IDENTIFICATION OF THE GUM NEBULA AS THE

FOSSIL STRÖMGREN SPHERE OF THE VELA X SUPERNOVA

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I will briefly outline the evidence for the fact that the Gum Nebula undoubtedly is not ionized by gamma Velorum and zeta Puppis, but was produced by some other source, which we have identified as the Vela X supernova (Brandt et al. 1971).

Figure 1 is a photographic mosaic from the Mount Stromlo H-alpha survey (Rodgers et al. 1960) which gives an impression of the size and extent of the Gum Nebula. This is probably only part of the nebula, however; its extent is more fully indicated in the chart of H-alpha emission given by Johnson (1971). The most probable angular dimension in the plane of the galactic equator is about 90° and the dimension perpendicular to the plane is about 40°.

Any attempt to determine what excites this nebula must be based on a model. Table 1 lists the "observed" quantities. The emission measure can be disputed, but is is undoubtedly not too far off. The emission measure that we have adopted can be verified to within a factor of 2 by taking the pulsar dispersion measure and scaling it up by some factor that takes account of the clumpiness. The dispersion measure in Table 1 is an average quantity for the path to the central region of the nebula, based on PSR 0833-45, which is in that region, and on three other pulsars that are probably on the other side of the nebula, and which have roughly double the dispersion measure of PSR 0833-45, as one would expect. These pulsars are MP 0736, MP 0835, and MP 0940. The hydrogen measure, that is, the amount of hydrogen between the Sun and the stars gamma Velorum and zeta Puppis (which also lie in the central region of the nebula) is based on rocket measurements of Lyman-alpha absorption and is nearly the same for the two stars.

By photometry of the B-star component of gamma Velorum and of a related small group of B stars that appears to be an association, we found a distance of 460 parsecs to the central region of the nebula (Brandt et al. 1971), in agreement with the estimated distance to the supernova remnant Vela X (Milne 1968).

The nebular temperature (Table 1) is derived from low frequency radio astronomy measurements (Alexander et al. 1971), as discussed in detail by Alexander (1971).

Table 1
The Gum Nebula
Observational Data

$EM = \int n_e^2\, ds = 1300\ cm^{-6}\ pc$	
$DM = \int n_e\, ds = 63\ cm^{-3}\ pc$	
$HM = \int n_H\, ds = 25\ cm^{-3}\ pc$	
Distance: 460 pc	
Temperature: $\gtrsim$ 50,000 °K	

Table 2
Assumptions in Model Building

L = radius of nebula
ℓ = distance to edge of nebula
$L + \ell = 460$ pc

Ionized Region	Neutral Region
$n_H \ll n_e$	$n_e \ll n_H$
$EM = 2L \langle n_e^2 \rangle$ $DM = L \langle n_e \rangle$	$HM = \langle n_H \rangle \ell$

Table 2 illustrates the assumptions involved in the model building. Basically, we suppose that the line of sight from the Sun through the nebula encounters mostly neutral hydrogen near the Sun, passes a boundary and then goes into a fully ionized region. These assumptions allow us to derive a model for the Gum Nebula on the basis of the quantities given in Table 1, providing that we adopt a value for the mean neutral hydrogen density near the Sun. Since we know the hydrogen measure, that will immediately give us the distance to the edge of the nebula, and hence also the radius of the nebula. The size can then be checked against the observations. This comparison is given in Table 3. The radio astronomy evidence cited in Brandt et al. implied that the neutral hydrogen density near the Sun is 0.4 cm^{-3}. Later, Alexander et al. took into account the OGO-5 satellite measurements that give a neutral hydrogen density of 0.1 cm^{-3}. This quantity refers to hydrogen streaming into the solar system and illuminated by solar Lyman-alpha; it is a very local measurement. So, in a "burst of creativity," we simply averaged these two values and adopted 0.25 cm^{-3}. This number implies a nebula with a mean dimension of 90°, as required by the observations. (The angular size was calculated to be arcsin L/460 pc + arctan L/460 pc because we don't know exactly how the boundary of the nebula should appear.)

Table 3
Implications of Three Assumed Values of $\langle n_H \rangle$

$\langle n_H \rangle$ (cm^{-3})	ℓ(pc)	L (pc)	Angular Diameter of Nebula
0.4	60	400	110°
0.25	100	360	90° ✓✓
0.1	240	220	55°

The result is our model of the nebula as shown in Figure 2. This diagram is intended to provoke discussion, and shows schematically that the boundary is irregular and the structure is filamentary (clumpy). The clumpiness factor X is 1 for a homogeneous nebula and greater if the clumpiness is important.

It is a simple calculation to see if gamma Velorum and zeta Puppis could maintain the ionized region. They fail, by at least one order of magnitude, if $\langle n_e^2 \rangle^{1/2} = 1\ cm^{-3}$ (Spitzer 1968). Hence, something else ionized the Gum Nebula.

The culprit is probably a supernova and there is considerable evidence for it. There is the pulsar PSR 0833-45 (Large et al. 1968), the nonthermal extended radio source (Milne 1968), and the X-ray source (Seward et al. 1971). The photograph by Bok (1971) of the radio source region shows the striking nebulosity that appears to be a supernova remnant located within the Gum Nebula.

The remaining calculation concerns the energy requirements, and the numbers are given in Table 4. If we assign a radius of 360 parsecs to the nebula, a height of 100 parsecs, and compute the volume of the cylinder, it comes out to be about $1.2 \times 10^{63}\ cm^3$. We know the average electron density, and, hence, can estimate that the nebula contains about 2×10^{62} electrons. If we assume 15 eV per ionization, we immediately find that 5×10^{51} erg, or to the accuracy appropriate for a calculation such as this one, 10^{52} erg, are required to ionize our model Gum Nebula. This is our suggestion – the supernova produced the energy to ionize this nebula. There are obviously many questions to be answered. In particular, we hope this symposium will stimulate a thorough discussion of the different ways of supplying energy to produce the nebula.

Table 4
Energy Requirements for Single Ionization
of the Gum Nebula

Nebular volume Radius: 360 pc Height: 100 pc $V \approx 1.2 \times 10^{63}\ cm^3$
Number of electrons in nebula $V \langle n_e \rangle \approx 2 \times 10^{62}$ electrons
Energy required 15 eV per ionization, $E \approx 5 \times 10^{51}$ erg

I will add in closing that there is another observation that may possibly exist, which would be of great interest. The age of the pulsar as inferred from its spin-down rate (Reichley et al. 1970) leads one to believe that there might have been a very bright supernova around 9000 B. C. The apparent magnitude may have been $m_v \approx -10$, which is comparable to the quarter moon, and much brighter than the Crab supernova as observed by the Chinese. We are pursuing the admittedly outside chance that evidence of such an observation may exist in the archaeological record; such data would hopefully yield a much more accurate estimate for the age of the pulsar and the Gum Nebula than is presently available.

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Figure 1. Mosaic of the Gum Nebula in H-alpha, from Rodgers et al. (1960).

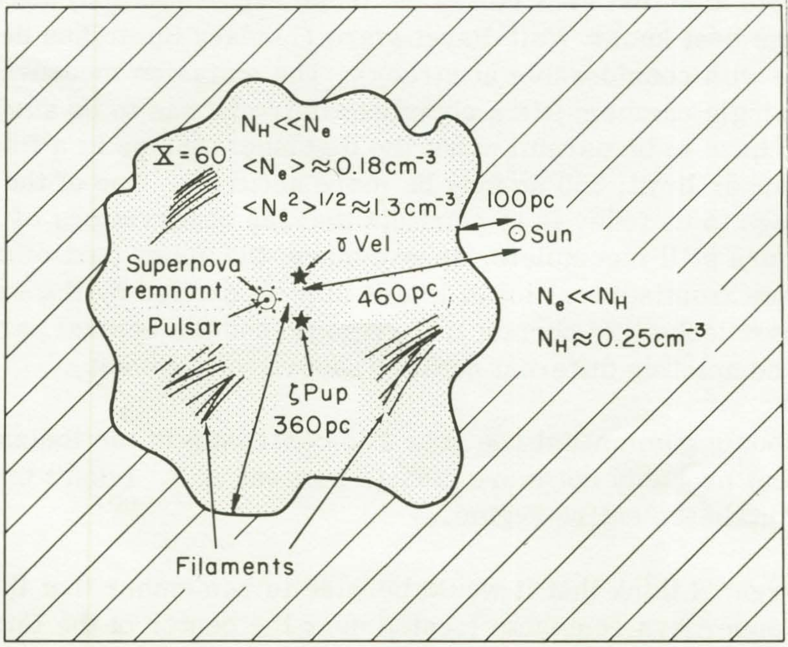

Figure 2. Schematic representation of the derived model for the Gum Nebula.

DISCUSSION

A. Poveda: If one takes the naive point of view that the H II region is just what we see in the photographs, then the volume is much smaller than the one that you have chosen and therefore the amount of energy needed to ionize it is correspondingly smaller.

J. C. Brandt: Gum quoted 60° × 30° in one paper and other, outlying H II regions have been discovered subsequently. The column density of electrons is an observed quantity, so if we take a smaller volume, the total electron content is only slightly reduced.

B. J. Bok: I am worried by the assumption that there is one Gum Nebula. From the photographic work that I have done, looking at the composite and the Schmidt photographs, I have the impression that there are two or three things that are going on in this region. First of all, there is the big emission blob around gamma Vel. That blob, which has a bite out of it due to a nearby dark nebula, is centered on gamma Vel and looks like an ideal Strömgren sphere. There is a similar nebulosity near zeta Pup. Then there is the entirely different nebulosity [Vela X] which looks like what we find in Cygnus: it appears that we have a big explosion, a shock wave affair. It is well to the north of the bright, normal-appearing blobs. Finally there is the nebulosity that seems to outline the outer part of the Gum Nebula. I think one should be very careful before one called the Gum Nebula a single unit. Note also that zeta Pup is the brightest O-star (05) and gamma Vel is one of the best known Wolf-Rayet stars (Lindsey Smith has determined its distance with considerable accuracy). The emission measure of this region isn't a single number; it's a complex affair and has to be studied carefully. We also have to be careful about the distance: 460 pc is a fine figure but it's an upper limit; 350 pc may be more accurate. One of the most important things to do today is to point out that the observations of this part of the sky are still incomplete. In summary, the upper part of the poster photo [see frontispiece] looks like it may be excited by the supernova, the lower part looks like normal H II regions, and the central part looks like it is of completely different nature [supernova remnant].

Brandt: Obviously gamma Vel and zeta Pup contribute to the ionization in this region but probably not more than 10 percent of it. I don't think that they can maintain the entire region.

S. van den Bergh: I think that it would be wise to remember that there are two optical supernova remnants located near the center of the Gum Nebula: Vela X and Puppis A (Baade and Minkowski 1954). There is no *a priori* reason to regard Vela X, which is roughly centered on the Vela pulsar (PSR 0833-45) as the more likely source of ionization for the Gum Nebula. Intercomparison of a recent 48-inch Schmidt plate of the Vela X remnant with the prints of the Whiteoak Sky Survey shows no evidence for expansion of the supernova remnant. This result indicates that the shell of the Vela supernova has either been decelerated or that it has an age $t \gtrsim 10{,}000$ years.

Reference: Baade, W., and Minkowski, R. 1954, Ap. J., 119, 206.