Cosmologia Física

Topics for the Presentations

I. Cosmological effects

1. 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 an error 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 distortion information in galaxy surveys is measured with the multipole estimator and used to estimate the growth f.

References:
L. Amendola and S. Tsujikawa (2010) "Dark Energy"[book] - Sections 4.8, 14.3
A. Hamilton (1997) - Sections 2, 4.1, 4.2, 5.2: https://arxiv.org/pdf/astro-ph/9708102.pdf

2. CMB 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). 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

3. 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

4. Time delays

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

References:
C. Kochanek and P. Schechter (2004): https://arxiv.org/pdf/astro-ph/0306040.pdf
R. Narayan and M. Bartelmann (1996), Sect. 3.3: https://arxiv.org/pdf/astro-ph/9606001
M. Possel (2019): https://arxiv.org/pdf/2001.00229
T. Treu and P. Marshall (2016) : https://arxiv.org/pdf/1605.05333

5. Gravitational waves

Present the Einstein equations for the case of tensor perturbations in the RW metric, and the resulting equations describing gravitational waves. Discuss the stochastic gravitational wave background, its large variety of sources from early universe cosmological sources to late universe astrophysical sources, and their observational signatures.

References
S. Dodelson and F. Schmidt (2021) "Modern Cosmology, 2nd edition"[book] - Section 6.4
N. Christensen (2019): https://arxiv.org/pdf/1811.08797.pdf (and specific references cited in this review)

II. ΛCDM problems: tensions, anomalies and exotic components

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 and baryonic effects

Present the four classic small-scale dark matter problems of the ΛCDM model. Describe also the impact of baryonic effects on the dark matter power spectrum, and how it can help in explaining some of these problems.

References
M. Buckley and A. Peter (2018) - Section 4: https://arxiv.org/pdf/1712.06615.pdf
M. van Daalen et al (2011) - Section 3: https://arxiv.org/pdf/1104.1174.pdf

7. The axis of evil and the lopsided universe

These are popular names for two anomalies detected in the CMB temperature maps related to directional dependencies that might be an indication of a breakdown of the cosmological principle. Describe the problems and the current state of the observations (Planck 2018). Discuss also possible causes and implications. Are they significant problems that put the ΛCDM model at stake?

References
P. K. Aluri et al (2023), Sect. III A,B: https://arxiv.org/pdf/2207.05765.pdf
L. Perivolaropolous and F. Skara (2022), Sect. III 2.4,5 https://arxiv.org/pdf/2105.05208.pdf

Abdalla et al. (2022),. Sect. VIII C 2,3 https://arxiv.org/pdf/2203.06142.pdf
(and more specific references cited in the 3 review papers above)
D. Schwarz et al (2016), Sect. 2.2, 2.3: https://arxiv.org/pdf/1510.07929
Planck 2018 paper VII, Sect. 6.2: https://arxiv.org/abs/1906.02552

8. Cold spot

The cold spot is a very large non-Gaussian feature detected in the CMB map, more specifically it is a large area with temperature lower than average. Present this feature and its current state of observations (Planck 2018). Discuss if the observation is statistically relevant, or if on the contrary this is a false problem. Present also the evidence for the existence of a supervoid in that direction and discuss if a supervoid could explain the cold spot.

References
L. Perivolaropolous and F. Skara (2022), Sect. III 2.3 https://arxiv.org/pdf/2105.05208.pdf
Abdalla et al. (2022),. Sect. VIII C 3 https://arxiv.org/pdf/2203.06142.pdf
P. K. Aluri et al (2023), Sect. III H: https://arxiv.org/pdf/2207.05765.pdf
(and more specific references cited in the 3 review papers above)
D. Schwarz et al (2016), Sect. 2.5: https://arxiv.org/pdf/1510.07929
Planck 2018 paper VII, Sect. 6.5: https://arxiv.org/abs/1906.02552
I. Szapudi et al (2015): https://arxiv.org/abs/1405.1566
S. Nadathur et al (2015): https://arxiv.org/pdf/1408.4720

9. The Hubble tension

Present the H_0 tension, a fundamental open problem in the ΛCDM model, showing its early and late time measurements including recent confirmation from JWST data. Mention also its relation with the sound horizon scale and discuss the shortcomings of trying to modify the sound horizon scale as a way to solve the tension (in a general way, without addressing specific theoretical models).

References
E. Di Valentino et al (2021) - Sections 2 and 3: https://arxiv.org/pdf/2103.01183.pdf
A. Riess et al (2024): https://arxiv.org/pdf/2308.10954
K. Jedamzik et al (2020): https://arxiv.org/pdf/2010.04158.pdf

10. Astrophysical anomalies

Recently, the bulk flow of a large volume of the local universe was measured for the first time. In an unrelated observation a large supervoid, named KBC, was also discovered. Present these discoveries and discuss why they pose problems for the ΛCDM scenario. Regardless of these problems, the idea that we may live in a local underdense region (a void) could be a simple explanation for the Hubble tension. Discuss, however, that this possibility is not capable of solving the Hubble tension.

References
R. Watkins et al (2023): https://arxiv.org/pdf/2302.02028
M. Haslbauer et al (2021), Sect. 1.1, 2: https://arxiv.org/pdf/2009.11292

Abdalla et al. (2022),. Sect. VII H 3 https://arxiv.org/pdf/2203.06142.pdf
E. Di Valentino et al (2021) - Section 3.1: https://arxiv.org/pdf/2103.01183.pdf
H. Y. Wu and D. Huterer (2017): https://arxiv.org/pdf/1706.09723.pdf

11. MOND: the Universe without dark matter

Modified Newtonian Dynamics (MOND) is a modification of Newtonian gravity suggested as an alternative to dark matter. It was originally based on empirical laws, rather than being the result of a physical theory. Present the MOND idea and describe how it is capable of explaining observations on different scales - rotation curves of spiral galaxies, pressure-supported systems, and cosmic structure - without relying on dark matter.

References
R. Sanders and S. McGaugh (2002) - Sections 1-4, and Section 6: https://arxiv.org/pdf/astro-ph/0204521.pdf
M. Haslbauer et al (2021), Sect. 1.3, 3 : https://arxiv.org/pdf/2009.11292

12. MOND cosmological model

The original MOND has problems explaining the dynamics of clusters without dark matter. A MOND cosmological model allowing the presence of sterile neutrinos as hot dark matter particles was proposed. It was very recently argued that this MOND cosmological model can solve the Hubble tension and explain the astrophysical anomalies discussed in topic 10. Present this model and its solutions to the problems.

References
S. Mazurenko et al (2024): https://arxiv.org/pdf/2311.17988
M. Haslbauer et al (2021) : https://arxiv.org/pdf/2009.11292
Cosmology Talks: https://www.youtube.com/watch?v=LMhjenB7V8g
The Dark matter crisis: https://darkmattercrisis.wordpress.com/2023/12/03/86-the-hubble-tension-is-solved/
The Dark matter crisis: https://darkmattercrisis.wordpress.com/2020/11/20/52-beyond-the-standard-model-of-cosmology-mond-as-a-way-out-of-the-current-cosmological-crisis/

13. Primordial black holes as dark matter

Primordial Black Holes (not yet observed) are considered possible candidates for dark matter. Present what are primordial black holes and describe some of the mechanisms proposed for their formation. Discuss theoretical constraints that bound their possible density range and mass functions, and present their possible observational signatures.

References
B. Carr et al (2020): https://arxiv.org/pdf/2006.02838
S. Clesse et al (2018): https://arxiv.org/pdf/1711.10458
J. Garcia-Bellido (2017): https://arxiv.org/pdf/1702.08275

14. Dark energy models

There is an enormous amount of dark energy models. They were first proposed as alternatives to the cosmological constant, but nowadays their main motivation is to try to solve the Hubble tension. Present a few (at least two) dark energy models of your choice: for example one of early DE type and other of late DE type, or also of the dark radiation type. Describe the models and their parameter constraints with relation to the Hubble tension problem.

References:
E. Di Valentino et al (2021) - Section 3.1: https://arxiv.org/pdf/2103.01183.pdf
N. Scheoneberg et al (2022): https://arxiv.org/pdf/2107.10291
(and specific references given in the two reviews above)

15. Post-quantum theory of classical gravity

There is a very recent attempt to reconcile gravity and quantum fields. This new theory is not a quantum theory of gravity, but it is a theory of classical gravity coupled to quantum matter fields. With this theory there is no need for dark matter or dark energy. Describe this controversial theory.

References:
J. Oppenheim et al (2024) https://arxiv.org/pdf/2402.19459
J. Oppenheim (2024): https://arxiv.org/pdf/1811.03116
The Guardian: https://www.theguardian.com/science/2024/mar/09/controversial-new-theory-of-gravity-rules-out-need-for-dark-matter
Seminar: https://www.youtube.com/watch?v=Vydjszp4Y6k