MODELS FOR THE X-RAY EMISSION FROM SUPERNOVA 1987 A

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An X-ray source coinciding in position with Supernova 1987 A was discovered in July 1987 by the group operating the Ginga satellite (Dotani et al. 1987). Its existence has been confirmed by measurements made on board the Mir-Kvant Observatory (Sunyaev et al. 1987), as well as by several balloon experiments. The emission extends at least from 6 KeV up to the MeV range (see the reviews by Tanaka and Trümper in this Conference).

A possible interpretation of this phenomenon involves the Compton diffusion of γ-ray photons emitted by radioactive Cobalt (see, e.g., Mc Cray et al. 1987; Sunyaev et al. 1987). This model is based upon the behavior of the bolometric light curve of the Supernova whose luminosity has been decaying with the same half-life of Co⁵⁶. Spectral lines which can be attributed to the presence of Co⁵⁶ have been detected in the infrared and in the γ-ray spectrum. It is then assumed that the original γ-ray photons emitted in the radioactive decay lose energy in the SN envelope when they are scattered by electrons. They escape as X-rays only if they can reach the outer regions of the envelope before their energy is decreased too much, otherwise they are inevitably absorbed by heavy elements (photoelectric opacity). At early times, all photons are absorbed while later on low and medium energy X-rays are no longer produced because of the reduced number of scatterings. The main predictions of this model are the following:

1. an X-ray luminosity around 10³⁹ ergs s⁻¹
2. a low energy cut-off below about 20 KeV, due to photoelectric absorption.
3. a progressive hardening of the X-ray spectrum.
4. a gradual disappearance of the X-ray emission in the energy range \( \lesssim 30 \) KeV, beginning around the end of 1987.

The observed properties of the source are not in complete agreement with the predictions. In particular, apart from some temporary fluctuations, the flux has remained nearly constant from September 1987 until Spring 1988.

If one wants to explain the persistency of the X-ray emission one must postulate an inhomogeneous mixing of Co\(^{56}\) inside the star. Some sort of Maxwell's demon may then have arranged the distribution of Co\(^{56}\) in such a way as to maintain a constant X-ray luminosity. The amount of Co\(^{56}\) which was initially produced can be determined from the bolometric light curve and it turns out to be about 0.07 \( M_\odot \). Provided that this material is suitably distributed, the X-ray luminosity of SN 1987 A can be maintained at the present level by radioactivity until late 1988 (Bandiera and Salvati, private communication). If this ultimate deadline will be violated, one will be forced to conclude that the X-ray photons produced by radioactivity do not contribute appreciably to the total flux and that an additional mechanism is also involved.

In any case, the existence of a flux below \( \sim 20 \) KeV cannot be explained by the radioactivity model and requires an additional mechanism. A definite possibility stems from the likely presence of a newly born neutron star inside SN 1987 A.

The burst of neutrinos detected from SN 1987 A at the time of the explosion is usually regarded as the signature certifying the birth of such a neutron star which is likely to have become a pulsar. Of particular importance would then be the properties of the non-thermal nebula produced in the central region of the Supernova by the relativistic pulsar wind and the ensuing synchrotron radiation.

This radiation should be visible if the SN envelope has already undergone fragmentation because of internal instabilities (Rayleigh-Taylor?). We will assume that this has happened within a few months after the explosion. In order to justify this assumption we recall the filamentary nature of the Crab Nebula (where internal fragmentation has occurred spontaneously, before any substantial interaction with the interstellar medium) and also the observational evidence for asymmetry, clumpiness and non-spherical motions in SN 1987 A (see the talk by Hillebrandt in this Conference). We also stress that the formation of filaments in a Supernova shell is likely to be an early event since it requires that the thermal velocities in the gas be larger than the general speed of expansion in the envelope.

In order to compute the observational properties of the pulsar nebula we have followed the methods discussed in previous papers (Pacini and Salvati 1973; Bandiera et al. 1984). As long as the pulsar energy