University of Glasgow

ScotDIST

Science & Technology Facilities Council

Effect of LSST Observing strategies on prospects for multi-messenger astronomy with serendipitous kilonova discoveries

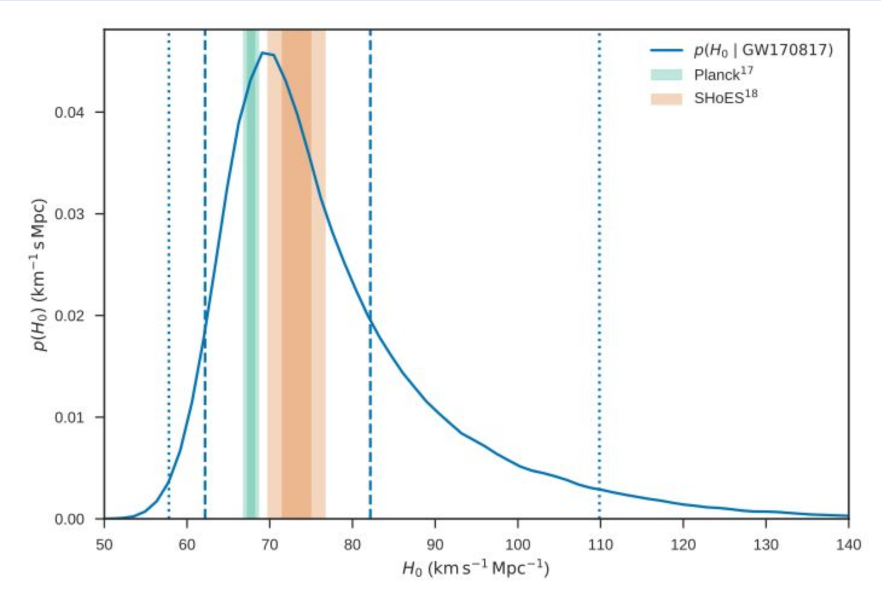
Laurence Datrier
In collaboration with Martin Hendry, Graham Woan, Ik Siong Heng, Michael J. Williams, Daniel Williams

Multi-messenger astronomy with GW and KNe

Multi-messenger astronomy with gravitational waves and kilonovae has many scientific returns:

- Cosmology
- Neutron star equation of state

We investigate prospects for MMA with gravitational wave and kilonova observations not triggered by a GW signal.



Abbott et al., 2017

Subthreshold and one detector GW detections

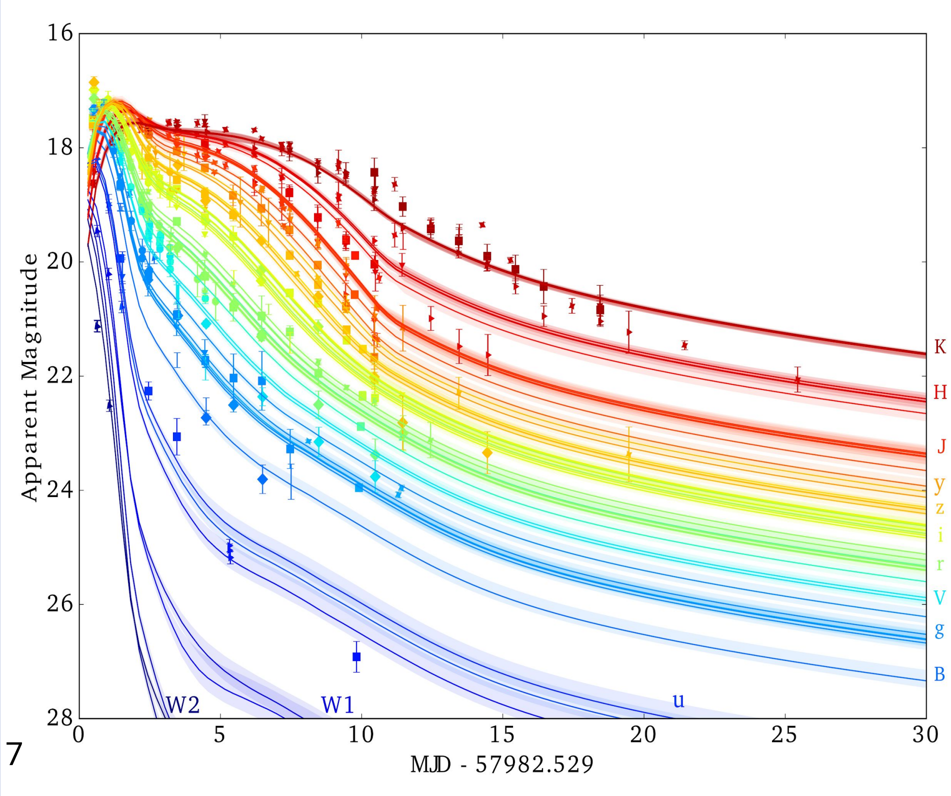
Artist impression of GW190425,
A. Simonnet

- We expect a number of BNS to be **subthreshold** (edge-on) or **single detector** events - an associated **EM counterpart** could confirm one of these detections as an event.
- We expect a number of untriggered kilonova detections associated with such subthreshold or one detector events. (Setzer, 2019)
- Already a pipeline in place for searches associated with sGRB, and pipelines for searches for burst signals associated with SNe.

LSST for uncovering non GW-triggered KNe

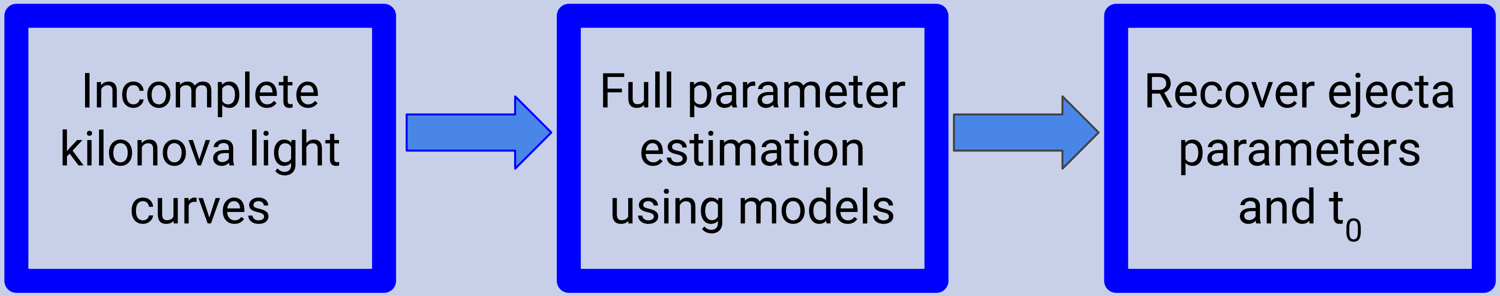
- Kilonovae are **faint** transients with a **rapid decline**

- Depth and field of view of LSST searches make it ideal for serendipitous kilonova discoveries



Villar et al., 2017

Method

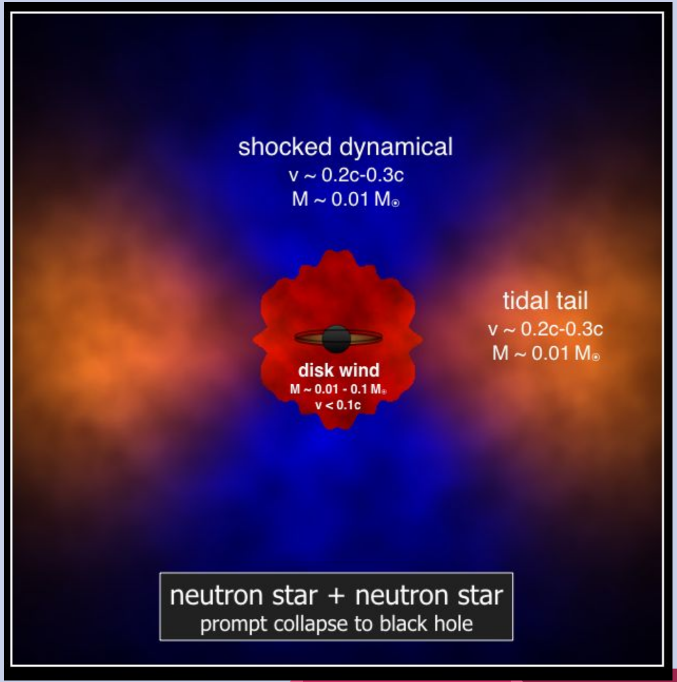

Incomplete kilonova light curves
Full parameter estimation using models
Recover ejecta parameters and t_0

Method - Kilonova models

We use the 2017 radiative transfer Kasen models. Two components (tidal red,dynamical blue) with 3 ejecta parameters each:

- Ejecta velocity
- Ejecta mass
- Lanthanide fraction

1 magnitude uncertainty on models

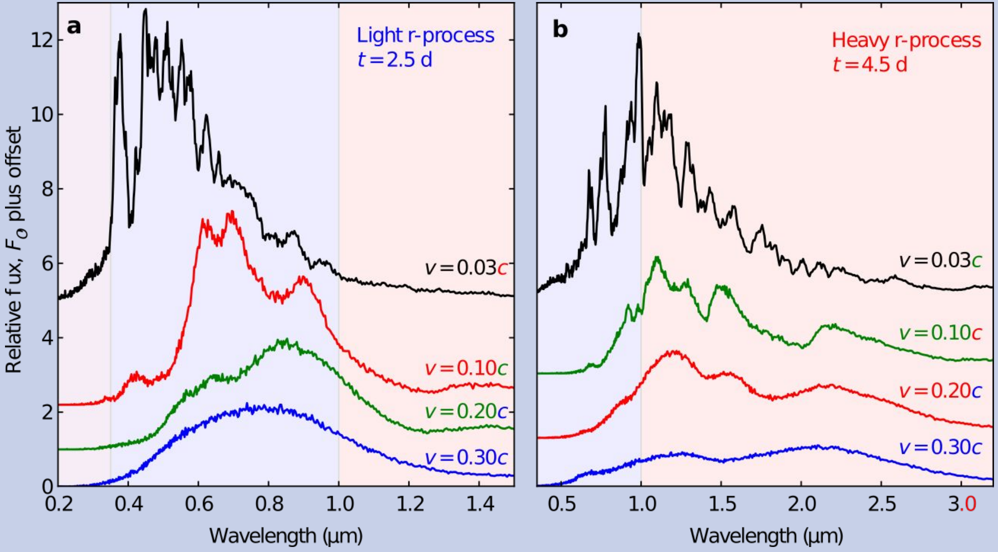


Models on a grid - expanded with Gaussian Process Regression.

Kasen et al. 2017

Method - Observations and Parameter Estimation

- Simulate apparent magnitude for different types of kilonovae from time resolved spectra, focusing at g,r,i bands
- Using LSST WFD single exposure magnitude limits
- Different cadences and start times (time of first observation in days most-merger)



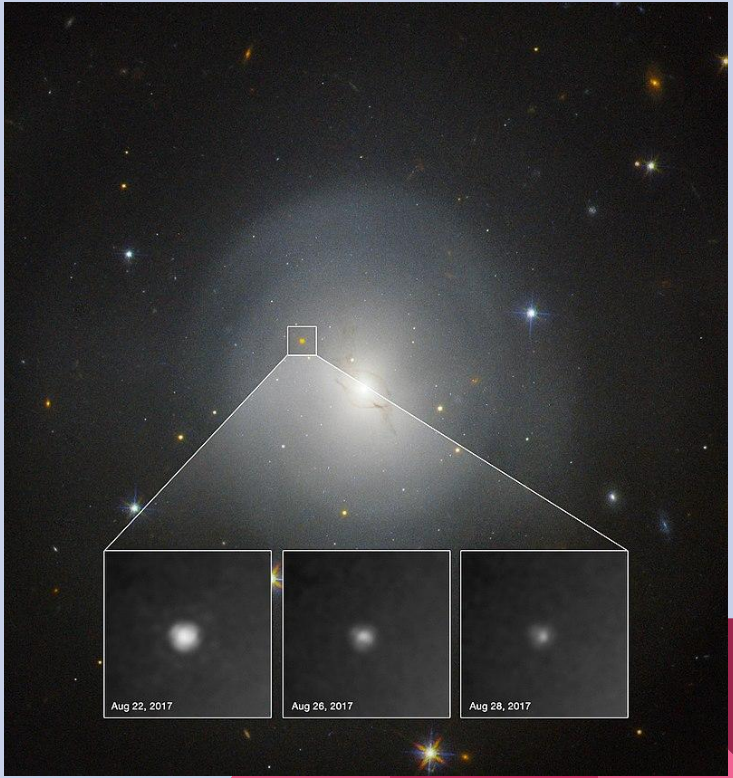
Kasen et al., 2017

Testing PE on AT 2017 gfo DECam data

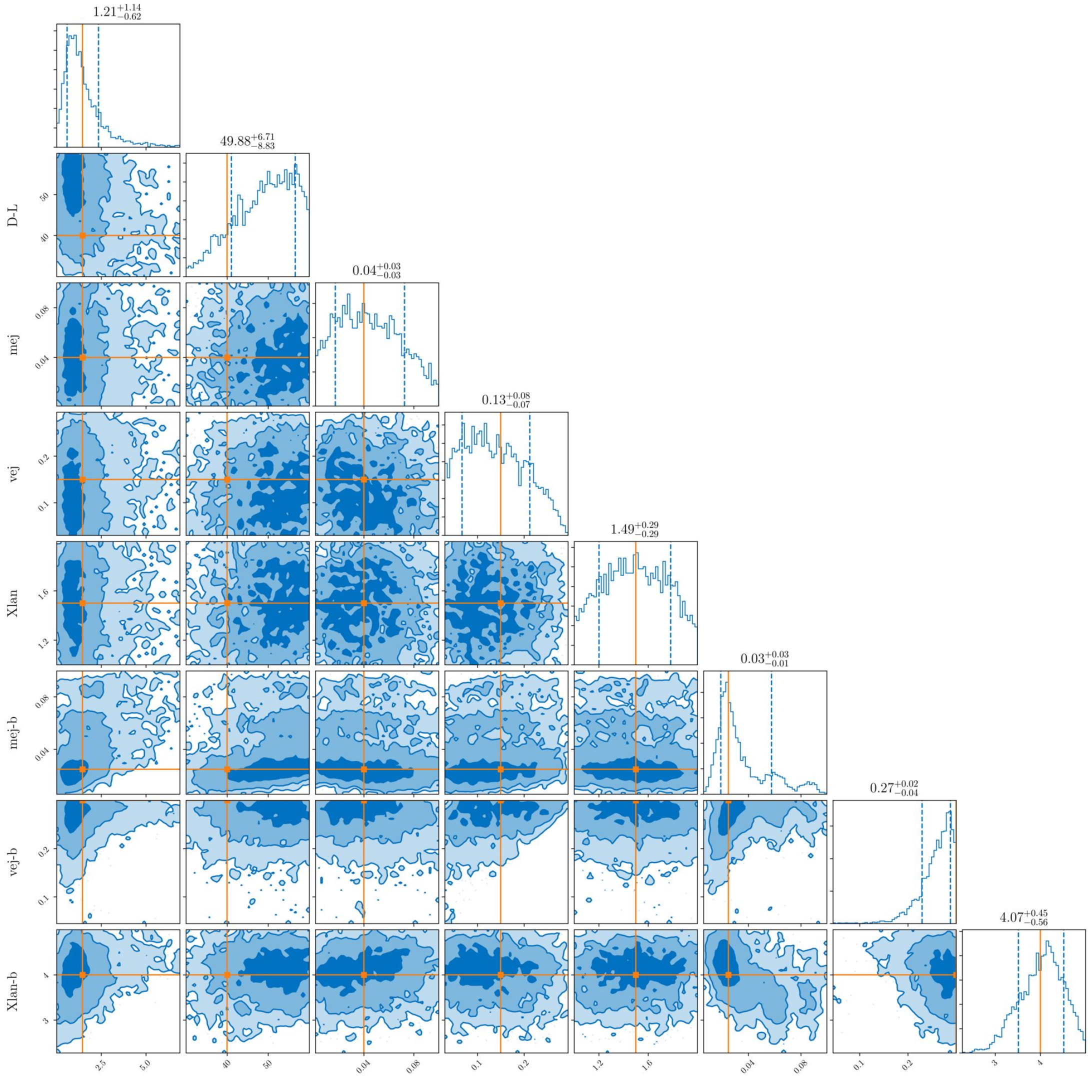
Full parameter estimation on truncated AT 2017 gfo light curves for *g,r,i* DECam data.

Start of observations t = 1.45 days

Recovered t = $1.21^{+1.14}_{-0.82}$ days

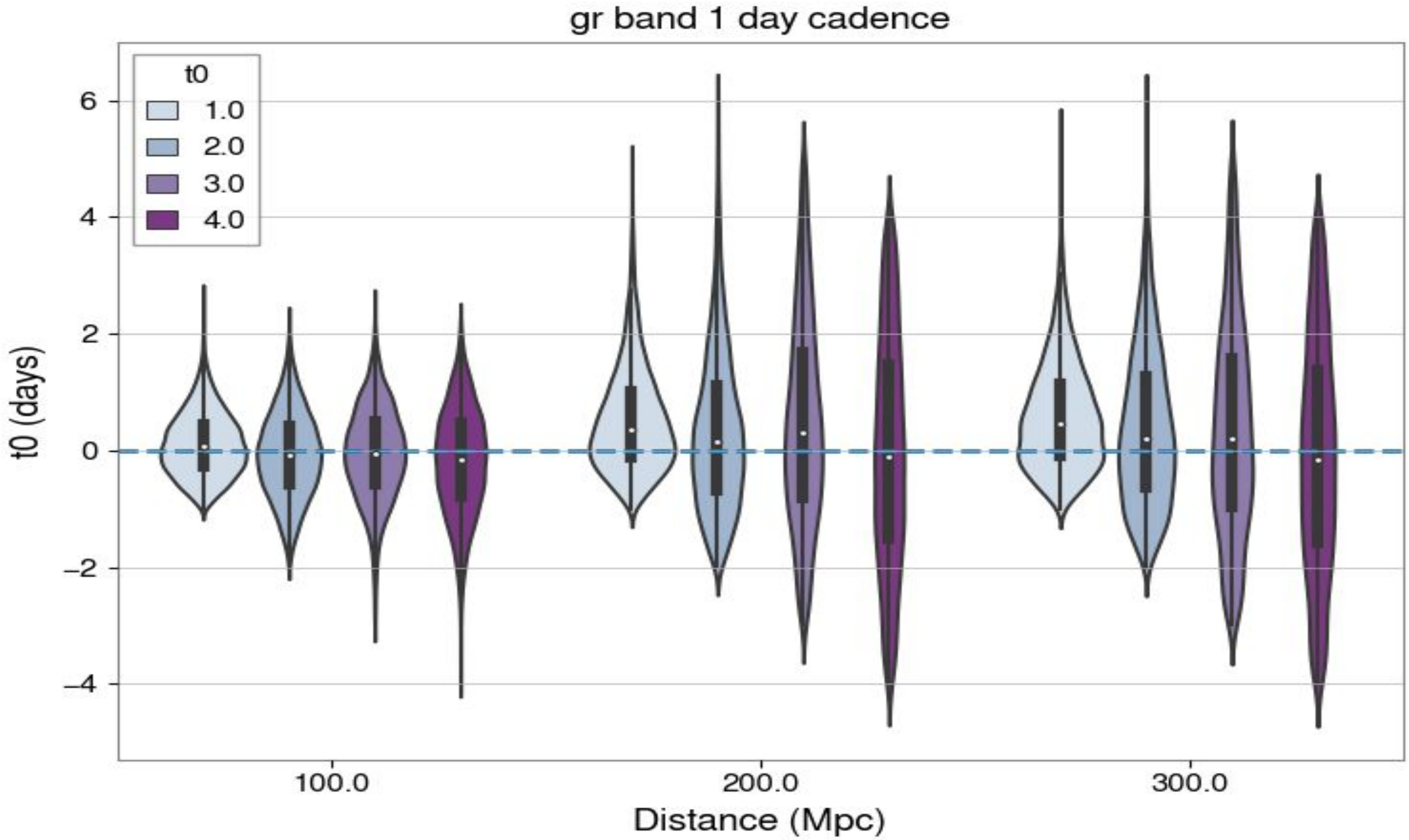


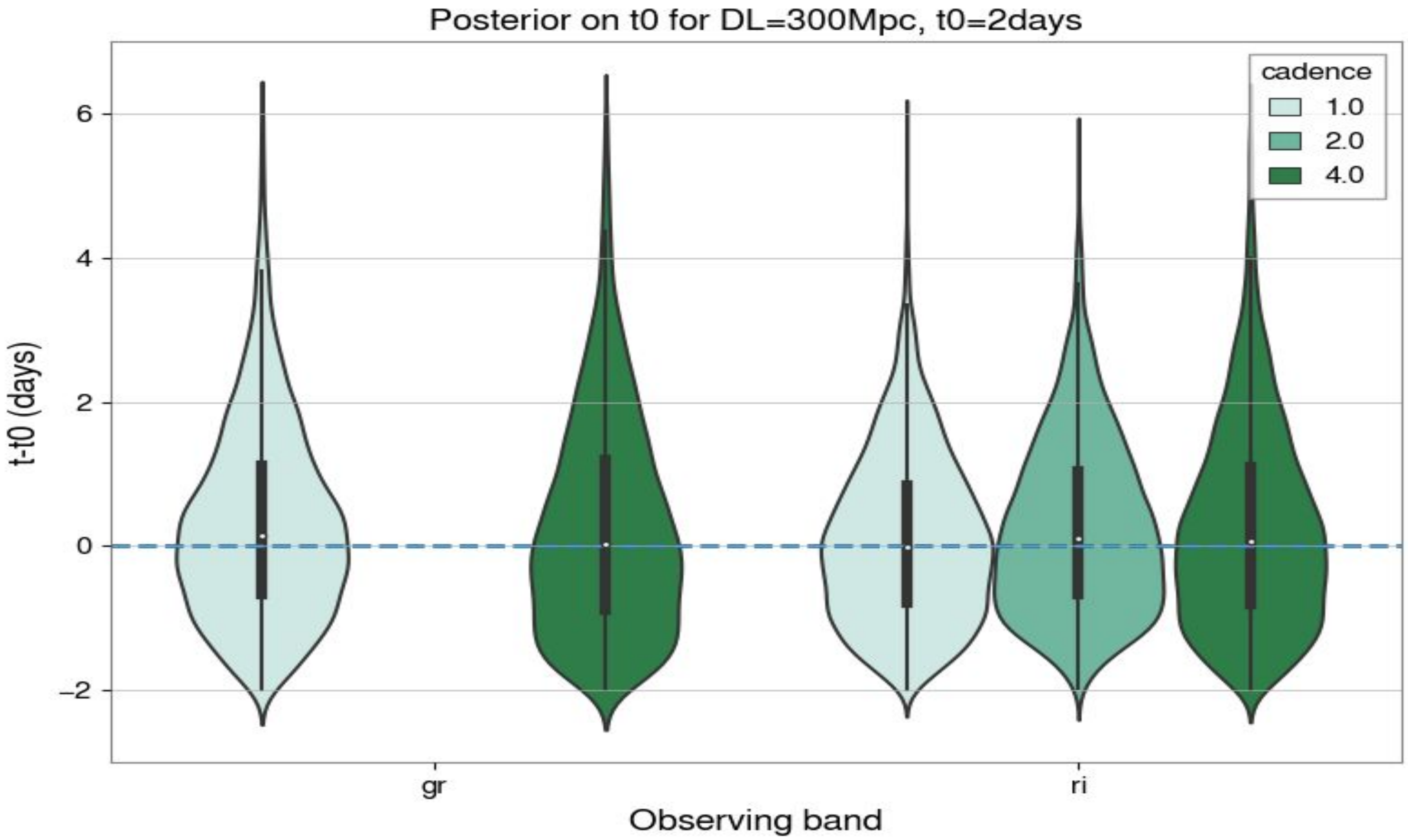
NASA/ESA



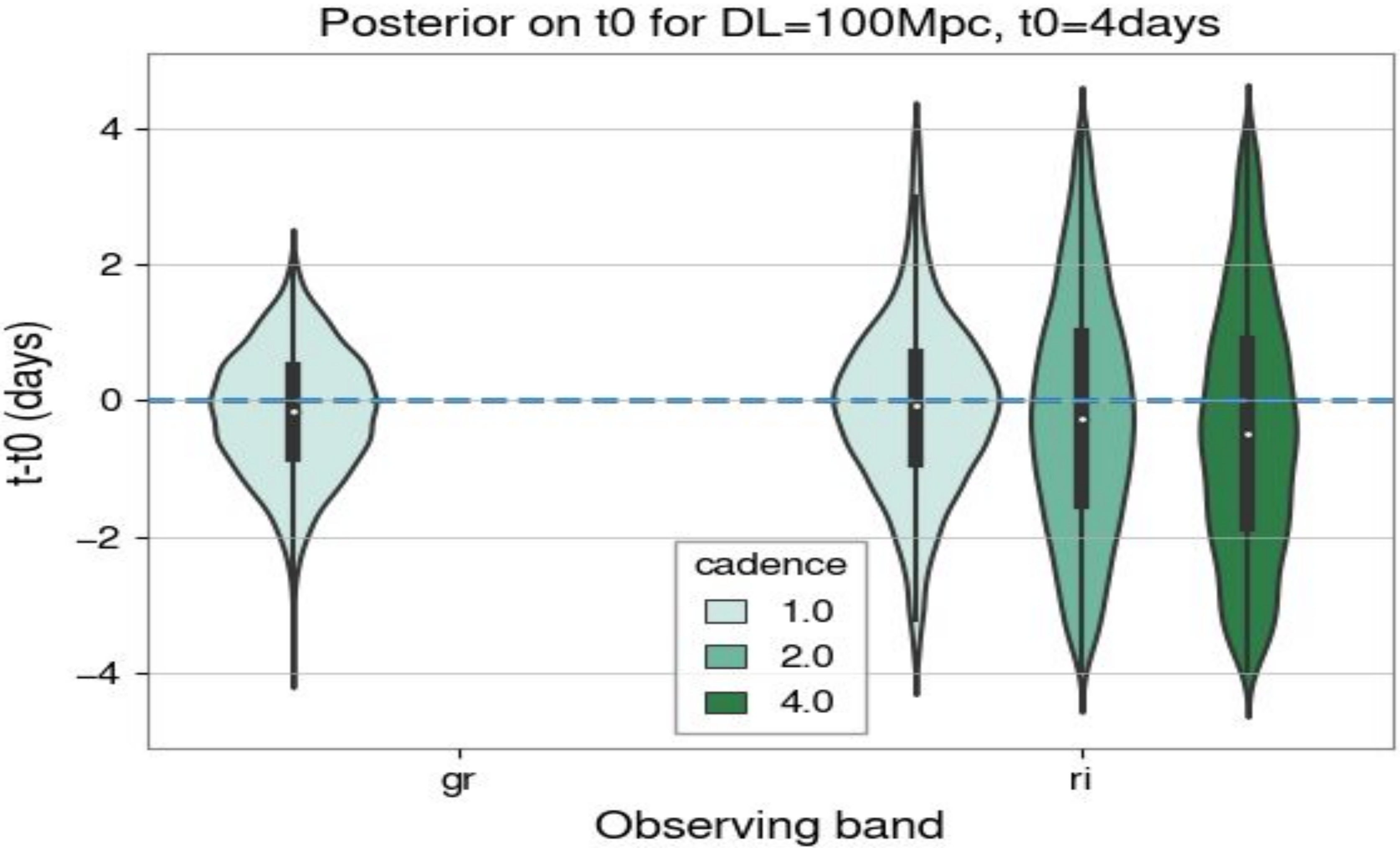
$1.21^{+1.14}_{-0.62}$
$49.88^{+6.71}_{-8.83}$
$0.04^{+0.03}_{-0.03}$
$0.13^{+0.08}_{-0.07}$
$1.49^{+0.29}_{-0.29}$
$0.03^{+0.03}_{-0.01}$
$0.27^{+0.02}_{-0.04}$
$4.07^{+0.45}_{-0.56}$
D-L
mej
vej
Xlan
mej-b
vej-b
Xlan-b

Results

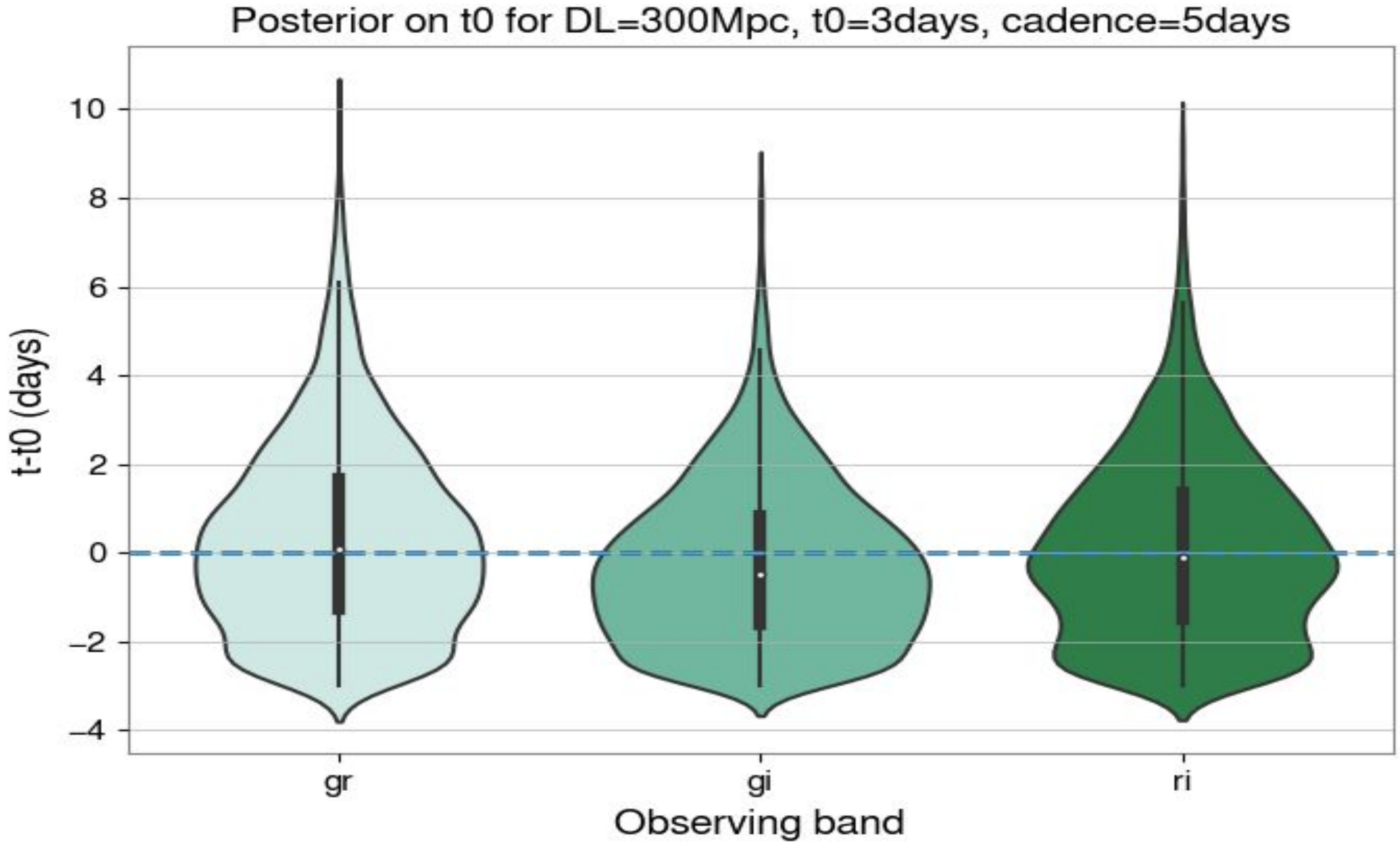

gr band 1 day cadence
t0
1.0
2.0
3.0
4.0
6
4
2
0
−2
−4
t0 (days)
100.0
200.0
300.0
Distance (Mpc)



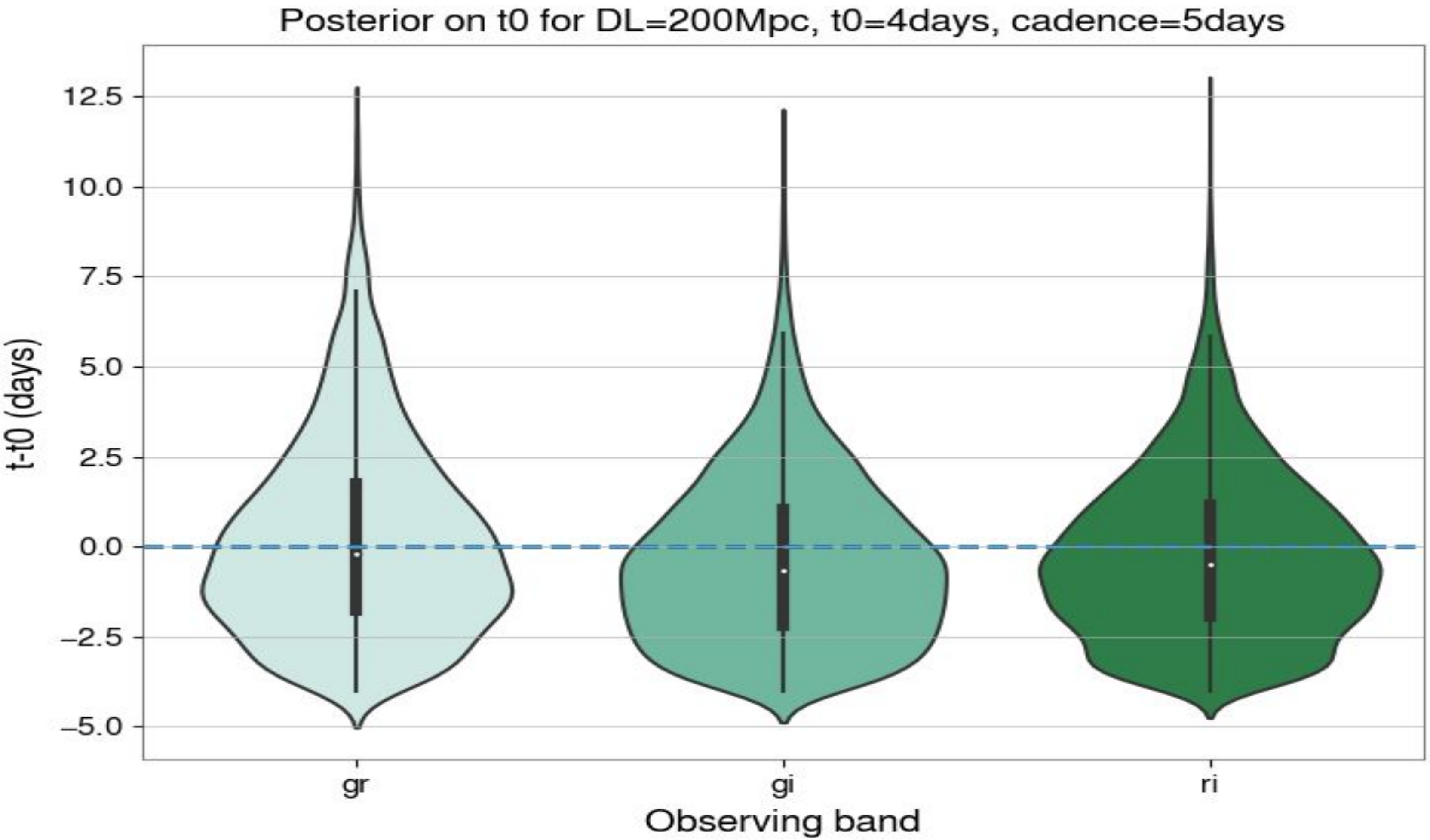
Posterior on t0 for DL=300Mpc, t0=2days
cadence
1.0
2.0
4.0
6
4
2
0
−2
t-t0 (days)
gr
ri
Observing band



Posterior on t0 for DL=100Mpc, t0=4days
4
2
0
−2
−4
t-t0 (days)
cadence
1.0
2.0
4.0
gr
ri
Observing band



Posterior on t0 for DL=300Mpc, t0=3days, cadence=5days
t-t0 (days)
10
8
6
4
2
0
−2
−4
gr
gi
ri
Observing band

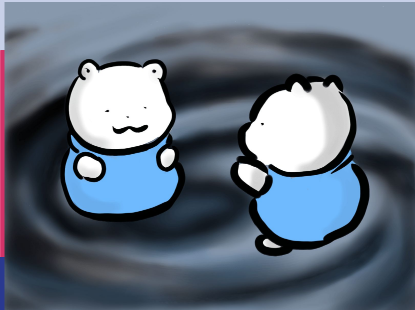


Posterior on t0 for DL=200Mpc, t0=4days, cadence=5days
12.5
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
t-t0 (days)
gr
gi
ri
Observing band

Conclusions

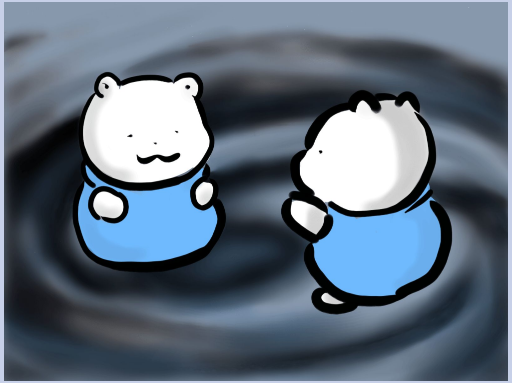
- ★ Even for more distant objects some information on t0 is recovered
- ★ **Cadence** becomes less important for more distant objects
- ★ Most important is to get observations in at least **two bands**
- ★ **Model uncertainties** are the main contribution to uncertainty on KN parameters

Searches can also be improved with sky localisation and observations from other telescopes.



Future work

★ Look even deeper and at later t0, with slower cadences.
★ Look at optimising search strategy for other kilonova parameters
★ Look at kilonova population



-What about detection criteria?

Assumed met here, as criteria:

-2 alerts in two bands

-At least one observation 20 days before

-At least one observation 20 days after