Multimessenger astrophysics in the gravitational-wave era

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August 30, 2023

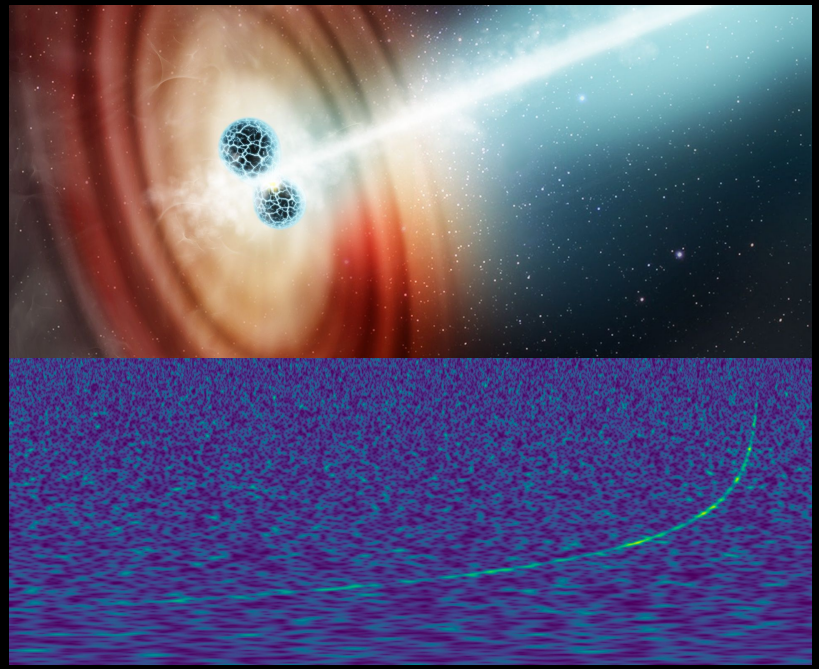
TAUP 2023

TAUP VIENNA 2023

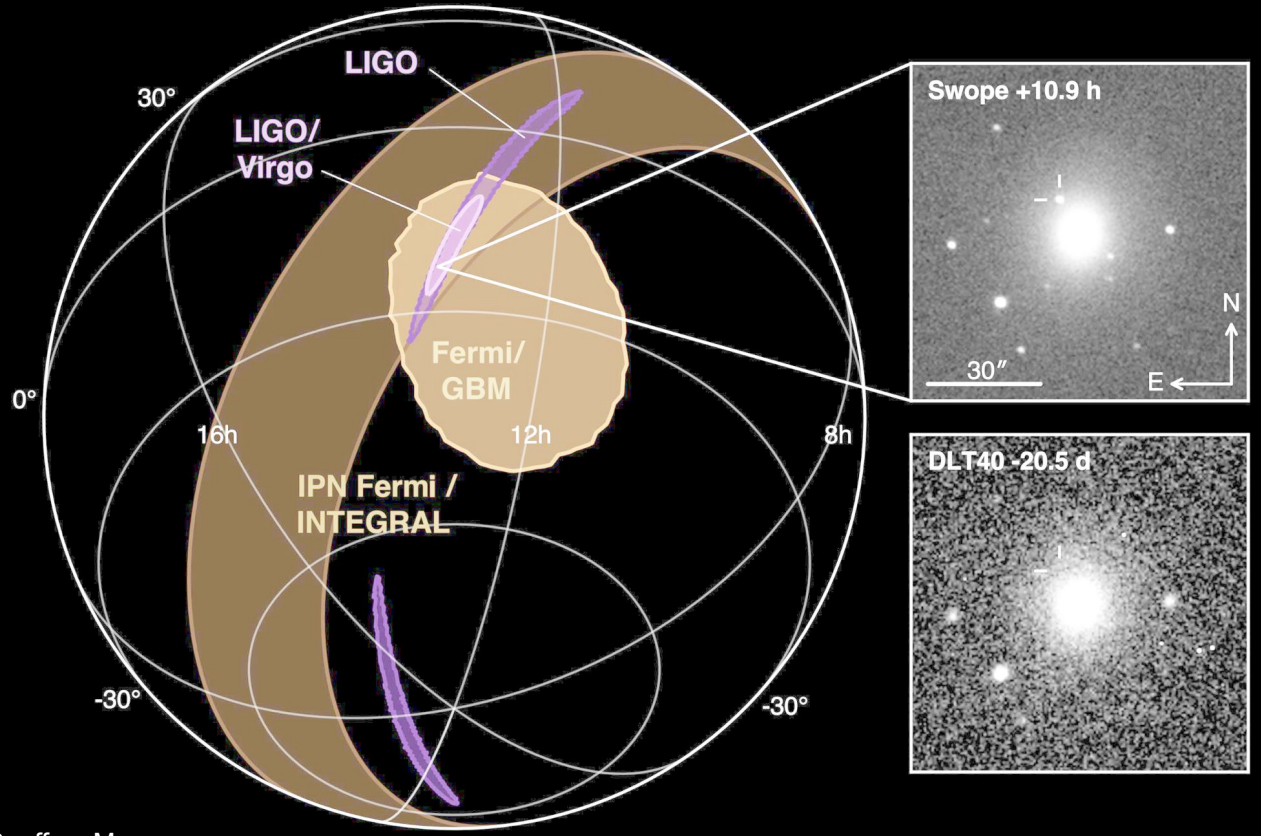
Multimessenger sources

I'll focus on **stellar mass** GW sources, and **EM** emission

- Binary neutron stars (GW170817)
- Neutron star – black hole
- Binary black holes?
- Supernovae, magnetars/GRBs/FRBs?
- Something else?



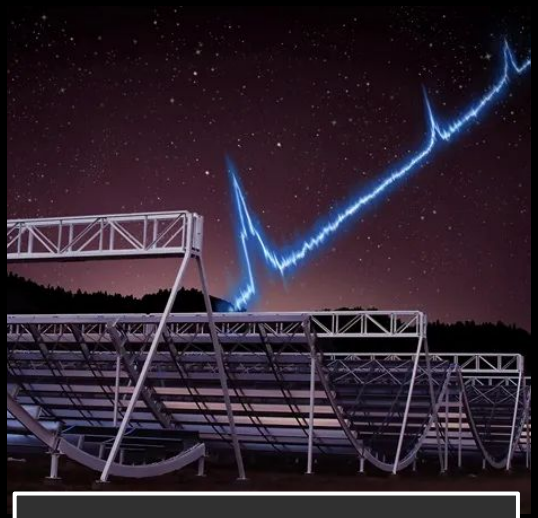
GW170817



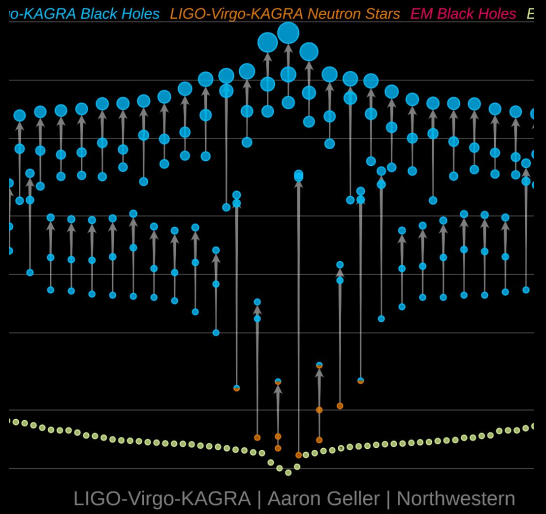
- Cosmology ✅
- EoS ✅
- Nucleosynthesis ✅
- GR tests ✅
- Jet physics ✅
- NS astrophysics ✅

O3 GW multimessenger results

First NSBHs



Upper limits on GW from fast radio bursts and GRBs



Rates and populations

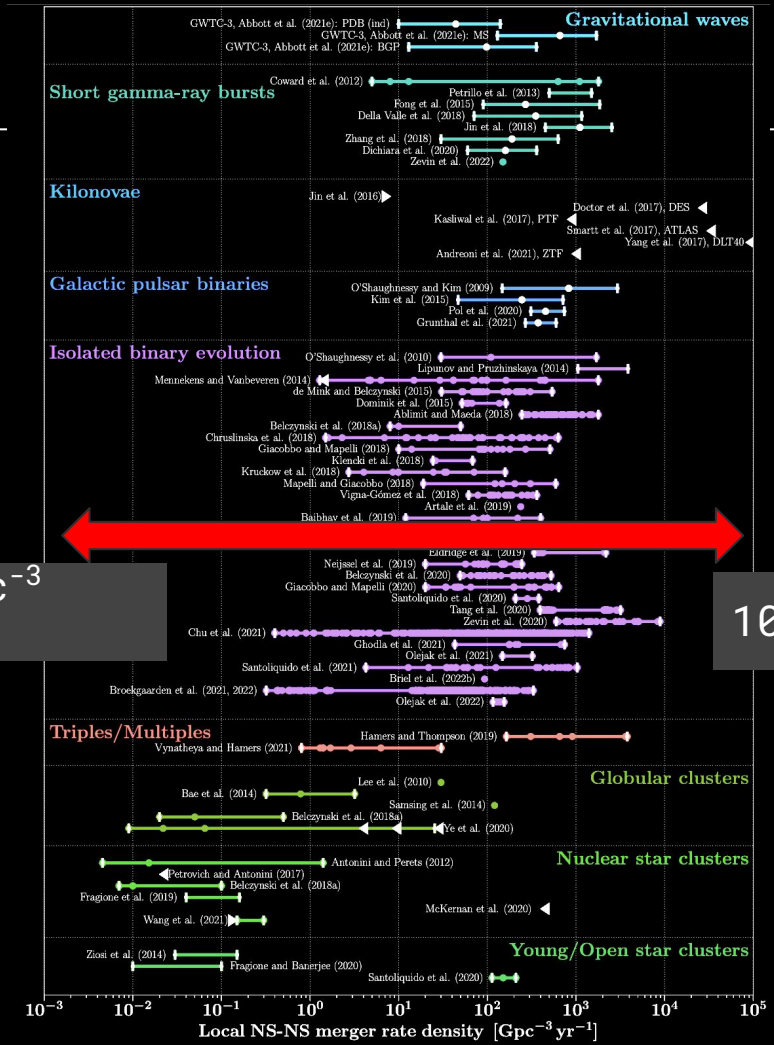
How often?

BNS merger rates span 8 orders of magnitude!

Very unconstrained, keep observing

10^{-3} Gpc^{-3} yr^{-1}

10^{5} Gpc^{-3} yr^{-1}



Mandel & Broekgaarden 2021

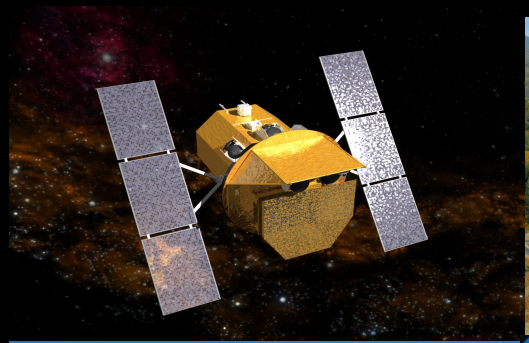
O4 so far

Event ID	Possible Source (Probability)	Significant	UTC	GCN	Location	FAR	Comments
S230825k	BBH (>99%)	Yes	Aug. 25, 2023 04:13:34 UTC	GCN Circular Query Notices | VOE		1 per 13.272 years	
S230824r	BBH (>99%)	Yes	Aug. 24, 2023 03:30:47 UTC	GCN Circular Query Notices | VOE		1 per 1932.8 years	
S230822bm	BBH (98%), Terrestrial (2%)	Yes	Aug. 22, 2023 23:03:37 UTC	GCN Circular Query Notices | VOE		1 per 1.2262 years	
S230820bq	BBH (96%), Terrestrial (4%)	Yes	Aug. 20, 2023 21:25:15 UTC	GCN Circular Query Notices | VOE		1.3351 per year	

- 35 events, 2 NSBH, 0 BNS
- No EM counterparts (yet)
- LIGOs only, Virgo joining soon for better localizations, sensitivity

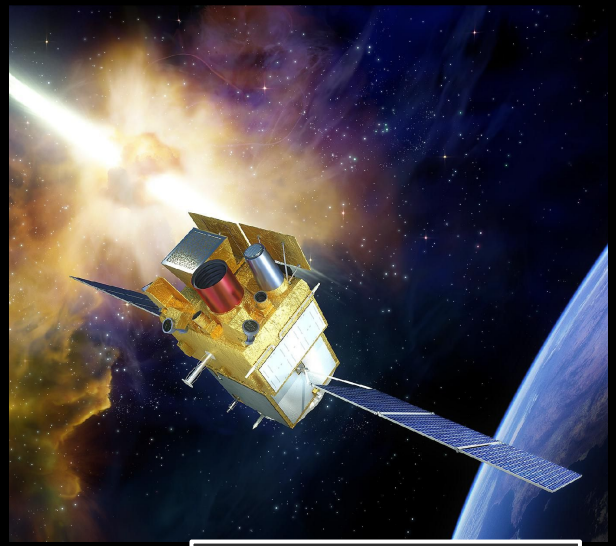
Current multimessenger searches

- Swift/BAT early warning
- **GRB/X-ray:** Fermi, Astrosat, MAXI/GSC, INTEGRAL, AGILE
- **Ground-based surveys:** ZTF, GRANDMA, Gecko
- **Neutrino**: IceCube

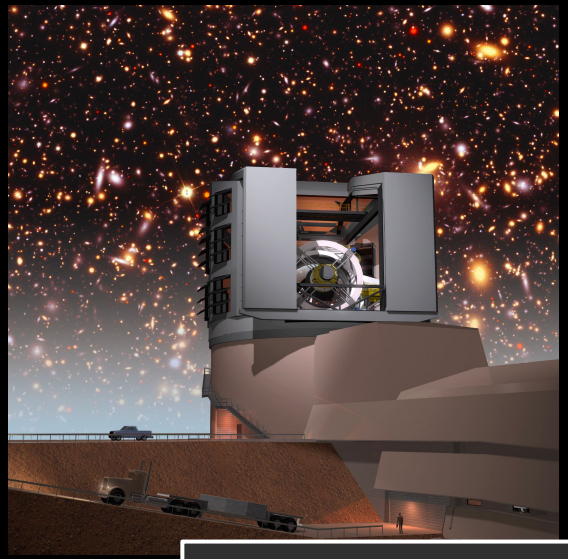


NASA, IPAC/Caltech, IceCube

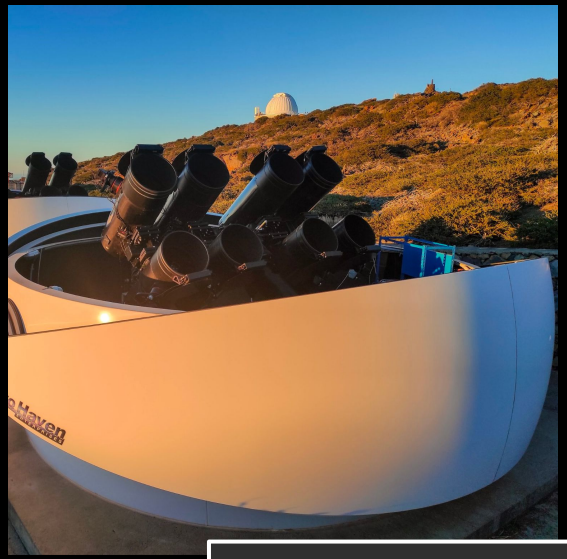
New and upcoming EM facilities



SVOM, 2024



Vera Rubin, 2024

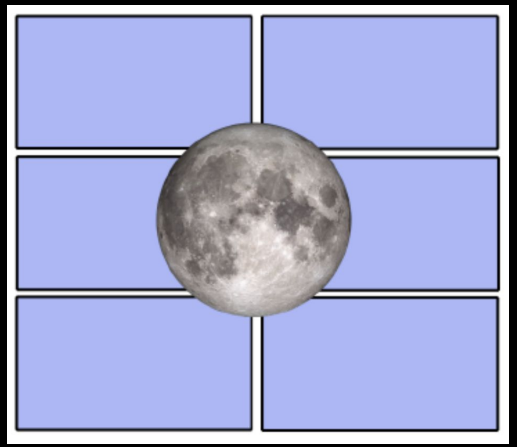


GOTO, 2022-2023

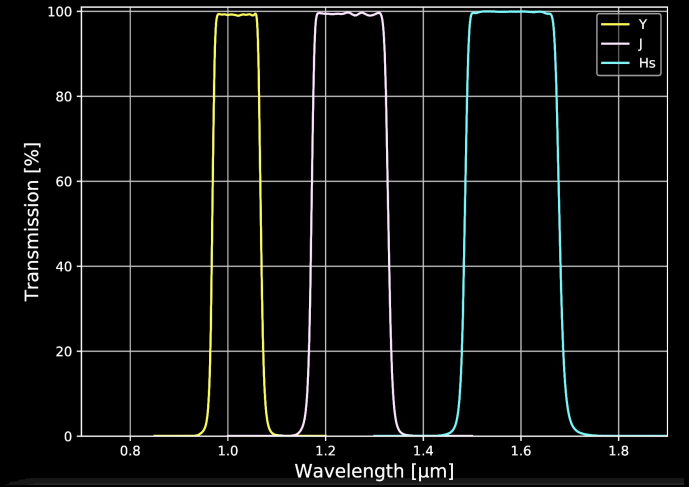
WINTER

Wide-field Infrared Transient ExploreR, on-sky and in commissioning

1m telescope at Palomar



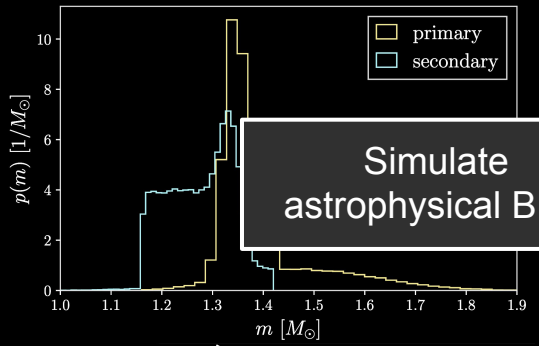
1 sq. deg FOV



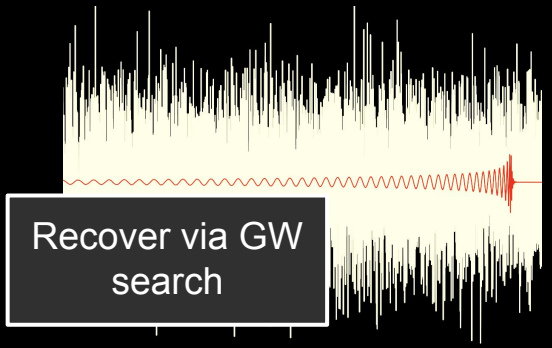
Y, J, short H band

Other new O/IR surveys: BlackGEM, DREAMS, PRIME, etc.

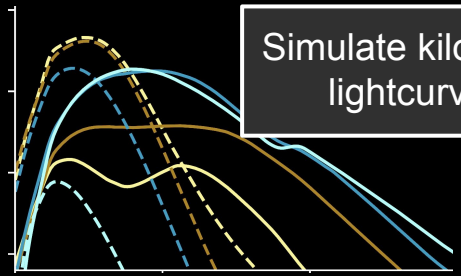
End-to-end BNS simulations



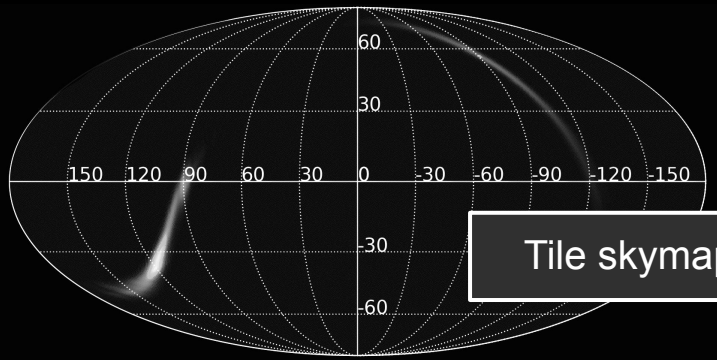
Simulate astrophysical BNS



Recover via GW search



Simulate kilonova lightcurve



Tile skymap

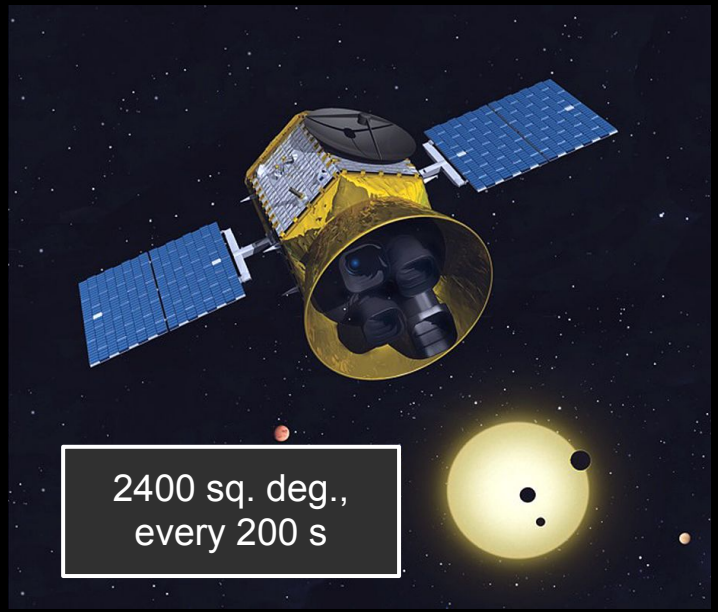
WINTER - kilonova detection

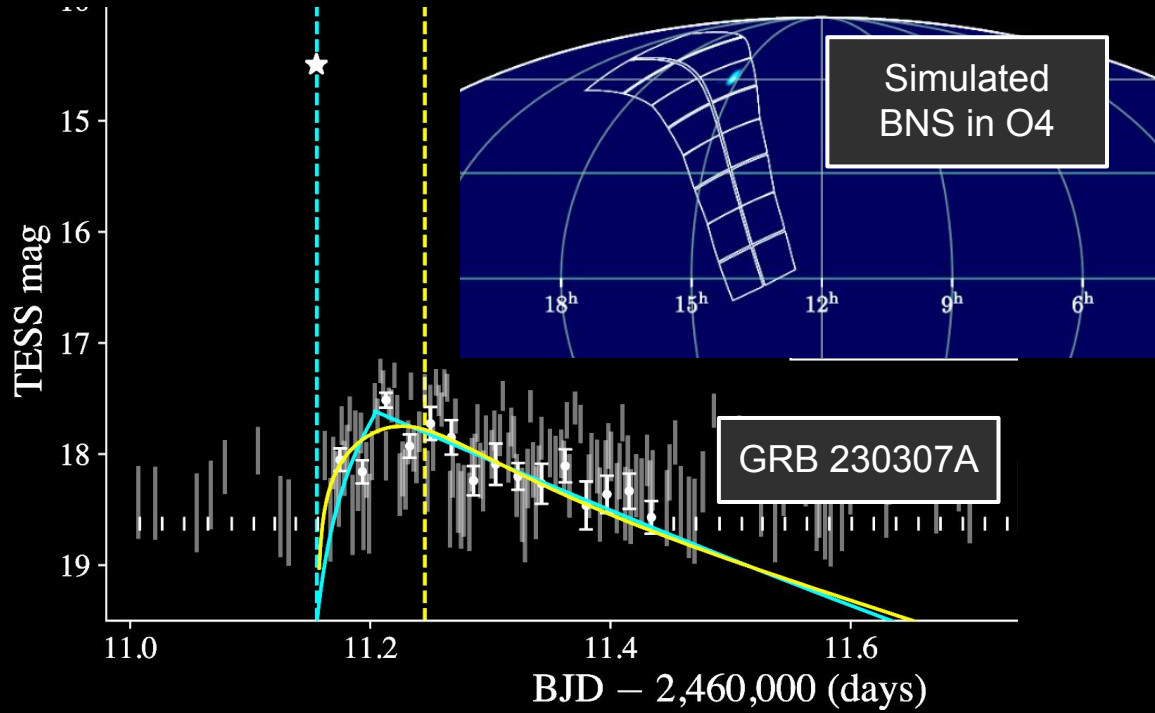
	Pessimistic	Realistic	Optimistic
GW Triggers	1	24	49
Localized 1 week	1	9	26
Localized 24 hr	1	5	6
Detected SNR=4	0	1	3
Detected SNR=5	0	1	3

- ~1 detection in IR per year, up to 3 possible

TESS

Transiting Exoplanet Survey Satellite





Simulated results in TESS

Another mode: subthreshold searches in TESS

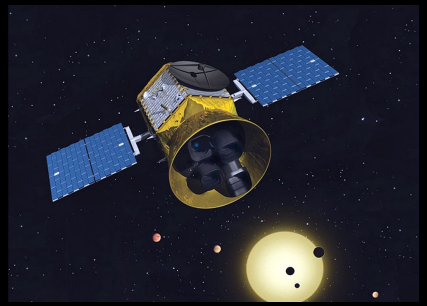
BNS which were *not* found in GWs but in the TESS FOV

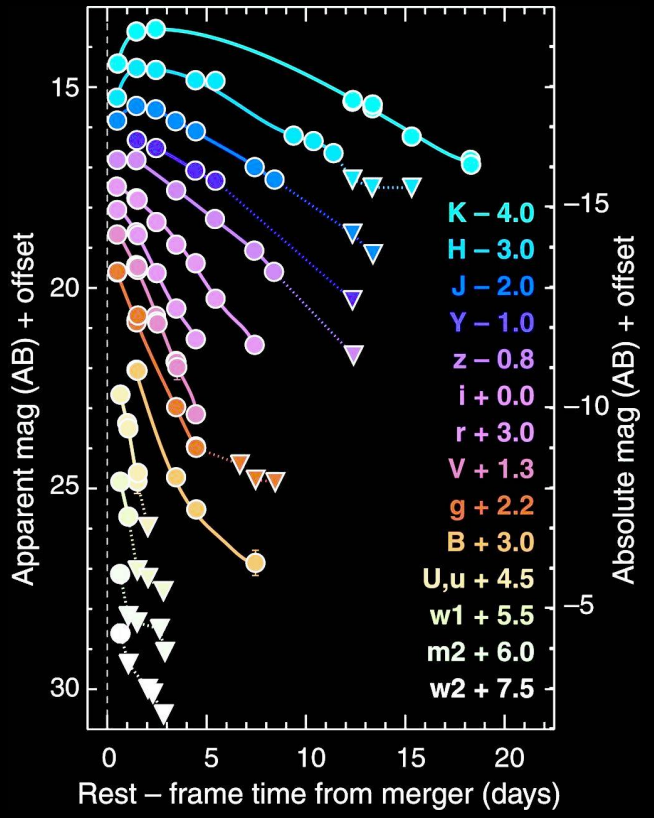
BNS rate ($\mathrm{Gpc^{-3}yr^{-1}}$)	Found in GWs	Covered by TESS	Bright at limiting mag 21.5	21	20.5
50	0	$0.6\ (0^{+2}_{-0})$	$0.2\ 0^{+1}_{-0})$	$0.2\ (0^{+1}_{-0})$	$0.1\ (0^{+1}_{-0})$
250	0	$2.7\ (3^{+2}_{-3})$	$1.1\ 1^{+2}_{-1})$	$0.7\ (1^{+1}_{-1})$	$0.6\ (0^{+2}_{-0})$
1000	0	$11.0\ (11^{+5}_{-4})$	$4.6\ 5^{+3}_{-4})$	$3.0\ (3^{+3}_{-3})$	$2.2\ (2^{+3}_{-2})$

It's a really good time for multimessenger science

TAUP VIENNA 2023

- O4 continues and will get more powerful
- BNS, NSBH counterparts, BBH? SNe?
- New instruments coming soon
- Working together: AMON up next

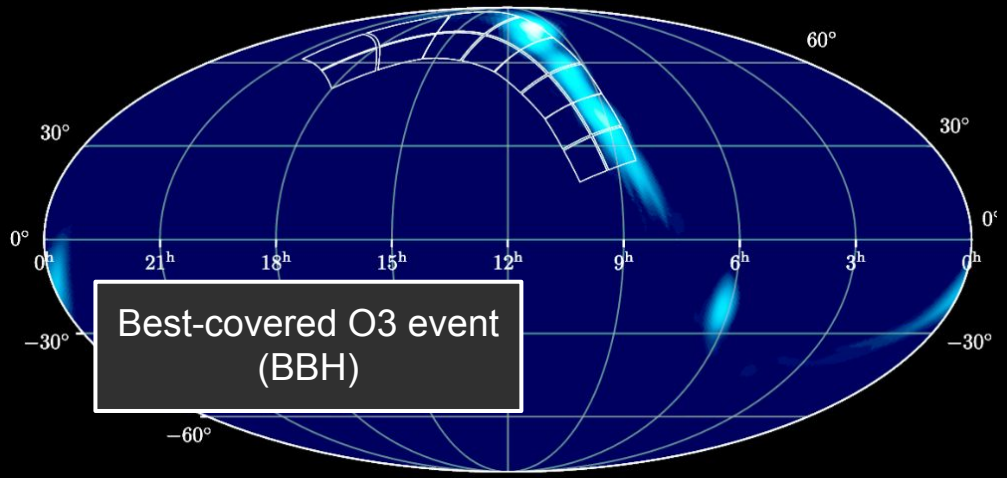




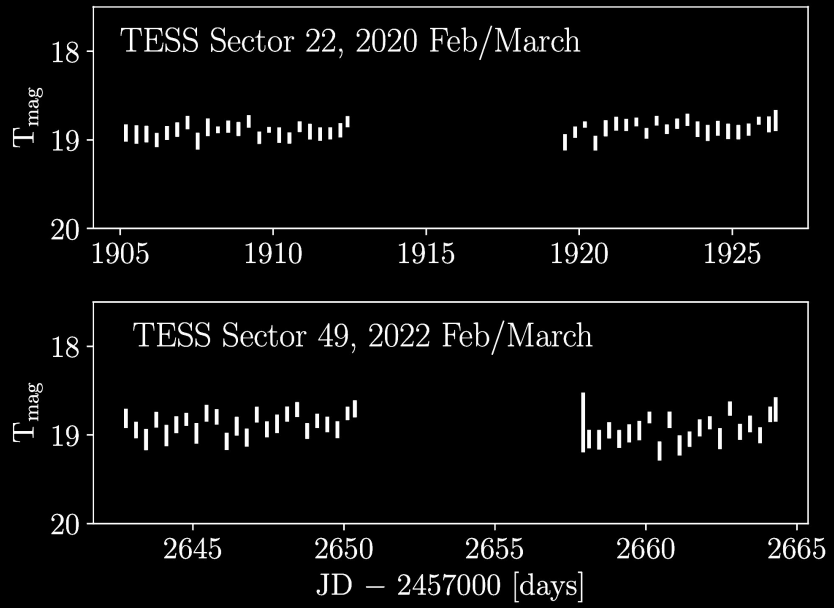
Drout+ 2017

Backup slides

Search in TESS data for O3 events



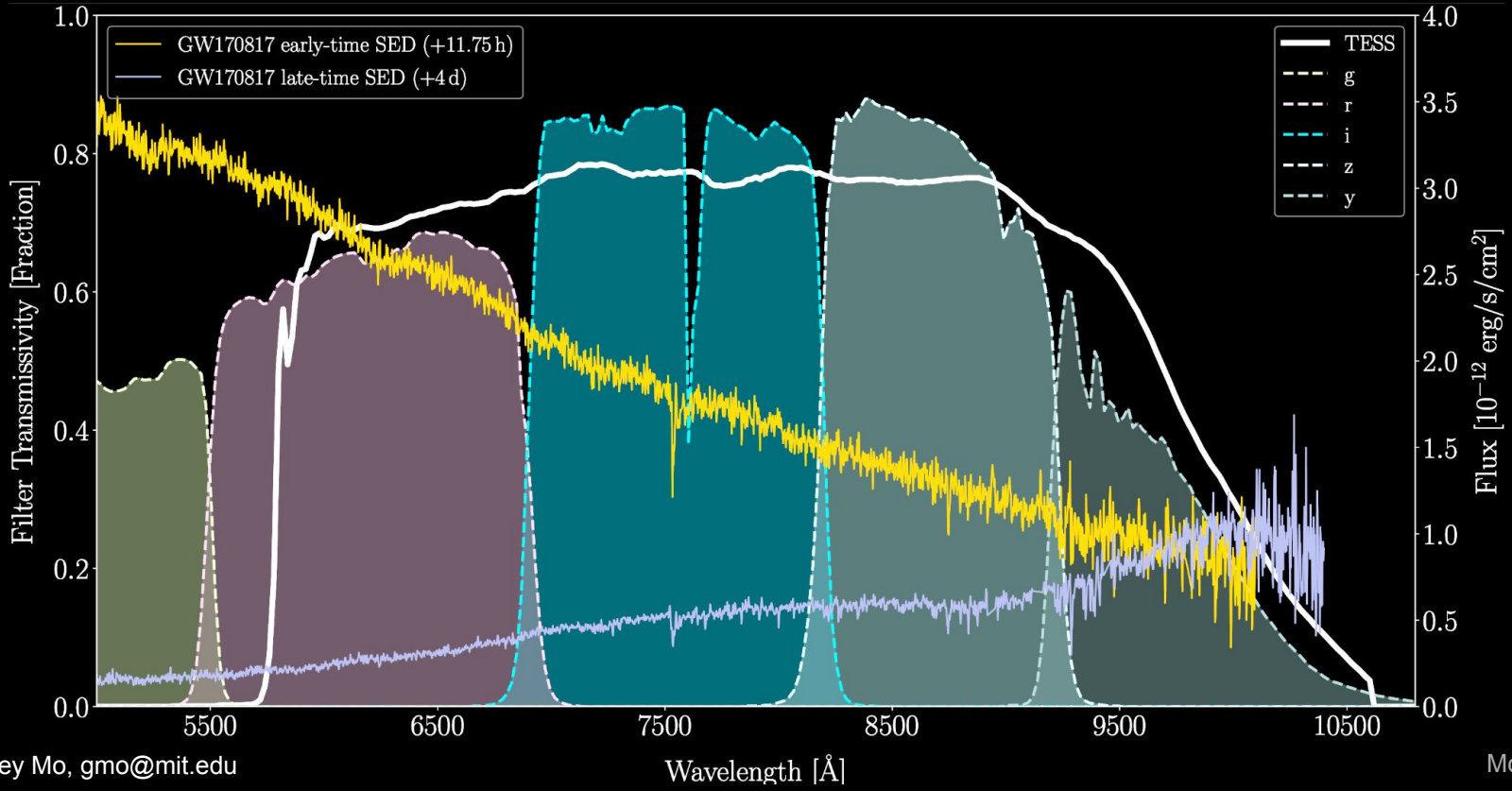
Best-covered O3 event (BBH)



No counterparts found, but:

Constraint on AGN re-flare from GW190521

TESS bandpass



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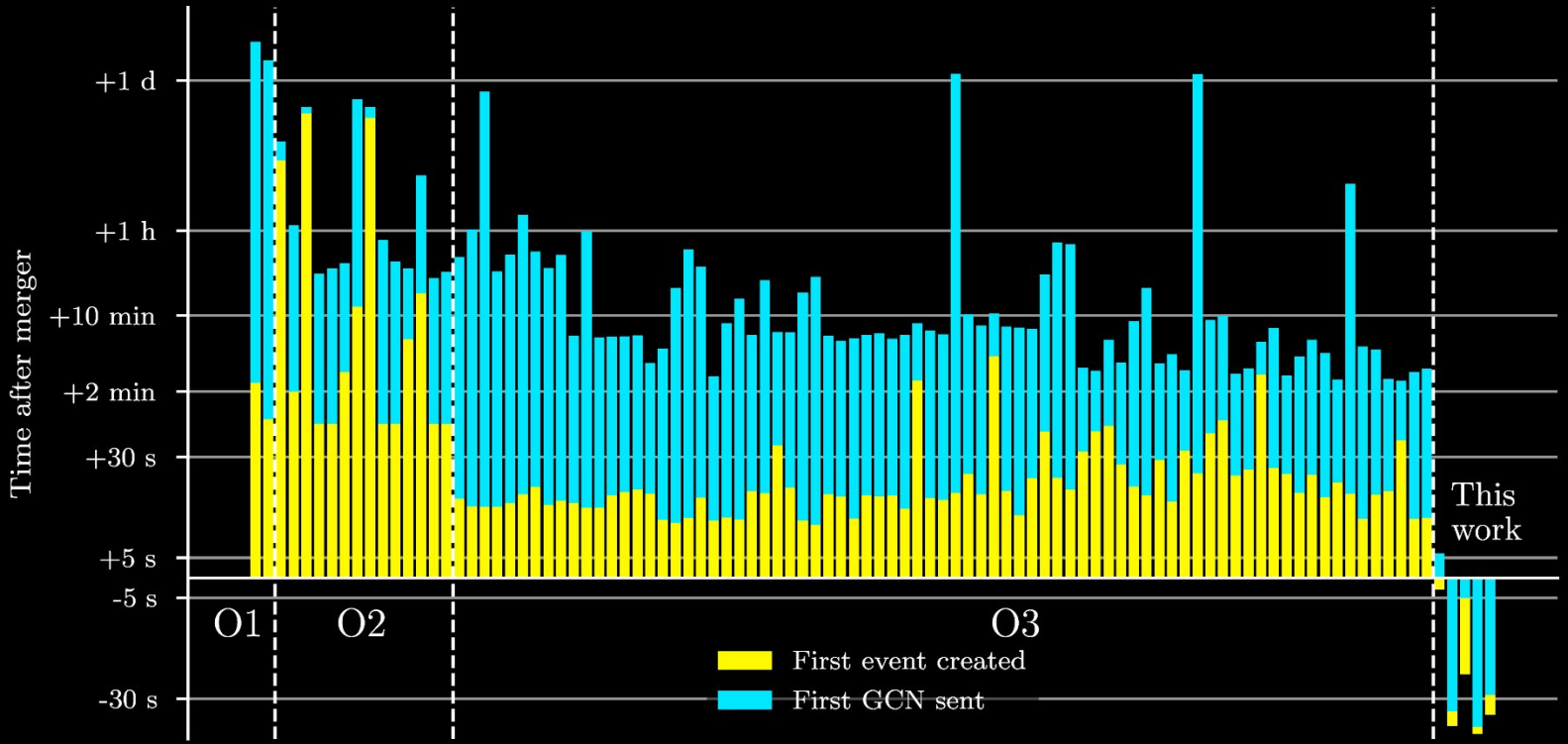
O4 early-warning pre-merger alerts



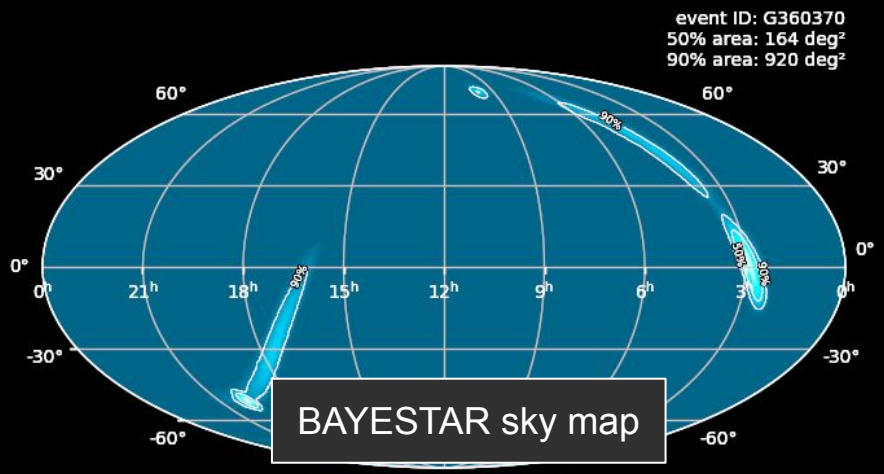
Magee+ 2021

Low-latency data products

GraceDB gracedb.ligo.org

```
TITLE:   GCN CIRCULAR
NUMBER:  26759
SUBJECT: LIGO/Virgo S200115j: Identification of a GW
compact binary merger candidate
DATE:    20/01/15 06:08:31 GMT
FROM:      Deep Chatterjee at University of Wisconsin,
Milwaukee  <deep@uwm.edu>

The LIGO Scientific Collaboration and the Virgo
Collaboration report:

We identified the compact binary merger candidate
S200115j during
real-time processing of data from LIGO Hanford
Observatory (H1), LIGO
Livingston Observatory (L1), and Virgo Observatory (V1)
at 2020-01-15
04:23:09.742 UTC (GPS time: 1263097407.742). The
candidate was found
by the GstLAL [1], PyCBC Live [2], MBTAOnline [3], and
SPIIR [4]
analysis pipelines.

S200115j is an event of inte
alarm rate, as
estimated by the online analy
about one in 1e3
years. The event's properties can be found at this URL:
https://gracedb.ligo.org/superevents/S200115j

The classification of the GW signal, in order of
descending
probability, is MassGap (>99%), Terrestrial (<1%), BNS
(<1%), NSBH
(<1%), or BBH (<1%).

Assuming the candidate is astrophysical in origin, the
probability
```

GCN Circular



BAYESTAR sky map

MassGap	>99%
Terrestrial	<1%
NSBH	0%
BNS	0%
BBH	0%

P-astro

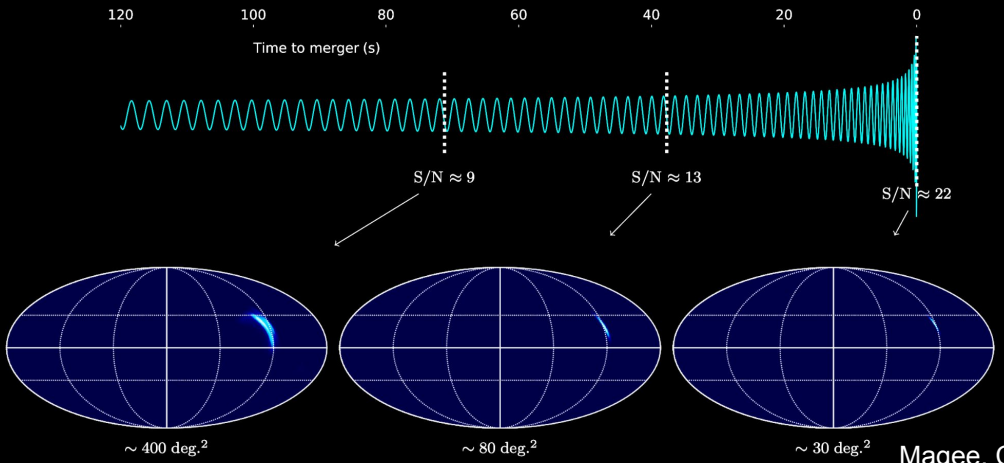
```
"HasNS":     1.0,
"HasRemnant":
0.0875
```

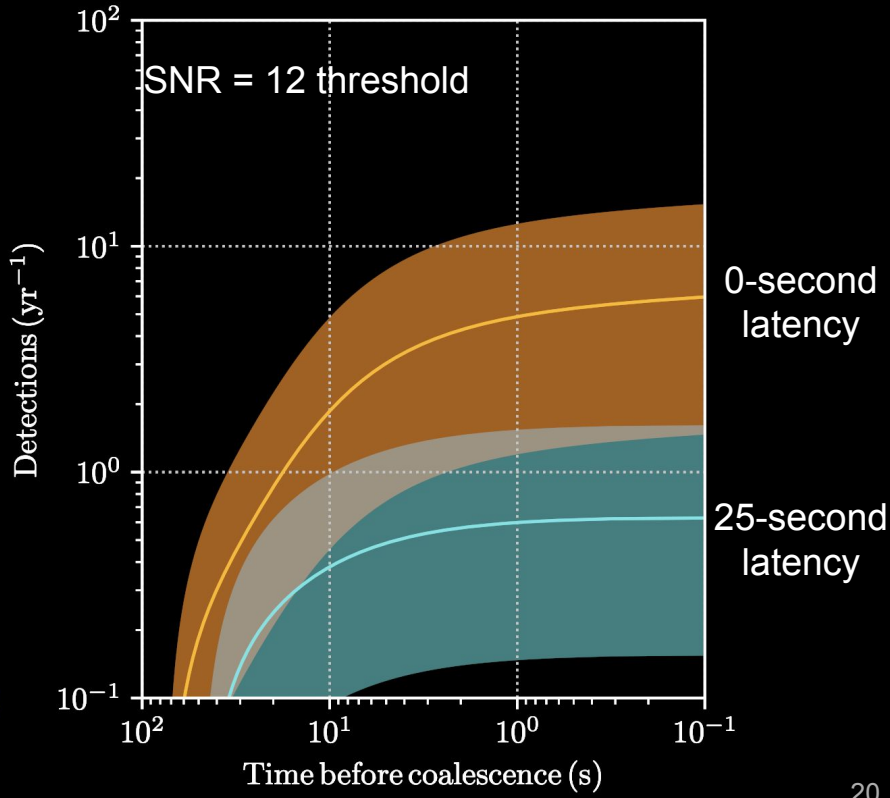
EM-bright

GraceDB S200115j

Prospects for early warning BNS in O4

- Alerts received 1 second before merger per year:
  - Optimistic: 5^{+7}_{-4}
  - Pessimistic: O(1)





Magee, Chatterjee, Singer, Sachdev, Kovalam, Mo et al. ApJL 910 L21, 2021

Future observing runs