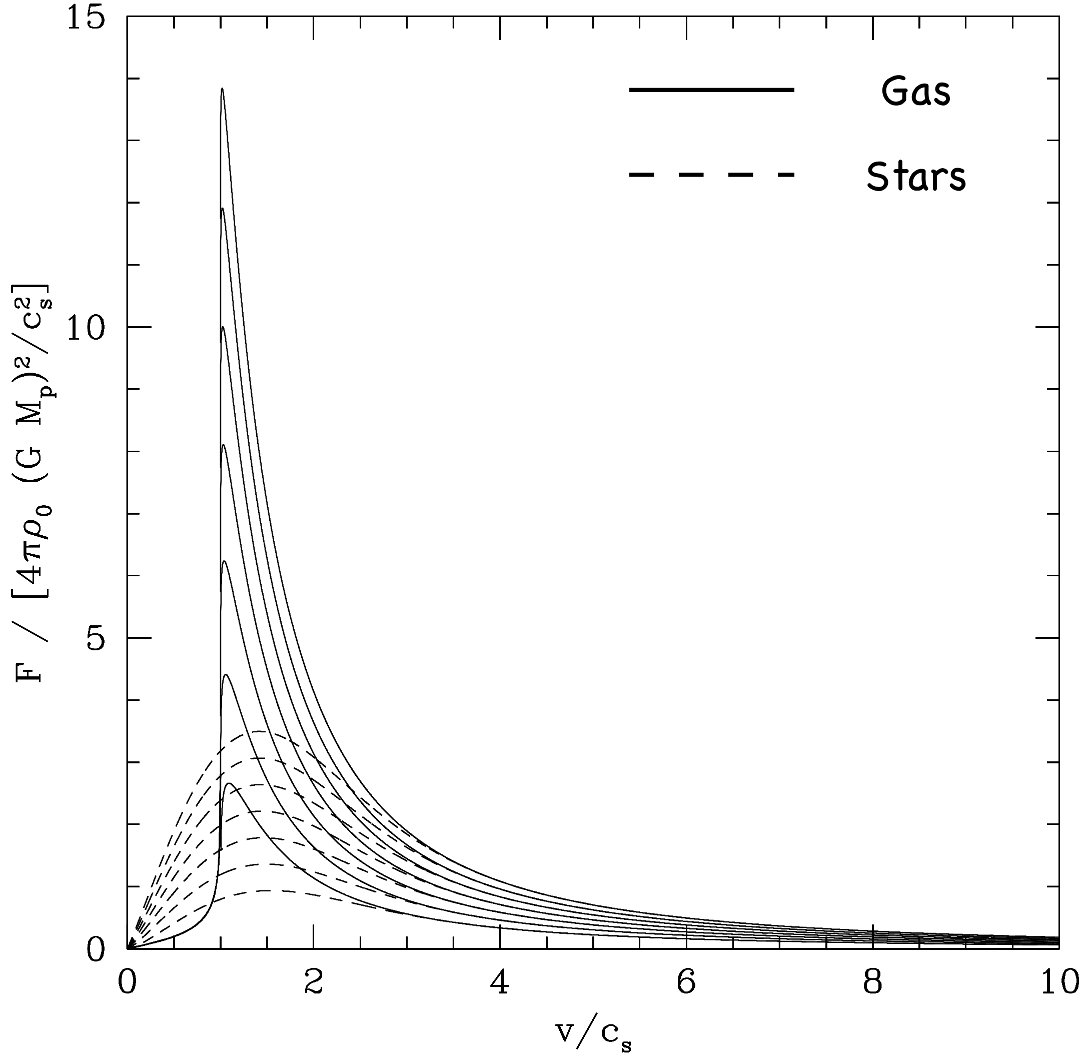
Separation (1000 -> 1) pc   Time scale: Million - Billion years



$$F_{\rm DF} = -I \times 4\pi(GM_p)^2\rho_0/V^2$$

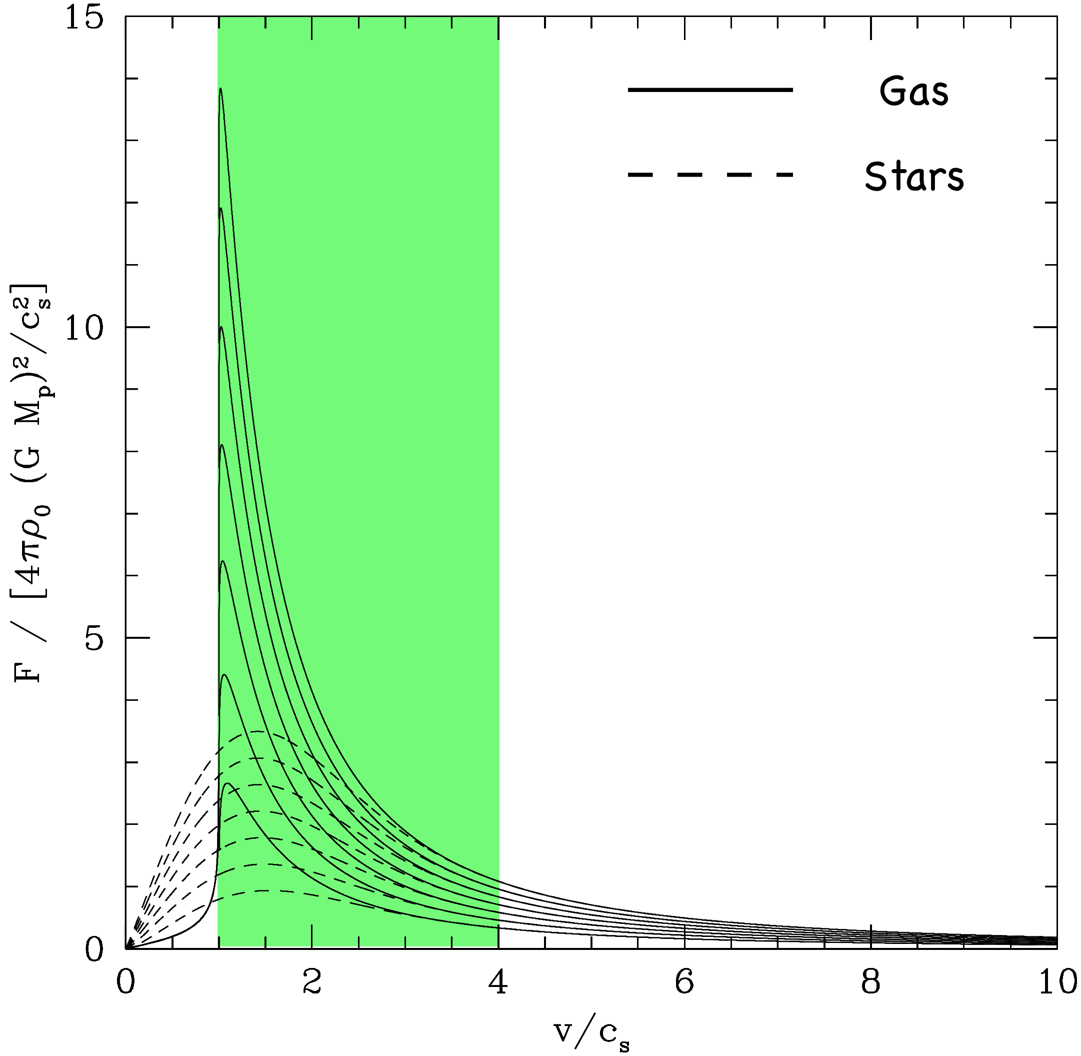
(Chandrasekhar 43, Ostriker 99, image from Semelin & Combes 02)

Stellar vs. gaseous dynamical friction



(Ostriker 99)

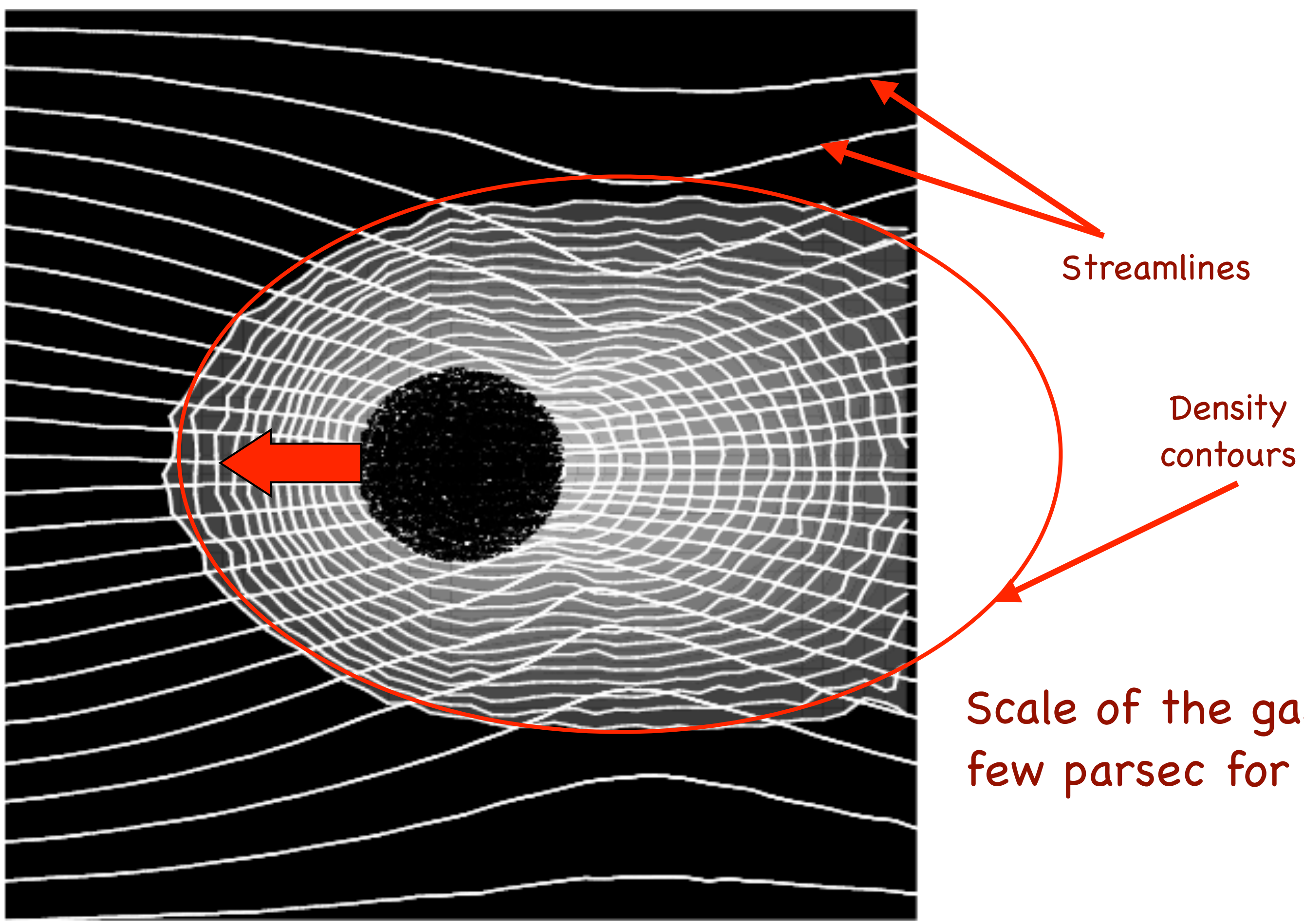
Stellar vs. gaseous dynamical friction



(Ostriker 99)

MBHs transported by dynamical friction

Separation (1000 -> 1) pc   Time scale: Million - Billion years

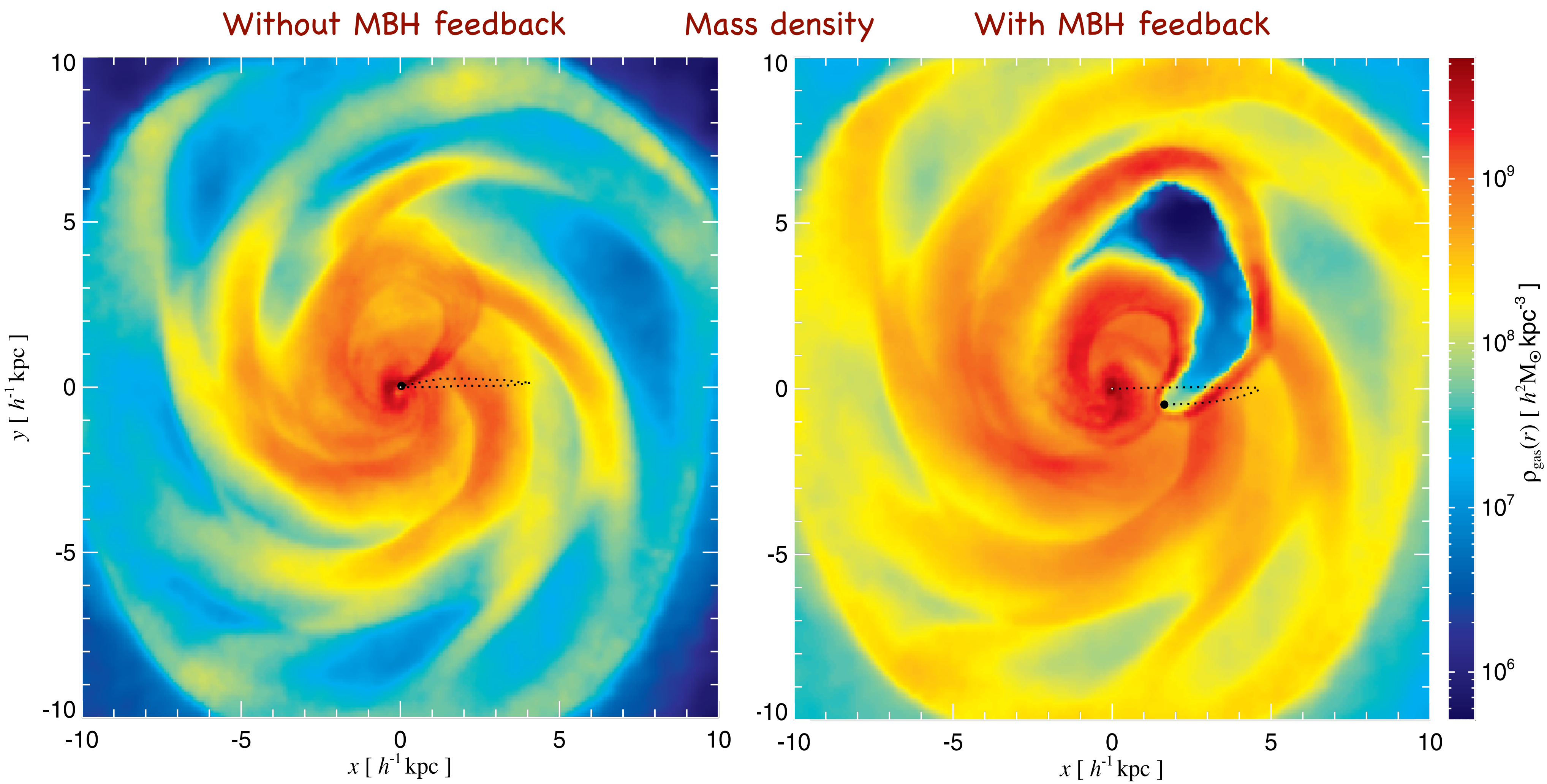


Scale of the gas DF wake: few parsec for 10^6 $M_\odot$ MBH

$$F_{\rm DF} = -I \times 4\pi (GM_p)^2 \rho_0 / V^2$$

(Chandrasekhar 43, Ostriker 99, image from Semelin & Combes 02)

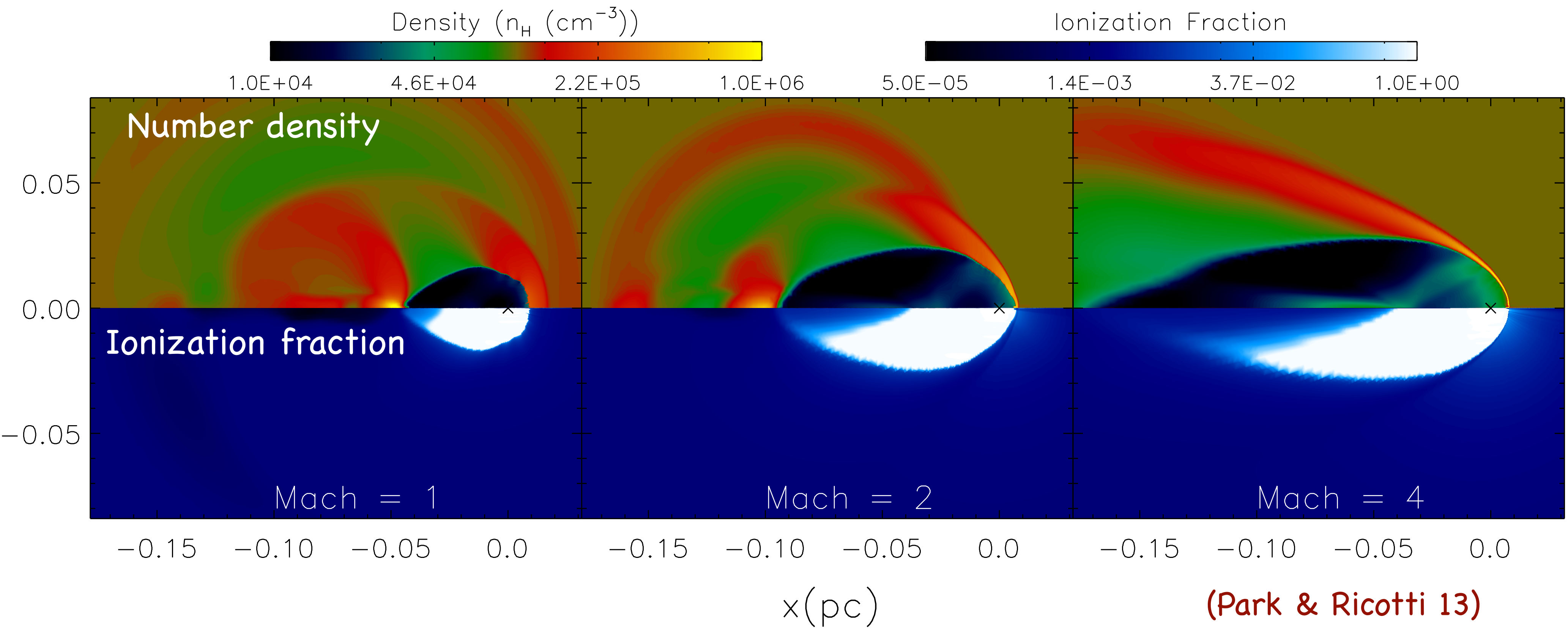
Wake evacuation by MBH feedback



(figures from Sijacki+ 11; Souza-Lima+ 17)

Wake evacuation by accreting BHs (big and small)

M_{bh} = 100$M_\odot$ BH, immersed in T_∞=10^4 K gas w/ n_∞ = 10^5 cm^{-3}

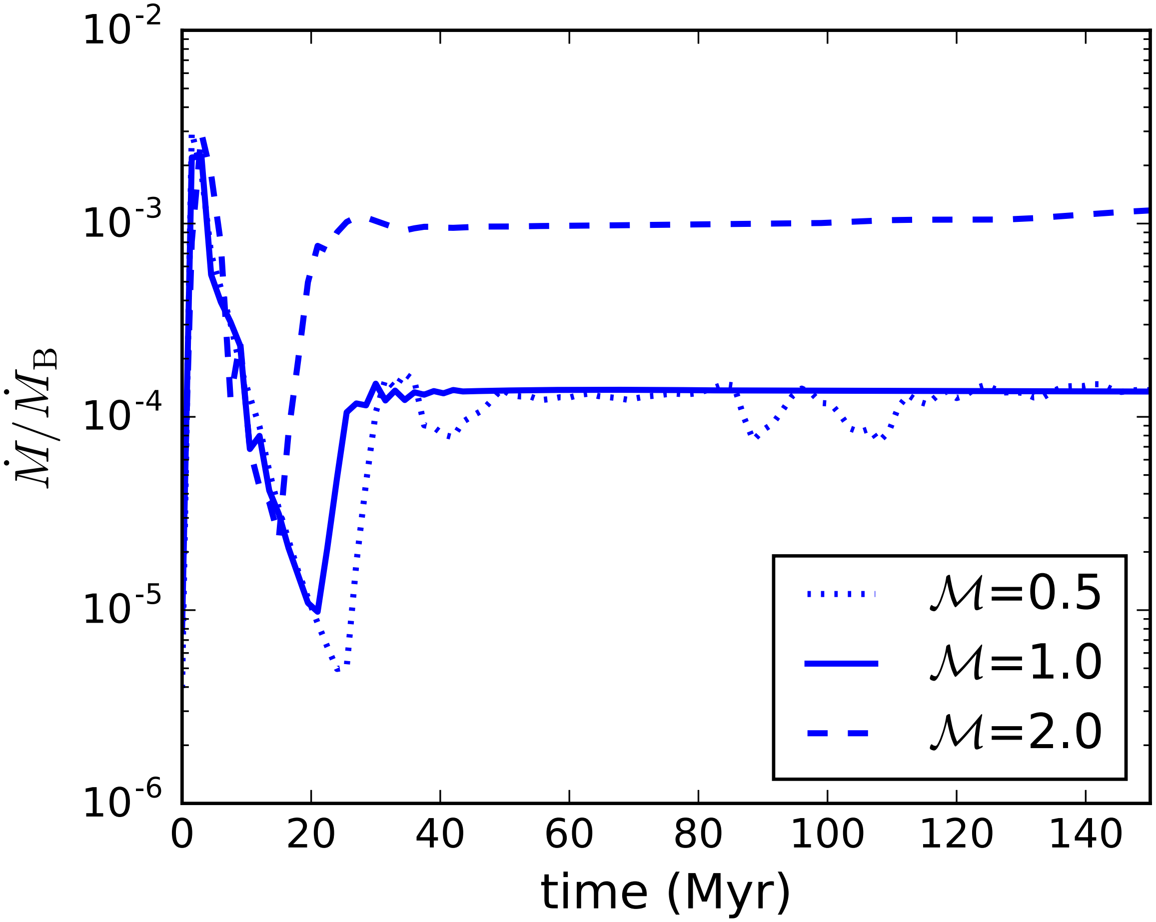


(Park & Ricotti 13)

Density of the shell increases as $\propto \mathcal{M}^2$ => accretion rate is suppressed

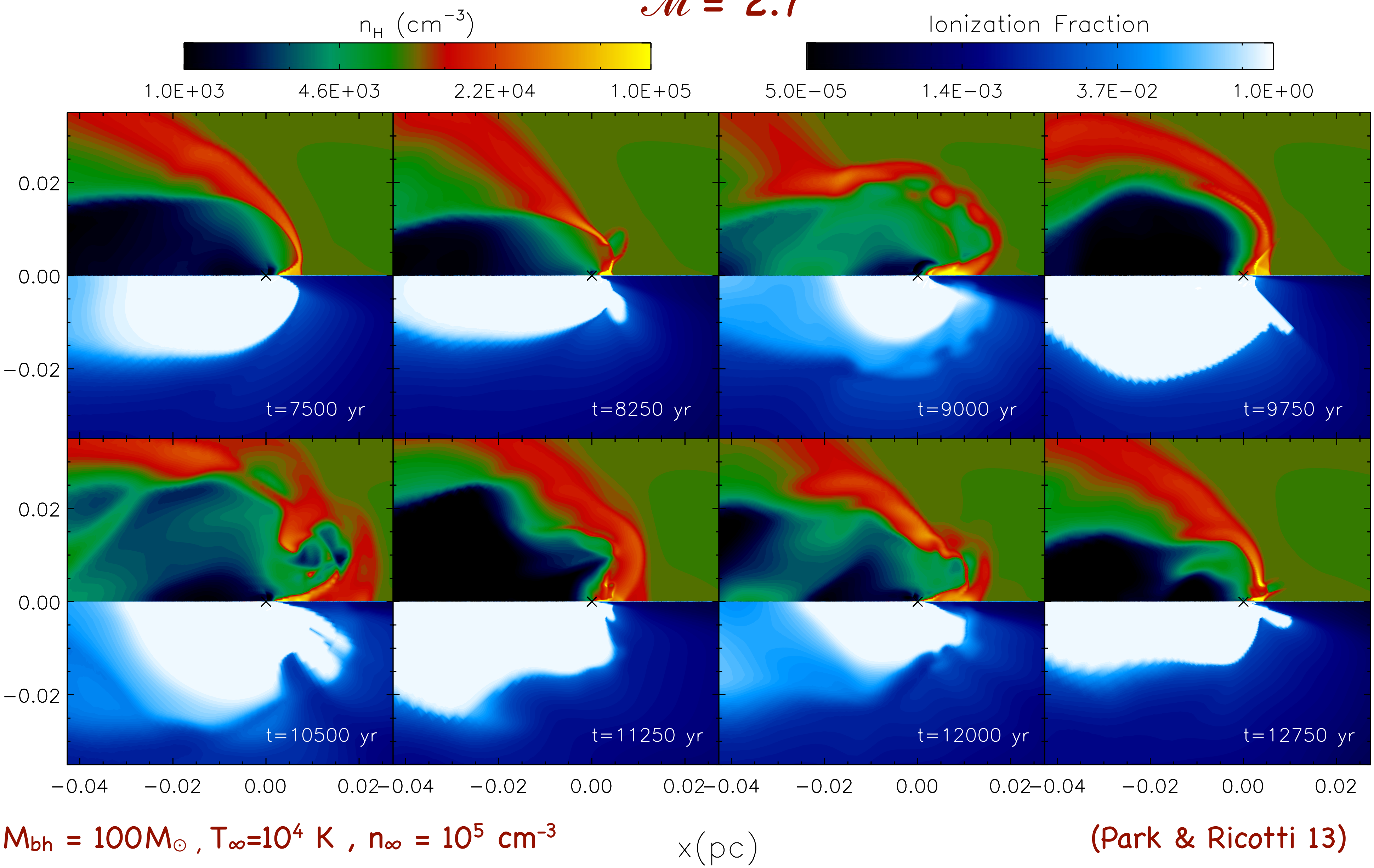
Radiation mediated accretion ($1 < \mathcal{M} < 4$)

$$\dot{M} \approx 1.2 \times 10^{-2} \mathcal{M}^2 \dot{M}_{\rm B} \left(\frac{T_\infty}{T_{\rm in}} \right)^{5/2}$$



A) Wake evacuation is prevented for fast perturbers

$\mathcal{M} = 2.7$

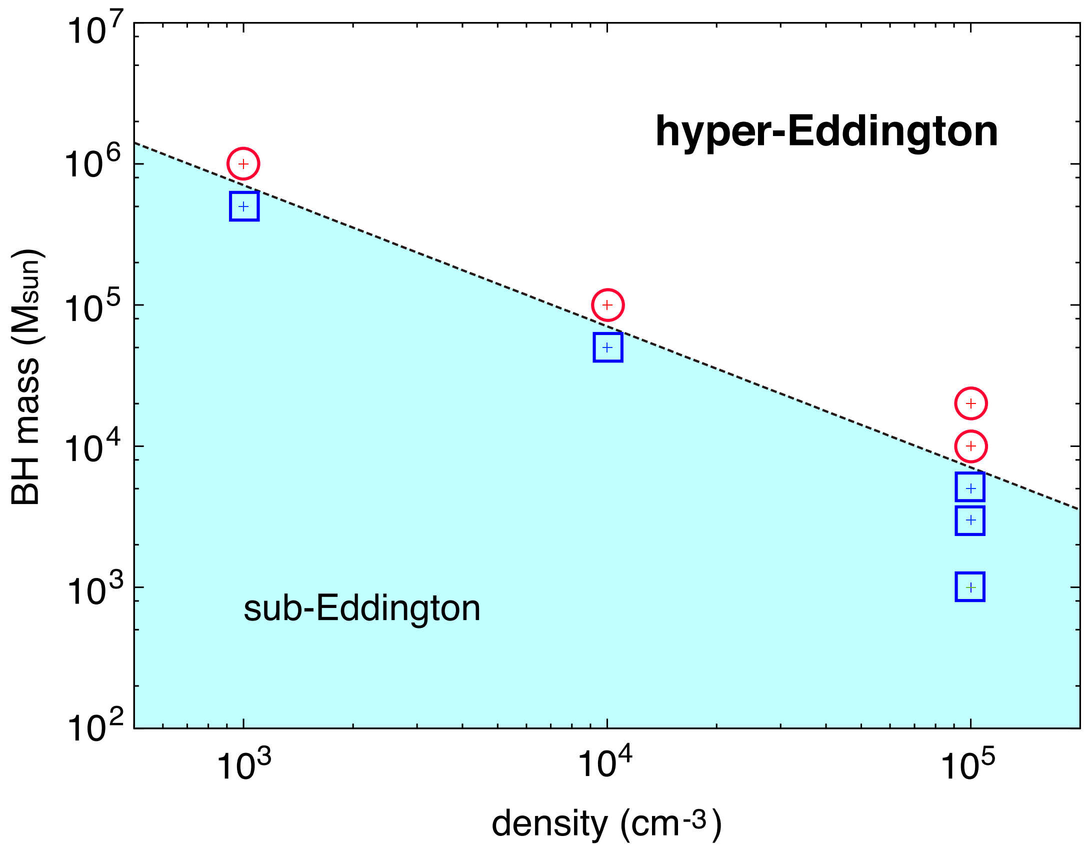


$M_{bh} = 100 M_\odot$, $T_\infty = 10^4$ K , $n_\infty = 10^5$ cm^{-3}

(Park & Ricotti 13)

B) Wake evacuation is prevented for super-Eddington accretors

Spherically symmetric accretion flows transition to unimpeded hyper-Eddington accretion when $R_{HII} < R_B$ (Park+ 14; figure from Inayoshi+ 16)

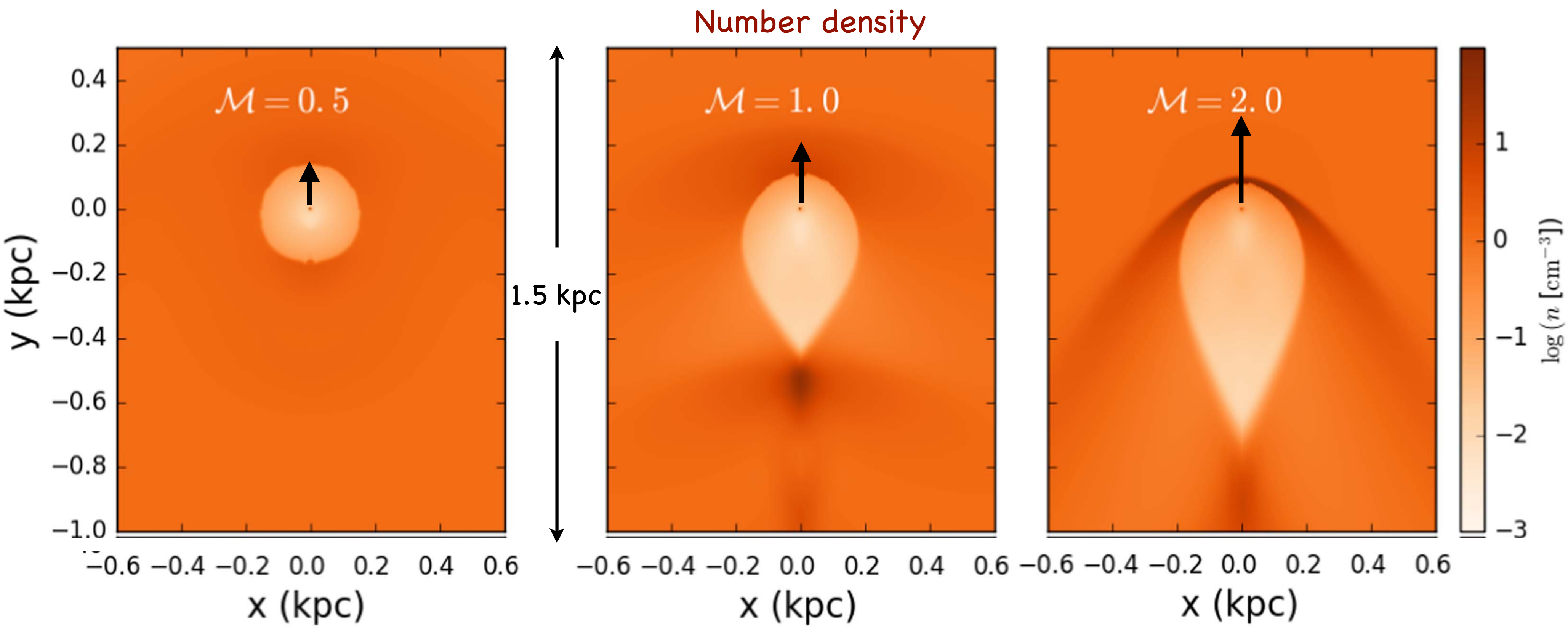


This happens when:

$$\dot{M}_B \gtrsim 5000\ \dot{M}_{Edd} \quad \Longleftrightarrow \quad \left(\frac{n_\infty}{10^5\ \mathrm{cm}^{-3}}\right) \gtrsim \left(\frac{M_{BH}}{10^4\ \mathrm{M}_\odot}\right)^{-1} \left(\frac{T_\infty}{10^4\ \mathrm{K}}\right)^{3/2}$$

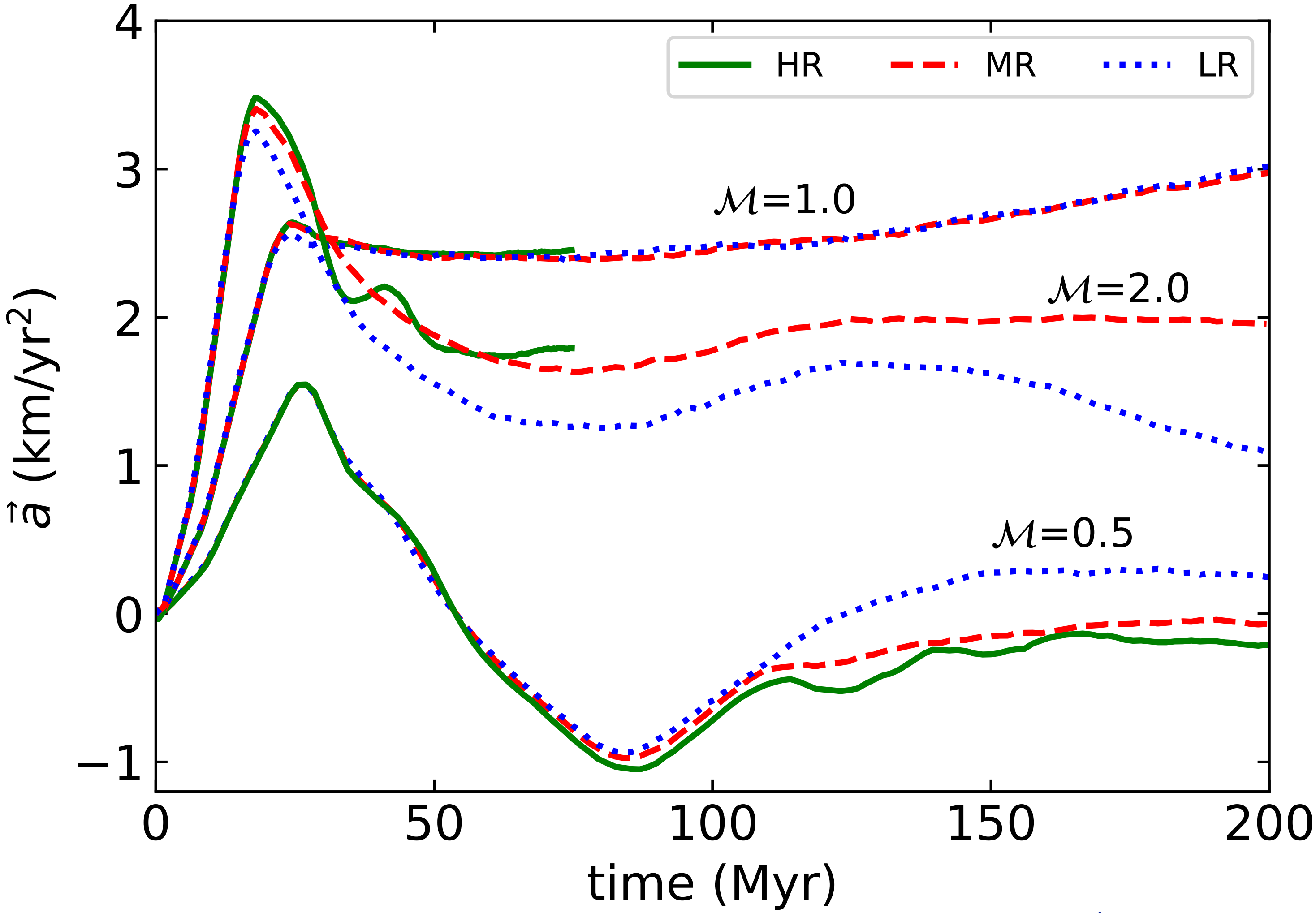
Efficiency of Gas Dynamical Friction in Presence of Radiative Feedback

2D RHD simulations of $10^6\ M_\odot$ MBH moving through a uniform, neutral background medium
– KwangHo Park & TB 17, 19 (the latter in prep.) –



wake evacuated when $\mathcal{M} < 4$ and $(1 + \mathcal{M}^2)\, M_{\rm BH}\, n_\infty < 10^9\, M_\odot\ {\rm cm}^{-3}$

MBH Acceleration as a Function of Time



(Park & TB 17, 19)

(Park & TB 17, 19)

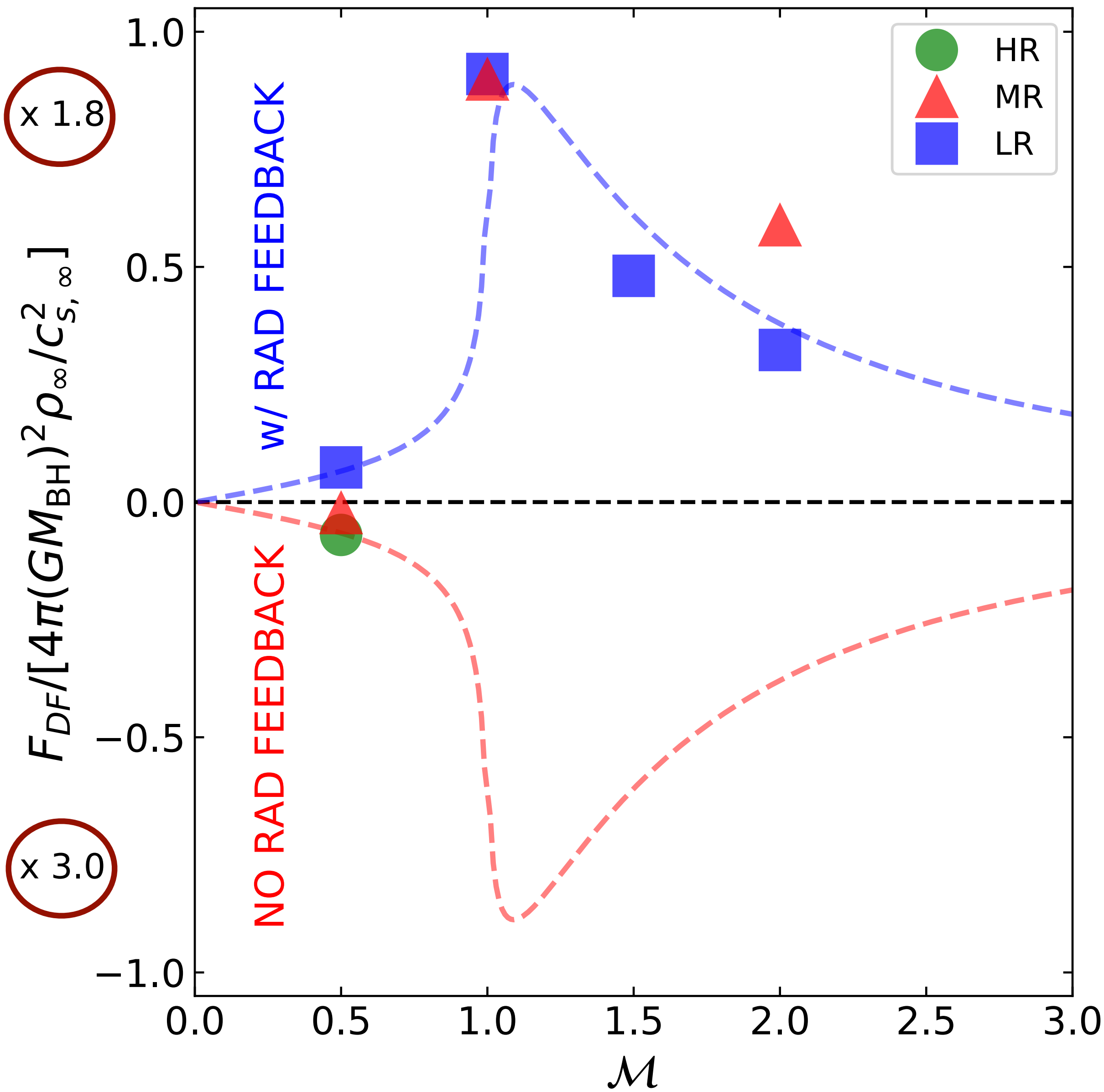
MBH Acceleration as a Function of the Mach Number

~60% of the classical value

x 1.8

"Classical" value (Ostriker 99)

x 3.0



Conclusions

- Ionizing radiation from MBHs gives rise to negative gas DF for a range of physical scenarios. Stellar DF may still operate unaffected but would have to work harder.

- The effect is more severe at the low mass end of BH spectrum => BHs with masses <10^7 $M_\odot$ have fewer means to reach the centers of merged galaxies.

$$\mathcal{M} < 4 \;\text{ and }\; (1 + \mathcal{M}^2)\, M_{\rm BH}\, n_\infty < 10^9\, M_\odot\ {\rm cm}^{-3}$$

- Prescription for sub-resolution model of gas DF for large-scale simulations.

- **Not taken into account:** gas inhomogeneities, anisotropic outflows, curved BH trajectories, other sources of shocks / radiation, magnetic fields, etc.