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H II REGIONS AS CAVITIES

Reginald J. Dufour[1]
Instituto de Astronomía, Universidad Nacional Autónoma de México

RESUMEN

Se presentan imágenes CCD calibradas de las regiones H II galácticas NGC 1624 y NGC 6523 (M8) en las líneas de emisión Hα, [O III]λ5007 y [S II]λ6723, con objeto de ilustrar la morfología "ampolla + cavidad" de la mayoría de las regiones H II galácticas. Además de mostrar la geometría del gas ionizado, las imágenes ilustran la diversidad de estructuras del medio interestelar que rodea a las estrellas jóvenes y calientes.

ABSTRACT

Calibrated CCD images of the galactic H II regions NGC 1624 and NGC 6523 (M8) in the emission lines of Hα, [O III]λ5007, and [S II]λ6723 are presented to illustrate the "blister + cavity" nature of most galactic H II regions. In addition to revealing the geometry of the ionized gas, the images illustrate a remarkable diversity of structure of the ISM surrounding young hot stars.

Key words: **H II REGIONS — ISM: INDIVIDUAL (NGC 1624, NGC 6523)**

1. INTRODUCTION

Photographs of H II regions in our galaxy and others reveal the structure of the ISM surrounding newl formed clusters of stars. With the advent of modern high quantum efficiency CCD imagers and interferenc filter technology, we can study the morphology of H II regions in different emission lines that provide ne information about the photoionized ISM and the physics of ionization fronts.

The physics of the H II region phenomenon for a homogeneous ISM was pioneered by Strömgren (1939 whereby he demonstrated that a static *Strömgren Sphere* would form around an O-star of a size which depenc on the balance between photoionizations and recombinations of the ISM gas (i.e., the stellar output in ionizin photons versus the ISM density in H and He). However, in subsequent decades it was appreciated that the ISM inhomogeneous, that most O-stars form on the edges of molecular clouds, and that the resulting H II regions a time-dependent entities with the star carving out cavities in the molecular cloud and the H II region developin into an ionization blister on the face of the cloud. The pioneer in developing the theoretical foundation for suc H II region evolution is, in the author's opinion, Tenorio-Tagle (1979). His H II region evolution scenario can b summarized into three phases: (a) *expanding sphere* —the O-star forms in the molecular cloud and the ionizatic front (I-front) expands more-or-less radially to form a small and bright compact H II sphere; (b) *breakout pha* —the I-front reaches the edge of the molecular cloud, where a steep drop in the ISM density is present, an the density discontinuity results in a pressure discontinuity and a shock front develops; (c) *champagne pha* —the strong supersonic shock propagates out into the intercloud medium and a "rarefaction wave" propagat inward into the ionized cavity of the molecular cloud, producing a supersonic outflow of ionized material in the outward intercloud medium. During phases (a) and (b) the nebula is optically thick and the time scal short, so most optically observed H II regions are expected to be seen in phase (c) —that is, as blisters wi cavities.

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[1] On sabbatical leave from the Department of Space Physics & Astronomy, Rice University, Houston, Texas U.S.A.

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2. IMAGERY RESULTS FOR TWO SELECTED GALACTIC H II REGIONS

In collaboration with J.J. Hester and P. Scowen of Arizona State University and R.A.R. Parker of NASA-Headquarters, we are publishing an *Atlas of CCD Imagery of Galactic H II Regions* (Hester et al. 1994) which gives unparalleled high signal-to-noise imagery of some 30-odd galactic H II regions north of –30° declination. The imagery was taken with the Palomar 1.5-m telescope and focal reducing system with an effective f-ratio of f/1.67 using a TI 800X800 CCD, resulting in a 16 arcmin diameter field at 1.2 arcsec per pixel. For each nebula, images were taken with interference filters isolating Hβ, [O III]λ5007, Hα, [N II]λ6583, and [S II]$\lambda\lambda$6717+30, and four continuum filters in between the emission lines. These data were flatfielded, aligned, and calibrated to produce emission line images of the nebulae with essentially all stars and continuum emission removed. While the *Atlas* gives both grey-scaled and color-coded surface brightness and line ratio maps of the nebulae, herein I will show only the surface brightness images of two nebulae (NGC 1624, NGC 6523) in Hα, [O III], and [S II].

2.1. NGC 6523, The Lagoon Nebula

Next to the Orion Nebula, NGC 6523 (The Lagoon Nebula) is the most prominent H II region in the Sagittarius Arm from our perspective in the Galaxy. Figure 1 (Plate 1) shows images of the nebula in Hα, [O III], and [S II]. For an assumed distance of 1.4 kpc (Georgelin & Georgelin 1970) the 16 arcmin CCD field corresponds to a 6.5 pc diameter field at the nebula. Note the different morphology of the nebula in the three emission lines: (a) in Hα the peak surface brightness is around the hourglass; (b) by contrast, the [O III] surface brightness is more like a flat plateau between the hourglass and 9 Sgr; (c) the [S II] emission peaks around the hourglass region, but is very filamentary, with an arclike "bay" south of the hourglass. In [S II] another curved arc structure is seen to the northwest of the hourglass and numerous ridges of filaments to the southeast of 9 Sgr across the dark lane.

2.2. NGC 1624

NGC 1624 is a spherical H II region located in the Perseus Arm, distance = 4.4 ±0.5 kpc (Georgelin & Georgelin 1970), selected because it is probably the best example of a *Strömgren Sphere* appearing H II region. The Hα image indicates a diameter of ~7 arcmin, or 9 pc at the 4.4 kpc distance (Figure 2, Plate 2). However, two aspects of the [S II] image suggests that it is not a Strömgren Sphere: (a) no [S II] bright rims are seen in the southern 180° half of the nebula and (b) a circular bright rim in [S II] is seen northward of the central cluster (indicative of a cavity north of the cluster stars).

3. DISCUSSION

Interpretation of the imagery requires an appreciation of the physics of photoionization and line formation. For the Hα surface brightness, which defines the H II region, one has for a uniformly filled volume: $S_{H\alpha} \propto {N_e}^2 dl$, where N_e is the electron density and dl is the line-of-sight path length. For a spherical homogeneous H II region, $S_{H\alpha}$ drops slowly from the center to the edge, then rapidly as dl diminishes suddenly at the edge of the sphere. Such is not seen, for both nebulae there is a rather steep drop off radially from the center. For NGC 6523, this is seen radially from the hourglass; and in NGC 1624, for the region north of the ionizing stars, which is brightest and drops outward roughly with slope 2 in the logarithmic surface brightness.

While such a variation could be produced by radial variations in density, another interpretation is that the H II region is just an ionized surface of a molecular cloud behind the ionizing star. For such a situation, $S_{H\alpha} \propto R^{-2}$, where R is the distance from the ionizing star to the wall that is appropriate to the line-of-sight (i.e., drops as the square of the angular distance from the star). Baldwin et al. (1991) noted that such seemed to be the case for the Orion Nebula, and Wen (1994) has used this (corrected for wall dust reflection) and [S II] density maps, to determine that θ^1 Ori C in M42 is 0.3 pc from the wall with a cavity existing around it.

Evidence for cavities in NGC 1624 and NGC 6523 are indicated from both [O III] and [S II] via very different surface brightness distributions. H° and O° have identical ionization potentials (13.6 eV), while that of O$^+$ is much higher (35.1 eV) and that of S° is significantly less (10.4 eV). Therefore, the [S II] emission emanates primarily at the ionization front and a little outward into the Photo-Dissociation-Region (Hester 1991). By contrast, [O III] emission emanates from highly ionized gas closer to the star. For a uniformly filled Strömgren Sphere, the [O III] emission will be in a sharply bounded smaller spherical region with a radial surface brightness distribution similar to Hα, but smaller. Alternatively, for the case of an ionization slab behind the star, the

[O III] distribution will vary with the radiation geometrical dilution factor, or as R^{-2}, for a uniform density slab. For both NGC 1624 and NGC 6523 (and for Orion), the [O III] surface brightness is rather constant at small distances from the exciting star(s), then it drops sharply. Therefore, at first look, the [O III] distribution would seem to suggest a uniform O^{+2} sphere around the star(s). However, if the star has cut a cavity into the cloud radially from the star, then R ~constant (distance from star to ionization front) on the face of the cloud, and the [O III] surface brightness would be uniform for small line-of-sight distances from the star. This is what is seen in NGC 1624, NGC 6523, M42 (Walter et al. 1993), and a majority of the galactic H II regions studied.

If such sharply bounded (i.e., density discontinuity) cavities exist around the exciting stars (presumably formed by photoevaporation of the cloud wall), not only would the [O III] distribution be rather flat around the star, but the ionization front edge, as indicated by [S II] emission of the cavity, would be seen just at the boundary of the flat [O III] plateau. This is seen in a majority of the H II regions studied; note the [S II] boundary south and southwest of 9 Sgr for NGC 6523 (Plate 1) and north of the three brightest stars in NGC 1624 (Plate 2). Not only are the inner [O III] cavities bounded by [S II] bright rims, but [S II] bright rims are seen for many objects farther out. The latter is explained if the H II region consists of an inner cavity and is largely optically thin towards the observer (or seen partially edge-on), such that the face of the backside ionization front wall has density ripples at distances farther away from the inner cavity, where ions with lower ionization potential than O^{+2} ([N II], [O II] and [S I]) show bright rims embedded in general emission. That parts of the H II regions are optically thin is clear for many by the lack of a [S II] boundary along parts of their outer perimeter; as can be seen in the southern (bottom) part of NGC 1624, for example.

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REFERENCES

Baldwin, J.A., Ferland, G.J., Martin, P.G., Corbin, M.R., Cota, S.A., Peterson, B.M., & Sletteback, A. 1991, ApJ, 374, 580
Georgelin, Y.M., & Georgelin, Y.P. 1970, A&A, 7, 133.
Hester, J.J. 1991, PASP, 103, 853
Hester, J.J., Dufour, R.J., Parker, R.A.R., & Scowen, P.A., 1994, CCD Atlas of Galactic H II Regions, NASA Research Publication, in preparation
Strömgren, B. 1939, ApJ, 89, 529
Tenorio-Tagle, G. 1979, A&A, 71, 59
Walter, D.K., Dufour, R.J., & Hester, J.J. 1993, RevMexAA, 27, 207
Wen, Zheng. 1994, Ph.D. thesis, Rice University

DISCUSSION

Carrasco: To further complicate matters, in Orion, "fingers" seen in H_2 seem to be coming out of the BN object. It would be interesting to see if they have counterparts in the various ratios images.

Dufour: In the near future we will be comparing the Orion imagery and ratio maps with new X-ray (*ROSAT*) and IR data; including the IR "fingers" recently published. One of the goals of our ATLAS project is to make such calibrated data on 30 H II regions to enable many investigators to pursue such multi-wavelength studies.

R.J. Dufour: Rice University, Dept. Space Physics/Astron., Box 1892, SS Bldg. Rm 232, Houston, TX 77251-1892 U.S.A. e-mail: rjd@rice.edu.

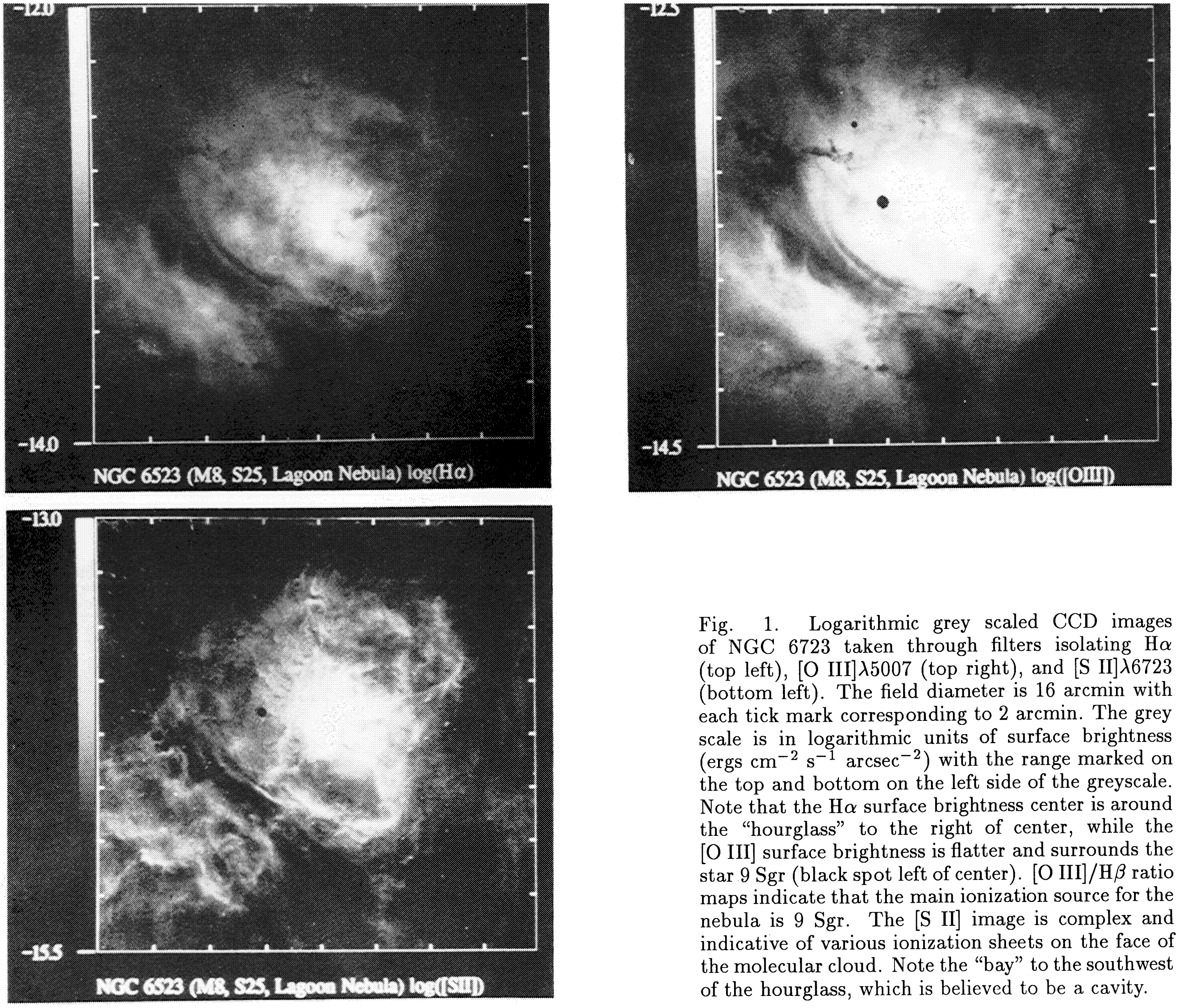

Fig. 1. Logarithmic grey scaled CCD images of NGC 6723 taken through filters isolating Hα (top left), [O III]λ5007 (top right), and [S II]λ6723 (bottom left). The field diameter is 16 arcmin with each tick mark corresponding to 2 arcmin. The grey scale is in logarithmic units of surface brightness (ergs cm^{-2} s^{-1} arcsec^{-2}) with the range marked on the top and bottom on the left side of the greyscale. Note that the Hα surface brightness center is around the "hourglass" to the right of center, while the [O III] surface brightness is flatter and surrounds the star 9 Sgr (black spot left of center). [O III]/Hβ ratio maps indicate that the main ionization source for the nebula is 9 Sgr. The [S II] image is complex and indicative of various ionization sheets on the face of the molecular cloud. Note the "bay" to the southwest of the hourglass, which is believed to be a cavity.

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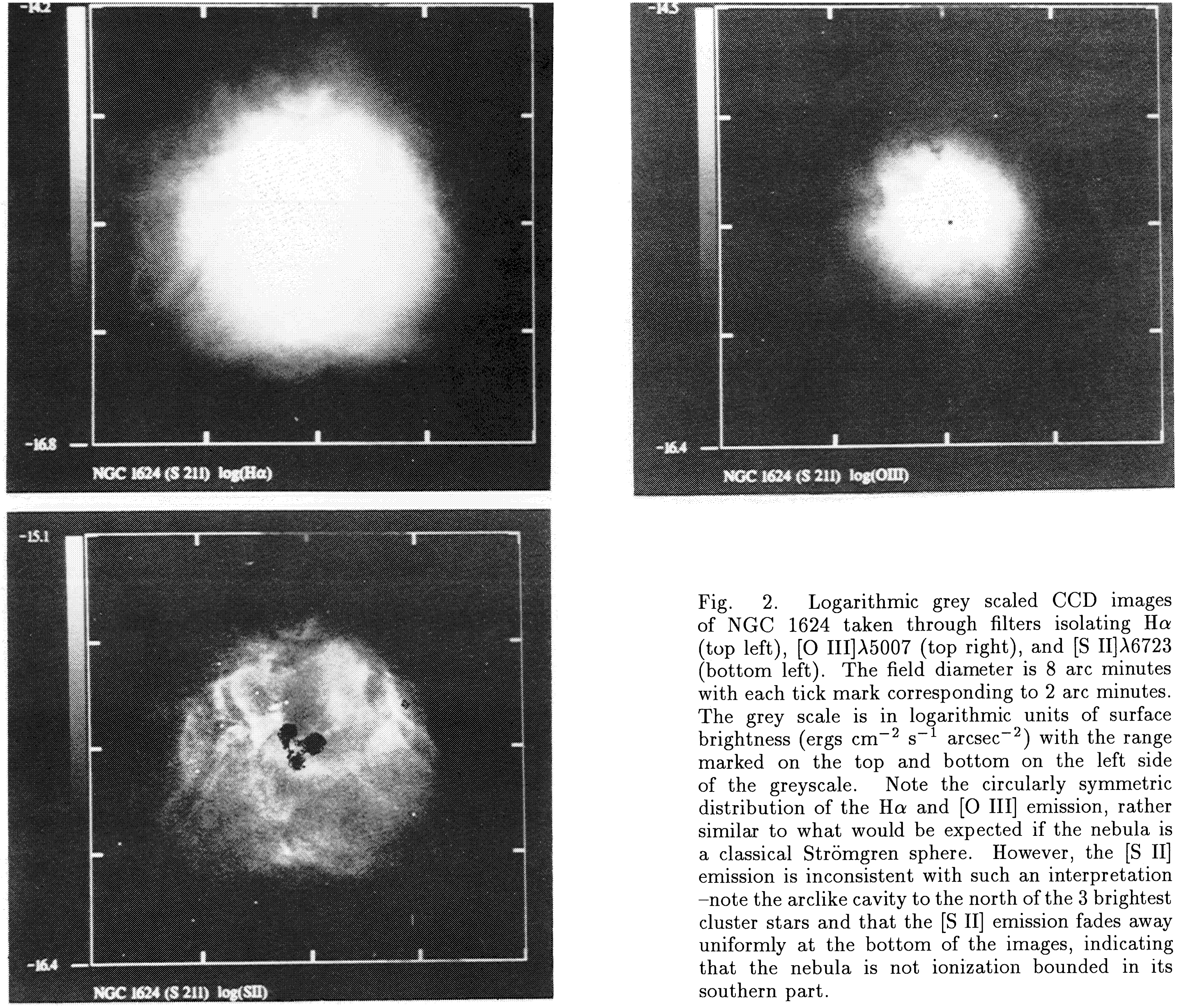

Fig. 2. Logarithmic grey scaled CCD images of NGC 1624 taken through filters isolating Hα (top left), [O III]λ5007 (top right), and [S II]λ6723 (bottom left). The field diameter is 8 arc minutes with each tick mark corresponding to 2 arc minutes. The grey scale is in logarithmic units of surface brightness (ergs cm^{-2} s^{-1} arcsec^{-2}) with the range marked on the top and bottom on the left side of the greyscale. Note the circularly symmetric distribution of the Hα and [O III] emission, rather similar to what would be expected if the nebula is a classical Strömgren sphere. However, the [S II] emission is inconsistent with such an interpretation –note the arclike cavity to the north of the 3 brightest cluster stars and that the [S II] emission fades away uniformly at the bottom of the images, indicating that the nebula is not ionization bounded in its southern part.