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INTERNAL MOTIONS IN H II REGIONS V. THE PLANETARY NEBULA M1-67, POSSIBLY AN H II REGION

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RESUMEN

Por medio de la interferometría de Fabry-Pérot se ha obtenido el campo de velocidades de M1-67 clasificada anteriormente como nebulosa planetaria. Las dispersiones normales de las velocidades son del orden de 40-70 km s^{-1}. Con respecto a la estrella central, el extremo norte tiene un exceso negativo de velocidades mientras que el extremo sur muestra un exceso positivo. Esto combinado con la bi-simetría del objeto sugiere que la nebulosa se ha formado por la eyección no isotrópica de masa de la estrella central a semejanza del mecanismo propuesto anteriormente para NGC 6164-5 y NGC 2359. La edad de la nebulosa se estima en 5.8×10^3 años. Se concluye que M1-67 debe ser considerada como una región H II y no como una nebulosa planetaria clásica.

ABSTRACT

We have obtained by Fabry-Pérot interferometry the radial velocity field of M1-67 classified earlier as a planetary. The standard deviations of the velocities are in the range 40-70 km s^{-1}. With respect to the central star, the northern edge has excess negative velocity and the southern edge, excess positive velocity. This and the bi-symmetry of the structure suggest that the nebula is formed essentially by non-isotropic mass ejection from the central star by a mechanism proposed earlier for NGC 6164-5 and NGC 2359.

The age of the nebula is estimated as 5.8×10^3 years. Arguments are presented to conclude that M1-67 should be considered an H II region rather than a classical planetary nebula.

Key words: **H II REGIONS — INTERFEROMETRY — NEBULAE, PLANETARY — RADIAL VELOCITIES.**

I. INTRODUCTION

In his search for faint emission objects Minkowski discovered that there was a nebula surrounding the star 209 BAC (Bordeaux Astrographic Chart), a star which Merrill had shown earlier to be a Wolf Rayet of the nitrogen sequence (WN8). The star is sometimes referred to as "Merrill's star". Minkowski classified the nebula as a planetary and so far this is regarded as the only one which has a WN star as a nucleus. Both star and nebula gave a high radial velocity, of the order of 200 km s^{-1}.

Bertola's photometric and spectroscopic study of this object (Bertola 1964) confirmed the high velocity of the nebula; Bertola moreover, showed that the degree of excitation was rather low for a planetary. Khromov and Kohoutek (1968) have suggested that this object "probably does not belong morphologically to the class of planetary nebulae". From optical, infrared and radio data Cohen and Barlow (1975) conclude that M1-67 is probably not a planetary nebula. We are in agreement with their conclusion as will be shown later.

II. DESCRIPTION OF MI-67

Figure 1 (Plate 1) is an enlargement from a positive print of a red plate taken with the 1.22 m reflector of Asiago Observatory. The nebula shows a great deal of structure in the form of blobs of material; however some symmetry is clearly present. Two branches starting from the ends of a bar-like structure curl around like spiral arms. Figure 2*a* and *b* (Plate 2) show two photographs in Hα of exposure time 5 min and 10 min respectively in which the bi-symmetry of the image is manifest. In this paper we present the radial velocity field of M1-67 obtained from our Fabry-Pérot interferometry in Hα. A discussion of our results together with previously known properties of the object provide sufficient elements to suggest that M1-67, rather than a planetary nebula in the classic sense, is an H II region.

III. THE OBSERVATIONS

In our program on the internal motions in H II regions we included the object M1-67 because of its interesting and peculiar morphology. The Fabry-Pérot interferometer used in the determination of the radial velocities is a focal reducer attached to the 33-inch reflector of the Observatory at San Pedro Mártir, Baja California. The interferometer is equipped with an étalon the spacing between the mirrors of which is 520 microns, giving an interorder separation of 190 km s^{-1} at Hα. The étalon has a "finesse" of around 12. A 10 Å halfwidth interference filter isolates the Hα line. Calibrations are made through interferograms of a hydrogen bulb attached to the focal reducer. The interferograms are taken on 103aG films through a one-stage Varo image tube. The scale of the interferograms is 90 arcsec per millimeter.

The observational material used in this study consists of three interferograms listed in Table 1. The first column gives the plate number; the second, the 1975 coordinates of the plate center; the third gives the number of measured points, column 4, the mean of the radial velocities to be discussed later; fifth column the exposure time. The last column gives the date of the observations.

The polar coordinates of the maximum intensity points of all significant details on the interferograms are measured using the Mann comparator at the NASA Johnson Space Center; the reductions are carried out following the method given by Courtès (1960). Further the interferograms are visually compared with the direct image of the region in order to eliminate those measurements which might be affected by the convolution of the interference pattern with the direct Hα image of the nebula.

The radial velocity of the object as previously determined by several authors is around 200 km s^{-1} (a list of these velocities is given later in this discussion). This velocity is very close to the interorder separation of the interferograms. The ambiguity of the interference order of the measured points was removed by adjusting the average velocity to a value in the range 190-220 km s^{-1}.

IV. THE VELOCITY FIELD

In Figure 3 are plotted the radial velocities of the individual measured points on FI 356; this is by far the best interferogram of our material. The individual velocities in the remaining interferograms are not of quality comparable to FI 356 to warrant a detailed discussion; therefore we have used these interferograms only for their average velocities and their standard deviations.

TABLE 1

Plate Number	Coordinates of Plate Center (1975) α	δ	Number of Points	Mean Radial Velocity* (km s^{-1})	Exposure Time (min)	Date of Observation
FI 356	19^h10^m;	+ 16°49.7	15	203 ± 69	17	13 August, 1977
FI 387	19 10 ;	+ 16 50.2	11	190 ± 41	25	16 November, 1977
FI 388	19 10 ;	+ 16 50.0	22	216 ± 50	35	16 November, 1977

* With standard deviations.

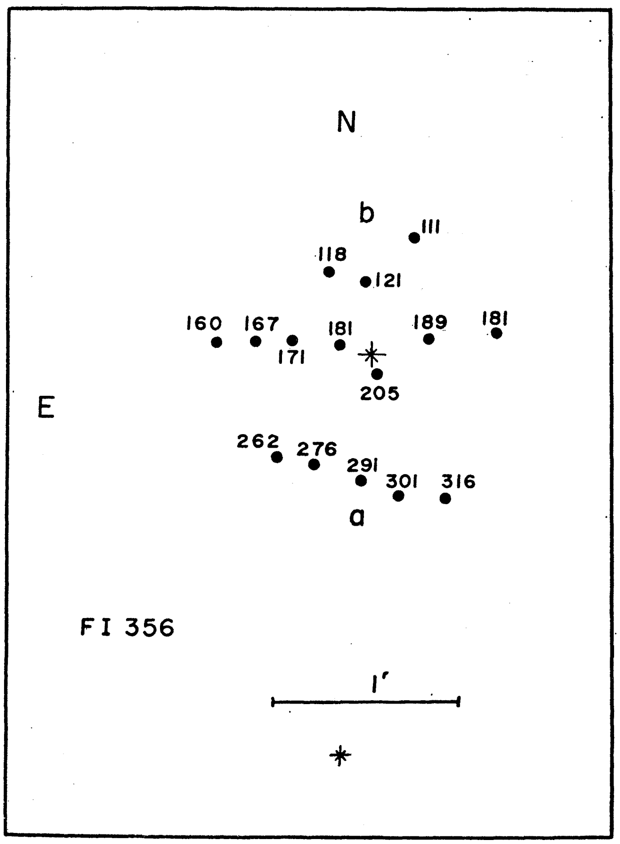

Fig. 3. A plot of the radial velocities determined at the indicated points from interferogram FI 356, exposure time 17 minutes.

The average velocity of M1-67 from our material is 203 km s^{-1}. The high value of the standard deviations which are in the range 40-70 km s^{-1} indicate that the internal motions are quite large. Further, the distribution of radial velocities from Figure 3 shows clearly that the motions are not chaotic but rather ordered. A representative value for the radial component of the expansion velocity in the vicinity of the star may be taken as -18 km s^{-1} which is the average of the two points nearest the exciting star if we exclude the closest point where the velocity might be vitiated by the presence of the star. Remembering that the velocity of radial expansion (if isotropic) is twice the average velocity in the line of sight we find that a radial velocity of 18 km s^{-1} yields 36 km s^{-1} for the velocity of ejection. If we include the neglected nearest point, the expansion velocity would be around 24 km s^{-1}. Moreover, the branch at the southern edge of the nebula (marked *a* on Figure 3) composed of a string of Hα knots exhibits excess negative velocity of the order of 85 km s^{-1} suggesting that it is moving away from the central star. We note that the radial velocity increases outwards along this feature and attains a maximum of 113 km s^{-1}. The northern edge shows an excess negative velocity of the order of 80 km s^{-1}, Unfortunately the faint branch (marked *b* in Figure 3) symmetrical to the southern branch (*a*) was not registered on our interferograms hence its velocity structure is not known.

We like to emphasize that our plate scale is rather small so that a more detailed analysis of the velocity field is not possible. In general, however, we may state that the central region exhibits an outward motion in the range 25-35 km s^{-1}, and furthermore that the southern and northern regions are going away from the central star in opposite directions.

We have estimated the age of M1-67 based on our values for the parameters involved. We adopt the radius (projected) of the nebula as 1 pc and the transverse velocity of expansion of the outermost measured points as 100 km s^{-1}. Further, we have used as a representative velocity of expansion the harmonic mean of 100 km s^{-1} and 600 km s^{-1}, the escape velocity from the surface of the star (Cohen and Barlow 1975). With these values the age of the first ejection from the parent star is roughly 5.8×10^3 years, smaller by a factor of 2 compared with the age estimated by Cohen and Barlow, 1.4×10^4 years.

V. DISCUSSION

As mentioned earlier, M1-67 is too small for our plate scale to say a great deal and in detail about its kinematics. However, the velocity field obtained in the present study points to the suggestion that M1-67 has essentially originated from the ejection of matter by the central star, 209 BAC, a star which at present is observed to be WN8. The morphology and the kinematics of the nebula suggest strongly that ejection of matter has not been isotropic but rather from active spots localized on a rotating star. The alignment of the blobs makes the assumption plausible that such ejection has proceeded in a discontinuous manner.

The velocity structure of M1-67 also suggests that the active spots are located on the opposite hemispheres of the star, perhaps opposite to one another along a diameter which is oblique to the axis of rotation. One can further point out that this ejection might have occurred when the star was not yet in the Wolf-Rayet stage.

VI. COMMENTS ON THE CLASSIFICATION AS A PLANETARY

We review here the physical parameters pertaining to M1-67 and the central star obtained in the present study as well as from other sources. Table 2 lists the pertinent data. We have estimated the distance to M1-67 as 4.5 kpc using Bertola's photometry and the absolute magnitude and intrinsic color calibrations by Crampton (1971). Our value is comparable to the distance, 4.3 kpc, obtained by Cohen and Barlow (1975) who have used data somewhat different from ours.

Several criteria will be applied to M1-67 to see whether it can be considered a "classical" planetary. These criteria are the following: *a)* morphology and size, *b*) distance from the galactic plane, *c*) kinematics in the galaxy, *d*) internal motions, *e*) excitation degree, and *f)* the central star.

a) From Table 2 it is clear that the size (2.0 × 1.6 pc), is outside the range covered by the planetaries. (Osterbrock 1974). As regards morphology, the nebula, quite symmetric with respect to its exciting central star, shows very intense emission blobs which are rather uncommon in planetary nebulae. Thus criterion *a* does not favor a planetary definition for the object.

b) We find that the average distance from the galactic plane is rather typical of planetaries; the latter show a marked concentration to the galactic plane, with a root-mean square z distance of 215 pc (Osterbrock 1974). Our object has an estimated z of about 260 pc for a distance of 4.5 kpc.

c) The line of sight velocity of this object is much higher than expected even of a planetary (see Figure 9.3, in Osterbrock 1974). Perek has found that the orbit of Merrill's star is hyperbolic (Perek 1956). His discussion is based on a model of the

TABLE 2

DATA RELATED TO CENTRAL STAR AND NEBULA

Star BAC 209 (Bordeaux Astrographic Chart 516)		
Coordinates α:	$19^h 10^m 29^s.7$ (1978)	
δ:	$+ 16°49'.8$	
l:	$50°21'$ b: $+ 3°31'$	
Spectrum:	WN8	(1)
m_v	11.24 mag	(1)
B − V	+ 1.00 mag	(1)
E(B − V)	~ 1.00 mag	(1)
A_v	3.00 mag	
M_V	− 5.00 mag	(2)
Distance	4.3 kpc	(3)
	4.5 kpc	(4)
Galactocentric	8.0 kpc (R_o = 10)	(4)
z	240 pc	(4)
Radial Velocity	+198, +194 km s^{-1}	(5)
	+195 km s^{-1}	(3)
Nebula		
Dimensions	90″ × 75″	(1)
	1.96 × 1.64 pc (at a distance of 4.5 kpc)	(4)
Radial Velocity	+220 km s^{-1}	(1)
	+203 km s^{-1}	(4)

(1) Bertola (1964), (2) Crampton (1971), (3) Cohen and Barlow (1975), (4) this paper, (5) Merrill (1938).

Galaxy consisting of a point mass, a homogeneous spheroid inside the solar circle and 11 homogeneous spheroids outside the sun. (Oort and van Woerkom 1941). Our estimate of the galactocentric distance is 8 kpc (R_0 = 10). With this new value, a line of sight velocity of 200 km s^{-1} and a circular velocity of 252 km s^{-1} (Schmidt 1965), we estimate the rotational velocity of the object to be 410 km s^{-1}. For a point mass the escape velocity at the location of M1-67 would be 1.4 times the circular velocity, or 353 km s^{-1}. However, this assumption is far from reality. We have therefore adopted a model consisting of a point mass in the center and a homogeneous spheroid; for this model the ratio V_{escape} to $V_{circular}$ can be obtained analytically. This ratio is 1.5 at 8 kpc so that the escape velocity of M1-67 in such a system is around 380 km s^{-1}. Thus the rotational velocity is larger than the parabolic velocity by 30 km s^{-1}.

Considering the uncertainties of the observational parameters employed, a more refined model for the galactic mass distribution did not seem to us necessary in the estimation of the velocity. In any case, it appears quite likely that the orbit of the object is hyperbolic.

d) The internal motions on which we commented earlier in this paper show a much higher dispersion than expected in planetaries; however the motions are ordered. Such large expansion velocities found in this study are not observed in planetaries.

e) The degree of excitation of M1-67 has been reported (Bertola 1964; Cohen and Barlow 1975) to be rather low for a planetary nebula.

f) The central star is classified as a Wolf-Rayet of the nitrogen sequence. So far all central stars of planetary nebulae of type Wolf-Rayet are of the carbon sequence; the fact that M1-67 is a unique case with a WN central star, also casts doubt on its being a typical planetary. It might be that ejection from the presumably more massive Population I stars would produce the symmetrical nebulae such as NGC 6164-5, NGC 2359 and M1-67 which resemble planetaries formed around the less massive central stars belonging to the disk population. It is conceivable that the observed physical conditions in a nebula formed by ejection and the mode of ejection are related to the integral properties such as total mass of the central star.

Summarizing we may say therefore, that the definitive arguments in deciding whether M1-67 should be taken as a planetary nebula or an H II region are afforded by criteria *a, d* and *e*. Criteria *a* and *d* are entirely consistent with an H II region. Criterion *c* refers to the high velocity of M1-67 which is much too high for a planetary. At the galactic longitude of this object the upper limit of the observed radial velocities of planetary nebulae are no larger than 70 km s^{-1} (Osterbrock 1974) while the observed velocity is 200 km s^{-1}, a value larger than the expected velocity by a factor 2.8. If a Population I object, the corresponding factor will be 4.0. In any event, be it a planetary or not, the high velocity cannot be explained in the frame of steady state galactic dynamics. One needs to postulate that the object has acquired kinetic energy by an encounter or by the disruption of a double or multiple star system. The occurrence of such an event giving rise to a runaway object appears more probable for a Population I rather than for a disk star. Thus criterion *c* does not rule out that M1-67 is not an H II region. The remaining criteria, namely *b* and *f* do not provide strong argument for or against the classification of this object as a planetary nebula.

We would like to emphasize, however that this conclusion is based on conventional views. It seems to us that the definition of a planetary is rather vague. It might be more convenient and less ambiguous to define a planetary as a nebula formed essentially by ejection of gas from a central star which is not a nova or a supernova; then M1-67 would be a planetary. This sort of a definition would embrace a few marginal or exceptional cases such as M1-67 with central stars of Population I while the classical planetaries have central stars belonging to the disk population.

VII. CONCLUSION

M1-67 is the third of a series of symmetrical nebulae we have studied by Fabry-Pérot interferometry; the other two are NGC 6164-5 and NGC 2359 (referred to as a ring nebula). In all three we have found evidence that the nebulae have originated essentially by gas ejected from their central stars and that the ejection has not been isotropic. The model for the ejection which we have proposed earlier (Pişmiş 1974; Pişmiş *et al* 1977) accounts for the observed velocity field and structural features of the three nebulae. In this picture the differences in the morphology and the velocity field between the three objects can be explained by the difference in the orientation of the ejecting diameter to the rotation axis and to the line of sight. These are estimated for NGC 6164-5 and NGC 2359 (Pişmiş 1974; Pişmiş *et al.* 1977). For M1-67 we do not attempt at this stage to determine the orientation of the model; all we can say is that the observed motions of the gas give evidence for non-isotropic ejection. A confrontation of model with observation will await a more detailed determination of the velocity field of M1-67.

We are thankful to Dr. F. Bertola for providing us with an enlargement on film of M1-67, reproduced in Figure 1. M. A. Moreno and A. Quintero have obtained the observational material used in this work.

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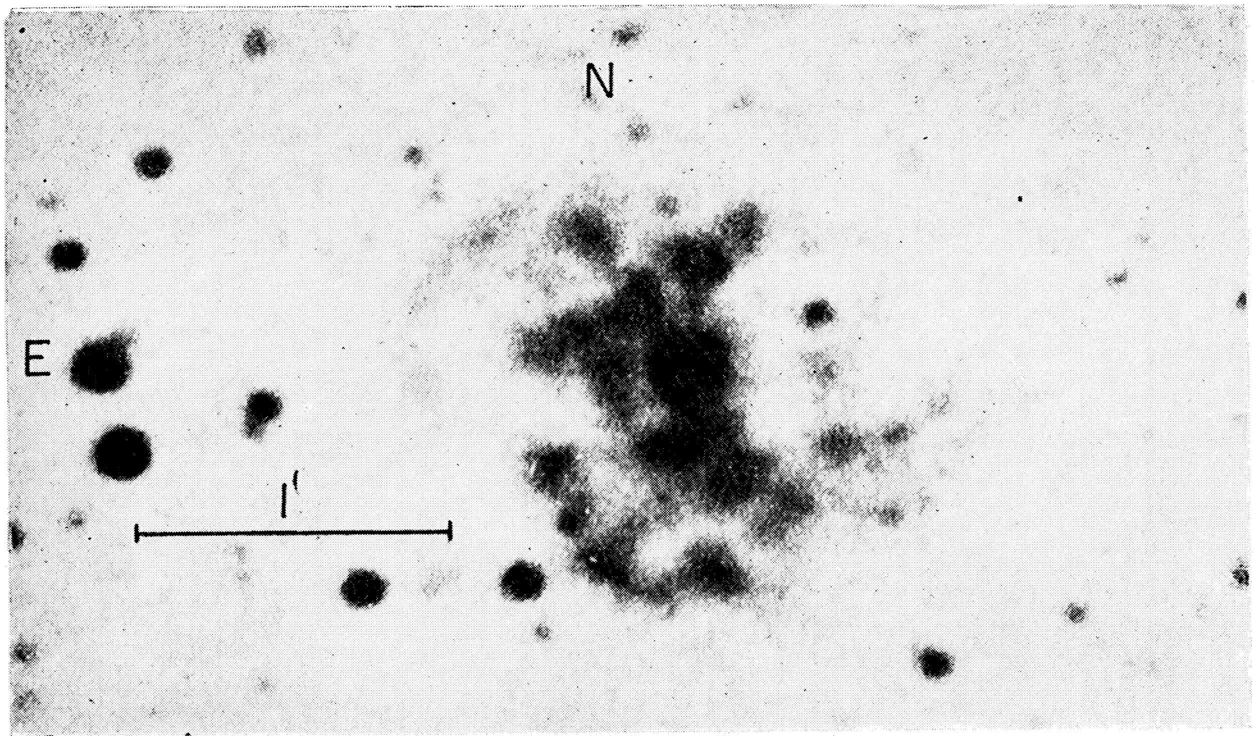
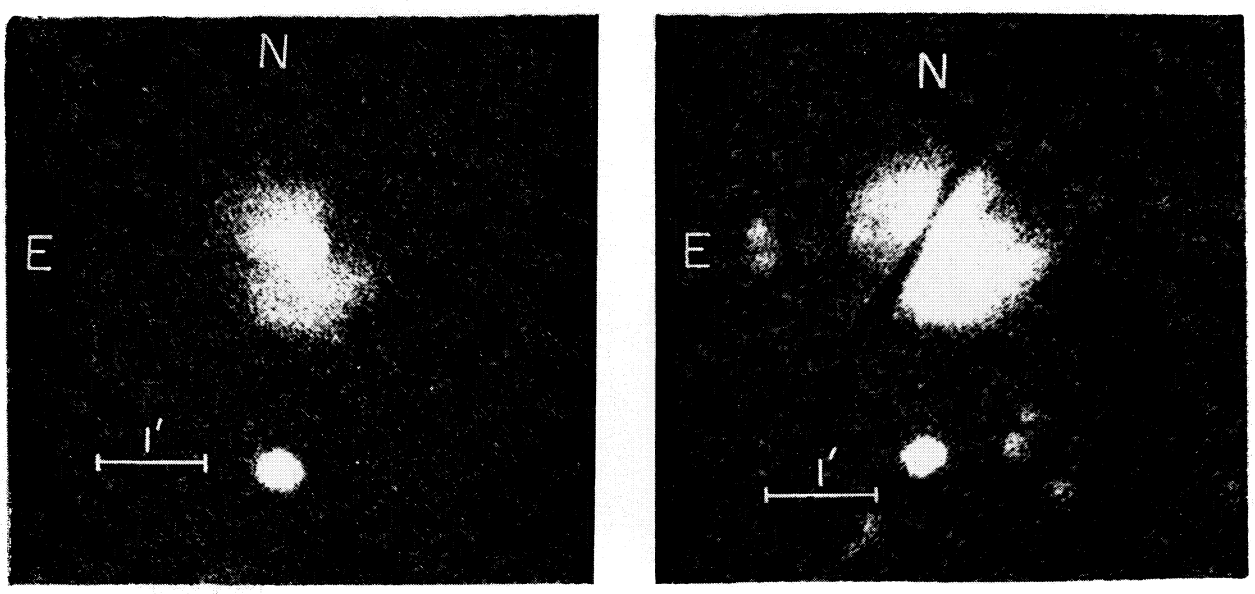


FIG. 1. (Plate 1) Enlargement of a red plate of M1-67 taken with the 1.22 m reflector of Asiago Observatory, courtesy of Dr. F. Bertola. The string of H II blobs is clearly manifested. The exposure time is 80 min.



a

b

FIG. 2*a*,*b*. (Plate 2) Enlargements of two photographs of M1-67, 5 min and 10 min of exposure time, respectively, taken with a 10Å halfwidth Hα filter and a Varo image tube with a focal reducer attached to the 82 cm reflector of the Observatorio Astronómico Nacional at San Pedro Mártir, B. C. The dark band in 2*b* is due to the cross-wire of the focal reducer. Scale on original film is 90 arcsec mm^{-1}. Although no details such as in Figure 1 are visible on the enlargements, the bi-symmetry of the object can be traced.