GIANT LOOPS – A NEW KIND OF NEBULA

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Four enormous, loop-shaped features were found in ground-based surveys of the low-frequency galactic radio emission (Ref. 1) (Fig. 1). With diameters of 40° to 116°, they include the Cetus Arc and the North Polar Spur and were formerly called the radio spurs. More recently, the tendency in the literature has been to call them "loops," and two leading theories for these objects have emerged.

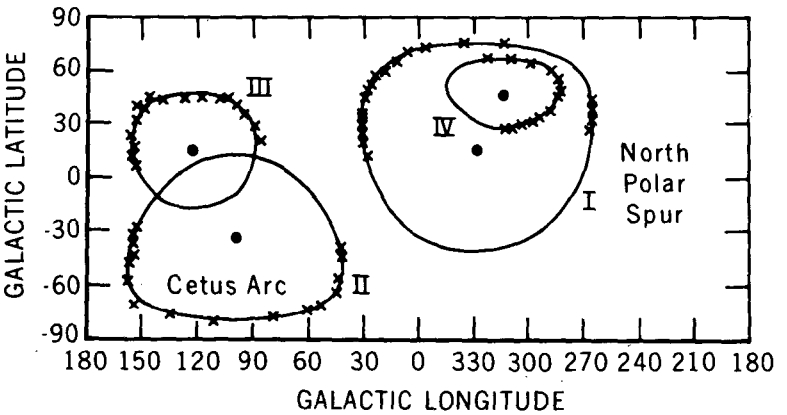

Figure 1—Map showing the distribution of the giant loops in new galactic coordinates, according to Haslam, Kahn, and Meaburn (Ref. 1).

One theory, by Mathewson in Australia (Ref. 2), ascribes the loops to synchrotron radiation by cosmic ray electrons that are spiraling in the helical pattern of the galactic magnetic field near the Sun. This idea is based on an apparent correspondence between the local field pattern that is derived from optical polarization measurements of stars and the pattern of the loops as obtained from the radio surveys. However, the model cannot explain the observation of H-alpha and H-beta emission filaments that are associated with the loops. In addition, the fit of the polarization pattern is poor in the case of Loop II (Cetus Arc), and it appears that the loops do not connect in the manner expected for the helix model of the galactic field.

The other theory, widely discussed but most notably advanced by the group at Manchester (Ref. 1), which has made almost all of the loop observations, suggests that they are very large, old, supernova remnants. Here are three of the many objections to this view:

(1) There is no evidence for expansion.

(2) The large angular size and relatively high galactic latitudes leave the supernova remnant theory with the problem of explaining why there are four remnants within an estimated 250 pc of the Sun.

(3) Whether you look at the few accepted supernova remnants for which diameters are accurately known, or at the roughly 100 known remnants in the galaxy for which estimated diameters are available, you find that the diameters are all less than 40 pc or less than 70 pc, depending on who did the estimates. The supernova remnant theory of the giant loops leads to lower limits on their diameters of about 170 pc, or even twice as much. Therefore, we are compelled to ask, "Where are all the supernova remnants with diameters between 70 and 170 pc?"

Now I wish to remind you of the Gum Nebula (Fig. 2, taken from Ref. 3), which we last year suggested was a new class of object, the fossil Strömgren sphere, that was created when the interstellar gas was ionized by ultraviolet light from a supernova explosion. The group at the Harvard College Observatory (Ref. 4), has calculated the evolution of fossil Strömgren spheres, as shown in Figure 3. Although the center of the sphere starts out about 10 times hotter than the exterior region, it cools much more rapidly. This occurs because a fully ionized plasma radiates more efficiently than does a partially ionized gas. Thus, it was predicted that after a million years have elapsed, the fossil Strömgren sphere will have the form of a large hot shell.

John C. Brandt and I now propose an alternative theory for the giant loops, which we believe is compelling although not conclusive: the loops are ancient fossil Strömgren spheres. On our model, there has been a slow expansion of the hot shell, due to the pressure difference between the hot gas and its cool surroundings. In fact, the velocities that have been observed in the optical filaments are of the order of the speed of sound at 10^4 K. This expansion produces an outward-directed hydromagnetic shock wave that compresses the ambient galactic magnetic field and thus generates

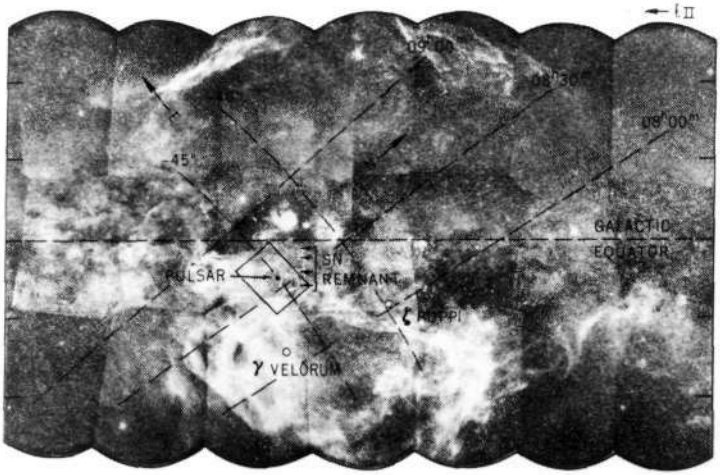

Figure 2–The Gum Nebula in H-alpha, a mosaic from Reference 3, prepared at the Australian National University. The box shows the region of Vela X that appears in the familiar ultraviolet-light photograph of B. J. Bok.

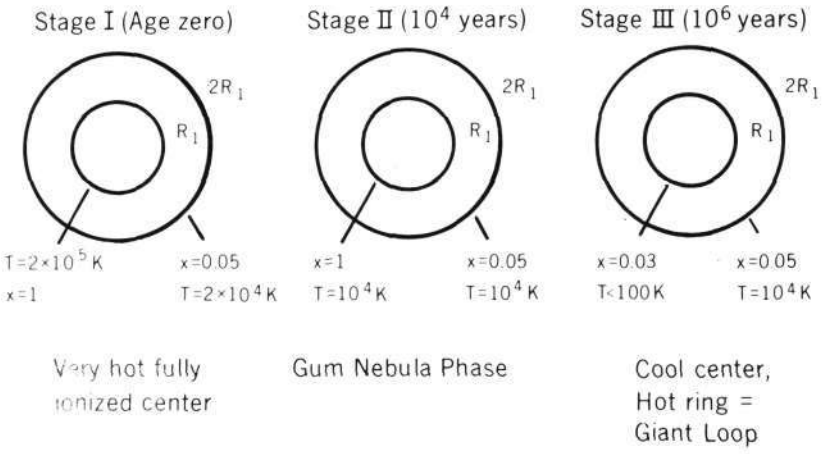

Figure 3–The evolution of a fossil Strömgren sphere, according to the computations of Richard McCray and Joseph Schwarz. At all stages, $x < 10^{-3}$ and $T < 100$ K at $3R_1$.

synchrotron radiation by the van der Laan mechanism. The emission is produced by the ambient cosmic ray electrons and not only by electrons from the supernova. This provides at least a qualitative explanation for the observed spectrum and polarization of the continuous radio emission from the loops. The optical radiation comes from the still partially ionized denser filaments of the fossil Strömgren sphere.

In our theory, the giant loops, so called to distinguish them from the Cygnus Loop and Vela X (which are much smaller and which are known to be supernova remnants), are much older than the remnants. Thus, there is a higher probability of finding several of them near the Sun than is given by the supernova remnant theory. Also, in our theory the size of the loops depends on the interstellar gas density, averaged over large regions, and on the ultraviolet luminosities of the supernovae. We have no problem with the deduced linear sizes and expansion speed limits and indeed could let them be more severe without compromising our theory.

In conclusion, we believe that the giant loops were created by radiation from supernovae and that they do not consist of matter ejected by the explosions.

REFERENCES

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