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Low Energy Gamma Ray Enhancement Observed During a Stratospkeric Balloon Flight

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An omnidirectional gamma ray detector was flown on a stratospheric balloon on December 15, 1978 from São José dos Campos, Brazil. After reaching ceiling, an increase in the count rate was observed. After considering the probable sources causing this increase, it is suggested that this increase might be due to the supernova remnant, first observed optically in May 1978 in galaxy MCG-4-32-23. The energy spectrum of supernova shows a flattening of slope above 1.5 MeV.

Um detetor de raios gama omnidirecional foi içado por um balão estratosférico em 15 de dezembro de 1978, partindo de São José dos Campos, Brasil. Após alcançar o teto, observou-se um aumento na taxa de contagem. Após consideração de fontes prováveis desse aumento, é sugerido que ele se deva ao remanescente de supernova observado oticamente pela primeira vez em maio de 1978 na galaxia MCG-4-32-23. 0 espectro de energia da supernova exibe um achatamento da inclinação acima de 1,5 MeV.

1. INTRODUCTION

Though high energy photon emission in gamma ray range had been predicted from extraterrestrial sources as early as 1958 (Morrison[26], 1958; Savedoff[34], 1959), little progress could only be made till recently because of low fluxes encountered in this range and also due to inherent difficulties in experimental techniques. In X-ray range, however, many sources were observed by balloon, rocket and satellite experiments, starting with the discovery of a source in Scorpius in 1962. The recent Uhuru satellite list runs to about 400 sources in 2 to 6 KeV energy range (Forman *et al*[16], 1978). The HEAO satellites also observed many sources in low energy X-ray range. Compared to this number, the SAS and COS B satellites observed about 30 sources at energies around 100 MeV and in the low energy gamma ray range, below 10 MeV, there are still fewer sources. Only Grab nebula (Walraven *et al*[41], 1975; Dolan *et al* [13], 1977; Wilson *et al*[42], 1977; Penningsfeld *et al*[29], 1979), Cyg X-I (Baker *et al* [2], 1973), Cyg X-2 (Dean *et al*[11], 1973) and Seyfert Galaxy NGC 4151 (Di Cocco *et al*[12], 1977; Graml *et al*[21], 1978), apart from galactic center region have thus far been identified as low energy gamma ray sources, though the confidence of their identification is still low. The gamma ray burst sources, which have been recently observed by balloon--and satellite - borne detectors (Cline *et* al[a], 1981: Teegarden and Cline[40], 1980: Mazets *et al*[24], 1980), form a separate class, as the energy in the range of 10^{38} - 10^{40} erg is released by them in small bursts lasting for times much less than few minutes. Though the small error boxes obtained from triangulation by satellite positions for these burst sources do not show any known sources or peculiar objects, it is believed that these gamma ray burst sources are neutron stars undergoing non-steady accretion (Mazets *et al*[24], 1980). Only one gamma ray burst source was identified thus far with the LMC supernova remnant, N49, using nine space probes and satellites of gamma ray burst sensor network (Cline *et al*[7], 1979). However, the characteristics of this phenomenon was quite different from the known variety of gamma ray bursts.

Supernovae have been recognized for a long time as the sources of high energy cosmic rays (Ginzburg and Syrovatsky[19], 1960; Shapiro[36], 1962), and Pinkau[30] (1970) has shown that the interaction of these cosmic rays with the ambient atmosphere may produce measurable gamma rays. It has also been recognized that the accretion of matter onto neutron stars and black holes gives rise to radiation in X - and gamma-ray range (Shapiro[37], 1973), But thus far, except the Crab nebula, and the transient gamma ray source, N 49, no other supernova has been definitely identified as the gamma ray source in the low energy range.

The purpose of the present paper is to show the observation of enhancement' in the gamma ray flux during a balloon flight and a possible source of this enhancement as due to a Supernova (SN).

2. INSTRUMENTATION AND FLIGHT DETAILS

An omnidirectional gamma ray detector was flown on a stratospheric balloon from São José dos Campos, Brazil, on 15 December, 1978. The detector consisted of a 4" x 4" NaI (Tl) crystal coupled to a RCA 80.54 photomultiplier tube. The crystal is surrounded by a 2 cm thick NE 102 A plastic scintillator viewed by a RTC XP 1030 photomultiplier tube. The plastic scintillator is used to monitor the charged particle count rate and operated in anticoincidence with the crystal. The accepted events were pulse height analyzed by a 256 channel analizer covering the energy range 0.30 to 10.40 MeV. A Rosemount type and a Springer type sensor were used to monitor pressure up to 7 millibars and a sensitive Rosemount sensor to measure pressures below 7 millibars to obtain the altitude inforrnation of the balloon. The encoded signals along with other scientific parameters (pressure, temperature etc.) were transmitted to ground via FM/FM telemetry. All the data were recorded on magnetic tapes for subsequent analysis.

The balloon was lauched at 0743 UT and reached a ceiling of 5.4 g/cm^2 at 0932 UT. The flight was terminated by a mechanical device at about 1600 UT. The electronics functioned well during all the flight. The pressure sensors showed that the float altitude remained constant at about (5.2 ± 0.2) g/cm^2 till about 1500 UT. The latitude variation of the flight was smooth and very srnall, being between -22.9 and - 23.1 degrees.

3. RESULTS AND DISCUSSION

In Figure 1 we show the variation of total count rate of gamma ray continuum (0.30 MeV to 10.4 MeV) from 0900 UT to 1300 UT. The figure shows that during the ascent to ceiling, which occurred atabout 0930

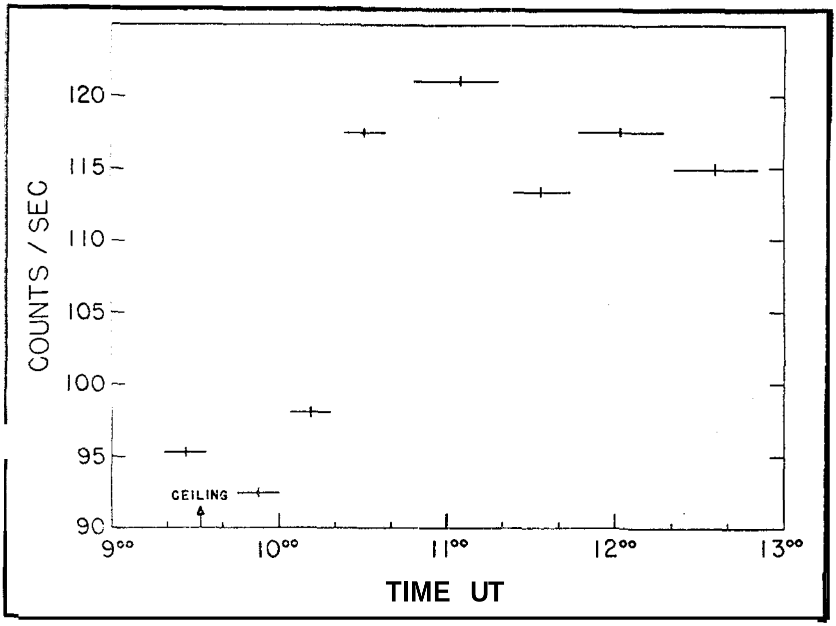

Fig.1 - Variation of gamma ray continuum from 0.30 MeV to 10.3 MeV with time.

UT, the counting rate went on decreasing. After 1000 UT there was an appreciable increase in counting rate till about 1120 UT. At this time the counting rate decreased again and remained almost constant till about 1400 UT. We examined all aspects like pressure change, gain change, rigidity cut off variation etc. to understand the sudden shift in the count rate level after 1000 UT but they did not show any correlated variation. Figure 2 shows the variation of counting rate in three different energy bands and variation of pressure with time. This figure shows that the counting rate variation is more pronounced at lower energies. The increase that was observed during 1030 to 1120 UT is more than that could be attributed to pressure variation and we believe must be due to extraterrestrial gamma ray events. Figure 3 shows two spectra, one immediately after attaining the ceiling between 0945 and 1000 UT (Curve a) and the other giving maximum counting rate between 1048 and 1118 UT (Curve b). Both have similar slopes and both curves indicate a break in their slopes at about 1.5 MeV, which may indicate the effects of charged particles. We do not have charged particle incidence rate to compare.

The detector, being omnidirectional sees, apart from many known galactic X-ray sources, a number of Seyfert galaxies, normal galaxies and sharp emission line galaxies which are known to b X-ray emitters and so the enhancement in the counting rate can not be attributed to any single source. Figura 4 shows the trajectory of the balloon in galactic coordinates along with the positions of some known X - and gamma ray sources. The time during which the enhancement is observed in the counting rate is shown as a shaded region below the trajectory. The numbers denote the gamma ray sources observed by COS - B satellite (Swanenburg et *al*[39], 1981) at energies greater than 100 MeV. Out of these, only two - no. 19 *(3C 273)* and no. *23* (ρ Oph) - have been identified by SAS *2* satellite (Bignami *et al*[5], 1980: Mayer - Hasselwander *et al*[25], 1980) also. Assuming a 50 percent attenuation in atmosphere from a point source, the

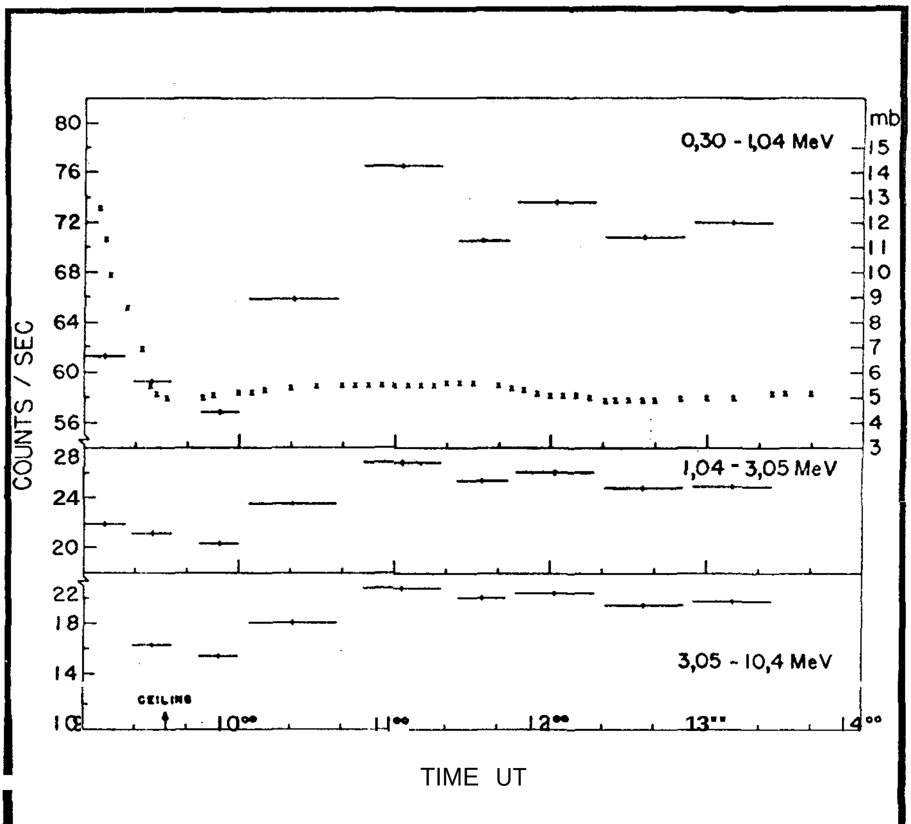

Fig.2 - Variation of gama ray counting rate in three different energy bands. The variation of pressure with time is also shown in the figure.

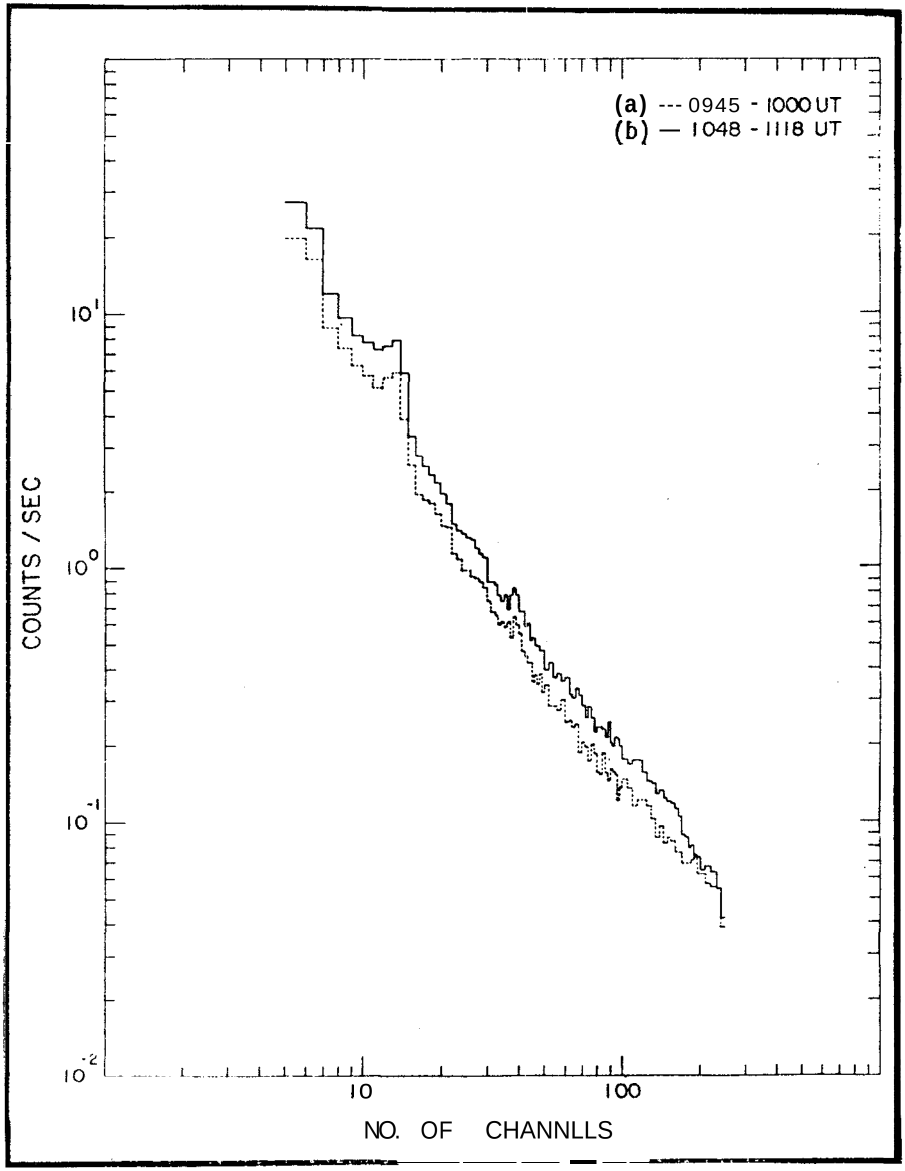

Fig.3 - Gama ray spectrum observed immediately after reaching the ceiling (---) and at the maximum counting rate (——).

detector would have a FWHM of about 105 degrees. The intensity of many of the galactic sources, which could influence the counting at more than 50 percent response within this field of view, are very low in the 2-6 KeV energy range (Forman et *al*[16], 1978) and we can assume that their in-

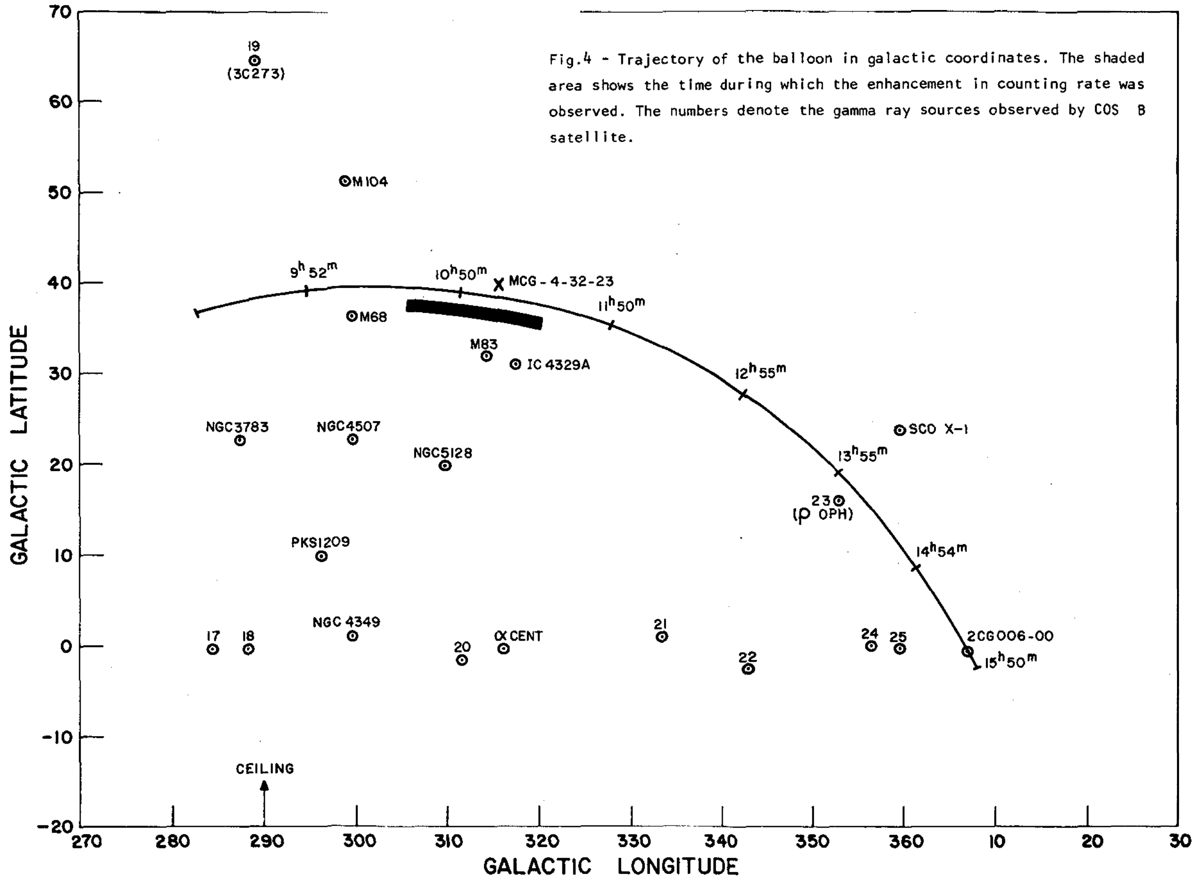

Fig.4 - Trajectory of the balloon in galactic coordinates. The shaded area shows the time during which the enhancement in counting rate was observed. The numbers denote the gamma ray sources observed by COS B satellite.

tensity do not contribute to the counting rate in the 0.30 to 10 MeV range. The Sun subtends a zenith angle of 57° at 1100 UT, which is at the periphery of the FWHM of the detector. Moreover, H_α flare data do not show any flares between 0907 UT and 1205 UT (Coffey, and Lincoln[9], 1979). The intensity of COS B sources, which the detector might see, is also very low, the flux being in the range 1.1 - 3.8 x 10^{-6} photons cm^{-2} s^{-1} (Swanenburg *et al*[39], 1981).

Of the extragalactic sources within the field of view, M68 is a galactic cluster whose X-ray spectrum would be thermal in nature and is unlikely to extend to gamma ray energies. M83 and M104 are spiral galaxies which have not been identified in X-rays or gamma rays so far. IC 4329 A is a Seyfert galaxy. On the basis of their X-ray luminosity function and relatively hard spectra Mushatzky *et al*[27], (1979) believe that the type I Seyferts are most likely gamma ray sources. However, only one Seyfert galaxy, NGC 4151, has so Far been observed in the 1-10 MeV range by many workers (Di Cocco *et al*[12], 1977; Schönfelder[35], 1978). The flux observed by SAS-2 in the 35 to 103 MeV range from Seyferts NGC 3783 and MRK 509 is substantially below extrapolations of their X-ray power law spectra (Bignami *et al*[4], 1979). The flux from IC 4329 A in the 35-100 MeV range as observed by SAS-2 detector gave an upper limit of 2.1 × 10^{-6} photons cm^{-2} s^{-1} keV^{-1}. If it is assumed that the spectrum of IC 4329 A would be similar to that of NGC 4151, the flux at 3 MeV from the former would beabout 1.5 x 10^{-6} photons cm^{-2} s^{-1} keV^{-1}. Assuming the source is seen for 30 minutes from 1048 to 1118 UT or December 15, 1978, the flux seen from the source in this range (~ 3 MeV) is nearly a factor of six greater (~ 8.9 ± 0.62) x 10^{-6} photons cm^{-2} s^{-1} keV^{-1} than the extrapolation given above. Thus the flux from IC 4329 A alone cannot account for the flux observed on December 15, 1978.

Another candidate source within the field of view is Centaurus A (4U 1322-42). This is a radio galaxy which has been observed from radio through low energy gamma rays (Hall *et al*[22], 1976). In the 2-6 keV X-ray range, the intensity of this source is very low as seen by Uhuru satellite (Forman *et al*[16], 1978) with intensity about 1 percent of Grab nebula. At 3 MeV, thefluxfromthissource is about 2.5 x 10^{-7} photons cm^{-2} s^{-1} keV^{-1} (Hall *et al*[22], 1976 and Mushatzky *et al*[27], 1979). This is one order less than the flux obtained by us, (8.9 ± 0.6) x 10^{-6} photons cm^{-2} s^{-1} keV^{-1} , on December 15, 1978 due to the source in the field of view of our detector. Thus Centaurus A alone or together with IC 4329 A do not appear to account for the flux of gamma rays observed by us.

Another likely source for the enhancementofcounting rate might be the galactic center region. In the low energy region, the diffuse component is due to the discrete source contribution while in the medium energy for an omnidirectional detector, the principal contribution may come from galactic center which has a spatial extent of about 40^{o} and where bremstrahlung electron processes are dominant. However, at the time of observation, the galactic center region is outside the field of view and its contribution, if any, would be very small.

As mentioned in the introduction, the supernova reninants, if they are within the field of view, might be responsible for a part or whole of gamma ray emission seen by the detector. The UK Schrnidt telescope unit has observed on May 8, 1978 a supernova at 17^{th} magnitudewith coordinates $\alpha = 13^{h}\ 27^{m}\ 32.6^{s}$ and $\delta = -21^{o}29'24.0''$, 20 seconds due west of the nucleus of 15^{th} magnitude galaxy MCG-4-32-23 (Gilmore[18], 1978). This appeared as a distorted or secondary nucleus of the galaxy. This supernova falls within the field of view of the detector.

As mentioned earlier, no supernova remnant has so far been identified with the gamma ray continuum emission, though is was theoretically predicted (Colgate and White[10], 1966) that the high energy shock wave associated with the burst could produce gamma ray photons. For supernova remnants, X-ray emission is the principal mode of radiation and accounts for a substantial fraction of their luminosity. The X-ray emission of the older supernova remnants (Vela, Puppis) occurs at lower energies (<2keV) than the younger remnants. The detector on the satellite HEAO-1 and HEAO-2 observed the young supernova remnants Tycho, Cas A and Kepler's up to about 25 keV. The ages of these remnants areabout 400 years and all of them show a similar spectrum. Only Crab nebula, which has an intermediate age of about 1000 years, has been observed up to about 150 keV in X-ray by balloon borne experiments (Ricker *et al*[33], 1975; Fukada[17], 1975) and at high energies of about 2.5×10^{11} eV by ground based Cerenkov detector (Fazio *et al*[15], 1972). Jacobson *et al*[23],

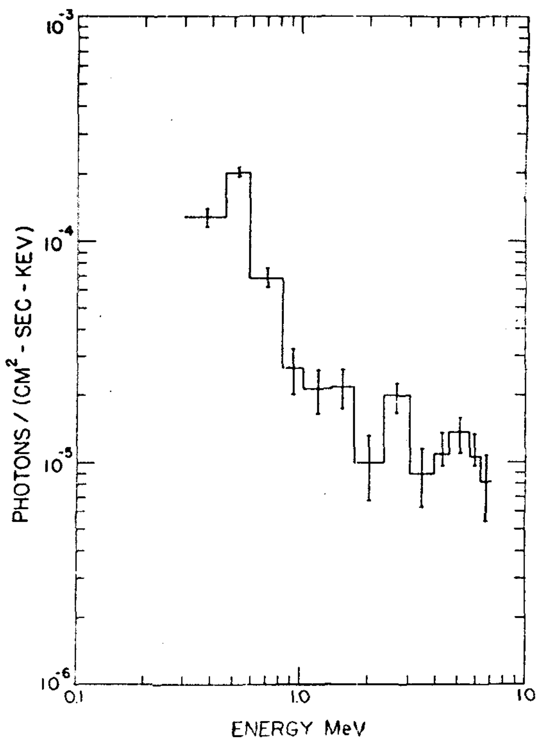

Fig.5 - Spectrum of the source responsible for the increase in counting rate. The source is suggested to be supernova remnant in MCG-4-32-23.

(1978) observed an enhancement in the counting rate of both Ge (Li) detector and the CsI (Na) shield during a balloon flight in 1974 in the energy range 0,4 to 6,6 MeV, which lasted for about 20 minutes. Their conclusion was that the enhancement is probably due to an extraterrestrial source. A supernova remnant IC 443, a pulsar - PSR 0611 + 22 and a high energy gamma ray source - γ 195 + 5, were included in the field of view of their detector and so, the cause of the enhancement in the counting rate could not be attributed to ary single source.

In the present experiment, however, as no other source within the field of view of the detector was found sufficiently strong enough to give rise to the observed flux, we are led to believe that the very young supernova (age about 7 months) situated on the axis of the detector could be the source of the enhancement in the counting rate. Figure 5 shows the observed spectrum of this source. This spectrum shows that after about 1.5 MeV slope becomes flat. This is contrary to the results obtained for Seyfert galaxy NGC 4151 (Schönfelder[35], 1978) and radio galaxy Cen A (Hall et *al*[22], 1976). This result also may indicate that the excess seen in the present results is not due to either Seyfert galaxy IC 4329 A or radio galaxy NGC 5128, but might be due to the supernova remnant in the galaxy MCG-4-32-23.

4. ESTIMATION OF THE EXPECTED FLUX FROM THE SUPERNOVA

Elliott et *al*[14], (1978) observed the spectrum of this supernova on May 29, 1978 and identified it as a subclass of type II. Assuming no interstellar absorption due to its high galactic latitude, the absolute magnitude was estimated to be M_V = - 17.1, and its distance was calculated to be 65 Mpc. No other observations of this supernova are available since then. Only few type II supernovae have been observed so far (Barbon *et al*[3], 1974) and all of them showa very wide variety in their photometric properties. A very few observations are available of this type of supernova beyond about 100 days after the maximum. Hence, the flux from this supernova can only the roughly estimated at the time of observation (about seven months after the maximum).

In general, the photometric characteristics of type II supernovae show a more gradual brightness decline, sometimes with a temporary delay (Pskovskii[32], 1967), the fall in luminosity during the first 90 days after maximum being $-2^m.5$ (Payne - Gaposchkin[28], 1957). According to Barbon *et al*[3], (1974) an average curve derived from thirteen type II supernovae shows a steady decline of $-1^m.8$ in about 25 days to reach the shoulder, the magnitude remaining almost constant at this value for about 56 days or more. Elliot et *al*[14] (1978) assume that the first observations of SN in MCG-4-32-23 were made between 21 and 51 days after the maximum. Assuming that the shoulder has been just reached at the time of first observation, the visual magnitude at maximum would be $m_V = 15^m.2$, which gives the luminosity at maximum $L_{max} = 1.1 \times 10^{43}$ erg s^{-1}. According to Pskovskii[32] (1967), the type II supernova shows a decline of 4.3 magnitudes in 100 days (β=4.3), while Arp[1] (1974) gives a value of 3.3 magnitudes in 100 days for the best observed type II supernova in

NGC 7331 seen in 1959. Taking this value of $\beta=3.3$, the supernova in MCG-4-32-23 would ãttain a visual magnitude of about 18.5 at the end of 100 days after the maximum. The absolute magnitude would then be M_V(100 days) = -15.6, and hence the luminosity, given by

$$L = 10^{0.4(4.79 - M_V)} L_{\odot}$$

would be $L_{100\ day} = 5.3 \times 10^{41}$ erg s^{-1}. As mentioned earlier, almost no observations are available for type II supernovae after 100 days. However, Gordon[20] (1960) shows that the luminosity of supernova type I has an exponential fall with luminosity decreasing by a factor of two during t = 55 days, which sets in 50 to 100 days after the maximum. Applying the same rule to type II supernova, we find α = 0.013 in the exponential law. Then

$$L_{210\ days} = L_{100\ days} \exp(-0.013 \times 110) = 1.27 \times 10^{41} \text{ erg s}^{-1}$$

With the distance of 65 Mpc, this gives a flux of 4.88×10^{-11} photons cm^{-2} s^{-1} keV^{-1} at the Earth in the 3.046 to 3.907 MeV range, which is less by an order of 5 compared to the flux of 8.9×10^{-6} photons cm^{-1} s^{-1} keV^{-1} observed in the same energy band. The discrepancy is very large and is mainly due to uncertainties in the theory of type II supernovae and in the estimation of distance.

Shklovskii[38] (1960) predicted an ejected mass of severa1 tens of solar masses in type II supernovae, whereas Poveda[31] (1964) showed that in a standard type II supernova, the ejected mass cannot be more thanabout 0.02 $M_{\odot}$ and would have an initial temperature of about 4×10^4 ^{0}K, this temperature being constant foratleast a few years as it does not have the chance of cooling itself by radiation. The energy liberated in the continuum during the blast would be about 6.6×10^{50} ergs and L_{max} = 6.6×10^{44} erg s^{-1}. With this initial value the flux in the 3 MeV range would 3.1×10^{-9} photons cm^{-2} s^{-1} keV^{-1}, still lower by an order of 3 compared to the observed flux. The two theories give two different values, much less than the observed value. The improvement in the theory of type II supernovae and their prolonged observations may solve this problem in the future. However, there is no doubt about the fact that gamma rays are released from a young supernova. Clayton *et al*[6], (1969) showed that the nucleosynthesis of the 77 day ^{56}Co, which decays to

^{56}Fe, are accompanied by a rich gamma ray spectrum that may be observable for a year or so in supernova remnants to distances of several Mpc. ^{44}Ti is also seen to decay with a 48 year half life to ^{44}Sc and then to ^{44}Ca with emission of a 1.156 MeV gamma quanta. This gamma ray line flux from the supernova in MCG-4-32-23 would be studied in a later paper.

5. SUMMARY

During gamma ray observations by an omnidirectional detector on December 15, 1978 excess counts were observed after the balloon reached the ceiling. After accounting for the likely sources within the field of view of the detector, it is shown that the excess flux seen might be due to a supernova remnant observed for the first time in May 1978. However, due to lack of collimation of the detector we do not rule out the effects of other possible sources. An energy spectrum due to the source is also constructed which shows a flattening of the slope at higher energies. The flux expected from this supernova 210 days after the maximum is estimated and the inadequacy of the present day theory of type II supernova indicated.

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