Advanced Cosmology Lectures

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1 Part I: Theoretical Cosmology

1.1 The standard model of cosmology

1. Introduction
2. The Robertson–Walker metric
3. Einstein equations for a Friedmann–Robertson–Walker universe
4. Scale factor dependence of the energy density
5. Time dependence of the scale factor
6. Age of the universe
7. The cosmological constant
8. Equilibrium thermodynamics in the expanding universe
9. Transition from radiation to matter domination
10. Cosmic microwave background radiation
11. Big-bang nucleosynthesis

1.2 Phase transitions in the early universe

1. Introduction
2. Partition functions
3. The effective potential at finite temperature
4. Phase transitions in the Higgs model
5. Phase transitions in electroweak theory
6. Phase transitions in grand unified theories
7. Phase transitions in supersymmetric GUTs
8. Phase transitions in supergravity theories
9. Nucleation of true vacuum

1.3 Topological defects

1. Introduction
2. Domain walls
3. Global cosmic strings
4. Local cosmic strings
5. Gravitational fields of local cosmic strings
6. Dynamics of local cosmic strings
7. Magnetic monopoles
8. Monopole topological quantum number
9. Magnetic monopoles in grand unified theories
10. Abundance of magnetic monopoles

1.4 Baryogenesis

1. Introduction
2. Conditions for baryogenesis
3. Out-of-equilibrium decay of heavy particles
4. Baryogenesis in GUTs
5. Baryogenesis in SO(10) GUTs
6. Status of GUT baryogenesis
7. Sphaleron-induced baryogenesis
8. CP-violation in electroweak theory
9. Phase transitions and electroweak baryogenesis
10. Supersymmetric electroweak baryogenesis
11. Affleck–Dine baryogenesis

1.5 Relic neutrinos and axions

1. Introduction
2. Relic neutrinos
3. Axions
   (a) Introduction: the strong CP problem and the axion solution
   (b) Visible and invisible axion models
   (c) Astrophysical constraints on axions
   (d) Axions and cosmology

1.6 Supersymmetric dark matter

1. Introduction
2. Weakly interacting massive particles or WIMPs
3. The gravitino problem
4. Minimal supersymmetric standard model (MSSM)
5. Neutralino dark matter
6. Detection of dark matter

1.7 Inflationary cosmology

1. Introduction
2. Horizon, flatness and unwanted relics problems
3. Old inflation
4. New inflation
5. Reheating after inflation
6. Inflaton field equations
7. Density perturbations
8. Complex inflaton field
9. Chaotic inflation
10. Hybrid inflation
11. The spectral index

1.8 Inflation in supergravity

1. Introduction
2. Models of supergravity inflation
3. D-term supergravity inflation
4. Hybrid inflation in supergravity
5. Thermal production of gravitinos by reheating
6. The Polonyi problem

1.9 Superstring cosmology

1. Introduction
2. Dilaton and moduli cosmology
3. Stabilization of the dilaton
4. Dilaton or moduli as possible inflatons
5. Ten-dimensional string cosmology
6. D-brane inflation
7. Pre-big-bang cosmology
8. M-theory cosmology—the ekpyrotic universe

1.10 The primordial density perturbation

1. A first look at the primordial perturbations
2. Cosmological perturbations
3. The evolution of cosmological perturbations
4. Primordial curvature perturbation
5. Linear density perturbations

1.11 Stochastic properties

1. Random fields
2. Fourier expansion
3. Gaussian perturbations
4. Non-gaussian perturbations

5. Ergodic theorem and cosmic variance
6. Spherical expansion
7. Correlators of the curvature perturbation

1.12 Newtonian perturbations

1. Free-streaming, oscillation, and collapse
2. Newtonian perturbations: total mass density
3. Effect of the cosmological constant
4. Baryon density perturbation

1.13 General relativistic perturbations

1. Scalar, vector, and tensor modes
2. Perturbing the metric and energy–momentum tensors
3. Evolution of the scalar mode perturbations
4. Separate fluids
5. Matter density transfer function
6. Acoustic oscillation
7. Silk damping
8. Synchronous gauge

1.14 The matter distribution

1. Smoothing
2. Bottom-up structure formation
3. Critical density for collapse
4. Virialization
5. Abundance of premature objects
6. The observed mass density perturbation

1.15 Cosmic microwave background anisotropy

1. CMB multipoles
2. Spectrum of the CMB anisotropy
3. Flat-sky approximation
4. Scalar mode
5. Sudden-decoupling approximation
6. Sachs–Wolfe plateau
7. Acoustic peaks and Silk damping
8. Reionization
9. Non-gaussianity of the CMB anisotropy

1.16 Boltzmann hierarchy and polarization

1. Perturbed Boltzmann equation
2. Boltzmann hierarchy
3. Collision term without polarization
4. Polarization and Thomson scattering
5. CMB polarization
6. Boltzmann hierarchy with polarization
7. Initial conditions and the transfer functions
8. Line-of-sight integral

1.17 Isocurvature and tensor modes

1. Isocurvature modes
2. Matter isocurvature mode
3. Neutrino isocurvature mode
4. The primordial lepton number perturbation
5. Tensor mode
6. Seeds and the vector mode
7. Spatial curvature

2 Part II: Cosmological Simulations

The second part of this curse requires a good level of *python* programming.

2.1 Introduction

1. First Simulations
2. Numerical Codes

2.2 State of the art: Simulations

1. The Millennium Simulation
2. The Aquarius Simulation
3. The Illustris Simulation
4. Other Cosmological Simulations: FIRE and NIHAO

2.3 The TNG Simulations

1. The next generation of cosmological simulations
2. Baryonic implementations in TNG
3. Work ongoing in TNG

2.4 TNG Usage at z=0

1. FoF Algorithm
2. Subfind Algorithm
3. Catalogues of Groups and Subhalos in TNG
4. Examples of the usage of the TNG Simulation
5. Hands on: Using TNG for your own science