Strong gravitational radiation from a simple dark matter model

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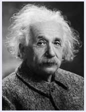
European Research Council
Established by the European Commission

Warsaw, Poland
Beyond General Relativity, Beyond Cosmological Standard Model

1st July, 2019

In collaboration with Iason Baldes
Based on JHEP 1905 (2019) 190

Gravitational Waves (GWs)

- Predicted by Poincaré (1905).  

This talk

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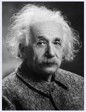

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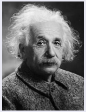
- Predicted by Poincaré (1905).  
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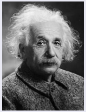
- Predicted by Poincaré (1905).  
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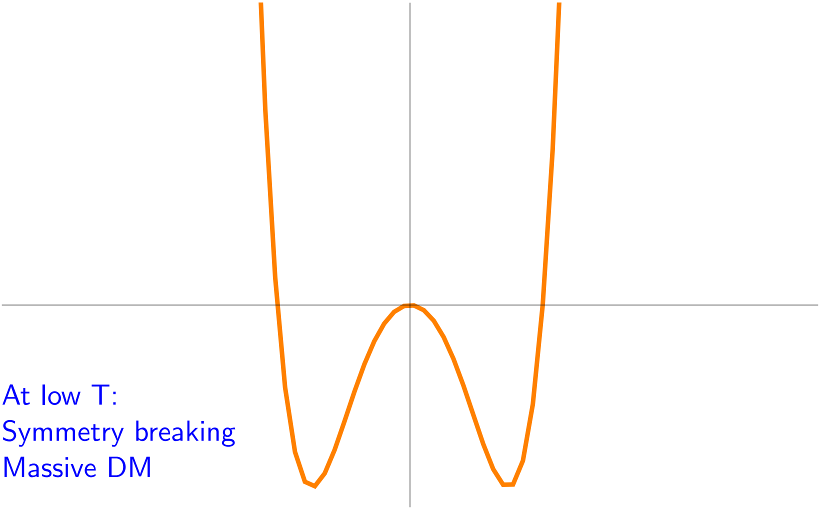
This talk

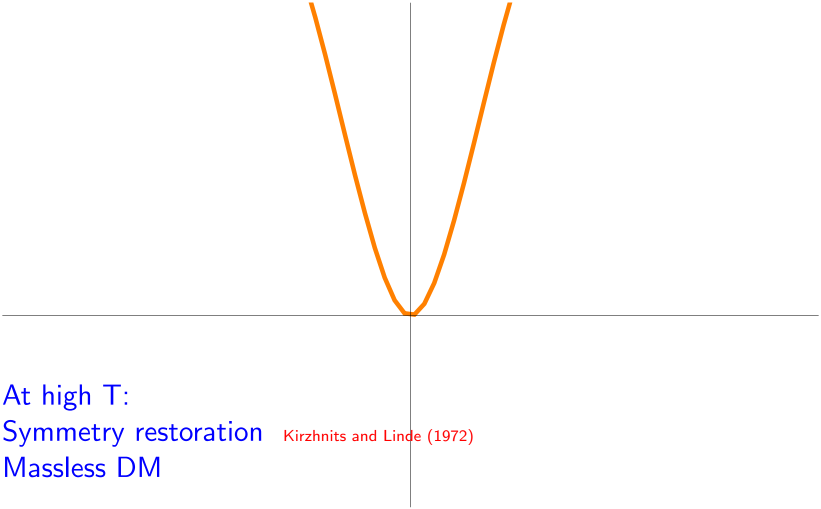
- Discuss a simple scenario where dark matter in the Early Universe undergoes a first-order phase transition.

First-order phase transition



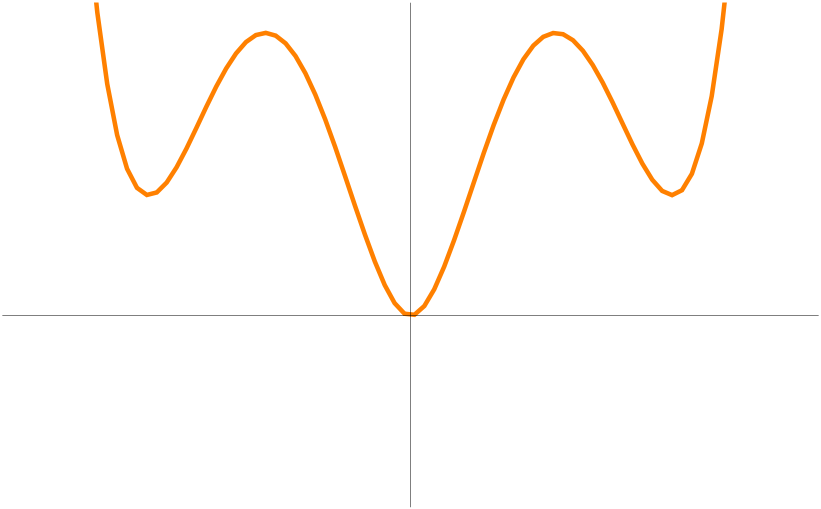
At low T:
Symmetry breaking
Massive DM

First-order phase transition



At high T:
Symmetry restoration Kirzhnits and Linde (1972)
Massless DM

First-order phase transition



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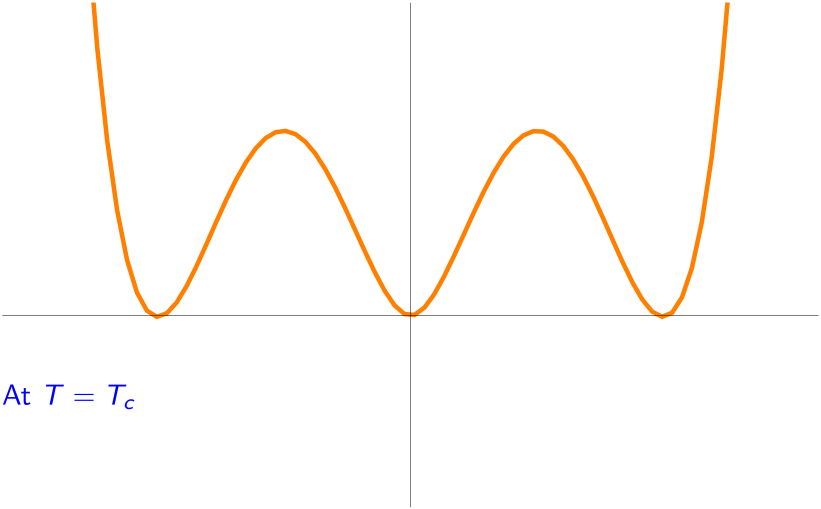
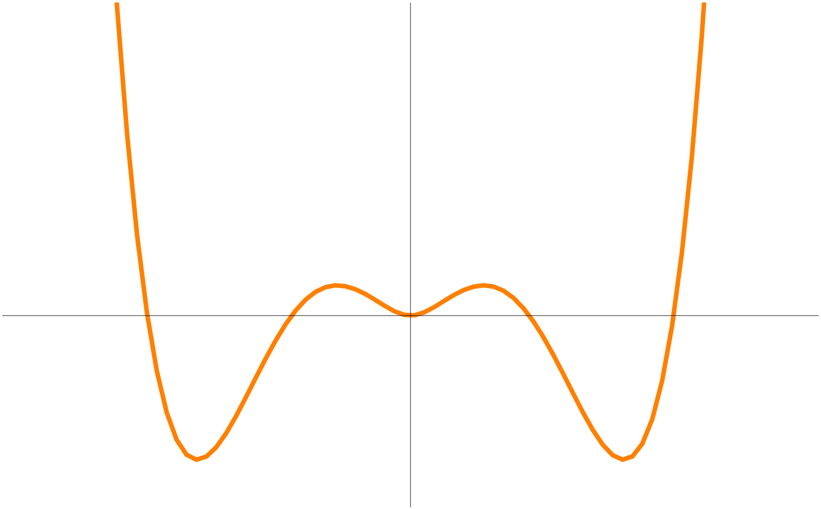
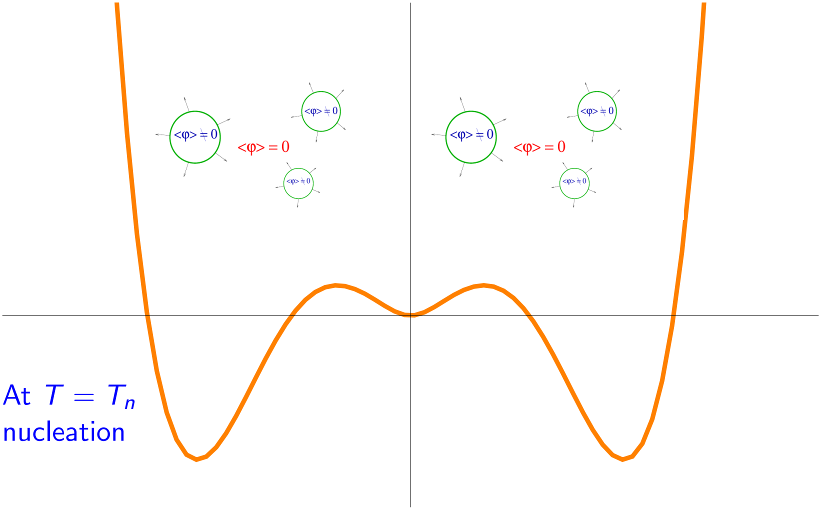


At $T = T_c$

First-order phase transition

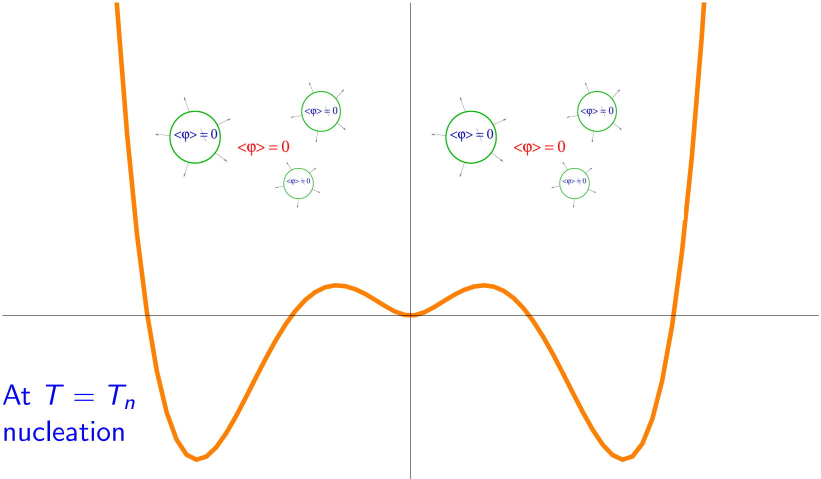


First-order phase transition



At $T = T_n$
nucleation

First-order phase transition



At $T = T_n$
nucleation

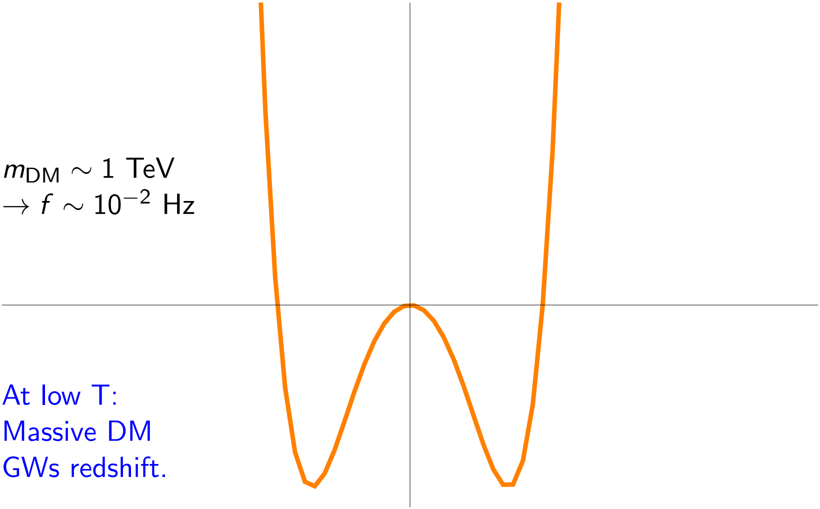
This produces produces gravitational waves E. Witten (1984)

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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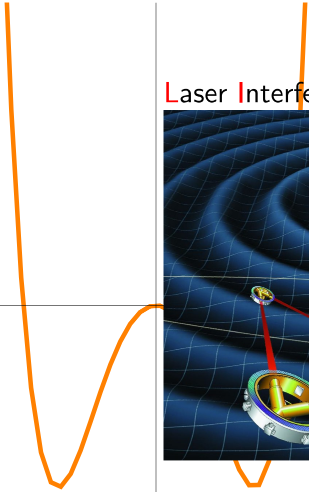
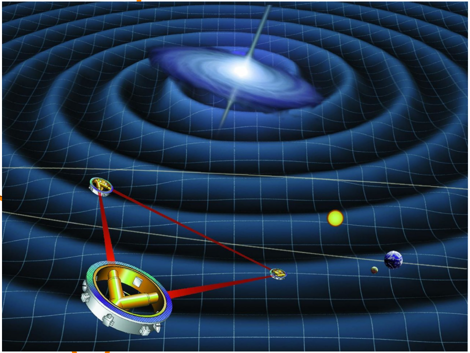


Laser Interferometer Space Antenna



Caprini et al (2015)

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- A few studies along these lines:

  P. Schwaller, PRL 115 (2015), Baldes JCAP (2017), Chao et al, JHEP (2017)
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  In general, it is hard to establish a correlation between the actual properties of dark matter (mass, spin, couplings, etc.) and the features of the gravitational waves.

- Unless the dark matter properties are closely related to the phase transition with the latter being determined by a handful of parameters.
- Objective: Find a dark matter model that overcomes these difficulties.

Mimic the EW sector: DM as gauge bosons

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

$$
\begin{array}{lcl}
\text{Local } SU(2)_D & \rightarrow & \text{Global } SO(3) \\
\text{Gauge Fields } A'_\mu & \rightarrow & \text{Massive Fields } A_\mu \\
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Hambye (JHEP 2009)

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High temperatures		Low temperatures	

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

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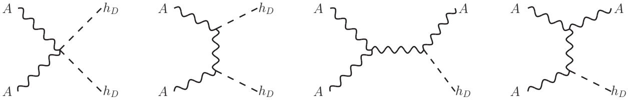

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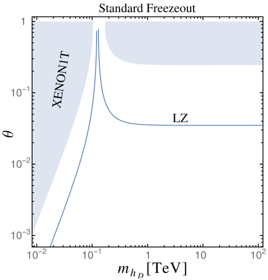

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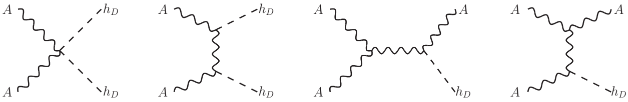


- Mixing angle constrained by direct detection: $\theta \lesssim 0.1$.

GW spectrum

Phase transition parameters

$T_n = 0.48$ TeV

$\eta_n = 3.8$ TeV

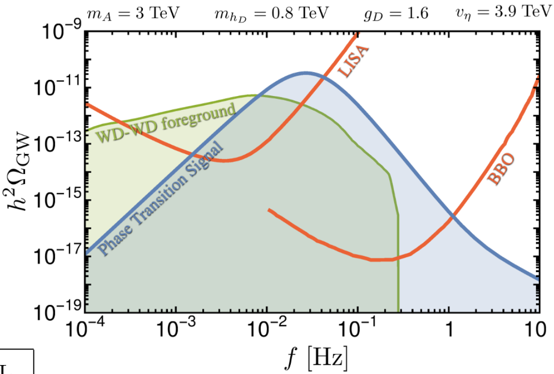
$\alpha = 0.29$, ∼(latent heat)

$\beta/H = 290$ ∼(fq. scale)

Simulations give Ω_{GW} from them

Caprini et al (2015)

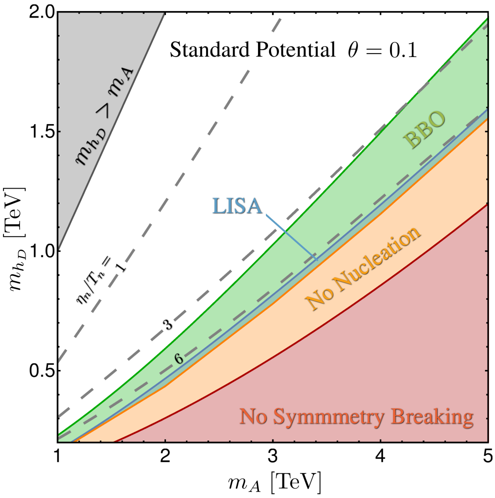
	SNR	SNR_{FGL}
LISA	15	1.8
BBO	3.7×10^5	2.3×10^3



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

Baldes, CGC 2018

- Only one free parameter after taking the relic density into account.
- Scale-invariant potential $\rightarrow$ strong signal.
- There is a large amount of supercooling

  See Marek Lewicki's talk

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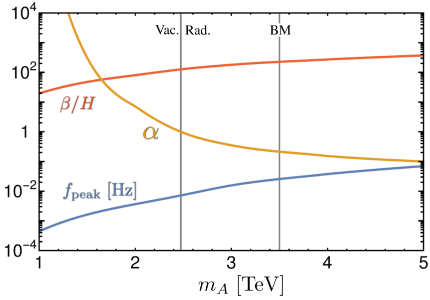

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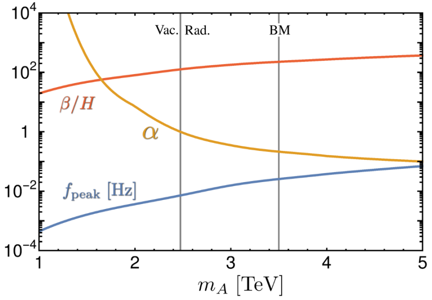
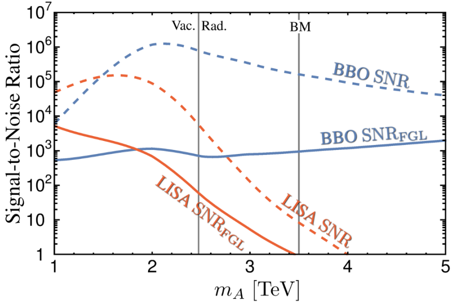
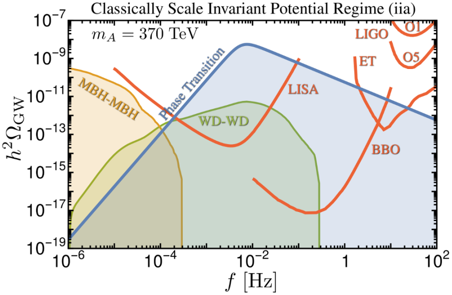
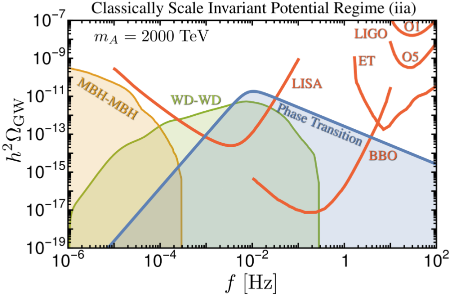






Dark Sector Parameters	m_A	370	TeV
	m_{h_D}	59	TeV
	v_η	780	TeV
	g_D	0.95	-
	θ	10^{-9}	-
Phase Transition	T_n	2.6	GeV
	$T_{\rm infl.}$	43	TeV
	$T_{\rm RH}$	13	TeV
	η_n	$\simeq v_\eta$	-
	α	10^{16}	-
	β/H	6.7	-
SNR	LISA	10^4	-
	LISA(FGL)	270	-
	BBO	10^8	-
	BBO(FGL)	10^7	-



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.
- Due to its simplicity, the model is 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