We present a long-slit spectroscopic analysis of Herbig-Haro 202 and the surrounding gas of the Orion Nebula using the FORS 1 spectrograph of the Very Large Telescope. Given the characteristics of the Orion Nebula, it is the ideal object to study the mechanisms that play a role in the evolution of H II regions, notably dust destruction by interstellar shocks, which is a poorly understood subject. The use of long-slit allowed us to determine the spatial variation in its physical conditions and chemical abundances; our results are consistent with those of previous studies albeit with improved uncertainties in some determinations. Special attention is paid to Iron (Fe) and Oxygen (O) abundances, which show a peak at the brightest part of HH 202; we have computed the amount of depletion of oxygen in dust grains, which amounts to 0.12 ± 0.04 dex. Finally we show that O/H abundances determined from collisionally excited lines and recombination lines are irreconcilable at the center of the shock unless thermal inhomogeneities are considered along the line of sight.

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1. INTRODUCTION

The Orion Nebula is the brightest H II region of the night sky. It is considered the standard for studying the chemical composition of H II regions and the mechanisms that play a role in the evolution of these objects (Esteban et al. 2004). Even though Herbig-Haro objects are a permanent feature of star forming regions, only a few of them have been identified and chemically characterized in H II regions, notably HH 202, which was studied by Mesa-Delgado et al. (2008) and Mesa-Delgado et al. (2009), the latter being a remarkably deep study using the UVES echelle spectrograph of the Very Large Telescope.
HH 202 is the brightest Herbig-Haro object discovered yet, meaning it is the ideal object to study the presence of thermal inhomogeneities in H II regions, which in turn have been linked the presence of an Abundance Discrepancy Factor (ADF) in H II regions (Peimbert 1967). It is also of particular interest to quantify the amount of interstellar dust that is destroyed by the gas flow; releasing heavy elements such as iron (Fe) and Oxygen into the gas. In this work we present a long-slit spectroscopic analysis of HH 202 using FORS 1 of the VLT, focusing on the physical conditions and chemical abundances and their variation across the Orion Nebula.

2. OBSERVATIONS

The observations were carried out during the night of September 11, 2002 with FORS 1 at the Very Large Telescope in Cerro Paranal, Chile. Data were obtained from three different grism configurations: GRIS-600B+12, GRIS-600R+14 with filter GG435+31, and GRIS-300V+10 with filter GG375+30. The slit was oriented North-South with a length of 410 arcseconds and the width was set to 0.51 arcseconds. This setting was chosen to have enough resolution to deblend the [O II] $\lambda 3726$ and $\lambda 3729$ emission lines, as well as to measure O II $\lambda 4642$ and $\lambda 4650$ with a significant signal to noise ratio. For the analysis of the spatial variations of the physical properties and chemical abundances, 54 extraction windows were defined. Windows North and South of the brightest part of HH 202 spanned 50 pixels (10 arcseconds) each, whereas those covering the object were 3 pixels long (0.6 arcseconds) each.

3. SPATIAL ANALYSIS

In Figure 1 we present the emission line intensities for [Fe II] $\lambda 7155$ and [Fe III] $\lambda 4658$. The peak present at the zero mark is not coincidental. Effectively it can be explained by the fact that interstellar dust is being destroyed at the brightest part of HH 202, releasing iron into the gas phase.

We present the total abundance for oxygen computed using PyNeb (Luridiana et al. 2015) in two ways: from collisionally excited lines (CELS) and optical recombination lines (ORLs). For the ORL oxygen abundance we used the emission lines of multiplet 1 of O II. The total intensity of all lines was estimated considering the dependence of density and temperature of the lines. The total oxygen abundance is presented in Fig. 2.

4. ANALYSIS FROM COMBINED SPECTRA

In order to increase the signal to noise ratio, spectra were combined, effectively representing the four following regions: the nebular un-shocked gas, north and south of HH 202; weakly shocked gas; and strongly shocked gas; the latter from the combination of three spectra near the zero mark of Figure 2. This procedure allowed us to compute chemical abundances with reduced error bars. Total and ionic abundances were computed considering the presence
Fig. 1. Dereddened emission line intensities for [Fe II] $\lambda$7155 and [Fe III] $\lambda$4658 along the field of view of the slit.

Fig. 2. Total O/H ratio computed using CELs and O II ORLs. Note that the difference is maximum at the zero mark, which represents the brightest part of HH 202.
of thermal inhomogeneities, modeled by means of the $t^2$ parameter introduced by Peimbert et al. (1967). In Figure 3, we present chemical abundances computed assuming $t^2 = 0.00$ and $t^2 \neq 0.00$. Notably, the $t^2$ value presents a peak at the brightest part of HH 202; it is also notable that ORL and CEL abundance determinations at this zone are irreconcilable unless the $t^2 \neq 0.00$ value is accounted for.

In order to quantify the amount of iron (Fe) and oxygen (O) being released into the gas phase as a consequence of the destruction of interstellar dust we have assumed that iron and oxygen are released in the same fraction. Assuming the value of Fe/O from the strongly shocked zone to represent maximum dust destruction we extrapolate to a total destruction, assumed to be the solar value for Fe/O (Rodríguez & Rubin 2005). With these considerations, we have obtained a depletion factor for oxygen in the Orion Nebula that amounts to $-0.12 \pm 0.04$.

5. CONCLUSIONS

We have performed a long-slit spectroscopic analysis of HH 202 using the FORS 1 spectrograph of the VLT. We have determined the spatial variations in electron temperature and density across the Orion Nebula and compared them to the ones in the shock. We have shown that oxygen (O/H) abundances determined from collisionally excited lines (CELS) and optical recombination lines (ORLs) are irreconcilable at the brightest part of HH 202 unless we consider the existence of thermal inhomogeneities along the line of sight, in agreement with a previous study by Mesa-Delgado et al. (2009). The abundance discrepancy factor (ADF) associated to O$^{++}$ and O is greater at the strongly shocked zone, coinciding with the peak of the $t^2$ parameter. This fact suggests that interstellar shocks may contribute a significant fraction to the $t^2$ parameter. Iron (Fe) emission and abundance also shows a peak at this zone, an effect that we attribute to dust destruction by the gas flow, which releases iron into the gas phase.

Comparing the total oxygen abundance at the Strongly Shocked Zone with the ambient gas, and taking the solar value as reference, we found a depletion factor of oxygen to be $-0.12 \pm 0.04$ dex.

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