WHAT CAN WE LEARN ABOUT COSMIC RAYS FROM THE UV, OPTICAL, RADIO AND X-RAY OBSERVATIONS OF SUPERNOVA 1979c IN M 100?

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Theories on the Origin of Cosmic Rays almost invariably invoke the Supernova (SN) phenomenon in its early phases as the cause for production and acceleration of high energy particles. So far only optical information about SNe has been available and from it there is no direct evidence of Cosmic Rays. It is not surprising then that models of Cosmic Ray production are still rich in free parameters. On April 19th 1979 a very bright ($\sim$12 mag) SN, labelled 1979c, was detected in the relatively nearby galaxy ($\sim$16 Mpc) M 100 ($\equiv$NGC 4321). This galaxy, incidentally has produced 4 SNe in 78 years. Event 1979c was followed quite intensively in the optical and UV (with IUE) regions of the spectrum as well as observed at radio and X-ray frequencies. A detailed account of these observations is in press (Panagia et al. 1980). Here we summarize only very briefly the results relevant to the present discussion.

While the SN photosphere, where the continuum and optical lines originate, was observed to expand at $v_{ph} \sim 10^4$ Km s^{-1} an external UV shell, where UV lines were formed, that about 1 week after maximum had a radius $R_{UV} \sim 2\ R_{ph}$, was observed to expand at $v_{UV} \sim (1\div4)\ 10^3$ Km s^{-1}. SN 1979c, identified as Type II had at maximum $M_{B\,max} = -19^{m}\!.4 \pm 0^{m}\!.8$. Seven days after maximum $R_{ph} \simeq 1.25\ 10^{15}$cm. The most probable origin of the UV shell is from preexisting material ejected into space as a stellar wind by the progenitor star when it was in the red giant stage. The wind was estimated to be $\sim 10^{-4} M_{\odot} yr^{-1}$ to provide the observed $\sim 0.2 M_{\odot}$ of the UV shell. The shell therefore had a density of $\sim 5\ 10^6$ atoms cm^{-3}. From optical and UV measurements, we have $L_{TOT} \simeq 2.4\ 10^{43}$erg s^{-1} and $E_{rad} \simeq 7\ 10^{49}$erg. In the early phases($\sim$10 days after max) radio measurements provided only upper limits. The same applies for X-ray observations. The best upper limit in the 0.5-4.5 KeV energy range comes from the Einstein Observatory HRI 239 days after max $L_X < 7.7\ 10^{39}$erg s^{-1}. Almost exactly one year after maximum the SNR has been detected at the VLA radio telescope (K. Weiler, private communication) with flux S_{6cm} = 5mjy corresponding to $L_R \sim 1.5\ 10^{36}$erg s^{-1}.

As far as the production of Cosmic Rays is concerned we argue as follows:

1) There is evidence of an X-ray flash in the pre-detonation stage.

G. Setti, G. Spada, and A. W. Wolfendale (eds.), Origin of Cosmic Rays, 51–52.

This comes from the presence of the UV shell. The X-ray flash, in fact, is the most likely cause of acceleration and ionization of the material surrounding the exploding star observed in the UV. The minimum energy required (if pure H) being >5 10^{45} erg, i.e., in the range of predictions for such an X-ray flash. One should remember that the X-ray flash is frequently associated with the shock wave which in Colgate model accelerates cosmic rays.

2) A substantial γ-ray ($\bar{E}_\gamma \sim 100$ MeV) flux ($\sim 10^{44}$ erg s^{-1}) has been estimated by Cavallo and Pacini (1980) from the reaction $pp \to pp\pi^o$ and $\pi^o \to 2\gamma$ in the specific case of SN 1979c. This flux was not observed because no γ-ray instrument available at the time was aimed at the SN. This is regrettable because detection of γ's from π^o decay would have provided the best evidence of Cosmic Ray acceleration from SNe.

3) Because of the difference in velocity the photosphere eventually reached the UV shell. When this happened a reverse schock may have occurred (Mc Kee 1974). The X-ray luminosity in the 0.5-4.5 KeV band is $L_{isoth} \sim 6.5\ 10^{37} n_1$. This again is a substantial emission of short duration which was not detected because no X-ray telescope was observing at the time.

4) The radio detection provides estimates of the magnetic field and of the total relativistic particle energy contained in the young remnant. With standard assumption of equipartition and ratio $K = W_p/W_e = 100$ (Ginzburg and Syrovatskii 1964) one finds $H \simeq 0.45$ Gauss and $W_{CR} \sim 10^{48}$ erg. For $K = 1$, $H = 0.12$ Gauss and $W_{CR} \simeq$ $\simeq 7.5\ 10^{46}$ erg. Apparently the radio observational frequency was very close to the syncrotron reabsorption turnover frequency with $\gamma_e \sim 190$. If no further injection occurs and one can somehow account for lifetime effects we can predict a t^{-5} decrease of the radio flux with time t. Also, when this remnant will have reached the size of Kepler's SNR both magnetic field and relativistic particle content will be of the same order of magnitude as in Kepler's.

In conclusion, Cosmic Rays are already present in the remnant after 1 year although ~ 2 orders of magnitude below the canonical requirement of $\sim 10^{50}$ erg per SNe. Moreover, one consideration is apparent from the above: when a nearby bright SN occurs X and γ-ray detectors should follow the first months of its evolution if one wants to learn more about Cosmic Rays from SNe.

References

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