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AGES, CHEMISTRY AND TYPE IA SUPERNOVAE: CLUES TO THE FORMATION OF THE GALACTIC STELLAR HALO

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ABSTRACT

We endeavor to resolve two confliciting constraints on the duration of the formation of the Galactic stellar halo – 2-3 Gyr age differences in halo stars, and the timescale inferred from the observed constant values of chemical element abundance ratios characteristic of enrichment by Type II supernovae – by investigating the timescale for the onset of Type Ia supernovae (SNIa) in the currently favored progenitor model – mergers of carbon and oxygen white dwarfs (CO WDs).

1. INTRODUCTION

Analysis of the kinematics, chemistry and spatial distributions of Galactic halo tracers have been the basis of differing estimates of the timescale of the collapse of the Galaxy (*cf.* Eggen, Lynden-Bell and Sandage 1962, Searle & Zinn 1978). More recently, two alternative methods again yield apparently conflicting answers. Recent isochrone-fitting to metal-poor globular clusters (*cf.* VandenBerg, Bolte & Stetson 1990) and field halo stars (Schuster & Nissen 1989) find 2-3 Gyr differences in their *relative* ages. In contrast, the observed constant chemical element ratios of halo stars (*e.g.*, [O/Fe] $\sim +0.5$) are in good agreement with theoretical yields of Type II supernovae (*cf.* Arnett, Schramm & Truran 1989). The onset of SNIa is identified with the decline in [O/Fe] at [Fe/H] $\simeq -1$, a metallicity higher than $\sim 80\%$ of the stellar halo and roughly in transition between halo and thick disk kinematics. Thus the abundance ratios suggest most of the halo formed before the explosion of numerous SNIa (*cf.* Wyse & Gilmore 1988, Matteucci *et al.* 1991), and the timescale for the onset of SNIa – ~ 0.1 Gyr in models of mergers of CO WD binaries – is an upper limit to the durat ion of the formation of the halo. Therefore, we explore the parameter space of SNIa models to determine the robustness of the derived timescale, and their ability to be consist with age differences.

2. THE SNIa MODEL

We adopt for the progenitors of SNIa the mergers of CO WD binaries with total degenerate mass $> 1.4\,M_\odot$ caused by orbital decay through the emission of gravitational wave radiation (*cf.* Iben & Tutukov 1987). Such catastrophic mergers occur in less than a Hubble time for WDs separated by $\lesssim 3\,R_\odot$. The initial separation, A, of the main sequence stars (M_1, M_2) is reduced during common-envelope (CE) phases of their evolution when a star overflows its Roche Lobe and its companion cannot accrete the material. The CE exerts tidal friction on the stars causing orbital energy and angular momentum to be transferred to the CE, expelling it and reducing the separation of the stars. The orbital energy lost by the binary is assumed to scale with the gravitational potential energy lost via α such that the reduced separation of the stars is proportional to αA. The value of α is poorly constrained *a priori*, and has usually been assumed to be unity which results in the timescale for the onset of the first SNIa, $\tau_{onset} = \tau_{\rm evoln,2} + \tau_{\rm gwr} \sim 0.1$ Gyr, where $\tau_{\rm evoln,2}$ is the timescale on which M_2 overflows its Roche Lobe, and $\tau_{\rm gwr}$ is the time for gravitational wave radiation to cause the WDs to merge. However, α has a strong, non-linear effect on $\tau_{\rm onset}$ as for two CE events characterized by α_1 and α_2,

$$\tau_{\rm gwr} = 0.15 \quad \alpha_1^4\alpha_2^4 \left(\frac{M_{CO1}}{M_1}\right)^8 \left(\frac{M_{CO2}}{M_2}\right)^4 \left(\frac{A^4}{M_{CO1}M_{CO2}(M_{CO1}+M_{CO2})}\right) \mathrm{Gyr}$$

where M_{CO} are the masses of the CO WDs. Hydrodynamical calculations and analytic analysis (*cf.* Livio & Soker 1988, Taam & Bodenheimer 1991) suggest spin-up of the envelope and preferential mass loss in the orbital plane causes α to be a funtion of the evolutionary state of the Roche Lobe-filling star; $\alpha < 1$ for red giants leading to a rapid merger of two stars in the CE stage rather than SNIa, and $\alpha > 1$ for asymptotic-giant branch (AGB) stars leading to CO WD binaries and possible SNIa.

3. RESULTS ON TIMESCALE FOR ONSET OF SNIa

Below we present results assuming that a requirement for SNIa is the primary experiencing Roche Lobe (RLO) overflow on the AGB. We assume the mass of the resulting CO WD equals the CO core mass of the star at the time of RLO. For simplicity we assume $\alpha_1 = \alpha_2 \equiv \alpha$. We vary α and search all possible (M_1, M_2, A) to ascertain the predicted range of $\tau_{\rm onset}$. The size of the star and hence the evolutionary state of the primary when it experiences RLO depends sensitively on the initial metallicity of the star. Therefore, we adopt stellar models calculated for a range of initial metallicities with *solar* element ratios. Note the mean abundance of the stellar halo is [Fe/H] ~ -1.5 corresponding to Z = 6×10^{-6} for solar element ratios. Table 1 lists the adopted values of α, the initial chemical composition of the stellar models (Y and Z), the component masses of the binaries which are the first to explode, $\tau_{\rm onset}$, and the source of the stellar models (TC86 = Tornambé & Chieffi 1986, CCS90 = Castellani, Chieffi & Stranerio 1990).

Table 1. Timescales for the onset of SNIa

α	Y	Z	$M_1(M_\odot)$	$M_2(M_\odot)$	$\tau_{\rm onset}$ (Gyr)	Source for Stellar Models
0.5	0.20	10^{-6}	6	6	0.062	TC86
0.5	0.23	0.002	7	7	0.11	CCS90
0.5	0.27	0.02	9	4	0.24	CCS90
1	0.20	10^{-6}	6	6	0.063	TC86
1	0.23	0.002	9	9	0.58	CCS90
1	0.27	0.02	7	5	7.2	CCS90
2	0.20	10^{-6}	6	6	0.066	TC86
2	0.23	0.002	9	9	7.6	CCS90
2	0.27	0.02	9	4	27	CCS90

In the transition from solar to low initial metallicity, τ_{onset} decreases to $\lesssim 0.1$ Gyr due to a decrease in $\tau_{\rm gwr}$, regardless of α. The decrease results from a decrease in the minimum separation of the stars leading to a suitable pair of CO WDs as the maximum size of the star on the RGB decreases for lower metallicity stars because of a decrease in H^- opacity and density of free electrons donated by ionized metals. Hence, for low metallicity models, the minimum size of the star as it ascends the ABG sets the limit on τ_{onset}.

4. CONCLUSION

We find that for stars with metallicities typical of the Galactic stellar halo SNIa explode on timescales < 1 Gyr, in conflict with the derived 2-3 Gyr age differences if interpreted within context of a homogeneous collapse. However, both the observed chemical element ratios and few Gyr differences in the ages of halo stars could be obtained in some hierarchical models of galaxy formation, in which galaxies, and in particular stellar halos, are produced by the merger of proto-galactic fragments. The fact that the observed break in [O/Fe] is well-defined, with little scatter, means that if fragments have their own unique star formation history, so that time and [Fe/H] are related differently in each fragment, and the internal timescale for star formation in the fragments is ~few Gyr, then the timescale conflict is resolved. We are currently examining Galactic chemical evolution in CDM dominated cosmological models to determine the effect of the power spectrum of initial mass fluctuations on the age spread and chemical evolution of the halo stars, with emphasis on the elemental abundance ratios (Carlberg, Dubinski, Smecker & Wyse, in preparation).

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References

Arnett, D., Schramm, D. & Truran, J.W. 1989, ApJ, 339, L25
Castellani, V., Chieffi, A. & Stranerio, O. 1990, ApJS, 74, 463
Eggen, O. J., Lynden-Bell, D. & Sandage, A.R. 1962, ApJ, 136, 748
Iben, I. & Tutukov, A.V. 1987, ApJ, 13, 727
Livio, M. & Soker, N. 1988, AJ, 329, 764
Ryan, S. & Norris, J. 1991, AJ, 101, 1865
Schuster, W.J. & Nissen, P.E. 1989, A&A, 222, 69
Searle, L. & Zinn, R. 1978, ApJ, 225, 357
Taam, R.E. & Bodenheimer, P. 1991, ApJ, 373, 246
Tornambé. A. & Chieffi, A. 1986, MNRAS, 220, 529
Wyse, R.F.G & Gilmore, G. 1988, AJ, 95, 1404
VandenBerg, D.A., Bolte, M. & Stetson, P. 1990 AJ, 100, 445