Study of the physical properties in extragalactic star-forming regions

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Resumen / El análisis de los procesos físicos entre una región de formación estelar y su medio requiere de un completo estudio de las componentes gaseosas. En este trabajo presentamos resultados preliminares del estudio de las propiedades físicas de regiones de formación estelar en tres galaxias: NGC 6070, NGC 5861 y Tol 1924-416. Estimamos la densidad y temperaturas electrónicas, abundancias químicas iónicas y totales y enrojecimiento usando datos de ranura larga de GMOS, obtenidos en el Telescopio Gemini Sur.

Abstract / The analysis of the physical processes between a star-forming region and its environment requires the complete study of the gaseous component. In this work we present preliminary results of a physical properties study of star-forming regions in three galaxies: NGC 6070, NGC 5861, and Tol 1924-416. We estimate the electron density and temperatures, ionic and total chemical abundances, and reddening using GMOS/Long-slit data obtained at the Gemini-South Telescope.

Keywords / galaxies: abundances — galaxies: individual(NGC 6070, NGC 5861, Tol 1924-416)

1. Introduction

The extragalactic star-forming regions are well-observed in the disks of spiral galaxies and occupy large areas in the blue compact dwarf galaxies. A large number of young and massive stars that ionizes the surrounding gas dominates the morphology and the physical conditions of their environment. The analysis of the physical processes between a star-forming region and its environment requires the complete study of the gaseous component.

We present preliminary results of the study of the physical properties and chemical abundances in a sample star-forming regions in two spiral and one Blue Compact Dwarf (BCD) galaxies.

2. Observations and data reduction

We have obtained a sample of star-forming regions located in NGC 5861, NGC 6070, and Tol 1924-416. The observations were performed with the Gemini-South Multi-Object Spectrograph (GMOS) in longslit configuration (program ID: GS-2007A-Q-30, PI: V. Firpo), using the B600 (blue) and R400 (red) gratings to cover a wavelength range ∼3350–9600 Å. Observations on each grating were made in 3 different central wavelengths so that the posterior combination would correct for chip gaps. Data reduction was performed using the GEMINI GMOS IRAF TASKS and included bias and overscan subtraction, flat fielding, wavelength calibration, and flux calibration. Observing conditions were good, with an average seeing of 0.7 arcsec. The R400 grating, centered at 7700 Å, gives a dispersion of 1.3 Åpix^{-1}. The B600 grating centered at 4800 Å gives a dispersion of 0.9 Åpix^{-1}.

3. Results

In each listed emission-lines (see Table 1), we measured the flux, continuum, and equivalent width (EW) with the respective uncertainties using the SPLOT task in IRAF and following the procedure described in Hägele et al. (2006). Table 1 shows, as example, the reddening-corrected emission-line ratios, for each measurement of the galaxy Tol 1924-416, along with the reddening constant and its error, taken as the uncertainties of the least-square fit and the reddening-corrected Hβ intensity. [S III] λ9532 flux was considered as the theoretical value 2.44×[S III] λ9069.

The physical conditions of the ionized gas in six star-forming regions (the two brightest regions observed within each slit) were derived following the methodology used in Hägele et al. (2012). The electronic density, n_e, was determined from the ratio R_{S2} of the lines [SII] $\lambda\lambda$6717,6731. The electron temperatures for each ion were derived using the Hägele et al. (2012) strategy (see discussion in its section §3.2). Table 2 shows the electron densities and temperatures, ionic and total chemical abundances derived for each observed region.

We derived the ionic chemical abundances of different species using the strongest available emission-lines

Table 1: Line intensities corrected by reddening ([F(Hβ)=I(Hβ)=10000]). 1: Measured emission-lines in region I and II of Tol 1924-416. Columns 2: Correction factor of region I and II. Columns 3 & 6: Equivalent widths of each measured line in region I and II respectively. Columns 4 & 7: intensity of each line in unities of Hβ with the corresponding error. Columns 5 & 8: Percentage error.

		Tol1924-416					
			I			II	
λ(Å)	f (λ)	–EW (Å)	I (λ)	Error (%)	–EW (Å)	I (λ)	Error (%)
3727 [OII]dob	0.271	87.82	13631±325	2.4	89.45	14065±421	3.0
3868 [NeIII]	0.238	36.64	4208±88	2.1	48.39	4957±169	3.4
3889 HeI+H8	0.233	13.58	1646±72	4.4	23.21	2027±92	4.5
3970 [NeIII]+He	0.215	47.78	3292±168	5.1	30.59	2673±133	5.0
4102 Hδ	0.188	34.26	2700±176	6.5	27.98	2664±437	16.4
4340 Hγ	0.142	74.78	4842±334	6.9	91.75	5263±149	2.8
4363 [OIII]	0.138	11.30	815±50	6.1	14.40	901±90	10.0
4471 HeI	0.106	7.32	471±30	6.4	...	...	...
4861 Hβ	0.000	179.99	10000±228	2.3	178.10	10000±200	2.0
4959 [OIII]	-0.024	281.76	17729±65	0.4	299.76	17691±26	0.1
5007 [OIII]	-0.035	786.43	53184±120	0.2	782.22	52661±106	0.2
5876 HeI	-0.209	25.48	971±19	1.9	34.18	1228±50	4.1
6300 [OI]	-0.276	11.33	363±18	5.1	13.57	548±19	3.5
6364 [OI]	...	...	...	...	5.80	234±19	8.3
6548 [NII]	-0.311	10.52	319±21	6.5	6.85	272±19	7.1
6563 Hα	-0.313	663.25	28366±186	0.7	767.78	29504±385	1.3
6584 [NII]	-0.316	28.02	854±30	3.5	18.01	727±30	4.1
6678 HeI	-0.329	11.86	311±13	4.3	8.87	302±53	17.7
6717 [SII]	-0.334	46.62	1283±32	2.5	43.76	1666±43	2.6
6731 [SII]	-0.336	32.97	928±29	3.1	30.51	1171±33	2.8
7065 HeI	-0.377	7.60	189±14	7.3	...	...	...
7136 [ArIII]	-0.385	20.23	476±18	3.7	18.48	544±22	4.1
7319 [OII]dob	-0.406	7.47	174±14	8.3	8.13	239±20	8.3
7330 [OII]dob	-0.407	7.69	179±22	12.3	5.89	174±17	9.8
7751 [ArIII]	-0.451	6.31	138±9	6.2	71.00	205±14	7.0
9069 [SIII]	-0.561	41.43	617±26	4.2	38.41	801±34	4.2
c(Hβ)			0.43 ± 0.03			0.25 ± 0.02	
I(Hβ)(erg seg^{-1} cm^{-2})			2.76×10^{-14}			1.60×10^{-14}	

detected in the analyzed spectra, and the equations given in Hägele et al. (2008), which were derived using ionic task the STSDAS package in IRAF, based in the five-level statistical equilibrium atom approximation. The ionic and total chemical abundances from forbidden lines O, S, N, Ne and Ar were derived from the measured forbidden emission-lines and using the estimated line temperatures as described in Hägele et al. (2008, 2012). The table includes the adopted value for He^+/H^+ as the average value, weighted by the errors, of the He ionic abundances derived from each HeII emission-line.

Empirical methods to determine abundances are based on the cooling system of the ionized nebulae. The most studied methods are based on the direct calibration of the relative intensities of some strong emission-lines compared with the abundances of relevant ions present in the nebula (empirical parameters). In the last seven lines of Table 2, we present the oxygen abundances of the observed regions (columns 2 to 7) derived with the strong-line empirical parameters (column 1).

4. Discussion

In all observed regions the electron densities were found to be well below the critical density for collisional de-excitation. In the two regions of Tol 1924-416 was possible to measure the auroral lines [OIII λ4363, and [OII] $\lambda\lambda$7319,7330, and we were able to estimate electron temperatures T([OIII]) and T([OII]) using the direct method. In both regions was possible to derive the oxygen abundances with values of ~0.18 and ~0.15 times the solar value (12+log(O/H)$_\odot$ = 8.69; Allende Prieto et al., 2001) for region I and II, respectively. These results, as well as the derived sulfur abundance, are in good agreement with the obtained by Kehrig et al. (2006) (0.16 times the solar value for the oxygen abundances and 6.08±0.12 for the sulfur abundances).

In the regions of the two spiral galaxies we assumed that T([OIII]) is equal to 10^4 K (as was discussed in §3.2 Hägele et al., 2012), then we estimated the oxygen abundances using photoionization models and empirical methods. The derived values for NGC 5861-I,II and NGC 6070-I are 0.1, 0.15 and 0.19 times the solar values, respectively. These oxygen abundances are consistent with the values estimated for both regions on Tol 1924-416. Meanwhile, NGC 6070-II has an oxygen abundance of 0.32 times the solar value, doubling the values of the BCD galaxy. The sulphur abundance for all regions are lower than the solar value (12+log(S/H)$_\odot$ = 7.33; Grevesse & Sauval, 1998). The log(S/O) ratio of NGC 5861-I,II and NGC 6070-I is consistent with the

Table 2: Densities in cm^{-3} and temperatures in 10^4K. [a] Derived using temperatures predicted by photionization models; [b] Derived using temperatures estimated from photoionization models and/or empirical methods; [c] Derived using Hägele et al. (2006) empirical method; [d] Derived using Díaz et al. (2007) empirical method; [e] Assumed temperature=10^4 K; [f] Derived using Pérez-Montero & Díaz (2003) empirical method.

	NGC 5861		NGC 6070		Tol 1924-416	
	I	II	I	II	I	II
n([SII])	10:	80:	10:	50:	30:	10:
T([OIII])	1.0^e	1.0^e	1.0^e	1.0^e	1.35±0.03	1.42±0.06
T([SIII])	0.87^c	0.87^c	0.87^c	0.87^c	1.29 ± 0.03^d	1.37 ± 0.05^d
T([OII])	1.21^f	1.05^f	1.21^f	1.08^f	1.29±0.12	1.47±0.12
T([SII]	0.98^f	0.98^f	0.98^f	1.01^f	1.04^b	1.16^b
T([NII])	1.21^a	1.05^a	1.21^g	1.08^g	1.06^c	1.075^c
			Total and relative abundances			
12+log(O/H)	7.67±0.01	7.87±0.03	7.96±0.01	8.20±0.02	7.95±0.06	7.87±0.06
ICF($S^+ + S^{2+}$)	1.04	1.00	1.22±0.01	1.04	1.37±0.12	1.48±0.09
12+log(S/H)	6.39±0.11	6.40±0.10	6.52±0.15	6.48±0.11	5.87±0.08	5.91±0.07
log(S/O)	-1.27±0.11	-1.47±0.10	-1.44±0.15	-1.72±0.11	-2.08±0.10	-1.96±0.09
log(N/O)	-0.49±0.02	-0.63±0.03	-0.67±0.02	-1.00±0.04	-1.31±0.18	-1.32±0.07
ICF(Ne^{2+})	...	...	...	...	1.08±0.01	1.08±0.01
12+log(Ne/H)	...	...	...	...	7.23±0.04	7.24±0.07
log(Ne/O)	...	...	...	...	-0.72±0.07	-0.64±0.09
ICF(Ar^{2+})	1.17	1.27±0.01	1.11	1.16±0.01	1.16±0.05	1.21±0.05
12+log(Ar/H)	5.73±0.21	5.50±0.30	5.99±0.18	5.69±0.59	5.10±0.05	5.04±0.07
log(Ar/O)	-1.94±0.21	-2.38±0.30	-1.97±0.18	-2.52±0.59	-2.95±0.08	-2.83±0.1
He^+/H^+(adopted)	0.11±0.01	0.06±0.01	0.08±0.002	0.08±0.001	0.08±0.01	0.1±0.1
Empirical Parameters			Oxygen abundances			
O_{23}	8.93±0.19	8.91±0.19	8.79±0.19	8.59±0.19	8.06±0.13	8.06±0.13
S_{23}	8.08±0.20	8.07±0.20	8.03±0.20	8.14±0.20	7.55±0.20	7.72±0.20
SO_{23}	8.63±0.27	8.60±0.28	8.29±0.27	8.14±0.28	7.37±0.27	7.55±0.27
O_3N_2	8.63±0.25	8.76±0.25	8.40±0.25	8.42±0.25	8.01±0.25	7.98±0.25
S_3O_3	8.46±0.25	8.54±0.25	8.27±0.25	8.18±0.25	7.55± 0.25	7.69±0.25
N_2	8.69±0.25	8.74±0.25	8.56±0.25	8.62±0.25	8.01±0.25	7.95±0.25
Ar_3O_3	8.56±0.23	8.59±0.24	8.38±0.23	8.05±0.47	7.63±0.23	7.73±0.23

solar value (log(S/O) $_\odot$ =-1.36; Grevesse & Sauval, 1998). The rest of regions present slightly lower values than solar ones. The log(N/O) ratio of NGC 5861-I,II and NGC 6070-I are slightly higher than the solar value (log(N/O) $_\odot$ =-0.88; Asplund et al., 2005). The other regions present log(N/O) values lower than the solar ones. Both regions of the Tol 1924-416 present similar log(Ne/O) ratio than the solar value (log(Ne/O) $_\odot$ =-0.61 dex; Grevesse & Sauval, 1998). The log(Ar/O) ratio of NGC 5861-I and NGC 6070-I are higher than the solar value (log(Ar/O) $_\odot$ =-2.29 dex; Grevesse & Sauval, 1998), the remaining regions have lower value than the solar one. The He total abundance estimated in all regions is similar at the typical values found for HII galaxies (Hägele et al., 2008). In all the studied regions the computed oxygen abundances using the empirical parameters are similar within the uncertainties. In both spiral galaxies, NGC 5861 and NGC 6070, the values estimated by the empirical parameters are higher than the once predicted by photoionization models and empirical methods. In both regions of Tol 1924-416 the estimated abundances are consistent with the derived abundances using the temperatures calculated by the direct method and by model-based and empirical temperature relationship.

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