

Gamma Ray Spectroscopy: Explosion Physics of Supernovae Type Ia

J.E. Grove, M. Baring, D. Bhattacharya, P. Bloser, S. Boggs, G. Case, M. Cherry, C.C. Cheung, V. Connaughton, G. De Nolfo, C. Dermer, M. Finger, J. Fishman, N. Gehrels, A. Harding, S. Hunter, K. Hurley, W.N. Johnson, T.J. Johnson, R. M. Kippen, H. Krawczynski, M. Leising, M. McConnell, R. Murphy, T. O'Neill, W. Paciesas, B. Philips, R. Preece, R. Rothschild, D. Lazzati, H. Marshall, J. Ryan, G. Share, D. Smith, S. Sturmer, J. Tomsick, W.T. Vestrand, C. Wilson-Hodge, E. Wulf, A. Zoglauer, A. Zych

The thermonuclear explosions of degenerate white dwarfs, SNe Ia are profoundly radioactive events. As much as one-half of the white dwarf mass is fused to ^{56}Ni ($\tau_{1/2}=6.1\text{d}$). After a short time, the decays of this nucleus and ^{56}Co ($\tau_{1/2}=77\text{d}$) power the entire visible display. Most of this power originates in γ -ray lines, which begin to escape after several days. These γ -rays are the most direct diagnostic of the dominant processes in the nuclear burning and explosion.

Despite extensive study of SNe Ia, and their essential use in cosmology, major fundamental questions about these explosions remain unanswered. We do not understand the nature of the progenitor systemsⁱ; how the nuclear flame propagates, how it proceeds as fast as it does, if or where it turns into a shockⁱⁱ; and to what extent instabilities break spherical symmetry, or whether their effects are wiped out by subsequent burning. We therefore do not understand the physicsⁱⁱⁱ behind the empirical correction to their magnitudes that allows them to be used as standard candles for measuring the geometry of our Universe, from which we infer the presence of Dark Energy.

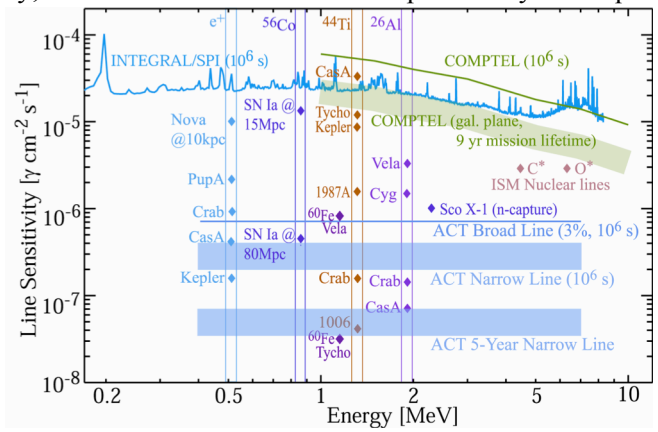
Thermonuclear supernovae are grand experiments in reactive hydrodynamic flows. Fundamental uncertainties in the combustion physics lead directly to differences in ^{56}Ni yields and locations^{iv}, which in turn are directly observable with a sensitive γ -ray telescope. Previous attempts to detect ^{56}Co emission have been unsuccessful due to instrumental sensitivities and supernova distances.

Nuclear γ -ray lines hold the key to solving these puzzles. The goals for an MeV spectrometer are therefore aggressive: (i) Standard Candles – Characterize the distribution of ^{56}Ni production in SNe Ia, and correlate with the optical light curves to determine the relationship between absolute magnitude corrections and ^{56}Ni production. (ii) Explosion Physics – Clarify the nuclear flame propagation by measuring total and ^{56}Ni ejecta masses and their kinematics for a handful of SNe in detail, to distinguish among current models.

To achieve these goals, an MeV spectrometer must have the sensitivity to provide, for hundreds of SNe Ia, direct correlation between the optical properties and the ^{56}Ni production, which is likely to be the underlying factor in the optical light curve variations. The velocity distribution of ejected ^{56}Ni and the total ejecta mass can be derived from high-sensitivity light curves and high-resolution nuclear spectroscopy. Simulations of a range of progenitor stars and explosion geometries show a range of time-dependent line profiles. Gamma-ray line measurements thus allow a direct probe of the underlying physical mechanisms driving the explosion and variations in optical curves and a much better understanding of the evolution of SNe Ia with redshift, calibrating their use as standard candles to high redshift.

Such a telescope will also transform our understanding of the nucleosynthesis of the chemical elements, providing high-sensitivity measurements of the radioactive γ -ray and positron emitters across the entire Milky Way, and mapping our galaxy in a broad range of nuclear line emissions from radioactive decays (^{22}Na , ^{26}Al , ^{44}Ti , ^{60}Fe), nuclear de-excitations (^{12}C , ^{16}O , ^{56}Fe) and puzzling e^+e^- annihilations.

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Target sensitivity for an imaging MeV spectrometer. Other science objectives achievable with this line sensitivity are shown. Taken from the 2005 Advanced Compton Telescope mission concept study final report (Boggs et al. 2006, NewAR, 50, 604).

ⁱ Branch, D., et al. 1995, *PASP* **107**.

ⁱⁱ Hillebrandt, W., and Niemeyer, J.C. 2000, *ARA&A* **38**, 191.

ⁱⁱⁱ Riess, A. and Livio, M. 2006, *ApJ*, **648**, 884.

^{iv} Woosley, S.E., et al. 2008, [NIC X](#).