18. Kosmologietag

Thursday, May 2, 2024 - Friday, May 3, 2024

ZiF | Bielefeld University

Book of Abstracts

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Flash talks / **1**

Is the Universe made entirely of baryons?

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Hydrogen “snow clouds” - which are so cold and dense that they contain particles of solid or liquid molecular hydrogen - are a well motivated form of baryonic dark matter. Theoretical models of snow cloud structure prefer cloud masses in the planetary range, but radii as large as planetary orbits. Increasingly there is evidence that such gas plays an important role in our own Galaxy, but the total mass in this form is poorly constrained by the available data. Within the ΛCDM cosmological model the baryonic content of the universe is gauged by the amplitude of the microwave background fluctuations, and in that model the sum total of baryons is inferred to be a small fraction of all the mass. More generally the low amplitude of the microwave background fluctuations, together with the rich structure we observe in matter in the low-redshift universe, tells us that our universe contains more than just baryons that are diffuse (tightly coupled to the radiation field) at recombination. But baryons that are already collapsed at recombination may suffice. I’ll highlight some key elements of snow cloud physics in the Galactic context, and sketch out some possible aspects of a Universe that is dominated by planetary mass lumps from very early times.

Session I / **4**

Minimal decaying dark matter: from cosmological tensions to neutrino signatures

Authors: Lea Fuß[1]; Mathias Garny[2]; Alejandro Ibarra[2]

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The invisible decay of cold dark matter into a slightly lighter dark sector particle on cosmological time-scales has been proposed as a solution to the S_8 tension. In this talk, I want to present a possible embedding of this scenario within a particle physics framework and discuss its phenomenology. The model is set up of a minimal dark matter decay, where the dark sector contains two singlet fermions $N_{1,2}$, quasi-degenerate in mass, and carrying lepton number so that the heaviest state (N_2) decays into the lightest (N_1) and two neutrinos via a higher-dimensional operator $N_2 \to N_1 \nu\nu$. Due to the present symmetries and small phase space, the decays into photons or charged leptons are strongly suppressed and thus its stringent constraints from indirect dark matter searches can be avoided. Additionally, complementary constraints on the model parameters arise from neutrino detectors, freeze-in dark matter production, collider experiments and blazar observations. Together, these single out dark matter masses below ~ 1 GeV where constraints still allow for model parameters addressing the S_8 tension. Signals of dark matter in this parameter space of interest could be detected by the upcoming JUNO neutrino observatory.

Flash talks / **5**

Simplifying GR - Geometric precession with Geometric Algebra

Author: Pablo Banon Perez[1]

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Combining Geometric Algebra with tetrads is an excellent tool to describe the geometric character of General Relativity. In this talk, I will briefly introduce the formalism and illustrate its potential by presenting the calculations of an orbital precision around a Schwarzschild black hole. Compared with tensor calculus, **we reduce a system of 4 coupled differential equations to a single, trivial one** with a clearly geometric solution.

Session I / **6**

Probing modified Hawking evaporation with gravitational waves from the primordial black hole dominated Universe

Authors: Alexander Ganz[1]; Gabriele Franciolini[2]; Guillem Domenech[3]; Jan Tränkle[4]; Shyam Balaji[5]

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Can modifications to Hawking evaporation of small black holes be probed by observing gravitational waves from the early Universe? In this talk I will argue that the answer to this tantalizing question may in fact be positive.

It has been recently proposed that Hawking evaporation might slow down significantly after a black hole has lost about half of its mass, considerably extending its lifetime. I will discuss the impact of this so-called "memory burden" effect on the Primordial Black Hole (PBH) reheating scenario, where tiny black holes temporarily dominate the Universe and reheat it via Hawking radiation.
Interestingly, in some models, the slope of the Gravitational Wave (GW) spectrum induced by PBH number density fluctuations might be sensitive to the modifications to Hawking evaporation. In some region of the allowed parameter space, the induced GW signal enters the observational window of several future GW detectors, as e.g. DECIGO and the Einstein Telescope, proving it may soon be possible to test the memory burden effect via induced GWs.

Flash talks / **7**

Matter-antimatter asymmetry and dark matter stability from baryon number conservation

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There is currently no evidence for a baryon asymmetry in our Universe. Instead, cosmological observations have only demonstrated the existence of a quark-antiquark asymmetry, which does not necessarily imply a baryon asymmetric Universe, since the baryon number of the dark sector particles is unknown. In this paper we discuss a framework where the total baryon number of the Universe is equal to zero, and where the observed quark-antiquark asymmetry arises from neutron portal interactions with a dark sector fermion N that carries baryon number. In order to render

a baryon symmetric universe throughout the whole cosmological history, we introduce a complex scalar χ, with opposite baryon number and with the same initial abundance as N. Notably, due to the baryon number conservation, χ is absolutely stable and could have an abundance today equal to the observed dark matter abundance. Therefore, in this simple framework, the existence of a quark-antiquark asymmetry is intimately related to the existence (and the stability) of dark matter.

Session IV / **8**

Cosmology with LOFAR Sky Surveys

Authors: Caroline Heneka[None]; Catherina Hale[None]; Dominik Schwarz[1]; Jinglan Zheng[None]; Lukas Böhme[2]; Morteza Pashapour-Ahmadabadi[3]; Szymon J. Nakoneczny[None]

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Over a combination of large areas as well as smaller, deep fields observations, the LOFAR Two-metre sky survey (LoTSS, Tasse+ 2021, Sabater+ 2021, Shimwell+ 2022) is producing detailed knowledge of sources at low radio frequencies (144 MHz), across large periods of cosmic time. The combined area of these surveys as well as their depth and ancillary information provides exciting opportunities for cosmological analyses to learn about large-scale structure and the cosmological parameters underpinning our Universe, as inferred from the radio skies. For example, what can we learn about how galaxies trace dark matter, the cosmic radio dipole and what are the inferred values of cosmological parameters.
This talk, given on behalf of the LOFAR surveys cosmology team, will detail the cosmological understanding which we have learnt from the ~5,000 sq. deg of the wide area LoTSS-DR2 data release (Shimwell+ 2022). I will provide details of the observations employed and a discussion of the methods used to account for systematics across the large field of view of the survey from factors such as incompleteness and source smearing. I will present the results from a combination of analyses from the LOFAR surveys cosmology team, including looking at the:

Counts-in-Cell statistics (Pashapour-Ahmadabadi, Böhme+, in prep.);
the cosmic radio dipole (Böhme+, in prep.);
angular clustering across the surveyed area (Hale+ 2023);
cross-correlation analysis with the cosmic microwave background (Nakoneczny+ 2023);
cross-correlation with the eBOSS survey (Zheng+, in prep.);
Combined cosmological analysis (Heneka+, in prep.)

I will then summarise the combined understanding we have gained from these investigations.

Flash talks / **9**

Exploring Minimally Modified Gravity Models

Author: Alexander Ganz[1]

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Minimally modified gravity models are a class of modified gravity theories with only two local degrees of freedom as in General Relativity. I want to discuss the implications on the early Universe.

As long as the non-dynamical scalar field is sub-dominant at the background one recovers the standard results for slow-roll inflation both for the power and biscpectrum. Otherwise, it is possible to construct viable models enhancing the local non-Gaussianities and violating Maldacena's consistency relation.
Last, I discuss that the bispectrum can be crucial to test bouncing scenarios, which have been proposed in this class of models.

Session IV / **10**

The Integrated 3-point correlation function of projected cosmic density fields

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The integrated 3-point correlation function (i3PCF) is a higher-order statistic (beyond traditional 2-point methods) that can be measured directly from weak lensing cosmic shear data by correlating local 1-point aperture mass statistics with local shear 2-point correlation functions (2PCF) measured within well-defined patches across a galaxy survey footprint. We have developed an accurate theoretical model using the response function approach to perturbation theory to calculate the i3PCF, included several known lensing systematic effects in our modelling and made use of machine learning emulator techniques to perform rapid MCMC analyses. We have measured and analysed the i3PCF in the blinded cosmic shear dataset of the Dark Energy Survey Year 3 (DESY3) data release and found that the addition of the i3PCF brings significant improvements on cosmological parameters relative to 2PCFs alone. Based on the encouraging results, we have extended our framework to propose the integrated 3-point cross-correlation functions of lensing and projected galaxy density fields. We forecast that these new higher-order lensing $\times$ galaxy clustering statistics hold the potential to bring further interesting improvements not only on cosmological but also on galaxy bias parameters.

Session II / **11**

Leptogenesis via bubble collisions

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We study leptogenesis from the decays of sterile (right-handed) neutrinos produced from bubble collisions at a first order phase transition. We explore the new parameter space opened up by this new mechanism, making comparisons with other existing leptogenesis scenarios (in particular involving bubbles), and find that bubble collisions enable leptogenesis with RHNs at the natural mass scale 10^{14} GeV, where they can also give rise to SM neutrino masses via type-I seesaw with $\mathcal{O}(1)$ couplings. The relevant phase transitions are at
$gtrsim10^8$ GeV, and can be within reach of future gravitational wave experiments.

Session I / **12**

ApPolLo - Apertif counterparts of polarised LOFAR sources

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Polarisation studies over a significant redshift range are an important tool in understanding the evolution of cosmic magnetic fields and unrevealing their origin. As most depolarisation effects are highly wavelength depended, the combination of different surveys allows us to distinguish between different effects.

We use the synergy of LOFAR and Apertif; starting with sources known to show significant polarised emission at 144 MHz, we image their 1.4 GHz counterparts and construct a catalogue of 598 polarised sources.
We present preliminary results of the comparison of polarisation properties and Rotation Measure values at 1.4 GHz and 144 MHz, including the first redshift-dependent estimate of the Rotation Measure dispersion in cosmic web filaments.

Session III / **13**

Spectral distortions and PBH constraints in presence of primordial non-Gaussianity

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The tight constraints on the μ type distortions in the CMB blackbody spectrum coming from the FIRAS observations can be used to set up the bounds on primordial curvature perturbations and thus on the Primordial Black Holes (PBHs). To do so, the conventional works assume the Gaussian initial conditions. However, it is well known that the enhancement in the primordial power spectrum needed to seed the PBH formation could lead to highly non-Gaussian statistics, hence, questioning such an assumption of Gaussianity. We shed light on this issue by providing a semi-analytic calculation of the spectral distortions in the presence of a local type non-Gaussianity, in perturbative and strong non-perturbative limits, in addition to a thorough comparison of the standard approximation schemes for the distortion source functions. Moreover, we also discuss a full calculation of PBH constraints on top of reassessing the question of PBHs as the seeds of SMBHs. This talk will be inspired by two articles in collaboration with J. Lesgourgues and C. Byrnes that will be published before this conference.

Session IV / **14**

From Tunneling to Friction and Back

Authors: Daniel A. Pinto[1]; Enrico Perboni[2]; Gláuber Carvalho Dorsch[1]; Thomas Konstandin[2]

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A cosmological first-order phase transition during the evolution of the Universe can give rise to intriguing phenomena like electroweak baryogenesis or the generation of a stochastic background of gravitational waves through bubble nucleation. This study aims at exploring critical aspects of the bubble wall velocity, which significantly impact these phenomena. Recent investigations have highlighted a singularity in the friction terms as the terminal wall velocity approaches the speed of sound; this behavior has been attributed to the linearization procedure. We try to solve this issue by proposing modifications to this procedure, employing non-equilibrium physics techniques; our aim would be to prevent the emergence of the singularity and ensure physical consistency.

Session II / **15**

Universality of structures from the small-scale limit of the dark matter power spectrum

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The growth of small-scale structures in dark matter is hard to
access with numerical, observational and conventional analytical methods.
However, information about initial conditions and the properties of dark matter are supposed to leave their footprints in these small scale structures.
I present analytical work, where we show with Kinetic Field Theory (KFT) that the dark matter density perturbation power spectrum of cosmic structures necessarily develop a k^{-3} tail when the initial phase space distribution is a Gaussian random field and trajectories are straight as in the famous Zel'dovich approximation. This result is independent of the initial power spectrum and also holds when no UV cutoff is imposed on the initial power spectrum. The power law exponent of -3 is a consequence of the number of spatial dimensions. Our result implies that universal small-scale structures necessarily form even when they are absent initially. From the asymptotic expansion that we derive, we are able to deduce time, length and mass scales characteristic for small structures in dark matter. These scales potentially leave measurable imprints in observables related to the CMB or the era of reionization, giving hints to the primordial n_s and the temperature of dark matter.
Additionally, in the analytical framework of KFT, particle-particle interactions beyond the Zel'dovich approximation can be computed with a mean field approach. This non-linear power spectrum agrees within a few percent with numerical simulations. We show that in this mean field theory, the power spectrum also has an asymptotic k^{-3} tail, proving the universality of cosmic structures.

Flash talks II / **16**

OLÉ - Active Sampling and Differentiable Emulation for Cosmology

Author: Sven Günther[1]

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Bayesian parameter inference is one of the key elements for model selection in cosmological research. However, the inference tools require a large number of calls to simulation codes which can

lead to high and sometimes even infeasible computational costs. In this work we combine fast and differentiable emulators with active sampling to accelerate MCMC analyses of CMB physics by 1-2 magnitudes and save 2-3 magnitudes of simulation calls. In particular, this novel approach emphasizes the uncertainty-awareness of the emulator, which allows to state the emulation accuracy and ensures reliable performance where needed.

Session II / **17**

Probing dark matter microphysics with structure formation

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The microphysics of dark matter remains a mystery, with current data only setting upper bounds on interaction cross sections, or lower bounds on the mass in the case of a thermal relic. Going to higher redshift and smaller scales will let us improve these bounds, but more importantly, may allow us to distinguish between models with otherwise similar signals. In particular, I will present a novel method for constraining models with suppressed small scale structure using gravitational waves, along with forecasts for complementary constraints from 21cm intensity mapping. The latter is especially important regarding what is necessary to distinguish interacting dark matter from warm dark matter.

Session III / **18**

Gravitational Waves from Low-Scale Cosmic Strings

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In this talk, I will discuss the effect of very low cosmic string tensions on the associated stochastic gravitational wave background. I will show that the gravitational wave spectrum is qualitatively different from the one produced by cosmic strings with larger tensions. In fact, it exhibits a very distinct oscillatory feature with dips in the amplitude at multiples of the frequency of the first dip. This feature arises if none of the cosmic string loops chopped off from the long-string network have fully decayed yet. Despite the low tensions, such an SGWB would be measurable in future experiments.

Session I / **19**

QED contribution to Neff at NLO

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The effective number of neutrinos, $N_{\rm eff}$, is an important parameter in standard hot big bang cosmology. In this work, we compute the dominant QED correction to the neutrino-electron interaction rate in the vicinity of neutrino decoupling in the early universe, and estimate its impact on $N_{\rm eff}$. We find that the correction to the interaction rate is at the sub-percent level. The fractional change in $N_{\rm eff}$ due to the rate correction is of order or below 10^{-5}, i.e., about a factor of 30 smaller than that recently claimed by Cielo et al., and below the nominal computational uncertainties of the current benchmark value of $N_{\rm eff} = 3.0440 \pm 0.0002$. We therefore conclude that aforementioned number remains to be the state-of-the-art benchmark for $N_{\rm eff}$ in the standard model of particle physics.

Based on arXiv:2402.18481

Flash talks II / 21

Small-Scale Asymptotics of the Free Density Perturbation Bispectrum

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Structure formation is a central topic for cosmology. The density perturbation power spectrum, i.e., Gaussian information, has already been constrained by data, but not much is known for the density perturbation bispectrum, the first cumulant beyond pure Gauss. For large-scales, conventional analytical methods based on hydrodynamic approximations provide accurate results, but for smaller distances they become quickly inaccurate. Kinetic Field Theory is able to give expressions for the density bispectrum valid even in the small-scale, non-linear regime as the theory naturally avoids stream crossing problems. For a restriction to the free Zel'dovich evolution of initially correlated particles, it is possible to derive analytic expressions for the bispectrum in the asymptotic small-scale regime. This is confirmed by numerical evaluations of the analytical integral expressions, showing that the validity of the description starts around k=1-10 h/Mpc. Universally for initial power spectra, a -5.5 power law exponent is found to leading order. This is due to a degeneracy in the Hessian of the exponent, which can only be found using asymptotic techniques. In contrast, large-scale expansions and hydrodynamics erroneously predict a -6 exponent for the power law at leading order.

Session III / 23

Quantum simulation of the dynamics in the early universe

Author: Stefan Floerchinger[1]

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The dynamics of the early universe is influenced by interesting quantum effects like the formation of scalar and tensor perturbations during inflation. I will discuss how such processes can be investigated more closely with quantum simulation. This uses modern quantum technology like ultracold quantum gases in optical traps with time-dependent scattering length. I will also discuss further perspectives for such a research program.

Session II / **24**

Journey into Anisotropy

Author: Robbert Scholtens[1]

[1] *University of Groningen*

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On the largest scales the Universe appears to be almost perfectly
homogeneous and isotropic, adhering to the cosmological principle. On smaller scales inhomogeneities and anisotropies become increasingly prominent, reflecting the origin, emergence and formation of structure in the Universe and its cosmological impact. Also, a range of tensions between various cosmological observations may suggest it to be necessary to explore the consequences of such deviations from the ideal uniform universe. In this study, we restrict this to an investigation of anisotropies on the nature of the Universe. The geometry of homogeneous yet anisotropic cosmologies can be fully represented by the class of Bianchi metrics. According to their symmetries, they can be divided into several classes. In our recent work, we develop a method to characterize Bianchi metrics by means of their symmetries in a direct fashion, namely starting from the desired isometries and then finding a metric on which these are realized as such. This presentation will introduce Bianchi metrics, and touch upon this construction.

Session IV / **25**

On a thermal Higgs width across an electroweak phase transition

Authors: Magdalena Eriksson[1]; Mikko Laine[1]

[1] *University of Bern*

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A framework to describe long-distance dynamics of an electroweak phase transition is offered by fluctuating hydrodynamics. In this setup the neutral Higgs component can be modelled to evolve according to a Langevin equation. In this talk we report on recent results for the thermal Higgs interaction rate close to a first order EW phase transition, which appears as a coefficient in a Langevin equation. We also contrast with the friction discussed in connection with bubble growth.

Session III / **26**

Parity-odd power spectra: Concise Statistics for Cosmological Parity Violation

Author: Drew Jamieson[1]

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Discovering primordial parity violation would have profound implications for our understanding of early Universe physics and would greatly inform inflationary models. Tantalizing evidence of cosmic parity violation in the four-point statistics of galaxy clustering is currently inconclusive due to uncertainty in observational systematics and covariance estimation. The covariance is challenging to estimate because of the high dimensionality of the trispectrum. In this talk, I will present a new

class of observables for cosmological signatures of parity violation. These observables are parity-odd power-spectrum-like statistics (POP spectra) that are compressions of the six-dimensional trispectrum down to one-dimensional power spectra. They are much faster to implement and easier to analyze and estimate their covariance compared to the full four-point statistics. We illustrate the signal and sensitivity of our POP spectra using simulated data of a primordial potential with a specific parity-odd trispectrum. Additionally, we provide theoretical calculations that agree well with the numerical simulation results.

Session I / **28**

Properties and Signatures of ALP Stars in the Milky Way

Authors: Dennis Maseizik[1]; Günter Sigl[2]; Hyeonseok Seong[3]; Sagnik Mondal[4]

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We apply current analytical knowledge on the characteristic mass and linear evolution of miniclusters down to redshift $z = 0$ to the hypothetical minicluster distribution of the Milky Way.
Using the core-halo relation for stable soliton solutions composed of axion-like particles (ALPs), we connect the galactic minicluster mass distribution to that of their ALP star cores.
We consider different temperature evolutions of the ALP field with masses in the range $10^{-12}\,\mathrm{eV} \leq m_a \leq 10^{-3}\,\mathrm{eV}$ and infer the abundance and properties of QCD axion- and ALP stars in our galaxy.
Our analysis shows that the galactic collision rates between miniclusters and neutron stars can become as large as $\sim 10^5\,\mathrm{yr}^{-1}\,\mathrm{galaxy}^{-1}$, but that the fraction of encounters that can lead to resonance between ALP mass and magnetosphere plasma frequency is generally well below $\sim 1\,\mathrm{yr}^{-1}\,\mathrm{galaxy}^{-1}$, depending on the ALP model.
For Bosenovae, we confirm previous results that merger rates of ALP stars are extremely small $< 10^{-12}\,\mathrm{yr}^{-1}\,\mathrm{galaxy}^{-1}$, while their host miniclusters can merge much more frequently, up to $\sim 10^3\,\mathrm{yr}^{-1}\,\mathrm{galaxy}^{-1}$ for the QCD axion.
Our results suggest that Bosenovae and parametric resonance are much more likely to lead to observable signatures than neutron star encounters.\\
We also propose a new detection mechanism in which the combined accretion and parametric resonance in solitonic cores can lead to observable radio lines for a wide range of ALP masses m_a and photon-couplings $g_{a\gamma\gamma}$.
We present different accretion models for galactic ALP stars in a companion paper and calculate the correspondig radio-line flux to constrain $g_{a\gamma\gamma}$.
We find that upcoming radio telescopes such as SKA have sufficient sensitivity to reach down to $g_{a\gamma\gamma} \simeq 10^{-11}\,\mathrm{GeV}^{-1}$ and even $10^{-12}\,\mathrm{GeV}^{-1}$, depending on the ALP masses $m_a = 10^{-7} - 10^{-3}\,\mathrm{eV}$ and the accretion models.

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eROSITA's X-Ray Eyes Focussed on the Dark Side of the Universe

Massive galaxy clusters are the youngest and, therefore, most massive objects in the Universe. Their dark matter-dominated gravitational potential wells are filled with gas, heated to 10s of millions of Kelvin by shocks and compression. The SRG/eROSITA X-ray space telescope recently surveyed the sky, hunting for this hot gas in clusters, detecting an unprecedentedly large number. Employing weak gravitational lensing to constrain cluster masses, tight constraints on, e.g., dark energy and the sum of neutrino masses have been obtained. Furthermore, eROSITA has started detecting the missing normal matter ("baryons"), hiding in the so-called warm-hot intergalactic medium (WHIM)

in filaments around nearby galaxy clusters. In this talk, I'll provide an overview of galaxy clusters, eROSITA and its measurements, and the resulting constraints on dark baryons, dark matter, and dark energy.

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Pushing the Limits of Dark Matter – New Approaches and Advanced Methods

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eROSITA's X-Ray Eyes Focussed on the Dark Side of the Universe

Author: Thomas Reiprich[1]

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Massive galaxy clusters are the youngest and, therefore, most massive objects in the Universe. Their dark matter-dominated gravitational potential wells are filled with gas, heated to 10s of millions of Kelvin by shocks and compression. The SRG/eROSITA X-ray space telescope recently surveyed the sky, hunting for this hot gas in clusters, detecting an unprecedentedly large number. Employing weak gravitational lensing to constrain cluster masses, tight constraints on, e.g., dark energy and the sum of neutrino masses have been obtained. Furthermore, eROSITA has started detecting the missing normal matter ("baryons"), hiding in the so-called warm-hot intergalactic medium (WHIM) in filaments around nearby galaxy clusters. In this talk, I'll provide an overview of galaxy clusters, eROSITA and its measurements, and the resulting constraints on dark baryons, dark matter, and dark energy.

Flash talks II / 32

Peering Behind the Screening Mechanisms of Horndeski Theories