Summer School on Cosmology | (SMR 4223)

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P01

Reheating and Inflationary dynamics driven by an inverse tangent potential

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Abstract

In this work, we study the early universe inflation and the post-inflation reheating era employing an inverse tangent potential of the form $V = V_0 \cdot [tan^{-1}(\frac{\kappa\phi}{m_p})]^2$, where κ is a free parameter of the potential and m_p is the reduced Planck mass. We derive the slow roll parameters, the number of e-folds(N), the scalar spectral index n_s, the tensor-to-scalar ratio r, and the tensor spectral index n_T for the inverse tangent potential. We examine the inflationary observables using the data of the *Planck*-2018 [1] and recent ACT collaboration [2, 3] and obtain constraints on the potential parameter κ. We also employ a reheating analysis by invoking the conservation of entropy between today and the time when reheating starts. We obtain bounds on the reheating temperature T_{re} and the number of e-folds of the reheating N_{re} using the spectral-index n_s constraints from *Planck* 2018 and the ACT results. We show that this inverse-tangent potential can act as an alternative to the standard inflationary potentials like Starobinsky [4] which are excluded at 2σ level by the recent sixth data release (DR6) of the Atacama Cosmology Telescope (ACT) collaboration.

[1] N. Aghanim et al. Planck Collaboration, arXiv:1807.06209. (2018)
[2] ACT Collaboration, arXiv:2503.14452. (2025)
[3] ACT Collaboration, arXiv:2503.14454. (2025)
[4] A. A. Starobinsky, Phys. Lett. **B91** 99–102. (1980)

P02

Stochastic lensing induced decoherence of astrophysical neutrinos.

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We propose a new source of neutrino decoherence arising from stochastic gravitational lensing by unresolved mass substructure. Unlike traditional models that treat the lensing potential as smooth and deterministic, we decompose the lensing potential into a smooth component and a stochastic population of compact clumps. The substructure induced fluctuations of the lensing potential generate stochastic corrections to the neutrino time delay thereby producing random relative phases between different neutrino mass eigenstates. Averaging over the clump ensemble converts these phase fluctuations into an effective dampening of flavour coherence. This framework connects stochastic gravitational lensing with neutrino phenomenology and offers a novel route to probe dark matter substructure through astrophysical neutrino flavour transitions.

[1] Acharya, B. K. , Banerjee, I. K. , Dey, U. K. , JCAP 12 (2025) 015
[2] Banerjee, I. K. , Dey, U. K. , Eur. Phys. J. C (2023) 83, 428

P03

Dark Matter Induced Scalarization as a Possible Solution to the Hyperon Puzzle

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We investigate neutron-star properties in the presence of a massive scalar field, a viable dark-matter candidate, non-minimally coupled to the Ricci scalar. For dark-matter masses below $\sim$ eV, the field is expected to be bosonic and behave as a classical wave with frequency set by its mass. Modeling dark matter as such a scalar field, we show that the non-minimal coupling induces additional contributions to the effective mass, which can trigger tachyonic instabilities in dense stellar environments and lead to rich phenomenology.

In neutron-star cores, the appearance of hyperons is expected to soften the equation of state, reducing the maximum mass to $\sim 1.4M_\odot$, the well-known hyperon puzzle. However, observations of massive pulsars, such as PSR J0348+0432 ($2.01 \pm 0.04M_\odot$) and PSR J1614–2230 ($1.97 \pm 0.04M_\odot$), challenge this expectation. Within the framework of dark-matter-induced scalarization, we obtain neutron-star configurations with maximum masses exceeding $2M_\odot$, even in the presence of hyperons.

We further find that sufficiently large coupling strengths give rise to multiple scalar-field configurations for a given stellar model. This multiplicity is traced to the structure of the associated effective potential, which we analyze in detail. Finally, we examine how including scalar self-interactions, in addition to the non-minimal coupling, modifies the resulting neutron-star properties.

DOI: arXiv:2603.14731

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[2] J. Antoniadis, P. C. C. Freire, and e. a. Wex, Science 340, 10.1126/science.1233232 (2013).

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P04

PROBING MAGNETIZED BLACK HOLE ENVIRONMENTS THROUGH QPO-BASED BAYESIAN CONSTRAINTS ON CHARGED PARTICLE DYNAMICS

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High-frequency quasi-periodic oscillations (HF QPOs) offer a unique observational probe of the strong-gravity regime surrounding black holes. In this work, we investigate the dynamics of charged particles with magnetic dipole moments orbiting a Schwarzschild black hole immersed in a paraboloidal magnetic field. Using the Hamilton–Jacobi formalism, we derive the exact equations of motion to map the effective potential, the innermost stable circular orbit (ISCO), and the fundamental epicyclic frequencies. We reveal that the external magnetic field strength and the dipole–field coupling parameter exert competing effects on orbital stability, leading to distinct, measurable shifts in predicted QPO signals. To test this theoretical framework, we apply the relativistic precession model to twin-peak QPO data across stellar-mass, intermediate-mass, and supermassive black holes. Using Markov Chain Monte Carlo (MCMC) Bayesian estimation, we successfully constrain critical system parameters, including black hole mass, magnetic field strength, field geometry, coupling parameters, and emission radii. Ultimately, we demonstrate that QPO timing observations, combined with robust magnetospheric interaction models, serve as powerful tools for charting magnetized black hole environments across all mass scales.

[1] Z. Ahal, H. El Moumni, K. Masmar, **arXiv preprint arXiv:2601.17953 (2026)**.

P05

Non-Gaussian corrections to the noise in stochastic inflation

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Recent hints for large, rare fluctuations at small cosmological scales motivate modeling cosmic inflation beyond standard perturbation theory. One such non-perturbative approach is the stochastic inflation formalism in which the outflow of quantum fluctuations crossing the Hubble radius is described as a stochastic noise. In this work, we consistently include the first non-Gaussian corrections to the noise, beyond the usual Gaussian white noise approximation. We characterize spatial and temporal correlations and demonstrate that the dominant source of non-Gaussianity originates from squeezed regions of the primordial bispectrum. This allows us to parameterize non-gaussian effects in terms of the parameter $f_{\mathrm{NL}}^{\mathrm{loc}}$ only. We find that the inflaton follows a modified Langevin equation that we solve numerically. By reconstructing the probability density function of primordial fluctuations, we quantify the impact of $f_{\mathrm{NL}}^{\mathrm{loc}}$ on the tails of the distribution, which is relevant for primordial black hole formation.

P06

REVISITING QUADRATIC SCALAR FIELD (FUZZY, WAVE, ULTRALIGHT) DARK MATTER IN LIGHT OF DESI DR2 AND CURRENT COSMOLOGICAL OBSERVATIONS

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We study the cosmological phenomenology of quadratic scalar field dark matter (SFDM) using an implementation in the Boltzmann code `CLASS`, in which dark matter is modeled as a single ultra-light scalar field with potential $V(\phi) = \frac{1}{2}m_\phi^2\phi^2$. Adopting a dynamical-systems approach, we analyze the evolution of the homogeneous scalar field together with its linear perturbations, enabling stable numerical predictions for the relevant cosmological observables [1, 2]. We derive the CMB temperature anisotropy spectrum and the linear matter power spectrum, verifying the numerical stability of our implementation across the parameter space.

We constrain the model with Planck 2018 CMB data, DESI DR2 BAO measurements, the three-dimensional Lyman-α forest matter power spectrum, and the Pantheon+ supernova compilation. We find that the standard cosmological parameters remain close to their ΛCDM counterparts, with no clear departures from the concordance scenario. For the scalar-field mass, the baseline dataset combination yields an essentially flat posterior over the explored range. The inclusion of Lyman-α information introduces non-trivial structure in the marginalized posterior, which becomes broad and non-unimodal and allows us to derive a one-sided 95% C.L. lower bound of $\log_{10}(m_\phi/\mathrm{eV}) > -22.15$. These results show that the quadratic single-field SFDM scenario remains observationally viable and motivate further discussion of the phenomenological implications associated with the allowed ultra-light mass range.

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[2] L. O. Téllez-Tovar, T. Matos, and J. A. Vázquez, "Cosmological constraints on the multiscalar field dark matter model," Phys. Rev. D **106**, 123501 (2022) [arXiv:2112.09337].

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P07

SIMULATION-BASED INFERENCE FOR 21 CM COSMOLOGY: PIPELINE DEVELOPMENT FOR FUTURE OBSERVATIONS

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This work presents the early-stage development of a simulation-based inference (SBI) pipeline for extracting astrophysical and cosmological information from the 21 cm signal, a key observable for upcoming experiments such as the Square Kilometre Array. The analysis of this signal is challenging due to the high dimensionality of parameter space, complex astrophysical modeling, and the intractability of traditional likelihood functions. The pipeline uses forward modeling via 21cmFAST to generate mock realizations of the 21 cm signal across a range of parameters. These simulations are combined with likelihood-free inference techniques, including neural posterior estimation, to learn the mapping between observables and posterior distributions without explicit likelihood construction. The project is carried out at the University of Bonn with affiliation to the Max Planck Institute for Radio Astronomy. Current efforts focus on pipeline construction, validation with mock datasets, and exploration of parameter degeneracies. This work aims to contribute to robust and scalable inference frameworks for next-generation cosmological observations and future 21 cm data analysis.

P08

CMB B-mode Delensing and Improved Constraints on the Tensor-to-Scalar Ratio, r

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The measurement of CMB B-modes represents a key objective in modern cosmology, as it provides a unique probe of primordial gravitational waves through the tensor-to-scalar ratio, r. However, this measurement is limited by contamination from lensing-induced B-modes, which act as an additional source of noise and limit the current sensitivity to r. While present observations constrain $r < 0.036$, upcoming experiments such as the Simons Observatory are expected to significantly improve this limit by combining large- and small-aperture telescopes. In this work, we investigate delensing techniques based on quadratic estimators of the CMB lensing potential and the incorporation of external large-scale structure tracers, such as the cosmic infrared background. We implement these methods in simulated datasets to evaluate their performance. Our expected results indicate that the combination of tracers can improve the reconstruction of the lensing signal, leading to an enhanced sensitivity to r.

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[2] T. Okamoto and W. Hu, Phys. Rev. D **67**, 083002 (2003).
[3] B. Sherwin and M. Schmittfull, Phys. Rev. D **92**, 043005 (2015).

Perturbation evolution with late-decaying dark matter

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We show how a recently developed iterative integral-equation approach to cosmological perturbations can be augmented to account for the effects of dark matter that undergoes late decays. The Boltzmann hierarchies for the hot/cold decay products are replaced by integral equations that are more efficiently computed. With the increase in accuracy and speed, we interpret decaying dark-matter models in the context of DESI DR2 results, addressing both the Hubble tension and the S8 tension.

[1] M. Kamionkowski, Cosmological perturbations without the Boltzmann hierarchy, Phys. Rev. D 104, 063512 (2021), arXiv:2105.02887 [astro-ph.CO].
[2] L. Ji, M. Kamionkowski, and J. L. Bernal, Cosmological perturbations: Noncold relics without the Boltzmann hierarchy, Phys. Rev. D 106, 103531 (2022), arXiv:2201.11129 [astro-ph.CO].
[3] N. Lee, J. L. Bernal, S. Günther, L. Ji, and M. Kamionkowski, Rapid and accurate numerical evolution of linear cosmological perturbations with noncold relics, Phys. Rev. D 112, 043529 (2025), arXiv:2506.01956 [astro-ph.CO].

P10

Effect of transient scalars on primordial gravitational waves

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Blanco Encalada 2008, Santiago, Chile.

Gravitational waves are an excellent tool for studying the early universe. With new technologies, such as LISA [1] and the Pulsar Timing Arrays [2], it is possible to detect these waves over a broader frequency range. In this work, we are interested in the two-point correlation of gravitational waves generated during the inflationary era of our universe. We focus on understanding the effects of transient scalars (in our case, inflatons) in a Minkowski background and its perturbations in the Arnowitt–Deser–Misner (ADM) formalism. For non-transient scalars, it is observed that when one performs scalar loops, there are infinite parts that require regularization [3]. Inspired by this, we are focused on searching for the infinite parts of the loops generated by the transient scalars.

[1] J. E. Gammal *et al.* (LISA Cosmology Working Group), JCAP **05**, 062 (2025).
[2] A. Afzal *et al.* (NANOGrav Collaboration), Astrophys. J. Lett. **951**, L11 (2023).
[3] G. Ballesteros, J. G. Egea, and F. Riccardi, arXiv:2512.20467 [hep-th] (2025).

P11

Optimising the PICASSO map-making code for QUIJOTE-TFGI data

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The Thirty and Forty Gigahertz Instrument (TFGI) is installed on the second telescope of the QUIJOTE CMB experiment[1], located at the Teide Observatory in Tenerife. TFGI observes the northern sky at 31 and 41 GHz with angular resolutions of 21' and 18', respectively. Currently TFGI has data from 7 receivers obtained during a commissioning phase (2021-2022), and new observations will start soon with 19 detectors. In this poster, we optimize the configuration parameters of the destriping map-making algorithm PICASSO [2] to produce intensity maps from TFGI data. In particular, we determine the optimal baseline length used by the destriper to remove correlated noise from the time-ordered data (TODs). For this purpose, we use PySM [3] sky simulations and consider both white noise and realistic $1/f$ noise with characteristics matching those of the experiment. By minimizing the residuals between the reconstructed output maps and the input sky maps, both in real and harmonic space, we determine the optimal baseline configuration. We also propose an extension of the existing PICASSO code to process polarization timelines from TFGI, and validate the approach using the same set of simulations. The novelty of our implementation lies in the ability of the code to destripe two timelines simultaneously, corresponding to the Stokes Q and Stokes U outputs measured by the TFGI phase switches.

[1] J. A. Rubiño-Martín, R. Rebolo, M. Aguiar, et al., *Ground-based and Airborne Telescopes IV*, **Proc. SPIE 8444**, 84442Y (2012).
[2] F. Guidi, et al., *The PICASSO map-making code*, **Mon. Not. R. Astron. Soc.** 507, 3707–3725 (2021).
[3] B. Thorne, et al., *The Python Sky Model: software for simulating the Galactic microwave sky*, **Mon. Not. R. Astron. Soc.** 466, 2272–2283 (2017).

P12

Probing Dark Matter Electromagnetic Properties with Direct Detection Experiments: Insights from XENONnT

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A wide range of cosmological and astrophysical observations indicate that nearly 85% of the matter content of the Universe is composed of dark matter (DM), whose microscopic properties remain unknown [1]. In many well motivated scenarios, DM is non-relativistic and may possess suppressed electromagnetic (EM) couplings to Standard Model particles. While such couplings are constrained to be weak, they are neither ruled out by observations nor excluded on theoretical grounds. This motivates dedicated searches for photon-mediated DM–nucleus scattering in direct detection experiments as a sensitive probe of DM EM properties [2]. In this presentation, I will discuss our recent work where we systematically investigate a broad class of DM EM interactions, including millicharge, charge radius, and electric and magnetic dipole moments. Using nuclear recoil data from the XENONnT experiment [3, 4], we derive updated constraints on these scenarios. A central aspect of our analysis is the inclusion of terrestrial attenuation effects. For sufficiently large EM couplings, DM particles lose a substantial fraction of their kinetic energy while propagating through the Earth, leading to their efficient capture before reaching underground detectors. This introduces an upper bound or "ceiling" on the parameter space accessible to experiments such as XENONnT, thereby highlighting an intrinsic limitation of underground searches. In addition, I will present our estimate of the neutrino floor for DM EM interactions, arising from irreducible backgrounds due to Coherent Elastic Neutrino-Nucleus Scattering. This provides a theoretical estimate of the onset of the neutrino floor, below which neutrino-induced backgrounds make the identification of DM signals increasingly challenging for direct detection experiments. Finally, I will compare our results with existing constraints from terrestrial experiments and cosmological observations, emphasizing the complementarity between different probes and the role of attenuation and neutrino backgrounds in shaping the viable parameter space.

[1] **Planck collaboration**, N. Aghanim et al., Astron. Astrophys. **641**, A6 (2020).
[2] A. Ibarra, M. Reichard, G. Tomar, JCAP **02**, 072 (2025).
[3] **XENONnT collaboration**, E. Aprile et al., Phys. Rev. Lett. **133**, 191002 (2024).
[4] **XENONnT collaboration**, E. Aprile et al., Phys. Rev. Lett. **134**, 111802 (2025).

P13

Non-linear Dynamics and Primordial Black Hole Formation During Kination

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This talk is based on the results of our recent paper [1]. The early universe may have experienced a kination epoch – a phase where a scalar field's kinetic energy dominates the expansion. In this talk, I will outline how scalar-field inhomogeneities during this era can trigger strong non-linear dynamics and how these can lead to gravitational collapse to form primordial black holes(PBHs). Based on numerical relativity simulations, I will show the conditions under which super-horizon perturbations grow non-perturbatively and the critical initial conditions for PBH formation. I will discuss how a non-standard background like kination opens new pathways for PBH formation and the cosmological implications.

[1] C. Cheng, P. Giannadakis, L. Heurtier and E. A. Lim, [arXiv:2507.19166 [astro-ph.CO]].

P14

Probing Primordial Non-Gaussianity with Euclid: A Joint Power Spectrum and Bispectrum Analysis

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The upcoming Data Release 1 (DR1) from the Stage-IV galaxy survey Euclid will contribute significantly to the era of precision cosmology. By mapping the large-scale structure (LSS) of the Universe with unprecedented volume, Euclid provides a unique window into both the late-time expansion and dark sector of the Universe, as well as the fundamental physics governing its initial conditions. In particular, one of the key theoretical opportunities opened by this latter aspect is the search for primordial non-Gaussianities (PNG) of the local type, parameterized by the amplitude $f_{\rm NL}^{\rm loc}$. In the standard cosmological paradigm, initial density fluctuations are nearly Gaussian ($f_{\rm NL}^{\rm loc} \approx 0$), reflecting a robust prediction of single-field slow-roll inflation. Crucially, because these baseline models strictly forbid a detectable local non-Gaussian signal, any definitive measurement of $f_{\rm NL}^{\rm loc} \neq 0$ would unequivocally rule out all single-field slow-roll scenarios. Such a detection would serve as a smoking gun for new fundamental physics, compelling a shift toward multi-field inflationary models and providing a direct window into the early Universe.

While traditional LSS analyses predominantly rely on the galaxy power spectrum, where local PNG induces a scale-dependent modification to the linear galaxy bias, $f_{\rm NL}^{\rm loc}$ also directly sources higher-order statistics like the bispectrum. Constraining $f_{\rm NL}^{\rm loc}$ exclusively through the scale-dependent bias in the galaxy power spectrum suffers from a fundamental parameter degeneracy with the non-Gaussian linear bias parameter. Because the observable power spectrum enhancement scales with the product of these two parameters, marginalizing over our uncertain knowledge of galaxy formation physics severely broadens the resulting $f_{\rm NL}^{\rm loc}$ posterior. Incorporating the galaxy bispectrum effectively breaks this degeneracy by supplying independent statistical information across diverse triangle configurations, decoupling the primordial signal from late-time tracer bias and yielding significantly tighter cosmological constraints.

In this talk, I will discuss why robust constraints on local primordial non-Gaussianity remain difficult to obtain in practice. The $f_{\rm NL}$ signal is strongest on the largest cosmic scales, where it is severely impacted by observational systematics—such as interloper contamination, targeting completeness, and survey window effects—as well as theoretical challenges like general relativistic corrections and wide-angle effects. Additionally, performing a joint analysis of the power spectrum and bispectrum is notoriously difficult due to the high dimensionality and non-trivial covariance structure of the combined data vector. I will then present the methods developed to overcome these challenges, enabling a consistent, efficient, and informative joint $P + B$ analysis for Euclid DR1.

P15

One-loop power spectrum corrections in interacting dark energy cosmologies

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Interacting Dark Energy (IDE) models offer a promising avenue to explore possible exchanges of energy and momentum between dark matter and dark energy, providing a dynamical extension of the standard ΛCDM paradigm. Such interactions modify the growth of cosmic structures, imprinting distinctive signatures on the matter power spectrum that can be tested through large-scale structure (LSS) observations. In this work, we compute the one-loop corrections to the matter power spectrum in IDE models. We then reinterpret these results within the standard framework of the Effective Field Theory of Large-Scale Structure (EFTofLSS), which provides a consistent description of mildly non-linear scales and allows for reliable comparisons with observational data. We investigate two commonly studied forms of the coupling function, Q, namely $Q = \xi \mathcal{H} \rho_{\rm m}$ and $Q = \xi \mathcal{H} \rho_{\rm DE}$, and introduce a novel interaction term, $Q = \Gamma \, \rho_{\rm m} \, \rho_{\rm DE} \, \theta_{\rm m}$, characterized by the non-linear coupling constant Γ, which links the interaction strength to the velocity divergence of dark matter. This coupling function is proposed to isolate the effects solely of the IDE model on mildly non-linear scales. Using Full-Shape (FS) measurements of the galaxy power spectrum from BOSS DR12, we constrain the interaction rate Γ, the cosmological parameters, and the bias parameters. We find $\Gamma = 0.0039 \pm 0.0082$, which is highly consistent with the ΛCDM model. This work opens the possibility of testing IDE models at mildly non-linear scales, potentially providing new insights for this class of models beyond the standard ΛCDM framework.

P16

Probing the Dark Energy Leakage Effect Through Gravitational Lensing

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The recent observations by DES and the DESI survey slightly favor an evolving dark energy. A varying dark energy is usually described by a dynamical scalar field acting at cosmological scales, which can lead to dark energy perturbations that directly affect structure formation, but such that the fifth force arising from the scalar is suppressed at large density regions via screening mechanisms. These theories can be described in a general manner by the Degenerate Higher-Order Scalar-Tensor (DHOST) Lagrangian [1]. Due to the very large freedom in the specification of such theories, a method to distinguish between them is provided by the Effective Field Theory of Dark Energy (EFTDE), so that distinct dark energy models can be properly constrained by observations [1]. This is done via the definition of a minimal set of parameters that describe the possible dark energy effects.

For DHOST theories within the EFTDE framework, however, certain dark energy parameters leak into nonlinear scales. The so-called Vainshtein screening mechanism is broken inside massive sources by the new interactions introduced by this class of theories. In the quasi-static regime, two possible solutions exist for the two metric potentials, which are distinct from one another, contrarily to the General Relativity (GR) case [2]. This allow us to probe these dark energy models by combining gravitational lensing with galaxy dynamics, specially in the case of strong lensing by early-type galaxies [3]. For $c_{GW} = c$ [2, 4], these models are mainly characterized for their mixing between kinetic terms of the matter perturbations and of dark energy, which is quantified by the EFTDE parameter α_H. Using a value-added compilation of 206 galaxy-galaxy lensing systems from the recently-released Last Stand Before Rubin (LaStBeRu) database [5], we have constructed a theoretical model and performed a joint Bayesian analysis of strong lensing and stellar velocity dispersions in order to investigate α_H.

For the beyond-Horndeski subclass, we find that $\alpha_H = 0.060 \pm 0.027$. For another subclass of DHOST solutions, which fully breaks the screening, the constraint on α_H takes the same numerical value as for the beyond-Horndeski case. Distinct flat cosmological backgrounds, such as ΛCDM, wCDM and $w_0 w_a$CDM, are also considered in our model. The final results are all compatible within one sigma. These are the first constraints on DHOST dark energy models obtained from kpc scales. The current data shows a slight preference for a stronger gravity ($\alpha_H > 0$) at these scales, but the results are compatible with GR within 2.2 sigma. Our results suggest a possible dark energy perturbative component affecting structure formation, whose kinetic terms mix with matter overdensity ones. With DESI redshift data and new incoming data from LSST and Euclid we wish to further improve these constraints, we hope that our results will contribute to the understanding of the nature of dark energy.

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P17

Two Fluid Quantum Bouncing Cosmology

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Bouncing cosmologies offer an alternative to inflation by resolving the initial singularity through a contracting phase followed by a bounce into expansion. In many such models, the contracting phase is dominated by a single matter component, typically pressureless dust, which leads to an almost scale-invariant spectrum of scalar cosmological perturbations with a slight blue tilt, so that generating the observed red-tilted spectrum within this framework was challenging. In this work, we consider a more realistic scenario in which the contracting phase includes both matter and radiation, as required on physical grounds. We show that the presence of radiation can naturally induce a red tilt in the spectrum of curvature perturbations seeded by quantum vacuum fluctuations in the remote past of the contraction. Since the perturbations of the two fluids are coupled via gravity, vacuum initial conditions must be carefully defined. We demonstrate that, without fine-tuning, the resulting entropy perturbations are subdominant with respect to curvature perturbations. This suggests that a minimal two-component bounce model, involving only ordinary matter and radiation, can connect to the standard expanding cosmology with observationally viable initial conditions. We conclude by also discussing the Markov Chain-Monte Carlo (MCMC) analysis of the model using cosmological data.

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P18

Poster: "Cleaning the Lyman-alpha forest with hydrodynamical simulations"

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High Column Density systems (HCDs) represent one of the primary sources of systematic uncertainty in small-scale Lyman-α forest statistics (such as P_{3D}, P_{1D} and Px). These absorbers, typically located near galaxies, span a wide range of column densities ($N_{HI} = 10^{17} - 10^{22}$ cm^{-2}). While the highest column density systems are relatively rare, their strong damping wings produce absorption features over scales much larger than their physical size, significantly contaminating the Lyman-α forest signal. Luckily, their detection and masking in observational data is achieved with a high level of accuracy. However, the identification of lower column density systems remains a challenge for current algorithms. As a result, residual HCD contamination persists in the data, becomes correlated with the Lyman-α forest field and results in errors in the inferred parameters.

In this poster I will show the effect of HCDs on the measured correlations of Lyman-α forest using the ASTRID hydrodynamical simulation. I will quantify the impact of different contributions arising from correlations between the HCDs and the Lyman-α forest fields. Based on these results, I will explore some models designed to capture HCD contamination, with the goal of identifying the optimal balance between accuracy and model complexity.

P19

Removing Galactic foregrounds on Cosmic Microwave Background polarization maps using Convolutional Neural Networks

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Inflationary models emerge within the standard cosmological model (ΛCDM) as an explanation to the homogeneity of the Cosmic Microwave Background (CMB), the flatness of the Universe, and the non-abundance of magnetic monopoles. The detection of primordial gravitational waves through the B-mode polarization of the CMB could be interpreted as the first indirect measurement of the cosmic inflationary period. However, this detection is challenging due to several factors, including galactic foreground contamination, weak gravitational lensing, and instrumental noise [1, 2, 3]. In this work, we focus on developing a method to remove galactic contaminants from polarization maps obtained by a CMB-S4–like telescope, using convolutional neural networks (CNNs). The use of CNNs arises as an alternative to traditional foreground removal methods [4, 5, 6], which typically require strong assumptions about the properties of these contaminants. In our study, we analyze different architectures to remove the foregrounds from low-resolution maps with the goal of detecting the recombination bump at the multipole scale $\ell \approx 200$. Our simulations include the lensing effect, Galactic foregrounds, and instrumental noise. In this work, we demonstrate that this technique effectively removes the contaminants with a relative error of less than 10% for the B-mode power spectrum and below 1% for the E-mode spectrum. In addition, we study the generalization capabilities of the CNNs by training and testing them on simulations of Galactic foregrounds generated with different modeling approaches. We find correlations between the generalization capability of the networks and statistical properties of the simulations, such as variance, skewness, and Shannon entropy. Finally, we show that correlations between different foreground simulators also affect the generalization, and we quantify this effect using the mutual information between simulations.

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P20

Can the high-mass black holes from gravitational-wave observations be explained by gravitational lensing?

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The high-mass ($M \gtrsim 30 M_\odot$) black holes (BHs) from the gravitational-wave (GW) observations of LIGO and Virgo came as a surprise to many astronomers. While such BHs could be produced by the collapse of the metal-poor massive stars, gravitational lensing has been invoked as an explanation for the high masses. Broadhurst, Diego, and Smoot (henceforth BDS) argued that the mass distribution of BHs in the coalescing binaries is very similar to that of the galactic BHs, and the inferred high masses are the result of neglecting the lensing magnification [1, 2]. They also proposed a redshift distribution of binary BH (BBH) mergers that would explain the observed LIGO-Virgo mass distribution. We ask whether such a model is consistent with different aspects of the GW observations: 1) the observed number of BBH mergers, 2) their mass distribution, 3) the non-observation of strongly lensed events producing multiple images, and 4) the non-observation of the stochastic GW background. By simulating lensed BBH mergers using the BDS model and comparing them with the observations, we conclude that no choice of parameters of the BDS model is consistent with all aspects of the observations. Lensing magnification is not a viable explanation for the high-mass BHs discovered by LIGO and Virgo.

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P21 On the power spectrum of primary gravitational waves at high frequencies

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Primary gravitational waves (PGWs) are generated from the quantum vacuum during inflation. In slow roll inflation, the power spectrum (PS) of PGWs over large scales, which leave the Hubble radius during inflation, is nearly scale-invariant. However, over very small scales, which never leave the Hubble radius, the PS of PGWs rises quadratically. In this talk, I will first argue that the PS has to be regularized in order to truncate the unphysical quadratic rise at high frequencies. Assuming instantaneous transitions from inflation to the epochs of radiation and matter domination, we carry out the method of adiabatic subtraction to regularize the PS of PGWs. Thereafter, I describe the effects of smoothing the transition from inflation to radiation domination (to be precise, we smooth the 'effective potential' governing the equation of motion of PGWs) and discuss the impact of the smoothing on the regularized PS of PGWs [1]. Lastly, I shall utilize the Born approximation to examine the behavior of the regularized PS of PGWs over small scales when it is evolved through smoother and smoother transitions from inflation to the epochs of radiation and matter domination. I shall illustrate that, at small scales or, equivalently, at high frequencies, the suppression in the regularized PS of PGWs occurs more and more sharply as the transition is smoothed further and further. I will conclude with a brief summary.

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P22

HMFast: A Differentiable, JAX-Accelerated Python Library for Halo Model Cosmology

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The halo model provides a vital framework for bridging cosmological theory with the observable structures detected by modern astronomical surveys. However, its computational cost can often become a bottleneck for rigorous likelihood-based analyses. To address this, we introduce HMFast [1], a fully differentiable, JAX-native [2] Python package for halo model cosmology. By leveraging JAX's Just-In-Time (JIT) compilation and hardware acceleration on GPUs and TPUs, HMFast enables the computation of cosmological observables, such as angular power spectra on millisecond timescales, with significant performance gains compared to existing codes. In addition to this, its differentiable nature makes HMFast ideal for performing gradient-based sampling techniques such as Hamiltonian Monte Carlo, as well as for use in Simulation-Based Inference (SBI) and machine learning pipelines. Designed as a higher-performance successor to the widely-used `class_sz` code [3, 4], HMFast maintains functional parity while introducing expanded modelling capabilities and an architecture optimised for the modern differentiable programming ecosystem.

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P23

Reconstructing and distinguishing the formation and evolution of supermassive black holes using multi-wavelength gravitational wave observations

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The formation and evolution of supermassive black holes (SMBHs) remain a central problem in modern astrophysics. Astrophysical models typically invoke the formation of some 'seed' black holes at high redshifts, which grow into SMBHs over cosmic time through a combination of gas accretion and mergers. Although the observation of high-redshift quasars has provided useful constraints on these models, the details remain unclear. We explore how future multi-wavelength gravitational-wave (GW) observations using ground- and space-based detectors can collectively constrain these formation scenarios. By observing a larger range of black-hole masses and redshifts, multi-wavelength GW observations will significantly improve constraints on the SMBH growth models compared to observations using any single detector. We also identify remaining gaps in parameter space where detection remains challenging, highlighting areas where future GW detector development or complementary electromagnetic observations could provide breakthroughs.

P24

Gravitational production of mass-varying dark gauge bosons

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We investigate production of dark gauge bosons by quantum fluctuations during inflation within the framework of the gauged quintessence model, which the quintessence is gauged by an Abelian gauge symmetry. In gauged quintessence, the dark $U(1)$ gauge boson acquires a time-dependent mass through its coupling to the quintessence scalar field. The mutual interaction between the gauge boson and the quintessence field provides a minimal, self-contained mechanism for dark energy production without requiring additional couplings to the visible sector. Since the dark gauge boson is produced purely through gravitational interactions during inflation, its relic abundance is directly determined by the inflationary Hubble parameter $H_{\rm inf}$. By requiring that the resulting energy density accounts for the observed dark energy density today, we can place a constraint on $H_{\rm inf}$, thereby connecting late-time cosmological observations to the energy scale of inflation regardless of misalignment of thermal production. This offers a testable link between inflationary dynamics and the origin of dark energy.

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P25

Second Leptogenesis Induced by Wave Dark Matter

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Wave dark matter provides a well-motivated cosmological framework in which a coherently oscillating scalar field constitutes the dark matter of the Universe. As the Universe expands, the energy density of wave dark matter redshifts, leading to a gradual decrease in the oscillation amplitude over cosmic history. This cosmic evolution allows wave dark matter to act as a slowly evolving background that induces time-dependent particle masses through feeble couplings to the Standard Model sector. In this talk, we explore the cosmological implications of such time-varying masses, focusing on their impact on leptogenesis in the early Universe.

We study a novel leptogenesis scenario in which the mass of heavy Majorana neutrinos varies with cosmic time due to their coupling to wave dark matter [1, 2]. This leads to a characteristic thermal history featuring two stages of leptogenesis. The first occurs above the electroweak scale, where the generated lepton asymmetry is partially converted into a baryon asymmetry via sphaleron processes. The second leptogenesis takes place after sphaleron decoupling, producing an additional lepton asymmetry without affecting the baryon sector. This mechanism offers a natural explanation for a significant discrepancy between baryon and lepton asymmetries, as recently reported by EMPRESS.

Beyond leptogenesis, the same wave dark matter dynamics can induce oscillating scalar potentials and time-dependent neutrino mass structures [3, 4], giving rise to rich phenomenology in both cosmology and neutrino physics. We briefly comment on possible imprints on low-energy observables, such as lepton-number-violating processes and the cosmic neutrino background. This work highlights wave dark matter as a unifying framework linking early-Universe cosmology with present-day neutrino phenomenology.

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P26

Abstract preparation for a Workshop

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Fuzzy dark matter (FDM) assumes that dark matter (DM) is ultralight and bosonic, where DM halos are characterized by central soliton cores. These cores form through condensation and are stabilized by quantum pressure, which inhibits further self-gravitational collapse. Researchers have demonstrated that simulations of the Schrödinger–Poisson equation spontaneously generate solitons in periodic boxes initialized with a random wave field [1]. This suggests that similar structures may also arise across the outer regions of the halo, potentially serving as seeds for subhalos—gravitationally bound DM clumps within a larger host halo that are crucial for understanding galaxy formation and evolution. However, the soliton formation timescales measured in these studies were obtained under idealized conditions, neither accounting for box size effects nor the dynamical complexity of a realistic DM halo. Here, we address these limitations by investigating the dependence of these descriptions on box size, initial density, velocity dispersion, and FDM particle mass, utilizing *Jaxion*—a JAX-based, multi-GPU simulation framework for FDM [2]. By characterizing soliton formation rates and spatial distributions across these parameters, we establish a foundation for future work aimed at understanding soliton formation in realistic halo environments, with implications for subhalo seeding and the small-scale structure of FDM halos.

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P27

Emulators for ULDM

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Dark matter constitutes about 85% of the matter density of the Universe. However, its fundamental nature is still unknown, representing a major gap in our understanding of the Universe. There are many models for this elusive component. Ultra-light dark matter (ULDM), or ultra-light axions (ULAs), are the lightest dark matter candidates, and, given their well-motivated microphysics and rich phenomenology, they have become one of the main dark matter candidates. Cosmological data, such as the matter and the cosmic microwave background power spectra, make a fundamental contribution to constrain the physical properties of ULDM [1]. There are Boltzmann codes able to provide cosmological theoretical predictions for ULDM, such as `AxiECAMB` [2]. However, due to the involved cosmological evolution of ultra-light spin-0 fields, which may oscillate quickly at late times, achieving good precision and efficiency is a challenge for those codes. The computational cost of these Boltzmann codes constitutes a barrier to robust parameter inferences for ULAs. To overcome this problem, we are constructing an emulator based on neural networks to accelerate the acquisition of theoretical predictions.

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P28

Probing ultralight axionlike dark matter: A pulsar timing arrays-pulsar polarization arrays synergy

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Ultralight axionlike dark matter (ALDM) is a leading candidate in the dark matter realm, characterized by its prominent wave properties on astronomical scales. Pulsar timing arrays (PTAs) and pulsar polarization arrays (PPAs) aim to detect this dark matter through timing and polarization measurements, respectively, of pulsars. The PTA relies on gravitational effects, as the ALDM halo perturbs the spacetime metric within the Milky Way, while the PPA detects non-gravitational effects, namely cosmological birefringence induced by the ALDM Chern-Simons coupling with photons. These two methods complement each other, synergistically enhancing the pulsar array's capability to identify the ALDM signals in the data. In this article, we provide a foundational development of this synergy. We begin by revisiting previously derived two-point correlation functions for both PTA and PPA, and extend the analysis to include the leading-order correlation between timing and polarization signals, which is encoded as a three-point function. We then explore the constructions of likelihood functions for PTA and combined PTA-PPA analyses within a Bayesian framework, aimed at detecting the characteristic correla-

tions of ALDM signals. We emphasize the non-Gaussianity of the ALDM timing signals, which arises from their nonlinear dependence on the field, in contrast to the Gaussian nature of its polarization signals. To address the complexities introduced, we approach this investigation in two ways: one involves a Gaussian approximation with proper justifications, while the other derives the formalism from the generic Gaussian characteristics of the ALDM field. Particularly, for the combined PTA-PPA case, a clear connection between the three-point correlation function and the likelihood is established. We anticipate that these efforts will lead to further developments in PTA and PTA-PPA analysis methods, better accounting for the influence of non-Gaussianity.

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Abstract for Summer School on Cosmology | (smr 4223)

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We investigate the isotropy of the deceleration parameter q_0 using a hemispherical comparison analysis applied to the Pantheon+ Type Ia supernovae sample [1]. The analysis is performed using redshifts from the heliocentric frame, CMB frame redshifts and fully corrected Hubble diagram redshifts, as well as by progressively excluding low redshift supernovae where velocity effects are most significant. We find that a dipole like anisotropy in q_0 is present when standard redshift corrections are adopted, with the preferred axis closely aligned with the CMB dipole. Allowing the CMB dipole amplitude and direction to be inferred directly from the supernova data leads to a statistically consistent but mildly lower dipole amplitude compared to Planck [2], and significantly reduces the hemispherical q_0 signal when recomputed using updated zHD redshifts constructed with the supernovae inferred dipole parameters. These results suggest that previously reported anisotropies [3, 4] in the late time expansion may be partly driven by residual kinematic effects associated with the choice of reference frame and the modeling of peculiar velocities, rather than indicating a genuine violation of large scale isotropy. Our findings are consistent with expectations from tilted cosmological scenarios [5-7] and highlight the importance of redshift corrections and velocity modeling in precision tests of the Cosmological Principle.

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P30

Thermodynamics Positivity Bound from 3-Form Black Holes and Inflation with Higher-Derivative Corrections

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We investigate the interplay between the thermodynamics positivity bounds and slow-roll inflation within a framework governed by a 3-form gauge field. Starting from classical considerations, we derive an upper bound on the mass of extremal charged black holes in dS spacetime which constrains the admissible parameter space. To incorporate quantum gravity effects, we introduce higher-derivative corrections to the 3-form action and obtain additional bounds on these terms, ensuring consistency with swampland criteria. We further analyze these corrections from a thermodynamic perspective, confirming that the Wald entropy remains compatible with the classical extremality bound. Extending this setup to cosmological inflation, we examine the scalar dual of the 3-form in both large- field and small-field regimes. In the large-field limit, the potential acquires a Higgs-like structure that supports slow-roll inflation. In contrast, the small-field limit leads to an effective potential with an AdS minimum, rendering it inconsistent with the dS swampland constraints. Notably, we find that thermodynamic consistency can impose constraints more stringent than those derived from inflationary dynamics alone. These results underscore the utility of swampland-inspired principles in shaping viable models of early universe cosmology.

P31

CMBubbles: Search for a multiverse in Planck data

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Chaotic eternal inflation theory proposes the existence of bubble universes. Due to physical limitations, these bubble universes cannot be directly observed as an observer from one universe would need to be super-relativistic to be able to observe another bubble from within their own. Indirect methods must then be found to infer the existence of other bubbles via universe collisions. When two bubbles collide, their collision can leave specific imprints in the Cosmic Microwave Background (CMB) temperature data. These can be identified using various filtering techniques. In this poster, we go identify the use of one such technique: optimal filtering. We highlight candidate features using the optimal filtering technique on the *Planck* CMB temperature data, finding the anomalous CMB Cold Spot as one of them. We notice specific patterns about these features, noting that they are all located in the southern hemisphere region. We conduct validation tests using a frequentist approach, and discuss the need for future higher resolution data alongside a study of the collision candidate profile in polarisation data.

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P32

Tidal Force in Newtonian Gravity

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Introduction

- The tidal force is the difference in gravitational pull that an extended object feels because of another massive body nearby.
- The gravitational force gets weaker as distance increases. This means that the side of the object closer to the massive body feels a stronger pull than the side that is farther away.
- To look at how tidal forces affect an object's stability, we used two model densities: i) **Power Law** and ii) **Sersic density profile**.
- We also considered that most systems are **not isolated** and are impacted by outside forces.
- Therefore, the stability criterion can change due to the gravitational potential caused by the mass distribution around the system.
- So, we determined the stability conditions and stability parameters for these systems under the above density profiles.

Methods

- The stability of a homogeneous system, mostly gaseous, is maintained by pressure and governed by **hydrodynamical equations**.
- We solved the hydrodynamic equations for small perturbations.
- The modified dispersion relation for linear perturbation (When the system is under the influence of external potential.)-

$$\nabla \cdot (\rho \quad) + \frac{\partial \rho}{\partial t} = 0 \quad \text{Continuity equation} \tag{1}$$

$$\rho \frac{\partial}{\partial t} + \rho(\quad \cdot \nabla) \quad = \quad \nabla(c^2 \rho) \quad \rho \nabla(\phi + \Phi_{ext}) \quad \text{Force equation} \tag{2}$$

$$\nabla^2 \phi = 4\pi G \rho \quad \text{Poisson Equation} \tag{3}$$

Jeans/Jog Length and Mass Analysis

Without External Potential ($\Phi_{ext} = 0$)	With External Potential ($\Phi_{ext} \neq 0$)
$\omega^2 = c^2 k^2 \quad 4\pi G \rho_0$	$\omega^2 = k^2 c^2 \quad 4\pi G \rho_0 + T_0$
$\lambda_{Jeans} = \left(\frac{\pi c^2}{G\rho_0}\right)^{1/2}$	$\lambda_{Jog} = \lambda_{Jeans} \left(1 \quad \frac{\rho_{eff}}{\rho_0}\right)^{1/2}$
$M_{Jeans} = \rho_0 \cdot \frac{4}{3}\pi \left(\frac{\lambda_{Jeans}}{2}\right)^3$	$M_{Jog} = M_{Jeans} \left(1 \quad \frac{\rho_{eff}}{\rho_0}\right)^{3/2}$

Stability of Density Fluctuation under Tidal Stresses

I) Power Law Profile:

$$\rho(r) = \rho_0 \left(\frac{r}{r_0}\right)$$

II) Sersic Density Profile:

$$\rho(r) = \rho_e \left(\frac{r}{R_e}\right)^{P_n} \exp\left(\quad b_n \left[\left(\frac{r}{R_e}\right)^{\bar{n}} \quad 1\right]\right) \quad \text{(With exponent factor)}$$

$$\rho(r) = \rho_e \left(\frac{r}{R_e}\right)^{P_n} \quad \text{(Without exponent factor)}$$

where:

$$P_n = 1 \quad \frac{0.6097}{n} + \frac{0.05463}{n^2}, \quad b_n = 2n \quad \frac{1}{3} + \frac{4}{405n} + \frac{46}{25515n^2}$$

Tidal tensor components:

$$\tau_{rr}^{sph} = \quad \frac{\partial^2 \Phi^{sph}(r)}{\partial r^2}, \quad \tau_{\theta\theta}^{sph} = \tau_{\phi\phi}^{sph} = \quad \frac{1}{r}\frac{\partial \Phi^{sph}(r)}{\partial r}$$

Note: Tidal tensor is spherically symmetric. And **only have diagonal components**.

Results

- We have looked into the effect of tidal forces on Jean's stability criterion.
- The corresponding modified criteria (Jog) are written down and analyzed for two different density profiles (power law and Sersic) and consequences thereof are obtained.
- We have tried to identify parameters (in the density profiles) of domains and their links with stability.
- Finally, we did the stability analysis of 142 observed fragments (real data set).

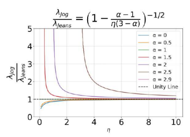

Figure 1. $\frac{\lambda_{Jog}}{\lambda_{Jean}}$ v/s η for different

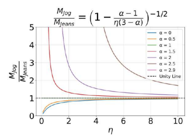

Figure 2. $\frac{M_{Jog}}{M_{Jean}}$ v/s η for different

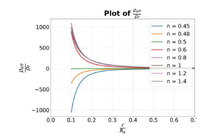

Figure 3. $\frac{\rho_{eff}}{\rho_f}$ v/s r/R_e (With exponent)

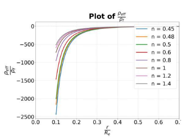

Figure 4. (Without exponent)

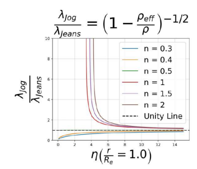

Figure 5. $\frac{\lambda_{Jog}}{\lambda_{Jean}}$ v/s η for $\frac{r}{R_e}$ =1

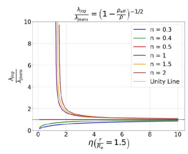

Figure 6. $\frac{\lambda_{Jog}}{\lambda_{Jean}}$ v/s η for $\frac{r}{R_e}$ =1.5

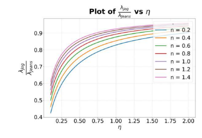

Figure 7. $\frac{\lambda_{Jog}}{\lambda_{Jeans}}$ v/s η (Without expo)

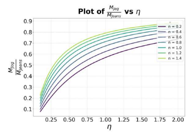

Figure 8. $\frac{M_{Jog}}{M_{Jeans}}$ v/s η (Without expo)

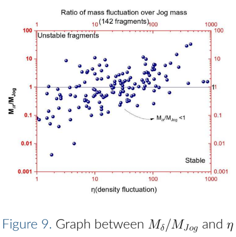

Figure 9. Graph between M_δ/M_{Jog} and η

1. The tidal force generated by the external potential can be either compressive or disruptive.
2. In with exponent case: For higher values of r compressive as well as disruptive strength increases.
3. For higher values of η (without exponent) there is **no tidal force** i.e. Jog length/mass **equal** to Jeans length/ mass respectively.

Conclusions

- The power law density profile shows a compressive nature (Contributes to collapse) for <1 and disruptive (Makes it harder to collapse) for >1 and no tidal force for ≈ 1.
- The sersic density profile shows compressive nature for $n<0.5$ and disruptive for $n>0.5$ and no tidal force for ≈ 0.5.
- **With exponential factor**: In the **Sersic profile**, as r increases, the system becomes compressible or disruptive very quickly for fixed different values of n.
- **Without expo. factor**: The system is **always compressive** irrespective of the value of n.
- M_δ/M_{Jog} for nearly 47% shows a compressive nature and rest disruptive nature (i.e. Most of the part shows a **stable nature** in 142 fragments.)
- **Future work:** To study the Tidal force in General relativity(GR) under cosmological background (FLRW) and how the stability conditions change under this analysis of GR.

Acknowledge

I express my sincere gratitude to my supervisor, **Dr. Sayan Kar**, for his invaluable time and effort throughout the year. His useful advice and suggestions were truly beneficial to me during the completion of the project. In this regard, I am deeply grateful to him.

I would also like to take this opportunity to thank my family members and classmates for their support.

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Appendix

Aspect	Disruptive Tidal Forces	Compressive Tidal Forces
Effect on Object	Pulls apart, potentially destroying the object	Compresses the object in certain directions
Condition	Strong differential forces exceed self-gravity	Strong forces compress along perpendicular axes
Examples	Roche limit, TDEs, disrupted moons	Star formation, planetary rings, Earth's tides

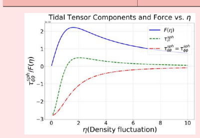

Figure 10. Isothermal distribution.

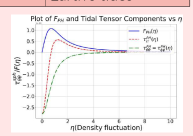

Figure 11. Plummer distribution

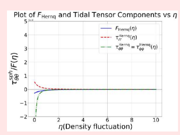

Figure 12. Hernquest distribution

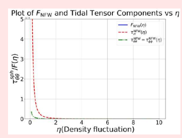

Figure 13. NFW distribution

P33

Accretion of Generalized Chaplygin Gas onto Cosmologically Coupled Black Holes

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We study the accretion of cosmic dark fluids, responsible for driving the accelerated expansion of the universe, onto cosmologically coupled black holes. More specifically, we focus on the accretion of the Generalized Chaplygin Gas (GCG) [1, 2]. To incorporate the global features of the GCG into this analysis, we employ the McVittie metric [3, 4, 5], which describes a black hole embedded in an expanding cosmological background. Within this framework, accretion is studied while consistently accounting for the backreaction on the metric components [6, 7]. Using a perturbative approach, we derive an expression for the effective black hole mass and for the evolution of both the black hole and cosmological apparent horizons under accretion. The analysis is performed in two distinct cosmological regimes: first, a matter-dominated era, and subsequently, a de Sitter era. In both cases, it is possible to determine analytically the instant in which accretion begins. For the matter-dominated era, the analytical expression shows that the greater the amount of matter available for accretion, the longer the accretion takes to start.

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CMB Circular Polarization from Photon-Dark Photon Forward Scattering

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In this article we examine the interaction between the dark photons and CMB photons to find its effect on the CMB polarization. Dark photons are hypothetical bosons in the dark sector that can interact with the visible photons through a kinetic mixing mechanism[1]. This interaction can cause the CMB photons to acquire circular polarization, which does not occur in the Standard Model (SM) [2], and could be a signature of the Beyond the Standard Model (BSM) physics. By studying the evolution of CMB circular polarization, calculating the polarization power spectrum, and comparing them with the CMB data, one can set new limits on the kinetic mixing parameter and the dark photon mass. The kinetic mixing portal is one of the few renormalizable portals between the SM and the dark sector, so studying the constraints on the dark photon in this portal is very important for understanding the dark sector. Additionally, if circular polarization for the CMB photons is detected in the future by some experiments like the Simons Observatory, it could strongly support BSM theories.

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P35

Abstract template for Detection of anomalies in the Large Scale Structure through cosmological inference

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Modern cosmology relies on the LambdaCDM model, which, despite its successes, faces significant theoretical uncertainties emerging from observational tensions. Traditional searches for "new physics" are limited by model bias, as they typically test specific parametric extensions, potentially overlooking unexpected anomalies. This project proposes a fully model-independent framework to detect deviations in the Large Scale Structure (LSS) data. We adapt the New Physics Learning Machine (NPLM) methodology to cosmology, training deep neural networks to approximate the likelihood ratio between observed data and the reference model directly. By integrating rigorous theoretical predictions from EFTofLSS with emulators, we will apply this agnostic pipeline starting with the power spectrum (P(k)), the bispectrum (B(k)) and the full field-level inference on 3D density maps; in order to harness deep learning to extract subtle non-Gaussian information inaccessible to standard compressed statistics, maximizing the sensitivity to unknown physics.

[1] Alejandro Morales Diaz, phd ongoing thesis project (2026)

P36

Toward Unbiased Primordial B-mode Detection: Mitigating Foreground Contamination in Ground-Based CMB Experiments

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Observations of the Cosmic Microwave Background (CMB) B-mode polarisation provide a powerful probe of inflationary physics [1]. Robust constraints on the tensor-to-scalar ratio r, however, require accurate removal of diffuse Galactic foregrounds, whose residuals can bias the signal. We present two extensions of the Needlet Internal Linear Combination (NILC) framework to mitigate foreground-induced biases in r [2]. The first incorporates deprojection of selected foreground moments within the component-separation step [3], while the second performs likelihood-level marginalisation over residual foreground power using a data-driven template [4].

Using Simons Observatory Small Aperture Telescope (SO-SAT)-like simulations, we show that both methods effectively suppress foreground contamination, yielding unbiased estimates of r and consistent reconstruction of the lensing B-mode amplitude [5]. These results highlight the importance of advanced foreground mitigation for next-generation CMB polarisation experiments.

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P37

Constraining Cosmic Inflation Using Fisher Matrix Formalism with N-Counts and Weak Lensing Observables

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The observable universe originates from a simple set of initial conditions established within a very short time at the beginning of cosmic evolution [1]. Cosmological inhomogeneities arise from the primordial curvature fluctuation, ζ, which is typically assumed to follow a Gaussian distribution. Deviations from Gaussianity emerge from nonlinear interactions of ζ, and their detection would provide valuable insight into the physics of the early universe. In this scenario, non-Gaussian model beyond the standard polyspectra approach has been proposed by the cosmology group at the University of Chile, extending the parameter space and improving our ability to probe it through observations of the cosmic microwave background (CMB) and large-scale structure (LSS). In this work, we adopt survey configurations such as LSST, Euclid, and HSC to construct a Fisher matrix, which enables us to constrain the non-gaussian model parameters using cosmological observables. Due to the nature of the model, we initially employ the number counts (N-counts) observable. However, the resulting uncertainties on the parameters are large compared to their fiducial values. We therefore propose that the inclusion of weak lensing observables could significantly improve these constraints. If successful, this approach would provide a viable method to probe the proposed non-Gaussian model.

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P38

Flavored Electroweak Baryogenesis

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The origin of the universal asymmetry between matter and antimatter remains a mystery. Electroweak baryogenesis is a well-motivated mechanism for generating the asymmetry dynamically, using interesting features of the Standard Model. The out-of-equilibrium nature of the problem requires an approximation scheme, but existing literature has order-of-magnitudes differences in the final baryon yield due to the different schemes. [1,2] We aim to provide a consistent approximation scheme that can be naturally extended to higher orders. We will first apply this scheme to a bosonic toy model, and afterwards a fermionic toy model. The research is still in progress, though we expect the bosonic model to be done by the time of the ICTP school.

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P39

Recalibrating the L-σ relation for H II galaxies: implications for independent measurements of H_0

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In this work, we present preliminary results on the recalibration of the anchor sample (the first rung) of the $L-\sigma$ relation, aiming to reduce the uncertainties in H_0 estimates and to investigate possible systematic trends. The $L-\sigma$ relation for H II Galaxies (HIIG) provides an alternative three-rung cosmic distance estimator that uses local Giant Extragalactic H II Regions (GEHR) as the anchor sample. GEHR and HIIG are blue massive starburst systems that exhibit a seemingly ubiquitous correlation between their Hβ luminosity and their spectroscopic velocity dispersion, known as the $L-\sigma$ relation [1, 2]. Chavez R., *et al.*[3], and works related ([4, 5, 6, 7]), have extensively applied this method to obtain precise estimates of H_0, as well as constraints on Ω_m and w_DE, both independently and through joint likelihood analyses with other cosmological probes. Although the $L-\sigma$ method is very promising, particularly given the redshift range it expands to ($z\sim 7$), its systematic error budget remains much less explored than that of the SN Ia method. We compiled and homogenized a sample of distance moduli for 32 host galaxies through an extensive review of the literature available in the astronomical database NED [8]. Our compilation includes values reported over the last 26 years, focusing on measurements obtained with primary distance indicators, namely Cepheids and TRGB, whose systematic uncertainties are relatively well understood. Using a hierarchical Bayesian framework for error propagation, and applying the $L-\sigma$ method to high-resolution spectroscopic data, we find that H_0 estimates based exclusively on Cepheid distances yield $H_0 = (74.1 \pm 3.8)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, in agreement with the SH0ES collaboration measurements [9]. We also found that there is no strong statistical disagreement on H_0 estimates with and without metallicity corrections for Cepheids data only. On the other hand, using only TRGB distances yields $H_0 = (67.3 \pm 3.8)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, consistent with the Planck collaboration and CCHP estimates [10, 11]. These results could reinforce the idea that part of the Hubble tension may be driven by internal systematic trends within the cosmic distance ladder, as suggested by [12] and similar works. Identifying the most appropriate anchor calibration for each host galaxy may therefore be valuable both for future applications of the $L-\sigma$ relation as a cosmological probe and for distance-dependent astrophysical analyses.

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P40

Study of clustering trends and gravitational potential profiles in the Large Scale Structure of Universe

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In our work, we try to understand how relativistic effects imprint themselves on galaxy clustering and how these signatures can be used as tests of gravity on cosmological scales. We particularly focus on the phenomenon of gravitational redshift, one of the fundamental predictions of GR, which can serve as an important tool in this scenario.

Since the expression for gravitational redshift is in terms of the underlying potential field, we investigate the gravitational potential profiles of simulated dark matter halos using high-resolution simulations. The aim is to model how the potential difference between pairs of dark matter halos evolves as a function of the separation between them. The challenge is to model this in such a way that the framework works well in the non-linear, linear, and intermediate regimes of halo separations. The non-linear regime can be well modelled by dark matter density profiles like NFW [1] and DK14 [2], while the linear regime will be in terms of the two-point halo–matter cross-correlation function. The intermediate regime has to be carefully looked into, which is what we plan to do with the high-quality Sahyadri simulations [3] that we are currently working on. We are also in the process of developing a Python code based on the Barnes–Hut tree algorithm used by GADGET [4], with performance-critical parts implemented in Cython, which can calculate potentials for targets up to billion order within feasible computational times.

In our earlier projects, we have tested the analytical framework for dark matter halo potentials in terms of halo–matter cross-correlations, linear bias, and the matter power spectrum using low-resolution simulations like RayGal, which gave good results, and we wish to improve on them in the near future. In a related work, we have also studied relativistic distortions in redshift-space galaxy clustering by means of the two-point correlation function and its multipoles. We have reproduced the results from the literature that peculiar velocities generate even multipoles in both auto-correlation and cross-correlation functions, while gravitational redshift produces a distinctive dipole in the cross-correlation of differently biased tracers. This dipole provides a clean relativistic signal that is insensitive to many Newtonian systematics, making it a promising observable for tests of General Relativity. Our goal would be to model this dipole in terms of the potential framework that we are building on, so that we can use it on real data from galaxy surveys.

Overall, my research aims to build analytically robust and observationally relevant models of relativistic effects in large-scale structure, with direct applicability to precision measurements from current and upcoming surveys such as DESI. We hope to improve on the current results with real data in the near future.

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P41

Accelerating reionization constraints: An ANN-emulator framework for the SCRIPT Semi-numerical Model

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The Epoch of Reionization (EoR) marks the last major phase transition in the universe, during which the intergalactic medium (IGM) was heated and ionized from an initially cold, neutral state [1]. Studying the EoR is crucial for understanding the formation of the first stars and galaxies, the buildup of large-scale structure, and the thermal and ionization history of the IGM that shaped the observable universe. Although recent theoretical and observational efforts have significantly advanced our understanding, key aspects of the reionization timeline and its physical drivers remain unresolved. A new generation of high-redshift observations is beginning to place stringent constraints on the underlying astrophysical processes. However, translating these constraints into quantitative inferences using physically motivated simulations remains computationally prohibitive with conventional approaches. In this work [2], we introduce an efficient emulator-based framework that dramatically reduces this bottleneck for the photon-conserving semi-numerical code `SCRIPT` [3, 4, 5]. Our approach combines (i) a reliable coarse-resolution MCMC to locate the high-likelihood region (exploiting the large-scale convergence of `SCRIPT`) with (ii) an adaptive, targeted sampling strategy to build a compact high-resolution training set for an artificial neural network based emulator of the model likelihood. With only $\approx 10^3$ high-resolution simulations, the trained emulators achieve excellent predictive accuracy ($R^2 \approx 0.97$–0.99) and, when embedded within an MCMC framework, reproduce posterior distributions from full high-resolution runs. Compared to conventional MCMC, our pipeline reduces the number of expensive simulations by a factor of ~ 100 and lowers total CPU cost by up to a factor of ~ 70, while retaining statistical fidelity. This computational speedup makes inference in much higher-dimensional models tractable (e.g., those needed to incorporate JWST and upcoming 21 cm datasets) and provides a general, scalable strategy for accelerating parameter inference across a wide range of cosmological applications.

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P42

Theoretical Uncertainties in Cosmological Phase Transitions: Hydrodynamics, Bubble Wall Velocity, and Beyond

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Gravitational waves from first-order cosmological phase transitions provide a powerful probe of physics beyond the Standard Model, and upcoming space-based gravitational wave observatories motivate increased precision in theoretical predictions for these signals. In this talk, I will describe a systematic framework for predicting the gravitational wave spectrum from such phase transitions. By combining a recent precision treatment of the fluid plasma hydrodynamics [1] with state-of-the-art calculations of the bubble wall velocity and the resulting gravitational wave power spectrum within the sound-shell model, we establish a self-consistent pipeline for first-order phase transition predictions. I will then discuss sources of theoretical uncertainty at each stage of this calculation and assess their relative impact on the predicted spectrum. I conclude by estimating the cumulative effect of these uncertainties, thereby setting a benchmark for the overall systematic error in gravitational wave predictions from cosmological phase transitions.

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P43

Signature of the non-linear structure formation on the early cosmic dawn 21-cm signal

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The 21-cm line of hydrogen is the most promising probe of the Dark Ages and Cosmic Dawn. We combine hydrodynamical simulations with a large-scale grid in order to calculate the effect of non-linear structure formation on the large-scale 21-cm power spectrum, focusing on redshifts $z = 20 - 40$. As the clumping effect arises from small-scale density fluctuations, it offers a unique opportunity to probe the standard cold dark matter model in a new regime and thus potentially investigate the properties of dark matter [1]. To this end, we also study a warm dark matter − like model with a Gaussian cutoff on a scale of 50 kpc. We find that clumping has a significant impact on the large-scale 21-cm power spectrum [2], requiring a substantial correction to standard theoretical predictions. For example, for the Dark Ages case at $z = 30$ and wavenumber $k = 0.05$ Mpc^{-1}, small-scale clustering enhances the 21-cm power spectrum by 13%. Once Lyman-α coupling kicks in due to the first stars, the 21-cm signal strengthens, and the effect of clumping grows; it suppresses the observable power spectrum at $z = 20$ by 45%, while the warm dark matter − like model has less than half the clumping impact. The clumping effect is significantly higher than the sensitivity of the planned Square Kilometre Array (SKA) AA* configuration, by up to a factor of 20 for standard cold dark matter, though detection will require separation from foregrounds and from astrophysical contributions to the 21-cm power spectrum.

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P44

Impact of self-interaction and photon interactions on solitonic structures in ultralight dark matter

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Ultralight dark matter (ULDM) has emerged as a compelling alternative to the standard cold dark matter (CDM) model by forming quantum-pressure-supported solitonic cores that address small-scale structure anomalies. In this work, we investigate the dynamics of solitons in ULDM by numerically evolving scalar field configurations under gravity, incorporating a range of interaction terms. We analyse soliton formation, stability, and collisions driven solely by quantum pressure and gravity, focusing first on the non-interacting case. We then introduce self-interactions via quartic, axion monodromy, logarithmic, and Sinh-Gordon potentials, each inducing distinct dynamical behaviour: repulsive quartic terms enhance stability, attractive interactions can lead to collapse, axion monodromy introduces saturation effects that modify core compactness, logarithmic terms suppress central density growth, and Sinh-Gordon interactions lead to deformation and fragmentation at high strengths. In order to analyse the effect of photon interactions beyond self-interactions, we observe the destabilization of solitonic structures even in the absence of scalar self-couplings. When both self- and photon-interactions are incorporated, soliton dynamics become highly sensitive to the specific potential, significantly influencing post-collision behaviour and long-term coherence. We provide a comprehensive analysis of soliton dynamics in ULDM across varying interaction types and parameter regimes, highlighting the complex dynamical behaviour of these quantum structures.

P45

Oscillon Formation in the Post-Inflationary Universe

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After inflation ends, the inflaton field typically begins to oscillate about the minimum of the inflationary potential. During this phase, parametric resonance between the field and its perturbations can cause inhomogeneities to grow. Some models support the existence of significantly overdense, oscillatory field configurations known as oscillons [1]. Oscillons are long-lived with respect to the Hubble time at their formation [2] and hence may leave observational traces, either via changing the post-inflationary expansion history or through the production of high-frequency gravitational waves [3]. We look at possible inflationary potentials and explore the regions of parameter space in which oscillons can form. We correlate those regions with cosmological observables set during inflation itself and show that in many specific models, parameter choices leading to a smaller inflationary gravitational wave background at CMB scales are more likely to lead to oscillon production.

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P46

Off the wall: halo spin alignments and the dynamical importance of cosmic walls

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The large-scale structure of the cosmic web shapes the properties of galaxies. Walls occupy a large part of the cosmic volume and mass, yet remain much less explored than filaments and voids,as they are harder to identify robustly. Here, the influence of nearby walls on void galaxies is studied as a function of distance to the closest wall, using halo spin as a proxy for galaxy morphology. N-body simulations combined with a topological web classifier provide a segmentation into voids and walls, which are then populated with galaxies from a semi-analytic model. Our preliminary results show that the spin distributions of galaxies in voids and walls are similar when compared at fixed halo mass. To disentangle the role of walls, we examine both spin magnitude and alignment as a function of galaxy distance to the nearest wall. These trends indicate that walls are dynamically important components of the cosmic web, bridging void and filaments as intermediate stages in the anisotropic collapse of structure.

Abstract template for poster presentation

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In typical inflationary scenarios, the inflaton field oscillates around its minimum after the accelerated expansion completes. In some cases, inhomogeneities can grow explosively, while in others, the universe is effectively matter-dominated and inhomogeneities grow gravitationally [1]. The dynamics in the latter case resemble structure formation in the present epoch, leading to the formation of "inflaton halos" that host localized overdensities, or "solitons", at their centres. On scales comparable to the de Broglie wavelength of the inflaton field, "quantum pressure" stabilizes the gravitational collapse, supporting stable, localised field configurations that can be interpreted as Bose–Einstein condensates (see [2] for a review). To first approximation, this epoch is described by the Schrödinger -Poisson equation [3, 4, 5], but inflaton self-interactions and relativistic gravitational corrections eventually become significant as the overdensities grow. Cosmic microwave background observations indicate that the inflationary potential must be quadratic near its minimum and flatten at large field values [6]. Therefore, nonlinearities must be included in the analysis of early solitons. Following the approach taken in [7], we examine two representative inflationary potentials to determine the extent to which the Schrödinger–Poisson description, and subsequently the Gross-Pitaevskii-Poisson description [8, 9], remains valid and we assess the likelihood that this formalism could become inconsistent prior to thermalization.

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P48

Bayesian Constraints on Primordial Black Hole Production from Cosmic Inflation

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Primordial black holes (PBHs) are a compelling dark matter candidate, yet no existing study has subjected PBH-producing inflationary models to direct statistical confrontation with CMB data. We present the first such Bayesian analysis. We perform Markov Chain Monte Carlo analyses of PBH-producing inflation models fit to CMB data from Planck, ACT, and SPT. We study a single-field inflection-point model and its spectator field extension, in which a light scalar field amplifies the small-scale enhancement of the curvature power spectrum while alleviating the fine-tuning required in the single-field case. We present posterior constraints on PBH model parameters, characterize degeneracies between PBH abundance and cosmological observables, and compare the single-field and spectator posteriors as a direct, data-driven measure of fine-tuning. This work brings PBH-producing inflation models into the era of precision cosmology.

P49

DATA ANALYSIS AND SYSTEMATICS MITIGATION FOR THE LSPE-SWIPE EXPERIMENT

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The LSPE-SWIPE[1] mission is a stratospheric balloon-borne experiment designed to measure the linear polarization of the Cosmic Microwave Background (CMB) at large angular scales, aiming to constrain the tensor-to-scalar ratio through the detection of primordial B-modes. Achieving the required sensitivity demands extreme control over instrumental systematics and an accurate separation of polarized galactic foregrounds.

In this contribution, I present the development and validation of an end-to-end data analysis pipeline for the SWIPE instrument. A central part of this work involves the mitigation of systematic effects introduced by the Half-Wave Plate (HWP) modulator. I implemented a maximum-likelihood map-making algorithm[2] combined with specific notch-filtering techniques to suppress HWP-induced signals.

Furthermore, I explore the integration of component separation methods, specifically utilizing the BROOM[3] (Blind Reconstruction Of Observables in the Microwaves) framework, to reconstruct the CMB signal from synchrotron and thermal dust emissions. I evaluate the pipeline's performance through the analysis of the recovered angular power spectra, assessing the impact of noise, residual systematics, and foreground emissions. This integrated approach, from TOD-level simulations to final power spectrum reconstruction, provides a complete pipeline to reconstruct the B-mode signal and investigate the physics of inflation.

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P50

The Clustering of Galaxy Clusters

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Abstract

Understanding how galaxy clusters trace the underlying dark-matter is vital for using them as cosmological probes. In this work, we measure the spatial correlation function of galaxy clusters that were selected from the Atacama Cosmology Telescope Data Release 6 (ACT DR6) Sunyaev-Zel'dovich (SZ) catalog [1]. We measure the two-point correlation function across redshift bins up to $z = 1.4$. We then compare observed clustering with that predicted by N-body simulations of structure formation in a standard cosmological model and explore a variety of mass and redshift cuts. Since clusters make up the extreme end of the dark-matter halo mass distribution and are expected to be highly biased, they provide a sensitive probe of the evolution of bias. Our measurements confirm that these clusters are highly biased and, across all mass bins, we observe a rising bias with redshift, consistent with theoretical expectations for rare, massive halos in ΛCDM. We note that the measured bias is scale dependent with an unexpected increase of bias on larger scales.

To interpret the results, we compare the measurements with several widely used halo-bias models, including models referenced in [2] and discuss the implications for structure formation theory and the use of clusters as cosmological probes.

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P51

Spectral transmittance functions of intergalactic medium for sources from Cosmic Down and Reionization epochs

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We analyse the formation of broad absorption troughs in the spectra of high-redshift ($5 \leq z \leq 15$) sources. We assume that neutral hydrogen and helium in a homogeneous intergalactic medium are predominantly in their ground states and absorb the radiation from distant sources through the Lyman-series lines and continua of HI, HeI, and HeII. We compute the wavelength-dependent optical depths in the Lyman-series lines of HI, HeI and HeII, as well as in the corresponding Lyman continua, and use them to derive spectral transmittance functions of the intergalactic medium. We show that spectral features in the continuous spectra of sources at $5 \leq z \leq 7$ are particularly sensitive to the reionization histories of both hydrogen and helium. We present a compact analytic prescription for the effective intergalactic spectral transmittance caused by hydrogen and helium absorption over the redshift range $0 \leq z \leq 15$. The formalism provides closed-form expressions for the wavelength-dependent transmission of the intergalactic medium, including the Lyman-series transitions and continua of HI, HeI, and HeII, calibrated to observationally constrained reionization histories.

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Constraining Non-Bunch-Davies Initial Conditions with Galaxy Power Spectrum and Bispectrum

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Standard models of cosmic inflation typically assume the Bunch-Davies vacuum for initial quantum fluctuations. However, relaxing this assumption to allow for generalized, non-Bunch-Davies initial states introduces distinct imprints on the primordial bispectrum, most notably peaking in the folded triangle configurations. In this work, we investigate the observational signatures of these non-Bunch-Davies initial conditions on the Large-Scale Structure (LSS) of the universe.

We develop an analysis pipeline with the Effective Field Theory of Large-Scale Structure (EFTofLSS) to model galaxy clustering in redshift space. The analysis pipeline computes the galaxy power spectrum at one-loop order and the bispectrum at tree-level, incorporating redshift-space distortions (RSD) and modifications to the scale-dependent bias and loop corrections induced by non-Bunch-Davies initial conditions. To evaluate the observability, we perform a Fisher Forecast for upcoming high-density spectroscopic surveys. We demonstrate that a joint analysis of the power spectrum and bispectrum breaks degeneracies between the primordial non-Gaussian signal and nonlinear galaxy bias parameters in a range of non-Bunch-Davies parameter space. The joint forecasting framework demonstrates that LSS serves as a high-precision laboratory for exploring the initial conditions of the universe.

P53

GRAVITATIONAL INSTABILITY AND LARGE-SCALE STRUCTURE FORMATION: A CATASTROPHE-THEORY PERSPECTIVE

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The large-scale structure (LSS) of the Universe arises from the gravitational amplification of primordial density fluctuations, forming the cosmic web of sheets, filaments, cluster nodes, and underdense voids [1-3]. While linear perturbation theory successfully describes the early stages of structure growth, it breaks down once density fluctuations evolve into the nonlinear regime. In a Lagrangian framework, the onset of nonlinearity is marked by shell-crossing, where multiple streams of the collisionless dark-matter flow overlap and multistream regions form. In the Zel'dovich approximation, these regions are associated with caustics, corresponding to formally divergent densities [3-4].

Catastrophe theory offers a geometric and analytic framework for classifying these nonlinear structures. In the caustic-skeleton approach, the folding of the dark-matter phase-space sheet is organized into a limited set of stable Lagrangian singularities, including folds (A_2), cusps (A_3), swallowtails (A_4), and umbilic catastrophes (D_4) [3,4]. The spatial distribution and connectivity of these singularities provide a natural description of the morphology and topology of the cosmic web [1,5].

For approximately Gaussian initial conditions, the statistical properties of catastrophe points and lines can be computed analytically using Rice-type formulae applied to the eigenvalue fields of the deformation tensor [1]. This yields number densities for point catastrophes and length densities for catastrophe lines in one and two dimensions within the Zel'dovich approximation [1,3]. These results demonstrate how catastrophe theory complements numerical simulations by providing analytic insight into the geometry and statistics of nonlinear gravitational collapse.

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