CHIN.PHYS.LETT. Vol.11,No.8(1994)480

Are Massive Main Sequence Stars and Wolf-Rayet Stars Detectable Sources of the Intersteller Medium ^{26}Al?*

PENG Qiuhe
Department of Astronomy, Nanjing University, Nanjing 210008

(Received 14 December 1993)

Taken the recent experiments of nuclear physics into account, the massive main sequence stars and Wolf-Rayet stars are hard to provide enough interstellar medium ^{26}Al to be detected, which is discussed in the text.

PACS: 25. 90. +k, 97. 10. Cv, 97. 20. Ec

Besides some γ-ray lines of ^{56}Co from SN1987A,[1] only the 1.809 MeV γ-ray line radiation due to the decay of ^{26}Al has been detected in the interstellar medium (ISM),[2] although many γ-ray lines due to the decay of radioactive isotopes, such as ^{22}Na, ^{26}Al, ^{44}Ti, ^{60}Fe, etc., were theoretically predicted to be detectable in ISM.[3]

Massive main sequence (MS) stars with mass loss and Wolf-Rayet (WR) stars, as two sources of the ISM ^{26}Al, have been discussed by many authors Ref. 4 and are emphasized again recently by Prantzos.[5] He claimed that the WR stars can produce up to about 20% of observed ISM ^{26}Al after publication of the detective results of the Compton Gamma-Ray Observatory (GRO).[6] But we would like to point out, in this letter, that those stars are hard to produce enough ISM ^{26}Al to be detected.

The information about the observations of spacecrafts in 1980s mainly gives: 1) The flux of the 1.809 MeV γ-ray radiation is about $4.8\times10^{-4}\gamma cm^{-2}s^{-1}sr^{-1}$. It means that the mass of ^{26}Al(M_{26}), which is ejected into ISM of the Galaxy every 10^6yr, is about $(2\text{–}3)M_\odot$. 2) The measured width (FWHM) of the 1.809 MeV line is about 3 keV (Ref. 2). 3) Neither of 1.275 MeV γ-ray due to the decay of ^{22}Na nor 0.078 MeV (and 1.157 MeV) γ-ray due to the decay of ^{44}Ti(^{44}Ti$\rightarrow^{44}$Sc$\rightarrow^{44}$Ca) has been detected up to now.

Recently the COMPTEL instrument aboard the Compton GRO definitely showed that the emission of 1.809 MeV is diffuse in the galactic plane and that the distribution map of emission is relatively flat but asymmetric in longitude profile with an important emission from the directions of both the galactic center (GC) and the Carina arm.[6] The observation of GRO may draw some conclusions: 1) The important emission of both the GC and the spiral arms implics that SNII+SNI$_b$ and/or the massive stars (including WR stars) must be important sources of the ISM ^{26}Al. 2) Besides, there must be sources other than the population I stars to give a significant contribution of the ISM ^{26}Al, due to the fact that the map of the 1.809 MeV γ-ray emission is not very flat.

The origin of the 1.809 MeV γ-ray radiation is still a mystery in astrophysics up to now.

MS stars with mass loss, as a source of the ISM ^{26}Al, are firstly suggested by Dearborn *et al.*[7] They declared that such massive MS stars might have a rather marginal contribution (up

*Supported by both the National Grand Project 'Climbing Up' and the National Natural Science Foundation of China.

©by the Chinese Physical Society

to $0.2\,M_\odot$) to the quantity of ^{26}Al in the Galaxy. This idea had been extended by Prantzos *et al.* to WR stars.[4] For both massive MS and WR stars, ^{26}Al can be nucleosynthesized in the H-burning core with $(3.5\text{–}9)\times10^7$ K temperature, and carried to the surfaces of the stars and then blown with the strong stellar wind into ISM. Recently, Prantzos claims that WR stars can produce up to about 20% (i.e. $(0.2\text{–}0.5)M_\odot$) of galactic ^{26}Al.[5] However, this conclusion is still based on his calculation in 1986 (Ref. 4) and some important experiments of nuclear physics related to the nuclear reaction rates in the MgAl chain of reaction (Fig. 1) after 1986 are not taken into account. The conclusion above should be greatly changed by these newer reaction rates. For example:

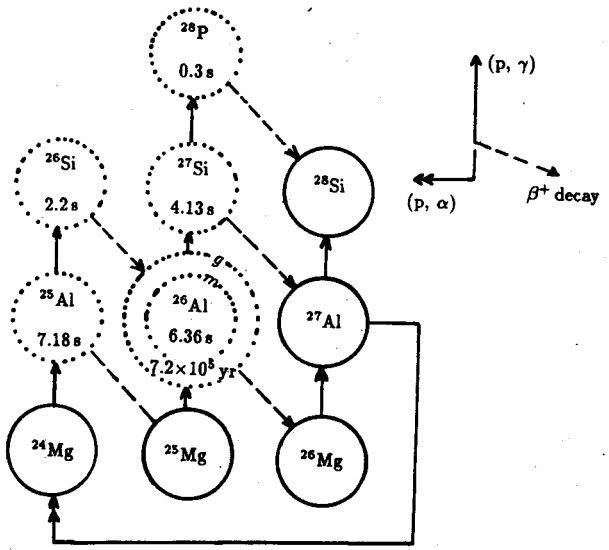

Fig. 1. The MgAl chain of nuclear reactions. $^{26}Al^g(\tau_{\frac{1}{2}}=7.2\times10^5$ yr) and $^{26}Al^m(\tau_{\frac{1}{2}}=6.365$ s) are the ground state and the first exited state of ^{26}Al, respectively. In the course of the reaction, ^{25}Mg(p, γ)^{26}Al, 80% of the products of ^{26}Al are $^{26}Al^g$ and 20% are $^{26}Al^m$. Both of $^{26}Al^g$ and $^{26}Al^n$ are transformed into ^{26}Mg by decay or by electron capture. The former emits the 1.809 MeV γ-ray and the latter does not any γ-ray radiation.

1) The experiment on the non-closed MgAl chain of reactions

The MgAl chain of nuclear reactions was basically considered a closed chain, at least in the temperature range $T_9 \leq 0.4$, for all calculations of ^{26}Al yield in various models except both SNII and SNI$_b$ before 1988, i.e., the branch ratio of the proton capture reaction on ^{26}Al, $R=\sigma(^{27}\text{Al(p, }\alpha)^{24}\text{Mg})/\sigma(^{27}\text{Al(p, }\gamma)^{28}\text{Si})$, was taken greater (or much greater) than 1 when $T_9 \leq 0.4$ (Ref. 3). Comparing the reaction rate of ^{27}Al(p, α)^{24}Mg (Ref. 8) with the rate of ^{27}Al(p, γ)^{27}Si (Ref. 9), it was concluded that $R \leq 0.01$ for the temperature range $T_9 \simeq (0.07-0.3)$. Therefore the MgAl chain does not cycle. Thus the ^{26}Al yield in the hydrostatic H-burning of massive MS stars and WR stars (and AGB stars) must be less than one calculated by many authors, including Prantzos *et al.*,[4] before 1988.

2) The experiment on the rate of ^{25}Mg(p, γ)^{26}Al

The most important reactions to nucleosynthesis of ^{26}Al in the MgAl chain of reactions

through the H-burning are $^{25}Mg(p, \gamma)^{26}Al$ and $^{26}Al(p, \gamma)^{27}Si$ which destroies the newly born ^{26}Al.

The experiment of the cross section of $^{25}Mg(p, \gamma)^{26}Al$ has been made not long before.[10] Comparing their result with the tabulated value in 1988,[11] Iliadis *et al.* found that the new rate is much lower than the old rate in the range $T_9 \leq 0.1$, e.g., it is only about 20% (in the temperature range $T_9 \approx (0.02 - 0.07)$) or 10% ($T_9 \approx 0.1$) of the old rate.[11] That is, the ^{26}Al yield in the hydrostatic H-burning of massive MS stars or of WR stars (and of AGB stars), including Prantzos' calculation in 1986,[4] must reduce by a factor of five, comparing with one calculated before 1990.

We would like to emphasize that the yield of ^{26}Al out of WR stars in our Galaxy is probably overestimated by more than a factor of five at least in the Prantzos' estimation[5] based on his calculation in 1986,[4] according to the two experiments above. But more serious difficulty comes from an experiment.

3) The experiment on the rate of $^{26}Al(p, \gamma)^{27}Si$

It is very difficult to estimate the cross section of the reaction $^{26}Al(p, \gamma)^{27}Si$, for the level structure of the short-lived nucleus ^{27}Si with $\tau_{\frac{1}{2}} = 4.13$ s is still unclear. Although Schmalbrock *et al.*[12] have uncovered previously undetected five levels (in the energy range $\sim (6-8)$ MeV) near the proton threshold, their experiment was unable to measure the radiative width, Γ_γ, of these resonant levels. Rangacharyulu *et al.*[13] indirectly estimated the level structure and their corresponding Γ_γ of ^{27}Si, through an experiment that an electron beam is scattered by a target made of ^{27}Al which is the mirror nucleus of ^{27}Si. They came to the conclusion that the new rate of $^{26}Al(p, \gamma)^{27}Si$ is (3–4) orders of magnitude at least higher than the old rate value of the reaction for the temperature below 1.0×10^8 K (more than 5 orders of magnitude for $T_9 \leq 0.05$). It must give an important effect on the net yield of ^{26}Al through the hydrostatic H-burning, although their new reaction rate of $^{26}Al(p, \gamma)^{27}Si$ has not been adopted yet up to now.

Due to the physical experiments above, we may draw the conclusion that the net yield of ^{26}Al through hydrostatic H-burning with $T_9 \leq 0.1$ will be much less than one calculated before 1990. That means all of hydrostatic H-burning models including the massive MS stars and the WR stars are hard to provide enough ISM ^{26}Al to be detected.

By the way, the situation about the asymptotic red giants branch (AGB) stars which were first considered by Nogaard[14] and Cameron[15] as an important source of ^{26}Al is similar to the WR stars. ^{26}Al may be nucleosynthesized in the H-burning shell with the temperature about $(3–7) \times 10^7$ K of the AGB stars. According to the calculations of Paulus and Forestini,[16] an average ^{26}Al yield of $\sim 0.1\, M_\odot$ can be injected into ISM from the AGB stars with initial MS mass in the range $(1–3)\, M_\odot$ every 10^6 years in our Galaxy. Thus they came to the conclusion that those AGB stars seem unable to account for the present ISM ^{26}Al content. Their calculation has included the experiments 1) and 2) above, although the experiment by Rangacharyulu *et al.*[13] has not been taken into account. We believe that the contribution of AGB stars to the ISM ^{26}Al may be neglective.

According to the analysis above, we may come to the conclusion that massive MS stars, WR stars and AGB stars of our Galaxy are negligible for the ISM ^{26}Al. Excluding those stars,

the observation by GRO has shown that SNII+SNI$_b$ should be the most important sources of the ISM ^{26}Al. ^{26}Al may be nucleosynthesized mainly through explosive neon-burning with the temperature above 10^9 K during SNII and SNI$_b$ explosion.[17] The yield of ^{26}Al produced in the explosive burning with $T > 10^9$ K is not effected by the three experiments above, but the present theoretical models of SNII and SNI$_b$ should be improved in order to overcome some difficulties that we will discuss in another paper.

REFERENCES

[1] S. M. Matz *et al.*, Nature, 331 (1988) 416.
[2] W. A. Mahoney *et al.*, Astrophys. J. 286 (1984) 578.
[3] D. D. Clayton and Leising, Phys. Rep. 144 (1987) 1.
[4] N. Prantzos, in *Proceedings of the Second IAP Workshop on Advances in Nuclear Astrophysics*, edited by E. Vangioni-Flam *et al.*, (1986) p. 321.
[5] N. Prantzos, Astron. Astrophys. Suppl. 97 (1993) 119.
[6] Diehl *et al.*, Astron. Astrophys. Suppl. 97 (1993) 181.
[7] D. S. P. Dearborn and J. B. Blake, Astrophys. J. 277 (1984) 783.
[8] R. Thielemann *et al.*, Nucl. Phys. A 477 (1988) 105.
[9] A. E. Champagne *et al.*, Nucl. Phys. A 505 (1989) 384.
[10] Ch. Iliadis *et al.*, Nucl. Phys. A 512 (1990) 509.
[11] G. R. Caughlam and W. A. Fowler, Atomic. Data Nucl. Data Tables 40 (1988) 283.
[12] P. Schmalbrock *et al.*, Nucl. Phys. A 457 (1986) 182.
[13] Rangacharyulu *et al.*, Astrophys. J. 320 (1987) 405.
[14] H. Nogaard, Astrophys. J. 236 (1980) 95.
[15] A. G. W. Cameron, Icarus. 60 (1984) 416.
[16] G. Paulaus and M. Forestini, *in Proceedings of the 6th Workshop on Nuclear Astrophysics*, edited by W. Hillebrandt and E. Miiller, 1991, p. 76.
[17] S. E. Woosley and T. A. Weaver, 1991, in *Supernovae*, edited by J. Audouze *et al.*, (Less Houches, Session LIV, 1990).