search & discovery

Is the Gum nebula the ghost of an exploding supernova?

A faint nebula that is one of the largest objects in our own galaxy and extends over 60 deg of the southern sky has been interpreted as the first clear example of a new class of galactic object, produced by the flash of ultraviolet and x-ray emission from an exploding supernova.

It has generally been assumed that the Gum Nebula (a region of ionized hydrogen named for Colin S. Gum, who mapped its Balmer alpha emission in the 1950's) is excited by two hot stars, γ^2 Velorum and ζ Puppis. Such regions are often called "Stromgren spheres" (after Bengt Stromgren, who worked out the relevant theory in the 1930's).

Now, however, John C. Brandt, Stephen P. Maran and Theodore P. Stecher of Goddard Space Flight Center and David L. Crawford of Kitt Peak National Observatory (*Astrophys. J. Lett.*, 1 February issue) have derived a new model for the nebula, showing that it is larger than previously realized and that the hot stars in its interior could not have ionized it. Noting that the supernova remnant Vela X, which contains pulsar PSR 0833-45, also lies near the center of the nebula, they have proposed that the supernova that produced Vela X and PSR 0833-45 also gave rise to the Gum Nebula when the burst of radiation from its explosion encountered the ambient neutral hydrogen of interstellar space.

Because in their model the exciting star of the Nebula no longer exists, they call it a "fossil Stromgren sphere." The existence of ionized regions produced in this way by supernovae was suggested by Philip Morrison and Leo Startori of MIT (*Astrophys. J.* **158**, 541, 1969). Their theory says that the light is produced by fluorescence of helium in the interstellar medium excited by a strong ultraviolet pulse that goes out from the explosion. Other theories, such as that of Stirling Colgate and Chester McKee (New Mexico Institute of Mining and Technology), say that the bulk of the light comes from heating by the radioactive decay of cobalt to iron. Or the basic energy source may be a pulsar.

The Goddard–Kitt Peak workers reached their conclusion when, adding up the number of electrons in the nebula, they found a total of 2.1×10^{62}

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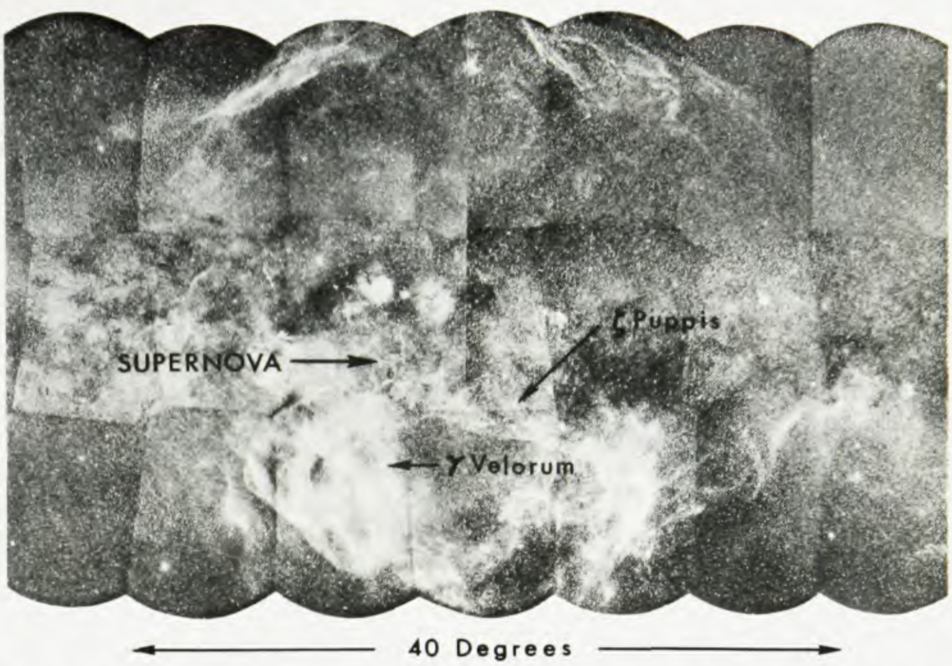


Central portion of the Gum nebula, which a Goddard Space Flight Center–Kitt Peak team says is the first clear example of an object produced by the flash of uv and x-ray emission from an exploding supernova (11 000 years ago). Photos to make this mosaic were taken in H-α light at Mount Stromlo Observatory, Australia.

Muon-pair experiment: no new particles

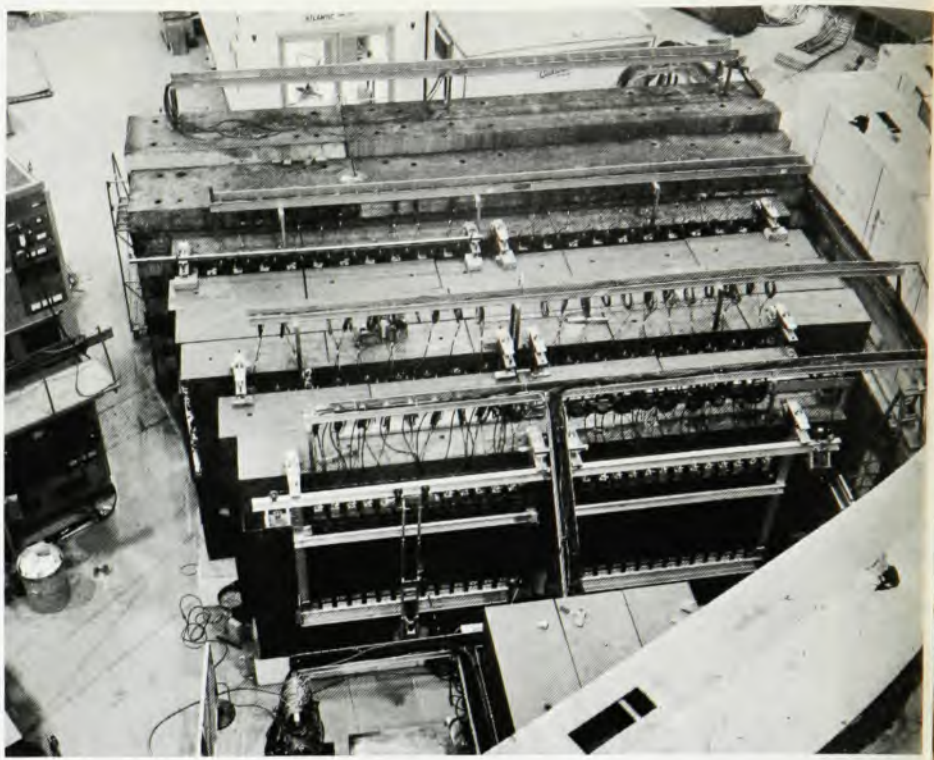
The Brookhaven AGS, a proton synchrotron, has turned into a useful tool for studying electromagnetic interactions at high energy and momentum transfer. James Christenson, George Hicks, Leon Lederman, Peter Limon, Bernard Pope (Columbia) and Emilio Zavattini (CERN) have studied the massive muon pairs produced when high-energy protons strike uranium nuclei (*Phys. Rev. Lett.* **25**, 1523, 1970). The experiment sets lower limits on the mass of the heavy photon proposed by T. D. Lee and Gian-Carlo Wick (Columbia) and on the intermediate vector boson. And the experiment offers a new way of elucidating the scaling and pointlike behavior in the nucleon.

Since the classic electron-scattering experiments of Robert Hofstadter much attention has been devoted to study of high-energy electromagnetic properties of hadrons, such as protons and pions. In these experiments the charge distribution of the proton was established; here one thinks of a single photon exchanged between the incoming electron and the target proton. This kind of process involves "spacelike" virtual photons because the square of the four momentum transfer is positive (and momentum rather than energy is transferred).

The structure of the resulting proton charge distribution is thought of in terms of a pion cloud, the pions resonating to produce certain particles that have quantum numbers like the photon (the vector mesons ρ, ω, ϕ). For timelike momentum transfers (square of the four momentum transfer negative) you can produce these resonances as real particles, which then decay into a lepton pair. "Tails" of the pion resonances are thought to account for the charge structure of the proton and neutron.

One way of studying the timelike domain is with electron–positron colliding beams, which have now produced observations up to about 1.5 GeV with storage rings at Orsay, Frascati and Novosibirsk. Out to about 1 GeV these observations have verified the vector-meson peaks. A second way to study the timelike domain is the experiment done by the Columbia group, which goes up to 6 GeV. They look at production of a muon pair plus hadrons, an interaction which also involves a virtual photon with timelike properties. They determine the effective mass of the virtual photon by measuring the momentum vectors of the two muons. The idea is to look only at the muons, disregarding the complex nuclear interactions taking place and the variety of other particles being emitted.

The experiment achieves great sensitivity by using the new external 29 GeV/c proton beam which delivers 10^{12} protons/pulse onto a target. Muons, being noninteracting, penetrate a thick iron shield that screens the detectors from the enormous flux of nuclear debris generated by the incident protons. The detector, an array of scintillation-counter hodoscopes and steel blocks, had to cope with a very large muon background from decay of pions in the target. The data are presented as a graph of the probability for production of a dimuon effective mass m where m is essentially the mass of the virtual photon decaying into muon pairs.



Detector used by Columbia group to study massive muon pairs produced when high-energy protons strike uranium. Scintillation-counter hodoscopes are in between blocks of steel. Muons emerge from ten-foot-thick concrete shield in foreground.

Although from proton form-factor considerations you might not expect to see any muons at high effective mass, the experimenters observed muon pairs out to the maximum energy of the AGS accelerator, where the cross section was less than about 10^{-38} cm^2. They had hoped to uncover a rich set of resonance "bumps." Instead a fairly smooth continuum was observed, setting rather restrictive limits on the existence of resonances in this region.

Another hope of the Columbia group was of finding the B^0 particle, suggested by Lee and Wick. Its existence is required by their formulation of quantum electrodynamics, which eliminates divergences. If its mass were small, then one would expect to see a dramatic peak in the Columbia data. Because such a peak was not observed, the experimenters say that the mass of the B^0 must be greater than 5.5 GeV. Further searches for B^0 will require the higher energies of the National Accelerator Laboratory (400–500-GeV protons) and the CERN Intersecting Storage Rings (two beams of 25-GeV protons).

Recent SLAC experiments on deep inelastic electron scattering show that the transfer of lots of momentum and energy seems to require pointlike constituents in the proton. The partons are a specific model of the general "scaling" behavior predicted by J.D. Bjorken (SLAC). Scaling asserts that at sufficiently high energy, the structure functions that determine the cross section depend only on dimensionless combinations of the variables. You would expect that scaling might be valid for reactions in which either a lepton pair annihilates to produce hadrons or a lepton pair emerges from a hadronic "hot box," Lederman says. If so, the Brookhaven data can be used to predict the probability for emission of virtual photons of extremely high mass, which he calls "very heavy light," in the hundred-GeV region.

By means of scaling or parton considerations, such as those of S. M. Berman (SLAC), Donald Levy (Berkeley) and Thomas Neff (SLAC), Sidney Drell and T. M. Yan (SLAC), Guido Altarelli, Richard Brandt and G. Preparata (Rockefeller University) you can predict from the Columbia data what the massive photons will do at NAL.

The Lee–Wick theory requires that the hadron system be capable of emitting B^0; once produced, the B^0 can decay into lepton pairs. The B^0 particle would then be observable as a very sharp bump on the pair continuum.

The heavy-photon emission can also be related to emission of the intermediate boson W, which is supposed to mediate weak interactions. The survey of dilepton masses at Brookhaven, the theoretical relation between weak and electromagnetic forces, and the scaling predictions lead to the conclusion that if the W mass is less than 40 GeV it will surely be observed in proton collisions at NAL, where the group plans to repeat the experiment. The CERN ISR, when running at its planned maximum intensity, should extend this limit to 50 GeV. Lederman notes that because you can essentially borrow some energy from a heavy nucleus, one collision in 10^5 of a 500-GeV proton is equivalent to a 1000-GeV proton; so one can look at even more massive photons than one would ordinarily expect. —GBL

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electrons in a cylinder of diameter 800 parsec (in the plane of the Galaxy) and length 200 parsec. Assuming 15 eV for the energy of a typical ionizing photon, they find that at least 5×10^{51} ergs were required to ionize the nebula. They say that the only likely source of this much energy is a supernova. It is known that supernovae generally emit about 10^{49} ergs in visible light, but little has been known about the output in other parts of the spectrum. Theoretical estimates for the total amount of energy emitted range many factors of ten higher.