Simulating Jet/Outflow Behavior in Massive Galaxies: A New Black Hole Feedback Model in NIHAO Simulations

NEW YORK UNIVERSITY

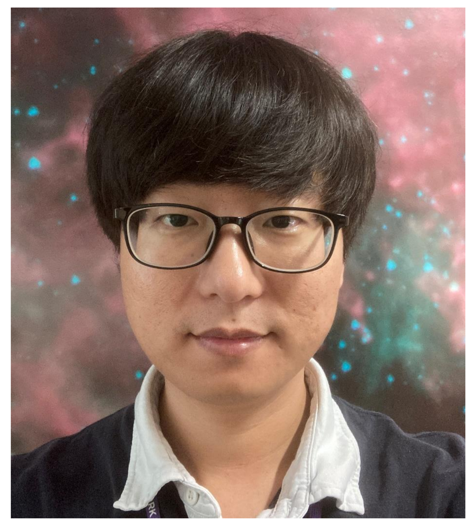
جامعة نيويورك أبوظبي NYU | ABU DHABI

Changhyun Cho[1,2,3] (cc6881@nyu.edu) and Andrea Macciò[1,2,3] (maccio@nyu.edu)

[1] New York University, [2] New York University Abu Dhabi

[3] Center for Astro, Particle, and Planetary Physics

CENTER FOR ASTRO, PARTICLE, AND PLANETARY PHYSICS



Introduction

Feedback from active galactic nuclei (AGNs) is commonly used to explain the suppression of star formation in massive galaxies and the relationship between black hole (BH) masses and the host galaxy properties.

"Quasar-mode" feedback simulates thermal energy distribution by luminous quasars.

"Radio-mode" feedback involves the injection of kinetic energy into the surrounding gas through powerful radio jets.

In this study, we explore the long-term consequences of the energy released through the AGN kinetic feedback on the overall galaxy and its star formation history.

Simulations

The NIHAO (Numerical Investigation of Hundred Astrophysical Objects) cosmological simulation is a suite of high-resolution 3D hydrodynamical simulations.

The simulations employ the TreeSPH code gasoline2 and adopt flat LCDM cosmological parameters derived from the Planck Collaboration.

We use one galaxy from the NIHAO suite for these tests. It has a **total mass of $2.7 \times 10^{12} M_\odot$** at z=0, and a **stellar mass of $\sim 5 \times 10^{10} M_\odot$**.

The galaxy is resolved with **1,275,416 dark matter particles**, and **677,851 gas & stellar particles**.

Accretion Modes

(0) Eddington (Maximum) Accretion

$$\dot{M}_{\rm Edd} = \frac{L_E}{c^2} = \frac{4\pi G M_{BH} m_p}{c\sigma_{Th}}$$

- m_p: proton mass
- σ_{Th}: Thomson cross section

(1) Bond (Spherical) Accretion

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

- M_{BH}: black hole mass
- ρ, c_s, and v: density, sound speed, and velocity of the gas surrounding the BH.

(2) Alpha-disk (Thin-disk) Accretion

$$\dot{M}_{\rm Alpha} = 3\pi\alpha\Sigma\frac{c_s^2}{\Omega}$$

- $\Sigma = \frac{M_{\rm gas}(R_0)}{\pi R_0^2}$: surface density of the gas within R_0
- $\Omega \approx \frac{GM(R_0)}{R_0^3}$: orbital velocity of the gas within R_0

BH Feedback Modes

(1) High Accretion Mode (Quasar Mode)

$$\Delta E_{\rm high} = \epsilon_{f,\rm high} \dot{M}_{BH} c^2$$

- $\epsilon_{f,\rm high}$: thermal efficiency (5%)

5% of the accretion energy is given as thermal energy to the nearest 50 gas particles.

5% of $\dot{M}_{\rm Edd}$

(2) Low Accretion Mode (Radio Mode)

$$\Delta E_{low} = \epsilon_{f,\rm low} \dot{M} c^2$$

- $\epsilon_{f,\rm low}$: kinetic efficiency (20%)

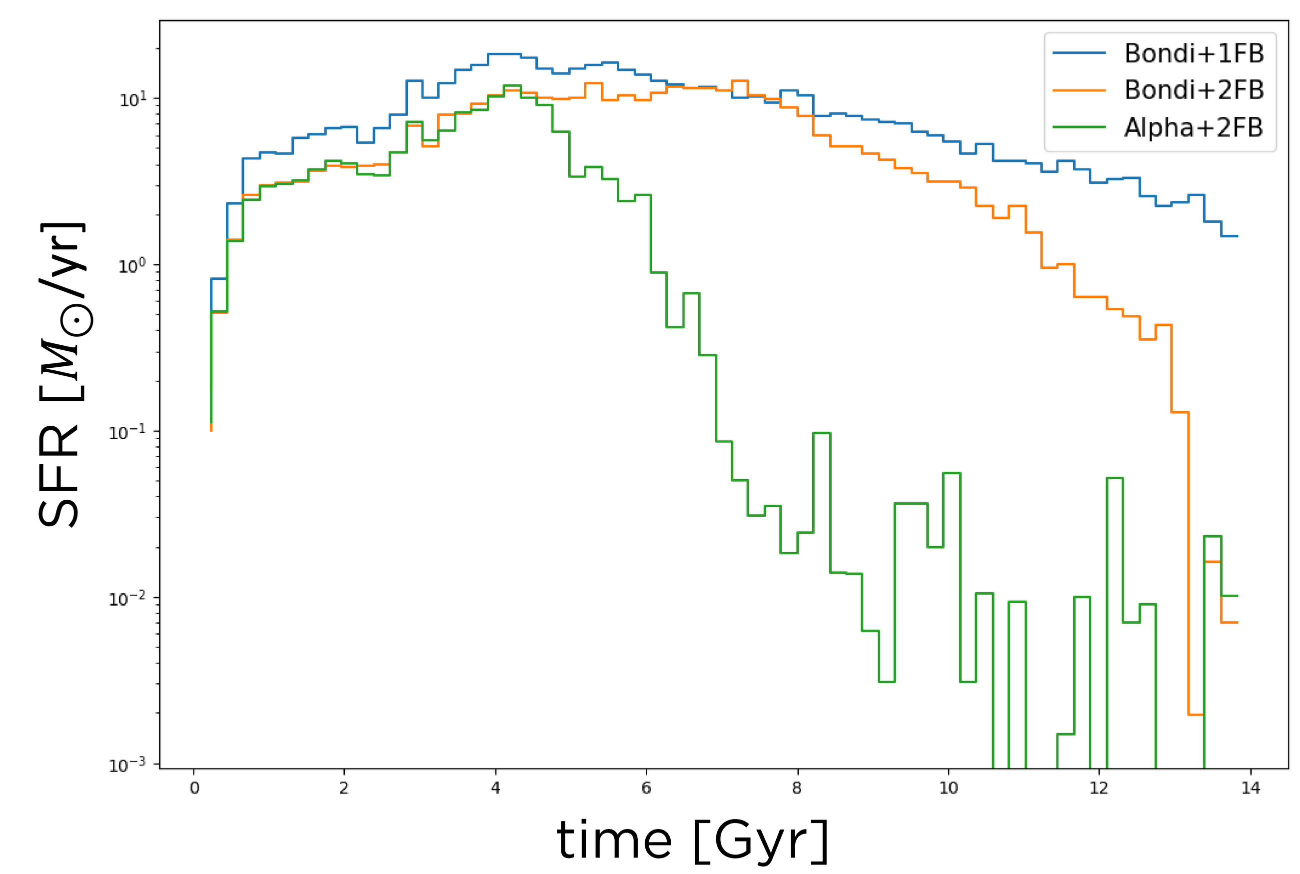
$$\vec{p}_j = \sum_j m_j \sqrt{\frac{2\Delta E_{low}\, w(\vec{r}_j)}{\rho}}\,\hat{n}$$

- $w(\vec{r}_j)$: kernel function

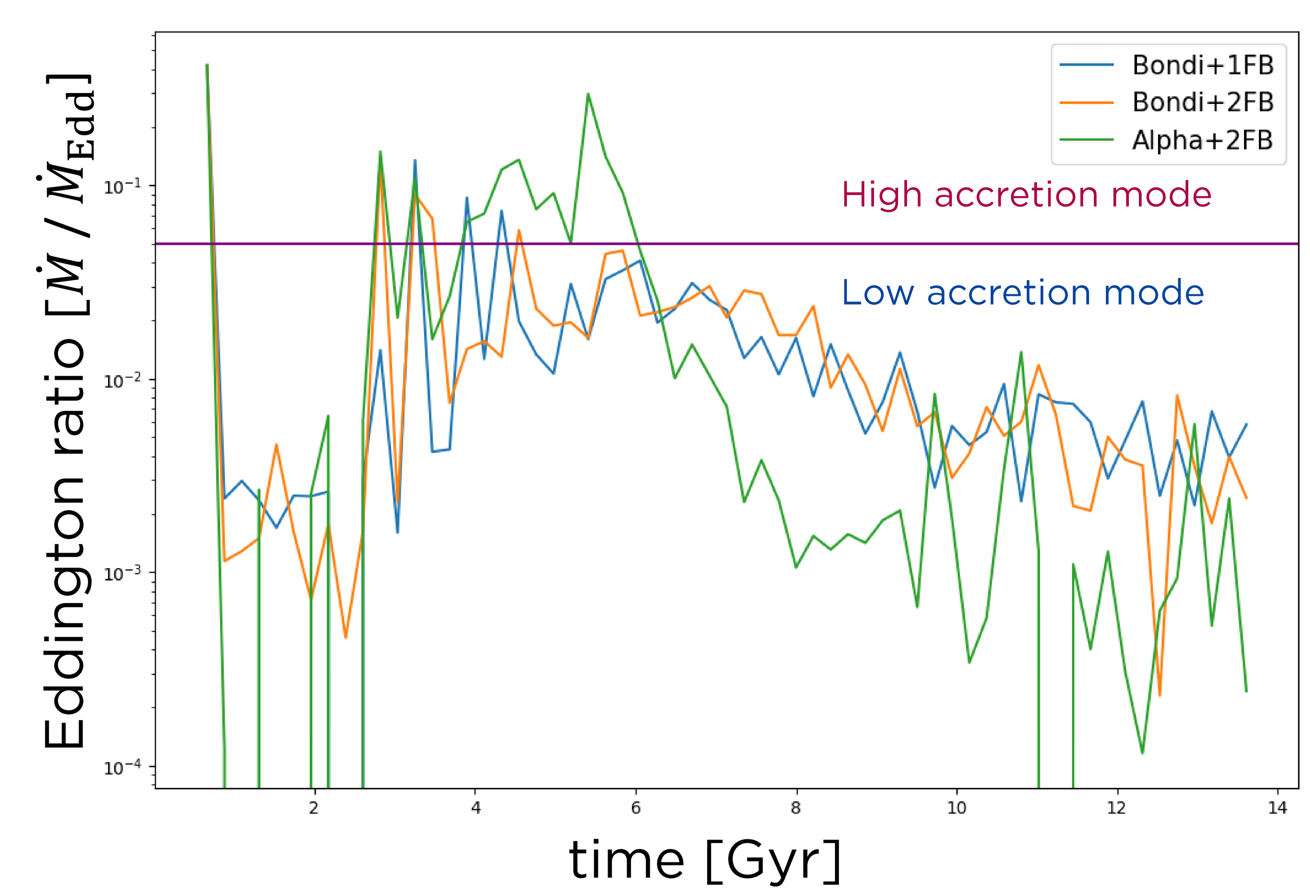
20% of the accretion energy is imparted as momentum to the 50 gas particles aligned with the normal direction of the BH's spin.

Results

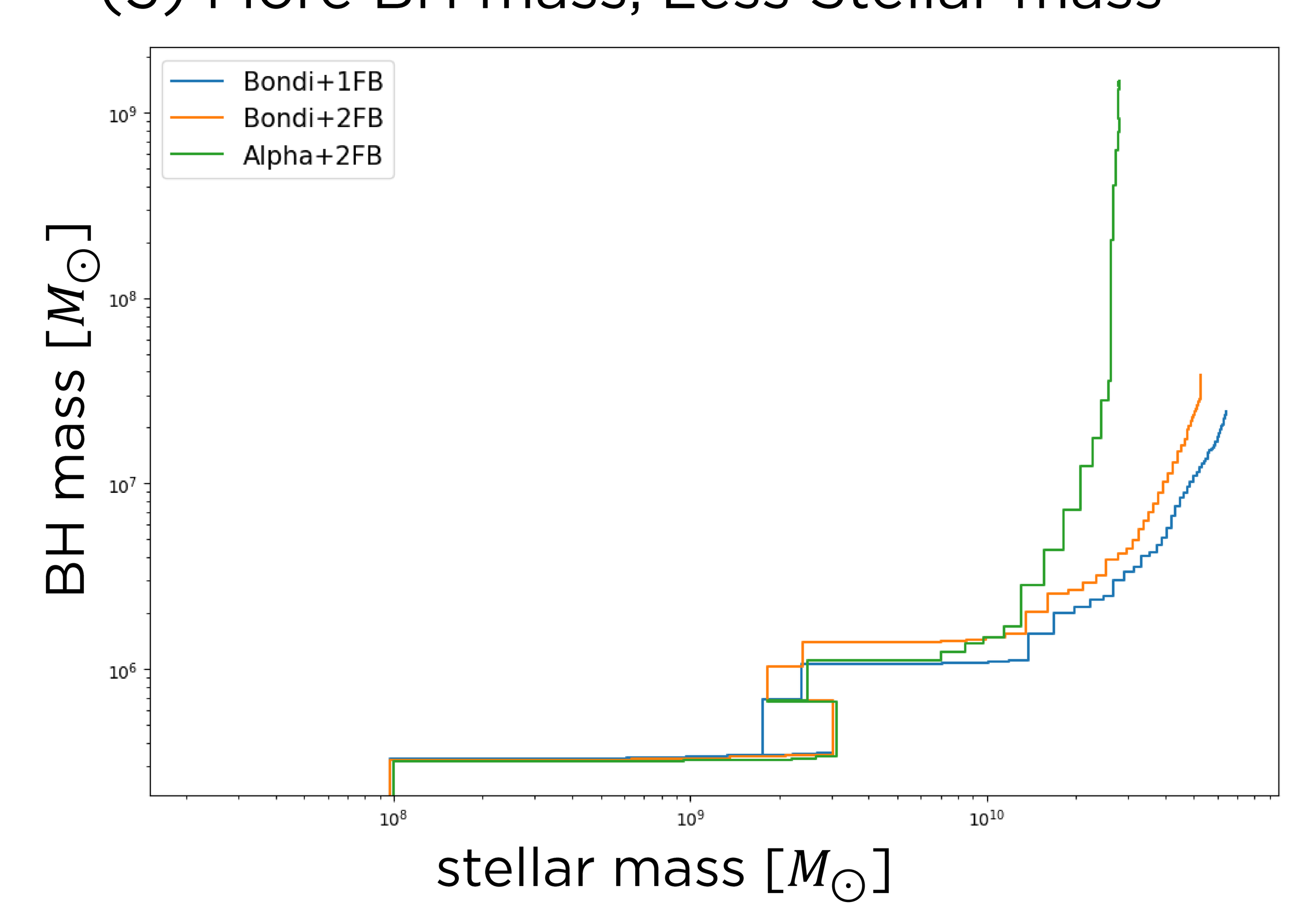
(1) Star formation quenching near z=0



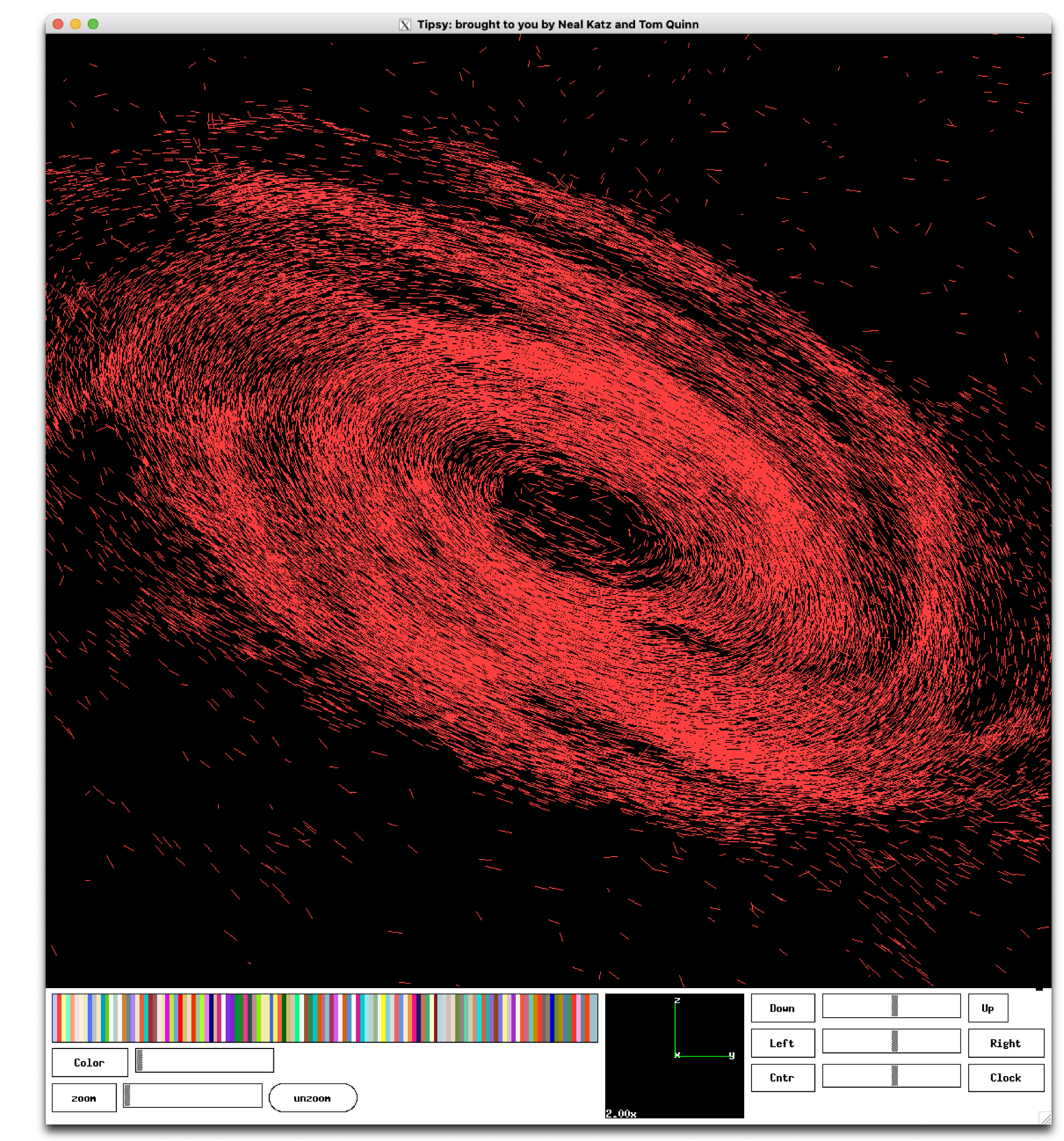
(2) More realistic accretion history



(3) More BH mass, Less Stellar mass



(4) More realistic galactic morphology



Conclusions

The new model implemented in the simulations effectively quenches star formation in massive haloes.

Once the transition of BH feedback to a low-accretion state is initiated, it remains throughout their subsequent evolution, exerting a lasting impact on the system.

The simulations produce massive galaxies characterized by red, mature stellar populations.

Future research utilizing this feedback model, alongside other accretion models, has the potential to broaden our understanding of galaxy formation and evolution.