Contribution ID: **67** Type: **Oral Contribution**

r-process nucleosynthesis and radioactively powered transients from magnetar giant flares

Tuesday 10 June 2025 11:50 (20 minutes)

We present nucleosynthesis and light-curve calculations for a new site of the *r*-process from magnetar giant flares (GFs). Motivated by radio afterglow observations which indicate sizable baryon ejecta from GFs, Cehula et al. (2024) recently proposed a scenario whereby magnetar crustal material is ejected as a result of a shock driven into its surface layers during the reconnection-driven GF. We confirm with nucleosynthesis calculations that these ejecta can synthesize moderate yields of third-peak *r*-process nuclei and substantial yields of first- and second-peak nuclei through the alpha-rich freeze-out mechanism. We use the nucleosynthesis output to make light-curve predictions of *novae breves*, kilonova-like optical/UV transients, and the gamma-ray transients powered by the radioactive decay of the unbound debris. We show that the predicted gamma-ray emission properties (light-curve, fluence, and spectrum) match a previously unexplained hard gamma-ray signal observed in the aftermath of the famous December 2004 giant flare from the magnetar SGR 1806-20. This MeV emission component is direct observational evidence for the synthesis of $\sim 10^{-6} M_{\odot}$ of *r*-process elements. The discovery of magnetar giant flares as confirmed *r*-process sites, contributing at least $\sim$ 1-10$\%$ of the total Galactic abundances, has implications for the Galactic chemical evolution, especially at the earliest epochs probed by low-metallicity stars.

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