

Theoretical Cosmology

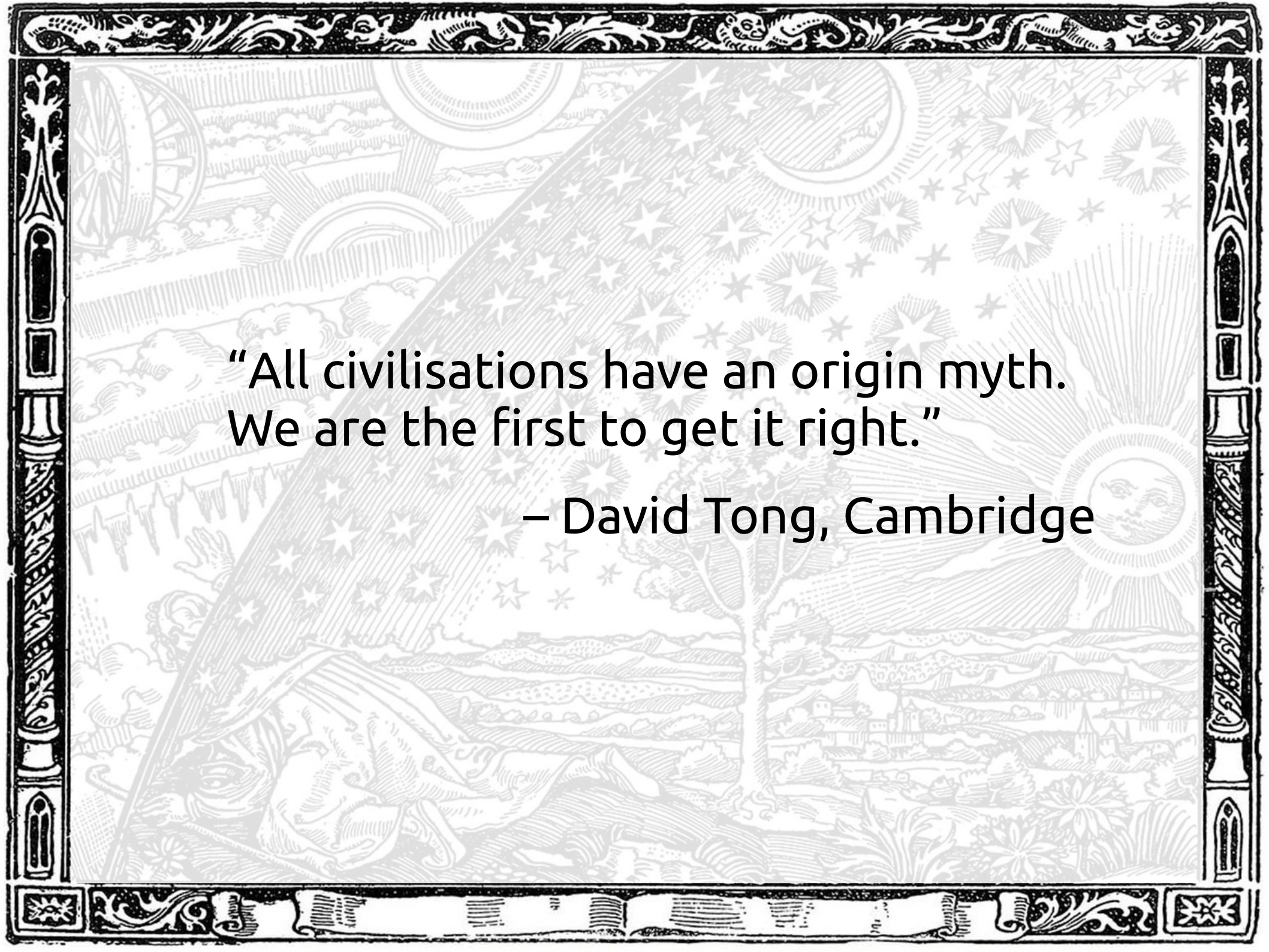
Lecture course – Sommersemester 2023



Felix Kahlhoefer
TTP - KIT

Introduction

- Junior professor at the Institute for Theoretical Particle Physics (TTP) at KIT since April 2022
- Research focus: Dark matter and other particles with very weak interactions (particle physics/astrophysics/cosmology)
- Office: Physikhochhaus, room 11/09
- Email: kahlhoefer@kit.edu
- Feel free to stop by or send emails with questions
- I'm recruiting master students to start in fall 2023



“All civilisations have an origin myth.
We are the first to get it right.”

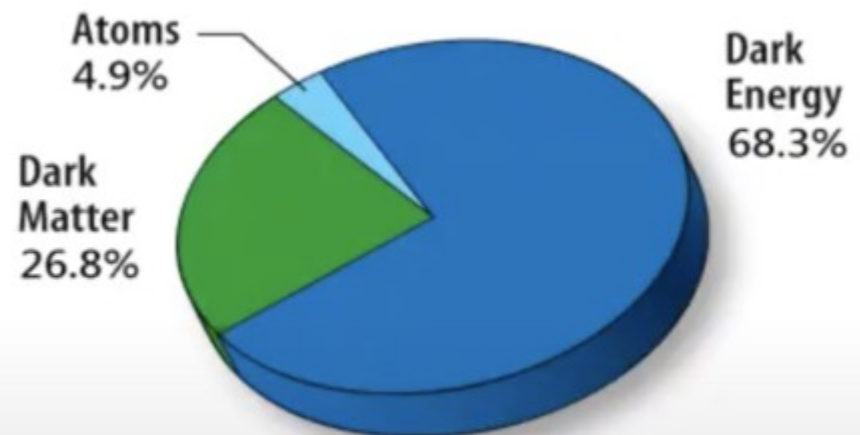
– David Tong, Cambridge

History of cosmology

- Birth of theoretical cosmology: Einstein's theory of general relativity (1915)
- Observational cosmology based on several ground-breaking discoveries
 - 1964-65: Discovery of Cosmic Microwave Background (CMB)
→ Nobel price 1978 (Penzias & Wilson)
 - 1989-93: Discovery of CMB anisotropies
→ Nobel price 2006 (Mather & Smoot)
 - 1998: Accelerated expansion of the Universe
→ Nobel price 2011 (Perlmutter, Schmidt & Riess)

Modern cosmology

- Big Bang theory
 - Universe has evolved to its present form from a very hot and dense initial state
 - Evolution of universe determined by its energy content
- Cosmological standard model: Λ CDM
 - All cosmological observations described in terms of 6 parameters
 - Requires two unknown forms of matter/energy



Outline

- **Part 1: Introduction**
 - The present universe
 - Brief introduction to General Relativity
- **Part 2: The expanding universe**
 - Cosmological expansion
 - The Λ CDM model
- **Part 3: The warm universe**
 - Early universe thermodynamics
 - Boltzmann equation
 - Big Bang Nucleosynthesis
 - Cosmic Microwave Background
- **Part 4: The inhomogeneous universe**
 - Cosmological perturbation theory
 - Baryon acoustic oscillations
 - CMB anisotropies
- **Part 5: The unknown universe**
 - Dark matter
 - Inflation

Hauptseminar: The Matter Puzzle

- Additional topics will be covered in a Hauptseminar

Time: Mo, 15h45-17h15, Room 11/12
(Presentations in English, German on demand)

Introduction

- Successes and shortcomings of the SM
- Beyond SM physics

Dark Matter

- Dark Matter - evidences and tests
- Dark Matter candidates

CP violation

- CP violation in particle physics
- Strong CP problem and axions

The big picture

- Thermal history of the Universe

Registration: Secretariat ITP
Renate Weiss, Room 12-05
12. floor physics highrise
or via email:
milada.muehlleitner@kit.edu

Leptogenesis

- Neutrino masses, seesaw mechanism
- Leptogenesis

Baryogenesis

- Electroweak baryogenesis
- Stochastic gravitational waves

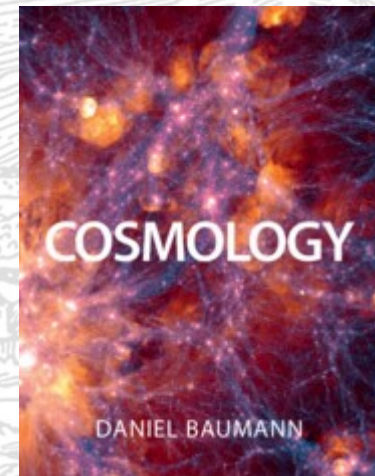
- First meeting today!

Prerequisites

- Lectures will be self-contained regarding general relativity
- For different perspective and deeper understanding, lecture course on general relativity highly recommended
 - Lecture course by Thomas Schwetz in WS2023/24
 - Sean Carroll, <https://arxiv.org/pdf/gr-qc/9712019.pdf>
- Basic knowledge of the Standard Model of particle physics will be assumed
- Methods of quantum field theory will only be used at the very end of the course
 - Gudrun Heinrich, Di 14:00-15:30 & Fr 09:45-11:15, Mittl. HS
 - David Tong, <https://www.damtp.cam.ac.uk/user/tong/qft.html>

Literature

- The course will mostly follow the text book “Cosmology” by Daniel Baumann (Cambridge University Press)
- Book largely identical with the lecture notes available at <http://cosmology.amsterdam/education/cosmology/>
- Additional resources available at <https://www.cambridge.org/baumann>



Literature

- Further books
 - **Rubakov & Gorbunov:** Introduction to the Theory of the Early Universe – Hot Big Bang Theory (2nd edition)
Emphasis on connections between cosmology and particle physics, sometimes a bit too mathematical
 - **Dodelson & Schmidt:** Modern Cosmology (2nd edition)
Standard textbook, somewhat different structure
 - **Steven Weinberg:** Cosmology
Very famous but somewhat outdated
 - **Yann Mambrini:** Particles in the Dark Universe
Very good overview of inflation and dark matter

Literature

- Lecture notes
 - **Matthias Bartelmann / Christoph Pfrommer**
<https://pages.aip.de/pfrommer/Lectures/cosmology.pdf>
 - **Antonio Riotto**
<https://www-ucjf.troja.mff.cuni.cz/~malinsky/cej2013/notes.pdf>
 - **Luca Amendola**
<https://www.thphys.uni-heidelberg.de/~amendola/teaching/cosmology.pdf>
 - **David Tong**
<http://www.damtp.cam.ac.uk/user/tong/cosmo.html>

Practicalities

- Lectures will be every Monday 9:45-11:15 and every second Thursday 11:30-13:00 in Kl. HS B
- On the other Thursdays (starting on 4 May), there will be tutorials (same time and place as the lectures)
- Tutor: **Nicoline Hemme** (nicoline.hemme@kit.edu)
- Materials will be made available via **ILIAS**
 - Hand-written lecture notes (LaTeX lecture notes in progress)
 - Short video summaries for each lecture
 - Links to slides, papers, plots, etc.
 - Discussion forum, feedback form, etc.

Problem sets / exam

- There will be a total of **6 problem sets**
- A new problem set will be published every second week
- Solutions need to be submitted via ILIAS or during lecture before the tutorial
- Model solutions will be discussed at the tutorial
- 60% correct solutions are required to pass the course
- Please get in touch if you would like to take an oral exams