

INTRODUCTION

In gas rich galaxies, the emission lines from ionized nebulae are used to determine chemical abundances or to identify and characterize processes (e.g. shocks) in the ISM. A good example of this is the emission from HII regions which are major data providers for research of galaxy chemical evolution and abundance. However, there are large uncertainties in abundance determination due to our incomplete understanding of nebulae physics.

HII regions are far from being simple objects. Parts of these nebulae are photodissociation regions where resides the interface with the parent molecular cloud and its complex chemistry. There are pressure differences, gas flows, stellar winds and jets, which lead to complex kinematics, turbulence obviously develops. Microphysics is misunderstood. The ionic abundances obtained from collisionally excited lines are 1.3 to 2.8 times smaller than those derived from the optical recombination lines for HII regions. This is the basis of the abundance discrepancy problem (ADP), a 80 years old problem.

Since we believe the solution lies in the connection between kinematics and microphysics, our goal is to drastically reduce the number of unknowns through a detailed and systematic study of Galactic ionized nebulae that only tridimensionnal wide-field spectroscopy can provide. We plan on analyzing and correlating complete bidimensionnal maps of all the diagnostic capabilities provided by the visible spectral domain (electronic temperature and density, abundance, dust scattering and kinematics) of a nebula using Monte-Carlo analysis to obtain those maps. The extent of this type of analysis has never been done before for an HII region even with MUSE, the integral-field spectrograph at the VLT.

METHODOLOGY

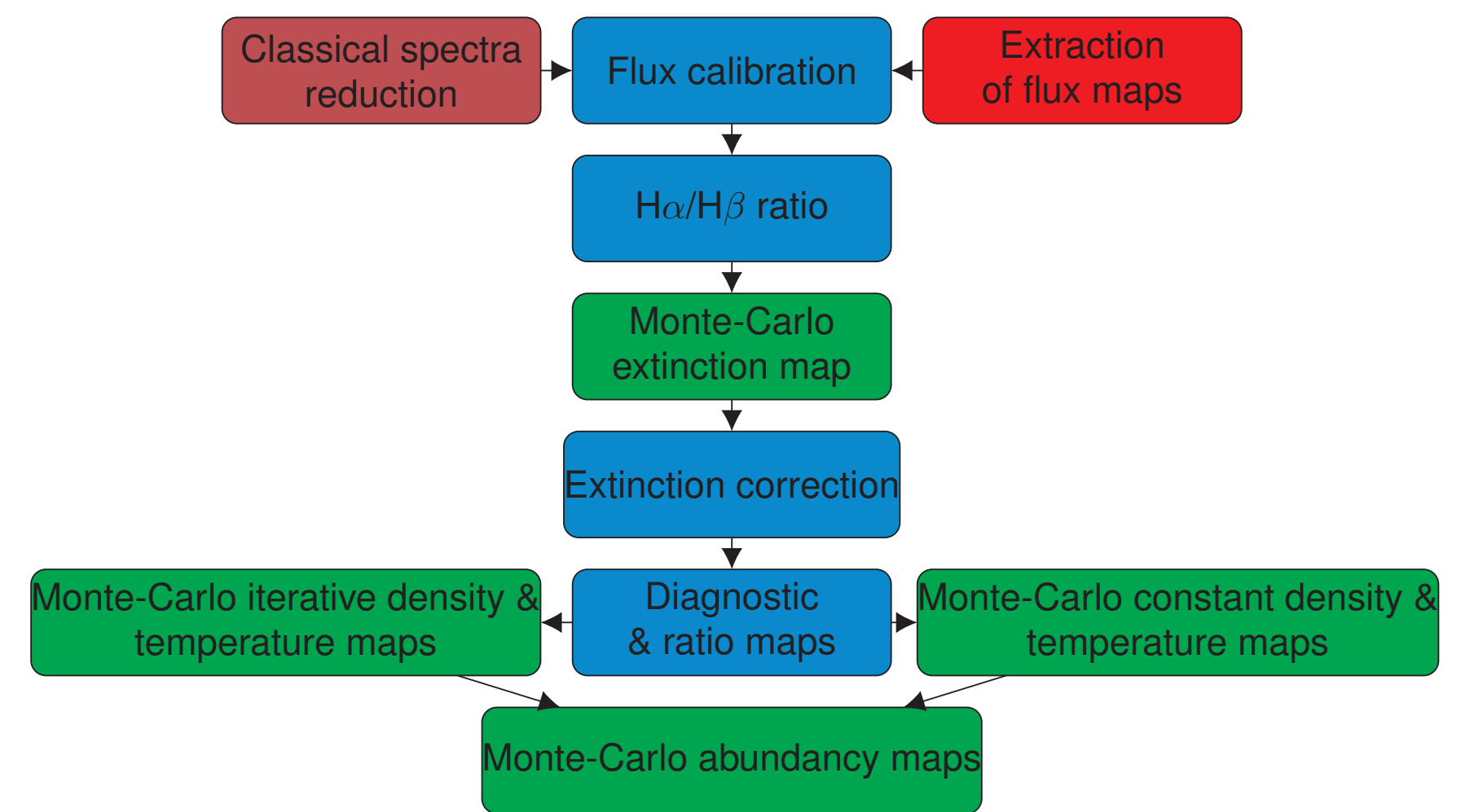


Figure 1: The box color indicates the program used for the reduction and analysis: red for ORCS (Outil de Réduction de Cubes Spectraux), purple for IRAF, blue for Python and green for PyNeb. There were flux calibration issues from one cube to another. Spectra were acquired to verify and recalibrate the flux maps. The density is dependent of the temperature and vice versa. A iterative process is necessary to obtain both maps at the same time. PyNeb does not gives error on the extinction, density, temperature and abundance parameters and thus a Monte-Carlo Analysis is required.

DENSITY AND TEMPERATURE

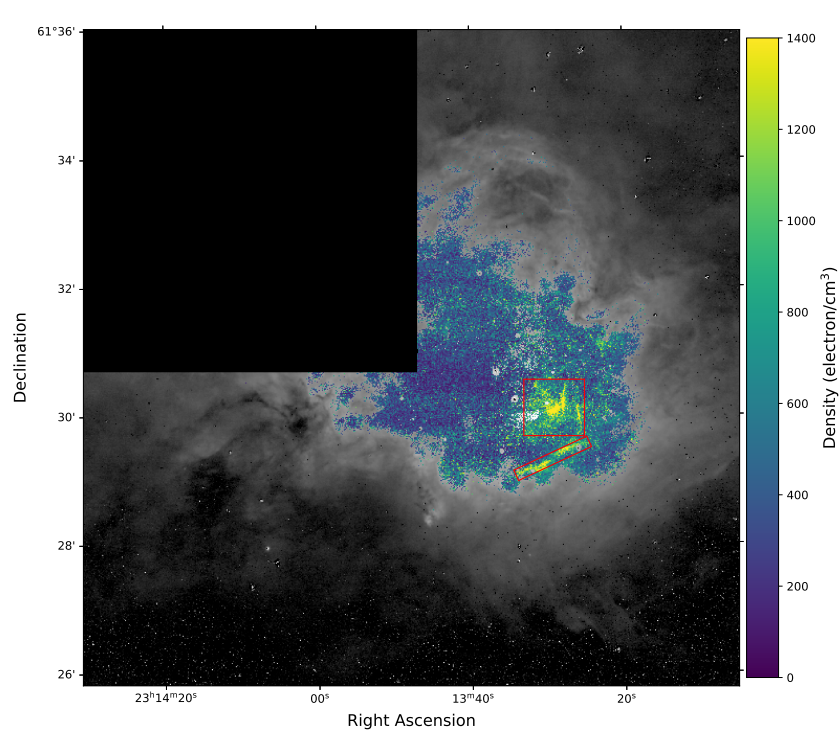


Figure 2: Constant density map obtained from 100 Monte-Carlo iterations. Red squares indicate regions of high densities and low temperatures.

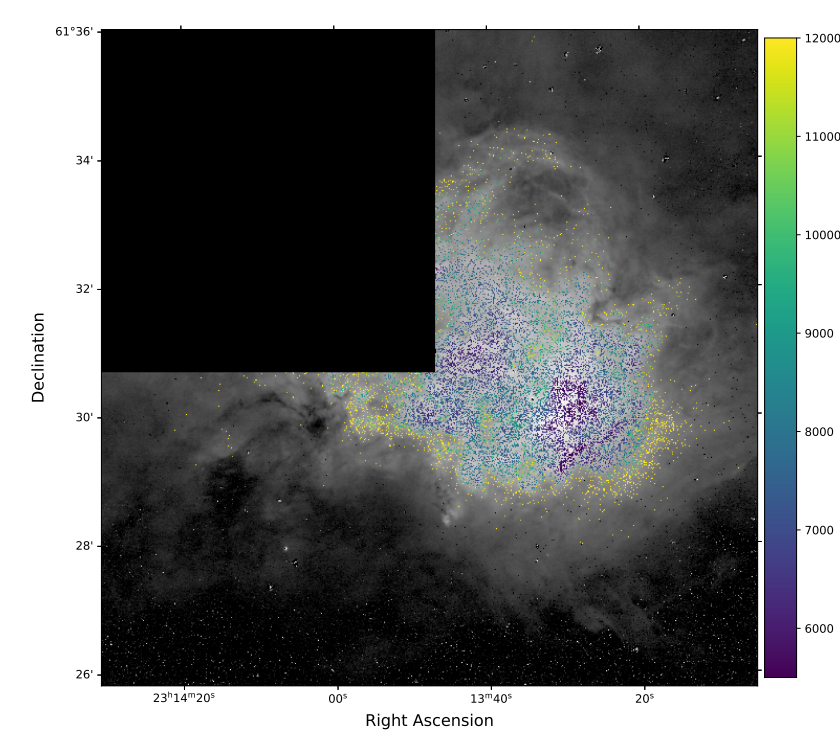


Figure 3: Constant temperature map obtained from 100 Monte-Carlo iterations. Pixelization comes from quality of the 5755 Å line.

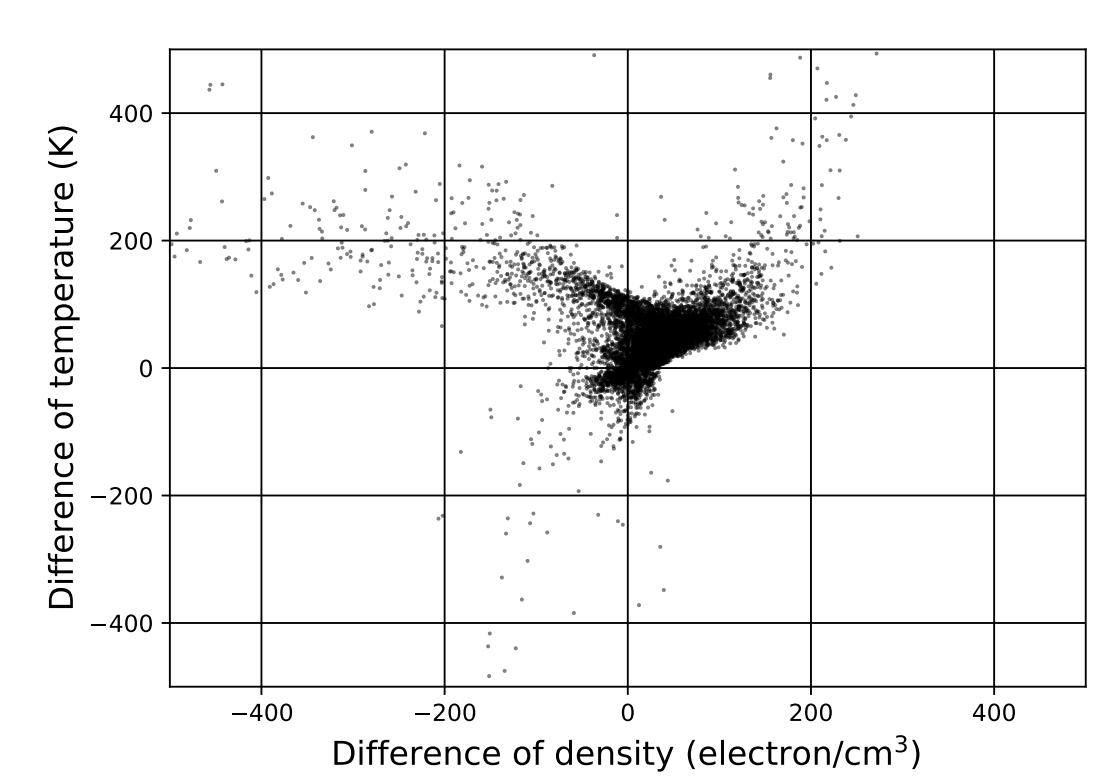


Figure 4: Differences between the calculated physical parameters by both iterative and constant methods.

DIAGNOSTICS AND ABUNDANCES

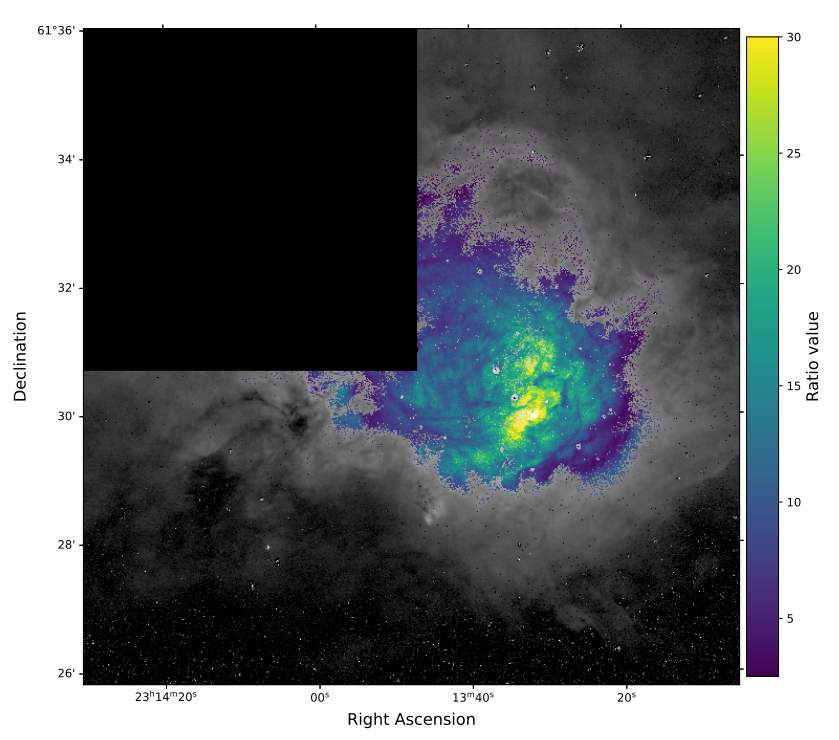


Figure 5: Map of the $H\alpha/[SII] \lambda\lambda 6716+6731$ line ratio. Background image $H\alpha$ emission.

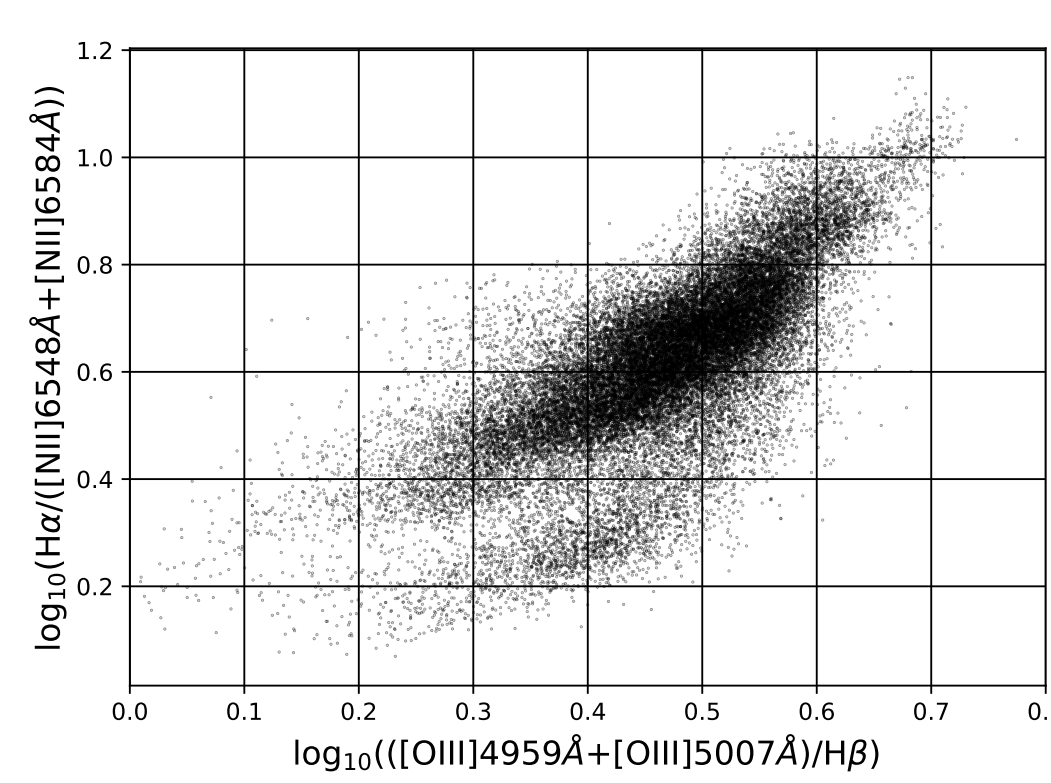


Figure 6: Diagnostic diagram of the $([OIII]4959\text{Å}+[OIII]5007\text{Å})/H\beta$ map versus the $H\alpha/([NII]6548\text{Å}+[NII]6584\text{Å})$ map. The separated cloud comes from both red regions shown in Figure 2

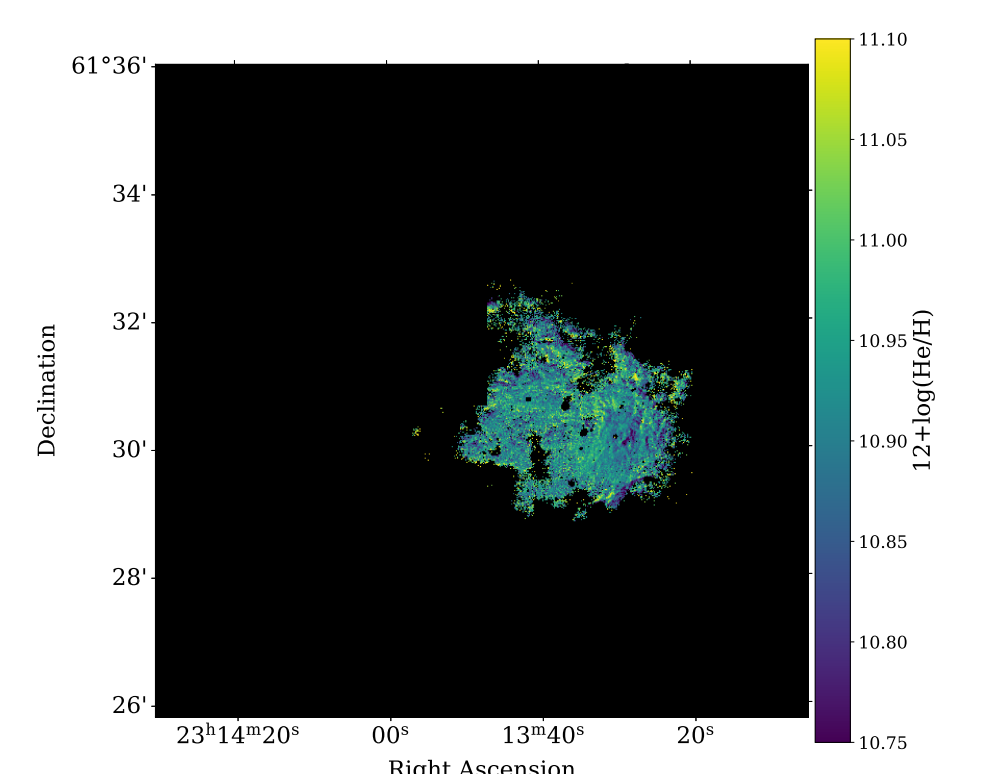


Figure 7: Abundance map of HeI measured from the HeI 5876Å/ $H\beta$ line ratio computed from 1000 Monte-Carlo iterations

SPECTRUM VS MAP COMPARAISON

	OMM	SITELLE
Density (electron/cm ³)	260±120	380±290
Iterative density (electron/cm ³)	250±130	360±250
Temperature (K)	8300±310	7440±670
Iterative temperature (K)	8250±300	7440±610

Table 1: Comparison of electron density and temperature at the position of the OMM slit spectrum. The constant density value were calculated with a constant 8300K temperature across all the map. For the constant temperature method a 300 electron/cm³ was chosen. The iterative density and temperature were calculate has the same time. The density and temperature values were obtain from 10000 Monte-Carlo analysis.

DENSITY AND TEMPERATURE FLUCTUATIONS

	n ²	t ²
Center region	0.212±0.013	0.0127±0.001
Small PDR-like feature	0.022±0.011	0.0044±0.0016
Filament/PDR	0.166±0.022	0.038±0.022
Diffuse gas	0.278±0.011	0.060±0.003

Table 2: We measure the density n² and temperature t² fluctuation of both red squares of Figure 2 along with the remaining diffuse gas. There is also a small PDR-like feature in the center region with high density and low temperature values which is the peak of emissivity in every flux maps except [OIII]. The fluctuation measurements could be improve with another temperature and density map from higher ionized atoms.

OBSERVATIONS

Tackling the thermodynamics of ionized nebulae is challenging, but possible thanks to SITELE. The emission lines detected from the observed maps provide us with most of the physical knowledge one can think of!

- 3 data cubes (R = 600 to 1400) obtained from 2016 to 2018 on the HII region Sh2-158.
- 11 emission lines were used in this analysis.
- \overline{RSB} approximately 5 for the [SII] lines, 15 for H β , 35 for [OIII] and above 100 for H α .
- The CCD was not properly initialized resulting in a missing quadrant in the upper left corner.
- Spectra were acquired with the long slit spectrometer of the Mont-Mégantic observatory in August 2017.

SITELLE



- SITELE stands for "Spectro-Interféromètre à Transformée de Fourier pour l'Étude en Long et en Large des raies d'Émission".
- Cameras size = 2048 X 2064 pixels each.
- Spectral resolution = 1 to 10000
- Pixel size = 0.32"
- Field of view = 11' X 11'
- Wavelength range = 350-900nm.

CONCLUSION

The main requirements of the project are abundance, temperature, density and velocity fluctuation maps across the nebula. The radial velocity data have already been published (Barriault and Joncas 2007). The kinematics of all the main ions: hydrogen, oxygen, nitrogen and sulphur were obtained. The figures shown here summarize some of the exploited SITELE data.

The highest density regions are associated with the ionisation fronts eroding the parent molecular cloud (thin [SII] filaments seen in the southwestern region in Figures 2) and 5. The densities vary along the filaments, reflecting the molecular gas clumpyness.

The temperature was obtained with the [NII] lines. The [NII]5755Å line is faint and has a SNR > 3 only in the center of Sh2-158. The coldest part of the HII region, with a calculated temperature of 6000K, is located in its center and corresponds to the densest region in the map (Figure 3). Since the temperature is very low in some regions of Sh2-158, we believe that the metallicity is higher than anticipated.

The results presented here were another step in a new approach to understand the origin of the ADP. Next is the comparison of the density, temperature and velocity fluctuation maps of a sub-region on the Orion Nebula. We will compare them with the results of Sh2-158.

CONTACT INFORMATION

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