Strong gravitational radiation from a simple dark matter model

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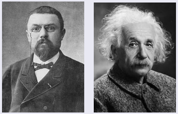
In collaboration with Iason Baldes
Based on arXiv:1809.01198

Gravitational Waves (GWs)

- Predicted by Poincaré (1905).



This talk

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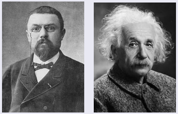

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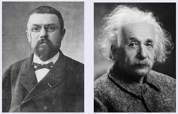

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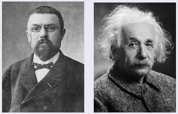

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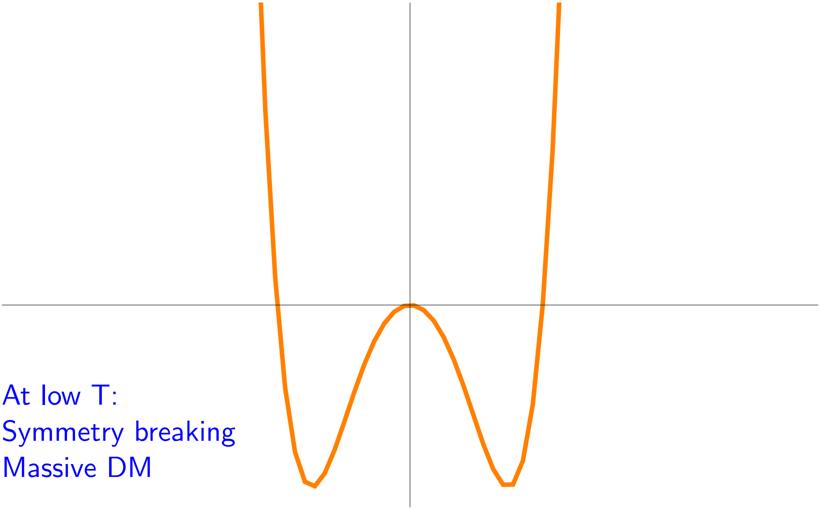
This talk

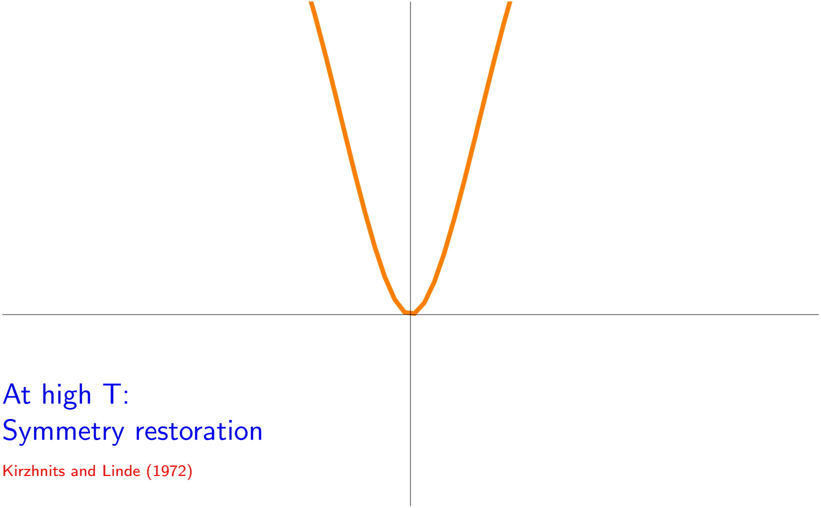
- Hypothesis: Dark matter are massive gauge bosons.
→There was a phase transition in the Early Universe: GWs.

First-order phase transition



At low T:
Symmetry breaking
Massive DM

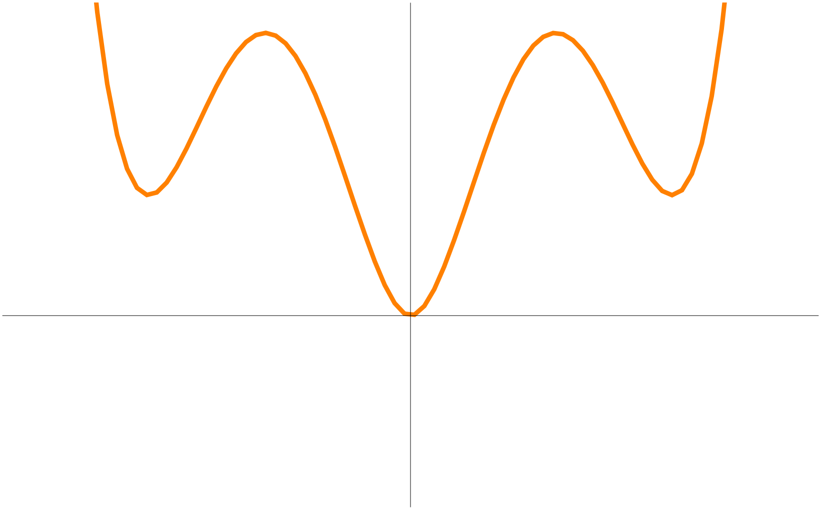
First-order phase transition



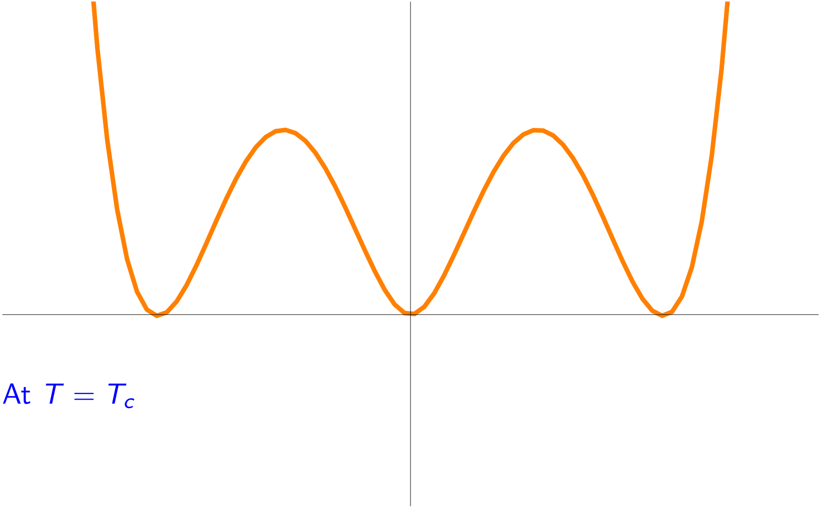
At high T:
Symmetry restoration

Kirzhnits and Linde (1972)

First-order phase transition

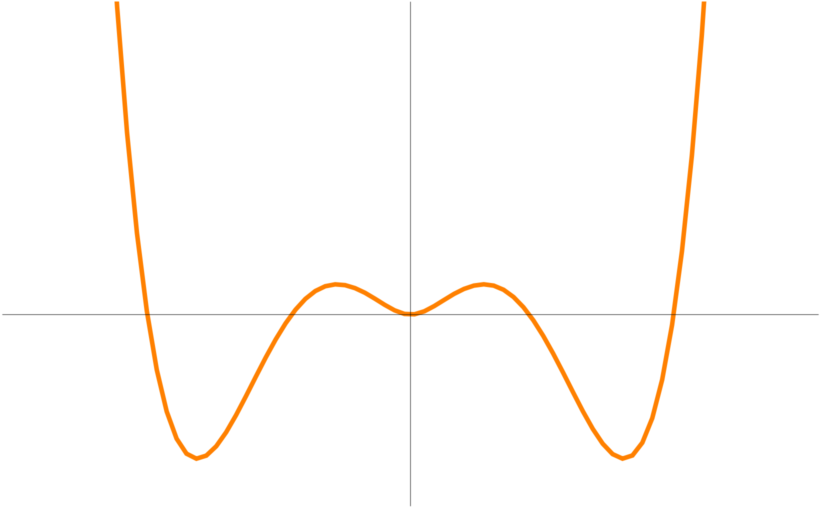


First-order phase transition

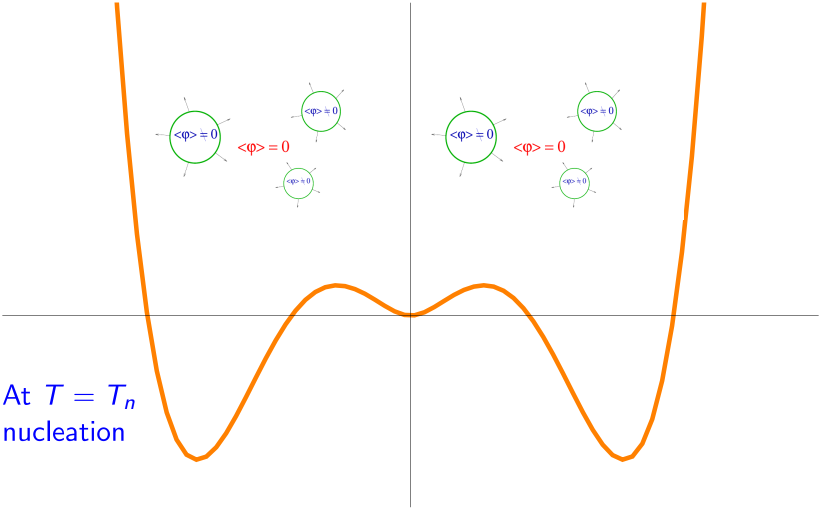


At $T = T_c$

First-order phase transition

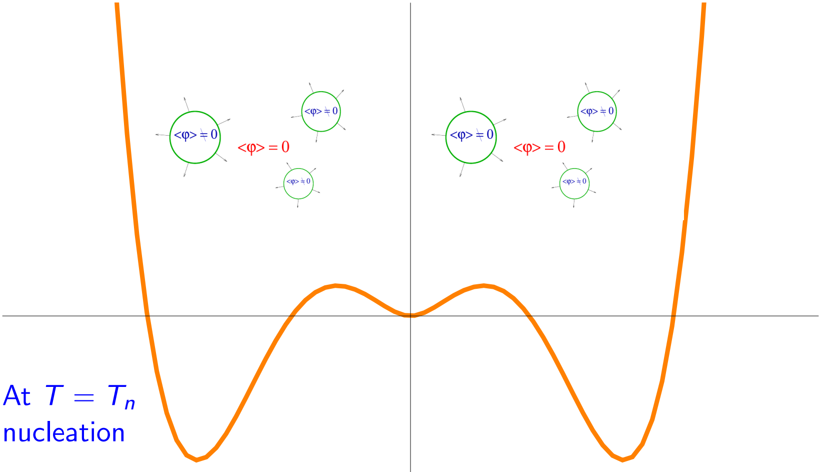


First-order phase transition



At $T = T_n$
nucleation

First-order phase transition



At $T = T_n$
nucleation

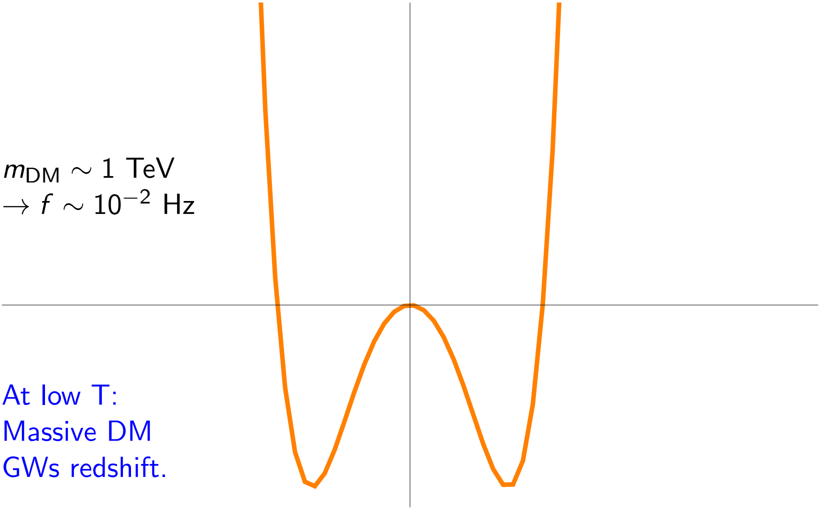
This produces produces gravitational waves E. Witten (1984)

First-order phase transition

At low T:
Massive DM
GWs redshift.

First-order phase transition

$m_{\text{DM}} \sim 1$ TeV
$\rightarrow f \sim 10^{-2}$ Hz



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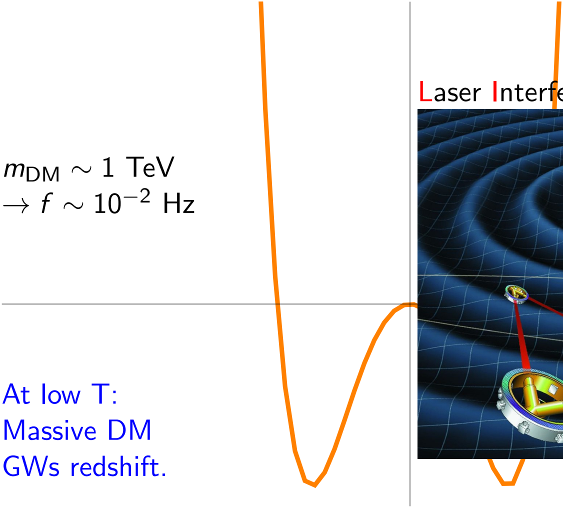

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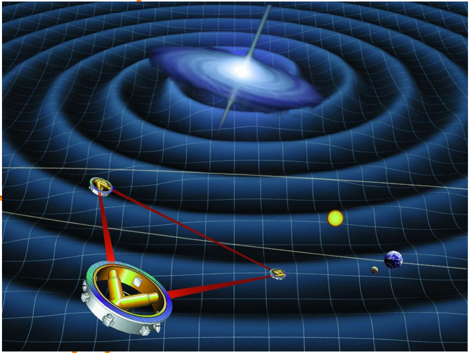
Laser Interferometer Space Antenna



Caprini et al (2015)

Focus on a scenario based on a $SU(2)_D$ group

Field	$SU(3)$	$SU(2)$	$U(1)_Y$	$SU(2)_D$
H	1	2	$\frac{1}{2}$	1
H_D	1	1	0	2

$$V = \mu_1^2 H^\dagger H + \mu_2^2 H_D^\dagger H_D + \lambda_1 (H^\dagger H)^2 + \lambda_2 \, (H_D^\dagger H_D)^2 + \lambda_3 \, H_D^\dagger H_D \, H^\dagger H \, ,$$

Local $SU(2)_D$	$\rightarrow$	Global $SO(3)$
Gauge Fields A'_μ	$\rightarrow$	Massive Fields A_μ
Dark doublet H_D	$\rightarrow$	Higgs-like h_D

Hambye (JHEP 2009)

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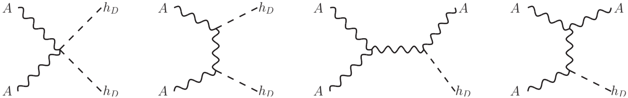
Dark doublet H_D	$\rightarrow$	Higgs-like h_D	It mixes with the Higgs
High temperatures		Low temperatures	

Hambye (JHEP 2009) Phase transition in the Early Universe!!!!!!!!!!!

Four parameters

- DM mass
- Higgs-like mass
- mixing angle. Direct detection in Xenon1T: $\theta \lesssim 0.1$.
- vev (or g_D) are set by the relic density (via freeze-out):

$$\begin{cases} g_D \approx 0.9 \times \sqrt{\frac{m_A}{1\,\mathrm{TeV}}} \\ v_\eta \approx 2.2\,\mathrm{TeV} \times \sqrt{\frac{m_A}{1\,\mathrm{TeV}}}. \end{cases}$$



GW spectrum

Phase transition parameters

$$T_n = 0.48\ \mathrm{TeV}$$

$$\eta_n = 3.8\ \mathrm{TeV}$$

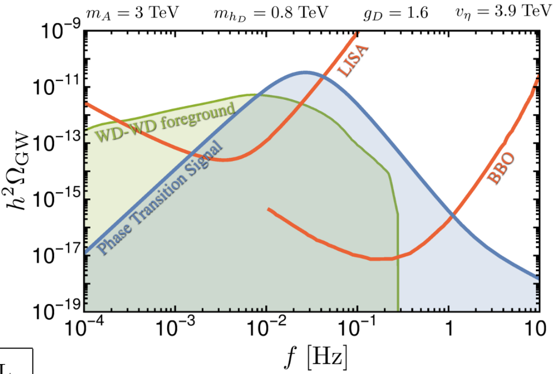
$$\alpha = 0.29,\ \sim\text{(latent heat)}$$

$$\beta/H = 290\ \sim\text{(fq. scale)}$$

Simulations give Ω_{GW} from them

Caprini et al (2015)

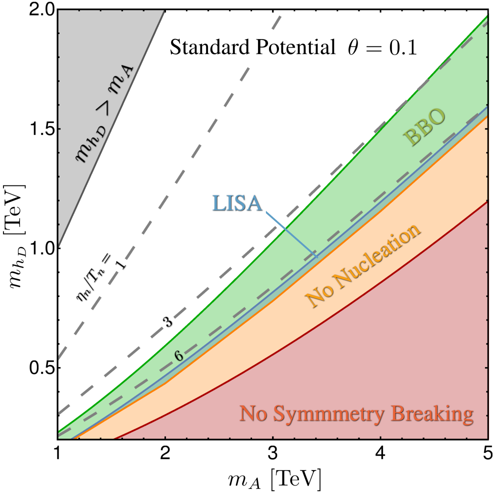
	SNR	$\mathrm{SNR_{FGL}}$
LISA	15	1.8
BBO	3.7×10^5	2.3×10^3



Baldes, CGC 2018

Parameter space for SNR>5.

$$\mathrm{SNR} = \sqrt{t_{\mathrm{obs}} \int \left[\frac{h^2\Omega_{\mathrm{GW}}(f)}{h^2\Omega_{\mathrm{sens}}(f)}\right]^2 df}$$



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Dark matter as massive dark gauge bosons

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Radiative effects break the $SU(2)_D$ symmetry Coleman-Weinberg (1973)
λ_2 runs to negative values.

Baldes, CGC 2018

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- Scale-invariant potential → strong signal.

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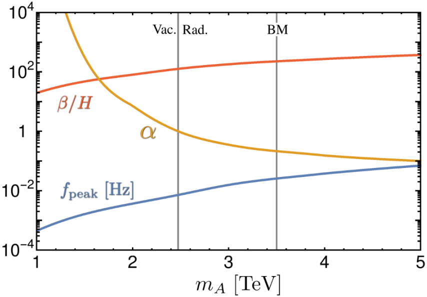

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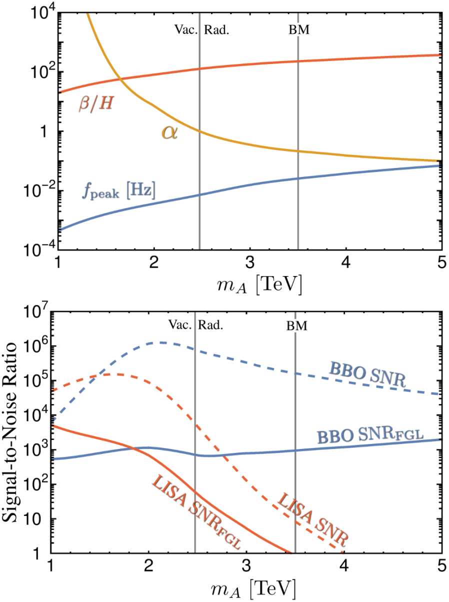
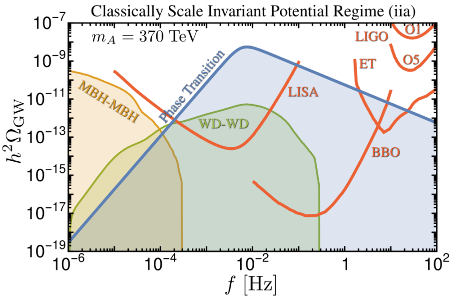
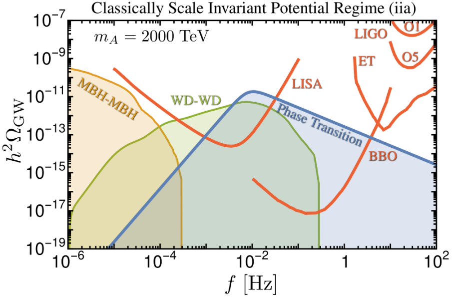




Dark Sector Parameters	m_A	370	TeV
	m_{h_D}	59	TeV
	v_η	780	TeV
	g_D	0.95	-
	θ	10^{-9}	-
Phase Transition	T_n	2.6	GeV
	$T_{\rm infl.}$	43	TeV
	$T_{\rm RH}$	13	TeV
	η_n	$\simeq v_\eta$	-
	α	10^{16}	-
	β/H	6.7	-
SNR	LISA	10^4	-
	LISA(FGL)	270	-
	BBO	10^8	-
	BBO(FGL)	10^7	-



Dark Sector Parameters	m_A	2000	TeV
	m_{h_D}	330	TeV
	v_η	4100	TeV
	g_D	0.98	-
	θ	10^{-11}	-
Phase Transition	T_n	32	GeV
	$T_{\rm infl.}$	230	TeV
	$T_{\rm RH}$	1.0	TeV
	η_n	$\simeq v_\eta$	-
	α	10^{15}	-
	β/H	7.1	-
SNR	LISA	44	-
	LISA(FGL)	1.0	-
	BBO	10^5	-
	BBO(FGL)	10^5	-

Conclusions

- We have explored the possibility of DM from a hidden $SU(2)_D$ gauge group. This implies a phase transition that will result in detectable gravitational waves.
- The model is therefore well suited as a case study for the sensitivity of future gravitational wave observatories to phase transitions in DM sectors.

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Thanks for your attention