HIGH ENERGY GAMMA RAY AND NEUTRINO PRODUCTION OF TECHNETIUM IN SUPERNOVAE AND RED GIANTS

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Abstract

The presence of technetium (Tc) with its short-lived isotopes in the atmospheres of AGB stars is regarded as strong evidence for recent occurrence of s-process nucleosynthesis in stars. However there is seen to be an opposite correlation between metallicity and the Tc present in most of these stars suggesting that one must also invoke alternative mechanism for Tc production. Supernovae are sites for production of neutron rich r-process elements as well as a copious source of gamma rays and neutrinos with energy of several Mev. The photonuclear fission of r-process isotopes such as Th-232, Zr-99, etc. can lead to significant yelds of Tc-99 of about five per cent. Also Mev neutrino interactions with Mo and Zr isotopes can again give Tc isotopes by spallation reactions. Again AGB stellar atmospheres containing r-process elements and subjected to gamma photons and neutrinos from enhanced CNO shell burning can also produce Tc isotopes.

<u>Introduction</u> Owing to the short half lives of its isotopes (^{97}Tc has the largest $t_{1/2} \simeq 2\cdot10^{6}$yr) the presence of technetium [Merill 1952] in the atmospheres of AGB stars is usually taken as irrefutable evidence for the recent production of s-process elements in these stars. Similar situation holds for Promethium (Pr) whose isotopes have half lives of only a few years but are still observed in some of these stars. These two short-lived intermediate elements of the periodic table do not occur on the earth and their presence in stellar atmospheres suggests ongoing stellar nucleosynthesis.

However contrary to what one would expect from s-process nucleosynthesis [Iben 1983], the hundred or so stars with Tc in their spectra show opposite correlation between metallicity and Tc production [Smith 1988]. This suggests that one must probably also consider alternative sites and different mechanisms for the production of Tc isotopes. One possibility may be provided by gamma-ray induced fission of heavy isotopes ($A \approx 230 \div 240$) initially present in stellar envelopes. Isotopes with A of this range are known to exist both in supernovae spectra and stellar atmospheres [Cowley 1975]. The photonuclear fission threshold energies of such heavy nuclei as ^{232}Th, ^{231}Pa are ~ 6 Mev and gamma rays of this energy range and with larger energies are copiously produced in supernovae. The heavy isotopes in γ,n reactions like ^{231}Pa, ^{237}Np photofission leading to production of neutron rich isotopes like ^{99}Zr whose decay leads to the relatively long-lived isotope of Tc. In fact we have the radioactive decay chain:

$$^{99}Zr(35s) \rightarrow {}^{99}Nb(2.4min) \rightarrow {}^{99}Mo(67hrs) \rightarrow {}^{99}Tc(2\cdot10^5 yr) \rightarrow {}^{99}Ru(stable)$$

The yeld P of photofission fragments that lead to ^{99}Tc is usually $\simeq$ 0.05 as a result of gamma ray induced fission reactions [Gorbachev 1980].

Again high energy neutrinos > 7 Mev produced in supernovae can interact with ^{98}Mo to produce ^{98}Tc and, as the threshold for neutron emission of ^{98}Tc is 7.28 Mev excitation of the state above this threshold, would also produce the long lived ^{97}Tc ($t_{1/2} = 2\cdot10^6$yr) via $^{98}Mo + \nu_e \rightarrow {}^{97}Tc + n + e$. We shall consider both of the above possibilities in supernovae.

<u>Gamma ray induced fission in supernovae shells</u> An important energy source in maintaining supernovae luminosity is radioactivity of Ni^{56} and Co^{56}. Ni^{56} can be formed by the shock heating and it is transmuted into Co^{56} with an electron capture with $t_{1/2} \approx 6$ days. Co^{56} captures further an electron with $t_{1/2} \approx 79$ days and is converted into an excited state of Fe^{56}. For line γ-rays, with ~ 0.2 $M_\odot$ of Ni^{56} being produced, the γ-ray luminosity can be as high as ~ 10^{47}photons/s in the few Mev range, or a photon density $\approx 10^{15}$photons/cm^3/s in the expanding shell. Again passage of the shock wave responsible for the explosion gives rise to a temperature at a shell of radius 'r' away from centre of $\sim(3E_o/4\pi r^3 a)^{1/4}$, E_o is the explosion energy (10^{51}ergs), a is the Stefan-Boltzmann constant. For r $\approx 10^9$cm this gives peak temperatures of $\approx 4\cdot10^9$ deg. Shells at this radii could be enriched with neutron rich r-process seed isotopes created from iron during the explosion itself and ejected. This temperature would imply an intense flux of gamma rays with energies of several Mev, which are capable of photofissioning the r-process seeds. Again in the H-burning shells of low mass AGB stars, the CN cycle dominates and the reactions $^{13}C + p \rightarrow {}^{14}N + \gamma$ and $^{14}N + p \rightarrow {}^{15}O + \gamma$ are intense sources of > 7Mev gamma rays and for every four protons converted we have two such gamma rays emitted, and again the photon density may reach $\approx 10^{14}cm^{-3}s^{-1}$ [Malaney 1984]. The photofission cross-section σ_{Pf} goes as the cube of the γ-ray energy as

[Vandenbosch]: $\sigma_{Pf} \approx 52(E/7Mev)^3(\Gamma_f/\Gamma_T)$mb; Γ_T is the total width and Γ_f is that for the fission channel. The γ-rays lose energy both in supernovae and H burning shells by electron Klein-Nishina scattering with $E'/E = [1 + \alpha(1 - \cos\Phi)]$, $\alpha = E_o/m_e c^2$, E_o is the initial energy and m_e is the electron rest mass, Φ is the scattering angle. For a scattering cross-section of ~ $2\cdot10^{-25}cm^2$, and a typical column density of 85 g/cm^2 (for supernovae) the optical depth is $\approx$ 6. The fraction of γ-rays absorbed by a fissioning nucleus without prior Compton scattering (σ_e) is given as ~ $\sigma_{Pf}N_f/\sigma_e N_e$, where N_f and N_e are number densities of heavy isotopes and electrons. The rate equation for Tc production is as usual [Sivaram 1988] $dN_{Tc}/dt = ePN_f - \lambda N_{Tc}$, where e is the expansion factor, due to the expanding shell, P is the yield given above, and λ is the beta decay rate of Tc. The estimated production of Tc would lead to an abundance of ~ 10^{-3} on the Si scale just on the limit of detectability. Moreover the photofission of isotopes like Th-232 and U-238 has important implications especially with respect to the Th/Nd ratio in Population II stars and other nuclear chronometers.

<u>Neutrino production of Tc</u> As discussed above high energy ν's > 7Mevproduced in supernovae can interact with ^{98}Mo to produce ^{97}Tc. The neutrino flux above this energy range emerging out of the collapsing core is $\approx 10^{29}cm^{-2}s^{-1}$ implying a production rate of ^{97}Tc of $\approx 10^{-9}$ per Mo nucleus per second. This is much more inefficient as compared to the gamma ray induced photofission of actinides. This process cannot take place in the H burning shells, as the neutrinos produced by the CN reactions are well below the required threshold. In fact there are suggestions to measure the ^{98}Mo/^{97}Mo ratio in molybdenum ores as an experiment to test the long term thermal stability of the sun, as the cumulative solar ν productions from ^{8}B can presumably cause measurable changes in such a ratio [Haxton 1988]

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