Fundamental Physics from Future Spectroscopic Surveys

Monday, 6 May 2024 - Wednesday, 8 May 2024

Building 50

Book of Abstracts

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Patchy dark screening

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I will discuss anisotropic (patchy) screening induced by the resonant conversion of cosmic microwave background (CMB) photons into light bosons in the dark sector as they cross non-linear large scale structure (LSS). Using kinetically mixed dark photon as an example, I will show how this conversion between CMB photon and light bosons leads to new CMB anisotropies that are correlated with LSS. These anisotropies from new physics, with their characteristic frequency dependence, can be separated from the primary CMB anisotropies. I will show analysis with existing CMB data, and how it improve significantly upon current constraints on light dark photons, while data from upcoming experiments such as CMB-S4, CMB-HD and upcoming LSS surveys can further further improve the reach by orders of magnitude.

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High Redshift Spectroscopy for Dark Energy and Inflation

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Spectroscopy at z=2-4.5 can explore whether dark energy fades away rapidly in the past, follows the cosmological constant energy density, or has extra early dark energy. Measuring growth over these high redshift slices also allows reconstruction of the inflationary power spectrum - freedom beyond an assumed power law. SpecS5 will thus give important information on both current and primordial acceleration.

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Kinematic Lensing with the Dark Energy Spectroscopic Instrument - Probing S8 Tension at Very Low Redshift

Authors: Jiachuan Xu[1]; Tim Eifler[1]

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We explore the science prospects of a 14,000 deg^2 Kinematic Lensing (KL) survey with the Dark Energy Spectroscopic Instrument (DESI) and overlapping imaging surveys. KL infers the cosmic shear signal by jointly forward modeling the observed photometric image and velocity field of a disk galaxy. The latter can be constrained by placing multiple DESI fibers along the galaxy major and minor axis, a concept similar to the DESI Peculiar Velocity Survey. We study multiple subsets of the DESI Legacy Survey Data Release 9 galaxy sample and quantify the residual shape noise, σ_ϵ, of each sample as a function of cuts in r-band magnitude. We conduct simulated likelihood analyses for these galaxy samples and find that a DESI-KL program can place highly interesting constraints on structure formation at very low redshifts, i.e. $\sigma_8(z < 0.15)$. We conclude that if the S_8 tension consolidates as a phenomenon, a KL survey can provide unique insights into this phenomenon in the very late universe. Further, we note that DESI-KL benefits multiple additional science cases, e.g. studies of modified gravity models when combined with peculiar velocity surveys, and dark matter studies that are based on galaxy-galaxy lensing of dwarf galaxies.

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Non-perturbative techniques for constraining the cosmological collider

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Upcoming large-scale structure (LSS) surveys will provide significant insight into the physics of the early Universe by searching for primordial non-Gaussianity (PNG). Whereas traditional approaches towards constraining PNG with LSS typically focus on phenomenological amplitudes, e.g., $f_{\rm NL}^{\rm loc.}$, which characterize a given "shape" of non-Gaussianity, there exist a range of inflationary scenarios that can produce unique signatures of PNG. A particularly compelling example is the cosmological collider scenario, wherein the presence of massive spinning particles during inflation can lead to poles or oscillations in the squeezed bispectrum. In this talk, I will present a novel approach towards running and analyzing N-body simulations with initial conditions generated for cosmological collider type models. Using these simulations, I will validate a model for the non-linear squeezed matter bispectrum and collapsed trispectrum for the collider physics scenario based on the LSS consistency relations – non-perturbative statements about the structure of LSS correlation functions derived from symmetries of the LSS equations of motion. Finally, I will comment on how these simulations and non-perturbative models can be used to develop pipelines to directly constrain the masses and spins of particles present during inflation.

Session 11 / 6

Recurrent axion star collapse and their cosmological constraints

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Axion-like dark matter whose symmetry breaking occurs after the end of inflation predicts enhanced primordial density fluctuations at small scales. This leads to dense axion minihalos (or miniclusters) forming early in the history of the Universe.
Condensation of axions in the minihalos leads to the formation and subsequent growth of axion

stars at the cores of these halos. If, like the QCD axion, the axion-like particle has attractive self-interactions there is a maximal mass for these stars, above which the star rapidly shrinks and converts an $\mathcal{O}(1)$ fraction of its mass into unbound relativistic axions. This process would leave a similar (although in principle distinct) signature in cosmological observables as a decaying dark matter fraction and thus is strongly constrained. We place new limits on the properties of axion-like particles that are independent of their non-gravitational couplings to the standard model. Future spectroscopic surveys may test this scenario or place stronger bounds on axion parameters.

Session 2 / 7

Non-Gaussian Statistics for Non-Gaussian Physics

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What statistics do we need to search for new physics? I will present a pedagogical overview of statistics beyond the galaxy power spectrum, and how they can be used to probe a wide variety of non-standard physics in inflation and beyond.

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Neutrino winds on the sky

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Neutrinos become nonrelativistic at late times and cluster anisotropically behind moving halos, forming neutrino wakes in the opposite direction to the halo motion and causing halos to slow down due to dynamical friction. We show that this effect can be best extracted from future large scale structure surveys via three point cross correlations involving galaxies and a tracer of the matter field, and discuss ongoing work on extracting this observable from simulations. The signatures of neutrino wakes on the large scale structure offer a promising avenue to constrain neutrino properties from cosmological observations in a way that is complementary to standard methods.

Session 2 / 9

Fundamental Physics from Galaxy Surveys

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I will present a new program of probing fundamental cosmology with spectroscopic galaxy surveys. This program builds on ideas of effective field theory and allows for sub-percent precision analytic understanding of galaxy clustering on large scales. I will highlight recent results of this program that include new measurements of fundamental cosmological parameters and constraints on new physics beyond the standard models of particles and cosmology.

Session 5 / 10

Synergies with CMB

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Scientific programs involving joint-analyses of galaxy surveys and CMB are increasingly gaining attention as they often increase the prospects to detect and characterize new signals by reducing systematics, cancelling cosmic variance and breaking degeneracies. The reconstruction of large-scale cosmological fluctuations at different epochs by using the CMB as a back-light will allow galaxy surveys to provide the most precise tests of fundamental physics, and has the potential to open new and unique windows into unexplored epochs of structure formation. Joint analysis of future Stage-5 Spectroscopic surveys with CMB will boost the Figure of Merit (FoM) of these surveys when constraining dynamics and interactions in the early Universe or fundamental principles that govern the major cosmological transitions such as helium reionization, for example, over two orders of magnitudes compared to considering galaxy surveys in isolation. In this talk, I will demonstrate the prospects of joint analyses of CMB and S5 spectroscopic galaxy surveys for inferring fundamental properties of our Universe.

Session 5 / 11

How much information can be extracted from galaxy clustering at the field level?

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Talk will be based on arXiv:2403.03220 and references therein.

LSS surveys have significantly advanced from measuring angular clustering of galaxies using photographic plates to mapping three-dimensional clustering with spectroscopic fibers and robots. Meanwhile, statistical methods to analyze galaxy clustering and other biased tracers of LSS still rely on modeling two- and three-point correlation functions. This leaves open the question:

"How much cosmological information can be robustly extracted from galaxies and LSS tracers?"

In this talk, I will introduce a Lagrangian, EFT-based, forward-modeling framework (LEFTfield) to perform field-level Bayesian inference (FBI) of galaxy clustering. The latter aims to extract simultaneous constraints on amplitude and growth rate of matter fluctuations, namely sigma8 and f(z). I will then present the first direct, apple-to-apple comparison between sigma8 constraints obtained with FBI versus those obtained with a combination of power spectrum plus bispectrum (P+B)—using the same LEFTfield forward model and analysis scale cut—on nonlinear clustering of dark matter halos in N-body simulations. The FBI constraints show an improvement [over P+B] of 1.7-2.6, increasing with the analysis cutoff scale. These results underline the wealth of cosmological information in (nonlinear) clustering, currently beyond the reach of low-order n-point functions, which will become more significant as the cosmological volumes and tracer densities further increase in Stage-V surveys.

Session 9 / 12

Cosmology from the matter power spectrum peak

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The position of the peak of the matter power spectrum is a different kind of standard ruler, with a scale set by the horizon size at the epoch of matter-radiation equality. It can easily be predicted in terms of the physics of the Universe in the relativistic era, and so used as a standard ruler independently of other rulers, such BAO. However, it requires a very large effective volume to be measured accurately, and the precision will lag other standard rulers that use smaller-scale information. We present a model-independent method to extract the geometric information from the so-called 'turnover scale.'We present a tentative detection from the eBOSS quasar sample, and measure the physical matter density to be $\Omega_m h^2 = 0.1592^{+0.041}_{-0.037}$, a measurement that is independent from the CMB power spectrum. We make forecasts for the effectiveness of this standard ruler for future large-scale spectroscopic surveys, including DESI, MSE and MegaMapper.

Session 11 / **13**

Forecasts for Galaxy Formation and Dark Matter Constraints from Dwarf Galaxy Surveys

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Dwarf galaxies are essential probes of dark matter (DM) microphysics. Here, we assess potential DM constraints from future dwarf galaxy surveys. We find that observations of all satellites around one (two) Milky Way-mass host can rule out warm DM models with $m_{\rm WDM} = 10$ keV (20 keV). We show that the same data constrain the subhalo mass function in a model-independent manner, and thus simultaneously test a wide variety of fundamental physics that affects the small-scale power spectrum. These results strongly motivate searches for faint dwarf galaxies beyond the Milky Way, which photometric surveys including Rubin LSST will significantly advance. Finally, we highlight the key role of spectroscopic surveys in this context, both to confirm the DM-dominated nature of dwarf galaxy candidates and to measure their mass profiles.

Session 6 / **14**

An Effective Cosmological Collider

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An upcoming suite of cosmological probes of large-scale structure poses a unique opportunity to search for physics beyond the Standard Model. Particles with masses of order Hubble during inflation create a distinct, oscillatory signal in the squeezed limit of the bispectrum. Fully leveraging this property to uncover new physics, a pursuit known as the "cosmological collider", necessitates a comprehensive understanding of contributing opreators and their effects. In this talk, I'll introduce our work that initiaties a systematic study of operator redundancies in inflationary spacetime. We establish a minimal operator basis for an archetypal example, an abelian gauge-Higgs theory that couples to the inflaton. Working up to dimension 9, we show that certain lower-dimensional operators are entirely redundant and identify new non-redundant operators with potentially interesting cosmological collider signatures. We expect particular reliance on 21 cm probes to distinguish them.

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Improved Constraints on Local Primordial Non-Gaussianity from Spectroscopic Data with Galaxy Bias

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Local Primordial non-Gaussianity (LPNG) - the most easily measurable signature of inflationary physics from large-scale structures - will be a primary science target for current and future spectroscopic surveys. Maximally extracting information about the amplitude of PNG (f_{NL}) will require knowledge of galaxy formation physics, which can robustly be embedded in the values of bias parameters in large-scale perturbative models. I will describe several theoretical developments related to PNG bias, including: field-level measurements of PNG bias in simulations, the origin of PNG assembly bias in Lagrangian bias models, and the relationship between PNG bias and (relativistic) evolution bias in simulations. Another challenge for constraining LPNG is large-scale systematics - I will also discuss potential strategies for mitigating such effects. These insights have the potential to be especially relevant for improving the amount of cosmological information extracted from future spectroscopic high-redshift surveys that will access very large scales relevant for constraining the physics of inflation.

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Primordial Features in Next-Generation Surveys

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Large-scale structure observations are remarkably sensitive to primordial features. They are already more constraining than the cosmic microwave background today and will significantly exceed its sensitivity in the future. These oscillatory imprints in the primordial spectra arise from a departure from scale invariance during inflation or its alternatives and, therefore, provide important insights into the primordial universe. In this talk, I will explain the theoretical significance of these inflationary signatures, give an overview of their current observational status and discuss why they are an interesting science target for future surveys.

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Self-Interacting Neutrinos in Light of Large-Scale Structure Data

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We explore a self-interacting neutrino cosmology in which neutrinos experience a delayed onset of free-streaming. We use the effective field theory of large-scale structure (LSS) to model matter distribution on mildly non-linear scales within the self-interacting neutrino cosmology for the first time. We perform the first combined likelihood analysis of BOSS full-shape galaxy clustering, weak lensing, and Lyman-α forest measurements, together with the cosmic microwave background (CMB) data from Planck. We find that the full data set strongly favors presence of a flavor-universal neutrino self-interaction, with a characteristic energy scale of order 10 MeV. The preference is at the $> 5\sigma$ level and is primarily driven by the Lyman-α forest measurements and, to a lesser extent, the weak lensing data from DES. The self-interacting neutrino model reduces both the Hubble tension and the S_8 tension between different cosmological data sets, but it does not fully resolve either. Finally, we note a preference for a non-zero sum of neutrino masses at the level of $\sim$0.3 eV under this model, consistent with previous bounds. These results call for further investigation in several directions, and may have significant implications for neutrino physics and for future new-physics searches with galaxy surveys.

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Mapping Distant Universe with Lyman Break Galaxies

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Future Spectroscopic surveys will be designed to probe a large volume of the Universe with a galaxy density sufficient to measure the extremely-large-scale density fluctuations required to explore primordial non-Gaussianity and therefore inflation. In addition, combining the spectroscopic surveys with the next generation CMB-S4 experiment can provide the first 5⊠ confirmation of the neutrino mass hierarchy from astronomical observations. Finally, these high-redshift measurements will probe a Dark Matter dominated era and test exotic models where Early Dark Energy properties vary at high redshift.

We propose to use Lyman Break Galaxies (LBGs) in the $2.0<z<4.5$ redshift range as tracers of the matter. These galaxies are selected by using a u/g-dropout approach based on a very deep u/g-bands that can be provided by imaging surveys such as LSST. We will present the results of pilot surveys observed in COSMOS and XMM fields by DESI from 2021 to 2024. We will show that we can achieve both the LBG densities and the redshift accuracy required for these future spectroscopic surveys.

Session 5 / 19

Making multi-wavelength, multi-redshift predictions for Cross-Survey Cosmological Analyses

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The standard cosmological model has been thus far successful at predicting the clustering of galaxies on large physical scales. However, the standard model has not been thoroughly tested on smaller scales, where the spatial distribution of galaxies is affected by both cosmology and the physics of galaxy formation and evolution. Measuring galaxy clustering on small scales with the next generation of spectroscopic survey will allow us to potentially explore the observational signatures of physics beyond the standard model. In addition to examining small scales, further constraints on our cosmological model can come from combining data from multiple galaxy surveys. Moreover, performing multi-redshift analyses will allow us to probe the dark energy equation of state over time. However, to fully take advantage of the next generation of cosmological survey data will require flexible models of the galaxy-halo connection that can make multi-wavelength, multi-redshift predictions in the nonlinear regime. In this talk, I will present a novel simulation-based forward model of the galaxy-halo connection, which targets multi-wavelength, multi-redshift joint analyses of large-scale structure data from multiple cosmological surveys, including cross-correlations. This forward modeling framework, Diffsky, utilizes high-resolution N-body simulations with merger trees, and includes differentiable prescriptions for smooth in-situ star formation, bursty star formation, dust attenuation, and galaxy merging. I will discuss recent applications of Diffsky in the generation of synthetic data for DESI and LSST, as well as ongoing work in cosmological forecasting and inference.

Session 10 / 20

Constraining running with the Lyman alpha forest

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The power spectrum of fluctuations in the Lyman alpha (Lya) forest can be used to measure the amplitude of the linear power spectrum on megaparsec scales, smaller than those accessible from galaxy surveys or the cosmic microwave background (CMB).

By combining CMB measurements from Planck with the Lya dataset of DESI one should be able to constrain running at the 0.002 level, a factor of 3 better than from Planck alone (DESI Collaboration 2016).

If there was interest on this, I could talk a bit about the challenges of this measurement in DESI, and about the possibility to do this measurement with Spec-S5.

Session 6 / 21

Hybrid cosmological collider of (iso)curvature

Author: Lingfeng Li[None]

If a sector other than inflaton survives in the late universe, its quantum fluctuation generically brings isocurvature modes. The typical case is the complex scalar with spontaneous symmetry breaking, with the remaining U(1) global symmetry and the associated massless goldstone boson. The goldstone mode can be recognized as the QCD axion or axion-like particle (ALP) and form cold dark matter via the misalignment mechanism. We found a whole new suite of cosmological observables for cold dark matter isocurvature, which could help test the presence of axions, as well as its coupling to the inflaton and other heavy spectator fields during inflation such as the radial mode of the Peccei-Quinn field. They include correlated clock signals in the curvature and isocurvature spectra, and mixed cosmological-collider non-Gaussianities involving both curvature and isocurvature fluctuations with shapes and running unconstrained by the current data analyses. We will also briefly mention further developments in progress.

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Cosmology with the Lyman-a forest

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The Lyman-a forest is a unique large-scale structure tracer at Mpc scales and below at high redshifts (2 < z < 4). One of the key advantages of the Lyman-a forest is that, since the density fields are only mildly non-linear at the respective redshifts, a much wider range of scales can be used to robustly probe cosmology than with most galaxy surveys, making the Lyman-a fluctuations a powerful probe of early-Universe physics when combined with tracers that are sensitive to very large scales, e.g,~cosmic microwave background (CMB) anisotropies. I will present the first measurement of the 3D Lyman-a forest power spectrum, the detection of the CMB lensing – Lyman-a forest power spectrum signal and discuss ongoing work to perform a full-shape cosmological analysis of Lyman-a forest data in the framework of the effective field theory of large-scale structure from cosmological surveys such as eBOSS, DESI and future spectroscopic surveys.

Session 9 / **23**

Late Time Modification of Structure Growth and the S8 Tension

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The S_8 tension between low-redshift galaxy surveys and the primary CMB signals a possible breakdown of the ΛCDM model.
Recently differing results have been obtained using low-redshift galaxy surveys and the higher redshifts probed by CMB lensing, motivating a possible time-dependent modification to the growth of structure.
We investigate a simple phenomenological model in which the growth of structure deviates from the ΛCDM prediction at late times, in particular as a simple function of the dark energy density. Fitting to galaxy lensing, CMB lensing, BAO, and Supernovae datasets, we find significant evidence - 2.5 - 3σ, depending on analysis choices - for a non-zero value of the parameter quantifying a deviation from ΛCDM.
The preferred model, which has a slower growth of structure below $z \sim 1$, improves the joint fit to the data over ΛCDM.
While the overall fit is improved, there is weak evidence for galaxy and CMB lensing favoring different changes in the growth of structure.
The upcoming large-scale structure surveys can further test this model.

Session 5 / **24**

Multi-Fidelity Emulation of Cosmological Simulations for High Dimensional Parameter Inference

Author: Ming-Feng Ho[1]

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In this talk, I will introduce a multi-fidelity emulation technique, designed to efficiently emulate summary statistics from cosmological simulations for high-dimensional parameter inference. Multi-fidelity emulation allows us to combine cosmological simulations of varying resolutions and volumes, enabling us to efficiently explore the high-dimensional parameter space of cosmological models with a much lower cost, making it possible for future surveys to probe the physics beyond LCDM and astrophysics effects. I will present a few applications of multi-fidelity emulators, including 9-dimensional parameter inference using galaxy formation simulations, PRIYA, constraining cosmology with the Lyman-alpha forest. Finally, I will briefly mention how multi-fidelity emulation is used for building an 11-dimensional beyond LCDM emulator using expensive high-fidelity N-body simulations.

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de Sitter as an Axion Detector

Authors: John Stout[1]; Priyesh Chakraborty[1]

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Axions, scalar fields with compact field spaces, are some of the most well-motivated candidates for physics beyond the Standard Model. In this talk, I will explain how inflationary correlations are uniquely sensitive to the topology of a scalar's field space, and can thus be used to distinguish axions from other light scalar fields even if they share the exact same action. As a proof of concept, I will show that axions can have a qualitatively distinct impact on a heavy field's cosmological collider signal. The talk will be based on arxiv: 2311.09219 and arxiv: 2310.01494.

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Constraining Interacting Dark Radiation with Lyman-alpha

Authors: Eashwar Sivarajan[1]; Hengameh Bagherian[2]; Martin Schmaltz[1]; Melissa Joseph[3]

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Models of dark sectors with a mass threshold exhibit significant cosmological signatures. When a relativistic species becomes non-relativistic before recombination and subsequently depletes in equilibrium, measurable effects on the cosmic microwave background (CMB) arise as entropy is transferred to lighter relativistic particles. Notably, if this transition occurs near z ~ 20,000, the model can naturally support higher values of H0. Additionally, if this stepped radiation interacts with dark matter, it significantly influences the matter power spectrum. Dark matter, coupled through a species that becomes non-relativistic and depleted, leads to suppressed power at scales within the sound horizon prior to the transition, while preserving conventional cold dark matter signatures beyond the sound horizon.

This presentation will explore the cosmological implications of such models and evaluate their potential to resolve the 5σ Hubble tension alongside discrepancies in Large Scale Structure (LSS) data, including the eBOSS Lyα forest measurement.

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Large-scale structure and new physics at the eV scale

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Ongoing and future spectroscopic surveys have prime sensitivities to comoving scales that became causal when the temperature of the Universe was in the ~1-100 eV regime. As such, these data are key to probing part of the so-called LambdaCDM 'desert'between e+e- annihilation and matter-radiation equality. This apparent desert has recently received renewed attention in light of possible cosmological tensions within the LambdaCDM model. Many proposed solutions point, in part, to this 1-100 eV window for new physics to appear. Although we naively expect eV-scale physics to be tightly constrained by laboratory experiments, we will discuss here examples of such physics that could affect galaxy clustering while evading laboratory constraints. Even without considering tensions, we point out several hints for physics at the eV scale in cosmological data and discuss their potential impact on upcoming large-scale structure observations.

Session 9 / 28

A new method to determine H_0 from cosmological energy-density measurements

Author: Alex Krolewski[None]

Co-author: Will Percival

We introduce a new method for measuring the Hubble parameter from low-redshift large-scale observations that is independent of the comoving sound horizon. The method uses the baryon-to-photon ratio determined by the primordial deuterium abundance, together with Big Bang Nucleosynthesis (BBN) calculations and the present-day CMB temperature to determine the physical baryon density $\Omega_b h^2$. The baryon fraction Ω_b/Ω_m is measured using the relative amplitude of the baryonic signature in galaxy clustering, scaling the physical baryon density to the physical matter density. The physical density $\Omega_m h^2$ is then compared with the geometrical density Ω_m from Alcock-Paczynski measurements from Baryon Acoustic Oscillations (BAO) and voids, to give H_0. Current data is only weakly constraining and therefore consistent with both the distance-ladder and CMB H_0 determinations, but near-future large-scale structure surveys (such as the full DESI and Euclid surveys) will obtain 3–4$\times$ tighter constraints. Including type Ia supernovae and uncalibrated BAO, and using the baryon signature in BOSS galaxy clustering, we measure $H_0 = 67.1^{+6.3}_{-5.3}$ km s^{-1} Mpc^{-1}. We find similar results when varying analysis choices, such as measuring the baryon signature from the reconstructed correlation function, or excluding supernovae or voids.

Session 7 / 29

Constraining local primordial non-Gaussianity using the large-scale modulation of small-scale statistics

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We implement a novel formalism to constrain primordial non-Gaussianity of the local type from the large-scale modulation of the small-scale power spectrum. Our approach combines information about primordial non-Gaussianity contained in the squeezed bispectrum and the collapsed trispectrum of large-scale structure together in a computationally amenable and consistent way, while avoiding the need to model complicated covariances of higher N-point functions. We perform a simulation based study and explore using both matter field and halo catalogues from the Quijote simulations. We find that higher N-point functions of the matter field can provide strong constraints local on non-Gaussianity parameter f_{NL}, but higher N-point functions of the halo field, at the halo density of Quijote, only marginally improve constraints from the two-point function. In subsequent work, we take this idea further and train a neural network to locally estimate the amplitude of linear fluctuation σ_8 from matter density field and correlate these local estimates with the large-scale density field. We apply our method to N-body simulations, and show that $\sigma(f_{NL})$ is 5.5 times better than the constraint obtained from a standard halo-based approach. We show that our method has the same robustness property as large-scale halo bias: baryonic physics can change the normalization of the estimated f_{NL}, but cannot change whether f_{NL} is detected.

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Wide-angle effects in full-sky surveys

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Current and upcoming redshift surveys will measure the galaxy distribution over an increasing volume, probing interesting physical effects that become important on large physical scales. In particular, the local primordial non-Gaussianity $f_{\rm NL}$ will be measured to $\mathcal{O}(1)$ precision with SPHEREx, which will allow us to distinguish between multi-field and single-field models of inflation. However, the curved nature of the sky becomes more apparent on large angular scales, and any effects that depend on the line-of-sight (LOS) of the observer must be accurately modeled to compute n-point statistics. In this work we quantify the importance of wide-angle effects - corrections to the approximation that all LOS's in the survey are parallel - in the context of $f_{\rm NL}$ constraints from the galaxy power spectrum and bispectrum. We show using a perturbative framework that these effects can mimic an $f_{\rm NL \sim 5}$ signal in the power spectrum multipoles measured by SPHEREx. We confront the perturbative modeling with dedicated simulations to ultimately recommend using exact methods based on spherical Fourier-Bessel (SFB) modes to fully account for the curved sky. Finally, for the first time we compute the bispectrum in the SFB basis and study its key features.

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Non-perturbative method for modeling the wide-angle effects in the power spectrum

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The three-dimensional galaxy power spectrum is a powerful probe of primordial non-Gaussianity and additional general relativistic effects, which become important on large scales. At the same time, wide-angle (WA) effects due to differing lines-of-sight (LOS) on the curved sky also become important with large angular separation. In this work, we accurately model WA and Doppler effects using the spherical Fourier-Bessel (SFB) formalism, before transforming the result into the commonly used power spectrum multipoles (PSM). This mapping from the SFB power spectrum to PSM represents a new way to non-perturbatively model WA and GR effects present in the PSM, which we validate with log-normal mocks. Moreover, for the first time, we can compute the analytical PSM Gaussian covariance on large scales, exactly including WA-induced mode-couplings, without resorting to any plane-parallel approximations.

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Theoretical systematics in Large-Scale Structure Surveys

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Large-Scale Structure (LSS) surveys have emerged as a promising avenue to probe the physics of cosmic inflation. Our limited quantitative understanding of the non-linear physics of structure formation poses modelling challenges when interpreting LSS data. In this talk I will give an overview of previous work that investigates some theoretical systematic effects in the context of large-scale galaxy surveys –especially those that seek to constrain local primordial non-Gaussianity. I will begin with describing our work on the gravitational effects of free-streaming light relics that are relativistic at late times (like massless neutrinos). The free-streaming of light relics non-trivially affects the coupling between large and small scales in structure formation and brings about a relative suppression in the galaxy bias at the largest scales –making it a potentially important systematic for any large-scale galaxy survey. I will then proceed to describe our work analysing the impact of free-streaming neutrinos and ionising radiation fluctuations in the late universe as post-inflationary phenomena that can bias a measurement of local primordial non-Gaussianity using observations of galaxy clustering. Accurate modelling of the effects of ionising radiation and free-streaming light relics is important in the context of future surveys like SPHEREx and MegaMapper that seek to robustly constrain local primordial non-Gaussianity as a distinguishing feature of some multi-field inflationary models. Towards the end, I will also present recent work on prospects for measuring local primordial non-Gaussianity parameters beyond f_{NL} using galaxy power spectra measurements by the SPHEREx all-sky survey.

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Probing self-interacting neutrinos with large-scale structure observations

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According to the Standard Model (SM), neutrinos begin to free-stream as the Universe cools to approximately 1.5 MeV, leaving distinctive imprints in cosmological observables. Interestingly, several analyses have revealed that some cosmic microwave background (CMB) data allow a cosmological scenario in which, due to self-interactions, the onset of neutrino-free streaming occurs close to the epoch of matter-radiation equality. While such results could hint at new physics at early times, this non-standard neutrino free-streaming scenario could arise from an accidental feature in the CMB data. To clarify this situation, we investigate, in a CMB-independent way, whether the large-scale distribution of galaxies allows for this cosmological scenario. We find that galaxy power spectrum data also aligns with this scenario, discarding the possibility of an accidental feature in the CMB. We further investigate the relevance of this non-trivial agreement between CMB and large-scale structure (LSS) data by analyzing both data sets employing the simplest representation of self-interacting neutrinos in cosmology. Our analysis reveals that, due to the S_8 discrepancy, self-interacting neutrinos fail to simultaneously accommodate a consistent scenario for both the CMB and galaxy power spectra, emphasizing the need to consider a broader range of phenomenologies in the early Universe. Our findings also highlight some of the challenges ahead if we aim to uncover the underlying free-streaming nature of neutrinos using spectroscopic surveys.

Session 10 / **34**

MUltiplexed Survey Telescope (MUST): an overview and current status

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While the current extragalactic spectroscopic surveys have accumulated millions of spectra of galaxies, more data are required for significant advancements in our understanding of the Universe and fundamental physical laws. To this end, the MUltiplexed Survey Telescope (MUST) is conceived by Tsinghua University to achieve this ambitious goal. Located at the Saishiteng Mountain, Qinghai Province of Northwest China, MUST will survey the northern sky. With a 6.5m diameter primary mirror and ~20,000 optical fibers on the focal plane, MUST will carry out cutting-edge wide-field spectroscopic surveys with unprecedented efficiency. It aims to pursue a wide range of studies, including but not restricted to the large-scale structure of the Universe, the nature of dark energy, the distribution of dark matter, and the formation and evolution of galaxies.

Session 6 / **35**

Primordial features

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The dynamics of early universe quantum fields generates a variety of signals amenable to observational tests. This talk will overview the theoretical origin of features in the power spectrum and beyond, including their motivation and structure in UV complete theory.

Session 2 / **36**

Higher-order statistics as probes for parity symmetry

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Parity symmetry, which posits the conservation of physical laws under spatial inversion, was initially presumed to extend from macroscopic phenomena down to subatomic scales. However, its applicability at cosmological scales remains largely unexplored. In this talk, I will briefly review using the galaxy four-point functions to search for parity violation at cosmological scales. In addition, I will also present a new estimator that is tailored to be sensitive to parity transformation. This new "compressed"estimator, the parity-odd power spectrum (POPS), is not only accelerates computation but also significantly reduces the number of degrees of freedom. This reduction directly addresses the computational challenges associated with the four-point function, especially concerning covariance matrix estimation. I will show preliminary results for the POPs and discuss how it complements the four-point function in the context of the next generation spectroscopic survey.

Session 11 / 37

Unveiling long range dark forces with the Large Scale Structure of the Universe

Author: Emanuele Castorina[None]

The equivalence between the inertial and gravitational mass is built-in the formulation of General Relativity as the curvature of space time. In the visible sector, the equivalence principle has been tested with extraordinary precision, but very little is known about the presence of long range fifth forces in the dark sector. In this talk I will describe how we can use cosmological data to test if dark matter violates the equivalence principle. The Universe itself will act as a scale, measuring whether dark matter particles fall in the same way as ordinary particles. After discussing the main effects of dark fifth forces on cosmological observables like the CMB and matter power spectrum, I will present the constraints on the strength of the new interaction using Planck and Large Scale Structure data. Our results indicate that equivalence principle violations in the dark sector are at most a few parts in one thousand, which is the best available bound on such new forces. Some implications of these bounds for the direct detection of dark matter will also be discussed.

Session 8 / 38

LSS Signals from Solutions to the Higgs or Neutrino Hierarchy Problems

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Cosmology offers a unique opportunity to explore new physics with tiny interactions to the Standard Model particles. This is particular useful for studying new physics scenarios that address hierarchy problems while evading collider detections. I will briefly review three examples where data from the Large Scale Structure is crucial for identifying signals of solutions to hierarchical problems, and explain why the high-redshift measurements of the matter spectrum may be the only way to examine these models. The examples include: (1) the Mirror Twin Higgs model, which addresses the little Higgs hierarchy problem from a well-defined atomic dark matter sector causing Dark Acoustic Oscillation signals in the matter power spectrum. (2) The N-naturalness model, which resolves the Higgs hierarchy problem and predicts a tower of warm dark matter particles creating a distinct signal of suppression in the matter power spectrum. (3) The Majoron scenario, which explains the

hierarchical mass spectrum of neutrinos compared to other fermions, and can lead to neutrino decays occurring on a cosmological time scale. The scenario results in a different redshift dependence in the evolution of matter power spectrum.

Session 5 / 39

Spec-S5 for Cosmic Acceleration and Beyond: A Snowmass Perspective

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A major focus of the Snowmass2021 Cosmic Frontier report from the Topical Group on "Dark Energy and Cosmic Acceleration in the Modern Universe" (CF4) was on the compelling science cases for developing a Stage 5 Spectroscopic Facility. This Topical Group considered probes of both late-time cosmic acceleration and inflation based on observations of phenomena in the post-reionization era (z⊠5), as well as other measurements which could be pursued simultaneously with the same datasets. In this talk, I will summarize the relevant community input that was considered by the CF4 Topical Group, including both the science cases and design considerations for Spec-S5 which the report describes.

Session 7 / 40

Probing primordial non-Gaussianity by reconstructing the initial conditions with machine learning

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Inflation remains one of the enigmas in fundamental physics. While it is difficult to distinguish different inflation models, information contained in primordial non-Gaussianity (PNG) offers a route to break the degeneracy. In galaxy surveys, the local type PNG is usually probed by measuring the scale-dependent bias in the galaxy power spectrum on large scales, where cosmic variance and systematics are also large. Other types of PNG need bispectrum, which is computationally challenging and is contaminated by gravity. I will introduce a new approach to measuring PNG by using the reconstructed density field, a density field reversed to the initial conditions from late time. With the reconstructed density field, we can fit a new template at the field level, or compute a near optimal bispectrum estimator, to constrain PNG. By reconstructing the initial conditions, we remove the nonlinearity induced by gravity, which is a source of confusion when measuring PNG. Near optimal bispectrum estimator mitigates computational challenges. This new approach shows strong constraining power, offers an alternative way to the existing method with different systematics, and also follows organically the procedure of baryon acoustic oscillation (BAO) analysis in large galaxy surveys. I will present a reconstruction method using convolutional neural networks that significantly improves the performance of traditional reconstruction algorithms in the matter density field, which is crucial for more effectively probing PNG. This pipeline can enable new observational constraints on PNG from the ongoing Dark Energy Spectroscopic Instrument (DESI) and Euclid surveys, as well as from upcoming surveys, such as that of the Nancy Grace Roman Space Telescope.

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Constraints on long-range neutrino self-interactions from large-scale structure

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Upcoming cosmological surveys will probe the impact of a non-zero sum of neutrino masses on the growth of structures. These measurements are sensitive to the behavior of neutrinos at cosmic distances, making them a perfect testbed for neutrino physics beyond the standard model at long ranges. In this talk, I will introduce a novel signal from long-range self-interactions between neutrinos. In the late-time universe, this interaction triggers the Jeans instability in the cosmic neutrino background. As a result, the cosmic neutrino background forms macroscopic bound states and induces large isocurvature perturbations in addition to the cold dark matter density perturbations. This enhancement of matter perturbation is uniquely probed by late-time cosmological observables. We find that with the minimum sum of neutrino masses measured by neutrino oscillation experiments, the current SDSS data already place strong constraints on the long-range neutrino self-interactions for interaction range greater than kpc.

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Search for CDM isocurvature with large-scale structure: a forecast for MegaMapper

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Isocurvature perturbations with a blue power spectrum are one of the natural targets for the future large scale structure observations which are probing shorter length scales with greater accuracy. We present a Fisher forecast for the MegaMapper in its ability to detect CDM blue isocurvature perturbations. We construct the theoretical predictions in the EFTofLSS and bias expansion formalisms at quartic order in overdensities which allows us to compute the power spectrum at one loop order and bispectrum at tree level and further include theoretical error at the next to leading order for the covariance determination. We find that MegaMapper is expected to provide about 1 to 1.5 orders of magnitude improvement on the isocurvature spectral amplitude compared to the existing Planck constraints for a broad range of spectral indices. We also find features that are specific to the blue isocurvature scenario including the leading parametric degeneracy being with the Laplacian bias and a UV sensitive bare sound speed parameter.

Session 11 / 43

Cosmological Signatures of Interacting Dark Sectors

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The precision of present-day cosmological measurements has enabled exploration into the characteristics of dark matter and other particles within the dark sector. As measurement precision improves, discrepancies among various datasets have emerged, suggesting a necessity to move beyond the standard ΛCDM model. Extensions of ΛCDM that incorporate interactions within the dark sector not only yield good fits to the CMB but also resolve tensions observed in cosmological data, such as the Hubble tension and discrepancies in recent Large-Scale Structure measurements of the matter power spectrum. These models of interacting dark sectors can exhibit unique cosmological signatures that can be investigated further by the upcoming generation of Large-Scale Structure surveys. I will present the observable signatures of a variety of interacting dark sector models and discuss how they may be distinguished in future spectroscopic surveys.

Session 2 / **44**

Promising Results and Prospective Probes of Parity

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In this talk, I will outline our recent work on the SDSS BOSS 4-point correlation function and an apparent 7 sigma detection of parity violation. Then I will provide an update on progress with the Year 1 DESI data. I will conclude with a presentation of two new methods to ensure that the apparent result is of genuine cosmological origin.

Session 5 / **45**

Detecting transverse velocities with the moving lens effect

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The advent of higher resolution and improved sensitivity CMB experiments in conjunction with deeper and wider galaxy surveys facilitates the exploration of cross correlations to detect weak signals. Among these, there is one of the two signals caused by the transverse velocity of halos: the moving lens effect. I will review the manifestation of the signal and summarize the perspective of detection, given our current knowledge of astrophysical foregrounds and survey specifications. I'll describe which competing effects are affecting the measurement, and discuss methodologies and strategies to improve the expected detection.

Session 7 / **46**

Extending the reach of the cosmological collider

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Massive field excitations during the inflationary era, imprinted on cosmological correlation functions, can provide us with a unique opportunity to probe heavy degrees of freedom far beyond the reach of terrestrial colliders. In the simplest inflationary models, any such cosmological collider signal is exponentially suppressed for particles much heavier than the inflationary Hubble scale, limiting the potential reach of such new physics searches. After reviewing the key observables, I will discuss some new mechanisms to go beyond this limitation for particles with varying charges and spins. Together, these mechanisms motivate novel searches in the context of future spectroscopic surveys, which would have the potential to directly access well-motivated high-scale scenarios, such as Grand Unified Theories.

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Opportunities for Dark Matter Searches in Cosmology

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Cosmological and astrophysical observations provide a unique opportunity to probe the fundamental properties of dark matter. Dark matter interactions with the Standard Model of particle physics, for example, can alter predictions from the standard cosmological model, permitting robust tests of new dark matter physics. In this talk, I will describe the impact that dark matter interactions have on the CMB and structure formation and show how observational data can constrain broad classes of dark matter models.

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Welcome & DESI Status

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Future Facilities and Instrument Considerations

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LSS Structure at High Redshift: Opportunities for New Physics

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Motivation and Targets for Measuring Primordial non-Gaussianity

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Beyond the Standard Model

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Summary of earlier European workshops (LSS and BSM Physics).

Author: Emanuele Castorina[None]

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Moderated Discussion: what we know/don't know about non-Gaussianity

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