# Introduction to Cosmological Perturbation Theory

## Overview

In cosmology, it is of fundamental importance to understand the behaviour of a cosmological background solution. After we find that a theory allows for an evolution of the universe which is consistent with the data at hand, we still need to check whether such a solution is stable. The study of the stability also sheds light on the crucial issue of the properties of degrees of freedom which belong to the theory and and define it. In particular, through cosmological perturbation theory, we can identify, on a cosmological background, whether a mode is stable, find its speed of propagation and even its mass. Therefore the investigations of a theory of gravity on a cosmollogical background requires the knowledge of its perturbation analysis.

## Objectives

The objectives of this class can be summurized as follows:
- To understand the Lagrange approach of perturbation theory in order to study both the background and the perturbation fields.
- To understand how to build gauge invariant variables and why gauge invariance is central idea for studying cosmoogical perturbations.
- To understand the ghost conditions in GR and modified theories.

## Lecture-wise Course Plan (December 16-23, 2016)

**Friday, December 16, 2016**

- Lecture 1 : One hour – 10.00 am – 11.15 am
  - The background of FLRW, Lagrange approach

- Tea Break

- Lecture 2: One hour – 11.45 am – 1.00 pm
  - Why perturbation theory

**Saturday, December 17, 2016**

- Lecture 3 : One hour – 10.00 am – 11.15 am
  - Is stability important

- Tea Break

- Lecture 4: One hour – 11.45 am – 1.00 pm
  - The variables

**Monday, December 19, 2016**

- Lecture 5 : One hour – 10.00 am – 11.15 am
    - Gauge transformation, guage invariant variables

- Tea Break

- Lecture 6 : One hour – 11.45 am  – 1.00 pm
    - Lagrangian with constraints

**Tuesday, December 20, 2016**

- Lecture 7 : One hour – 10.00 am – 11.15 am
    - Expansion at second order in the fields

- Tea Break

- Lecture 8 : One hour – 11.45 am  – 1.00 pm
    - Worked example. GR with a fluid

**Wednesday, December 21, 2016**

- Lecture 9 : One hour – 10.00 am – 11.15 am
    - Looking for Lagrange multipliers

- Tea Break

- Lecture 10 : One hour – 11.45 am  – 1.00 pm
    - Integrating out the Lagrange multipliers

**Thursday, December 22, 2016**

- Lecture 11 : One hour – 10.00 am – 11.15 am
    - No ghost conditions and  speed of propagation

- Tea Break

- Lecture 12 : One hour – 11.45 am  – 1.00 pm
    - Massive gravity and No ghost condition.

**Friday, December 23, 2016**

- Examination :    10.00 am – 12.00 Noon

| Modules | A: Duration: | December 16-23, 2016 |
|---|---|---|
| | B: Venue | Center For Theoretical Physics, Jamia Millia Islamia (A Central University), New Delhi – 25, India |
| | *Number of participants for the course will be limited to fifty.* | |
| You Should Attend If… | *Phd students, Post-Doctoral Fellows, Faculties working in the field of Cosmology can participate. Advanced MSc students with basic knowledge of General Theory of Relativity can also attend.* | |
| Fees | **The participation fees for taking the course is as follows:**<br><br>• **Participants from abroad: US $200**<br>• **Industry/Research Organisations: Rs. 5000/-**<br><br>**Academic Institutions:**<br><br>**Faculty members: Rs. 2000/-**<br>**Masters/PhD Students: Rs. 1000/-**<br><br>The above fee includes all instructional materials, tutorials and assignments, 24 hour free internet facility. The participants will be provided accommodation on payment basis, subject to the availability.<br>**Course Fees Payment: The DD should be prepared in favour of "Registrar, Jamia Millia Islamia" , payable at New Delhi and submit to the office, Centre for Theoretical Physics, JMI** | |

## Teaching Faculty

**Prof. Antonio De Felice** is an associate professor at the Yukawa Institute for Theoretical Physics at the Kyoto University. He works on modified gravity models, namely massive gravity, bigravity, f(R) theories, non-gaussianities for general models of one scalar field, etc. Before joing Kyoto University, He worked as If, Naresuan University, Thailand. He has published more than 80 papers in highly accmalaimed international journals. Dr De Felice is considered as one of the leaing experts on modified theories of gravity. His review on f(R) theories is used world wide by the experts. His work on massive gravity brought him a world fame. He had shown that FRW cosmology has ghost at the level of perturbations. He demonstrated that Anisotropic background could be stable in this case. His work opened up new directions in massive gravity. He is one of the leading experts on these issues. He has lectured cosmological perturbations world wide.

*https://sites.google.com/site/adefelic/*

**Prof. M. Sami** did MS in theoretical physics from People's friendship University Moscow in 1978. He obtained Ph. D in high energy physics from Moscow state university in 1983. In 1986, he joined Jamia Millia Islamia as a lecturer. In 2006, M. Sami established the centre for theoretical physics in Jamia of which he is the founding director.

*http://ctp-jamia.res.in/people/sami.html*

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