PBH from domain wall networks

Motivated by PTA signal

Yann Gouttenoire

Postdoc in Tel Aviv U.

TEL AVIV UNIVERSITY

Axion ++ conference in Annecy

27th September 2023

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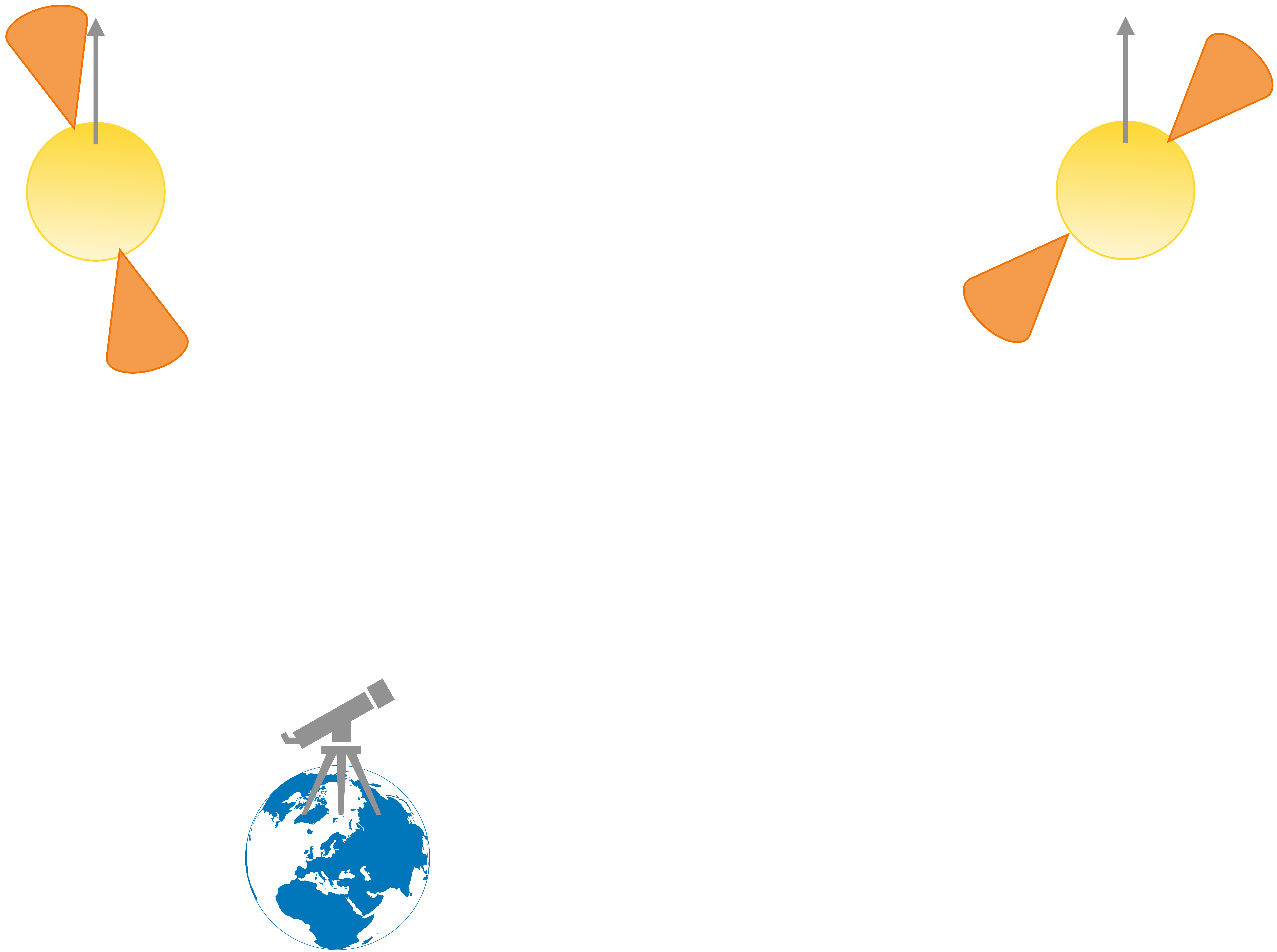
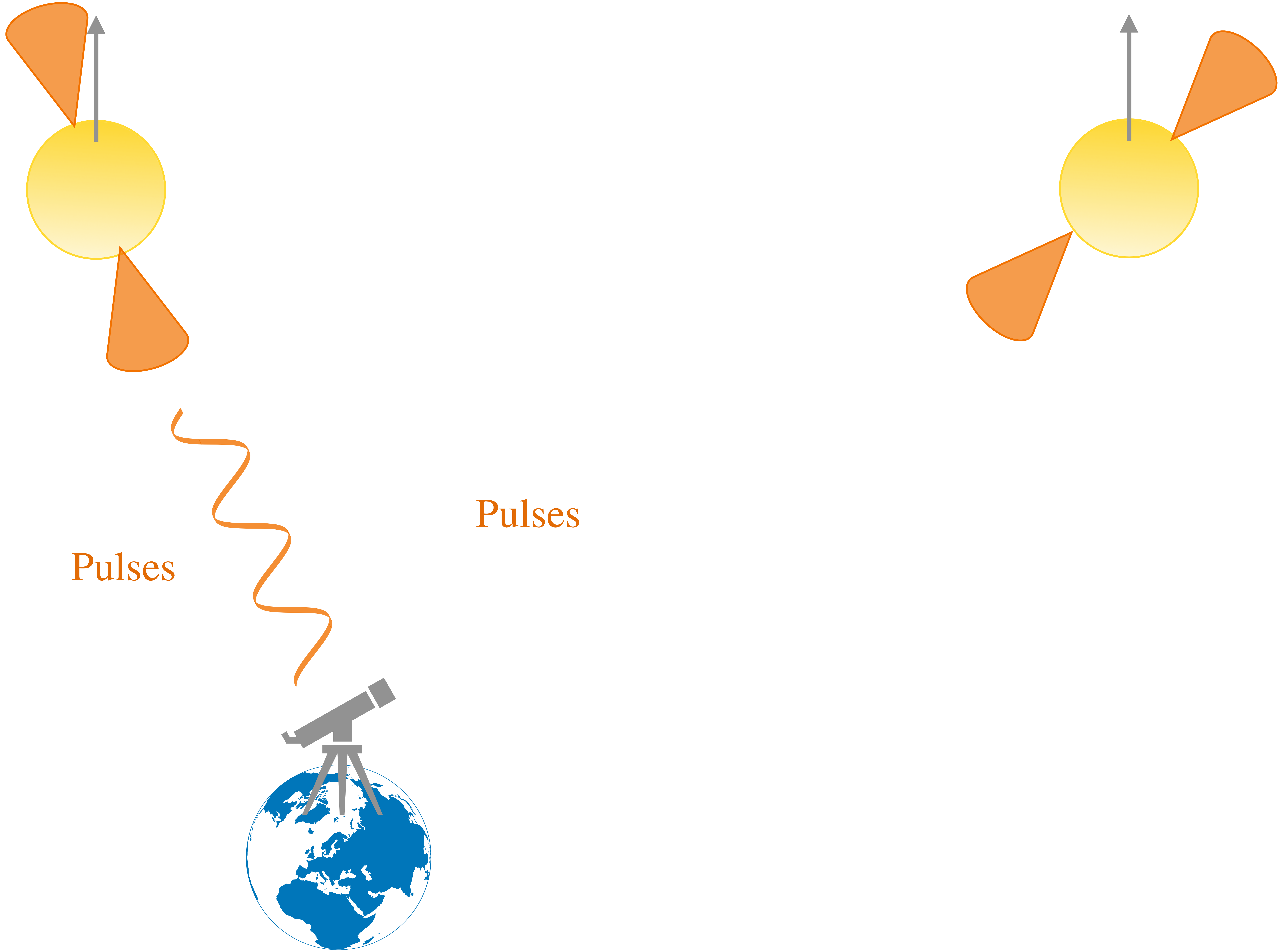
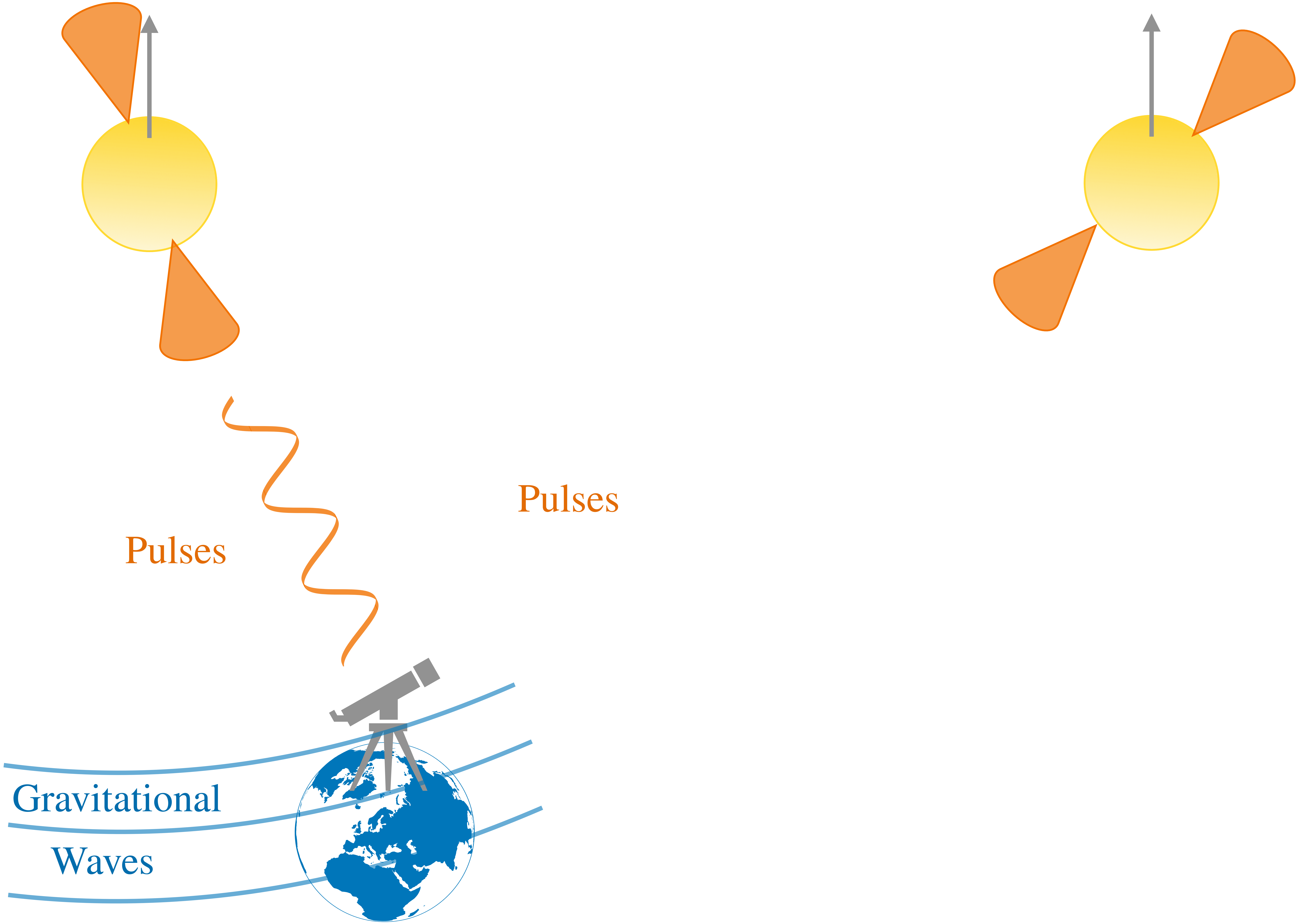
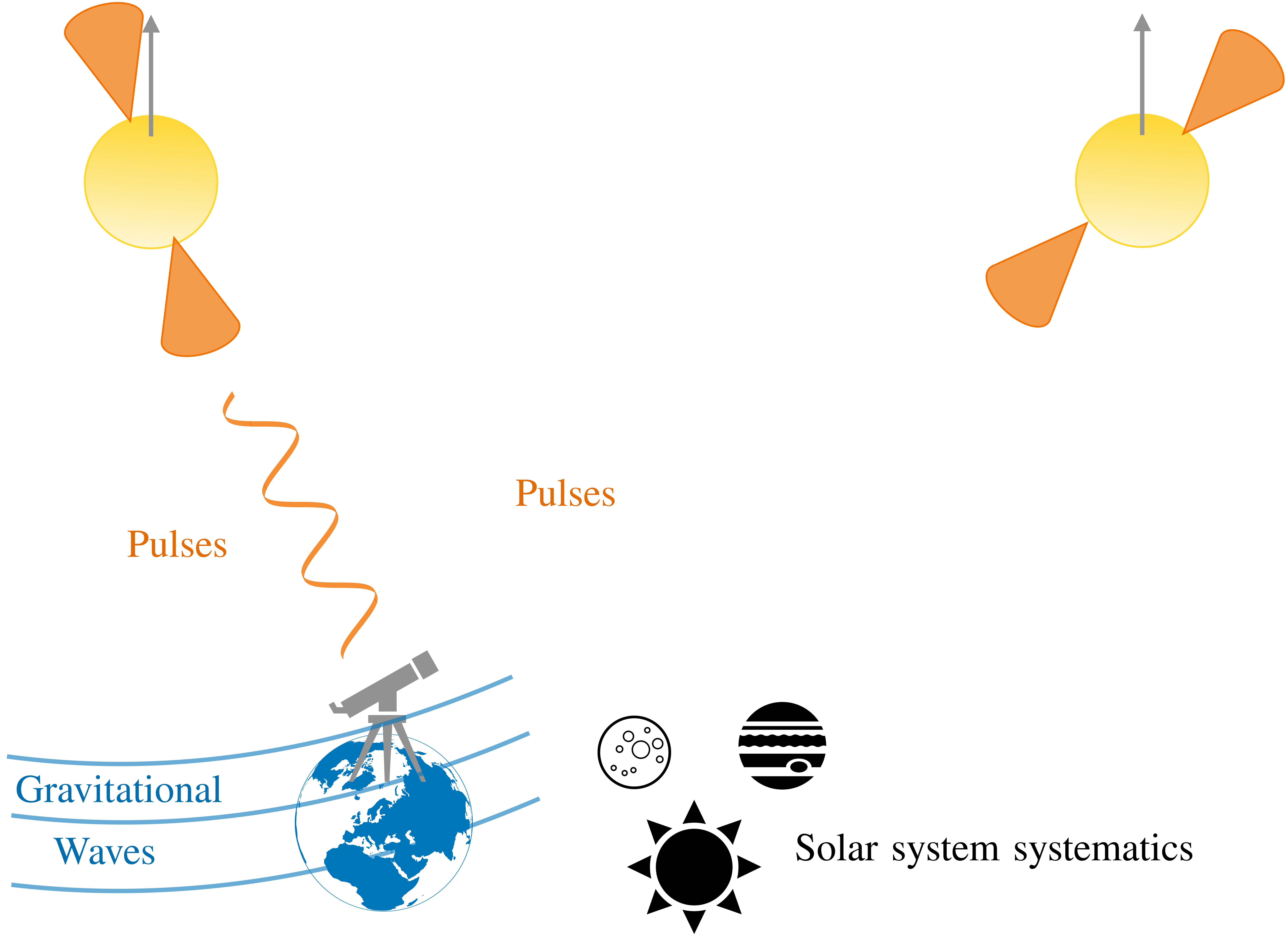
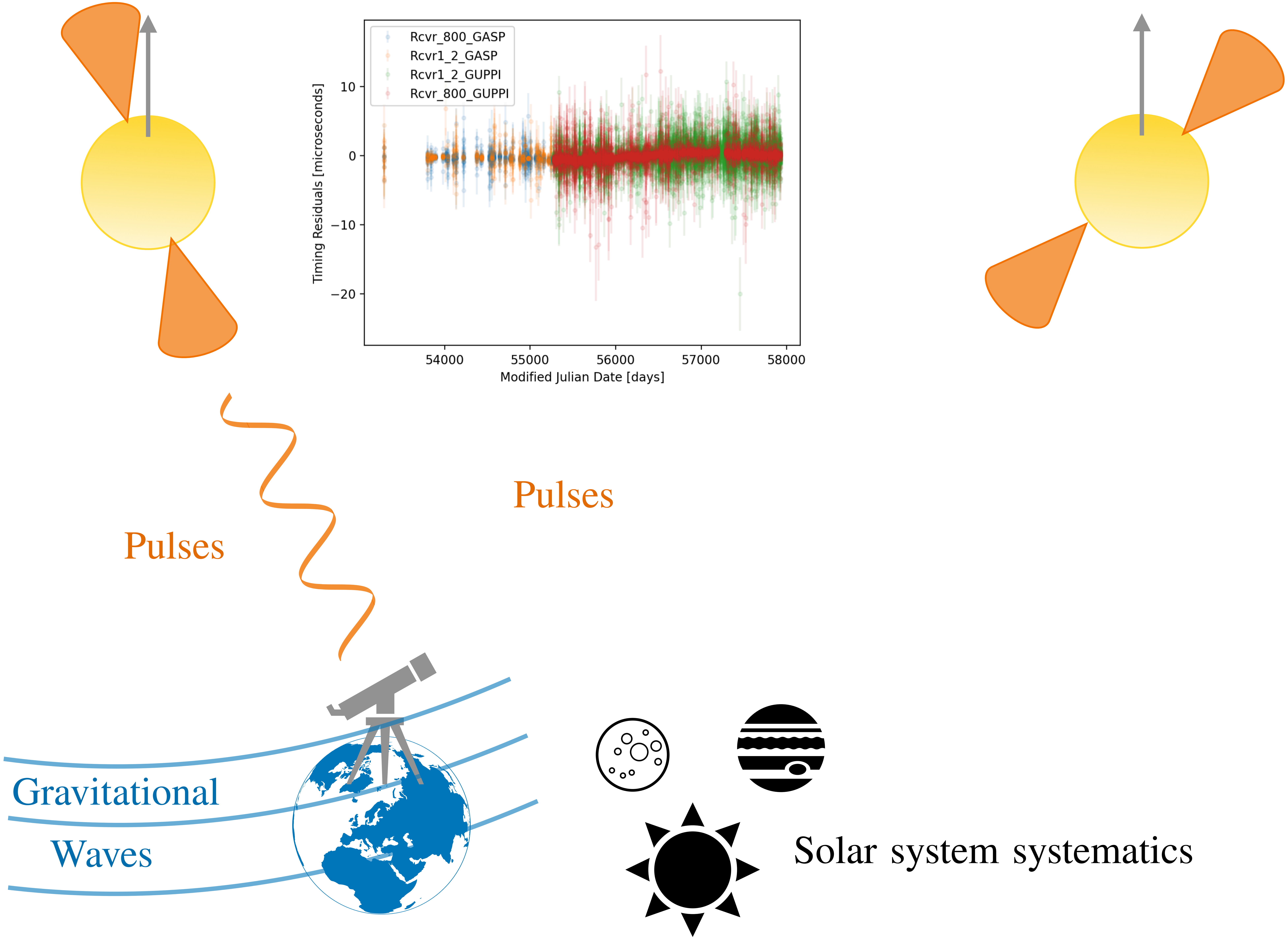
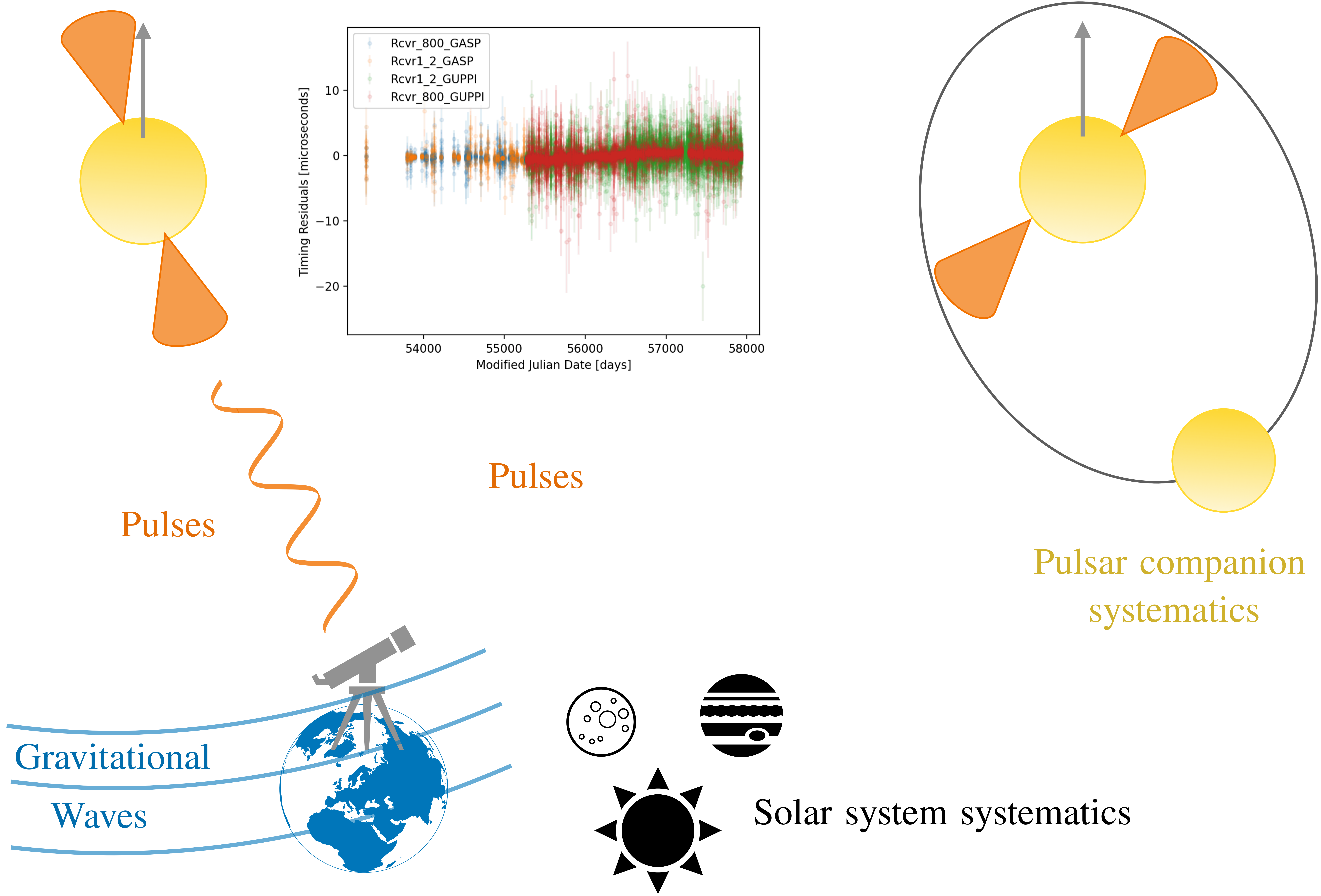



Pulses
Pulses

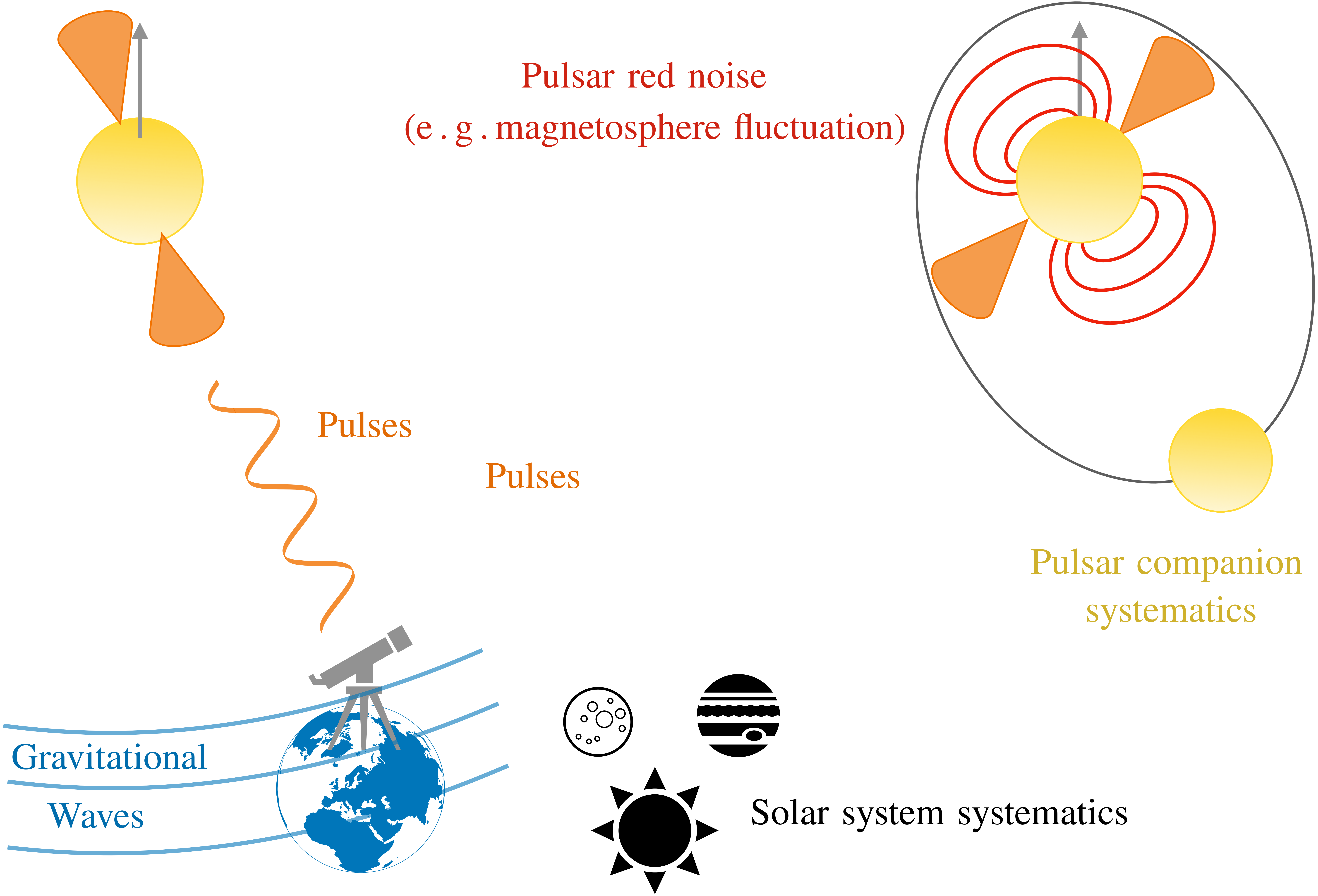

Pulses
Pulses
Gravitational
Waves

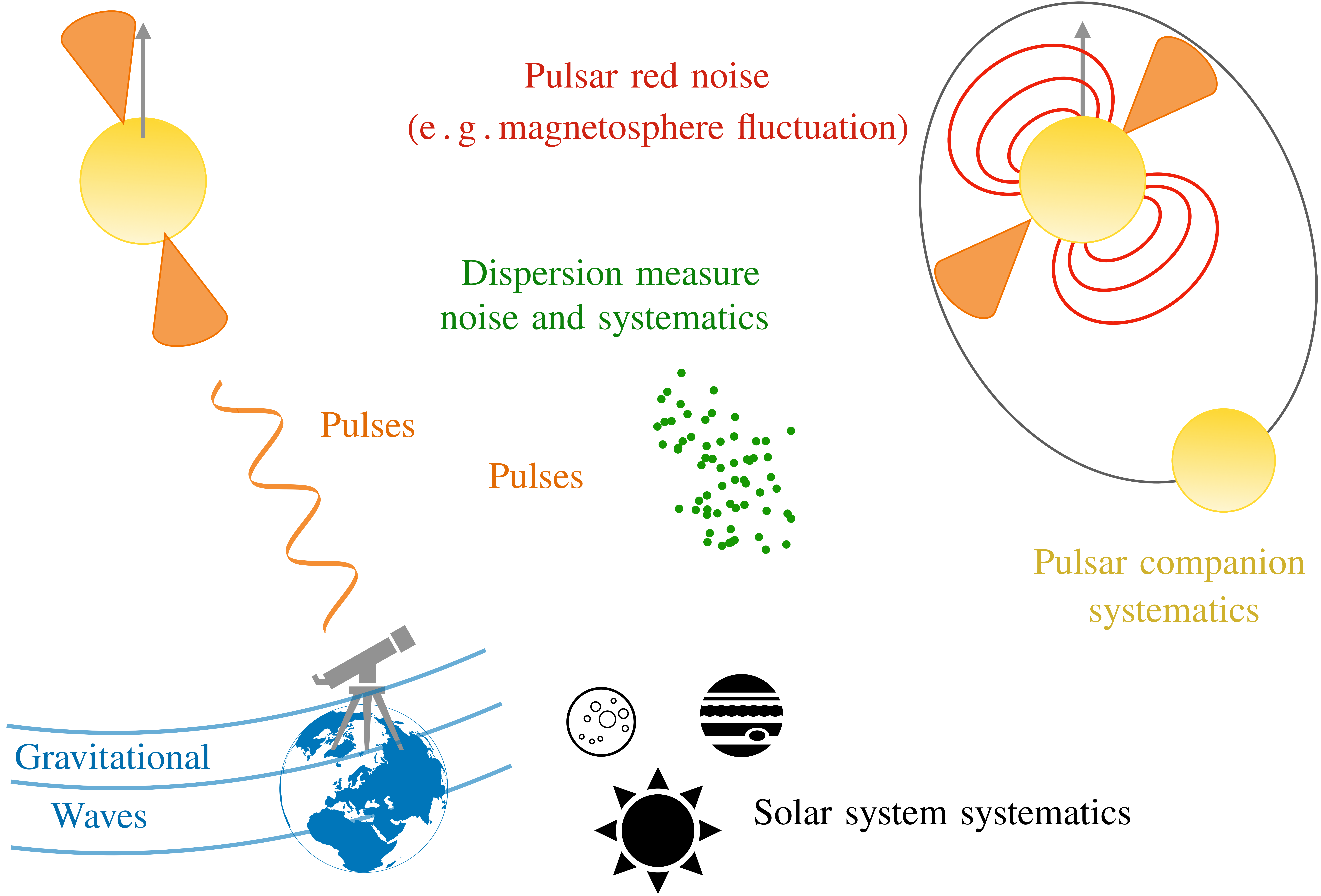

Pulses
Pulses
Gravitational
Waves
Solar system systematics


Rcvr_800_GASP
Rcvr1_2_GASP
Rcvr1_2_GUPPI
Rcvr_800_GUPPI
Timing Residuals [microseconds]
Modified Julian Date [days]
Pulses
Pulses
Gravitational
Waves
Solar system systematics

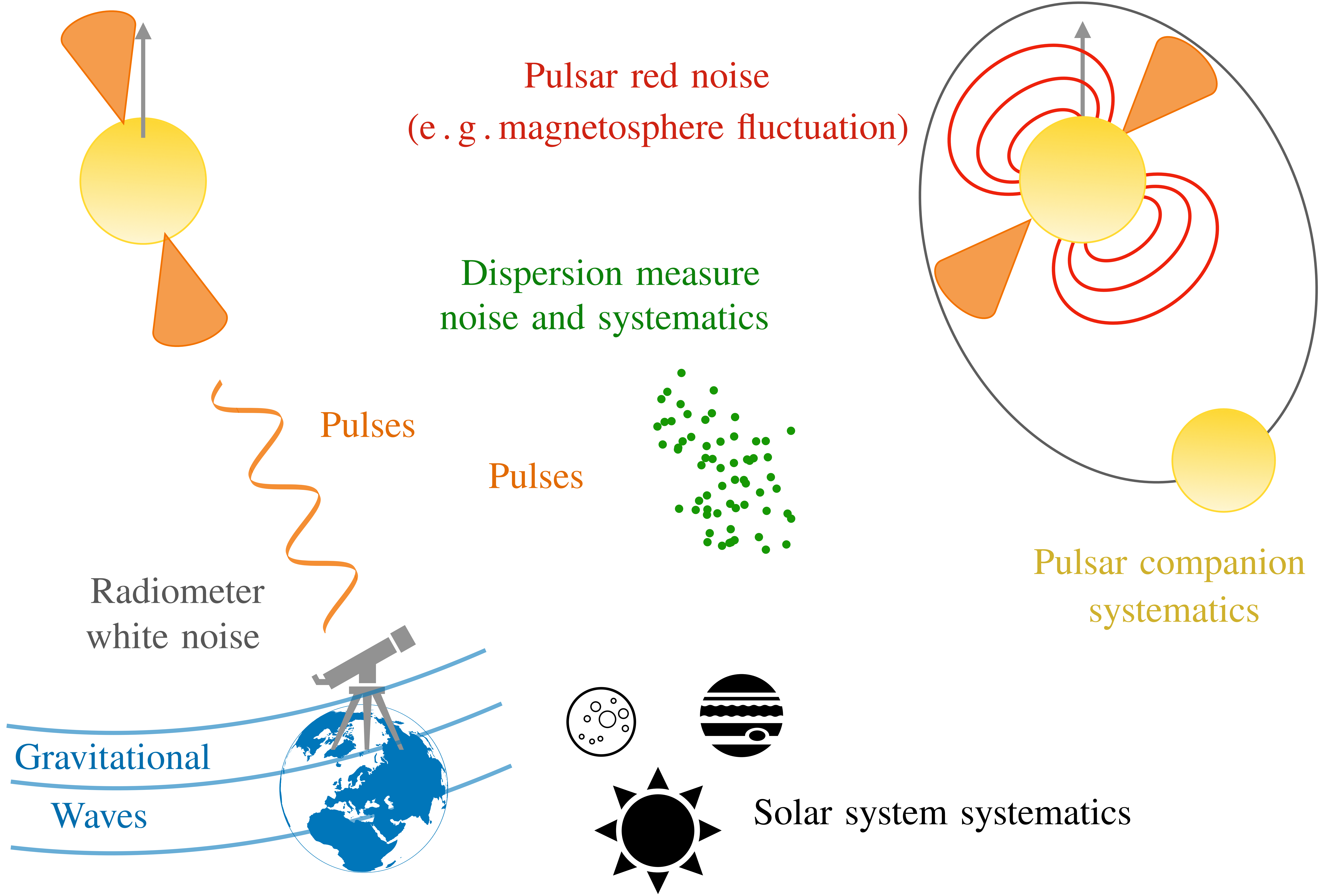


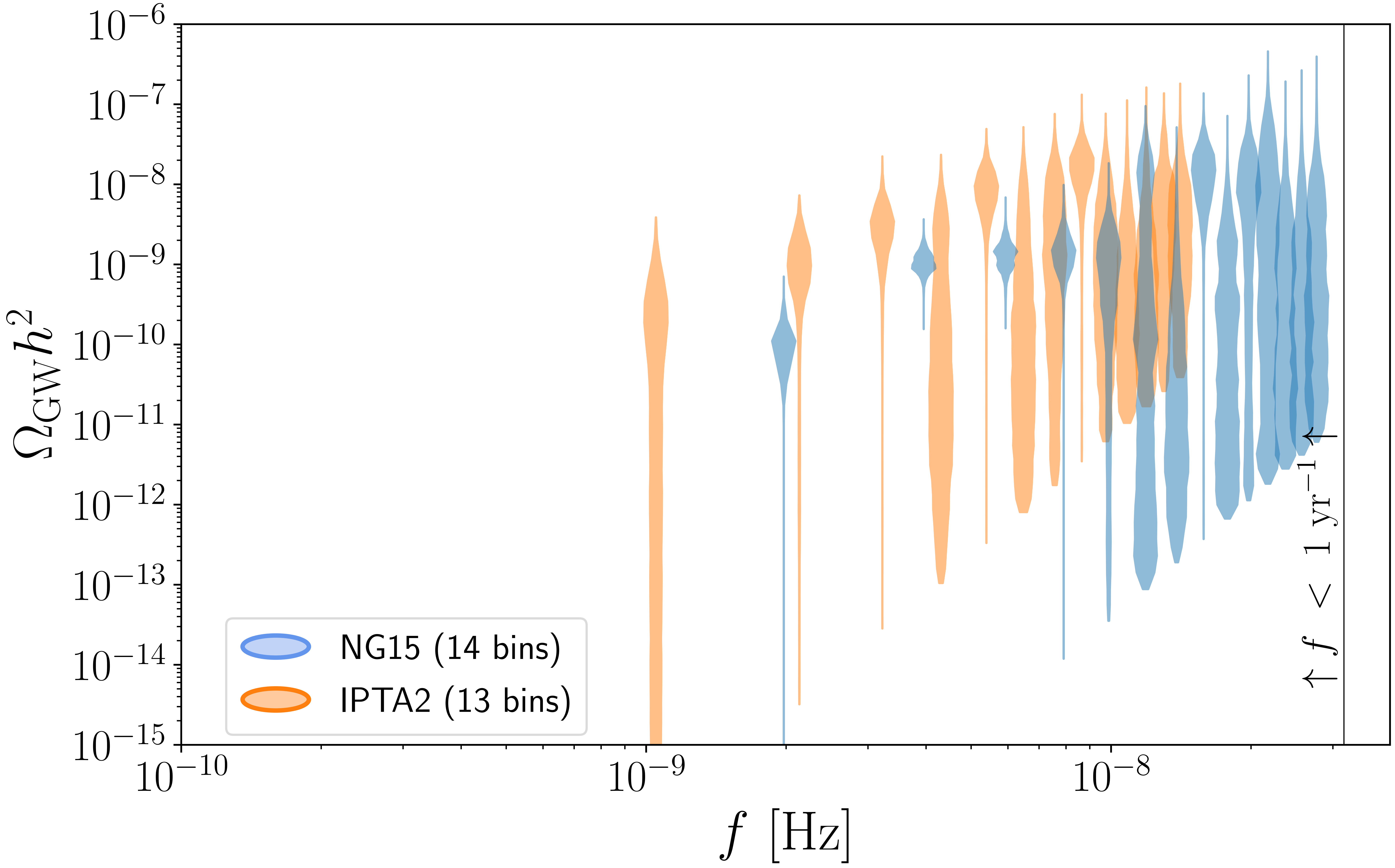
Rcvr_800_GASP
Rcvr1_2_GASP
Rcvr1_2_GUPPI
Rcvr_800_GUPPI
Timing Residuals [microseconds]
Modified Julian Date [days]
10
0
−10
−20
54000
55000
56000
57000
58000
Pulses
Pulses
Pulsar companion systematics
Gravitational Waves
Solar system systematics


Pulsar red noise
(e.g. magnetosphere fluctuation)
Pulses
Pulses
Pulsar companion systematics
Gravitational Waves
Solar system systematics

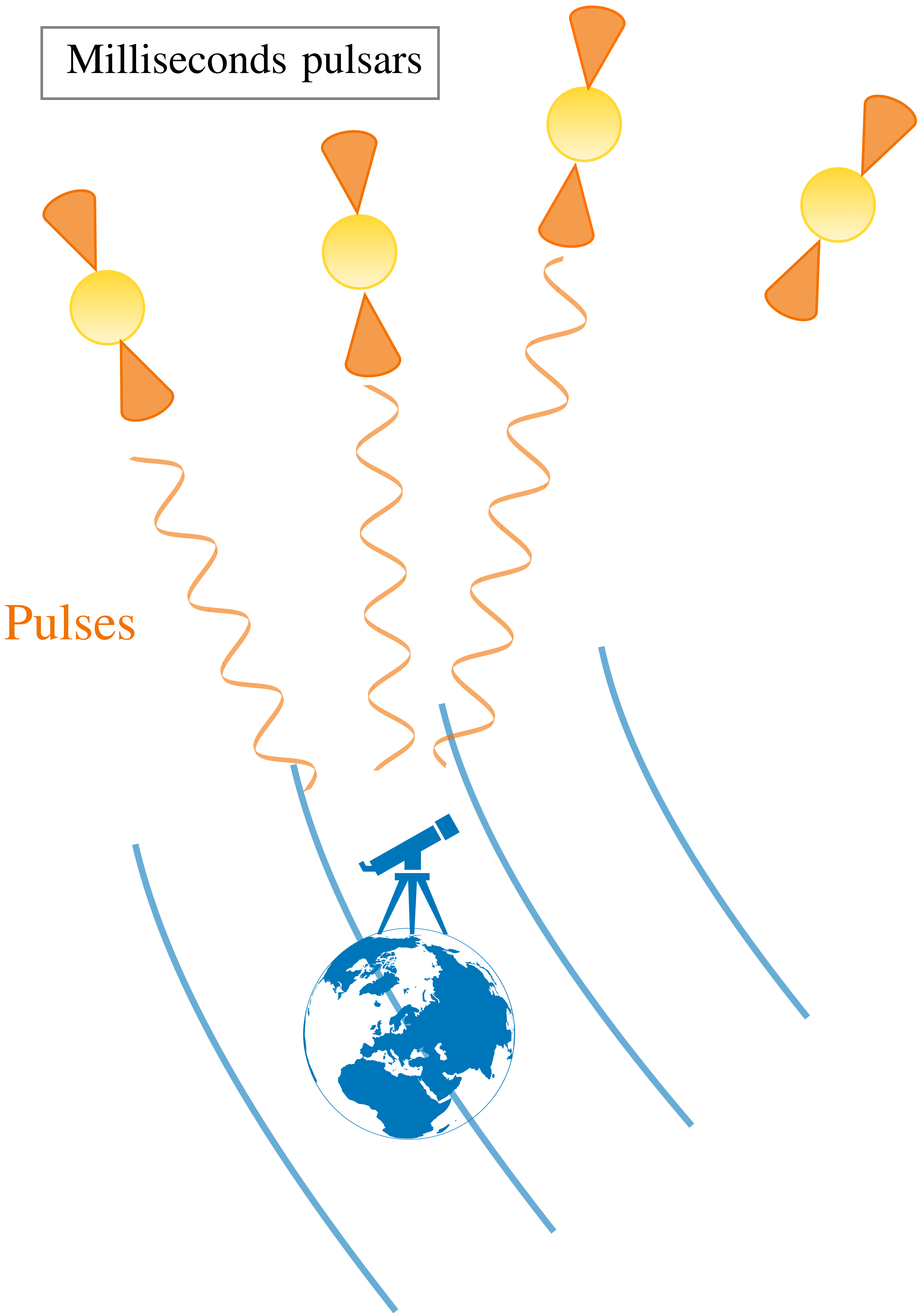


Pulsar red noise
(e.g. magnetosphere fluctuation)
Dispersion measure
noise and systematics
Pulses
Pulses
Pulsar companion
systematics
Gravitational
Waves
Solar system systematics

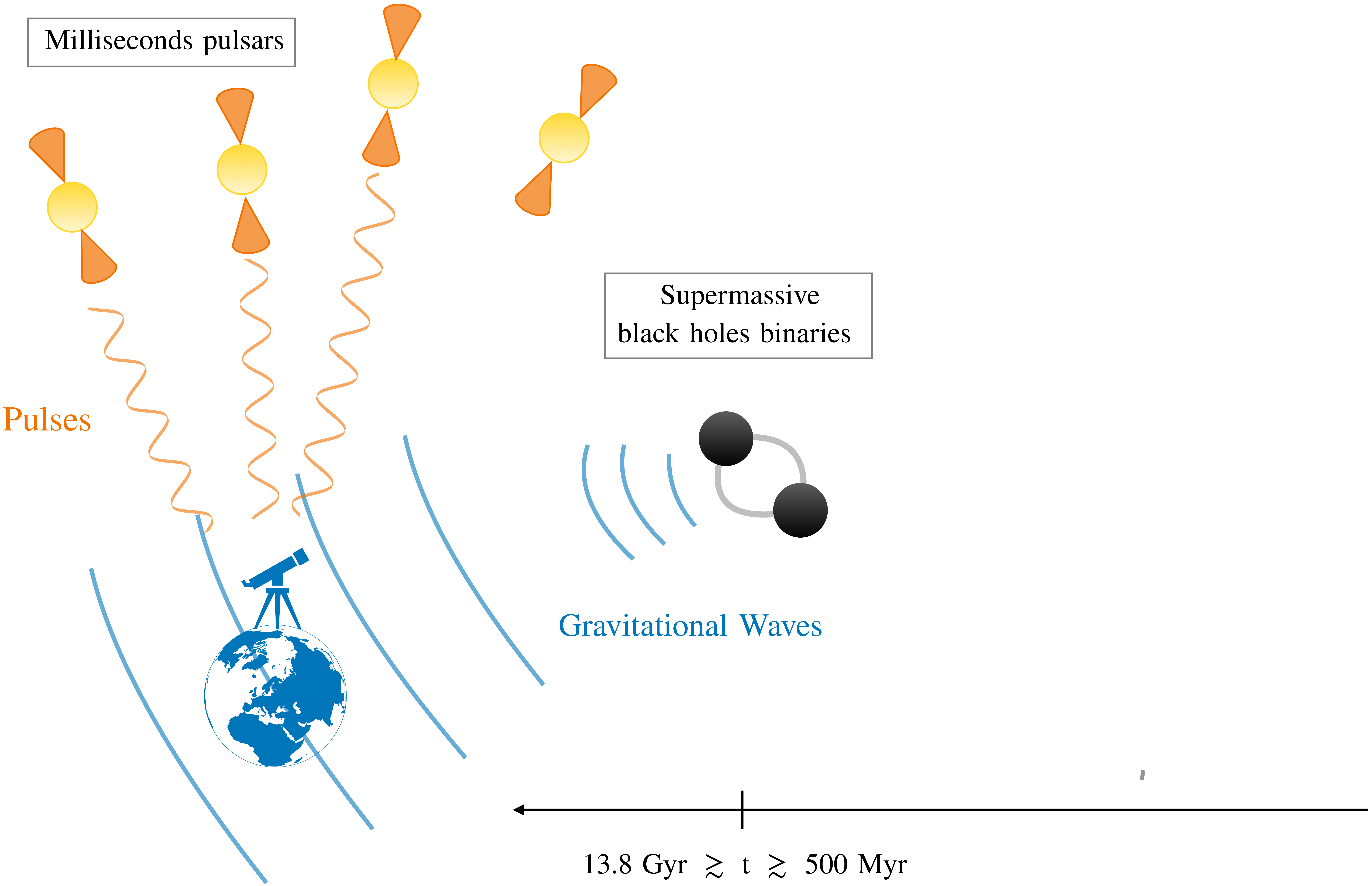

Pulsar red noise
(e.g. magnetosphere fluctuation)
Dispersion measure
noise and systematics
Pulses
Pulses
Pulsar companion
systematics
Radiometer
white noise
Gravitational
Waves
Solar system systematics



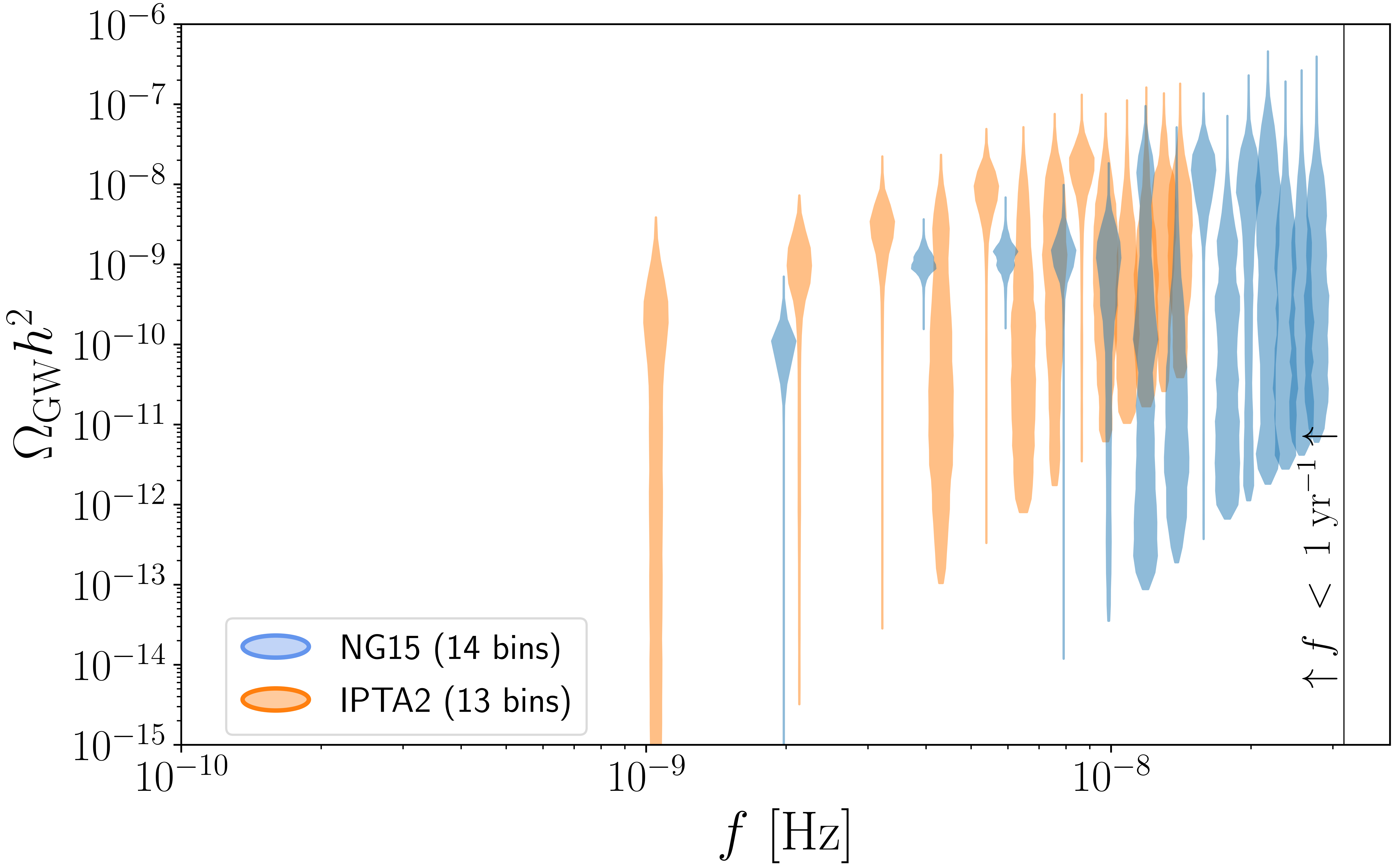
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
$\Omega_{\rm GW}h^2$
10^{-10}
10^{-9}
10^{-8}
f [Hz]
$\uparrow f < 1\ {\rm yr}^{-1} \uparrow$
NG15 (14 bins)
IPTA2 (13 bins)



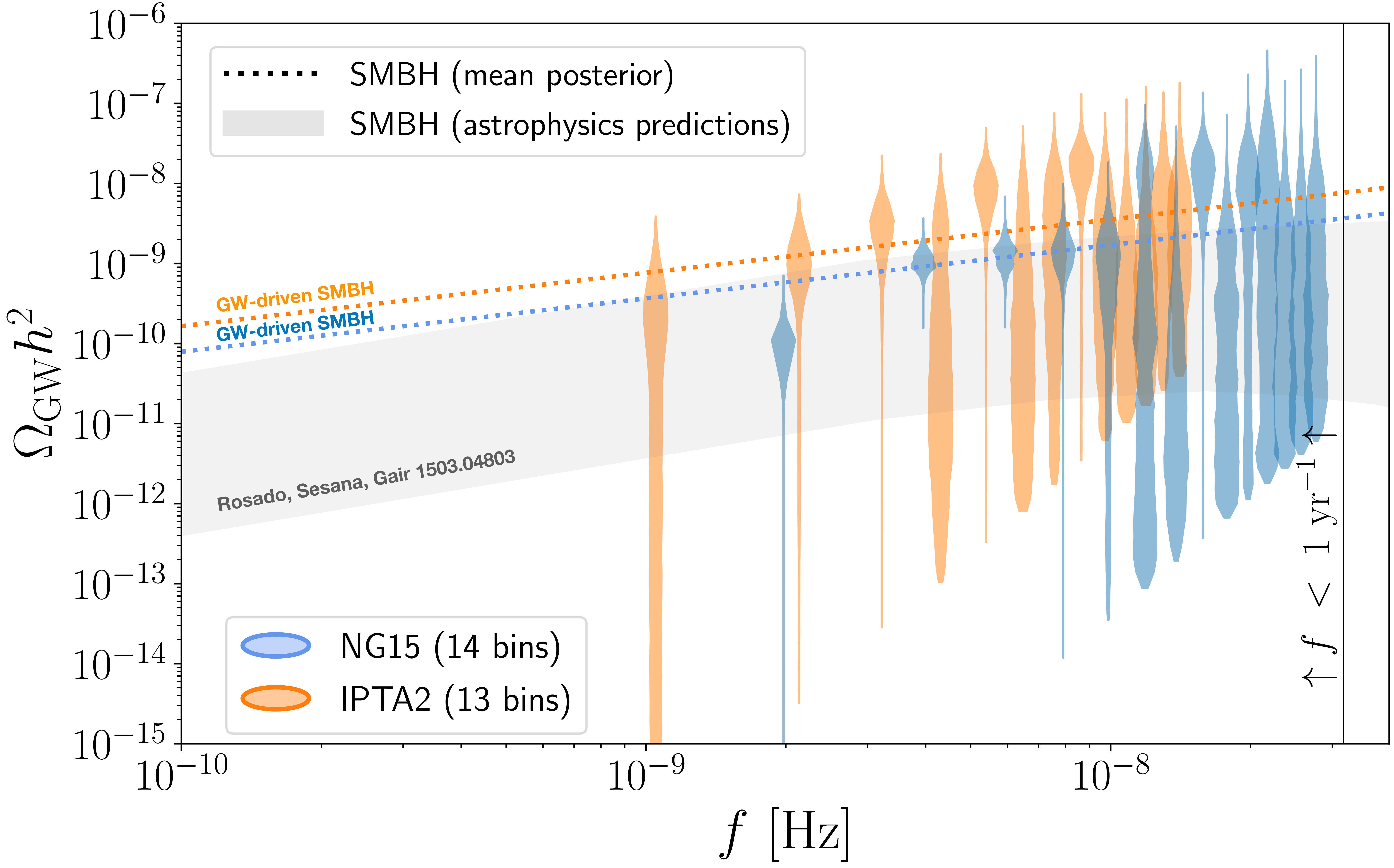
Milliseconds pulsars
Pulses



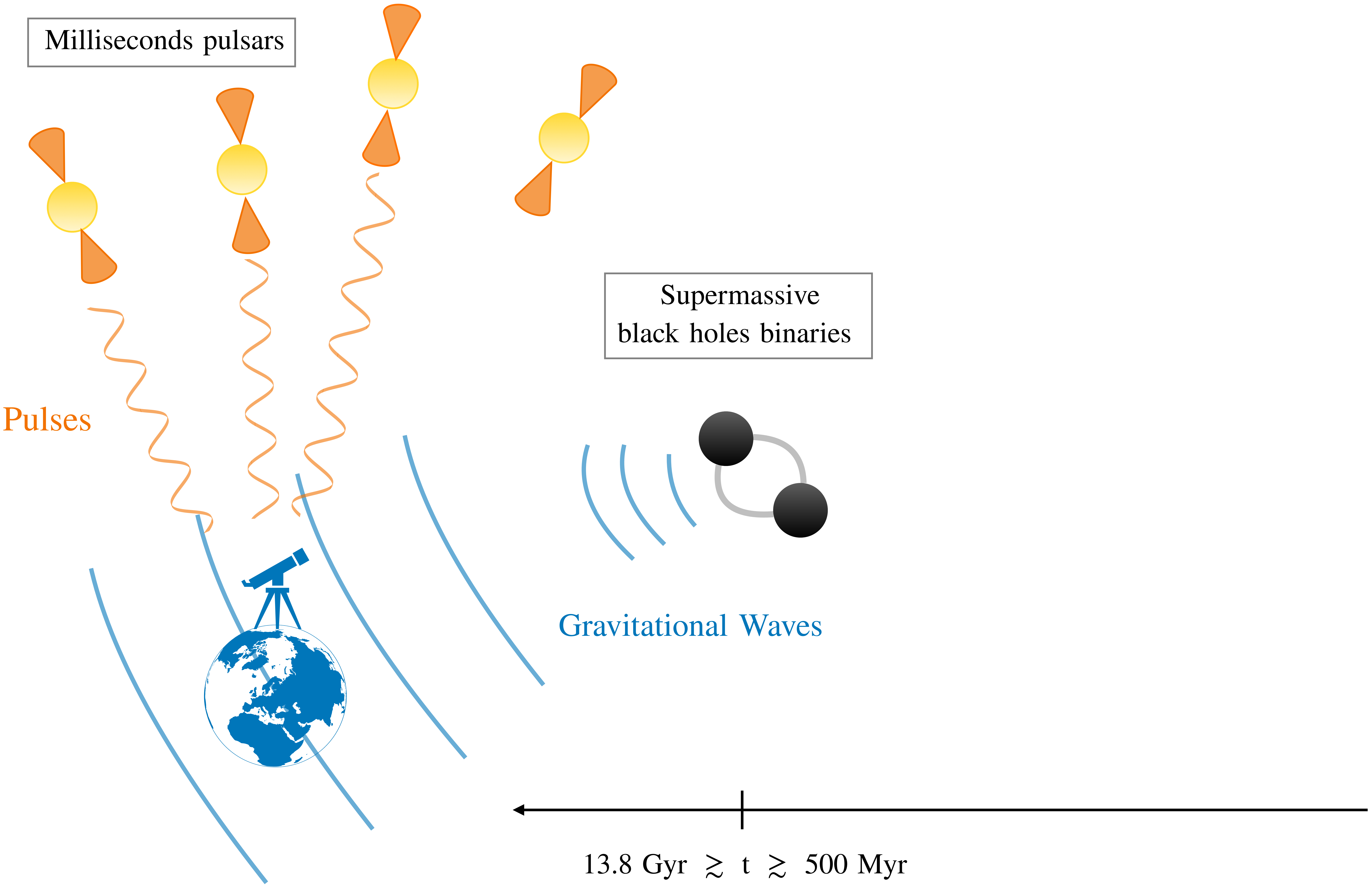
Milliseconds pulsars
Supermassive black holes binaries
Pulses
Gravitational Waves
13.8 Gyr $\gtrsim$ t $\gtrsim$ 500 Myr

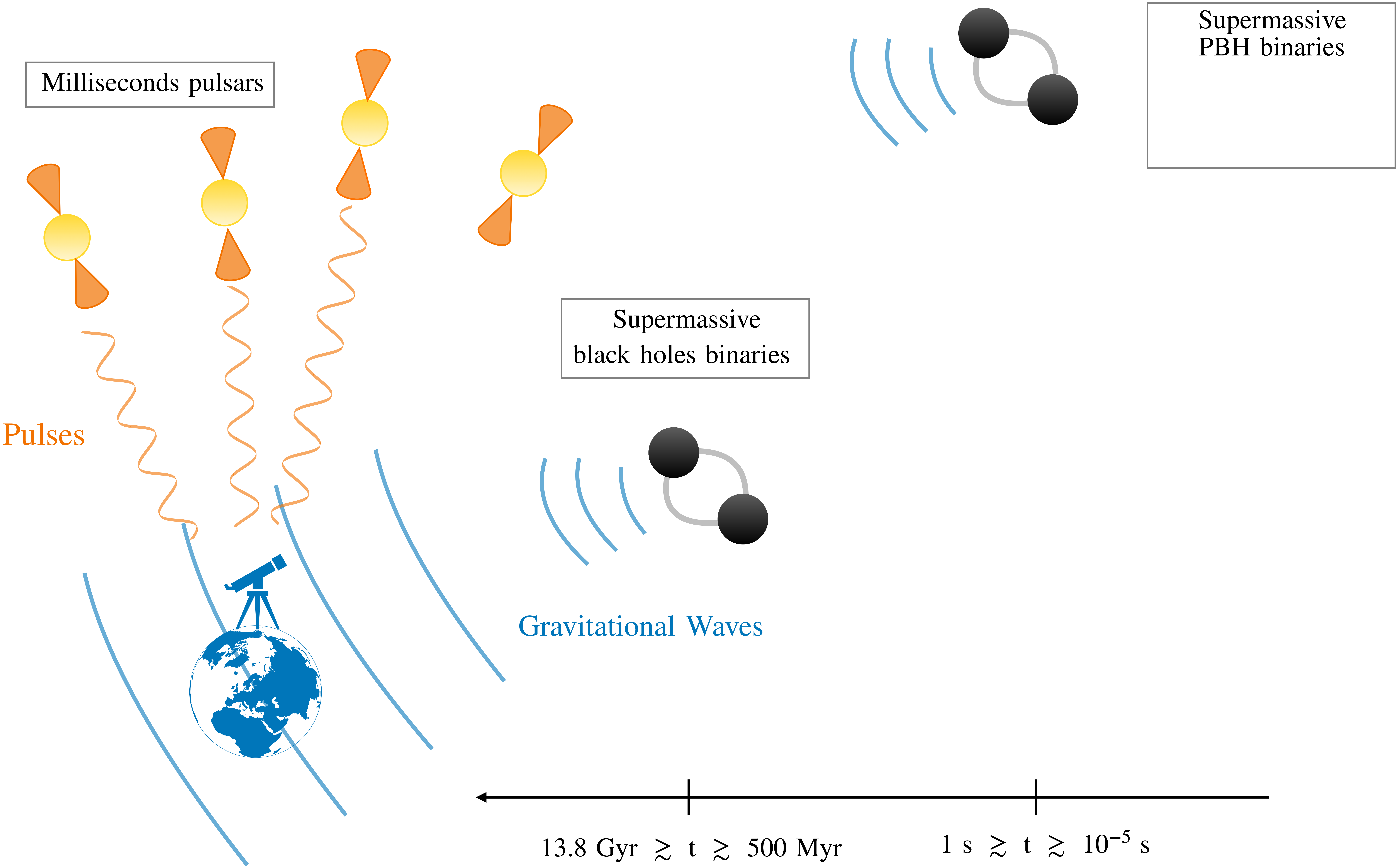


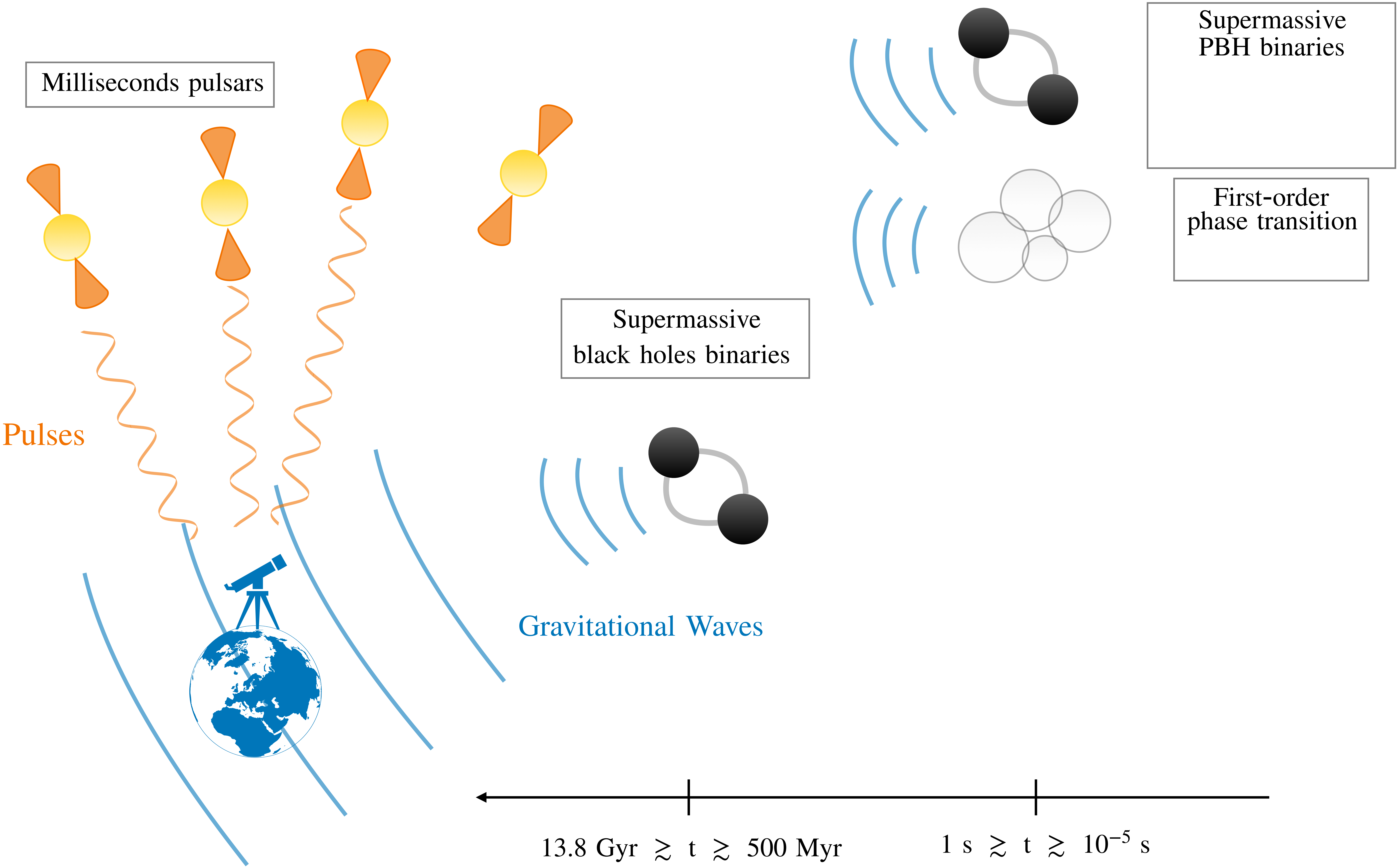
$\Omega_{\rm GW}h^2$
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-10}
10^{-9}
10^{-8}
f [Hz]
NG15 (14 bins)
IPTA2 (13 bins)
$\leftarrow f < 1\ {\rm yr}^{-1} \rightarrow$



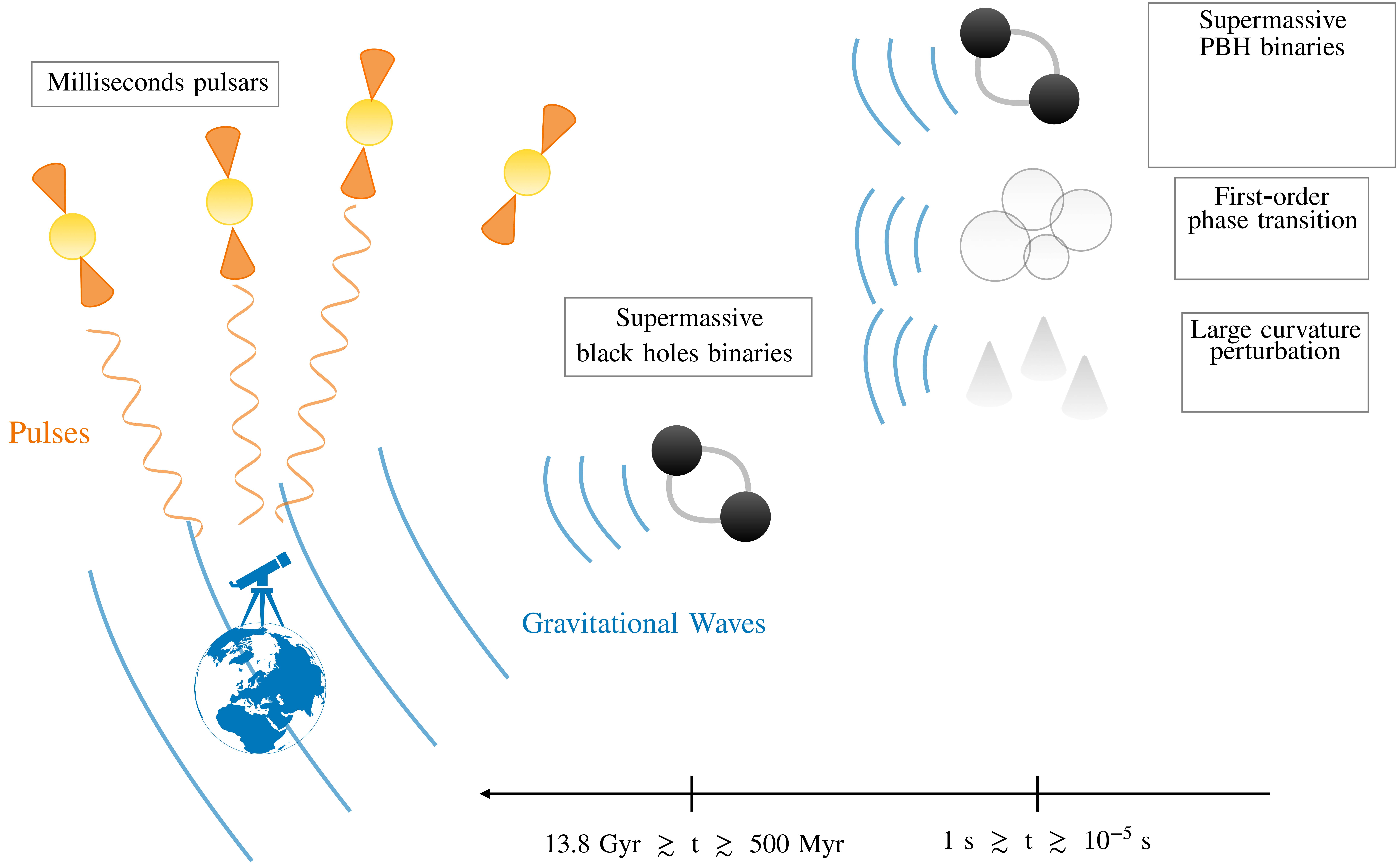
SMBH (mean posterior)
SMBH (astrophysics predictions)
GW-driven SMBH
GW-driven SMBH
Rosado, Sesana, Gair 1503.04803
NG15 (14 bins)
IPTA2 (13 bins)
$\leftarrow f < 1\ \mathrm{yr}^{-1} \rightarrow$
$\Omega_{\rm GW} h^2$
f [Hz]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-10}
10^{-9}
10^{-8}


Milliseconds pulsars
Pulses
Supermassive
black holes binaries
Gravitational Waves
13.8 Gyr ≳ t ≳ 500 Myr

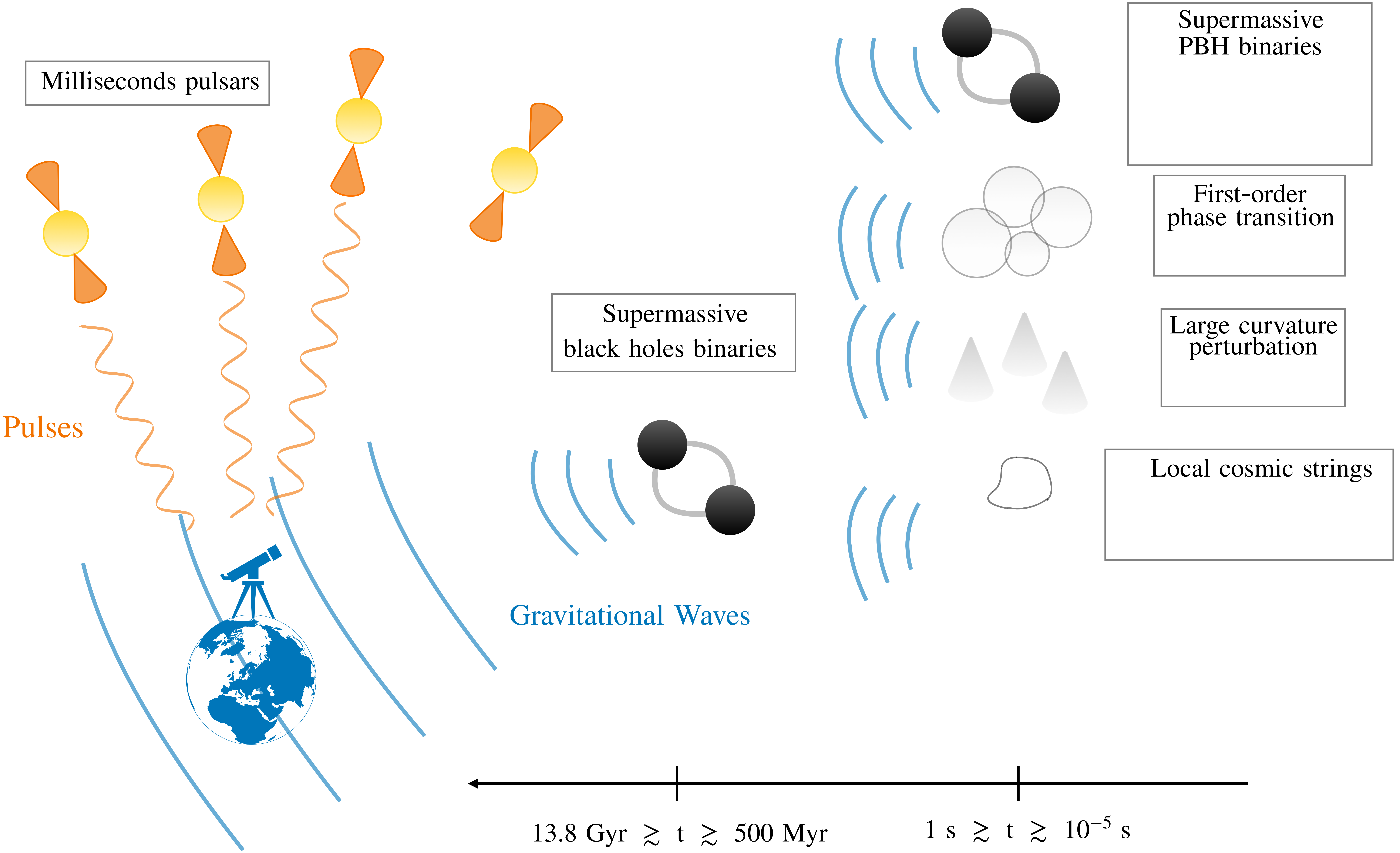

Milliseconds pulsars
Supermassive PBH binaries
Supermassive black holes binaries
Pulses
Gravitational Waves
13.8 Gyr ≳ t ≳ 500 Myr
1 s ≳ t ≳ 10^{-5} s



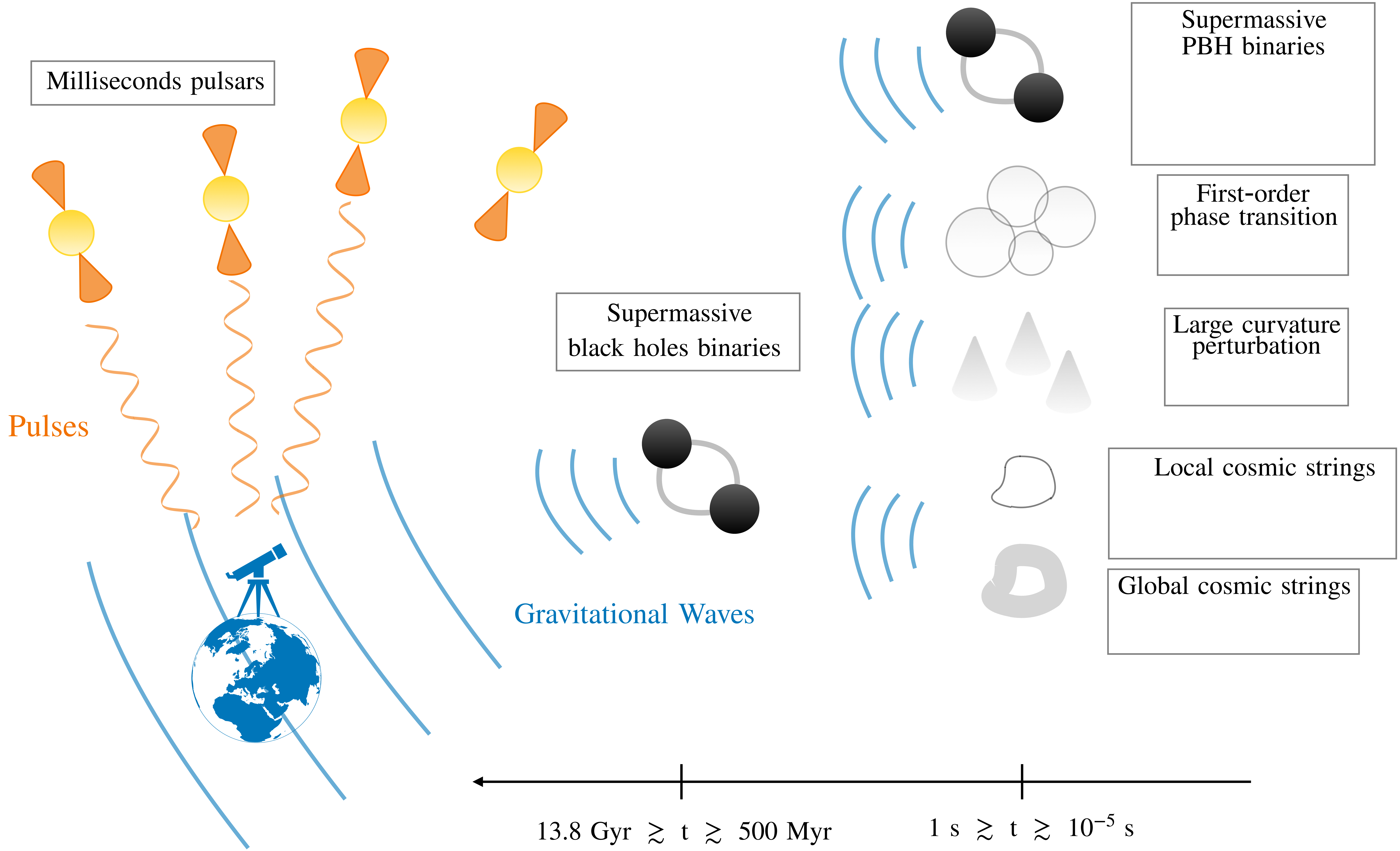
Milliseconds pulsars
Supermassive PBH binaries
First-order phase transition
Supermassive black holes binaries
Pulses
Gravitational Waves
13.8 Gyr ≳ t ≳ 500 Myr
1 s ≳ t ≳ 10^{-5} s



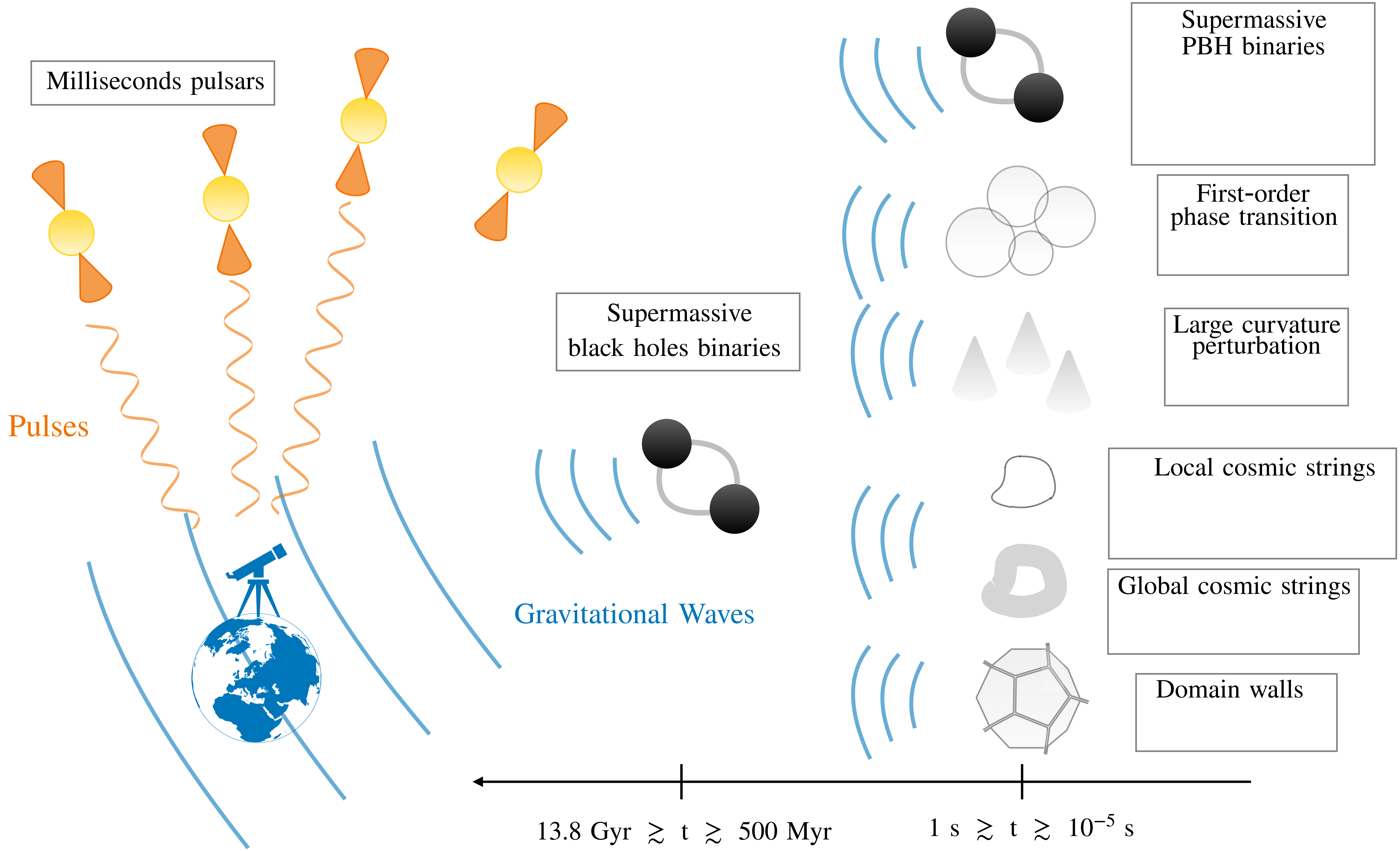
Milliseconds pulsars
Supermassive PBH binaries
First-order phase transition
Large curvature perturbation
Supermassive black holes binaries
Pulses
Gravitational Waves
13.8 Gyr ≳ t ≳ 500 Myr
1 s ≳ t ≳ 10^{−5} s

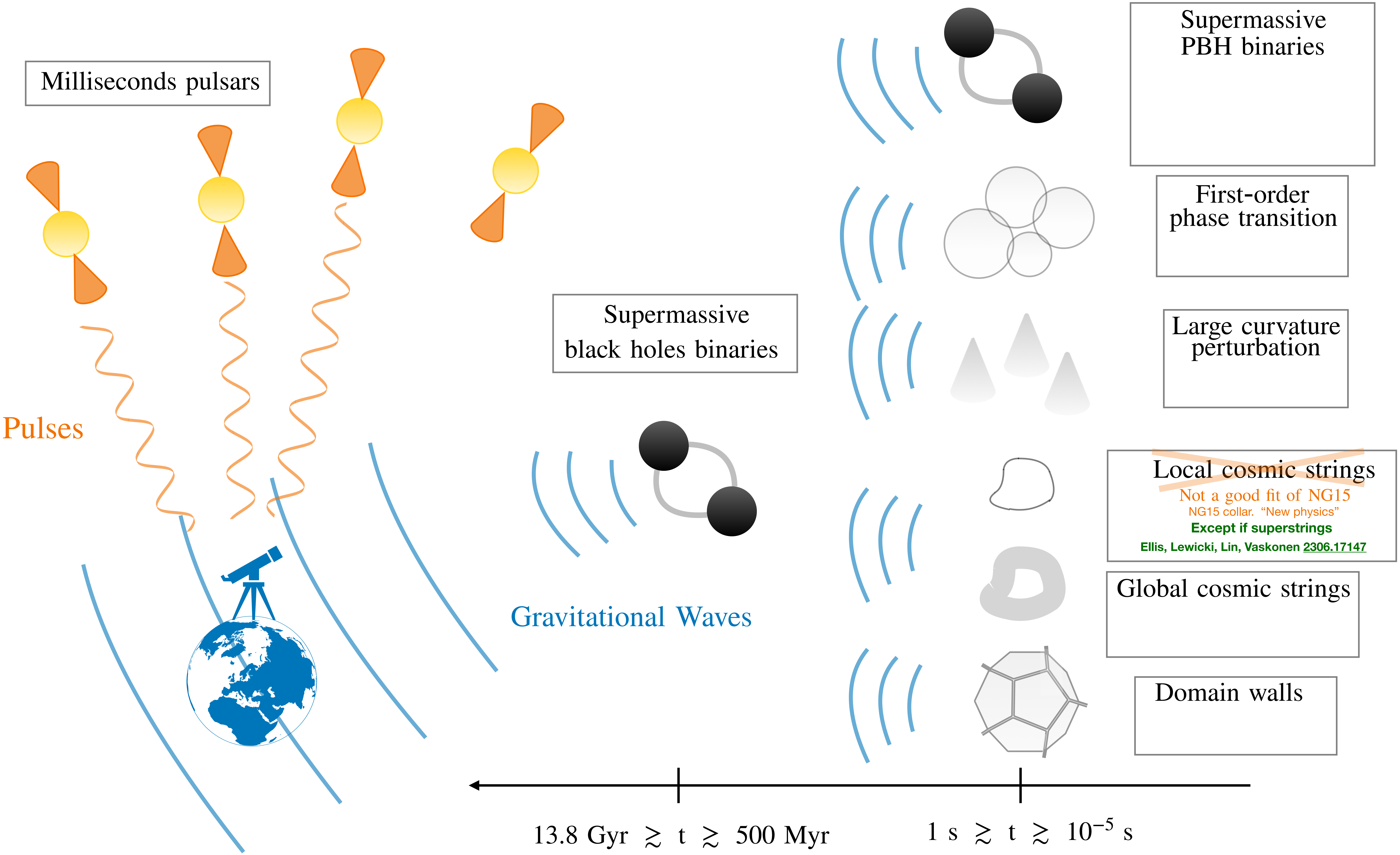


Milliseconds pulsars
Pulses
Gravitational Waves
Supermassive black holes binaries
Supermassive PBH binaries
First-order phase transition
Large curvature perturbation
Local cosmic strings
13.8 Gyr ≳ t ≳ 500 Myr
1 s ≳ t ≳ 10^{-5} s

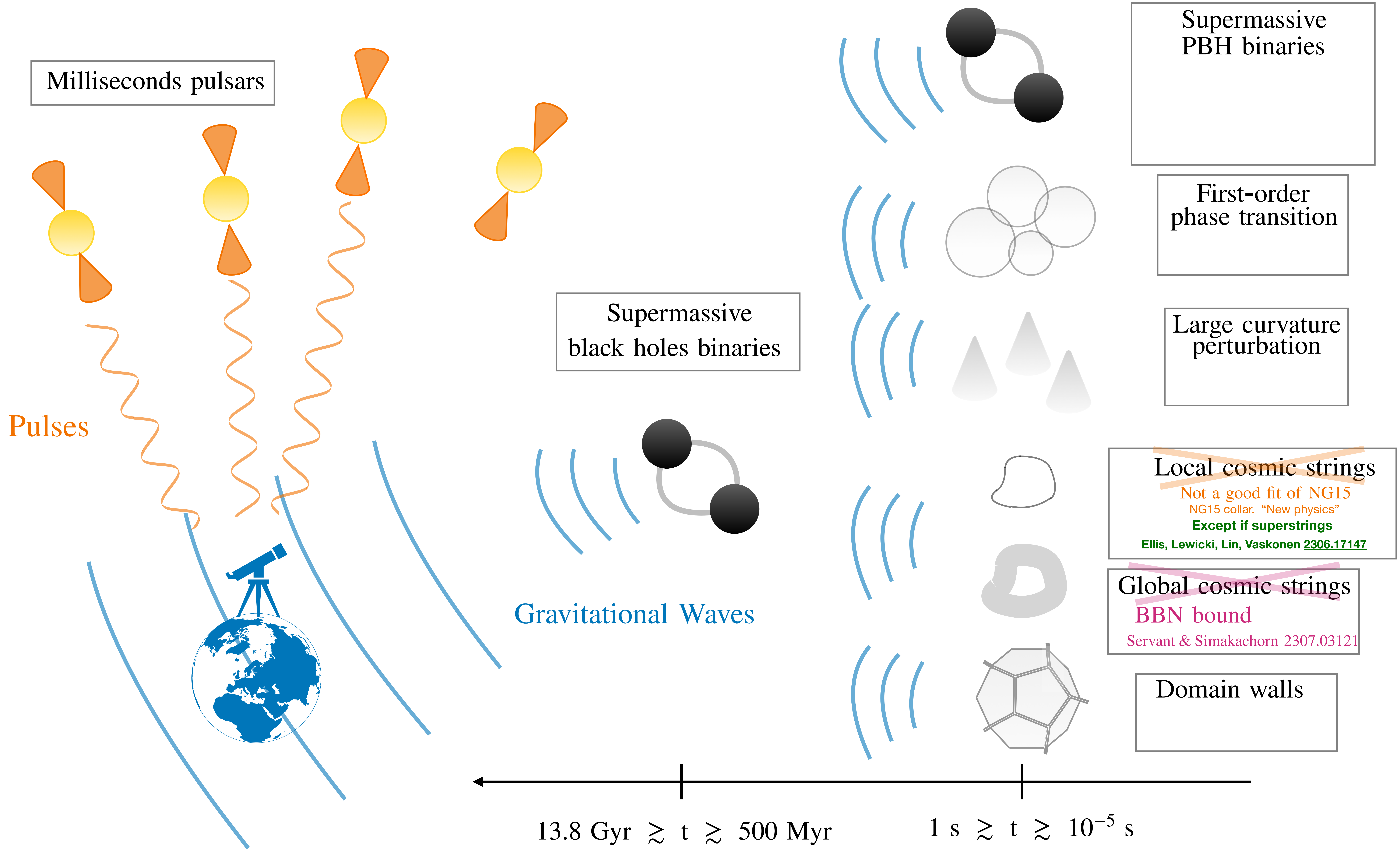


Milliseconds pulsars
Pulses
Supermassive black holes binaries
Gravitational Waves
Supermassive PBH binaries
First-order phase transition
Large curvature perturbation
Local cosmic strings
Global cosmic strings
13.8 Gyr $\gtrsim$ t $\gtrsim$ 500 Myr
1 s $\gtrsim$ t $\gtrsim$ 10^{-5} s


Milliseconds pulsars
Pulses
Supermassive black holes binaries
Gravitational Waves
Supermassive PBH binaries
First-order phase transition
Large curvature perturbation
Local cosmic strings
Global cosmic strings
Domain walls
13.8 Gyr ≳ t ≳ 500 Myr
1 s ≳ t ≳ 10^{-5} s



Milliseconds pulsars
Pulses
Supermassive black holes binaries
Gravitational Waves
Supermassive PBH binaries
First-order phase transition
Large curvature perturbation
Local cosmic strings
Not a good fit of NG15
NG15 collar. "New physics"
Except if superstrings
Ellis, Lewicki, Lin, Vaskonen 2306.17147
Global cosmic strings
Domain walls
13.8 Gyr ≳ t ≳ 500 Myr
1 s ≳ t ≳ 10^{-5} s



Milliseconds pulsars
Pulses
Supermassive black holes binaries
Gravitational Waves
Supermassive PBH binaries
First-order phase transition
Large curvature perturbation
Local cosmic strings
Not a good fit of NG15
NG15 collar. "New physics"
Except if superstrings
Ellis, Lewicki, Lin, Vaskonen 2306.17147
Global cosmic strings
BBN bound
Servant & Simakachorn 2307.03121
Domain walls
13.8 Gyr $\gtrsim$ t $\gtrsim$ 500 Myr
1 s $\gtrsim$ t $\gtrsim$ 10^{-5} s

Milliseconds pulsars
Pulses
Supermassive black holes binaries
Gravitational Waves
Supermassive PBH binaries
LSS and UV LF galaxy
YG,Trifinopoulos,Valogiannis,Vanvlasselaer, 2307.01457
Except if clustering
Depta, Schmidt-Hoberg, Schwaller, Tasillo 2306.17836
First-order phase transition
Large curvature perturbation
Local cosmic strings
Not a good fit of NG15
NG15 collab. "New physics"
Except if superstrings
Ellis, Lewicki, Lin, Vaskonen 2306.17147
Global cosmic strings
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Domain walls
13.8 Gyr $\gtrsim$ t $\gtrsim$ 500 Myr
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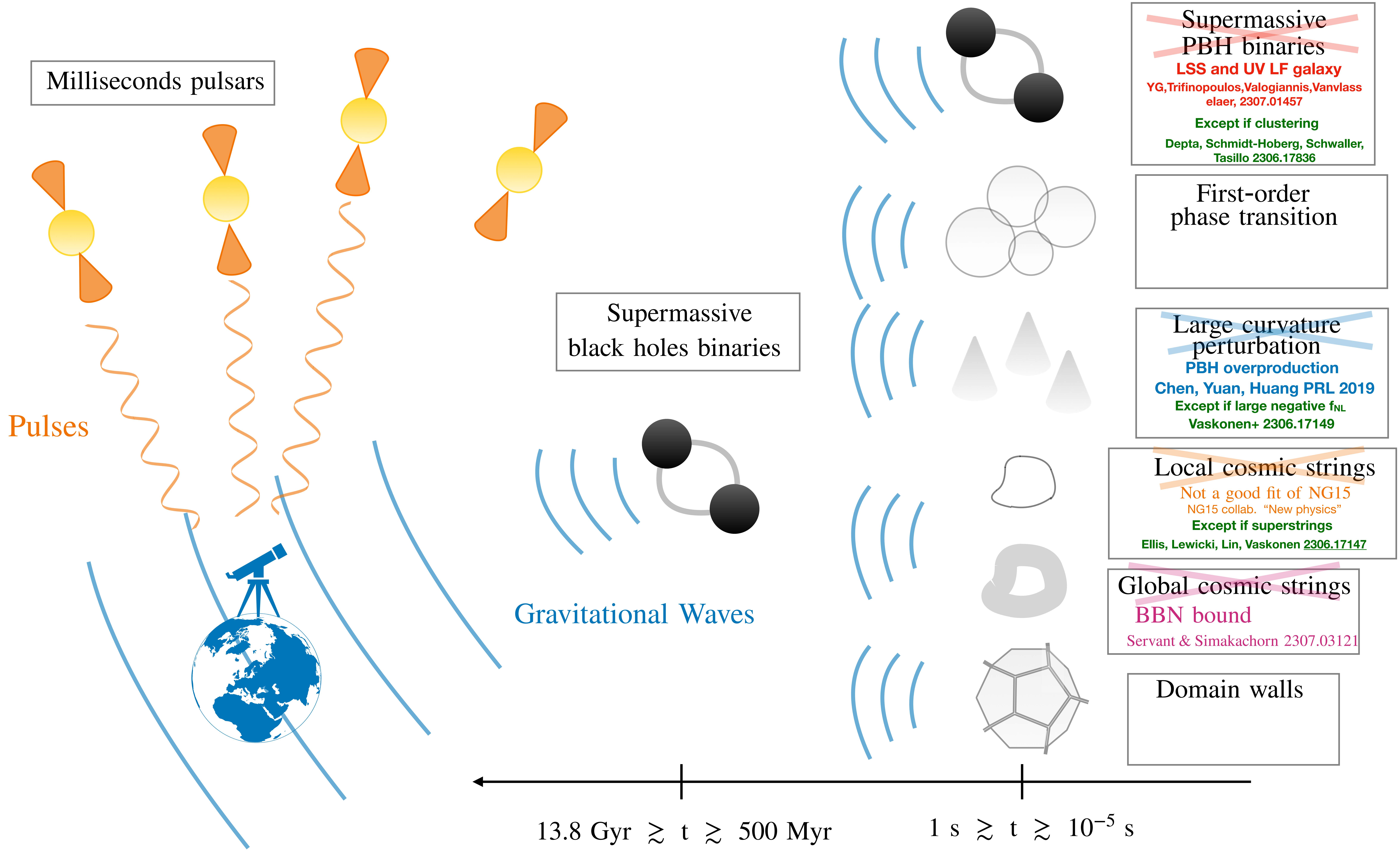

Milliseconds pulsars
Pulses
Supermassive black holes binaries
Gravitational Waves
Supermassive PBH binaries
LSS and UV LF galaxy
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Except if clustering
Depta, Schmidt-Hoberg, Schwaller, Tasillo 2306.17836
First-order phase transition
Large curvature perturbation
PBH overproduction
Chen, Yuan, Huang PRL 2019
Except if large negative f_{NL}
Vaskonen+ 2306.17149
Local cosmic strings
Not a good fit of NG15
NG15 collab. “New physics”
Except if superstrings
Ellis, Lewicki, Lin, Vaskonen 2306.17147
Global cosmic strings
BBN bound
Servant & Simakachorn 2307.03121
Domain walls
13.8 Gyr $\gtrsim$ t $\gtrsim$ 500 Myr
1 s $\gtrsim$ t $\gtrsim$ 10^{-5} s

Milliseconds pulsars
Pulses
Supermassive black holes binaries
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Supermassive PBH binaries
LSS and UV LF galaxy
YG,Trifinopoulos,Valogiannis,Vanvlasselaer, 2307.01457
Except if clustering
Depta, Schmidt-Hoberg, Schwaller, Tasillo 2306.17836
First-order phase transition
Produce solar-mass PBH
YG, 2307.04239, PRL
Large curvature perturbation
PBH overproduction
Chen, Yuan, Huang PRL 2019
Except if large negative f_{NL}
Vaskonen+ 2306.17149
Local cosmic strings
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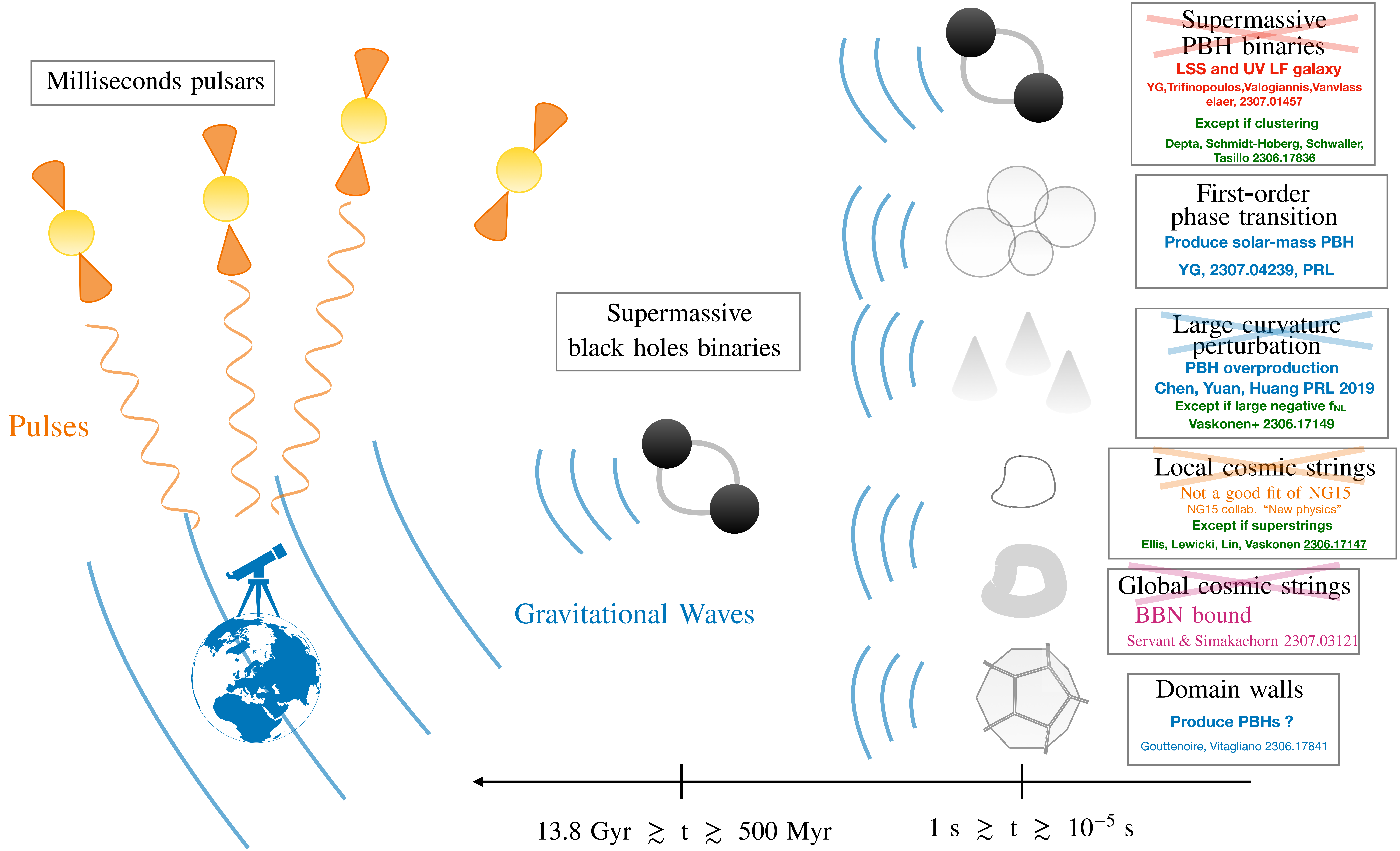
NG15 collab. "New physics"
Except if superstrings
Ellis, Lewicki, Lin, Vaskonen 2306.17147
Global cosmic strings
BBN bound
Servant & Simakachorn 2307.03121
Domain walls
13.8 Gyr $\gtrsim$ t $\gtrsim$ 500 Myr
1 s $\gtrsim$ t $\gtrsim$ 10^{-5} s



Milliseconds pulsars
Pulses
Supermassive black holes binaries
Gravitational Waves
Supermassive PBH binaries
LSS and UV LF galaxy
YG,Trifinopoulos,Valogiannis,Vanvlasselaer, 2307.01457
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First-order phase transition
Produce solar-mass PBH
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Local cosmic strings
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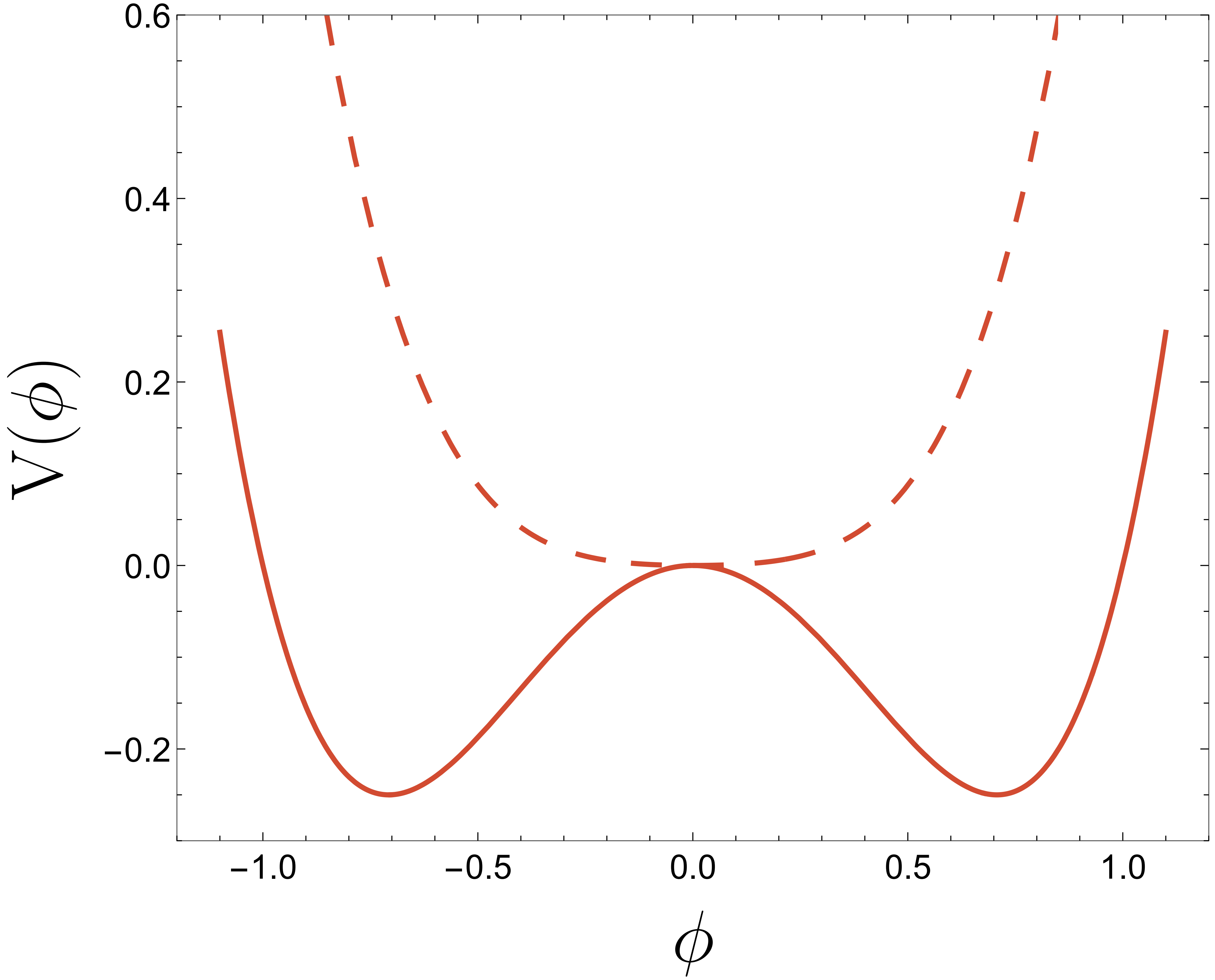
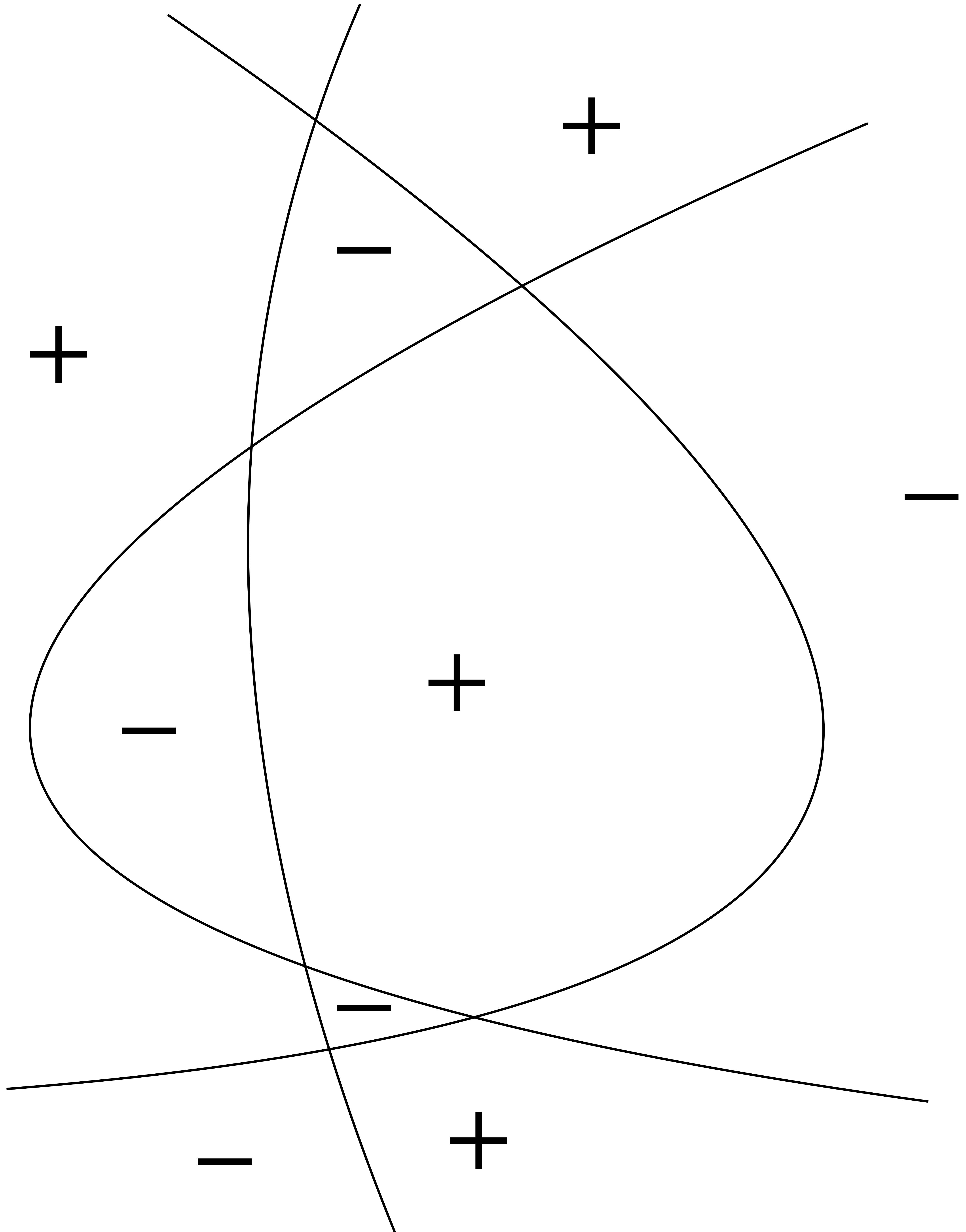
Ellis, Lewicki, Lin, Vaskonen 2306.17147
Global cosmic strings
BBN bound
Servant & Simakachorn 2307.03121
Domain walls
Produce PBHs ?
Gouttenoire, Vitagliano 2306.17841
13.8 Gyr $\gtrsim$ t $\gtrsim$ 500 Myr
1 s $\gtrsim$ t $\gtrsim$ 10^{-5} s

Formation of Domain Wall

$$V(\phi) = \lambda(\phi^2 - v_\phi^2)^2$$

Break $\mathbb{Z}_2$

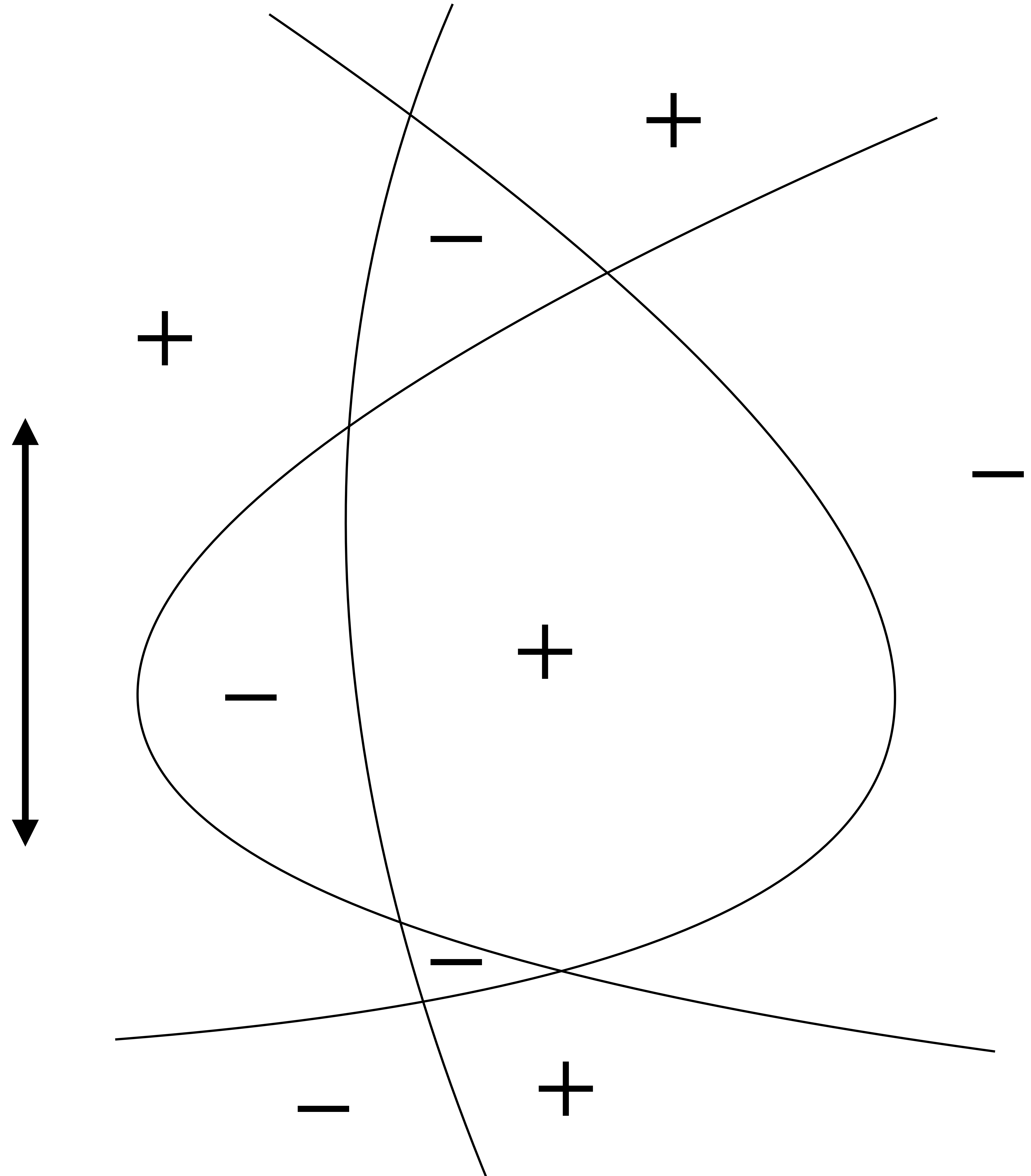


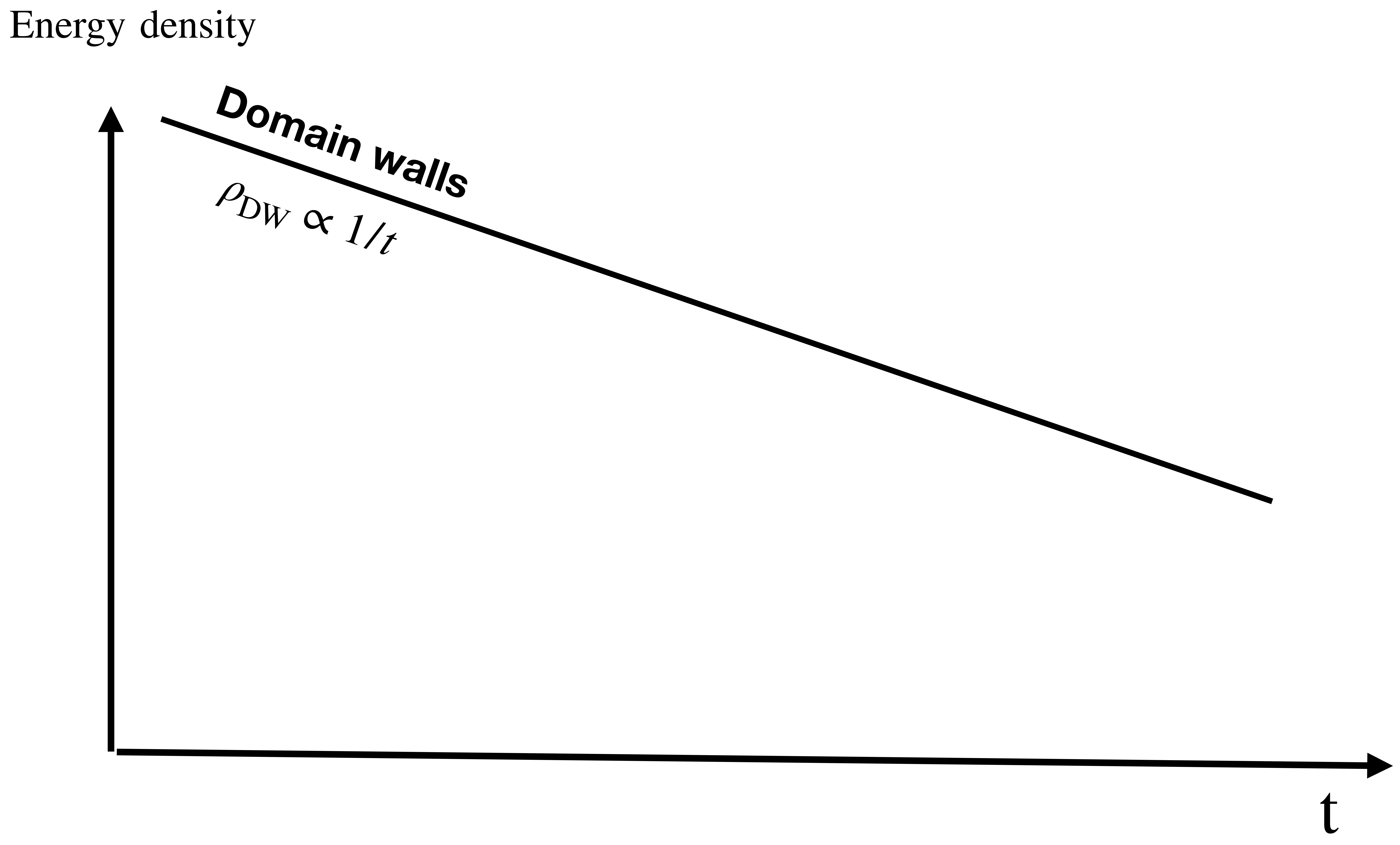


Formation of Domain Wall

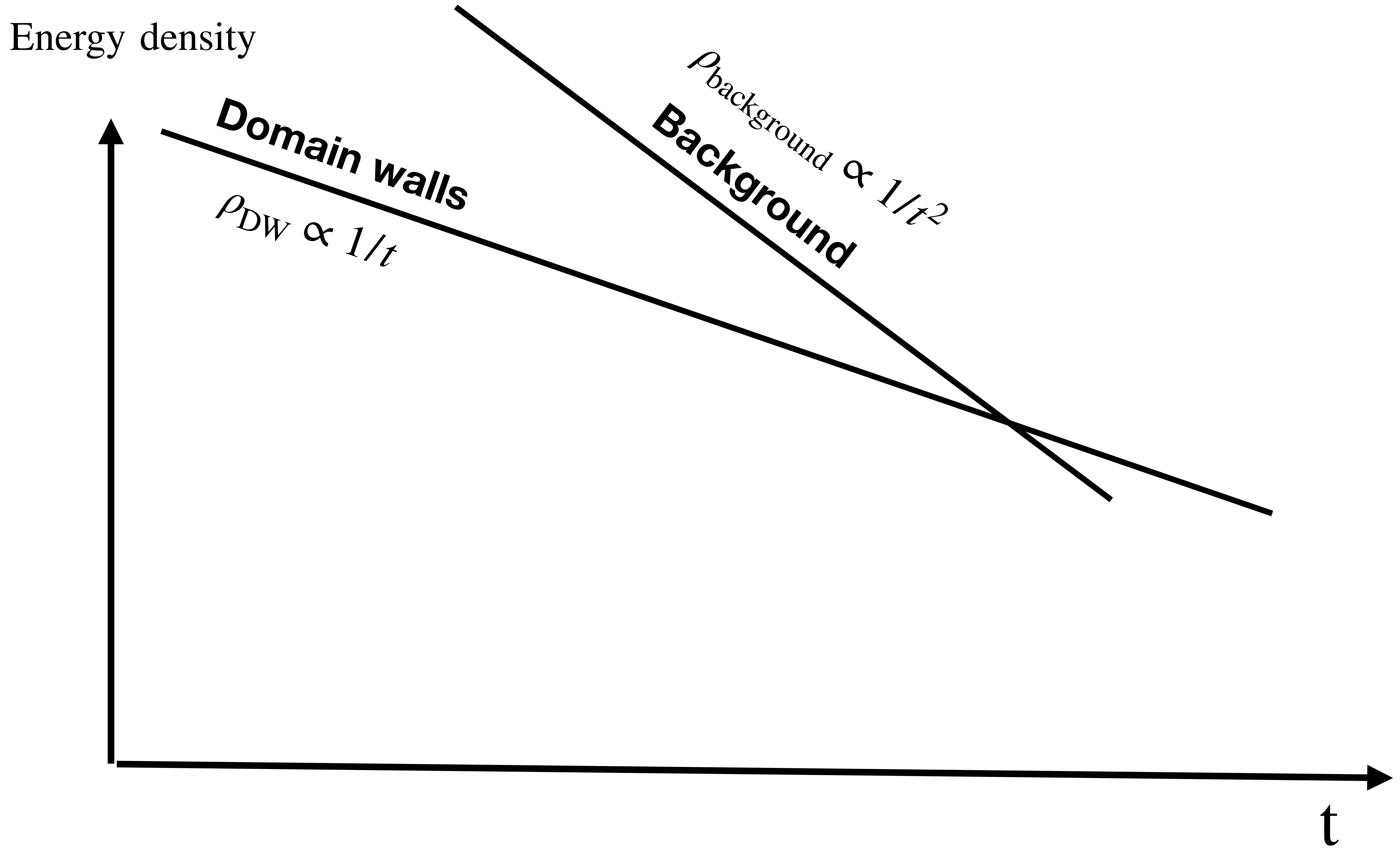
Scaling regime : $R \simeq t$

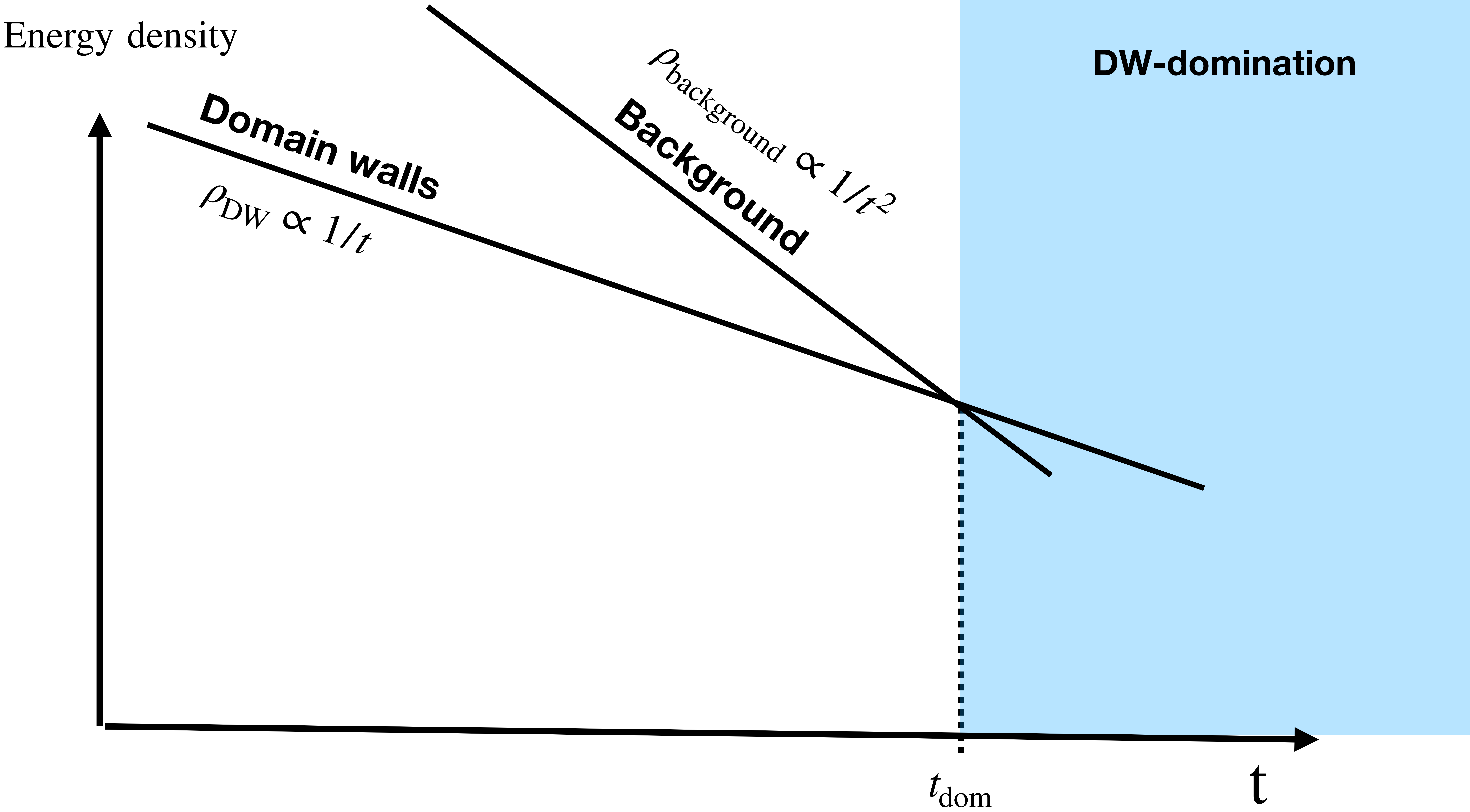
$$\rho_{\mathrm{DW}} \simeq \frac{\sigma}{\mathrm{R}} \simeq \frac{\sigma}{\mathrm{t}}$$





Energy density
Domain walls
$\rho_{\rm DW} \propto 1/t$
t

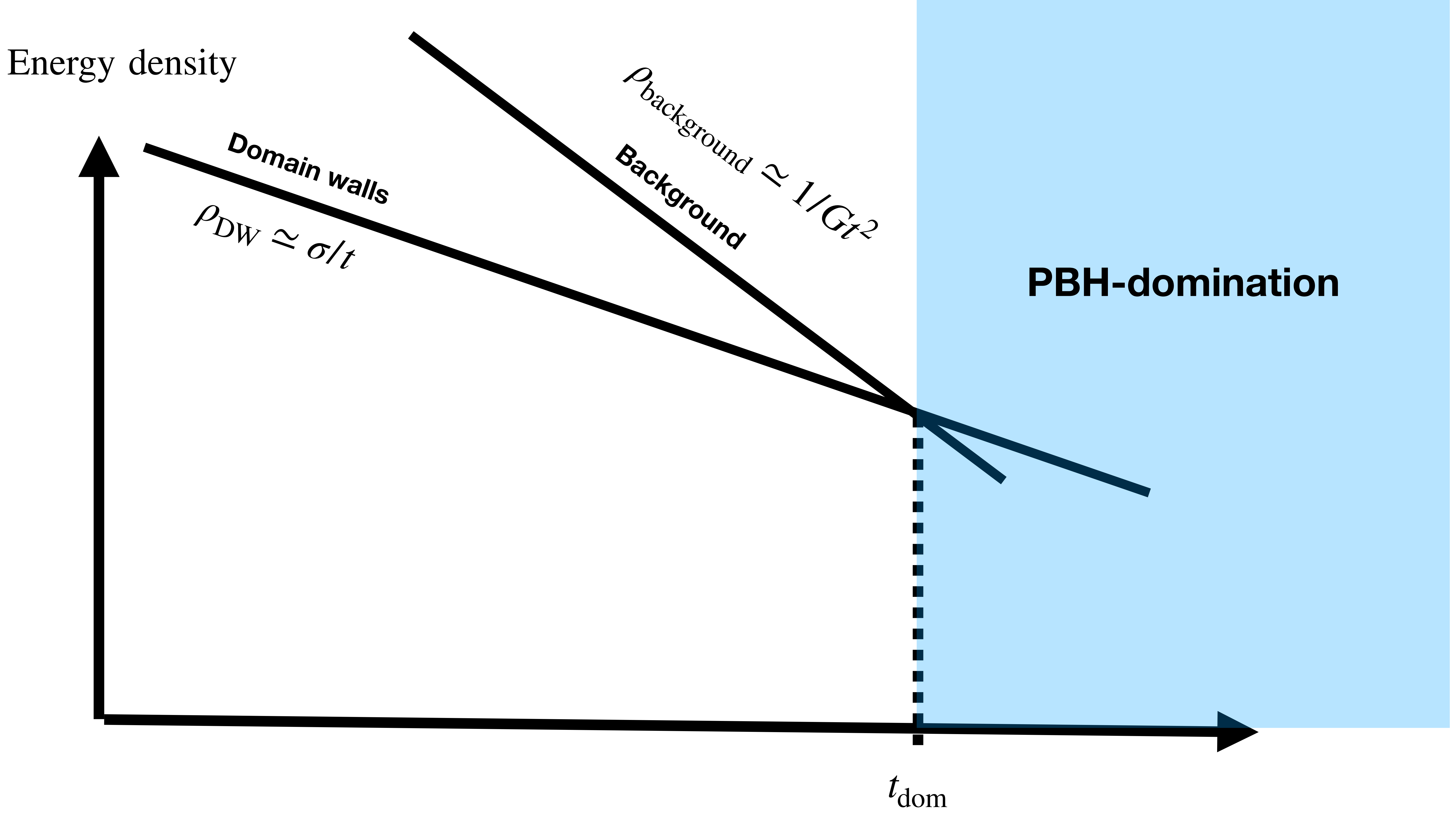

Energy density
Domain walls
$\rho_{\rm DW} \propto 1/t$
$\rho_{\rm background} \propto 1/t^2$
Background
t

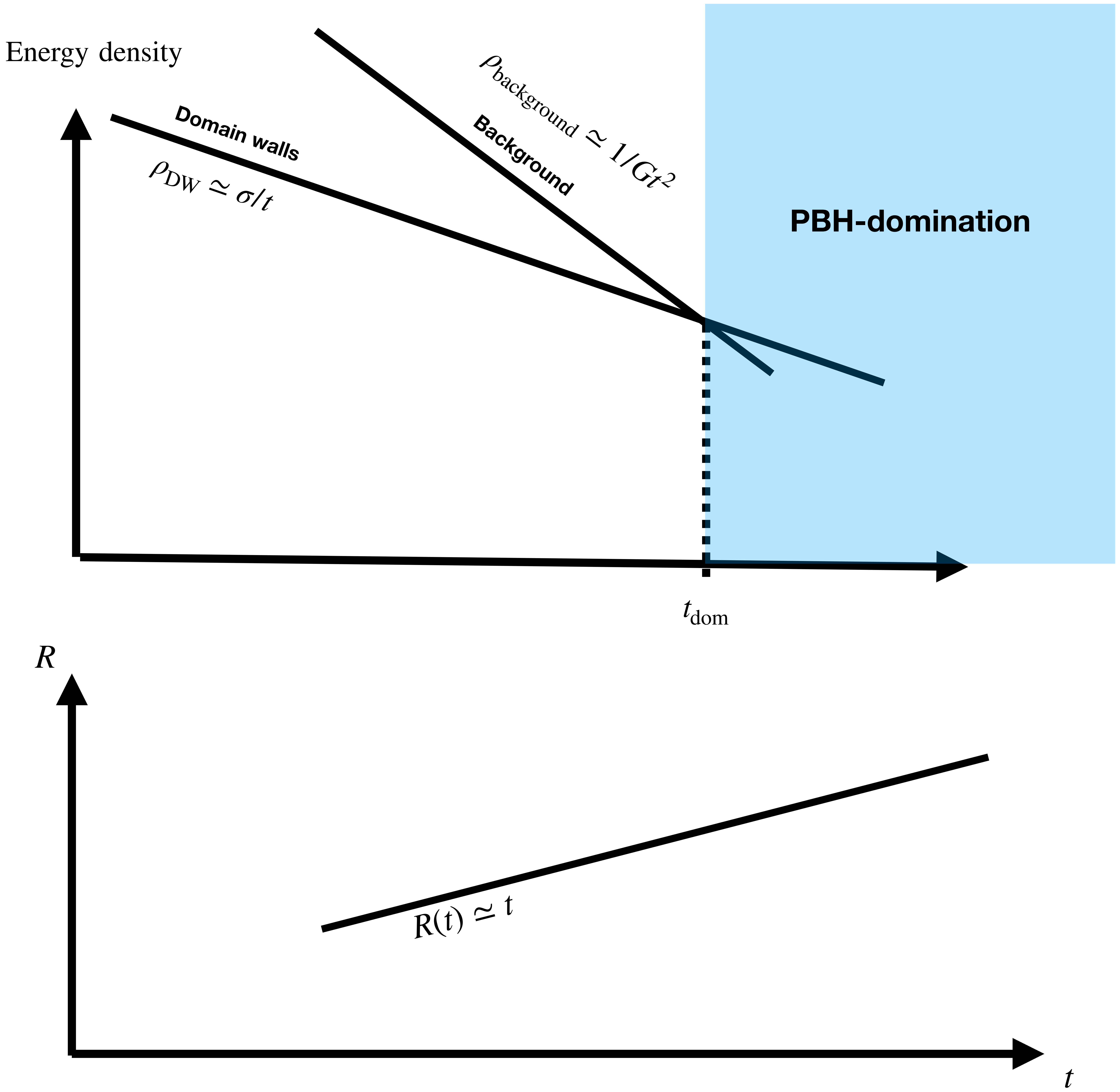

Energy density
Domain walls
$\rho_{\rm DW} \propto 1/t$
$\rho_{\rm background} \propto 1/t^2$
Background
DW-domination
$t_{\rm dom}$
t

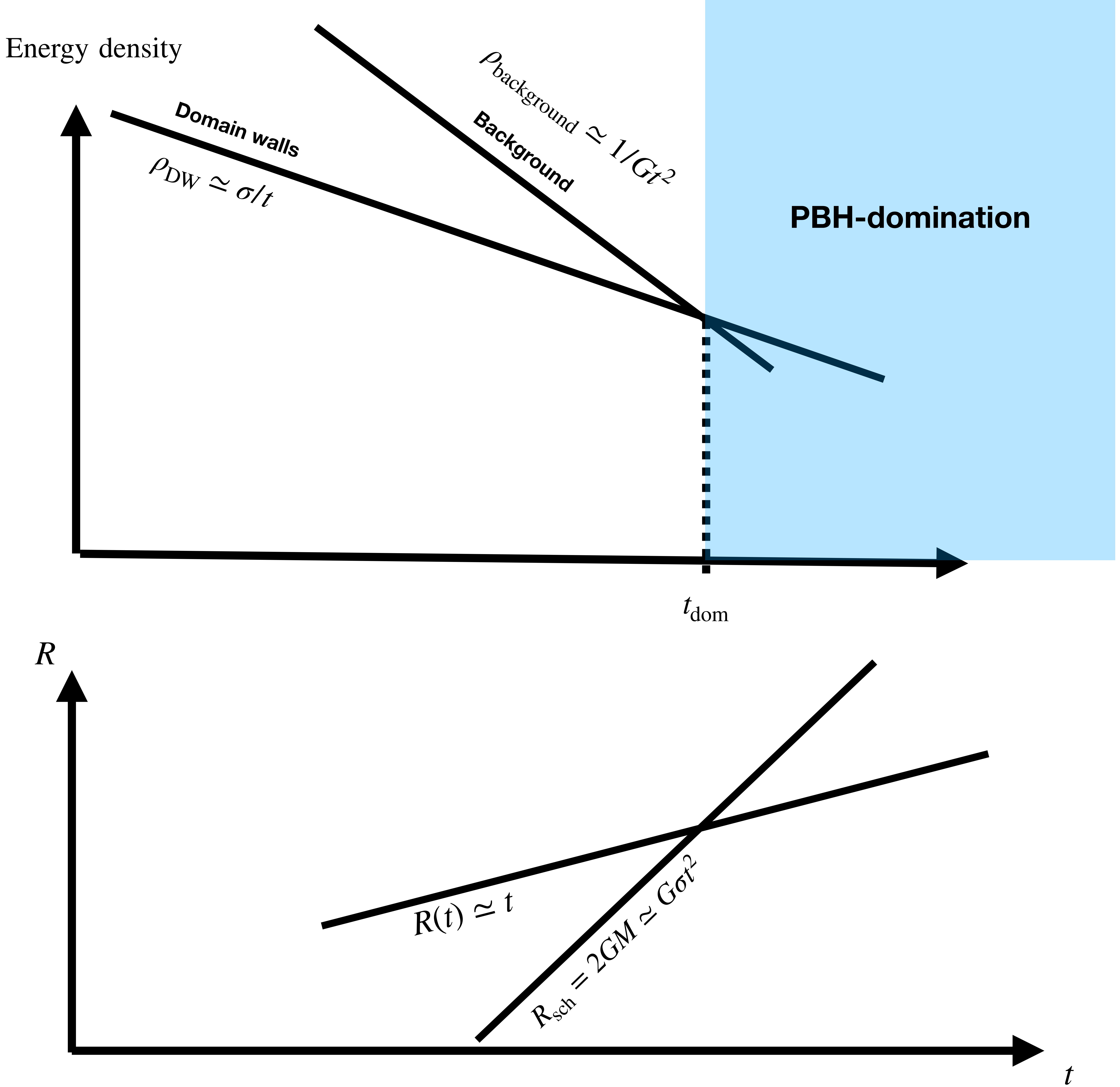
Energy density
Domain walls
$\rho_{\rm DW} \propto 1/t$
$\rho_{\rm background} \propto 1/t^2$
Background
DW-domination
Vilenkin and Shellard
2000, Cambridge University Press
“Observers will see the false vacuum regions bounded by the walls collapse to form black holes. Soon afterwards, the universe will become black-hole dominated”
$t_{\rm dom}$
t

Energy density
$\rho_{\mathrm{background}} \propto 1/t^2$
Background
Domain walls
$\rho_{\mathrm{DW}} \propto 1/t$
DW-domination
Vilenkin and Shellard
2000, Cambridge University Press
"Observers will see the false vacuum regions bounded by the walls collapse to form black holes. Soon afterwards, the universe will become black-hole dominated"
PBH-domination
t_{dom}
t

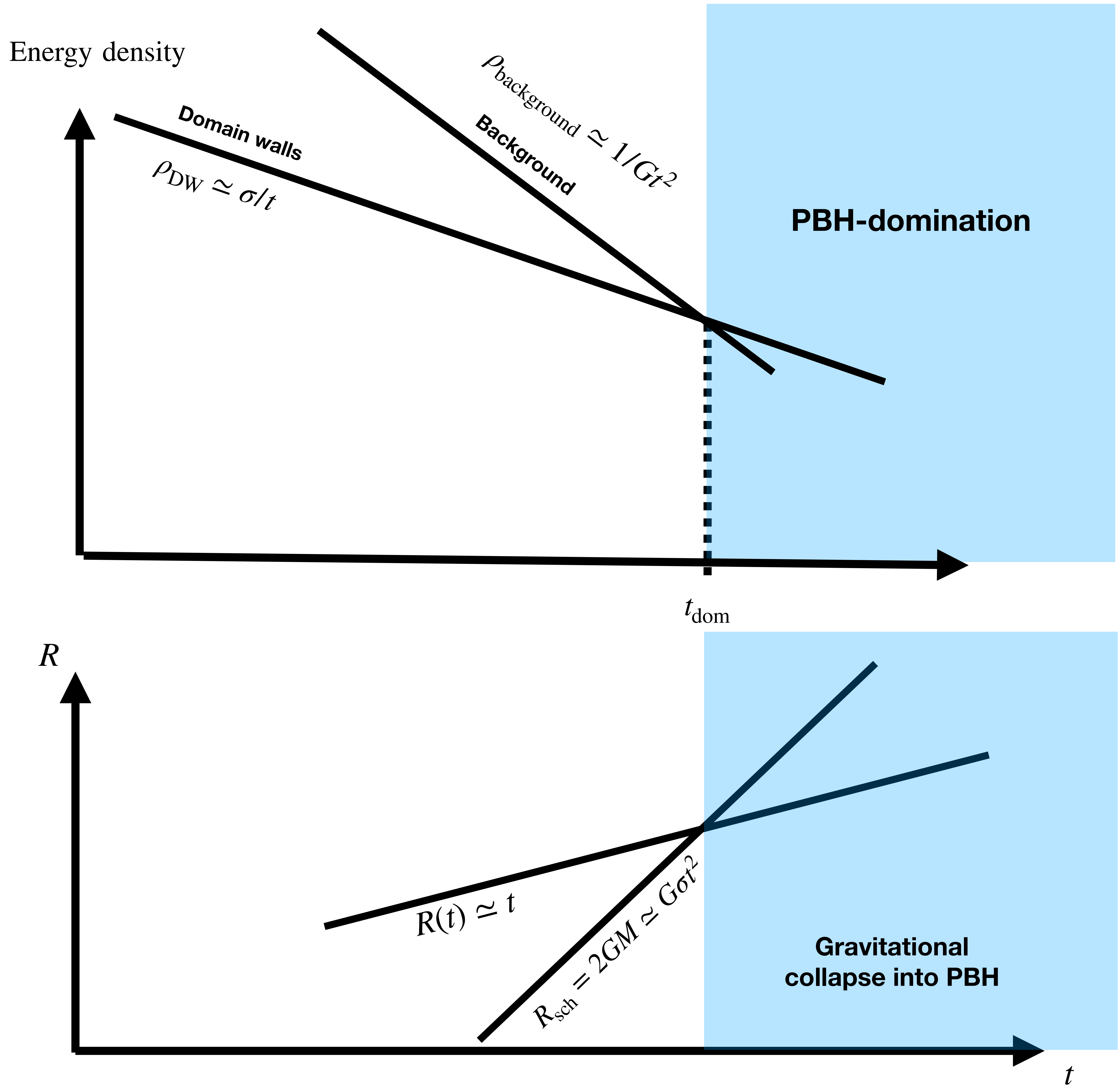
Energy density
Domain walls
$\rho_{\rm DW} \propto 1/t$
$\rho_{\rm background} \propto 1/t^2$
Background
PBH-domination
$t_{\rm dom}$
t


Energy density
Domain walls
$\rho_{\rm DW} \simeq \sigma/t$
Background
$\rho_{\rm background} \simeq 1/Gt^2$
PBH-domination
$t_{\rm dom}$


Energy density
Domain walls
$\rho_{\rm DW} \simeq \sigma/t$
Background
$\rho_{\rm background} \simeq 1/Gt^2$
PBH-domination
$t_{\rm dom}$
R
$R(t) \simeq t$
t



Energy density
$\rho_{\rm background} \simeq 1/Gt^2$
Background
Domain walls
$\rho_{\rm DW} \simeq \sigma/t$
PBH-domination
$t_{\rm dom}$
R
$R(t) \simeq t$
$R_{\rm sch} = 2GM \simeq G\sigma t^2$
t

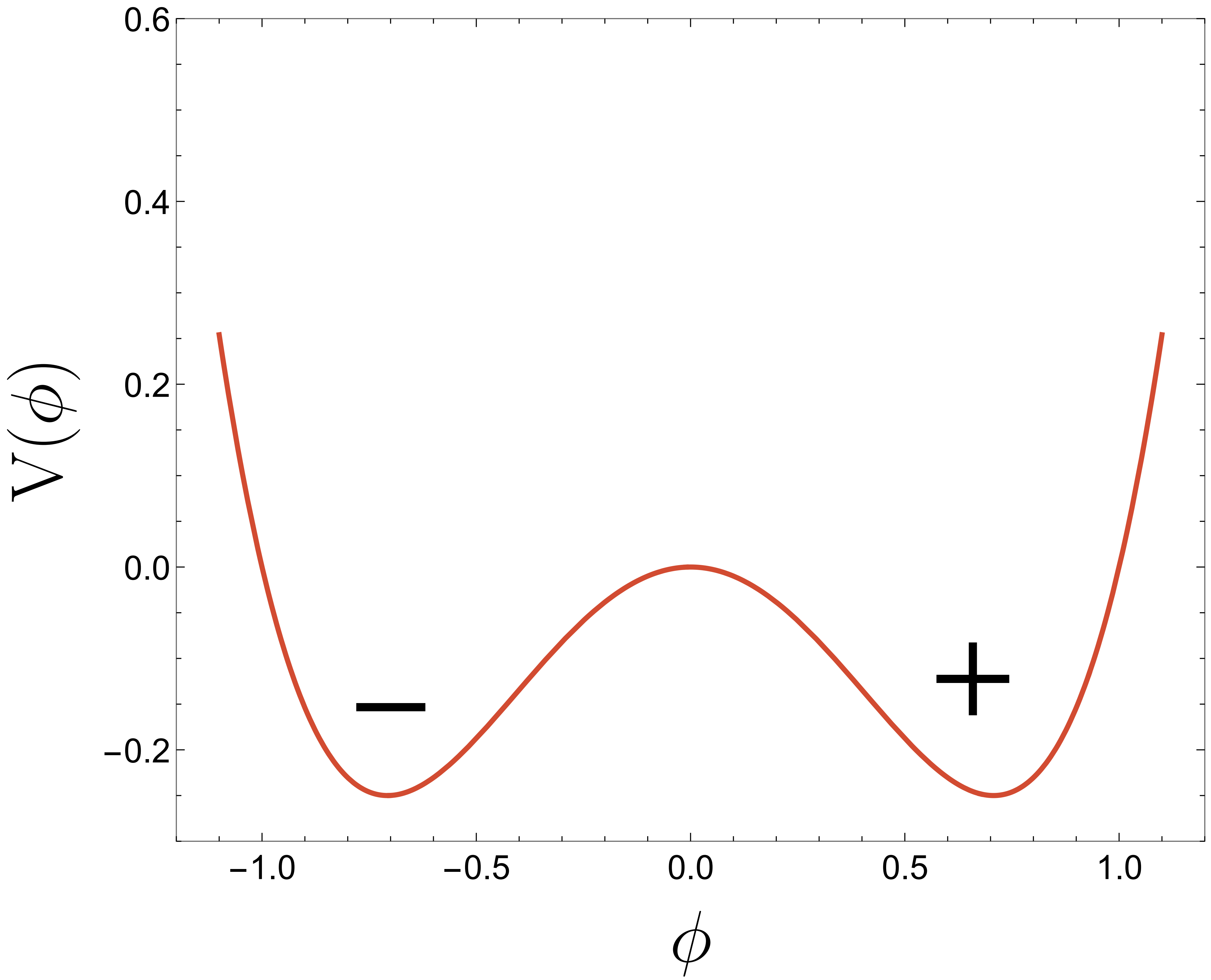


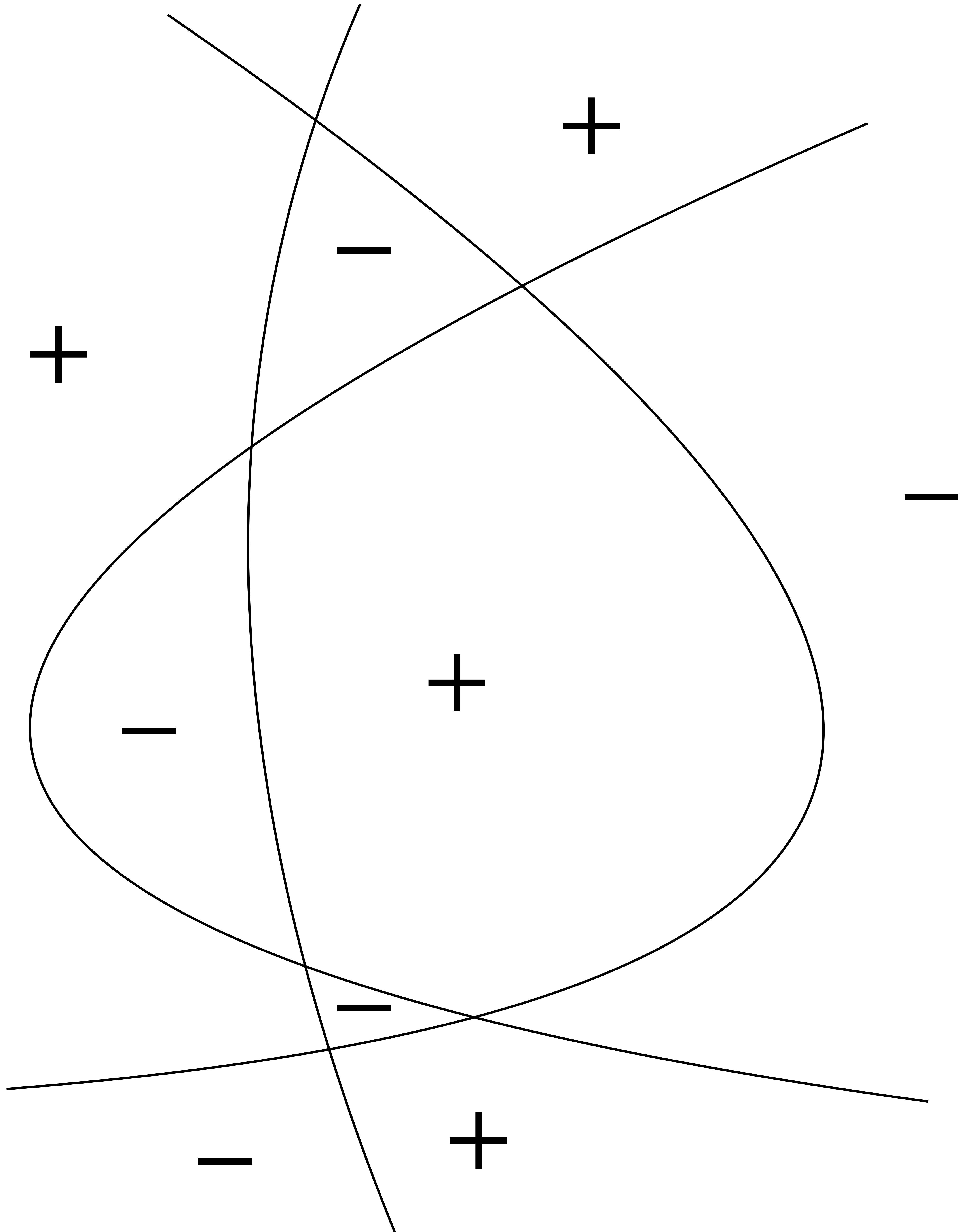
Energy density
$\rho_{\rm background} \simeq 1/Gt^2$
Background
Domain walls
$\rho_{\rm DW} \simeq \sigma/t$
PBH-domination
$t_{\rm dom}$
R
$R(t) \simeq t$
$R_{\rm sch} = 2GM \simeq G\sigma t^2$
Gravitational
collapse into PBH
t

Formation of Domain Wall

$$V(\phi) = \lambda(\phi^2 - v_\phi^2)^2$$

Break $\mathbb{Z}_2$

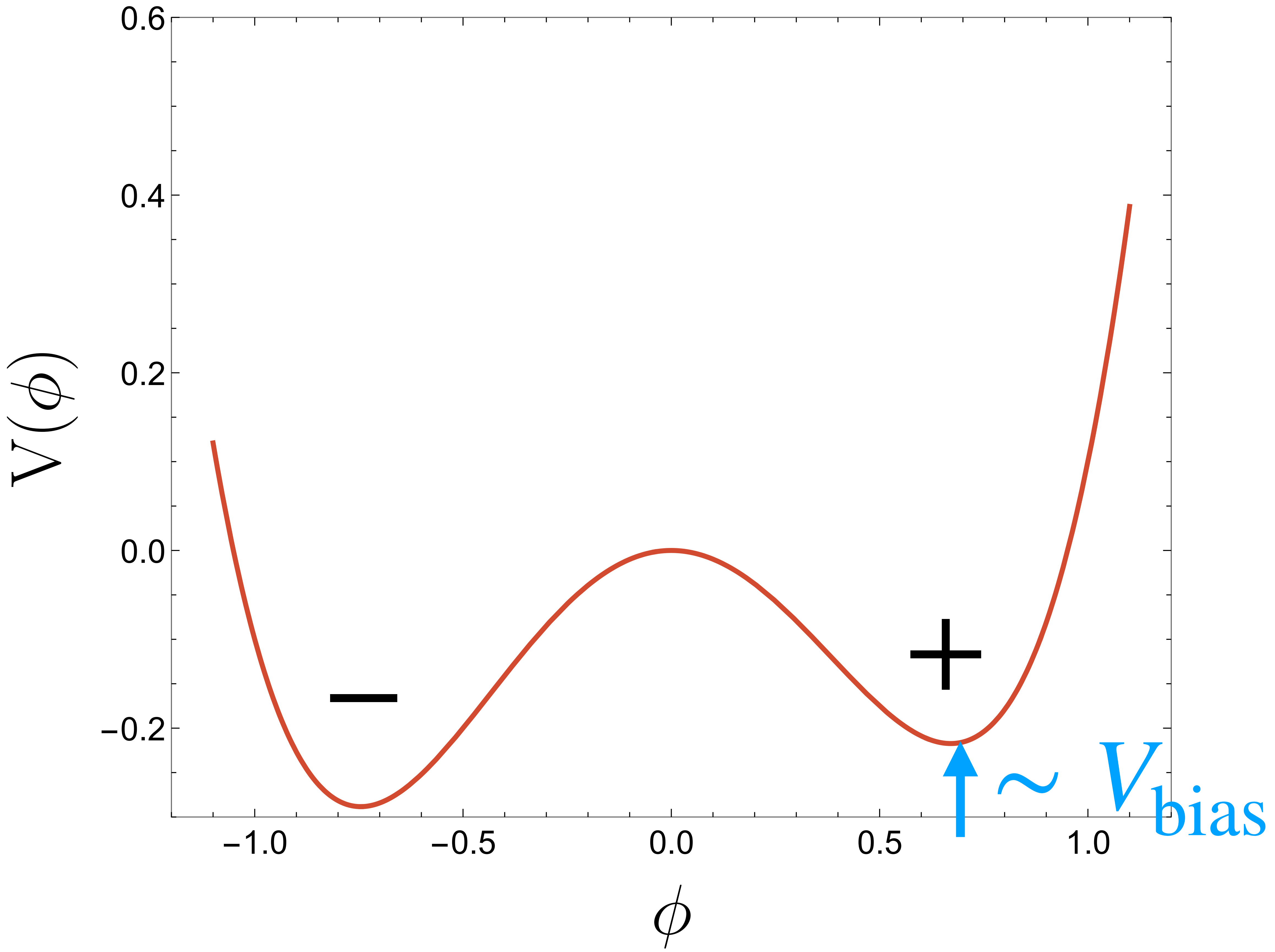


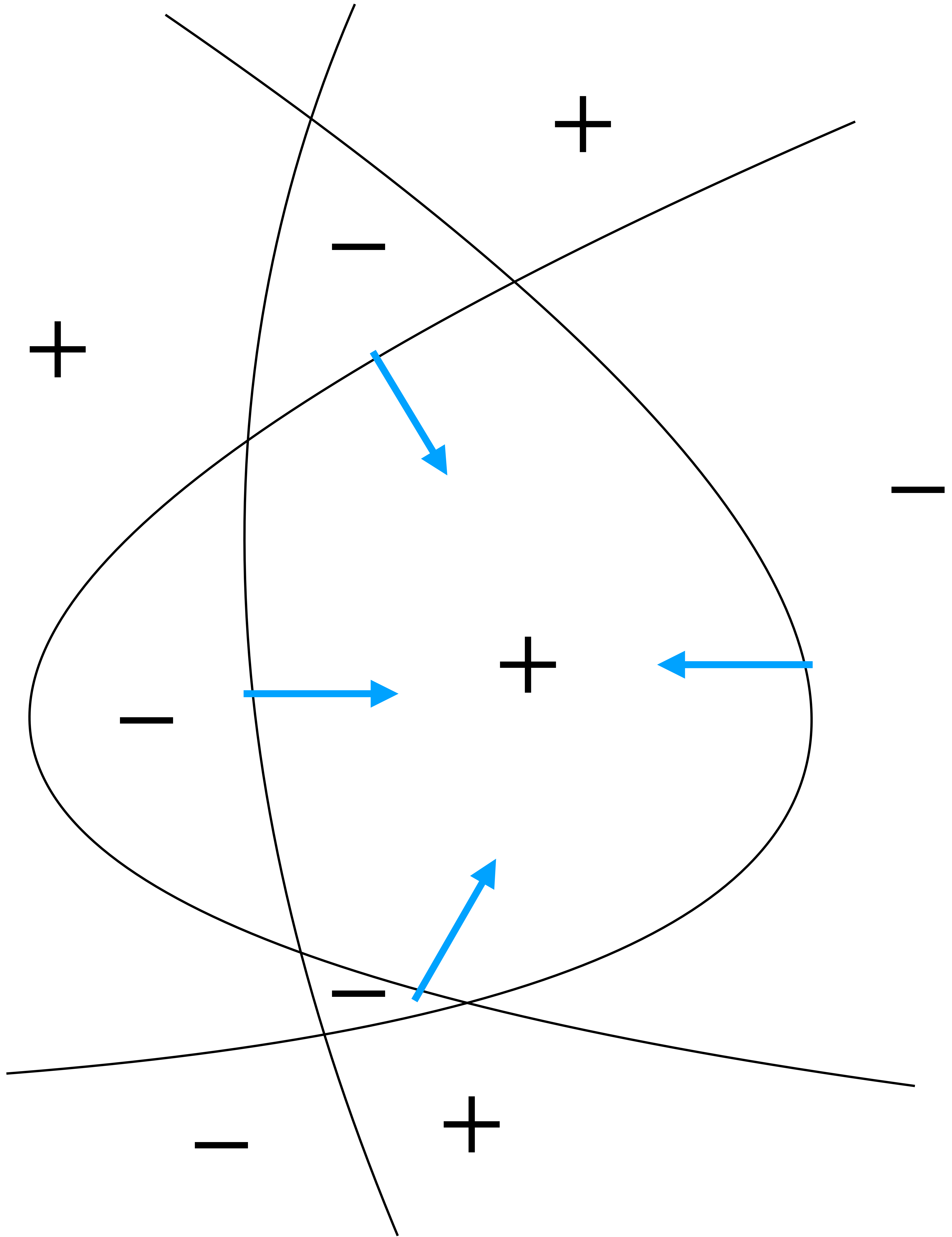


Formation of Domain Wall

$$V(\phi) = \lambda(\phi^2 - v_\phi^2)^2 + \epsilon\phi^3$$

Break $\mathbb{Z}_2$



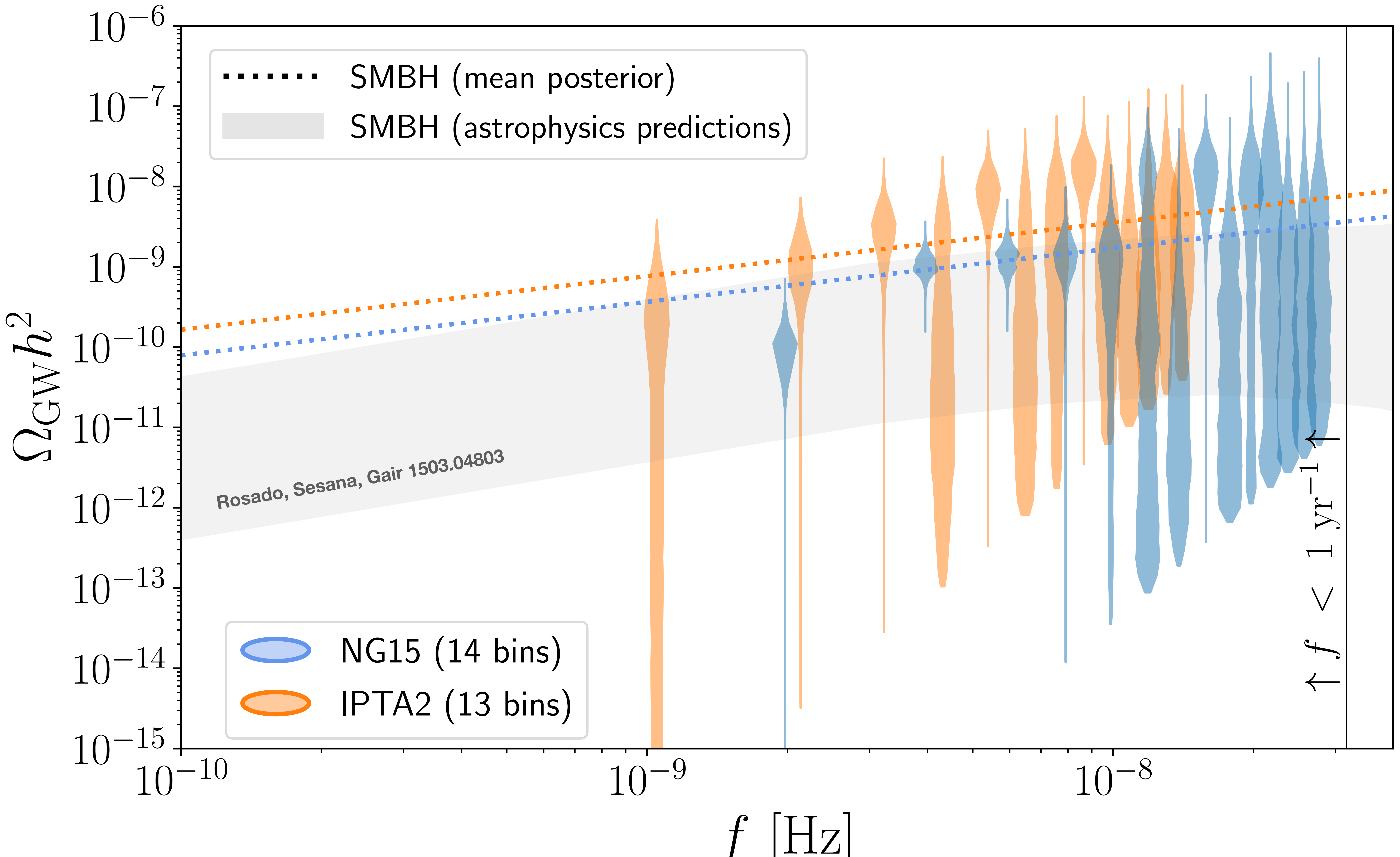


Energy density
Domain walls
$\rho_{\rm DW} \propto 1/t$
Background
$\rho_{\rm background} \propto 1/t^2$
PBH-domination
$t_{\rm dom}$

Energy density
Domain walls
$\rho_{\rm DW} \propto 1/t$
$\rho_{\rm background} \propto 1/t^2$
Background
PBH-domination
Annihilation
$t_{\rm ann}$
$t_{\rm dom}$

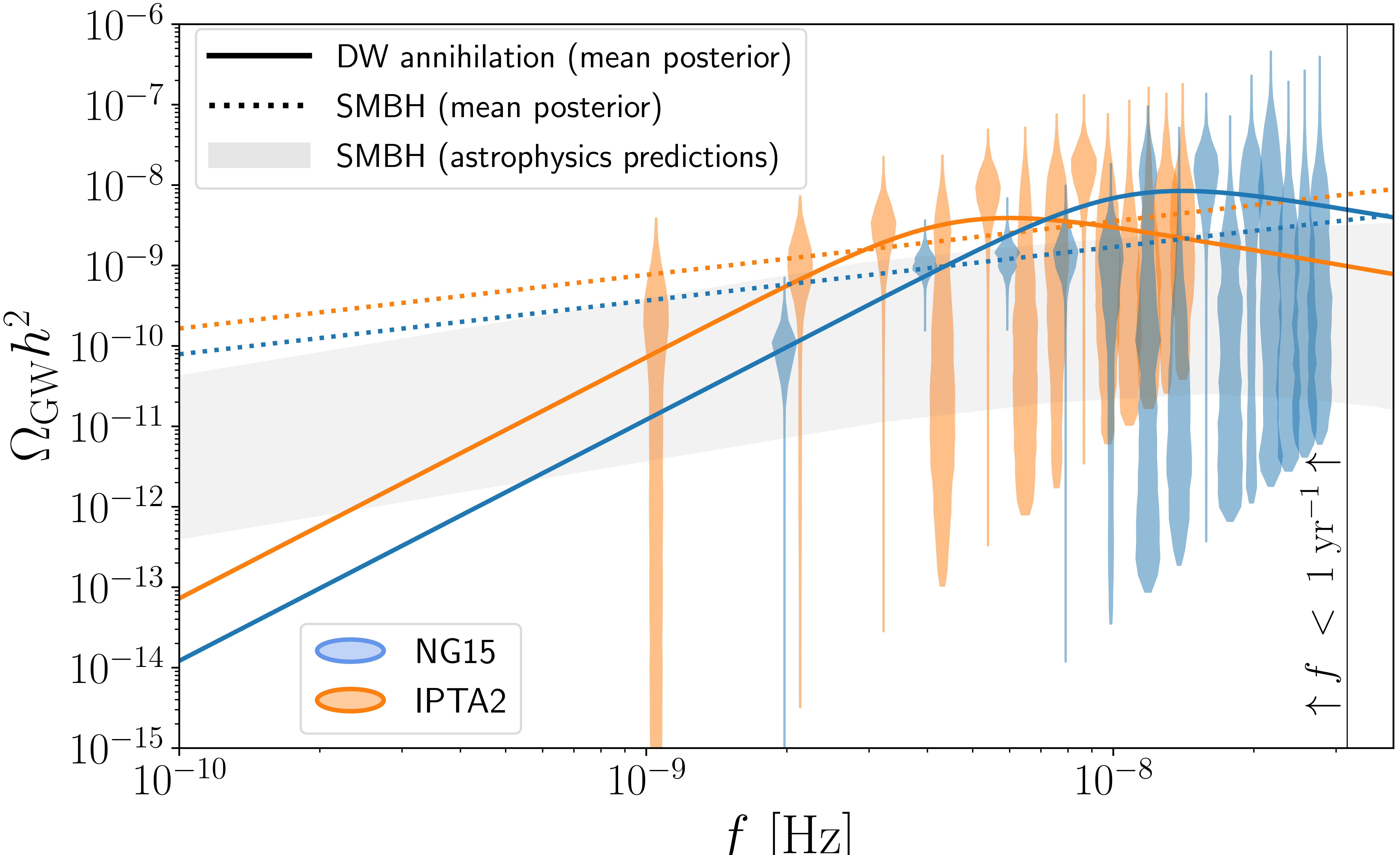
Energy density
Domain walls
$\rho_{\rm DW} \propto 1/t$
$\rho_{\rm background} \propto 1/t^2$
Background
Gravitational waves
PBH-domination
Annihilation
$t_{\rm ann}$
$t_{\rm dom}$

GW from DW annihilation in Pulsar Timing arrays



GW from DW annihilation in Pulsar Timing arrays

YG, E. Vitagliano, 2306.17841



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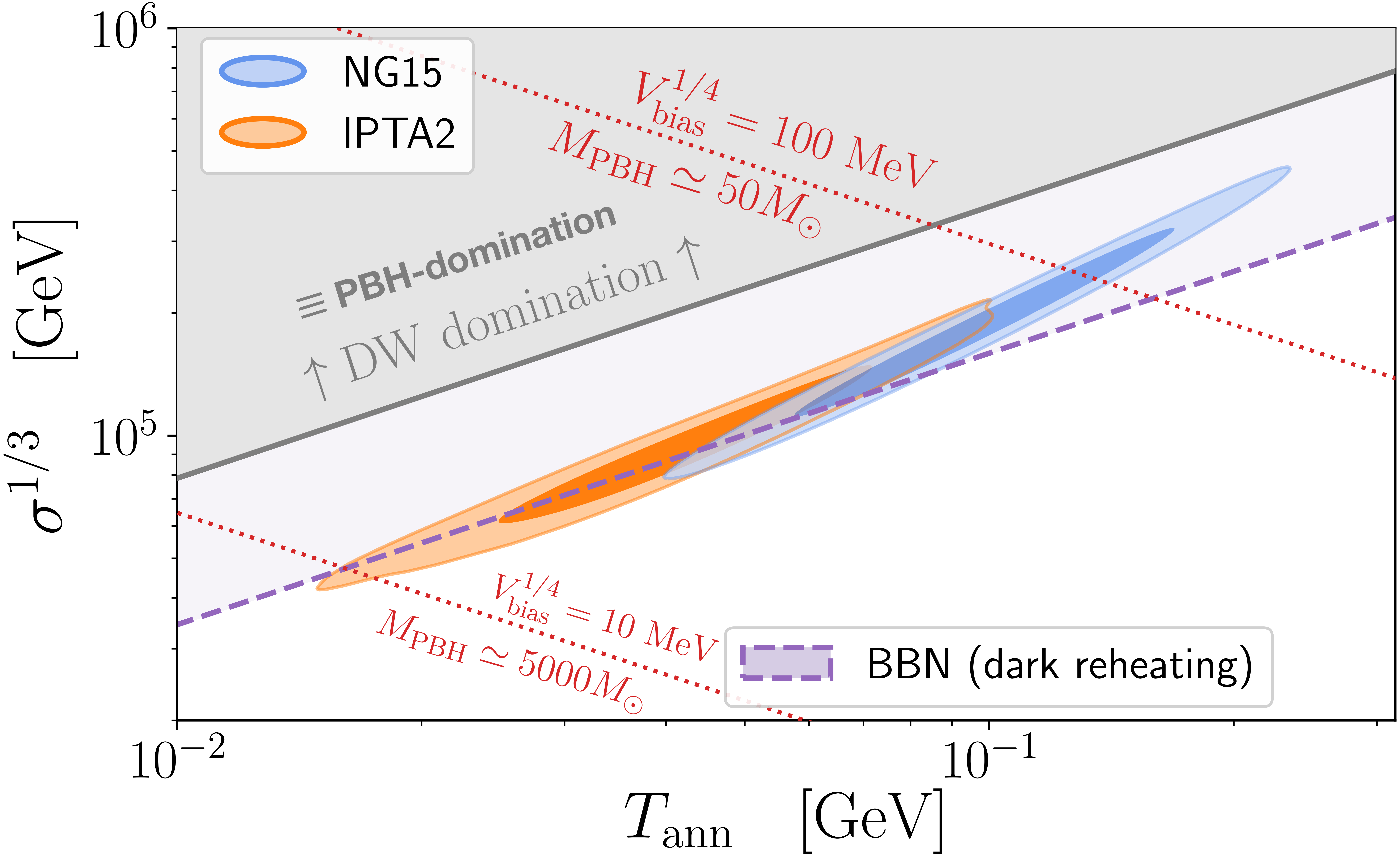

Energy density
Domain walls
$\rho_{\rm DW} \propto 1/t$
$\rho_{\rm background} \propto 1/t^2$
Background
Gravitational waves
PBH-domination
$t_{\rm ann}$
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Lattice results
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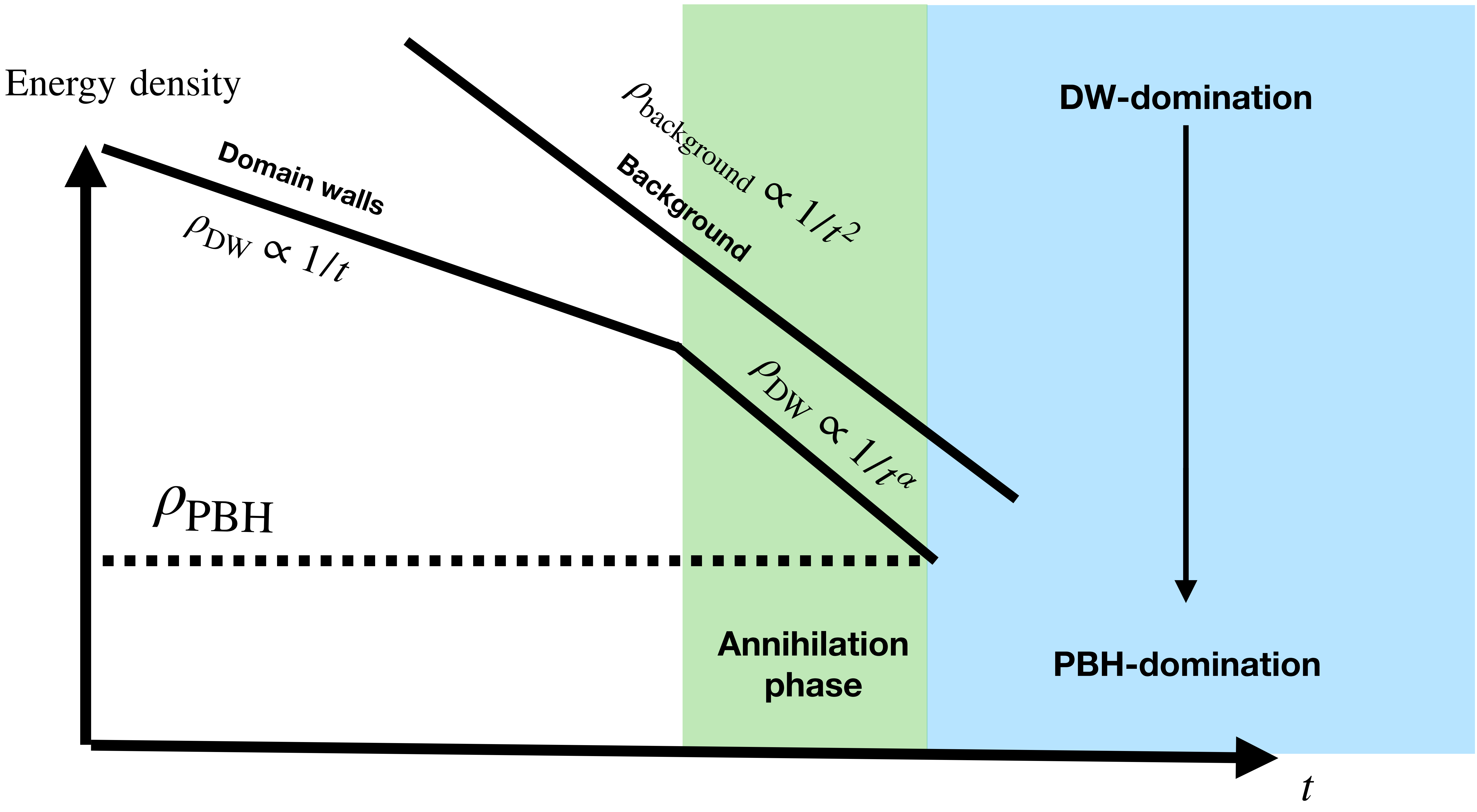

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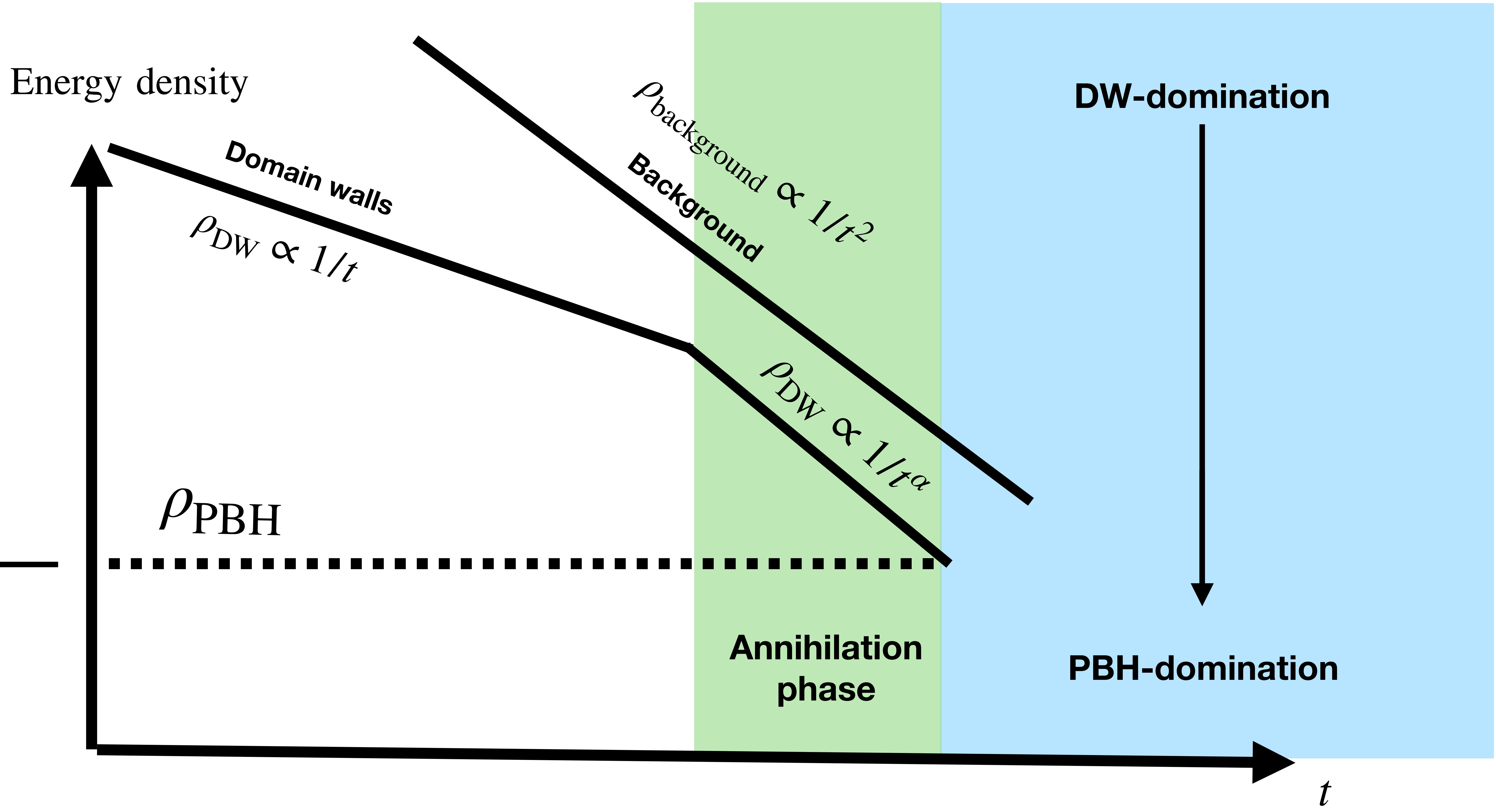

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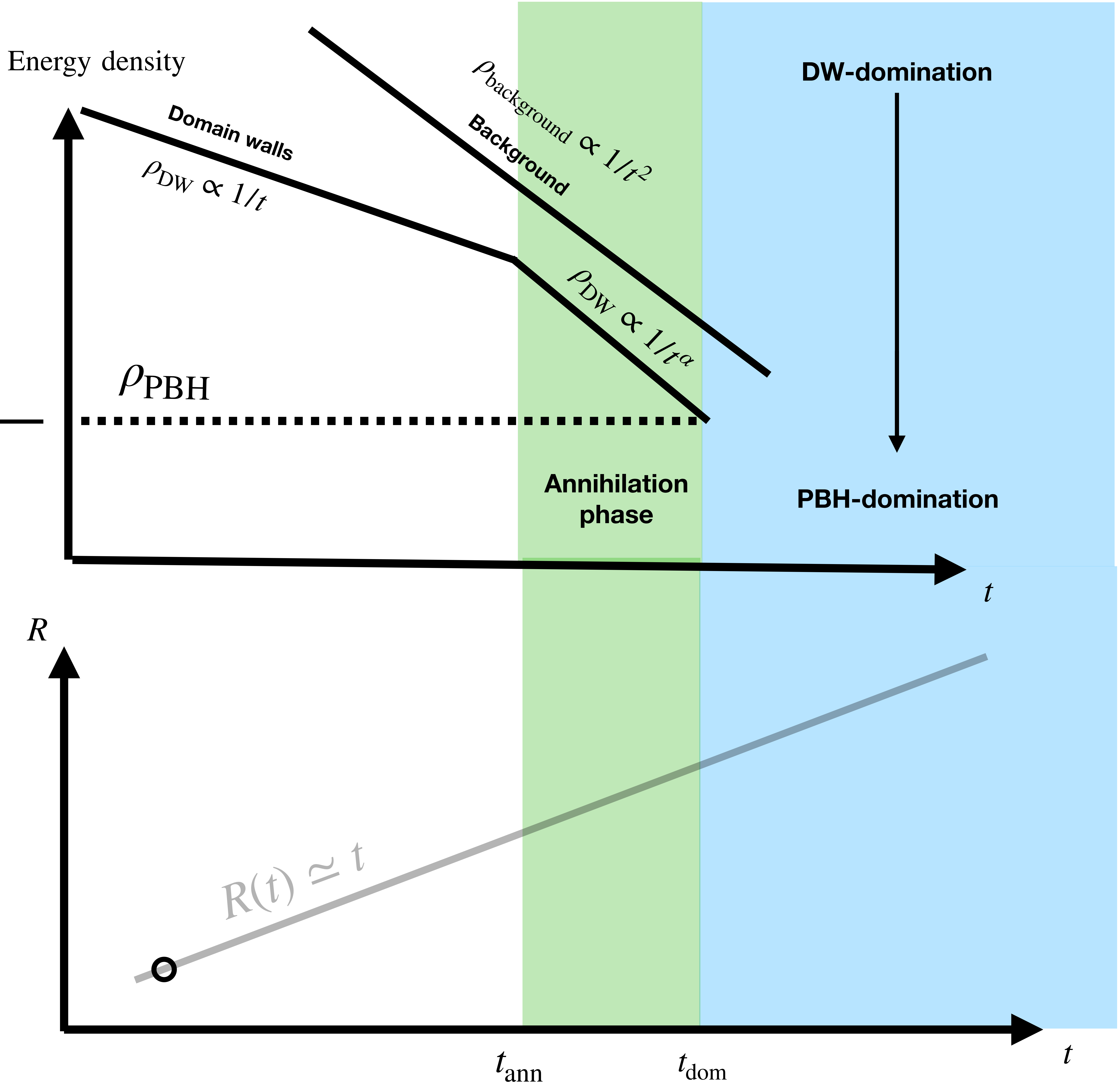

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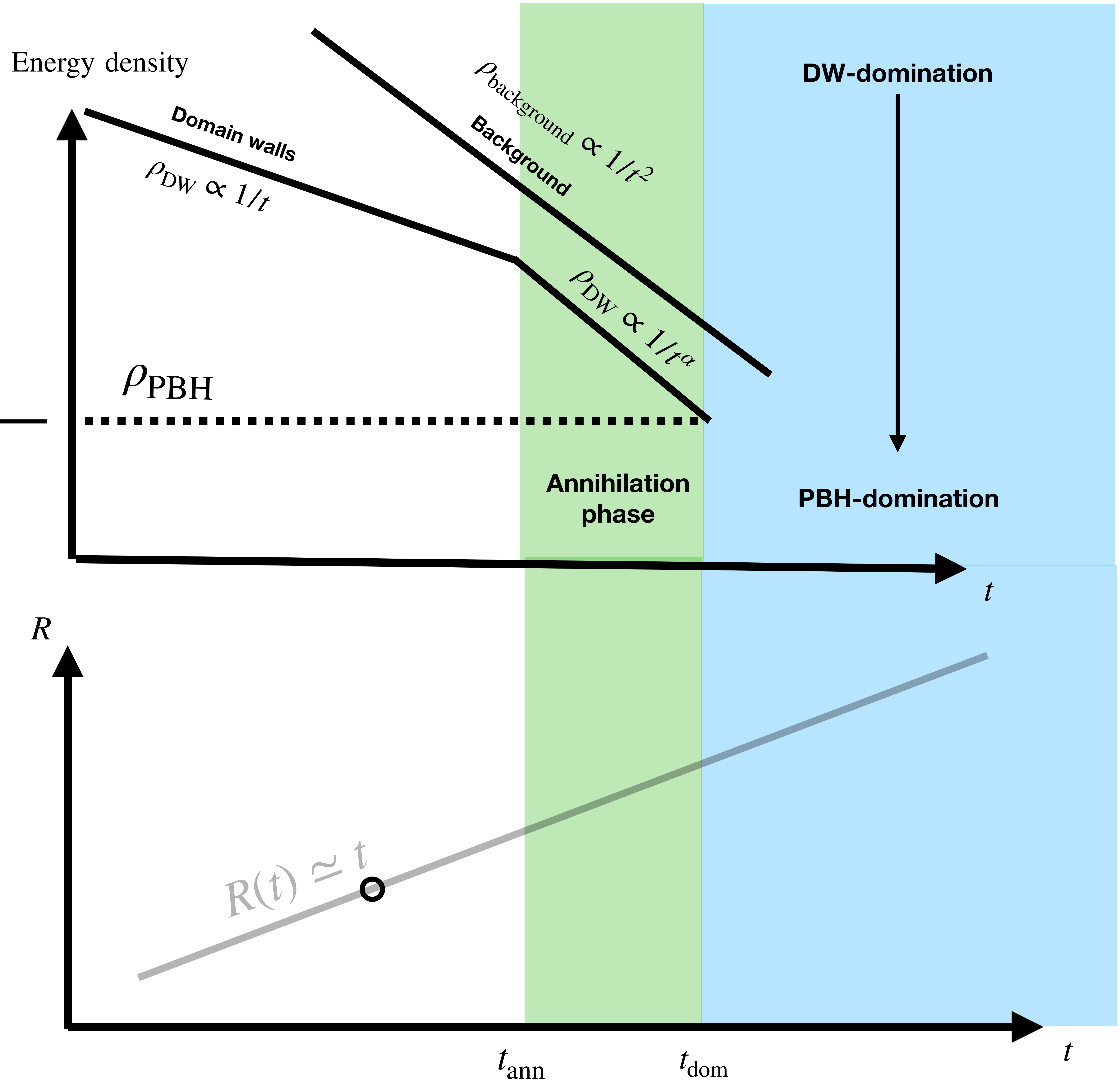

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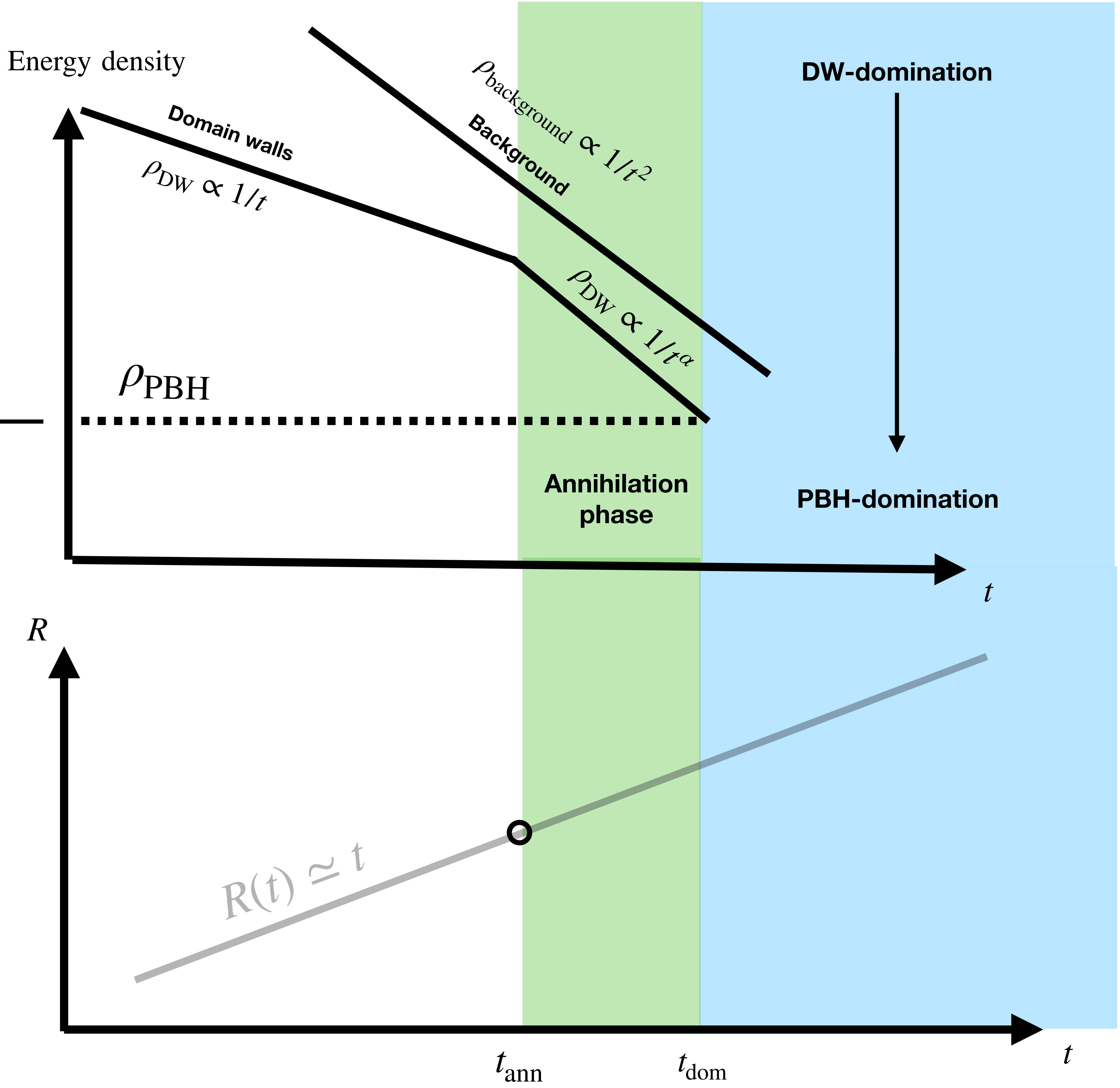

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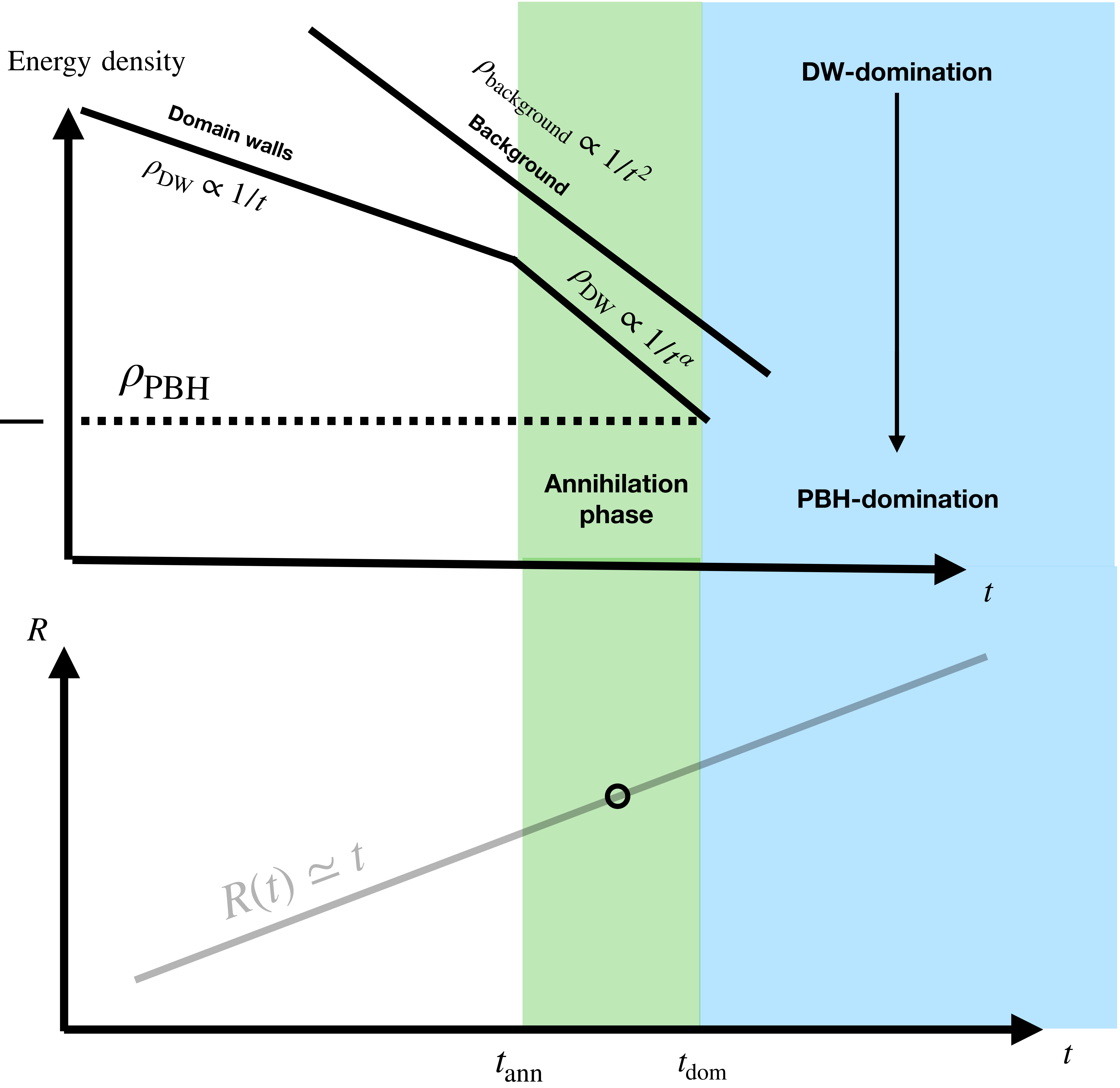

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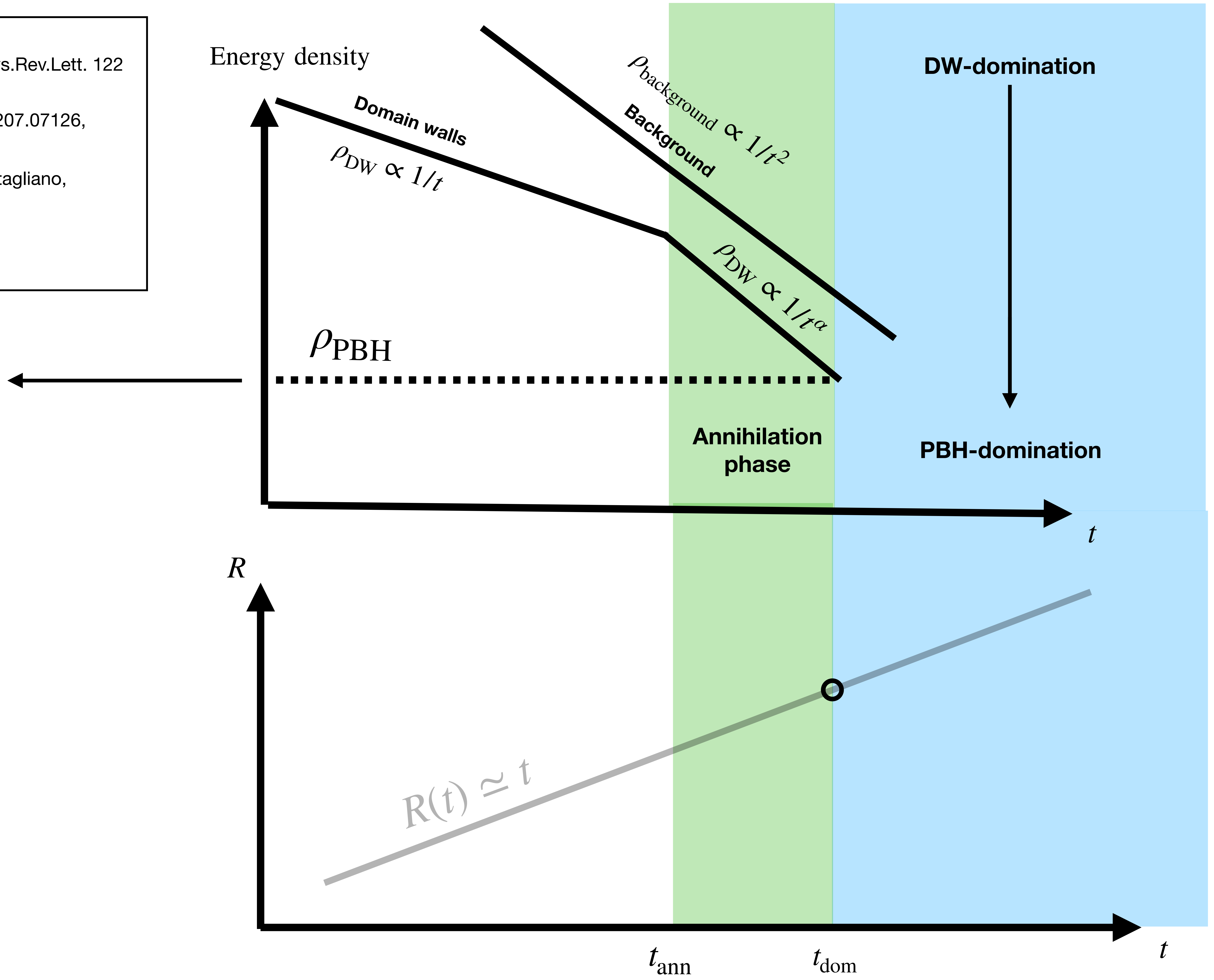

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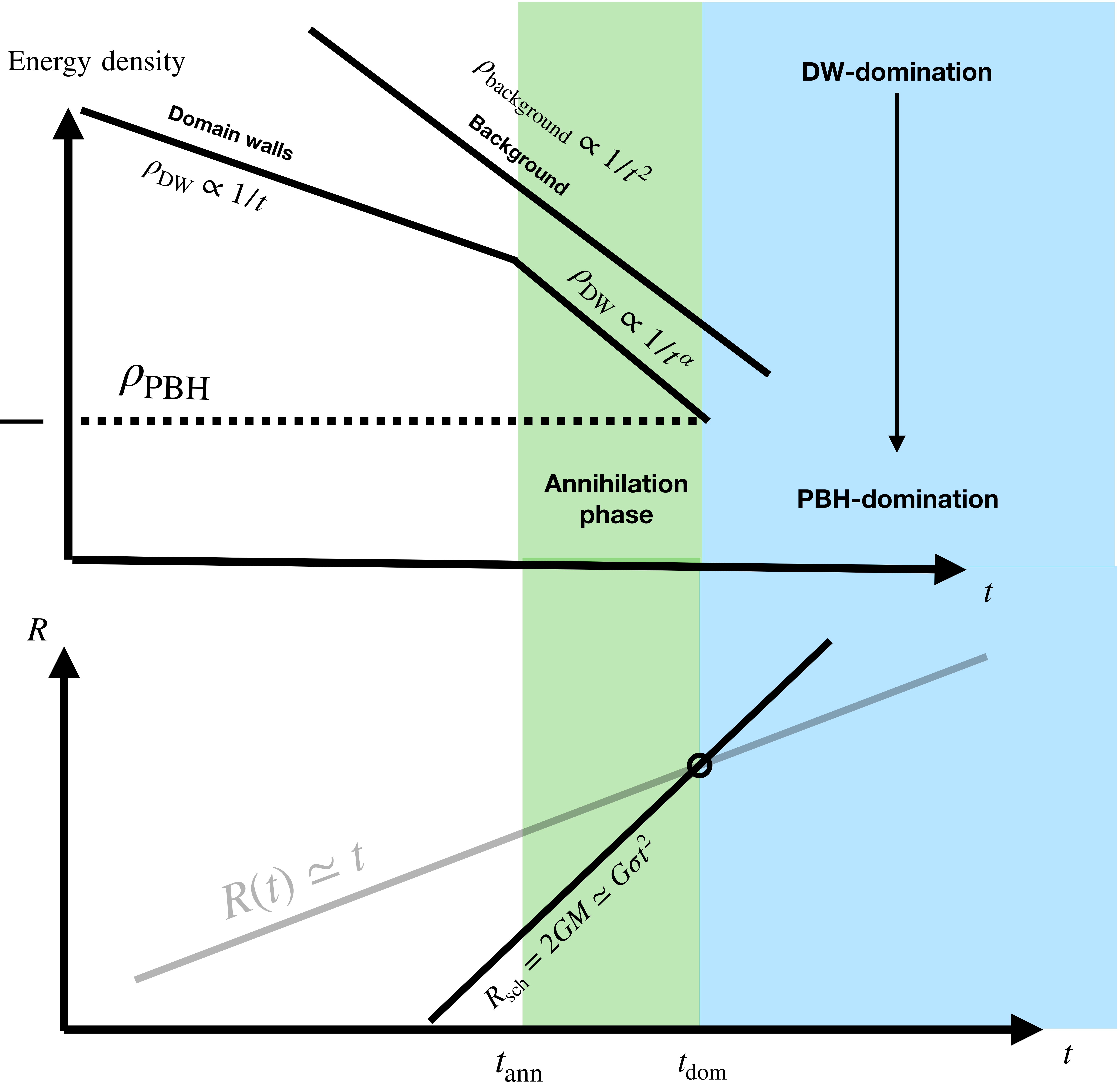

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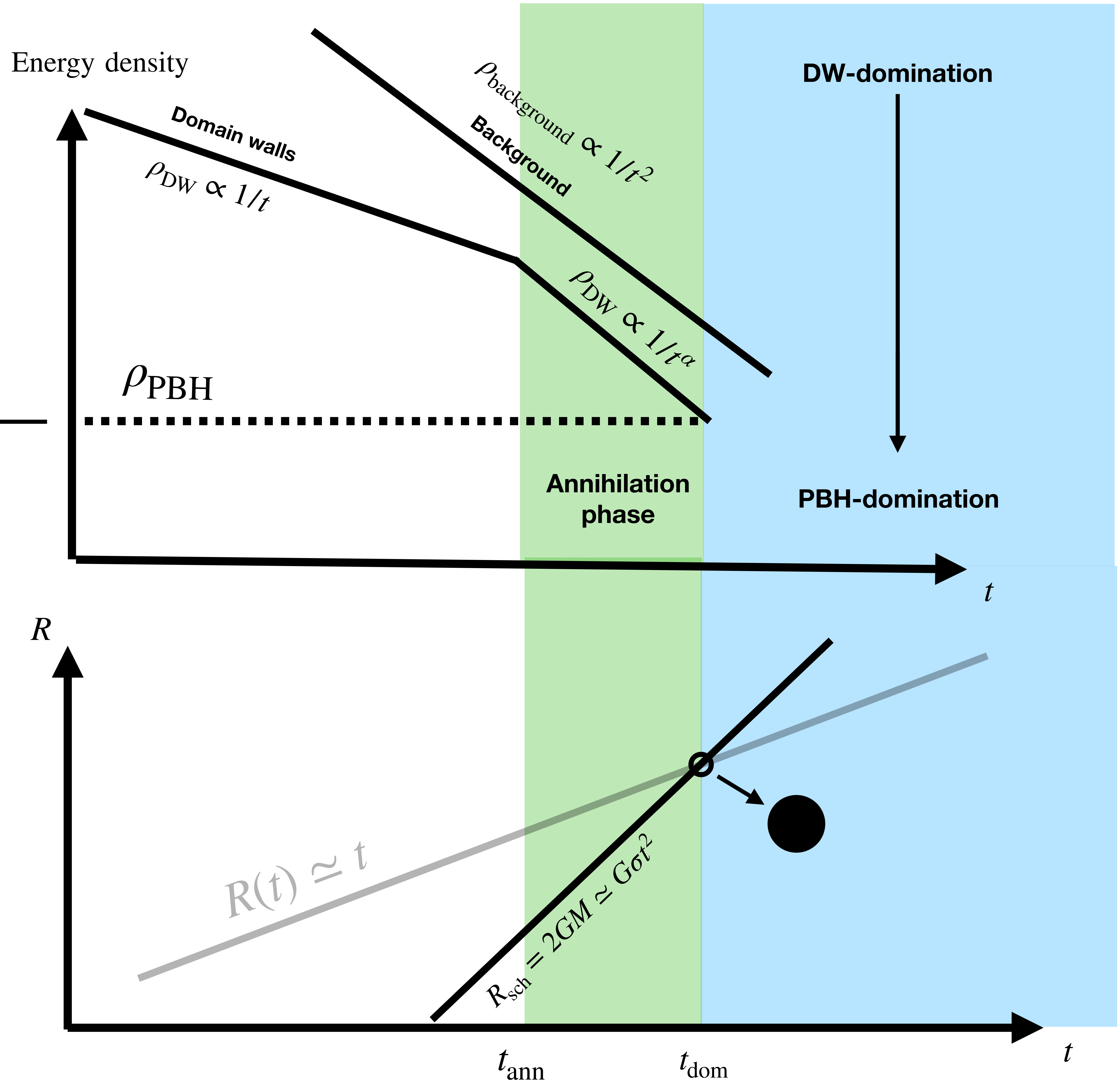

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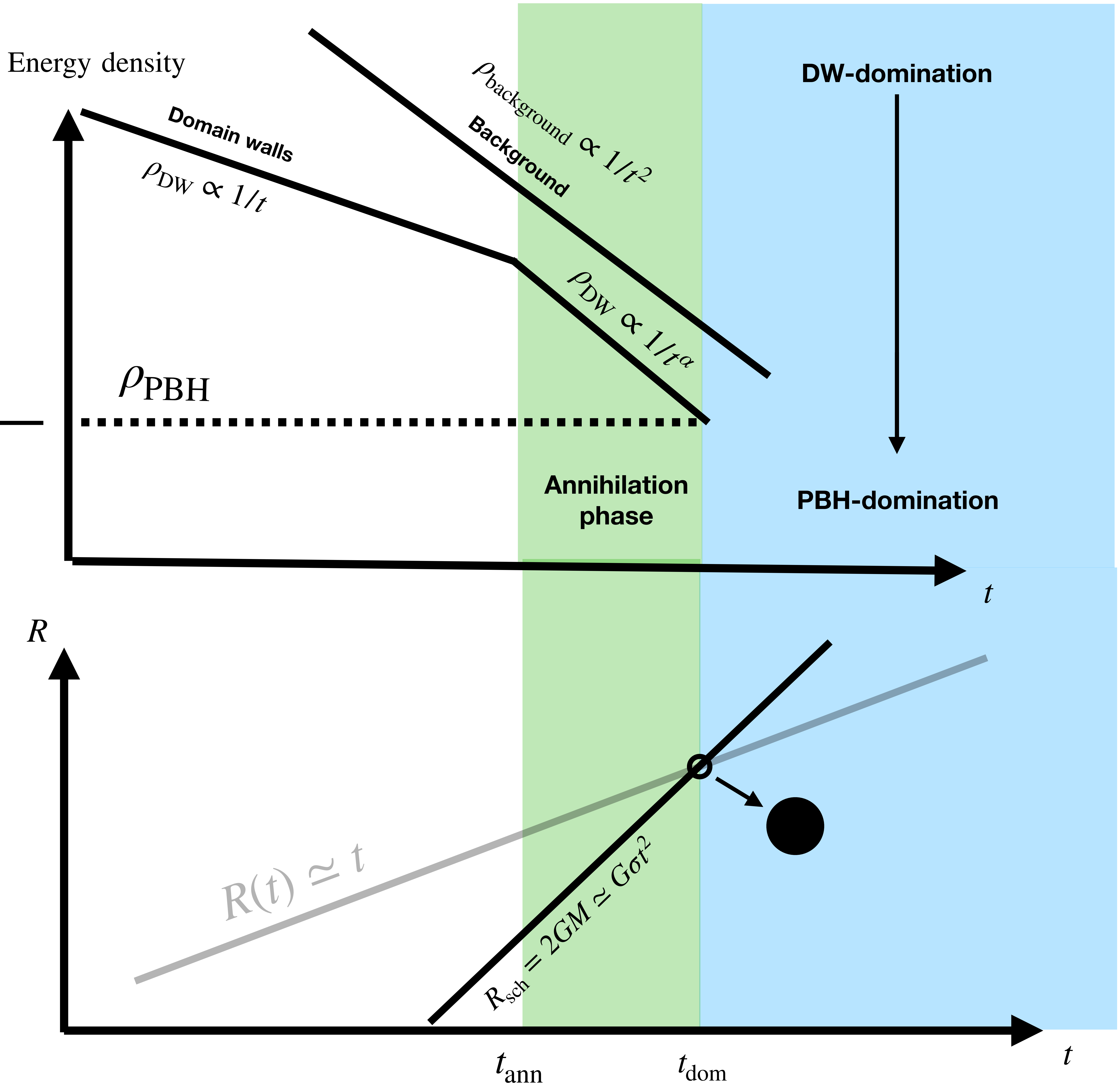

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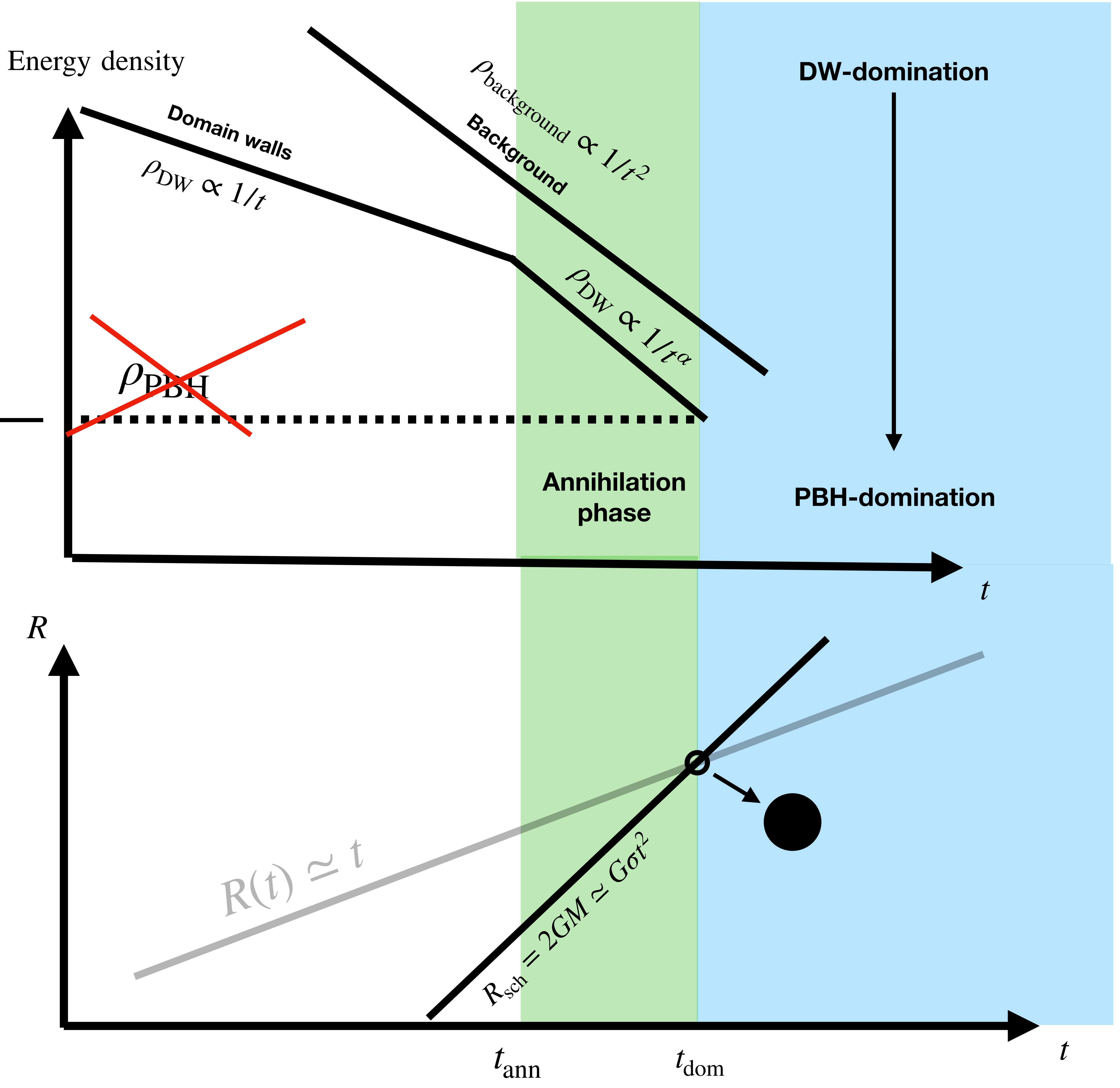

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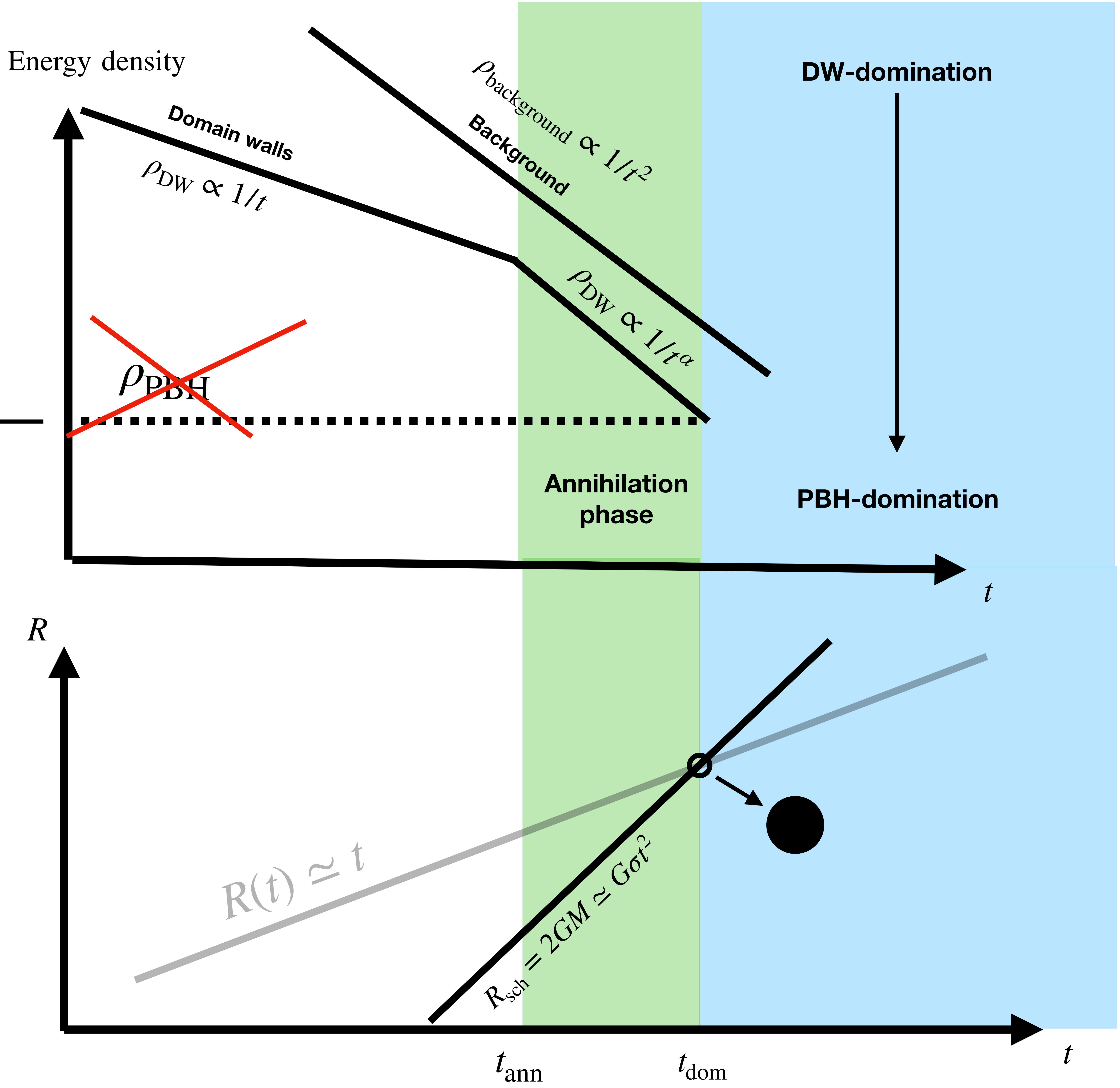

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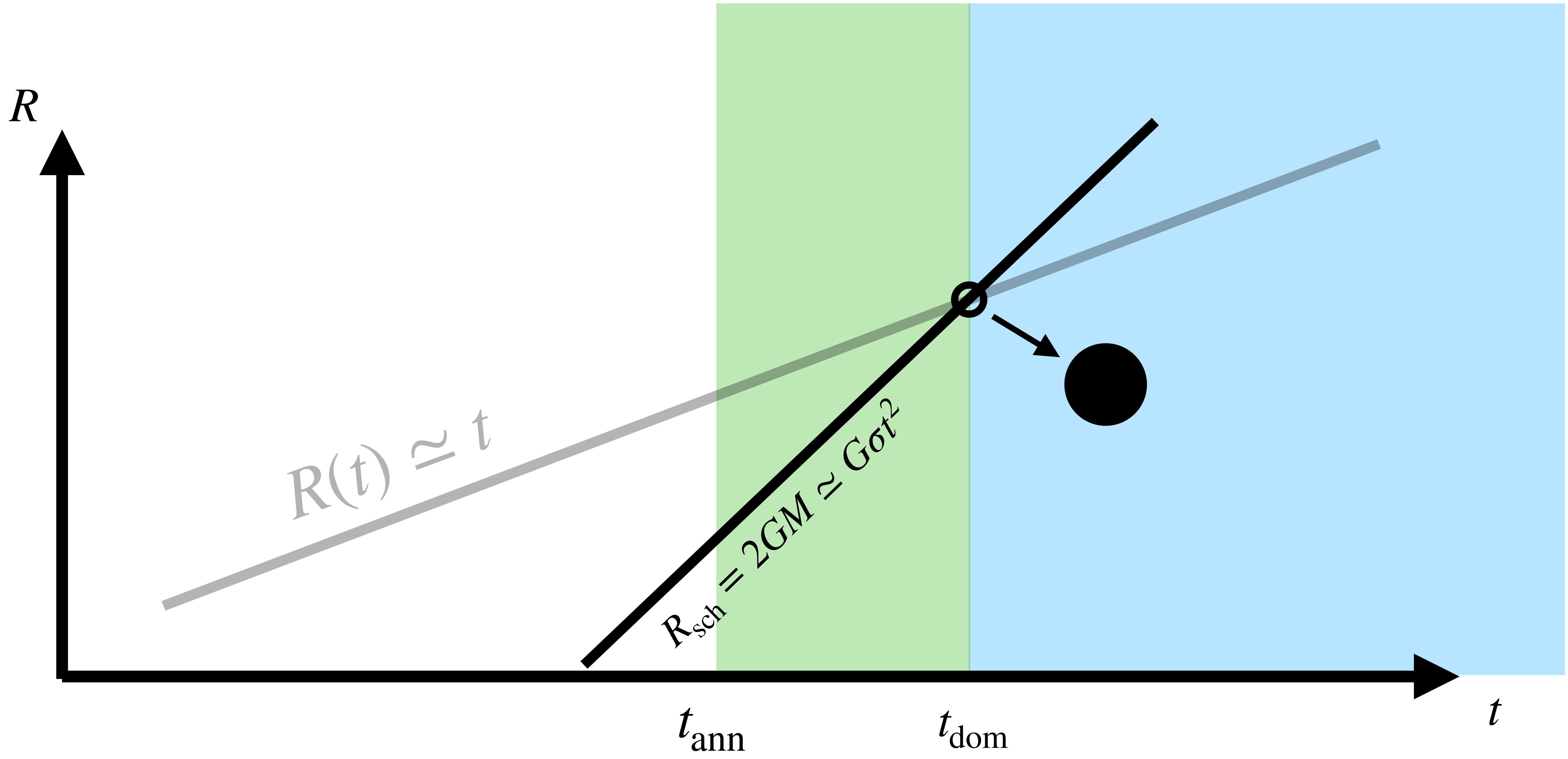

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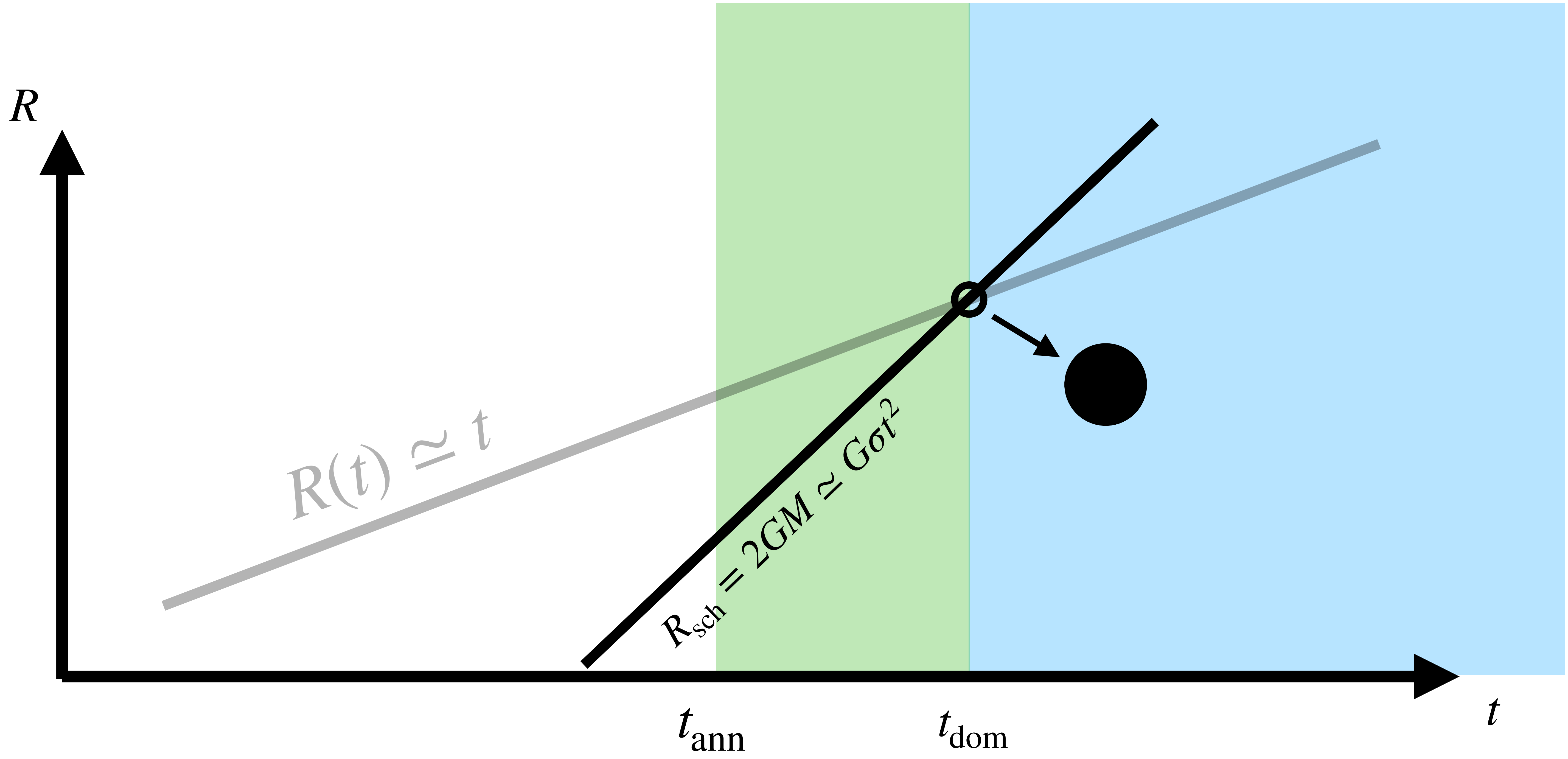

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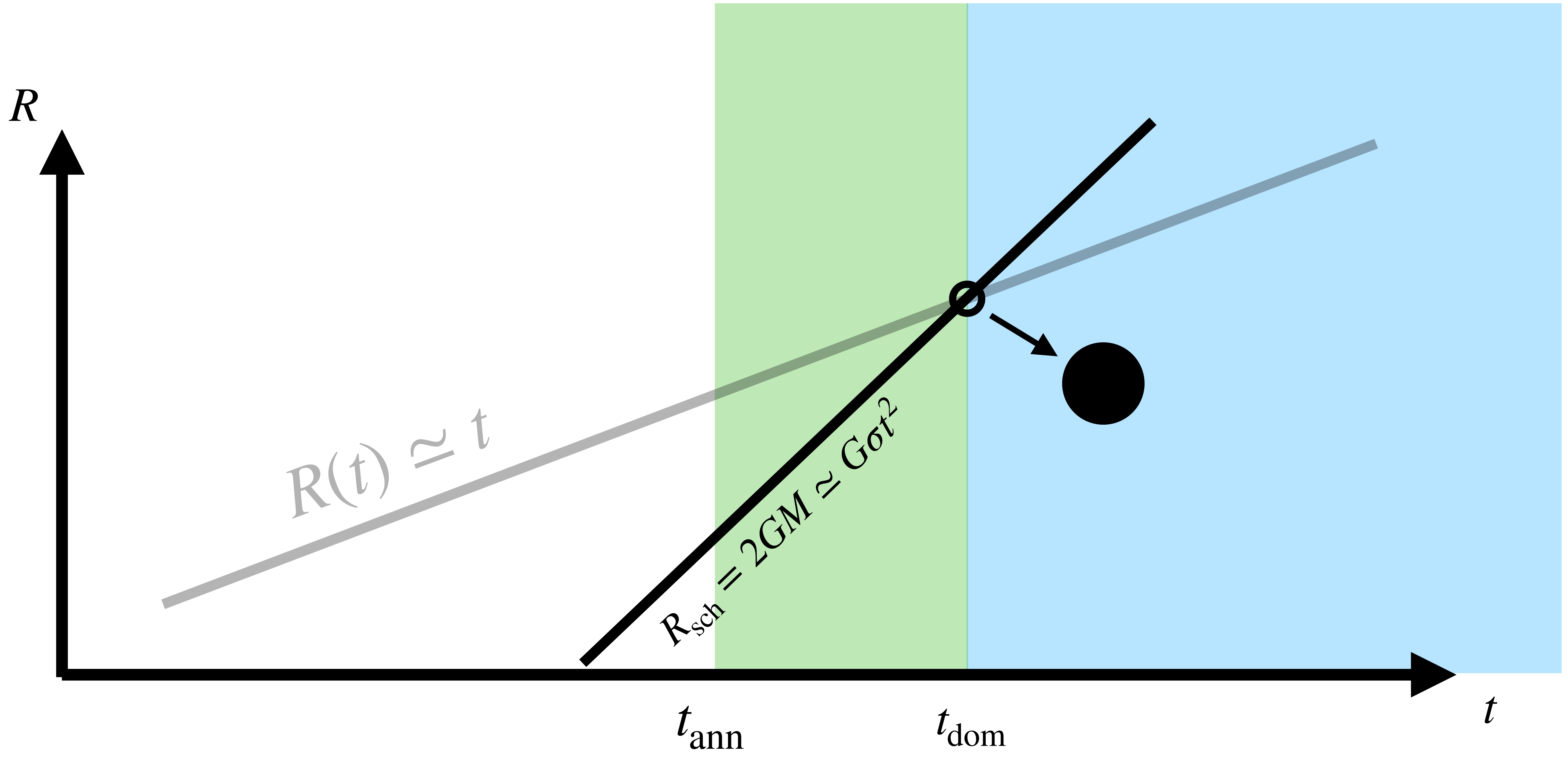
$R(t) = a(t)\chi(t)$



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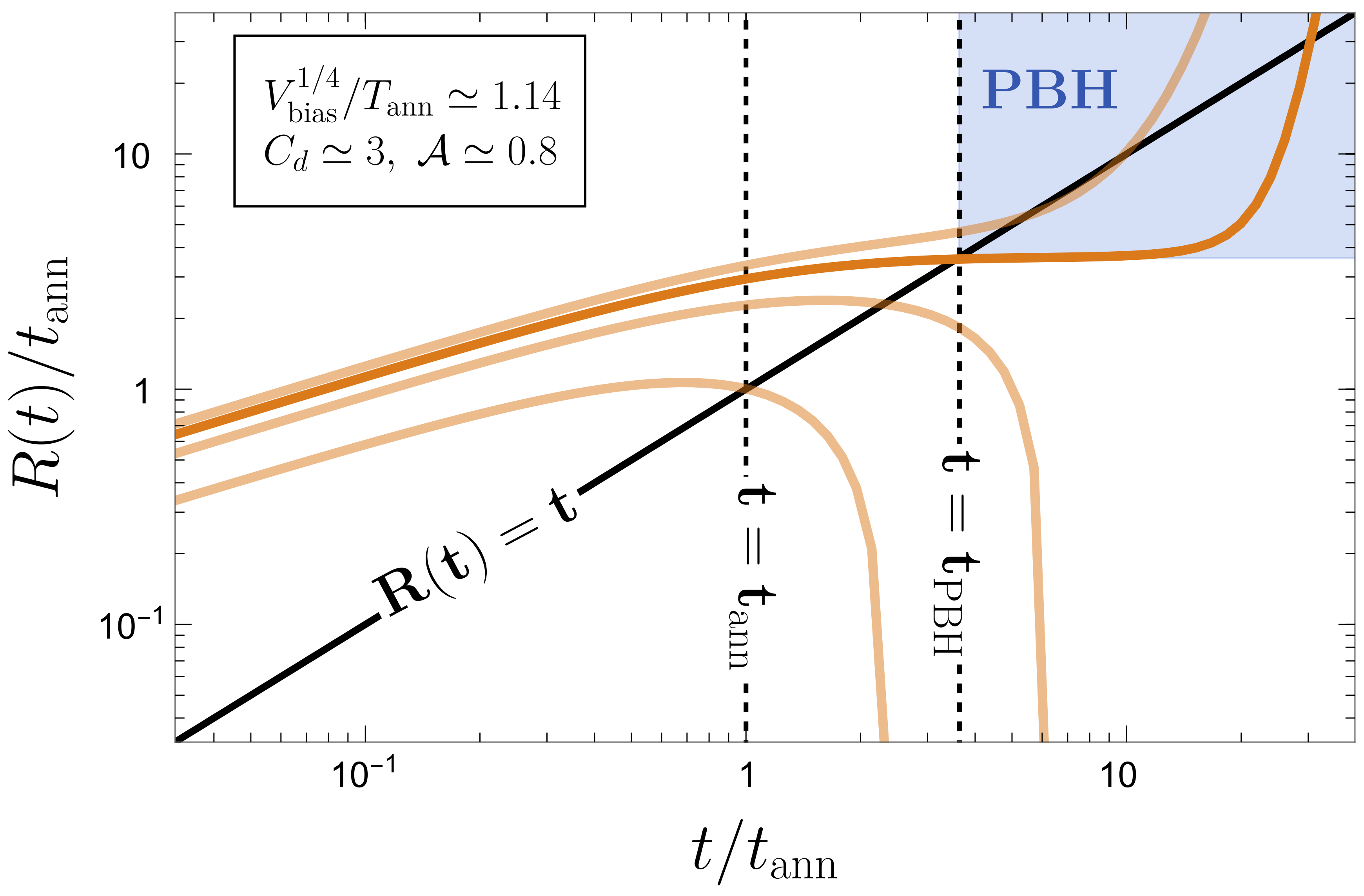

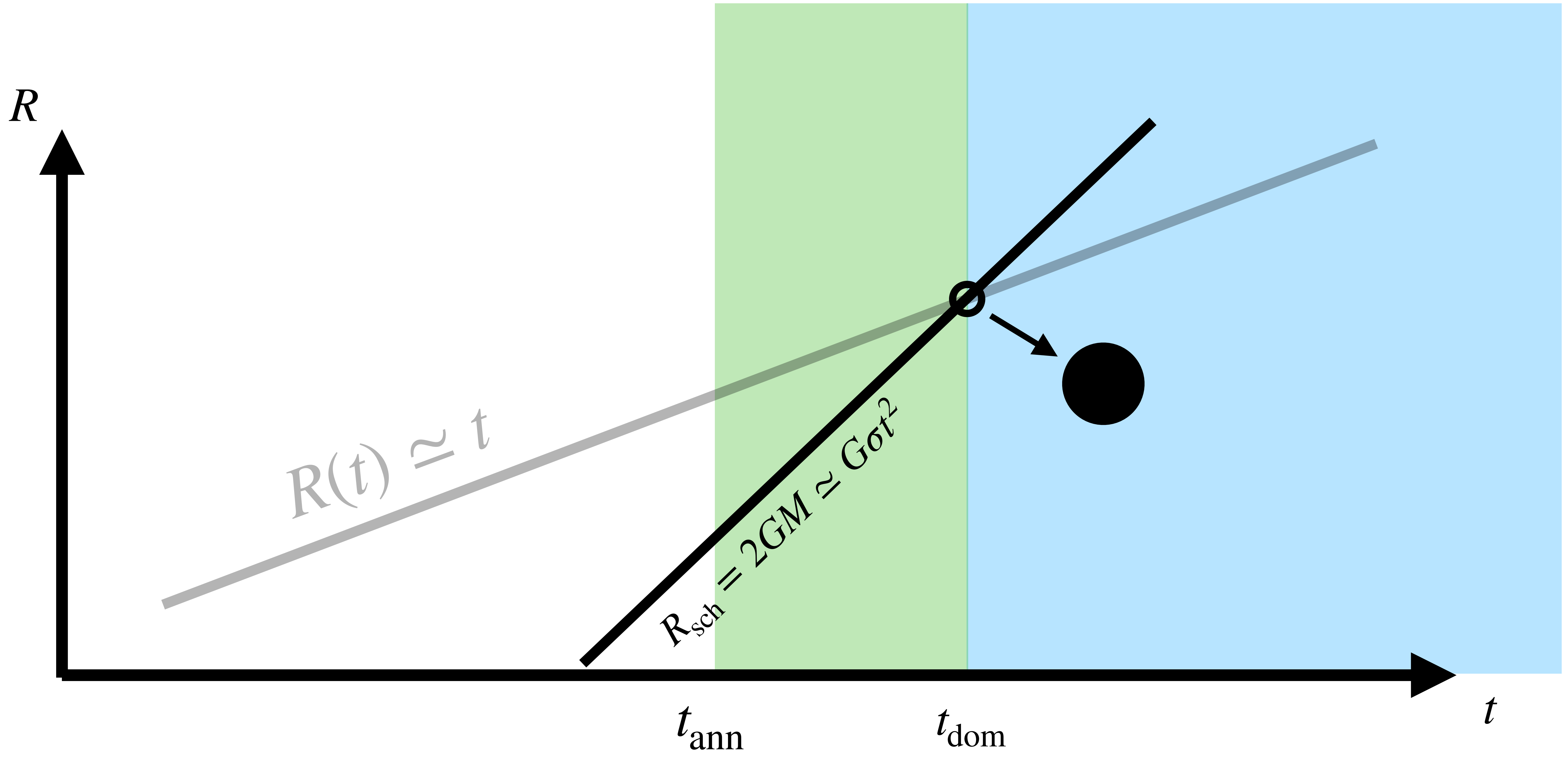

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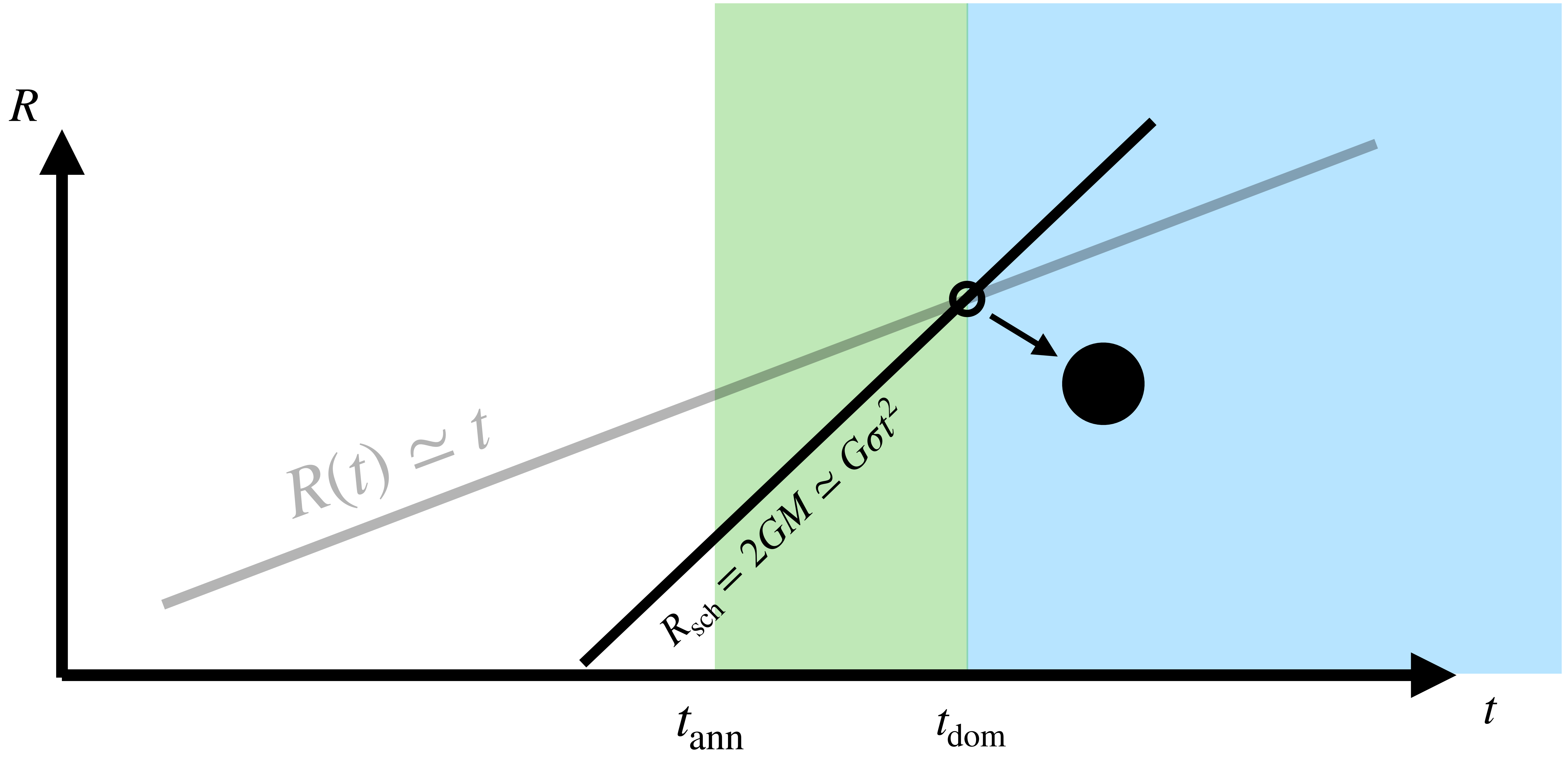

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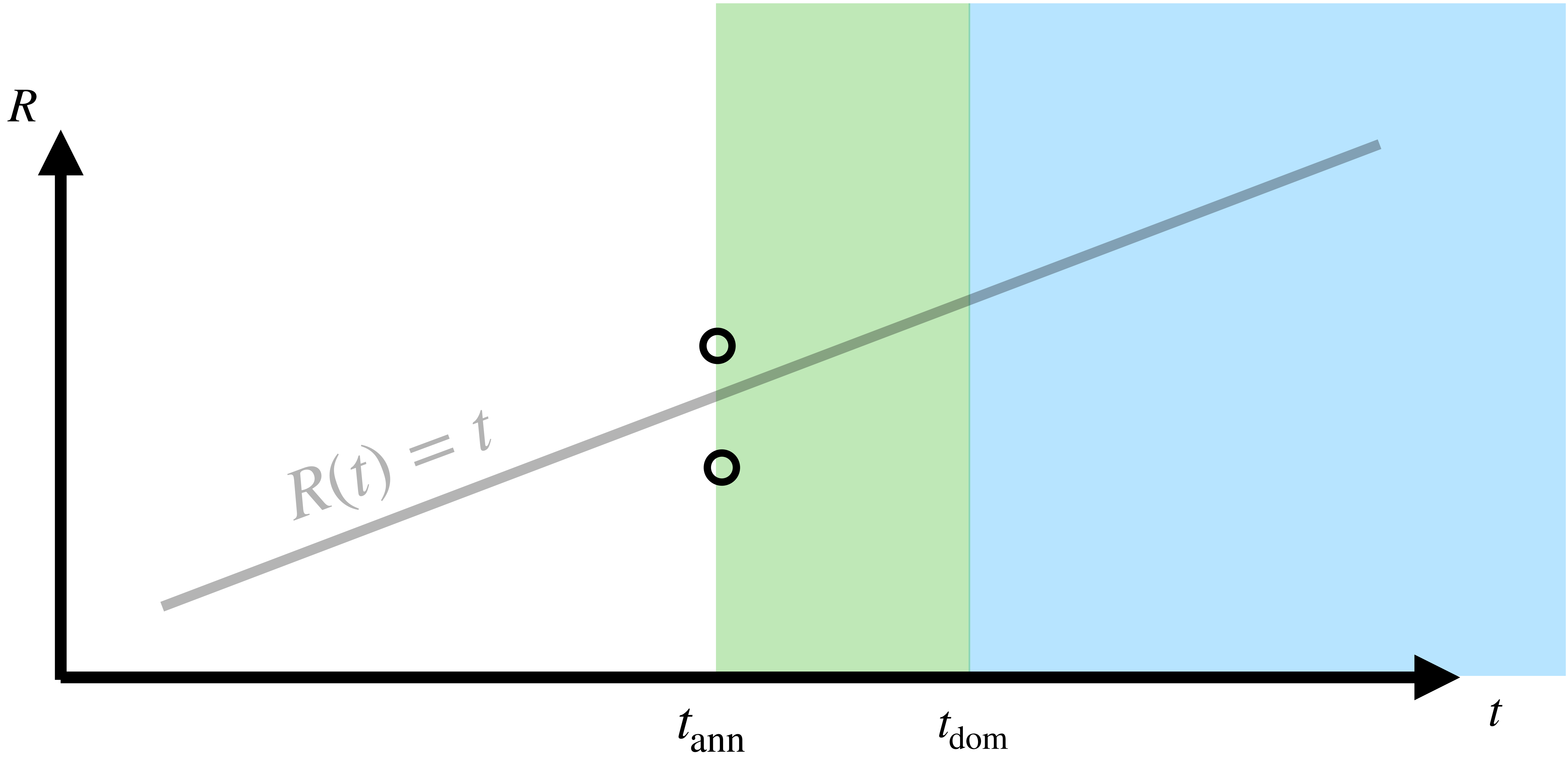

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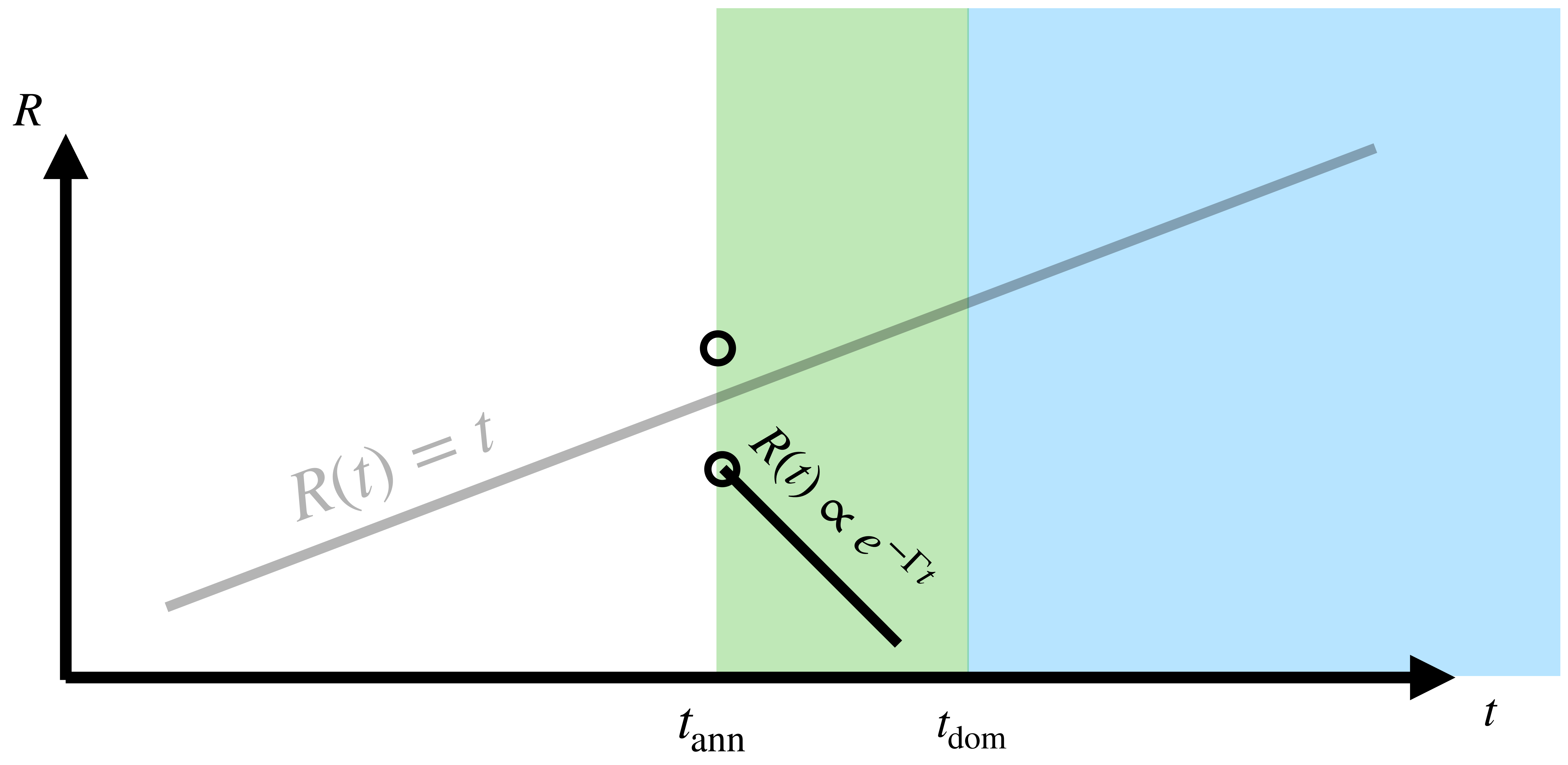

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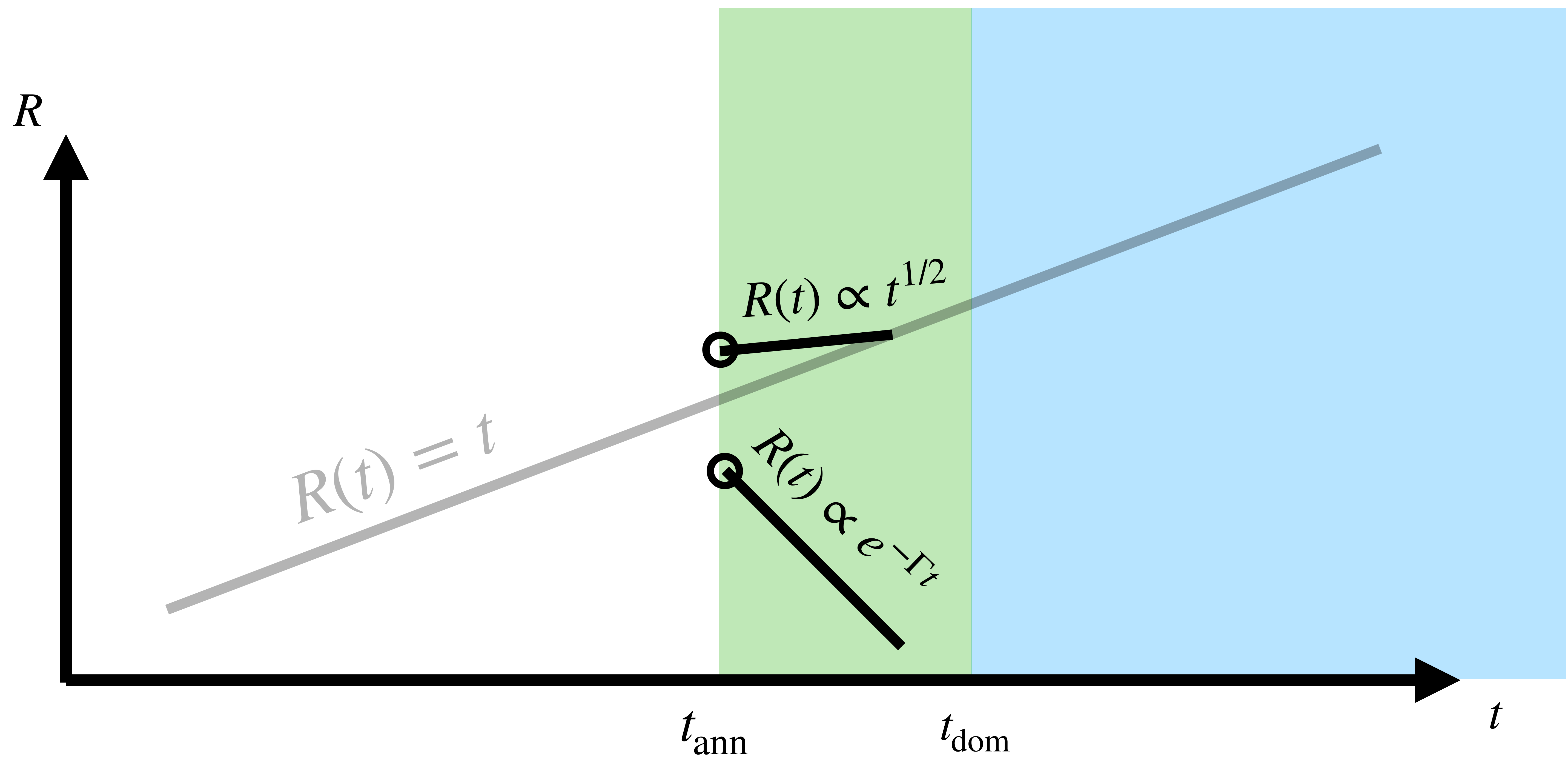

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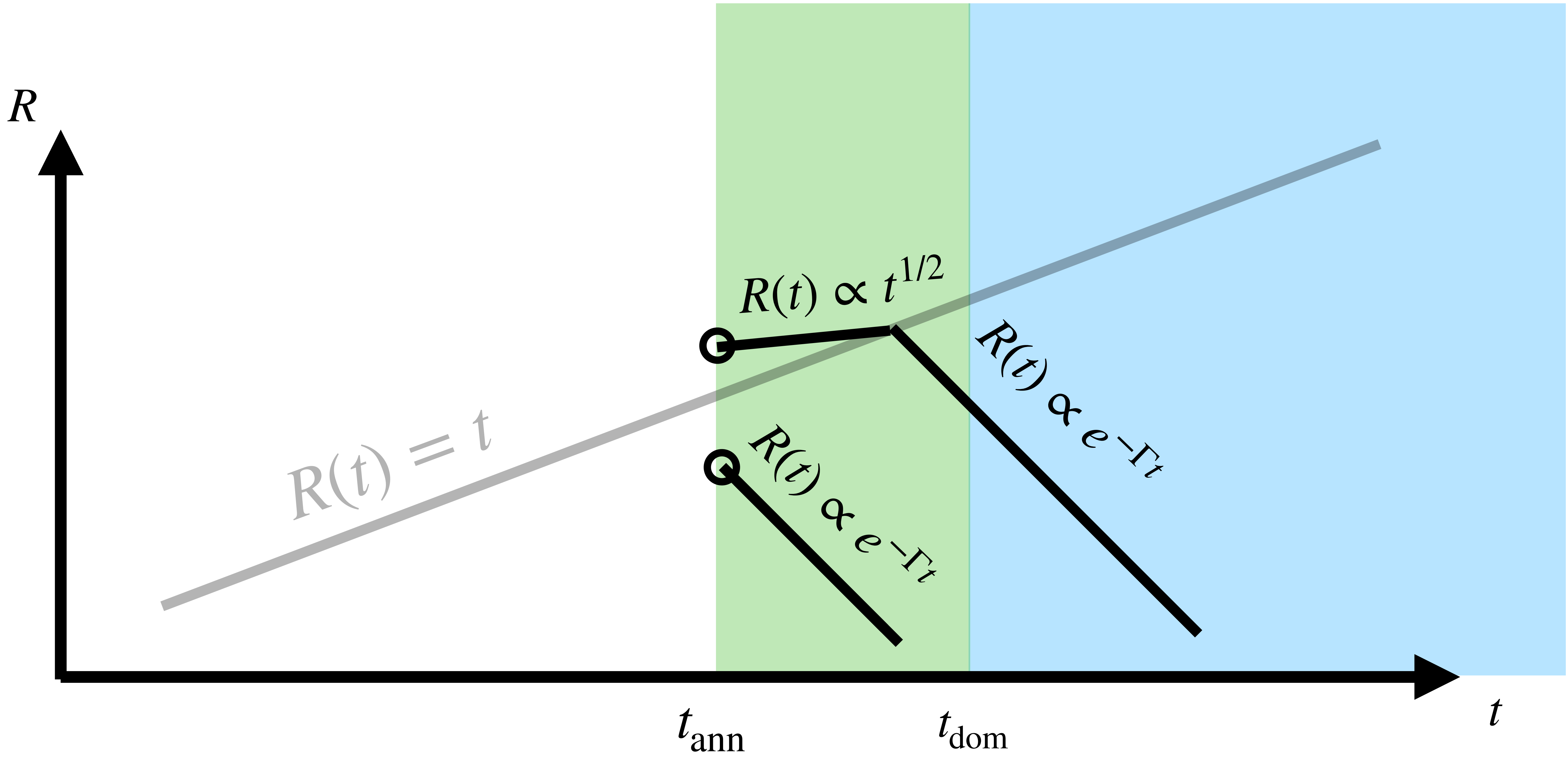

Scaling regime: $\langle R(t) \rangle \simeq t$

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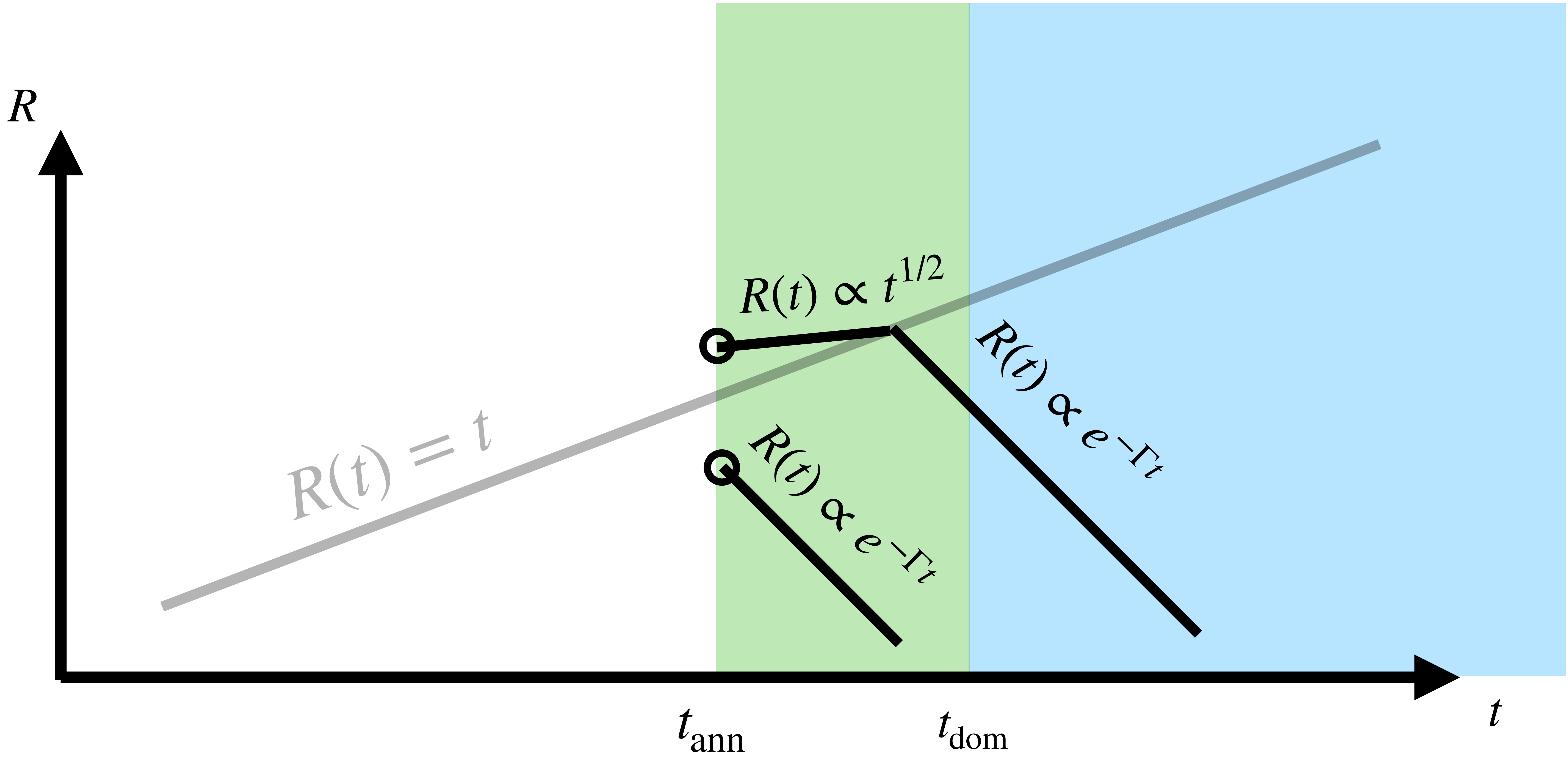

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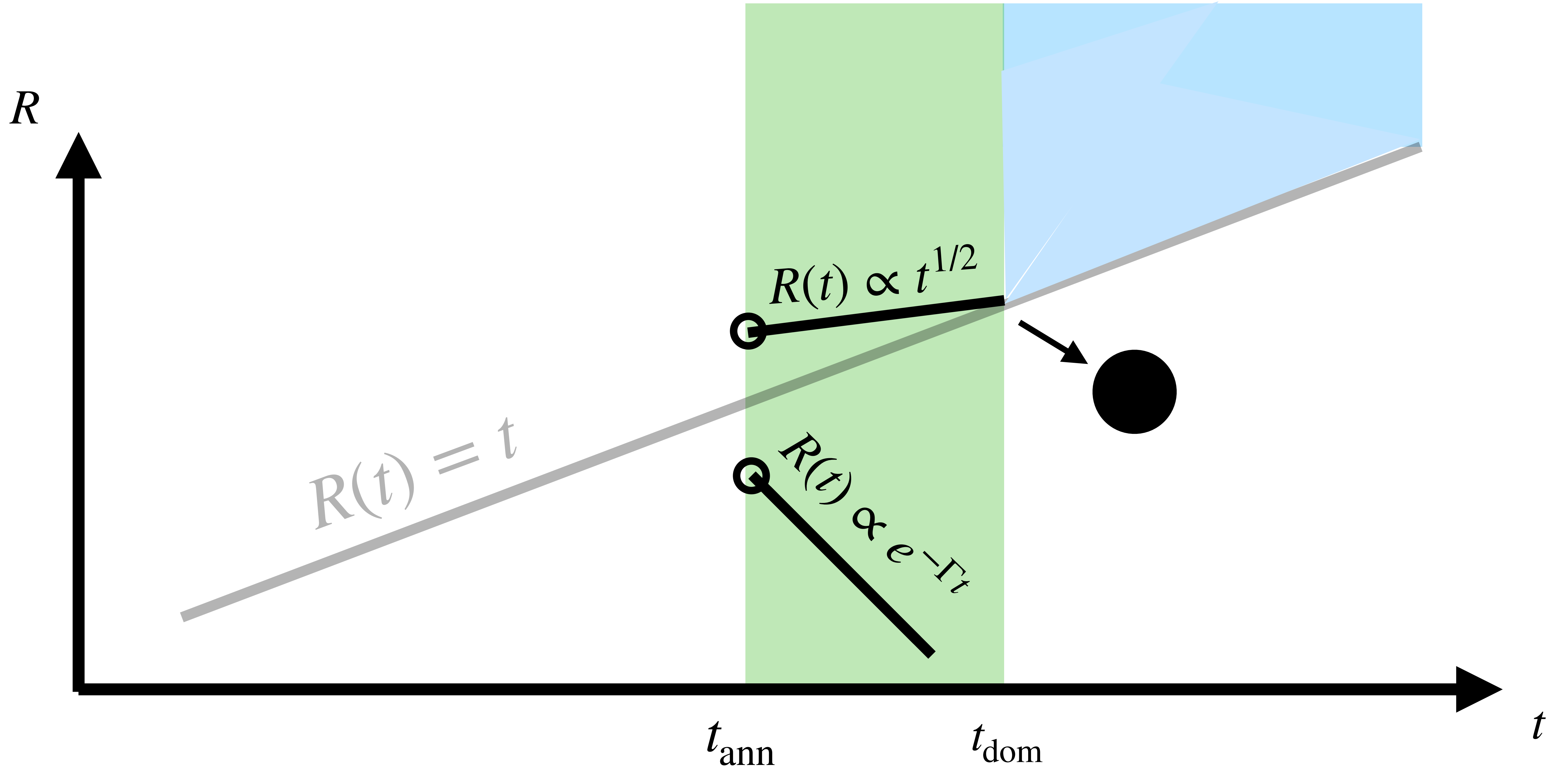

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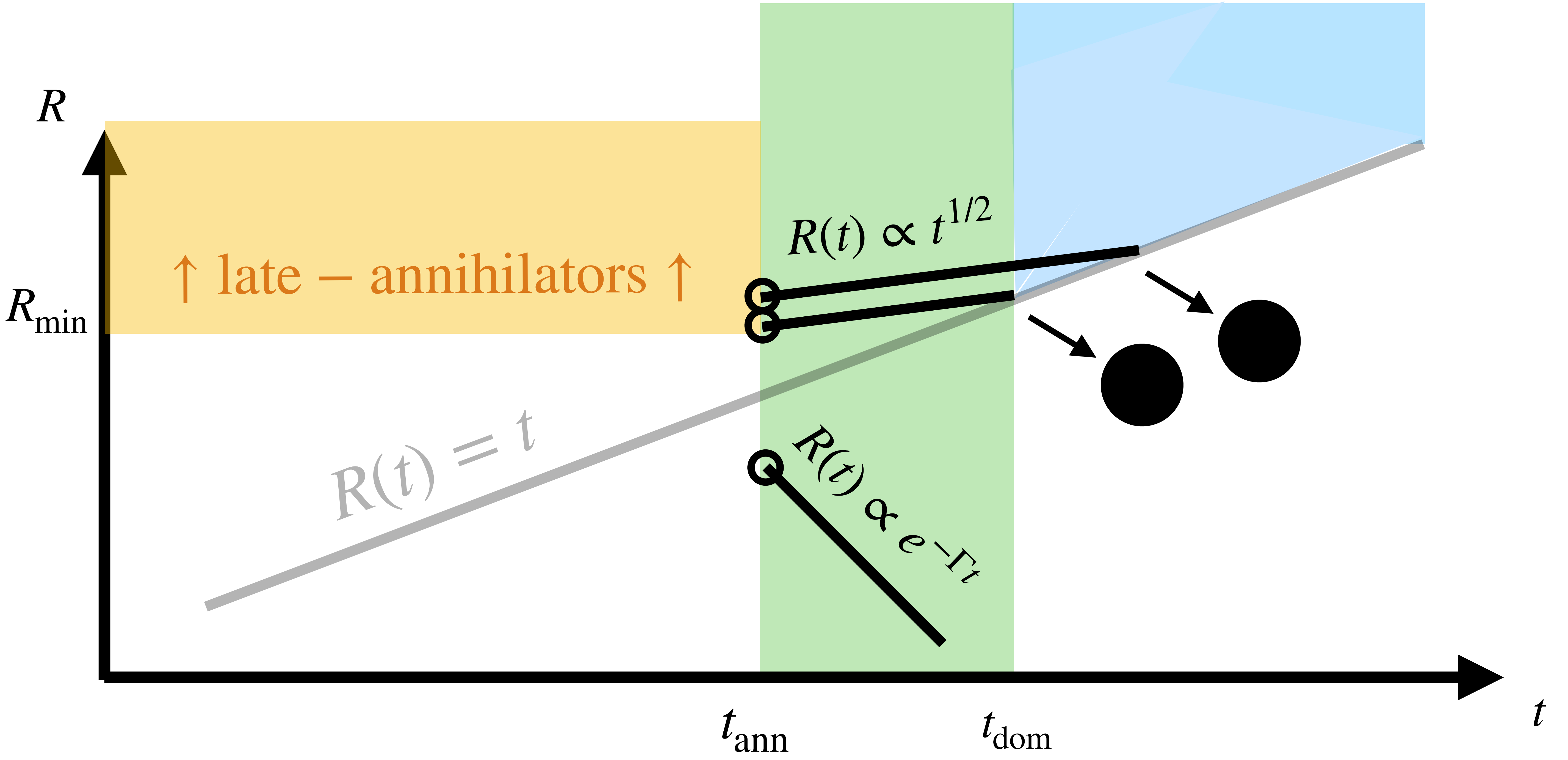

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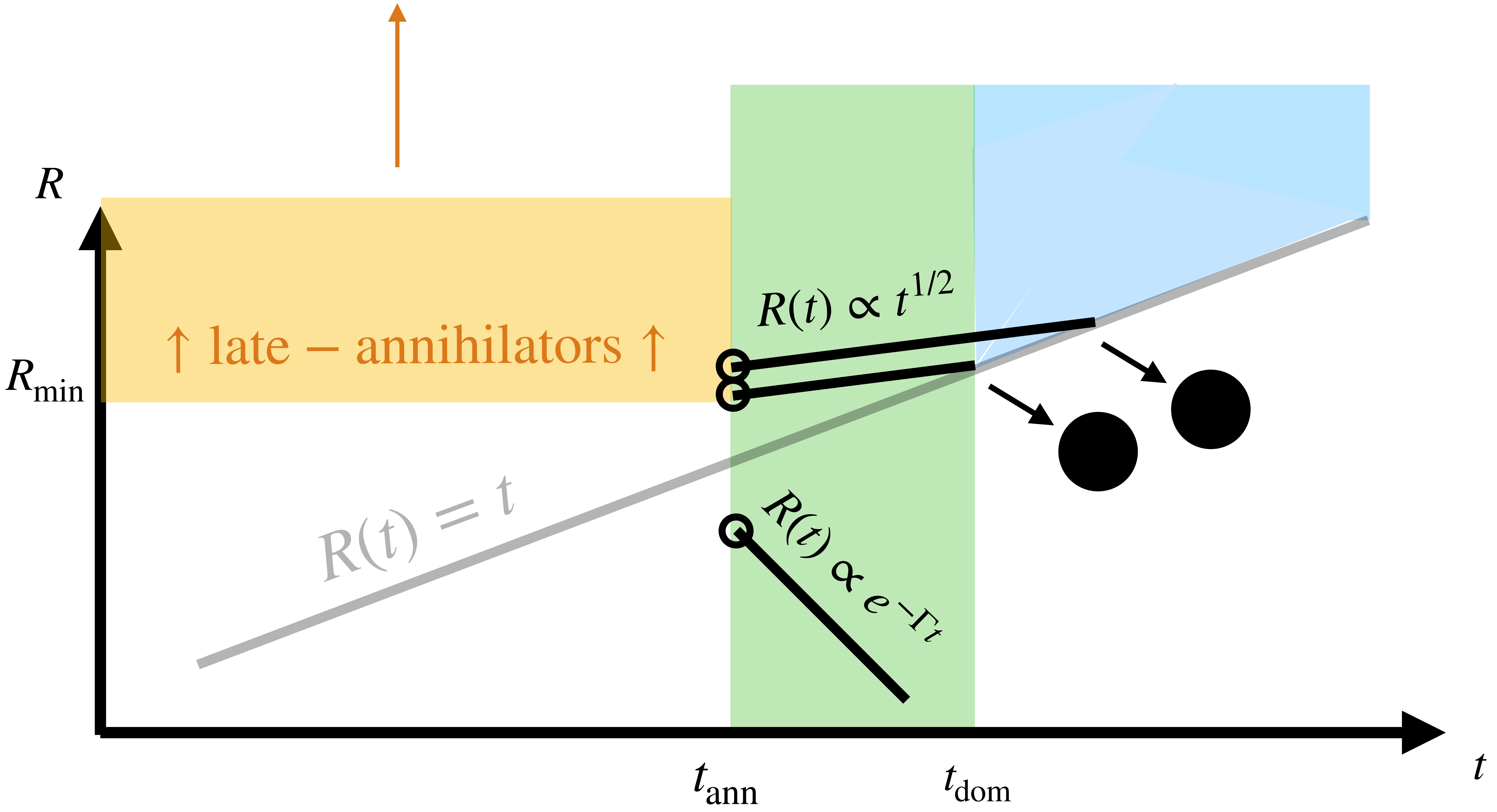
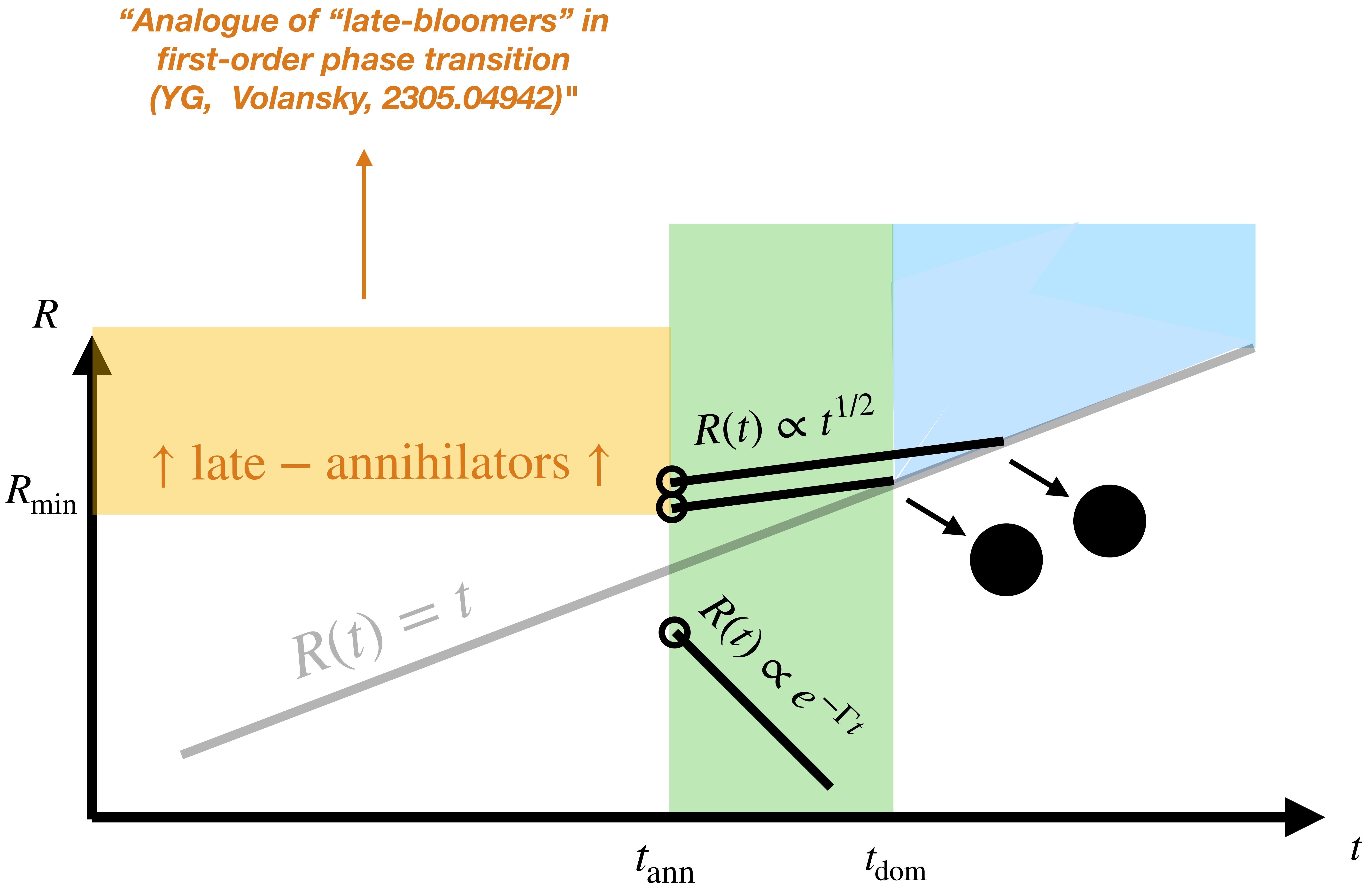
“Analogue of “late-bloomers” in first-order phase transition (YG, Volansky, 2305.04942)"



PBH abundance:

$$f_{\rm PBH} \simeq \mathscr{F} \times \left(\frac{T_{\rm dom}}{T_{\rm eq}} \right)$$



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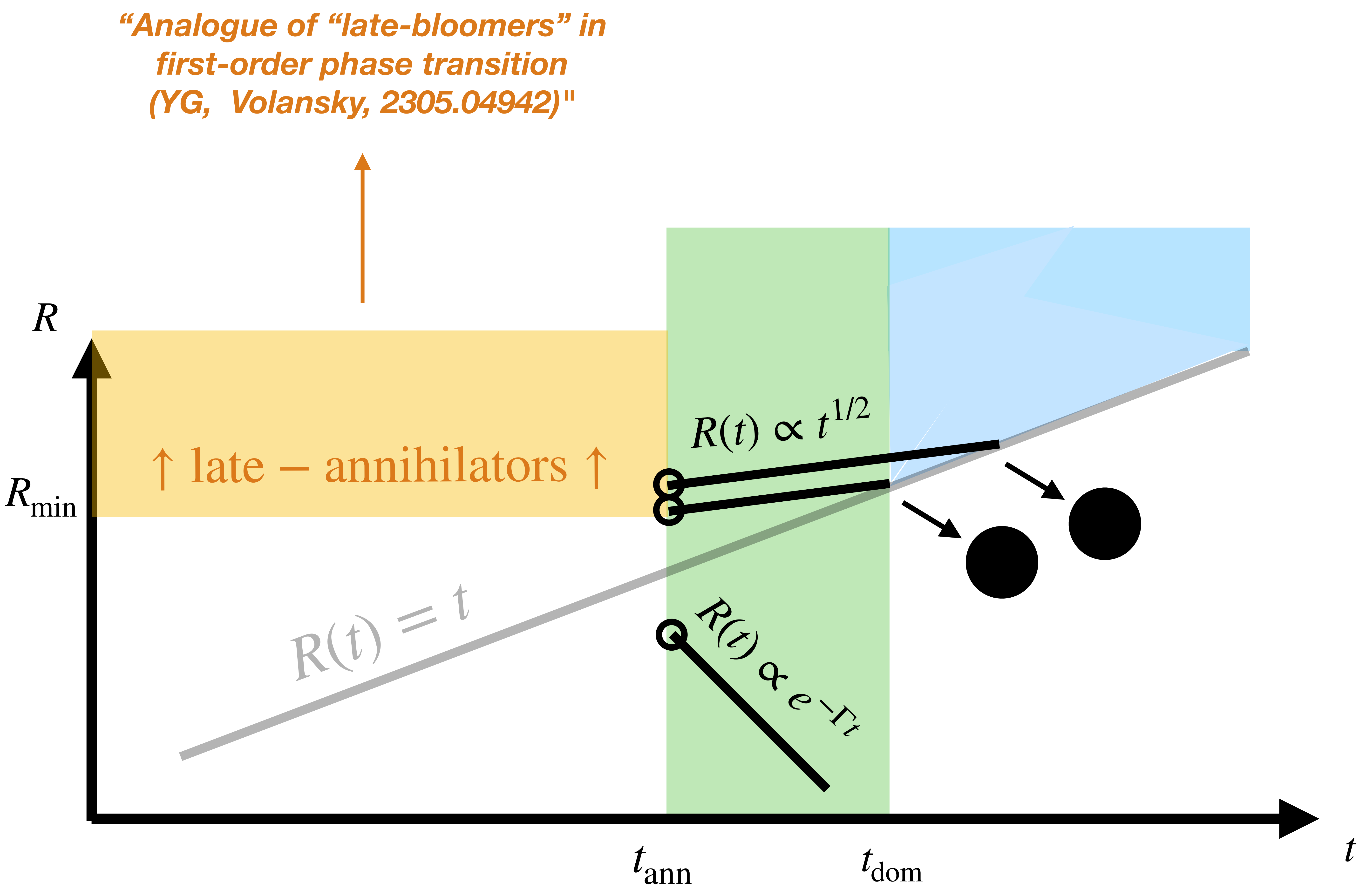
Redshift factor



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Late-annihilators fraction

Redshift factor

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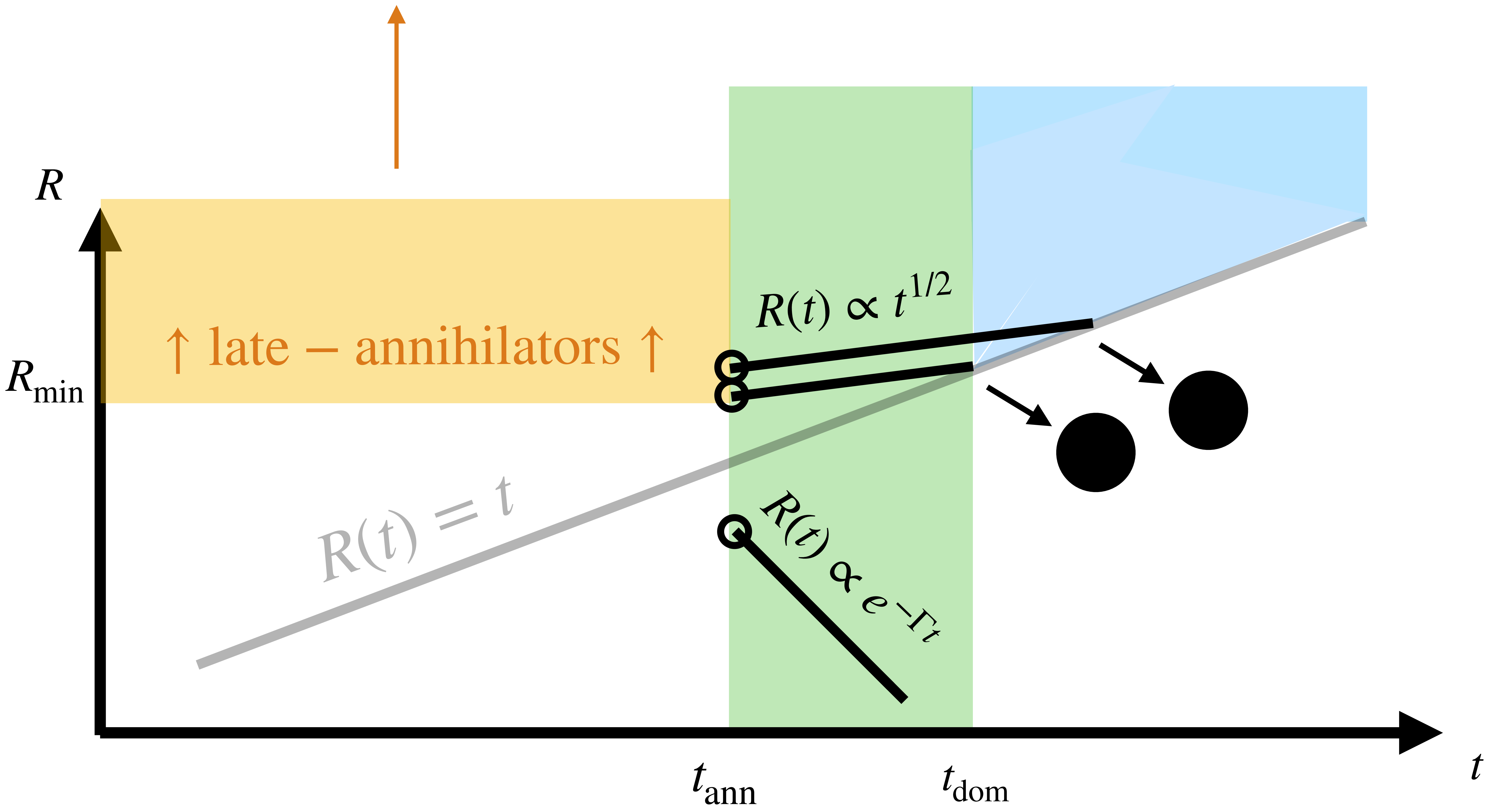

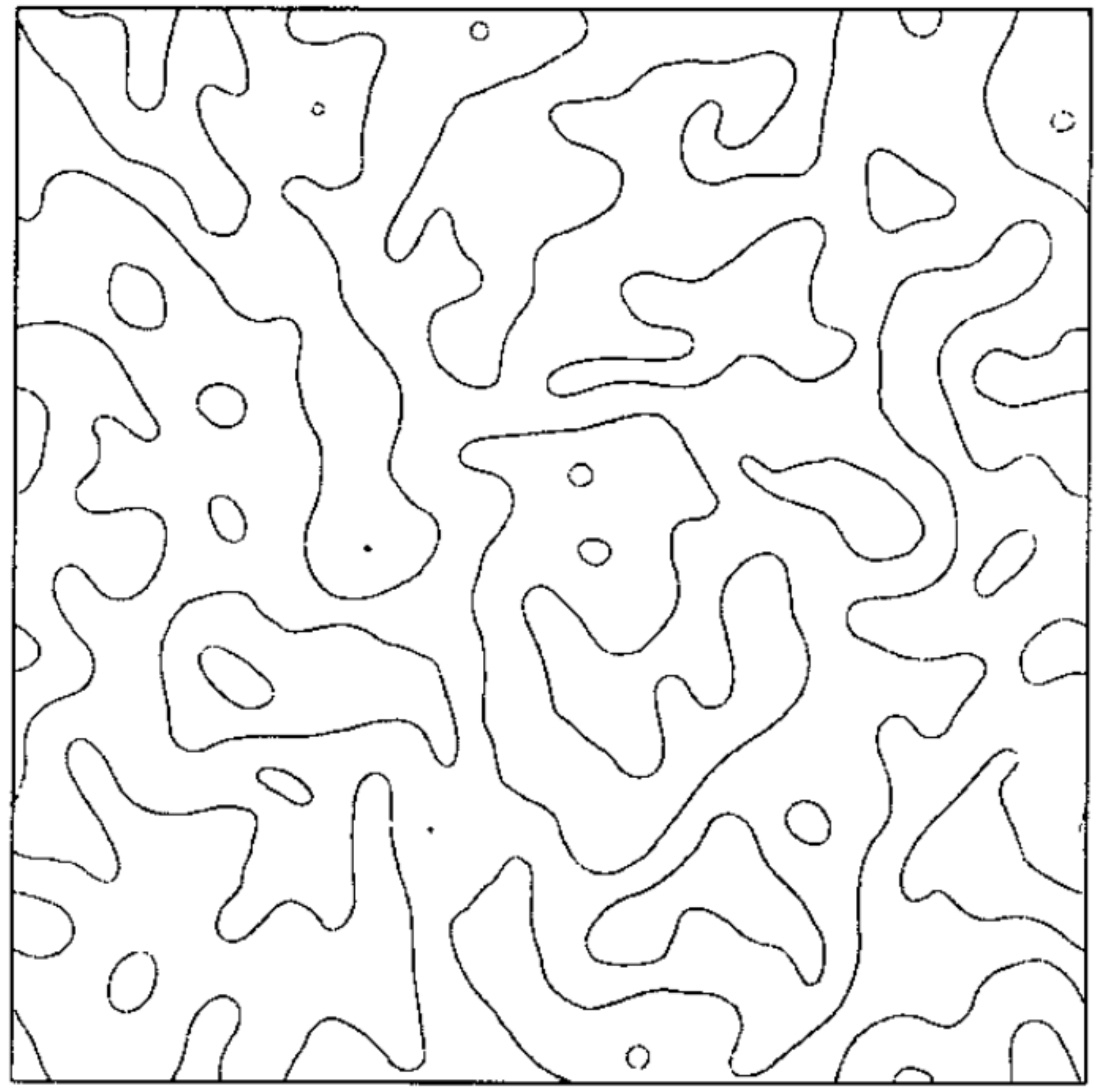

Vilenkin&Shellard 2000

Abundance of late-annihilators $\mathscr{F}$

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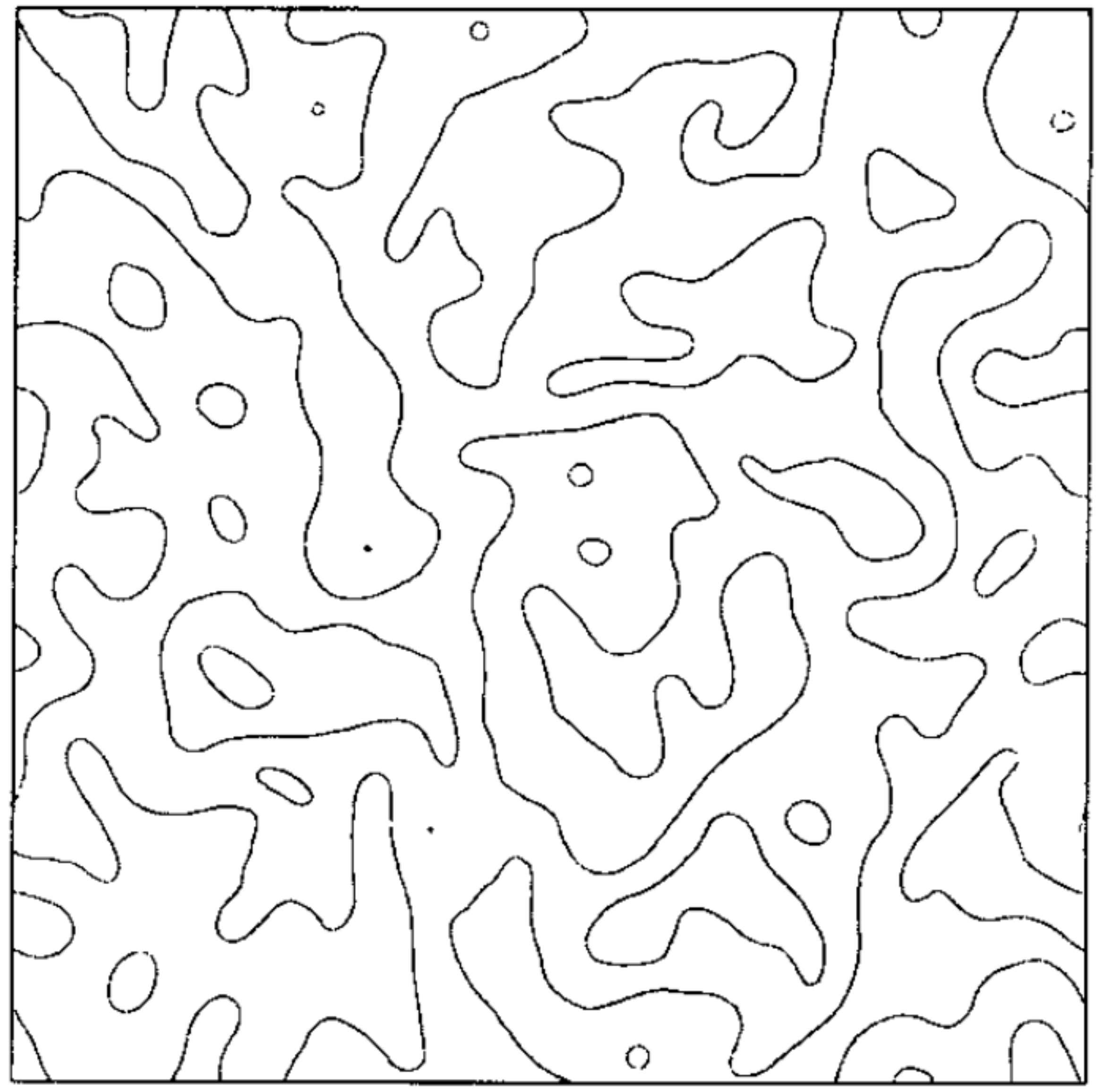
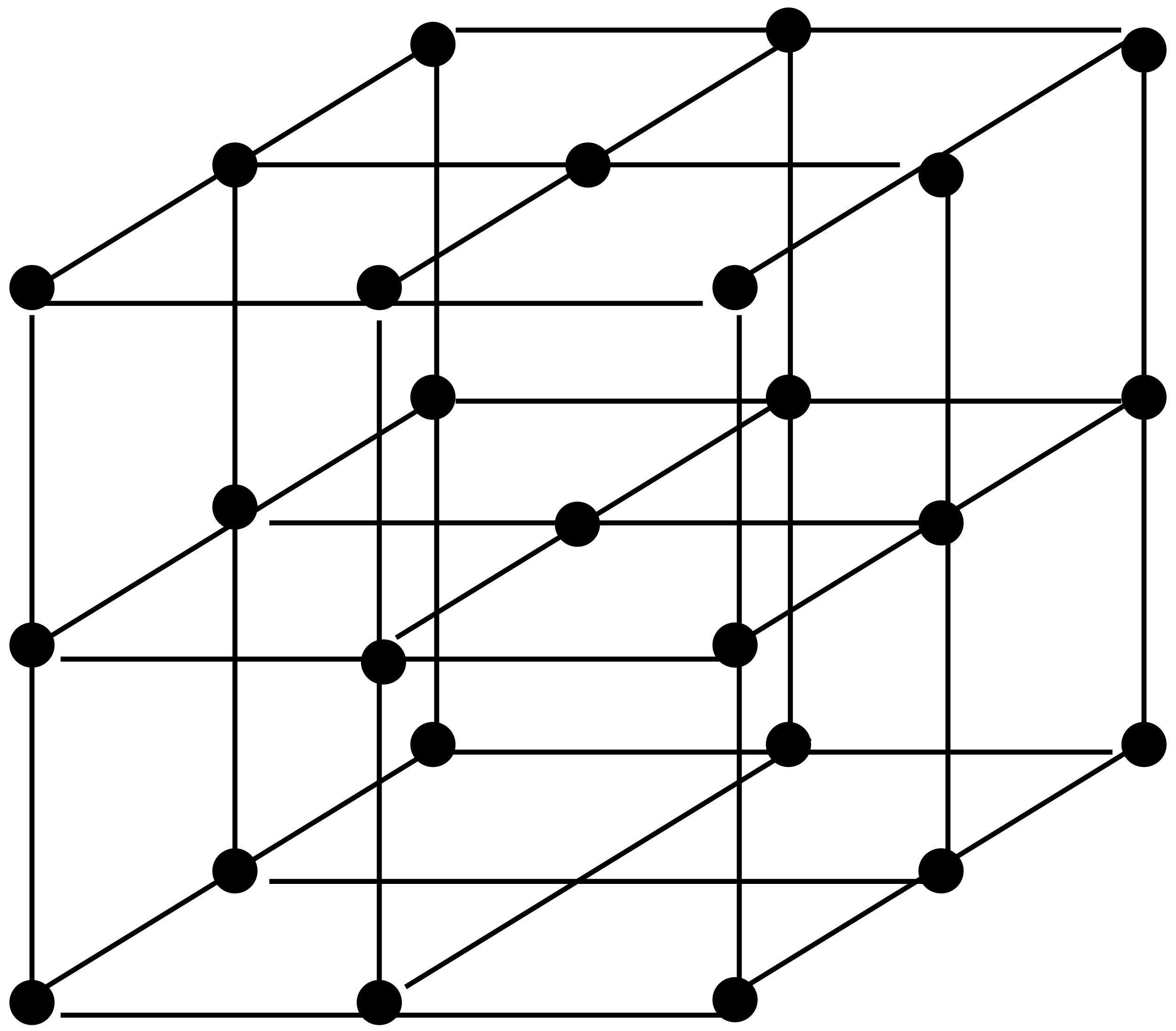


Vilenkin&Shellard 2000

Discretization



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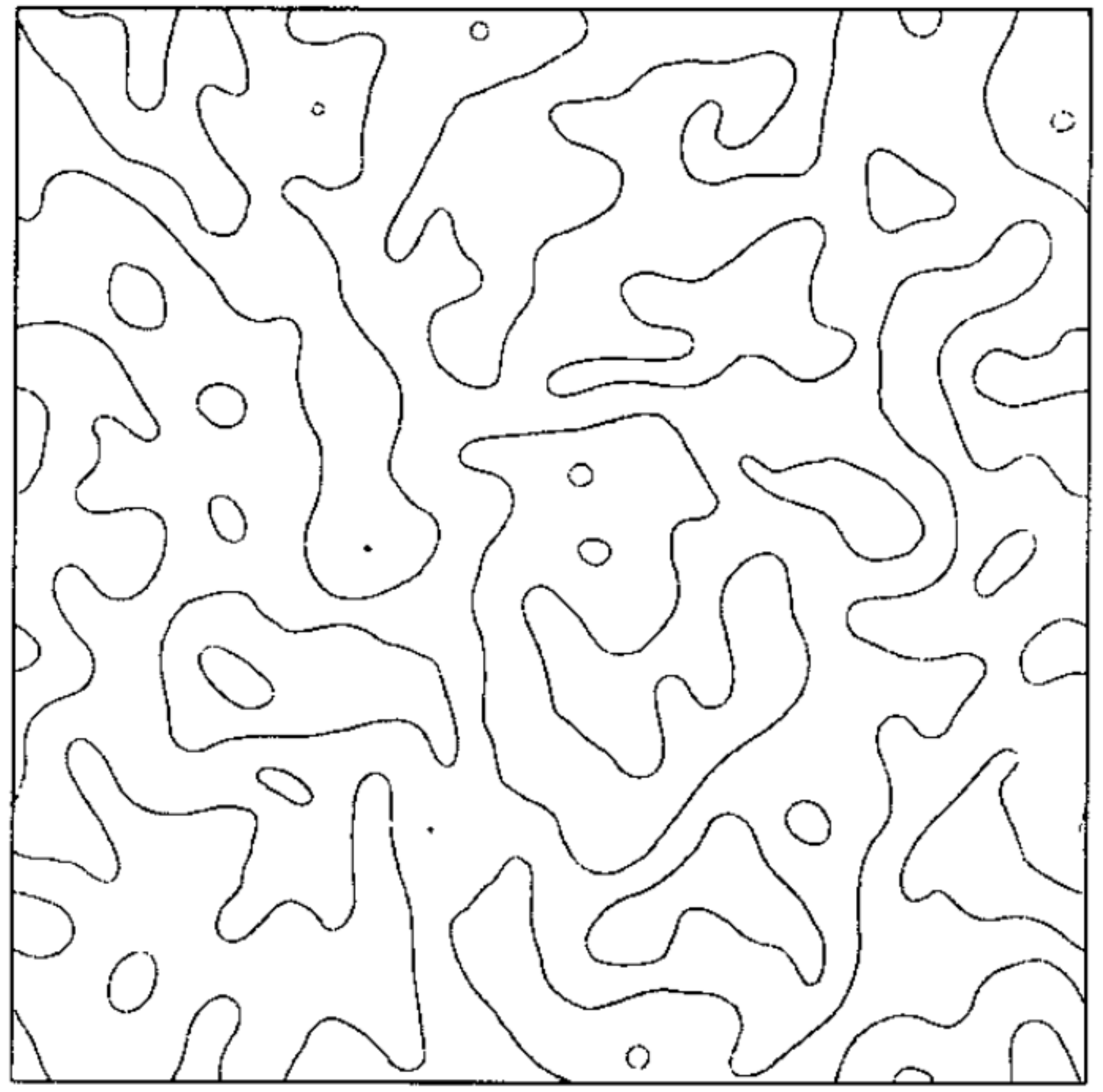

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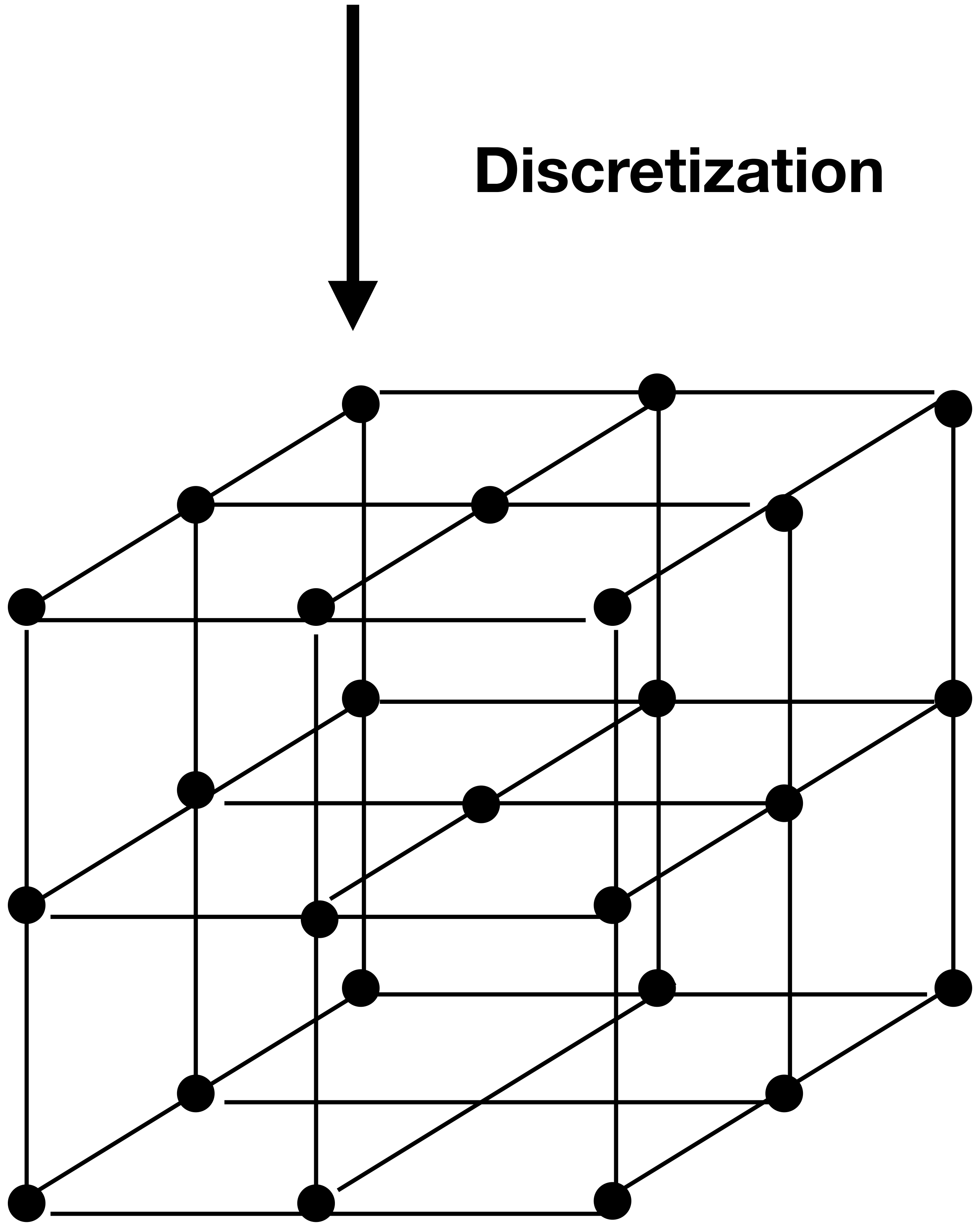

Percolation theory on a lattice:

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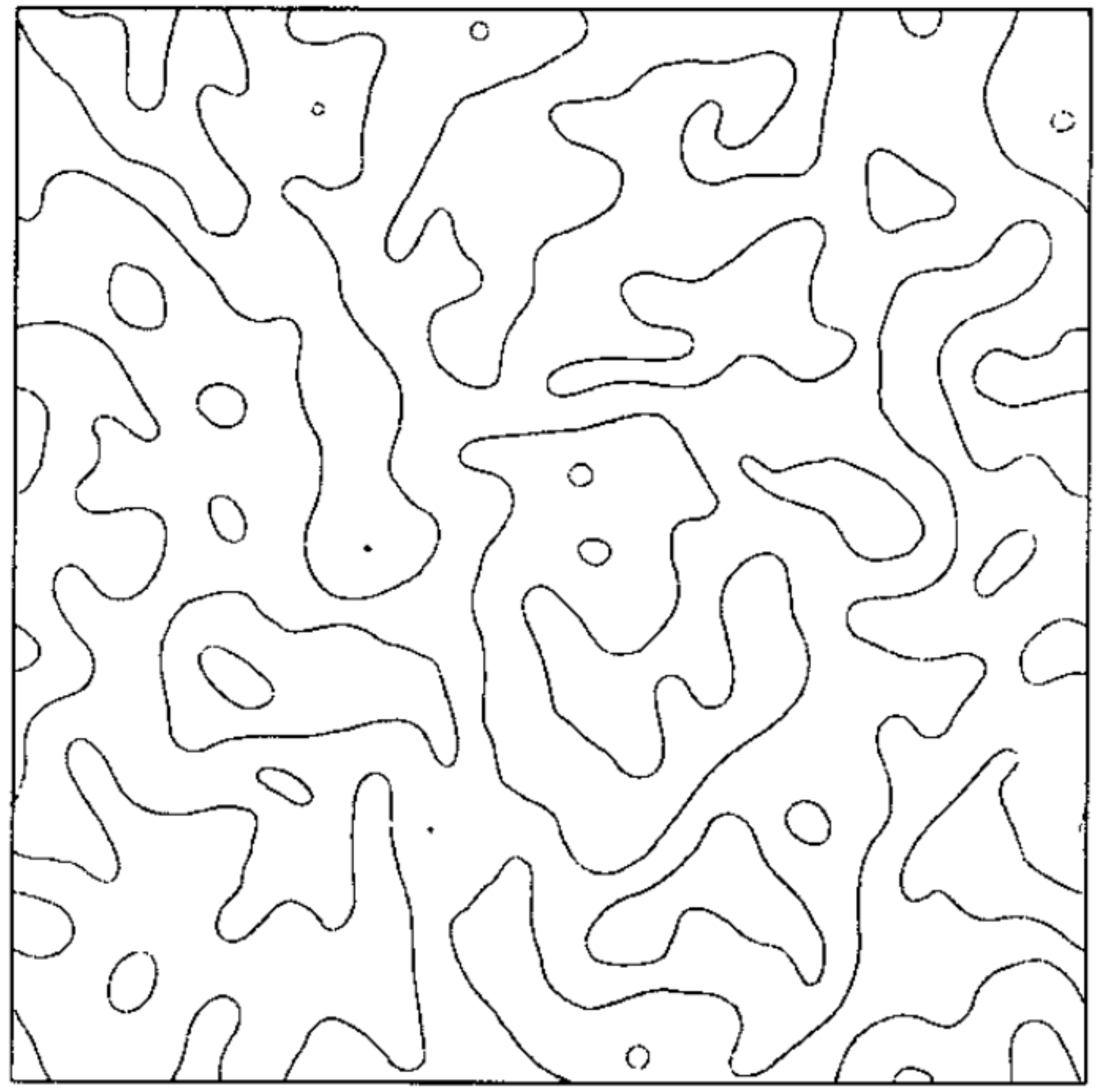

Vilenkin&Shellard 2000

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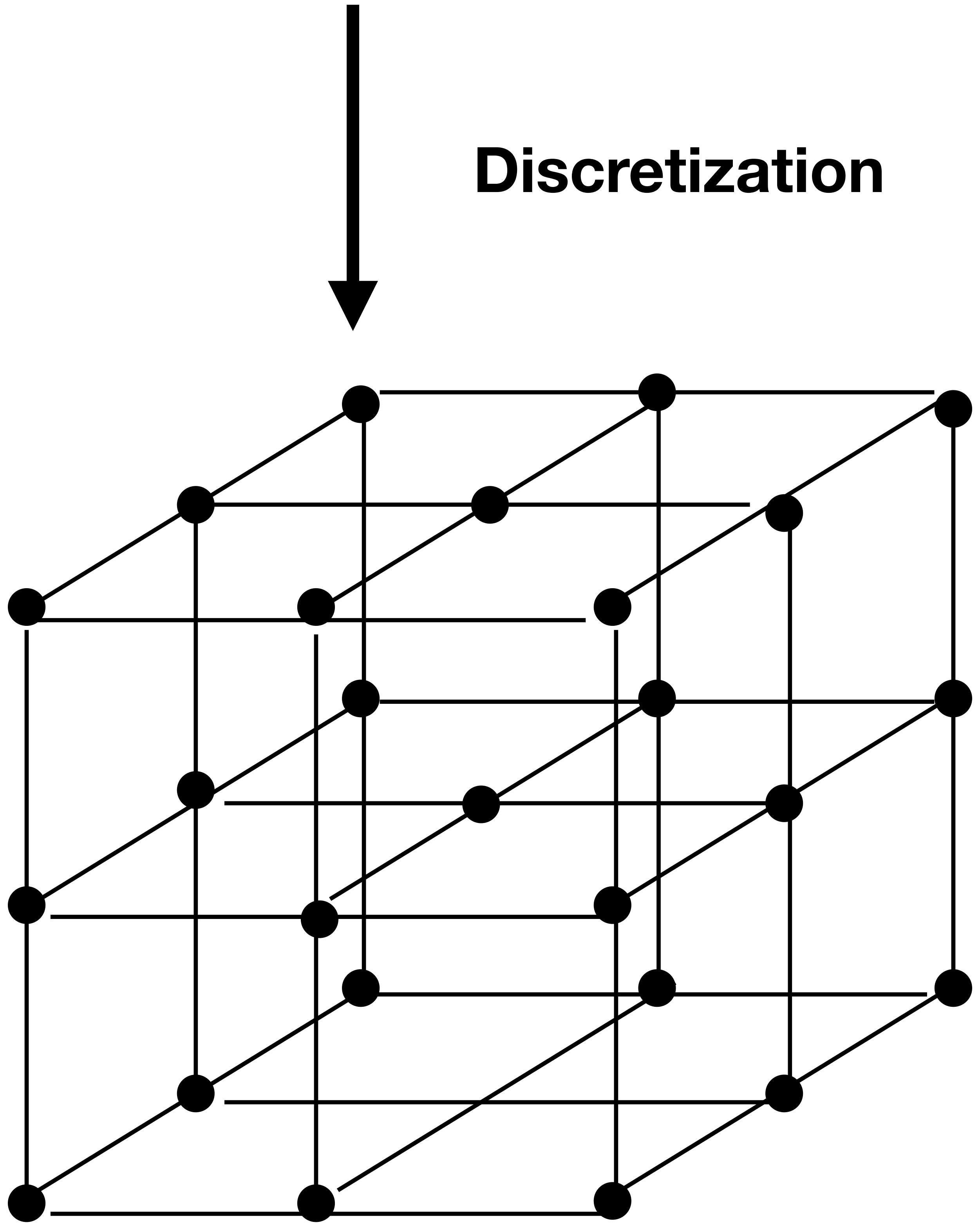

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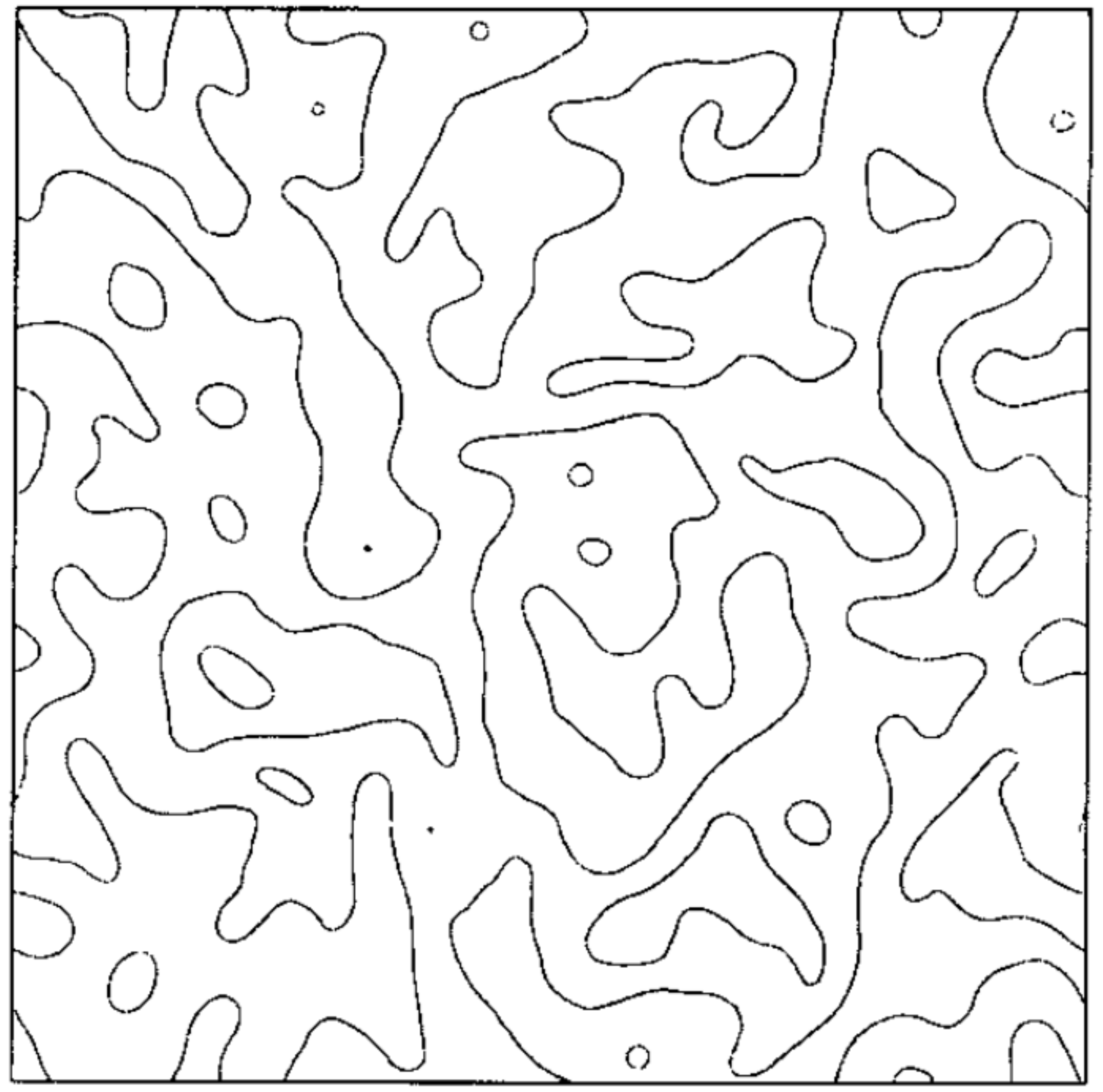

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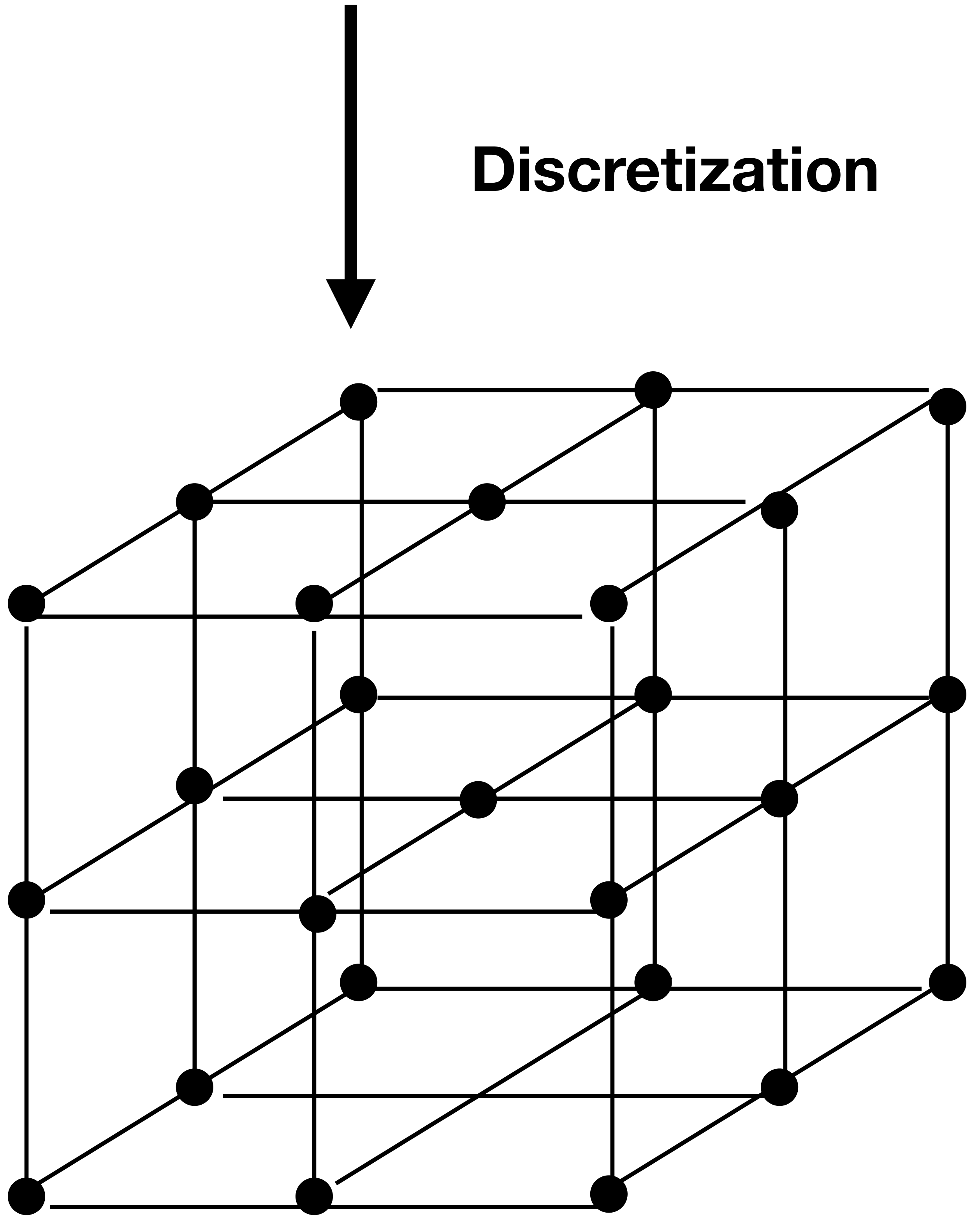

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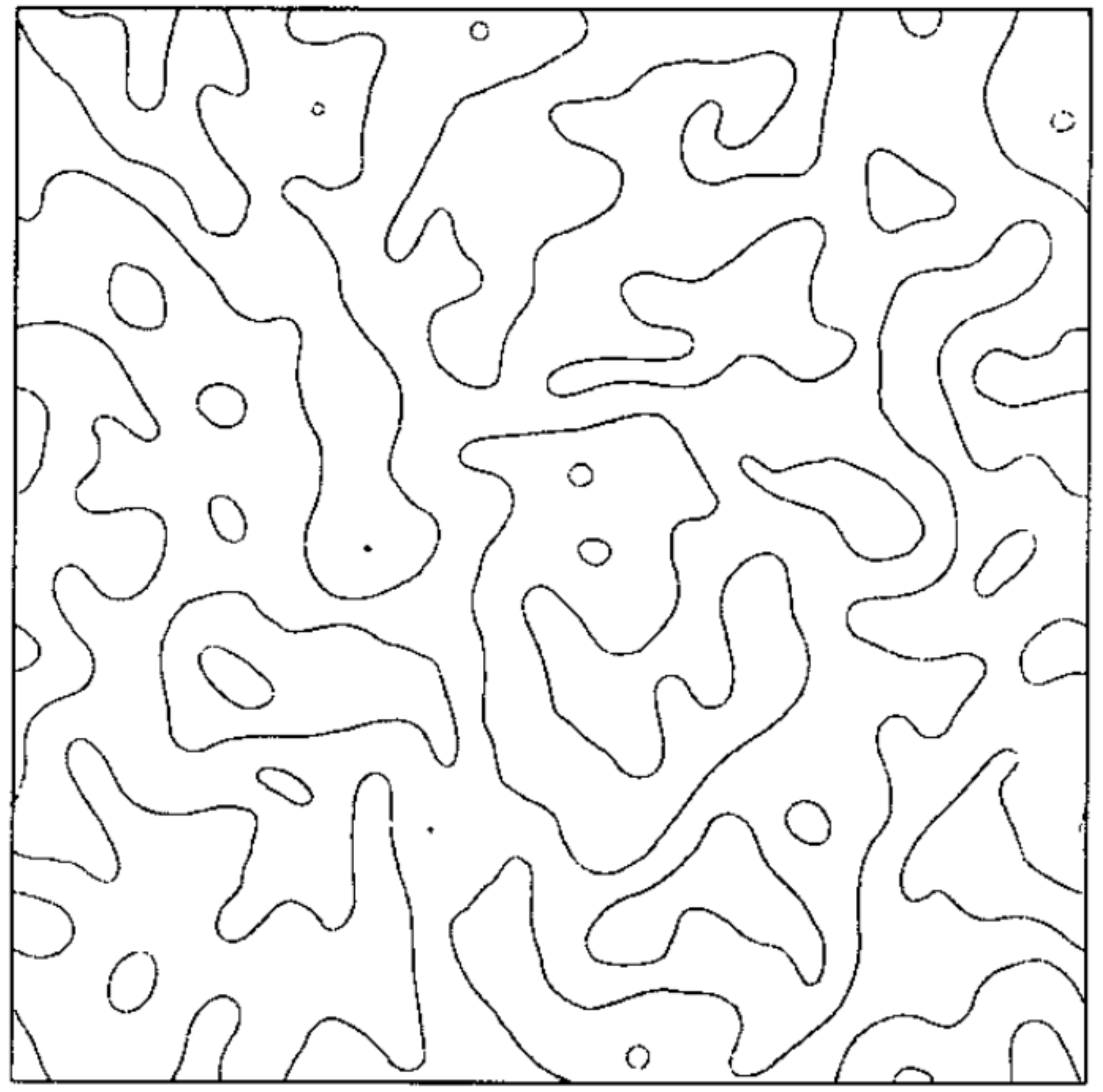
Abundance of late-annihilators $\mathscr{F}$



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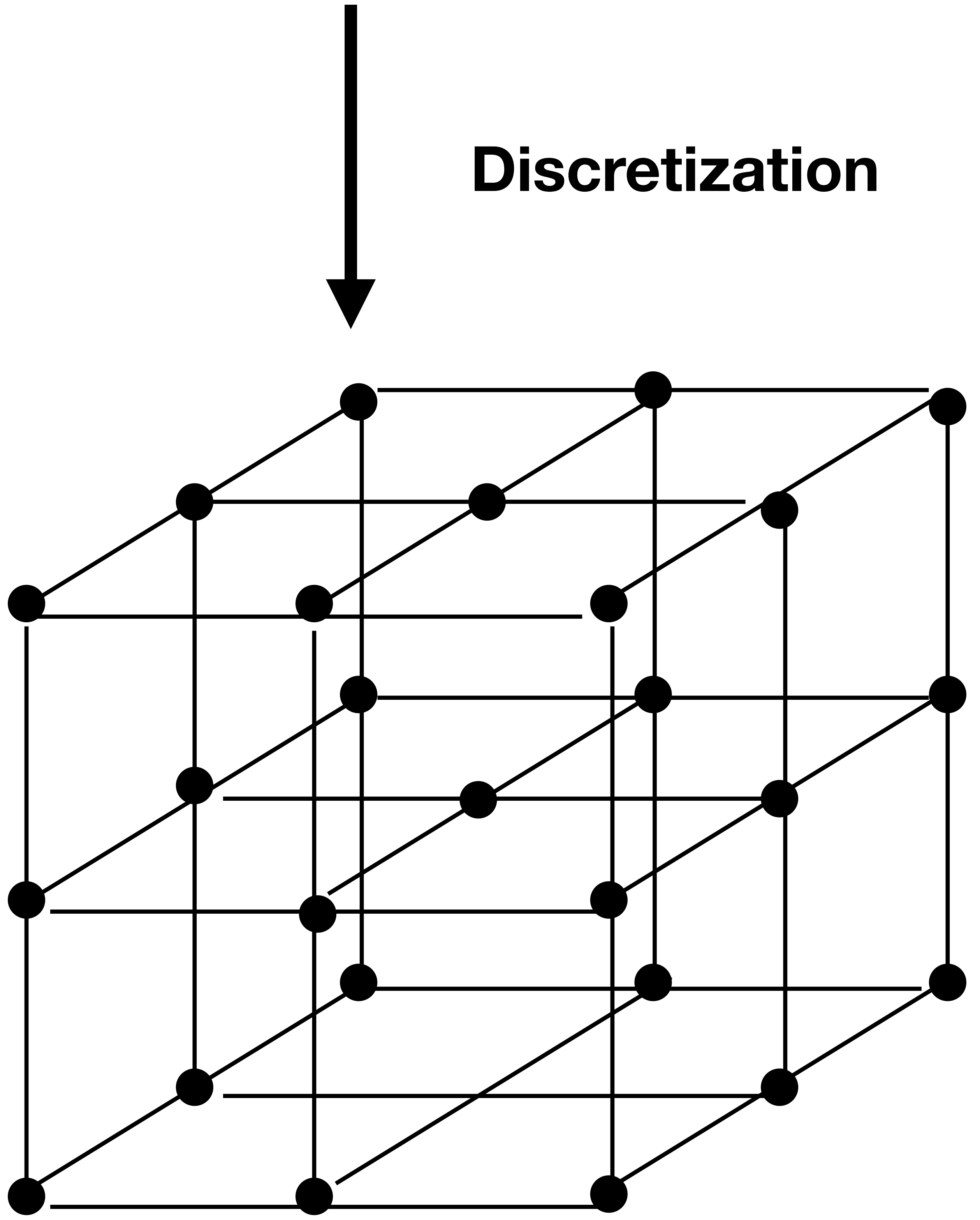

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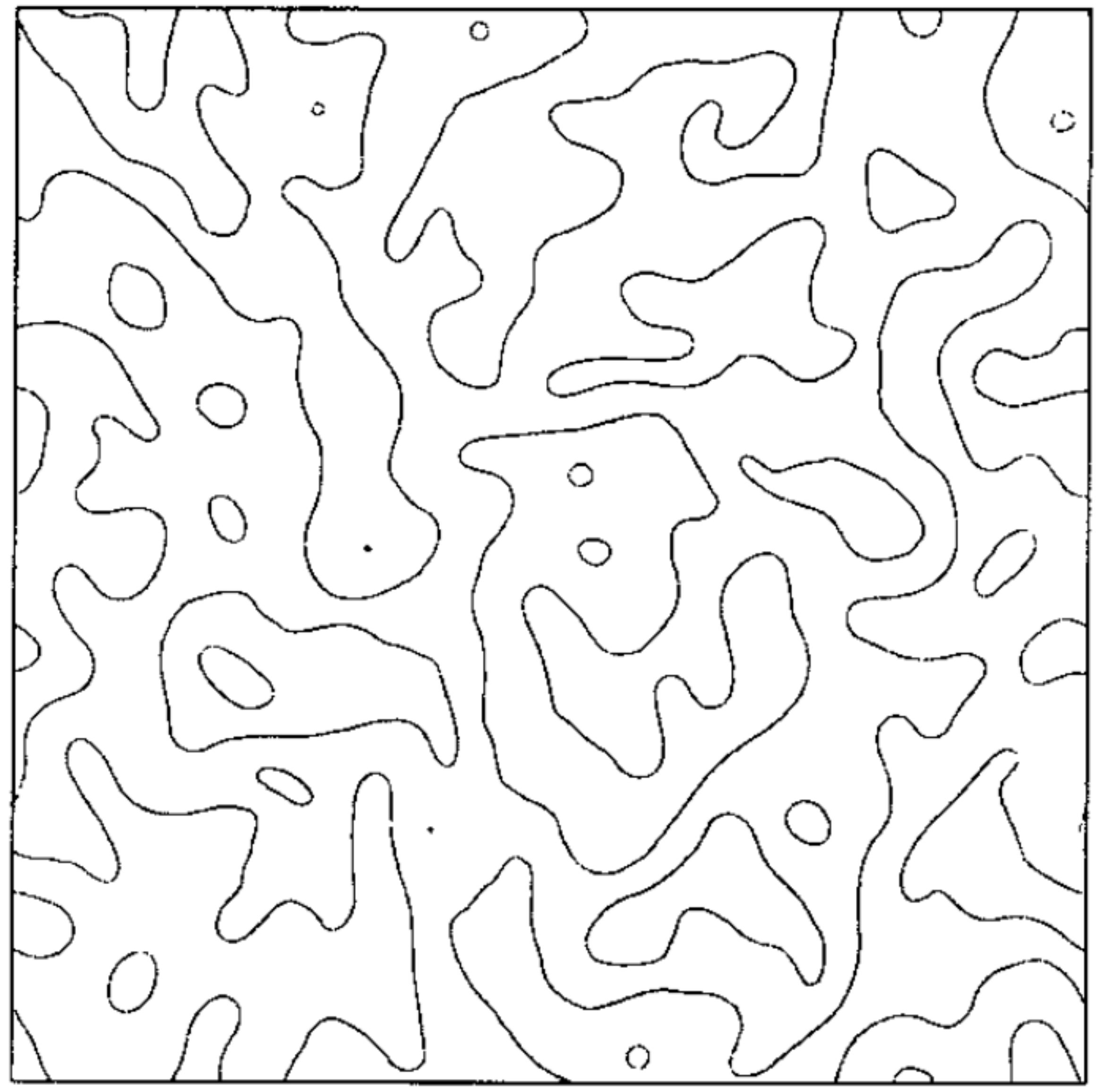

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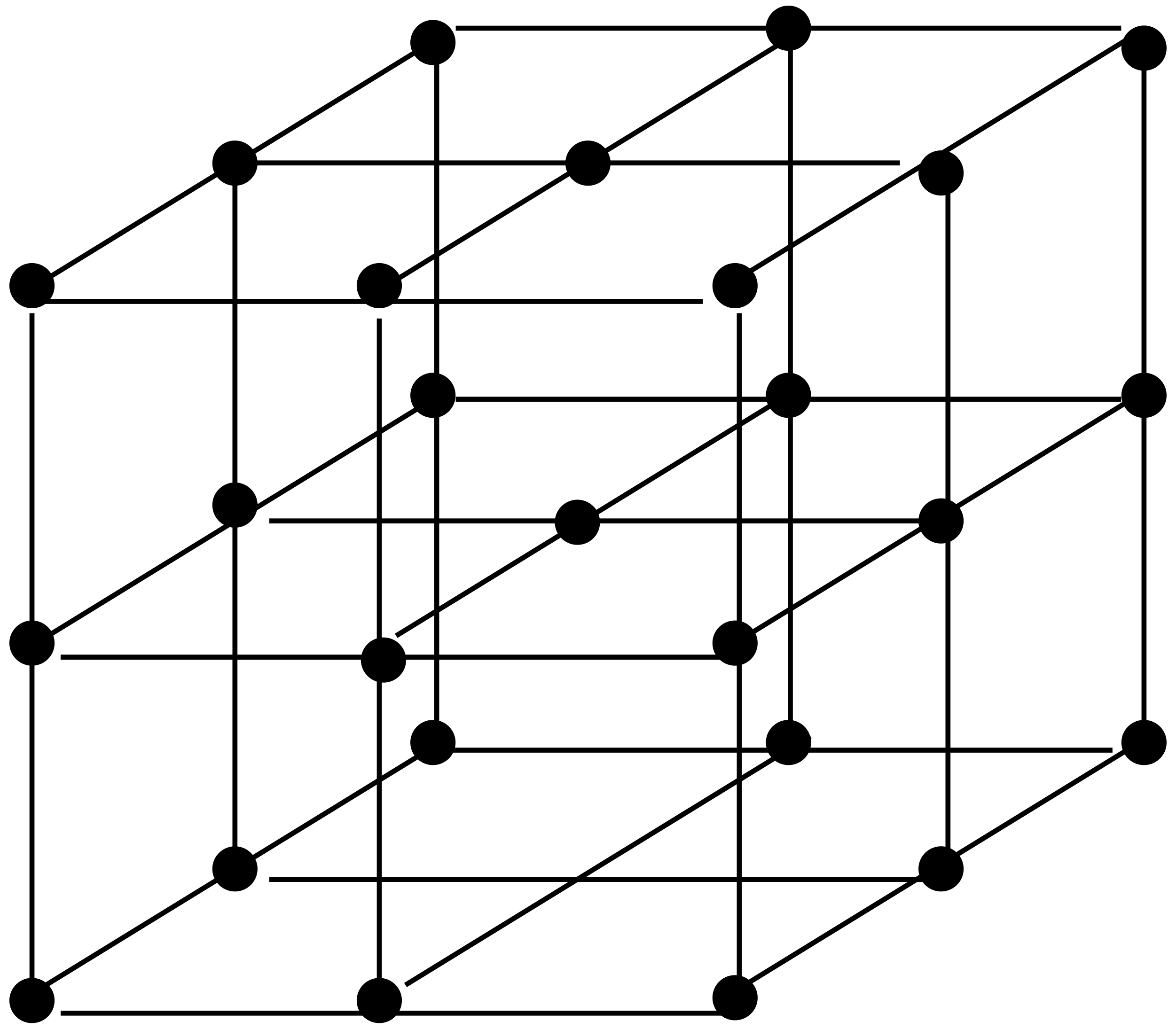

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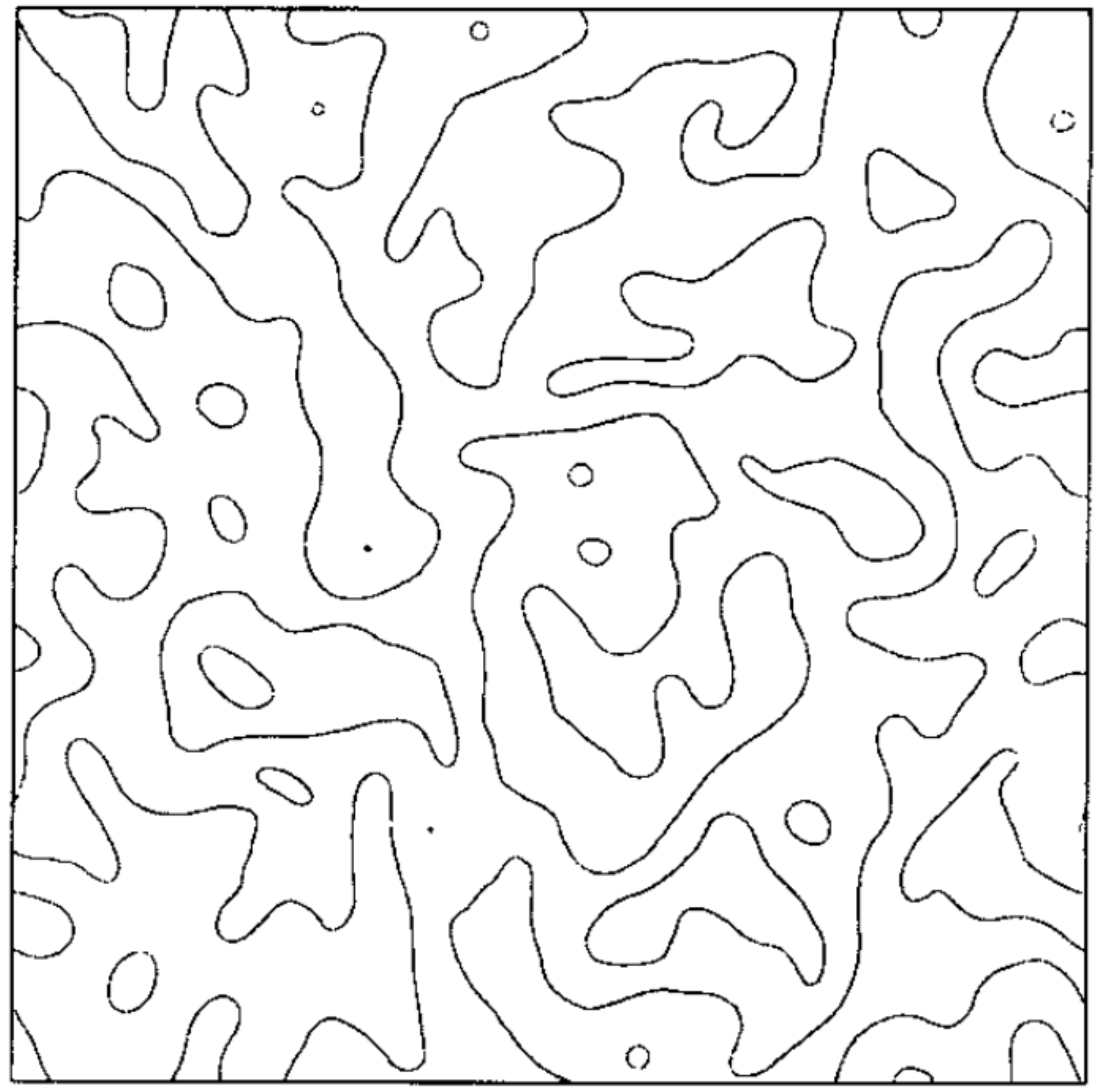

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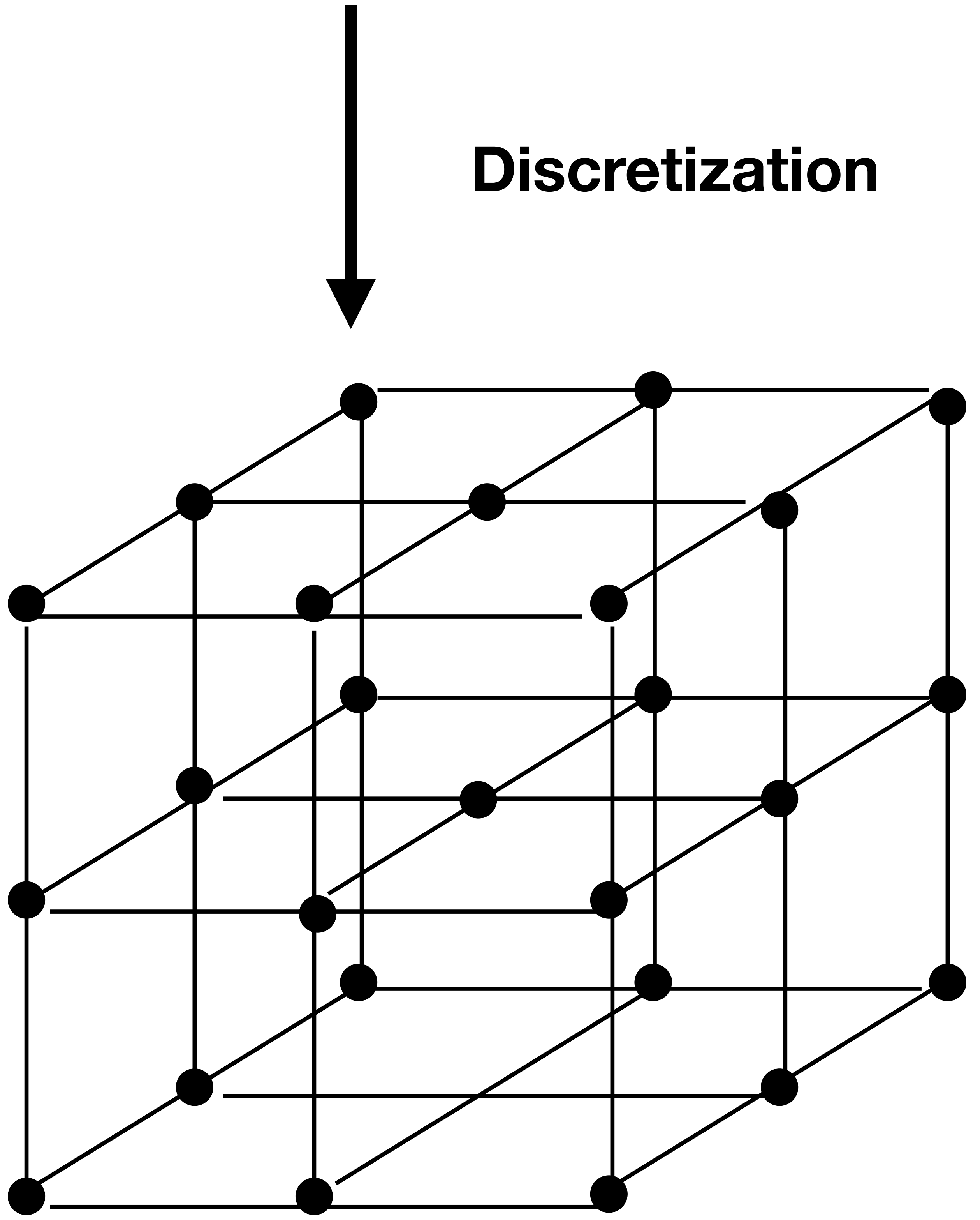

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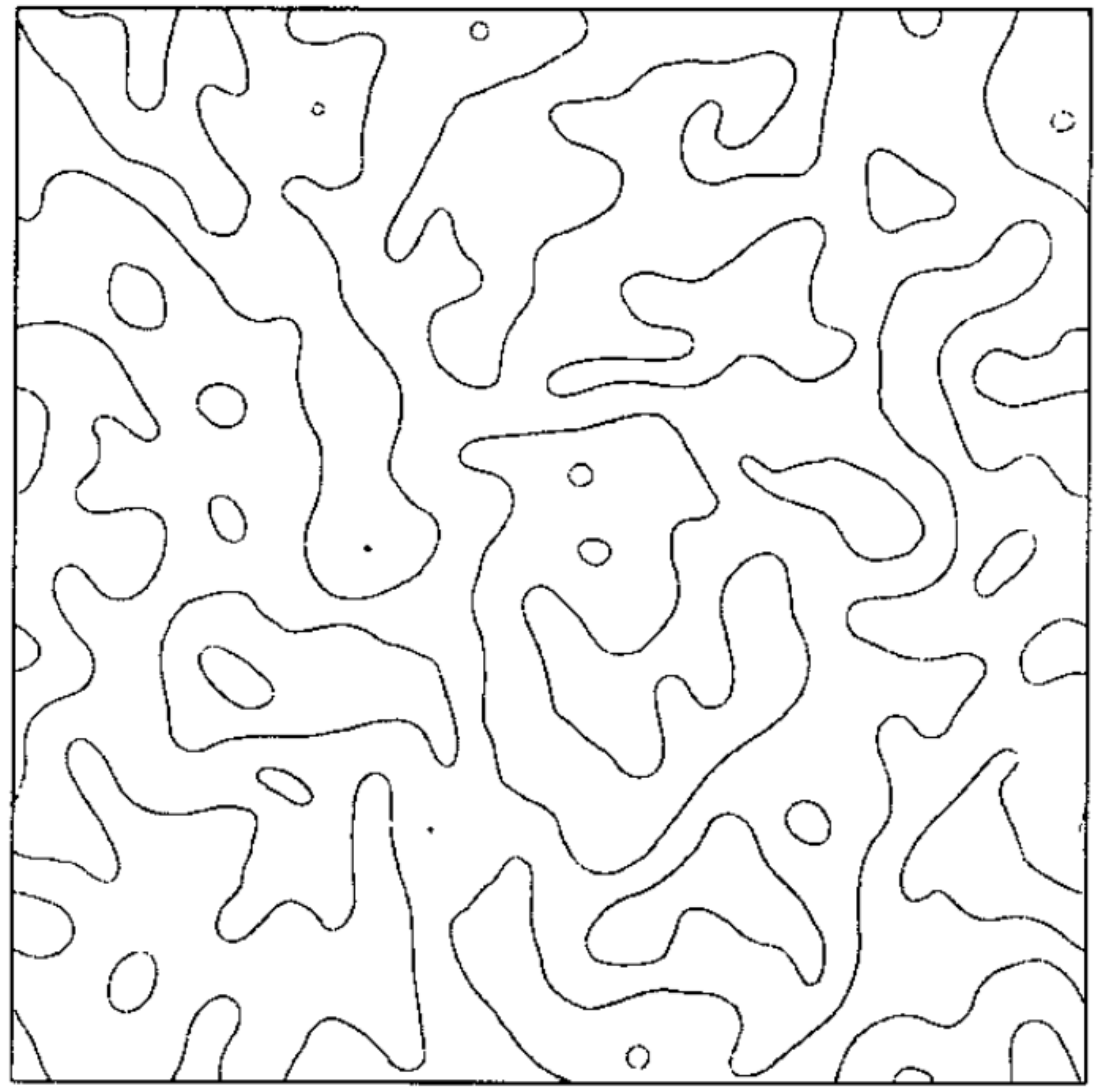

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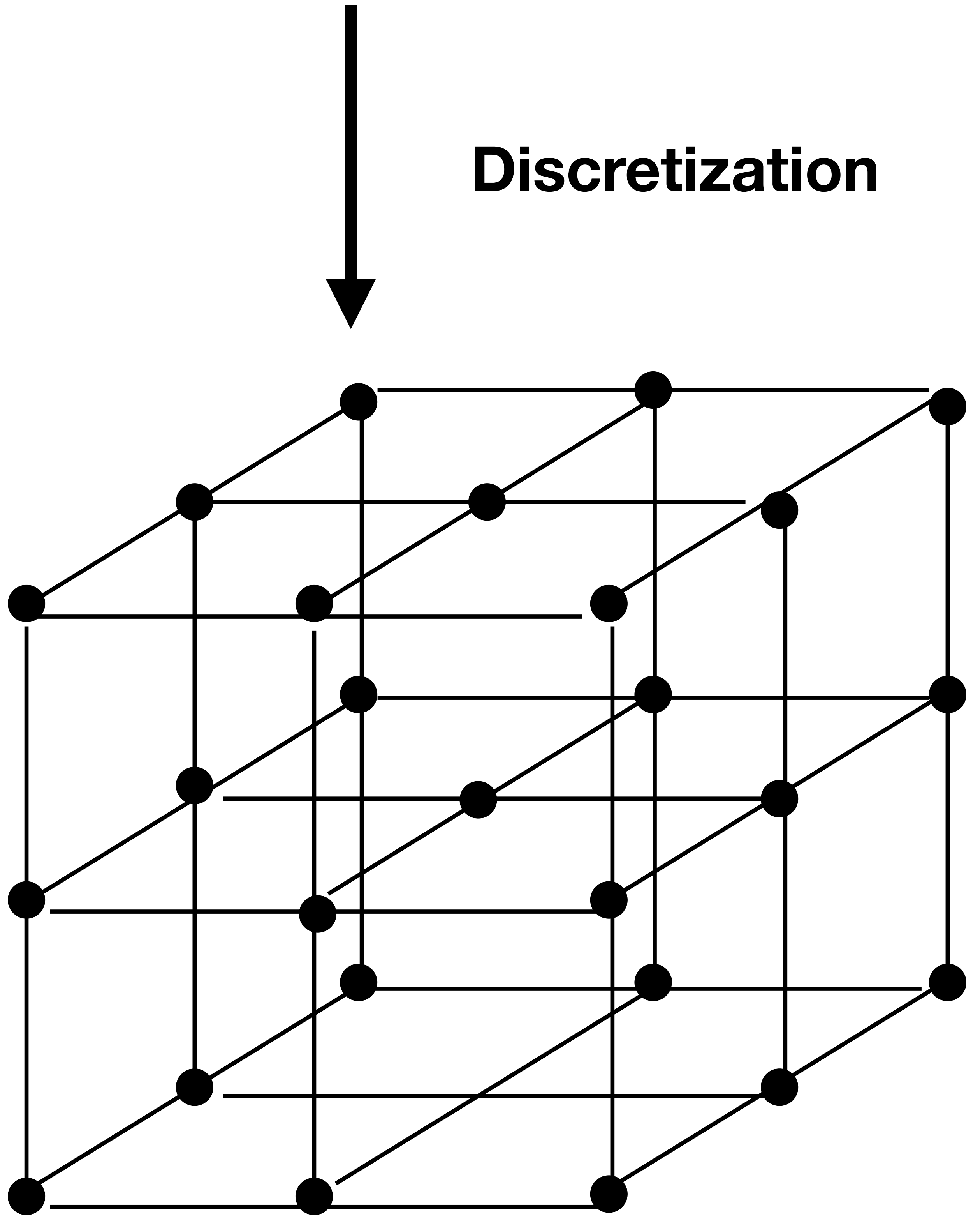

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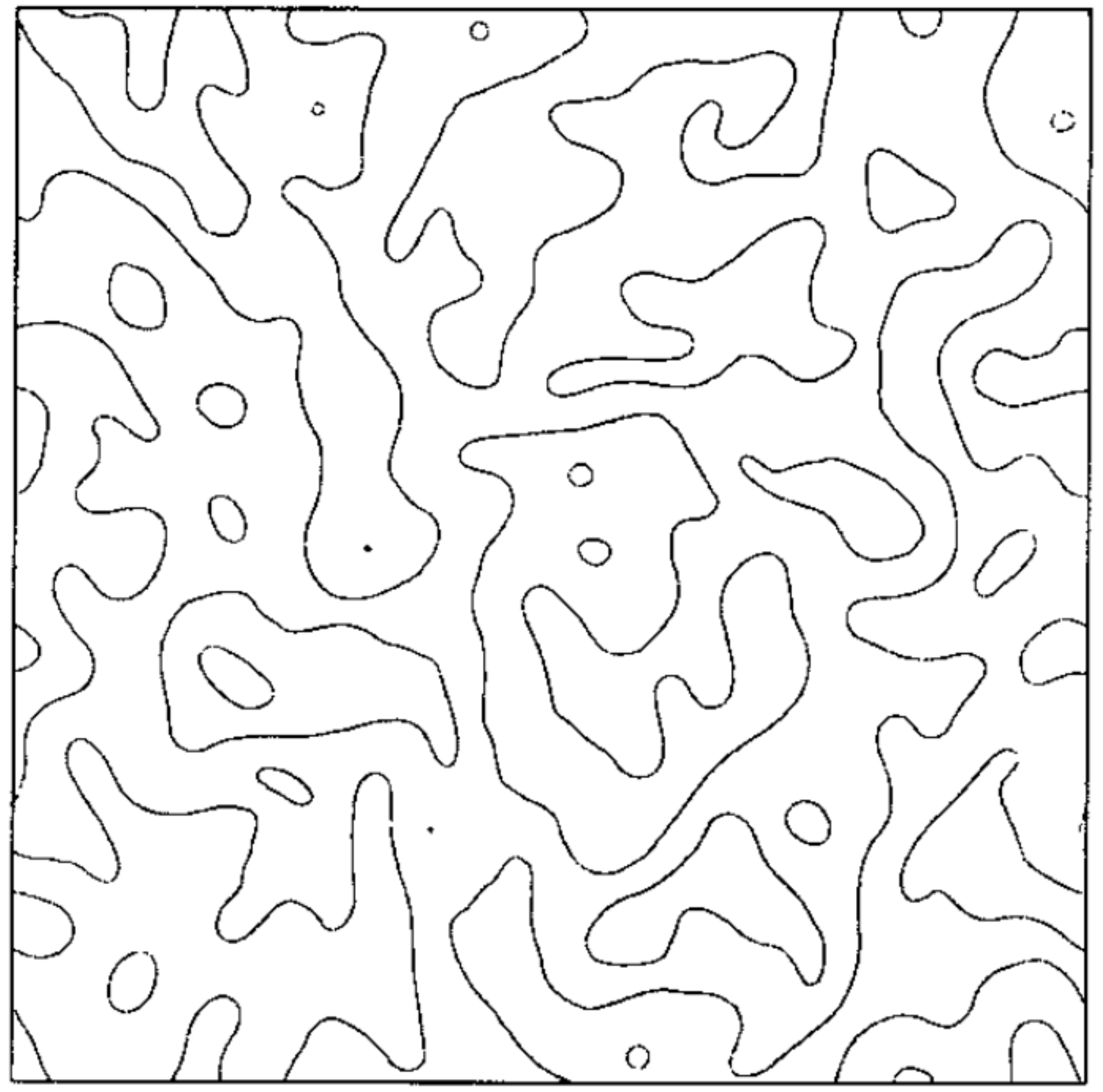
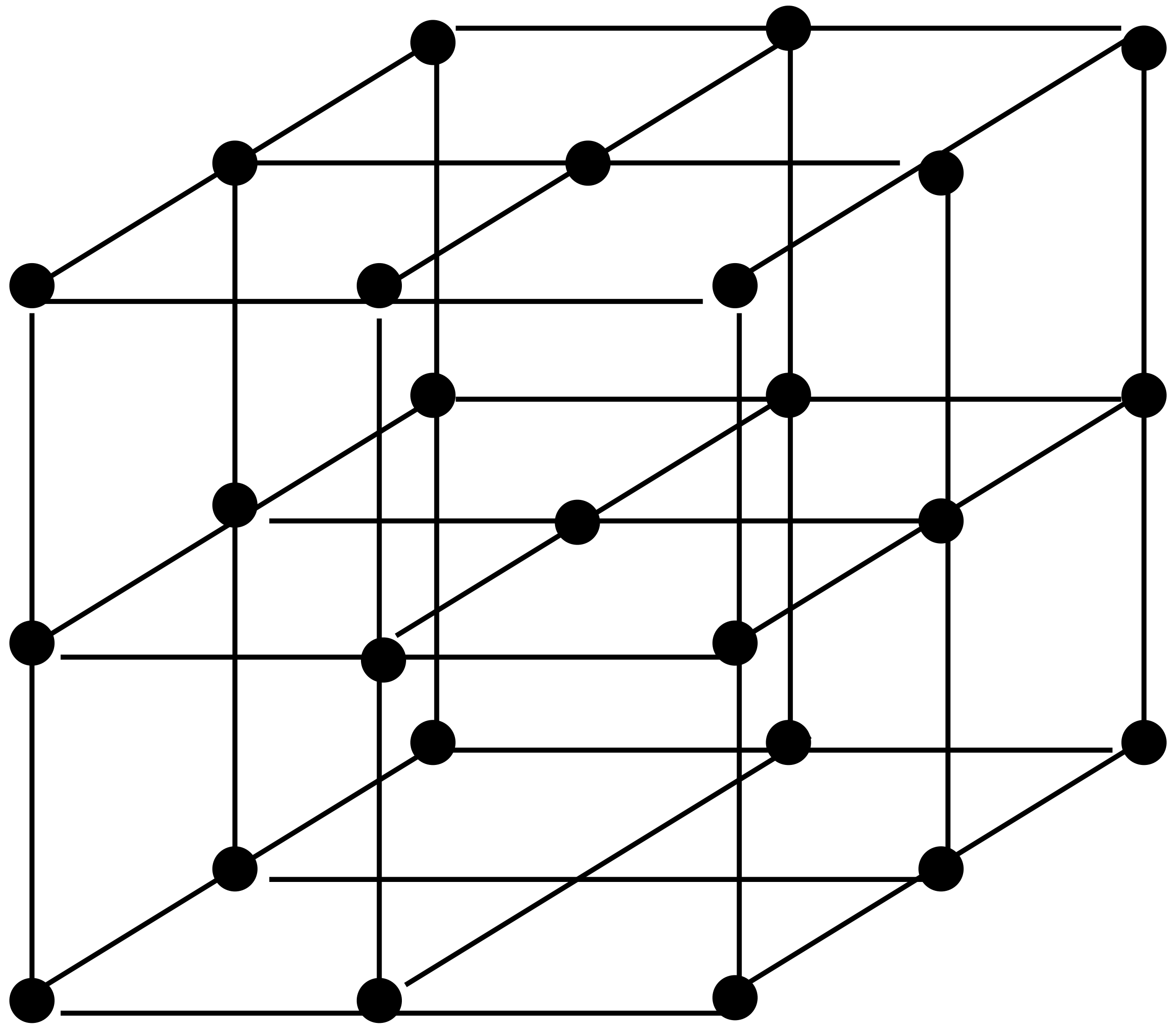


Vilenkin&Shellard 2000

Discretization



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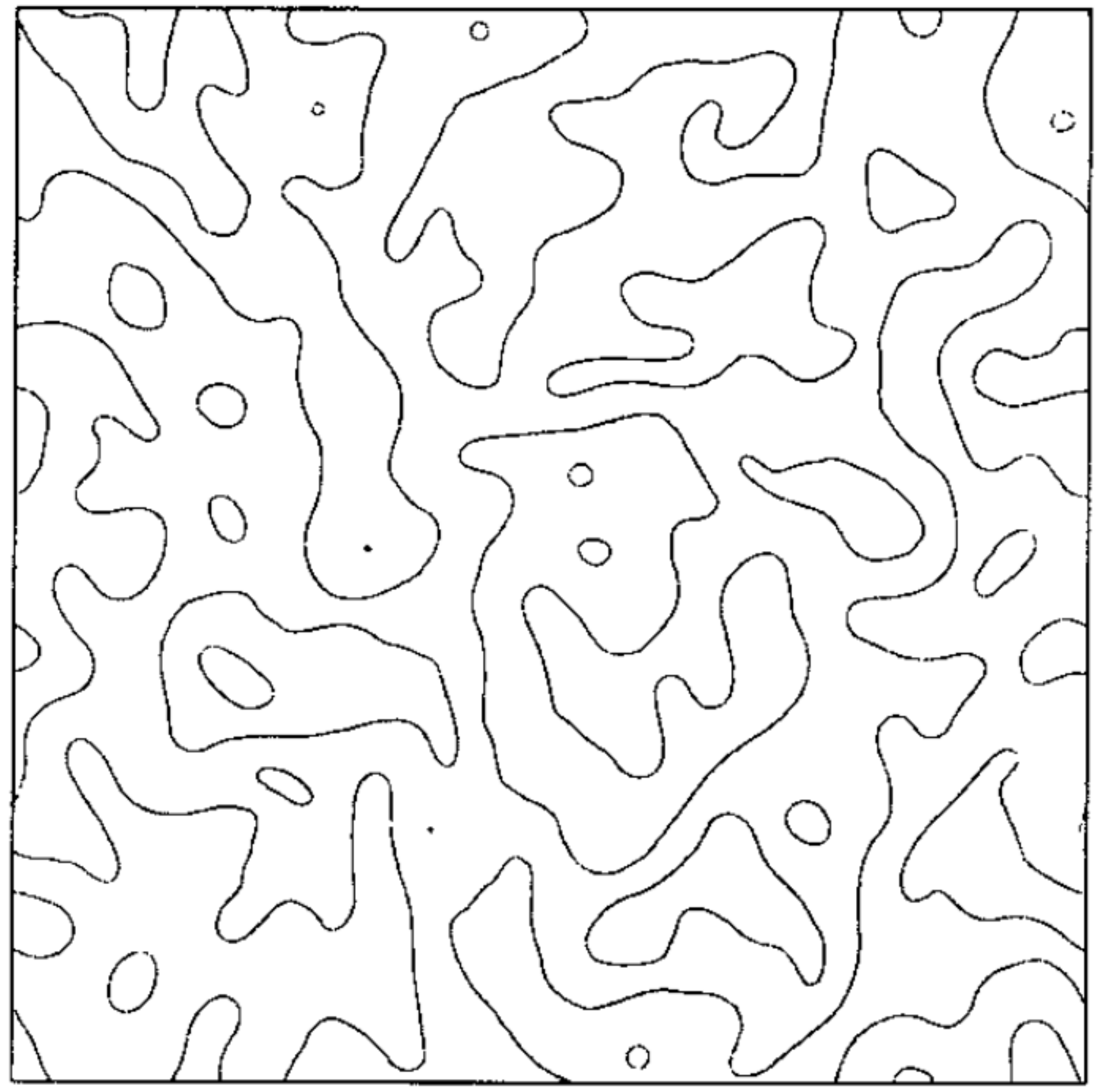

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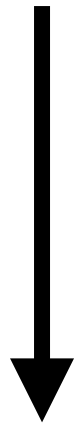

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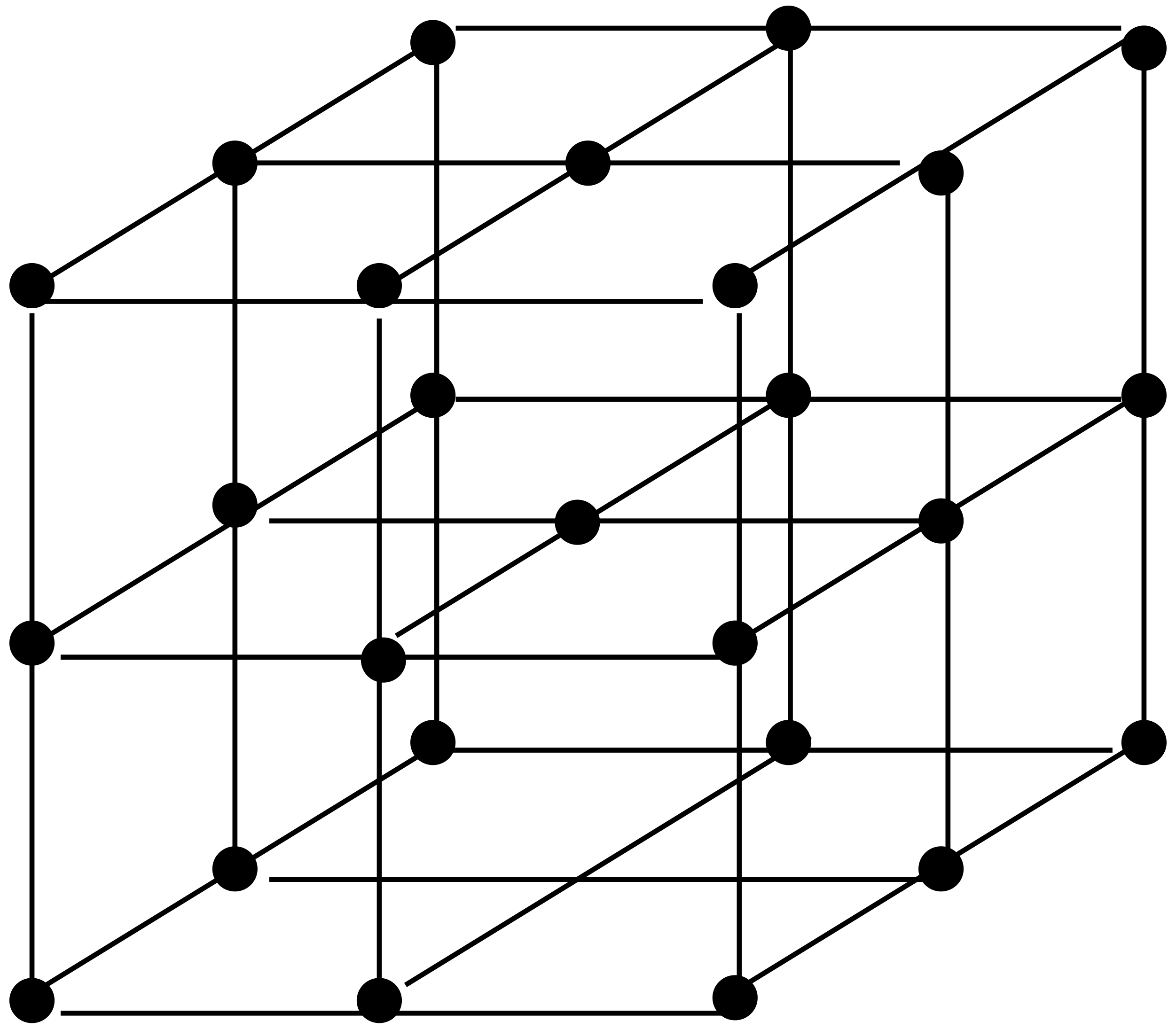

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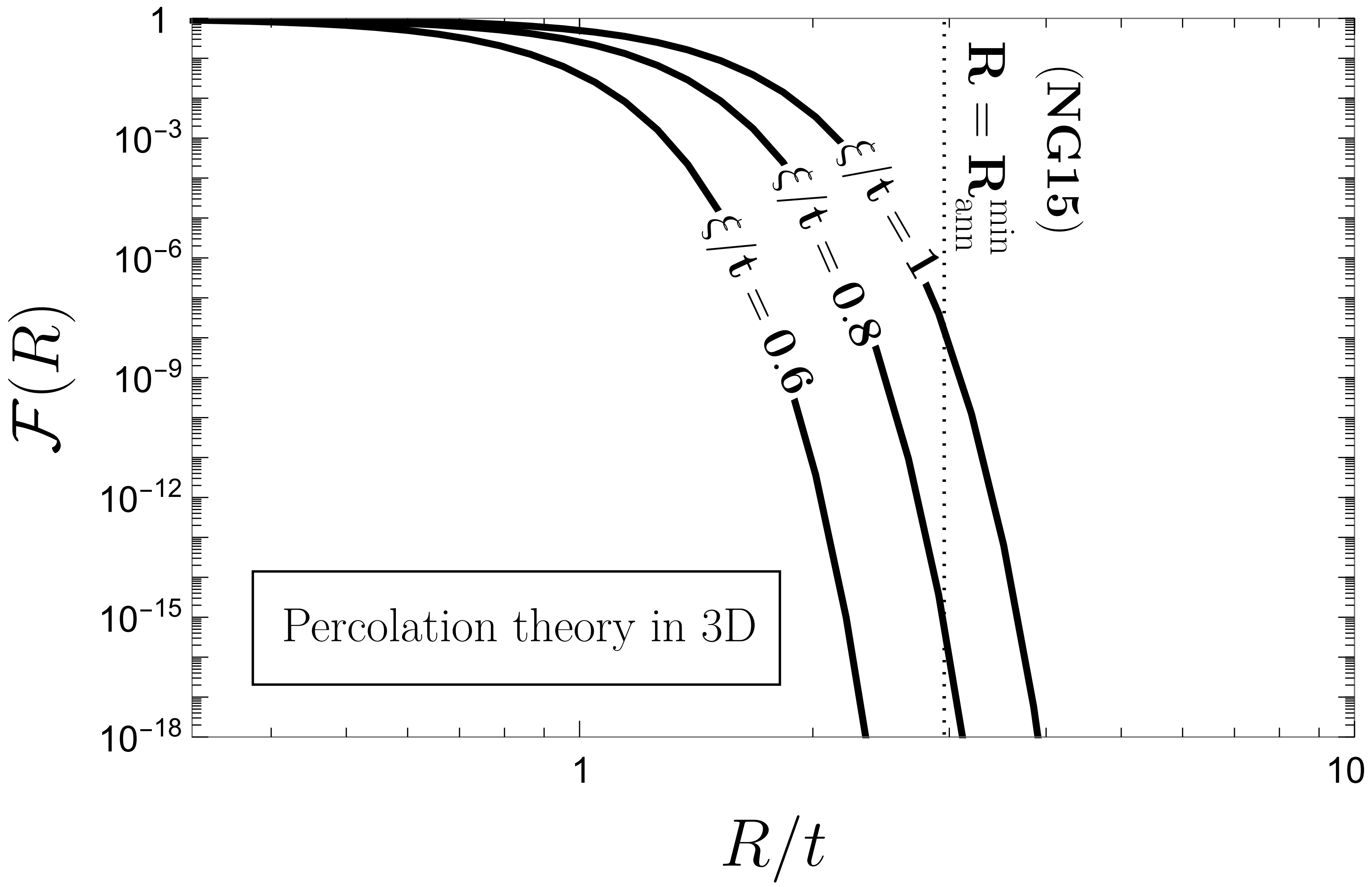
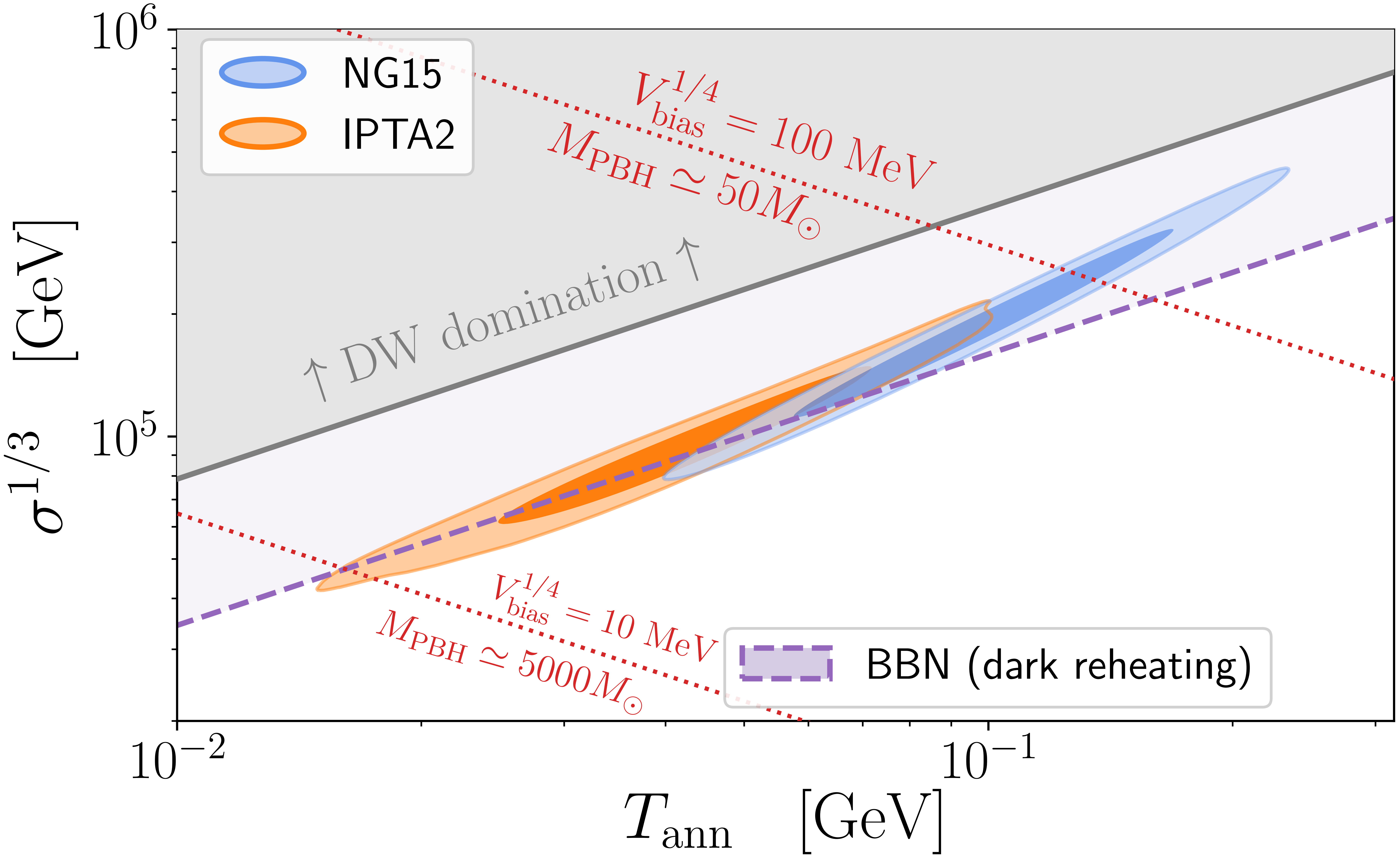
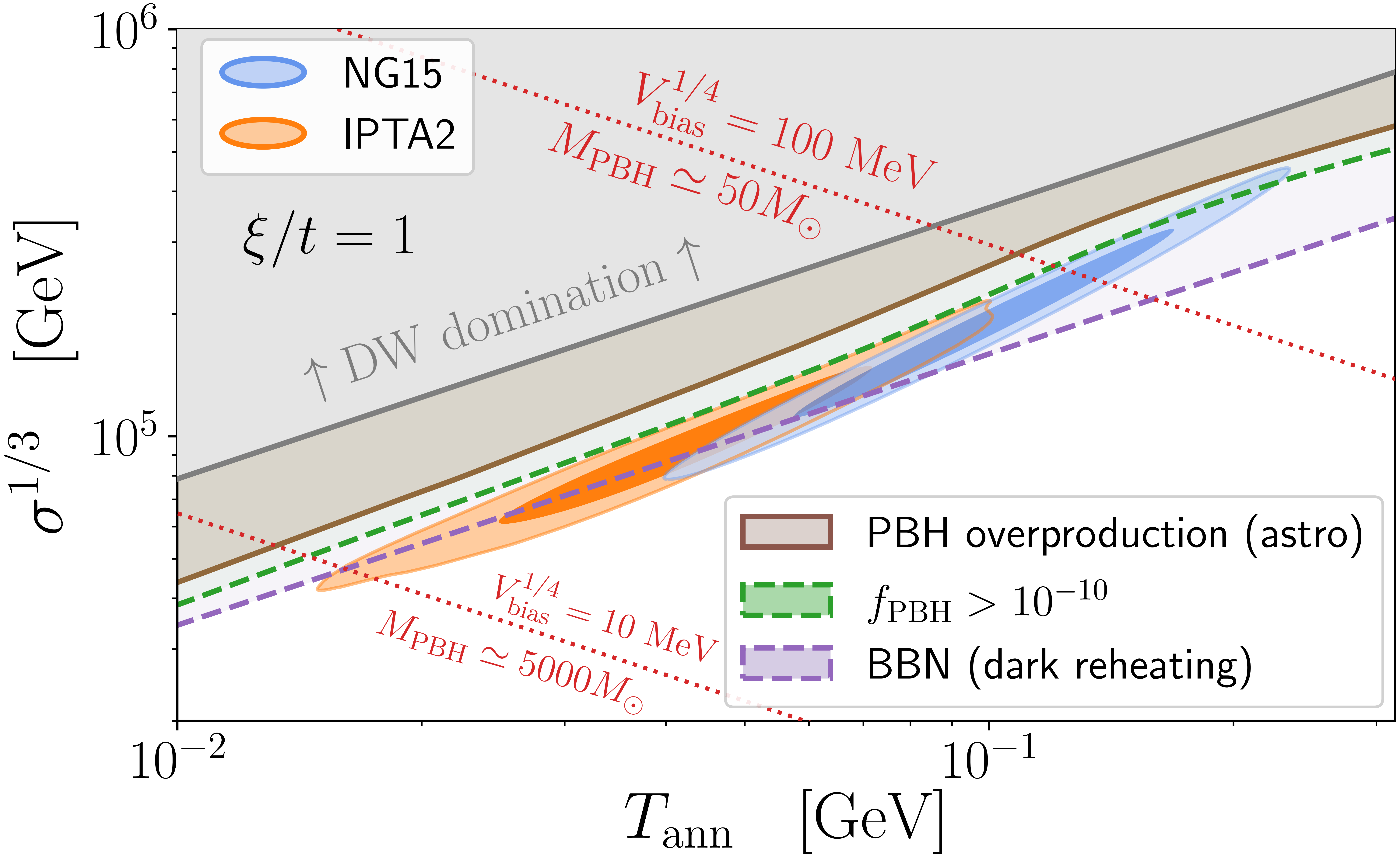




NG15
IPTA2
$V_{\rm bias}^{1/4} = 100$ MeV
$M_{\rm PBH} \simeq 50 M_\odot$
↑ DW domination ↑
$V_{\rm bias}^{1/4} = 10$ MeV
$M_{\rm PBH} \simeq 5000 M_\odot$
BBN (dark reheating)
10^6
10^5
$\sigma^{1/3}$ [GeV]
10^{-2}
10^{-1}
$T_{\rm ann}$ [GeV]


NG15
IPTA2
$\xi/t = 1$
↑ DW domination ↑
$V_{\rm bias}^{1/4} = 100$ MeV
$M_{\rm PBH} \simeq 50 M_\odot$
$V_{\rm bias}^{1/4} = 10$ MeV
$M_{\rm PBH} \simeq 5000 M_\odot$
PBH overproduction (astro)
$f_{\rm PBH} > 10^{-10}$
BBN (dark reheating)
$\sigma^{1/3}$ [GeV]
$T_{\rm ann}$ [GeV]
10^{6}
10^{5}
10^{-2}
10^{-1}

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YG, 2307.04239, to appear in PRL

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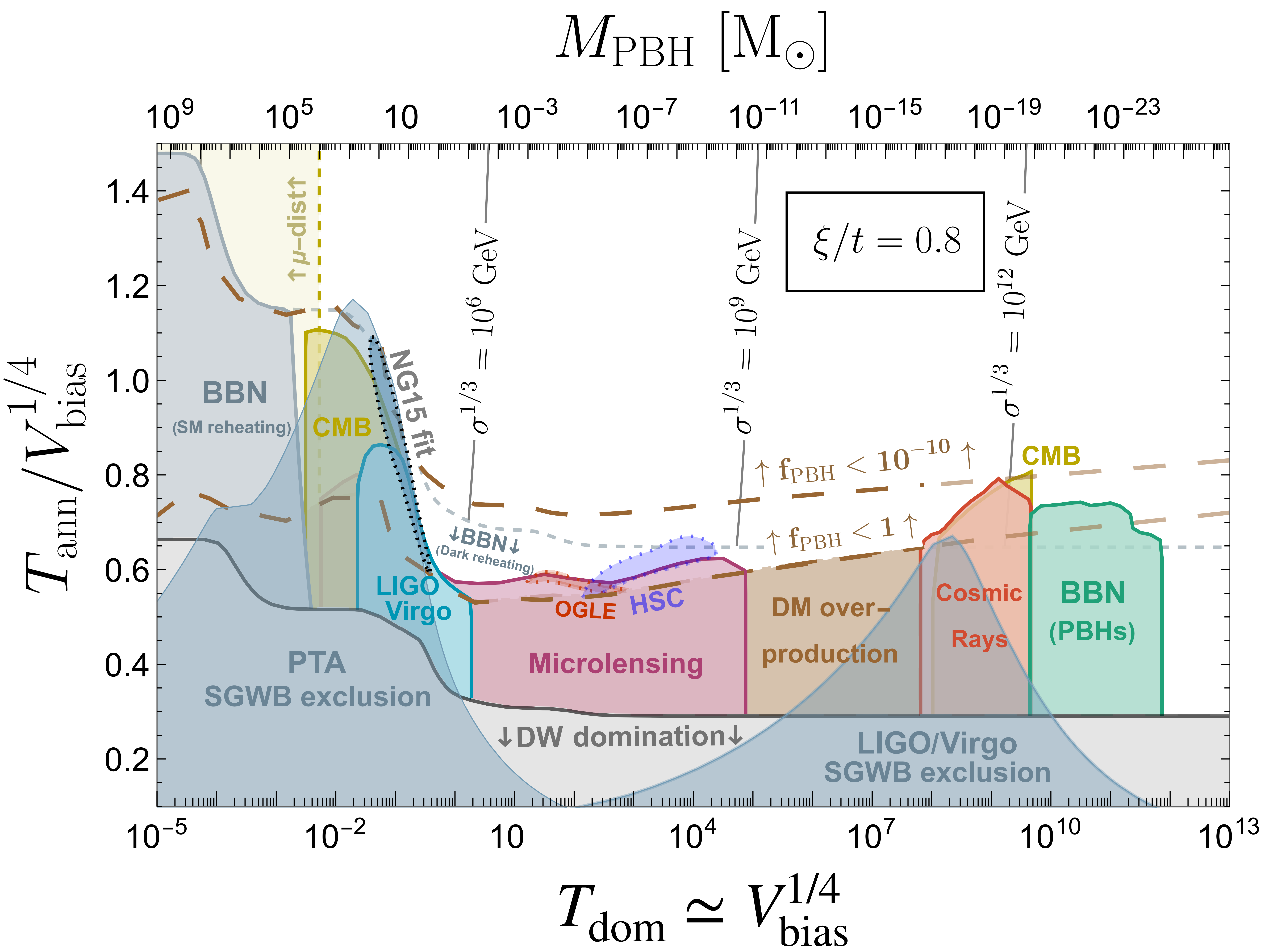
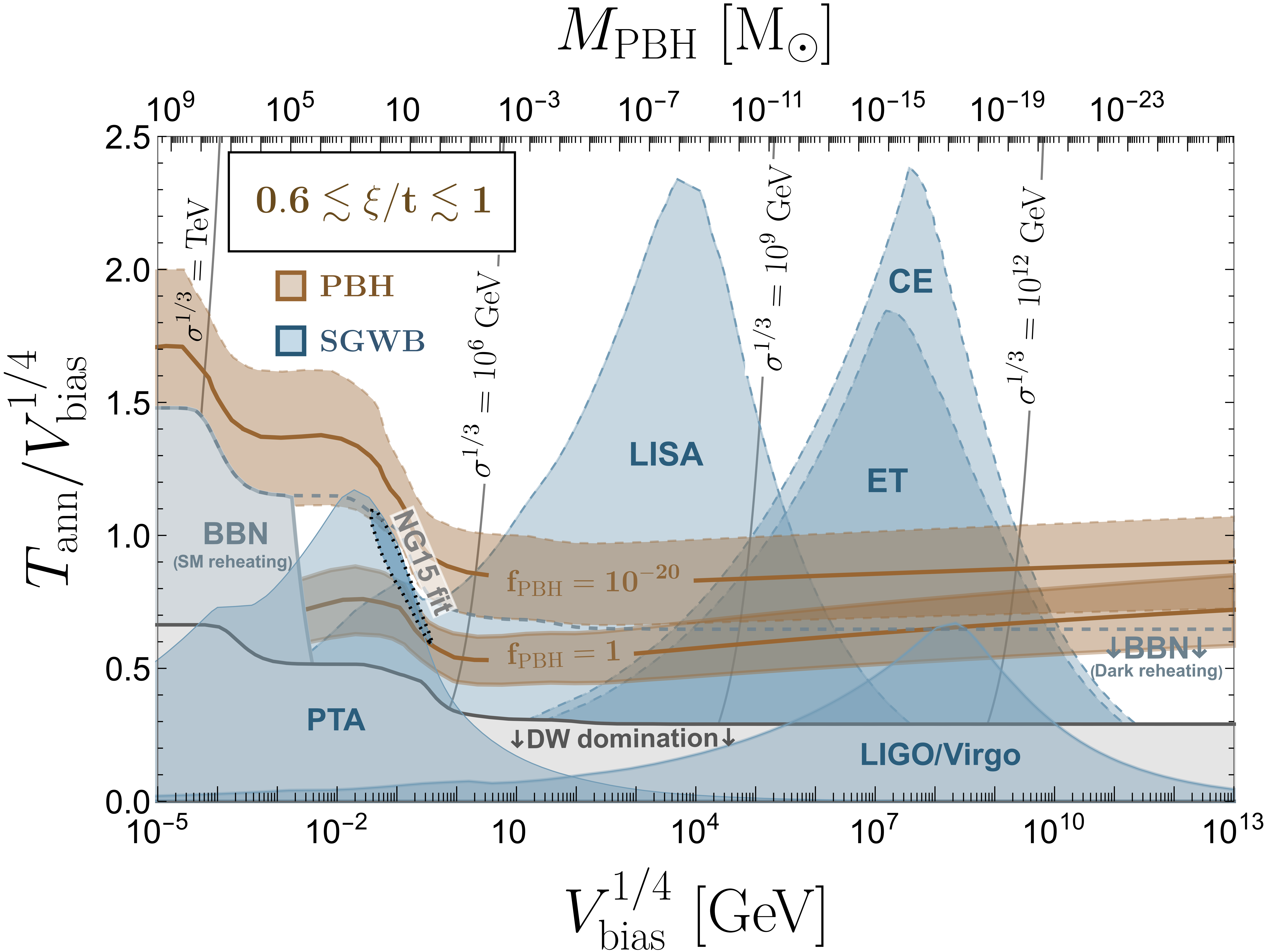
Outlooks: Many applications beyond PTA

(Except if GW from DW has been over-estimated)



$M_{\rm PBH}$ [$M_\odot$]
10^9
10^5
10
10^{-3}
10^{-7}
10^{-11}
10^{-15}
10^{-19}
10^{-23}
$\xi/t = 0.8$
↑μ-dist↑
$\sigma^{1/3} = 10^6$ GeV
$\sigma^{1/3} = 10^9$ GeV
$\sigma^{1/3} = 10^{12}$ GeV
NG15 fit
BBN
(SM reheating)
CMB
↑ $f_{\rm PBH} < 10^{-10}$ ↑
↑ $f_{\rm PBH} < 1$ ↑
CMB
↓BBN↓
(Dark reheating)
LIGO
Virgo
OGLE
HSC
DM over-
production
Cosmic
Rays
BBN
(PBHs)
PTA
SGWB exclusion
Microlensing
↓DW domination↓
LIGO/Virgo
SGWB exclusion
1.4
1.2
1.0
0.8
0.6
0.4
0.2
$T_{\rm ann}/V_{\rm bias}^{1/4}$
10^{-5}
10^{-2}
10
10^4
10^7
10^{10}
10^{13}
$T_{\rm dom} \simeq V_{\rm bias}^{1/4}$



$M_{\rm PBH}$ [$M_\odot$]
10^9
10^5
10
10^{-3}
10^{-7}
10^{-11}
10^{-15}
10^{-19}
10^{-23}
$0.6 \lesssim \xi/t \lesssim 1$
PBH
SGWB
$\sigma^{1/3}$ = TeV
$\sigma^{1/3} = 10^6$ GeV
$\sigma^{1/3} = 10^9$ GeV
$\sigma^{1/3} = 10^{12}$ GeV
LISA
CE
ET
BBN
(SM reheating)
NG15 fit
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$f_{\rm PBH} = 1$
↓BBN↓
(Dark reheating)
PTA
↓DW domination↓
LIGO/Virgo
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2.5
2.0
1.5
1.0
0.5
0.0
10^{-5}
10^{-2}
10
10^4
10^7
10^{10}
10^{13}
$V_{\rm bias}^{1/4}$ [GeV]