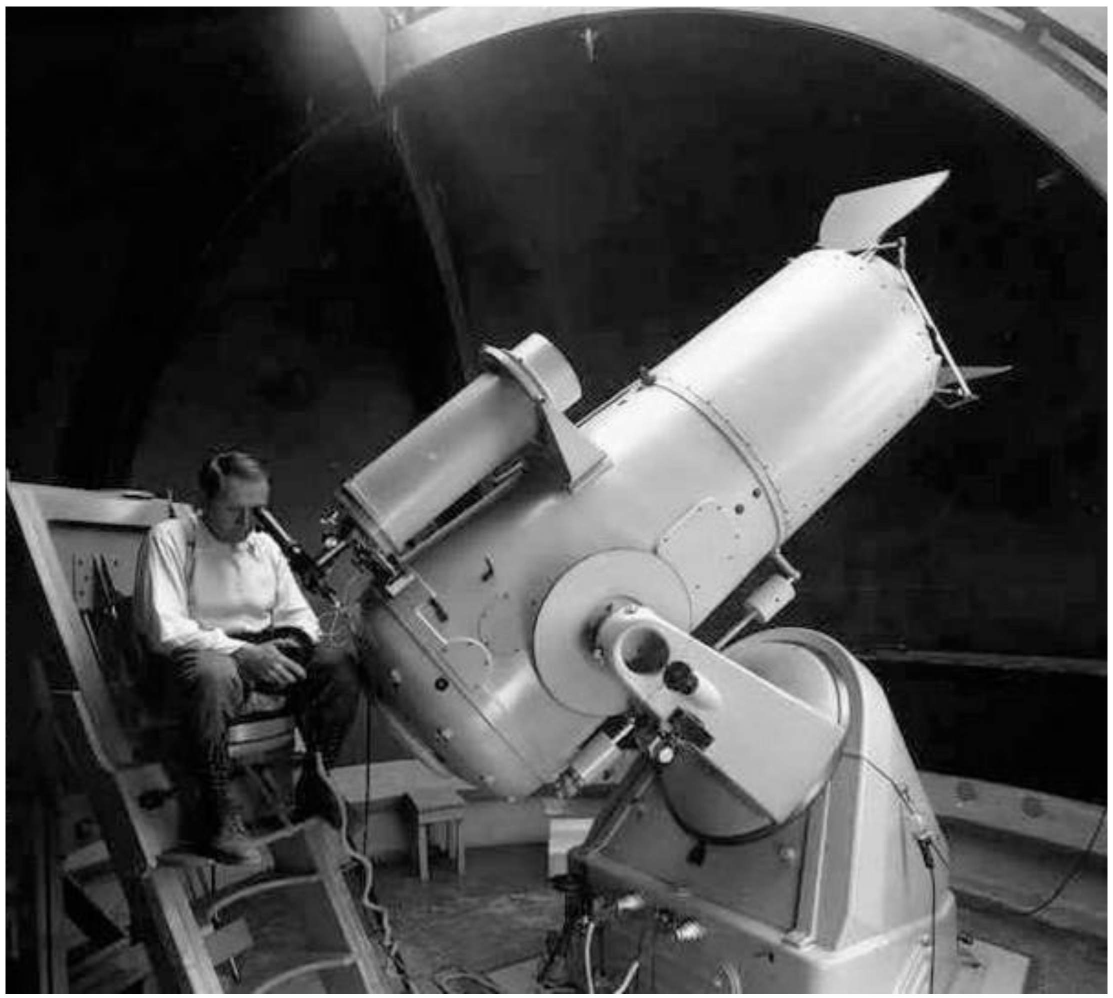
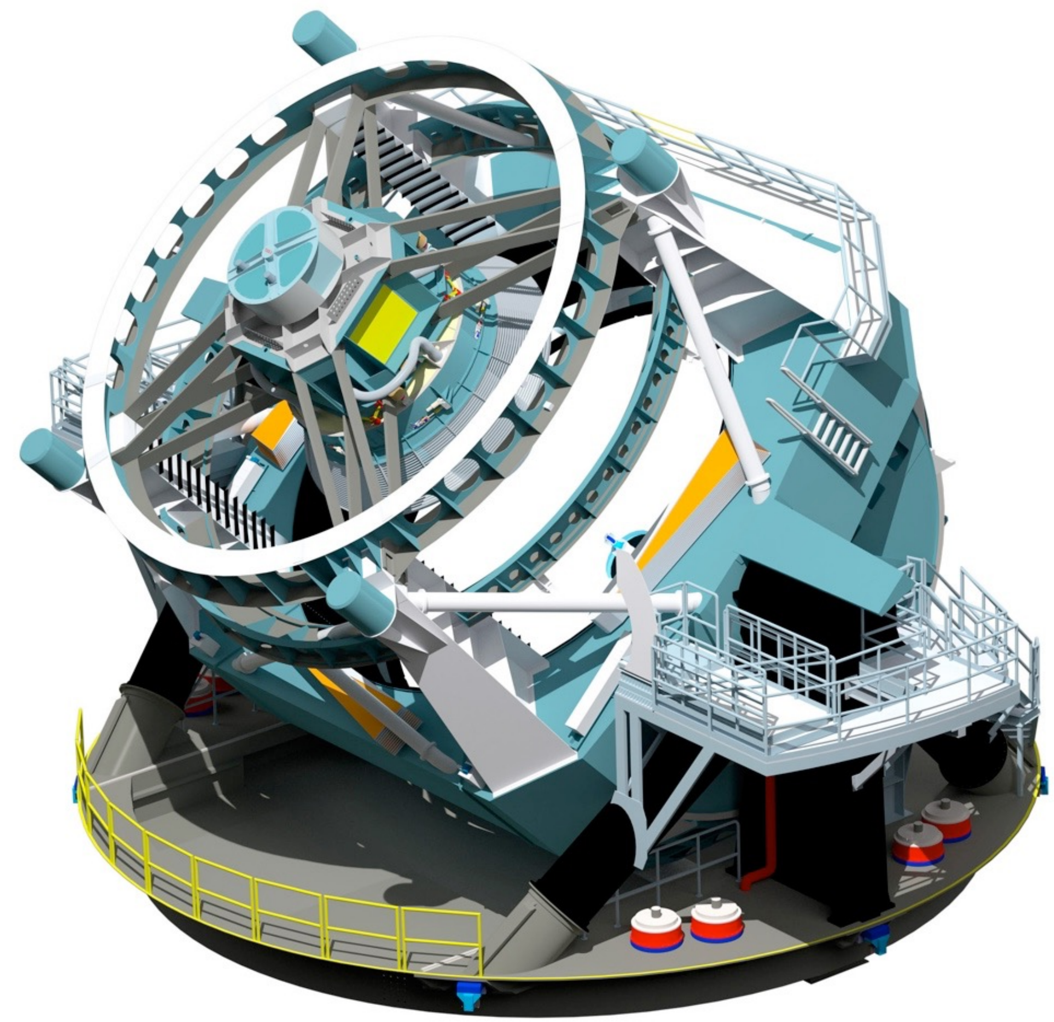
Detection rates for GW170817-like events with ZTF and LSST





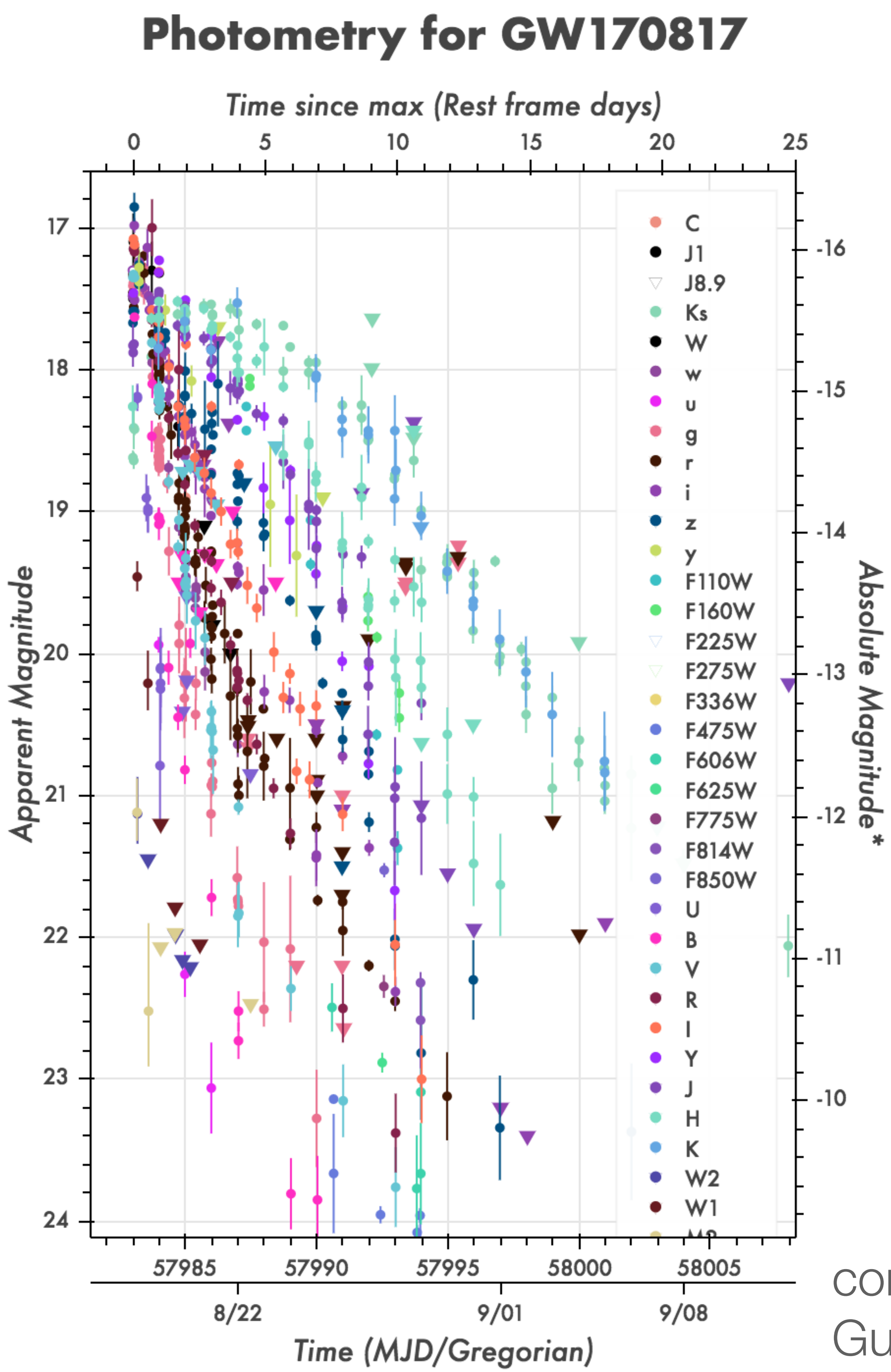
Eric Bellm

University of Washington

ZTF Survey Scientist

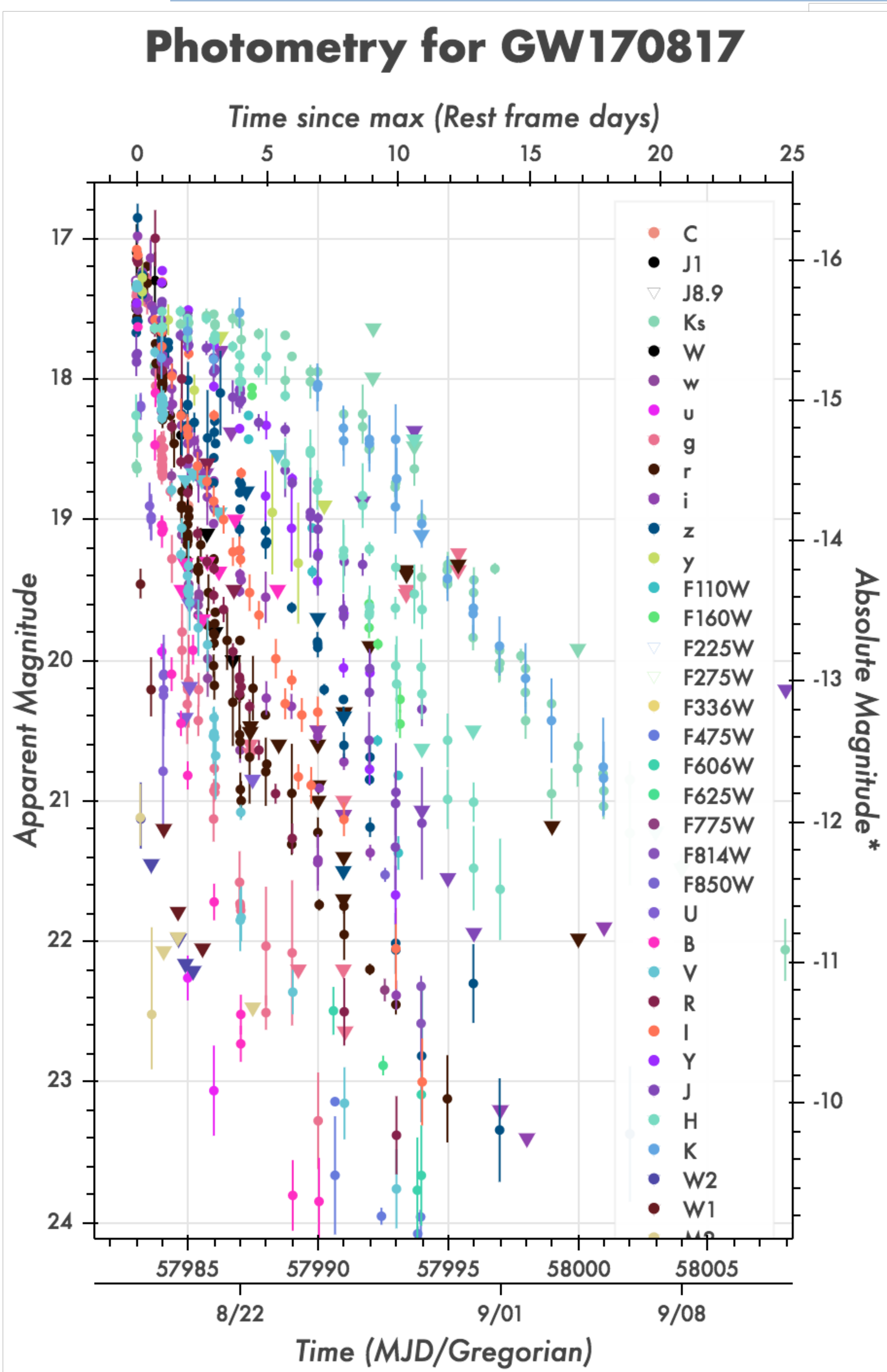
Alert Production Science Lead, LSST Data Management

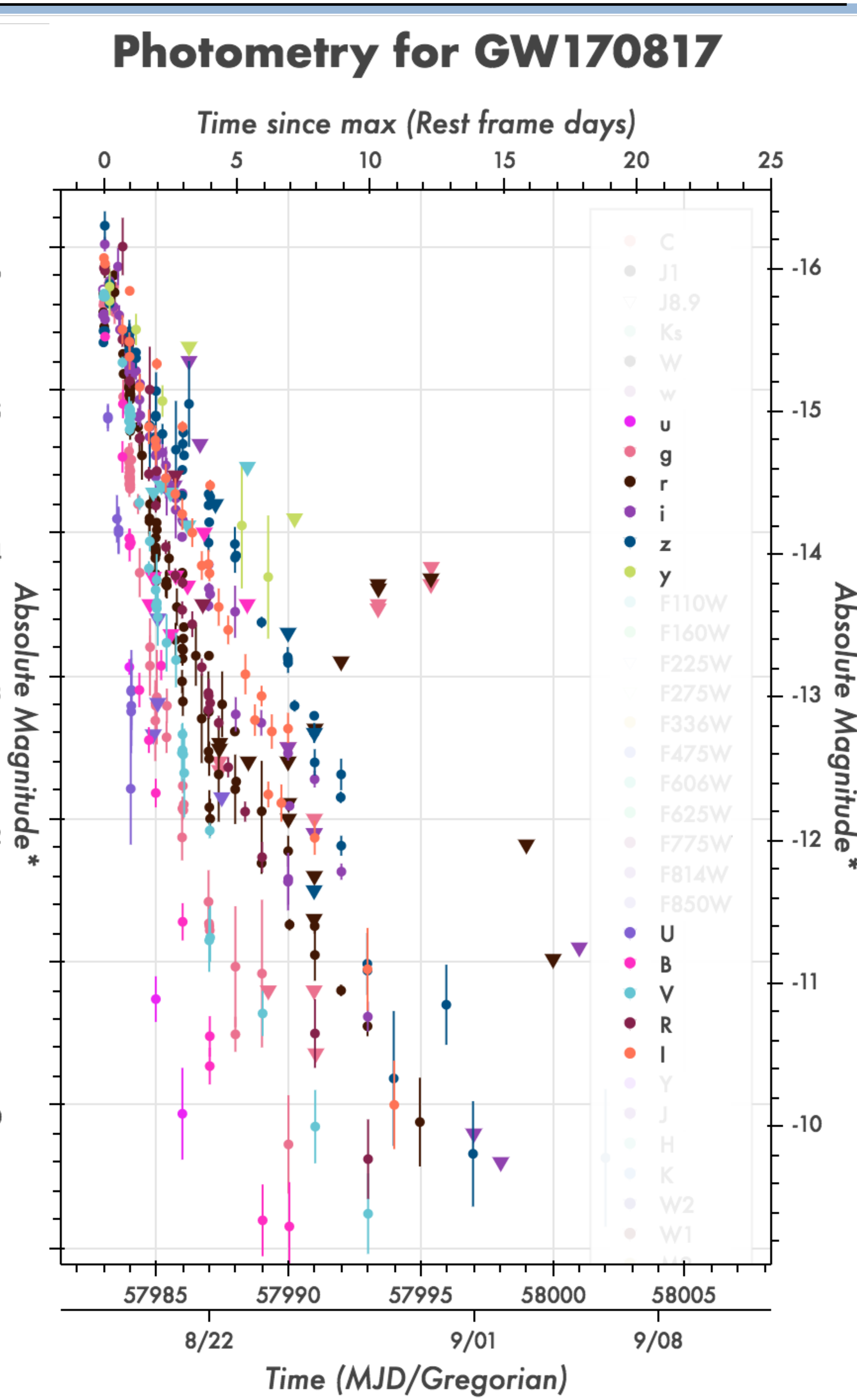
Why haven't we seen GW170817 before?



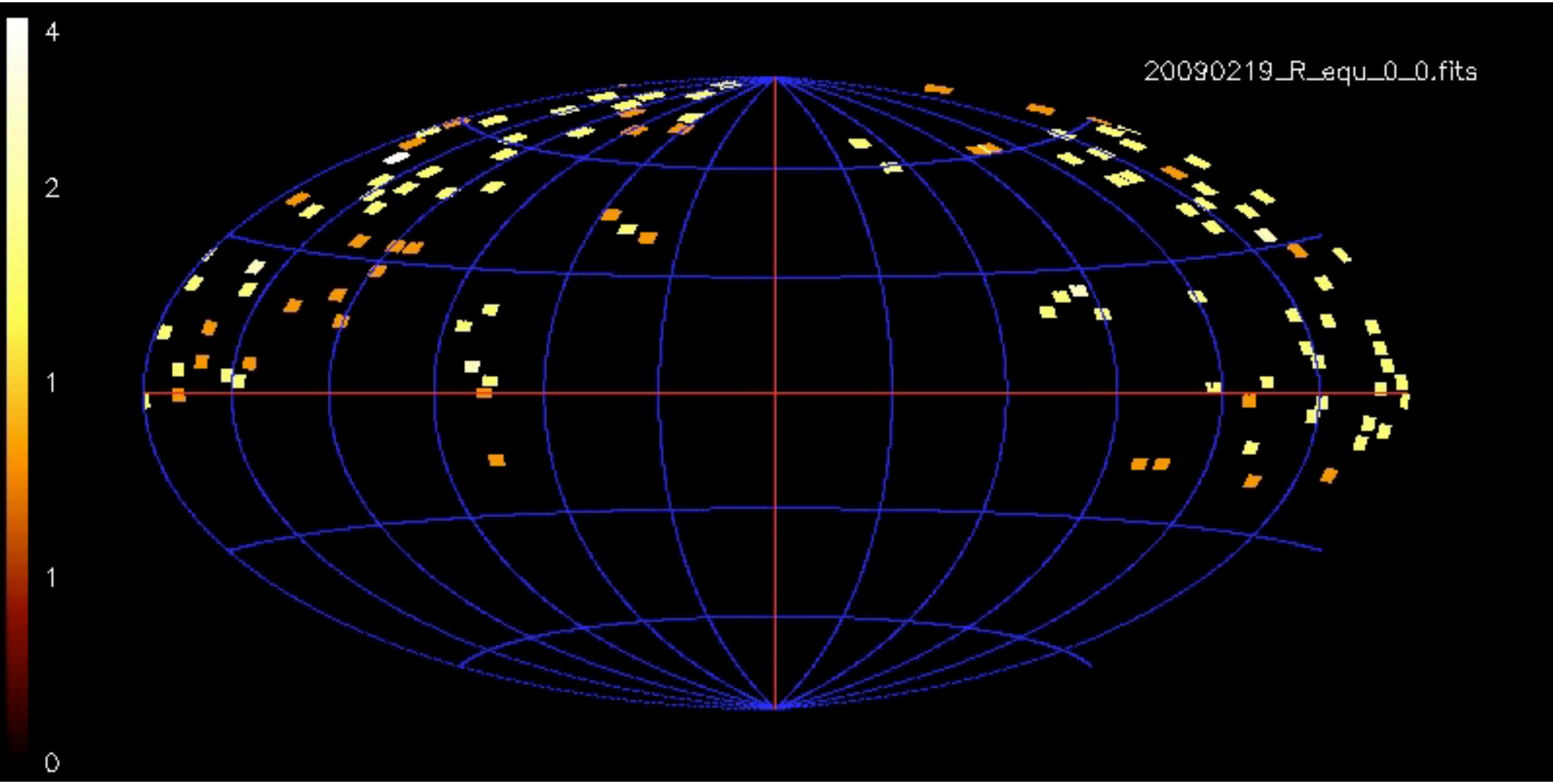
compiled by kilonova.space
Guillochon+ 17

Why haven't we seen GW170817 before?





Transient surveys have been scanning the sky.



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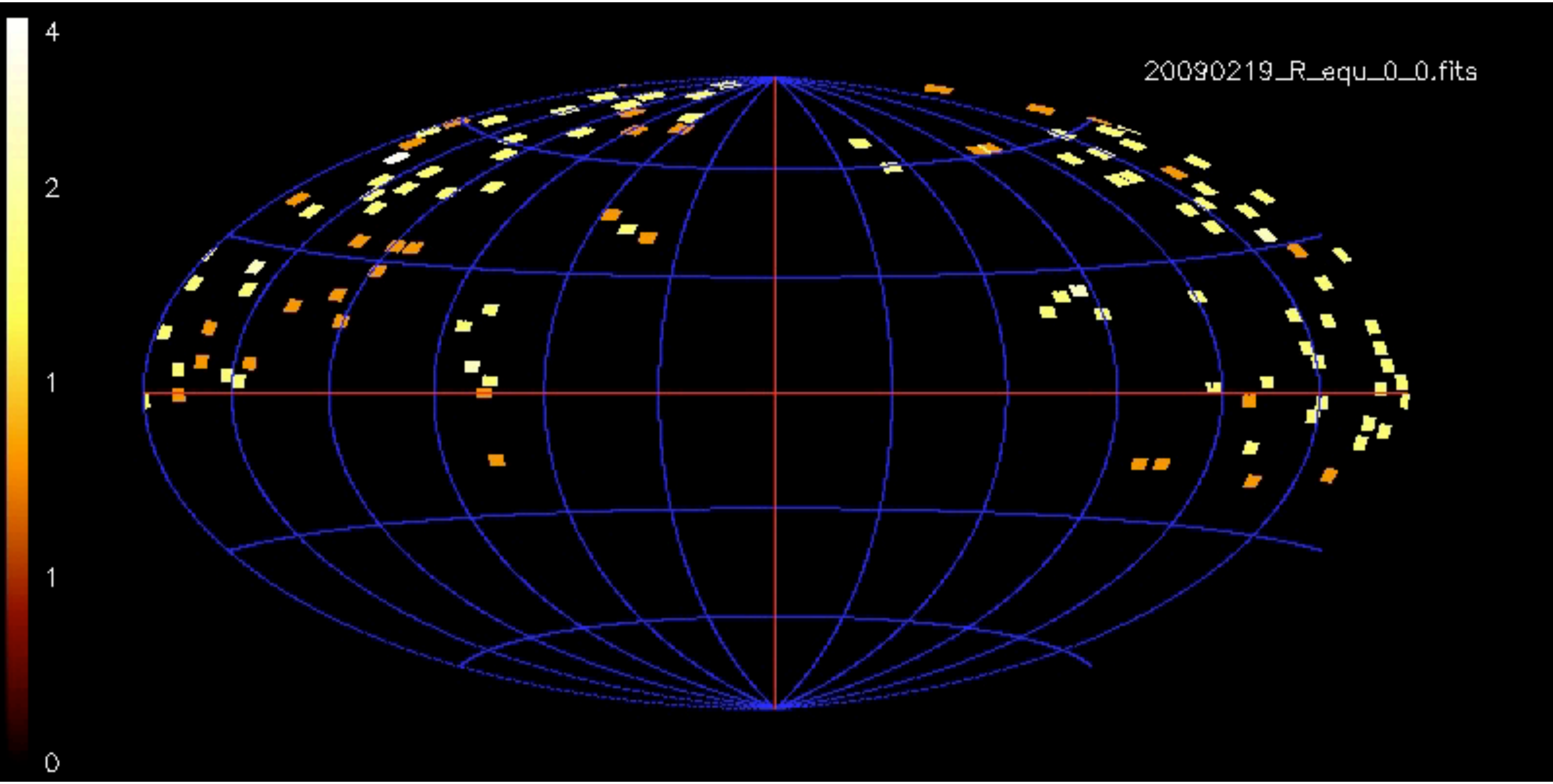


EM-only kilonova detections would still be valuable.

GW detectors not always online

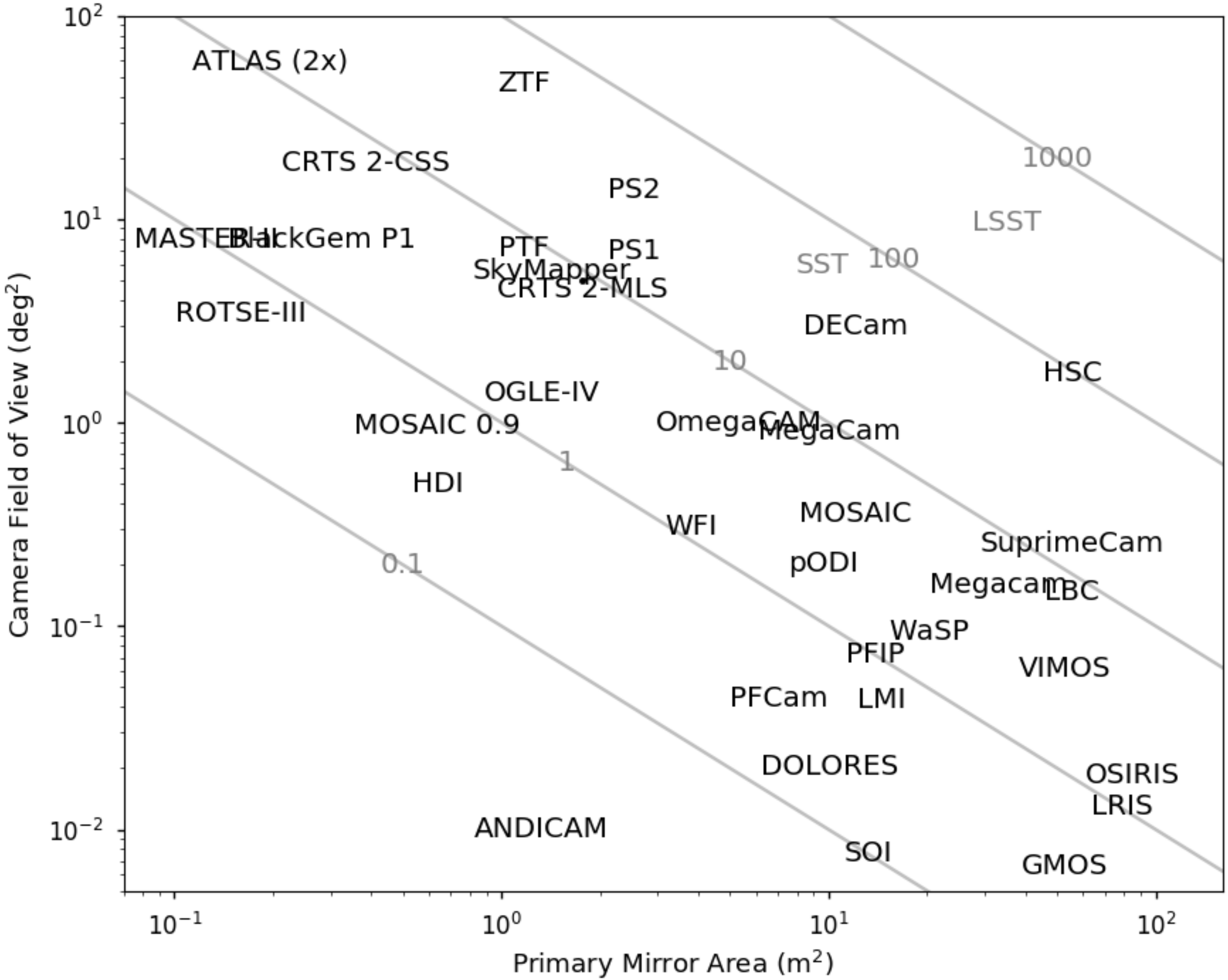
find events below GW trigger thresholds

understand diversity of events

[sometimes] probe beyond GW detector horizon

understand astrophysical contaminants

Optical survey cameras are increasing in capability.



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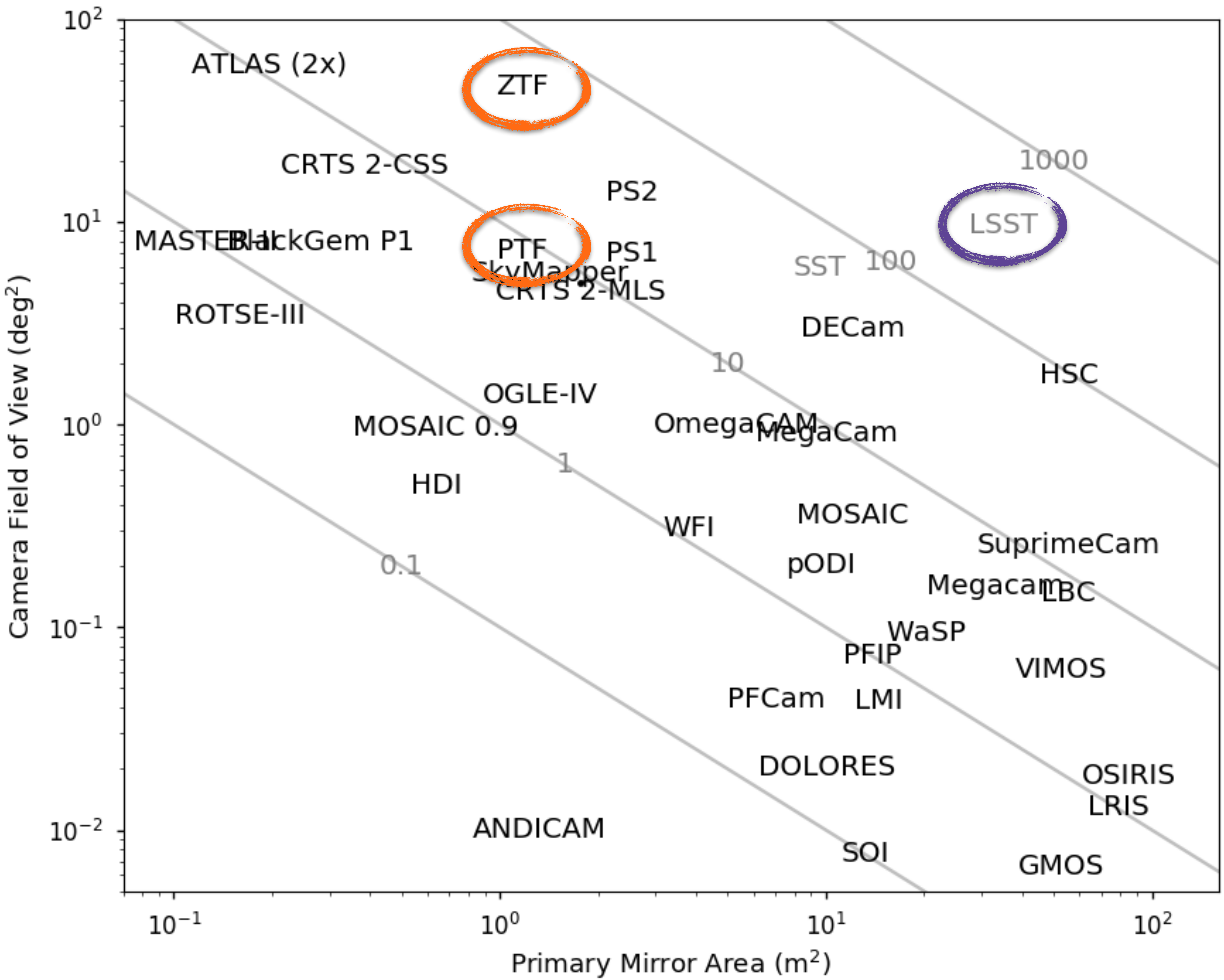
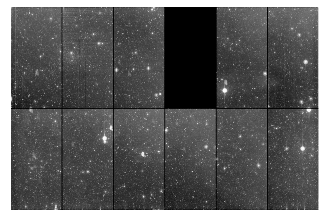
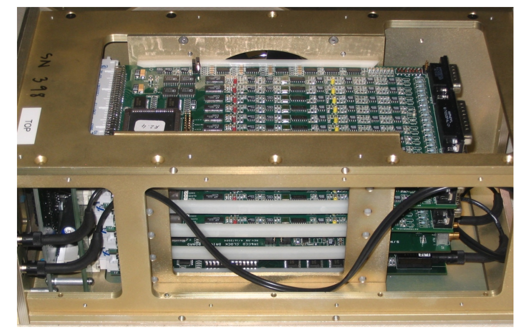


ZTF will survey more than an order of magnitude faster than PTF.

PTF & iPTF



7.25 deg^2
field of view



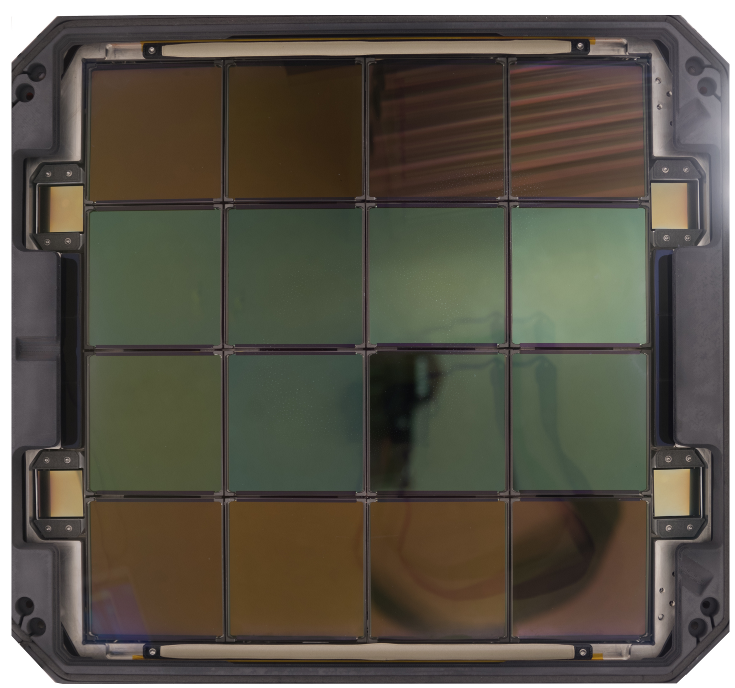
36 sec
readout

250 deg^2/hr

$m_{lim} = 20.7$,
$t_{exp} = 60$ sec

Palomar 48-inch Schmidt

ZTF



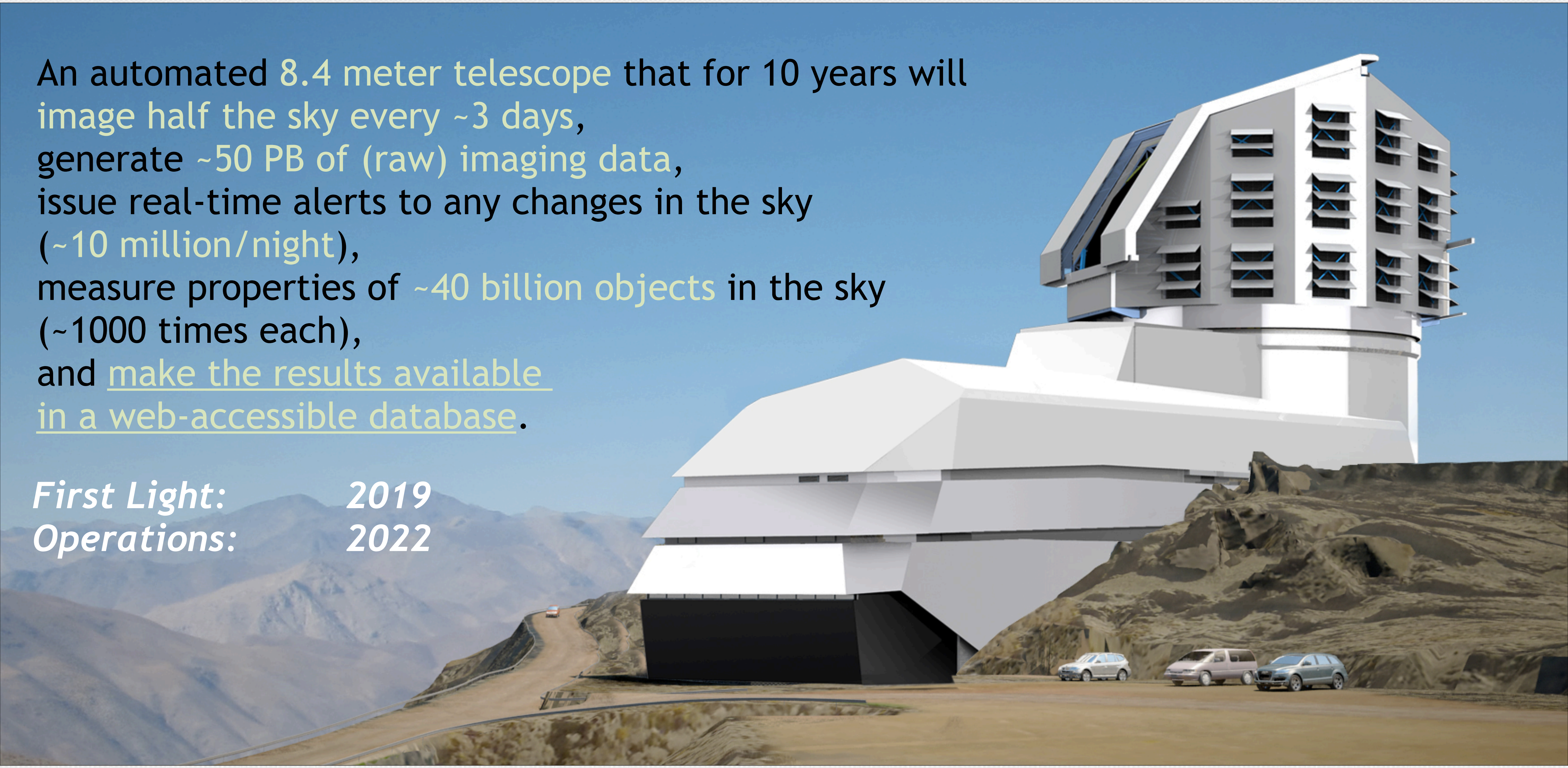
47 deg^2
field of view

10 sec
readout

3750 deg^2/hr

$m_{lim} = 20.4$,
$t_{exp} = 30$ sec

The Large Synoptic Survey Telescope will conduct an unprecedented time-domain survey.



An automated 8.4 meter telescope that for 10 years will
image half the sky every ~3 days,
generate ~50 PB of (raw) imaging data,
issue real-time alerts to any changes in the sky (~10 million/night),
measure properties of ~40 billion objects in the sky (~1000 times each),
and make the results available in a web-accessible database.

First Light: *2019*
Operations: *2022*

Scolnic+ simulated untriggered detection rates of GW170817-like kilonovae.

THE ASTROPHYSICAL JOURNAL LETTERS, 852:L3 (7pp), 2018 January 1 https://doi.org/10.3847/2041-8213/aa9d82

How Many Kilonovae Can Be Found in Past, Present, and Future Survey Data Sets?

D. Scolnic[1], R. Kessler[1], D. Brout[2], P. S. Cowperthwaite[3], M. Soares-Santos[4,5], J. Annis[4], K. Herner[4], H.-Y. Chen[1],

Table 1
Summary Information for Each Survey

Survey	Filters	Depths (5σ mag)	Cadences[a] (Days)	Area[b] (Deg^2)	Duration[c] (Years)	Citation[d]
SDSS	*ugriz*	21.8, 22.9, 22.5, 22.	2.2, 2.2, 2.2, 2.2	300	2	Frieman et al. (2008)
SNLS	*griz*	26.1, 25.4, 24.8, 23.8	8.8, 6.3, 5.3, 8.5	4	5	Astier et al. (2006)
PS1	*griz*	23.4, 23.2, 23.4, 22.8	8.8, 8.7, 8.2, 6.3	70	4	Scolnic et al. (2014)
DES	*griz*	24.0, 23.9, 23.7, 23.5	6.8, 6.4, 6.3, 6.5	27	5	Kessler et al. (2015)
ASAS-SN	*V*	17.5	2	15000	5	Shappee et al. (2014)
SMT	*gr*	20.6, 20.4	17.4, 14.9	11000	5	Scalzo et al. (2017)
ATLAS	*co*	20.3, 20.3	1.3, 1.3	11000	5	Tonry (2011)
ZTF	*gr*	20.5, 20.5	3.0, 3.0	15000	5	Bellm (2014)
LSST DDF	*ugrizy*	24.8, 25.4, 25.6, 25.1, 24.7, 23.3	5, 6, 7, 7, 7, 7	40	10	LSST Science Collaboration et al. (2009)
LSST WFD	*ugrizy*	23.2, 24.8, 24.5, 23.8, 22.5, 21.7	30, 35, 18, 19, 21, 18	18000	10	LSST Science Collaboration et al. (2009)
WFIRST	*RZYJHF*	26.2, 25.7, 25.6, 25.5, 25.4, 24.9	5, 5, 5, 5, 5	45	2	Hounsell et al. (2017)

Current and future surveys should find kilonovae.

Table 2
Expected Number of KNe Found in Each Sample

Survey	# KNe[a]	Survey Years	KN Redshift Range	#/year
SDSS	0.13	2	0.02–0.05	
SNLS	0.11	4	0.05–0.20	
PS1	0.22	4	0.03–0.11	
DES	0.26	5	0.05–0.20	
ASAS-SN	<0.001	3	…	
SMT	0.001	5	0.01–0.01	
ATLAS	8.3	5	0.01–0.03	1.7
ZTF	10.6	5	0.01–0.04	2.1
LSST WFD	69	10	0.02–0.25	6.9
LSST DDF	5.5	10	0.05–0.25	0.5
WFIRST	16.0	2	0.1–0.8	8.0

Note.
[a] Total for the entire duration of the survey.

Scolnic+ 17

The detection criteria may be optimistic.

We simulate KN detections in two steps. The first step is the trigger simulation, requiring two detections that are separated by at least 30 minutes to reject asteroids. A detection is characterized by the efficiency versus signal-to-noise ratio (S/N), and the efficiency is typically 50% at S/N = 5. The second step is the analysis, which uses the following selection requirements designed to reject supernova backgrounds.

1. At least two filter bands have at least one observation with S/N > 5. This requirement is largely redundant with the trigger.
2. The time period when transient measured with S/N > 5 is less than 25 days (30 days for *WFIRST*).
3. There is at least one observation within 20 days prior to the first S/N > 5 observation.
4. There is at least one observation within 20 days after the last S/N > 5 observation.

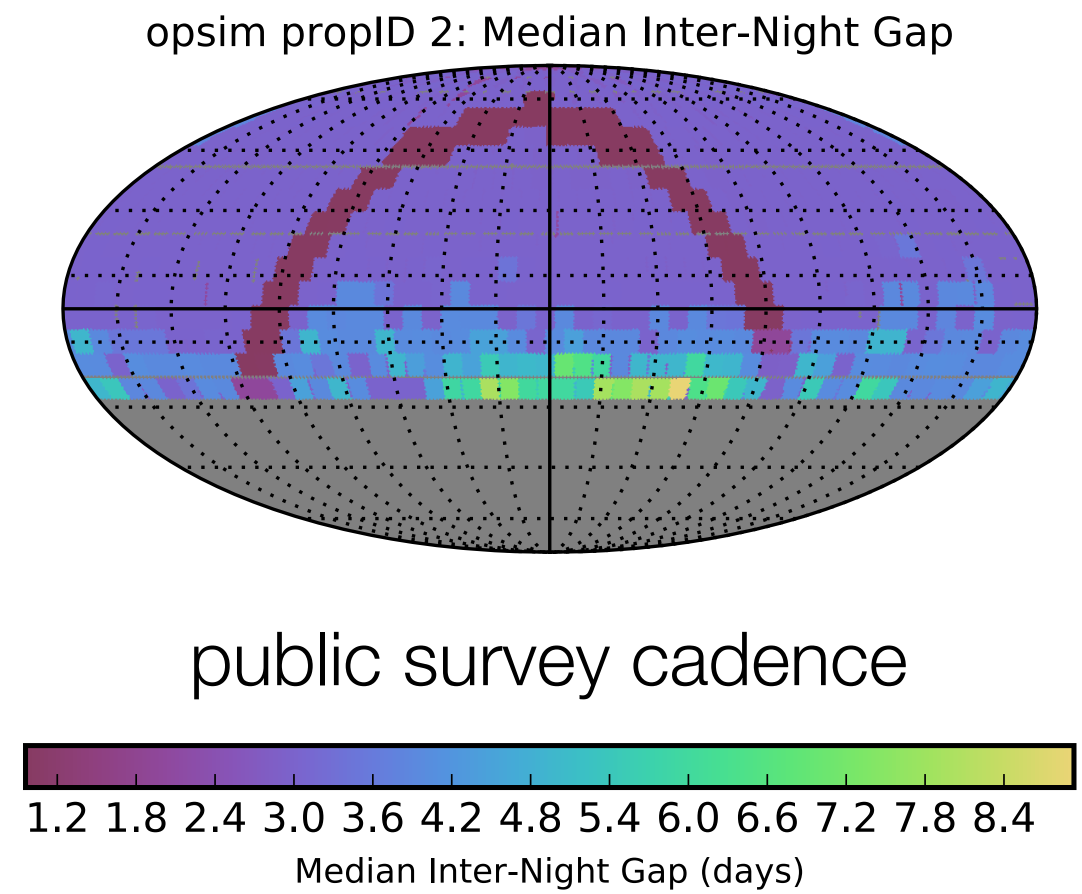
The second requirement explicitly rejects long-lived light curves. The last two requirements reject events that peak before or after the survey time window.

ZTF will conduct several simultaneous surveys.

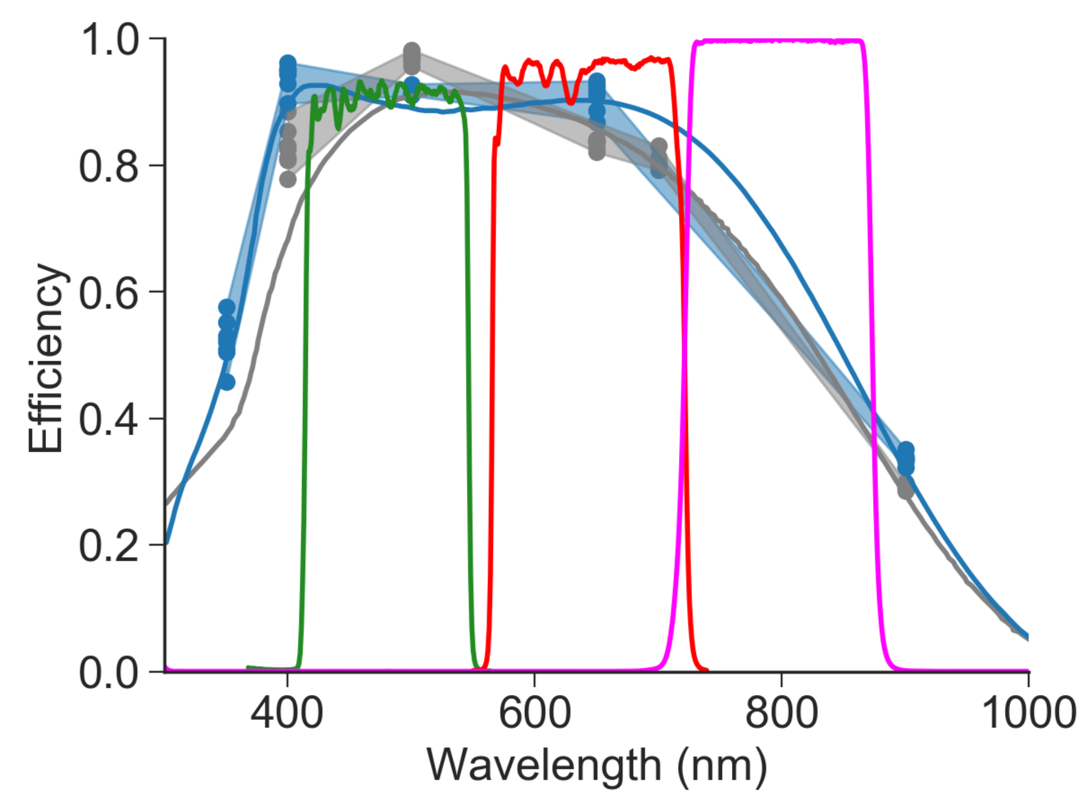
Public (40%)
all-sky 3-day cadence (18k deg^2+)
nightly Galactic Plane
(both surveys take one g and one r exposure per field when observed)

Collaboration (40%)
high cadence (3400 deg^2)
5-day cadence i-band (11700 deg^2)
other Galactic Plane & asteroid surveys

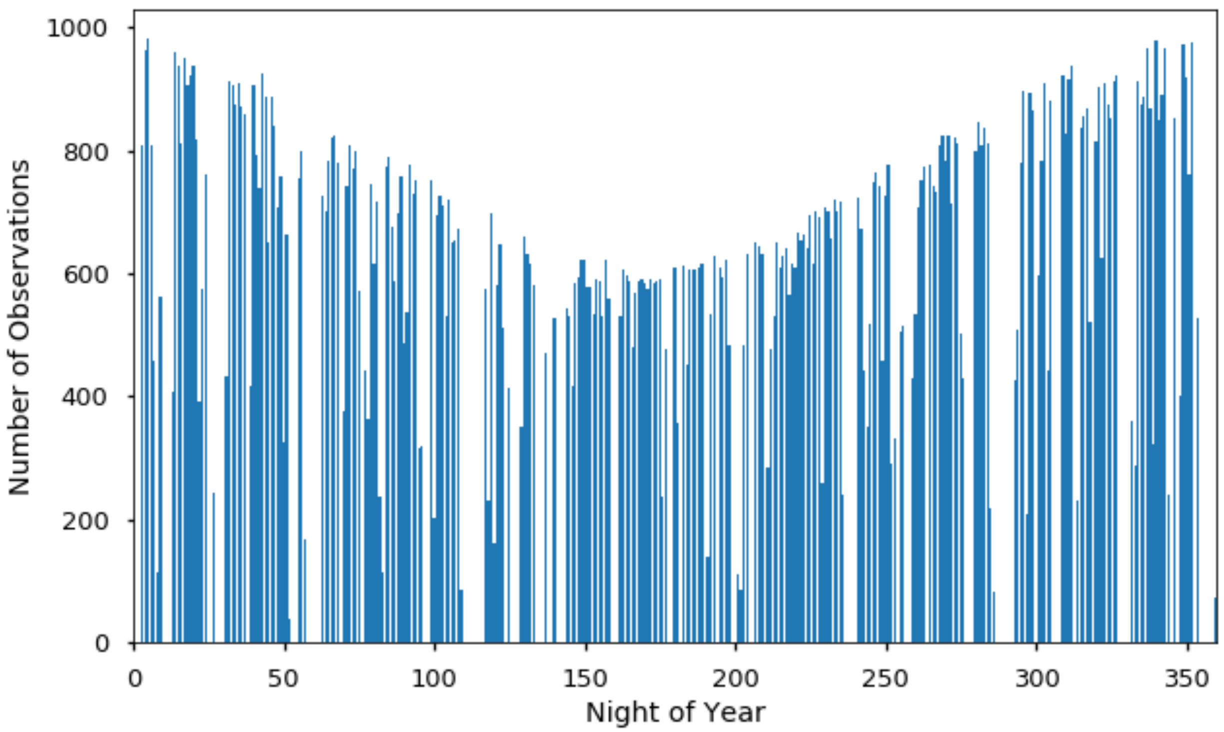
Caltech (20%)
rotating TAC-allocated programs

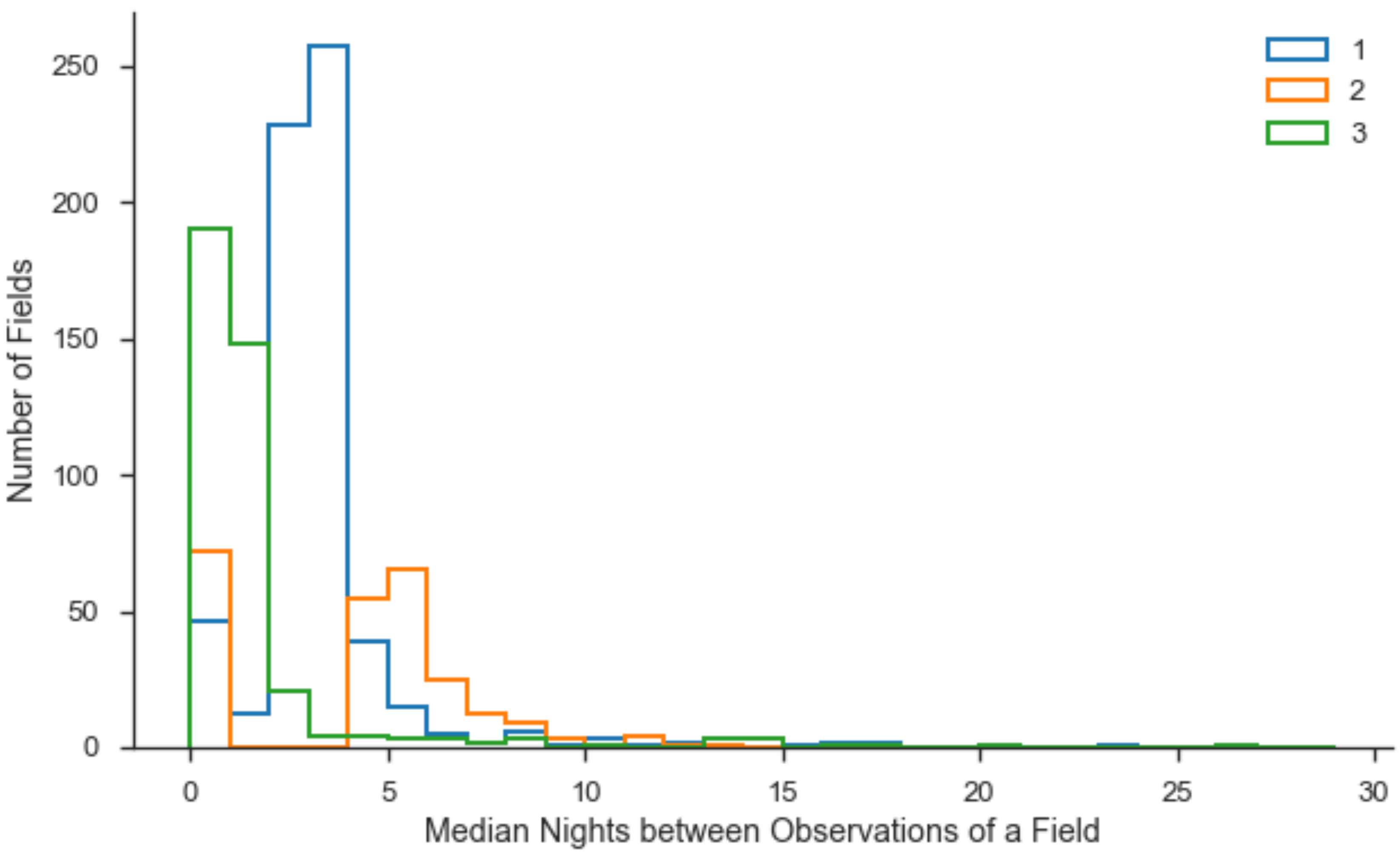


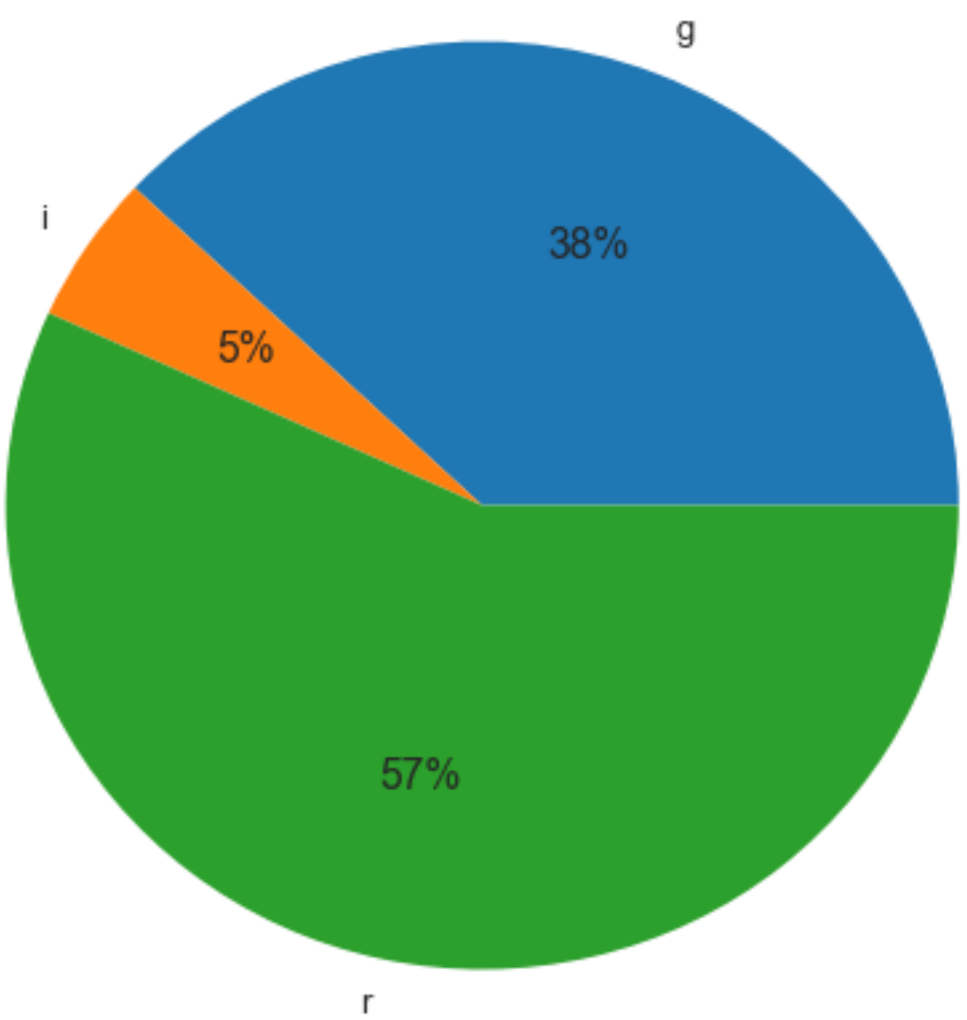
public survey cadence



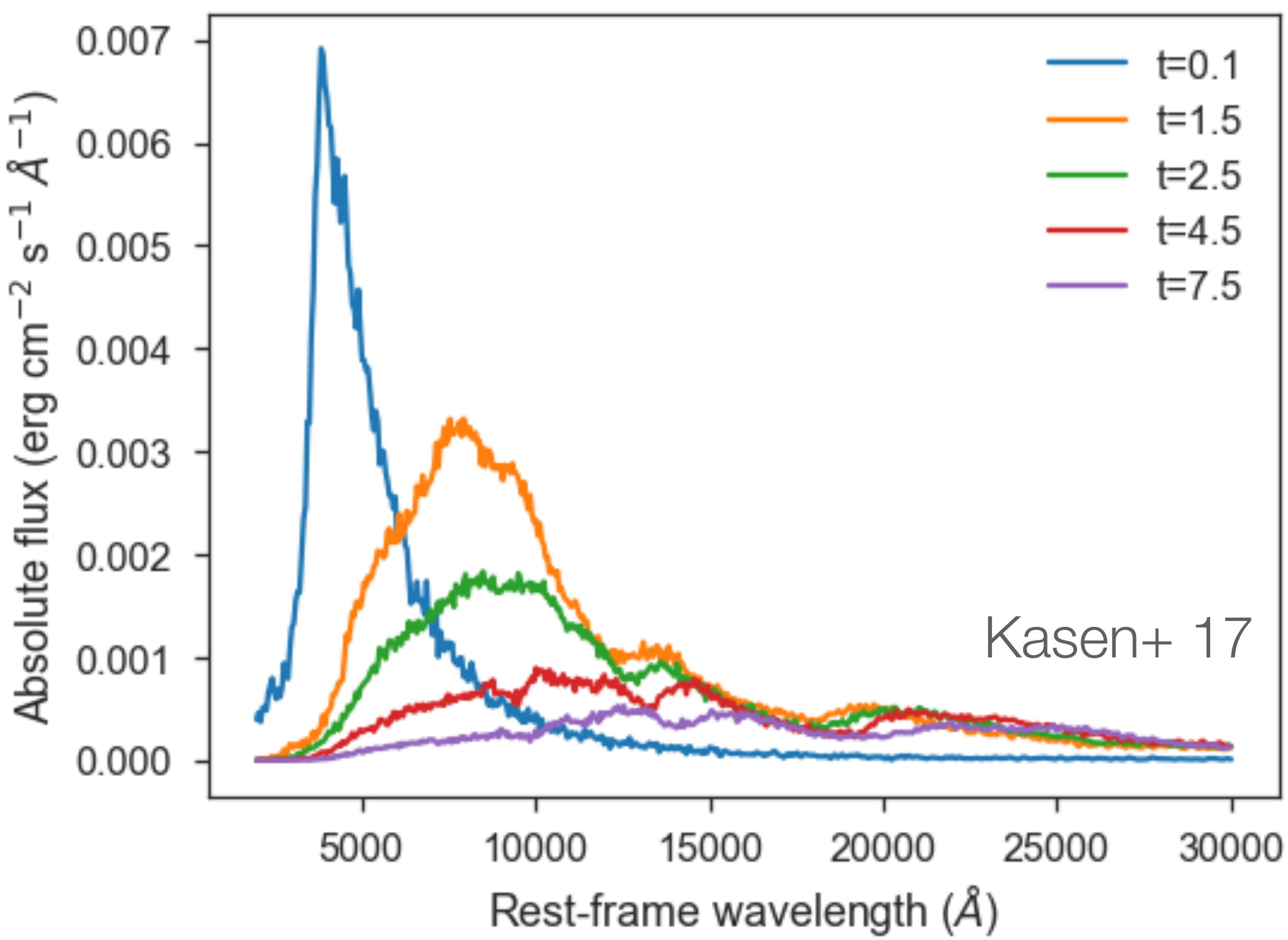
Simulations with the production scheduler provide useful cadence estimates.

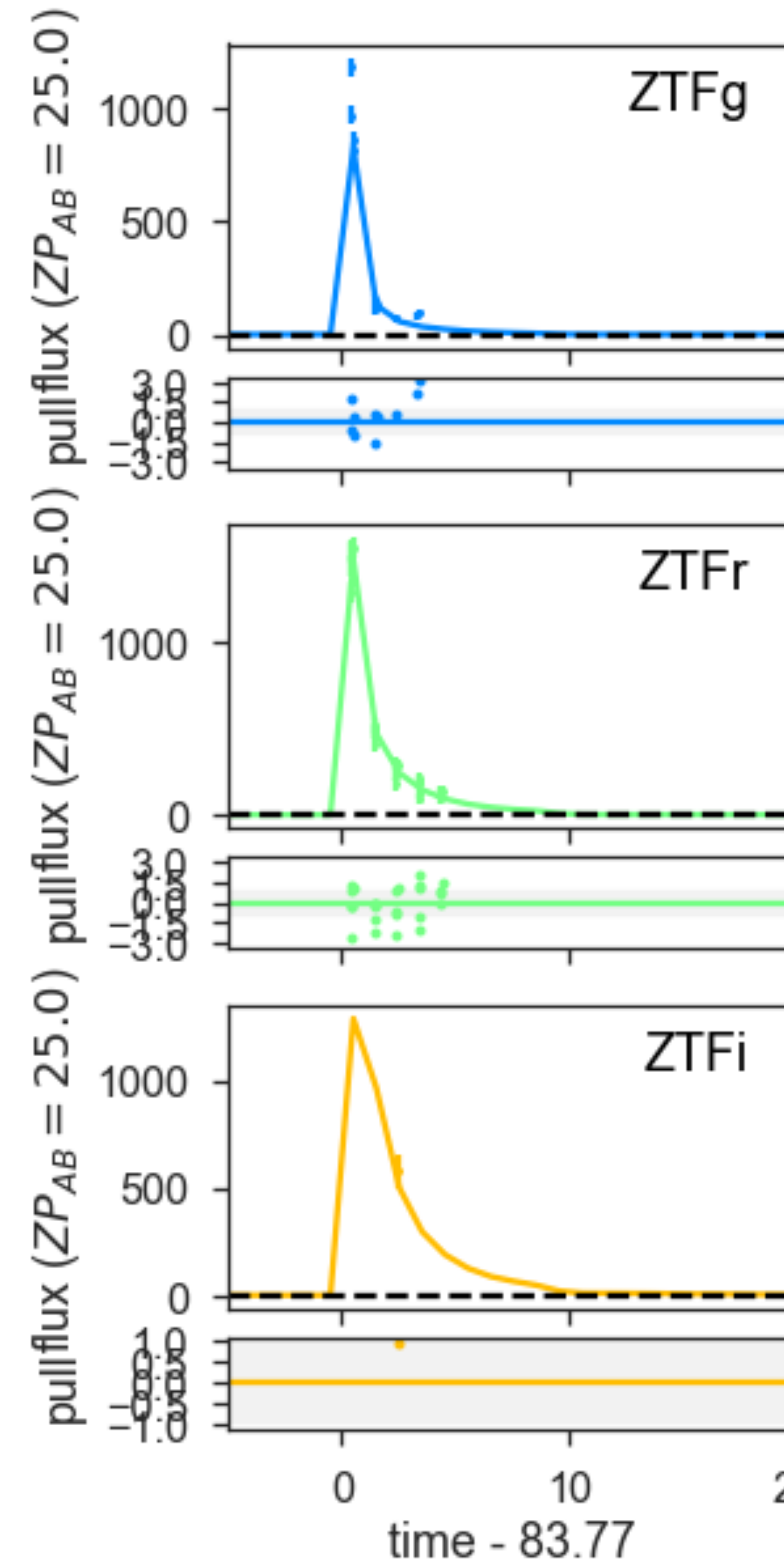






We used realistic ZTF observing simulations to generate kilonova lightcurves.





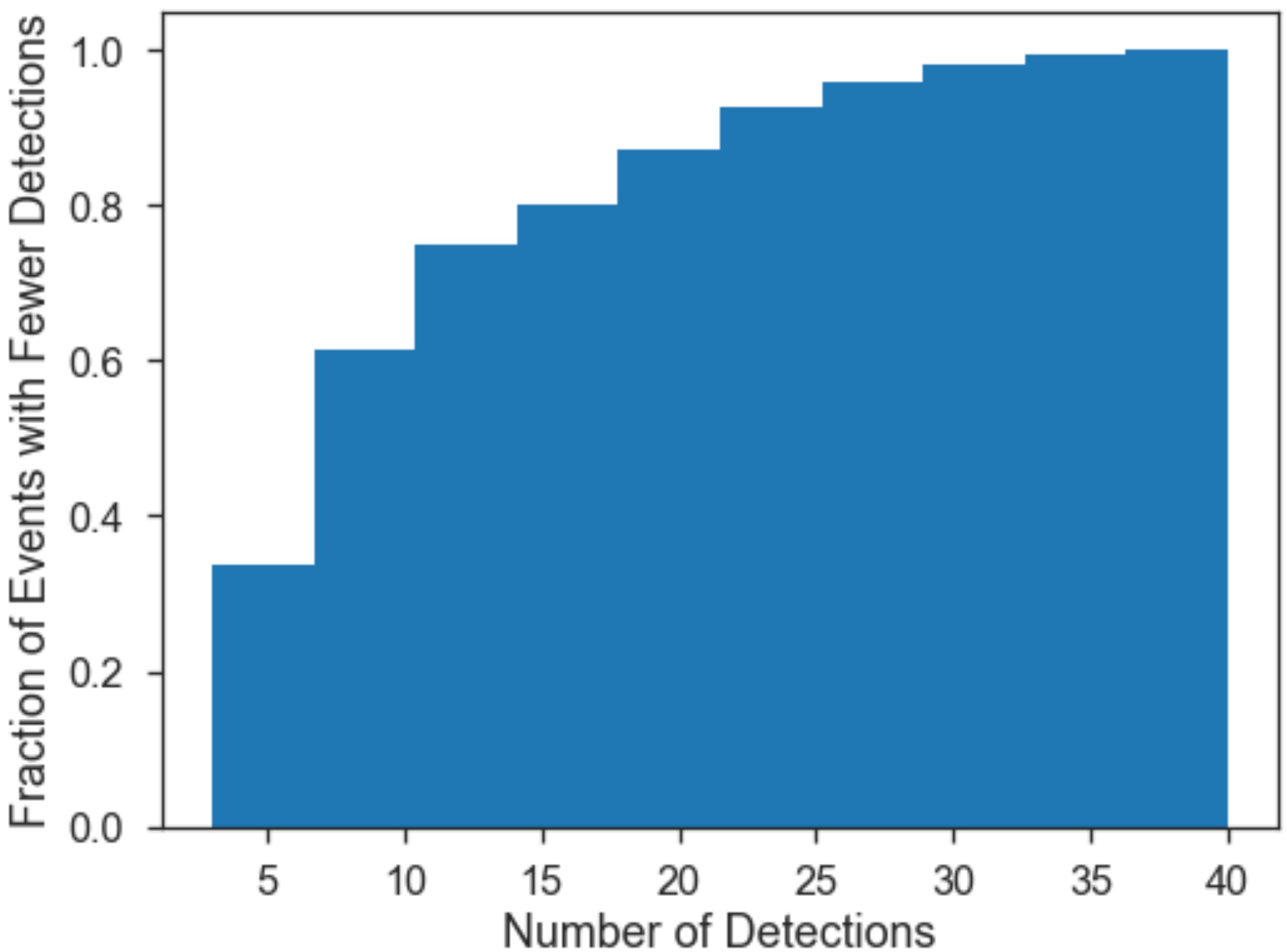
Rate = 320 Gpc^{-3} yr^{-1}
(Kasliwal+ 2017)

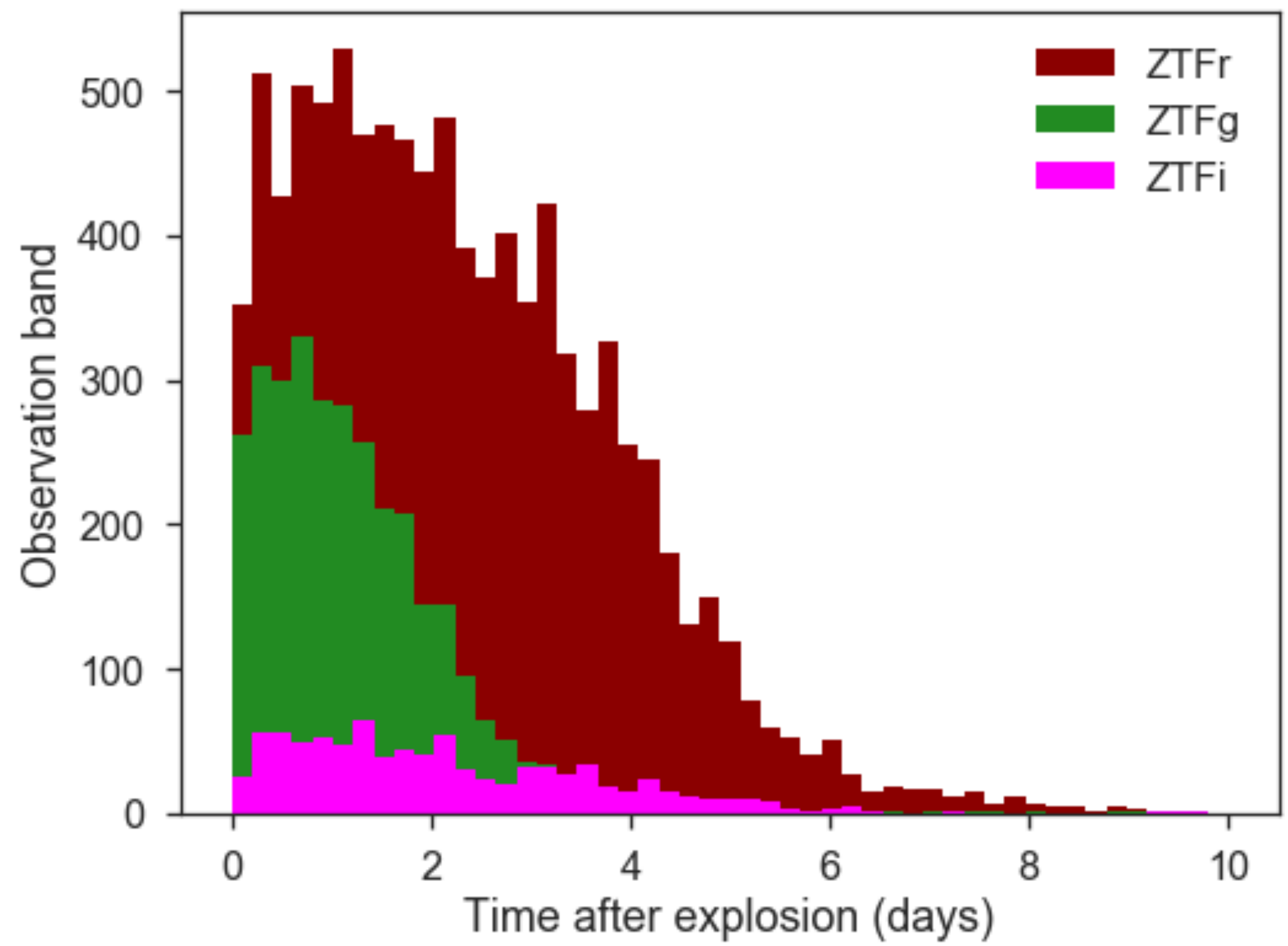
sncosmo
A Python Library for Supernova Cosmology

ZTF could discover about 1 kilonova per year.

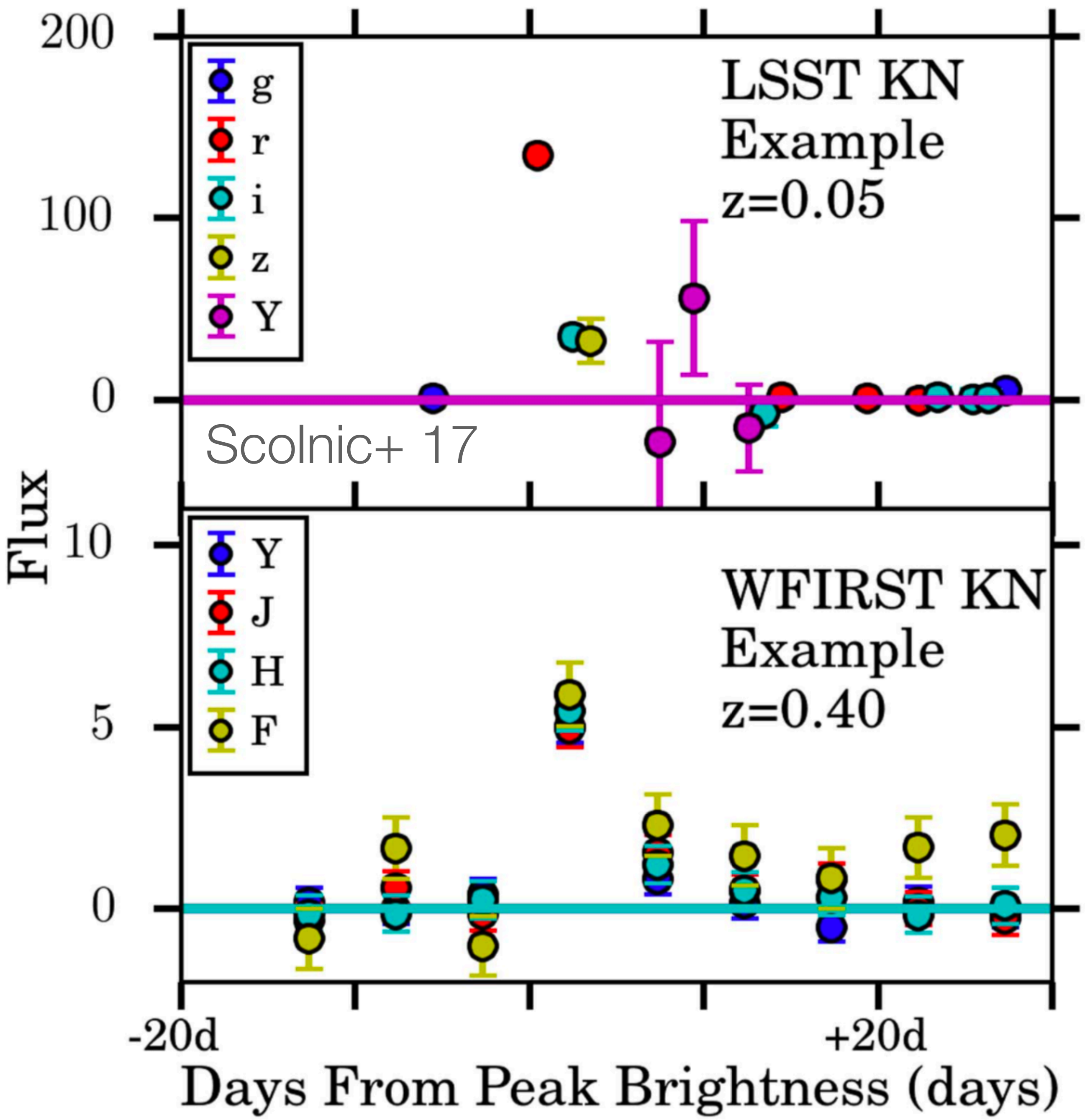
Requiring at least 1 detections of SNR > 5:
    3.1 events/year

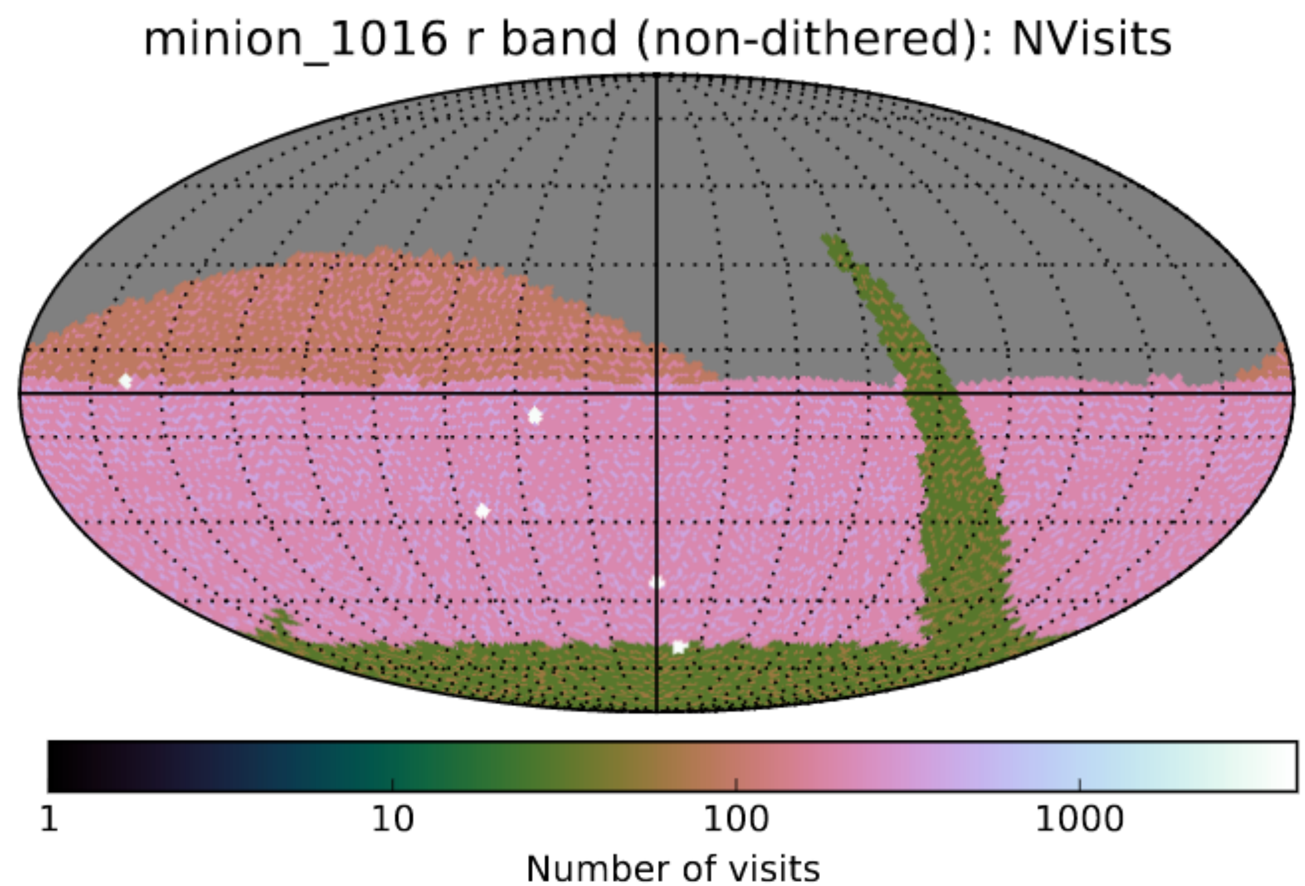
Requiring at least 3 detections of SNR > 5:
    1.3 events/year

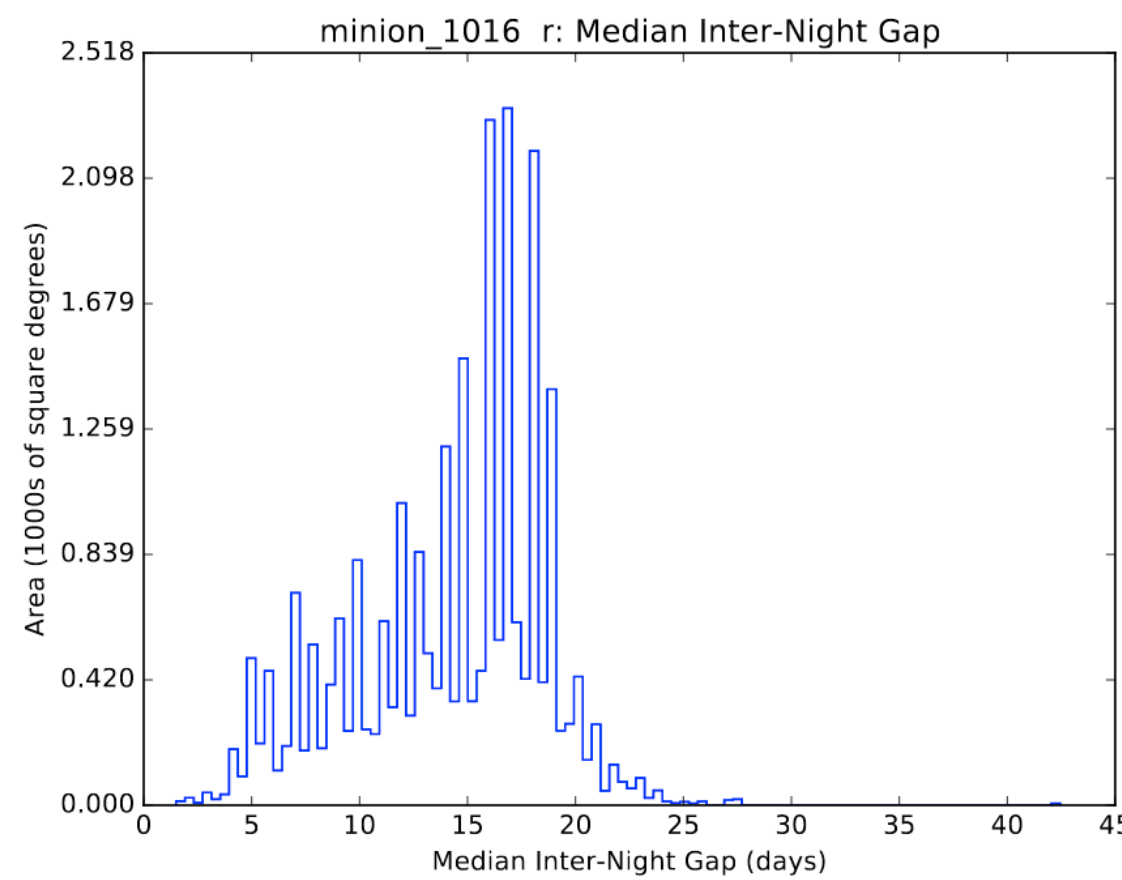




LSST will *detect* many kilonovae, but cadence may hinder *discovery.*







Upcoming sky surveys should detect a few-tens of kilonovae without a GW trigger

The observation cadence will strongly influence whether we can recognize and follow these up in real time.