NGC 6946: HII Regions and Star Formation

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Abstract

We study NGC 6946, a face-on spiral galaxy located at a distance of 5.5 Mpc using the neutral atomic Hydrogen (HI) and ionized atomic Hydrogen (HII) content, two key components in the Interstellar Medium (ISM). Our project focuses on characterizing the star forming rate and the star formation efficiency in the HII regions of NGC 6946 using various emission lines. We present these results as functions of the galactocentric radius of NGC 6946 and discuss the implications of their trends. InAstroL8 addition we investigate two different methods to estimate the metallicity content of the HII regions using the [OIII]λ5007 and [NII]λ6583 emission lines and another relation using the [NII]λ6583 and Hα lines. Using the two methods we confirm their consistency and present their trends as a function of the galactocentric radius. This project uses data from the SITELLE instrument at the Canada-France-Hawaii Telescope, which covers Hα and Hβ emission, along with ancillary data of HI and CO emission.

NGC 6946

Our data is taken from observations obtained at the Canada-France-Hawaii Telescope (CFHT) which is operated from the summit of Maunakea by the National Research Council of Canada, the Institut National des Sciences de l'Univers of the Centre National de la Recherche Scientifique of France, and the University of Hawaii. We are grateful to the Hawaiian people to be aloud to use this site to extend our knowledge of the Universe and Imiloa (in Hawaiian for Seek Far)", SITELLE, is a joint project between Université Laval, ABB-Bomem, Université de Montréal and the CFHT.

We use three filters of the SITELLE instrument to conduct our research, and list the relevant emission lines used below.

Filter	Filter Coverage (nm)	Line	Emission (Å)
SN1	365-385	OII	3727
SN2	480-520	Hβ	
		OIII	4959,5007
SN3	651-685	Hα	
		NII	6548,6583
		SII	6716,6731

Table 1. SITELLE filters and wavelength coverage.

NGC 6946 is an actively studied galaxy with abundant HII regions, making it an excellent candidate to study.

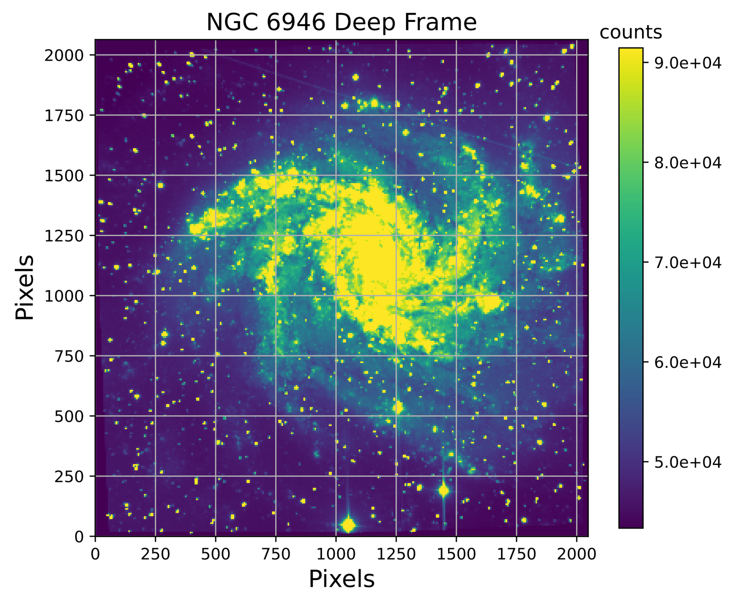

Figure 1. SN3 filter depiction of NGC 6946 taken with the SITELLE instrument.

Dust Extinction Correction

Correcting for dust reddening the emission lines is done through the Balmer correction, using the Hα and Hβ emission lines and taking their ratio [3].

$$\text{E(B-V)} = \frac{2.5}{1.07}\log_{10}\left(\frac{H\alpha/H\beta}{2.87}\right) \quad (1)$$

The corrected emission lines are calculated using this E(B-V) parameter and the dust_extinction library in Python.

$$\text{Corrected Line} = \frac{\text{Line}}{\text{Ext. amount(Wavelength, E(B-V))}} \quad (2)$$

The amount dust extinction can be inspected as a function of the galactocentric radius of NGC 6946 to show its trend.

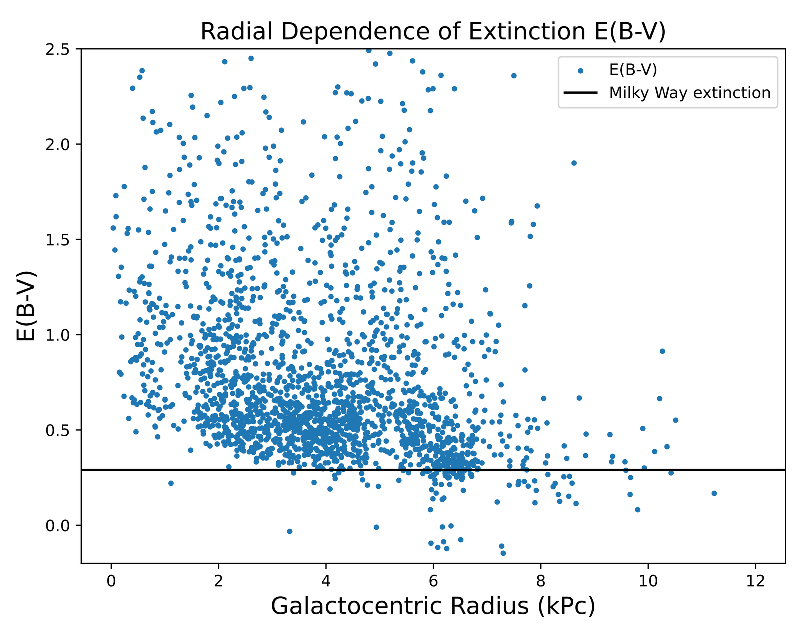

Figure 2. We expect a general downtrend of the extinction correction as we move to the outer regions of NGC 6946. This is due to the dust and gas content being more concentrated at the center of the galaxy, rather than the outskirts.

Components of the Interstellar Medium

The Interstellar Medium (ISM) is composed of vast regions of different gas, ionic species, and astronomical bodies. Two major components of the ISM are HI and HII regions; regions where there is abundant neutral atomic hydrogen and weakly ionized atomic species or ionized atomic Hydrogen respectively [4]. We focus on HII regions, which are linked to regions of recent massive star formation, ionized by the photons from hot O and B-type stars with energies above 13.6 eV. We trace the HII regions in NGC 6946 in order to determine where the regions of recent star formation have occurred and look at the content of various emission lines to determine properties of the region such as: Star Formation Rate (SFR), Star Formation Efficiency (SFE), and Metallicity content.

Dust is prevalent throughout the ISM, and can have the effect of reddening an observed spectra. Outgoing photons leaving stars can interact through absorption or scattering off the particles, and can even change the radiation of the environment if it is dusty enough.

Star Formation Rate

We use the luminosity of the Hα emission line, written $L(\text{H}\alpha$, to quantify the SFR of NGC 6946 [1]. This is calculated for each of the HII regions using:

$$\text{SFR} = \frac{L(\text{H}\alpha)}{1.12\times10^{41}\text{ergs s}^{-1}} M_{\odot}\text{yr}^{-1} \quad (3)$$

This takes into account the total SFR from all masses of stars from $0.1 \leq m \leq 100M_{\odot}$, and places a lower limit on the SFR. Luminosity of the Hα line in NGC 6946 is the total flux coming from each pixel across the field of observation, written as:

$$L(H\alpha) = 4\pi(1.711\times10^{25})^2 \times (\text{Corrected H}\alpha\text{ Line}) \quad (4)$$

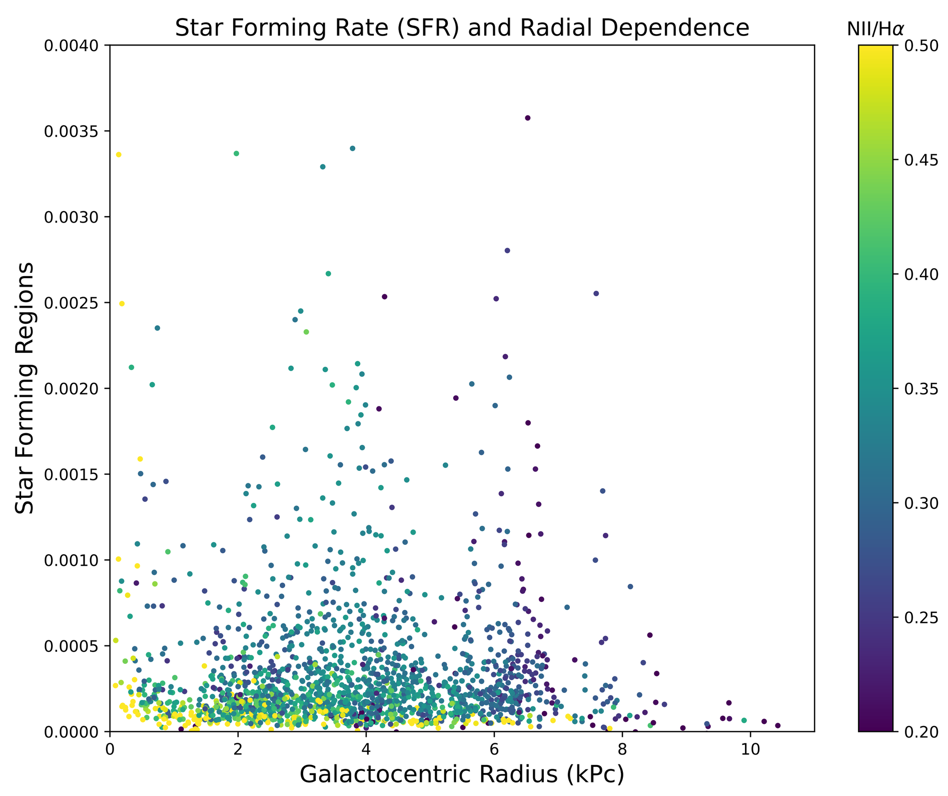

Figure 3. The SFR of HII regions in NGC 6946 as a function of the galactocentric radius in kpc. We notice trends in the SFR distributed throughout the galaxy, likely corresponding to spiral arms in the galaxy. The colorbar for this plot represents metallicity calculated through the NII and Hα emission lines normalized between 0.2-0.5. Yellower points correspond to regions that have a higher metallicity, and purpler corresponding to lower.

Star Formation Efficiency

The SFE is defined as the SFR surface density, measured using the Hα emission from HII regions, per unit neutral gas (HI) surface density over the same aperture. This is related to the SFR [2] by:

$$\text{SFE} = \frac{\Sigma_{\text{SFR}}}{\Sigma_{\text{HI}}} \quad (5)$$

In general, SFE is the inverse of the gas depletion time, which is the time required for the current star formation to use the entire gas reservoir. Therefore we would expect the SFR, and in turn the SFE to decrease with galactocentric radius as the amount of available HI gas depletes.

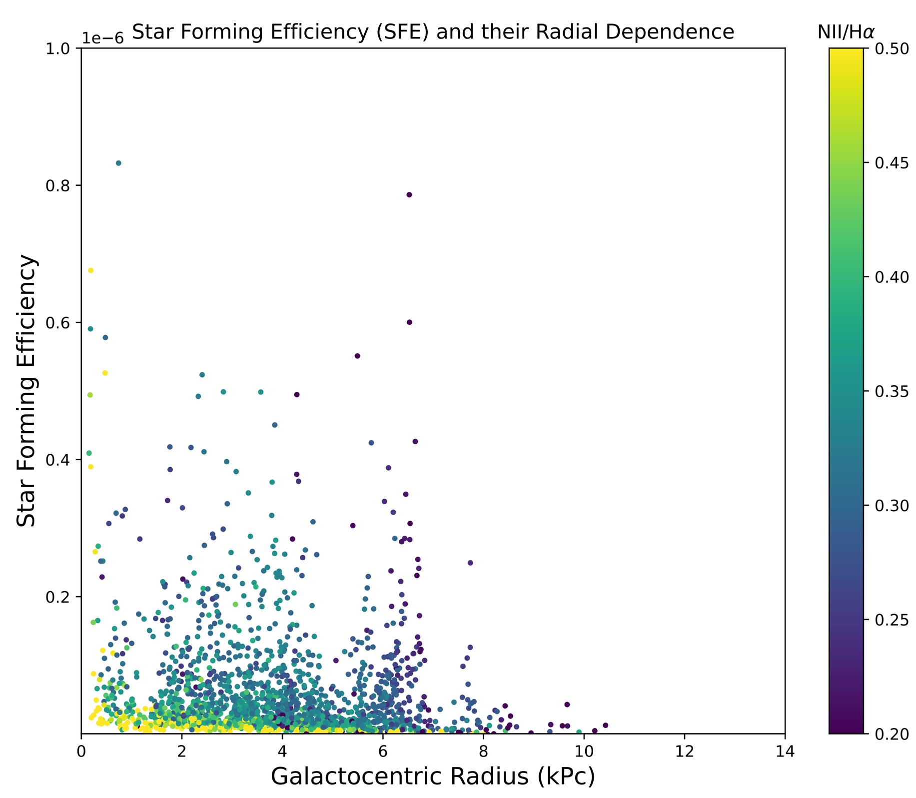

Figure 4. The SFE of HII regions in NGC 6946 as a function of the galactocentric radius in kpc. We observe some trends in the SFE corresponding to the SFR, increases in efficiency occurring at the spiral arms due to abundant HI gas. The colorbar for this plot represents metallicity calculated through the NII and Hα emission lines normalized between 0.2-0.5. Yellow to green points correspond to regions that have a higher metallicity, and purpler corresponding to lower.

Metallicity

The result of star formation and evolution produces elements heavier than He, typically referred to as metals. The ISM and surroundings areas can become enriched by metals from processes such as stellar nucleosynthesis and affect the star formation and gas observed. Metallicity in star forming regions can be used as an indicator of evolution history of galaxies and can tell the story of its star-formation history.

We use two methods to estimate the metallic population using a series of emission lines. The first relation we use to calculate metallicity are the [OIII]λ5007 and [NII]λ6583 emission lines.

$$12 + \log[\text{O/H}] = 8.73 - 0.32\text{O3N2} \quad (6)$$

Where,

$$\text{O3N2} = \log\left(\frac{[\text{OIII}]\lambda5007}{[\text{NII}]\lambda6583}\right) \quad (7)$$

We can compare the method for quantifying metallicity using another relation between the [NII]λ6583 and Hα lines.

$$12 + \log[\text{O/H}] = \frac{F([\text{NII}]\lambda6583}{F(\text{H}\alpha)} \quad (8)$$

Where F represents the flux of the line.

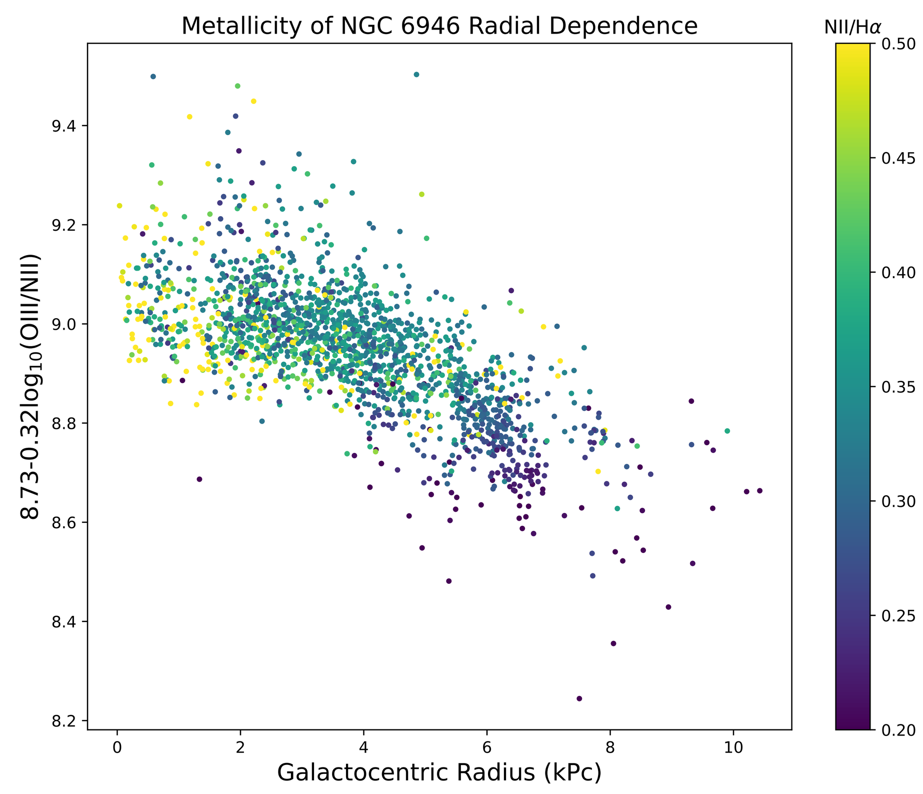

Figure 5. The two different methods of calculating the metallicity using Equations 7 and 8 for the HII regions in NGC 6946. Equation 7 confirms the expected downward trend in metallicity content moving radially outward from the center of the galaxy. The colorbar here is consistent with Figures 3 and 4, representing the second method we use to calculate the metallicity using Equation 8. The colorbar is normalized between 0.2-0.5. Note that these values for normalization were chosen to best depict the trend in the data for clarity. Yellow to green points correspond to regions that have a higher metallicity, and purpler corresponding to lower.

Conclusions

Dust Extinction using Balmer Decriment

In practice, the most reliable technique to estimate interstellar extinction is to measure the flux ratio of two nebular Balmer emission lines such as Hα and Hβ (Equation 1). We expect that the majority of the dust causing the reddening of observed emission lines to be concentrated at the center of NGC 6946, and this is confirmed in Figure 2. Slight densities in the amount of extinction can be attributed to spiral arms and dust lanes in the galaxy.

Trends in SFR and SFE

We present results for the SFR and SFE for NGC 6946 as a function of the galactocentric in kPc in Figures 3 and 4. NGC 6946 is a large spiral galaxy, and we can expect an increase in the SFR and SFE within the spiral arms where there is more freely available HI gas to convert into stars.

Consistency between methods of estimating metallicity

We chose two methods to estimate the metallicity of the HII regions of NGC 6946. Equations 7 and 8 serve as a consistency check between one another to ensure that we do not get wildly different answers for the same quantity. This agreement is shown in Figure 5, and neatly displays the decrease in metal content in the HII regions moving radially outward from the center of the galaxy.

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