Supercritical growth of seed BHs at cosmic dawn and co-evolution with host galaxies: Long-term evolution regarding outflows

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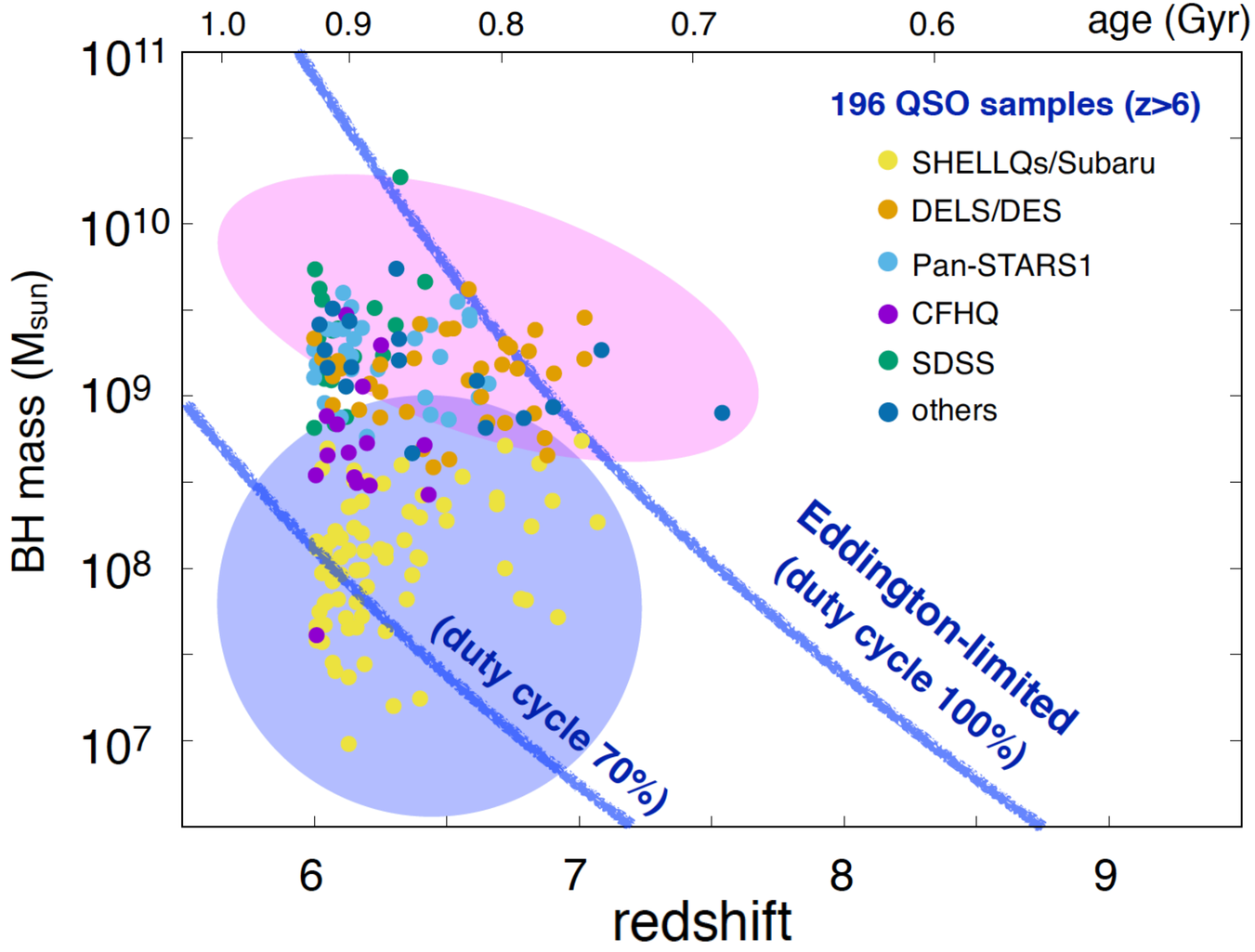
https://www.nsf.gov/sites/default/files/thumbnails/image/simulated_bh.jpg

High-z Quasars & SuperMassive Black Holes

From Inayoshi, compiled from Inayoshi, Visbal and Haiman (2020) ARA&A

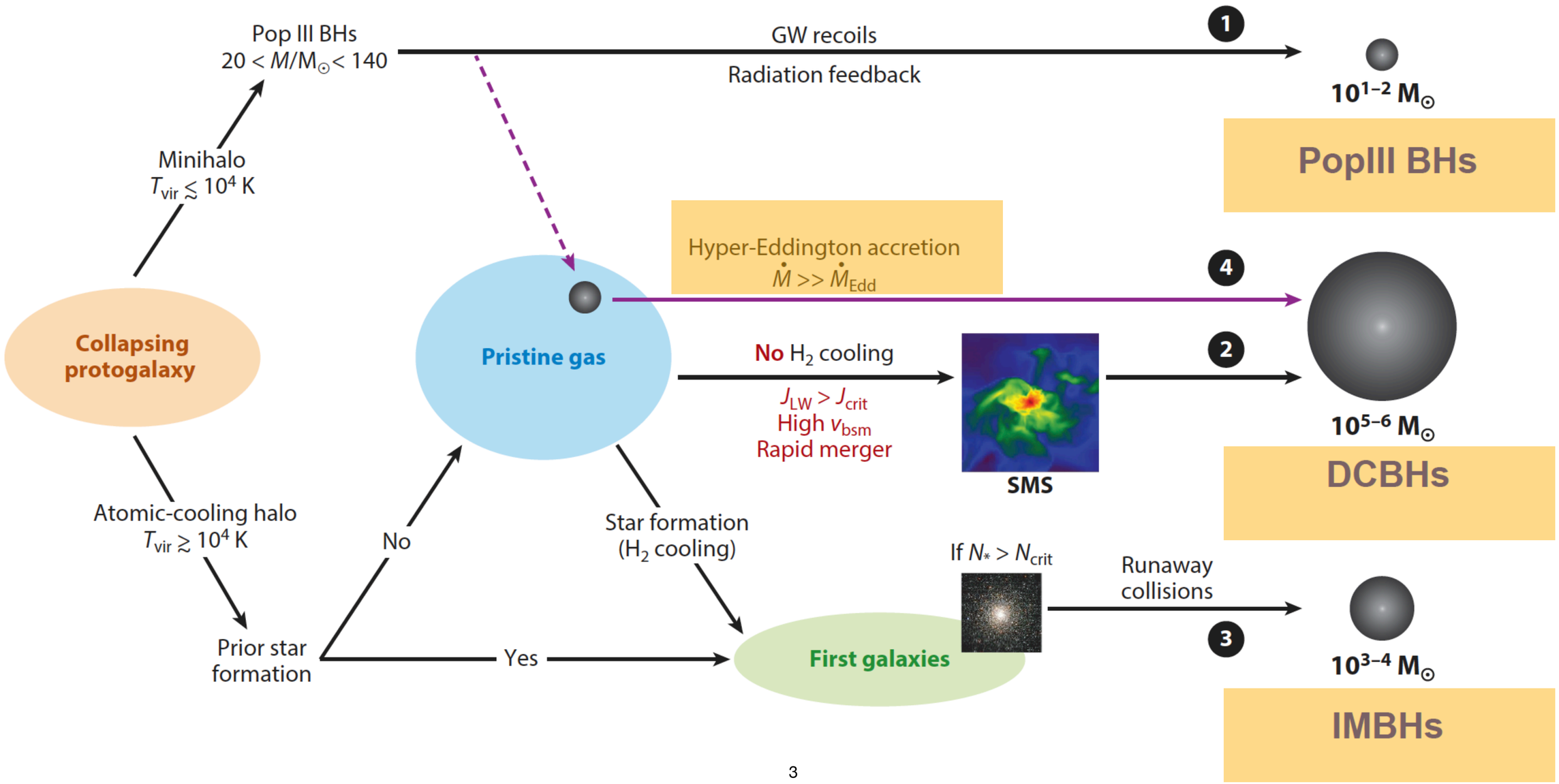


- Existence of SMBHs at z>6
- $\dot{M}_{\rm Edd}$ can marginally grow such SMBHs
- Alternatives
  - Heavy seeds
  - Supercritical accretion

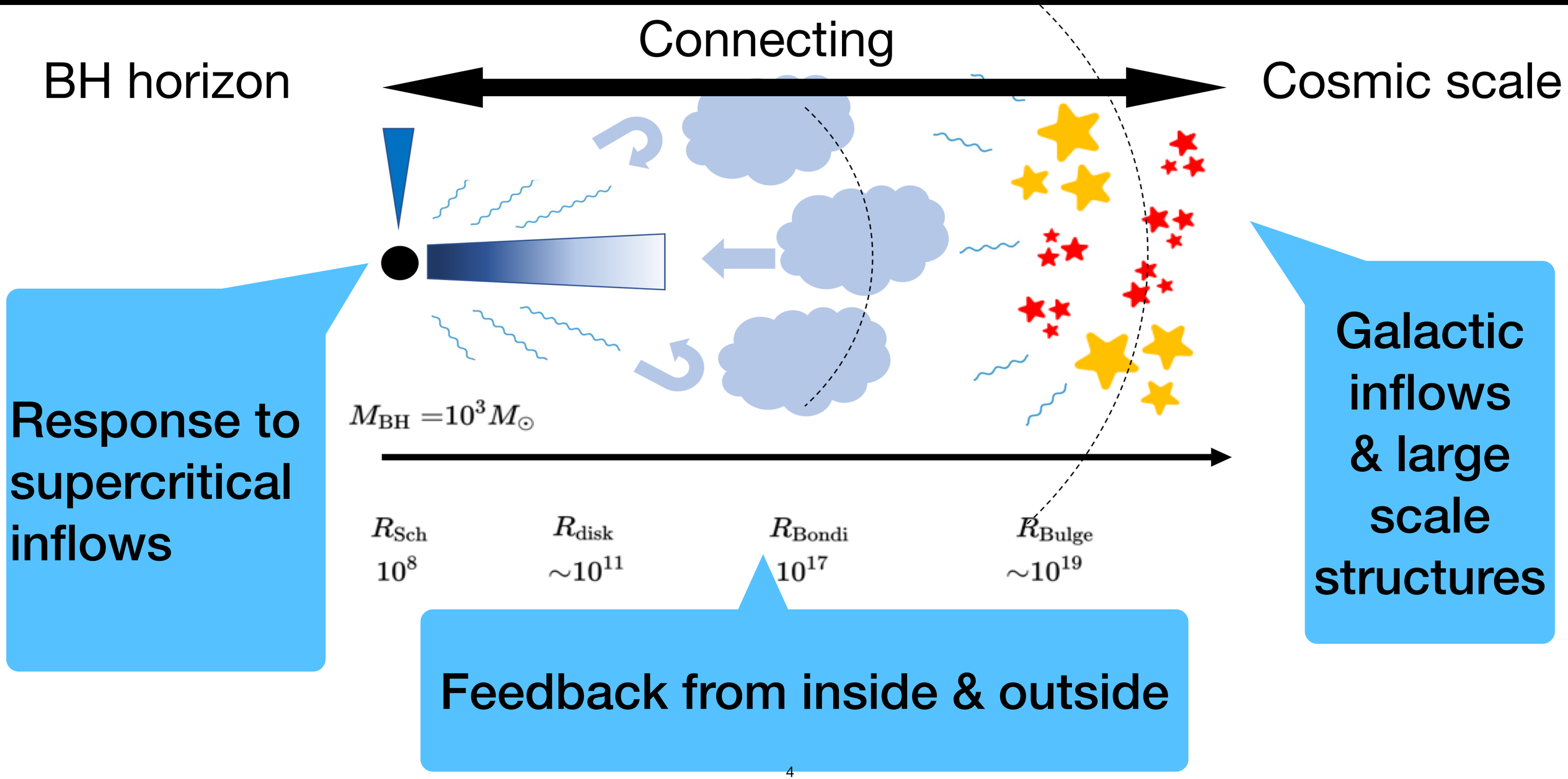
Note: $\lambda_{\rm Edd} = 1$ is assumed if no BH mass measurements

Formation Channels of Early BHs

Inayoshi, Visbal and Haiman (2020) ARA&A

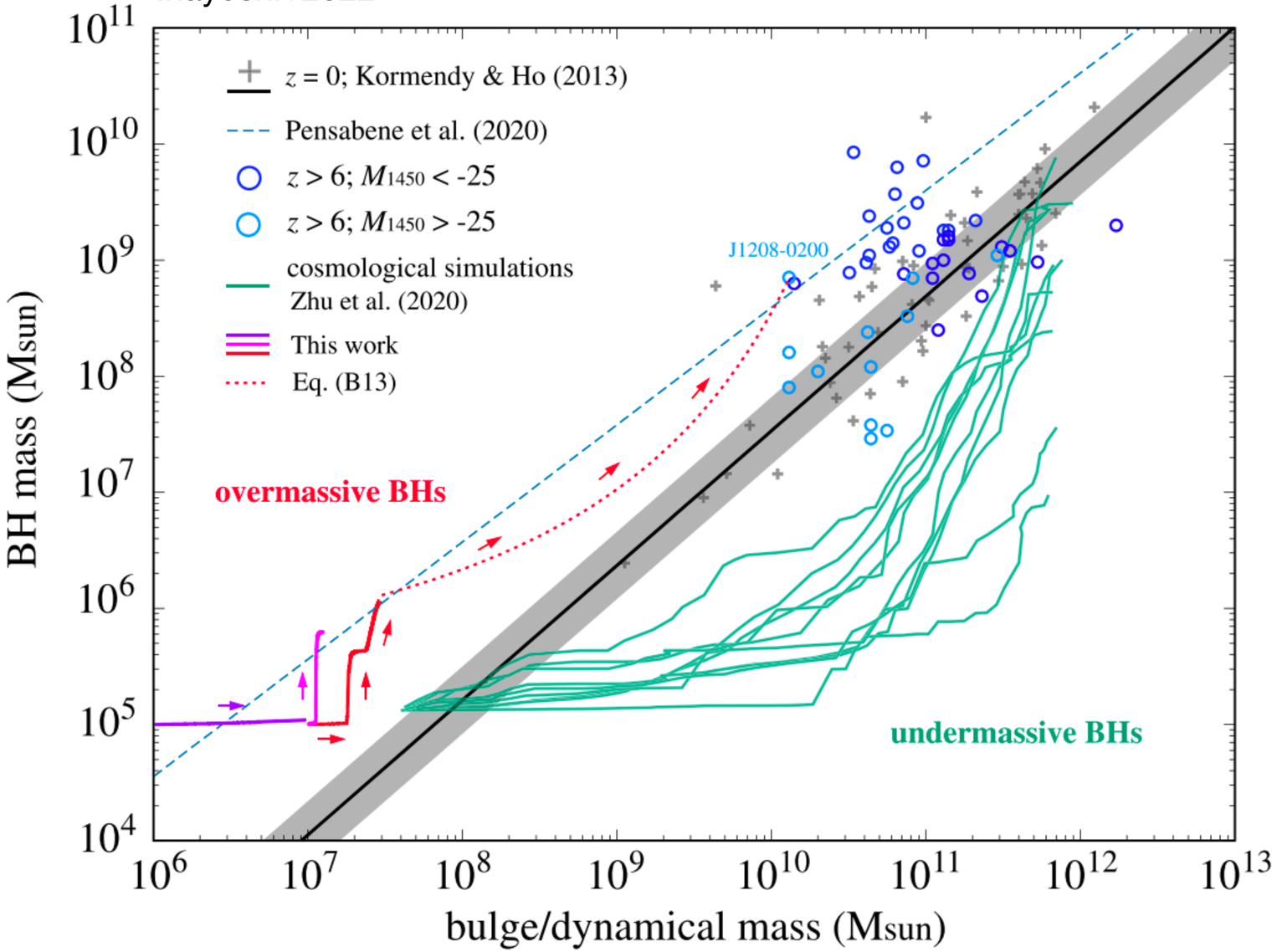


Global structure of BH accretion



Co-evolution btw SMBHs & host galaxies

Inayoshi+2022

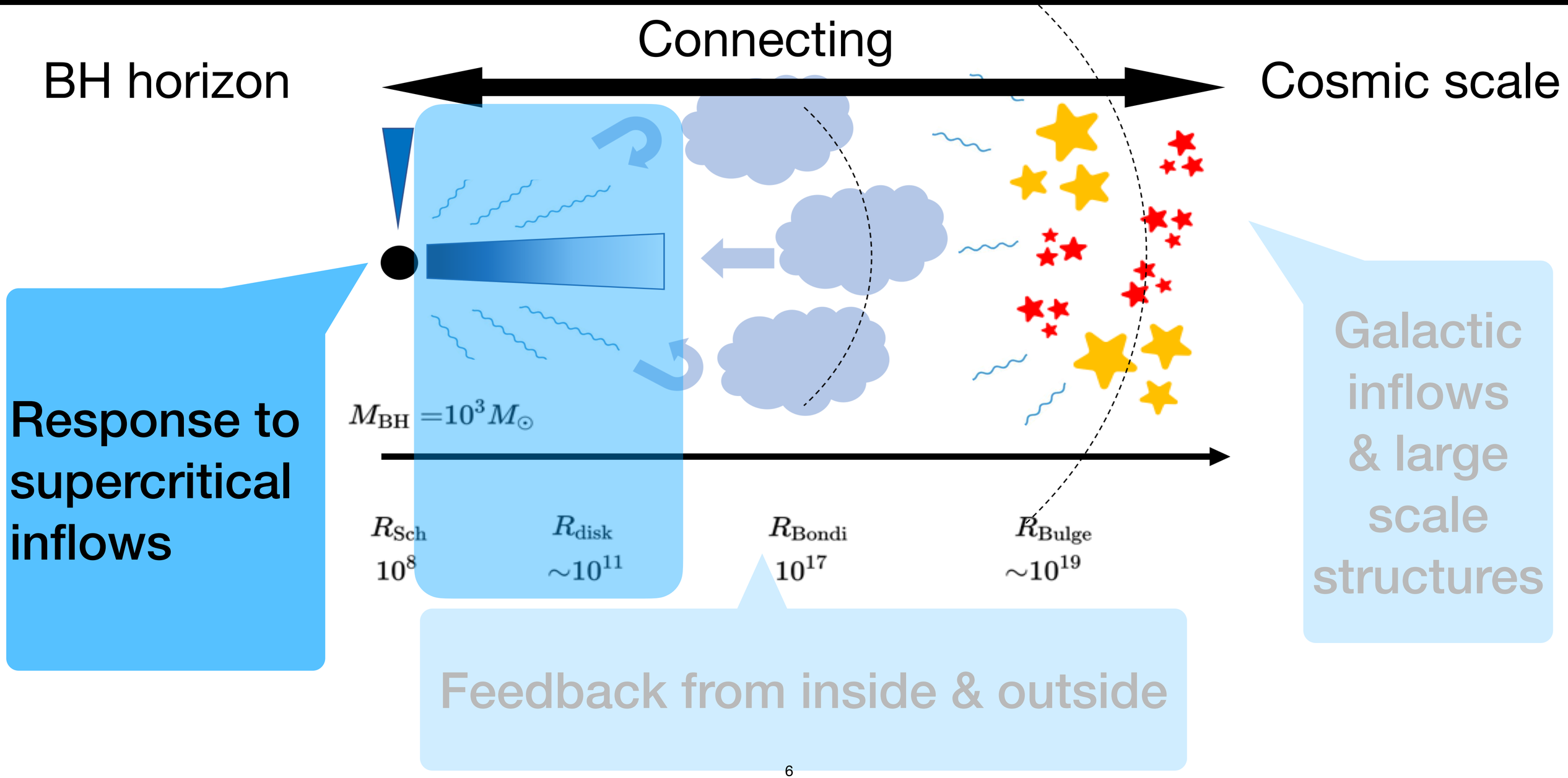


Rapid growth of BH?

Rapid assembly of galaxies?

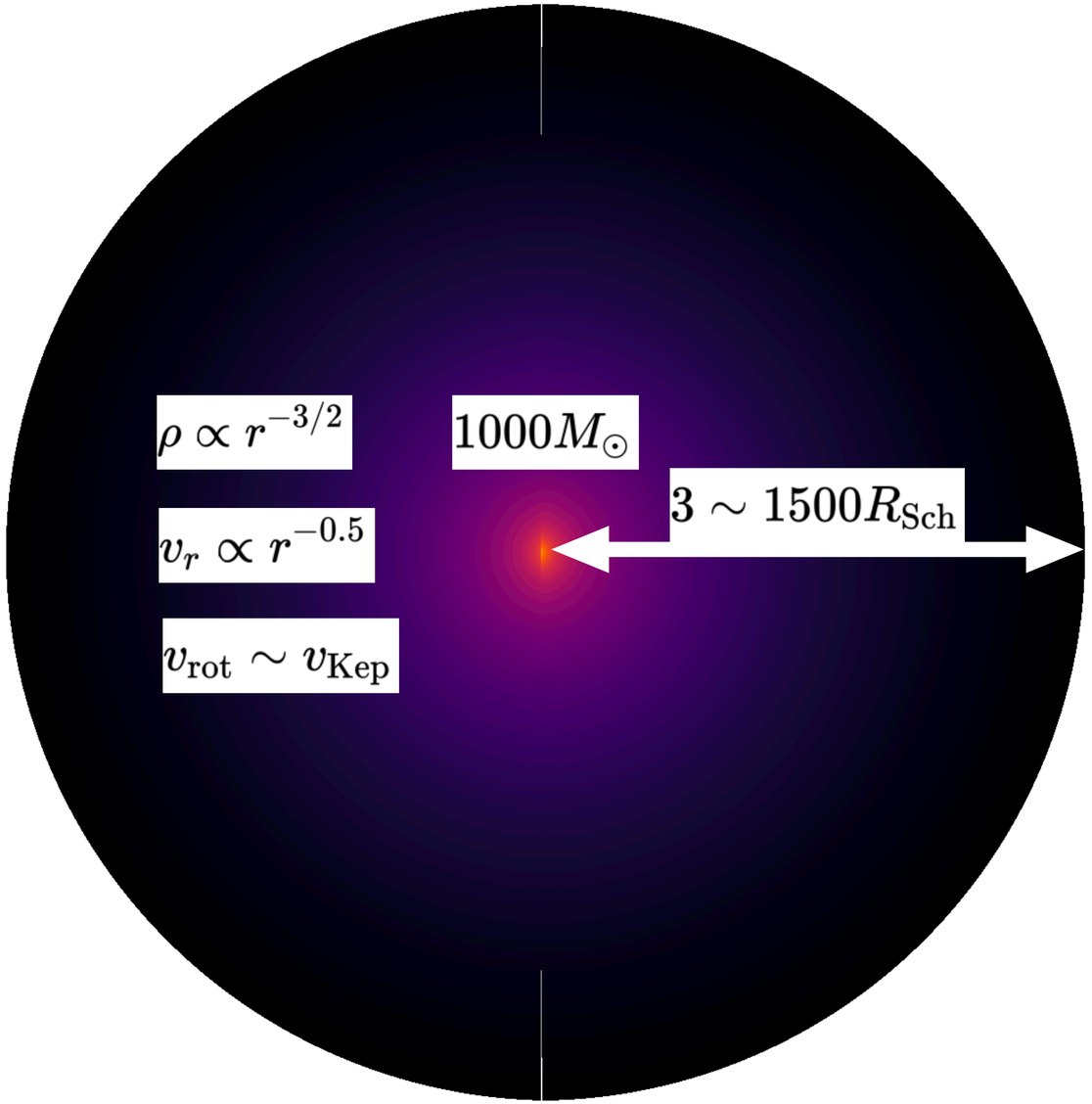
Coevolution over cosmic time

Aim of the project

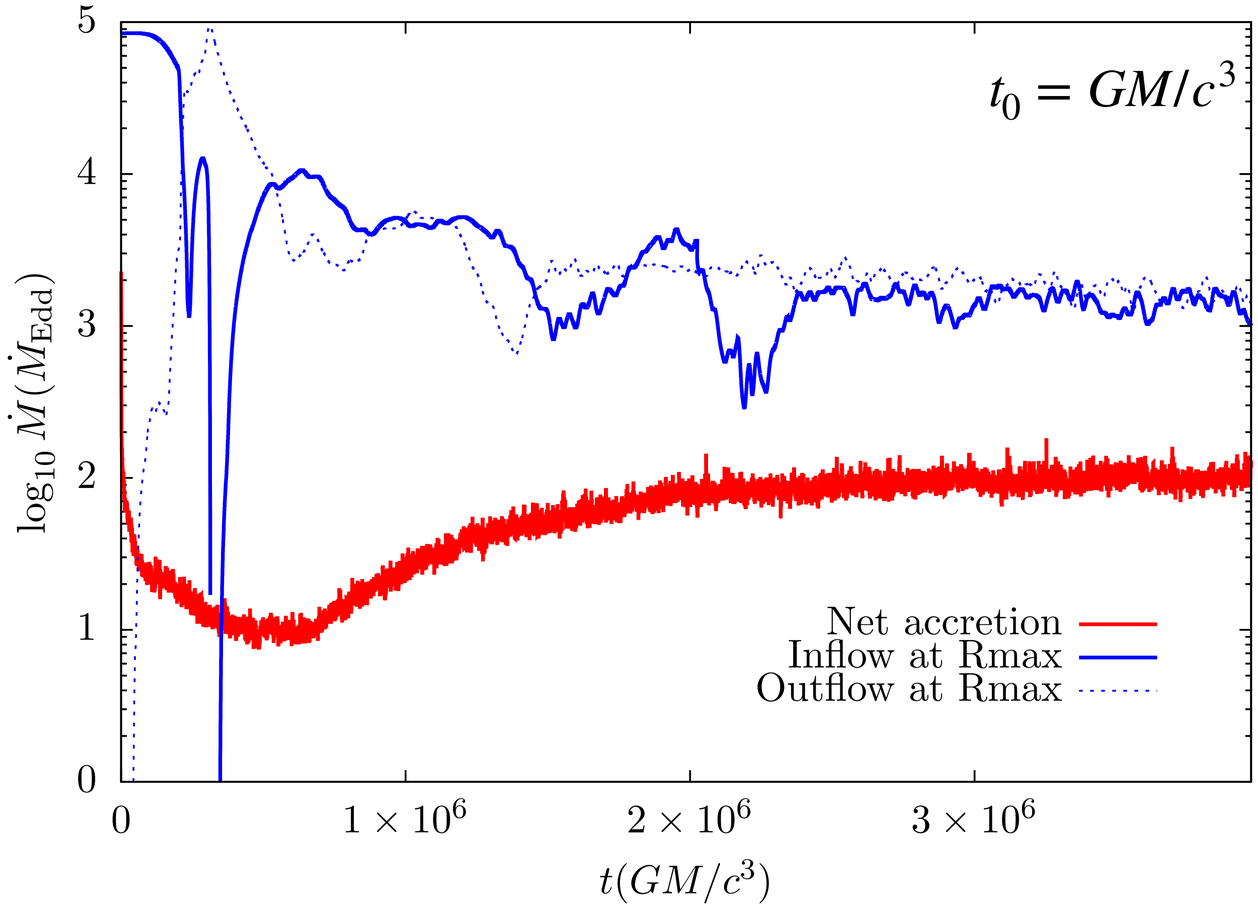


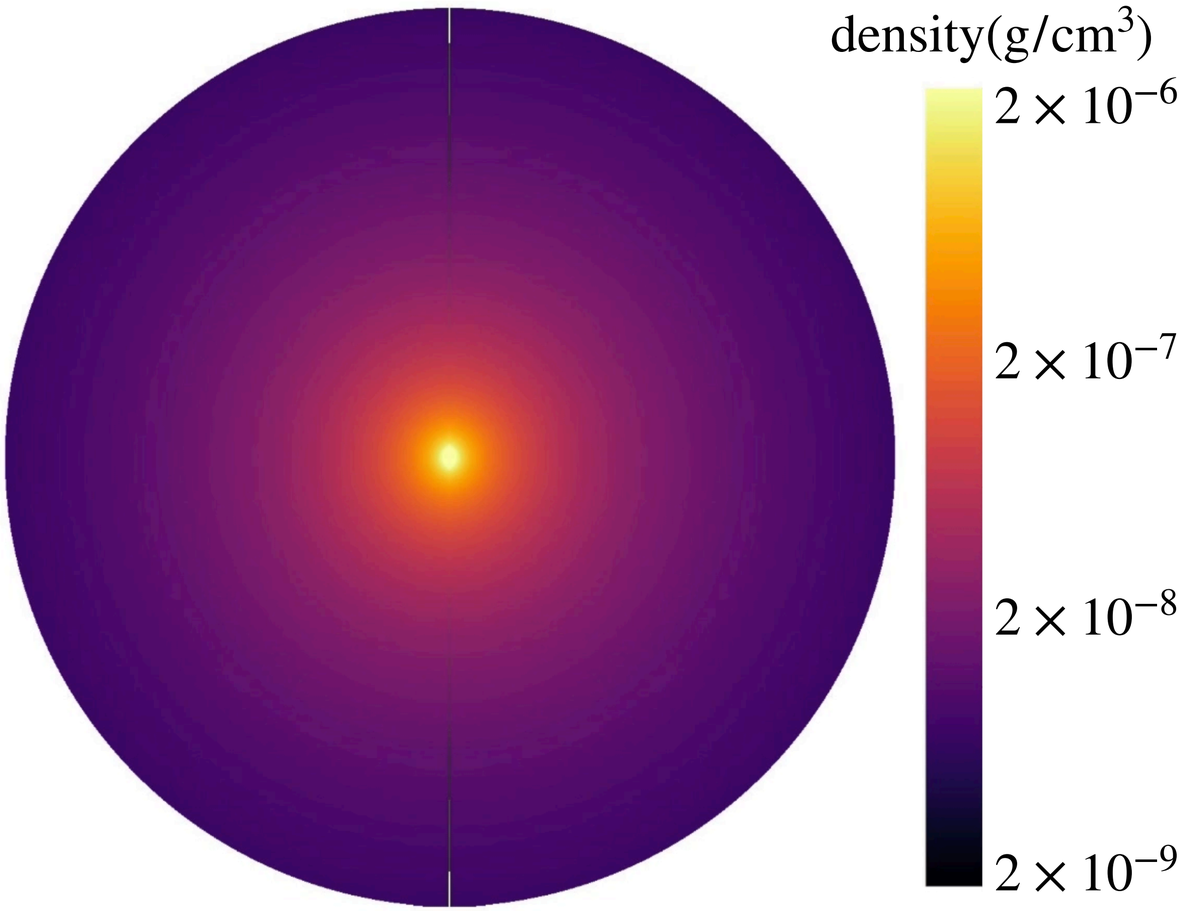
Supercritical accretion in vicinity of a BH

- BH vicinity
  - 3-1500 r_{Sch}
- Gas supply
  - Boundary condition
- Supercritical inflow
  - P_rad dominates $\gamma = 4/3$
  - Optically thick



Supercritical accretion in vicinity of a BH





$t > 10^6 t_0$, **steady state**

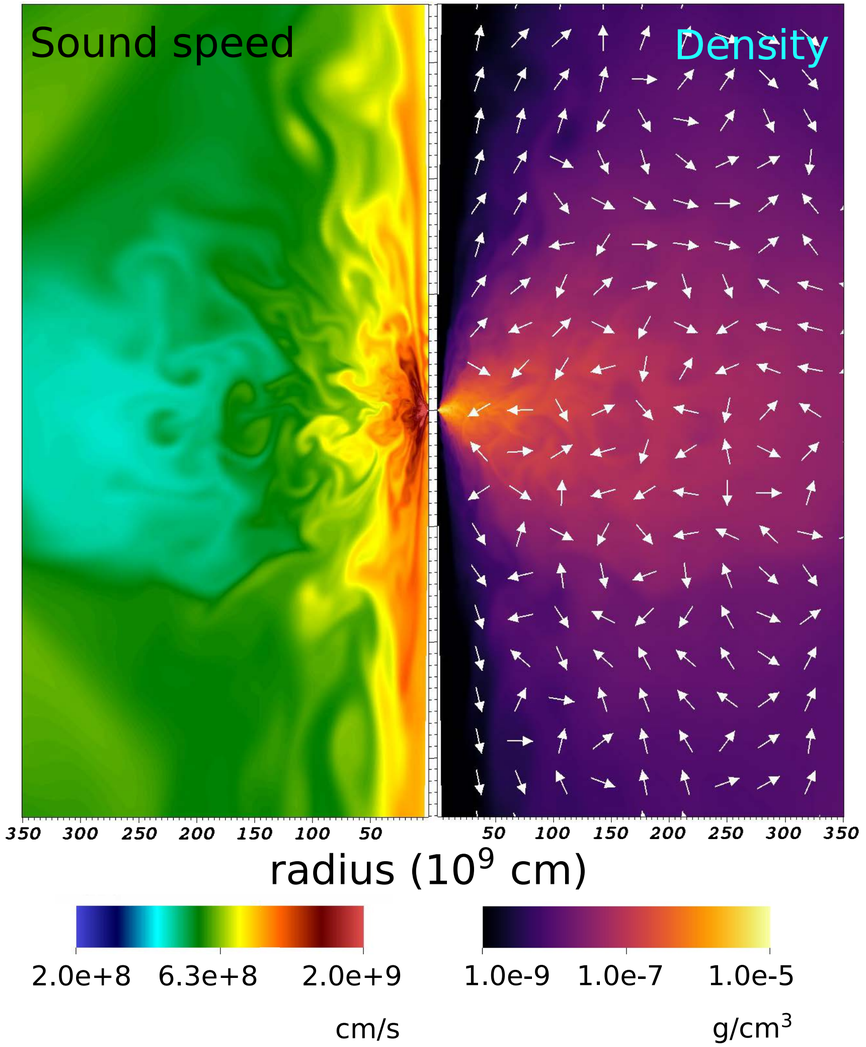
$t < 10^6 t_0$, **non-steady state**

Equator: inflow & outflow

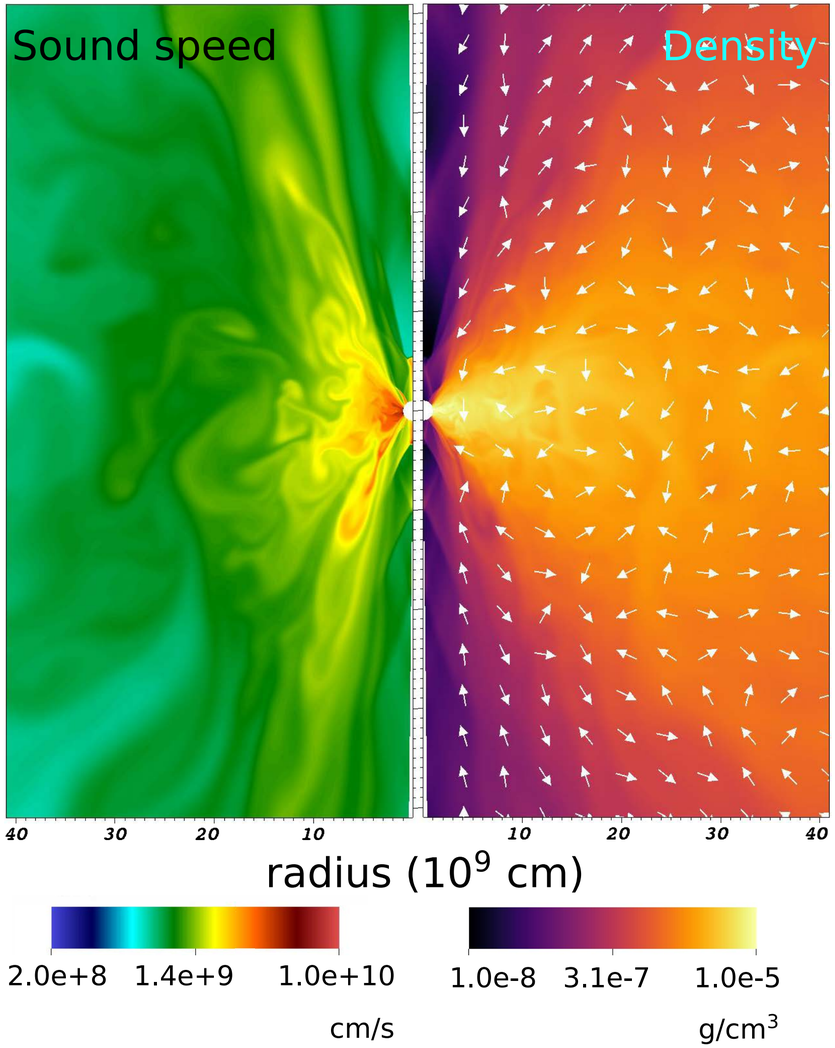
Polar: outflows

Supercritical accretion in vicinity of a BH

Large scale (~1000 r_{Sch})



Small scale (~120 r_{Sch})



Large:

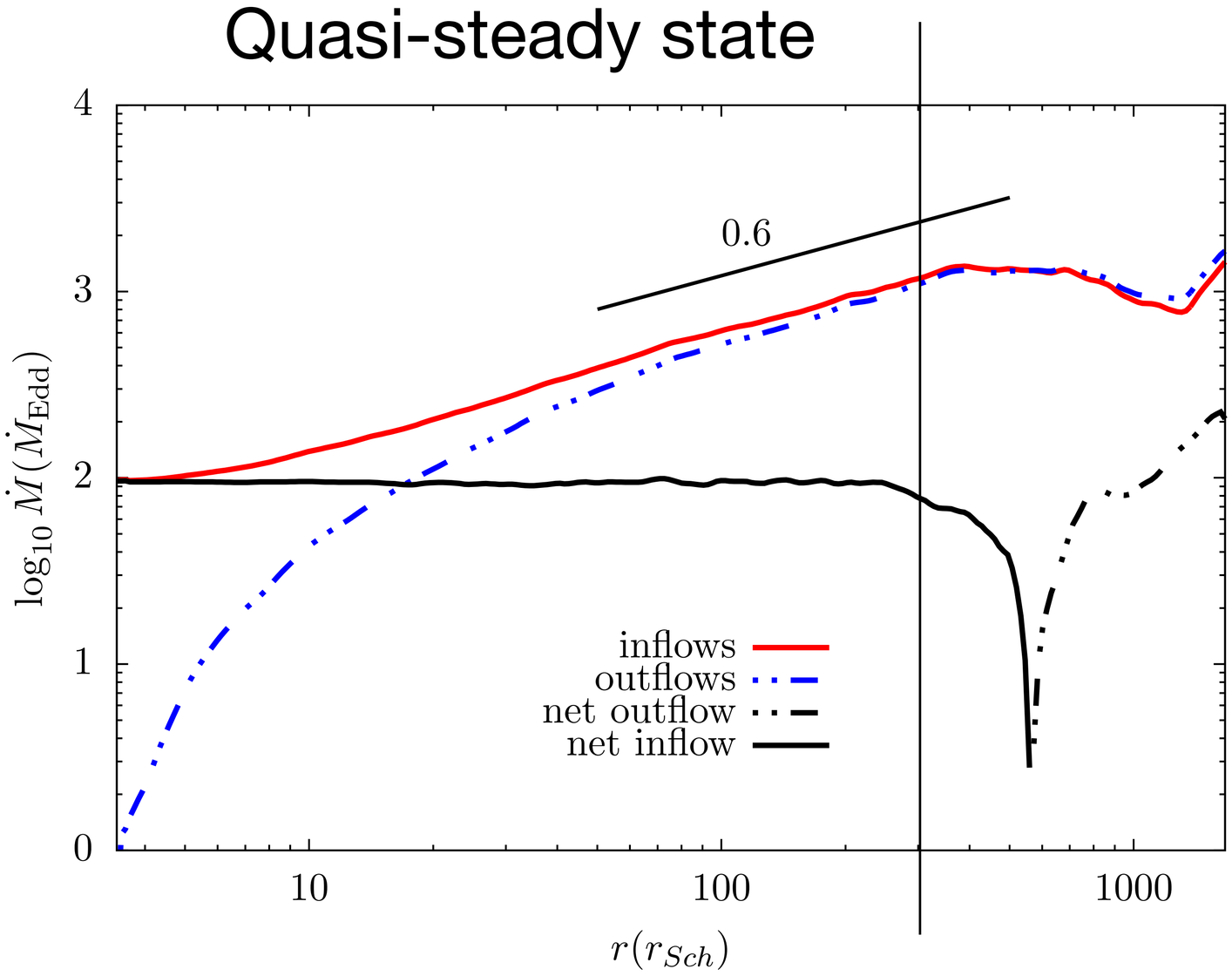
Poles: outflows

Equator: convection

Small: Inflows

High T near polar region

Mass Flow Profile



Large scale

$$\dot{M}_{\rm in} \simeq \dot{M}_{\rm out}$$

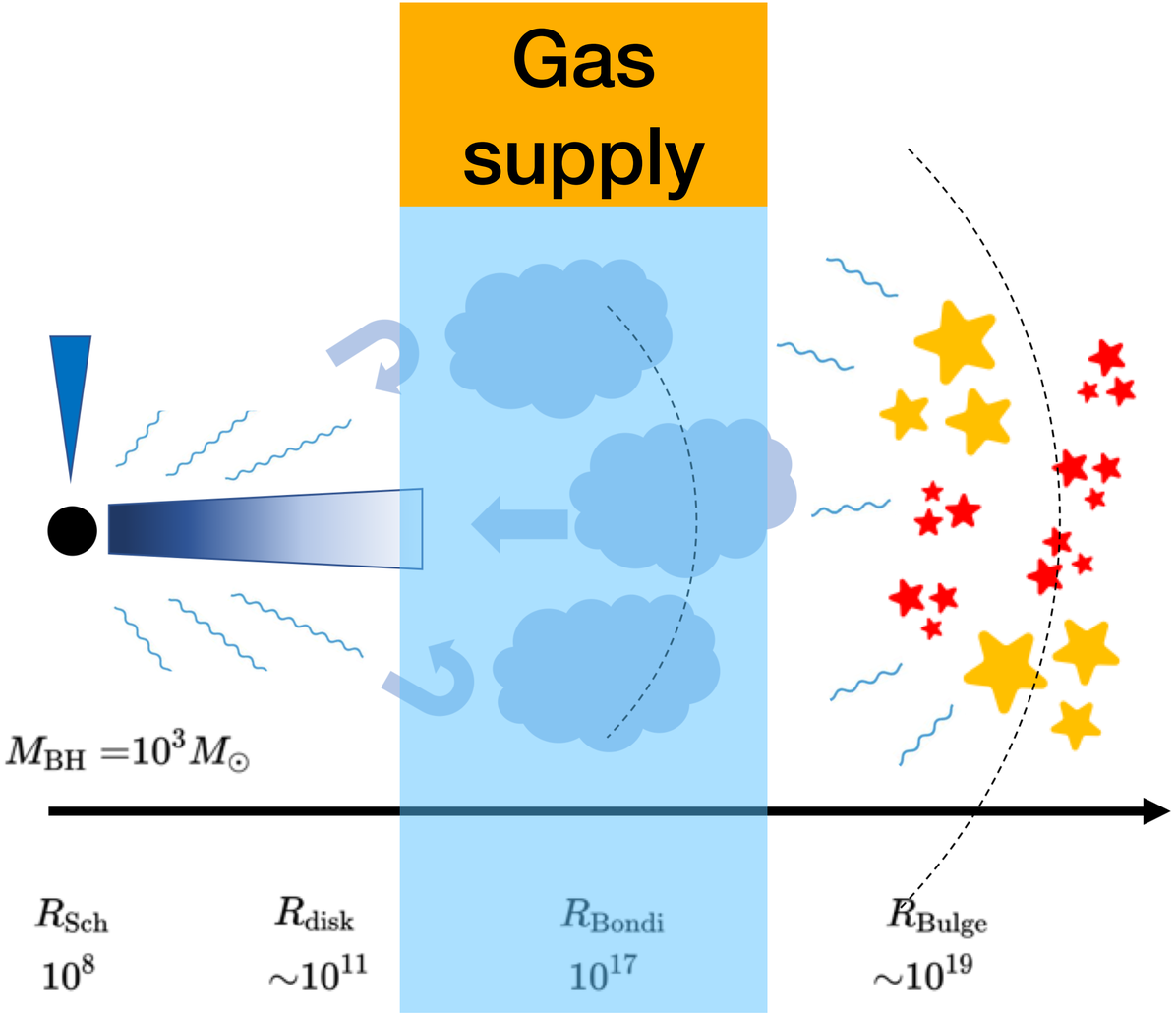
Inner region

$$\dot{M}_{\rm out} \sim 0, \quad \dot{M}_{net} \simeq 100\dot{M}_{\rm Edd}$$

Inflow rates

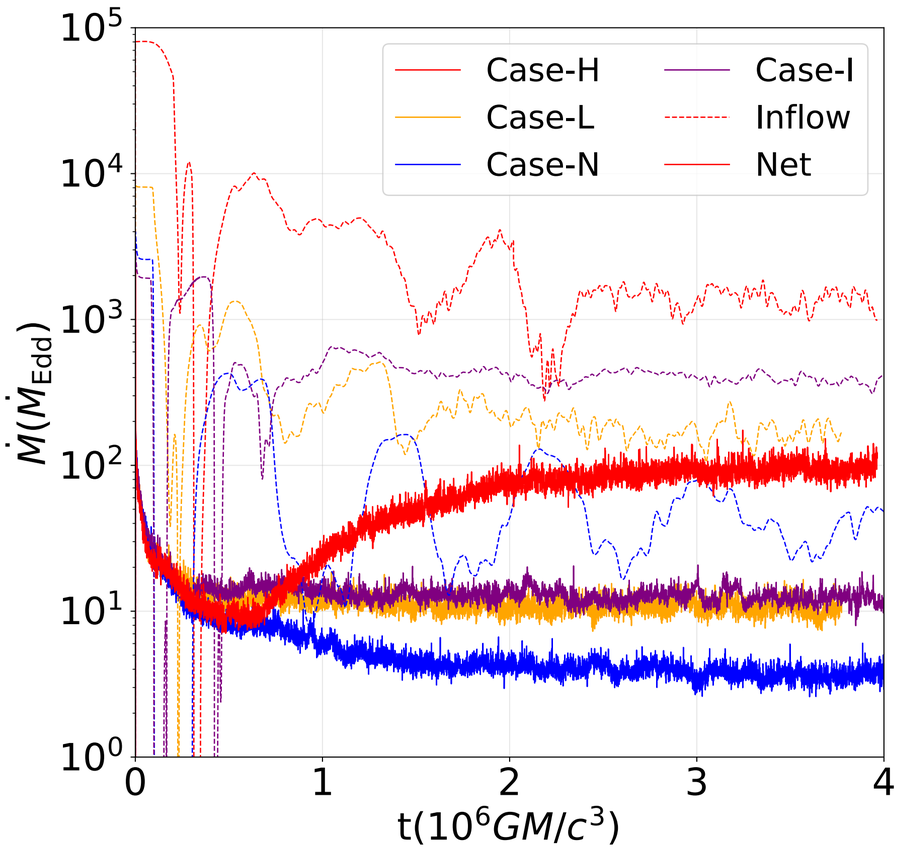
$$\dot{M}_{\rm in} \propto r^p, \; p \sim 0.5 - 0.7$$

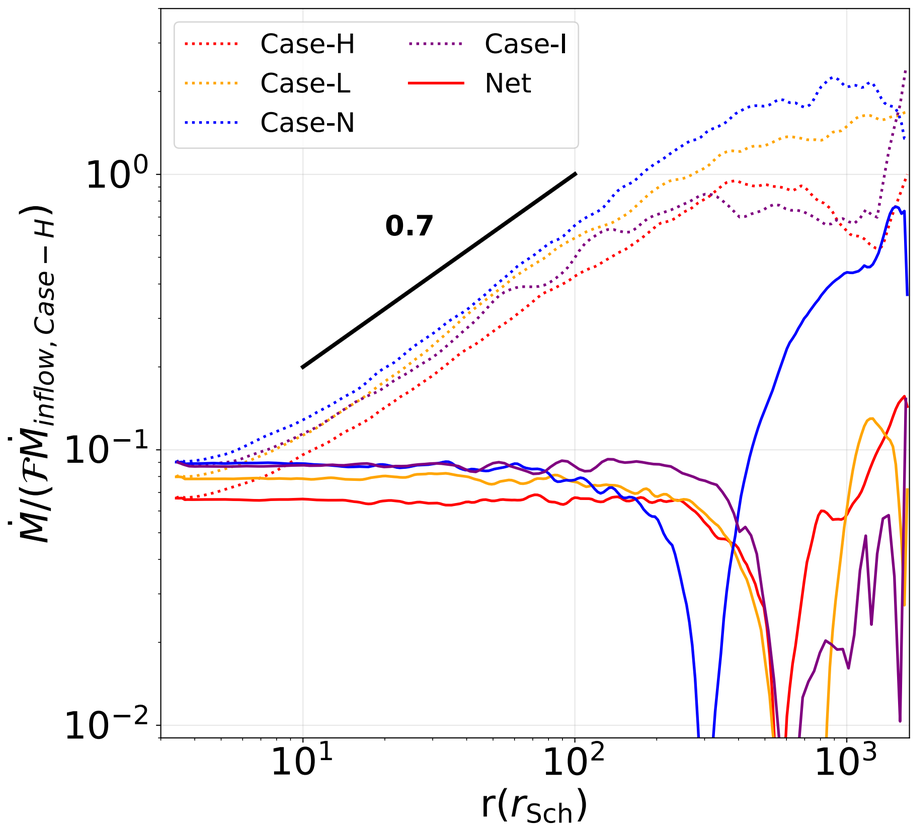
Different Boundary Conditions



- Large scale gas feeding:
  - Major uncertainty
  - Different BCs to mimic the gas feeding from large scales

Different Boundary Conditions





—Inflow: $\dot{M}_{\rm in} \sim 100 - 2000\dot{M}_{\rm Edd}$

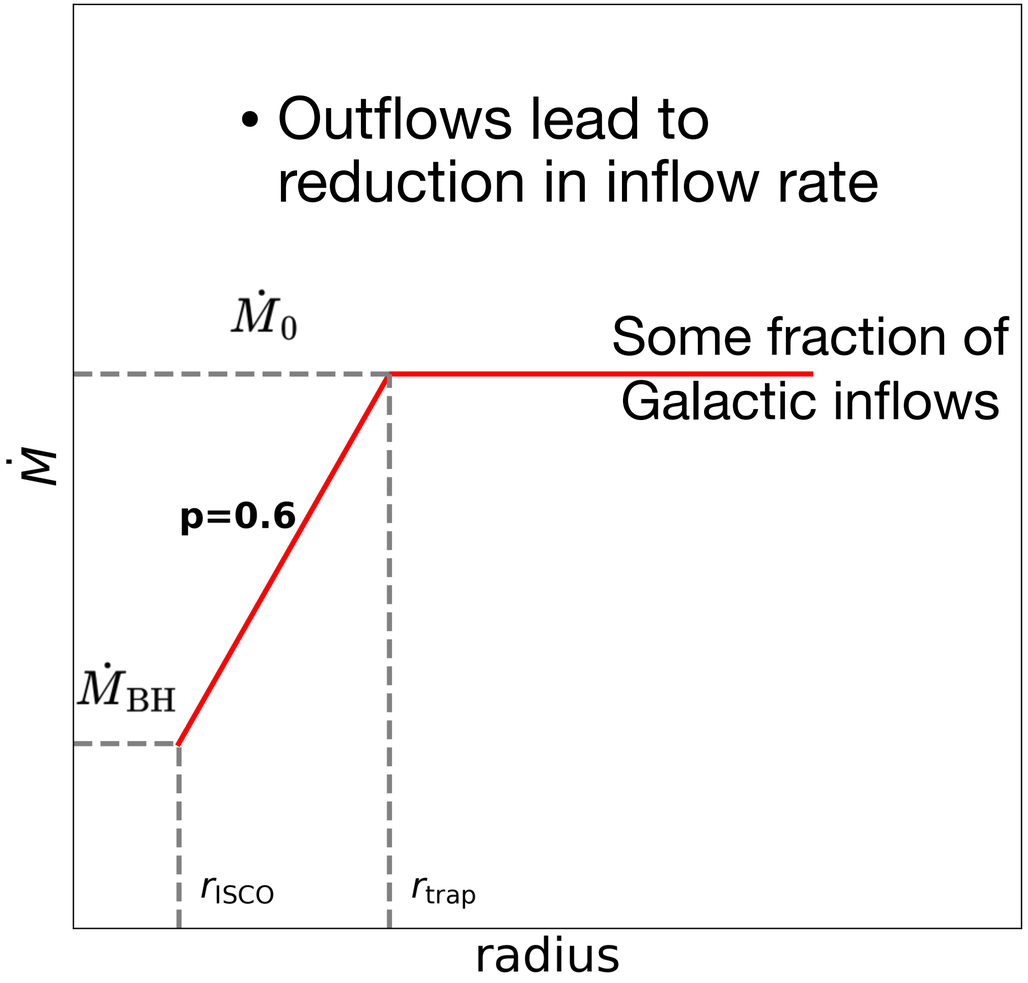
—Net accretion: $5\,\%\,\dot{M}_{\rm in}$

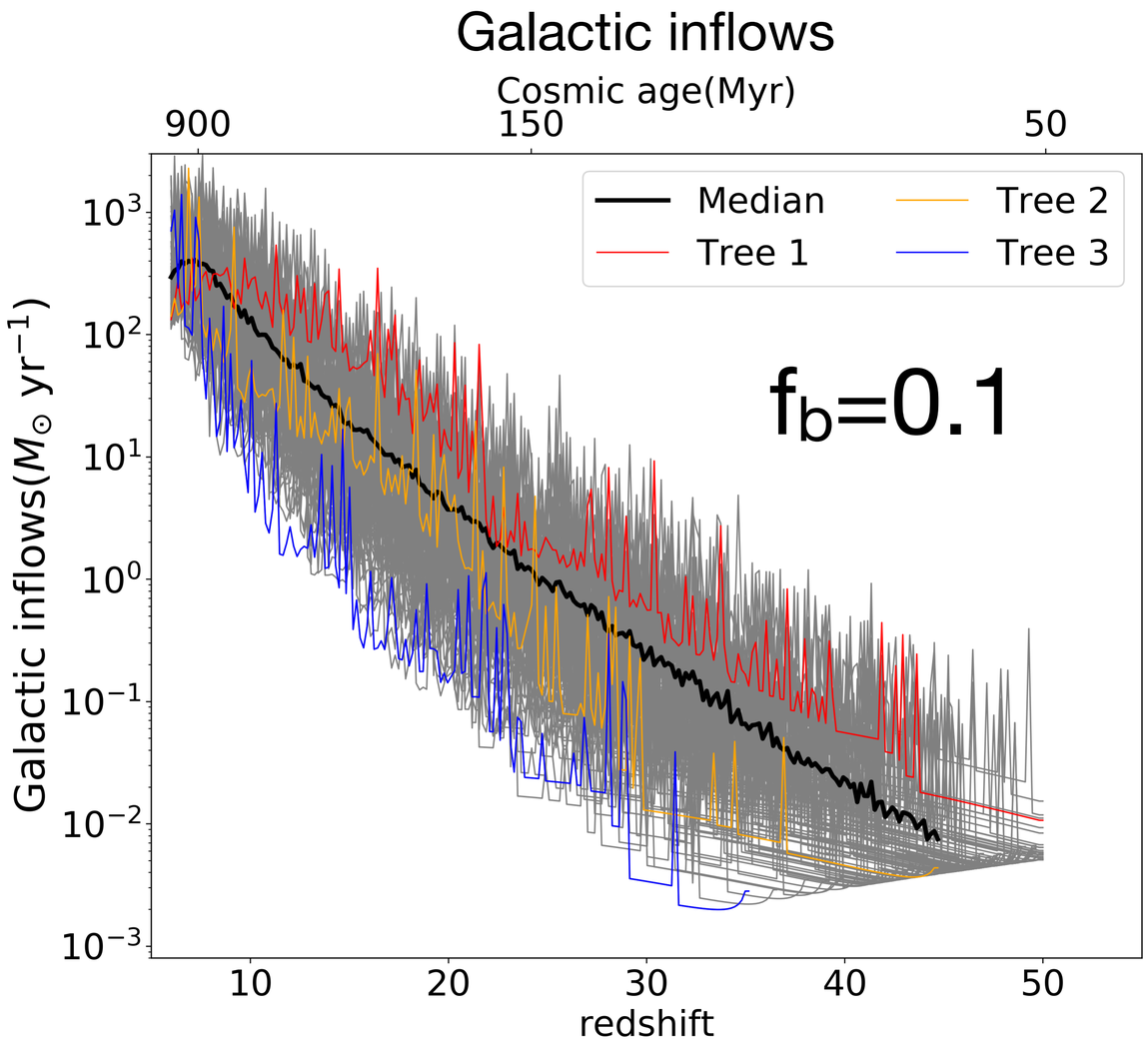
—self-similar behaviour

Merger history for high-z quasars

From Li+2021

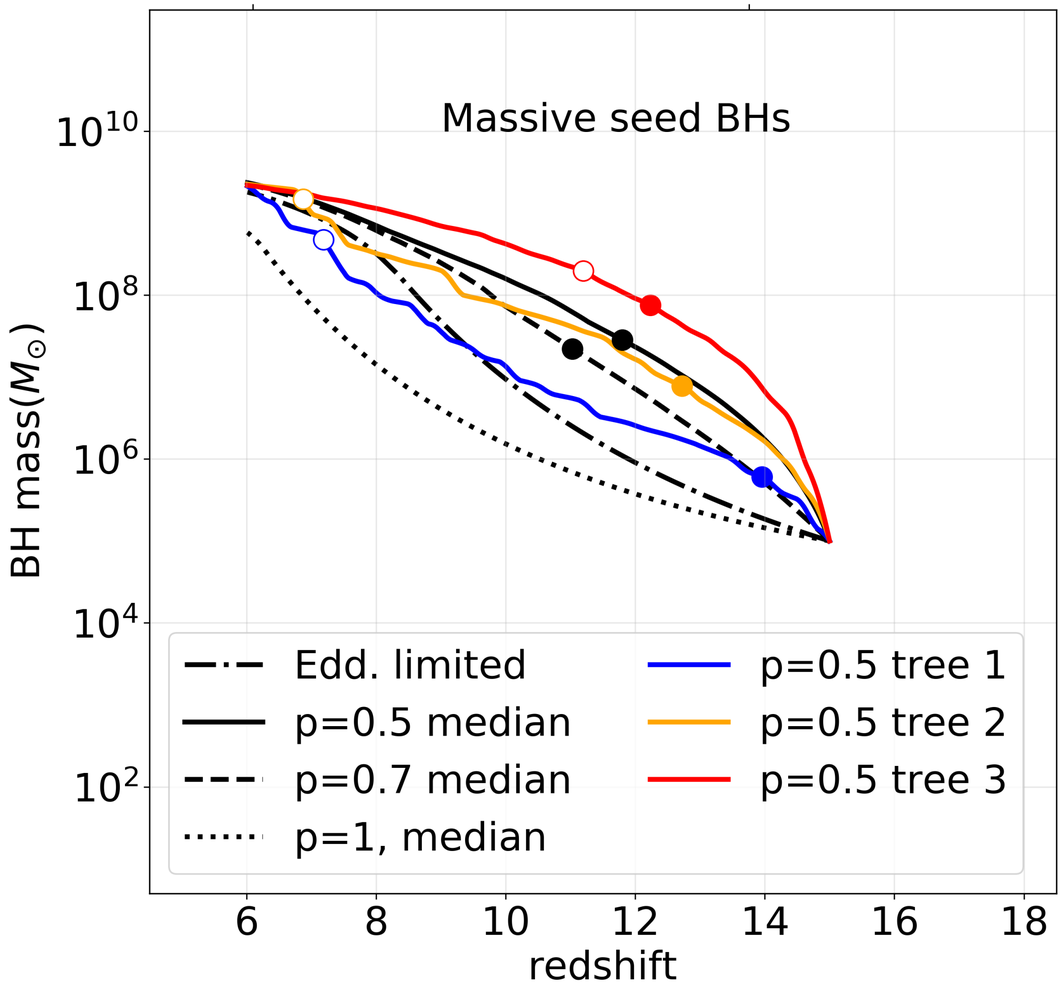
$$M_{\rm halo}(t) \longrightarrow f_{\rm b}\frac{dM_{\rm halo}}{dt}$$



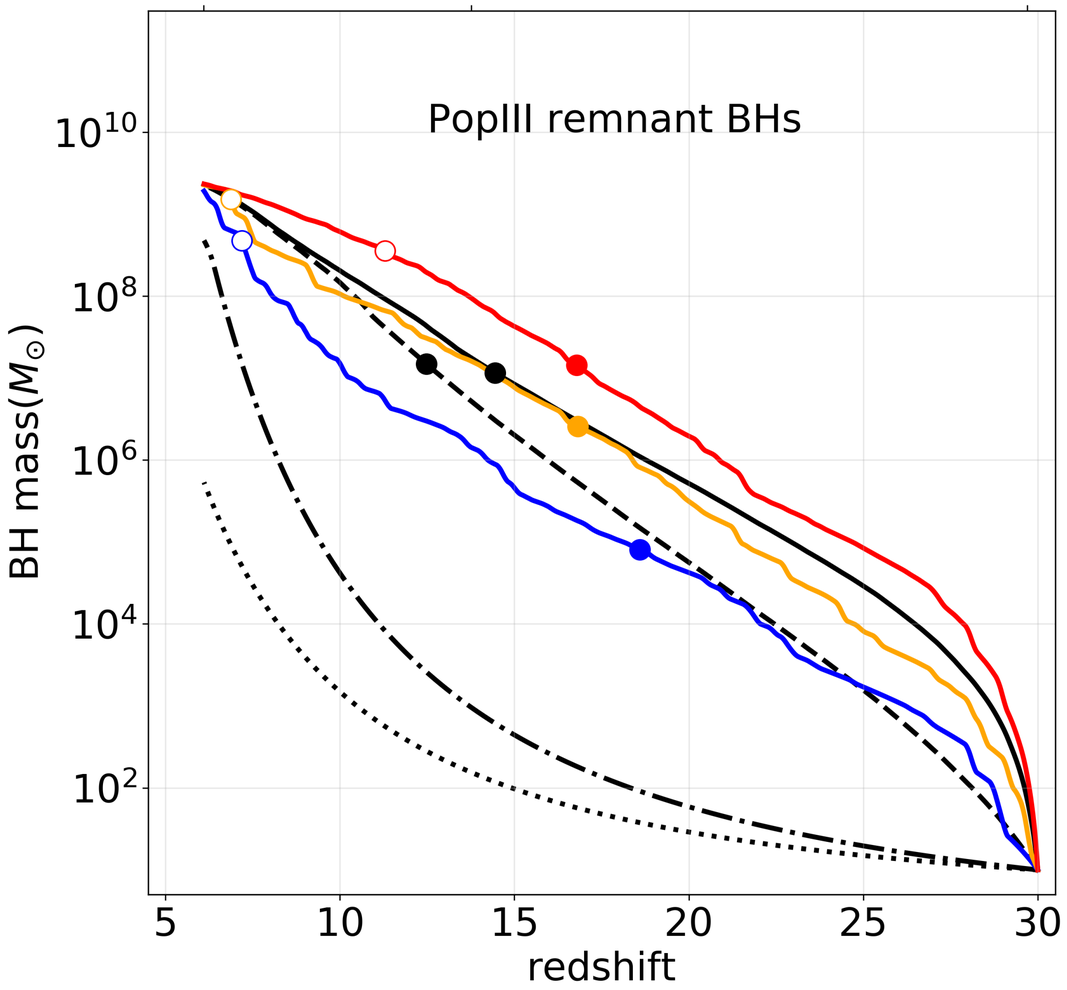


Growth history for two seeding models

Heavy seeds $M = 10^5\ M_\odot, z = 15$



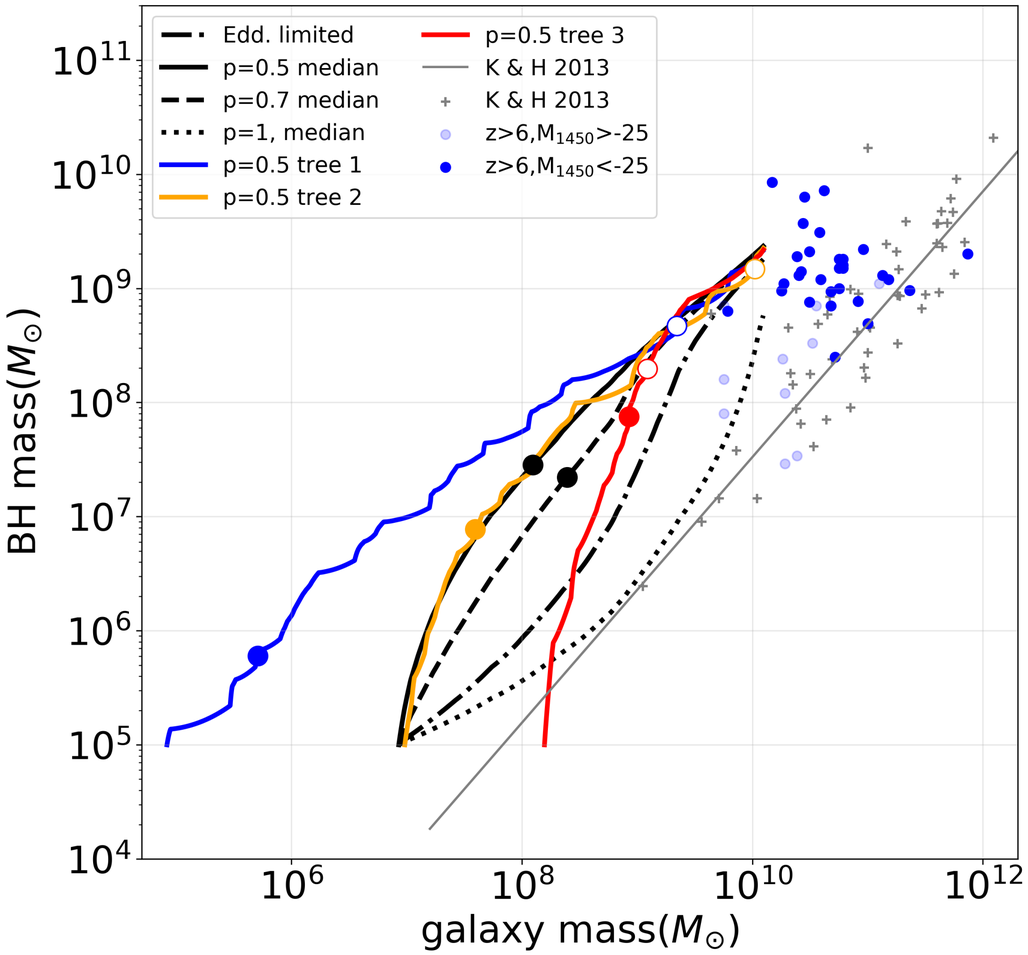
Light seeds $M = 10\ M_\odot, z = 30$



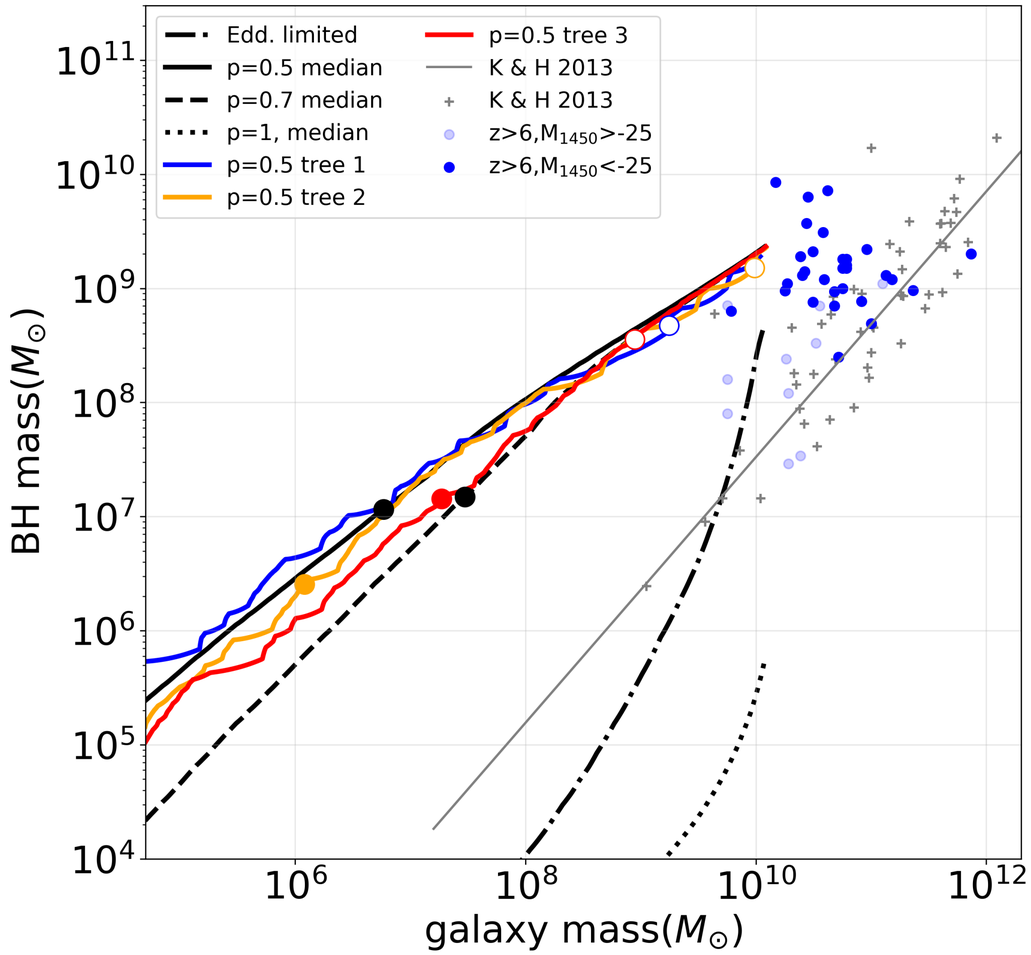
Strong outflow (p=1) suppress the light seed BH growth

Co-evolution of seed BHs & host galaxies

Heavy seeds



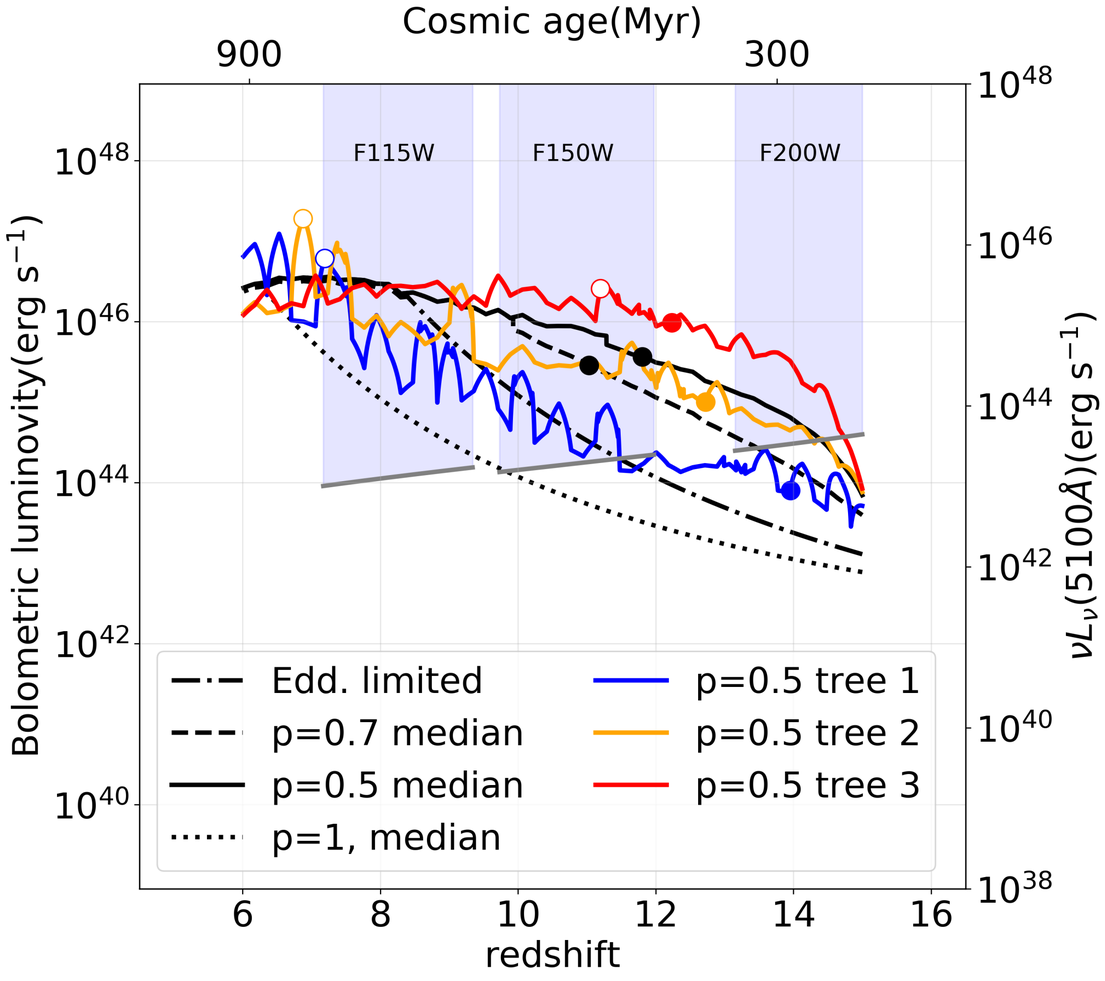
Light seeds



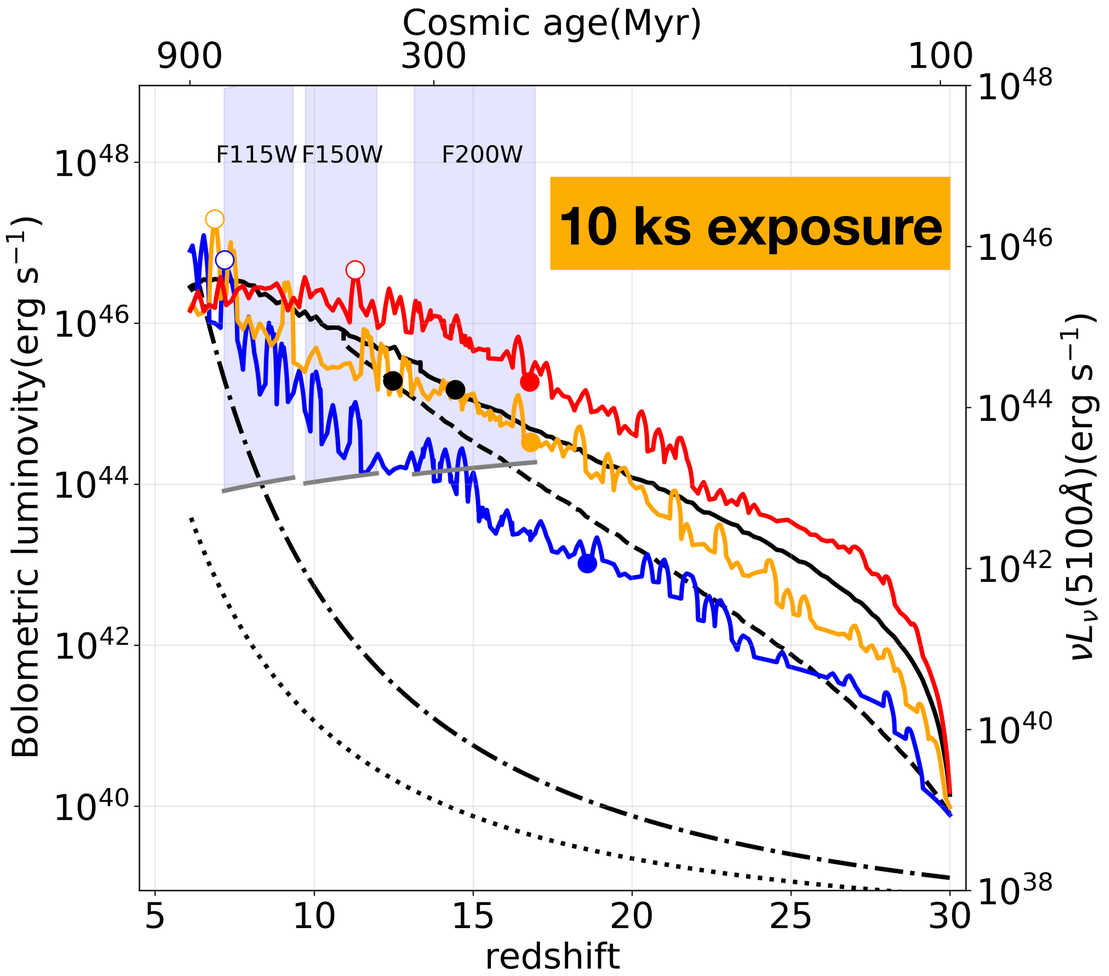
- SMBHs grow faster than host galaxies to the overmassive region

JWST Detectability

Heavy seeds



Light seeds



- Promising to detect seed BHs in rapid growth phase

Summary (2203.14994 & 2204.12513)

- 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