

# Presentation of the group

**Alberto Mariotti**



**On behalf of the TENA and PHENO groups at VUB**

*COSPA meeting*

*29 October 2021*



## Theory investigation includes TENA and PHENO groups

<https://we.vub.ac.be/en/theoretical-particle-physics>

<https://hep.research.vub.be/phenomenology-team>

*Many fundamental questions still open...*

Force Unification ?

String Theory ?

Quantum Gravity ?

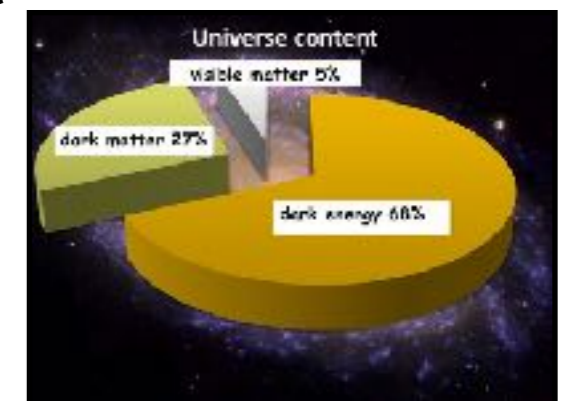
Inflation ?



Hierarchy problem ?

Dark matter nature?

Matter-Antimatter ?



*They connect to cosmoparticle physics*

# The group on BSM and GW physics

STAFF



Alberto Mariotti



Mairi Sakellariadou

10% ZAP



Alex Sevrin

POSTDOC



Simone Blasi

BSM, Cosmology  
and GW physics

Modeling and  
data analysis for GW

Joint with UAntwerp

PHD



Kevin Turbang



Aaron Rase



Sam Junius

Unconventional  
Dark Matter Models

Joint with ULB

# The group on BSM and GW physics

STAFF



Alberto Mariotti



Mairi Sakellariadou

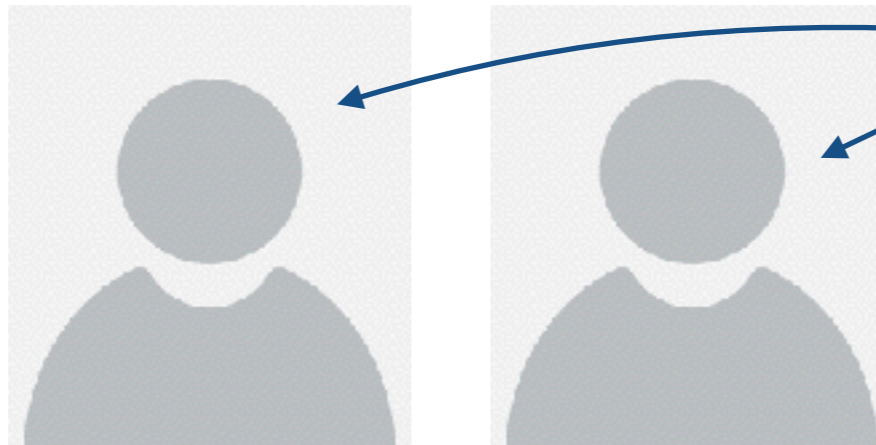


Alex Sevrin

POSTDOC



Simone Blasi



<https://inspirehep.net/jobs/1889113>

*Opening for two PostDoc positions to reinforce modeling and data analysis for SGWB*

PHD



Kevin Turbang



Aaron Rase



Sam Junius

# Activities and topics in GW

## Focus on the *Stochastic Gravitational Wave Background*

- ★ Modeling for the cosmological SGWB (Phase Transitions, Cosmic strings)
- ★ SGWB and BSM scenarios in particle physics
- ★ New data analysis techniques for the SGWB

*Closely collaborating with*



## Activities

- ★ Active Role in LIGO/Virgo collaboration (stochastic group)

- ★ Instrumentation: ET PathFinder <https://www.etpathfinder.eu>

- ★ Connect with VUB photonics



B-PHOT  
BRUSSELS  
PHOTONICS

- ★ iBOF network "*Unlocking the dark Universe with GW observations*"

# Stochastic Background of GW



**WHAT IS IT?** *Looks like noise, detected by cross-correlation*  
 Allen Romano gr-qc/9710117

Analog of CMB  
but for GW

## ★ Described in terms of

SGWB  
energy density  
over critical one

$$\Omega_{\text{GW}}(f) = \frac{f}{\rho_c} \frac{d\rho_{\text{GW}}}{df}$$

$$\rho_c = \frac{3c^2 H_0^2}{8\pi G}$$

## ★ Assumed to be

- \* *Isotropic ("or not")*
- \* *Unpolarized*
- \* *Stationary*
- \* *Gaussian random process*
- \* *Smaller than detector noise*

**Should be detected by cross correlation between different detectors**

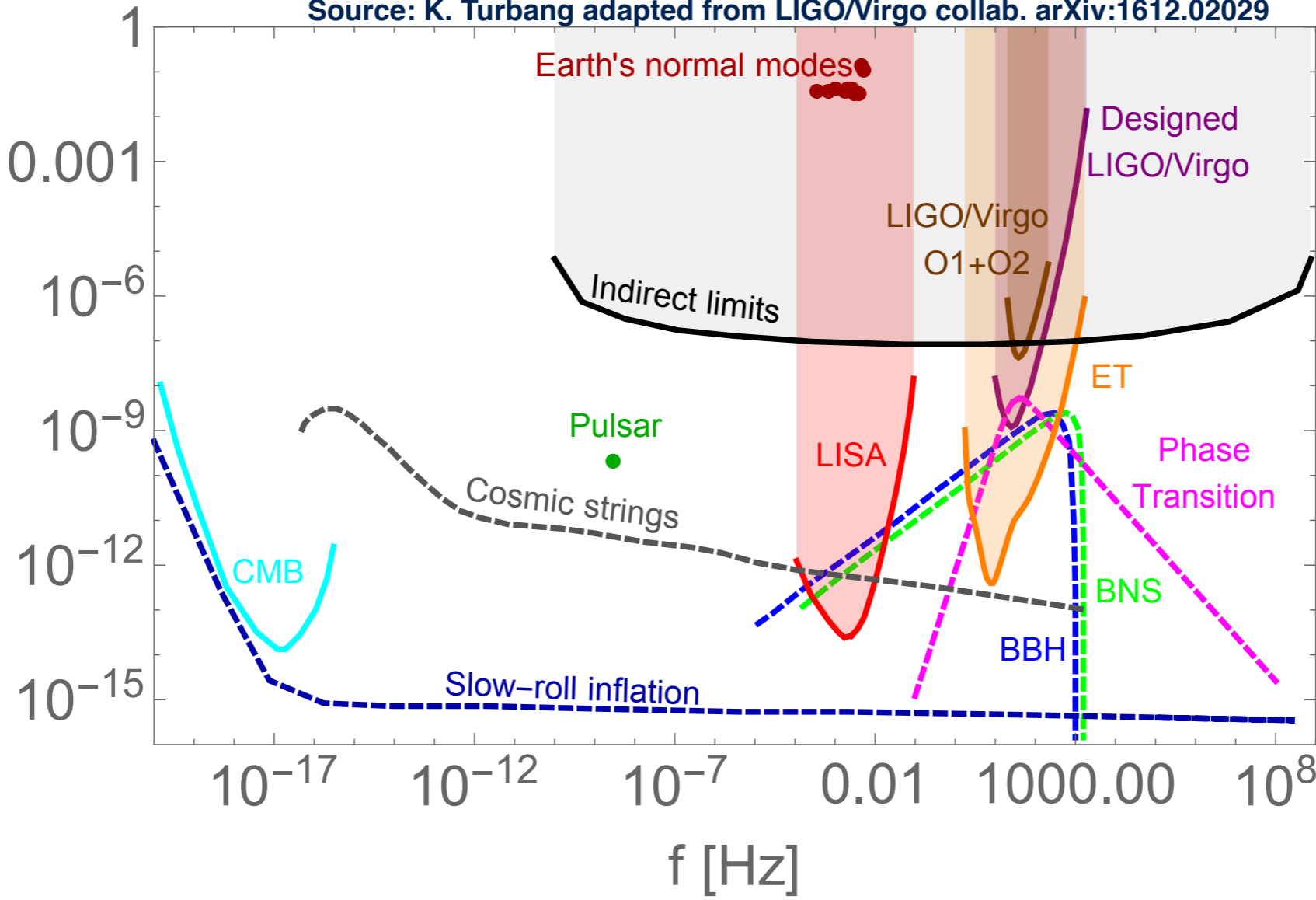
# Stochastic Background of GW



**WHAT IS IT?** *Looks like noise, detected by cross-correlation*  
 Allen Romano gr-qc/9710117

Analogue of CMB  
 but for GW

Source: K. Turbang adapted from LIGO/Virgo collab. arXiv:1612.02029



SGWB energy density over critical one  $\Omega h^2$



# Stochastic Background of GW

## ★AstroPhysical SGWB

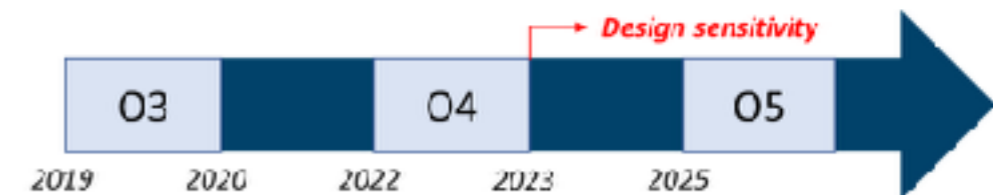
- \* Superposition of unresolvable sources

**BBH**

**BNS**

- \* Predictable after LIGO/Virgo observations  
LIGO/Virgo Phys.Rev.D 100 (2019)

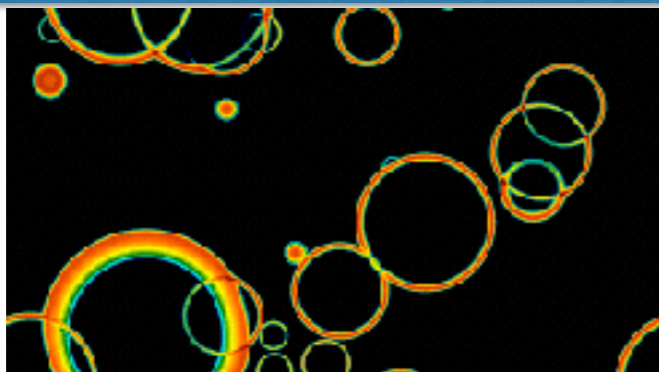
**! Most likely measured in next few years !**



## ★Cosmological SGWB

- \* Generated by energetic events during cosmological evolution

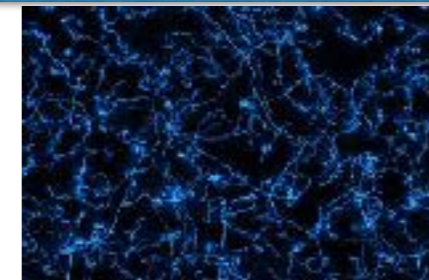
**First Order Phase Transitions**



arXiv: 1705.01783 D. Weir

**Inflation**

**Cosmic strings**

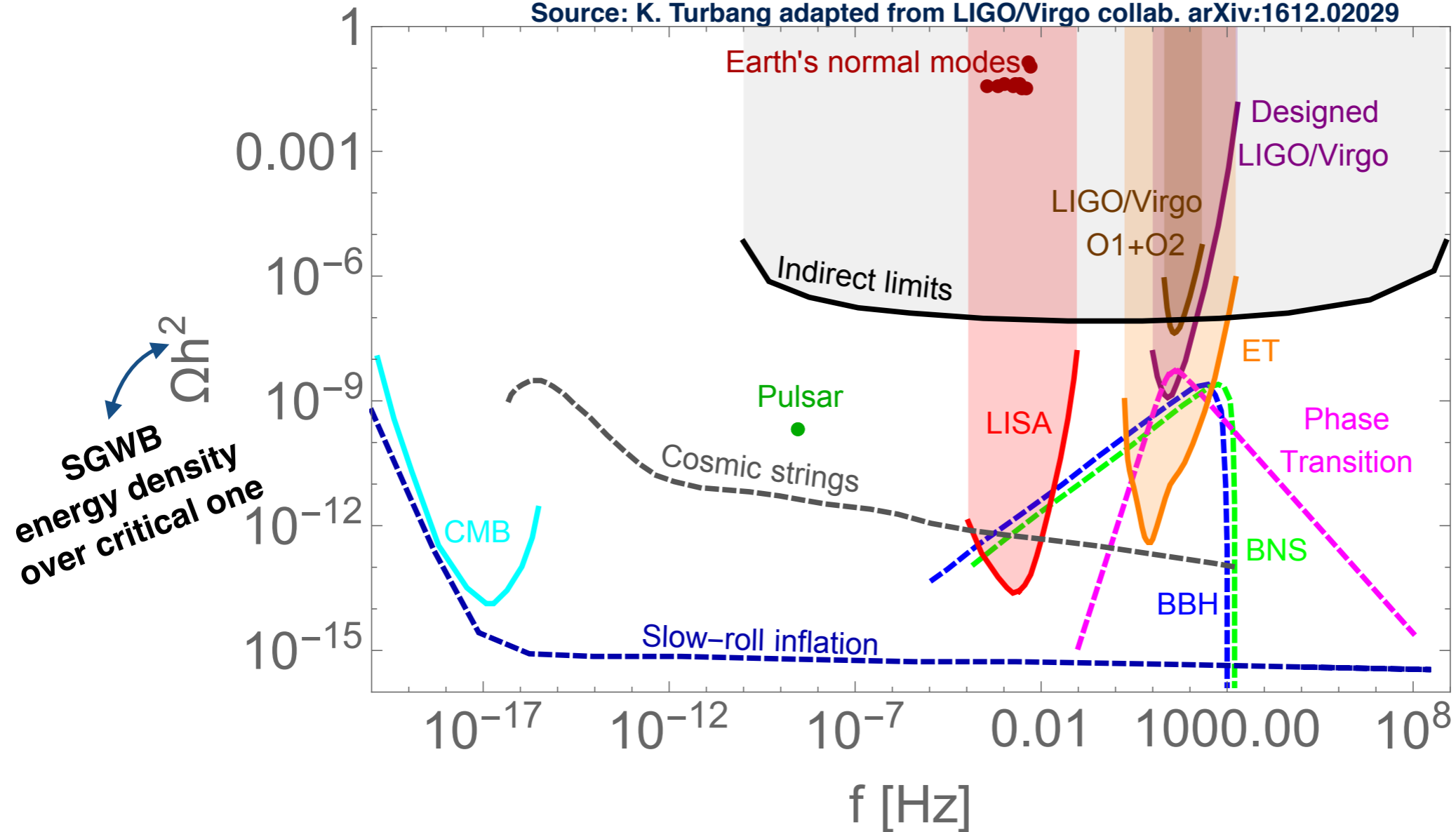


**Explore Universe earlier than CMB!**



# Stochastic Background of GW

Source: K. Turbang adapted from LIGO/Virgo collab. arXiv:1612.02029



## Experimental probes

- ★ CMB, Pulsar timing arrays (NANOgrav)
  - ★ Interferometers (LIGO/Virgo, LISA, ET, CE, BBO ....)
- LIGO/Virgo arXiv:2101.12130

**Note: Astrophysical SGWB and cosmological SGWB will superimpose**

# How cosmological SGWB is generated?

***Example: first order phase transitions***

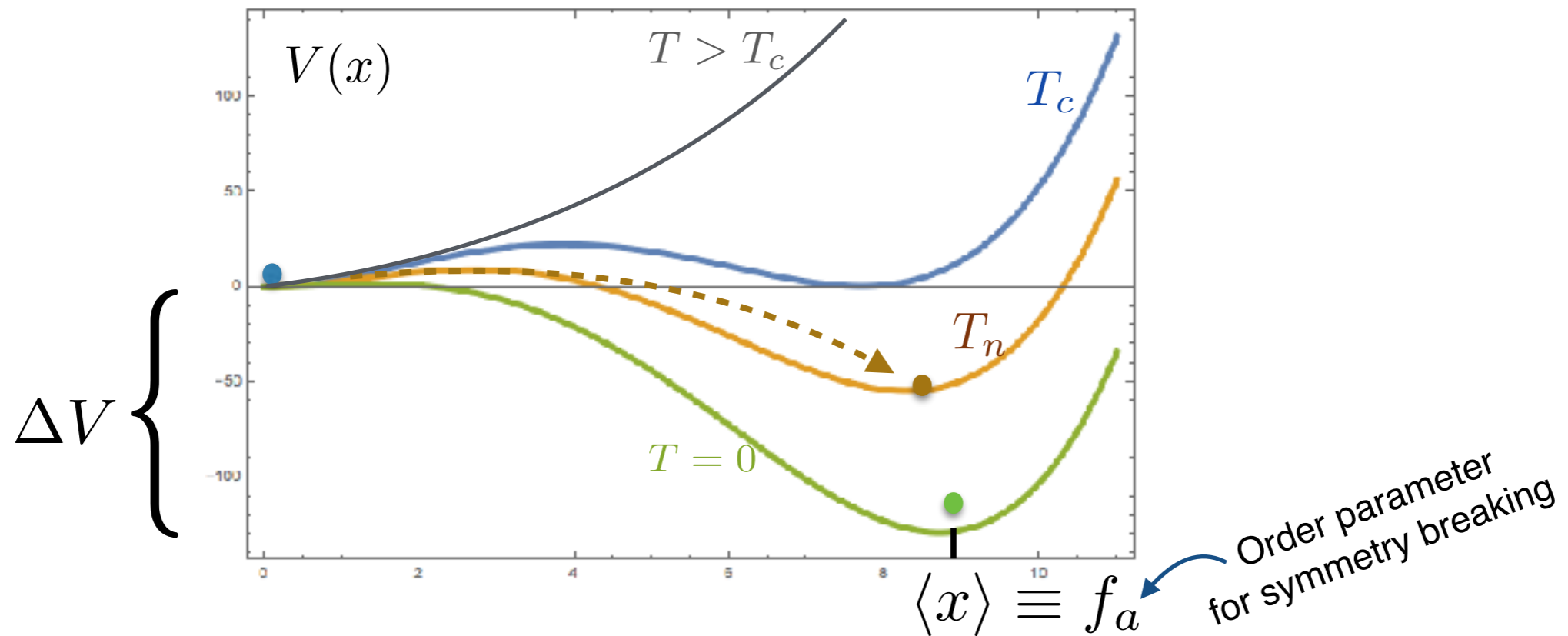


*Discontinuous transition between symmetric to non-symmetric phase*

# First order phase transitions

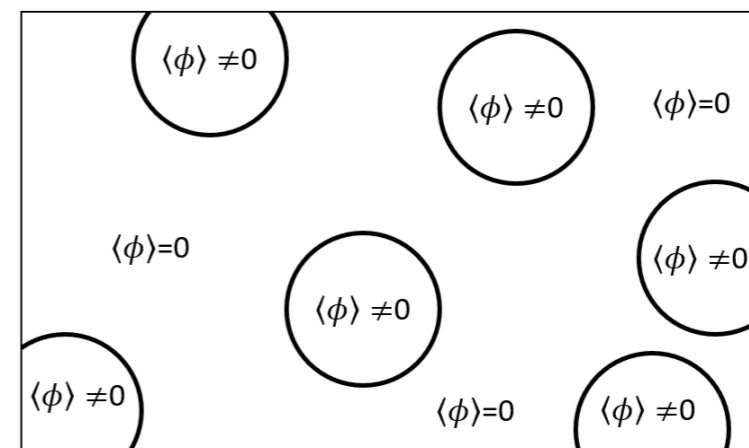
*Described in terms of potential evolution with temperature*

*Transition from metastable minimum to symmetry breaking vacuum*



$T_c$  minima are degenerate

$T_n$  nucleation to symmetry breaking vacuum occurs through formation of bubbles of the true vacuum



# SGWB from FOPT

## ***3 mechanisms to generate SBGW from FOPT***

- ◆ ***Bubble collisions***
- ◆ ***Sound Waves in the plasma***
- ◆ ***Turbulence***

**Which dominates depends on PT properties**

## ***Many subtleties in computation of correct GW signal***

- **Bubble wall velocity/acceleration**
- **Correct estimation of friction in plasma**
- **Energy budget determines production mechanism**
- **Hydrodynamic simulations**

Bodeker Moore '17

# SGWB from FOPT

## 3 mechanisms to generate SBGW from FOPT

- ✦ *Bubble collisions*
- ✦ *Sound Waves in the plasma*
- ✦ *Turbulence*

Which dominates depends on PT properties

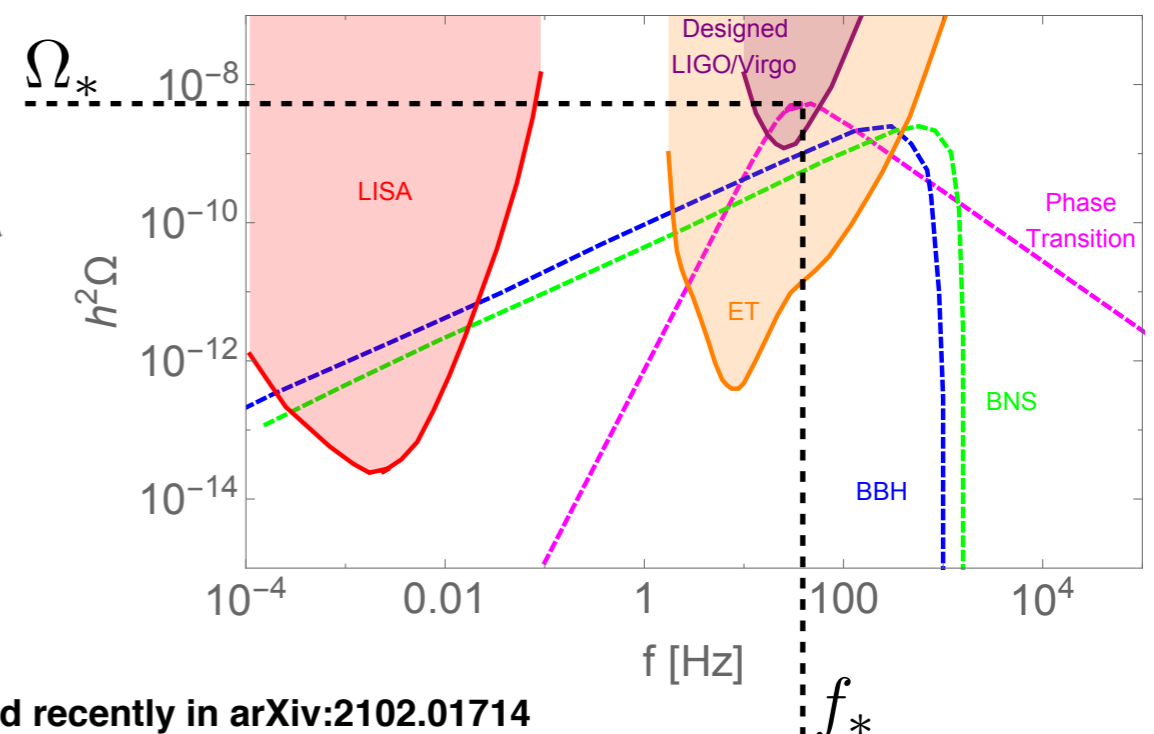
## Many subtleties in computation of correct GW signal

- Bubble wall velocity/acceleration
- Correct estimation of friction in plasma
- Energy budget determines production mechanism
- Hydrodynamic simulations

## GW signal is broken power law

$$h^2\Omega(f) = \Omega_* \left(\frac{f}{f_*}\right)^{a_1} \left(1 + \left(\frac{f}{f_*}\right)^\Delta\right)^{(a_2 - a_1)/\Delta}$$

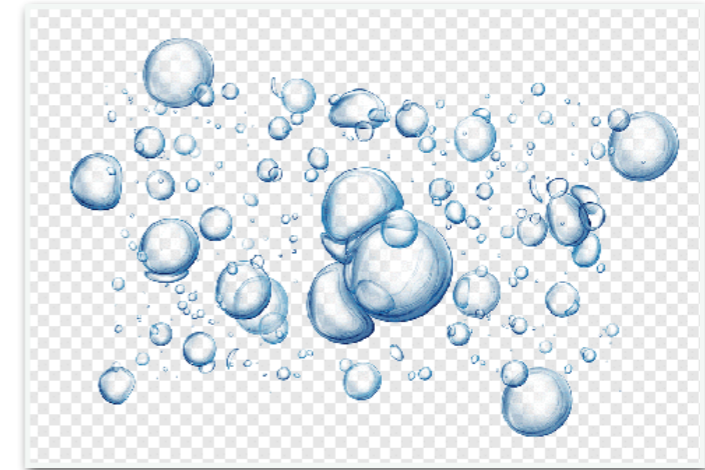
constants  $a_1, a_2, \Delta, f_*, \Omega_*$



See e.g. LISA W.G. arXiv:1910.13125, O3 data of LIGO/Virgo analysed recently in arXiv:2102.01714

# First order phase transitions

- ◆ Discontinuous Transition between symmetric to non-symmetric phase (order parameter)
- ◆ Characterized by bubble formation
- ◆ *Bubbles can source GW*



## ★ In the Standard Model

- \* QCD Phase Transition ( $T \sim \text{GeV}$ )? In SM No first order
- \* EW Phase Transition ( $T \sim 100 \text{ GeV}$ )? In SM No first order

(If very light Higgs it could have been strongly first order)  
'81 Witten

		Top Generation de masse (fermion)			
		I	II	III	IV
Majorana					
Dirac	U	C	t	q	H
Majorana					
Dirac	d	s	b	g	
Dirac	$\nu_e$	$\nu_\mu$	$\nu_\tau$	$Z^0$	
Dirac	e	$\mu$	$\tau$	W	

**FOPT is signal of BSM physics**

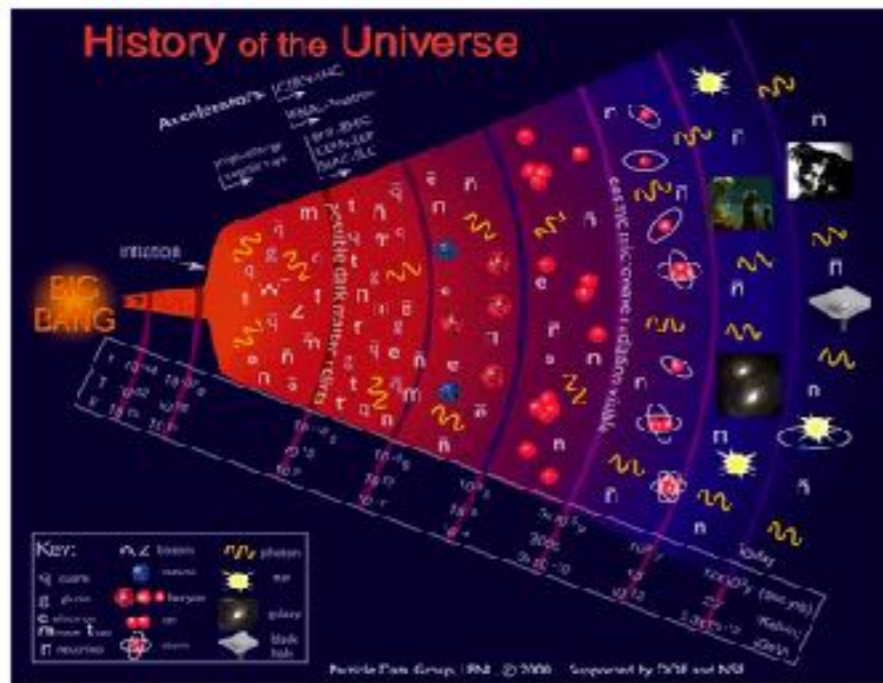
## ★ In Beyond the Standard Model

Modify EW or QCD phase transition  
 New symmetries which undergo PT  
 PT in dark sectors

E.g. arXiv:2106.15602 with Iason Baldes for **baryogenesis**

# Conclusions

*Many years of interesting Physics are in front of us!*



*Shedding light into  
Early History  
of our Universe*

