# Global Learning Initiatives Program Course Syllabus

**Course Information**

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| Course Name | Particle Cosmology (Live) |
| Lecturer(s) | Prof. Yifu CAI |
| Course Description | This is a fundamental course in preparation for the study of astronomy and particle physics and their crossing field. Particle cosmology has been one of the most crucial subject that has made numerous breakthrough since the discover of the cosmic microwave background in 1960s. At present, we already have a standard paradigm of modern cosmology, which is dubbed as the hot big bang theory. However, our knowledge about the universe is still dramatically developing along with the high level developments of observational technologies in precision cosmology. Therefore, how to study cosmology lies in the core of hot topics. Particle cosmology is the disciplinary subject between cosmology and particle physics. In particular, it focuses on the very early moments of the universe where the energy scale is much higher than that any particle experiments could reach. Thus, it can help us to better understand the fundamental knowledge of particle physics as well as the origin of the universe. |
| Course Objectives | The setup of this course is to advocate the graduate students majored in astrophysics and theoretical physics to manage the basic knowledge about the cosmology study and to learn the research frontiers. Through this course, the graduate students are expected to access the baseline of professional research in their forthcoming study. |
| Suggested Proficiencies (if any) | Extensive and intensive reading ability<br>Analytical skills<br>Master of Mandarin is a plus |

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| Reading List<br>(if any) | Mukhanov's textbook Physical Foundation of Cosmology |
| Grading Criteria | Usual grades (50%)= learning progress (15 points) + learning performance (35 points)<br><br>Test scores for each chapter (10%): 12 chapters in total<br><br>Final grade (40%)=actual final exam (online) score / final exam total score * weight |

**Course Schedule**

| Class | Date (YYYY/MM/DD) | Course Topic | Lecturer |
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| 1 | 2021/03/01 | 1. Introduction<br>1.1 class information and goals<br>1.2 books and references | Prof. Yifu CAI |
| 2 | 2021/3/8 | 2. Review of General Relativity<br>2.1 brief history<br>2.2 basics of GR<br>2.3 introduction to cosmology<br>2.4 cosmological principle and FRW metric<br>2.5 cosmological kinematics<br>2.6 cosmological dynamics<br>2.7 Friedmann equation and background evolution | Prof. Yifu CAI |
| 3 | 2021/3/22 | 3. The Hot Big Bang<br>3.1 the very early universe<br>3.2 hot big bang fireball<br>3.3 radiation dominated universe and the key point of thermal history<br>3.4 thermodynamics(1) - distribution function | Prof. Yifu CAI |

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| | | 3.5 thermodynamics(2) - thermal equilibrium and effffective number of relativistic species<br>3.6 thermodynamics(3) - entropy<br>3.7 electroweak phase transition, neutrinos decouple and electron-positron annihilation<br>3.8 Big Bang nucleosynthesis | |
| 4 | 2021/4/5 | 4. Cosmological Perturbation Theory<br>4.1 the origin of perturbation theory<br>4.2 the scenario and picture of cosmological perturbation theory<br>4.3 perturbed metric and helicity decomposition<br>4.4 gauge transformation and guage fixing<br>4.5 matter perturbation<br>4.6 equations of perturbations - at linear order<br>4.7 statistical property in cosmology<br>4.8 perturbed energy momentum conservation equation<br>4.9 perturbed Einstein equation<br>4.10 statistics in cosmology | Prof. Yifu CAI |
| 5 | 2021/4/19 | 5. Boltzmann Equation<br>5.1 introduction to Boltzmann equation<br>5.2 Boltzmann equation in | Prof. Yifu CAI |

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| | | cosmology<br>5.3 the collisionless Boltzmann equation for the massless particle(1)<br>5.4 the collisionless Boltzmann equation for the massless particle(2)<br>5.5 the collisionless Boltzmann equation for the massless particle(3)<br>5.6 the Boltzmann equation for photon<br>5.7 the Boltzmann equation for cold dark matter<br>5.8 the Boltzmann equation for baryons and summary for Boltzmann equation | |
| 6 | 2021/5/3 | 6. Inflation<br>6.1 the problems of the standard cosmological model<br>6.2 the general picture of inflation<br>6.3 the problems of Big Bang theory revisited(1)<br>6.4 the problems of Big Bang theory revisited(2)<br>6.5 slow-roll inflation<br>6.6 the general picture of quantum fluctuation<br>6.7 conservation at super Hubble scale(super-horizon)<br>6.8 curvature perturbations<br>6.9 equation of motion of curvature perturbation<br>6.10 quantum fluctuations<br>6.11 power spectrum of scalar perturbation | Prof. Yifu CAI |

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| | | 6.12 power spectrum of gravitational waves from inflation | |
| 7 | 2021/5/17 | 7. Inhomogeneities<br>7.1 the general picture<br>7.2 introduction to the evolution of perturbations<br>7.3 Einstein-Boltzmann equations at early times<br>7.4 evolution on large scale(1)<br>7.5 evolution on large scale(2)<br>7.6 evolution on small scale(1)<br>7.7 evolution on small scale(2)<br>7.8 transfer function and growth function<br>7.9 matter power spectrum | Prof. Yifu CAI |
| 8 | 2021/5/31 | 8. Anisotropies<br>8.1 what are Cosmic Microwave Background Radiations(1)8.2 what are Cosmic Microwave Background Radiations(2)<br>8.3 CMB observations<br>8.4 photon free streaming(1)<br>8.5 photon free streaming(2)<br>8.6 tightly coupled limit of the Boltzmann equations<br>8.7 large scale and small scale evolution<br>8.8 the definition of observable and the anisotropy spectrum today | Prof. Yifu CAI |
| 9 | 2021/6/14 | 9. Non-Gaussian<br>9.1 the meaning of non-Gaussianity<br>9.2 the expressions of non- | Prof. Yifu CAI |

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| | | Gaussianity<br>9.3 in-in formalism<br>9.4 ADM formatism | |
| 10 | 2021/6/21 | 10. Bounce Cosmology<br>10.1 lesson from inflationary cosmology<br>10.2 the basic picture of a bounce<br>10.3 an overview of bounce models<br>10.4 towards a healthy nonsingular bounce(1)<br>10.5 towards a healthy nonsingular bounce(2) | Prof. Yifu CAI |
| 11 | 2021/6/28 | 11. Reheating<br>11.1 why is there a necessity for reheating<br>11.2 a basic picture<br>11.3 mathematical modeling of the reheating era | Prof. Yifu CAI |
| 12 | 2021/7/5 | 12. Topological Defects<br>12.1 the physical meaning of topological defects<br>12.2 phase transitions<br>12.3 cosmic strings<br>12.4 observational constraints of cosmic strings | Prof. Yifu CAI |
| 13 | 2021/7/19 | Examination | Prof. Yifu CAI |