Contribution of Novae towards the Galactic Diffuse Gamma lines

Indirał Bardoloi*, **Monmoyuri Baruah**†

*Principal,Handique Girls' College,Guwahati-781001, Assam, India
†Physics Department,Don Bosco University, Azara,Guwahati -781017, Assam, India
Email: monmoyuri_b@yahoo.com

***Abstract*. Diffuse galactic γ-lines and spectral features have been observed by different experiments on board the space probes, like SPI (Spectrometer INTEGRAL) on board the INTEGRAL (Weidenspointer et al. 2006), COMPTEL, OSSE, HEAO-3 and others. Some of these lines of energy 1.809 MeV and 1.275 MeV due to β^+-decay of radioactive nuclei $^{26}Al_g$ and ^{22}Na respectively have significant flux to be detected. Obseved data on 1.809 MeV with measurable line intensity from galactic $^{26}Al_g$ nuclei have been inspected by Diehl et al. 2006, Leleux et. al. 2006. $^{26}Al_g$ and ^{22}Na are found to be produced in White Dwarf during Nova Burst . In the present work, detail calculation have been made with Yaron et. al. 2005 nova model with multicycle outburst calculations. Yaron's new full grid having entire parameter space for CO-White Dwarf resulted lower mass transfer rate with lower temperature. At this lower density temperature condition, considering up-to-date BRUSLIB and NETGEN reaction rate (Aikawa et al. 2005), it has been tested whether H-burning thermonuclear synthesis process during burst phenomenon can produce $^{26}Al_g$ and ^{22}Na nuclei and also whether the process ejects enough of these nuclei to contribute Inter Stellar Matter wherein these nuclei will decay resulting detectable diffuse γ -lines emission. Some more lines due to de-excitation of excited nuclides may be expected, but the detection chance is very feeble. Comparison between the diffuse galactic observed line properties and calculated line flux from nova eject indicates chemical as well as physical properties of the nucleosythesis sites i.e., novae of these γ -emitter excited nuclei.**

***Keywords*: Novae, Gamma-lines**

I. INTRODUCTION

Study of Astronomical gamma ray (γ) lines is very important because γ-ray lines can provide the most direct method of studying chemical as well as physical properties of the nucleosynthesis sites and nucleosynthesis theoretical models. J. Paul (1999) remarked that "A Golden Age of Nuclear Astrophysics" will open with the launch of the INTEGRAL spacecraft which aims mainly to observe γ lines from varieties of cosmic sites. Since the year 1974, several space missions, have been performed; some of which are showing excellent results (Haymes et al. 1975; Fishman and Meegan, 1995; Ramaty et al. 1979; Diehl et al. 1987; Knodleseder et al. 1995; Purcell et al. 1995, Weidenspointer et al. 2006; Diehl et al. 2006, Leleux et al. 2006). Emission line energy ranging between 0.5 MeV and 15 Mev may be interpreted as redshifted electron - positron annihilation or de - excitation of excited nuclei produced in the nucleosynthesis processes. Compton telescopes, has detected 1.8 MeV radiation from $^{26}Al_g$. The fluxes expected from steady galactic nucleosythesis are quite uncertain but generally in the range of 10^{-4} - 10^{-6} photons $cm^{-2}s^{-1}$. HEAO-3 has observed 1.275 MeV line with flux 4.4×10^{-4} photons $cm^{-2}s^{-1}$ which is due to β^+ -decay of ^{22}Na nuclei. At present, INTEGRAL spacecraft has observed about 300 γ -lines in the energy range 2-8 MeV with the help of the SPI (Spectrometer INTEGRAL) on board the INTEGRAL (Weidenspointer et al. 2003; Diehl et al. 2006; Leleux et al. 2006).

To explain the cause of these observed astronomical γ- ray lines having varied energy with varied flux, astrophysicists have suggested various possible sources, mainly some explosive events which eject out excited nuclei which emit energetic γ -radiations.

In the present work, it is examined whether explosive events like nova outbursts may be the possible sources of excited nuclei, which may emit γ -lines due to β^+ -decay and de - excitation with detectable intensity range. Nova explosion occurs when mass is transferred onto a binary white dwarf (WD) from its companion star. Nova models have been studied since decades. Most recently in the year 2005, Yaron et al have studied an extented grid of multicycle nova evolution model using increased computer power, better modern physical concepts for C-O WD. Yaron's new frame work included parameters for accreted H-rich material on the cool W-D surface which leads to thermonuclear runaways (TNR). When accretion continues from the companion star onto the WD, the accreted material becomes compressed. The gravitational energy due to compression raises the temperature of the accreted layers leading to ignition.

In the present work, two sets from the Yaron's range of temperature of H layer have been considered: **Set I** with $T_H = 4.7 \times 10^8 k$ for mass of WD, $M_{wd} = 1.40 M_{\odot}$, WD core temperature $T_{wd} = 10 \times 10^6 k$ and accreted mass $log\dot{M} = -11 M_{\odot} yr^{-1}$. **Set II** with $T_H = 1.1 \times 10^8 k$, $M_{wd} = 0.65 M_{\odot}$, $T_{wd} = 50 \times 10^6 k$ and $log\dot{M} = -11 M_{\odot} yr^{-1}$.

It is hoped that consideration of this modern Yaron's model and detail calculations on γ- emission during outbursts will certainly result to simulate the actual picture of contribution of novae towards the galactic observed γ- lines.

II. NUCLEOSYNTHESIS DURING NOVA OUTBURSTS:

In the accreted layer heavy seed nuclei C, O, Ne and Mg with total mass fraction 4×10^{-5} , each one having equal shares, may capture proton P or alpha particles with hydrogen mass fraction $X_H = 0.7$ and helium mass fraction $X_{He} = .29996$. Considering the recent BRUSLIB and NETGEN nuclear reaction rates (Aikawa et. al., 2005), it is found that in the considered scenario, all the proton capturing rates for all the nuclei are much faster than the α- capturing rates leading to CNOF, NeNa, MgAlSi cycles to operate (Bardoloi and Barua, 2002).

Abundances of the nuclosynthesis product nuclides during outbursts for the considered first and second sets have been calculated for 100 sec using Bateman equation and considering branching ratios, leakages from the cycles (Bardoloi et al. 1996). During outbursts, the excited product nuclei will be ejected out into the inter stellar matter. During these CNOF, NeNa, MgAlSi cyclic operations, some radio - active β^+ -decay nuclei such as ^{13}N,$^{14,15}O$,$^{17,18}F$, ^{22}Na,$^{26}Al_g$ are also produced. During β^+ -decay of these unstable nuclei, gamma (γ) emission will be there. The nuclei which have longer β^+ -decay life time will contribute to diffuse galactic gamma radiation and which have shorter β^+ -decay life time, will contribute to prompt γ-emission. Since each excited product nuclei is to emit one photon, number density of γ- photons received on earth $cm^{-2}\ s^{-1}$ i.e intensity I is given by , $I = n_j(t) \times m_{ej}/4\pi D^2$ photons $cm^{-2}\ s^{-1}$ where, $n_j(t)$ =no. density of the j^{th} product during time t in a nuclear chain reaction. m_{ej} = ejected mass per sec during explosion and D= distance of the nova from the earth. According to Yaron 2005, during nova outbursts, a WD ejects mass m_{ej} amounting about $0.78\times10^{23}\ gms^{-1}$ to $3.276\times10^{23}\ gms^{-1}$ (the observed range).

The observed novae are at different distances from us (Senziani et al. 2008). So, the present calculations are done considering the sources to be in a range 1-10 kpc.

III. EXPECTED INTENSITY OF THE EMITTED γ-LINES DUE TO β^+ DECAY

1) **Decay of $^{26}Al_g$:** Considering 96% of $^{26}Al_g$ β^+ -decay to 1.809 MeV level of ^{26}Mg, γ - line emission of energy 1.809 MeV will result. Calculated intensity of these 1.809 MeV line due to Nova outburst event to receive on earth for Set I and Set II at distances 1 and 10 kpc, m_{ej} with extreme observed range are presented in the figures 1-8. Comparison with the observed flux of range $10^{-4} - 10^{-6}$ photons $cm^{-2}s^{-1}$ is also shown in the figures with two parallel dashed lines having $I = 10^{-4}$ and 10^{-6} on the graph.
2) **Decay of ^{22}Na:** Considering 99.938% of ^{22}Na β^+ -decay to 1.275 MeV level of ^{22}Ne, the γ - line emission of energy 1.275 MeV will result. Calculated intensity of these 1.275 MeV line due to a nova outburst event to receive on earth for the Set I and Set II at distances 1 and 10 kpc, m_{ej} with extreme observed range are presented in the figures 1-8. Comparison with the observed flux of range $10^{-4} - 10^{-6}$ photons $cm^{-2}s^{-1}$ is also shown in the figures with two parallel dashed lines having $I = 10^{-4}$ and 10^{-6} on the graph.
3) **Decay of ^{14}O :** ^{14}O decay to the excited state of ^{14}N, which de-excite by emitting photons at 2.312 MeV. Calculated intensity of these 2.312 MeV line due to a nova outburst event to receive on earth for the Set I and Set II and comparison with the observed flux of range $10^{-4} - 10^{-6}$ photons $cm^{-2}s^{-1}$ are also shown in the figures 1-8 for the same ranges as considered in case of $^{26}Al_g$.
4) **Decay of ^{13}N:** ^{13}N are β^+ -unstable nuclei with relatively short lifetimes, which produce positrons. These positrons annihilate with electrons producing photons of .511 MeV. Calculated intensity of .511MeV line due to a nova outburst event to receive on earth for the Set I and Set II and comparison with the observed flux are also presented in the figures 1- 8 for the same ranges as considered above.

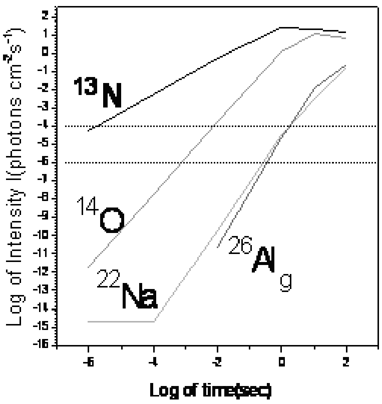

Fig. 1: D=1kpc, $T_H = .11 \times 10^9 k$ $m_{ej} = .78 \times 10^{23} gms^{-1}$

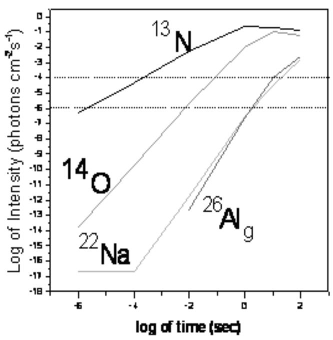

Fig. 2: D=10kpc, $T_H = .11 \times 10^9 k$ $m_{ej} = .78 \times 10^{23} gms^{-1}$

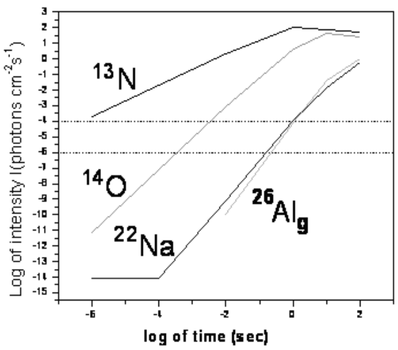

Fig. 3: D=1kpc, $T_H = .11 \times 10^9 k$ $m_{ej} = 3.276 \times 10^{23} gms^{-1}$

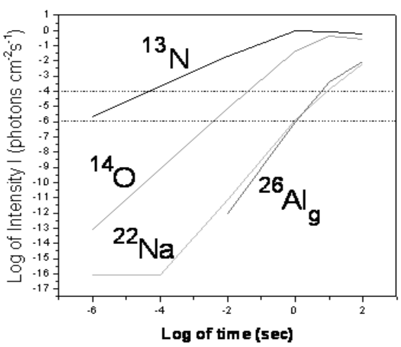

Fig. 4: D=10kpc, $T_H = .11 \times 10^9 k$ $m_{ej} = 3.276 \times 10^{23} gms^{-1}$

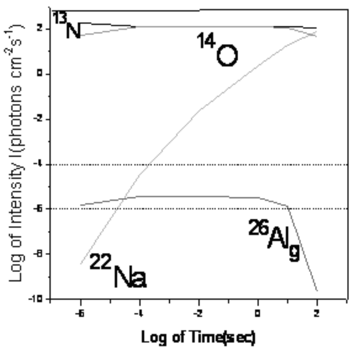

Fig. 5: D=1kpc, $T_H = .45 \times 10^9 k$ $m_{ej} = .78 \times 10^{23} gms^{-1}$

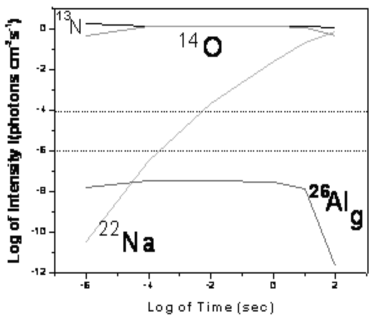

Fig. 6: D=10kpc, $T_H = .45 \times 10^9 k$ $m_{ej} = .78 \times 10^{23} gms^{-1}$

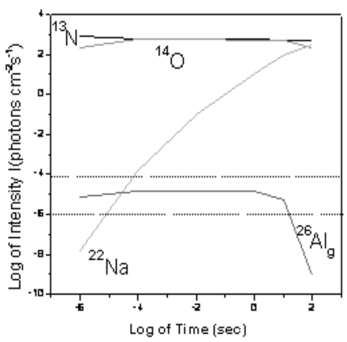

Fig. 7: D=1kpc, $T_H = .45 \times 10^9 k$ $m_{ej} = 3.276 \times 10^{23} gms^{-1}$

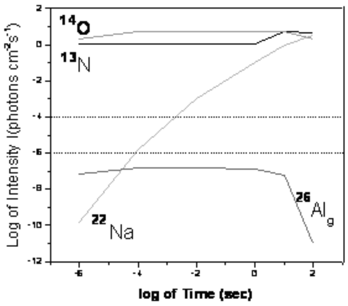

Fig. 8: D=10kpc, $T_H = .45 \times 10^9 k$ $m_{ej} = 3.276 \times 10^{23} gms^{-1}$ *[Fig1-8:Log of time (sec) vs. Log of Intensity I(photons $cm^{-2}s^{-1}$)of the calculated gamma-lines. The parallel dashed lines having I=10^{-4} and 10^{-6} gives the detectable range of gamma-lines detected by telescopes on space missions]*

IV. Conclusion:

Leaving aside the sensitivity and field of view of the telescopes, detection possibility also depends on intensity of the emitted γ-lines which in turn depends on suitable distance of source, whether exact time peak intensity coincides with the time of observation. From the results of the present work, considering recent Yaron's model and recent nuclear reaction rates, it is found that there is every possibility of novae outbursts to be the sources of some detectable diffused galactic as well as prompt γ-line emissions. From the fig.1-8, it is well established that the detection of γ-lines from the radioactive nuclei $^{26}Al_g, ^{22}Na, ^{14}O$ with energies 1.809 MeV, 1.275 MeV , 2.312 MeV respectively are possible in most of the considered scenario. Figures also show that detection of .511MeV line due to ^{13}N is very feeble except for the parameters $T_H = .11 \times 10^9 k$, D = 10kpc, $m_{ej} = .78 \times 10^{23} gms^{-1}$ and $m_{ej} = 3.276 \times 10^{23} gms^{-1}$. Though till date, no γ- line detection has been practically possible from novae by Swift, CGRO, WIND and others (Senziani et. al., 2008, Harris et.al., 2000), yet as the Burst Alert Telescope (BAT) on board the SWIFT is opening new opportunities to search for the prompt γ- line from novae, astrophysicists may hope for these detections very soon.

References

[1] Aikawa, M. , et. al., 2005, A and A, 441, 1195 − 1203.
[2] Bardoloi, I and Barua, M., *Bull. Astr. Soc. India,*, 2002, 30, 305-311.
[3] Bardoloi, I. et. al., *Bull. Astr. Soc. India,*, 1996, 24, 749.
[4] Diehl, R., et. al.,, 2006, A and A, 449,1025,
[5] Diehl et. al., *1987, 20th ICRC Papers, Moscow,*1, 144 ,
[6] Fishman, *and Meegan*, 1995, ARA and A, 33:415
[7] Harris, M. J. et.al., *2000, ApJ, 542, 1057*,
[8] Haymes et. al., 1975, ApJ, 201, 165
[9] Knodleseder, J., et. al., 1995, 24th ICRC Papers, Rome, Italy 2:186
[10] Leleux et. al., 2006 *(website: http://en.wikipedia.org/wiki/Gamma-ray-astronomy)*,
[11] Paul, J., *1999, 26th ICRC Papers, Utah, USA 5:144-147*,
[12] Purcell, et. al., , *1995, 24th ICRC Papers, Rome, Italy 2:211.*
[13] Ramaty et. al., *1979, ApJS, 40, 487*.
[14] Senziani, F., et. al., *2008, A and A, 485, 223-231.*
[15] Weidenspointer, G. et. al., *2006, A and A, 450, 1013.*
[16] Weidenspointer, G. et. al., 2003, A and A, 411, L113
[17] Yaron, O., et. al., 2005,ApJ, 623, 398