Proposal

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Introduction & Background

Actinides are the heaviest elements known to man, and 87% of them are man-made. So is there such a place where all the actinides would naturally form? The leading theory is that actinides are produced following the merging of binary neutron stars (BNS), and decay during what is called a kilonova. A kilonova is a visible transient following a neutron star (NS) merger, powered by the decay of the elements that were fused during such an event. A BNS merger could potentially cause enough fission to produce most lanthanides, or even actinides, due to the extreme density achieved when the stars merge. Because kilonovae are visible, observations of their bolometric light curves can be analyzed to determine what elements may be decaying within. By modeling light curves of actinide-containing emissions, we can compare such models to kilonovae observations in order to determine if there is any resemblance. The best current observation we have to work with is GW170817, a NS merger event in 2017 that resulted in the kilonova AT2017gfo.

Goals & Expectations

The major goal of this research is to lay the groundwork for the future of kilonovae research. We expect to develop light curve models for actinide-dominating emissions for most, if not all, actinides. Currently, only three models are in use – light curves of emission for β-decays, α-decay actinides, and spontaneous fission of 254Cf. We hope to use the light curve from the kilonova AT2017gfo, in order to determine if that event contained any actinides. That is the extend of observations we can compare to, which is why our priority is to create the models first and foremost. We expect future researchers to use our models and method in order to determine if any BNS mergers are producing actinides. We hope to produce as many models as we can during the time allotted, in an effort to expand the capabilities of kilonovae studies.

Method & Timeline

Creating light curve models of actinide-emissions begins by analyzing the chemical compositions and determining how the elements decay. Plotting these emissions over time, a model is achieved to represent the light curves of the actinide(s). By modeling light curves for any variation of actinides, we can establish which one best fits our observations of kilonova light curves, and thus conclude that the observation did contain actinides. In particular,

we'd like to analyze the light curve of the kilonova AT2017gfo, since it has many recorded light curve data points. We can start by using already developed models of light curves of emission dominated by β-decays, α-decay actinides, and spontaneous fission of 254Cf. When these light curves are plotted over a time t = 100 days, some resemblances between the AT2017gfo light curve and the modeled actinide-containing light curves will hopefully be noticed. Figure 1 shows this plot. We will expand upon this method by creating more models of light curves for other actinides. We can even model emission dominated by multiple actinides and/or lanthanides. This project is to be completed during the summer of 2023, from May through August. The first 3 months will be spent developing the models for actinide light curves, and the remaining month will be spent analyzing and compiling the results against the light curve of AT2017gfo or any other kilonovae data that arises.

Feasibility

This project is feasible for the current models in practice, the β-decays, α-decay actinides, and spontaneous fission of 254Cf emissions. However, to reach the goal of this research, we will need to spend time developing new models to include all actinides and lanthanides. This will take the majority of the time allotted, but we are hopeful that we can produce a considerable amount of models.

A major part of this research is also to compare our models to observed kilonovae light curves, which are very limited at this time. This is why our project is focused on creating the light curve models, so that future analyzing can be done when more kilonovae are observed.

Summary & Broader Impacts

By modeling light curves for any variation of actinides, we can establish which one best fits our observations of kilonova light curves, and thus conclude that the observation did contain actinides. This will allow researchers to name BNS mergers the natural parents of actinides. Villanova University could be at the forefront of this major discovery. With enough modeled light curves and real observations, we'll eventually have compelling evidence to definitively say that actinides originate from BNS mergers.

Trajectory & Future Goals

I am very interested in the future of the kilonovae field of research; I feel that there is so much to be discovered. A lot of advancements can't be made without these new models of light curves and improved ideas of physics, which is a daunting task to face. But, it is also very exciting that this field is so new, in that there are new discoveries around every corner. The future work that can be done using the results of this research will result in major discoveries. Those discoveries will then allow for so many more advancements to follow. I would love to be a part of the field that will shape the future of astronomy and astrophysics research.
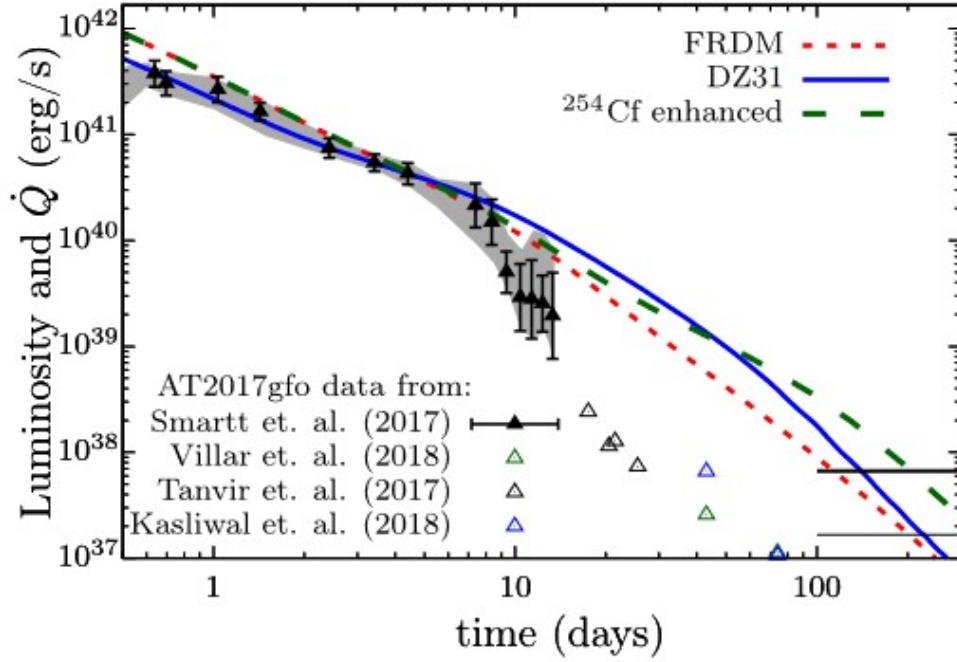
Figures

Figure 1: Shown is the impact of the existence of actinides on the bolometric lightcurve of kilonovae. The dotted red, solid blue, and dashed green lines (labeled by FRDM, DZ31, and 254Cf enhanced) represent cases where the lightcurves are dominated by the energy release from β-decays, α-decay actinides, and spontaneous fission of 254Cf, normalized to t = 6 days. The filled and the hollow triangles are the observed and the lower bound of the brightness of the GW170817 kilonova.