The Kilonova Data Challenge (KDC)

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Introduction

The KDC is an attempt to assess how well the Legacy Survey of Space and Time (LSST) Dark Energy Science Collaboration (DESC) will be able to find optical transients called kilonovae.

Vera C. Rubin Observatory in Chile will begin the LSST in late 2023 using "the largest digital camera ever built for astronomy." [1]

Fig. 1: The Rubin Observatory in Chile which will run the LSST after construction is completed. "It will provide the widest, fastest and deepest views of the night sky ever observed." [1]

Kilonovae are a result of a neutron star merging either with another neutron star or with a black hole. A neutron star is the extremely dense, collapsed core of a massive star. Kilonovae are thought to emit short gamma ray bursts (sGRBs) as a result of this collision.

GW170817, the results of two neutron stars merging in 2017, was the first kilonova to be detected. GW170817 has made a breakthrough in astronomy due to its creation of the concept of multi-messenger astronomy which is getting information with more than one way (i.e. electromagnetic signals and gravitational waves).

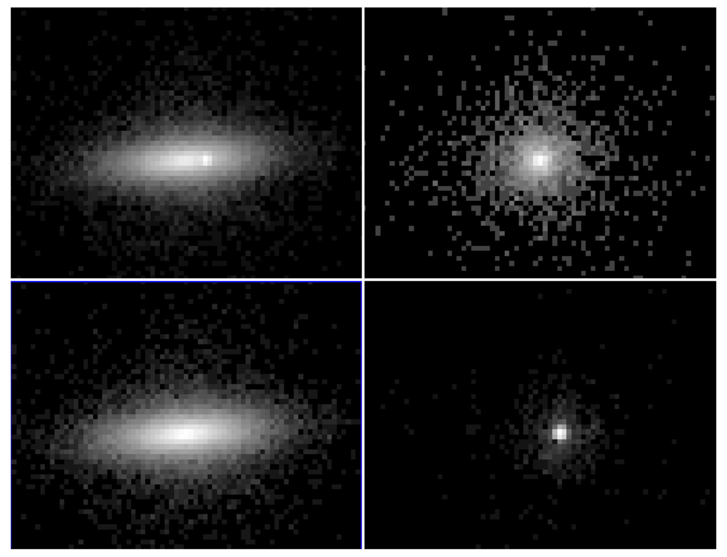

Fig. 2 (left): Simulated galaxy displaying all parts (top left), bulge only (top right), disk only (bottom left), and kilonova only (bottom right).

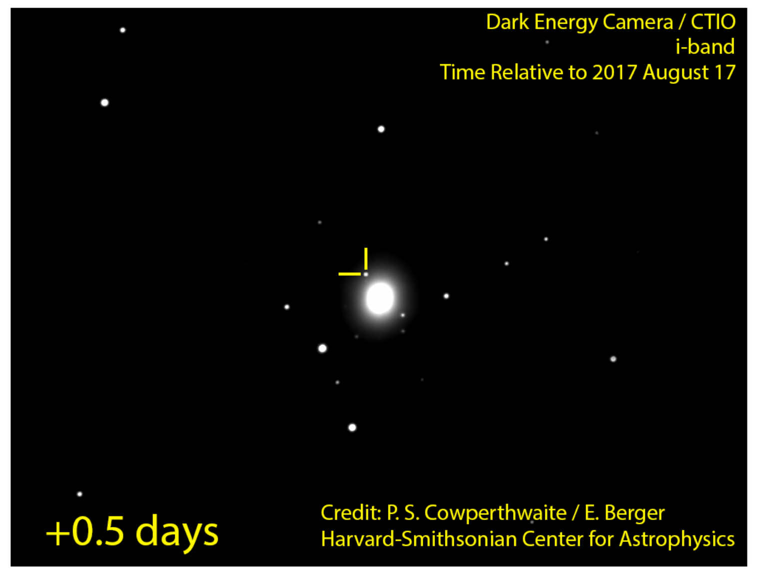

Fig. 3 (right): GW170817's kilonova fading over a few days

Simulating Data

The galaxies which were chosen in DESC's second data challenge (DC2) to host the kilonovae were selected based on similarity of r – i color, redshift, and size to galaxies which hosted short gamma ray bursts (sGRBs). sGRBs are thought to be connected to neutron star - neutron star collisions, and thus may have hosted kilonovae in the past.

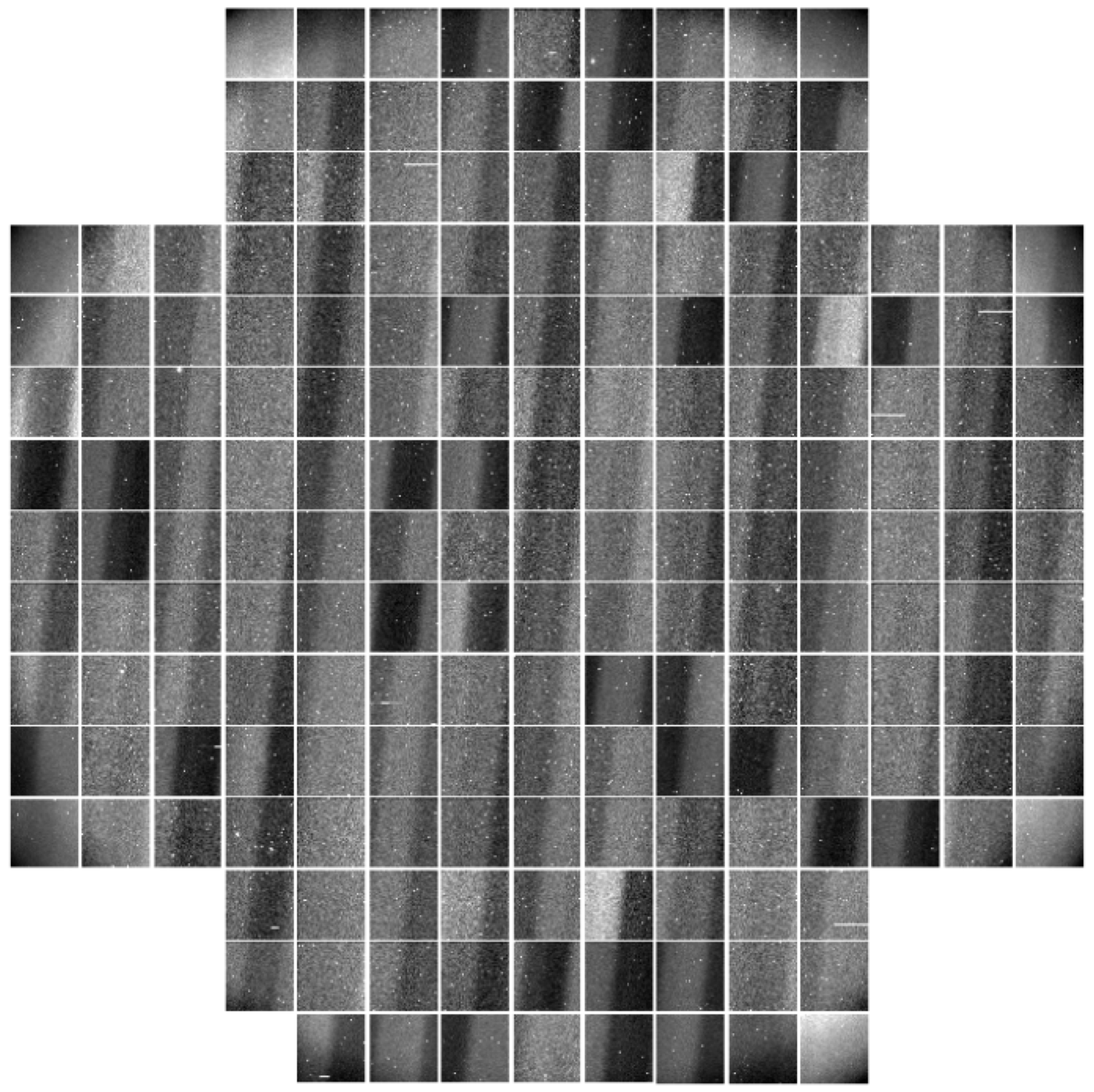

Fig. 3: Simulated the focal plane of the camera – consists of 189 charge-coupled device (CCD) sensors. CCDs convert photons to electrons, and images are produced based on the intensity of the light captured.

A spectral energy distribution (SED) is a graph of the energy emitted by an object. We generated SEDs that match the correct time after the kilonovae events based on the DC2 instance catalogs we used. Light curves show magnitude over time and whose value is seen with events with rapidly changing brightness such as kilonovae. We created light curves for different lengths of time for the kilonovae to last. We then made instance catalogs (lists of objects in a particular area of search) using those SEDs.

The kilonovae were then randomly added to the simulated galaxies chosen above. We generated astronomical images using the photon simulator PhoSim with the instance catalogs as input.

Conclusion

This Challenge is expected to be completed in winter 2022. With the production of all simulated astronomical images containing kilonovae completed, the last step is analyze the images to calculate how many inputted kilonovae are found, thus providing us with an indication of LSST's future ability to detect kilonovae

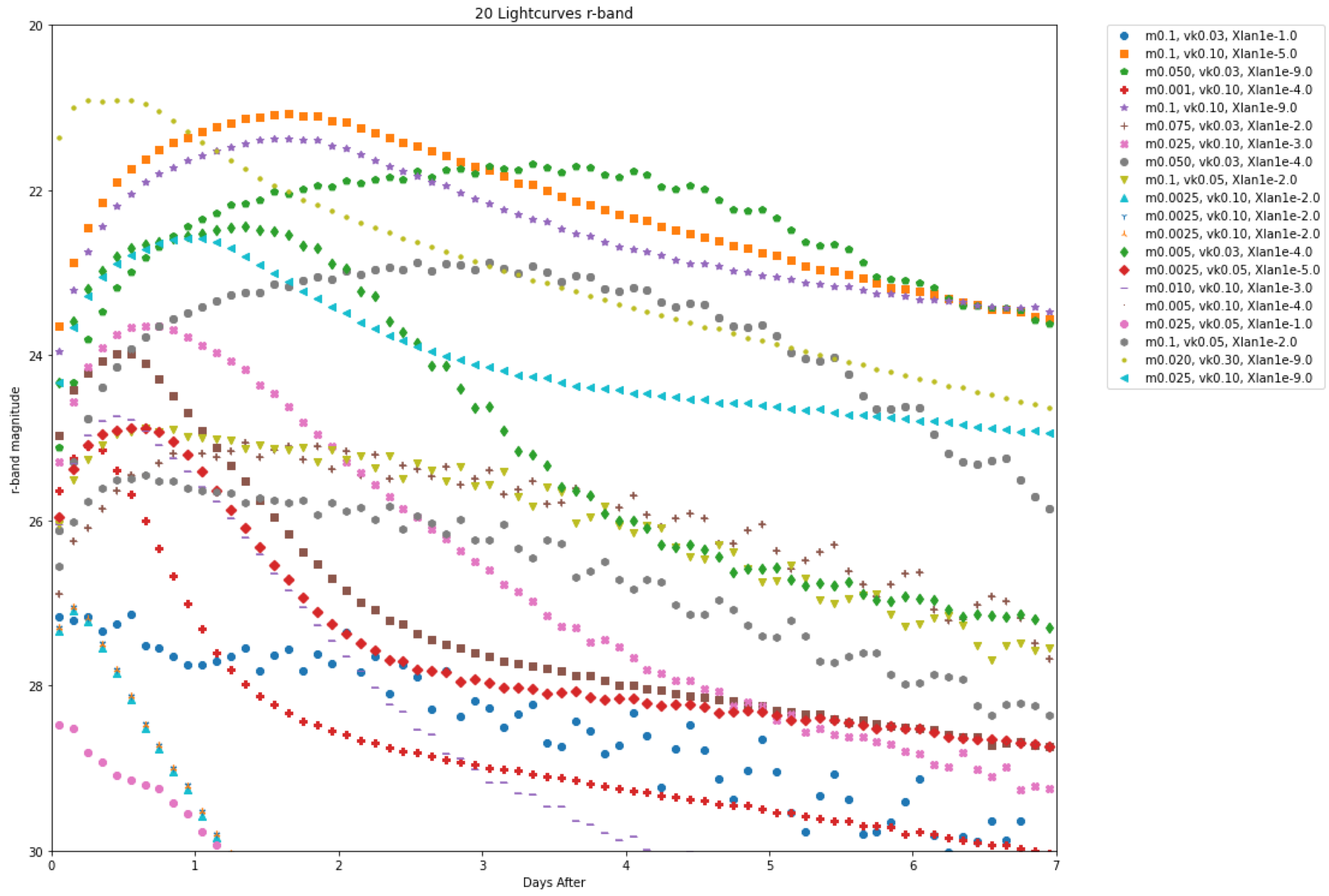

Fig. 5: The apparent brightness in magnitudes vs. time in days --- *a light curve* --- for each of 20 simulated kilonovae.

Future Work

We will use the Rubin Science Platform and the Rubin DM Stack to process the data and find all transients. We will also use the DESC Difference Image Analysis tools to search for transients in the images. These two techniques will provide an answer to how effective LSST will be able to detect kilonovae. Supernovae, star explosions which are optical transients similar to kilonovae, are why we hypothesized that the purity of the sample will be about 80% since they could be misclassified as kilonovae.

References

1: Communications, SLAC National Accelerator Laboratory. "LSST Camera." *Rubin Observatory's Legacy Survey of Space and Time (LSST) | SLAC National Accelerator Laboratory*, https://lsst.slac.stanford.edu/.

Kasen, D., Metzger, B., Barnes, J. et al 2017. "Origin of the heavy elements in binary neutron-star mergers from a gravitational-wave event," *Nature* 551, 80–84 (2017). https://doi.org/10.1038/nature24453. Code for kilonova models available here: https://github.com/dnkasen/Kasen_Kilonova_Models_2017