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GAMMA-RAY LINE EMISSION FROM ^{26}Al PRODUCED BY WOLF-RAYET STARS

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1.Introduction The recent satellite observations of the 1.8 MeV line from the decay of ^{26}Al (HEAO 3:Mahoney et al, 1984,SMM:Share et al,1985),has given a new impetus to the study of the nucleosynthesis of ^{26}Al (e.g. Clayton,1984 and Fowler,1984)
In this communication we discuss the production and ejection of ^{26}Al by massive mass-losing stars (Of and WR stars), in the light of recent stellar models (see also Dearborn and Blake,1984,1985).We also derive the longitude distribution of the ^{26}Al gamma-ray line emission produced by the galactic collection of WR stars,based on various estimates of their radial distribution. This longitude profile provides i) a specific signature of massive stars on the background of other potential ^{26}Al sources,as novae,supernovae,certain red giants and possibly AGB stars (Cameron,1984). and ii) a possible tool to improve the data analysis of the HEAO 3 and SMM experiments.

2.The production and ejection of ^{26}Al by Of and WR stars.
An evolutionary model of massive stars (initial mass from 50 to 100 $M_{\odot}$),including mass loss and extended mixing,has been recently developed,aimed at following O stars trough their subsequent evolution into the Of,WN,WC and WO stages (de Loore et al,1985,Prantzos et al,1985).This mass range seems to correspond to most of the WR progenitors (Humphreys et al,1985).The nucleosynthesis of all species up to ^{30}Si is closely followed thanks to a detailed nuclear network supplied with updated nuclear data relevant to the H and He-burning phases (for details of the network interesting specifically ^{26}Al,see Prantzos et al,1985 and Cassé and Prantzos,1985). ^{26}Al is produced and homogenized in the stellar convective core during H-burning,through the reaction $^{25}Mg(p,\gamma)$,and destroyed at the onset of He-burning through (n,α) and (n,p) reactions.This nuclide is also β^+ unstable with a mean lifetime τ_{26}~1 million years.It appears at the stellar surface when the H-rich envelope is dispersed by the intense stellar wind (Of and WN phases),and disappears at the beginning of the WC phase,when it is the turn of He-burning products to emerge at the surface.The ^{26}Al dispersed by the wind in the interstellar medium still decays long after the final explosion of Wolf-Rayet stars.

The quantity of ^{26}Al ejected is found to increase with mass and should depend almost linearly on metallicity of the stellar progenitor (see also Dearborn and Blake 1984,1985). The ^{26}Al yield and the corresponding gamma-line luminosity, averaged over i) the initial mass function of Humphreys and McElroy,1984 (assumed to be uniform across the galactic disk),and ii) the radial metallicity gradient derived by Shaver et al,1983 (extrapolated up to about 4 kpc from the galactic center),amount to $Y_{26}=1.1\ 10^{-4}\ M_{\odot}$ and $L_{\gamma}=1.3\ 10^{38}$ photons sec^{-1} respectively.These values should be characteristic of an average galactic WR star

Assuming a steady state abundance (e.g. Clayton 1984),the total mass of live ^{26}Al scattered in the whole galaxy at present time is $M_{26}=N_T.Y_{26}$,where N_T is the total number of WR stars having contributed to the galactic ^{26}Al production in one lifetime (10^6 years).N_T,in turn,is proportional to the WR birthrate,$B_{WR}=n_{WR}/\tau_{WR}$,n_{WR} being the present number of WR stars in the galaxy and τ_{WR} their average lifetime. Current models (e.g. Maeder and Lequeux 1982,Prantzos et al,1985) predict that $\tau_{WR}=3$ to $5\ 10^5$ years,at least for solar metallicity.We assume provisionally that this number applies to the whole galaxy as well.The error introduced by this simplification is expected to be small compared to the uncertainty on n_{WR},which is ,as we shall see,considerable.

3.The number of WR stars in the galaxy. A reasonable estimate of the total number of WR stars present in the galaxy is difficult,but it must include one of the two following factors or both:
a)the increase of the star formation rate with decreasing galactocentric distance. Since the WR catalogs are complete only up to 2.5 kpc from the sun (e.g. Hidayat et al,1982 and Conti et al,1983),we rely on qualitative tracers of star formation to derive the radial distribution of young and massive stars inward,including the very central region.
b)the increase of the ratio WR to O stars with metallicity,Z. From counts of WR and O stars in the Magellanic Clouds and regions of the galaxy of varied distances,Maeder(1984) derived the relation $N_{WR}/N_O \propto Z^{1.7}$.
We assume that this relation still holds for Z>0.03 (i.e.in the inner galaxy and in the very central region where Z~0.09, Güsten and Ungerechts,1985). Indeed an increase of N_{WR}/N_O with Z,presumably due to an increase of the mass loss rate of O star with Z,is not unexpected (Maeder 1982) and can be understood,at least qualitatively,in the framework of radiation driven wind models of O stars (e.g. Abbot,1982).

Both effects tend to increase significantly the gamma-line luminosity of the inner galaxy.Three different cases have been considered to illustrate their relative importance.

A.following Maeder and Lequeux (1982),we assume that WR star follow the distribution of giant HII regions,as given by Guibert et al (1978).In this case n_{WR}~1000 and

and $M_{26} \sim 0.4\ M_\odot$ (leaving aside the very central region), much less than the mass required to sustain the 1.8 MeV line at the observed level ($\sim 3\ M_\odot$, Mahoney et al, 1984).

B. the WR surface density has been scaled to that of molecular hydrogen (Sanders et al, 1985, modified locally as prescribed by Dame and Thaddeus, 1985). This is equivalent to assuming that the formation rate of the WR progenitors is proportional to the gas density, at large scale, and that the N_{WR}/N_O ratio is uniform across the galactic disk. n_{WR} is then 3000 (2000 in the disk, 1000 in the center) and $M_{26} \sim 1.3\ M_\odot$.

C. Applying to distribution B the metallicity correction discussed above, we get distribution C, n_{WR} is now ~ 8000 (6000+2000) and $M_{26} \sim 3.2\ M_\odot$. This last case is encouraging, but remember that it rests on a rather speculative basis; dedicated models of metal-rich WR stars are needed to substantiate these ideas.

4. Longitude distribution of the WR gamma-line emission

Knowing the typical luminosity of individual sources and their galactic distribution, it is a matter of numerical integration to calculate the longitude distribution of the arriving flux (e.g. Harding 1981). The fluxes resulting from radial profiles A, B and C are shown in figure 1a,b. Only in case C, as expected, the flux from the galactic center direction is comparable to the one derived from the HEAO and SMM data.

Note that the three proposed profiles are sharper than the COS B one, Which serves as a reference in the HEAO and SMM data treatment. For consistency it would be desirable to reiterate the data analysis on the basis of theoretical profiles A, B and C.

5. Conclusion

We have tentatively estimated the contribution of WR stars to the 1.8 MeV line emission of the galactic plane on the basis of recent models of stellar evolution. These seem to be interesting candidates, but because of i) large uncertainties in their galactic distribution, and ii) the lack of dedicated metal-rich WR models, it would be premature to conclude that they are the unique sources of ^{26}Al in the galaxy. Future experiments with improved spatial resolution (<5°) will help to identify the most generous ^{26}Al sources, galaxy wise. At present, it would be desirable to refine the data analysis of the HEAO 3 and SMM satellite in the light of theoretically derived distributions, as for instance, distributions A, B and C.

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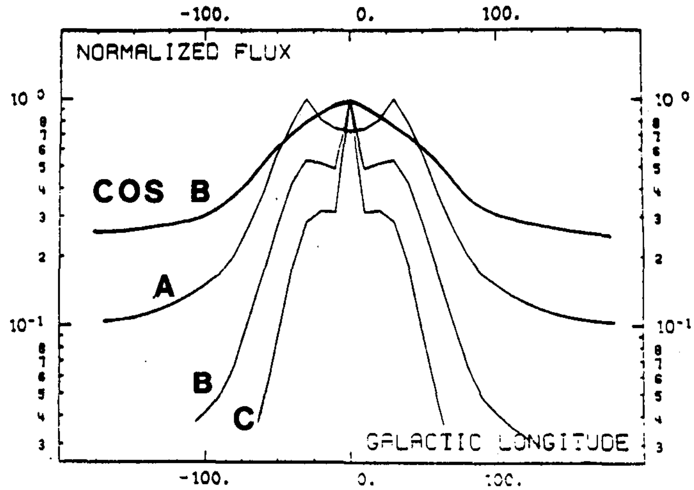

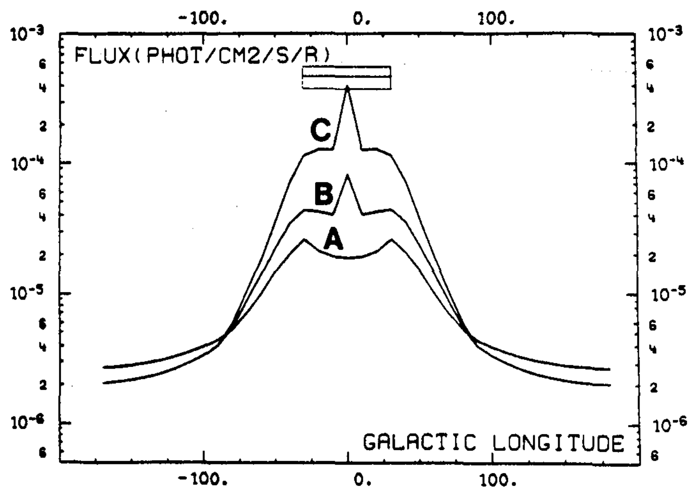

Fig. 1 a,b *Longitude profiles derived from the three possible WR distributions*
a) Normalized at peak value to show the center/anticenter contrast, of interest for the observers. The COSB profile is shown for comparison.
b) Expected flux (in photons cm^{-2} s^{-1} rad^{-1}) versus longitude in the A, B and C cases. The shaded area indicates the measured value $(4.8 \pm 1) \times 10^{-4}$ photons cm^{-2} s^{-1} rad^{-1}, between $\pm$ 30° in longitude, Mahoney et al., 1984).