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^{7}Li GAMMA-RAY LINES FROM NOVAE

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ABSTRACT

Recent work has shown that nova explosions could provide the nucleosynthetic origin of the ^{7}Li abundance. The opportunity to test this cosmologically important idea and simultaneously to test nova theory lies in observing the 478 keV gamma-ray line emitted as ^{7}Be decays ($\tau_{1/2} = 53\overset{d}{.}3$) to ^{7}Li in the expanding ejecta. The anticipated flux, 10^{-4} cm^{-2} s^{-1} at 1 kpc, is within range of the Gamma-Ray Observatory.

Subject headings: gamma rays: general — nucleosynthesis — stars: novae

Arnould and Nørgaard (1975) and Starrfield *et al.* (1978) have shown that novae explosions may provide the long-sought nucleosynthetic source of ^{7}Li: it comes about by ^{3}He, present in the matter transferred to the white dwarf, radiatively capturing an α-particle during the thermonuclear runaway and being ejected as ^{7}Be. I here point out, at a crucial time when *HEAO C* is already flying and when the Gamma-Ray Observatory has been selected as a new project by NASA, that detection of gamma-rays from the decay of those ^{7}Be nuclei is possible. A successful detection would yield invaluable information on the dynamics of novae and on one of the important puzzles in nucleosynthesis. The nova diagnostic has already been introduced (Clayton and Hoyle 1974) for other gamma-emitting radioactivities, but the key role of ^{7}Li in big-bang nucleosynthesis (Wagoner 1973) bestows special significance upon ^{7}Li detection. I derived the idea for this gamma-ray search from a brief remark by Audouze and Reeves (1981).

It is not necessary to repeat the thorough nucleosynthesis study of Starrfield *et al.* (1978). They find that the amount of ^{7}Be ejected is about one-tenth of the initial concentration of ^{3}He. Specifically, the overproduction factor for ^{7}Li is roughly

$$[^7\mathrm{Li}] \approx 200\langle X_{3i}/X_{3\odot}\rangle \,, \qquad (1)$$

where $\langle X_{3i}/X_{3\odot}\rangle$ is an average concentration of He^3 in the prenova envelope, expressed in units of the solar mass fraction $X_{3\odot} = 2 \times 10^{-5}$. This somewhat pessimistic estimate could be too small if the nova conditions are such that a higher fraction of ^{3}He can form ^{7}Be. The overabundance in equation (1) is about 10–20 times too small to account for ^{7}Li nucleosynthesis if the initial X_{3i} is solar, but Starrfield *et al.* (1978) also point out that ^{3}He richness is to be expected (Iben 1967; Rood, Steigman, and Tinsley 1976) in the transferring giant atmosphere. They estimate $\langle X_{3i}/X_{3\odot}\rangle = 5$–$50$, values just right to make equation (1) an adequate nucleosynthesis yield. I follow their lead in taking $\langle X_{3i}/X_{3\odot}\rangle = 20$ as an average for estimating the gamma-ray flux; but I note in advance that fluctuations by a factor of 5 in both directions are to be expected from individual novae.

With M representing the ejected mass, the number of ^{7}Be ejected becomes

$$N(^7\mathrm{Be}) = 3.4 \times 10^{46}\langle X_{3i}/X_{3\odot}\rangle \frac{M}{10^{-4}\, M_\odot}\,, \qquad (2)$$

which yields 6.8×10^{47} nuclei for $\langle X_{3i}/X_{3\odot}\rangle = 20$ and $M = 10^{-4}\, M_\odot$. The ^{7}Be in the ejecta decays with $\tau_{1/2} = 53\overset{d}{.}3$, emitting 10.4% of the time a 478 keV gamma-ray following that branch to the first excited state of ^{7}Li in the ^{7}Be electron capture. Letting f_γ designate that branching ratio, the flux at Earth becomes

$$\begin{aligned} F_\gamma &= f_\gamma \frac{N(^7\mathrm{Be})}{4\pi R^2 \tau} \exp(-t/\tau) \\ &= 4.3 \times 10^{-6} \frac{\langle X_{3i}/X_{3\odot}\rangle}{R^2\,(\mathrm{kpc})} \\ &\quad \times \left(\frac{M}{10^{-4}\, M_\odot}\right) e^{-4.75\,t(\mathrm{yr})}\ \mathrm{cm^{-2}\ s^{-1}} \\ &\approx 10^{-4}/R^2\,(\mathrm{kpc}) \text{ initially for } ^7\mathrm{Li} \\ &\quad \text{nucleosynthesis.} \end{aligned} \qquad (3)$$

The numerical form assumes $f_\gamma = 0.104$, that the ^{7}Be electron capture rate equals its laboratory rate, and that the nova ejecta are transparent to 478 keV gamma-rays. Although the last two simplifications are not true early in the expansion, they should become valid during the first week, before the ^{7}Be decays. Taking $\langle X_{3i}/X_{3\odot}\rangle = 20$ on the average and $M = 10^{-4}\, M_\odot$ gives $F_\gamma = 8.6 \times 10^{-5}/R^2(\mathrm{kpc})$ cm^{-2} s^{-1} as indicated on the last line of equation (3) for novae as the origin of ^{7}Li.

The point is that this flux is observable—not easily, and not often, but observable. The presently flying *HEAO 3* Gamma-Ray Spectrometer (A. S. Jacobson, JPL, principal investigator) could resolve this line with 3 σ assurance if $F_\gamma = 3 \times 10^{-4}$ cm^{-2} s^{-1}. A flux this large would, according to equation (3), be observable only at the large-yield end of the parameters, and only then for novae also nearby. Within $R = 2$ kpc there may be roughly one per year. Therefore, the 6 month *HEAO 3* mission has little chance outside an improbable occurrence.

The prospects are much better for the Gamma-Ray Observatory (GRO), which currently has "new-start" NASA approval for a 1985 launch target followed by three years of selective observing. Both the Gamma-Ray Spectroscopy Experiment (GRSE: L. E. Peterson, UCSD, principal investigator) and the Oriented Scintillation Spectrometry Experiment (OSSE: J. Kurfess, NRL, principal investigator) can resolve gamma lines at the level 10^{-5} cm^{-2} s^{-1} with about a week on source. Approximately 10 novae with the average expected ^3He_i enhancement of 20 should be observable above this flux level during GRO's flight, so that variations in $\langle X_{3i}/X_{3\odot}\rangle$ and in M should also be observable.

Interestingly, Johnson and Haymes (1973) and Haymes *et al.* (1975) reported a line feature that Fishman and Clayton (1972) and Clayton and Dwek (1976) attempted to interpret as a ^{7}Li line excited by nuclear collisions. Perhaps the present discussion raises, instead, the possibility of a high-yield unobserved nova in the direction of the Galactic center. That this approximately 480 keV feature subsequently disappeared in favor of sharp 511 keV radiation (Leventhal, MacCallum, and Stang 1978) might be consistent with the decay of the ^{7}Be.

These results confirm again that novae should play a big targeting role for GRO. That already has been planned, because the ^{22}Na flux was initially predicted to be some 20 times larger than the ^{7}Li flux (Clayton and Hoyle 1974); however, Wallace and Woosley (1981) have shown that this estimate was optimistic owing to an underestimate of the rate of ^{22}Na destruction during the outburst. But the ^{22}Na flux illuminates only nova dynamics, whereas the ^{7}Li flux illuminates one of the profound questions of nucleosynthesis and cosmology as well.

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