Physics 224: Homework 2
Spring 2018

The Orion Nebula is the closest H II region that we can study in detail. In this homework assignment you will measure some of its properties using observations of optical line emission. Please answer the following questions and provide any relevant literature citations and plots to illustrate the process by which you answered them.

1. Do some research and figure out which star or stars are responsible for ionizing gas in the Orion Nebula. What are the spectral types of the star or stars in question? What is their ionizing photon production rate? Cite any literature sources you use.

2. Estimate the size of the Stromgren sphere for the Orion Nebula using the ionizing photon rates you have found. Make a plot of the predicted Stromgren radius for a range of different gas densities. Discuss the following: 1) Do you need to consider multiple sources of ionizing photons? 2) How would the spatial arrangement of multiple ionizing sources affect your assessment of the predicted Stromgren radius?

3. Measure the radius of the Orion Nebula using an Hα image of the region. There are multiple ways you could do this. Orion is also not spherical, which makes defining a radius more challenging. Whichever way you choose, document the steps you took, provide any relevant figures and give an estimate of your uncertainty on the measured value. Aside from the definition of a radius for a non-spherical region, what are the other main uncertainties that affect your measurement of the size of Orion? (One simple technique for measuring the size is to use the `ds9`[1] program to load an image of Orion and create a circular region that covers the approximate size of the nebula. `ds9` will tell you the radius of the region in arcsec, which you can then convert to pc using the distance to the Orion Nebula. An Hα image of the nebula is linked on the website.)

4. Compare your measured size to the predictions from your Stromgren sphere estimate. What density would you need to make the radius of the Orion Nebula agree with the Stromgren sphere prediction? Use the uncertainty you estimate on the region size to give a range of densities where Orion's size would be comparable to the Stromgren radius.

5. On the class website you can download a representative spectrum of the Orion Nebula from a recent observation with the MUSE instrument on the Very Large Telescope[2] (Weilbacher et al. 2015 A&A 528, A114). I recommend taking a bit of time to marvel at this spectrum - it is beautiful!

   (a) Identify a ratio of two lines in the spectral coverage of the MUSE observation that traces the density of the gas. Write a brief explanation of why this line ratio traces density.

[1] `http://ds9.si.edu/site/Home.html`
[2] `http://muse-vlt.eu/science/m42/`

(b) Measure the line ratio in the spectrum. (Note: first you'll need to measure the integrated intensity of the relevant lines. You can do this however you see fit. It is acceptable to do a by-eye fit if you are unfamiliar with the tools in python/IDL/matlab to fit Gaussians. You can also measure the peak of the spectrum and the width of the line and approximate it by a triangle to get an integrated area under the line.) Whichever technique you use, provide an assessment of the uncertainty in your measured line ratio. Note: if you are an astro student, it is worth spending some time to make sure you have a Gaussian fitting tool - this comes up a lot.

(c) Plot the theoretical values of the line ratio you have chosen as a function of density. Overplot your measured line ratio. What is the electron density you infer from the line ratio? Provide an assessment of the uncertainty on the electron density.

(d) *Extra Credit* Find some other nebular diagnostic ratios that are within the spectral coverage. Measure other properties of Orion from those line ratios (e.g. electron temperature).

6. Compare the measured electron density to what you predicted Orion would need to have to match the Stromgren sphere radius. Do the densities agree? Describe some of the reasons why Orion might not match the predicted Stromgren sphere radius (there are plenty).