Course presentation
"*Advanced Topics in Theoretical Physics*"

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UNIVERSITÀ
DI TRENTO

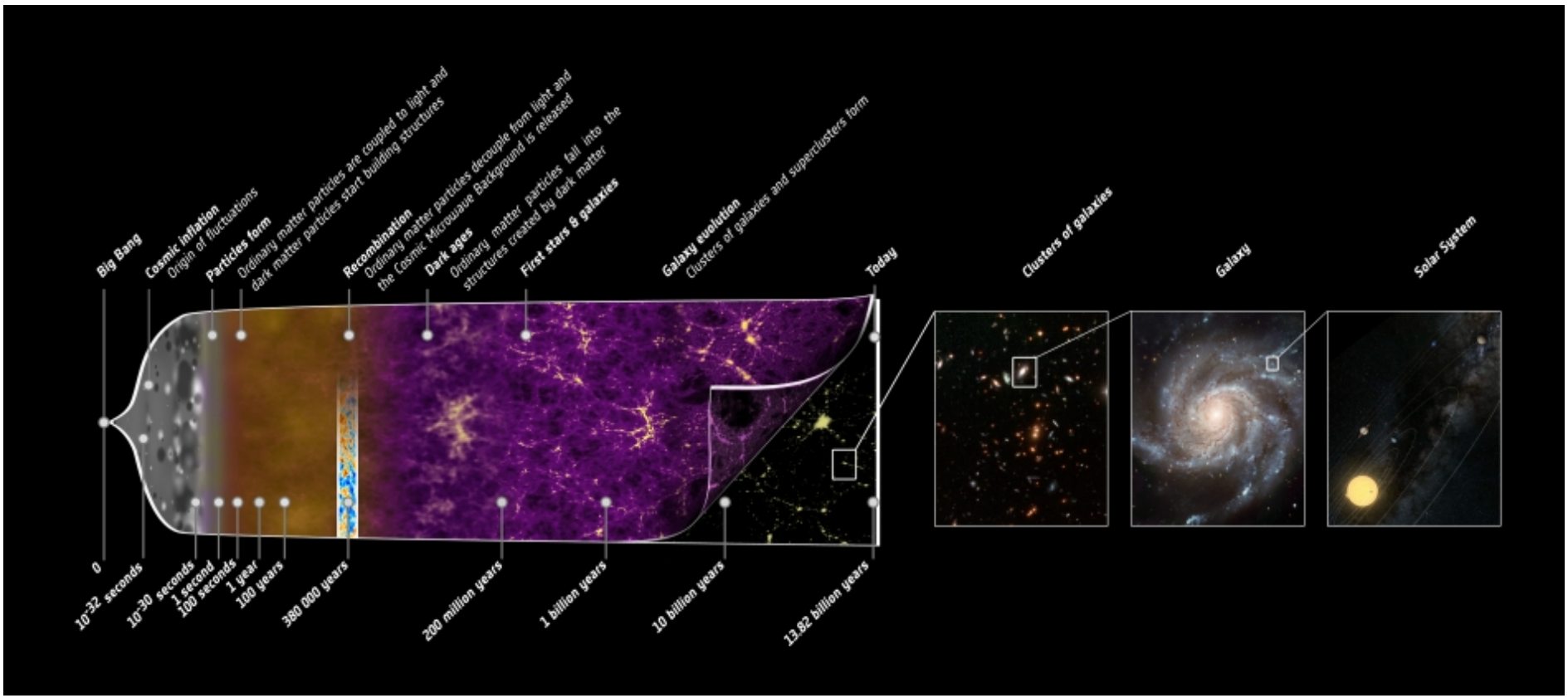
What is cosmology

Cosmology is essentially about answering three questions:

- What is the Universe made of?
- How was the Universe born?
- How did the Universe evolve and what is its fate?

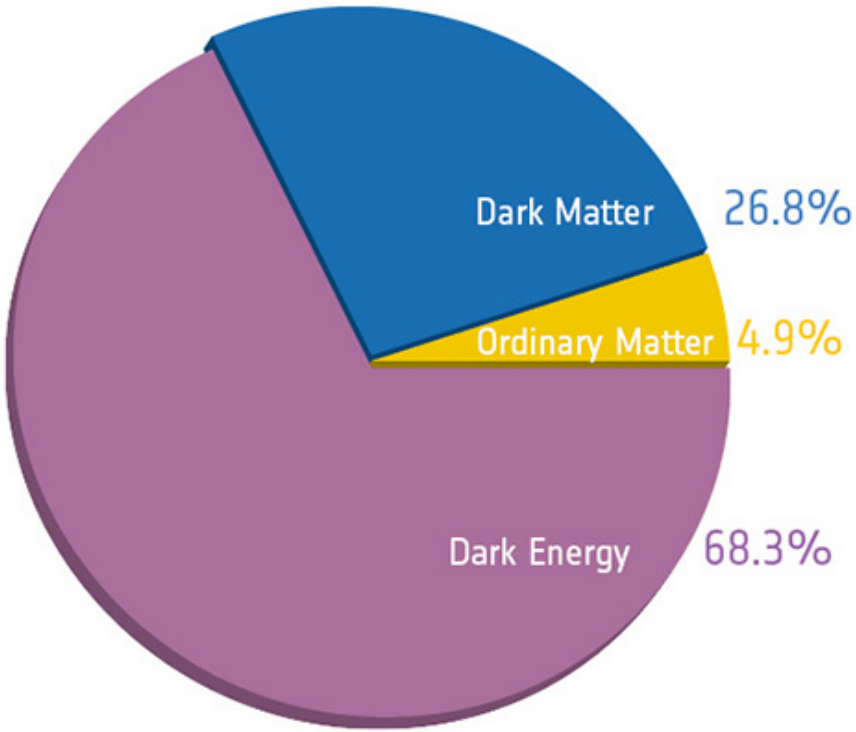
These are nothing but the modern versions of some of the **deepest** and **oldest** questions ever asked by humankind (what are we made of/where do we come from/where are we going)

History of the Universe

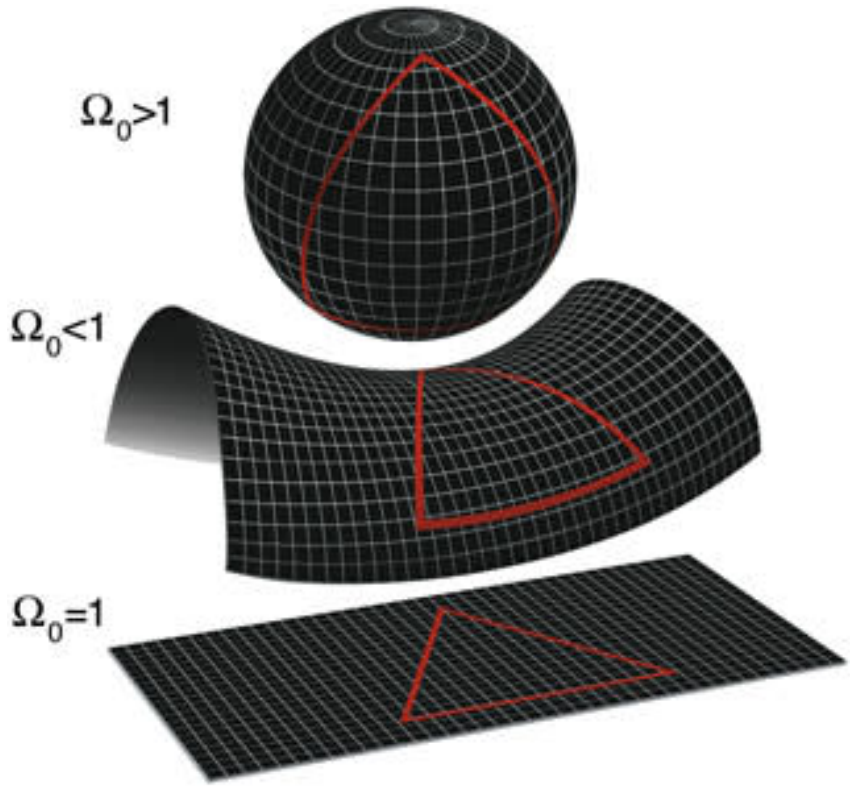


Contents and shape of the Universe

95% of the Universe is unknown!



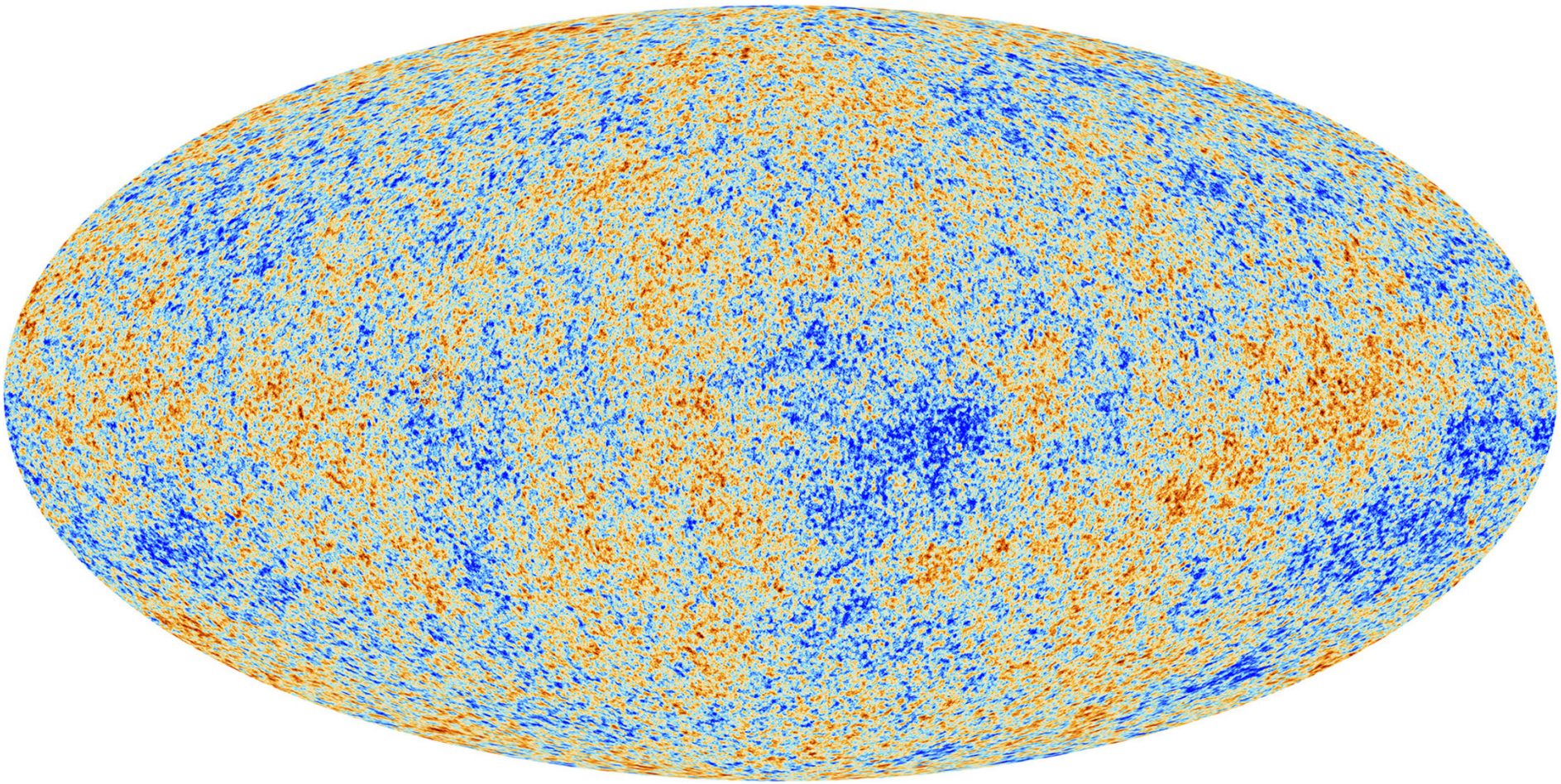
Essentially only three possible shapes



How do we know all this? Through precision measurements across a wide range of times and scales!

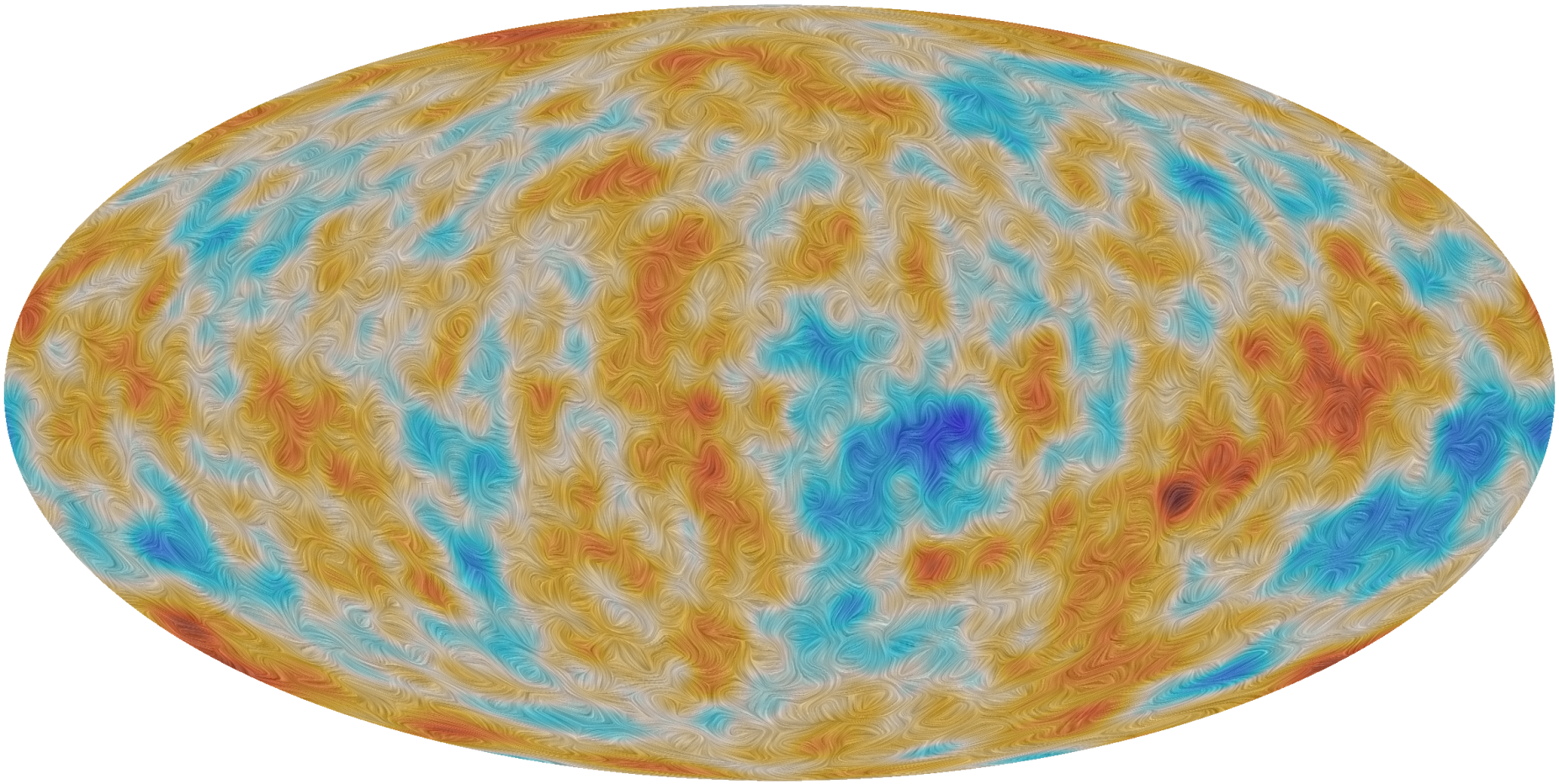
Precision cosmological measurements

Cosmic Microwave Background (temperature)



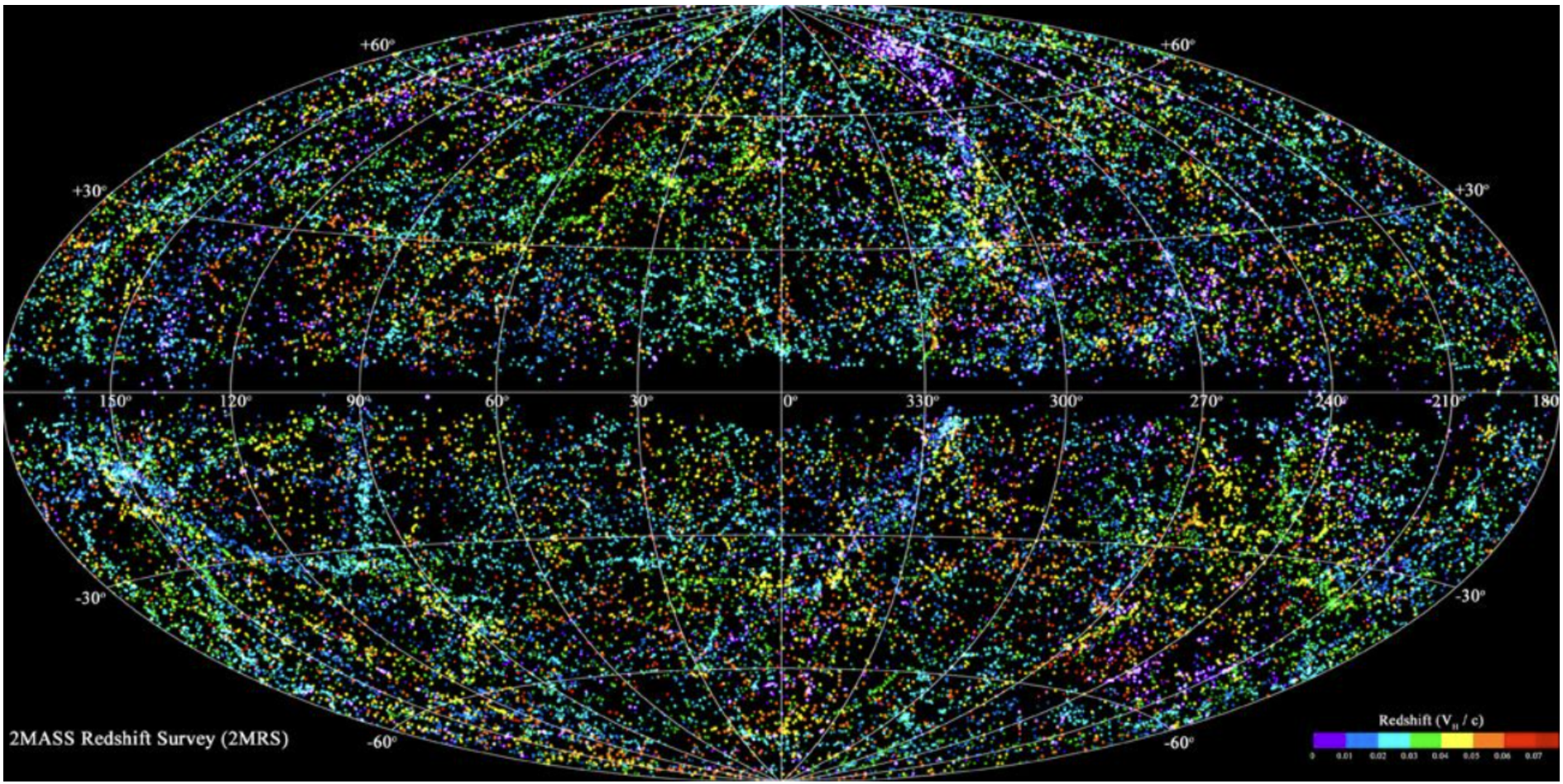
Precision cosmological measurements

Cosmic Microwave Background (polarization)



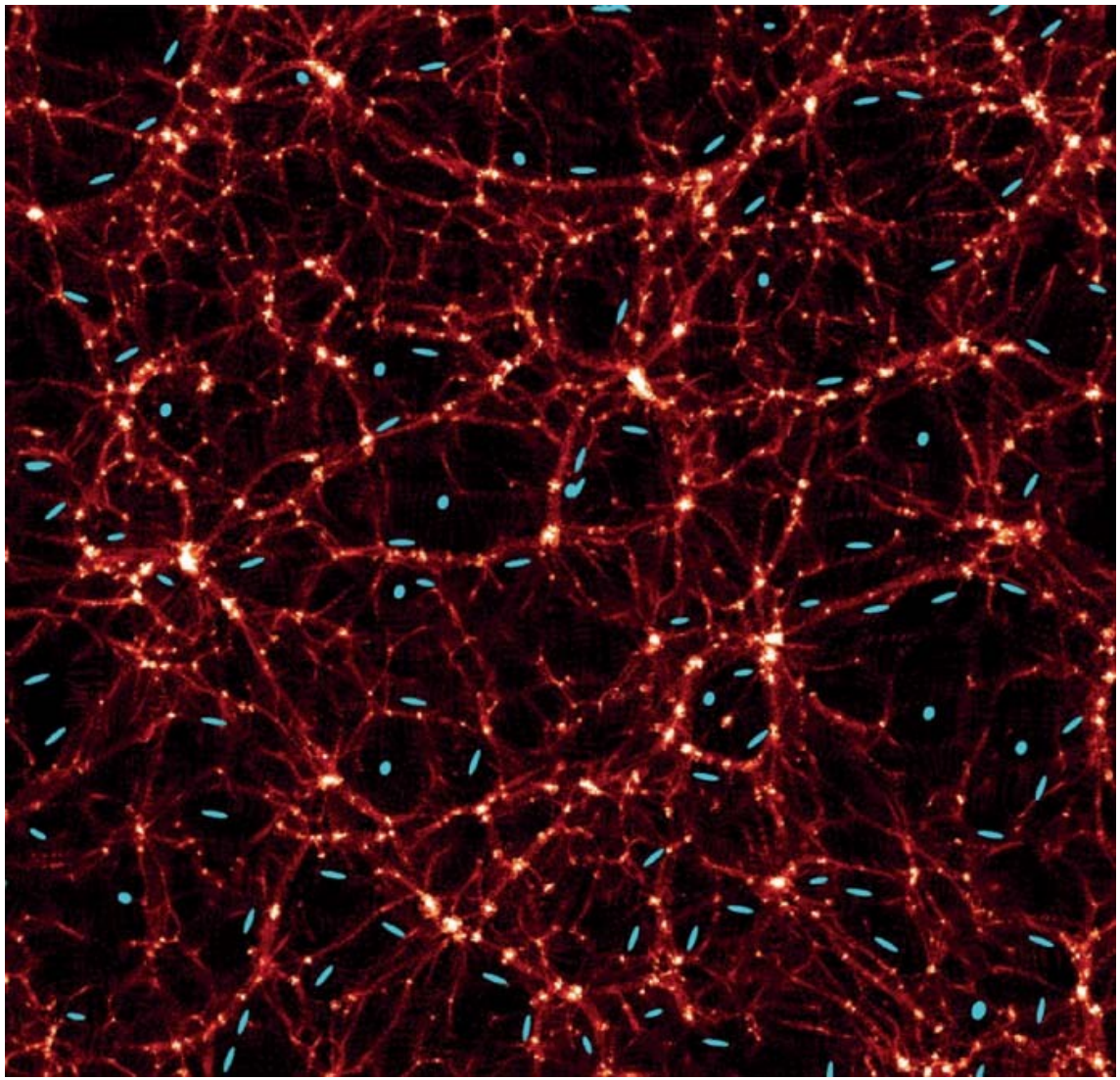
Precision cosmological measurements

Large-Scale Structure (galaxy surveys)



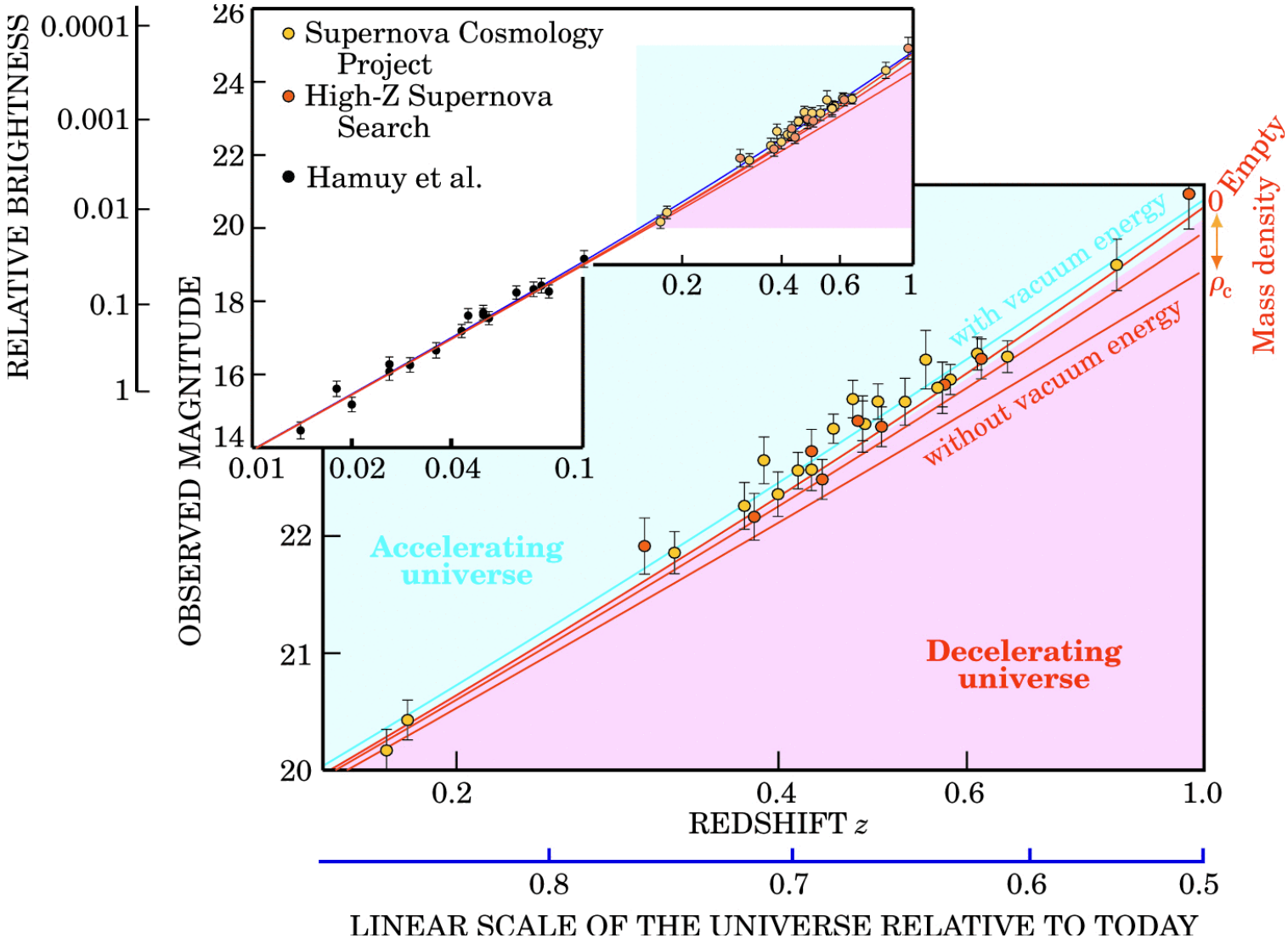
Precision cosmological measurements

Galaxy weak lensing (cosmic shear)



Precision cosmological measurements

Supernovae: the first evidence for an accelerating Universe

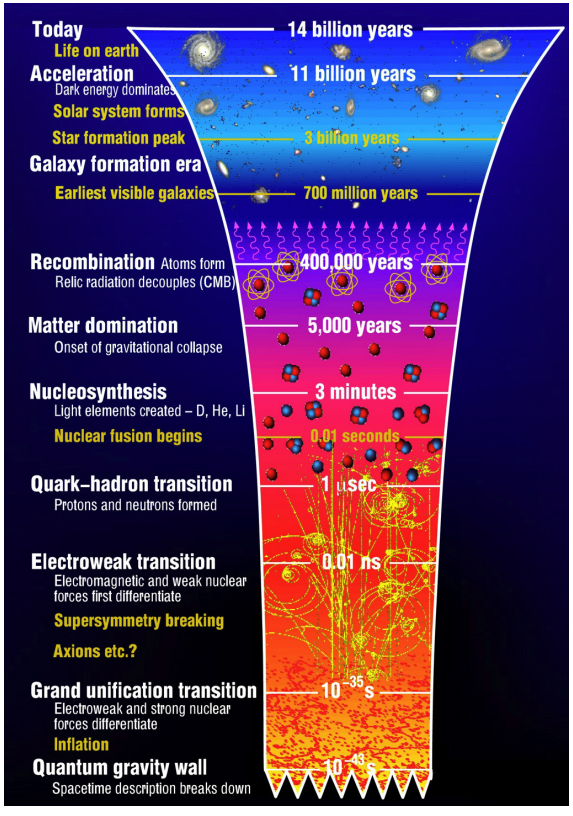


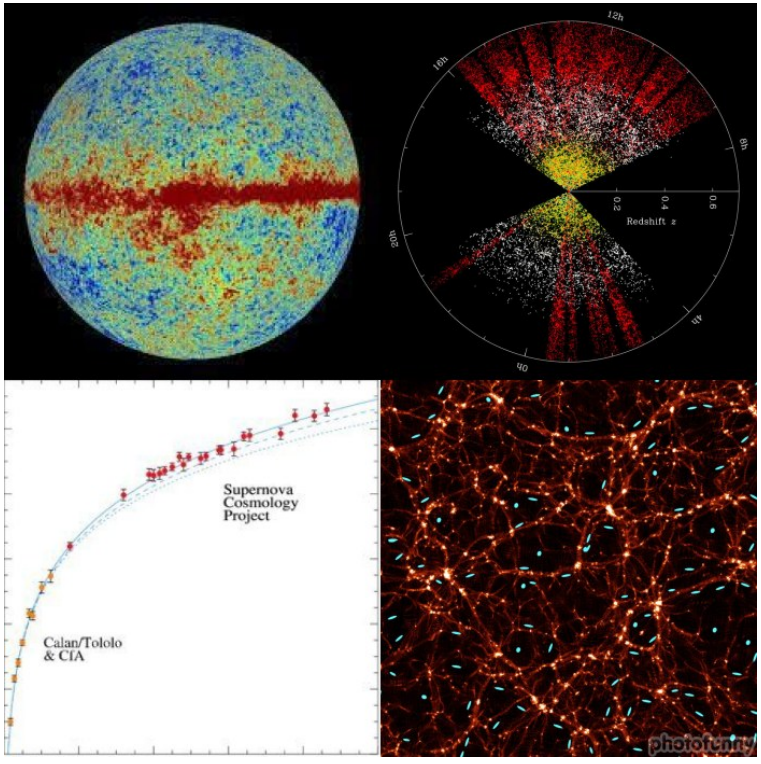
What you will learn in this course

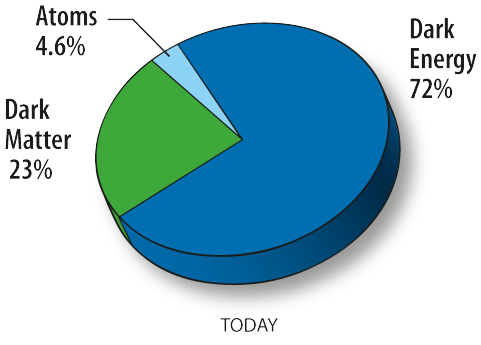
The details behind this sketch: the Universe's past, present, and future

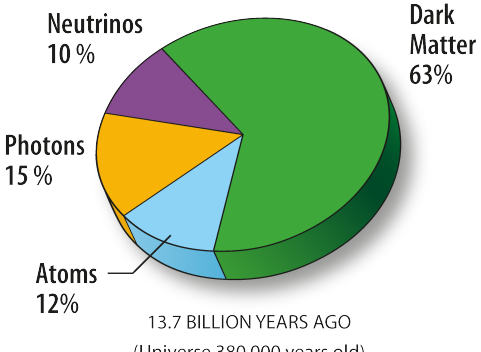
How to make theoretical predictions for these measurements, and how they helped us understand the Universe

What the Universe is made of, and why this is one of the biggest mysteries in physics









Course contents

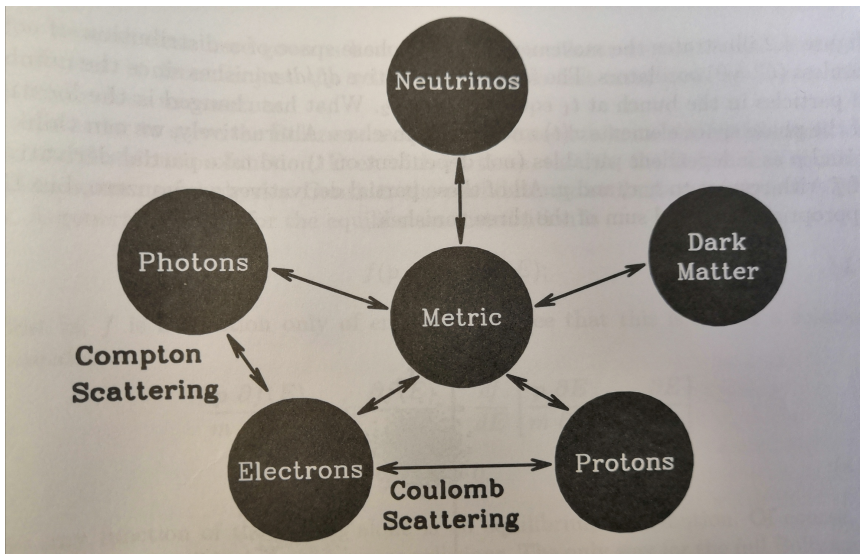
1st part ($\sim$ 14 hrs) – the smooth expanding Universe, and deviations from equilibrium

- Basic concepts in cosmology (redshift, expansion of the Universe, Hubble's law, etc.), preview of the rest of the course [2 hrs]
- Review of GR, FLRW metric, Friedmann equations, distances in an expanding Universe [8 hrs, covered by Prof. Rinaldi]
- Introduction to out-of-equilibrium processes and the Boltzmann equations: applications to Big Bang Nucleosynthesis (production of light elements), recombination (formation of Hydrogen atoms), freeze-out of thermal relics (production of dark matter) [4 hrs]

Course contents

2nd part ($\sim$ 18 hrs) – the coupled Einstein-Boltzmann equations: how perturbations to the metric and particle distributions affect each other

- Boltzmann equations for γ, dark matter, and visible matter [8 hrs]
- Perturbed Einstein equations and the decomposition theorem [4 hrs]
- Initial conditions, cosmic inflation, production of scalar and tensor perturbations (gravitational waves) during inflation [6 hrs]

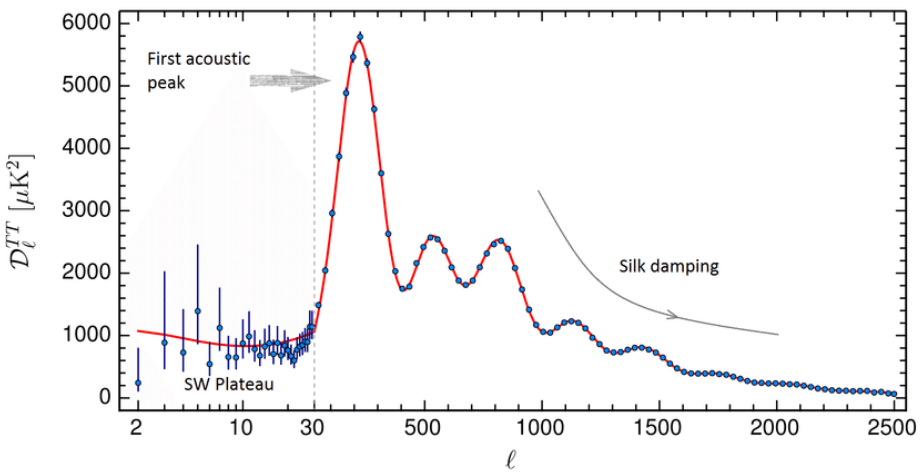


Mathematically most demanding part of the course! (here is where it becomes important to keep the big picture in mind)

Course contents

3rd part ($\sim$ 16 hrs) – solutions to the Einstein-Boltzmann equations: evolution of inhomogeneities and anisotropies, applications to observations

- Inhomogeneities $\rightarrow$ predictions for the matter power spectrum [6 hrs]
- Anisotropies $\rightarrow$ predictions for the CMB power spectrum [6 hrs]
- The ΛCDM model and observations which led to its development, dark matter and dark energy, shortcomings [4 hrs]
- Other topics which can be covered time allowing: weak lensing, CMB polarization, statistical methods for the analysis of cosmological data, concrete models of dark matter and dark energy, big open problems



Practical information

Weight: 6 CFU (48 hrs)

Books

- Scott Dodelson, "Modern Cosmology"
- (Daniel Baumann, Part III Mathematical Tripos Cosmology notes)

Lecture notes: handwritten notes will gradually be posted on my website www.sunnyvagnozzi.com/en/teaching. These are **not** a substitute of the textbook and discussions in class. **Attendance is highly recommended**

Exam: exclusively oral, general questions and broad discussions

Any other useful information: some of the mathematically more complex derivations will be deliberately left open (only quoting the final results), completing them left as (optional but highly recommended) homework for the student

Why follow this course

- We have *all* been curious about the Universe at some point: cosmology will give you (some) answers
- Promising and rapidly developing field, ideal if you later want to do a PhD in a dynamical field
- Several open problems, still a few "low-hanging fruits"
- Connections to several other fields: particle physics, astrophysics, statistics,...
- (*Note: if you want to do your Master's thesis with me you will have to have followed this course!*)