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IDENTIFYING KILONOVA

WITH THE KILONOVA AND TRANSIENTS PROGRAM (KNTRAP)

WHY SEARCH FOR KILONOVAE??

Kilonova (KN) occur as multiwavelength thermal emission in the aftermath of a binary neutron star or black hole-neutron star merger. They are important as they are sites of r-process nucleosynthesis and are the theorised primary origin location for a large fraction of the heavy elements in our universe [1]. The extreme nature of KNe can teach us about compact object physics, dense matter equation of state, gamma-ray burst physics, and they can be used to measure the expansion rate of the universe [2].

Currently, there is only one spectroscopically confirmed KN; AT2017gfo [3,4] discovered as an electromagnetic counterpart to gravitational wave GW170817 found with LIGO/Virgo during the O2 run in 2017.

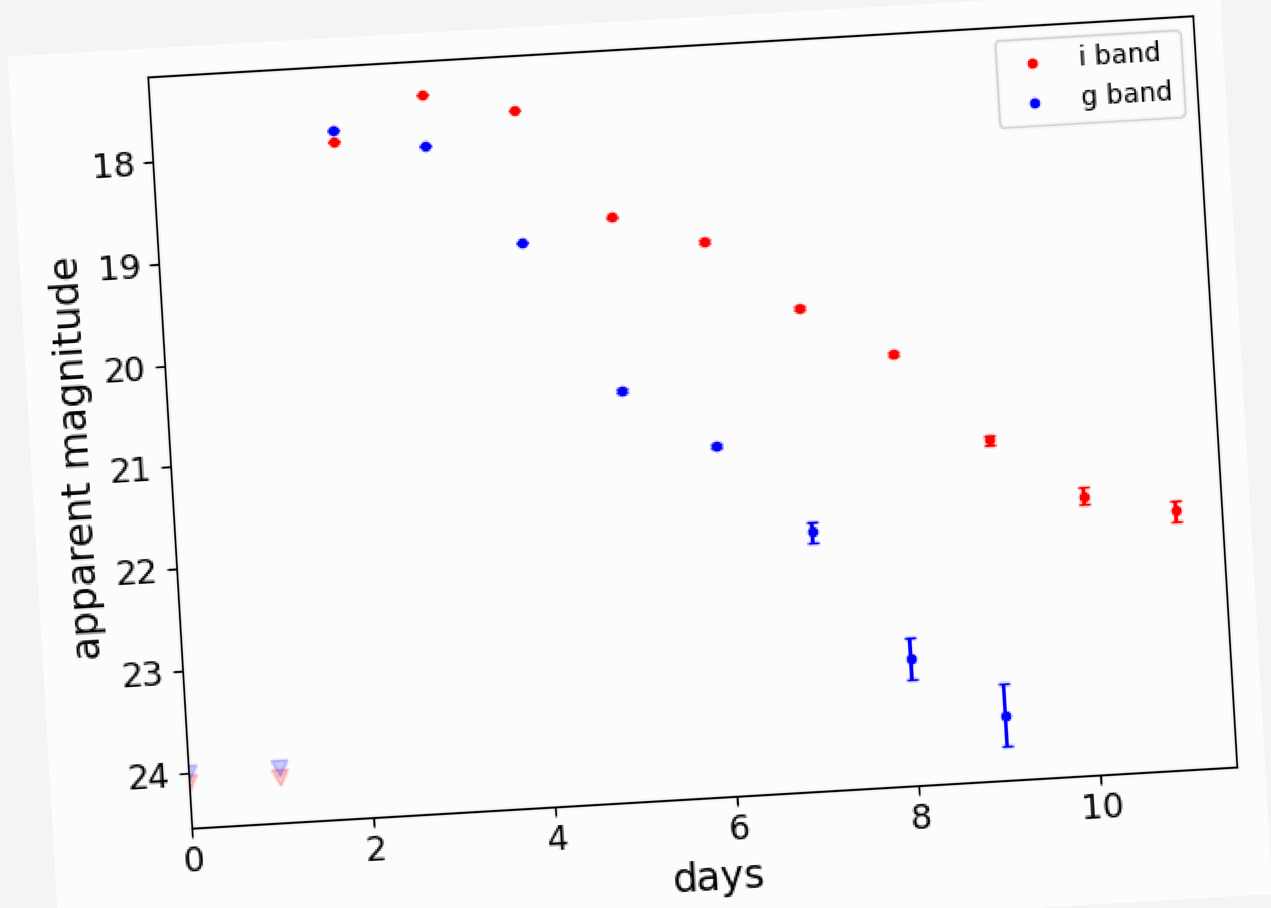


Figure 1: If AT2017gfo was captured during the KNTraP run, it would appear like the above light curve.

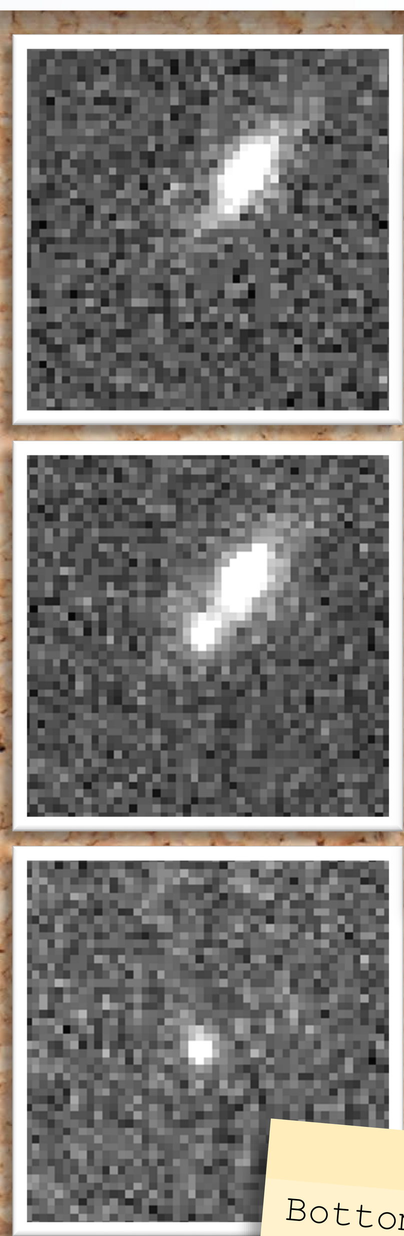


Figure 2
Top: template image, used for comparison. Either using archival data or first night's data for new fields

Middle: science image, taken nightly over the observing run

Bottom: difference image, created by subtracting the template from the science image. New and variable objects will be visible here

OBSERVING STRATEGY

KNTraP is considered an "untriggered" search, as we do not rely on gravitational wave (GW) triggers to find KNe. The electromagnetic emission of a KN is emitted isotropically, whereas GW detector sensitivity is dependent on the observing angle of the merger. The use of 4m-class optical instruments allow us to probe to depths past the horizon of GW detectors. Additionally, we are not restricted to the schedules of GW detectors.

We utilise the sensitive, wide-field, and fast cadence capabilities of the Dark Energy Camera (DECam) mounted on the Victor M. Blanco 4m Telescope. This allows us to search larger cosmological volumes than 1m-class telescopes, such as the Zwicky Transient Facility (ZTF), which comparatively, KNTraP reaches 65x deeper than. We predict up to 1 KN to be discovered per run.

In 2022 we observed 31 fields for 11 nights, using the i- and g-bands. These bands were chosen to allow us to distinguish a KN light curve (Fig 1) from other transient events like a supernova. In general, the characteristics we expect from the light curve is a fast rise in both bands, an early peak in bluer wavelengths, and a slower fade in redder wavelengths.

The data are processed nightly, for next day visual inspection of transient candidates. In the case of a promising KN candidate found in real-time, follow-up observations can be triggered for additional imaging evolution at different wavelength regimes and spectroscopic confirmation.

KNTRAP VS ZTF

DISTANCE REACHED PER POINTING
(ZTF 10min exposures, 1.2' seeing)

~1000 Mpc | ~ 120 Mpc

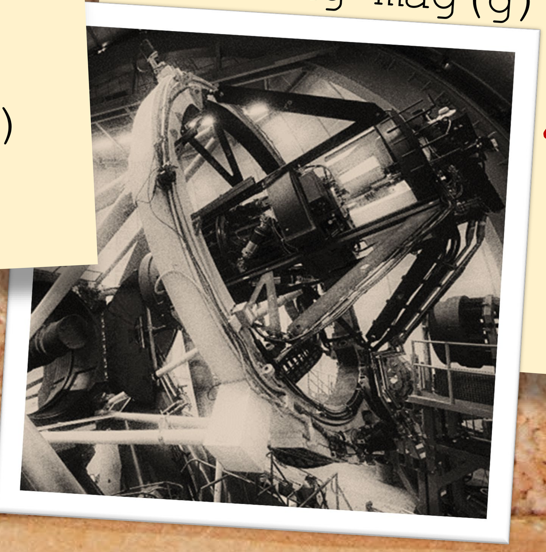
z < ~0.25 | z < ~0.028

DEPTH (i-BAND, BRIGHT TIME)

~24 mag | ~19.5 mag

DECAM PROFILE

FOV	:	3 deg^2
Filters used	:	i,g
Exposure time (i)	:	170 secs
Exposure time (g)	:	140 secs
Limiting mag(i)	:	22.6 mag
Limiting mag(g)	:	23.7 mag



DECam mounted on the Blanco 4m Telescope in Chile
Credit: Reidar Hahn, Fermilab

FILTERING CANDIDATES

After the data were processed, photometry and difference imaging was done (Fig 2), and potential transient candidates selected from there. The requirement for a candidate was it had to change magnitude by ≥3σ and be present in the difference image for ≥ 2 nights. The issue is that there were far too many potential candidates for a human to search through. A pipeline was written to filter down these candidates to only the most promising KN and fast transient candidates. It is important that our criteria stays conservative as we expect a KN to match models but are open to some variation. The following shows the vetting process.

Number of candidates...

273,377	initially after processing all the data in all 31 fields.
216,177	removing candidates with a star-like object in the template image, as these events are new and did not burst during the run.
16,377	with a KN-like evolution. Must either rise faster than 1 mag day^{-1} or fade quick than 0.3 mag day^{-1} [5].
1550	with ≥ 3 consecutive "good" detections in g-band OR ≥ 2 in i-band – *"secondary candidates"*. A good detection is defined as appearing star-like, quantified using PSF modelling and Source Extractor outputs.
240	with ≥ 3 consecutive good detections in i-band – *"primary candidates"*.

WORK IN PROGRESS

These primary candidates are the most likely in our dataset to be a KN and are currently undergoing modelling and image analysis.

A KNTraP Paper is in prep! (Van Bemmel & Zhang)

Transient Alerts and Publications from 2022 Run:

Andreoni et al. 2022, Nature, 612, 430
Valdes et al. 2014, ASPC, 485, 379
Zhang et al. 2022, TNS, 450
Freeburn et al 2022, GCN, 31647
Zhang et al. 2022, TNS, 1335
Van Bemmel et al. 2022, TNS, 1418

References

[1] Symbalisty+1982, Astrophys. Lett., 22, 143
[2] Dietrich T., Coughlin M. W., Pang P. T. H. *et al.* 2020 *Sci* **370** 1450
[3] Abbott+ 2017, PRL, 119:161101; Arcavi+ 2017, Nature, 551;
[4] Metzger+ 2017, Living Reviews in Relativity, 23:1;
[5] Andreoni+2020, ApJ, 904, 155