Bull. Astr. Soc. India (1996) **24,** 749–755

1.8 MeV emission lines from galactic plane region

Indira Bardoloi[1], K. Duorah[2], H.L. Duorah[2], Mon Mayuri Barua[1]

[1] *Handique Girls' College, Guwahati 781 001, India*

[2] *Gauhati Universy, Guwahati 24, India*

Abstract. The COMPTEL telescope aboard the CGRO satellite has revealed highly significant 1.8 MeV emission lines from the Galactic plane region of the Milky Way Galaxy. The observed concentrated emission region may contain a single object or superposition of multiple objects. To explain the observed emission features, an accreting neutron star has been considered as a possible source candidate. During the explosive event in the neutron star, radioactive isotopes of ^{26}Al are produced and ejected into the interstellar matter, wherein ^{26}Al$_g$ decays emitting 1.8 MeV γ-emission lines. The considered candidate should well explain the observed flux of the 1.8 MeV line.

Key words : 1.8 MeV gamma line — neutron star

1. Introduction

Gamma ray lines arise directly in nuclear or high energy processes. So, observations of astronomical γ-lines can tell us about nucleosynthesis processes going on in the calestial objects as well as about the source direction. Gamma-emission line energy ranging between 0.5 MeV and 15 MeV may be interpreted as decay as de-excitation of excited nuclei and as red-shifted $e^- - e^+$ annihilation. Haymes *et al.* (1975) detected from balloon flights in 1974 first astronomical gamma lines, 4.6 MeV line with flux 9.5×10^{-4} photons cm^{-2} s^{-1}, 0.5 MeV line with flux $(8.0 \pm 2.3) \times 10^{-4}$ photons cm^{-2} s^{-1}, Ramaty *et al.* (1979) suggested these lines to be produced in one or more discrete sources in the Galactic centre region. Since then observaitonal and theoretical work on these gamma lines are processing well. Diehl *et al.* (1987) observed with balloon flights a 1.275 MeV line from the galactic centre region. The expected fluxes of the line are in the range $10 - 10^{-2}$ photons cm^{-2} s^{-1}. A prominenet line on 1.80 MeV was believed to come from a point source in the galactic centre region (Ballmoos *et al.*, 1987). Moreover, very recently, some γ-ray lines have been observed in the γ-ray burst 20 Dec., 1990 by the high pressure xenon ionization chamber installed on board of the orbital station "MIR". The instrument "BUKET" registered several hundred gamma transient events where it recorded some events with lines in energy spectra (Bolotnikov *et al.*, 1993). Though

BATSE and Ginga observations on some of γ-lines are yet to be solved (Fishman and Meegan, 1995), astronomers and astrophysicists are concentrating more on 1.8 MeV γ-emission lines. After three years of observations with the COMPTEL telescope and OSSE experiments aboard the CGRO satellite (Cosmic Gamma Ray Observatory), they have the first map of the Milky Way Galaxy in the light of 1.8 MeV. They have found that most of the patchy emission regions are confined to the Galactic plane region. In addition to the Galactic centre direction, they have found significant 1.8 MeV emission from the Carina region with point-like appearance (Knödleseder *et al.*, 1995). Oberlack *et al.* (1995) have put limits on 1.8 MeV line from the Orion region while Purcell *et al.* (1995) have presented data on diffuse Galactic gamma-ray emission detected within ~10° of the galactic center and also significant 1.8 MeV line observed when multiple observations of the Galactic plane are combined.

To fit the observed data on 1.8 MeV emission lines, some celestial settings have to be choosen from which $^{26}Al_g$ isotopes will be produced and ejected at high velocities into the inter stellar matter (ISM) by stellar winds or explosions. $^{26}Al_g$ nuclide undergoes β^+-decay emitting a γ-photon of energy 1.8 MeV. Several workers have suggested various sources, such as Type II supernovae, W-R stars, novae and AGB stars as source of the emitter nuclei.

In the present work, we have considered an accreting neutron star during a γ-burst phenomenon as a possible source of $^{26}Al_g$ production and ejection into the interstellar matter. The intensity of the line expected on earth is shown in Figure 4.

2. Production of ^{26}Al in an accreting neutron star

Since April, 1991, CGRO satellite has recorded data regarding γ-ray burst phenomenon. To fit the observed intensity and time profile of the bursts, scientists have suggested different models. Poirier (1995) have suggested that divergent sources are possible for γ-bursts to occur. Some new models suggest involvement of compact neutron stars or white dwarfs of Galactic origin or at cosmological distance (Sivaram, 1995). But, till today since no models have been accepted for the new γ-burst data, the old models of the source can be considered which can explain well about the source energy. Woosley and Wallace (1982) suggested highly magnetised neutron star (N.S.) in a binary star system to fit the intensity and time profile.

In a binary neutron star system, accretion occurs from the companion star to the neutron star surface. In a highly magnetised star, accreted matter at the rate of ~ 10^{-13} $M_\odot$ yr^{-1} is focused onto the polar region of ~1 kilometer size (Fig. 1). Accreted matter consists of hydrogen, helium and some heavy particles like C, O, Ne and Mg. As matter accumulates, temperature rises (~10^8K) and density ξ is ~ 10^5g cm^{-3}. At this high temperature and density condition, hydrogen burns rapidly increasing the helium mass. When helium mass reaches a critical amount there will be an explosion pushing the hot plasma above the surface leading to γ-ray outburst. In this scenario of γ-ray burst in an accreting neutron star surface, starting with ^{24}Mg as seed nuclei in a hydrogen - helium plasma, magnesium may capture either a proton or ω alpha particle from surrounding. (p, γ), (p, α), (p, η), (α, γ), (α, η), (α, β) all these reactions for Mg, Al nuclides have been examined with the recent rates available (Harris *et al.*, 1983; Buchman *et al.*, 1984; Cauglan *et al.*, 1985). It is found that the proton capturing rates of all the MS, Al nuclides are much faster than the alpha capturing reactions resulting in the completion of a Mg Al S_i cycle (Bardoloi and Duorah, 1993). Mg Al S_i cycle is compelte via the reactions :

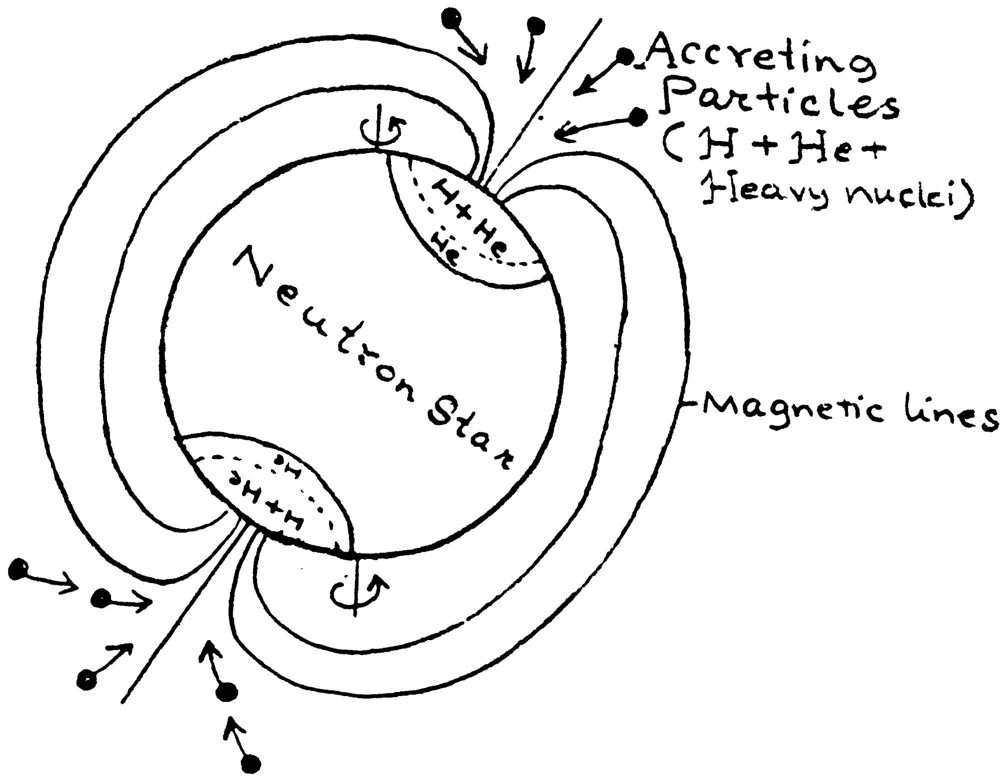

Figure 1. Magnetically focused accretion on neutron star leading to burst phenomenon.

$$^{24}Mg\ (p,\ \gamma)\ ^{25}Al\ (\beta^+,\ \upsilon)\ ^{25}Mg\ (p,\ \gamma)\ ^{26}Al_g\ (p,\ \gamma)\ ^{27}S_i\ (\beta^+,\ \upsilon)\ ^{27}Al\ (p,\ \alpha)\ ^{24}Mg,$$

with additional reactions :

$$^{25}Mg\ (p,\ \gamma)\ ^{26}Al_m\ (\beta^+,\ \upsilon)\ ^{26}Mg\ (p,\ \gamma)\ ^{27}Al \text{ and}$$

leakages via –

$$^{27}Al\ (p,\ \gamma)\ ^{28}S_i \text{ and } ^{27}S_i\ (p,\ \gamma)\ ^{28}p \text{ reactions.}$$

During the cyclic reactions, 25Mg definitely captures proton producing ^{26}Al in two states, one at ground state ($^{26}Al_g$) and the other at isometric state ($26Al_m$). These two states will have to be treated seperately at $T_9 \lesssim 1$ as the thermal equilibrium between $^{26}Al_g$ and $^{26}Al_m$ is not achieved (Rodney and Rolfs, 1982). $26Al_m$ at $E_x = 0.23$ MeV has a β^+ – decay with $\tau_{1/2} = 6.3$ Sec while $5^{+26}Al_g$ has $\tau_{1/2} = 8 \times 10^5$ yr. Only 4% of $^{26}Al_g$ decays to ^{26}Mg at $E_x = 2.97$ MeV while 96% decays to $2^{+26}Mg$ state with $E_x = 1.8$ MeV which then jumps down to 0^+ ^{26}Mg state emitting a 1.8 Mev γ-photon (Fig. 2).

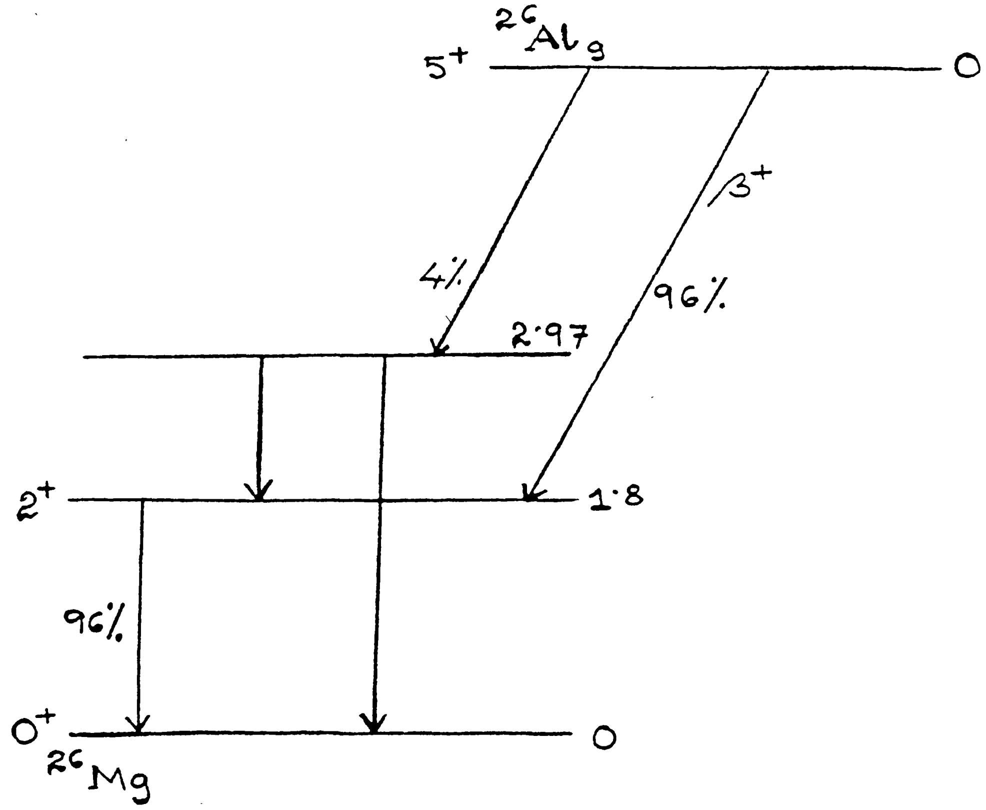

Figure 2. Beta-decay of $^{26}Al_g$ nuclei with $\tau_{1/2} = 8 \times 10^5$ yr. 1.8 Mev γ-photon is emitted when $2^{+26}Mg$ state with $E_x = 1.8$ Mev jumps down to $0^{+26}Mg$ state.

3. Expecting flux of 1.8 MeV γ-photons at earth

Isotopic abundances of the Mg AlSi cyclic products during the considered explosive event on the neutron star, have been calculated with the help of Bateman equation. The equation for radioactive chain decay is given by,

$N_j(t) = N_0$ \i\su(i=1,j, $h_{ij}\ e^{-\lambda_i t}$, (1)

where N_j (t) is the J^{th} product at time 't' and N_0 is the initial abundance of the seed nuclei. The h_{ij} s are functions of λs, the reaction probabilities which are the inverse of lifetimes. h_{ij}s are given by,

$$h_{ij} = \prod_{k=1}^{j-1} \lambda_k \Big/ \prod_{m \neq 1}^{j} (\lambda_m - \lambda_i), \qquad (2)$$

where i can take on the values 1, 2, 3 .... j.

As the MgAlSi cycle has some additional branching reactions and leakages, branching ratios have to be considered in determining the abundance distribution. The branching ratios for the formation of $^{26}Al_g$ and $^{26}Al_m$ from ^{25}Mg are found out. The branching through ^{25}Mg (p, γ) $^{26}Al_g$ is quite large (87.37% – 77.79%) at $T_9 = 0.2 - 1.0$ ($T_9 = T \times 10^9 k$). Starting with the seed nuclei with mass fraction $X_z = 0.02$ and all other heavy elemental abundances being taken as zero, the operation of the cycle distributes the seed element amongst all other nuclei. As here, in this paper, we are mainly interested in the production of $^{26}Al_g$ nuclide, the abundance distribution of $^{26}Al_g$ at different times during a γ-burst event are shown in the Figure 3 for $T_9 = 0.1$ and $\zeta = 10^5 g\ cm^{-3}$. The reactions are presumed to take place in the neutron star's polar region of radius $r \simeq 1$ km size with a thickness $\eta = 9m$ (Woosley and Wallace, 1982). As the energy released in the burst event is sufficient enough to explosively eject the combined surface and accreting matter (Ramanamurthy and Wolfendale, 1986), our considered setting would be a good injector of product nuclei from the star surface into the intersteller mass (ISM). So $^{26}Al_g$ along with other product nuclei will be ejected into the ISM.

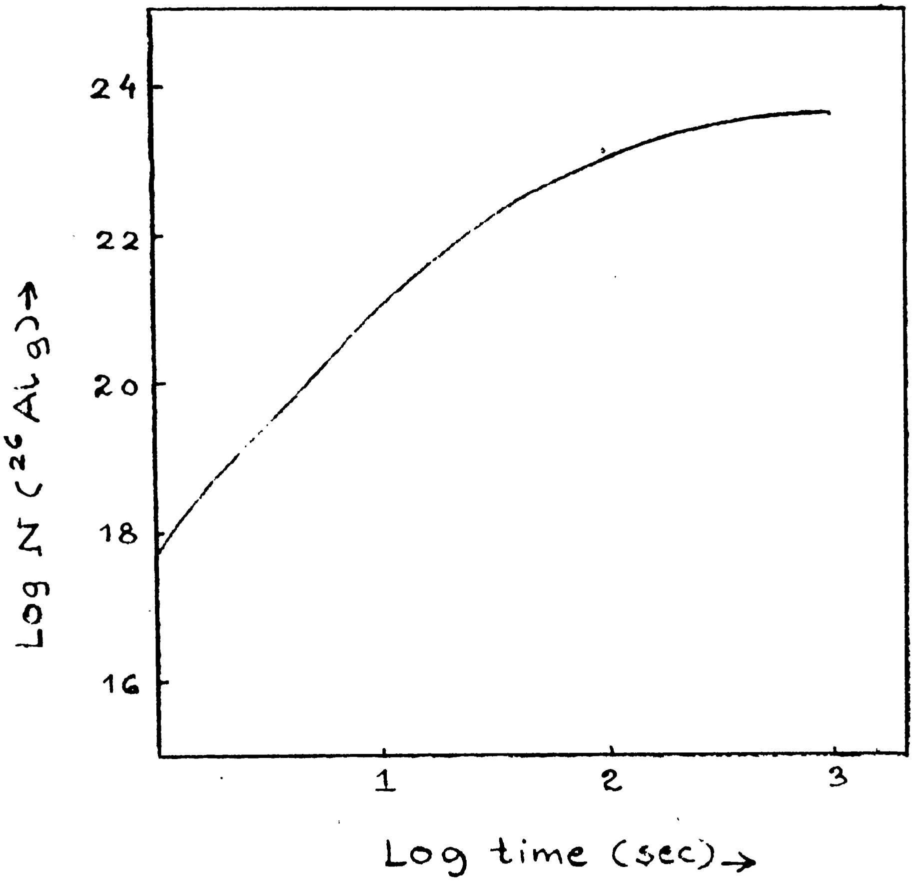

Figure 3. Variation of N($^{26}Al_g$) with time during the explosive event on an accreting Neutron Star.

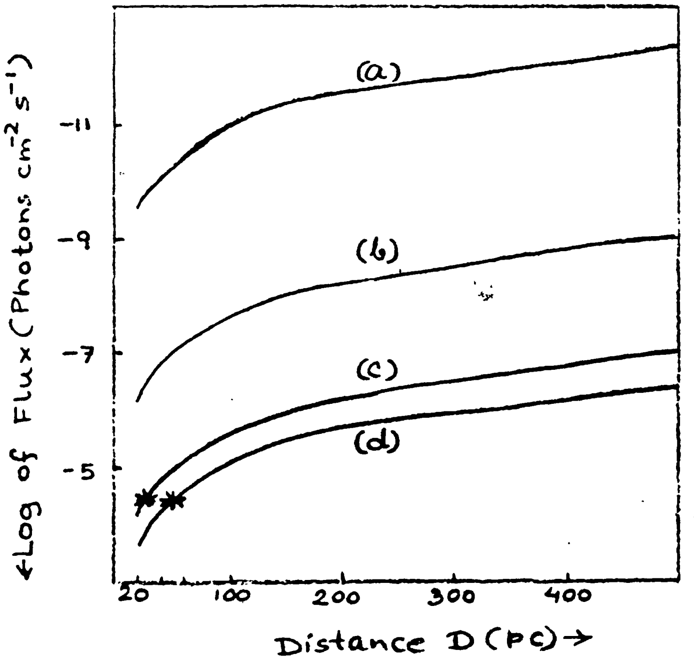

Figure 4. Expected flux (Photons cm^{-2} s^{-1}) of the 1.8 Mev γ-lines received on earth vs. source distance D(pc). (a), (b), (c), (d) represent the variation at times t = 1s, 10s, 100s, 500s respectively. Esterisk marks (*) representing the CGRO observed flux by Knödleseder *et al.* (1995).

In the ISM $^{26}Al_g$ decays (lifetime = 8 x 10^5 yrs.) emitting 1.8 MeV γ-photons. The nucleosynthetic yields N_j at the polar region and the distance of the source, D par Sec., from the earth controls the flux of photons received on earth. Flux is given by

$$\text{Flux} = \frac{\pi r^2 h N_j}{4 \pi D^2}$$

$$= 2.3718 \times 10^{-23} \frac{N_j}{D^2} \text{ photons cm}^{-2} \text{ s}^{-1},$$

where, Nj is the number density of the jth product at the instant 't'. The calculated flux of photons received on earth at D pc ranging 20 pc – 500 pc are shown in Figure 4.

4. Results and discussion

Astrophysicists have offered different possible source candidates as the origin of production of $^{26}Al_g$ which can emit the observed astronomical 1.8 MeV γ-emission lines. To fit the observed flux of 1.8 MeV γ-emission lines Knödleseder *et al.* (1995) have considered O-Ne-Mg novae at a maximal distance of 20 pc for the measured flux of 3.3.10^{-5} photons cm^{-2} s^{-1} by the CGRO experiments. Moreover, they suggested an AGB star with ^{26}Al yield of ~10^{-9} – 10^{-5} $M_\odot$ at a distance of 1 – 60 pc and a massive W – R star or SNe II at < 600 pc. Bardoloi *et al.* (1996) suggested a nova outburst associated with the white dwarf component of close binary system at a distance of 146 – 25 pc. In the present work an accreting magnetised neutron star has been considered which yields $^{26}Al_g$ of the order of ~10^{18} – 10^{24} by number density during the explosive event on the polar region of the star. Analysing the variation of flux with distance of the source, it is seen that during different times of the burst, flux of the photons expected on earth varies with distance. At time 1 and 10 sec, the source is suggested to be within a 40 pc distance to have flux ~ 10^{-6} photons cm^{-2} s^{-1}. At the later stage of the explosion, flux is $1.03.10^{-7}$ – 6.45, 10^{-5} photon cm^{-2} s^{-1} ($3.38.10^{-7}$ – $2.11.10^{-4}$) at time 100 s (500 s), source at distances ranging 500 pc to 20 pc. It is seen from Fig. 4 that at times 100 s – 500 s, flux of the photons is of observable order ~10^{-5} photons cm^{-2} s^{-1}. To fit the COMPTEL detection of the significant 1.8 MeV flux of $3.3.10^{-5}$ photons cm^{-2} s^{-1} from the carina region (Knödlsedor *et al.* 1995), we can well suggest an accreting neutron star also during an explosive event at a distance of ~30 – 50 pc. Since there is significant variation of flux with time, the detected lines data by the space probes depend at what particular moment the detector is pointing towards that source.

References

Ballmoos P. *et al.* 1987, 20th ICRC papers, Moscow, 1, p. 140.

Bardoloi I., Duorah H.L. 1993, J of Ass. Sc. Soc. 35 (2) p. 102.

Bardoloi I. *et al.* 1996, XVII Annu. Meet of ASI, p. 52.

Bolotnikov A.E. *et al.* 1993, XXIII ICRC papers, Calgary, Canada, 109.

Buchmann L. *et al.* 1984, Nucl. Phys. A., 415, 93.

Caughlan G.R. *et al.* 1985, Atomic Data and Nucl. Data Tables, 32, p. 197.

Diehl R. *et al.* 1987, 20th ICRC papers, Moscow, 1, p. 144.

Fishman, G.J., Meegan C.A., 1995, ARA&A, 33, p. 415.

Harris M.J., *et al.* 1983, ARA&A, 21, p. 165.

Haymes R.C., *et al.* 1975, ApJ, 201, p. 593.

Knödlseder J., *et al.* 1995, 24th ICRC papers, Rome, 2, p. 186.

Oberlack U., *et al.* 1995, 24th ICRC papers, Rome, 2, p. 207.

Poirier J., 1995, 24th ICRC papers, Rome, 2, p. 211.

Purcell W.R. *et al.* 1995, 24th ICRC papers, Rome, 2, p. 211.

Ramanamurthy P.V., Wolfendale A.W., 1986, in Gamma-ray astronomy, Cambridge Univ. Press.

Ramaty R., *et al.*, 1979, ApJS, 40, p. 487.

Rodney W.S., Rolfs C., 1982, in Essays in Nuclear Astrophysics, Cambridge University Press, p. 171.

Sivaram C., 1995, 24th ICRC Papers, Rome, 3, p. 352.

Woosely S.E., Wallace R.K., 1982, ApJ, 258, p. 716.