

4th EuCAPT Symposium

Poster and Lightning talk Prizes







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Signatures of ultralight bosons in the orbital eccentricity of binary black holes

Signatures of ultralight bosons in the orbital eccentricity of binary black holes [2403.02415]

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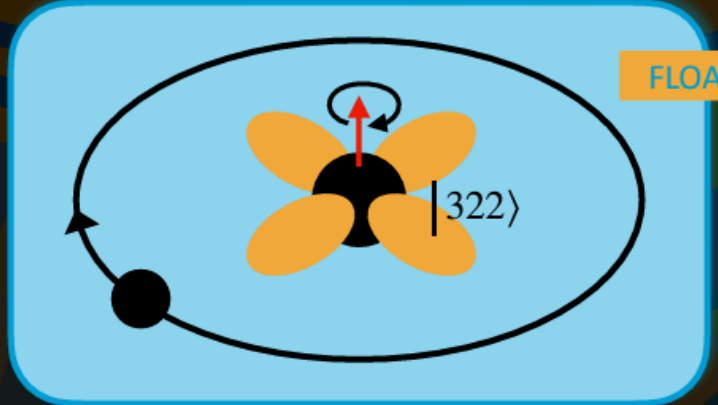



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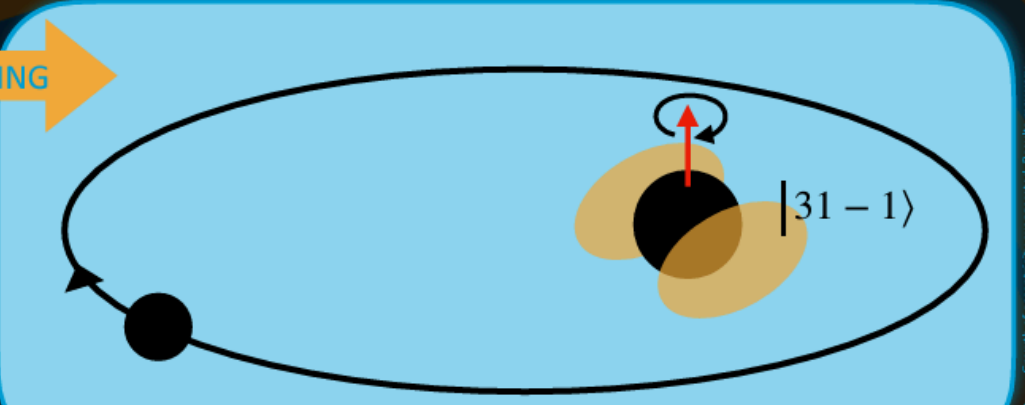
TL;DR

- If black holes carry a superradiant cloud of ultralight particles¹ (e.g., axion-like-particles), a perturbation by a binary object on an eccentric orbit can trigger overtones of the well-known Landau-Zener transition.
- If these transitions float (i.e., stall the mean orbital frequency), they can significantly increase the eccentricity of the orbit.





FLOATING



GRAVITATIONAL ATOM CRASHCOURSE²
= instead of proton + electron → **black hole + ultralight bosons**

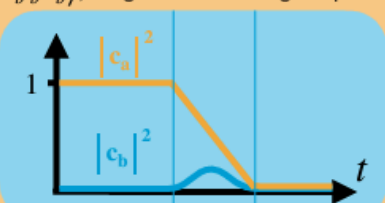
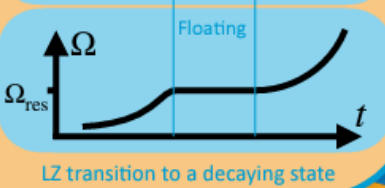
$\alpha_{\text{em}} \rightarrow \alpha_{\text{grav}} \equiv GM\mu/(hc)$ $\alpha \approx 0.1 \left(\frac{M}{15M_{\odot}}\right) \left(\frac{\mu}{10^{-12}\text{eV}}\right)$	$\text{Im}(\omega_{nlm}) = 0 \rightarrow \text{Im}(\omega_{nlm}) \neq 0$ i.e. SUPERRADIANCE³ Fastest growing modes: $ 211\rangle, 322\rangle$ 1 fermion → many bosons
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Excitation via photons with $\omega \propto \omega_{n,l,m_2} - \omega_{n,l,m_1}$ → Excitation via binary companion:⁴

For a two-state system $|a\rangle \equiv |n_a, l, m_a\rangle$ and $|b\rangle \equiv |n_b, l, m_b\rangle$, we get at a Schrödinger eqn.:

$$i \begin{pmatrix} \dot{c}_a \\ \dot{c}_b \end{pmatrix} = \begin{pmatrix} -\frac{\Delta E}{2} & \eta(R_*)e^{i\Delta m \varphi_*} \\ \eta(R_*)e^{-i\Delta m \varphi_*} & \frac{\Delta E}{2} - i\Gamma_b \end{pmatrix} \cdot \begin{pmatrix} c_a \\ c_b \end{pmatrix}$$

- $\Delta E, \Delta m$: energy and angular momentum differences, respectively, Γ_b : decay rate of $|b\rangle$
- $\eta(R_*)$: mixing due to the perturbation by the companion, φ_* : the true anomaly of the orbit.
- When $\Omega_{\text{res}} \equiv \dot{\varphi}_* = \Delta E/\Delta m$, we get a Landau-Zener (LZ) transition.
- If the cloud loses energy, its backreaction to the orbit stalls the inspiral → **the orbit floats!**

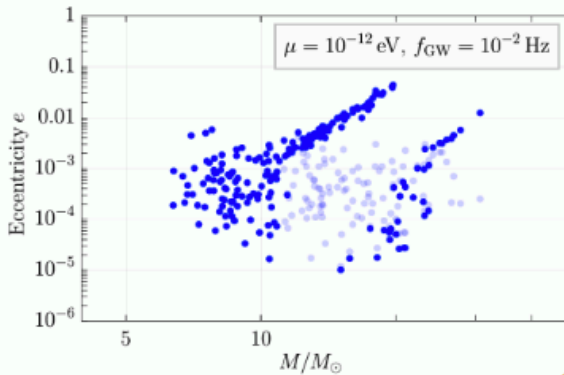
LZ transition to a decaying state

Binary Black Hole Populations in LISA⁷

We take a population of binary BHs with **chirp masses** $< 10M_{\odot}$, formed in isolation at an orbital frequency of $10^{-4}\pi\text{Hz}$. If the ultralight particle has a mass of 10^{-12}eV , the binaries experience **hyperfine and fine transitions**, mostly from $|322\rangle$ to $|31-1\rangle$.

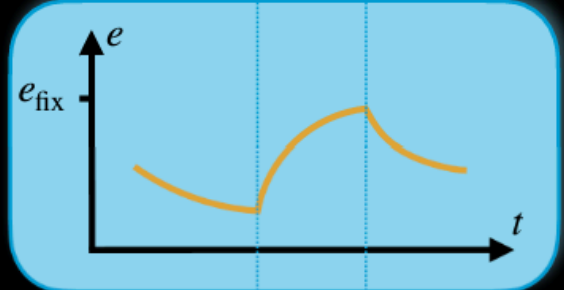
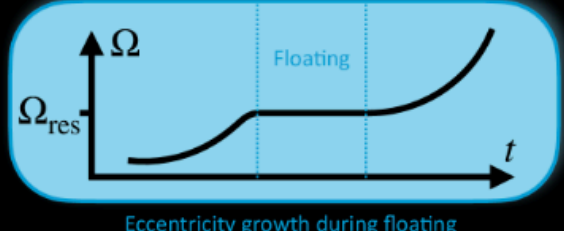
At the strongest early resonances, $k \leq -1$, the eccentricity can grow. **On the right**, we show the eccentricity distribution at 10^{-2}Hz , possibly visible in LISA. Transparent dots show the distribution without the clouds.

For larger masses, $M_1 = 20M_{\odot}$, with companion $M_2 = 40M_{\odot}$, the eccentricity growth can also fall into the LISA band, with floating times of $\mathcal{O}(\text{yrs})$.



!Eccentricity Growth!

Because for eccentricity $e: \varphi_* = \vartheta + 2e \sin \vartheta + \mathcal{O}(e^2)$, with φ_* , ϑ the true and mean anomaly, respectively, we get $e^{i2e \sin \vartheta} = \sum_{k=-\infty}^{\infty} e^{k/|k|!} e^{ik\vartheta}$ in the mixing term. The condition for resonance becomes $\Omega_{\text{res},k} \equiv \dot{\vartheta} = \Delta E/(\Delta m + k) \rightarrow$ we get **early and late resonances due to overtones** ($k \neq 0$).⁶ During floating, the orbital energy is constant, while the angular momentum scales as $\dot{L}_0 \propto \Omega_{\text{res},k} - \Omega_{\text{res},0} + \mathcal{O}(e^2)$. We have $d(L_0^2) \propto -d(e^2)$, and find that **e can change towards a non-zero fixed point!** For early resonances, the **eccentricity grows**.

Eccentricity growth during floating


References:

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A non perturbative test of nucleation calculations for strong phase transitions



A nonperturbative test of nucleation calculations for strong phase transitions
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Want to know more?



INTRODUCTION

First order phase transitions in the early universe have long sustained interest as they play an important role when considering the following

- Baryogenesis
- Early universe stochastic gravitational wave (GW) background
- Analogue experiments
- Testing perturbative calculations.

The bubble nucleation rate – how quick the conversion between the metastable and stable phase is – can be written as a product of the dynamical and statistical information of the system in question. At high temperatures, the rate can be solved in classical field theory, but these perturbative methods depend on the semiclassical picture [1-12].

With the future GW detection projects, we need reliable predictions with controlled systematic uncertainties. We calibrate the accuracy of nucleation rate calculations in relativistic finite-temperature field theory at a simulation point in the real scalar theory [13], where the assumption has been that perturbation theory works well.

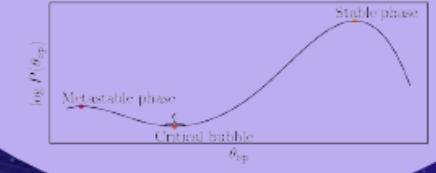
$$\Gamma = A_{\text{dyn}} \times A_{\text{stat}}$$

$$= A_{\text{dyn}} \times \text{functional det} \times \left(\frac{S_b}{2\pi}\right)^{3/2} e^{-S_b}$$

METHODS

The calculation is done in two stages: [14,15]

1. Lattice Monte Carlo simulations using multicanonical method to simulate probability $P(\theta_{\text{op}})$ distribution and to draw configurations from the exponentially suppressed critical bubble $[\theta_c - \epsilon/2, \theta_c + \epsilon/2]$
2. Numerically evolve these critical bubble configurations in a thermal bath to determine if a configuration tunnels or not and calculate the rate of change of order parameter.



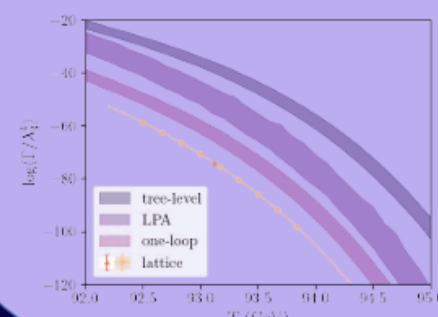
TAKE-HOME BUBBLE

Nucleation rate calculations are inaccurate in perturbation theory, lattice is significantly better.

RESULTS

The main result is the logarithm of the nucleation rate yielding -74.08(5). Comparing our result to the perturbative results – and reweighting our results to different temperatures and taking the infinite-volume limit – we see that the systematic uncertainty is much smaller on the lattice, compared to the perturbative methods. The perturbative methods reflect the different ways of approximating the dynamical prefactor and functional determinant.

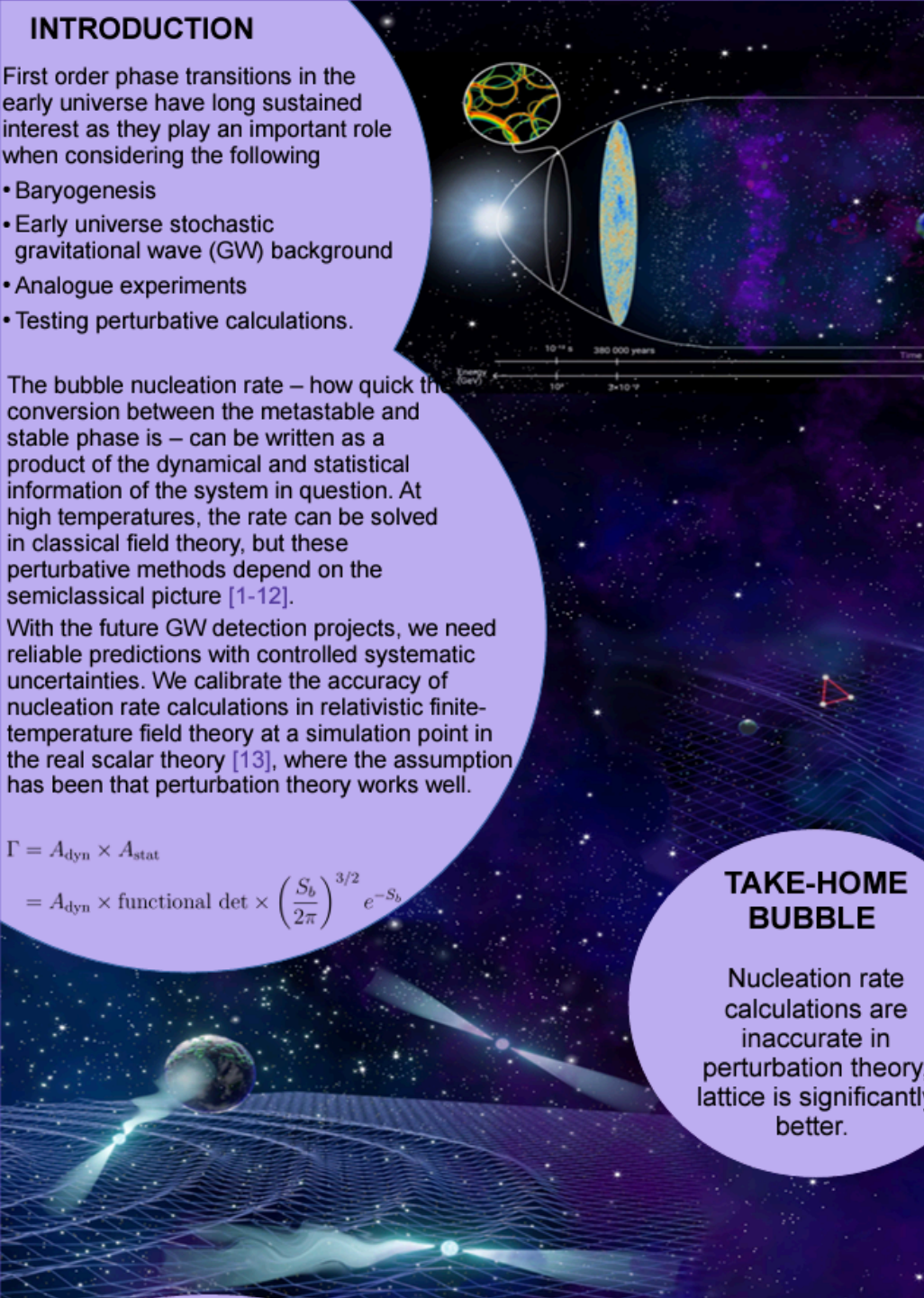
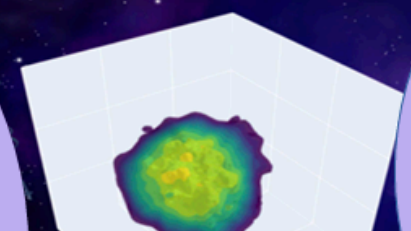
- Tree-level: T⁴
- LPA: local potential approximation, drop imaginary parts
- One-loop: Full one-loop calculation
- Lattice: Triangle – simulation point, Circle – reweighted points



OUTLOOK

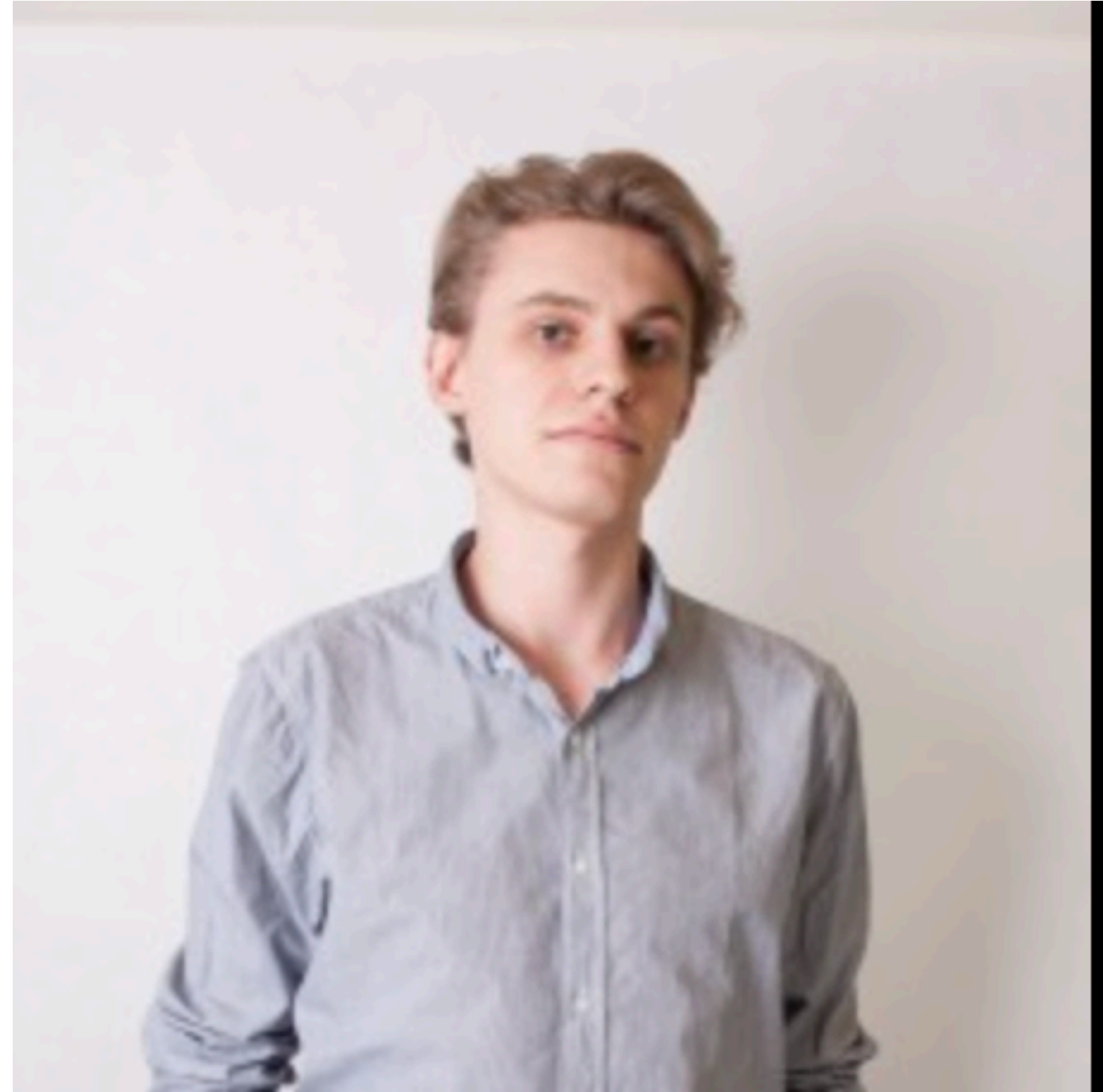
The simulated parameter point was chosen because it is known to work well in perturbation theory, with less than a 1% disagreement in the latent heat at one-loop and 10% at tree-level [13]. However, our results show a disagreement of 20% at one-loop and 100% at tree-level in $|\log \Gamma|$.

- The discrepancy could be explained by the need for higher loop orders, but what if this isn't the case?
- Maybe there are other saddle points that are relevant for the nucleation rate calculation? [16, 17]
- What if the saddle point approximation breaks down? [18, 19]

BUBBLE, BUBBLE, PERTURB & TROUBLE

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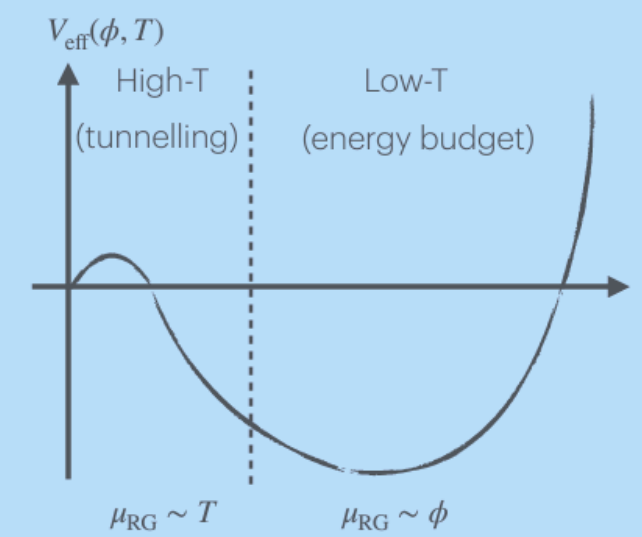
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EFT for supercooled phase transitions in the early Universe

EFT for supercooled phase transitions

Maciej Kierkla (University of Warsaw),
Bogumiła Świeżewska, Tuomas V.I. Tenkanen and Jorinde van de Vis

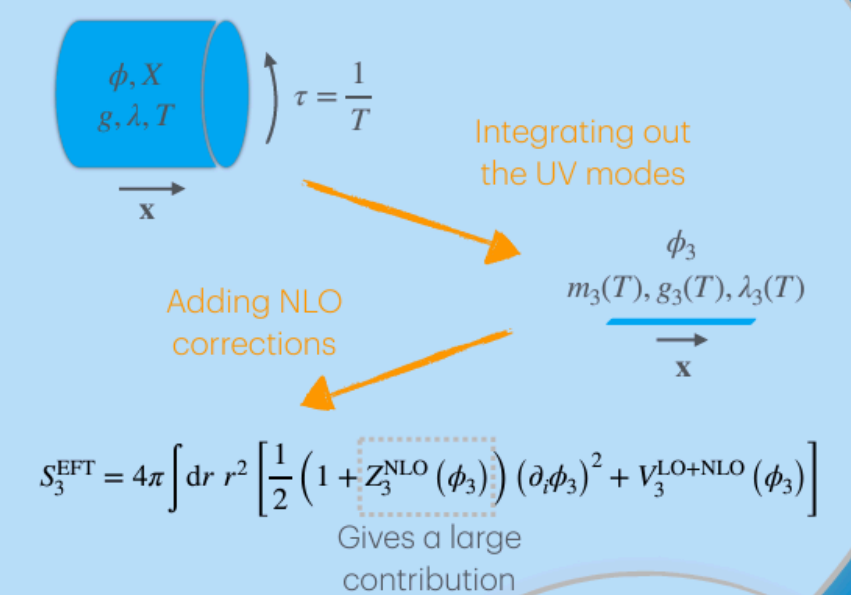
Supercooled PT in a classically scale-invariant model



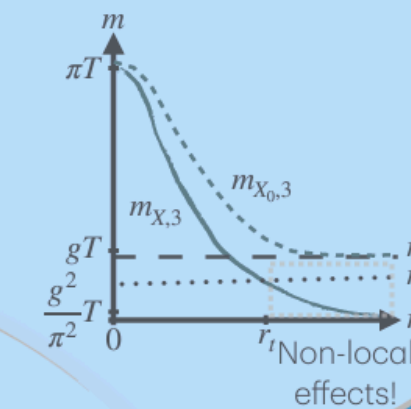
concrete model: $SU(2)_cSM$

$$V_0(\phi) = \frac{1}{4}\lambda_1 h^4 + \frac{1}{4}\lambda_2 \phi^2 h^2 + \frac{1}{4}\lambda_3 \phi^4$$

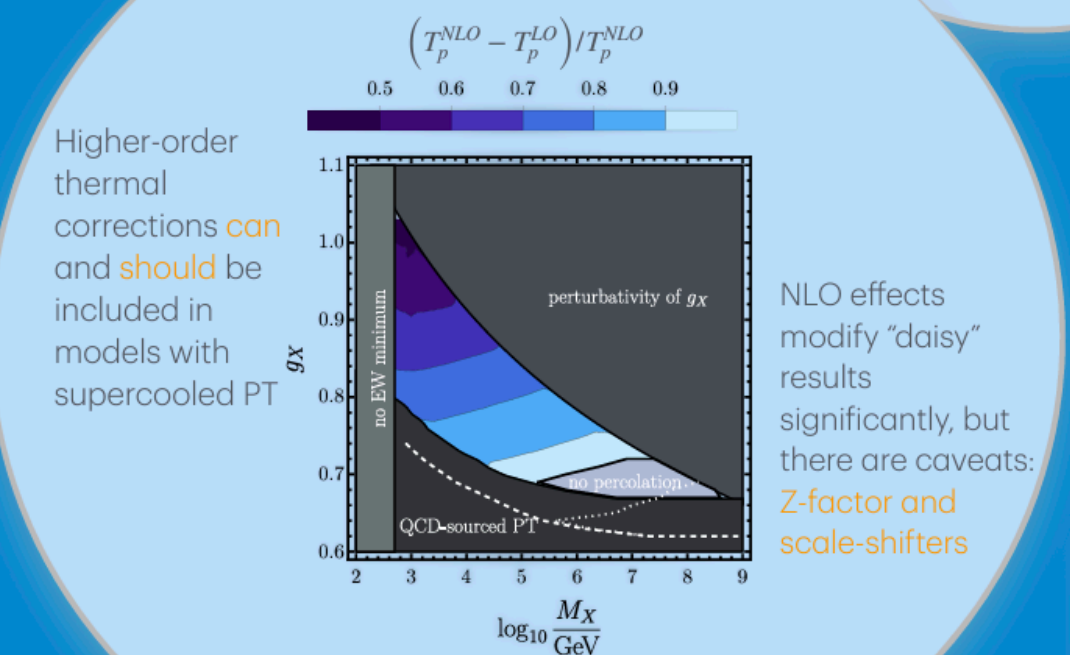
High-temperature dimensional reduction



Scale-shifters



Results



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Lightning Talks

30 Lightning Talks!

	Timekeepers of the Universe: The recent gravitational wave observation and Primordial black holes <i>Antonio Junior Iovino</i>	
	High Frequency Gravitational Wave Bounds from Galactic Neutron Stars <i>500/1-001 - Main Auditorium, CERN</i>	<i>Virgile Dandoy</i> 11:54 - 11:59
12:00	Signatures of ultralight bosons in the orbital eccentricity of binary black holes <i>500/1-001 - Main Auditorium, CERN</i>	<i>Matthias Koschnitzke</i> 11:47 - 11:52
	A model-independent test of gravity from the Weyl potential evolution <i>500/1-001 - Main Auditorium, CERN</i>	<i>Nastassia Grimm</i> 11:54 - 11:59
	Cosmology from ACT DR6 lensing cross-correlated with DES Y3 galaxies <i>500/1-001 - Main Auditorium, CERN</i>	<i>Omar Darwish</i> 11:54 - 11:59
12:00	Probing the LCDM Universe with 21cm intensity mapping surveys <i>500/1-001 - Main Auditorium, CERN</i>	<i>Maria Berti</i> 12:01 - 12:06
	The Hitchhiker's Guide to the Galaxy (peculiar velocities) <i>500/1-001 - Main Auditorium, CERN</i>	<i>Francesco Sorrenti</i> 12:08 - 12:13
	X-rays constraints on sub-GeV Dark Matter <i>500/1-001 - Main Auditorium, CERN</i>	<i>Jordan Koechler</i> 16:17 - 16:22
	Riding the dark matter wave: Novel limits on general dark photons from LISA Pathfinder <i>500/1-001 - Main Auditorium, CERN</i>	<i>Jonas Frerick</i> 16:24 - 16:29
	Global Fits of sub-GeV Dark Matter <i>500/1-001 - Main Auditorium, CERN</i>	<i>Taylor Gray</i> 16:31 - 16:36
	Burst Signals from Axion String Travelling Wave Collisions <i>500/1-001 - Main Auditorium, CERN</i>	<i>Amelia Drew</i> 16:38 - 16:43
	Dynamical constraints on PBH clusters <i>500/1-001 - Main Auditorium, CERN</i>	<i>Francesca Scarcella</i> 16:45 - 16:50
	EFT approach to sterile neutrino dark matter <i>500/1-001 - Main Auditorium, CERN</i>	<i>Stefan Sandner</i> 16:52 - 16:57
	One-loop power spectrum in ultra slow-roll inflation and implications for primordial black hole dark matter <i>500/1-001 - Main Auditorium, CERN</i>	<i>Stavros Garbin Egea</i> 11:54 - 11:59
	Reaction of axion-SU(2) dynamics during inflation <i>500/1-001 - Main Auditorium, CERN</i>	<i>Oksana Iarygina</i> 11:54 - 11:59
	e-invariant inflation <i>500/1-001 - Main Auditorium, CERN</i>	<i>Chiara Cecchini</i> 12:01 - 12:06
	Black holes and gravitational waves from slow phase transitions <i>500/1-001 - Main Auditorium, CERN</i>	<i>Piotr Toczek</i> 12:08 - 12:13
	Leptogenesis: A naturalness-motivated solution to baryon asymmetry <i>500/1-001 - Main Auditorium, CERN</i>	<i>Ansh Bhatnagar</i> 12:15 - 12:20
	Gravitational wave spectral distortions from dark sector anisotropies <i>500/1-001 - Main Auditorium, CERN</i>	<i>Nicklas Ramberg</i> 12:22 - 12:27
	Status of Direct Determination of Solar Neutrino Fluxes after Borexino <i>500/1-001 - Main Auditorium, CERN</i>	<i>Joao Paulo Pinheiro</i> 16:15 - 16:20
	White dwarf cooling through neutrinos and $L_{\mu} - L_{\tau}$ <i>500/1-001 - Main Auditorium, CERN</i>	<i>Jaime Hoefken Zink</i> 16:22 - 16:27
	Stochastic modelling of cosmic ray sources sped up <i>500/1-001 - Main Auditorium, CERN</i>	<i>Anton Stall</i> 16:29 - 16:34
	Constraints on the Cosmic Neutrino Background from NGC1068 <i>500/1-001 - Main Auditorium, CERN</i>	<i>Jack Franklin</i> 16:35 - 16:40
	New bounds on monopole abundance from cosmic magnetic fields <i>500/1-001 - Main Auditorium, CERN</i>	<i>Daniele Perri</i> 16:43 - 16:48
	Fast particle acceleration in 3D hybrid simulations of quasi-perpendicular shocks <i>500/1-001 - Main Auditorium, CERN</i>	<i>Luca Orusa</i> 16:50 - 16:55

Lightning Talks, who voted?



EuCAPT Steering committee



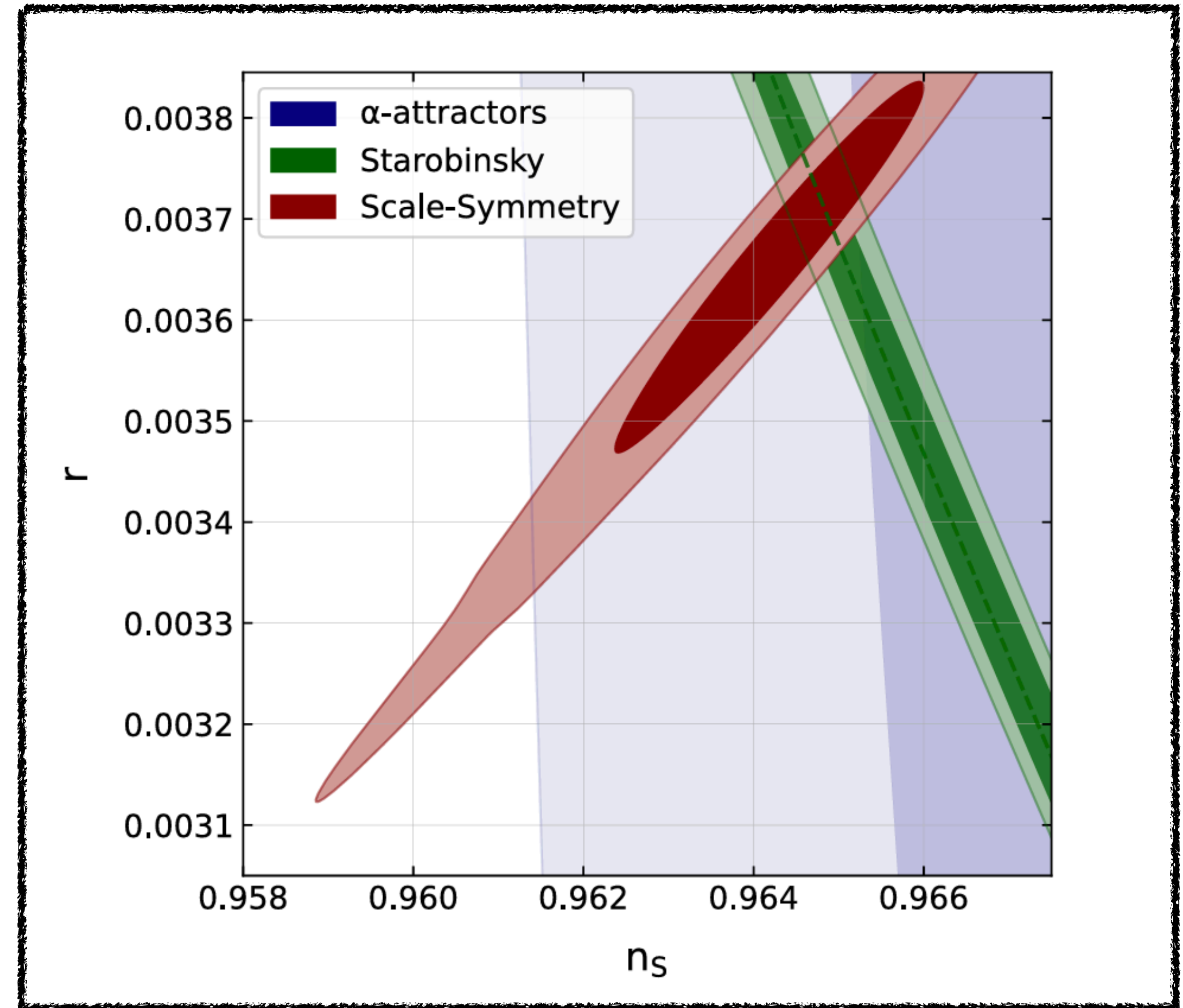
EuCAPT local organizing committee

Chiara Cecchini



(University of Trento)

Scale-invariant inflation

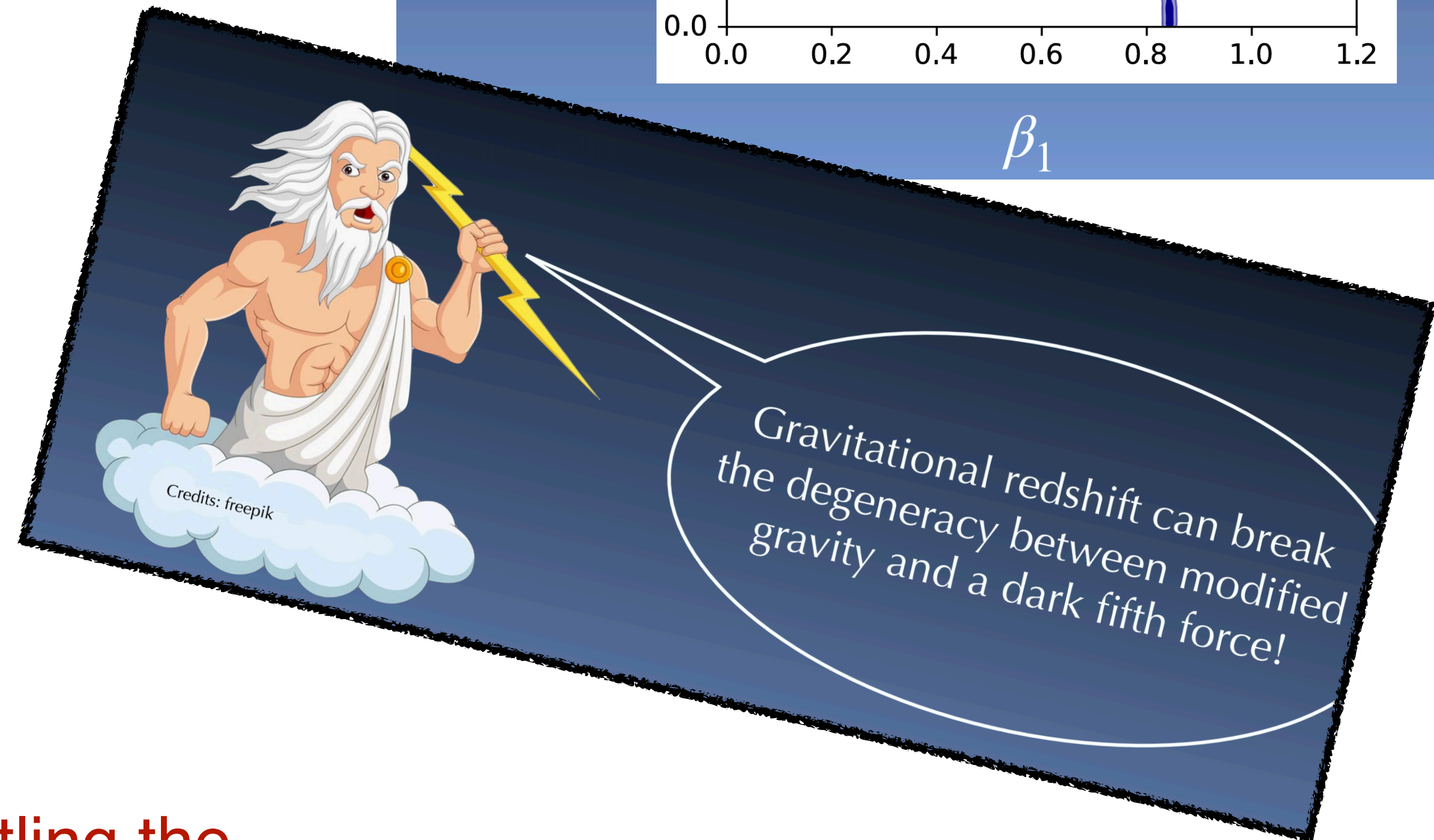
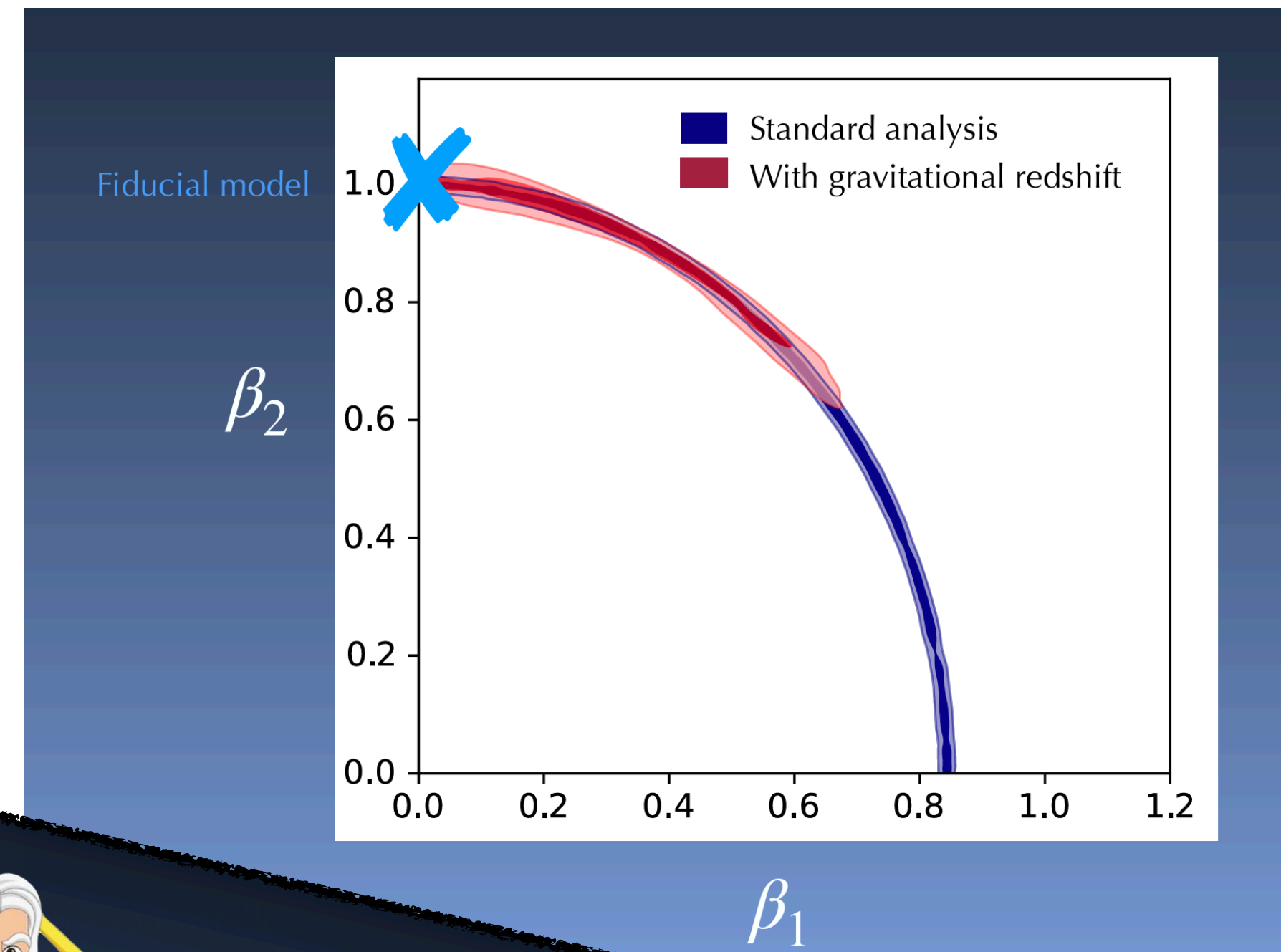


Sveva Castello

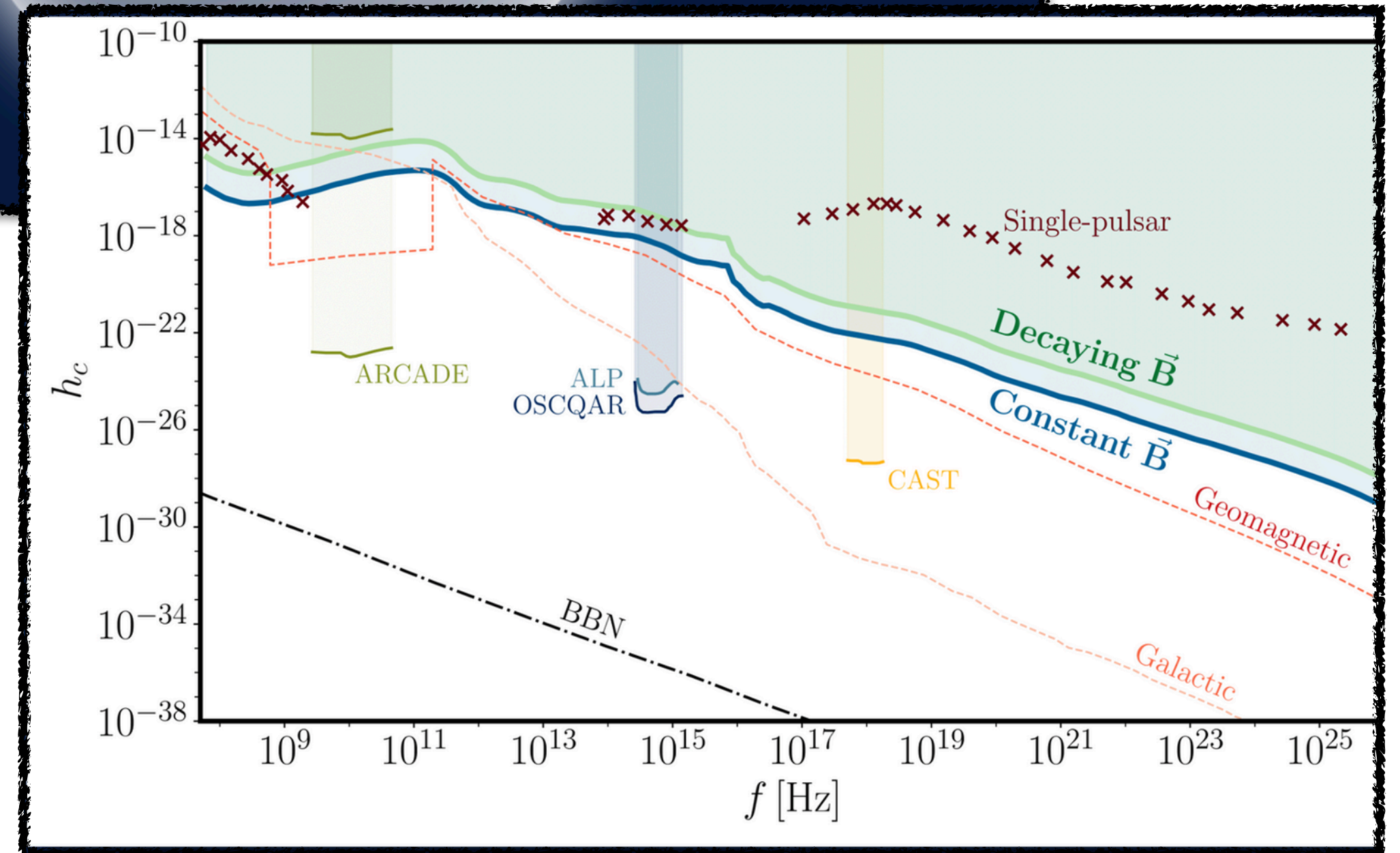
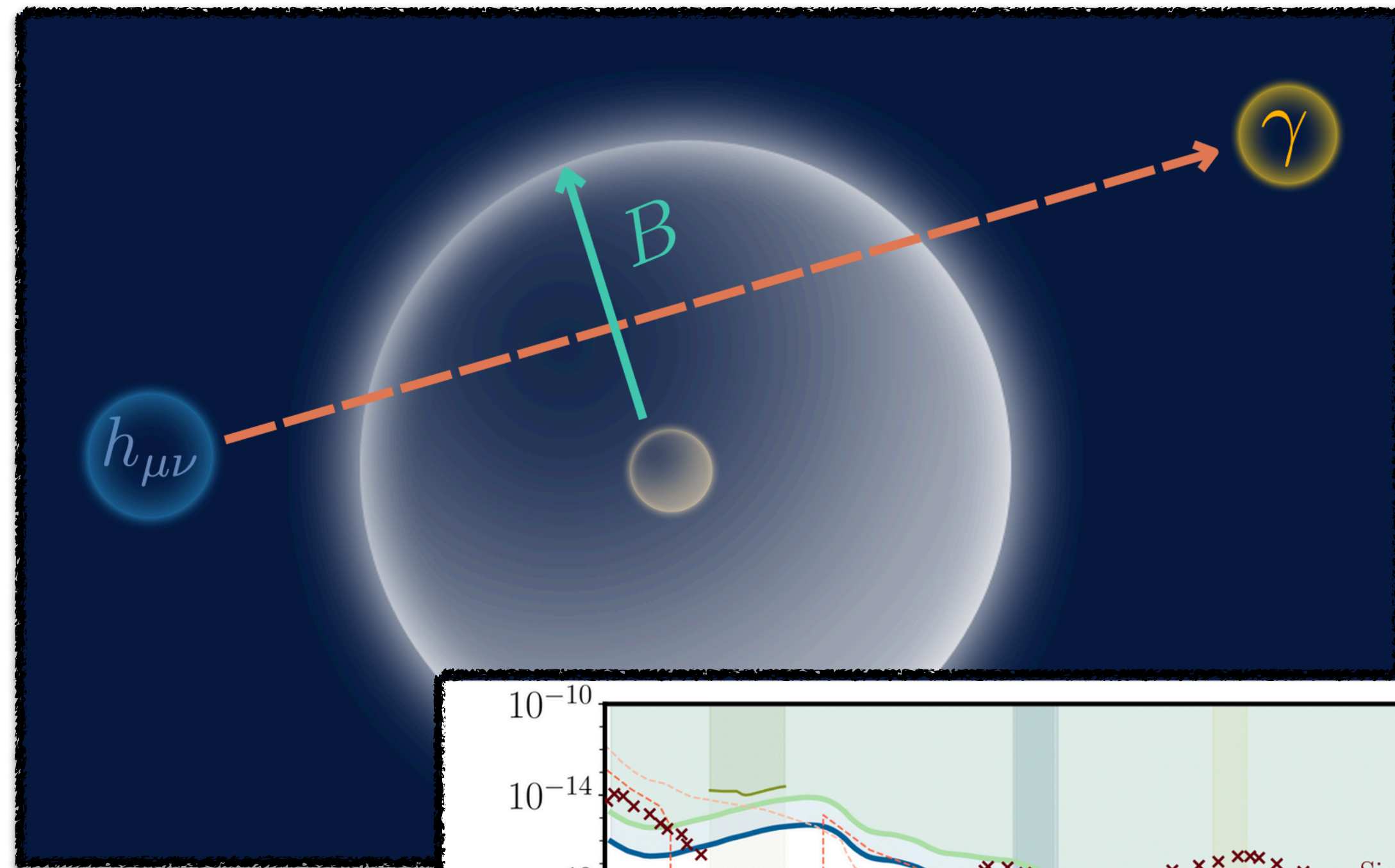


(University of Geneva)

Modified Gravity vs Dark Interactions: Settling the Dispute through the Distortion of Time



Virgile Dandoy



(Universite Libre de Bruxelles)

High Frequency Gravitational Wave Bounds from Galactic Neutron Stars