Summer School on Cosmology | (SMR 3945)

17 Jun 2024 - 28 Jun 2024
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T01

Constraints on inflation model from preheating

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Abstract

Production of gravitationally coupled light moduli fields must be suppressed in the early universe so that their decay products do not alter Big Bang Nucleosynthesis (BBN) predictions for light elements. On the other hand, the moduli quanta can be copiously produced non-thermally during preheating after the end of inflation. In this work, we study the production of moduli in the α-attractor inflationary model through parametric resonances. For our case, where the inflationary potential at its minimum is quartic, the inflaton field self-resonates, and subsequently induces a large production of moduli particles. We find that this production is suppressed for small values of α. Combining semi-analytical estimation and numerical lattice simulations, we infer the parametric dependence on α and learn that α needs to be $\lesssim 10^{-8} m_{\rm Pl}^2$ to be consistent with BBN for $\mathcal{O}(1)$ coupling between the inflaton and moduli. This, in turn, predicts an upper bound on the energy scale of inflation and on the reheating temperature.

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T02

Gravitational waves induced by scalar-tensor mixing

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This talk explores second-order gravitational waves (GWs) originating from scalar-tensor perturbation interactions during the radiation-dominated phase of the Universe [1]. We investigate the unique features and detectability of these GWs compared to the scalar-induced ones. Unlike scalar-scalar induced GWs, scalar-tensor induced GWs lack resonances or logarithmic running in the low frequency spectrum with peaked primordial spectra. However, they exhibit inheritance of primordial parity violations from tensor modes, particularly in the ultraviolet (UV) region due to chirality in primordial GWs. We also address potential divergences in our GWs analysis and explore solutions. This study significantly contributes to understanding GWs in the early Universe, with implications for cosmology and GWs detection.

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T03

Constraining compact dark matter from the non-observation of strong lensing of gravitational waves

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In this paper, we have used the non-observation of strong lensing of gravitational waves in the first three observation runs of LIGO-VIRGO detectors to constrain compact dark matter in the mass range $10^5 - 10^8$ $\mathrm{M}_\odot$. Using a Bayesian formalism supplemented by astrophysical simulations of strong lensing of GWs, we are able to constrain the fraction of such compact objects to $\lesssim 40 - 60\%$ with currently available data and show that they can get significantly tighter in the future. We find that multiple lensing of the same source is possible, though, through a thorough analysis, we show that it would affect the final result by $\lesssim 10\%$. We give a general prescription to analyze the importance of multiple lensing and show that it will be even less important for more sensitive detectors in the future.

T04

Impact of Non-stellar Sources on IGM : Interpretation of Lyman-ɑ Forest Observations

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The Epoch of Reionization (EoR) marks a critical phase in the evolution of the universe, yet remains poorly understood. While star-forming galaxies are acknowledged as key contributors to ionized bubble formation, the extent of contribution from alternative sources such as shock-heated ISM or emission from X-ray binaries remains unclear. In this study, we employ cosmological radiative transfer simulations to explore the impact of diverse sources on intergalactic medium (IGM) properties. Our focus is not merely data fitting, but rather understanding whether the interpretation of Lyman-ɑ forest observations is changed by using theoretical models incorporating non-stellar sources. By decoupling various sources, we also aim to discern their individual contributions to the reionization process. In this presentation, I'll discuss our simulation methodology and initial insights into our findings.

T05

Early Universe phase transitions in a Scale Invariant Standard Model

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The mass hierarchy problem is concerned with the large differences in scale present in our universe, namely between the Higgs mass (125 GeV) and the Planck mass ($1.2\times10^{1}9$ GeV). The Standard Model currently offers no explanation for this difference which prompts the investigation of other fundamental theories. It has been argued that scale invariance of physical laws would be a solution to the hierarchy problem [1]. In this theory, physical laws are invariant under mass, energy or length scalings and it is only through quantum mechanical effects that scales and the hierarchy of scales emerge. A general cosmological consequence of this theory is that electroweak symmetry breaking doesn't occur until later in the universe's evolution, at lower temperatures [2]. Here, it is triggered by chiral symmetry breaking, when the unbound quarks of the universe cool and condense into bound hadron states. The change in conditions may result in a change in the type of phase transition that the universe undergoes during the electroweak symmetry breaking. If a first order phase transition occurred, then this may have produced gravitational waves which could be detectable today in the gravitational wave background. In this work, effective field theory was used at both zero and non-zero temperatures to model the Higgs, dilaton (an effective scalar field which ensures scale invariance) and meson fields. Parameters in the model were found by matching predictions of the model at zero temperature with observables today, then these same parameters were used in the non-zero temperature model to understand the electroweak and chiral phase transitions.

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T06

Modelling the properties of star-forming galaxies at high redshifts

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Early results from the James Webb Space Telescope (e.g. [1, 2, 3]) have reported an unexpected surplus of UV-bright galaxies at $z \geq 10$, which appears to challenge the predictions from standard galaxy formation models in ΛCDM cosmology at these early redshifts (e.g. [4, 5]). To address this, several cosmological (e.g. [6, 7]) as well as astrophysical interpretations (e.g. [3, 8]) have been advanced. However, all of these proposed scenarios carry noteworthy consequences for other large-scale processes in the early Universe, particularly cosmic reionization, as high-redshift galaxies are believed to be the primary ionizing sources during the Epoch of Reionization (EoR). To investigate this, we developed a semi-analytical model that explains the evolving galaxy UV luminosity function (UVLF) over $6 \leq z \leq 15$, and also jointly tracks the time evolution of the global neutral hydrogen fraction in the intergalactic medium. The model self-consistently accounts for the suppression of star formation in low-mass galaxies due to reionization feedback and is constrained by comparing theoretical predictions with the new UVLF data from HST and JWST, recent measurements of the globally averaged neutral hydrogen fraction, and the CMB scattering optical depth. The analysis shows that a rapid enhancement in the star-formation rate efficiency and/or UV luminosity per unit stellar mass formed is necessary for consistency with recent JWST UVLF estimates at $z \geq 10$. The model aligns well with existing EoR constraints when the escape fraction is assumed to be halo-mass dependent, requiring increased Lyman-continuum leakage from low-mass galaxies. Using our model, we have also examined the relative contribution of galaxies having different luminosities towards the ionizing photon budget and investigated the large-scale bias of galaxies in the early Universe. The above framework has recently been integrated into semi-numerical simulations of cosmic reionization and will allow us to probe the interplay between galaxy formation and evolution and reionization more precisely through additional summary statistics like the 21-cm power spectrum, galaxy two-point correlation function, 21cm-galaxy cross-correlations.

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T07

Utilizing kNN-Field Framework to Robustly Detect Neutral Hydrogen (HI) Clustering Post-Reionization

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In the post-reionization universe ($z \lesssim 6$), large-scale structure (LSS) is traced by dense self-shielded clumps of neutral hydrogen (HI) within galaxies, making Line-Intensity-Mapping of 21cm an effective observational technique to probe LSS and constrain cosmology. Auto-clustering studies of HI are heavily impacted by survey systematics, making HI detection challenging. Cross-correlation analysis between HI and galaxies is crucial. Firstly, it's important due to their anticipated correlation. Secondly, it helps mitigate individual survey systematics. Traditional two-point statistics (2PCFs) capture complete Gaussian information of the underlying field but are limited in capturing the non-Gaussian part. Given the highly non-linear clustering of dark matter, especially at small scales, in a low redshift universe, it's essential to go beyond 2PCFs to maximally extract cosmological information from the upcoming surveys probing LSS. Recently, k-nearest neighbor cumulative distribution functions (kNN-CDFs) have emerged as improved and easy-to-calculate higher-order summary statistics, being sensitive to all N-point functions of the underlying field. The effectiveness of the kNN-Field framework is particularly evident in its ability to accurately identify clustering patterns between discrete and continuous tracers even in high levels of noise. Despite a few direct detections of HI clustering around galaxies using 2PCFs, a more robust detection technique is necessary due to the extremely weak nature of the HI signal itself and the significant contaminations of foreground and thermal noise, which further degrade it. In this talk, I'll present our work on developing a pipeline that robustly detects HI clustering around galaxies. We validated our approach using Illustris TNG-300 simulation data and found that the kNN-Field framework offers significantly higher detection than 2PCFs. Additionally, we demonstrate the reliability of this framework in capturing clustering patterns from a realistic Tb field in terms of observations, while considering foreground and thermal noise effects. The results are promising for HI detection using the kNN-Field framework, especially in scenarios where some information is lost due to foreground filtering and thermal noise contamination. Our next step involves working with observational data and modeling the HI-galaxy clustering signal.

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T08

Measuring the LAE Correlation Function in HETDEX

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Current tensions within the standard cosmological model (ΛCDM) demand new data to constrain the evolution of the universe between the time of the cosmic microwave background (CMB) and the present day. The Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) is a decade-long effort to constrain dark energy in this intermediate redshift regime. To accomplish this, HETDEX observed $>$ 1M spectroscopically identified Lyman-alpha emitting galaxies (LAEs) in the redshift range 1.8<z<3.5. Similar to other spectroscopic surveys (e.g. SDSS and DESI), HETDEX aims to constrain dark energy by analyzing the clustering properties of this large sample of galaxies. Specifically, we aim to locate the baryon acoustic oscillation (BAO) peak in the 2-point correlation function (2pcf) of LAEs, which is an excellent probe of the Hubble parameter, $H(z)$, and the angular diameter distance, $D_A(z)$.

I will present the current progress toward measuring the correlation function with HETDEX. The survey design presents unique challenges that must be understood and overcome to ensure the reliability of our measurement. I discuss how we overcome these challenges, including contamination from low-redshift [OII] galaxies, evolution of the LAE luminosity function, and construction of random catalogs that properly contain observational systematics.

T09

Cogenesis of baryon and dark matter with PBH and QCD axion

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We study the role of an ultra-light primordial black hole (PBH) dominated phase on the generation of baryon asymmetry of the Universe (BAU) and dark matter (DM) in a type-I seesaw framework augmented by Peccei-Quinn (PQ) symmetry which solves the strong CP problem. While the BAU is generated via leptogenesis from the decay of heavy right-handed neutrino (RHN) at the seesaw scale dictated by the PQ scale, DM can arise either from QCD axion or one of the RHNs depending upon the PQ scale. The ultra-light PBH not only affects the axion DM production via misalignment mechanism, but can also produce superheavy RHN DM via evaporation. Depending upon the PBH parameters and relative abundance of axion DM, axion mass can vary over a wide range from sub-μeV to sub-eV keeping the detection prospects promising across a wide range of experiments. While hot axions produced from PBH evaporation can lead to observable ΔN_{eff} to be probed at future cosmic microwave background (CMB) experiments, stochastic gravitational waves (GW) produced from PBH density fluctuations can be observed at future detectors like CE, DECIGO, LISA and even future runs of LIGO-VIRGO.

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T10

Optimization of cosmic filament finders and unbiased recovery of filament phase space profiles using mock filaments

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Cosmic filaments, the most prominent features of the cosmic web, possibly hold untapped potential for cosmological inference. While it is natural to expect the structure of filaments to show universality similar to that seen in dark matter halos, the lack of agreement between different filament finders on what constitutes a filament has hampered progress on this topic. We initiate a programme to systematically investigate and uncover possible universal features in the phase space structure of cosmic filaments, by generating particle realizations of mock filaments with *a priori* known properties. Using these, we identify an important source of bias in the extraction of radial density profiles, which occurs when the local curvature κ of the spine exceeds a threshold determined by the filament thickness. We show that this bias can be nearly eliminated by simply discarding the regions with the highest κ, with little loss of precision. An additional source of bias is the noise generated by the filament finder when identifying the spine, which depends on both the finder algorithm as well as intrinsic properties of the individual filament. We find that, to mitigate this bias, it is essential not only to smooth the estimated spine, but to optimize this smoothing separately for each filament. We propose a novel optimization based on minimizing the estimated filament thickness, along with Fourier space smoothing. We expect the techniques developed here to be useful in calibrating the performance of filament finders, thereby enabling searches for filament universality.

T11

Towards 21-cm Intensity Mapping at z = 2.2 using uGMRT

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The neutral hydrogen (HI) 21-cm Intensity Mapping is a promising technique to quantify the matter distribution in the Universe at large scales. We present a tight upper limit on the HI mass density and the HI bias $[\Omega_{HI}\ b_{HI}] < 0.010$ at $z = 2.2$, using a 25-hour uGMRT observation at the radio band 394 - 494 MHz. The upper limit is within an order of magnitude of the expected 21-cm signal. The technique we use has two steps: first, we estimate the multifrequency angular power spectrum (MAPS) using the Tapered Gridded Estimator, which suppresses the bright point sources that appear through the sidelobes of the telescope. Then, we remove the residual foregrounds from the measured MAPS by using our newly developed polynomial fitting and Gaussian process regression techniques [1, 2]. We find the power spectrum to be consistent with noise in the entire Fourier space. We show that a 2σ detection is possible with an additional 50 hours of observation, provided we have minimal data loss due to radio frequency interference. The techniques and the results are encouraging for ongoing and future 21-cm intensity mapping surveys with MeerKAT, CHIME, HIRAX and SKA-mid.

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T12

The Mass Distribution of LIGO's Events for Indirect Search Of Dark Matter

Abstract:

Primordial black holes (PBHs) may contribute to the observed abundance of dark matter. We use the black-hole mass distribution obtained from the detected binary black hole merger events by the LIGO/VIRGO gravitational-wave observatories, to search for and place limits on PBHs in the stellar-mass range. In using the LIGO/VIRGO observations, we obtain the black-hole mass distribution by associating a skewed normal distribution to each detected event with a signal to noise ratio (SNR) > 8, summing all distributions. We then simulate binary black holes following models of formation of two separate populations of merging binaries: stellar-origin binary black holes and PBH binaries. For those we calculate the signal to noise ratio that would result on the LIGO detectors. Selecting only simulated merger events with a SNR>8, we fit the combination of these two components to the LIGO/VIRGO data. In our work, we rely on a wide range of black-hole mass distributions expected from models of formation of stellar-origin black holes and of PBHs.

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T13

Dispersion in the Hubble-Lemaitre constant measurements from gravitational clustering

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Measurements of the Hubble-Lemaitre constant H_0 require us to estimate the distance and recession velocity of galaxies independently. Gravitational clustering that leads to the formation of galaxies and the large scale structure leaves its imprints in the form of peculiar velocities of galaxies. In general, it is not possible to disentangle the peculiar velocity component from recession velocities of galaxies, and this introduces an uncertainty in the determination of H_0. We use cosmological N-body simulations to quantify the impact of peculiar velocities on the estimation of H_0. We consider observers to be located in dark matter halos and target galaxies to be distributed amongst dark matter halos. We compute the distribution of the estimated value of H_0 across all such observers in the simulation, and we study the distribution as a function of distance from the observer. We find that the dispersion of this distribution is large at small scales, and it diminishes as we go to large separations, reaching the level of the quoted statistical error in Planck and SH0ES measurements well beyond 135Mpc and 220Mpc respectively. Measurements at smaller scales are susceptible to errors arising from peculiar motions and this error can propagate to measurements at larger scales in the distance ladder. Notably, we observe a weak negative correlation between the local over-density around an observer and the deviation of the local and the global value of H_0. We show that deviations more significant than 5% of the global values can be encountered frequently at scales of up to 40 Mpc, and this is considerably larger than the statistical errors on local estimates.

T14

Constraints on primordial black holes for nonstandard cosmologies

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We study how the bounds on the abundance of Primordial Black Holes (PBHs) and the constraints on power spectrum are modified if a non-standard evolution phase takes place between the end of inflation and the Standard radiation-dominated (RD) universe after inflation[1, 2]. The constraints on PBH abundance and power spectrum are computed using the new, freely available, `PBHBeta` library, which accounts for the effects of non-standard expansion and specific criteria for PBH formation in such non-standard scenarios. As working examples, we consider three different cases: a pure matter-dominated (MD) phase, a scalar field-dominated (φD) universe, and a stiff fluid-dominated (SD) scenario. While the background expansion is the same for the MD and φD scenarios, the PBH formation criteria lead to different constraints to power spectrum. On the other hand, the duration of the non-standard expansion phase alters the bounds, with longer MD periods resulting in weaker constraints on power spectrum, and longer SD scenarios leading to an enhanced abundance due to the dust-like redshifting of PBHs. The modifications to the constraints are reported in all cases and we highlight those where the power spectrum may be significantly constrained.

An interesting extension for this work will be to explore the implications of time-dependent equations of state for the background, which may represent more realistic scenarios. For example, realistic models of the QCD transition, suggest a time-dependent equation of state, which is well-motivated by models of string cosmology [3]. It is important to assess whether PBHs could impose constraints on these models. Additionally, one could explore the production of gravitational waves and their evolution within nonstandard cosmologies (see for example [4]) or gravitational waves produced by the collision of PBHs, which persist after black hole evaporation. Such observables can be integrated into our set of constraints on ultra-light mass PBHs [5]. These and other extensions will be addressed in future work.

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T15

Probic dark and baryonic structures with wave-optics lensing

Gravitational waves (GWs) detection has opened a new window to the universe. One promising new avenue to study the growth of structure in our Universe using GWs is by investigating the gravitational lensing of the waves. Much like electromagnetic waves, GWs have their propagation affected when they pass through massive objects in their path. The frequency in which GWs operate is also considerably broad, ranging from nHz for Pulsar-timing array sources, to a few Hz for resolved stellar-mass binary black holes probed by ground-based detectors. LISA will be able to detect gravitational waves from massive black hole binaries (MBHBs), which lie in the frequency range of milli-Hz. This new window will allow us to use the lensing of GWs to the distribution of matter in the universe in a complementary way to what is currently done in the LIGO-Virgo-Kagra collaboration, as well as to the regimes in which lensing of electromagnetic waves allows us to probe. We show that the LISA could observe the wave-optic features due to lensing by the dark and baryonic structures for up to 1% of the detected MBHBs. We find the rates to be sensitive to the lens mass profile assumptions for these structures. The (non) observation of such features would allow us to constrain the populations of dwarf galaxies, halos and subhalos at high redshift which aren't yet accessible.

T16

Cross-Correlation between CIB and Galaxy Clustering

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Understanding the intricate relationship between star-formation rates from Comic Infrared Background(CIB) and other large scale structure tracers holds key insights into the evolving cosmic landscape. By cross-correlating the CIB data and other large-scale structure (i.e. CMB lensing and galaxy clustering), we can unravel the underlying dynamics and give better constrains on the models as well as retrieve the primordial information hidden behind the interference of these tracers. With the galaxy clustering data from Euclid in the near future, we can unravel the information hidden in the redshift distribution of star forming rate by its cross-correlation with Cosmic Infrared Background data from Planck. Thus, a better tomographic constrain on the halo model can be achieved.

T17

Abstract template for Poster/ Talk

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Weak gravitational lensing is a key cosmological probe. By measuring the coherent distortions of shapes of background galaxies, one can study the matter distribution in the foreground. This technique will allow us to study dark matter and dark energy, thus providing strong tests for the ΛCDM paradigm. One of the key systematics to weak lensing is the intrinsic alignment of galaxies. This effect, if not accounted for properly, can severely bias cosmological parameters in the weak lensing analysis of Euclid data.

In order to study this effect, I will use the state-of-the-art FLAMINGO suite of simulations. I will present results on the alignment of cluster and group scale haloes in FLAMINGO, with unprecedented statistics afforded by the large box size of the simulations.

I will also attempt to bridge the gap between simulations and observations, providing key tests of assumptions related to different methods of measuring the halo orientation. Different methods of measuring halo ellipticity can change the inferred IA signal, and using the simulations, I will test study the impact they have on the IA parameters. I will also test the assumption that the BCG light distribution and the satellite members trace the dark matter halo orientation, and thus understand the effect of these methods on the inferred IA amplitude. This work will also enable priors to be placed on the higher order terms of the IA models tested, which is very useful for the weak lensing analyses of Euclid data.

I will also present results on the effect of baryonic feedback on the inferred IA signal, as well as the redshift evolution of the IA parameters, which are both unexplored problems in alignment studies. I am also exploring the effect of particle noise bias on the calculation of the inertia tensor. The rule of thumb has been to only use halos with at least 300 particles. My results show that characterising this bias and possibly correcting for it will allow us to maximally use the FLAMINGO suite for the study of IA down to smaller scales than was previously thought possible.

T18

Strong Lensing Cosmology and the Line-of-Sight

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The effects of matter along the line-of-sight in strong gravitational lensing systems are widely recognised to have a non-negligible effect on lensing observables. In this talk, I will discuss the parameterisation of these effects, degeneracies which arise between line-of-sight effects and the properties of the main lens, and the influence of these effects on measurements of strong lensing time delays. With reference to measurements made from a dataset of mock lensing events, I will describe the prospects of measuring the line-of-sight shear from Einstein rings, multiply-imaged point sources, and time delay measurements, as well as the consequences of using oversimplified line-of-sight models for measurements of the Hubble constant from time-delay cosmography.

T19

Imprints of reheating on scalar-induced gravitational waves and compatibility with the NANOGrav 15-year data

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Abstract. The recent detection of the stochastic gravitational wave background (SGWB) by the pulsar timing arrays (PTAs) has opened up the possibility of directly probing the very early universe. A possible source of the observed background are the secondary GWs generated by excess scalar power on small scales. However, when such scalar-induced secondary GWs are assumed to be generated during the epoch of radiation domination to explain the PTA data, it has been found that the process leads to the excessive production of primordial black holes (PBHs). In this talk, I shall discuss the production of PBHs and the scalar-induced secondary GWs during the phase of reheating, which precedes the standard epoch of radiation domination. I shall consider an inflationary scalar power spectrum with a broken power law form and construct scenarios wherein the spectral densities of scalar-induced secondary GWs fit the NANOGrav 15-year data quite well without leading to the overproduction of PBHs [1]. I shall conclude with a brief summary and outlook.

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T20

Search for GeV Gamma-Ray Emission from SPT-SZ selected Galaxy Clusters with 15 years of Fermi-LAT data

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Galaxy clusters could produce gamma rays from Inverse Compton scattering of cosmic ray electrons or hadronic interactions of cosmic ray protons with the intracluster medium. It is still an open question on whether gamma-ray emission (> GeV energies) has been detected from galaxy clusters. We carry out a systematic search for gamma-ray emission based on 300 galaxy clusters selected from the 2500 deg.^{2} SPT-SZ survey after sorting them in descending order of M_{500}/z^2, using about 15 years of Fermi-LAT data in the energy range between 1-300 GeV. We were able to detect gamma-ray emission with a significance of about 6.1σ from one cluster, viz SPT-CL J2012-5649. The estimated photon energy flux from this cluster is approximately equal to 1.3×10^{-6} MeV cm^{-2} s^{-1}. The gamma-ray signal is observed between 1 – 10 GeV with the best-fit spectral index equal to -3.61 ± 0.33. However, since there are six radio galaxies spatially coincident with SPT-CL J2012-5649 within the Fermi-LAT PSF, we cannot rule out the possibility this signal could be caused by some of these radio galaxies. Six other SPT-SZ clusters show evidence for gamma-ray emission with significance between 3 – 5σ. None of the remaining clusters show statistically significant evidence for gamma-ray emission.

T21

"The Interplay between the Dark Matter Axion and Primordial Black Holes" for Summer School on Cosmology, Trieste, Italy, 2024

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We show that the relic abundance and expected mass range of the QCD axion, would be greatly modified if primordial black holes (PBHs) had come to dominate the energy density of the early Universe when oscillations in the axion field began. Since the QCD axion is a potential candidate for dark matter (DM), we refer to it as the DM axion. We predominantly explore PBHs in the mass range $(10^6 - 5 \times 10^8)$ g. We investigate the relation between the relic abundance of DM axions and the parameter space of PBHs. We numerically solve the set of Boltzmann equations, that governs the cosmological evolution during both radiation and PBH-dominated epochs, providing the bulk energy content of the early Universe. We further solve the equation of motion of the DM axion field to obtain its present abundance. Alongside non-relativistic production mechanisms, light QCD axions are generated from evaporating PBHs through the Hawking mechanism and could make up a fraction of the dark radiation (DR). If the QCD axion is ever discovered, it will give us insight into the early Universe and probe into the physics of the PBH-dominated era. We estimate the bounds on the model from DR axions produced via PBH evaporation and thermal decoupling, and we account for isocurvature bounds for the period of inflation where the Peccei-Quinn symmetry is broken. We assess the results obtained against the available CMB data and we comment on the forecasts from gravitational wave searches. We briefly state the consequences of PBH accretion and the uncertainties this may further add to cosmology and astroparticle physics modeling.

[1] **K. Mazde** and L. Visinelli, The Interplay between the Dark Matter Axion and Primordial Black Holes, Journal of Cosmology and Astroparticle Physics **JCAP01(2023)021** DOI: 10.1088/1475-7516/2023/01/021 (2023).

T22

Non-Gaussianity consistency relations and their consequences for the peaks

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Strong deviations from scale invariance and the appearance of high peaks in the primordial power spectrum have been extensively studied for generating primordial black holes (PBHs) or gravitational waves (GWs). It is also well-known that the effect of non-linearities can be significant in both phenomena. In this talk, we advocate the existence of a general single-field consistency relation that relates the amplitude of non-Gaussianity in the squeezed limit $f_{\rm NL}$ to the power spectrum and remains valid when almost all other consistency relations are violated. In particular, it is suitable for studying scenarios where scale invariance is strongly violated[1]. We discuss the general and model-independent consequences of the consistency relation on the behavior of $f_{\rm NL}$ at different scales. Specifically, we study the size, sign and slope of $f_{\rm NL}$ at the scales where the power spectrum peaks and argue that generally the peaks of $f_{\rm NL}$ and the power spectrum occur at different scales. As an implication of our results, we argue that non-linearities can shift or extend the range of scales responsible for the production of PBHs or GWs, relative to the window as determined by the largest peak of the power spectrum, and may also open up new windows for both phenomena[2].

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T23

Impact of the sources of Epoch of Reionization on the 21-cm bispectrum

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The Epoch of Reionization (EoR) marks a period in cosmic history during which the radiation from the first luminous sources ionized the neutral hydrogen in the intergalactic medium (IGM). Many fundamental questions regarding the EoR are yet to be answered. The 21-cm radiation emitted by the neutral hydrogen present in the intergalactic medium (IGM) carries a wealth of information about the EoR [1]. The topology of the IGM 21-cm signal during the EoR depends on the properties of the sources of ionizing radiation and the underlying physical processes within the IGM. Variation in the topology of the IGM 21-cm signal due to the different source characteristics of the EoR is expected to have a significant impact on the 21-cm bispectrum [2,3,4], which is one of the crucial observable statistics that can quantify the non-Gaussianity present in the signal and which can also be estimated from radio interferometric observations of the EoR. We present the 21-cm bispectrum for different reionization scenarios, assuming different simulated models for the sources of reionization. We demonstrate how well the 21-cm bispectrum can distinguish between different IGM 21-cm signal topologies, which will help us shed light on the nature of the sources of ionizing photons. Our estimated large scale bispectrum for all unique k-triangle shapes show a significant difference in their magnitude and sign as one goes from one reionization scenario to the other. Additionally, our focused analysis of bispectrum for a few specific k-triangle shapes (e.g. squeezed limit, linear and shapes in the vicinity of the squeezed limit) show that the large scale 21-cm bispectrum can distinguish between reionization scenarios that show inside-out, outside-in and a combination of inside-out and outside-in topologies. These results highlight the potential of using the 21-cm bispectrum for constraining different reionization scenarios.

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T24

RELATIVISTIC EFFECTS IN GALAXY CLUSTERING WITH DESI

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Understanding the accelerated expansion of the Universe remains as one of the key challenges in cosmology. The main candidates to explain this observation, which do not rely on a cosmological constant, are dark energy and modifications of General Relativity, but they require robust tests on cosmological scales.

The Dark Energy Spectroscopic Instrument (DESI) offers unprecedented precision in measuring galaxy clustering from spectroscopic data, allowing for the detection of relativistic features beyond the standard redshift space distortions (RSD). In particular, we will focus on the dipole generated in the cross-power spectrum of two galaxy populations due to these relativistic effects [1, 2]. For this study, we employ a mock catalogue of synthetic galaxies, produced from a high accuracy N-body simulation, which mimics the galaxies in the DESI Bright Galaxy Survey (BGS) [3]. We analyse ways to amplify the relativistic dipole by separating these galaxies into a bright and a faint population [4], while conserving their redshift distribution. We also examine techniques for accurately estimating the magnification bias, a key parameter entering the amplitude of the dipole signal. Our results indicate an improved detectability of the relativistic dipole with fewer bright sources and that the measured distortions are well described by the predictions of linear theory.

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T25

Strong Mixing at the Cosmological Collider

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Apart from its manifest interest in the understanding of the first moments of the universe, the framework of cosmic inflation is also the best way we know to probe fundamental physics at very high energies. In particular, the spontaneous production of massive particles due to the expanding background can leave potentially visible imprints in cosmological correlation functions known as the cosmological collider signal [1, 3].

Within the effective field theory of inflation (EFTI) [4], it is possible to treat these exchange processes in a model independent way, and explicit computations taking advantage of the conformal invariance of late time observables have been carried out using various technics such as the cosmological bootstrap [5]. More recently, the full parameter space allowed by the EFTI has been explored allowing for boost breaking setups leading to more striking phenomenological signatures [6, 7], and the recently developed cosmological flow approach numerically gives us access to any correlation function [8, 9].

In this talk, I will expose a treatment of a parameter space region that remains analytically unknown: the strong mixing regime where the inflaton field and the massive particle can experience an infinite number of flavour transformations during the process. I will describe ongoing efforts to describe this regime based on extensions of standard single field effective field theory technics.

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T26

Hubble tension in the light of LISA/ET: A Three-Pronged Approach with Fisher, MCMC and ML

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Cosmology today, although precise, is perhaps not accurate. The prevalent tensions in the standard Λ Cold Dark Matter (ΛCDM) model have been cited as a crisis in the field. With there being no clear evidence of systematical errors, nor a foolproof alternative theory as of now, this crisis is often attributed to an insufficiency of data at hand, which calls for future missions. I would present here the prospects of future gravitational wave missions, namely the space-based Laser Interferometer Space Antenna (LISA) and the ground-based Einstein Telescope (ET), set to probe up to the "intermediate" redshifts, in addressing the Hubble tension. I'll demonstrate a three-pronged approach [1] - using Fisher matrices (the standard forecasting tool in cosmology), Markov chain Monte Carlo (MCMC) algorithms (the conventional parameter estimation scheme), and a machine learning algorithm like Gaussian processes (GP) (for non-parametric reconstruction), to help shed light on this disparity. By considering a few representative cosmological models as fiducials, some of which show promise at varied levels in alleviating the Hubble tension when confronted with current datasets (Cosmic Microwave Background (CMB) from Planck2018 + Baryon Acoustic Oscillations (BAO) + Type Ia Supernovae (SNIa) from the Pantheon compilation), we constructed realistic mock-catalogues of bright standard siren events. Using these catalogues, I'll demonstrate the inference of the Hubble constant independently from the three techniques, and the dependence of GP reconstruction on the fiducial inputs [2]. Finally, a comparative analysis among the methods, as well as the fiducial model inputs, would be presented, along with some possible future directions, stressing on the importance of using varied data analysis and machine learning techniques.

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T27

Auto from cross: CMB lensing power spectrum without noise bias

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Upcoming surveys will measure the cosmic microwave background (CMB) weak lensing power spectrum in exquisite detail, allowing for strong constraints on the sum of neutrino masses among other cosmological parameters. Standard CMB lensing power spectrum estimators aim to extract the connected non-Gaussian trispectrum of CMB temperature maps. However, they are generically dominated by a large disconnected, or Gaussian, noise bias, which thus needs to be subtracted at high accuracy. This is currently done with realistic map simulations of the CMB and noise, whose finite accuracy currently limits our ability to recover the CMB lensing on small-scale. In this talk, I will describe a novel estimator which instead avoids this large Gaussian bias. This estimator relies only on the data and avoids the need for bias subtraction with simulations. Thus, this bias avoidance method is (1) insensitive to misestimates in simulated CMB and noise models and (2) avoids the large computational cost of standard simulation-based methods like "realization-dependent $N^{(0)}$" ($\mathrm{RDN}^{(0)}$). I will show that this estimator is as robust as standard methods in the presence of realistic inhomogeneous noise (e.g. from scan strategy) and masking. Moreover, this method can be combined with split-based methods, making it completely insensitive to mode coupling from inhomogeneous atmospheric and detector noise. Although in this talk I specifically consider CMB weak lensing power spectrum estimation, I will illuminate the relation between this new estimator, $\mathrm{RDN}^{(0)}$ subtraction, and general optimal trispectrum estimation. Through this discussion I will show that our estimator can be applicable to analogous problems in other fields which rely on estimating connected trispectra/four-point functions like large-scale structure.

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T28

Comparing Galaxy Formation Models using the Bias Expansion

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Our ability to extract cosmological information from galaxy surveys is limited by uncertainties in the galaxy-dark matter halo relationship for a given galaxy population, which is determined by the intricacies of galaxy formation. To quantify these uncertainties, we examine quenched and star-forming galaxies using an empirical semi-analytic model [1] and a hydrodynamical model [2]. Building on [3], we fit a perturbative bias expansion to the density fields of these galaxies, and compare our results against predictions made using the standard halo occupation distribution model. Our approach enables direct comparison between distinct modeling approaches and provides an understanding of how uncertainties in galaxy formation physics and the galaxy-halo connection impact the parameters of this bias expansion. This study will be used in precision cosmology analyses as a way to inform priors on these parameters, an ingredient that is essential for getting the most out of current and future data from large galaxy surveys.

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T29

Abstract for the Summer School on Cosmology

BREAKING PLANCK'S LENSING ANOMALY: A PARAMETRIC APPROACH

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Parametrising the growth of large scale structure is a powerful tool, as it allows us to detect deviations from the Standard Model of cosmology (SM) in a *general* way, without having to make limiting assumptions about their fundamental nature. We will be presenting the results of a series of analyses carried on two such parametrisations: the *growth index* 'γ_L' [1], a precise modification of the growth of linear, sub-horizon matter perturbations in the SM, and the '$\mu_0 - \Sigma_0$' framework [2], a modification of the Poisson and lensing equations from General Relativity (GR). Notably, Planck's 2018 analysis [3] has shown a 2σ evidence of Modified Gravity (MG) (i.e., $\mu_0, \Sigma_0 \neq 0$), while other Cosmic Microwave Background (CMB) experiments such as ACT and SPT showed consistency with GR [4]. Could Planck's lensing anomaly [3] be responsible for the discrepancy? The goal of our work is to show if the link between the loss of power at high multipoles in the anisotropy power spectra of Planck and the detected evidence for MG stands the test of alternative approaches to analyse Planck's data, as the one taken by the HiLLiPoP team who, consistently with other CMB experiments, have found no sign of abnormal lensing signals [5]. We find that the usage of the HiLLiPoP likelihood on Planck data does not reveal any deviation from the SM, suggesting that the lensing anomaly could plausibly explain the MG detection by Planck.

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T30

The importance of accuracy in the modeling of large scale galaxy clustering

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Future galaxy surveys will observe tens of million of sources over large fraction of the sky and various cosmic epochs. Currently, statistical analyses of galaxy distributions and their clustering are performed employing simplifying assumptions such as the flat sky and plane parallel ones. In order to obtain not only precise, but accurate analyses for future datasets, a more precise formalism will be required (e.g., including the so-called wide angle and unequal time corrections). In this talk I will present how tests of cosmological models will be biased when not including such corrections for future large scale structure experiments.

T31

The Linear Point Standard Ruler with the DESI Year 1 Survey

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Redshift surveys like SDSS and eBOSS heralded the era of precision cosmology and provided robust constraints on cosmological distance measurements via standard rulers. The length scale of baryon acoustic oscillations (BAOs), observed as the peak in the two-point correlation function (2pcf), is a commonly used standard ruler and has been measured to sub-five percent precision. Modern surveys like the Dark Energy Spectroscopic Instrument (DESI) will enable measurements of this feature at sub-percent precision. However, the location of the BAO peak is distorted by nonlinearities in late-time structure formation and effects like redshift space distortions such that it cannot be used for constraints at the sub-percent level. These distortions will affect distance calibrations and have a cascading effect on our ability to constrain cosmological parameters that determine the evolution of large-scale structure.
In recent years, an alternative standard ruler known as the linear point has been proposed, which is defined as the mean of the BAO peak and the preceding trough in the 2pcf. The linear point is a purely geometrical feature and provides additional robustness against late-time nonlinearities when compared to the BAO peak [1, 2]. We attempt the first measurement of the linear point using data from the DESI Year 1 (Y1) survey. We first use mock catalogs created for DESI using the AbacusSummit N-body simulations to validate the linear point as a standard ruler. To do so, we compare the migration of the linear point as a function of redshift against that of the BAO peak and study its robustness to redshift space distortions. Finally, we apply this linear point pipeline to Y1 data and report our best estimate of the linear point standard ruler.

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