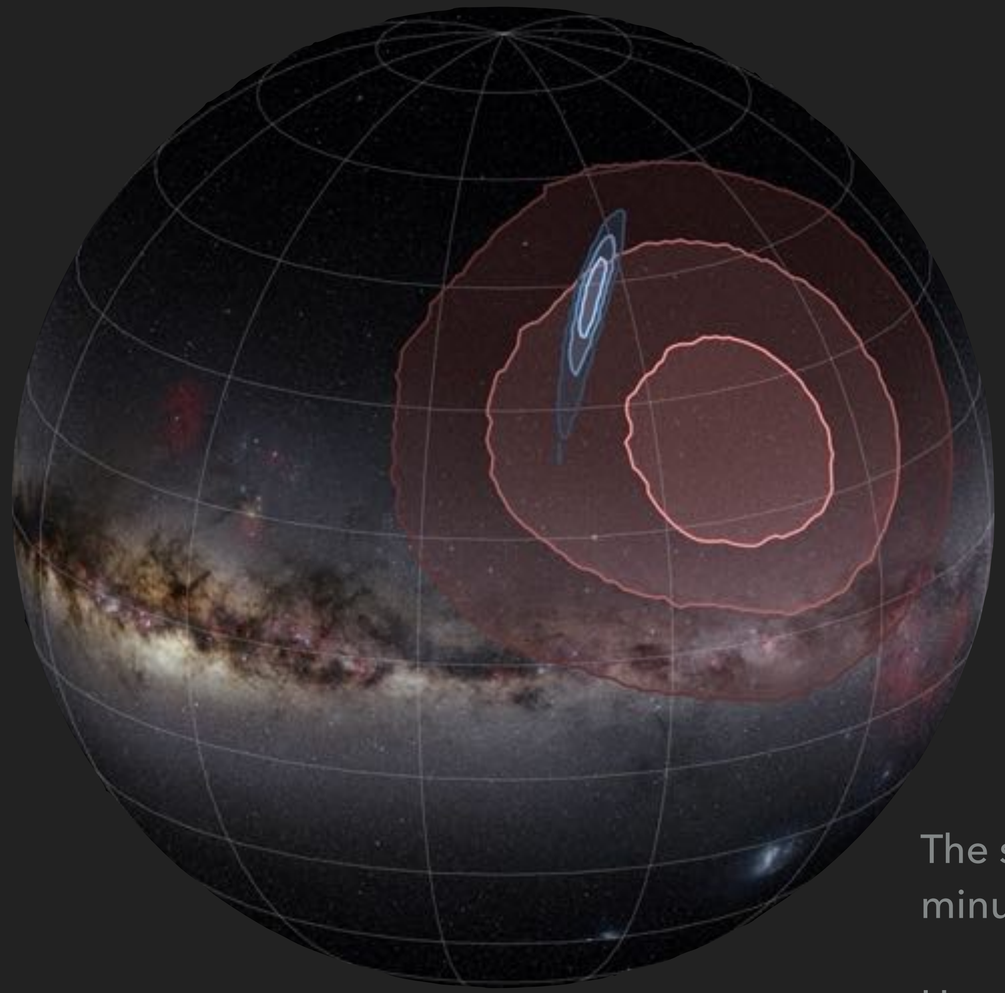
OVERVIEW OF THE NEXT GENERATION TRANSIENT FOLLOW-UP ECOSYSTEM

ANDY HOWELL
LAS CUMBRES OBSERVATORY,
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

MULTI MESSENGER ASTROPHYSICS AS A CASE STUDY

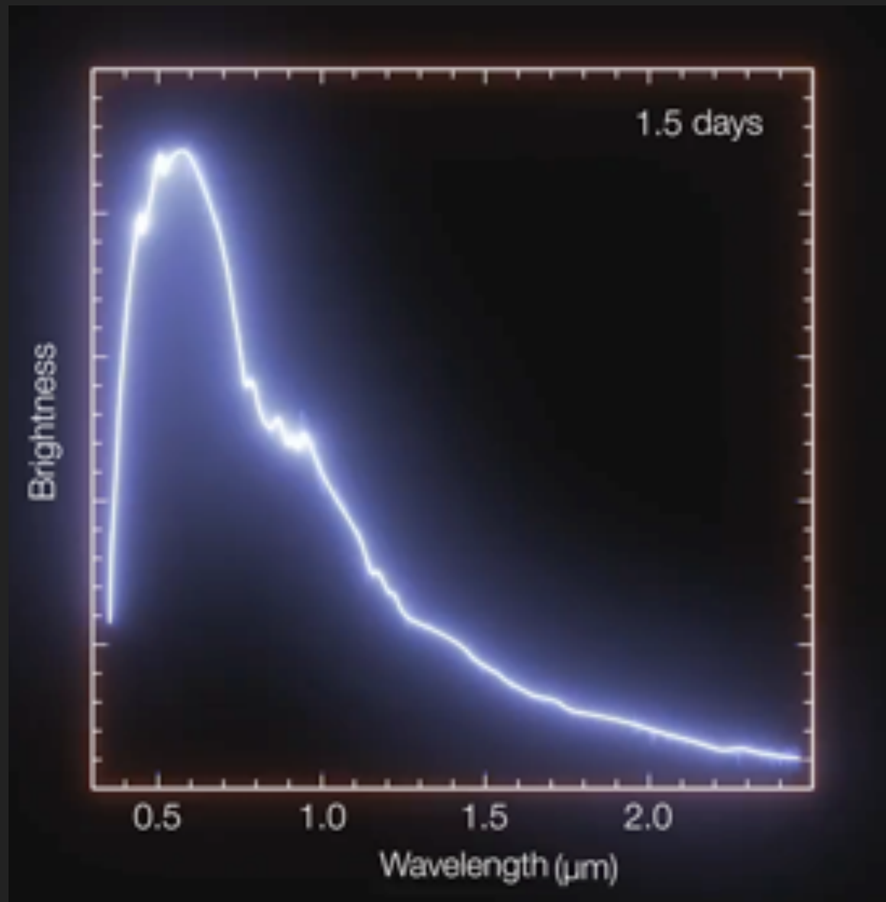


Two neutron stars merge together and this is detected by LIGO/Virgo/Kagra. Data from other facilities (e.g. Swift, Fermi, IceCube) may be added to change the localization. Hundreds of transients may exist in the localization region. They have to be found, observed, their properties determined, and communicated.

The source is changing minute-by-minute so every second counts.

Humans are the slow step, so automation is essential.

Data from Pian et al. 2017. Credit: ESO



HOW IT WORKS TODAY

```
TITLE:   GCN CIRCULAR
NUMBER:  21505
SUBJECT: LIGO/Virgo G298048: Fermi GBM trigger 524666471/170817529: LIGO/Virgo Id
DATE:    17/08/17 13:21:42 GMT
FROM:    Reed Classy Essick at MIT  <ressick@mit.edu>

The LIGO Scientific Collaboration and the Virgo Collaboration report:

The online CBC pipeline (gstlal) has made a preliminary
identification of a GW candidate associated with the time
 of Fermi GBM trigger 524666471/170817529 at gps time 1187008884.47
 (Thu Aug 17 12:41:06 GMT 2017) with RA=186.62deg Dec=-48.84deg and an error radi

The candidate is consistent with a neutron star binary coalescence with
False Alarm Rate of ~1/10,000 years.

An offline analysis is ongoing. Any significant updates will be provided
by a new Circular.

[GCN GPS NOTE(17aug17): Per author's request, the LIGO/VIRGO ID
was added to the beginning of the Subject-line.]
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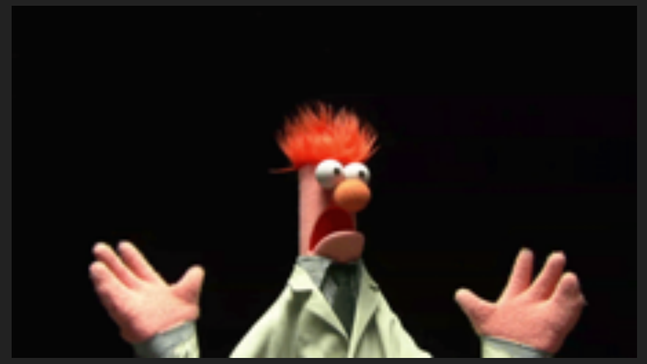
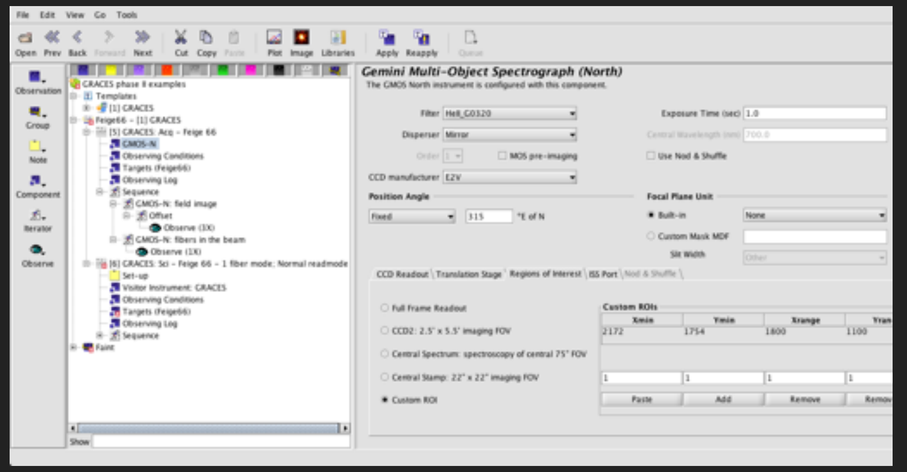
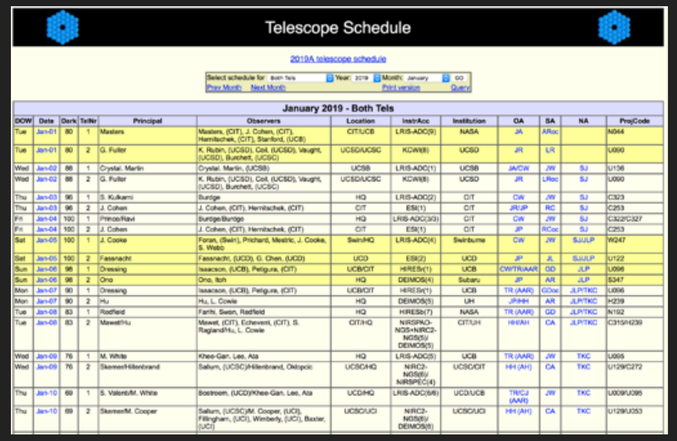
1. Receive alert via GCN or automatic listener.



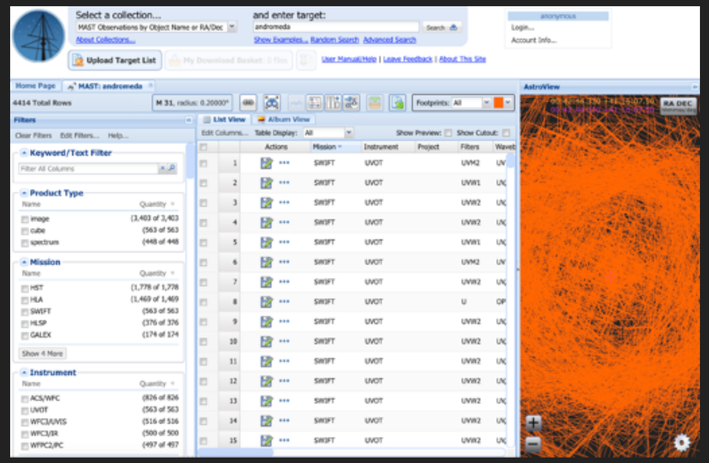
2. Panic



3. Trigger approved resources by filling out Phase II forms



4. Look up other resources available. Beg, plead, cajole for time. Form collaborations.



5. Download data from different archives and reduce it.

```
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.
```

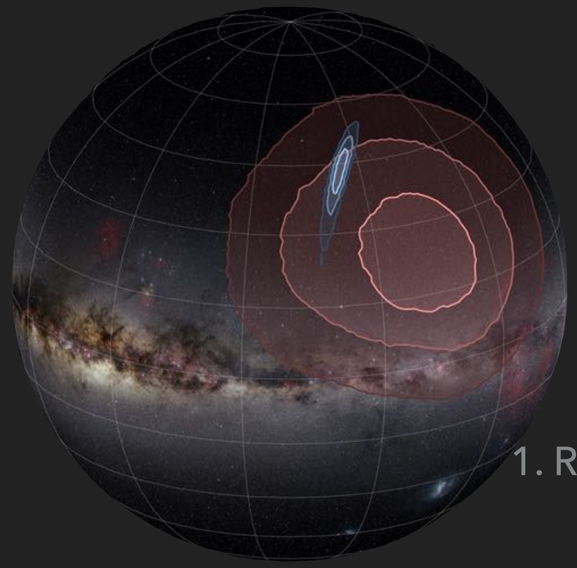
6. Communicate information to the community, via text

AND YOU MIGHT HAVE TO DO THIS DOZENS OF TIMES, IN REAL-TIME

We are here, manually routing, “answering”, etc.

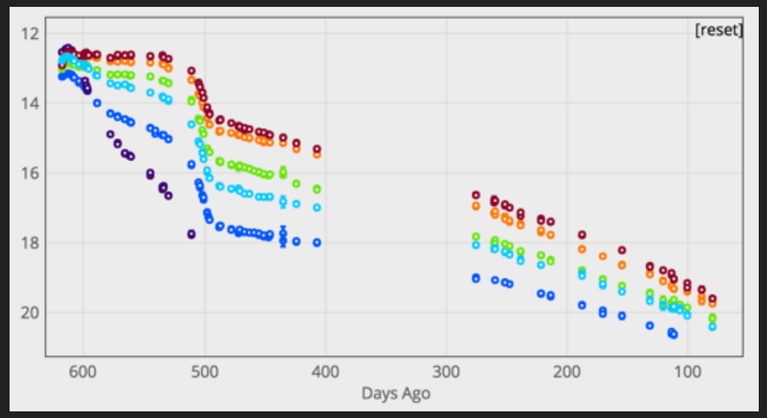
We want to be here - everything is automatic, can be done from anywhere, many ways to communicate, access to all known information in seconds

VISION FOR TOMORROW



1. Receive alert

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

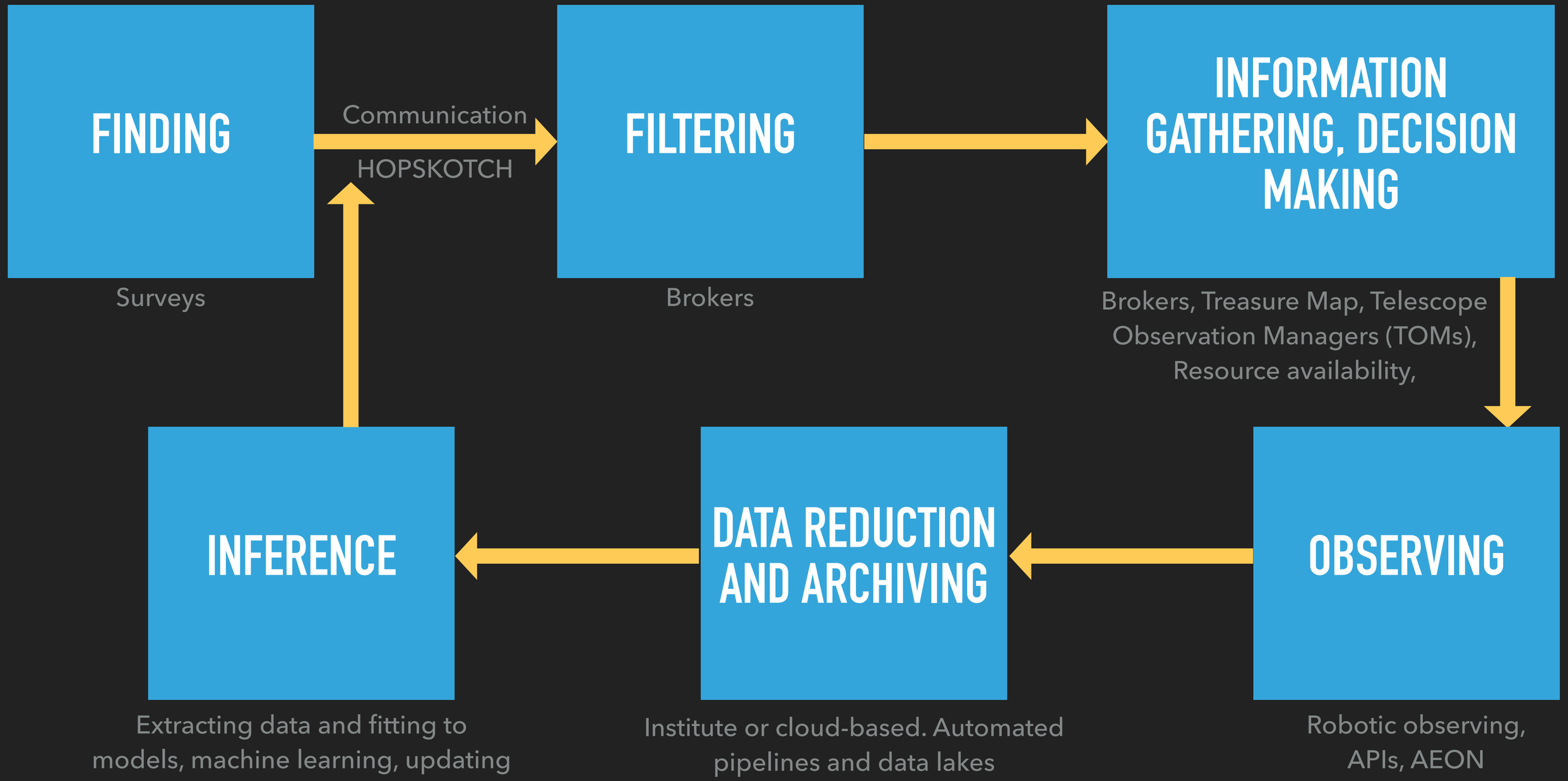


3. Data are automatically reduced, instantly made available to community

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

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

SIMPLIFIED FLOWCHART FOR TRANSIENT FOLLOW-UP



HOPSKOTCH

- New messaging system being built by SCIMMA (Scalable Cyberinfrastructure for Multimessenger Astrophysics) funded by the NSF - see scimma.org
- Pub-sub model - only subscribe to the information you want.
- Will carry existing existing astronomical messages, e.g. GCN Circulars and Notices, Transient Name Server messages, Astronomer's Telegrams.
- Goal is to increase machine readable information.
- Can ultimately support other types of messages, e.g. sending images, spectra, data points, observation plans, instrument availability.

- Based on Apache Kafka – will scale to LSST era.
- Cloud-based. Hosted by Amazon Web Services
- Integrated with Identity and Access Management system (currently COmanage).

PUB-SUB

- Current astronomical messaging services can be hard to parse - they aren't threaded
- Publish-subscribe model is transformative for a messaging service
- If you don't have to worry about every user receiving everything, you can send many more messages.
- Private messages should be allowed

HOPSKOTCH MESSAGE FORMAT - MACHINE READABILITY

- The GCNs are split between machine-readable Notices, and human, but not machine-readable Circulars. Most multimessger follow-up is reported via circulars.
- The TNS has machine readable alerts and human readable AstroNotes.
- Astronomer's telegrams are human readable and don't have an API.
- Can we come up with a solution that is both machine and human readable?
  - Use VOEvent?
  - Transmit information in JSON
  - Should Key-value pairs be approved or just documented?
  - Will this require an API and web form to send and receive? Should this be a TOM Module?
- I plan to create a working group to define a message format. All are welcome to contribute. Contact me at: ahowell@lco.global.

IDENTITY AND ACCESS MANAGEMENT

- Sign in to Hopskotch with existing credentials. System knows about your collaborations
- Extend to TOM Toolkit, Treasure Map?

BROKERS

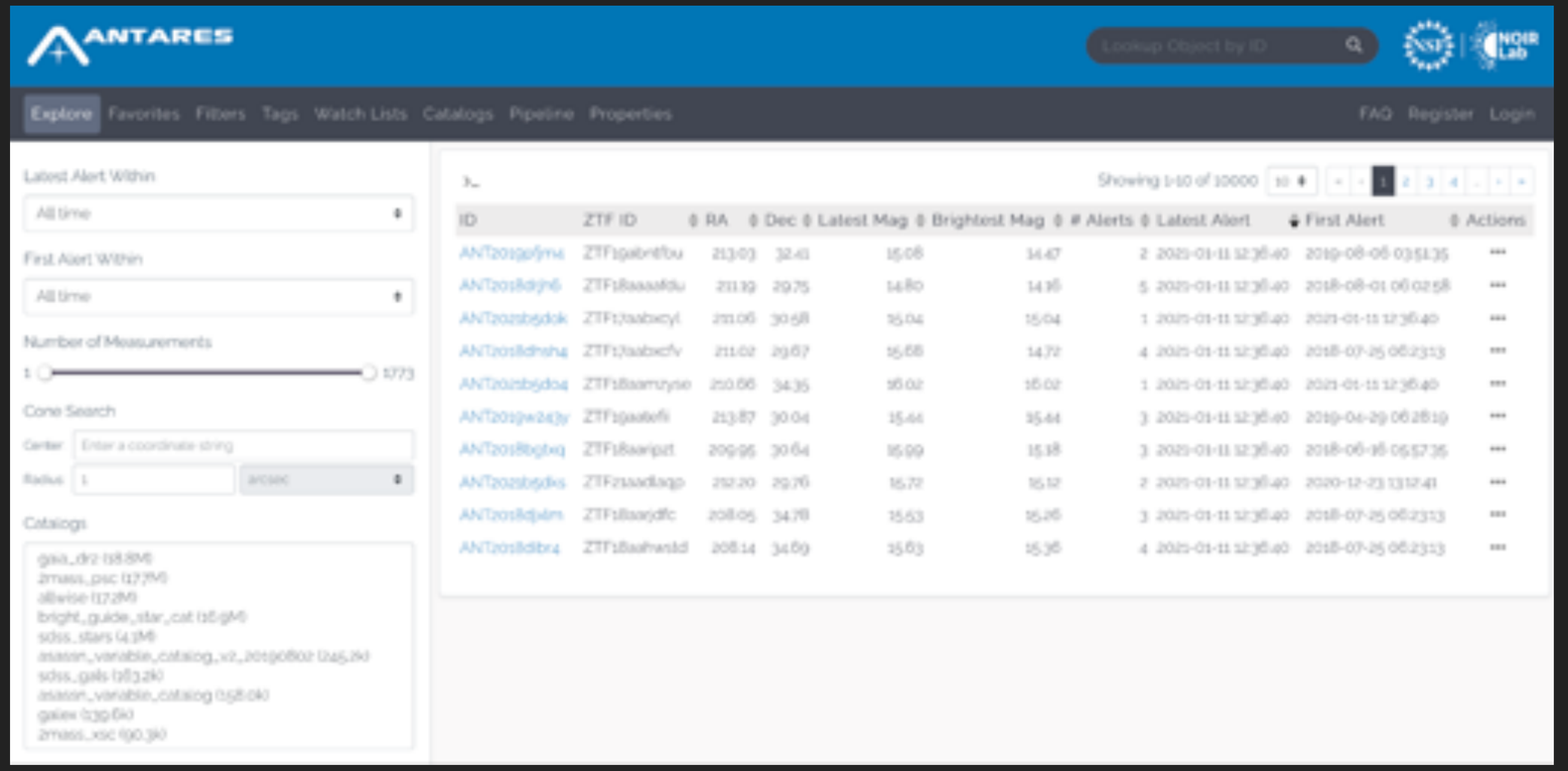
ZTF produces about a million alerts per night, LSST will increase this 10x

Brokers parse, filter, and add value to this alert stream by adding context information, e.g. is it a star, the past history, galaxy redshift, etc., allowing you to find the interesting targets.

You can define custom filters, e.g. only new targets with a certain color range that rise a certain number of magnitudes per day.

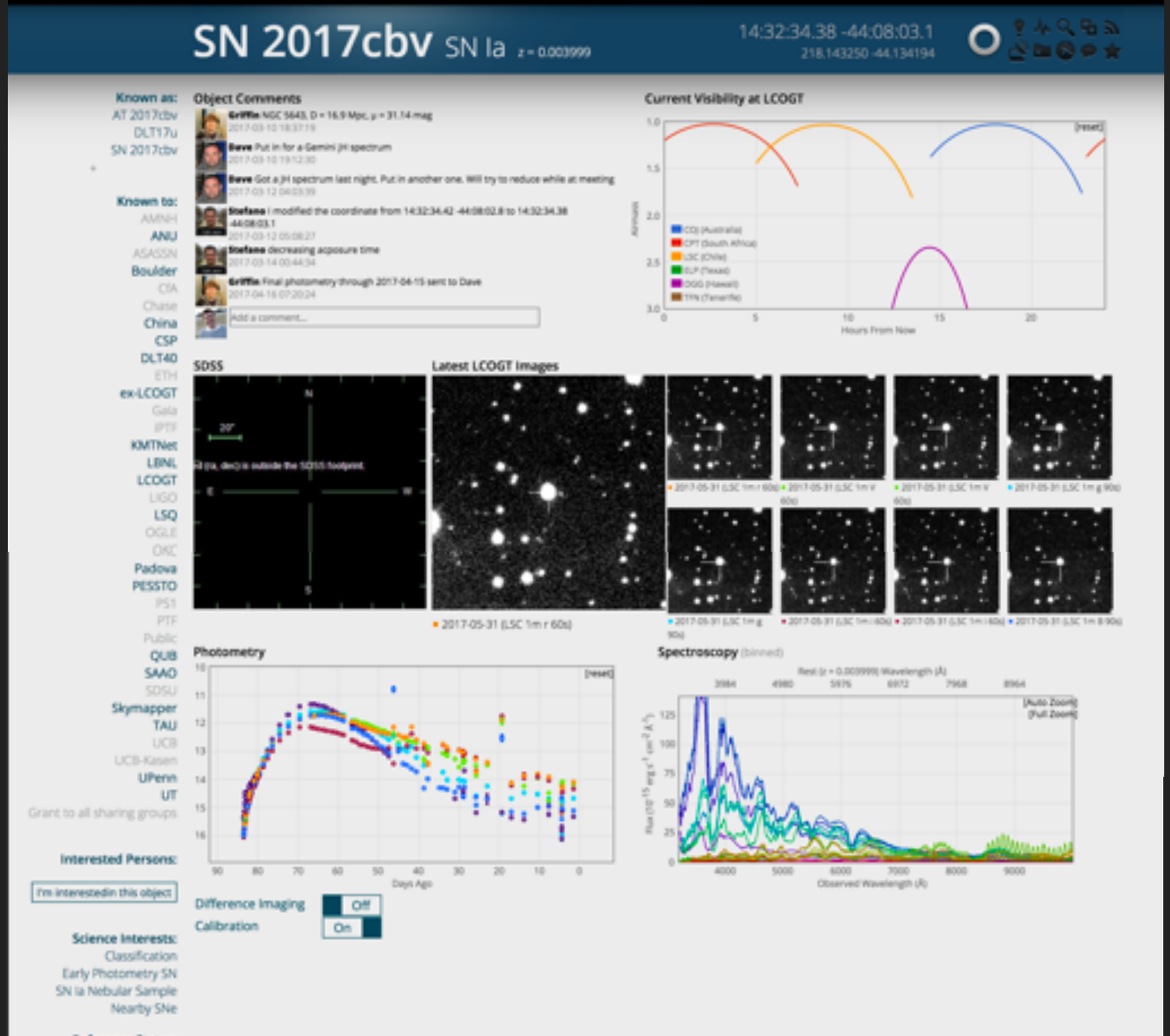
Examples:

- MARS (LCO)
- LASAIR (Edinburgh / QUB)
- ANTARES (NOIR Lab)
- ALeRCE (Chile)



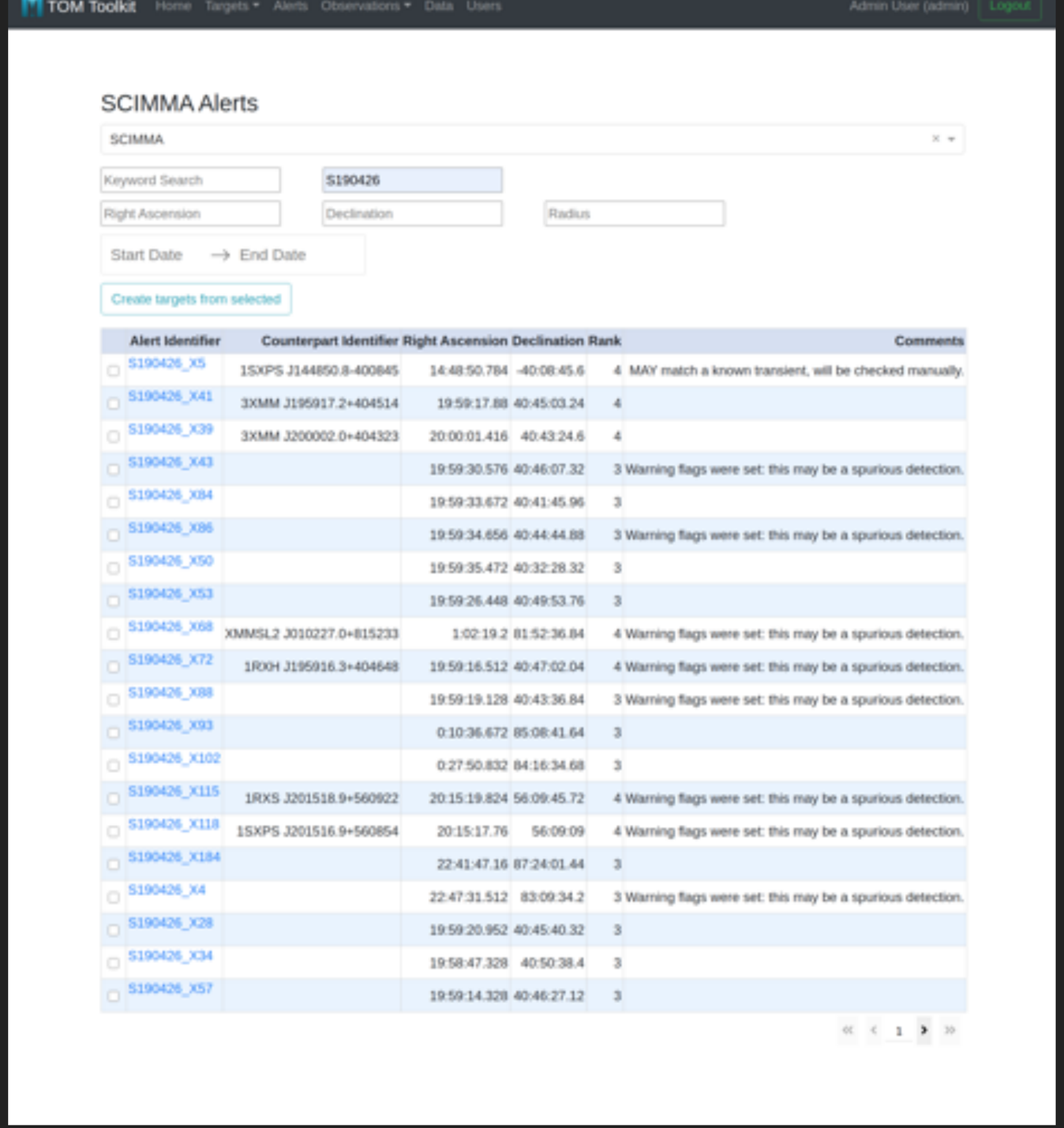
TELESCOPE / OBSERVATION MANAGERS (TOMS)

- For example, the Supernova Exchange.
- Organize information about a target
- Automated data reduction
- Tools for visualization
- Tools for communication, organizing follow-up data, coordinating papers.
- Directly request new data from telescopes



HOPSKOTCH/TOM INTEGRATION

- Hopskotch carries GCNs
- Pulls machine readable info into a database with an API
- We (SCIMMA and LCO) are making modules for the TOM Toolkit to display and filter GCNs
- This should work with future message formats

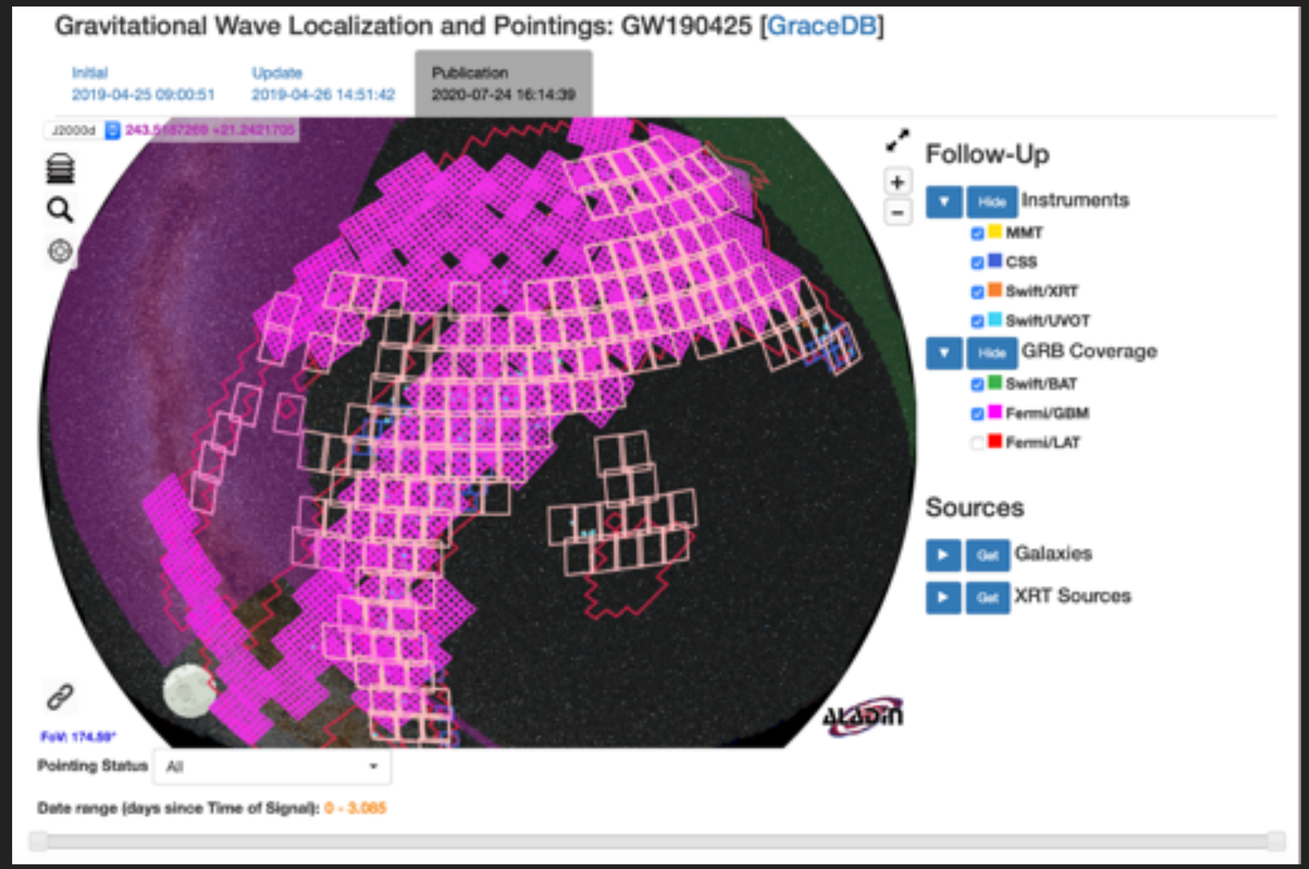


Alert Identifier	Counterpart Identifier	Right Ascension	Declination	Rank	Comments
S190426_X5	1SXPS J144850.8-400845	14:48:50.784	-40:08:45.6	4	MAY match a known transient, will be checked manually.
S190426_X41	3XMM J195917.2+404514	19:59:17.88	40:45:03.24	4	
S190426_X39	3XMM J200002.0+404323	20:00:01.416	40:43:24.6	4	
S190426_X43		19:59:30.576	40:46:07.32	3	Warning flags were set: this may be a spurious detection.
S190426_X84		19:59:33.672	40:41:45.96	3	
S190426_X86		19:59:34.656	40:44:44.88	3	Warning flags were set: this may be a spurious detection.
S190426_X50		19:59:35.472	40:32:28.32	3	
S190426_X53		19:59:26.448	40:49:53.76	3	
S190426_X68	XMMSL2 J010227.0+815233	1:02:19.2	81:52:36.84	4	Warning flags were set: this may be a spurious detection.
S190426_X72	1RXH J195916.3+404648	19:59:16.512	40:47:02.04	4	Warning flags were set: this may be a spurious detection.
S190426_X88		19:59:19.128	40:43:36.84	3	Warning flags were set: this may be a spurious detection.
S190426_X93		0:10:36.672	85:08:41.64	3	
S190426_X102		0:27:50.832	84:16:34.68	3	
S190426_X115	1RXS J201518.9+560922	20:15:19.824	56:09:45.72	4	Warning flags were set: this may be a spurious detection.
S190426_X118	1SXPS J201516.9+560854	20:15:17.76	56:09:09	4	Warning flags were set: this may be a spurious detection.
S190426_X184		22:41:47.16	87:24:01.44	3	
S190426_X4		22:47:31.512	83:09:34.2	3	Warning flags were set: this may be a spurious detection.
S190426_X28		19:59:20.952	40:45:40.32	3	
S190426_X34		19:58:47.328	40:50:38.4	3	
S190426_X57		19:59:14.328	40:46:27.12	3	

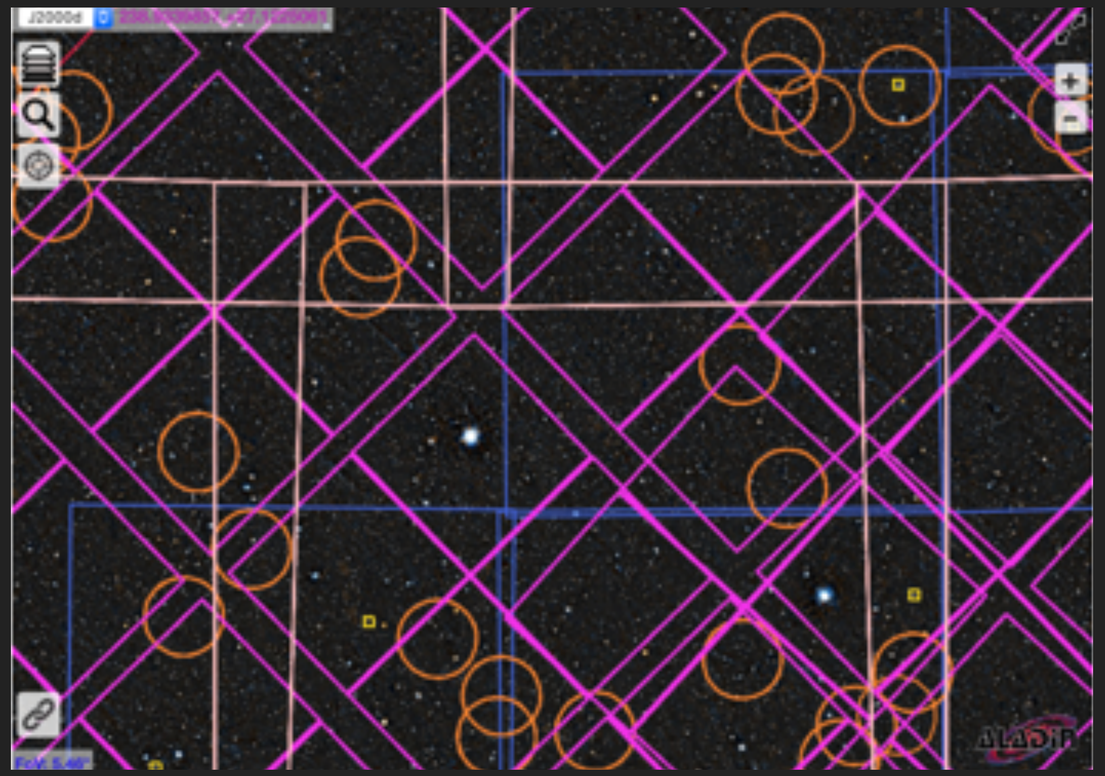
TREASURE MAP

treasuremap.space

Wyatt et al. 2020, ApJ, 894, 127



- Visualize gravitational wave localization information on the sky
- Communicate information about planned and completed observations via API
- Overplot on sky maps where the base layer is changeable.

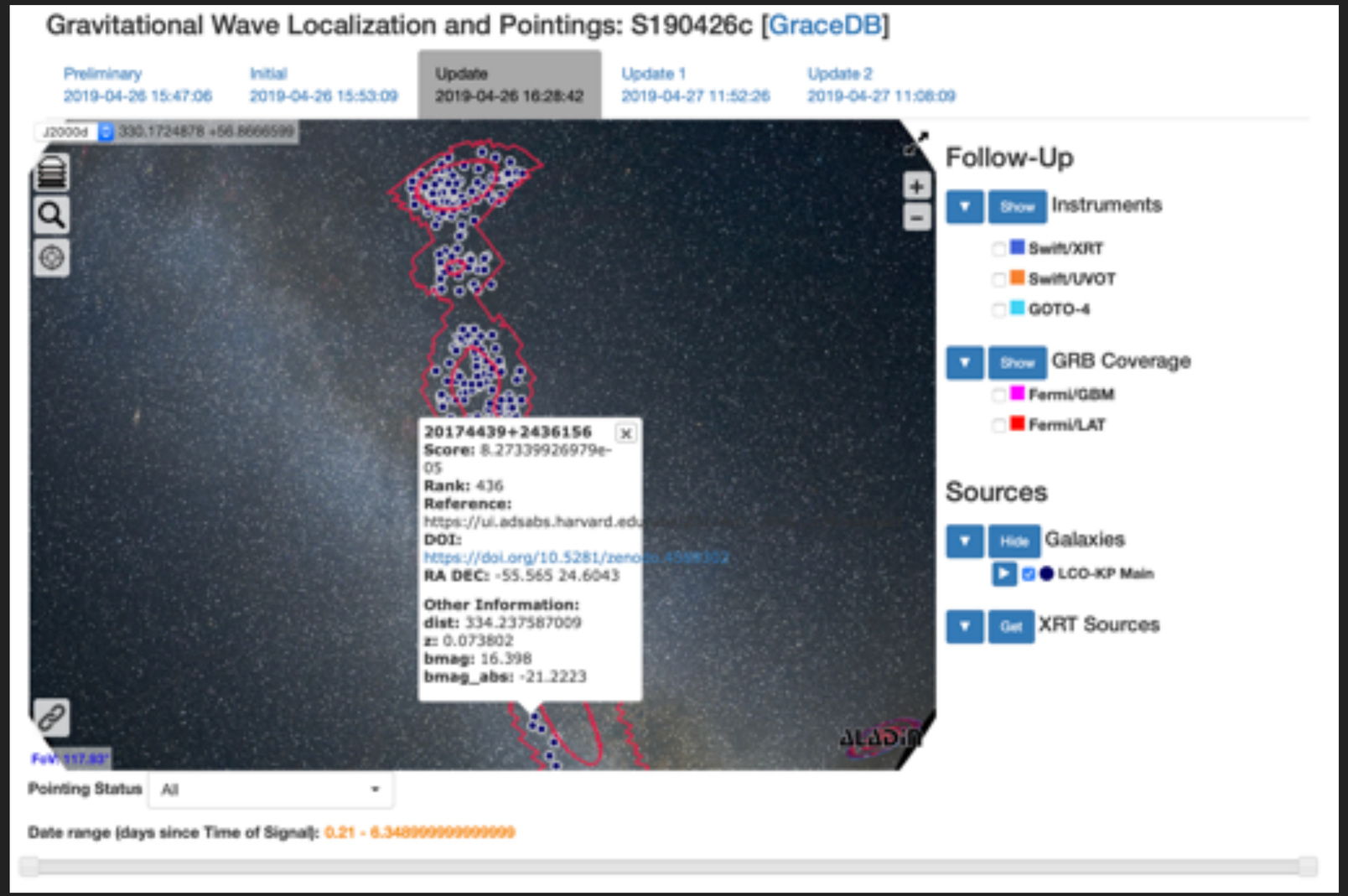


- Plot percentage observed vs. time.
- Show known galaxies, or known X-ray sources
- Integration with Hopskotch being tested.

TREASURE MAP – GALAXY INFORMATION

Wyatt et al. 2020, ApJ, 894, 127

treasuremap.space

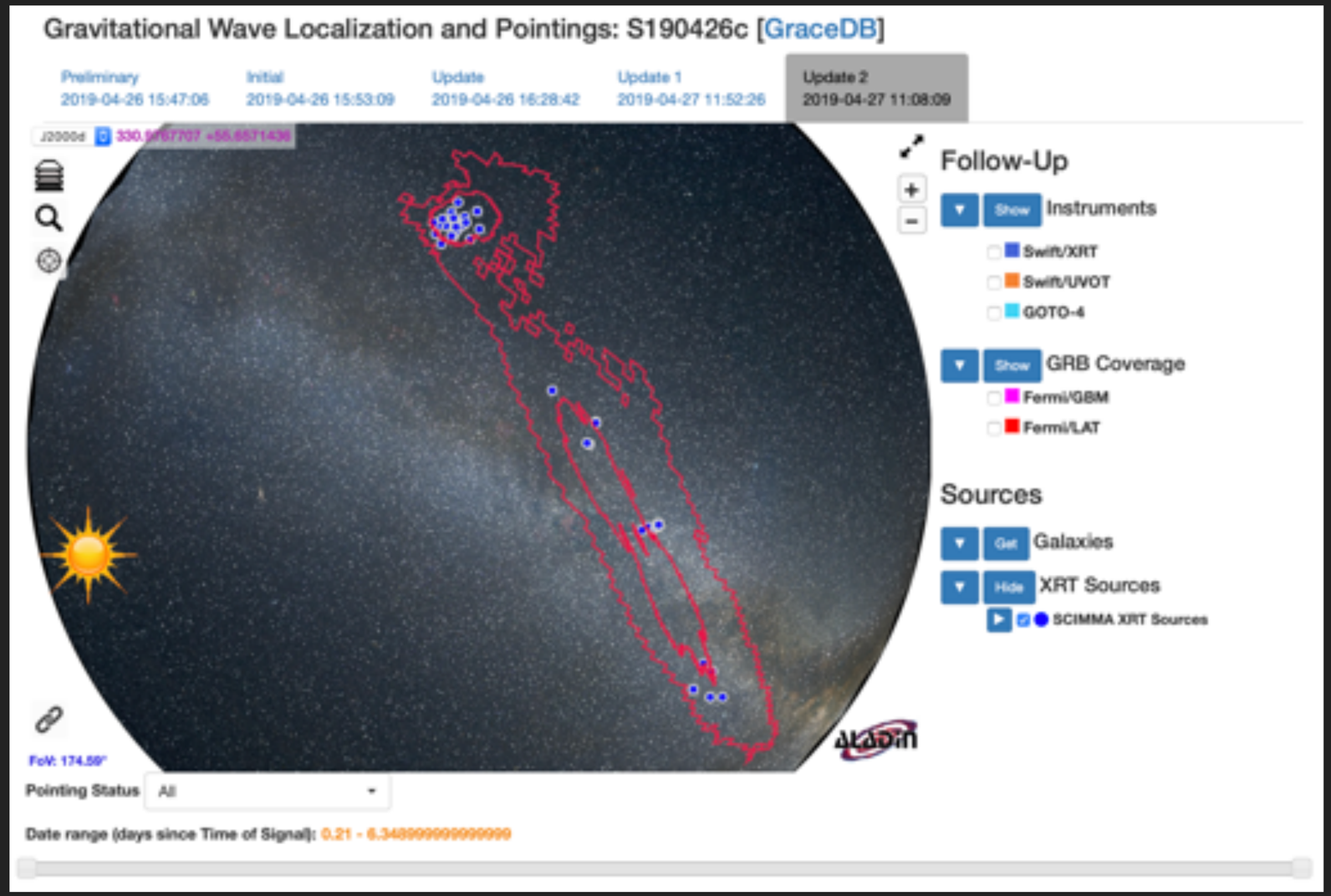


- Users can submit ranked lists of galaxies to an API
- Treasure Map can display multiple user's lists
- A tooltip shows information, e.g. rank, redshift, magnitude.

TREASURE MAP – HOPSKOTCH INTEGRATION

Wyatt et al. 2020, ApJ, 894, 127

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.

RESOURCE AVAILABILITY

- Example: you want to make an observation of a transient immediately. Which facilities can you use?
- Which facilities are closed because of COVID? Which instruments are available when?
- What is my target's observability at each facility.
- This information is not centralized - it is distributed across hundreds of web sites with no common protocol.
- Prototype created by Rachel Street

Mauna Kea at Mon Jan 11 16:01:06 2021

Gratings currently available in GMOS-N today...

mirror

B600+_G5307

R831+_G5302

R400+_G5305

Slits currently available in GMOS-N today...

IFU-2

0.5arcsec

0.75arcsec

1.0arcsec

1.5arcsec

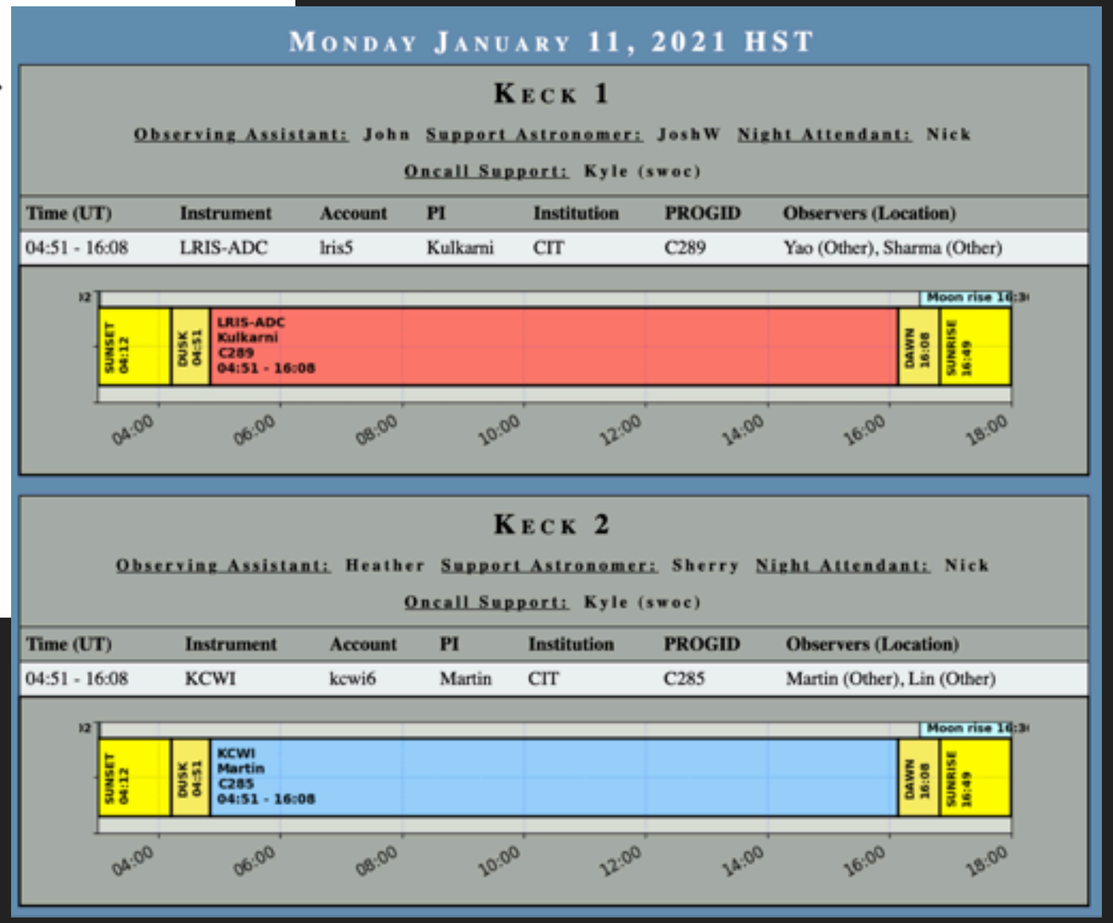
2.0arcsec

5.0arcsec

NS0.75arcsec

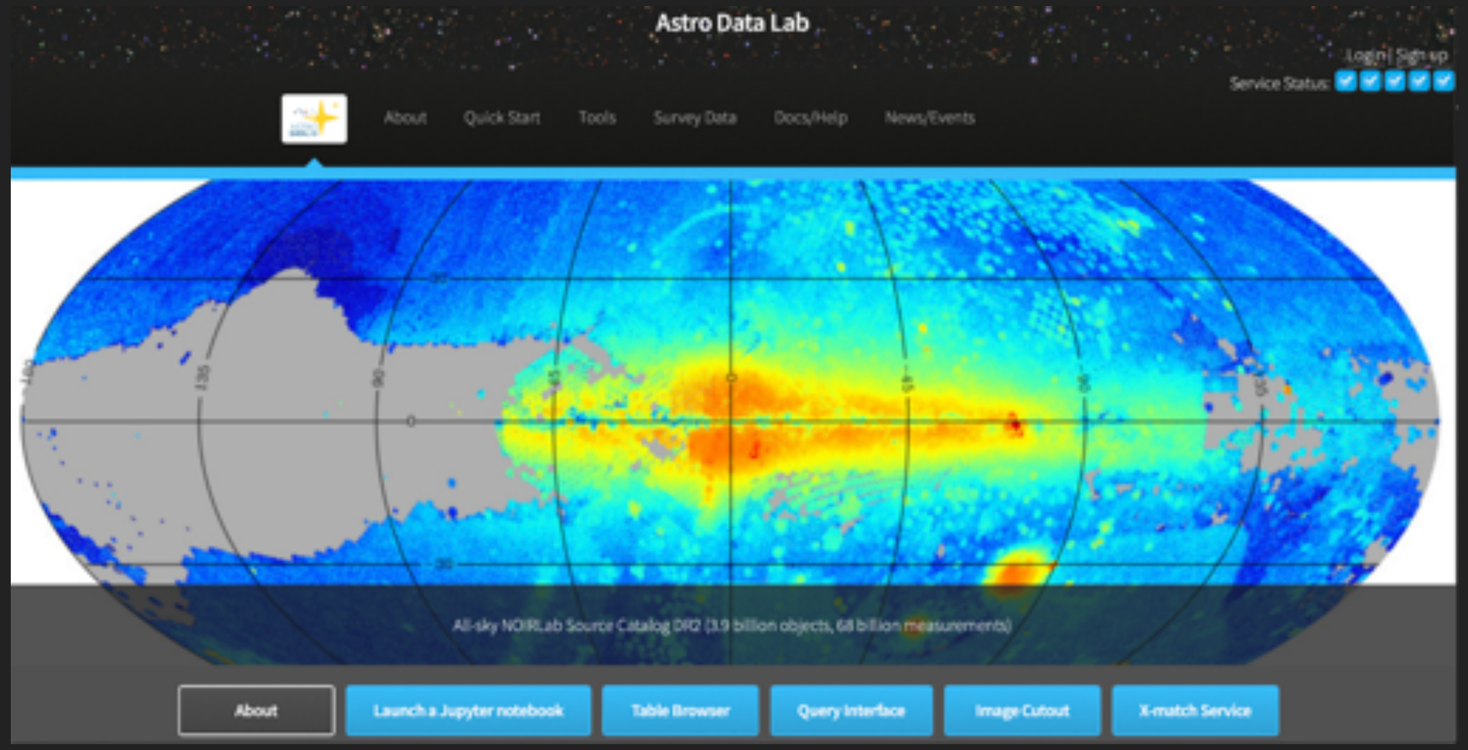
NS1.0arcsec

0.25arcsec



DATA LAKES

- Some data sets are too large for the community to download and must be accessed within the cloud. (e.g. LSST)
- Archives are distributed – there is not one centralized place.
- There is no standard for cloud interoperability (e.g. Amazon Web Services vs. Google).



- Automated data reduction pipelines are primitive. There are not even general purpose spectroscopic reduction facilities available in Python.
- We need Python-based platforms for accessing and analyzing cloud-based archives.
- NOIRLab's Astro Data lab is a good example, but has limited functionality.

ROBOTICIZING FACILITIES & IMPROVING SCHEDULING

- Queue - based and robotic facilities can respond faster to transient events.
- LCO's scheduler re-optimizes all 23 telescopes every ~10 minutes.
- LCO is making its robotic, API-driven observatory control system open source (led by Elisabeth Heinrich-Josties).

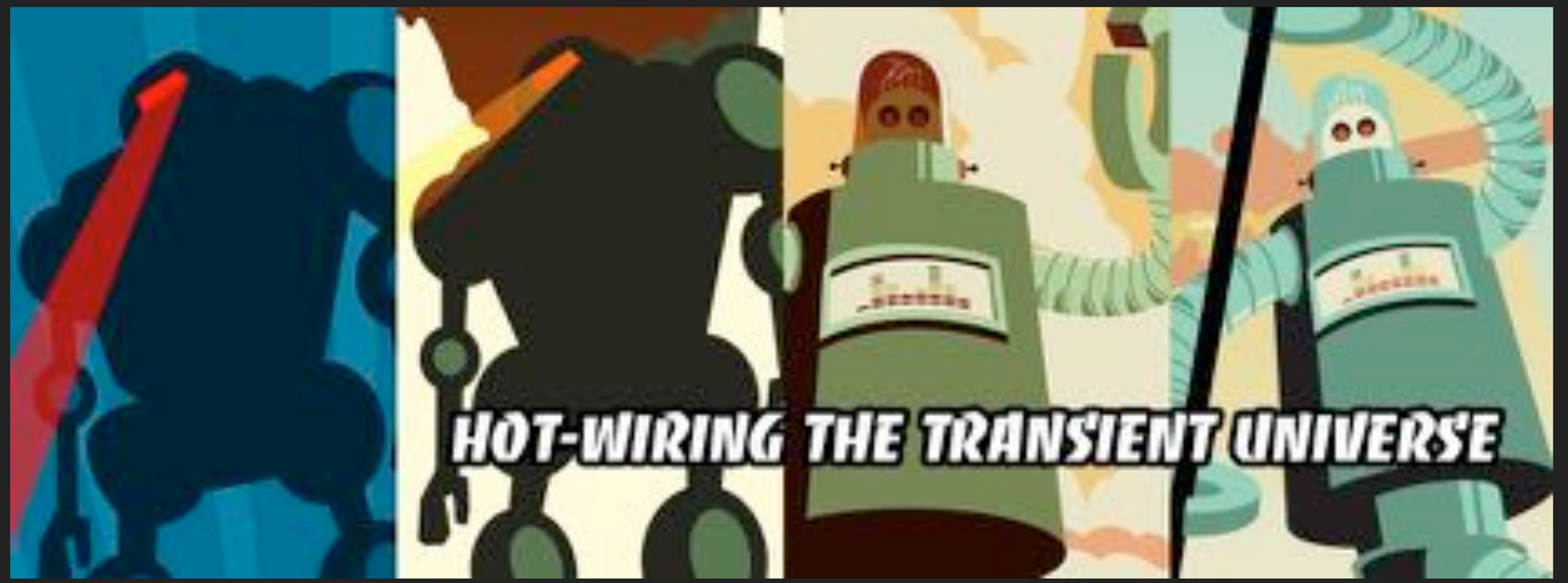


Image credit Pete Marenfeld

AEON: ASTRONOMICAL EVENTS OBSERVATORY NETWORK

- Idea: make programmatic telescope requests easily.
- Consortium of observatories who have agreed on common API telescope request protocols
- Includes Las Cumbres Observatory, SOAR, Gemini, in talks with other facilities
- Some scheduling shared between facilities
- A common pool of telescope time in some cases
- See lco.global/aeon, talk by Rachel Street