EVOLUTION TO WEAK NUCLEAR STATISTICAL EQUILIBRIUM AND THE NEUTRON-RICH IRON GROUP ISOTOPES.

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Introduction: FUN CAIs and hibonite grains show roughly correlated excesses and deficits in the neutron-rich iron-group isotopes such as ^{48}Ca and ^{50}Ti (e.g., [1] and references therein). Such effects seem to call for correlation of these isotopes in the precursor dust of the Solar System. From a nucleosynthesis point of view, this makes sense because the neutron-rich iron-group isotopes are copiously co-produced in low-entropy expansions of neutron-rich matter [2], which presumably occur in rare Type Ia (thermonuclear) supernovae. The production of these isotopes in such expansions, however, depends on how neutron-rich the material becomes, which in turn depends on the complicated nuclear dynamics of hot, dense, neutron-rich matter.

Weak-Interaction Rates: To explore the production of the neutron-rich iron-group nuclei, we have developed tools [3] to follow the evolution of nuclear reaction networks into weak nuclear statistical equilibrium (WSE). Weak interaction rate compilations have been calculated before (e.g. [4,5]). However these compilations do not guarantee a network evolves to a weak nuclear statistial equilibrium (WSE) that is consistent with the other nuclear data in the problem because the compilations treat forward and reverse rates separately. We have developed tools to compute the reverse weak rates from detailed balance. This enables us to compare network and equilibrium calculations consistently.

Results: With our tools, we calculated the nucleosynthesis in matter at fixed high temperature ($6x10^9$ K) and density ($9x10^9$ g/cc) and found that Y_e (number of net electrons per nucleon) evolves to 0.397, the WSE value. If we instead do not insist on weak detailed balance, Y_e evolves to 0.419 with rates from reference [3]. This value is inconsistent with WSE. The resulting ^{48}Ca abundance differs significantly in the two calculations. Another interesting result is that the system evolves into WSE via a quasi-equilibrium, not a nuclear statistical equilibrium (NSE). NSE is a state in which all nuclei are in equilibrium under strong and electromagnetic, but not necessarily weak, reactions. The reason for this is that, as dense, hot matter is undergoing the electron captures to reduce Ye, the number of heavy nuclei Y_h must also change. The tight balance between forward and reverse strong and electromagnetic reactions causes the effective timescale for Y_h to evolve to become comparable to that for Y_e to change.

Conclusions: A proper treatment of forward and reverse weak-interaction rates is important for calculations of the yields of neutron-rich isotopes in low-entropy freezeouts. We also have found that in such low-entropy environments, the nuclear populations can evolve to WSE through a quasi-equilibrium instead of a regular NSE. This result will be important for those computing effective neutronization rates in dense Type Ia supernovae.

References: [1] Meyer B. S. and Zinner E. in *Meteorites and the Early Solar System II* (Tucson: University of Arizona Press), p.69-108. [2] Meyer B. S. et al. 1996. *Astrophys. J.* 462:825-838. [3] See https://sourceforge.net/projects/nucnettools/ [4] Fuller G. M. et al. 1985. *Astrophys. J.* 293:1-16. [5] Langanke K. and Martínez-Pinedo G. 2000. *Nucl. Phys. A* 673:481-508.