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Abundance Ratios of M82 and Nucleosynthesis of Hypernovae

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Abstract. The abundance in M82 is Si and S rich, and can not be explained by the combination of conventional Type I and II supernova yields. We show that these abundance patterns, as well as the observed hot plasma energy to metal mass ratios can be explained by the hypernova nucleosynthesis. This hypothesis is consistent with the expected age after the star-burst of M82.

1. Abundances in M82

M82 is the most active nearby starburst galaxy. From the emission lines, Tsuru et al. (1997) obtained abundances of O, Ne, Mg, Si, S and Fe by ASCA. The abundance pattern is interesting: Si and S are much abundant than O and Fe compared with the solar ratio. The O/Fe ratio is almost the solar ratio. They concluded that these abundance patterns cannot be reproduced by any combination of the previous Type I & II supernova (SNe I & II) yields.

2. Hypernova nucleosynthesis, Energy to metal mass ratios

In Figure 1 (left), we plot the observed abundances compared with our $25M_\odot$ SNe II models. (More detailed discussion and descriptions on our massive star evolution, explosion simulation and nucleosynthesis calculations are given in Umeda et al. 2001, Umeda et al. 2000 and Umeda & Nomoto 2001). The overall abundance is normalized to the observed Si abundance. In this figure, we can only compare theoretical and observed abundance ratios. The overall normalization is constrained by the energy to metal mass ratios described below.

Recent observations suggest that at least some of massive SNe with $M \gtrsim 25-30M_\odot$ explode very energetically, called "Hypernovae" (e.g., Nomoto et al. 2000). We have found that the large Si/O ratio may be the sign of the energetic supernova explosions (Umeda et al. 2000; Nakamura et al. 2001). This is because in the more energetic explosion, the temperature attained by the supernova shock heating is higher, and thus more O layer is burnt into Si. The observed large abundance ratio of Si/O can be realized for $E_{51} \equiv E/10^{51}$erg $\gtrsim 10$ (Figure 1).

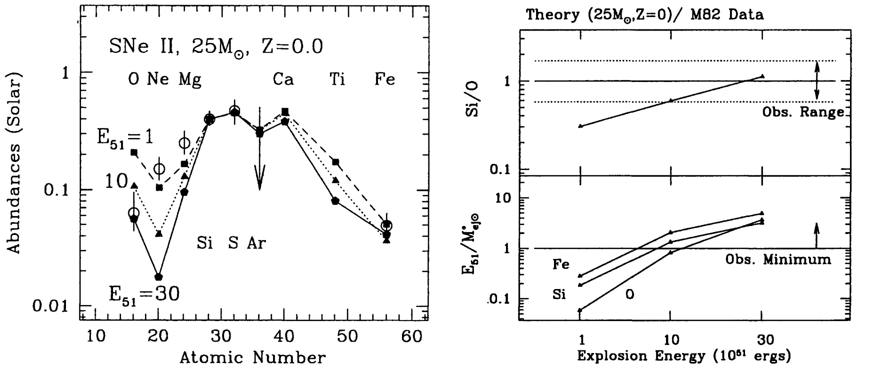

Figure 1. Abundance patterns of M82 compared with hyper(super)nova yields (left). Theoretical models' Si/O mass fraction ratio , and the energy to metal (Fe, Si and O) mass ratios as a function of explosion energy (right).

Suppose that the origin of the plasma in M82 is a mixture of the SN ejecta and interstellar gas, and most of the thermal energy of the hot plasma was supplied by supernovae, and then we can constrain the ratio of the energy released by one supernova to the metal mass (Tsuru et al. 1997, Umeda et al. 2001). The constraints for O, Si, and Fe are: $(E_{51}/M^*_{\mathrm{ej}\odot})_{\mathrm{min}}$ for (O, Si, Fe) $=(7.9^{+3.5}_{-2.7}$, $17.5^{+2.4}_{-2.7}$, $51.2^{+11.4}_{-11.5})$, respectively.

These observational constraints can be compared with theoretical models. For the $E_{51} = 1$ model, the $E_{51}/M^*_{\mathrm{ej}\odot}$ for all elements are smaller than the observed lower limits. On the other hand, the $25M_\odot$ models with $E_{51} \gtrsim 10$ (similarly $30M_\odot$ models with $E_{51} \gtrsim 50$) matches with both the observed abundance pattern and the energy to mass ratio constraints (Figure 1 - right).

Then, how hypernovae can dominate in M82? From the size of the hot plasma in M82 (Strickland et al. 1997) divided by the sound velocity, the age after the star burst is estimated to be $\sim 10^7$ years. This suggest that only stars with $M \gtrsim 25M_\odot$ have exploded as SNe. Therefore, if most of these massive stars explode as hypernovae, their abundance pattern can dominate in M82.

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