Galaxy formation and evolution – Problem set 1. Autumn 2020

The answers should be returned by ***Wednesday (16.9) 4pm (16.00)*** *by email to the course assistant Stuart McAlpine (stuart.mcalpine@helsinki.fi). Please put "Galaxy formation – Problem set 1" in the title of your email.*

– The problem set will be discussed on Friday (18.9) after the lecture (at 14.00) on Zoom.

1. The bulge-to disk ratio for a spiral galaxy is the ratio of the luminosity in the bulge to that in the disk. Calculate the bulge-to-disk ratio (B/D) for a typical spiral galaxy with a de Vaucouler's Law bulge and an exponential disk as a function of the variables r_D, r_e, I_D and I_e, where the intensity for the components are given by:

$$\text{Disk component :} \quad I(R) = I_D e^{-r/r_D}$$

$$\text{Bulge component :} \quad I(R) = I_e e^{-7.67[(R/R_e)^{1/4}-1]}$$

2. Galaxy formation timescales. Estimate the 1) Hubble time, 2) Dynamical time and 3) Star formation time for the two galaxies below. Here we are only interested in the disk component for which the surface mass distribution can be described by the function: $\Sigma = \Sigma_0 e^{-r/r_D}$ with units of $[M_\odot \mathrm{pc}^{-2}]$, where Σ_0 is the central surface density and r_D is the scale radius. Estimate both the dynamical time and star formation time in the central galaxy within $r < 1$ kpc. In calculating the Hubble time use the Planck ΛCDM model with $\Omega_{\mathrm{bar}} = 0.049$, $\Omega_{\mathrm{CDM}} = 0.2685$ and $\Omega_\Lambda = 0.6825$.

   (a) The Milky Way at $z = 0$ with total disk mass of $M_{\mathrm{D}} = 5.5 \times 10^{10} M_\odot$ and a scale radius of $r_D = 3.5$ kpc. The gas fraction of the disk is $f_{\mathrm{gas}} = 10\%$ and the central star formation rate within $r < 1$ kpc is $SFR \sim 1 M_\odot/\mathrm{yr}$.

   (b) The recently discovered compact galaxy GOODS-N-774 at redshift $z = 2$ with a total disk mass of $M_{\mathrm{D}} = 10^{11} M_\odot$ and a scale radius of $r_D = 1$ kpc. The gas fraction of the disk is $f_{\mathrm{gas}} = 50\%$ and the central star formation rate within $r < 1$ kpc is $SFR \sim 90 M_\odot/\mathrm{yr}$.

3. Integrate the Schechter luminosity function to find the total luminosity density in the Universe:

$$\Phi(L)dL = \Phi^* \left(\frac{L}{L^*}\right)^\alpha e^{-L/L^*} \frac{dL}{L^*}$$

   (a) What is the value of this luminosity density in units of $[L_\odot \ \mathrm{Mpc}^{-3}]$ if we adopt the following values: $\Phi^* = 1.64 \times 10^{-2} h^3 \ \mathrm{Mpc}^{-3}$, $M^* - 5\log(h) = -19.67$ and $\alpha = -1.21$, use $h = 0.7$. Explain also what the physical meaning of Φ^*, M^* and α are.

   (b) Calculate both the baryonic matter density and the total matter density of the Universe for the standard Planck ΛCDM model with $\Omega_{\mathrm{bar}} = 0.049$, $\Omega_{\mathrm{CDM}} = 0.2685$ and $\Omega_\Lambda = 0.6825$ in units of $[M_\odot \ \mathrm{Mpc}^{-3}]$. Finally, calculate the average mass-to-luminosity ratio [M/L] for the Universe for the case where the Universe only consists of baryons and for the case where the Universe consists of both baryons and dark matter.

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4. Download and read the paper: *"A Substantial Population of Massive Quiescent Galaxies at z 4 from ZFOURGE"* by Straatman et al., 2014, ApJL, 783, 14 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) Describe the observations done in this paper. What is the size of their observational sample and what telescope did they use? What are the CDFS, COSMOS and UDS fields and why were the objects selected from these fields?

   (b) Most of their objects have only photometric redshifts, what are photometric redshifts and why are they used for most of the objects? In addition to their own data they use Spitzer/MIPS 24 μm and Herchel/PACS 100 μm and 160 μm data, what is the primary additional information that can be gained from these longer wavelength observations?

   (c) Describe the selection technique for quiescent galaxies. Why does the two-colour criterion work? The authors discuss the Balmer/4000 Å break. What is causing this break and why is a strong Balmer break an indication of an old stellar population and a suppressed level of star formation?

5. (a) Studying the SEDs in Figure 2., how can you tell that these galaxies have old non-starforming stellar populations? How would the SEDs change if the objects would have strong ongoing visible star formation or alternatively have strong dust-obscured star formation? The authors also mention the specific star formation rate, what is meant by this?

   (b) Studying Fig 3., what is the derived number density of quiescent galaxies at $z \sim 4$. Is this in line with what one would expect from lower redshifts? What is the fraction of quiescent galaxies in their sample at $z \sim 4$? Is the fraction expected of surprising?

   (c) Finally, what type of galaxies are the likely progenitors of the observed quiescent population at $z \sim 4$? Are the currently observed UV-luminous galaxies at $z \sim 10$ likely progenitor candidates? If not, why not? The authors argue that the main star formation episode of these galaxies at higher redshifts was dust-obscured. What is the motivation behind this claim?