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THE IONIZATION STRUCTURE OF THE ORION NEBULA

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RESUMEN

Se usaron nuevos espectros de rendija larga e imágenes CCD ya existentes para examinar la estructura de ionización y desarrollar un nuevo esquema de los 5′ centrales de M42. El esquema básico es el de una cavidad altamente ionizada que rodea al Trapecio, una zona de baja ionización al sudoeste de θ^1 Ori C, y una region de baja ionización más alejada al sudoeste donde la nube molecular se curva hacia el observador. También se discute un rasgo en forma de barra al noreste del Trapecio y un objeto Herbig Haro hacia el oeste.

ABSTRACT

New long-slit spectra and existing CCD imagery were used to examine the ionization structure and develop a new picture of the central 5′ of M42. The basic picture is of a highly ionized cavity surrounding the Trapezium, a low ionization zone to the southwest of θ^1 Ori C, and a region of high ionization further to the southwest where the molecular cloud curves back toward the observer. A bar-like feature to the northeast of the Trapezium and a Herbing Haro object to the west are also discussed.

Key words: **H II REGIONS – ISM: INDIVIDUAL OBJECTS (ORION NEBULA)**

1. INTRODUCTION

Recent studies of the Orion Nebula (NGC1976, M42) have employed a variety of approaches to better understand this object. O'Dell et al. (1993) used kinematical information, Baldwin et al. (1991) matched surface brightness and ionization data from long-slit spectra to their own model, while Rubin et al. (1991) used existing line ratio data from the literature and a 2D nebular code to develop a model of the nebula. We have acquired new long-slit spectra and combined it with existing CCD imagery to study the physical conditions and ionization structure of the inner region of M42. Using this approach we have examined both new and previously known features and formed a more detailed picture of the core of the Orion Nebula.

2. OBSERVATIONS

We acquired deep, long-slit spectra on the 82 inch telescope at McDonald Observatory in October 1991 and April 1992. Two positions to the west of the Trapezium were observed and are shown in Figure 1. The details of the image are discussed below. The slit positions are shown as the horizontal lines with vertical tic marks. The slits covered ~190 arcseconds in Right Ascension and 4.1 arcseconds in width. This gave us coverage out to five arcminutes to the west of the Trapezium (beyond the edge of Figures 1–3). We binned the data every 5.4 arcseconds in Right Ascension as indicated by the vertical tic marks. Our wavelength coverage was from 3300–7900 Å at a resolution of 7 Å FWHM. The high signal-to-noise of the spectra enabled us to derive five temperature and three density diagnostics across the face of the nebula (Walter 1993).

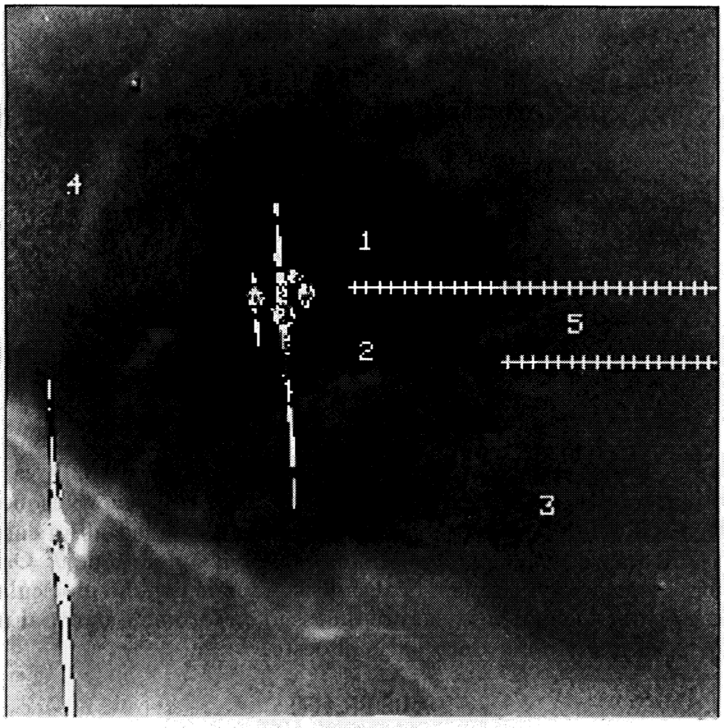

Figure 1: Ratio map of λ5007 [O III]/Hβ. North is up and East is to the left. The field of view is approximately 5′ square. A portion of each slit position is shown as a horizontal line. The numbered features are discussed in the text. The gray scale is linear and ranges from 1.0 (white) to 3.8 (black).

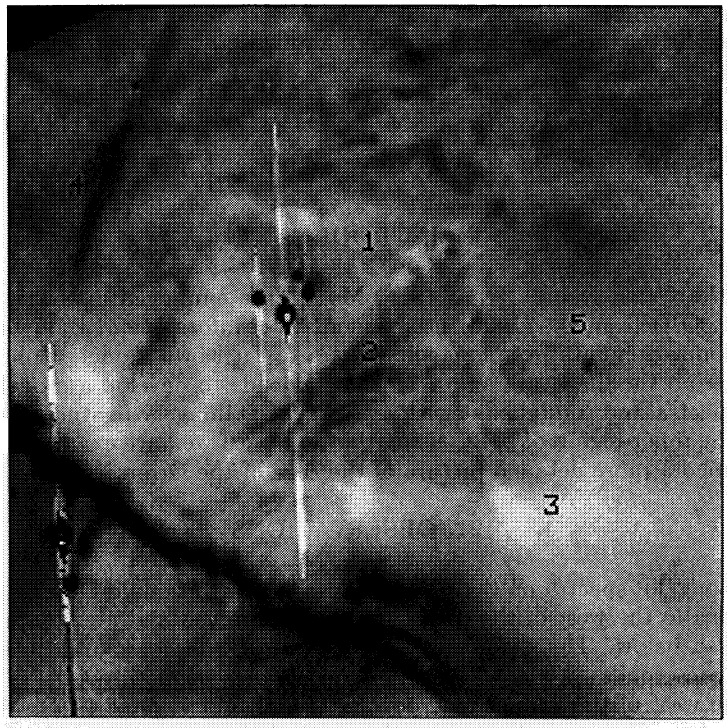

Figure 2: Ratio map of λ6584 [N II]/Hα. See Figure 1 and text for further details. The gray scale is linear and ranges from 0.10 (white) to 0.35 (black).

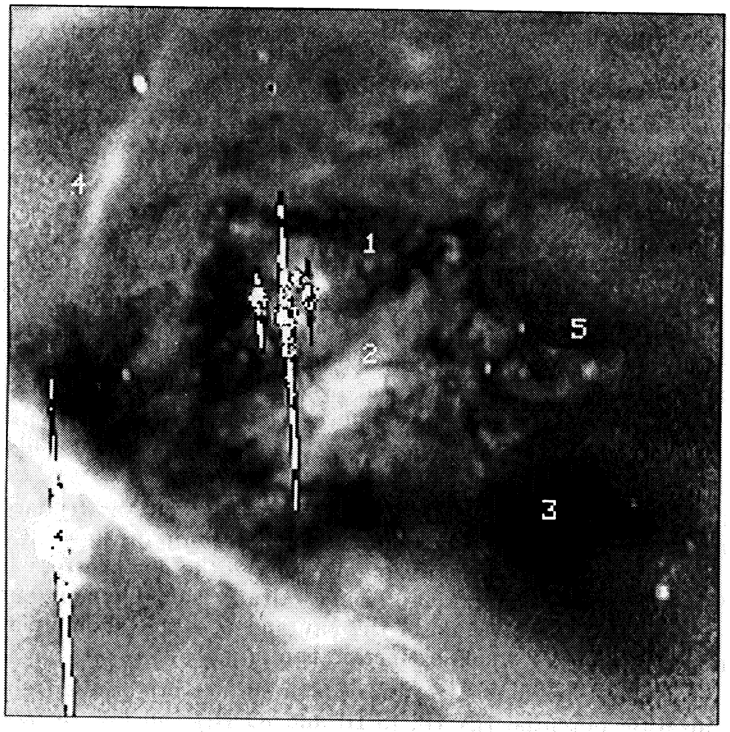

Figure 3: Ratio map of extinction corrected λ5007 [O III]/ λ7325 [O II]. See Figure 1 and text for further details. The gray scale is linear and varies from 15 (white) to 85 (black).

The details regarding the CCD imagery and its calibration were discussed previously in Walter, Dufour & Hester (1992) and Walter (1993). Briefly, images were acquired on the Palomar 60 inch telescope at six emission line and three continuum band wavelengths. The original images are 16 arcminutes square with a spatial resolution of 1.2 arcseconds pixel^{-1}. Examples of ratio maps made from the images can be seen in Figures 1–3.

3. DISCUSSION

Figure 1 is the λ5007 [O III] image divided by the Hβ image and is a measure of regions of high ionization (darker features). The features marked in the images include: #1 is a high ionization cavity approximately centered on the Trapezium; #2 is a low ionization zone to the southwest of the Trapezium; #3 is a high ionization region further to the southwest, beyond the low ionization zone; #4 is a bar-like feature to the northeast of the Trapezium; #5 is an ellipse of high density material which may be a Herbing Haro object. Since the features differ in their level of ionization some are not readily visible in Figure 1, but they are visible in one or more of the other figures.

Figure 2 is the ratio of λ6584 [N II] to Hα, where the low ionization features are enhanced (darker) in the images. As expected, this image is anticorrelated with Figure 1. Figure 3 is the ratio of the extinction corrected λ5007 [O III] to λ7325 [O II]. This is a measure of the oxygen ionization (darker = high O^{++}/O^{+}) where any abundance effect is minimized by using the two dominant ionization stages of oxygen. Additional images, ratio maps and variations in ionization for several ions can be found in Walter (1993).

The central cavity (#1) results from the radiation of θ^1 Ori C carving into the background molecular cloud. At the edge of the cavity, 30″ (0.08 pc) to the southwest of θ^1 C Ori, there is a sharp linear feature where the [O III]/Hβ ratio drops by more than 25% over a linear projected distance of 0.02 pc. The bright linear feature may be interpreted as the background molecular cloud curving toward the observer so that one is looking down the region of emission with the resultant increase in surface brightness, a so called "limb brightening" similar to what one sees across the bar to the south of the Trapezium.

Detailed examination of the surface brightness and line ratios across the low ionization zone (#2) shows a drop of 2 and 3 in [O III]/Hβ and [O III]/[O II], respectively (Walter 1993). On first examination this might be attributed to a shadowing effect, but more detailed calculations of the scattered radiation field (O'Dell private communication) show that the region is not shadowed but rather attenuated. At the sharp boundary between the high ionization cavity and low ionization zone the ionization front (IF) turns from being nearly in cross section to the observer's line of sight (LOS), to being perpendicular to the observer's LOS across the low ionization zone. Ionizing radiation from θ^1 Ori C will be heavily attenuated as one moves across the zone and away from the Trapezium, resulting in a drop in ionization.

Continuing to the southwest and out of the low ionization zone, the level of ionization begins to increase and peaks about 2.5′ (0.38 pc) from the Trapezium (see Figures 1–3). Our slit positions go further west than the high ionization zone to the southwest (see Figure 1), but they do not directly cross into this region. Nonetheless, Walter (1993) and Baldwin et al. (1991) have both shown that along the observer's LOS the depth of the hydrogen emission zone increases as one moves west of the Trapezium. We interpret this and the increase in ionization at Feature #3 to mean that the molecular cloud is curving back toward the observer. The increase in ionization results because the IF is now closer to being perpendicular to the LOS from θ^1 Ori C, so the path length of the ionizing radiation through the attenuating gas is decreased. The geometric dilution of the radiation field is more than compensated by the decrease in attenuation, so the overall ionization level increases with distance.

Feature #4 to the northeast of the Trapezium is similar to the well known bar south of θ^1 Ori C. The northeastern bar is a density enhancement since it shows a sudden jump in the square root of the Hα surface brightness, which is $\propto N_e$. Furthermore, the ionization level across the northeastern bar drops (Walter 1993). The northeastern bar is located about 0.25 pc (100″) from θ^1 Ori C, is 0.30 pc long and has a maximum width of 0.04 pc. It lies in the heavily obscured region of the bay and does not show up well except in extinction corrected images or in line ratio maps for which extinction is minimal.

Finally, Feature #5 is an elliptical shaped region of high surface brightness (relative to the surrounding nebula) in ions of low ionization potential ([N II], [S II] and [O II]) and low surface brightness in the high ionization ion [O III]. The approximate center of the loop is located at: R.A.(2000.0) = 5^h 35^m $09^s\!.16$, Dec.(2000.0) = $-5°$ 23′ 44″, 1.5′ (0.21 pc) to the west of the Trapezium. The major axis of the loop is nearly east-west and is approximately 40″ (0.10 pc) long while the minor axis is 23″ (0.06 pc) long. This feature was briefly noted in Feibelman (1976). One of our slit positions ran along the major axis of the loop and enabled us to measure temperature and density diagnostics across the feature. Our study (Walter 1993) shows that the S^+ density in the knots at each end of the loop jump suddenly to $\sim$2500 cm^{-3}, double the value inside the loop and the surrounding nebula. Furthermore, the depth of emission along the observer's LOS is constant across the center of the loop, but decreases sharply by a factor of 2–4 at the edges of the loop. This indicates that the loop of material and its associated knots are foreground to at least part of the nebula and block out some background emission. The line ratios, density enhancement and overall appearance makes it a likely a bright Herbig Haro object (Reipurth 1991).

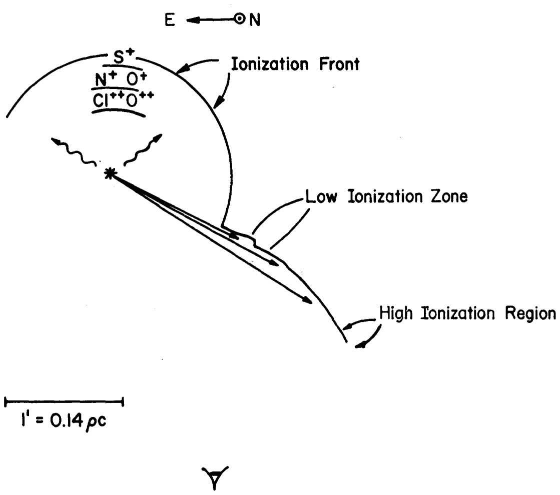

Figure 4: Schematic representation of the core of M42 showing features discussed in the text.

4. CONCLUSIONS

New long-slit spectra and existing CCD imagery of the core of the Orion Nebula have allowed us to form a picture of this region based on its ionization structure. This picture includes: a high ionization cavity approximately centered on the Trapezium; a low ionization zone to the southwest of θ^1 Ori C where the ionizing radiation is heavily attenuated; a region of increased ionization $\sim$2.5′ (0.38 pc) to the southwest of θ^1 Ori C where the background molecular cloud and the IF curve back toward the observer; a bar-like feature $\sim$1.5′ (0.23 pc) to the northeast of θ^1 Ori C; and, an ellipse of high density $\sim$1.5′ (0.23 pc) west of the Trapezium which is likely a Herbig Haro object. The major features in this picture are shown schematically in Figure 4.

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REFERENCES

Baldwin, J.A., Ferland, G.J., Martin, P.G., Corbin, M.R., Cota, S.A., Peterson, B.M., & Slettebak, A. 1991, ApJ, 374, 580

Feibelman, W.A. 1976, PASP, 88, 677

O'Dell, C.R., Valk, J.H., Wen, Z., & Meyer, D.M. 1993, ApJ 403, 678

Reipurth, B. 1991, in The Physics of Star Formation and Early Stellar Evolution, ed. C.J. Lada and N.D. Kylafis (Dordrecht, Kluwer), p. 497

Rubin, R.H., Simpson, J.P., Haas, M.R., & Erickson, E.F. 1991, ApJ 374, 564

Walter, D.K. 1993, Ph.D. thesis, Rice University

Walter, D.K., Dufour, R.J., & Hester, J.J. 1992, ApJ 397, 196

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