THE MIXING OF NEUTRAL GAS AND DUST WITH THE IONIZED GAS OF H II REGIONS

M. C. LORTET-ZUCKERMANN

Département d'Astronomie Fondamentale, Observatoire de Meudon, 92190 Meudon, France

Abstract. Two arguments are presented in support of the now well-established fact of the tight mixing of neutral gas and dust with the ionized gas of H II regions.

1. Theoretical Point of View

(1) Take a blue star and compute the mass of gas which it is able to ionize. This mass is inversely proportional to the density of the ionized gas

$$\mathfrak{M}_{\mathrm{H\,II}} \propto N_e^{-1}.$$

The results are given in Table I, where the mass of ionized gas is expressed in units of the mass of the exciting star; the computation is made for a density $N_e = 100$ and using the rate of ultraviolet photons given by Rubin (1968). Now, if clumping is present, for instance, if the true density is rather 10^3 or 10^4 (may be 10^5), all the figures in the last column should be divided by ten or one hundred (may be one thousand) and it is seen that the star is able to ionize but a very small mass of gas. This result holds even when we take into account the fact that the ıate of ultraviolet photons given by Rubin may be underestimated by a factor as large as 8 (Davidson and Terzian, 1969; Churchwell and Walmsley, 1973; Chopinet *et al.*, 1972) and so may

TABLE I

Mass of ionized gas in a medium where $N_e = 100$, compared to the mass of the exciting star. The radius of the Strömgren's sphere has been taken from Rubin (1968) and may be underestimated (see text)

Sp	T_{eff}	$\mathfrak{M}_*/\mathfrak{M}_\odot$	$\mathfrak{M}_{\mathrm{H\,II}}/\mathfrak{M}_*$
O4	50	58.4	11.1
O5	45	33.7	7.7
O6	40	24.5	3.6
O7	38	22.1	2.3
O8	36	19.7	1.2
O9	35	18.3	0.90
O9.5	33	16.1	0.34
B0	31	14.8	0.088
B0.5	29	14.2	0.023

Greenberg and Van de Hulst (eds.), Interstellar Dust and Related Topics, 477–481.

be the mass of ionized gas given in Table I. The question is *where is the initial mass out of which the star was formed gone*? and the answer is: it is still neutral, around or inside the nebula.

(2) The second argument is related to the origin of the high degree of clumping, which has been found in *all* the H II regions investigated carefully enough. Aperture synthesis continuum radio maps (see for instance Wynn-Williams, 1971) analysis of the recombination line data (Hjellming and Gordon, 1971: M 17 and Ori A; Andrews *et al.*, 1971, five H II regions; Gordon and Wallace, 1971: W 49) and optical determinations of density (see for instance Deharveng-Baudel, 1972a) show that the actual density of the ionized gas may be 10 to 10^3 higher than the rms density obtained from a few arc minutes resolution radio maps and that steep density gradients are present. How are these inhomogeneities and gradients formed and *maintained*? The only explanation at hand at the moment and which does work is that neutral gas is present in high density clumps, inside the whole H II region.

2. Observational Results

The existence of large H I–H II complexes has been established beyond doubt in a number of cases: often, the mass of neutral gas is much larger than that of the ionized part (Table II).

A common case is that in which the ionized gas visible in the optical wavelengths (Hα) constitutes but a very unimportant fraction of the total mass of ionized gas. As

TABLE II

Association of H I and H II

Region	$\mathfrak{M}_{\mathrm{H\,I}}/\mathfrak{M}_{\odot}$	$\mathfrak{M}_{\mathrm{H\,II}}/\mathfrak{M}_{\odot}$	Notes	Ref. H II, H I
S–86 NGC 6820, 23	1 E 3	$\simeq$ 1.8 E 3	Assumed distance 1.65 kpc	Gordon *et al.* (1968) from Felli and Churchwell (1972)
S–131 IC 1396	2 E 4	$\leqslant$ 7 E 3	$\mathfrak{M}_{*} \simeq$ 1 E 3	Pottasch (1965), Simonson (1968) (stars) Simonson (1973)
S–222 IC 1579	>80	0.22	Reflex. neb.	Riegel (1967), Chopinet *et al.* (1972) from Terzian and Pankonin (1972)
S–125 IC 5146	6.7 E 2	2.0 E 1	cluster	Riegel (1967)
S–184 NGC 281	1.6 E 4	8.8 E 2	cluster	Riegel (1967)
Orion	7 E 4	8	Ori A	Schraml and Mezger (1969) Gordon (1970)
Cyg X	6.2 E 4		assumed distance 2 kpc	Cutcheon and Shuter (1970)
W 58 S–99 and 100 K 3–50	1.0 E 5 to 2.5 E 5	1.4 E 2		Felli and M. Fossi (1970) Bridle and Kesteven (1970)

https://doi.org/10.1017/S0074180900054656 Published online by Cambridge University Press

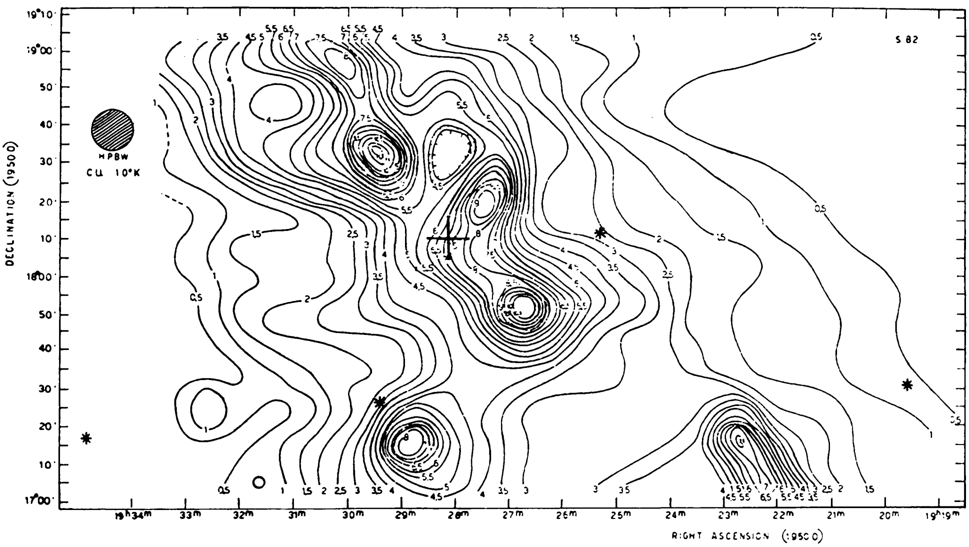

Fig. 1. From Felli and Churchwell, 1972: Radio isophotes at 1400 Mhz in the region of Sharpless 82. The optical region is indicated by a cross.

an example, Figure 1 shows a continuum radio map of the region of Sharpless 82 (taken from Felli and Churchwell, 1972); the optical part is indicated by the cross. The optical aspect is seen in Figure 2: it is a fairly small and rather symmetrical nebula, north of which a smaller reflection nebula DG 159 is visible.

As a rule, the optical aspect may be largely determined by the presence of a large mass of neutral gas and associated dust, as is probably the case for the strange claw-like shaped nebula Sharpless 157 (see Figure 1a in Chopinet and Lortet-Zuckermann 1972a). This nebula contains a bright Hα-knot, designated Sh2-157 A, which has been studied by these authors and Deharveng-Baudel (1972b) and which shows the following properties:

– it is excited from the inside by a blue O9–B0 star,

– the rms density, deduced from poor spatial resolution radio observations (half power beam width 2$'$.8, Aikman, 1968) is about 120 cm^{-3} and the corresponding mass of ionized hydrogen is 10 solar masses.

– the true density, deduced from the S II lines intensity ratio 6717/6731 ranges from 500 to 3500 cm^{-3}.

– thus the actual mass of ionized gas is about one solar mass, that is about 1/20 of the mass of the star.

– Finally, the most unexpected result is that the brightness and density distributions seem to be anticorrelated in this object: the ionized gas density has a minimum *inside* the bright bar east of the central star and increases where the brightness begins to fall down, on each side.

The interpretation is that the knot of ionized gas is associated with a large mass of

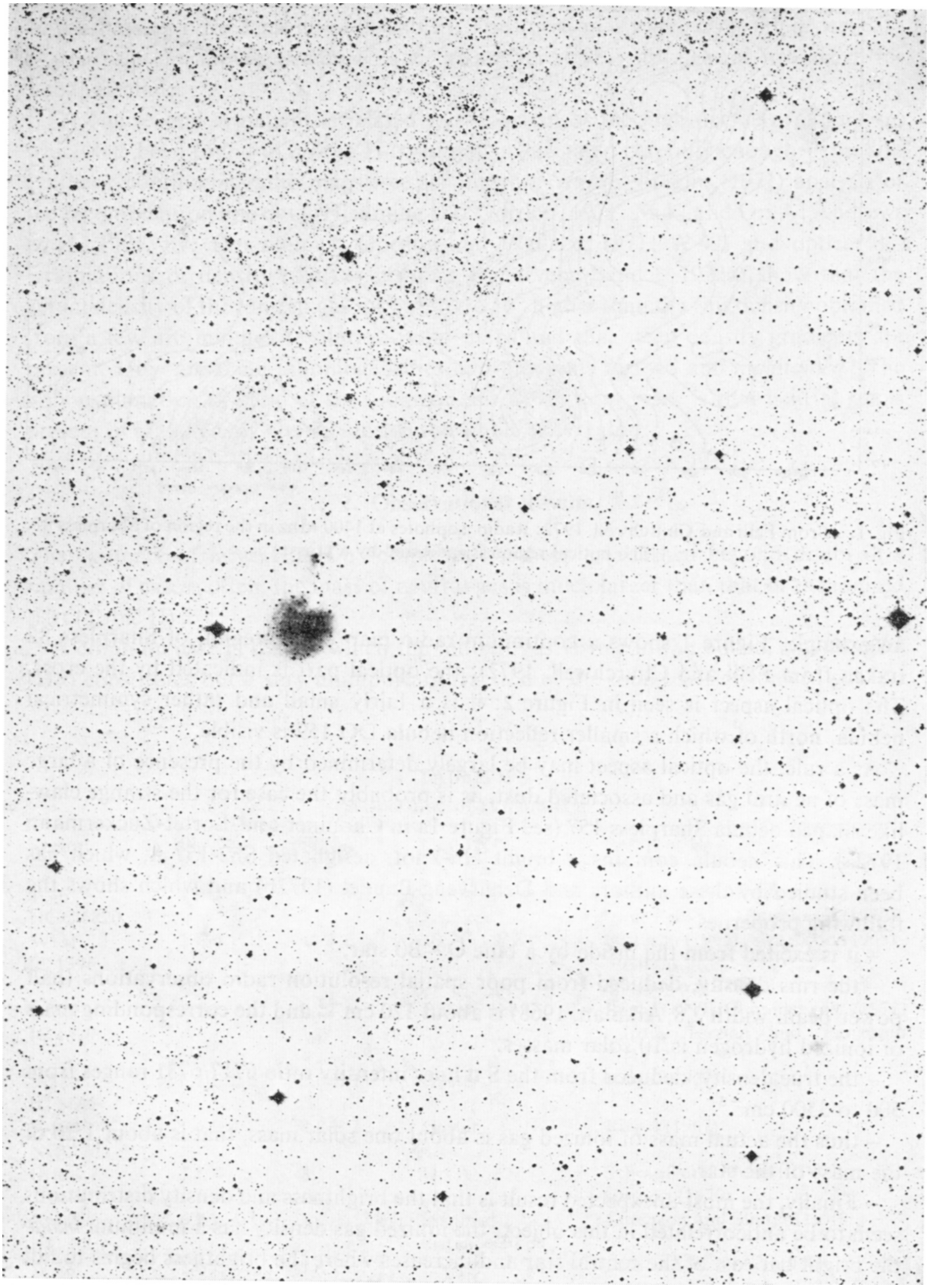

Fig. 2. Optical aspect of Sharpless 82 on the red print of the Palomar Observatory Sky Survey. North is at the top, east at the left (as in Figure 1). The scale is one degree represented by 154 mm.

https://doi.org/10.1017/S0074180900054656 Published online by Cambridge University Press

neutral gas and dust a fraction of which is inside the knot (the remaining fraction probably being around the knot).

Similar bright bars are being studied in other nebulae, as for instance in Sharpless 206 (Chopinet and Lortet-Zuckermann, 1972b): they are certainly always associated with the existence of a large amount of neutral gas and dust, and this is suggested in the specific case of Sharpless 206 by the presence of the neutral oxygen forbidden line at 6300 Å in the brightest bars.

3. Conclusion

The most important points to be now investigated are to determine the exact amount of neutral gas and dust associated with H II regions, in connection with the problem of infrared emission and molecular formation and emission. New results such as those currently obtained by infrared observations (comparisons of the radio and infrared sources dimensions) or on the high positive charge of grains in the transition region between neutral and ionized regions (Flower, 1972) may be of considerable significance.

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