Massive Primordial Black Holes and High z galaxy formation

(Symbiosis of JWST+LISA Universe with the EHT Black Hole Physics)

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PANE Conference 2026 @ Bodoland University (18-20 Nov. 2026)

Being correct is not important, what is important is to try to understand .



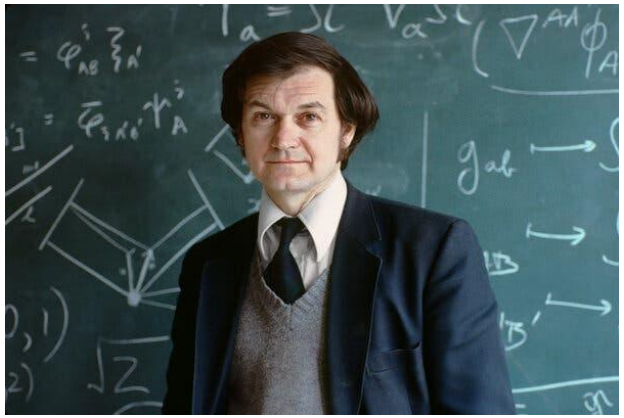
-Carlo Rovelli

Talk plan

- Black hole in general
- Massive black holes in cosmic infancy & cosmology
- Existing models
- Growth of seed black holes: Early Universe channel -I
- Massive Primordial Black Holes: Early Universe channel-II and JWST
- Merger signature in the context of LISA
- Dark matter spike and understanding black hole physics
- Concluding remarks

Black holes in general

- Black holes are generic outcomes of continued gravitational collapse.



Three types of black holes:

(a) Stellar mass (~ few solar mass)

(b) Galactic centre black holes (~ few million to billion solar mass)

(c) Primordial black holes (Planck mass to million solar mass)

Massive black holes.....

Lynden Bell – Rees proposal (1971)

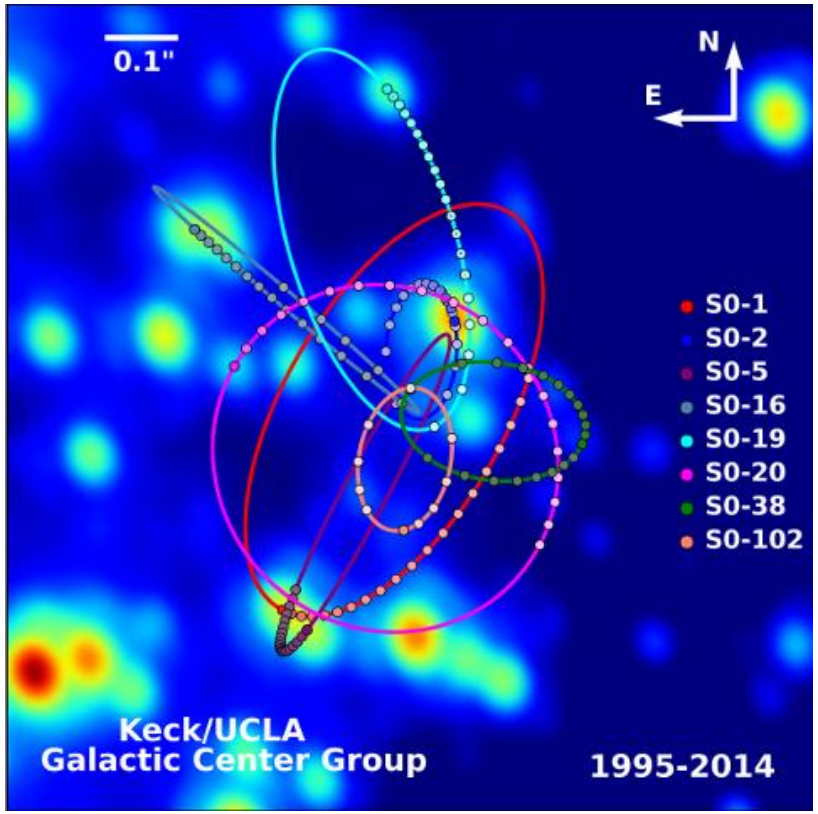
All galaxies must harbour massive black holes at their nuclei.



Andrea Ghez (Keck) and Reinhard Genzel (VLT) (1998-2010)

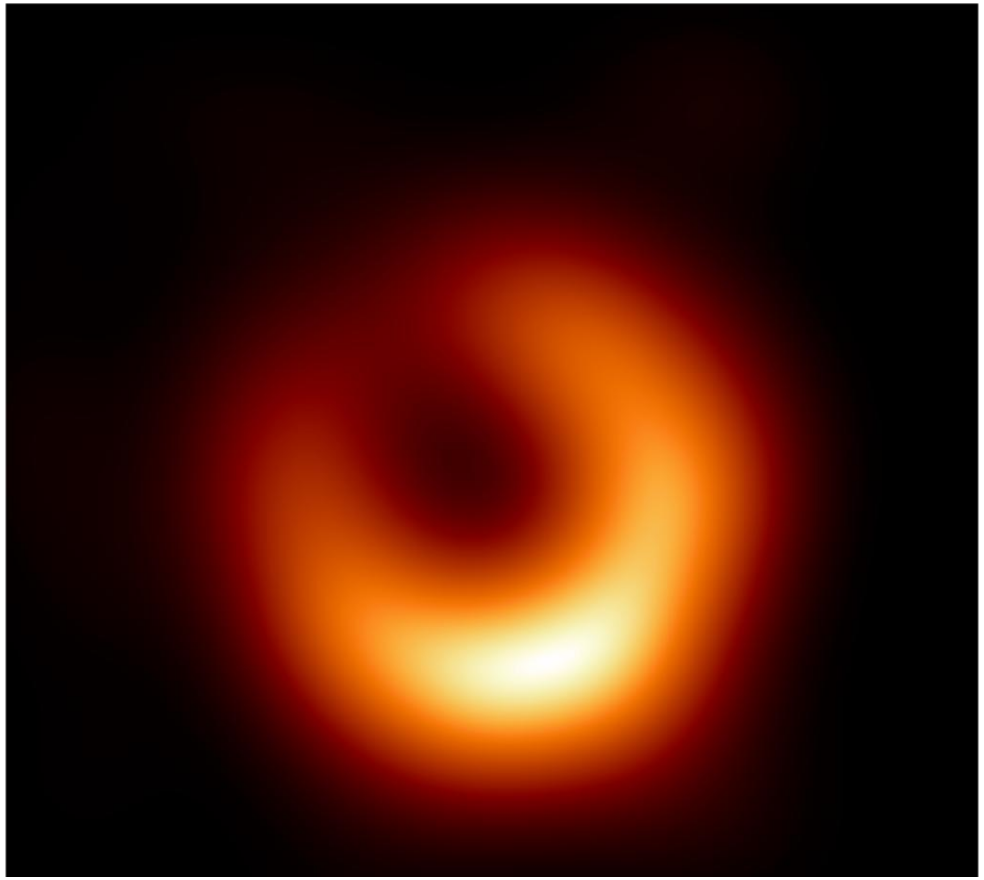
(Ghez et al. 1998; Eckart et al. 2001)

$$M_{BH} \approx 4{\times}10^6 M_\odot$$
$$R_o \approx 8\ kpc$$

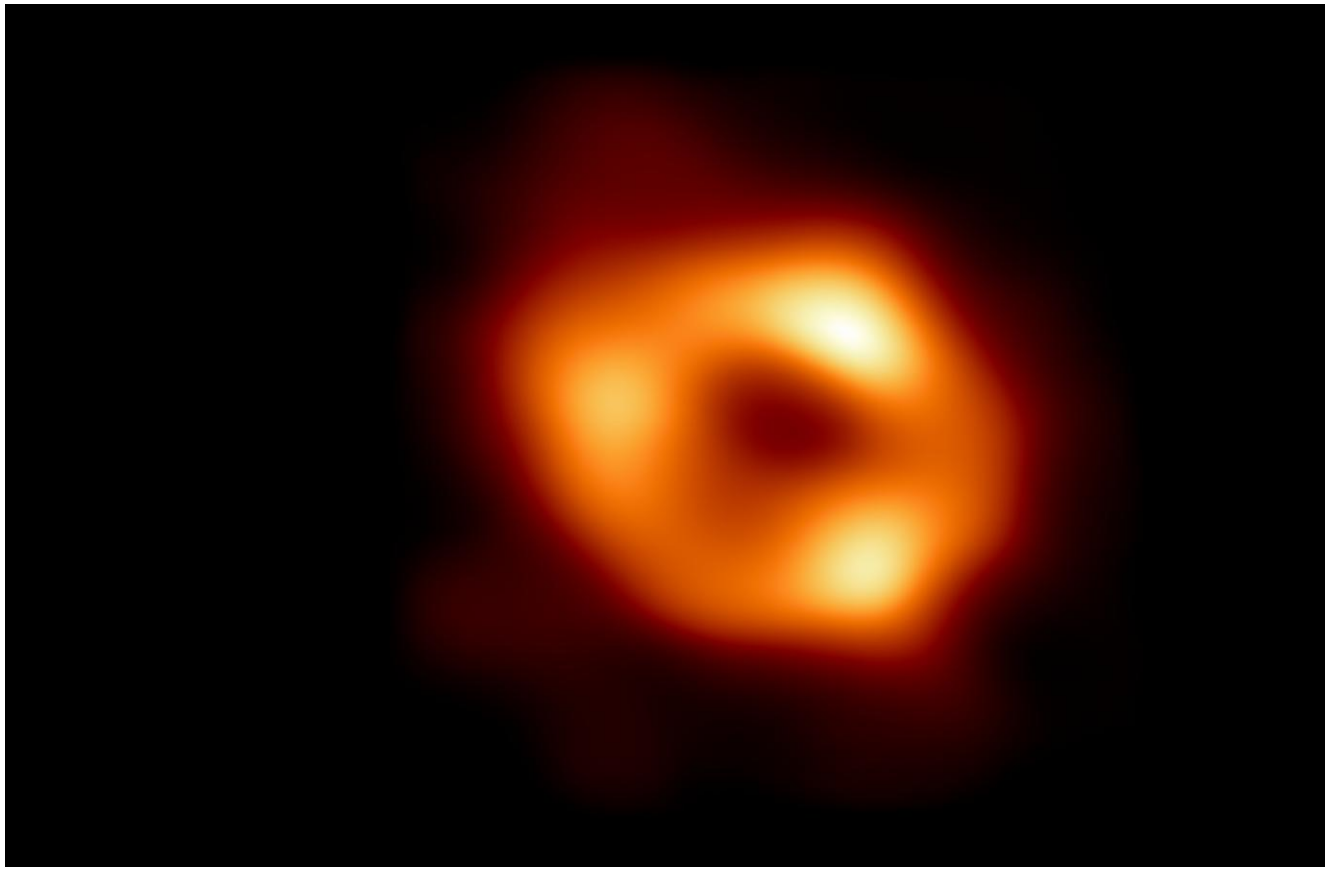




Shadow of the massive black hole at the centre of the galaxy M87 (EHT) (left) and centre of the Milky Way (right)

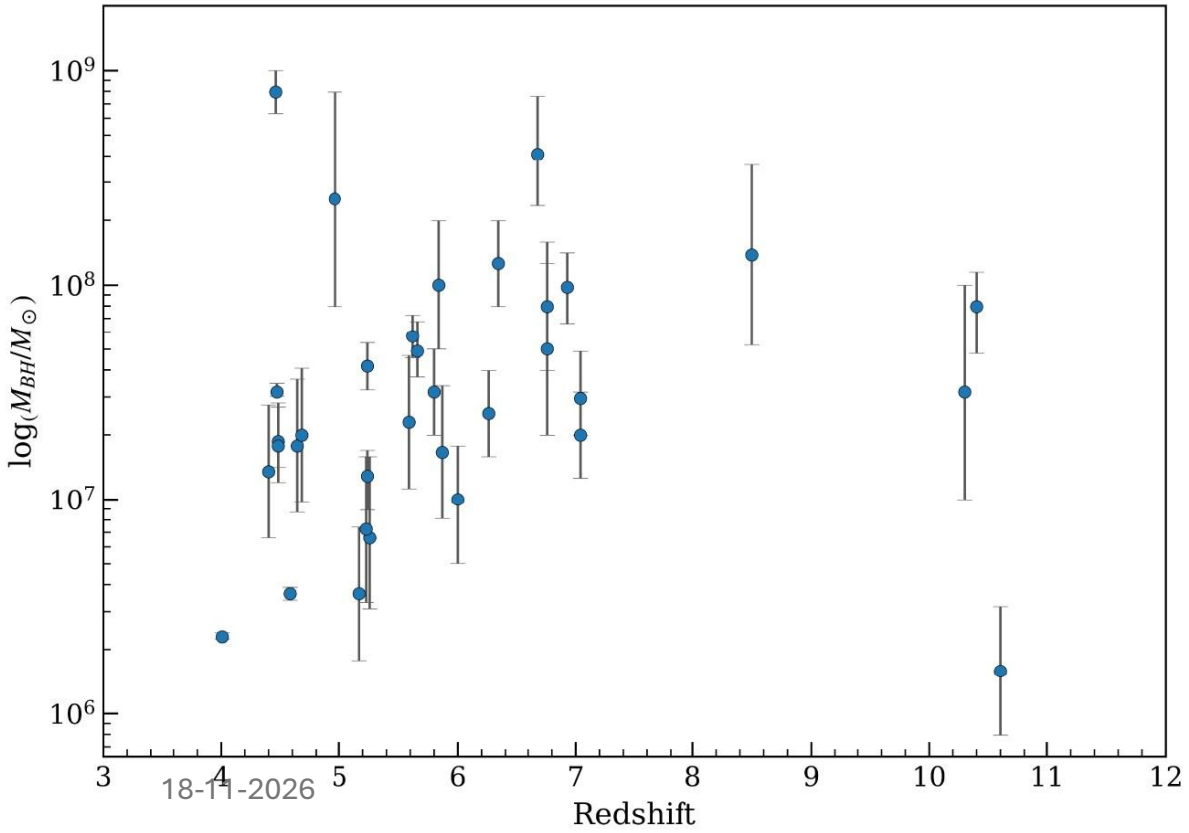


A 6.5 billion solar mass black holes



A 4.2 million solar mass black holes

- Cosmological observations show that massive black holes were already in place when the universe was not yet 1 billion years old.
  - Existence of quasars at high redshift signifies that black holes must predate galaxies.
- Black holes with $M \sim 10^7 - 10^9 M_\odot$ exist around cosmological redshift z ~6.67 – 10.3 (some of them are reported by JWST; Dayal 2024 A&A 690, A182).



From Das, Kalita & Kakati 2026 (MNRAS)
https://doi.org/10.1093/mnras/stag205

Cosmological redshift	Cosmic Time (Gyr)
6.67	0.821
7.00	0.771
10.3	0.459

How do overly massive black holes form in cosmic infancy ? (Existing models)

- Collapse of very massive Pop III stars (Bromm et al. 1999; 2002).
- Collapse of supermassive primordial gas cloud (Haehnelt & Rees 1993) in pre-galactic haloes.
  - Super-Eddington growth of stellar mass seed to $10^4 - 10^6 M_\odot$ black hole (Begelman et al. 2006).
- $10^4 - 10^5 M_\odot$ heavy seed black hole from Direct Collapse of pre-galactic gas (Natarajan et al. 2023).
  - Hierarchical black hole mergers in dense star clusters (Antonini et al. 2018).
  - Collapse of Self Interacting Dark Matter (SIDM) via gravothermal process to massive seed (Balberg & Shapiro 2002; Feng et al. 2021; Das and Kalita 2024).
- Collapse of cosmic string loop around redshift, z ~30 can give $10^5 M_\odot$ black holes (Bramberger et al. 2015)

Growth of seeds: Early Universe cosmology channel -I

(*Das & Kalita 2024, ApJ 961, 105 ; Das , Kalita & Kakati 2026, MNRAS 546, 205*)





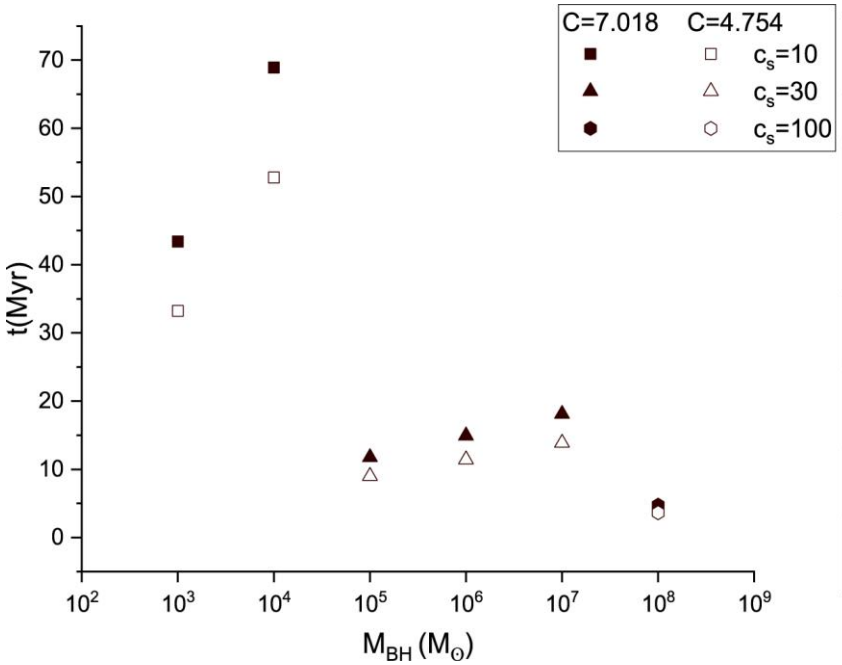
- Primordial density perturbation helps in formation of dark matter cocoon/halo near seed black hole.
- If dark matter is self interacting , it undergoes gravothermal collapse due to heat loss, followed by Hoyle-Lyttleton-Bondi accretion.

Theoretical model:

.A $20M_{\odot}$ seed moving with 100 km/sec accreting SIDM with NFW, Singular Isothermal profile, power law profile and core profile of dark matter.

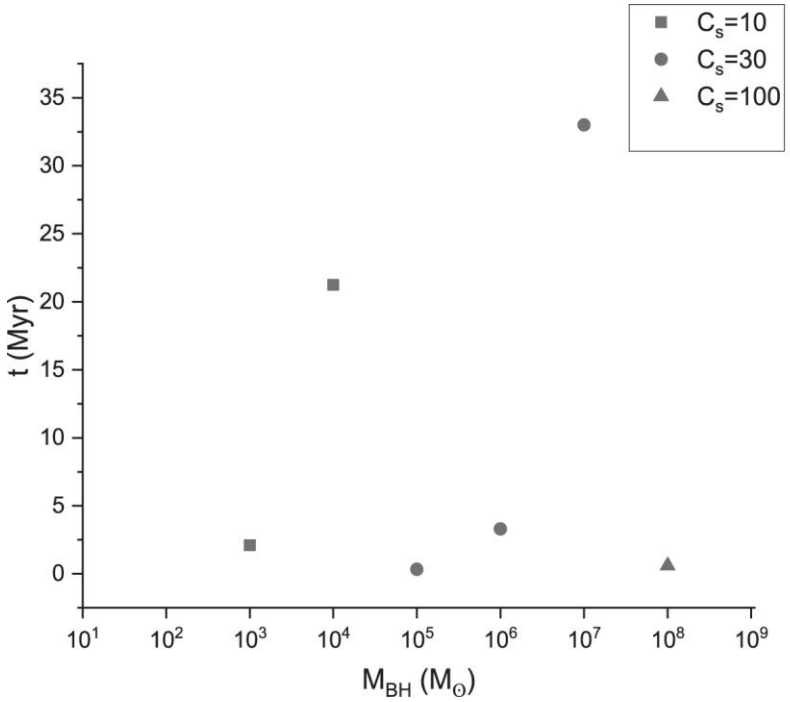
- Sound speed Cs = 10-100 km/sec
- Halo concentration at various redshifts (~8-30) with halo mass $M_{200} = (10^{12} - 10^{14})M_{\odot}$ for NFW profile.
- SIDM specific cross section: $\frac{\sigma}{m_{dm}} = 0.1 - 5\ cm^2/g$

Time scale of formation of black holes with M=$(10^3 - 10^8)M_\odot$ starting accretion at z =20 and z = 30



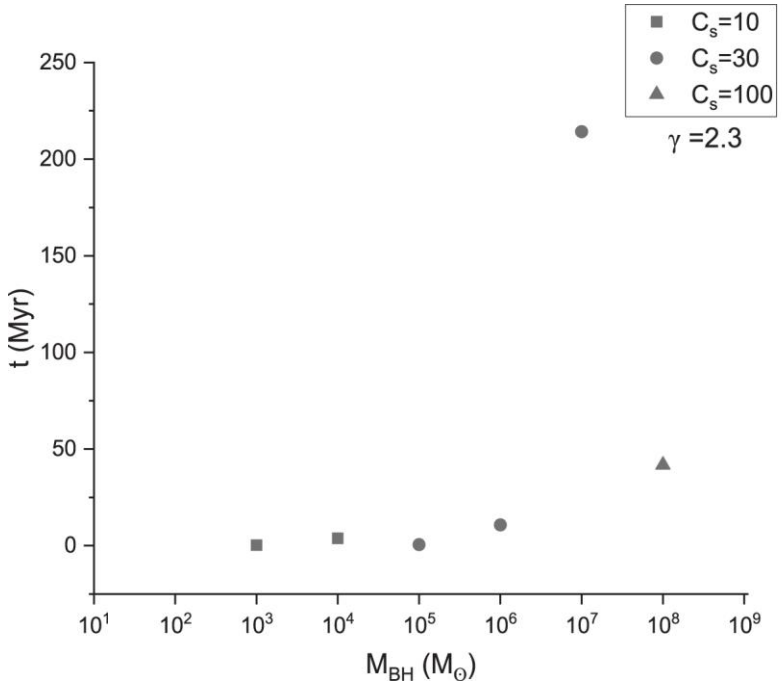
	C=7.018 Zi=20	C=4.754 Zi=30
	zf	zf
1.	17.17	17.748
2.	15.9	16.679
3.	19.12	19.324
4.	18.91	19.150
5.	18.69	18.981
6.	19.63	19.719

NFW profile with halo mass $10^{12}M_\odot$



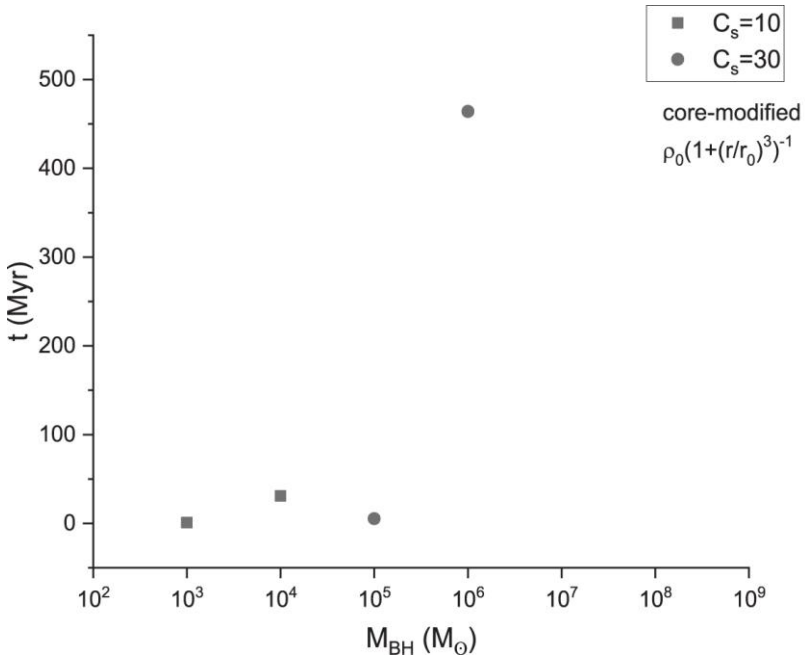
	z_i	z_f
1	20	19.84
	30	29.57
2	20	18.49
	30	26.26
3	20	19.97
	30	29.93
4	20	19.74
	30	29.33
5	20	17.76
	30	24.63
6	20	19.95
	30	29.88

Singular Isothermal Sphere



z_i	z_f
1 20	19.98
30	29.96
2 20	19.71
30	29.24
3 20	19.96
30	29.89
4 20	19.20
30	27.96
5 20	11.43
30	13.44
6 20	17.26
30	23.56

Power law profile with $\rho(r) \sim r^{-\gamma}$, $\gamma = 2.33$ $(Cusp)$



z_i	z_f
1 20	19.93
30	29.81
2 20	17.89
30	24.92
3 20	19.59
30	28.94
4 20	7.95
30	8.77

Core –modified profile

Early Universe cosmology channel – II: Massive Primordial Black Holes

- Primordial black holes (PBH) are produced by large density fluctuations in the chaotic initial conditions (Carr & Hawking 1974), cosmic string loops (Hawking 1989) and softening of equation of state during QCD phase transition.

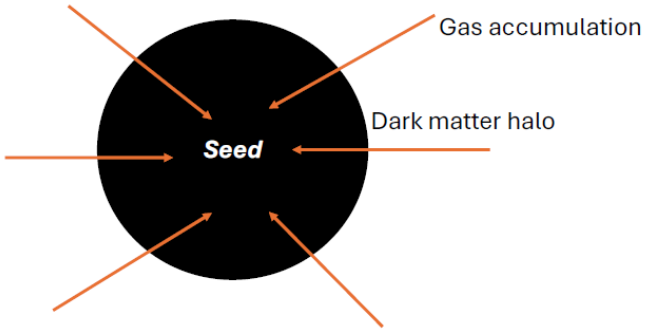
  - Massive PBHs can seed massive black holes and galaxies through Poisson fluctuations and gravitational Coulomb effect (Hoyle & Narlikar 1966; Carr & Silk 2018).

    - PBHs as candidates of dark matter: $f_{PBH} \sim 1,\ M_{PBH} \lesssim 100 M_{\odot}$.

    - PBHs as seeds of MBHs + galaxies: $f_{PBH} \lesssim 10^{-3}$, $M_{PBH} \sim 10^{6} M_{\odot}$.

Gravitational Coulomb effect:

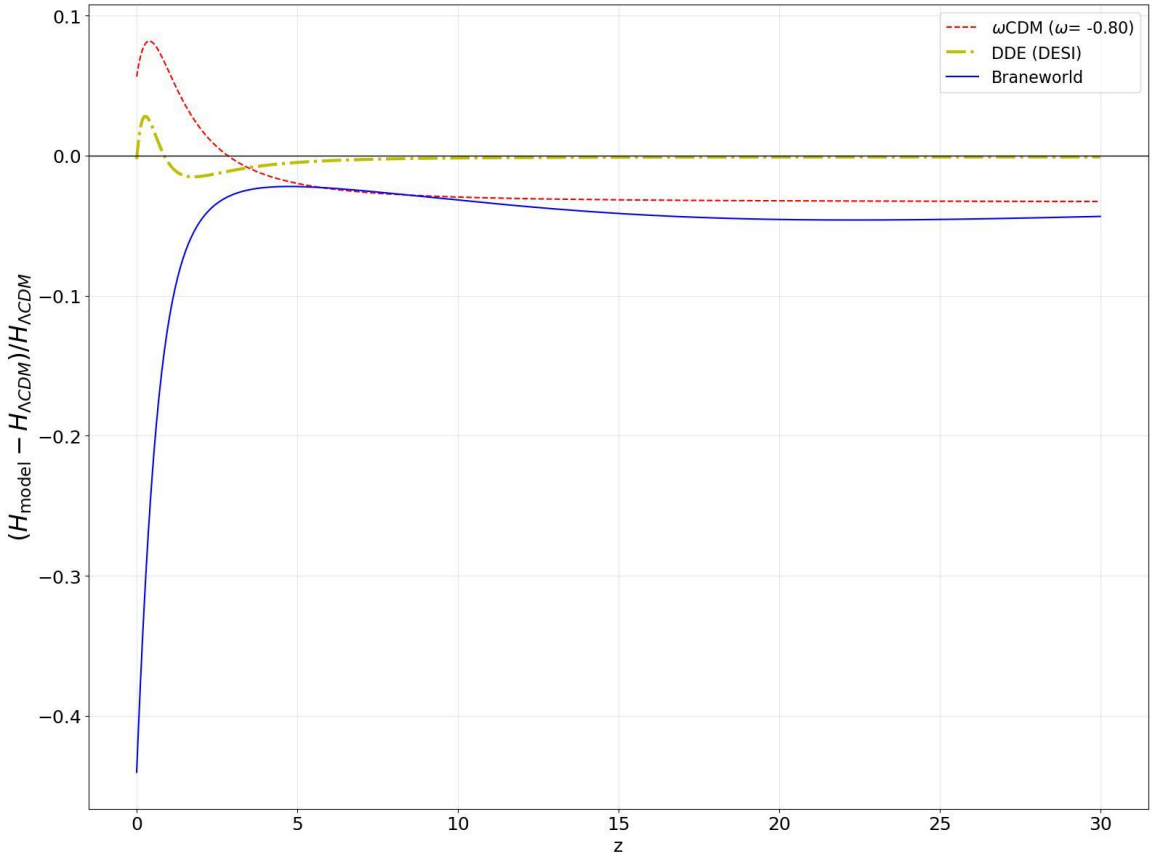
A massive black hole ($10^{9} M_{\odot}$) can seed elliptical galaxy of $10^{12} M_{\odot}$ (Hoyle & Narlikar 1966; **gravitational Coulomb /seed effect**).



Carr and Silk 2018

Stretch the cosmic time after the Big Bang

- Lambda (Λ) CDM cosmology
- Dynamical Dark Energy model (constrained by DESI data)
- Constant equation of state dark energy (ωCDM cosmology)
- 5 Dimensional braneworld cosmological model

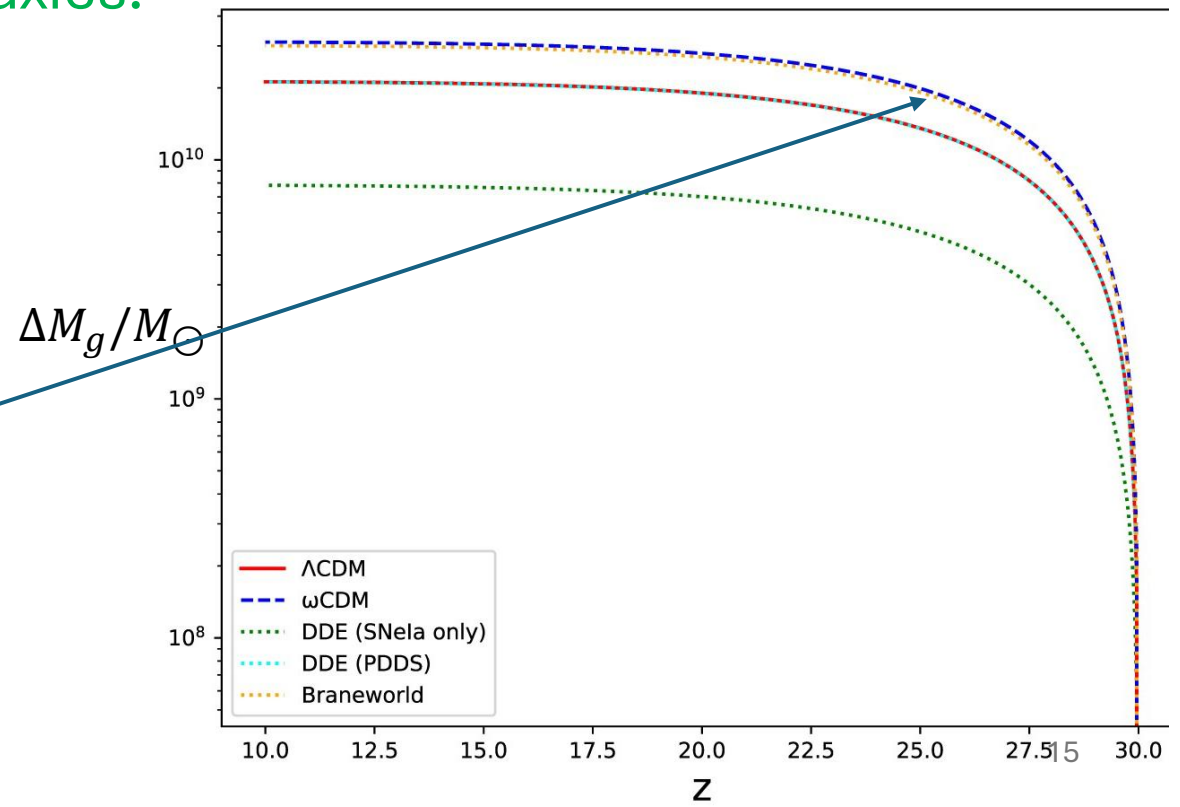


Consequence: Black Hole – Galaxy Coevolution

- Mass of the central black hole in galaxies is correlated with velocity dispersion of the spheroidal bulge (Tremaine et al. 2002) and the halo (Ferrarese et al. 2002).

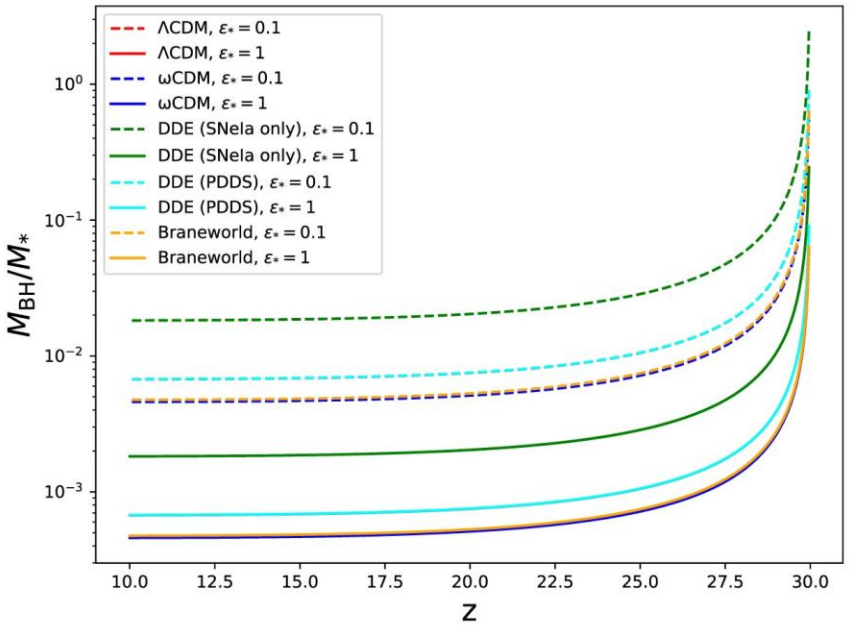
- The supermassive black holes in galactic nuclei must have co-eval growth with host galaxies.

Evolution of accreted gas mass with redshift inside a black hole seeded dark matter halo.

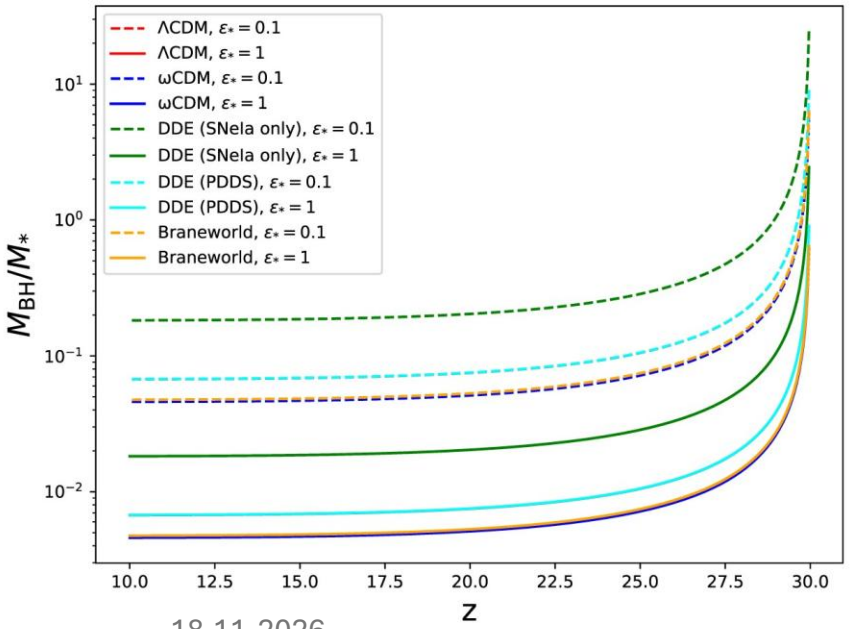


- DDE of DESI parameters (Planck +DESI+DESY5) as well as ΛCDM can generate Milky Way like gas content.

- Braneworld + ω CDM can produce even massive gas content,



(a)



(b)

The JWST Universe

- We consider massive seed $(10^5 - 10^8)M_\odot$ produced by gravothermal collapse of dark matter or gas accretion onto massive seeds in time stretched cosmology (Das, Kalita & Kakati 2026).

- Stellar mass accumulated by gas accretion in the Coulomb effect is calculated by taking star formation efficiency of 0.1 – 1.0.

- Black hole to stellar mass ratio: $\frac{M_{BH}}{M_*} = (0.001 - 10)$

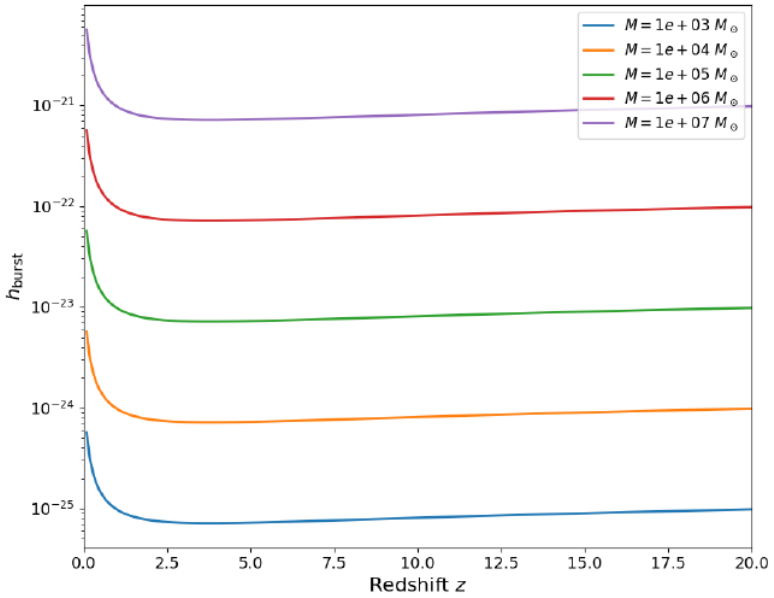
Compatible with Little Red Dots (LRDs)

Merging JWST universe with LISA's Gravitational Wave Sky

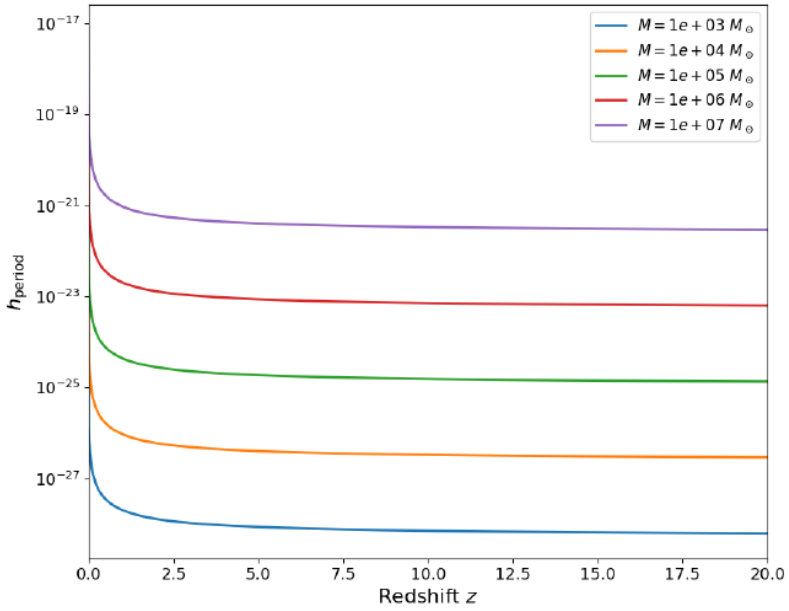
- Massive black holes emit gravitational waves if they evolve through dynamical friction in host galaxies to the state of hard binaries or undergo burst activity.

  - $h_{period} \sim h_{burst}$ x $M^{2/3}$

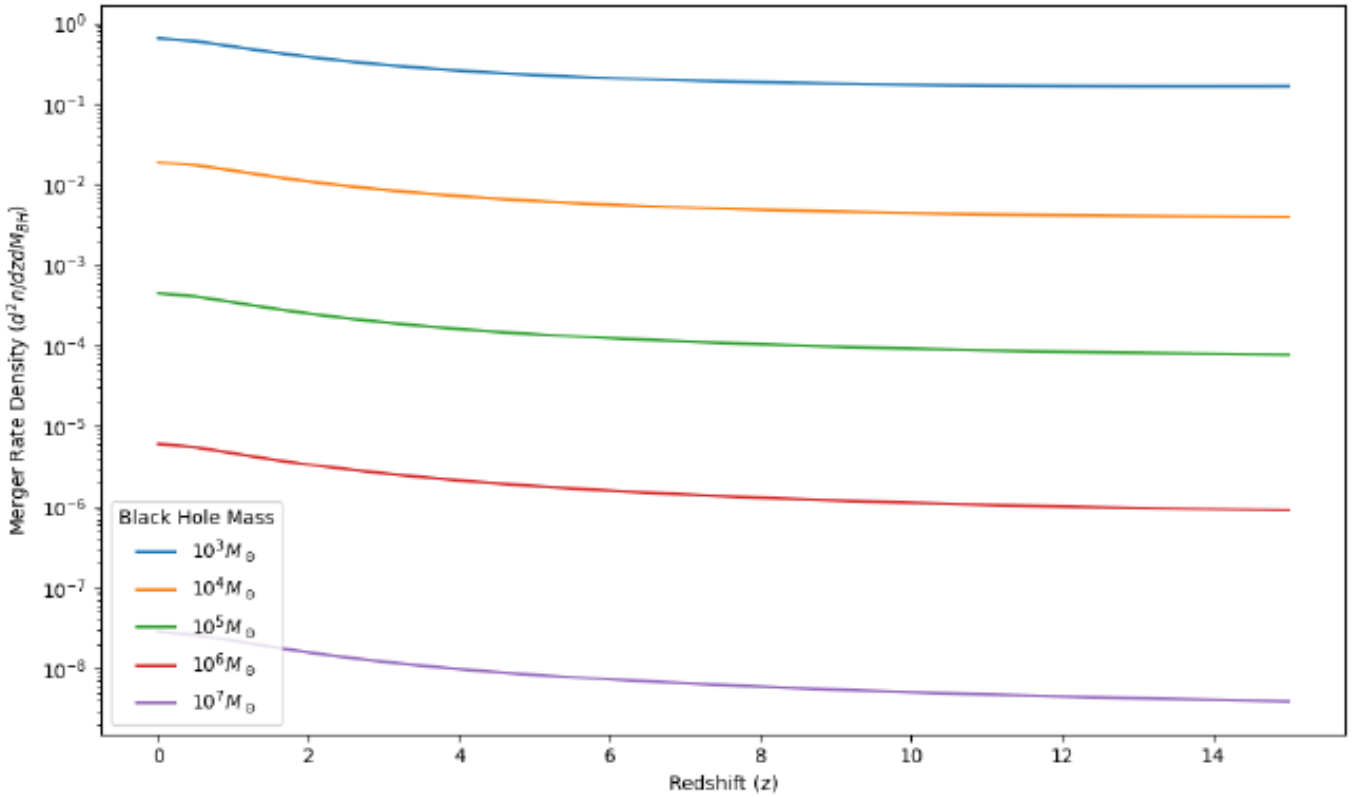
- LISA has capability to detect $10^3 - 10^7 M_{\odot}$ black holes out to z ~20 with detector frequency of 0.1mHz to 0.1 Hz



- LISA is sensitive to $h \sim 10^{-23} - 10^{-20}$



Massive black hole merger rate depends on occupation fraction, galaxy merger rate, massive black hole mass function, black hole to stellar mass ratio, delay time between galaxy merger and black hole merger (Fang & Yang 2023; Fang & Cai 2025)



Occupation fraction 50%

Das & Kalita (November 2026); manuscript in preparation

Unifying the universes of JWST+LISA and the universe of EHT black hole physics

- Merger rate is enhanced if black holes form in pre-galactic dark matter halo (Ding et al. 2025).
- A massive black hole converts primordial halo into a dark matter spike (Gondolo & Silk 1999).
  - Merger via gravitational bremsstrahlung has a rate :

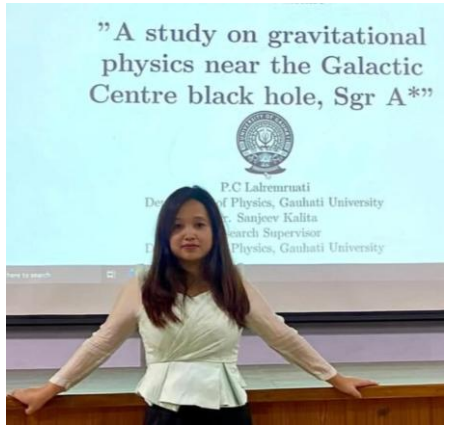
$$N_{sp} = \int_{4R_s}^{r_{sp}} \frac{1}{2} \left(\frac{f_{PBH} \rho_{sp}(r)}{M_{PBH}} \right)^2 \sigma_m(r)\, v_{rel}(r) 4\pi r^2 dr$$

- Dark matter spike affects black hole quadrupole moment.

$$q_2 = q_2(Kerr)[1 + f(R, M_{BH})], \quad q_2(Kerr) = -\chi^2.$$

- It affects black hole "no-hair" theorem which can be tested through EHT black hole shadow shape measurements.





Stellar orbits near Sgr A*



Shadow of Sgr A*

Concluding remarks

- Possibility of massive black hole origin through primordial cosmology cannot be ruled out.

- Black holes must predate galaxies.

- If PBHs (massive) is not entirely dark matter, galaxy formation at high redshift through black hole based perturbation is a possibility.

- Formation channel of massive black holes, dark matter distribution and black hole physics are likely to be in symbiosis.

THANK YOU VERY MUCH !