3rd EuCAPT Symposium

Poster and Lightning talk Prizes

Posters

- **45 posters presented, online + in person**

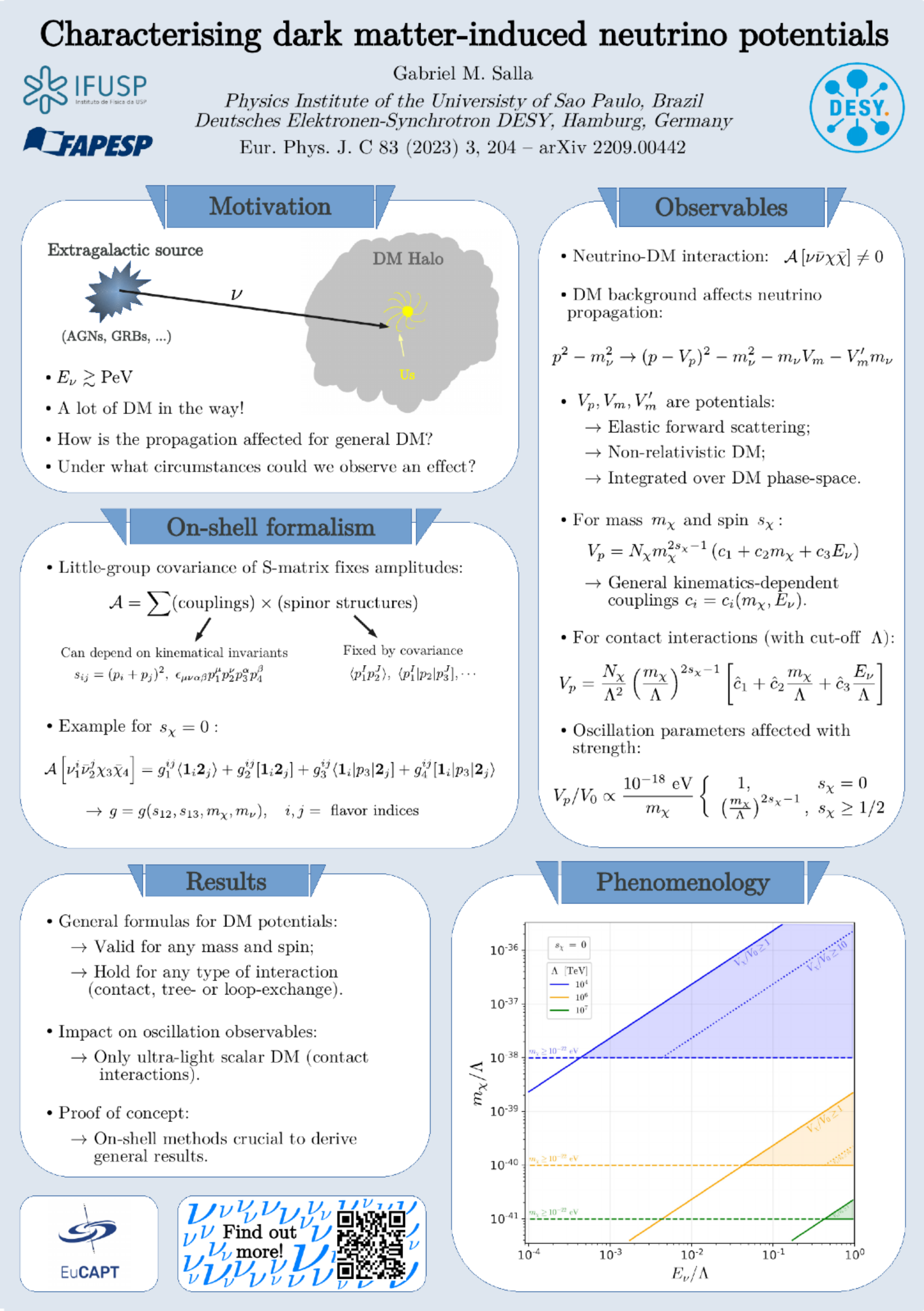
(a subset taken from mattermost)

37

Gabriel Massoni Salla

University of Sao Paulo and DESY

Characterizing dark matter-induced neutrino potentials



Characterising dark matter-induced neutrino potentials

Gabriel M. Salla
Physics Institute of the University of Sao Paulo, Brazil
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Eur. Phys. J. C 83 (2023) 3, 204 – arXiv 2209.00442

Motivation

- $E_\nu \gtrsim$ PeV
- A lot of DM in the way!
- How is the propagation affected for general DM?
- Under what circumstances could we observe an effect?

On-shell formalism

- Little-group covariance of S-matrix fixes amplitudes:

$$\mathcal{A} = \sum (\text{couplings}) \times (\text{spinor structures})$$

Can depend on kinematical invariants
$s_{ij} = (p_i + p_j)^2,\ \epsilon_{\mu\nu\alpha\beta} p_1^\mu p_2^\nu p_3^\alpha p_4^\beta$

Fixed by covariance
$\langle p_1^I p_2^J \rangle,\ \langle p_1^I | p_2 | p_3^J], \cdots$

- Example for $s_\chi = 0$:

$$\mathcal{A}\left[\nu_1^i \bar{\nu}_2^j \chi_3 \bar{\chi}_4\right] = g_1^{ij} \langle \mathbf{1}_i \mathbf{2}_j \rangle + g_2^{ij} [\mathbf{1}_i \mathbf{2}_j] + g_3^{ij} \langle \mathbf{1}_i | p_3 | \mathbf{2}_j] + g_4^{ij} [\mathbf{1}_i | p_3 | \mathbf{2}_j \rangle$$

$$\to g = g(s_{12}, s_{13}, m_\chi, m_\nu), \quad i, j = \text{ flavor indices}$$

Results

- General formulas for DM potentials:
  - → Valid for any mass and spin;
  - → Hold for any type of interaction (contact, tree- or loop-exchange).
- Impact on oscillation observables:
  - → Only ultra-light scalar DM (contact interactions).
- Proof of concept:
  - → On-shell methods crucial to derive general results.

EuCAPT

Find out more!

Observables

- Neutrino-DM interaction: $\mathcal{A}[\nu\bar{\nu}\chi\bar{\chi}] \neq 0$
- DM background affects neutrino propagation:

$$p^2 - m_\nu^2 \to (p - V_p)^2 - m_\nu^2 - m_\nu V_m - V'_m m_\nu$$

- V_p, V_m, V'_m are potentials:
  - → Elastic forward scattering;
  - → Non-relativistic DM;
  - → Integrated over DM phase-space.
- For mass m_χ and spin s_χ :

$$V_p = N_\chi m_\chi^{2s_\chi - 1} (c_1 + c_2 m_\chi + c_3 E_\nu)$$

  - → General kinematics-dependent couplings $c_i = c_i(m_\chi, E_\nu)$.
- For contact interactions (with cut-off Λ):

$$V_p = \frac{N_\chi}{\Lambda^2} \left(\frac{m_\chi}{\Lambda}\right)^{2s_\chi - 1} \left[\hat{c}_1 + \hat{c}_2 \frac{m_\chi}{\Lambda} + \hat{c}_3 \frac{E_\nu}{\Lambda}\right]$$

- Oscillation parameters affected with strength:

$$V_p/V_0 \propto \frac{10^{-18}\ \text{eV}}{m_\chi} \begin{cases} 1, & s_\chi = 0 \\ \left(\frac{m_\chi}{\Lambda}\right)^{2s_\chi - 1}, & s_\chi \geq 1/2 \end{cases}$$

Phenomenology

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Liina Chung-Jukko

King’s College London

The electromagnetic weight loss of axion stars

The electromagnetic weight loss of axion stars

arXiv: 2302.10100 | Liina Chung-Jukko* et al.
*liina.jukko@kcl.ac.uk

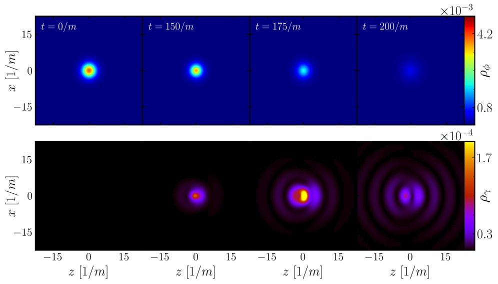
Axion star

(Seidel & Suen, 1991)

An axion star is a **self-gravitating compact object** with a finite mass, composed of the axion, a particle **dark matter** candidate. It is a solution of the Einstein-Klein-Gordon equations with a time-periodic metric, in contrast to boson and Proca stars, which have a static metric. In this work, the axion real scalar field is coupled to the electromagnetic field strength tensor.

KEY QUESTION

What happens when a stable axion star interacts with ambient electromagnetic radiation in full general relativity?



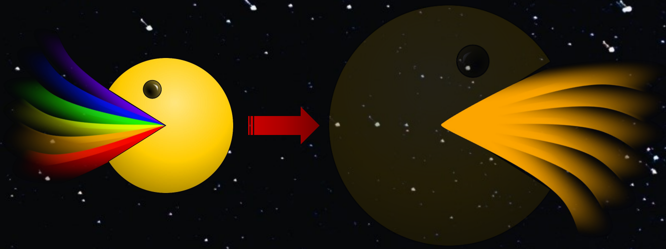
Theory

$$S = \int d^4x \sqrt{-g}\left[\frac{R}{16\pi G} - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m^2\phi^2 - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{g_{a\gamma}}{4}\phi F_{\mu\nu}\tilde{F}^{\mu\nu}\right]$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu, \qquad \tilde{F}^{\mu\nu} = \frac{1}{2\sqrt{-g}}\epsilon^{\mu\nu\rho\sigma}F_{\rho\sigma}$$

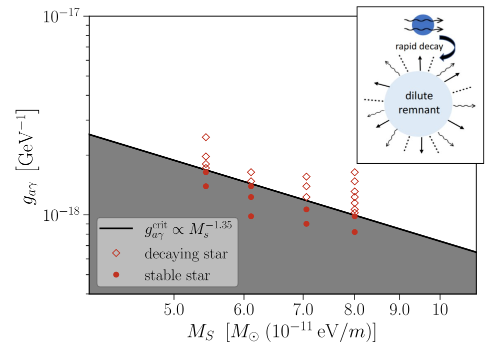
The system of the coupled real scalar ϕ and electromagnetism $F_{\mu\nu}$ is solved using **numerical relativity** on **GRChombo**[1]. We consider compact axion stars, with masses scaling as $\sim m_{Pl}^2/m$, where m is the scalar field mass. The initial conditions for the axion star are obtained from previous numerical work[2], and the electromagnetic radiation is set as a plane wave with subdominant energy to the star, modelling an EM seed from ambient radiation.

It has been demonstrated that parametric resonance can generate photons from axion stars without the need for an external magnetic field[3], which is often used in axion direct detection experiments. The basic idea behind parametric resonance is that the oscillating axion star solution provides a driving force to excite photons from the EM field. In this work, parametric resonance creating photons from axion stars is observed for the first time in full general relativity.



Critical coupling

Simulations were run for different axion star masses to confirm the existence of the critical coupling $g_{a\gamma}^{crit}$, below which the characteristic frequency scale of the star does not match the parametric resonance band set by the axion-photon coupling, and hence the star stays stable. Our results restrict the existence of compact axion stars, as the decay process for these stars (above the critical coupling) is estimated to happen within seconds assuming only the Cosmic Microwave Background photons.



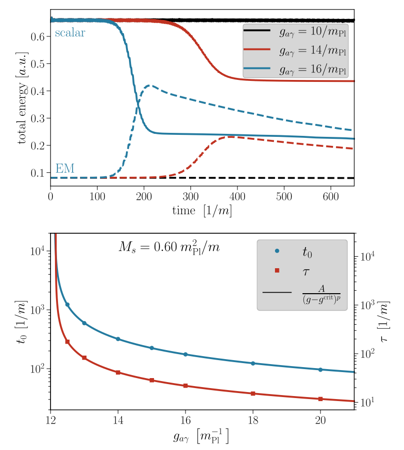
Results

In our simulations, the axion star emits a strong burst of electromagnetic radiation for axion-photon couplings $g_{a\gamma}$ larger than a critical value. This emission carries away energy from the star, resulting in a much lighter and less compact remnant, illustrated in the figures above. The timescale for the emission to start (t_0) and for the duration of the burst (τ) are quantized through a fit to the total electromagnetic energy in our simulation box. Sampling these timescales for several coupling values, the existence of a critical value becomes clear (see figures below).

Why does the star decay?

We postulate that the decay is due to parametric resonance, which explains why the star doesn't decay immediately: it first needs to drive energy into the EM field through its oscillations. This is further confirmed through the power spectrum of the emitted radiation, which peaks at the characteristic frequency of the star, indicating that it is the inherent oscillations of the scalar field that are behind the decay mechanism.

When axion stars go on an electromagnetic diet, they lose a lot of mass....



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[1] K. Clough, P. Figueras, H. Finkel, M. Kunesch, E. A. Lim, and S. Tunyasuvunakool, GRChombo : Numerical Relativity with Adaptive Mesh Refinement, Class. Quant. Grav. 32, 245011 (2015), arXiv:1503.03436

[2] T. Helfer, E. A. Lim, M. A. G. Garcia, and M. A. Amin, Gravitational Wave Emission from Collisions of Compact Scalar Solitons, Phys. Rev. D 99, 044046 (2019), arXiv:1802.06733

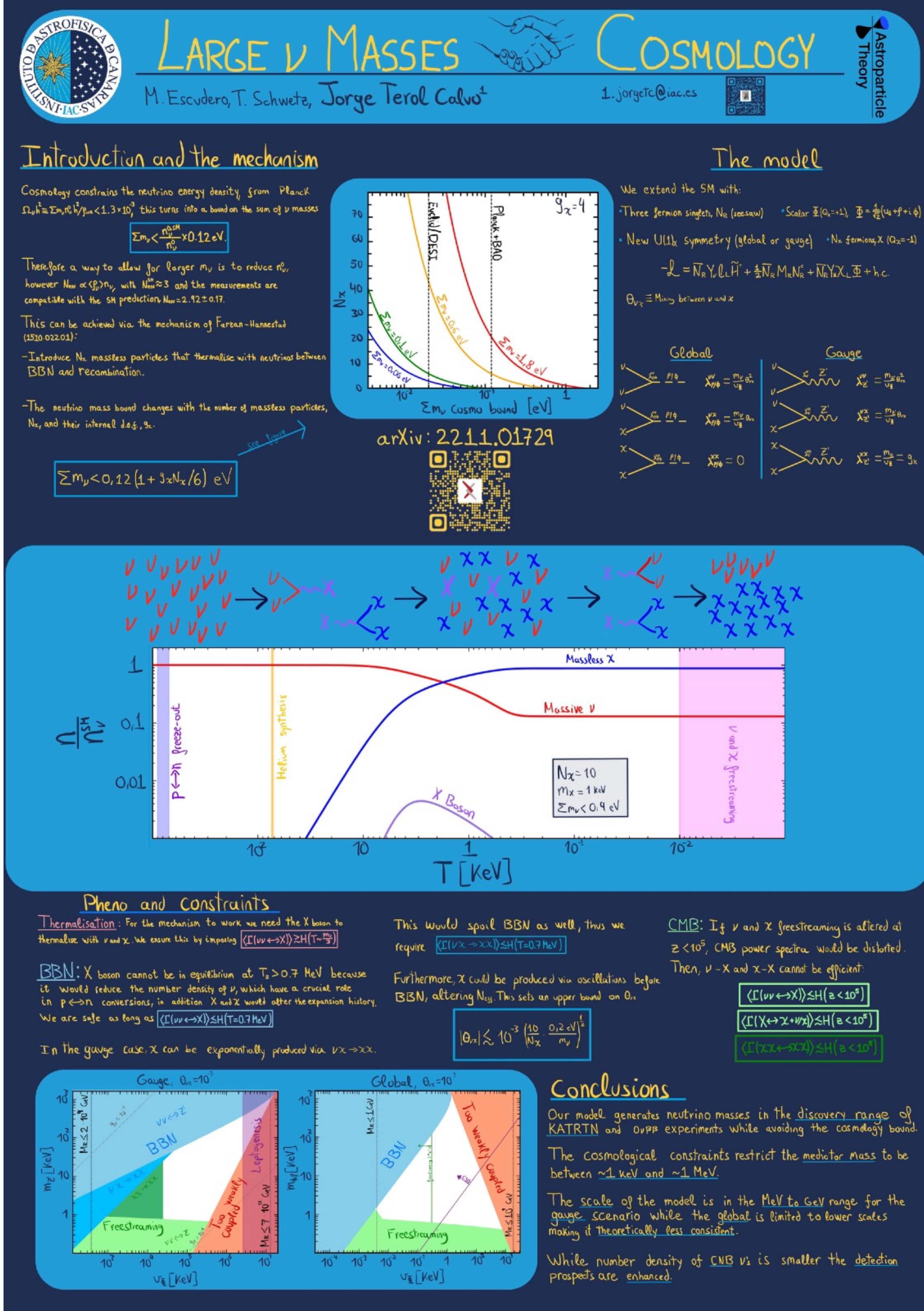
[3] D. G. Levkov, A. G. Panin, and I. I. Tkachev, Radio-emission of axion stars, Phys. Rev. D 102, 023501 (2020), arXiv:2004.05179

23

Jorge Terol Calvo

Instituto de Astrofisica de Canarias

Large Neutrino Masses meet Cosmology



LARGE ν MASSES COSMOLOGY

M. Escudero, T. Schwetz, Jorge Terol Calvo[1]

[1] jorgetc@iac.es

Introduction and the mechanism

Cosmology constrains the neutrino energy density, from Planck $\Omega_\nu h^2 \equiv \sum m_\nu n_\nu^0 h^2/\rho_{crit} < 1.3\times10^{-3}$, this turns into a bound on the sum of ν masses

$$\boxed{\sum m_\nu < \frac{n_\nu^{0,SM}}{n_\nu^0} \times 0.12\,\text{eV}}$$

Therefore a way to allow for larger m_ν is to reduce n_ν^0, however $N_{eff} \propto \langle \rho_\nu \rangle n_\nu$, with $N_{eff}^{SM} \approx 3$ and the measurements are compatible with the SM prediction $N_{eff} = 2.92 \pm 0.17$.

This can be achieved via the mechanism of Farzan-Hannestad (1510.02201):

- Introduce N_χ massless particles that thermalise with neutrinos between BBN and recombination.

- The neutrino mass bound changes with the number of massless particles, N_χ, and their internal d.o.f., g_χ.

see figure

$$\boxed{\sum m_\nu < 0{,}12\,(1 + g_\chi N_\chi/6)\ \text{eV}}$$

arXiv: 2211.01729

The model

We extend the SM with:

- Three fermion singlets, N_R (seesaw)
- Scalar $\Phi\,(Q_\chi=+1)$, $\Phi = \frac{1}{\sqrt{2}}(v_\Phi + \rho + i\phi)$
- New $U(1)_\chi$ symmetry (global or gauge)
- N_χ fermions, $\chi\,(Q_\chi=-1)$

$$-\mathcal{L} = \overline{N_R} Y_\nu \ell_L \tilde{H}^\dagger + \tfrac{1}{2}\overline{N_R} M_R N_R^c + \overline{N_R} Y_\chi \chi_L \Phi + \text{h.c.}$$

$\theta_{\nu\chi} \equiv$ Mixing between ν and χ

Global

$\lambda^{\nu\nu}_{\rho/\phi} = \frac{m_\nu}{v_\Phi}\theta_{\nu\chi}^2$

$\lambda^{\nu\chi}_{\rho/\phi} = \frac{m_\nu}{v_\Phi}\theta_{\nu\chi}$

$\lambda^{\chi\chi}_{\rho/\phi} = 0$

Gauge

$\lambda^{\nu\nu}_{Z'} = \frac{m_{Z'}}{v_\Phi}\theta_{\nu\chi}^2$

$\lambda^{\nu\chi}_{Z'} = \frac{m_{Z'}}{v_\Phi}\theta_{\nu\chi}$

$\lambda^{\chi\chi}_{Z'} = \frac{m_{Z'}}{v_\Phi} = g_\chi$

Pheno and constraints

Thermalisation: For the mechanism to work we need the X boson to thermalise with ν and χ. We ensure this by imposing $\boxed{\langle\Gamma(\nu\nu \leftrightarrow X)\rangle \gtrsim H(T \sim \frac{m_X}{3})}$

BBN: X boson cannot be in equilibrium at $T_\gamma > 0.7$ MeV because it would reduce the number density of ν, which have a crucial role in $p \leftrightarrow n$ conversions, in addition X and χ would alter the expansion history. We are safe as long as $\boxed{\langle\Gamma(\nu\nu \leftrightarrow X)\rangle \lesssim H(T = 0.7\,\text{MeV})}$

In the gauge case, χ can be exponentially produced via $\nu\chi \to \chi\chi$.

This would spoil BBN as well, thus we require $\boxed{\langle\Gamma(\nu\chi \to \chi\chi)\rangle \lesssim H(T = 0.7\,\text{MeV})}$

Furthermore, χ could be produced via oscillations before BBN, altering N_{eff}. This sets an upper bound on $\theta_{\nu\chi}$

$$\boxed{|\theta_{\nu\chi}| \lesssim 10^{-3}\left(\frac{10}{N_\chi}\cdot\frac{0{,}2\,\text{eV}}{m_\nu}\right)^{\frac{1}{2}}}$$

CMB: If ν and χ freestreaming is altered at $z < 10^5$, CMB power spectra would be distorted. Then, ν-X and χ-X cannot be efficient:

$$\boxed{\langle\Gamma(\nu\nu \leftrightarrow X)\rangle \lesssim H(z < 10^5)}$$

$$\boxed{\langle\Gamma(X \leftrightarrow \chi + \nu/\chi)\rangle \lesssim H(z < 10^5)}$$

$$\boxed{\langle\Gamma(\chi\chi \leftrightarrow \chi\chi)\rangle \lesssim H(z < 10^5)}$$

Conclusions

Our model generates neutrino masses in the discovery range of KATRIN and $0\nu\beta\beta$ experiments while avoiding the cosmology bound.

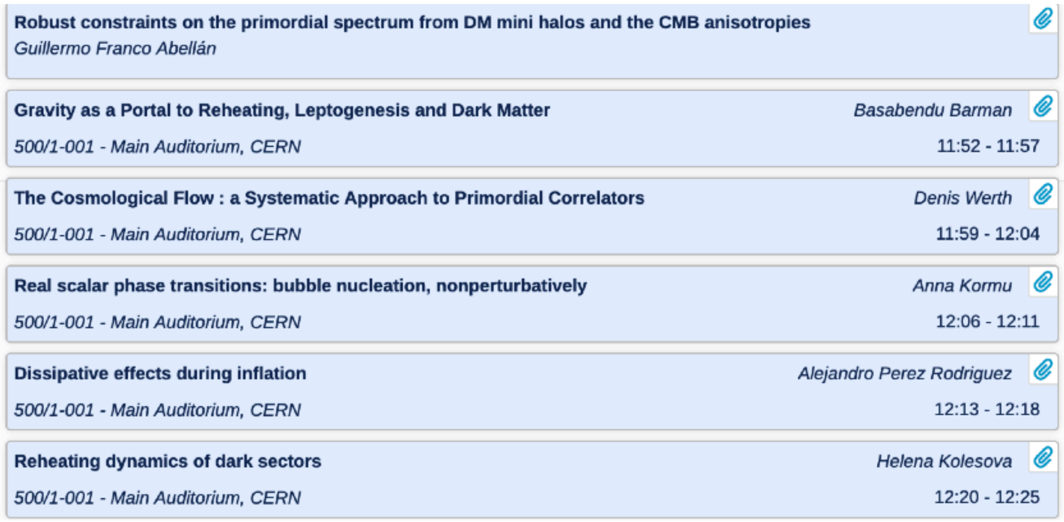
The cosmological constraints restrict the mediator mass to be between ~1 keV and ~1 MeV.

The scale of the model is in the MeV to GeV range for the gauge scenario while the global is limited to lower scales making it theoretically less consistent.

While number density of CNB ν's is smaller the detection prospects are enhanced.

Lightning Talks

30 Lightning Talks presented


Robust constraints on the primordial spectrum from DM mini halos and the CMB anisotropies
Guillermo Franco Abellán

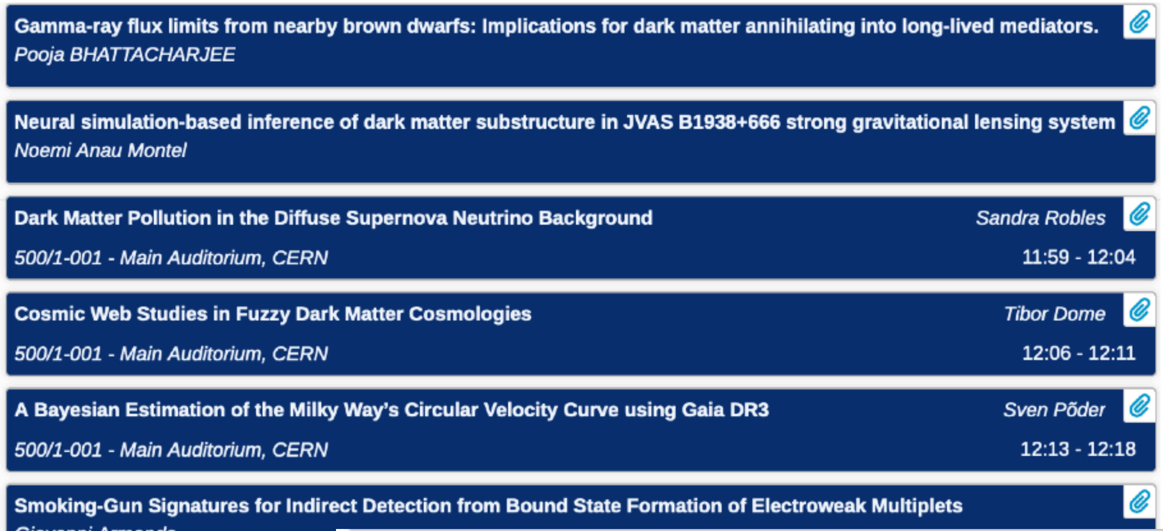
Gravity as a Portal to Reheating, Leptogenesis and Dark Matter *Basabendu Barman*
500/1-001 - Main Auditorium, CERN 11:52 - 11:57

The Cosmological Flow : a Systematic Approach to Primordial Correlators *Denis Werth*
500/1-001 - Main Auditorium, CERN 11:59 - 12:04

Real scalar phase transitions: bubble nucleation, nonperturbatively *Anna Kormu*
500/1-001 - Main Auditorium, CERN 12:06 - 12:11

Dissipative effects during inflation *Alejandro Perez Rodriguez*
500/1-001 - Main Auditorium, CERN 12:13 - 12:18

Reheating dynamics of dark sectors *Helena Kolesova*
500/1-001 - Main Auditorium, CERN 12:20 - 12:25


Gamma-ray flux limits from nearby brown dwarfs: Implications for dark matter annihilating into long-lived mediators.
Pooja BHATTACHARJEE

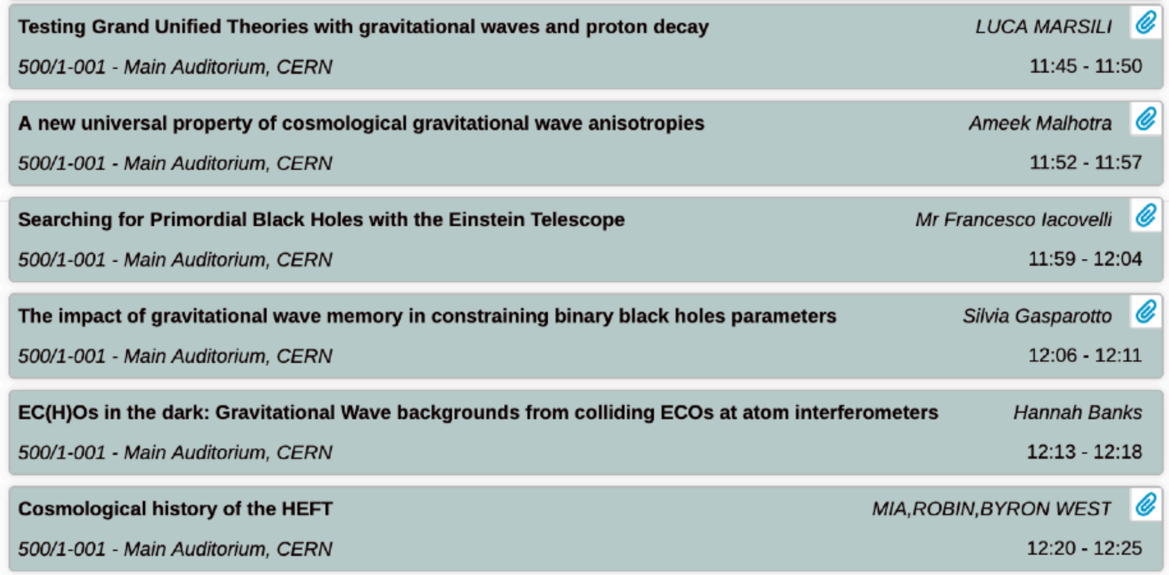
Neural simulation-based inference of dark matter substructure in JVAS B1938+666 strong gravitational lensing system
Noemi Anau Montel

Dark Matter Pollution in the Diffuse Supernova Neutrino Background *Sandra Robles*
500/1-001 - Main Auditorium, CERN 11:59 - 12:04

Cosmic Web Studies in Fuzzy Dark Matter Cosmologies *Tibor Dome*
500/1-001 - Main Auditorium, CERN 12:06 - 12:11

A Bayesian Estimation of the Milky Way's Circular Velocity Curve using Gaia DR3 *Sven Põder*
500/1-001 - Main Auditorium, CERN 12:13 - 12:18

Smoking-Gun Signatures for Indirect Detection from Bound State Formation of Electroweak Multiplets
Giovanni Armando


Testing Grand Unified Theories with gravitational waves and proton decay *LUCA MARSILI*
500/1-001 - Main Auditorium, CERN 11:45 - 11:50

A new universal property of cosmological gravitational wave anisotropies *Ameek Malhotra*
500/1-001 - Main Auditorium, CERN 11:52 - 11:57

Searching for Primordial Black Holes with the Einstein Telescope *Mr Francesco Iacovelli*
500/1-001 - Main Auditorium, CERN 11:59 - 12:04

The impact of gravitational wave memory in constraining binary black holes parameters *Silvia Gasparotto*
500/1-001 - Main Auditorium, CERN 12:06 - 12:11

EC(H)Os in the dark: Gravitational Wave backgrounds from colliding ECOs at atom interferometers *Hannah Banks*
500/1-001 - Main Auditorium, CERN 12:13 - 12:18

Cosmological history of the HEFT *MIA,ROBIN,BYRON WEST*
500/1-001 - Main Auditorium, CERN 12:20 - 12:25


Impact of Neutrino Decay on the Cosmic Neutrino Background *Leonardo Jose Ferreira Leite*
500/1-001 - Main Auditorium, CERN 16:15 - 16:20

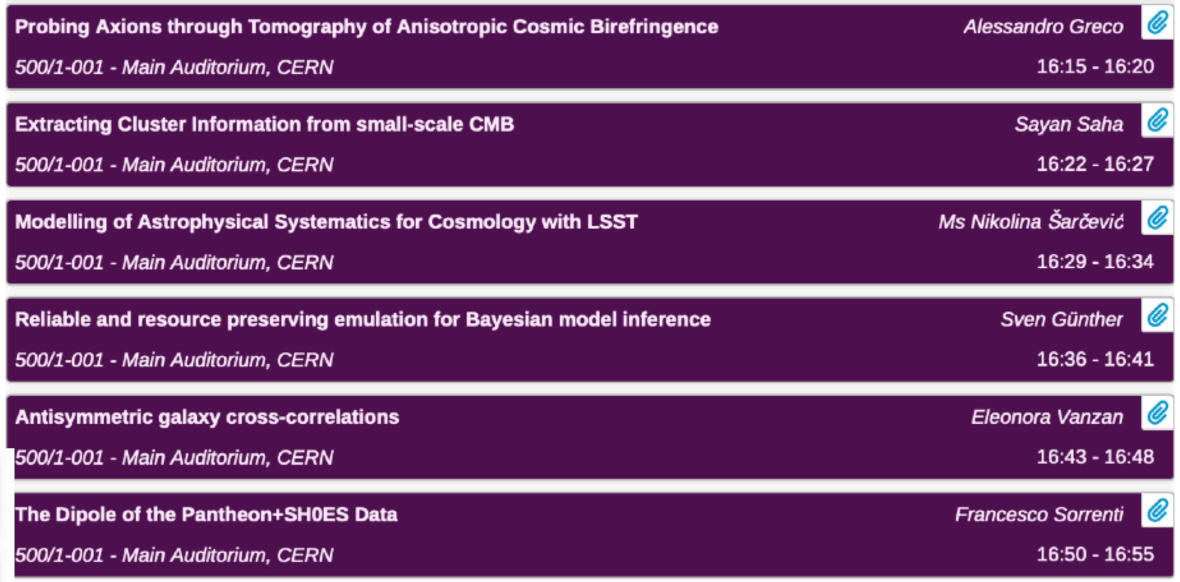
A First Look at Sky Anosotripies of High-Energy Neutrino Flavours *Bernanda Telalovic*
500/1-001 - Main Auditorium, CERN 16:22 - 16:27

Dark Sectors and MiniBooNE Low Energy Excess *Jaime Hoefken Zink*
500/1-001 - Main Auditorium, CERN 16:29 - 16:34

Space Plasma Instabilities Resolve GeV-TeV Tension and Constrain Light Axions *Oindrila Ghosh*
500/1-001 - Main Auditorium, CERN 16:36 - 16:41

The origin of ANITA-IV events from the sinergies with IceCube *Antoni Bertólez-Martínez*
500/1-001 - Main Auditorium, CERN 16:43 - 16:48

CR antinuclei predictions and their detectability in the next years *Pedro De la Torre Luque*
500/1-001 - Main Auditorium, CERN 16:50 - 16:55


Probing Axions through Tomography of Anisotropic Cosmic Birefringence *Alessandro Greco*
500/1-001 - Main Auditorium, CERN 16:15 - 16:20

Extracting Cluster Information from small-scale CMB *Sayan Saha*
500/1-001 - Main Auditorium, CERN 16:22 - 16:27

Modelling of Astrophysical Systematics for Cosmology with LSST *Ms Nikolina Šarčević*
500/1-001 - Main Auditorium, CERN 16:29 - 16:34

Reliable and resource preserving emulation for Bayesian model inference *Sven Günther*
500/1-001 - Main Auditorium, CERN 16:36 - 16:41

Antisymmetric galaxy cross-correlations *Eleonora Vanzan*
500/1-001 - Main Auditorium, CERN 16:43 - 16:48

The Dipole of the Pantheon+SH0ES Data *Francesco Sorrenti*
500/1-001 - Main Auditorium, CERN 16:50 - 16:55

Lightning Talks, who voted?

- **EuCAPT Steering committee**

- **EuCAPT local organizing committee**

EuCAPT

Sven Günther

RWTH Aachen University

Reliable and resource preserving emulation for Bayesian model inference

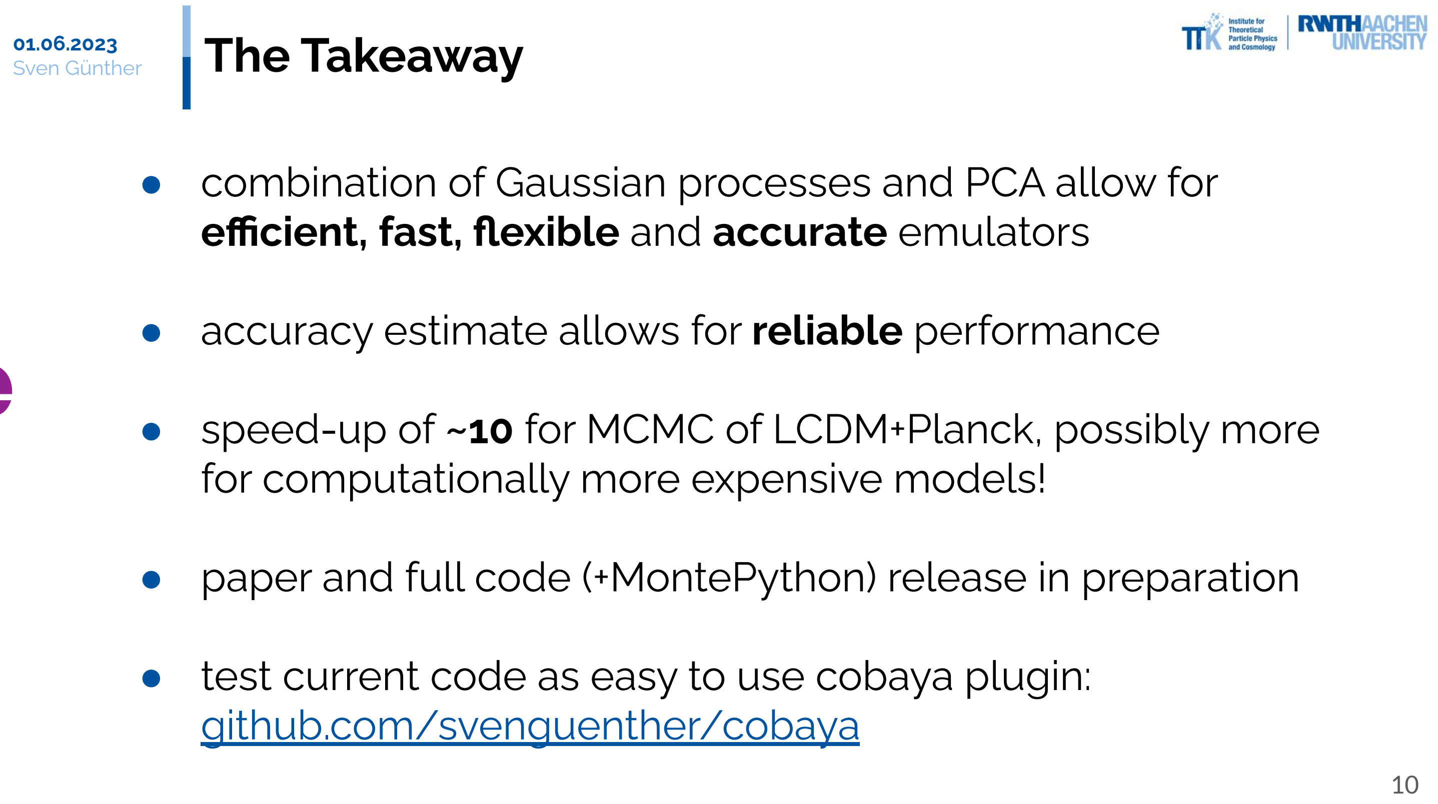
Third EuCAPT Annual Symposium

Sven Günther

June 1st 2023

Reliable and resource preserving emulation for Bayesian model inference

(RWTH Aachen CLAIX-18 Computing Cluster)



01.06.2023
Sven Günther

The Takeaway

- combination of Gaussian processes and PCA allow for **efficient**, **fast**, **flexible** and **accurate** emulators
- accuracy estimate allows for **reliable** performance
- speed-up of ~**10** for MCMC of LCDM+Planck, possibly more for computationally more expensive models!
- paper and full code (+MontePython) release in preparation
- test current code as easy to use cobaya plugin: github.com/svenguenther/cobaya

Toni Bertólez-Martínez

Universitat de Barcelona

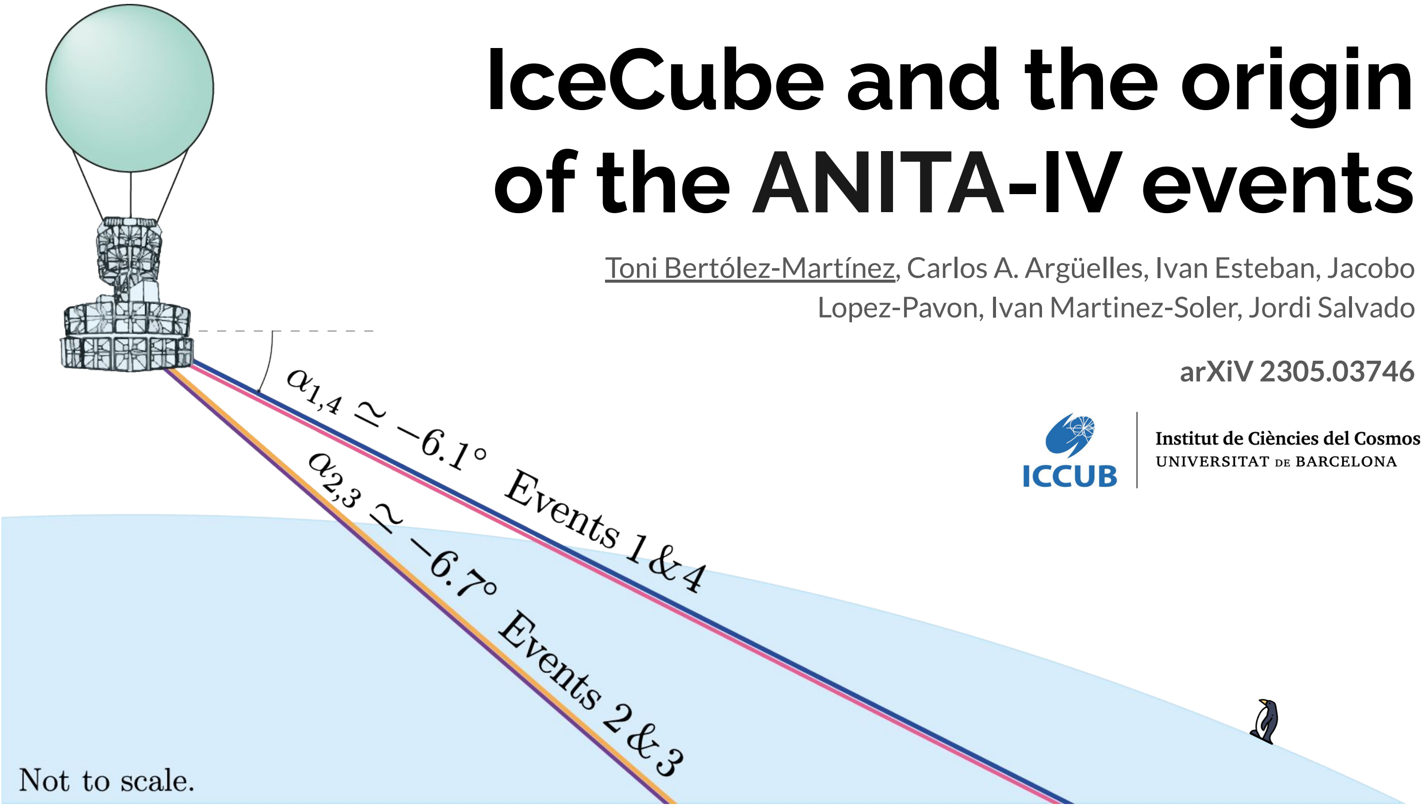
The origin of ANITA-IV events from the synergies with IceCube

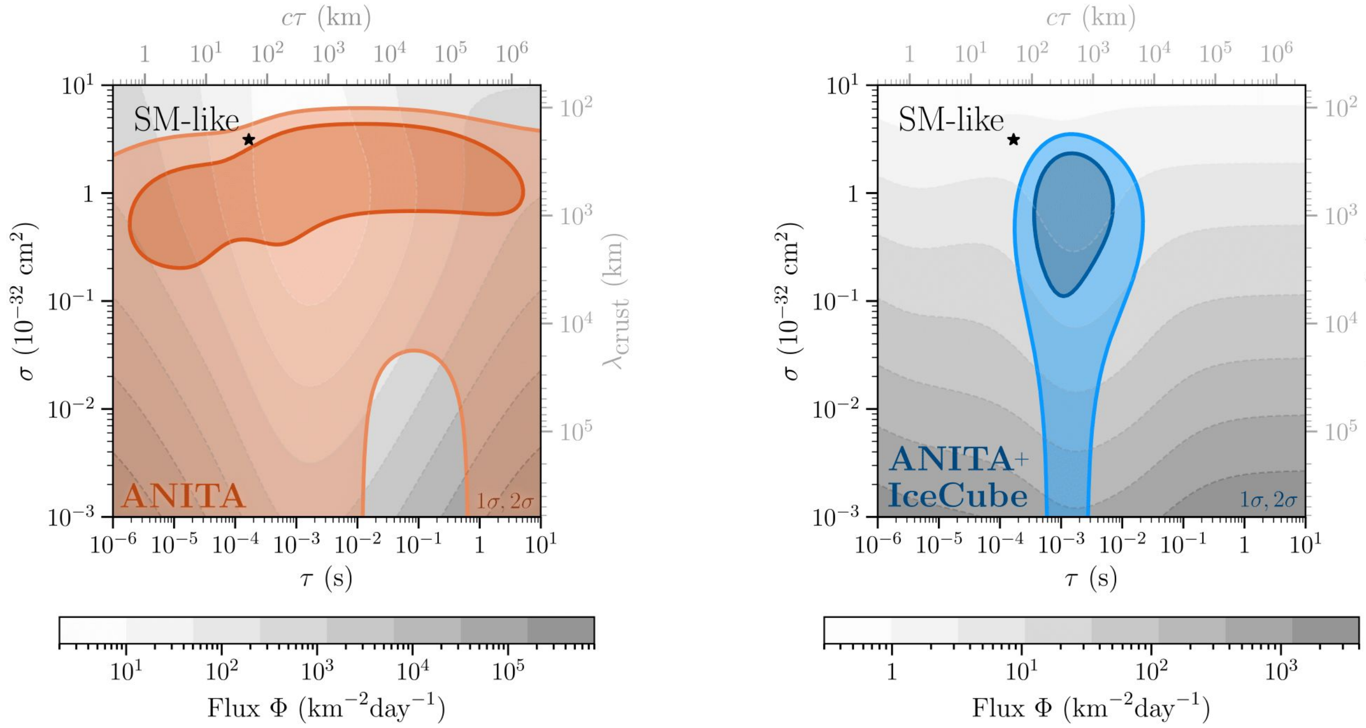
IceCube and the origin of the ANITA-IV events

Toni Bertólez-Martínez, Carlos A. Argüelles, Ivan Esteban, Jacobo Lopez-Pavon, Ivan Martinez-Soler, Jordi Salvado

arXiV 2305.03746

ICCUB | Institut de Ciències del Cosmos
UNIVERSITAT DE BARCELONA





Thanks!

Find me around, in the poster or in the arXiV: 2305.03746

Anna Kormu

University of Helsinki

Real scalar phase transitions: bubble nucleation, nonperturbatively

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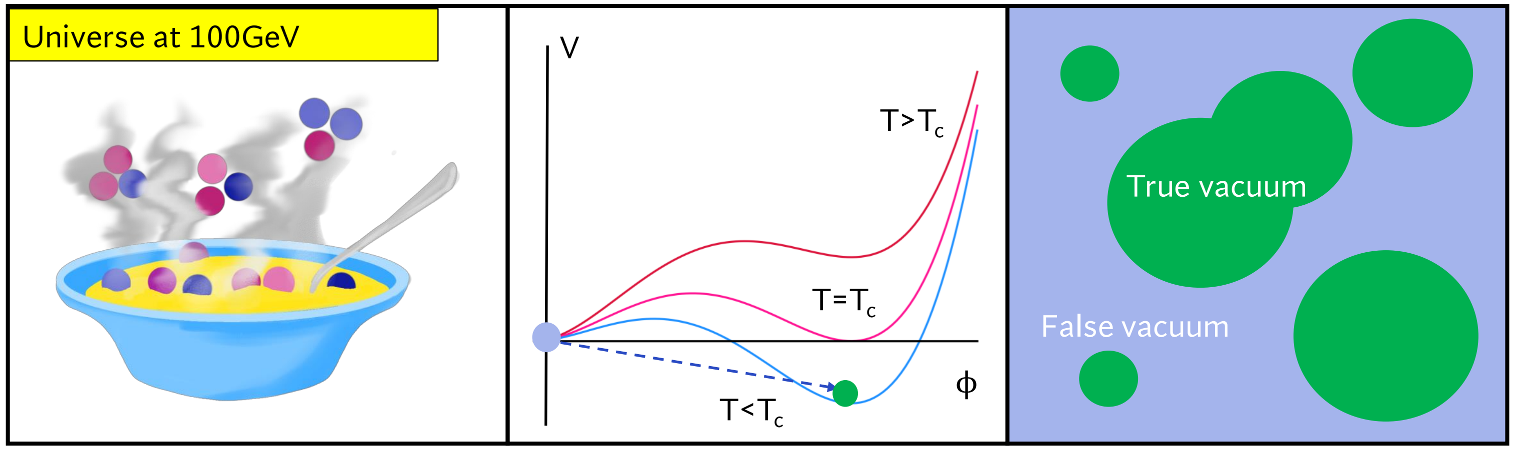
Real Scalar Phase Transitions: Bubble Nucleation, Nonperturbatively

with Oliver Gould & David Weir



Anna Kormu (she/her)

Third EuCAPT Annual Symposium

1.6.2023

University of Helsinki & Helsinki Institute of Physics

Real Scalar Phase Transitions: Bubble Nucleation, Nonperturbatively

- Allows us to calibrate the uncertainty in phase transition parameters when obtained from perturbative results
- Accurate computations of the nucleation rate are crucial for calculating e.g. the GW power spectrum

One-bubble takeaway

There can be large uncertainties in nucleation rates calculated from the bounce action