GRAVOTHERMALIZING INTO CANNIBAL STARS AND PRIMORDIAL BLACK HOLES

Pranjal Ralegankar

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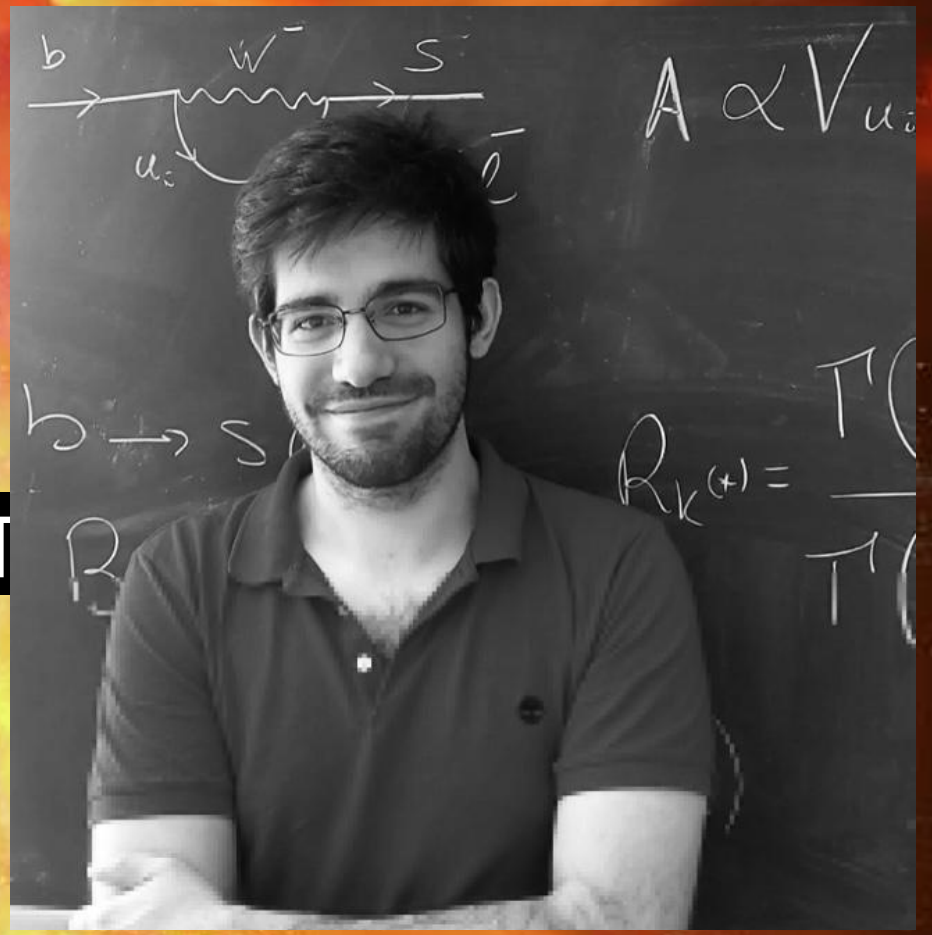

GRAVOTHERMAL EVOLUTION: UNAVOIDABLE CONSEQUENCE IN GRAVITATIONAL SYSTEMS

- Virial Theorem: $K = -U_G/2$

- $E_{tot} = K + U_G = -K \propto -T$

Negative heat capacity

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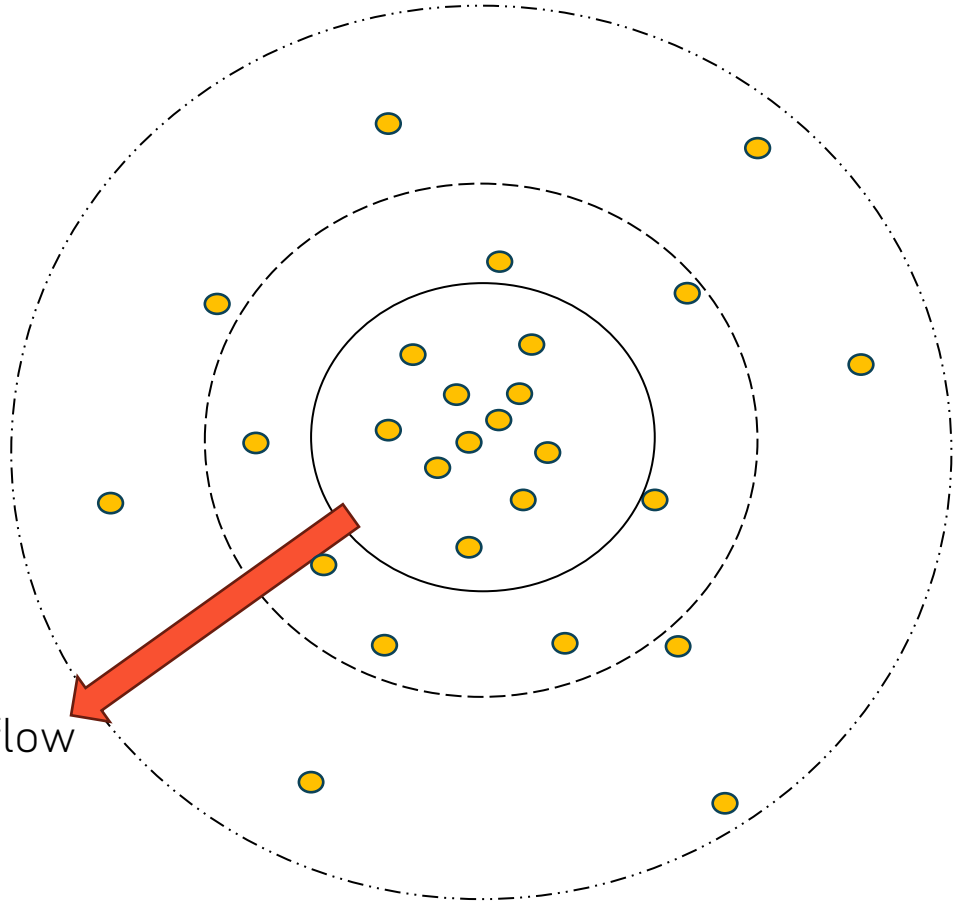
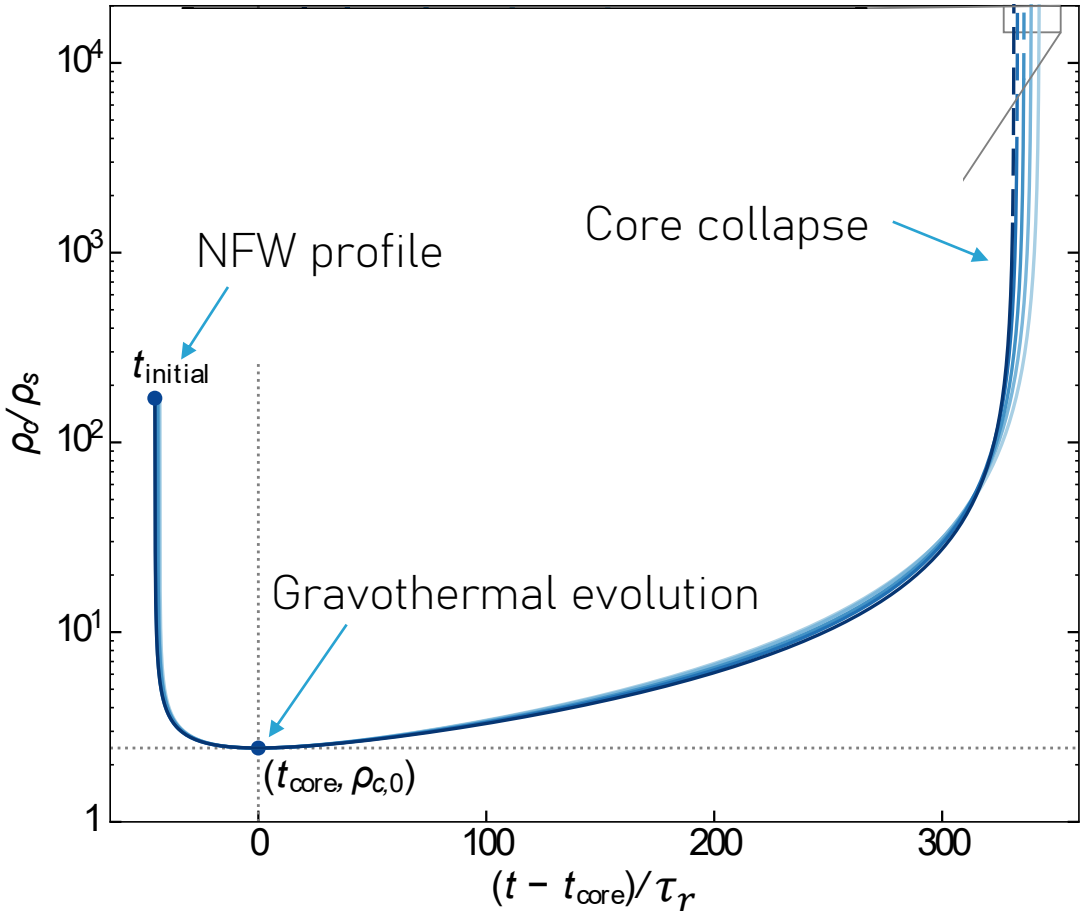
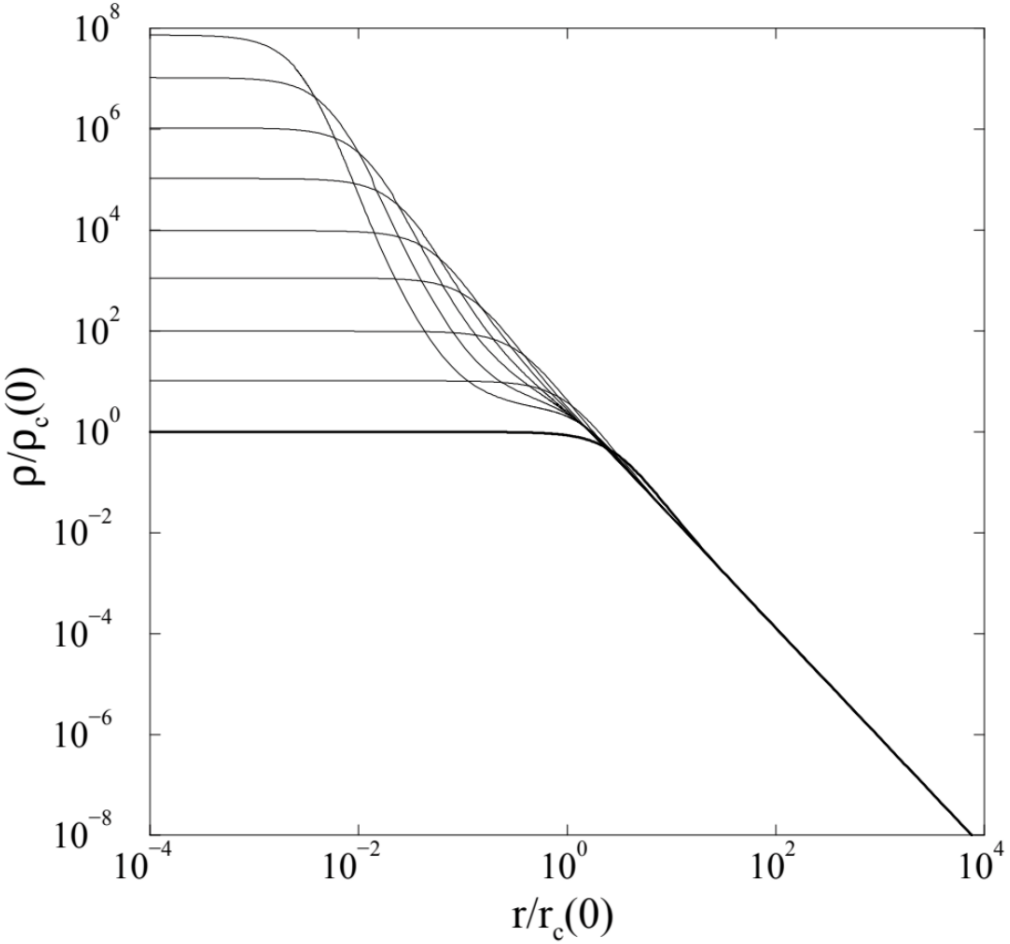


GRAVOTHERMAL IN SELF INTERACTING DARK MATTER

Outmezguine, Boddy, Nasr, et. Al. (2022)

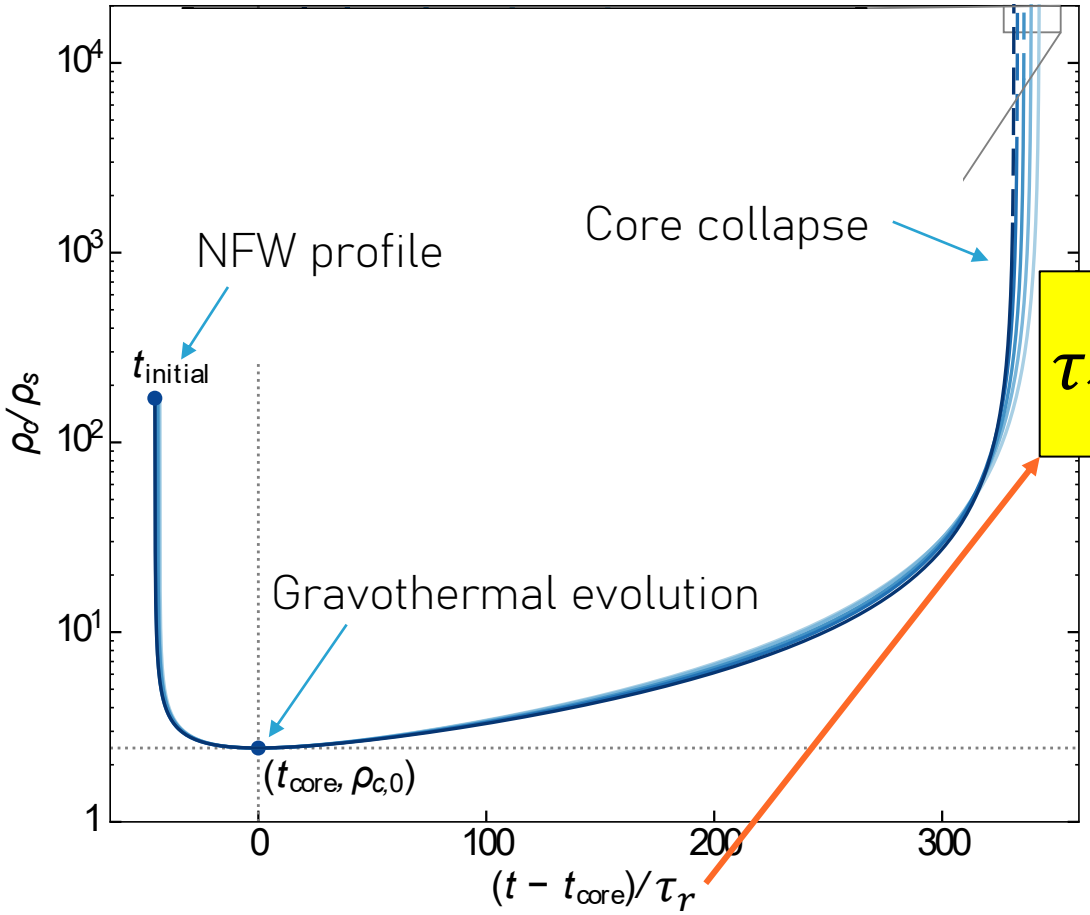


Balberg, Shapiro, Inagaki (2001)



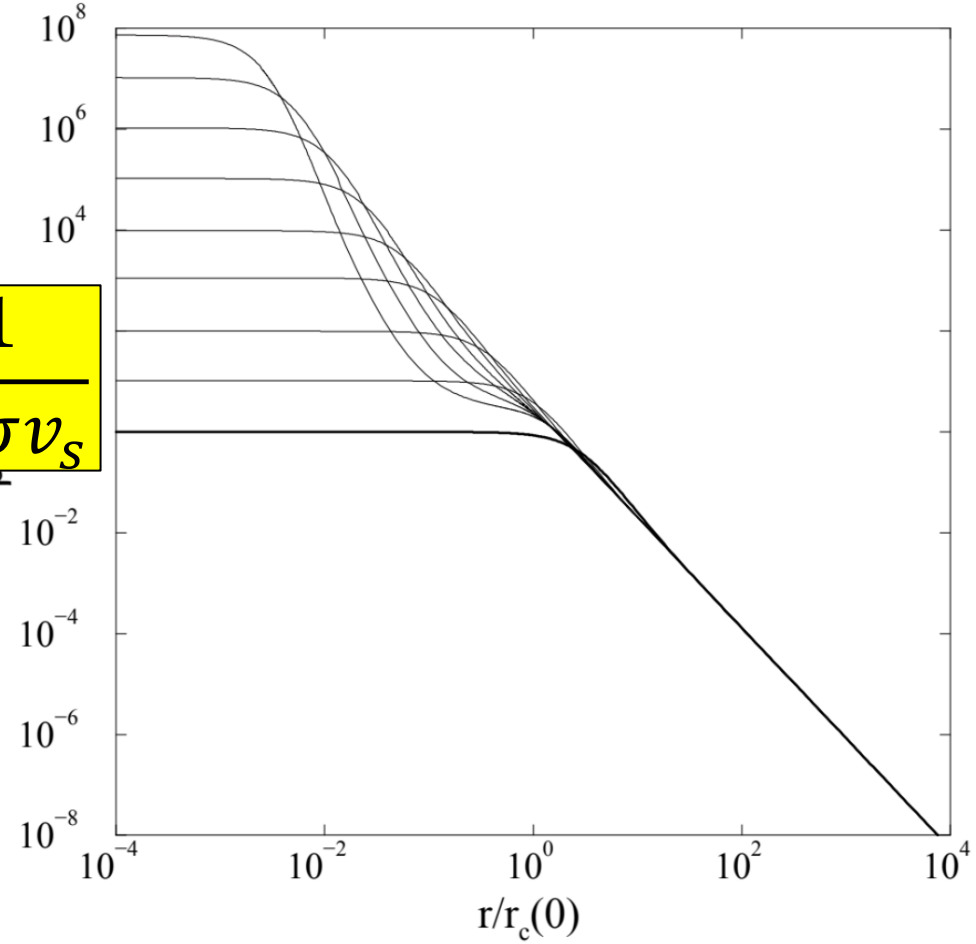
GRAVOTHERMAL IN SELF INTERACTING DARK MATTER: RELAXATION TIMESCALE

Outmezguine, Boddy, Nasr, et. Al. (2022)



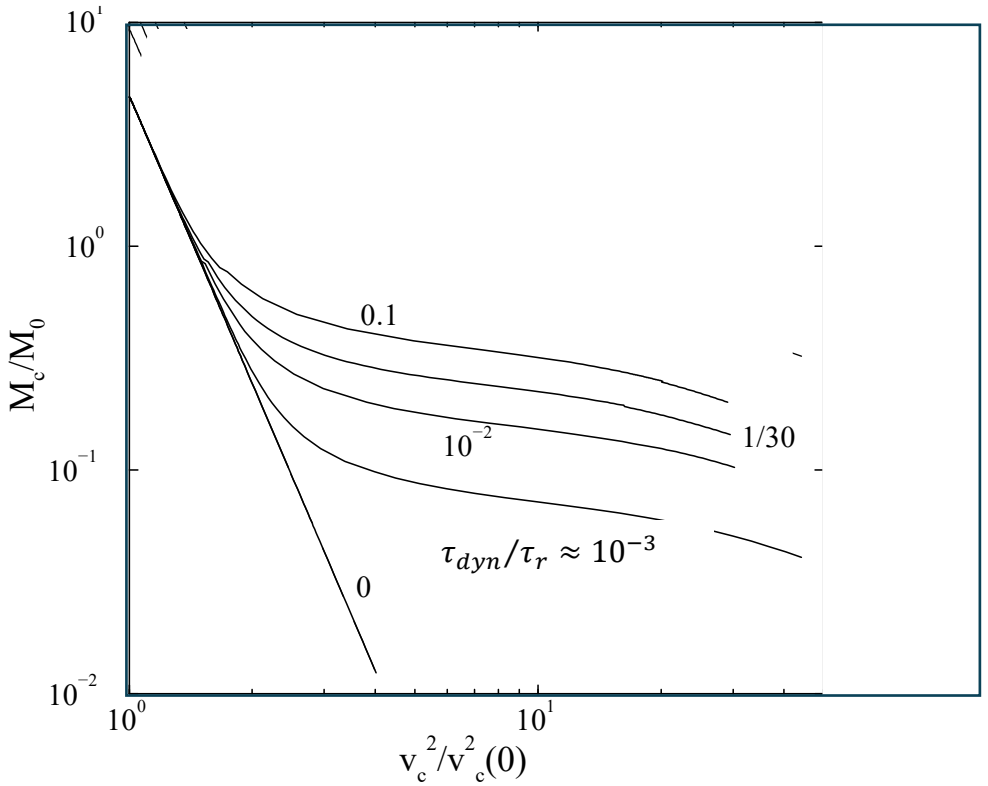
$$\tau_r = \frac{1}{\rho_s \sigma v_s}$$

Balberg, Shapiro, Inagaki (2001)



GRAVOTHERMAL BLACK HOLE FORMATION

Balberg, Shapiro, Inagaki (2001)



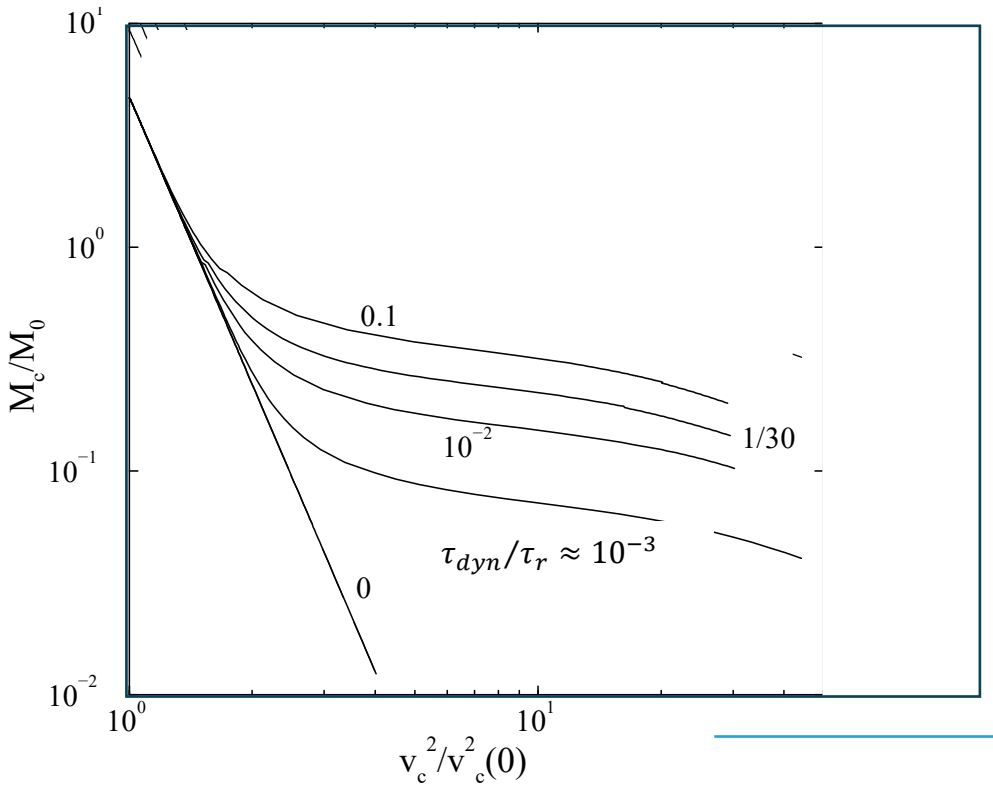
Core mass

Core virial velocity

GRAVOTHERMAL BLACK HOLE FORMATION

Core mass

Balberg, Shapiro, Inagaki (2001)



Core virial velocity

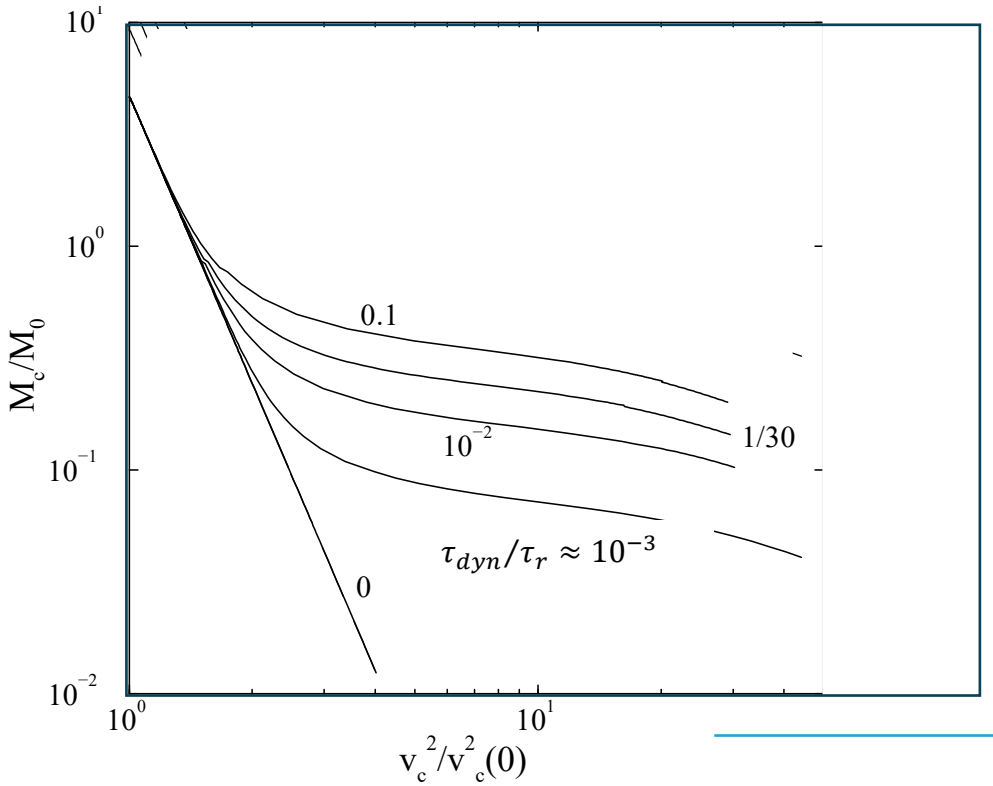
$$v_c^2 = \frac{GM}{R} \sim \left(\frac{1}{3}\right)^2$$

BH formation

GRAVOTHERMAL BLACK HOLE FORMATION

Core mass

Balberg, Shapiro, Inagaki (2001)



Core virial velocity

$$\frac{M_{BH}^{seed}}{M_{halo}} \sim 10^{-5} \left(\frac{\tau_{dyn}}{\tau_r}\right)^{0.5}$$

$$v_c^2 = \frac{GM}{R} \sim \left(\frac{1}{3}\right)^2$$

BH formation

SIDM TOO STRONGLY CONSTRAINED TO FORM BLACK HOLES

- For gravothermal collapse to occur by today: $\frac{\sigma}{m} > 100\ cm^2/g$

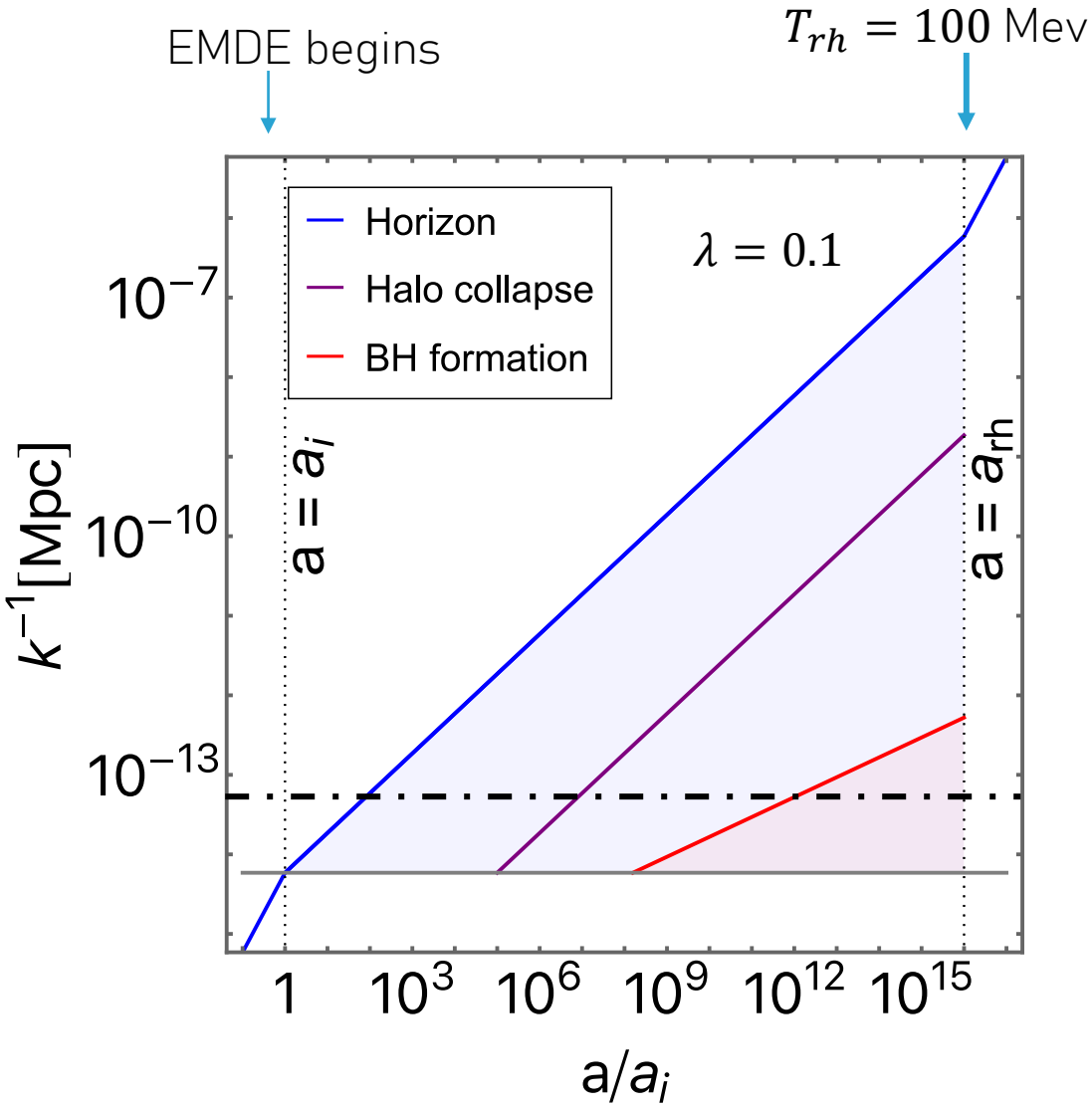
- SIDM constraints: $\frac{\sigma}{m} < 1\ cm^2/g$

NO RESTRICTIONS ON SELF INTERACTIONS DURING AN EARLY MATTER DOMINATED ERA (EMDE) BEFORE BBN

GRAVOTHERMAL IN AN EARLY MATTER DOMINATED ERA (EMDE)

- A simple model of self-interacting nonrelativistic scalar particles dominating the universe after inflation and then decaying into SM:

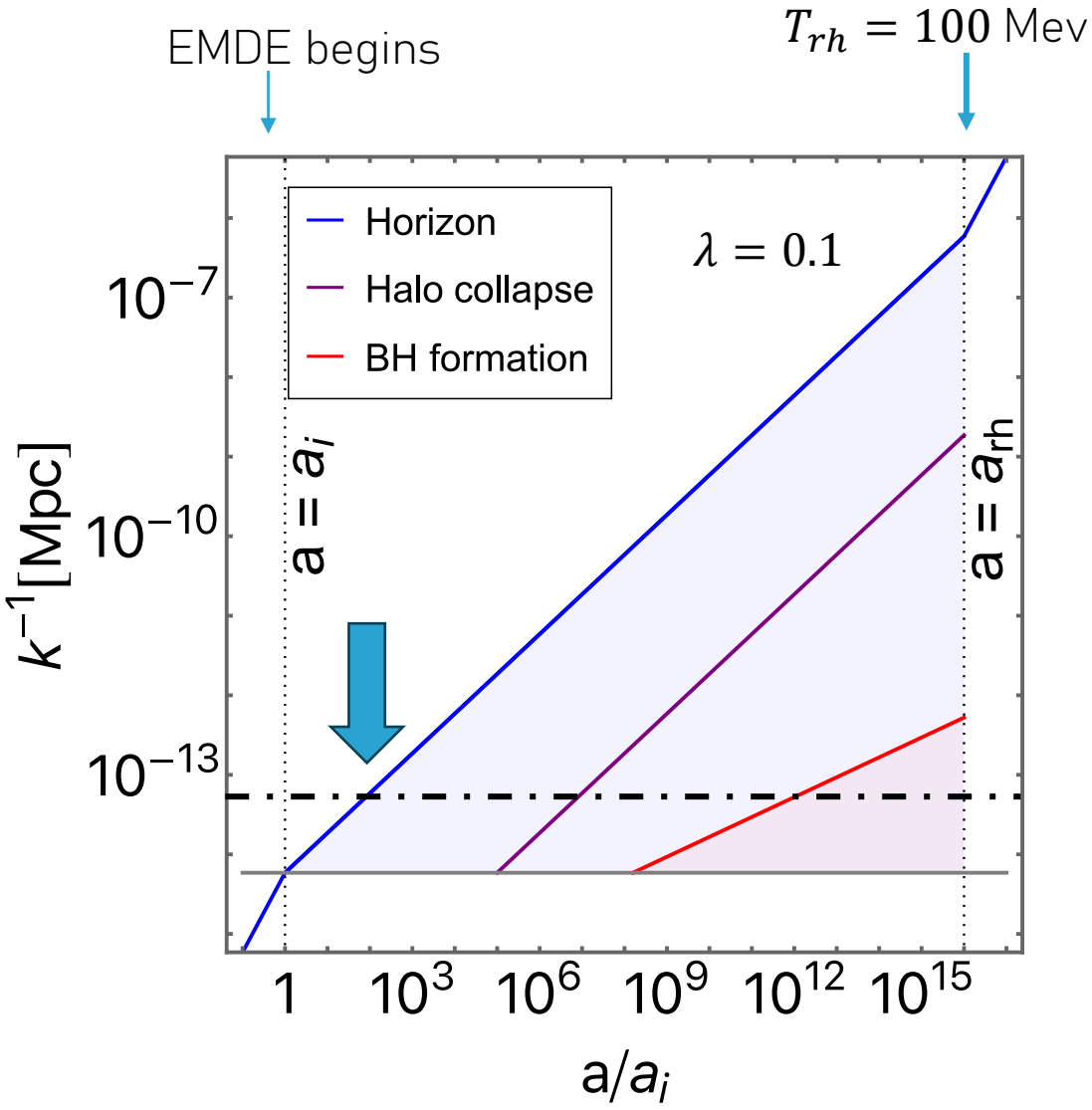
$$\mathcal{L} = \frac{1}{2} m\phi^2 + \frac{\lambda}{4!}\phi^4$$



GRAVOTHERMAL IN AN EARLY MATTER DOMINATED ERA (EMDE): HORIZON ENTRY

- A simple model of self-interacting nonrelativistic scalar particles dominating the universe after inflation and then decaying into SM:

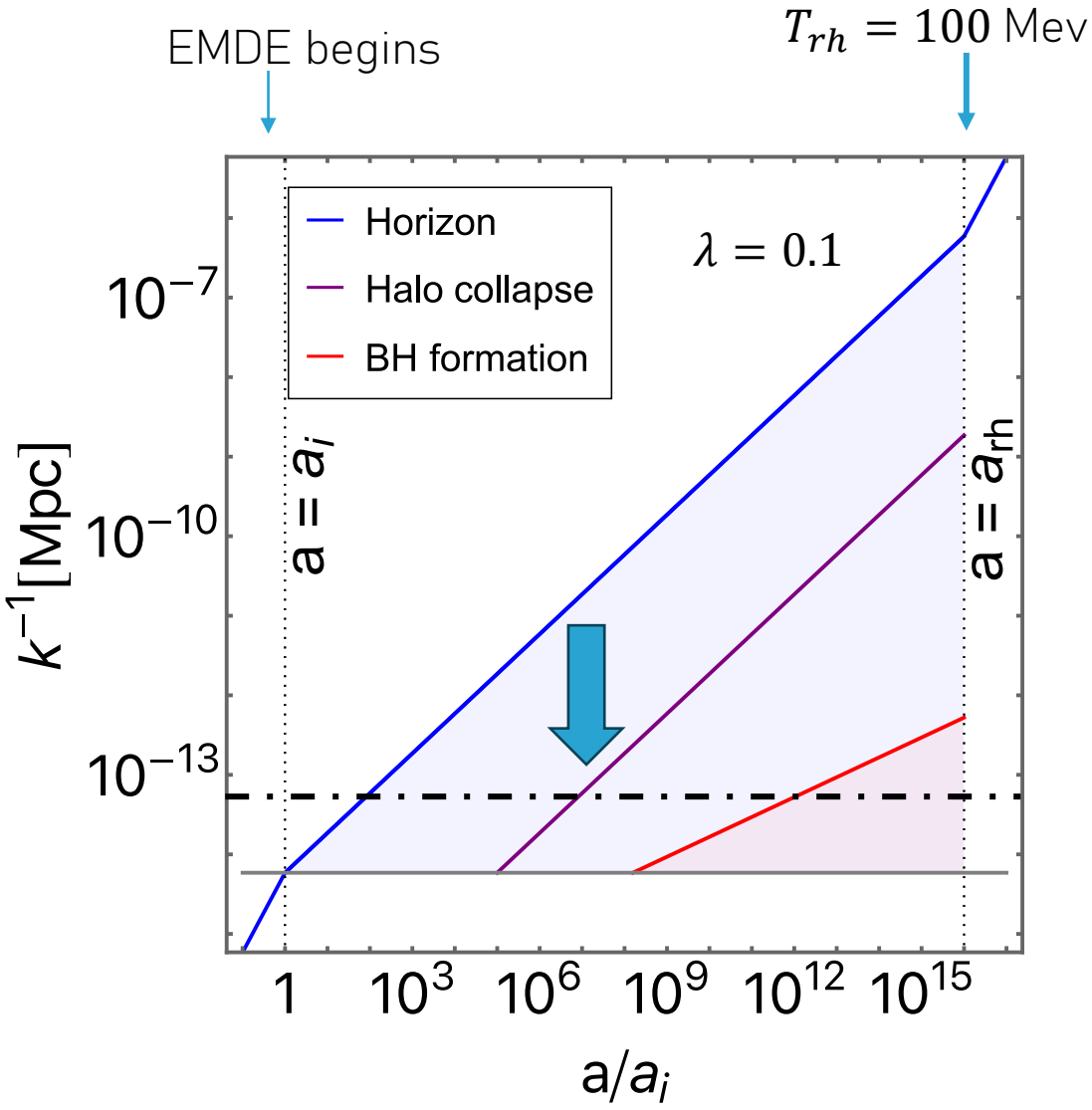
$$\mathcal{L} = \frac{1}{2} m\phi^2 + \frac{\lambda}{4!}\phi^4$$



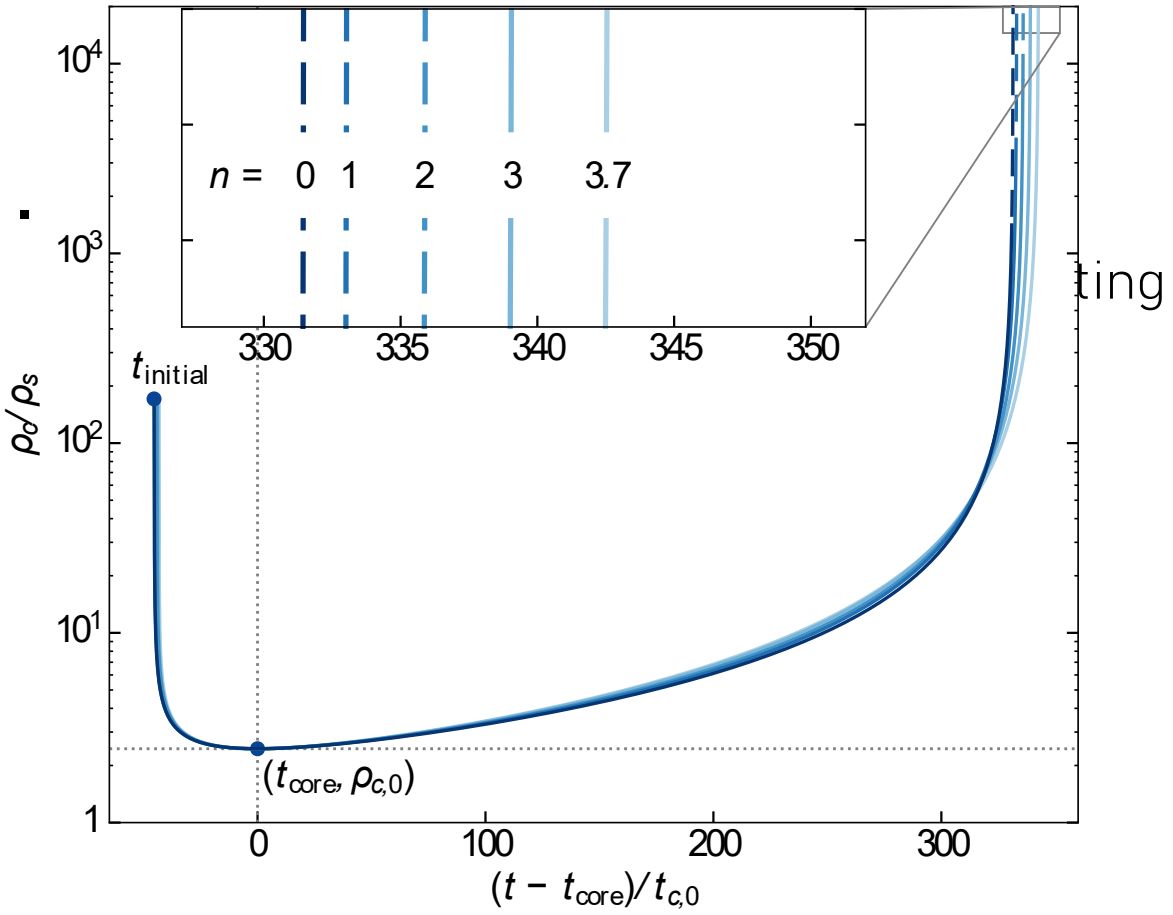
GRAVOTHERMAL IN AN EARLY MATTER DOMINATED ERA (EMDE): HALO FORMATION

- A simple model of self-interacting nonrelativistic scalar particles dominating the universe after inflation and then decaying into SM:

$$\mathcal{L} = \frac{1}{2} m\phi^2 + \frac{\lambda}{4!}\phi^4$$



GRAVOTHERMAL IN AN EARLY MATTER DOMINATED ERA (EMDE): GRAVOTHERMAL COLL.



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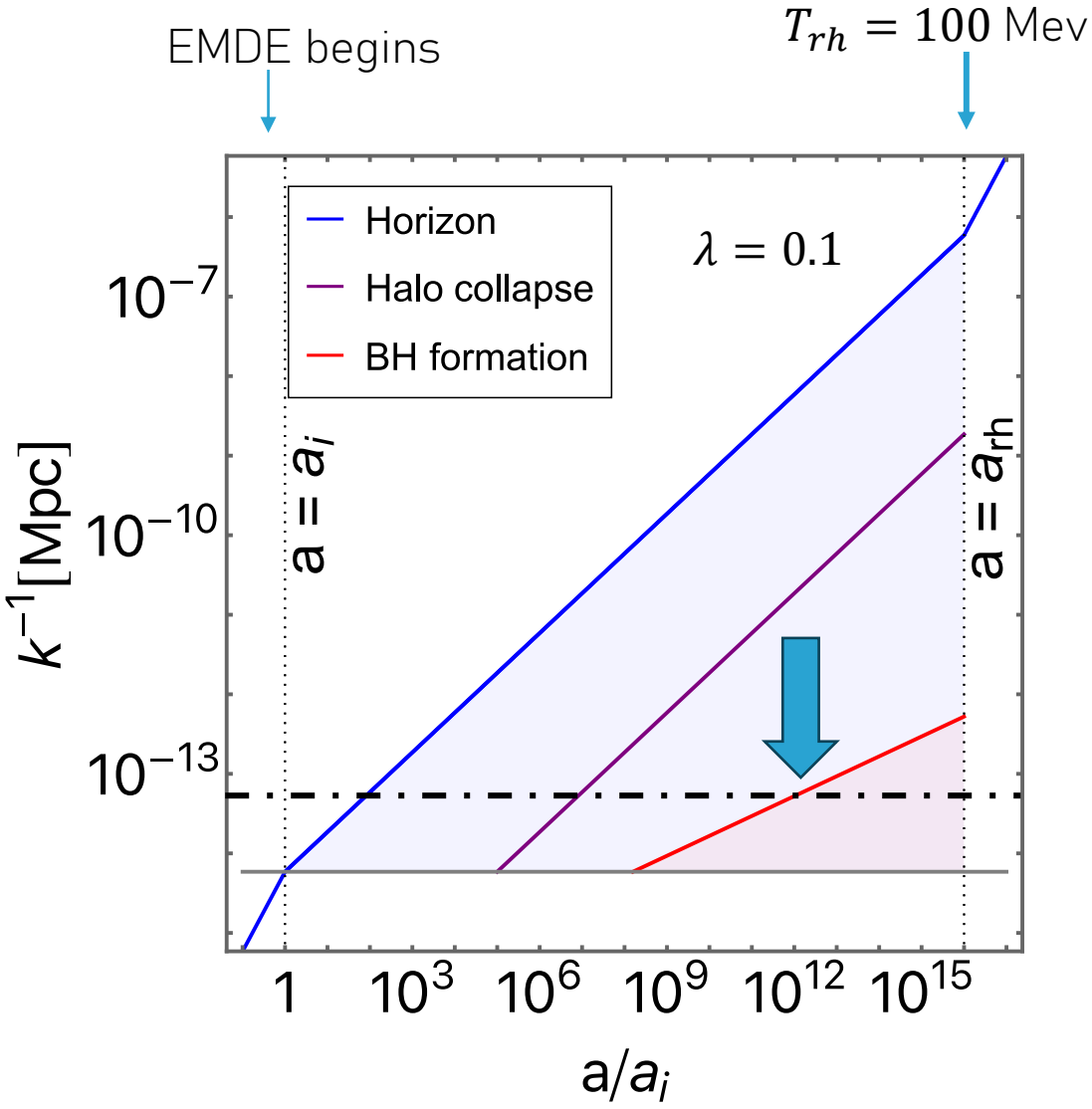


UNKNOWNS: BLACK HOLE ACCRETION

- Gravothermal theory developed for self-interacting dark matter only provides seed black hole mass

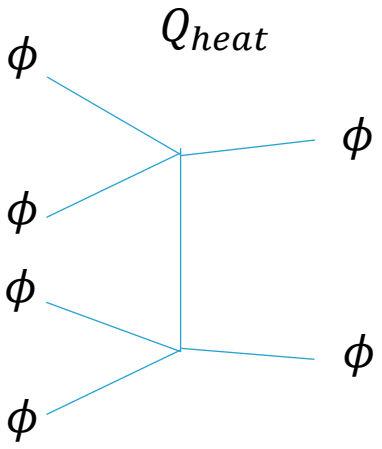
$$\frac{M_{BH}^{seed}}{M_{halo}} \sim 10^{-5} \left(\frac{\tau_{dyn}}{\tau_r} \right)^{0.5}$$

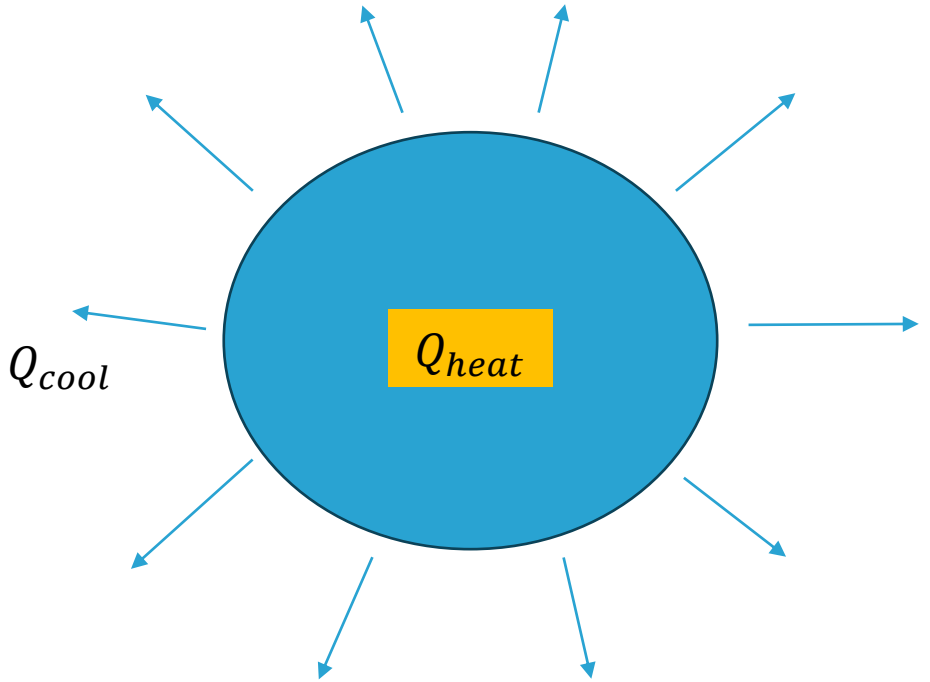
- Gravothermal accretion of surrounding halo by black hole. Energy conservation:

$$\frac{M_{BH}^{max}}{M_{halo}} \sim 10^{-3}$$

UNKNOWNS: CANNIBAL STARS

- During the collapse, in the inner core can be so dense that 4-to-2 interactions become important.

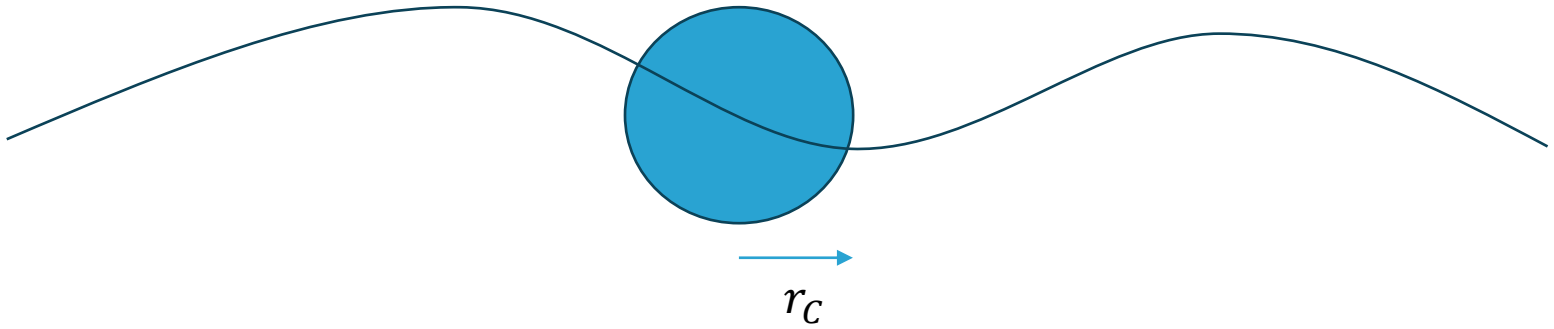




- If $Q_{\mathrm{cool}} < Q_{\mathrm{heat}}$ the final result is a cannibal star at the center of the halo.

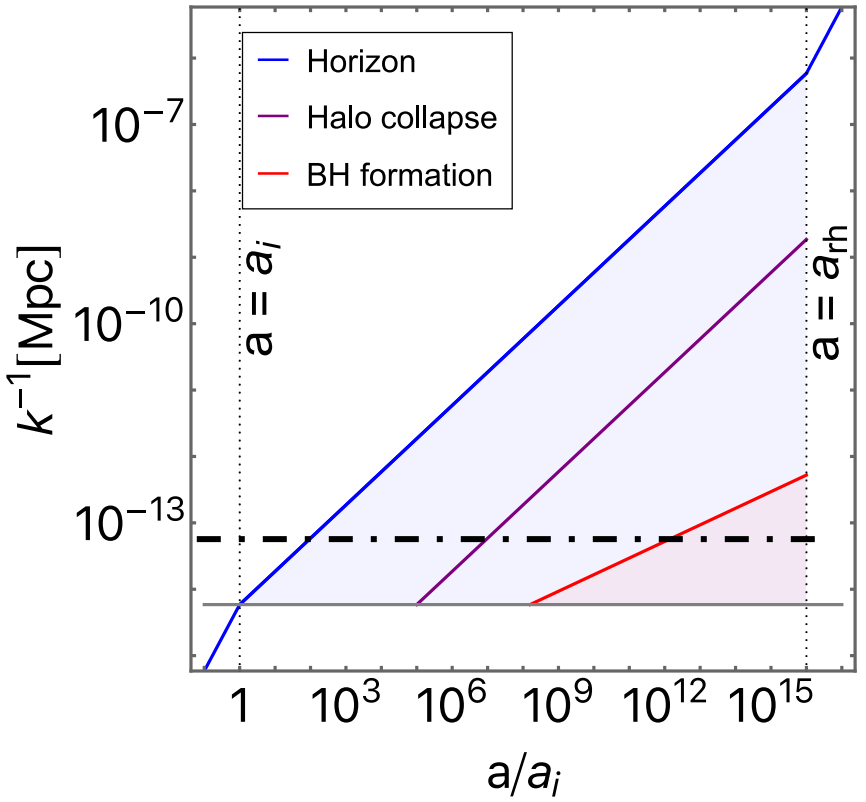
UNKNOWNS: WAVE NATURE OF PARTICLES

$$\lambda = \frac{1}{mv}$$



UNKNOWNS: ABUNDANCE

- Assume BHs only formed in halos that remain isolated until gravothermal collapse



PBH SPECTRUM AND CONSTRAINTS

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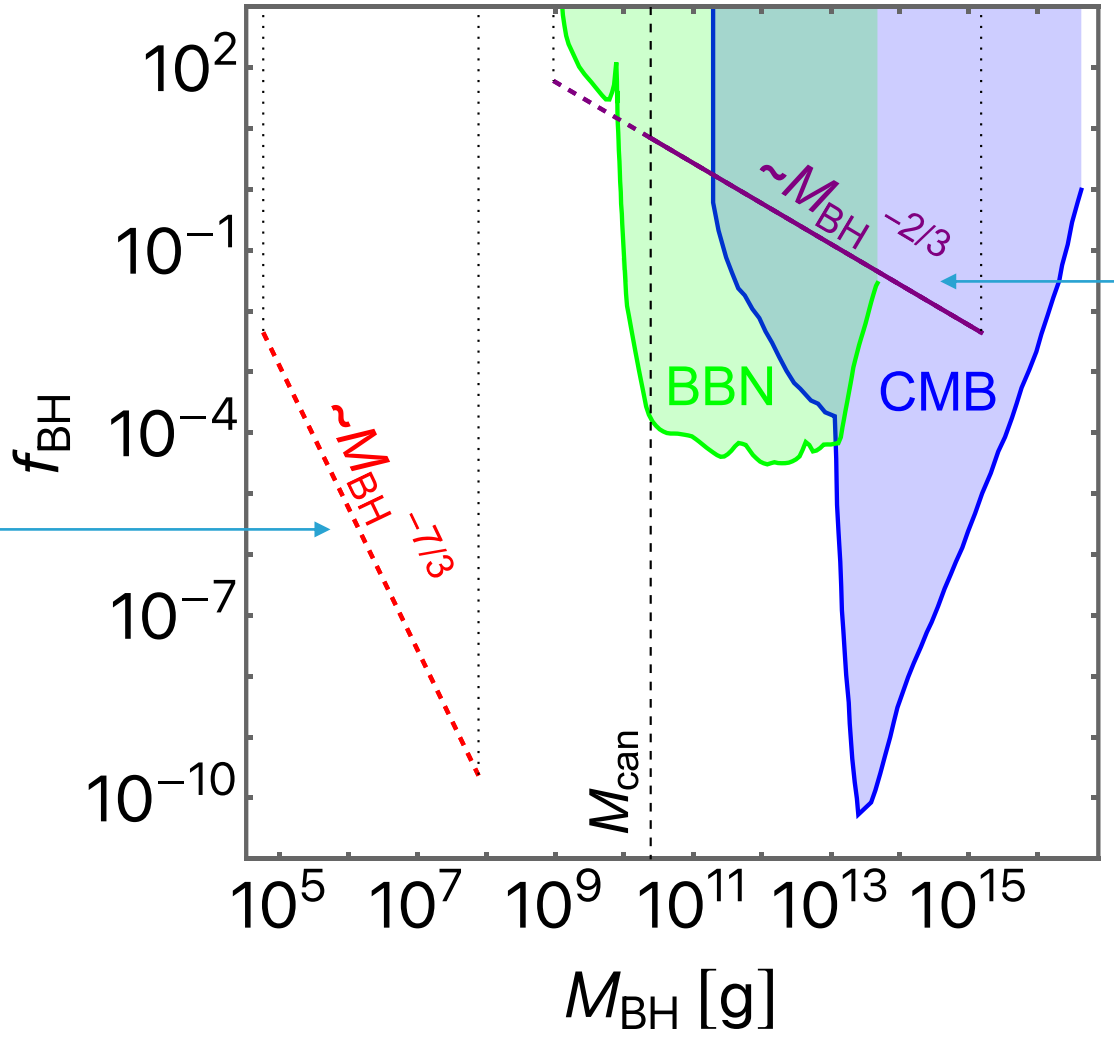
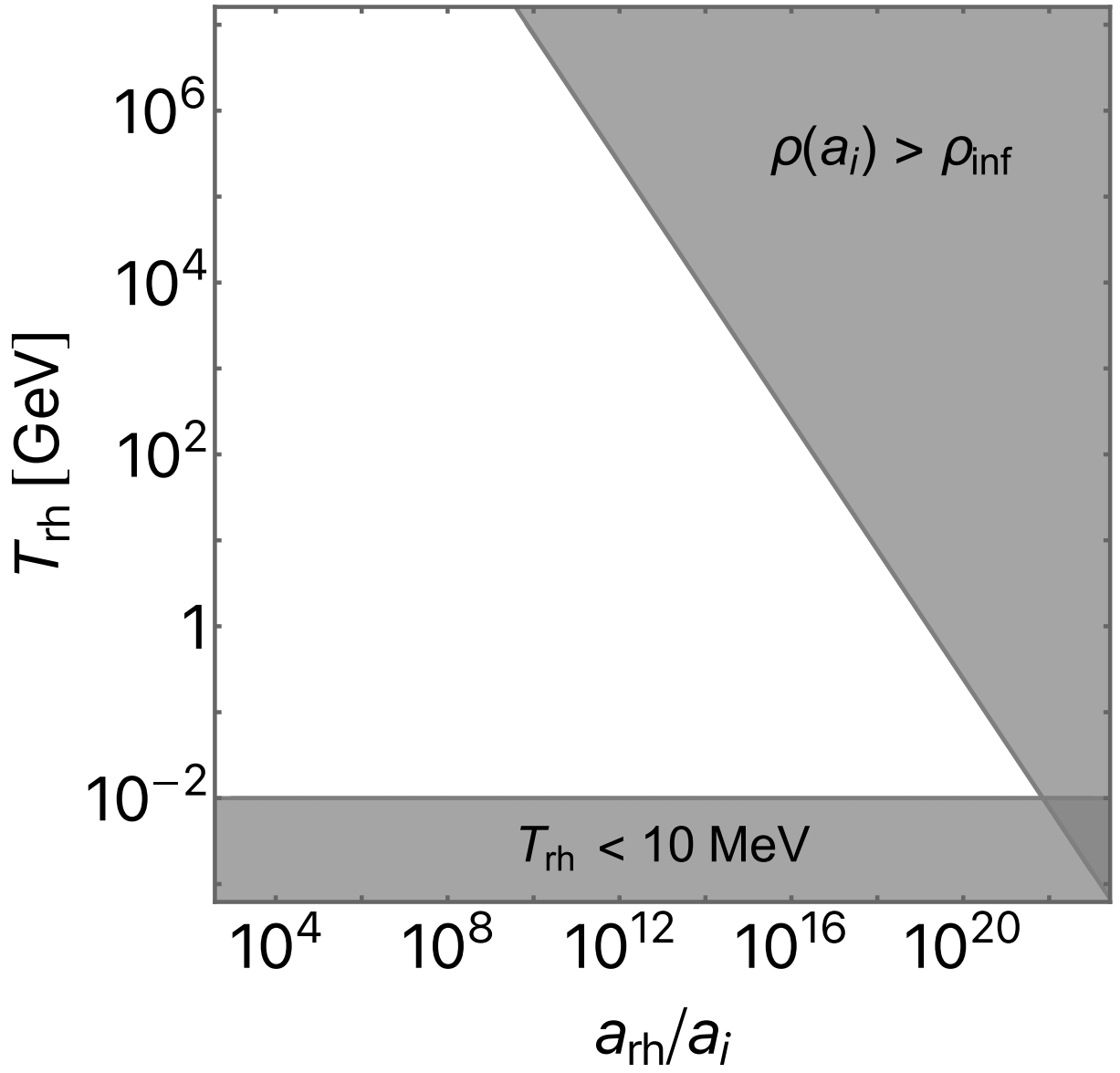


No accretion

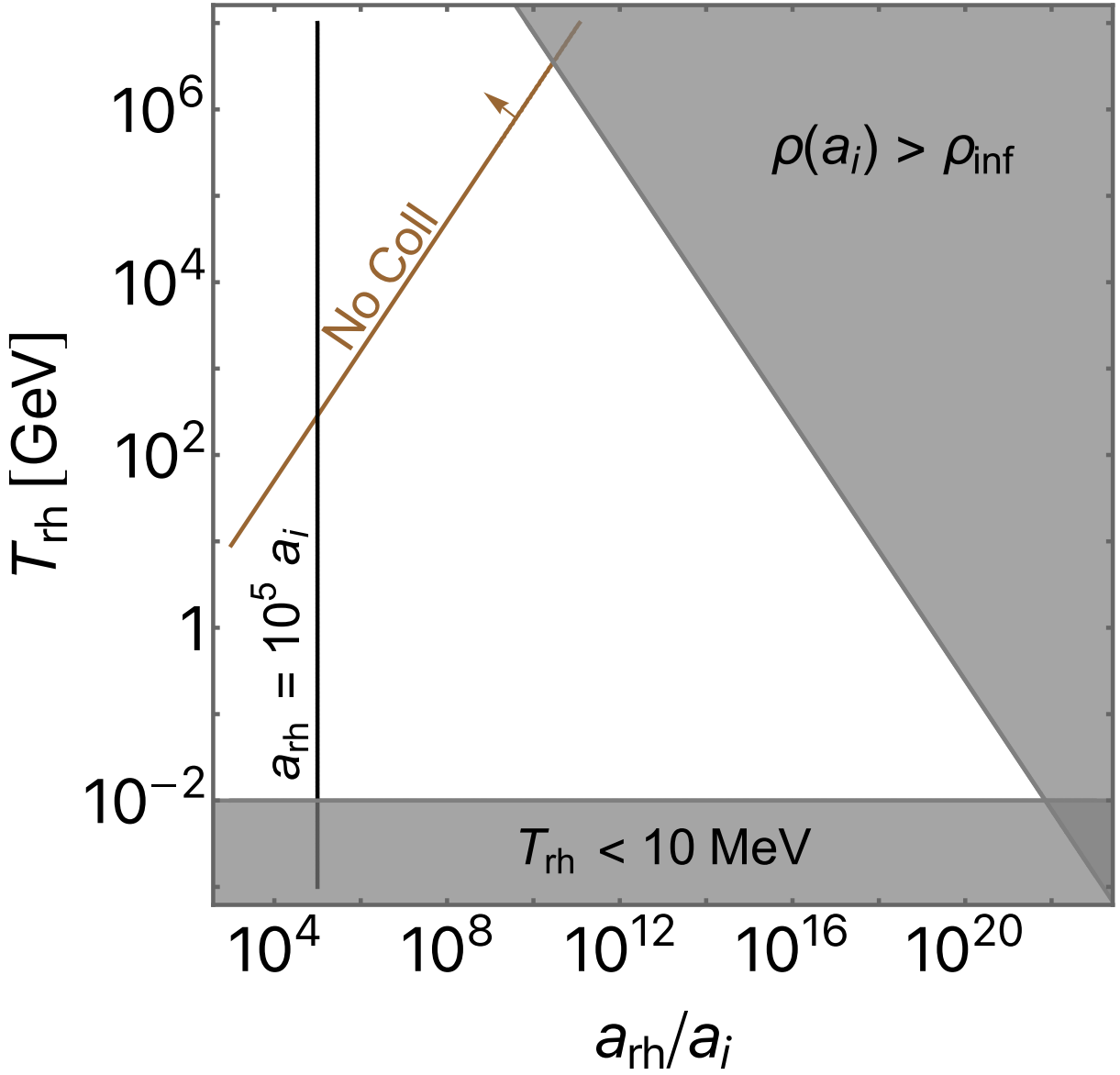
Max accretion

$\lambda = 0.1, T_{rh} = 10\ Mev,$
$\frac{a_{rh}}{a_i} = 10^{16}$

PARAMETER SPACE: CONSTRAINTS ON EMDE

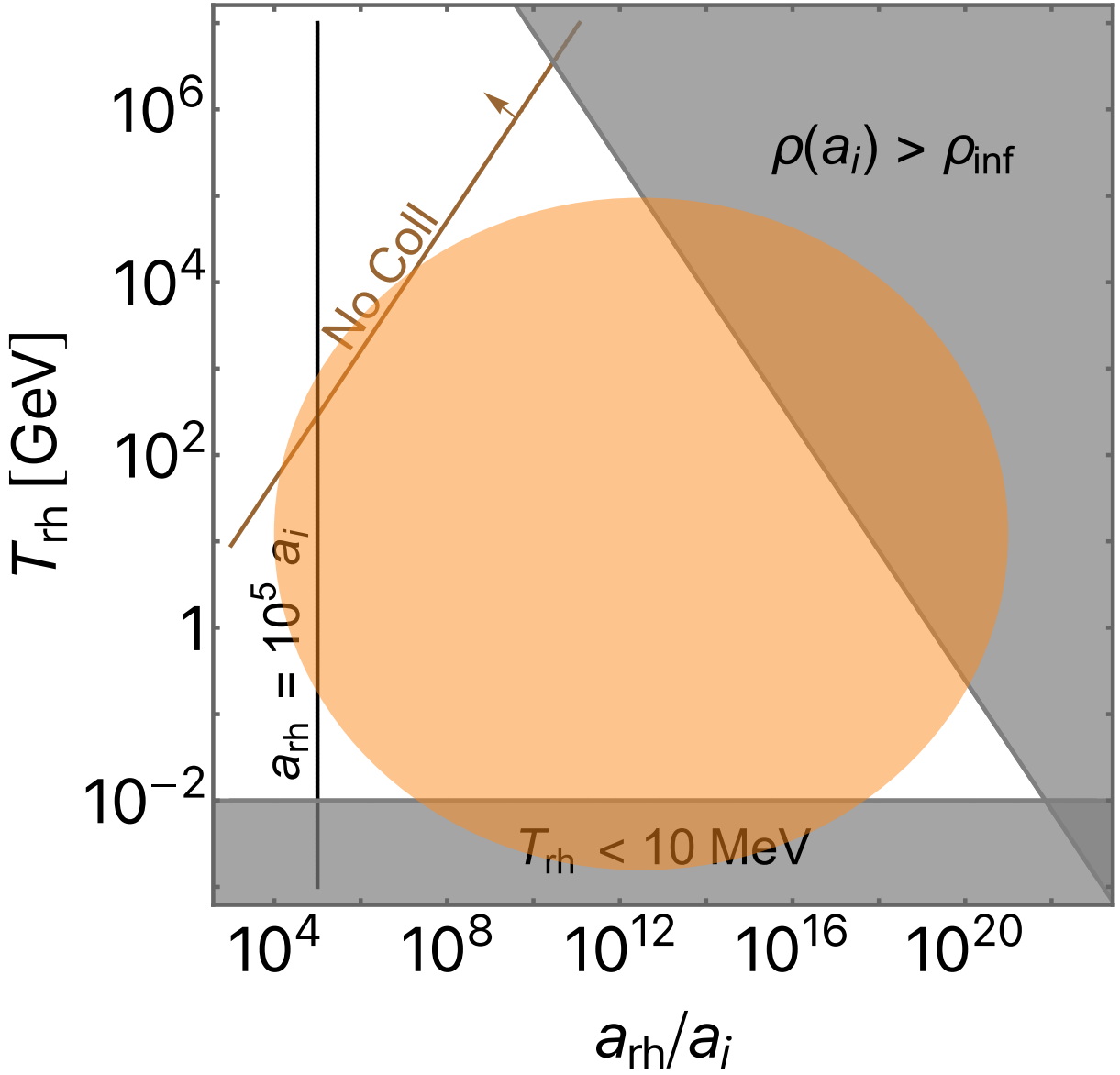


PARAMETER SPACE: LONG ENOUGH EMDE FOR GRAVOTHERMAL COLLAPSE



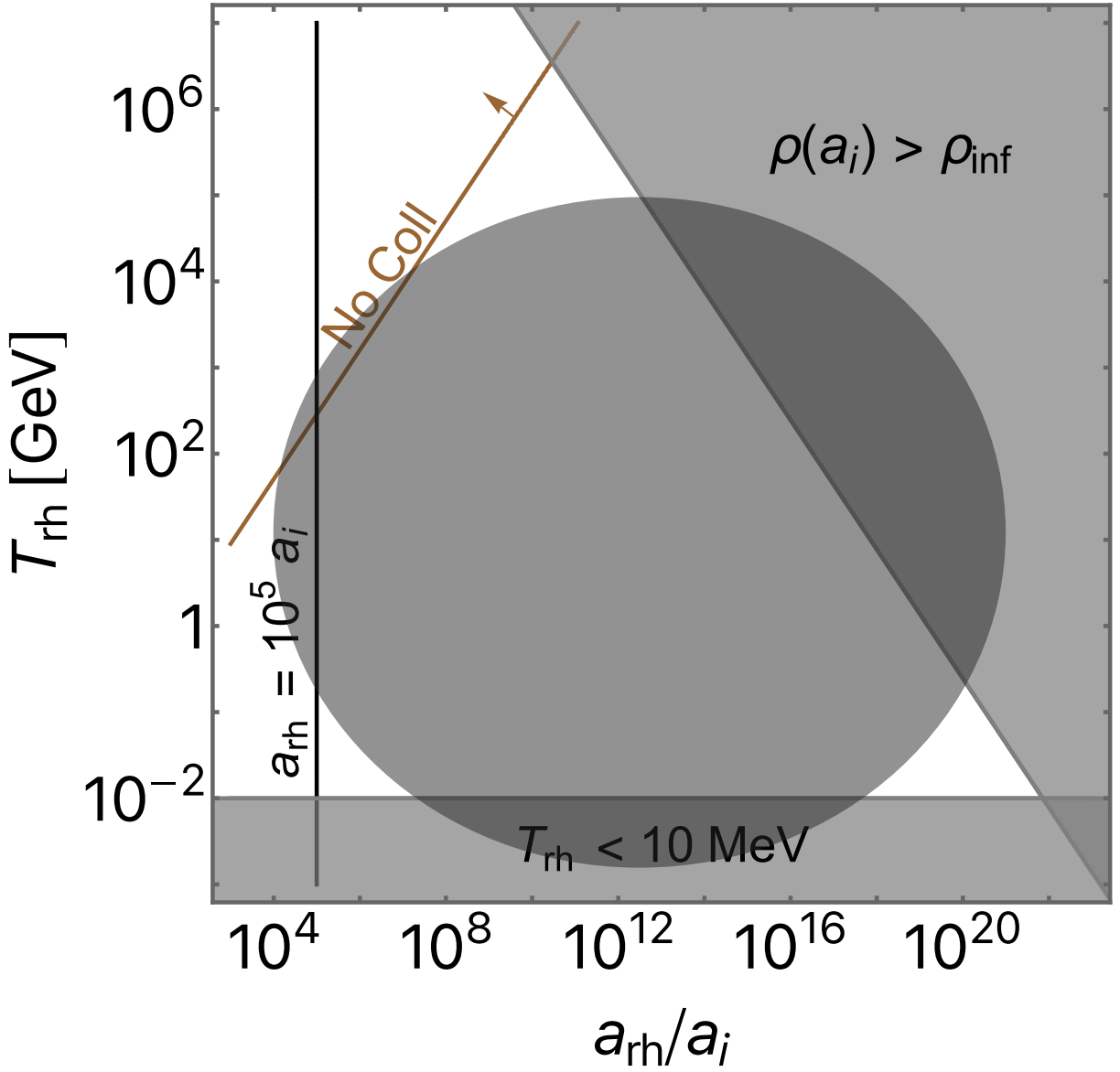
$\lambda = 0.1$

PARAMETER SPACE: REST SPACE ACCRETION DEPENDENT



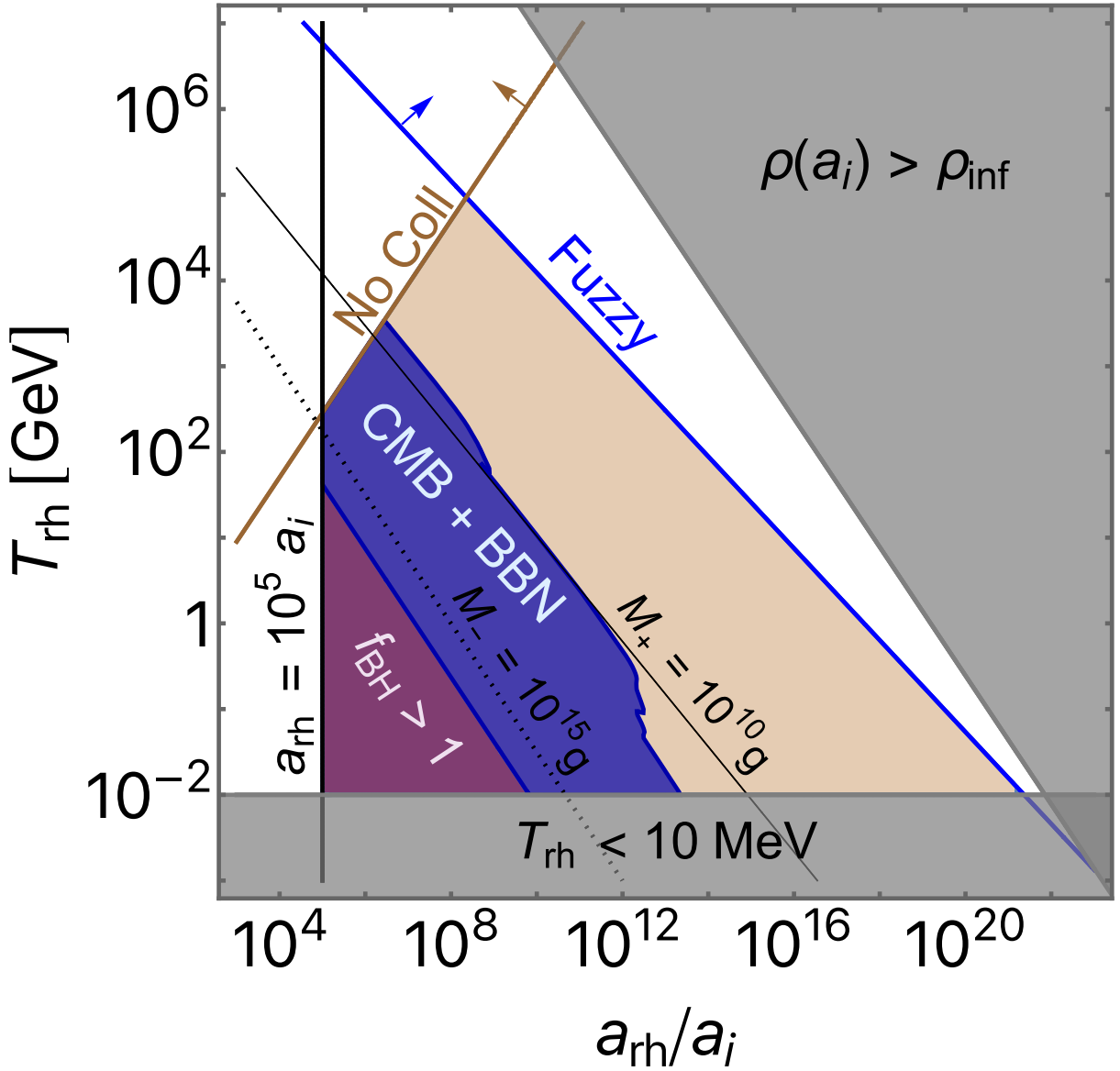
$\lambda = 0.1$

PARAMETER SPACE W/O ACCRETION: NO PBH FOR MINIMAL MODEL



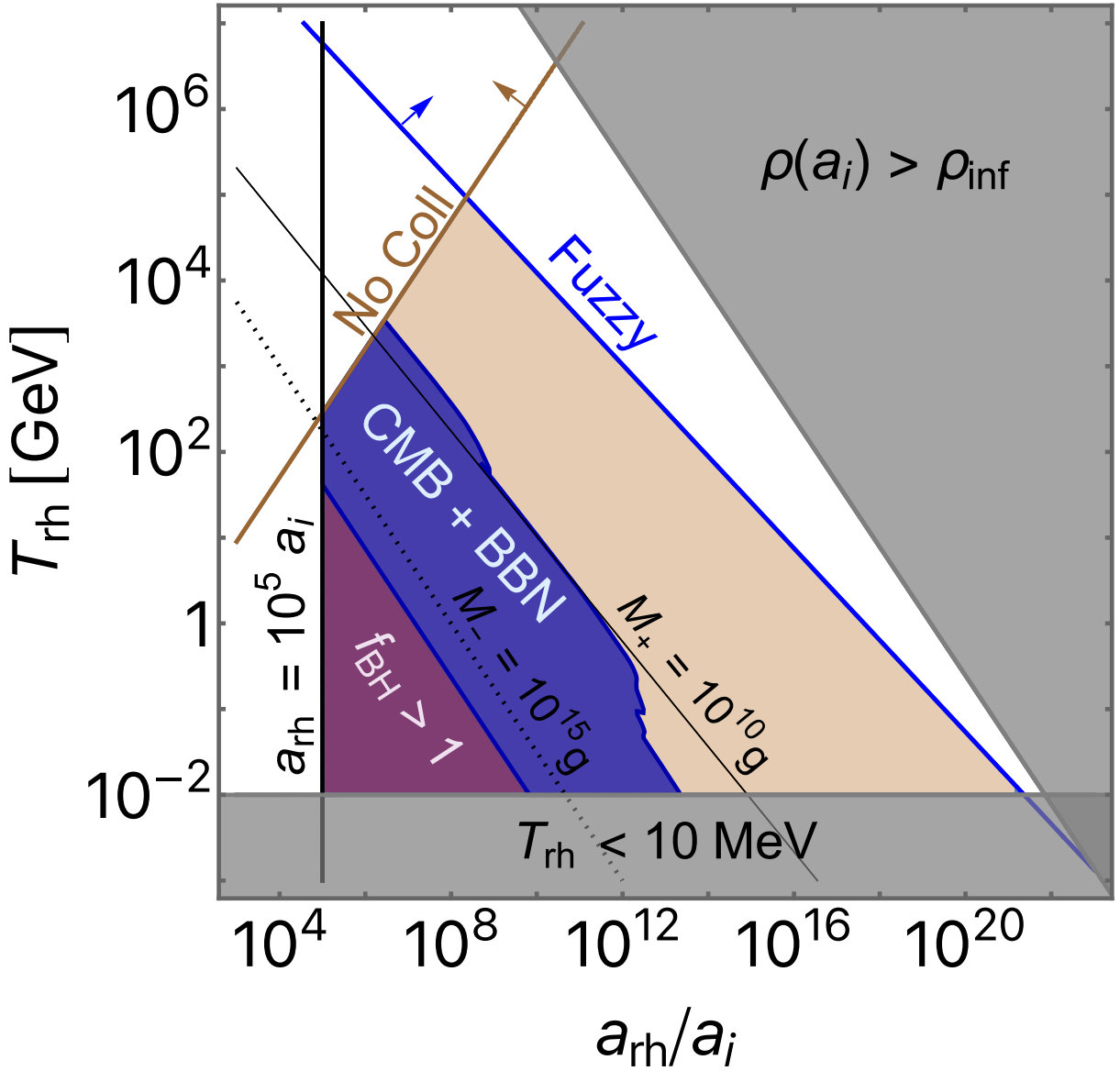
$\lambda = 0.1$

PARAMETER SPACE W/O ACCRETION W/O CANNIBALISM:



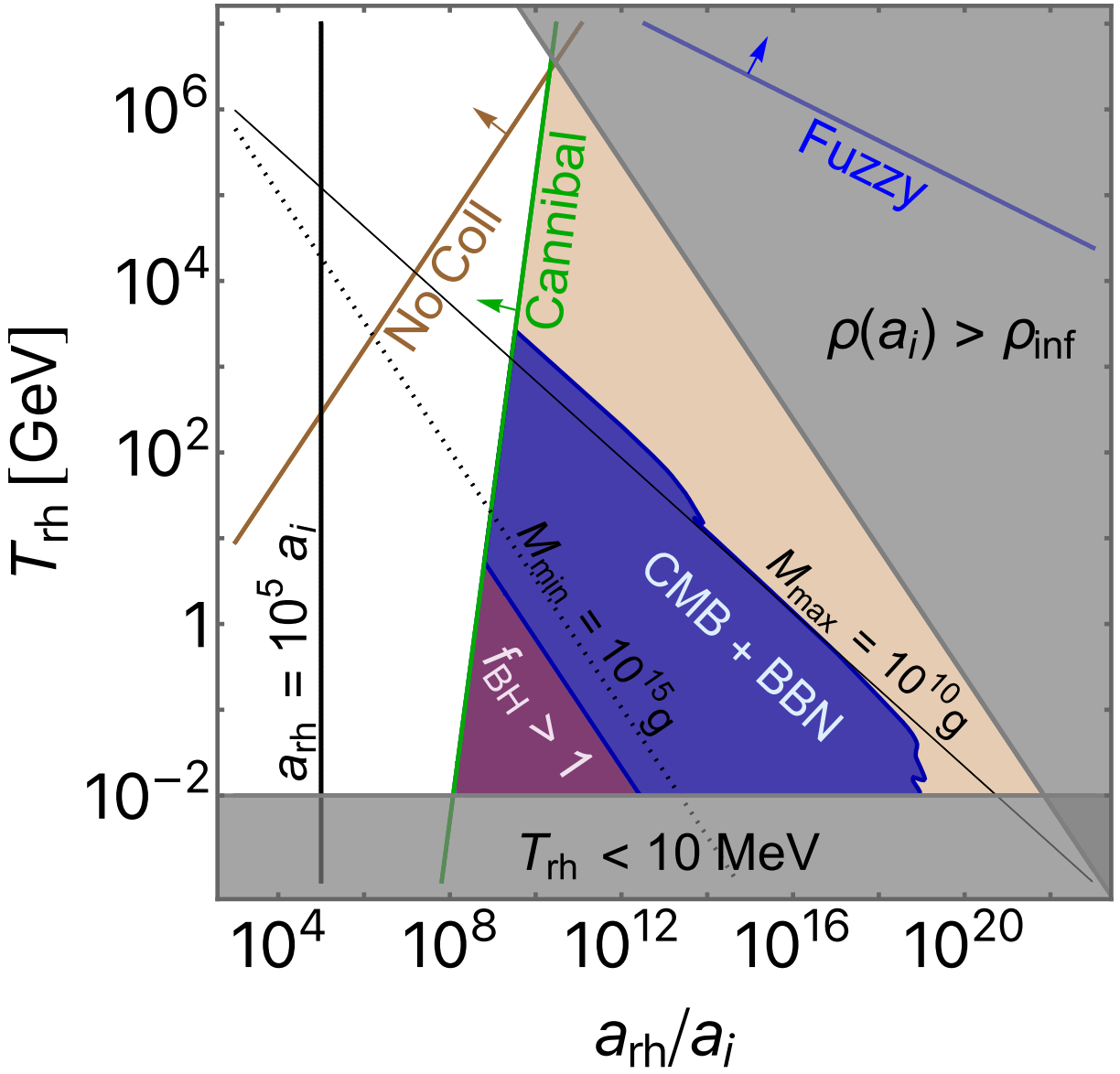
$\lambda = 0.1$

PARAMETER SPACE W/O ACCRETION W/O CANNIBALISM: PBH TODAY OVERDOMINATE



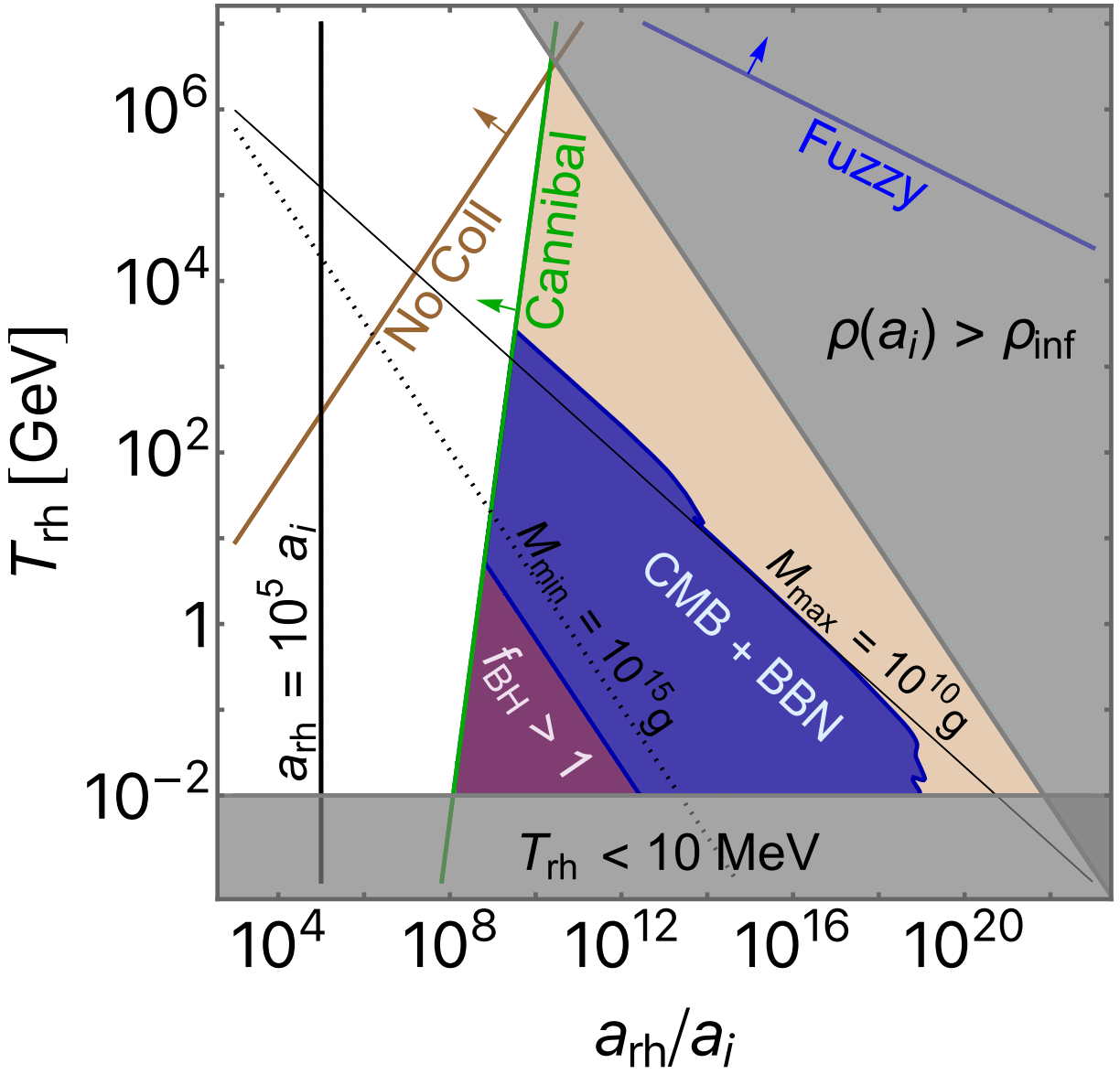
$\lambda = 0.1$

PARAMETER SPACE WITH MAX ACCRETION: PBHS EVEN FOR MINIMAL MODEL



$\lambda = 0.1$

PARAMETER SPACE WITH MAX ACCRETION: QUALITATIVELY SAME CONSTRAINTS



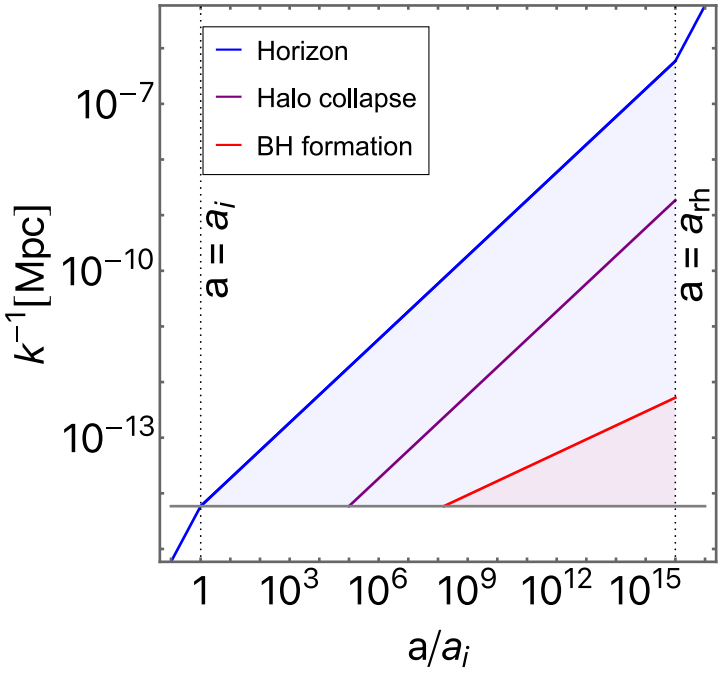
$\lambda = 0.1$

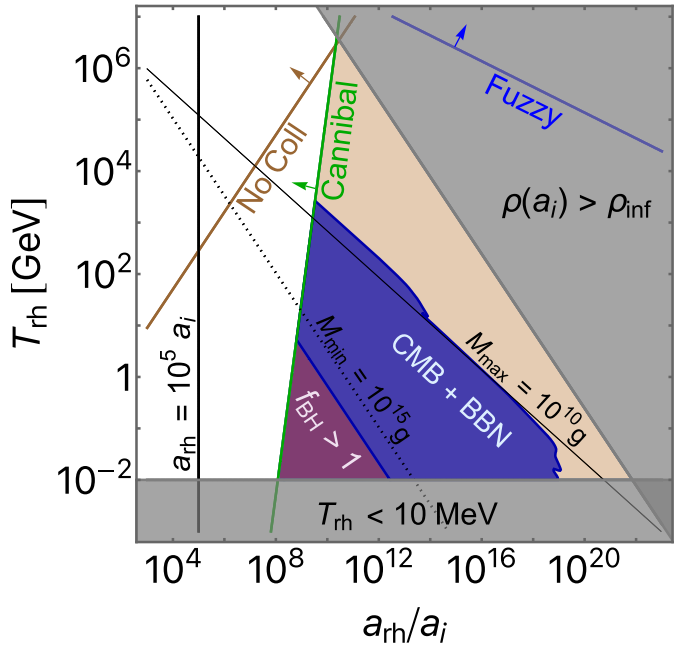
SUMMARY

- Gravothermal Collapse natural during EMDE
- END products: PBHs / cannibal stars / fuzzy core (?)
- No accretion: cannibalism prohibits PBH formation
- Max accretion: PBHs readily formed
- In all cases: fine-tuned region with $f_{BH} \leq 1$

FUTURE OUTLOOK

- PBH: new way to constrain EMDEs
- PBH domination prior to BBN exciting possibilty

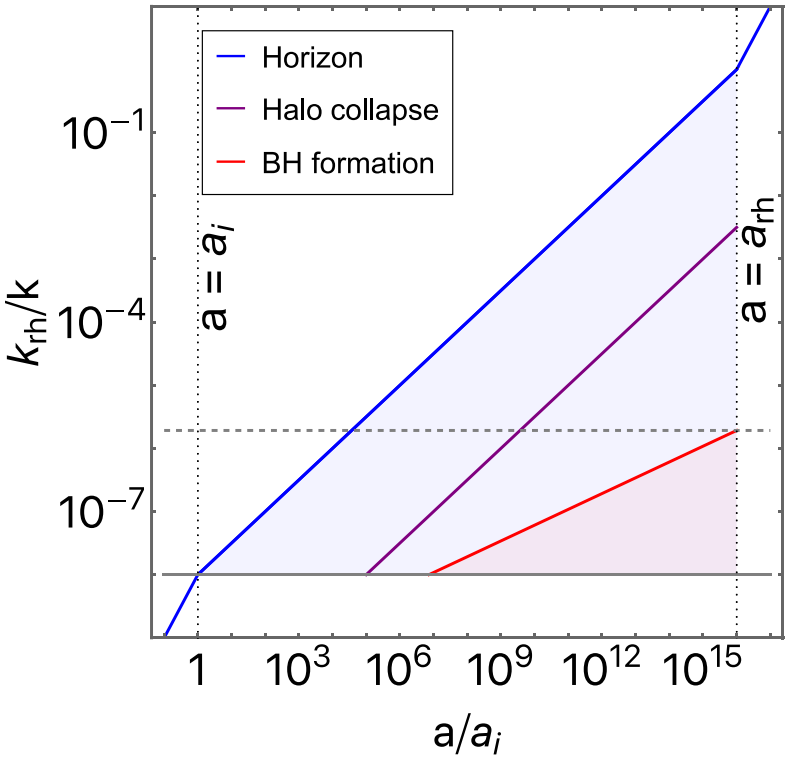




BACKUP SLIDES

UNKNOWNS: ABUNDANCE

- Assume BHs only formed in rare halos that remain isolated until gravothermal collapse



Fraction of matter energy density in halos at BH formation

$$\rho_{BH}(k) \sim \frac{M_{BH}(k)}{M_{halo}(k)} \frac{a_{BH}(k)}{a_{coll}(k)} \rho_\phi$$

Fraction of halo mass going into BHs