A Monte-Carlo approach for the ADP

Maxime Royer and Gilles Joncas
Université Laval, Départ. de physique, génie physique et d'optique and Centre de recherche en astrophysique du Québec

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 70 year 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

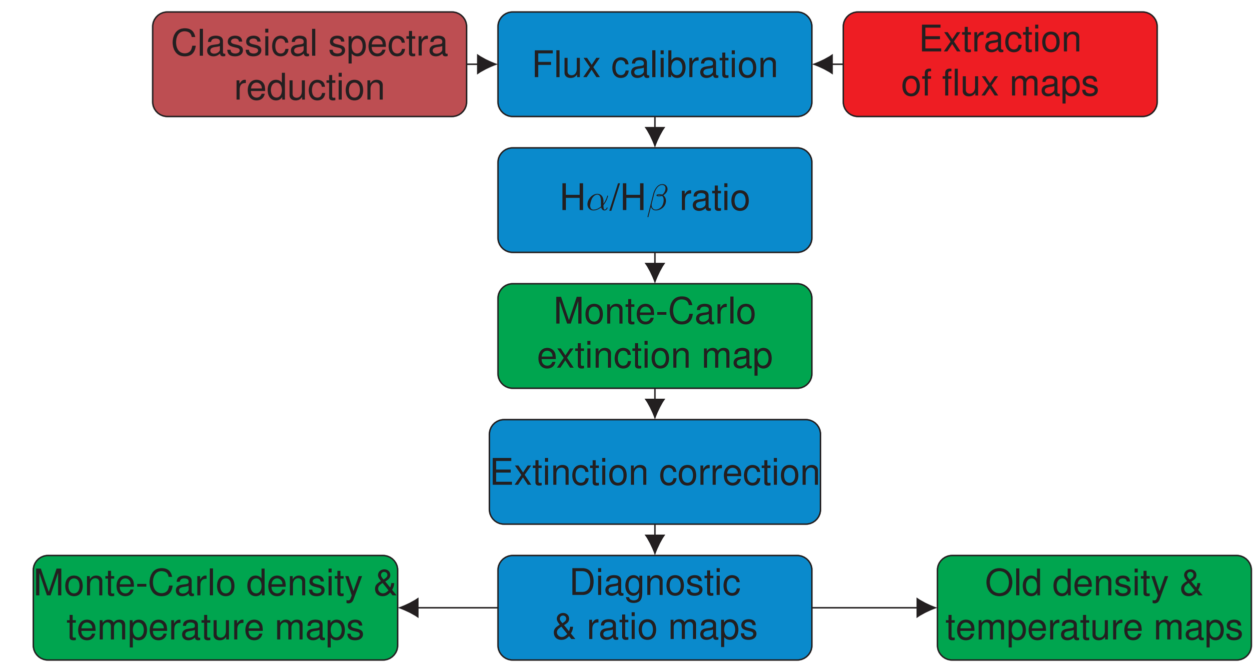

Figure 1: The box color indicates the program used for the reduction and analysis: red for ORCS (Outil de Réduction de Cubes Spectraux), purple for IRAF, blue for Python and green for PyNeb. There were flux calibration issues from one cube to another. Spectra were acquired to verify and recalibrate the 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 and temperature parameters and thus a Monte-Carlo Analysis is required.

Density

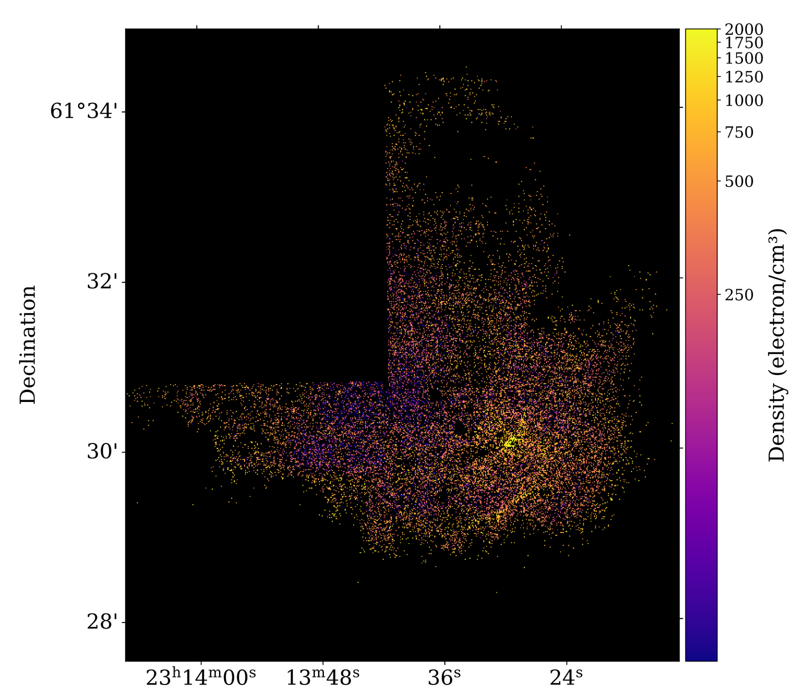

Figure 2: Iterative density map obtained from 100 Monte-Carlo analysis

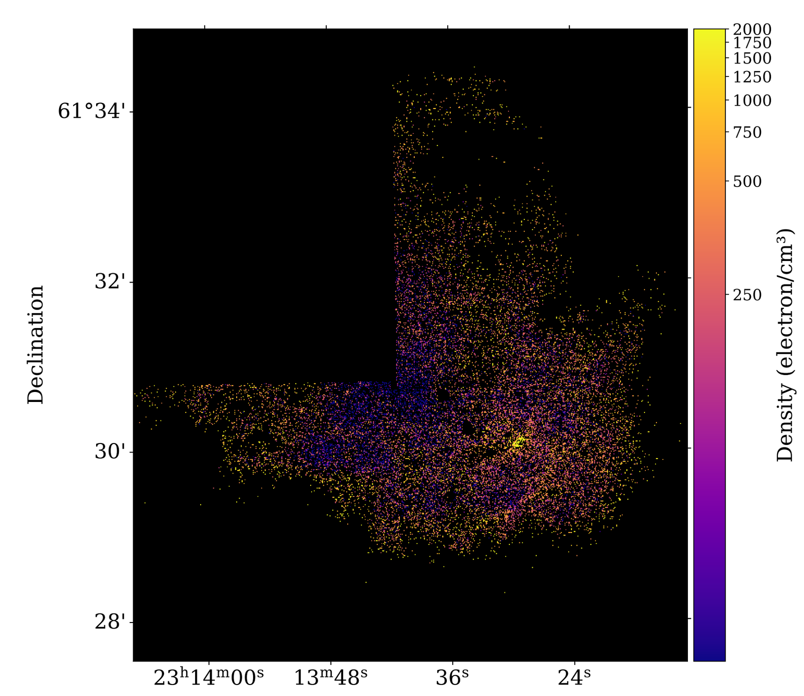

Figure 3: Iterative density error map obtained from 100 Monte-Carlo analysis

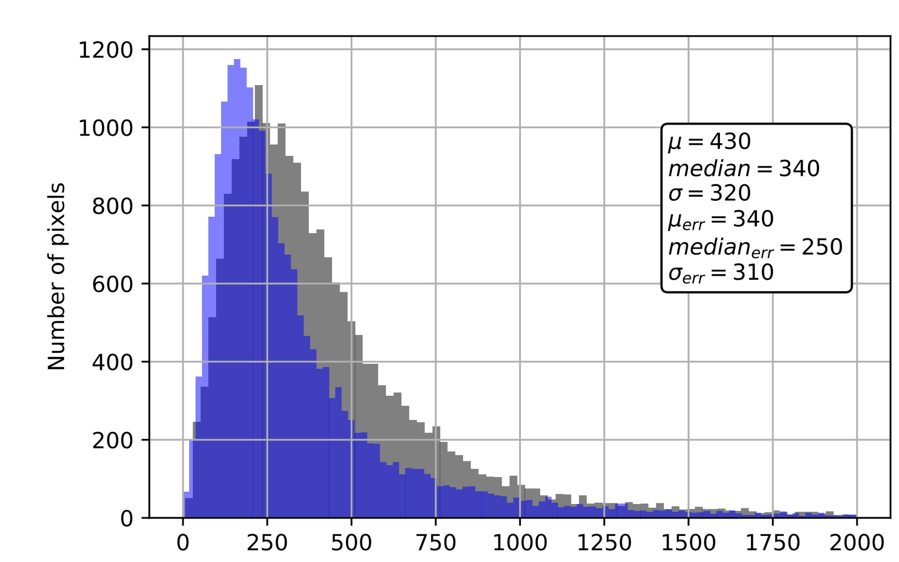

Figure 4: Density and error histograms obtained from the Monte-Carlo iterative method. Black is the density and blue the error.

Temperature

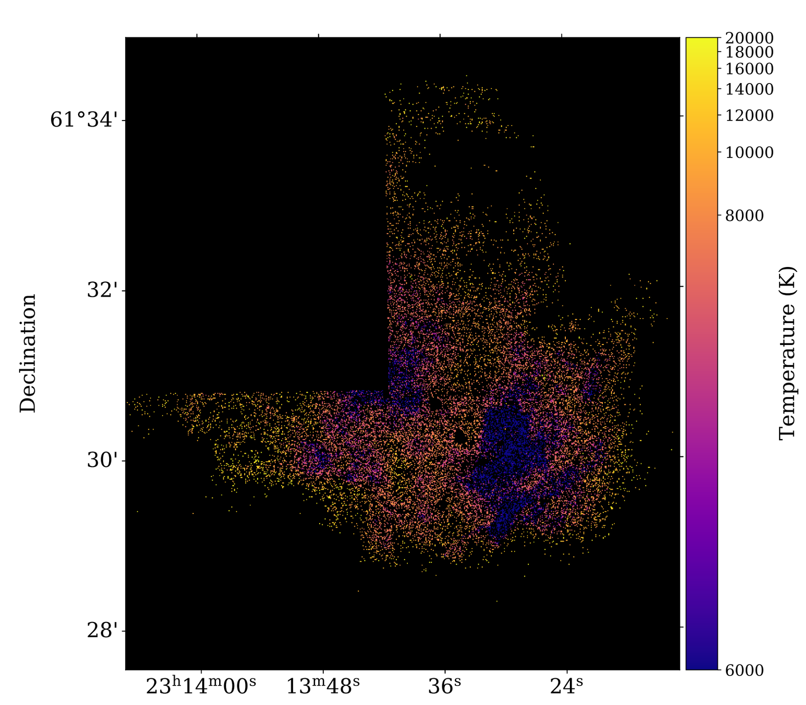

Figure 5: Iterative temperature map obtained from 100 Monte-Carlo analysis

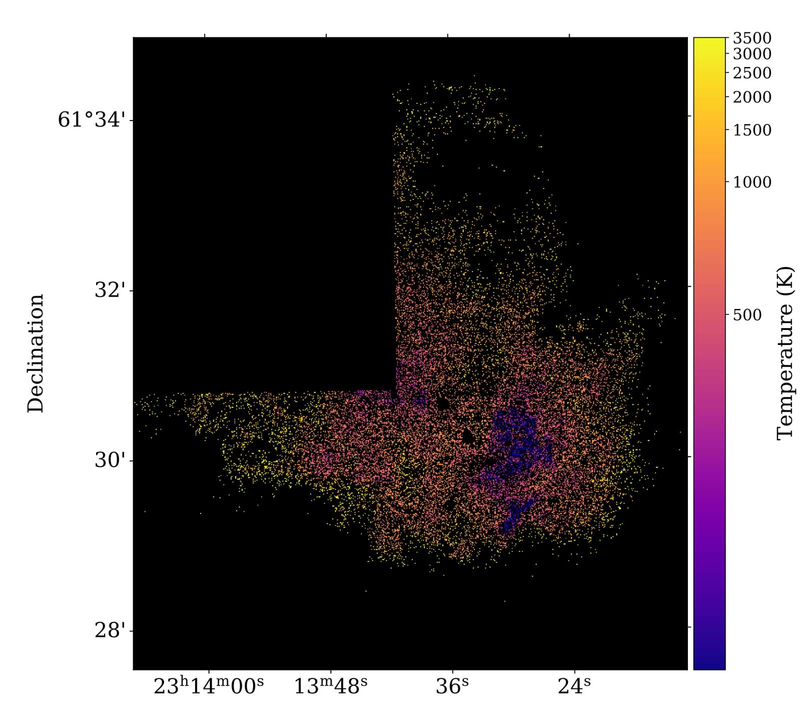

Figure 6: Iterative temperature error map obtained from 100 Monte-Carlo analysis

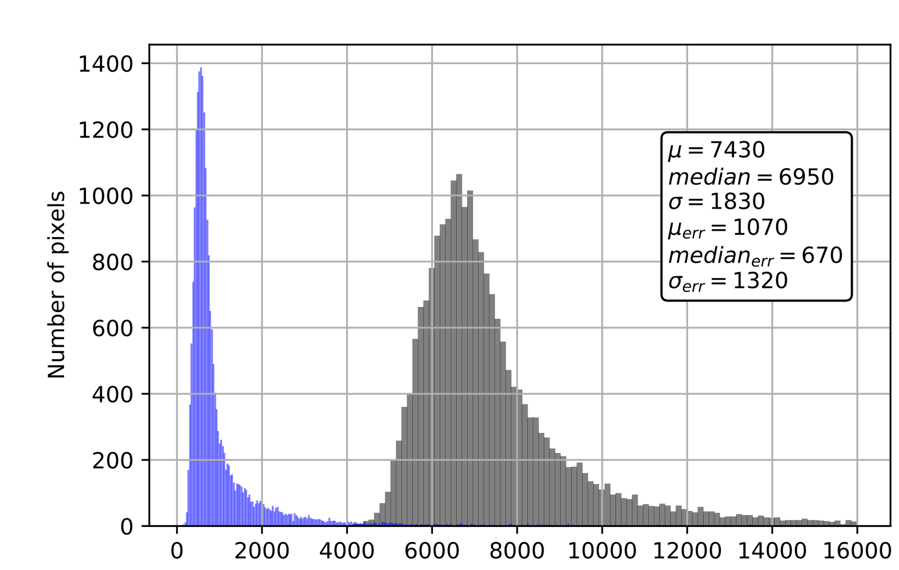

Figure 7: Temperature and error histograms obtained from the Monte-Carlo iterative method. Black is the density and blue the error.

Spectrum vs map comparaison

	Constant Density Electron/cm^3	Iterative Density Electron/cm^3	Constant Temperature K	Iterative Temperature K
OMM Spectrum	240±50	230±50	6740±110	6740±110
SITELLE Spectrum pixels	340±310	290±210	7010±720	6850±630
SITELLE Map	400±360	340±250	7100±740	6950±670

Table 1: Electronic density and temperature measured from the OMM spectrum , OMM spectrum position on the SIELLE map and full SITELLE map. The constant density value were calculated with a constant 7000K temperature across all the map. For the constant temperature method a 300 electron/cm^3 was chosen. The iterative density and temperature were calculate has the same time. The density and temperature values were obtain from 5000 Monte-Carlo analysis. The SITELLE maps were calculated from 100 Monte-Carlo analysis and are much longer to calculate.

	Density Electron/cm^3	Temperature K
Difference constant spectrum/pixels	100	270
Difference costant spectrum/map	60	90
Difference iterative spectrum/pixels	60	110
Difference iterative spectrum/map	50	210

Table 2: Differences of density and temperature between. The values are all under the uncertainties obtained by the Monte-Carlo analysis and indicates that the uncertainties of the flux maps used to derivates those maps are larger than anticipated. This brings the question of the possible precision we can reach for the affects of the density on the temperature and vice versa.

Observations

Tackling the thermodynamics of ionized nebulae is challenging, but possible thanks to SITELLE. 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 Hβ, 35 for [OIII] and above 100 for Hα.
- 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

- SITELLE 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 SITELLE 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 Figure 2). The densities vary along the filaments, reflecting the molecular gas clumpyness.

The temperature was obtained with the [NII] lines. The [NII]5755λ 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 5000K, is located in its center and corresponds to the densest region in the map (Figure 5). Since the temperature is very low in some regions of Sh2-158, we believe that the metallicty 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 comparaison 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

maxime.royer.2@ulaval.ca