



VRIJE  
UNIVERSITEIT  
BRUSSEL

2022

BELGIAN-DUTCH  
MEETING

GRAVITATIONAL

WAVES

## Gravitational waves from dark matter production

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arXiv:2101.05721, 2207.02230

7 october 2022

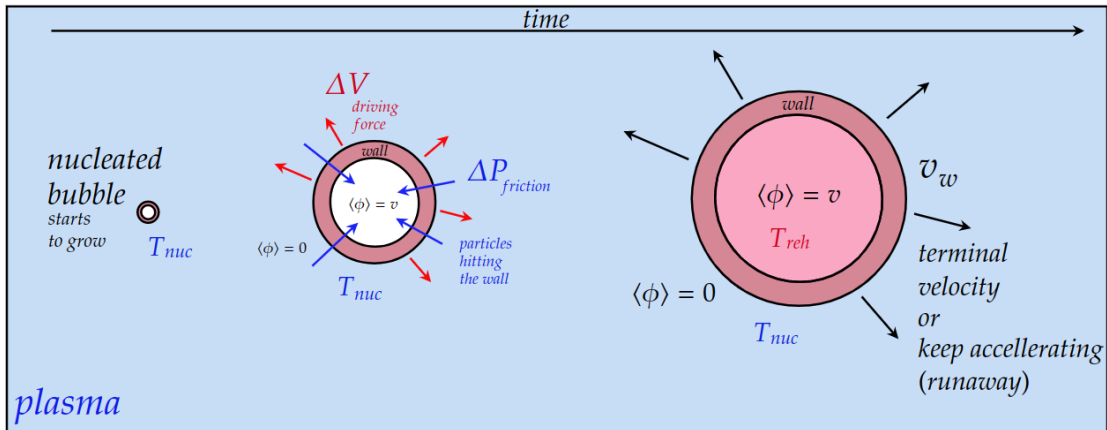
**Collaborators:** Aleksandr Azatov

Sabyasachi Chackraborty

Wen Yin

Giulio Barni

# FOPT: Bubble dynamic



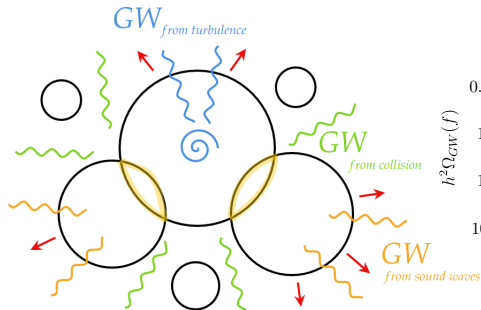
# GW from FOPT

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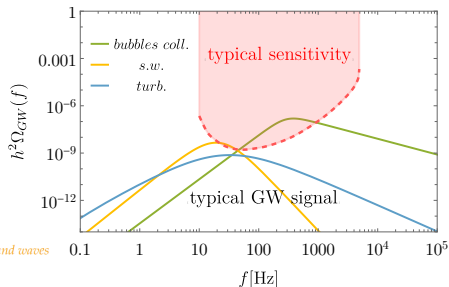
- bubble collision
- sound waves
- turbulence



- GW signal grows with  $\alpha$ ,  $\alpha \propto \frac{v}{\rho_{\text{plasma}}}$  !

- 

$$f_{\text{peak}} \quad T_{\text{reh}} \quad v_h$$



# Production of heavy particles in PT

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[[arXiv:2010.02590](https://arxiv.org/abs/2010.02590)] with *Aleksandr Azatov* and *Wen Yin*

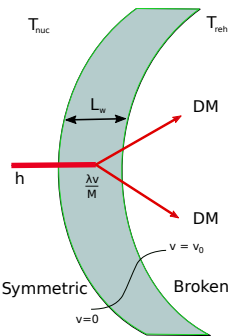
# Production of out-of-equilibrium heavy states via wall [2010.02590]: Idea

## Out-of-equilibrium heavy states

$h$  PT scalar,  $\phi$  heavy DM candidate:  $L = -\frac{\lambda}{2}h^2\phi^2 - M^2\phi^2 - V(h)$

$$n_\phi = e^{-M/T}$$

- $h$  undergoes FOPT with relativistic walls

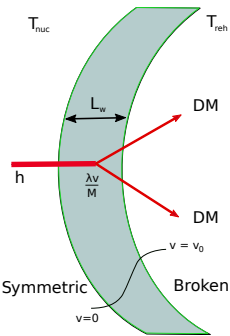


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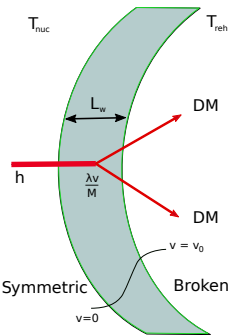
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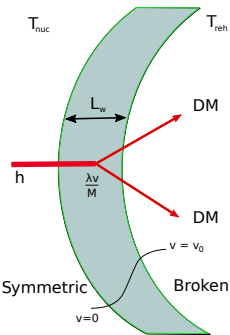


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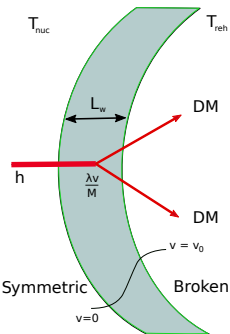
- No wall:**  $(2\pi)^4 \delta^4(p_h - \sum_i p_\phi^i)$ :  $h \not\rightarrow \phi\phi$
- With wall:** if  $E > 2M$ ,  $h \phi\phi$  allowed

$$\int d^3x e^{i p \cdot x} \int \phi(z) e^{iz \cdot p_z} dz (2\pi)^3 \delta^2(p) \delta(E) \frac{\sin \frac{p_z L_w}{p_z L_w}}{p_z L_w}$$

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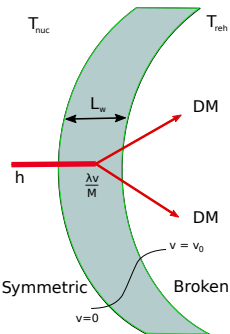


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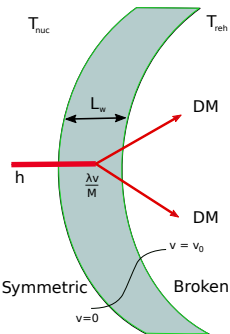


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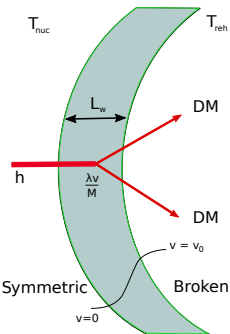


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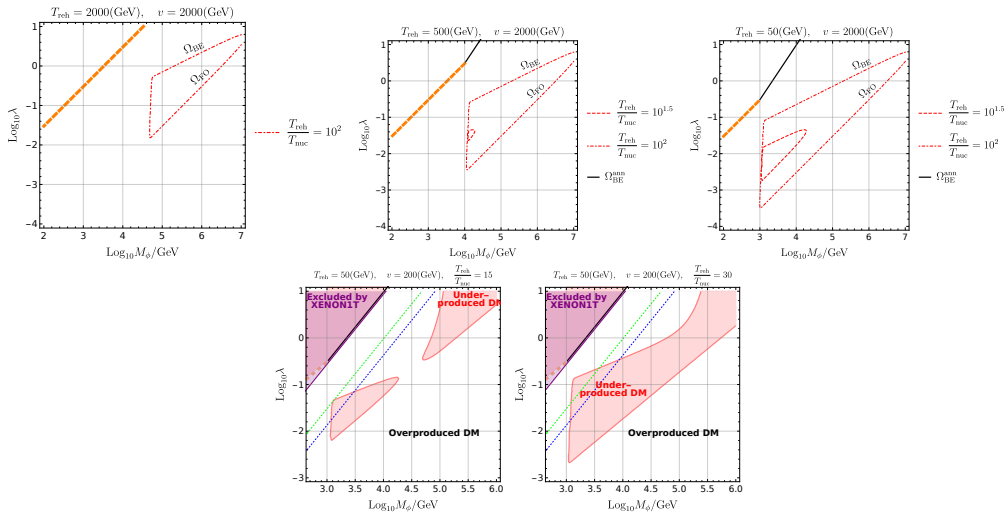


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- Behind the wall, accumulation of relics  $\phi$

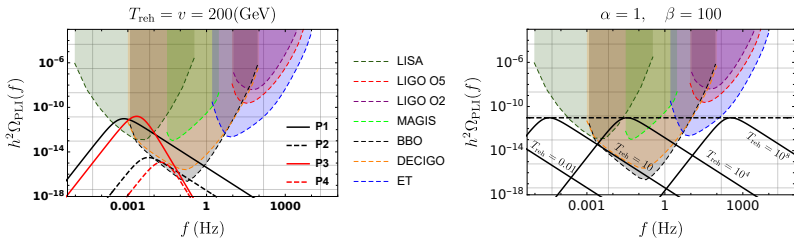
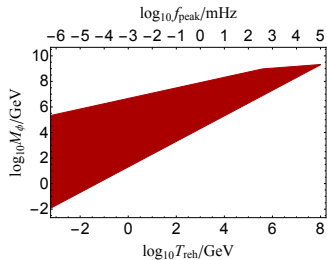
$$n_{\phi}^{\text{BE}} = \frac{T^3}{12\pi^4} \frac{\lambda^2 v^2}{M_{\phi}^2} e^{-\frac{M_{\phi}^2}{2vT\gamma_{wp}}} + O(1/\gamma_w)$$

$$n_{\phi, \text{BE}}^{\text{today}} h^2 = 5.4 \times 10^5 \times \left( \frac{1}{g_{*S}(T_{\text{reh}})} \right) \left( \frac{\lambda^2 v}{M_{\phi}} \right) \left( \frac{v}{\text{GeV}} \right) \left( \frac{T_{\text{nuc}}}{T_{\text{reh}}} \right)^3 e^{-\frac{M_{\phi}^2}{2vT\gamma_{wp}}}$$

# Large supercooling: $\left(\frac{T_{\text{nuc}}}{T_{\text{reh}}}\right) \quad 1$



# Range of emission and signal



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- Other proposals: [1912.02830\(Baker, Kopp, Long\)](#), [1805.01473\(Hambye, Strumia, Teresi\)](#),...