Cosmologia Física

Topics for the Presentations

I. The scale of the Universe

1. The Hubble tension

Describe the H_0 tension, a fundamental open problem in the ΛCDM model, presenting its early and late time measurements. Mention also its relation with the sound horizon scale and discuss the shortcomings of early time solutions as a way to solve the tension (in a general way, without addressing specific models).

References
E. Di Valentino et al (2021) - Sections 2 and 3:
https://arxiv.org/pdf/2103.01183.pdf
K. Jedamzik et al (2020): https://arxiv.org/pdf/2010.04158.pdf

2. The local void

Present the idea that a local void (the fact that we may leave in a local underdense region) might be the reason for the Hubble tension.

References
E. Di Valentino et al (2021) - Section 3:
https://arxiv.org/pdf/2103.01183.pdf
W. Kenworthy et al (2019): https://arxiv.org/pdf/1901.08681.pdf
H. Y. Wu and D. Huterer (2017): https://arxiv.org/pdf/1706.09723.pdf

3. Cosmic chronometers and spatial curvature

Present the method of the cosmic chronometers, which is a way to measure $H(z)$. Discuss its recent contribution to the debate about the spatial curvature (solving an announced crisis for cosmology). Summarize also that crisis, mentioning the tensions between Planck data and other datasets and the anomalous CMB lensing signal.

References
S. Vagnozzi et al (2020): https://arxiv.org/pdf/2011.11645.pdf
E. Di Valentino et al (2019): https://arxiv.org/pdf/1911.02087.pdf

4. Time delays

Time delay is a strong lensing effect observed in some astrophysical systems. Describe the effect, deriving its central equation. Explain how it is used to constrain the Hubble parameter.

References:
P. Schneider (1985): http://articles.adsabs.harvard.edu/pdf/1985A%26A...143..413S
C. Kochanek and P. Schechter (2004): https://arxiv.org/pdf/astro-ph/0306040.pdf

S. Suyu et al (2013) - example of a time-delay survey:
https://arxiv.org/pdf/1208.6010.pdf

II. Dark matter

5. Neutrinos

Present the neutrino properties that are relevant in cosmology (mass, effective number, neutrino hierarchy) and describe their effects on the main cosmological probes. Discuss also (briefly) the complementarity between cosmological and laboratory neutrino searches.

References
M. Gerbino and M. Lattanzi (2018) - Sections 2, 3, 4, 8, 9, 10:
https://arxiv.org/pdf/1712.07109.pdf

6. Dark matter particles

Present the main dark matter candidates and their classification in terms of partical physics and astrophysical properties (the Λ^{-1} and $\mathrm{M}_{\mathrm{halo}}$ parameters, respectively).

References
M. Buckley and A. Peter (2018) - Sections 2 and 3:
https://arxiv.org/pdf/1712.06615.pdf

7. CDM problems

Present the four dark matter open problems in the ΛCDM model. Discuss also the importance of including baryons in the analysis (through hydrodynamic simulations) for a better evaluation of these problems.

References
M. Buckley and A. Peter (2018) - Section 4:
https://arxiv.org/pdf/1712.06615.pdf

III. Dark energy and Modified gravity

8. Quintessence

An equation-of-state with dark energy behaviour can be found by introducing a scalar field as an additional component of the cosmological fluid. The best known dark energy scalar field model is the quintessence dark energy. Give an introduction to field theory, to explain how the equation of motion for the new field, and its energy-momentum-tensor can be obtained. Then explain how these are solved to get the background dynamics of the Universe.

References:
D. Lyth and A. Liddle (2009) "The Primordial Density Perturbation"[book] - Chapter 13:
Ask me for the book if you do not find it
L. Amendola and S. Tsujikawa (2010) "Dark Energy"[book] - Sections 7.1, 7.2:

Ask me for the book if you do not find it

9. Modifications to General Relativity

Present the various methods used in the literature to quantify deviations from General Relativity. Then show the observational constraints obtained for those deviations. Discuss also (briefly) the distinction between dark energy (DE) and a modification of gravity (MG) as means of introducing an accelerated expansion.

Note that this presentation is not about theories of gravity alternative to GR (the subject of Sect. 7 of the reference below), but about practical methods (usually phenomenological) to quantify deviations from GR to be used in observational tests.

<u>*References*</u>
M. Ishak (2019) - Sections 5 and 6, and also 7.2 (for the DE/MG distinction):
https://link.springer.com/content/pdf/10.1007/s41114-018-0017-4.pdf

IV. Structure formation

10. Boltzmann equation

The dynamics of the Universe is described by a set of constraint and conservation equations, the Einstein-Boltzmann equations. Present the Boltzmann equation in the inhomogenous Universe. Apply it to the case of dark matter, to derive the continuity and Euler equations.

<u>*References*</u>:
S. Dodelson and F. Schmidt (2021) “Modern Cosmology, 2nd edition”[book] - Sections 3.3, 3.4, 5.4:
Ask me for the book if you do not find it

11. Perturbation theory

The mild non-linear evolution of cosmological fields can be studied in expanding orders of perturbations. This evolution also leads to non-Gaussian density fields. Present the perturbative approach and describe the non-linear corrections to the power spectrum and the bispectrum to leading order (tree level) and next order (loop) perturbation theory. Explain the diagrammatic representation used in those descriptions.

<u>*References*</u>:
F. Bernardeau et al (2002) - Sections 4.1 and 4.2 :
https://arxiv.org/pdf/astro-ph/0112551.pdf
R. Scoccimarro (1996): https://cds.cern.ch/record/317323/files/9612207.pdf

12. The halo model fitting function

Make a brief presentation of the halo model description of non-linear clustering, and then describe the proceeding of building a halo model -based fit to the dark mater power spectrum found from N-body simulations.

<u>*References*</u>:

A. Mead et al (2015) - up to Section 5:
https://arxiv.org/pdf/1505.07833.pdf
R. Smith et al (2003): https://arxiv.org/pdf/astro-ph/0207664.pdf
A. Cooray and R. Sheth (2002) - Section 4:
https://arxiv.org/pdf/astro-ph/0206508.pdf

13. N-body dark matter simulations

N-body simulations allow us to compute the evolution of the dark matter density contrast field in the linear and non-linear regimes. Present the main steps and equations of the process. Describe also the most used approaches: PM codes, AMR codes and Tree codes.

References:
A. Klypin (2018):
https://fenix.ciencias.ulisboa.pt/downloadFile/844562369091758/KlypinNbody.pdf
M. Vogelsberger et al (2019) - Section 3:
https://arxiv.org/pdf/1909.07976.pdf

14. Hydrodynamical simulations of galaxy formation

Simulating baryons is crucial to make predictions for the visible Universe. Hydrodynamical simulations simulate the process of galaxy formation and also find out the impact of baryons in the dark matter power spectrum. Explain what are hydrodynamical simulations, show the equations used and the baryonic effects that can be simulated. Present also the impact of the main baryonic effects on the dark matter power spectrum.

References:
M. Vogelsberger et al (2019) - Section 4:
https://arxiv.org/pdf/1909.07976.pdf
M. van Daalen et al (2011) - Section 3:
https://arxiv.org/pdf/1104.1174.pdf

V. Cosmological probes

15. Redshift-space distortions

Present the RSD effect, describing its theory in the linear regime. Explain also how RSD is measured in galaxy surveys with the multipole estimators.

References:
S. Saito (2016):
https://fenix.ciencias.ulisboa.pt/downloadFile/844562369091759/SaitoRSD.pdf
A.Hamilton (1997) - Sections 4.1, 5.2:
https://arxiv.org/pdf/astro-ph/9708102.pdf
F.Beutler et al (2014) - example of a galaxy clustering RSD survey:
https://arxiv.org/pdf/1312.4611.pdf

16. Weak lensing theory

Derive the lens equation $\vec{\beta} = \vec{\theta} - \vec{\alpha}(\theta)$ and define convergence and shear from the linearized lens equation. Then, describe the phenomena of light propagation in the inhomogeneous Universe, leading to the expressions for cosmic shear and cosmic convergence, and to the relation between the shear power spectrum and the matter power spectrum.

References:
M.Bartelmann and P.Schneider (2001) - Sections 3 and 6:
https://arxiv.org/pdf/astro-ph/9912508.pdf
I. Tereno (2021) - Slides Cosmologia Fisica - Chapters 6 and 20

17. Weak lensing measurements

Define the polar vector ellipticity χ as an the estimator of shear, and derive that in the weak lensing approximation the transformation between the ellipticity of a source galaxy and the ellipticity of its lensed image is $\chi_i^{(s)} = \chi_i - 2g_i$. Then, present the process of measuring the correlation functions of cosmic shear, describing the estimators and possible biases.

References:
M.Bartelmann and P.Schneider (2001) - Section 4.2
https://arxiv.org/pdf/astro-ph/9912508.pdf
I. Tereno (2021) - Slides Cosmologia Fisica - Chapter 20
H. Hildebrandt et al (2017) - example of a weak lensing survey:
https://arxiv.org/pdf/1606.05338.pdf

18. CMB power spectrum estimator

The direct measurement of a power spectrum from a map is not identical to the theoretical predicted power spectrum. This is because "experimental complications"such as finite resolution of the instruments, or incomplete coverage of the sky, or observing window functions, bias the measured power spectrum. Therefore, an estimator must be used to obtain a good determination of the theoretical power psectrum from the measured one.

Present the derivation of a simple estimator for the CMB power spectrum for the case of an experiment where the only "experimental complications"are the finite beam resolution, and the presence of noise. Then describe the more used Pseudo-Cl estimator, used for example in the WMAP measurements of the CMB.

References:
S. Dodelson and F. Schmidt (2021) "Modern Cosmology, 2nd edition"[book] - Section 14.4.1 (for the simple estimator):
Ask me for the book if you do not find it
B. Wandelt et al (2000): https://arxiv.org/pdf/astro-ph/0008111.pdf
G. Hinshaw et al (2003) - - example of a CMB survey:
https://arxiv.org/pdf/astro-ph/0302217.pdf

19. CMB polarization

Present the effect of polarization of the CMB. Describe the formalism of the Stokes parameters, their power spectra and the decomposition in E and B modes. Mention also gravitational waves as a source of CMB polarization.

References:
P.Cabella and M.Kamionkowski (2004) - Section 1, 2, 3, 7: https://arxiv.org/pdf/astro-ph/0403392.pdf
A.Balbi et al (2006): https://arxiv.org/pdf/astro-ph/0606511.pdf
S. Naess et al (2014) - example of a CMB polarization survey: https://arxiv.org/pdf/1405.5524.pdf

20. Intensity Mapping

Intensity mapping is a new technique with potential to probe the linear structures in the high-redshift Universe and in particular to probe the epoch of reionization. Explain what is intensity mapping, and mention various types of line-intensity mapping used (in particular the 21 cm emission). Explain also what is the epoch of reionization.

References:
E. Kovetz et al (2018): https://arxiv.org/pdf/1709.09066.pdf
J. Wise et al (2019): https://arxiv.org/pdf/1907.06653.pdf