Cosmologia Física

Topics for the Presentations - 2026 -

I. Power spectra

1. Halo model

The halo model is a framework that describes the distribution of matter on non-linear scales, enabling the computation of the non-linear matter power spectrum. It relies on various ingredients: a mass function (dN/dMdV, i.e. the abundance of halos as function of mass), halo bias, and a dark matter density profile.

Present the halo model and its ingredients, including a description of the Press-Schechter theory for the statistics of dark matter halos (that predicts the mass function).

References:
M. Asgari et al (2023): https://arxiv.org/pdf/2303.08752 (halo model)
D. Baumann (2022) "Cosmology"[book] - Section 5.4.4 (mass function theory)

2. Baryonic feedback

Galaxy formation in the late Universe introduces various baryonic processes that modify the matter power spectrum in addition to the original baryonic acoustic oscillations. These effects need to be included in a precise theoretical computation of the power spectrum.

Describe the main processes (AGN feedback, SN feedback, among others) and their impact on the matter power spectrum.

References:
M. van Daalen et al (2011): https://arxiv.org/pdf/1104.1174.pdf
C. Dalla Vecchia & J. Schaye (2008): https://arxiv.org/pdf/0801.2770

3. CMB temperature anisotropies

The coupled radiation-baryon cosmological fluid can only be properly described in the formalism of the Boltzmann equation.

Present in this formalism the derivation of the perturbation equations for δT CMB temperature anisotropies (yealding eqs. 4.170, eq. 4.179 of the reference below). Discuss also its solution $\Theta_\ell(k)$ (eq. 5.23), which leads to the CMB temperature power spectrum.

References:
L. Amendola and S. Tsujikawa (2010) "Dark Energy"[book] - Sections 4.9, 5.3

4. CMB polarization

CMB radiation is polarized, and the spatial variation of the polarization is treated in the standard way, with correlation functions and power spectra.

Present the effect of polarization of the CMB radiation. Describe the polarization field in the formalism of the Stokes parameters, and the decomposition in E and B modes of the polarization power spectra, explaining also that the B-mode polarization is not produced by interaction with baryons at the last scattering surface, but by gravitational waves. Mention the power of CMB polarization as a cosmological probe.

References:
P.Cabella and M.Kamionkowski (2004): https://arxiv.org/pdf/astro-ph/0403392.pdf (theory of CMB polarization)
A.Balbi et al (2006): https://arxiv.org/pdf/astro-ph/0606511.pdf (simpler overview)

II. Cosmological probes

5. Redshift-space distortions

When measuring the 3D correlation functions of galaxies, the distances between them must be known. However, the peculiar velocities of the galaxies introduce a bias on the distances estimated from redshifts, which results in an anisotropy in the correlation function and in observational features such as the fingers-of-god. This effect is known as a redshift-space distortion (RSD).

Present the RSD effect, describing its theory in the linear regime. Describe also how the RSD signal in galaxy surveys is measured with the multipole estimator, and how it is used to estimate the growth f.

References:
L. Amendola and S. Tsujikawa (2010) “Dark Energy”[book] - Sections 4.8 (theory), 14.3 (estimator)
Y. Wang (2010) “Dark Energy”[book] - Sections 5.3.2 (theory), 5.6 (estimator)

III. ΛCDM problems

Despite the success of the ΛCDM scenario in producing excellent fits to diverse cosmological data, the fits of different datasets are not always consistent with each other (tensions). In addition, there is also a long list of observations of various types that ΛCDM is not capable of explaining (anomalies). And, of course, the model stands on two unknown and exotic entities (Λ and CDM). The topics of this section address some of these problems.

6. ΛCDM small-scale problems

Some of the oldest open problems in the ΛCDM model are related with its predictions on small-scales (halo substructure, dwarf galaxies, etc.).

Present the four main small-scale dark matter problems (cusp/core, missing satellites, too-big-to-fail, satellite plane), and briefly mention possible solutions to these problems.

References
J. Bullock & M. Boylan-Kolchin (2017): https://arxiv.org/pdf/1707.04256

7. Self-interacting dark matter

Self-interacting dark matter (SIDM) is an alternative to WIMP cold dark matter that gained a new interest as a mechanism to produce dark matter halos with cores, hence solving the core/cusp problem.

Present the properties and cosmological impact of SIDM.

References
E. Carlton et al. (1992): https://articles.adsabs.harvard.edu/pdf/1992ApJ...398...43C (the original paper)
D. Spergel & P. Steinhardt (2000): https://arxiv.org/pdf/astro-ph/9909386 (original proposal as a solution to small-scale problems)
S. Tulin & H-B Yu (2018): https://arxiv.org/pdf/1705.02358 (a modern review)

8. The Hubble tension

The Hubble tension is a discrepancy between the H_0 value estimated from early-time probes (mainly the CMB) and the more direct measurement from late-time probes (SuperNovae, mainly from two teams: SHoES and the Hubble Program), and persists with recent JWST observations.. This tension may be a hint for a need to modify the ΛCDM model, but it may also come from biases in the distance ladder used in the late-time methods.

Present the problem, and describe the main distance ladder calibration methods used in the late-time observations (TRGB stars, Cepheids, and JAGB stars). Present also implications on the cosmological model (possible indication of so-called new physics).

References
A. Riess et al (2024): https://arxiv.org/pdf/2308.10954 (short overview of the problem)
A. Riess et al (2022): https://arxiv.org/pdf/2112.04510 (SHoES results and methods)
W. Freedman et al (2025) https://arxiv.org/pdf/2408.06153 (Hubble program results and methods)
V. Poulin et al (2024): https://arxiv.org/pdf/2407.18292 (cosmological implications)
(and associated news: https://www.wired.com/story/the-biggest-controversy-in-cosmology-just-got-deeper/ ; https://cerncourier.com/a/the-hubble-tension/)

9. JWST massive early galaxies and primordial black holes

The James Webb space telescope provides a direct view of structure at high redshift ($z > 10$). Recent JWST observations are finding massive and luminous galaxies at high redshift, which may be in contradiction with galaxy formation models or with ΛCDM cosmological structure formation. One way recently proposed to reconcile the cosmological model with the new observations is the role of primordial black holes (PBH) as seeds of these galaxies. Primordial black holes are possible macroscopic candidates for dark matter that are postulated to exist but they were not yet observed in a decisive way.

Discuss this recent problem, presenting the observations. Explain what are primordial black holes and the mechanisms proposed for their formation, and how can they potentially solve the problem. On the other hand, it is also possible that it is the star formation model that needs to be modified to understand the observations, implying an astrophysical instead of a cosmological solution for the problem. Present also this possibility.

References

A. Dolgov (2023): https://arxiv.org/pdf/2310.00671 (JWST observations and PBH)

B. Carr et al (2020): https://arxiv.org/pdf/2006.02838 (review of PBH)

K. Chworowsky et al (2024): https://iopscience.iop.org/article/10.3847/1538-3881/ad57c1/pdf (star formation explanation)

(and associated news: https://science.nasa.gov/missions/webb/webb-finds-early-galaxies-werent-too-big-for-their-britches-after-all/)

10. Cold spot

The cold spot is a large non-Gaussian feature detected in the CMB map, more specifically it is a large area with temperature lower than average.

Describe this feature and present the current status of observations in the Planck 2018 results. Present one of the possible explanations proposed for the existence of the cold spot, namely the integrated Sachs-Wolfe effect (ISW) caused by a void in that direction. For this discussion, it is also relevant to present the metric of a void (the Lemaitre-Tolman-Bondi metric).

References

L. Perivolaropolous and F. Skara (2022), Sect. III.2.3 https://arxiv.org/pdf/2105.05208.pdf (short overview of the problem)

Planck 2018 paper VII, Sect. 6.5: https://arxiv.org/abs/1906.02552 (CMB measurements)

I. Szapudi et al (2015): https://arxiv.org/abs/1405.1566 (detection of a void in that direction)

S. Nadathur et al (2015): https://arxiv.org/pdf/1408.4720 (the void as an explanation for the cold spot)

11. The cosmic dipole anomaly

The CMB temperature map has larger fluctuations on one side of the sky than on the other, which may be an indication of a conflict with the cosmological principle.

Describe the problem, its measurements in Planck data and consistency tests.

References

L. Perivolaropolous and F. Skara (2022), Sect. III.2.4: https://arxiv.org/pdf/2105.05208.pdf (short overview of the problem)

Planck 2015 paper XVI, Sect. 6: https://arxiv.org/pdf/1506.07135 (CMB measurements)

N. Secrest et al. (2025): https://arxiv.org/pdf/2505.23526 (consistency test)

(and associated news: https://www.space.com/astronomy/the-universe-may-be-lopsided-new-research-says)