Nucleosynthesis Constraints on The Energy Growth Timescale of a Core-Collapse Supernova Explosion

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Details of the explosion mechanism of core-collapse supernovae (CCSNe) are not yet fully understood. There are an increasing number of numerical examples by ab-initio core-collapse simulations leading to an explosion [1]. Most, if not all, of them represent a 'slow' explosion in which the 'observed' explosion energy ($\sim 10^{51}$ ergs) is reached in a timescale of $\sim$1 second, or even longer [2]. On the other hand, traditionally the SN explosive nucleosynthesis has been studied assuming an instantaneous explosion ($\lesssim 10$ ms) [3].

In this work, we investigate how the nucleosynthesis products are affected by the energy growth timescale ($t_{\rm grow}$; the timescale in which the explosion energy is reached to 10^{51} ergs since the initiation of the explosion). We employ one-dimensional hydrodynamic and nucleosynthesis simulations above the iron core, by parameterizing the nature of the explosion mechanism by $t_{\rm grow}$. The results are then compared to various observational constraints; the masses of ^{56}Ni derived for typical CCSNe, the masses of ^{57}Ni and ^{44}Ti observed for SN 1987A, and the abundance patterns observed in extremely metal-poor stars. We find that these observational constraints are consistent with the 'rapid' explosion ($t_{\rm grow} \lesssim 200$ ms), and especially the best match is found for a nearly instantaneous explosion ($t_{\rm grow} \lesssim 100$ ms). On the other hand, the slow mechanism ($t_{\rm grow} \gtrsim 500$ ms), which is suggested by recent ab-initio simulations, is rejected from these constraints. Our finding places a strong constraint on the explosion mechanism; the rapid growth of the explosion energy, at most within ~ 200 ms, should be realized in typical CCSNe.

[1] Janka, H.-T. 2012, Annual Review of Nuclear and Particle Science, 62, 407

[2] Marek, A., & Janka, H.-T. 2009, ApJ, 694, 664

[3] Woosley, S. E., & Weaver, T. A. 1995, ApJS, 101, 181