the same number of stars, and that we consider flares of the same absolute intensity.

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ARCADIO POVEDA

Observatorio Astronómico,
Universidad Nacional de Mexico,
Observatorio Astrofísico de Tonantzintla,
Mexico

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The Neutron-star Hypothesis of Celestial X-ray Sources

THE discovery of galactic X-rays by Giacconi *et al.*[1], confirmed by Friedman *et al.*[2], which was quite unexpected from our present understanding of physical processes in astronomical objects, has induced a variety of theoretical investigations[3]. Among various mechanisms so far proposed to explain the X-ray sources, the neutron-star hypothesis suggested by several authors[4] seems to present a reasonable combination of the radiative power, the distance, the life and the frequency of occurrence of the X-ray sources although the existence of neutron stars is still open to question.

A neutron star is expected to appear after a supernova explosion occurs. Typical characteristics may be described as follows: The radius is about 10 km; the mass is about one solar mass, the density being about 10^{15} g/c.c.; the surface temperature may be originally 10^7 °K and cools down with a half-life of about a thousand years. This star, which radiates mostly in the X-ray region, can be a strong source of X-rays, if it is at a distance of the order of a thousand light years. This distance, considering that the life of the neutron star is about a thousand years, is compatible with occurrence frequency of supernovæ in the galaxy. Indeed, an X-ray source was reported by Friedman the direction of which agrees well with the Crab Nebula, which is a remnant of the supernova of A.D. 1054.

Let us take this neutron-star hypothesis for X-ray sources temporarily. The intensity of the X-ray source, which presumably is in the Crab Nebula, is reported to be one-eighth as strong as a source which was originally found in the constellation Scorpius. The Scorpius-source, therefore, may be about three times nearer to us than the Crab Nebula. Why, then, do we not see a prominent remnant like the Crab Nebula surrounding the neutron star of the Scorpius source ?

The Crab Nebula radiates most of its energy in the radio and the optical region by means of synchrotron radiation of energetic electrons, the energy spectrum of which is well approximated by a power law, in the magnetic field of the Nebula. It can be shown easily that the radiative power in the radio and the optical region is a very sensitive function of the exponent of the power law spectrum. If, for example, the electron energy spectrum for electrons of energy greater than 10^7 eV of the Crab Nebula were like $E^{-4}\,dE$ instead of $E^{-1 \cdot 5}\,dE$ as is believed, the total number of electrons being conserved, the radio power and the optical energy would be approximately 10^4 and 10^{13} times lower than they are respectively. It is very probable that the difference of the density of the environmental ionized gas causes the difference in the resistance to the expansion of the Nebula and that a larger resistance to the expansion may produce a condition which is more favourable to the acceleration of electrons. It is, hence, plausible to suppose that because of the difference of the environment there is a wide variation in the radiative power of the supernova remnant.

About 1 per cent of the total luminosity of the Crab Nebula is known to be the emission of excited gas of its filamentary part. Since the magnitude luminosity of the Crab Nebula is $M = 8 \cdot 6$, the magnitude of the radiation, which is not the synchrotron radiation, is about $M = 13 \cdot 2$. If the Nebula were three times closer, the magnitude would be $M = 10 \cdot 8$. This is 10^2–10^3 times brighter than the minimum sensitivity of the Palomar Survey and could not be overlooked. The remnant surrounding the Scorpius source, therefore, must be visible if its gas is excited in the same manner as the gas of the Crab Nebula.

The filamentary part of the Crab Nebula stores energy of the order of 10^{44} ergs[5] and loses energy at a rate of about 10^{36} erg/sec. Therefore, some energy supply is likely to be needed to keep this part very hot for 10^3 years. The customary supposition that ultra-violet light from stars seen in the centre of the Crab Nebula supplies the energy to the gas does not seem to work, since these stars are now recognized not to belong to the Crab Nebula. While the Crab Nebula expands, it collides with the atoms of the interstellar gas and the atoms transfer a part of the energy of the bulk motion of the gas to thermal energy. If one nebula of radius 10^{18} cm is expanding with a speed of 1,000 km/sec in the interstellar gas of the density 1 atom/cm^3 the rate of gain of thermal energy is 10^{37} ergs/sec, which is sufficient to keep the Nebula hot. On the other hand, if the remnant is in the interstellar gas of lower density, the energy supply is not enough to keep it hot.

The galactic co-ordinate of the Crab Nebula ($l_{II} = 184°$, $b_{II} = -6°$) and the estimated distance (3,000 light years) are consistent to say that it is in the arm of the galaxy where the density of the gas is as high as 1 atom/cm^3, whereas the Scorpius source, because of its high galactic latitude, is supposed to be in a region between arms or in the galactic halo where the density is low. This possible difference of environment may cause a steep energy spectrum of electrons and, hence, much weaker synchrotron radiation of the Scorpius source compared with the Crab Nebula. Also this difference may easily explain more than a thousand times less intensity of the excited gas of the Nebula. Thus, the neutron star hypothesis for X-ray sources is compatible with the invisibility of the supernova remnant which possibly surrounds the Scorpius source.

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MINORU ODA*

Laboratory for Nuclear Science,
Massachusetts Institute of Technology,
Cambridge, Mass.

* On leave of absence from the Institute for Nuclear Study, University of Tokyo.

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