Cosmologia Física

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Ciências
ULisboa

instituto de astrofísica
e ciências do espaço

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Welcome

The course

Cosmology studies the global properties of the Universe using physics to describe/understand:

- the current state of the Universe,
- its past and future evolution,
- its structures and their large-scale spatial distributions

Two courses on physical cosmology in FCUL:

- **Cosmology I**: *Universo primordial* (homogenous universe, expansion, thermal history, general relativity, particle physics, field theory)

"Theoretical/Physical/Primordial Cosmology"

- **Cosmology II**: *Cosmologia Física* (homogeneous universe, inhomogeneous universe, structure formation, cosmological probes, general relativity, astrophysics, statistics)
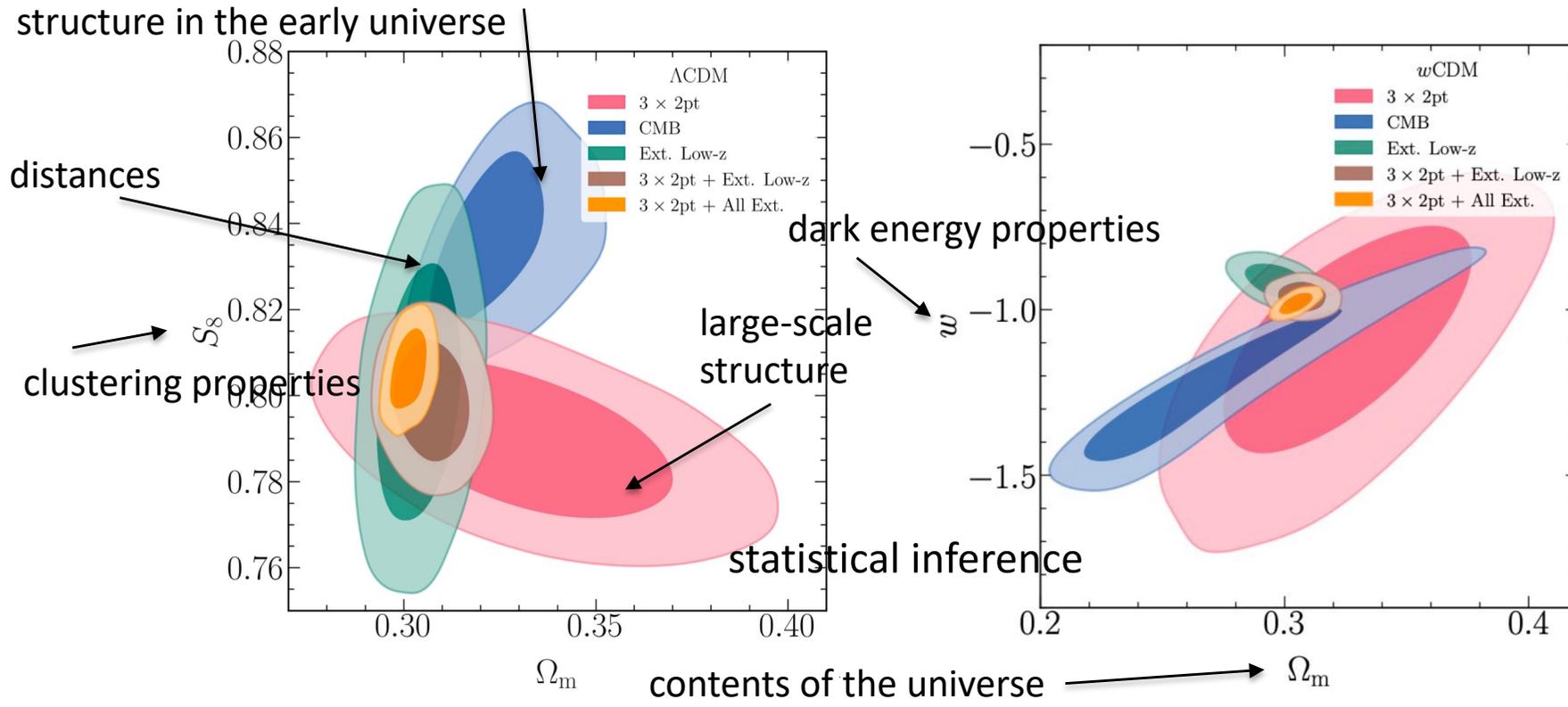
"Observational/Astrophysical/Statistical/Modern Cosmology"

Primordial Universe

Physical Cosmology

Time	Temperature (K)	Event
The Quantum Gravity Era		
$1 \times 10^{-43}\,\mathrm{s}$ (Planck time)	1×10^{32}	quantum limit of general relativity
The Inflation Era		
$1 \times 10^{-35}\,\mathrm{s}$	1×10^{28}	grand unification symmetry breaking
$1 \times 10^{-34}\,\mathrm{s}$	1×10^{27}	start of inflation
$1 \times 10^{-32}\,\mathrm{s}$	1×10^{27}	start of reheating and end of inflation
$1 \times 10^{-11}\,\mathrm{s}$	3×10^{15}	ew unification symmetry breaking
The Quark-Lepton Era		
$1 \times 10^{-5}\,\mathrm{s}$	2×10^{12}	formation of hadrons from quarks
$0.1\,\mathrm{s}$	3×10^{10}	neutrinos decouple
$1\,\mathrm{s}$	1×10^{10}	neutron to proton ratio freezes out
$10\,\mathrm{s}$	5×10^{9}	electron positron annihilation
The Radiation Era		
$3\,\mathrm{min}$	1×10^{9}	nucleosynthesis begins
$30\,\mathrm{min}$	4×10^{8}	nucleosynthesis ends
$2000\,\mathrm{anos}$	$6 \times 10^{4}\ (z \approx 10^{4})$	matter-radiation equivalence
The Matter Era		
$10\,\mathrm{mil\ anos}$ (the plasma epoch)	1×10^{4}	matter is fully ionized
$300\,\mathrm{mil\ anos}$	3.5×10^{3}	electrons and protons recombine
$400\,\mathrm{mil\ anos}$	$3.0 \times 10^{3}\ (z \approx 1100)$	photon decoupling (last scattering surface)
$400\,\mathrm{milhoes\ de\ anos}$	$(z \approx 15)$	first bound structures form formation of intergalactic medium first dark halos of galaxies first stars (first heavy elements) clusters filaments and voids
The Dark Energy Era		
$13.6\,\mathrm{mil\ milhoes\ de\ anos}$	2.726	today

The goal of this course is to understand what goes into plots like these:

structure in the early universe

distances

clustering properties

large-scale structure

dark energy properties

statistical inference

contents of the universe

Dark Energy Survey Year 6 Results: https://arxiv.org/pdf/2601.14559

Properties of observable astrophysical quantities that allow us to evaluate cosmological models → cosmological probes

For this, we need to study:

The Homogeneous Universe: *the zeroth order Universe, or the background*
    geometry, dynamics, age, **distances**, **cosmological parameters**,
    contents of the Universe (dark matter, dark energy, radiation, baryonic matter)

The Inhomogeneous Universe: *the first order Universe, or linear structure formation*
    the density contrast random fields and its statistical properties correlation functions and
    power spectra, Newtonian structure formation, structure formation in GR, for dark and
    baryonic matter, non-linear structure

The Inhomogeneous Universe: *the second order Universe, or non-linear structure formation*
    spherical collapse, mass function

Testing the Homogeneous Universe: *cosmological probes of geometry*
    standard candles (Supernovae), standard rulers (Baryonic Acoustic Oscillations)

Testing the Inhomogeneous Universe: *cosmological probes of structure*
    weak gravitational lensing (cosmic shear), galaxy clustering, CMB anisotropies

Stastistical inference
    Fisher matrix, MCMC

Classes

    Thursday   11h30-13h30   C8.2.04

    Friday   14h30-15h30   C8.2.04

T

TP – examples, quiz, codes, papers

Evaluation

<u>Homework</u>: series of exercises (60-70%)

<u>Presentation</u>: of a topic chosen from a list to be given (for example to go in greater depth into a topic from the course) (30-40%)

Communication: Fénix page and email

Links to lecture notes, homework, and other courses material are given in this page:

https://fenix.ciencias.ulisboa.pt/courses/cfis-1973404328527846/lecture-notes

Contact

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Bibliography

I. Tereno - Lecture notes (slides)

D. Baumann - *Cosmology* (2022) – Ch. 2 (Hom. Univ), 5/6 (Inh. Univ), 7 (CMB)

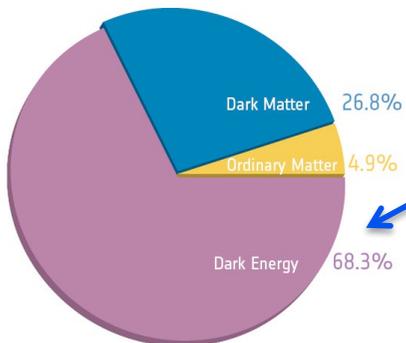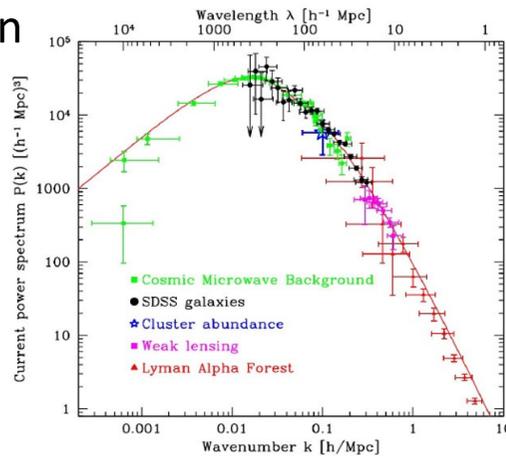Y. Wang - *Dark Energy* (2010) - Ch. 4 (SNIa), 5 (GC, BAO), 6 (WL), 7 (Clusters)

S. Dodelson and F. Schmidt - *Modern Cosmology* 2nd ed. (2021) – Ch 14 (Inference)
the full book gives a detailed coverage of the inhomogeneous Universe and the theoretical
aspects of observational cosmology (in general it has a more advanced level)

The teacher

Cosmological gravitational lensing: the deflection of (galaxy) light in the Universe can be observed → discover the dark matter structures in the Universe and also other properties of the Universe (dark energy, behavior of gravity on large scales)


A matéria que não se via

A MATÉRIA negra, invisível mesmo para os telescópios poderosos, é um dos grandes mistérios da ciência. Apesar de se supor que constitui 90 por cento da massa do Universo, nada se sabe sobre a sua composição ou distribuição. Da resolução deste enigma ficar-se-á a saber o destino do Universo. Se irá expandir-se para sempre ou se, como um elástico depois de puxado ao máximo, irá contrair-se devido à força de gravidade da matéria ou, ainda, se irá oscilar como uma bola de pingue-pongue entre a expansão e a contracção.

Uma equipa de 13 cientistas internacionais (liderada por

Yannick Mellier, do Instituto de Astrofísica de Paris) obteve o primeiro mapa da distribuição da matéria escura numa larga secção do espaço.

A simulação aqui publicada foi elaborada em computador a partir de imagens de 500 mil galáxias distantes. Os discos azuis alongados são as galáxias distantes e os filamentos vermelhos e brancos a matéria escura. As imagens das galáxias aparecem alongadas, de forma paralela aos filamentos de matéria escura, devido à força de gravidade destes. Ao medir as distorções na luz emitida pelas galáxias, pôde "ver-se" a matéria escura.

(2000)

Institut d'Astrophysique de Paris

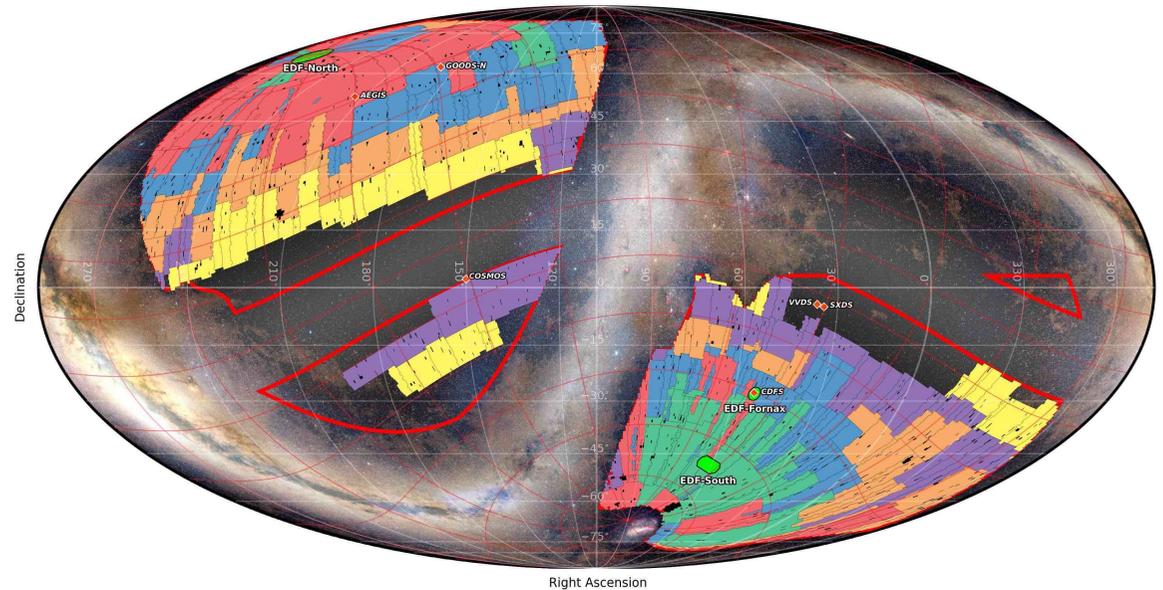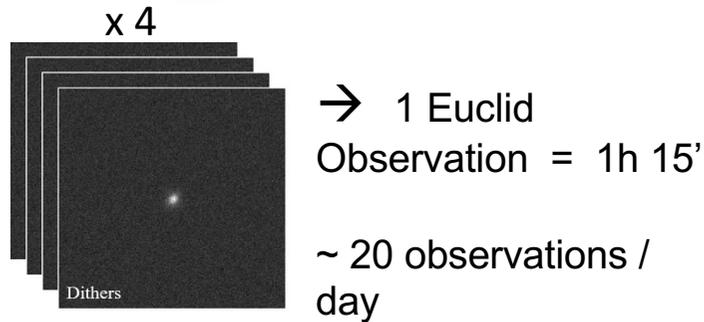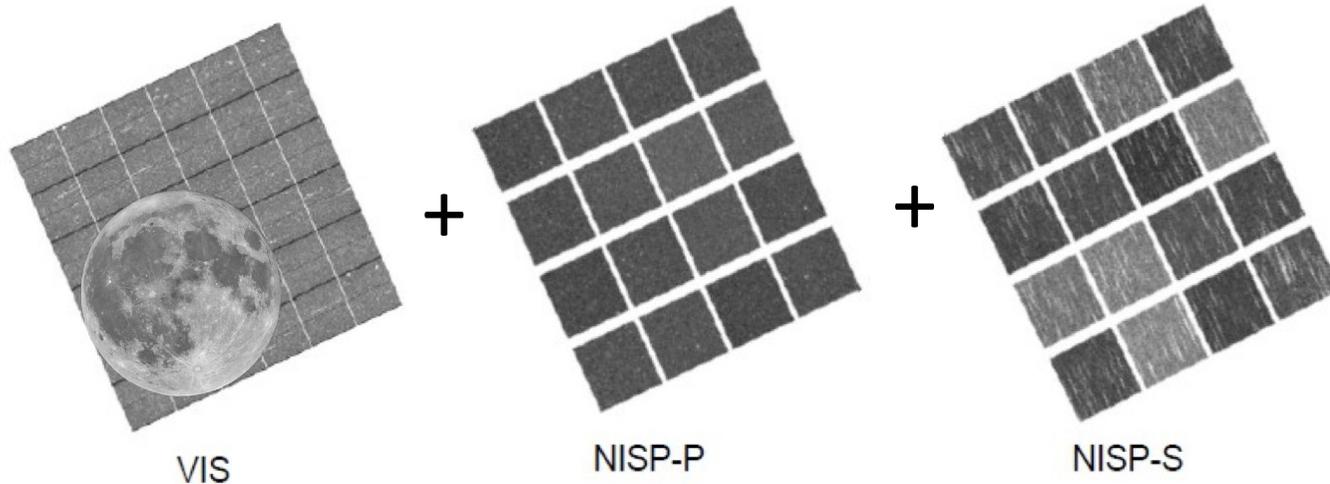**Argelander Institut fuer Astronomie, University of Bonn**
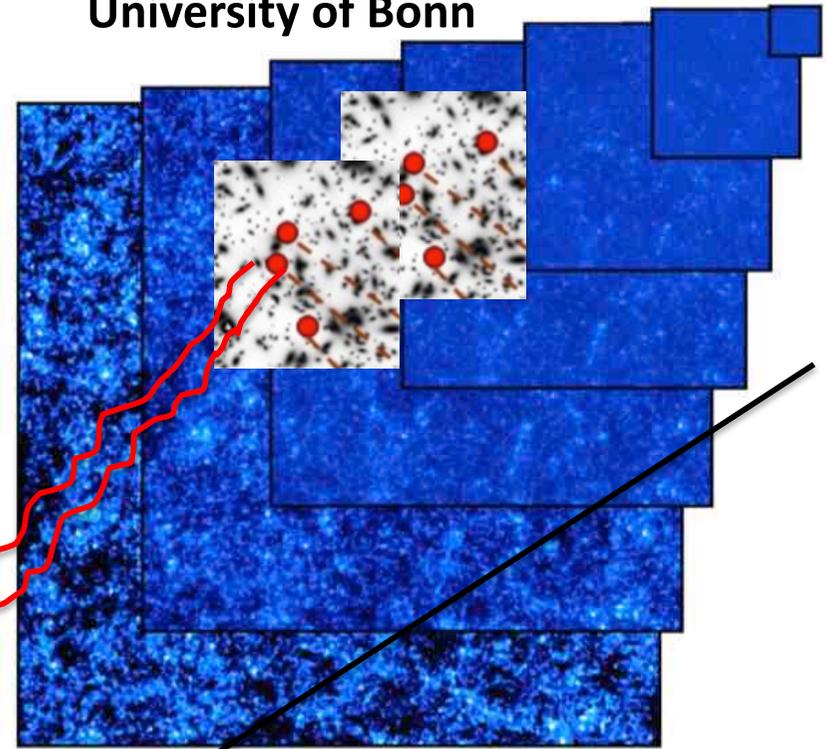
time

Euclid space mission
a sequence of 50 000 observations over the sky during 6 years − started on 14/02/2024

to measure weak lensing on ~10^9 galaxies and redshift (the 3D positions) of ~ 10^7 galaxies

To get enough statistics to probe the large-scale structure of the Universe and its evolution → dark energy and gravity

VIS

+

NISP-P

+

NISP-S

x 4

Dithers

→ 1 Euclid Observation = 1h 15'

~ 20 observations / day

I. Tereno **(Euclid Survey Scientist)**

J. Dinis

A. da Silva

Declination

Right Ascension

EDF-North   GOODS-N
AEGIS
COSMOS
VVDS   SXDS
CDFS
EDF-Fornax
EDF-South

RSD 2026a ECTile realization of the Euclid Wide Survey : 13,133 deg² over 6 years in 411 patches

☐ Euclid Region of Interest : 16 Kdeg² core science compliant with 690 blinding spots skipped [black, 154 deg² over the RSD]

☐ Euclid Deep Field (EDF, 3 fields from north to south : 20+10+23 deg²)

◇ Euclid deep auxiliary field (6 fields : 6.5 deg² in total)

Euclid Wide Survey chronology (2.2Kdeg²/yr)

Year1 Year2 Year3 Year4 Year5 Year6

Background image: Euclid Consortium / Planck Collaboration / A. Mellinger