WP4 SUMMARY

GIANPIERO MANGANO AND FRANCESCO VILLANTE

NAT-NET MEETING L'AQUILA 18 JULY 2023

PLAN OF THE SESSION

- Summary of the WP4 activity (Gianpiero Mangano & Francesco Villante)
- Highlight talk: Impact of trans-Planckian quantum noise on the Primordial Gravitational wave and scalar spectrum (Mattia Cielo)
- Higlight talk: Primordial Blach Holes (PBH) in cosmology (Roberta Calabrese)

WP4 ISSUES

THE STANDARD COSMOLOGICAL MODEL AND BEYOND:

- Cosmological perturbations
- Neutrino cosmology and dark radiation (N_{eff})
- Big bang Nucleosynthesis
- Dark matter
- Archimedes project
- Pre-big bang cosmology
- Axion cosmology

PAPERS IN THE WP4 (2021 – TODAY)

22 papers in peer review journals (PRD, JHEP, JCAP, …)

- 14 published 😇
- 2 submitted
- 5 no acknowledgments to NAT-NET 😢
- 1 experimental paper of the PTOLEMY Collaboration

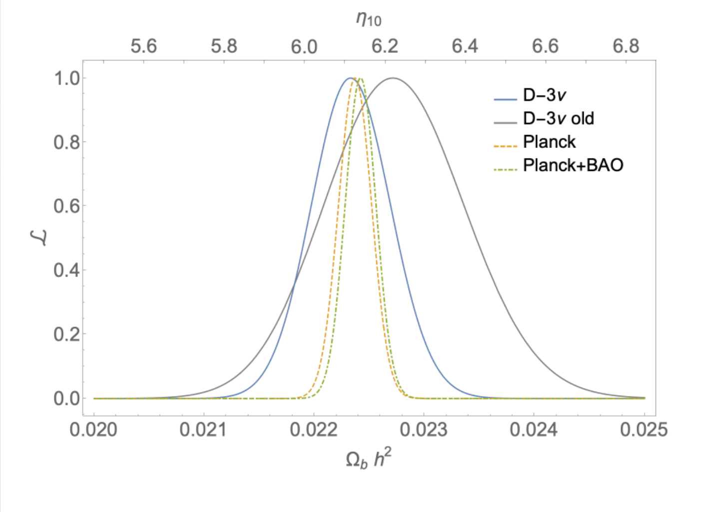
BIG BANG NUCLEOSYNTHESIS

A follow up of the Nature paper on LUNA results on d(p,gamma)^{3}He

Primordial Deuterium after LUNA, concordances and error budget

O. Pisanti, G. Mangano, G. Miele and P. Mazzella,

JCAP 04 (2021) 020



Ofelia Pisanti, Gianpiero Mangano, Gennaro Miele, and Pierpaolo Mazzella

Dipartimento di Fisica E. Pancini, Università di Napoli Federico II, and INFN, Sezione di Napoli, Via Cintia, I-80126 Napoli, Italy

Abstract

The accurate evaluation of the nuclear reaction rates and corresponding uncertainties is an essential requisite for a precise determination of light nuclide primordial abundances. The recent measurement of the D(p,)^{3}He radiative capture cross section by the LUNA collaboration, with its order 3% error, represents an important step in improving the theoretical prediction for Deuterium produced in the early universe. In view of this recent result, we present in this paper a full analysis of its abundance, which includes a new critical study of the impact of the other two main processes for Deuterium burning, namely the deuteron-deuteron transfer reactions, D(d, p)^{3}H and D(d, n)^{3}He. In particular, emphasis is given to the statistical method of analysis of experimental data, to a quantitative study of the theoretical uncertainties, and a comparison with similar studies presented in the recent literature. We then discuss the impact of our study on the concordance of the primordial nucleosynthesis stage with the Planck experiment results on the baryon density $\Omega_b h^2$ and the effective number of neutrino parameter $N_{\rm e}$, as function of the assumed value of the ^{4}He mass fraction Y_p. While after the LUNA results, the value of Deuterium is quite precisely fixed, and points to a value of the baryon density in excellent agreement with the Planck result, a combined analysis also including Helium leads to two possible scenarios with different predictions for $\Omega_b h^2$ and $N_{\rm e}$. We argue that new experimental results on the systematics and the determination of Y_p would be of great importance in assessing the overall concordance of the standard cosmological model.

BIG BANG NUCLEOSYNTHESIS

PArthENoPE evolutions

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INFN, Sezione di Torino, Via P. Giuria 1, I–10125 Torino, Italy
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Abstract

This paper presents the main features of a new and updated version of the program PArthENoPE, which the community has been using for many years for computing the abundances of light elements produced during Big Bang Nucleosynthesis. This is the third release of the PArthENoPE code, after the 2008 and the 2018 ones, and will be distributed from the code's website, http://parthenope.na.infn.it. Apart from minor changes, the main improvements in this new version include a revisited implementation of the nuclear rates for the most important reactions of deuterium destruction, ^{2}H(p,γ)^{3}He, ^{2}H(d, n)^{3}He and ^{2}H(d, p)^{3}H, and a re-designed GUI, which extends the functionality of the previous one. The new GUI, in particular, supersedes the previous tools for running over grids of parameters with a better management of parallel runs, and it offers a brand-new set of functions for plotting the results.

Keywords: primordial nucleosynthesis, cosmology, neutrino physics

VIOLATION OF EQUIVALENCE PRINCIPLE

IceCube constraints on violation of equivalence principle

D.F.G. Fiorillo, G. Mangano, S. Morisi and O. Pisanti

JCAP 04 (2021) 079

$$i\frac{dc}{dl} = \sum_{j,\beta} U_{\beta j} U^*{}_{j} \frac{\delta m_j^2}{2E} c_\beta + V(\mathbf{r})\delta \;{}_{e} c_e + 2E\phi \sum_{a,\beta} \tilde{U}_{\beta a} \tilde{U}^*{}_{a} \gamma_a c_\beta .$$

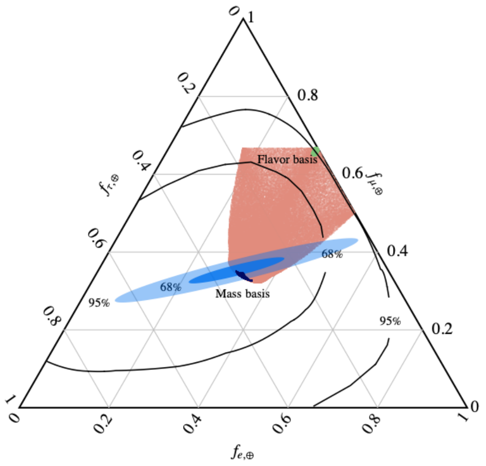

Figure 2. Flavor ratio at the Earth from a pion beam source after averaged VEP oscillations with $\gamma\phi > 10^{\;31}$: the orange region spans the whole possibilities for the gravitational basis; the green region corresponds to the case of gravitational basis coinciding with flavor eigenstates, while the black region corresponds to the case of gravitational basis coinciding with mass eigenstates. In the latter case we vary the oscillation parameters in the 3 σ intervals. The 68% and 95% confidence level obtained by IceCube [63] are shown (black contours), as well as the projected flavor sensitivity of IceCube-Gen2 [64] at 68% and 95% confidence level (blue ellipses).

Damiano F G Fiorillo[a,b] **Gianpiero Mangano**[a,b] **Stefano Morisi**[a,b] **Ofelia Pisanti**[a,b]

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Abstract Among the information provided by high energy neutrinos, a promising possibility is to analyze the effects of a Violation of Equivalence Principle (VEP) on neutrino oscillations. We analyze the recently released IceCube data on atmospheric neutrino fluxes under the assumption of a VEP and obtain updated constraints on the parameter space with the benchmark choice that neutrinos with different masses couple with different strengths to the gravitational field. In this case we find that the VEP parameters times the local gravitational potential at Earth can be constrained at the level of $10^{\;27}$. We show that the constraints from atmospheric neutrinos strongly depend on the assumption that the neutrino eigenstates interacting diagonally with the gravitational field coincide with the mass eigenstates, which is not *a priori* justified: this is particularly clear in the case that the basis of diagonal gravitational interaction coincide with the flavor basis, which cannot be constrained by the observation of atmospheric neutrinos. Finally, we quantitatively study the effect of a VEP on the flavor composition of the astrophysical neutrinos, stressing again the interplay with the basis in which the VEP is diagonal: we find that for some choices of such basis the flavor ratio measured by IceCube can significantly change.

See also: Sensitivity of Km3Net to Violation of Equivalence Principle M. Chianese et al Symmetry 13(2021) 8, 1353

PRIMORDIAL PERTURBATION AND BUNCH DAVIS VACUUM. BH (REAL AND VIRTUAL) AS A SOURCE

Impact of trans-Planckian quantum noise on the Primordial Gravitationa Wave spectrum

M. Cielo, G. Mangano and O. Pisanti

2211.04316, in print in Phys. Rev. D (2023)

$$\begin{aligned} h_k'' + 2\mathcal{H}h_k' + k^2 h_k &= 16\pi G a^2\, \Pi_k \qquad && \tau < \bar{\tau}_k \\ h_k'' + 2\mathcal{H}h_k' + k^2 h_k &= 0 && \tau > \bar{\tau}_k, \end{aligned}$$

$$\begin{aligned} \langle \Pi_k(\tau) \rangle &= 0 \\ \langle \Pi_k(\tau)\Pi_k^*(\tau') \rangle &= \Lambda^6 \delta(\tau \quad \tau')\ F\left(\frac{k}{a\Lambda}, \frac{\Lambda}{m_{Pl}}\right)^2 \end{aligned}$$

Imp ct of tr ns-Pl ncki n qu ntum noise on the Primordi l Gr vit tion l W ve spectrum

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(Dated: November 18, 2022)

We investigate the impact of stochastic quantum noise due to trans–Planckian effects on the primordial power spectrum for gravity waves during inflation. Given an energy scale Λ, expected to be close to the Planck scale m_{Pl} and larger than the Hubble scale H, this noise is described in terms of a source term in the evolution equation for comoving modes k which changes its amplitude growth from early times as long as the mode physical wavelength is smaller than Λ . We model the source term as due to a gas of black holes in the trans–Planckian regime and the corresponding Hawking radiation. In fact, for energy scales larger than, or of the order of Λ, it is expected that trapped surfaces may form due to large energy densities. t later times the evolution then follows the standard sourceless evolution. We find that this mechanism still leads to a scale-invariant power spectrum of tensor perturbations, with an amplitude that depends upon the ratio $\Lambda\ m_{Pl}$.

P CS numbers: 98.80.-k, 98.80.Cq, 04.60.-m

THE «ULTIMATE» CALCULATION OF N_{EFF}

Neff in the Standard Model at NLO is 3.043

M. Cielo, M. Escudero, G. Mangano and O. Pisanti

2306.05460, submitted to Phys. Rev. Lett.

$$Q \equiv \left.\frac{\delta\rho}{\delta t}\right|_{e\ e\ \to\bar{\nu}\nu}$$
$$= \int \frac{d^3\ _1}{(2\pi)^3 2E_1} \int \frac{d^3\ _2}{(2\pi)^3 2E_2} (E_1+E_2)\,\mathcal{F}_e\ (E_1)\,\mathcal{F}_e\ (E_2)$$
$$\frac{1}{(2\pi)^2} \int \frac{d^3\mathbf{q}_1}{2\,\omega_1} \int \frac{d^3\mathbf{q}_2}{2\,\omega_2}\, \delta^{(4)}(p_1+p_2\quad q_1\quad q_2)$$
$$(1\quad \mathcal{F}_\nu(q_1))\,(1\quad \mathcal{F}_{\bar{\nu}}(q_2)) \sum_{spin,\nu} |M|^2$$

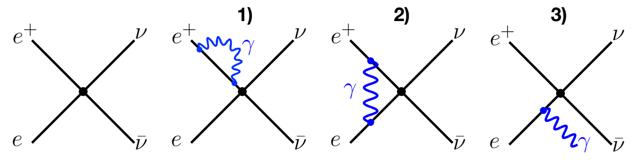

FIG. 1. Born diagram for $e^+e\ \to\ ^-$ annihilations and NLO QED corrections to the $e^+e\ \to\ ^-$ process, including processes contributing to: 1) electron mass and wavefunction renormalization, 2) electromagnetic vertex correction, and 3) photon emission and absorption.

Ne in the Standard Model at NLO is 3.043

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The e ective number of relativistic neutrino species is a fundamental probe of the early Universe and its measurement represents a key constraint on many scenarios beyond the Standard Model of Particle Physics. In light of this, an accurate prediction of N_e in the Standard Model is of pivotal importance. In this work, we consider the last ingredient needed to accurately calculate N_e^{SM}: standard zero and finite temperature QED corrections to $e^+e\ \leftrightarrow\ ^-$ interaction rates during neutrino decoupling at temperatures around $T \sim$ MeV. We find that this e ect leads to a reduction of 0.0007 in N_e^{SM}. This NLO correction to the interaction rates, together with finite temperature QED corrections to the electromagnetic density of the plasma, and the e ect of neutrino oscillations, implies that $N_e^{SM} = 3.043$ with a theoretical uncertainty that is much smaller than any projected observational sensitivity.

PTOLEMY, NEUTRINO MASS AND NCB

Heisenberg's uncertainty principle in the PTOLEMY project: a theory

Apponi et al Phys. Rev. D 106 (2022) 5, 053002

Heisenberg s uncertainty principle in the PTOLEMY project: a theory update

We discuss the consequences of the quantum uncertainty on the spectrum of the electron emitted by the -processes of a tritium atom bound to a graphene sheet. We analyze quantitatively the issue recently raised in [1], and discuss the relevant time scales and the degrees of freedom that can contribute to the intrinsic spread in the electron energy. We perform careful calculations of the potential between tritium and graphene with different coverages and geometries. With this at hand, we propose possible avenues to mitigate the effect of the quantum uncertainty.

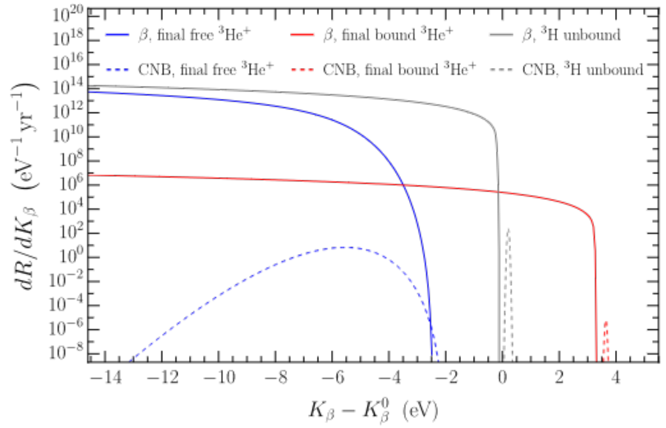

FIG. 1. Event rates for different configurations as a function of the outgoing electron kinetic energy, measured with respect to the endpoint in vacuum at zero neutrino mass, $K^0 \equiv m_{^3H} \; m_{^3He} \; m_e \; K_{rec}$, with $K_{rec} \simeq 3.44$ eV. We assume a target mass of 100 g, corresponding to $N_T \simeq 2 \times 10^{25}$ atoms of tritium. The presence of the graphene in the initial state shifts the event rate to different energies and makes the absorption peaks (CNB) much rarer, and hidden under the -decay part of the spectrum. For illustrative purposes we have set $m_\nu = 0.2$ eV, taken the initial wave function to be the ground state of the full coverage graphane potential presented later in Section IV, and convolved with an experimental resolution described by a Gaussian with full width at half maximum $\;= 0.05$ eV. Moreover, we only considered the two extreme scenarios: the free helium (solid and dashed blue lines) and the helium bound to the ground state with no emission of vibrational modes (solid and dashed red lines). Intermediate instances will populate the regions between the blue and red lines, resulting in a smooth total rate. For comparison, we report the rate expected if the process were to happen in vacuum, i.e. with an initial free atomic ^3H (gray lines).

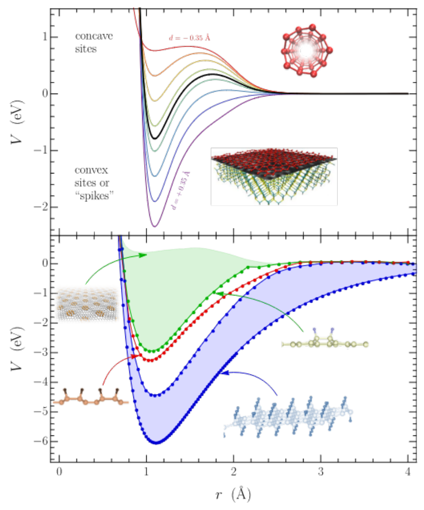

FIG. 2. Graphene–hydrogen binding potential as a function of the distance from the binding site. **Upper panel:** Binding potential for a single hydrogen atom for different local curvatures (puckering) of the binding site—see Figure 5 for a definition. Flat graphene corresponds to $d = 0$ (thick black line), while $d > 0$ corresponds to convex sites (outward puckering, as in the spikes of crumpled supported sheets shown in the lower inset) and $d < 0$ to concave ones (inward puckering, as within the nanotube shown in the upper inset). The potentials are parametrized as an interpolation between a van der Waals potential at large distances and a binding potential at short distances. The depth of the latter depends on the curvature—see Appendix C for details—which has been varied between $d = \; 0.35$ Å and $d = +0.35$ Å. Tritium is expected to have the same chemical properties as hydrogen. **Lower panel:** Effect of the hydrogen coverage. Same side binding has a positive cooperative effect for dimers (red line) or cluster up to a small value of the coverage (green line). As the clusters size increases (i.e. when more atoms are added on the same side) the binding destabilizes due to mechanical distortion (green shade). Conversely, two sides coverage is more stable (blue lines) although still dependent on coverage (blue shade). Representative structures are reported. Energy profiles are obtained with a standard Density Functional Theory calculation, as reported in Appendix D.

AI FOR DARK MATTER

Limits of DM distribution in galaxies:

All of the above methods are based on assumptions known to hold in controlled environments, for instance and only as a non-comprehensive example: the fact that the stellar disk is rotationally supported in disk galaxies for rotation curve methods, or some simplifying assumptions on the shape of, e.g. the anisotropy velocity parameter for reconstructing the DM potential in dwarf galaxies [53].

These assumptions are known to eventually break down and introduce unavoidable systematics for which one must account, e.g. [55].

Machine learning (hereafter, ML) techniques have proved to be powerful tools for classification and regression tasks in astronomy and astrophysics, e.g. [20, 40, 7, 33], as they look for correlations between the input variables and the output variables one wants to infer. It is important to remark that, in order to achieve this goal, it is necessary to have a reliable data set for which the input variables are known (in the present analysis, photometric images and spectroscopy of galaxies), as well as the output variables (in the present analysis, the underlying DM distribution).

etermining the ark Matter distribution in galaxies with eep Learning

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November 18, 2021

bstract

We present a novel method to infer the Dark Matter (DM) content and spatial distribution within galaxies, based on convolutional neural networks trained within state-of-the-art hydrodynamical simulations (Illustris–TNG100). The framework we have developed is capable of inferring the DM mass distribution within galaxies of mass $\sim 10^{11}$ – $10^{13}\,M_\odot$ with very high performance from the gravitationally baryon dominated internal regions to the DM-rich, baryon–depleted outskirts of the galaxies.

With respect to traditional methods, the one presented here also possesses the advantages of not relying on a pre-assigned shape for the DM distribution, to be applicable to galaxies not necessarily in isolation, and to perform very well even in the absence of spectroscopic observations.

PBH'S IN COSMOLOGY I

"Towards baryogenesis via absorption from primordial black holes".
A. Ambrosone, R. Calabrese, Damiano F.G. Fiorillo, G. Miele, S. Morisi.
Arxiv: 2106.11980 [hep-ph]. Phys.Rev.D 105 (2022) 4, 0450015)

"Limits on light primordial black holes from high-scale Leptogenesis".
R. Calabrese, M. Chianese, J.Gunn, G. Miele, S.Morisi, N. Saviano.
Arxiv: 2305.13369 [hep-ph]. Phys.Rev.D 107 (2023) 12, 123537

Towards baryogenesis via absorption from Primordial lack Holes

ntonio mbrosone,[1,2,*] Roberta Calabrese,[1,2,†] Damiano F.G. Fiorillo,[1,2,‡] Gennaro Miele,,[1,2,3,§] and and Stefano Morisi[1,2,¶]

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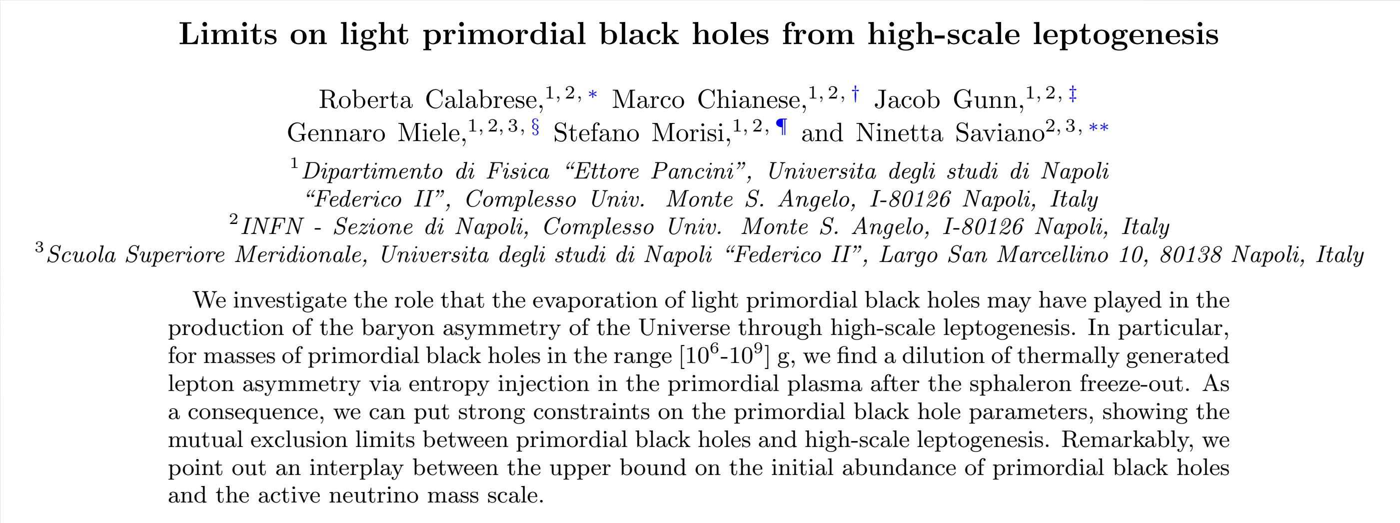
Recently Dolgov and Pozdnyakov proposed a new baryogenesis mechanism in which baryon asymmetry is produced without violating baryon number at the Lagrangian level. In this scenario, baryon asymmetry is generated by absorption of a new particle X carrying baryon number onto Primordial Black Holes (PBHs). ssuming CP-violation, the particle X is absorbed at a different rate than the antiparticle X, producing an asymmetry in the baryonic number. We independently test this scenario, finding that it suffers from two fundamental issues.
t the phenomenological level, strong absorption by PBHs initially increases the baryon asymmetry. However, at later times such asymmetry is completely absorbed by PBHs. In order to overcome this issue, we account for PBH evaporation, which provides a natural way of halting the absorption while keeping a finite baryon asymmetry. We provide a systematic study of the parameter space, identifying the regions leading to the production of the baryon asymmetry without violating the known constraints on PBHs concentration.
t the theoretical level, a model realizing the CP-violation postulated in this scenario is difficult to realize. We show, by implementing a minimal model, that the framework proposed in the original work in order to produce CP-violation, even if qualitatively correct, is quantitatively in disagreement with the observed baryon asymmetry, namely this mechanism produces only a fraction of the total baryon asymmetry.

PBH'S IN COSMOLOGY II



Limits on light primordial black holes from high-scale leptogenesis

Roberta Calabrese,[1,2,*] Marco Chianese,[1,2,†] Jacob Gunn,[1,2,‡]
Gennaro Miele,[1,2,3,§] Stefano Morisi,[1,2,¶] and Ninetta Saviano[2,3,**]

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[2] *INFN - Sezione di Napoli, Complesso Univ. Monte S. Angelo, I-80126 Napoli, Italy*
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We investigate the role that the evaporation of light primordial black holes may have played in the production of the baryon asymmetry of the Universe through high-scale leptogenesis. In particular, for masses of primordial black holes in the range [10^6-10^9] g, we find a dilution of thermally generated lepton asymmetry via entropy injection in the primordial plasma after the sphaleron freeze-out. As a consequence, we can put strong constraints on the primordial black hole parameters, showing the mutual exclusion limits between primordial black holes and high-scale leptogenesis. Remarkably, we point out an interplay between the upper bound on the initial abundance of primordial black holes and the active neutrino mass scale.

ARCHIMEDES

1) Quantum zero point electromagnetic energy difference between the superconducting and the normal phase in a high-Tc superconducting metal bulk sample

Annalisa Allocca, et al.

Phys. Rev. B 106, 134502 – Published 3 October 2022

2) Casimir energy for N superconducting cavities: a model for the YBCO (GdBCO) sample to be used in the Archimedes experiment

Annalisa Allocca, et al.

The European Physical Journal Plus volume 137, Article number: 826 (2022)

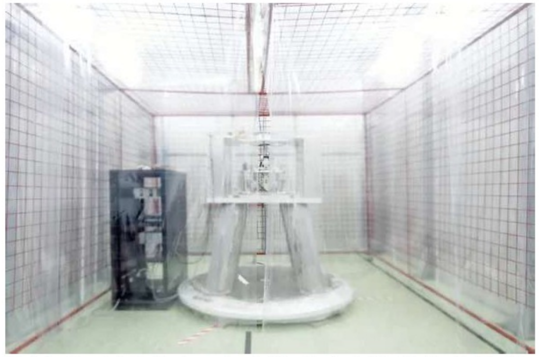
3) Picoradiant tiltmeter and direct ground tilt measurements at the Sos Enattos site Annalisa Allocca, et al.

The European Physical Journal Plus volume 136, Article number: 1069 (2021)

How Much Does ‘Nothing’ Weigh?

The Archimedes experiment will weigh the void of empty space to help solve a big cosmic puzzle

By Manon Bischoff on May 1, 2023
Scientific American May 2023 Issue



A dust sheet shrouds the Archimedes experiment, which will try to weigh the “virtual particles” that fill empty space. Credit: Vincent Fournier

It does something to you when you drive in here for the first time,” Enrico Calloni says as our car bumps down into the tunnel of a mine on the Italian island of Sardinia. After the intense heat aboveground, the contrast is stark. Within seconds, damp, cool air enters the car as it makes its way into the depths. “I hope you're not claustrophobic.” This narrow tunnel, which leads us in almost complete darkness to a depth of 110 meters underground, isn't for everyone. But it's the ideal site for the project we are about to see—the Archimedes experiment, named after a phenomenon first described by the ancient Greek scientist, which aims to weigh “nothing.”

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- Lascio a te la cura dei seguenti papers

- M. Gasperini,
From pre- to post-big bang: an (almost) self-dual cosmological history,
in ``The future of mathematical cosmology''',
ed. by S. Cotsakis and A. Yefremov,
published in Phil.Trans. Roy. Soc. A 380, 2230 (2022).
https://doi.org/10.1098/rsta.2021.0179
[arXiv:2106.12865 [hep-th]]

- M. Gasperini,
Gravity at finite temperature, equivalence principle, and local Lorentz invariance,
in ``Breakdown of the Einstein's Equivalence Principle'',
ed. by A. G. Lebed (World Scientific, 2023), Cap. 3, p. 77.
ISBN: 978-981-125-358-4
https://doi.org/10.1142/9789811253591_fmatter
[arXiv:2101.00458 [gr-qc]]

- M. Gasperini and G. Veneziano,
"Non-singular pre-big bang scenarios from all-order α' corrections",
arXiv:2305.00222 [hep-th]

Unfinished fabric of the three neutrino paradigm
F. Capozzi et al, Phys. Rev. D 104 (2021) 8,083031

Precession shift in curvature base extended theories of gravity and quintessence fields A. Capolupo, G. Lambiase and A. Tedesco Eur. Phys. J C82 (2022) 4, 286

Axion-like particles from primordial black holes shining through the Universe, F. Schiavone, D. Montanino, A. Mirizzi and F. Capozzi JCAP 08(2021) 063

Massive sterile neutrinos in the early universe: from thermal decoupling to cosmological constraints, L. Mastrototaro, P.D. Serpico, A. Mirizzi and N. Saviano, Phys. Rev. D 104 (2021 1 016026

Thermal axions with multi-eV masses are possible in low reheating scenarios
P. Carenza, M. Lattanzi, A. Mirizzi and F. Forastieri JCAP 07 (2021) 031