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Extended Abstract

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The secondary supernova machine: Gravitational compression, stored Coulomb energy, and SNII displays

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The author wants to present an uncommon description of an energy transfer process in core-collapse supernovae: namely, a gravitational machine that increases Coulomb energy within nuclei via silicon burning. Excess of that Coulomb energy is returned weeks and months later by weak nuclear decays (EC and beta+). Those decays energize several observable quantities: gamma-ray lines, X-ray luminosity, free chemical energy and optical light curves. The delay of the energy return is essential for visibility of these activations. These secondary displays have rich literatures; but expressing them as observables of a supernova machine, whose action can be summarized as gravitational compression→Coulomb nuclear energy increase→release of excess of that Coulomb nuclear energy by electroweak decays→supernova displays, is novel.

Radioactive power for several delayed optical displays of core-collapse supernovae is commonly described as having been provided by decays of ^{56}Ni nuclei. This review analyses the provenance of that energy more deeply: the form in which that energy is stored; what mechanical work causes its storage; what conservation laws demand that it be stored; and why its release is fortuitously delayed for about 10^6 s into a greatly expanded supernova envelope. We call the unifying picture of those energy transfers the secondary supernova machine owing to its machine-like properties; namely, mechanical work forces storage of large increases of nuclear Coulomb energy, a positive energy component within new nuclei synthesized by the secondary machine. That positive-energy increase occurs despite the fusion decreasing negative total energy within nuclei. The excess of the Coulomb energy can later be radiated, accounting for the intense radioactivity in supernovae. Detailed familiarity with this machine is the focus of this review. The stored positive-energy component created by the machine will not be reduced until roughly 10^6 s later by radioactive emissions (EC and β+) owing to the slowness of weak decays. The delayed energy provided by the secondary supernova machine is a few × 10^{49} erg, much smaller than the one percent of the 10^{53} erg collapse that causes the prompt ejection of matter; however, that relatively small stored energy is vital for activation of the late displays. The conceptual basis of the secondary supernova machine provides a new framework for understanding the energy source for late SNII displays. We demonstrate the nuclear dynamics with nuclear network abundance calculations, with a model of sudden compression and reexpansion of the nuclear gas, and with nuclear energy decompositions of a nuclear-mass law. These tools identify excess Coulomb energy, a positive-energy component of the total negative nuclear energy, as the late activation energy. If the value of fundamental charge *e* were smaller, SNII would not be so profoundly radioactive. Excess Coulomb energy has been carried within nuclei radially for roughly 10^9 km before being radiated into greatly expanded supernova remnants. The Coulomb force claims heretofore unacknowledged significance for supernova physics.

A large volume of research has been published on diverse aspects of the core-collapse supernova phenomenon (e.g. Woosley and Weaver, 1986). The SNII events raise complex physical questions. We review one of those questions, the synthesis of radioactive nuclei by supernovae and their later decays causing displays of observable radiations. We describe this as a consequence of a new stimulating picture of what we call the secondary supernova machine owing to its machine-like properties. That machine has not been discussed previously. We focus on its clarifying physical picture of the manner in which energy is stored and released later into the supernova envelope, and we show that excess Coulomb energy within nuclei is the form of positive, releasable energy carried radially within particles from the first supernova second until it is released months later. This picture is not likely to alter how numerical computations are done, but it may enlarge the way in which SNII are thought of by physicists and astronomers. A supernova machine is a device that makes use of prompt gravitational work to release energy to overlying SN regions where that energy is capable of causing observable phenomena. Other than being triggered by the gravitationally caused compression, the secondary supernova machine is but a spectator of the primary machine in which it is embedded. These two supernova machines have no feedback on one another. It is their separateness that endows the concept of the secondary supernova machine with intellectual relevance. As physicists we wish to compartmentalize our thinking where doing so is both possible and appropriate. We find the secondary machine to be an original and useful compartment for understanding the energy source for the late supernova displays. As a contrast, think instead of more common words attributing the secondary displays simply to radioactive nuclei synthesized within the high temperatures and densities of the supernova explosions. Both statements are correct; however they augment our physical understanding differently. The secondary supernova machine carries along its physical concepts. It also emphasizes the surprise of Coulomb energy being the carrier of the energy in a nuclear world dominated by the strong nuclear force, and why that surprise happens.

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