Dark Matter, Black Holes and Phase Transitions

Michael J. Baker

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1912.02830 (PRL) - MJB, J. Kopp, A. Long
2105.07481 - MJB, M. Breitbach, J. Kopp, L. Mittnacht
2110.00005 - MJB, M. Breitbach, J. Kopp, L. Mittnacht

THE UNIVERSITY OF MELBOURNE

Outline

- Introduction I

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  - a new DM production mechanism

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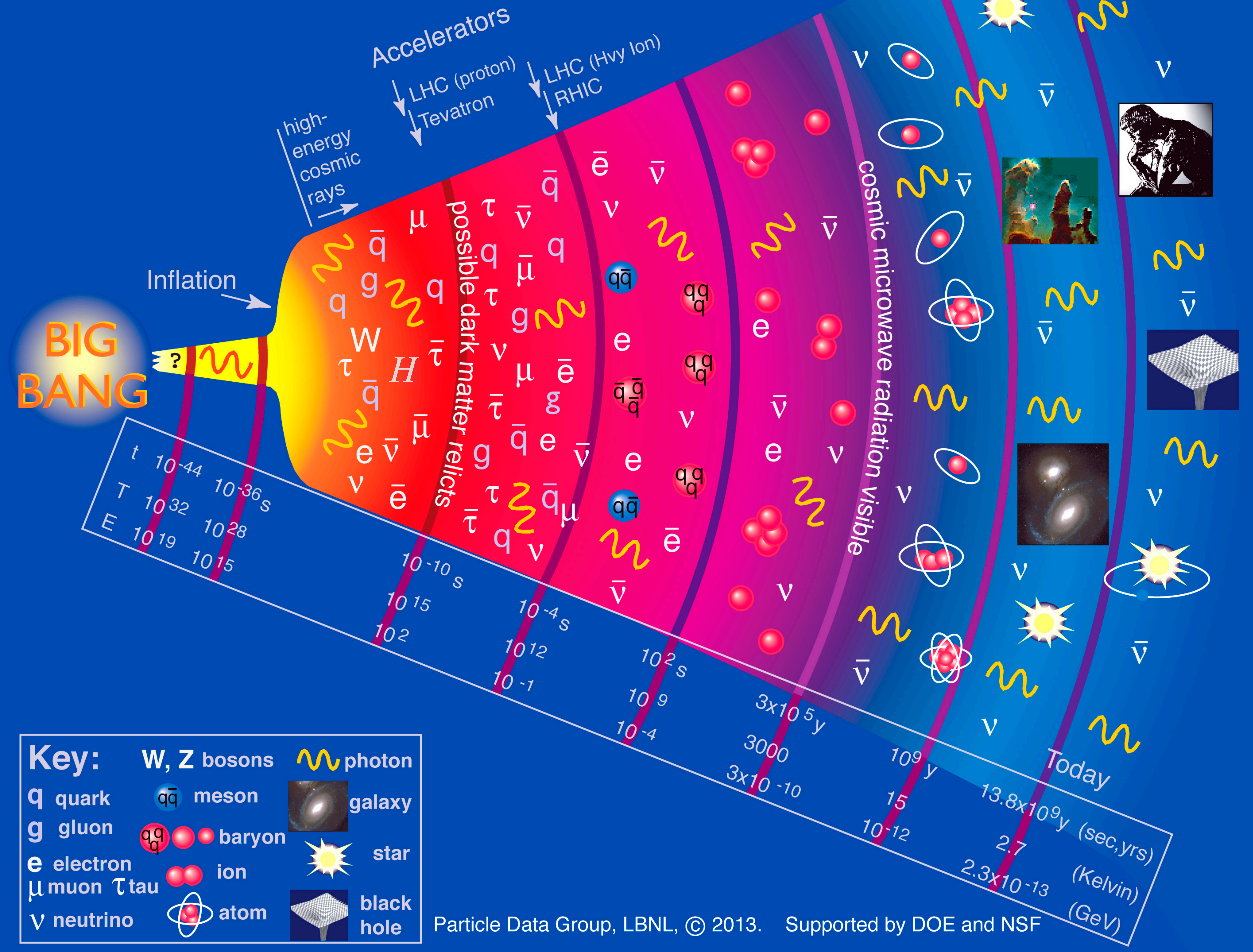
Introduction

History of the Universe



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$$\Omega_{\rm DM}h^2 \overset{\rm f.o.}{\sim} \frac{1}{\langle \sigma v \rangle} \overset{\rm p.w.}{\gtrsim} \frac{1}{\left(\frac{4\pi}{m_{\rm DM}^2 v_{\rm rel}}\right)} \implies m_{\rm DM} \lesssim 300 \ {\rm TeV}$$

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- We present a new mechanism which has a large viable parameter space and goes beyond the GK bound

Filtered Dark Matter at a First Order Phase Transition

Toy Model

$$\mathcal{L} \supset -y_\chi \phi \bar{\chi} \chi - \beta \, \phi^2 H^\dagger H - V(\phi)$$

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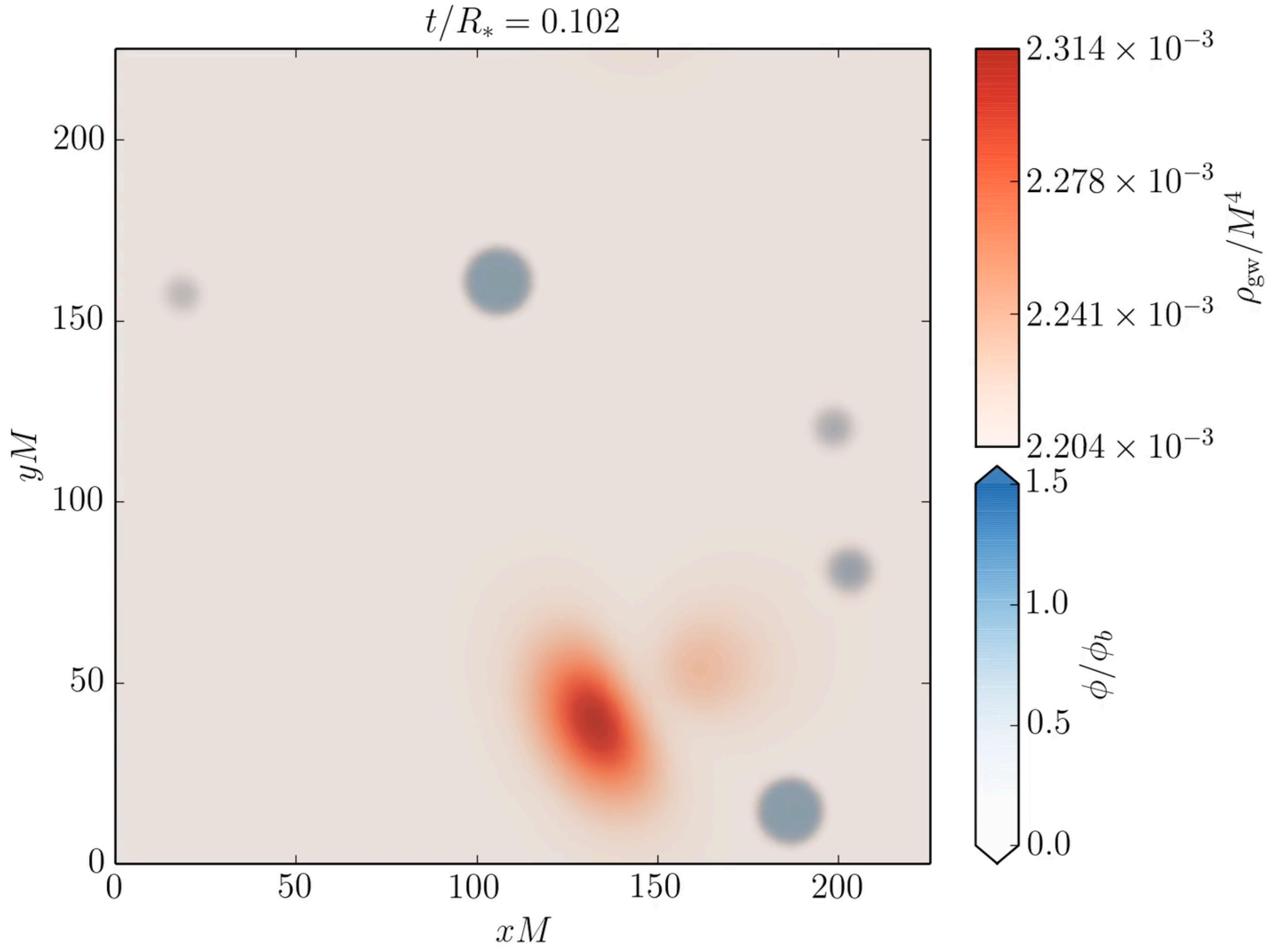
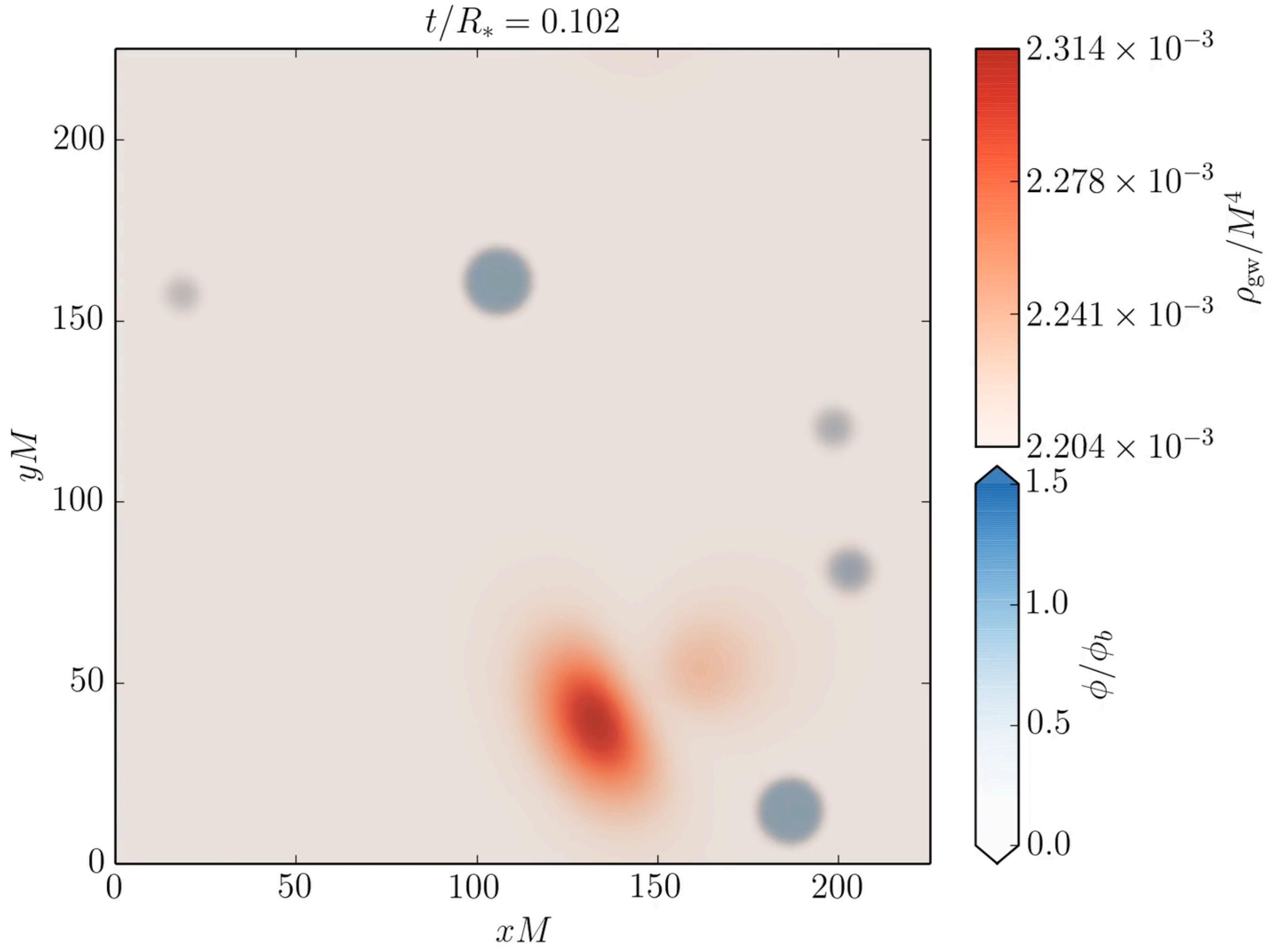
$$-y_\chi \phi \bar{\chi}\chi \overset{\text{PT}}{\to} -y_\chi \langle\phi\rangle \bar{\chi}\chi = -m_\chi \bar{\chi}\chi$$



https://vimeo.com/255031420 - Cosmic Defects - Gravitational waves from a cosmological vacuum phase transition - scalar field value

Phase Transitions



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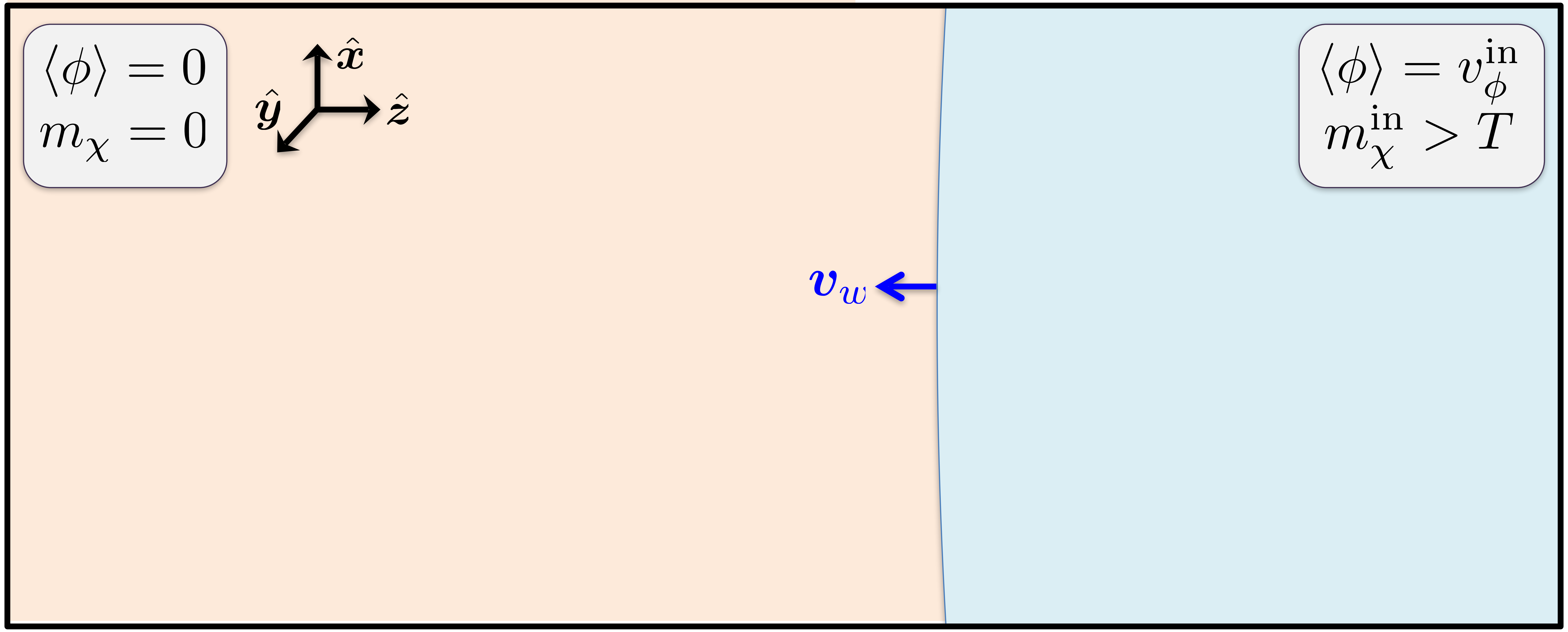

$\langle\phi\rangle = 0$
$m_\chi = 0$
$\hat{\boldsymbol{x}}$
$\hat{\boldsymbol{y}}$
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$\boldsymbol{v}_w$
$\langle\phi\rangle = v_\phi^{\text{in}}$
$m_\chi^{\text{in}} > T$

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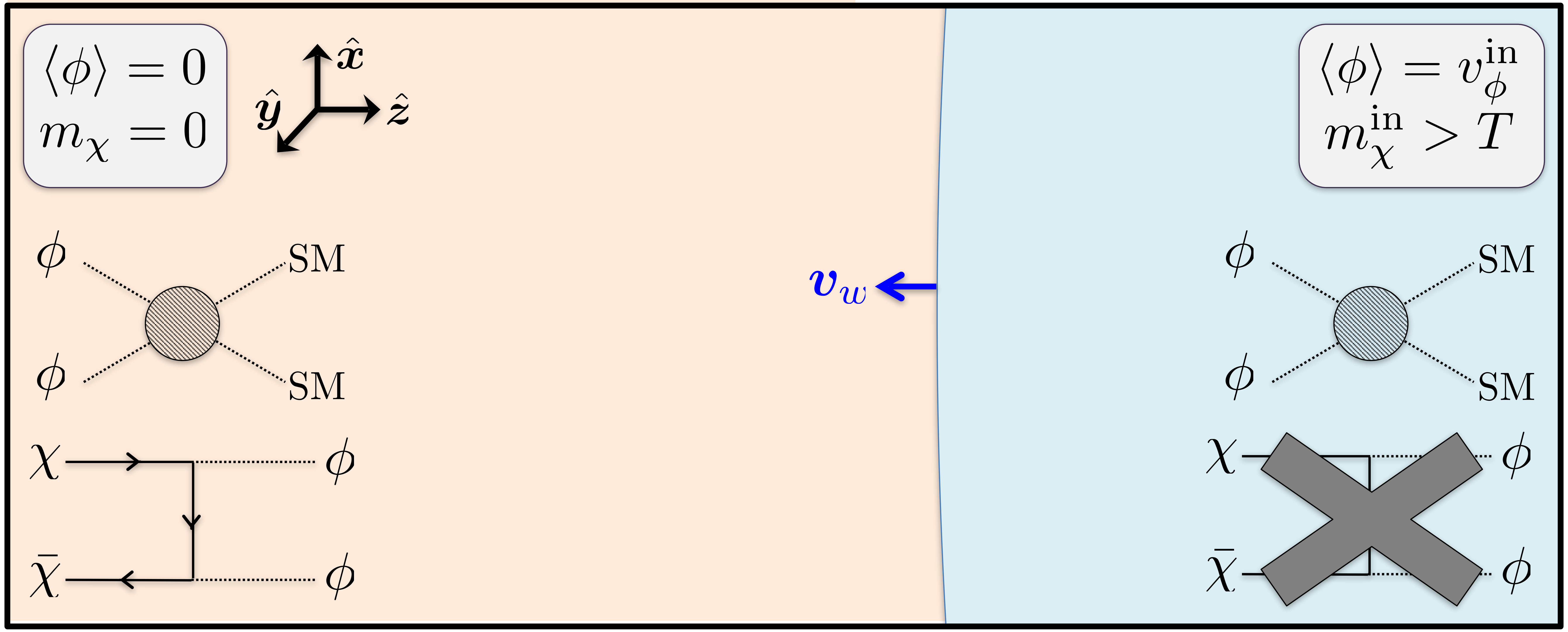

In massless phase, DM in thermal equilibrium, orders of magnitude too much DM

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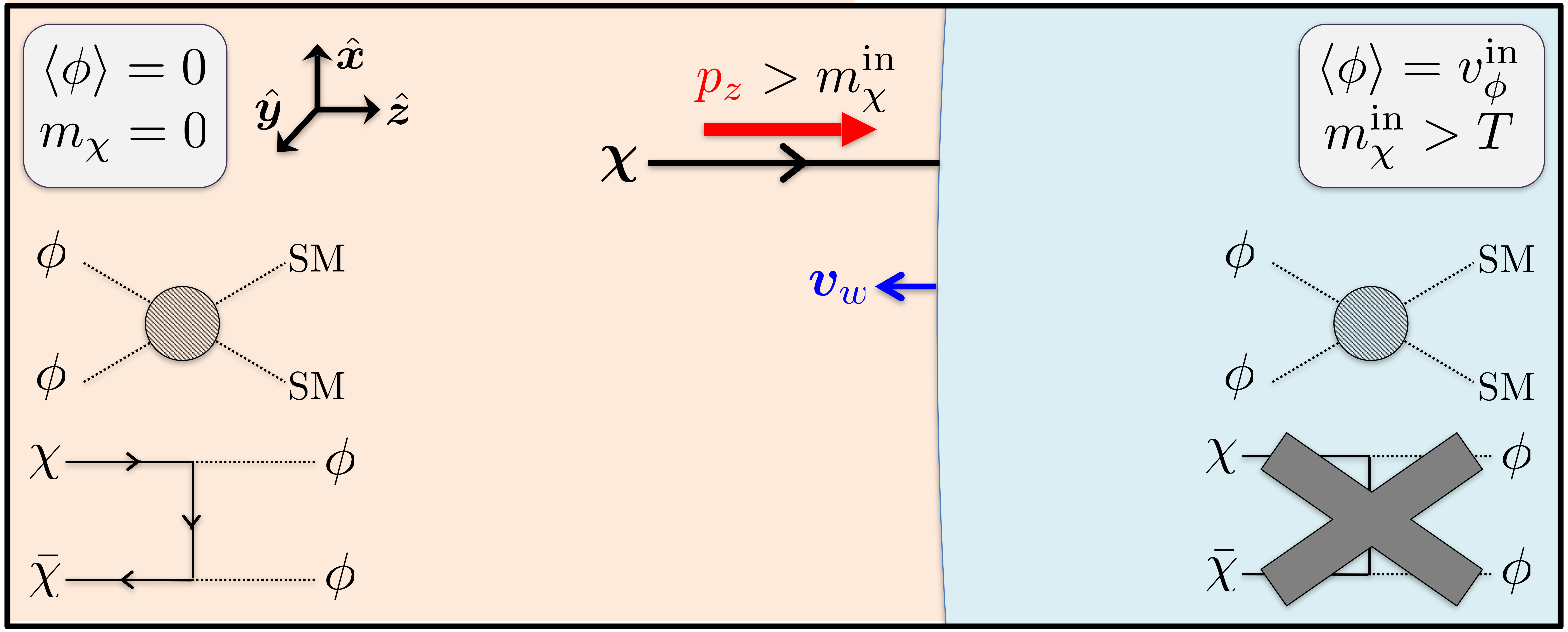

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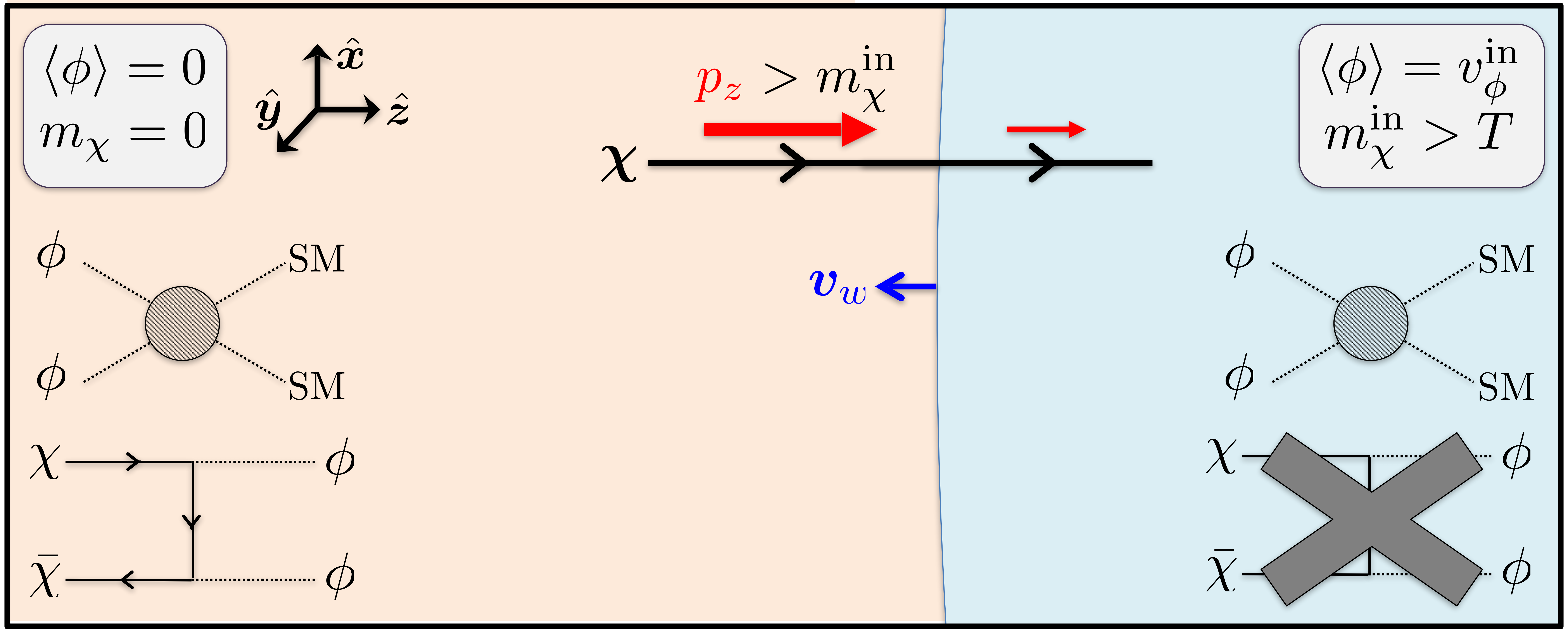

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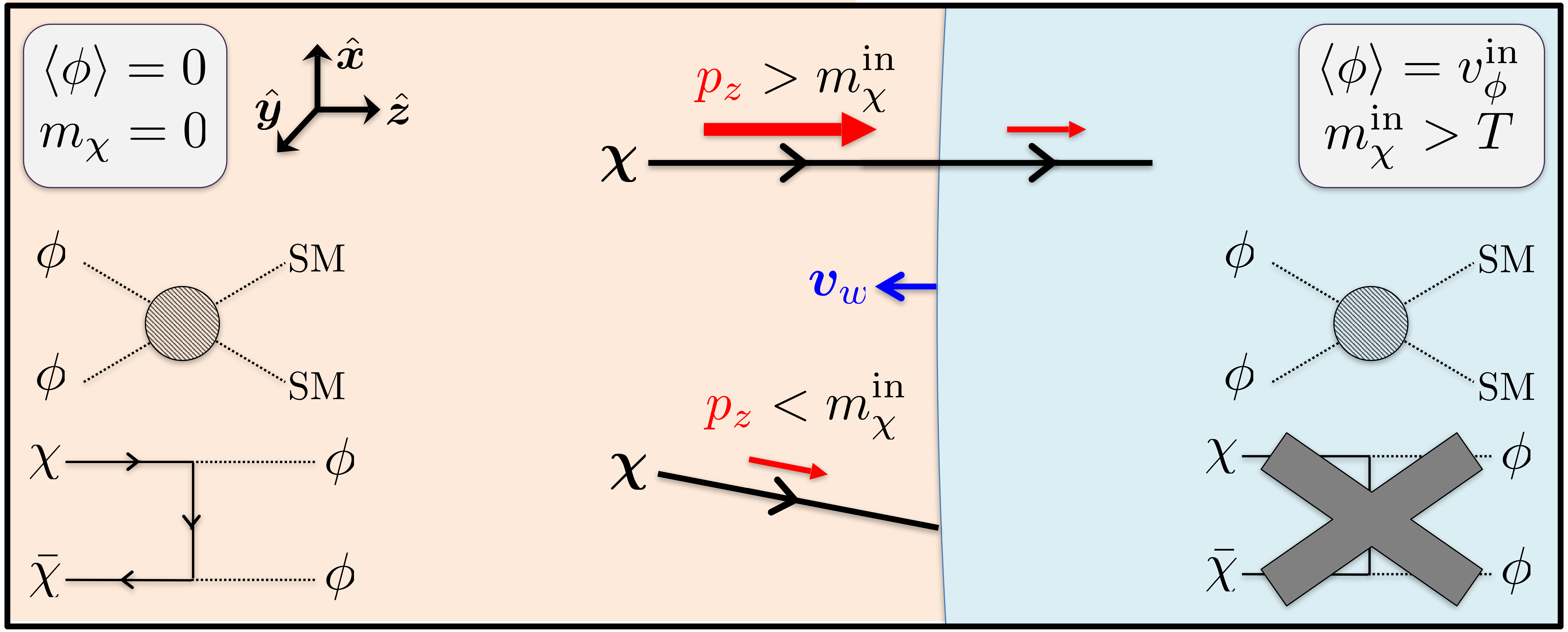

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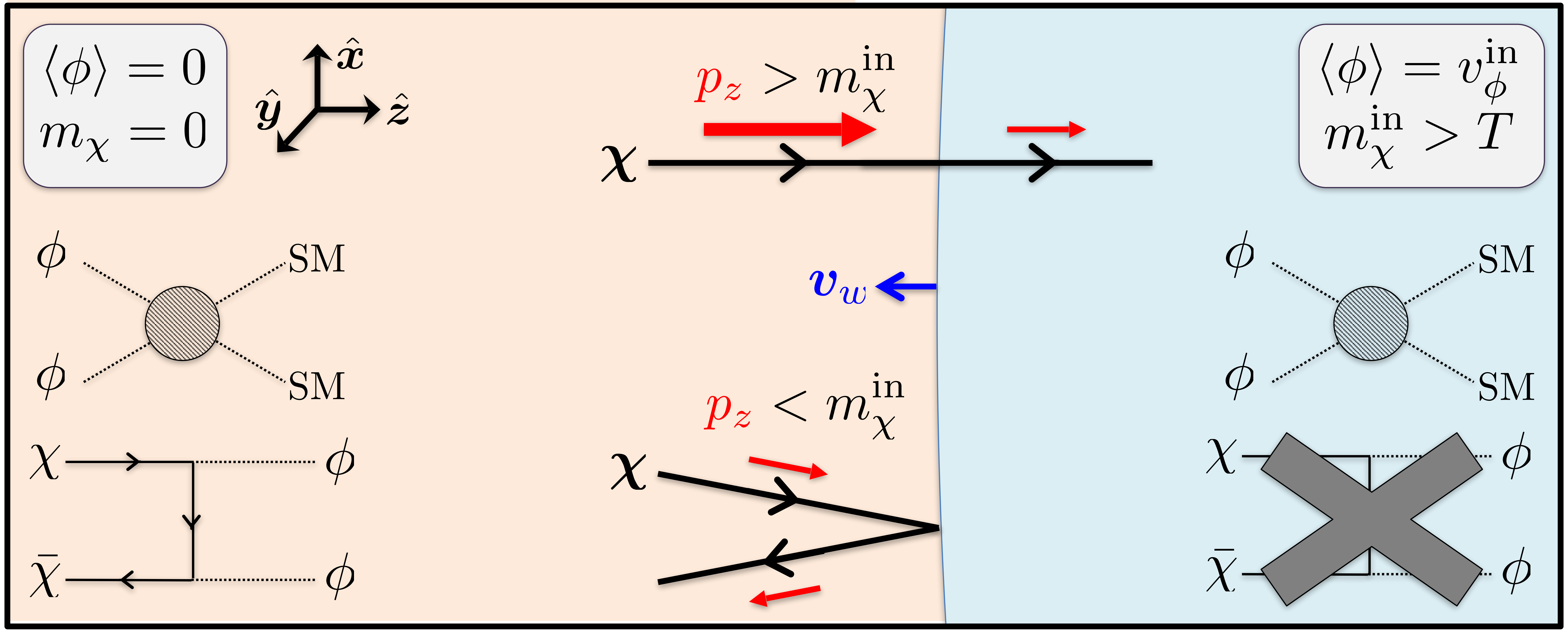

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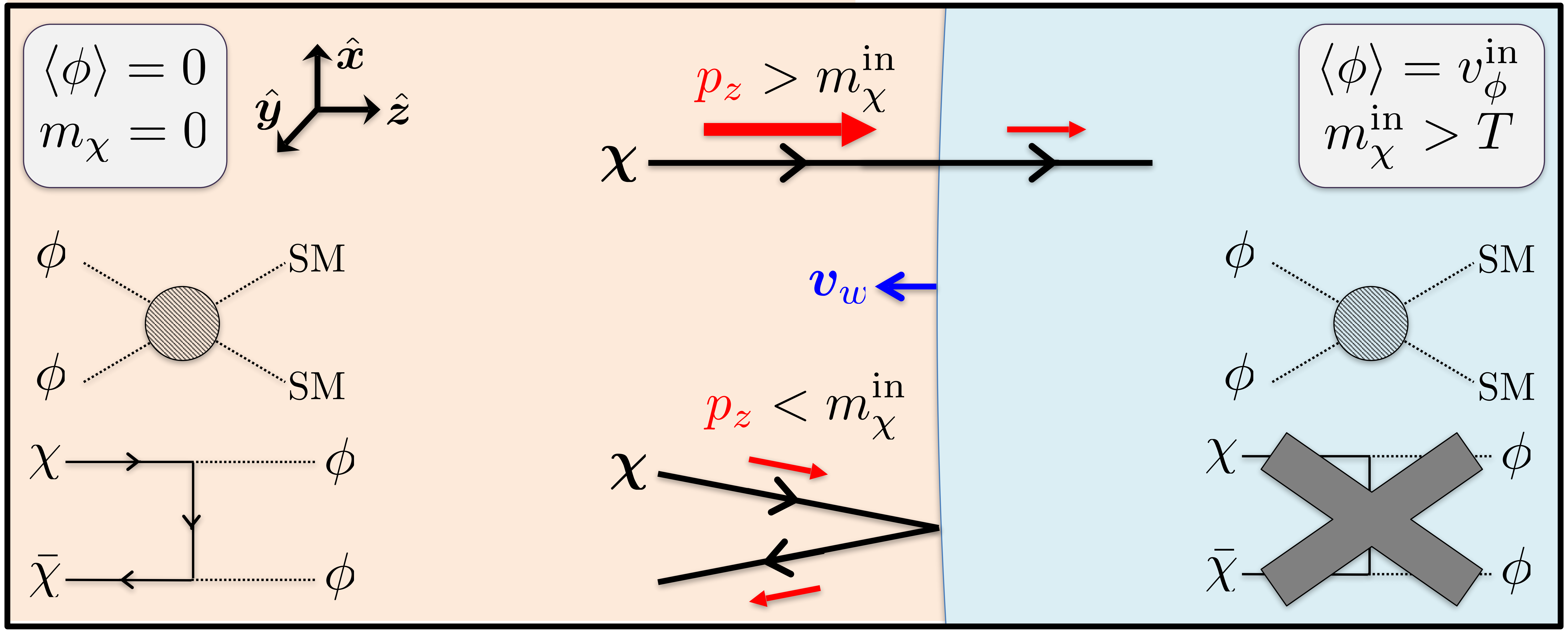

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Only high momentum DM pass through bubble wall and survive, reduces abundance

Numerical Calculation

Numerically solve Boltzmann equation $\mathbf{L}[f_\chi] = \mathbf{C}[f_\chi]$

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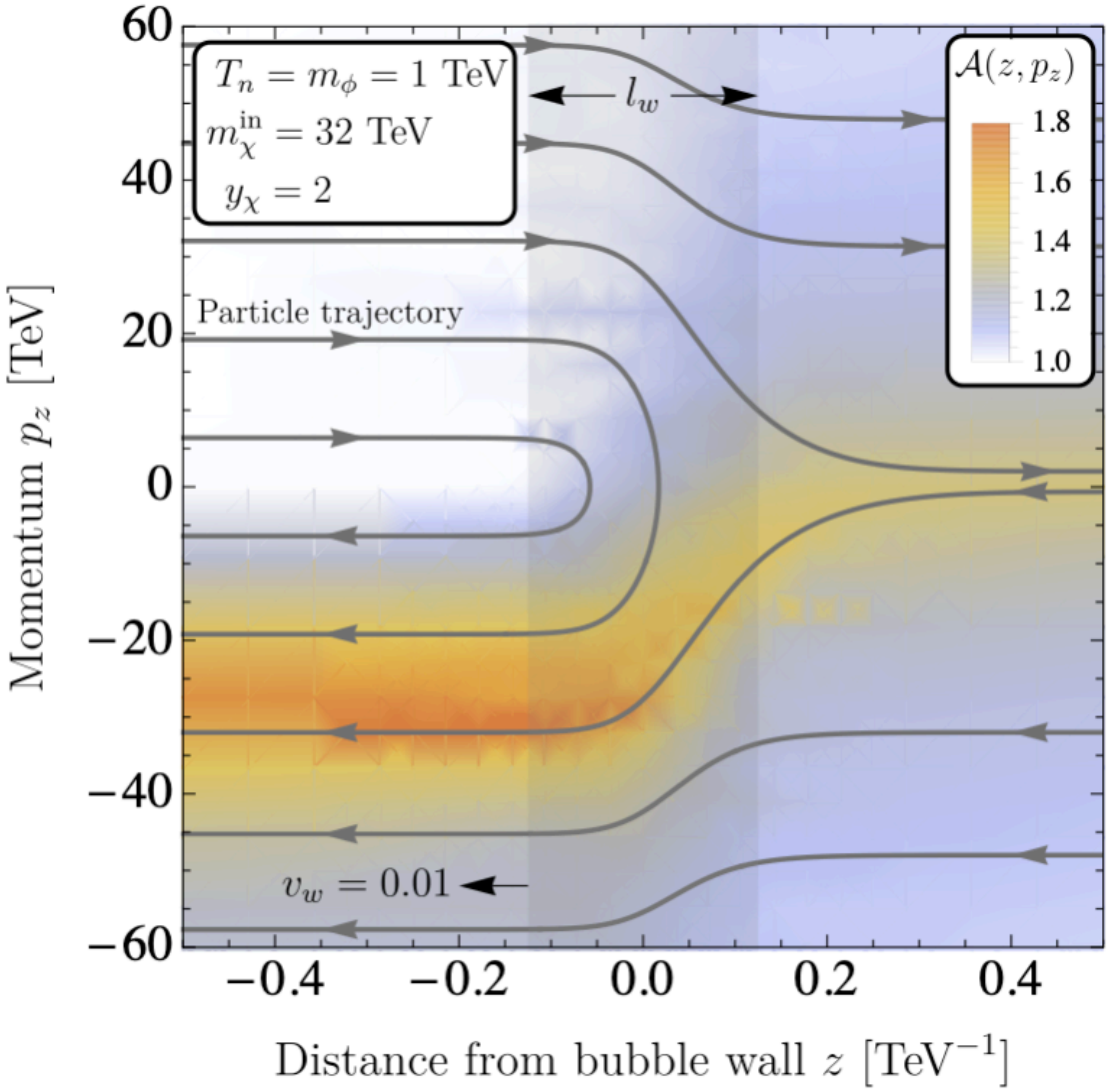
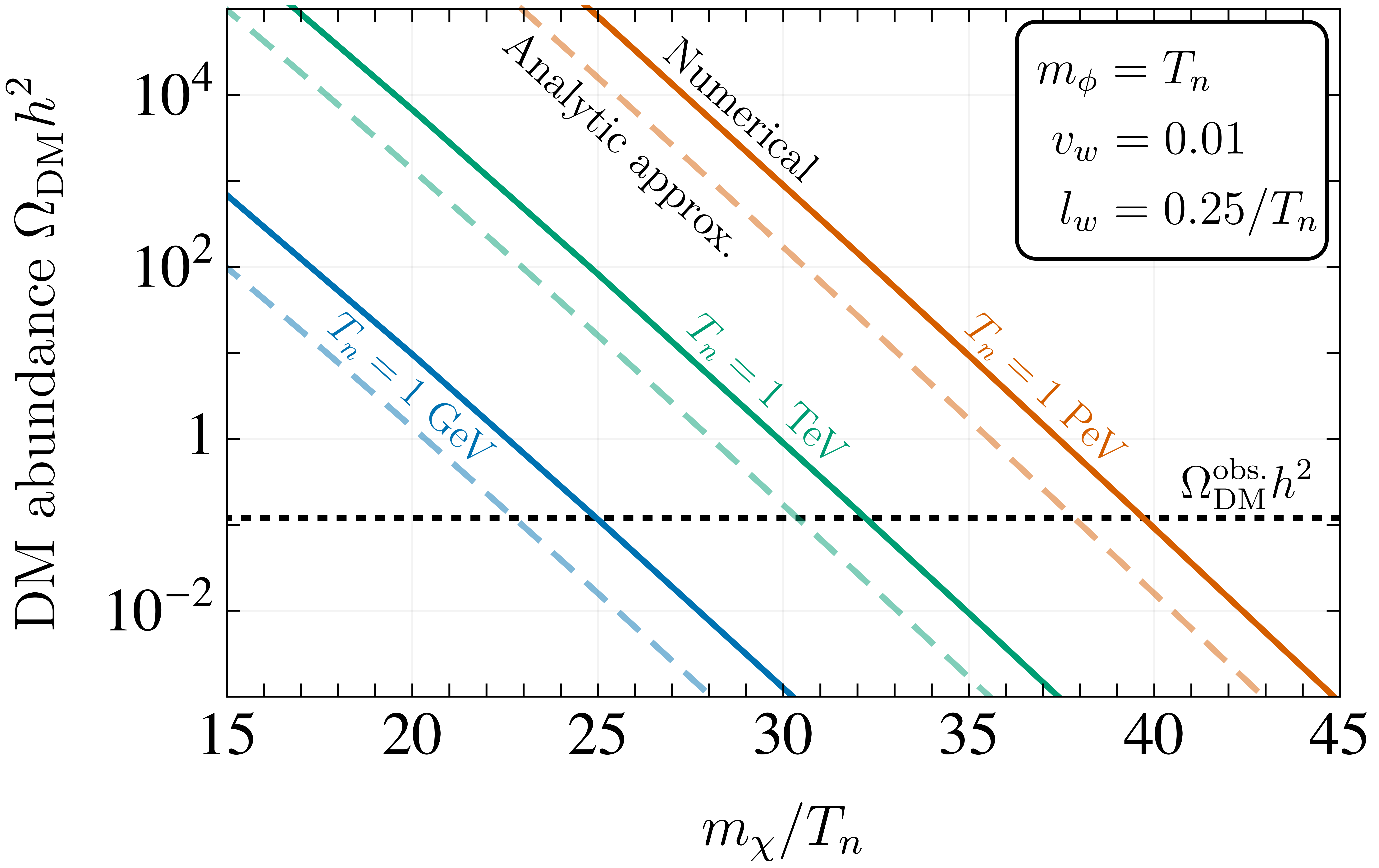
We leave z-momentum un-integrated, and look for steady state solution near bubble wall

$$g_\chi \int \frac{dp_x dp_y}{(2\pi)^2} \mathbf{L}[f_\chi] = g_\chi \int \frac{dp_x dp_y}{(2\pi)^2} \mathbf{C}[f_\chi]$$

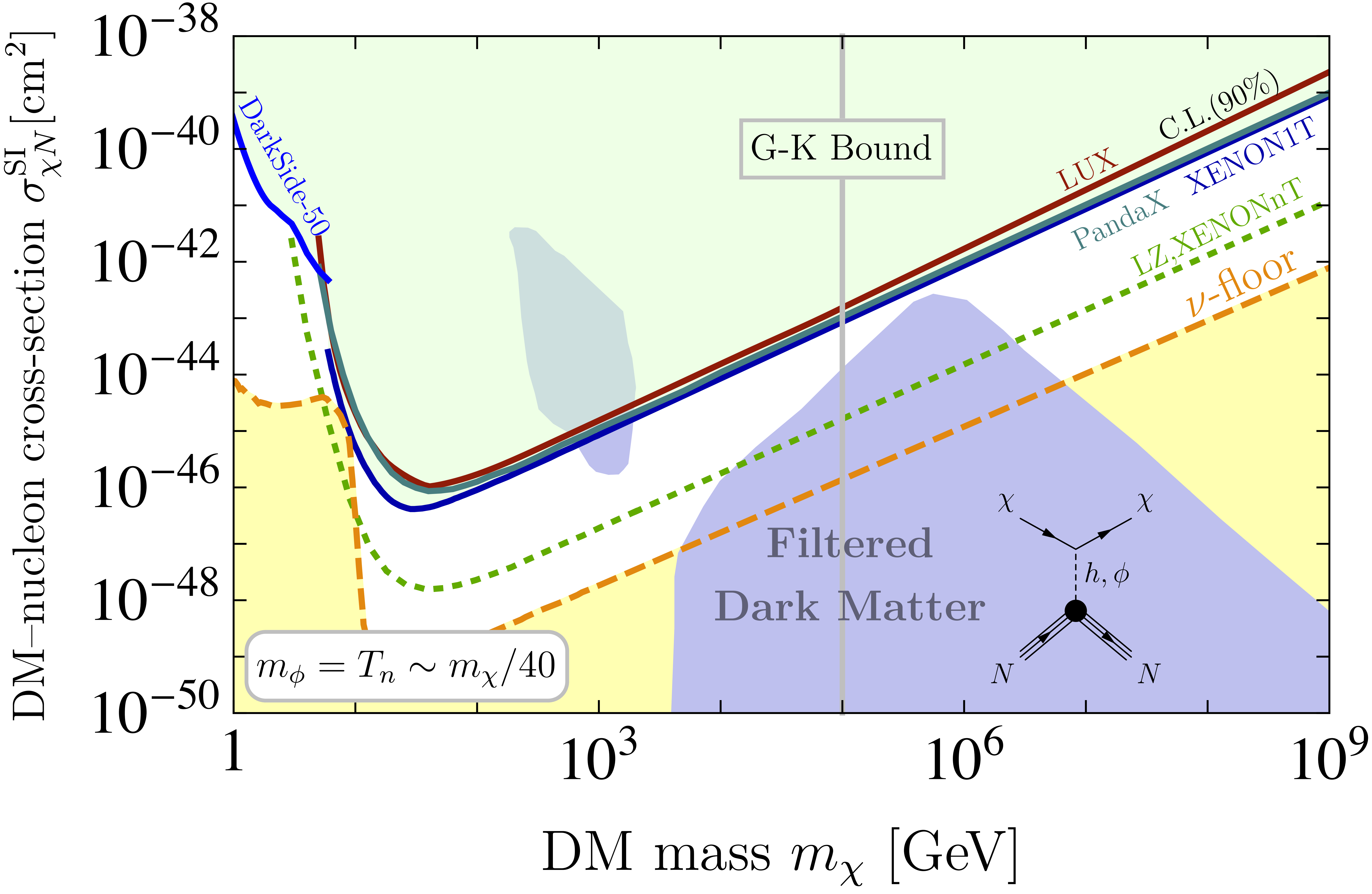


$T_n = m_\phi = 1$ TeV
$m_\chi^{\rm in} = 32$ TeV
$y_\chi = 2$
l_w
$\mathcal{A}(z, p_z)$
1.8
1.6
1.4
1.2
1.0
Particle trajectory
$v_w = 0.01$
60
40
20
0
−20
−40
−60
−0.4
−0.2
0.0
0.2
0.4
Momentum p_z [TeV]
Distance from bubble wall z [TeV^{-1}]

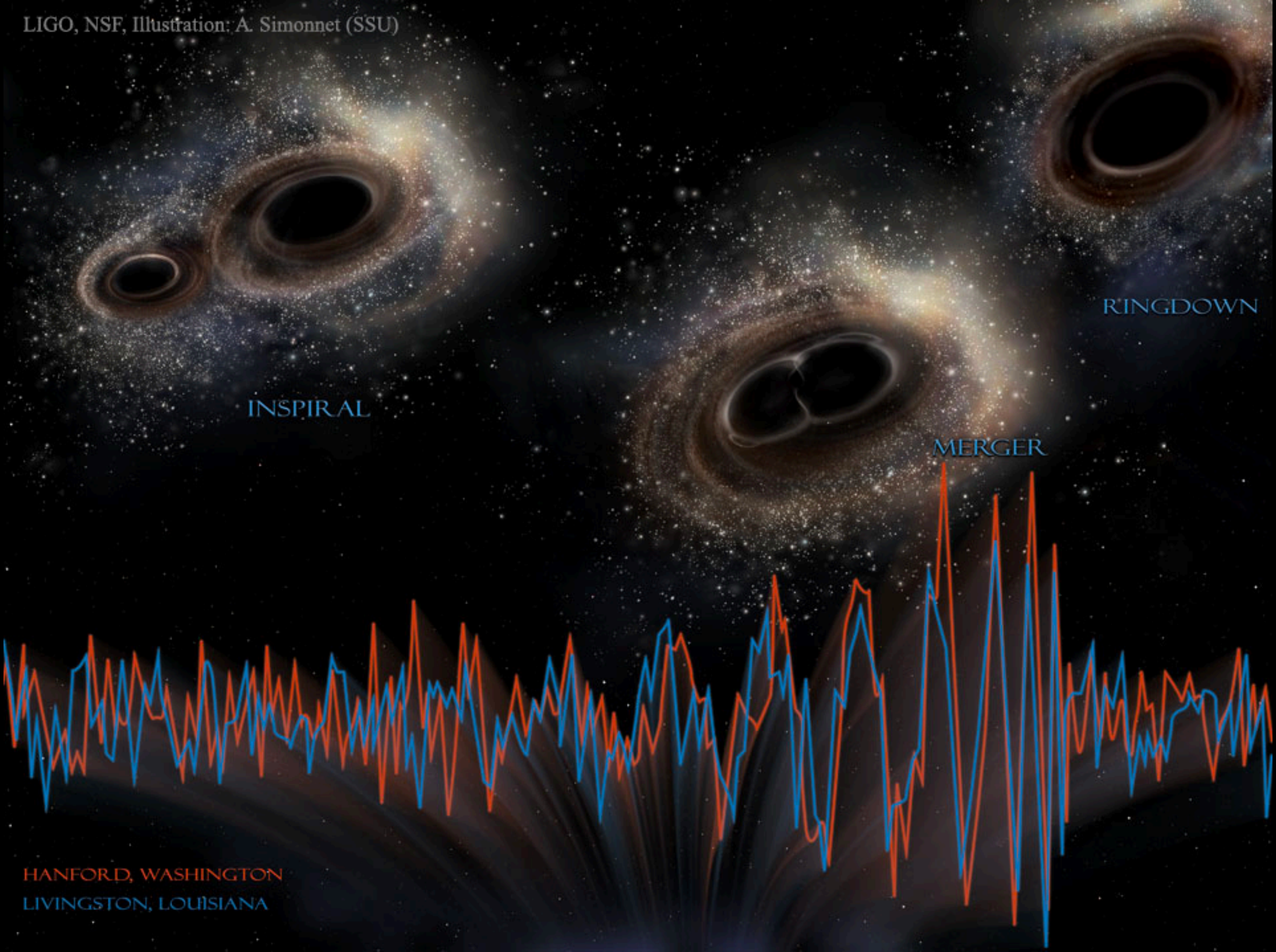
Numerical Calculation



Parameter Space and Constraints



Introduction: Black Holes


LIGO, NSF, Illustration: A. Simonnet (SSU)
INSPIRAL
MERGER
RINGDOWN
HANFORD, WASHINGTON
LIVINGSTON, LOUISIANA

Event Horizon Telescope Collaboration

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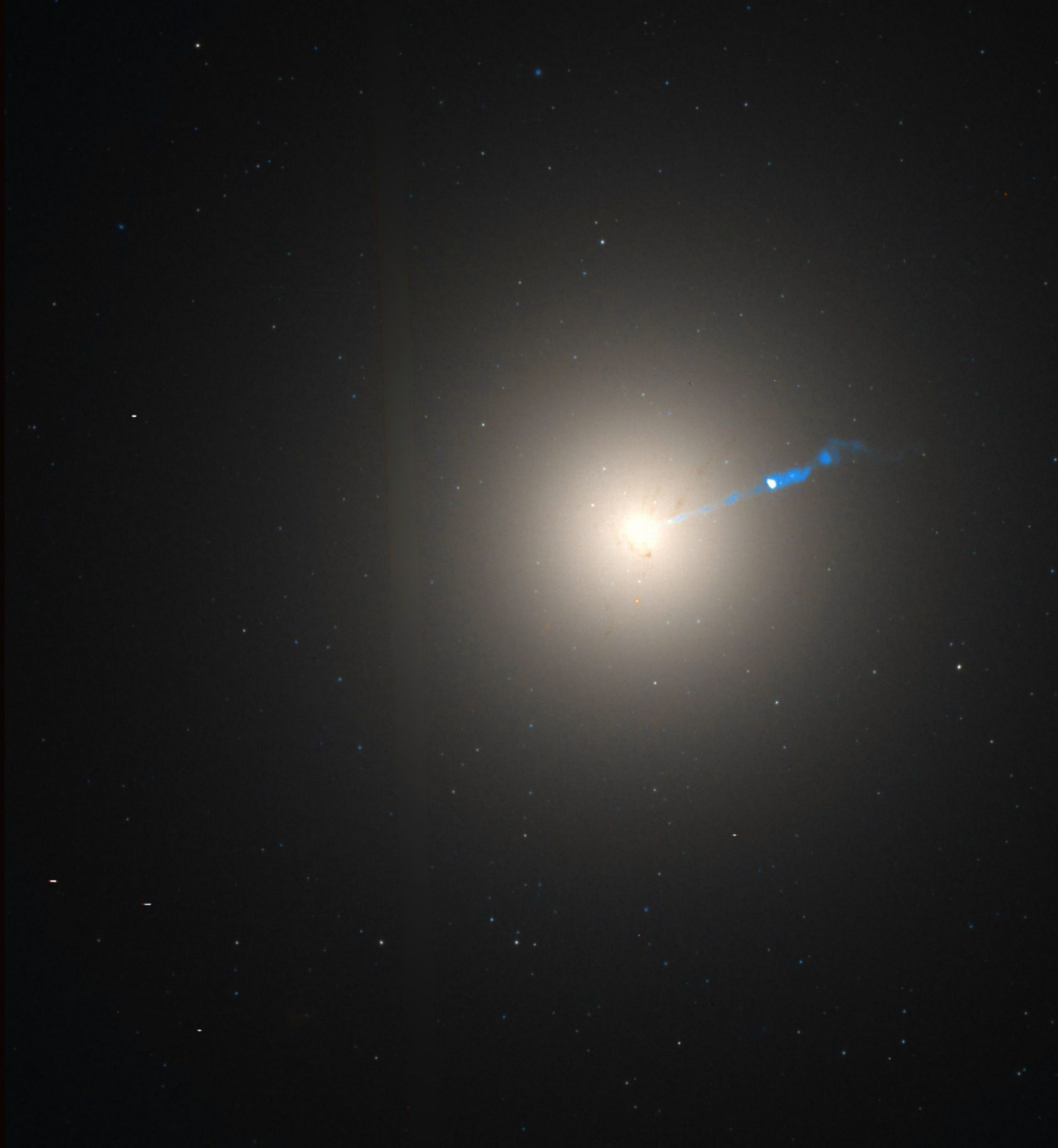
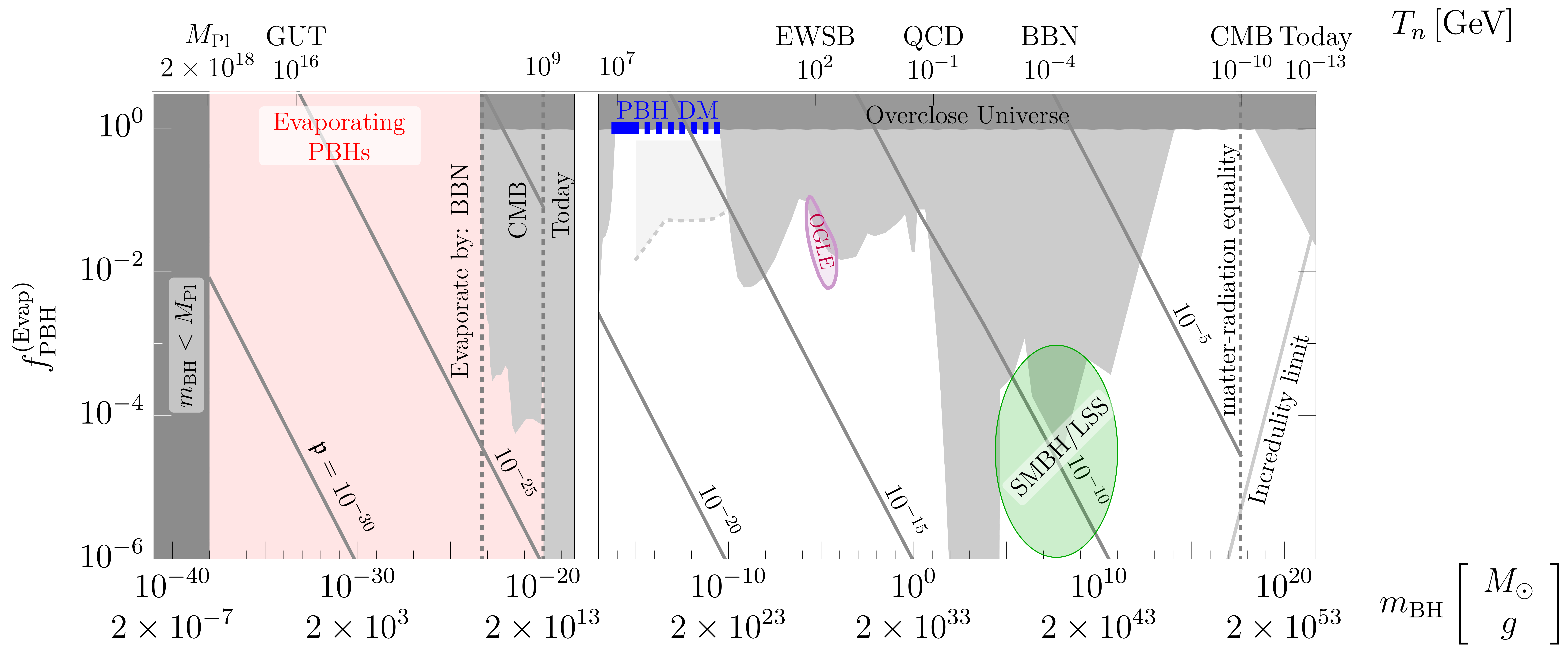


M87 - Hubble Space Telescope

Primordial Black Holes



PBH production mechanisms

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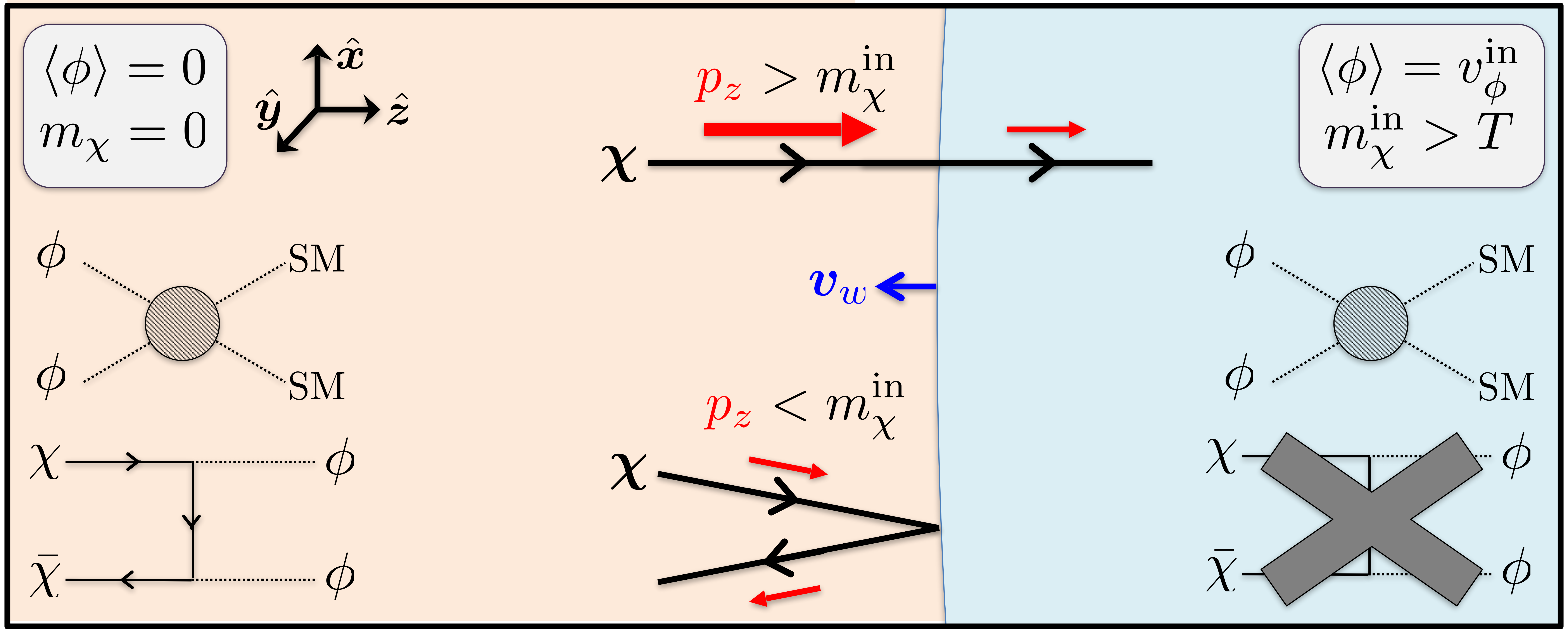
- Several possible production mechanisms
  - Collapse of density perturbations generated during inflation
  - Collapse of topological defects
  - Dynamics of scalar condensates
  - Collision of bubble walls during a first-order PT

- Previous work on first-order PT has only considered energy stored in bubble walls. We focus on a population of particles that interact with the bubble wall

Primordial Black Holes from First-Order Cosmological Phase Transitions

Cartoon


$\langle\phi\rangle = 0$
$m_\chi = 0$
$\hat{x}$
$\hat{y}$
$\hat{z}$
$\langle\phi\rangle = v_\phi^{\rm in}$
$m_\chi^{\rm in} > T$
$p_z > m_\chi^{\rm in}$
χ
v_w
$p_z < m_\chi^{\rm in}$
χ
ϕ
SM
ϕ
SM
χ
ϕ
$\bar{\chi}$
ϕ
ϕ
SM
ϕ
SM
χ
ϕ
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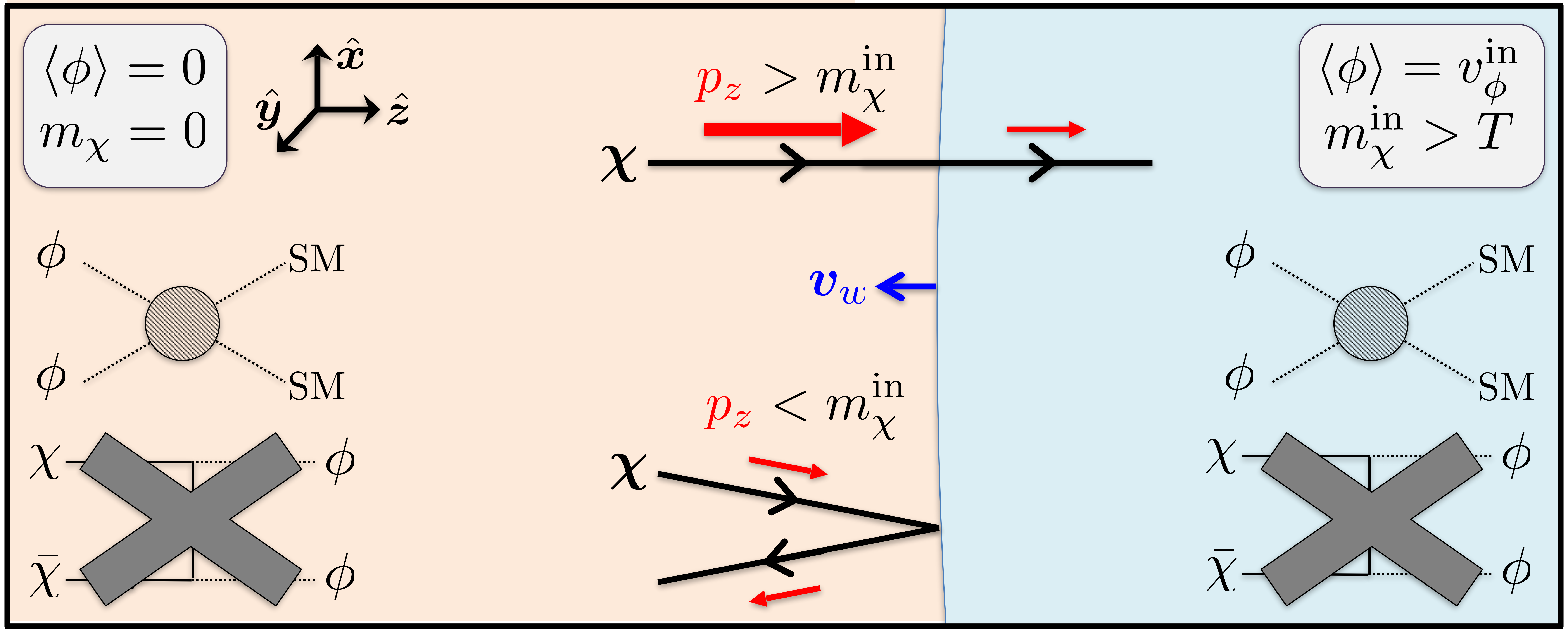
ϕ

Cartoon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χ
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ϕ ϕ SM SM
v_w
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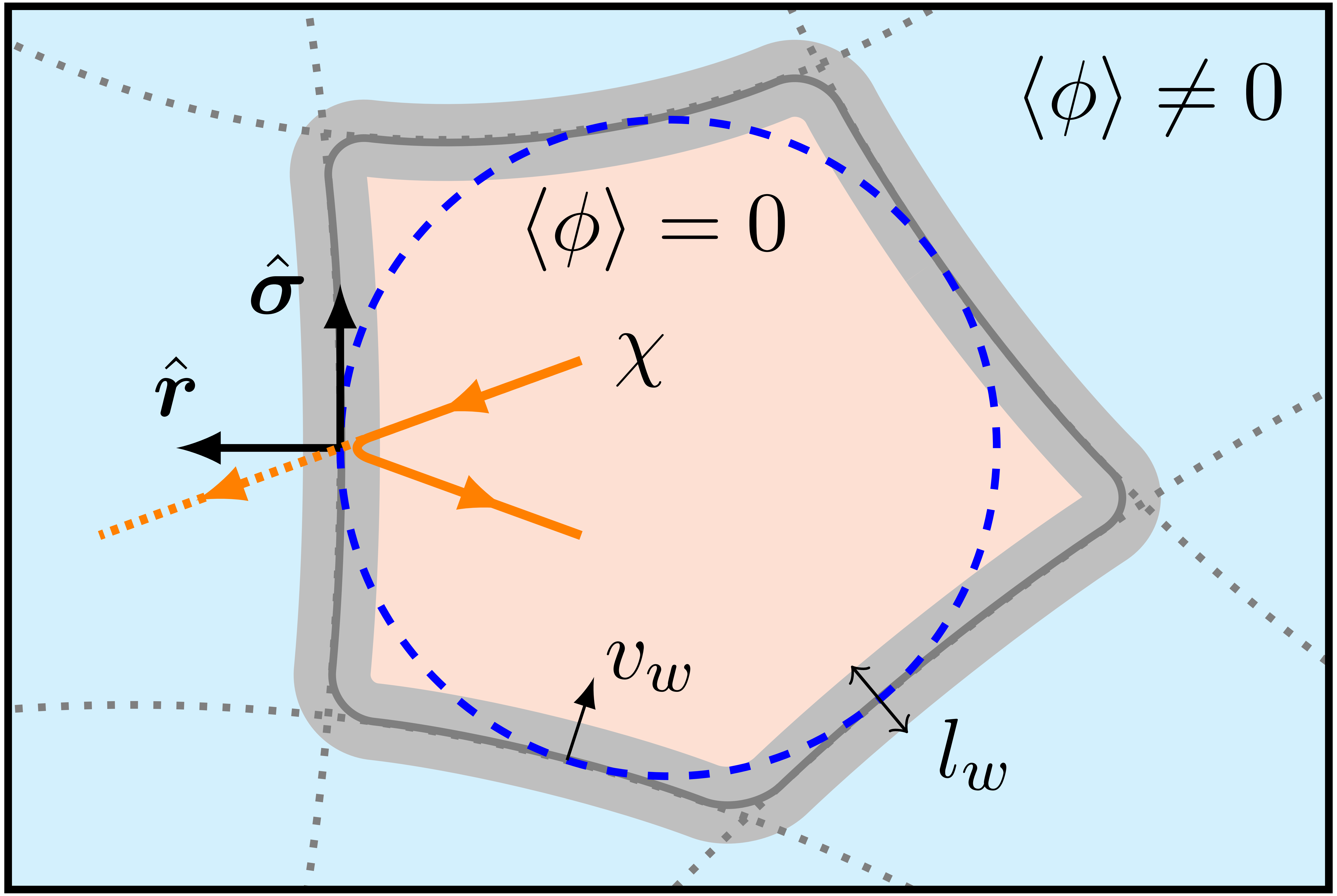
χ $\bar{\chi}$ ϕ ϕ



$\langle \phi \rangle \neq 0$
$\langle \phi \rangle = 0$
$\hat{\boldsymbol{\sigma}}$
$\hat{\boldsymbol{r}}$
χ
v_w
l_w

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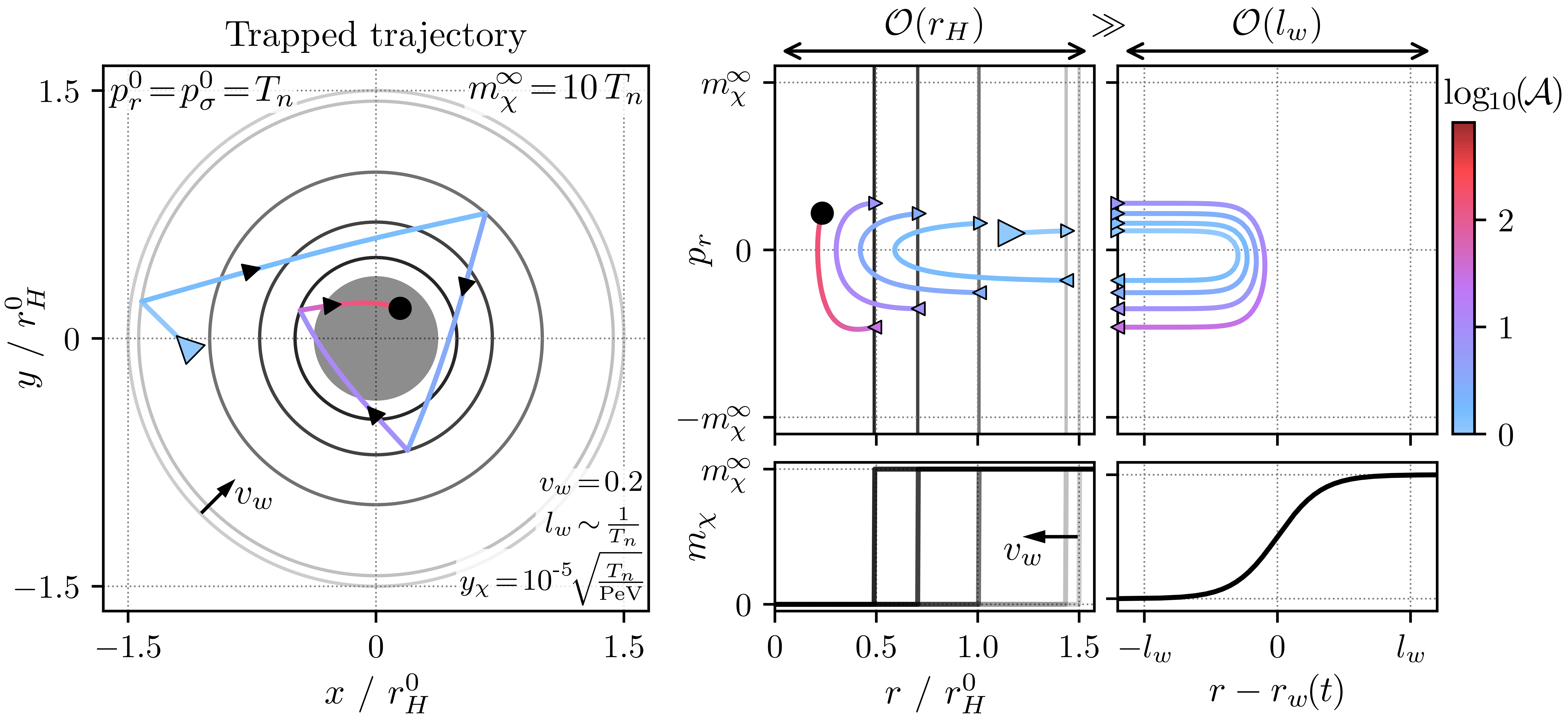
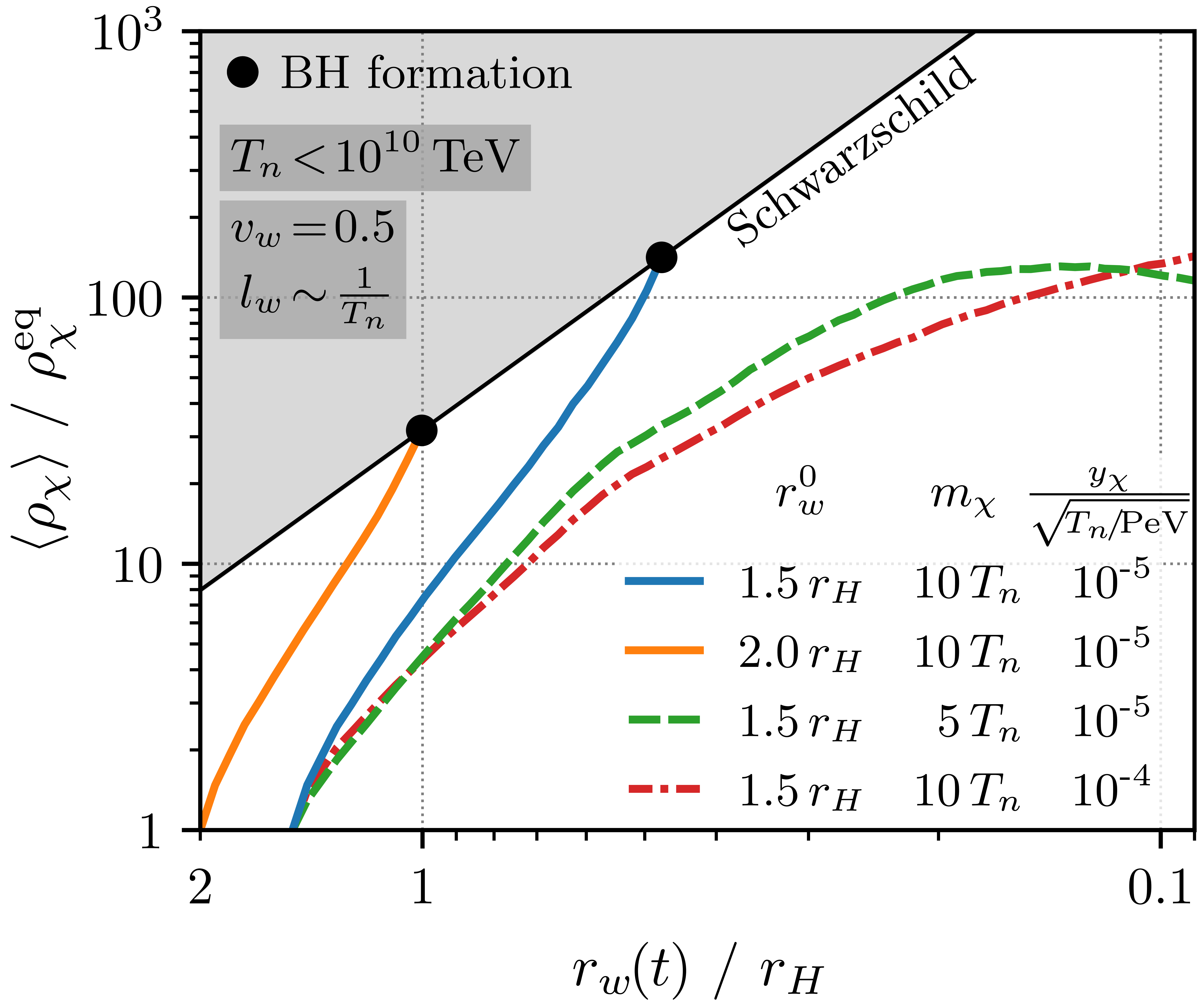
Now considerably more complicated:

- Far from equilibrium
- Retain two momentum directions
- Time dependence
- Need to solve in whole volume, not just near wall

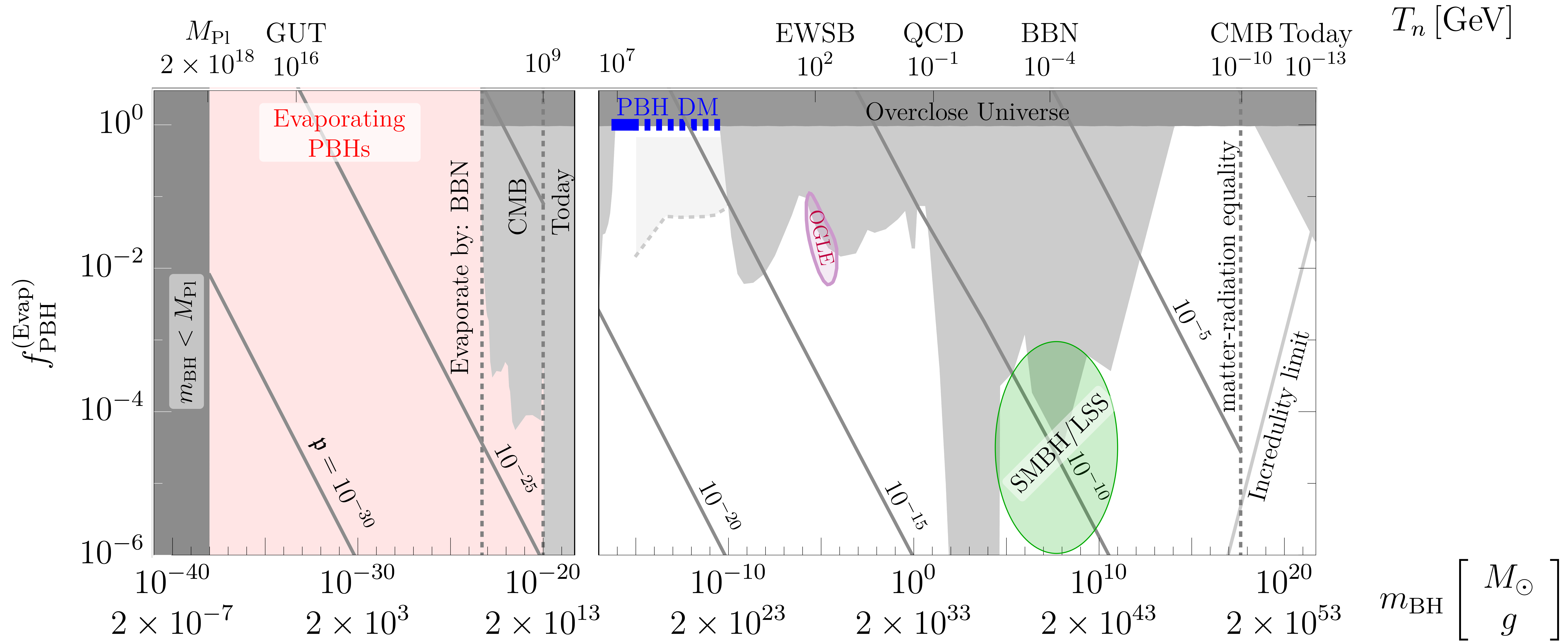
Phase Space Evolution



PBH formation



PBH mass and density



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Thank you!