ASTROPHYSICAL COUNTERPARTS OF GW SOURCES (LECTURE)

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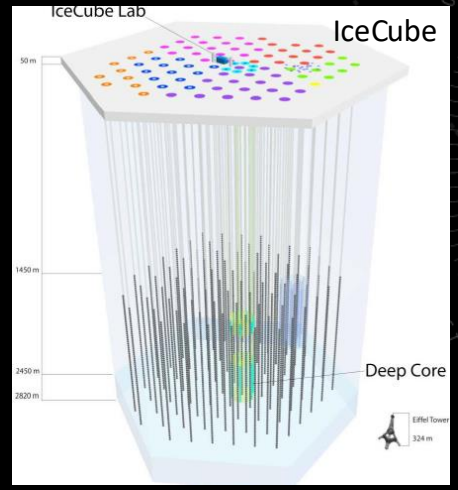
Electromagnetic Waves

Neutrinos

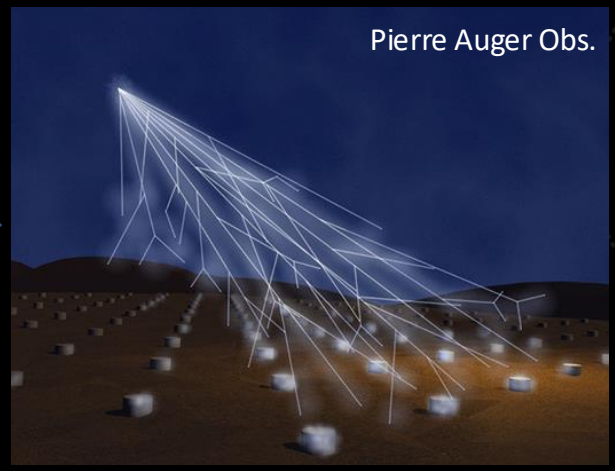


MULTI-MESSENGER ASTRONOMY

(MMA)

Gravitational Waves

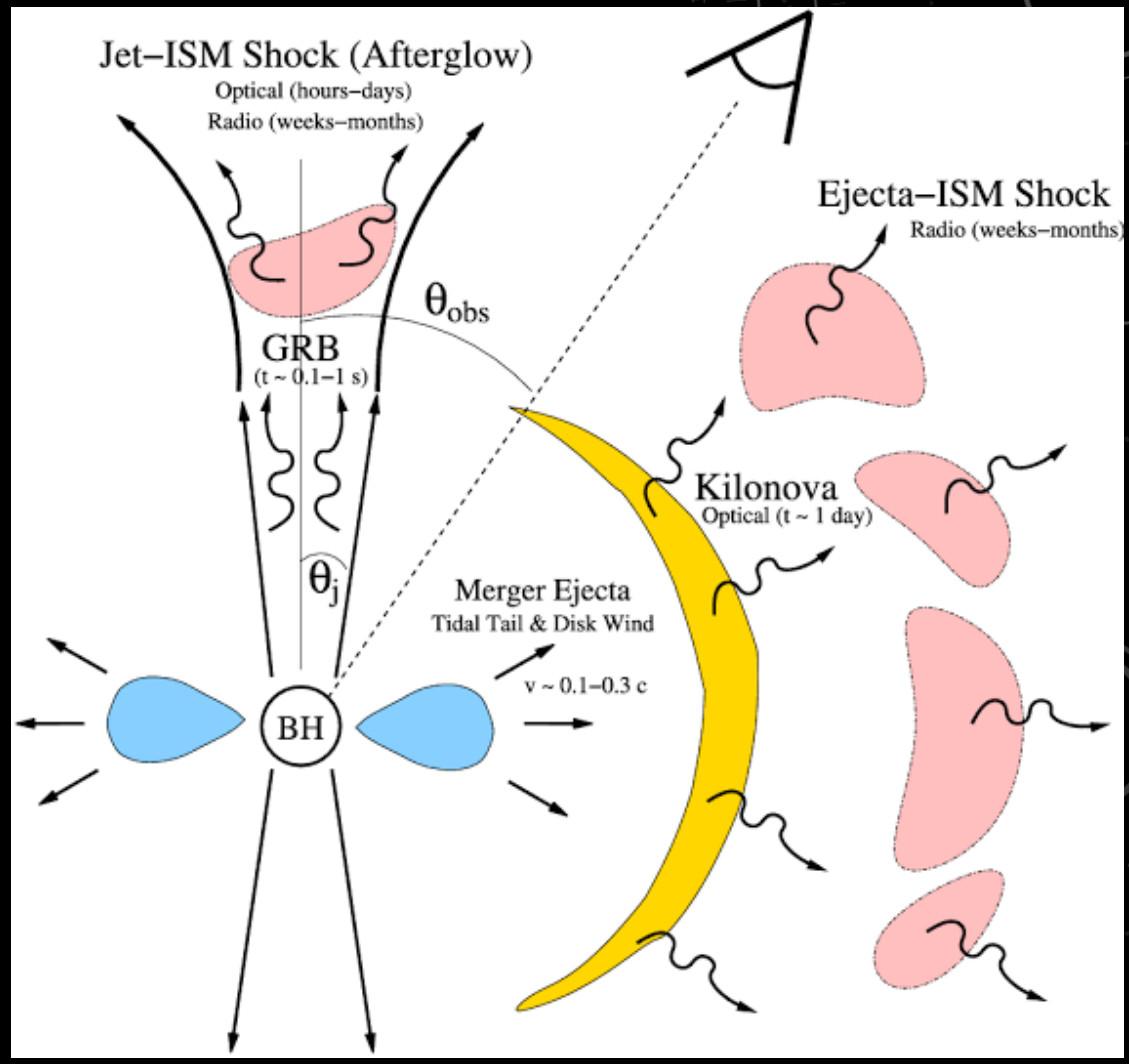
Cosmic Rays



GW-EM COUNTERPARTS

- Prompt: Gamma-ray Burst (GRB) – Gamma/X-rays
- Kilonova (KN) – Optical/NIR
- Afterglow (GRB, KN) – Radio

Metzger 2019

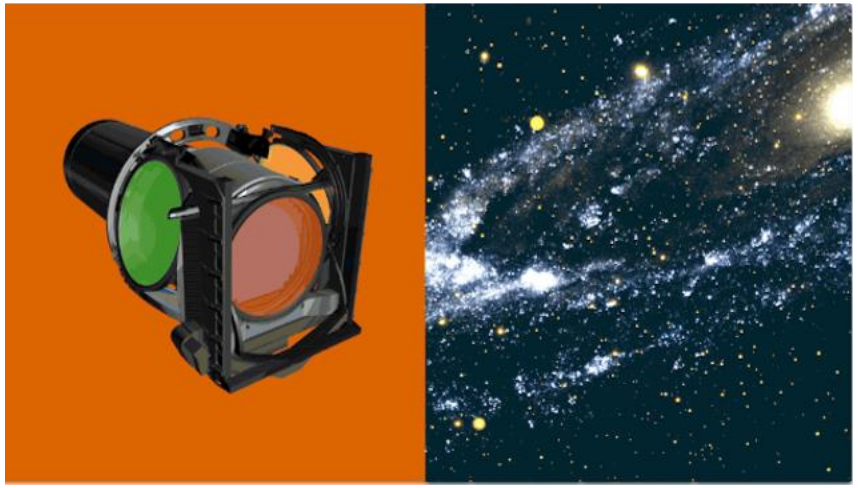


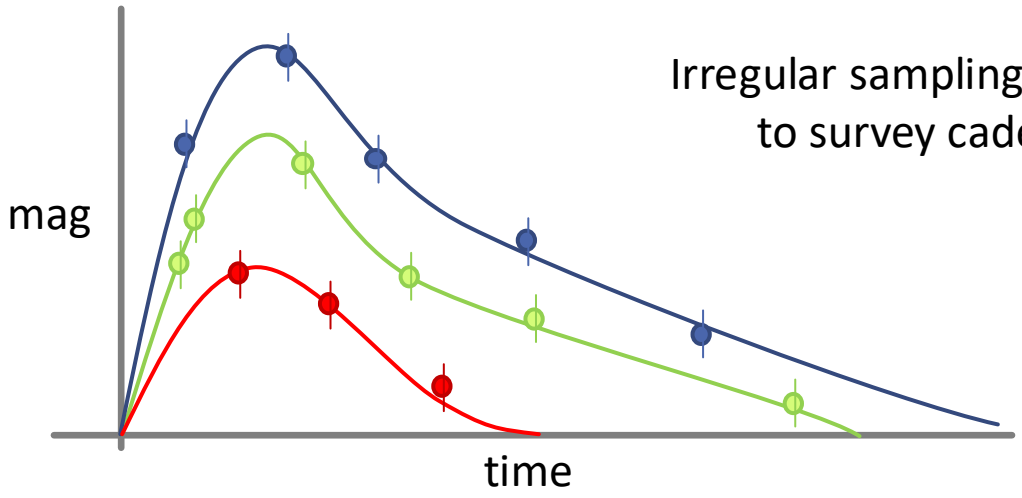
RUBIN OBSERVATORY

- Ten year survey (LSST) starting 2026
- ~ 10 million alerts/night or 20TB per night
- Broadcast worldwide within 60s
- 37 billion light curves
  - 6 filters (u,g,r,i,z,y or 320–1050 nm, 3 day cadence)

MULTI-COLOR LIGHT CURVES

(MULTI-CHANNEL TIME SERIES)

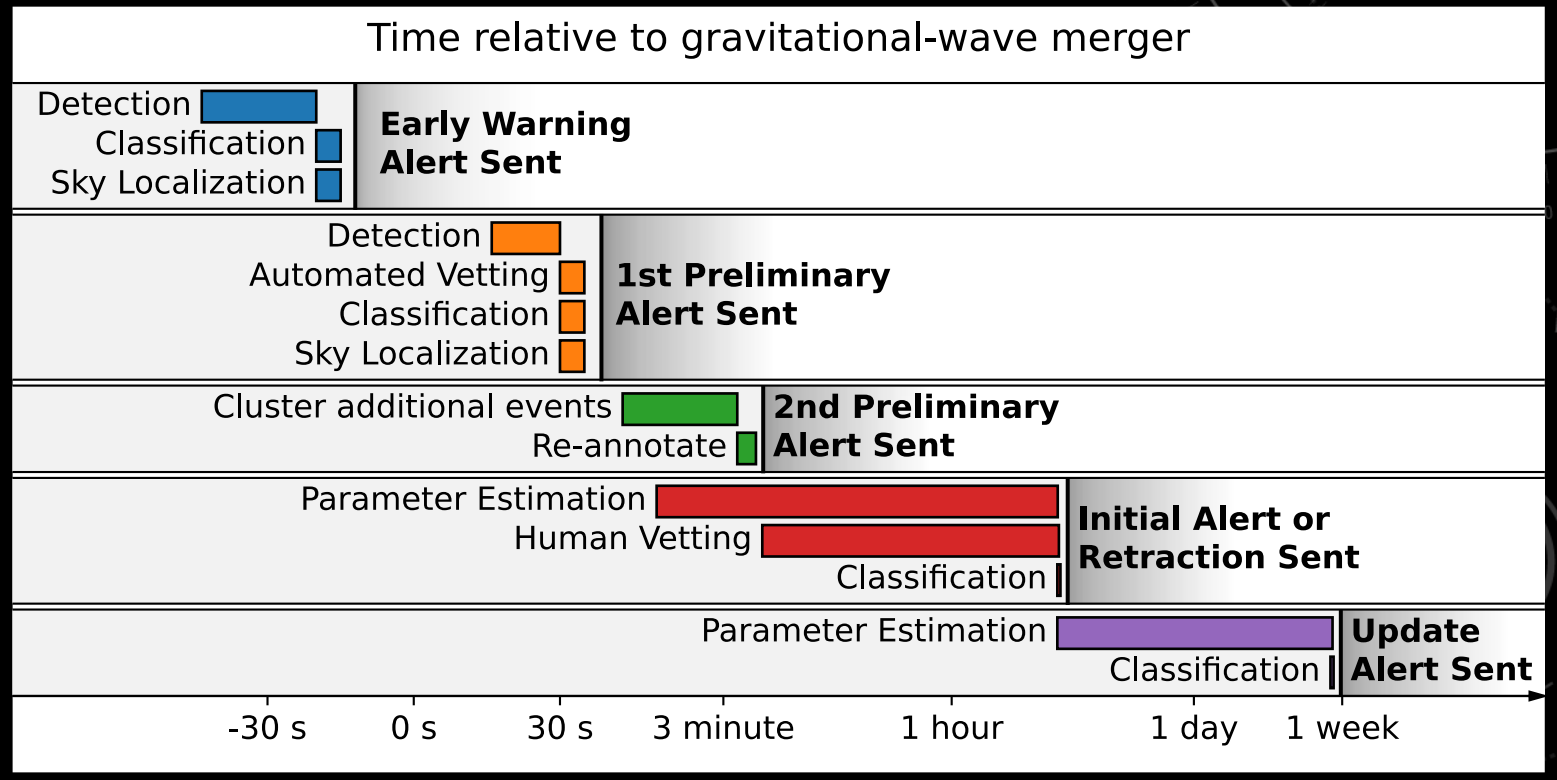


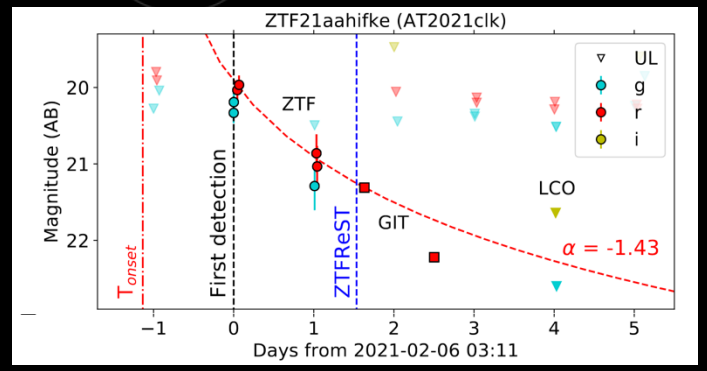


Irregular sampling due to survey cadence

GRAVITATIONAL WAVE ALERTS

- Update alerts and circulars are sent whenever the sky localization area or significance accuracy
- Notice contents:
  - Significance (FAR)
  - Skymap
  - Classification (BNS, NSBH, BBH, Terrestrial)
  - Properties (HasNS, HasRemnant, HasMassGap, HasSSM)
  - Binned chirp mass

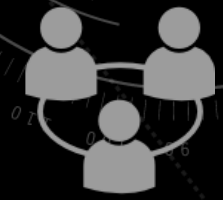


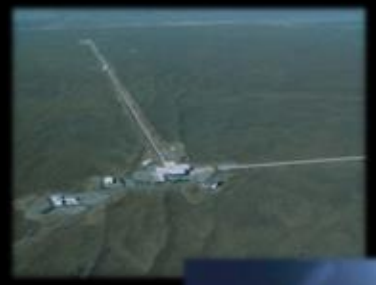


<~~1 week

Rule out stellar/AGN/SSO
Consider host/cross-matches, community reports
Follow-up (photometry/spectroscopy)

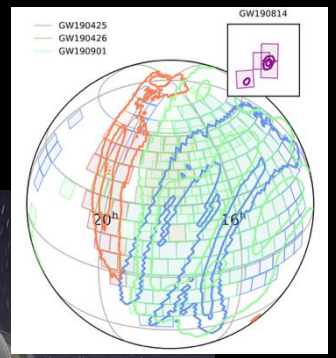
manual





~sec-mins

surveys



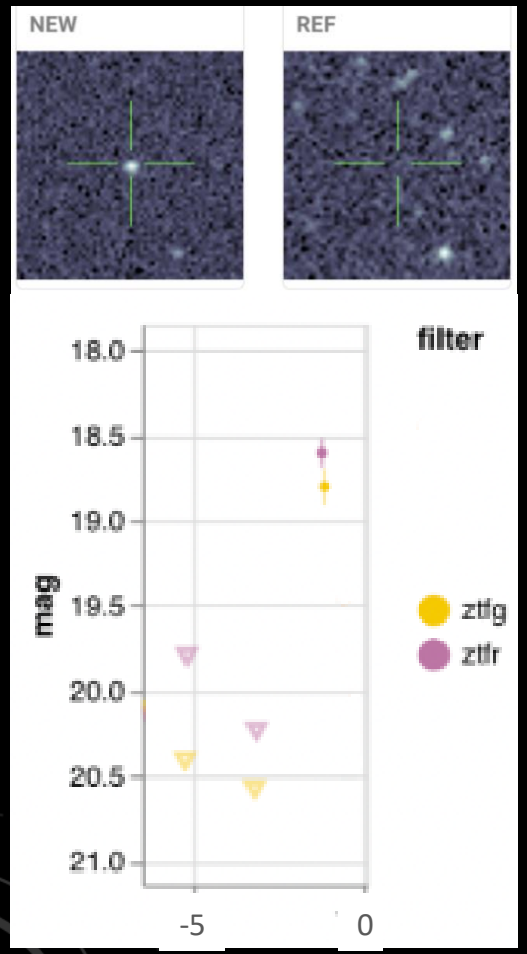
~mins

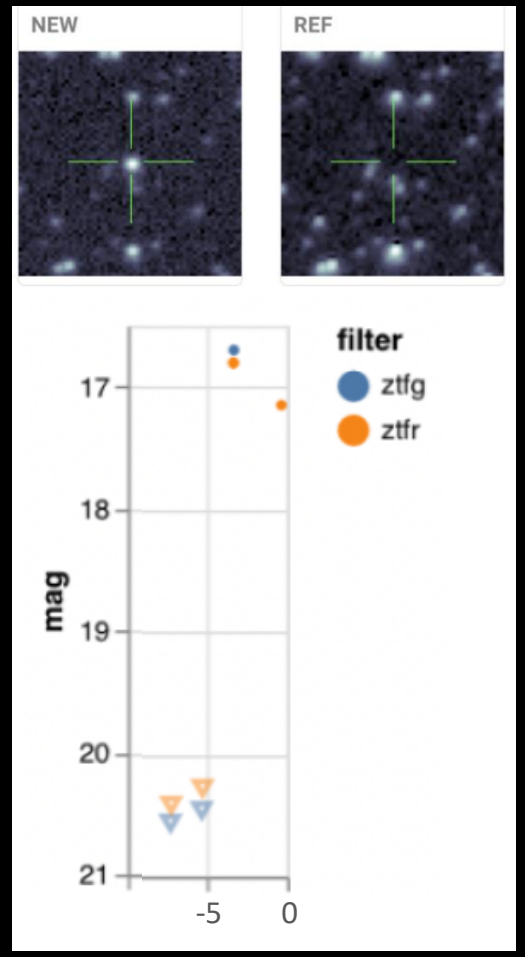
Automated culling
- Likely bogus
- Moving objects
- Known sources (new)
- Spatially coincident

~secs-mins
~10s candidates

Public via GCN
- Event time
- Sky localization
- Distance

~10s candidates





Goal:

- Use limited resources to acquire more information to:
  - Identify the event
  - Maximize constraints on interesting light curve physics

Additional follow-up is critical!

Process needs to be:

✓ Free from fatigue/bias
✓ Low-latency
✓ Scalable

GW detectors are getting more sensitive

- IR1 this fall
- Localizations will not improve by much (LIGO-India 2030+)

Rubin will produce 10x as many candidates for human experts to analyze

Follow-up resources will not increase at the same rate

Current protocol not suitable to get at statistics

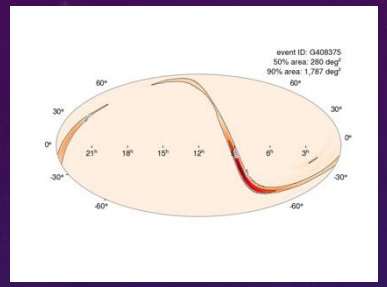
Need better techniques!

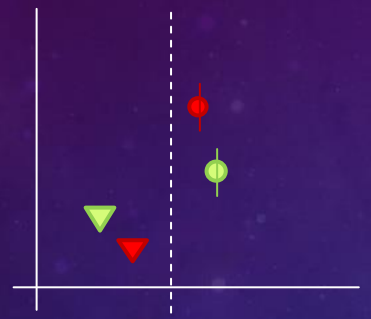
SCHEMATIC RESOURCE ALLOCATION PROBLEM

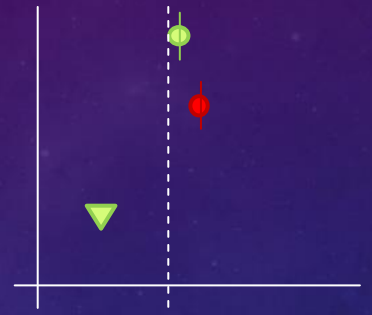
30 hr per semester
g, r, i, z

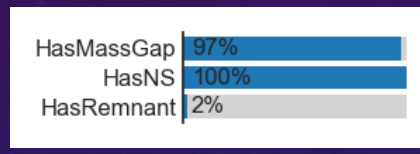
1 per night
g, r

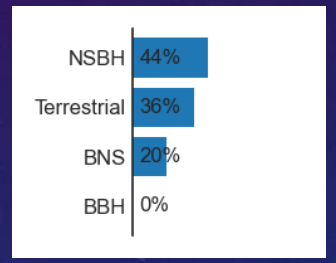
low res spec
~19mag
up to 5 per night



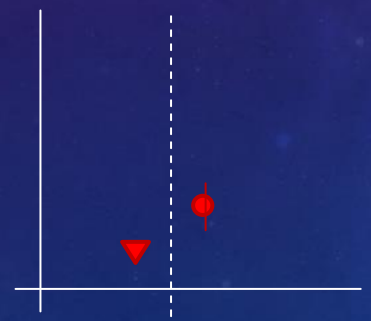


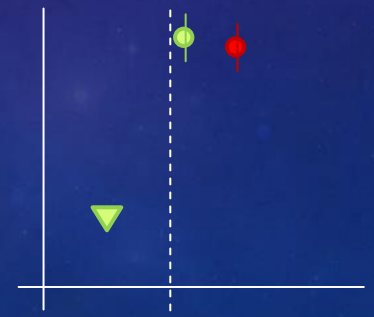






FAR – 9.59 per year





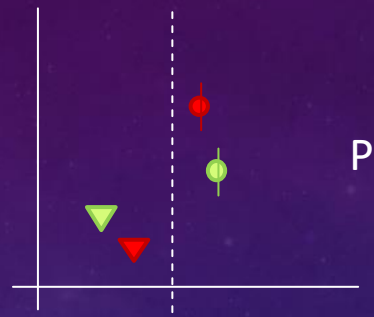
N ~ 100

Goal: Allocate resources optimally over all events over 7 days

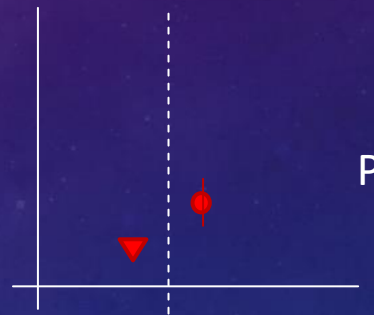
EXPLORE/EXPLOIT TRADEOFF

- Greedy: Rank by confidence is kilonova
  - Allocate one of each type in order of decreasing confidence until exhausted?
  - Allocate to improve classification scores, light curve characteristics (color, model fits)?
- Follow-up could be misallocated and this may be apparent with a delay
- Maybe better to improve understanding by trying other options because still can allocate later to best guess

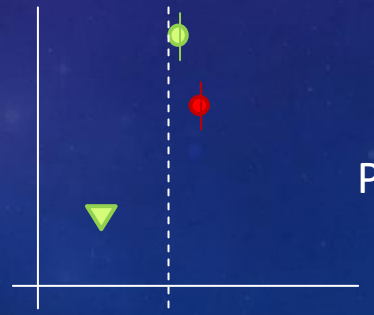
Ideal strategy is optimal given all future allocations and all future outcomes



P(KN)=0.73



P(KN)=0.12



P(KN)=0.11

30 hr per semester
g, r, i, z

1 per night
g, r

low res spec
~19mag
up to 5 per night

LABORATORY

- For our lab we will develop a myopic greedy classifier-based resource allocation model
  - You will use simulated GW events and Rubin transients enclosed in the skymaps of the events to train a classifier to distinguish between KNe and non-KNe using information in GW and Rubin alerts
- Then we will evaluate the classifier on ”scenarios” where the classifier will assess thousands more non-KNe than KN and see how close the true KN is at the top of your list.
  - Remember classifiers output probabilities
- Expect that top-k recovery
  - will improve over time with more photometry – but ideally want to find it in the first 2-3 days
  - be better for smaller skymaps (i.e. nearby events) -- not the case for most of the alerts from IGWN
  - be better for shallower surveys as this only have the brighter events (KNe and non-KNe)