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THE Hα VELOCITY FIELD OF THE OMEGA NEBULA (M17)

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ABSTRACT

Using a Fabry-Pérot camera, 9054 H α radial velocities were measured across the H II region M17. The mean $v(LSR) = 18.6 \pm 0.1$ km s⁻¹, which is 1.4 km s⁻¹ blueshifted with respect to the mean velocity of the associated molecular cloud M17 SW. The dispersion of the velocity histogram is slightly skewed to the blue. A gradient in radial velocity is observed from west to east, with the most blueshifted velocities appearing closest to the molecular cloud. The velocity field can be explained as a flow of ionized gas approximatively in the plane of the sky. There is a relation between random velocity and size, with velocity fluctuations increasing as some power of size; the power index depends on the sampling method of the velocity field. An interpretation of the relation is suggested in terms of turbulence, and a brief discussion of mechanisms for turbulent kinetic energy input is presented.

Subject headings: nebulae: individual — radial velocities

I. INTRODUCTION

The velocity fields of a majority of H II regions are best described as disordered, with little evidence of expansion. However the presence of line splitting at many points in nebulae reveals important differences along the line of sight (e.g., Wilson *et al.* 1959; Goudis and Meaburn 1976; Deharveng 1980; Clayton *et al.* 1985). Dynamical effects are present in diffuse nebulae, but they are not as systematic as in planetary nebulae and supernova remnants. The large-scale behavior revealed by detailed and extensive velocity maps (Wilson *et al.* 1959; Fischel and Feibelman 1973; Mufson *et al.* 1981; Fountain, Gary, and O'Dell 1983*a*, *b*, Joncas and Roy, 1984*a*, *b*) can be qualitatively interpreted in terms of a gas expansion away from regions of high density (Zuckerman 1973; Balick, Gammon, and Hjellming 1974; Bodenheimer, Tenorio-Tagle, and Yorke 1979).

The small-scale velocity fields may hide more information on the dynamics of H II regions. For example, the scaling of velocity fluctuations with linear size was first found in the Orion Nebula (von Hoerner 1951; Courtès 1955; Münch 1958). We also found a similar behavior of the velocity fluctuations in a recent interferometric investigation of the more evolved H II region S142 (Roy and Joncas 1985). Velocity fluctuations in S142 increase roughly with size to the 0.3-0.5 power, depending on the method of sampling of the velocity field. The correlation between random velocity and size is close but significantly steeper than that found in a Kolmogorov turbulence spectrum (0.33). Although it is not clear how velocity fluctuations reveal the presence of turbulence, these motions are worth studying because they are likely to reflect the processes acting locally in H II regions. The presence of significant turbulent kinetic energy may require reconsideration of the conditions determining energy equilibrium in H II regions. To understand the link between thermal and kinetic energy (Osterbrock 1974; O'Dell 1986) and to identify the sources of the turbulence, better knowledge of the global velocity fields and of the behavior of the velocity fluctations of H II regions of various ages is necessary. Following our interferometric study of the evolved H II region S142 (Joncas and Roy 1984; Roy and Joncas 1985), we chose to observe the younger H II region M17.

The Omega nebula (M17, NGC 6618, S45) is a powerful galactic source; it has thus been observed extensively at optical, radio, and infrared wavelengths (see Goudis 1976). Although the M17 complex has the appearance of an active star-forming region, whether star formation is occurring at the moment is still debated (Thronson and Lada 1983; Gatley *et al.* 1979; Jaffe and Fazio 1982). The nebula is part of a huge complex of molecular and atomic gas; the H II region M17 and its associated molecular cloud show a favorable line of sight for the study of interactions between the various gas components since they are viewed edge-on. Its high surface brightness makes it an ideal object for study at high spectral resolution.

We have conducted an investigation of the velocity field of the brightest central part of M17 at H α , using a Fabry-Pérot camera. The aim of our study was to obtain several thousand radial velocity measurements across the surface of the nebula to reconstruct its large-scale velocity structure and to investigate the correlation between random velocity and size.

II. BACKGROUND INFORMATION ON M17

The H II region M17 is located in the Sagittarius-Carina arm of the Galaxy ($l = 15^{\circ}.09$, $b = -0^{\circ}.74$). From their radial velocity survey of H II regions, Georgelin, Georgelin, and Roux (1973) give a mean V(LSR) of 19.0 km s⁻¹, implying a kinematical distance of 2.2 \pm 0.5 kpc, a distance adopted throughout this paper. Chini, Elsässer, and Neckel (1980) made multicolor photometry of stars in the region of the M17 " dark bay" (Fig. 1), the location at which Beetz *et al.* (1976) found a severely obscured star cluster ($A_v > 10$ mag); spectral types and a photometric distance of 2.2 \pm 0.2 kpc were derived from these observations. Nine stars, spread over the western part of M17, were given spectral types B0 V or earlier. The earliest



type star is O4 V. Felli, Churchwell, and Massi (1984) have given a summary of the ionization properties of the nebula.

Goudis and Meaburn (1976) and Elliot, Meaburn, and Terrett (1978) studied the internal motions of M17 at high spectral resolution (FWHM = 10.5 and 6.3 km s⁻¹) by observing the [O III] and [N II] lines. Both studies cover mainly the brightest part of M17. They measured velocities at 96 and 185 points, respectively, and found several instances of multiple splitting of these forbidden lines, especially where neutral intrusions of gas appear to be present. This occurs in the central and southern fainter regions of the nebula; the other parts display mostly single lines. Meaburn (1977) concluded that M17 is composed of superposed, partial shells of material, each of which presents an outer neutral surface and an ionized inner side facing the hot stars. The complex inner structure of the nebula is emphasized in recent echelle observations of the Ha and [N II] lines obtained along a N-S and E-W lines of M17 by Clayton et al. (1985). Radio recombination line observations (Gull and Balick 1974; Wink, Wilson, and Bieging 1983) in the area close to the peak of radio continuum emission (which is strongly obscured at optical wavelengths) also show line splitting. Finally, Meaburn and Walsh (1981) have discomponents covered high-velocity ranging from V(LSR) = -50 to -80 km s⁻¹ in a small region which makes the kinematical behavior of fine structure in the nebula more intriguing.

Radio continuum maps (Löbert and Goss 1978; Matthews, Harten, and Goss 1979; Wilson et al. 1979) reveal two major peaks of emission (M17 N and M17 S) located in the western part of the complex. Southwest of M17 S the emission falls off rapidly in the direction of a massive molecular cloud. Similarly, M17 N extends as a sharp edge along a southeast-northwest axis. These strong continuum gradients suggests the presence of ionization fronts (IF) disrupting neutral material. While M17 S has no optical counterpart, the edge of M17 N coincides with a bright bar visible at all optical wavelengths. Figure 1 shows a superposition of the 3.5 cm radio continuum map by Wilson et al. (1979) on a red photograph of M17. From highresolution VLA continuum maps, Felli, Churchwell, and Massi (1984) have confirmed the existence of an IF southwest of M17 S; the IF plane is tilted by 70° with respect to the line of sight. These observations also show a large number of neutral gas clumps in M17 N and M17 S, whose existence sets an upper limit of 5×10^5 yr to the age of M17. The rms density of the diffuse component of the ionized gas is between 300 and 500 cm^{-3} , while it reaches 1000 in M17 N and M17 S.

Lada (1976) and Thronson and Lada (1983) have studied a $30' \times 15'$ section (M17 SW) of the $4^{\circ} \times 1^{\circ}$ giant molecular cloud known to be associated with M17. They find two velocity components. First, a 20 km s⁻¹ cloud (see Fig. 1) is associated with the southern part of the dark bay west of the nebula. There is a drastic drop in CO brightness at this velocity when one approaches the interface with the H II region; this sharp boundary probably arises from a dissociation front and fits well with the radio continuum observations. The density of M17 SW is of the order of 10^4 cm⁻³ for a total mass of 3×10^4 M_{\odot} . A second molecular cloud with V(LSR) = 23 km s⁻¹ coincides in position with the H II region. Lada (1976) has argued for its location to be in front of the nebula. We will show contrary evidence.

Infrared observations of M17 at 10–21 μ m (Kleinmann 1973; Lemke and Low 1972) show bright emission coexisting with and peaking at the same position as the thermal radio

emission. This indicates that dust, heated by the exciting stars, is mixed with the ionized gas or associated with the ionization fronts surrounding the H II region. At longer wavelengths, this coincidence between infrared and radio continuum emission no longer exists, since cooler dust grains located outside the H II region are sampled (Wilson *et al.* 1979; Gatley *et al.* 1979); the cold dust is present mainly to the northeast and southwest of the ionized gas.

III. OBSERVATIONS AND DATA PROCESSING

High-resolution spectroscopy of the brightest central portion of the H II region M17 was conducted by using a Fabry-Pérot (F-P) camera that combines a guiding and calibration head, an $f/8 \rightarrow f/0.95$ focal reducer, and a servostabilized piezoelectrically scanned F-P interferometer; the interferometer has a FWHM = 20 km s⁻¹ and a free spectral range of 283 km s⁻¹ at H α (656.282 nm). The interferograms were recorded photographically on hypersensitized IIIa-F photographic plates. A full description of the instrument is given in Joncas and Roy (1984a). The observations were obtained with the 1.6 m telescope of the Observatoire Astronomique du Mont Mégantic (Québec) during one short summer night in July 1983. In addition to filtergrams a H α and [N II] 658.4 nm, five interferograms, corresponding to different spacings of the F-P etalon, were obtained; they cover most of the central part of M17 (Fig. 2).

Comparison interferograms of calibration rings produced by a hydrogen lamp were also taken before and after the nebular interferogram in order to check the stability of the interferometer; drifts were less than 1.5 km s⁻¹. The plates were digitized with a PDS microdensitometer at the Laboratoire d'Astronomie Spatiale (Marseille). The pixel size was 1".9 on the plane of the sky. The algorithms used to extract the radial velocities and to produce the velocity histograms and maps are described in Joncas and Roy (1984*a*, *b*). One of the five H α interferograms of M17 and a [N II] filtergram showing the field of view are presented in Fig. 2.

IV. THE H& VELOCITY FIELD

a) Histogram of the LSR Velocity Points

The histogram of the 9054 H α LSR velocities measured over the central part of M17 is shown in Figure 3. The mean LSR velocity is 18.6 \pm 0.1 km s⁻¹; the most probable velocity is 21 km s⁻¹. This is in close agreement with the results of Georgelin, Georgelin, and Roux (1973) at H α and with those of Goudis and Meaburn (1976) at [O III] 500.7 nm. A mean LSR velocity of 18.2 (σ = 2.1) km s⁻¹ was calculated from the compilation of radio line observations made by Goudis and Meaburn (1976) and from more recent radio line observations. This is very close to the mean H α velocity. The standard deviation of the H α velocity histrogram is 10.1 \pm 0.1 km s⁻¹; there is a slight skewness (-0.6) in the velocity distribution favoring blueshifted velocities. The mean H α velocity is shifted by only -1.4 km s⁻¹ with respect to the velocity of the M17 SW molecular cloud.

b) Velocity Maps

Velocity maps (Fig. 4) were constructed at a spatial resolution of 15" by taking the average LSR velocity from all measurements in each $15'' \times 15''$ window across M17. This gridding corresponds to a smoothing over projected 0.16 pc \times 0.16 pc squares at the inferred distance of 2.2 kpc. The

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FIG. 2.—(a) H α interferogram of the central part of M17 with a f/8 \rightarrow f/0.95 Fabry-Pérot camera attached to the Mont Mégantic Observatory 1.6 m telescope. Exposure time is 35 minutes on a hypersensitized IIIaF photographic plate. Reference pointers are used to pinpoint the center of each interferogram. (b) [N II] 658.4 nm filtergram of the central part of M17. Exposure time is 40 minutes. Four of the exciting stars are circled; the arrow indicates the northern ionization front. Star A is of spectral type O4 V, B and C are O5 V, and D is O8 V.

velocity maps are displayed in steps of 7 km s⁻¹. The various alphabetical letters indicate the number of velocity points averaged in each 15" × 15" windows: A (1 point), B (2–9 points), C (10–25), and D (26–50). Velocity points within 1 σ of the mean can be found almost all over the nebula. The highest blueshifted velocities (about -12 km s^{-1} with respect to the mean) are located in the obscured western and southwestern sections of the nebula and in the northwestern bright section. The highest redshifts (+12 km s⁻¹ with respect to the mean) are found in the bright eastern tail and in the southeastern section of our field of view. Near the end of the dark bay, velocities are close to that of the molecular cloud or slightly redshifted by 5 km s⁻¹.

A slight west-to-east velocity gradient can be seen across the

nebula. The nebula is bordered by an IF in the west (§ II). This IF could induce a gas flow perpendicular to the line of sight; this would explain why the majority of the velocity points have a V(LSR) close to the one of the molecular cloud. Another IF, also seen edge-on, is present to the north, but no particular behavior is obvious along the north-south axis. However, no velocity greater than 20 km s⁻¹ is seen at the declination of the norther IF ($-16^{\circ}12'$ to $-16^{\circ}10'$).

c) Velocity Dispersion M17

To study the velocity fluctuations across M17, we computed the standard deviation from the mean V(LSR) in each 15" window, provided that more than 10 velocity measurements were available. This standard deviation is called "velocity dis-

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FIG. 2b

persion," as in Joncas and Roy (1984b). The histogram of the velocity dispersion is shown in Figure 5. The mean value of the velocity dispersion is 7.5 ± 0.1 km s⁻¹, but the histogram is skewed by ~0.25, and the most probable velocity dispersion is 5.0 km s⁻¹.

The maps of velocity dispersion (not shown) show some systematic trend. The dispersion appears to increase roughly radially away from the center of the field. This behavior can be caused in part by the lower S/N of the outer fainter Fabry-Perot rings combined with their lower spectral resolution; spectral dispersion becomes smaller for the outer rings on a F-P interferogram. However, a few bright regions also display high velocity dispersion. Another effect is the possible variation of the depth of the line of sight. It had been noticed a long time ago by Baade *et al.* (1933) that the brightest parts of a nebula show small dispersion in velocity than the fainter ones. Furthermore, many of the positions experiencing large dispersions $(>10 \text{ km s}^{-1})$ are located in regions where line splitting has been observed by the Manchester group; that is, west of the dark bay and in the central southern section. However, the correlation is not clear since small dispersions $(0-5 \text{ km s}^{-1})$ can also be found in the central southern section. The velocity dispersion is low on either side of the northern IF as well as near the two O5 V stars (Fig. 2b).

V. A KINEMATICAL MODEL FOR M17

The reader should be reminded that H α observations reveal only a restricted view of the H II region kinematics (see Clayton *et al.* 1985) and that we observe properties as projected on an apparent surface; the three-dimensional picture can the NASA Astronhysics Data System

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FIG. 3.—Histogram of 9054 $V_{\rm LSR}$ measured at H α over the central part of M17. The mean is 18.6 km s⁻¹ with a standard deviation of 10.1 km s⁻¹.

be extrapolated only with difficulty. If we assume that the M17 complex is viewed edge-on, one interpretation of the velocity field displayed in Figure 4 is that the ionized gas is flowing away from a cavity etched into the molecular cloud by the photoionizing stars. The Champagne model (Bodenheimer, Tenorio-Tagle, and Yorke 1979) predicts such a flow, but it is difficult to compare our observations with the model because of the uncertainties in the geometry. We can only say that our observations are consistent with a Champagne flow viewed from the side; however, this is not a unique interpretation of the observations. The gradient could be interpreted as a rotation of the H II region or it could be a chance anisotropy of gas motions on the largest scales (Kleiner and Dickman 1985). If we assume that the kinematics of the nebula is dominated by a Champagne flow, the small difference (-1.4 km s^{-1}) between the mean V(LSR) of the ionized gas and that of the M17 SW molecular cloud suggests that the cavity axis is roughtly perpendicular to the line of sight and open to the east; the axis of the main flow would be roughly in the plane of the sky. The candidate exciting stars are distributed east and north of the radio continuum peak emission. Some of the blueshifted velocities with respect with the molecular cloud (i.e., $-3.0 \leq V(\text{LSR}) \leq 18.0 \text{ km s}^{-1}$) are found over the dark bay, which suggests that the molecular cloud could have been pierced here and there by UV photons, allowing the ionized gas to escape in our direction. The O4 V star is seen close to one of these regions of blueshifted gas (Figs. 2b and 4). Ionization by foreground stars is a less likely alternative because all ionizing stars are highly reddened and no early-type star can be identified in the foreground in that part of the nebula. Extending from the dark bay to east and northeast is a redshifted lane $(20 \leq V(\text{LSR}) \leq 32 \text{ km s}^{-1})$. A sketchy representation of M17 summarizing the above

A sketchy representation of M17 summarizing the above configuration is shown in Figure 6. The redshifted lane has its origin at a slab of neutral or molecular material corresponding with the dark bay; it is located somewhere between the observer and the majority of the ionizing stars. Close to the dark bay, the velocity of the ionized gas is $\sim 20 \text{ km s}^{-1}$, the velocity of M17 SW. The slab is disrupted by the UV photons, its breaking-up revealing itself by the presence of large blueshifts. The redshifted lane has an extent of 6 pc against the plane of the sky, implying a projected velocity gradient of less than 2 km s⁻¹ pc. With respect to the molecular cloud, the largest redshifts are 10–12 km s⁻¹, while the largest blueshifts reach -20 km s^{-1} .

Almost every part of the nebula has radial velocities close to the systemic velocity of the M17 complex, i.e., 20 km s⁻¹. We suggest that these velocities correspond with the main flow in the plane of the sky. Slightly red- and blueshifted velocities $(20 \pm 5 \text{ km s}^{-1})$, found everywhere east of the dark bay, could arise from divergence in the flow as it comes out of the molecular cavity. The blueshifted velocities seen in the bright northwestern section and to the south of the field of view could arise from the IF eating away M17 SW; indeed, this IF is tilted by $\sim 70^{\circ}$ with respect to the line of sight (Felli, Churchwell, and Massi 1984). Finally, it should be noted that the varying depth in the line of sight caused by extinction could cause systematic trends in the observed radial velocities if dust was present in the ionized gas on a global scale. Ishida and Kawajiri (1968) and Chini, Elsasser, and Neckel (1980) have shown a gradient in extinction going from east (~ 2 mag) to west (~ 10 mag), with the maximum extinction occurring near the radio continuum peak of M17 S. However, there is no severe effect on the $H\alpha$ velocity maps; if this were the case one would observe related behaviors in the radial velocity and velocity dispersion maps. This is not what we observe.

In regions where the radio recombination line profiles (Gull and Balick 1974) are split, the H α velocity corresponds to the strongest radio component (always the redshifted component); when the radio components are of equal strength, $H\alpha$ is observed at both velocities over the area of the $2' \times 2'$ radio beam. This may reflect the varying depth of the optical line of sight in the western part of M17. The splitting of the radio lines observed over a large portion of the obscured western part of M17 suggests the cavity configuration and the presence of dust in it. The red component, which has a mean V(LSR) = 25.2km s^{-1} , could be associated with the near side of the cavity, while the blue component at 8.6 km s⁻¹ would originate from the far side. In the regions where Goudis and Meaburn (1976) measured single profiles in [O III] (e.g., northern bright part near the IF), there is excellent agreement with the H α velocities; in the central southern part of M17, where [O III] and [N II] show splitting, the H α velocities are about equal to the mean velocity of the multiple components (18.5 km s⁻¹), Because $H\alpha$ arises from a more diffuse volume of gas than forbidden lines and because of its large intrinsic width, large velocity gradients are required to produce splitting.

A puzzling aspect of the kinematics of M17 is a 23 km s⁻¹ molecular cloud claimed by Lada (1976) to be in the foreground with respect to the nebula. Lada and Chaisson (1975) found an H₂CO cloud at 23.5 ($\sigma = 0.2$ km s⁻¹) in absorption; thus they suggested that the 23 km s⁻¹ molecular cloud was a foreground object absorbing the 6 cm continuum emission from the ionized gas. If this were the case, M17 would hardly be visible at optical wavelengths, considering the column density of 2 × 10¹⁸ cm⁻¹ (equivalent to $A_V \approx 15$ mag) inferred for the molecular cloud. We propose instead that the H₂CO cloud is not related with the 23 km s⁻¹ CO cloud but with some intervening atomic hydrogen. Lockhart and Goss (1978) made high-resolution maps (2' × 2' × 0.84 km s⁻¹) of H I



FIG. 4.—H α LSR velocity maps of M17 in steps of 7 km s⁻¹ averaged over 15". The different letters represent the number of velocity points averaged over each 15" × 15" window: A(1 point), B(2–9 points), C(10–25), and D(26–50). Plus signs (+) represent the stars A, B, and C (see Fig. 2b). Crosses (×) indicate the positions of the two peak radio continuum emission: M17 N and M17 S. Dot shows the position of the peak ¹²CO emission of the M17 SW molecular cloud.



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FIG. 5.—Histogram of the velocity dispersion across the central part of M17 ($15'' \times 15''$ window). The most probable velocity dispersion is 5.0 km s⁻¹.

absorption lines in the direction of M17. The optical depth profiles were well fitted by eight Gaussians. The component of interest to us is at $V(LSR) = 24.0 \text{ km s}^{-1}$ and has an optical depth of 0.8; this is large enough to protect the H₂ molecules from being dissociated by the UV photons (Davies and Matthews 1972). Although there is no direct way of deriving the distance to the 23 km s⁻¹ molecular cloud, it is more probably located behind M17. Instead, a foreground H I cloud is present, possibly explaining the H₂CO seen in absorption; this





cloud would not be closely related to M17. H_2CO is known to be present not only in molecular clouds but also in H I clouds (Watson 1977).

The presence of an IF along the northern section of the nebula is a bit surprising. No 20 km s⁻¹ CO has been detected there. However, the Berkeley Low Latitude Survey (Weaver and Williams 1973) reveals H I emission at $(l = 15^{\circ}5, b = -10^{\circ})$ peaking at $V(\text{LSR}) = 20 \text{ km s}^{-1}$, and at $(l = 15^{\circ}0, b = -0^{\circ}75)$ peaking at 19 km s⁻¹ (see Fig. 2 of Sato and Fukui 1978). Even if it is difficult to separate H I components in this galactic direction, these observations support the presence of an H I cloud north of M17.

VI. VELOCITY FLUCTUATIONS IN M17

a) Dispersion of LSR Velocities

The study of velocity dispersion in the interstellar medium is a useful tool for the evaluation of the role of local dynamical processes, in particular, turbulence. Turbulence characterizes a fluid in irregular motion but structured by a hierarchy of vortices. If turbulence is present, a power-law relationship between velocity fluctuations and the linear size of these vortices can be present (Kleiner and Dickman 1985). To study the relationship between velocity dispersion and linear size, we divided the velocity map of M17 into grids of different mesh size as in Roy and Joncas (1985). The grids, varying in mesh size from 15" and 120", were chosen to ensure that a sufficient number of velocity measurements would be present in each window and that a sufficient number of windows would cover the nebula to give statistically significant results. An example of histogram of velocity dispersion is shown in Figure 5. Following the principle that in a gas where the motions have a Maxwellian distribution, the most probable velocity corresponds with the *e*-folding width of the emitted Doppler line profile, we related each window size with its most probable velocity dispersion. The relationship is shown in Figure 7. The coefficient of correlation (Pearson product-moment) is 0.95. The point at 9 pc is the e-folding width of the histogram of the 9054 LSR velocities. A linear regression through the points leads to a relation of the form

$$\sigma(V) = 8.8(\pm 1.1)l^{0.25 \pm 0.04} . \tag{1}$$

This is, within uncertainties, very close to the relation found for S142 (see Fig. 2 in Roy and Joncas 1985). The relation for M17 has a lesser number of velocities; we had close to 41,000 V(LSR) for S142. One interpretation of such a power-law relationship is in term of an energy cascade in a turbulent hierarchy of eddies (Fleck 1983; Roy and Joncas 1985; Kleiner and Dickman 1985). However, there are difficulties with this intepretation (Kleiner and Dickman 1985); the structure function provides a more rigorous tool for this (Scalo 1984).

b) Structure Function

If a medium is turbulent, a characteristic property will be fluctuations in velocity and density which are related to linear size. One can investigate such possible relationships with correlation functions such as the structure function or the autocorrelation function (Kaplan 1966; Scalo 1984; Kleiner and Dickman 1985). The structure function is

$B(r) = [v(r') - v(r'')]^2,$

where r = r' - r'' and v(r') and v(r'') are the velocities measured at points r' and r'' and r is the scale under investigation for

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FIG. 7.—Logarithmic plot of the velocity dispersion as a function of mesh size on the nebula. Width of each window has been converted into parsecs using an assumed distance of 2.2 kpc. The vertical bars correspond to the statistical uncertainty of the calculated points. A linear regression through the points gives the relation $\sigma(V) = (8.8 \pm 1.1) \times l^{0.25 \pm 0.04}$.

velocity correlation. Our data set roughly satisfies the conditions under which this method of investigation must be applied (Kaplan 1966; Scalo 1984).

The structure function for M17 is shown in Fig. 8, where r is the projected separation in parsecs. Apart from the fact that the structure function of M17 is noisier (larger statistical uncertainties) than that of S142 (Roy and Joncas 1985), their



FIG. 8.—Logarithmic plot of the structure function as a function of the separation between radial velocity points. Vertical bars correspond to the statistical uncertainty of the calculated points. Horizontal bar indicates the sound velocity in M17.

resemblance is striking, except that velocity fluctuations are larger on average in M17. Furthermore, the range of scales over which a power-law relation applies is limited to scales less than 2 pc only. We recognize three main regimes. (1) The structure function increases slightly for 0.03 < r < 1 pc; such behavior could be explained by projection effects which smear the small velocity dispersions (corresponding to small scales) with the large dispersions due to distant points seen close to each other by projection. The net result is a leveling-off of the structure function at small scales (Kaplan 1966; Scalo 1984). (2) For 1 < r < 2.0 pc, the structure function takes the form $B(r) \approx r$, i.e., $\Delta V \approx r^{1/2}$. If turbulence is responsible for the observed power-law scaling of velocity fluctuations with linear size, the relation is steeper than the one predicted from Kolmogoroff law for incompressible subsonic turbulence (Kolmogoroff 1941). This steeper slope could be explained by a dissipative turbulent energy cascade in a supersonic regime (Fleck 1981; Scalo and Pumphrey 1982). (3) For r > 2.0 pc, decorrelation occurs; this happens in M17 at a much smaller fraction of the H II region diameter than for S142. If turbulence is present in M17, this could be explained by the absence of eddies larger than a few parsecs. Because M17 is younger than S142, turbulence may not have had the time to grow beyond that scale. This is based upon the suggestion that Kelvin-Helmhotz instabilities can develop in H II regions experiencing Champagne flows (Roy and Joncas 1985). Since K-H vortices need $\sim 10^6$ yr to grow and that the inferred age for M17 is 5×10^5 yr, large eddies would be absent in M17. Decorrelation can also be due to the inadequacy of the spatial correlation approach in dealing with large eddies (Cantwell 1981). In this range, the value of B(r) is nearly constant at 196 ($\sigma = 10$) km² s⁻², and is close to the decorrelation limit of twice the variance of all the velocity points (206 km² s⁻²). Finally, it should be pointed out that uncertainties due to the observational technique will change the shape of the low end of the structure function. Our F-P measurements have typical uncertainties of a few km s^{-1} ; however, this is a lower limit because other effects, such as nonuniform surface brightness, increase the effective uncertainty. Some of the leveling-off of the structure function at the low end may be due to this experimental uncertainty.

c) Origin of Turbulent Motions

The correlation of random velocities with size for scales smaller than 2 pc in M17 is consistent with a turbulent energy cascade. Osterbrock (1974) suggested some time ago that turbulence could result from photoionization of an initially very homogeneous neutral gas complex. The dynamics of such a configuration has been studied in another context by Sanford, Whitaker, and Klein (1982), who have shown that jets of ionized gas moving into the intercloud medium with velocities of the order of 25 km s⁻¹ can be produced by the interaction of the radiation-driven ionization shock fronts with the geometrically inhomogeneous molecular cloud. As in the case of the Champagne flow, the interaction of these supersonic ionized flows with the surrounding gas is subject to instabilities (Norman et al. 1982); these could develop into the turbulent eddies. Such ionized jets in M17 could develop at the northern IF and from the IF in contact with M17 SW. Another possibility is the interaction of the ionized flows emanating from the neutral intrusions discussed by Meaburn (1977). M17 harbors several early-type stars which must produce strong stellar winds. Although it is not clear how such winds will affect the global nebular velocity fields, their energy input will eventually

be shared by the small-scale velocity fields. The presence of many large sheets of ionized material has been well documented by Elliott, Meaburn, and Terrett (1978) and Clayton et al. (1985), for example. Moving sheets or partial shells created by stellar winds or other means are ordered, but their motions will be randomized by collisions with other sheets (Dickey 1985). The larger amplitude of velocity fluctuations observed in M17 compared with S142 may reflect the input of stellar winds which are likely more preponderant in the former H II region. M17 has numerous OB stars (Chini, Elsässer, and Neckel 1980); it has at least two O4 and two O5 stars while the main ionizing stars in S142 are the O6 binary DH Cep.

The origin of similar line-width-size correlations for molecular clouds (Larson 1979, 1981; Myers 1983; Kleiner and Dickman 1985) and for H II regions (Roy and Joncas 1985; Roy, Arsenault, and Joncas 1986; O'Dell 1986) is puzzling. However, it has been pointed out by Kleiner and Dickman (1985) that the utility of these relations as a probe of turbulence in the interstellar medium rests upon the premise that gas motions within all clouds are part of a single homogeneous velocity field which uniformly pervades the Galaxy. The finding that molecular clouds and some H II regions share a similar kinematical behavior supports such a Galaxian velocity field.

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VII. CONCLUSION

More than 9000 radial velocities have been measured at $H\alpha$ across the H II region M17, using a Fabry-Pérot camera. The $H\alpha$ velocity field is consistent with a flow of ionized gas seen mostly edge-on, which could originate at the molecular cloud west and southwest of the H II region; this interpretation, however, may not be unique. Analysis of the velocity dispersions and fluctuations as a function of linear size reveals a power-law relationship; one possible mechanism producing such a relationship is a dissipative energy cascade of turbulent eddies. The structure function shows that the velocity fluctuations in M17 display a similar behavior to that of S142, except that velocity fluctuations are larger in M17, and that a powerlaw relationship between velocity fluctuations and linear size is observed over only a limited range of scales.

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