Prospects to scrutinise or smash SM*A*S*H

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Cosmology Seminar
Helsinki Institute of Physics
Helsinki, Finland
April 17, 2024

Outline

- Standard Model*Axion*Seesaw*Higgs-Portal Inflation (SM*A*S*H):

  A minimal model of particle physics and cosmology
- Vacuum Stability in SM*A*S*H
- Inflation in SM*A*S*H
- (P)reheating in SM*A*S*H
- Dark Matter in SM*A*S*H
- Stochastic Gravitational Wave Background in SM*A*S*H
- Summary

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Minimal model of particle physics and cosmology

[Ballesteros, Redondo, AR, Tamarit, arXiv:1608.05414; 1610.01639]

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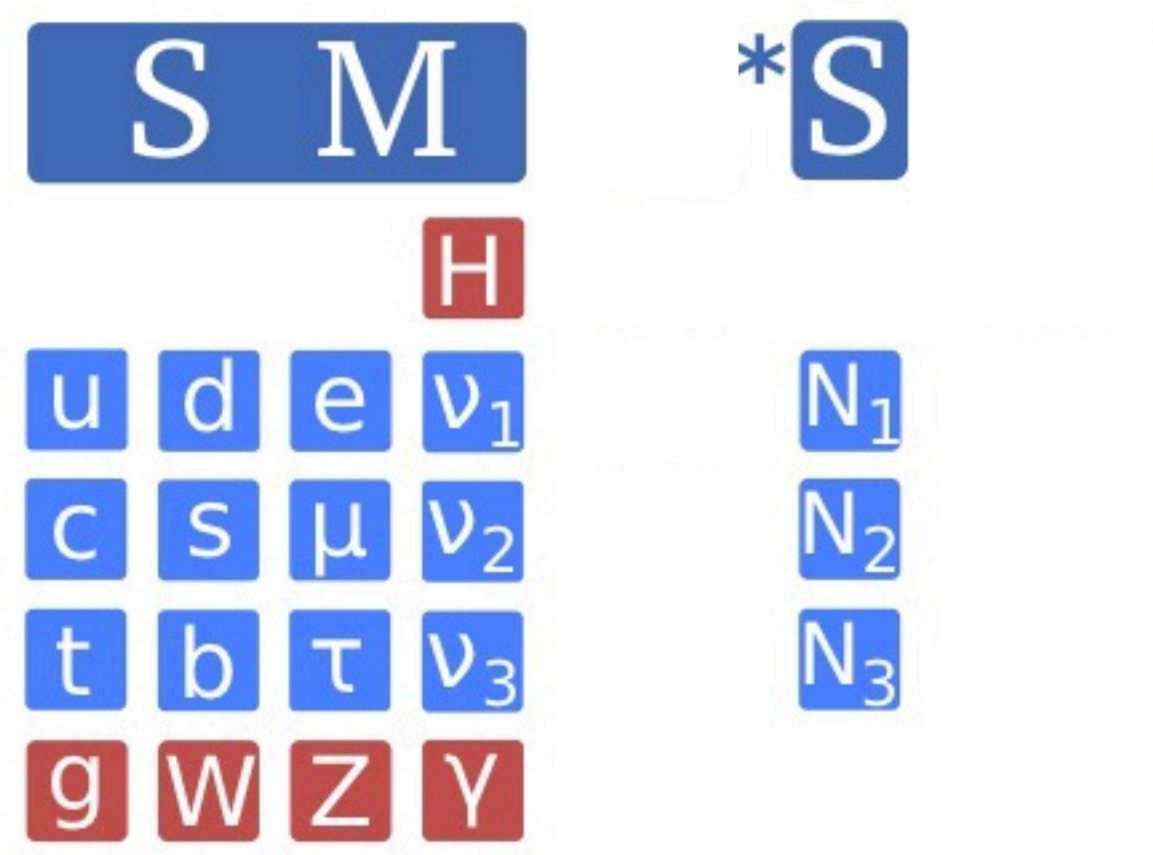

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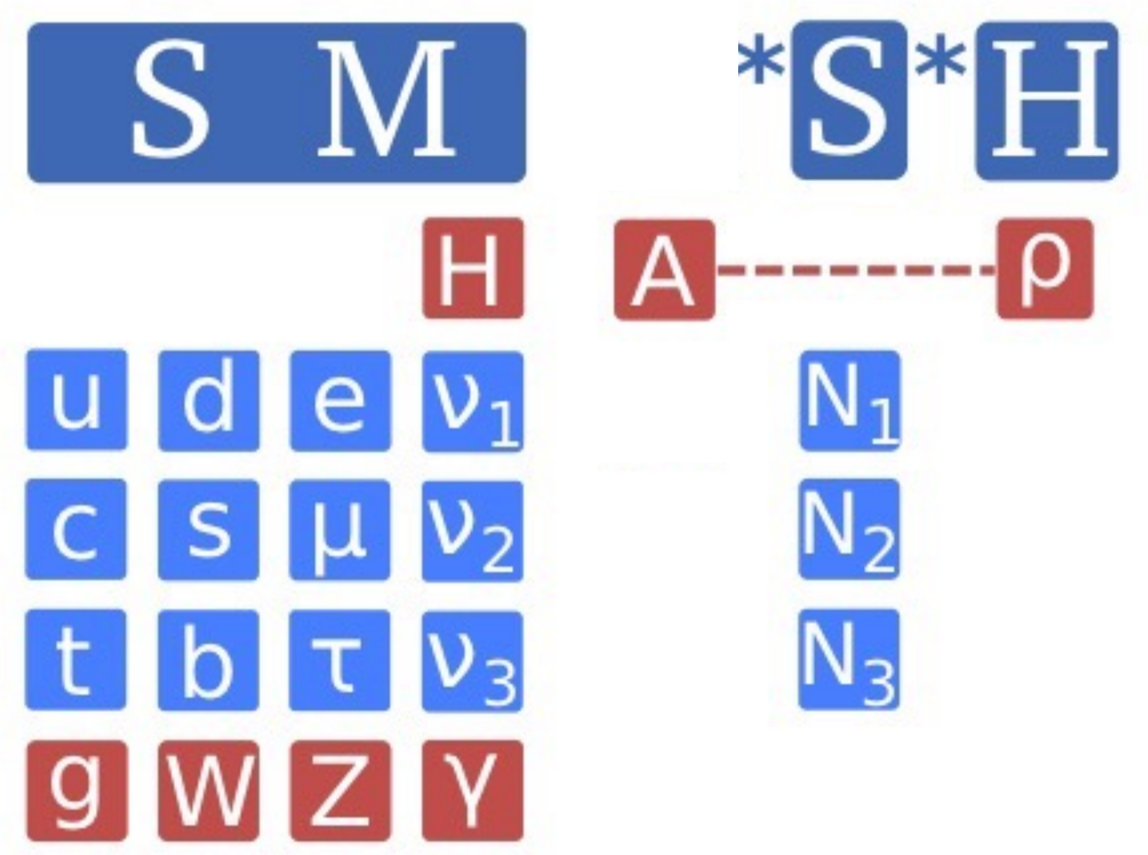

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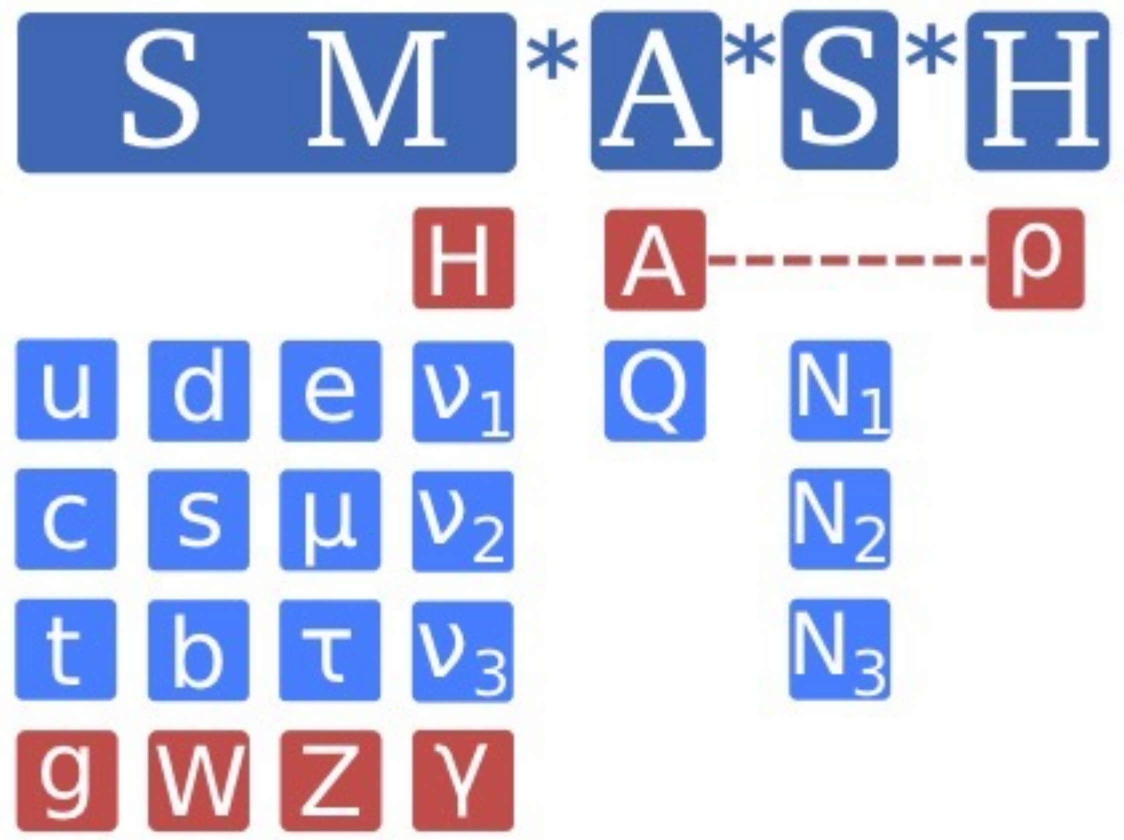

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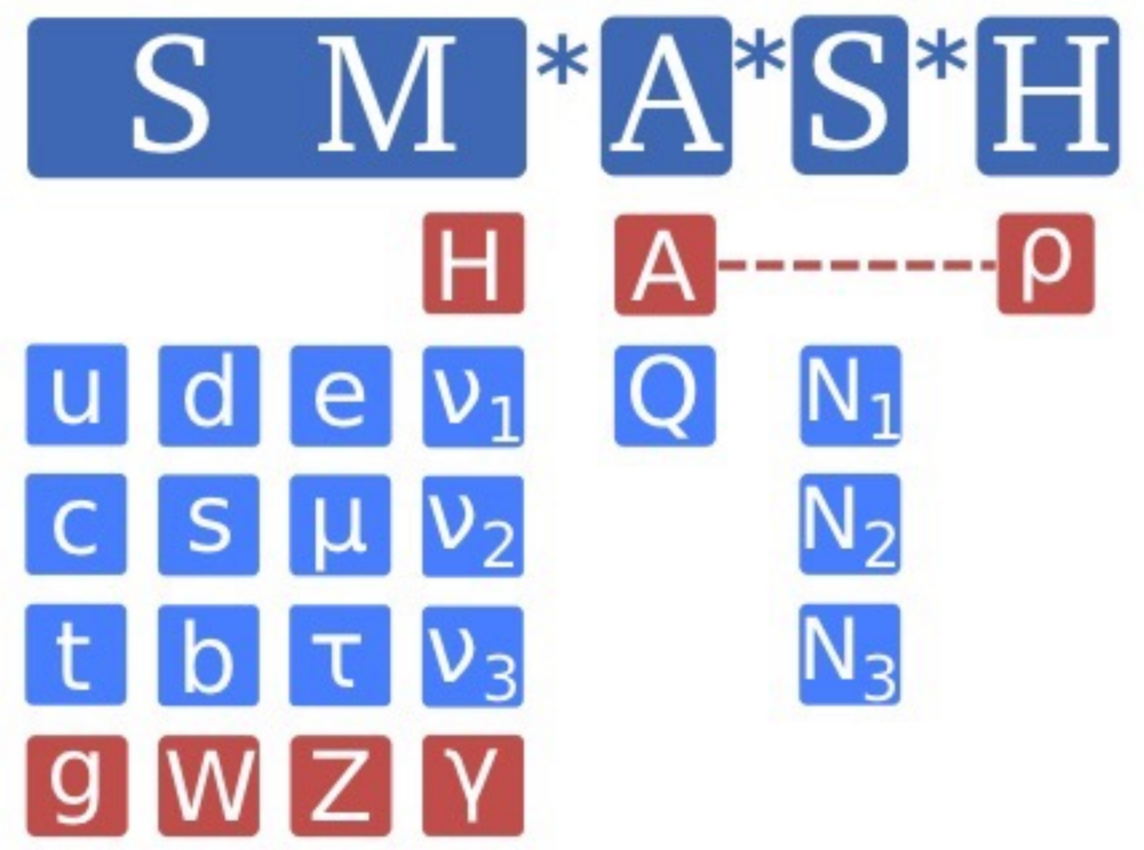

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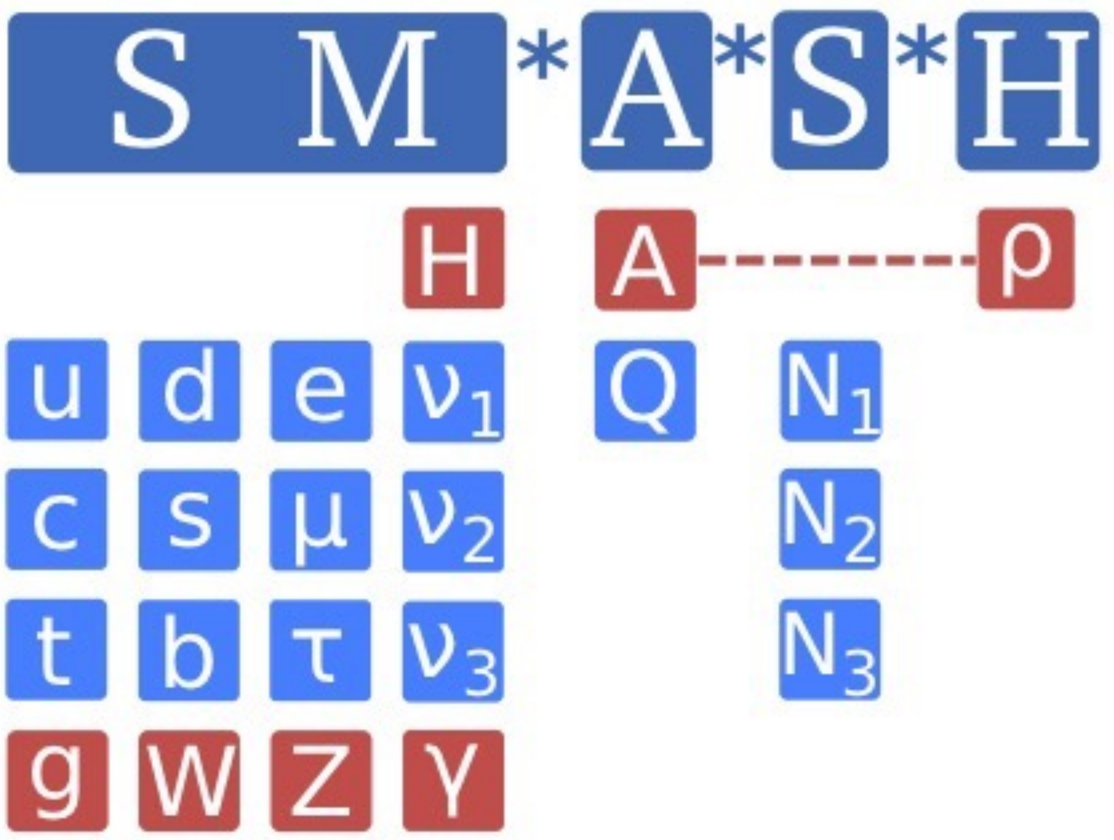

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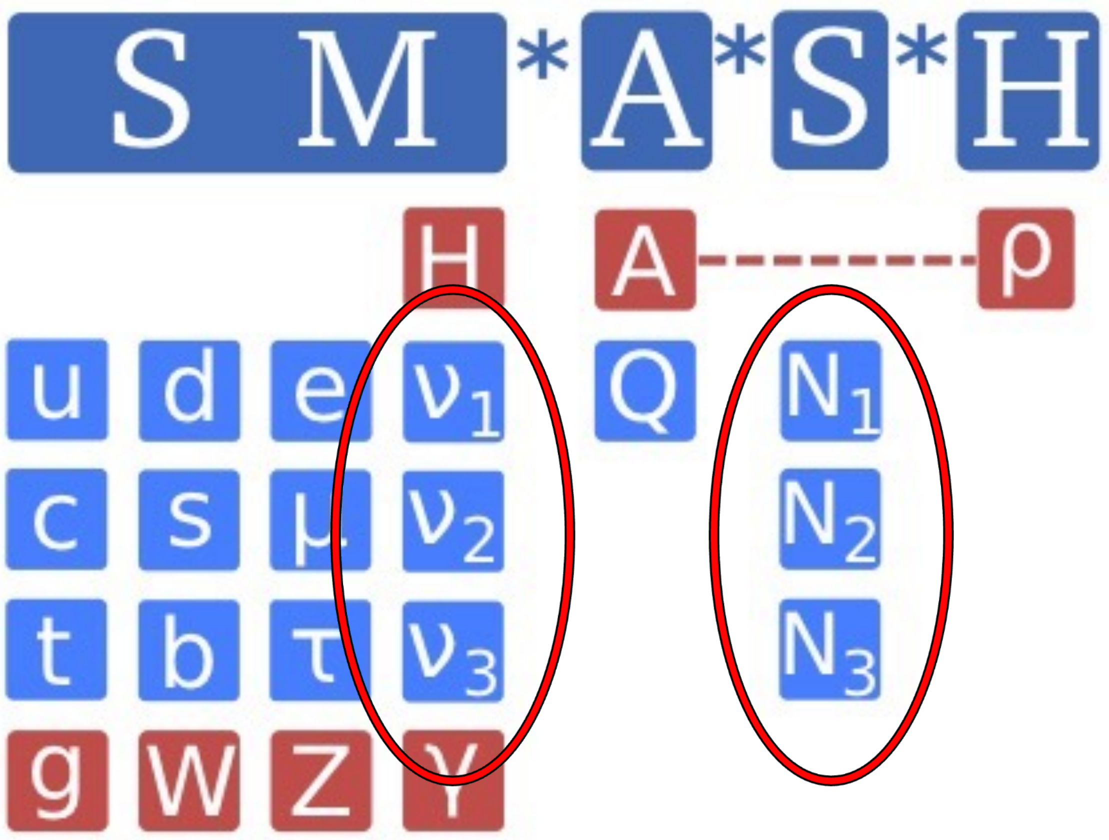
4. **Baryon asymmetry** (Thermal leptogenesis)



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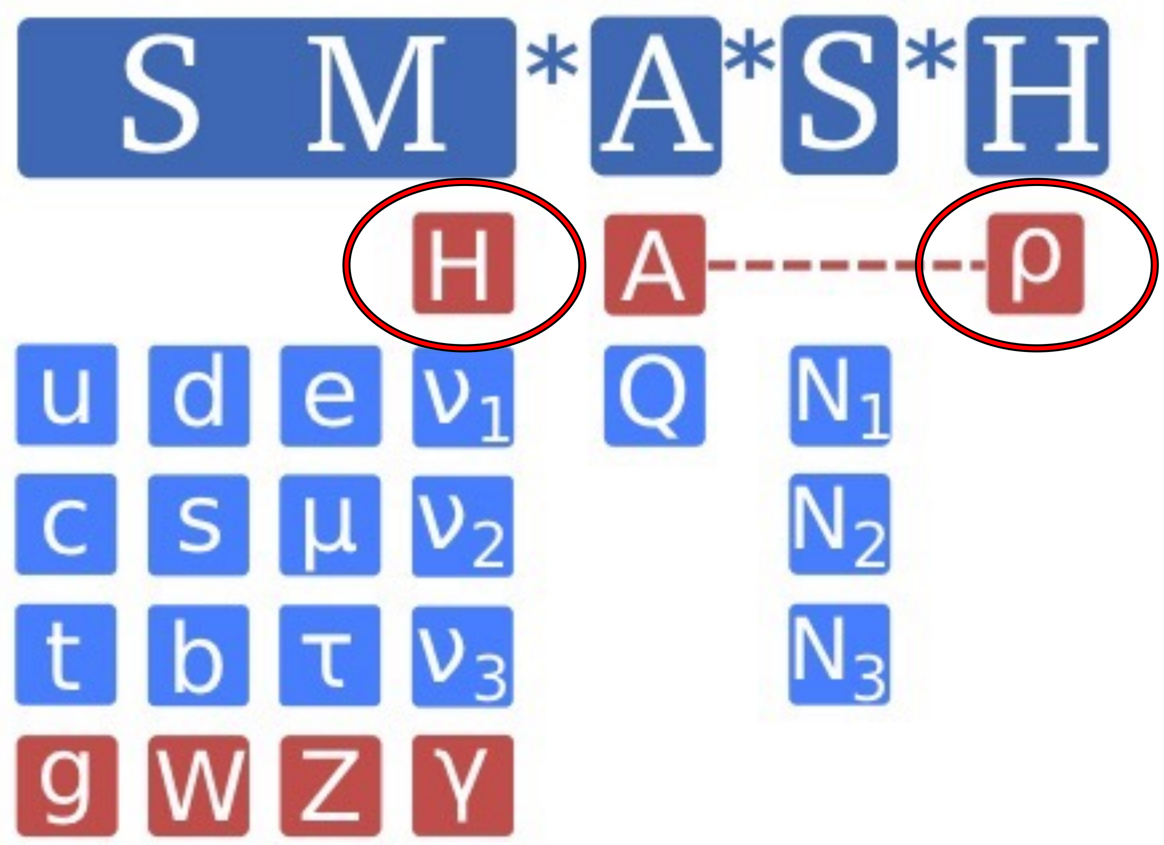

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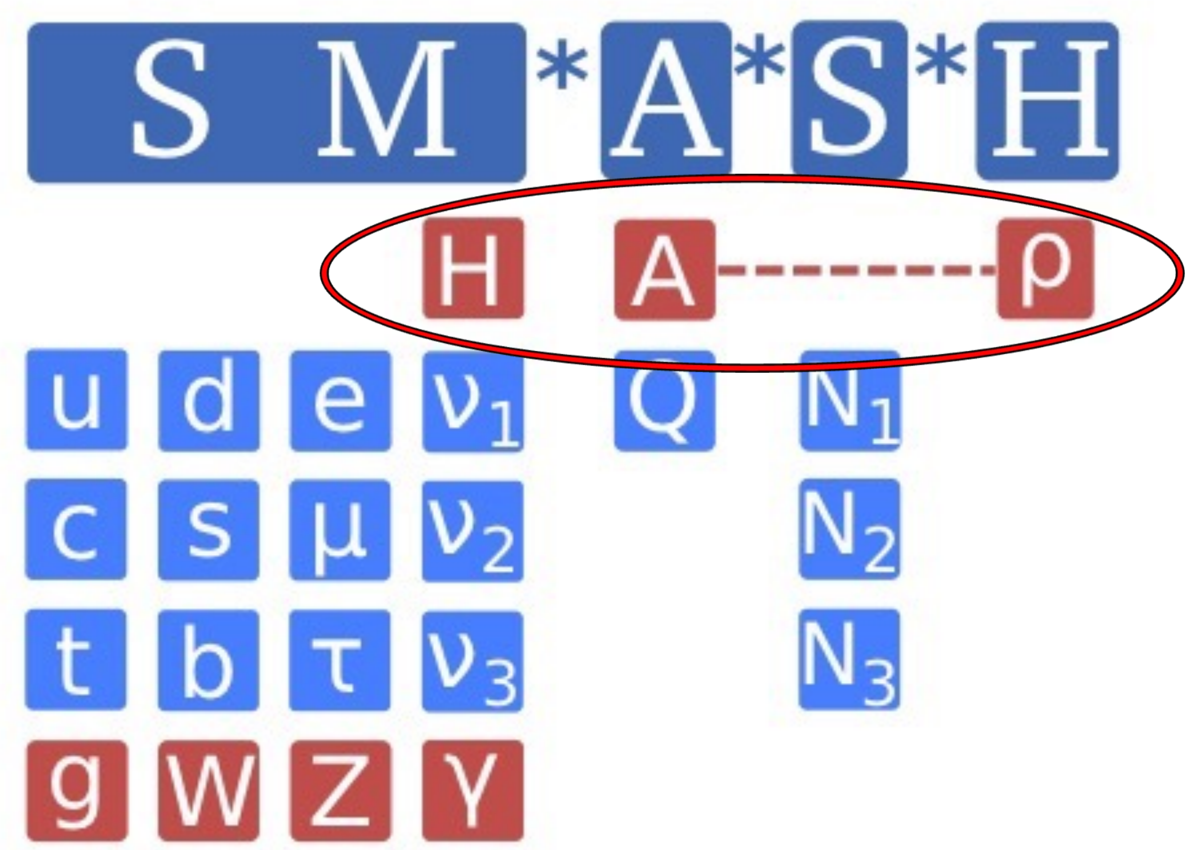

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6. **Vacuum stability**

Standard Model*Axion*Seesaw*Higgs-Portal Inflation

Parameters and their values constrained by symmetries and requirements to solve puzzles

- Peccei-Quinn charge assignments: [Shin 88; Dias et al. 14; Boucenna et al. 14; Ballesteros et al. 16]

q	u	d	L	N	E	Q	$\tilde{Q}$	σ
$1/2$	$-1/2$	$-1/2$	$1/2$	$-1/2$	$-1/2$	$-1/2$	$-1/2$	1

- PQ-invariant Lagrangian:

$$\mathcal{L} = \mathcal{L}_{\text{kin}} + \mathcal{L}_{\text{yuk}}^{SM}$$

$$-\left[\frac{M^2}{2} + \xi_H H^\dagger H + \xi_\sigma |\sigma|^2\right] R$$

$$-\lambda_H \left(H^\dagger H - \frac{v^2}{2}\right)^2 - 2\lambda_{H\sigma}\left(H^\dagger H - \frac{v^2}{2}\right)\left(|\sigma|^2 - \frac{v_\sigma^2}{2}\right) \quad \text{STABILITY}$$

$$-\lambda_\sigma \left(|\sigma|^2 - \frac{v_\sigma^2}{2}\right)^2 - [y\sigma\tilde{Q}Q + y_{Q_{d_i}}\sigma Q d_i + c.c] \quad \text{CP PROBLEM, DARK MATTER}$$

$$-[F_{ij} L_i \epsilon H N_j + \frac{1}{2} Y_{ij}\sigma N_i N_j + c.c.] \quad \text{SEESAW AND LEPTOGENESIS}$$

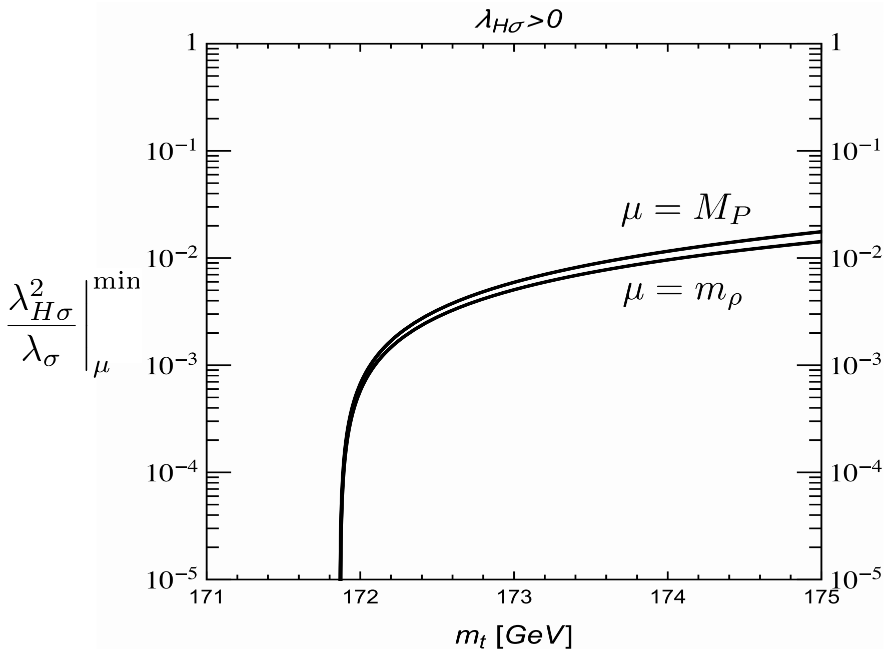
INFLATION

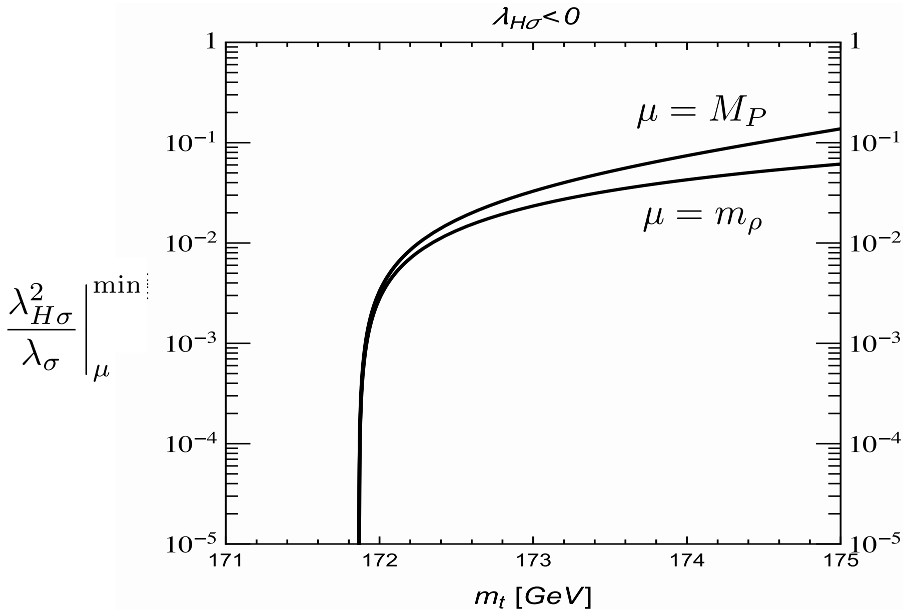
Vacuum Stability in SM*A*S*H

Constraints on scalar and Yukawa couplings

- Stability in Higgs direction:
  - SM-singlet scalar σ helps to stabilize scalar potential in Higgs direction through threshold effect associated with Higgs portal [Lebedev 12; Elias-Miro et al. 12]
  - Stability up to Planck scale ensured if $\delta = \lambda_{H\sigma}^2/\lambda_\sigma\big|_\mu$ exceeds a minimum value dependent on top mass
- Stability in ρ direction:
  - imposes upper limit on the Yukawas of the right-handed neutrinos and the exotic quark:

$$\sum Y_{ii}^4 + 6y^4 \lesssim 16\pi^2\lambda_\sigma/\log\left(M_P/\sqrt{2\lambda_\sigma}v_\sigma\right)$$



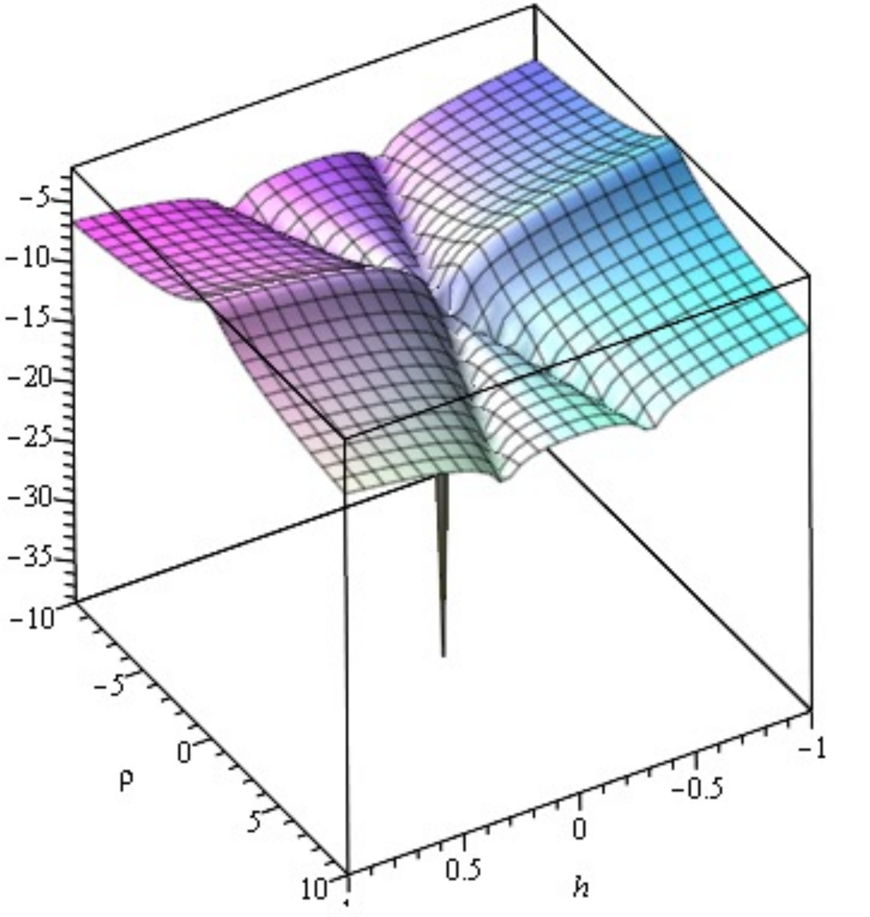


[Ballesteros,Redondo, AR,Tamarit, 1610.01639]

Inflation in SM*A*S*H

Higgs-portal inflation

- The scalar potential in the Einstein frame has a valley = attractor at large field values along the line $h/\phi = \sqrt{-\lambda_{H\sigma}/\lambda_H}$, $\phi = \sqrt{2}\,\mathrm{Re}\sigma$, provided that $\xi_\sigma \gg \xi_H \geq 0$ and $\lambda_{H\sigma} < 0$



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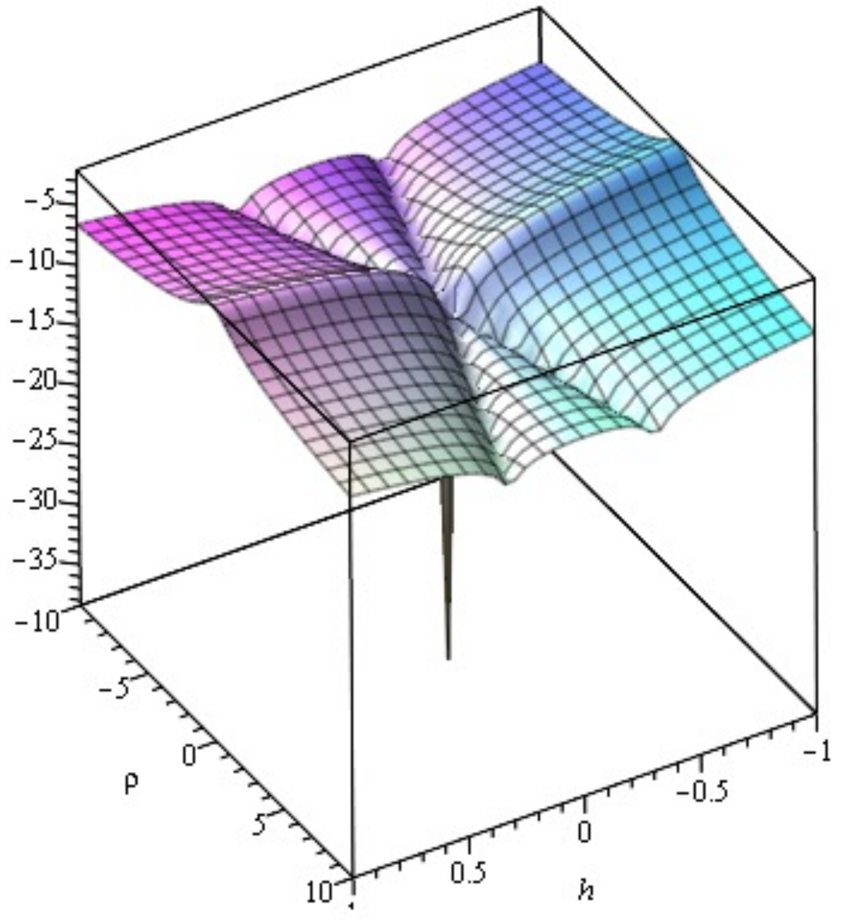
- Results in effectively single field inflation along that field direction with potential (in Einstein frame)

$$\tilde{V}(\chi) = \frac{1}{4}\tilde{\lambda}_\sigma \phi(\chi)^4 \left(1 + \xi_\sigma \frac{\phi(\chi)^2}{M_P^2}\right)^{-2} \quad , \quad \tilde{\lambda}_\sigma \equiv \lambda_\sigma \left(1 - \frac{\lambda_{H\sigma}^2}{\lambda_\sigma \lambda_H}\right)$$

where canonically normalized inflaton field χ and ϕ are related by

$$\Omega^2 \, d\chi/d\phi \simeq (b\,\Omega^2 + 6\,\xi_\sigma^2\,\phi^2/M_P^2)^{1/2}$$

with $\Omega^2 = 1 + \xi_\sigma \frac{\phi(\chi)^2}{M_P^2}$ and $b = 1 + |\lambda_{H\sigma}/\lambda_H|$



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Confronting with CMB data

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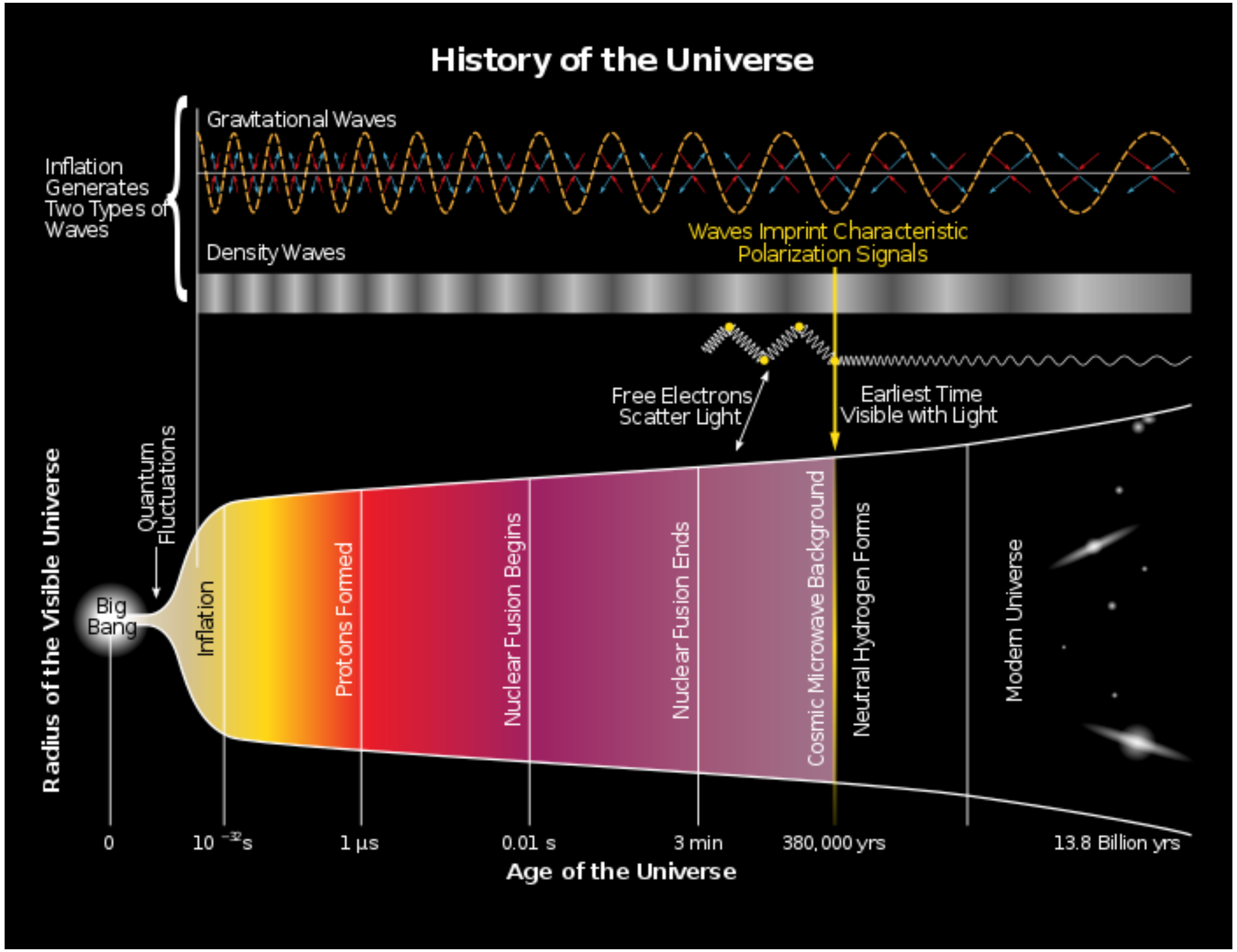
$$\Delta^2_{s/t}(k) = A_{s/t}(k_*)\,(k/k_*)^{n_{s/t}(k_*)-1+\cdots}$$



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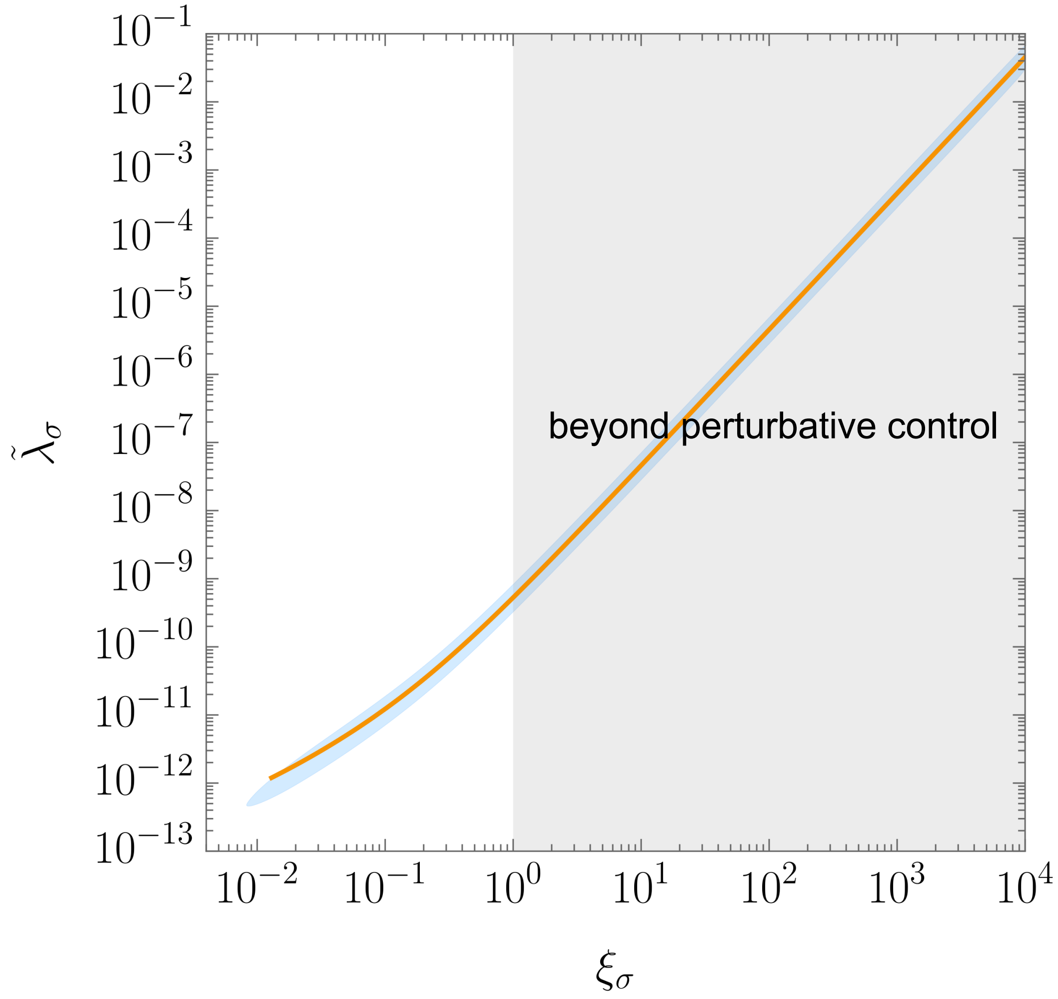

[AR,Tamarit, arXiv:2203.00621]

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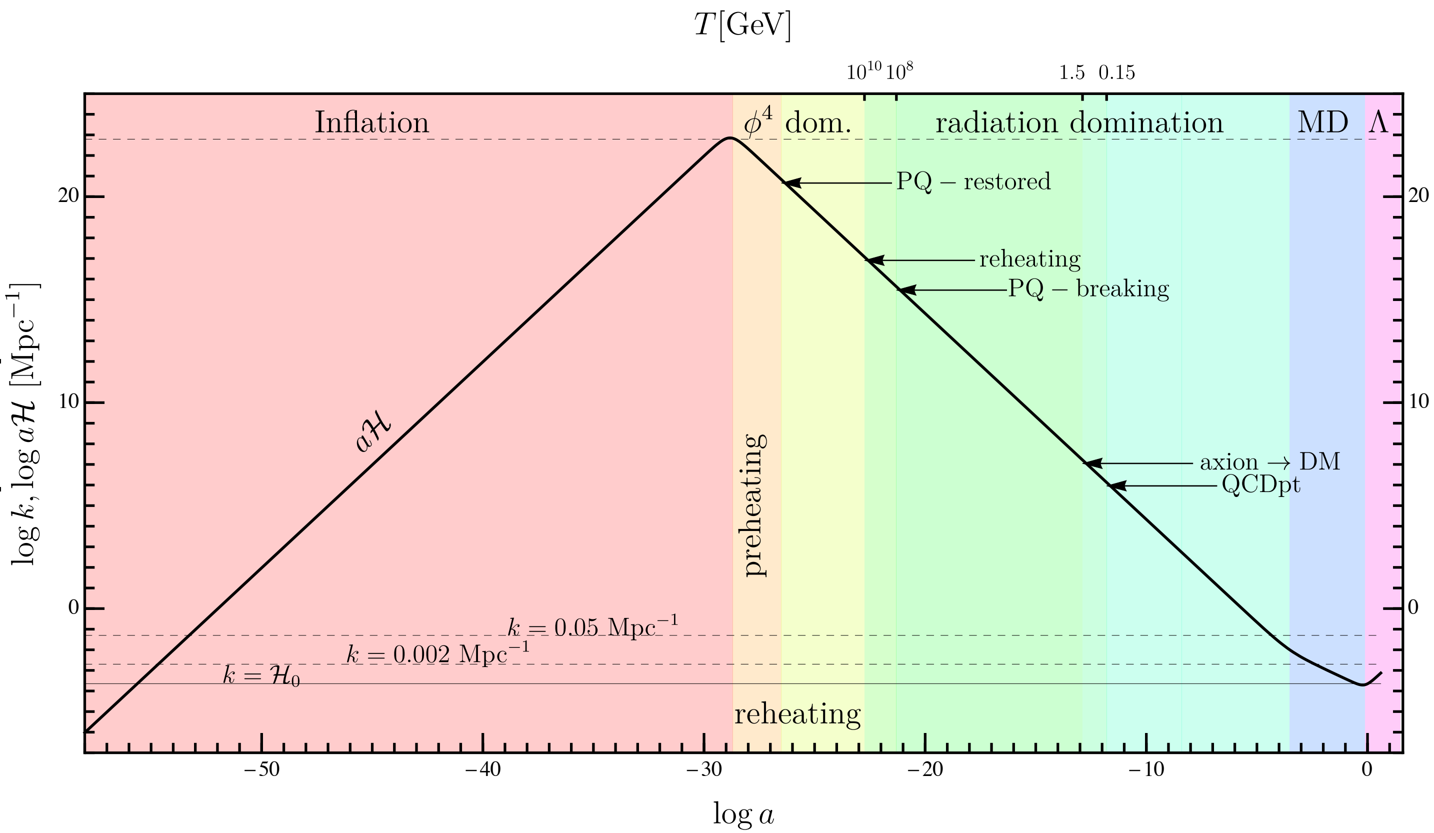

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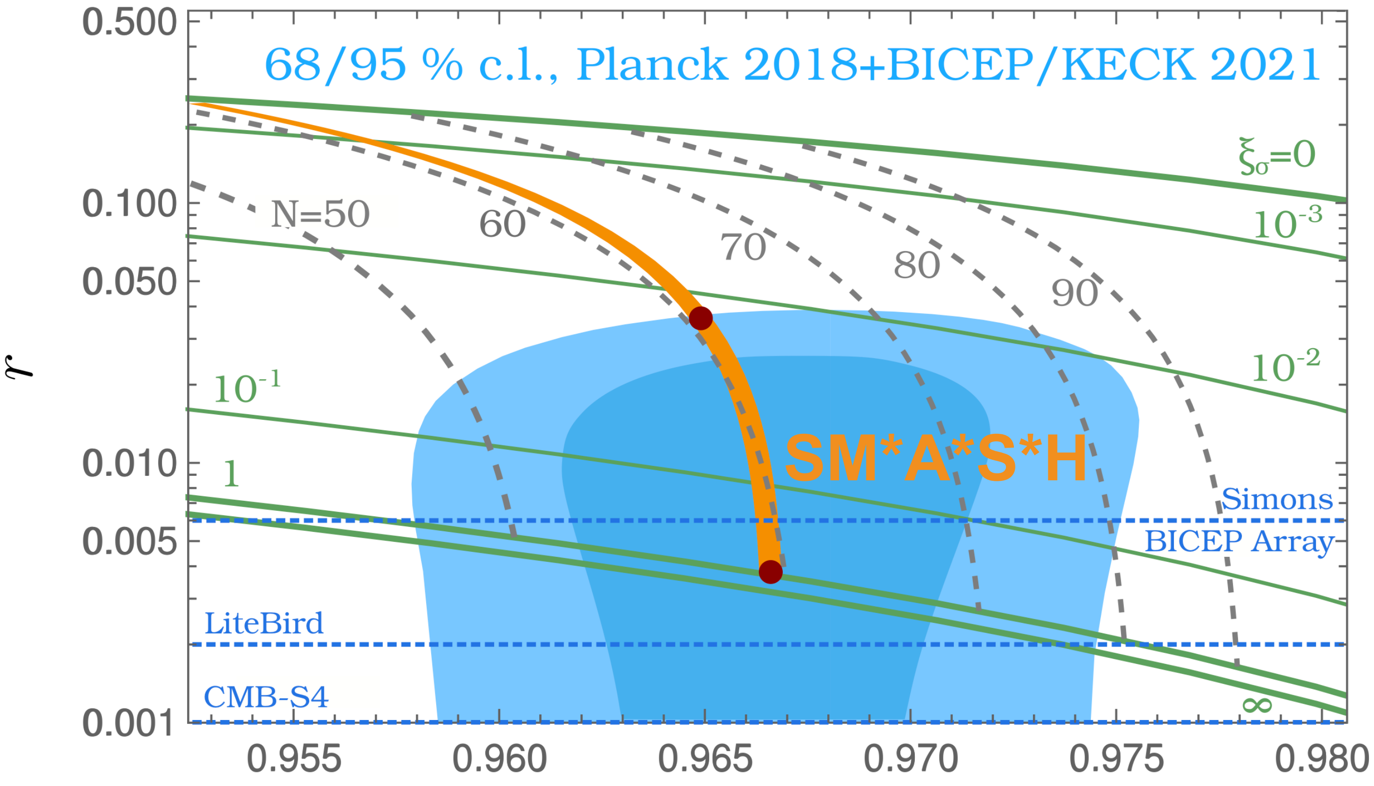

[AR,Tamarit, arXiv:2203.00621] n_s

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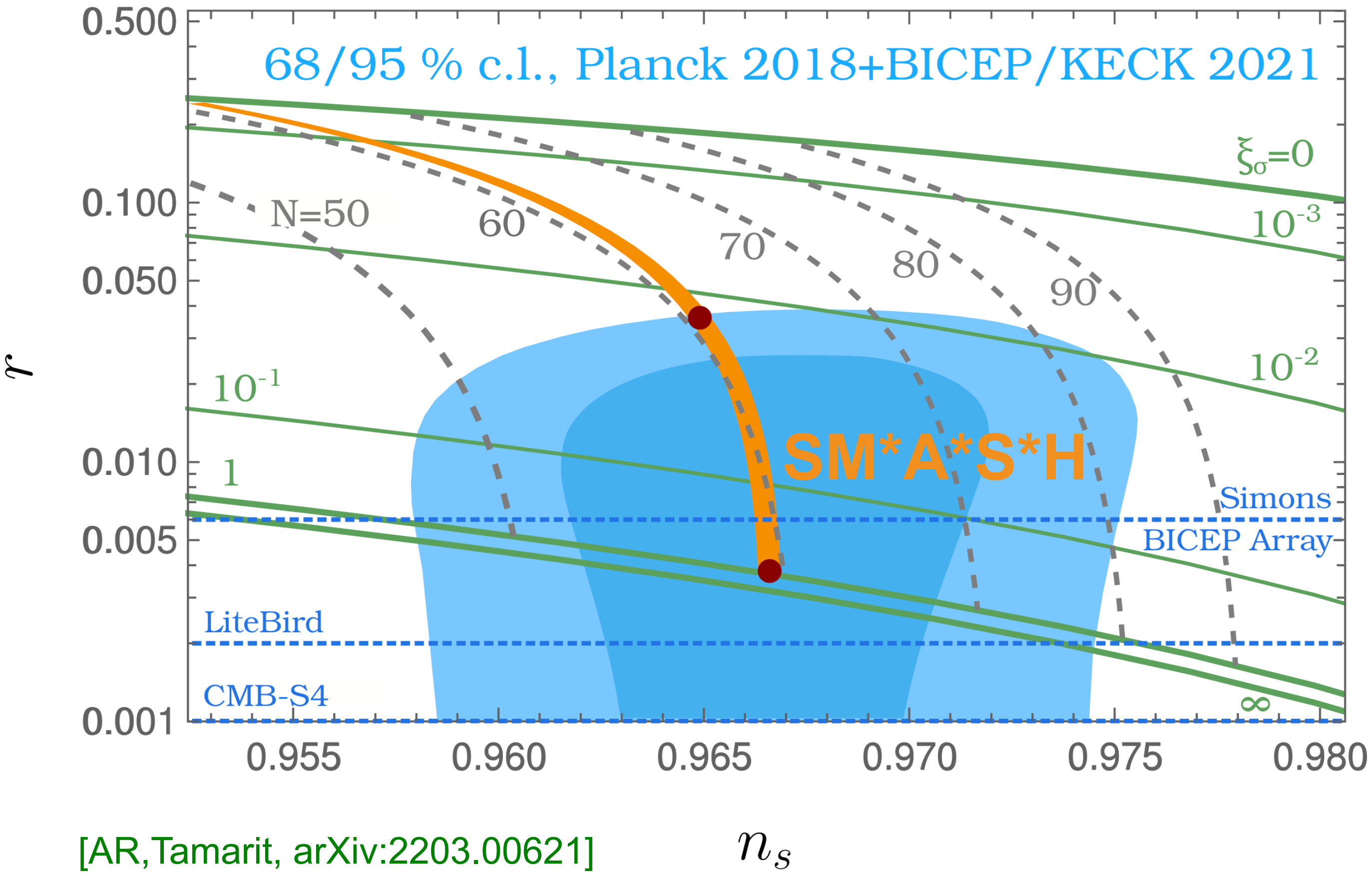

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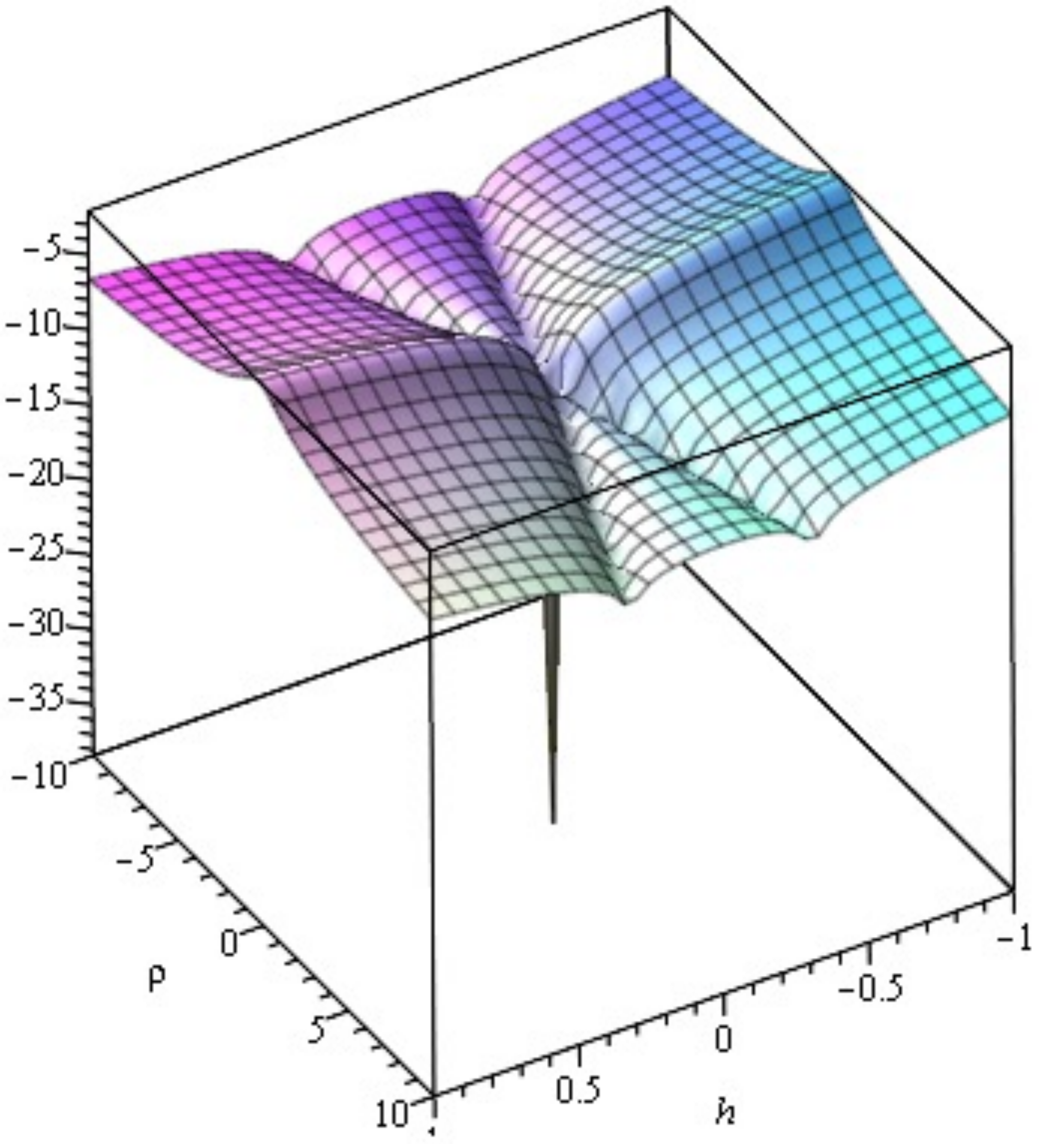
SM*A*S*H smashed if CMB-S4 or LiteBird do not discover B-modes from inflation!

Reheating in SM*A*S*H

PQ symmetry restoration

- Inflation ends at a value of $\phi \sim M_P$



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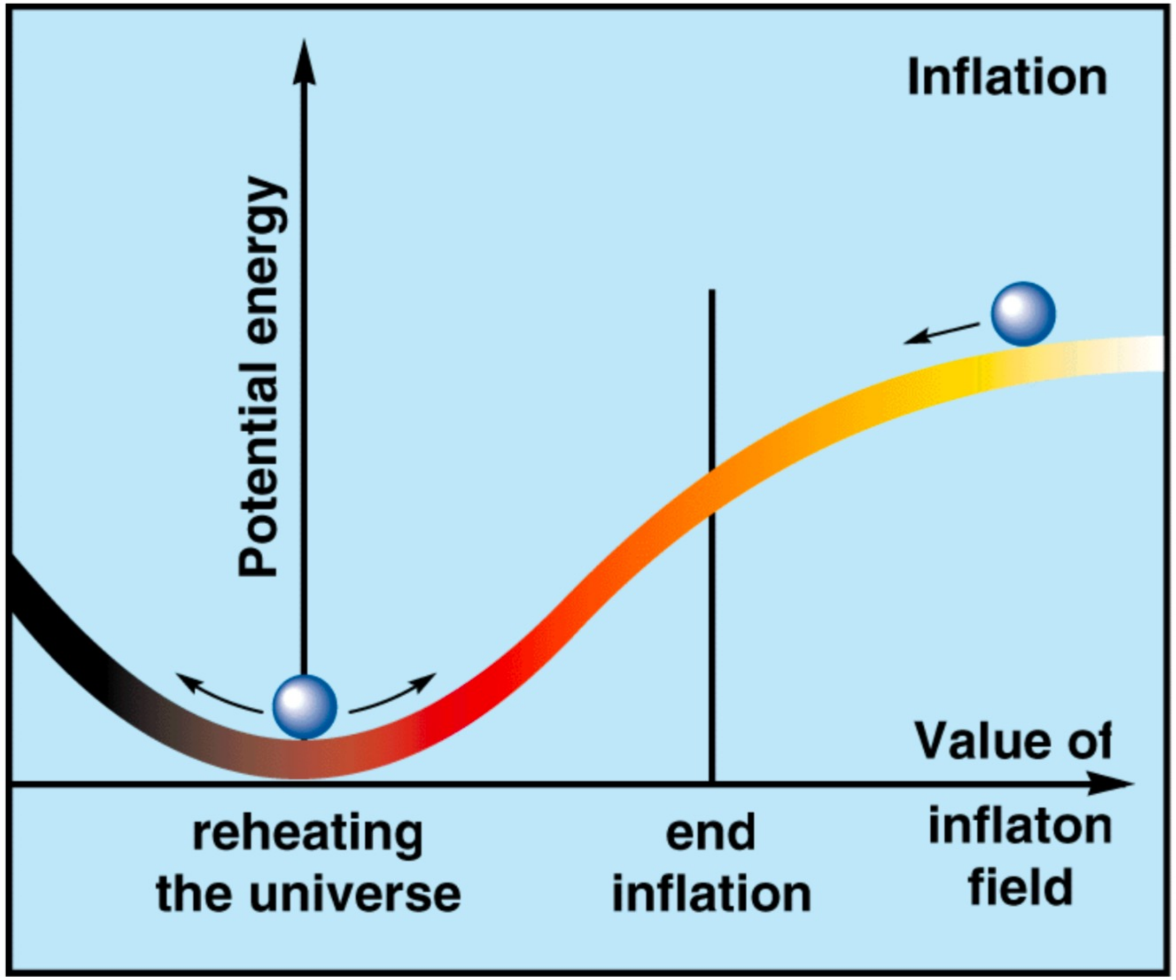

[Garcia-Bellido 99]

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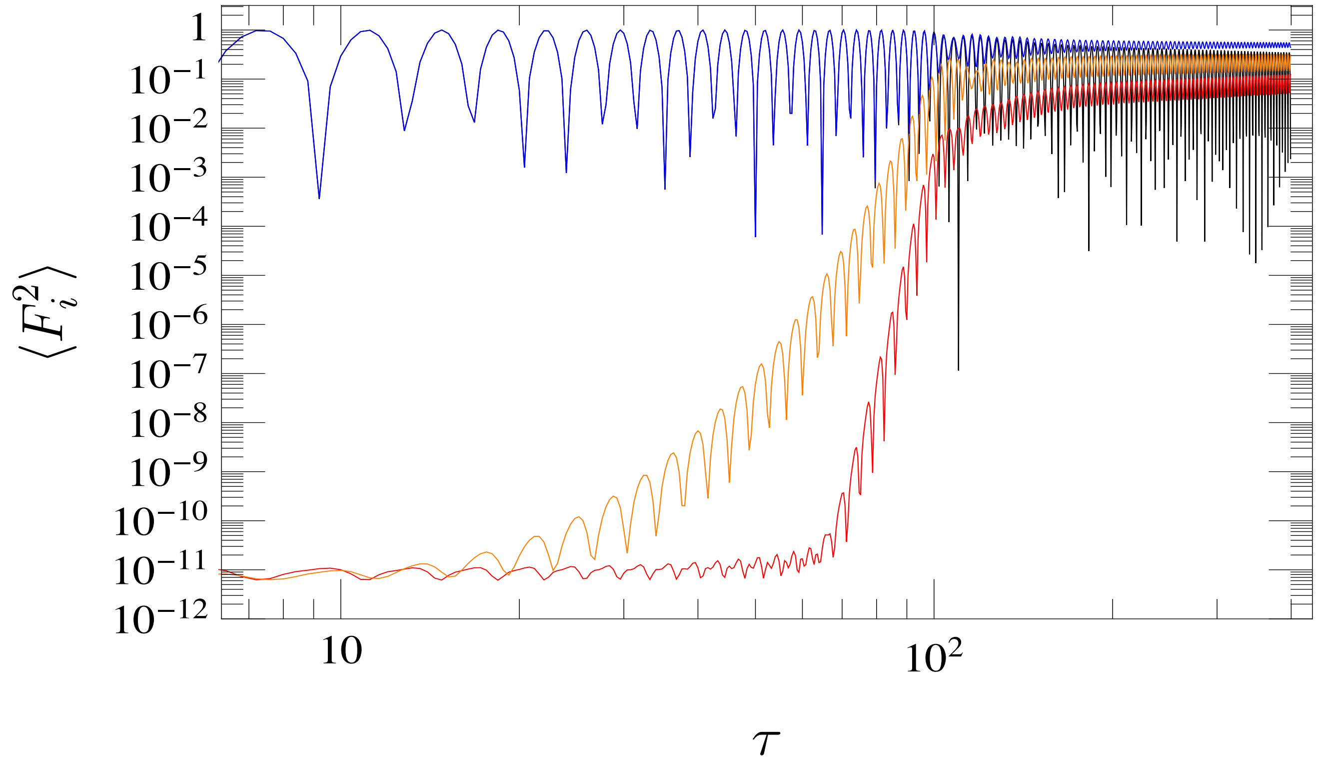

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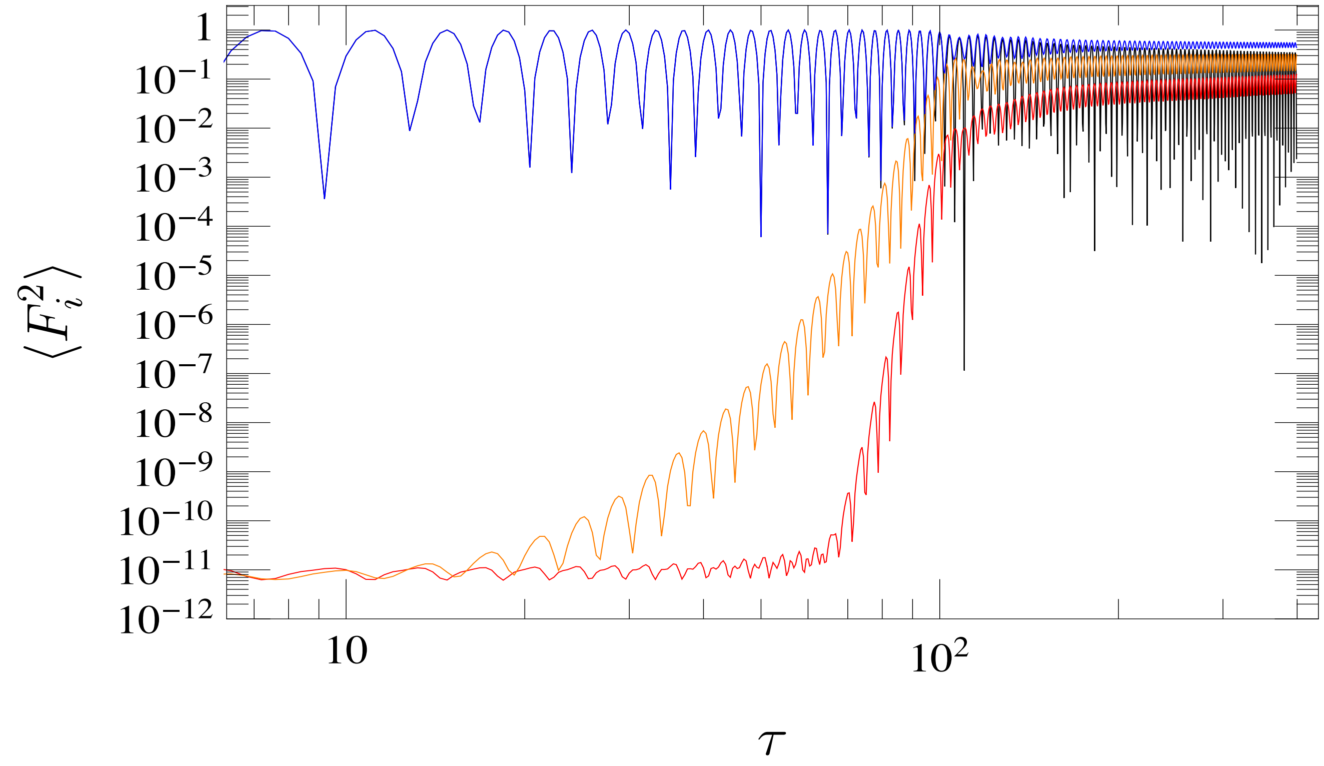

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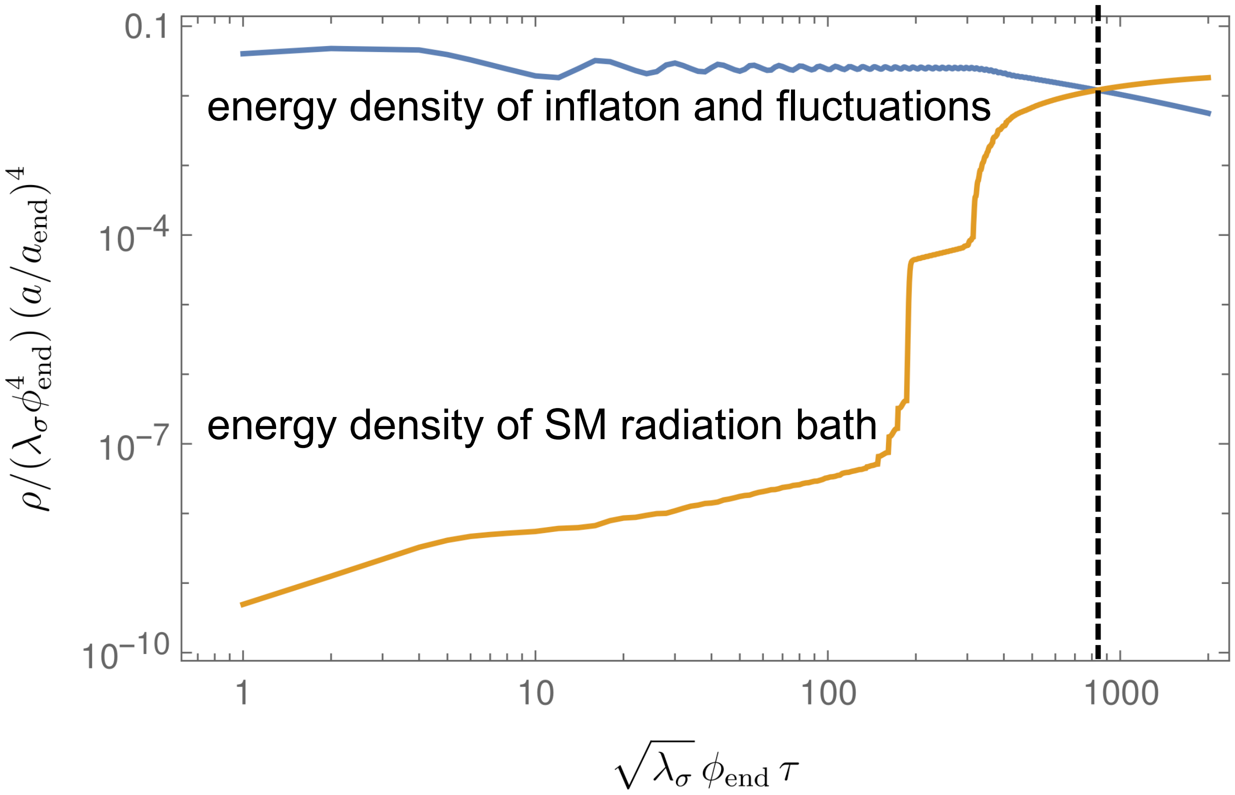
- Reheating temperature from lattice simulations:

$$T_{\rm rh} = (30\, \rho_{\rm rad}(\tau_{\rm rh})/(\pi^2 g_{\star\rho}(T_{\rm rh}))^{1/4} \approx 10^{12-13}\,\mathrm{GeV}$$



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PQ symmetry breaking scale / axion mass

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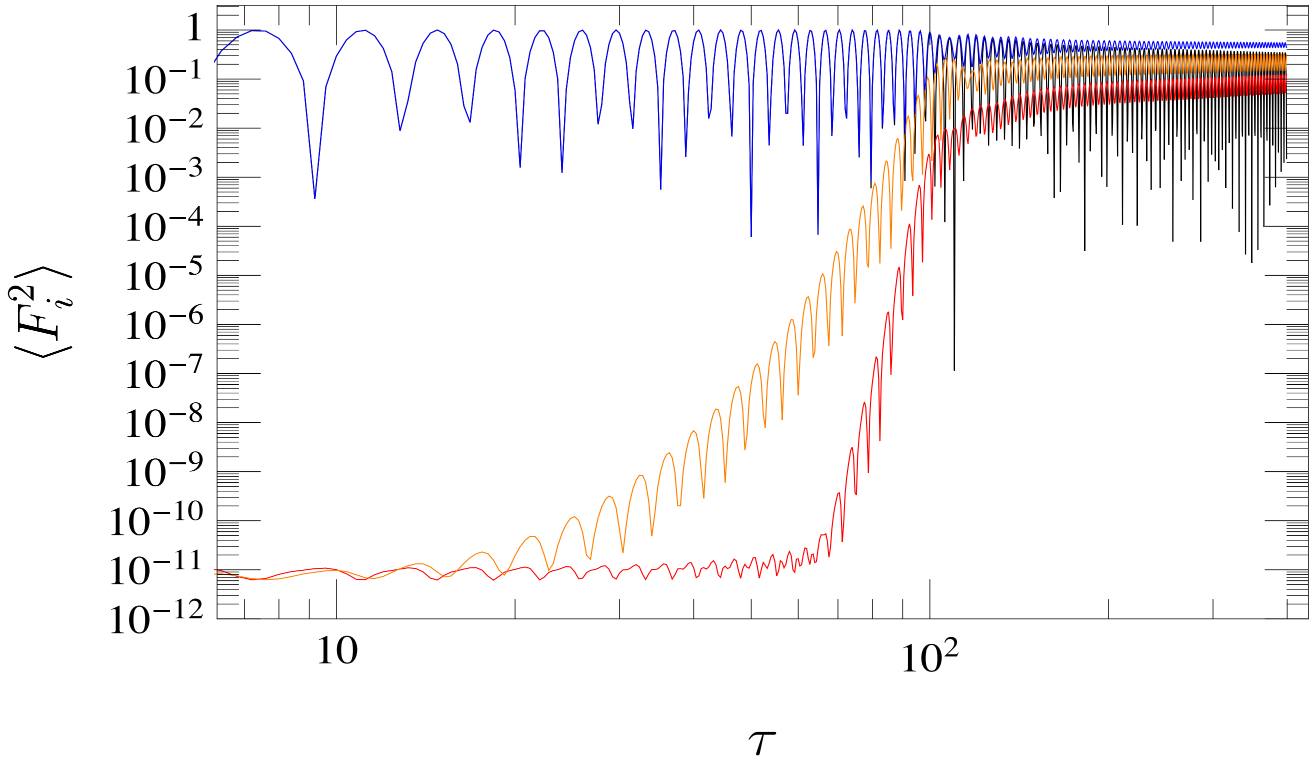

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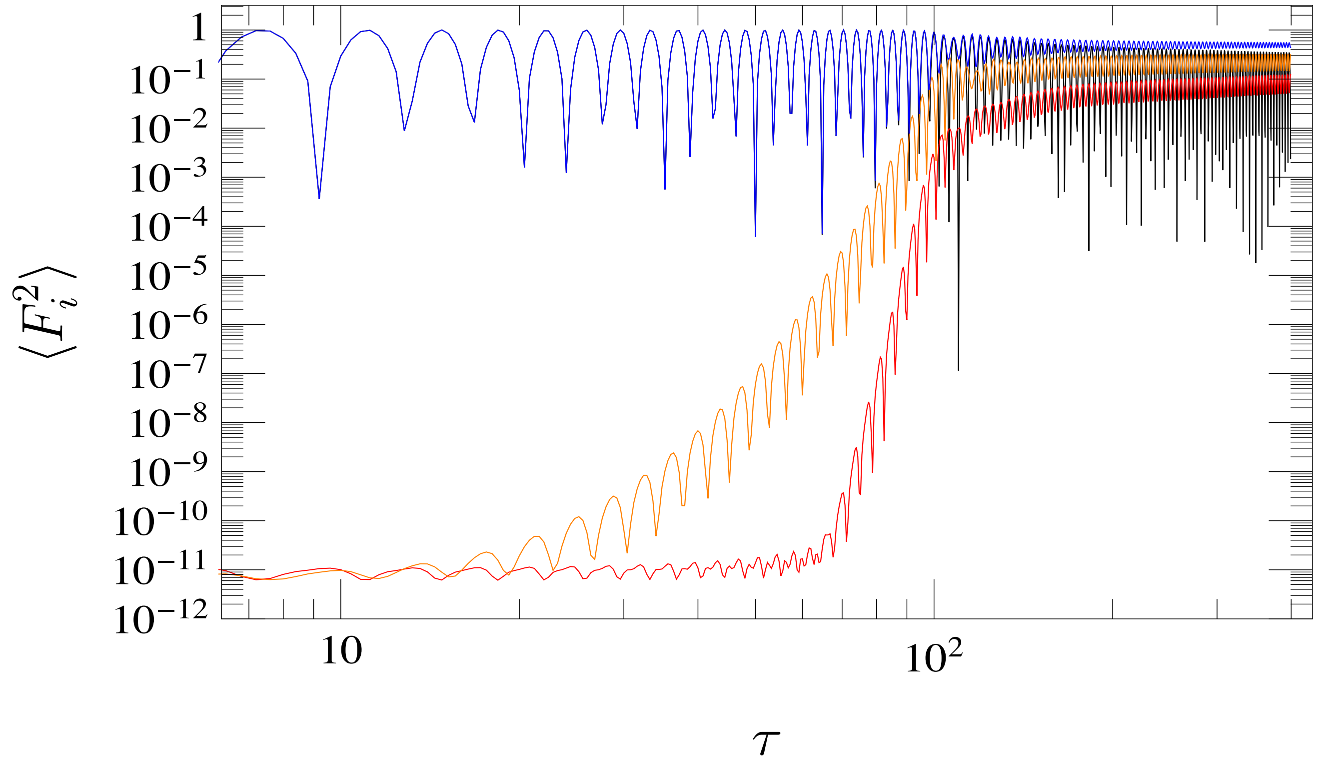

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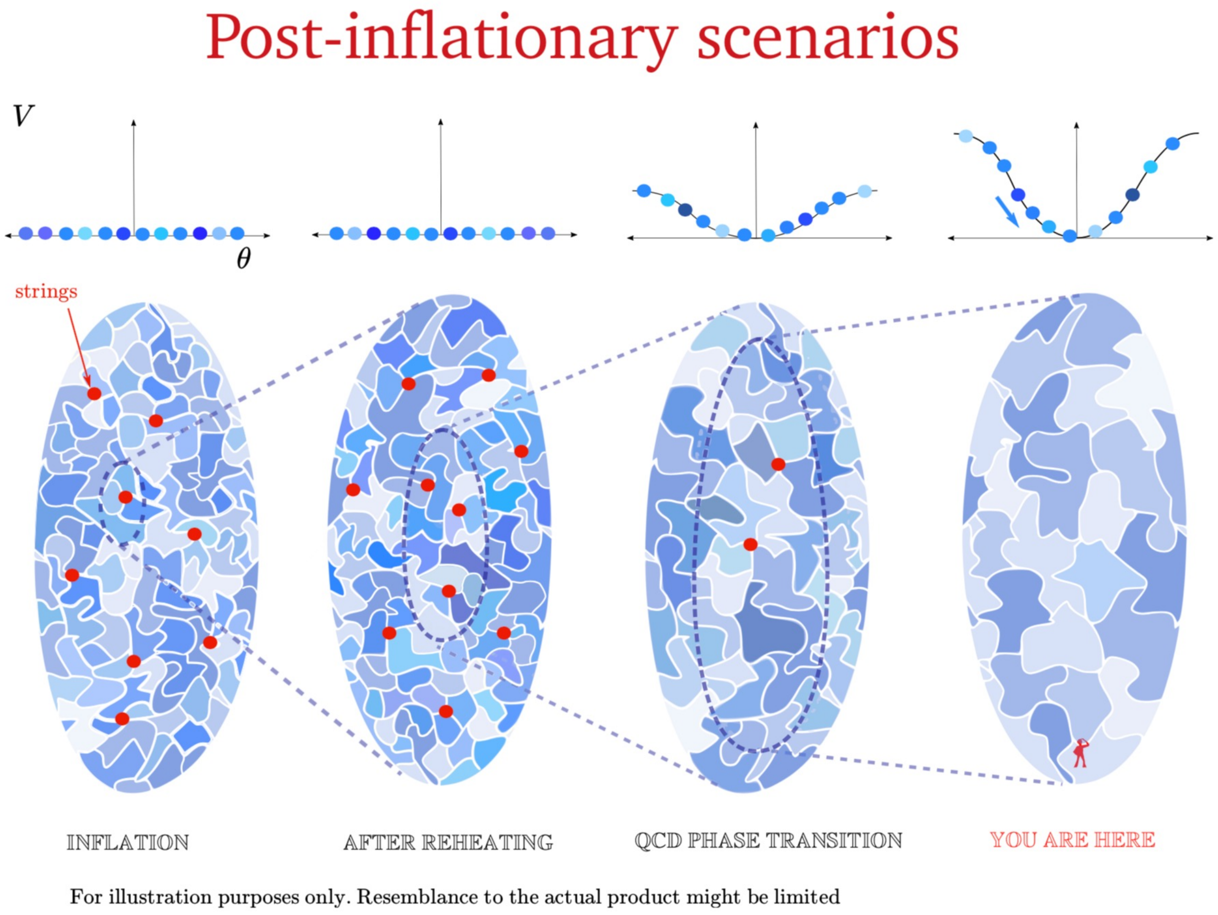

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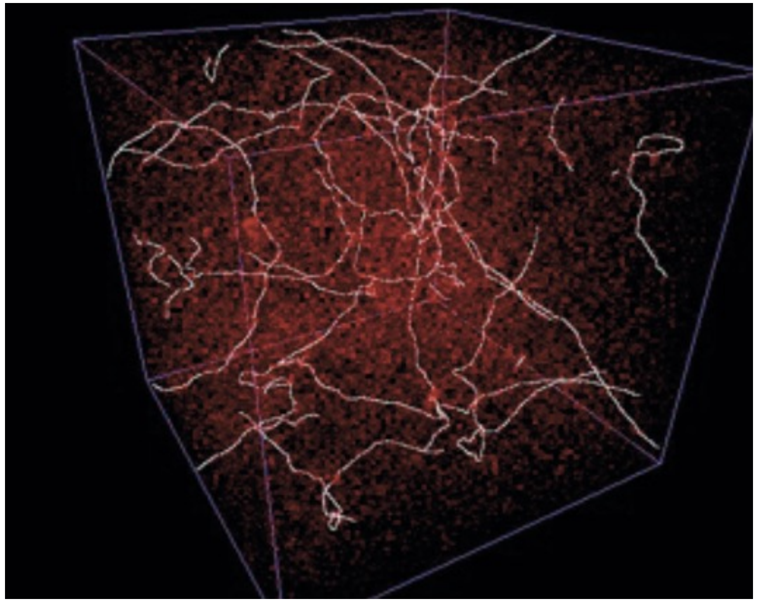

[Hiramatsu et al.]

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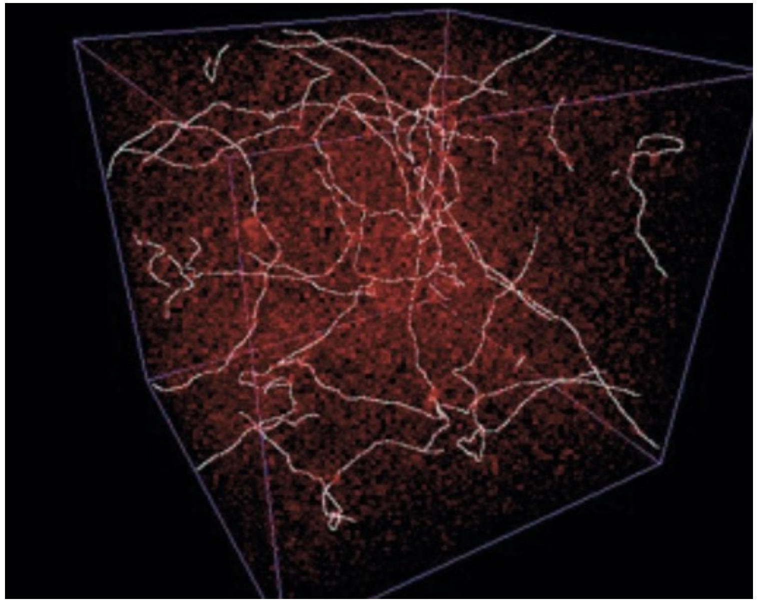

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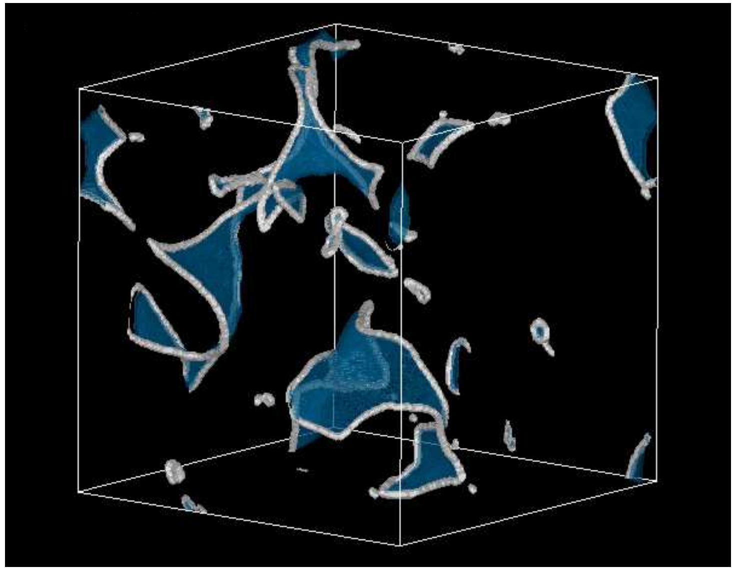

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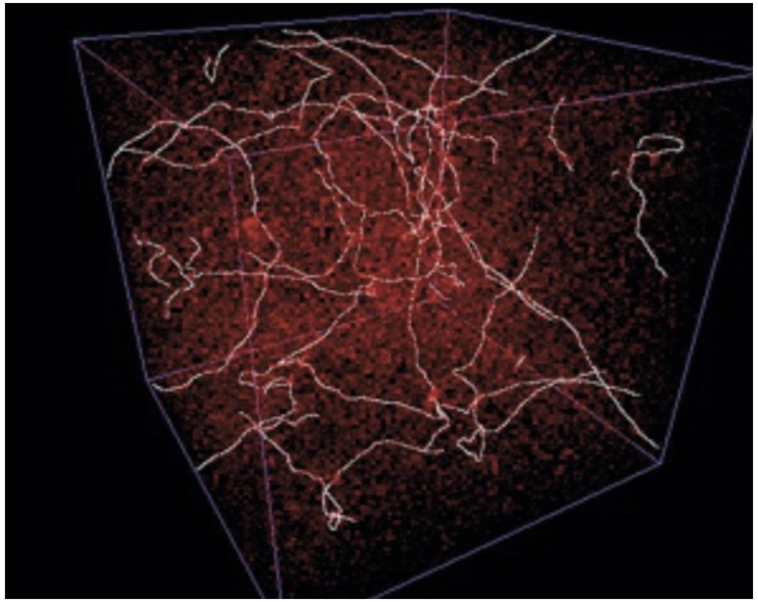
- Contribution of the latter determined by lattice simulations and extrapolations – still large uncertainties in predicted decay constant or mass to explain DM

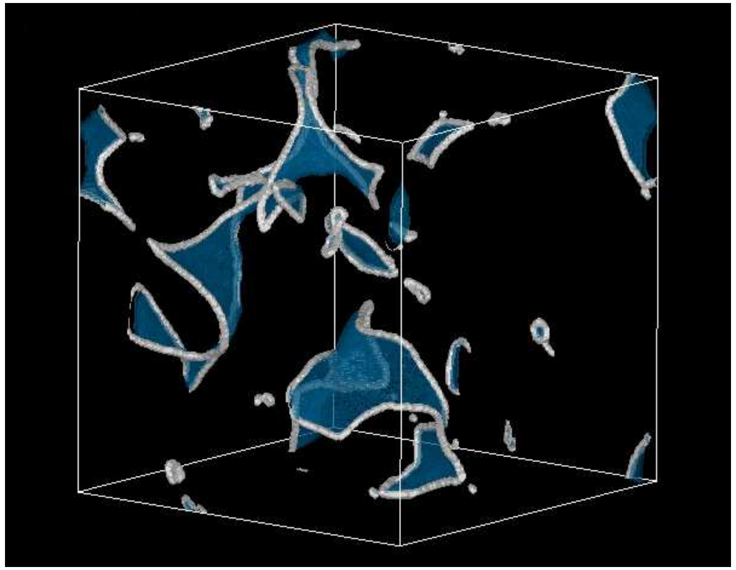
$$1.1 \times 10^{10}\,\mathrm{GeV} \lesssim f_a = v_\sigma < 2.2 \times 10^{11}\,\mathrm{GeV}$$

$$26\ \mu\mathrm{eV} < m_a \lesssim 0.5\ \mathrm{meV}$$

[Hiramatsu et al. 11,12,13; Kawasaki,Saikawa,Segikuchi 15; AR,Saikawa `16; Borsanyi et al. `16; Klaer,Moore `17; Gorghetto,Hardy,Villadoro `18; Buschmann et al. 19; Hindmarsh 19; Gorghetto,Hardy,Villadoro ’20; Buschmann et al. 21 Saikawa et al. 24;...]



[Hiramatsu et al.]



Dark Matter in SM*A*S*H

PQ symmetry breaking scale / axion mass

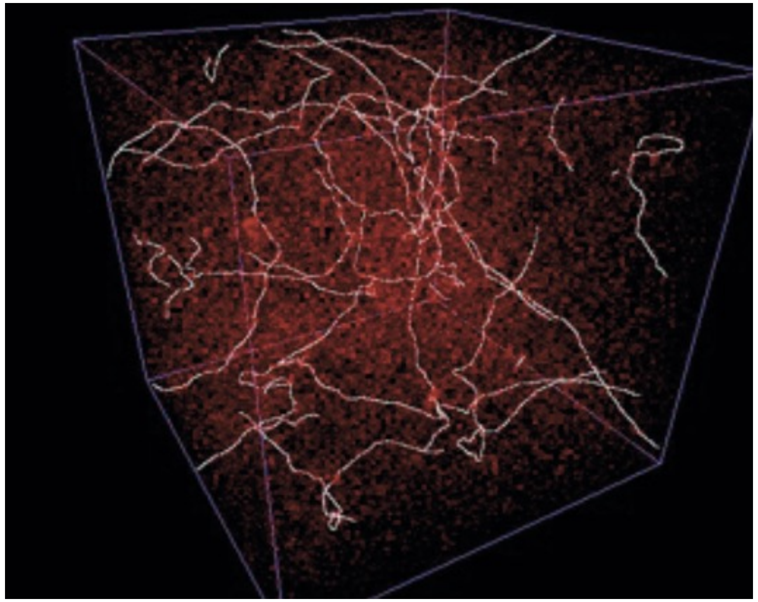
- PQ symmetry restored in preheating
- Latest PQ symmetry breaking occurs during the radiation-dominated hot big bang phase
- Axion dark matter produced by misalignment and the collapse of network of strings and domain walls
- Contribution of the latter determined by lattice simulations and extrapolations – still large uncertainties in predicted decay constant or mass to explain DM

$$1.1 \times 10^{10}\,\mathrm{GeV} \lesssim f_a = v_\sigma < 2.2 \times 10^{11}\,\mathrm{GeV}$$

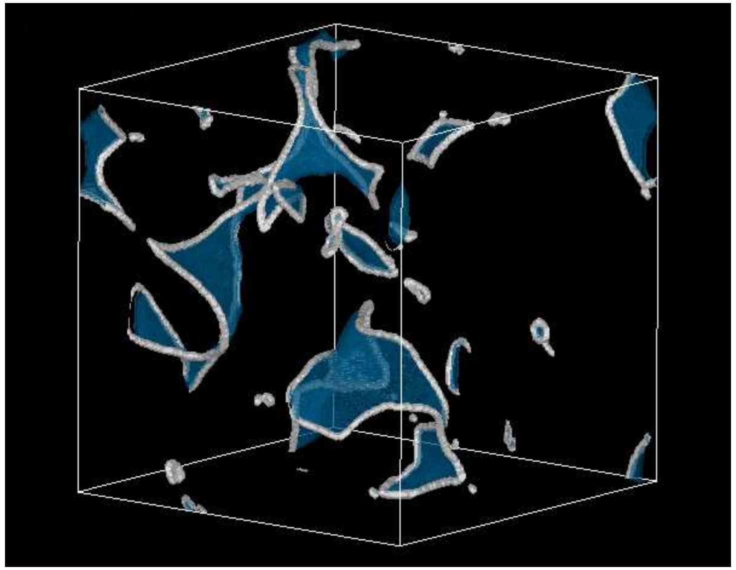
$$26\ \mu\mathrm{eV} < m_a \lesssim 0.5\ \mathrm{meV}$$

  - Conservative upper (lower) bound on $f_a(m_a)$ obtained by exploiting QCD lattice results on topological susceptibility and using only the misalignment contribution, i.e. neglecting axions from strings

[Hiramatsu et al. 11,12,13; Kawasaki,Saikawa,Segikuchi 15; AR,Saikawa `16; Borsanyi et al. `16; Klaer,Moore `17; Gorghetto,Hardy,Villadoro `18; Buschmann et al. 19; Hindmarsh 19; Gorghetto,Hardy,Villadoro '20; Buschmann et al. 21 Saikawa et al. 24;...]



[Hiramatsu et al.]

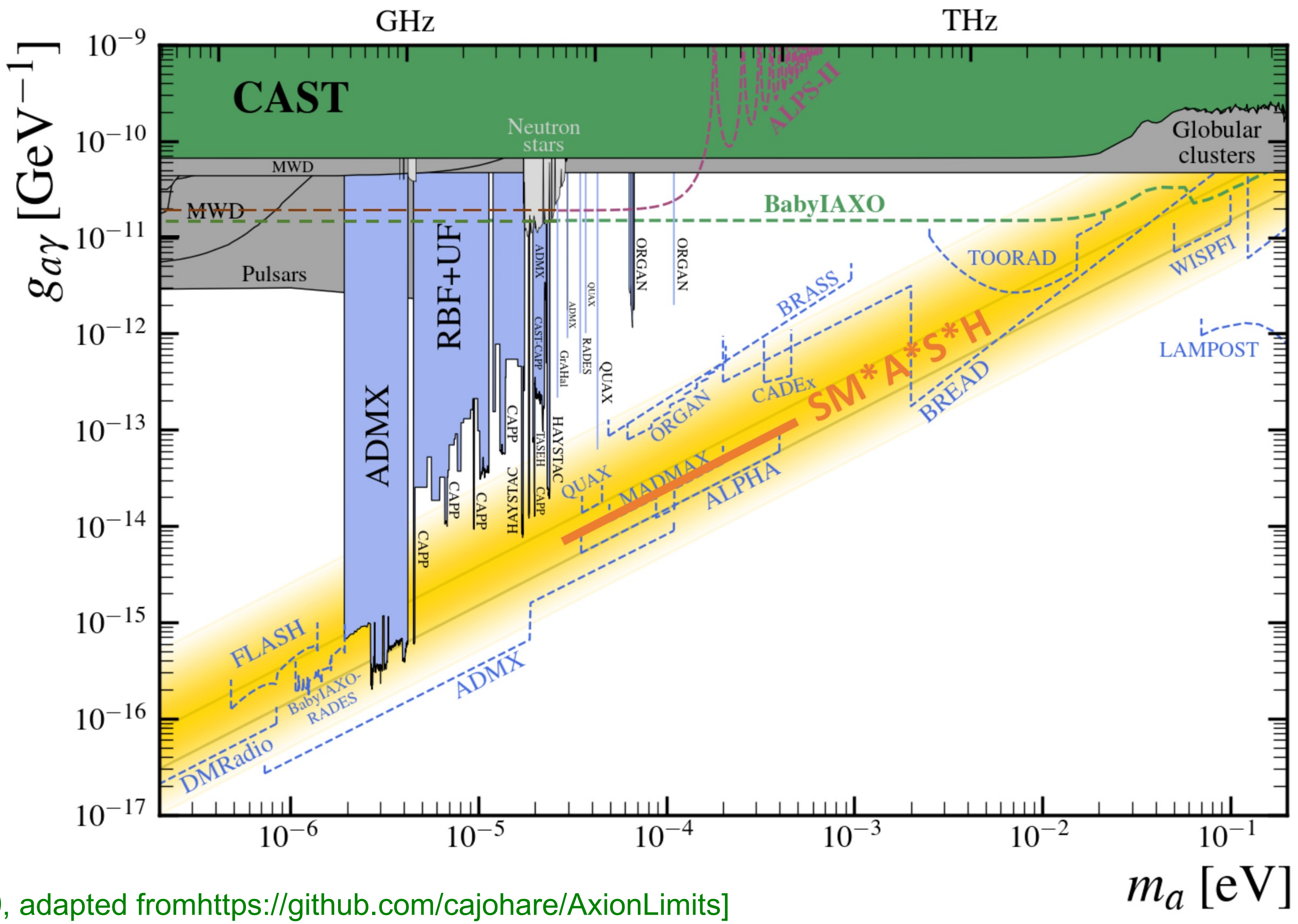


[Borsanyi et al., Nature `16 [1606.0794]]

Dark Matter in SM*A*S*H

PQ symmetry breaking scale / axion mass

- SM*A*S*H prediction will be probed in the upcoming generation of axion haloscopes:



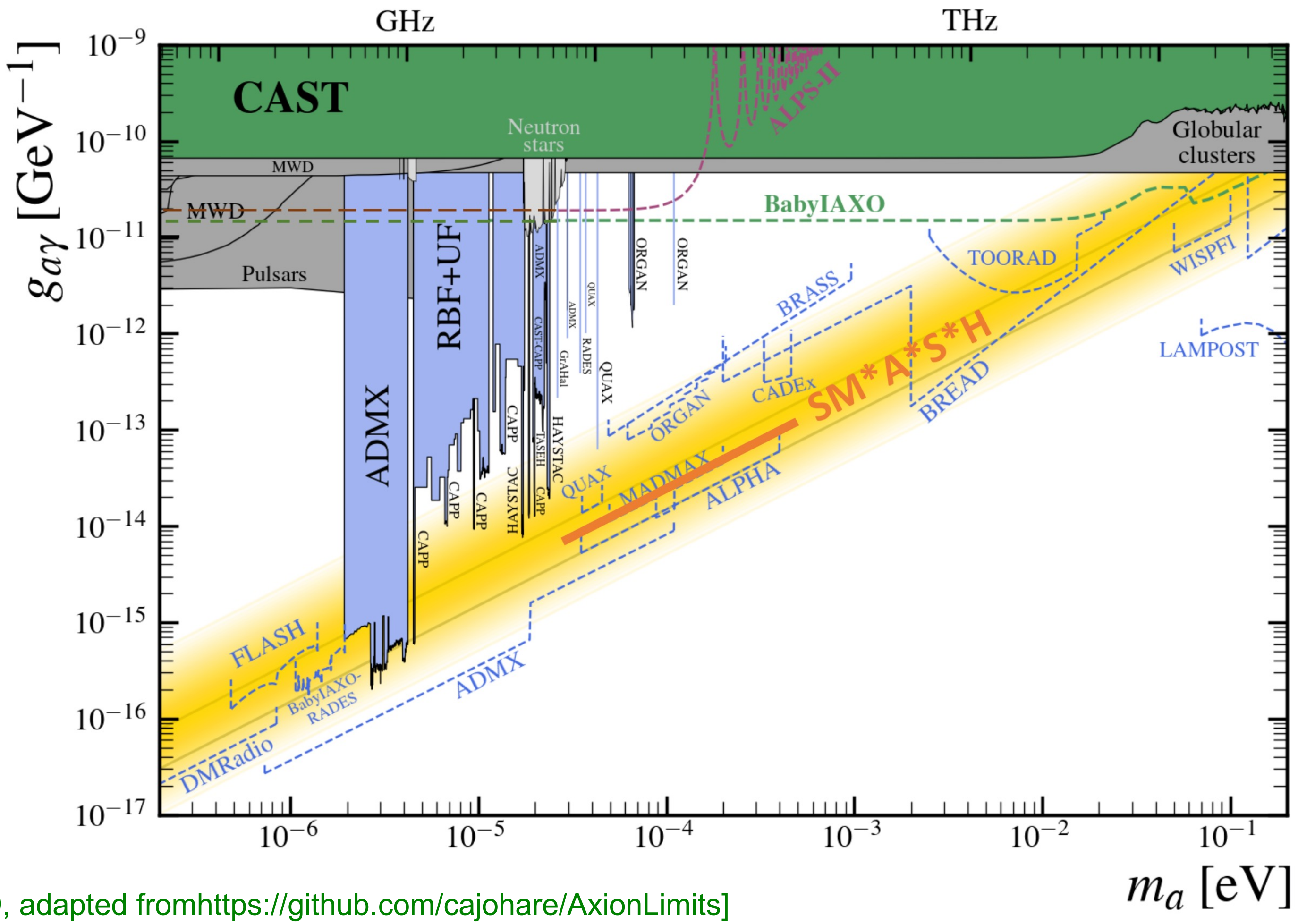
[AR 2312.14679, adapted fromhttps://github.com/cajohare/AxionLimits]

Dark Matter in SM*A*S*H

PQ symmetry breaking scale / axion mass

- **SM*A*S*H smashed if axion dark matter experiments discover an axion with a mass below 26 micro-eV**

- SM*A*S*H prediction will be probed in the upcoming generation of axion haloscopes:



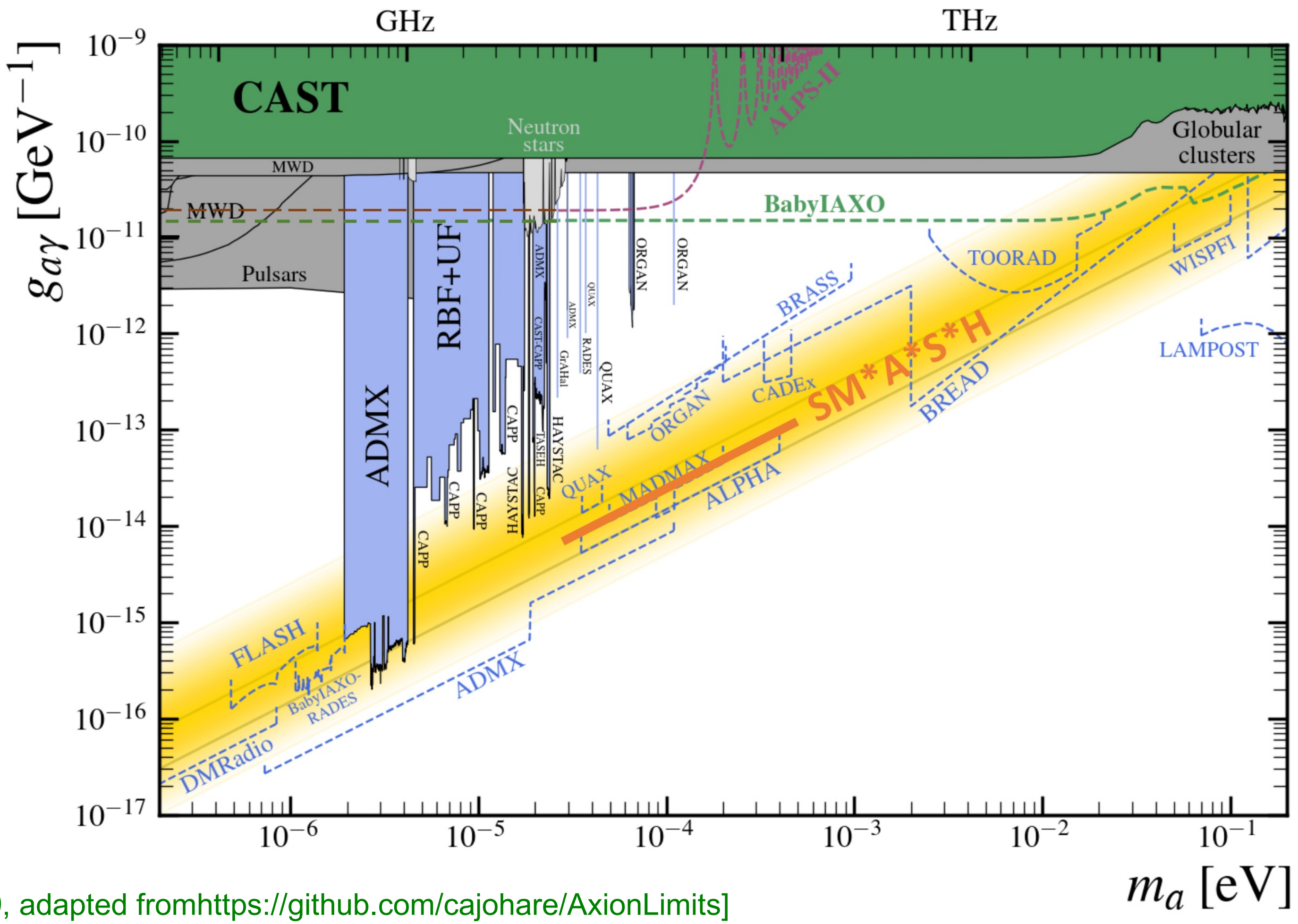
[AR 2312.14679, adapted fromhttps://github.com/cajohare/AxionLimits]

Dark Matter in SM*A*S*H

PQ symmetry breaking scale / axion mass

- **SM*A*S*H smashed if axion dark matter experiments discover an axion with a mass below 26 micro-eV**
- **ALPHA and MADMAX have good prospects to detect axion from SM*A*S*H**

- SM*A*S*H prediction will be probed in the upcoming generation of axion haloscopes:



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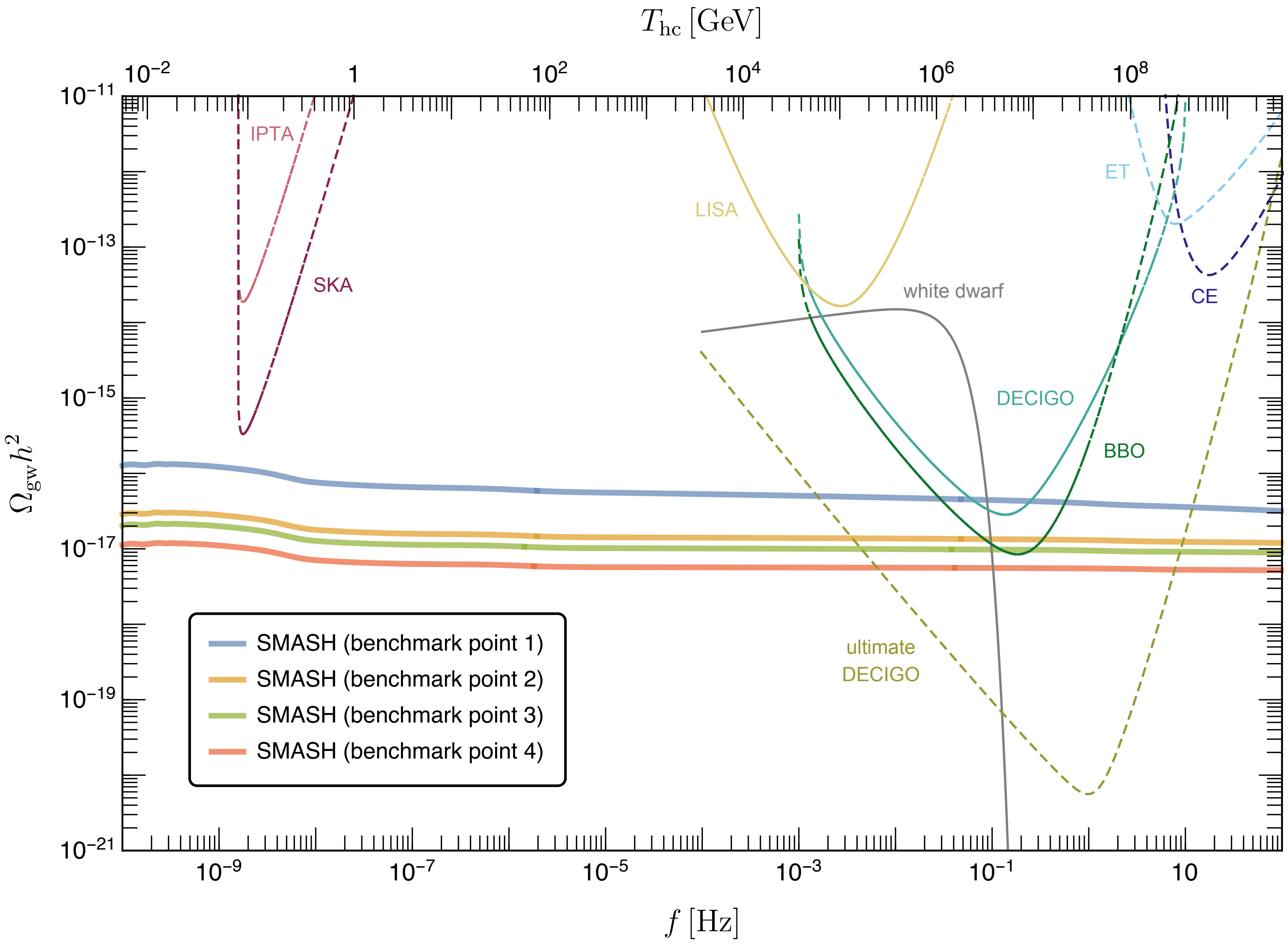
Stochastic GW Background from Inflation in SM*A*S*H

Can be probed directly by future space-born interferometer

[AR, Saikawa, Tamarit, arXiv:2009.02050]

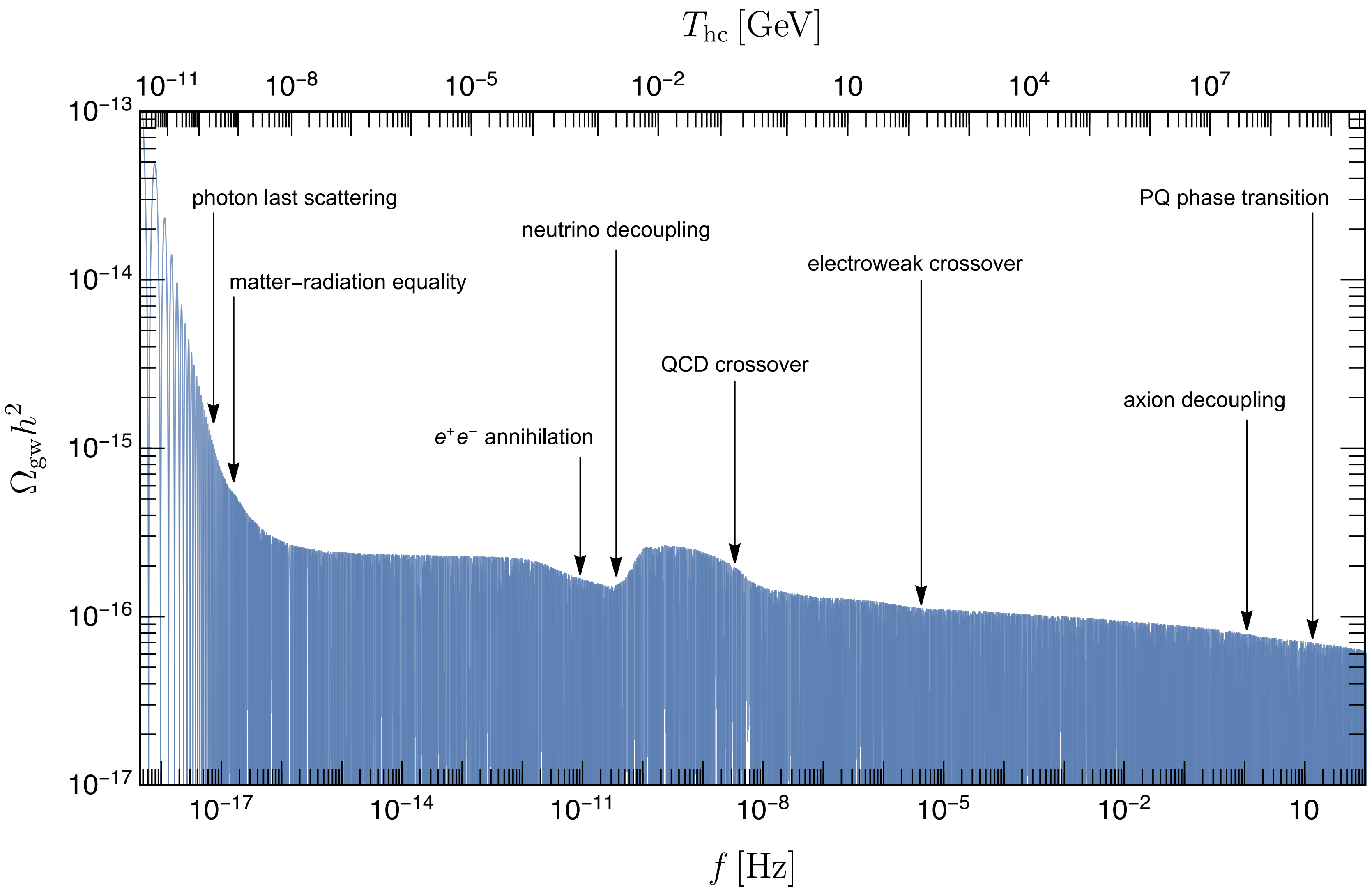


Benchmark point	1	2	3	4
$r(0.002\ \mathrm{Mpc}^{-1})$	0.048	0.0096	0.0068	0.0037
$n_s(0.002\ \mathrm{Mpc}^{-1})$	0.9642	0.9663	0.9665	0.9666
ϕ_*/M_P	22	18	16	8.4
$\xi_\sigma(\phi_*)$	0.0096	0.079	0.14	1.0
$\tilde{\lambda}_\sigma(\phi_*)$	9.1×10^{-13}	9.0×10^{-12}	2.0×10^{-11}	5.3×10^{-10}
$\lambda_\sigma(M_P)$	4.4×10^{-12}	1.4×10^{-10}	5.0×10^{-11}	4.4×10^{-9}
$\lambda_{H\sigma}(M_P)$	-1.5×10^{-6}	-6.0×10^{-6}	-6.5×10^{-6}	-2.9×10^{-5}
$\lambda_H(M_P)$	0.63	0.26	1.2	0.21
$y(M_P)$	0.00056	0.0014	0.00086	0.0027
$Y_{ii}(M_P)$	0.0011	0.0025	0.0016	0.0045

Stochastic GW Background from Inflation in SM*A*S*H

Cosmic history of SMASH imprinted on SGWB

[AR, Saikawa, Tamarit, arXiv:2009.02050]



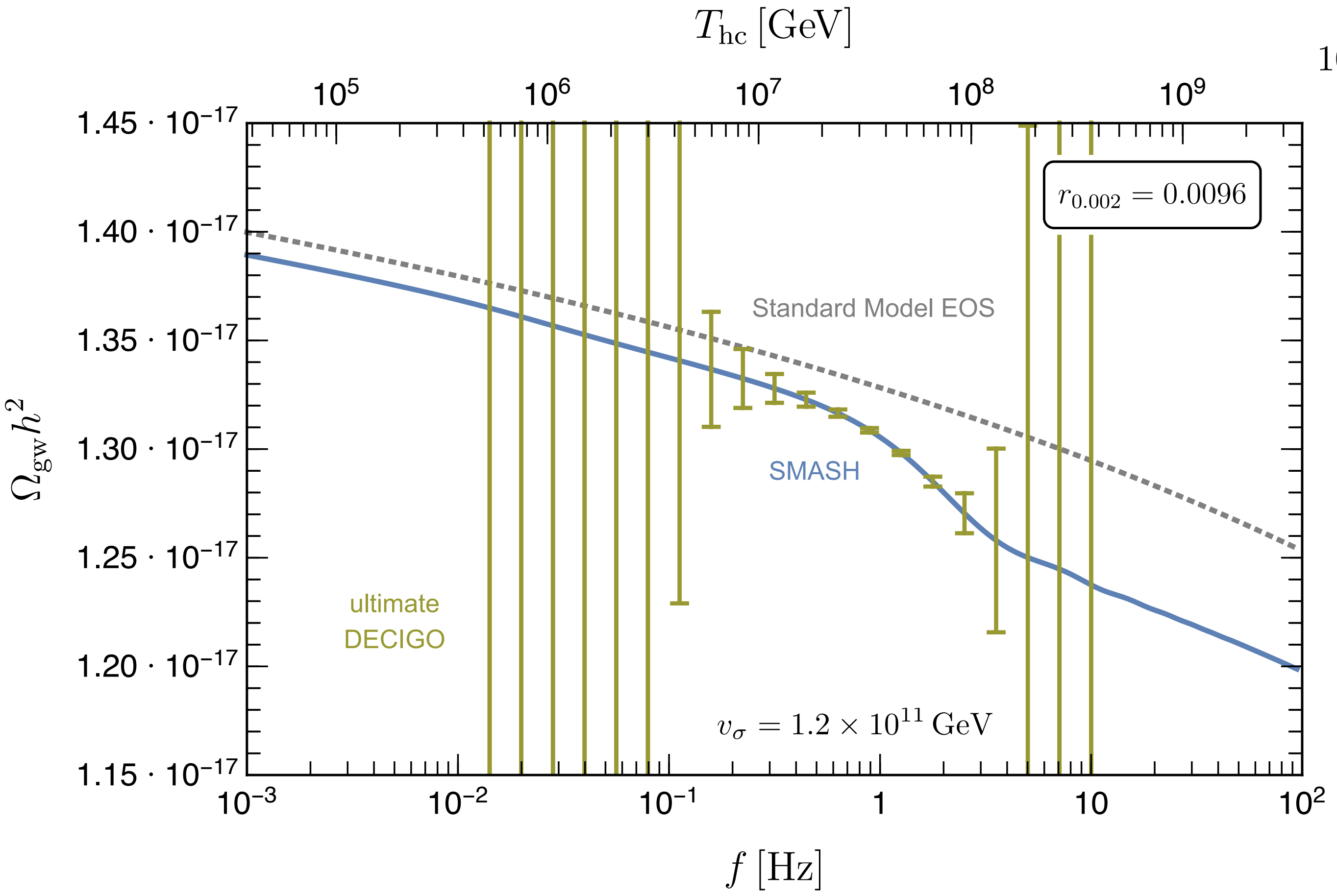
Stochastic GW Background from Inflation in SM*A*S*H

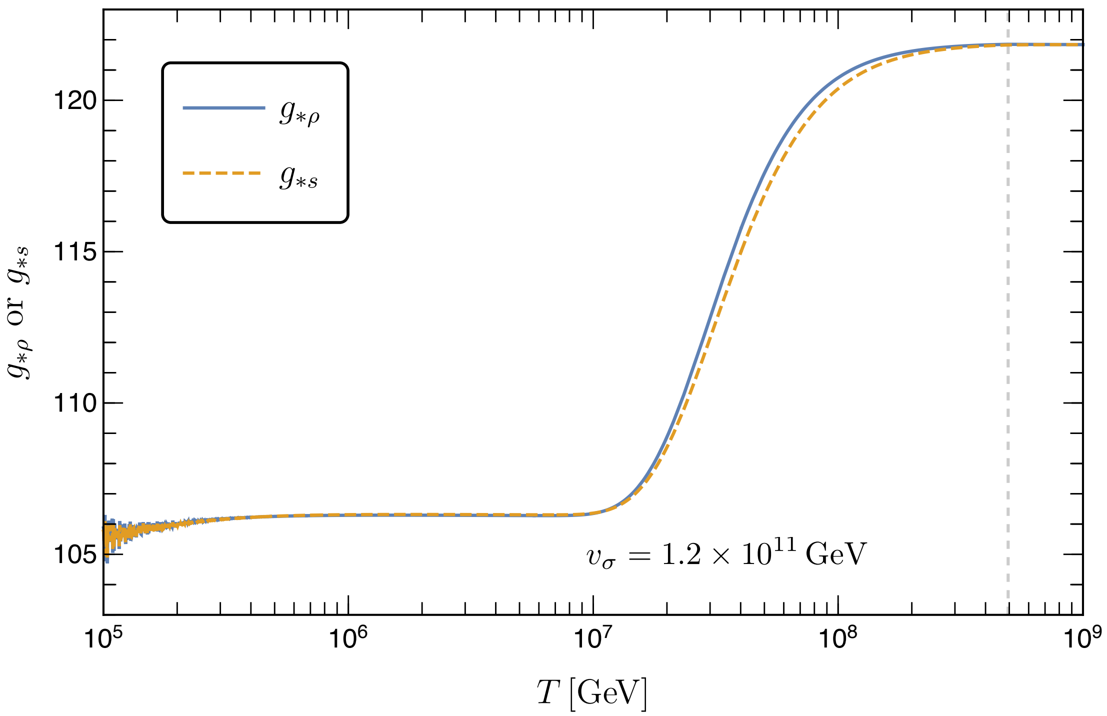
Ultimate DECIGO sensitive to step in SGWB spectrum due to step in EOS at PQ phase transition

Axion 100% DM: $1.1 \times 10^{10}\,\mathrm{GeV} \lesssim v_\sigma < 2.2 \times 10^{11}\,\mathrm{GeV}$

Viable inflation: $10^{-12} \lesssim \lambda_\sigma \lesssim 10^{-9}$

$$10^7\,\mathrm{GeV} \lesssim T_c \simeq \frac{2\sqrt{6\lambda_\sigma} v_\sigma}{\sqrt{8(\lambda_\sigma + \lambda_{H\sigma}) + \sum_i Y_{ii}^2 + 6y^2}} \sim \lambda_\sigma^{1/4} v_\sigma \lesssim 10^9\,\mathrm{GeV}$$





[AR, Saikawa, Tamarit, arXiv:2009.02050]

Stochastic GW Background from Inflation in SM*A*S*H

Ultimate DECIGO sensitive to step in SGWB spectrum due to step in EOS at PQ phase transition

Future space-born GW laser interferometer such as Ultimate DECIGO can probe details of PQ sector that may not be reached in other high-energy experiments

Axion 100% DM: $1.1 \times 10^{10}\,\text{GeV} \lesssim v_\sigma < 2.2 \times 10^{11}\,\text{GeV}$

Viable inflation: $10^{-12} \lesssim \lambda_\sigma \lesssim 10^{-9}$

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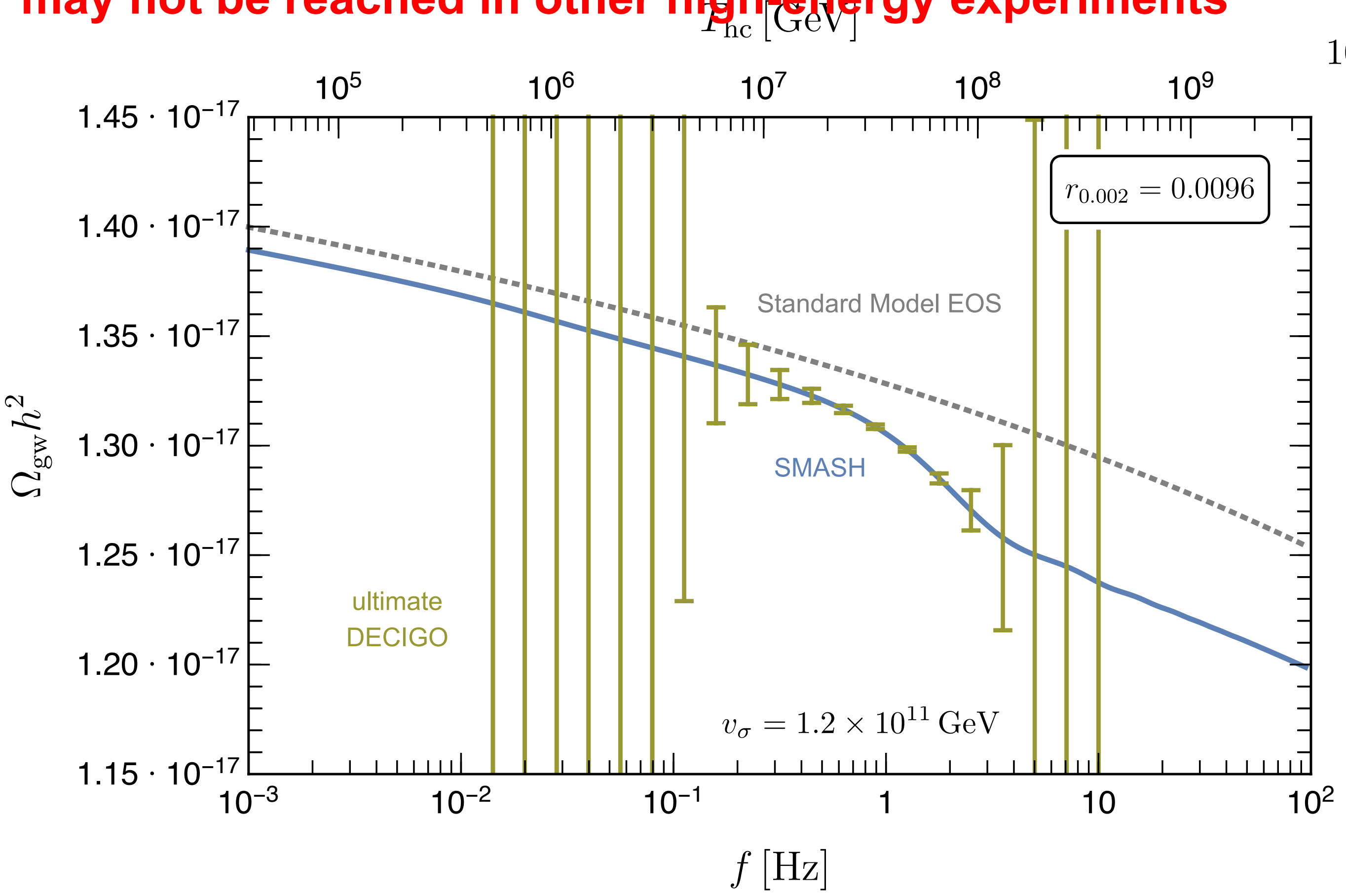
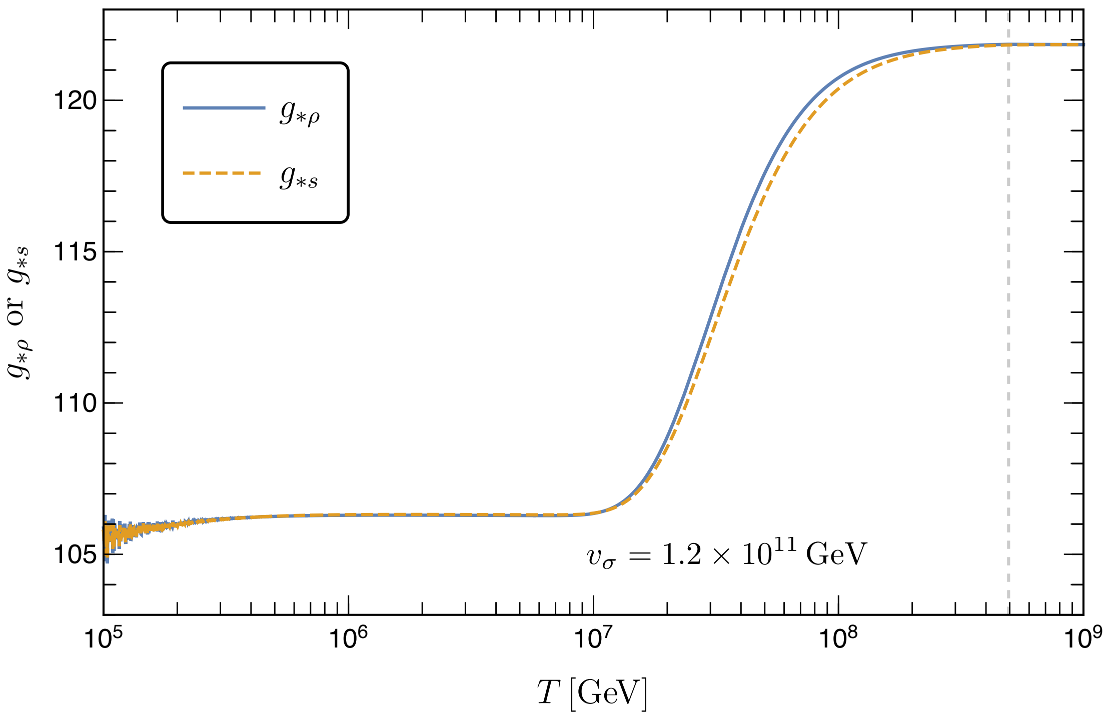


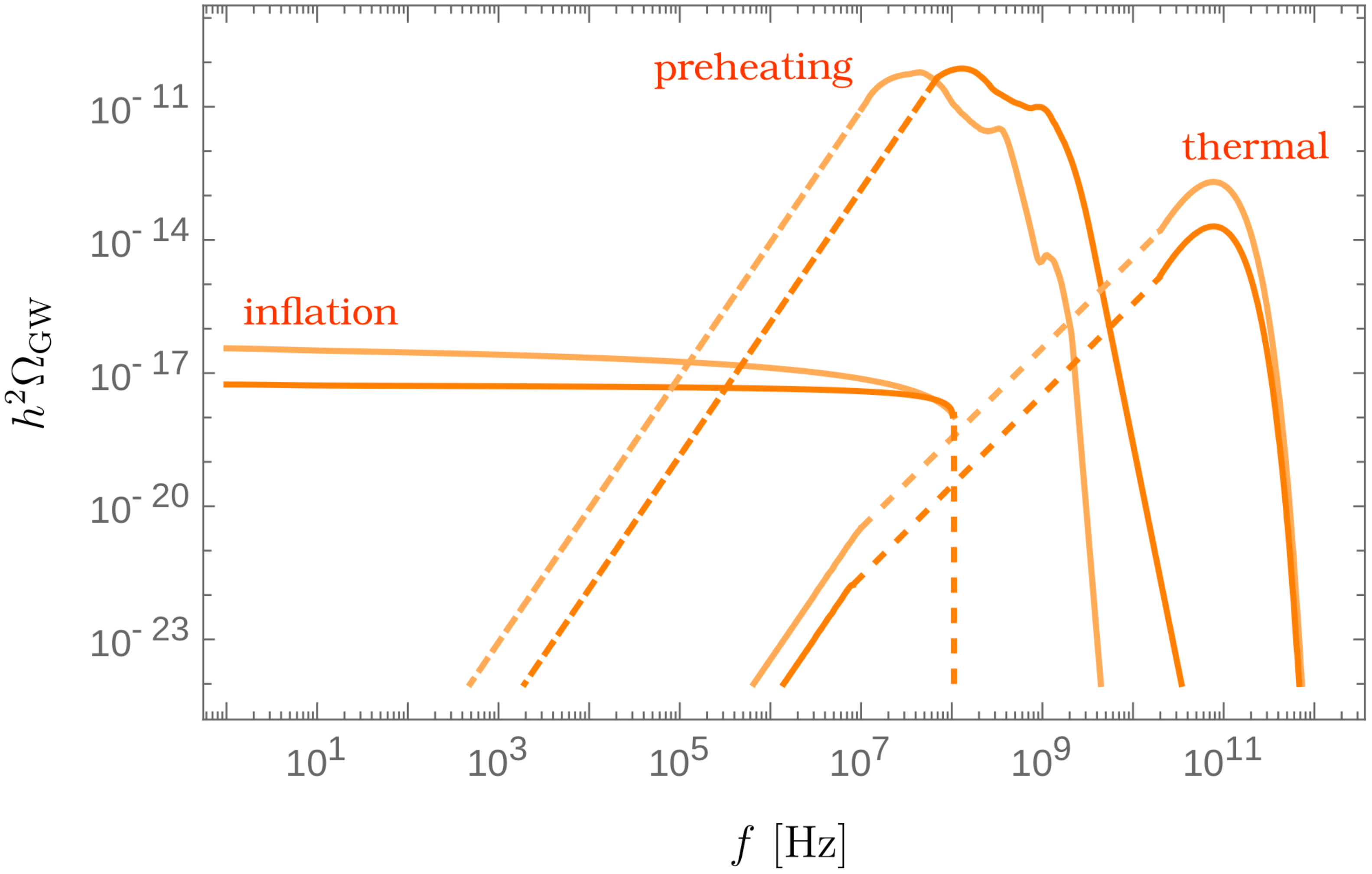


[AR, Saikawa, Tamarit, arXiv:2009.02050]

Stochastic GW Background from SM*A*S*H

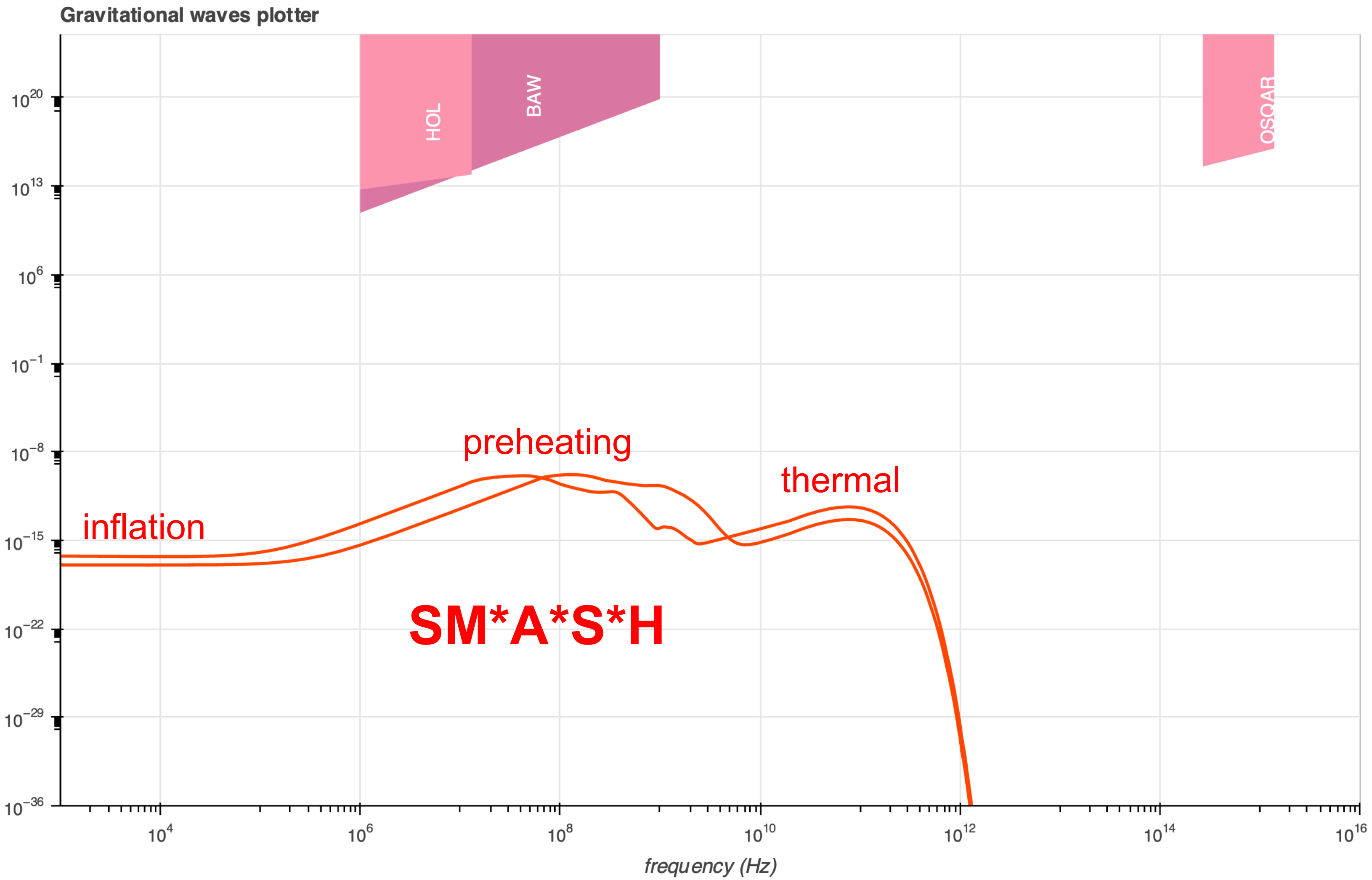
Complete spectrum

[AR, Carlos Tamarit, arXiv:2203.00621]



Stochastic GW Background from SM*A*S*H

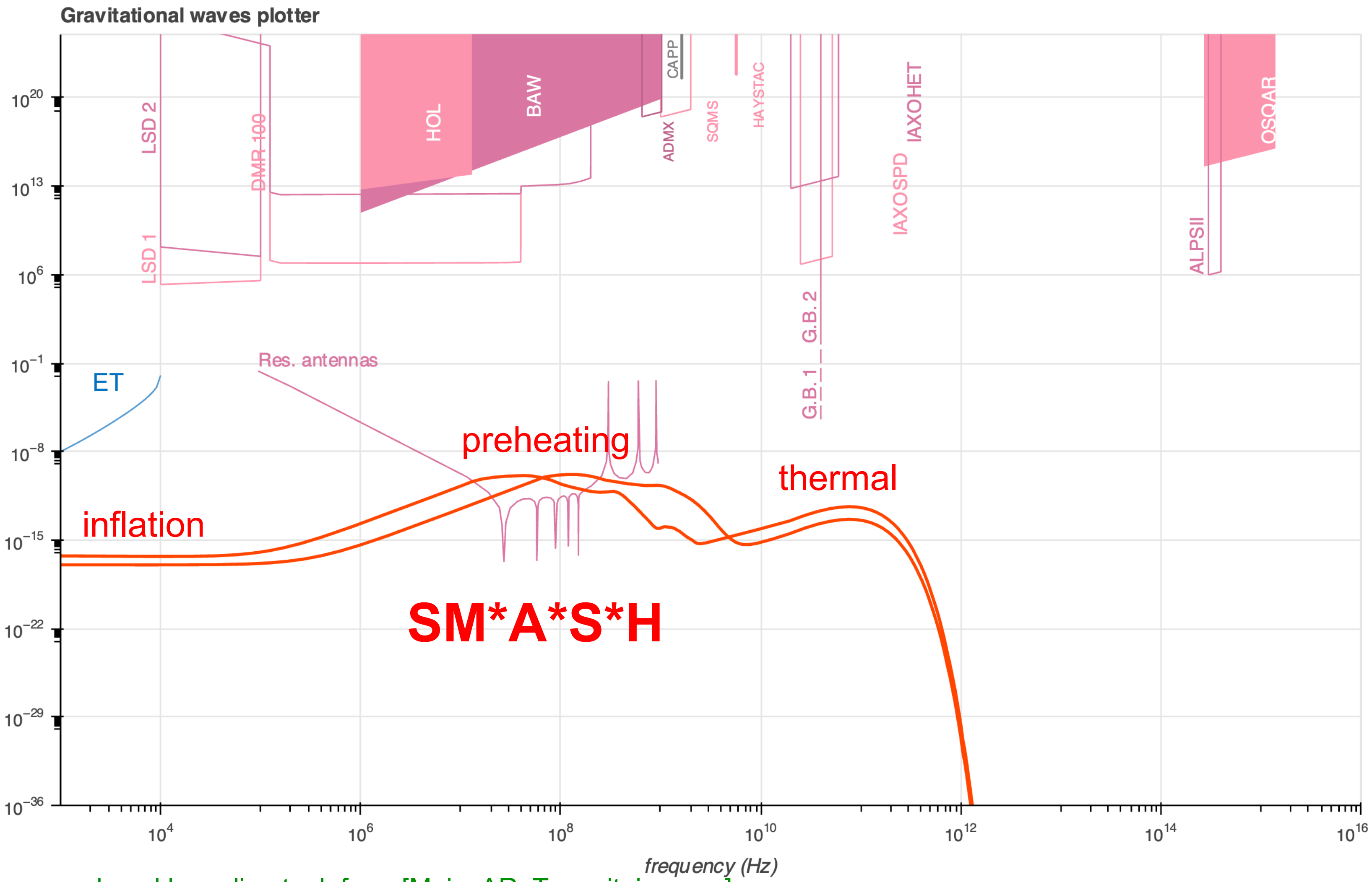
Confronting with current upper bounds from Ultra-High-Frequency (UHF) GW experiments



produced by online tool from [Muia, AR, Tamarit, in prep.]

Stochastic GW Background from SM*A*S*H

Confronting with projected sensitivities of proposed GW experiments



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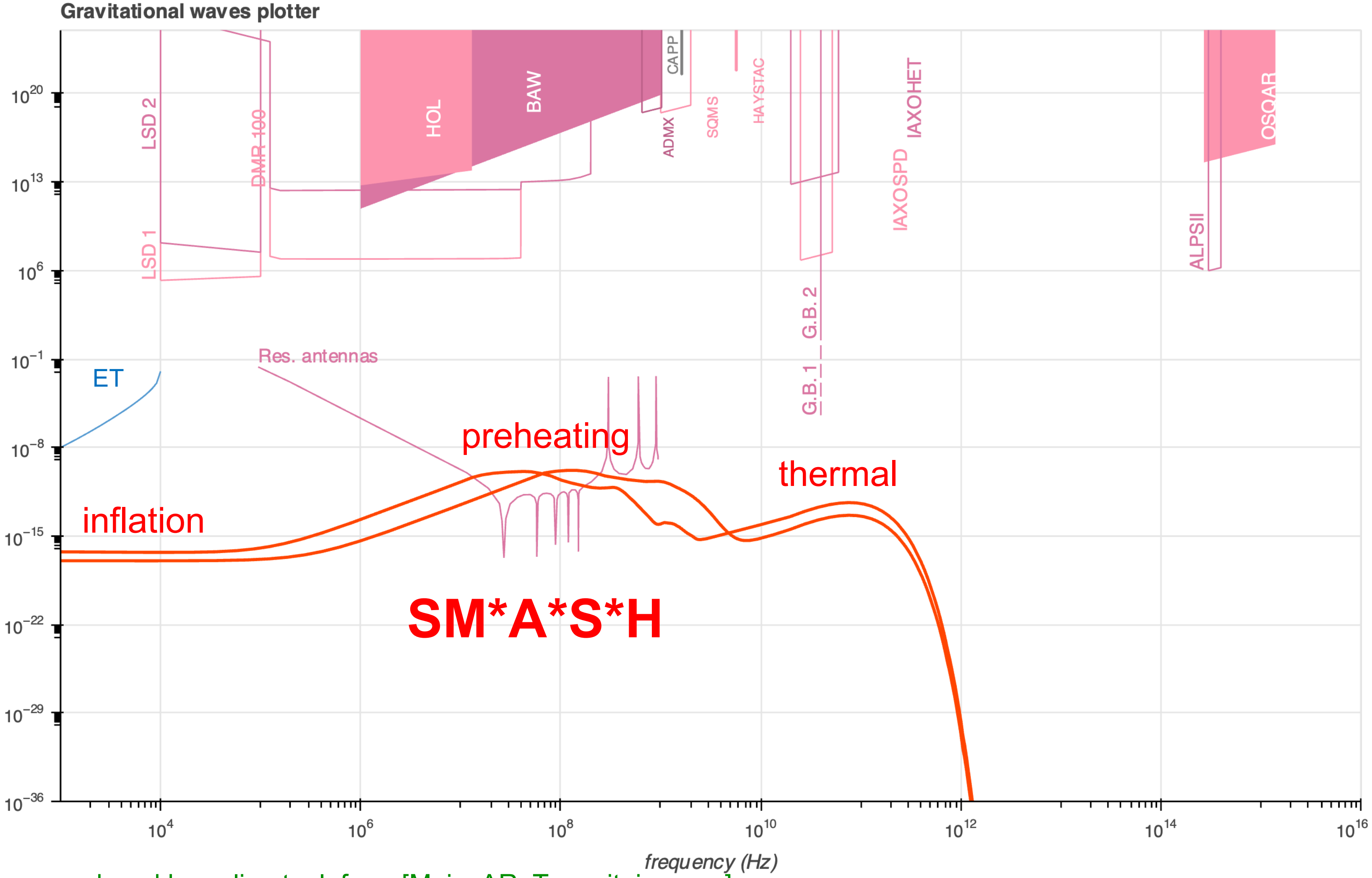


produced by online tool from [Muia, AR, Tamarit, in prep.]

A hypothetical detection of the complete spectrum in different frequency ranges would allow to cross-check for the correlations predicted in SM*A*S*H, opening new possibilities for falsifying the model.

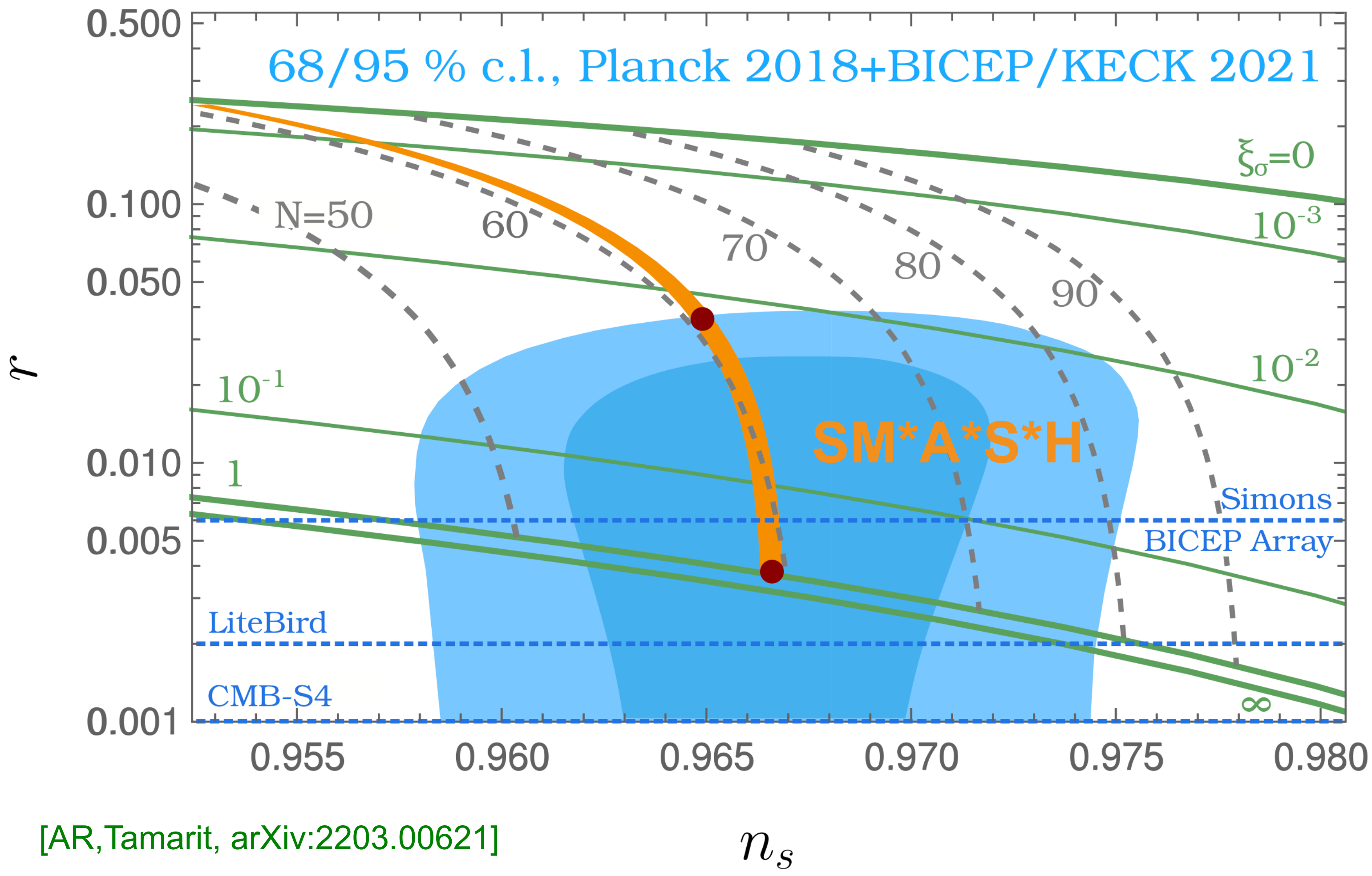
A Pipe Dream

Timeline for establishing SM*A*S*H as effective field theory of particle physics and cosmology

A Pipe Dream

Timeline for establishing SM*A*S*H as effective field theory of particle physics and cosmology

- **In 2030s:** CMB-S4 and LiteBird discover B modes consistent with predictions from SM*A*S*H

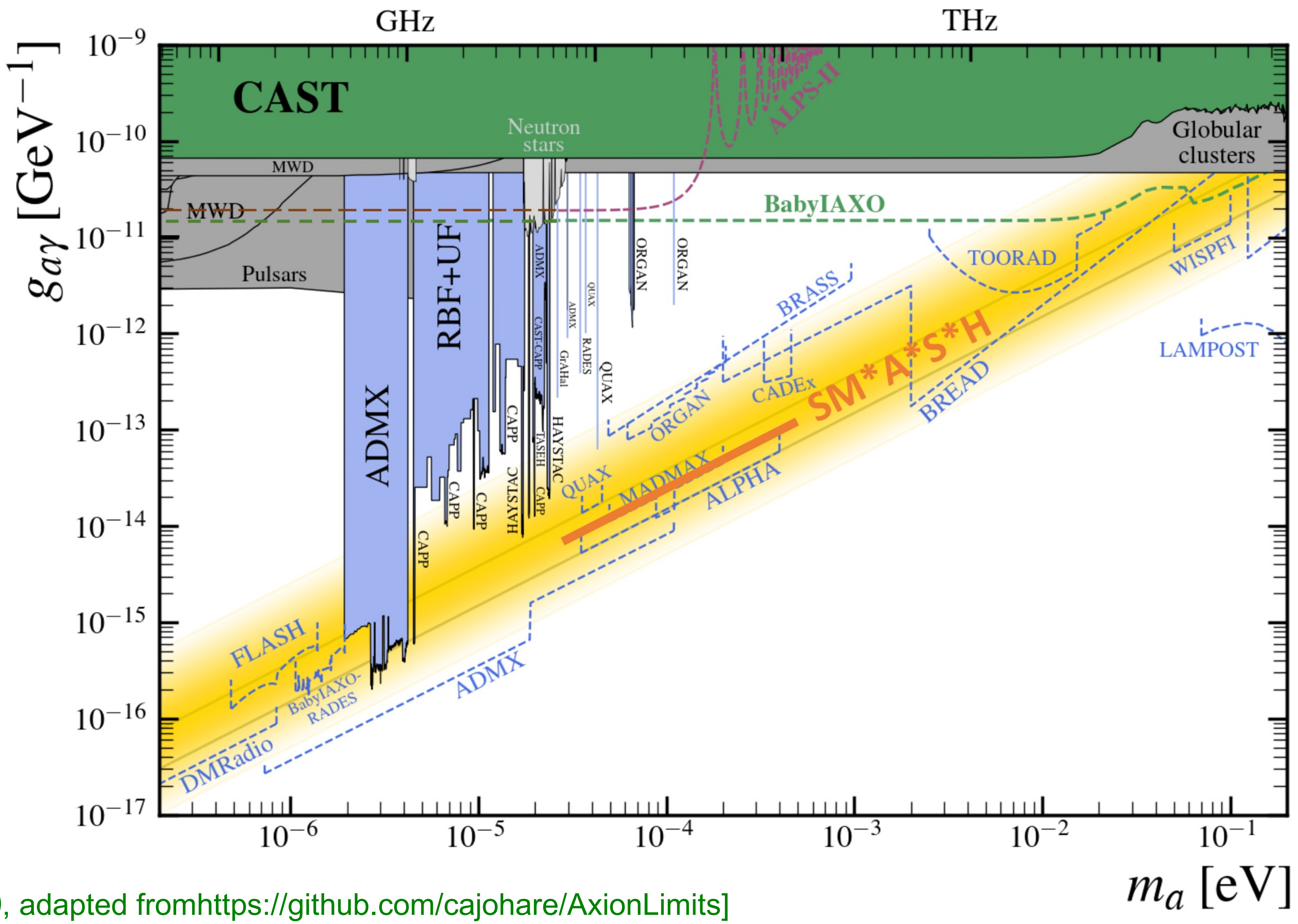


[AR,Tamarit, arXiv:2203.00621]

A Pipe Dream

Timeline for establishing SM*A*S*H as effective field theory of particle physics and cosmology

- **In 2030s:** ALPHA and MADMAX discover axion dark matter in the mass region predicted by SM*A*S*H

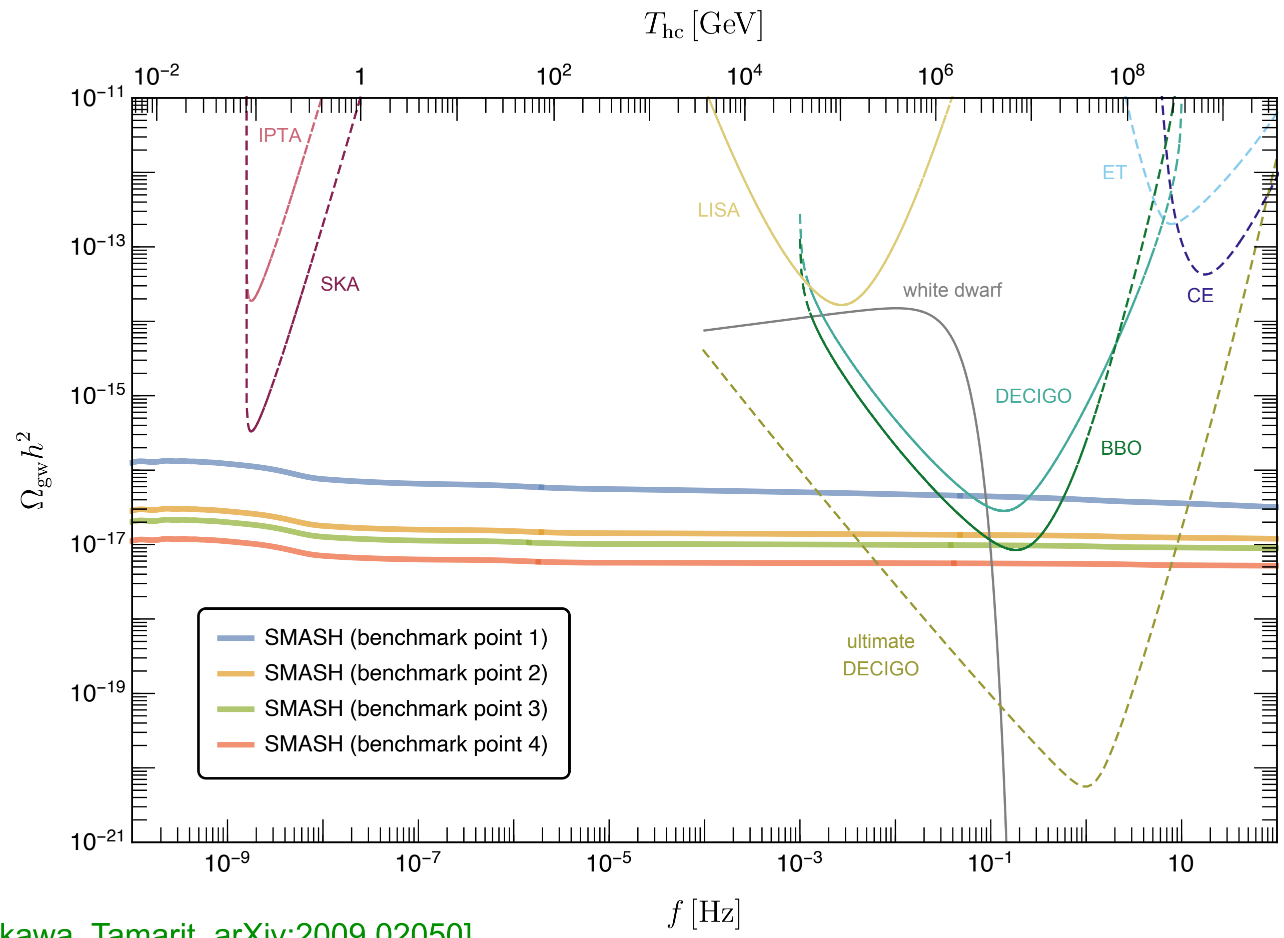


[AR 2312.14679, adapted fromhttps://github.com/cajohare/AxionLimits]

A Pipe Dream

Timeline for establishing SM*A*S*H as effective field theory of particle physics and cosmology

- **In 2060s:** Space-born laser interferometer detects SGWB background predicted from inflation in SM*A*S*H

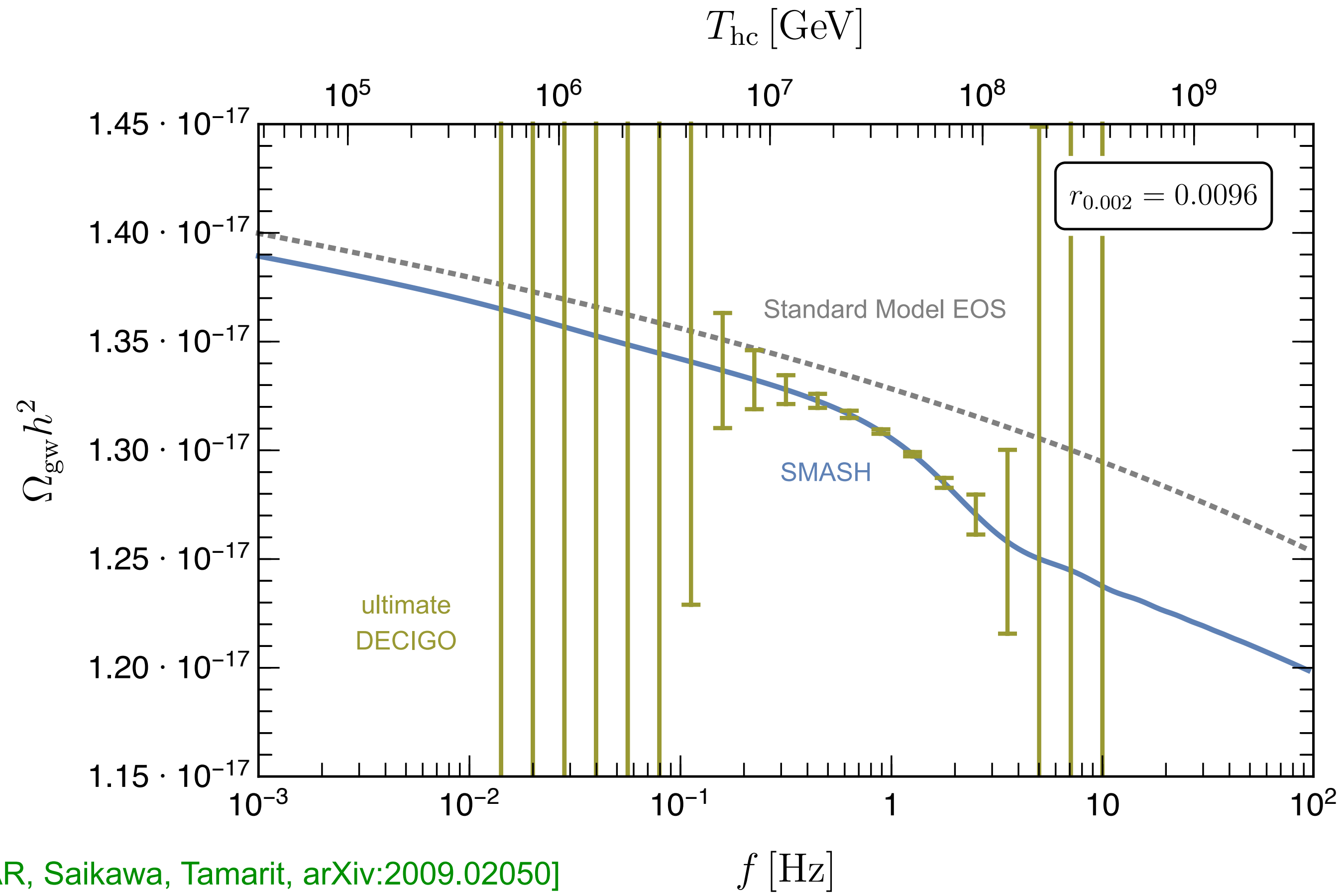


[AR, Saikawa, Tamarit, arXiv:2009.02050]

A Pipe Dream

Timeline for establishing SM*A*S*H as effective field theory of particle physics and cosmology

- **In 2080s:** Upgraded space-borne GW detector discovers step in SGWB from PQ phase transition in SM*A*S*H



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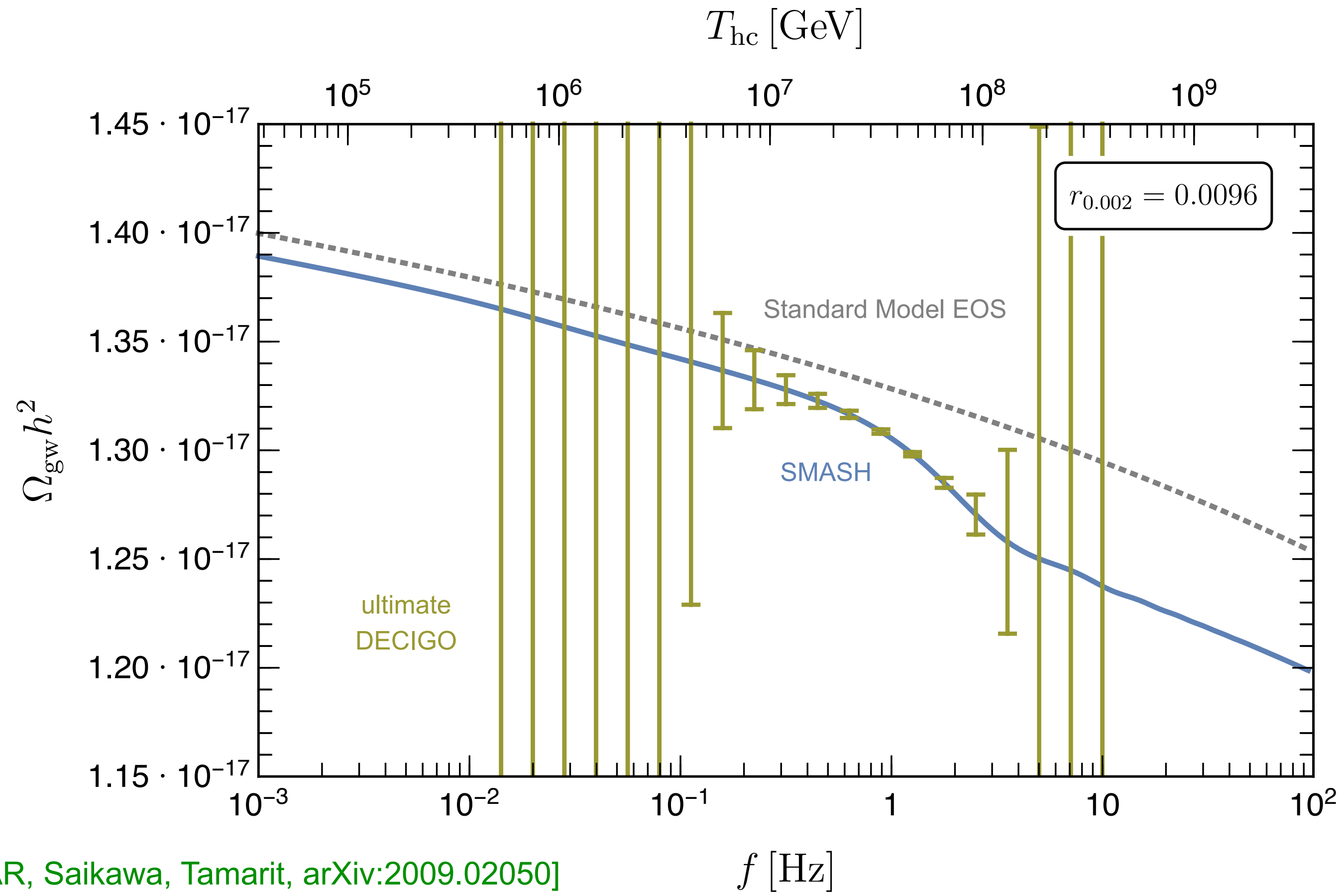


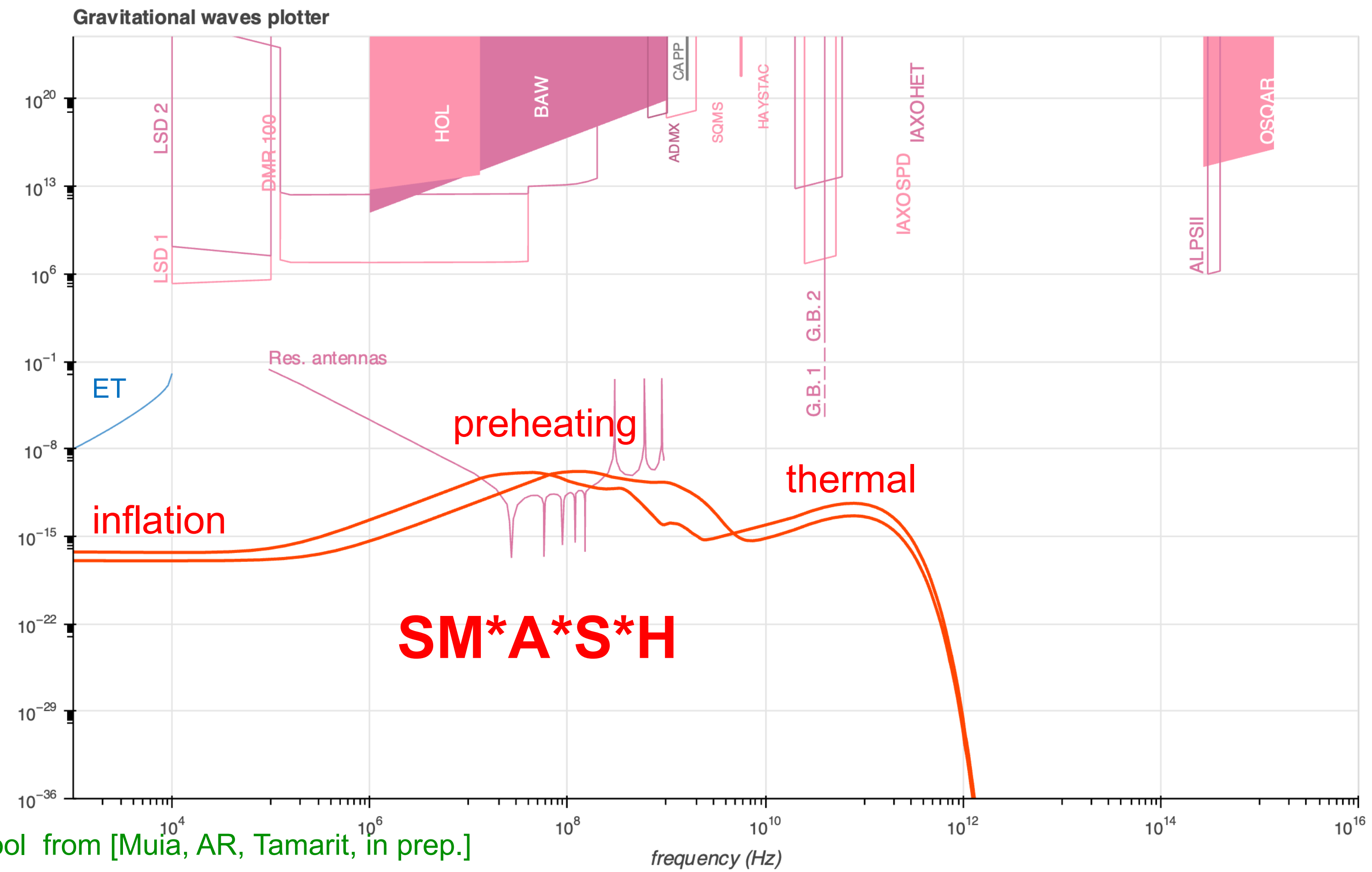
[AR, Saikawa, Tamarit, arXiv:2009.02050]

- SM*A*S*H parameter ranges inferred from the position of the step is consistent with the parameter ranges inferred from the measurements at CMB polarisation experiments and axion haloscopes

A Pipe Dream

Timeline for establishing SM*A*S*H as effective field theory of particle physics and cosmology

- **In 20??s:** New Ultra-high-frequency GW detectors may allow to scrutinise also SM*A*S*H predictions from preheating and thermal plasma



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Backup Slides

Summary

- Presented state-of-the-art predictions for the complete spectrum of primordial stochastical GWs in a well-motivated and highly predictive minimal model of particle physics
- Can be seen as a conservative benchmark for the expected GWs from the early universe
- Provides strong motivation for future space-born GW interferometers such as Ultimate DECIGO and for the development of new GW detectors sensitive at MHz to GHz frequencies
- Currently, a community is forming which seriously considers the search for ultra-high frequency GWs

CERN-TH-2020-185
HIP-2020-28/TH
DESY 20-195

Challenges and Opportunities of Gravitational Wave Searches at MHz to GHz Frequencies

N. Aggarwal[a,*], O.D. Aguiar[b], A. Bauswein[c], G. Cella[d], S. Clesse[e], A.M. Cruise[f], V. Domcke[g,h,i,*], D.G. Figueroa[j], A. Geraci[k], M. Goryachev[l], H. Grote[m], M. Hindmarsh[n,o], F. Muia[p,i,*], N. Mukund[q], D. Ottaway[r,s], M. Peloso[t,u], F. Quevedo[p,*], A. Ricciardone[t,u], J. Steinlechner[v,w,x,*], S. Steinlechner[v,w,*], S. Sun[y,z], M.E. Tobar[l], F. Torrenti[α], C. Unal[β], G. White[γ]

arXiv:2011.12414v1 [gr-qc] 24 Nov 2020

Abstract

The first direct measurement of gravitational waves by the LIGO and Virgo collaborations has opened up new avenues to explore our Universe. This white paper outlines the challenges and gains expected in gravitational wave searches at frequencies above the LIGO/Virgo band, with a particular focus on the MHz and GHz range. The absence of known astrophysical sources in this frequency range provides a unique opportunity to discover physics beyond the Standard Model operating both in the early and late Universe, and we highlight some of the most promising gravitational sources. We review several detector concepts which have been proposed to take up this challenge, and compare their expected sensitivity with the signal strength predicted in various models. This report is the summary of the workshop *Challenges and opportunities of high-frequency gravitational wave detection* held at ICTP Trieste, Italy in October 2019.

Summary

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Ultra-High-Frequency GWs: A Theory and Technology Roadmap

Oct 12 – 15, 2021
CERN
Europe/Zurich timezone

Enter your search term

Overview
Timetable
Registration
Participant List

Support
THworkshops.secretaria...

This workshop is part of the Ultra-High-Frequency Gravitational Waves initiative (see the website of our initiative) and comes after a first meeting held at ICTP in Trieste in 2019 (see the website of the first workshop) that led to a review paper on the subject.

The aim of this meeting is to foster the technology development that is necessary to get to ultra-high-frequency gravitational wave detection. In particular, we will discuss

- the science case for UHF-GW searches
- new detector concepts
- feasibility studies and construction of prototypes for proposed detector concepts
- coordinating an international effort to support collaborations working on UHF-GW detectors

The workshop will combine theoretical developments regarding GW sources in different parts of the ultra-high-frequency band with experimental concepts aiming at probing them.

Each day we will have a discussion session with the aim of setting up working groups around one or more detector concepts and/or theoretical aspects of sources, which will be encouraged to continue their work after the end of the workshop, hopefully contributing to the technology development that is needed to make concrete progress in the field.

If you would like to contribute a talk, please contact the organizers.

Starts Oct 12, 2021, 12:00 PM
Ends Oct 15, 2021, 8:00 PM
Europe/Zurich

CERN
Zoom only

Nancy Aggarwal
Valerie Domcke
Francesco Muia
Fernando Quevedo
Andreas Ringwald
Jessica Steinlechner
Sebastian Steinlechner

https://indico.cern.ch/event/1074510/

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Ultra-high frequency gravitational waves: where to next ?

4 Dec 2023, 09:00 → 8 Dec 2023, 19:00 Europe/Zurich

4/3-006 - TH Conference Room (CERN)

Description The direct detection of gravitational waves has opened a new window of observation for phenomena in which gravity, instead of light, is the messenger. The goal of the Ultra-High-Frequency Gravitational Waves (UHF-GW) initiative is to promote scientific progress in a new area of research, gravitational waves at ultra-high-frequency, both from theoretical and experimental points of view. The ultra-high-frequency band (above 10 kHz) is particularly important and interesting because gravitational wave detection in this range would give us important insights about the very early Universe and particle physics at energy scales that cannot be probed with colliders in the foreseeable future.

This workshop, hosted by CERN TH and the CERN-Korea Theory Collaboration, is the third in a series of workshops organized by the UHF-GW initiative, aiming at addressing theoretical open questions about the nature of ultra-high-frequency gravitational wave sources and at stimulating the technological progress that is necessary to detect gravitational waves in this frequency range. This workshop will be focussed on assessing various new detector concepts that have been proposed recently, discussing progress and challenges in implementing high frequency GW detectors as well as on discussing recent progress in the understanding of some UHF-GW sources.

This workshop will feature a small number of longer talks on different aspects of UHF GW detection, as well as plenary sessions of short contributed talks and topical discussion sessions. In addition, there will be ample time for informal discussions and work on collaborative projects. We encourage submissions for short contributed talks on all aspects of UHF GWs by September 15th.

Previous editions of this series where held in Trieste (2019) and online (2021), leading to a Living Review on UHF GWs.

This workshop is partially funded by the CERN-Korea Theory Collaboration and by the UKRI/EPSRC Stephen Hawking fellowship, grant reference EP/T017279/1.

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Invited speakers:

Aldo Ejlli (Cardiff U.)
Sebastian Ellis (Geneva U.)
Gabriele Franciolini (Rome U.)
Elina Fuchs (Hannover U., Braunschweig U.)
Camilo Garcia-Cely (Valencia U.)
Andrew Geraci (Northwestern U.)
Bianca Giacconi (Fermilab)
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https://indico.cern.ch/event/1257532/

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- **Revealing the cosmic history sets an ambitious, but rewarding goal for this enterprise**

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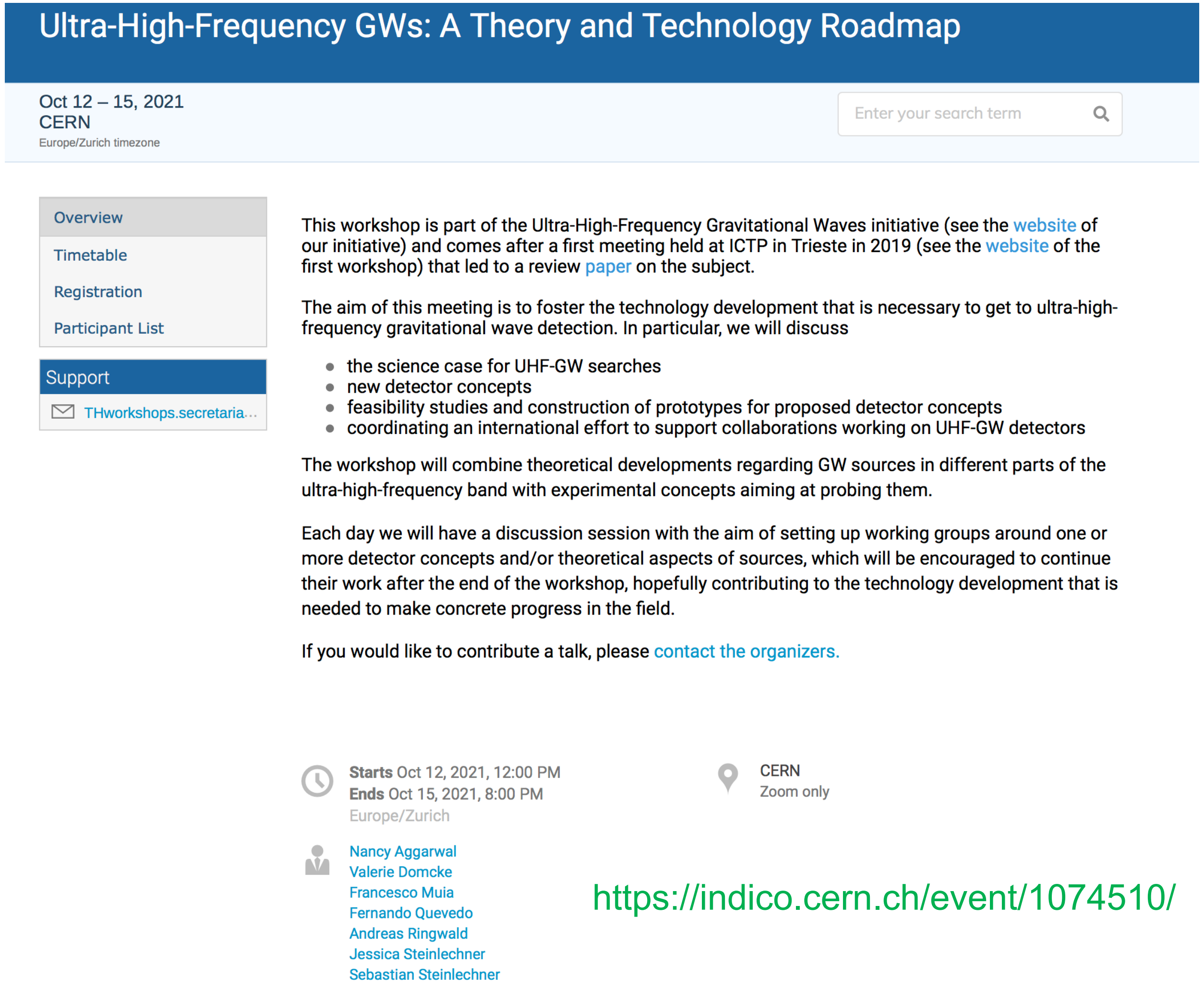
Ultra-High-Frequency GWs: A Theory and Technology Roadmap

Oct 12 – 15, 2021
CERN
Europe/Zurich timezone

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Overview
Timetable
Registration
Participant List

Support
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This workshop is part of the Ultra-High-Frequency Gravitational Waves initiative (see the website of our initiative) and comes after a first meeting held at ICTP in Trieste in 2019 (see the website of the first workshop) that led to a review paper on the subject.

The aim of this meeting is to foster the technology development that is necessary to get to ultra-high-frequency gravitational wave detection. In particular, we will discuss

- the science case for UHF-GW searches
- new detector concepts
- feasibility studies and construction of prototypes for proposed detector concepts
- coordinating an international effort to support collaborations working on UHF-GW detectors

The workshop will combine theoretical developments regarding GW sources in different parts of the ultra-high-frequency band with experimental concepts aiming at probing them.

Each day we will have a discussion session with the aim of setting up working groups around one or more detector concepts and/or theoretical aspects of sources, which will be encouraged to continue their work after the end of the workshop, hopefully contributing to the technology development that is needed to make concrete progress in the field.

If you would like to contribute a talk, please contact the organizers.

Starts Oct 12, 2021, 12:00 PM
Ends Oct 15, 2021, 8:00 PM
Europe/Zurich

CERN
Zoom only

Nancy Aggarwal
Valerie Domcke
Francesco Muia
Fernando Quevedo
Andreas Ringwald
Jessica Steinlechner
Sebastian Steinlechner

https://indico.cern.ch/event/1074510/

GWs from Stochastic Scalar Fluctuations during Reheating

Lattice simulations

- Simulated 3 real scalars, $\phi_1 = \sqrt{2}\mathrm{Re}\sigma(\mathrm{t},\mathbf{x}), \phi_2 = \sqrt{2}\mathrm{Im}\sigma(\mathrm{t},\mathbf{x}), \mathrm{h}(\mathrm{t},\mathbf{x})$, with h decaying into a relativistic bath of SM particles with energy density $\rho_{\rm SM}(t)$, in an expanding FRW universe:

$$\ddot{\phi}_n + 3\frac{\dot{a}}{a}\dot{\phi}_n - \frac{1}{a^2}\vec{\nabla}^2\phi_n + \frac{\partial V}{\partial \phi_n},\ n = 1, 2,$$

$$\ddot{h} + 3\frac{\dot{a}}{a}\dot{h} - \frac{1}{a^2}\vec{\nabla}^2 h + \frac{\partial V}{\partial h} + \Gamma_h \dot{h} = 0,$$

$$\dot{\rho}_{\rm SM} + 4\frac{\dot{a}}{a}\rho_{\rm SM} - \Gamma_h \dot{h}^2 = 0,$$

$$3M_P^2\left(\frac{\dot{a}}{a}\right)^2 = \rho_{\rm SM} + V + \frac{1}{2}\left(\dot{\phi}_1^2 + \dot{\phi}_2^2 + h^2\right) + \frac{1}{2a^2}\left((\nabla\phi_1)^2 + (\nabla\phi_2)^2 + (\nabla h)^2\right).$$

- Used modified version of “CLUSTEREASY” [Felder, Tkachev 08] . Changes account for Higgs decay, SM radiation and impact on scale factor evolution, modified initial conditions for super-horizon modes

[Ballesteros,AR,Tamarit,Welling, arXiv:2104.13847; AR,Tamarit, arXiv: 2203.00621]

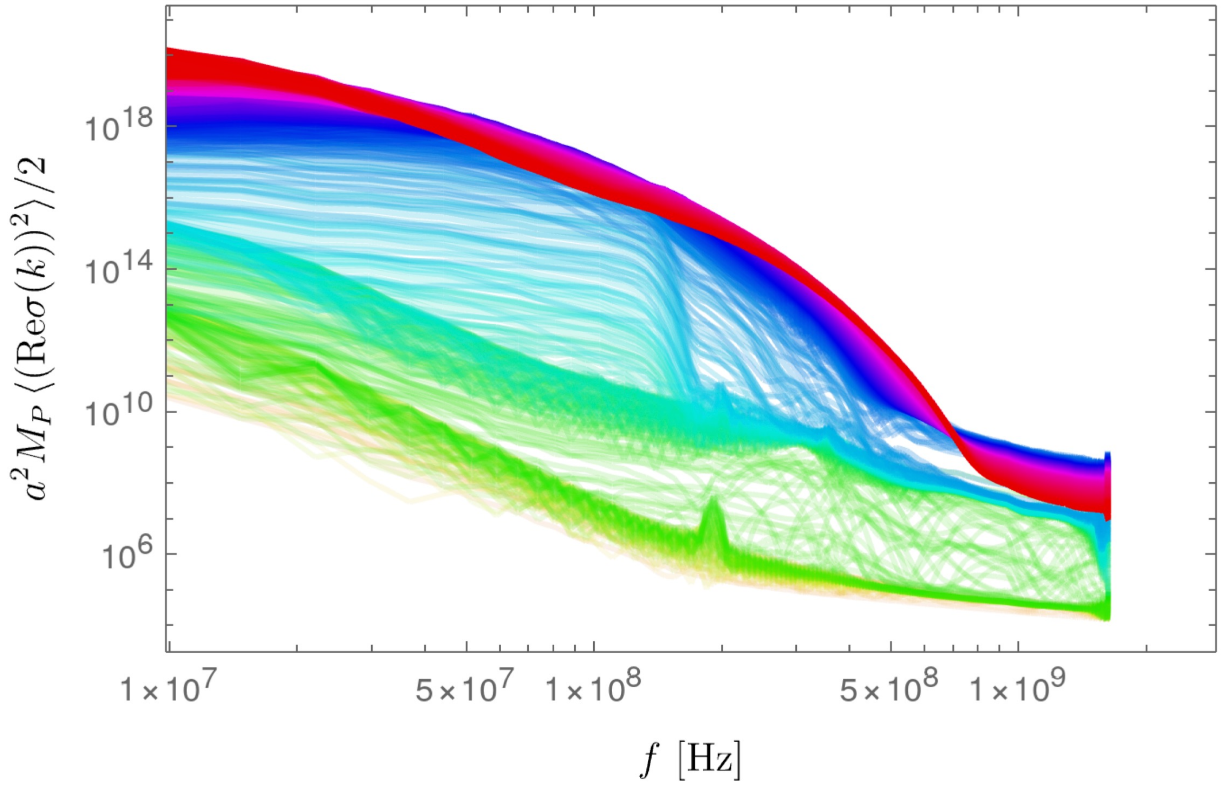
- Used lattices with 256^3 points
- Used 8 powerful CPU cores running for ~7 days,
- Computed up to tau = 2000 (rescaled conformal time in program units)

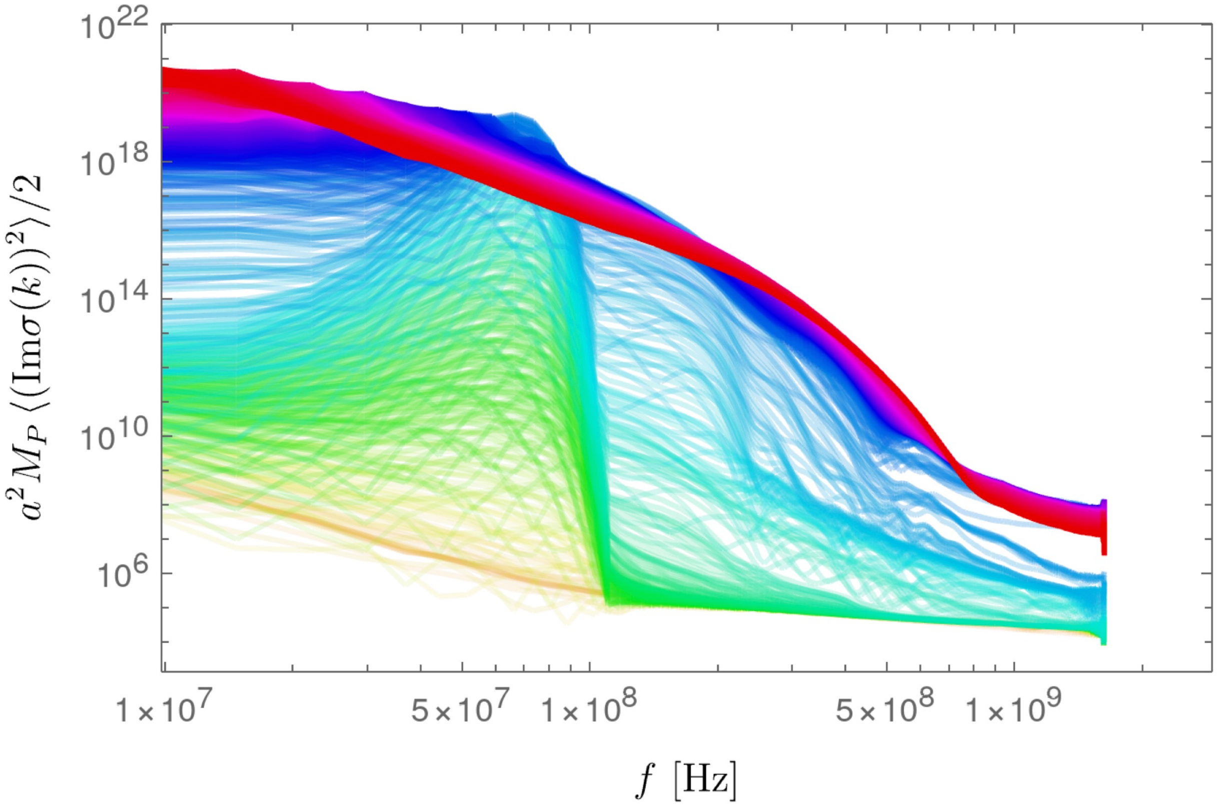
GWs from Stochastic Scalar Fluctuations during Reheating

Power spectra obtained by lattice simulations

[AR, Carlos Tamarit, arXiv: 2203.00621]

Power spectra of $\mathrm{Re}\,\sigma$ (left) and $\mathrm{Im}\,\sigma$ (right) for BP1, as a function of today's frequency for subsequent values of the conformal time. The red line corresponds to the final time of the simulation.



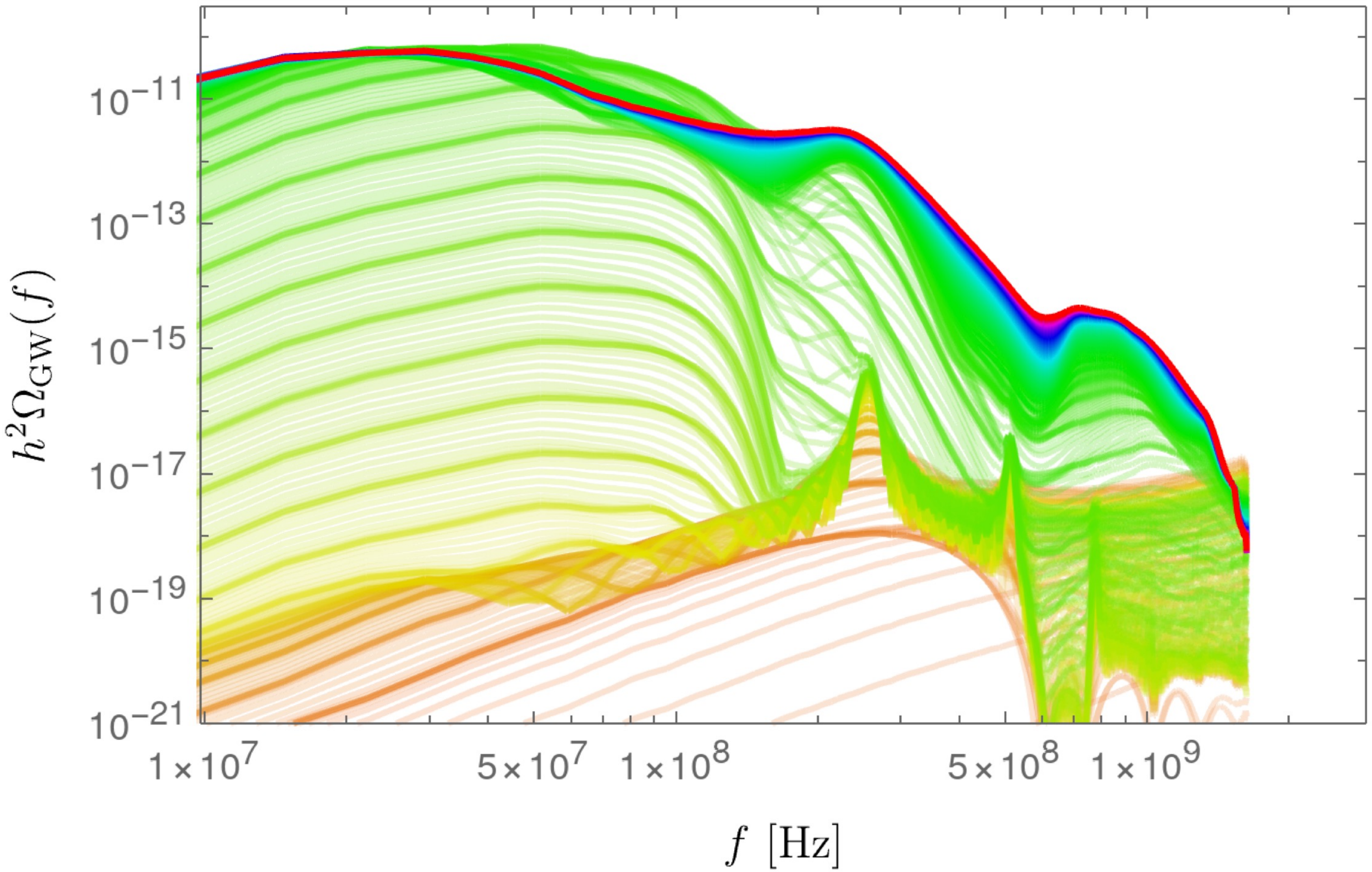


GWs from Stochastic Scalar Fluctuations during Reheating

Power spectra obtained by lattice simulations

[AR, Carlos Tamarit, arXiv: 2203.00621]

Present energy density of GWs for BP1, with the source integrated up to different times. The red line corresponds to the final time of the simulation.



GWs from Thermal Fluctuations after Reheating

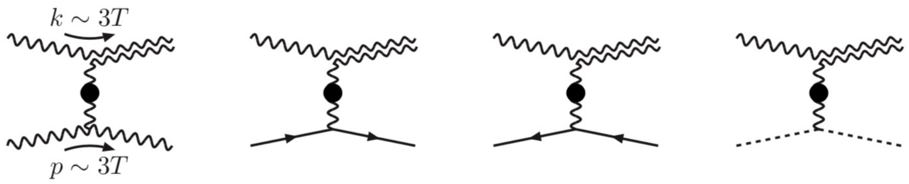
Cosmic Gravitational Microwave Background (CGMB)

$$h^2\,\Omega_{\rm CGMB}(f) \approx 4.0\times 10^{-12}\left[\frac{T_{\rm rh}}{M_P}\right]\left[\frac{g_{*s}(T_{\rm rh})}{106.75}\right]^{-5/6}\left[\frac{f}{\rm GHz}\right]^3 \hat{\eta}\left(T_{\rm rh}, 2\pi\left[\frac{g_{*s}(T_{\rm rh})}{3.9}\right]^{1/3}\frac{f}{T_0}\right)$$

- **At large wavelengths**, corresponding to small wave numbers, $k \ll T$, CGMB sourced by macroscopic hydrodynamic fluctuations, described by the shear viscosity of the plasma:

$$\hat{\eta}\left(T, \frac{k}{T}\right) \simeq \frac{\eta^{\rm shear}(T)}{T^3}\,, \ \text{for}\ k \ll T$$

- **At small wavelengths**, corresponding to large wave numbers, $k \gg T$, CGMB sourced by particle collisions:



  - Corresponding source term suppressed by gauge couplings and Boltzmann factor:

$$\hat{\eta}\left(T, \frac{k}{T}\right) \sim g(T)^2\,\exp\left(-k/T\right),\ \text{for}\ k \gg T\ .$$

  - Known to complete leading order for generic weakly interacting BSM extension (gauge fields, fermions, scalars) [Ghiglieri,Laine ’15; Ghiglieri,Jackson,Laine,Zhu ’20; AR,Schütte-Engel,Tamarit ‘20]
  - For N=4 SUSY YM known also for strong coupling [Castells-Tiestos, Casalderrey-Solana ´22]

Is SM*A*S*H smashed by swampland conjectures?

- This is not expected, since ordinary Higgs inflation can be in landscape:

[Cheong et al., arXiv:1811.03622; Liu, arXiv:2112.14571]

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Higgs inflation and the refined dS conjecture

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The refined de Sitter derivative conjecture provides constraints to potentials that are low energy effective theories of quantum gravity. It can give direct bounds on inflationary scenarios and determine whether the theory is in the Landscape or the Swampland. We consider the 'Higgs inflation' scenario taking the refined de Sitter derivative conjecture into account. Obtaining the critical lines for the potential, we find a conjecture parameter space in which the 'Higgs inflation' is to be in the Landscape. Comparing with the model independent observational bounds from recent data we find that the observational bounds represent the Higgs inflation can be in the Landscape.

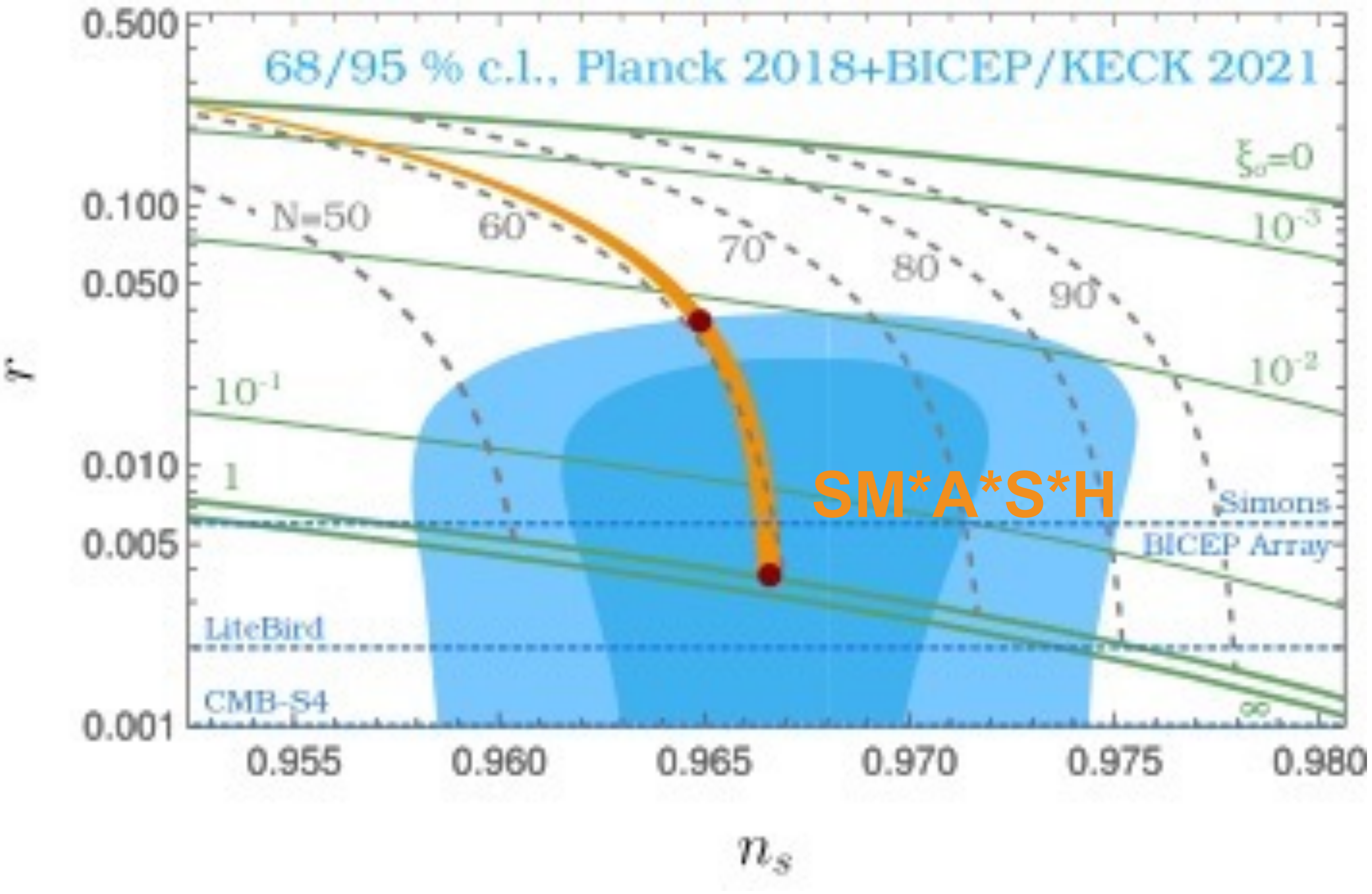
- Could be an interesting prospect to investigate whether the requirement of being in the landscape gives further restrictions to the allowed parameter space in SM*A*S*H

Is SM*A*S*H smashed by swampland conjectures?

- In observationally constrained SM*A*S*H inflation, inflaton field travels a distance of O(10) M_P:

Benchmark for $r(k_*) = 0.0037$:

$$\phi_* = 8.4 M_P$$
$$\xi_\sigma(\phi_*) = 1.0$$
$$\tilde{\lambda}_\sigma(\phi_*) = 5.3 \times 10^{-10}$$
$$\hat{\kappa} = 0.08$$
$$\phi_{\rm end} = 0.76\, M_P$$
$$N_{\rm post} = 64.0$$
$$\alpha = 3 \times 10^{-4}$$
$$\mathcal{H}_{\rm end} = 2.4 \times 10^{-6} M_P$$



[AR,Tamarit, arXiv:2203.00621]

Benchmark for $r(k_*) = 0.036$:

$$\phi_* = 21.4 M_P$$
$$\xi_\sigma(\phi_*) = 0.014$$
$$\tilde{\lambda}_\sigma(\phi_*) = 1.25 \times 10^{-12}$$
$$\hat{\kappa} = 0.05$$
$$\phi_{\rm end} = 2.2\, M_P$$
$$N_{\rm post} = 64.3$$
$$\alpha = 1 \times 10^{-5}$$
$$\mathcal{H}_{\rm end} = 1.8 \times 10^{-6} M_P$$

Backup: Resonant Cavity Detector

- Based on conversion of GWs to EMWs in magnetic field background through inverse Gertsensthein effect

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1. WO2019129745 - DEVICES FOR THE DIRECTIONAL EMISSION AND RECEPTION OF GRAVITATIONAL WAVES

PCT Biblio. Data | Description | Claims | Drawings | ISR/WOSA/A17(2)(a) | National Phase | Patent Family | Notices | Documents

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Applicants UNIVERSITÉ DE NAMUR [BE]/[BE] rue de Bruxelles 61 5000 Namur, BE
Inventors FÜZFA, André
Agents GEVERS Holidaystraat 5 1831 Diegem, BE
Priority Data 17210675.9 27.12.2017 EP
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Designated States View all

Title
[EN] DEVICES FOR THE DIRECTIONAL EMISSION AND RECEPTION OF GRAVITATIONAL WAVES
[FR] DISPOSITIFS D'ÉMISSION DIRECTIONNELLE ET DE RÉCEPTION D'ONDES GRAVITATIONNELLES

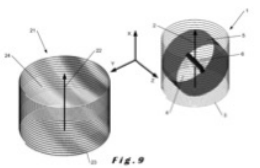

Fig. 9

Abstract
[EN] The present invention relates to electromagnetic devices 1, 21 and associated methods for the directional emission and the detection of gravitational waves. The gravitational wave generating device 1 consists of a cavity 4 carrying electromagnetic waves, which is immersed into an external static magnetic field appropriately oriented for boosting the emission of gravitational waves. It is possible to detect the generated gravitational waves, first through the related energy loss in the generating device 1, and second through the electromagnetic fields that are remotely induced in a gravitational wave detecting device 21. This last device 21 comprises an electromagnet 23 producing a magnetic field which interacts with the incoming gravitational waves in such a way that a magnetic energy is accumulating in a detection region 24 defined by the electromagnet 23.
[FR] La présente invention concerne des dispositifs électromagnétiques 1, 21 et des procédés associés, destinés à l'émission directionnelle et à la détection d'ondes gravitationnelles. Le dispositif de génération d'ondes gravitationnelles 1 se compose d'une cavité 4 transportant des ondes électromagnétiques, qui est immergée dans un champ magnétique statique externe orienté de façon appropriée pour amplifier l'émission d'ondes gravitationnelles. Il est possible de détecter les ondes gravitationnelles générées, en premier à travers la perte d'énergie connexe dans le dispositif de génération 1, et en second à travers les champs électromagnétiques qui sont induits à distance dans un dispositif de détection d'ondes gravitationnelles 21. Ce dernier dispositif 21 comprend un électroaimant 23 produisant un champ magnétique qui interagit avec les ondes gravitationnelles entrantes d'une manière telle qu'une énergie magnétique s'accumule dans une région de détection 24 définie par l'électroaimant 23.

Related patent documents WO/2019/129746

Latest bibliographic data on file with the International Bureau

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1. WO2019129746 - DEVICES FOR THE DIRECTIONAL EMISSION AND RECEPTION OF GRAVITATIONAL WAVES

PCT Biblio. Data | Description | Claims | Drawings | ISR/WOSA/A17(2)(a) | National Phase | Patent Family | Notices | Documents

PermaLink Machine translation

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Agents GEVERS PATENTS Holidaystraat 5 1831 Diegem, BE
Priority Data 17210675.9 27.12.2017 EP
Publication Language English (en)
Filing Language English (EN)
Designated States View all

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[EN] DEVICES FOR THE DIRECTIONAL EMISSION AND RECEPTION OF GRAVITATIONAL WAVES
[FR] DISPOSITIFS D'ÉMISSION DIRECTIONNELLE ET DE RÉCEPTION D'ONDES GRAVITATIONNELLES

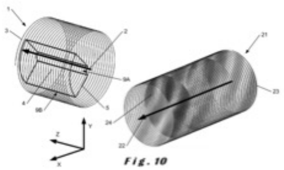

Fig. 10

Abstract
[EN] The present invention relates to electromagnetic devices 1, 21 and associated methods for the directional emission and the detection of gravitational waves. The gravitational wave generating device 1 consists of a cavity 4 carrying electromagnetic waves, which is immersed into an external static magnetic field appropriately oriented for boosting the emission of gravitational waves. It is possible to detect the generated gravitational waves, first through the related energy loss in the generating device 1, and second through the electromagnetic fields that are remotely induced in a gravitational wave detecting device 21. This last device 21 comprises an electromagnet 23 producing a magnetic field which interacts with the incoming gravitational waves in such a way that a magnetic energy is accumulating in a detection region 24 defined by the electromagnet 23.
[FR] La présente invention concerne des dispositifs électromagnétiques 1, 21 et des procédés associés, destinés à l'émission directionnelle et à la détection d'ondes gravitationnelles. Le dispositif de génération d'ondes gravitationnelles 1 se compose d'une cavité 4 transportant des ondes électromagnétiques, qui est immergée dans un champ magnétique statique externe orienté de façon appropriée pour amplifier l'émission d'ondes gravitationnelles. Il est possible de détecter les ondes gravitationnelles générées, en premier à travers la perte d'énergie connexe dans le dispositif de génération 1, et en second à travers les champs électromagnétiques qui sont induits à distance dans un dispositif de détection d'ondes gravitationnelles 21. Ce dernier dispositif 21 comprend un électroaimant 23 produisant un champ magnétique qui interagit avec les ondes gravitationnelles entrantes d'une manière telle qu'une énergie magnétique s'accumule dans une région de détection 24 définie par l'électroaimant 23.

Related patent documents WO/2019/129745

Latest bibliographic data on file with the International Bureau

[Füzfa, https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2019129745]

[Füzfa, https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2019129746]

PHYSICAL REVIEW D **104,** 023524 (2021)

Detecting planetary-mass primordial black holes with resonant electromagnetic gravitational-wave detectors

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[2]*Cosmology, Universe and Relativity at Louvain, Institute of Mathematics and Physics, Louvain University, 2 Chemin du Cyclotron, B-1348 Louvain-la-Neuve, Belgium*
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Electromagnetic Antennas for the Resonant Detection of the Stochastic Gravitational Wave Background

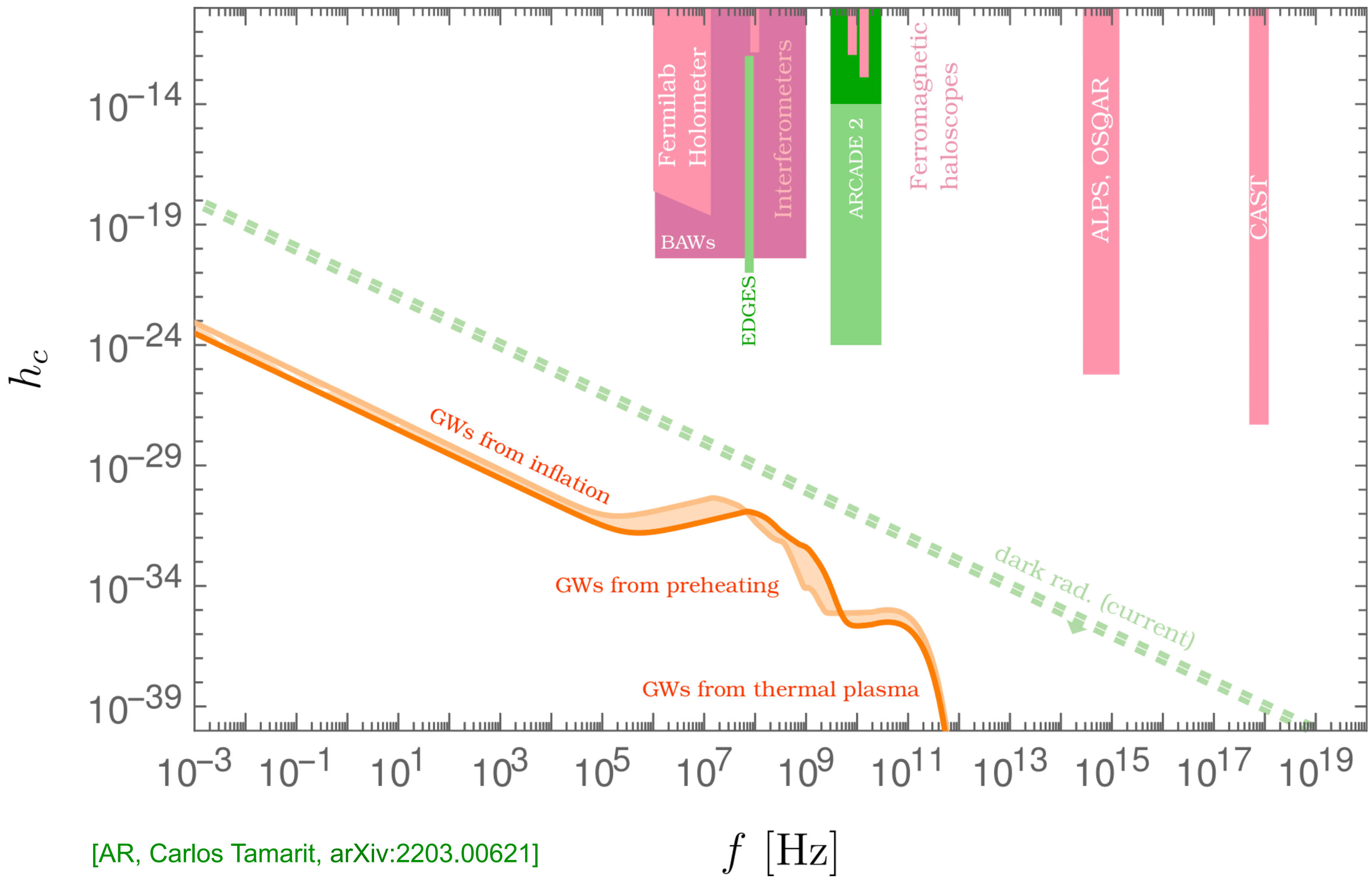
Nicolas Herman,[1,*] Léonard Lehoucq,[1,2,†] and André Füzfa[1,‡]
[1]*Department of Mathematics and Namur Institute for Complex Systems (naXys), University of Namur, Rue Grafé 2, B-5000, Namur, Belgium*
[2]*Department of theoretical physics at the ENS Paris-Saclay, University of Paris-Saclay, avenue des Sciences, 91190, Gif-sur-Yvette, France*
(Dated: March 30, 2022)

Stochastic gravitational wave background from the early Universe has a cut-off frequency close to 100 MHz, due to the horizon of the inflationary phase. To detect gravitational waves at such frequencies, resonant electromagnetic cavities are very suitable. In this work, we study the frequency sensitivity of such detectors, and show how we could use them to probe this cut-off frequency and also the energy density per frequency of this stochastic background. This paper paves the way for further experimental studies to probe the most ancient relic of the Universe.

[https://arxiv.org/abs/2203.15668]

Stochastic GW Background from SM*A*S*H

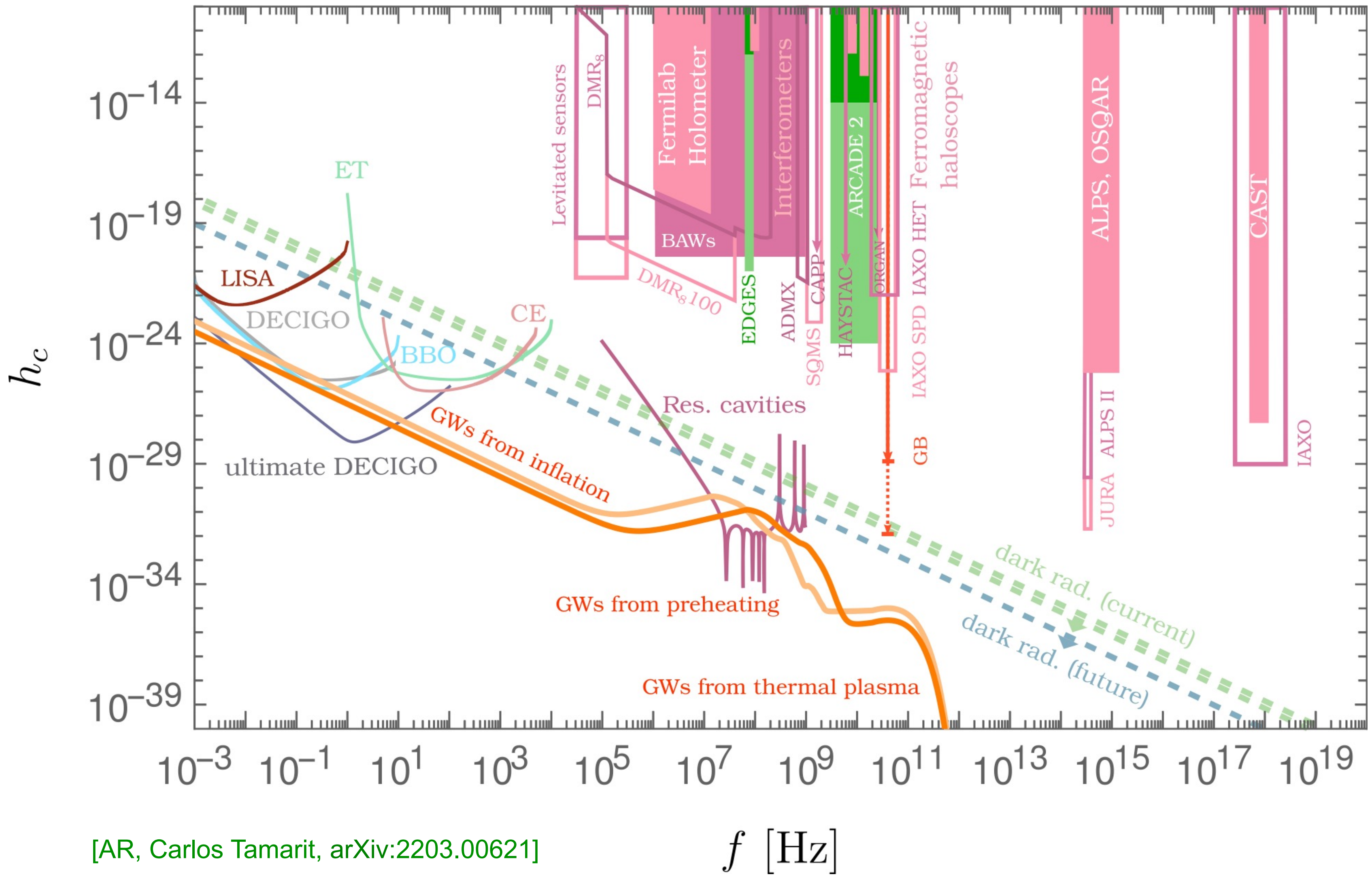
Confronting with current upper bounds from Ultra-High-Frequency (UHF) GW experiments



[AR, Carlos Tamarit, arXiv:2203.00621]

Stochastic GW Background from SM*A*S*H

Confronting with projected sensitivities of proposed GW experiments



[AR, Carlos Tamarit, arXiv:2203.00621]

Stochastic GW Background from SM*A*S*H

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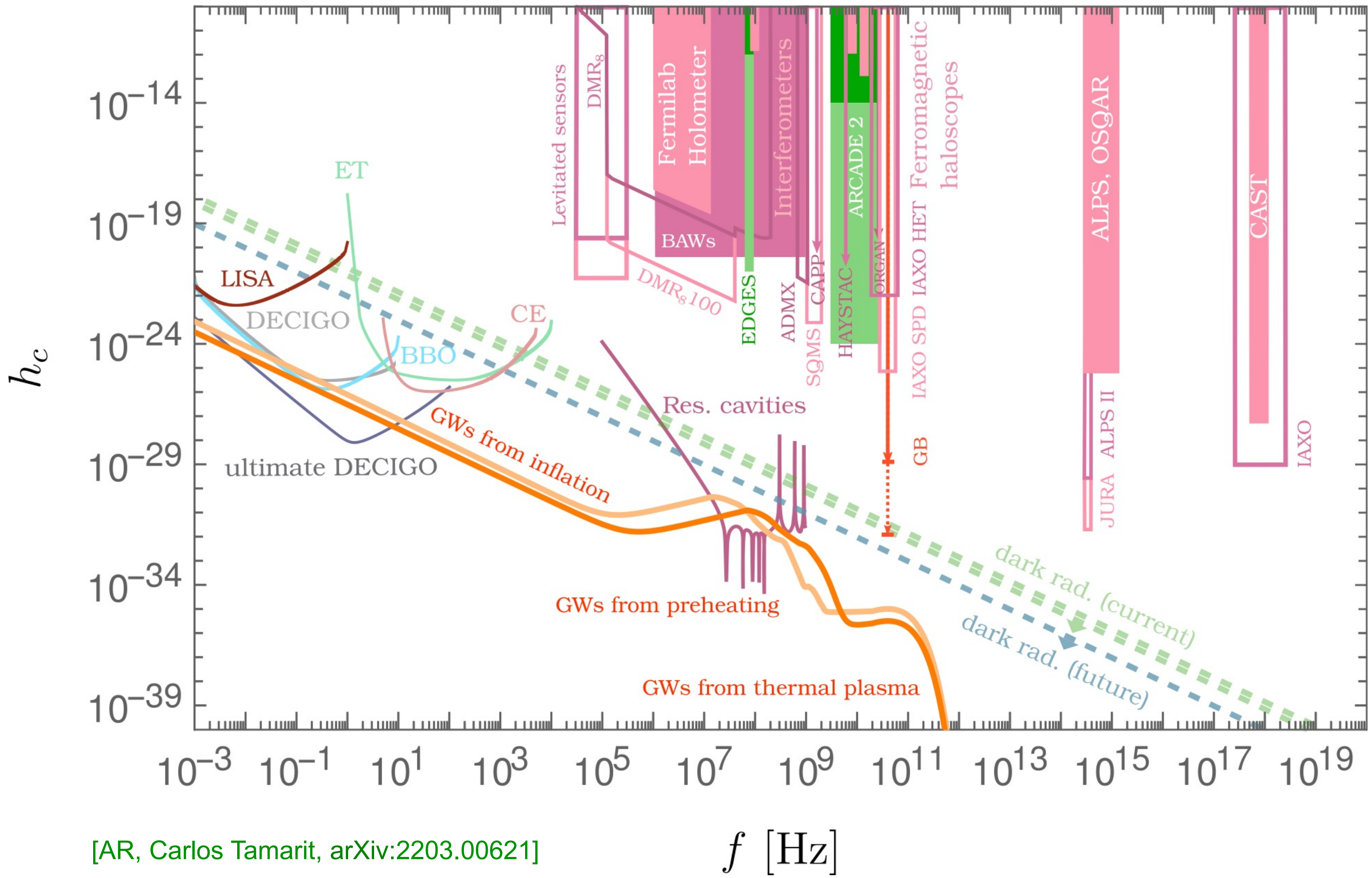

[AR, Carlos Tamarit, arXiv:2203.00621]

A hypothetical detection of the complete spectrum in different frequency ranges would allow to cross-check for the correlations predicted in SM*A*S*H, opening new possibilities for falsifying the model.