Small-Scale Physical Properties of Nebulae in Nearby Disk Galaxies

Abstract

My research project consists of analyzing small-scale physical properties of star-forming regions (HII regions) in several nearby disk galaxies. The main objective is to better understand the massive star formation and chemical enrichment processes in spirals. Using already collected data from the innovative imaging spectrograph SITELLE, recently commissioned at the Canada-France-Hawaii Telescope, I will be able to evaluate physical nebular properties such as dust extinction, electronic density, ionization parameter, star formation rate, oxygen abundance, and gas kinematics. I am focusing on some large region "complexes" and, using different calibration and modeling methods, I am investigating whether variations on these properties occur on different spatial scales. This information will be very useful to build reliable models describing HII regions in galaxies as well as for our understanding of chemical evolution of spiral galaxies.

Research Background

Understanding large-scale star formation and chemical enrichment mechanisms of the interstellar medium is the foundation of galaxy evolution studies and in establishing better models for the formation of planetary systems[1]. We can study star formation in other galaxies by examining regions known as "HII regions". These regions are locations in a galaxy disk where hydrogen has been ionized by UV photons that were emitted from massive stars, formed from this gas[2]. As a consequence, the interstellar medium surrounding these new, hot massive stars has a temperature of 8-10,000K and contains mostly ionized hydrogen and free electrons. When these free electrons recombine with ionized hydrogen atoms, the traditional Balmer emission lines for hydrogen are formed in the visible spectrum (e.g. the Hα line at 6563Å is responsible for the typical red color of nebulae; see figure 1).

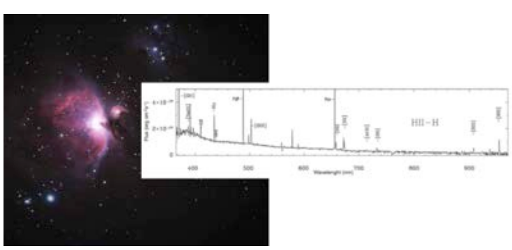


Figure 1. (Left) Image of the Orion Nebula (UHH). (Right) Typical emission spectrum from an HII region.

Other chemical elements are also found within the interstellar medium. These elements like oxygen, nitrogen and sulfur came from previous generations of evolved stars, which released them in the interstellar medium at the end of their lives. As a result, studying these elements provides critical information on the chemical enrichment processes taking place in galaxies, which in return depend on several factors like the rate of star formation and mixing mechanisms. We can study these elements through their spectral emission lines. Frequent collisions between the free electrons and electrons at different energy levels in these elements cause them to spike in energy, then release radiation when transitioning back down. Some of these transitions are not possible in terrestrial laboratories because there is not enough time for the electron to come back down in energy. In other words, the time for natural de-excitation of the electron from a higher to a lower energy level is longer than the time for a new collision to occur. But in nebulae the electronic density is low enough to allow enough time for the electrons to make the transitions. They can create "forbidden lines", such as for oxygen, nitrogen and sulfur (see figure 1). The strength of these "forbidden" emission lines depends on several factors, for instance the nebular temperature, the electronic density, the flux of hard-UV photons, the presence of shocks, the age of the nebulae and the abundances of the chemical elements in question[2]. Therefore, the study of these emission lines allows us to determine many physical properties of HII regions, and by consequence, to obtain clues on the evolution of galaxies themselves.

The project I worked on is part of a larger observing program called SIGNALS (Star formation, Ionized Gas, and Nebular Abundances Legacy survey with SITELLE). The general goal is to better establish the formation processes of massive stars in nearby galaxies, through an unprecedented detailed study of their HII regions. To achieve this, the SIGNALS team is using a new innovative instrument called SITELLE installed at the 3.6 meter Canada-France-Hawaii Telescope[3]. SITELLE is an optical imaging Fourier transform spectrometer designed to observe between wavelengths of 3600Å and 9000Å. The instrument is designed in such a way as to observe within different spectral bands, as opposed to viewing the entire spectrum as a whole. SITELLE data comes in the form of datacubes. These datacubes are comprised of a series of two-dimensional images, each taken at a specific wavelength that represents a step in motion of the movable mirror in the interferometer. As a result, a single datacube on one galaxy produces one spectrum for every pixel in the image, that is, 4 million spectra all at once for one galaxy. Other advantages of SITELLE includes its large field-of-view (11'' x 11''), 100 times larger than other integral field spectrographs, an adjustable spectral resolution, an excellent spatial resolution and very high contrast. For this project, I used three specific SITELLE wavelength bands that include the main nebular lines [OII]λ3727, [OIII]λλ4959,5007, Hα, Hβ, [NII]λλ6548,6584, S[II]λλ 6717,6731, and many more.

Progress

During Fall 2016, I was able to complete various crucial steps to begin the analysis of the spiral galaxy NGC 628 for my Senior Lab Thesis project. I read several research papers about extragalactic HII regions and similar research to what I am conducting. I learned how emission lines can be used to derive element abundances and structural properties of these HII regions. Next, I was given a computer running Linux Ubuntu, where I installed Python and numerous astronomy and data handling packages for the analysis. I was then transferred reduced data for NGC 628, as well as various Python scripts already written to do analysis on these data. I worked with a graduate student from Universite Laval (Quebec) who developed this code and she described to me how to use it. Once I became familiar with the software, my mentor and I chose 20 interesting large HII region complexes in NGC 628 that we wanted to analyze further. These complexes include several HII regions each and are distributed all across the disk of the galaxy. I used SAO DS9 to view these regions using the Hα line. I used the selection tool to highlight these 20 regions and recorded the right ascension and declination coordinates for the four corners of the boxes to get the low and high values for x and y.

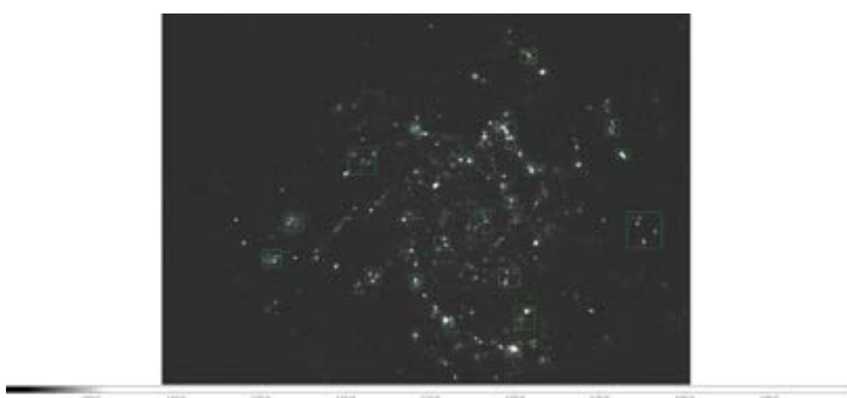
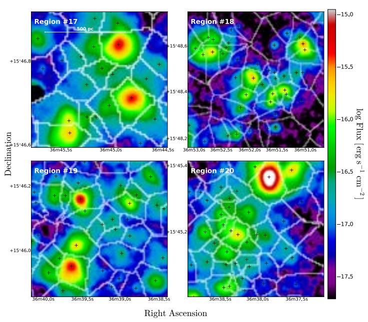


Figure 2. (Above) This map shows the 20 HII region complexes chosen for this project. Complexes were chosen from close to the central bulge to the outer reaches of the spiral arms with a variety of sizes.

Then, I used the provided Python programs to graph various properties of the 20 HII complexes I started with a plot of the Hα emission. The peaks in these graphs will tell us where there are stars forming. To confirm this, we must use other properties of various flux emission line ratios. So far, we have plotted and looked at the following line ratios: Hα/Hβ, ([OII]λ3727+[OIII]λλ4959,5007)/Hβ, S[II]λ6731/S[II]λ6717, [NII]λλ6548,6584/Hα, [OII]λ3727/[NII]λλ6548,6584, [OIII]λλ4959,5007/[NII]λλ6548,6584, and finally S[II]λλ6717,6731/[NII]λλ6548,6584. I also used the programs to plot the velocity maps to see gas motions gas within each complex. Using the coordinates from DS9 I found earlier, I inputted them into each programs code to plot four regions at a time (see figures below).



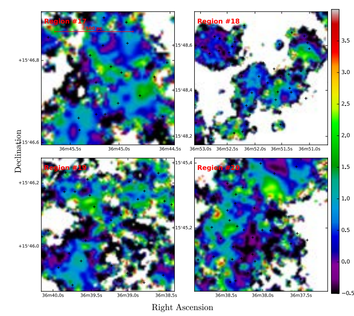
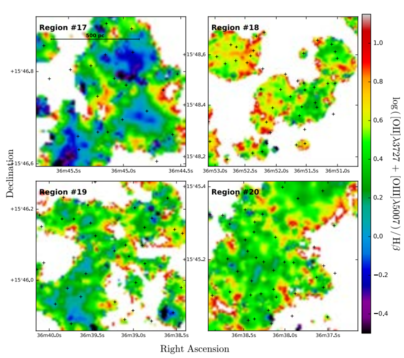


Figure 3. (Left) This plot shows Hα emission peaks in four of our twenty selected HII region complexes. Figure 4. (Right) This plot shows our Hα/Hβ flux emission line ratio. This ratio can help us to examine the property of dust extinction in our regions. We can see pixel to pixel variations within the regions due to the incredible quality of SITELLE.



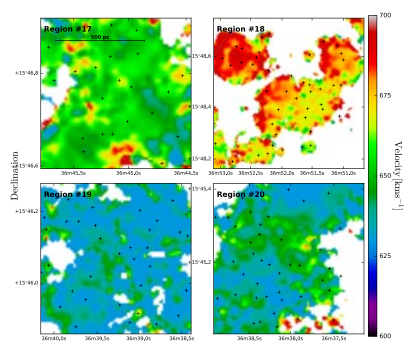


Figure 5. (Left) This plot shows the ([OII]λ3727+[OIII]λ5009)/Hβ line ratio to give us insight into oxygen abundances within our complexes. Although, many other line ratios we evaluated can also give us insight into oxygen abundance. Figure 5. (Right) This plot shows us the velocities of the gases within our complexes. These graphs are important to seeing how the gases are mixing in each region complex within the galaxy.

There are steps I did not have time to accomplish in my first semester. Initially, I had planned to analyze three galaxies when I actually only had time for one. This was due to the fact that it took a while to receive the programs and learn how they worked. Also, data reduction was still being done on the other two galaxies, which prevented me from receiving the data. In addition, there is more analysis to be done on NGC 628 with statistical analysis and modeling. My last goal was to start on an interpretation and draft paper for our initial findings. Since other tasks took long to complete, I was not able to start on a draft paper.

References

[1]Sanchez et al., 2014, A&A, 563, 49; [2]Osterbrock, D. 1989, *Astrop. Of Gaseous Nebulae and AGNs*;
[3]Drissen et al., 2014, Ad. Astronomy, 9