Rapid Black Hole Growth in the Early Universe

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(2025, ApJ, 989, 197)

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Findings in recent years

Many early black holes

JWST has revealed a significant number of supermassive black holes in the early Universe.

Overmassive and dormant

JADES GN-1001830, at $z = 6.68$, hosts a black hole of about 4×10^8 solar masses (Juodžbalis et al., Nature, 2024).

Possible scenario

Short bursts of super-Eddington bursts in a heavy black hole seed between dormant phases where they spend most of their life (Schneider et al. 2023).

Other proposed scenarios

Massive seeds

Relatively massive BH seeds accreting in sub-Eddington regime or from light stellar remnants (Trinca et al. 2022).

Inefficient accretion

Radiatively inefficient accretion flow onto slowly rotating BHs (Inayoshi & Ichikawa 2024).

New cosmology

New cosmological models like $R_h = ct$ universe (Melia 2023, 2024)

Our approach: Eddington-limited growth

Accretion rate

$dM/dt = kM$, implies $M_f = M_i e^{kt}$: Final BH mass after accreting for time t.

The constant

$k = 4\pi G m_p / (\eta c \sigma)$, set by the radiative efficiency η and the electron cross-section σ.

Parameters

Generally $\eta = 0.1$ and the Thomson scattering cross-section, $\sigma = 6.65 \times 10^{-29}\ m^2$. We play with both the parameters.

Our approach: accretion events and mergers

Setup

BH of initial mass M_i undergoes n accretion events.

Mergers

Each accretion event followed by a doubling or non-doubling merger.

Accretion time

Every accretion event lasts a time that is some constant (λ) multiple of the previous accretion time.

Eddington-limited growth with equal accretion times

Growth cycle

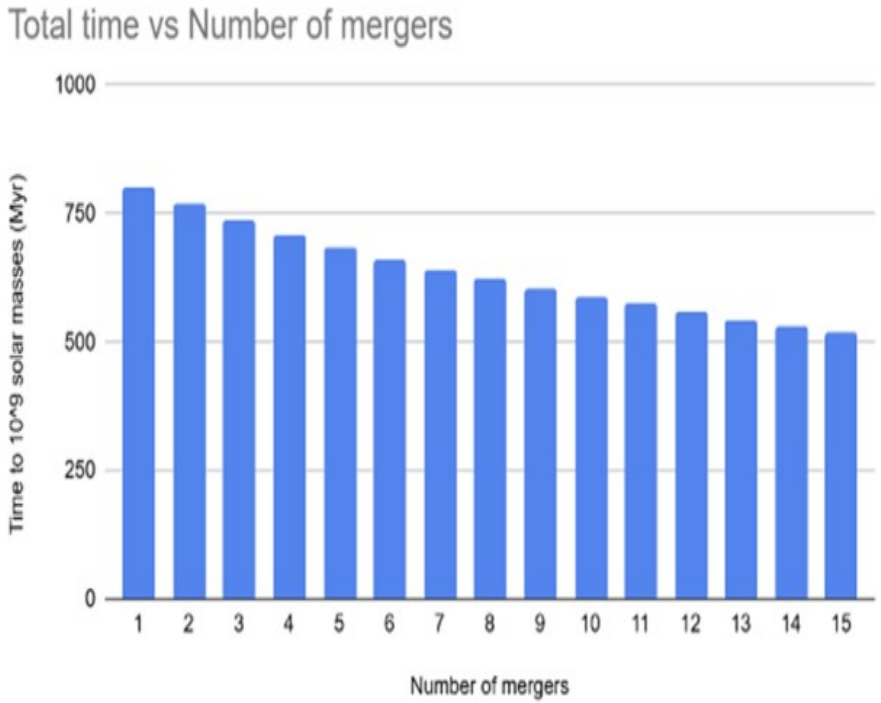
A 10 solar-mass BH seed grows by alternating accretion and doubling mergers, the most rapid growth channel allowable.

Timescales

Relaxation after a merger scales with mass, 75 Myr for two 10^8 solar-mass holes.

Diminishing returns

Each added merger lowers the total time less, since mergers grow the hole quickly compared with accretion.



Eddington-limited growth with nonequal accretion times

Definition

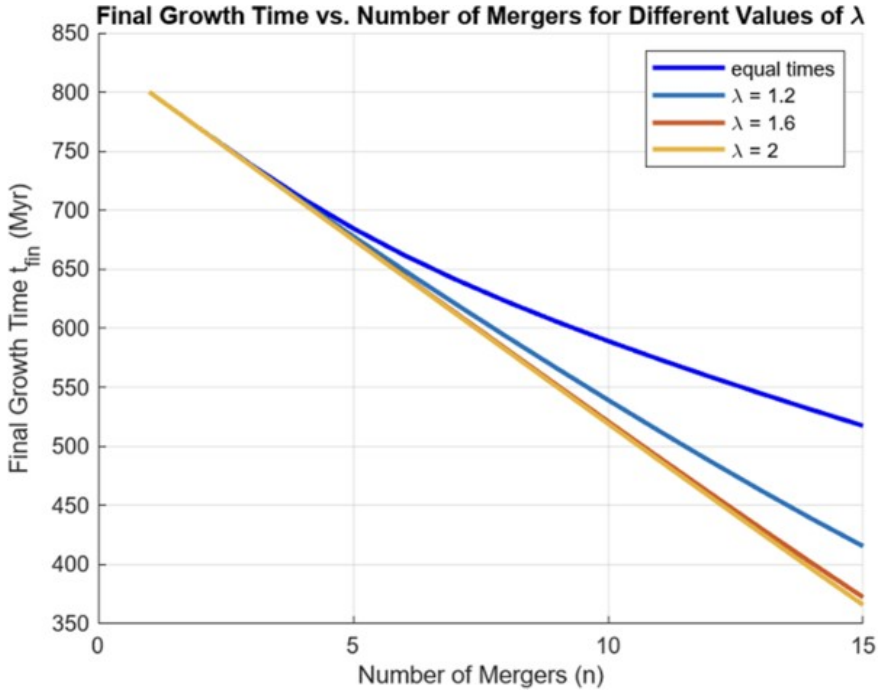
Every accretion event is some constant multiple (λ) of previous accretion time.

Upper limit

Any value of λ greater than 2 results in unrealistically shorter times between early mergers.

Higher λ

Higher λ values associated with a larger percentage of mergers and relaxation time approaches zero.



Spin-dependent efficiency slows growth

Efficiency

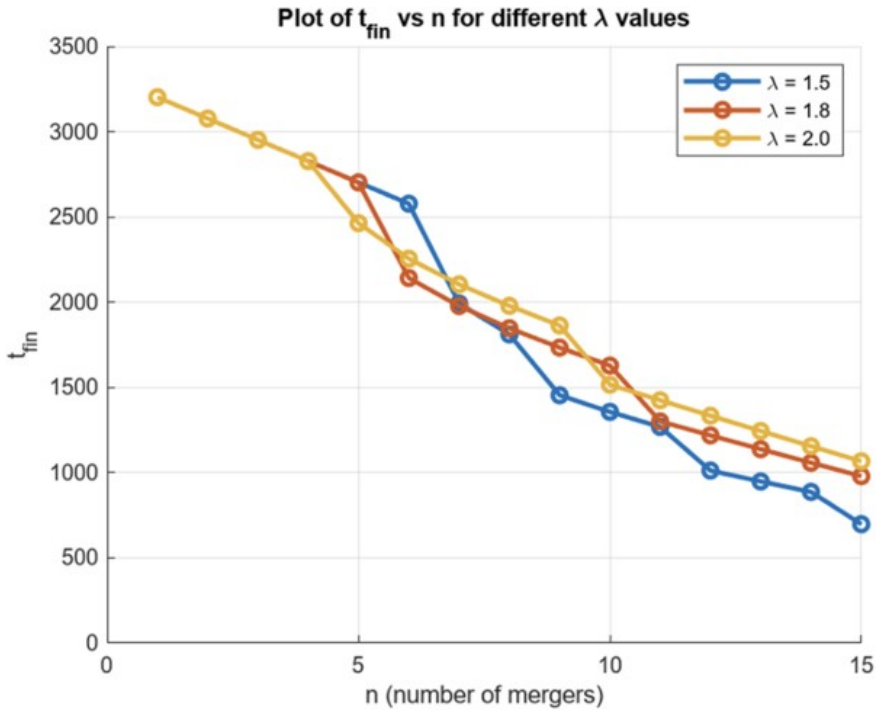
Accretion events that last 100 Myr or more treated with average efficiency of 0.4 while any event lasting under 100 Myr with 0.1 efficiency.

Lower λ is most optimal

Fewer accretion events over 100 Myr leading to decreased radiative efficiency and faster accretion.

The problem

Almost all growth times fall outside of 800 Myr range set by JWST observations.



Eddington-limited growth with relativistic cross-section

Hot inner flow

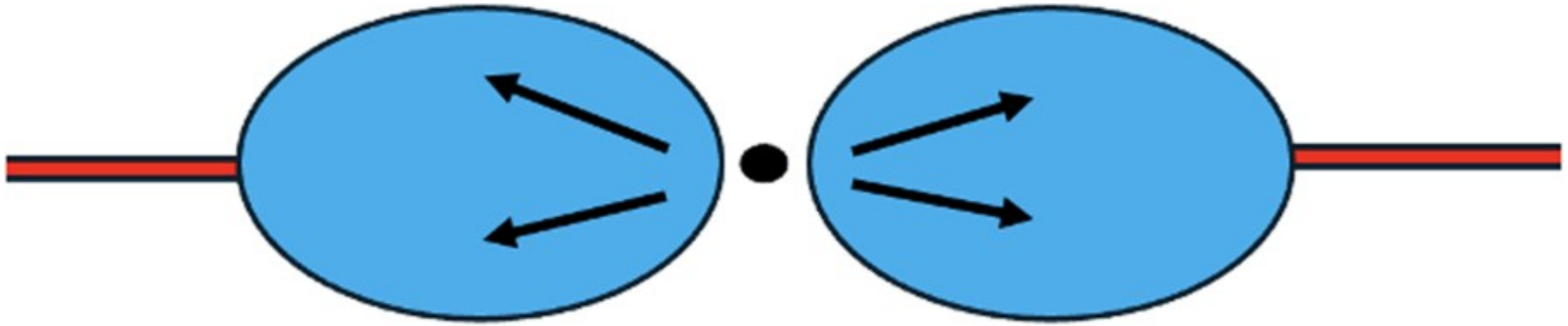
A radiation-dominated hot flow at 10^9 K or more, between the inner disk edge and the horizon.

Why Eddington

The one region that radiates quasi-spherically, so it can enforce the limit.

Klein–Nishina correction

$\varepsilon = E_{photon}/m_{electron}c^2 = 0.17$ lowers the cross-section from 6.65 to 5.05×10^{-29} m^2, raising the allowed accretion rate.

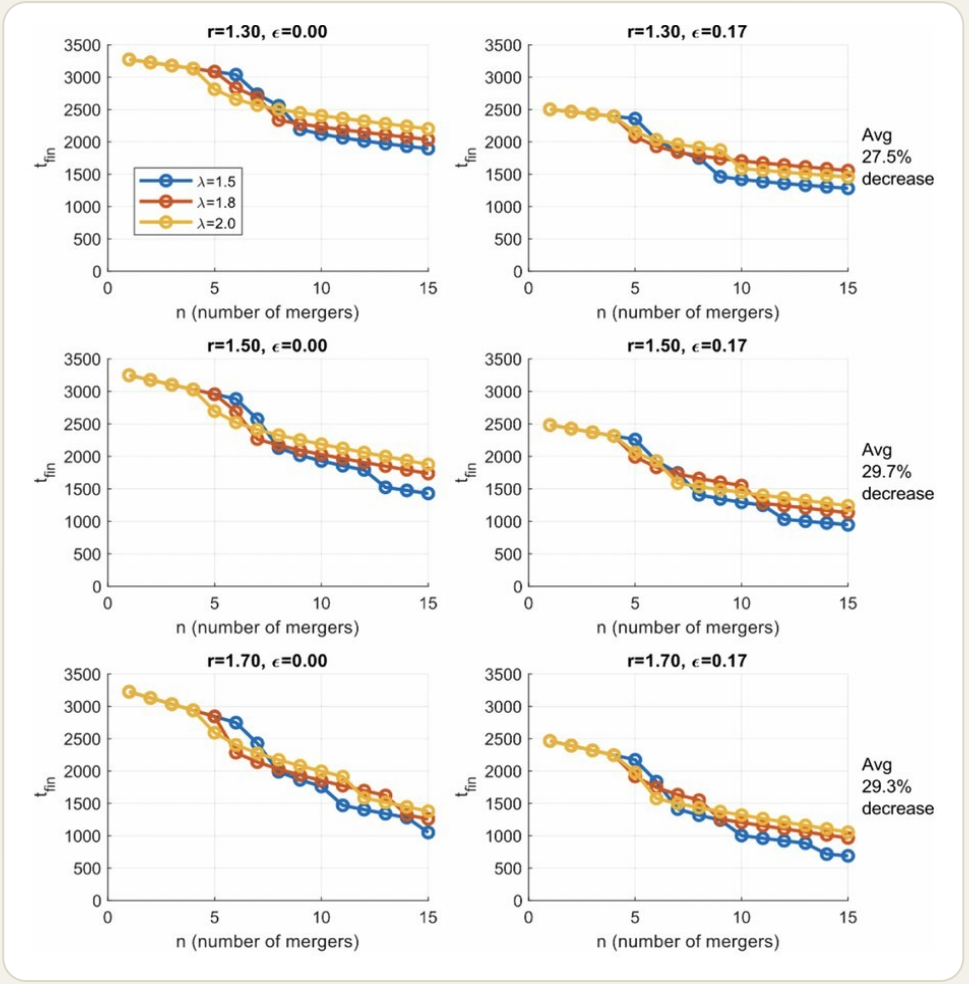


Shorter formation times

47% maximum reduction in SMBH formation time

32.1% average reduction across all merger numbers

~30% average reduction for non-doubling mergers, r = 1.3 to 1.7



A 10^9 solar-mass black hole within 500 Myr

Fiducial path

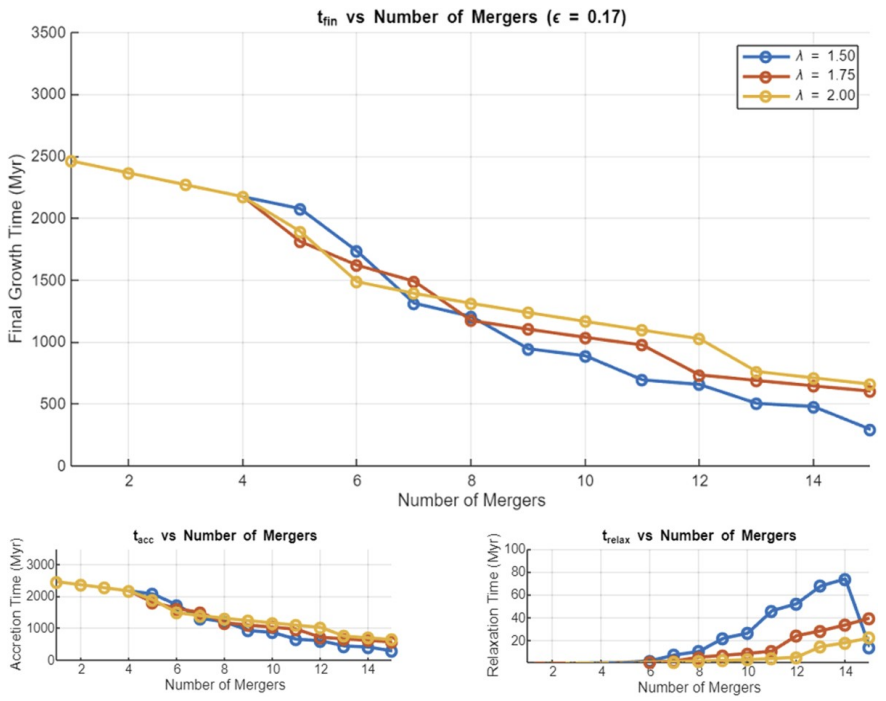
14 doubling mergers with λ = 1.5, from a 10 solar-mass BH seed.

Where it grows

BH only breaks a million solar masses during its last two mergers after only 178 Myr.

Timeline

1.89 x 10^8 solar mass BH formed around 470 Myr after the big bang, resulting in formation of a billion solar SMBH about 670 Myr after the big bang.



Limitations

Spin

The hot flow sits between the disk edge and the horizon, so it needs spin below maximal. At maximal spin it vanishes, and a bout of super-Eddington accretion follows.

Late events

High spins occur only in the last handful of accretion events of the fiducial path.

Simplifications

Spin and efficiency are tracked simply, mass loss in mergers is optimistic, and relaxation times scale linearly.

Conclusions and caveats

Conclusions

A hot quasi-spherical inner flow can explain why black holes obey the Eddington limit.

The Klein–Nishina cross-section shortens formation times by about 30%.

This may replace the need for super-Eddington accretion.

Caveats

Spin and efficiency are tracked simply, mass loss in mergers is optimistic, and relaxation times scale linearly.

The hot flow needs spin below maximal.

Numerical studies are the next step.

Where I would welcome collaboration

Cosmological models

Test whether this merger-and-accretion pathway appears in cosmology.

JWST samples

Compare the growth histories with measured masses of early black holes.

The inner flow

Studies of the hot quasi-spherical region and its photon energies.

Gracias. Reach me at chandratalk@gmail.com