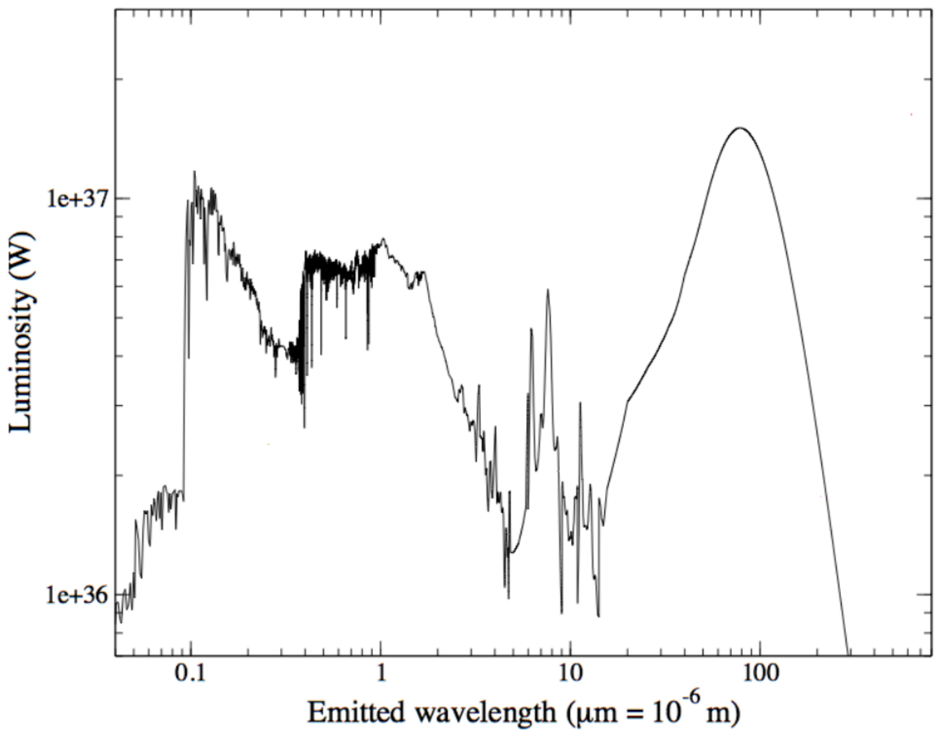
Practice session: Physics of Galaxies

Kapteyn Learning Community Sirius A
Give motivations and/or derivations for your answers.

1. **Conceptual starter questions**

   (a) Explain briefly Hubble's classification for late-type galaxies.
   (b) What does the Closed-Box galaxy evolution model assume?
   (c) In general, what changes in the received light from a galaxy if it contains considerable amount of dust compared to no dust?
   (d) What are all the main components of the Milky Way?
   (e) Explain differential rotation.
   (f) What does the morphology distribution of galaxies look like within a galaxy cluster compared to a more empty region in the Universe?
   (g) How does the spiral structure in a spiral galaxy not disappear due to the rotation?
   (h) Explain the concept of self-propagating star formation.

2. **Spectrum**
   This question will be mainly about the spectrum of a galaxy.



   (a) What are the 4 components of the spectrum and which component of the galaxy contributes to this part of the spectrum

(b) Assume a single stellar population. Which stars dominate the luminosity of a galaxy a few million years, a few 50 million years and a billion years after that single star formation episode?

(c) How will the spectrum of a galaxy change if it were younger, i.e., you look at a galaxy at high redshift ($z > 5$)?

(d) Consider that this galaxy has a collision with an almost identical galaxy and this produces an enormous star formation peak after which star formation is quenched in the galaxy, How does this change the spectrum in the first few million years and how does the spectrum look like after a billion years.

3. **Spherical galaxy**

Consider a spherical galaxy for which the galaxy mass density can be described as:

$$\rho = \rho_0 \exp\left(-\frac{r^2}{2R_{\text{gal}}^2}\right). \tag{1}$$

with $\rho_0 = 20\ \mathrm{M}_\odot/\mathrm{pc}^3$ and $R_{\text{gal}} = 2$ kpc.

(a) What is the total mass of the galaxy? Your answer should be a number. (Use $\int_0^\infty y^2 e^{-y^2} = \frac{\sqrt{\pi}}{4}$)

(b) What is the ratio between the circular velocities of two stars, one at a distance $r_1 = 0.5$ kpc from the centre, and the other at $r_2 = 1.0$ kpc from the centre? (Use $\int\limits_0^b \mathrm{d}y\ y^2 e^{-y^2} = \frac{1}{4}\left(\sqrt{\pi}\mathrm{erf}(b) - 2be^{-b^2}\right)$, $\mathrm{erf}(1/4\sqrt{2}) \approx 0.197$ and $\mathrm{erf}(1/2\sqrt{2}) \approx 0.383$)

(c) The average mass-to-light ratio of the galaxy in the V band is $M/L_V \approx 2.5\ \mathrm{M}_\odot/\mathrm{L}_\odot$. If this galaxy were located at distance of $D = 200$ Mpc, what would its apparent V-band magnitude (m_V) be? Give your answer in AB magnitudes (Use that the absolute V-band magnitude of the sun is 4.862).

(d) Close to this galaxy, there is a galaxy that is 20 arcseconds on the sky, what is the physical size of this galaxy?

4. **Astronomical distances**

This question surrounds astronomical distances and how to interpret different answers.

(a) A galaxy is observed with a redshift of 0.11. At what distance is the galaxy located according to the Hubble law?

(b) The Galaxy has an absolute magnitude of -19.5. what is the expected apparent magnitude

(c) The apparent magnitude of the Galaxy is found to be 1 magnitude higher then expected. Assuming the Absolute magnitude is correct what could be the reason for this error.

(d) Using the magnitudes calculate the actual distance to the galaxy

(e) Calculate the peculiar velocity(velocity that deviates from Hubble law) and the actual redshift due to Hubble expansion.

5. **The Initial Mass Function (IMF)**
The IMF of a galaxy governs the initial distribution of stellar mass among a stellar population, i.e., the number of stars of a particular mass. Consider a stellar population with the Salpeter IMF $1.72 \times 10^4\,(\mathrm{M/M_\odot})^{-2.35}$ and a stellar mass range of $(0.1 - 100)\mathrm{M_\odot}$.

   (a) At the time the stellar population is born, what percentage of stars have masses in the range $(0.1 - 1.0)\mathrm{M_\odot}$?
   (b) What is the total mass of this stellar population?
   (c) What can you say about which stars dominate the total mass, and which stars dominate the total luminosity of this stellar population based on the IMF? (Assume luminosity $L \propto M^{3.5}$)

6. **A Galaxy with no Dark Matter?**
In 2018, a team of astronomers reported their discovery of a galaxy with much less dark matter than the galaxy evolution model predicted (van Dokkum et al. 2018, Nature).

This galaxy, named NGC 1052-DF2, is located close to the elliptical galaxy NGC 1052 ($D = 20$ Mpc from the Sun) in the sky. The shape of NGC 1052-DF2 resembles an ellipse with a semi-major axis (a) of 22.6" and $a/b = 0.85$.

Half of the total light from the galaxy comes from within this ellipse and the mean surface brightness within the ellipse is about 24.7 $\mathrm{mag\,arcsec^{-2}}$.

   (a) Calculate the total apparent magnitude of this galaxy.
   (b) The team suggested the galaxy is a companion of NGC 1052. Determine the total mass of stars in NGC 1052-DF2, assuming it has a mass to light ratio ($\frac{M/M_\odot}{L/L_\odot}$) of 2.0.
   (c) The team identified 10 globular clusters in NGC 1052-DF2 with a mean galactocentric distance of 78.4". They also measured the velocity dispersion of these clusters to be not more than 8.4 km/s. Estimate the dynamical mass of this galaxy. For simplicity, assume the mass distribution in the galaxies is uniform and is spherically symmetric.
   (d) This discovery was challenged by other groups (Kroupa et al., Nature, 2018, Truijlo et al., MNRAS, 2018), who claimed that NGC 1052-DF2 is not a satellite of NGC 1052, and it is located at a much smaller distance to us. Show why a smaller distance would weaken the assertion of the dark matter deficiency in NGC 1052-DF2.

7. **Kinematic classes of early-type galaxies**
Two early-type galaxies are observed with an integral-field spectrograph, yielding the following measurements:

	Galaxy C	Galaxy D
Rotation velocity V	140 $\mathrm{km\,s^{-1}}$	35 $\mathrm{km\,s^{-1}}$
Velocity dispersion σ	110 $\mathrm{km\,s^{-1}}$	260 $\mathrm{km\,s^{-1}}$
Ellipticity ε	0.32	0.06

   (a) Using the proxy for the λ_R estimator,

$$\lambda_R \approx \frac{V}{\sqrt{V^2 + \sigma^2}},$$

classify each galaxy as a fast or slow rotator, given that the dividing line is $\lambda_R = 0.1$.

(b) Galaxy C is significantly flattened, while Galaxy D is nearly round. Explain qualitatively why this is consistent with their kinematic classification.

(c) Which of the two galaxies is more likely to have formed through repeated dry mergers? Briefly justify your answer.

(d) Fast rotators are often described as being more "disk-like" than slow rotators. Explain what is meant by this statement in terms of the balance between ordered motion and random motion.