CLASS@CosmoTools2018

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Overview

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Exercise: Background

Cosmological distances

Reproduce figure 2.3 from Dodelson *Modern Cosmology*. Note that Dodelson plots the three cosmological distances d_X in units of $[1/H_0]$.

36 THE SMOOTH, EXPANDING UNIVERSE

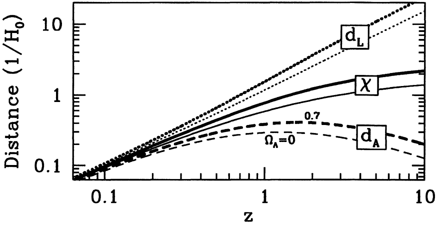
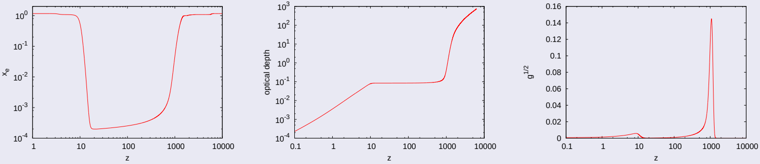


Figure 2.3. Three distance measures in a flat expanding universe. From top to bottom, the luminosity distance, the comoving distance, and the angular diameter distance. The pair of lines in each case is for a flat universe with matter only (light curves) and 70% cosmological constant Λ (heavy curves). In a Λ-dominated universe, distances out to fixed redshift are larger than in a matter-dominated universe.

Exercise: Thermodynamics

Free electron fraction

Plot the following three thermodynamics quantities: The free electron fraction x_e, the optical depth $\kappa(\tau)$ and the (square root of the) visibility function $g(\tau) = \kappa' e^{-\kappa}$ as a function of redshift z:



Exercise: Perturbations

Reproduce figure 8.1 from Dodelson *Modern Cosmology*. This is one of the terms in the CMB temperature source function:

$$S_T(\tau, k) \equiv \underbrace{g\left(\Theta_0 + \psi\right)}_{\text{SW}} + \cdots$$

$g(\tau)$ is strongly peaked at recombination (η_* in figure). The four wave numbers are $k = (0.00077, 0.022,$
$0.034, 0.045)$Mpc^{-1}.

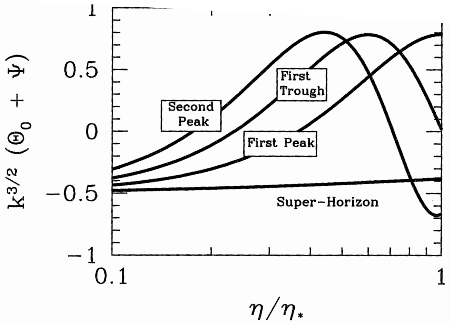


Figure 8.1. Evolution of photon perturbations of four different modes before recombination at η_*. Normalization is arbitrary, but the relative normalization of the 4 curves is appropriate for perturbations with a Harrison–Zel'dovich–Peebles ($n = 1$) spectrum. Model is standard CDM with $h = 0.5$, $\Omega_m = 1$, and $\Omega_b = 0.06$. Starting from the bottom left and moving upward, the wavenumbers for the modes are $k = (7 \times 10^{-4}, 0.022, 0.034, 0.045)$ Mpc^{-1} or $(8, 260, 400, 540)/\eta_0$.

Exercise: Perturbations -> hints

Time of recombination

You will need the conformal time of recombination. This is by definition the peak of the visibility function $g(\tau)$, so just compute $g(\tau)$ from the thermodynamics and find out where it peaks..

Normalisation of modes

In CLASS all modes are normalised to a comoving curvature perturbation $\zeta = -1$ on super-horizon scales. The code Dodelson used to make the plot had a different convention, and it included the factor $k^{-\frac{3}{2}}$ in the initial condition. Furthermore, we have $4\Theta_0 = \delta_\gamma$ (ask me why if you want to know!). Thus, the quantity we should plot is $-2\left(\delta_g/4 + \psi\right)$.

Exercise: Primordial

Chaotic inflation

Plot the primordial scalar and tensor power spectrum for the chaotic inflation model, $V(\phi) = m^2\phi^2$.

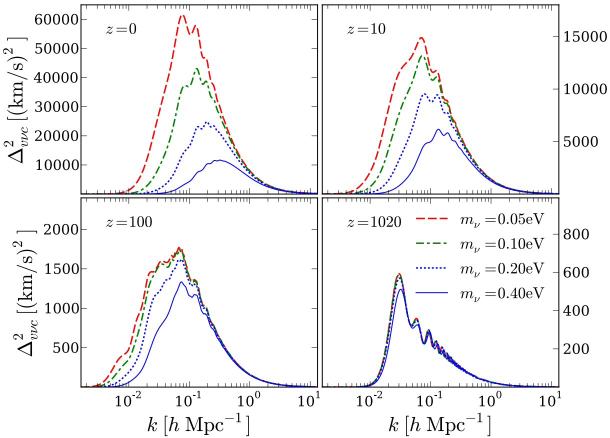
Check that the values of A_s, n_s, α_s, r are reasonable for $m^2 = 1.6 \times 10^{-12}$.

```
xxx.set({'output':'tCl', 'modes':'s,t',
  'P_k_ini type':'inflation_V_end',
  'Vparam0':0,'Vparam1':0,
  'Vparam2':1.6e-12,
  'Vparam3':0,'Vparam4':0,
  'ln_aH_ratio':55,
  'primordial_verbose':2})
```

Exercise: Transfer

Reproduce the following plot from Ue-Li Pen et. al., 1311.3422:

$$\Delta^2_{v\nu c}(k,z) \equiv \mathcal{P}(k)\left[\frac{\theta_\nu(k,z)-\theta_c(k,z)}{k}\right]^2 .$$



Exercise: Angular TT and BB power spectra

Effect of lensing

- Check the difference between lensed and unlensed C_ℓ^{TT} to see the effect of smoothing of the peak contrast and additional damping.
- Same as above for C_ℓ^{BB} assuming $r_{0.05} = 0.2$. Observe that B-modes are dominated by lensing at smal scales.

Exercise: Input parameter

Baryon fraction as input parameter

Add the baryon fraction `eta_b` to CLASS following the example in the lecture.

Non-trivial: σ_8 as input parameter

Implement σ_8 as an input parameter using the shooting method.