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Supercritical growth of seed BHs at cosmic dawn and co-evolution with host galaxies

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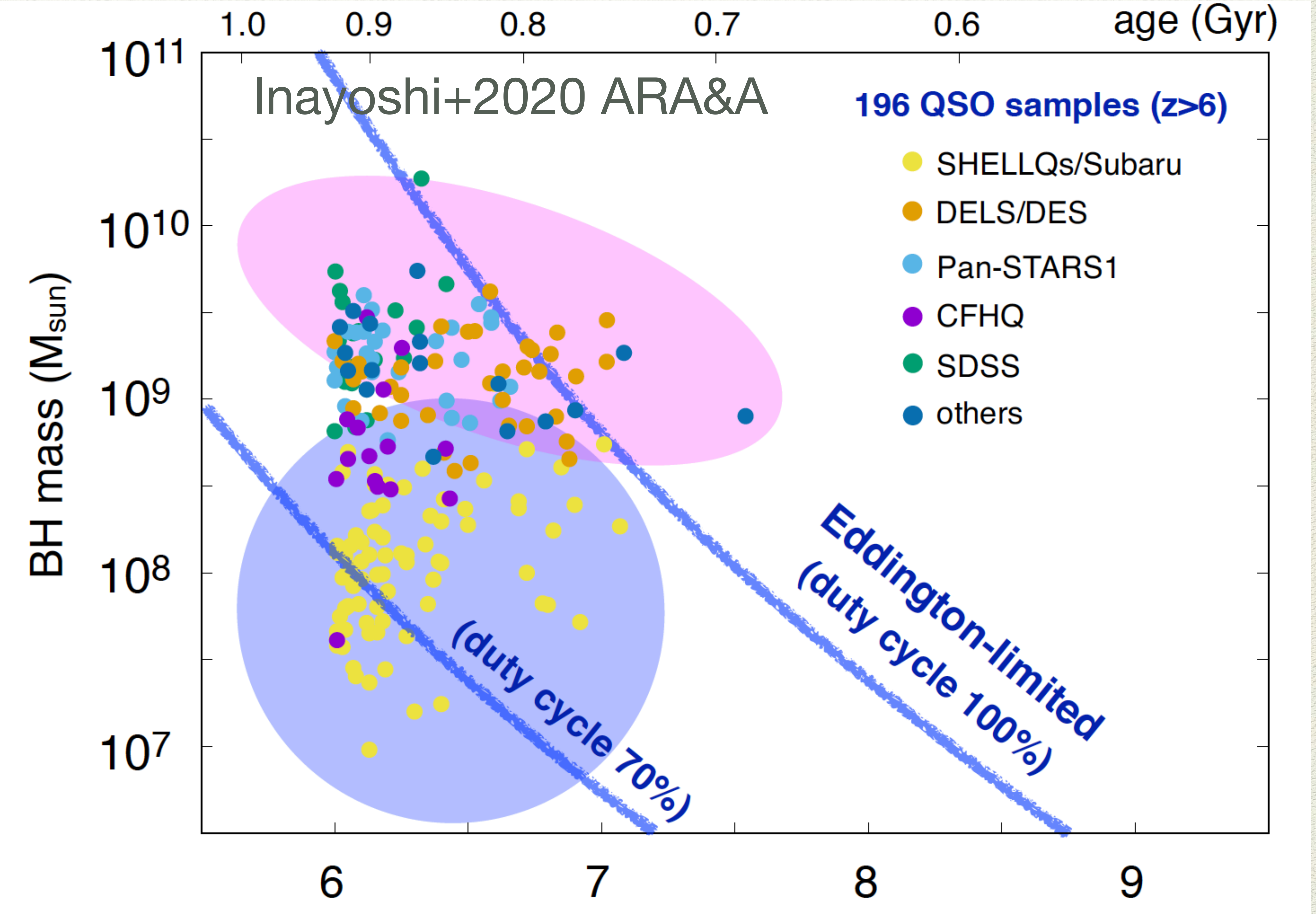
Illustration

Contents

Background—The need for Supercritical accretion

- Cosmic age: ~ 1 Gyr
- ~200 SMBHs (# is growing)
- Hard to growth
- Solutions:
  - **Rapid growth**
  - Heavy seeds

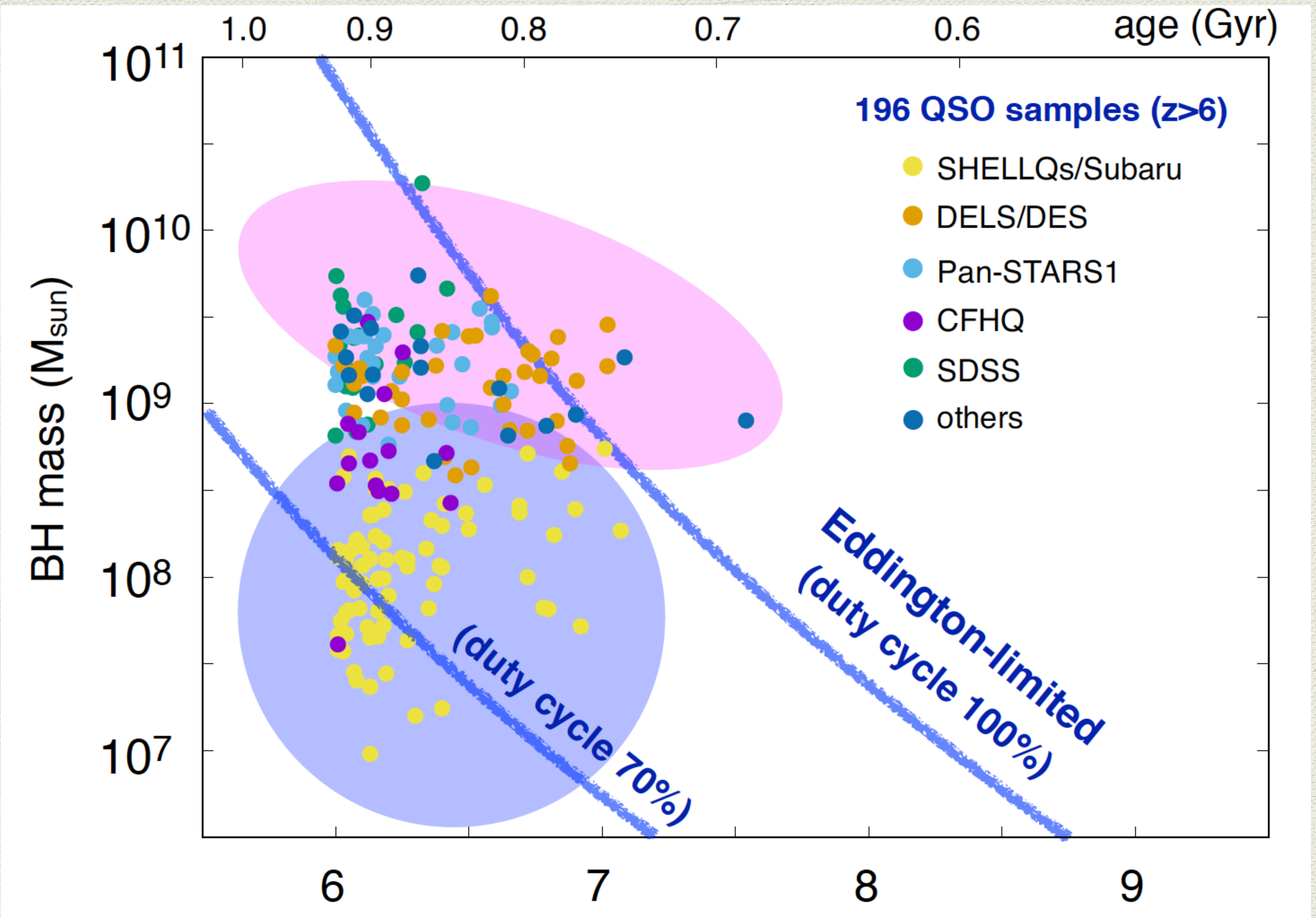


Note: $\lambda_{\rm Edd} = 1$ is assumed if no BH mass measurements

Background—The need for Supercritical accretion

Inayoshi+2020 ARA&A

- Cosmic age: ~ 1 Gyr
- ~200 SMBHs (# is growing)
- Hard to growth
- Solutions:
  - **Rapid growth** This talk
  - Heavy seeds



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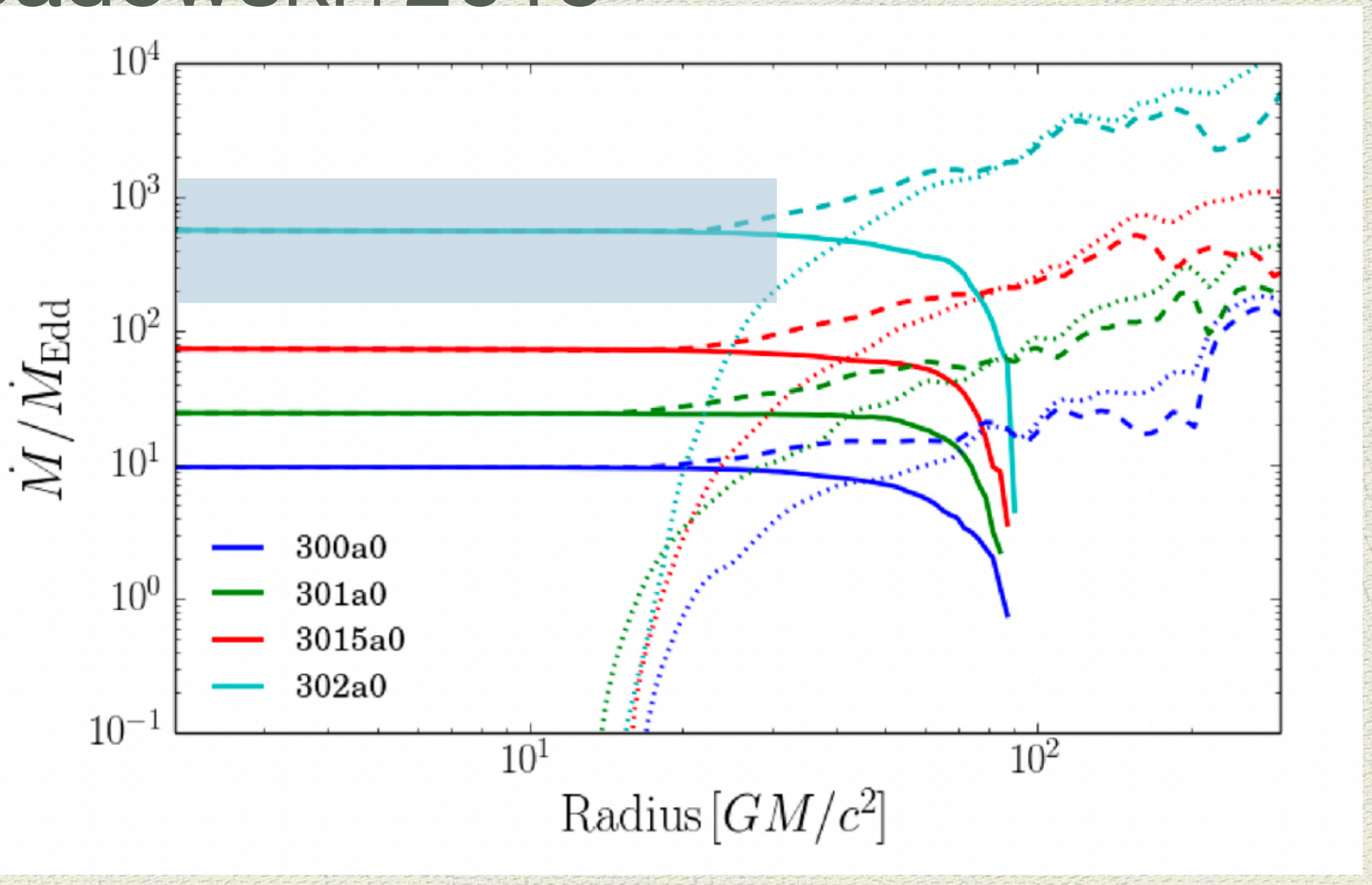
Background—Current Status

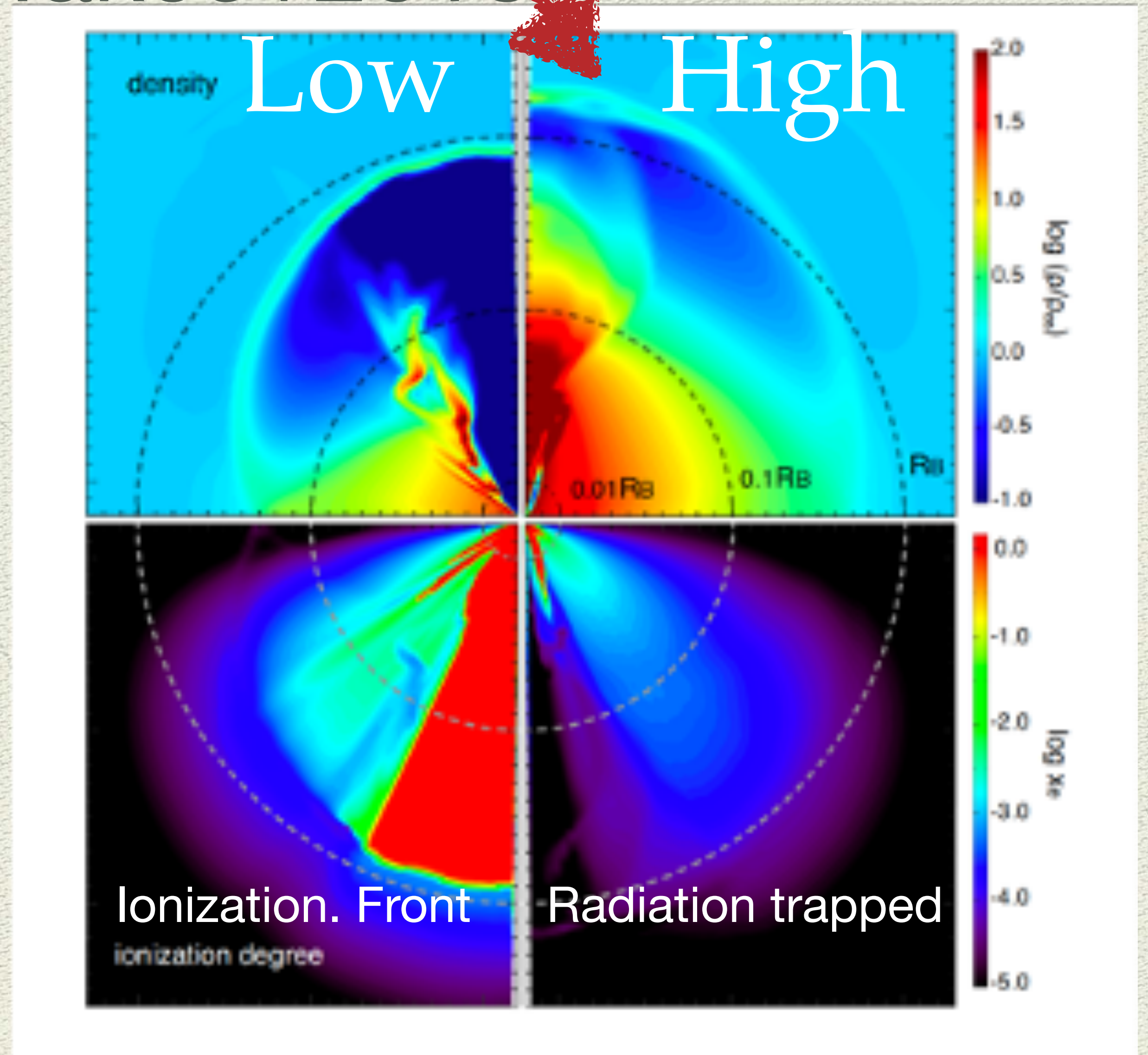
Sadowski+2015



Supercritical inflows onto BH

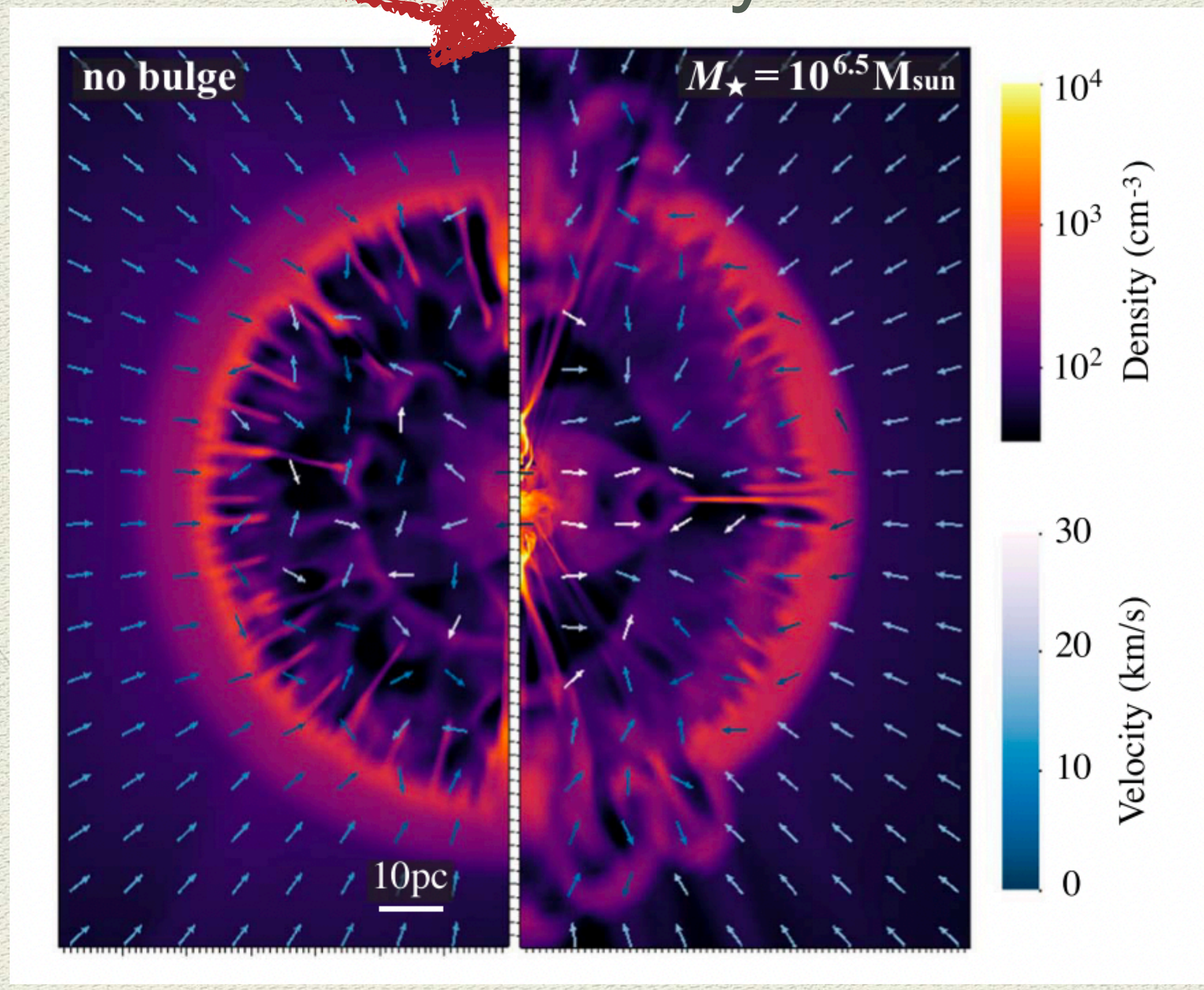
See also Jiang+2014;Kitaki+2021

Takeo+2018



High acc. rate when Radiation is trapped

Inayoshi+2022

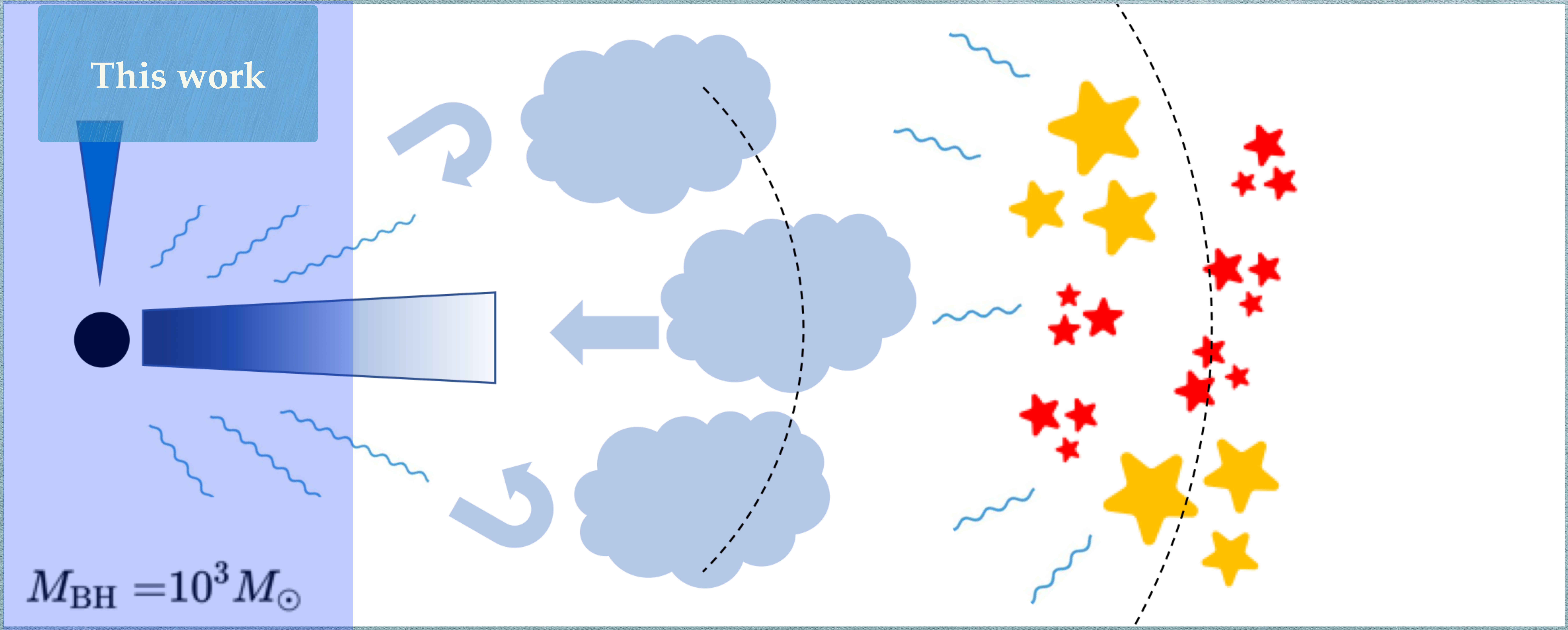


Bulge helps transition to high acc.

Motivations

- Idealized initial conditions
  - Dense torus & low ang. mom.
- Non-steady states
- Local simulations
  - Little insights for large sim.

- More realistic boundary condition
  - Inflow gas & large ang. mom.
- Long-term evolution
- Global solution
  - Subgrid feedback models

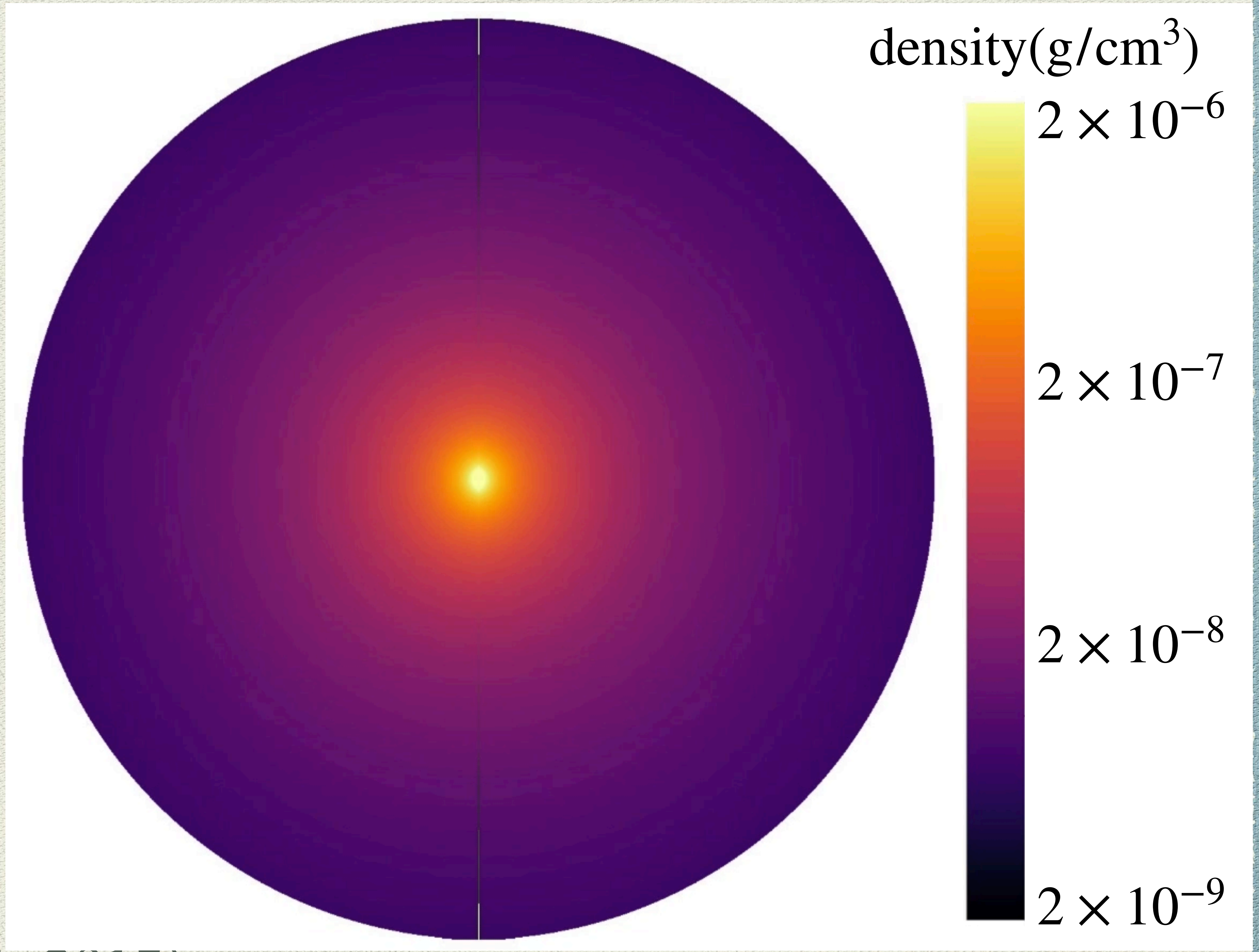


Aims: BH's response to supercritical inflows & Feedback to large dynamics

Simulations—setups

Details in Hu+2022a

- Code: PLUTO
- Radiation hydrodynamical sim. (FLD)
- BH vicinity: $3 \sim 1500\ R_{\mathrm{Sch}}$
- Supercritical inflows: $\sim 1000\ \dot{M}_{\mathrm{Edd}}$
- Long-term evolution:
  - Quasi-steady state
  - 10-100 X longer (Ohsuga+2005, Sadowski+2015)



Simulations—setups

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- Code: PLUTO
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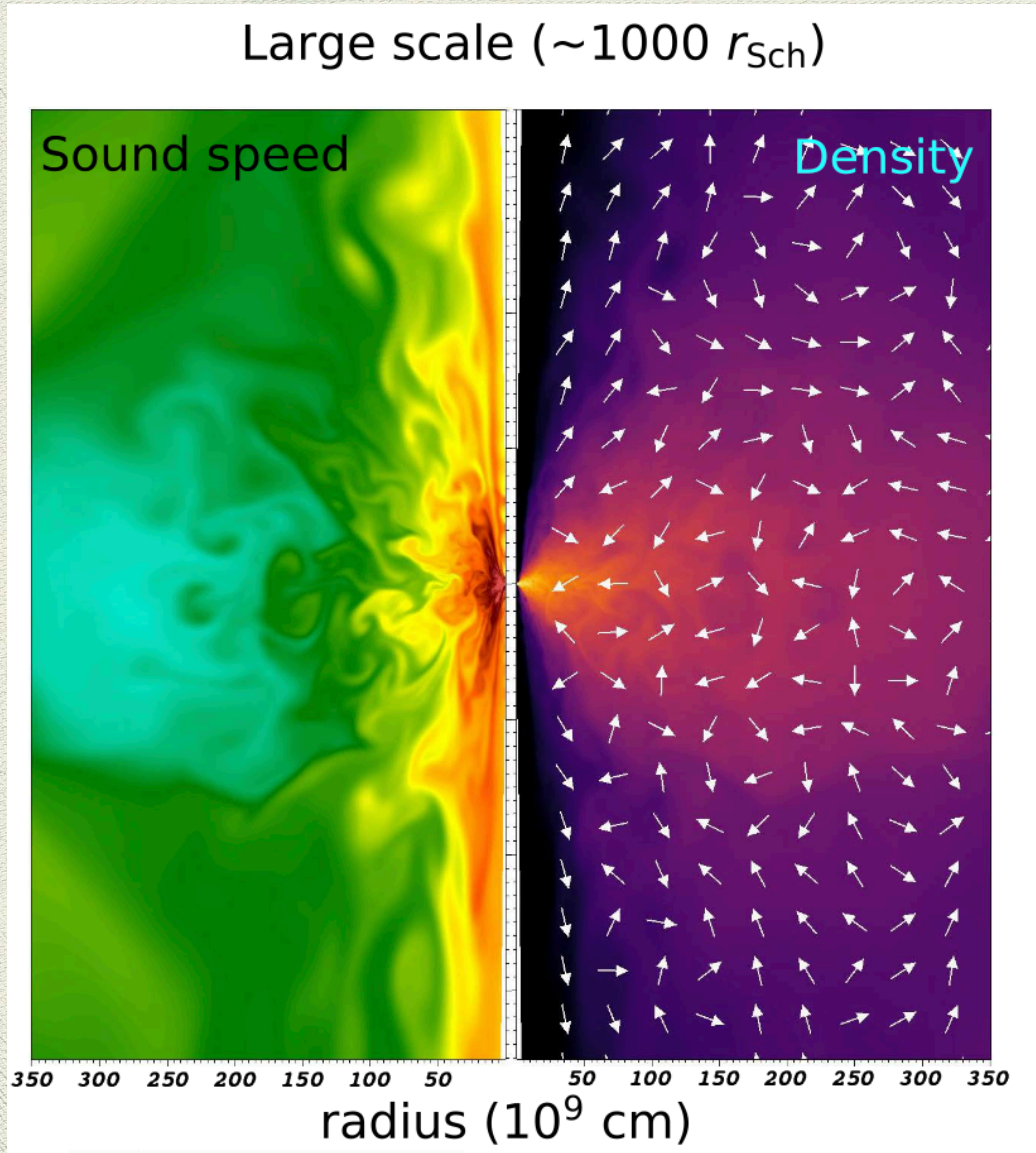
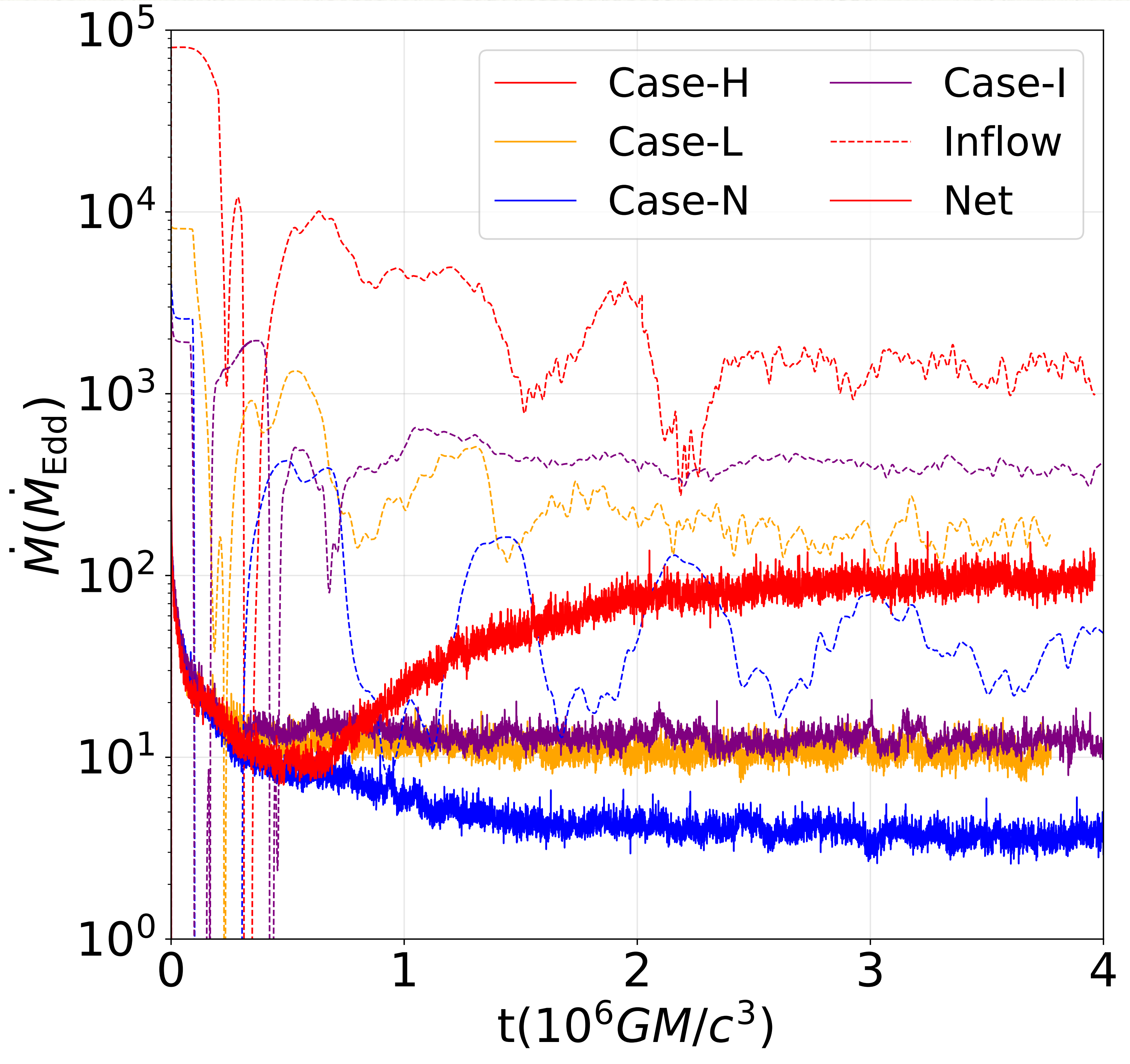


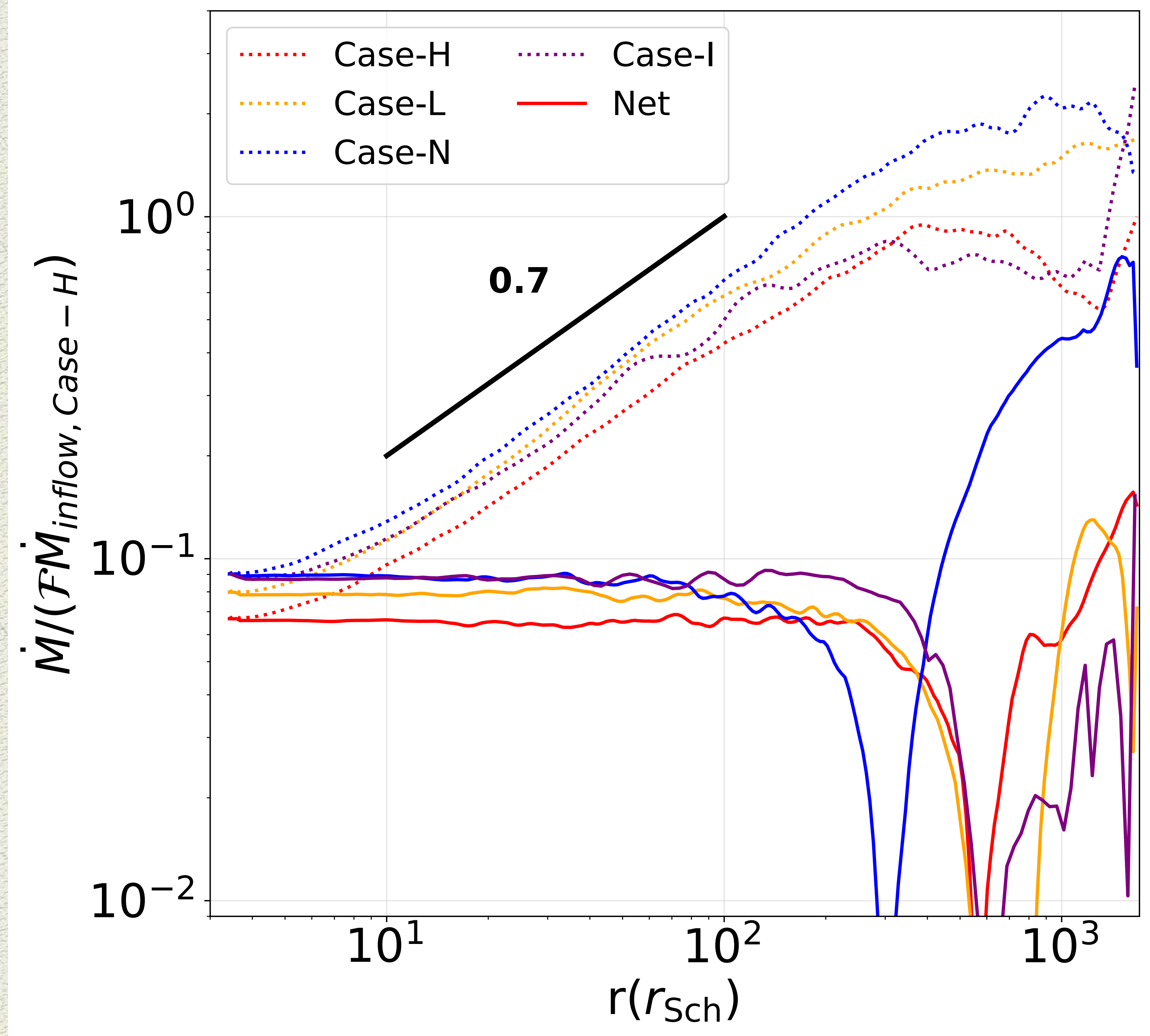
Simulations—results

Details in Hu+2022a

- Long-term evolution
- outflow $\simeq$ inflows
- Mild supercritical growth
- Self-similar behavior
- $\dot{M}_{\rm inflow} \propto r^p, p \sim 0.5 - 0.7$
  - Often seen in low acc. sys such as ADAF sims.



10-100 X longer
(Ohsuga+2005, Sadowski+2015)

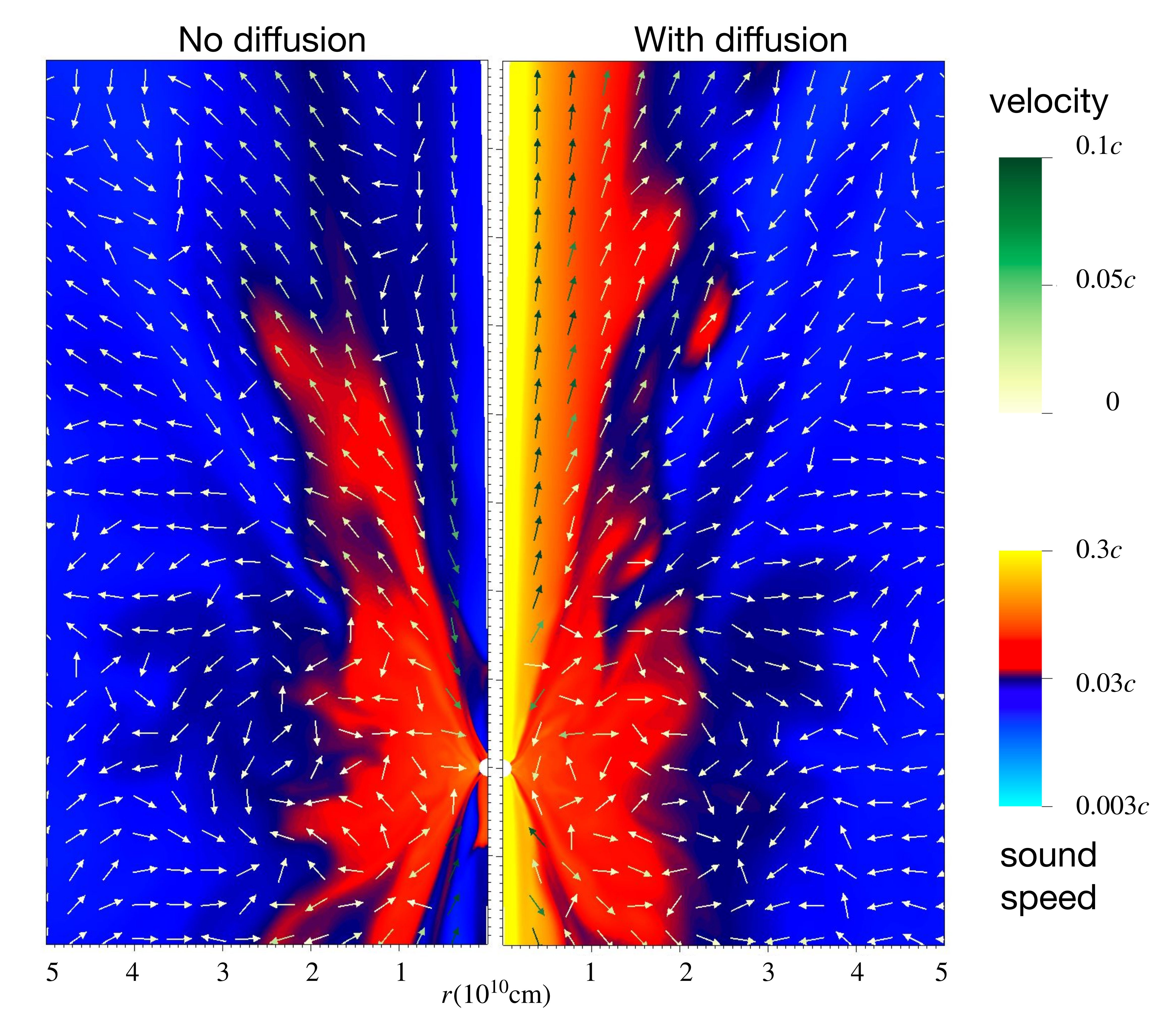


5% of $\dot{M}_{\rm inflow}(r_{\rm out})$
Fed to the BH

Simulations—photon-trapping & radiative diffusion

- Photons are trapped in dense region
- Radiation diffuses away at polar region
- Diffusion drives outflows
- But no effects at large scales

Details in Hu+2022

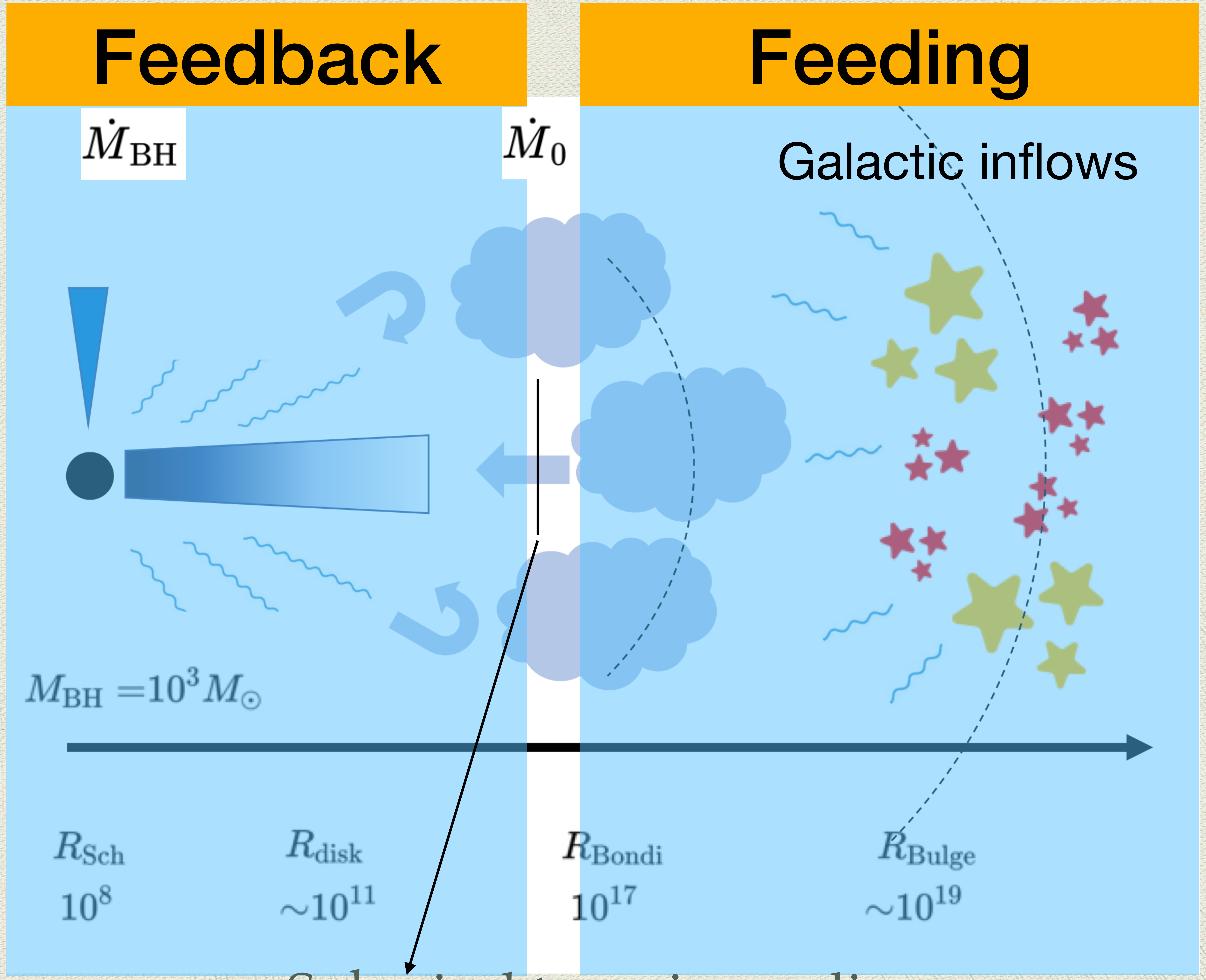


Summary I—Hu+2022a

- Long-term evolution of accretion flow: bi-polar outflow and inflows near equator.
- Mass reduction due to outflows, $\dot{M}_{\rm in} \propto r^p, p \sim 0.5 - 0.7$.
- Radiative diffusion accelerates outflows near polar region, but has little effects on the global accretion structure. (Maybe on SED?)

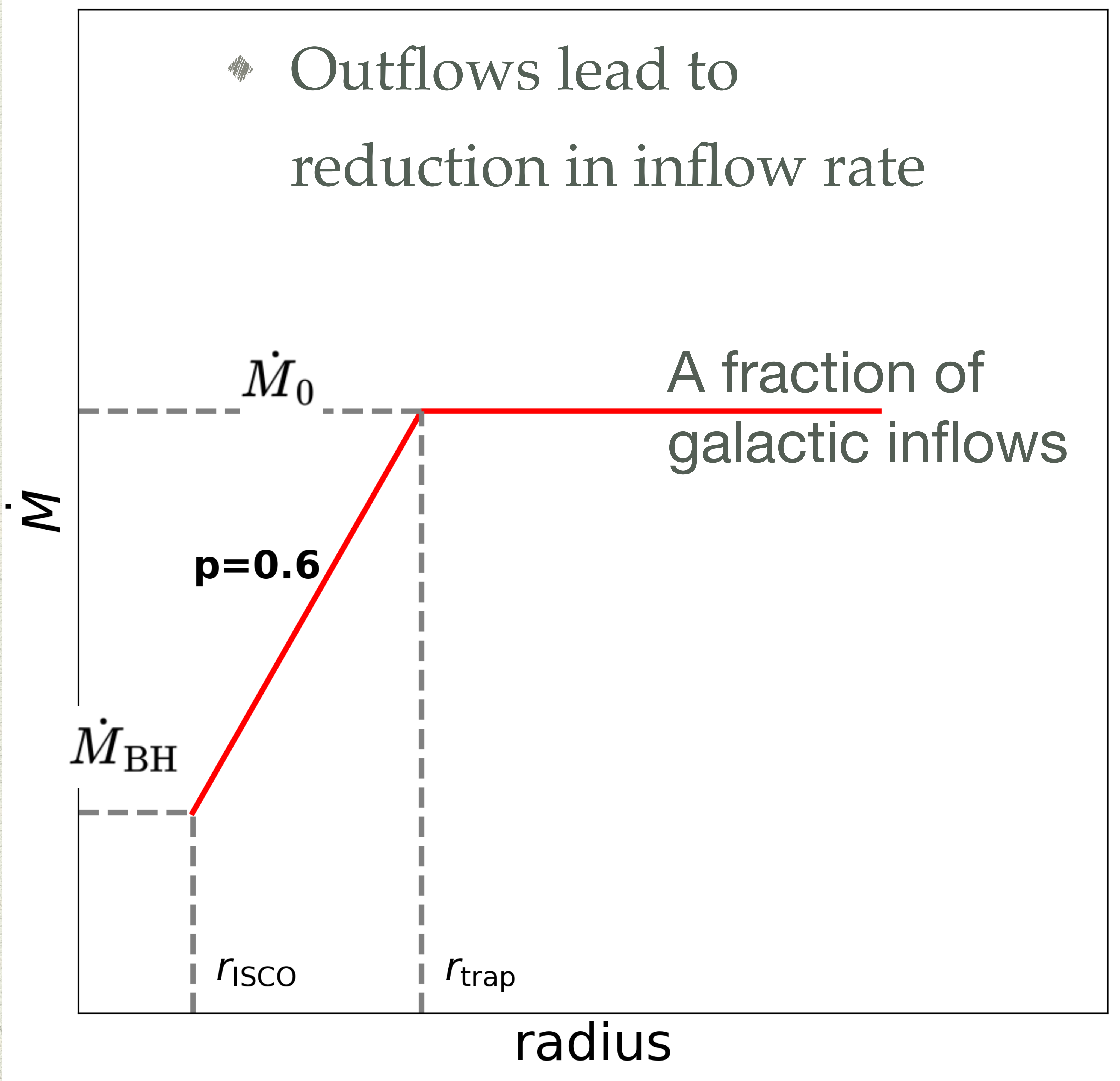
Simulations—Subgrid feeding model

Detail in Hu+2022b, also Li+2021



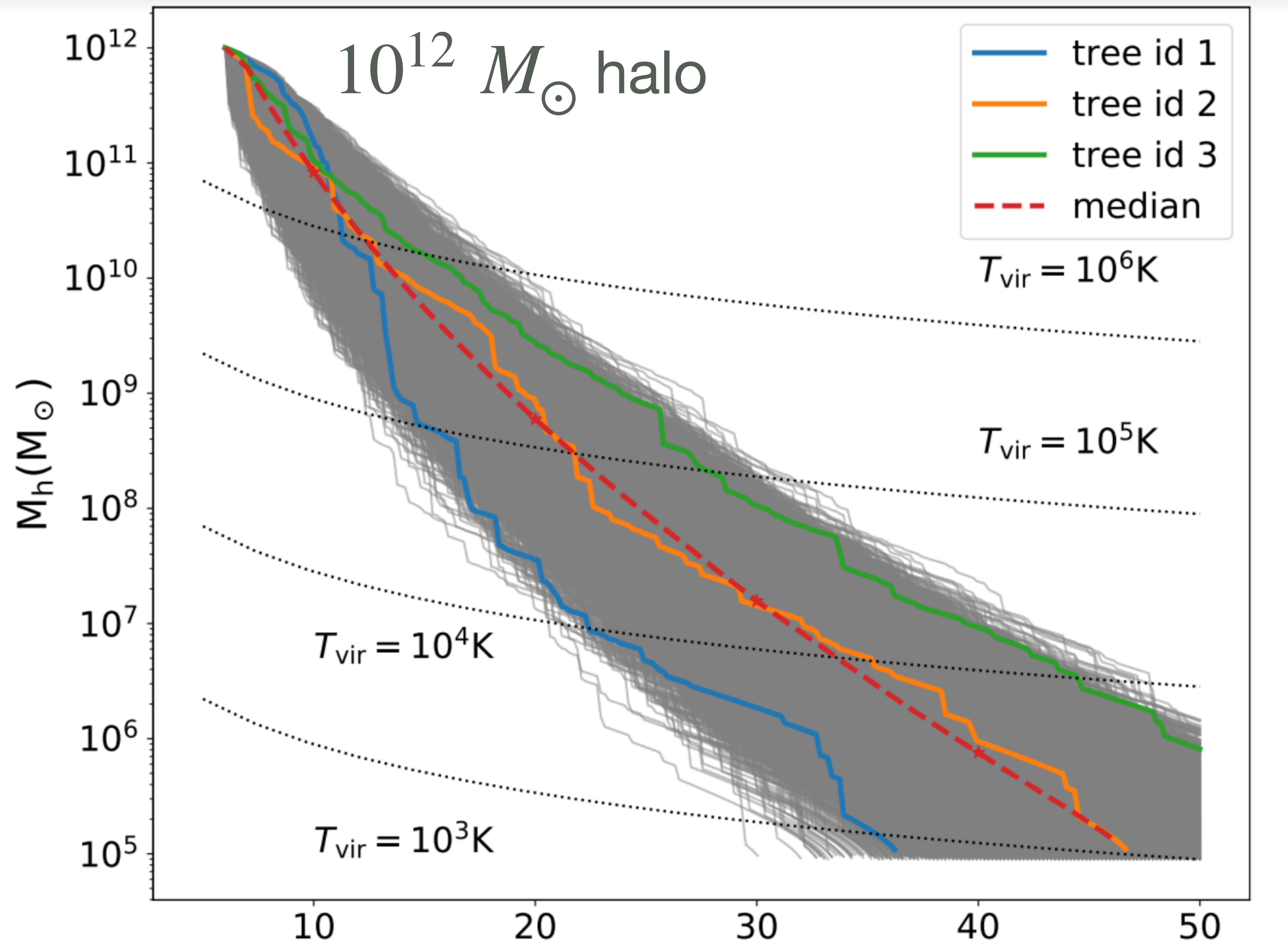
- Spherical trapping radius

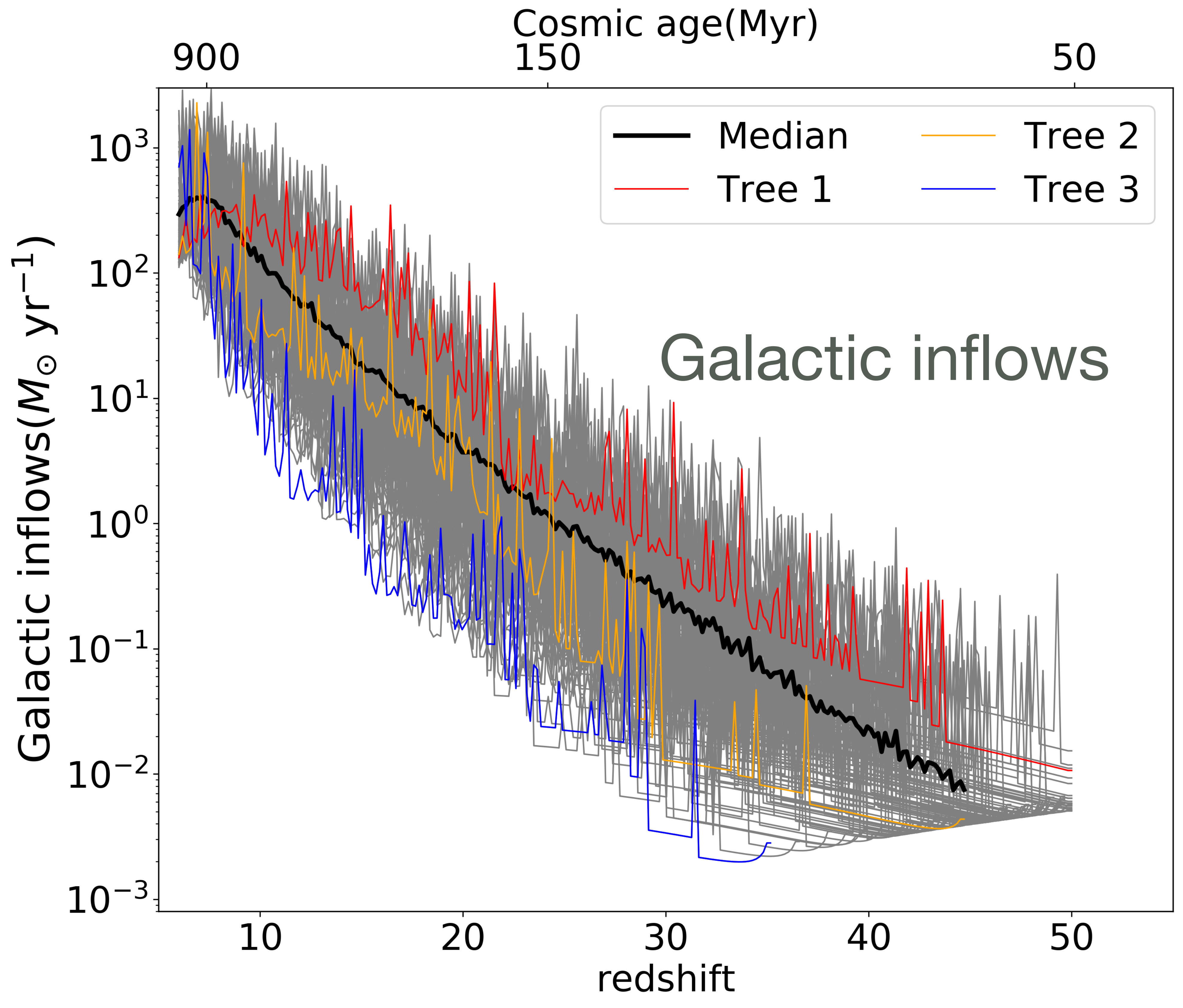
- Outflows lead to reduction in inflow rate



Simulations—Subgrid feeding model

Details in Hu+2022b, also Li+2021

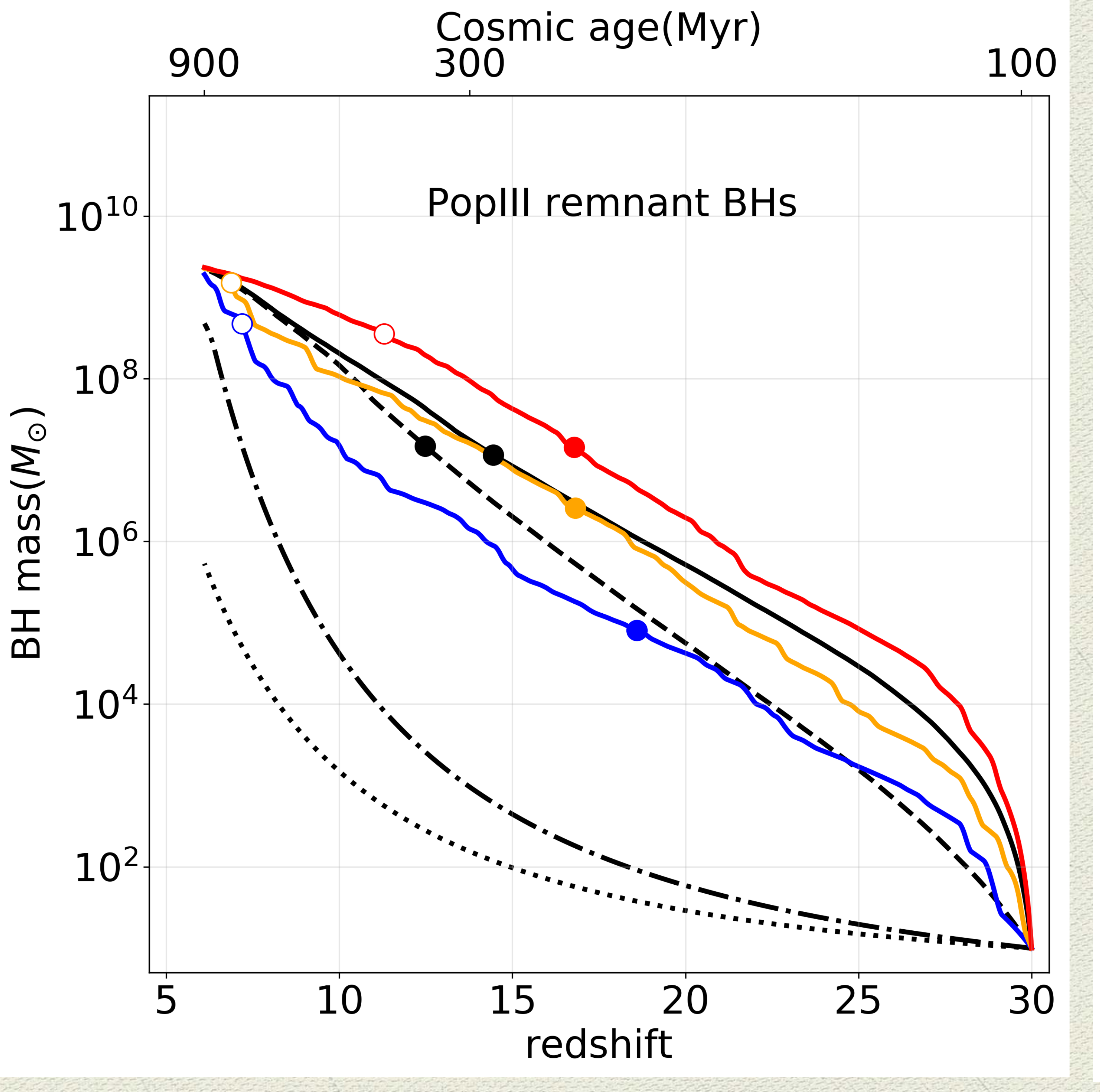




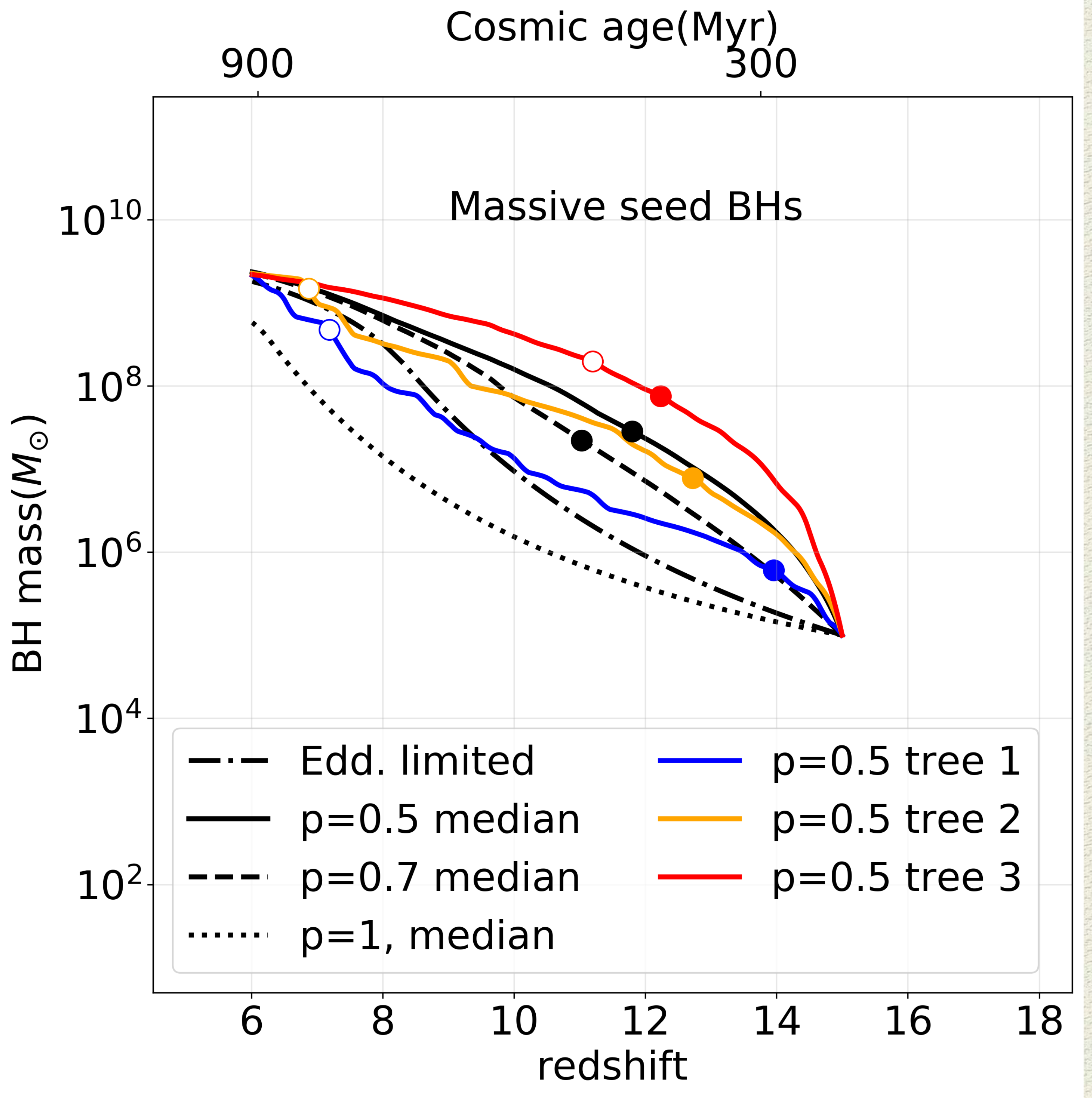
Evolution—growth of Seed BHs

Details in Hu+2022b

- Outflow strength: p
- Heavy seeds: successful
- Light seeds:
  - Strong outflow ✗
  - **Moderate outflow** ✓
  - Eddington rate ✗



Seed: z=30, M=10 $M_\odot$

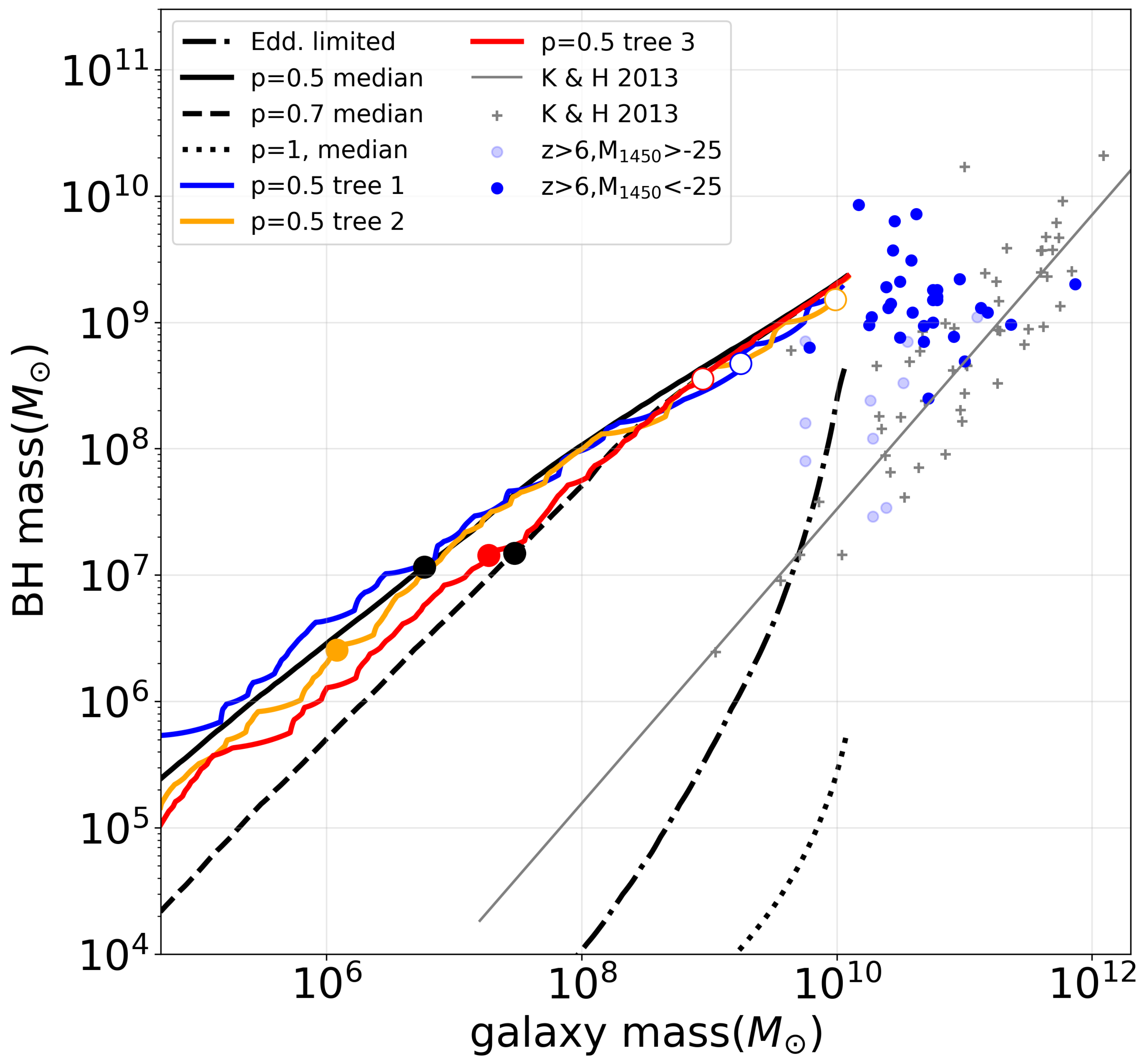


Seed: z=15, M= 10^5 $M_\odot$

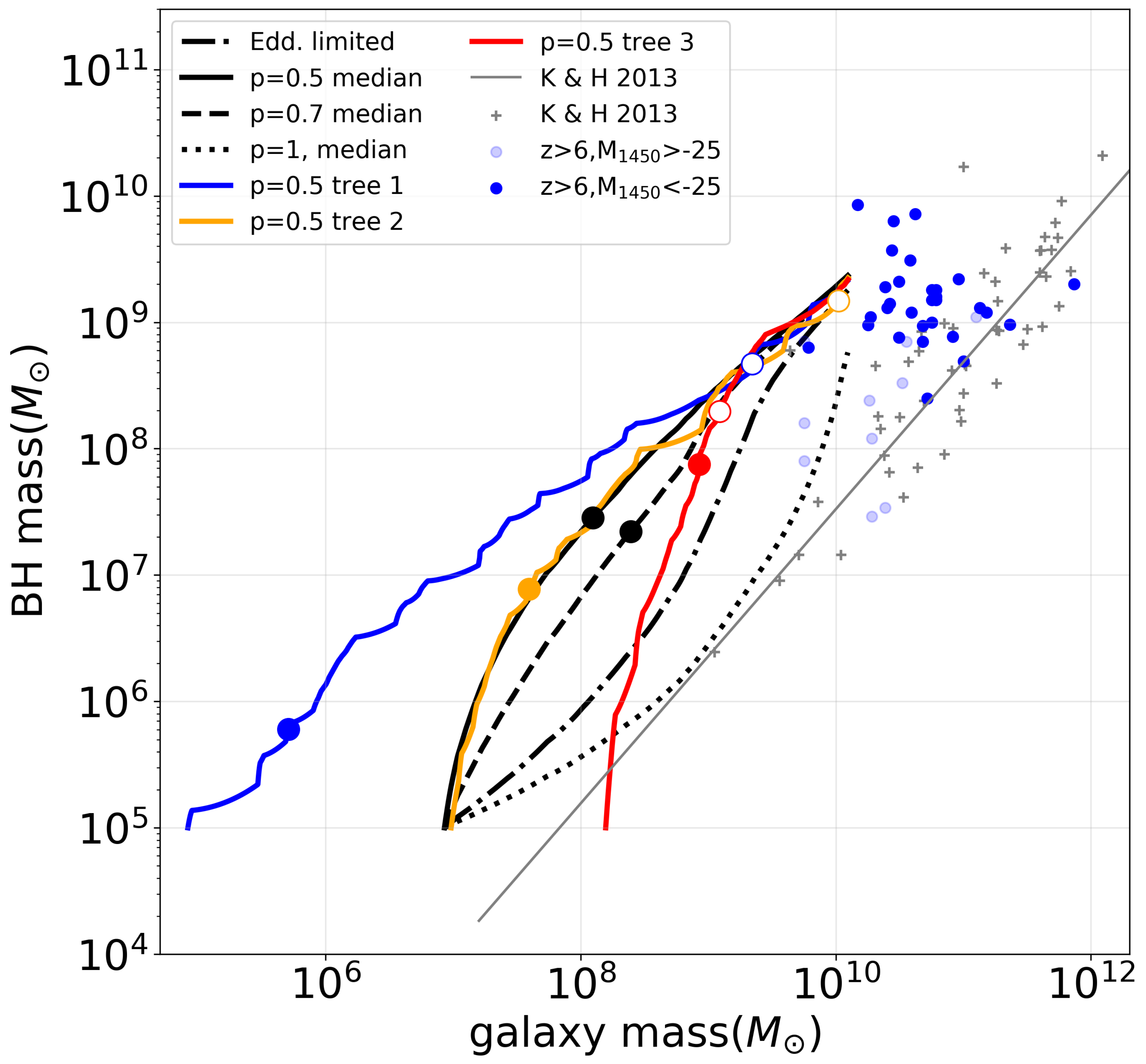
Evolution—growth of Seed BHs

Details in Hu+2022b

- Outflow strength: p
- Successful:
  - Overmassive BHs
- Or higher SFE?



Seed: z=30, M=10 $M_\odot$

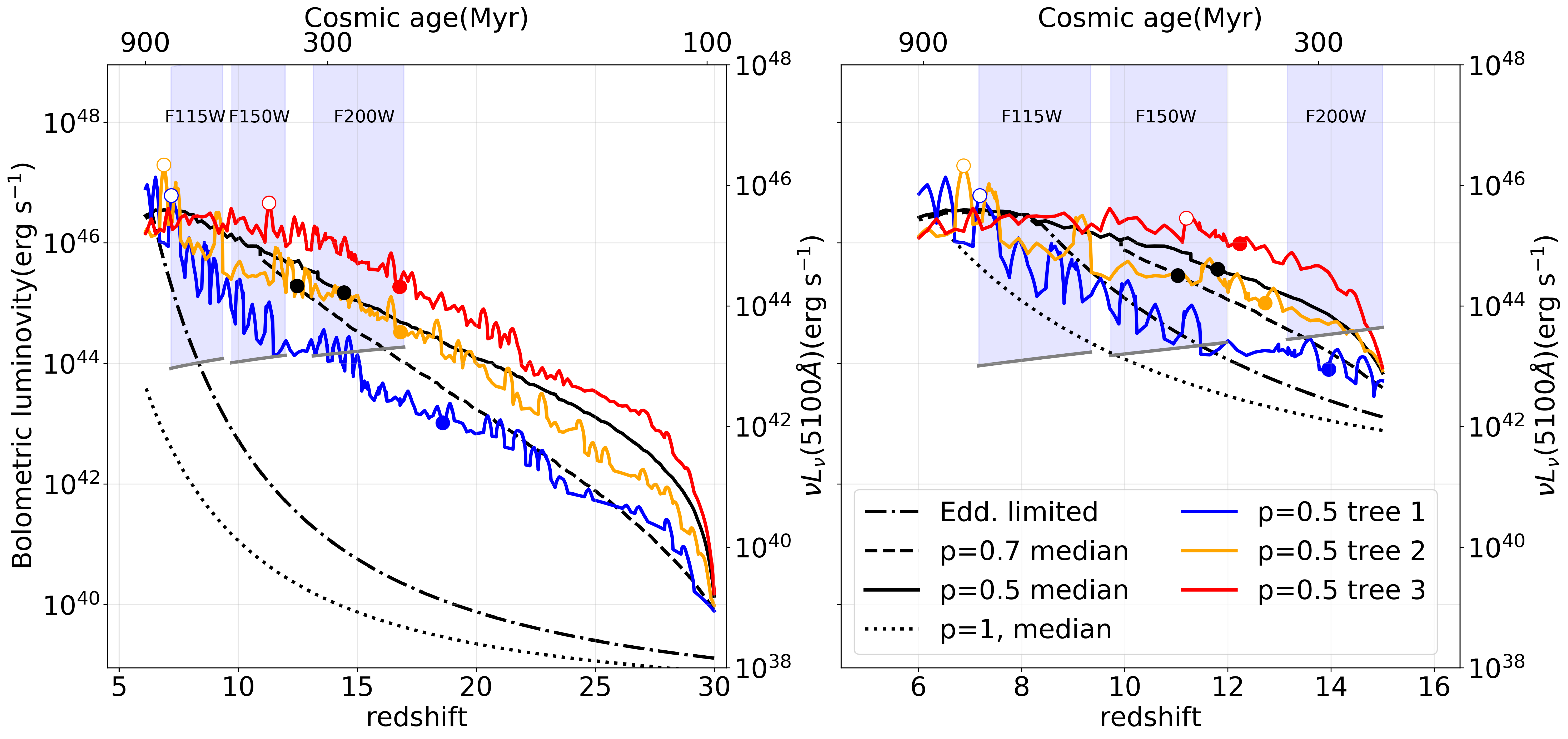


Seed: z=15, M= 10^5 $M_\odot$

Evolution—Detectability with JWST

Details in Hu+2022b

- Detectable if rapid growing
- Rate: 1 in 10 FoVs for JWST
- (See also, Inayoshi+2022
- Onoue+2022)



Seed: z=30, M=10 $M_\odot$

Seed: z=15, M= 10^5 $M_\odot$

Summary—Hu+2022a, 2022b

- Long-term evolution of accretion flow: bi-polar outflow and inflows near equator.
- Mass reduction due to outflows, $\dot{M}_{\rm in} \propto r^p, p \sim 0.5 - 0.7$.
- Subgrid model (feeding & feedback) for seed BHs at high-z universe:
  - Strong outflows can suppress the early growth of seed BHs.
  - Moderate outflows cannot suppress the growth, BHs grow faster than host galaxy, reaching the overmassive region.
  - It is very promising for JWST to detect rapid accreting BHs