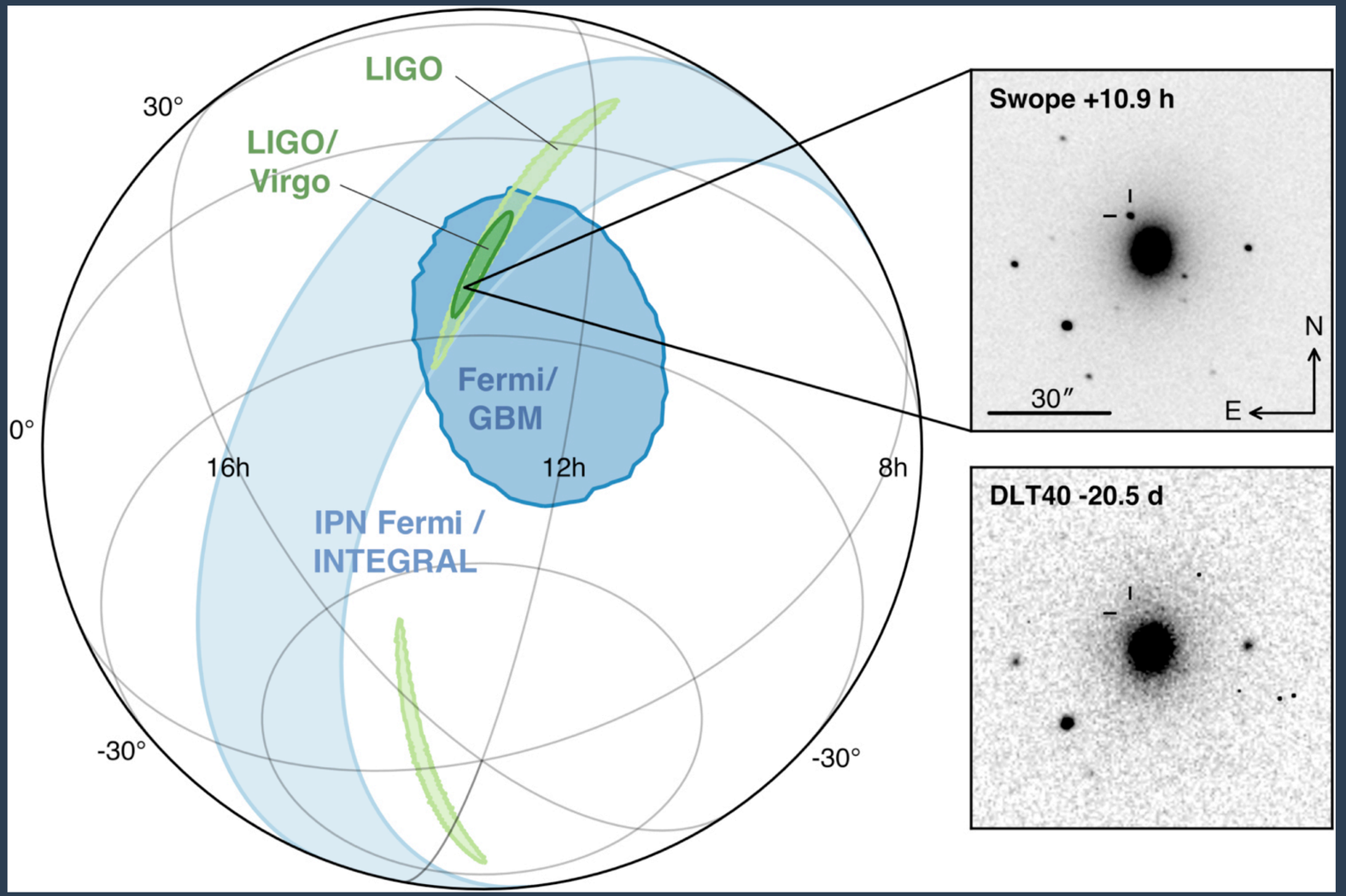
The Inefficiency of Uncoordinated Gravitational-Wave Followup

Iair ("ya-eer") Arcavi
Tel Aviv University

We Missed the GW190425 Kilonova Because We Didn't Coordinate

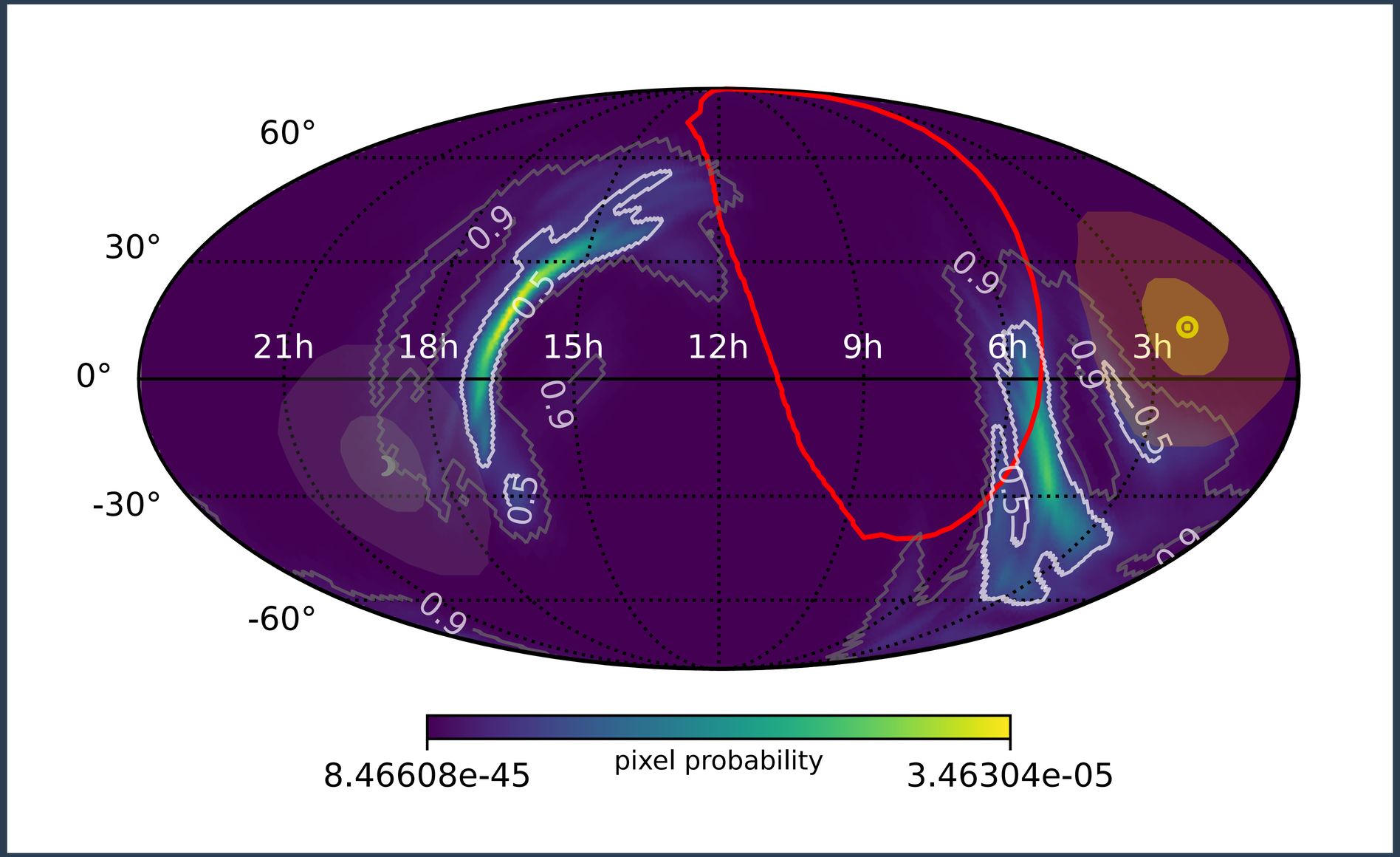
Iair ("ya-eer") Arcavi
Tel Aviv University

We Were Incredibly Lucky in 2017

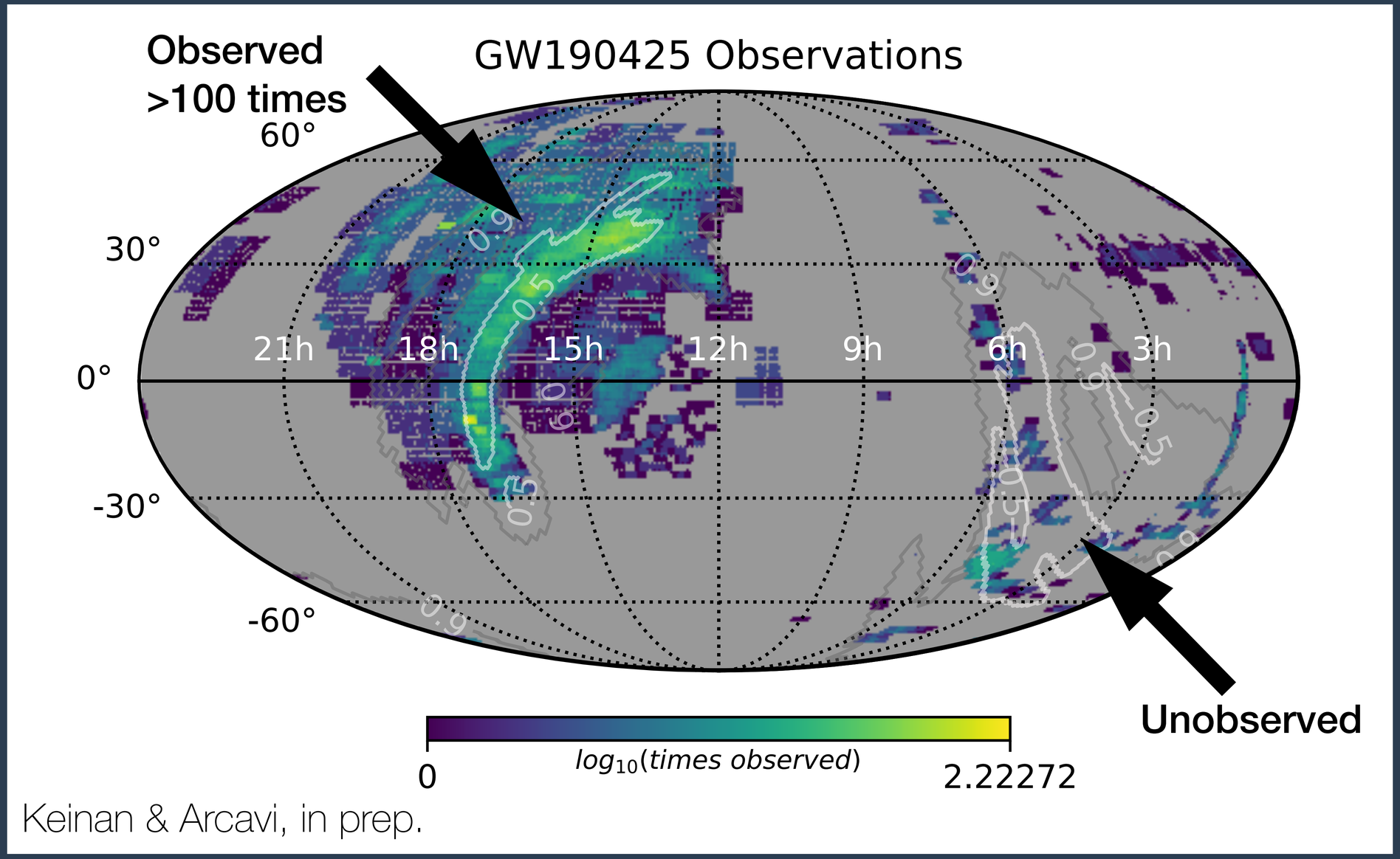


Abbott et al. 2017

GW190425 - The Only Confident BNS Merger Since 2017

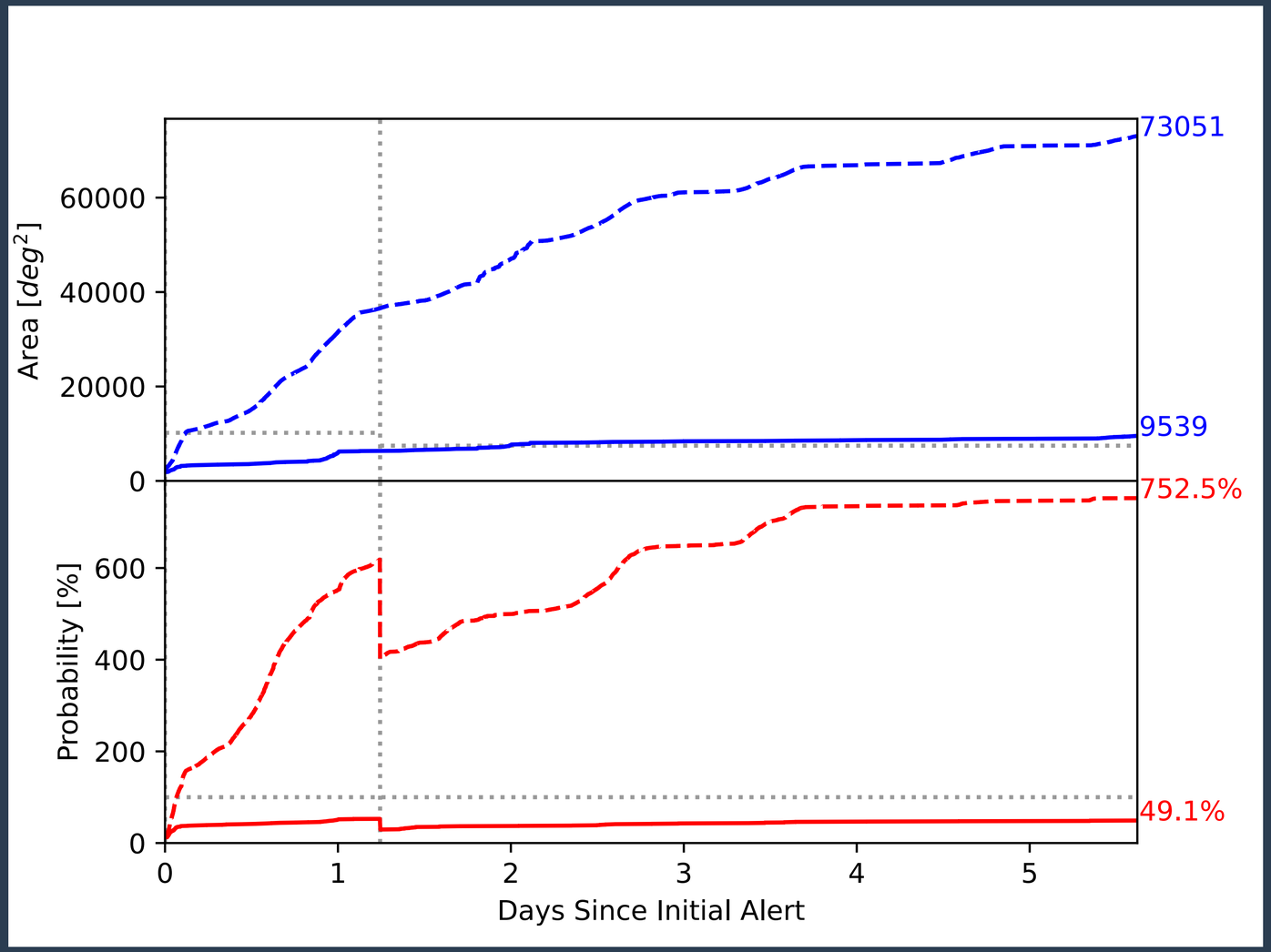


GW190425 - Non-Uniform Followup Coverage



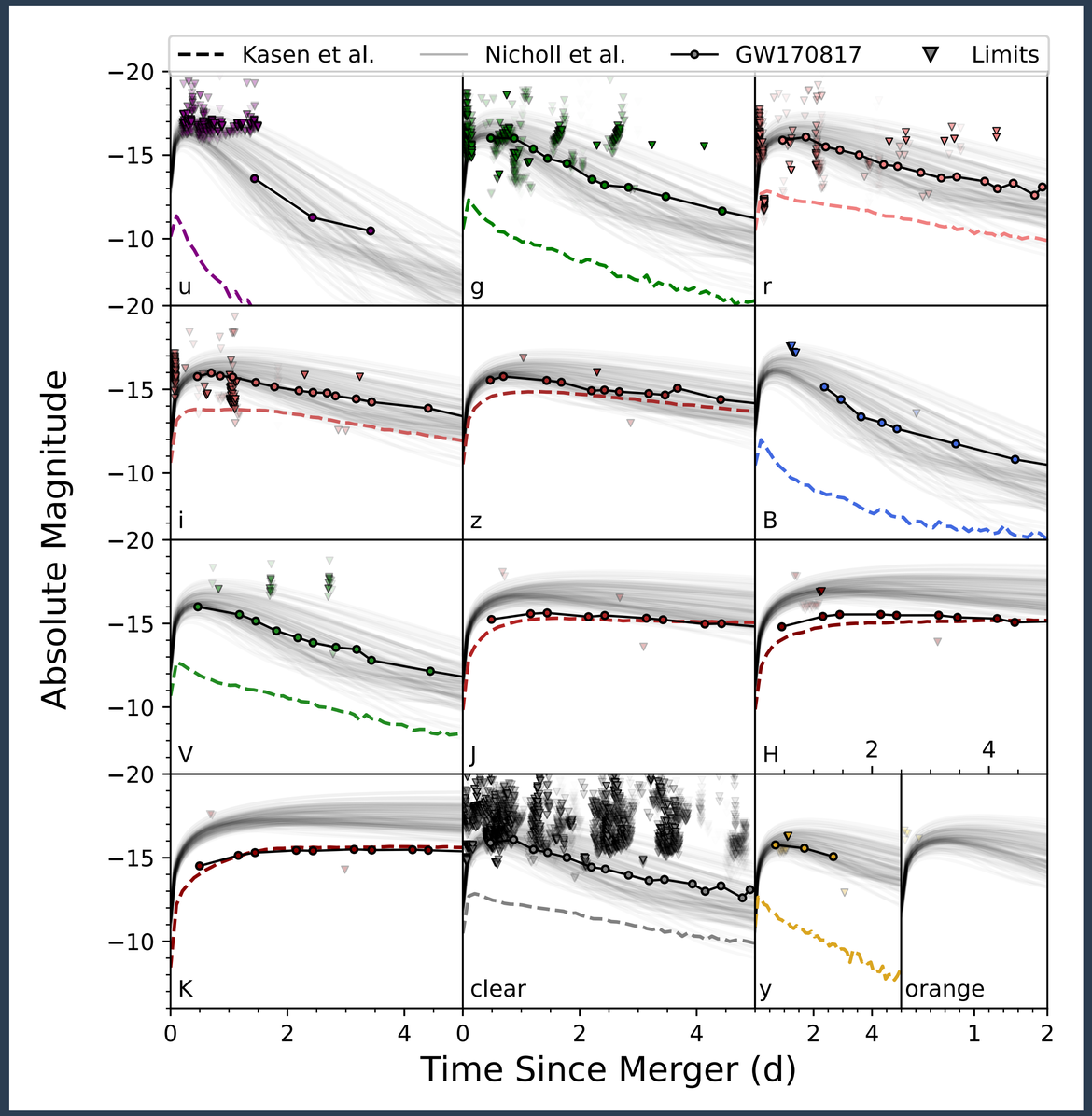
Keinan & Arcavi, in prep.

GW190425 - We Could Have Covered the 90% Localization in Hours



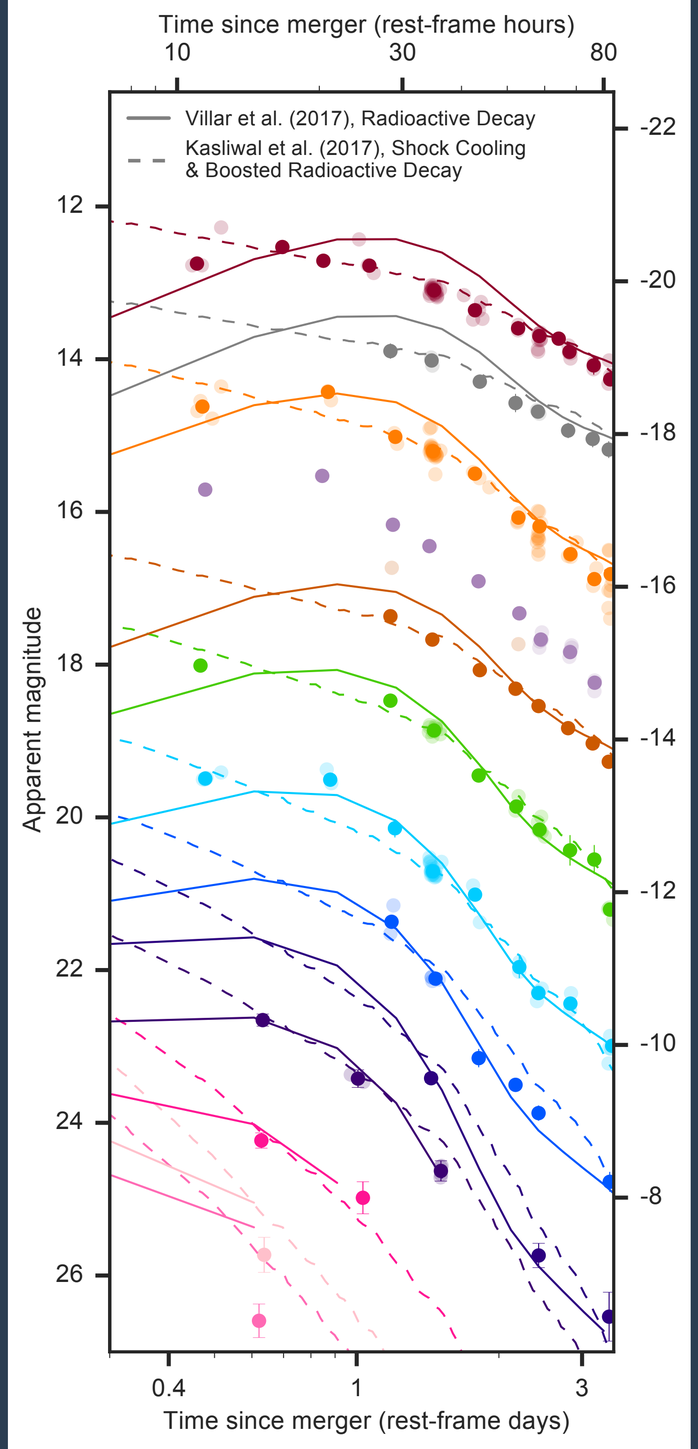
Keinan & Arcavi, in prep.

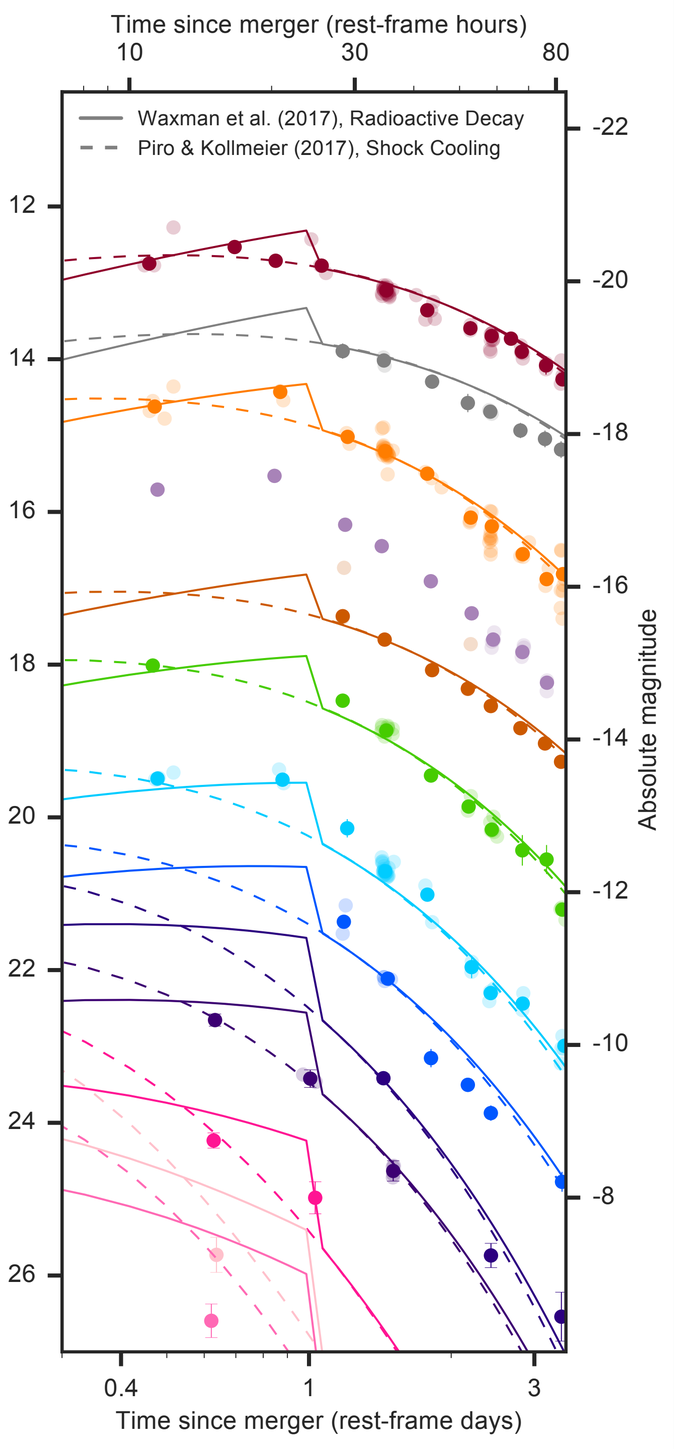
GW190425 - Might Have Seen the Kilonova



Keinan & Arcavi, in prep.

If we would have coordinated, we might have found the EM counterpart to GW190425, or at least better constrained models (and saved a lot of telescope time)

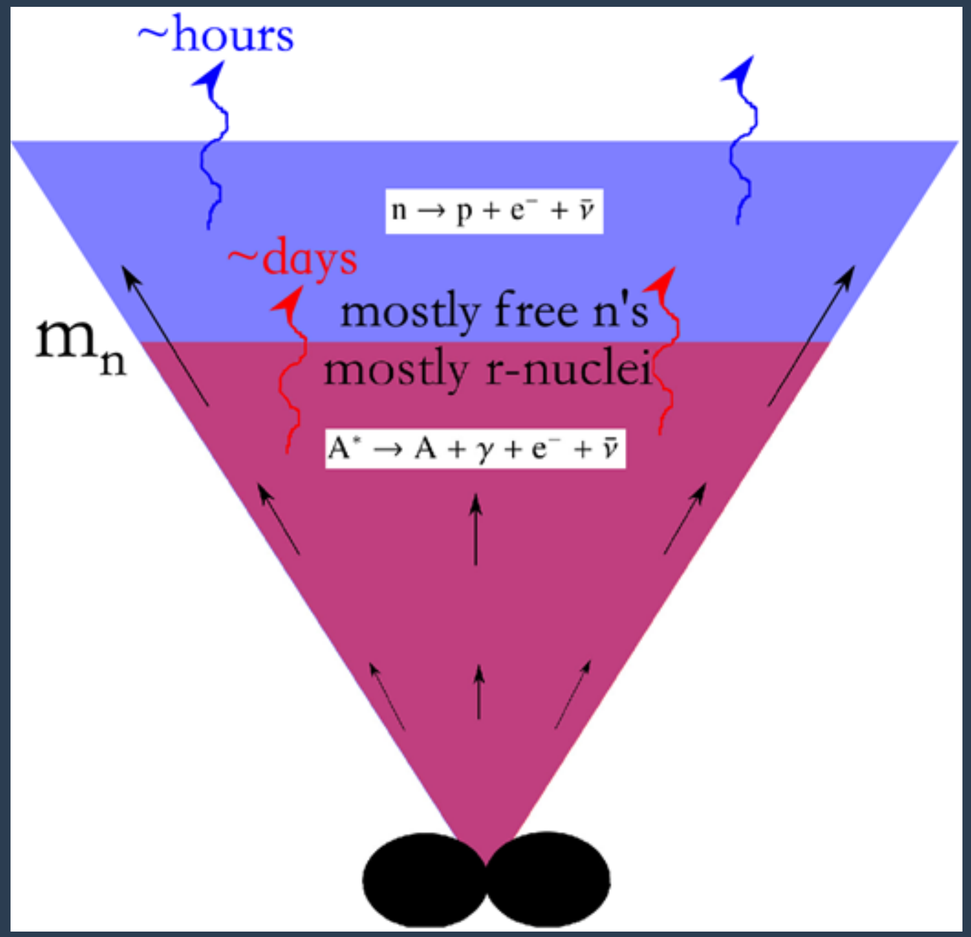


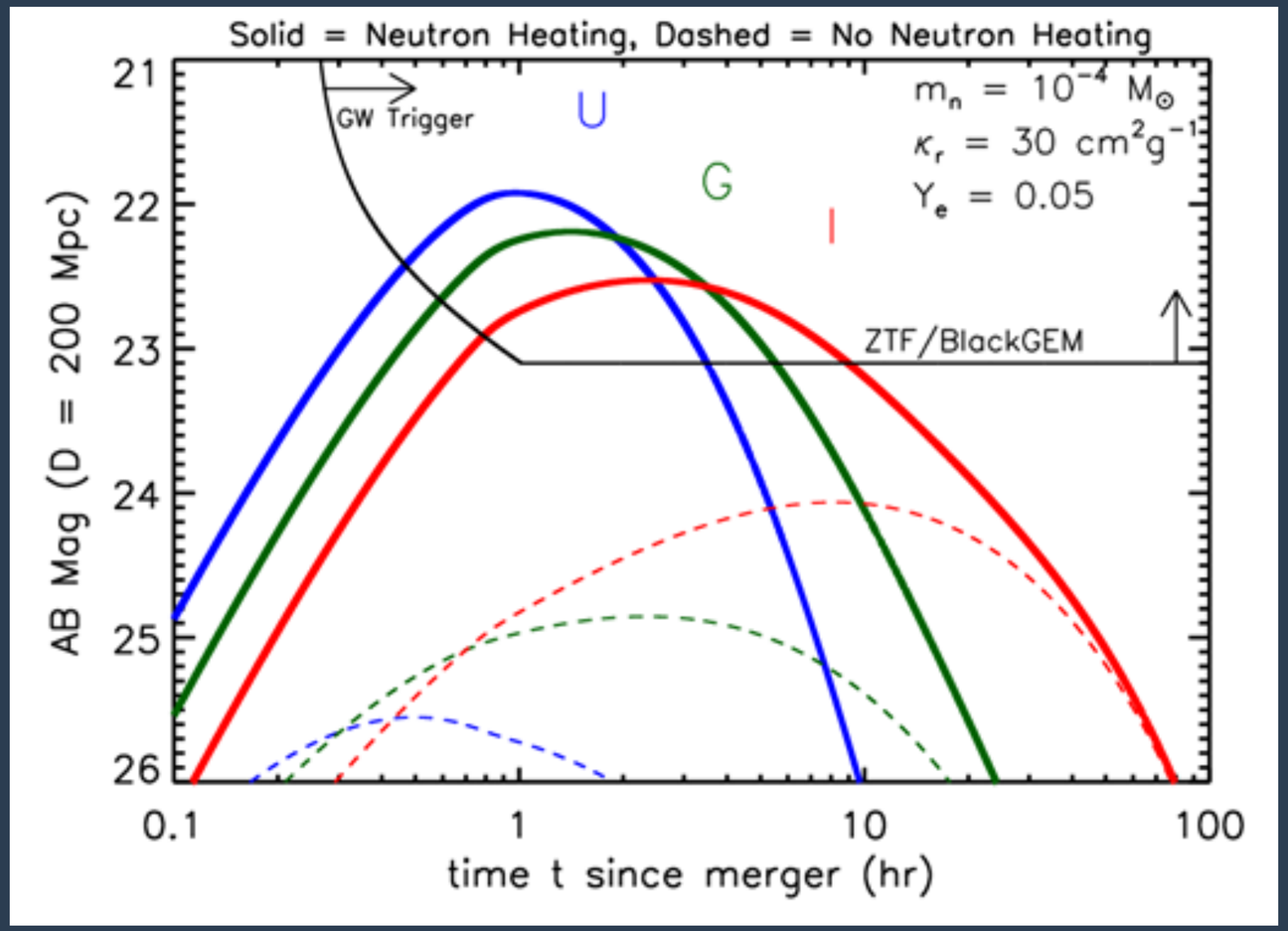


Competing models for the blue emission can be distinguished only <10 hours from merger

Arcavi 2018

Predicted One-Hour Time Scale Blue Emission





Metzger et al. 2015

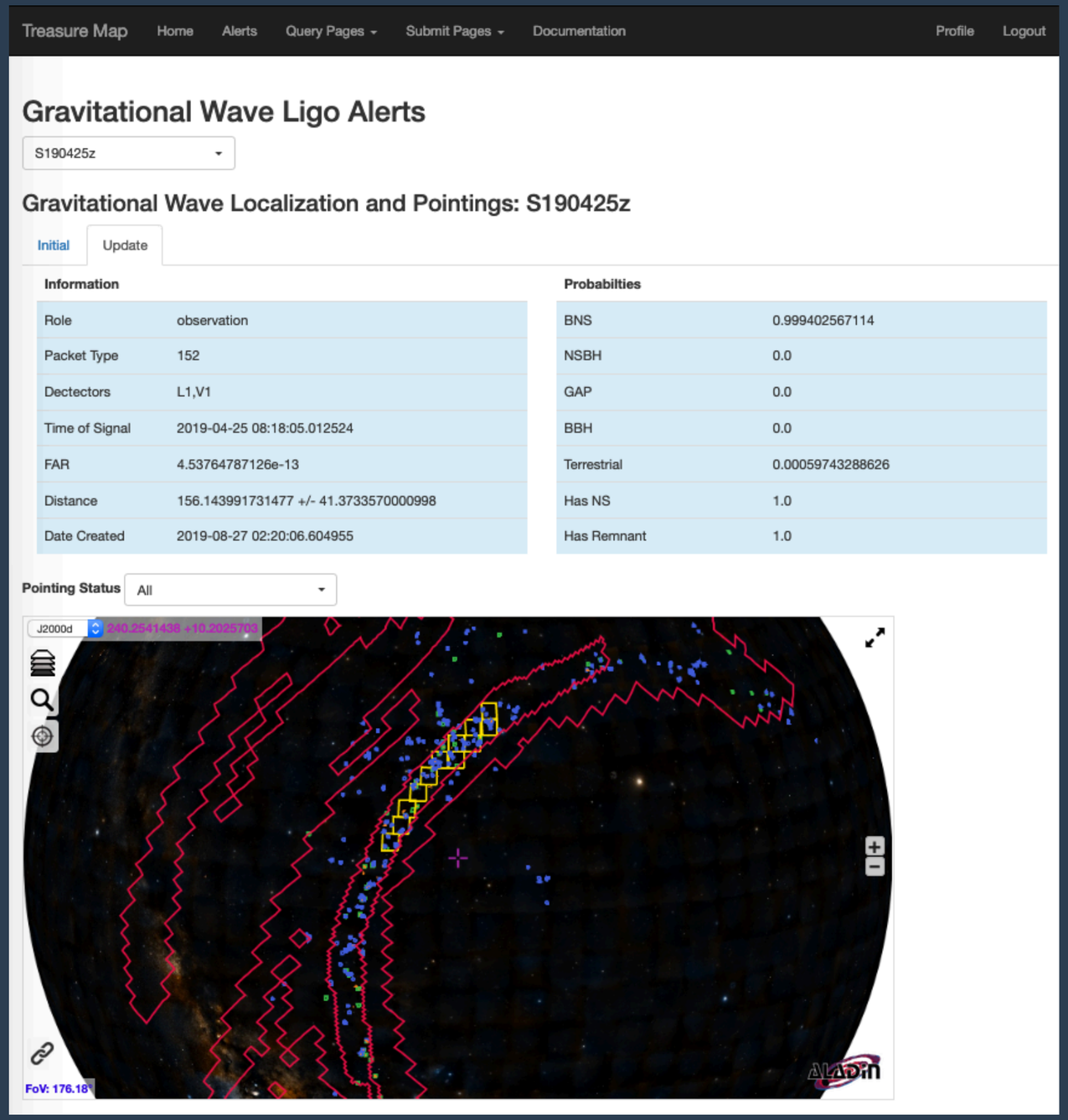
Optical-UV Observations
in the first ~hour
after a NS mereger
followed by sub-day cadence
ARE CRUCIAL

MUST coordinate to find the EM counterpart, and to find it fast

The “Treasure Map”

http://treasuremap.space

Report your pointings and retrieve other’s pointings (and other information) with one line of code + web visualization



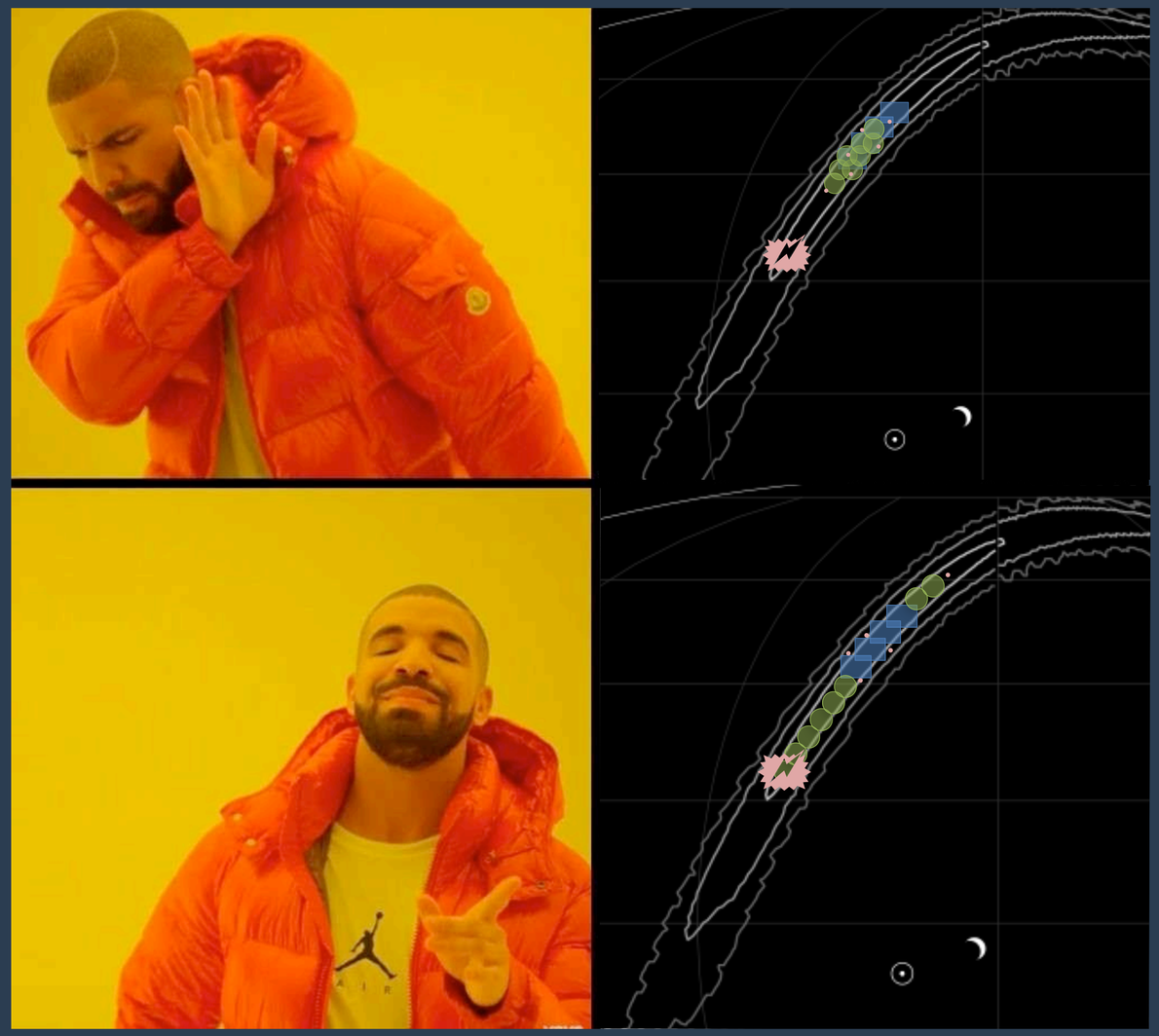
* **Sam Wyatt (U of Arizona)**
* **Aaron Tohuvavohu (U of Toronto)**
* And: Austin Riba (Pedal Driven Programming), Dave Sand & Michael Lundquist (U of Arizona), Andy Howell (Las Cumbres Observatory)

The “Treasure Map”

http://treasuremap.space

Ideal use case:

* **Team A** submits their planned & later executed observations.
* **Team B** sees Team A’s strategy and plans observations around them, instead of duplicating them, while submitting this as well.



The “Treasure Map” - Submit Your Instrument’s Footprint (once)

Instrument DECam

Information

Name: DECam

Short Name: None

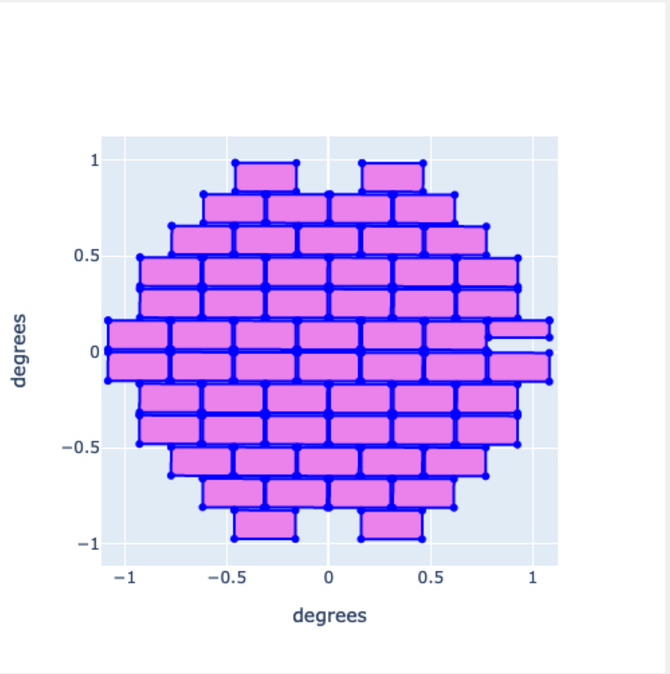
Type: photometric

Submitted User:gwtm

Events Contributed

Grace ID	Pointings

Footprint



The “Treasure Map” - Submit & See Planned / Completed Obs.

Search Pointings

Grace ID GW190425

Bandpasses All, U, B, V

Status All

Show Only My Pointings ☐ (required for DOI request)

Search

☐	ID	Position (RA, DEC)	Status	Instrument	Band	Depth	Position Angle	Time	Submitter	DOI
☐	569	POINT(-116.259003 21.938314)	planned	Sinistro	r	20.0	0.0	2019-04-25 09:40:58	gwtm	
☐	570	POINT(-116.259003 21.938314)	planned	Sinistro	g	20.0	0.0	2019-04-25 09:40:58	gwtm	
☐	571	POINT(-107.30542 4.604737)	planned	Sinistro	i	20.0	0.0	2019-04-25 09:40:58	gwtm	
☐	572	POINT(-107.30542 4.604737)	planned	Sinistro	r	20.0	0.0	2019-04-25 09:40:58	gwtm	
☐	573	POINT(-107.30542 4.604737)	planned	Sinistro	g	20.0	0.0	2019-04-25 09:40:58	gwtm	
☐	574	POINT(-108.522339 -23.451662)	planned	Sinistro	i	20.0	0.0	2019-04-25 09:40:58	gwtm	
☐	575	POINT(-108.522339 -23.451662)	planned	Sinistro	r	20.0	0.0	2019-04-25 09:40:58	gwtm	
☐	576	POINT(-108.522339 -23.451662)	planned	Sinistro	g	20.0	0.0	2019-04-25 09:40:58	gwtm	
☐	577	POINT(-107.611832 6.016252)	planned	Sinistro	i	20.0	0.0	2019-04-25 09:40:58	gwtm	

Submit Pointing

Planned ID pre-loads existing information for your planned pointings

Grace ID Select **Observation Status** Select

RA **DEC**

Instrument Select **Bandpass** Select

Depth **Depth Error** **Depth Unit** Select

Submit

The “Treasure Map” - Automate Reporting and Querying

```
TARGET = 'pointings'

#To post pointings you need to first declare the LIGO Gravitational graceid
graceid = 'TEST_EVENT'

#Set some parameters
ra, dec='256.','-12.'
time='2019-11-11T5:45:00.00'
instrumentid="11"

pointings = [
    {
        "status":"planned",
        "position":"POINT("+ra+" "+dec+")",
        "instrumentid":instrumentid,
        "pos_angle":20.0,
        "time":time,
        "band":"open",
        "depth":21.5,
        "depth_unit":'ab_mag'
    }
]

json_data = {
    "graceid":graceid,
    "api_token":api_token,
    "pointings":pointings
}
r = requests.post(url = BASE+'/'+TARGET, json = json_data)
print(r.text)
```

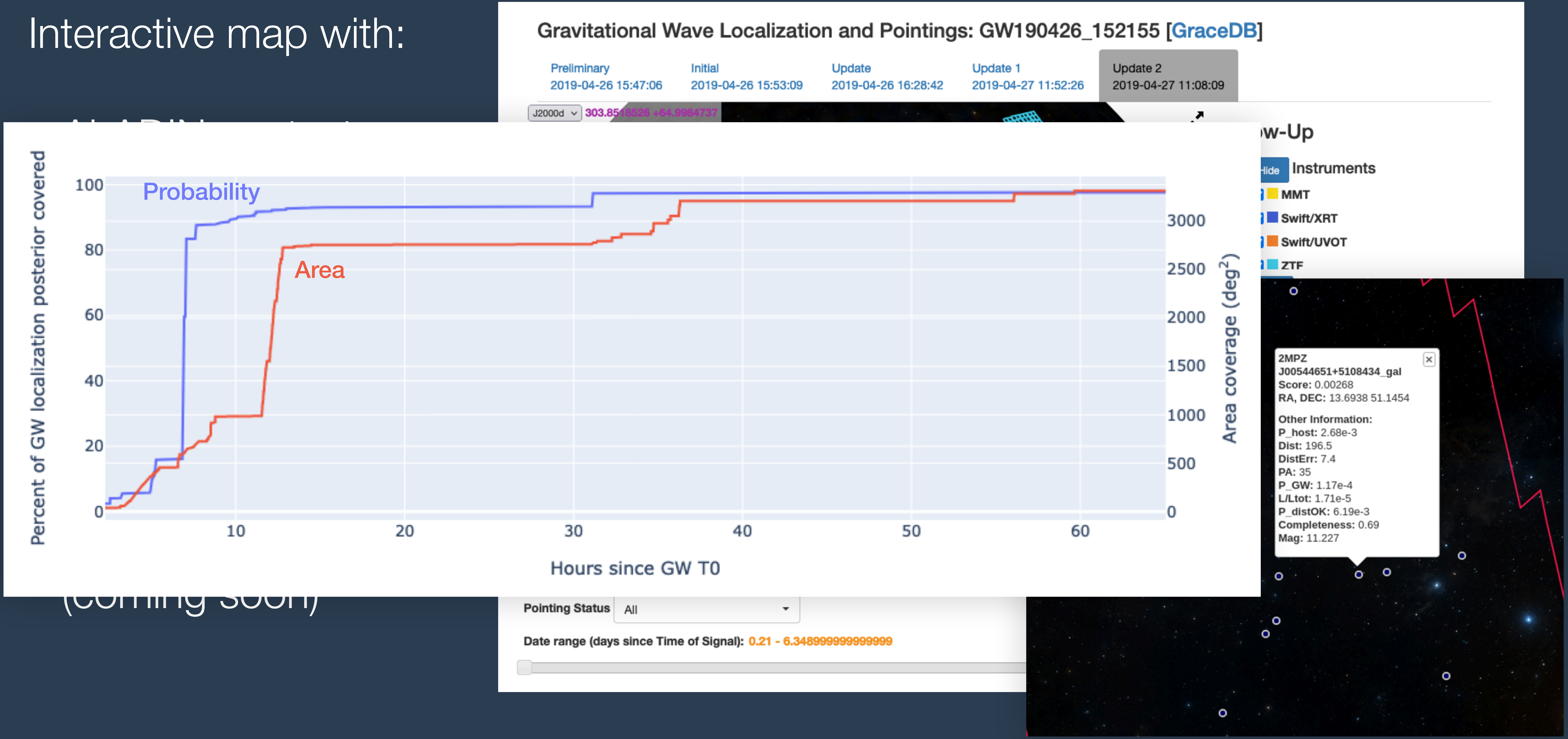
Reports are citable (DOI automatically issued for each report)

```
TARGET = 'pointings'

#define the filtering parameters
#grab all of the completed pointings taken with a specific instrument for a given event

graceid = 'S190425z'
instrument = 'CSS'

params = {
    "api_token":api_token,
    "instrument":instrument,
    "graceid":graceid,
    "status":"completed"
}

url = "{}/{}?{}".format(BASE, TARGET, urllib.parse.urlencode(params))
r = requests.get(url = url)
print("There are %s pointings" % len(json.loads(r.text)))

#print the first
print(json.loads(r.text)[0])
```

```
There are 12 pointings
{"id": 4139, "status": "completed", "position": "POINT (-112.788 16.5661)", "galaxy_catalog": "", "galaxy_catalogi
d": "", "instrumentid": 11, "depth": 21.3, "depth_err": "", "depth_unit": 1, "time": "2019-04-25T09:34:31", "datecre
ated": "2019-08-19T20:43:10.239772", "dateupdated": "", "submitterid": 3, "pos_angle": 0.0, "band": "open", "doi_ur
l": "", "doi_id": ""}
```

The "Treasure Map" - Visualize What's Going On

Interactive map with:

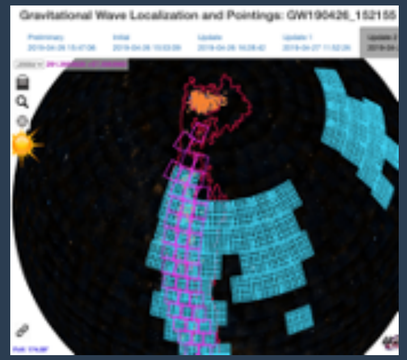


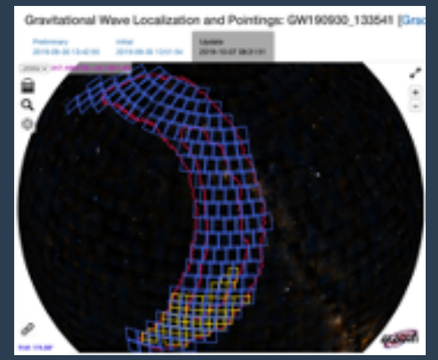
(coming soon)

The “Treasure Map” - Future Plans

- Manage transient candidates - through TNS?
- Suggest highest probability regions left to search
- Support other multi-messenger searches (neutrinos)
- Integrate with TOMs

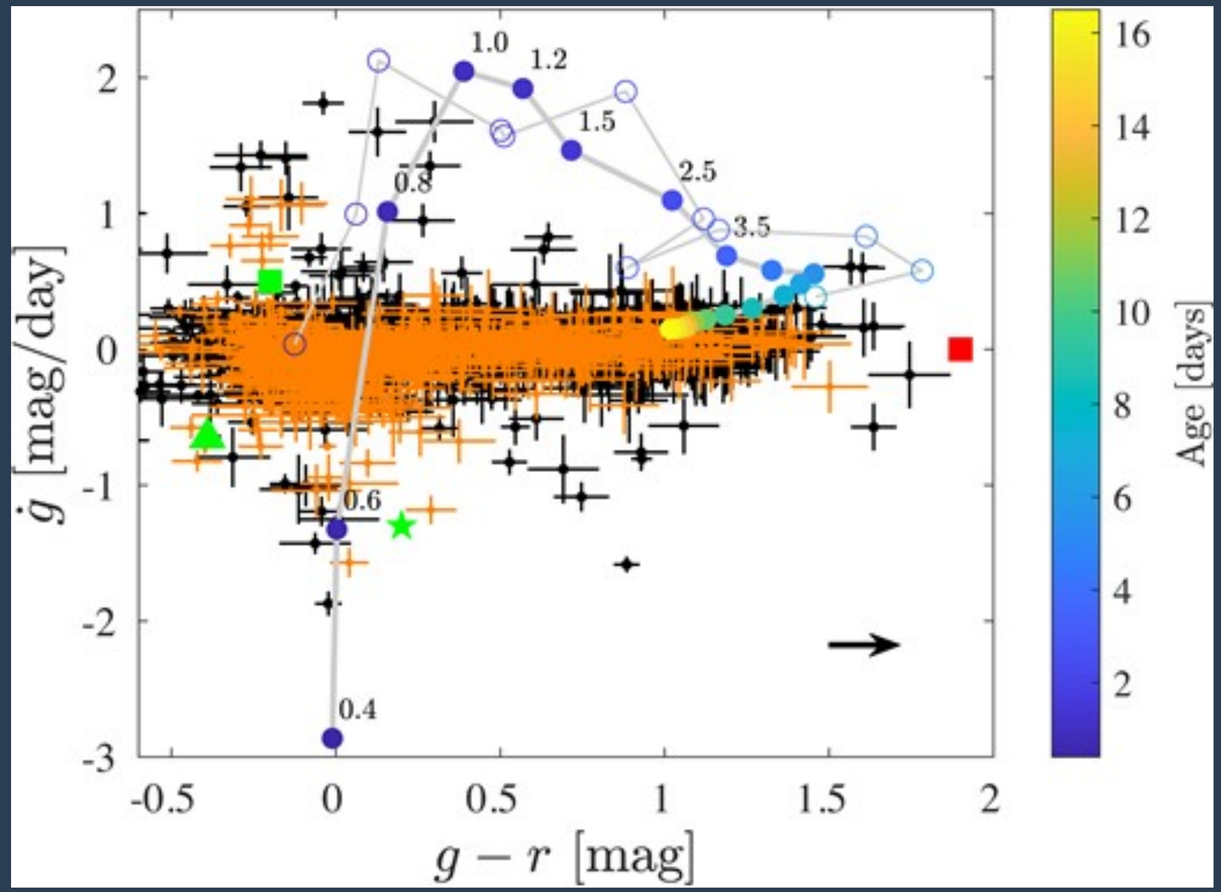
- **Get community feedback and buy-in (this tool is only as strong as its user base).**





But Need to Also Vet Candidates in Real Time - Photometry Sharing Crucial!

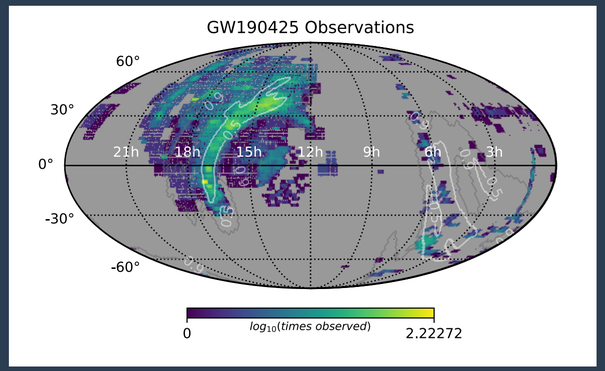
- Kilonovae stand out from other transients by photometric evolution rate
- We will have this information for many of the candidates in real time, **but dispersed across different groups.**
- **Must share individual photometry measurements for quick real time vetting.**

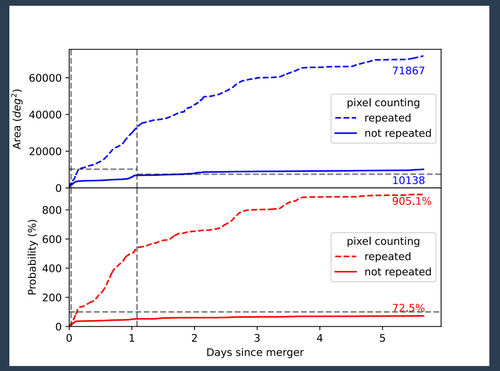


Ofek et al. 2024

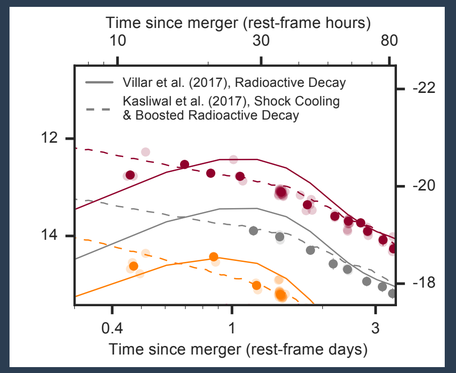
Summary

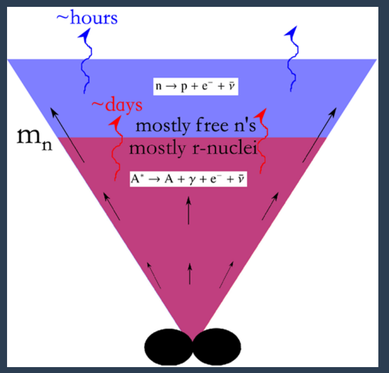
- Uncoordinated GW followup delays the discovery of EM counterparts or disrupts it completely.





- We’re missing a lot of science while wasting a lot of telescope time because of this!





- The Treasure Map is trying to fix this, but we need more tools (photometry sharing) and importantly: a **culture of coordination & transparency**.