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ON TWO HII REGIONS NEAR THE NUCLEUS OF M82

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SUMARIO

A partir de placas fotográficas tomadas con varios filtros y con el prisma objetivo de la cámara Schmidt de Tonantzintla se ha hecho un estudio de las regiones nucleares de M82.

Se analiza, además de la región H II asociada con el núcleo, otra región H II de 9.6 segundos de arco de diámetro localizada a 14″ al suroeste del centro y que probablemente fue expulsada por el núcleo hace menos de 3×10^6 años. Se reportan valores de la intensidad en Hα, de la masa y de la energía invertida en la expulsión de esta región H II.

ABSTRACT

Schmidt camera objective prism and direct photographic plates taken with different filters are used in this study of the nuclear regions of M82.

In addition to the nuclear H II region, an extremely bright H II region 9.6″ in diameter at 14″ SW of the center is analyzed; the latter probably was ejected from the nucleus less than 3×10^6 years ago. Estimates of the mass, the Hα intensity and the energy involved in the ejection process of this H II region are given.

I. Introduction

Haro and Rivera Terrazas (1951) reported the presence of two very bright H II regions of approximately equal brightness near the nucleus of M82. These H II regions can be seen in a short exposure objective prism plate around Hα (Fig. 1). The Hα intensity of these H II regions is considerably stronger than the Hα emission which spreads over all the galaxy. We decided to investigate these two H II regions and in particular to find out which of the two, if any, was associated with the nucleus of M82. From now on we will refer to the larger region as M82 I and to the smaller one as M82 II. M82 I is the H II region studied earlier by Peimbert and Spinrad (1970).

Figures 2 and 3 show two direct plates in blue and infrared light, respectively; these were used as comparison plates. It is well known that M82 is immersed in dust. Therefore, from the blue plate it is very difficult to decide whether M82 has a nucleus at all; however at infrared wavelengths the effect of the absorption diminishes considerably. Thus from Figure 3 and other infrared plates (Raff 1969; Bertola, D'Odorico, Ford, and Rubin 1969; van den Bergh 1969 *a, b)* it is clear that M82 I is associated with the brightest continuum source present in those plates. In fact, it is the very region adopted as the nucleus of M82 by Burbidge, Burbidge, and Rubin (1964) and by Peimbert and Spinrad (1970). Figure 4 shows a schematic drawing of the two H II regions as well as of the rectangle within which Kleinmann and Low (1969) observed the 5-22 μ emission; from this figure it appears probable that the infrared emission also originates in M82 I. Therefore from the direct plates in the 0.8 - 1.0 μ region, under the assumption that the center of mass and the center of continuum light coincide, it follows that the nucleus and M82 I are coincident.

II. The Two H II Regions

From the objective prism plate, reproduced in Figure 1, the relative sizes and positions of the two H II regions were estimated. M82 I is located at 114″.5 N and 90″ E of BD + 70° 587, these relative positions being uncertain by about 1″; the line joining the centers of the two HII regions has a position angle of $\sim$ 58° which is very similar to the position angle of the major axis (62° according to Burbidge *et al.* 1964). To estimate the ratio of the Hα intensity of M82 I to that of M82 II we assumed the same reddening for both regions. Some support for this assumption comes from the following argument: Elvius (1969) determined $B-V = +1.26$ for a region 42″ in diameter (point O) centered on M82 I and which included M82 II; Burbidge *et al.* found an A2 - A5 spectral type for a region 25″ - 65″ NE from the center and Peimbert and Spinrad (1970) found an even earlier type for the center; consequently $(B-V)_i \sim 0.00$ can be adopted, from which it follows that $E(B-V) \sim +1.26$ for Elvius región O. This value is in excellent agreement with $E(B-V) = +1.24$ derived for M82 I with a diaphragm 10″ in diameter by Peimbert and Spinrad from the hydrogen emission lines. Therefore, since the reddening values obtained with two different diaphragms are about the same it follows that possibly the reddenings of M82 I and M82 II are not very different.

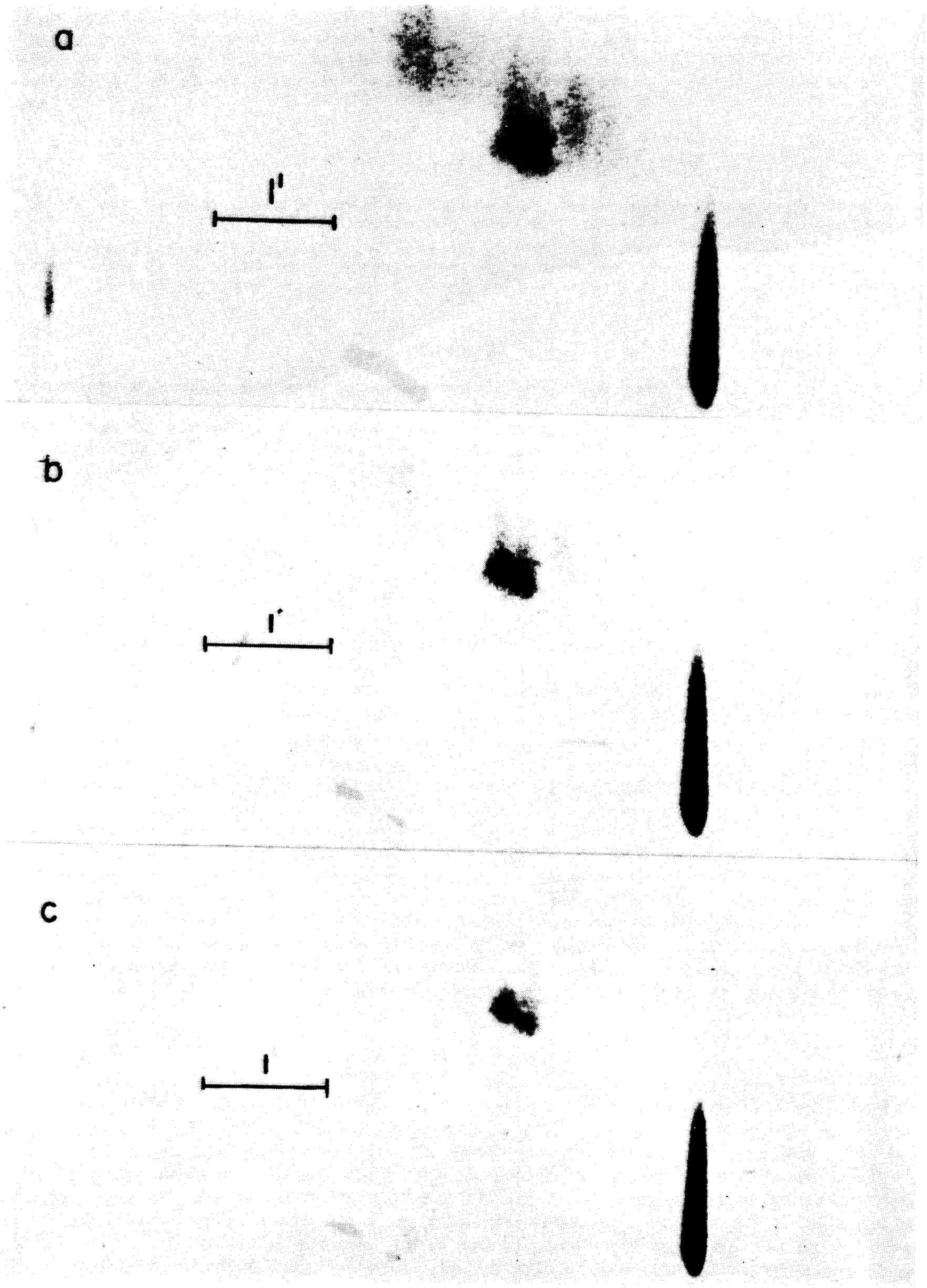

Fig. 1a, 1b, 1c.—*Enlargements, with three different limiting intensities, of a 27- min 103-a-E objective prism plate. North is at top and east at left. Star BD + 70° 587 is at right lower corner.*

If we use now the absolute flux derived by Peimbert and Spinrad (1970) for M82 I and take into account that the diaphragm used by them is slightly smaller than the size of the H II region and assume that the surface brightness is constant, we obtain $I(\mathrm{H}\alpha)_{\mathrm{I}}$, the intrinsic flux at

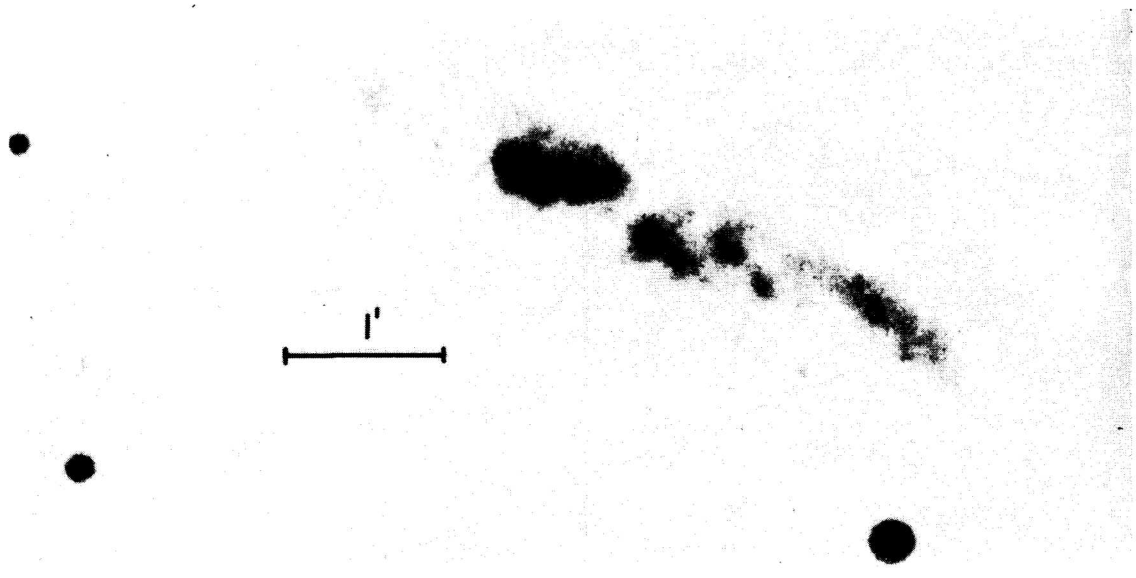

Fig. 2.—*Enlargement of a direct blue plate of 9-min exposure taken on emulsion 103-a0. North is at top and east, at left. Star BD +70°587 is at right lower corner.*

Fig. 3.—*Enlargement of a direct hypersensitized infrared plate of 12-min exposure taken on emulsion IN. North is at top and east, at left. Star BD +70°587 is at right lower corner.*

Hα corrected for reddening. $I(\mathrm{H}\alpha)_I$ thus computed is listed in Table 1. From microphotometric tracings of the objective prism plate it was found that the images were not saturated and it was possible to estimate the relative intensities of the two H II regions as

$$\frac{I(\mathrm{H}\alpha + c)_I}{I(\mathrm{H}\alpha + c)_{II}} = 1.6 \ , \tag{1}$$

where Hα denotes the contribution due to the emission line and c the contribution due to the continuum. It was estimated that about 25% of the light in the objective prism plate at the position of M82 I is due to the continuum and 75% to Hα emission. This result was obtained from the objective prism dispersion and the emission line to continuum ratio in the neighborhood of Hα reported by Peimbert and Spinrad; on the other hand by comparing Figures 1 and 3 it is clear that the contribution of the continuum to M82 II is small and will be neglected. Consequently, from (1) it follows that

$$\frac{I(\mathrm{H}\alpha)_I}{I(\mathrm{H}\alpha)_{II}} = 1.2$$

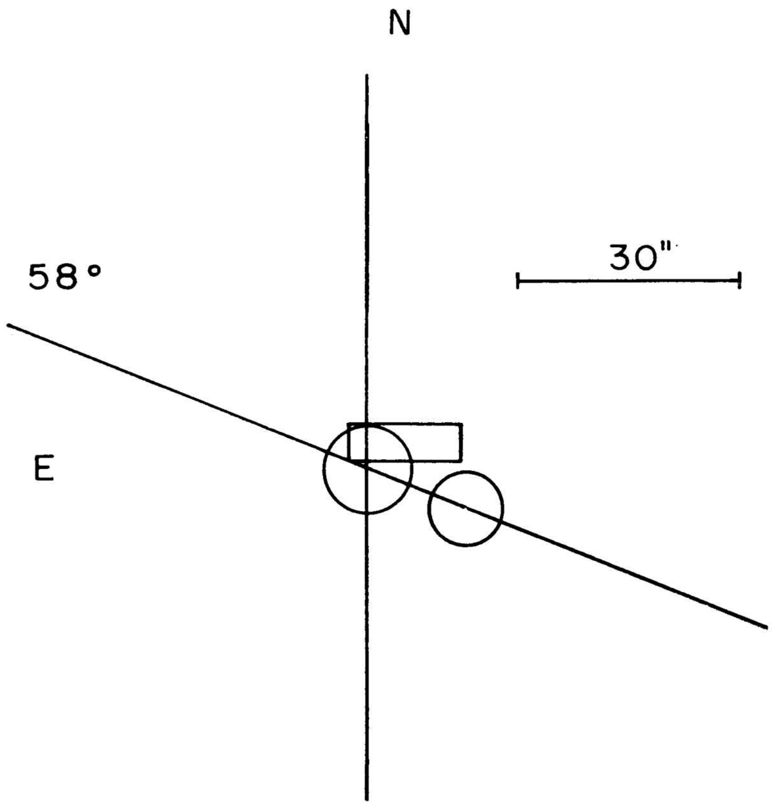

Fig. 4.—*Schematic drawing showing relative positions of M82 I, M82 II and a rectangle which indicates the position of the infrared emission detected by Kleinmann and Low.*

TABLE 1

Physical parameters

Region	I(Hα) (*erg cm*$^{-2}$ *sec*$^{-1}$)	r_o	*d* (*cm*)	r_o (*cm*)	N_e (*rms*) (*cm*$^{-3}$)	*M* (*rms*) ($M_\odot$)	*L*(Hα) (*erg sec*$^{-1}$)	N^*_{star}
M82 I	7.8×10^{-11}	5.″8	1×10^{25}	2.82×10^{20}	5.6×10^{1}	6.3×10^{6}	9.7×10^{10}	9.7×10^{3}
M82 II	6.5×10^{-11}	4.″8	1×10^{25}	2.33×10^{20}	6.8×10^{1}	4.3×10^{6}	8.2×10^{10}	8.2×10^{3}
Orion	4×10^{-7}	22′	1.39×10^{21}	8.9×10^{18}	1.0×10^{2}	3.3×10^{2}	1×10^{37}	1

* Where N_{star} represents the number of O6 main sequence stars needed to maintain the ionization.

From the observed flux at Hα corrected for absorption, I(Hα), given in erg cm^{-2} sec^{-1} and assuming that M82 I and M82 II are isothermal homogeneous spheres, it is possible to obtain the average electron density from the following equation

$$I(\mathrm{H}\alpha) = \frac{r_o^3}{3\,d^2}\, N_e\,(rms)\; N_p\,(rms)\; a\,(3 \rightarrow 2)\; h\nu\;, \qquad (2)$$

where r_o is the radius of the object in cm, d is the distance to the observer in cm, and $a(3 \rightarrow 2)$ is the effective recombination coefficient. For the case of $T_e = 10000$ °K, $a\,(3 \rightarrow 2) = 1.17 \times 10^{-13}$ (Pengelly 1964), adopting $d = 1 \times 10^{25}$ (Sandage 1962; Tammann and Sandage 1968) and assuming the proton to electron density ratio of M82 I (Peimbert and Spinrad 1970), the values of N_e *(rms)* were derived for both H II regions and are presented in Table 1.

The distance to M82 was obtained by assuming that this galaxy is a member of the M81 group. This assumption has been questioned in the past; however, from 21 cm observations of the M81 and M82 region (Roberts 1970) the physical connection between these two galaxies seems to be beyond doubt.

The total mass of an H II region is given by

$$M(rms) = m_H \; f \; N_e \; (rms) \left[1 + 4 \frac{N(\mathrm{He})}{N(\mathrm{H})} \right] V \; , \qquad (3)$$

where m_H is the mass of the hydrogen atom, f is the proton to electron density ratio and V is the volume. The value $N(He)/N(H) = 0.13$ determined by Peimbert and Spinrad (1970) for M82 I was used for both H II regions to determine the total masses which are given in Table 1.

The thermal radio radiation received from an optically thin isothermal homogeneous sphere is given by (Minkowski 1968):

$$I(\nu) = \frac{r_o^3}{3\,d^2} \, 3.75 \times 10^{-38} \, T_e^{-\frac{1}{2}} \, N_e \, (rms) \, N_i \, (rms) \left(17.74 + \ln \frac{T_e^{3/2}}{\nu} \right) . \qquad (4)$$

For comparison, the N_e *(rms)* for the Orion Nebula was derived from equation (4) adopting a total flux of 4×10^{-24} W m^{-2} Hz^{-1} (Howard and Maran 1965) for $\nu = 1 \times 10^{10}$ and is presented in Table 1. Using this density and the N (He)/N (H) ratio derived by Peimbert and Costero (1969) for the Orion Nebula the M *(rms)* was obtained and is also presented in Table 1. It should be mentioned that adopting the *rms* radial distribution of the density for the Orion Nebula given by the model of Menon (1961, 1964), a mass equal to 135 $M_\odot$ is derived; furthermore, this latter mass is an upper limit to the real mass since spatial density fluctuations are not taken into account (Peimbert 1966). From the radio emission the $I(H\alpha)$ for the Orion Nebula was calculated and is also given in Table 1.

From the expansion velocity of the filaments of M82 with Hα in emission Lynds and Sandage (1963) suggested that an explosion had occurred in the nucleus of M82, (1-2) $\times$ 10^6 years ago; assuming a different model for the explosion, Burbidge *et al.* (1964) estimated that the explosion had occurred (2-3) $\times$ 10^6 years ago. Figure 5 shows the radial velocities determined from

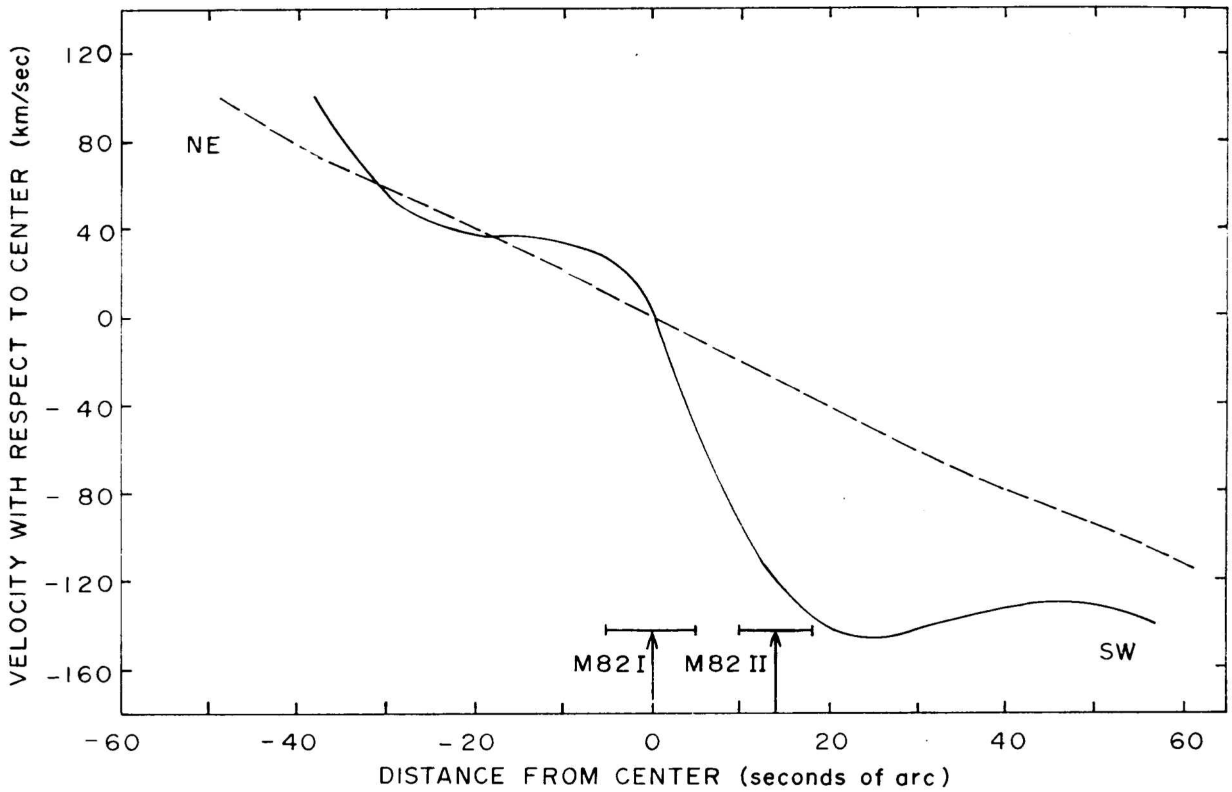

Fig. 5.—*Emission-line velocities, with respect to center of galaxy, as a function of distance from center (solid line), for position angle 62° and adopted rotation curve from Mayall's absorption-line measures (dashed curve). Positions and sizes of M82 I and M82 II are also depicted.*

emission lines by Burbidge *et al.* at a position angle of 62° and their adopted rotation curve based mainly on the absorption line radial velocity measurements by Mayall (1960). Looking at this figure and at the analogous one at position angle 57°3, also by Burbidge *et al.*, it is clear that the velocity of M82 II is anomalous with respect to the rotation curve, the average deviation from both position angles is 70 km sec^{-1}. A plausible interpretation of this anomaly is that the gas that constitutes M82 II was also expelled from the nucleus during the explosion. A more extreme case of probable ejection of a massive gas cloud from a galactic nucleus is present in NGC 4939 (Burbidge and Demoulin 1969).

The average radial velocity difference between the two H II regions in the two angles mentioned earlier is about 100 km sec^{-1}; assuming that the velocity tangential to the plane of the sky is the same as the radial velocity and that no deceleration has taken place, then the H II region would have been ejected from the nucleus about 2×10^6 years ago. This age for the explosion is similar to that derived from the velocities of the filaments on the minor axis.

The characteristic recombination time, the time needed to reduce to one half the initial electron density, N_{e_i}, in a gas of pure hydrogen is given by

$$t = \frac{1}{N_{e_i} \alpha_2} , \qquad (5)$$

where α_2 is the total recombination coefficient to all levels but the first, and according to Pengelly (1964) it is equal to 2.6×10^{-13} for $T_e = 10000°K$; consequently the characteristic recombination time for M82 II, $t \sim 2 \times 10^3$ years, is relatively small and it is necessary to inquire on the source of ionization. If M82 II has been radiating with the same intensity in the last 2×10^6 years the energy dissipated by Hα emission only is $\sim 5 \times 10^{54}$ erg. We may compare this value with the kinetic energy of M82 II. If we adopt a spatial velocity of 140 km sec^{-1} with respect to the nucleus and the mass given in Table 1, the kinetic energy is $\sim 9 \times 10^{53}$ erg. This value will be smaller if there are spatial density fluctuations present because then *M (rms)* is an upper limit to the real mass. Therefore from the high value of the Hα intensity and the relatively small kinetic energy associated with M82 II it seems very unlikely that the ionization is due to the dissipation of the original radial kinetic energy associated with the explosion, although the initial kinetic energy could have been higher if some deceleration has taken place; it is also possible that the ionization might be due to the dissipation of other type of energy.

From the values of Table 1 it is clear that M82 I and M82 II are almost 10^4 times brighter in Hα than the Orion Nebula. It is known that the Orion Nebula is mainly ionized by the O6 star in the Trapezium, ϑ^1 (C) Ori; therefore, if the ionization of M82 II is radiative it follows that there should be about 8.2×10^3 main sequence stars of type O6, in this H II region. In Table 1 we have tabulated the number of O6 main sequence stars needed to produce the observed ionization.

It was shown by Peimbert and Spinrad (1970) that synchrotron radiation from a single reservoir model can not be responsible for most of the ionization in M82 I. Using this argument the same result can be obtained for M82 II. Furthermore Bash (1968), using the results from two element interferometry at 2695 MHz, made a model of M82 consisting of a concentric halo and core with Gaussian brightness distributions. The model requires the halo to have a size of 10″5, the core to be smaller than 1″5, and the core-to-halo flux ratio to be 1.00. From this model it follows that at most one of the two H II regions is associated with the observed radio radiation since the separation between both H II regions is 14″.

Peimbert and Spinrad (1970) have shown that the thermal radio radiation predicted from the Hα flux of M82 I is negligible in comparison to the observed radio radiation; similarly the thermal radio radiation predicted from the Hα flux of M82 II is also negligible in comparison to the observed radio radiation. Moreover, following Peimbert and Spinrad, since the radio flux from M82 is not substantially reduced at the low frequency end, it follows that most of the nonthermal radiation originates in front or at the sides of M82 I and II or that one of the two H II regions is in form of filaments that obscure only a very small area of the nonthermal emitting region.

It is of great interest to report that from a comparison of the optical data with a radio map at 4995 MHz with a 6″ resolution (Graham 1970), it was found that M82 II coincides very accurately with the peak of the radio emission.

III. Conclusions

Of the two very bright H II regions present in M82 one is associated with the nucleus of the galaxy and it appears that the other, which lies on the major axis, was expelled from the nucleus during the explosion.

Synchrotron radiation based on the single reservoir model is not responsible for most of the ionization in M82 II. It is very unlikely that the ionization is due to the dissipation of the translational kinetic energy associated with the explosion. If the ionization is collisional, the particles causing the ionization would have to be injected continuously. If the ionization is radiative this would imply the presence of about 8×10^3 main sequence stars of type O6. These stars need not be associated with the explosion.

It is important to derive with higher accuracy the position and angular distribution of the infrared emission in the 5-22 μ region to decide if it is centered on M82 I or if it is offset by about 5″ of arc.

The apparent relationship between the explosion, M82 II and the peak of the radio emission should be investigated further.

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