Title: Ultraswift: A coordinated effort to detect prompt EM emission from binary neutron star mergers

Speakers: Chad Hanna

Collection/Series: Charting the Future Symposium

Subject: Cosmology, Particle Physics, Strong Gravity

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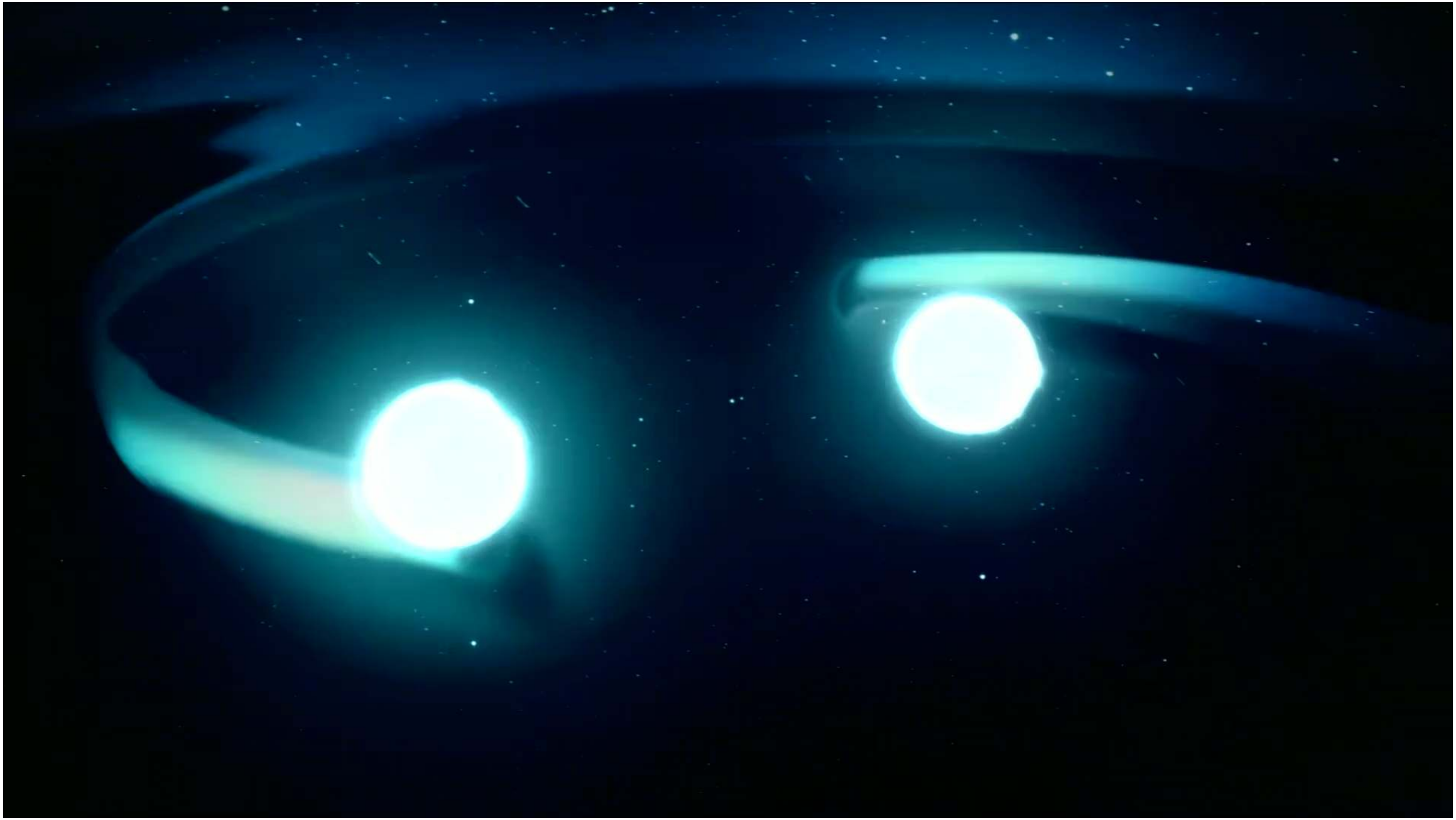
Abstract:

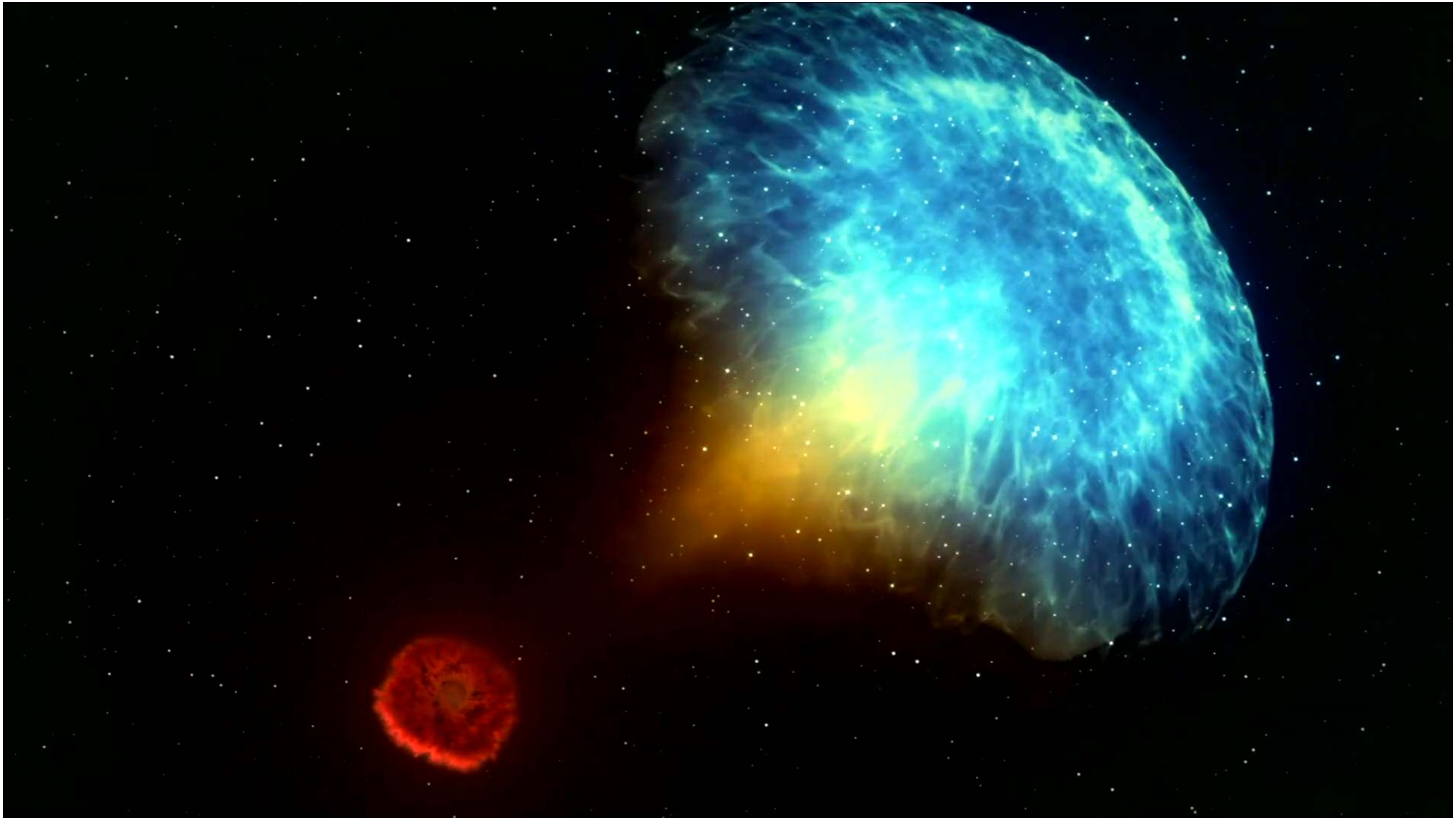
To date only one astronomical event has been observed in both gravitational waves and electromagnetic waves -- the merger of two neutron stars known as GW170817. This event was detected in gamma rays simultaneously with gravitational waves, but was poorly localized initially. No other counterparts were detected until localization was improved leading to an 11 hour dearth of data in other EM wavelengths. GW170817 also demonstrated that realistic neutron star mergers may have off-axis GRB observations that could be sub-threshold in modern instruments. Here we describe an ongoing coordinated effort to detect binary neutron stars before they merge using gravitational waves and to slew NASA's Swift observatory to catch prompt potentially sub-threshold GRB and x-ray emission. If successful, this ambitious project would pin down the event location allowing for prompt follow-up observations across all other wavelengths. Multimessenger observations of binary neutron star mergers (gravitational waves and electromagnetic waves) have deep implications for nuclear physics, strong gravity and cosmology.

ultraswift: A coordinated effort between LIGO and NASA Swift to detect prompt EM emission from binary neutron star mergers

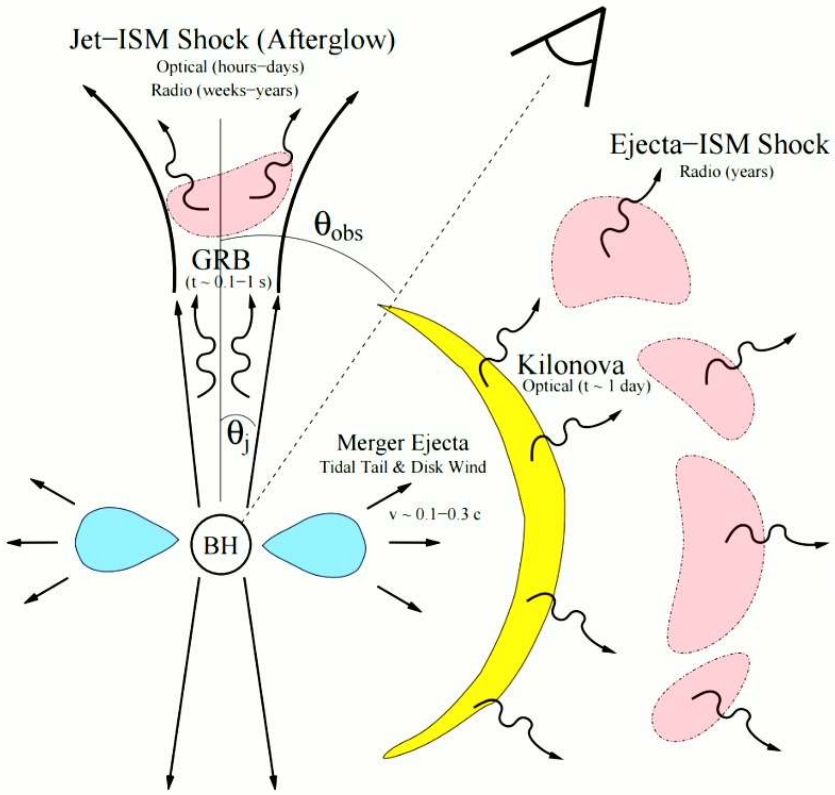
Amanda Baylor, William Benoit, Brad Cenko, Deep Chatterjee, Michael Coughlin, Becca Ewing, Patrick Godwin, **Chad Hanna,** Yun-Jing Huang, Prathamesh Joshi, Jamie Kennea, Ryan Magee Cody Messick, Jameson Rollins, Samuele Ronchini, Surabhi Sachdev, Leo Singer, Ron Tapia, Aaron Tovuvavohu, Madeline Wade.

LIGO, Virgo, KAGRA (LVK) and NASA Swift

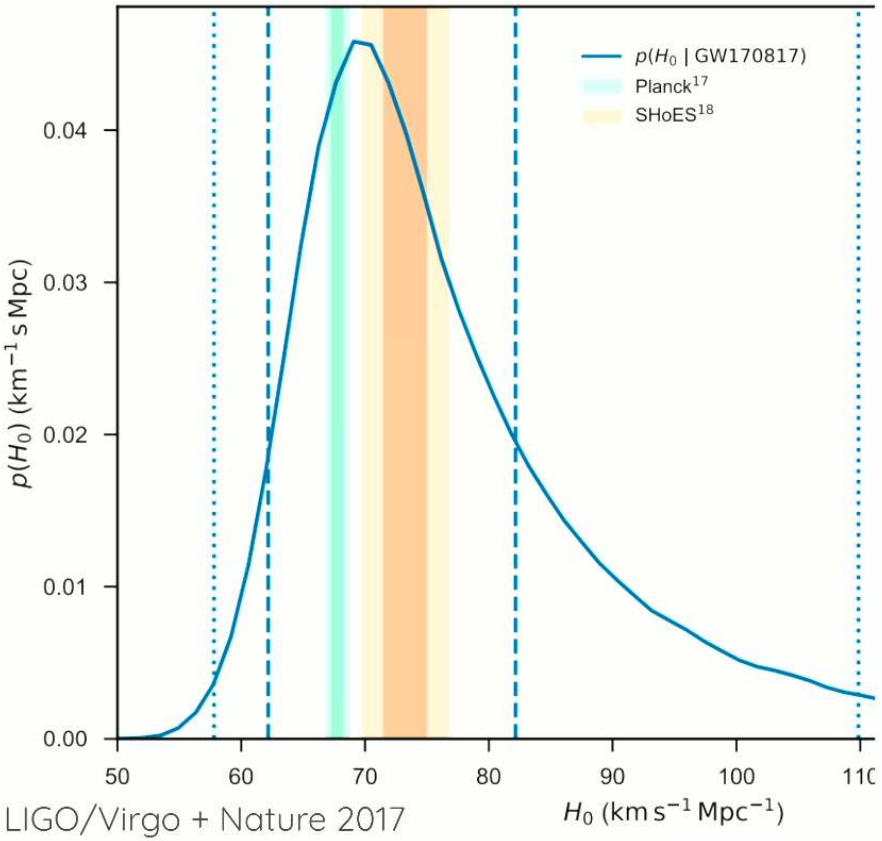




Why search for multi-messenger binary neutron stars?



Metzger and Berger 2012



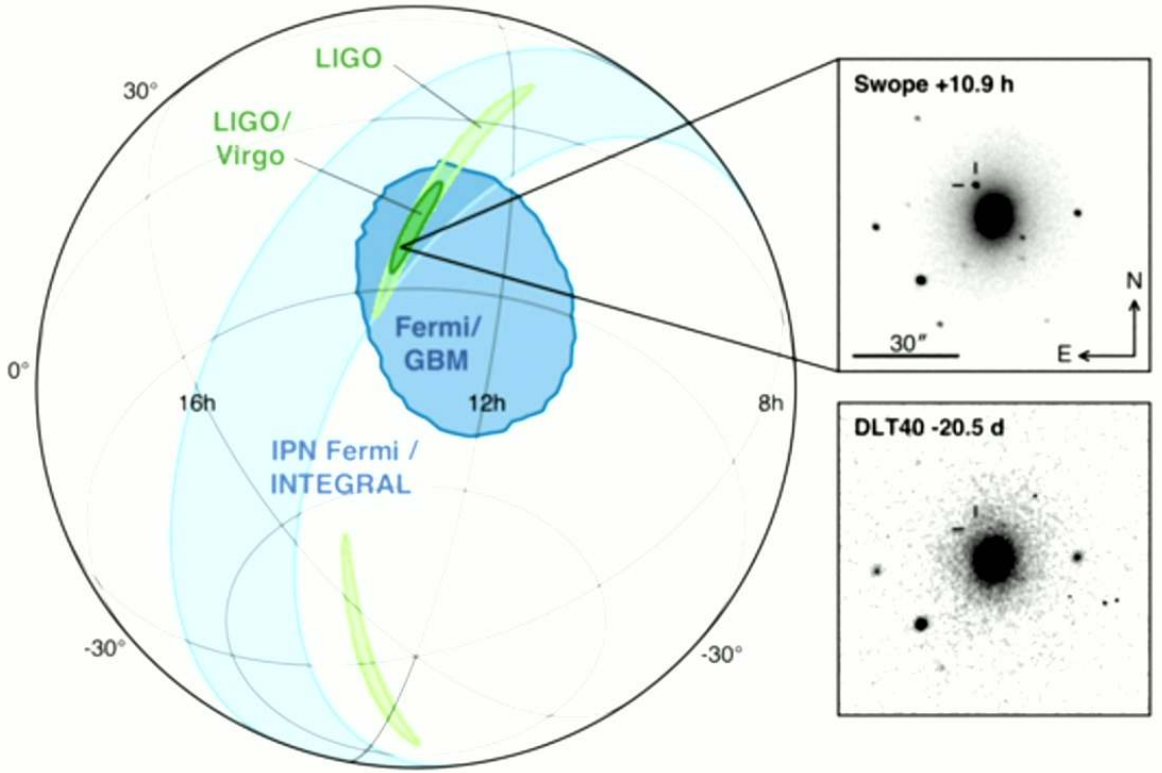
LIGO/Virgo + Nature 2017

GW170817

GW170817 is the only definitive GW+EM source to date

Detected in gamma rays as low-flux, off-axis burst with poor localization

Improved localization yielded optical counterpart ~11 hours later. Multiple wavelength observations followed.

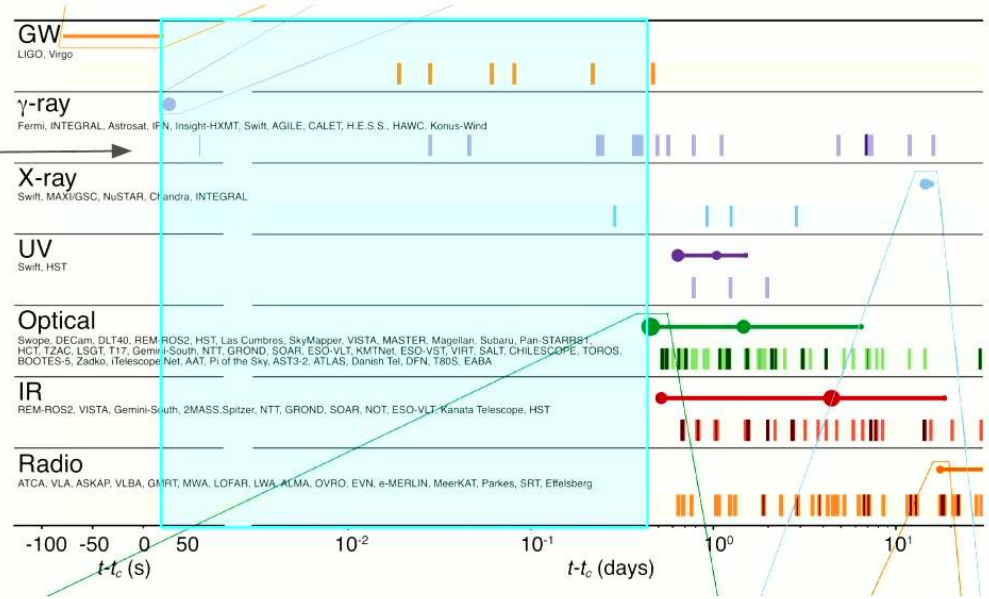


LVK 2017

GW170817

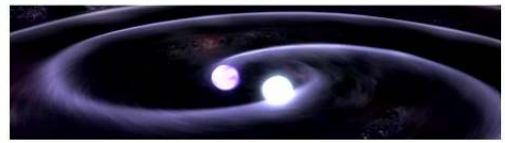
What might have been missed in the first 11 hours?

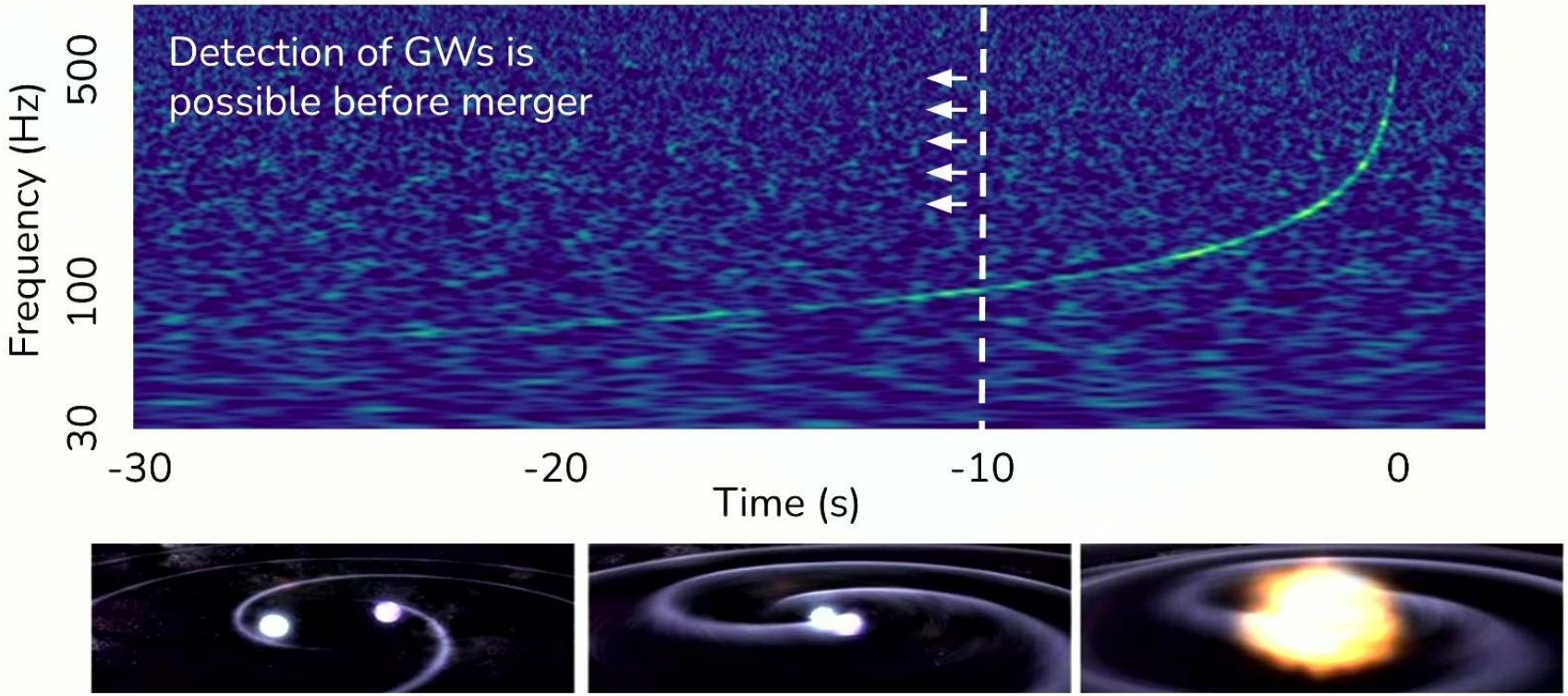
How to we improve the success of detecting similar systems going forward?



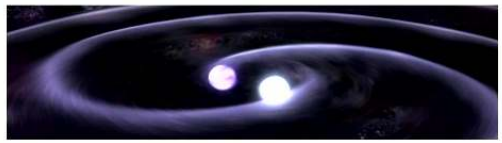
LVK 2017

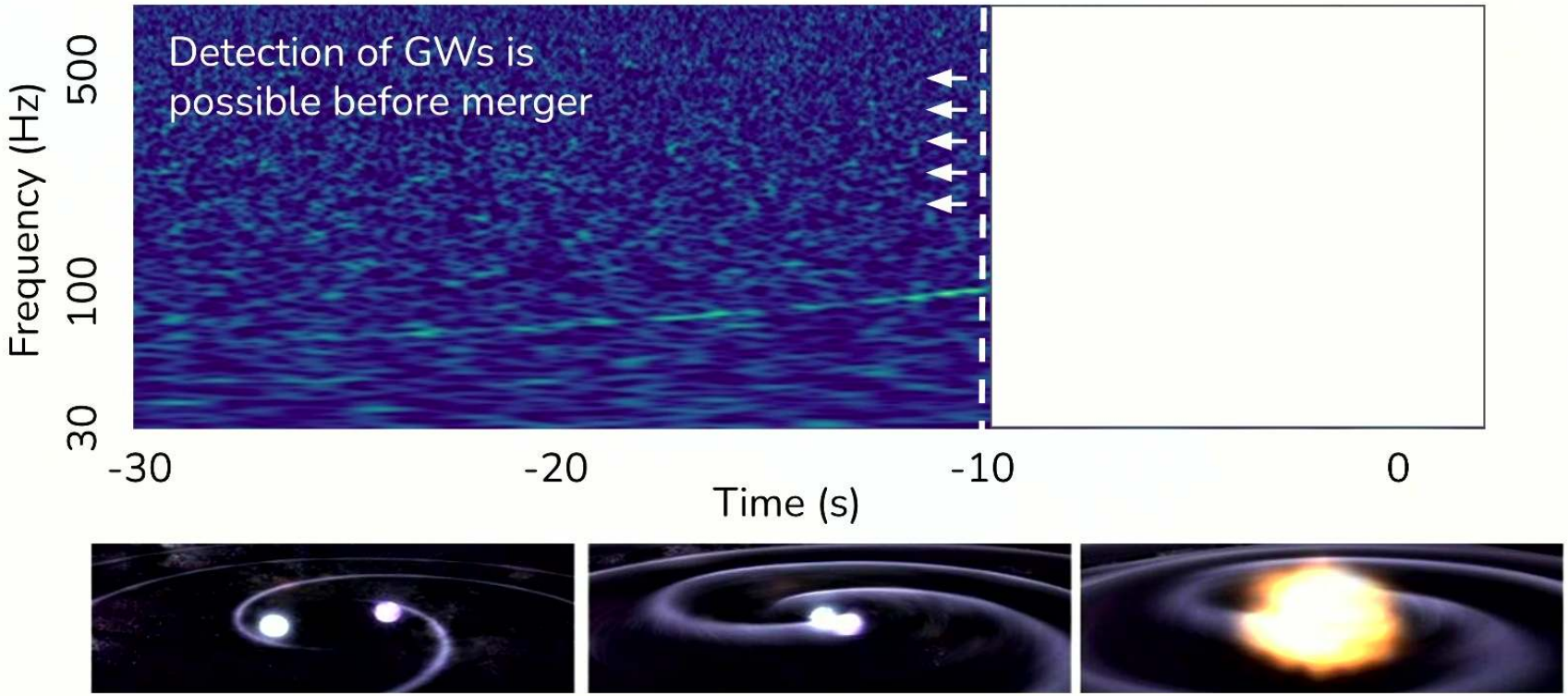
Gravitational wave early warning



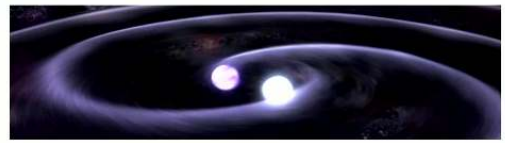


Gravitational wave early warning



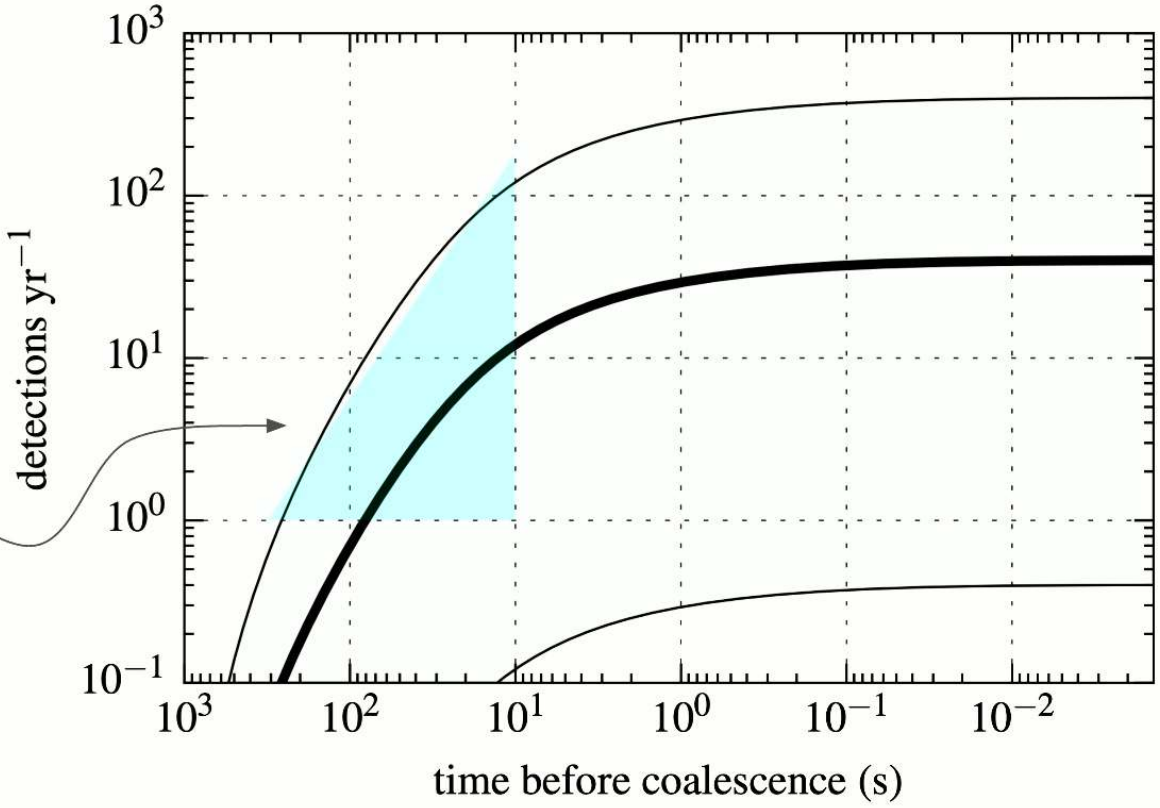


Gravitational wave early warning



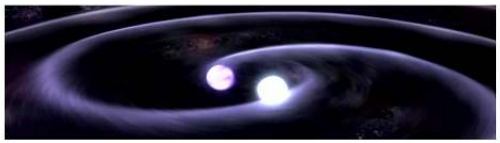
Research conducted while a **postdoc at PI (2010-2013)** estimated how often it might be possible to detect BNS before merger for advanced LIGO

It was plausible enough that we invested considerable time in algorithm and infrastructure development since ~2010

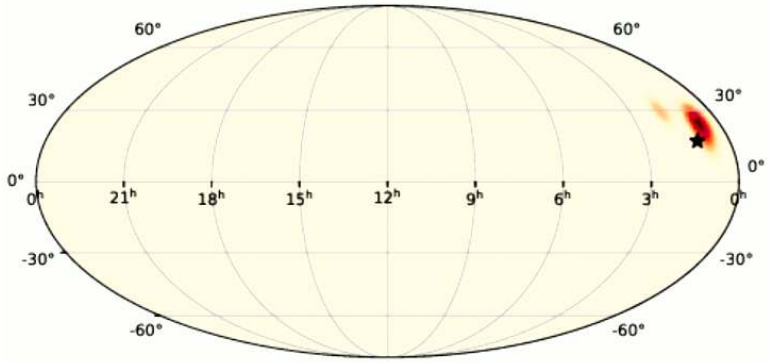


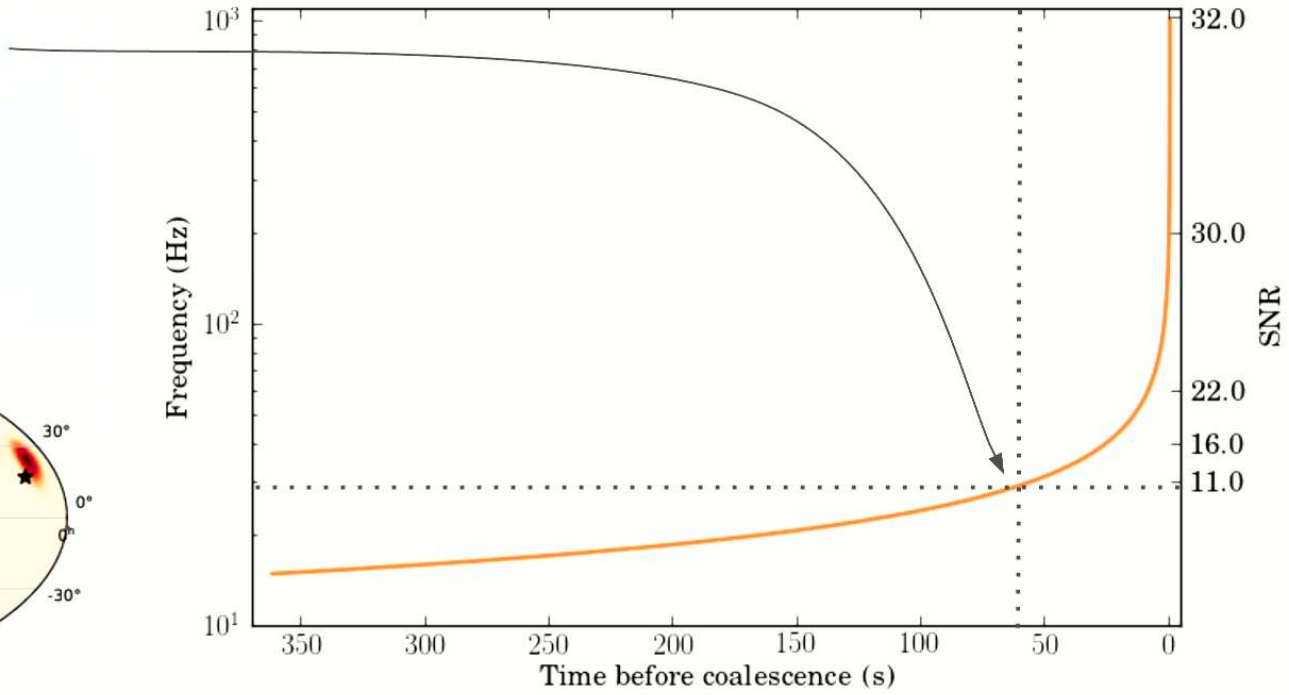
Cannon+ 2012 ApJ 748 136

Gravitational wave early warning



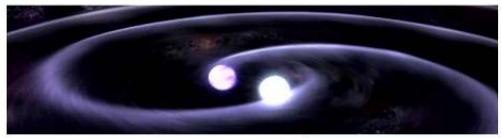
Although early warning searches were not in place for GW170817, it **did prove that it was possible to detect real GW events early**.

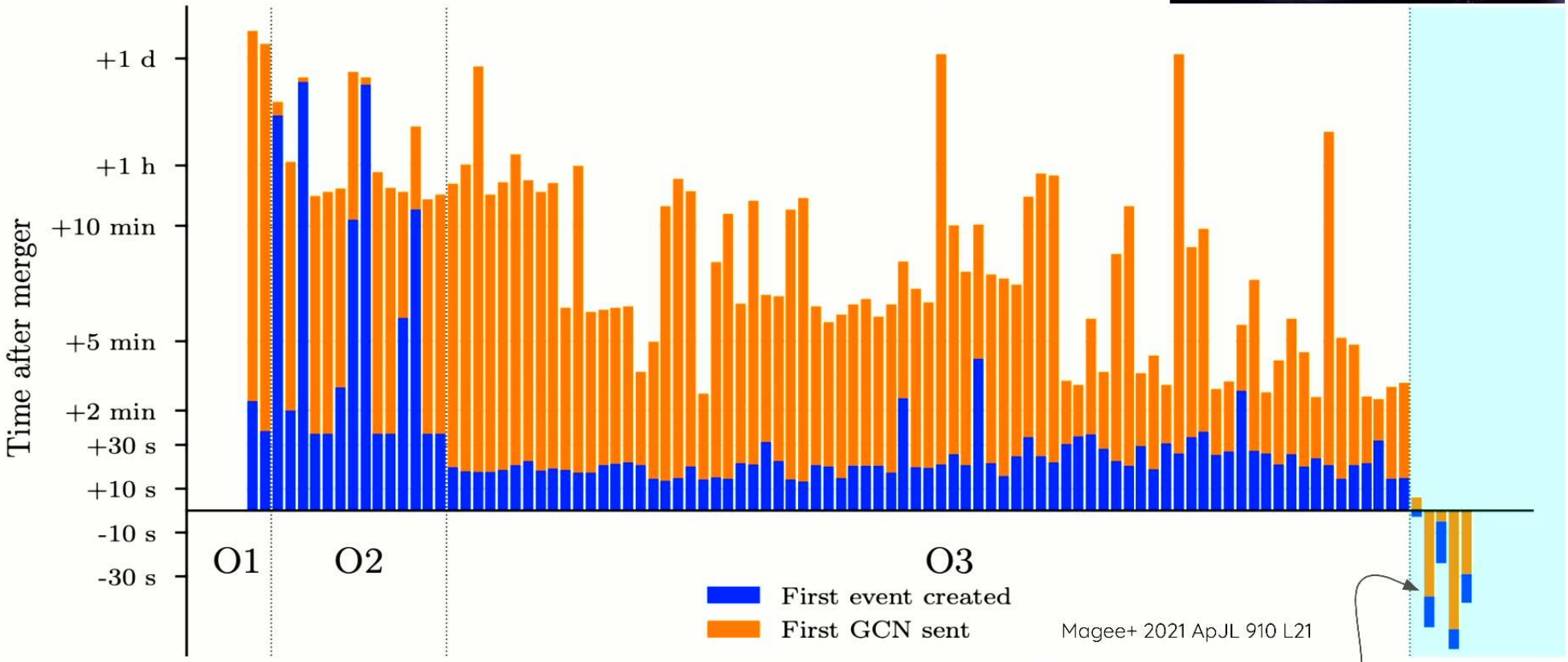




Sachdev + 2020 ApJL 905 L25

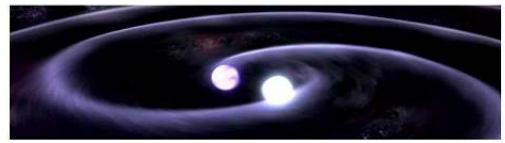
Gravitational wave early warning





LVK demonstrated EW capabilities end-to-end after O3

Gravitational wave early warning alerts are public in the current observing run!



IGWN | Public Alerts User Guide Search userguide

Question? Issues? Feedback?

Email emfollow-userguide@support.ligo.org

Early-Warning Alerts

BNS mergers spend several minutes in band of the Advanced ground-based gravitational-wave detectors. For some loud and nearby BNS mergers, it is possible to accumulate enough SNR and detect them several tens of seconds before merger. During O3, automated public alerts for CBC events have been sent within as little as 2 minutes after merger. In O4, we have commissioned search pipelines that can detect BNS events before merger if the signal is sufficiently strong.

Since it is generally assumed that detectable electromagnetic (or neutrino) emission starts shortly *after* merger, a pre-merger gravitational-wave detection would provide *early warning* of an impending electromagnetic transient and might make it possible for automated follow-up facilities to capture any prompt emission from the merger environment, the jet, and other unknown activity.

We had previously conducted a trial early warning public alert infrastructure in June 2020 replaying an 8-day period of archival LIGO data from O3. Results from this study were published in [1]. This study demonstrated that in principle it is possible to send out GCN Notices in advance of a BNS merger.

https://emfollow.docs.ligo.org/userguide/early_warning.html

In the last nine months, we have been working to further improve EW capabilities and have partnered with NASA Swift to conduct observations.

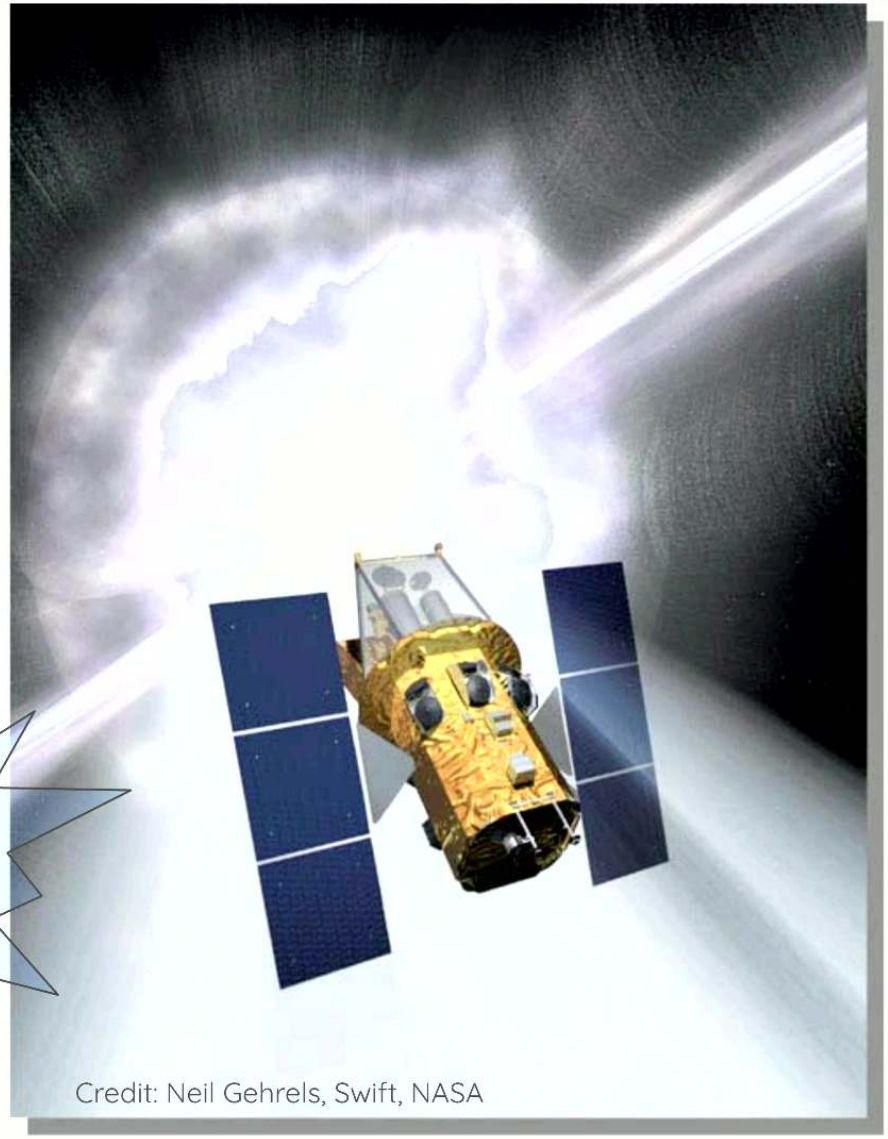
- ❑ Lower latency GW data generation and calibration
- ❑ Lower latency GW data transfer
- ☑ Lower latency GW search [Huang et al arXiv:2410.16416]
- ❑ Lower latency localization
- ☑ Lower latency alert communication
- ☑ Direct automated command of NASA Swift for BNS early warning candidates in time to improve prospects of GRB detection for realistic scenarios

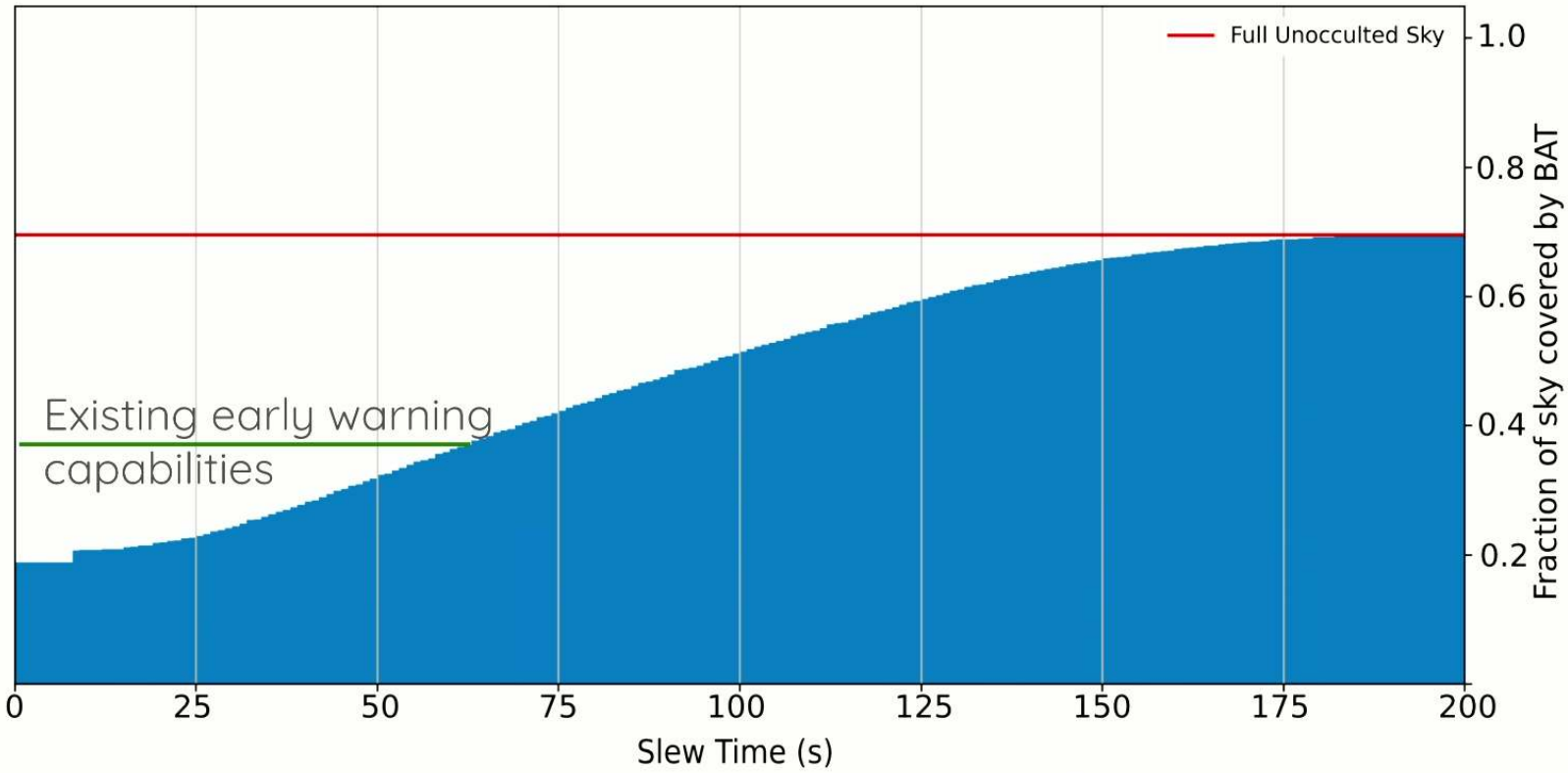
The other three items are ongoing and we hope to complete them before the end of the current observing run (O4)

Swift as an early warning discovery engine

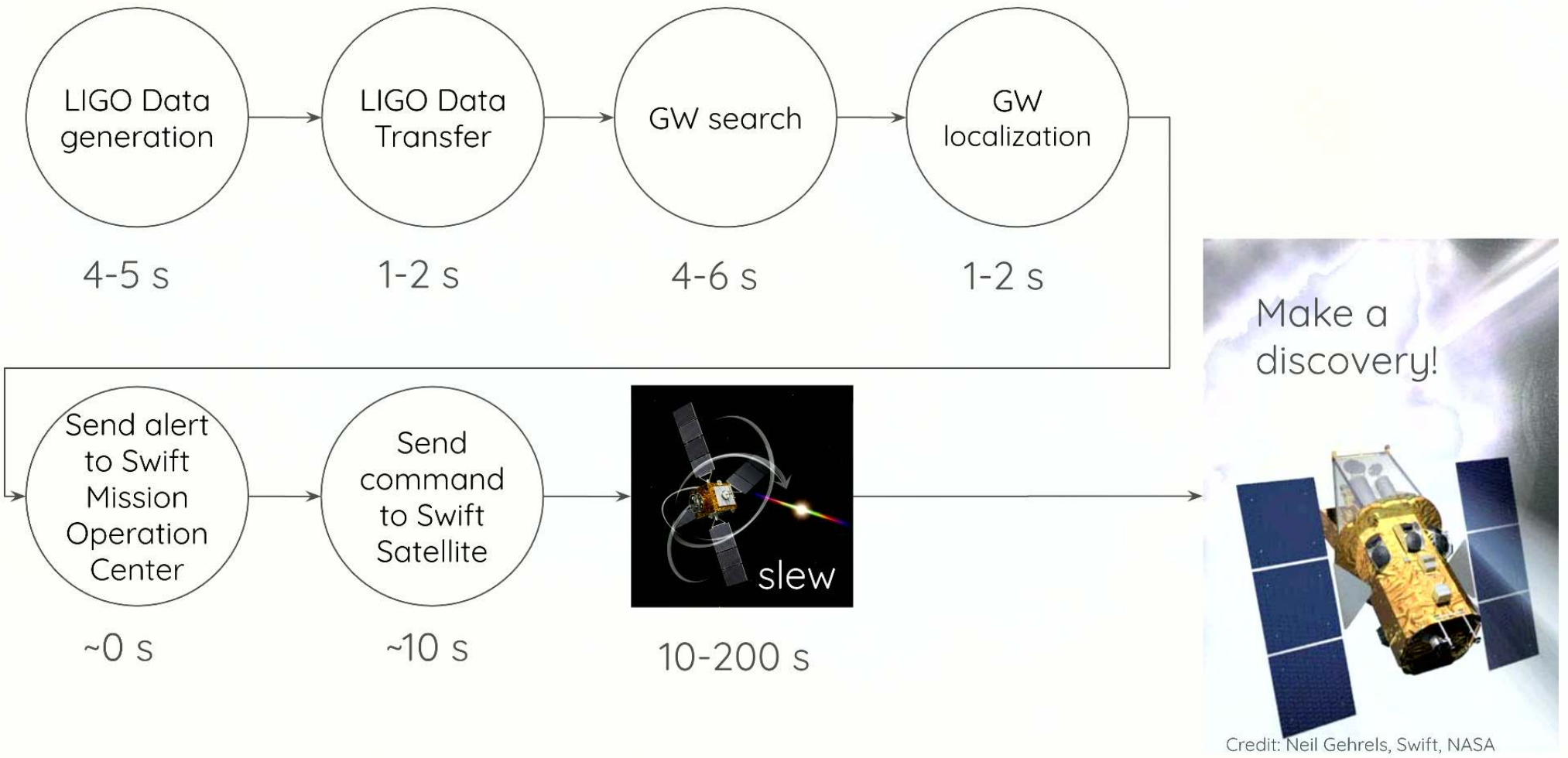
- Swift, sees ⅛ of the sky simultaneously,
- It can take as little as 6 seconds from the time that the Swift mission operations sends a command to the time that the spacecraft starts to slew.
- Swift is working on making this even faster.

Launched 20+ years ago!





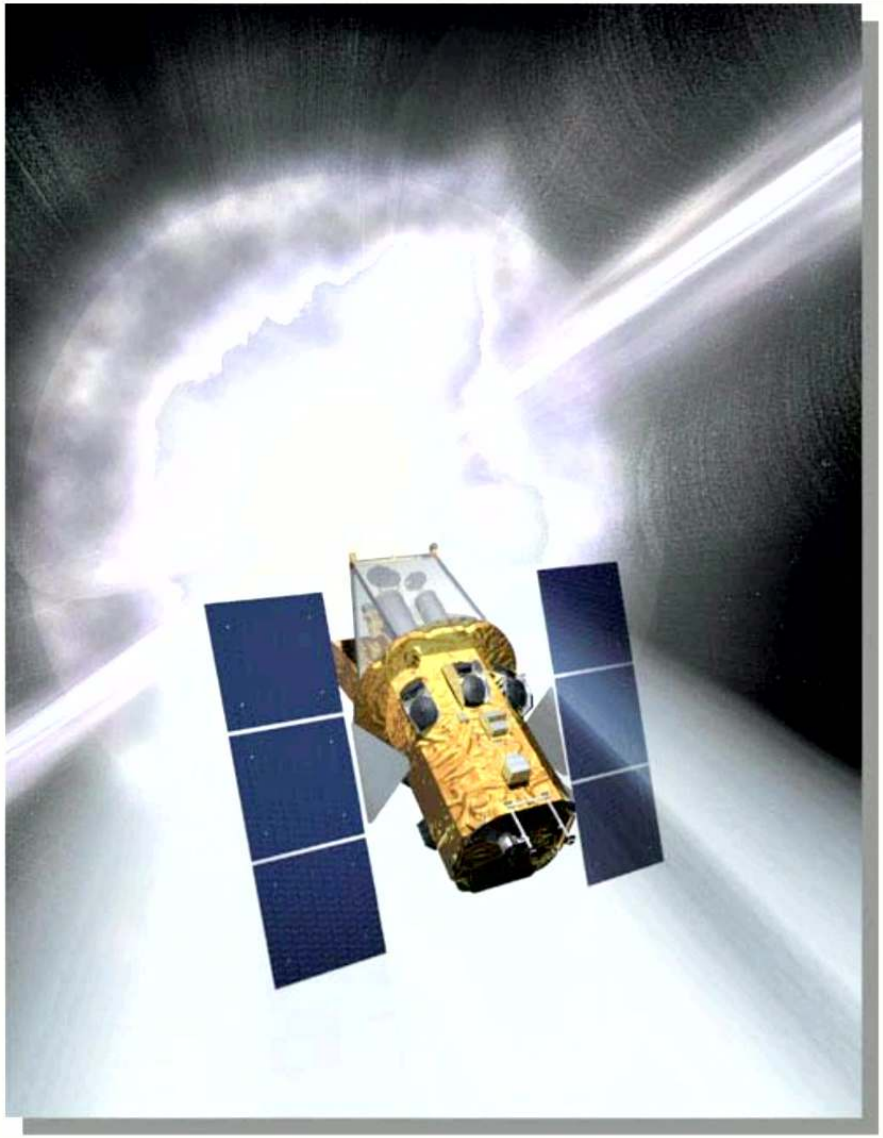
Aaron Tohuvavohu *et al* 2024 *ApJL* 975 L19



Aaron Tohuvavohu *et al* 2024 *ApJL* 975 L19

Sadly, we have not had any BNS early warnings, but we have a low threshold and have followed up candidates that haven't panned out. This one was from last week...

Time relative to merger	time	log
-20 s	19:12:40	Alert received
-11 s	19:12:49	Swift BAT receives command
-7 s	19:12:53	Acknowledgment of TOO slew
0 s	19:13:00	BNS merged! (if real)
+57 s	19:13:57	Swift begins slew
+109 s	19:14:49	Swift observes



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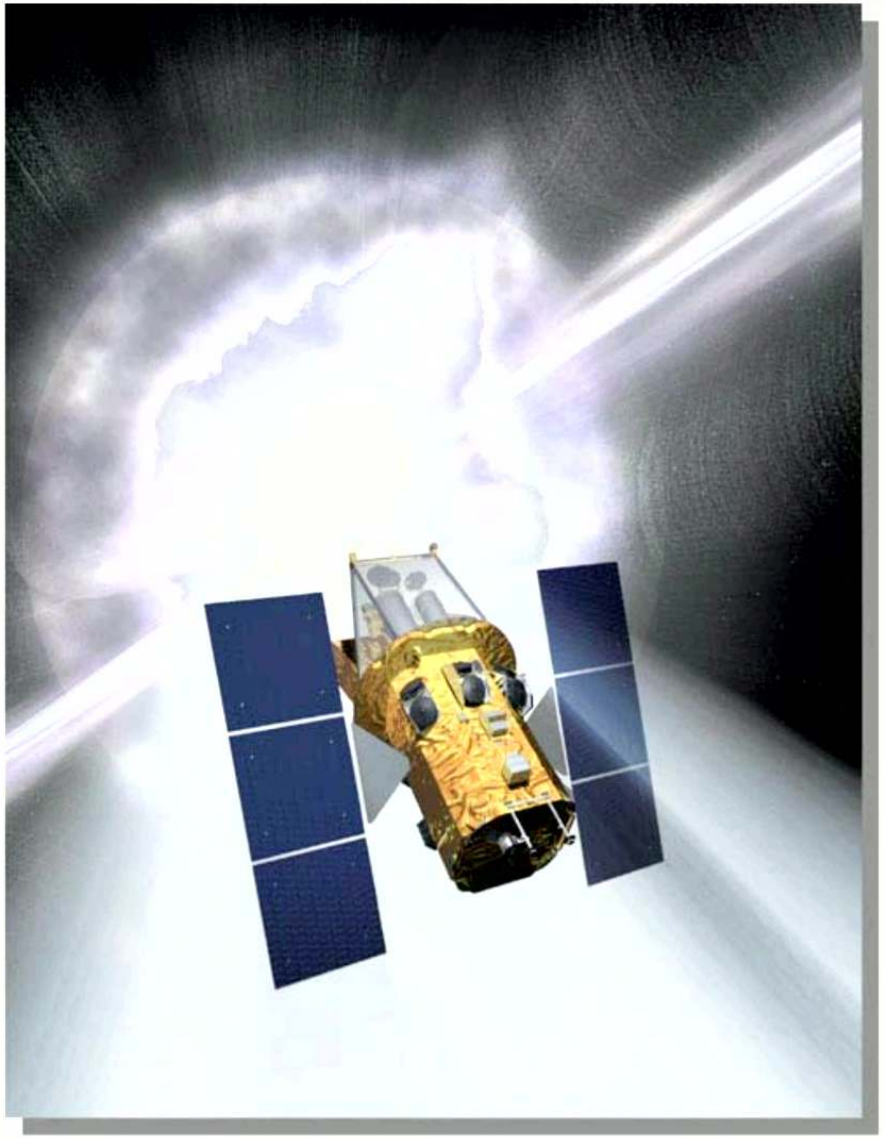
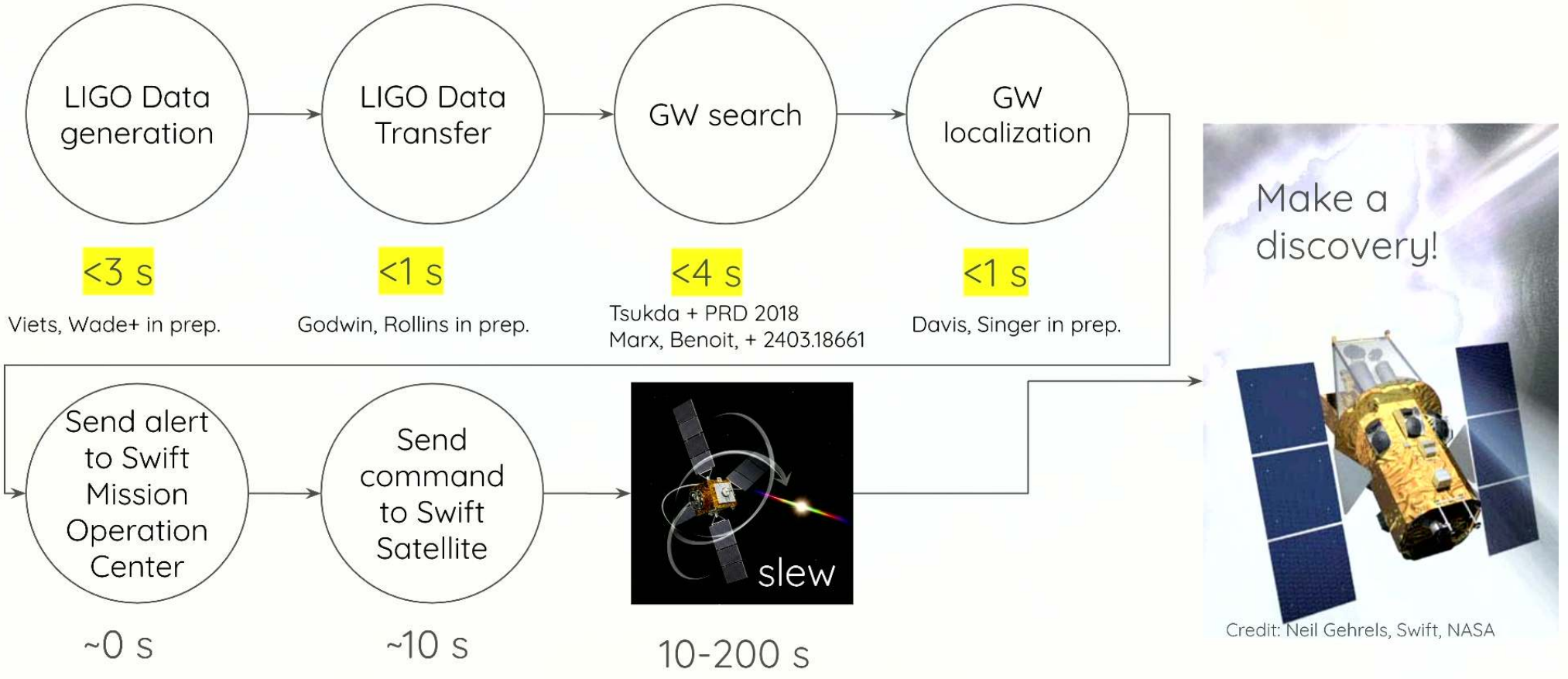
+57 s	19:13:57	Swift begins slew
+109 s	19:14:49	Swift observes

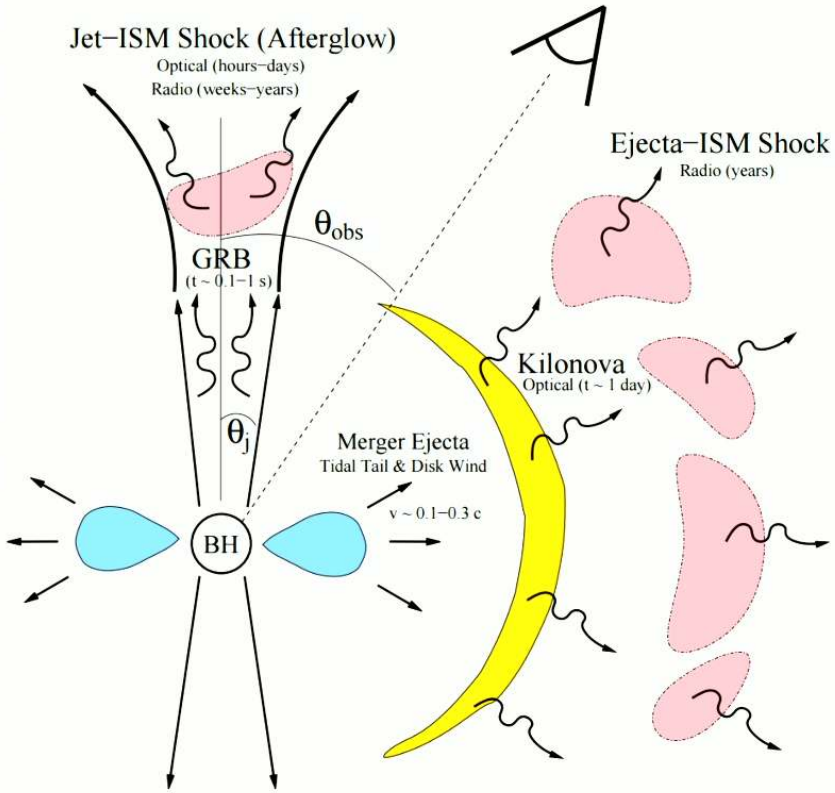
Why so long? It turns out that swift was already slewing for another TOO! Unfortunate but a good reason.



We are still hopeful that before the end of O4 (November) we can make the following improvements



We hope to get eyes and ears on this whole process



Metzger and Berger 2012

GraceDB Public Alerts Latest Search Documentation Login

Please log in to view full database contents.

gracedb.ligo.org

Google Chrome
Update complete.

LIGO/Virgo/KAGRA Public Alerts

- More details about public alerts are provided in the LIGO/Virgo/KAGRA Alerts User Guide.
- Retractions are marked in red. Retraction means that the candidate was manually vetted and is no longer considered a candidate of interest.
- Less-significant events are marked in grey, and are not manually vetted. Consult the LVK Alerts User Guide for more information on significance in O4.
- Less-significant events are not shown by default. Press "**Show All Public Events**" to show significant and less-significant events.

O4 Significant Detection Candidates: **225** (251 Total - 26 Retracted)

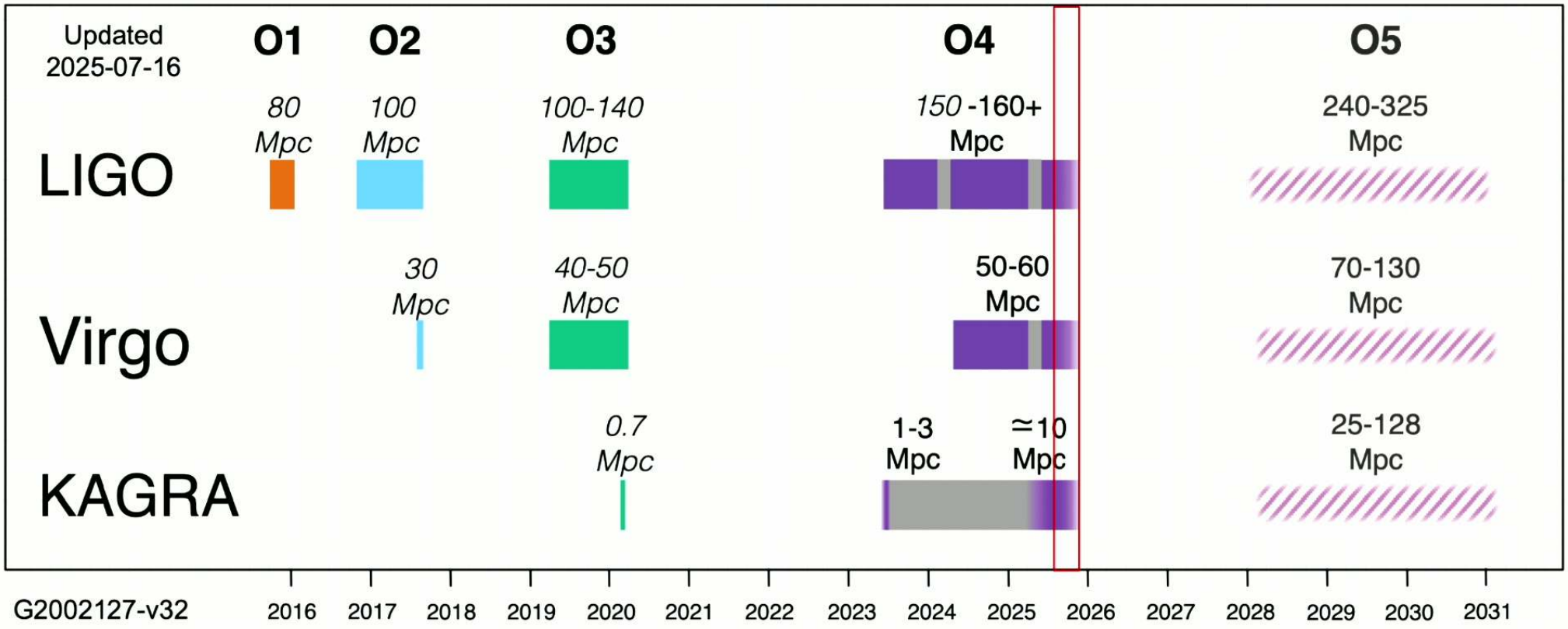
O4 Low Significance Detection Candidates: **4422** (Total)

Show All Public Events

Page 1 of 17. next last »

SORT: EVENT ID (A-Z)

Event ID	Possible Source (Probability)	Significant	UTC	GCN	Location	FAR	Comments
S250827l	BBH (>99%)	Yes	Aug. 27, 2025 01:27:57 UTC	GCN Circular Query Notices | VOE		1 per 100.04 years	
S250818t	BBH (>99%)	Yes	Aug. 18, 2025 02:08:58 UTC	GCN Circular Query Notices | VOE		1 per 1846.6 years	
S250818k	Terrestrial (71%), BNS (29%)	Yes	Aug. 18, 2025 01:20:06 UTC	GCN Circular Query Notices | VOE		2.1491 per year	



We are in the home stretch of O4 which will end in November 2025

After that there will be a ~2 year break before O5 starts in 2028

Conclusion

- The O4 run has for the first time added early warning alerts to its core data products.
- Telescopes are (in principle) informed of a merger before it happens
- In practice, we have had a bit of a dry spell for GW+EM coincidences
- Recently the LVK + Swift have been working on the ultraswift project which lowers the response time even further to (in principle) increase the chances of capturing prompt gamma ray x-ray and UV emission from BNS mergers
- The idea that Swift can slew before the merger happens is no longer science fiction! We are doing it as recently as last week.
- It's a long shot, but the reward is huge if we are successful
- Otherwise the LVK multimessenger program is strong with > 200 confident real-time detections in O4 so far.
- Our community is still committed to working to make prospects even better for the next observing run (O5) which will start in 2028