MeV Gamma Rays from r-Process Sites: A Distinct Signature of Heavy-Element Production

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Abstract

The exact astrophysical sites of the rapid neutron capture process (r process) nucleosynthesis remains a mystery for decades. During r process, thousands of unstable nuclei are synthesized and gamma-ray photons can be emitted from the decays of these isotopes. These MeV gamma rays may provide a unique and direct probe of the neutron-rich environment as well as insight into the nature of the r process. As neutron star mergers (NSMs) are the first verified r-process sites, since the multi-messenger observations of GW170817. We first estimated the MeV gamma-ray signal expected from an NSM event, including the photons from both beta decays and fission processes and find that the predicted signal at photon energies above ∼3.5 MeV and at a relatively late time, several days after the merger event, is sensitive to whether or not fissioning nuclei are produced. These signals can serve as distinct probe of the actinides productions in NSMs and can be detectable up to ∼10ˆ4 days post event by future MeV detectors. Importantly, we find that the 2.6 MeV gamma-ray emission line from thallium (Tl)-208 alone could serve as a real-time indicator of in situ lead production. Tl-208 line could be detectable from ∼12 hours to ∼ten days, and again ∼1–20 years after a Galactic NSM by future mission, indicating a robust r-process nucleosynthesis occurs. Rare core collapse supernovae like magneto-rotational supernovae (MR-SNe) are a theoretically predicted r-process site. We find that at various epochs after a Galactic MR-SN explosion with a certain model, some weak r-process isotopes, such as I-131 and Sb-125, can emit gamma-ray lines that emerge above the signals from explosive burning products and positron annihilation and could be detectable by future MeV mission.

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