Quantum Gravity, Cosmology and Black Holes 2022

Covilhã, Portugal, CMA-UBI, March 14 – 18, 2022

Titles and Abstracts

14th March 2022 Morning Session:

Chair: Sravan Kumar

Speaker: Alexei A. Starobinsky (Landau Institute for Theoretical Physics)
Time: 10:30 AM-11:15 AM (CET)

Title: Inflation does have hair
Abstract:
All inflationary models, in spite of locally approaching the de Sitter space-time inside the Hubble radius, have scalar and tensor hair – spatial inhomogeneity - outside it. This inhomogeneity does not disappear with time. Just the opposite, its amplitude at a given comoving scale typically remains constant not only during inflation, but long time after its end up to the moment of the second Hubble radius crossing of this scale. Moreover, a part of these scalar inflationary hair have been already observed through measurements of CMB angular temperature anisotropy and polarization, and we expect the discovery of tensor hair (primordial gravitational wave background from inflation) in future. In terms of 'no-hair' theorems, this situation is similar, but just opposite to that in General Relativity (GR), where we have the 'no-hair' property of black holes outside their event horizons, but not inside them. I consider the structure of these hairs in different classical and one-loop quantum models in GR and modified gravity both in linear and non-linear regimes. The description of scalar quantum hair in the non-linear regime during inflation is possible in the closed form in the scope of the stochastic inflation formalism using the Fokker-Planck equation.

Speaker: Alexanderv Dolgov (Novosibirsk, JINR)
Time: 11:15-12:00 (CET)

Title: Primordial black holes and anti-stars in the Milky Way
Abstract:
A review of observational data indicating that our Galaxy is rich with antimatter is presented. Theoretical model which predicted this striking phenomenon is described. The same model leading to the abundant population of primordial black holes in all mass ranges in the universe is

analysed. The comparison of the theoretical predictions with the data, confirming both predictions is presented.

Speaker: Alberto Salvio (Tor Vergata Univ.)
Time: 12:00 PM-12:45 PM (CET)

Title: Natural-Scalaron Inflation
Abstract:
A pseudo Nambu-Goldstone boson (such as an axion-like particle) is a theoretically well-motivated inflaton as it features a naturally flat potential (natural inflation). This is because Goldstone's theorem protects its potential from sizable quantum corrections. Such corrections, however, generically generates an R^2 term in the action, which leads to another inflaton candidate because of the equivalence between the R^2 term and a scalar field, the scalaron, with a quasi-flat potential (Starobinsky inflation). I will discuss a recently proposed multifield scenario in which both the scalaron and a pseudo Nambu-Goldstone boson are active (natural-scalaron inflation). A robust inflationary attractor is present even when the masses of the two inflatons are comparable. Moreover, the presence of the scalaron allows to satisfy all observational bounds in a large region of the parameter space, unlike what happens in pure-natural inflation.

14th March 2022 Afternoon Session:

Chair: Alexey S Koshelev

Speaker: David Wands (Portsmouth Univ., ICG)
Time: 15:00-15:45 (CET)

Title: Primordial Black Holes from Stochastic Inflation
Abstract:
There has been renewed interest recently in the possibility of producing primordial black holes from large density perturbations after a period of inflation in the very early universe. Such large fluctuations would be the result of very rare, extreme excursions in the fields driving inflation which are not well described by standard perturbation theory techniques. I will discuss a nonperturbative description using the stochastic approach to study inflationary dynamics, identifying primordial density fluctuations with local variations in the duration of inflation. I will present recent analytical and numerical work to reconstruct the non-Gaussian tail of the probability distribution function of density fluctuations from inflation, and discuss its application to the abundance of primordial black holes.

Speaker: Latham Boyle (Perimeter Institute)
Time: 15:45 PM-16:30 PM (CET)

Title: A two-sheeted, CPT-symmetric universe
Abstract: After reviewing some key hints and puzzles from the early universe, I will introduce recent work with Neil Turok suggesting a rigid and predictive new approach to addressing them.
Our universe seems to be dominated by radiation at early times, and positive vacuum energy at late times. Taking the symmetry and analyticity properties of such a universe seriously suggests a picture in which spacetime has two sheets, exchanged by a symmetry that, in turn, selects a preferred (CPT-symmetric) vacuum state for the quantum fields that live on the spacetime. In this picture, the Big Bang may be regarded as a kind of mirror.
I will explain how this line of thought suggests new explanations for a number of observed properties of the universe, including: its homogeneity, isotropy and flatness; the arrow of time; several properties of the primordial perturbations; the nature of dark matter (which, in this picture, is a right-handed neutrino, radiated from the Big Bang like Hawking radiation from a black hole); and even the existence of three generations of standard model fermions. I will also mention some observational predictions that will be tested in the coming decade, and some key open questions.

Speaker: Chris Ripken (Mainz U.)
Time: 16:30-17:15 (CET)

Title: De Sitter scattering amplitudes in the Born approximation

Abstract:
A basic calculation in QFT is the construction of the Yukawa potential from a tree-level scattering amplitude. In the massless limit, this reproduces the 1/r potential. For gravity, scattering mediated by a massless graviton is thus consistent with the Newtonian potential. In de Sitter spacetime, the cosmological constant gives rise to a mass-like term in the graviton propagator. This raises the question what the classical potential looks like when taking into account curvature effects. In this talk, I will introduce an operator-based formalism to compute scattering amplitudes in curved spacetime, and I will show how to construct the Newtonian potential in a dS background. Remarkably, the potential gives rise to an additional repulsive force, and encodes the de Sitter horizon in a novel and non-trivial way.

Speaker: Artem Starodubtsev (St.-Petersburg Univ.)
Time: 17:15-17:45 (CET)

Title: Quantization of gravitating point particle and the spectrum of quantum spacetime
Abstract:
The dynamics of a massive particle in a frame of a test particle in 3+1 spacetime dimensions is considered with gravitational interaction taken into account. The total action (gravity+particles) collapses to a boundary separating the massive particle and the test particle, and is further reduced to a finite dimensional action depending only on relative particle coordinates and momenta. It turns out that the momentum space is a coadjoint orbit of the Lorentz group. The momentum space is thus curved and its curvature falls off with the particle relative distance according to the Newton law. This defines the modified form of the Poisson brackets. At the quantum level, this results in non-commutativity and partial discreteness in coordinate space.

17:50-18:20 Discussion session with all speakers of the day

15th March 2022 Morning Session:

Chair: Benjamin Knorr

Speaker: Robert Brandenberger (McGill U.)
Time: 10:30 AM-11:15 AM (CET)

Title: Emergent Cosmology from Matrix Theory
Abstract:
I will suggest a construction of emergent time, emergent space and an emergent early universe phase starting from the BFSS matrix model, a proposed non-perturbative definition of superstring theory. Thermal fluctuations in this state yield a scale-invariant spectrum of cosmological perturbations and gravitational waves.

Speaker: Ivano Basile (Mons Univ.)
Time: 11:15 AM-12:00 PM (CET)

Title: Asymptotic safety and the swampland
Abstract:
We investigate the consequences of combining swampland conjectures with the requirement of asymptotic safety. To this end, we explore the infrared regime of asymptotically safe gravity in a toy model, quadratic gravity at one loop. We identify the hypersurface spanned by the endpoints of asymptotically safe renormalization group trajectories. These comprise the allowed values of higher-derivative couplings as well as standard logarithmic form factors. We determine the intersection of this hypersurface with the regions of parameter space allowed by the de Sitter conjecture, the trans-Planckian censorship conjecture and the weak gravity conjecture under the hypothesis of electromagnetic duality. The latter two depend on some order-one constants, for generic values of which we show that the overlap region is a proper subspace of the asymptotically safe hypersurface. Moreover, the latter lies inside the region allowed by the weak gravity conjecture.

Speaker: Anupam Mazumdar (Groningen U.)
Time: 12:00 PM-12:45 PM (CET)

Title: How to test quantum nature of gravity in a laboratory
Abstract:
I would like to explore to test quantum nature of gravity in a laboratory. I will discuss both local and non-local aspects of gravity and what kind of signatures would they leave in a realistic quantum experiment. I will discuss these ideas in the context of quantum superposition, quantum entanglement and the nature of quantum vacuum in presence of matter degrees of freedom.

15th March 2022 Afternoon Session:

Chair: Luca Buoninfante

Speaker: Georgi Dvali (Munich U.)
Time: 15:00-15:45 (CET)

Title: Black Hole = Saturon
Abstract:
TBA

Speaker: Roberto Casadio (Bologna U.)
Time: 15:45-16:30 (CET)

Title: An effective quantum state for neutral and charged black holes
Abstract: Starting from the idea that the spacetime geometry must be described by suitable states in the complete quantum theory of matter and gravity, we shall present an explicit construction in terms of coherent states for spherically symmetric black holes with and without electric charge.

Speaker: Xavier Calmet (Sussex U.)
Time: 16:30-17:15 (CET)

Title: Quantum Hair from Gravity
Abstract:
I discuss the relationship between the quantum state of a compact matter source and of its asymptotic graviton field. For a matter source in an energy eigenstate, the graviton state is determined at leading order by the energy eigenvalue. Insofar as there are no accidental energy degeneracies there is a one to one map between graviton states on the boundary of spacetime and the matter source states. Effective field theory allows us to compute a purely quantum gravitational effect which causes the subleading asymptotic behavior of the graviton state to depend on the internal structure of the source. This establishes the existence of ubiquitous quantum hair due to gravitational effects. Implications for the information paradox are then discussed.

Speaker: Luca Smaldone (Warsaw U.)
Time: 17:15-18:00 (CET)

Title: Fermionic Xons and Bekenstein bound
Abstract:
Bekenstein bound implies that every local quantum system has a finite number of degrees of freedom. This consideration leads to a unified view of spacetime and matter as low energy manifestations of a fundamental quantum dynamics, in terms of unknown building blocks. On the

other hand, in the context of black hole evaporation, and assuming that such "Xons" are fermions, we naturally obtain that an entropy bound derives from the Pauli exclusion principle. Moreover, we show that entanglement, Bekenstein and thermodynamic entropies of an evaporating black hole all stem from the same approach based on Takahashi and Umezawa's Thermofield Dynamics.

18:05-18:35 Discussion session with all speakers of the day

16th March 2022 Morning Session:

Chair: Alessia Platania

Speaker: Masahide Yamaguchi (Tokyo Institute of Technology)
Time: 10:30 AM-11:15 AM (CET)

Title: Polychronic Tunneling: New Tunneling Processes Experiencing Euclidean and Lorentzian Evolution Simultaneously

Abstract:
We discuss new possible tunneling processes in the presence of gravity. We formulate quantum tunneling using the Wheeler-deWitt canonical quantization and the WKB approximation. The distinctive feature of our formulation is that it accommodates the coexistence of Euclidean and Lorentzian evolution. It opens up a new possibility of quantum tunneling; e.g. a bubble wall itself tunnels the potential barrier pulling the field nearby, where the wall region experiences the Euclidean evolution while the other regions experience the Lorentzian evolution simultaneously. We execute numerical analysis and find that such a process can have a much higher tunneling rate than that of the Coleman-De Luccia bounce. We also find that the new tunneling processes exist even in the decoupling regime of gravity and affect low energy phenomenology.

Speaker: Carlos Herdeiro (Aveiro U.)
Time: 11:15 AM-12:00 PM (CET)

Title: The imitation game: bosonic stars, ultra-light dark matter and gravitational waves

Abstract:
We discuss, with a concrete example and real data, how strong gravity systems and observables could assess the nature of dark matter, or at least part of it. In the theoretical modelling, I will focus on fuzzy dark matter and bosonic stars. The real data example will concern the GW190521 gravitational wave event.

Speaker: Alexander Andrianov (Petersburg Univ.)
Time: 12:00 PM-12:45 PM (CET)

Title: BTZ black hole formation due to collapse of a dust shell: quantum dynamics in the neighborhood of central singularity.

Abstract:
We perform canonical analysis of a model in which gravity in 2+1 spacetime dimensions with negative cosmological constant is coupled to a cylindrically symmetric dust shell. It results in a reduced action depending on a finite number of degrees of freedom. The phase space consists of two copies of ADS2 – both coordinate and momentum space are curved. Different regions in the Penrose diagram can be identified with different patches of ADS2 momentum space. Quantization

of this model results in quantum double D(SL(2)q). Deformation parameter is real if the collapse results in naked singularity and is a root of unity when BTZ black hole forms. The spectrum of the shell radius inside the black hole is discrete and bounded, so that its space of states is finite dimensional. We also calculate quantum transition amplitudes between different shell radii near black hole center. They turn out to be all finite, indicating resolution of the central singularity.I would like to explore to test quantum nature of gravity in a laboratory. I will discuss both local and non-local aspects of gravity and what kind of signatures would they leave in a realistic quantum experiment. I will discuss these ideas in the context of quantum superposition, quantum entanglement and the nature of quantum vacuum in presence of matter degrees of freedom.

16th March 2022 Afternoon Session:

Chair: Francesco Di Filippo

Speaker: Irina Aref'eva (Steklov Math. Inst.)
Time: 15:00-15:45 (CET)

Title: Black hole explosions?
Abstract:
The problem of complete evaporation of Schwarzschild black holes raised by Hawking is that one has an explosion of the temperature $T=1/8\pi M$ for vanishing black hole mass M. We consider the Reissner-Nordstrom black hole and study under which conditions the complete evaporation of black holes without blow-up of temperature is possible. We describe curves on the surface of state equations such that the motion along them provides complete evaporation. Under the assumption of slow evaporation, we estimate the time dependence of the entanglement entropy of radiation on island configurations along these curves.

Speaker: Alessia Platania (Perimeter Institute)
Time: 15:45-16:30 (CET)

Title: Sifting quantum black holes through the principle of least action
Abstract:
We tackle the question of whether regular black holes or other alternatives to the Schwarzschild solution can arise from an action principle in quantum gravity. Focusing on an asymptotic expansion of such solutions and inspecting the corresponding field equations, we demonstrate that their realization within a principle of stationary action would require either fine-tuning, or strong infrared non-localities in the gravitational effective action. This points to an incompatibility between large-distance locality and many of the proposed alternatives to classical black holes.

Speaker: Gonzalo J. Olmo, (University U.- CSIC (Spain) & UFC (Brazil))
Time: 16:30-17:15 (CET)

Title: Metric-Affine Chern-Simons Modified Gravity (a first look)
Abstract:
Modifying GR by means of a Chern-Simons term coupled to a scalar field offers an interesting opportunity to explore parity violations in the gravitational sector. As usual, the original representation of this theory appeared in the metric formalism, though there are good reasons to reconsider it within a metric-affine approach. By doing so, one may improve the original action in order to make it projectively invariant. Though the connection equation is hard to tackle, we manage to obtain an approximate solution around a Schwarzschild background, which allows us to explore small perturbations and quasi normal modes. We compare our findings with those

obtained in the metric formulation and in GR, finding that the metric-affine version presents certain features that could facilitate their detectability via gravitational waves observations.

Speaker: Andrea Giusti (ETH)
Time: 17:15-18:00 (CET)

Title: Thermodynamics of scalar-tensor gravity
Abstract:
In the 90s it was shown that the Einstein equation could be understood as an equation of state, general relativity as the equilibrium state of gravity, and f(R) gravity as a non-equilibrium one. In this presentation I discuss how the application of Eckart's first order thermodynamics to the effective dissipative fluid describing scalar-tensor gravity leads to thermodynamics for the space of theories of gravity. Surprisingly, within this picture one obtains simple expressions for the effective heat flux, "temperature of gravity", shear and bulk viscosity, and entropy density, plus a generalized Fourier law in a consistent Eckart thermodynamical picture. Furthermore, a well-defined notion of the approach to equilibrium, missing in the current thermodynamics of spacetime scenarios, naturally emerges.

18:05-18:35 Discussion session with all speakers of the day

17th March 2022 Morning Session:

Chair: Leslaw Rachwal

Speaker: Ilya Shapiro (Juiz de For a U.)
Time: 10:30 AM-11:15 AM (CET)

Title: Effective quantum gravity, cosmological constant and the Standard Model of particle physics

Abstract:

The cosmological constant problem (CCP) and the formulation of consistent quantum gravity belong to the shortlist of the most important unsolved fundamental problems of physics. In the case of CCP the problem is to explain the extremely precise (55 orders in the Standard Model) fine-tuning between the independent vacuum part and the induced one, that is a function of symmetry breaking in the models of particle physics. The situation with CCP is so difficult that it makes sense to give up from attempting its solution and accept the need for a fine tuning between the vacuum and induced counterparts of the observed energy density of the vacuum. In this case, we meet the challenging situation with the renormalization group running of the vacuum or induced summands of the cosmological constant at low energies.

Assuming the effective approach to quantum gravity and the Vilkovisky-DeWitt scheme of unique effective action, one can derive the exact, well-defined, renormalization group running of the vacuum cosmological constant. It turns out that, owing to the mentioned fine-tuning with the induced part, this running imposes severe restrictions on the possible extensions of the Minimal Standard Model of particle physics, concerning the magnitude of the vacuum expectation value of the corresponding Higgs fields.

Observation: The talk is based on collaborations with B. Giacchini and T.P. Netto.

Speaker: Manuel Asorey (Zaragoza Univ.)
Time: 11:15 AM-12:00 PM (CET)

Title: New Aspects of Higher Derivative Theories

Abstract:

Theories with higher derivatives provide new families of models with interesting UV behaviors. However. usually, they also suffer consistency problems. We analyse these features from new perspectives.

Speaker: Anna Tokareva (Imperial College London)
Time: 12:00 PM -12:45 PM (CET)

Title: Anomaly-free scale and conformal symmetry

Abstract:

I address the question of whether the conformal invariance can be considered as a global symmetry of a theory of fundamental interactions. To describe Nature, this theory must contain a

mechanism of spontaneous breaking of the scale symmetry. Besides that, the fundamental theory must include gravity, whereas all known extensions of the conformal invariance to the curved space-time suffer from the Weyl anomaly. We show that conformal symmetry can be made free from the quantum anomaly only in the flat space. The presence of gravity would reduce the global symmetry group of the fundamental theory to the scale invariance only. We discuss how the effective Lagrangian respecting the scale symmetry can be used for the description of particle phenomenology and cosmology.

17th March 2022 Afternoon Session:

Chair: Ivano Basile

Speaker: Philip Mannheim (University of Connecticut)
Time: 15:00-15:45 (CET)

Title: How to quantize gravity and how to not quantize gravity
Abstract:
Taking the quantization of electromagnetism as the paradigm, we show how this procedure cannot work for Einstein gravity. However, it does work for conformal gravity, a fourth-order derivative, renormalizable theory of gravity that Bender and Mannheim have shown to be ghost free. We show that gravity cannot be quantized canonically. Rather, because of an interplay between the zero-point energy of gravity and that of it its matter source, gravity is quantized purely by its coupling to a quantized matter source, with gravity being intrinsically quantum mechanical. Treating the zero-point energy this way provides a solution to the cosmological constant problem, With the gravitational zero-point energy issue having been ignored in standard Einstein gravity, it is not possible to solve the cosmological constant problem in standard gravity,
since without the zero-point contribution gravity does not know where the zero of energy is.

Speaker: Fabio Scardigli (Milano Politecnico)
Time: 15:45-16:30 (CET)

Title: Generalized uncertainty principle and Asymptotic Safe Gravity
Abstract:
We present a procedure to link the deformation parameter of the generalized uncertainty principle (GUP) to the free parameters of the running Newtonian coupling constant emerging from the Asymptotic Safe Gravity (ASG) approach. Then, we proceed to compute explicit values of the parameters through a comparison with a quantum corrected Newtonian potential, and we discuss potential new implications of the values so found.

Speaker: Georgios Karananas (Munich Univ.)
Time: 16:30 PM-17:15 PM (CET)

Title: Field redefinitions, perturbative unitarity and Higgs inflation
Abstract:
I will give an overview of known results associated with Higgs Inflation and also point out a straightforward way to estimate the energy scale around which perturbation theory breaks down. This approach neither relies on a gauge choice nor does it require any calculation of amplitudes. Instead, it exploits the fact that the S-matrix is invariant under field redefinitions. In agreement with previous findings, I will demonstrate that the cutoff is significantly higher during inflation than in vacuum, which ensures the self-consistency of Higgs Inflation as an effective theory.

Along the way, I will comment on the usefulness of employing the exponential parametrization for the Higgs doublet.

Speaker: Alexander Vikman (CEICO)
Time: 17:15 PM-18:00 PM (CET)

Title: Ghosts without Runaway
Abstract:
I will discuss our recent work Phys.Rev.Lett. 128 (2022) 4, 041301 in which we present a simple class of mechanical models where a canonical degree freedom interacts with another one with a negative kinetic term, i.e., with a ghost. We prove analytically that the classical motion of the system is completely stable for all initial conditions, notwithstanding that the conserved Hamiltonian is unbounded from below and above. Numerical computations fully supported this. Systems with negative kinetic terms often appear in modern cosmology, quantum gravity, and high energy physics and are usually deemed as unstable. Our result demonstrates that for mechanical systems this common lore can be too naïve and that living with ghosts can be stable.

18:05-18:35 Discussion session with all speakers of the day

18th March 2022 Morning Session:

Chair: Ilya Shapiro

Speaker: Leonardo Modesto (SUSTech)
Time: 10:00 AM-10:45 AM (CET)

Title: Nonlocal Quantum Gravity: Theory and Implications
Abstract:
In the quantum field theory framework, ``Nonlocal Quantum gravity'' (with or without matter) turns out to be an excellent candidate for all fundamental interactions compatible with linear and nonlinear classical stability, perturbative unitarity, causality, and quantum finiteness. In particular, the latter property implies that there is no Weyl anomaly and the theory turns out to be conformal invariant at classical as well at quantum level. Therefore, nonlocal quantum gravity is a conformal invariant theory in the spontaneously broken phase of the Weyl symmetry.
As an implication of the theory, the anomaly-free Weyl conformal symmetry elegantly solves the problem of spacetime singularities, otherwise unavoidable at classical level in a generally covariant local or non-local gravitational theory. According to the last statement, we
provide explicit examples of singularity-free black hole solutions, enjoying finite curvature invariants and, most importantly, geodetically complete. Indeed, no massive or massless particle can ever reach the singularity. Avoiding the singularities, we avoid the Hawking's information loss problem too.
In addition to the solution of the singularity problem based on the classical and quantum conformal invariance, we can address the same issue on a purely quantum gravitational ground. Indeed, we will show how to reconstruct singularity-free spacetime metrics starting from the scattering amplitudes after a partial resummation of the one-loop one-particle irreducible amplitudes. Finally, we propose a new scenario for the early Universe and the current one in finite quantum gravity and based on conformal invariance as an alternative to dark matter and inflation.

Speaker: Leslaw Rachwal (Juiz de Fora)
Time: 10:45 AM-11:30 AM (CET)

Title: Exact Beta Functions in Six-derivative Quantum Gravity
Abstract:
The exact one-loop beta functions for the four-derivative terms (Weyl tensor squared, Ricci scalar squared, and the Gauss-Bonnet) are derived for the minimal six-derivative quantum gravity (QG) theory in four spacetime dimensions. The calculation is performed by means of the Barvinsky and Vilkovisky generalized analytic Schwinger-DeWitt technique. With this result we gain, for the first time, the full set of the relevant beta functions in a super-renormalizable model of QG. The complete set of renormalization group (RG) equations, including also these for the Newton and the
cosmological constant, is solved explicitly in the general case and for the six-derivative Lee-Wick (LW) quantum gravity. In the ultraviolet regime, the minimal theory is shown to be asymptotically

free and describes free gravitons. The explanation for the structure of these exact beta functions is also provided by comparison with Stelle quadratic gravity. We argue that an extension of the theory that involves operators cubic in Riemann tensor may change the beta functions and be useful for constructing UV-finite theory of quantum gravity.

Speaker: Benjamin Knorr (Perimeter Institute)
Time: 11:30 AM-12:15 PM (CET)

Title: Essential couplings in quantum gravity and matter
Abstract:
Physics only depends on so-called essential couplings. By contrast, inessential couplings can be eliminated from a concrete computation by imposing renormalisation conditions. I will present recent progress on the non-perturbative renormalisation group flow of the essential couplings in quantum gravity and matter, and discuss the fate of asymptotic safety within this scheme.

Speaker: Anish Ghoshal (Warsaw U.)
Time: 12:15 PM-13:00 (CET)

Title: Beyond standard particle theory with Lee-Wick & Infinite derivatives
Abstract:
We will discuss constructions of string-inspired higher-derivative and Lee-Wick non-local extension of particle theory. We will discuss weakly coupled and strongly coupled regimes of the theory. In particular we will discuss the RGE flow. In the non-perturbative regimes, we discuss when the theory is confined and the mass gap with the Dyson-Schwinger approach. Finally, we will discuss signatures of non-local theory in laboratory-based phenomenology: collider, dark matter, inflation and dark energy aspects**.**

13:05-13:35 Discussion session with all speakers of the day

Concluding Remarks: 13:35-13:45
Chair: Organizers