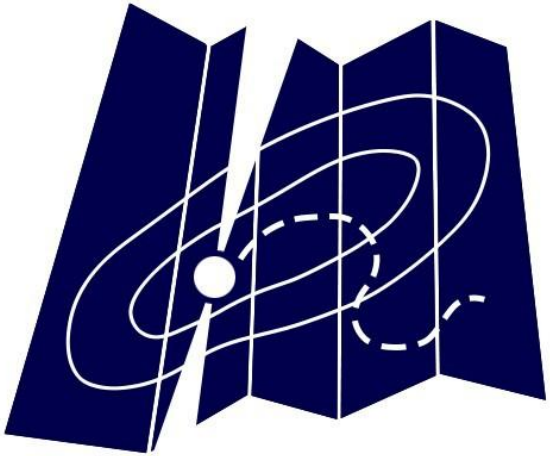
AstroColibri Workshop 09/17/2024



THE GRAVITATIONAL WAVE
TREASURE MAP
treasuremap.space

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

Treasure Map Team

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Andy Howell
Curtis McCully

Motivations

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

Discovery is key

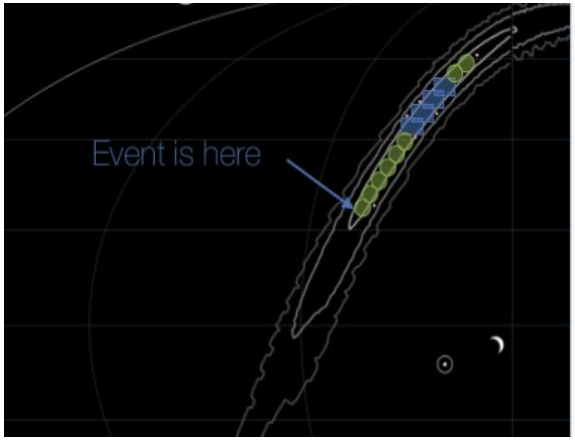
Motivations

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

Discovery is key

GW Treasure Map

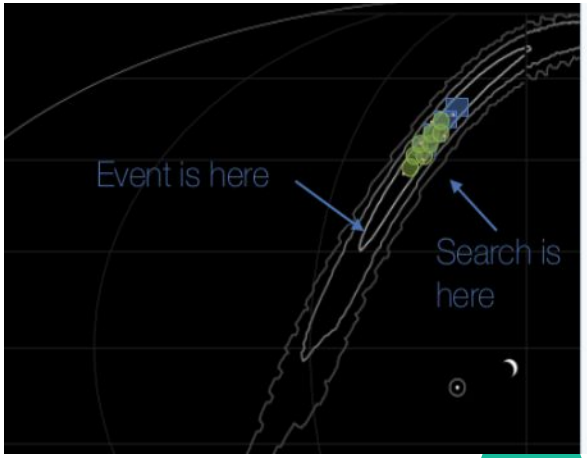
- Ideal Search Scenario
  - Team A submits their planned observations
  - Team B queries Team A's observation strategy via the API, and plans their search around Team A, while also submitting to the Treasure Map



This

vs.

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.**

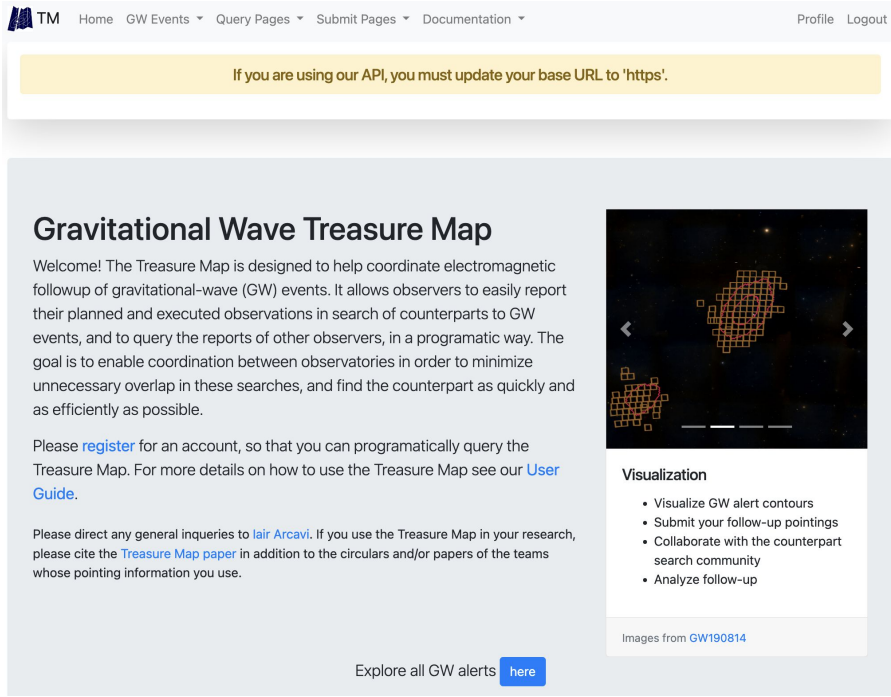
Motivations

THE GRAVITATIONAL WAVE TREASURE MAP
treasuremap.space

If we build it…

GW Treasure Map

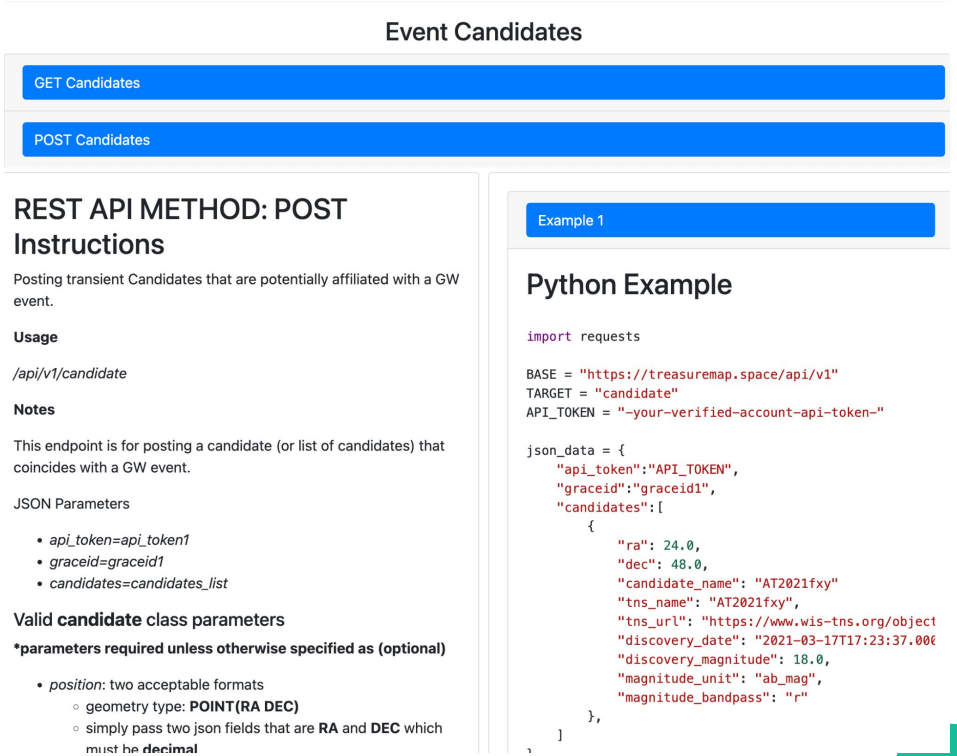
- **Web Based application**
  - User interface+REST API
  - ALADIN visualization interface (does not require account)
  - Web page querying and submitting for:
    - Instruments, Pointings
      - any submission requires Account registration
- API
  - **Account Registration is required**
  - Fully documented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



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"
        },
    ]
```

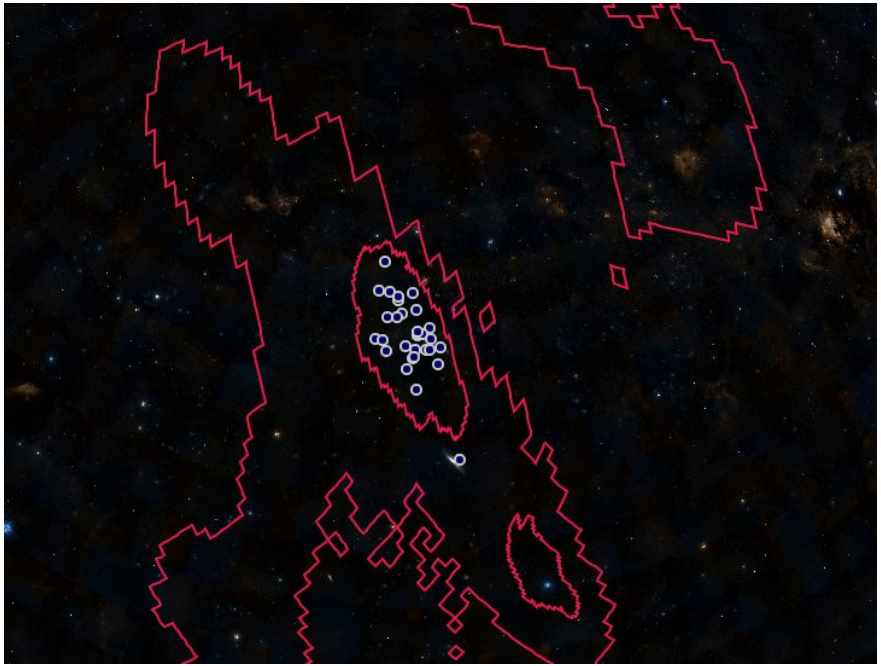
GW Treasure Map

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

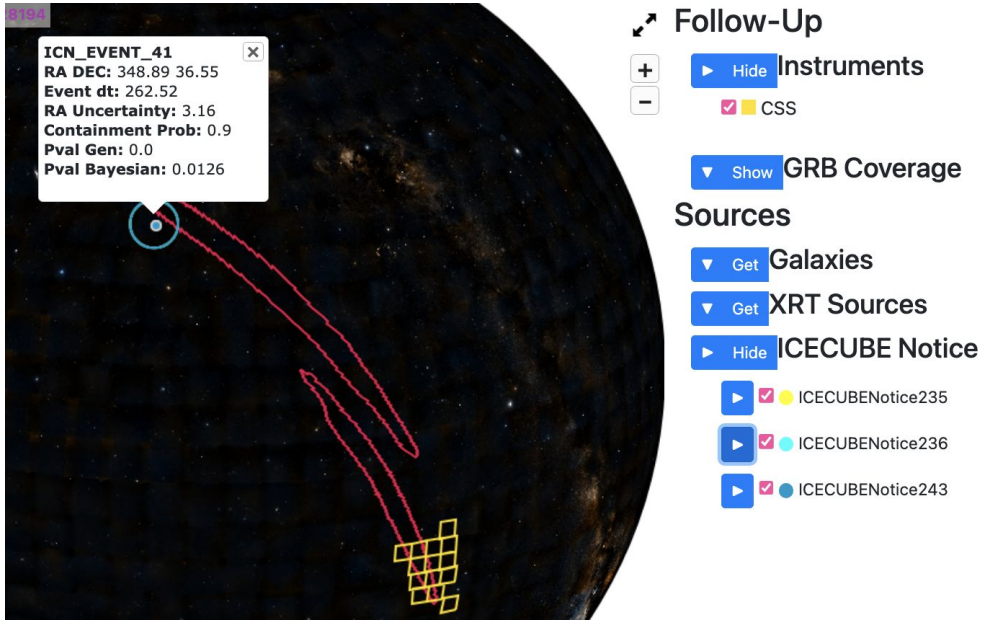
Visualization: Galaxy or Source Information



GW Treasure Map

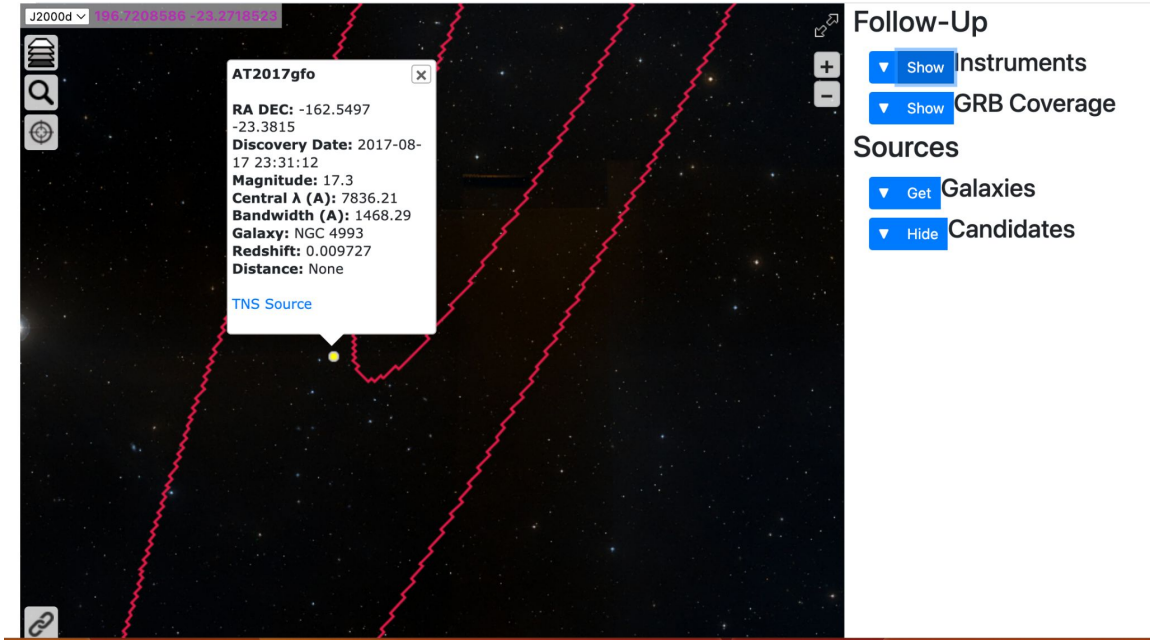
- Ingest *gcn.notices.icecube.lvk_nu_track_search* alerts.
  - Coincident neutrino signal detections within 1000s of GW event
- Only displayed on visualization at the moment, API GET endpoints coming soon.

S230924an P P1 I U	BBH: (100.0%)
S230922q P P1 I U	BBH: (100.0%)



GW Treasure Map

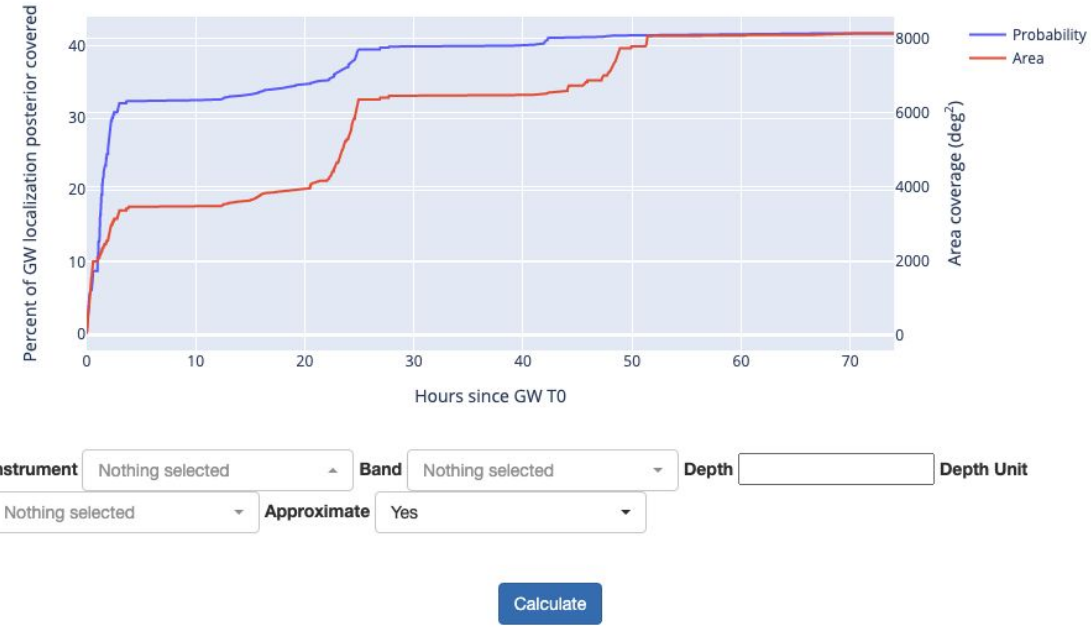
Visualization: Counterpart Candidates



GW Treasure Map

Coverage Calculator

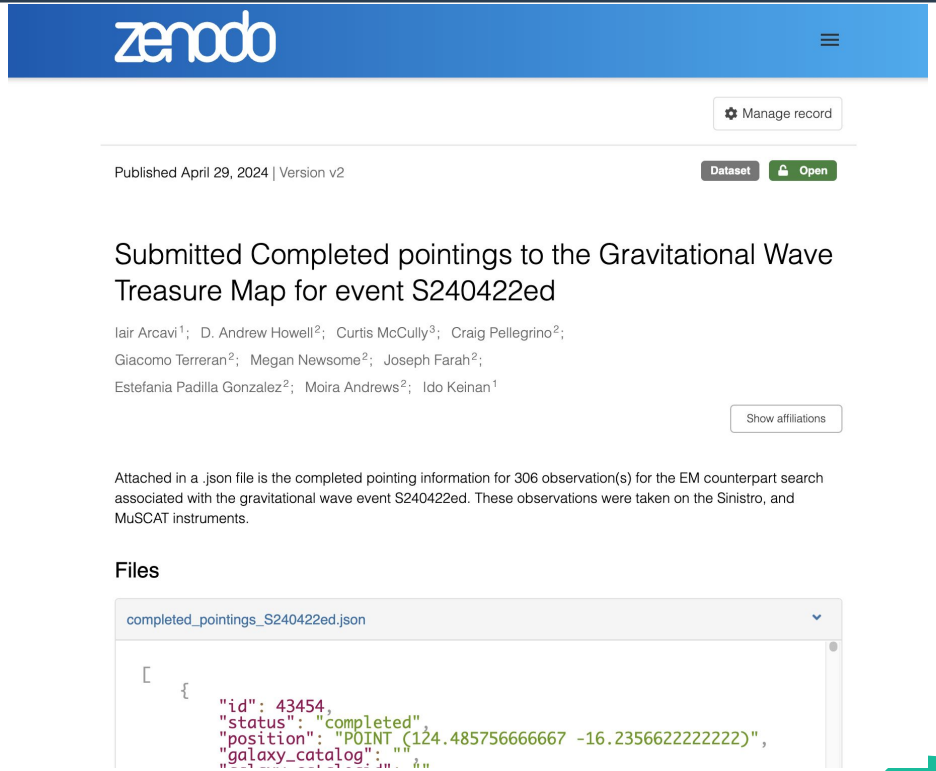
- Calculates the follow-up coverage of the GW localization over time.
- Can limit the coverage calculation based on:
  - Instruments, wavelengths, depths, etc



GW Treasure Map

Validation

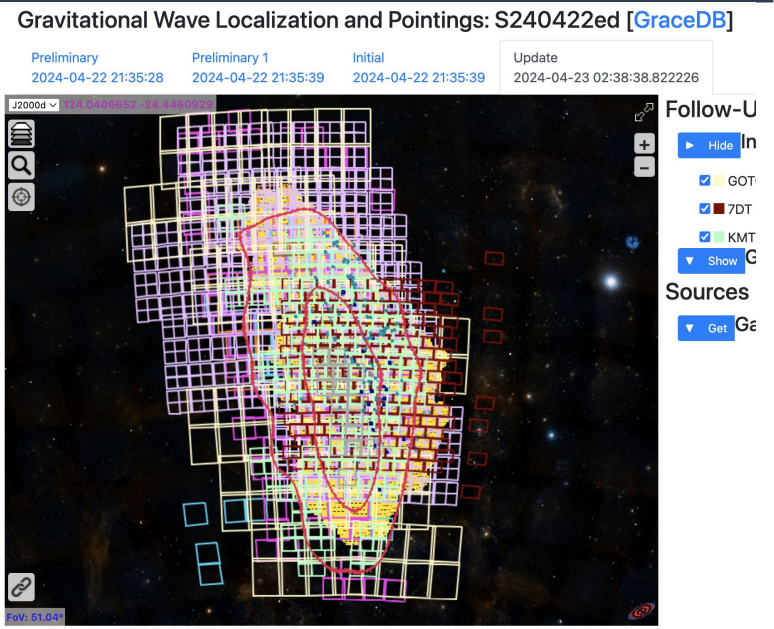
- How to incentivize effort for covering lower-probability regions?
- Pointing DOI's via zenodo!
  - Digital Object Identifiers are citable
  - API endpoints requesting on submission, and post-facto



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**



GW Treasure Map

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

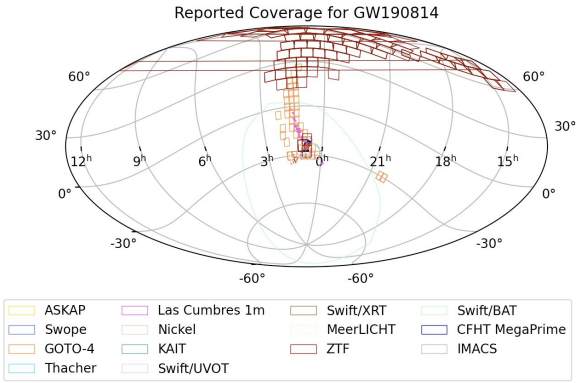
Event Tools

For a given GW event, you can utlize 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[1] and Iair Arcavi[1]

[1] *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-

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barely been detectable 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?

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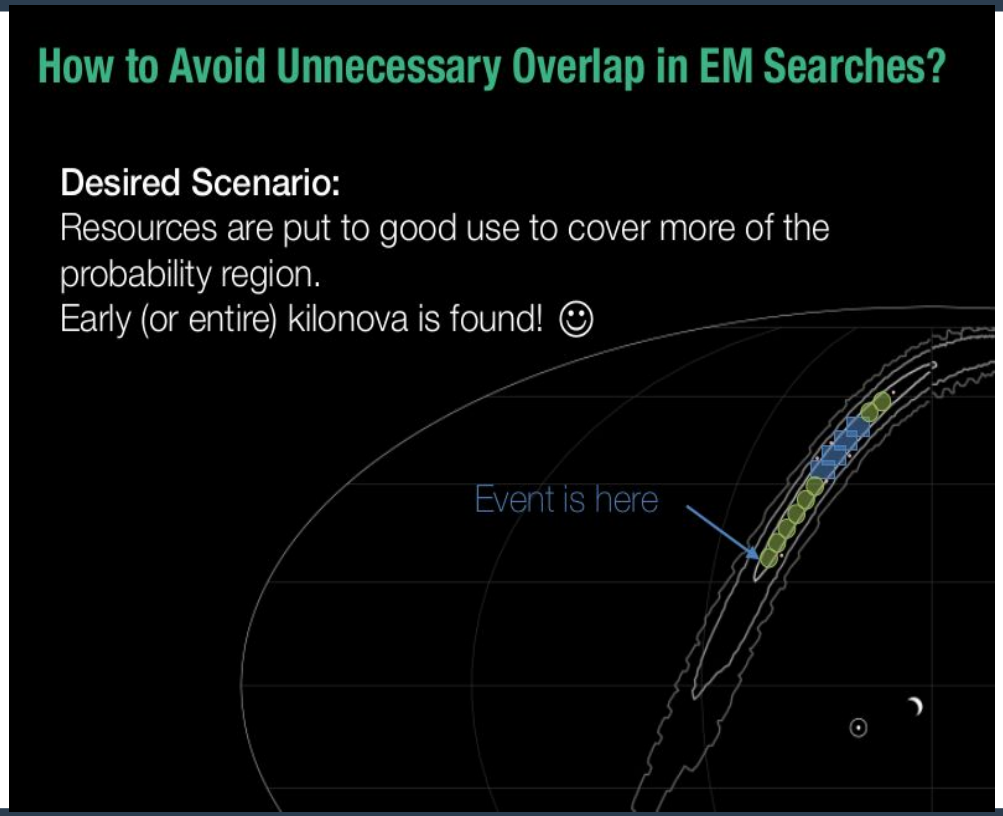
Motivations



GW Treasure Map

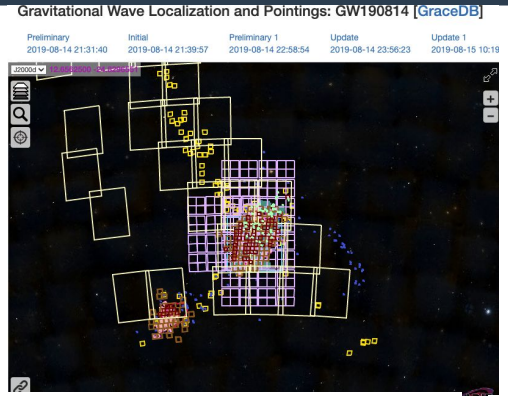
- Highlighted Results from O3
  - ~27,000 completed pointings reported for O3

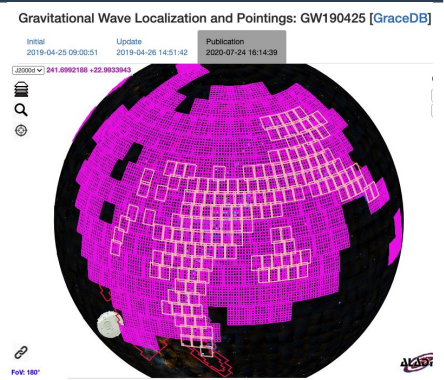
Instruments Reporting

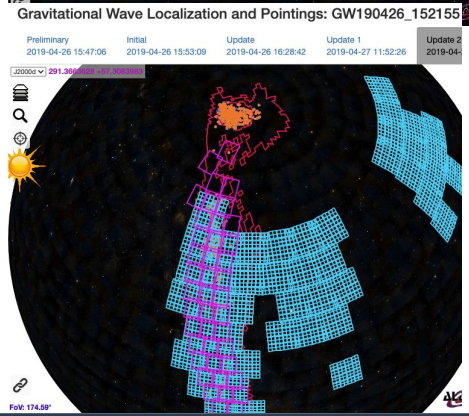
Name	Pointings reported
Swift X-ray Telescope	7803
Swift Ultraviolet/Optical Telescope	6625
Gravitational-wave Optical Transient Observer (GOTO-4 prototype)	2714
ZTF	2586
Swope	1011
MLS10KCCD-CSS	980
Sinistro	728
Thacher ACP Camera	337
Nickel Direct Camera	315
J-GEM/Subaru/Hyper Suprime-Cam	240
Katzman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

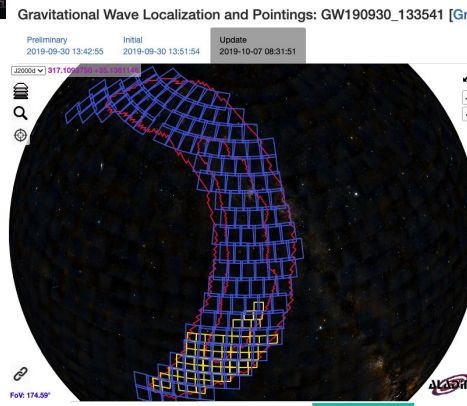
GW Treasure Map

- 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



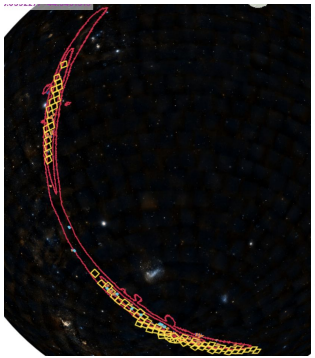






GW Treasure Map

- Highlighted results from O4…
  - ~2000 completed pointings reported for O4
  - ~60 planned pointings
- … **S230518h**:
  - 23% posterior + 180sq deg
  - 459 pointings (4 instruments)

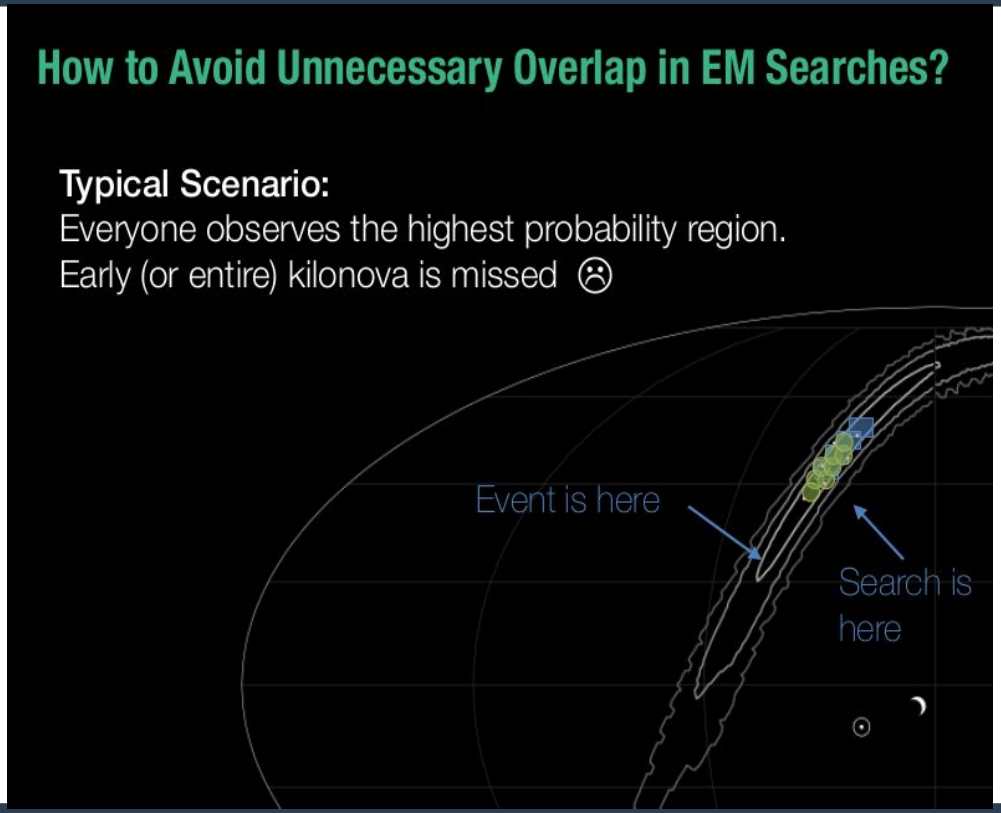


- What about Depth?
  - Significant BNS >0 + HasNS
    - 4 events ~265Mpc
    - 265Mpc Kilonova (15.5abs = 21.6app)
  - Average O4 depth:
    - ~20.6 mag (i band)
    - ~21.6 mag (g band)

Reporting Instruments

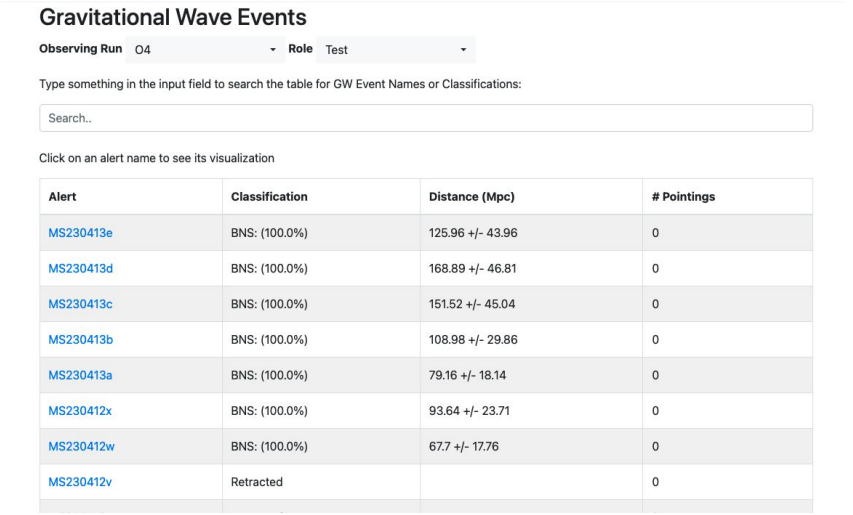
Name	Pointings reported
ZTF	356
MeerLICHT	342
MLS10KCCD-CSS	299
DECam	251
T80S_T80S-Cam	68
Swift X-ray Telescope	54
Swift Ultraviolet/Optical Telescope	54
Swope	9

Motivations



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:

Search..

Click on an alert name to see its visualization

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

Could GW190425 have been detected?

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> 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).