OAC-1841625
OAC-1934752
OAC-2311355
AST- 2432428

INTER-AGENCY COORDINATION ON MULTI-MESSENGER ASTROPHYSICS

GAUTHAM NARAYAN

University of Illinois, Urbana-Champaign
SCIMMA Team PI

On behalf of the SCIMMA team:
Fabian Bastian-Arraneda (NCSA), Adam Brazier (Cornell), Becca Ewing (PSU), Bryce Cousins (UIUC),
Chad Hanna (PSU/LIGO), Andy Howell (Las Cumbres), David Jones (U. Hawaii), Lindy Lindstrom (Las Cumbres),
Andrew Manning (NCSA), Tom Matheson (NOIRLab), Curtis McCully (Las Cumbres), Jon Nation (Las Cumbres),
Don Petravick (NCSA), Steve Pothiers (NOIRLab), Ron Tapia (PSU), Chris Weaver (MSU), Rich Wolski (UCSB)

and a long list of collaborators and affiliates

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0. WHY TRY AND COORDINATE OBSERVATIONS?

I.E. WHY CAN'T I JUST DO MY OWN THING?

HOW DOING YOUR OWN THING WORKED FOR GW170817

skymap	https://gracedb.ligo.org/api/superevents/S231017bj/files/bayestar.multiorder.fits,0
gracedb	https://gracedb.ligo.org/superevents/S231017bj/view/

EVENT KEYPAIRS ≡

Key	Value
far	0.00000526891153640463
time	2023-10-17T13:28:29.537Z
group	CBC

1. Receive text alert

Slide Credit: Andy Howell

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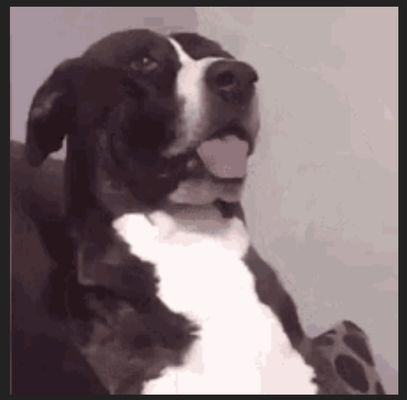

2. What?!?

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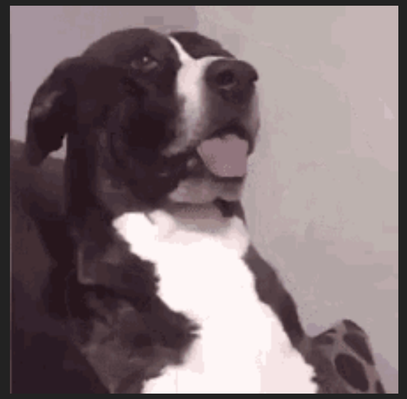

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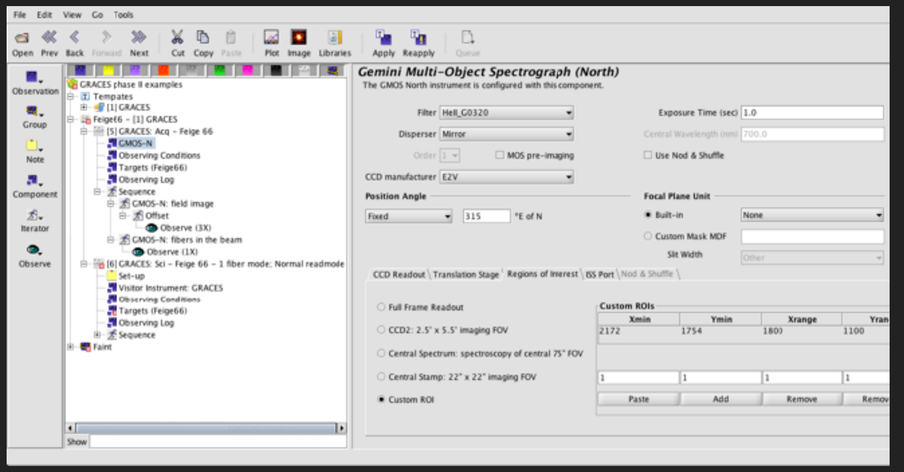

3. Trigger approved resources by filling out Phase II forms

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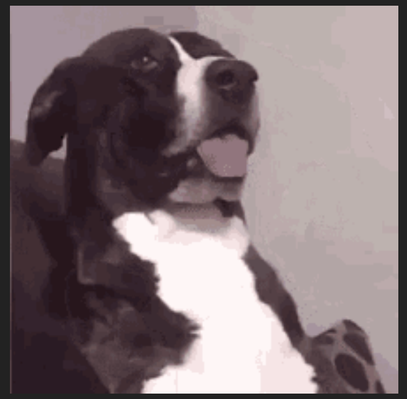

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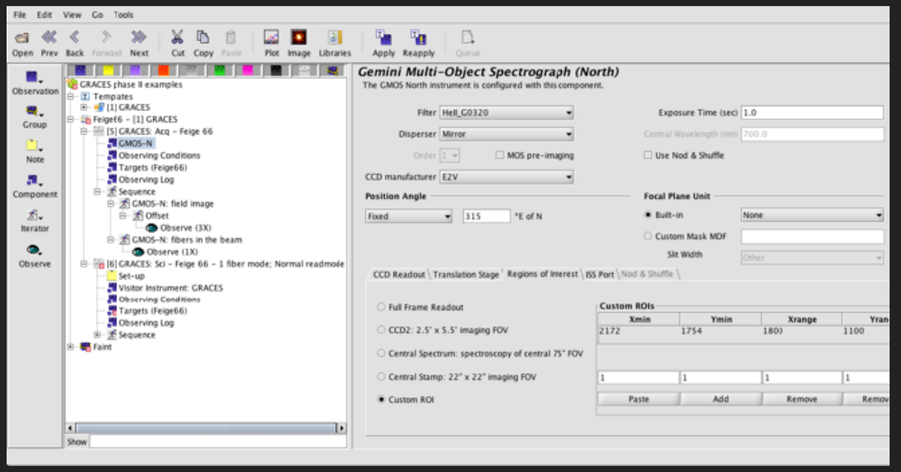

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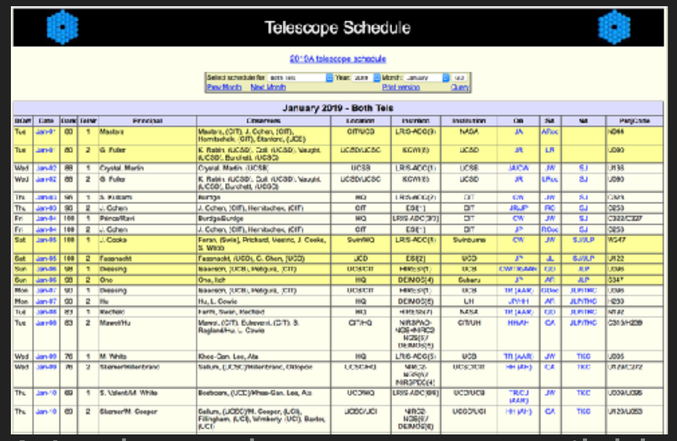

4. Look up other resources available. Beg, plead, cajole for time. Form collaborations. Gather information from dozens of sources.

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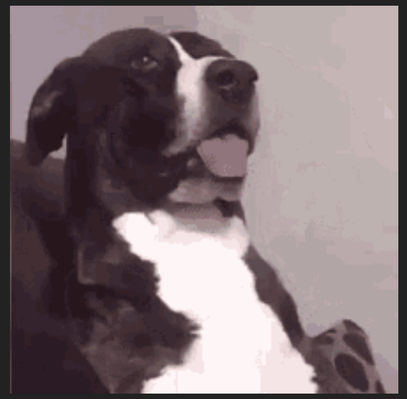

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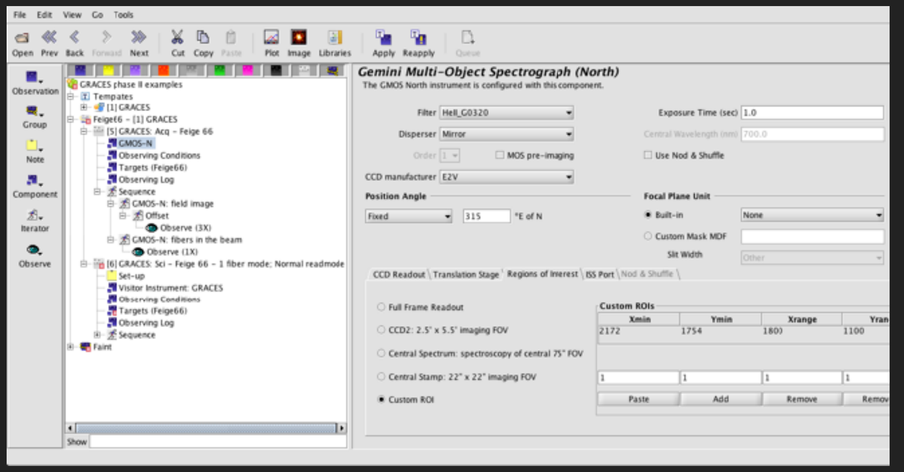

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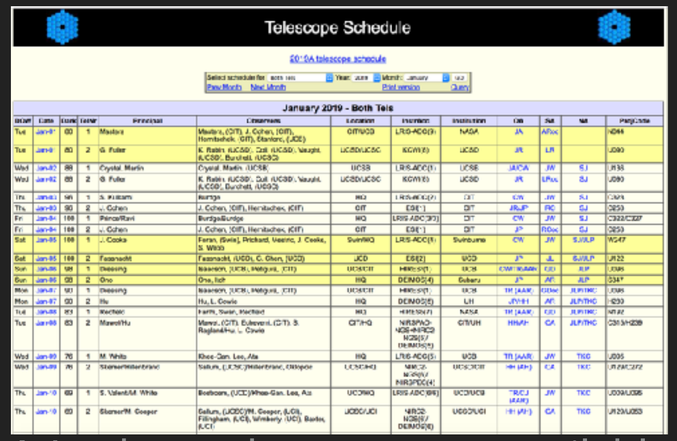

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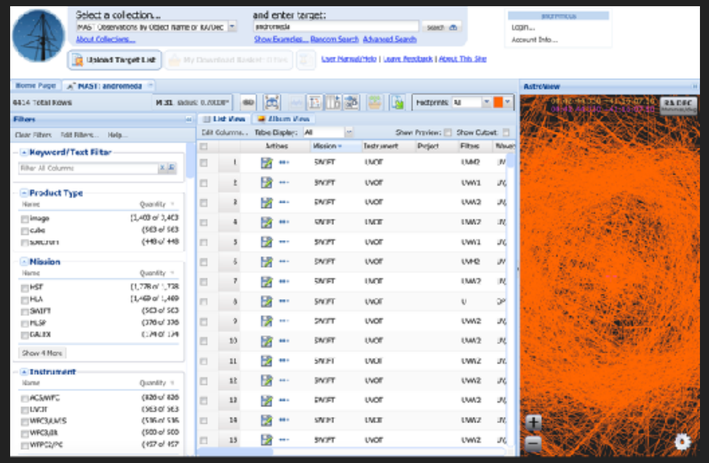

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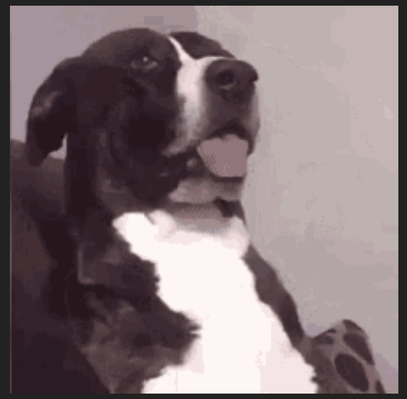

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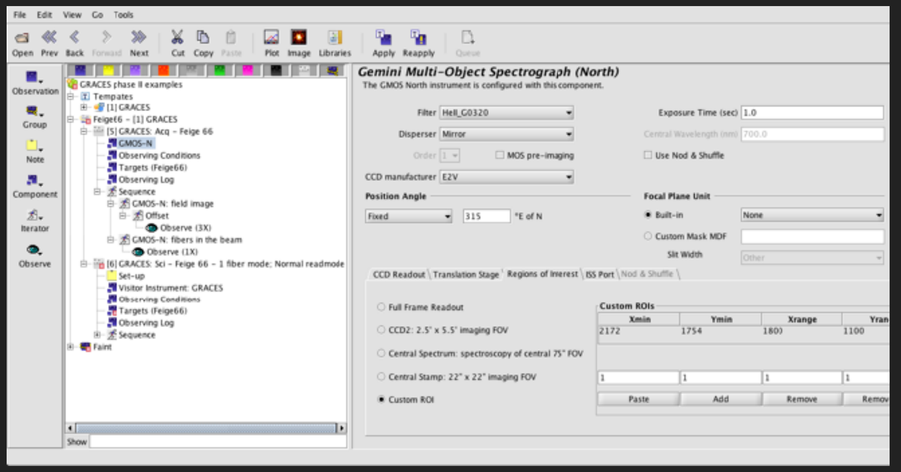

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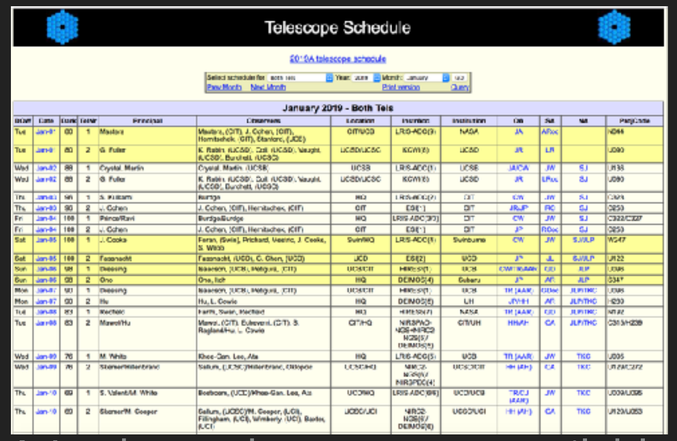

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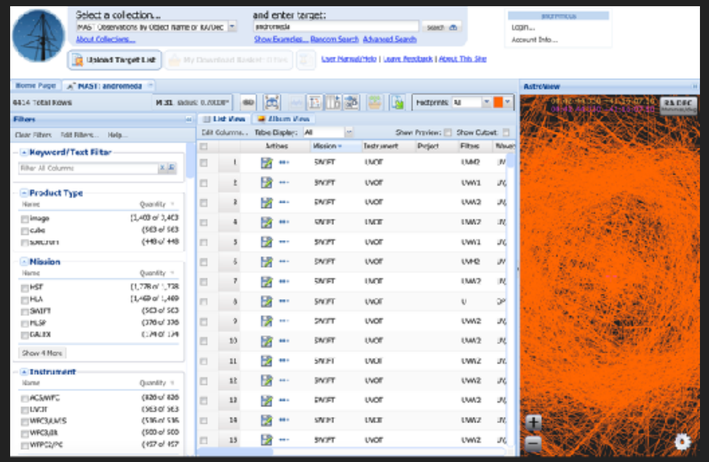

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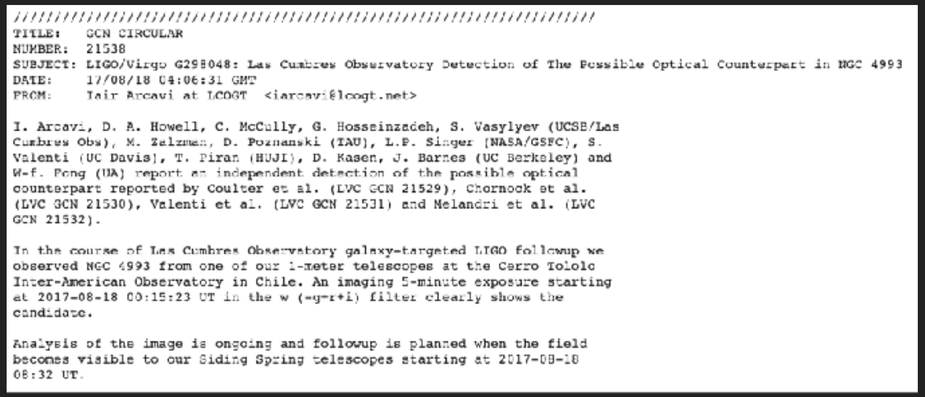
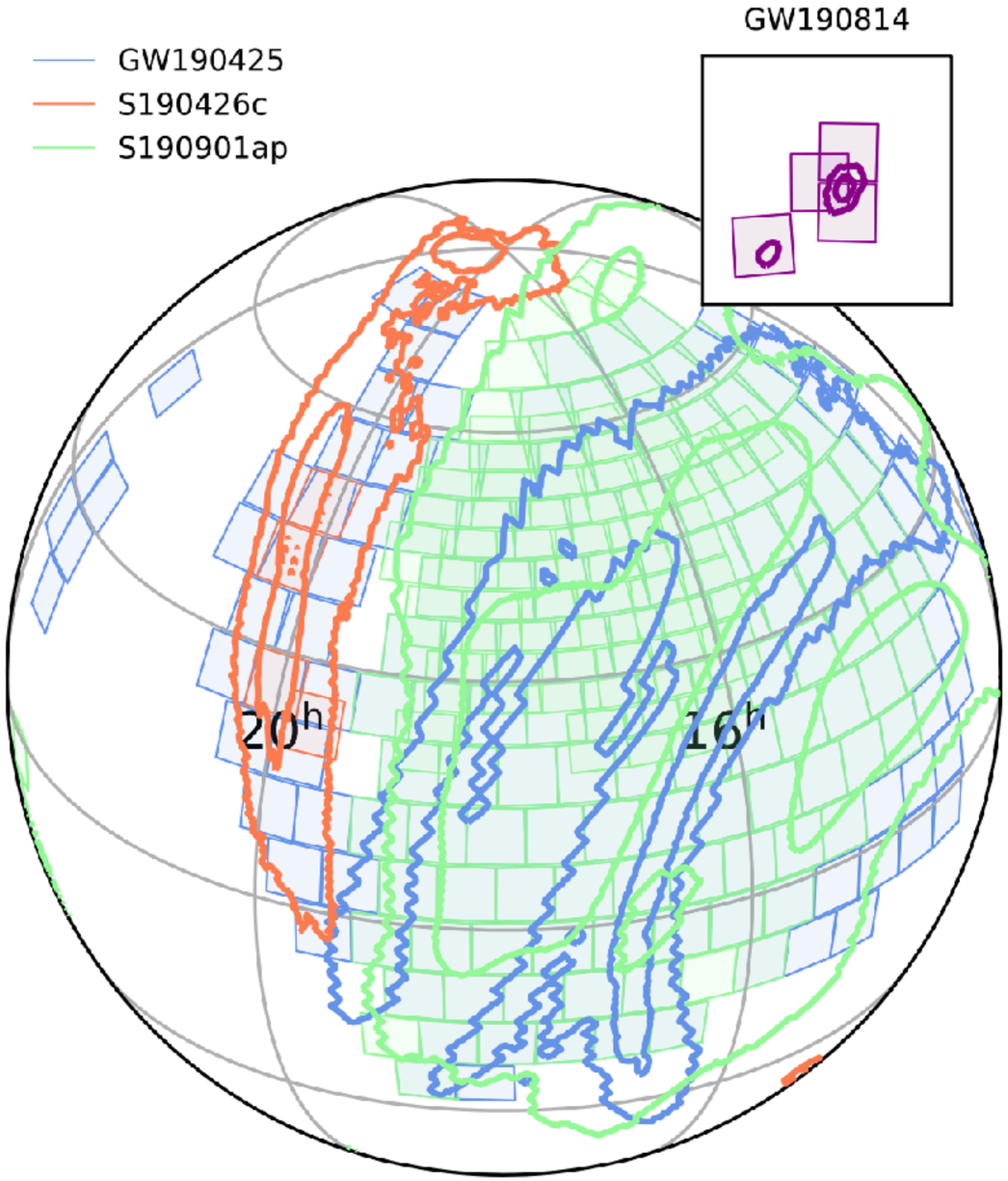


```
////////////////////////////////////////////////////////////////////////
TITLE:   GCN CIRCULAR
NUMBER:  21538
SUBJECT: LIGO/Virgo G298048: Las Cumbres Observatory Detection of The Possible Optical Counterpart in NGC 4993
DATE:    17/08/18 04:06:31 GMT
FROM:    Iair Arcavi at LCOGT  <iarcavi@lcogt.net>

I. Arcavi, D. A. Howell, C. McCully, G. Hosseinzadeh, S. Vasylyev (UCSB/Las
Cumbres Obs), M. Zalzman, D. Poznanski (TAU), L.P. Singer (NASA/GSFC), S.
Valenti (UC Davis), T. Piran (HUJI), D. Kasen, J. Barnes (UC Berkeley) and
W-f. Fong (UA) report an independent detection of the possible optical
counterpart reported by Coulter et al. (LVC GCN 21529), Chornock et al.
(LVC GCN 21530), Valenti et al. (LVC GCN 21531) and Melandri et al. (LVC
GCN 21532).

In the course of Las Cumbres Observatory galaxy-targeted LIGO followup we
observed NGC 4993 from one of our 1-meter telescopes at the Cerro Tololo
Inter-American Observatory in Chile. An imaging 5-minute exposure starting
at 2017-08-18 00:15:23 UT in the w (=g+r+i) filter clearly shows the
candidate.

Analysis of the image is ongoing and followup is planned when the field
becomes visible to our Siding Spring telescopes starting at 2017-08-18
08:32 UT.
```

6. Communicate information to the community, via text

Slide Credit: Andy Howell

IF WE FIND ONE, THE NATURAL FIRST QUESTION IS CAN WE FIND MORE



- Hard work - need to know survey pointings over the localization region, what detections are, which of those aren't artifacts, report candidates, hope some get spectroscopy, get more photometry from around the world, and then hit the jackpot
- Groups like ZTF have done this, here for 4/13 events analyzed from O3 from **Kasliwal, Anand, Ahmuda et al. (2020)**

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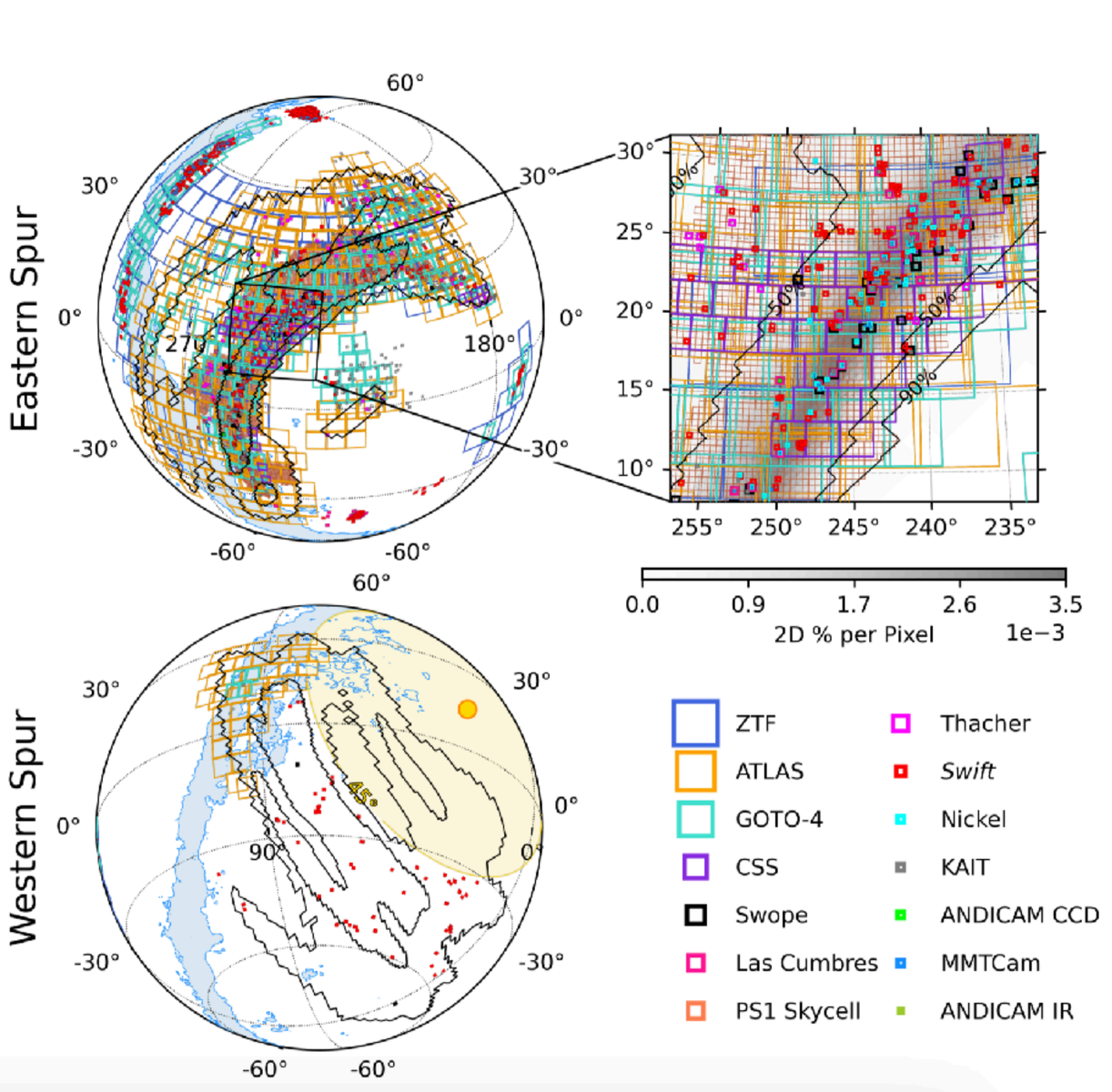

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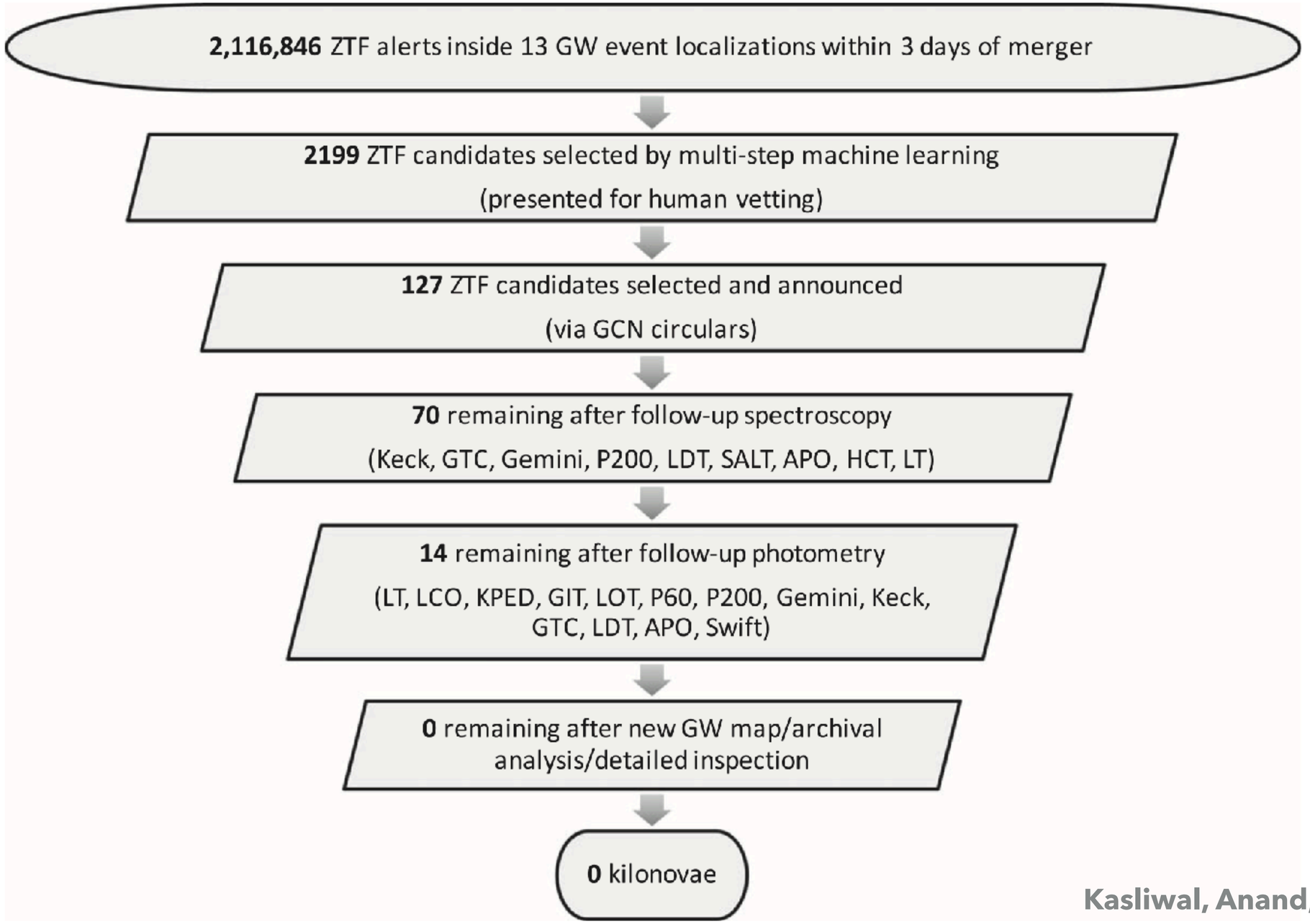
- **The resources dedicated to this search are staggering** - from just ZTF: a 47 sq deg camera tiling the sky for several nights every year to r~21 mag. But also DECAM, LCO, Magellan, PS1 + space-based facilities - here from **Coulter et al. (2020)**

AND AFTER ALL THAT…



Kasliwal, Anand, Ahmuda et al. 2020

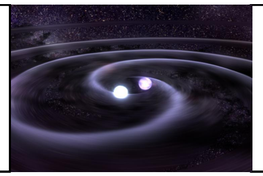
THIS IS A NON-DETECTION

THIS IS A NON-DETECTION

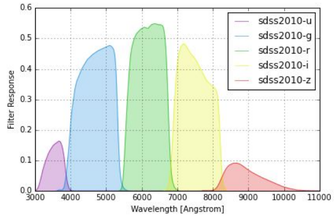
BUT IT'S A VERY SIGNIFICANT NON-DETECTION

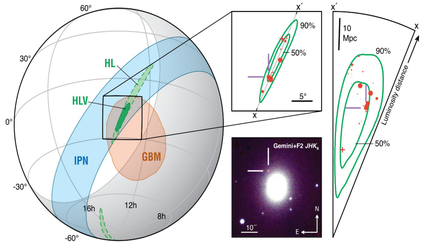
MMA EVENTS ARE RARE, FAINT, FAST, AND LVK ISN'T SEARCHING A VERY LARGE VOLUME

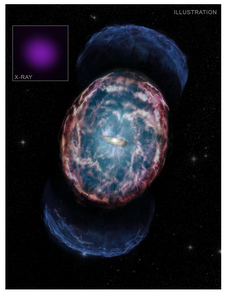
Sample BNS masses



Sample merger distance







LVK Detectable?

LIGO VIRGO KAGRA

Passband transmission

Survey mag threshold

Kilonova

yes

yes

Sample / Compute SED model parameters

SED Approximation

Synthetic SED

Synthetic light curve

EM Survey Detectable?

WEBB SPACE TELESCOPE

DECam

HUBBLE SPACE TELESCOPE

VERA C. RUBIN OBSERVATORY

SciPy

no

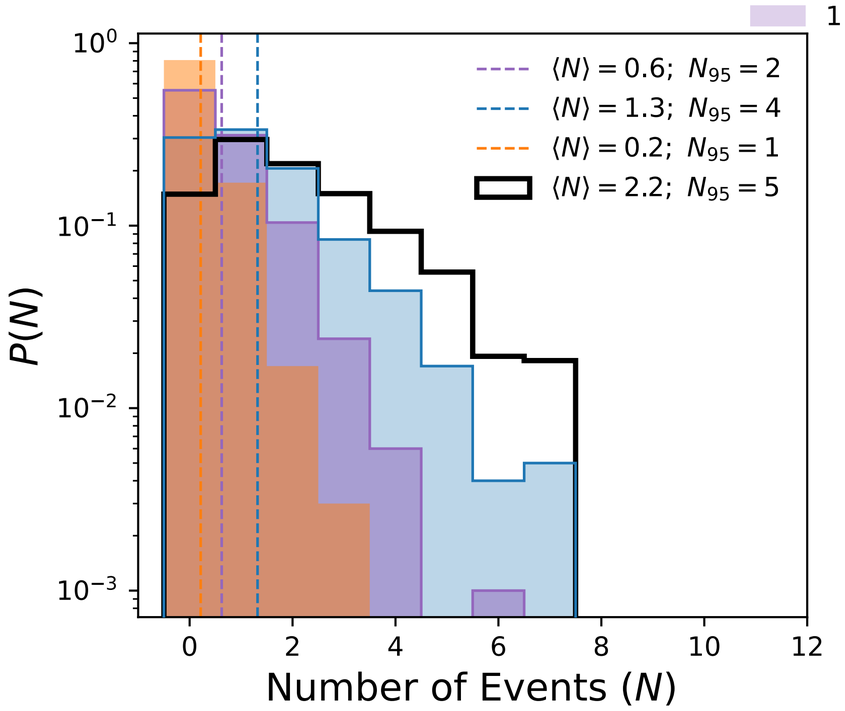
Bulla SED Grid

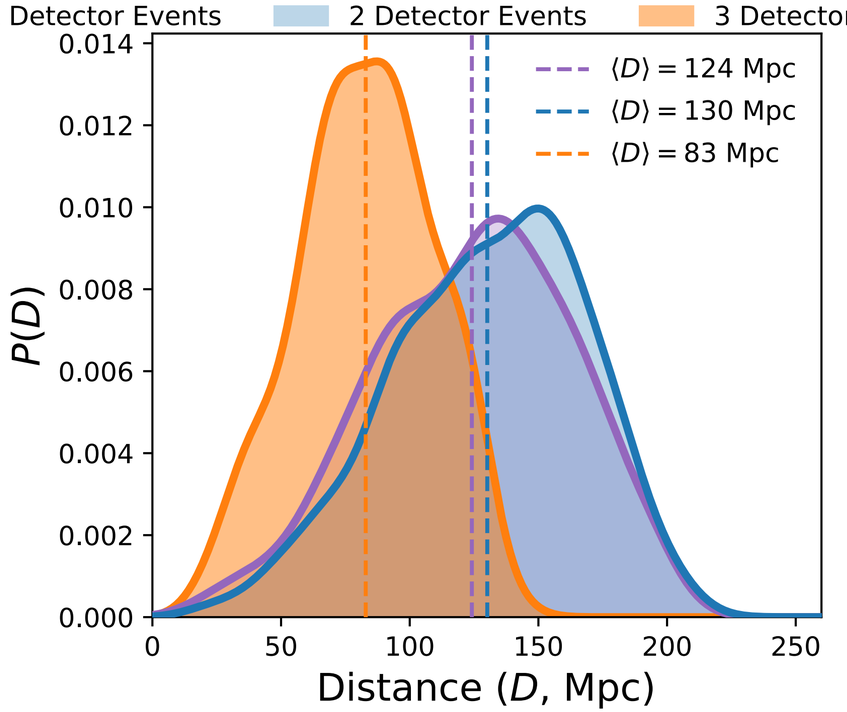
Sample coordinates, extinction, and redshift and treat SEDs

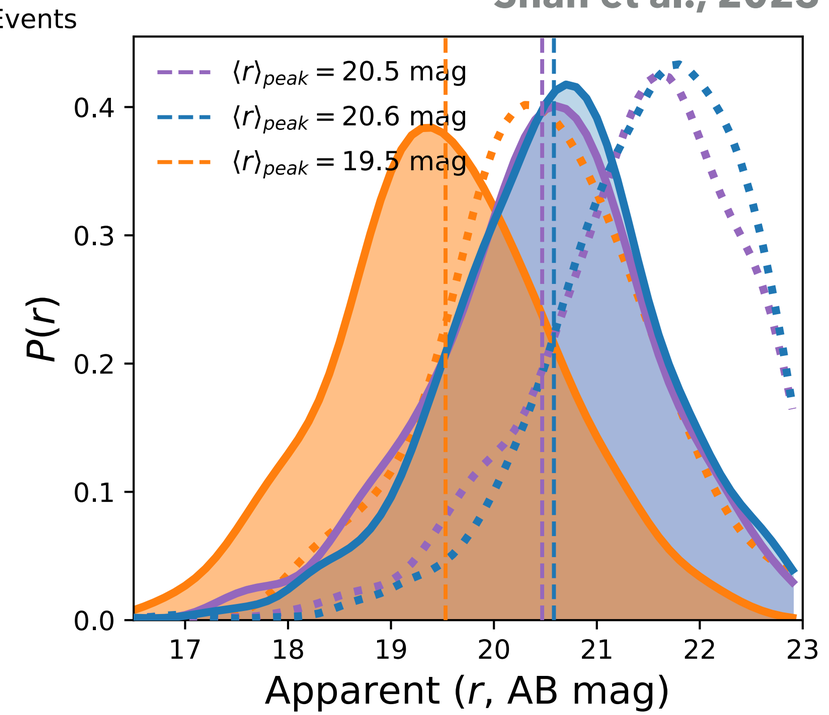
No EM Counterpart

Shah et al., 2023 (UIUC -> Northwestern)

Shah et al., 2023

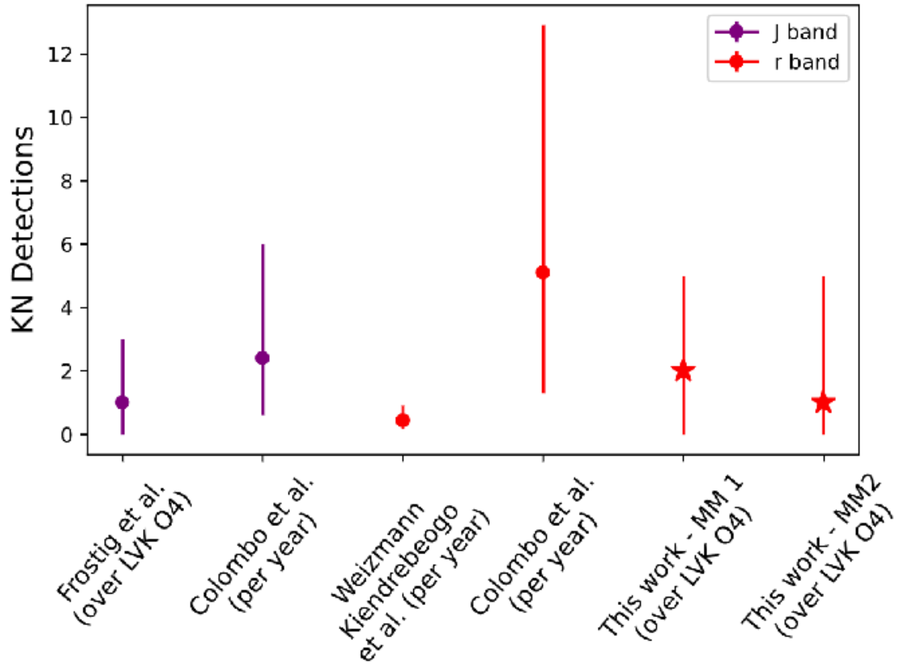




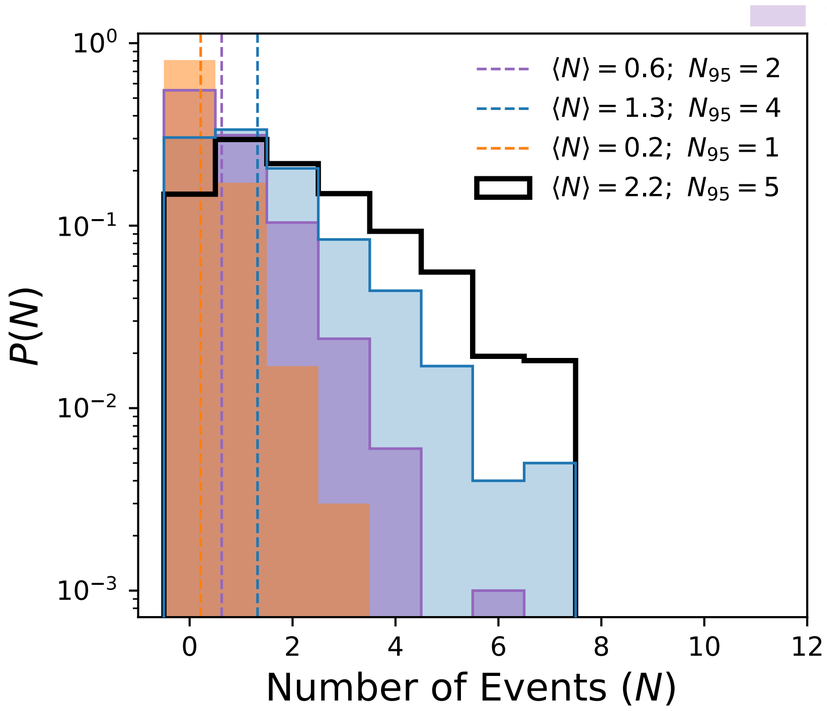


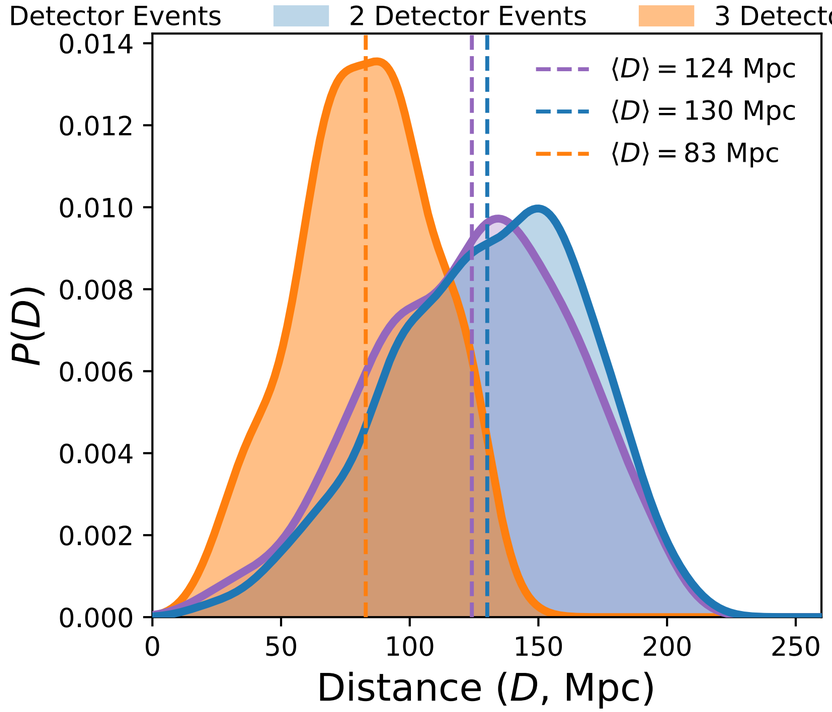
The number of MMA events we should expect in O4 is ~1.
In the most optimistic scenarios, 4.

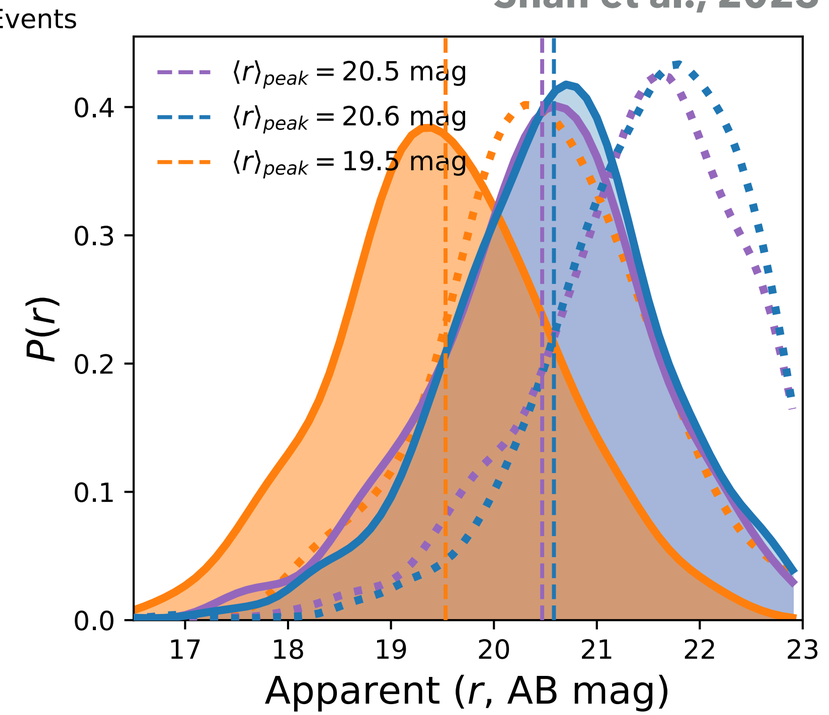
In O5 this goes up to ~20



Shah et al., 2023







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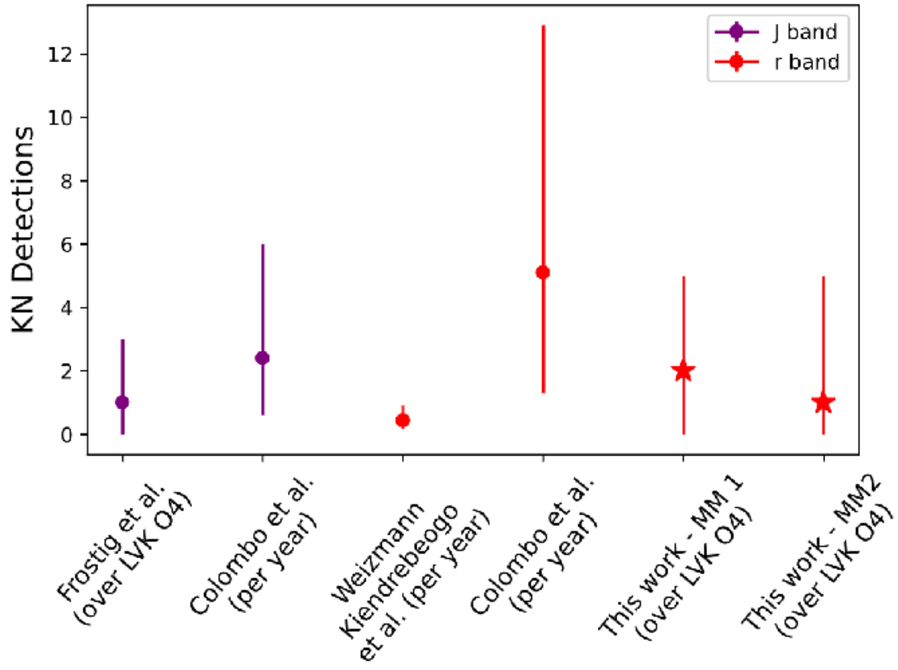

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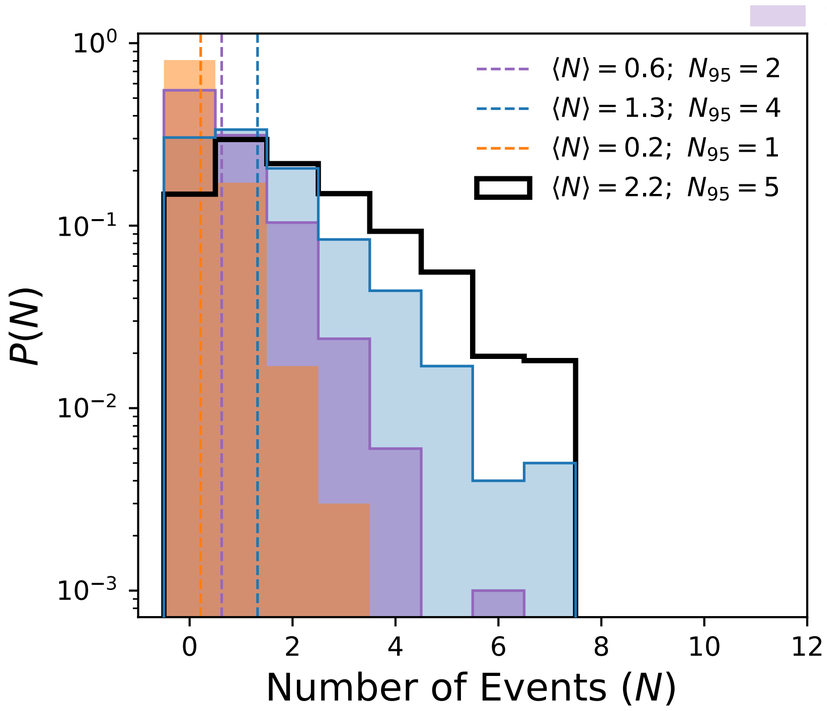

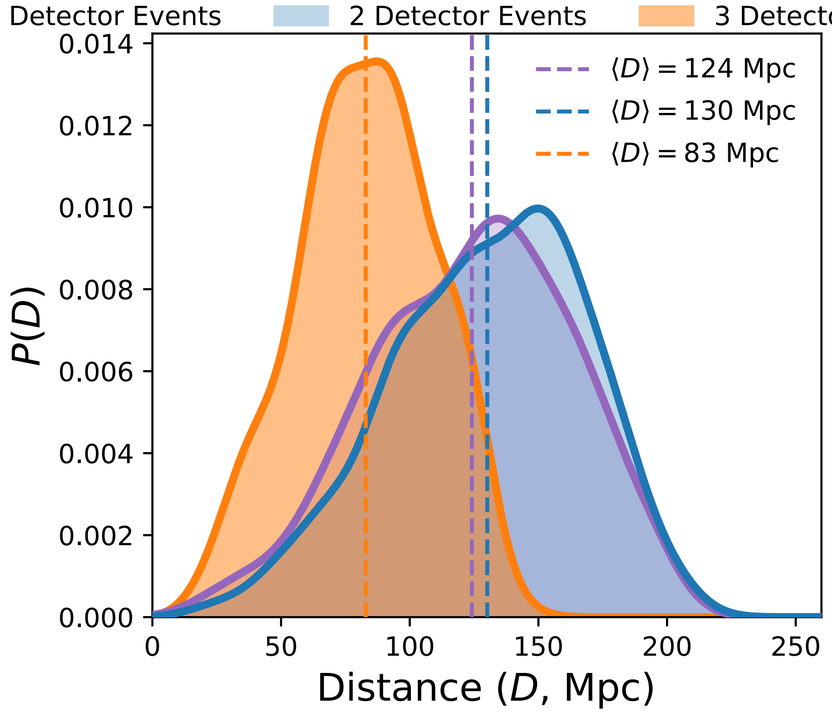

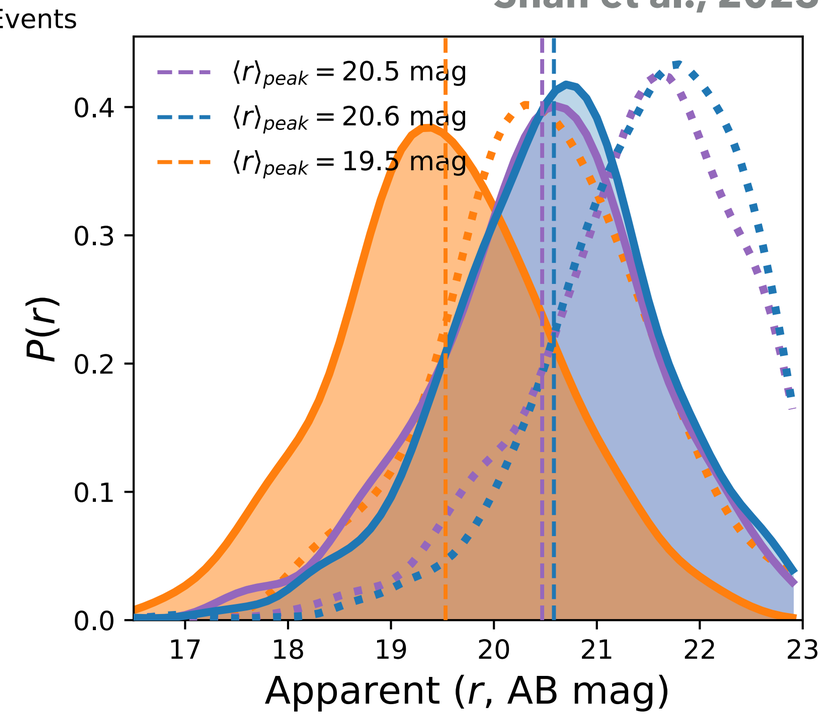

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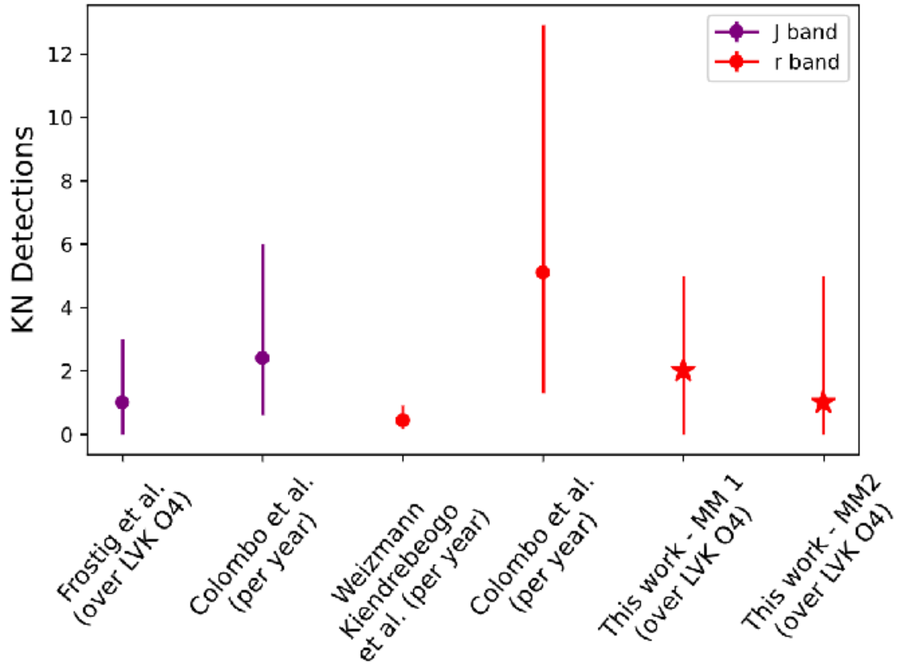
If we do not coordinate, we will miss the second BNS merger.



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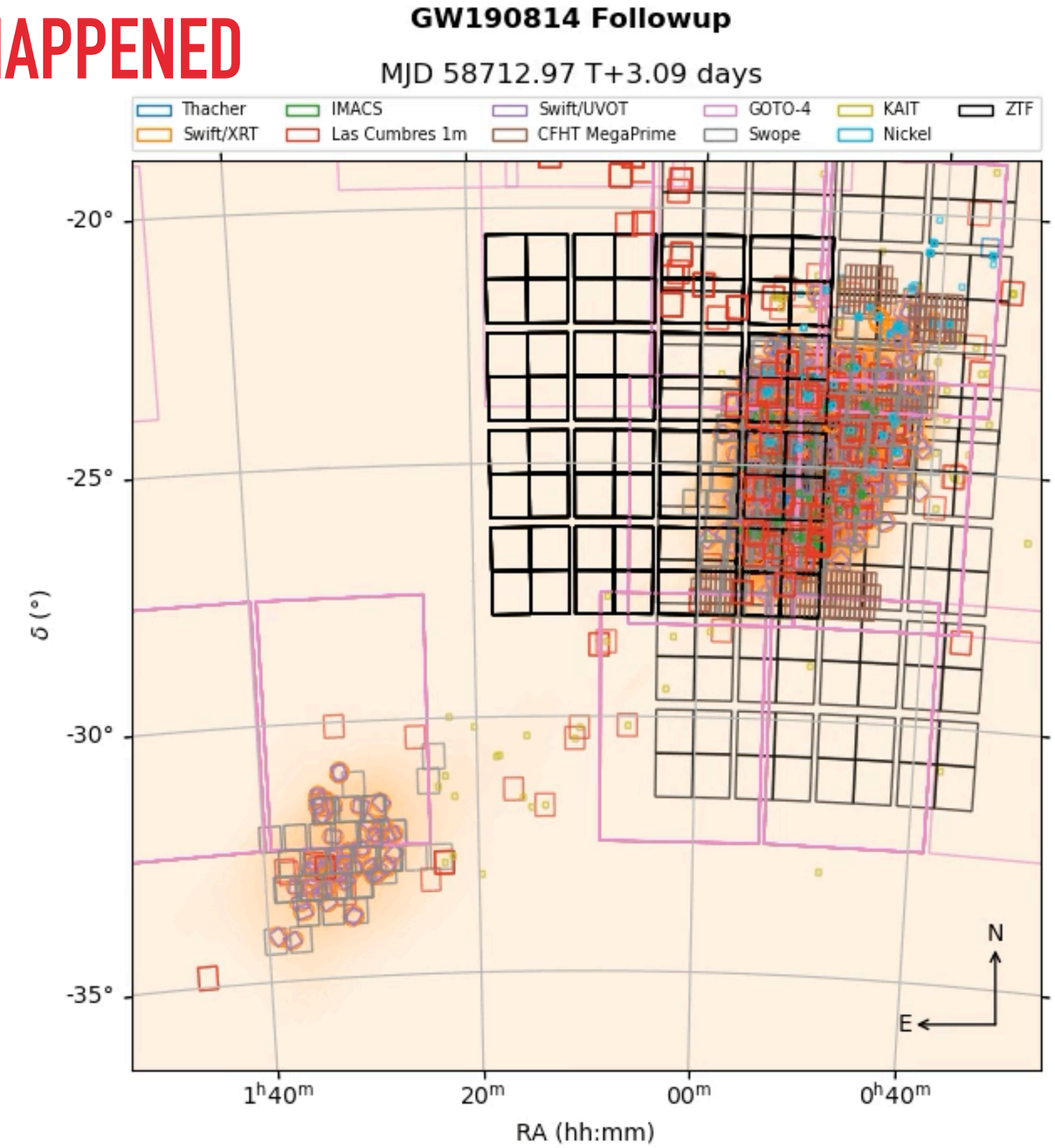

Data from Curtis McCully using The Gravitational Wave Treasure Map https://treasuremap.space/ (Wyatt et al. 2020)

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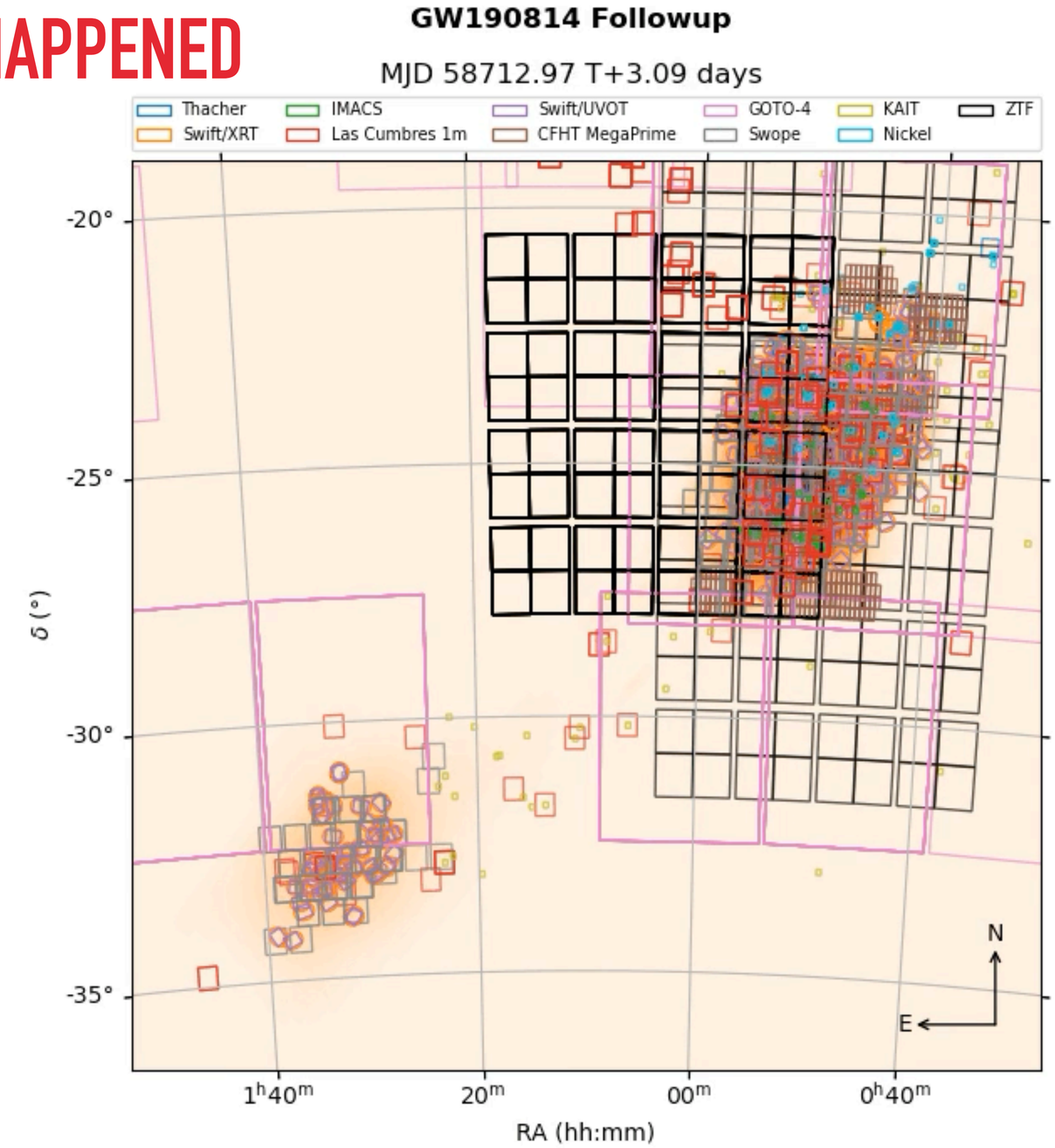

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THIS WAS A FAILURE TO COORDINATE

THIS WAS A FAILURE TO COORDINATE

BUT I'M NOT BLAMING ANYONE

THIS WAS A FAILURE TO COORDINATE

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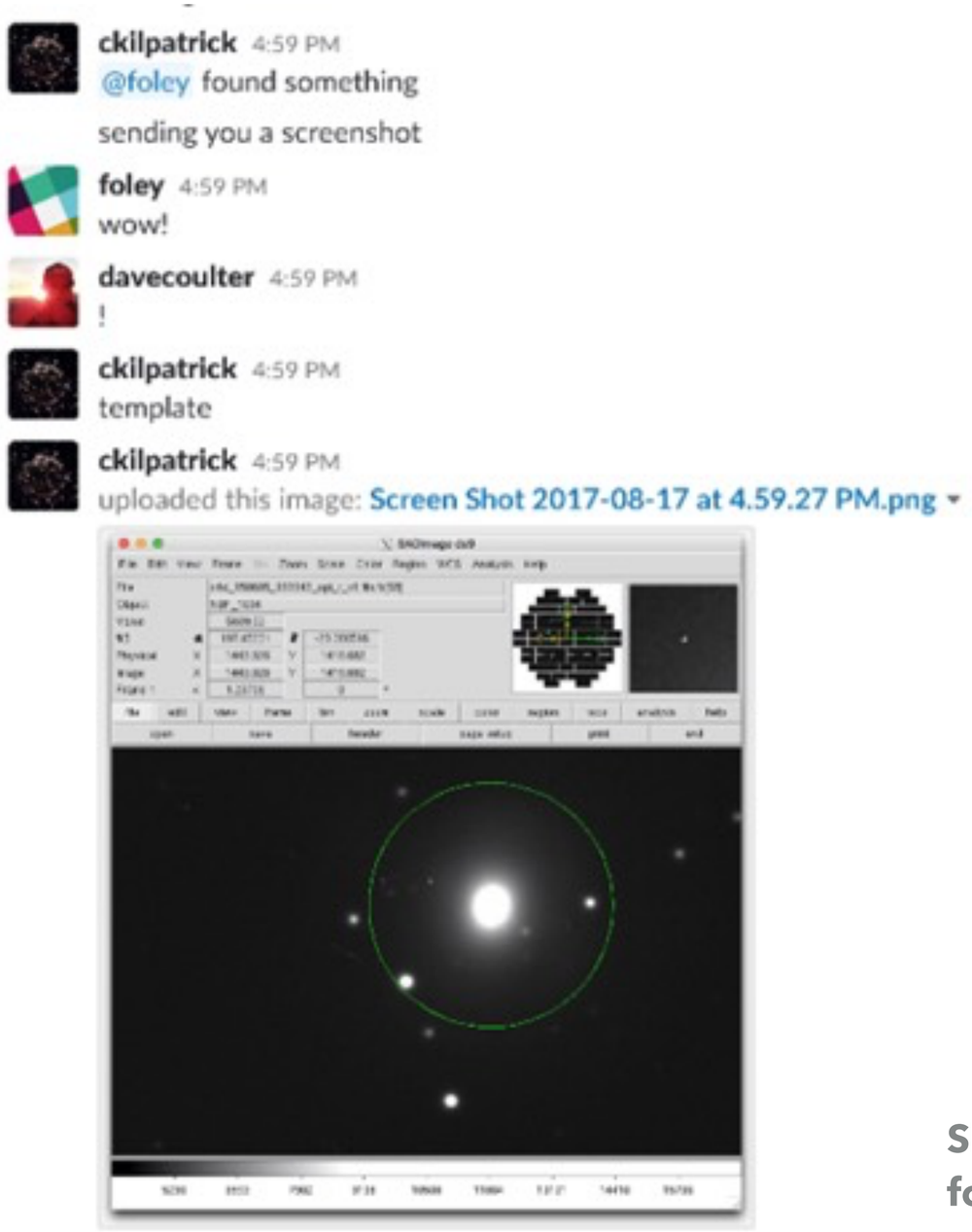
EVERY TOOL WE HAD IN 2017 WAS A ONE-WAY STREET – EVERY FACILITY IS SILOED

1. COORDINATION TAKES INFRASTRUCTURE

I.E. WHAT WE HAVE BUILT ALREADY

PUB/SUB:
WE NEED A ROBUST WAY TO BUILD A NETWORK BETWEEN SURVEYS/ EXPERIMENTS AND THE USER COMMUNITY

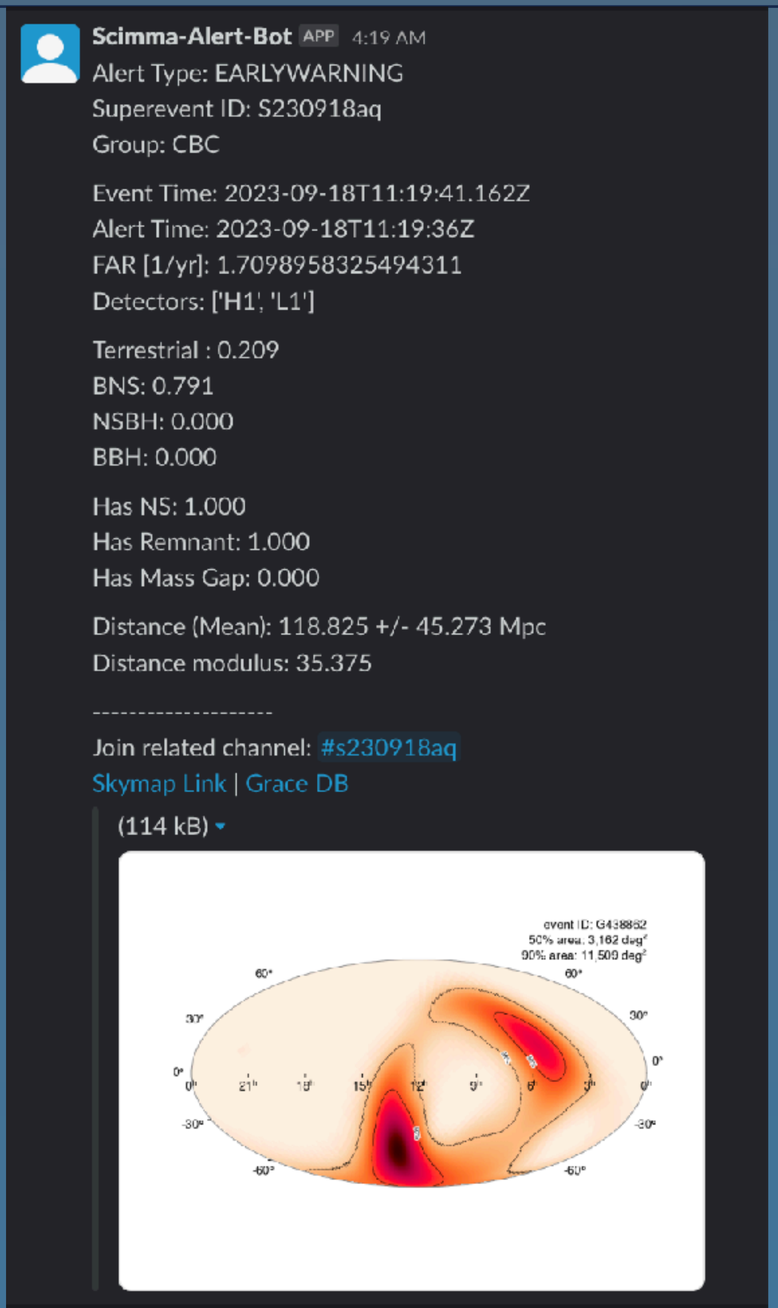
MAKING MISSION-CRITICAL COMMUNICATION ROBUST



Slack messages from R. Foley's Group for AT2017gfo discovery

KEY COMPONENTS OF THE ECOSYSTEM: MESSAGING

- Hopskotch is an pub-sub system with identity and access management
- Use your own institutional sign-in (or ORCiD) with CILogon to sign up: https://hop.scimma.org/
- Public “topics” including LVK alerts in O4, AMON, GCN (over Kafka!), IceCube, SNEWS - get DOIs for discovery messages
- Private “topics” are fine too - you have to join the appropriate group
- Cloud-based on AWS - highly scalable (< 1s latency for us to process messages through Run O4) - **or stand up your own instance for your project - works with small or large experiments**
- Granular permissions control, an easy-to-use python client, all open-source
- Designed to handle high volume, high throughput streams for big surveys and experiments -
  e.g. all of IGWN Alert: https://rtd.igwn.org/projects/userguide/en/v17.1/tutorial/receiving/scimma.html



https://my.hop.scimma.org/hopauth/ 150%

SCiMMA Auth

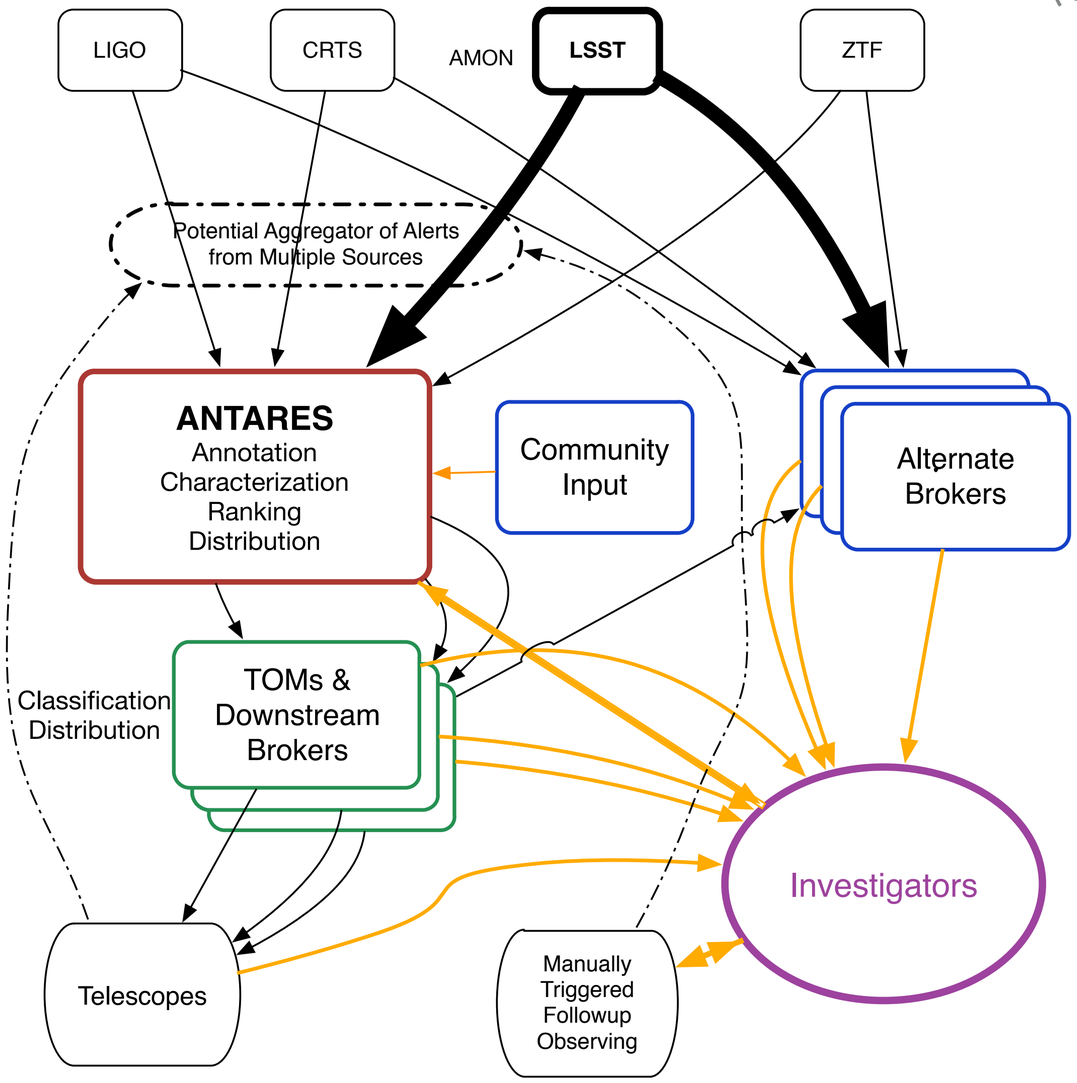
Current user: Gautham Narayan (gsn@illinois.edu) Log out

amon.nuem	AMON neutrino+gamma-ray multi-messenger alerts	public	
gcn.circular	GCN Circulars, wrapped in JSON	public	
gcn.notice	GCN Notices, wrapped in JSON	public	
hermes.astrometry	Target astrometry data	public	
hermes.discovery	New target discoveries	public	
hermes.message	HERMES formatted messages that don't fit in other topics	public	
hermes.photometry	Target photometry data	public	
hermes.spectroscopy	Target classifications our spectroscopy data	public	
hermes.test	Test messages - aren't saved in production, only on the dev site	public	
icecube.HE-tracks	High-energy track events with significant probabilities of being neutrinos of astrophysical	public	

BROKERS:
IF YOU CAN COMMUNICATE MESSAGES ABOUT TARGETS, YOU CAN CHARACTERIZE, CLASSIFY AND FILTER THOSE TARGETS

WHAT IS ANTARES

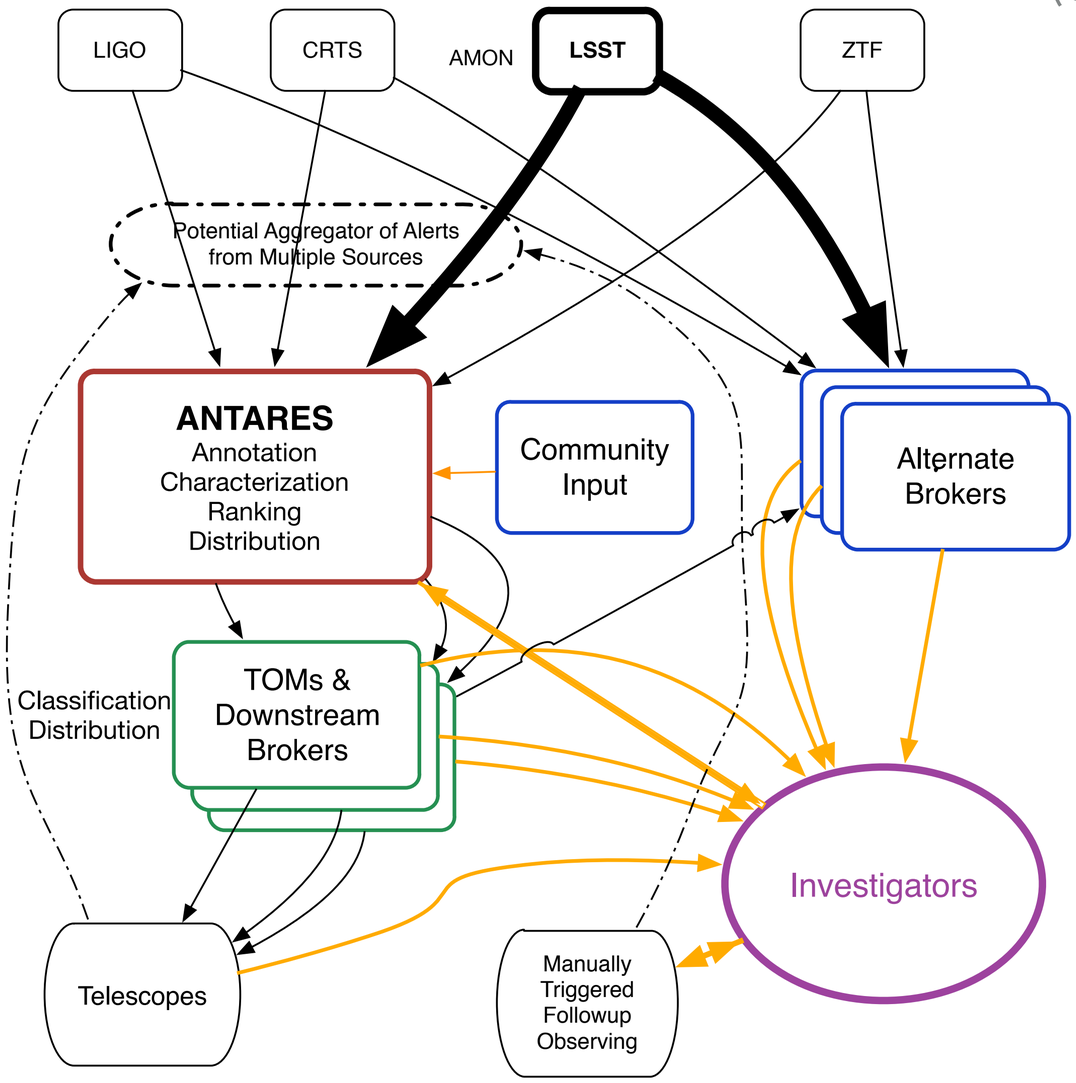
Monika Soraisam, Ryan Lau, Nicolas Esquivel, Sebastian Vincenzo (NOIRLab), Patrick Aleo (UIUC->Kansas National Security Center), Kostya Malanchev (CMU/LINCC)



- ANTARES manages **alert streams**, adding contextual information, characterizing events, ranking & distributing (PI Tom Matheson)

WHAT IS ANTARES

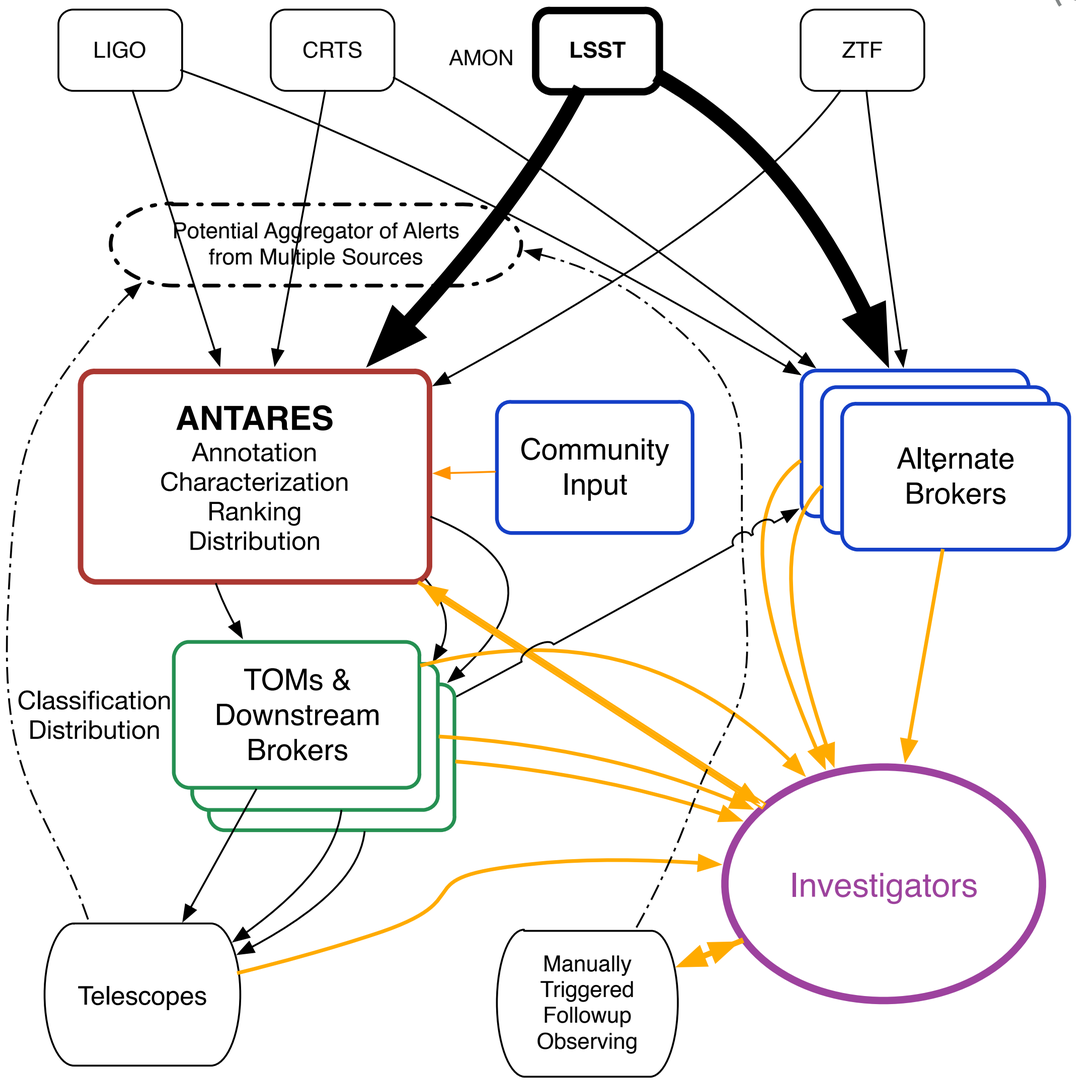
Monika Soraisam, Ryan Lau, Nicolas Esquivel, Sebastian Vincenzo (NOIRLab), Patrick Aleo (UIUC->Kansas National Security Center), Kostya Malanchev (CMU/LINCC)



- Write your filters for complex, targeted processing, or broad analysis of large datasets - **do YOUR science!**

WHAT IS ANTARES

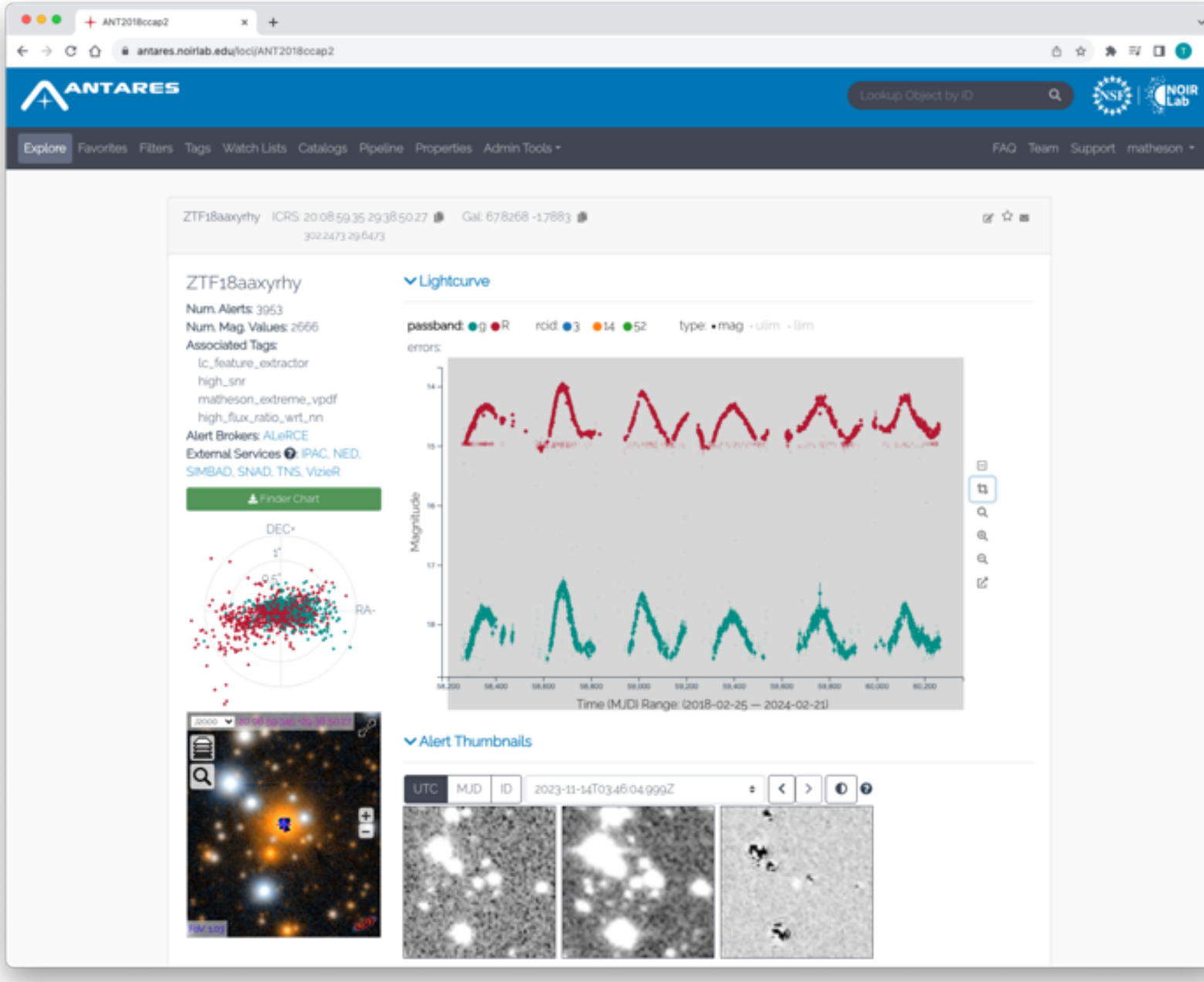
Monika Soraisam, Ryan Lau, Nicolas Esquivel, Sebastian Vincenzo (NOIRLab), Patrick Aleo (UIUC->Kansas National Security Center), Kostya Malanchev (CMU/LINCC)



- https://antares.noirlab.edu/

WHAT IS ANTARES

- Built with modern technologies, K8s, deployed on Google Cloud Platform (GCP), provenance tracking, open-source
- Flexibility of cloud hosting enables testing at Rubin scale, large archival catalogs, complex search, custom filters…
- **Fulfilling Rubin internal "alert filtering service" - was always designed with a view to working with NASA missions too.**
- 'Concept' paper: Narayan et al. ApJS 2018 (arXiv:1801.0732) 'Instrument' paper: Matheson et al. AJ, 2021 (arXiv 2011.12385)



ANTARES SEARCH

Lookup Object by ID

NSF NOIR Lab

Explore Favorites Filters Tags Watch Lists Catalogs Pipeline Properties FAQ Support gnarayan

Active Filters

- Latest alert after MJD 59382.34
- First alert after MJD 59382.34
- Catalogs: veron_agn_qso

Number of Measurements

1 — 2

Cone Search

Center: Enter a coordinate string

Radius: 1 arcsec

Catalogs

veron_agn_qso (4)
2mass_xsc (3)
2mass_psc (2)
allwise (2)
bright_guide_star_cat (2)
ned (2)
RC3 (1)
gaia_dr2 (1)
nyu_valueadded_gals (1)
sdss_gals (1)

>_

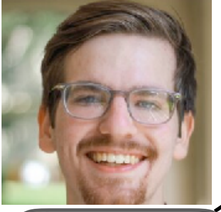
Showing 1-4 of 4 25 « ‹ 1 › »

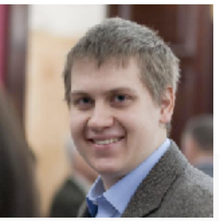
ID	ZTF ID	RA	Dec	Latest Mag	Brightest Mag	# Alerts	Latest Alert	First Alert
ANT2021q6f76	ZTF21abhotwz	28.68	27.33	18.39	18.39	2	2021-06-19 11:15:56	2021-06-19 11:12:58
ANT2021qq4ls	ZTF18abkxozh	262.30	70.55	18.69	18.69	1	2021-06-18 05:14:08	2021-06-18 05:14:08
ANT2021qqh76	ZTF18aaqdill	195.50	27.78	19.07	19.07	1	2021-06-18 04:42:25	2021-06-18 04:42:25
ANT2021qp26k	ZTF19abahorj	48.76	42.04	18.74	18.74	1	2021-06-17 11:15:00	2021-06-17 11:15:00

You can think of ANTARES as a search engine for astrophysical variabilityYou can conesearch, cross-match against large list of existing catalogs
https://antares.noirlab.edu/catalogs

Even require objects that have “tags” attached to them
https://antares.noirlab.edu/tags

Or create a private watch list to monitor activity for your own sources
https://antares.noirlab.edu/watch-lists





Extract light curve features

Alert Stream

GHOST

Host association & extract host features

Transients

Contaminants

Keep transients & remove contaminants

Upsample minority classes with SMOTE/ PZFLOW

Train/Test split

Dimensionality reduction

ANNOY

Calculate ANNs

Similarity Search

Random Forest Classifier

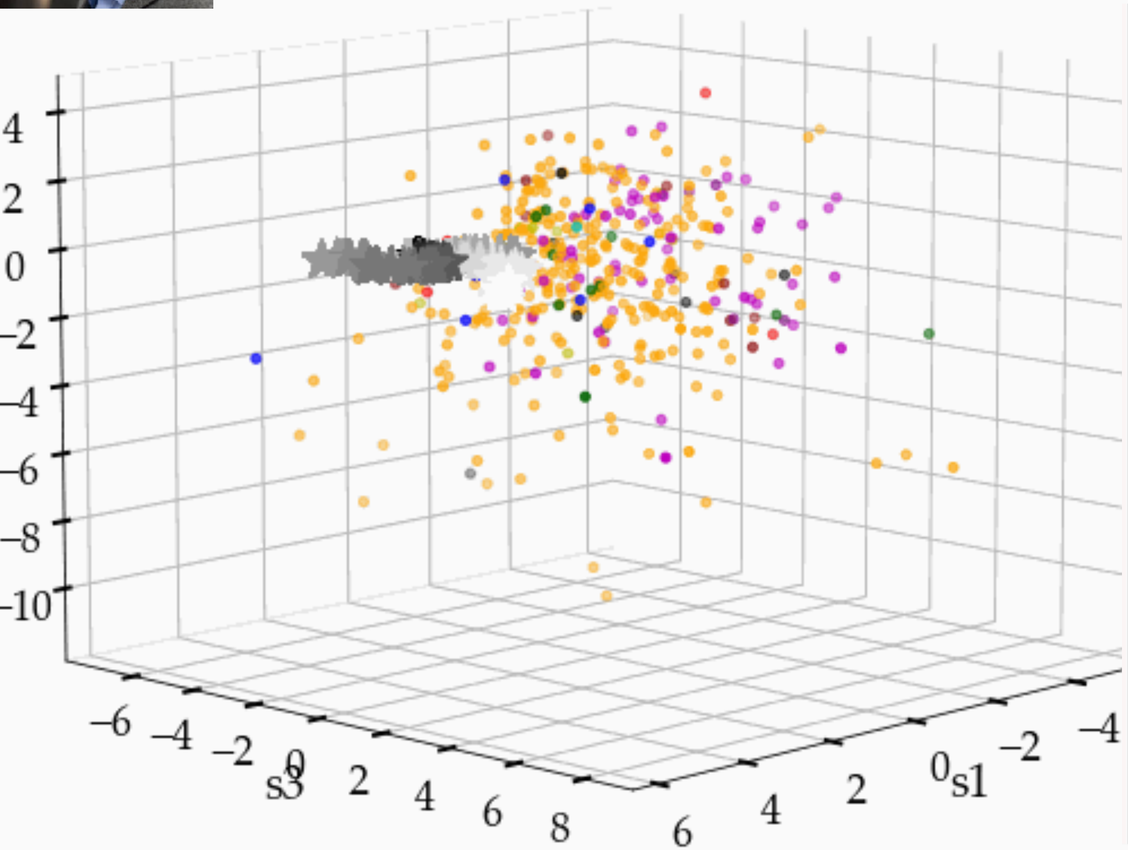
Isolation Forest

Anomaly Detection

Prioritize

TRANSIENT NAME SERVER

Spectroscopic & photometric follow up



ZTF22aaezyos

Num. Alerts: 133

Num. Mag. Values: 105

Associated Tags:

iso_forest_anomaly_detection

lc_feature_extractor

extragalactic

high_amplitude_transient_candi...

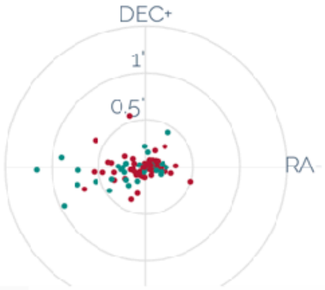
high_flux_ratio_wrt_nn

young_extragalactic_candidate

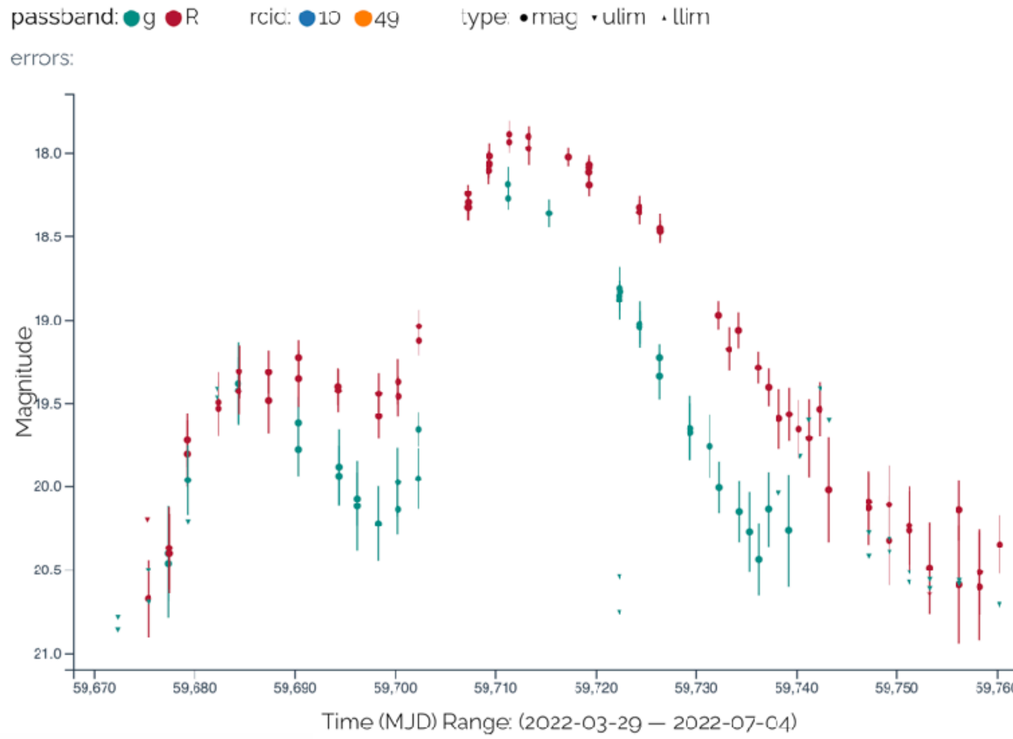
Alert Brokers: ALeRCE

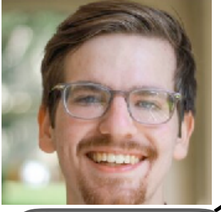
External Services: IPAC, NED, SIMBAD, SNAD, TNS, VizieR

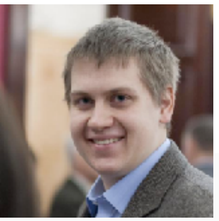
Finder Chart



Lightcurve







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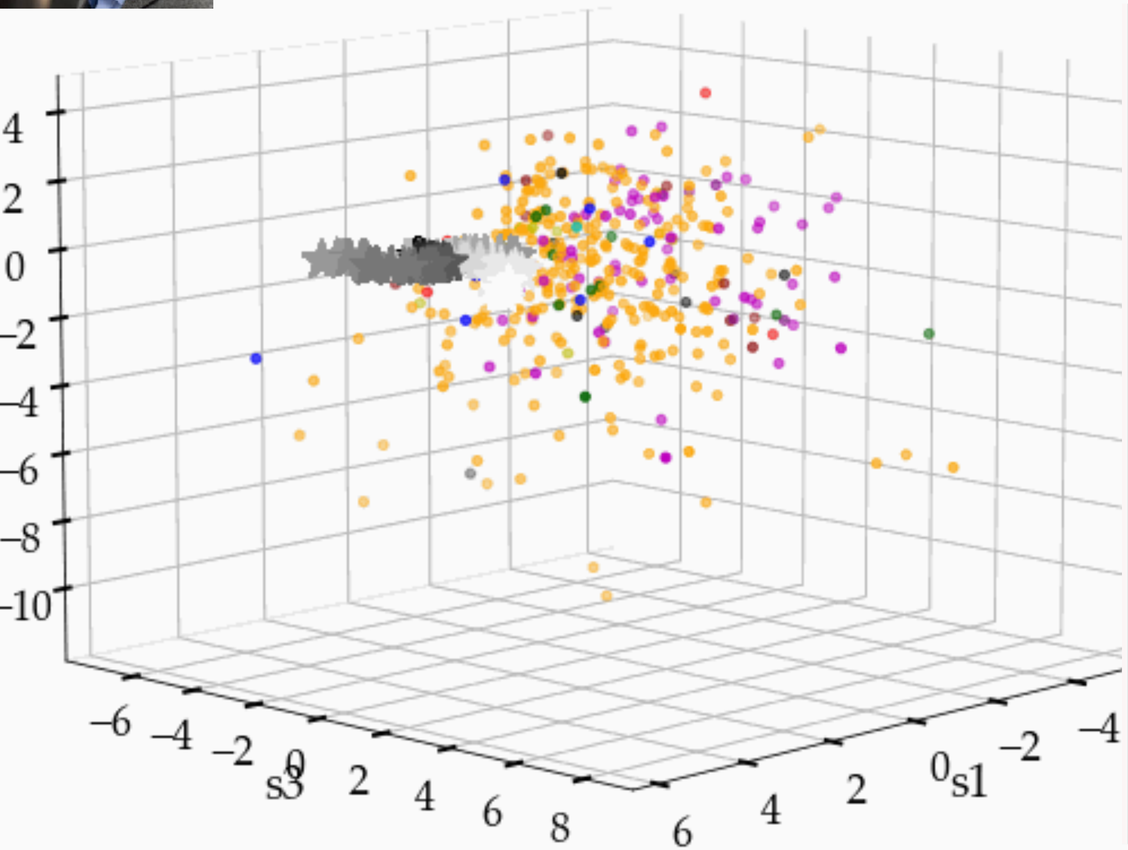

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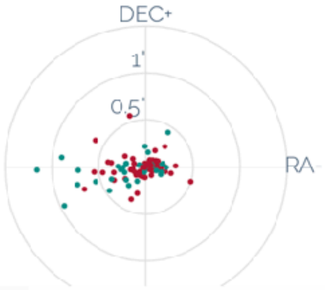
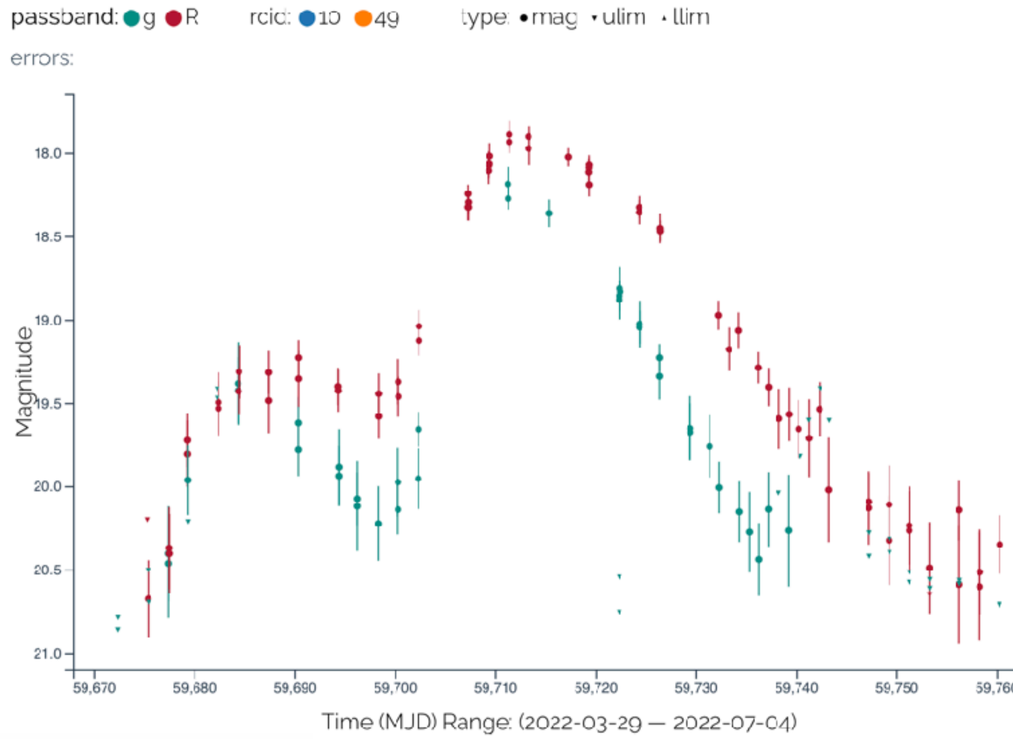


Lightcurve



FILTERS CREATE LATENT SPACES, YOU DEFINE DISTANCE METRICS

REF: ZTF21aaublej, d=0
2021ixf, SN Ia, z=0.041

ANN=1: ZTF21abbkefe, d=40
2021mid, SN Ia, z=0.042

ANN=2: ZTF21aafgljq, d=44
2021ars, SN Ia, z=0.05

ANN=3: ZTF20abqaqgv, d=45
2020qqn, SN Ia, z=0.045

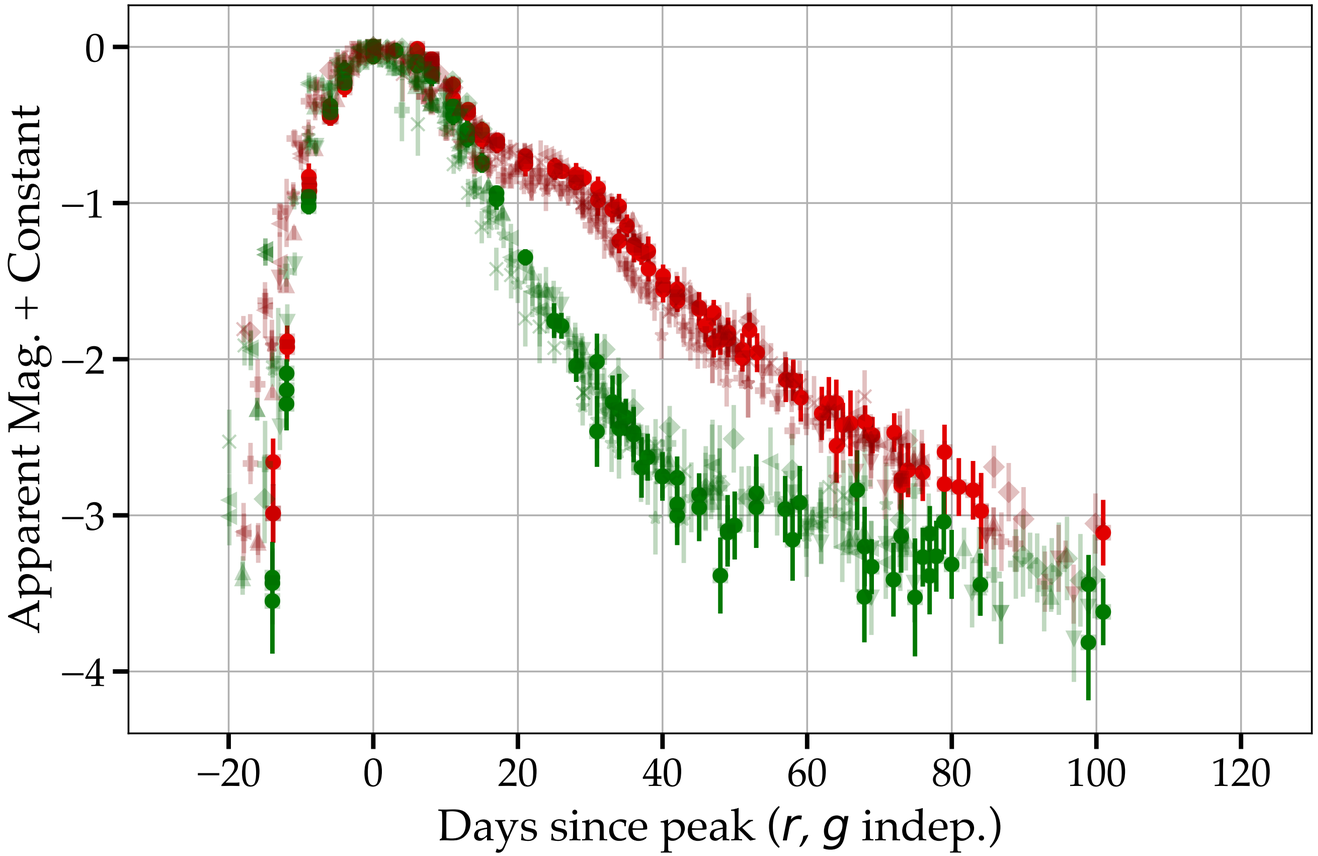
ANN=4: ZTF21absvlrr, d=45
2021vtq, SN Ia, z=0.021

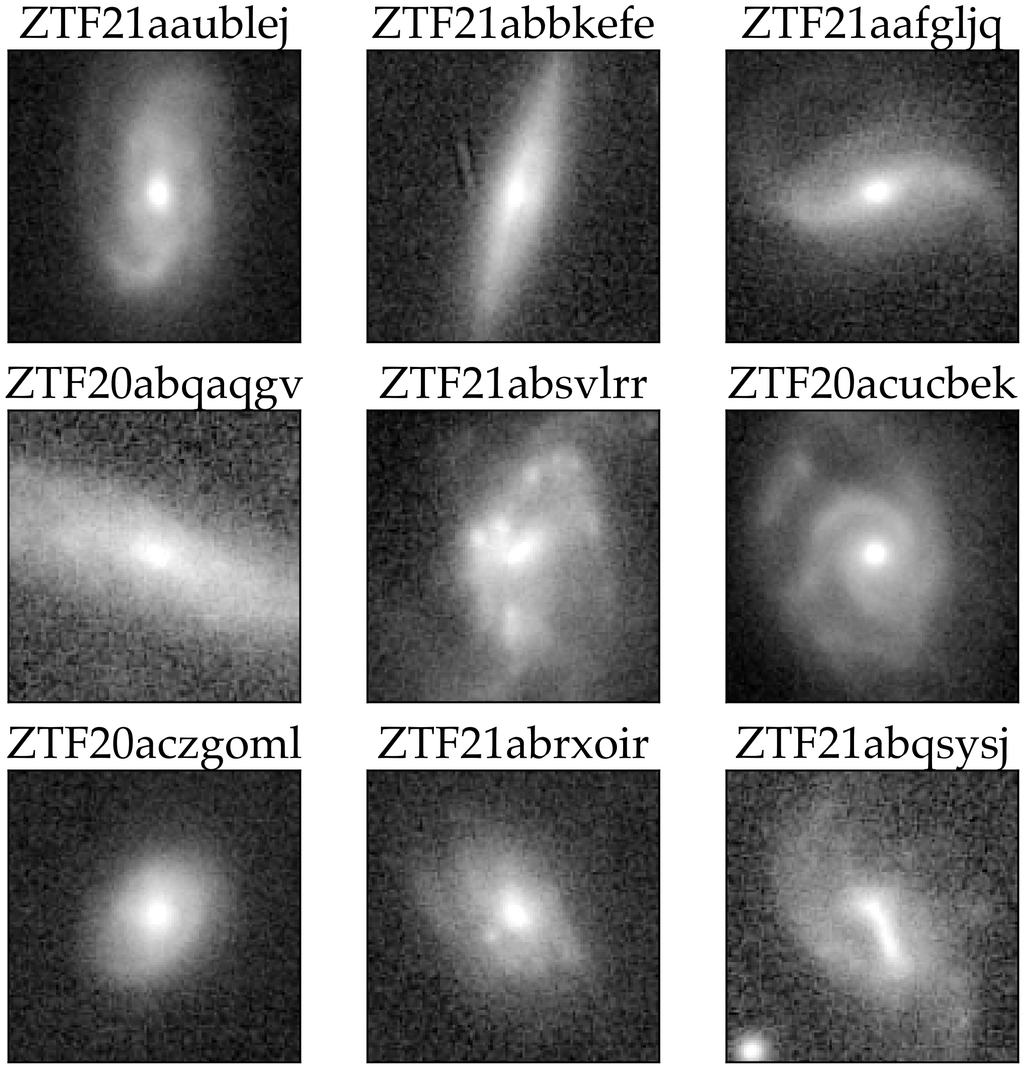
ANN=5: ZTF20acucbek, d=46
2020abcl, SN Ia, z=0.039

ANN=6: ZTF20aczgoml, d=46
2020adis, SN Ia-91T-like, z=0.045

ANN=7: ZTF21abrxoir, d=47
2021vju, SN Ia, z=0.027

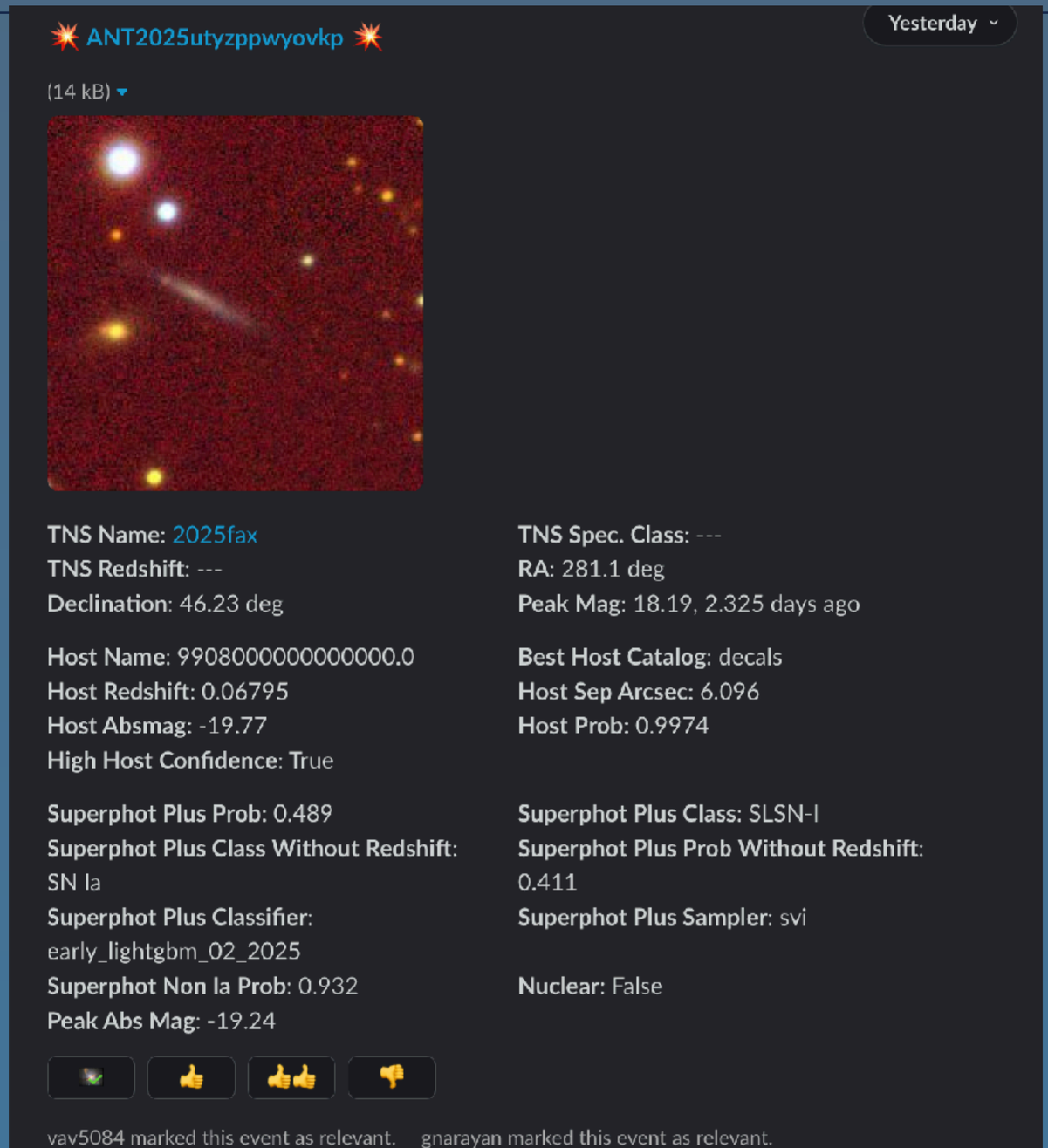
ANN=8: ZTF21abqsysj, d=47
2021vpv, SN Ia-91T-like, z=0.04





COORDINATING FACILITIES CHANGES HOW WE CAN DO SCIENCE

- Same SCIMMA slack bot that works to send Kafka alerts from LVK to the Gravity Wave Collective also works to send interesting transient alerts from ANTARES to the Young Supernova Experiment
- We can vet the most promising objects and trigger followup in seconds
- We're currently using slack emojis to collect user feedback each night, and iteratively re-train the classifier (active learning) **- we can't be doing this by eye with Rubin and Roman**

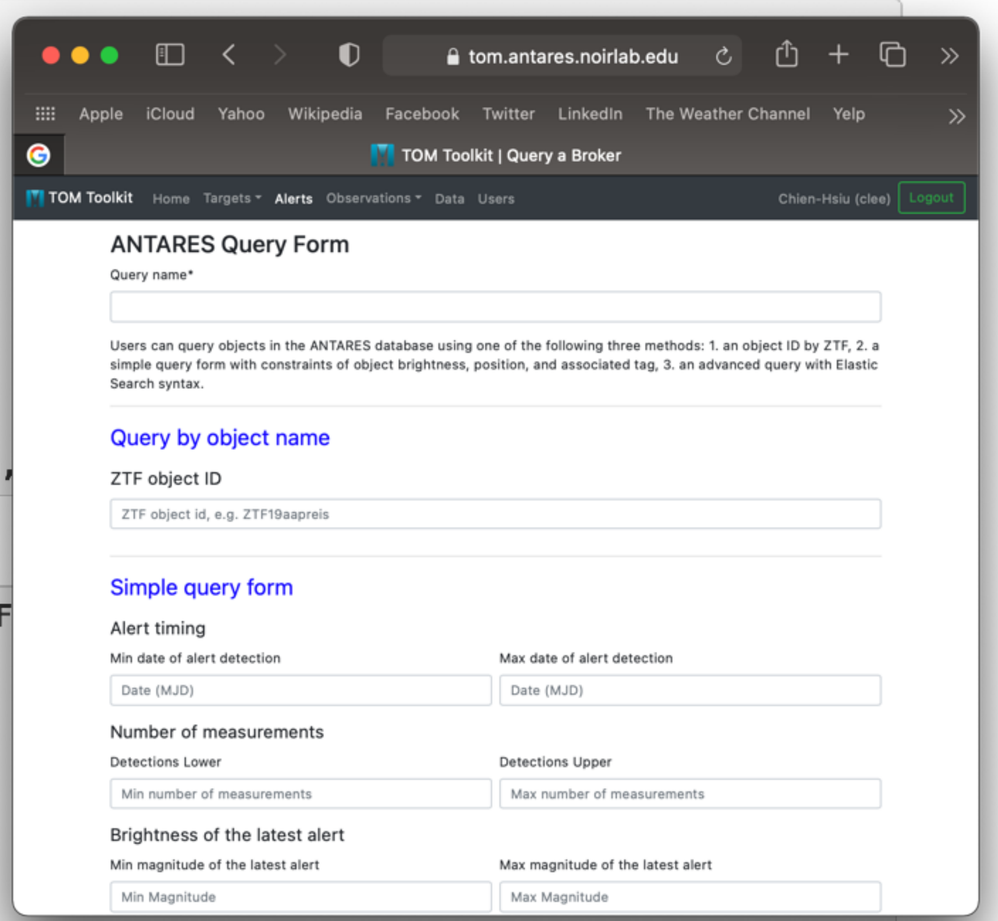


REAL-TIME FOLLOWUP FROM ANTARES WITH TOMS

In [69]:
```
from antares_client.search import get_by_id, get_by_ztf_object_id
#get locus by ANTARES ID
locus = get_by_id("ANT2018c7igm")

#get locus by ZTF ID
#locus = get_by_ztf_id("ZTF18abhjrcf")

print(locus.locus_id, locus.ra, locus.dec)

import os
os.environ["DJANGO_ALLOW_ASYNC_UNSAFE"] = "true"
from tom_targets.models import Target
t = Target.objects.create(name=locus.locus_id, type='SIDEREAL', ra=locus.ra,
```

```
ANT2018c7igm 280.6927190683333 -12.904117143333334
```

In [64]:
```
from tom_observations.facilities.lco import LCOFacility, LCOBaseObservationF

target = Target.objects.get(name=locus.locus_id)

form = LCOBaseObservationForm({
    'name': 'Programmatic Observation',
    'proposal': 'TOM2020A-012',
    'ipp_value': 1.05,
    'start': '2020-10-09T00:00:00',
    'end': '2020-10-10T00:00:00',
    'filter': 'R',
    'instrument_type': '1M0-SCICAM-SINISTRO',
    'exposure_count': 1,
    'exposure_time': 20,
    'max_airmass': 4.0,
    'observation_mode': 'RAPID_RESPONSE',
    'target_id': target.id,
    'facility': 'LCO'
})
```



Convince a TAC to give you time

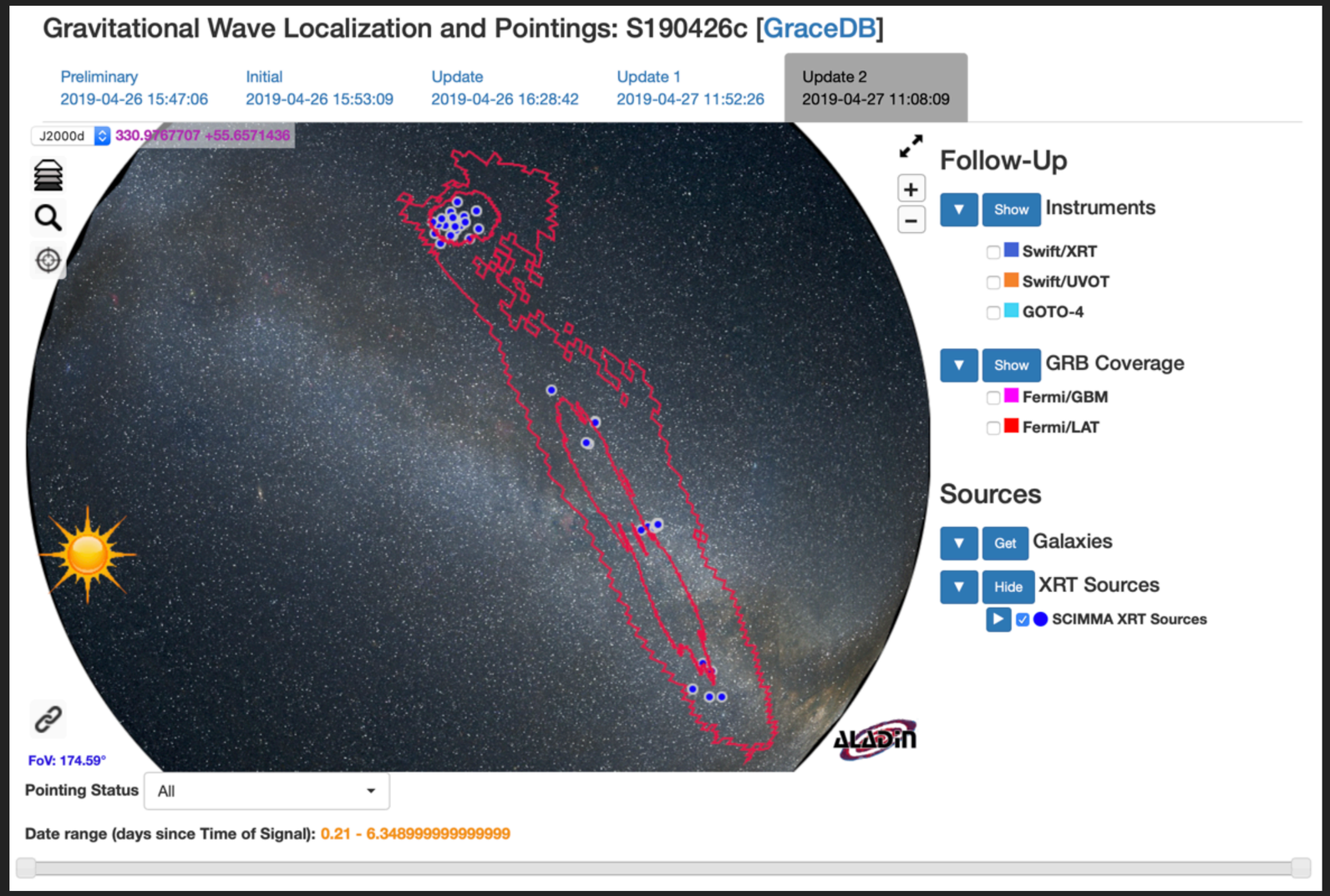
Find object of interest in the stream

Create a followup observation request and submit

TREASURE MAP – HOPSKOTCH INTEGRATION

Wyatt et al. 2020, ApJ, 894, 127

https://treasuremap.space



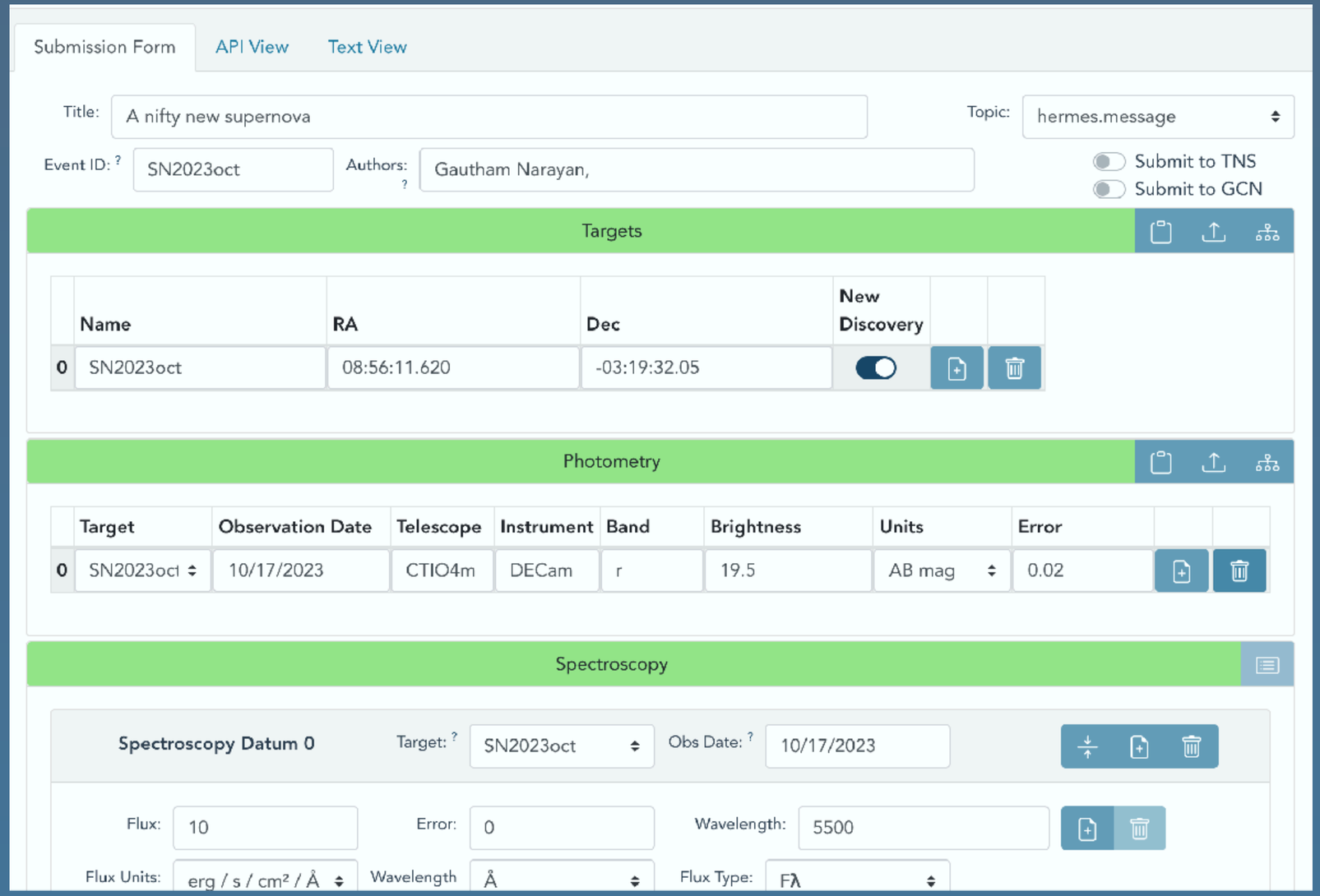
- X-ray sources are reported by Swift in GCN notices.
- When a GCN notice is carried through Hopskotch, the X-ray sources are extracted into a database
- Treasure map queries this database via API to report X-ray sources.
- Building the connections with TOM Toolkit and AEON automagically means we can keep TreasureMap updated in real-time.

NOTICES:

IF YOU CAN OBSERVE TARGETS, YOU CAN COMMUNICATE THE RESULTS OF YOUR FOLLOW-UP TO EVERYONE IN REAL-TIME IN A MACHINE READABLE WAY

HERMES: MESSAGING FROM YOUR BROWSER

- HERMES: Hopskotch-enabled Realtime Message Exchange Service
- Where Hopskotch serves big groups, Hermes serves users and small teams working on follow-up
- Nothing to install - https://hermes.lco.global/ use your SCIMMA credentials and you are ready to go
- **Connects with TNS/NASA GCN** – one stop shop to submit a discovery
- Messages are human-readable AND machine-parseable, all form fields are validated, neat API



HERMES Browse Submit Message Stream Status: About gsn@illinois.edu

igwn.gwalert ×

Search Terms

TIMESTAMP	TOPIC	TITLE	SUBMITTER
2 days ago	igwn.gwalert	S240104bl - UPDATE	cody.messick-30d512c8
2 days ago	igwn.gwalert	S240104bl - INITIAL	cody.messick-30d512c8
2 days ago	igwn.gwalert	S240104bl - PRELIMINARY	cody.messick-30d512c8
2 days ago	igwn.gwalert	S240104bl - PRELIMINARY	cody.messick-30d512c8
2 days ago	igwn.gwalert	S240104ao - PRELIMINARY	cody.messick-30d512c8
2 days ago	igwn.gwalert	S240104ao - PRELIMINARY	cody.messick-30d512c8
2 days ago	igwn.gwalert	S240104ah - PRELIMINARY	cody.messick-30d512c8
2 days ago	igwn.gwalert	S240104ah - PRELIMINARY	cody.messick-30d512c8
2 days ago	igwn.gwalert	S240104ae - PRELIMINARY	cody.messick-30d512c8
2 days ago	igwn.gwalert	S240104ae - PRELIMINARY	cody.messick-30d512c8

« ‹ 1 2 3 4 … › »

Show: 10

S240104bl - INITIAL

Message ID: c6f1cc7a

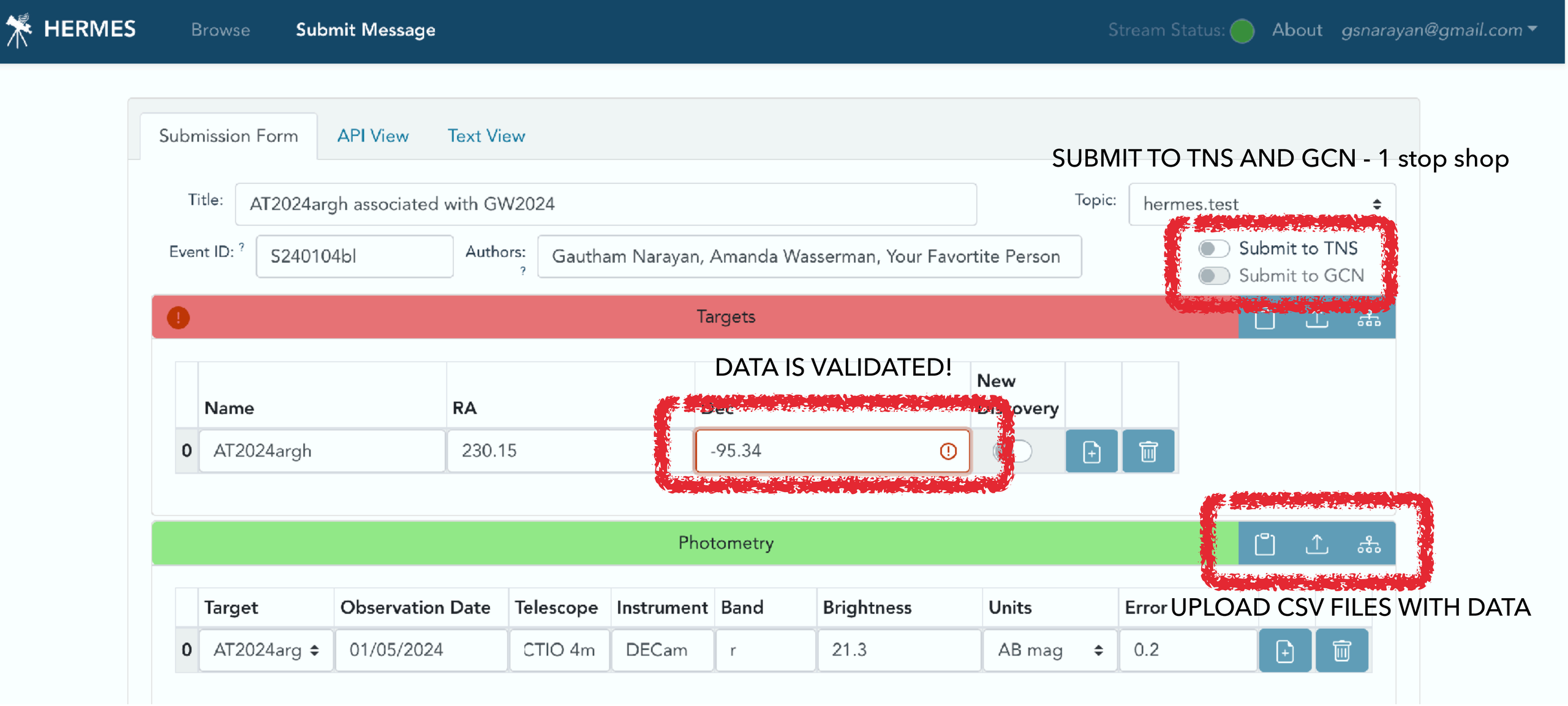
Superevent Messages: S240104bl

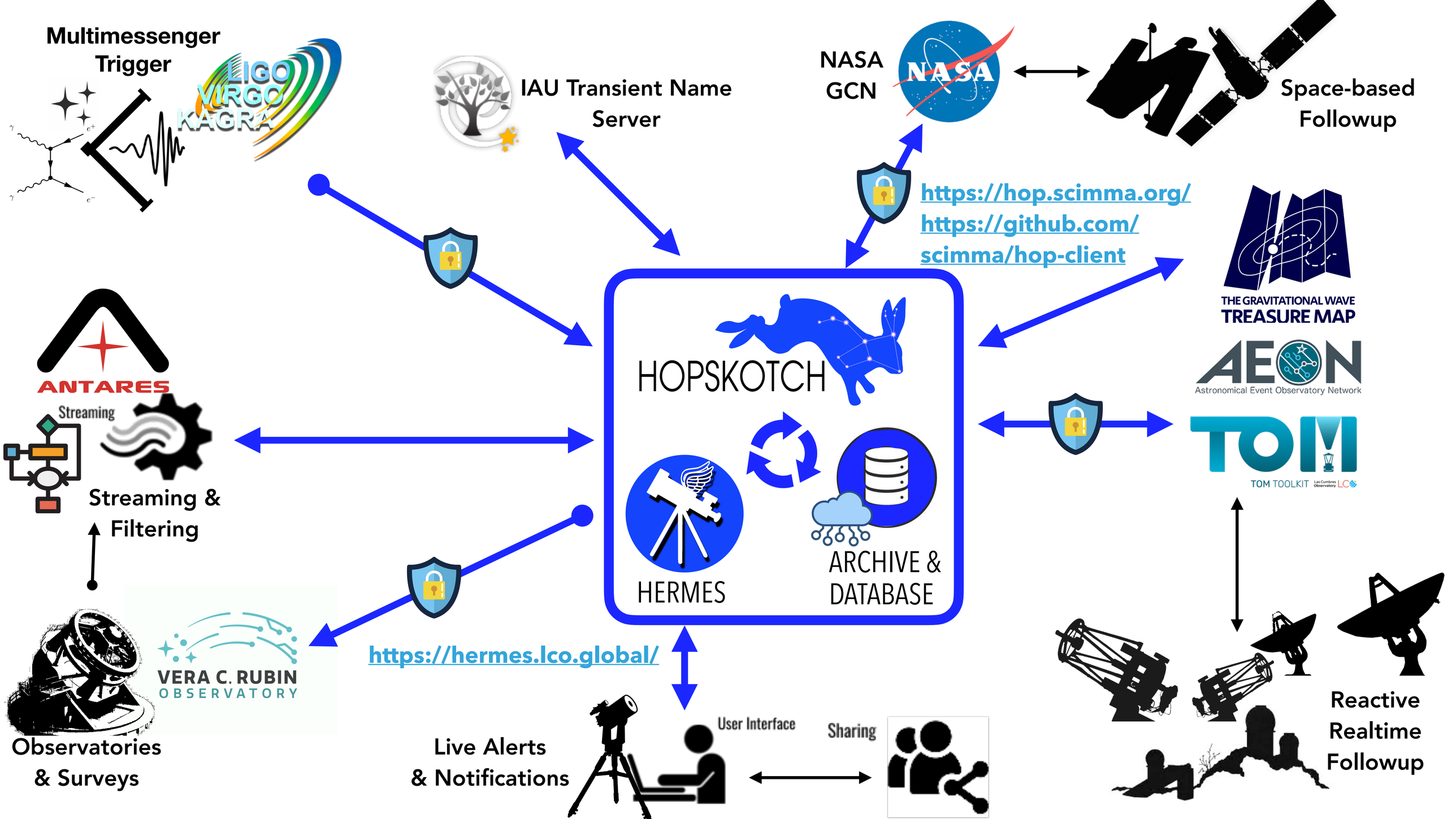
URLS KEYPAIRS ≡

Key	Value
skymap	https://gracedb.ligo.org/api/superevents/S240104bl/files/bayestar.multiorder.fits,1
gracedb	https://gracedb.ligo.org/superevents/S240104bl/view/

EVENT KEYPAIRS ≡

Key	Value
far	3.554967487258808e-17


HERMES
Browse
Submit Message
Stream Status:
About
gsnarayan@gmail.com
Submission Form
API View
Text View
SUBMIT TO TNS AND GCN - 1 stop shop
Title:
AT2024argh associated with GW2024
Topic:
hermes.test
Event ID:
S240104bl
Authors:
Gautham Narayan, Amanda Wasserman, Your Favortite Person
Submit to TNS
Submit to GCN
Targets
DATA IS VALIDATED!
Name
RA
New
0
AT2024argh
230.15
-95.34
Photometry
UPLOAD CSV FILES WITH DATA
Target
Observation Date
Telescope
Instrument
Band
Brightness
Units
Error
0
AT2024arg
01/05/2024
CTIO 4m
DECam
r
21.3
AB mag
0.2


Multimessenger Trigger
LIGO VIRGO KAGRA
IAU Transient Name Server
NASA GCN
NASA
Space-based Followup
https://hop.scimma.org/
https://github.com/scimma/hop-client
THE GRAVITATIONAL WAVE TREASURE MAP
AEON
Astronomical Event Observatory Network
TOM
TOM TOOLKIT
ANTARES
Streaming
Streaming & Filtering
HOPSKOTCH
HERMES
ARCHIVE & DATABASE
https://hermes.lco.global/
VERA C. RUBIN OBSERVATORY
Observatories & Surveys
Live Alerts & Notifications
User Interface
Sharing
Reactive Realtime Followup

2. COORDINATION TAKES POLICY

I.E. WHY I'M HERE

OBSERVATORY STATUS

IF INDIVIDUAL OBSERVERS CAN COMMUNICATE,

FACILITIES OUGHT TO COMMUNICATE THEIR CURRENT STATUS

heroic.scimma.org/summary?ra=122.689&dec=-26.5919&begin=2024-05-09&end=2024-05-11

Bad Weather | Sun up | Downtime | Calibration | Failed | Observed | Visible Window

RA: 122.689 deg

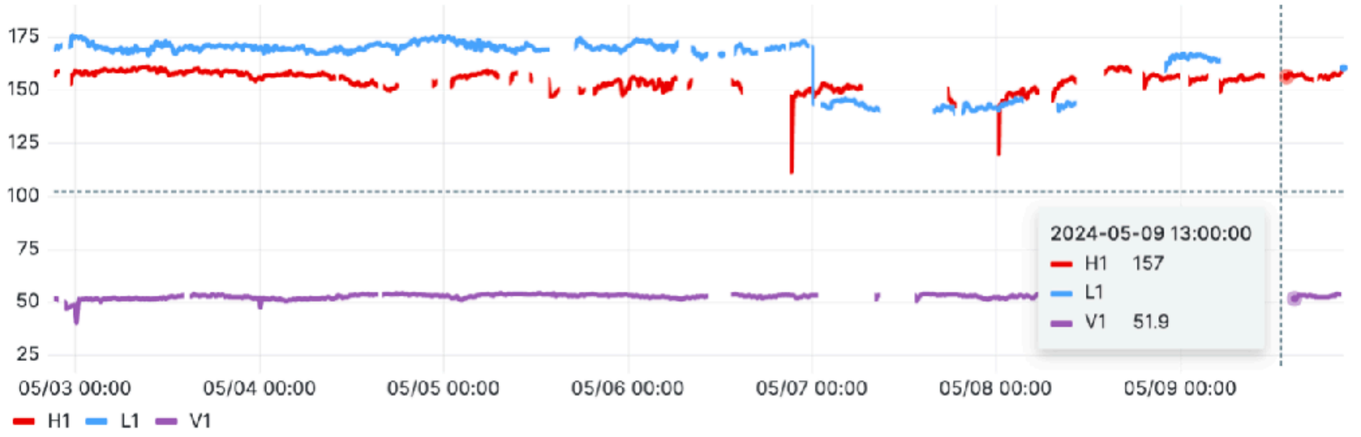
Dec: -26.5919 deg

Start: 2024-05-09

End: 2024-05-11

PI: John Doe
Date: 2024-05-09
Band: r (60 sec exposure)
Avg Seeing: 1.3”
Limiting mag: 22.5

LVK Sensitivities:



Add Telescope

CTIO - Blanco

CTIO - SOAR

McDonald - GMT

May 9, 2024

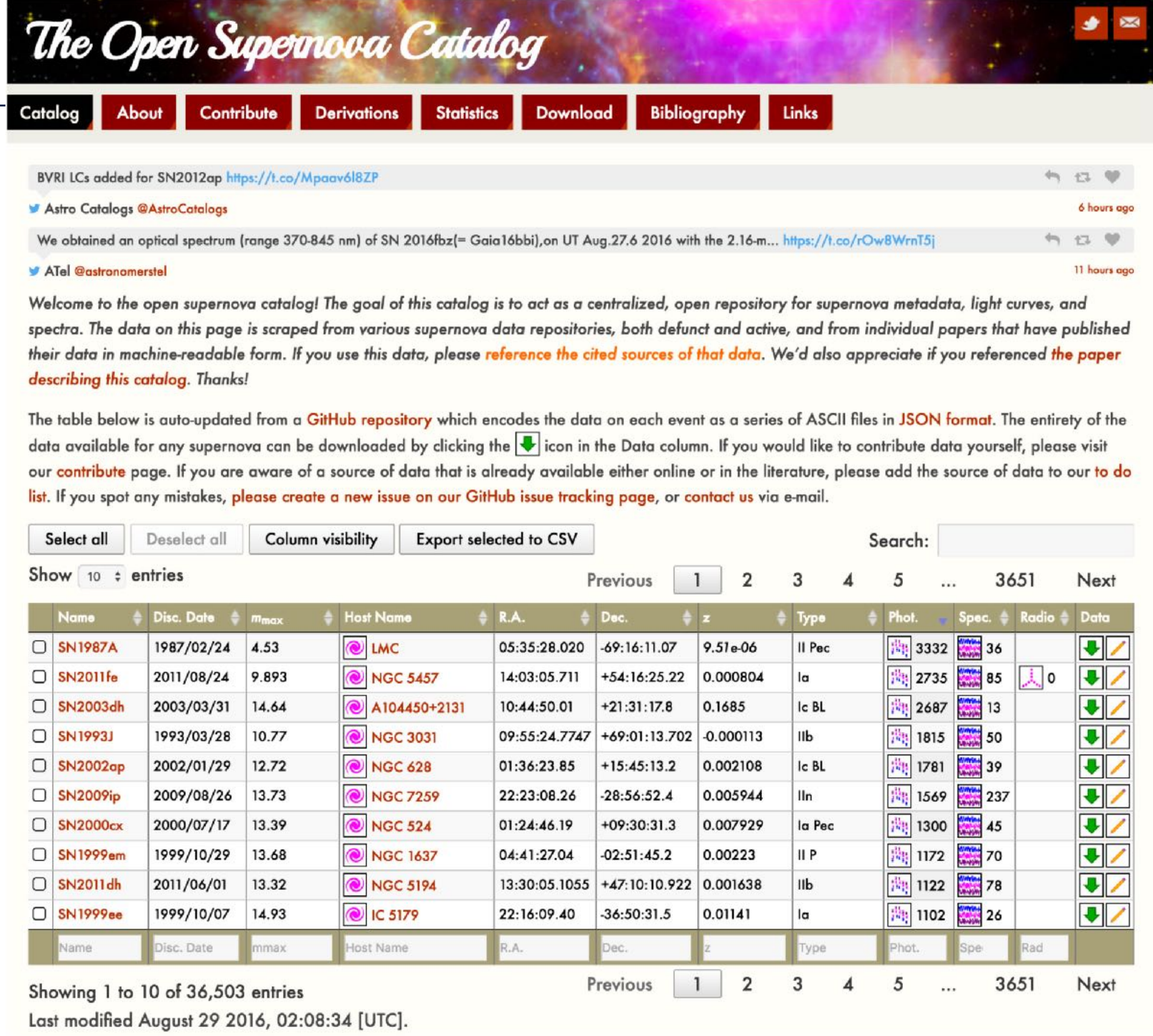

HOPSKOTCH
LIGO VIRGO KAGRA
NOIR Lab
LCO
NASA
DSA
VERA C. RUBIN OBSERVATORY
HEROIC
ARCHIVE & DATABASE
python
TOM
TOM TOOLKIT
AEON
Astronomical Event Observatory Network
ANTARES
THE GRAVITATIONAL WAVE TREASURE MAP
treasuremap.space
SNEx
REST API
User Interface
Observatories & Experiments
Streaming
SINGLE FACILITY STATUS & TELEMETRY STREAMS
MULTI FACILITY SUMMARY TABLES AND VISUALIZATIONS
Individual Scientists & Teams

ARCHIVES

IF OBSERVATORIES CAN SHARE CURRENT AND PLANNED STATUS, THEY OUGHT TO SHARE RECORDS FOR PAST OBSERVATIONS

APIS TO ARCHIVES

- Our archives are static - you login, do a cone search, get a list of FITS files (or maybe catalogs) that you download and then process on your own
- But given a new alert from LVK, I want to identify any source in the high probability region, get Rubin pixels, get photometry even if the source never had a significant alert in the past
- All observations - i.e. LVK too - enable sub-threshold searches on optical detected sources
- We need an archive of observations for MMA, - or more broadly programmatic access to all historical data even more (5 years)
- **That will not happen unless it is mandated by the agencies**



BLAST DEMO

https://blast.scimma.org/

David Jones (Hawaii), Peter McGill (LBNL)

Blast Home Transients Acknowledgements Docs Login

2024byg

Download data

Information

Transient

Name: SN2024byg
Right ascension: 12h51m53.83s
Declination: -4d34m24.79s
Discovery Date: Feb. 8, 2024, 1:12 p.m.
Classification: SN II
Redshift: 0.008800
MW E(B-V): 0.022

Host

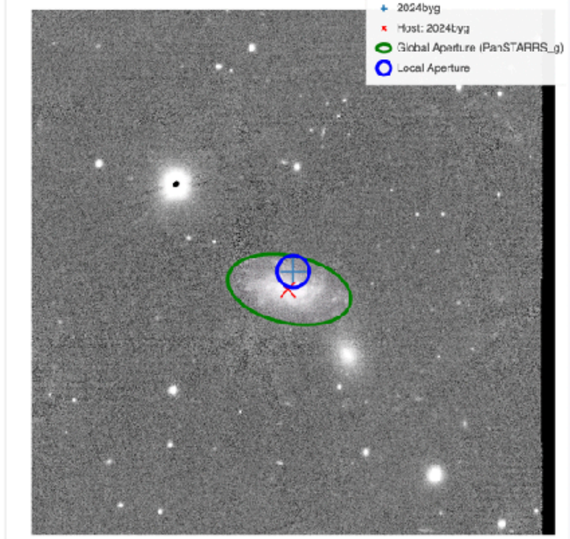
Name: 2024byg
Right ascension: 12h51m54.07s
Declination: -4d34m37.20s
Redshift: 0.008800
Photometric Redshift: 0.273

Processing Status

Task Name	Status	Time taken (s)	Warning Flag
Host match	processed	2.46	Report
Cutout download	processed	0.2	Report
Global aperture construction	processed	0.54	Report
Local aperture photometry	processed	3.42	Report
Global aperture photometry	processed	3.64	Report

Imaging data

PanSTARRS g



Choose cutout | Get Cutout

Spectral Energy Distribution

Global | Local

Report bugs and issues on Github here | UCSC Transient team web pages here

Global aperture photometry	processed	2.28	Report
Validate local photometry	processed	0.01	Report
Validate global photometry	processed	7.75	Report
Host information	processed	0.06	Report
Global host SED inference	processed	493.55	Report
Local host SED inference	processed	378.29	Report
Transient information	processed	0.0	Report
Transient MWEBV	processed	0.06	Report
Host MWEBV	processed	0.07	Report
Log transient processing status	processed	None	Report

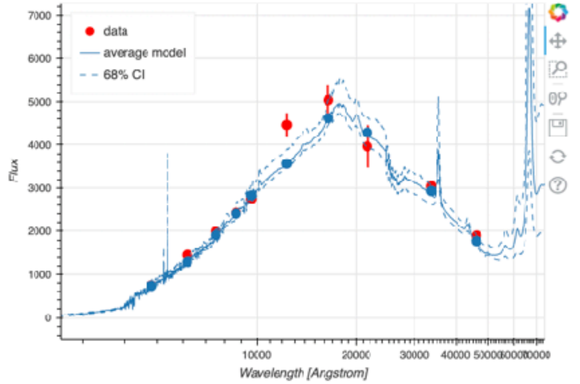
Cutout Download Report

2MASS_H: ✓ 2MASS_J: ✓ 2MASS_K: ✓ WISE_W1: ✓ WISE_W2: ✓ WISE_W3: ✓ WISE_W4: ✓
GALEX_NUV: ✗ GALEX_FUV: ✗ PanSTARRS_g: ✓
PanSTARRS_r: ✓ PanSTARRS_i: ✓ PanSTARRS_z: ✓
PanSTARRS_y: ✓ SDSS_i: ✗ SDSS_r: ✗ SDSS_u: ✗
SDSS_z: ✗ SDSS_g: ✗ DES_g: ✗ DES_r: ✗ DES_i: ✗ DES_z: ✗ DES_Y: ✗

Spectral Energy Distribution

Global | Local

Download Best-Fit Model



Host SED inference

Global | Local

Global parameter details

Download Chains | Download Percentiles

Parameter	Lower Bound (16%)	Median	Upper Bound (84%)
mass	10.819	10.924	11.034
sfr	0.145	0.496	0.777
ssfr	-10.804	-10.432	-10.132
age	3.909	4.991	6.179

COORDINATION NEEDS PEOPLE TALKING

- OpenMMA is joint slack for all groups, liaisons between SCIMMA and surveys (e.g. LVK, IceCube, Rubin, etc) so users have a channel to provide feedback, ask questions, help each other. **Next telecon is April 10th**
- MMA has different cultures, different groups that have spent decades competing for science, funding etc. **Talk with, not talk at.**
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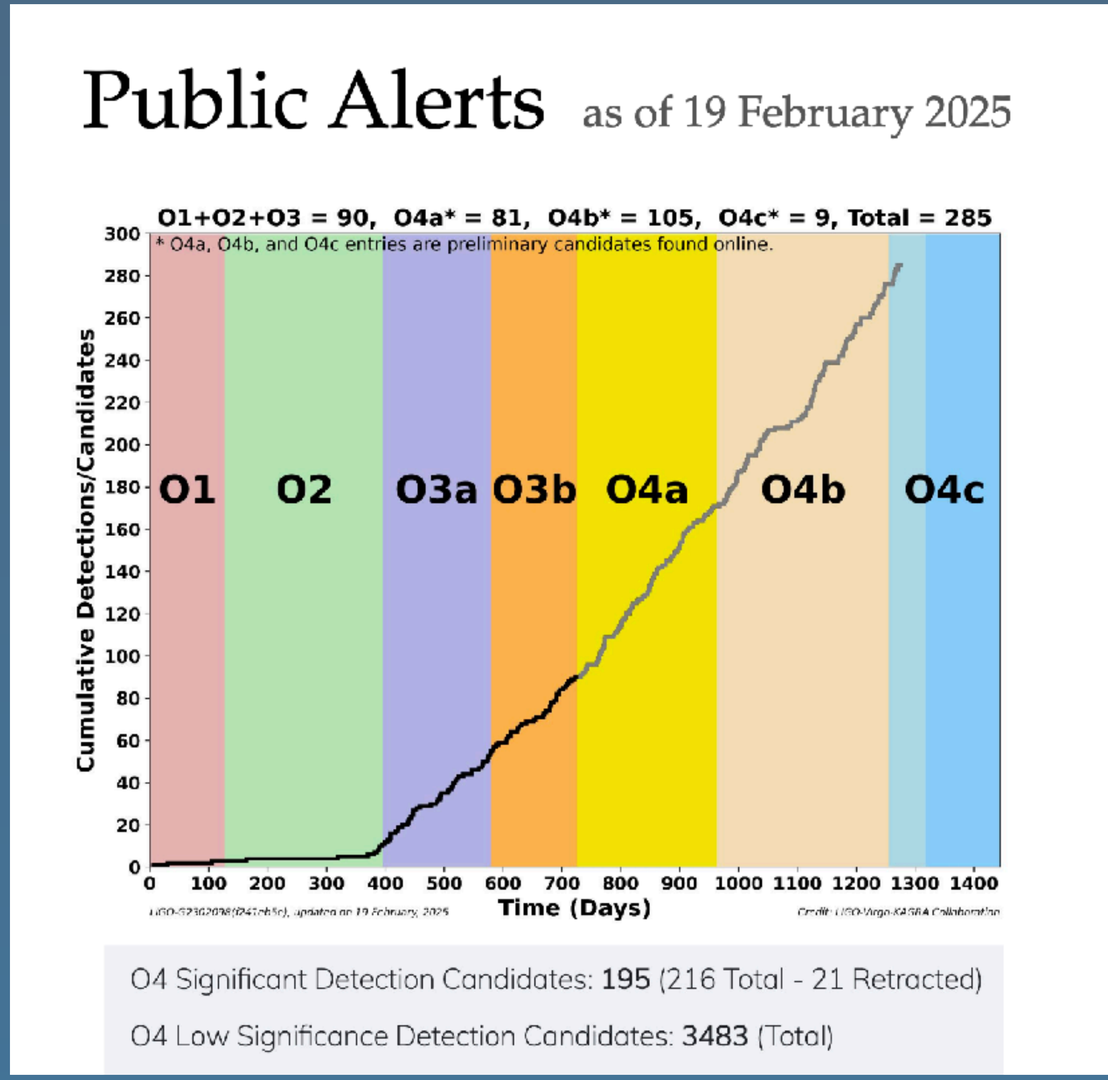

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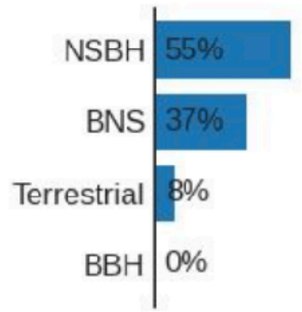
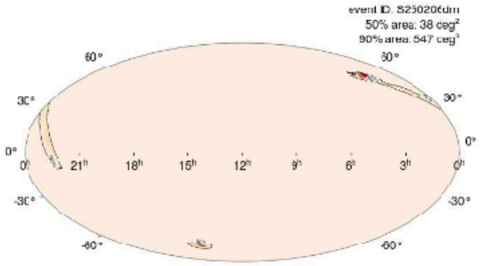
Public Alerts as of 19 February 2025

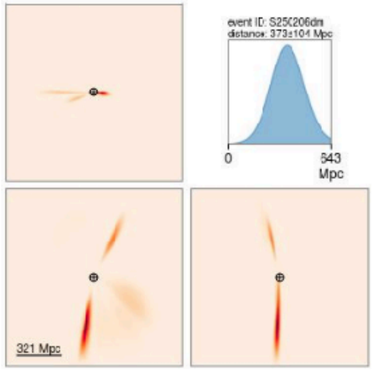
S250206dm

- GW compact binary merger candidate
- 2025-02-06 21:25:30.439 UTC (GPS time: 1422912348.439)





HasMassGap = 35%
HasNS > 99%
HasRemant = 13%



- GraceDB event page: https://gracedb.ligo.org/superevents/S250206dm/view/

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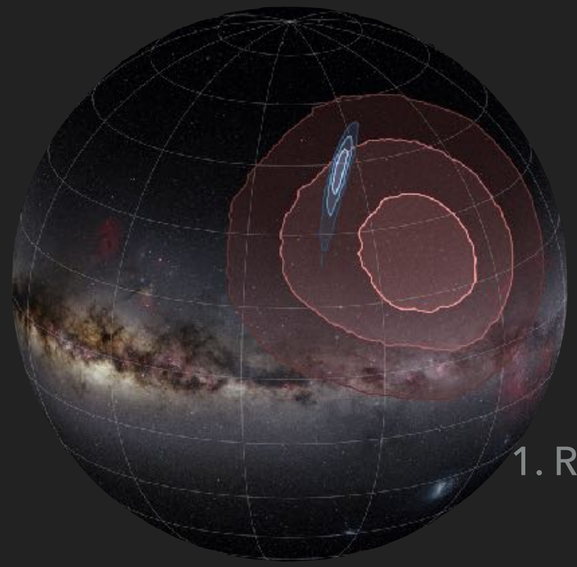
- **But fundamentally, there’s no mechanism for cross-agency funding.**
- **Coordination is a technical challenge. Cooperation is a policy choice.**

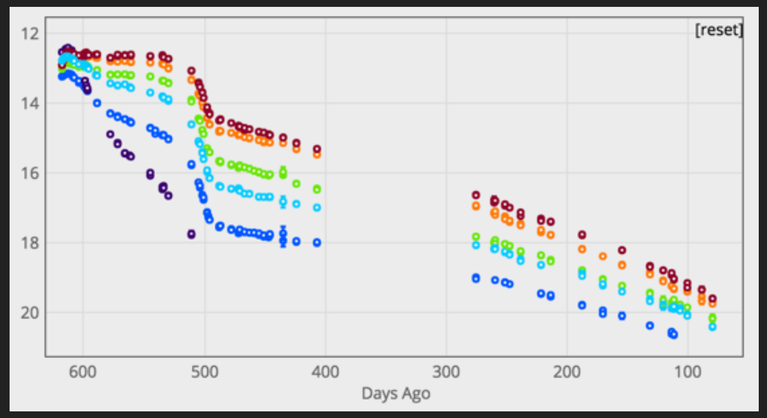
3.WHAT MMA OUGHT TO BE

VISION FOR GRAVITATIONAL WAVE FOLLOWUP OF THE FUTURE



1. Receive alert

2. Telescopes automatically observes target, negotiates priorities, data access



3. Data are automatically reduced, instantly made available to community

$$p_{\mathrm{dist}}(\mathrm{R.A.}, \mathrm{decl.}, D) = N_{\mathrm{dist}}(\mathrm{R.A.}, \mathrm{decl.}) \cdot e^{-\frac{[D-\mu_{\mathrm{dist}}(\mathrm{R.A.}, \mathrm{decl.})]^2}{2\sigma^2_{\mathrm{dist}}(\mathrm{R.A.}, \mathrm{decl.})}}$$

4. Machines and humans make inferences based on all available data, repeat

INFERENCE AT RUBIN SCALE

- While we might only have ~20 MMA alerts in O5, we'll have thousands of BBH alerts
  - e.g. fun science question is **"What is beyond GR?"**
  - **this is why there's an Einstein Telescope**
  - waveforms for CBC from post-Einsteinian theories are expensive - can't do matched filter searches and inferenc with each theory separately
- Train a NN to encode all post-Einsteinian models in a continuous latent, space, and do inference with that instead (Xie et al., 2024, PRD)
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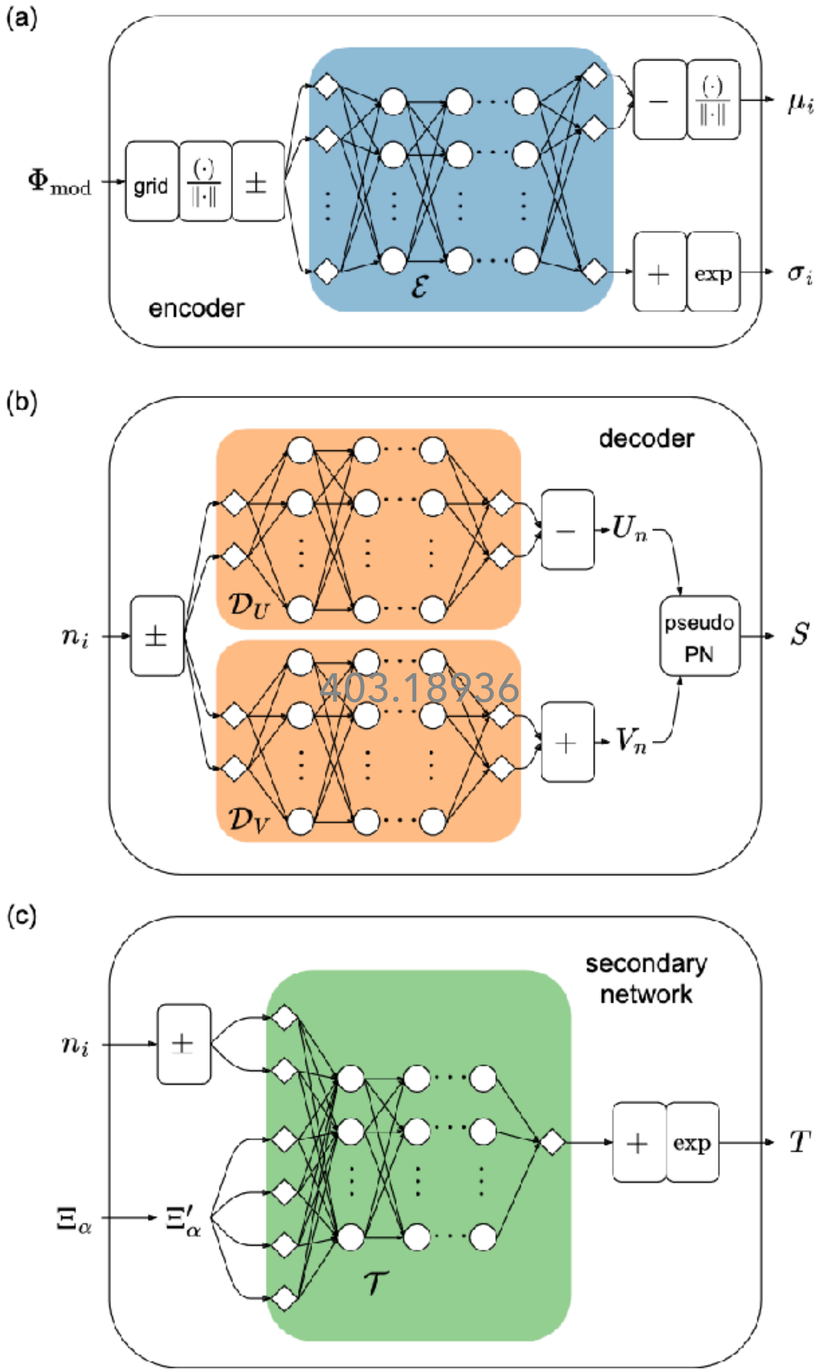

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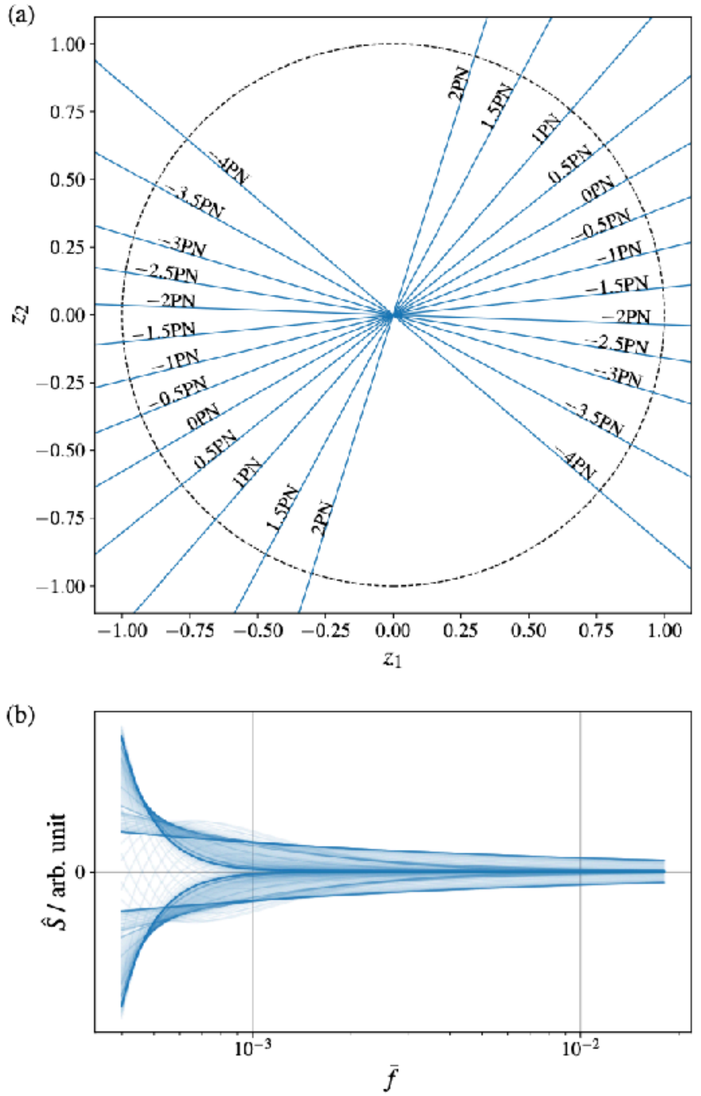

FIG. 5. Latent space angular parametrization learned by the VAE. (a) shows the representation of ppE theories (given by the encoder mean) in the latent space. Observe that each ppE index maps to a radial line. Different indices are separated, and are put in order in the latent space. (b) overlays the shape functions generated from a grid of the latent space polar angles separated by 1°. Observe that these shape functions form a continuous band, confirming that the learned npE angular paramctrization is continuous.

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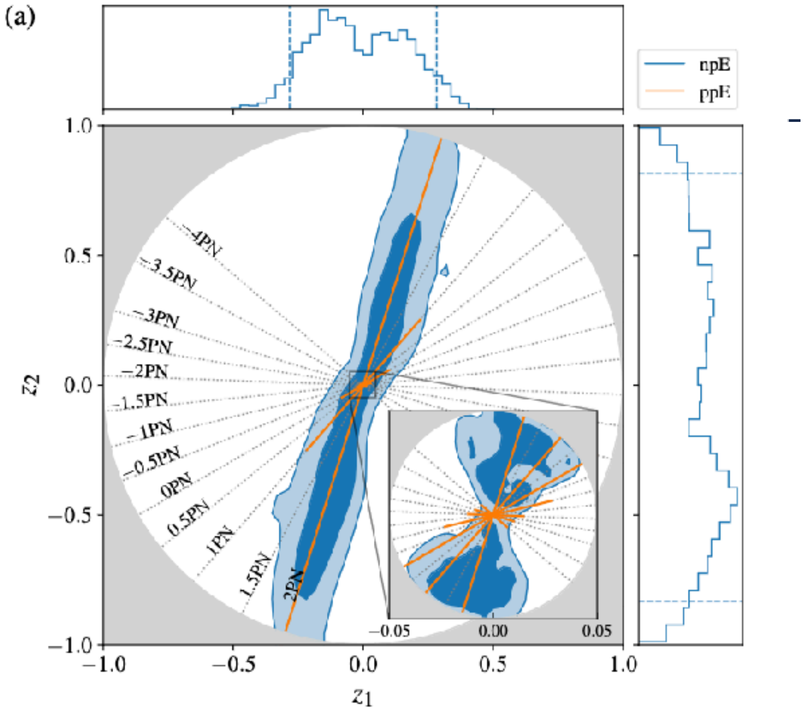

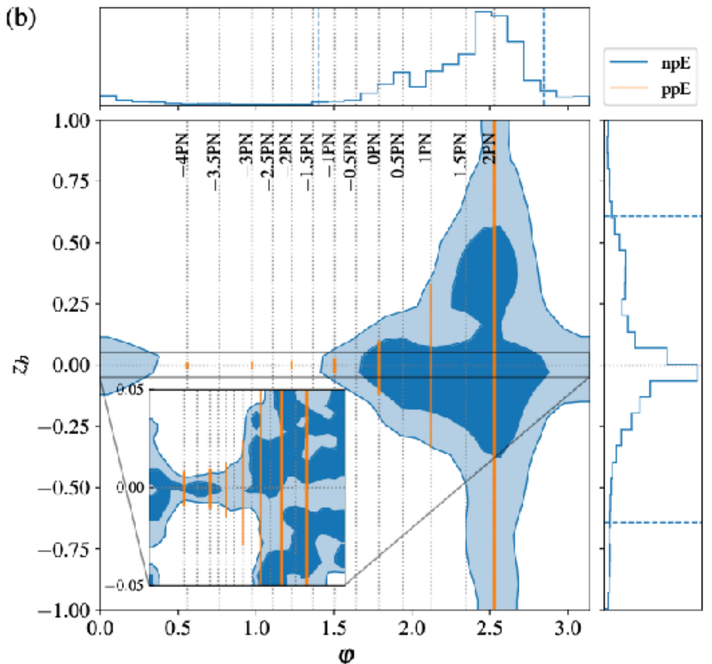

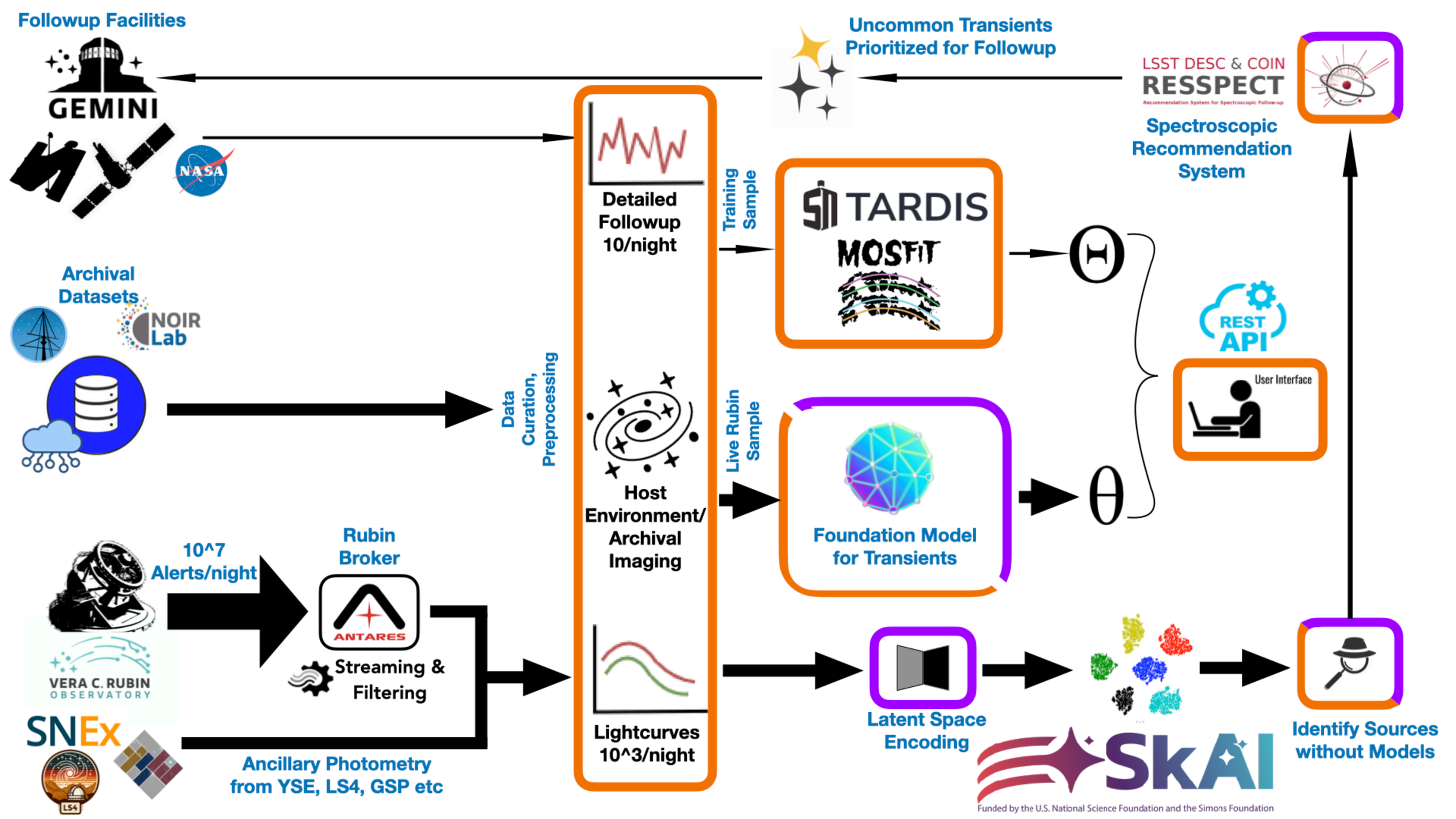
Followup Facilities
GEMINI
NASA
Uncommon Transients Prioritized for Followup
LSST DESC & COIN
RESSPECT
Recommendation System for Spectroscopic Follow-up
Spectroscopic Recommendation System
Archival Datasets
NOIR Lab
Detailed Followup 10/night
Training Sample
TARDIS
MOSFiT
Θ
REST API
User Interface
Data Curation, Preprocessing
Host Environment/ Archival Imaging
Live Rubin Sample
Foundation Model for Transients
θ
10^7 Alerts/night
Rubin Broker
ANTARES
Streaming & Filtering
VERA C. RUBIN OBSERVATORY
SNEx
LS4
Ancillary Photometry from YSE, LS4, GSP etc
Lightcurves 10^3/night
Latent Space Encoding
SkAI
Funded by the U.S. National Science Foundation and the Simons Foundation
Identify Sources without Models

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  - More to the point, by building interoperability into the DNA of these services, we get people working together
  - **Which is ultimately what we need to discover the next MMA source, and what we need to do science in the era of Rubin**

FIN