Galaxy formation and evolution – Problem set 2. Autumn 2022

*The answers should be returned by **Monday (3.10) 4pm (16.00) in Moodle**, link through the official course homepage. The answers to the problem set will be discussed on Wednesday (5.10) at 12.15-14.00 in Room BK114, Exactum.*

1. Calculate the age of the universe at $z = 0$ and at redshifts $z = 6$ and $z = 10$ for the following models assuming a present-day Hubble parameter of $H_0 = 67.1\ \mathrm{kms^{-1}Mpc^{-1}}$:

   (a) The Einstein-de Sitter (EdS) universe, with $\Omega_{m,0} = 1$, $\Omega_{\Lambda,0} = 0$ and a flat geometry ($K = 0$), $\Omega_0 = 1$.

   (b) An open universe ($K = -1$), with $\Omega_{m,0} = 0.32$, $\Omega_{\Lambda,0} = 0$ and $\Omega_0 = 0.32$.

   (c) A flat ($K = 0$) ΛCDM model with $\Omega_{m,0} = 0.32$ and $\Omega_{\Lambda,0} = 0.68$, $\Omega_0 = \Omega_{m,0} + \Omega_{\Lambda,0} = 1$.

   In calculating the ages one can use the equations of the lecture notes, i.e. no need to rederive the equations. Interpret also the results, how different are the ages of the various models at $z = 10$ and $z = 0$. Which model gives the oldest age at $z = 0$ and why?

2. Solve the Friedmann equations by deriving an expression for the scale factor, a, as a function of time and the cosmological parameters in the following two models:

   (a) The Einstein-de Sitter (EdS) universe, with $\Omega_{m,0} = 1$, $\Omega_{\Lambda,0} = 0$ and a flat geometry ($K = 0$), $\Omega_0 = 1$.

   (b) The standard Planck ΛCDM model with $\Omega_{m,0} = 0.32$ and $\Omega_{\Lambda,0} = 0.68$, $\Omega_0 = \Omega_{m,0} + \Omega_{\Lambda,0} = 1$. *Hint: Use an appropriate subsitution in solving the integral.*

   Finally show that at early times (high redshift z, small a) the evolution of the scale factor a in the standard ΛCDM model is similar to the Einstein-de Sitter (EdS) model. Finally, how does the evolution of the scale factor differ in the two models at present and how will this difference develop in the future?

3. The discovery of the most distant confirmed object in the universe, a high-redshift galaxy named GN-z11, was announced in March 2016. This object has a confirmed redshift of $z = 11.09$ Calculate the angular-diameter and luminosity distances to this object in the following three models:

   (a) The Einstein-de Sitter (EdS) universe, with $\Omega_{m,0} = 1$, $\Omega_{\Lambda,0} = 0$ and a flat geometry ($K = 0$), $\Omega_0 = 1$.

   (b) An open universe ($K = -1$), with $\Omega_{m,0} = 0.32$ and $\Omega_{\Lambda,0} = 0$ and $\Omega_0 = 0.32$.

   (c) A flat ($K = 0$) ΛCDM model with $\Omega_{m,0} = 0.32$ and $\Omega_{\Lambda,0} = 0.68$, $\Omega_0 = \Omega_{m,0} + \Omega_{\Lambda,0} = 1$.

   Finally assume that this galaxy is a compact proto-galaxy with a very high intrinsic mean surface brightness in the rest-frame B-band of $\langle \mu \rangle_B \sim 18$ mag arcsec^{-2}. What would the observed surface brightness be, corrected for cosmological surface brightness dimming and at what wavelength would the rest-frame B-band light be observed?

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4. Download and read the paper: *"Two Remarkably Luminous Galaxy Candidates at* $z \approx 11 - 13$ *Revealed by JWST"* by Naidu, Oesch, van Dokkum et al., 2022, ApJL submitted, ArXiV: 2207.09434 using the link on the course homepage. Based on the paper answer the questions below. In answering some of the questions you might need to search for additional information on the internet and/or in textbooks.

   (a) In this paper the authors study candidate galaxies at very high redshifts detected in two JWST Early Release Science programs. What are these two programs and what are their principal science goals?

   (b) The authors single out two $z \gtrsim 10$ galaxy candidates. Based on Fig 1. and Fig 2., what spectral features are used to determine that these two galaxies are potentially at very high redshifts? Why are the two objects only high-redshift galaxy candidates, i.e. not confirmed detections, as is the case for GNz11? Is it possible that these sources could be lower redshift ($z \sim 3$) interlopers instead?

   (c) What is meant by photometric redshifts? The best fit redshifts are found with SED (Spectral Energy Distribution) fitting codes (Prospector and EAZY). Describe briefly what parameters go into these codes and why the existence for strong clear spectral breaks is important when determining photometric redshifts.

5. (a) What are the derived stellar masses and morphologies of the two candidate galaxies? Are the candidate galaxies surprisingly bright or not? In answering this question study in particular Fig 3., Fig 4. and Fig. 5.

   (b) What are the main caveats of this study, i.e. on how secure a footing are the results. Are more data required to draw more concrete conclusions? Can two objects already be used to constrain the observed high-z luminosity function?

   (c) Studying Fig 5. how does the observations of the bright end of UV luminosity function compare with the observational predictions, as given by the Schechter function and the theoretical models, as predicted by the Universe Machine and Delphi models? The best fitting model is a double-power luminosity function model. Explain very briefly what this model is.