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^{26}Al PRODUCTION IN AGB STARS AND 1.809 MeV LINE EMISSION IN THE GALAXY

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RESUMEN

Describimos la nucleosíntesis de ^{26}Al en las envolventes convectivas con fondo caliente en combustión de las estrellas de la RGA de masa intermedia. Usando un modelo esquemático de la evolución de las estrellas, calculamos los rendimientos de ^{26}Al para estrellas de la RGA de diferentes masas iniciales y metalicidades, y éstos se emplean en un modelo de evolución química en equilibrio. Se calcula la intensidad de la emisión en la línea de 1.809 MeV resultante del ^{26}Al residual en el medio interestelar como función de longitud en el plano galáctico. Se consideran las distribuciones de emisividad correspondientes a las distribuciones observadas de estrellas de la RGA y a una galaxia espiral con formación estelar descrita por la teoría de ondas de densidad espiral.

ABSTRACT

We describe the nucleosynthesis of ^{26}Al in hot-bottom burning convective envelopes of intermediate mass AGB stars. Using a schematic model of AGB star evolution, we calculate ^{26}Al yields for AGB stars of different initial masses and metallicities, and these are employed in an equilibrium chemical evolution model. The intensity of the 1.809 MeV line emission resulting from the residual ^{26}Al in the interstellar medium is calculated as a function of longitude in the galactic plane. Emissivity distributions corresponding to observed distributions of AGB stars and a star forming spiral galaxy describable by spiral density wave theory are considered.

Key words: **GALAXY: EVOLUTION — GAMMA RAYS: THEORY — NUCLEAR REACTIONS, NUCLEOSYNTHESIS, ABUNDANCES — STARS: ABUNDANCES — STARS: LATE TYPE**

1. INTRODUCTION

First observed via the 1.809 MeV emission line from its β^+-decay by the HEAO-3 satellite (Mahoney *et al.* 1982), ^{26}Al remains the only radionuclide to have had a 3σ detection in the interstellar medium. Because of the 7.2×10^5 year half life of ^{26}Al, proposed sources have included any stage of stellar evolution that combines proton captures onto ^{25}Mg and heavy mass loss. Previously considered sites have included O and C burning shells in supernova progenitors (Timmes & Woosley 1993), Wolf-Rayet stars (Walter & Maeder 1987), novae

(Clayton & Hoyle 1976), and AGB stars (Norgaard 1980). Except for AGB stars, for which yields have never been calculated, yields from the above mentioned sources, in conjunction with their respective galactic source distributions, have not been able to account for the estimated galactic content of ^{26}Al. In this study, we examine the ability of AGB stars containing "hot-bottom" burning convective envelopes (Scalo, Despain, & Ulrich 1975) to produce ^{26}Al. We comment on the distribution of 1.809 MeV emission and comment on the relationship to the more recent observations by instruments on the GRO satellite.

2. ^{26}Al PRODUCTION IN AGB STARS

In Bazan (1991), both AGB star interior and exterior evolution properties from recent stellar models were combined with the results of earlier work (Iben & Truran 1978) and cast into analytic expressions of schematic evolution. We use these expressions in envelope models to determine ^{26}Al production. T and ρ structure of the envelope, important to the nucleosynthesis, is determined by inward integration in the envelope code of Iben (1975). Upper boundary conditions of L and T_{eff} are varied until ∇_{rad} differs from ∇_{ad} by no more than 0.1% at the convective envelope base. We adopt a mixing length/pressure scale height ratio of $\alpha = 1.0$.

Nucleosynthesis is carried out for 36 nuclei from H to ^{36}S according to the prescription developed by some of the original work on the subject of "hot-bottom" burning envelopes (Sackmann, Smith, & Despain 1974). The expression governing nucleosynthesis is,

$$\frac{dY_i}{dt} = \frac{1}{r^2}\frac{d}{dr}\left(\frac{1}{3}v_{conv}\alpha h_P r^2 \frac{dY_i}{dr}\right) + \left(\frac{dY_i}{dt}\right)_{nuc}, \quad (1)$$

where the second time derivative contains the relevant nuclear reaction rates to and from nucleus i. We solve this equation over a 200 zone equidistantly spaced grid for the time specified by the relations in Bazan (1991). Reaction rates are taken from the latest compilation (Caughlan & Fowler 1988).

The resulting ^{26}Al yields are shown in Figure 1 for a range of initial masses and metallicities appropriate to the Galaxy and the LMC. We note that intermediate mass stars can produce at least as much ^{26}Al as massive stars (Prantzos 1993), with the implication that, when averaged over an initial mass function, AGB stars should be responsible for most of the 1.809 MeV emission seen in our galaxy. The yields have values inversely proportional to initial metallicity, with added effects of evolution (*i.e.*, mass loss).

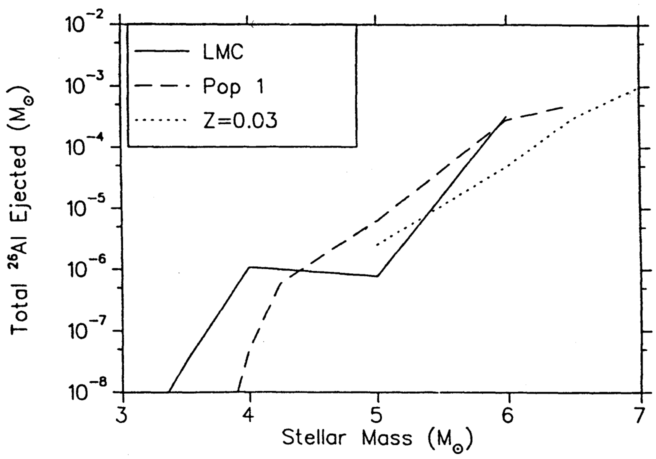

Fig. 1. — ^{26}Al yields as a function of initial mass and metallicity.

3. 1.809 MeV EMISSION IN THE GALAXY

Because of the short ^{26}Al half-life, its chemical evolution can be considered to be in equilibrium, with its local surface mass density given by,

$$\sigma_{26} = \frac{\int_2^8 m_{26}(m)\phi(m)\psi(t-\tau(m))dm}{\frac{1}{\sigma_g}\frac{d\sigma_g}{dt} + \lambda_{26}}, \quad (2)$$

where σ_g is the total gas density and λ_{26} is the ^{26}Al decay rate. We adopt a total gas depletion rate of 4 ± 1 $M_\odot/pc^2/Gyr$ (Gusten & Mezger 1982) at a galactocentric radius of 8.5 kpc. The present local gas density is assumed to be 13 ± 3 $M_\odot/pc^2$ (Kuijken & Gilmore 1988). The IMF is from Scalo (1986). The local number density of ^{26}Al is determined by the assumed scale height of the dominant producers or distribution of the ISM as a function of height above the galactic plane. In the calculations to be shown, we employ only the solar metallicity model yields.

3.1. AGB Star Distribution and 1.809 MeV Emission

Number density and emissivity as a function of position in the Galaxy can be found by normalizing to the relative number of observed AGB stars in the Galaxy. The expected intensity of the 1.809 MeV line as a function of galactic longitude and latitude is determined from line of sight integrations. We have adopted three different AGB stars distributions for comparison with the overall sky distribution of 1.809 MeV emission. In Figure 2, we show the emission magnitudes and distributions resulting from AGB star distributions of the IRAS IR flux survey (Habing 1988, solid line), a kinematically determined distribution of OH/IR stars (te Lintel Hekkert 1992, dashed line), and an OH/IR star survey (Herman & Habing 1985, dot-dashed line). Regarding emission magnitude, our models are much stronger than most optimistic observations would allow (Harris *et al.* 1990). When compared to the recent results of the COMPTEL instrument on the GRO satellite (Diehl *et al.* 1993), these models fail to show the present structure in the galactic plane.

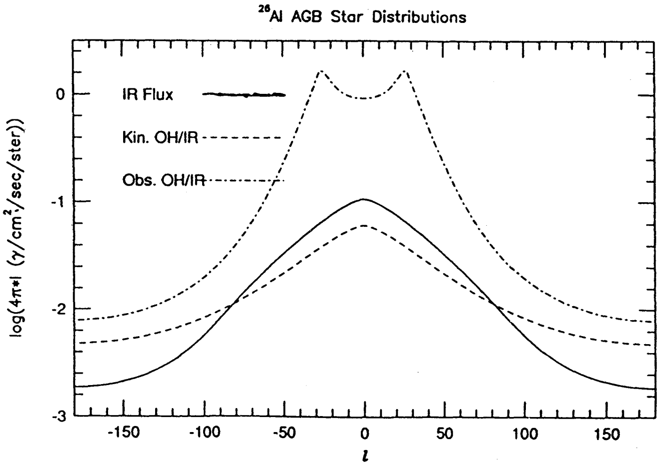

Fig. 2. — ^{26}Al emission as a function of galactic longitude for three adopted AGB distributions.

3.2. Spiral Galaxy Models of 1.809 MeV Emission

As pointed out by Prantzos (1993), a stellar source with a lifetime shorter than a galactic rotation timescale is likely to result in a galactic distribution that has azimuthal variations at any given galactic radius. Such a distribution could explain the structure seen in recent GRO observations. Since our stars have timescales of this range, we must consider the consequences. Calculation of the surface mass density as a function of azimuth behind a spiral arm is accomplished with the same expression as earlier, except that a star formation history must be assumed. We use a spiral density wave model of the galactic mass distribution (Roberts 1969), a star formation rate proportional to some power of the total gas density (Kennicutt 1989), and a rotation model of the Galaxy (Haud & Einasto 1989)

The resulting intensity distributions at galactic longitude of $b = 0$ are shown in Figure 3 as a function of assumed star formation efficiency. The solid line shows the results of star formation at a given radius proportional to the number of HII regions (Lockman 1990). The dashed line is the same case with star formation inhibited in regions where the local surface mass density falls below the gravitational instability limit. The dot-dashed line considers star formation to follow the observed light distribution in our galaxy (de Vaucouleurs & Pence 1978) with the disk instability criterion. As is seen, significant intensity structure in the galactic plane is the result of spiral arms (at $l = -40°, +50°$) and the molecular gas distribution (at $l = \pm 30°$).

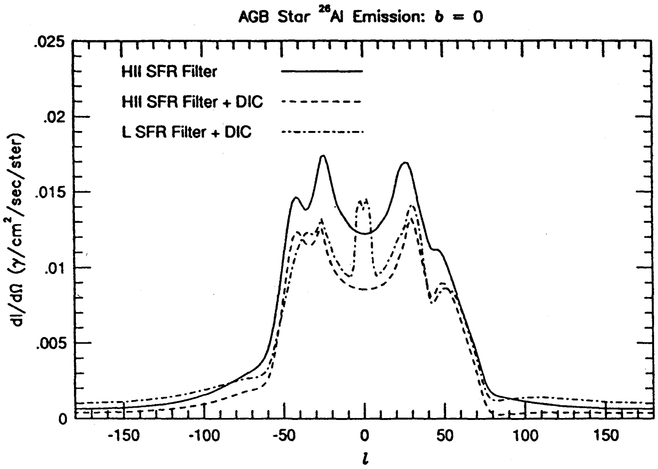

Fig. 3. — 1.809 MeV emission distribution from a spiral density wave model of the Galaxy.

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