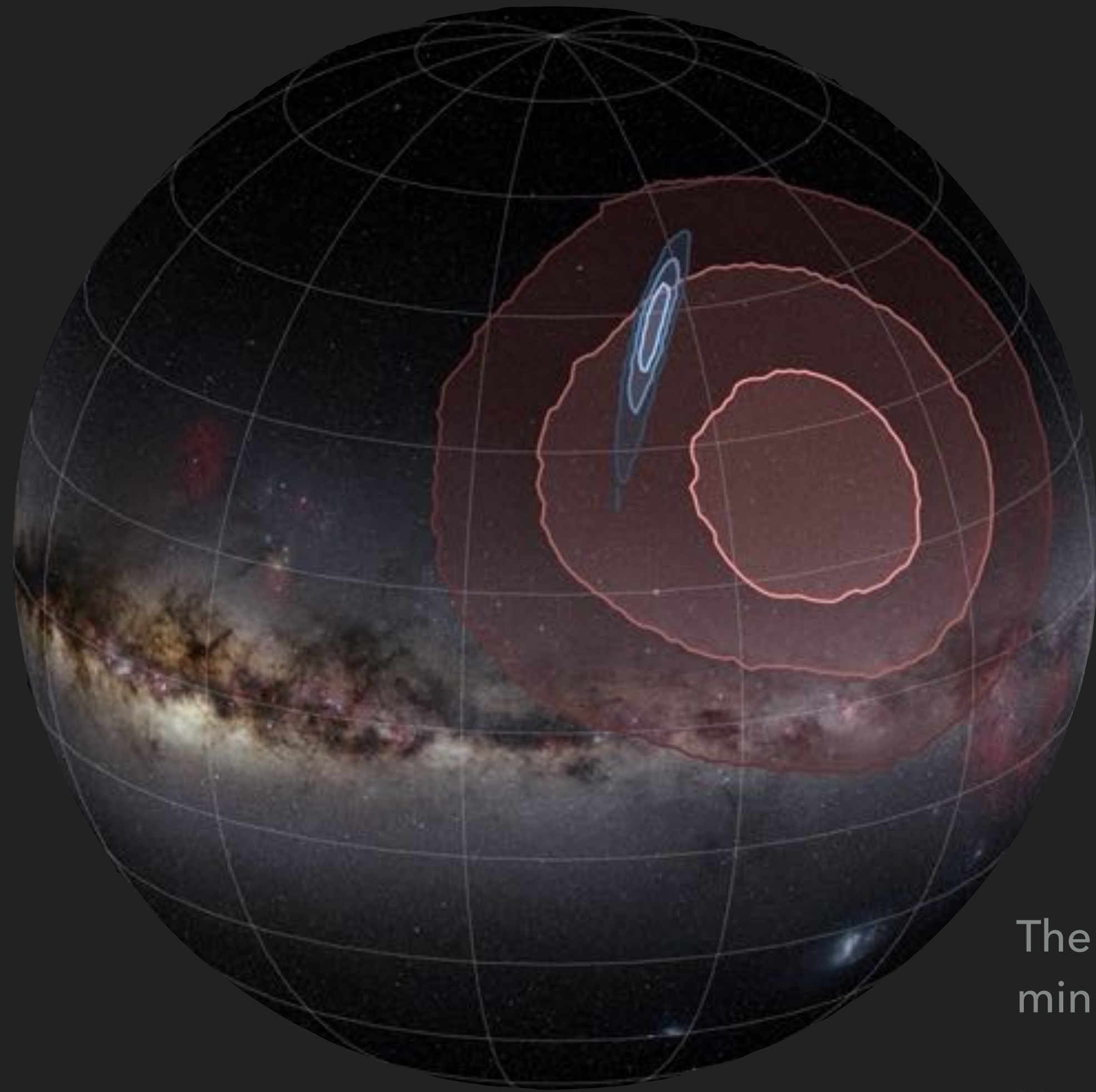


OVERVIEW OF THE NEXT GENERATION TRANSIENT FOLLOW-UP ECOSYSTEM



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

MULTI MESSENGER ASTROPHYSICS AS A CASE STUDY

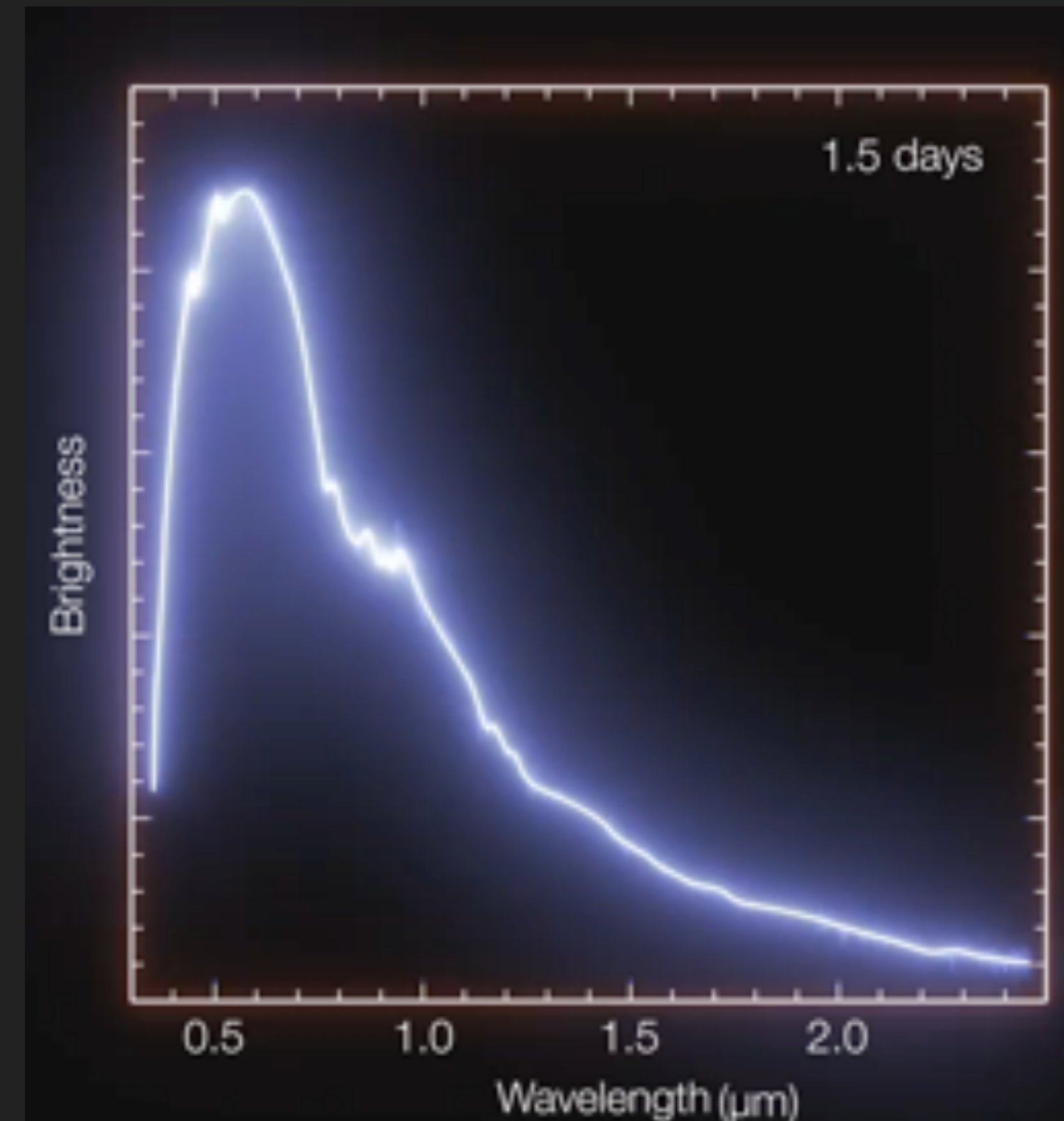


Two neutron stars merge together and this is detected by LIGO/Virgo/Kagra. Data from other facilities (e.g. Swift, Fermi, IceCube) may be added to change the localization. Hundreds of transients may exist in the localization region. They have to be found, observed, their properties determined, and communicated.

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: 21535
SUBJECT: LIGO/Virgo G298048: Fermi GBM trigger 524666471/170817529: LIGO/Virgo ID
DATE: 17/08/17 13:21:42 GMT
FROM: Reed Clasey 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 1187038884.47
(Thu Aug 17 12:41:06 GMT 2017) with RA=186.62deg Dec=-48.84deg and an error radiu

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

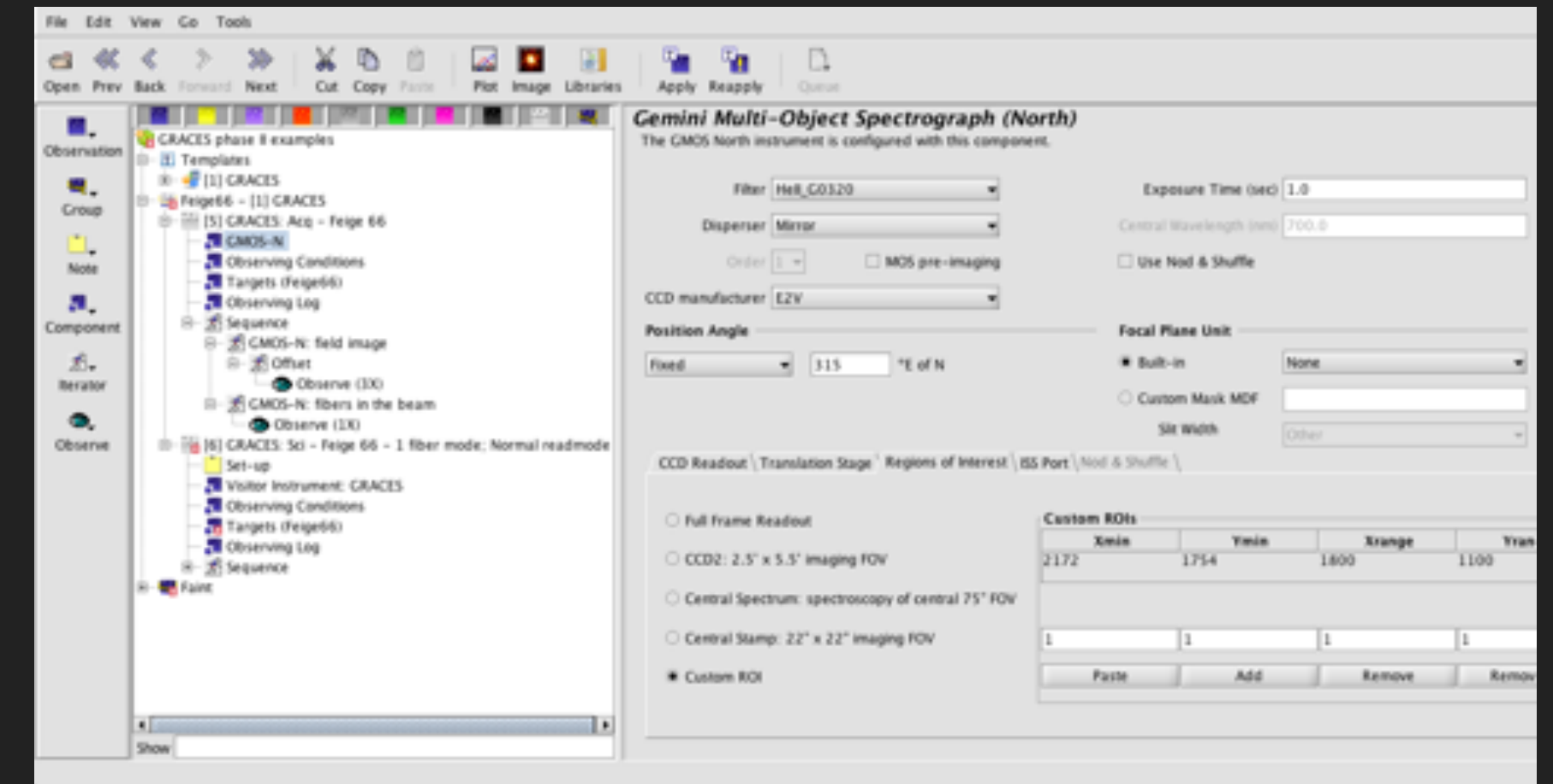
An offline analysis is ongoing. Any significant updates will be provided
by a new Circular.

[GCN OPS NOTE(17aug17): Per author's request, the LIGO/VIRGO ID
was added to the beginning of the Subject-line.]
    
```

1. Receive alert via GCN or automatic listener.



2. Panic



3. Trigger approved resources by filling out Phase II forms

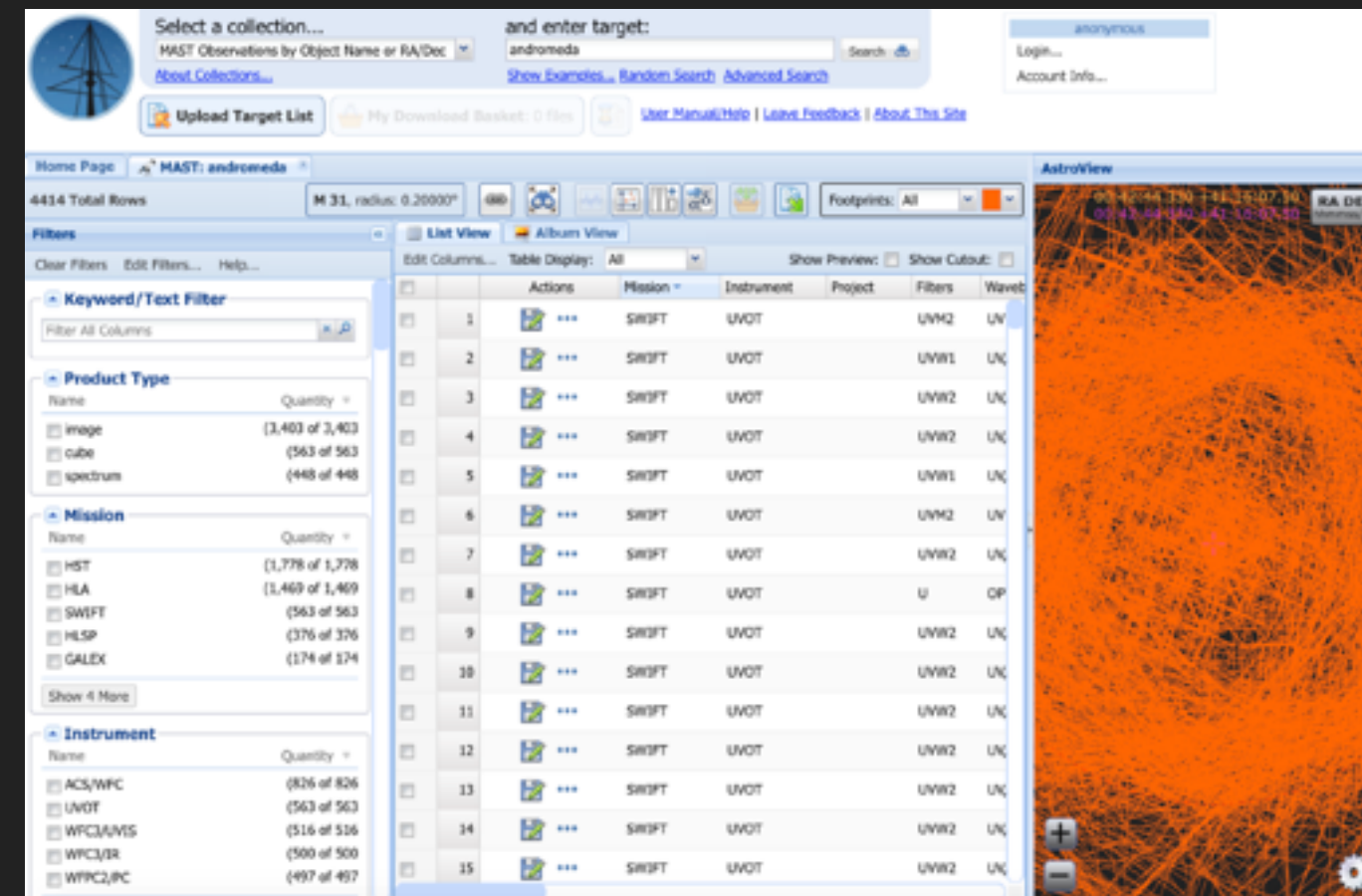
Telescope Schedule

2019A telescope schedule

Select schedule for: Sun Feb Year: 2019 Month: January Day: 03
 Prev Month: Next Month: Prev Day: Next Day: Print Schedule: Query

DOY	Date	Dark	Tel#	Principal	Observers	Location	InstAcc	Institution	QA	SA	NA	ProjCode
Tue	Jan-01	80	1	Masters	Masters, (CIT), J. Cohen, (CIT), Hermschek, (CIT), Starbuck, (UCB)	CITUCB	LRIS-ADG(S)	NASA	JA	AR		M044
Tue	Jan-01	80	2	G. Fuller	K. Rubin, (UCSD), Col. (UCSD), Vaught, (UCSD), Buchert, (UCSC)	UCSD/UCSC	KCWB(S)	UCSD	JR	LR		U090
Wed	Jan-02	86	1	Crystal, Marín	Crystal, Marín, (UCSB)	UCSB	LRIS-ADG(1)	UCSB	JACW	JW	SJ	U136
Wed	Jan-02	86	2	G. Fuller	K. Rubin, (UCSD), Col. (UCSD), Vaught, (UCSD), Buchert, (UCSC)	UCSD/UCSC	KCWB(S)	UCSD	JR	LR		U090
Thu	Jan-03	96	1	S. Kulkarni	Burdge	HQ	LRIS-ADG(2)	CIT	CP	JW	SJ	C323
Thu	Jan-03	96	2	J. Cohen	J. Cohen, (CIT), Hermschek, (CIT)	CIT	ES(1)	CIT	JR/JP	RC	SJ	C253
Fri	Jan-04	100	1	PrinceRaut	Burdge/Burdge	HQ	LRIS-ADG(3)	CIT	GW	JW	SJ	C323C327
Fri	Jan-04	100	2	J. Cohen	J. Cohen, (CIT), Hermschek, (CIT)	CIT	ES(1)	CIT	JP	RC	SJ	C253
Sat	Jan-05	100	1	J. Cooke	Farrar, (SwRI), Pritchard, Meech, J. Cooke, S. Webb	SwRIHQ	LRIS-ADG(4)	SwRI/UCB	GW	JW	SJ/SJP	W247
Sat	Jan-05	100	2	Farrarnacht	Farrarnacht, (UCD), G. Chen, (UCD)	UCD	ES(2)	UCD	JP	A	SJ/JP	U122
Sun	Jan-06	96	1	Dressing	Isaacson, (UCB), Pelguse, (CIT)	UCB/CIT	HERES(1)	UCB	CW/TJ/AAR	GD	JLP	U096
Sun	Jan-06	96	2	Oró	Oró, Ish	HQ	DEMOS(4)	Subaru	JP	AR	JLP	S347
Mon	Jan-07	90	1	Dressing	Isaacson, (UCB), Pelguse, (CIT)	UCB/CIT	HERES(1)	UCB	TR/AAR	GD	JLP/TKC	U096
Mon	Jan-07	90	2	Hu	Hu, L. Cowie	HQ	DEMOS(5)	UH	JR/JP	AR	JLP/TKC	H259
Tue	Jan-08	83	1	Radford	Farrar, SwRI, Radford	HQ	HERES(7)	NASA	TR/AAR	GD	JLP/TKC	N152
Tue	Jan-08	83	2	Messethu	Messeth, (CIT), Echeverri, (CIT), S. Rajaguru, L. Cowie	CIT/HQ	NIRSPAC-NIR2-NIR3-DEMOS(3)	CIT/UH	HR/AR	CA	JLP/TKC	C315H239
Wed	Jan-09	76	1	M. White	Khee-Gan, Lee, Ata	HQ	LRIS-ADG(5)	UCB	TR/AAR	JW	TKC	U095
Wed	Jan-09	76	2	Stamenkovic	Saluri, (UCSC)/Stamenkovic, Olopinic	UCSC/HQ	UCSCGT	UCSCGT	HH(AH)	CA	TKC	U129U272
Thu	Jan-10	69	1	S. ValentiM. White	Borotom, (UCD)/Khee-Gan, Lee, Ata	UCD/HQ	LRIS-ADG(6)	UCD/UCB	TR/CJ/AAR	JW	TKC	U099U396
Thu	Jan-10	69	2	Stamenkovic	Saluri, (UCSC)/M. Cooper, (UCB), Ffithighan, (UC), Winkler, (UC), Baxter, (UC)	UCSC/UCJ	NIR2-NIR3-DEMOS(3)	UCSC/UCJ	HH(AH)	CA	TKC	U129U353

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

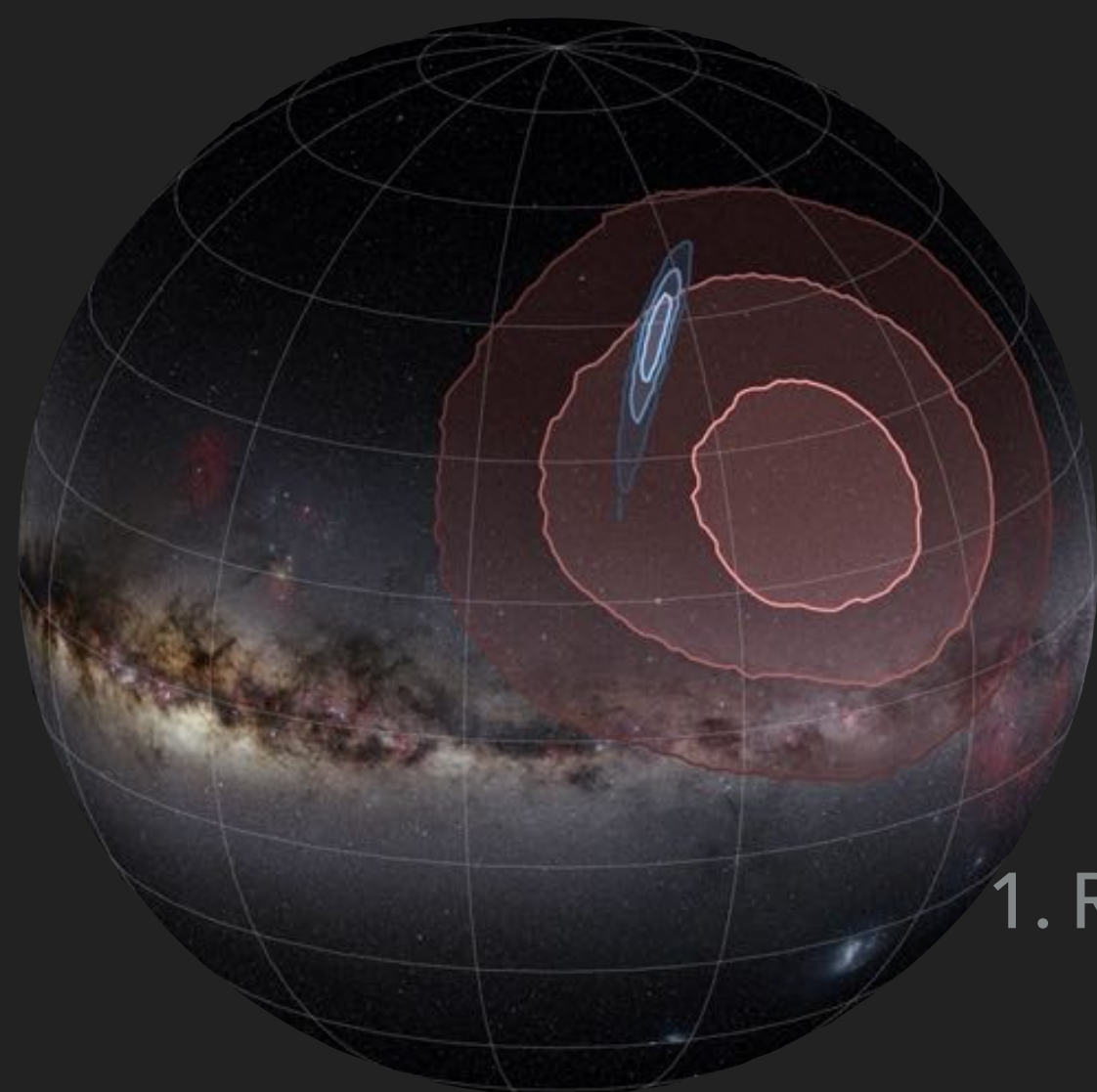


We are here, manually routing, "answering", etc.

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



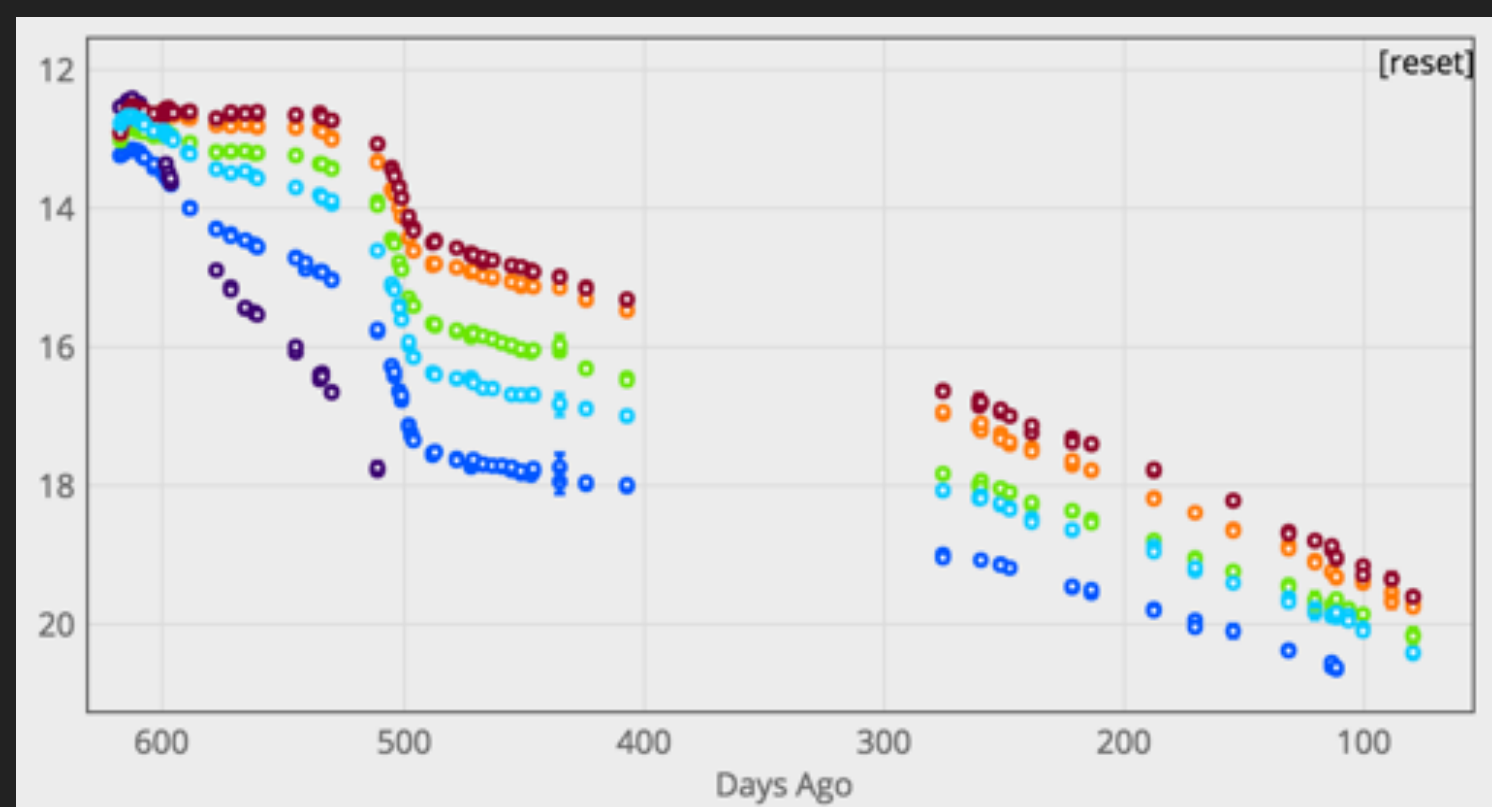
VISION FOR TOMORROW



1. Receive alert



2. Telescopes automatically observe target, negotiate priorities, data access

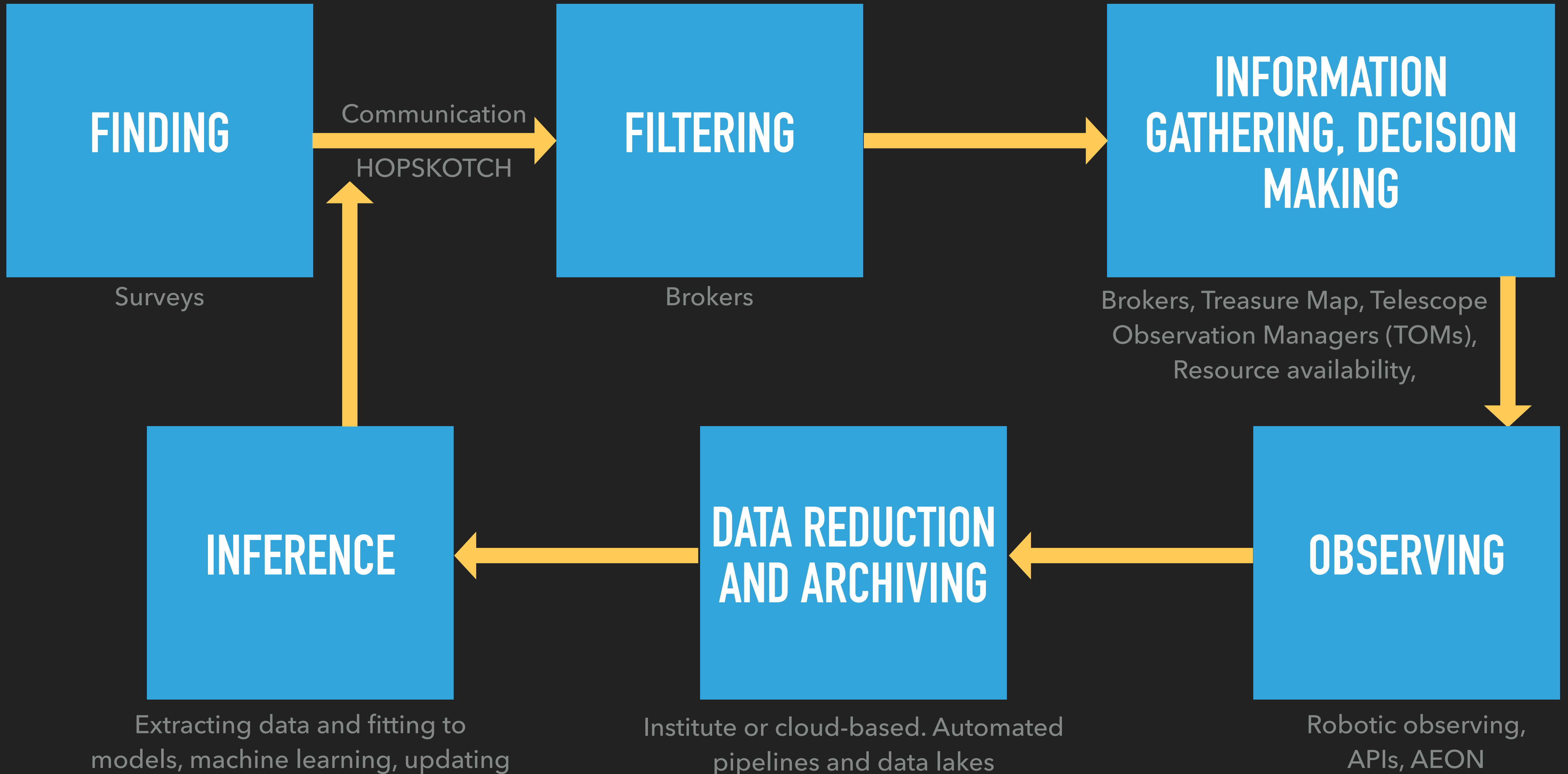


$$p_{\text{dist}}(\text{R.A.}, \text{decl.}, D) = N_{\text{dist}}(\text{R.A.}, \text{decl.}) \cdot e^{-\frac{[D - \mu_{\text{dist}}(\text{R.A.}, \text{decl.})]^2}{2\sigma_{\text{dist}}^2(\text{R.A.}, \text{decl.})}}$$


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

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 multimessenger 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

SCMMA

Powered By CILogon

Consent to Attribute Release

SCMMA Registry PROQ requests access to the following information. If you do not approve this request, do not proceed.

- Your CILogon user identifier
- Your name
- Your email address
- Your username and affiliation from your identity provider

Select an Identity Provider

Google

Remember this selection

Log On

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

BROKERS



Examples:

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

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.

The screenshot shows the ANTARES web interface. The top navigation bar includes 'Explore', 'Favorites', 'Fibers', 'Tags', 'Watch Lists', 'Catalogs', 'Pipeline', and 'Properties'. A search bar is labeled 'Lookup Object by ID'. The main content area is divided into a left sidebar and a main table.

Left Sidebar:

- Latest Alert Within: All time
- First Alert Within: All time
- Number of Measurements: 1 to 1773
- Cone Search: Center (Enter a coordinate string), Radius: 1 arcsec
- Catalogs: gsa_dr2 (15.8M), 2mass_psc (17.7M), allwise (17.2M), bright_guide_star_cat (15.6M), sdss_stars (4.3M), asson_variable_catalog_v2_20190802 (245.2K), sdss_gals (253.2K), asson_variable_catalog (158.0K), galax (239.6K), 2mass_xsc (190.3K)

Main Table:

ID	ZTF ID	RA	Dec	Latest Mag	Brightest Mag	# Alerts	Latest Alert	First Alert	Actions
ANT20190fym	ZTF1gabvfu	213.03	32.41	15.08	14.47	2	2025-01-11 12:36:40	2019-08-08 03:51:35	...
ANT2018d9n6	ZTF1baawfdu	211.39	29.75	14.80	14.36	5	2025-01-11 12:36:40	2018-08-01 06:02:58	...
ANT2018b9dk	ZTF1aabxcyl	211.06	30.58	15.04	15.04	1	2025-01-11 12:36:40	2025-01-11 12:36:40	...
ANT2018dhs4	ZTF1aabxcfv	211.02	29.67	15.68	14.72	4	2025-01-11 12:36:40	2018-07-25 06:23:13	...
ANT2018b9d4	ZTF1baamyse	210.86	34.35	16.02	16.02	1	2025-01-11 12:36:40	2025-01-11 12:36:40	...
ANT2019w243y	ZTF1gaabvfi	213.87	30.04	15.44	15.44	3	2025-01-11 12:36:40	2019-04-29 06:28:19	...
ANT2018b9tq	ZTF1baarpit	209.95	30.64	16.09	15.18	3	2025-01-11 12:36:40	2018-06-16 05:57:36	...
ANT2018b9ds	ZTF1baawfap	212.20	29.76	16.72	16.12	2	2025-01-11 12:36:40	2020-12-23 13:17:41	...
ANT2018d9m	ZTF1baaydfc	208.05	34.78	15.53	15.26	3	2025-01-11 12:36:40	2018-07-25 06:23:13	...
ANT2018dbr4	ZTF1baahwid	208.14	34.69	15.63	15.36	4	2025-01-11 12:36:40	2018-07-25 06:23:13	...

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

SN 2017cbv SN Ia $z = 0.003999$
14:32:34.38 -44:08:03.1
218.143250 -44.134194

Known as:
AT 2017cbv
DLT17u
SN 2017cbv

Known to:
AMNH
ANU
ASASSN
Boulder
CSA
Chase
China
CSP
DLT40
ETH
ex-LCOGT
Gala
IPTF
KMTNet
LENL
LCOGT
LIGO
LSQ
OGLE
ORC
Padova
PISSTO
PS1
PTF
Public
QUB
SAO
SDSU
Skymapper
TAU
UCB
UCB-Kasen
UPenn
UT

Grant to all sharing groups

Interested Persons:
 I'm interested in this object

Science Interests:
Classification
Early Photometry SN
SN Ia Nebular Sample
Nearby SNe

Object Comments

Griffie NGC 5643, D = 16.9 Mpc, $\mu = 31.14$ mag
2017-03-10 18:37:19

Dave Put in for a Gemini JH spectrum
2017-03-10 19:12:30

Dave Got a JH spectrum last night. Put in another one. Will try to reduce while at meeting
2017-03-12 04:03:39

Stefano I modified the coordinate from 14:32:34.42 -44:08:02.8 to 14:32:34.38 -44:08:03.1
2017-03-12 05:08:27

Stefano decreasing aperture time
2017-03-14 00:44:34

Griffie Final photometry through 2017-04-15 sent to Dave
2017-04-16 07:20:24

Current Visibility at LCOGT

SDSS

Latest LCOGT Images

Photometry

Spectroscopy (binned)

Difference Imaging Calibration

Off
 On

Auto Zoom
 Full Zoom

HOPSKOTCH/TOM INTEGRATION

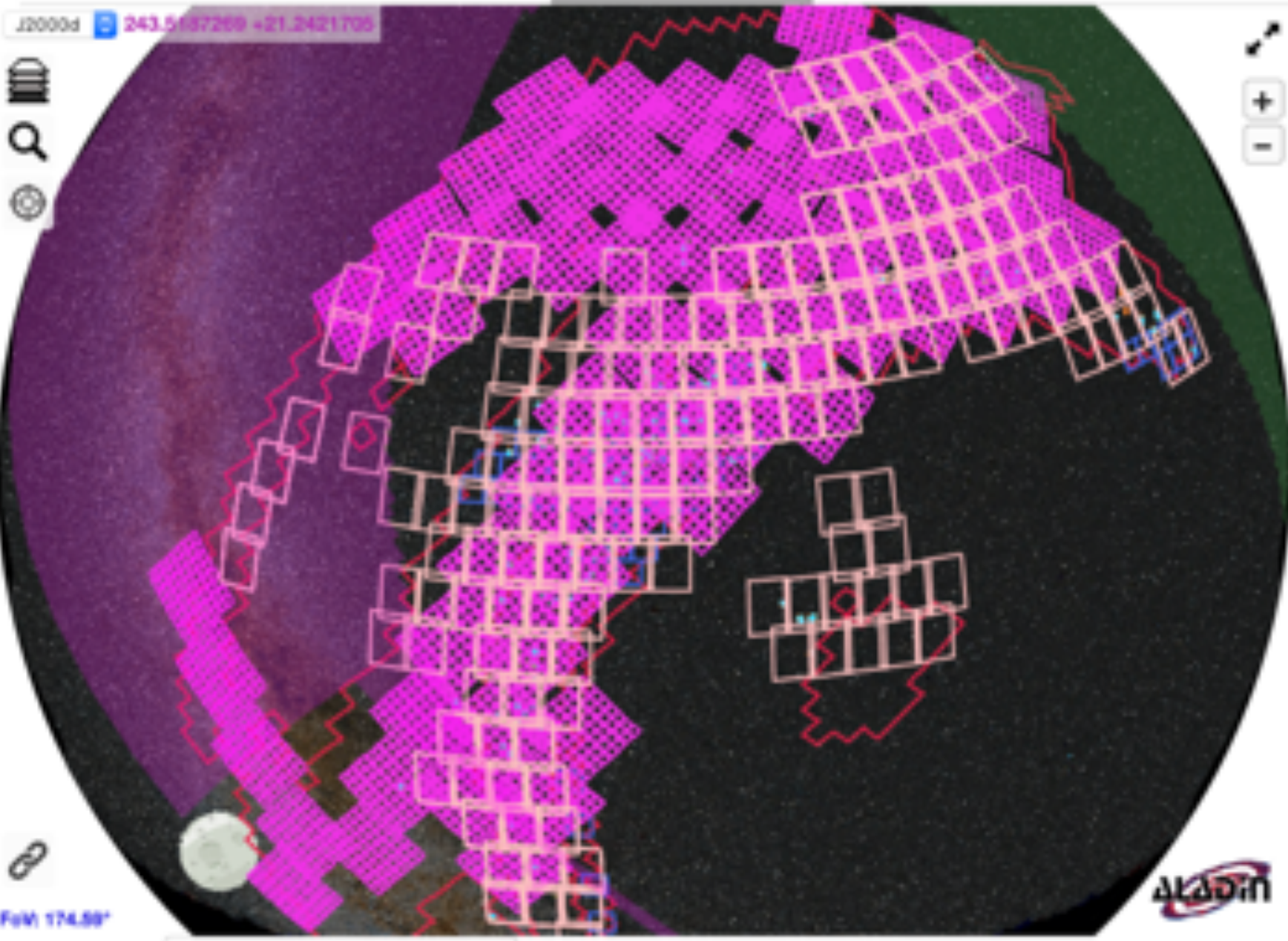
- ▶ Hopskotch carries GCNs
- ▶ Pulls machine readable info into a database with an API
- ▶ We (SCIMMA and LCO) are making modules for the TOM Toolkit to display and filter GCNs
- ▶ This should work with future message formats

The screenshot shows the TOM Toolkit interface for SCIMMA Alerts. At the top, there is a navigation bar with 'TOM Toolkit' and various menu items. Below the navigation, there is a search and filter section with a dropdown menu set to 'SCIMMA'. There are input fields for 'Keyword Search' (containing 'S190426'), 'Right Ascension', 'Declination', and 'Radius'. A date range selector is also present. A 'Create targets from selected' button is located below the filters. The main content is a table of alerts with the following columns: Alert Identifier, Counterpart Identifier, Right Ascension, Declination, Rank, and Comments. The table contains 20 rows of data, each with a checkbox in the first column. The comments for several rows mention 'Warning flags were set: this may be a spurious detection.' or 'MAY match a known transient, will be checked manually.'

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

Gravitational Wave Localization and Pointings: GW190425 [GraceDB]

Initial: 2019-04-25 09:00:51
Update: 2019-04-26 14:51:42
Publication: 2020-07-24 16:14:39

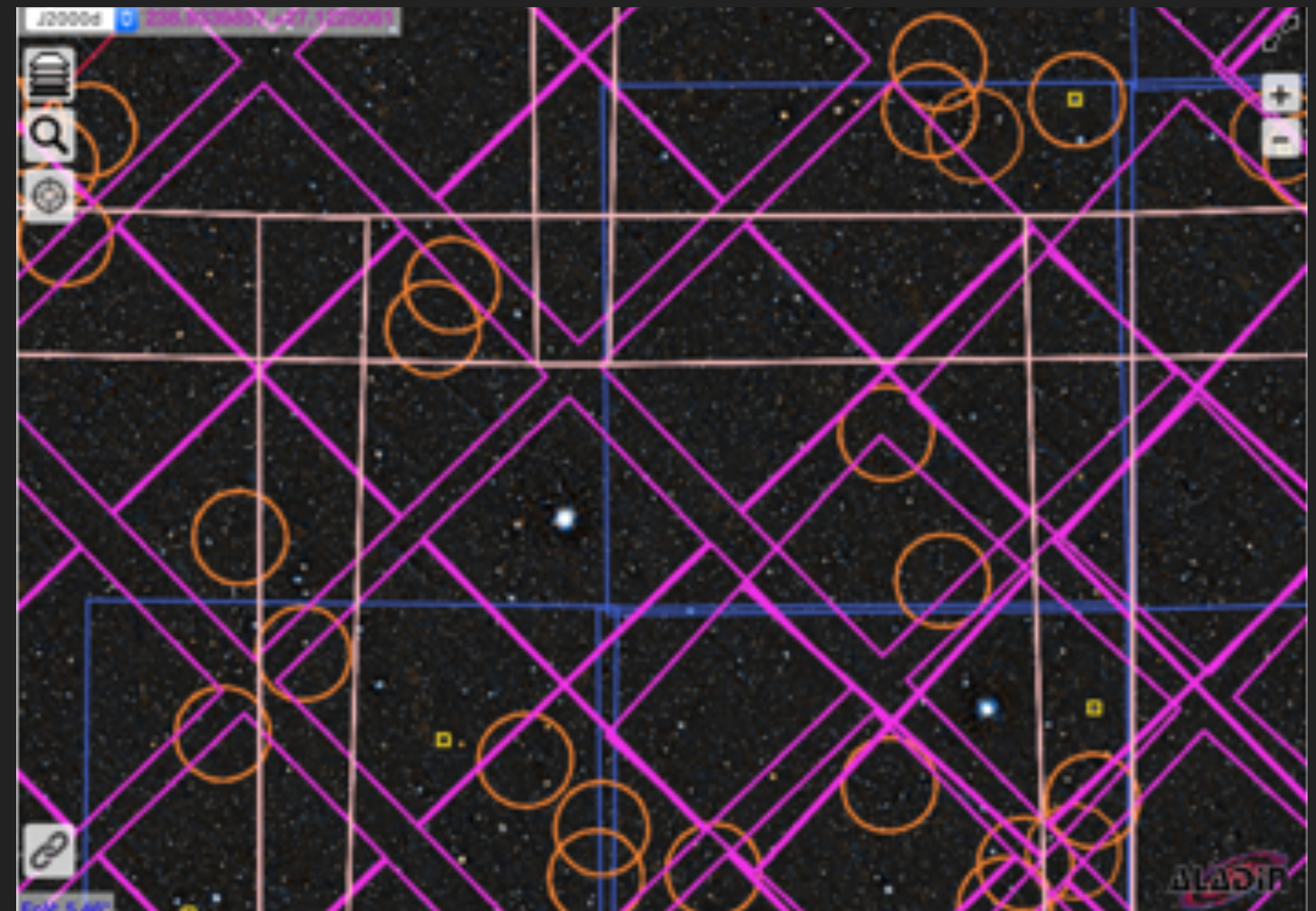


- ### Follow-Up
- Hide Instruments
 - MMT
 - CSS
 - Swift/XRT
 - Swift/UVOT
 - Hide GRB Coverage
 - Swift/BAT
 - Fermi/GBM
 - Fermi/LAT

- ### Sources
- Galaxies
 - XRT Sources

RA: 174.58°
Pointing Status: All
Date range (days since Time of Signal): 0 - 3.085

- ▶ 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.



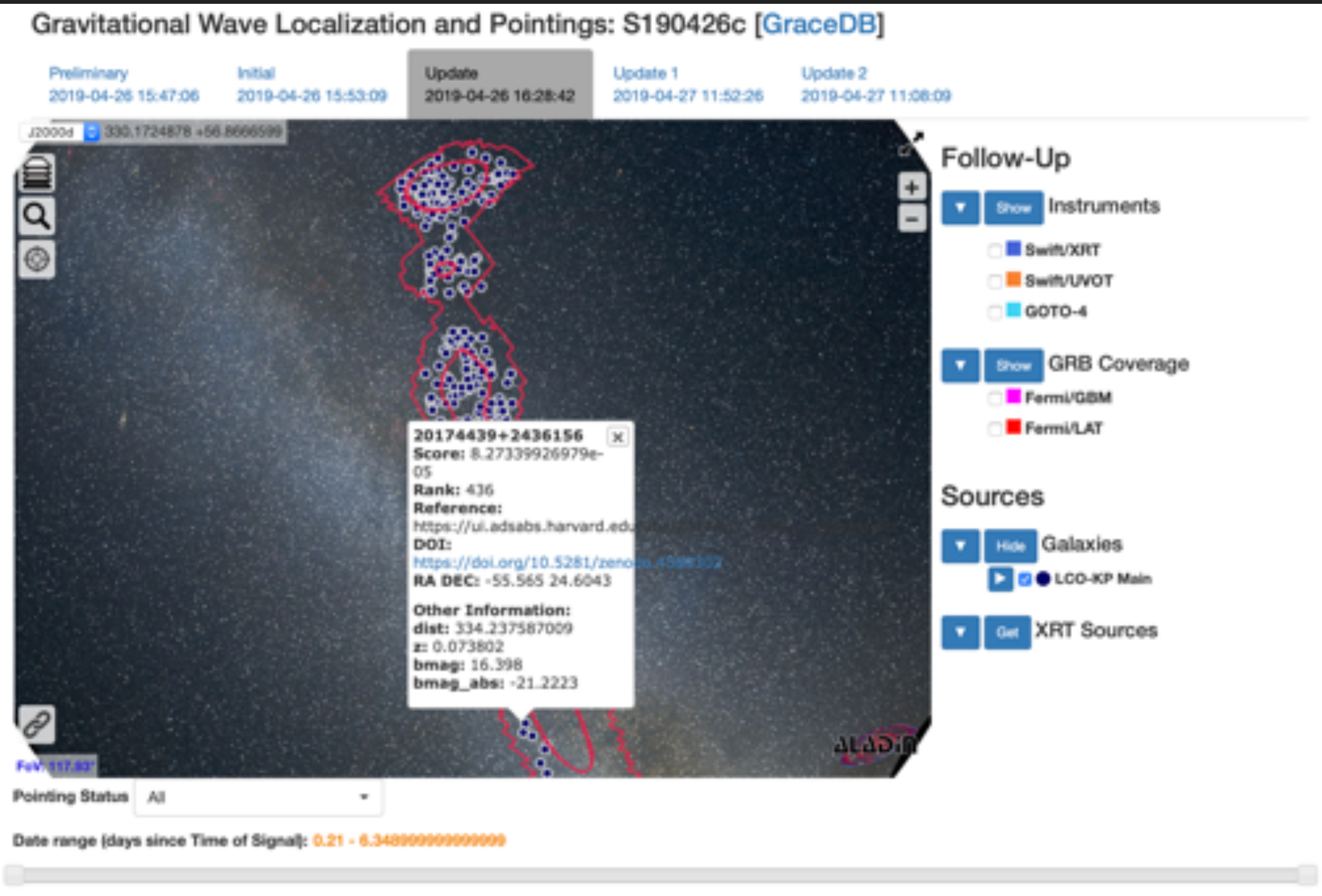
- ▶ Plot percentage observed vs. time.
- ▶ Show known galaxies, or known X-ray sources
- ▶ Integration with Hopskotch being tested.

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.



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

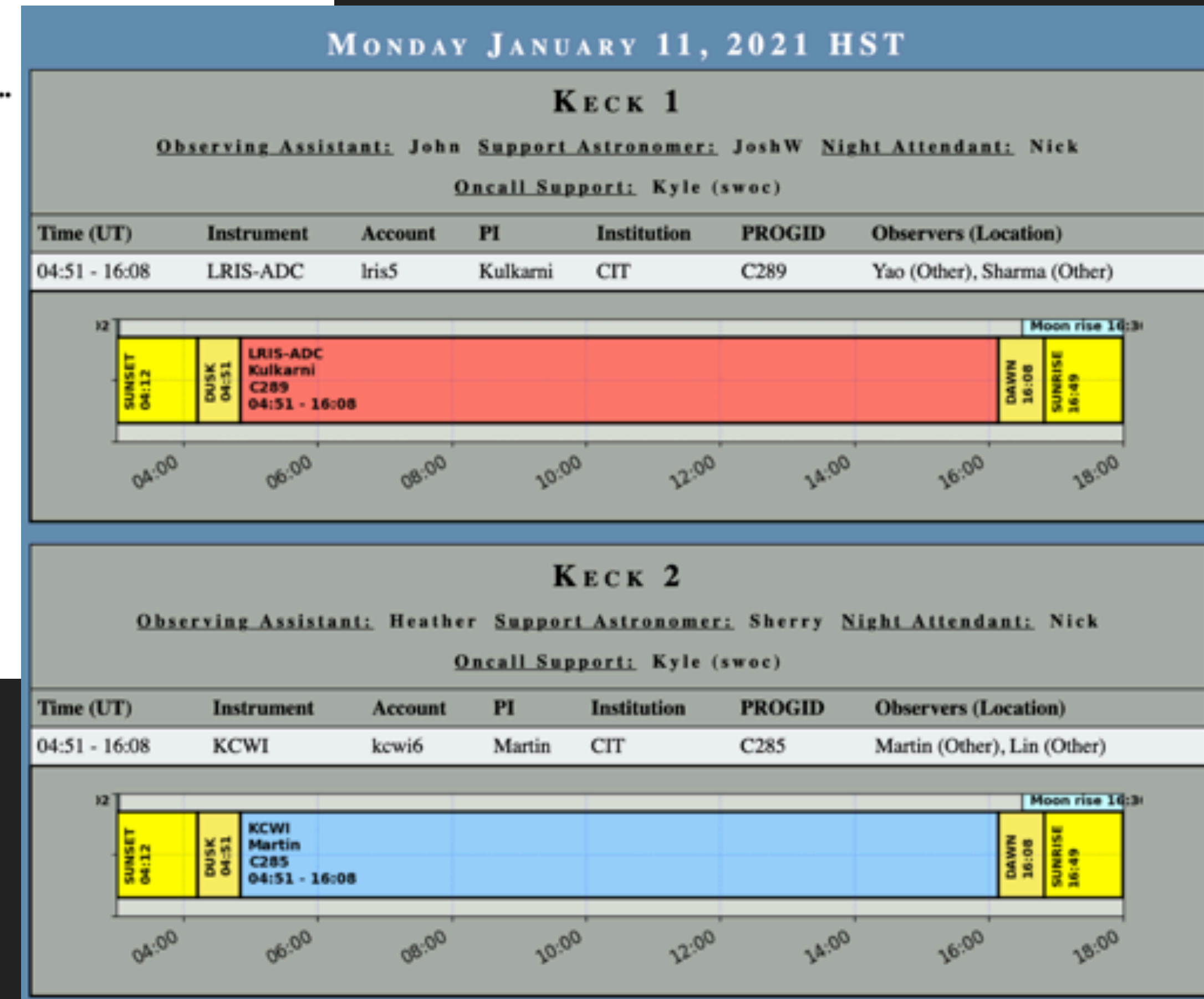
Mauna Kea at Mon Jan 11 16:01:06 2021

Gratings currently available in GMOS-N today...

mirror
 B600+_G5307
 R831+_G5302
 R400+_G5305

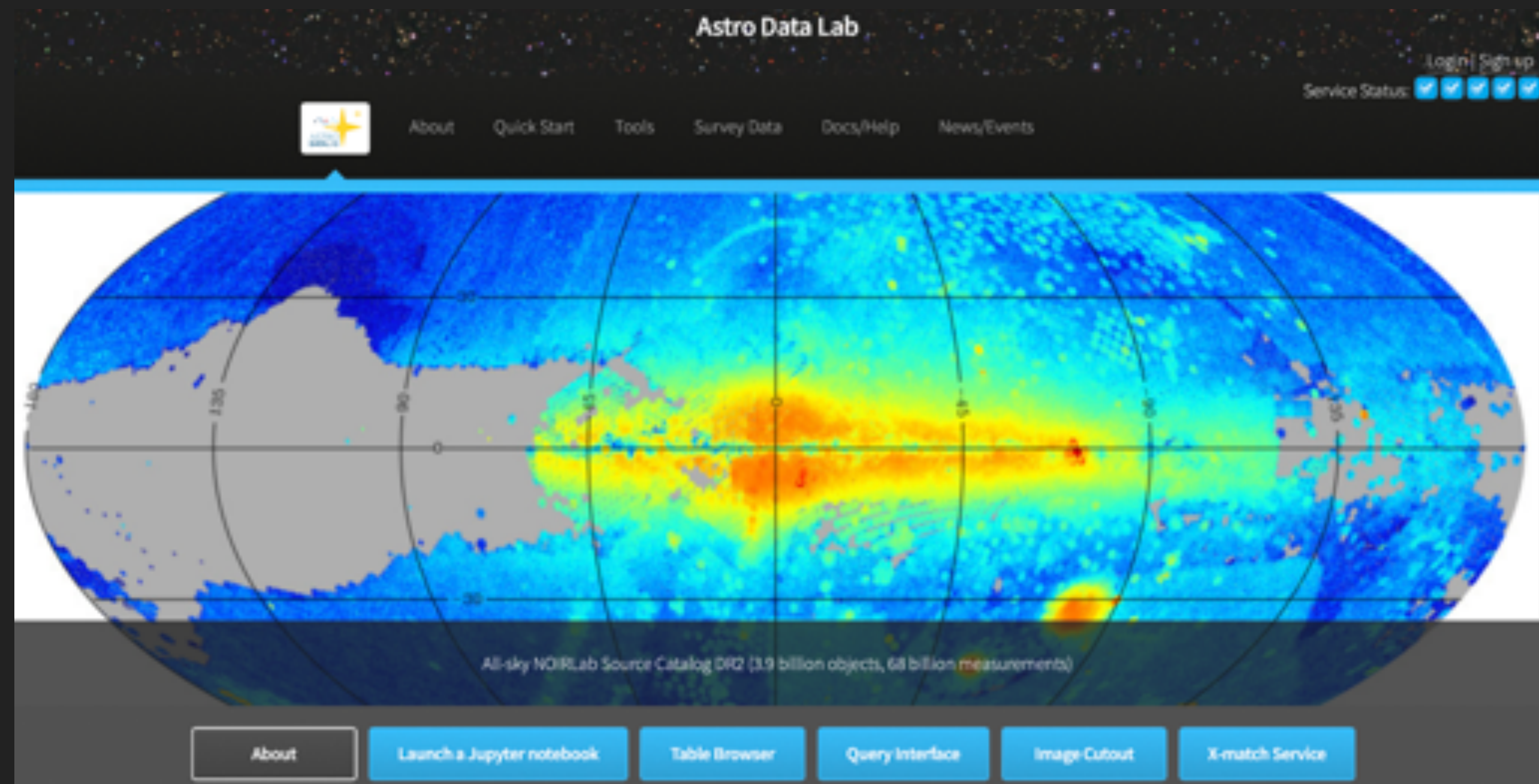
Slits currently available in GMOS-N today...

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

