The Pheno Group and GW activities

Alberto Mariotti

HEP@VUB VRIJE UNIVERSITEIT BRUSSEL

Also on behalf of the TENA group for the GW activities

Joint HEP@VUB and IIHE meeting

16 November 2021

VIRGO

Pheno @ VUB

Many fundamental questions still open…

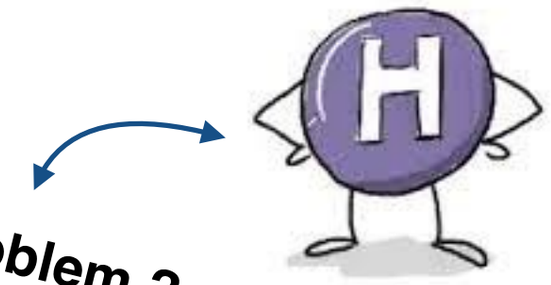
Force Unification ?

String Theory ?

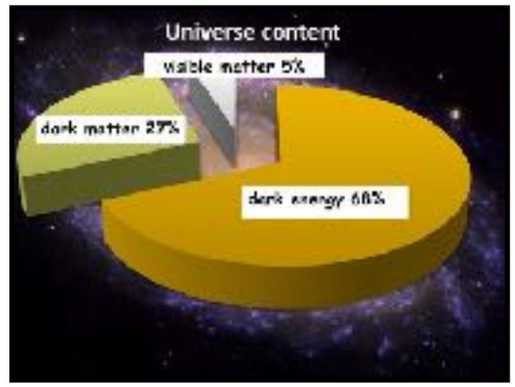
Quantum Gravity ?

Inflation ?

Hierarchy problem ?



Dark matter nature?



Matter-Antimatter ?

What is their signatures in:

? Collider Physics ?

? Cosmoparticle Physics ?

? Gravitational Waves ?

The group on BSM and GW physics

STAFF

Alberto Mariotti

10% ZAP

Mairi Sakellariadou

Alex Sevrin

POSTDOC

Simone Blasi

BSM , Cosmology and GW physics

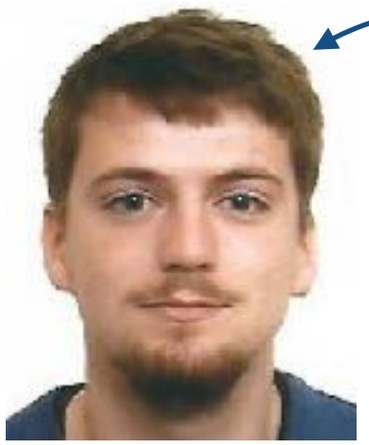
Modeling and data analysis for GW

Joint with UAntwerp

PHD

Kevin Turbang

Aaron Rase



Sam Junius

Unconventional Dark Matter Models

Joint with ULB

The group on BSM and GW physics

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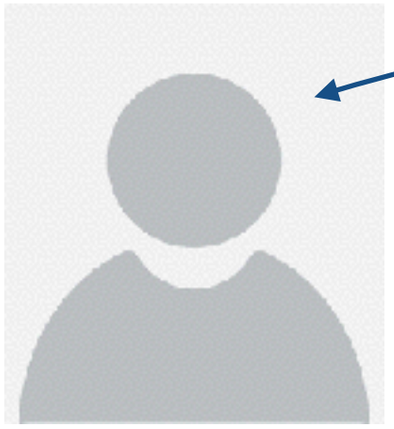
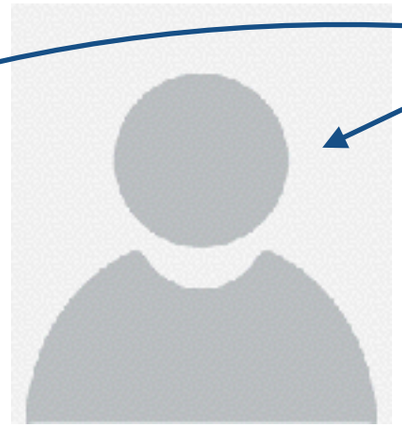




https://inspirehep.net/jobs/1889113

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

PHD

Kevin Turbang

Aaron Rase

Sam Junius

L.Calibbi, F.D'Eramo, S.Junius, L.Lopez-Honorez, A.M.
JHEP 05 (2021) 234

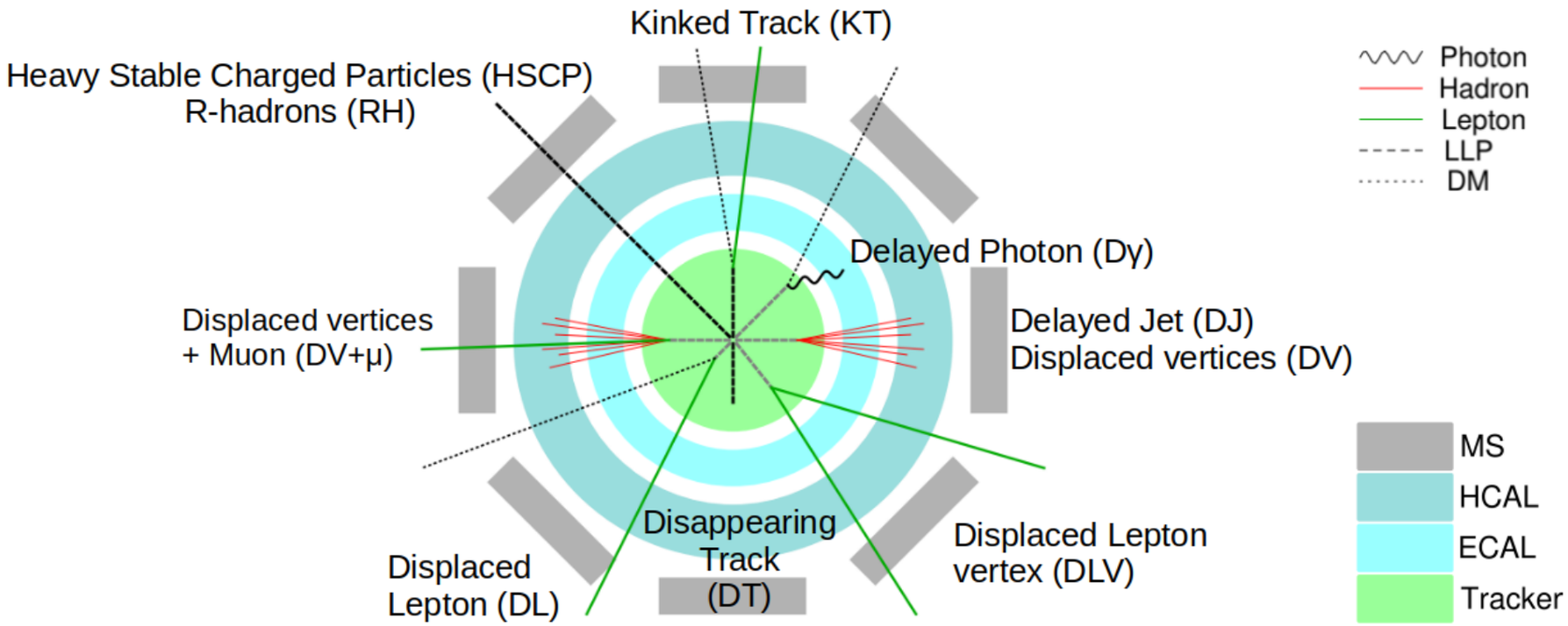
Unconventional DM models

★Feebly interacting Dark Matter (FIMP)

★Produced during the early Universe with Freeze-in mechanism

★Avoids most of standard DM experimental constraints

★Can lead to Long Lived Particles Signatures at the LHC



Large variety of signatures with challenging triggers and reconstructions

L.Calibbi, F.D'Eramo, S.Junius, L.Lopez-Honorez, A.M.
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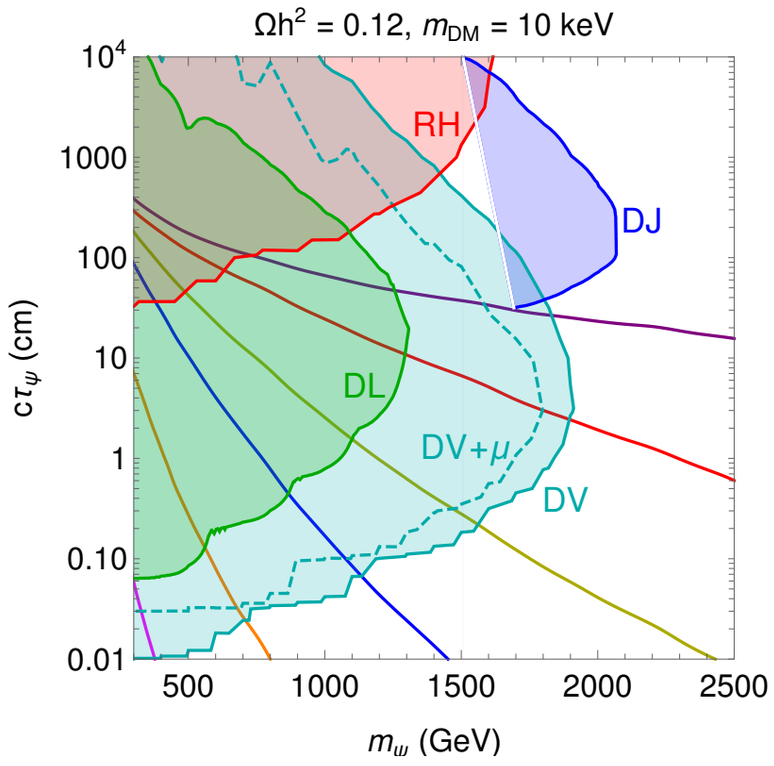
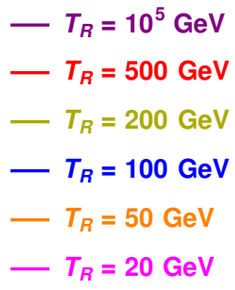




Reheating temperature upper bounds

Example for a topphilic FIMP DM model

Lifetime and mass of dark sector mediator can pinpoint to cosmological history of our Universe (reheating temperature)

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

Universiteit Antwerpen

Activities

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

★**Instrumentation: ET PathFinder** https://www.etpathfinder.eu

★**Connect with VUB photonics** ⟷ VUB 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

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

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

★Assumed to be

- ✳ ***Isotropic ("or not")***
- ✳ ***Unpolarized***
- ✳ ***Stationary***
- ✳ ***Smaller than detector noise***

Should be detected by cross correlation between different detectors

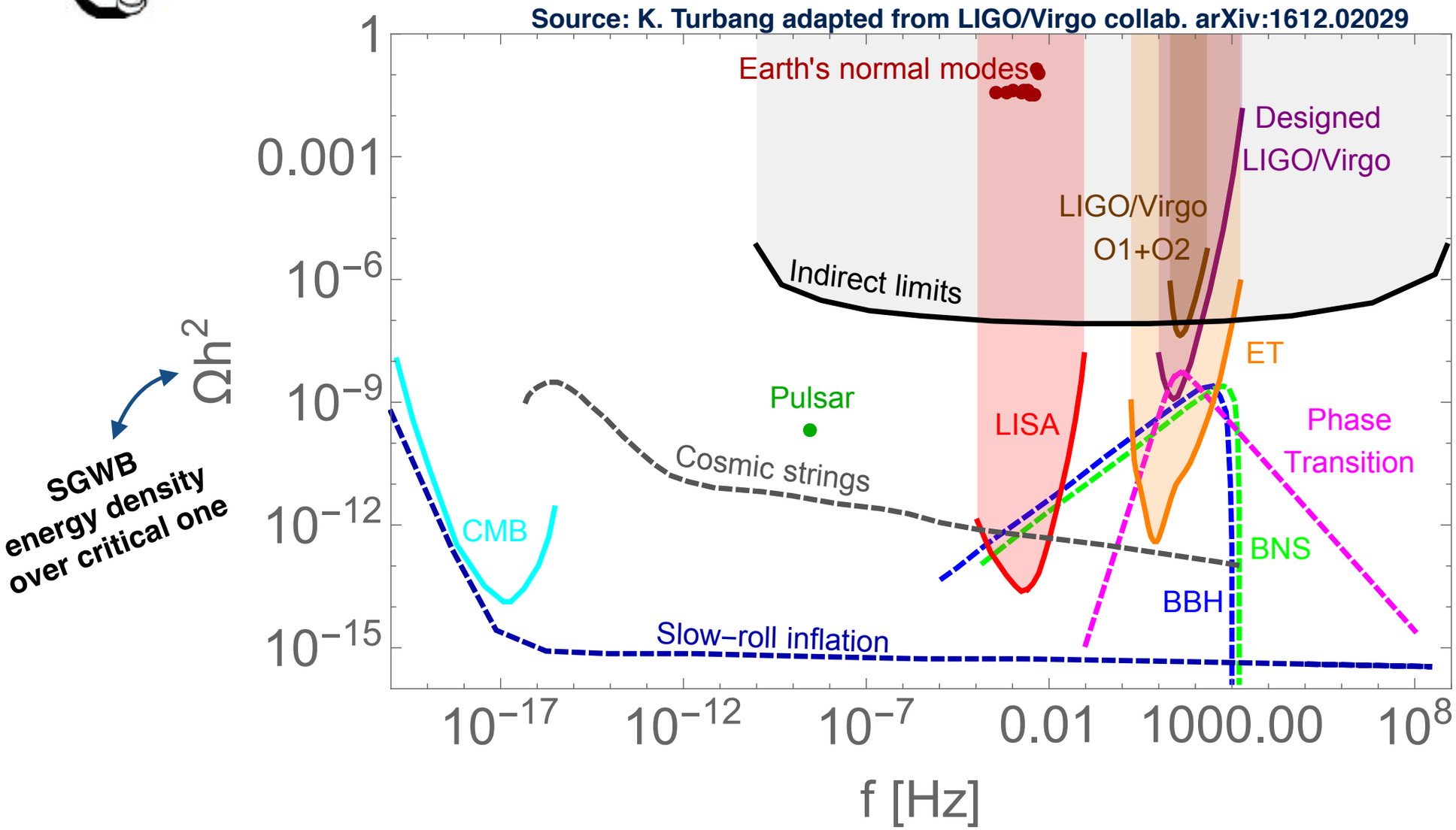
Stochastic Background of GW

WHAT IS IT? *Looks like noise, detected by cross-correlation*

Allen Romano gr-qc/9710117

Analog of CMB but for GW

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



SGWB energy density over critical one

AstroPhysical SGWB ⟷ **Cosmological SGWB**

Experimental probes

Stochastic Background of GW

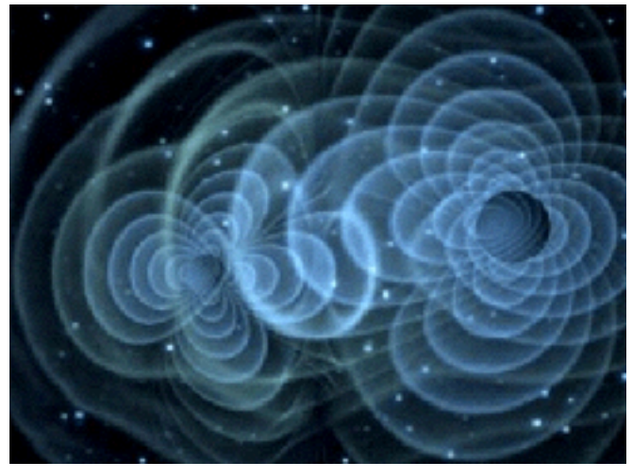
★AstroPhysical SGWB

✳ Superposition of unresolvable sources

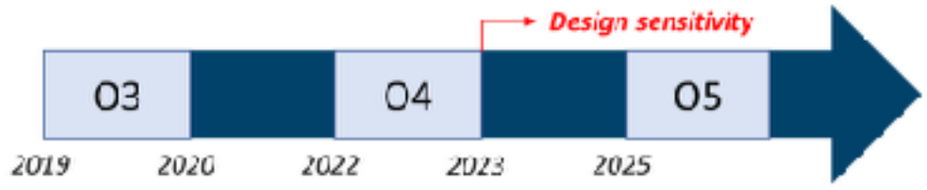
BBH **BNS**

✳ Predictable after LIGO/Virgo observations

LIGO/Virgo Phys.Rev.D 100 (2019)



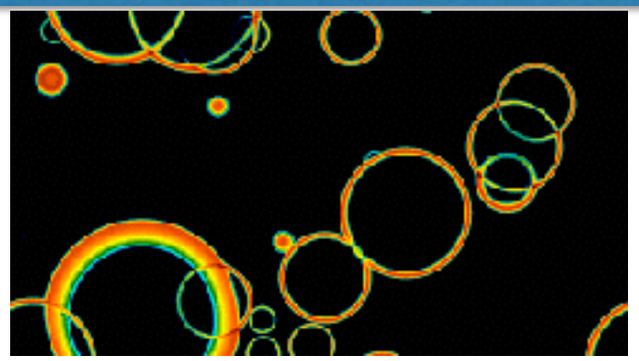
! Most likely measured in next few years !



★Cosmological SGWB

✳ Generated by energetic events during cosmological evolution

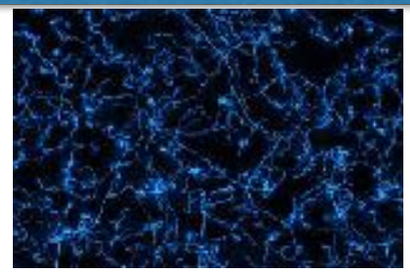
First Order Phase Transitions



arXiv: 1705.01783 D. Weir

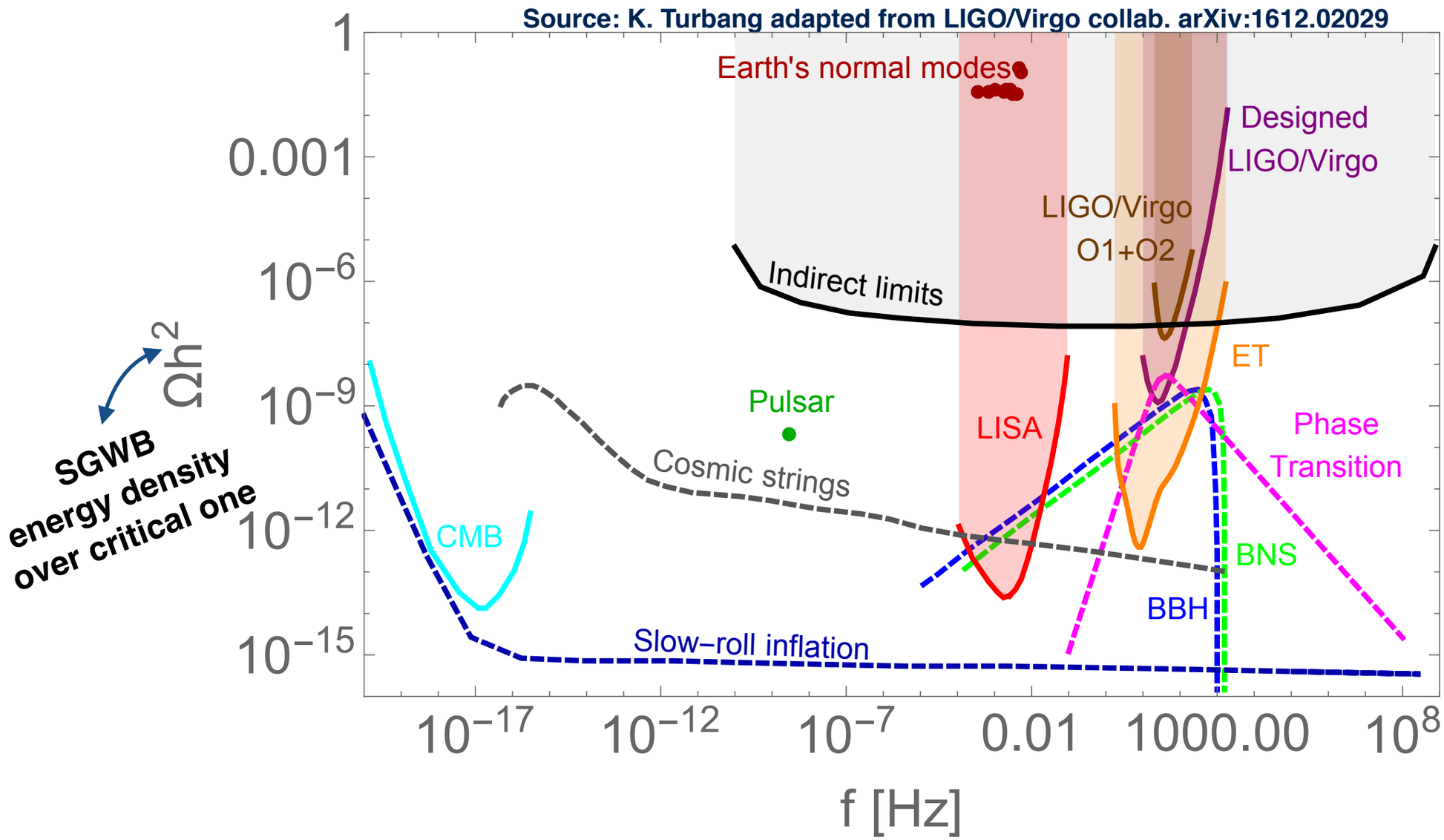
Inflation

Cosmic strings



Explore Universe earlier than CMB!

Stochastic Background of GW



Experimental probes

★CMB, Pulsar timing arrays (NANOgrav)

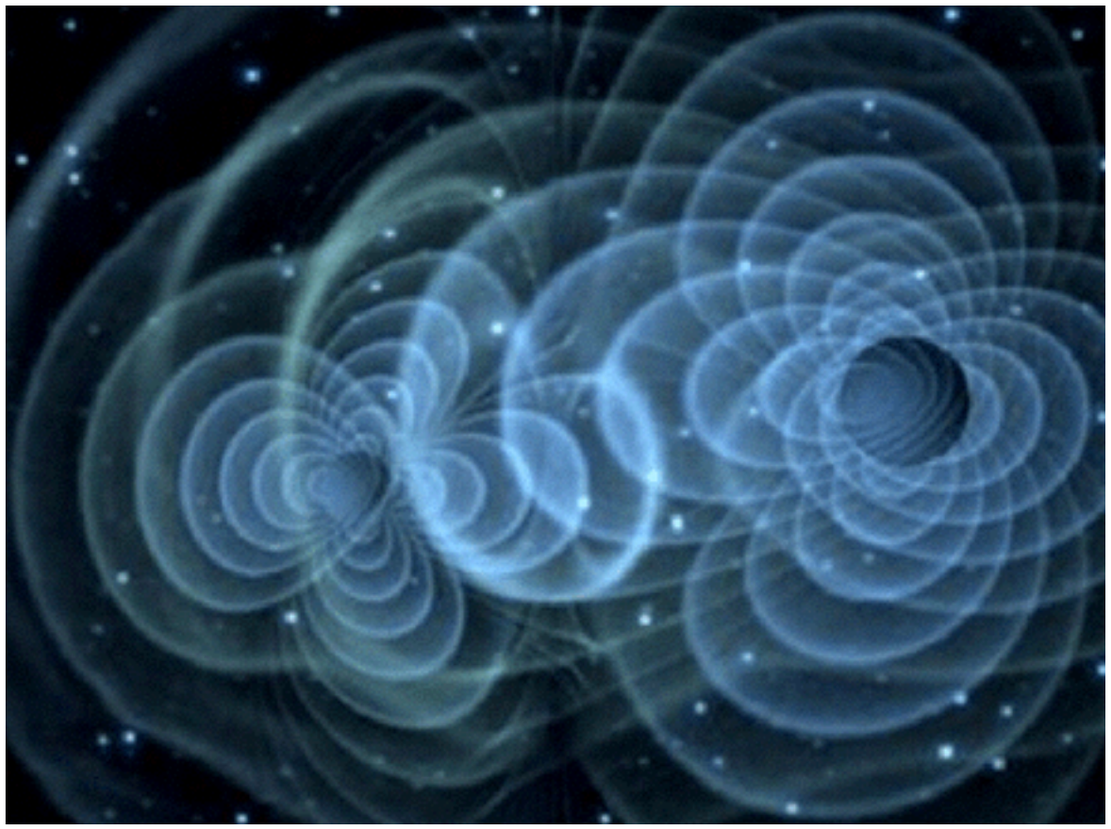
★**Interferometers (LIGO/Virgo, LISA, ET, CE, BBO ....)**

LIGO/Virgo arXiv:2101.12130

Note: Astrophysical SGWB and cosmological SGWB will superimpose

How we detect SGWB?

Do we have some extra handle for the astrophysical SGWB?



How cosmological SGWB is generated?

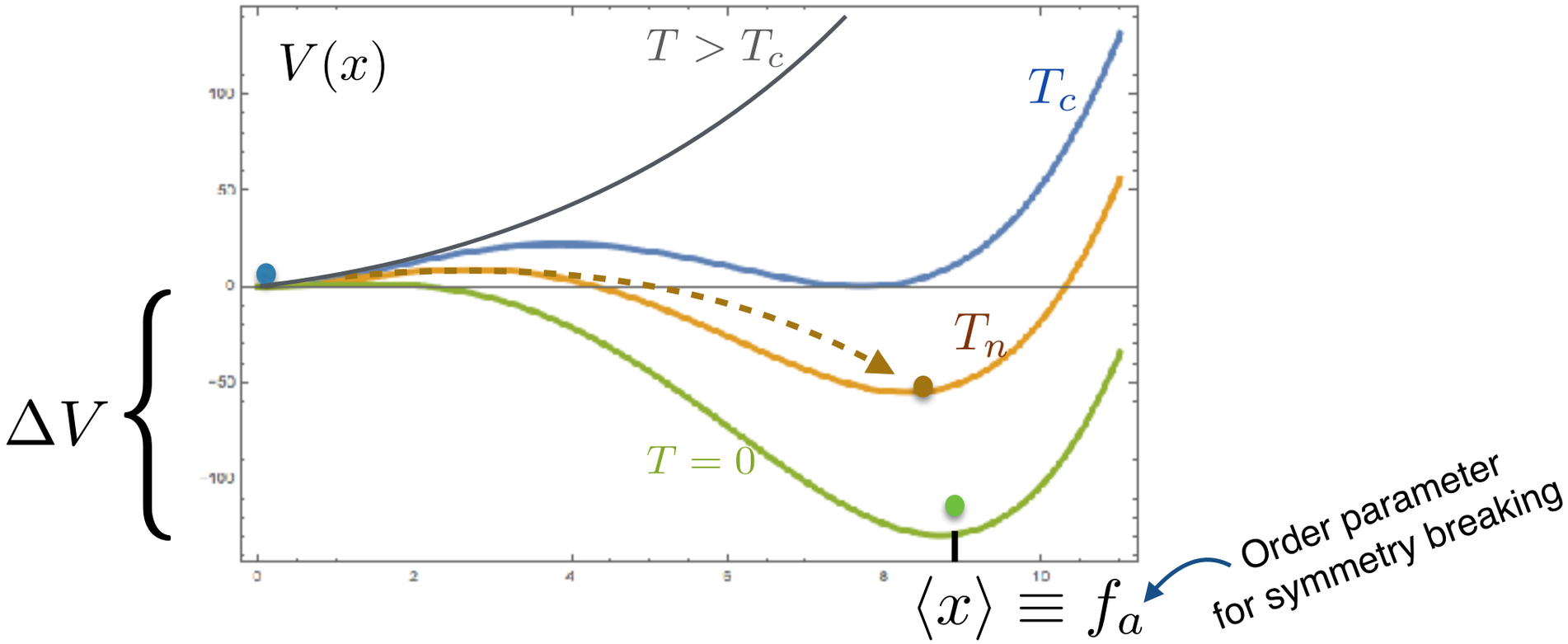
Example: first order phase transitions

Discontinuous transition between symmetric to non-symmetric phase

First order phase transitions

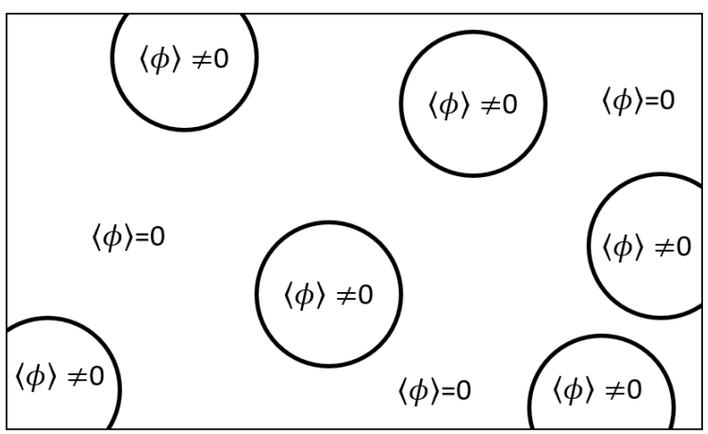
Described in terms of potential evolution with temperature

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

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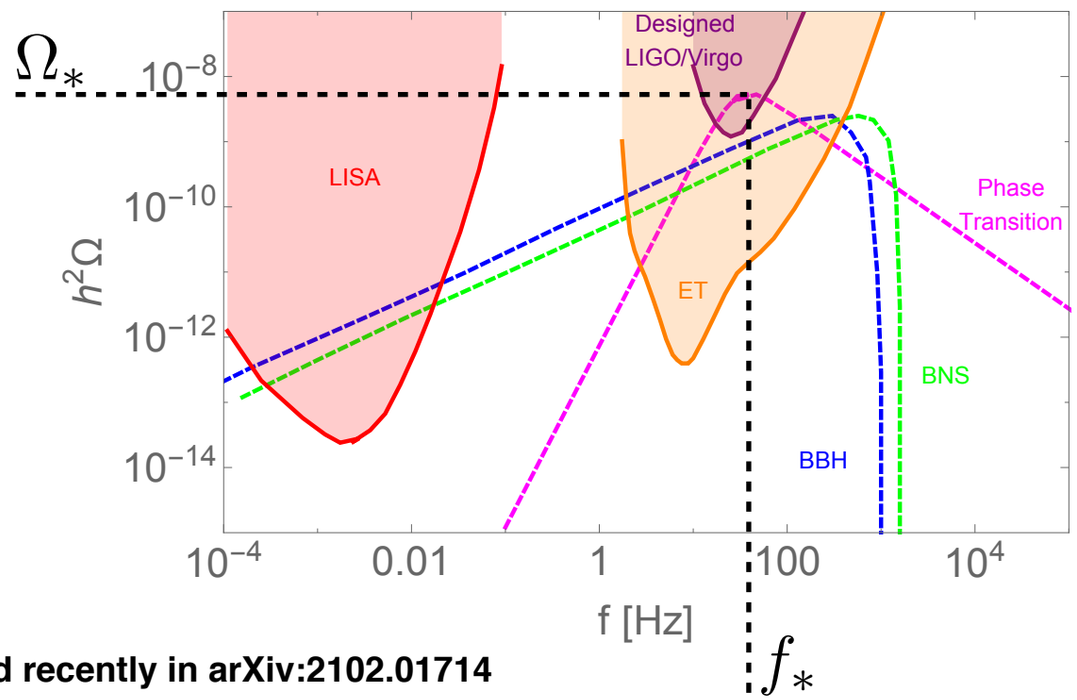
GW signal is broken power law

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

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

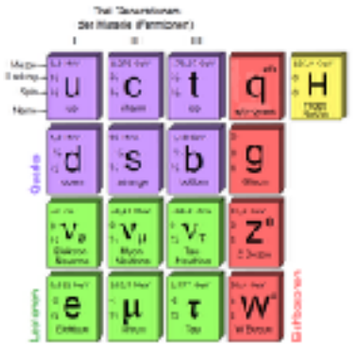


See e.g. LISA W.G. arXiv:1910.13125, O3 data of LIGO/Virgo analysed recently in arXiv:2102.01714

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 ~ GeV)? In SM No first order
- ✳EW Phase Transition (T~ 100 GeV)? In SM No first order

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

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*

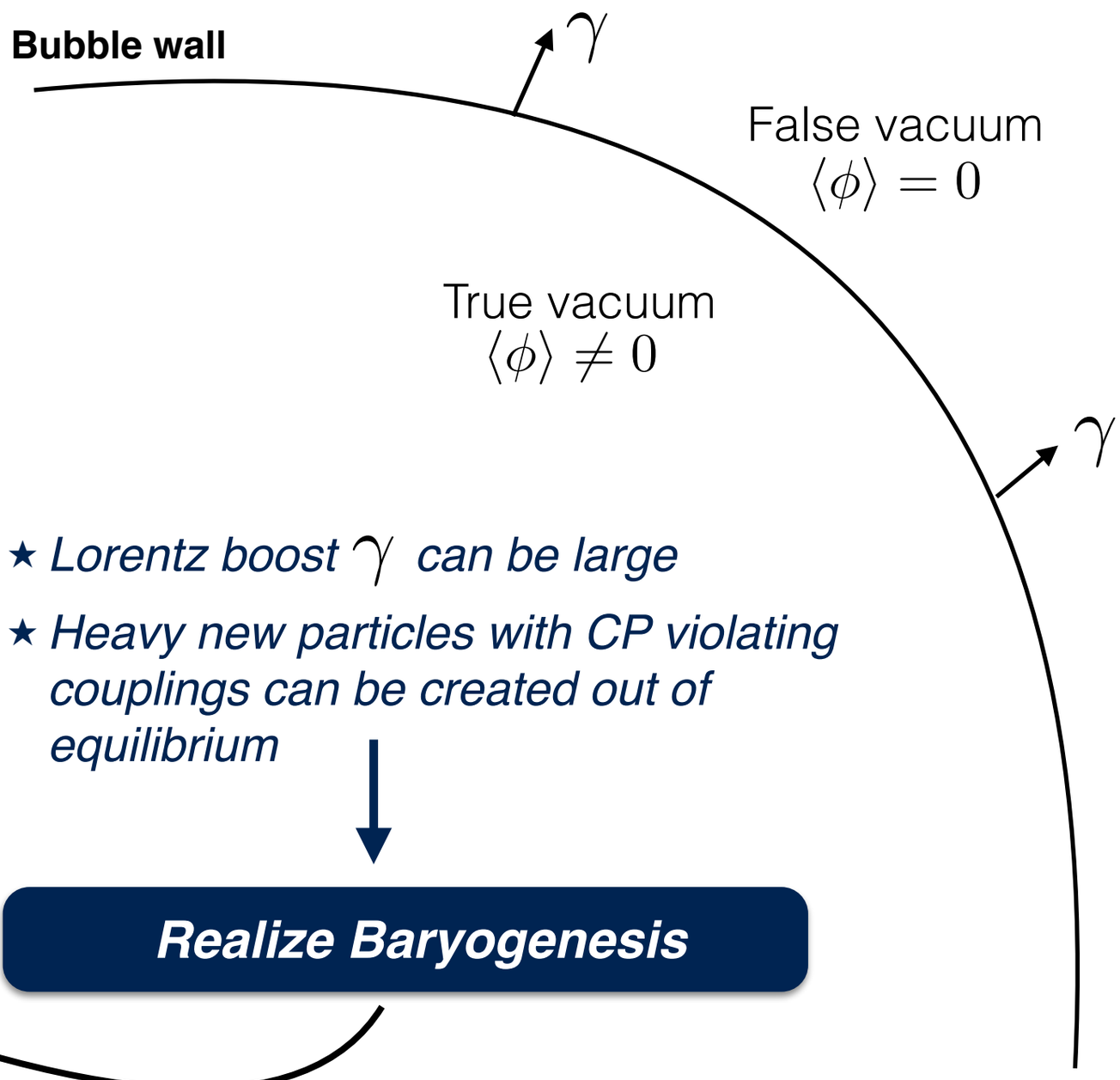
E.g. arXiv:2106.15602 with Iason Baldes for *baryogenesis*

I. Baldes, S. Blasi, A.M, A.Sevrin, K.Turbang

arXiv:2106.15602

FOPT and baryogenesis

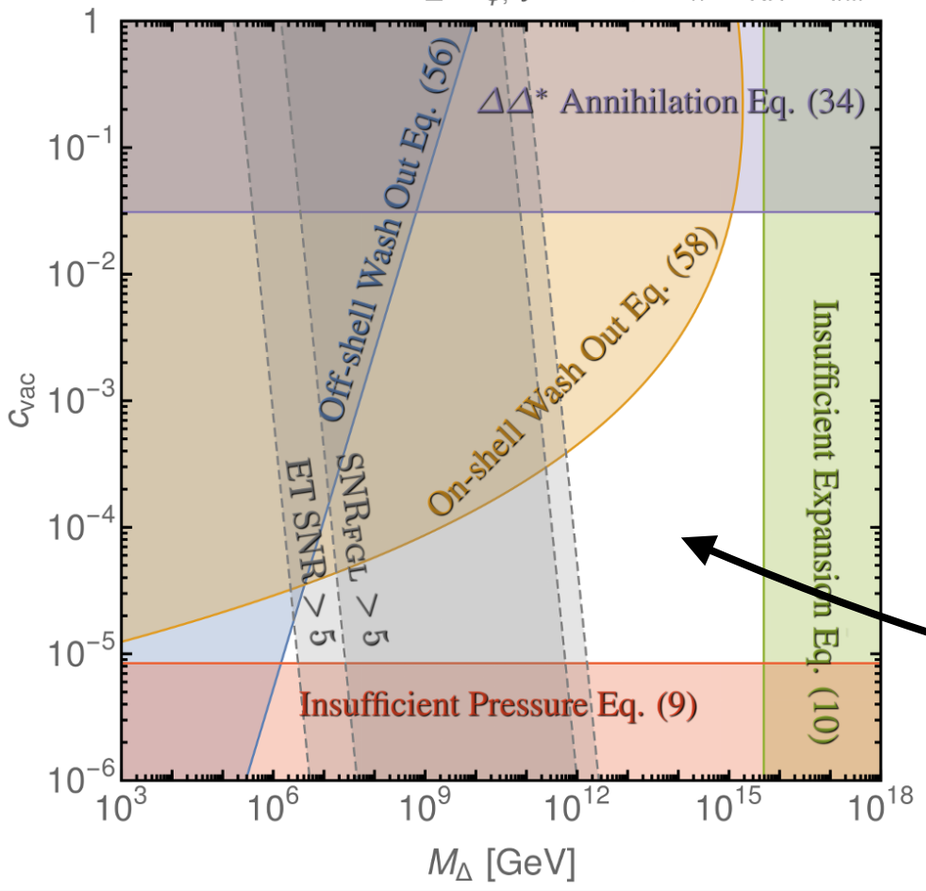
✦FOPT implies bubble formation and expansion



- ★ *Lorentz boost γ can be large*
- ★ *Heavy new particles with CP violating couplings can be created out of equilibrium*

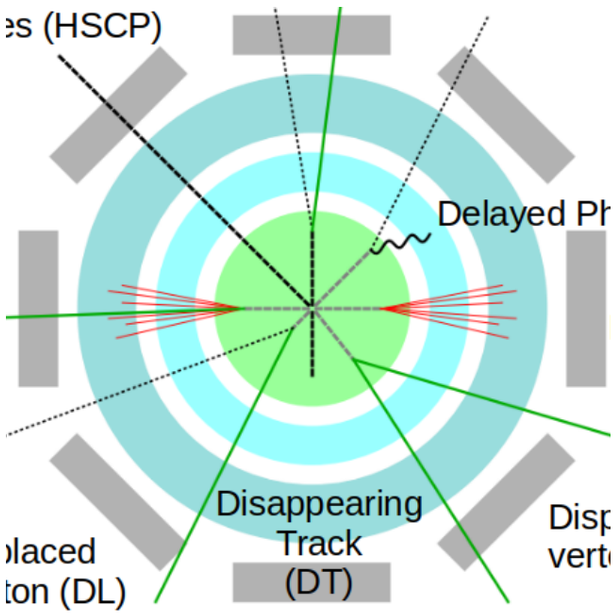
Realize Baryogenesis

viable region to explain matter-antimatter asymmetry



Conclusions

Many years of interesting Physics are in front of us!



Shedding light into Fundamental Questions in HEP