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A Rapidly Moving Shell in the Orion Nebula

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ABSTRACT. A well-resolved elliptical shell in the inner Orion Nebula has been investigated by monochromatic imaging plus high- and low-resolution spectroscopy. We find that it is of low ionization and the two bright ends are moving at -39 and -49 km s^{-1} with respect to OMC-1. There is no central object, even in the infrared J bandpass although H_2 emission indicates a possible association with the nearby very young pre-main-sequence star J&W 352, which is one of the youngest pre-main-sequence stars in the inner Orion Nebula. Many of the characteristics of this object (low ionization, blue shift) are like those of the Herbig-Haro objects, although the symmetric form would make it an unusual member of that class.

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1. INTRODUCTION

The basic structure of the Orion Nebula (NGC 1976, M42) is now understood to be that of a blister of ionized gas (Zuckerman 1973; Balick et al. 1974; Meaburn 1975; Pankonin et al. 1979; Balick et al. 1980) on the near side of the Orion Molecular Cloud. The relatively thin layer of ionized material is the background to a highly dense nearby cluster of young stars (Herbig 1982) and both of these regions are viewed through a layer of material optically thick to ionizing radiation but marginally optically thick in visual wavelengths (van der Werf and Goss 1989; O'Dell et al. 1992). Astrophysical methods have been used to determine a three-dimensional model of the ionized material (Wen and O'Dell 1995), which is a highly irregular concave form. The nebula is known to be populated by at least ten objects considered to be Herbig-Haro (HH) objects (Reipurth 1994) and numerous features resembling shock fronts which are blue shifted with respect to the main emitting layer (O'Dell et al. 1993a).

The cluster of stars associated with M42 is no more than 2 million years old (Prosser et al. 1994) and contains a large range of stellar masses, the lower-mass stars still being in their pre-main-sequence contraction. Most of these lower-mass stars are surrounded by circumstellar material which is likely to be distributed as disks, which may be protoplanetary. The facing side of most of these circumstellar disks, called proplyds, are photoionized by the same stars creating the ionized nebula. This causes local conditions of flow of the ionized material, which certainly occurs in the tails that point away from the sources of ionization (O'Dell et al. 1993b; O'Dell and Wen 1994) and may also occur on the cusps formed on the substellar sides (McCullough et al. 1994).

Given the presence of these very young stars, whose formation is commonly believed to produce disks and jets as necessary components, it is hardly surprising that imaging and spectroscopy reveal numerous examples of compressed material at large velocity. In this paper we report on observations made of a unique object, which is the only elliptical form object known in M42, while arcs are quite common. We will refer to this object as HH 269, using the serial designation of Reipurth for HH objects (Reipurth 1994). We shall see in this paper that this object has many of the properties of an HH object (albeit not all), so that the use of an HH catalog number here is appropriate. HH 269 was first pointed out by Feibelman (1976) although it is readily apparent in most of the color images of M42 that are in wide circulation. Feibelman noted its symmetric oval shape, described it as having a parachute form, and roughly determined that its proper motion was large. In his Ph.D. thesis on spectroscopy of M42, Walter (1993,1994) serendipitously found that HH 269 was also a region of enhanced density. The report of its very large expansion in the plane of the sky and local density enhancement indicated that this object merited further study.

2. OBSERVATIONAL MATERIAL

We have three types of data available on HH 269, monochromatic imaging, low-resolution spectroscopy, and high-resolution spectroscopy. Each type of data provides complementary information to the others and will be discussed in turn in this section.

2.1 Monochromatic Imaging

M42 has been imaged by one of the authors (O'Dell) with the *Hubble Space Telescope's* WFPC2 in Hα, [N II] and [O III]. Extracted portions centered on HH 269 are shown in Fig. 1. Lower spatial resolution (3.″3 FWHM) images in additional ions [O II] and [S II] are also available in the source "A CCD Imagery Atlas of Galactic H II Regions" (Hester et al. 1991). Figure 1 shows the form of the object quite well against the bright background of the nebula in [N II] while it is faintly visible in Hα and very weak in [O III]. The center of symmetry is at $5^h32^m41.^s72 - 5°25'38''$ (1950) and the dimensions are $41'' \times 23''$ with the long axis east–west. Although there are local variations in ionization ratios, the size

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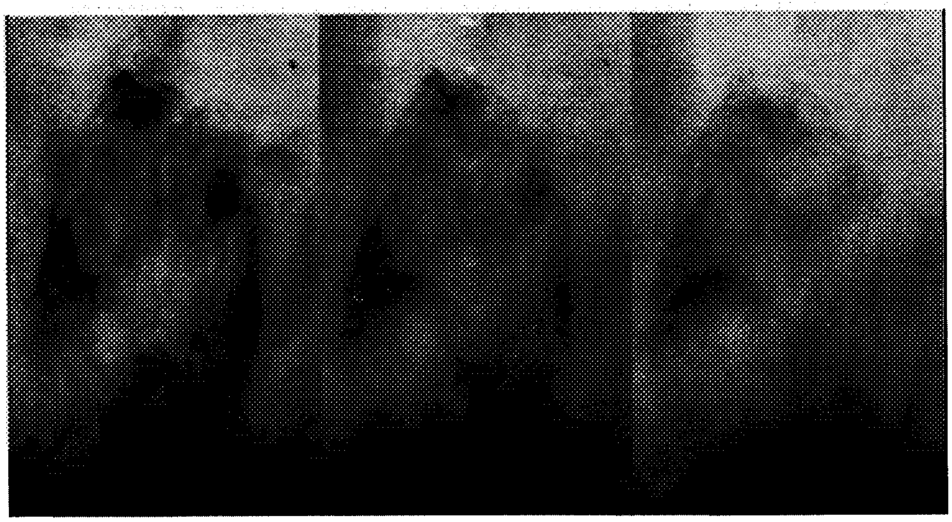

FIG. 1—A mosaic of a 50″×30″ region around HH 269 as imaged with the *HST*. The left is in [N II] 6583 Å, the middle is in Hα 6563 Å and the right is in [O III] 5007 Å. North is at the left in each image.

is indistinguishably the same in low- and moderate-ionization lines. The object is best defined in [S II], [O II], and [N II].

2.2 Low-Resolution Spectroscopy

Low-resolution spectra were obtained with the ES2 Cassegrain spectrograph on the 2.08-m telescope at McDonald Observatory in 1991 October and 1992 April. The details of the instrument configuration and observing conditions can be found in Walter (1993). The subset of spectra used for this study covered the range 3700–5050 and 5500–6900 Å at a resolution of 7 Å FWHM. The slit covered an effective area which was approximately 190 arcsec long and 4.1 arcsec wide and was oriented with the long dimension east–west through the guide star Parenago 1784, also known as J&W 352 (Jones and Walker 1988) and Orion 107–345 (O'Dell and Wen 1994). The slit lay essentially along the long axis of HH 269.

A succession of exposure times was used, up to 1800 s, to cover a large dynamic range in line fluxes. The spectra were rendered into absolute flux units through the use of standard stars as described in Walter (1993). To determine the physical conditions in HH 269 we sampled three regions, the eastern and western knots and the center of the elliptical shell. The surface brightness at the center of the shell shows little or no enhanced emission from HH 269 and is representative of the ambient nebular medium. Figures 2 and 3 were prepared from our longest exposures on which the [O III] 5007 Å plus 4959 Å and H I 6563 Å plus 4861 Å lines were saturated. The spectrum shown are the average of the east and west knots, with the central-region spectrum subtracted. Detailed spectrophotometry was not made due to the uncertainties in the nebular background subtracted caused by its strong and irregular nature. HH 269 is about one fourth as bright as the nebula, on the average.

Electron densities were calculated using the [S II] lines at 6717 and 6731 Å without subtraction of the nebular background. The sulfur densities arise from a lower-ionization region and have values of 2200, 2500, and 1300 cm^{-3} in the eastern knot, western knot, and central region. Since the ratios are composites of the lower density nebular background (the middle region is characteristic) and the higher density HH object, these densities are lower limits for HH 269.

A similar examination was made of the electron temperature using the [N II] lines at 5755 and 6583 Å. The temperatures from the [N II] lines were 9000, 9500, and 9000 K from the eastern knot, western knot, and central region, respectively. The limited number of spectra preclude an error analysis, and it is probably correct to say that there is no evidence for significant differences in the electron temperature.

We could get some idea of the spectra of HH 269 by the method of differencing, although the results are only quali-

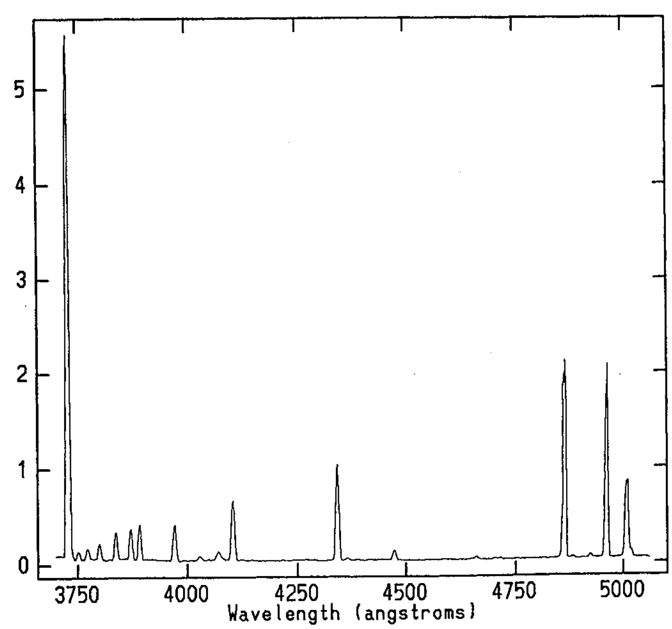

FIG. 2—The blue spectrum of HH 269 as described in the text. It has been normalized so that Hγ (4340 Å) is unity. The anomalous values of Hβ 4861 Å, and [O III] 4959 plus 5007 Å are due to saturation of these lines.

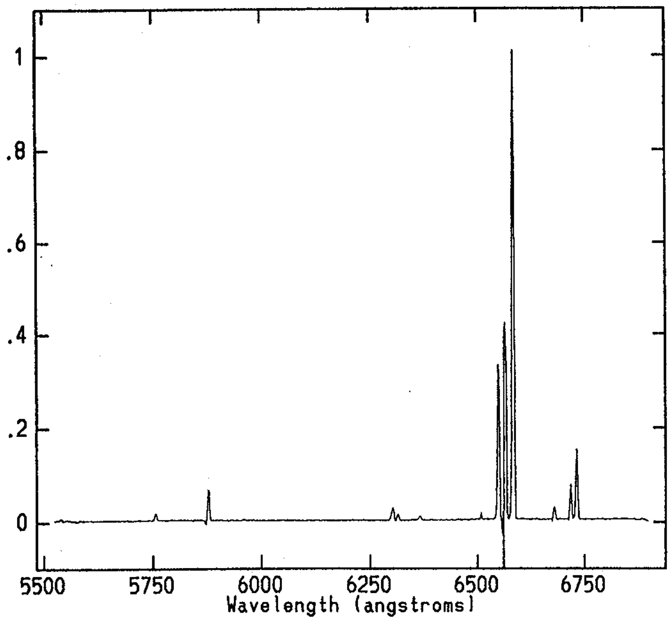

FIG. 3—The red spectrum of HH 269 as described in the text. It has been normalized so that the [N II] 6583 Å line is unity and the Hα 6563 Å intensity is anomalous as it was saturated in the original exposures.

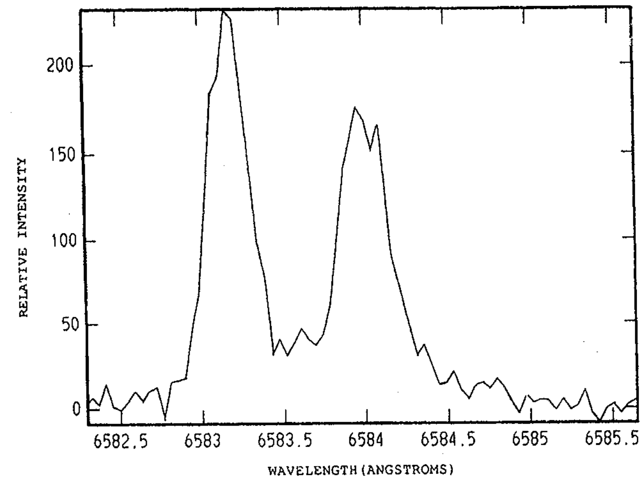

FIG. 4—The spectrum of the [N II] 6583 Å line on the west limb of HH 269 is shown with its red-velocity component due to the primary ionization front of the Orion Nebula and the blueshifted component due to HH 269.

tative. We used the spectra from each of the three regions (eastern and western knots plus the central region) and scaled the recombination lines Hγ and He I 5876 Å to be the same in all three regions and subtracted the middle spectrum from that of the bright knots of HH 269. The resulting difference spectra give a guide to the strengths of lines as compared with these recombination lines. These normalized difference spectra indicate enhancements in the object in emissions from [S II], 4068, 6717, 6731 Å, [O I] 6300 6364 Å, [N II] 5755, 6548, 6583 Å, and [O II] 3727 Å and reductions in [O III] 4959, 5007 Å and [Ne III] 3869 Å.

In the course of examining the spectra of each area we identified many weak lines which have only been reported earlier in Orion by Osterbrock et al. (1992). In the wavelength regions in common we can confirm essentially all of their identifications. Numerous weaker lines were also present, but they could all be ascribed to nightsky OH emission (Osterbrock and Martel 1992).

2.3 High-Resolution Spectroscopy

We also obtained high-resolution spectra of HH 269 with the Coude Feed system at Kitt Peak National Observatory on 1993 December 27–1994 January 2. The velocity FWHM of this system, which uses an echelle grating and grism cross dispersion was 4.2 km s^{-1}. Again an east–west slit orientation was used and was held constant during the 1800–2700 s exposures by use of an image rotator. The guide star used for the low-resolution spectra could not be seen with the slit viewing TV, so that we had to point the slit by offsets from θ^1C Ori. This pointing method results in a position uncertainty of several arcseconds. Line profiles were obtained for Hα, [O III] 5007 Å, [O II] 3726 and 3729 Å, [S II] 6717 and 6731 Å, He I 5876 Å, and [N II] 6548 and 6583 Å.

The spectra were deconvolved in units of 3 pixels, which extend over 3.3″, into multiple velocity components. Previous investigations (Castañeda 1988; O'Dell and Wen 1992; Jones 1992; Wen and O'Dell 1993; O'Dell et al. 1993a) have shown that high-resolution spectra of the Orion Nebula are composed of multiple velocity components which are due to different regions. Therefore, it was not surprising that each line broke down into three velocity systems extending over the 180″ length of the slit. These velocity systems naturally grouped themselves according to like velocities with [N II] and [S II] being similar (the low ionization ions) and H I, He I, [O II], and [O III] being similar (the high-ionization ions). The low-ionization systems occurred at 6.5±2.6, 22.4 ±1.3, and 34.6±2.2 km s^{-1} with the 22.4 km s^{-1} being much stronger. The high-ionization systems occurred at 2.0 ±0.8, 15.6±3.0, and 29.8±1.6 km s^{-1}, with the 15.6 km s^{-1} being much stronger. All velocities in this paper are heliocentric. An additional, blue shifted, velocity component was seen on the spectra corresponding to the east and west limbs of HH 269. This was present on all lines except [O II] and [O III]. A characteristic spectrum is shown in Fig. 4. The component for Hα is badly blended with the nebular emission due to the great thermal widths (25 km s^{-1}) of the low-mass H I atoms. We know from the low-resolution spectra and monochromatic images that the [O III] emission from HH 269 is weak. The absence of detected [O II] components was surprising, since the low-resolution spectra indicated that [O II] was strong. Perhaps the answer to this lies in the [O II] emission being of low-velocity relative to the principal ionization front. A blueshifted component at −22.5±2.4 km s^{-1} was seen in five lines (He I 5876, [S II] 6717 and 6731, [N II] 6548 and 6583 Å) and at −13±1.4 km s^{-1} in the two [N II] lines for the east limb. The coincidence of these blueshifted components with the positions of the knots in the shell is clear evidence for these knots approaching the observer.

3. DISCUSSION

Clearly HH 269 is a peculiar object, but its exact nature and geometry is ill defined. Its low ionization and expansion are similar to the characteristics of H II regions, but its elliptical form and absence of a central object argue against that classification. The various arguments for its classification are made in this section.

3.1 Radial Velocities and Proper Motion

Our high-resolution spectra indicate that its east and west components have heliocentric velocities of -13 and -22.5 km s^{-1}, respectively. O'Dell et al. (1993a) argue that the high-ionization component seen here at $+15.6$ km s^{-1} represents the main layer of emission, with the low-ionization component representing the motion of the actual ionization front of the blister, which is determined from more extensive data to be at 28 ± 2 km s^{-1}, an argument expanded upon by O'Dell (1994). The ionization front is not moving with respect to OMC-1. This means that the east and west components are moving 39 and 49 km s^{-1} blueward with respect to OMC-1 and its associated star cluster, which has the same velocity as the cloud. These velocities are only slightly lower than those of the two Herbig Haro regions (HH203 and HH204) found near θ^2A Ori and comparable to the lower end of the blueshifted velocities found for the Orion Herbig Haro objects northwest of the Trapezium and associated with the center of OMC-1. Meaburn (1986) has found an extended zone of blueshifted high-ionization emission near the northwest object HH 202 at -54 km s^{-1} with respect to OMC-1 and O'Dell et al. (1991) have found that HH 202 has low-ionization relative-velocity components of -60 to -117 km s^{-1}. O'Dell et al. (1993b) also measured velocities of HH 203 and 204 and found relative velocities of -50 to -74 km s^{-1}. There also seem to be high-velocity flow very near the proplyds that populate the region around the Trapezium (Meaburn et al. 1993; Massey and Meaburn 1993).

The high proper motions for HH 269 reported by Feibelmann (1976) deserve re-examination in the light of our new results. The intent of that paper was to note the possible presence of a large rate of expansion in the plane of the sky, rather than to claim a measurement of great accuracy. He used images made in 1909, 1960, and 1966 with three different telescopes, with the first epoch images being made with an unfiltered Seed emulsion and the last two images with plate–filter combinations that isolated the combination of Hα and the adjacent [N II] lines. Measurement of a knot on the west limb and two others on the south edge indicated an expansion velocity of 3."6/century with a very uncertain probable error, although he noted that the expansion was apparent even when comparing the two more recent images. This result needs to be taken with considerable caution because of the use of different telescopes for each image and also the different effective bandpasses. Feibelmann cautions the reader that the earlier image would have been dominated by Hβ and the [O III] lines (4861, 4959, and 5007 Å, respectively), because the Seed plate would have possessed the rapid drop in sensitivity near 5000 Å characteristic of the natural halide sensitivity curve. The more recent images are dominated Hα and [N II]. The rather poor-seeing quality monochromatic images that we have used do not reveal any difference in size in the various images, but do indicate that [N II] is enhanced in certain regions of the object. Moreover, these images and the spectra indicate that [O III] emission is at best very weak in the object. This means that the earliest image was actually dominated by Hβ emission while the more recent images were more strongly influenced by [N II]. This means that there is the possibility that the reported large expansion velocities are at least in part due to ionization stratification, the ameliorating factor to this conclusion being the report that the similarly filtered image pair also appeared to show expansion. At a distance of 500 pc, this expansion motion of 3."6/century would correspond to a tangential velocity of 85 km s^{-1}, which is not dissimilar to the radial velocity relative to OMC-1. This means that the expansion motion is plausible. Comparable values have been found (7."6–9."9/century) by Jones and Walker (1988) for the motion of HH 201, 205, and 210 away from the center of activity within OMC-1. Aside from any arguments of comparison, it is very important to determine the expansion in the plane of the sky by repeating the Palomar 5-m images made in 1960.

3.2 Is HH 269 Really an Herbig Haro Object?

Our object has many of the characteristics of an HH object, but not all. The standard model for the appearance of an HH object has a pair of opposed jets terminated by bow shocks and mach disks, the redshifted components often being obscured. In the case of HH 269 we have similar low ionization and velocities, but the shape is elliptical with no obvious source near the middle. The features already accepted as HH objects in M42 fall into two distinct class. Those in the north (HH 201, 205–10) are highly irregular knots followed by shocks while the others (HH 203–4) being similar to shocks. HH 202 falls in between the two extremes and HH 269 defines a new extreme for symmetry.

We looked for associated infrared features in digital copies of the J band, H_2, and [Fe II] images of Orion by Allen and Burton (1993). In the J band only a faint outline of the entire ellipse could be seen and nothing was present in the [Fe II] image. However, the eastern knot was very bright in the 2.1 micron line of H_2 and was elongated east–west for several arcseconds. There was a much fainter extension of this linear feature all of the way to J&W 352, which is 11″ east of the eastern knot. J&W 352 is also the variable LQ Ori, which Herbig and Terndrup (1986) spectroscopically classify as K2V. Recent photometry by Prosser et al. (1994) place this star well above the main sequence and at a position corresponding to a pre-main-sequence star of a contraction age of about 300,000 yr. An association of HH 269 and J&W 352 is difficult to assess since there are many bright arcs and linear features in the inner part of Orion. Perhaps forthcoming *HST* emission-line images of this region will resolve this question.

Although the classification of HH as an HH object is not established and it may not belong in this class, the object we call HH 269 is certainly interesting and deserves further study by spectroscopy and imaging.

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