# Fundamental Physics and Cosmology

## Inflation, Dark Energy, Modified Theories of Gravity

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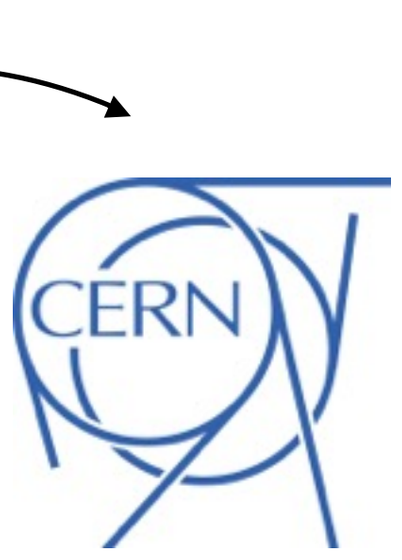


CERN Theory Group Retreat 2015

Les Houches Centre de Physique

# History of the Universe

Inflation Generates Two Types of Waves

Gravitational Waves

Density Waves

Waves Imprint Characteristic Polarization Signals

Free Electrons Scatter Light

Earliest Time Visible with Light

Radius of the Visible Universe

Quantum Fluctuations

Big Bang

Inflation

Protons Formed

Nuclear Fusion Begins

Nuclear Fusion Ends

Cosmic Microwave Background

Neutral Hydrogen Forms

Modern Universe

0

$10^{-32}$ s

1 µs

0.01 s

3 min

380,000 yrs

13.8 Billion yrs

Age of the Universe

# Early time cosmology

## Motivations

- How many degrees of freedom are responsible for Primordial Perturbations (PPs)?
- Do the PPs have quantum origin? Thermal? Other?
- How much will we be able to learn about these questions from future experiments?
- If quantum, why, when, and under which conditions can they be treated as classical?
- How robust are the predictions obtained in the semiclassical approximation?
- Are quantum corrections and back-reaction important?
  Under perturbative control?

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## General objectives

1. To identify and characterize observable signatures of inflationary models
   (e.g. a gravitational wave background, non-gaussianities)
2. To assess the robustness of the theoretical predictions

# Early time cosmology

## Main focus (and recent achievements)

1. Observational signatures of inflationary models
   (mainly with P. Creminelli, M. Simonović, G. Trevisan, and M. Zaldarriaga)

   - How much will we be able to learn about inflation from future experiments?
   - How well will future experiments be able to constraint the amplitude of a primordial gravitational wave background?

**Our latest contributions:**

- *Detecting Primordial B-Modes after Planck*, arXiv:1502.01983 [astro-ph.CO].
- *Implications of the scalar tilt for the tensor-to-scalar ratio* (with S. Dubovsky and G. Villadoro), arXiv:1412.0678 [astro-ph.CO].
- $\phi^2$ *inflation at its Endpoint,* PRD90, 083513 (2014).
- $\phi^2$ *or not* $\phi^2$*: Testing the Simplest Inflationary Potential,* PRL112, 241303 (2014).

# Early time cosmology

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**2.** Nonperturbative techniques for quantum field theories on curved backgrounds
(with F.D. Mazzitelli and L. Trombetta)

- Interacting quantum fields on de Sitter spacetimes
(infrared effects and non-perturbative treatments)
- Relevant for inflationary models

**Our recent contributions:**

- *Hartree approximation in curved spacetimes revisited: The effective potential in de Sitter spacetime,* PRD89, 024006 (2014).
- *Idem. II. The semiclassical Einstein equations and de Sitter self-consistent solutions,* PRD89, 084013 (2014).

# Late times

## Motivations

- The acceleration of the Universe can be described by properly adjusting $\Lambda$
- Other models provide alternative explanations of this acceleration
  (e.g. dynamical dark energy, modified theories of gravity)
- The predictions of each candidate model must be confronted with data
  *Not just cosmological data* but data on all scales where the models make *calculable predictions* that can be tested observationally or experimentally
- To what extent is it possible to discriminate among the different models?
- Is any of the models better at fitting the data than $\Lambda$?

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## General objectives

1. To characterize the observable predictions for dark energy models and modified theories of gravity
2. To deepen the understanding of the predictions of the standard model

# Late times

## 1. Main focus

- Structure formation in non-standard models: Clustering Dark Energy and Modified theories of gravity (mainly with S. Anselmi)

**Our contributions so far:**

- *Extreme parameter sensitivity in quasidilaton massive gravity*, (with G. Starkman) PRD92, 084033 (2015).
- *Nonlinear effects of dark energy clustering beyond the acoustic scales*, (with E. Sefusatti) JCAP 1407, 013 (2014).

- Violations of the equivalence principle (mainly with P. Creminelli and L. Trombetta)

**Work in progress**

- ...

# Main topics of my previous research

- Non-gaussianities and dissipative effects during inflation using effective field theory (EFT) techniques for open systems

**Contributions:**

- *The consistency condition for the 3pt function in dissipative single-clock inflation (with Porto and Zaldarriaga), JCAP1209,004 (2012).*
- *Dissipative effects in the EFT of Inflation, (with Porto, Senatore, and Zaldarriaga), JHEP1201,075(2012).*

- Renormalization process for Lorentz-violating theories on curved spacetimes

**Contributions:**

- *Lifshitz scalar fields: one loop renormalization in curved backgrounds (with Mazzitelli, and Trombetta), PRD85, 024051(2012).*
- *Counterterms in semiclassical Horava-Lifshitz gravity, (with Giribet and Mazzitelli), JHEP1009,009(2010).*
- *On the renormalization procedure for quantum fields with modified dispersion relation in curved spaces (with Mazzitelli), IJMPA24,1565(2009).*
- *Renormalization in theories with modified dispersion relations: Weak gravitational fields (with Mazzitelli),PLB672, 294 (2009).*
- *New counterterms induced by trans-Planckian physics in semiclassical gravity (with Mazzitelli),PRD78, 044001 (2008).*
- *Backreaction in trans-Planckian cosmology: Renormalization, trace anomaly and self-consistent solutions, (with Mazzitelli), PRD76, 024013(2007).*
- *Adiabatic renormalization in theories with modied dispersion relations (with Mazzitelli and Simeone), JPA40, 6895 (2007).*
- *Renormalized stress tensor for trans-Planckian cosmology, (with Mazzitelli and Simeone), PRD72,124013(2005).*

- Decoherence process for quantum fields: Generation of classical inhomogeneities from quantum fluctuations in inflationary models

**Contribution:**

- *Decoherence during inflation: The Generation of classical inhomogeneities, (with Lombardo), PRD 2, 063506 (2005).*

# THANKS!