Can we hope to find gravitational waves from the early cosmos?

THEP day, May 8th, 2025

Carlo Tasillo,
Uppsala University

Based on ongoing work in collaboration with

- Torsten Bringmann, Felix Kahlhöfer, Thomas Konstandin, Jonas Matuszak and Kai Schmidt-Hoberg in Oslo, KIT, CERN-TH and DESY
- Safa, André, Rikard and Stefano in our THEP group

UPPSALA UNIVERSITET

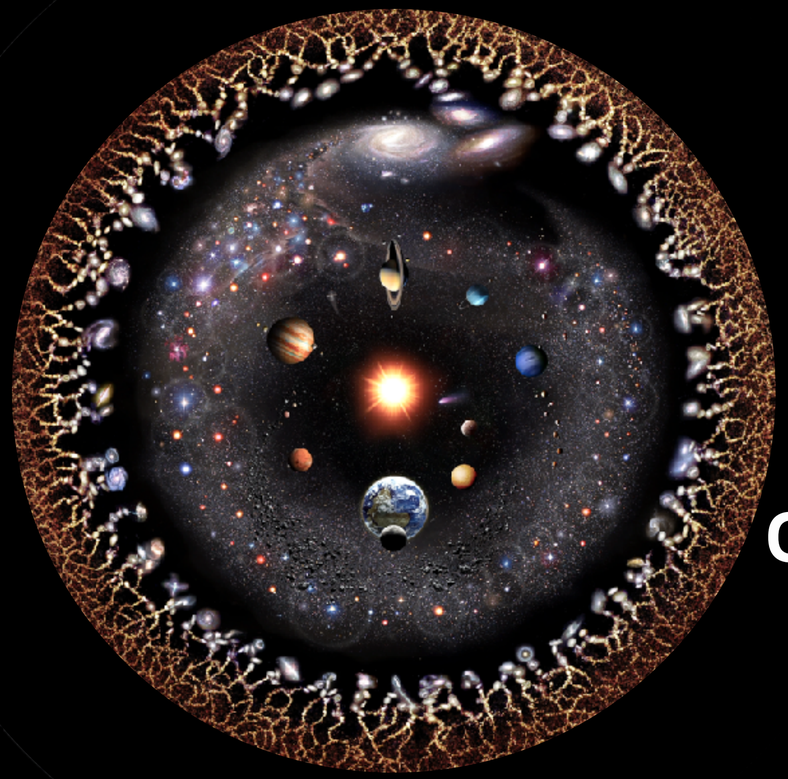
The observable universe

Our Solar System

The observable universe

Our galaxy

The observable universe

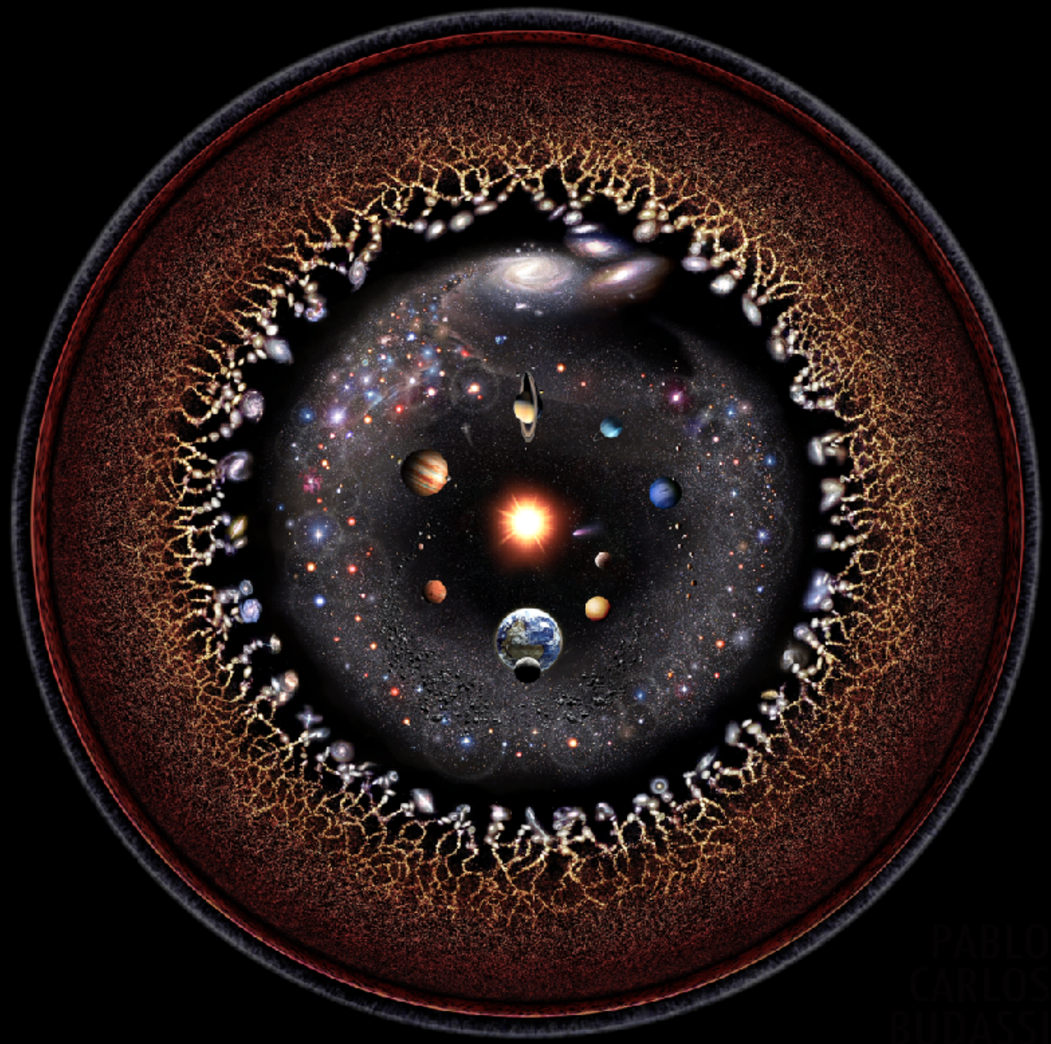


Other galaxies

PABLO CARLOS BUDASSI

[Pablo Carlos Budassi]

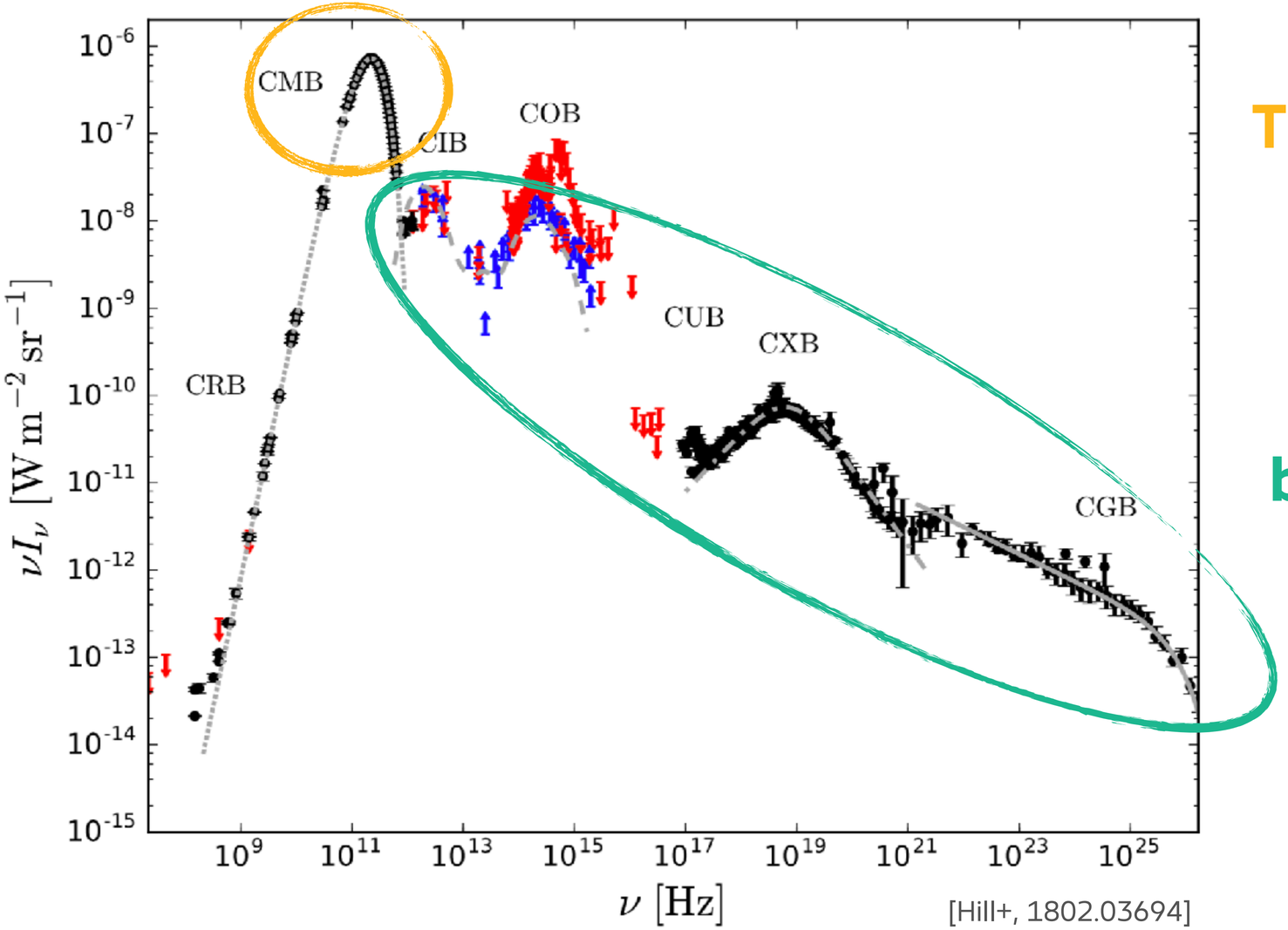
The observable universe



The CMB…
and the CGWB?

[Pablo Carlos Budassi]

Finding the cosmic microwave background: We were lucky!

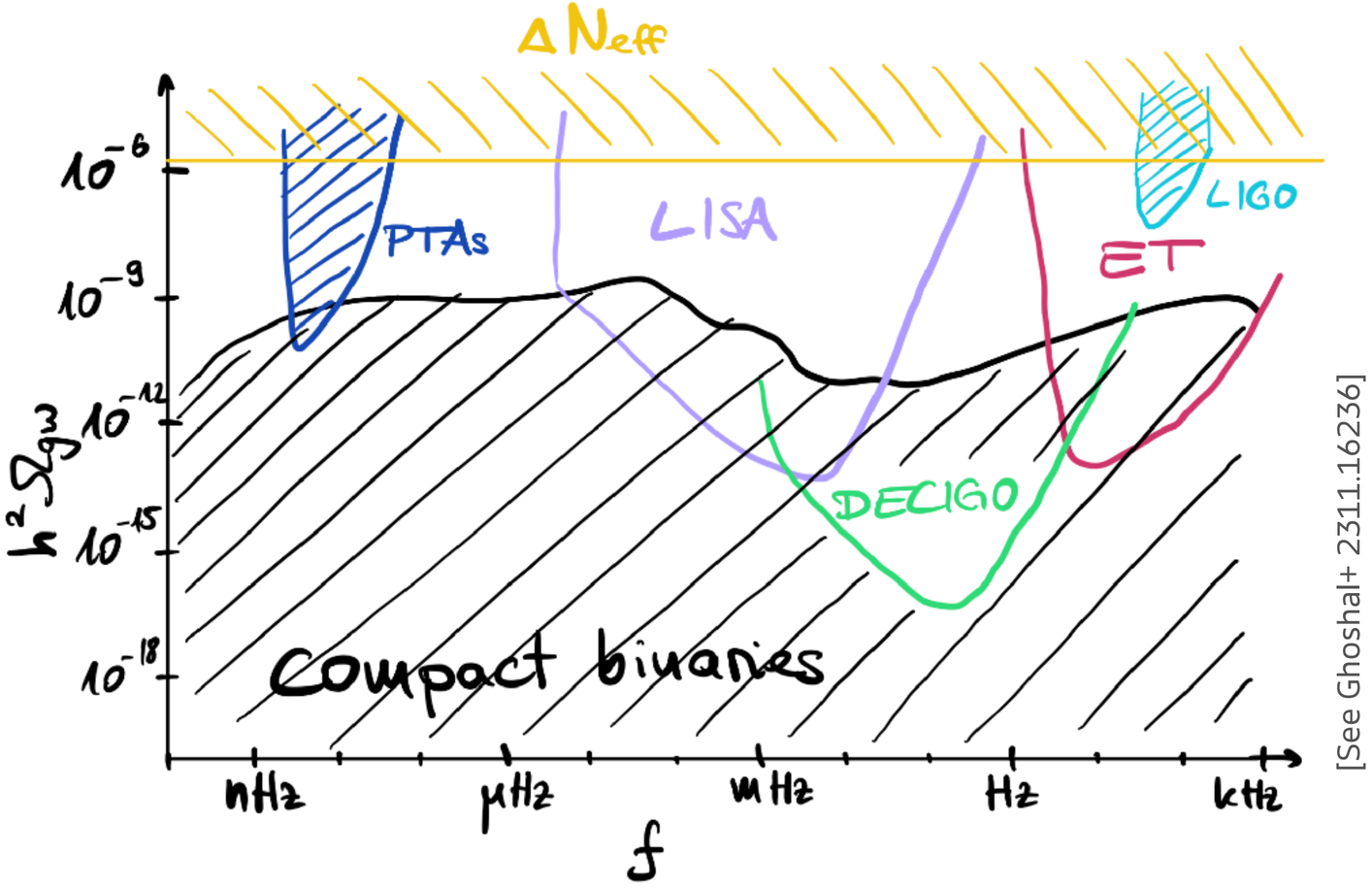


[Hill+, 1802.03694]

The CMB dominates the photon spectrum!

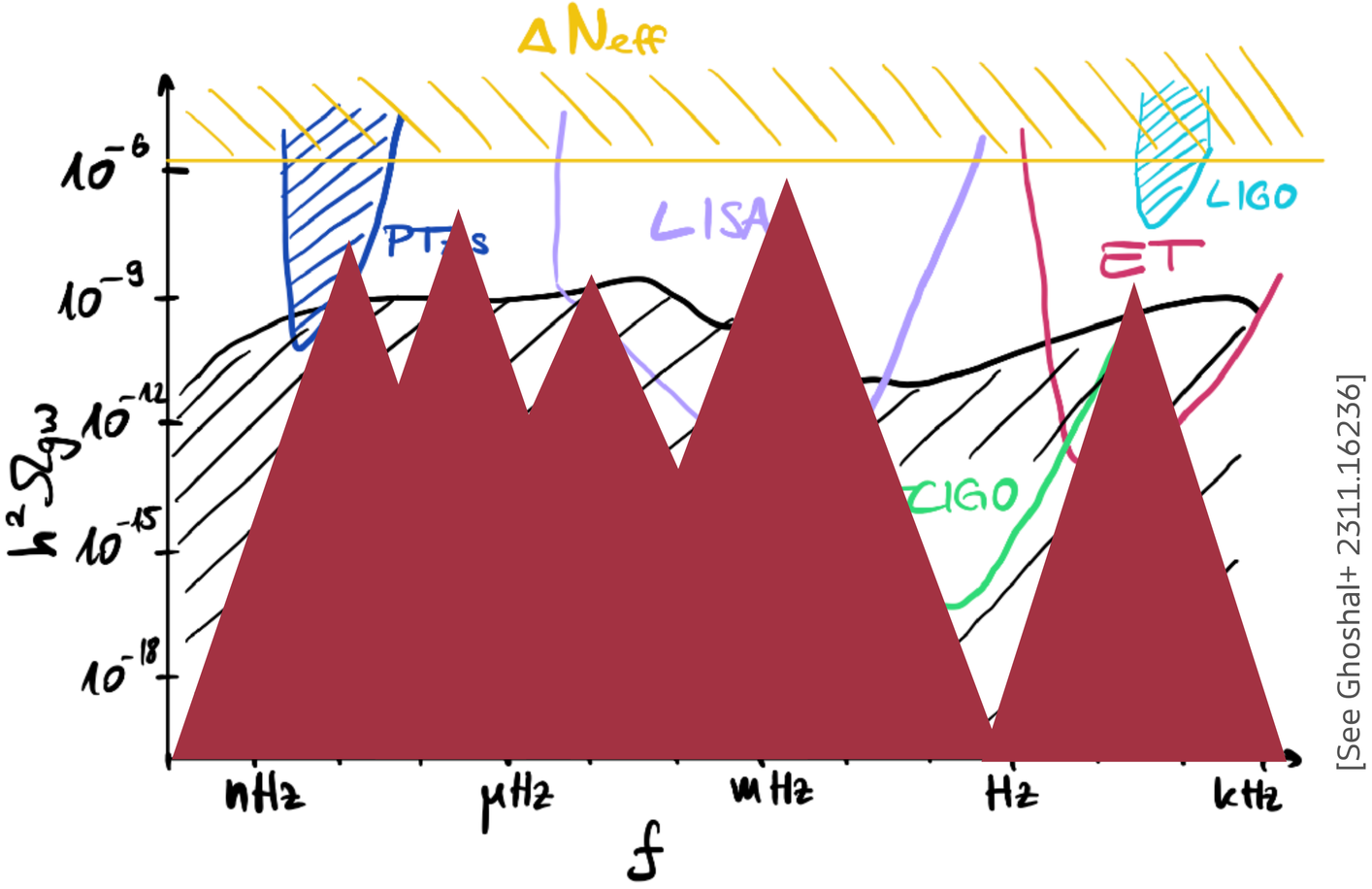
Astrophysical backgrounds are luckily only active at higher frequencies (or can be masked out)

An attemptive map of the gravitational wave background



[See Ghoshal+ 2311.16236]

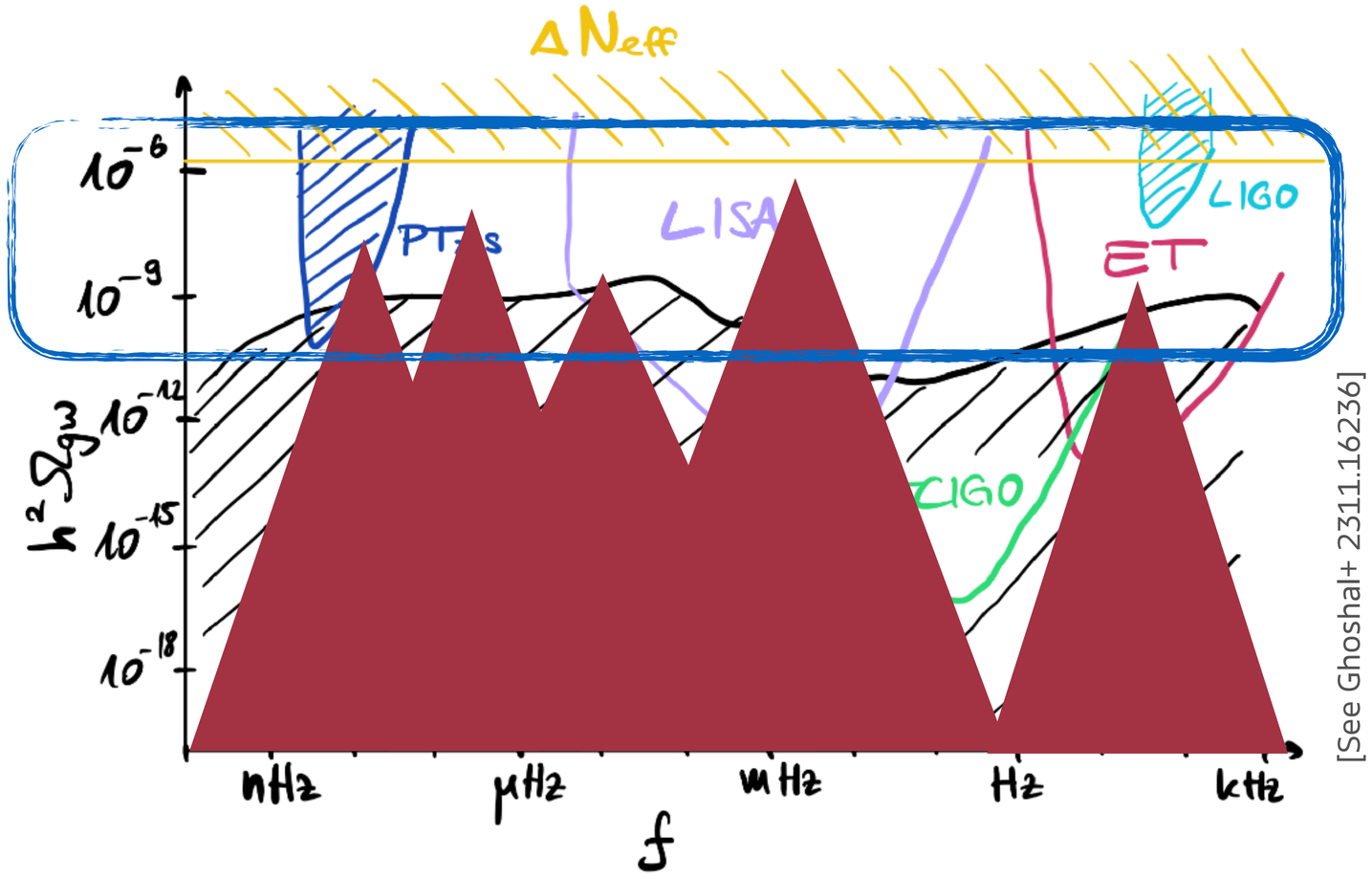
An attemptive map of the gravitational wave background



[See Ghoshal+ 2311.16236]

The CGWB would appear as a bump(s) on top of the astrophysical background

An attemptive map of the gravitational wave background

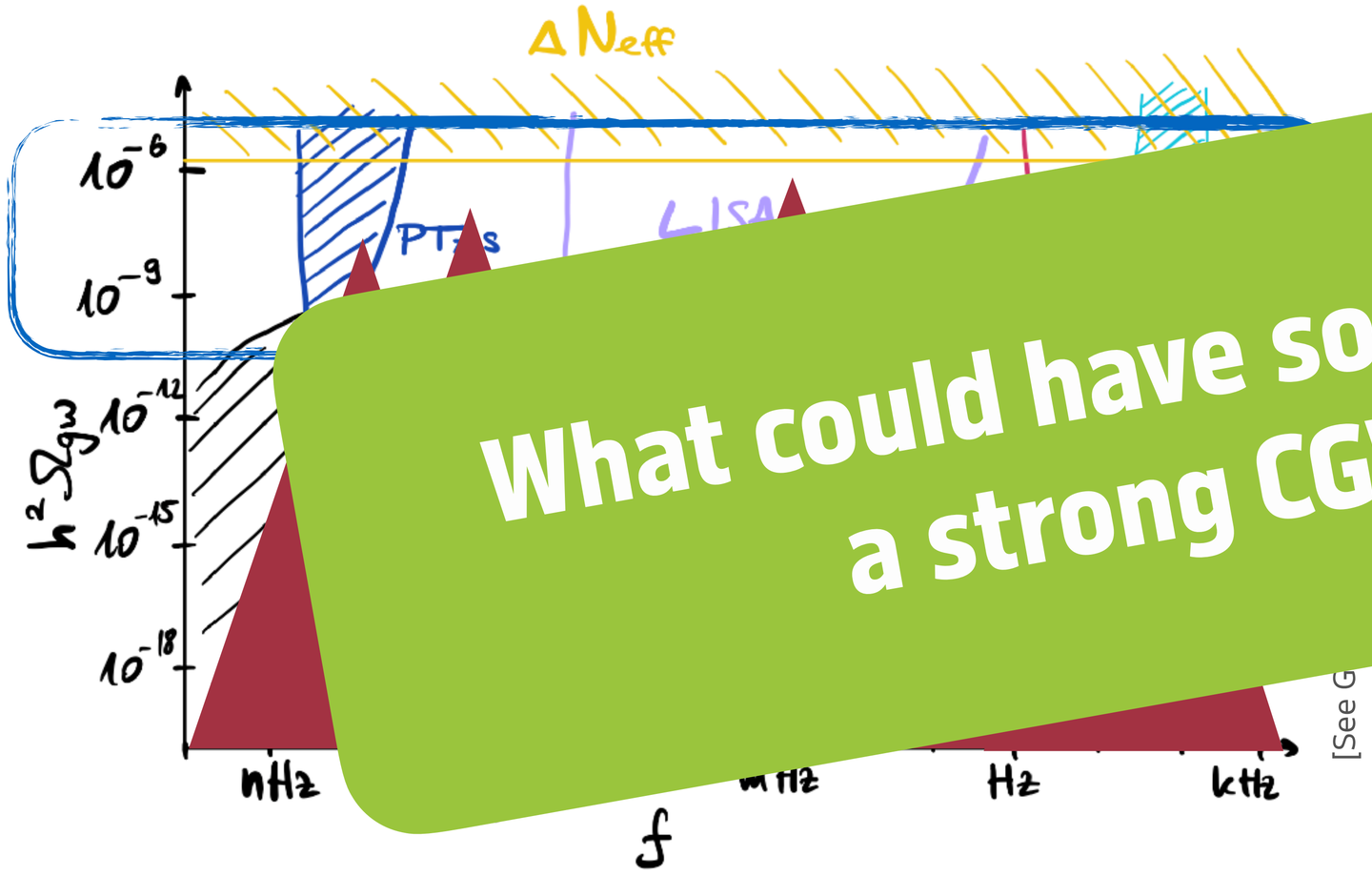


[See Ghoshal+ 2311.16236]

The CGWB would appear as a bump(s) on top of the astrophysical background

There's just a small band of 3 order of magnitude in which gravitational waves from the early cosmos could be detected within the next 20 years!

An attemptive map of the gravitational wave background



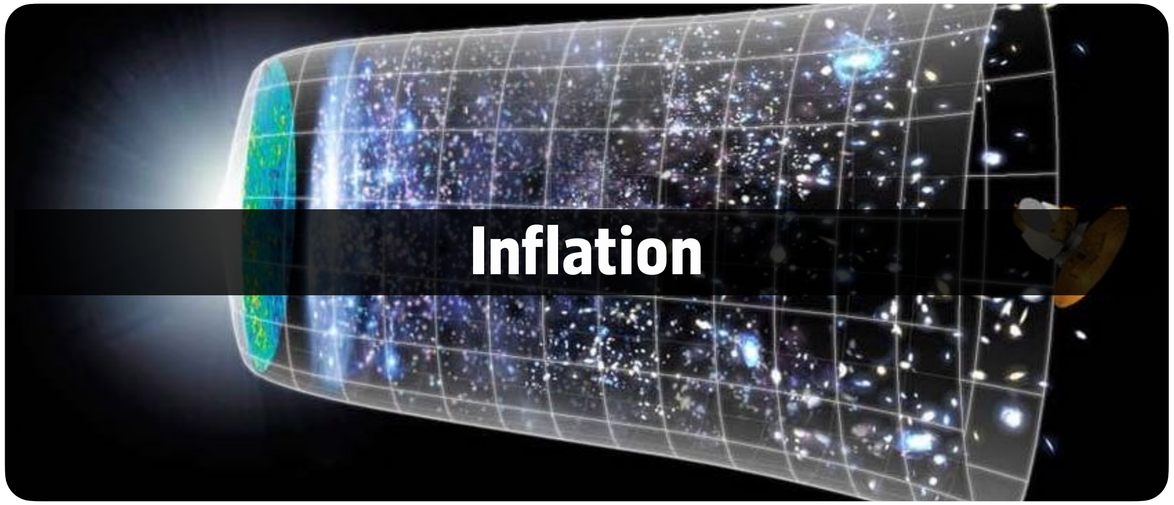
What could have sourced such a strong CGWB?

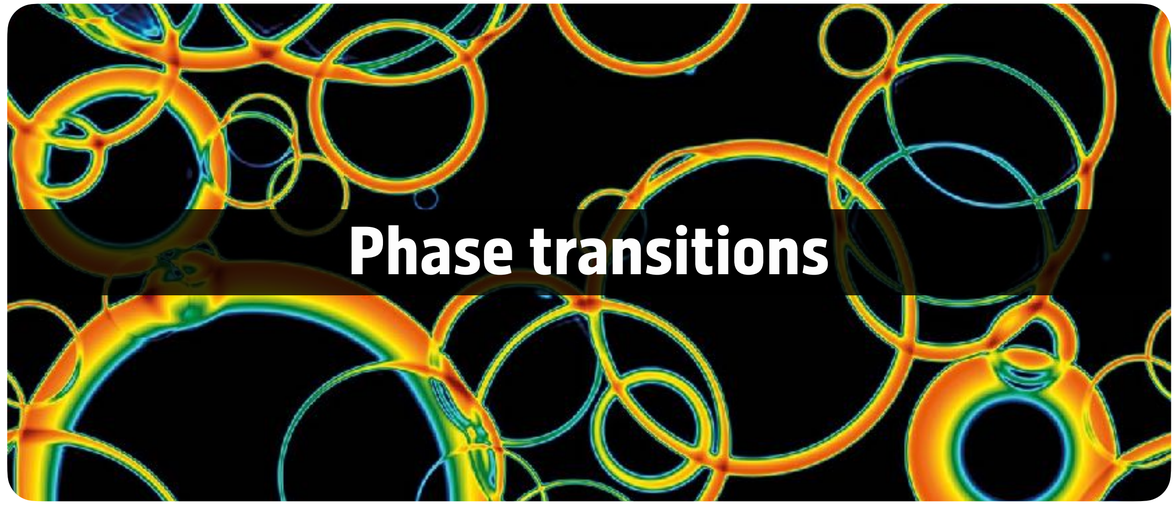
Th… …ppear as a …of the …ground

…and of 3 …ude in which …gravitational waves from the early cosmos could be detected within the next 20 years!

[See G…

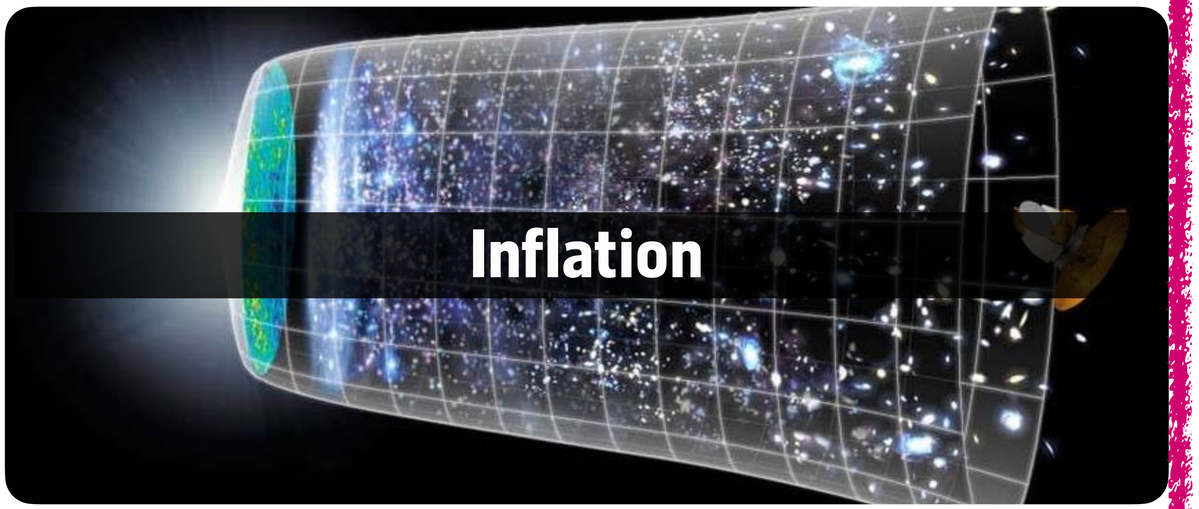
Possible sources of a loud CGWB

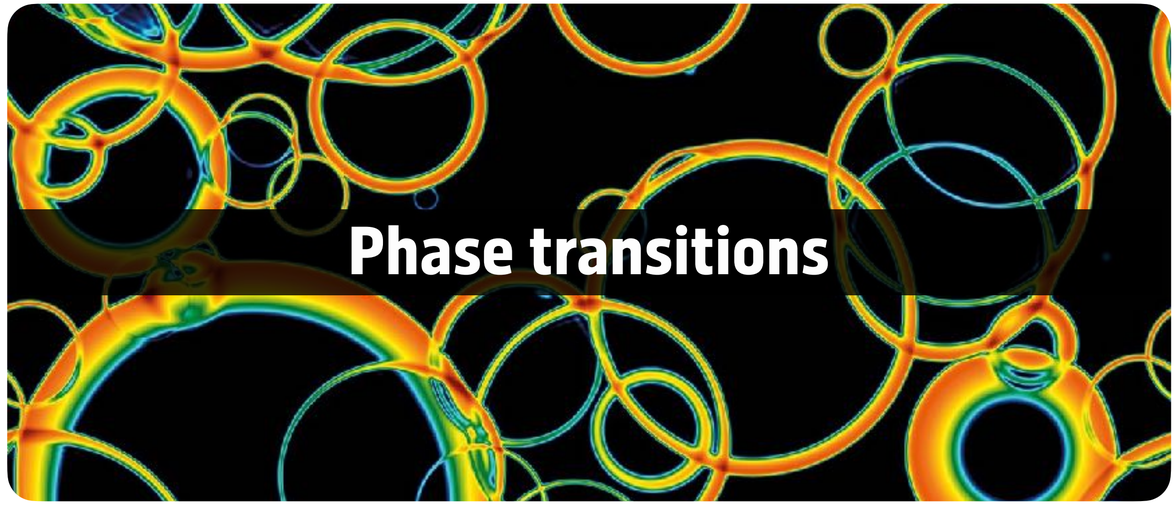




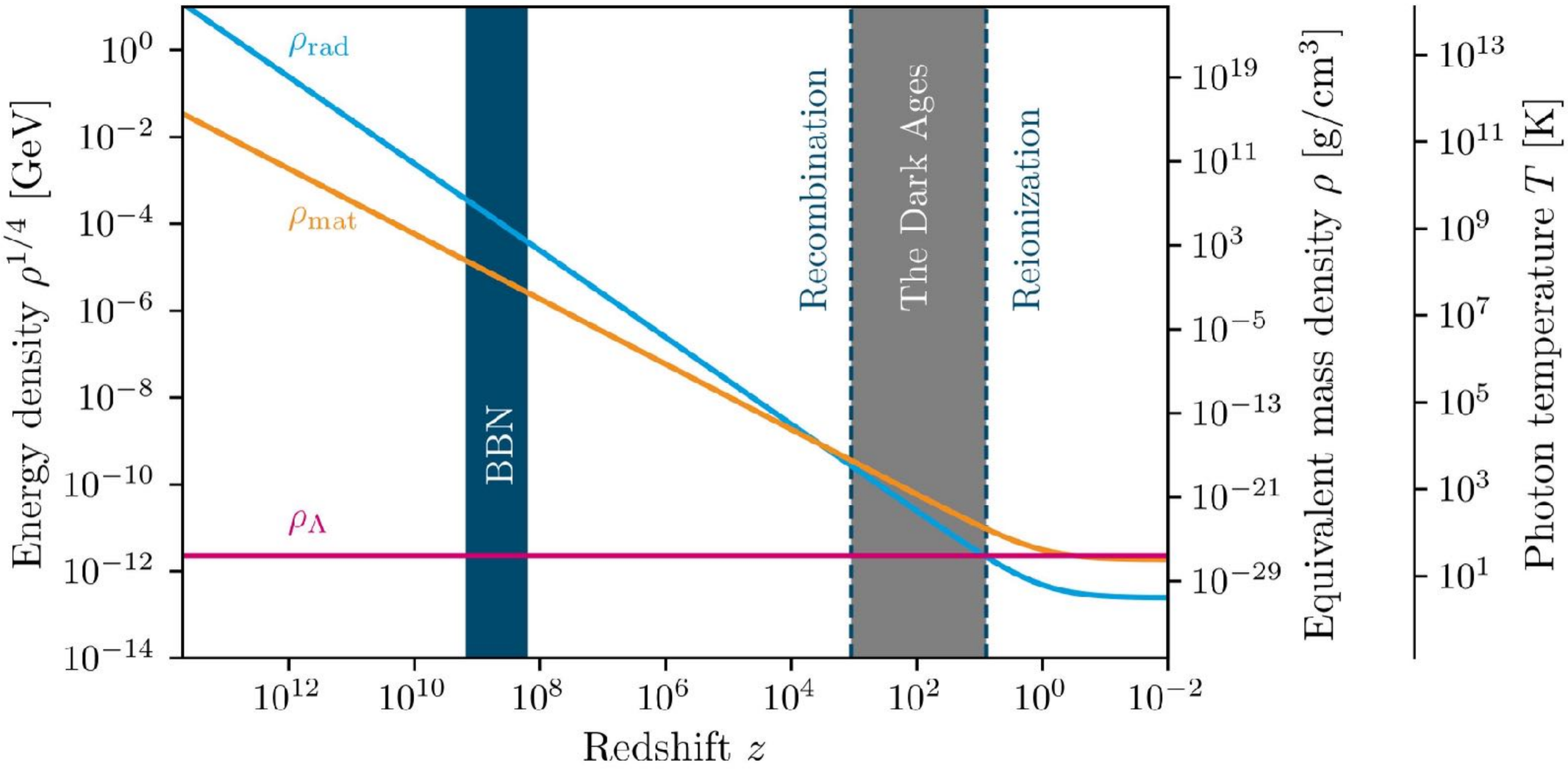
Possible sources of a loud CGWB

Today's focus

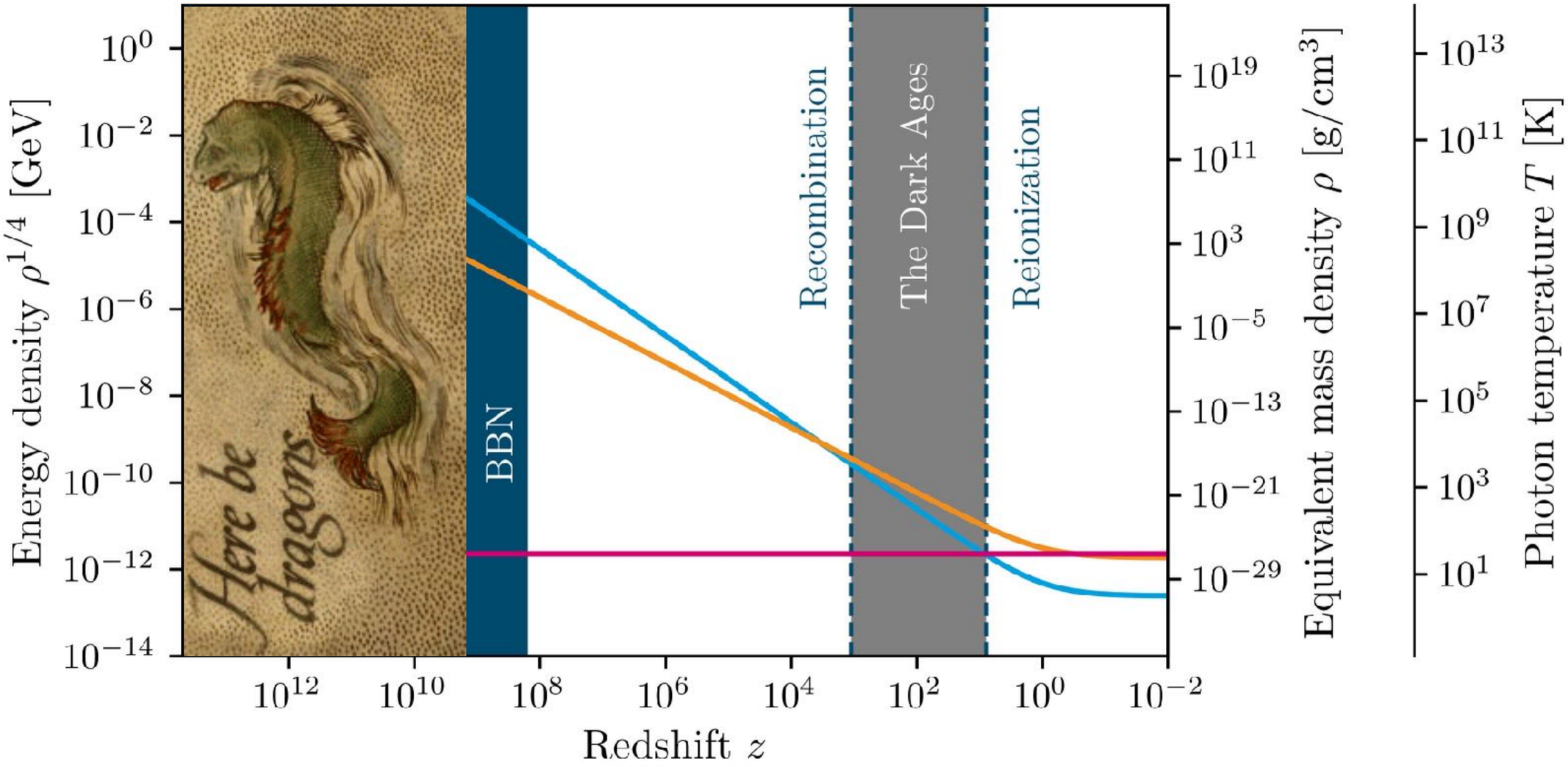




A brief history of time.

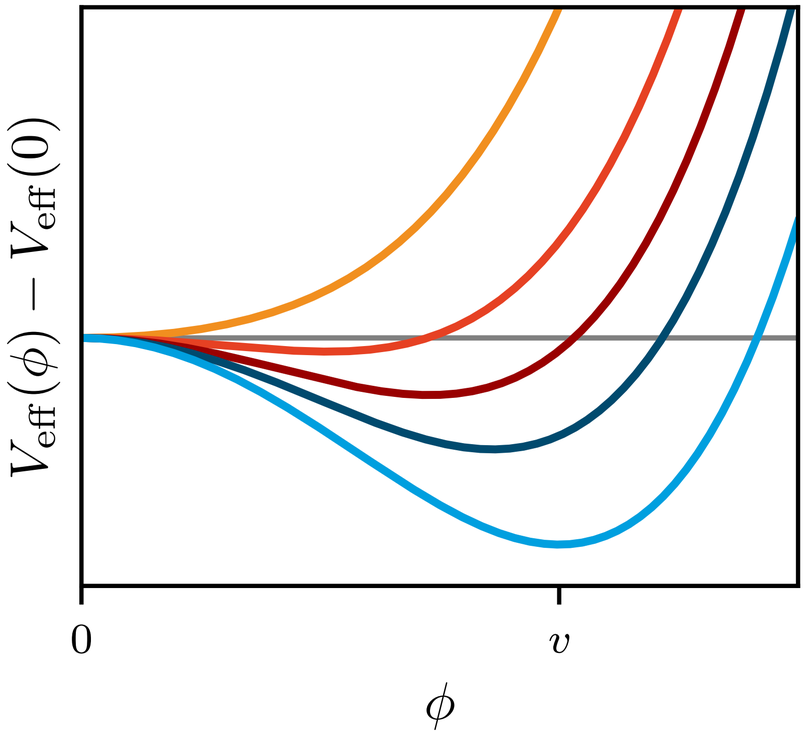


A brief history of time.



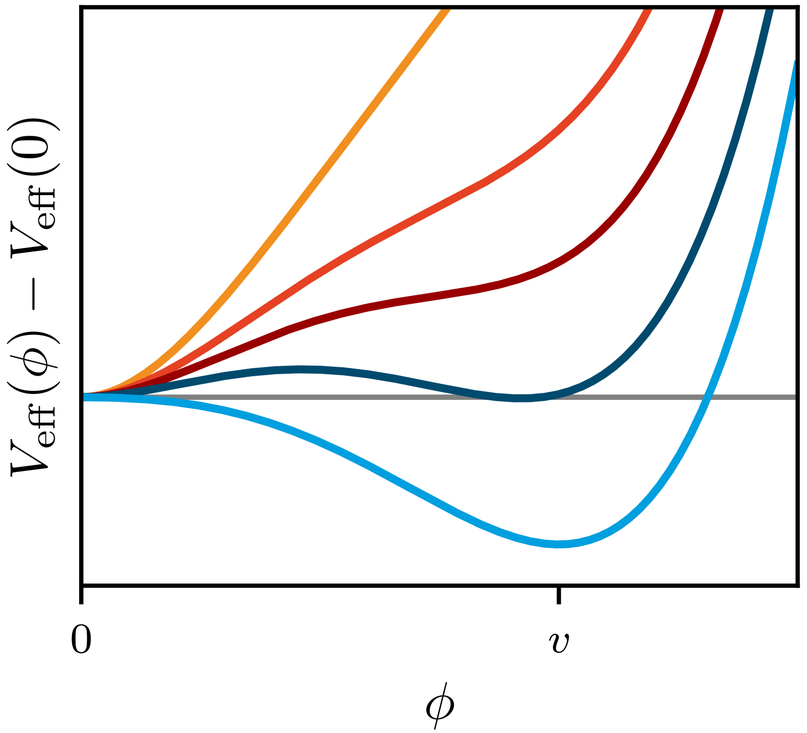
First-order phase transitions vs. cross-overs

Cross-over phase transition



A scalar field “rolls down” from $\phi = 0$ to $\phi = v$, when the plasma cools from high temperatures to low temperatures.

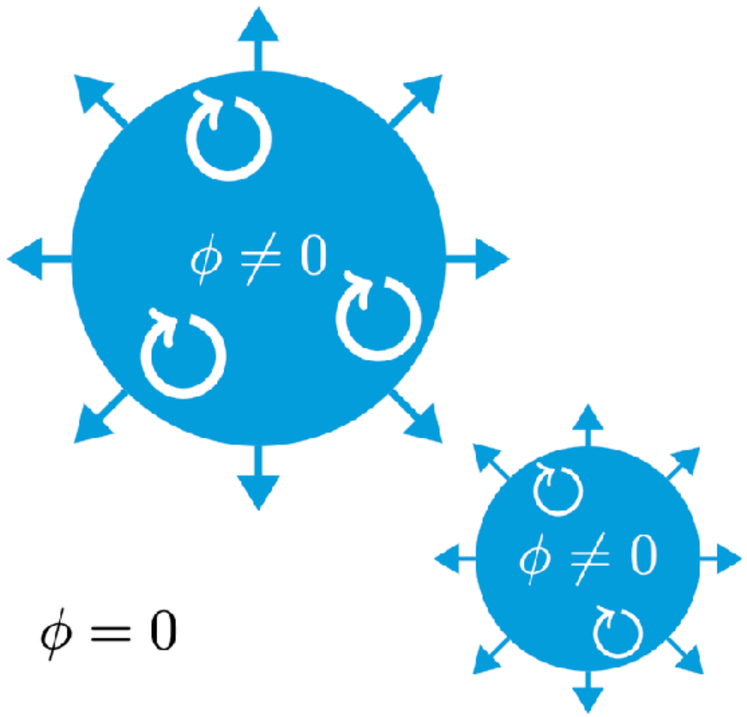
First-order phase transition

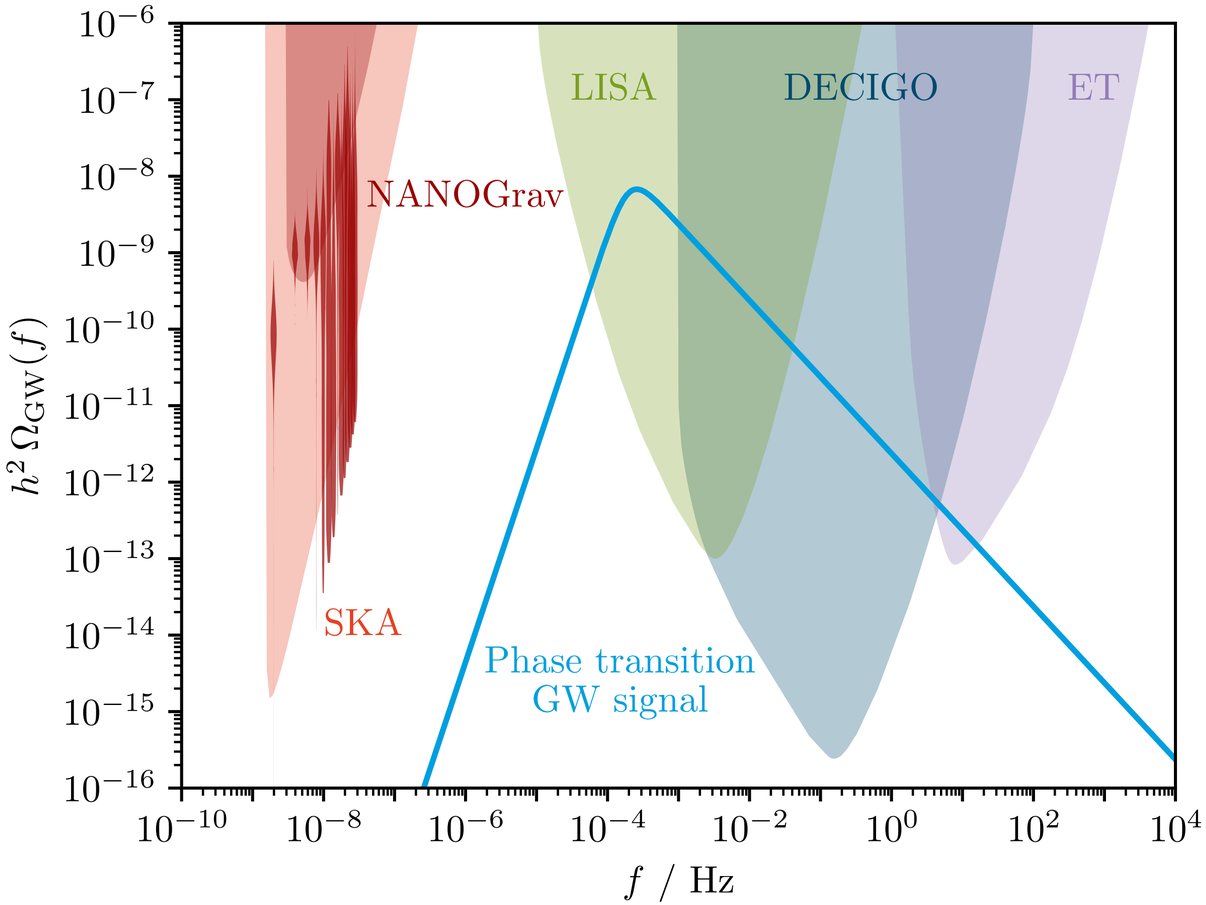


A scalar field tunnels to the true potential minimum $\phi \neq 0$ to minimize its free energy / its action.

First-order phase transitions produce GWs

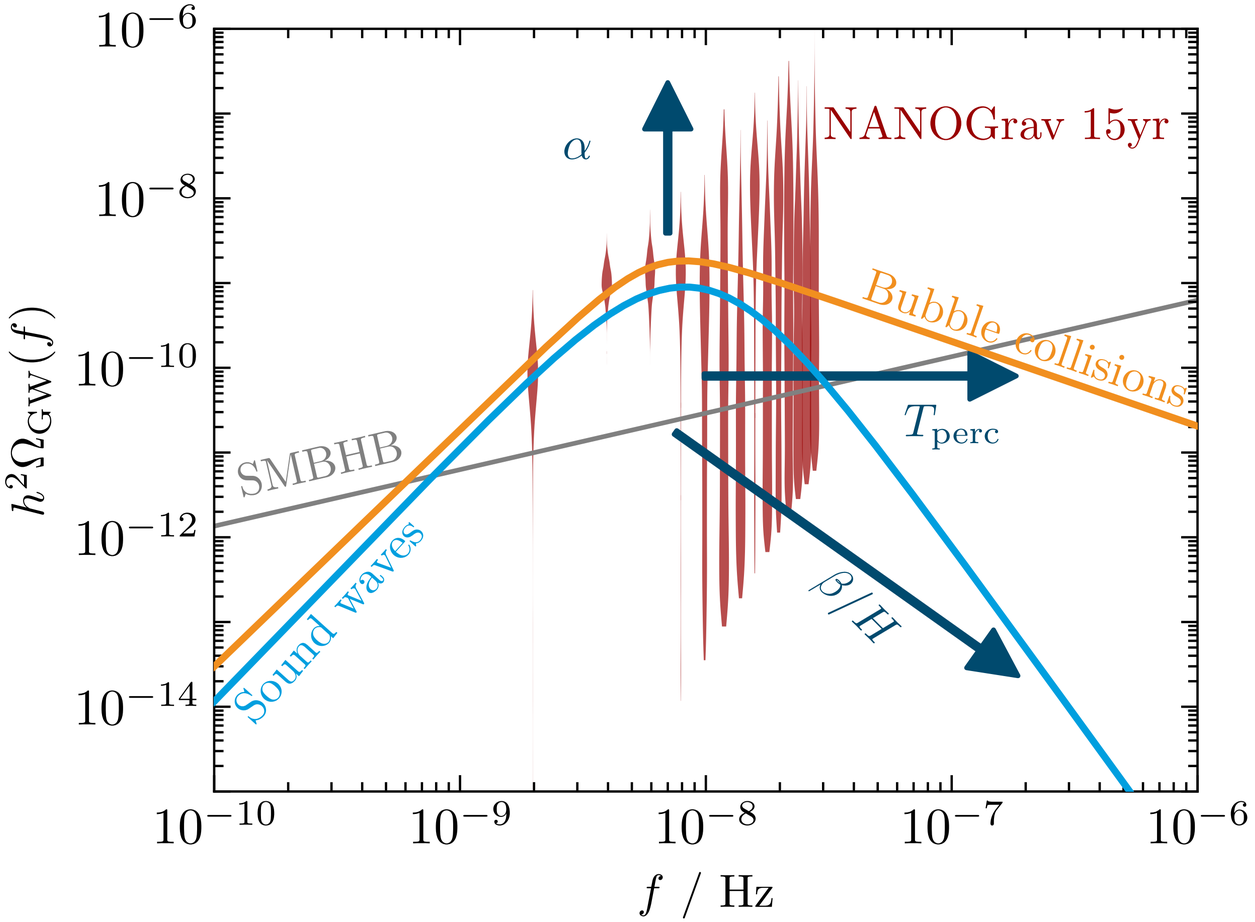
Bubbles of the new phase nucleate, collide and perturb the plasma…





… giving rise to an observable stochastic gravitational wave background.

How loud can a first-order phase transition be?



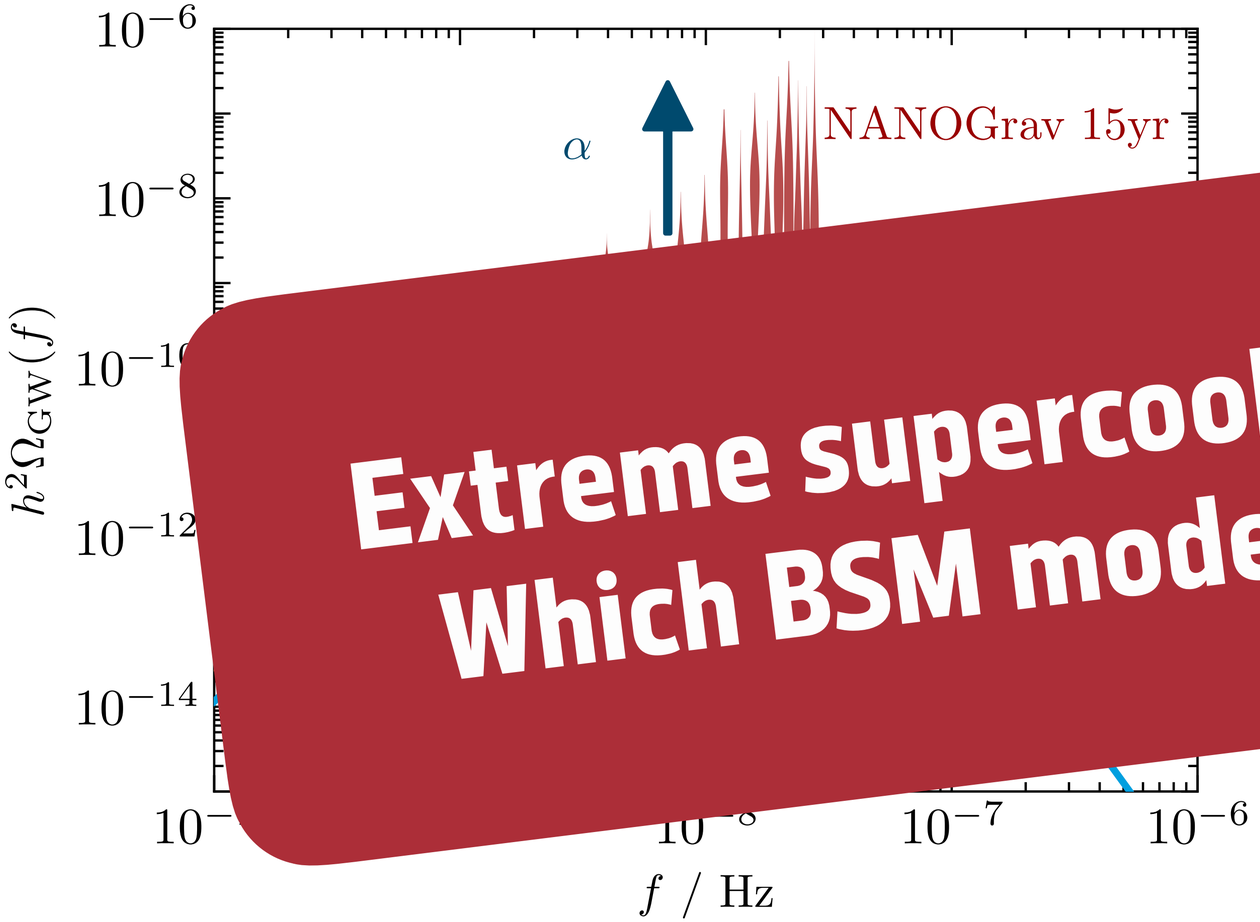
$$h^2\Omega_{\rm GW}^{\rm sw,bw}(f) \simeq 10^{-6}\left(\frac{\alpha}{\alpha+1}\right)^2\left(\frac{H}{\beta}\right)^{1,2}\mathcal{S}\left(\frac{f}{f_{\rm peak}}\right)$$

with $\quad f_{\rm peak} \simeq 0.1\,\text{nHz} \times \frac{\beta}{H} \times \frac{T}{\text{MeV}}$

In order to be louder than astrophysics (in the PTA & LISA band)

- Strong transitions, $\alpha \gtrsim 1$
- Slow transitions, $\beta/H \approx 10$

How loud can a first-order phase transition be?

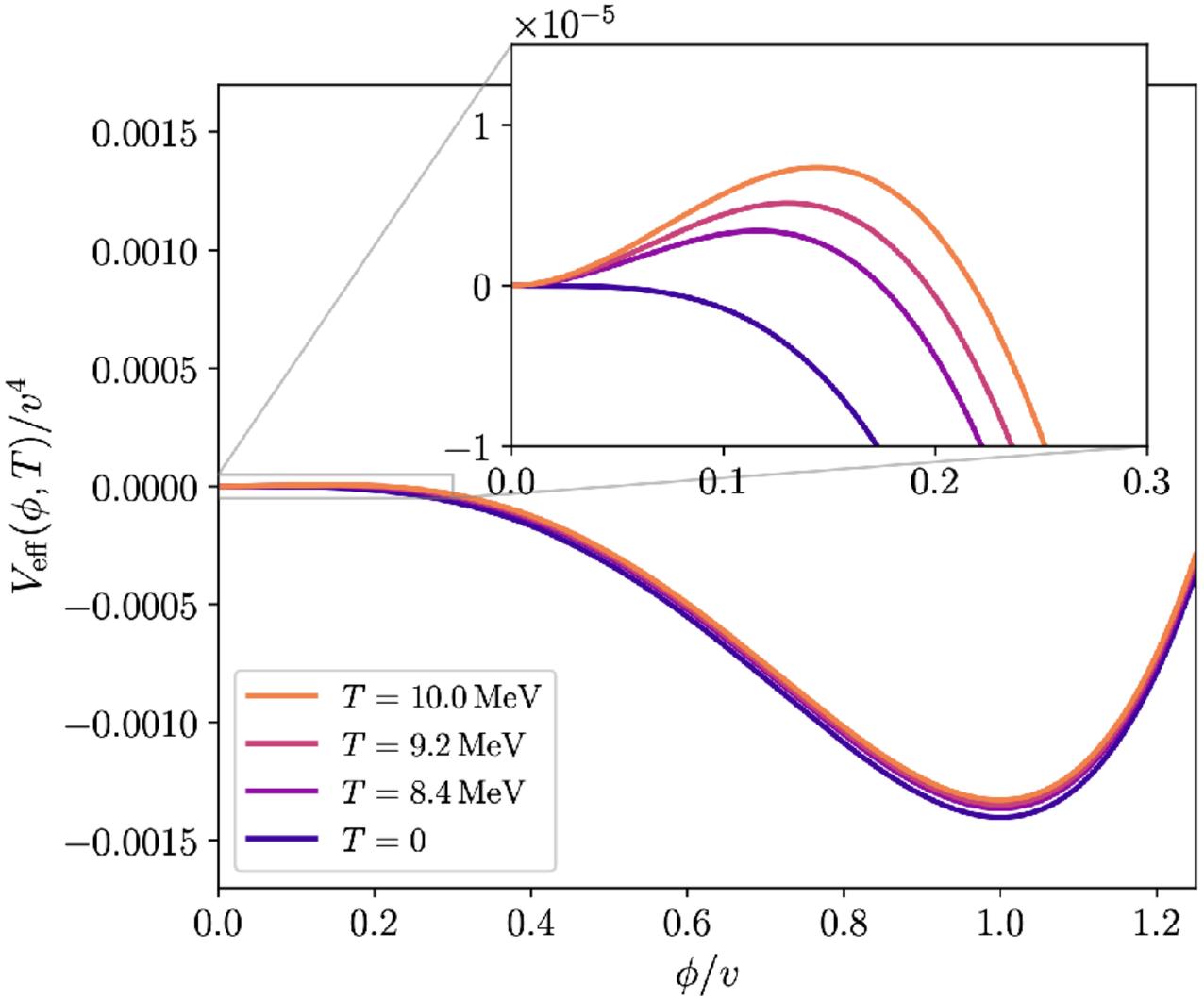


$$h^2\Omega_{\rm GW}^{\rm sw,bw}(f) \simeq 10^{-6}\left(\frac{\alpha}{\alpha+1}\right)^2\left(\frac{H}{\beta}\right)^{1,2}\mathcal{S}\left(\frac{f}{f_{\rm peak}}\right)$$

Extreme supercooling is necessary!
Which BSM models feature that?

- Slow transitions, $\beta/H \approx 10$

How to generate a potential barrier and make it last for long?



1) A generic model allowing for a first-order phase transition with **a lot of fine tuning**

[Ongoing work with Safa and Rikard on dim-6 operators in SMEFT]

2) A model with a so-called „*vev flip-flop*" and **some fine tuning**

[Ongoing work with André, Harri and Stefano on the (N)2HDM]

3) A classically conformal model, **no fine-tuning** needed

[Ongoing work with Torsten Bringmann, Kai Schmidt-Hoberg, Thomas Konstandin, Jonas Matuszak]

Reliable computation of the GW spectra for strong supercooling?

There's currently no public code that can deal with strong supercooling!

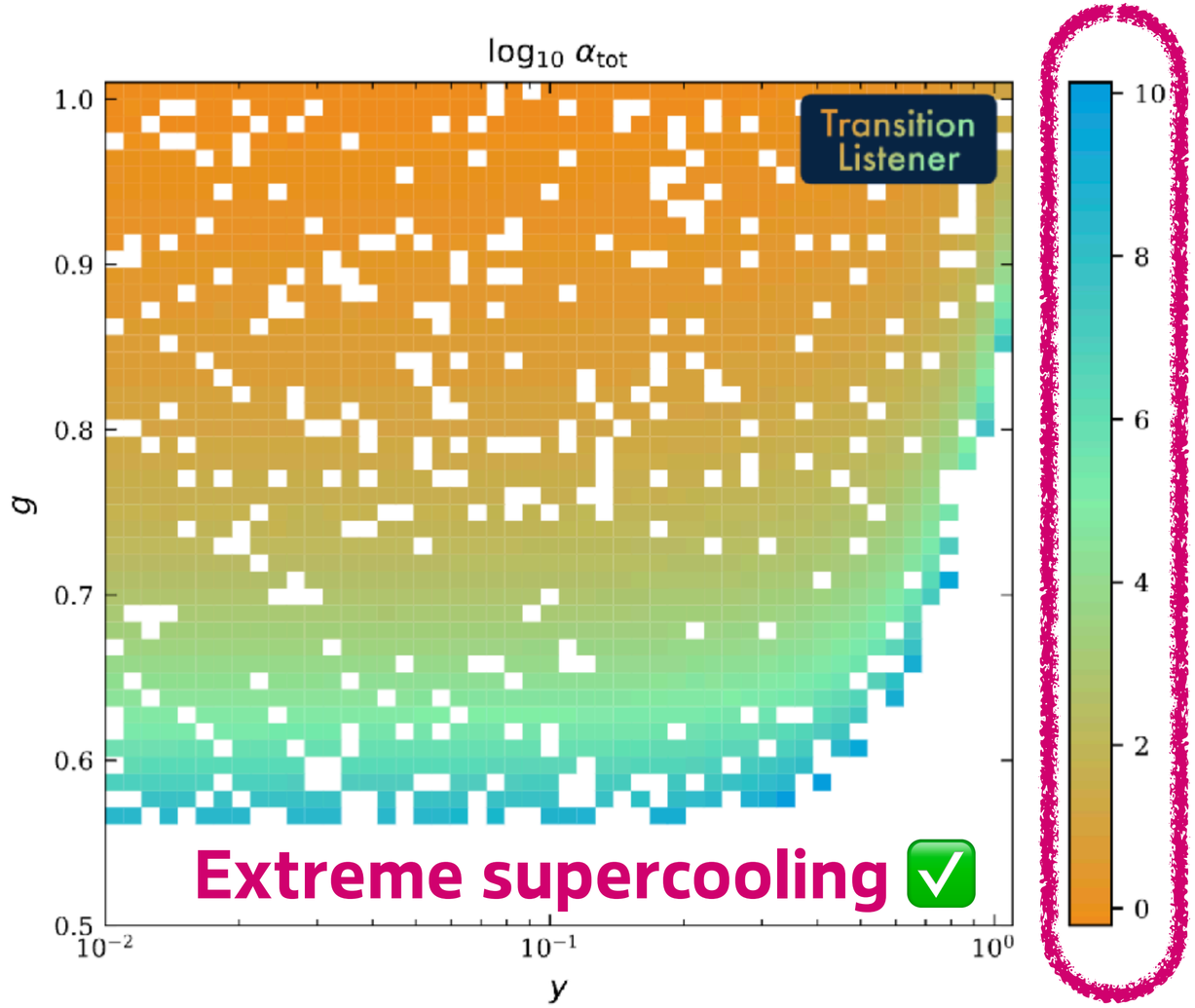
The available codes are specific to the Electroweak symmetry breaking

Available codes are specialized on specific sub-tasks like phase tracing, the bounce action, the bubble nucleation rate, ...

They are not integrated into the ecosystem of global fits, i.e. GAMBIT

[Ongoing work Jonas Matuszak]

We're on it!



[Ongoing work Jonas Matuszak]

$T_{\rm perc}$

$T_{\rm reh}$

$v_{\rm wall}$

Documentation

Warnings & error handling

Quicker than BSMPT

User-friendly

Not just EWSB

PTA likelihoods

Written in python

SNR for LISA, ET, …

Integration into GAMBIT

At Last, There's
A globe-spa
Astronomers detect 'cosmic bass note' of gravitational waves
Sound comes from the merging of supermassive black holes across the universe, according to scientists
Scientists 'hear' cosmic hum from gravitational waves
Gravitational
Scientists have finally 'heard' the chorus of gravitational waves that ripple through the universe
Scientists have observed for the first time the faint ripples caused by the motion of holes that are gently stretching and squeezing everything in the universe
The New York Times
ack H
Galax
Space
Gravitational wave
at the center of the M
Scientists r
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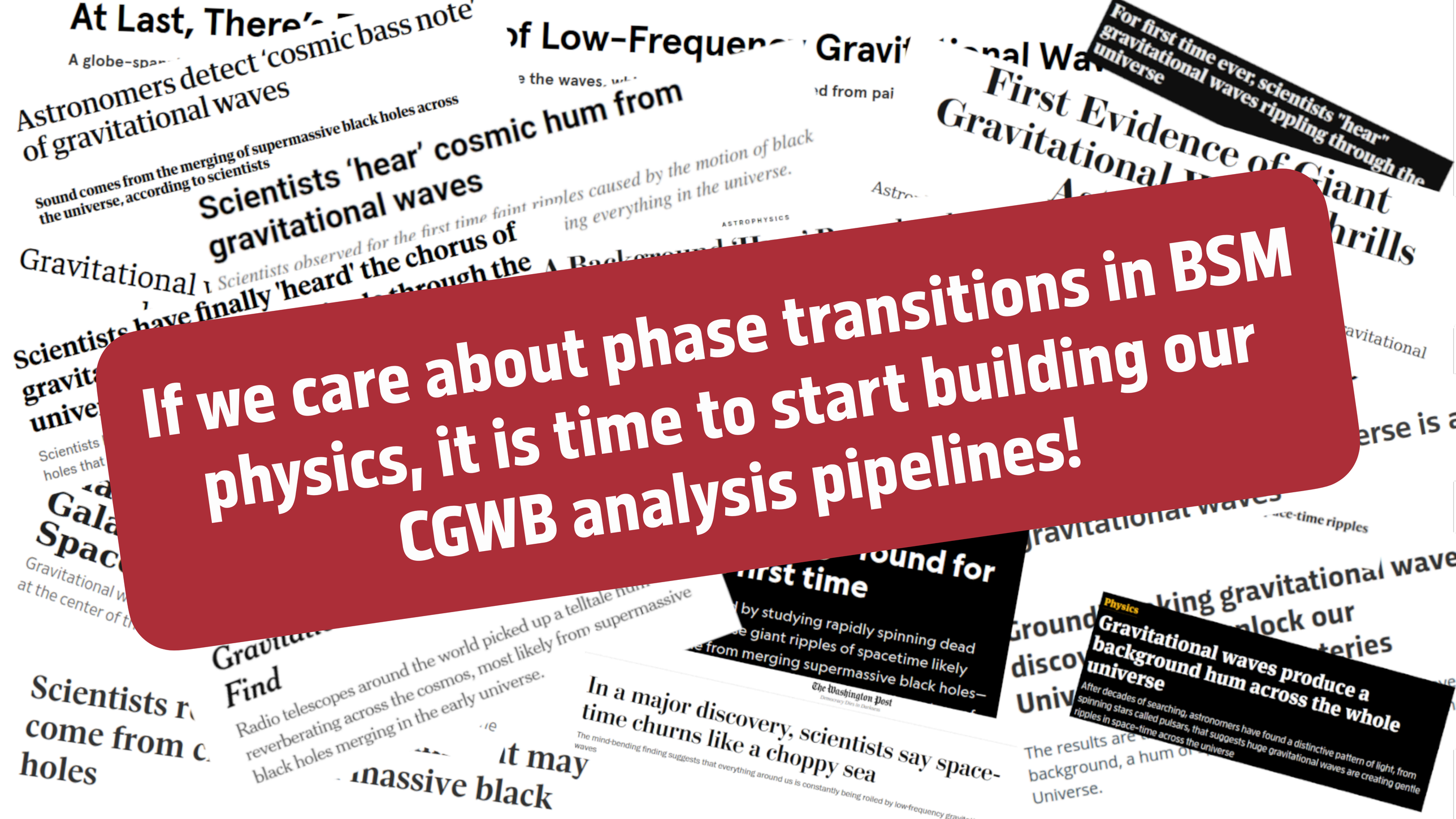
holes
The Cosmos Is Thrumming With Gravitational Waves, Astronomers Find
Radio telescopes around the world picked up a telltale hum reverberating across the cosmos, most likely from supermassive black holes merging in the early universe.
t may
massive black
of Low-Frequen
e the waves, wh
Scientists observed for the first time faint ripples caused by the motion of black
ing everything in the universe.
ASTROPHYSICS
A Background 'Hum' Pervades the Universe. Scientists Are Racing to Find Its Source
Astronomers are now seeking to pinpoint the origins of an exciting new form of gravitational waves that was announced earlier this year
Gravi
d from pai
Astro
vitationa
SCIENCE
Colossal gravitational waves—trillions of miles long—found for the first time
by studying rapidly spinning dead
giant ripples of spacetime likely
from merging supermassive black holes—
The Washington Post
Democracy Dies in Darkness
In a major discovery, scientists say space-time churns like a choppy sea
The mind-bending finding suggests that everything around us is constantly being roiled by low-frequency gravita
waves
For first time ever, scientists "hear" gravitational waves rippling through the universe
First Evidence of Giant Gravitational Waves Thrills Astronomers
re tuning in to a never-before-seen type of gravitational
pawned by pairs of supermassive black holes
rs used dead stars to
w form of ripple in
Monster gravitational
spotted for first
ntists discover that universe is a
gravitational waves
-time ripples
king gravitational wave
lock our
teries
Ground
disco
Univ
The results are
background, a hum o
Universe.
Physics
Gravitational waves produce a background hum across the whole universe
After decades of searching, astronomers have found a distinctive pattern of light, from spinning stars called pulsars, that suggests huge gravitational waves are creating gentle ripples in space-time across the universe


If we care about phase transitions in BSM physics, it is time to start building our CGWB analysis pipelines!

Summary

- **We can indeed hope to find (or even *have found*) GWs from cosmology!**
- But: It still remains to be seen if the early universe has produced **stronger GWs than astrophysics**
- We should put our emphasis in the **study of the strongest GW sources!**
- There are **three model classes** which can give strong GWs from phase transitions with varying levels of fine-tuning
- Soon: **TransitionListener v2** for studying all these models and comparing with data

Backup slides