ZAH - Astronomisches Rechen-Institut
Galactic and Extragalactic Astronomy (MVAstro3) - Winter semester 2021
Hitesh Lala `Hitesh.Lala@uni-heidelberg.de`

Exercise Sheet #1

Submit by Tuesday 23-03-2021

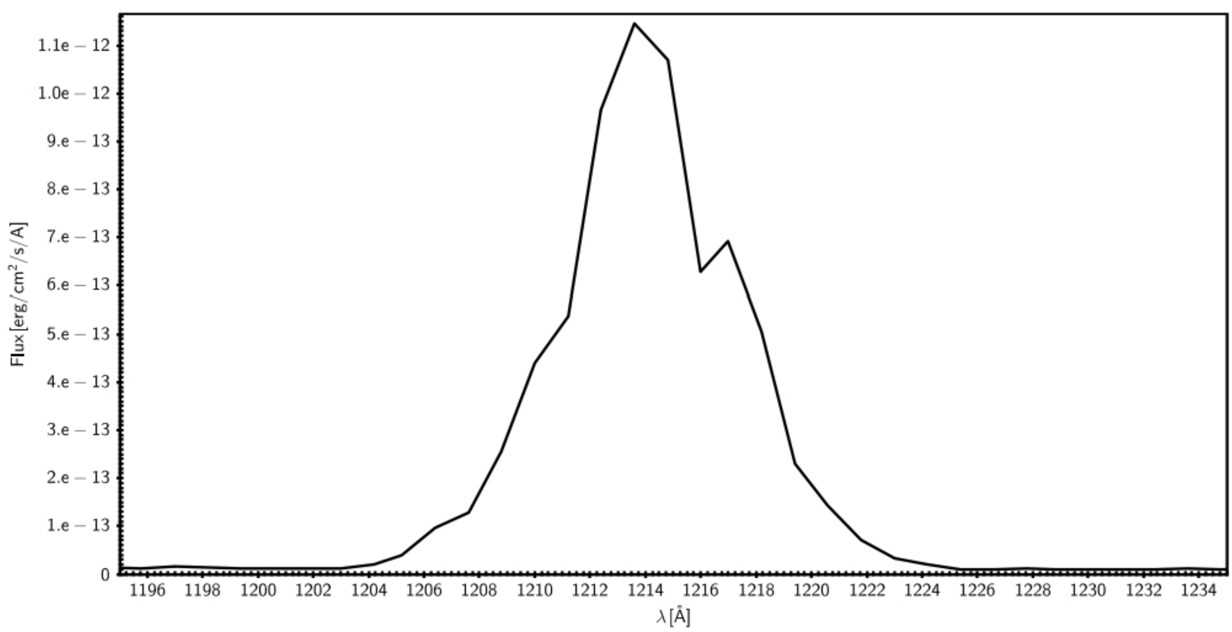

Figure 1: Integrated spectrum of Andromeda in the range 1195 − 1235 Å taken from the NASA/IPAC Extragalactic Database (Kinney et al. 1993, `https://ned.ipac.caltech.edu/`)

Exercise 1. According to the Hubble law $v = H_0 D$, the expansion of the Universe causes distant objects to move away from our rest-frame faster than objects in the vicinity of our Local Group of galaxies. The Fig. 1 displays the UV part of Andromeda's spectrum, where the most prominent emission line represents the Lyman-α transition.

(a) Determine the redshift of the Andromeda galaxy and its radial velocity with respect to an observer on Earth. (10 points)

(b) Andromeda lies roughly at a distance of 780 kpc from the Milky Way. Derive its expected radial velocity using the Hubble law and assuming a Hubble constant $H_0 = 71\,\mathrm{km/s/Mpc}$. Are expectations and measurements consistent with one another? Comment, briefly, on your results. (10 points)

(c) Let's now assume that we observe the spectrum of a distant galaxy which shows a redshift of $z = 0.05$. Calculate its radial velocity and distance from the Milky Way. (10 points)

Exercise 2. During the first seconds of the Universe the conditions for the existence of baryonic matter, and thus life, were set. As the temperature, and thus the energy of the photons ($E \sim k_\mathrm{b} T$), dropped with the expansion of the Universe ($(T/K) \sim 1.5 \cdot 10^{10} \cdot (t/s)^{-1/2}$ * during the radiation dominated era), reactions needing a high amount of energy could no longer take place.

*This is a convention followed by many astrophysics texts. (T/K) stands for Temperature in kelvins; similarly, (t/s) stands for Time in seconds.

(a) Consider the electron-positron pair production $\gamma + \gamma \rightarrow e^- + e^+$. At which temperature will this reaction freeze out and why?, thus leading to the progressive annihilation of the e^- and e^+. (10 points)

After the matter anti-matter annihilation, at $t \sim 1\,\mathrm{s}$ the baryons left in the Universe started reacting to form heavier nuclei.

(b) What is the ratio between photons and baryons at this time? Calculate the temperature and energy of the photons. (HINT: Lecture-1) (10 points)

(c) Deuterons were the first isotopes to be produced through the very efficient reaction $p + n \rightleftharpoons D + \gamma$. Calculate which energy is needed to photo-disintegrate deuteron. What is the frequency of these photons capable of disintegrating the deuterons? How can you explain that deuterons are present in such small amount in the Universe? (10 points)

Uploading solutions

1. Create a GitHub account if you don't have one already (Free account or Student account with Pro benefits).
2. Send me your GitHub usernames (You will set your username while setting up your account).
3. I will send you a link with which you will be added to a GitHub Classroom.
4. You have to accept assignments using the links posted on the Classroom's discussion portal.
5. There will be 3 assignments in total - 4 exercises sheets each in the first two and 3 in the last one.
6. When you 'accept' an assignment, a new repository will be created for you on your GitHub account. Only you and I will be able to access the files you add to that repository.
7. Upload your scanned solutions as PDF to this newly-created repository on the day of submission by 12:30 pm.
8. The PDF filename should be in the format YourName_Exercise_Numbers.pdf (For example: JohnDoe_Exercise_01to04.pdf).
9. You can either upload one solution PDF per exercise sheet or one combined PDF per assignment.
10. If you are stuck, plenty of GitHub tutorials are available online. Please contact me if none of them solve your problem.
11. It is recommended to work in pairs to solve the exercise sheets.
    If you choose to do so, add both partners' names to your uploaded solutions. (For example: MyName_PartnerName_Exercise_01.pdf OR MyName_PartnerName_Exercise_05to08.pdf).
    It is fine if only one of the partners upload their solutions.