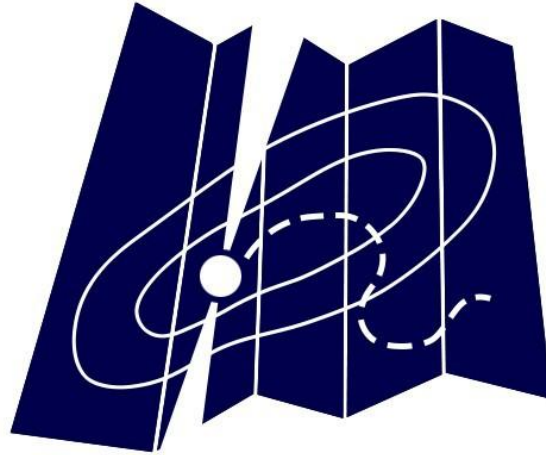


# AstroColibri Workshop 09/17/2024



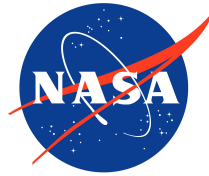
THE GRAVITATIONAL WAVE  
**TREASURE MAP**  
treasuremap.space

Wyatt et al. 2020: ApJ...894..127W



# Treasure Map Team

Samuel Wyatt  
David Sand



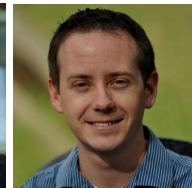
Iair Arcavi



Aaron Tohuvavohu



Andy Howell  
Curtis McCully



# Motivations

- If we want to comprehensively study EM counterparts, we need to efficiently find them **first**

**Discovery is key**



# Motivations

- If we want to comprehensively study EM counterparts, we need to efficiently find them **first**



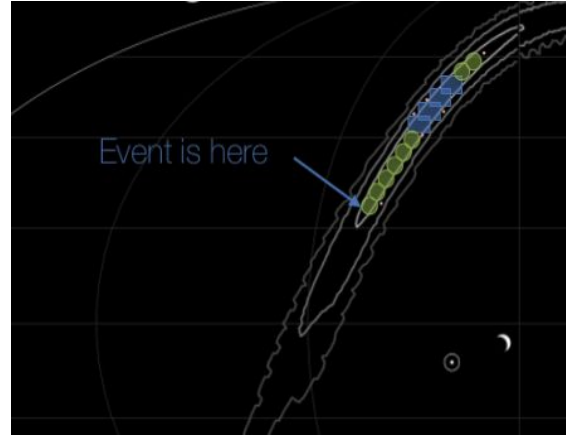
**Discovery is key**



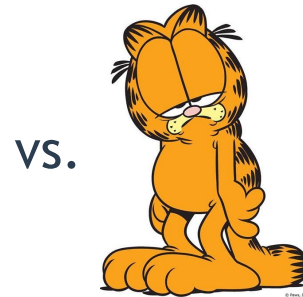
# GW Treasure Map

- Ideal Search Scenario

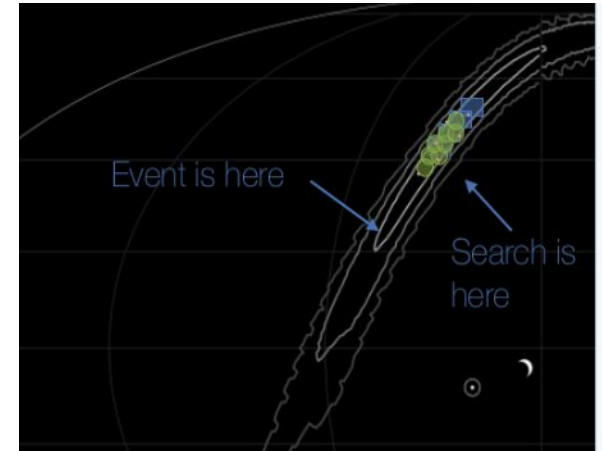
- **Team A** submits their planned observations
- **Team B** queries **Team A**'s observation strategy via the API, and plans their search around **Team A**, while also submitting to the Treasure Map



← This



this →



# GW Treasure Map



- Thus there is a need for a service that can:
  - Host observation strategies
    - submission and querying
  - Offer observing strategy tools:
    - What has been observed?
    - Where is the most optimal area that I can look at this time with my instrument?
- This can enable real-time observing collaboration between all teams with any instrument.



# Motivations



THE GRAVITATIONAL WAVE  
TREASURE MAP  
treasuremap.space

If we build it...



# GW Treasure Map



- **Web Based application**
  - User interface+REST API
  - ALADIN visualization interface (does not require account)
  - Web page querying and submitting for:
    - **Instruments, Pointings**
      - any submission requires Account registration
- **API**
  - **Account Registration is required**
  - Fully documented with multiple python examples
  - Endpoint suggestions?
  - python API wrapper ([gwtm\\_api](#)) (new!)

TM Home GW Events Query Pages Submit Pages Documentation Profile Logout

If you are using our API, you must update your base URL to 'https'.

## Gravitational Wave Treasure Map

Welcome! The Treasure Map is designed to help coordinate electromagnetic followup of gravitational-wave (GW) events. It allows observers to easily report their planned and executed observations in search of counterparts to GW events, and to query the reports of other observers, in a programatic way. The goal is to enable coordination between observatories in order to minimize unnecessary overlap in these searches, and find the counterpart as quickly and as efficiently as possible.

Please [register](#) for an account, so that you can programatically query the Treasure Map. For more details on how to use the Treasure Map see our [User Guide](#).

Please direct any general inquiries to [Iair Arcavi](#). If you use the Treasure Map in your research, please cite the [Treasure Map paper](#) in addition to the circulars and/or papers of the teams whose pointing information you use.

**Visualization**

- Visualize GW alert contours
- Submit your follow-up pointings
- Collaborate with the counterpart search community
- Analyze follow-up

Images from [GW190814](#)

Explore all GW alerts [here](#)



# GW Treasure Map



## REST API

- Ultimately, the primary strength of this tool
  - GET/POST/UPDATE pointing information
    - DOI requests
  - GET Instrument
    - Footprints
  - GET/POST Convolved Galaxies
  - GET/POST/PUT/DELETE candidates
- Fully Documented on the website with ipython notebook tutorials available.

### Event Candidates

GET Candidates

POST Candidates

#### REST API METHOD: POST Instructions

Posting transient Candidates that are potentially affiliated with a GW event.

**Usage**

```
/api/v1/candidate
```

**Notes**

This endpoint is for posting a candidate (or list of candidates) that coincides with a GW event.

**JSON Parameters**

- `api_token=api_token1`
- `graceid=graceid1`
- `candidates=candidates_list`

**Valid candidate class parameters**

**\*parameters required unless otherwise specified as (optional)**

- `position`: two acceptable formats
  - geometry type: **POINT(RA DEC)**
  - simply pass two json fields that are **RA** and **DEC** which must be **decimal**

#### Example 1

#### Python Example

```
import requests

BASE = "https://treasuremap.space/api/v1"
TARGET = "candidate"
API_TOKEN = "--your-verified-account-api-token--"

json_data = {
    "api_token": "API_TOKEN",
    "graceid": "graceid1",
    "candidates": [
        {
            "ra": 24.0,
            "dec": 48.0,
            "candidate_name": "AT2021fxy",
            "tns_name": "AT2021fxy",
            "tns_url": "https://www.wis-tns.org/object",
            "discovery_date": "2021-03-17T17:23:37.000",
            "discovery_magnitude": 18.0,
            "magnitude_unit": "ab_mag",
            "magnitude_bandpass": "r"
        }
    ]
}
```



# GW Treasure Map



## Visualization:

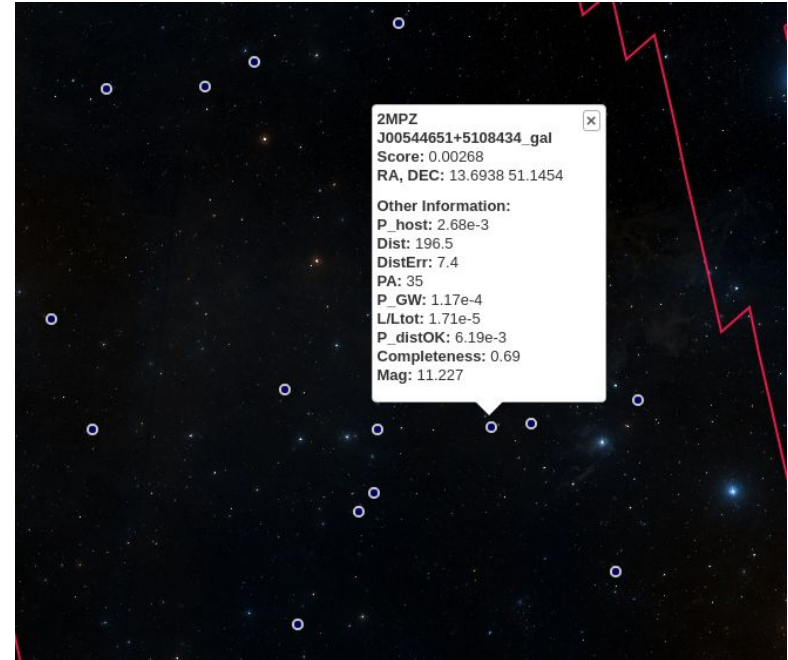
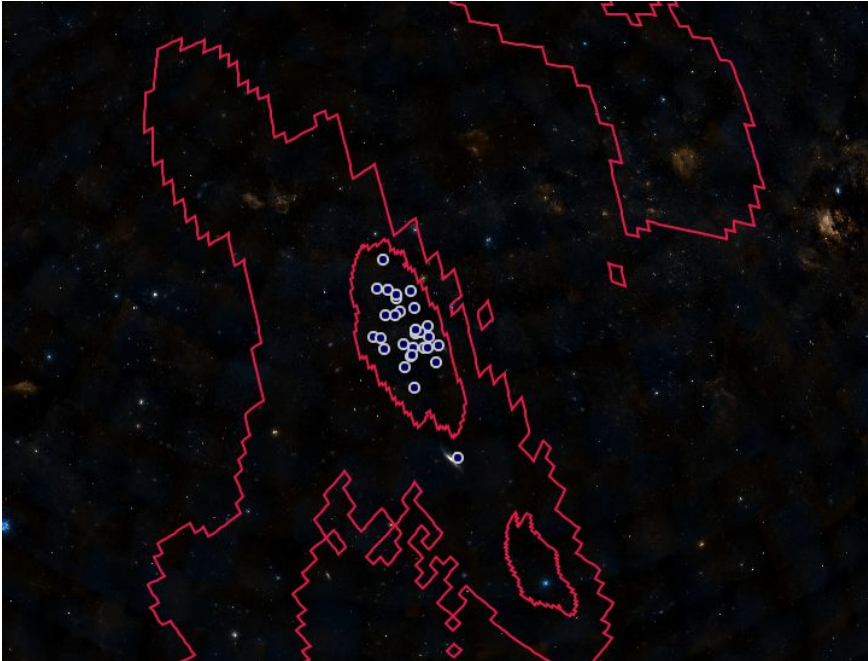
- Interactive ALADIN
  - (BIL, Color Maps, Scroll, Zoom)
- Toggle 90/50 contours and instrument footprints
- Filter pointings
  - (date, range, completed, planned, etc)
- Overlay source info:
  - Convolved Galaxies
  - Icecube Nu Track alerts
  - Candidates



# GW Treasure Map



## Visualization: Galaxy or Source Information

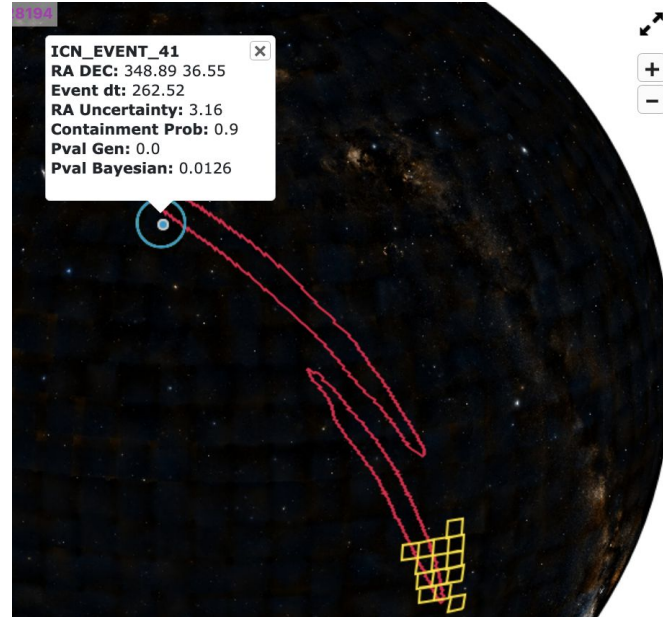


# GW Treasure Map



- Ingest [gcn.notices.icecube.lvkn.gov/track\\_search](https://gcn.notices.icecube.lvkn.gov/track_search) alerts.
  - Coincident neutrino signal detections within 1000s of GW event
- Only displayed on visualization at the moment, API GET endpoints coming soon.

S230924an <b>P</b> <b>P1</b> <b>I</b> <b>U</b> ❄️	BBH: (100.0%)
S230922q <b>P</b> <b>P1</b> <b>I</b> <b>U</b> ❄️	BBH: (100.0%)



🔗 Follow-Up

+  Instruments  
-   CSS

▾  GRB Coverage

Sources

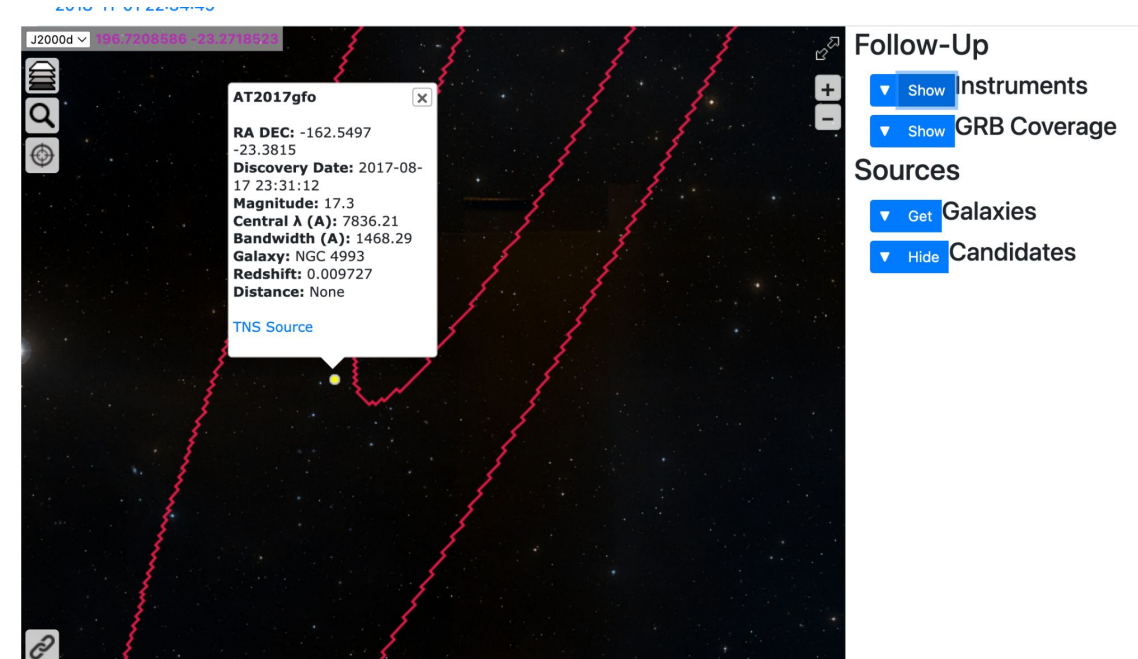
▾  Galaxies  
▾  XRT Sources  
▶  ICECUBE Notice

- ICECUBENotice235
- ICECUBENotice236
- ICECUBENotice243



# GW Treasure Map

## Visualization: Counterpart Candidates

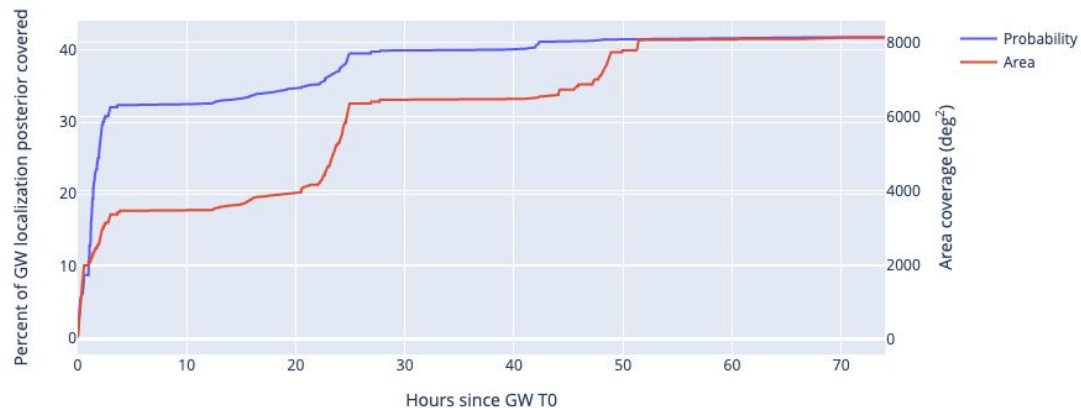


# GW Treasure Map



## Coverage Calculator

- Calculates the follow-up coverage of the GW localization over time.
- Can limit the coverage calculation based on:
  - Instruments, wavelengths, depths, etc



Instrument  Band  Depth  Depth Unit

Approximate

Calculate



# GW Treasure Map



## Validation

- How to incentivize effort for covering lower-probability regions?
- Pointing DOI's via zenodo!
  - Digital Object Identifiers are citable
  - API endpoints requesting on submission, and post-facto

zenodo



Manage record

Published April 29, 2024 | Version v2

Dataset

Open

## Submitted Completed pointings to the Gravitational Wave Treasure Map for event S240422ed

Iair Arcavi<sup>1</sup>; D. Andrew Howell<sup>2</sup>; Curtis McCully<sup>3</sup>; Craig Pellegrino<sup>2</sup>;  
Giacomo Terreran<sup>2</sup>; Megan Newsome<sup>2</sup>; Joseph Farah<sup>2</sup>;  
Estefania Padilla Gonzalez<sup>2</sup>; Moira Andrews<sup>2</sup>; Ido Keinan<sup>1</sup>

Show affiliations

Attached in a .json file is the completed pointing information for 306 observation(s) for the EM counterpart search associated with the gravitational wave event S240422ed. These observations were taken on the Sinistro, and MuSCAT instruments.

## Files

completed\_pointings\_S240422ed.json

```
[
  {
    "id": 43454,
    "status": "completed",
    "position": "POINT (124.485756666667 -16.2356622222222)",
    "galaxy_catalog": ""
  }
]
```

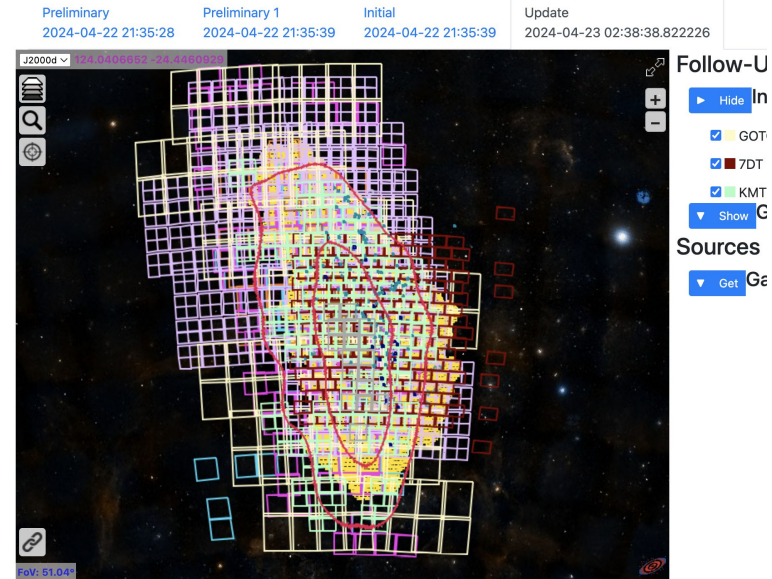


# GW Treasure Map



- **S240422ed** (an interesting O4 event!)
  - ~2200 completed pointings, up to ~5days after t0.
  - ~70% prob covered within first 6 hours of event at a depth of 20.5mag
  - ~90% covered within first 24hr for all pointings.
- These pointings were submitted in near real-time

Gravitational Wave Localization and Pointings: S240422ed [[GraceDB](#)]





# GW Treasure Map



IAW  
IAAP  
pace

## Current work:

- **NOW RELEASED:** python API wrapper: `gwtm_api`
- Encompasses most API endpoints for the GWTM in an easier to manage python library (stable)
- Extended capability for follow-up tools as well:
  - visualization, coverage-calc, map renormalization, candidate coverage, more to come!
- [https://github.com/TheTreasureMap/gwtm\\_api](https://github.com/TheTreasureMap/gwtm_api)

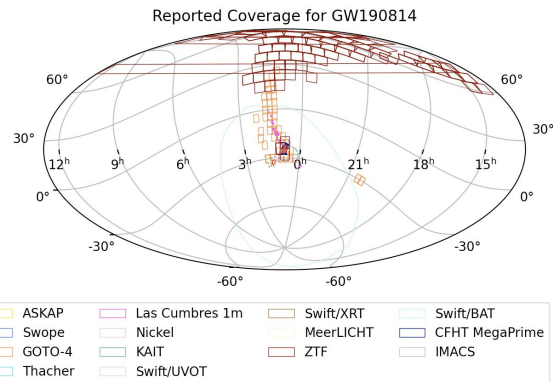
## Event Tools

For a given GW event, you can utilize the the `event_tools` library to perform some analytics of a GW event with the data supported on the Treasure Map.

## Visualizing coverage

```
import gwtm_api

gwtm_api.event_tools.plot_coverage(graceid="GW190814", api_token=API_TOKEN)
```



The `plot_coverage` function allows you to pass in your own list of pointings, along with caching the queried results so you don't have to hit the API for large queries every time.

```
conda create -n gwtm_api python=3.11
conda activate gwtm_api
python -m pip install gwtm_api
```

# GW Treasure Map: What's next for O4



- **Future Implementations**

- Scheduling suggestions
  - Provide observers with unobserved areas to tile/search with a given instrument footprint
- Support Candidate follow-up
  - Photometry
  - Spectroscopy

- **Community feature suggestions**

- We want to hear from our users as O4 is ongoing for desired functionality



# Could GW190425 have been detected?



- <https://arxiv.org/pdf/2405.17558>

## Coordinated Followup Could Have Enabled the Discovery of the GW190425 Kilonova

IDO KEINAN<sup>1</sup> AND IAIR ARCAVI<sup>1</sup>

<sup>1</sup>*The School of Physics and Astronomy, Tel Aviv University, Tel Aviv 69978, Israel*

### ABSTRACT

The discovery of a kilonova associated with the GW170817 binary neutron star merger had far-reaching implications for our understanding of several open questions in physics and astrophysics. Unfortunately, since then, only one robust binary neutron star merger was detected through gravitational waves, GW190425, and no electromagnetic counterpart was identified for it. We analyze all reported electromagnetic followup observations of GW190425 and find that while the gravitational-wave localization uncertainty was large, most of the 90% probability region could have been covered within hours had the search been coordinated. Instead, more than 5 days after the merger, the unco-



# Could GW190425 have been detected?



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The discovery of a kilonova associated with the GW170817 binary neutron star merger had far-reaching implications for our understanding of several open questions in physics and astrophysics. Unfortunately, since then, only one robust binary neutron star merger was detected through gravitational waves, GW190425, and no electromagnetic counterpart was identified for it. We analyze all reported electromagnetic followup observations of GW190425 and find that while the gravitational-wave localization uncertainty was large, most of the 90% probability region could have been covered within hours had the search been coordinated. Instead, more than 5 days after the merger, the unco-

ordinated search could not have been conducted by the search.

### 4. SUMMARY AND CONCLUSIONS

We analyzed all reported ultraviolet, optical and infrared followup observations of GW190425, the only robust BNS merger detected since GW170817, and showed that:

1. Roughly 75% of the localization region of GW190425 was accessible at the time of the trigger due to sun and moon constraints.
2. Enough observational resources were invested in the followup of GW190425 to allow the accessible part of the 90% probability region to have been covered potentially in a few hours. Instead, several regions were observed over 100 times, while others were never observed, and more than 5 days after the merger, only 50% of the probability was covered.
3. Even if the GW190425 kilonova were 3–4 magnitudes fainter than the GW170817 kilonova in its optical peak, it could still have been detected. According to more conservative models without a blue emission component, the kilonova might have been only marginally detected around peak.

# Conclusions



- **Takeaways:**
  - This utility is only as strong as its user base
  - This infrastructure won't solve all of GW MMA problems, but can optimize discovery
  - **Observing strategies in O4 are being reported in ~real-time!**
- Any Questions?

[samuel.d.wyatt@nasa.gov](mailto:samuel.d.wyatt@nasa.gov)



# Motivations

## How to Avoid Unnecessary Overlap in EM Searches?

### Desired Scenario:

Resources are put to good use to cover more of the probability region.

Early (or entire) kilonova is found! 😊



# GW Treasure Map



- Highlighted Results from O3
  - ~27,000 completed pointings reported for O3

Instruments Reporting

Name	Pointings reported
<a href="#">Swift X-ray Telescope</a>	7803
<a href="#">Swift Ultraviolet/Optical Telescope</a>	6625
<a href="#">Gravitational-wave Optical Transient Observer (GOTO-4 prototype)</a>	2714
<a href="#">ZTF</a>	2586
<a href="#">Swope</a>	1011
<a href="#">MLS10KCCD-CSS</a>	980
<a href="#">Sinistro</a>	728
<a href="#">Thacher ACP Camera</a>	337
<a href="#">Nickel Direct Camera</a>	315
<a href="#">J-GEM/Subaru/Hyper Suprime-Cam</a>	240
<a href="#">Katzman Automatic Imaging Telescope</a>	213
<a href="#">MMTCam</a>	119



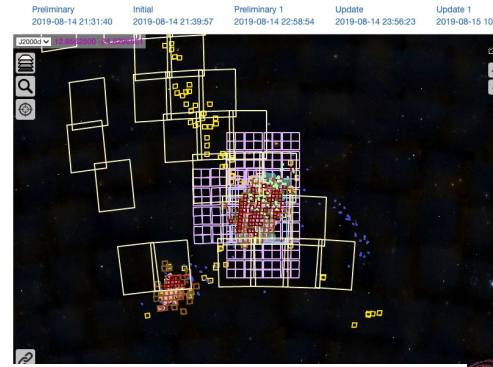
# GW Treasure Map



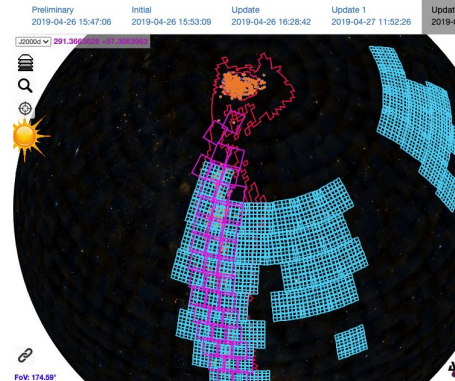
- Highlighted results from O3

- GW190930\_133541:
    - 91% posterior + 2200sq deg covered
    - 330 pointings
  - GW190814:
    - 98% posterior + 700sq deg covered
    - 4000 pointings
  - GW190426\_152155:
    - 75% posterior + 2800sq deg covered
    - 2270 pointings
  - GW190425:
    - 42% posterior + 8100sq deg
    - 2100 pointings
- \*\*All pointings were reported post-facto

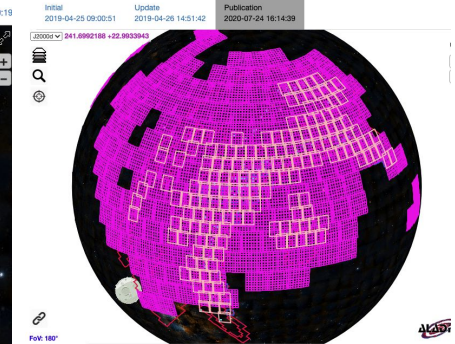
Gravitational Wave Localization and Pointings: GW190814 [GraceDB]



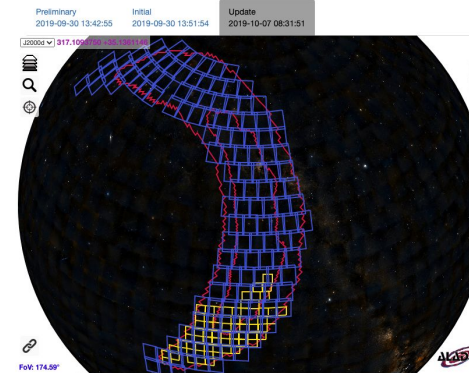
Gravitational Wave Localization and Pointings: GW190426\_152155 [GraceDB]



Gravitational Wave Localization and Pointings: GW190425 [GraceDB]



Gravitational Wave Localization and Pointings: GW190930\_133541 [GraceDB]

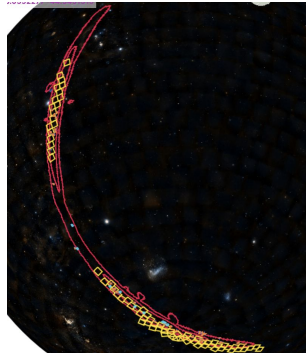




# GW Treasure Map



- Highlighted results from O4...
  - ~2000 completed pointings reported for O4
  - ~60 planned pointings
- ... S230518h:
  - 23% posterior + 180sq deg
  - 459 pointings (4 instruments)
- What about Depth?
  - Significant BNS  $>0$  + HasNS
    - 4 events ~265Mpc
    - 265Mpc Kilonova (15.5abs = 21.6app)
  - Average O4 depth:
    - ~20.6 mag (i band)
    - ~21.6 mag (g band)



## Reporting Instruments

Name	Pointings reported
ZTF	356
MeerLICHT	342
MLS10KCCD-CSS	299
DECam	251
T80S_T80S-Cam	68
Swift X-ray Telescope	54
Swift Ultraviolet/Optical Telescope	54
Swope	9



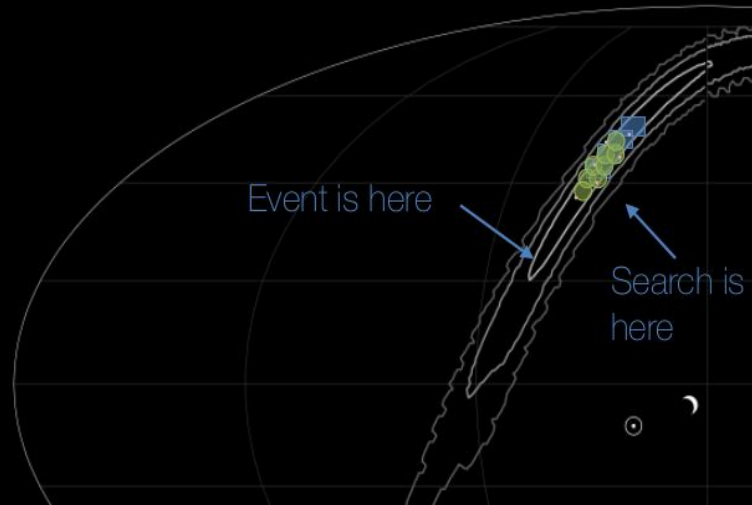
# Motivations

## How to Avoid Unnecessary Overlap in EM Searches?

### Typical Scenario:

Everyone observes the highest probability region.

Early (or entire) kilonova is missed ☹️



# GW Treasure Map



- **Currently**

- O4 is happening currently.
  - We listen to all alerts (Significant/Subthreshold/test). Any teams who follow-up these events are encouraged to post their follow-up strategies
- Listening to IceCube alerts

## Gravitational Wave Events

Observing Run O4 Role Test

Type something in the input field to search the table for GW Event Names or Classifications:

Click on an alert name to see its visualization

Alert	Classification	Distance (Mpc)	# Pointings
<a href="#">MS230413e</a>	BNS: (100.0%)	125.96 +/- 43.96	0
<a href="#">MS230413d</a>	BNS: (100.0%)	168.89 +/- 46.81	0
<a href="#">MS230413c</a>	BNS: (100.0%)	151.52 +/- 45.04	0
<a href="#">MS230413b</a>	BNS: (100.0%)	108.98 +/- 29.86	0
<a href="#">MS230413a</a>	BNS: (100.0%)	79.16 +/- 18.14	0
<a href="#">MS230412x</a>	BNS: (100.0%)	93.64 +/- 23.71	0
<a href="#">MS230412w</a>	BNS: (100.0%)	67.7 +/- 17.76	0
<a href="#">MS230412v</a>	Retracted		0



# Could GW190425 have been detected?



- <https://arxiv.org/pdf/2405.17558>

Real-time coordination in such a competitive field, requiring rapid response, is challenging. Tools like the **Treasure Map** have been built exactly to overcome this challenge. We encourage the community to report their pointings to the **Treasure Map**, and to use the information there to guide their search, even if it means searching lower probability areas (instead of contributing the 100th observation to a higher probability region).

