Primordial Black Holes from supercooled phase transitions

Yann Gouttenoire

Postdoc in Tel Aviv U.

RUBAKOV CONFERENCE` 23

3rd October 2023

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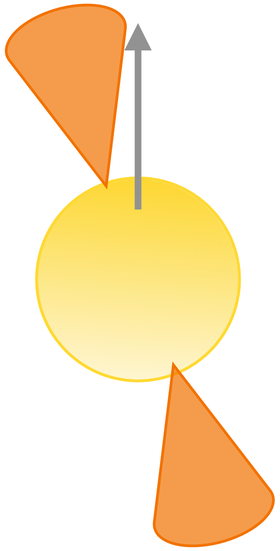
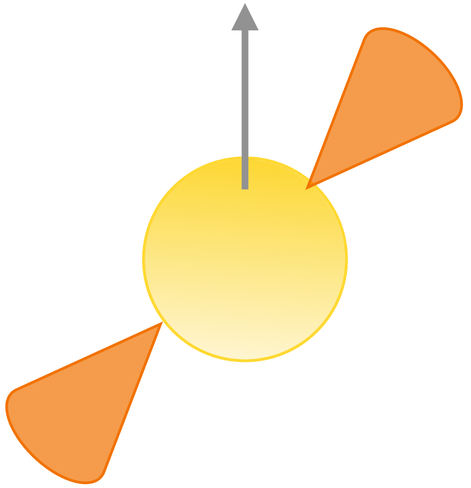
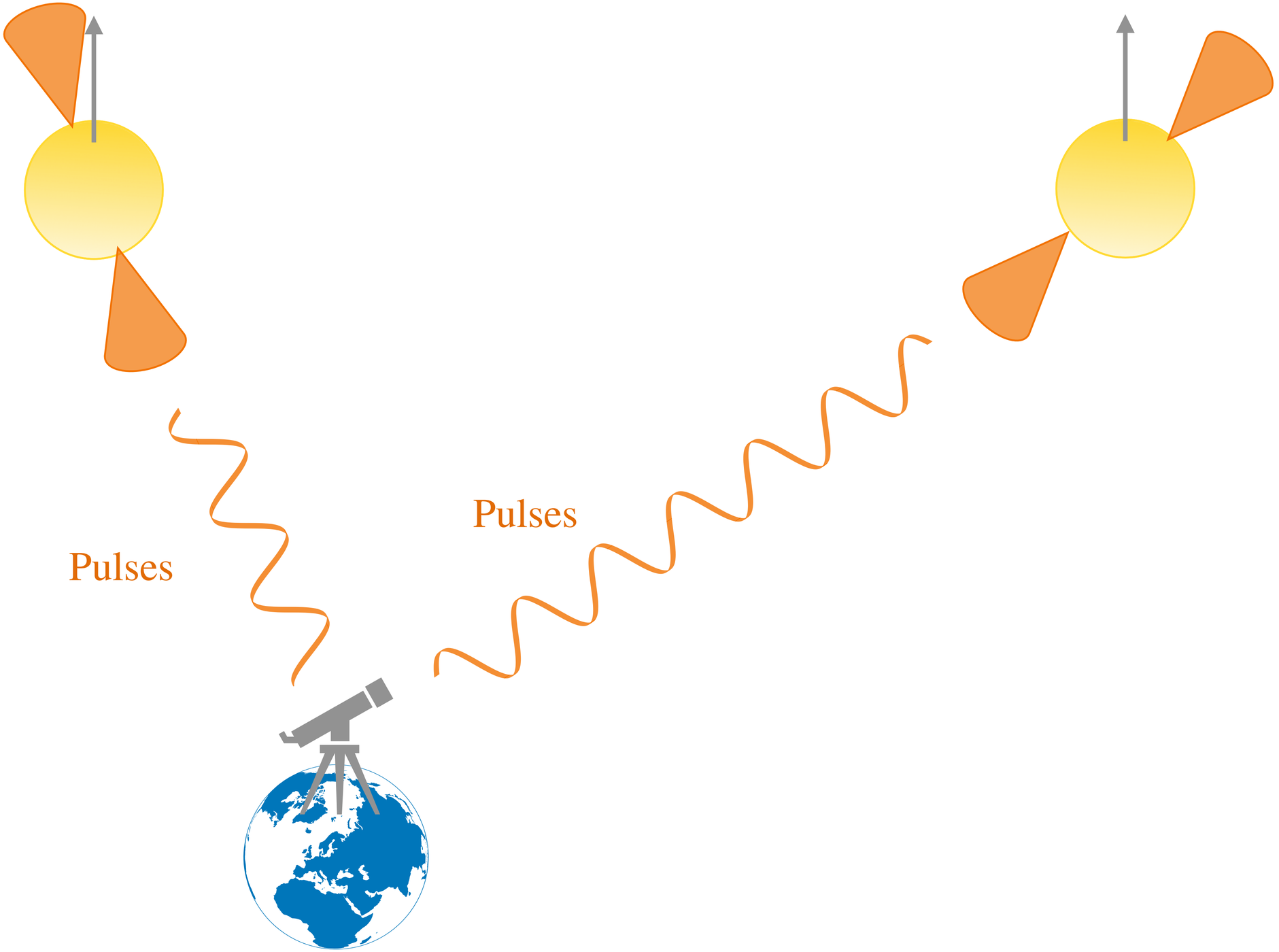
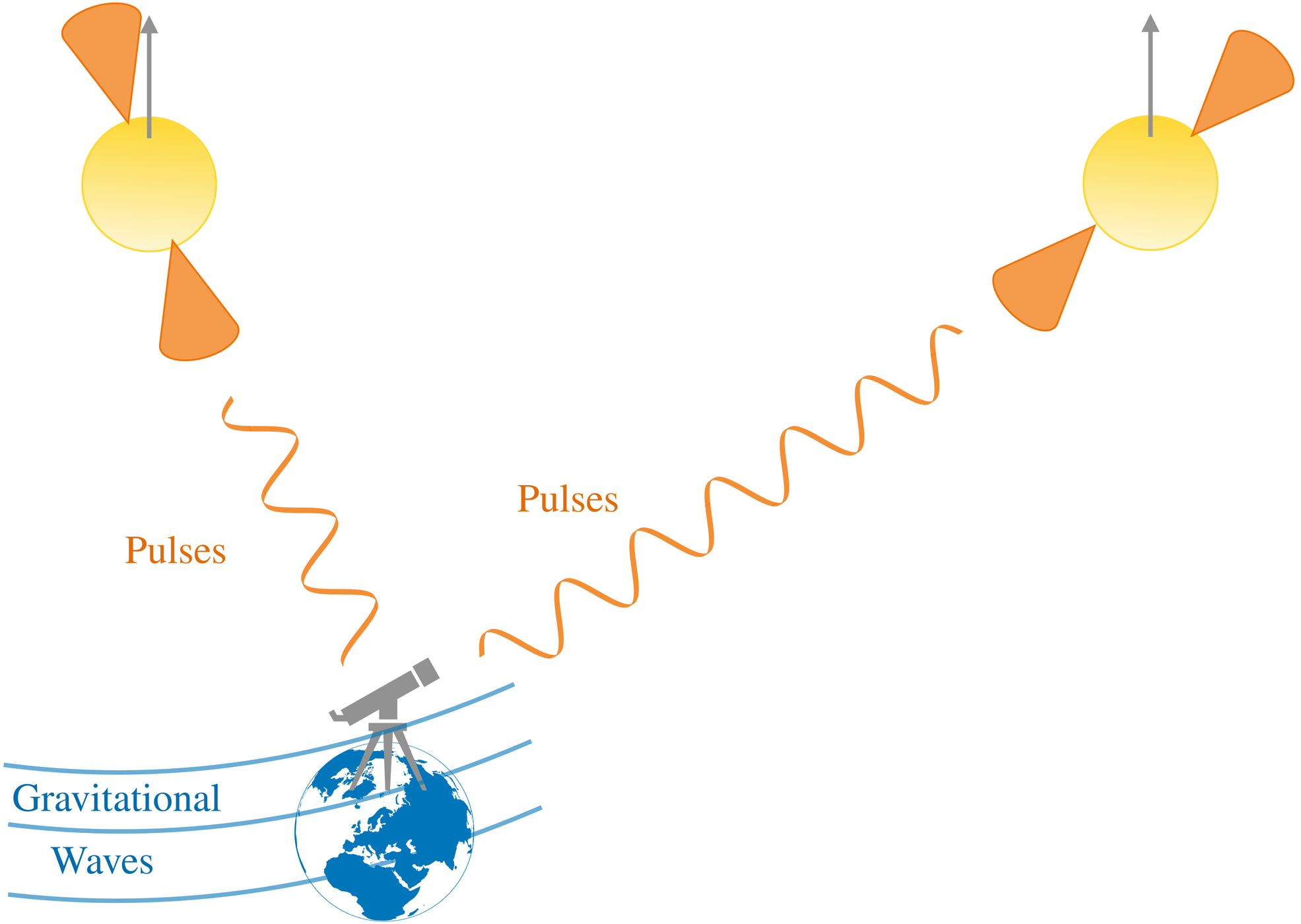
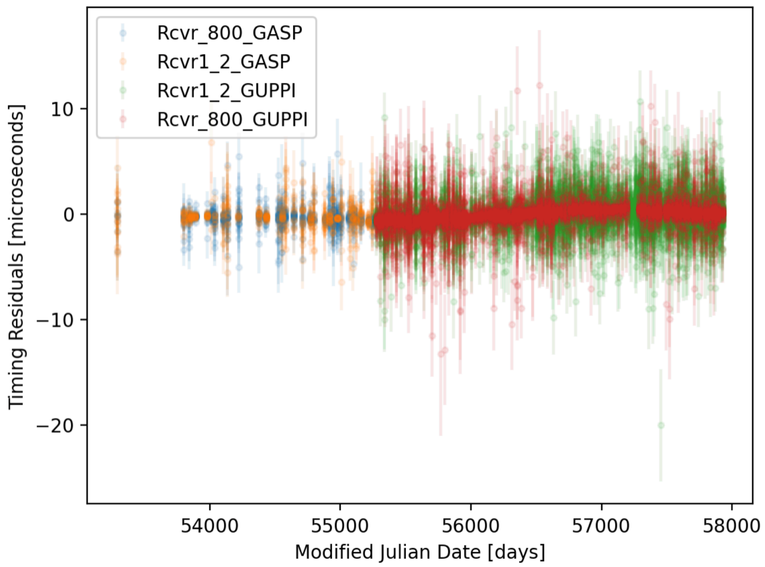





Pulses
Pulses


Pulses
Pulses
Gravitational
Waves

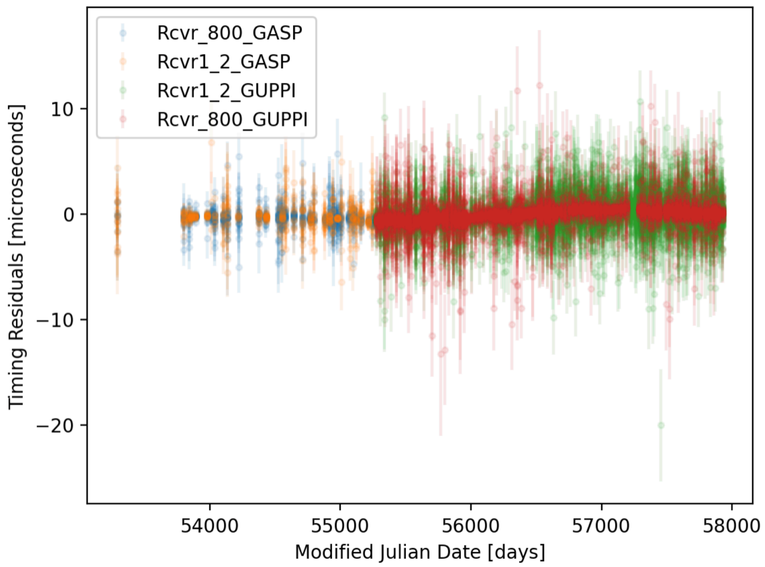


Pulses

Pulses

Gravitational

Waves



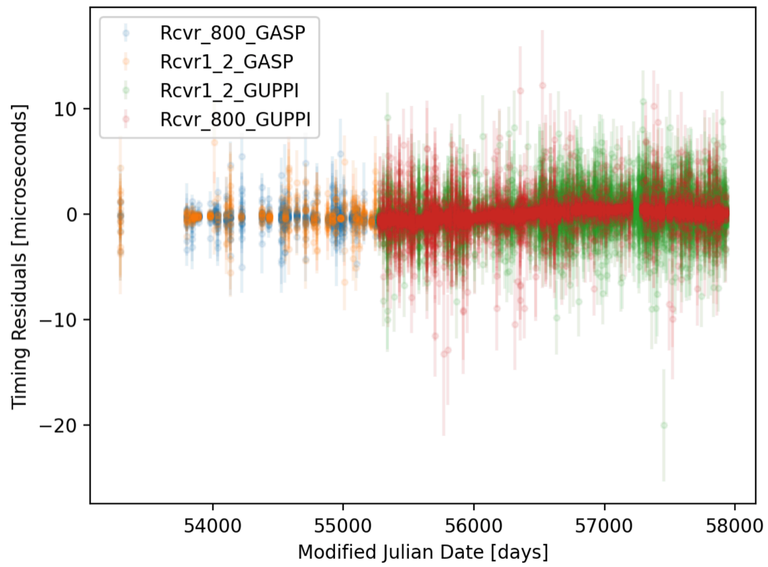
Pulses

Pulses

Gravitational

Waves

Solar system systematics



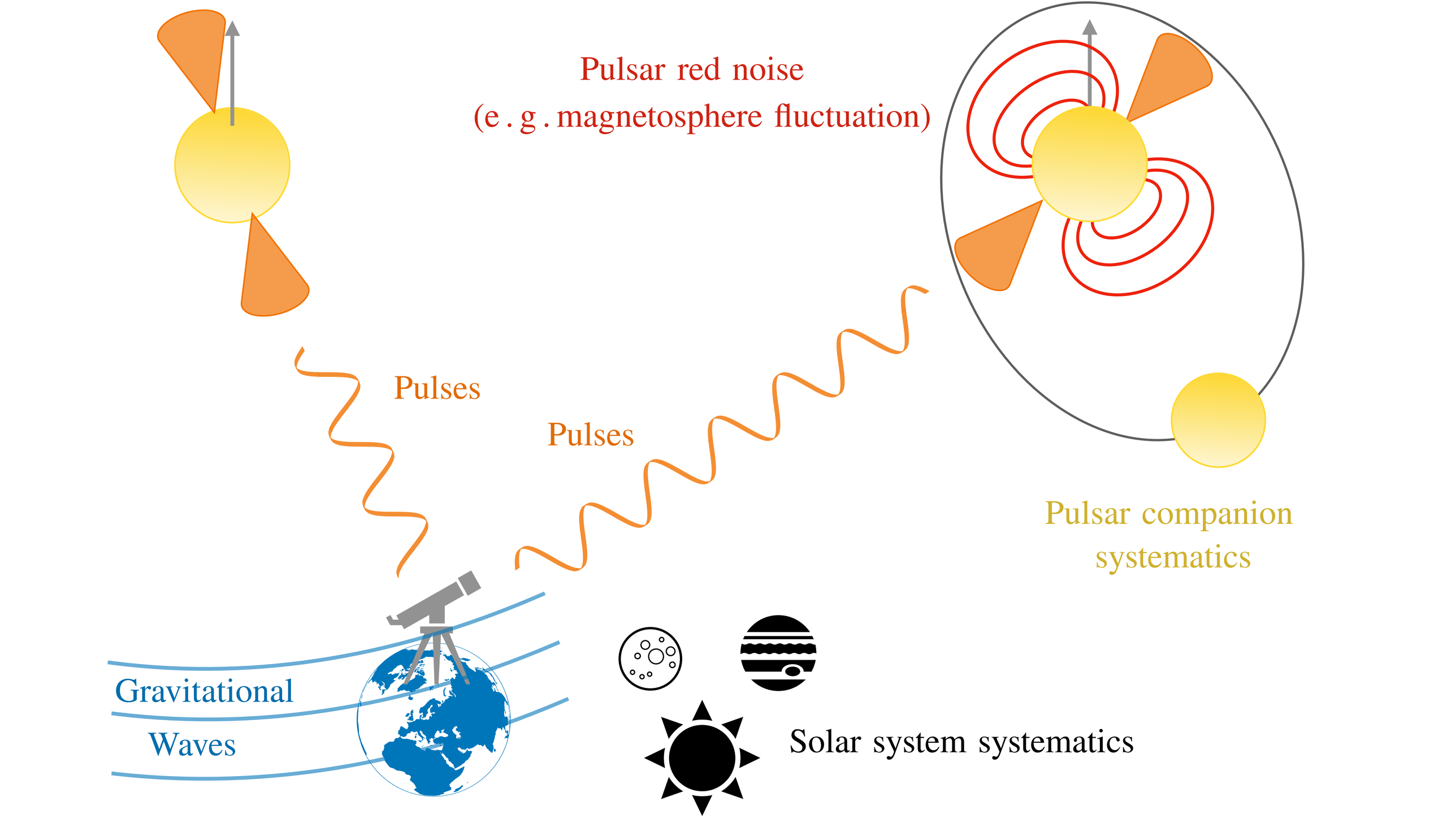
Pulses

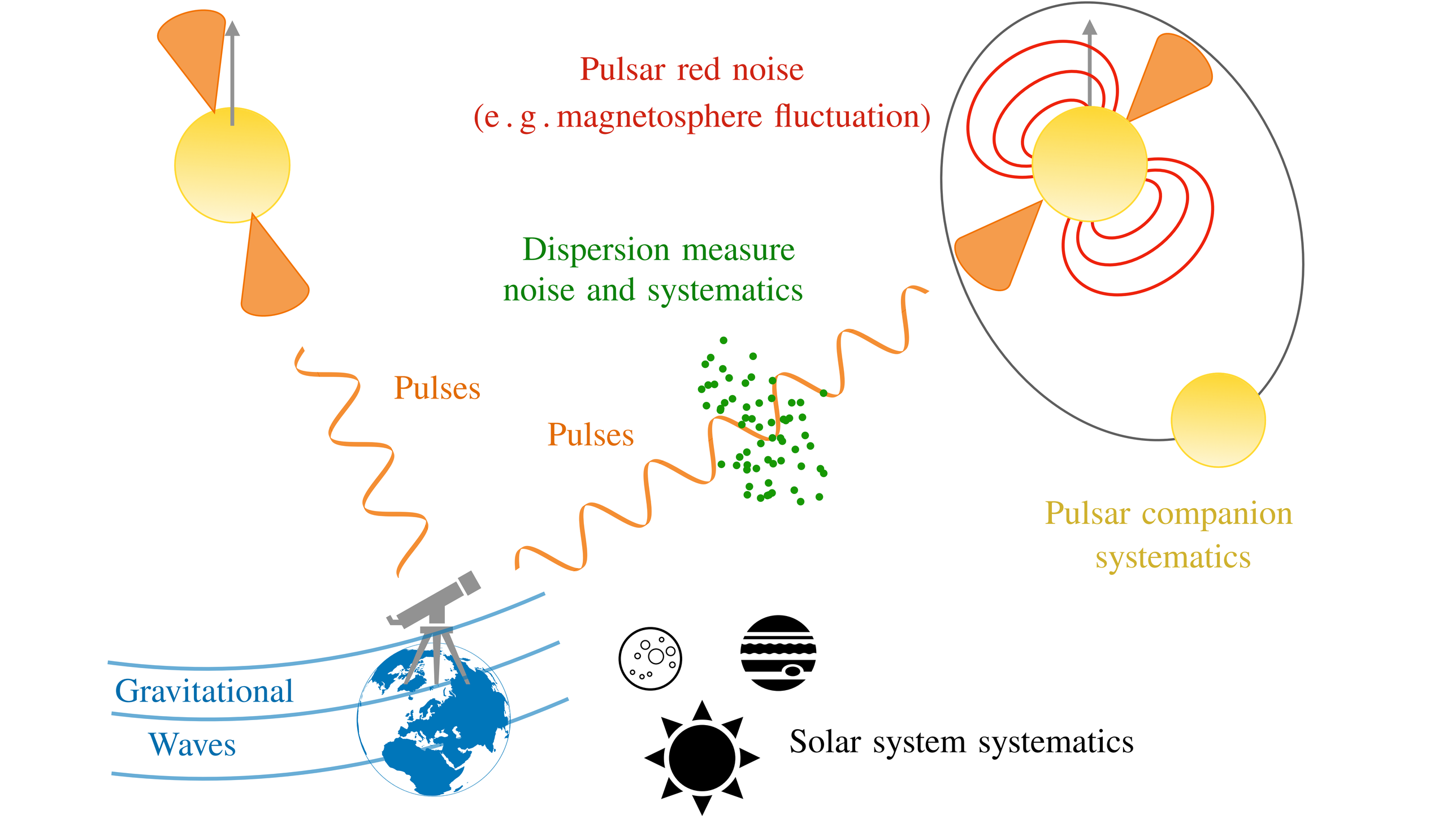
Pulses

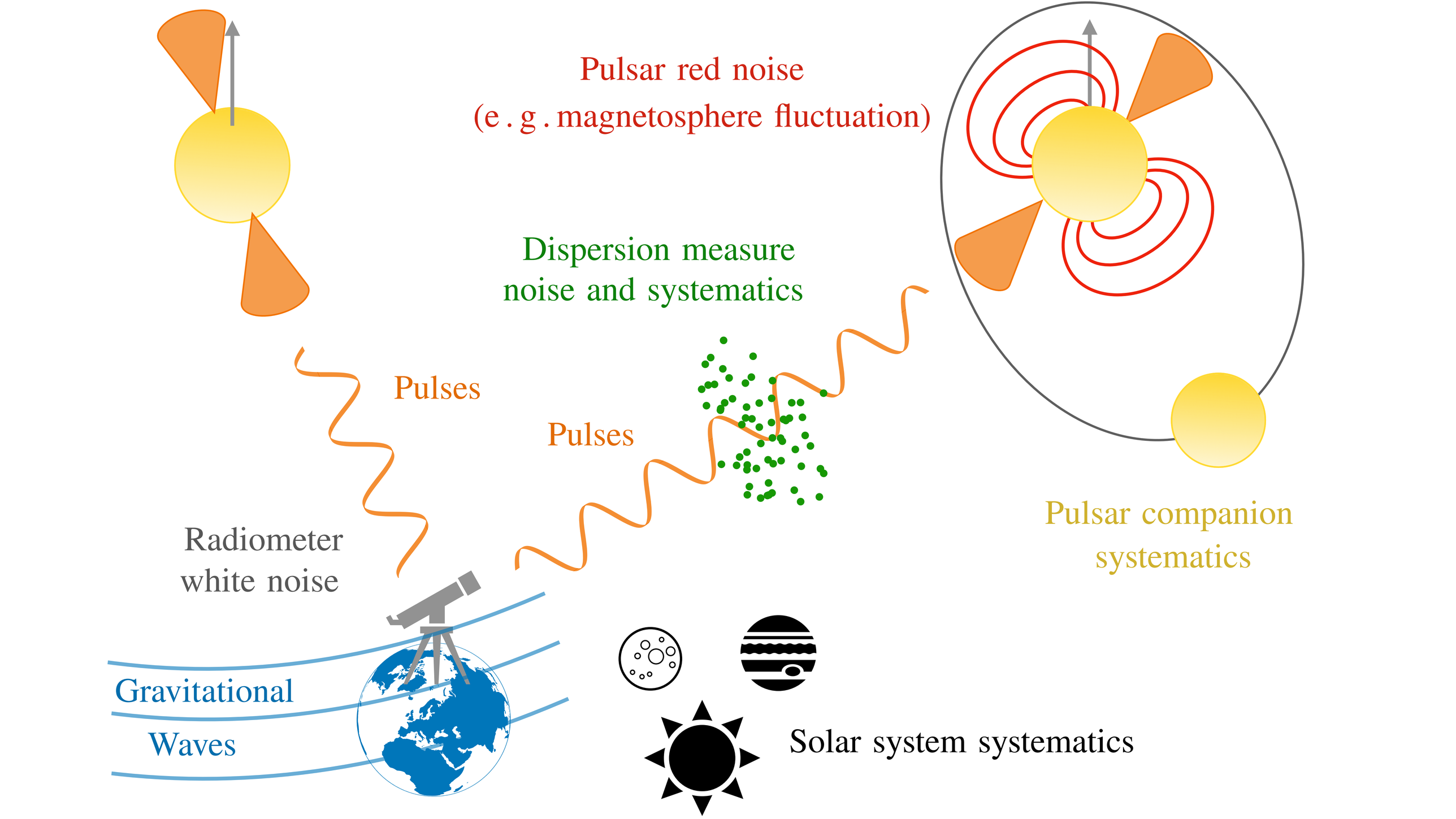
Pulsar companion systematics

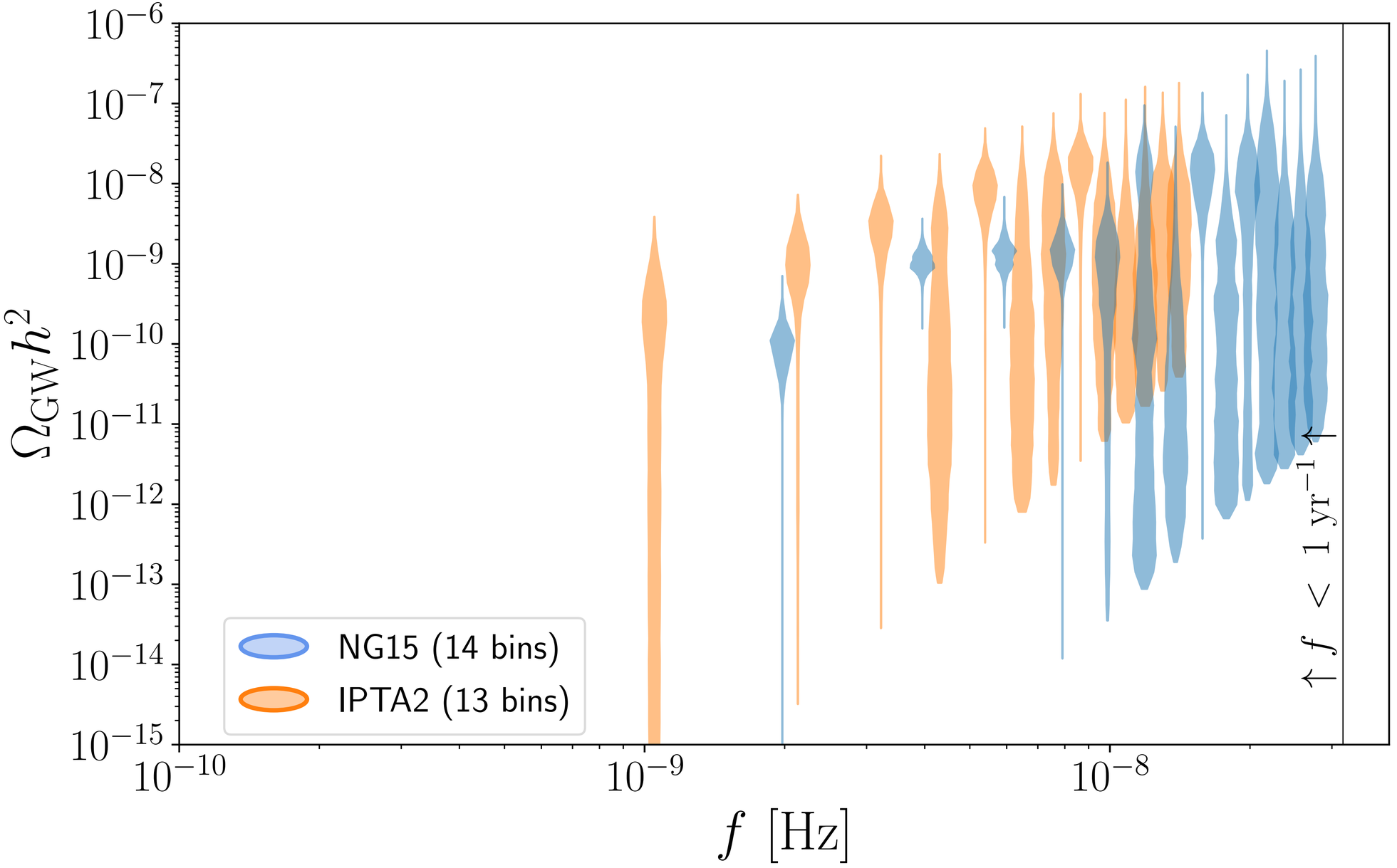
Gravitational Waves

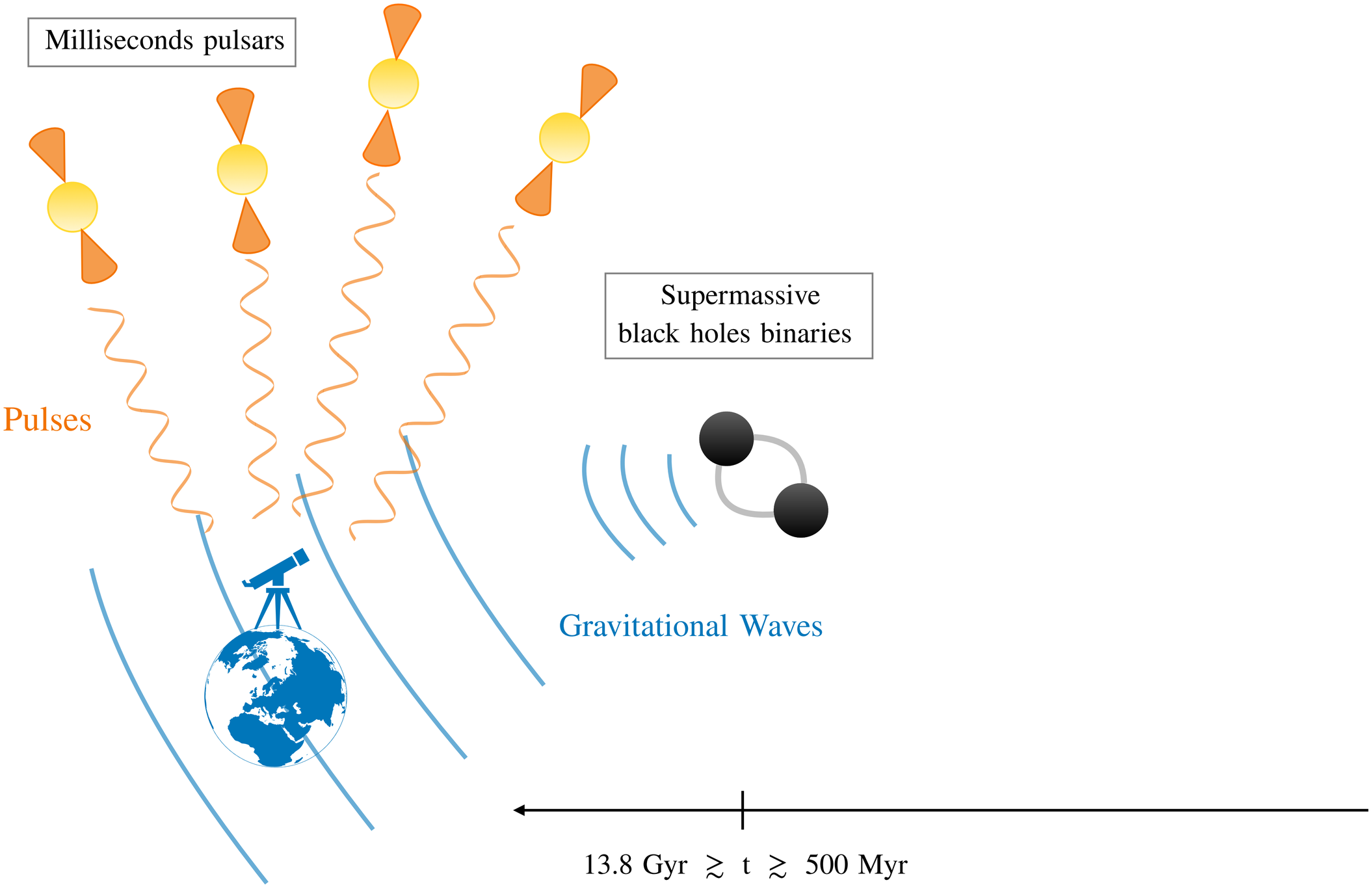
Solar system systematics

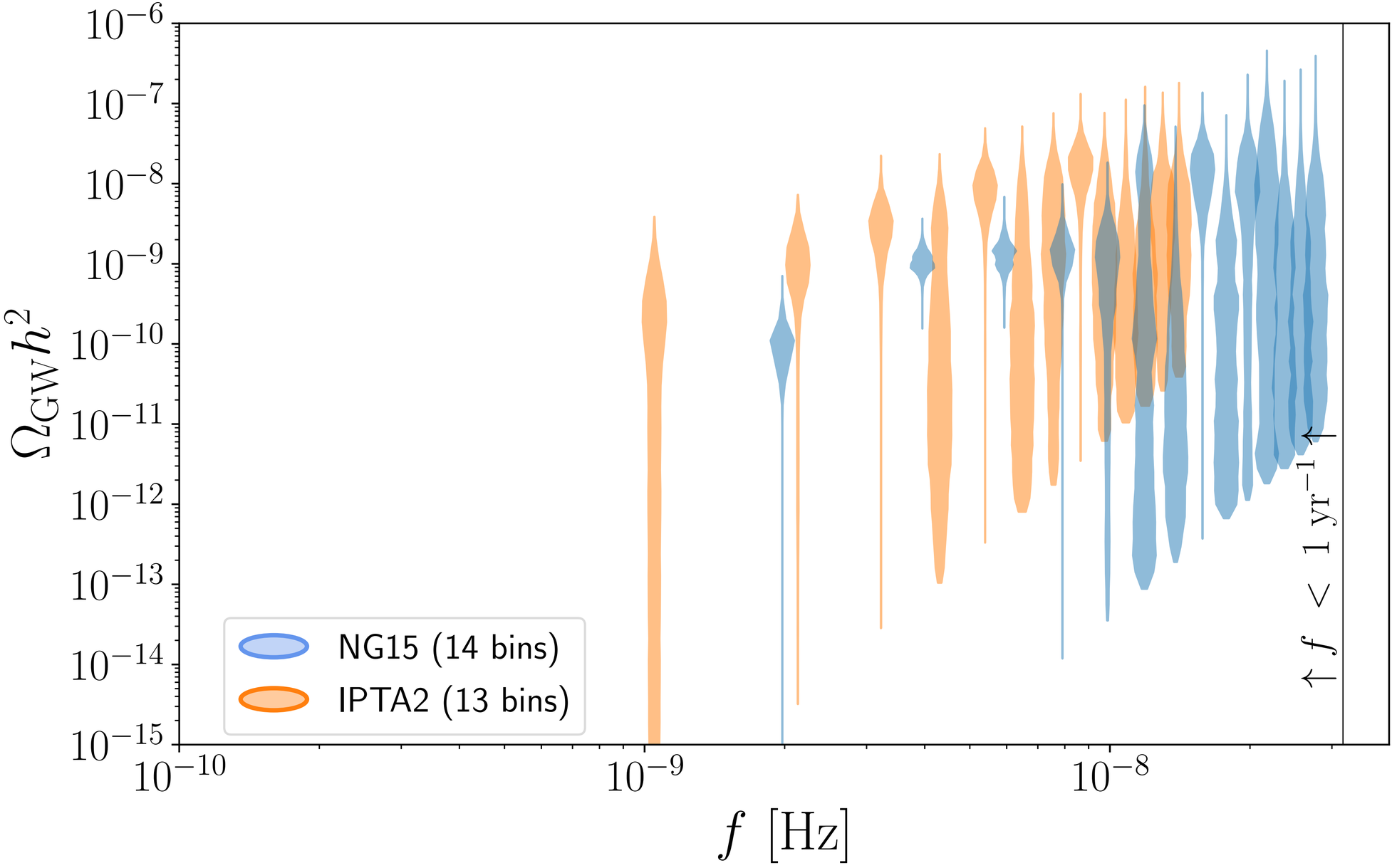

Pulsar red noise
(e . g . magnetosphere fluctuation)
Pulses
Pulses
Pulsar companion
systematics
Gravitational
Waves
Solar system systematics


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
Radiometer
white noise
Pulsar companion
systematics
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]
NG15 (14 bins)
IPTA2 (13 bins)
$\uparrow f < 1\ \mathrm{yr}^{-1} \uparrow$


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


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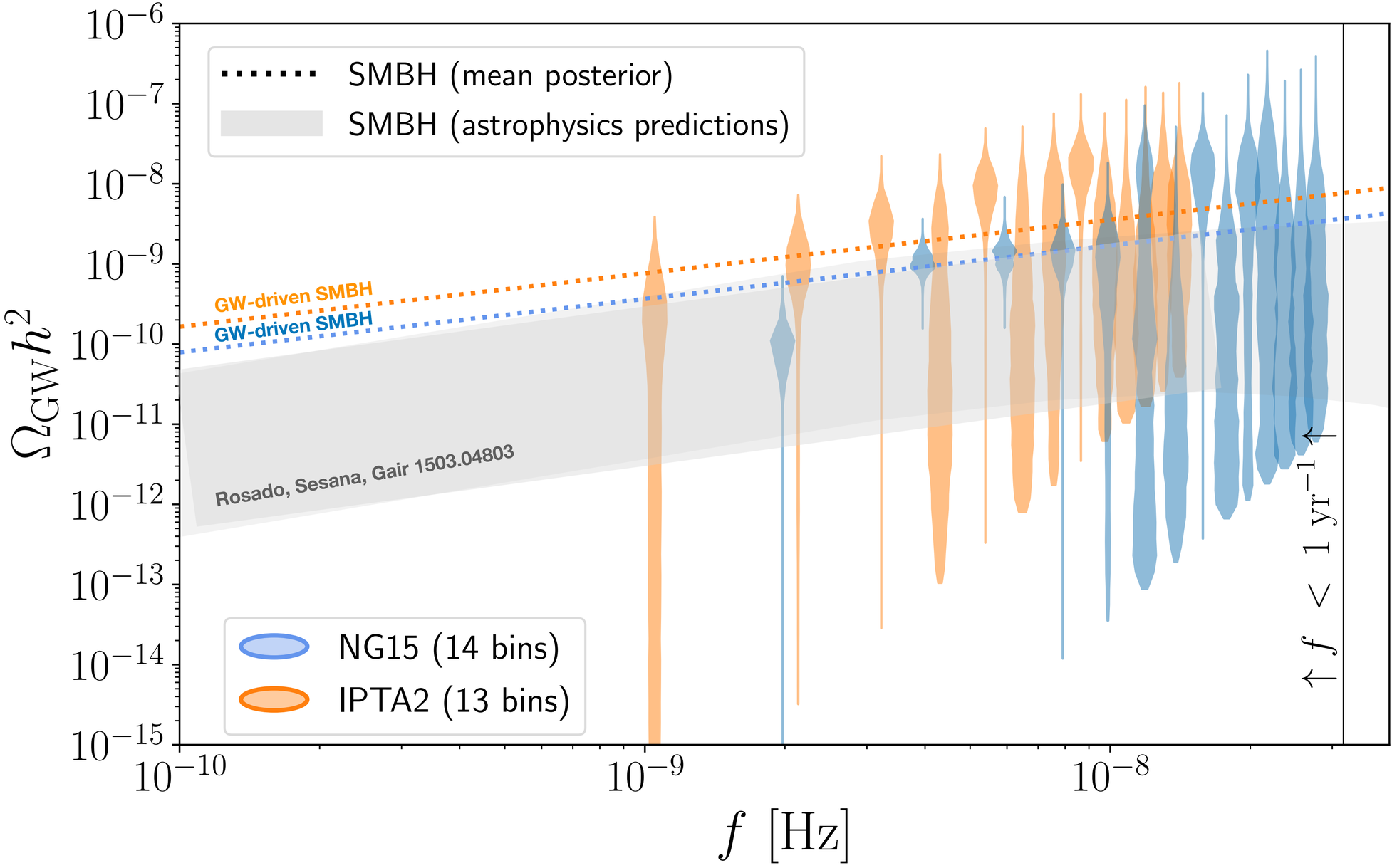
SMBH (mean posterior)
SMBH (astrophysics predictions)
GW-driven SMBH
GW-driven SMBH
Rosado, Sesana, Gair 1503.04803
NG15 (14 bins)
IPTA2 (13 bins)
$\uparrow f < 1\ \mathrm{yr}^{-1} \uparrow$
$\Omega_{\mathrm{GW}} h^2$
f [Hz]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}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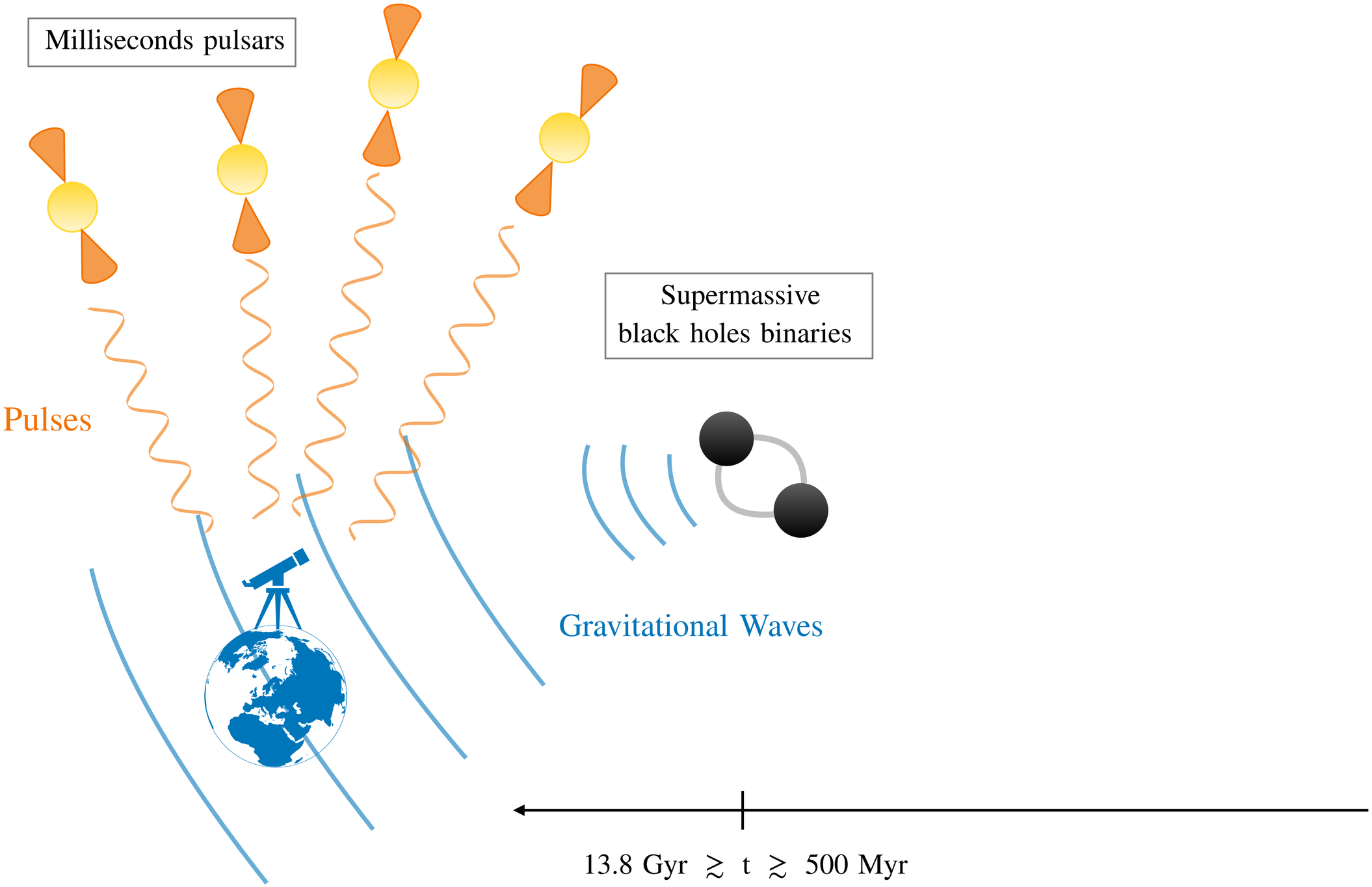
10^{-9}
10^{-8}


Milliseconds pulsars
Supermassive
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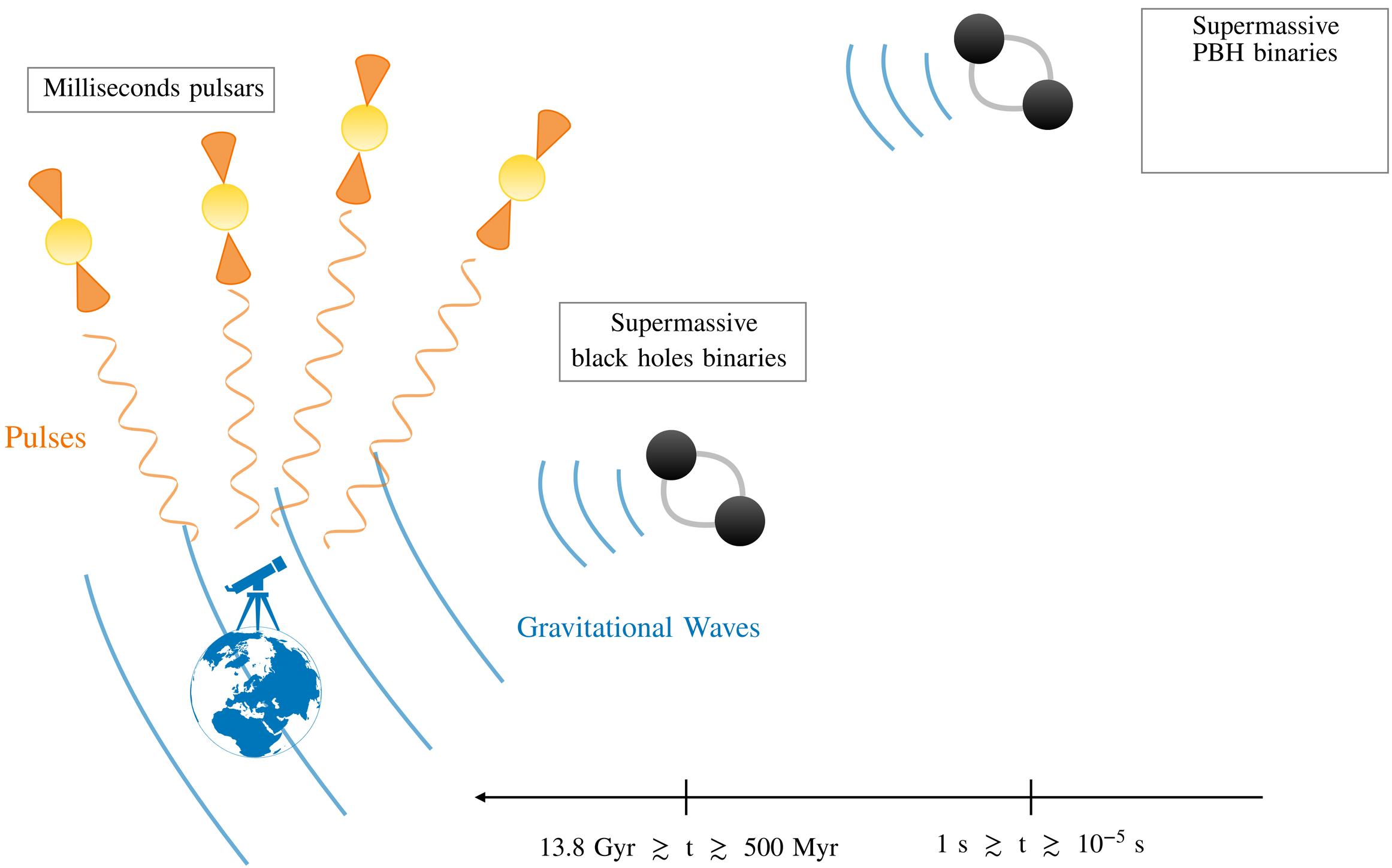
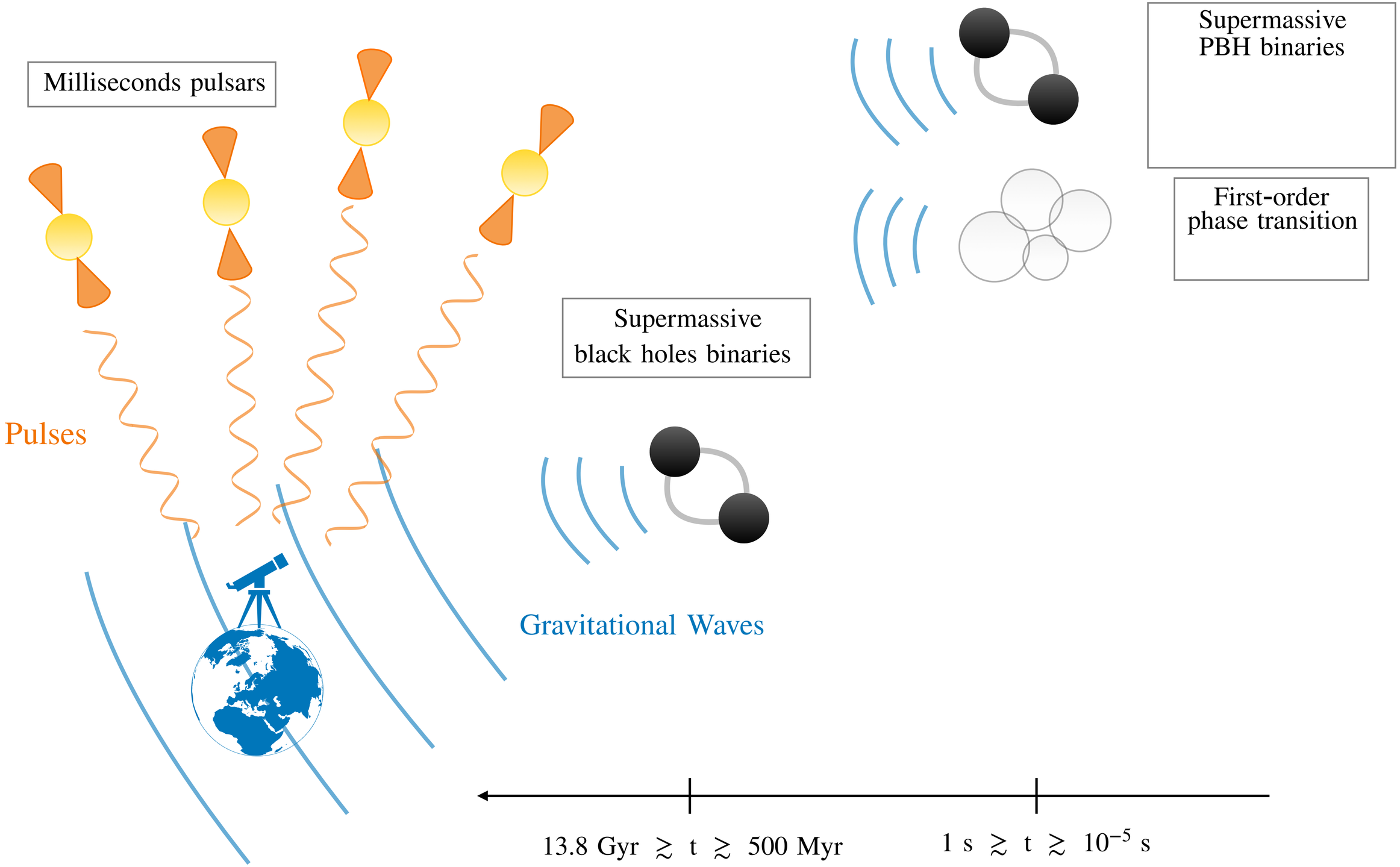

Milliseconds pulsars
Supermassive
PBH binaries
Supermassive
black holes binaries
Pulses
Gravitational Waves
13.8 Gyr ≳ t ≳ 500 Myr
1 s ≳ t ≳ 10^{-5} s


Milliseconds pulsars
Pulses
Supermassive
black holes binaries
Gravitational Waves
Supermassive
PBH binaries
First-order
phase transition
13.8 Gyr ≳ t ≳ 500 Myr
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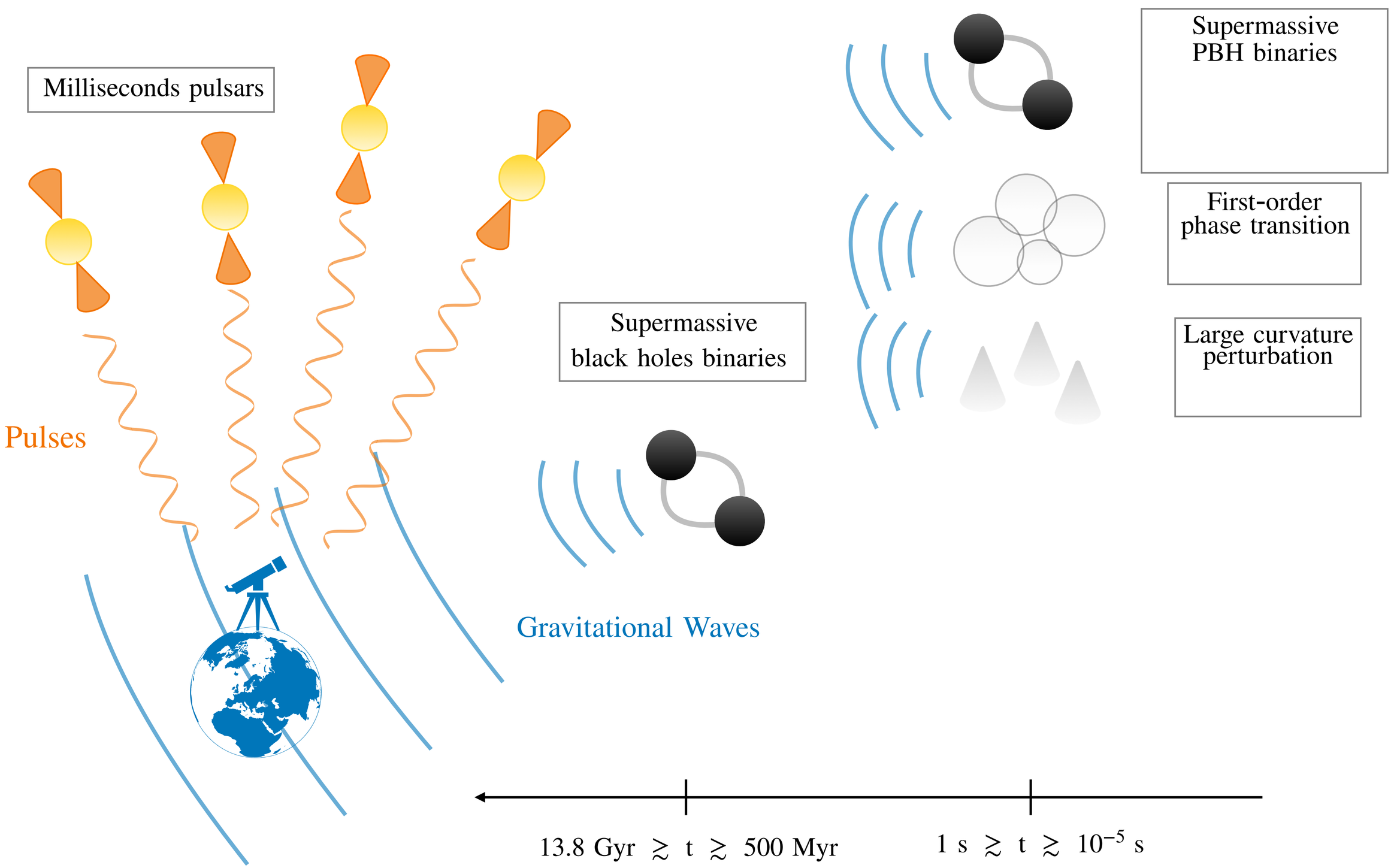
Milliseconds pulsars
Pulses
Supermassive
black holes binaries
Gravitational Waves
Supermassive
PBH binaries
First-order
phase transition
Large curvature
perturbation
13.8 Gyr ≳ t ≳ 500 Myr
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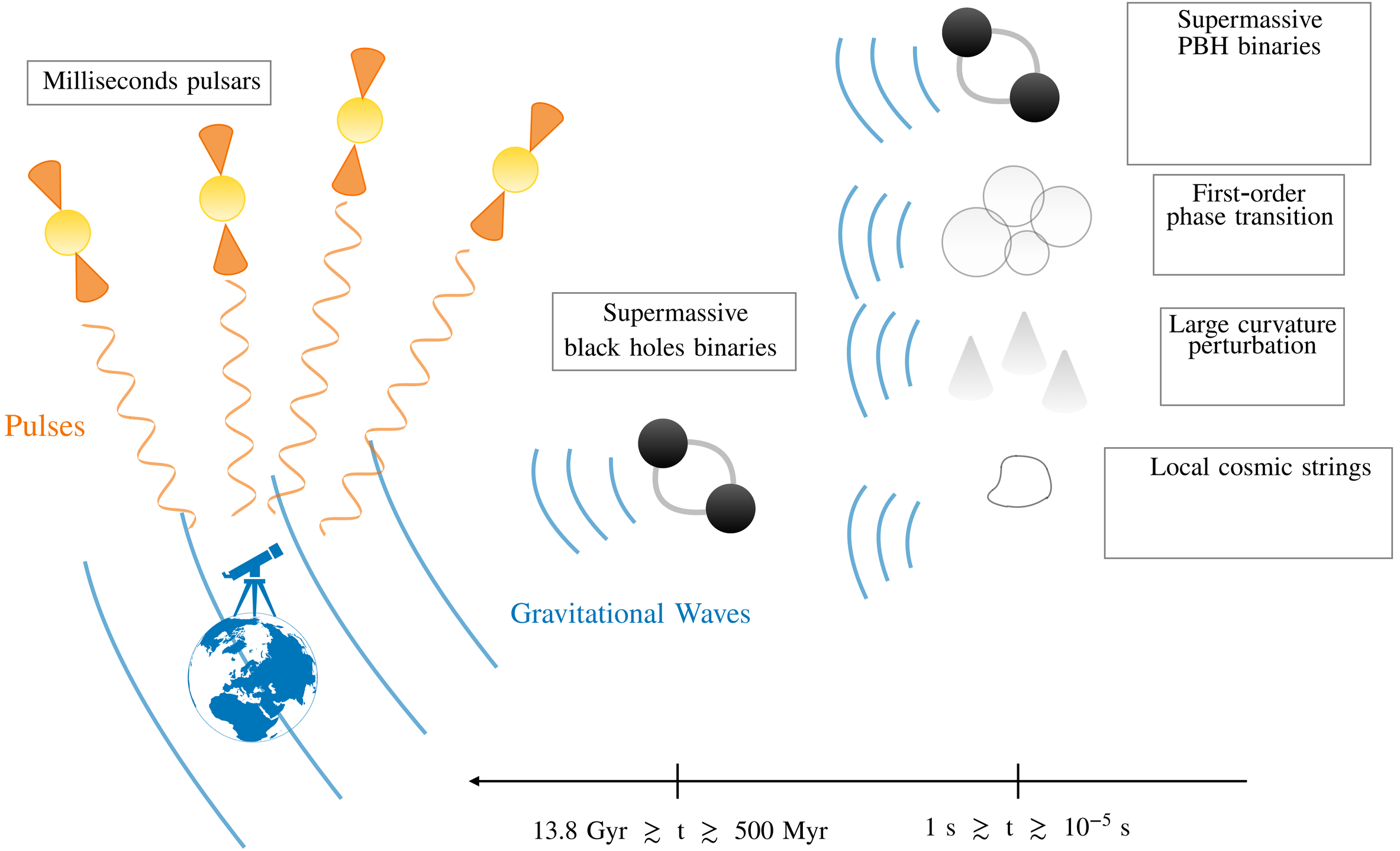
Milliseconds pulsars
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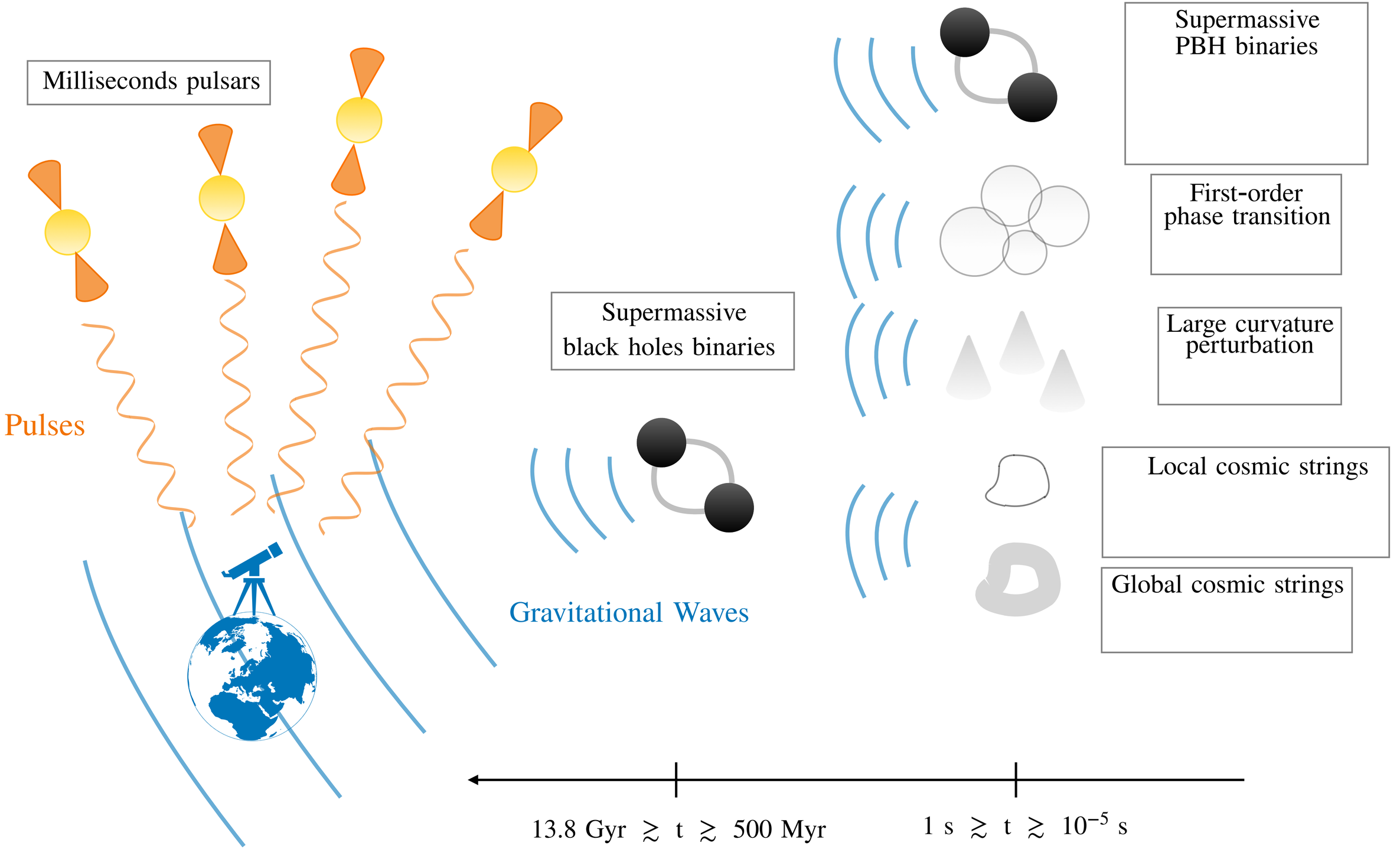
PBH binaries
First-order
phase transition
Large curvature
perturbation
Local cosmic strings
13.8 Gyr ≳ t ≳ 500 Myr
1 s ≳ t ≳ 10^−5 s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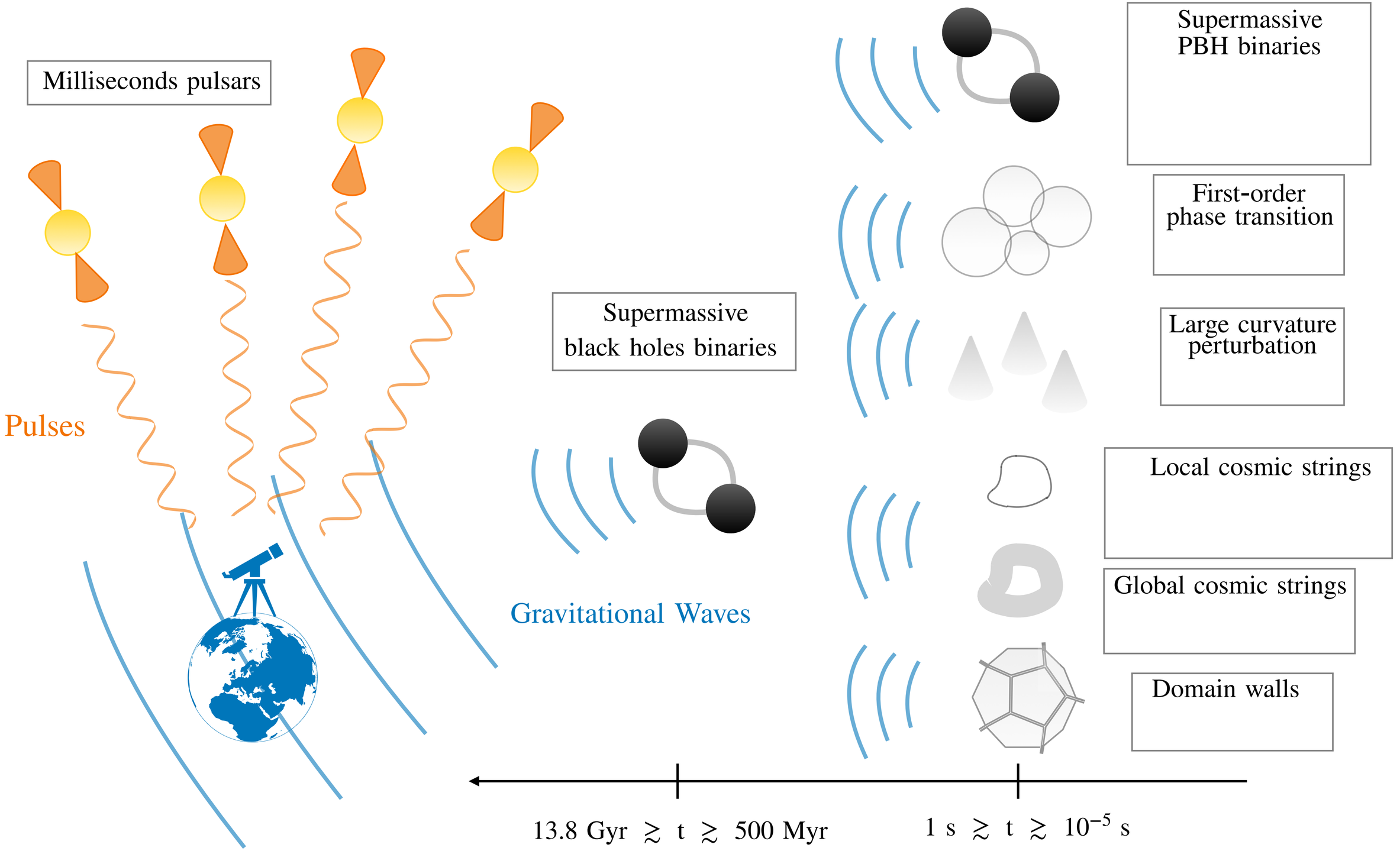
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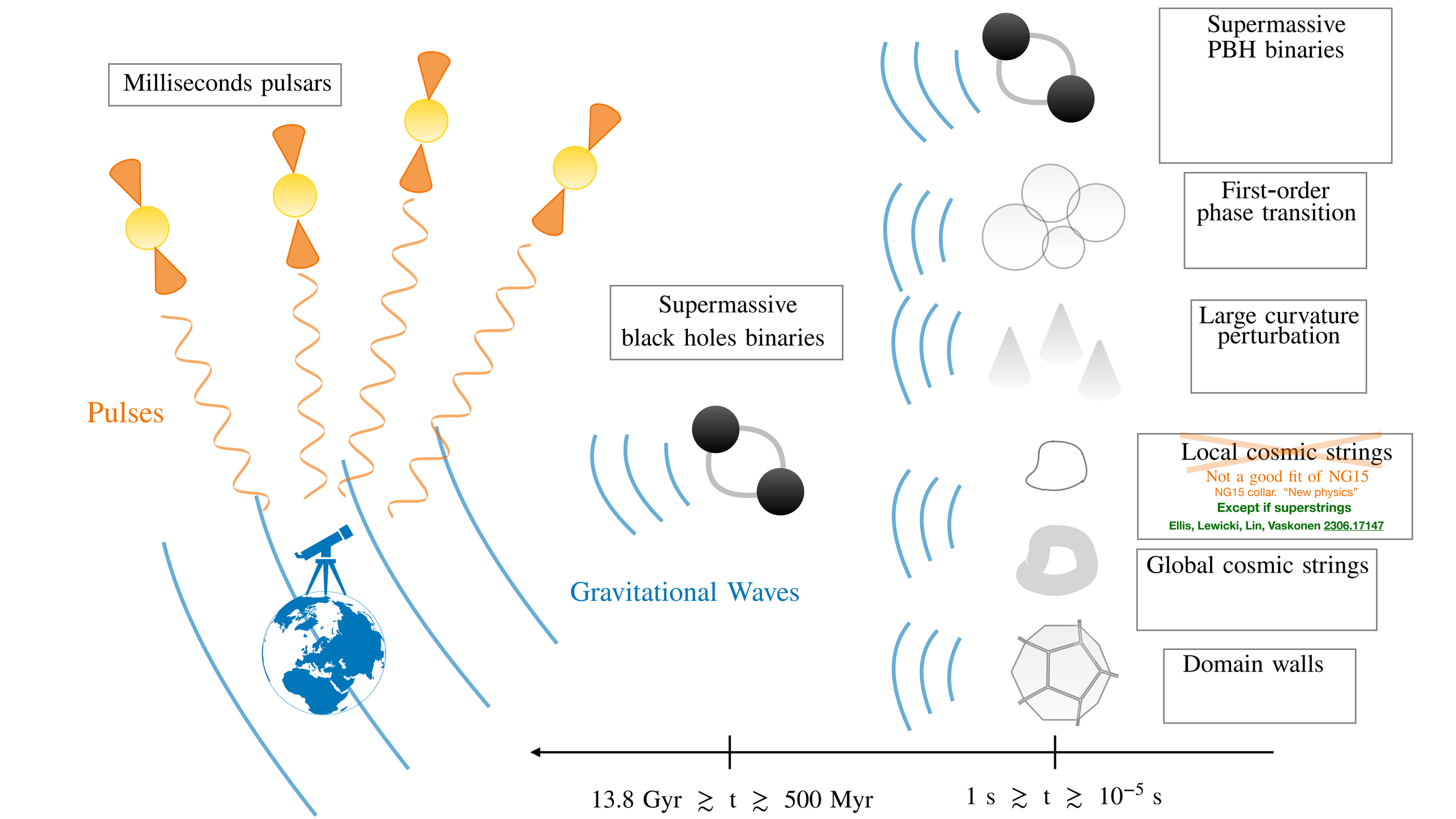
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Local cosmic strings
Not a good fit of NG15
NG15 collar. “New physics”
Except if superstrings
Ellis, Lewicki, Lin, Vaskonen 2306.17147
Global cosmic strings
Domain walls
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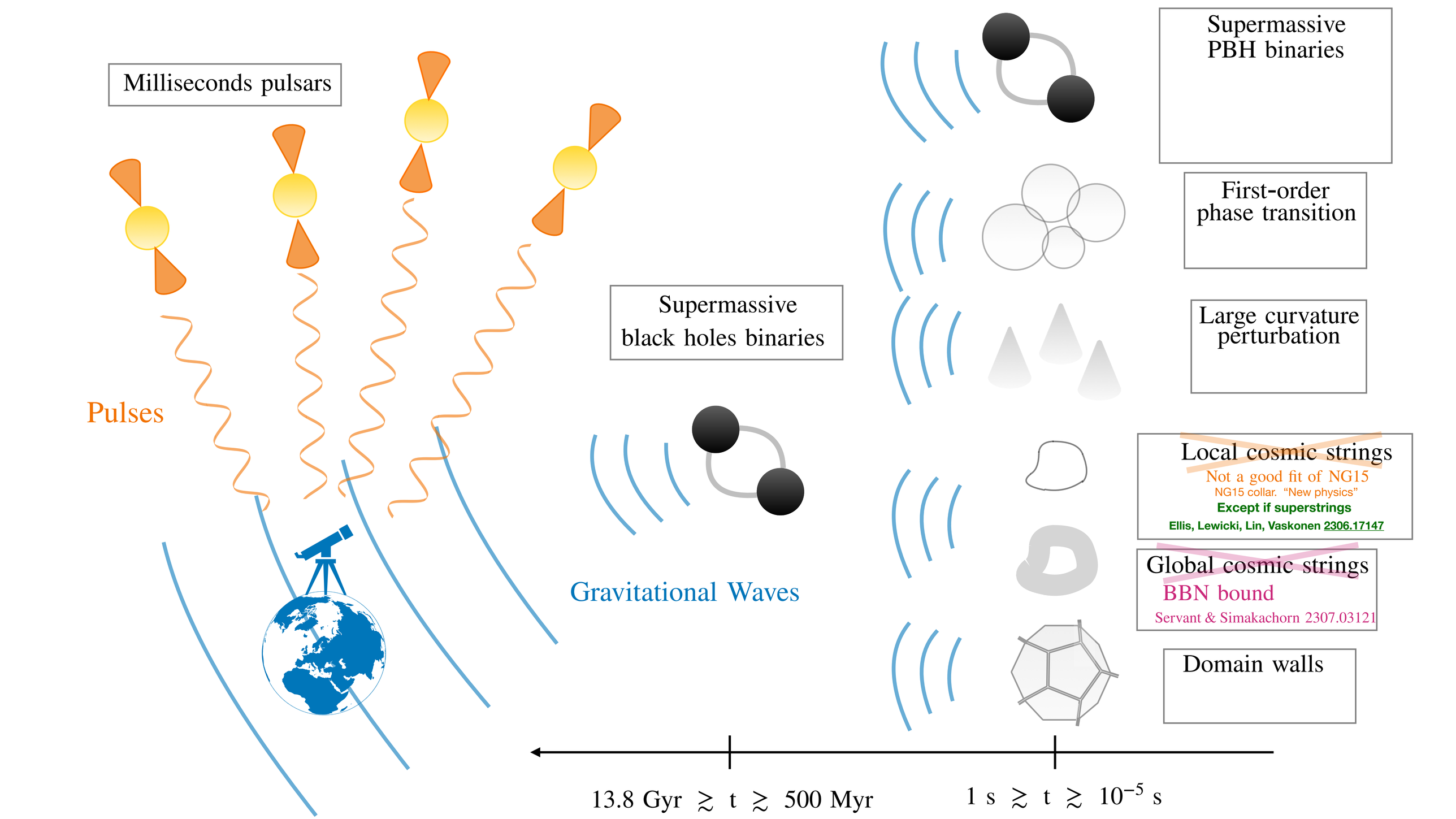
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Global cosmic strings
BBN bound
Servant & Simakachorn 2307.03121
Domain walls
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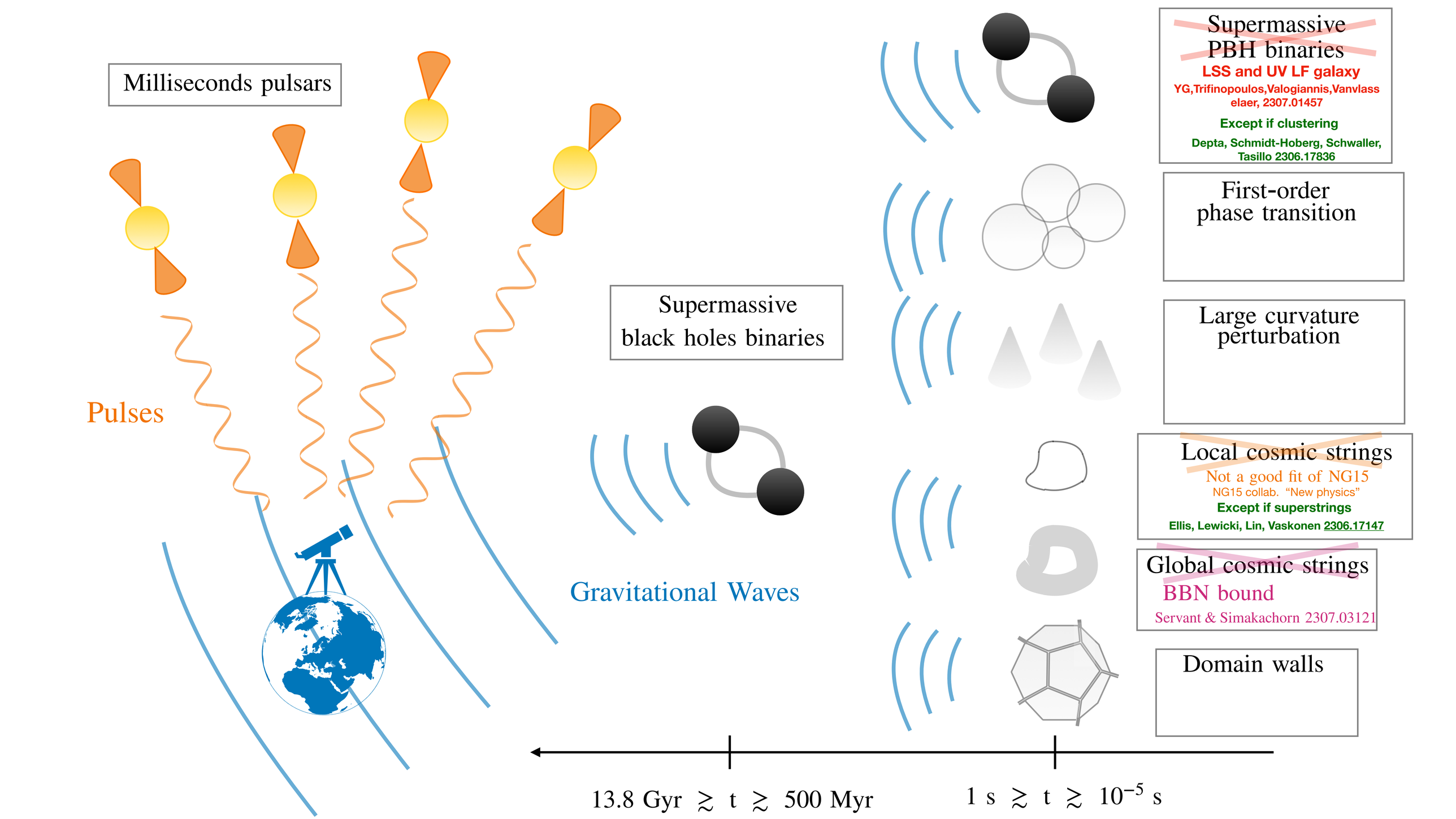
Milliseconds pulsars
Pulses
Supermassive
black holes binaries
Gravitational Waves
Supermassive
PBH binaries
LSS and UV LF galaxy
YG,Trifinopoulos,Valogiannis,Vanvlasselaer, 2307.01457
Except if clustering
Depta, Schmidt-Hoberg, Schwaller, Tasillo 2306.17836
First-order
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NG15 collab. “New physics”
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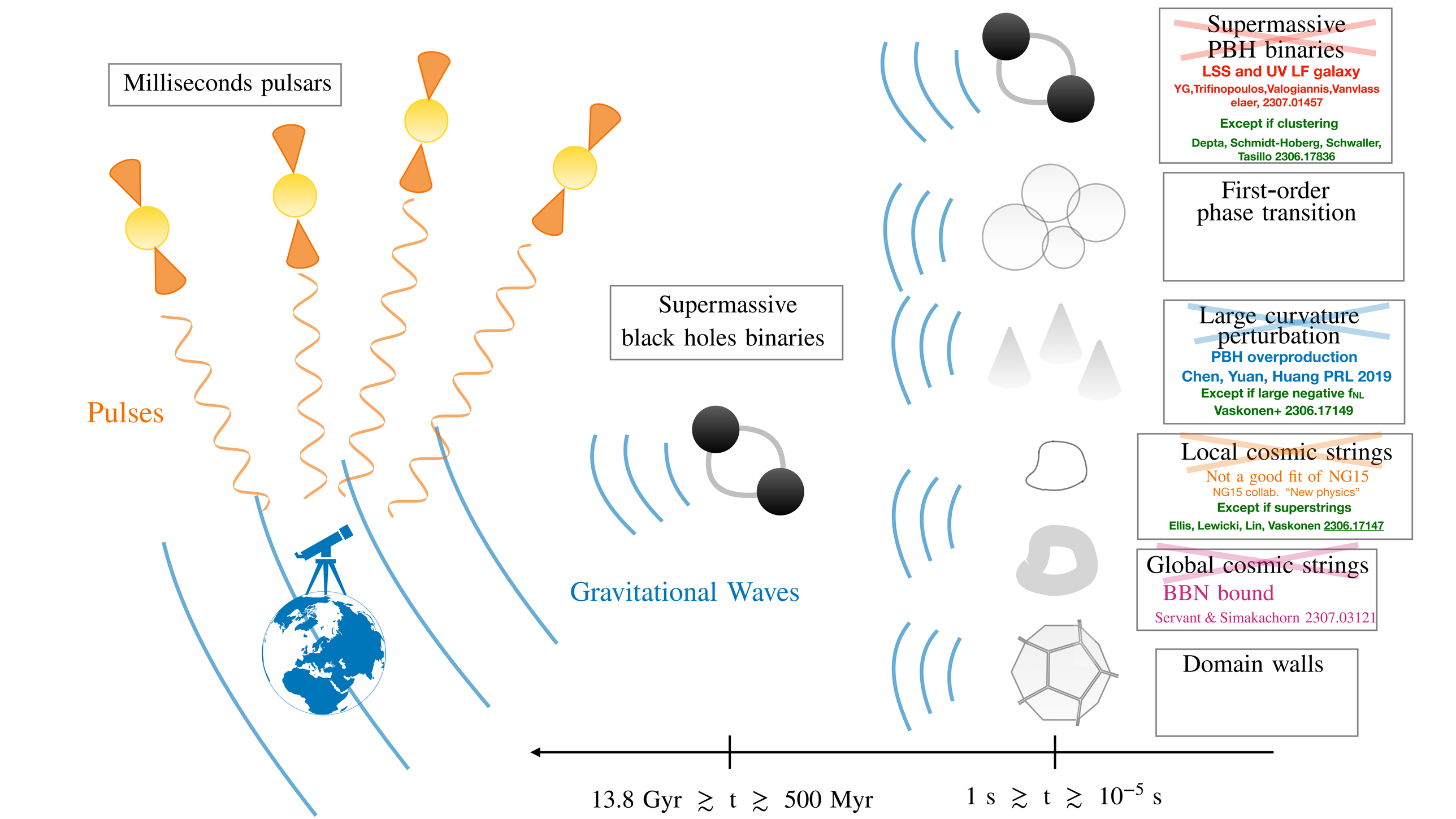
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Chen, Yuan, Huang PRL 2019
Except if large negative f_{NL}
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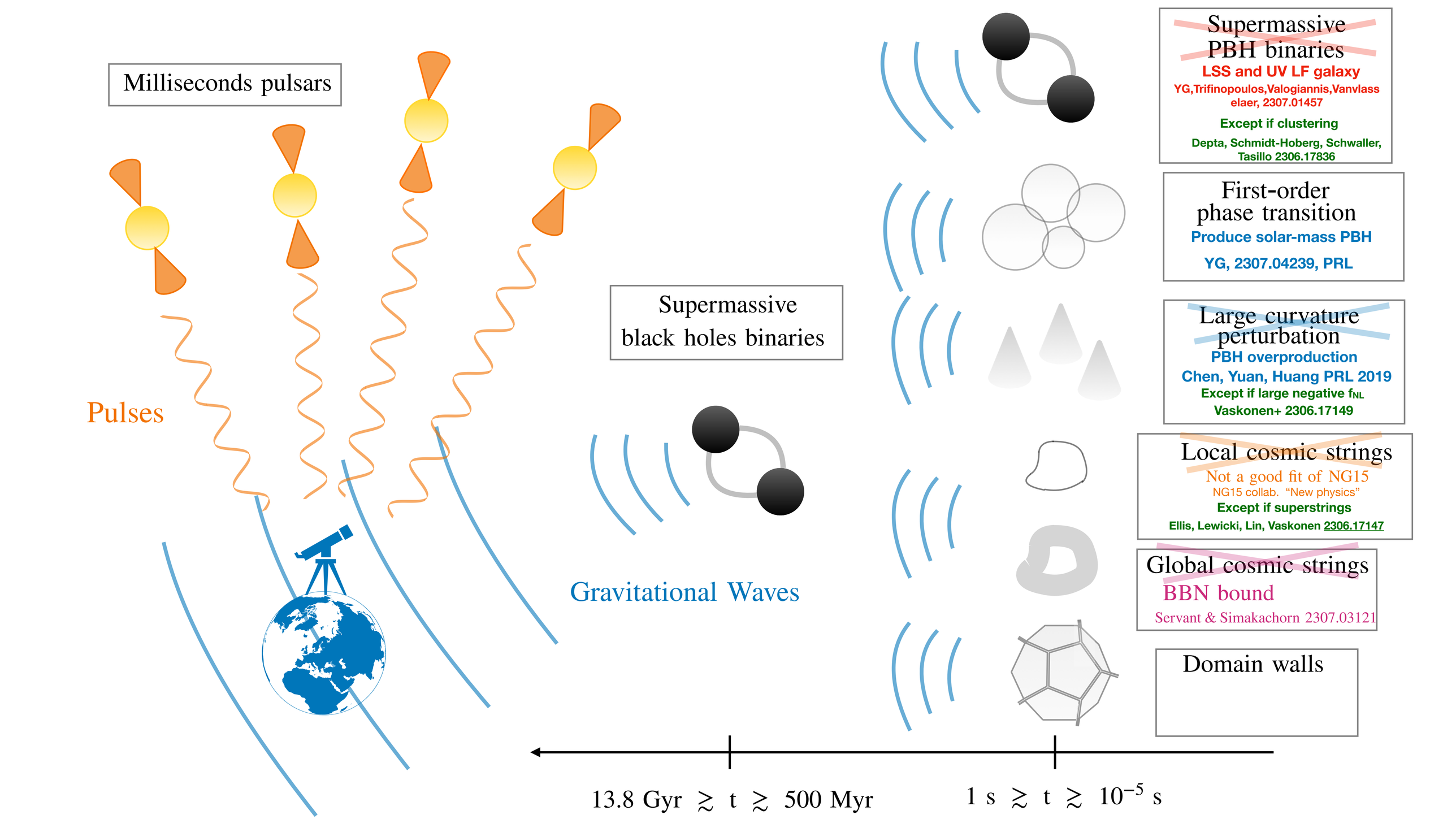
Global cosmic strings
BBN bound
Servant & Simakachorn 2307.03121
Domain walls
13.8 Gyr $\gtrsim$ t $\gtrsim$ 500 Myr
1 s $\gtrsim$ t $\gtrsim$ 10^{-5} s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elaer, 2307.01457
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Tasillo 2306.17836
First-order
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Produce solar-mass PBH
YG, 2307.04239, PRL
Large curvature
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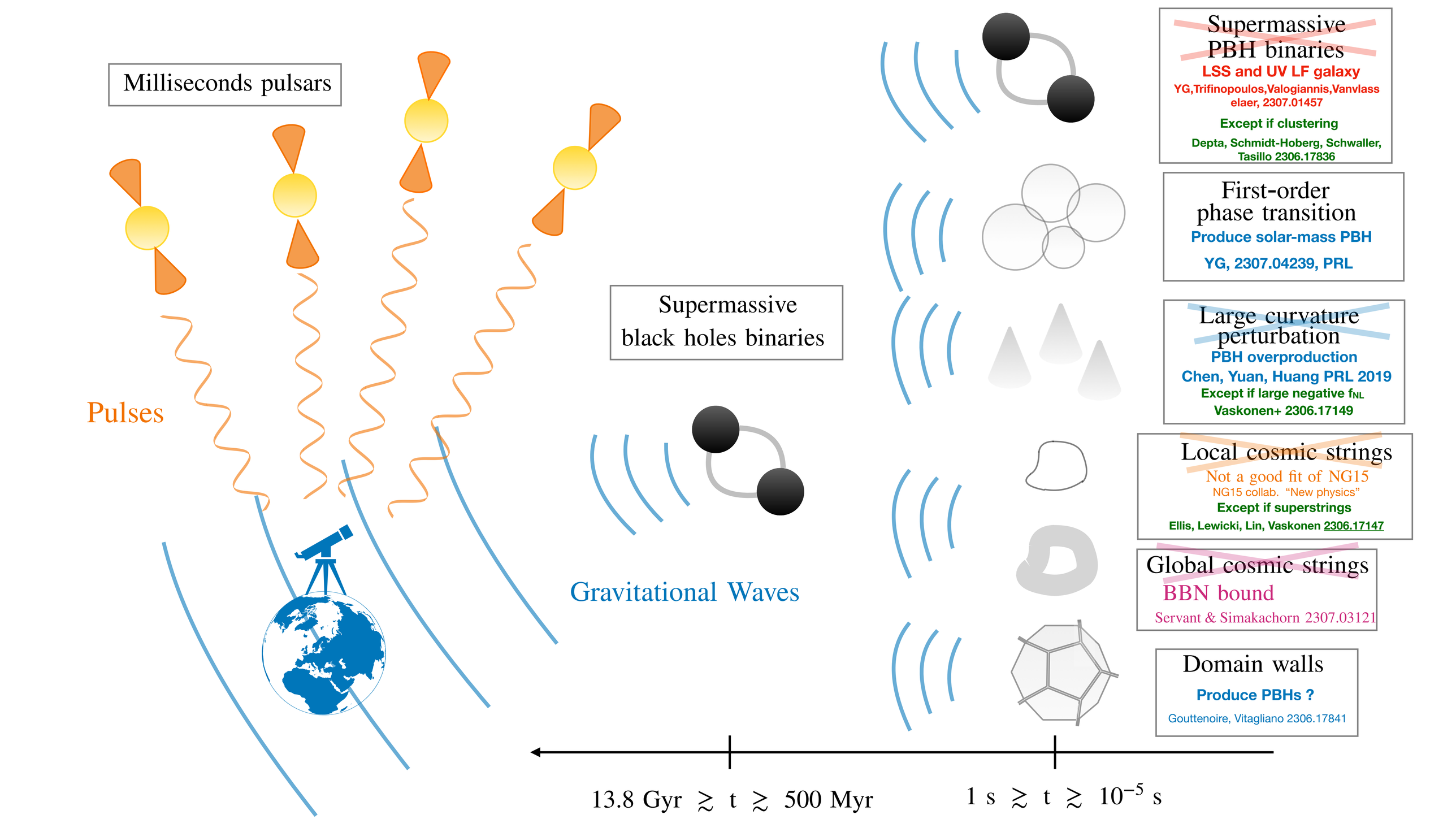
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Servant & Simakachorn 2307.03121
Domain walls
Produce PBHs ?
Gouttenoire, Vitagliano 2306.17841
13.8 Gyr ≳ t ≳ 500 Myr
1 s ≳ t ≳ 10^{-5} s

What is Primordial Black Holes ?

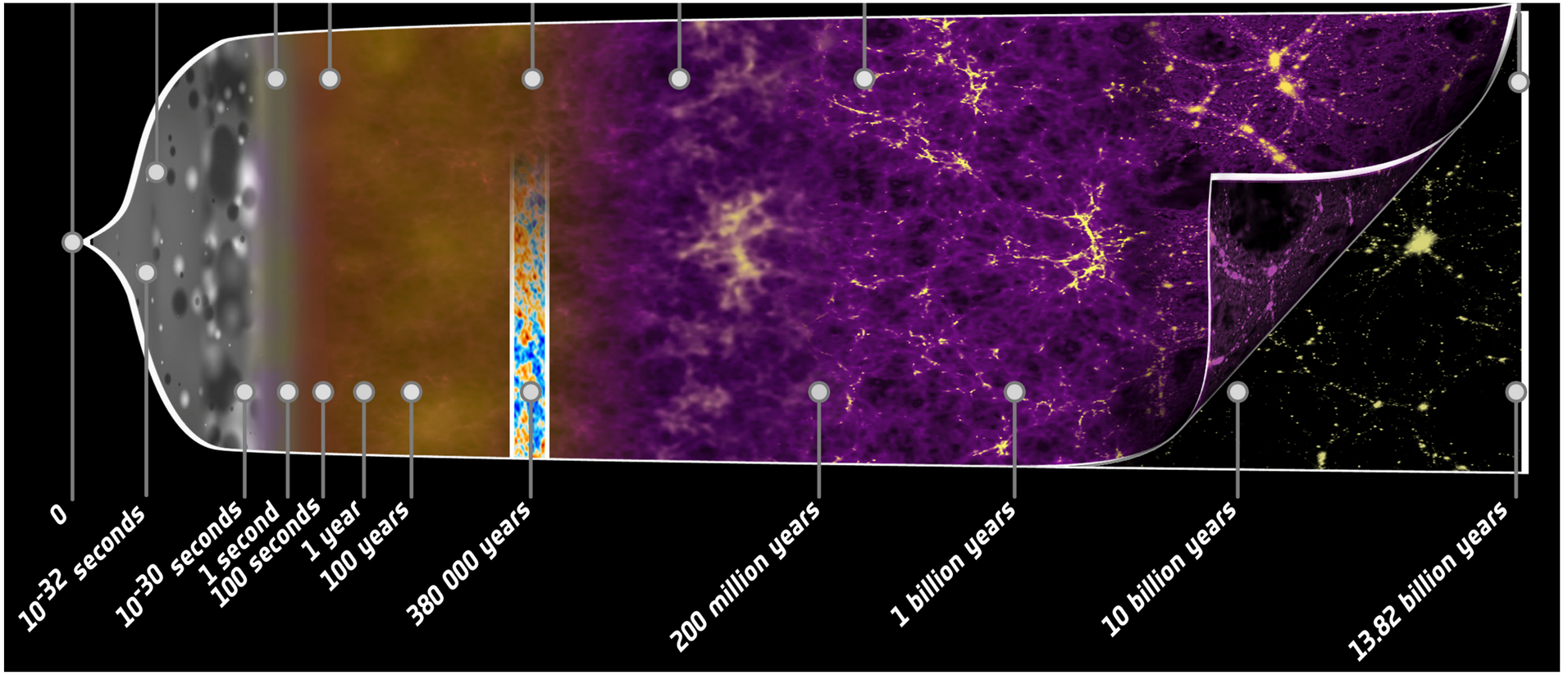
→ **BH formed before any astrophysical objects exists**

PBH formation

$z \gg 10^3$

Star formation

$z \lesssim 30$



How do they form ?

Friedmann's equation :

$$H^2 = \frac{8\pi G}{3}\rho$$

How do they form ?

Friedmann's equation :

$$H^{-3} \times H^2 = \frac{8\pi G}{3}\rho \times H^{-3}$$

How do they form ?

Friedmann's equation :

$$H^{-1} = 2G \times \frac{4\pi H^{-3}}{3}\rho$$

How do they form ?

Friedmann's equation :

$$H^{-1} = 2G \times \frac{4\pi H^{-3}}{3}\rho$$

$$\equiv R_{\mathrm{H}}$$

$$\equiv M_{\mathrm{H}}$$

How do they form ?

Friedmann's equation :

$$R_{\mathrm{H}} = 2GM_{\mathrm{H}}$$

How do they form ?

Friedmann's equation :

$$R_{\mathrm{H}} = 2GM_{\mathrm{H}}$$

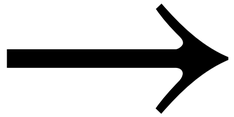
Schwarschild's equation

How do they form ?

Friedmann's equation :

$$R_{\mathrm{H}} = 2GM_{\mathrm{H}}$$

Schwarschild's equation



Hubble patches are on the edge to collapse into black holes

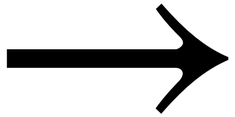
How do they form ?

Friedmann's equation :

$$\frac{R_{\mathrm{H}} - 2GM_{\mathrm{H}}}{R_H} \gtrsim 0.45$$

Radiation pressure

Schwarschild's equation



Hubble patches are on the edge to collapse into black holes

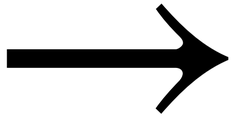
How do they form ?

Friedmann's equation :

$$\frac{\langle \delta\rho \rangle_H}{\rho} \gtrsim 0.45$$

Radiation pressure

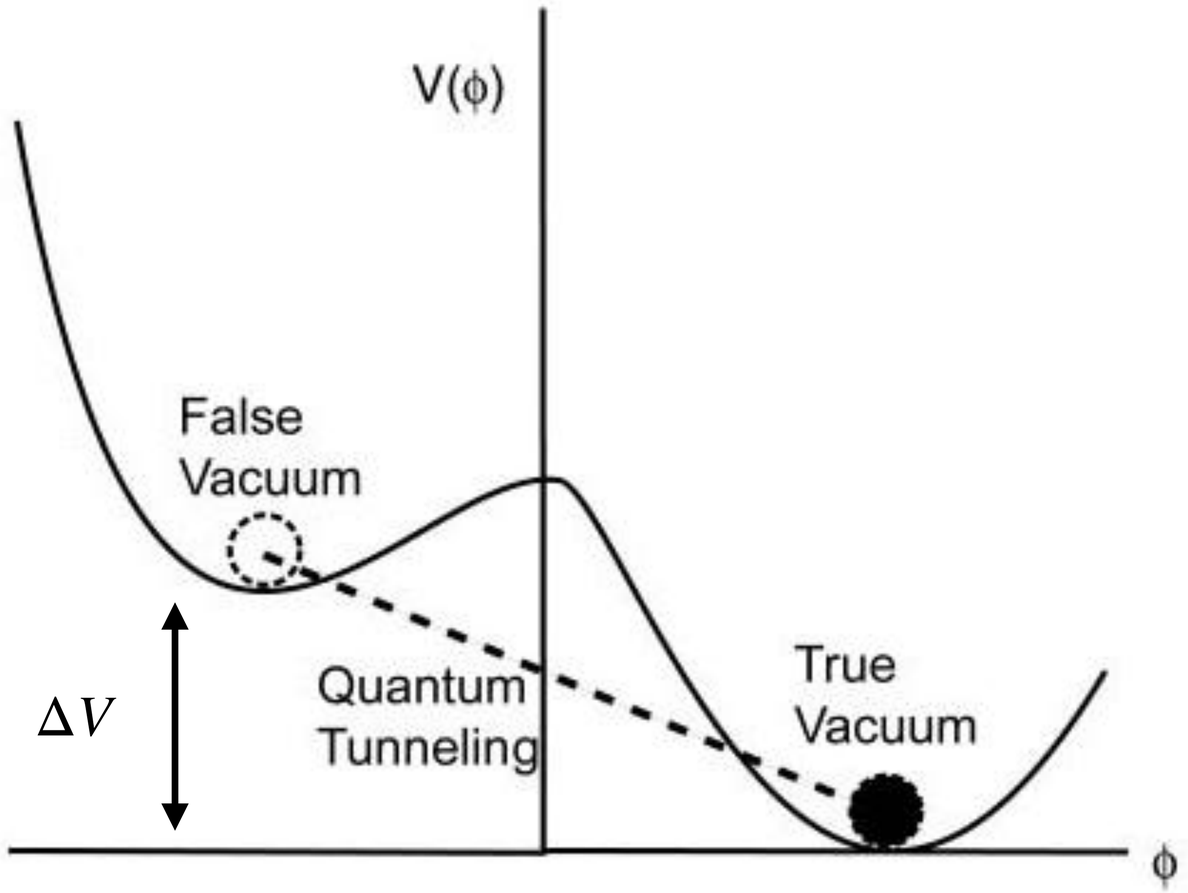
Schwarschild's equation



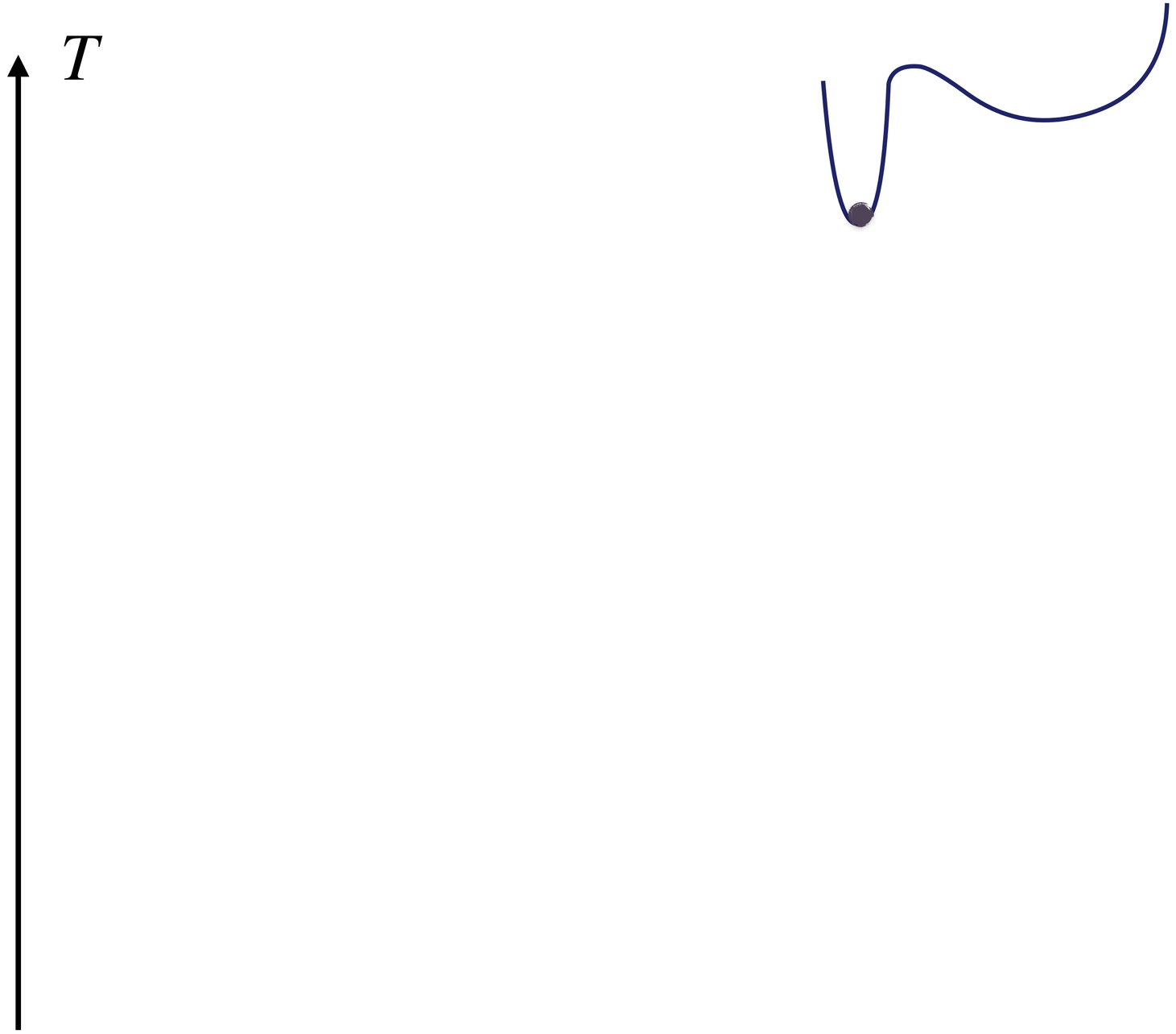
Hubble patches are on the edge to collapse into black holes

PBHs formation during supercooled phase transition

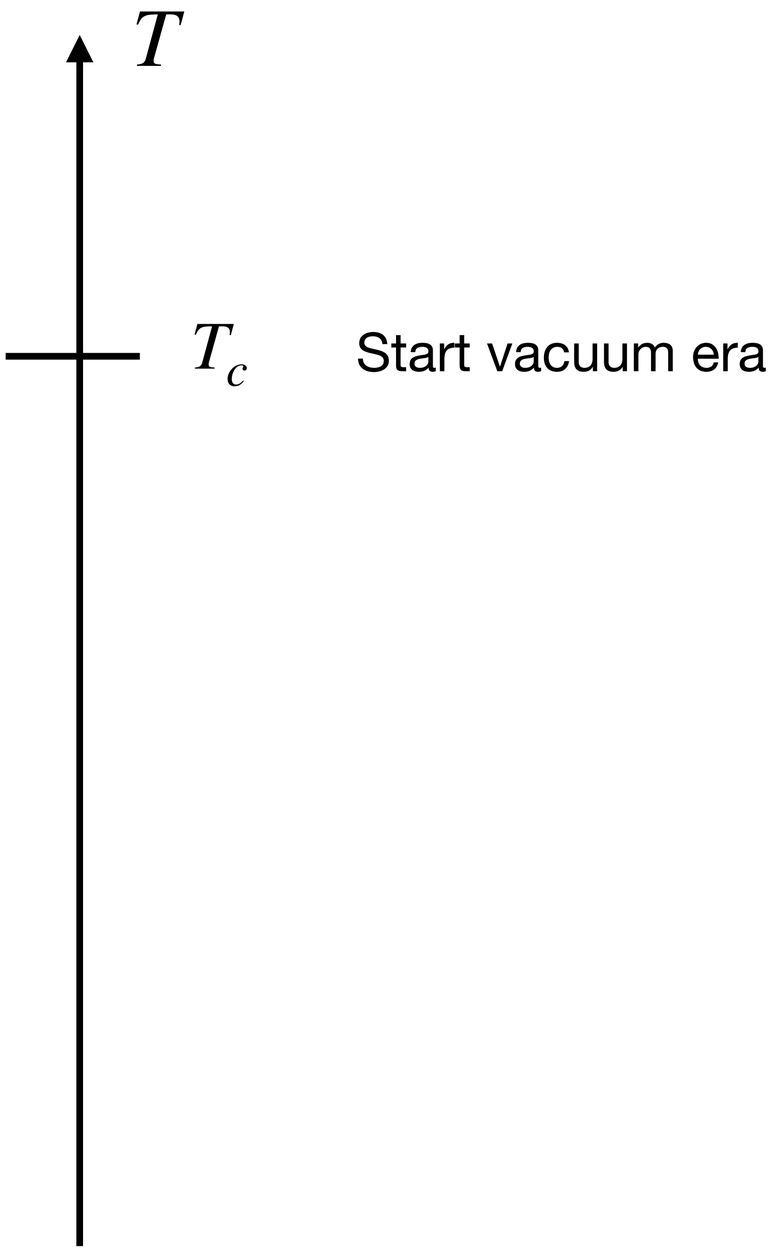
Guth 1980 "Old inflation idea"



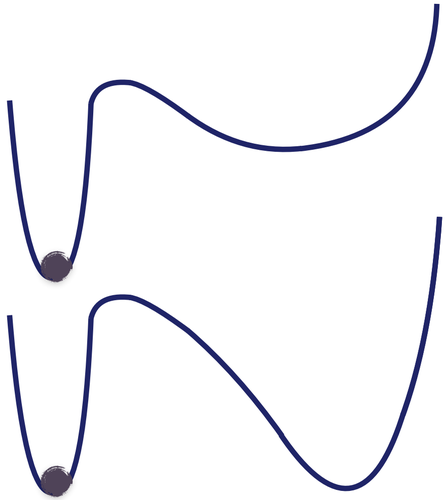
Supercooled 1stOPT = delayed PT



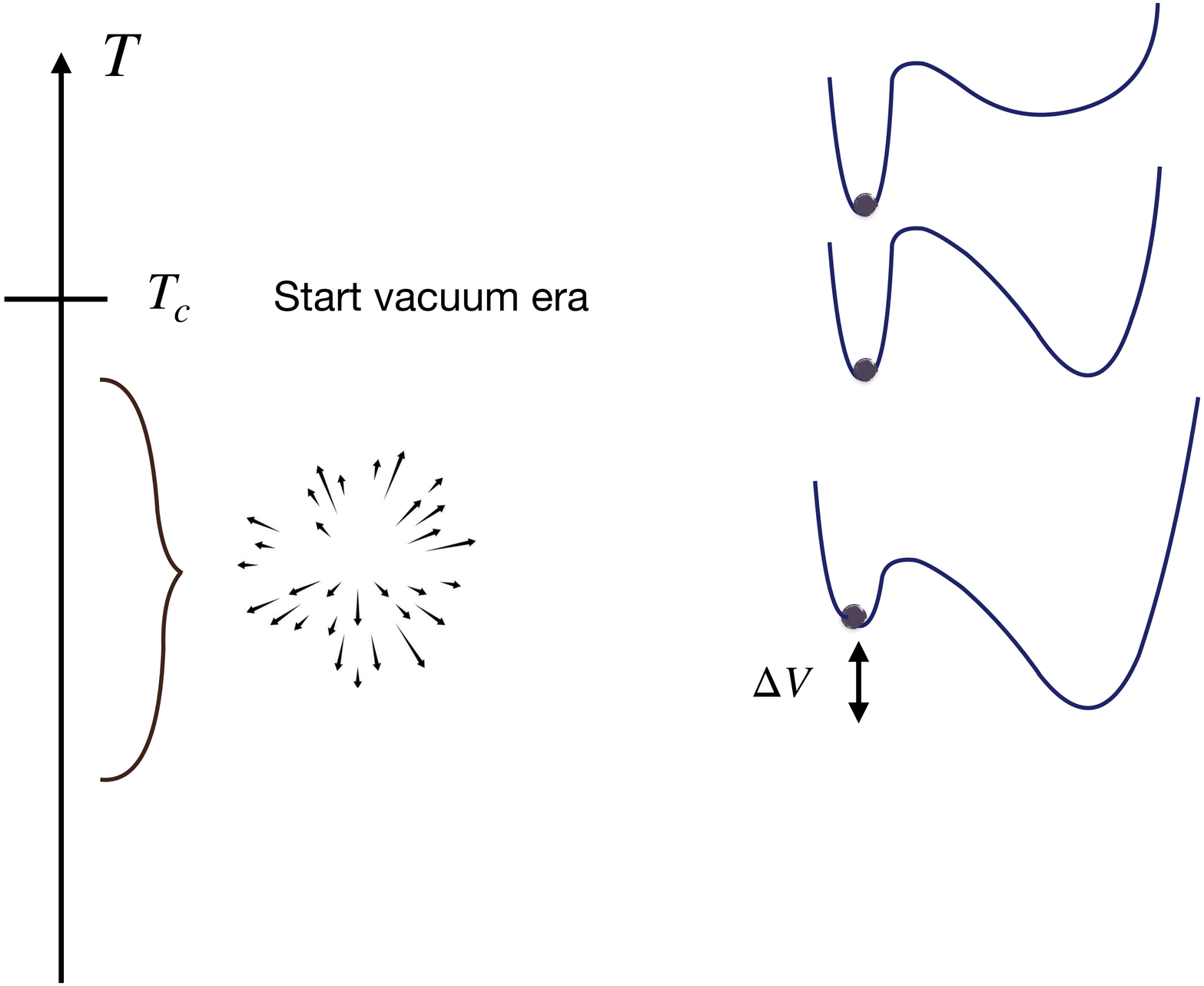
Supercooled 1stOPT = delayed PT



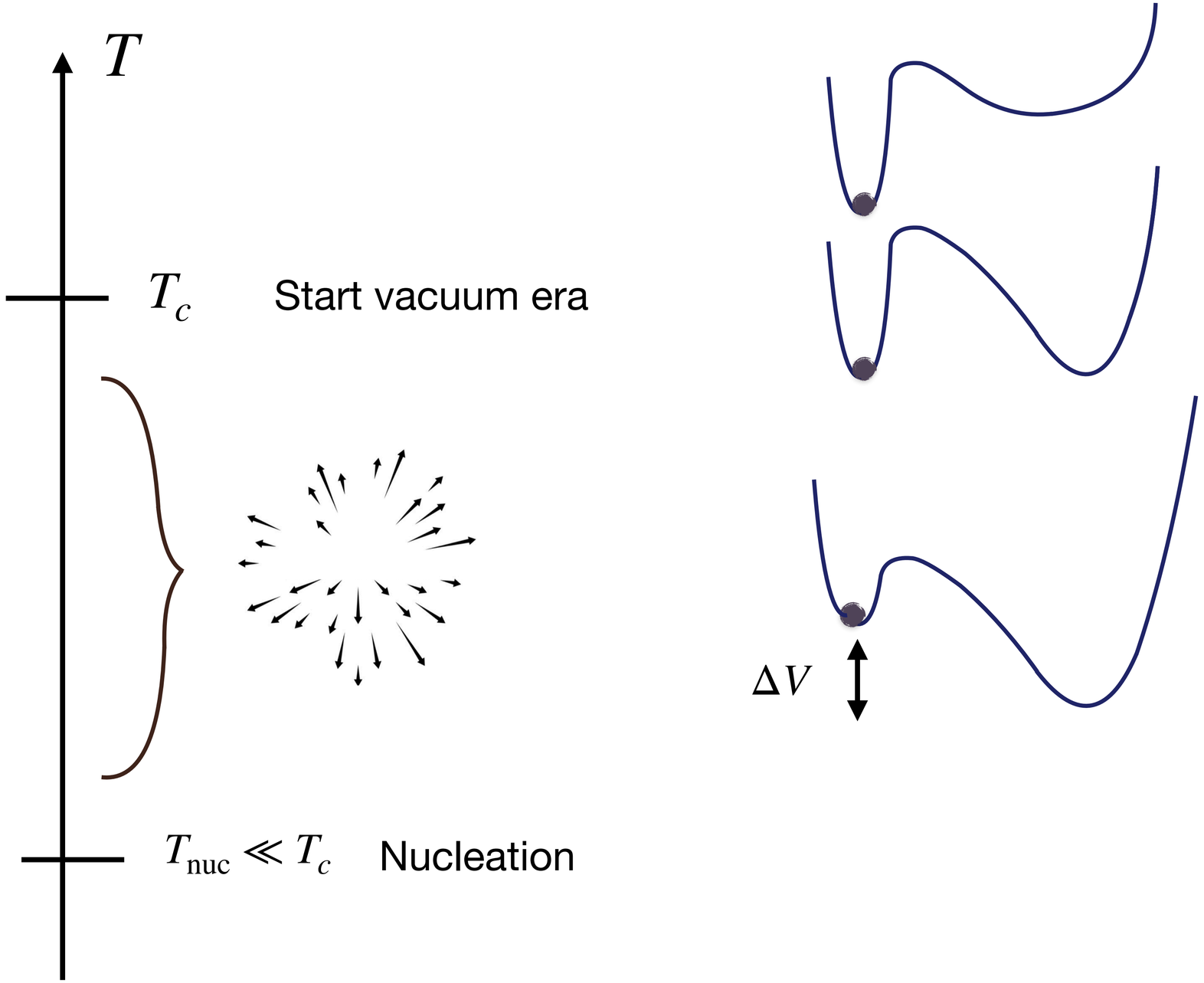
Start vacuum era



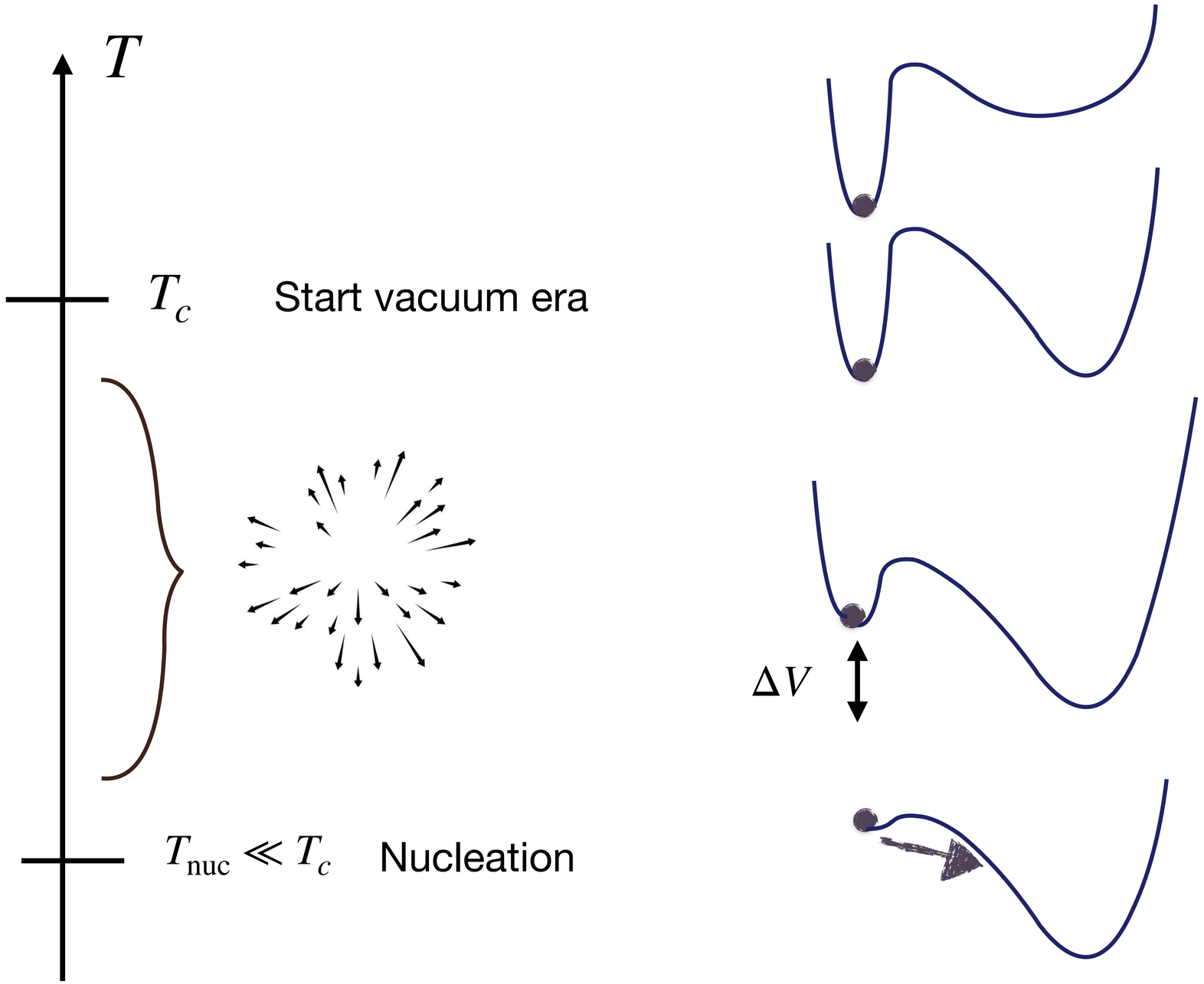
Supercooled 1stOPT = delayed PT



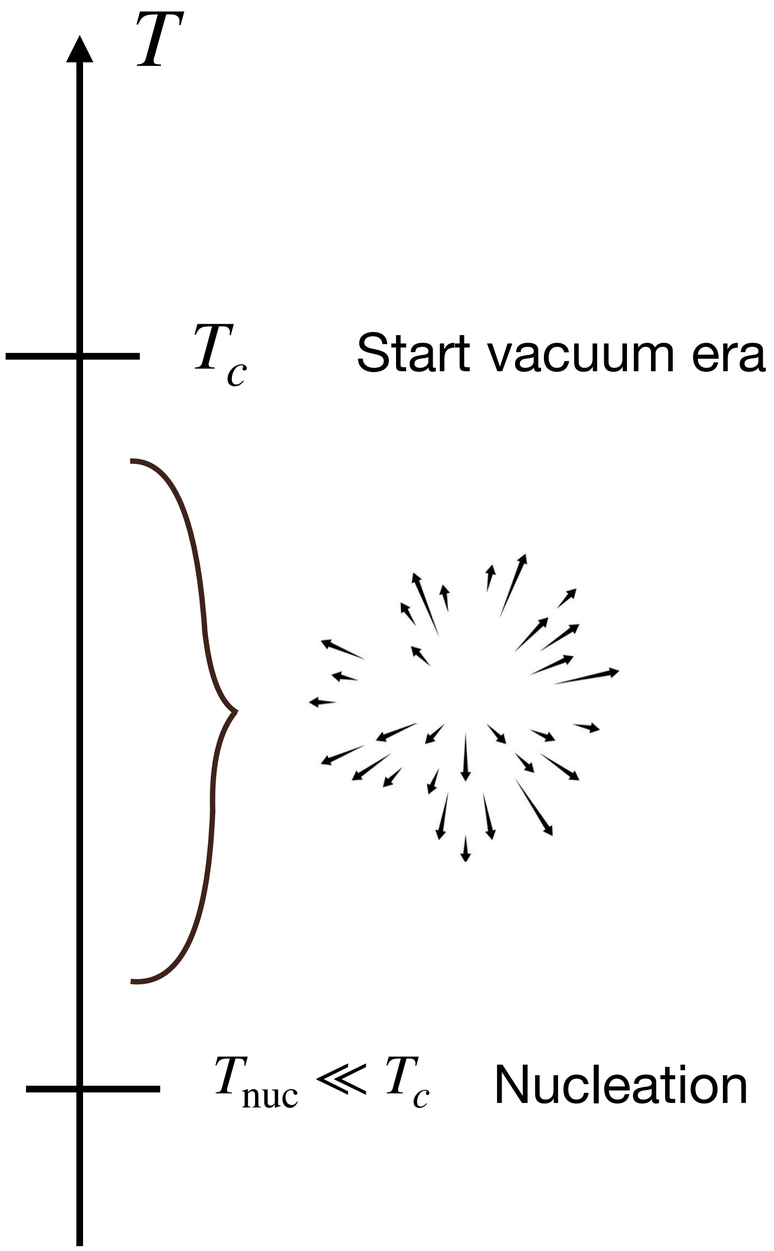
Supercooled 1stOPT = delayed PT

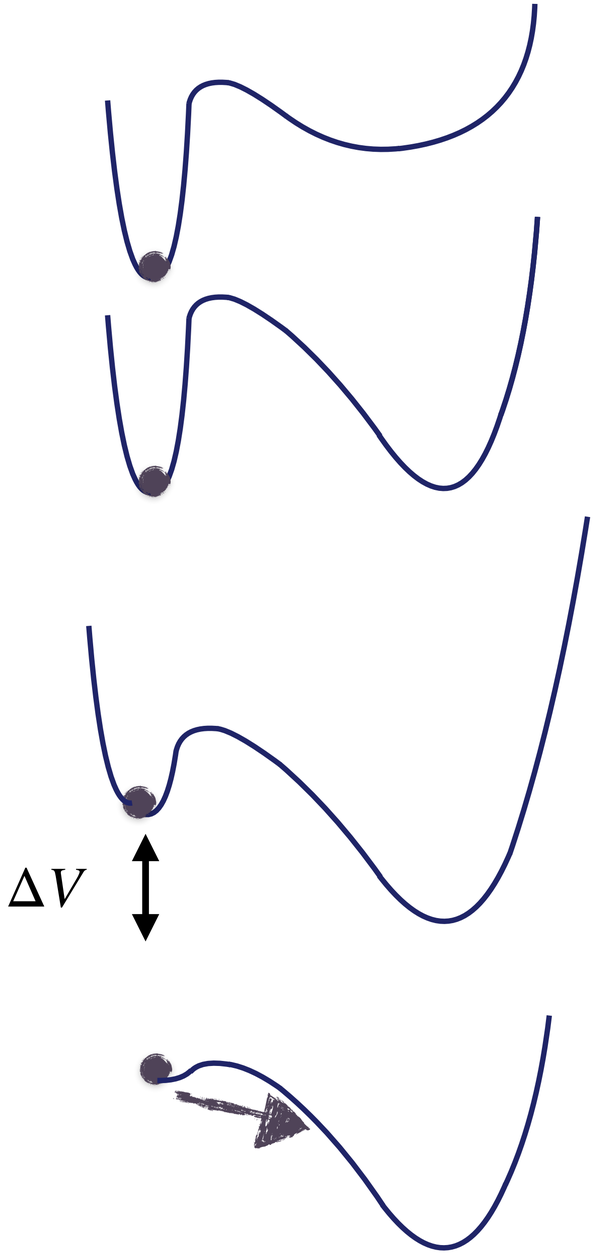


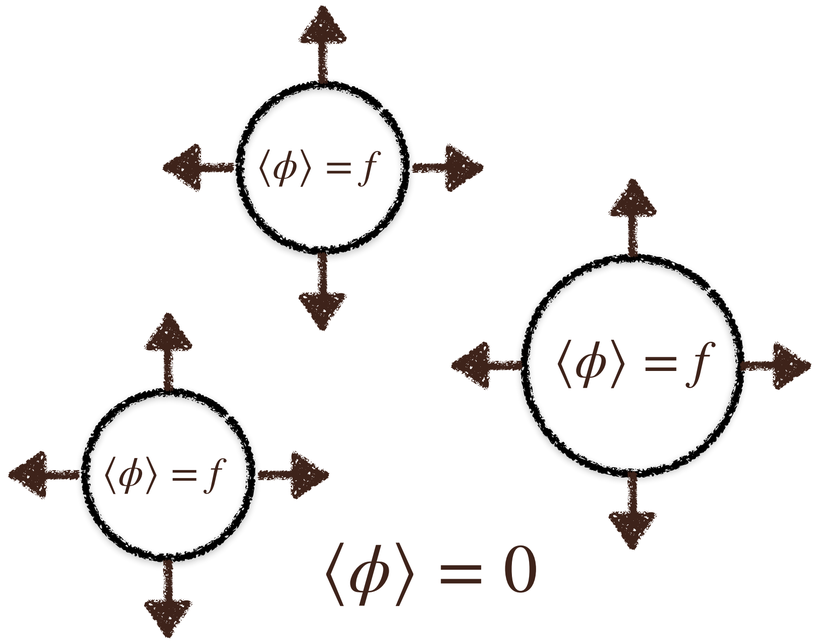
Supercooled 1stOPT = delayed PT



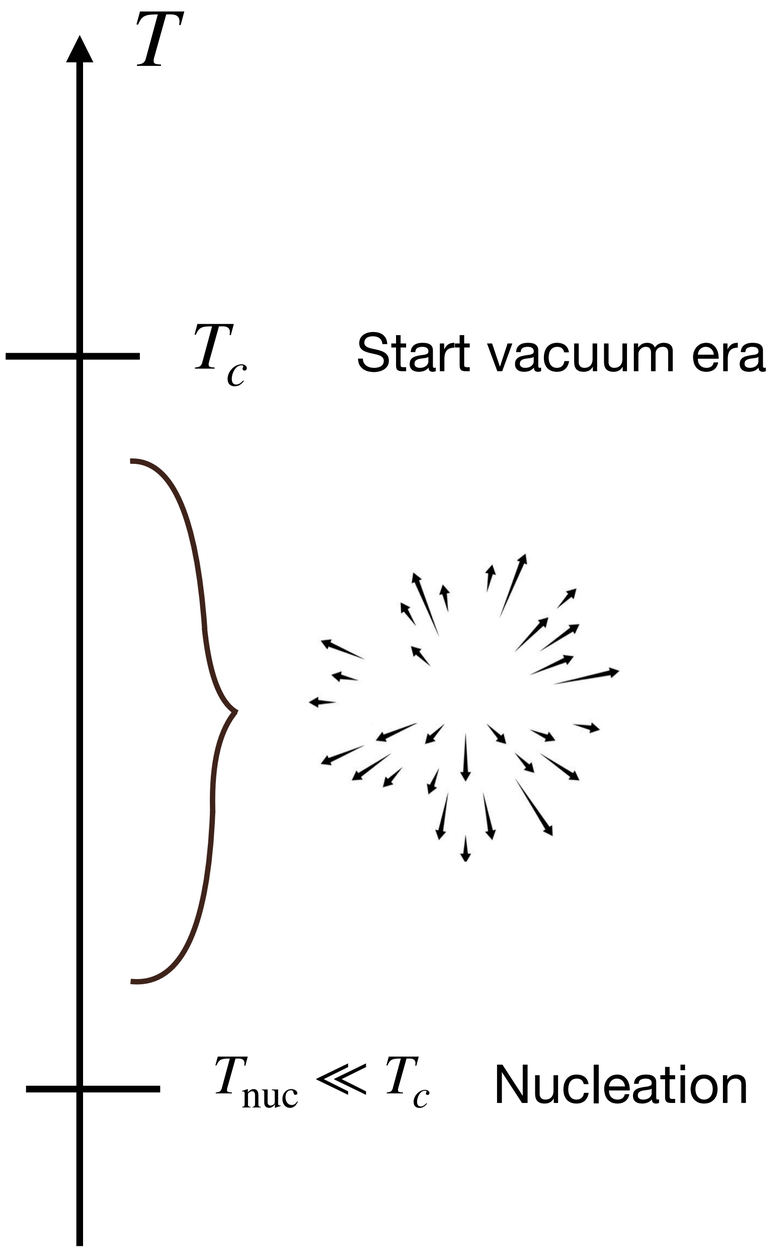
Supercooled 1stOPT = delayed PT

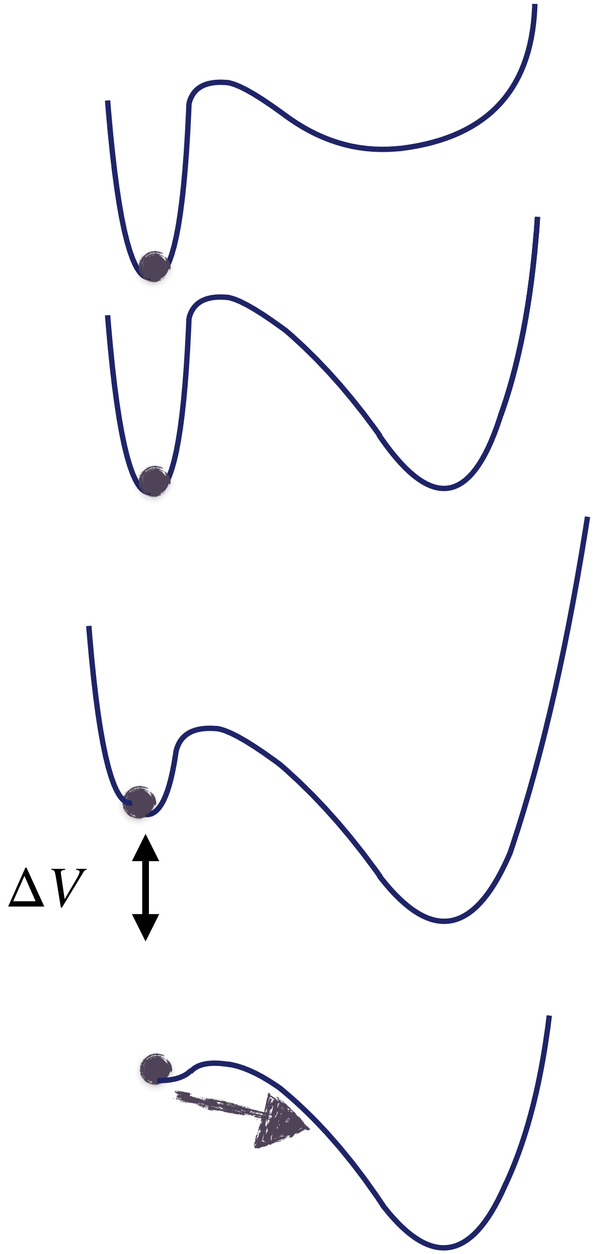


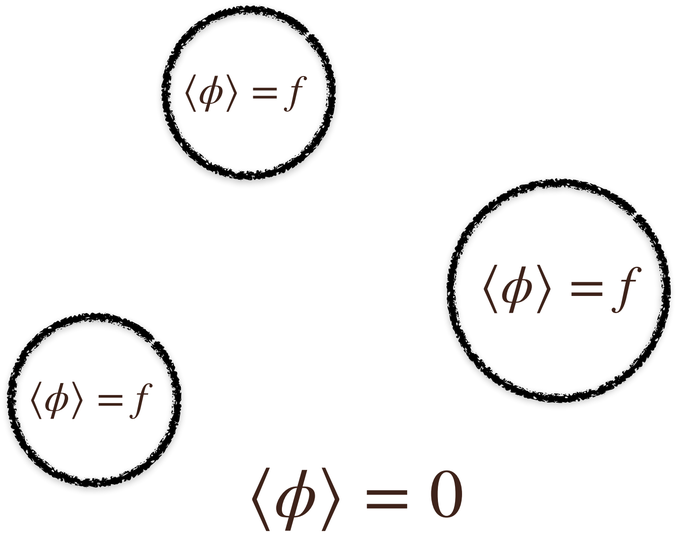




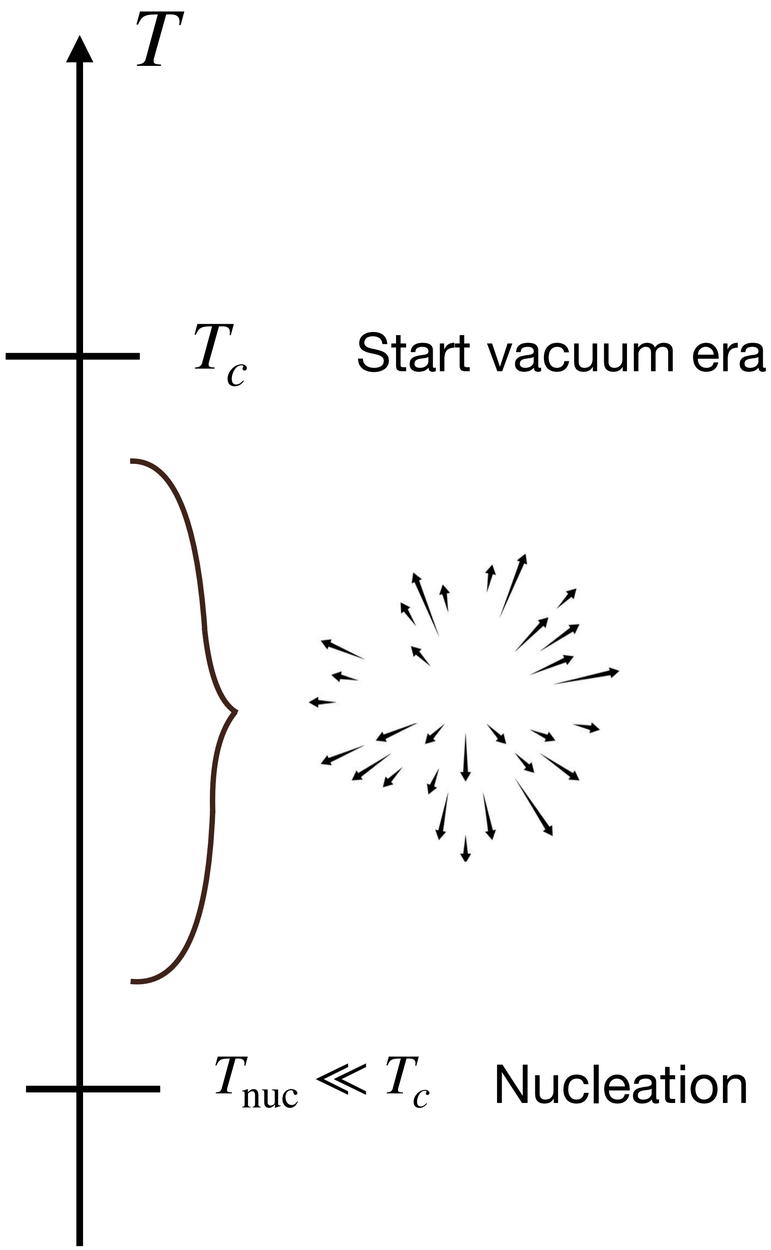
Supercooled 1stOPT = delayed PT

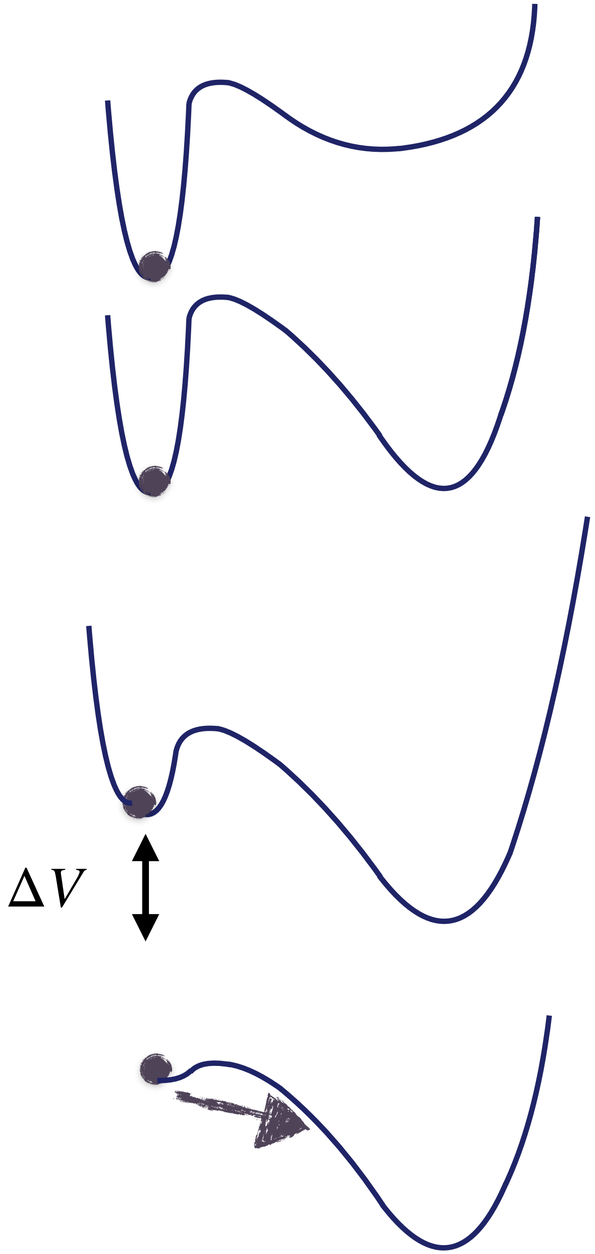


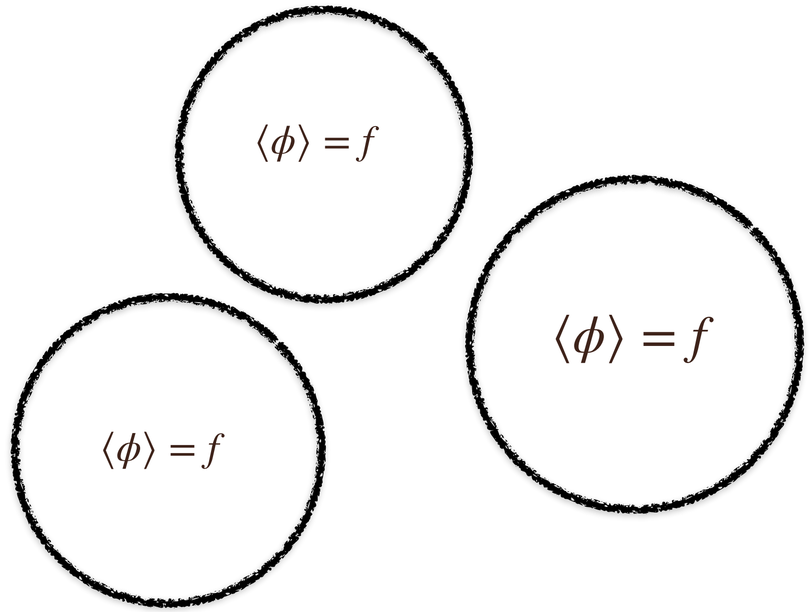




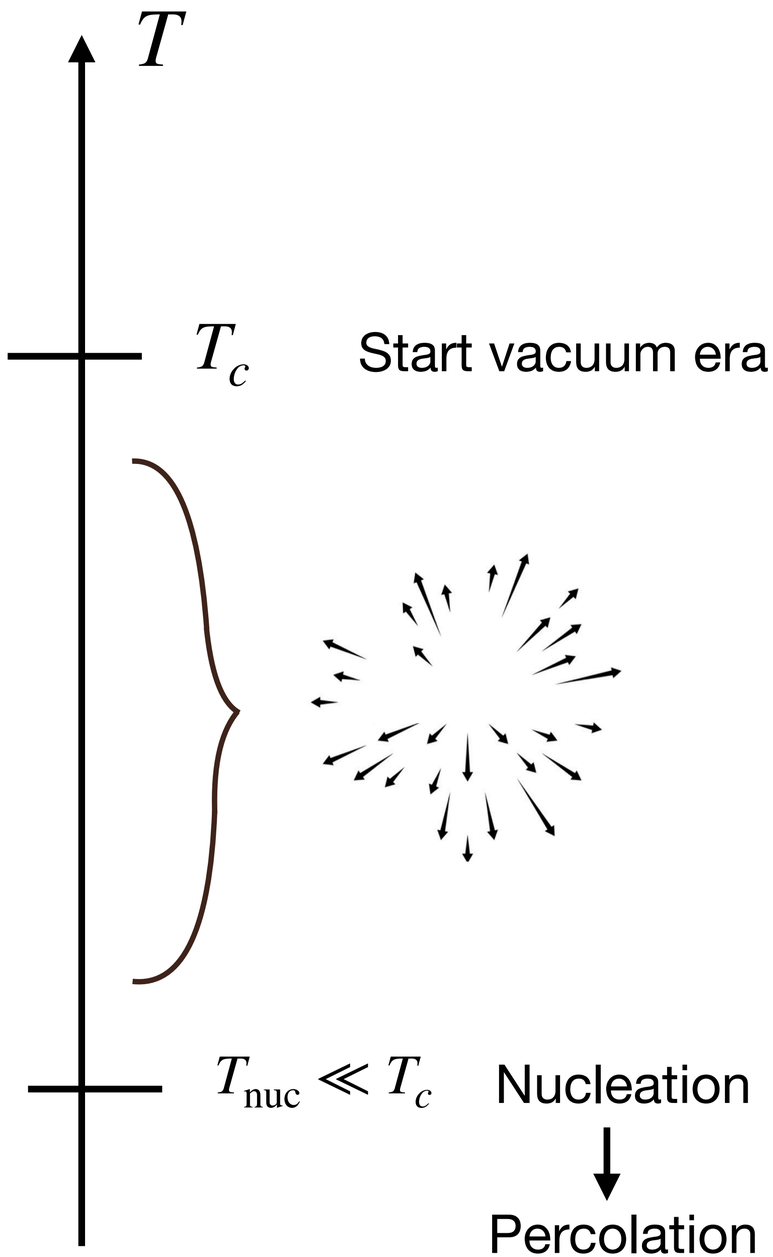
Supercooled 1stOPT = delayed PT

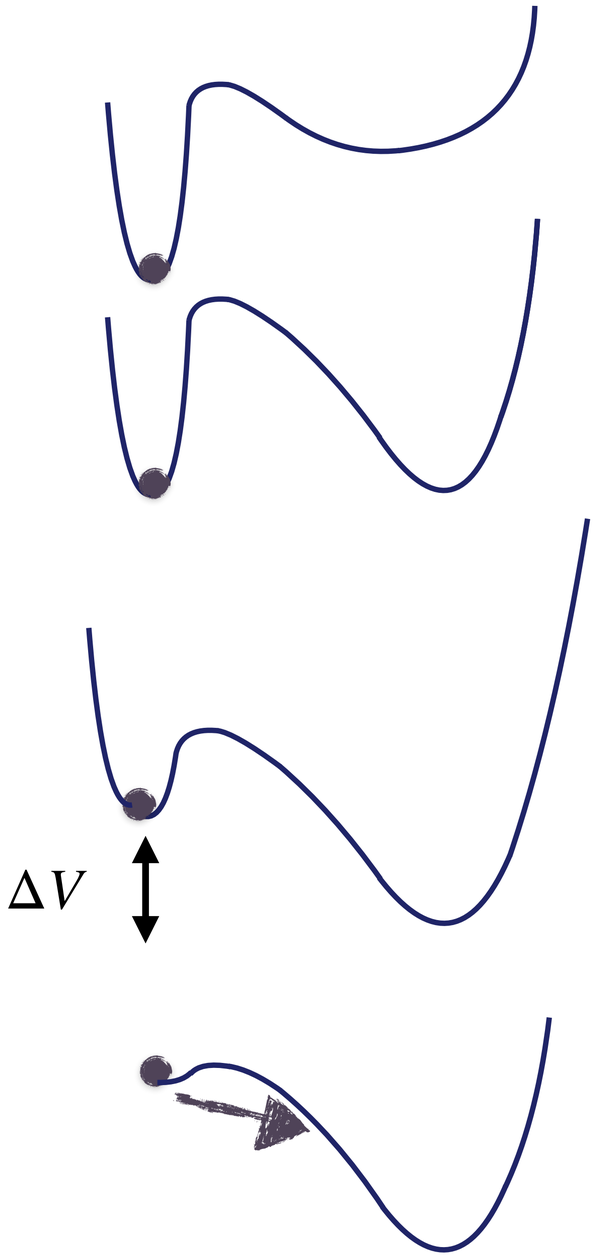


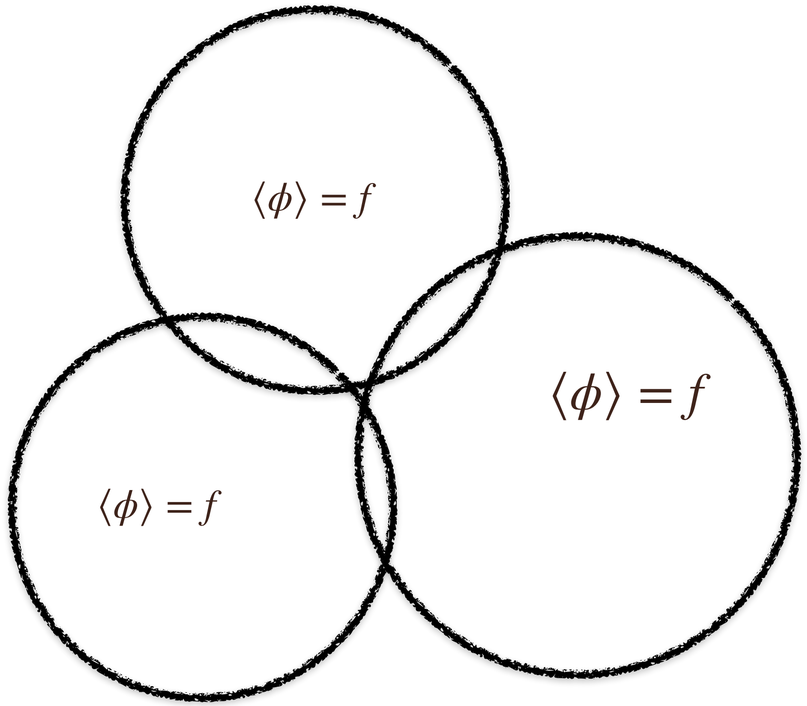




Supercooled 1stOPT = delayed PT

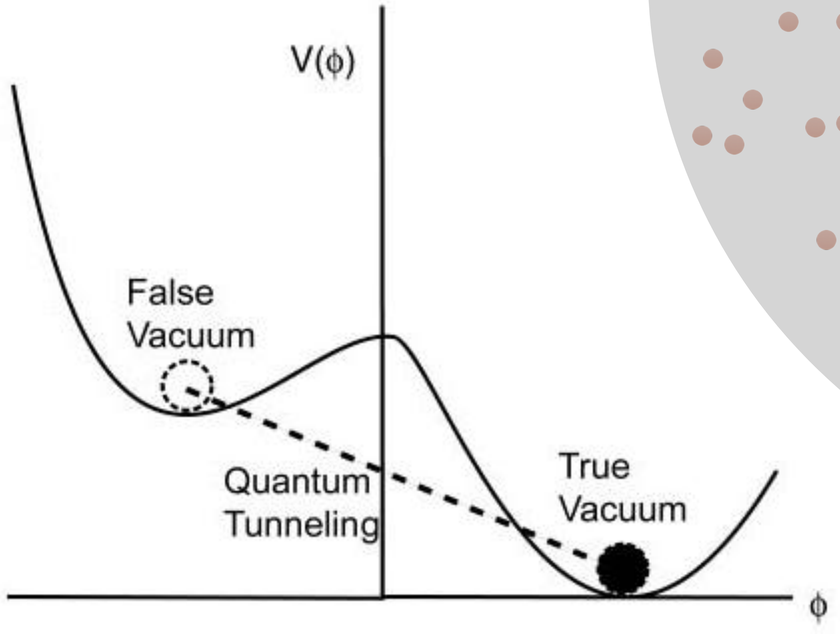


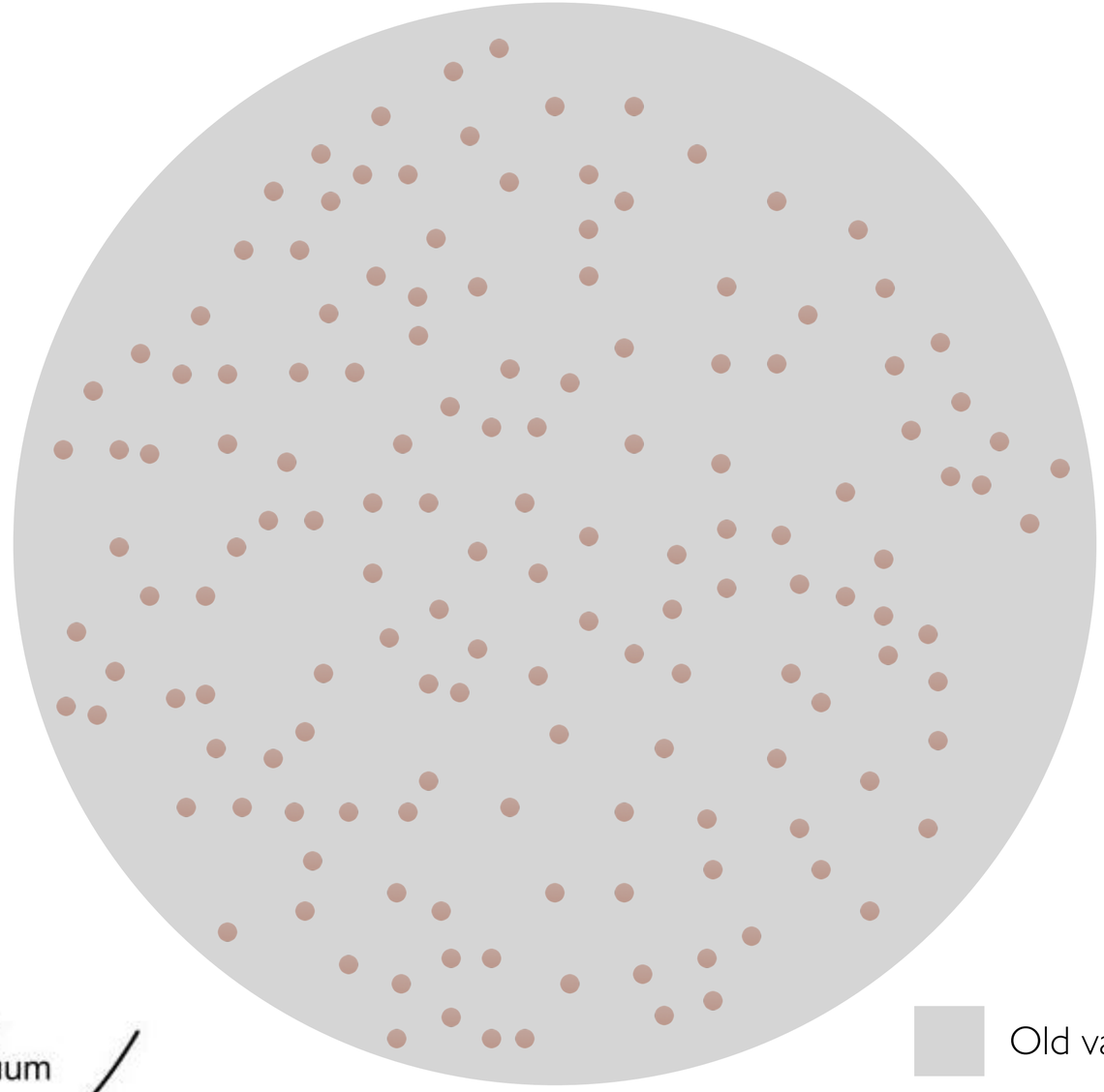




PBHs from 1stOPT

YG, Volansky 2305:04942



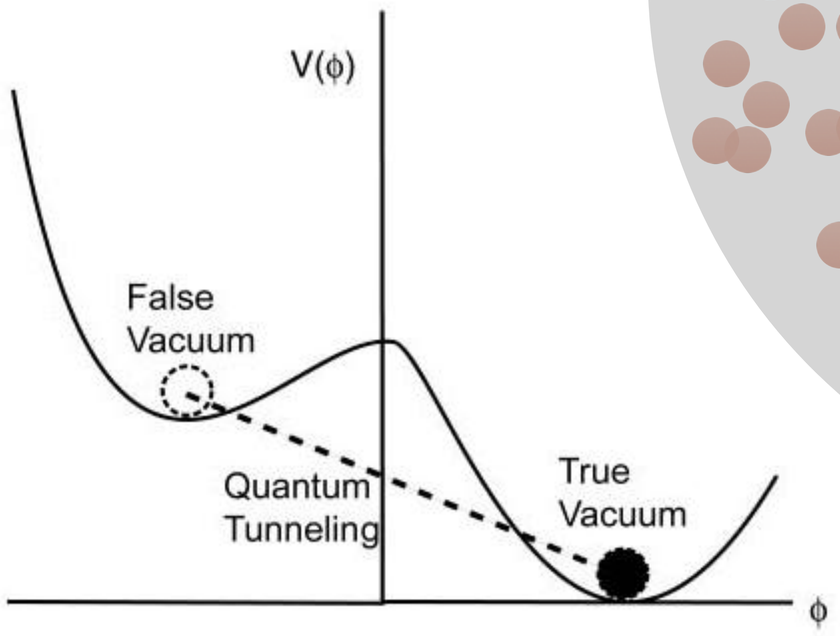


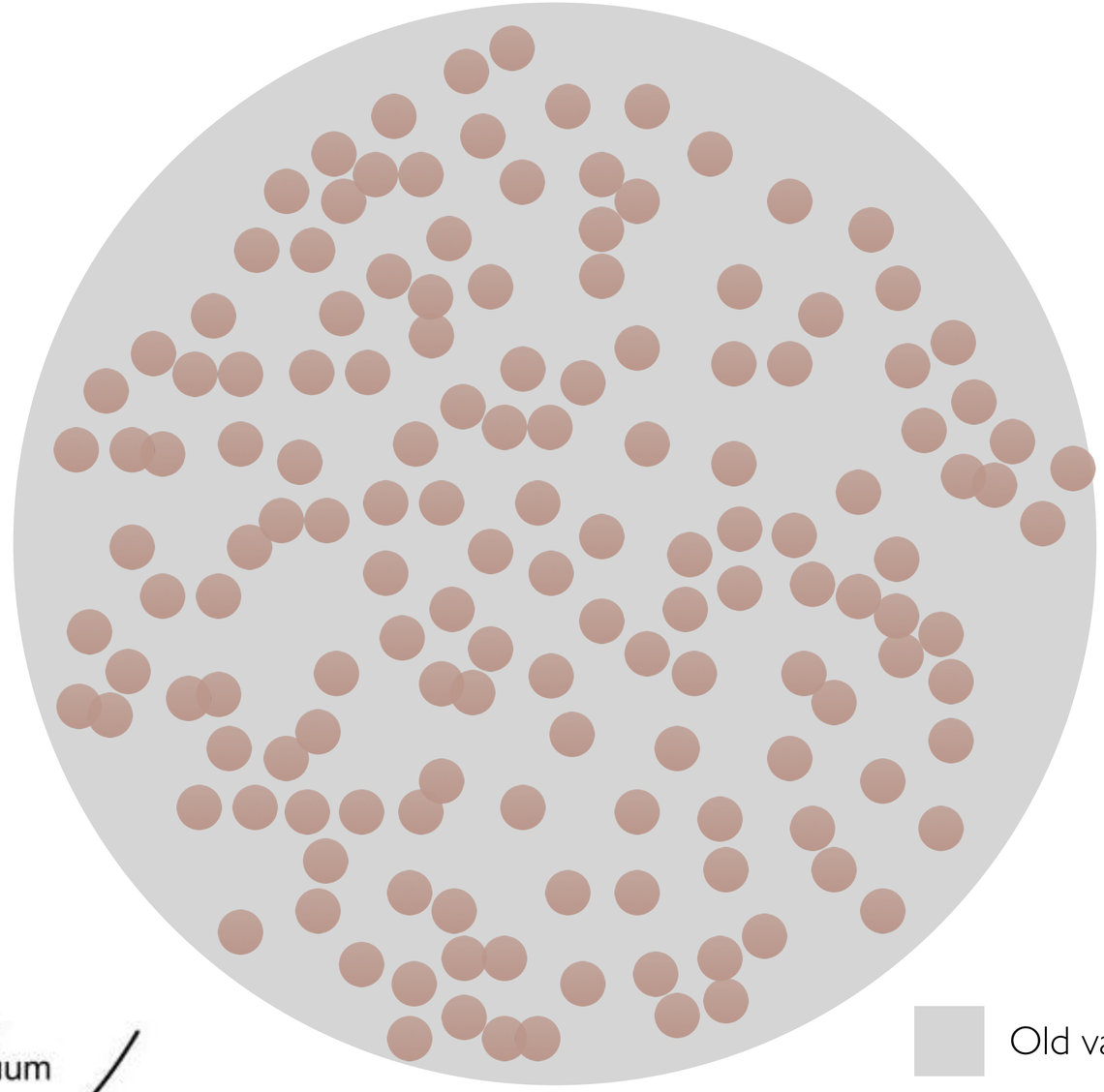
Old vacuum-dominated region (outside bubbles)

New radiation-dominated region (inside bubbles)

PBHs from 1stOPT

YG, Volansky 2305:04942





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New radiation-dominated region (inside bubbles)

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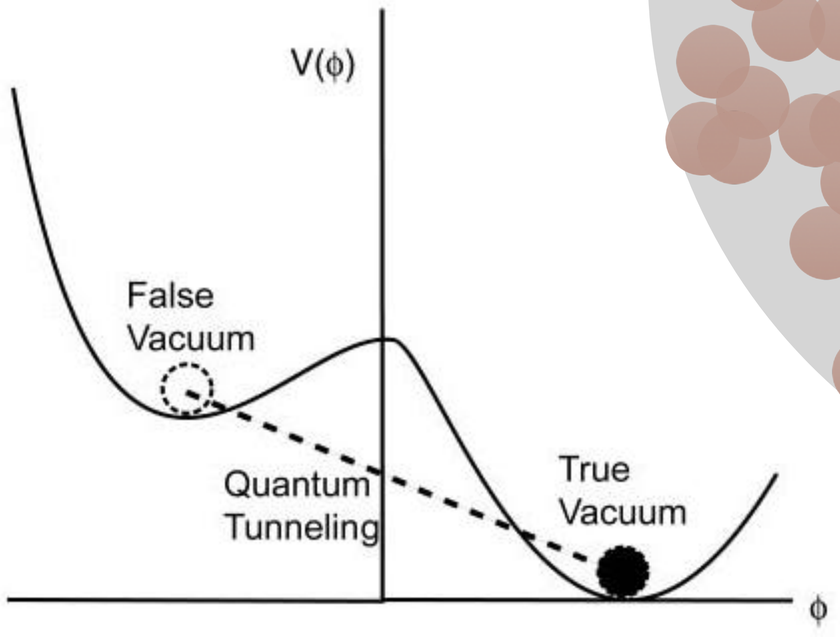

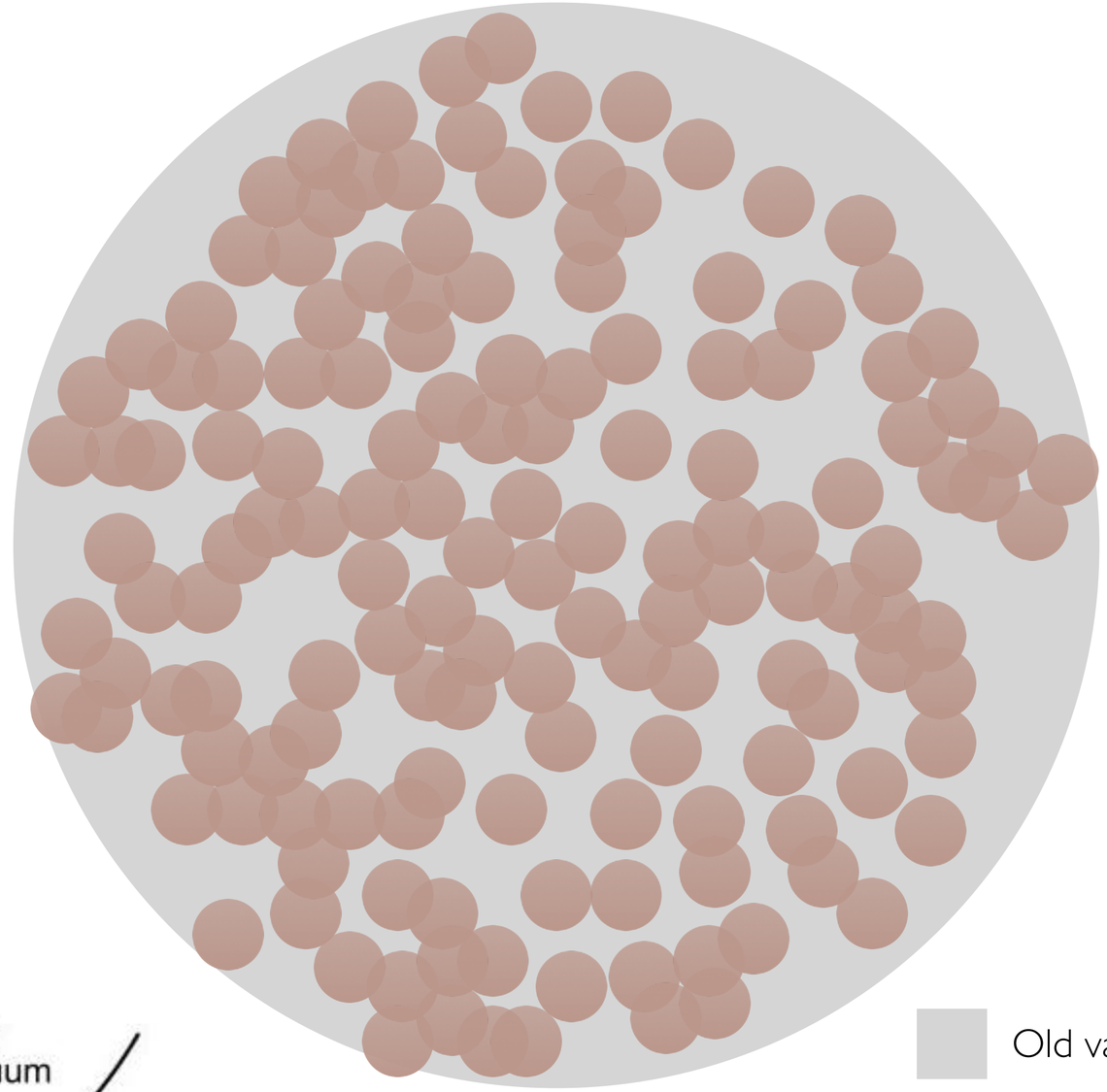

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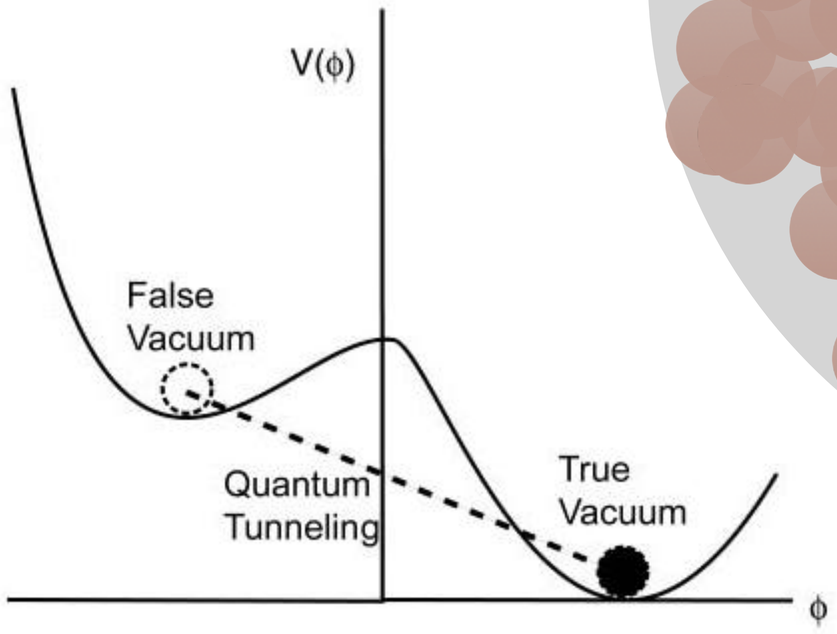

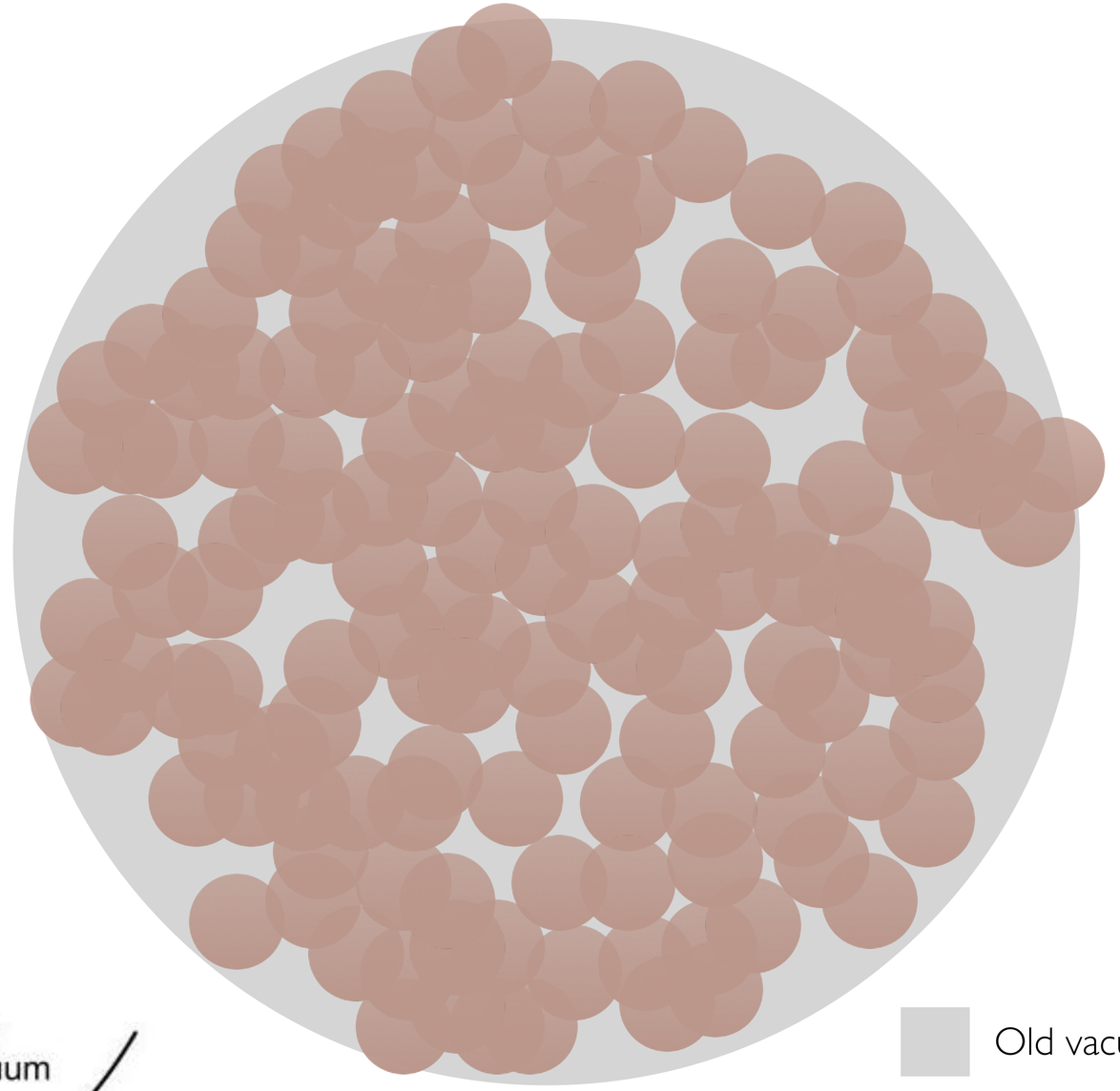

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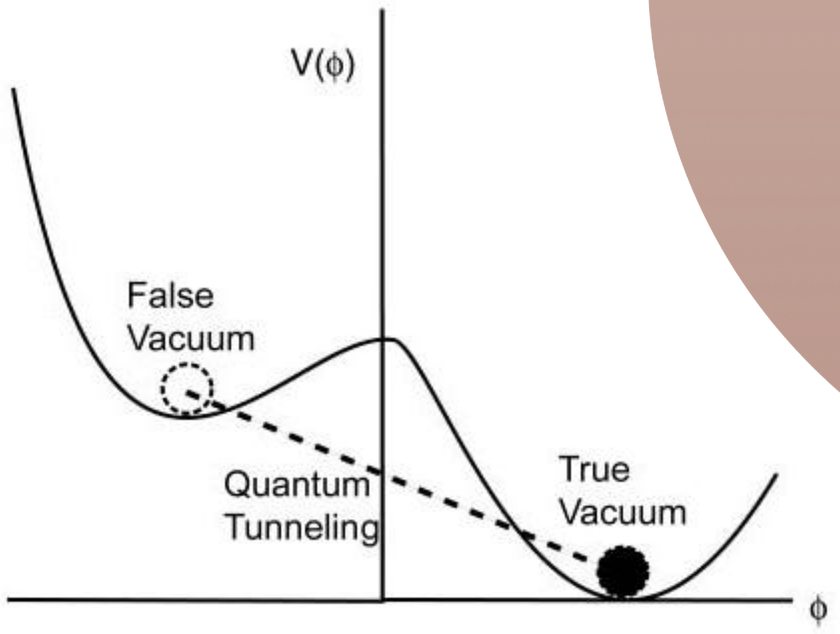

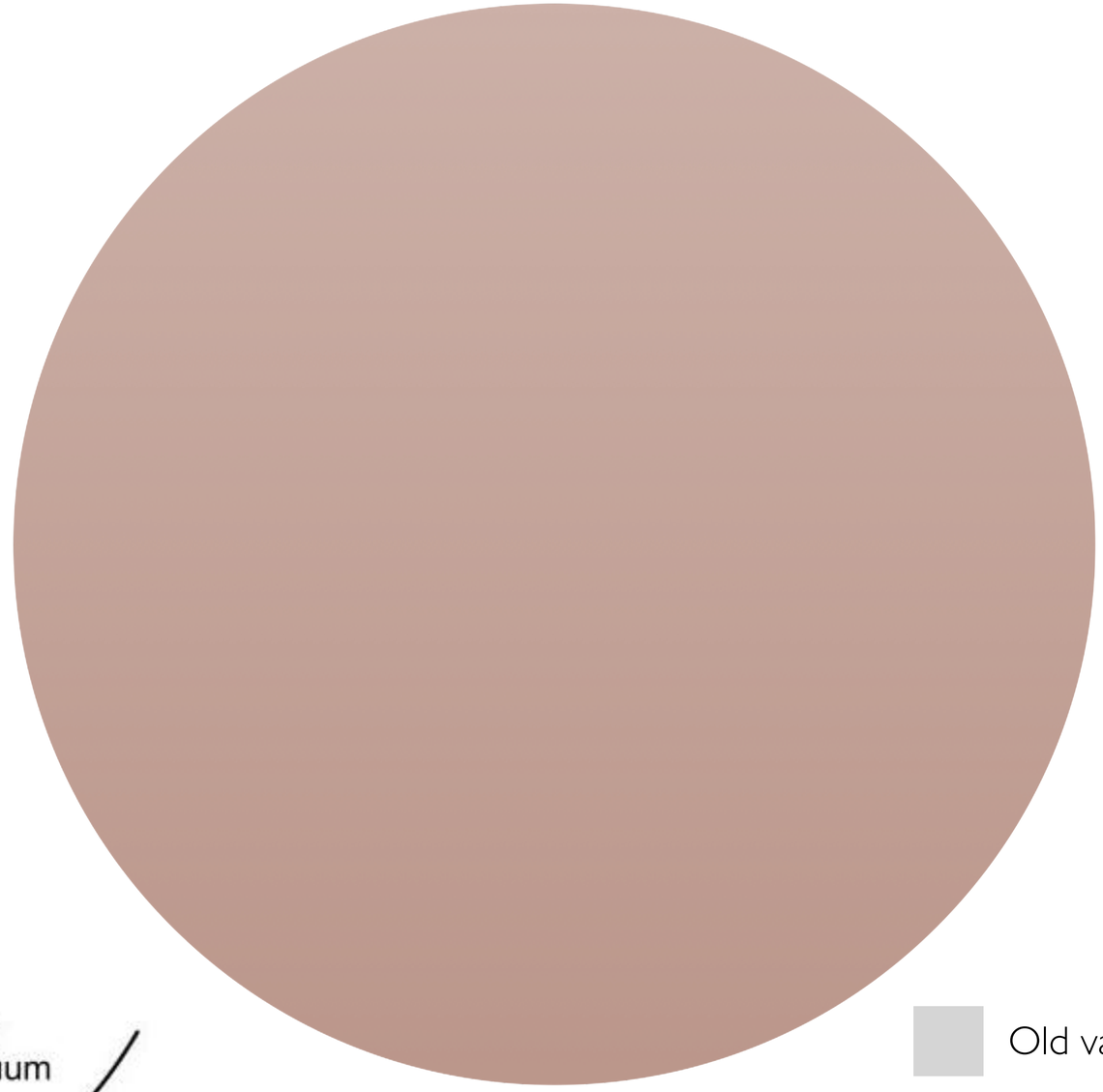

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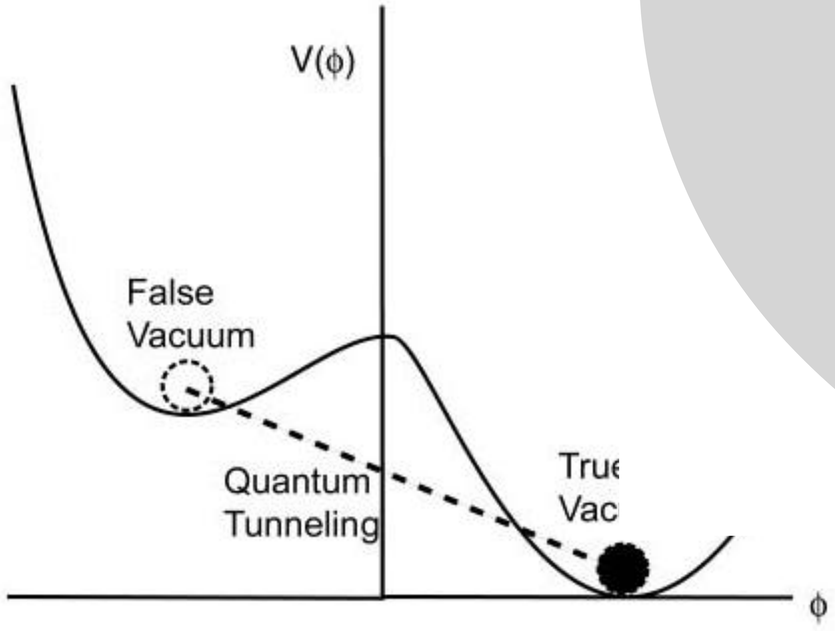

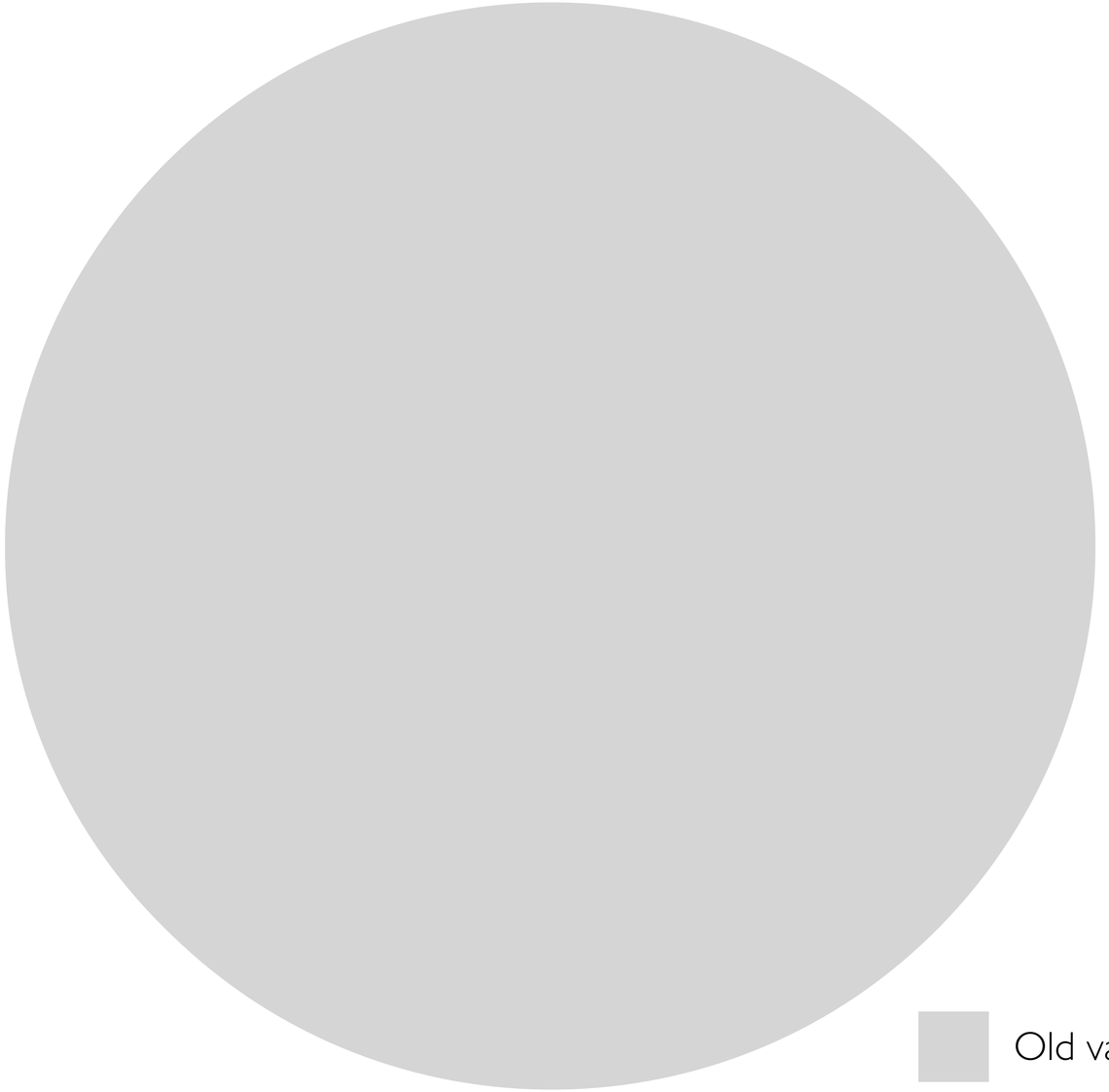

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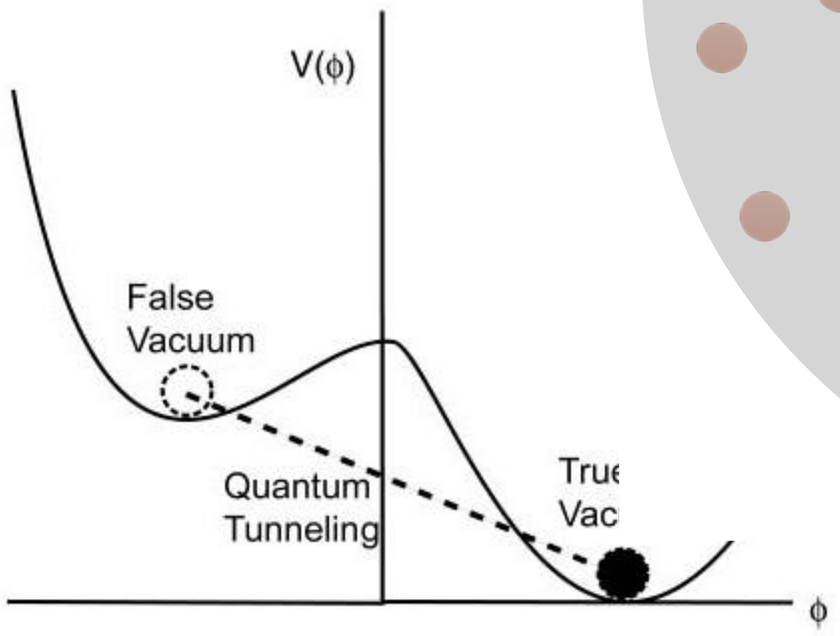

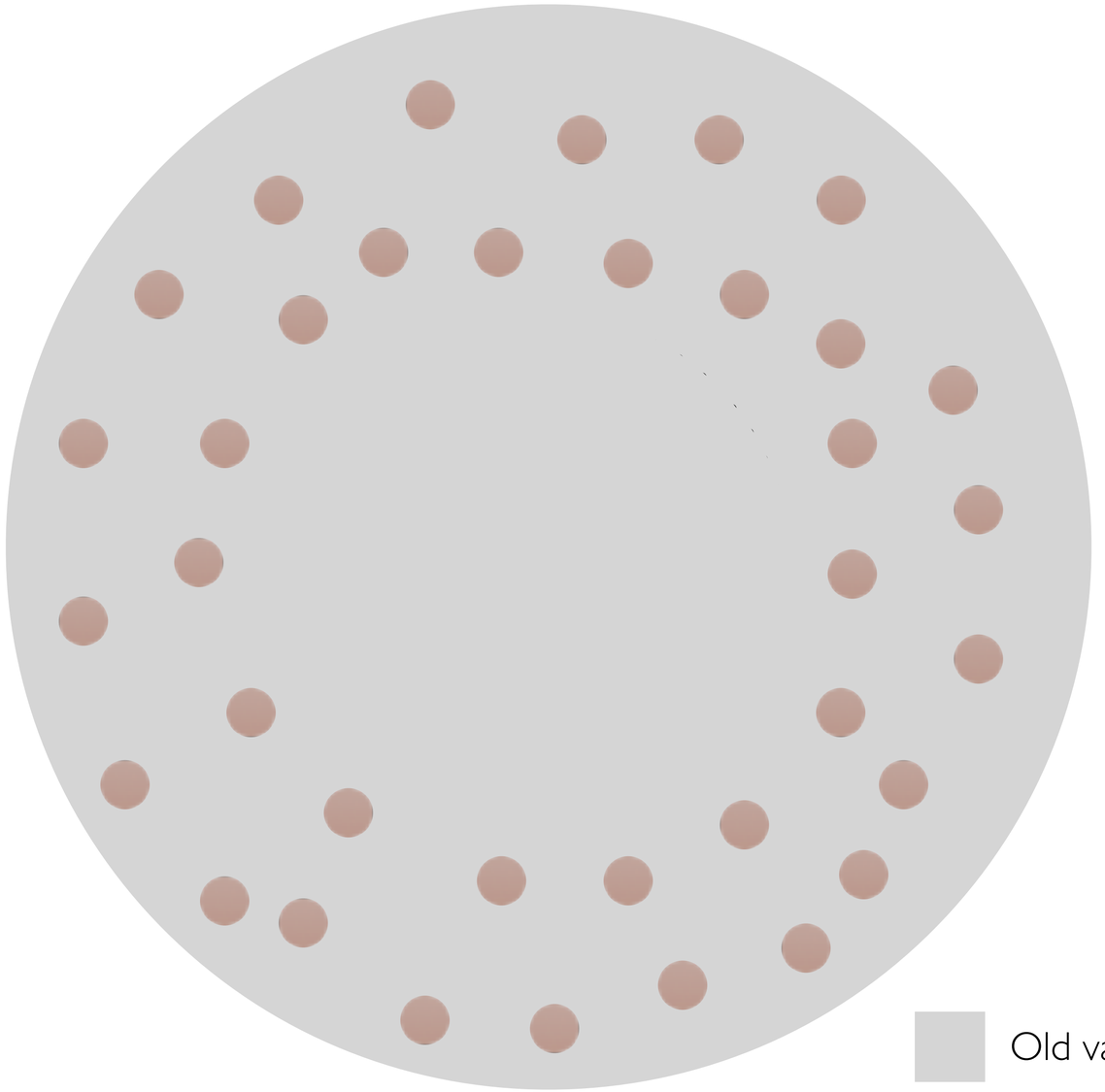

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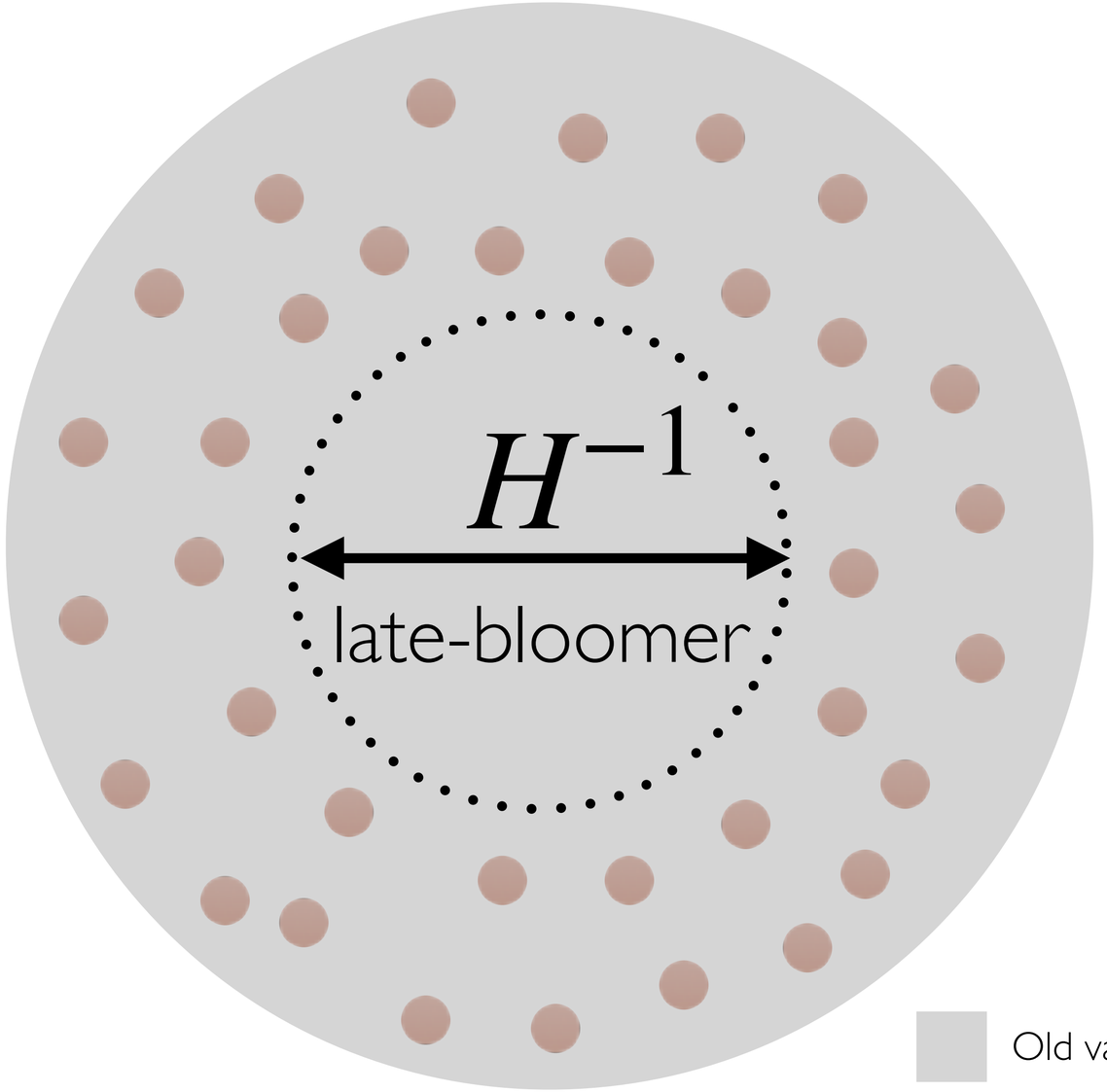

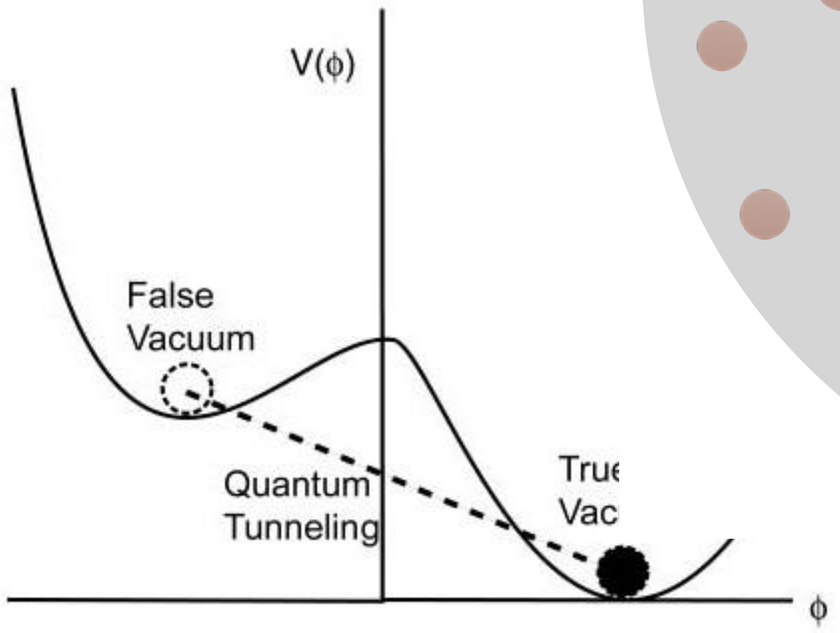

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PBHs from 1stOPT

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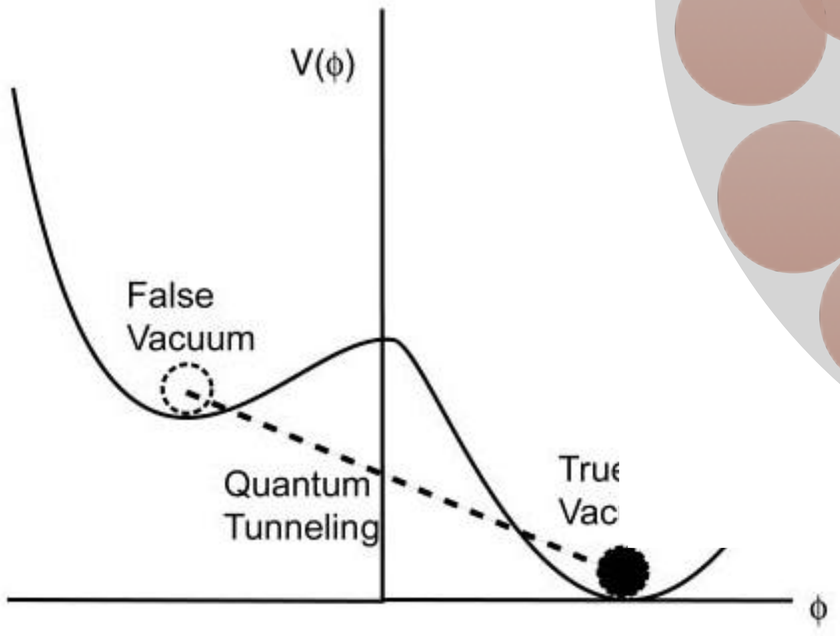

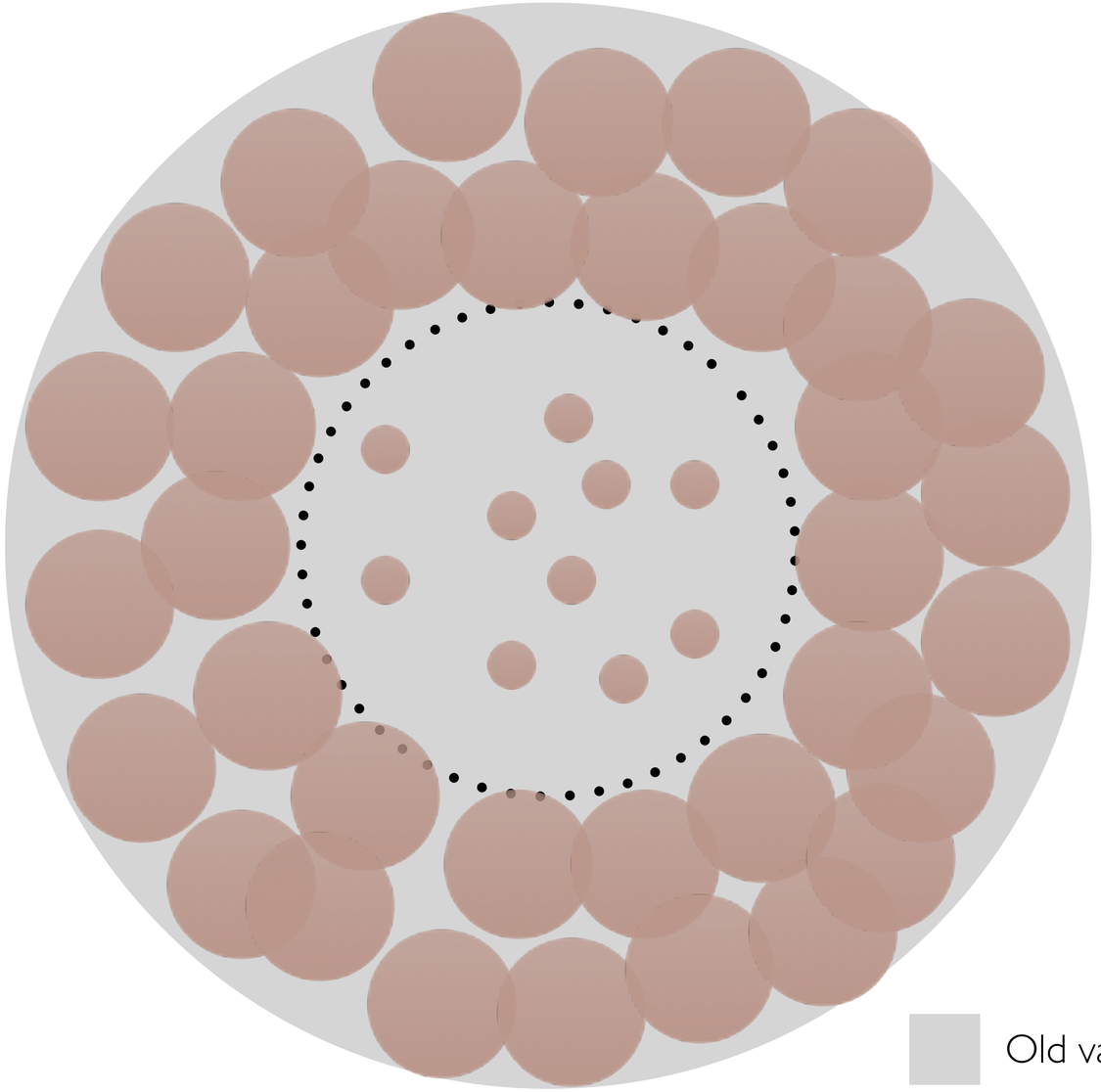

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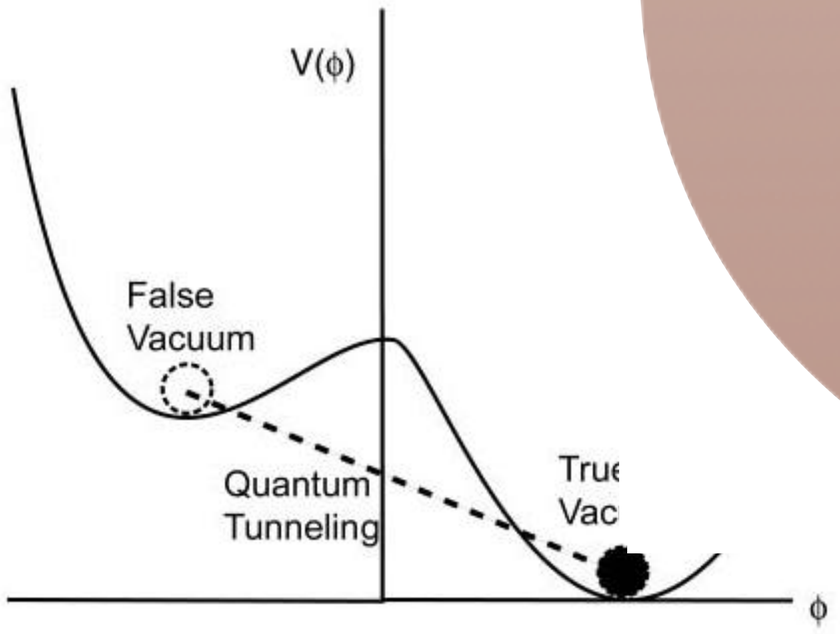
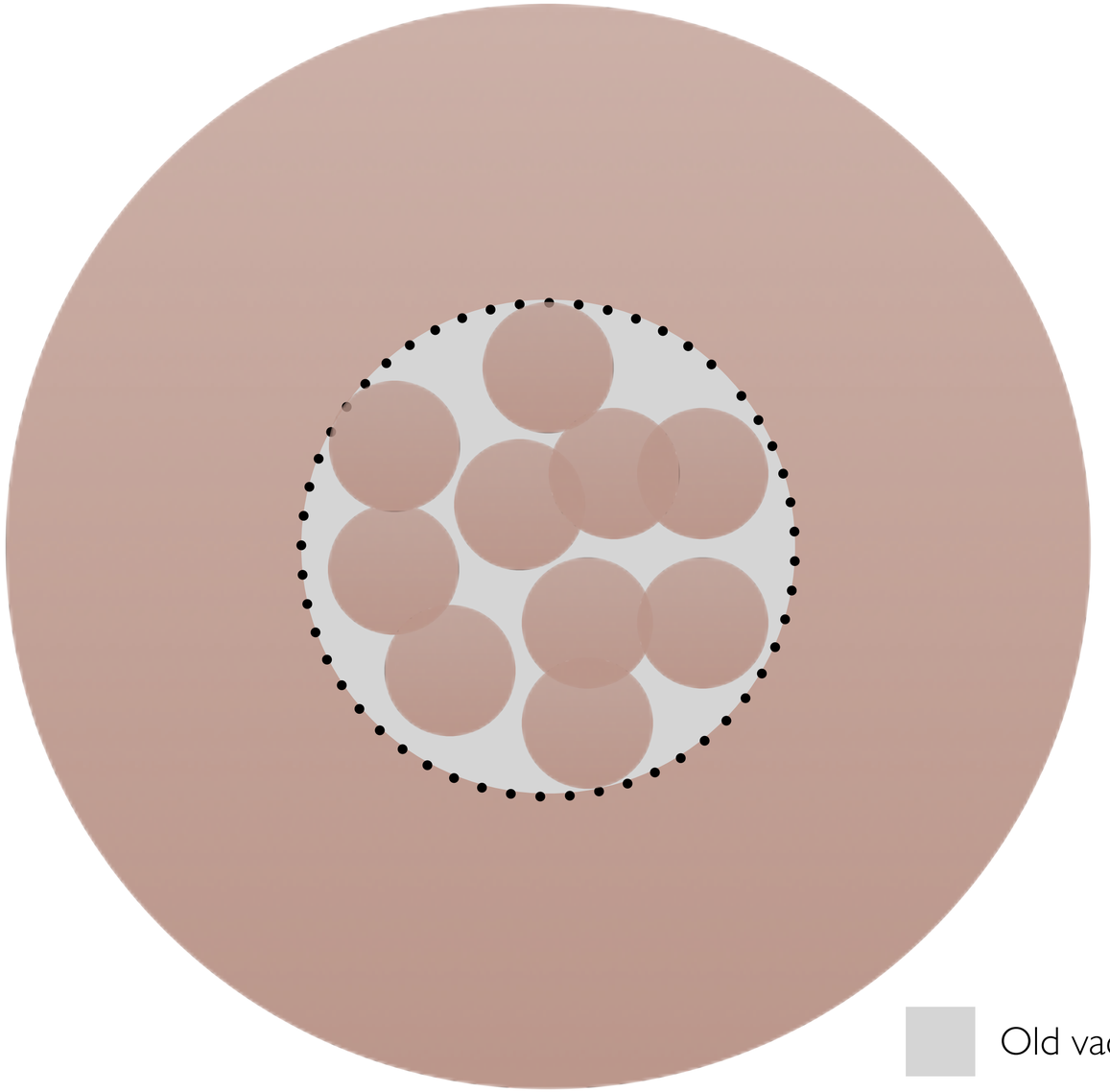


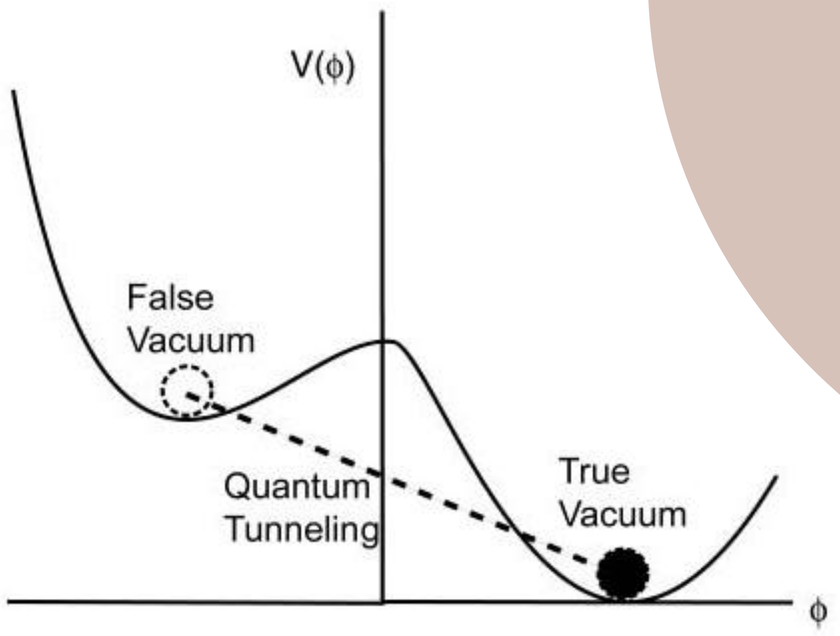


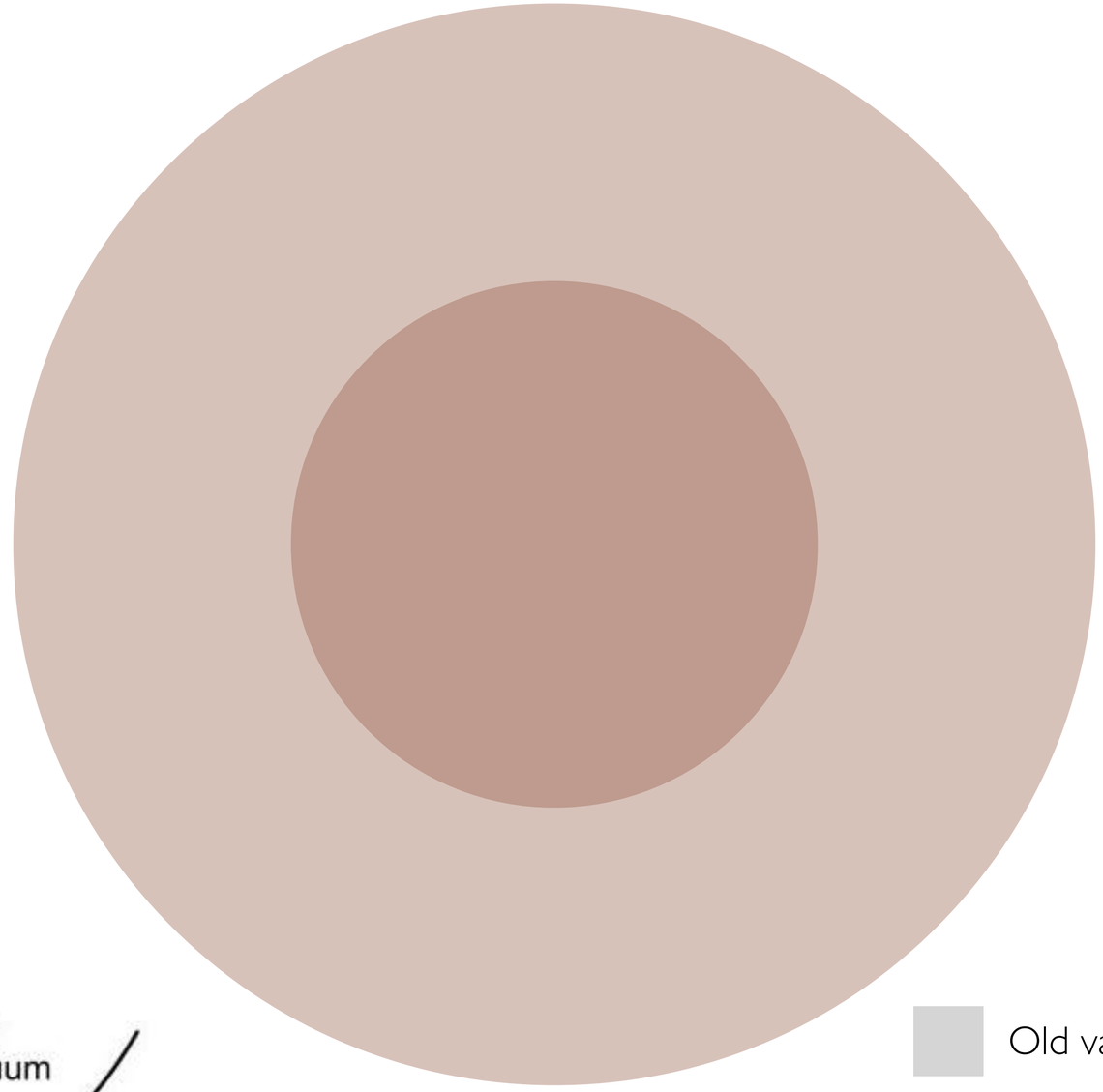
Old vacuum-dominated region (outside bubbles)

New radiation-dominated region (inside bubbles)

PBHs from 1stOPT

YG, Volansky 2305:04942



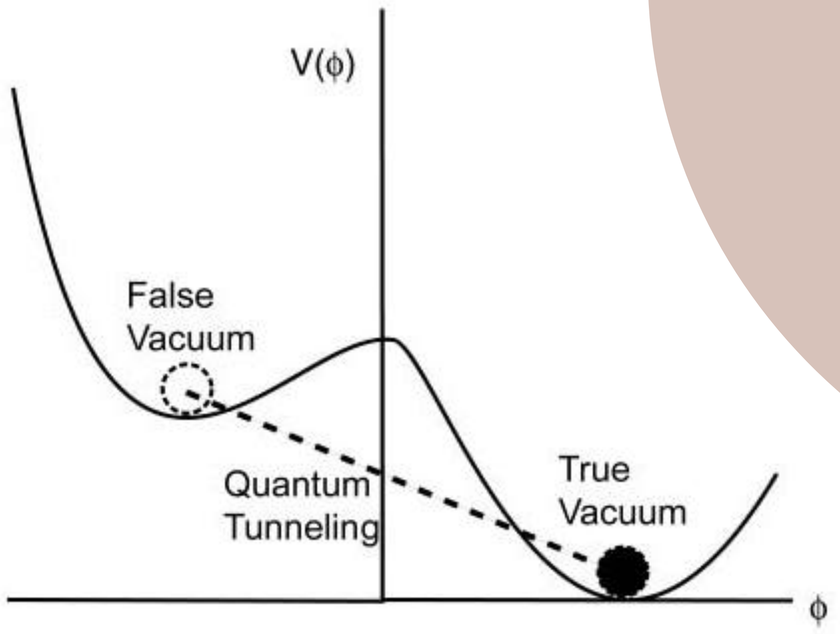


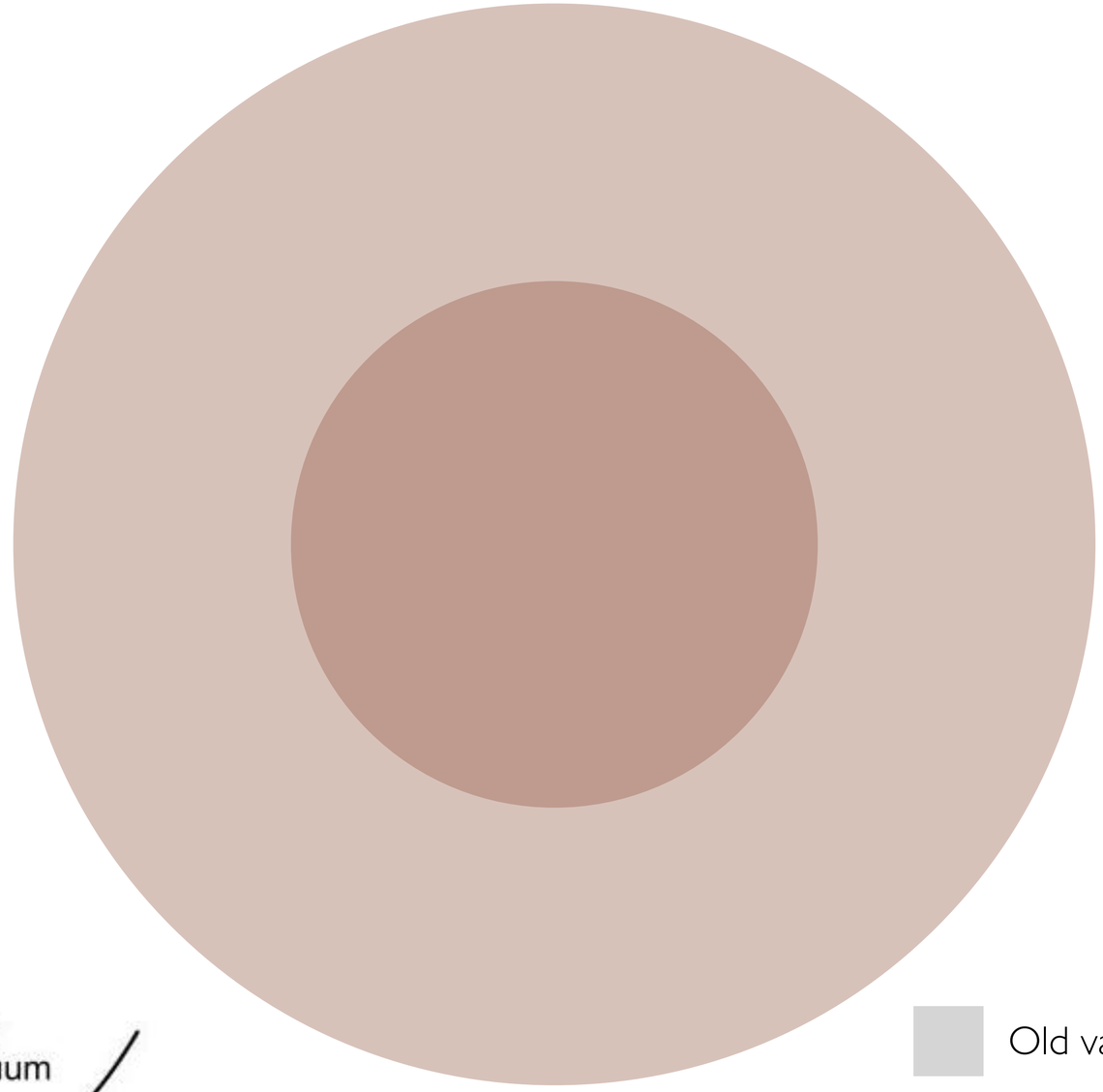
Old vacuum-dominated region (outside bubbles)

New radiation-dominated region (inside bubbles)

PBHs from 1stOPT

YG, Volansky 2305:04942





if

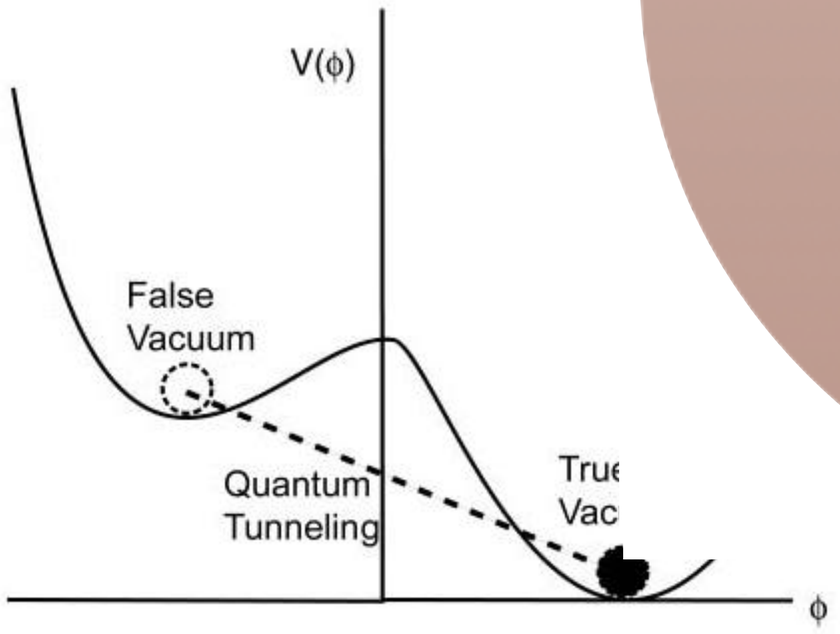
$$\delta\rho/\rho \gtrsim 0.45.$$

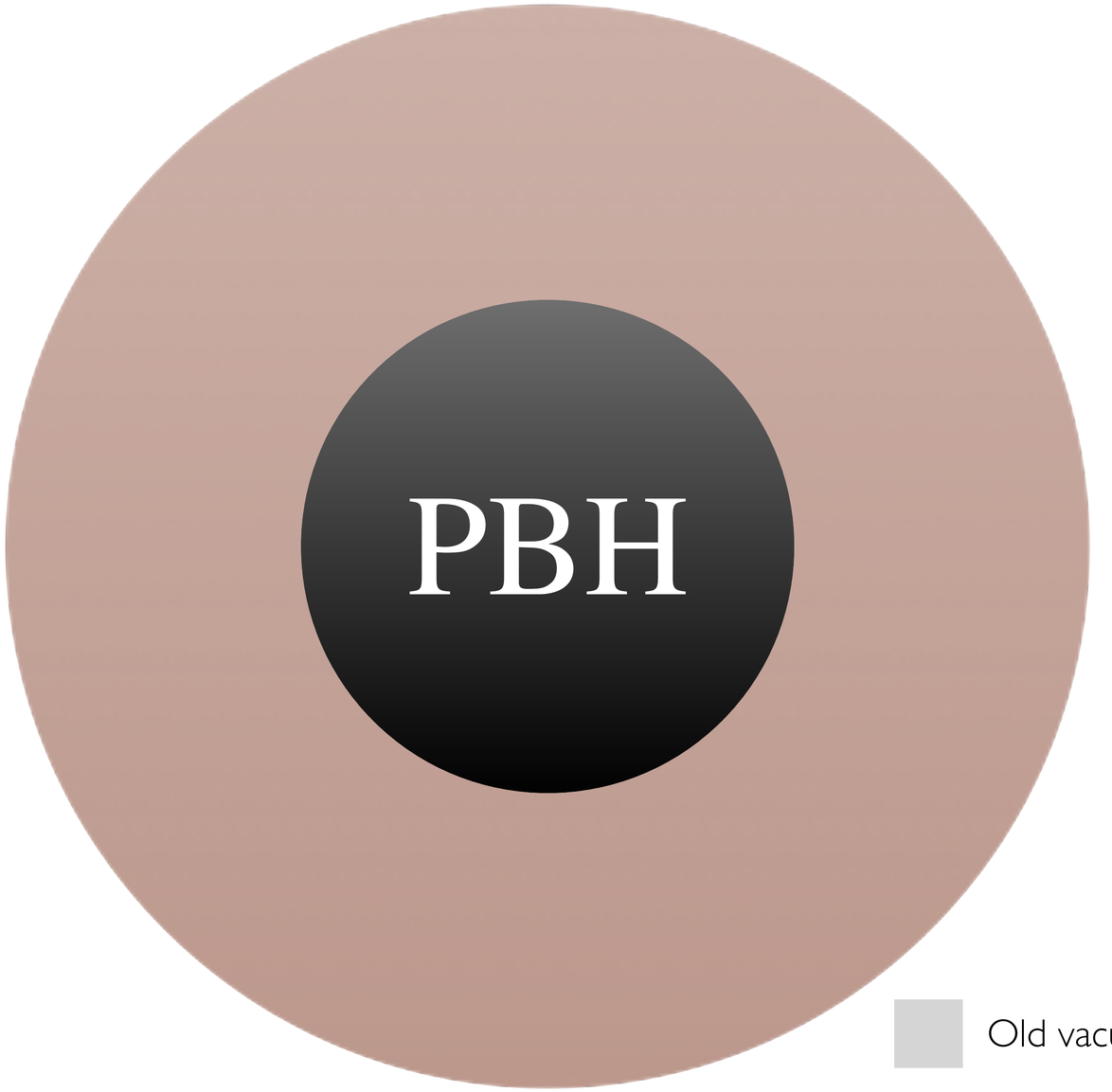
Old vacuum-dominated region (outside bubbles)

New radiation-dominated region (inside bubbles)

PBHs from 1stOPT

YG, Volansky 2305:04942





if

$$\delta\rho/\rho \gtrsim 0.45.$$

then

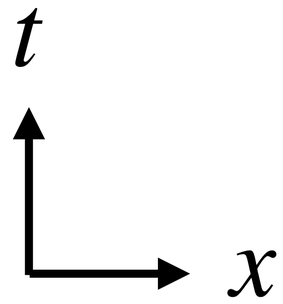
PBH

Old vacuum-dominated region (outside bubbles)

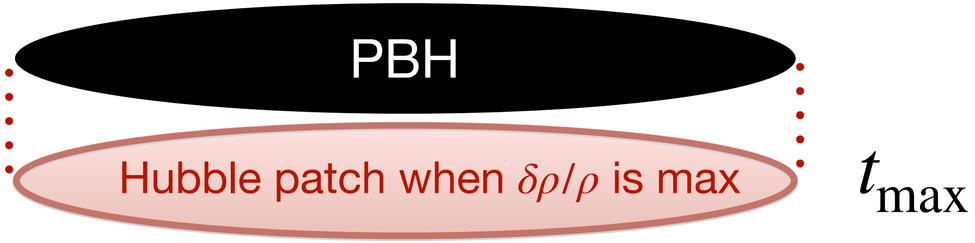
New radiation-dominated region (inside bubbles)

PBH

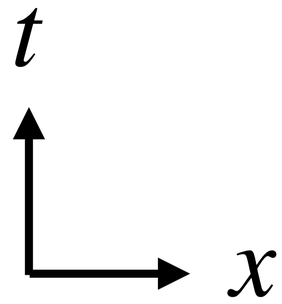
YG, Volansky 2305:04942

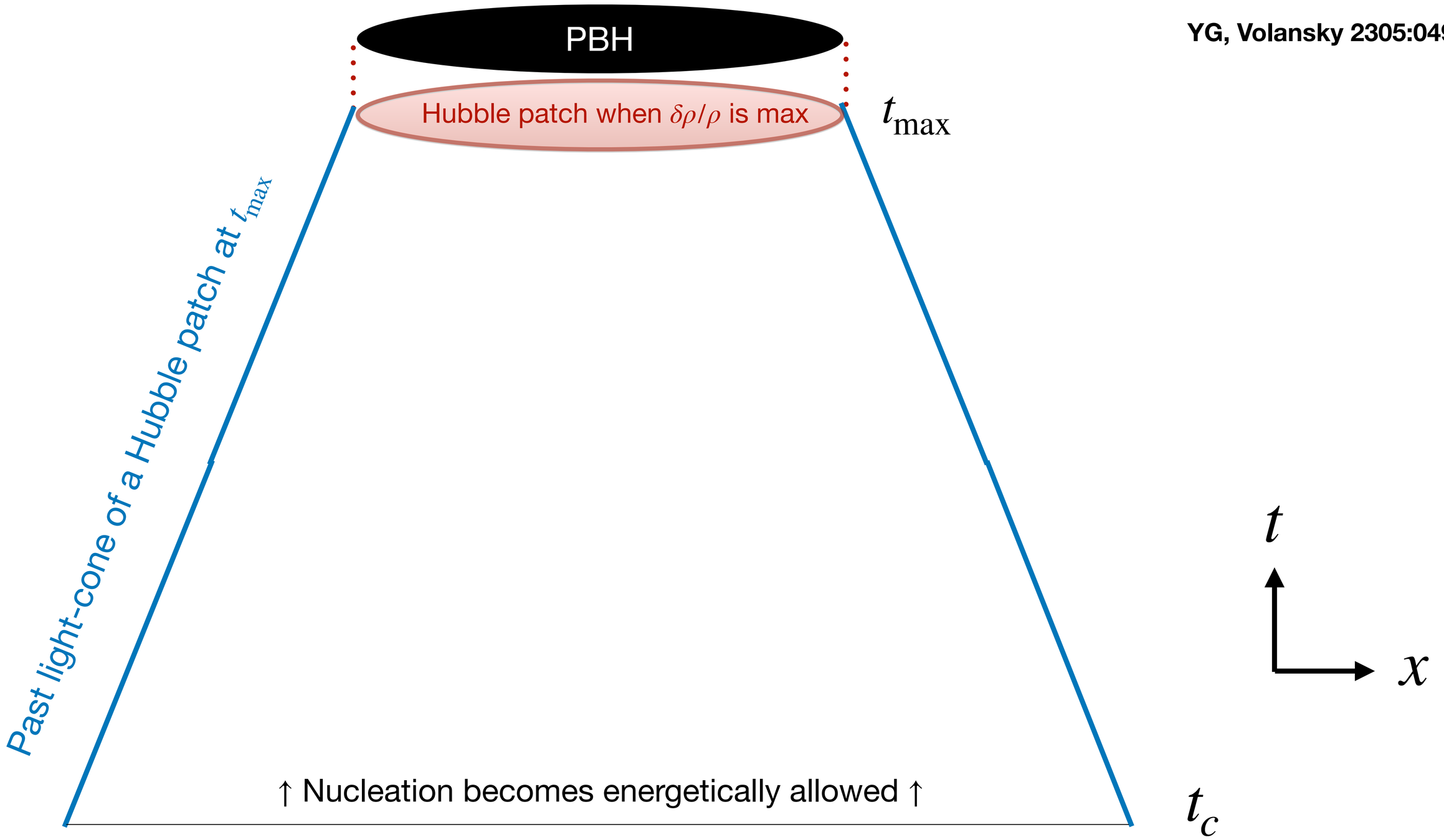


YG, Volansky 2305:04942

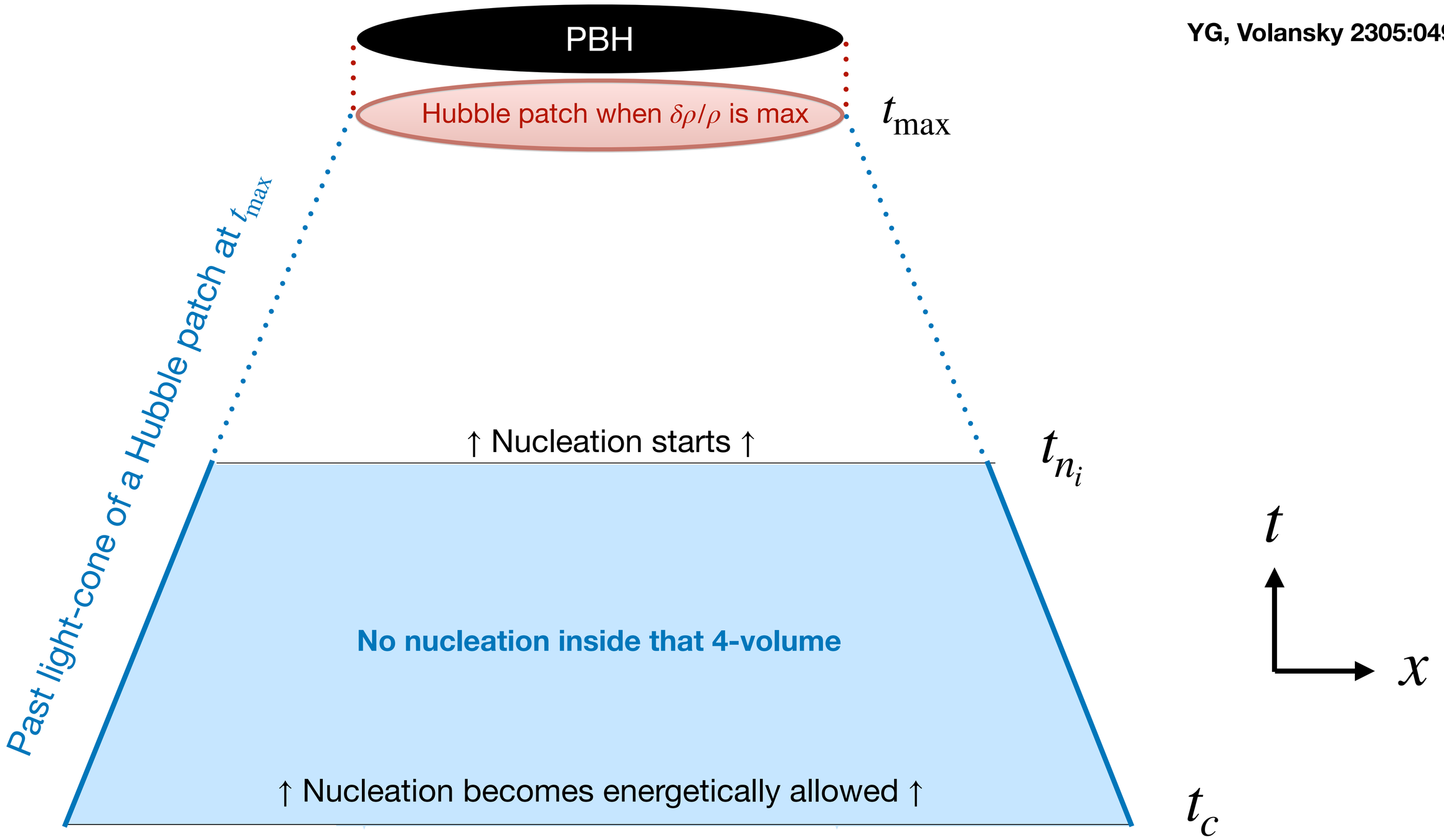


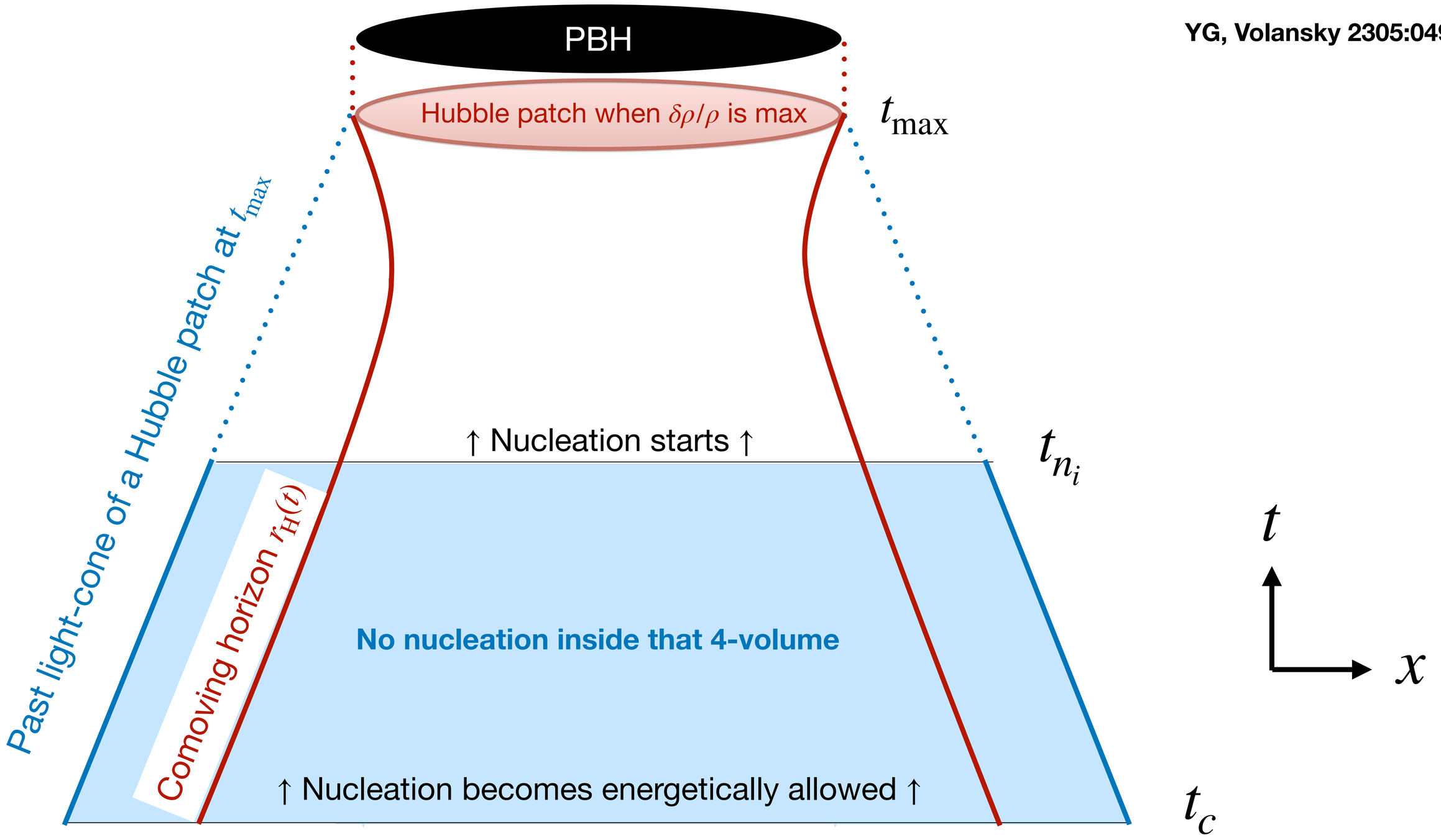
$t_{\rm max}$

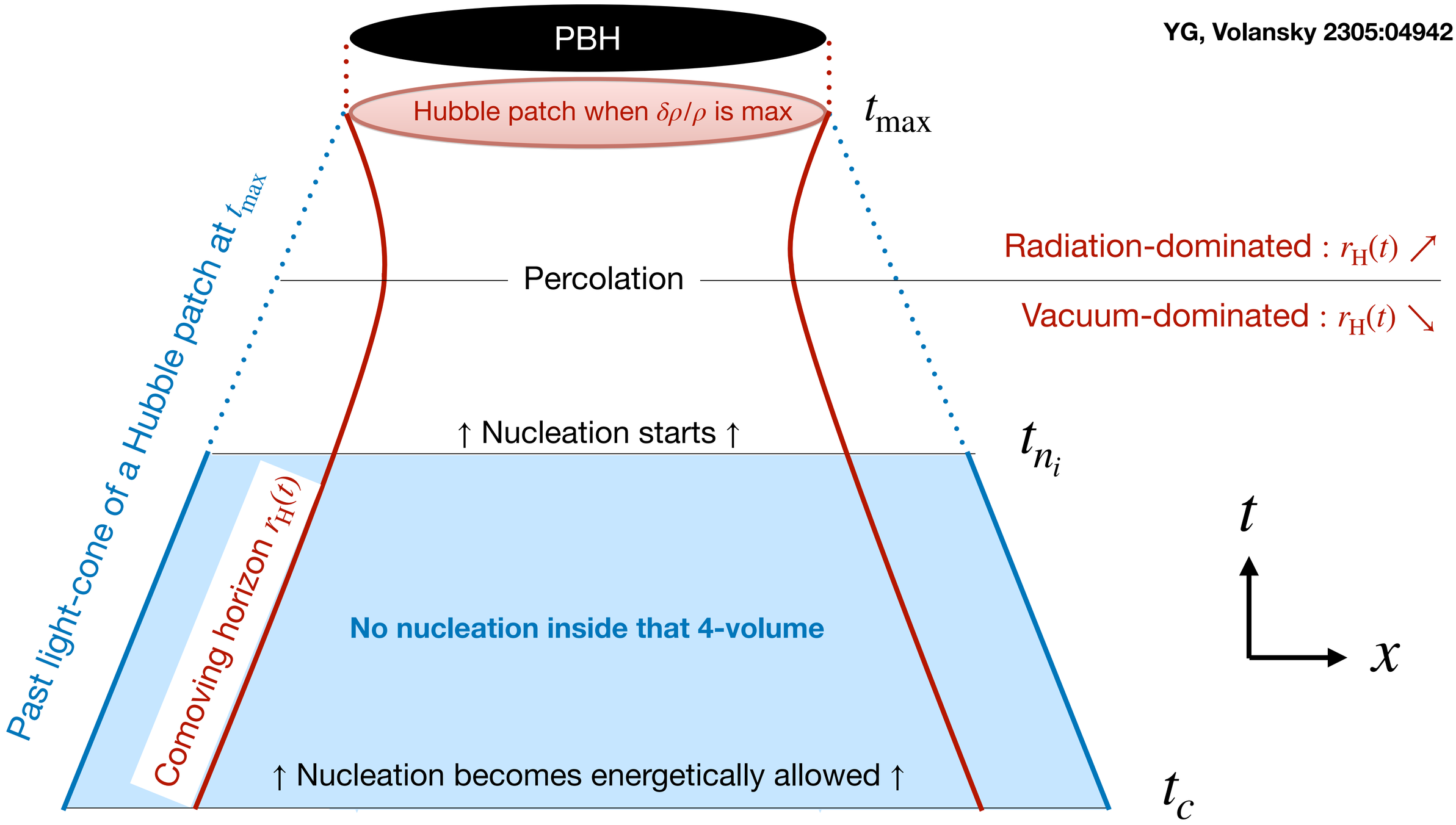




YG, Volansky 2305:04942


YG, Volansky 2305:04942
PBH
Hubble patch when $\delta\rho/\rho$ is max
$t_{\max}$
Past light-cone of a Hubble patch at t_{max}
↑ Nucleation starts ↑
t_{n_i}
No nucleation inside that 4-volume
↑ Nucleation becomes energetically allowed ↑
t_c
t
x


YG, Volansky 2305:04942
PBH
Hubble patch when $\delta\rho/\rho$ is max
$t_{\max}$
Past light-cone of a Hubble patch at t_{max}
↑ Nucleation starts ↑
t_{n_i}
Comoving horizon $r_H(t)$
No nucleation inside that 4-volume
↑ Nucleation becomes energetically allowed ↑
t_c
t
x


YG, Volansky 2305:04942
PBH
Hubble patch when $\delta\rho/\rho$ is max
$t_{\max}$
Past light-cone of a Hubble patch at t_{max}
Radiation-dominated : $r_{\rm H}(t)\nearrow$
Percolation
Vacuum-dominated : $r_{\rm H}(t)\searrow$
↑ Nucleation starts ↑
t_{n_i}
Comoving horizon $r_{\rm H}(t)$
No nucleation inside that 4-volume
t
x
↑ Nucleation becomes energetically allowed ↑
t_c

Collapse probability :

$$\boxed{\mathscr{P}_{\rm coll} = \exp\left[-\int_{t_c}^{t_{n_i}} dt'\,\Gamma(t')a(t')^3\frac{4\pi}{3}\left(\frac{1}{a(t_{\rm max})H(t_{\rm max})}+\int_{t'}^{t_{\rm max}}\frac{d\tilde{t}}{a(\tilde{t})}\right)^3\right]}$$

Friedmann equation :

$$\frac{\dot{a}(t)}{a(t)} = \sqrt{\frac{\rho_{\rm V}(t;t_{n_i})+\rho_{\rm R}(t;t_{n_i})}{3M_{\rm pl}^2}}$$

Vacuum energy :

$$\rho_V(t;t_{n_i}) = \Delta V \exp\left[-\int_{t_{n_i}}^{t} dt'\,\Gamma(t')a(t')^3\frac{4}{3}\pi\left(\int_{t'}^{t}\frac{d\tilde{t}}{a(\tilde{t})}\right)^3\right]$$

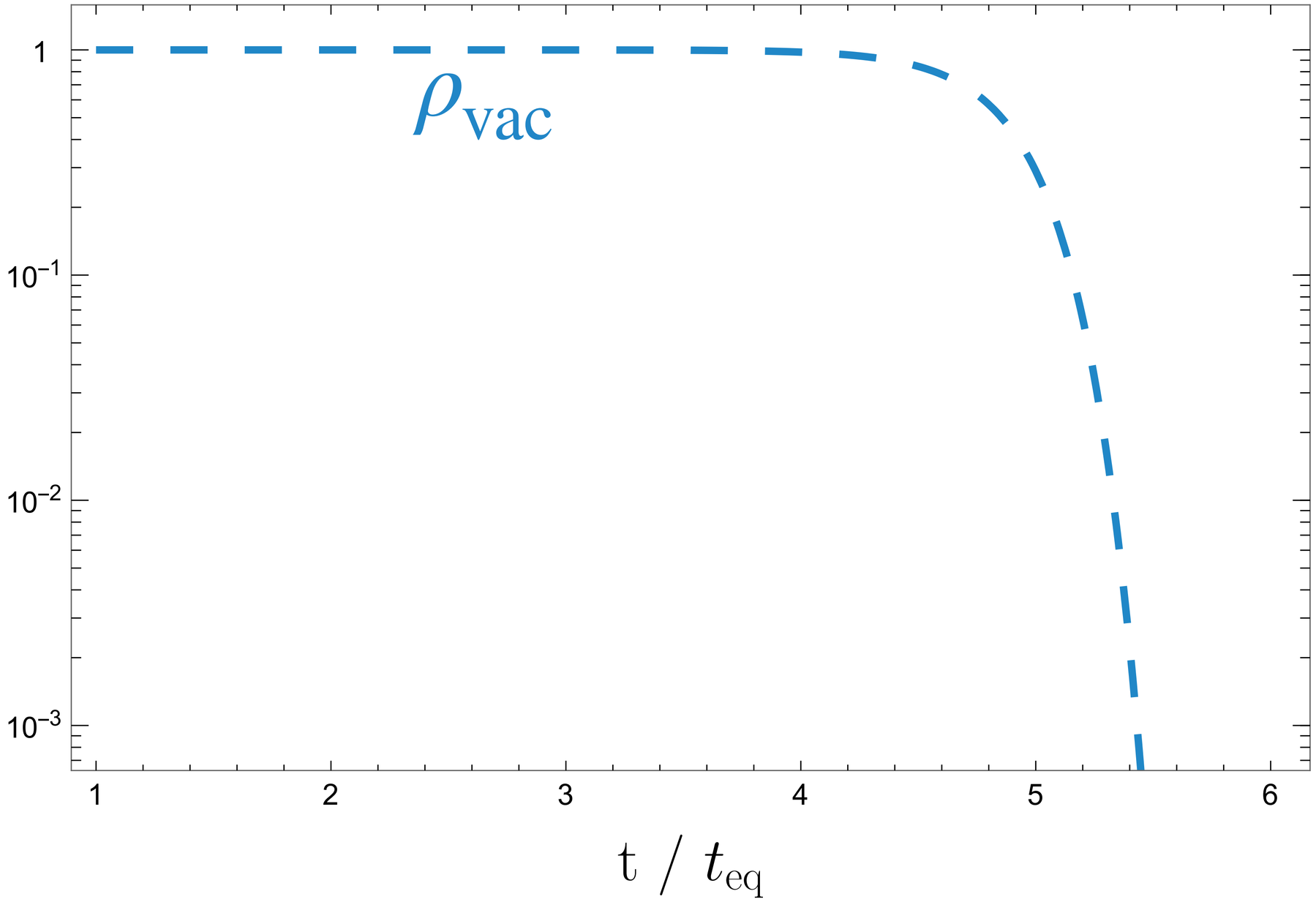
Radiation energy :

$$\dot{\rho}_{\rm R}(t;t_{n_i}) + 4H\rho_{\rm R}(t;t_{n_i}) = -\,\dot{\rho}_V(t;t_{n_i})$$

PBH formation threshold :

$$\frac{\rho_{\rm R}(t_{\rm max};t_{n_i})-\rho_{\rm R}(t_{\rm max};t_c)}{\rho_{\rm R}(t_{\rm max};t_c)} \simeq 0.45\,,$$

YG, Volansky 2305:04942



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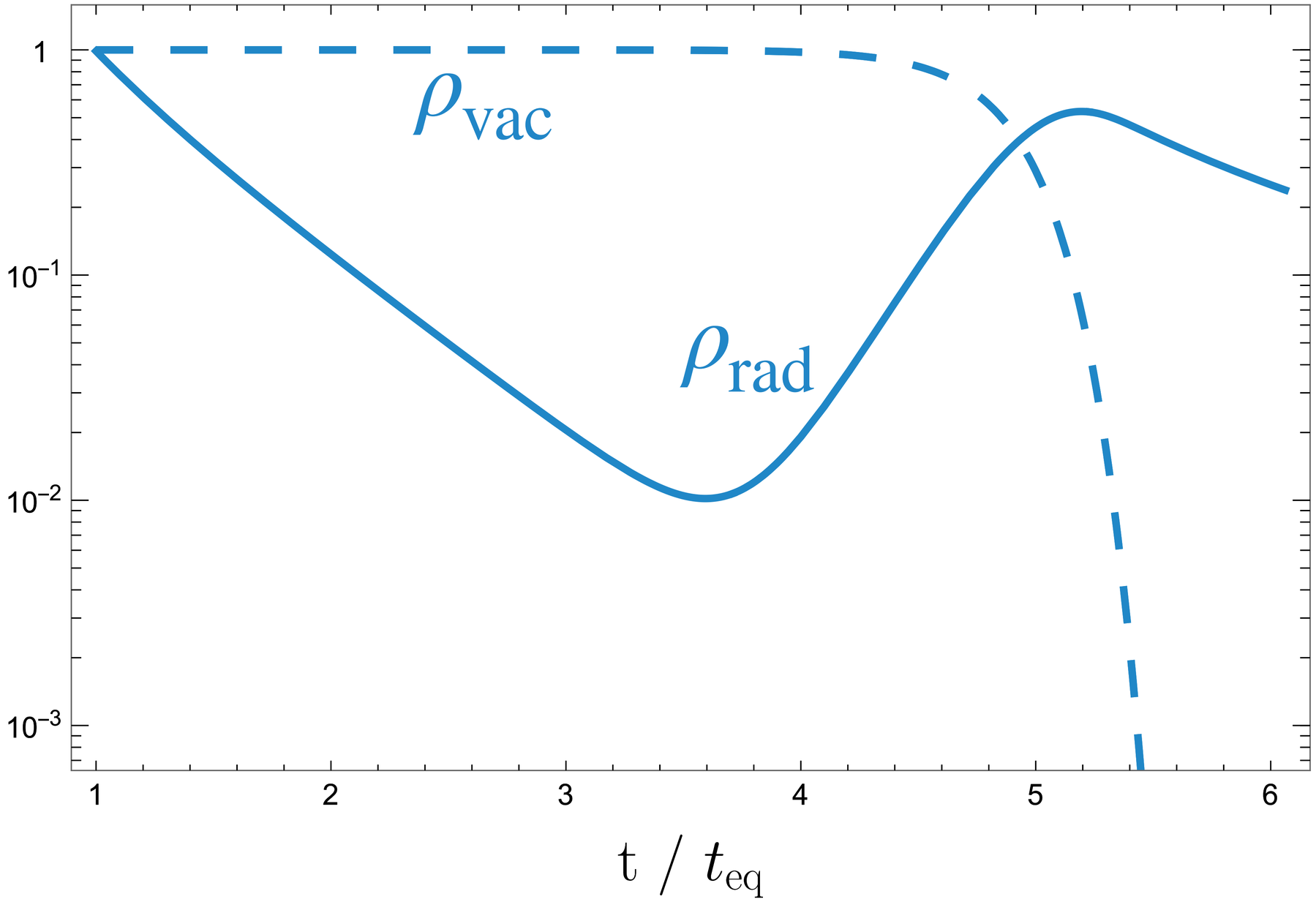

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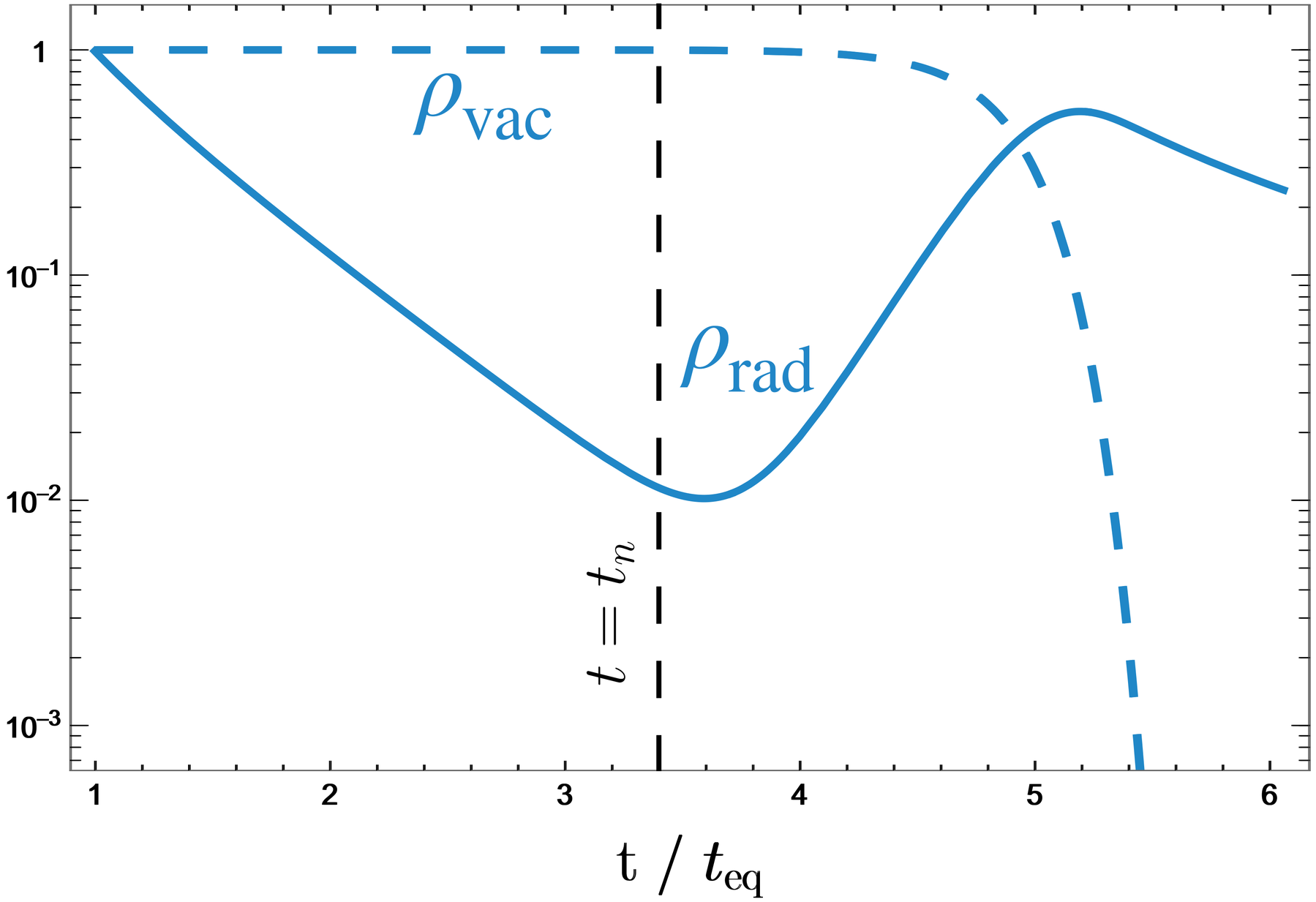

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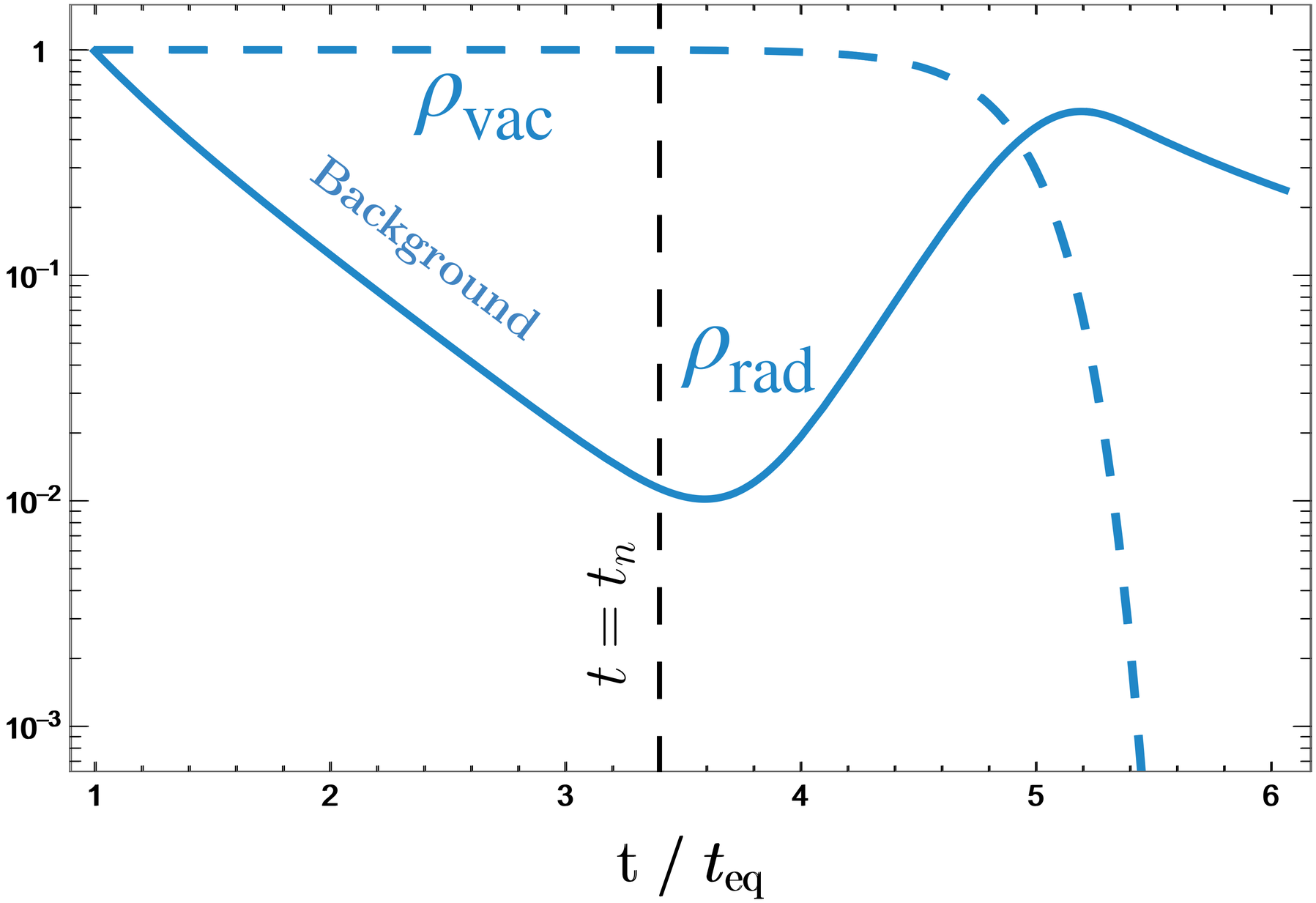

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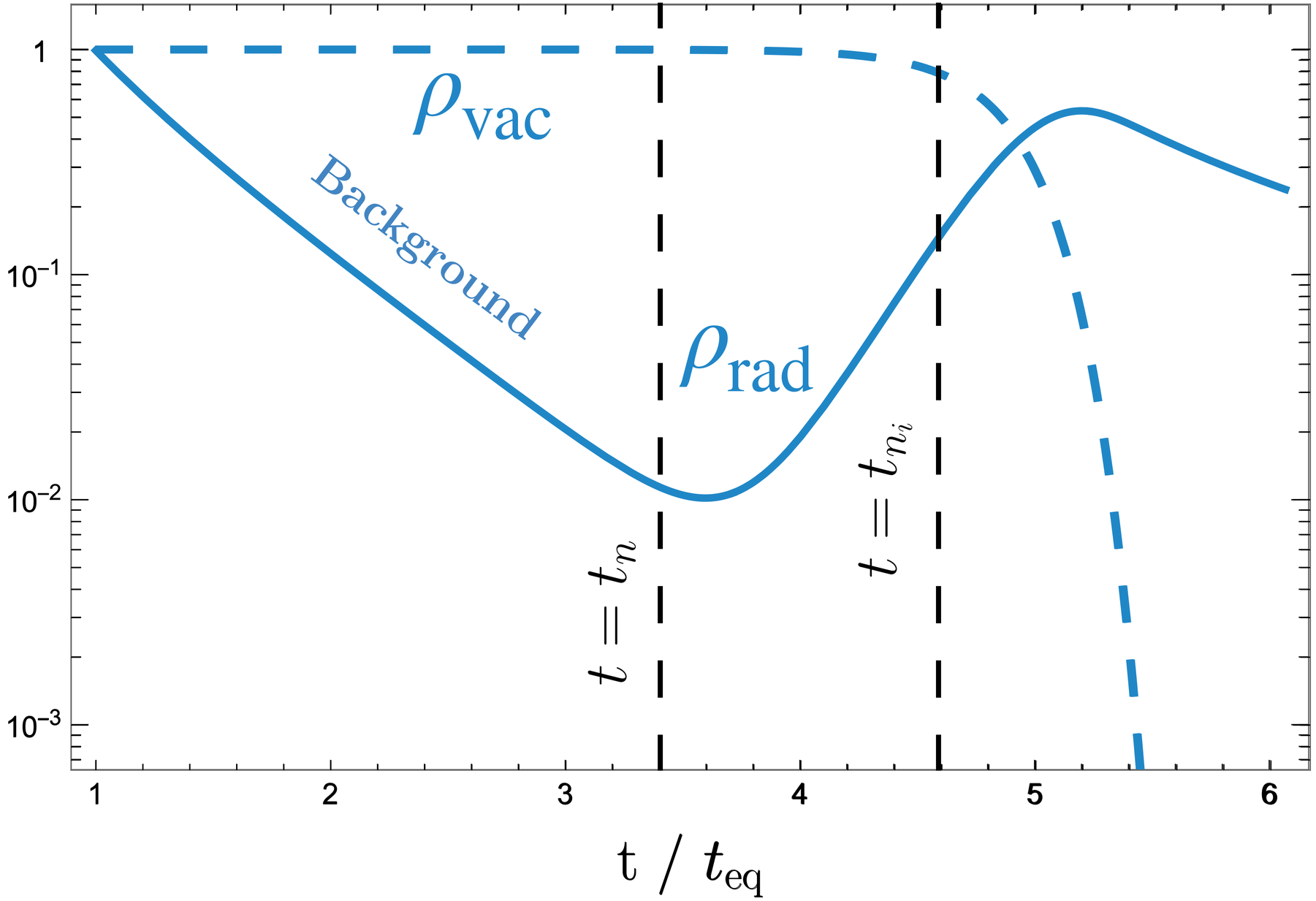

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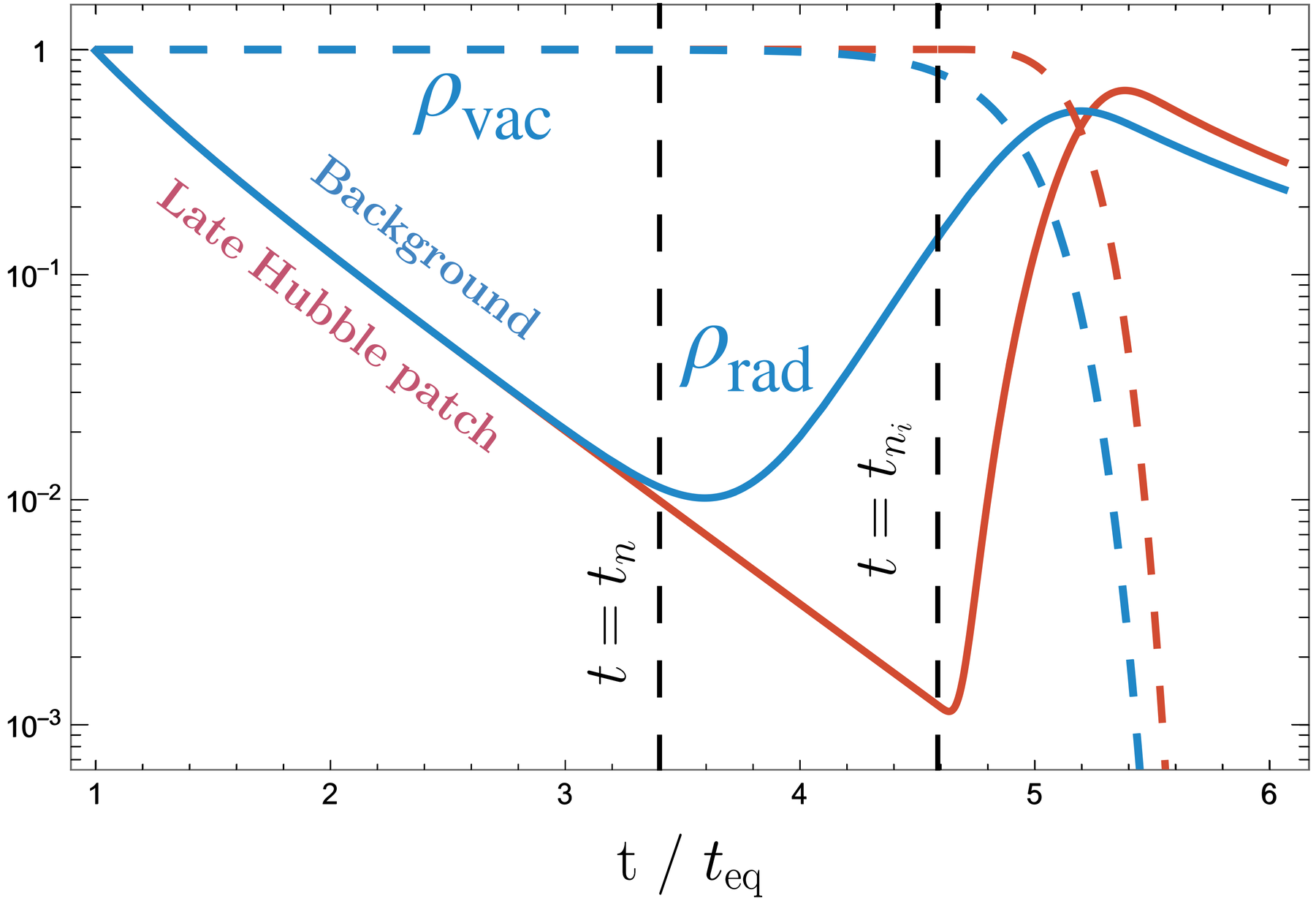

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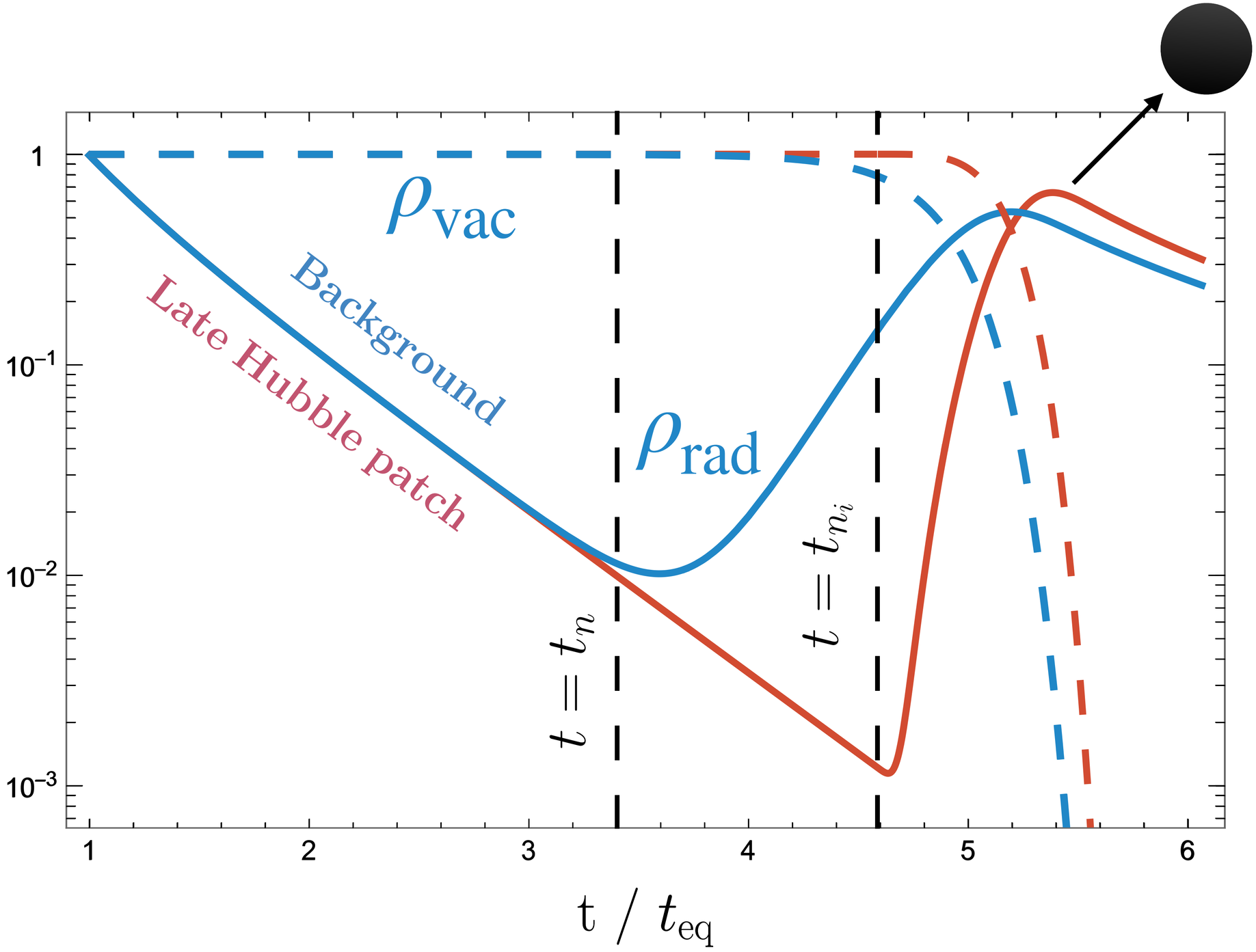

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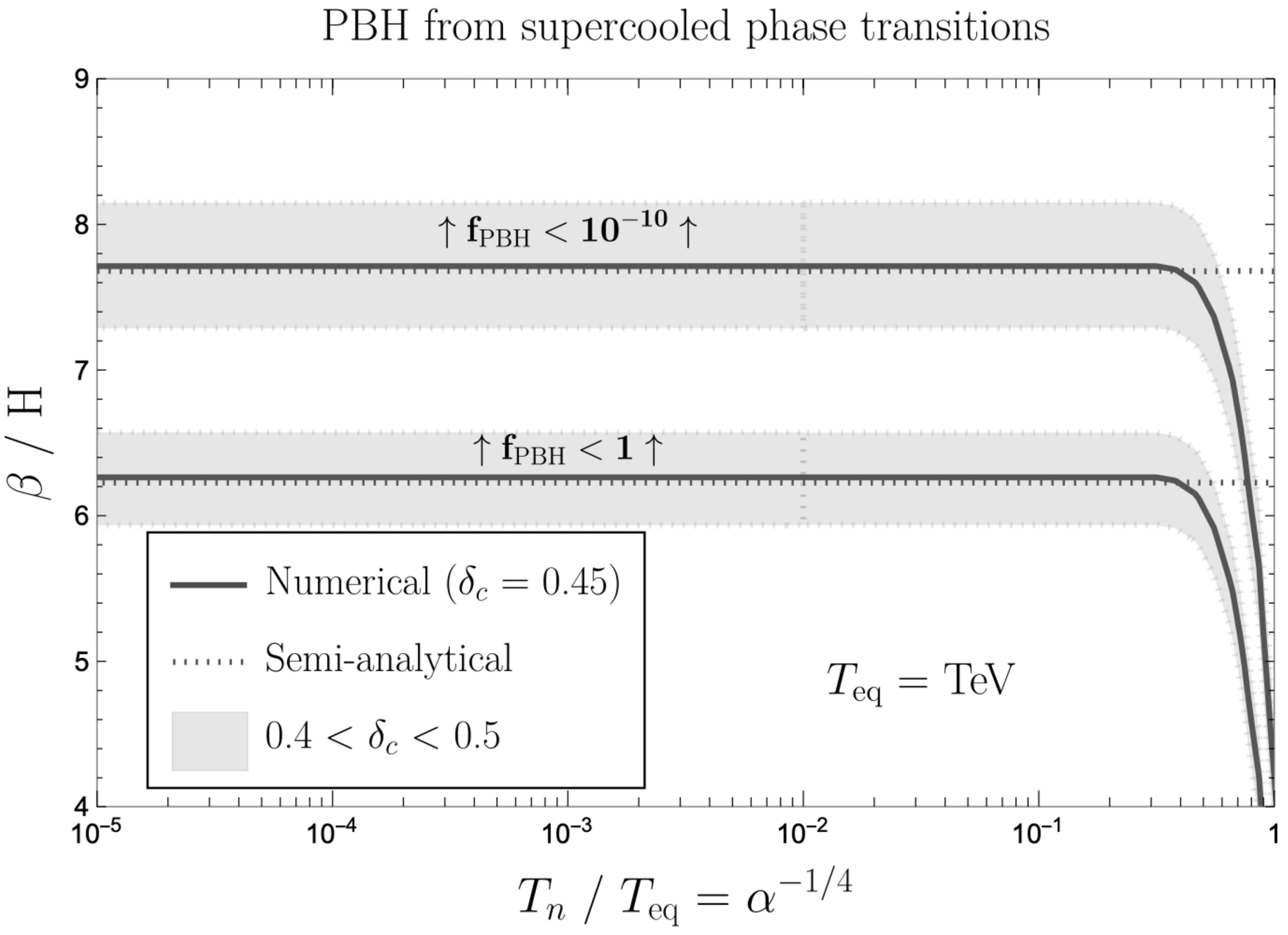
Tunneling rate :

$$\Gamma = \Gamma_0 e^{\beta t}$$

$\beta^{-1} \simeq$ PT duration

$\simeq$ bubble size



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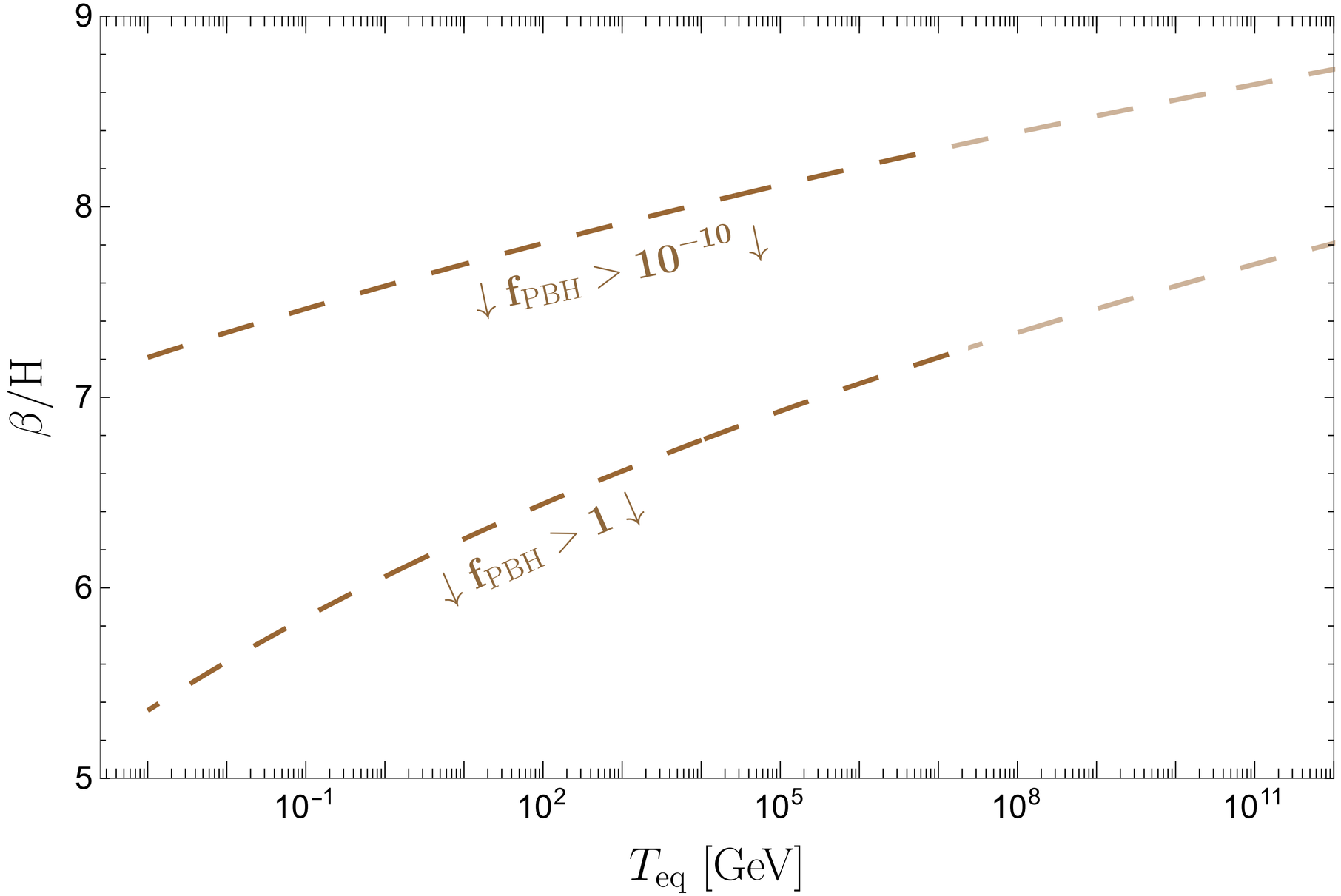

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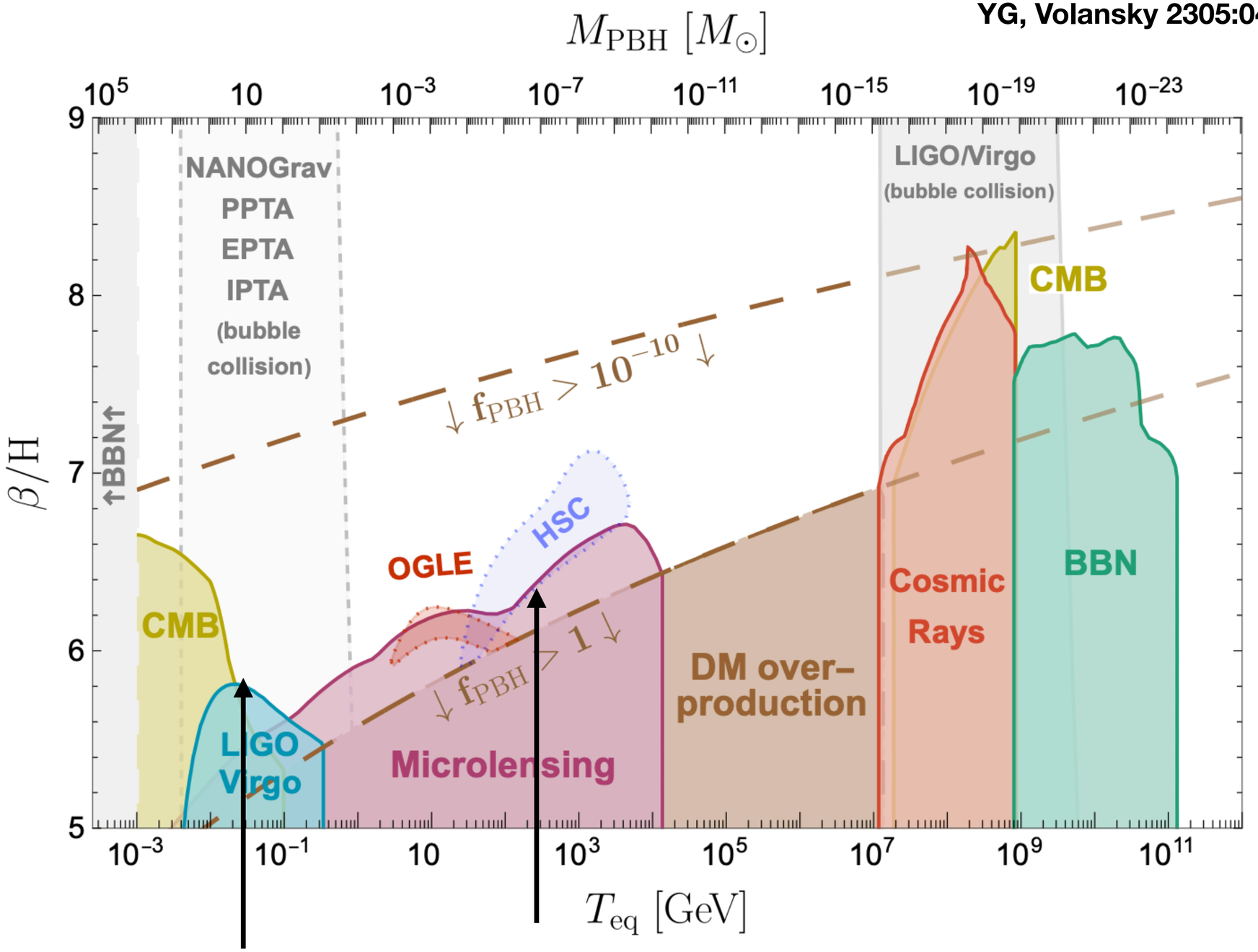
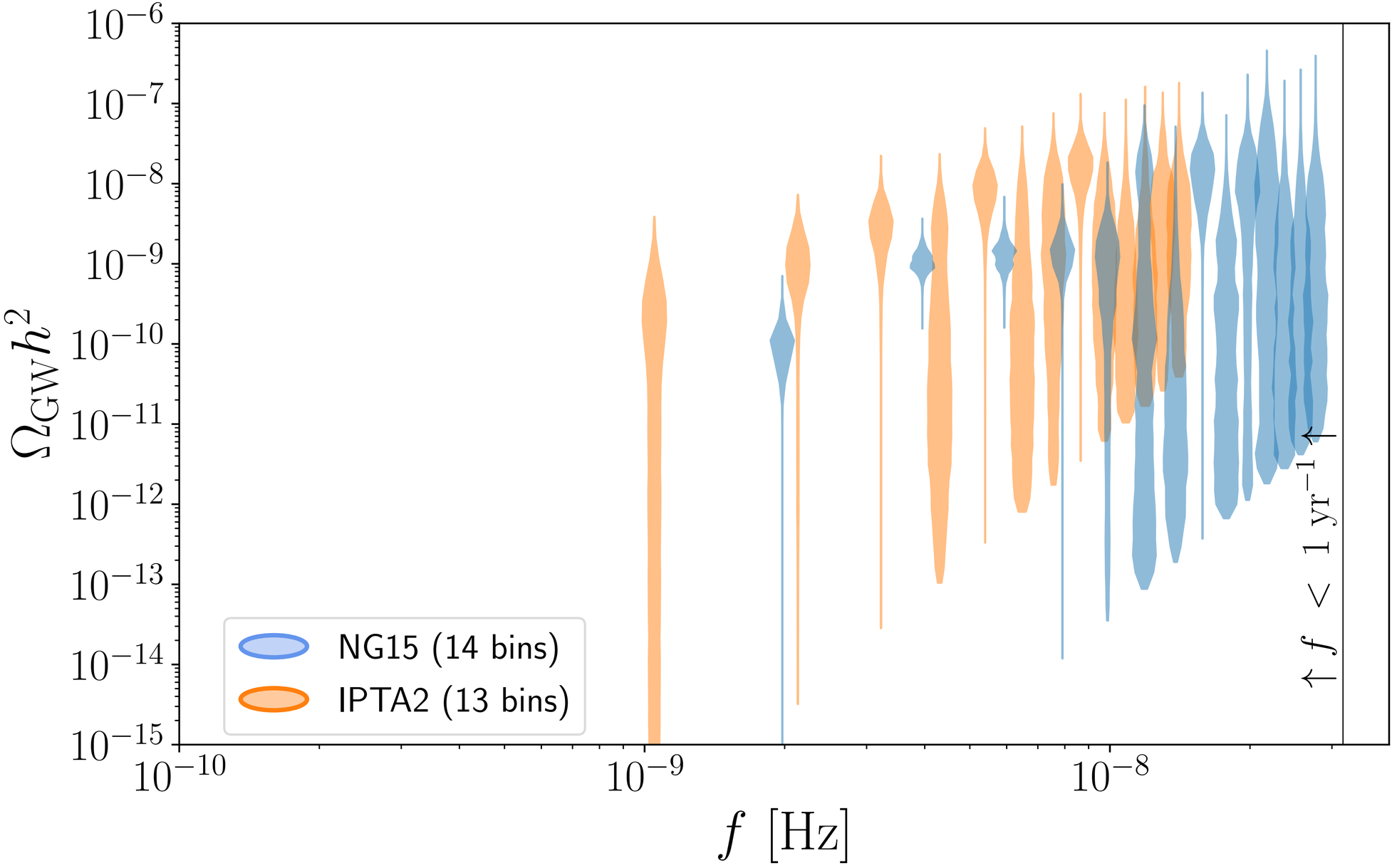
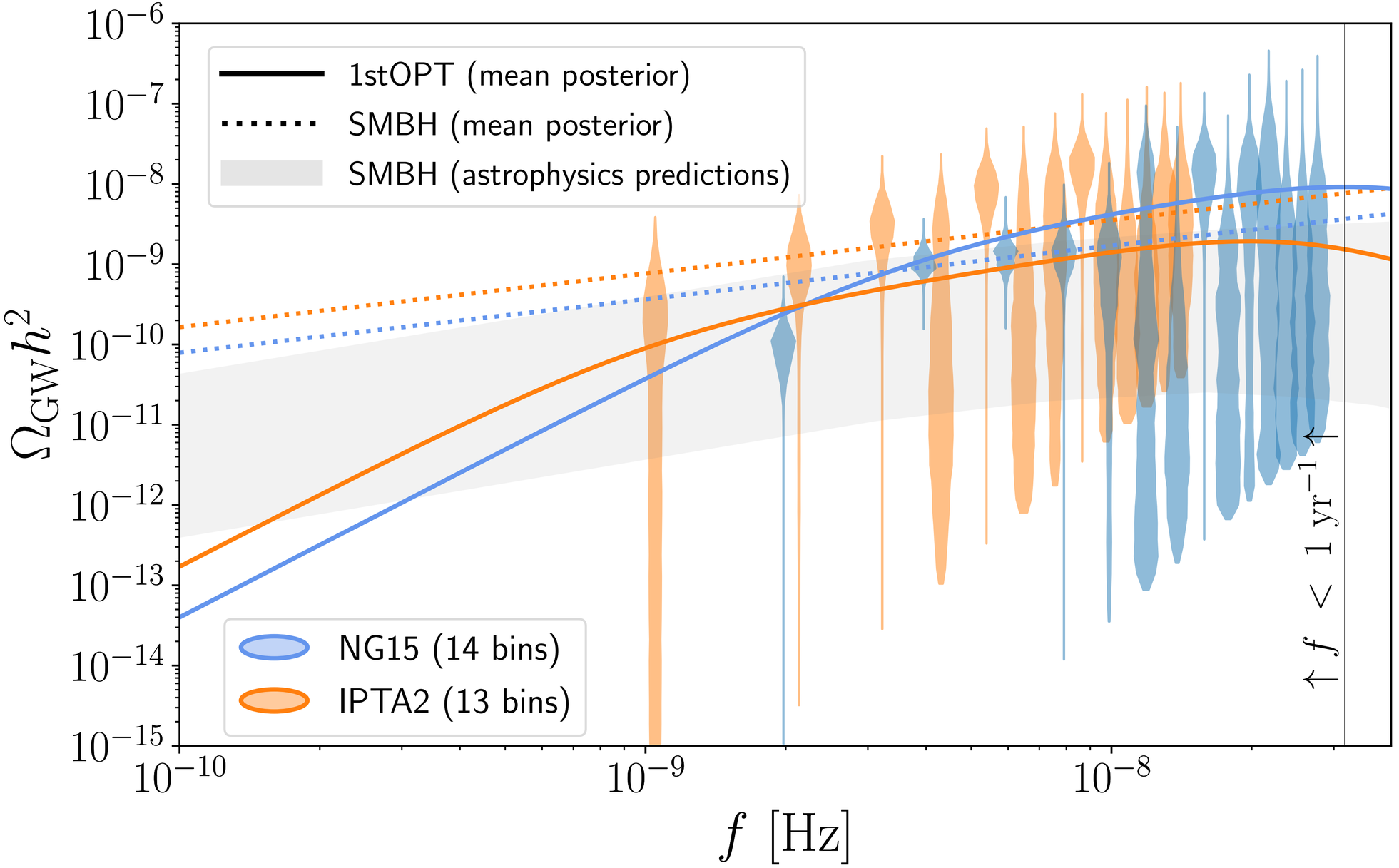


YG, 2307.04239, PRL

YG, Volansky 2310:XXXX


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]
NG15 (14 bins)
IPTA2 (13 bins)
$\uparrow f < 1\ \mathrm{yr}^{-1} \uparrow$


1stOPT (mean posterior)
SMBH (mean posterior)
SMBH (astrophysics predictions)
NG15 (14 bins)
IPTA2 (13 bins)
$\uparrow f < 1\ \mathrm{yr}^{-1} \uparrow$
$\Omega_{\mathrm{GW}} h^2$
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10^{-6}
10^{-7}
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10^{-13}
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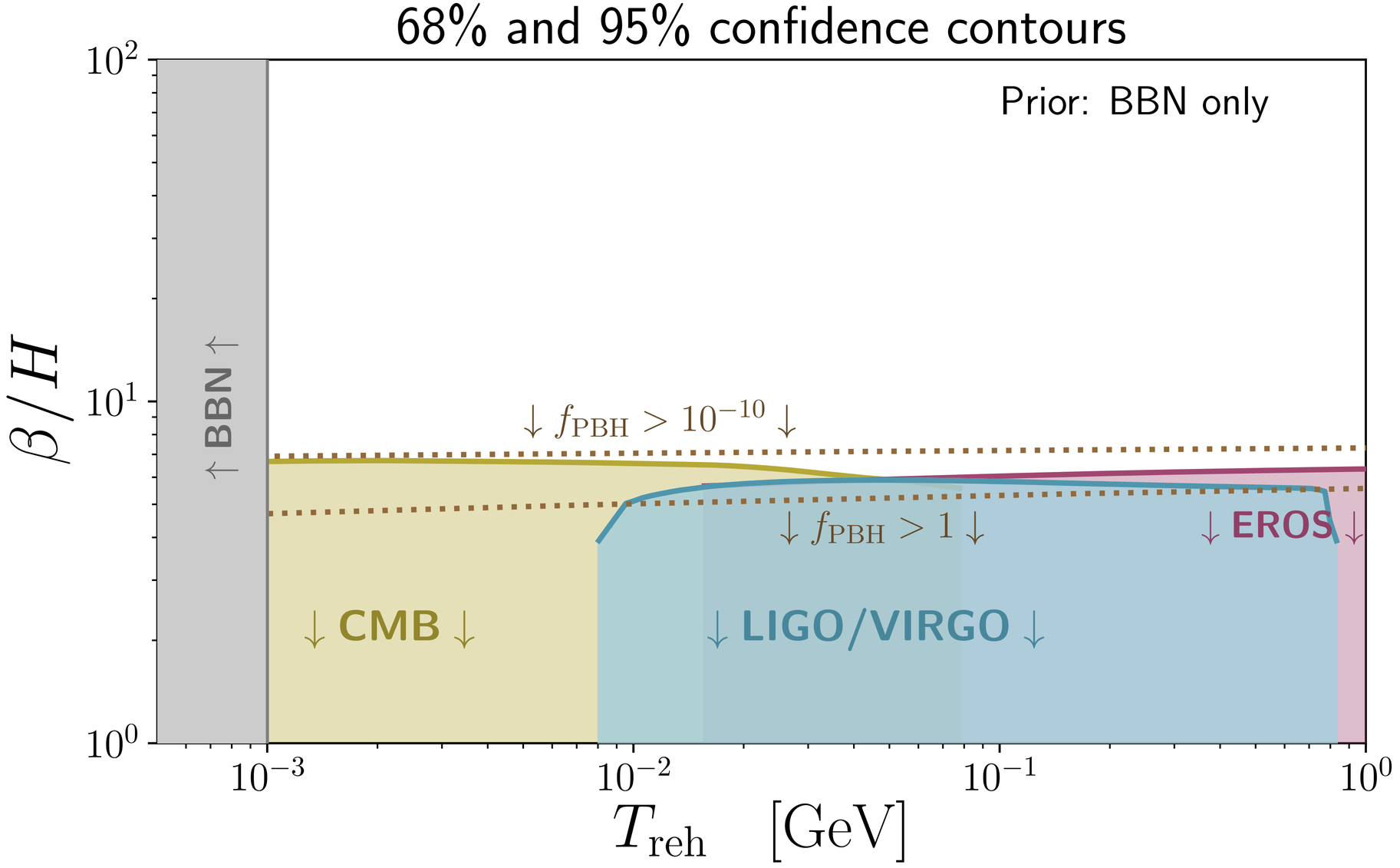

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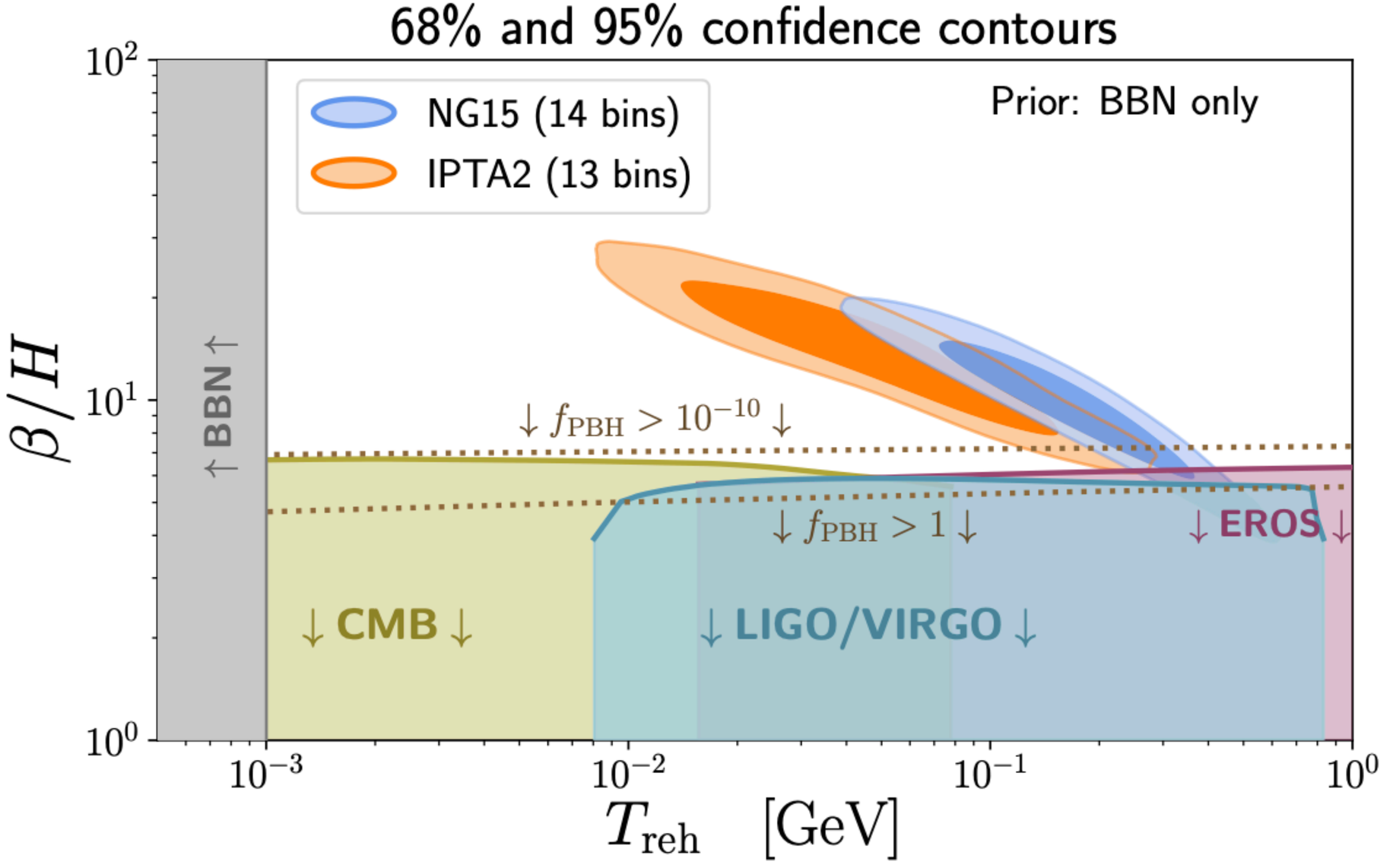

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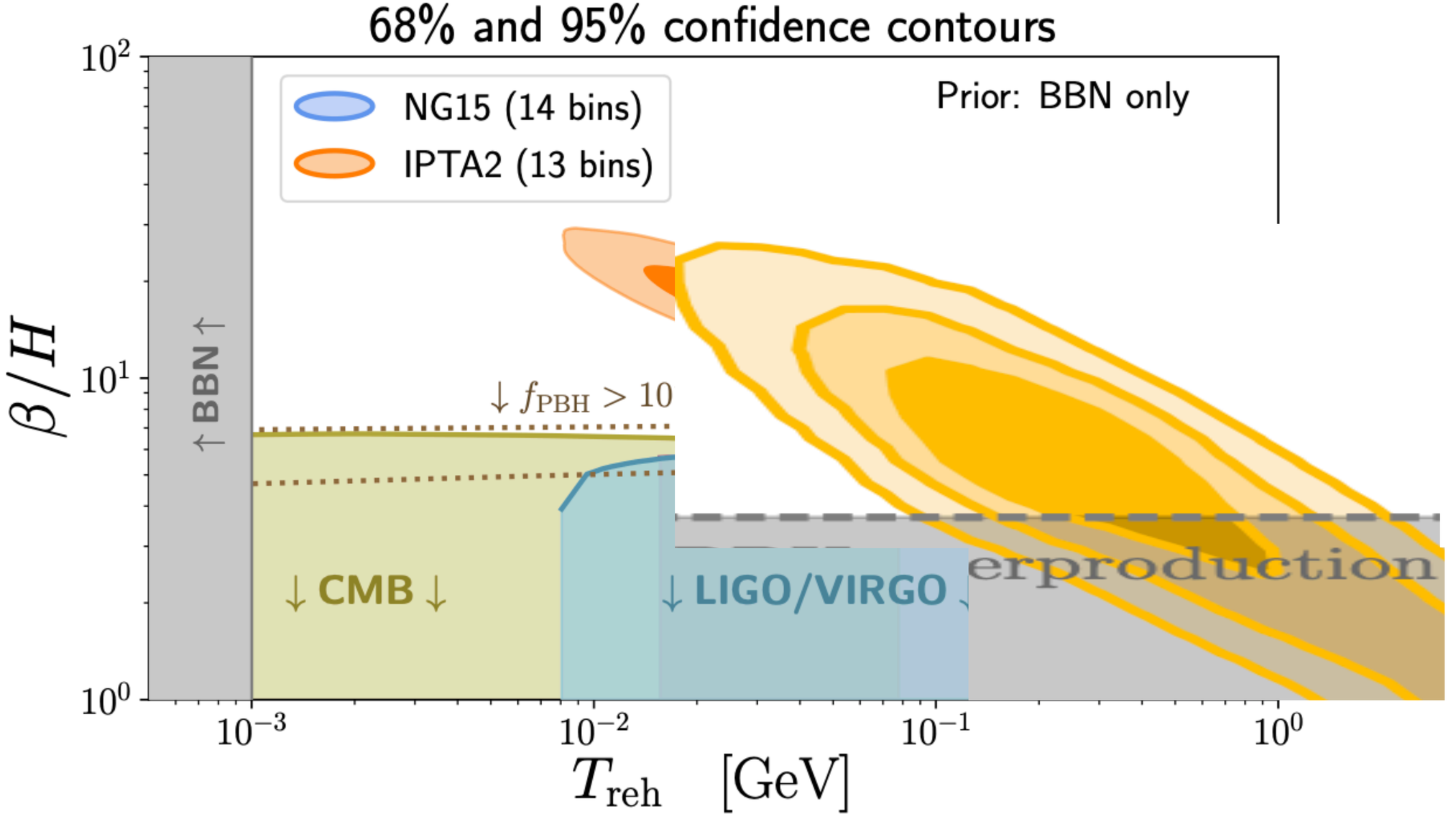
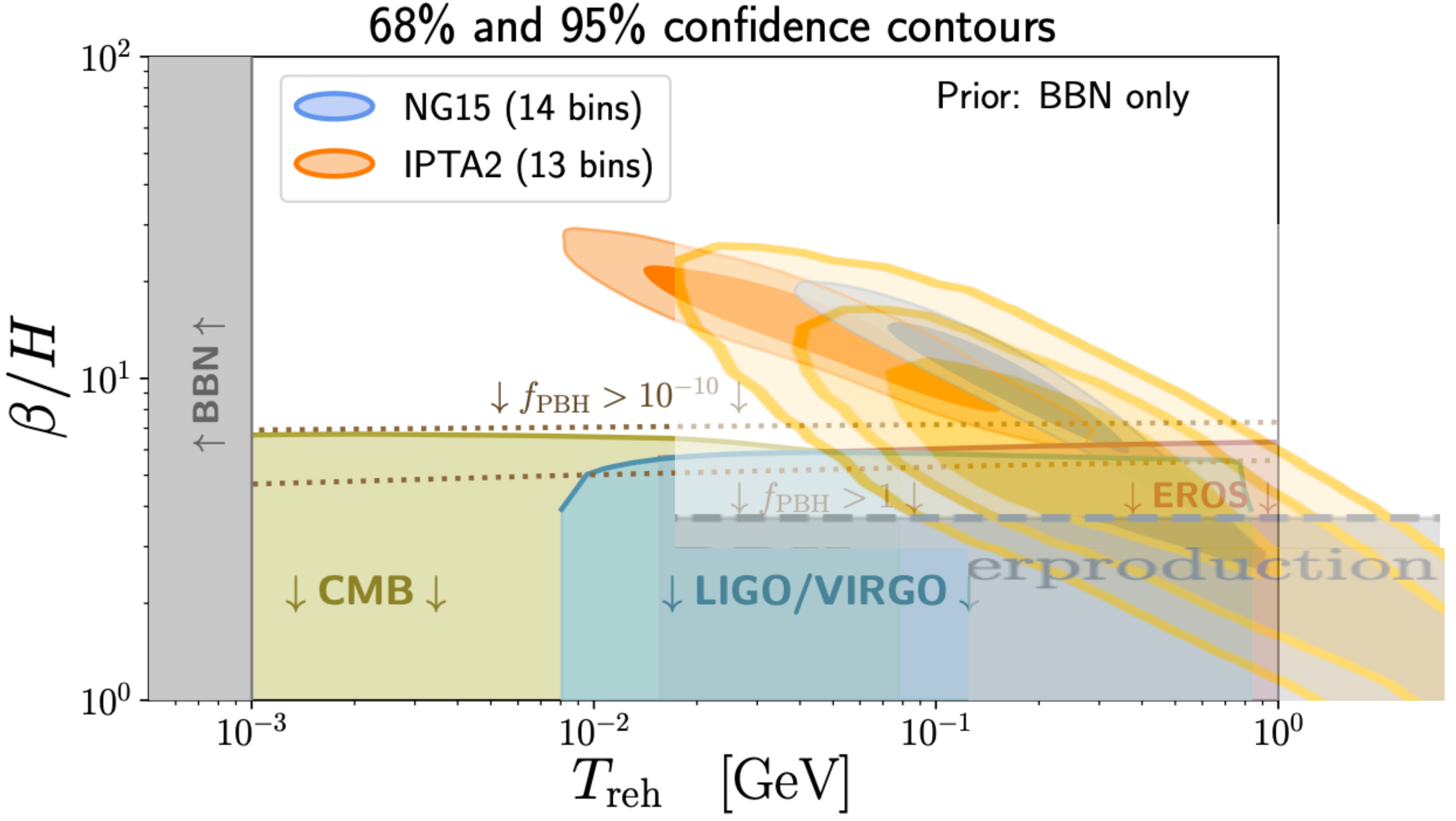


Ellis+, What is the source of the PTA GW signal?, 2308.08546

YG, 2307.04239, PRL



Ellis+, What is the source of the PTA GW signal?, 2308.08546

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YG, Vitagliano, 2306.17841, v2 to appear