SURFACE ABUNDANCES RESULTING FROM DEEP MIXING*

(Abstract)

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Dr Sugimoto has just presented a cause for deep mixing. We wish to report here the kind of surface abundances that result if one *assumes* deep mixing.

The stage of evolution was that near the red giant tip. The interior structure of the star was that during the helium-shell flashes. We assumed that convection could exist from the surface right down to the center of the helium-burning shell. Elements from envelope could be swept down and elements synthesized in the interior could be transported to the surface. In our models, for simplicity, the temperature-density grids in the star were not considered varying with time as we followed 17 reactions involving the 11 elements H, ^{3}He, ^{4}He, ^{7}Be, ^{7}Li, ^{12}C, ^{13}C, ^{14}N, ^{15}N, ^{16}O, and ^{17}O. There were three free parameters: namely, (i) T_{base}, the temperature at the base of the convective region (for which values $\sim 2\times10^8$ K, $\sim 1\times10^8$ K and $\sim 5\times10^7$ K) were used; (ii) Δt, the duration of the deep mixing phase, and (iii) N, the number of deep mixing flashes.

We found that we could easily bring a large amount of ^{12}C to the surface. It appeared possible to form carbon stars both from stars of low ($\sim 1\ M_\odot$) and intermediate masses ($\sim 5\ M_\odot$) and both population types. A single helium-shell flash followed by deep mixing sufficed for the former case but on the order of 100 such flashes were required for the latter. No more than the order of 100 flashes are possible for the former and 1000 for the latter.

We found a great amount of ^{7}Li can be formed. The Cameron-Fowler mechanism for the production of high *lithium* abundances in late-type stars was shown to work satisfactorily, producing ^{7}Li/H up to about 10^{-7} in a single flash. This value is nearly independent of mass and population type.

For high values of T_{base}, namely, ~ 1 or 2×10^8 K, *eruptive stars* result as the convective envelopes reach into helium-burning layers. Large amounts of energy can be liberated in a very short time, e.g., the binding energy of the envelope, 10^{48} erg, can be exceeded in $\sim 10^6$ s.

Many of the gross features of the *R Coronae Borealis* stars can be understood by

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erupting carbon star models. For example, observed surface abundances of H, He, ^{7}Li, ^{12}C/^{16}O, ^{14}N/^{12}C, and ^{12}C/^{13}C can be accounted for.

For the lower base temperature case ($T_{base} \sim 5 \times 10^7$ K) there were the cases of unrepeated deep mixing ($N = 1$) or repeated deep mixing ($N > 1$). For an *unrepeated* deep mixing, an upper limit could be placed on the mass of a carbon star, roughly $\sim 2\, M_{\odot}$. For short duration mixing, ^{7}Li/H reaches its peak value (^{7}Li/H$\simeq 10^{-7}$), ^{12}C/^{16}O>1 or <1, depending on the mass, $10^{-3} <$ ^{14}N/^{12}C<1 and $5 <$ ^{12}C/^{13}C<100; for intermediate duration mixing, ^{7}Li/H$<10^{-8}$, ^{12}C/^{16}O<1, $1 <$ ^{14}N/^{12}C<40, and $2.4 <$ ^{12}C/^{13}C<5; for long duration mixing, ^{7}Li/H$=0$, ^{12}C/^{16}O>1, ^{14}N/^{12}C$=40$, and ^{12}C/^{13}C$=3.2$. These abundance ratios agree quite well with the observations in the oxygen and carbon stars, S, BaII, C, and CH, ordering these spectral types in a sequence determined by the duration of deep mixing.

Repeated deep mixing can explain the observations known for S, BaII, and C stars when they are considered to be intermediate mass objects. S stars would be interpreted as those with few flashes, BaII stars as those with an intermediate number of flashes. However, repeated deep mixing phases cannot explain the observations of ^{7}Li and ^{13}C seen in CH stars, when the latter are considered to be low mass objects.