Anthropic likelihood for Λ and Q using the History of Milky Way and Local Group

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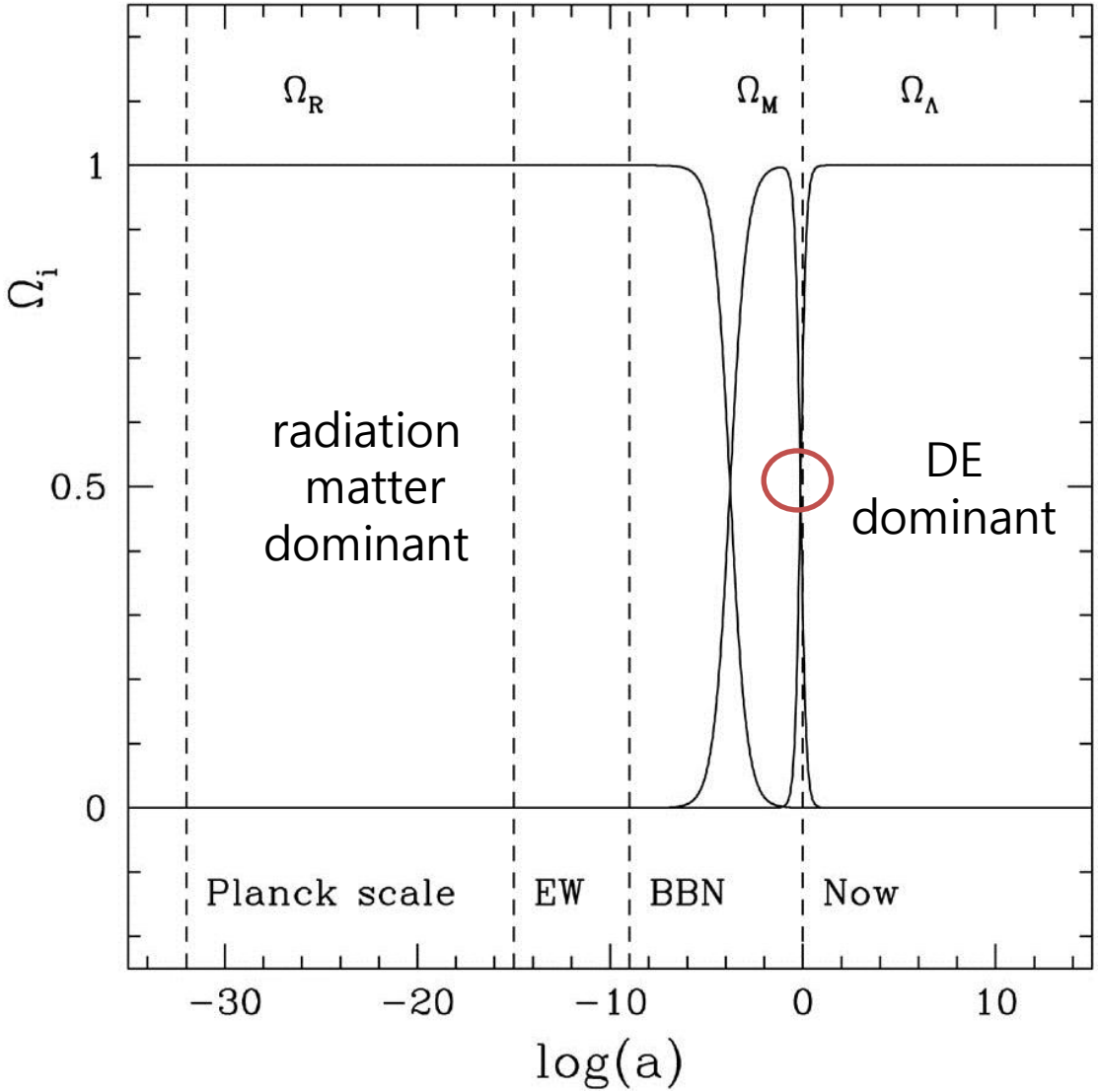
SEH, Ewan D. Stewart (KAIST) and Heeseung Zoe (Ankara), in preparation

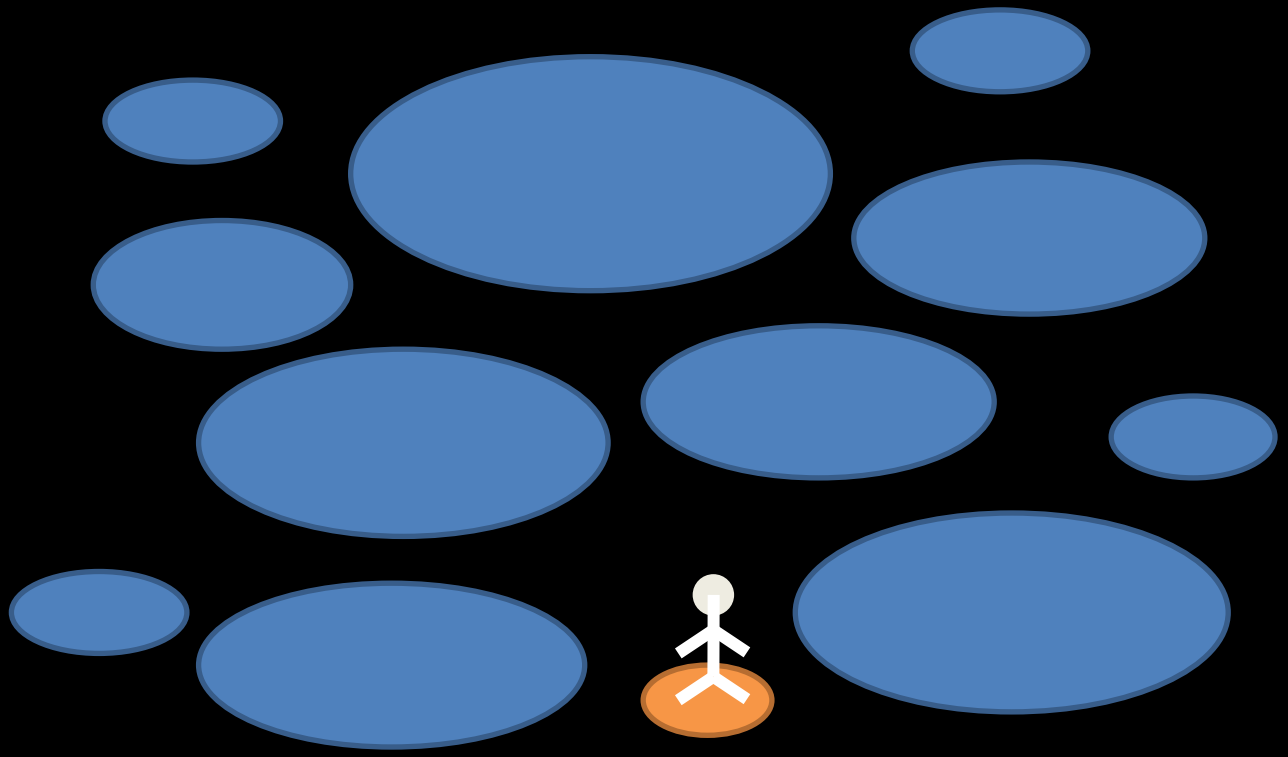
Hierarchy Problem

- Theory: $\Lambda \sim M_{Pl}^4$
- Observation: $\Lambda \sim 10^{-120} M_{Pl}^4$

Coincidence Problem



Anthropic Selection



- $\Lambda \leq 1000\ \Lambda_0$ for structure formation

  Weinberg, PRL **59**, 2607 (1987)

Probability with the existence of Observers

$$P(\mathrm{O}|obs) = P_\phi(\mathrm{O})\, W_c(\mathrm{O}, t_{obs})\, L_c(\mathrm{O}|obs)$$

Primordial
- Fundamental theory
- Multiverse ambiguity at primordial stage

Time-dependent
- Multiverse ambiguity up to $t = t_{obs}$

Anthropic likelihood
- Number of observers in comoving volume
- Purely astrophysical

Case I: cosmological constant

$$P(\Lambda|obs) = P_\phi(\Lambda)\, W_c(\Lambda, t_{obs})\, L_c(\Lambda|obs)$$

constant

depends on multiverse measure

Anthropic likelihood

- Number of observers in comoving volume
- Purely astrophysical

$P_c(\Lambda)$ and Multiverse Measure

- Pocket based measure

  Garriga, Tanaka & Vilenkin, PRD **60**, 023501 (1999)

  – the number of observers within comoving volume

- Scale factor cutoff measure

  De Simone, Guth, Salem & Vilenkin, PRD **78**, 063520 (2008)

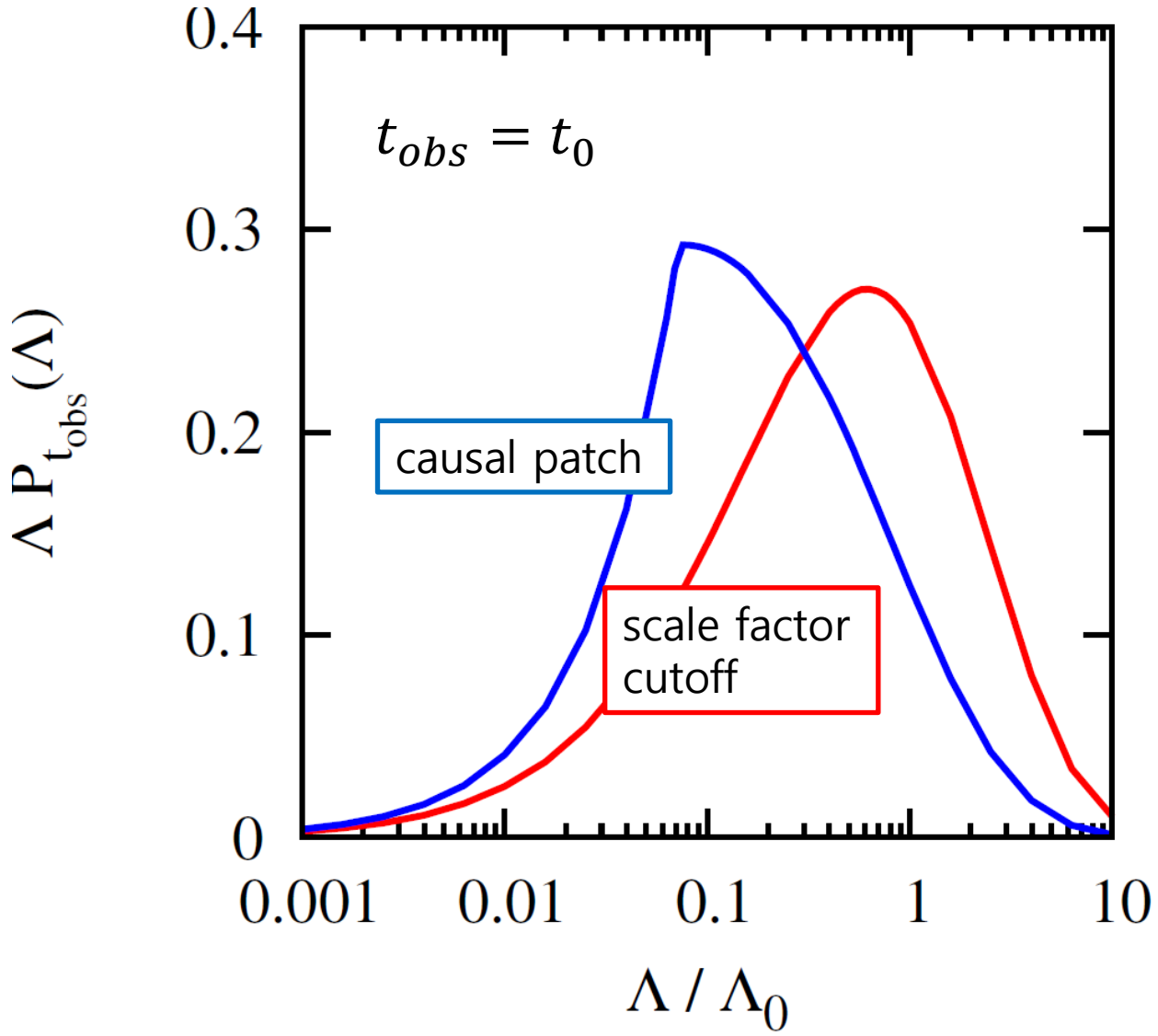
  – the number of observers within physical volume

- Causal patch measure

  Bousso, PRL **97**, 191302 (2006)

  – the number of observers within Hubble volume

$P_c(\Lambda)$ and Multiverse Measure



Typicality

Page, hep-th/0610101

- pocket based: 0%
- scale factor cutoff: 55%
- causal patch: 14%

Case II:
primordial density perturbation amplitude

$$P(\mathrm{Q}|obs) = P_\phi(\mathrm{Q})\, W_c(\mathrm{Q}, t_{obs})\, L_c(\mathrm{Q}|obs)$$

- Flat in linear scale
- Flat in log scale

constant

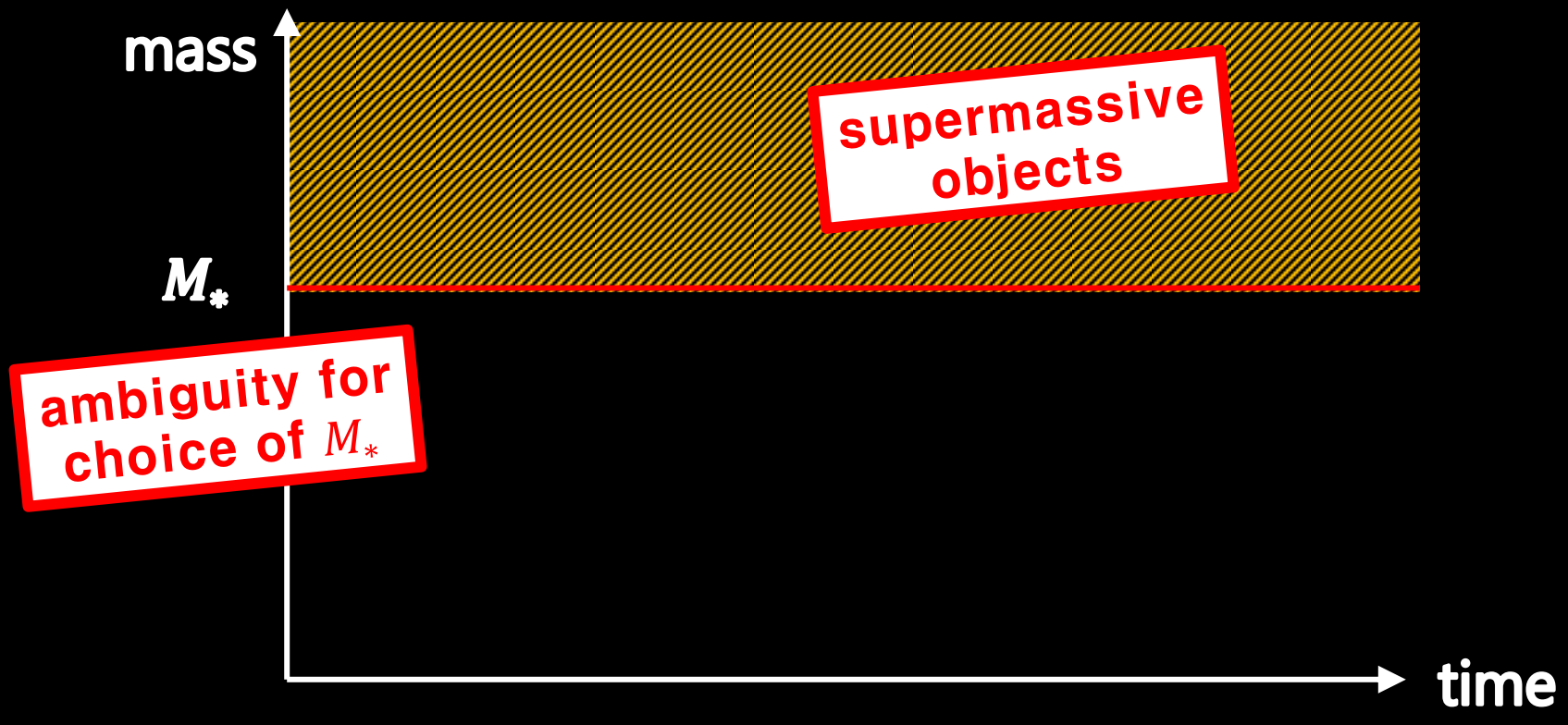
Anthropic likelihood

- Number of observers in comoving volume
- Purely astrophysical

Anthropic Models using Single Mass Constraint

- $M \geq M_*$ at $t \to \infty$

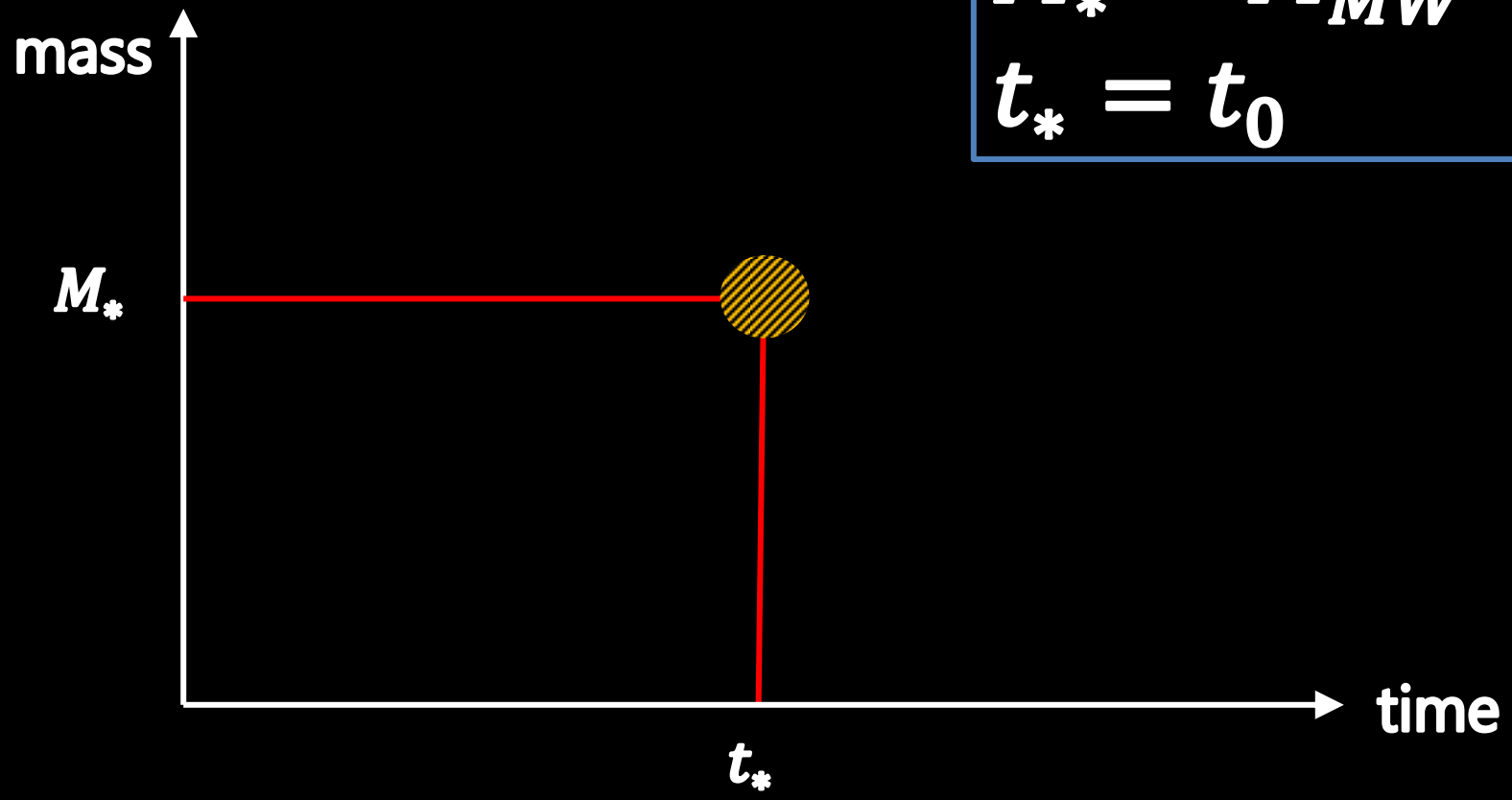
  Martel, Shapiro & Weinberg, ApJ **492**, 29 (1998),
  Pogosian & Vilenkin, JCAP **0701**, 025 (2007)



Anthropic Models using Single Mass Constraint

- $M = M_*$ at $t = t_*$

$$M_* = M_{MW}$$
$$t_* = t_0$$



Anthropic Models using Single Mass Constraint

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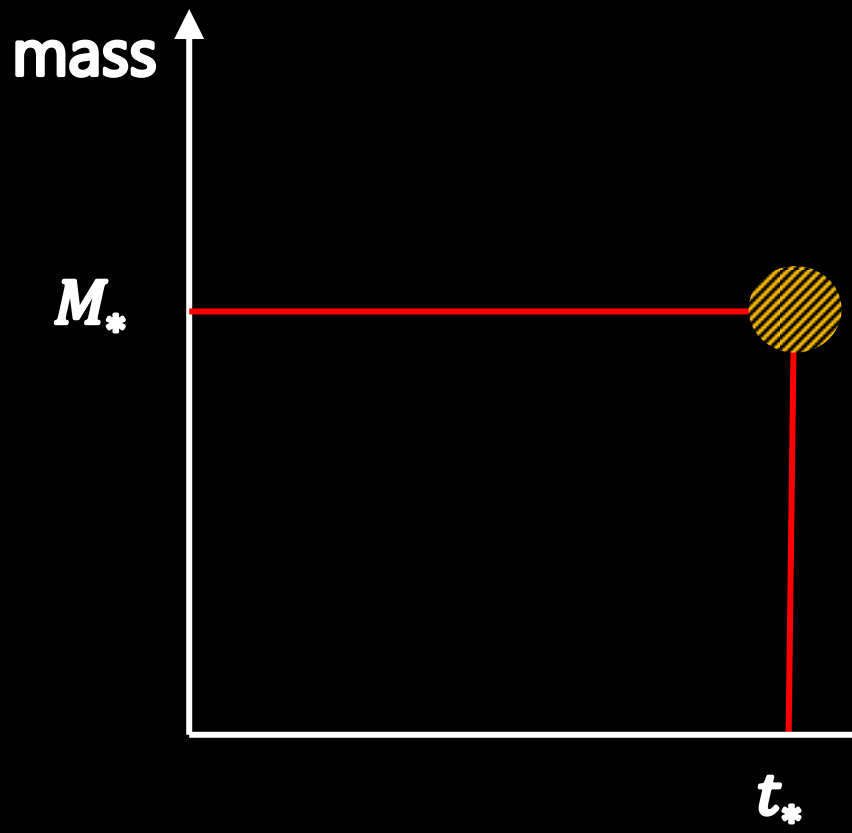
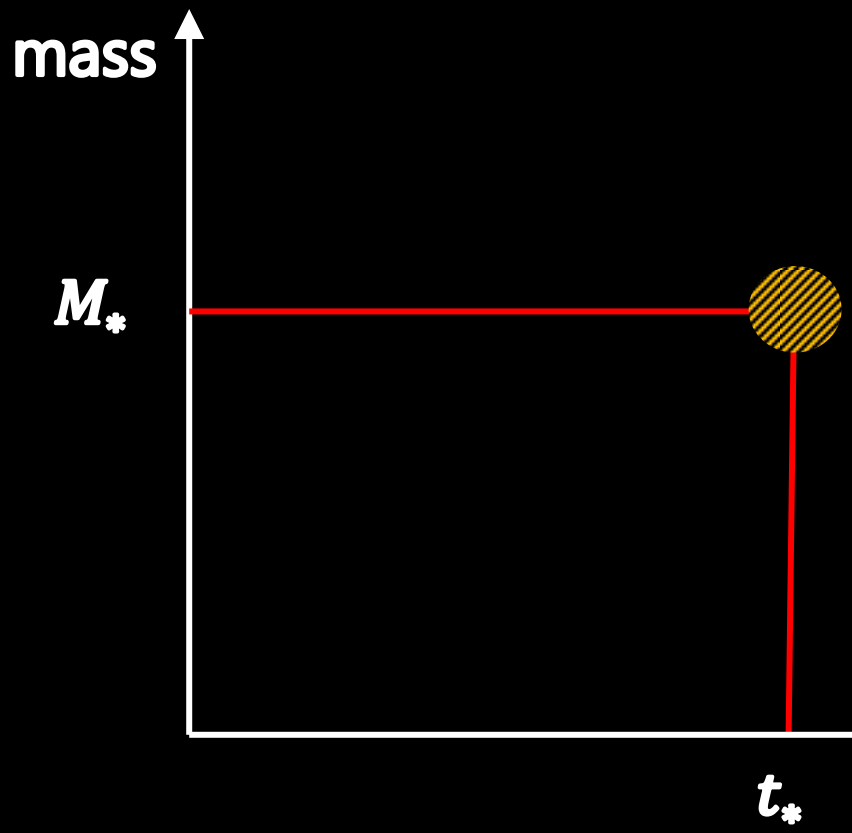


~~$M_* = MW$~~
~~$t = t_0$~~

Press-Schecter formalism identifies us as Local Group at $t = t_0$

Anthropic Models using Single Mass Constraint

- $M = M_*$ at $t = t_*$



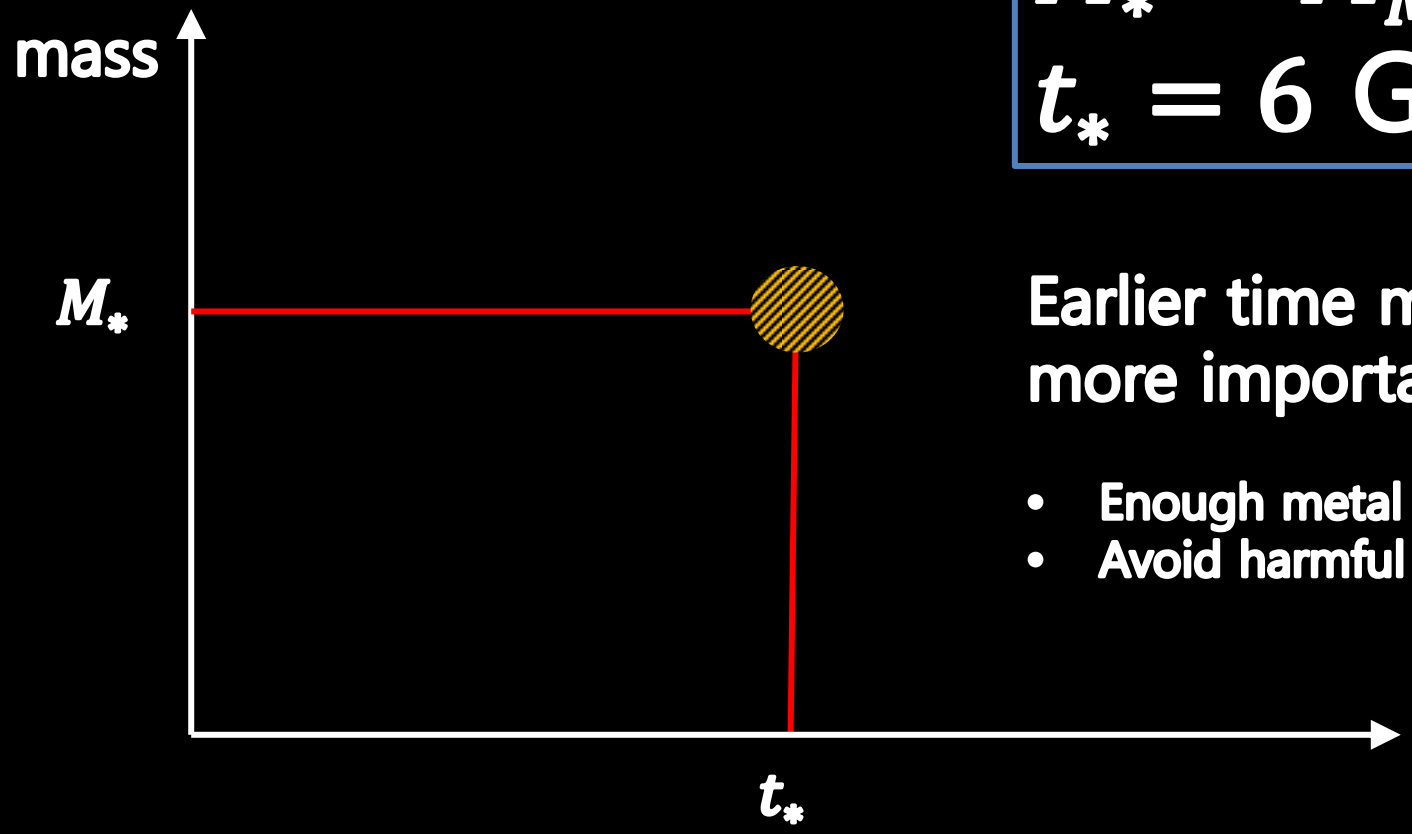
~~$M_* = M_{MW}$~~
~~$t_* = t_0$~~

Earlier time may be more important:

- Enough metal
- Avoid harmful interaction

Anthropic Models using Single Mass Constraint

- $M = M_*$ at $t = t_*$

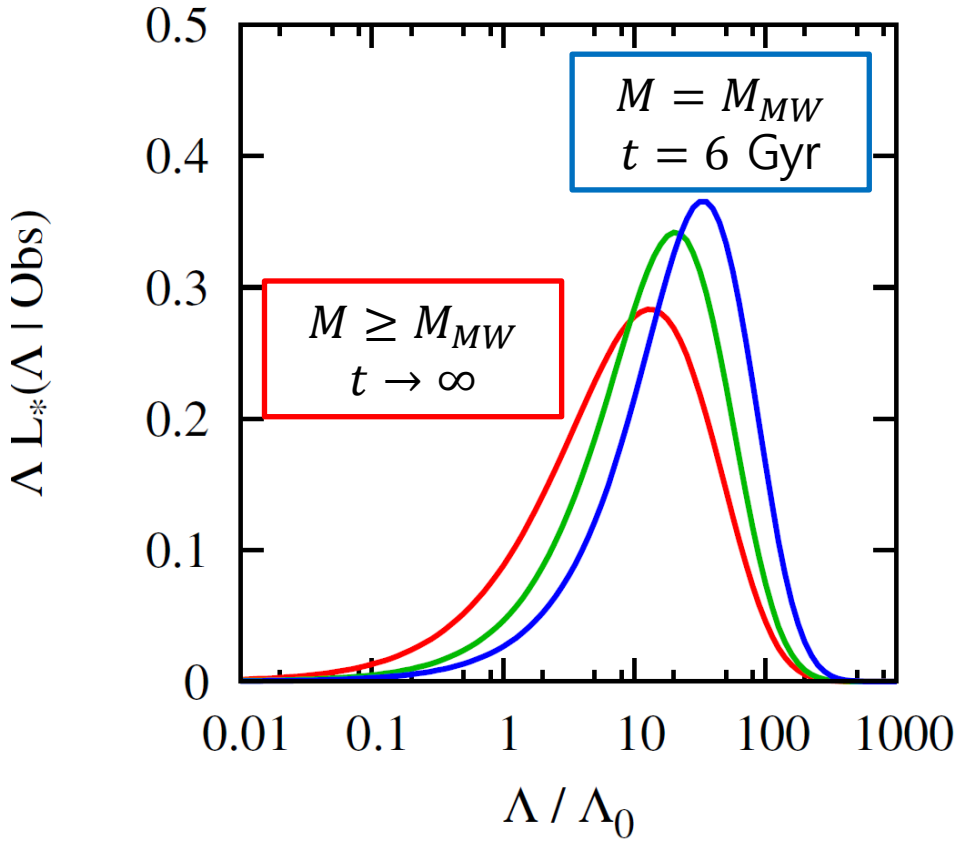


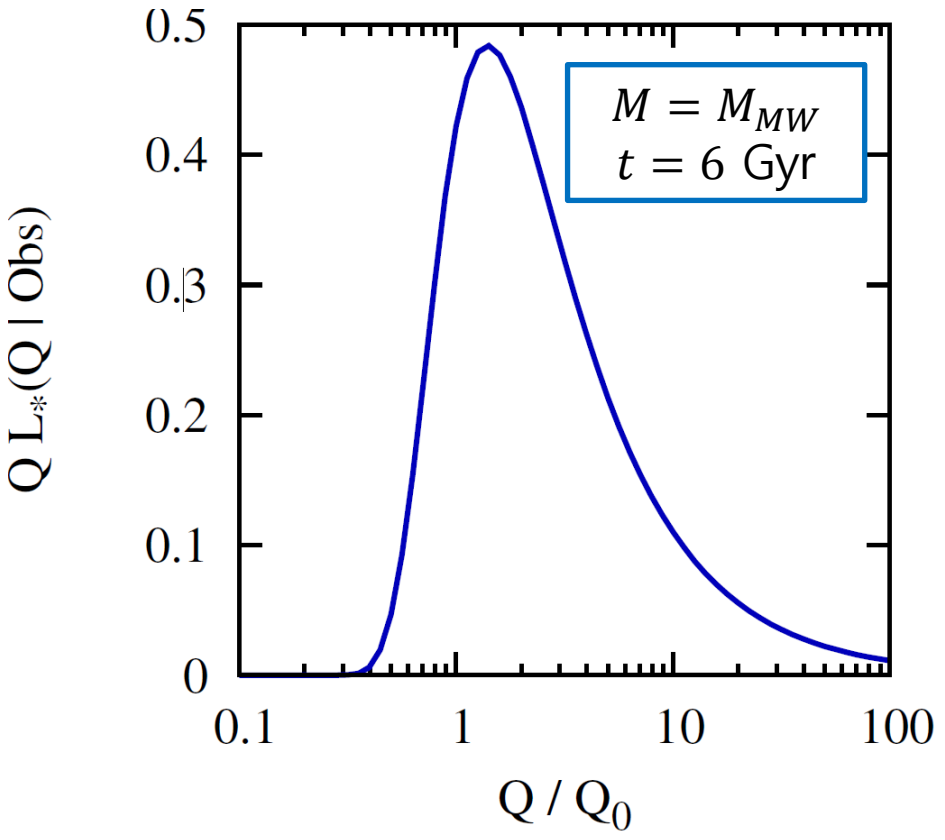
$$M_* = M_{MW}$$
$$t_* = 6 \text{ Gyr}$$

Earlier time may be more important:

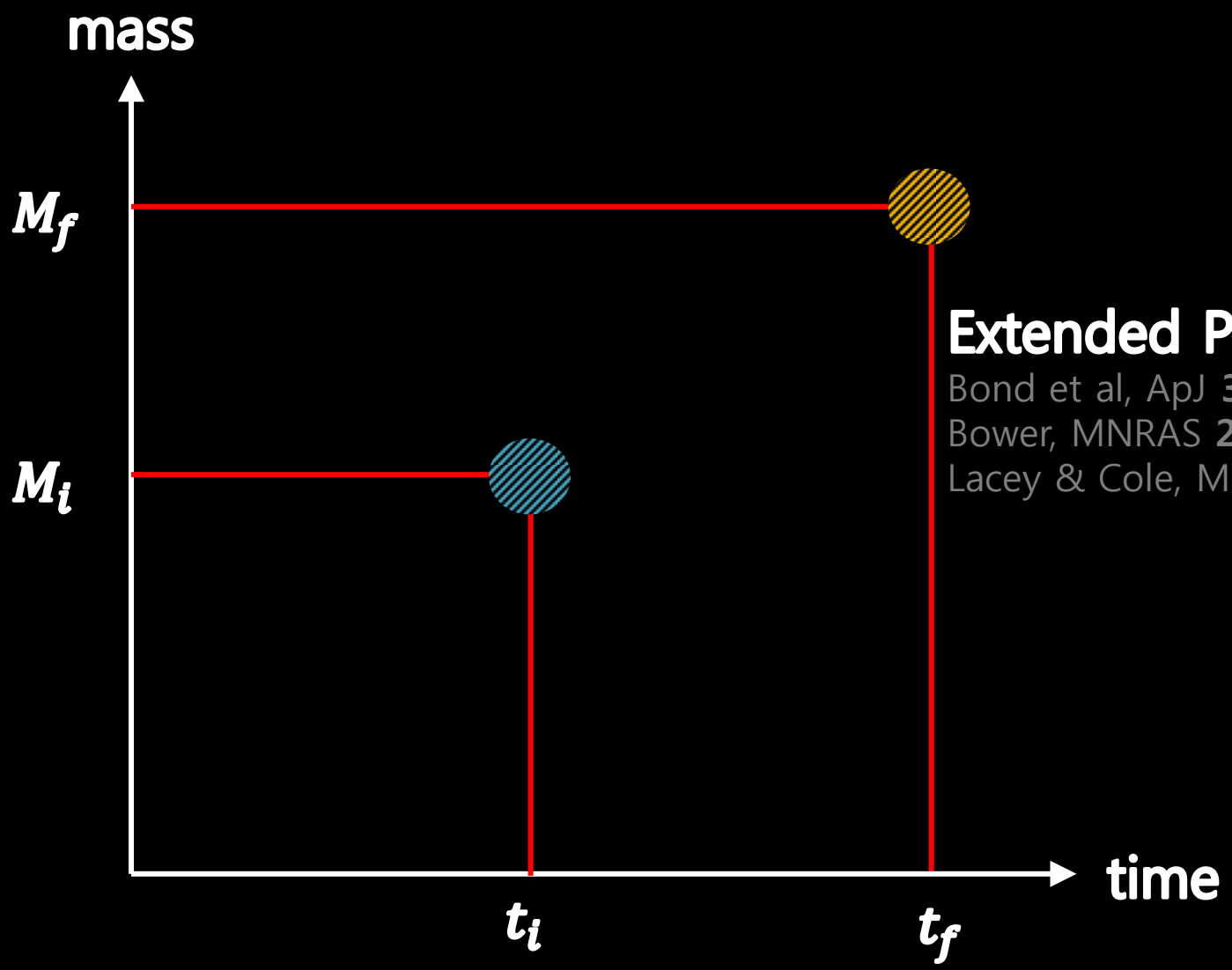
- Enough metal
- Avoid harmful interaction

Anthropic Models using Single Mass Constraint





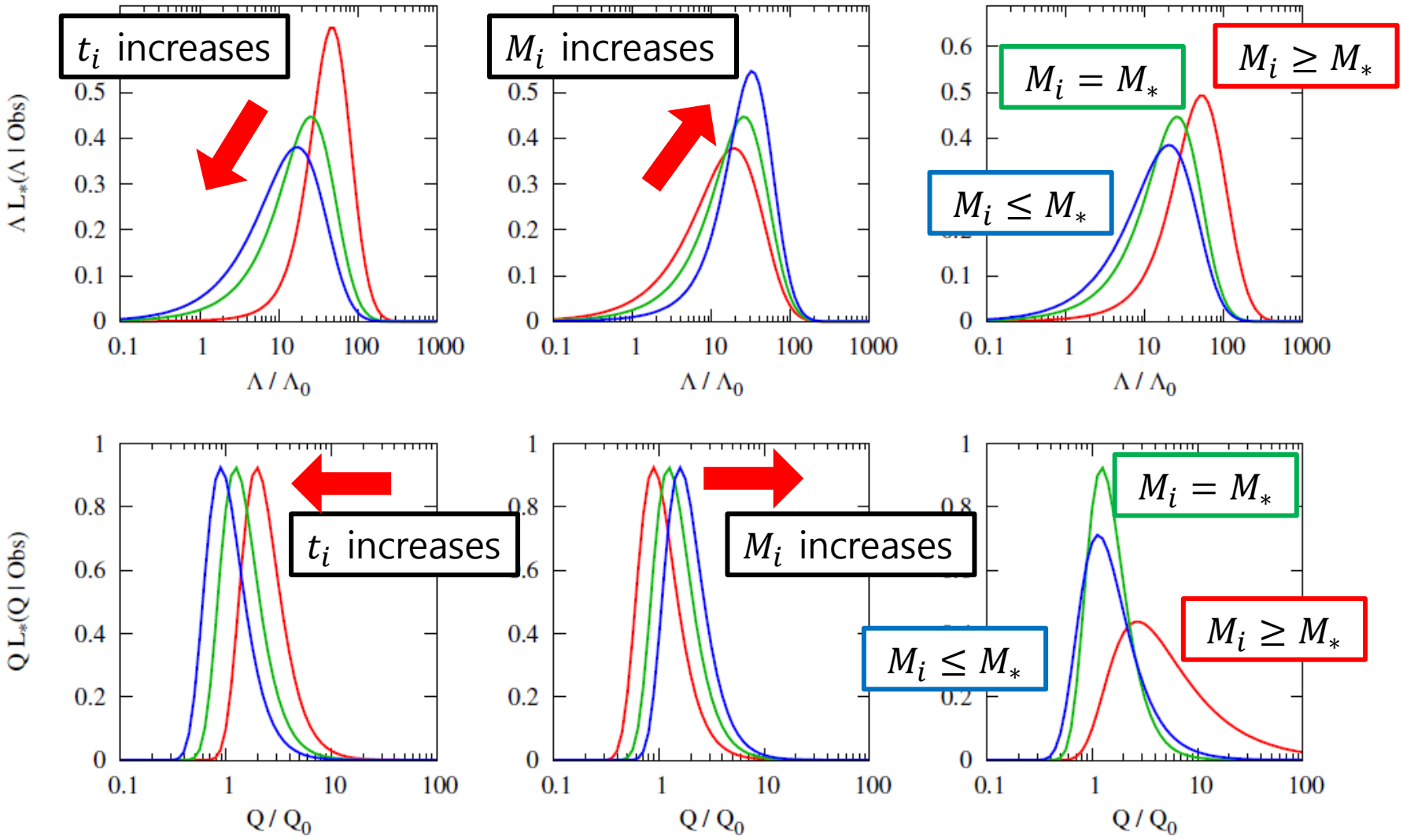
Anthropic Models using Mass History



Extended Press-Schecter

Bond et al, ApJ **379**, 440 (1991)
Bower, MNRAS **248**,332 (1991)
Lacey & Cole, MNRAS **262**, 627 (1993)

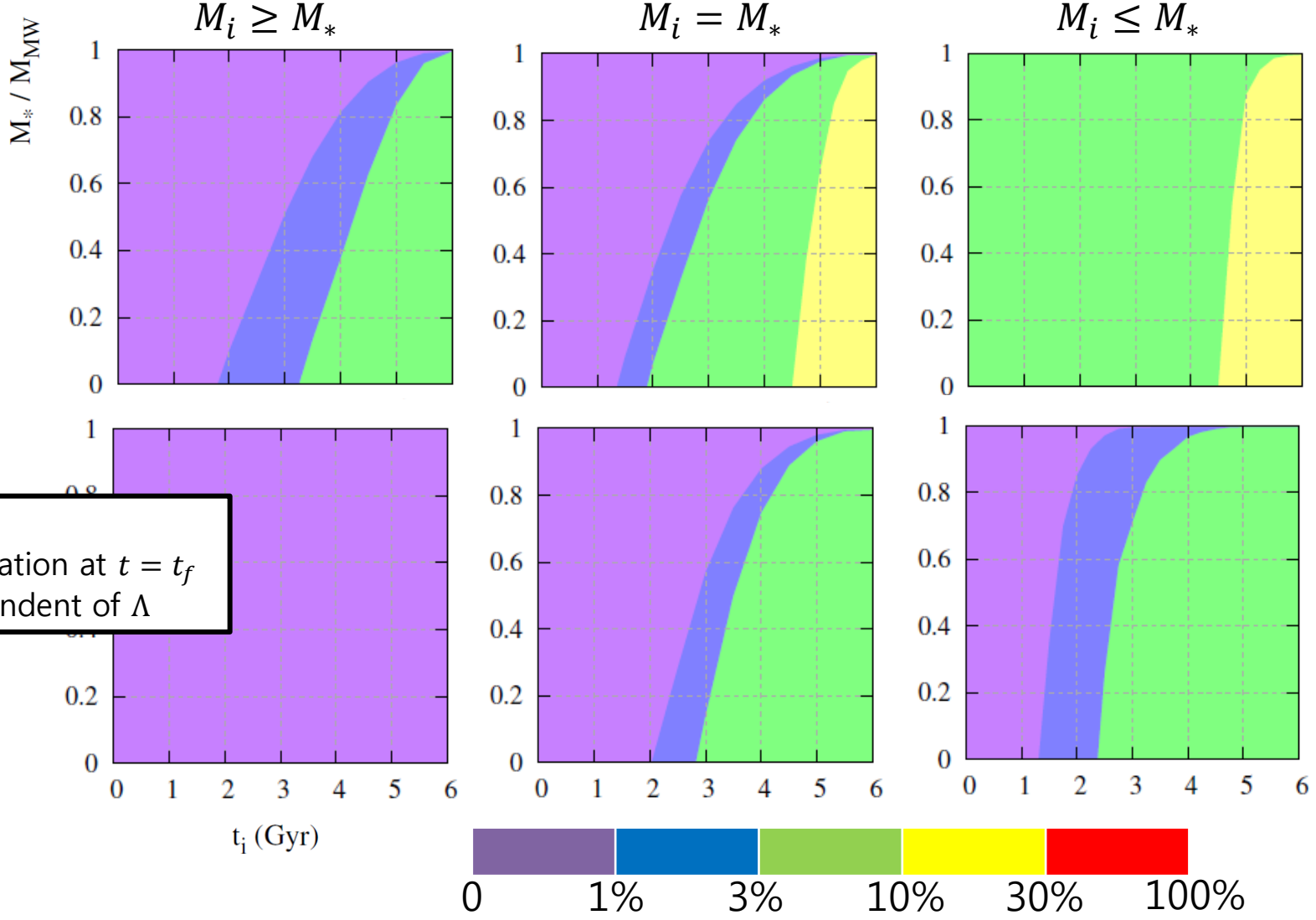
Anthropic Models using Mass History



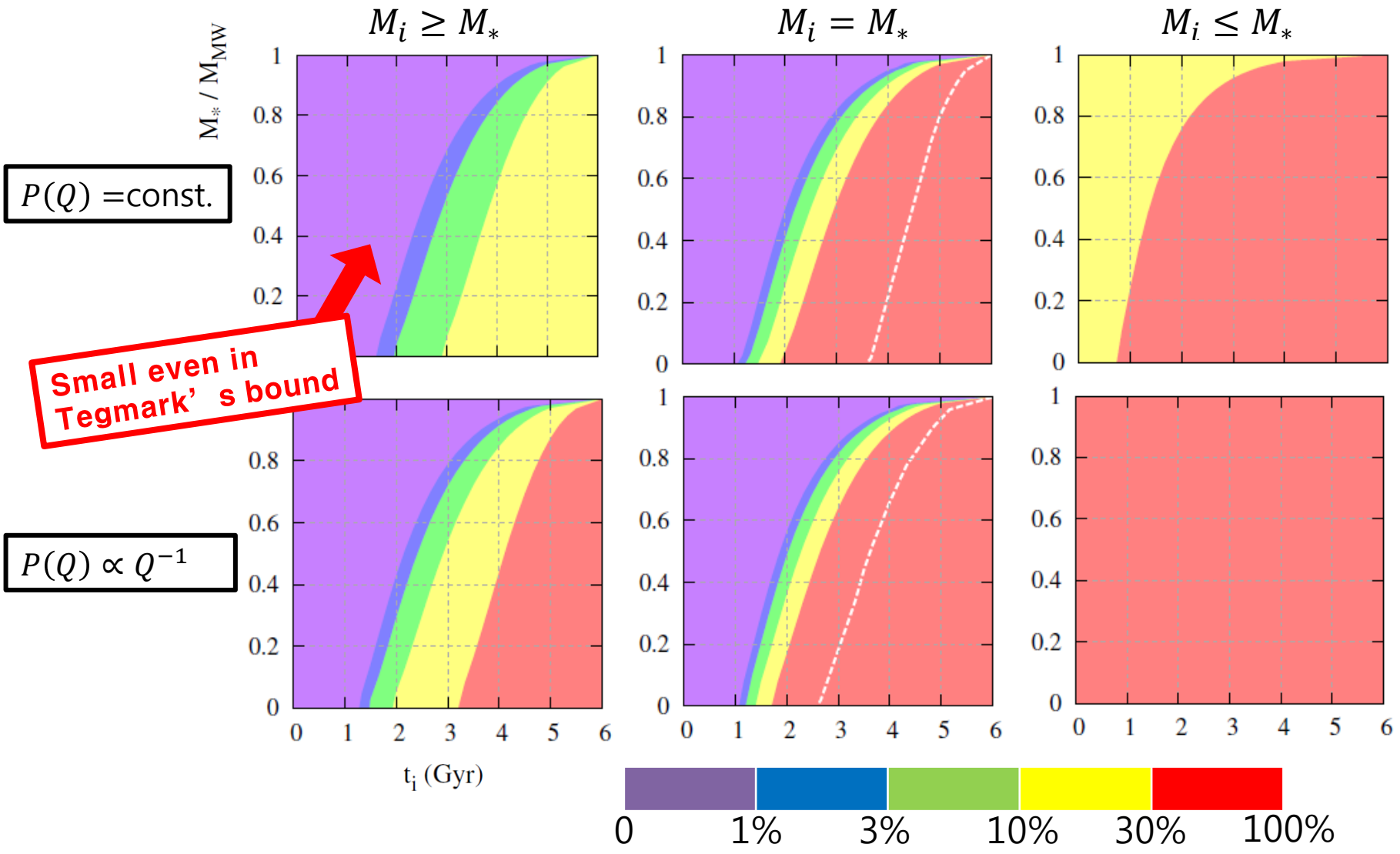
Degeneracy between Λ and Q broken

$Q = Q_0$

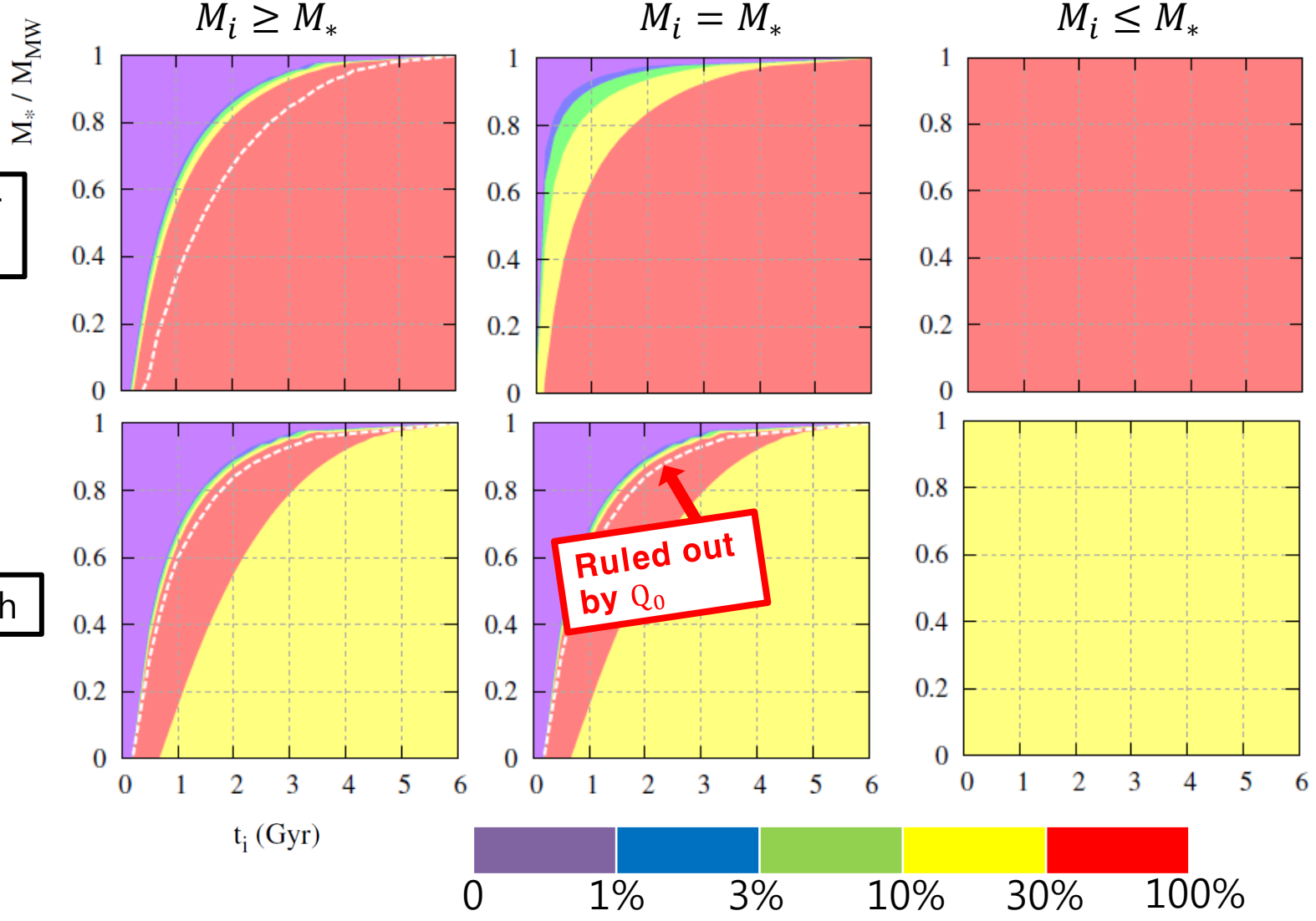
$Q = Q(\Lambda, t_f)$:
galaxy population at $t = t_f$
to be independent of Λ



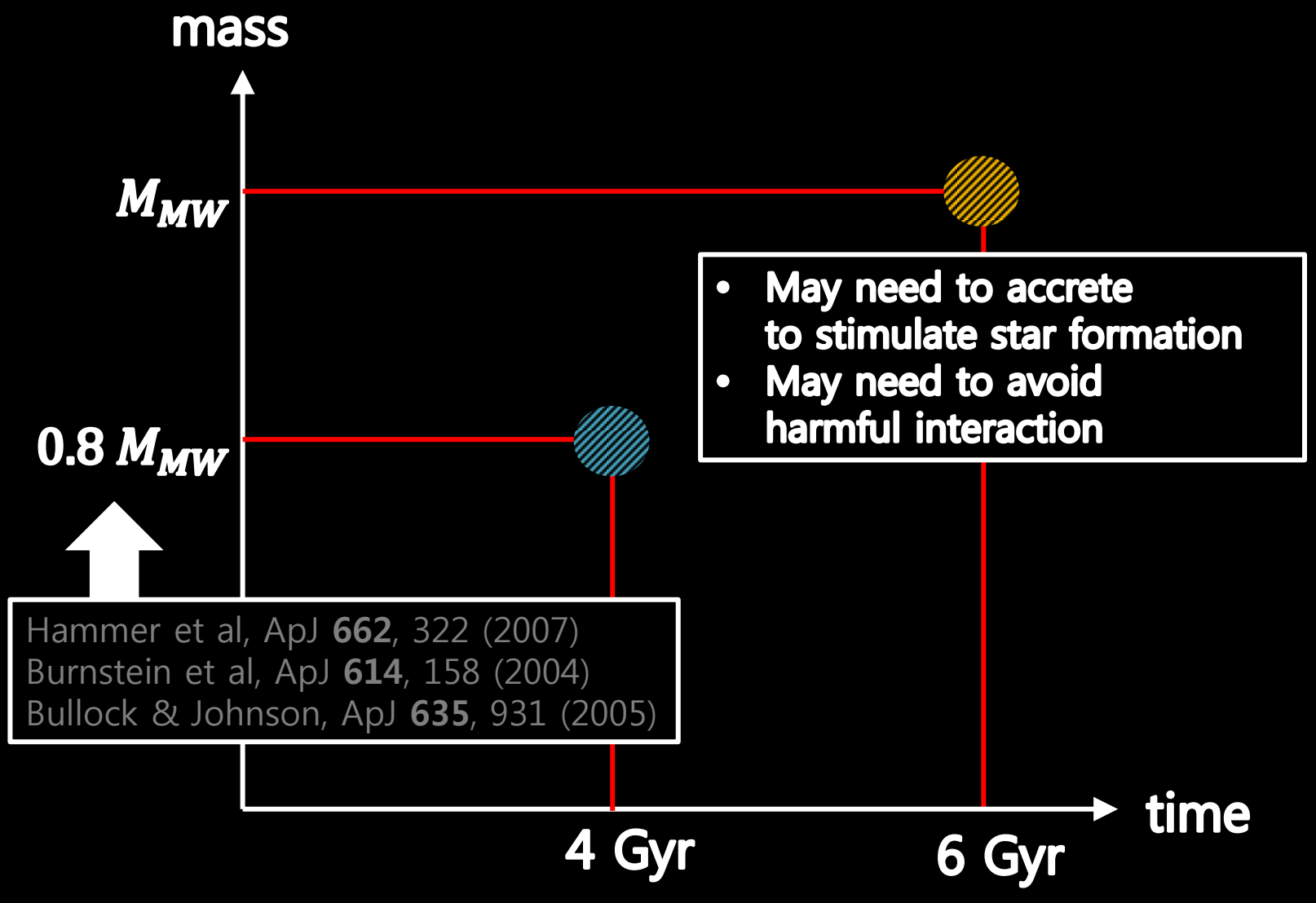
Typicality of Q_0



Typicality of Λ_0 with various Measures



Example of Specific Model



Typicality of Λ_0	pocket based	pocket based $Q = Q(\Lambda, t_f)$	scale factor cutoff	causal patch
-	0	0	55%	14%
$M \geq M_{MW}$ at $t \to \infty$	22%	0	36%	11%
$M = M_{MW}$ at $t = 6$ Gyr	4.9%	0	52%	17%
$M = 0.8M_{MW}$ at $t = 4$ Gyr $M = M_{MW}$ at $t = 6$ Gyr	4.5%	2.3%	55%	25%

degeneracy broken

depends only on $t_{obs} = t_0$?

Typicality of Q_0	$P(Q)$ =const.	$P(Q) \propto Q^{-1}$
-	0	63%
$M \geq M_{MW}$ at $t \to \infty$	0	0
$M = M_{MW}$ at $t = 6$ Gyr	33%	76%
$M = 0.8M_{MW}$ at $t = 4$ Gyr $M = M_{MW}$ at $t = 6$ Gyr	41%	67%

needs Tegmark's bound

THANK YOU!
ありがとうございます!
감사합니다!