

CERN TH RETREAT 2022

FABRIZIO ROMPINEVE



RESEARCH INTERESTS

THEORY



OBSERVATIONS

*Beyond the SM
(Naturalness, strong CP,
Gravity,...)*

*Cosmology
(Early Universe,
Dark matter, ...)*

Some topics I have worked on:
*Inflation in string theory, Weak Gravity Conjecture,
cosmology of TeV-scale BSM, topological defects,
QCD axion, oscillons, dark sectors, ...*

*Gravitational
Waves*

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*Some topics I have worked on:
Tensions in cosmological datasets,
Stochastic GW background,
Large scale structure constraints on ULAs
(in progress w/ Marko, Seung)*

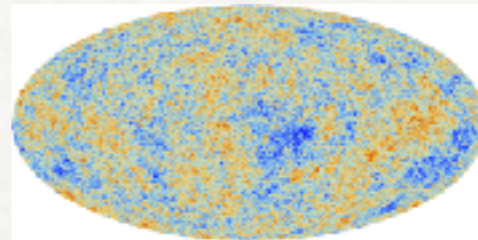
*Gravitational
Waves*

COSMOLOGY

Visible Universe

Not directly visible

Recombination



Cosmic Microwave
Background (CMB)

$$T \sim 0.3 \text{ eV}$$

$$z_{\star} \simeq 1000$$

z, T



DARK ENERGY DOMINATED

INFLATION

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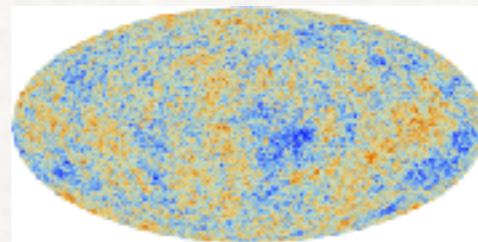
Structure formation
(galaxies, clusters, stars, ...)

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QCD Phase Transition (PT)
Electroweak PT
New Physics?!

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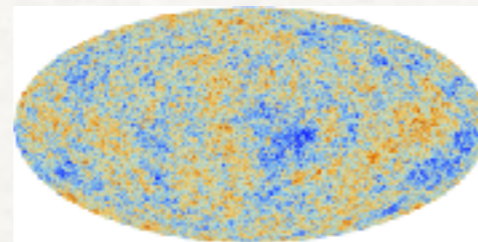
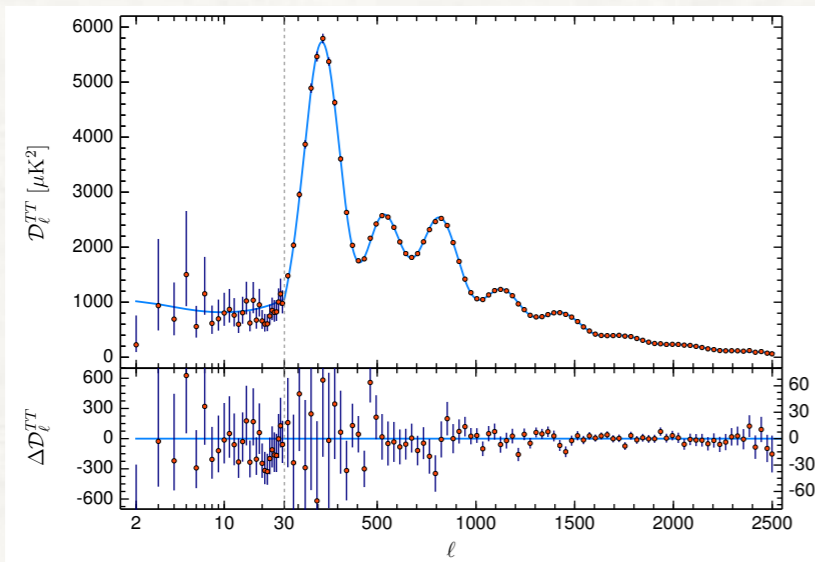
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Nonetheless, if particle is produced in early Universe, it can affect CMB and (Large Scale Structure) via gravitational effects: on (Hubble) expansion rate and on energy density fluctuations

e.g. Effective number of neutrino species

$$N_{\text{eff}} = 3.046 + \rho_{\phi} / \rho_{\nu}$$

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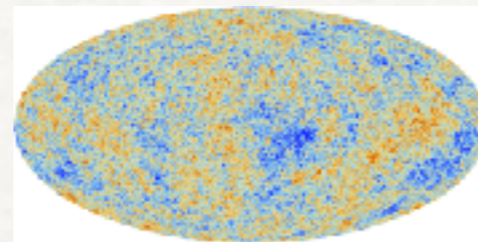
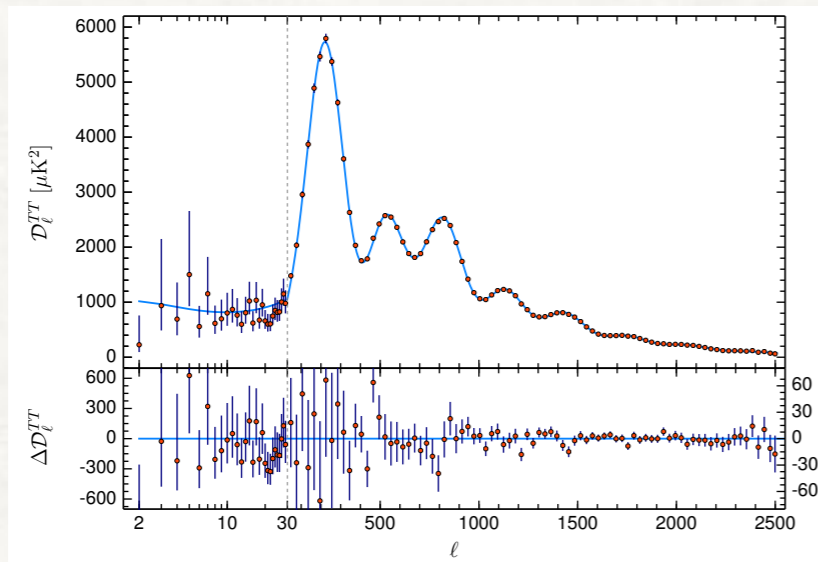
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SM neutrinos
 ΔN_{eff}

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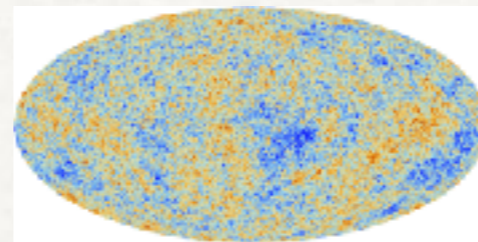
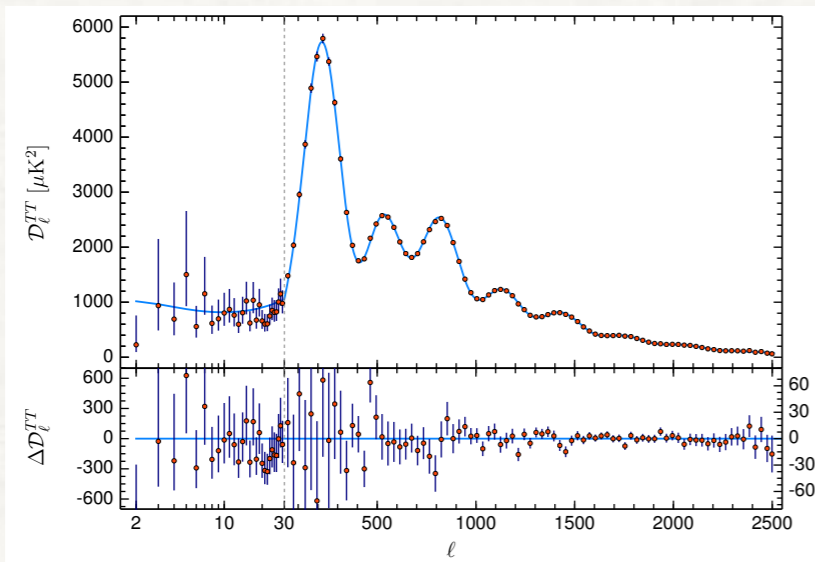
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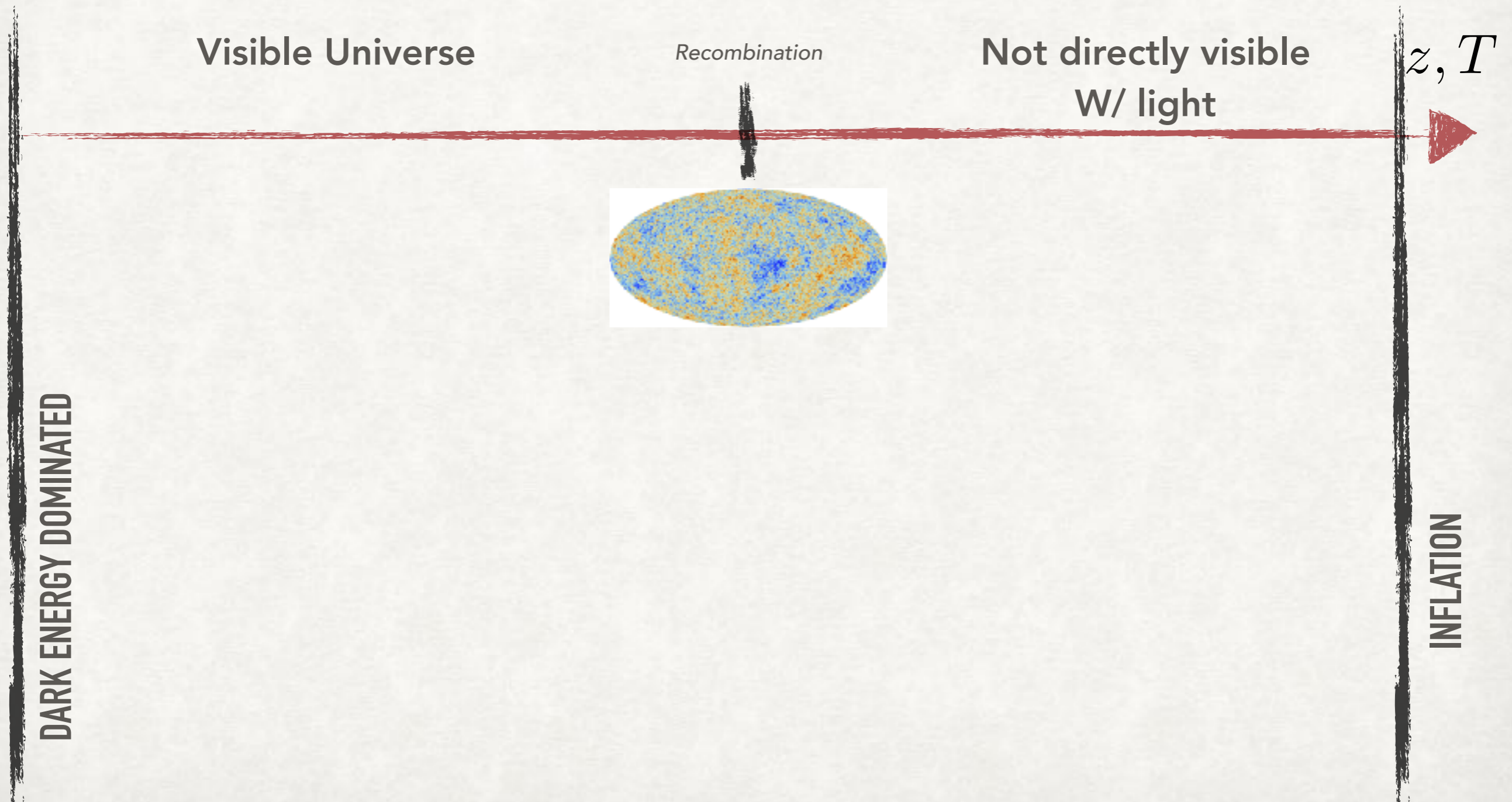
More energy in radiation alters fit to CMB data

$$\Delta N_{\text{eff}} \leq 0.3 \text{ (95\% C.L.)}$$

Planck18+BAO

GRAVITATIONAL WAVES (GW)

Additionally: the early Universe is transparent to gravitational waves
(only very weak, gravitational interactions) !



GRAVITATIONAL WAVES (GW)

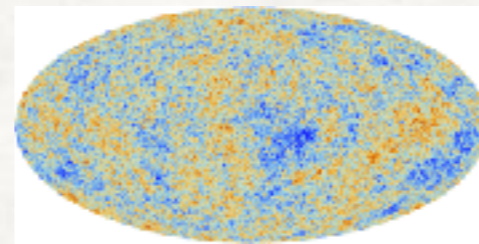
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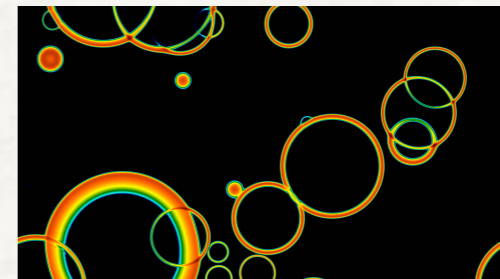
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W/ light

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New Physics sourcing GWs

e.g.



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INFLATION

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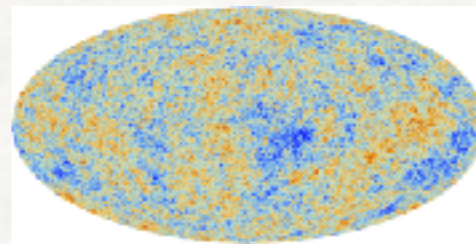
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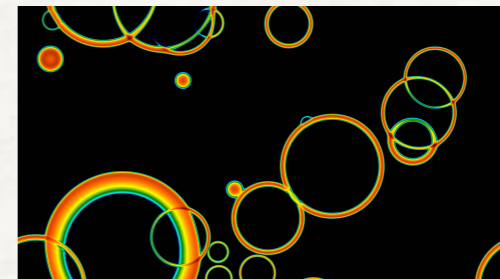
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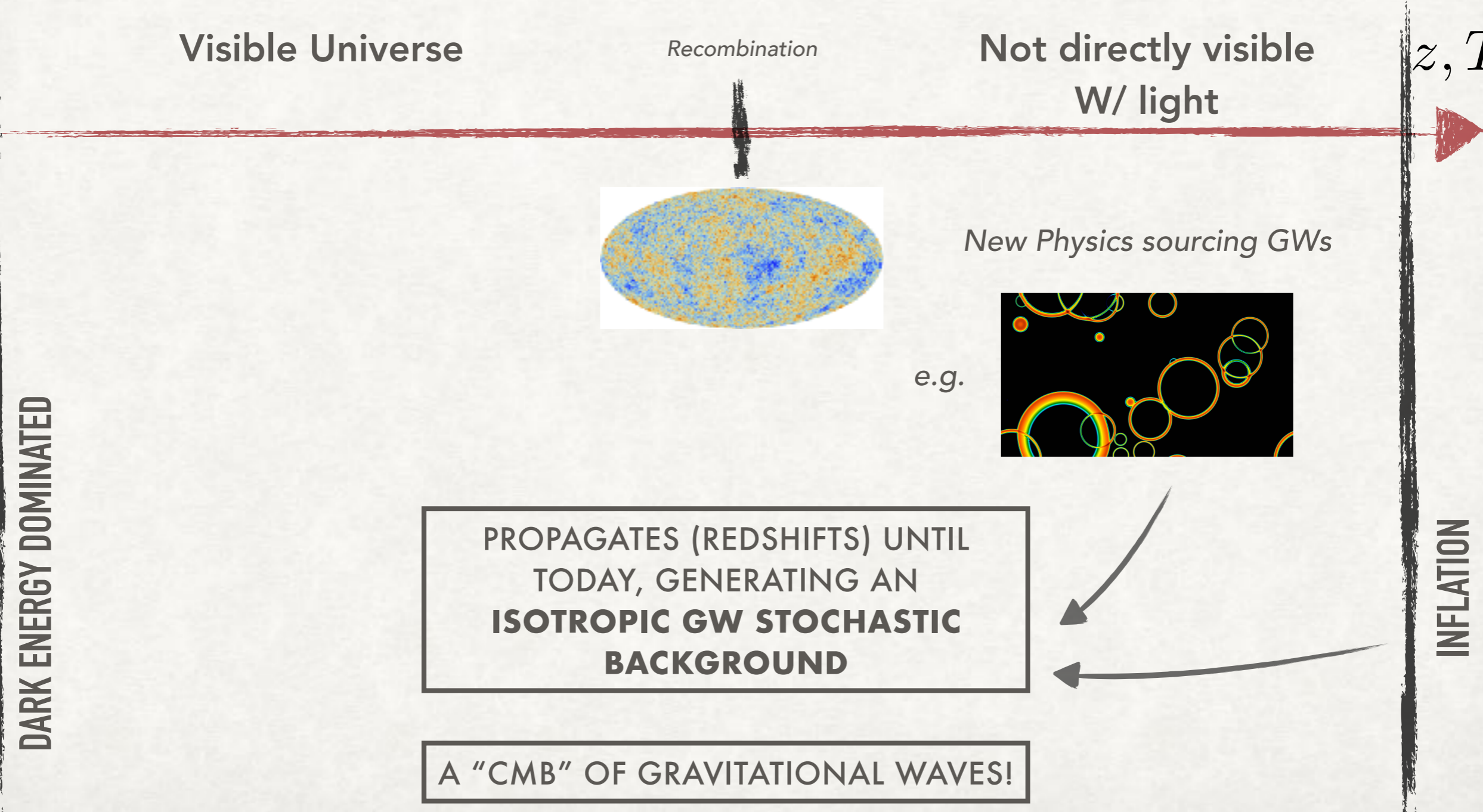


PROPAGATES (REDSHIFTS) UNTIL
TODAY, GENERATING AN
**ISOTROPIC GW STOCHASTIC
BACKGROUND**

A "CMB" OF GRAVITATIONAL WAVES!

DARK ENERGY DOMINATED

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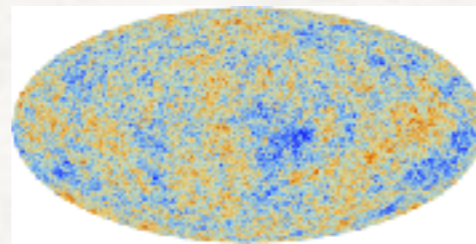
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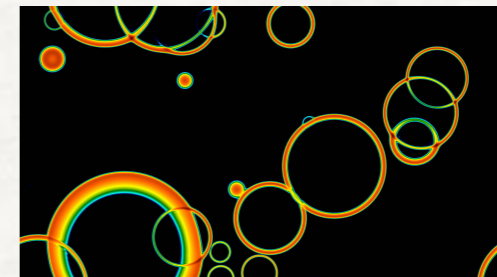
z, T

Interferometers
VIRGO (& LIGO/KAGRA)



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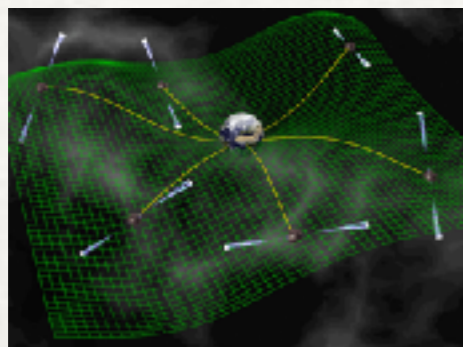
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DARK ENERGY DOMINATED

INFLATION

From CERN Courier



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Pulsar Timing Arrays (e.g. NANOgrav)

NEW PHYSICS AT PULSAR TIMING ARRAYS

Ferreira, Notari, Pujolàs, FR 22

Dandoy, Domcke, FR, in progress

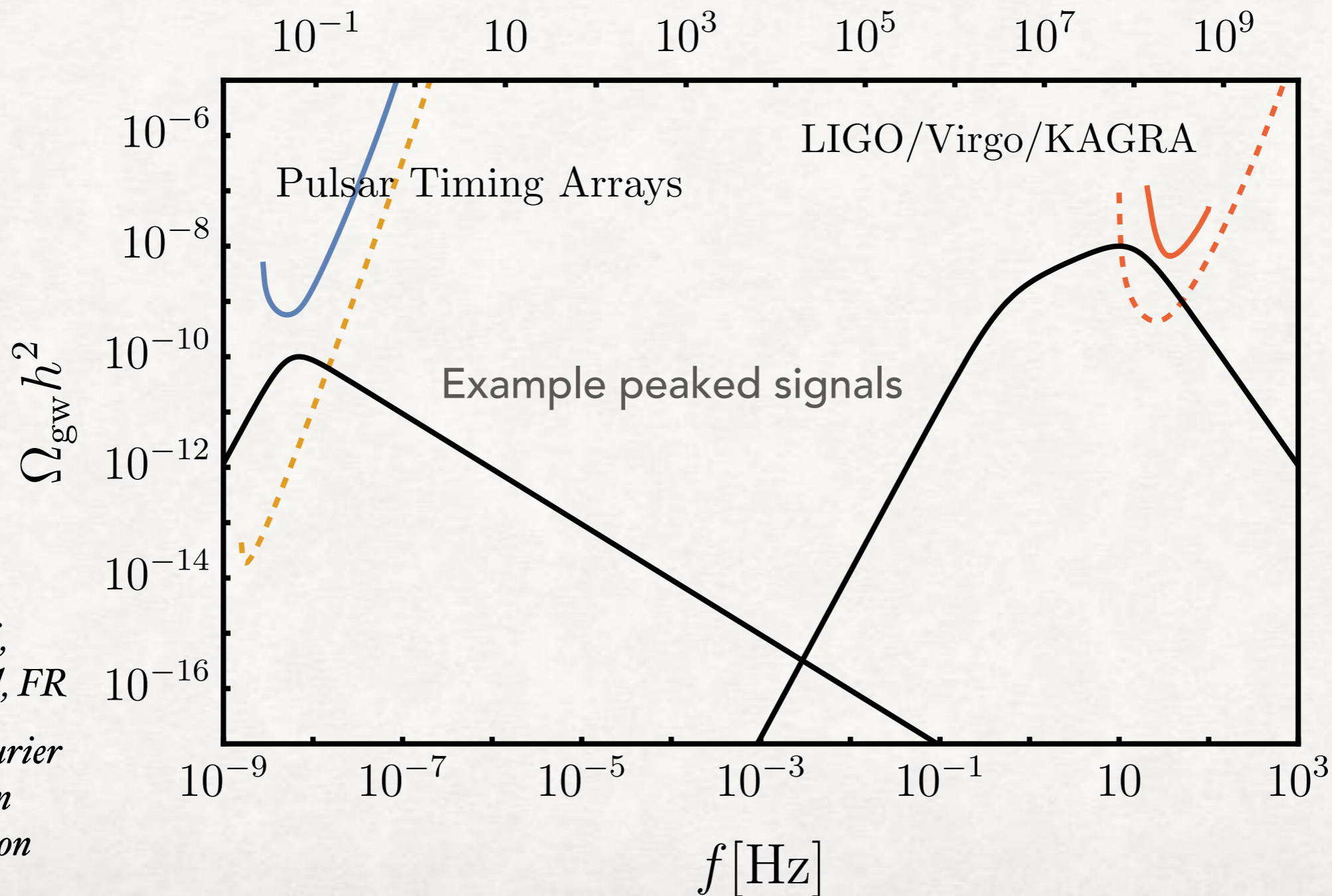
STOCHASTIC GW BACKGROUND

$$\Omega_{\text{GW}}(\omega) \equiv \frac{d\rho_{\text{GW}}}{d\log\omega} / (3H_0^2 M_p^2)$$

*Early Universe temperature
at which GWs are generated*

$$h \equiv H_0 / (100 \text{ km/s/Mpc})$$

$$T_H [\text{GeV}]$$



*Caprini,
Maleknejad, FR
CERN Courier
article in
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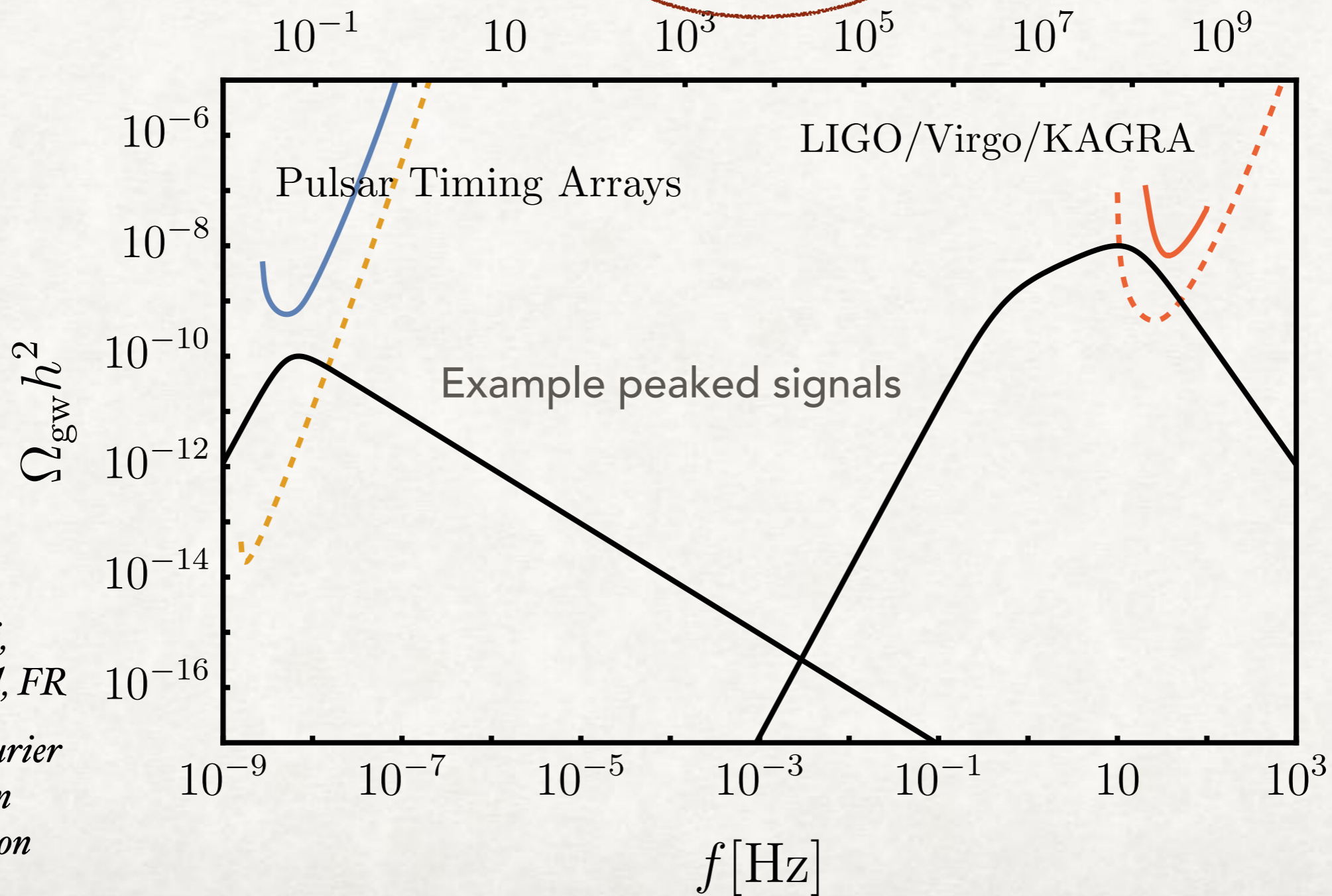
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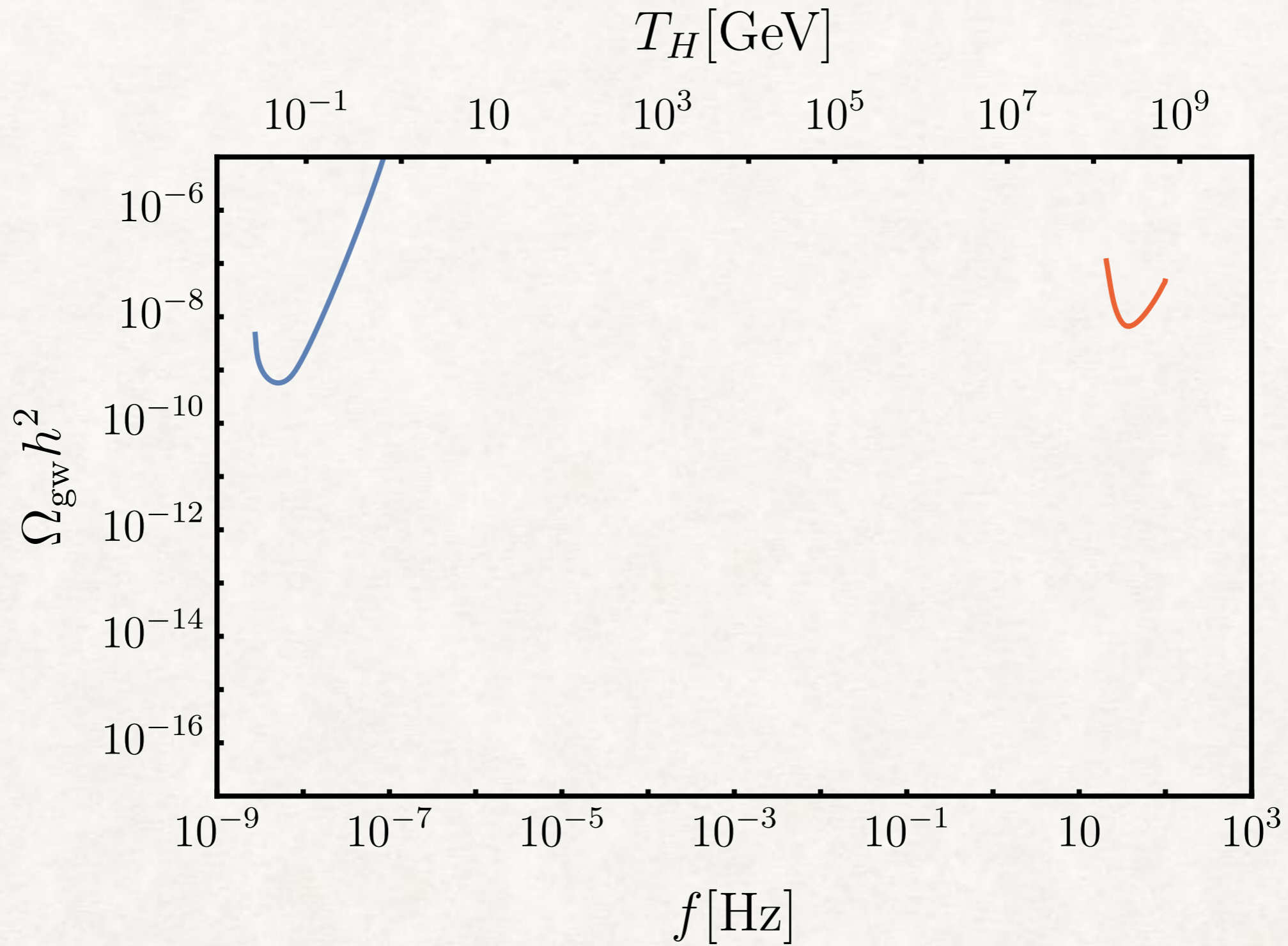
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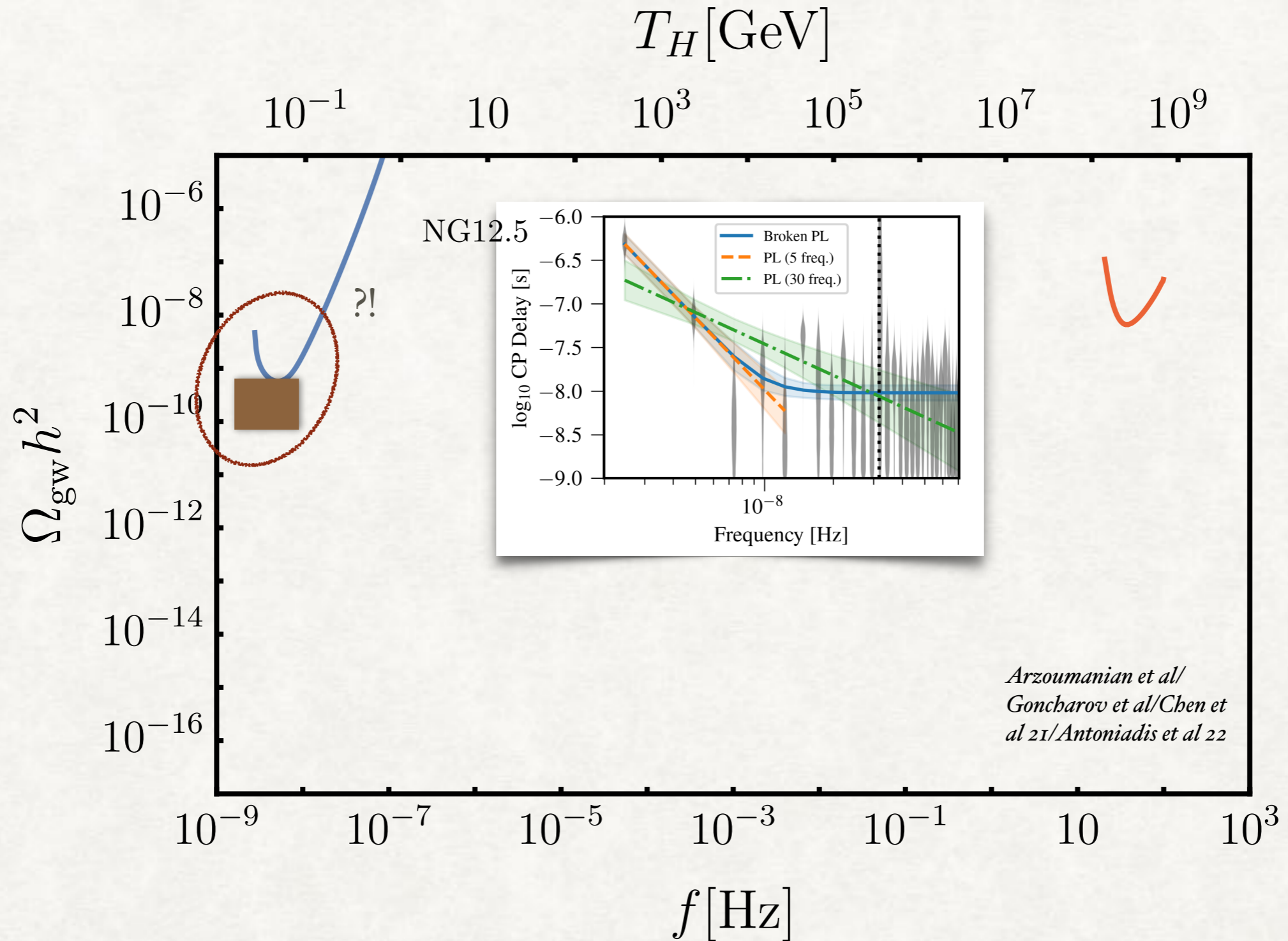


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PULSAR TIMING ARRAYS (PTA)



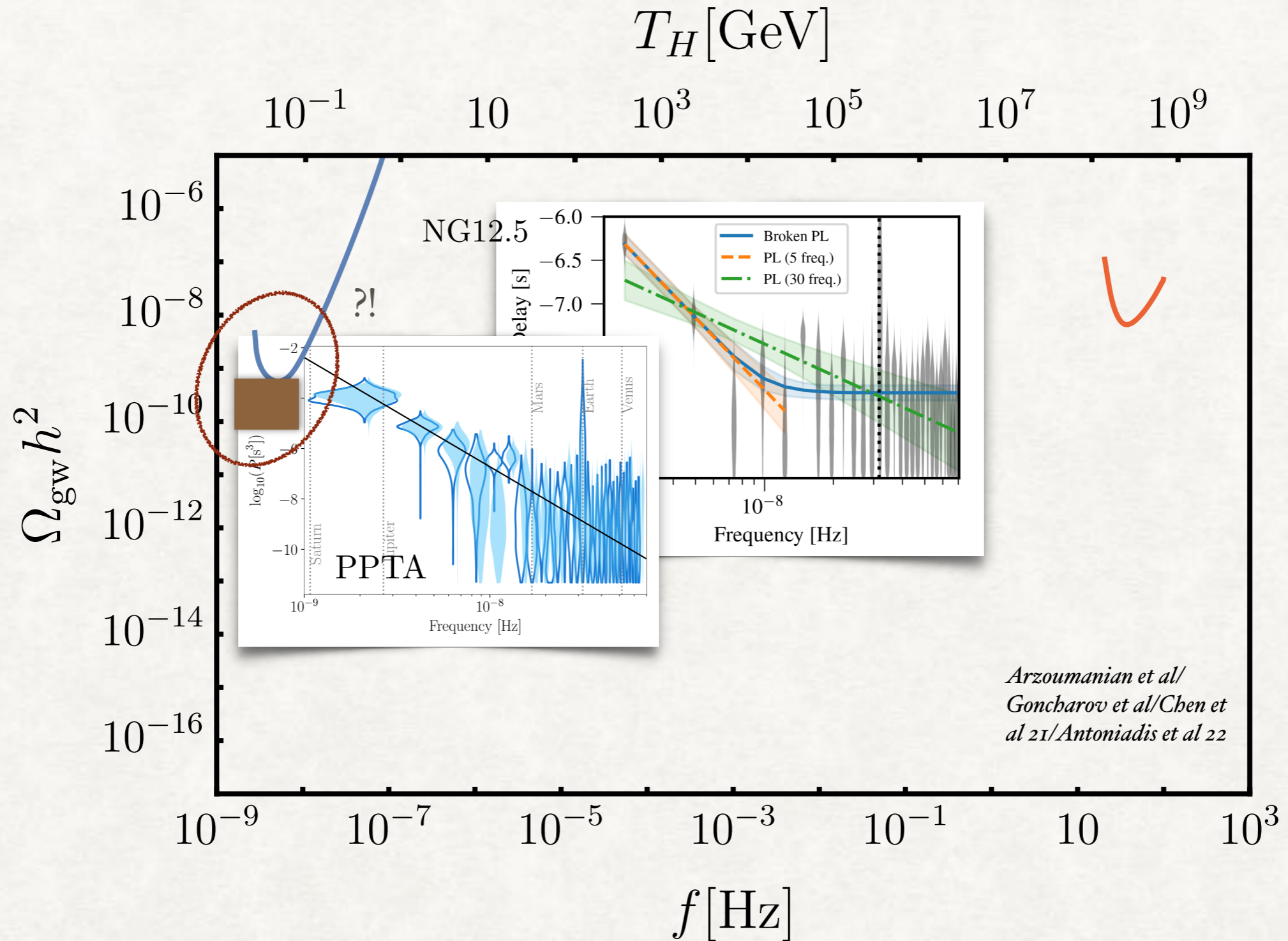
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**Strong evidence for common spectrum process
in their measurement of pulsar time delays.**

(Caveat: Not yet evidence for stochastic GWs, since no significant evidence for quadrupolar correlations)

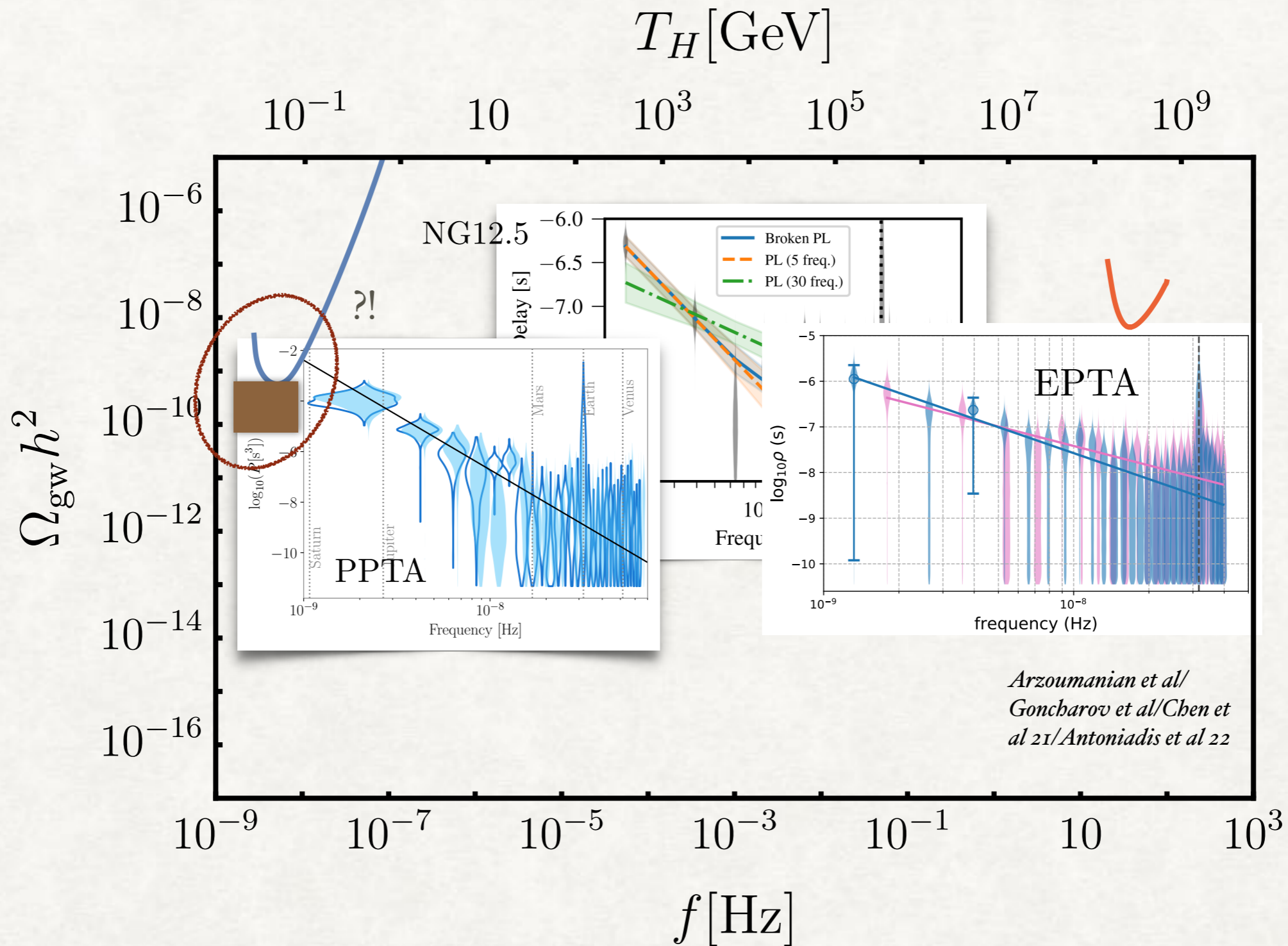
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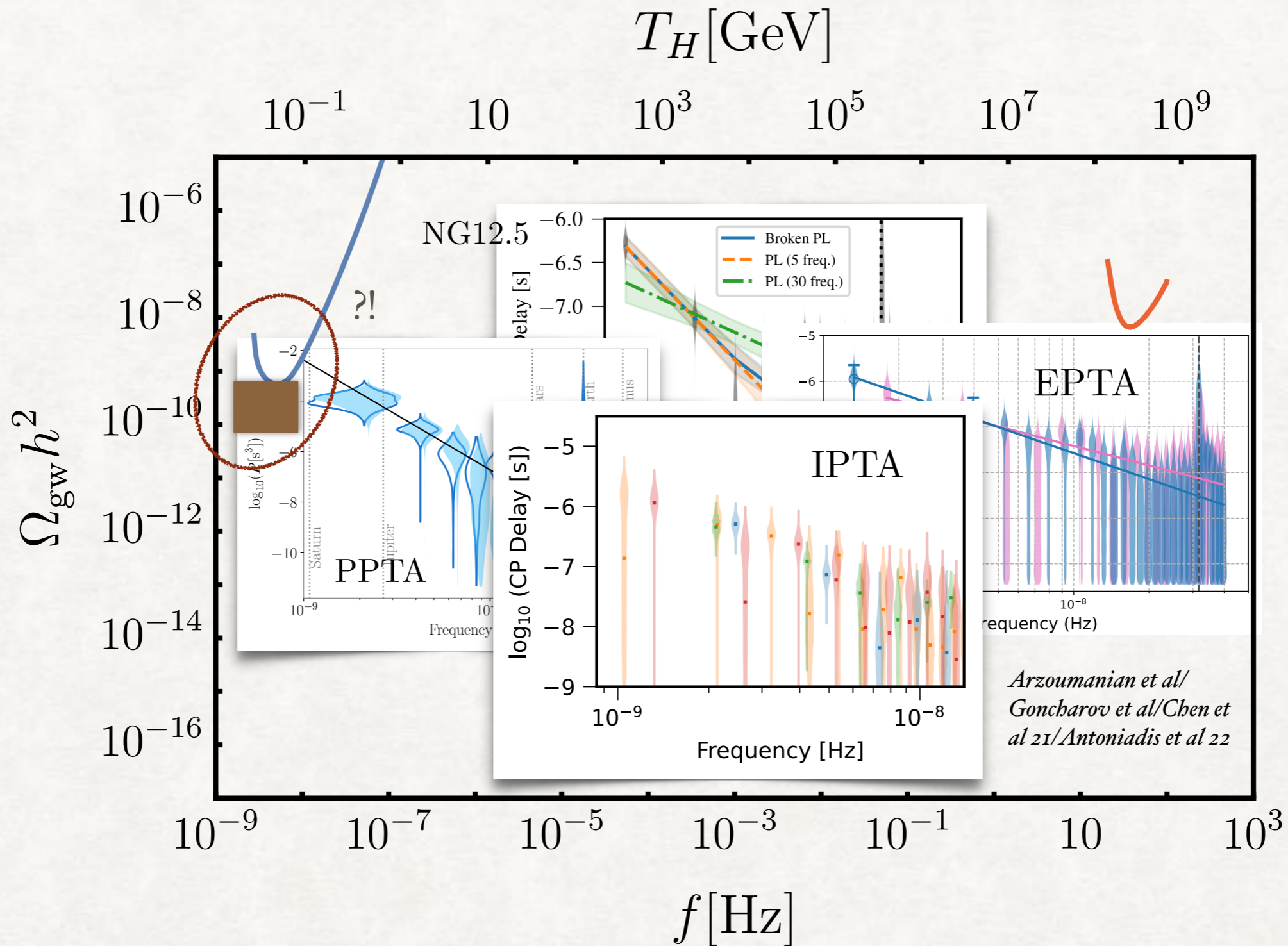
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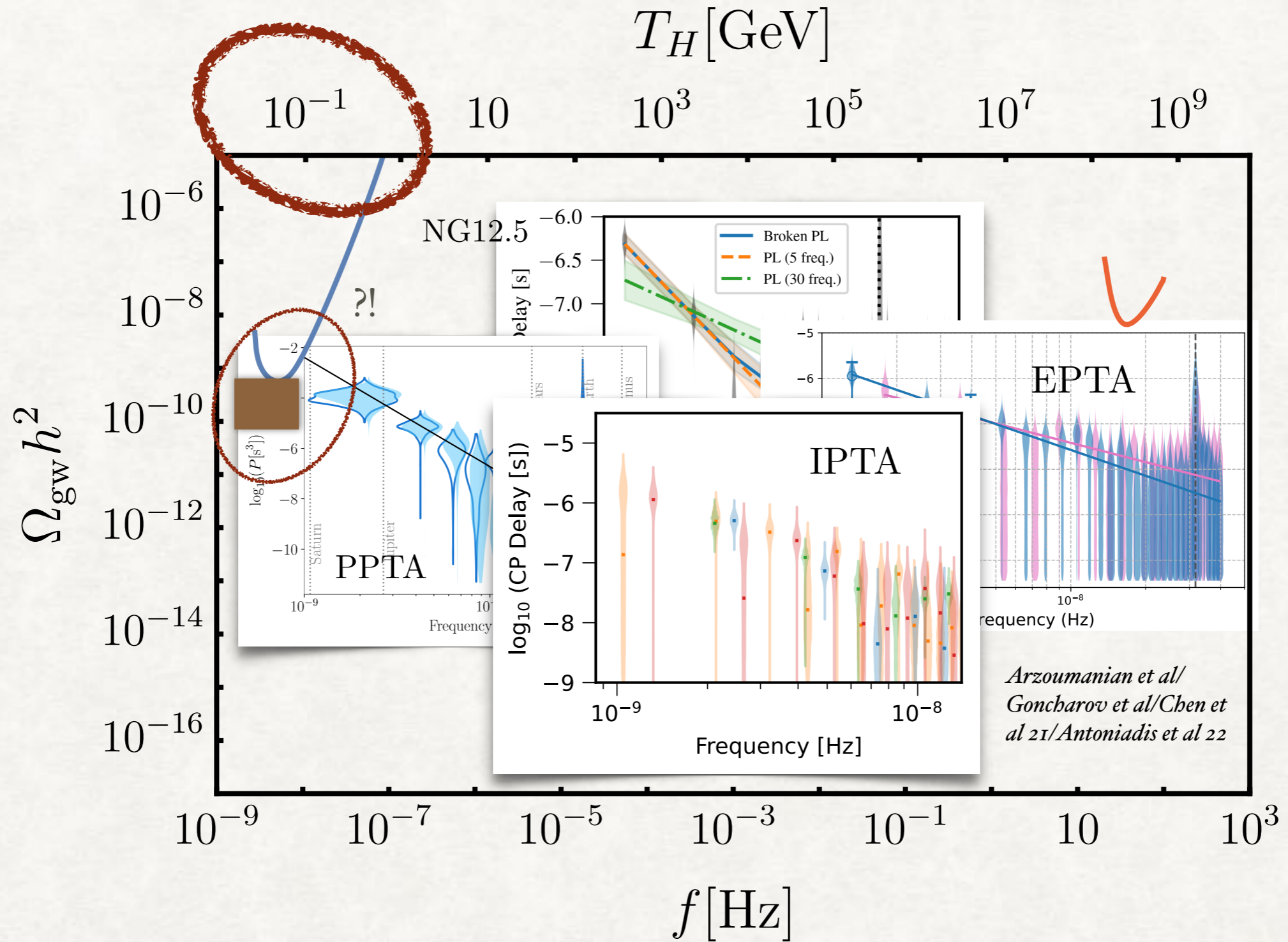
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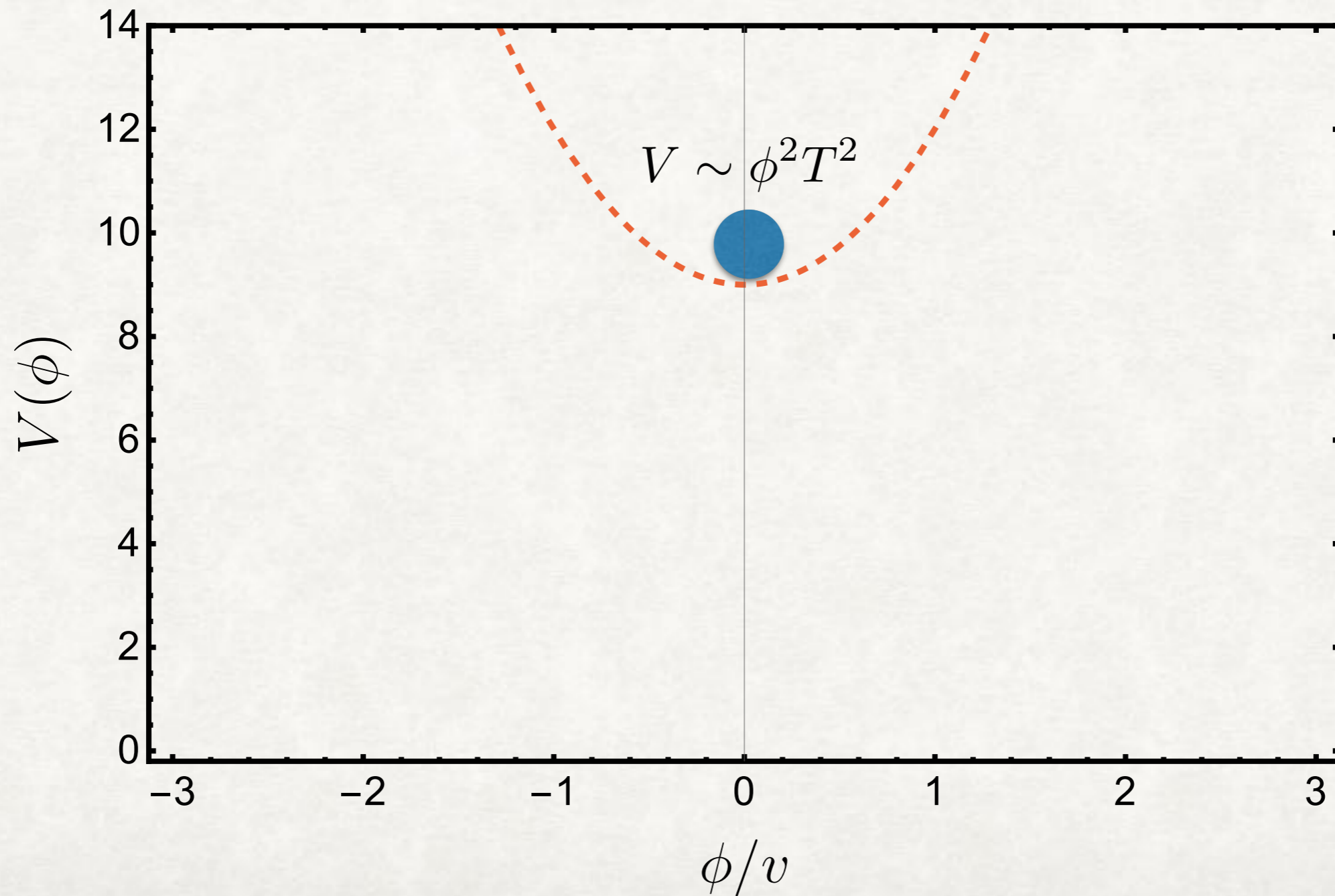
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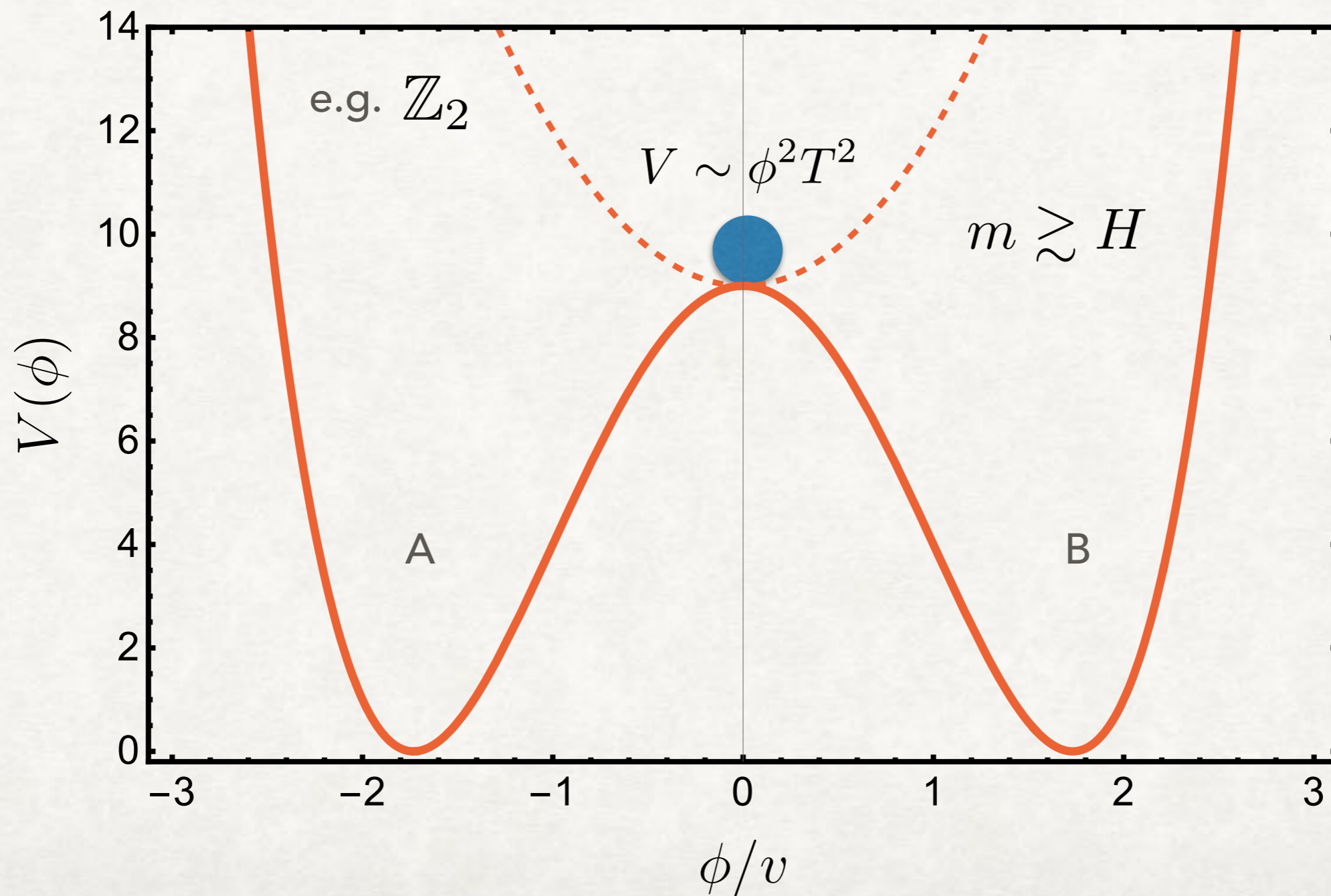


If GWs, signal is commonly interpreted as due to Supermassive Black Hole Binaries.
 However, new physics interpretation also possible and far-reaching.

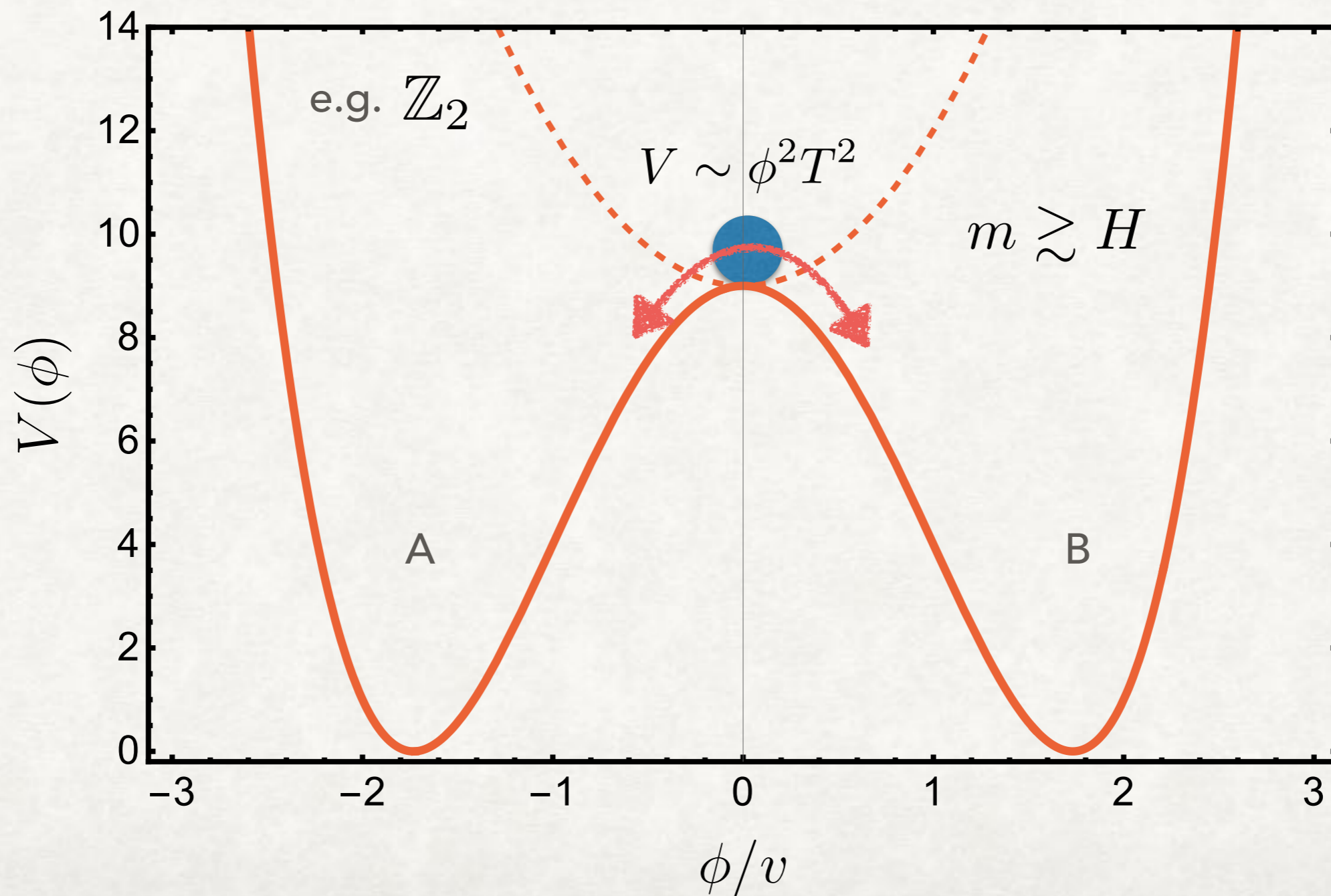
COSMOLOGICAL IMPLICATION OF DISCRETE SYMMETRY



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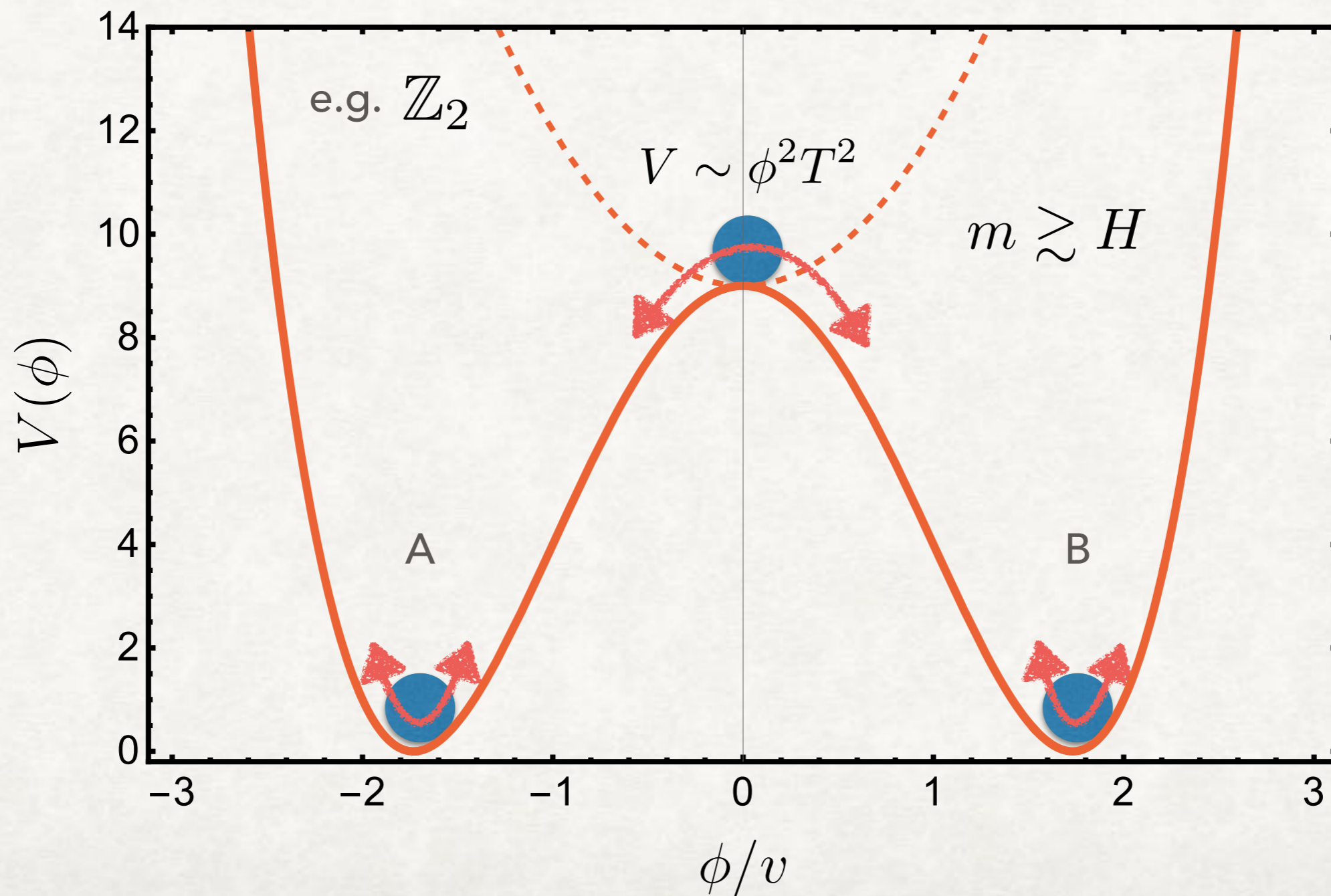


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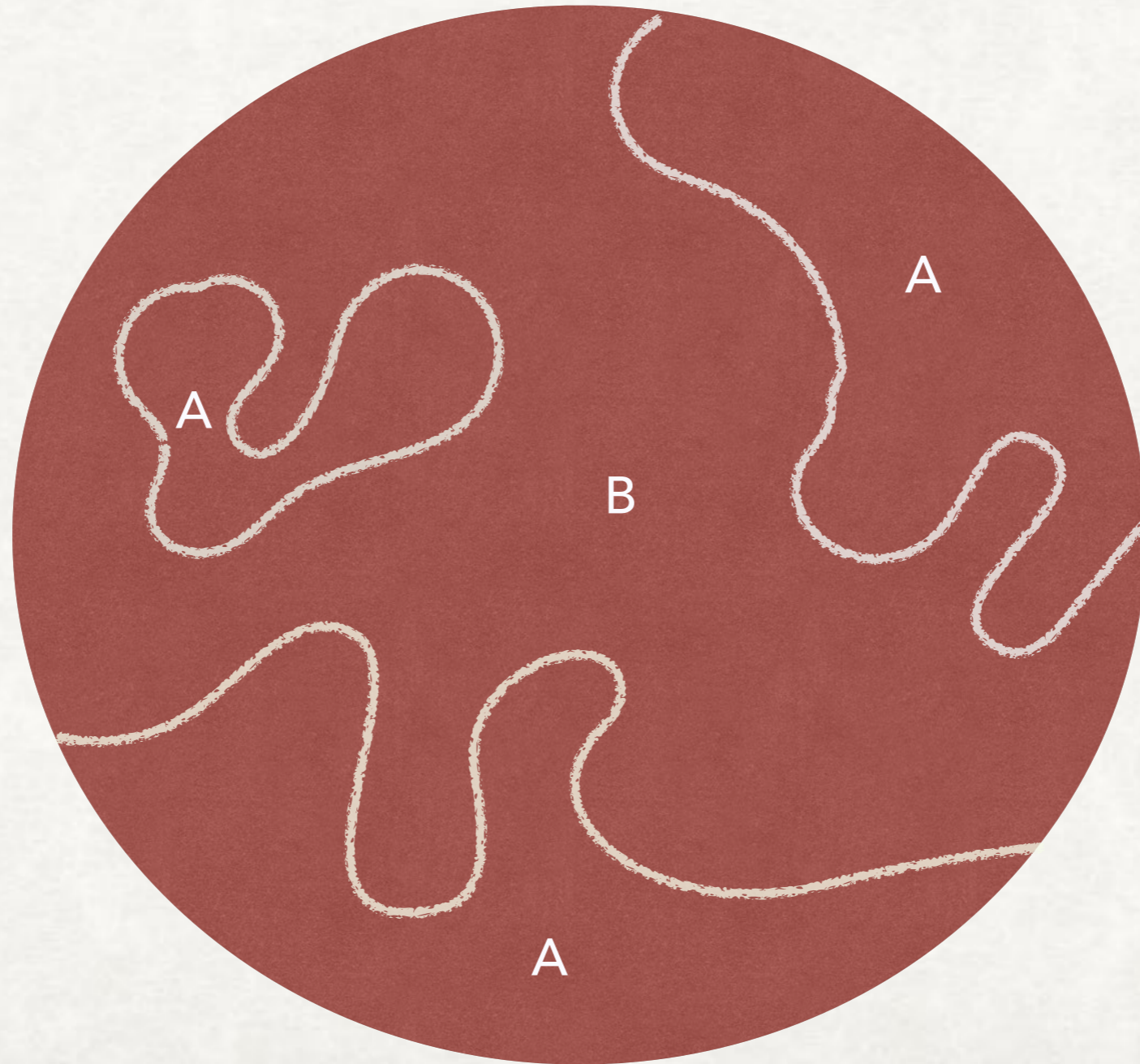


COSMOLOGICAL IMPLICATION OF DISCRETE SYMMETRY

*Universe is divided into domains with different physics,
separated by walls!*

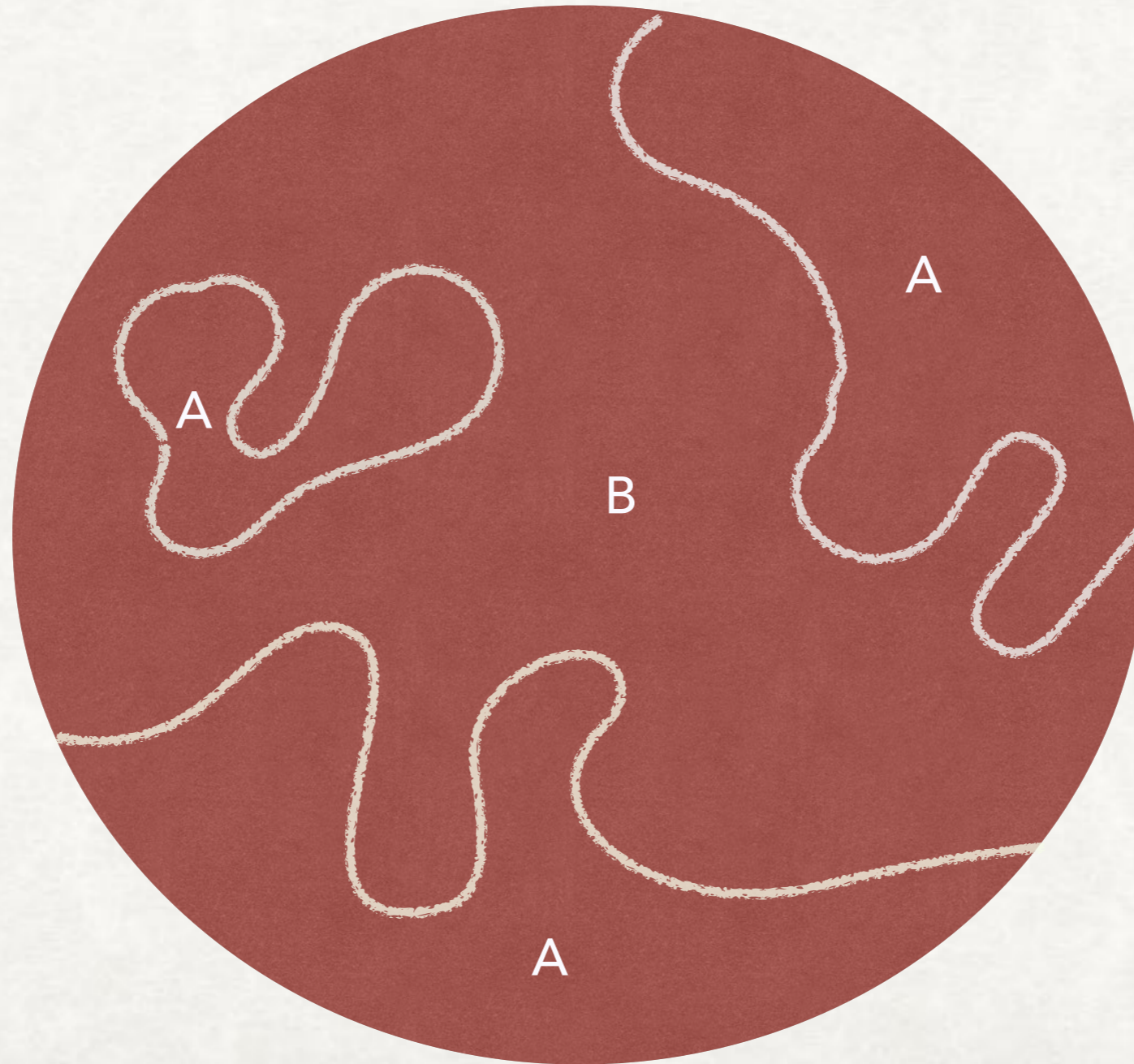


COSMIC DOMAIN WALLS



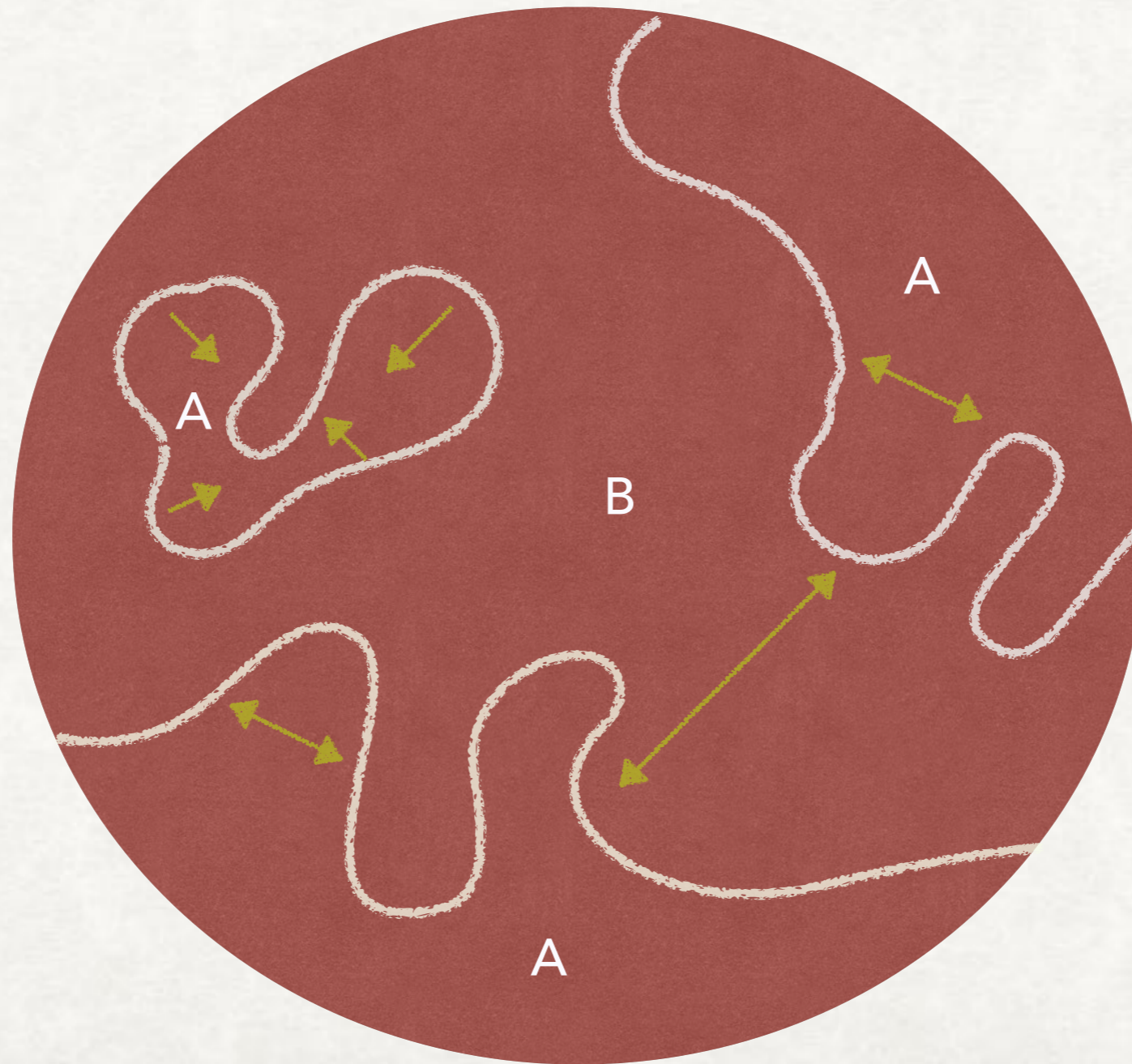
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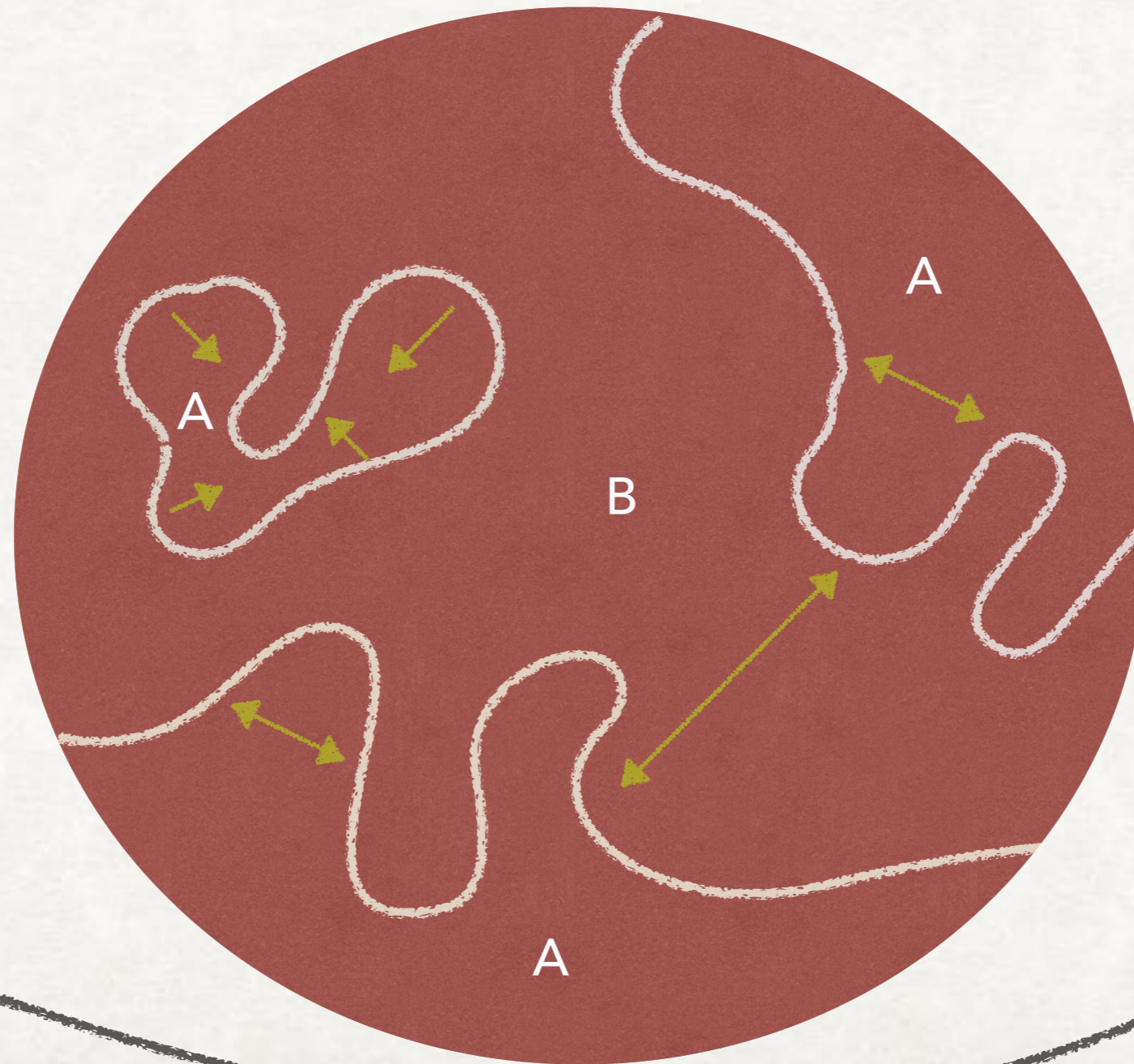
COSMIC DOMAIN WALLS

*Walls have rapidly varying mass quadrupole moment, source GWs until they annihilate at some temperature T_**



COSMIC DOMAIN WALLS

Walls have rapidly varying mass quadrupole moment, source GWs until they annihilate at some temperature T_*



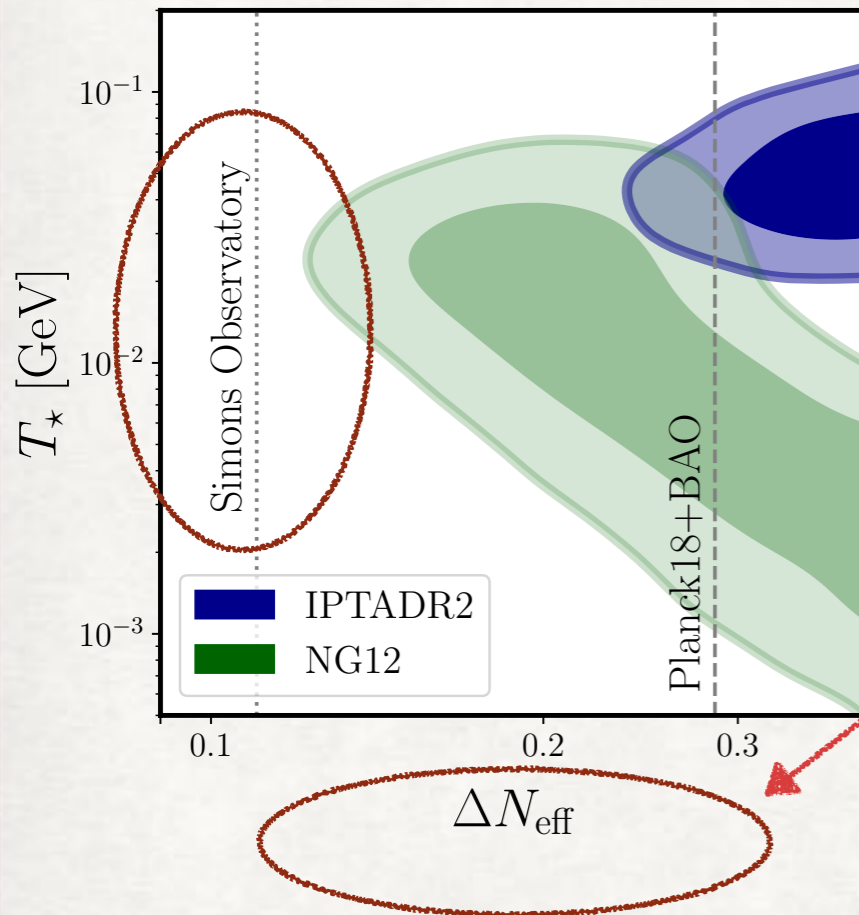
Interesting:
For axionic symmetries annihilation temperature is set by "quality" of associated U(1)

GWs from domain walls can be measure of global symmetry breaking!

SEARCH FOR DISCRETE SYMMETRY IN PTA DATA

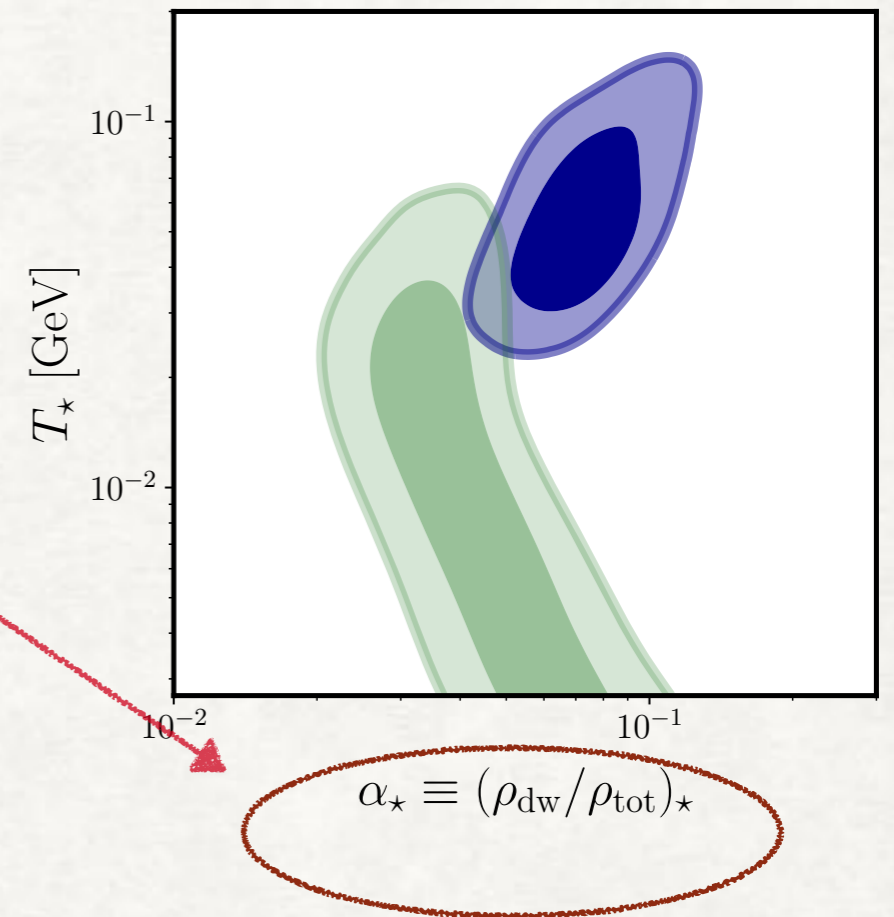
Ferreira, Notari, Pujolàs, FR 2204.04228

Decay to Dark Radiation



Fraction of total energy density at time of annihilation

Decay to Standard Model

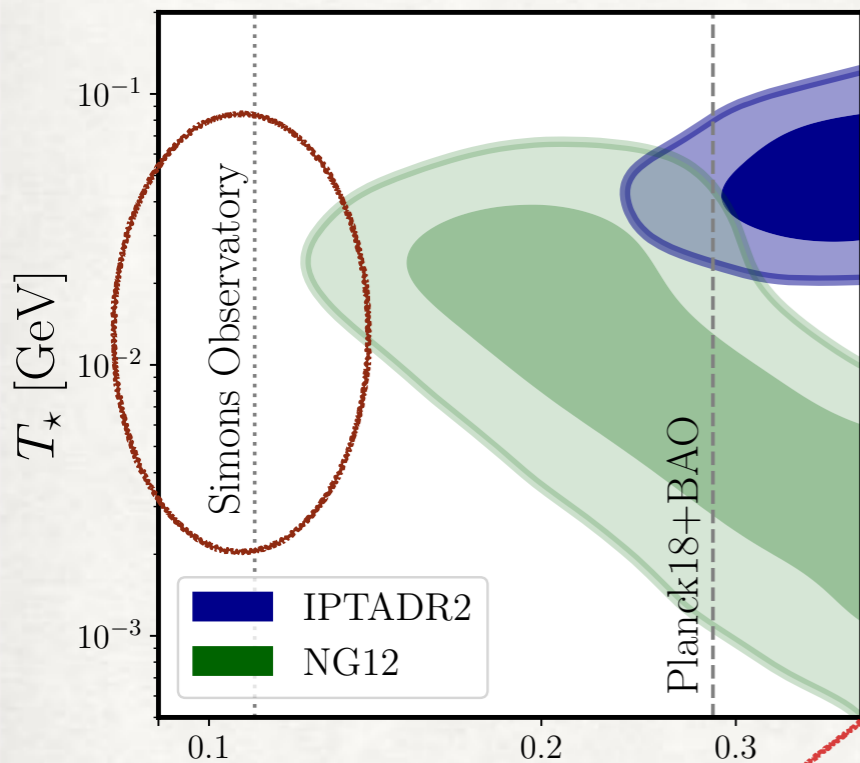


Results obtained running on CERN LXPLUS cluster

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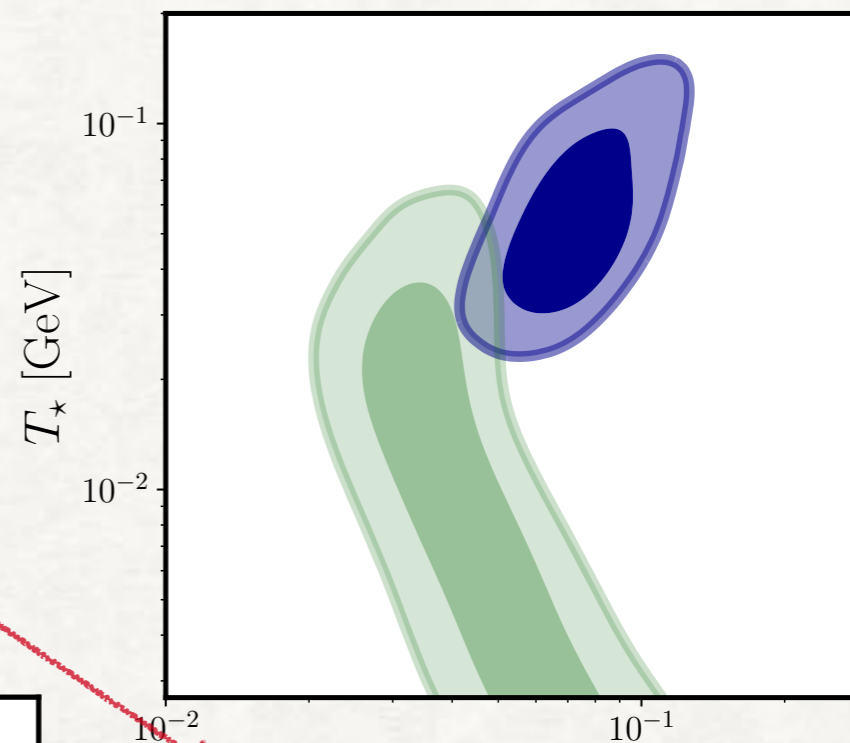


ΔN_{eff}

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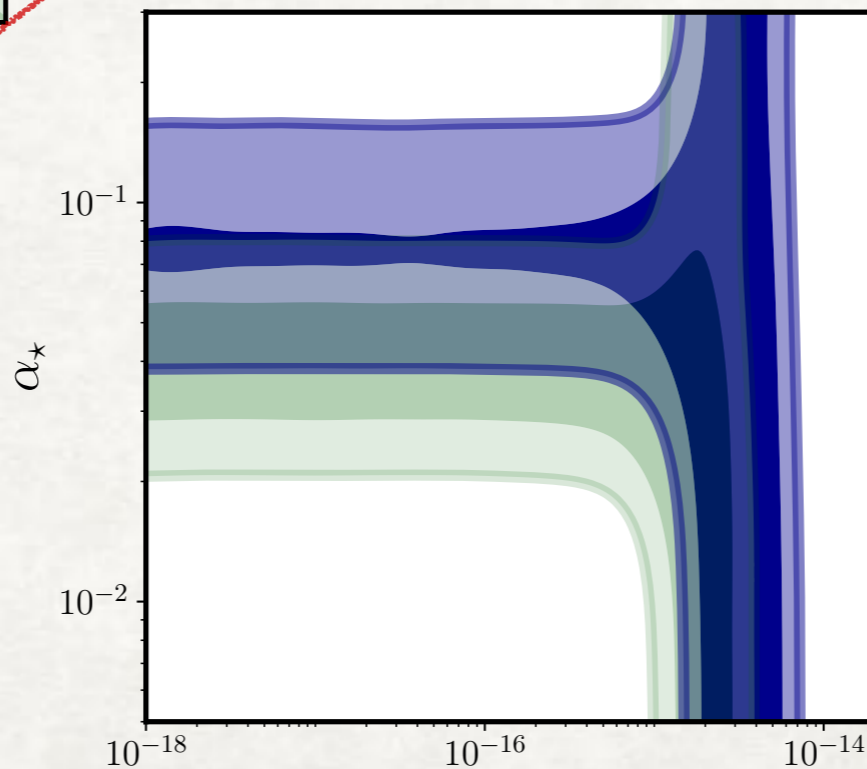
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$\alpha_{\star} \equiv (\rho_{\text{dw}}/\rho_{\text{tot}})_{\star}$

New physics interpretation fits data as good as astrophysical origin

DWs+SMBHBs, Decay to SM



A_{GWB}

Amplitude of astrophysical signal

THE QCD AXION AS DARK RADIATION

Notari, FR, Villadoro

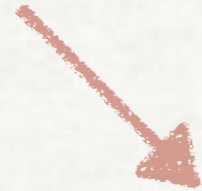
TOMORROW ON HEP (& ASTRO)-PH

THE QCD AXION

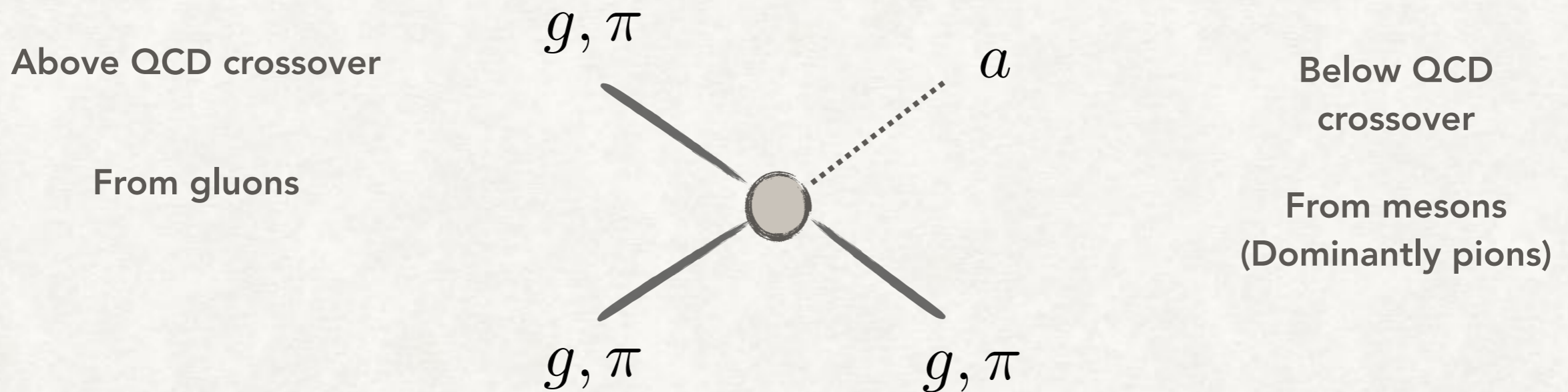
$$\mathcal{L}_{\text{QCD}} \supset \frac{\alpha_s}{8\pi} \theta_{\text{SM}} G \tilde{G}$$

Peccei-Quinn solution to
strong CP problem :

$$\theta_{\text{SM}} \rightarrow \frac{a(x, t)}{f_a}$$



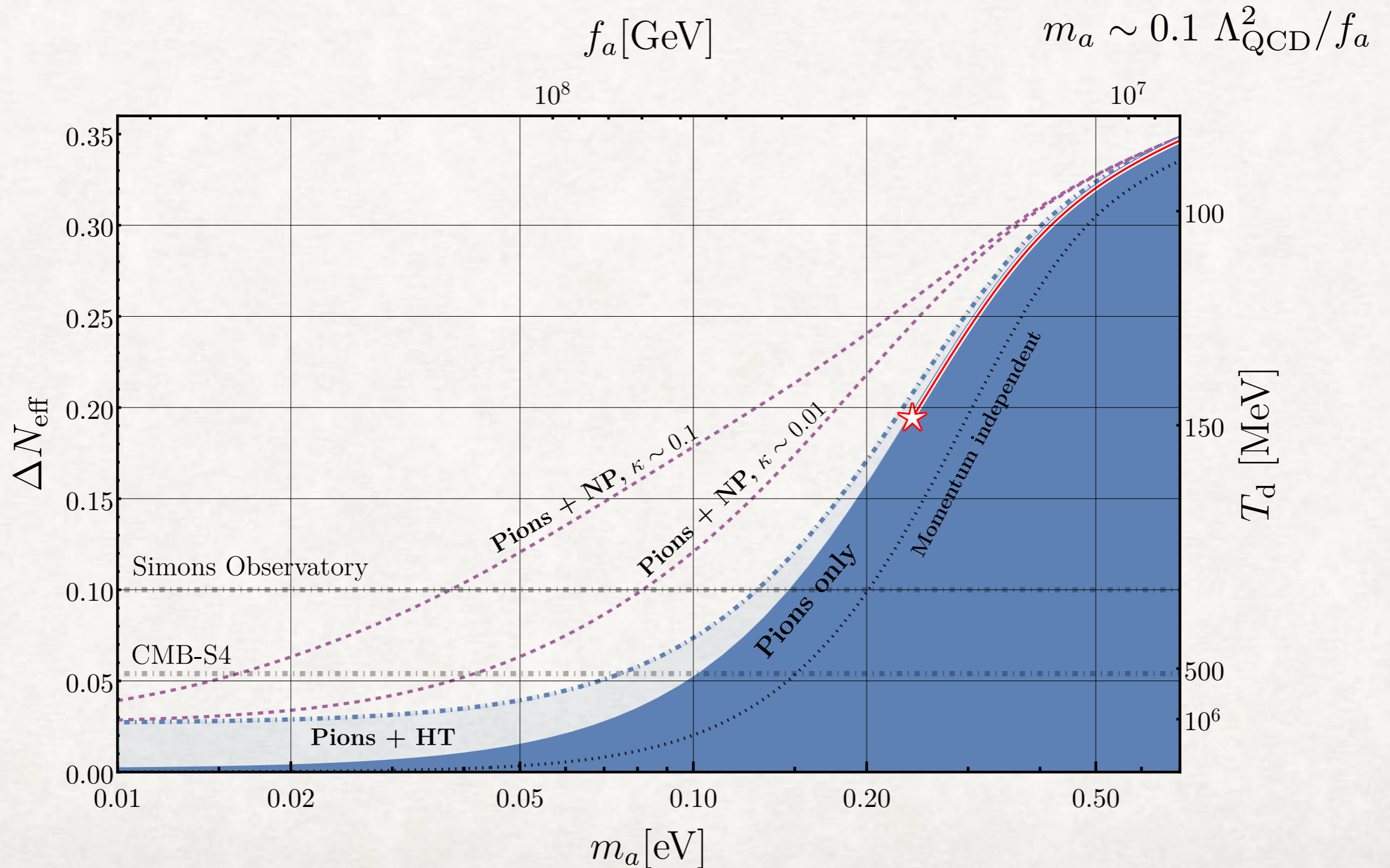
Minimal model-independent interactions lead to
production of "hot" relic axions in the early Universe



Similar to additional (massive) neutrinos, can be seen in CMB
and other cosmo datasets

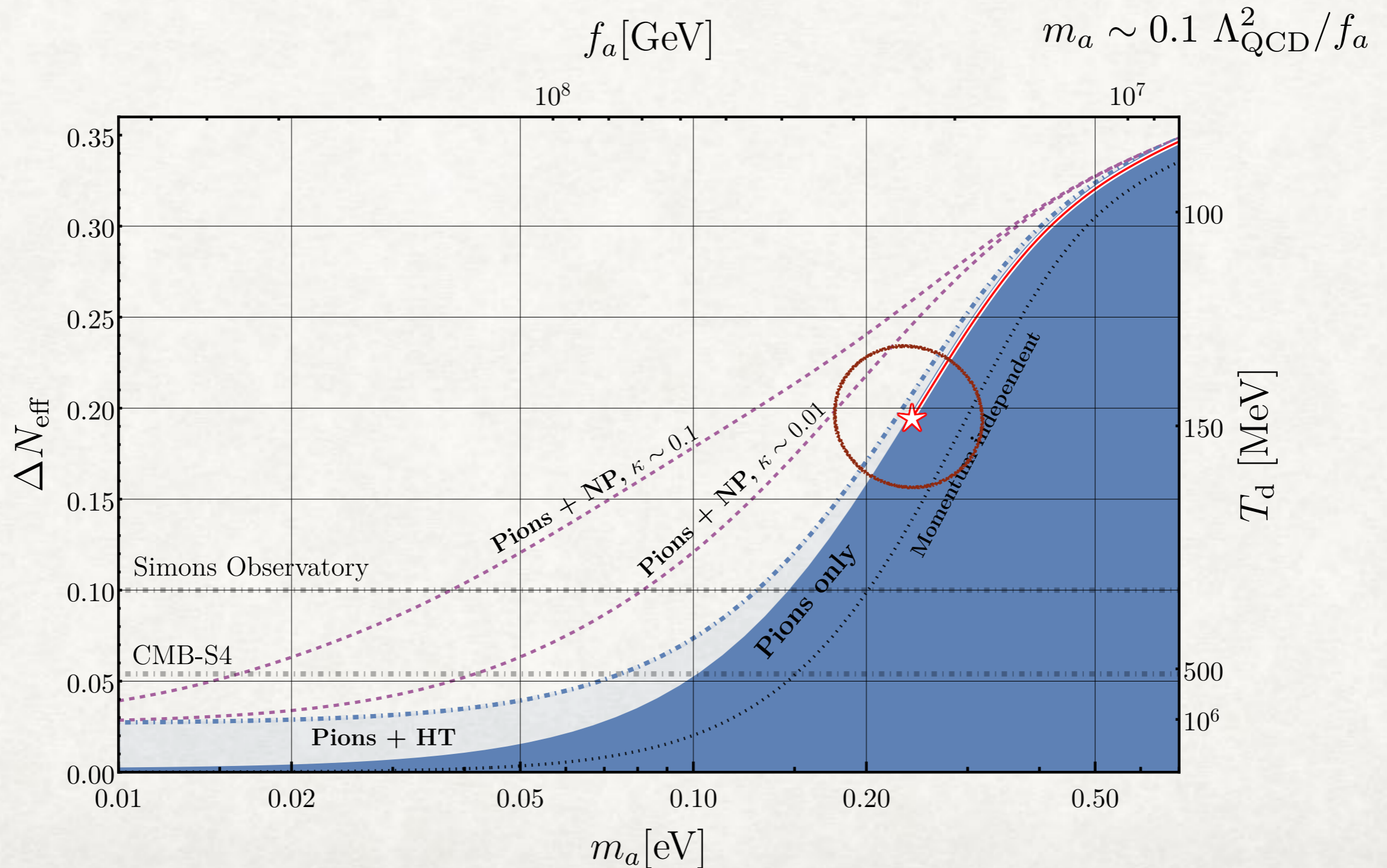
A RELIABLE UPPER BOUND ON THE QCD AXION MASS

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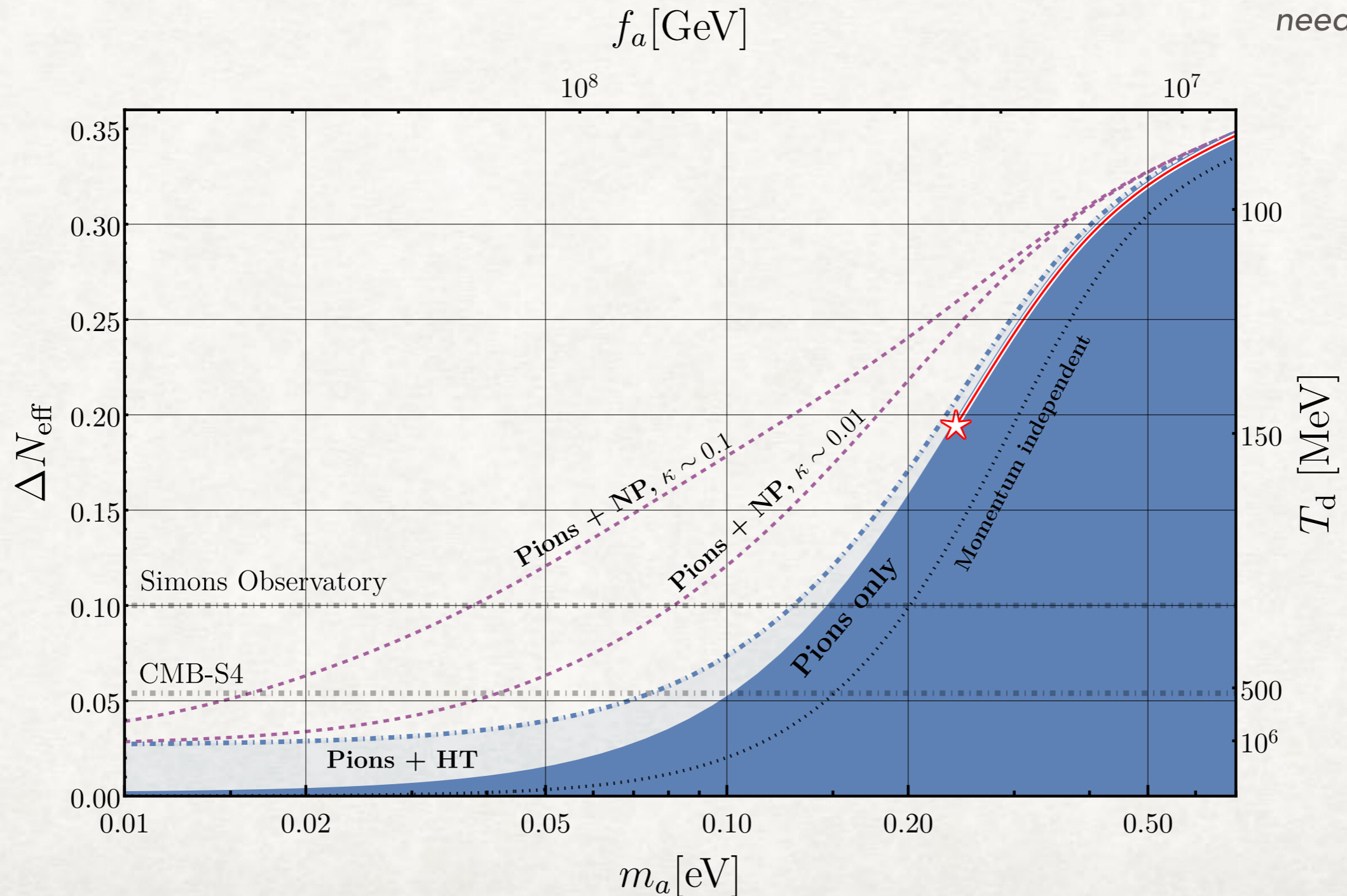
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IMPROVING THE BOUND/DISCOVERING THE AXION

Sensitivity reach of upcoming cosmological surveys requires reliable non-perturbative calculation of thermal rates!

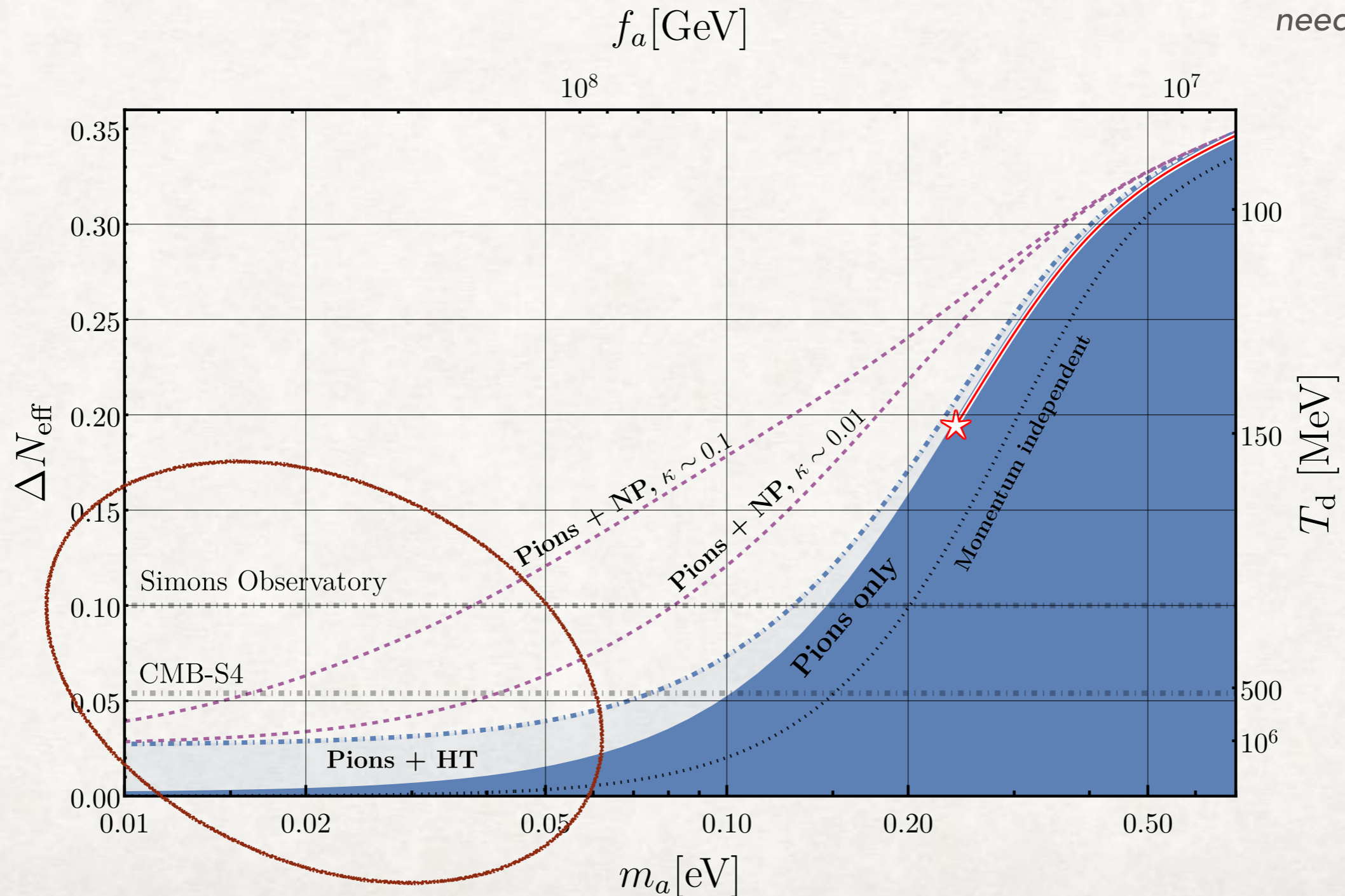
Help from lattice needed!



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The possible near future

- a) Detection of stochastic GW background?
- b) Detection/strong constraints on dark radiation?
- c) Deviations from Cold Dark Matter?

Plenty of theory+data work to do



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THANK YOU!



ft. Daniele Teresi



ft. Gauthier Durieux