THE SIZE AND SHAPE OF GUM'S NEBULA

Hugh M. Johnson
Lockheed Missiles and Space Company,
Palo Alto, California 94304

The title of the original paper by Brandt et al. (1971) is deceptively simple. The H II region is certainly not a sphere, and we shall examine this important fact. Nor is it a fossil if it shows the recombination spectrum of hydrogen. Rather it was the ionizing light of the causative supernova which is now "fossilized" in the still live though failing H II region.

H-alpha has been recorded spectrographically in Gum's nebula by Gum (1952, 1955). However, Gum used a spectrograph which was probably incapable of resolving H-alpha and [N II] 6548, 6583 Å. Large interstellar regions may show [N II] 6583 Å in emission without H-alpha (cf.: Rubin and Ford 1970) so that it is probably still uncertain how much H-alpha is radiated in Gum's nebula.

The critical point in the paper by Brandt et al. is the energy required to produce the observed ionization of the nebula. This is estimated in that paper by granting 15 eV per photon and by equating the minimum number of photons to the number of electrons in the nebula. The latter is nebular volume V times a mean electron density $\langle n_e \rangle$, where V was represented by a circular cylinder of radius 400 pc and height 100 pc and where $\langle n_e \rangle = \langle DM \rangle / L$. $\langle DM \rangle = 63$ cm^{-3}pc is estimated from observations of four pulsars, one taken to be in the center of the nebula and three to be beyond it. Path length L is equated to the radius of the model nebula for the central pulsar or 2L for the three supposedly distant pulsars. Thus all of the dispersion is said to occur in the nebula, and the nebula is said to occupy 400/460 of the distance to the center at the Vela pulsar, taken to be $r_\odot = 460$ pc. The good point about this procedure is the apparently unbiased sampling of coordinates in the nebula, and it is interesting that the rms error of $\langle n_e \rangle$ is only ±8 percent despite the patchy structure of the gas. Of course, the rms error would be much increased by almost any other arbitrary assumption of the relative values of path length to be assigned for computing the DM of each pulsar.

Brandt et al.'s derivation of L = 400 pc for nebular radius is contradicted by the observed angular radii. Arc sin 400/460 = 60°, the angular radius of the model cylinder, is far larger than the known nebula. Gum (1956) estimated total dimensions of 30° × 60°. A second paper by Alexander et al. (1971) revises the angular diameter downward.

If the center is at the Vela pulsar, the nebula is somewhat asymmetrical with the most distant fragment reported by Gum (1956) 40° from center, around $\ell = 292°$, b = -25°. Another fragment reported by Johnson (1959) is about 45° from center around $\ell = 284°$, b = -38°. Other possible fragments are RCW 63 (Rodgers, Campbell, and Whiteoak 1960) at $\ell = 297°$, b = +7°; the nebula catalogued by Lynds (1965) at $\ell = 244°20$, b = +34°18; and S 313 (Sharpless 1959) = A 35 (Abell 1966) at $\ell = 304°$, b = +40°, a nebula which Hromov and Kohoutek (1968) regard as not a planetary. The I.A.U. system of galactic coordinates is used here. Figure 1 shows the nebulae in the ranges of $220° < \ell < 310°$ and $-24° < b < +24°$, as outlined schematically (and impartially with respect to this conference) by Rodgers, Campbell, Whiteoak, Bailey, and Hunt (1960), to which the outlying fragments mentioned above are added. The fragments at large radii are at high latitudes.

The main body of the nebula certainly suggests a hollow center or shell-form with a characteristic radius about half the distances of the outlying fragments. The edges of the main-body patches are typically sharp and are often bright parts. Figure 2 illustrates these remarks. In places an outer edge of dust was suggested by a close inspection of the original 8-inch Schmidt plates at the Mount Stromlo Observatory in 1959. These observations imply a "front" of some kind more definite than the limit of ionization, as though expansion of the gas was under way. The spin-down age of the Vela pulsar, 1.1×10^4 years (Reichley, Downs, and Morris 1970) is the available time for expansion and shock-front formation, without making special hypotheses. The apparent hollowness of the formation might be a consequence of lower Balmer-line emissivity at higher electron temperature if the center has been heated most. We conclude that the structure of the Gum Nebula appears to be dependent on the event of ionization and possibly on the details of heating; and it is not now an unstructured ambient medium as it may have been before the recent ionization. The alternative of a structured ambient medium requires special hypotheses. One of them is structuring by previous supernova events near the site of the Vela pulsar. At a rate of one randomly distributed supernova per galaxy per 100 years, about 5 supernova events per million years are predicted within the volume of the nebula ionized at present. The effects of such events may be cumulative and not relaxed between events.

Another hypothesis is that Gum's nebula, by accident of its present state, reveals the cross-section of the neutral-hydrogen arm in Vela at the distance of 460 pc. It has not been shown elsewhere or by other means that galactic arms tend to be tubular with fairly sharp perimeters, as this hypothesis suggests.

The great size of Gum's nebula must reflect the gradient of ambient interstellar density normal to the galactic plane, and possibly in the orthogonal

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directions, if the Vela supernova event or events did not perturb the interstellar structure very much. According to Kerr (1969) the thickness of the H I layer between points at half the density in the galactic plane is 200 pc in the range 4-10 kpc from the galactic center. For an exponential z-distribution, the scale height $H = 144$ pc. If hydrogen obeys the distribution $n_H(z) = n_o \exp(-z/H)$ in smooth strata of large extent, and if it is photoionized by any source near the galactic plane to a radius $r = 230$ pc in the galactic plane, then the H II zone is bounded as shown in Figure 3, where the Strömgren radii S are computed from the definition

$$\int_0^S n_H^2(r)\, r^2\, dr = \text{constant}.$$

The radii of photoionization are unbounded in the cone of radius 55° around the axis normal to the plane of the Galaxy at the Vela pulsar. This shape is quite different from that of the observed main body of the nebula. For example, hydrogen may be photoionized at $b = +90°$ and at $|z| > 270$ pc by the agent of Gum's nebula. The emission measure of the galactic polar Gum nebula with smooth, exponential z-distribution of the mass is

$$\text{EM}\,(b = \pm 90°) = \int_{270}^{\infty} n_o^2 \exp(-2z/H)\, dz$$

$= 1.69\, n_o^2$ cm^{-6} pc, where n_o^2 is the mean-square electron density at $z = 0$. Outlying clouds of the kind discussed earlier, or fainter fragments, may be expected over a large part of the sky on the model of an exponential z-distribution of the interstellar gas. The Sun remains sheltered in H I, but it is partially enveloped by the nebula as Gum intuitively suspected. The shape and size of the nebula for other agents of ionization should also be computed.

The mean electron density of the nebula near the galactic plane is $\langle n_o \rangle = \langle DM \rangle / L = 0.27$ cm^{-3}, and the equivalent volume V_{eq} at this density is the sphere of radius $L = 230$ pc so that $V_{eq} \langle n_o \rangle = 4 \times 10^{62}$ electrons. The predicted value of the emission measure in the direction of the center of Gum's nebula is EM = $2L\, n_o^2 = 34$ cm^{-6} pc for uniform density. Nebular irregularities, as observed on photographs, would increase the predicted EM at the same mean $\langle n_o \rangle$. The question of maximum EM in Gum's nebula is complicated by the presence of ζ Pup and γ_2 Vel, which are nearer the brightest parts than the Vela pulsar is. There is no reliably observed mean $\langle EM \rangle$ in the nebula for use in the determination of $\langle n_e^2 \rangle$, and no $\langle EM_o \rangle$ for the determination of $\langle n_o^2 \rangle$. Thus X = $\langle n_e^2$ (EM) $\rangle / \langle n_e$ (DM) $\rangle^2$ and X_o are very poorly known.

In conclusion, we draw attention to an apparent giant complex of nebulae which is nearly opposite to Gum's nebula in the sky. According to Lynds' (1965) map and catalogue of bright nebulae, which she produced from an inspection of all of the Palomar Sky Survey charts, the complex may be defined inside a circle of about 45° radius centered near $\ell = 110°$, $b = 0°$. These nebulae are obviously distinct from the brighter and much more compact Cygnus complex of radius 8° centered near $1 = 75°$, $b = 0°$, and also distinct from many other distant nebulae which lie in the circle but quite close to the galactic equator (see Figure 4). The complex lies, like Gum's nebula, near a node of Gould's Belt or the "local system" of OB stars and interstellar matter. This distinguishes its members from the many nearby nebulae at moderately high latitudes in Scorpius and Taurus. The distance of the proposed complex is not known, but we suggest tentatively that its significance is similar to that of Gum's nebula.

References

Abell, G. O. 1966, Ap. J., 144, 259.

Alexander, J. K., Brandt, J. C., Maran, S. P., and Stecher, T. P. 1971, Ap. J., 167, 487.

Brandt, J. C., Stecher, T. P., Crawford, D. L., and Maran, S. P. 1971, Ap. J. (Letters), 163, L99.

Gum, C. S. 1952, Observatory, 72, 151.

Gum, C. S. 1955, Mem. R.A.S., 67, 155.

Gum, C. S. 1956, Observatory, 76, 150.

Hromov, G. S., and Kohoutek, L. 1968, B.A.C., 19, 90.

Johnson, H. M. 1959, Pub. A.S.P., 71, 342.

_____1960, Mem. Mount Stromlo Observatory, No. 15.

Kerr, F. J. 1969, Ann. Rev. Astron. and Ap., 7, 39.

Lynds, B. T. 1965, Ap. J. Suppl., 12, 163.

Reichley, P. E., Downs, G. S., and Morris, G. A. 1970, Ap. J. (Letters), 159, L35.

Rodgers, A. W., Campbell, C. T., and Whiteoak, J. B. 1960, M.N., 121, 103.

Rodgers, A. W., Campbell, C. T., Whiteoak, J. B., Bailey, H. H., and Hunt, V. O. 1960, An Atlas of H-Alpha Emission in the Southern Milky Way (Canberra: Mount Stromlo Observatory).

Rubin, V. C., and Ford, W. K., Jr. 1970, Ap. J., 159, 379.
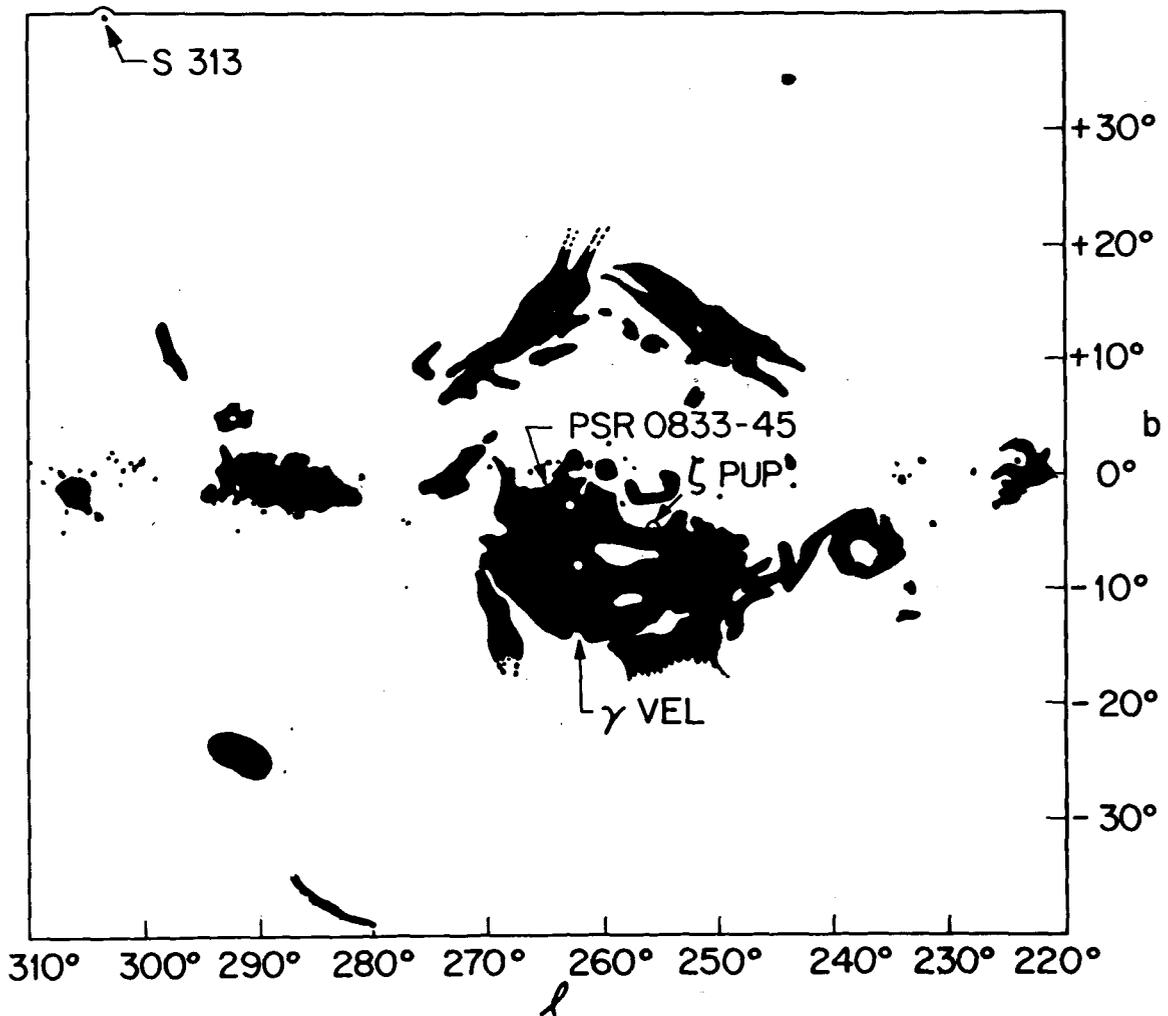
Sharpless, S. 1959, Ap. J. Suppl., 4, 257.

Figure 1. Gum's nebula and all field nebulae from the map by Rodgers, Campbell, Whiteoak, Bailey, and Hunt (1960), with some outlying fragments and some stellar objects added to their picture.
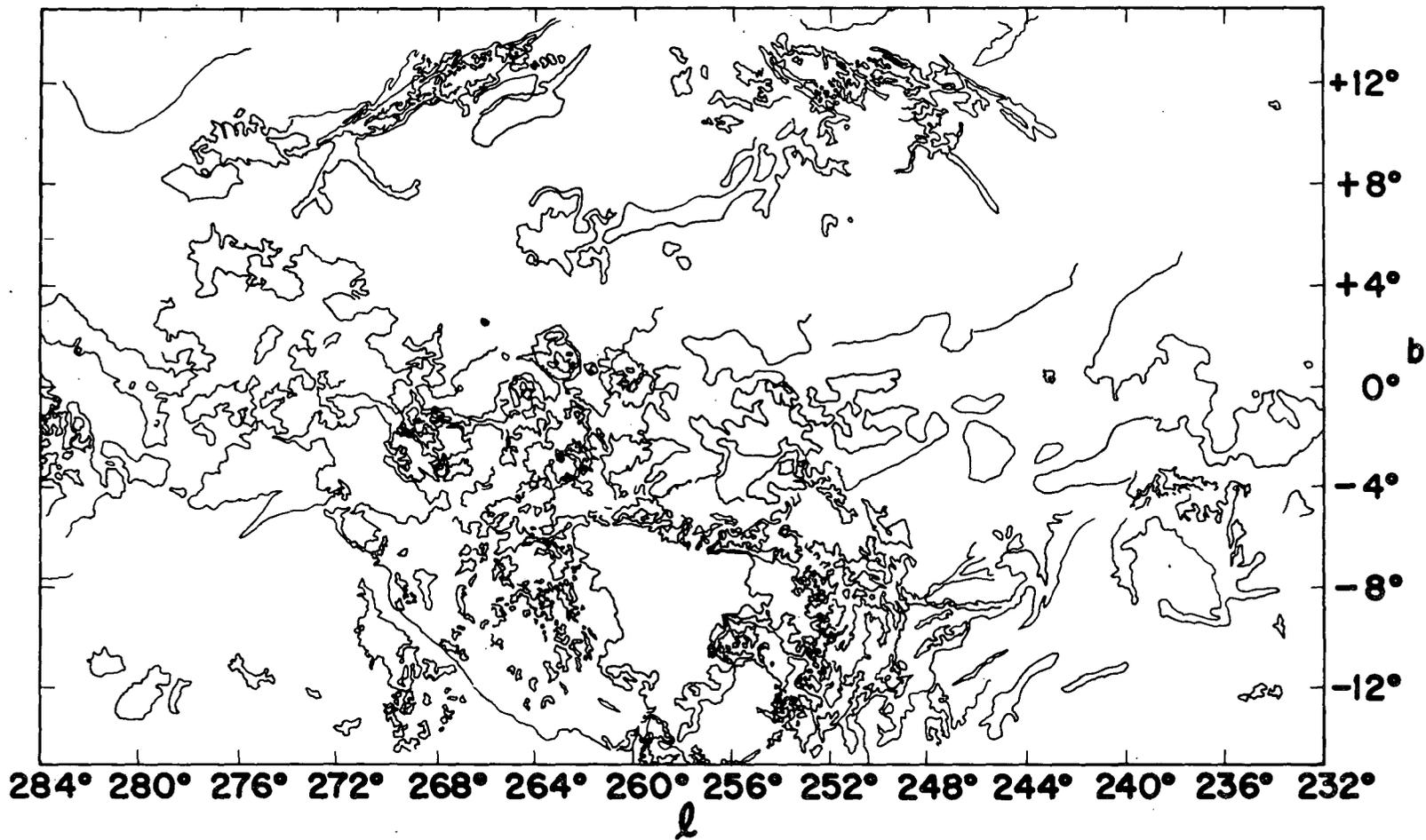
Figure 2. Mosaic of maps of Gum's nebula made with a bandpass of 326Å around H-alpha. The original maps give measured intensities of the isophotes (Johnson 1960).
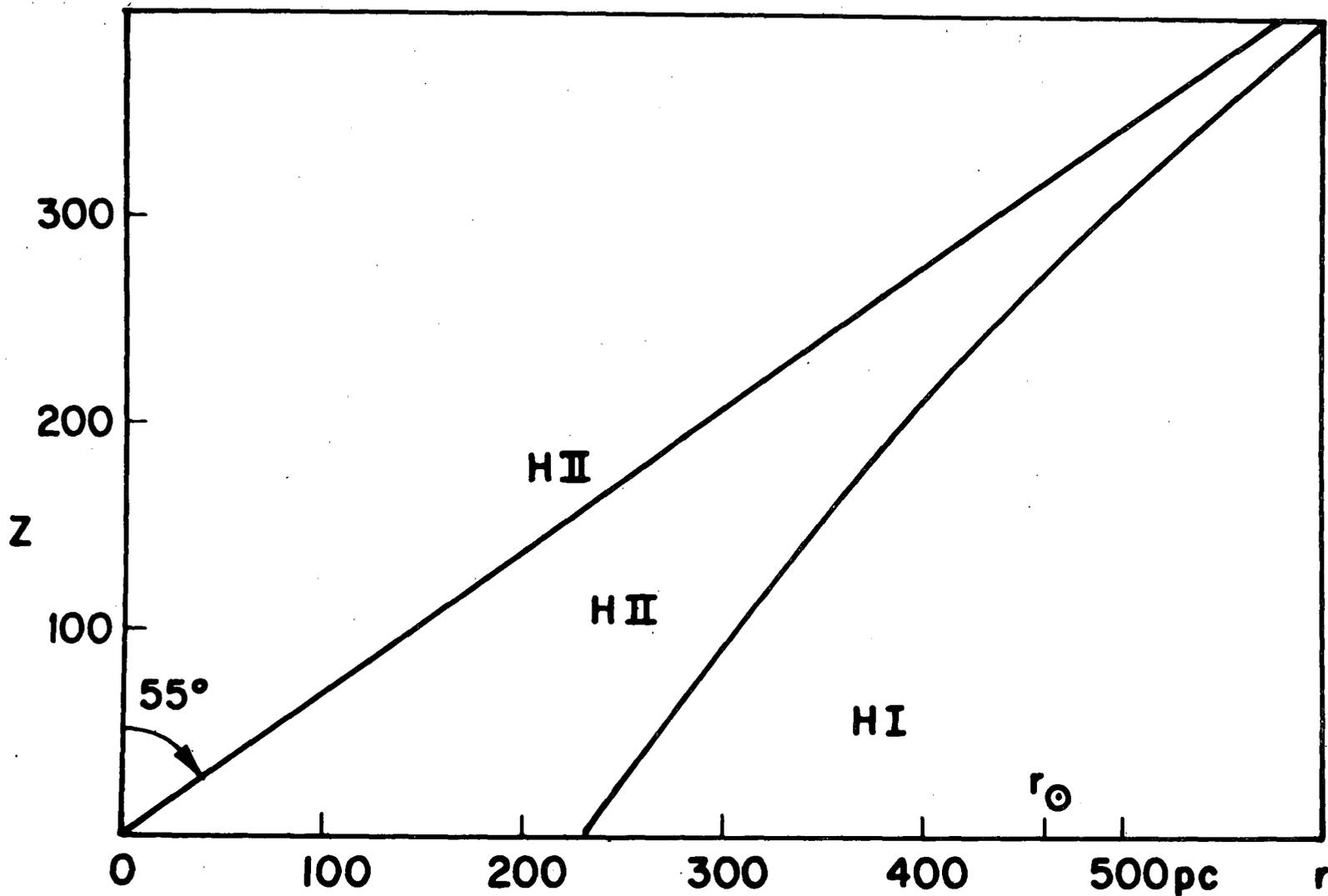
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Figure 3. Cross-section of a plane which contains the center of Gum's nebula at the origin, the Sun at $r_\odot = 460$ pc on the abscissa axis, and the ordinate z-axis normal to the galactic plane. The ambient interstellar gas is ionized to $r = 230$ pc at $z = 0$ and elsewhere to the curved boundary which approaches asympotically to the cone of radius 55° around the ordinate axis. In this cone the radius of ionization is unbounded.
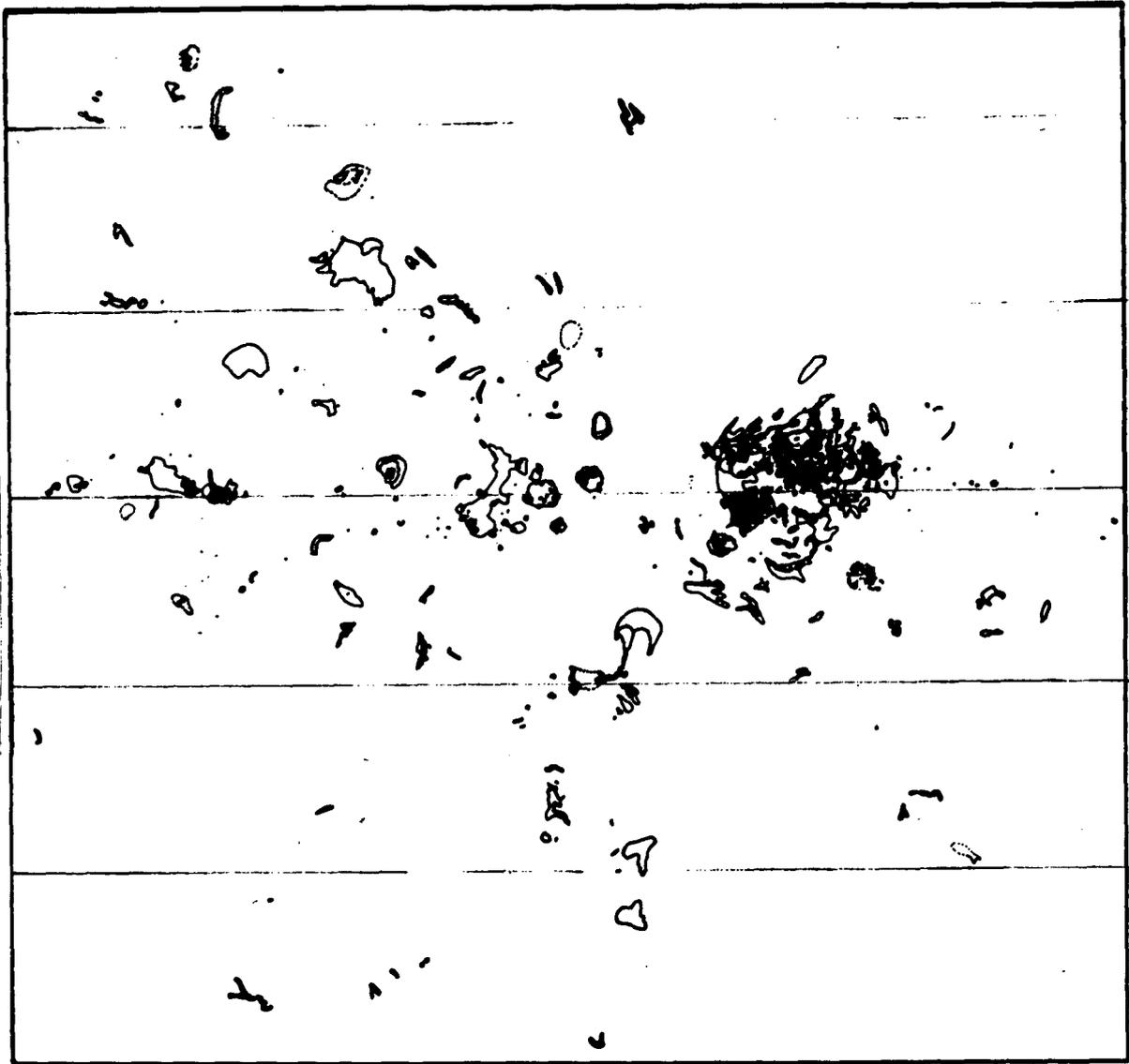
Figure 4. Nebulae on the map by Lynds (1965) centered near $\ell = 110°$, b = 0°. The grid of galactic latitudes (interval = 20°) has been added to the illustration published by The University of Chicago Press. Copyright 1965 by The University of Chicago; all rights reserved.

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DISCUSSION

T. P. Stecher: We haven't said much yet about the two stars (gamma Vel and zeta Pup) themselves. I observed them with a rocket-borne scanner to determine their temperatures. With no correction for interstellar absorption, the temperatures were about 30,000 °K. There is very little absorption in this direction, so I set an upper limit of about 40,000 °K. If this temperature is correct, these stars are not capable of ionizing the Gum Nebula. This result was confirmed by Hanbury Brown and colleagues, using the optical interferometer in Australia; in fact they obtained an even lower temperature.

B. J. Bok: If the Strömgren sphere of these stars had a radius of 50 to 60 pc, it could account for the brightest part of this region, and one must be very careful about estimating the emission measures of the faint outer parts; they may be much fainter, as indicated by Poveda and by Johnson.

S. P. Maran: The emission measure in the brightest parts is about 3000; Brandt et al. took a mean of 1300 and other values are discussed by Alexander et al.