

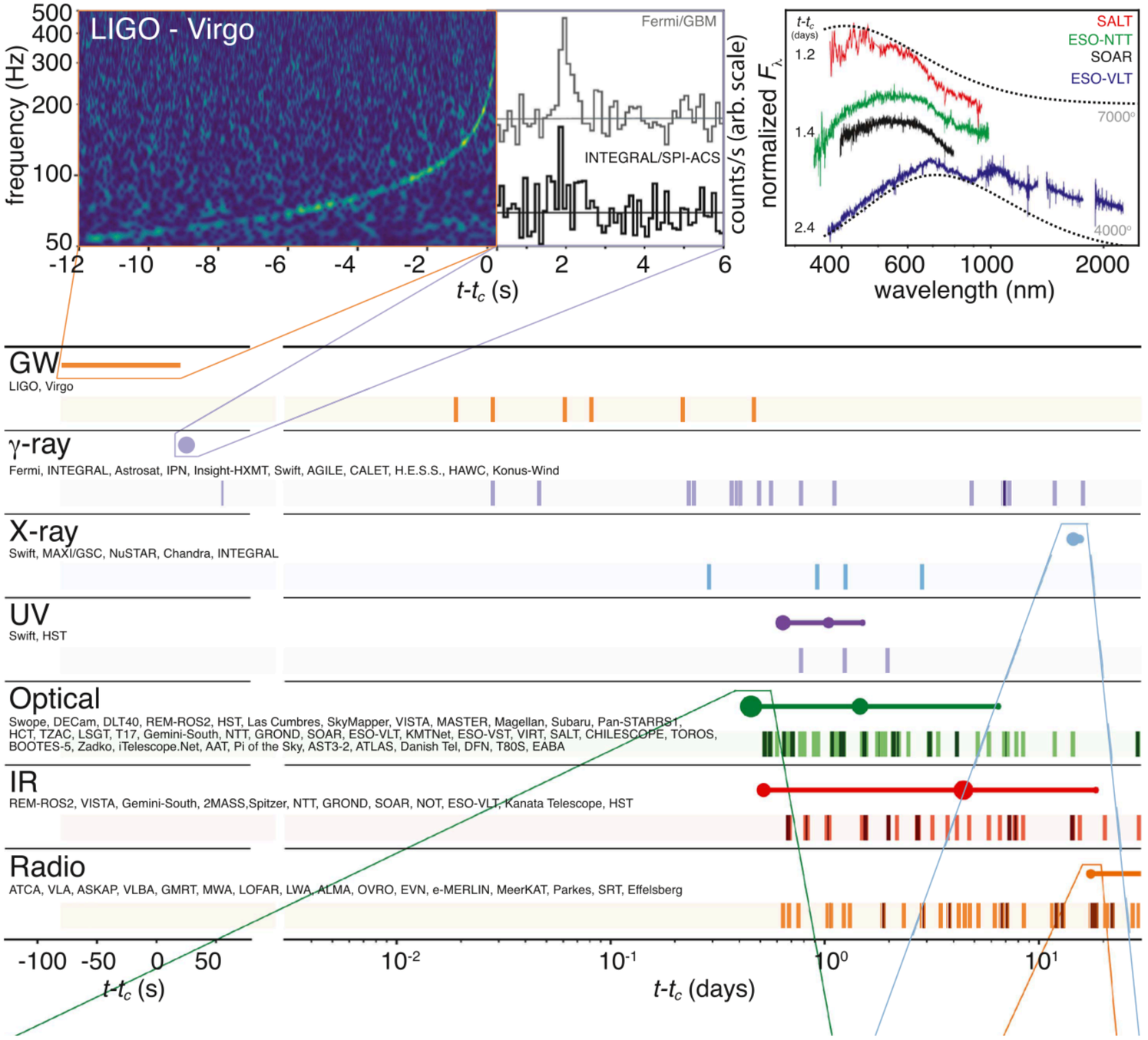

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

# Multi-messenger astronomy infrastructure for optical follow-ups

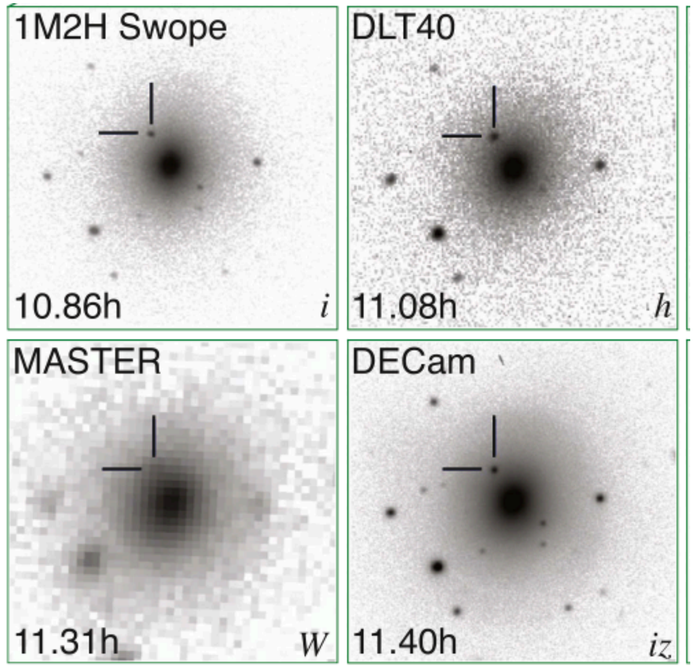
**Konstantin Malanchev, Gautham Narayan**
**UIUC**

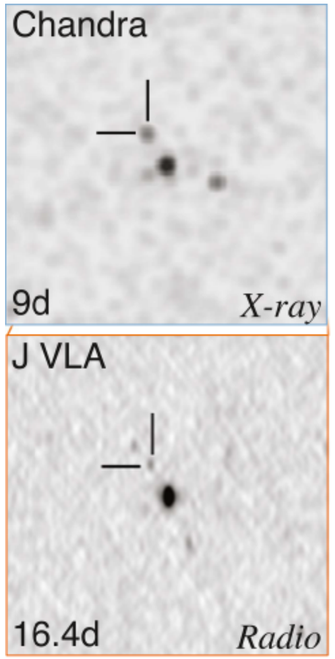
**ML@MIT 2023.01.30**

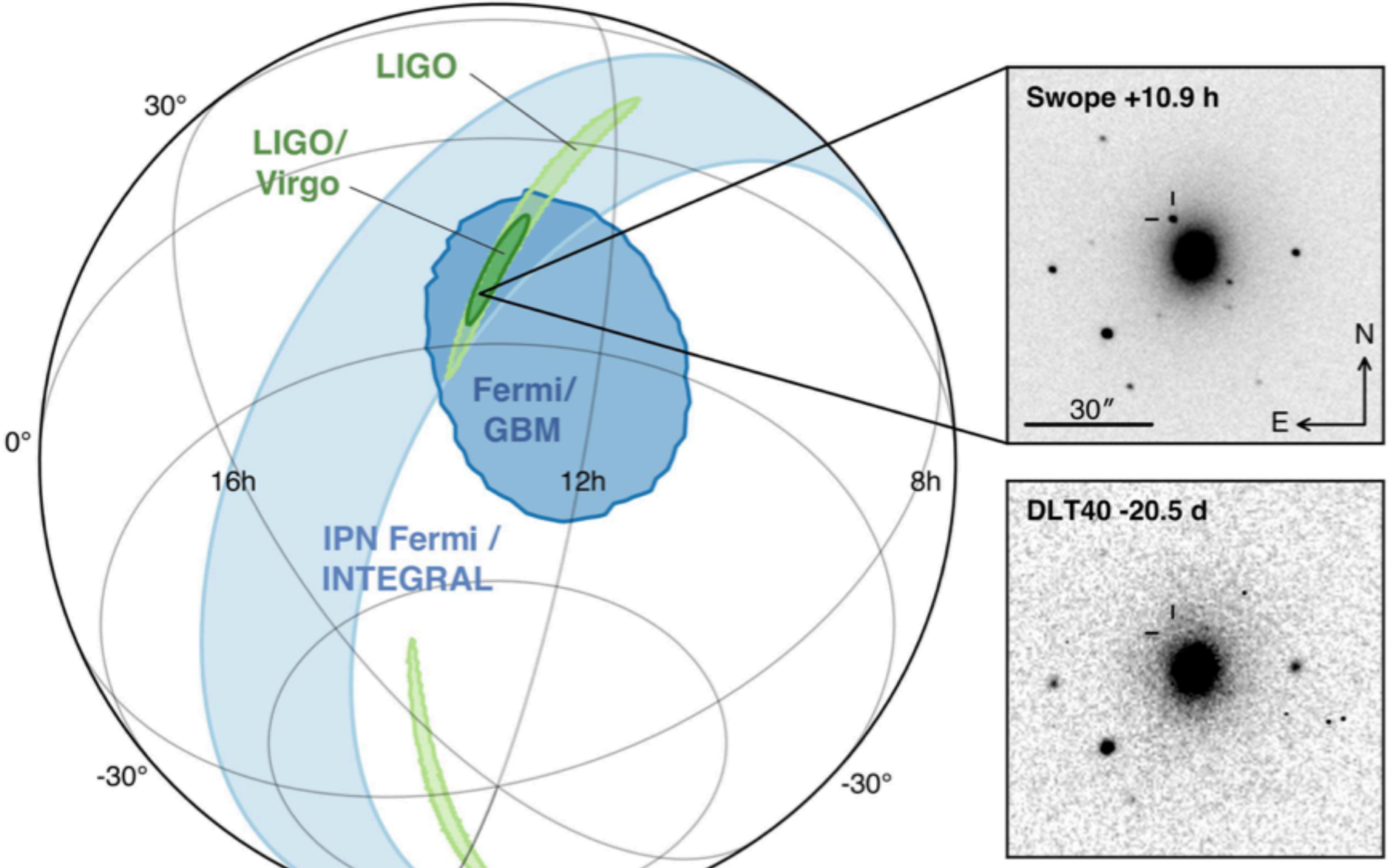
# Kilonova search


LIGO - Virgo
frequency (Hz)
500
400
300
200
100
50
-12 -10 -8 -6 -4 -2 0 2 4 6
t-t_c (s)
Fermi/GBM
INTEGRAL/SPI-ACS
counts/s (arb. scale)
t-t_c (days)
1.2
1.4
2.4
SALT
ESO-NTT
SOAR
ESO-VLT
7000°
4000°
normalized F_λ
400 600 1000 2000
wavelength (nm)
GW
LIGO, Virgo
γ-ray
Fermi, INTEGRAL, Astrosat, IPN, Insight-HXMT, Swift, AGILE, CALET, H.E.S.S., HAWC, Konus-Wind
X-ray
Swift, MAXI/GSC, NuSTAR, Chandra, INTEGRAL
UV
Swift, HST
Optical
Swope, DECam, DLT40, REM-ROS2, HST, Las Cumbres, SkyMapper, VISTA, MASTER, Magellan, Subaru, Pan-STARRS1,
HCT, TZAC, LSGT, T17, Gemini-South, NTT, GROND, SOAR, ESO-VLT, KMTNet, ESO-VST, VIRT, SALT, CHILESCOPE, TOROS,
BOOTES-5, Zadko, iTelescope.Net, AAT, Pi of the Sky, AST3-2, ATLAS, Danish Tel, DFN, T80S, EABA
IR
REM-ROS2, VISTA, Gemini-South, 2MASS,Spitzer, NTT, GROND, SOAR, NOT, ESO-VLT, Kanata Telescope, HST
Radio
ATCA, VLA, ASKAP, VLBA, GMRT, MWA, LOFAR, LWA, ALMA, OVRO, EVN, e-MERLIN, MeerKAT, Parkes, SRT, Effelsberg
-100 -50 0 50
t-t_c (s)
10^-2 10^-1 10^0 10^1
t-t_c (days)

Abott+17


1M2H Swope
10.86h
i
DLT40
11.08h
h
MASTER
11.31h
W
DECam
11.40h
iz

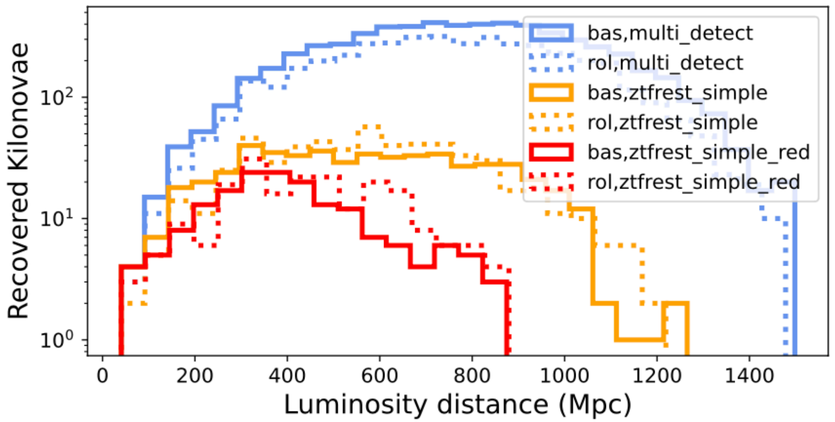

Chandra
9d
X-ray
J VLA
16.4d
Radio

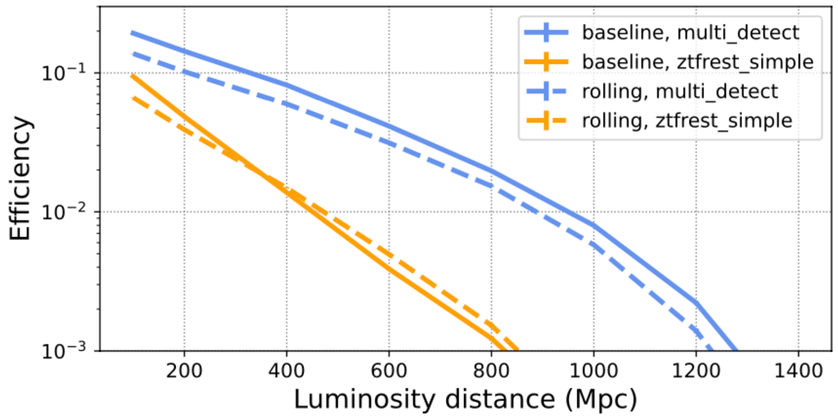

LIGO
LIGO/
Virgo
Fermi/
GBM
IPN Fermi /
INTEGRAL
30°
0°
-30°
16h
12h
8h
-30°
Swope +10.9 h
I
N
E
30″
DLT40 -20.5 d
I

Abott+17

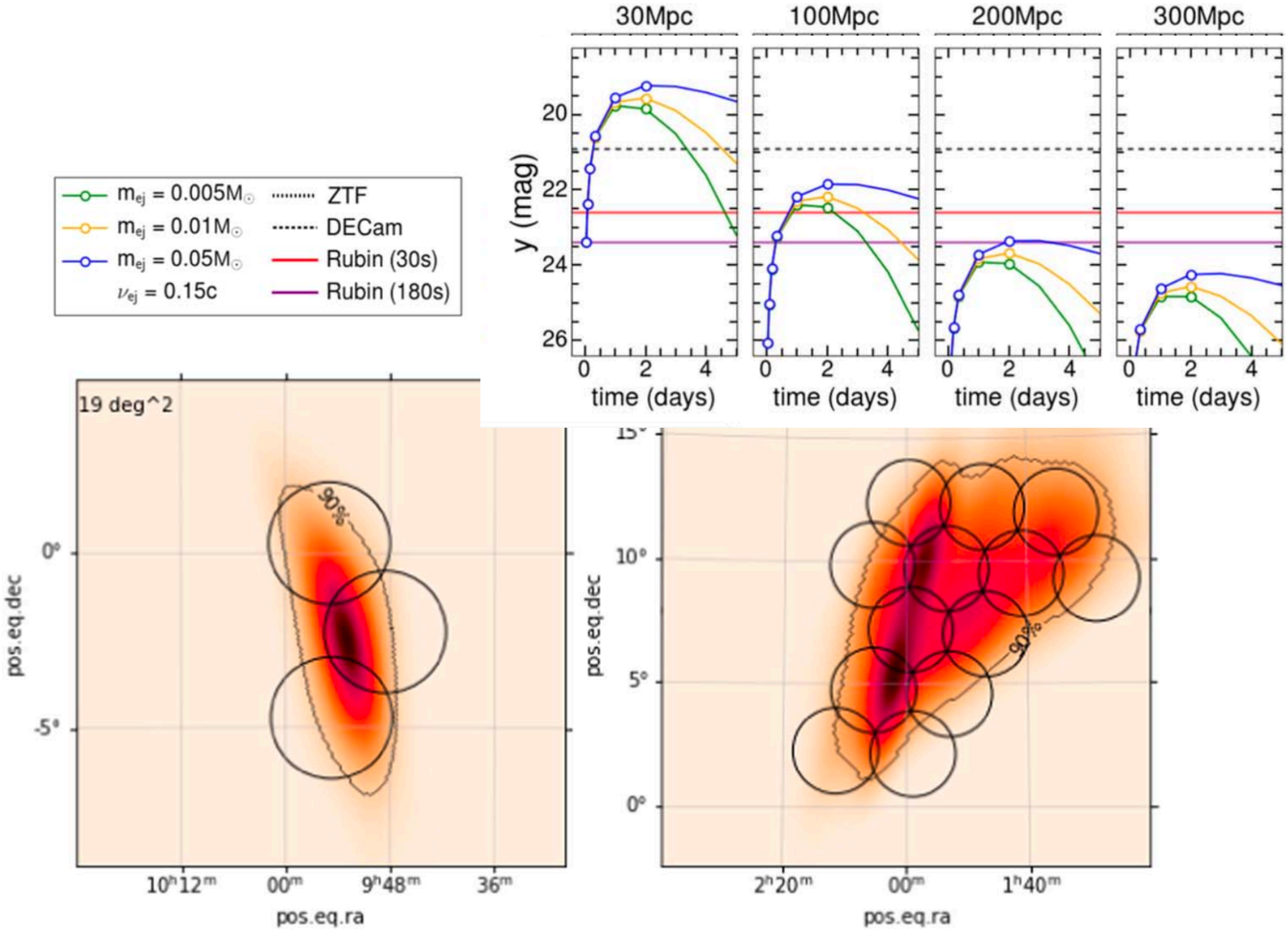
# LSST observation strategy

Serendipitous detection efficiency for different obs strategies (Andreoni+22a)



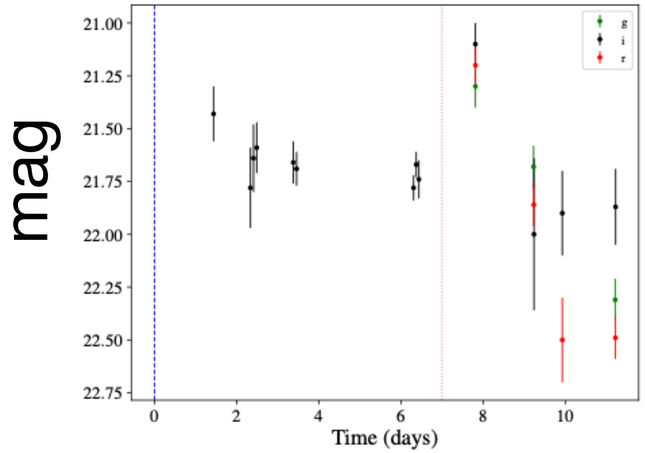




Target of opportunity strategy, O5 (Andreoni+22b)

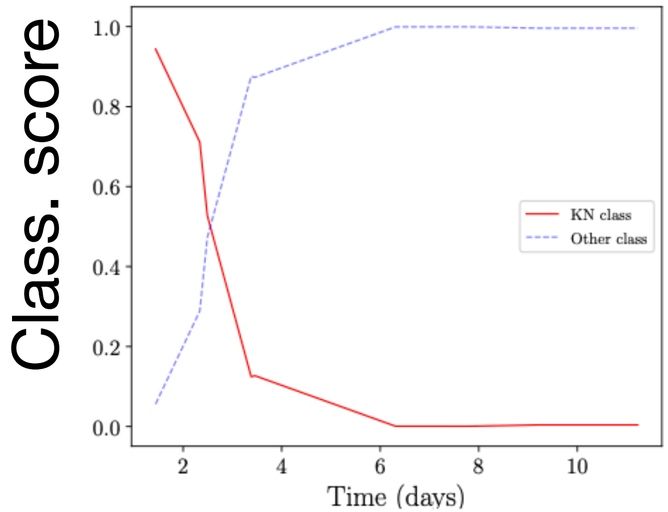


# Binary classification vs SN and TDE

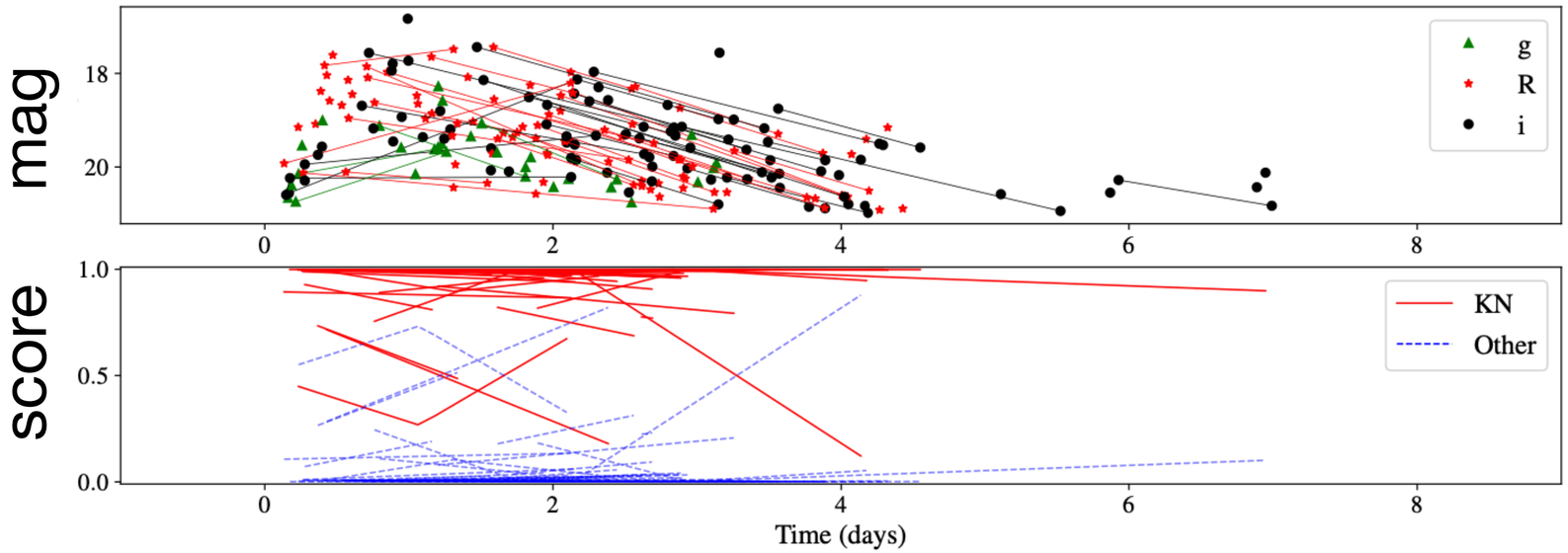
## Chatterjee, KM+ 2022




SN 2019npv, ZTF

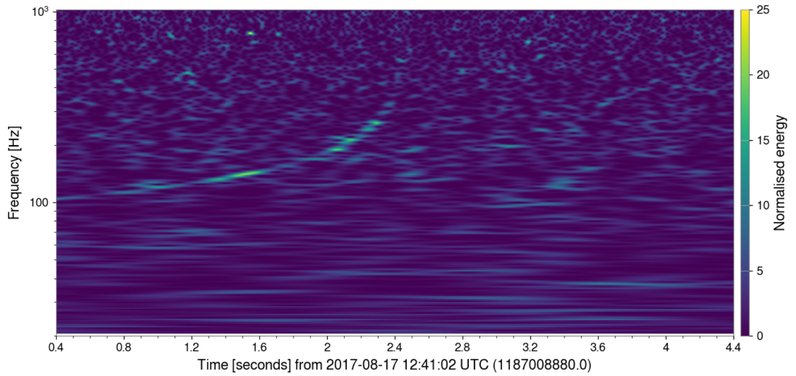


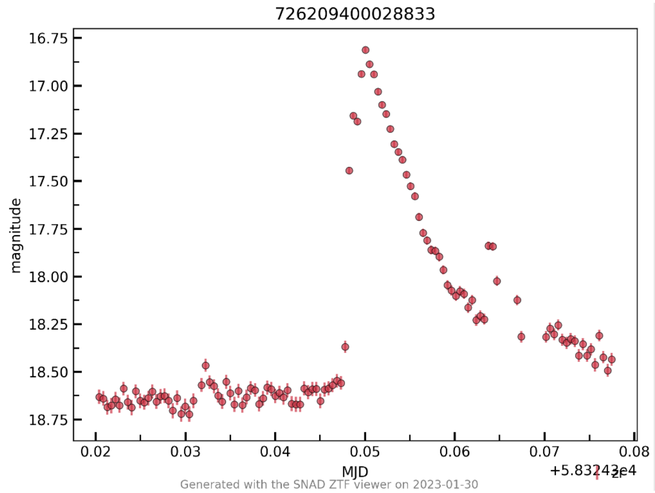

LSST simulations



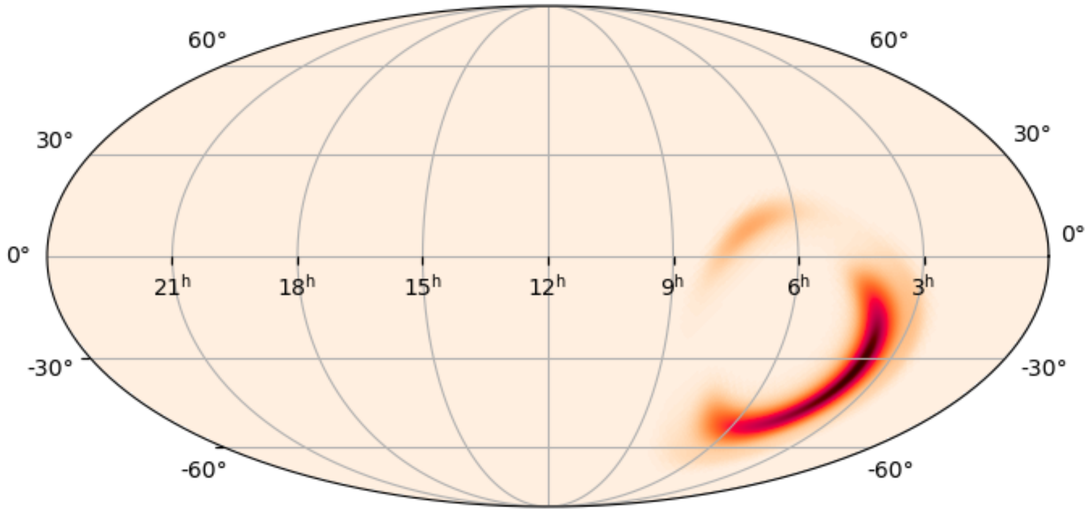
# Classification vs M-dwarf flares

## WIP Ved Shah, KM+

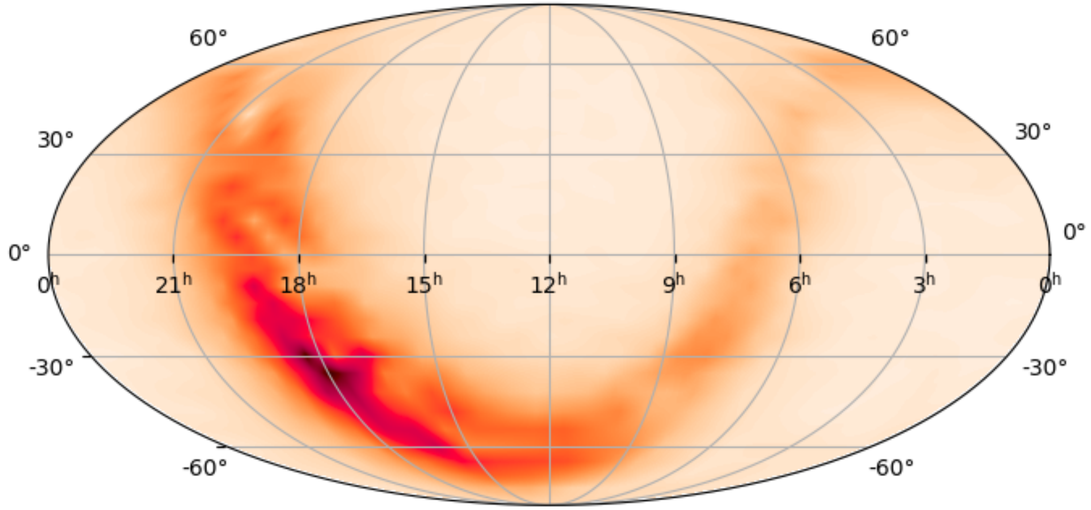



Example localization map



M-dwarf sky distribution model



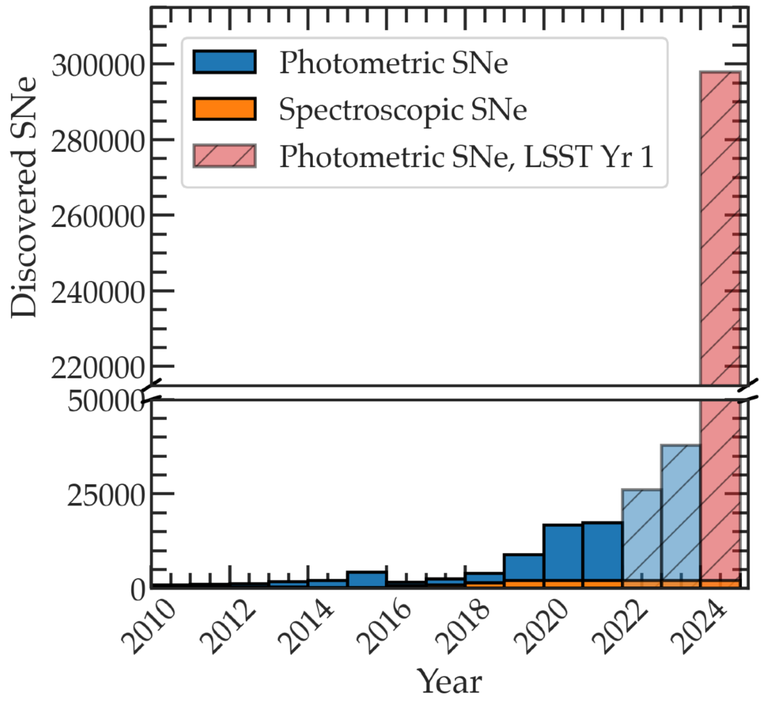
# Getting ready for LSST

# Vera C. Rubin Observatory Legacy Survey of Space and Time

## Key numbers

- 10 year survey, starting in 2024-2025
- 20B galaxies, 17B stars, 6M solar system bodies
- 10M alerts / night, 80 GB / night
- Primary mirror: 8.4m
- Field of view: 9.6 sq degrees
- Detector: 3.2 Gpx
- Camera: six passbands

SN detection rate

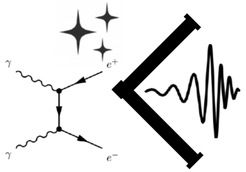



Alex Gagliano

# Future of the photometric alert infrastructure

Rubin Observatory **streams 10 million alerts/night** to 7 broker teams (e.g. ANTARES - Time-Domain Astronomy at NSF's NOIRLab Splinter Session)

VERA C. RUBIN
OBSERVATORY



# Future of the photometric alert infrastructure

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# Future of the photometric alert infrastructure

These brokers **run user algorithms to characterize, classify and filter events**

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The community ingests classifications from the brokers, decides follow-up actions and works to meet their science requirements

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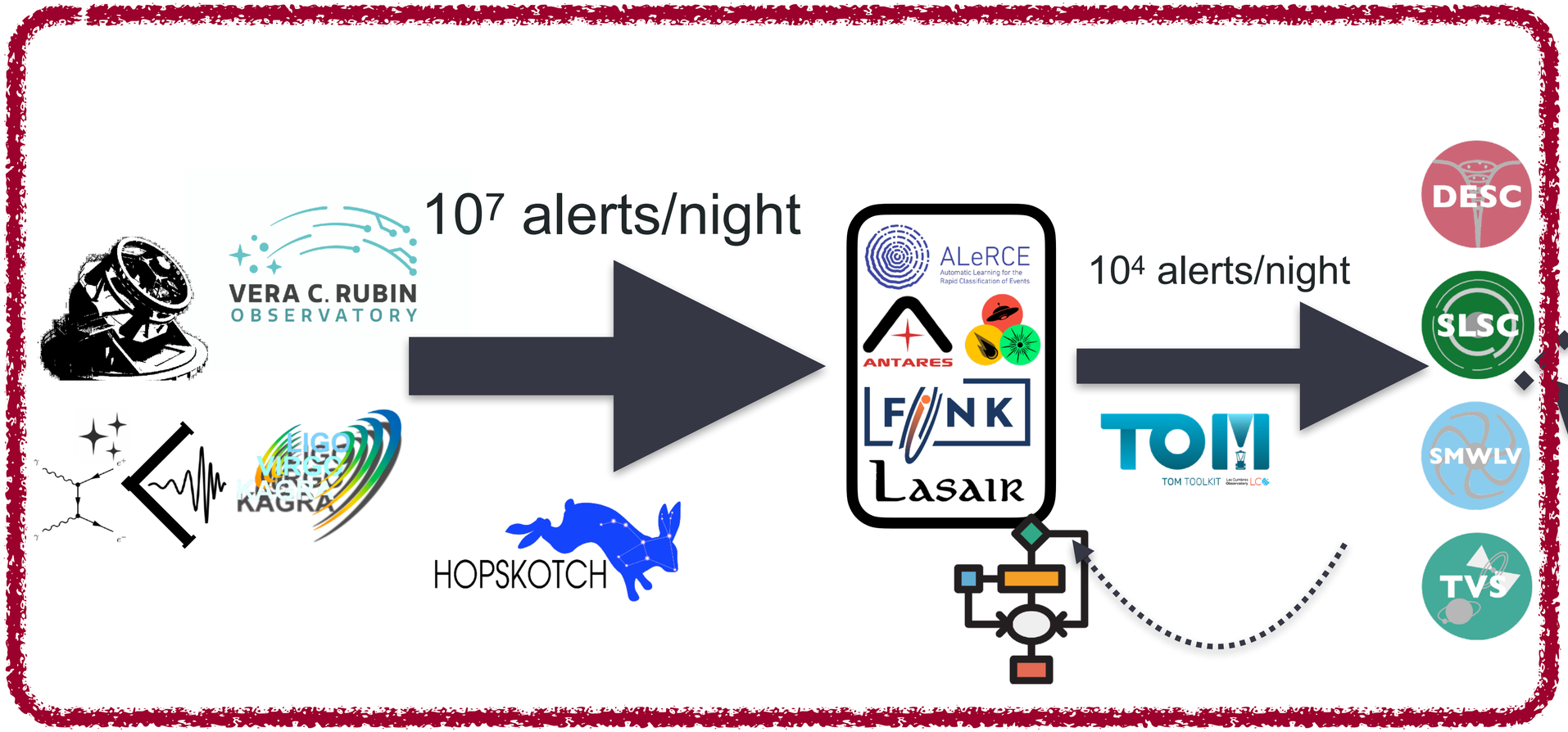
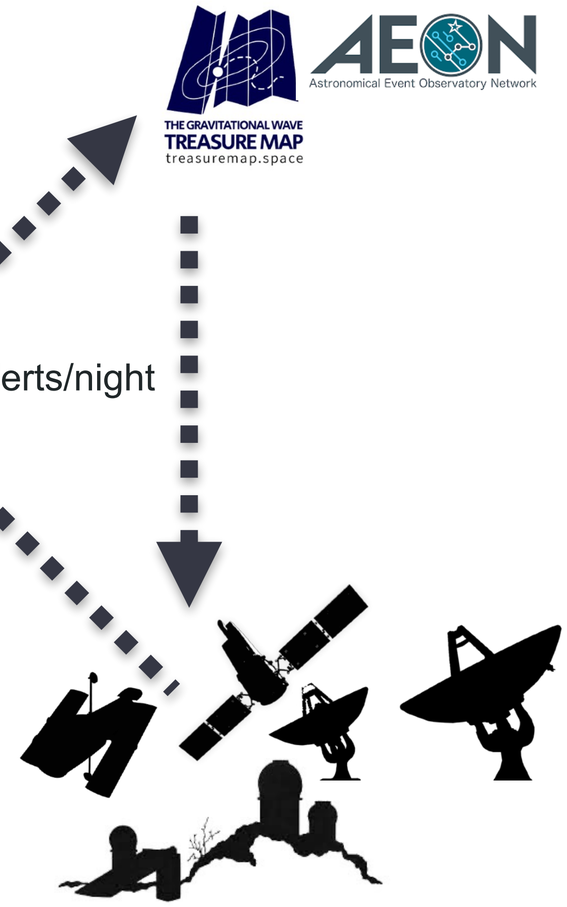
# Future of the photometric alert infrastructure

**Big infrastructure challenge with multiple potential points of failure along chain. ELAsTiCC simulates the entire chain to identify these.**

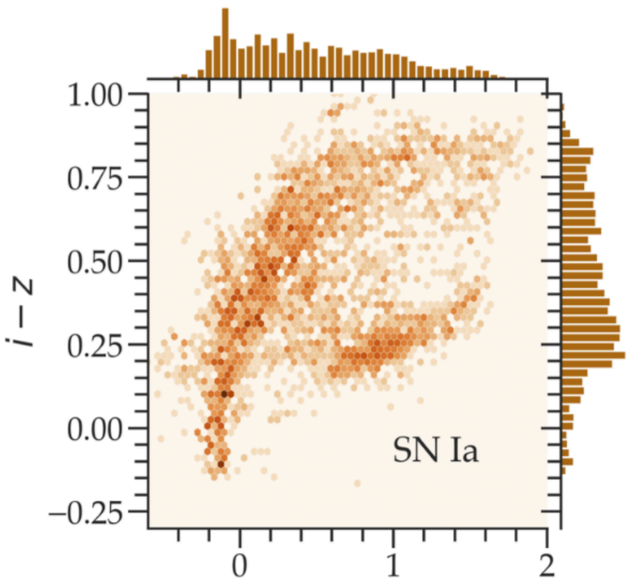


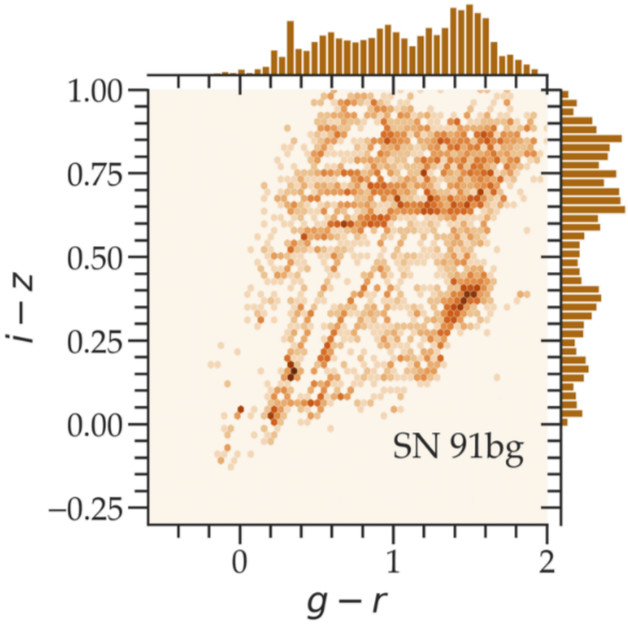



# ELAsTiCC is the largest simulation of the time-domain sky

**End-to-end real-time stress test LSST alert system and classifiers.**

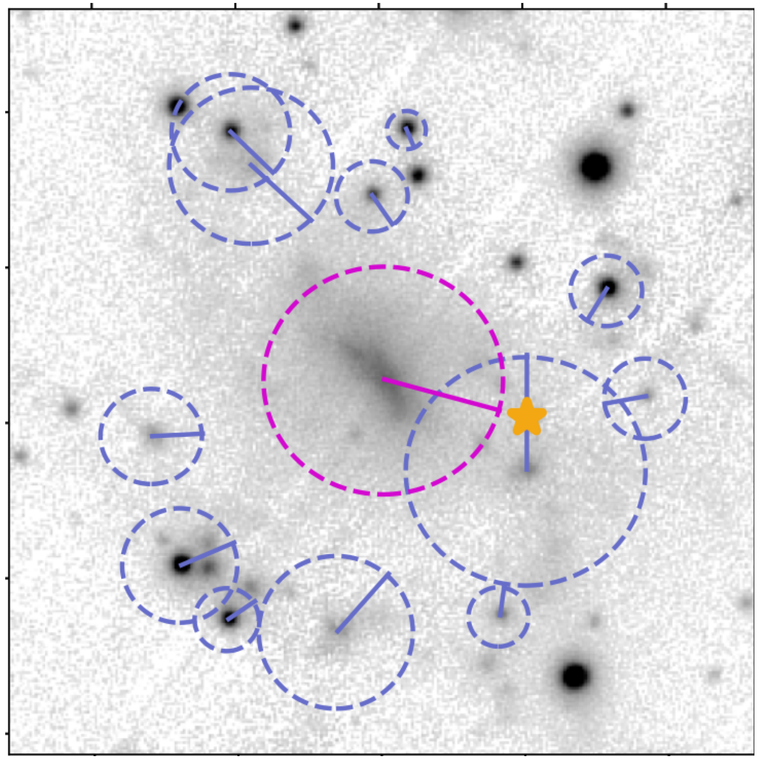
- **few GW alerts for kilonovae** and
- 53 million alerts charting the time-evolution of
- 4.3 million objects from
- 20 classes  (galactic + extragalactic) with
- realistic host-galaxy associations (SCOTCH, Lokken+22)
- 3 years of LSST simulated with the current baseline
- streamed to LSST AP team to broadcast to
- 4 LSST brokers (ALeRCE, AMPEL, ANTARES, FINK)
- running 10 different classifiers
- over 3 months of real time i.e. ~0.5e6 alerts/night



# ELAsTiCC alert data

1. LSST event
   - **Photometry**
   - Milky way dust redding
   - **Probable hosts**, 0 for the Galactic sources, 0 to 2 for the extragalactic transients:
     - Separation
     - Photometric and rarely spectroscopic redshifts
     - Magnitudes and morphology
2. GW event: localization map



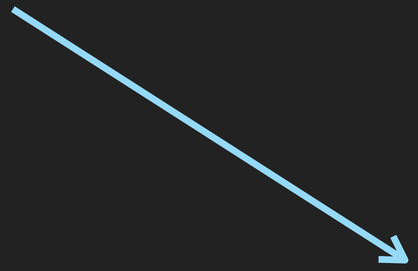
Gagliano+21, arXiv:2008.09630

# Message passing


Multimessenger trigger

Adopted from Andy Howell, Boom 2022


Multimessenger trigger




**General Coordinates Network**

Adopted from Andy Howell, Boom 2022


Multimessenger trigger


General Coordinates Network


Survey facility

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Multimessenger trigger


General Coordinates Network


Coordinate, visualize follow-up


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Multimessenger trigger



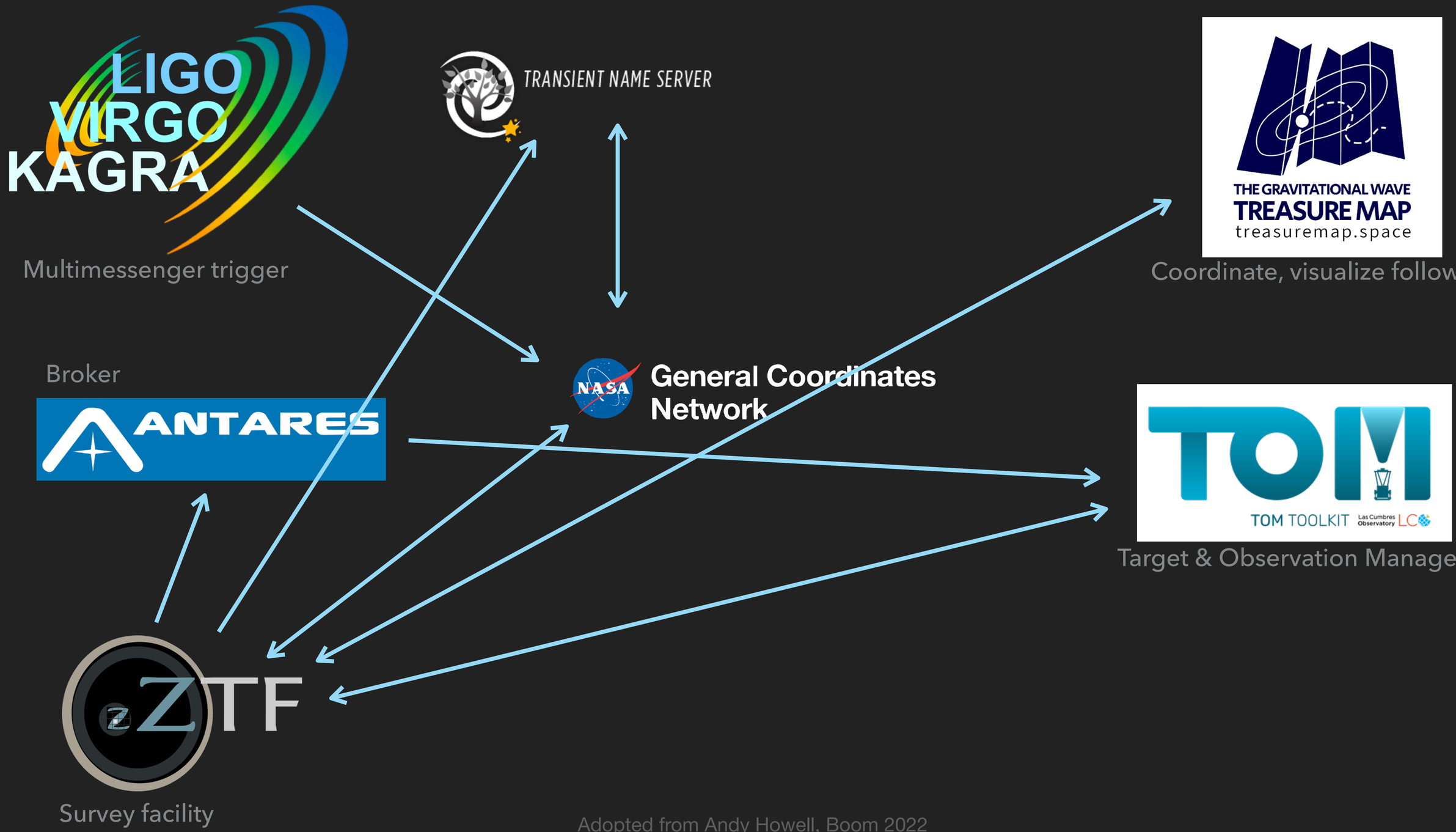
General Coordinates Network


Coordinate, visualize follow-up


Target & Observation Manager


Survey facility

Adopted from Andy Howell, Boom 2022

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Multimessenger trigger



Coordinate, visualize follow-up

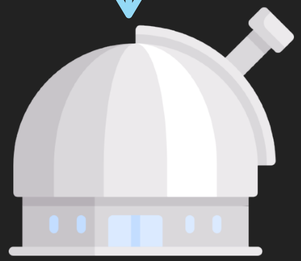
Broker



General Coordinates Network

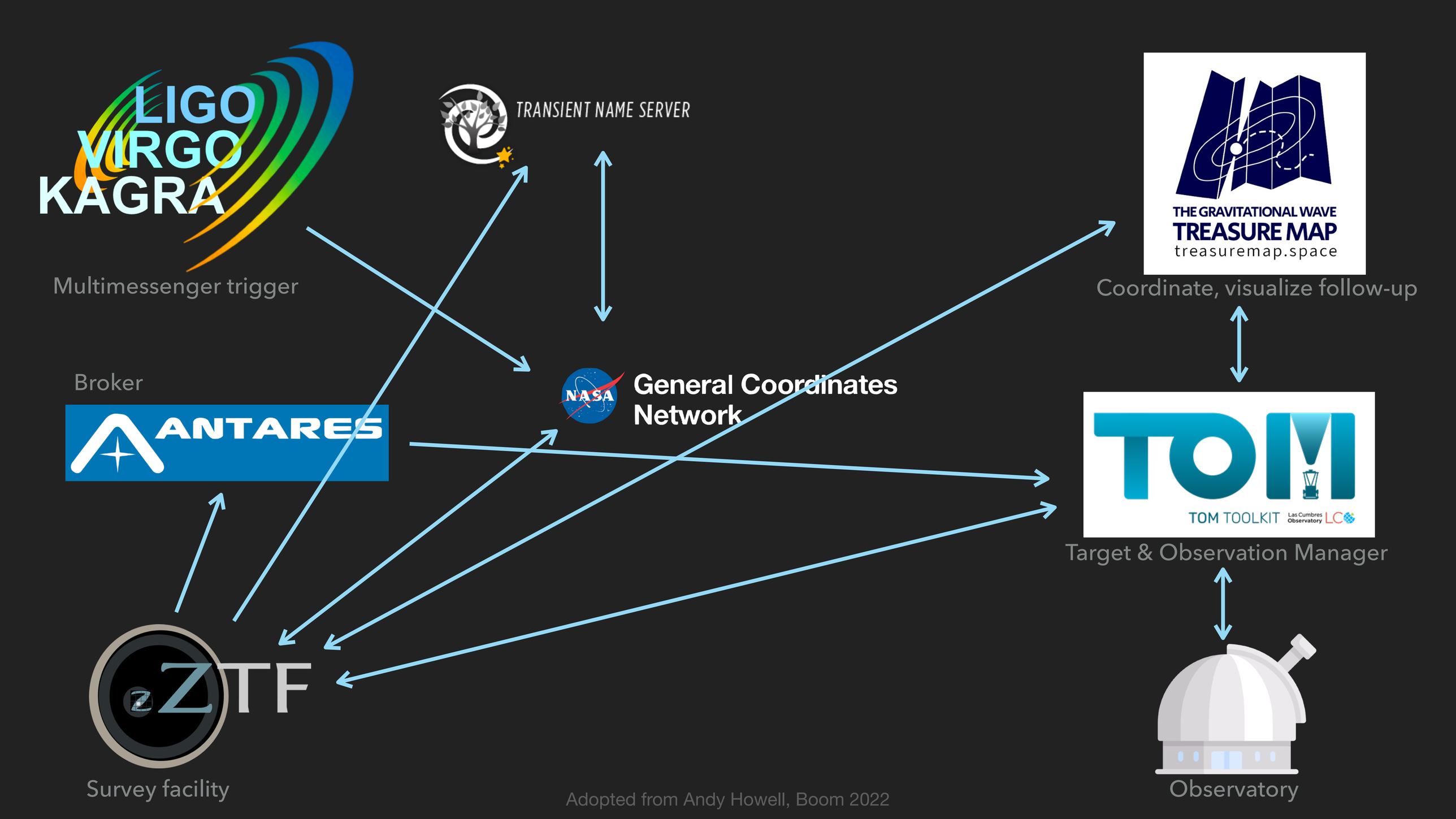

Target & Observation Manager


Survey facility



Observatory

Adopted from Andy Howell, Boom 2022

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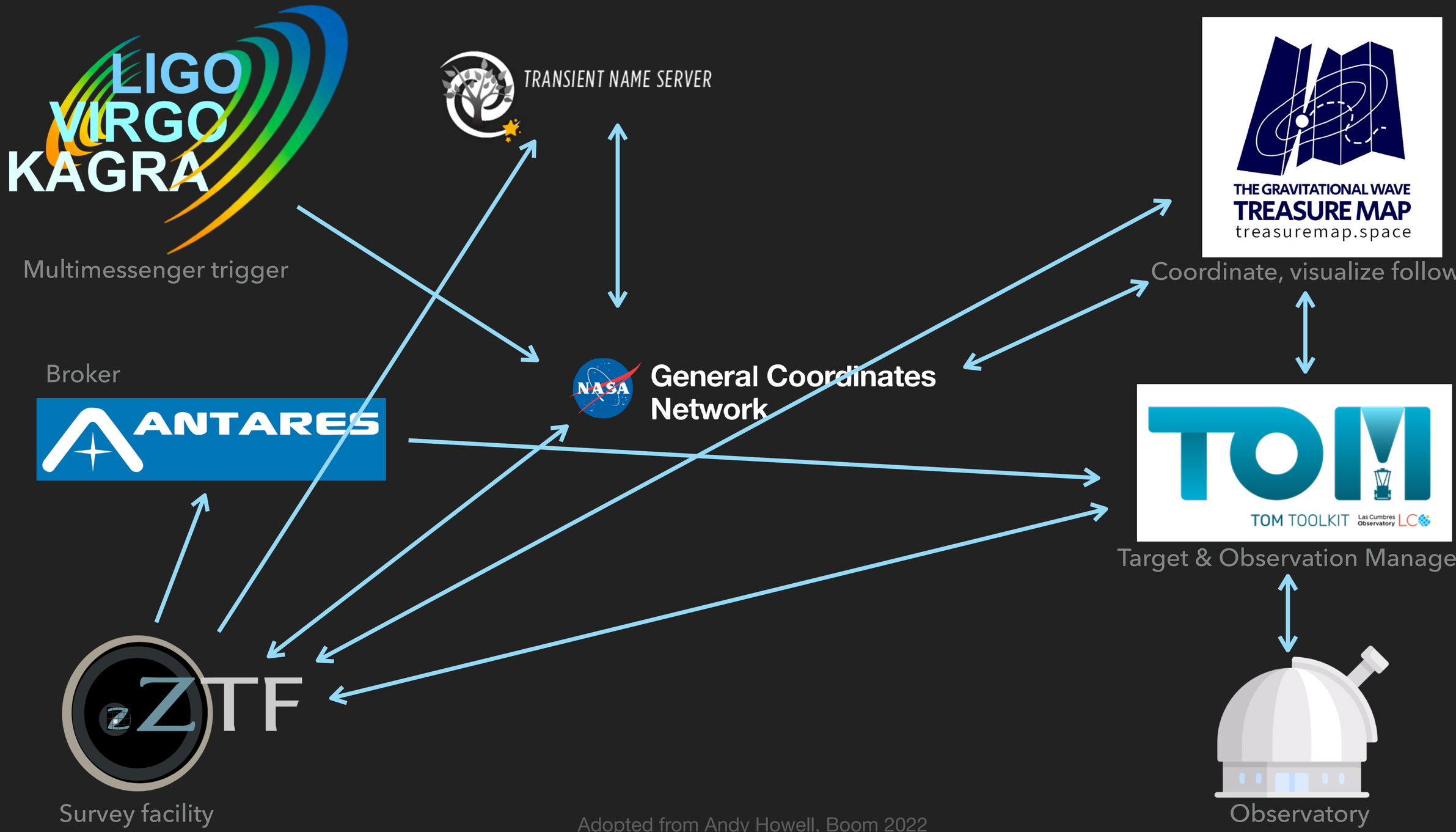


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Multimessenger trigger



Coordinate, visualize follow-up

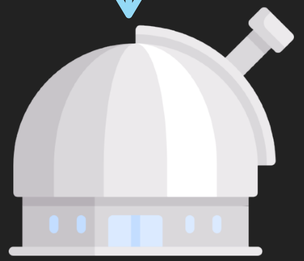
Broker



General Coordinates Network

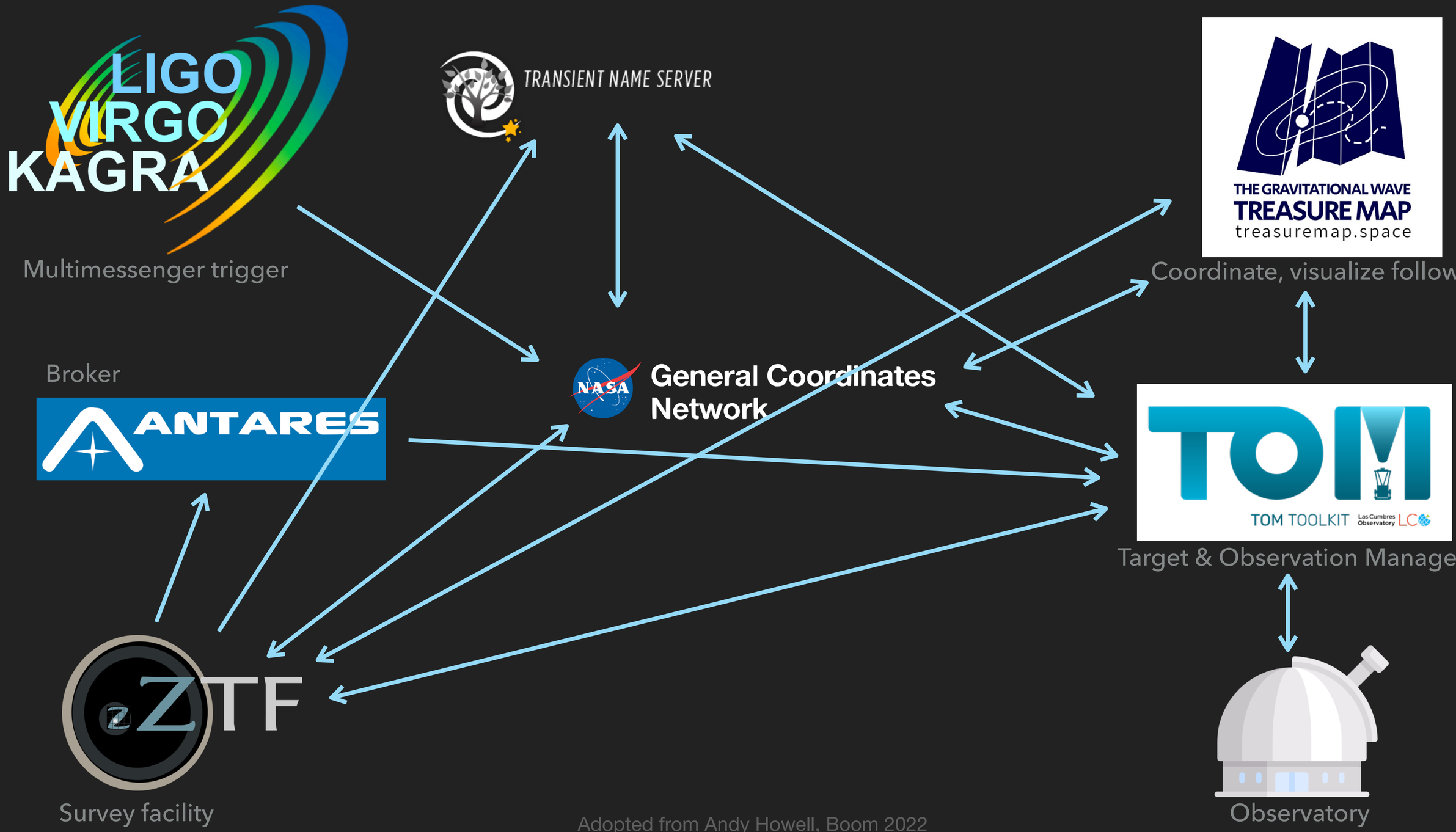

Target & Observation Manager


Survey facility

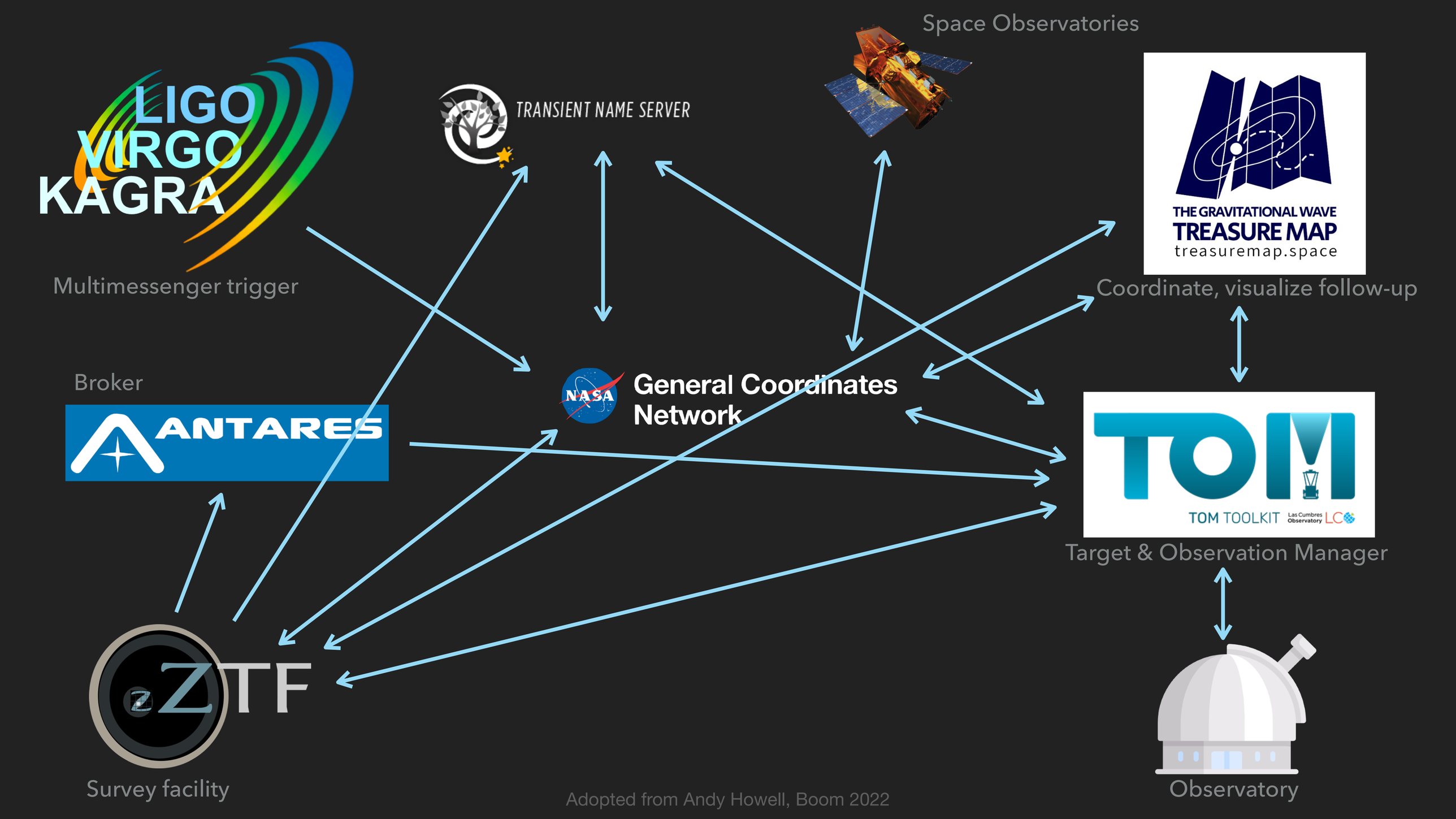


Observatory

Adopted from Andy Howell, Boom 2022




Adopted from Andy Howell, Boom 2022

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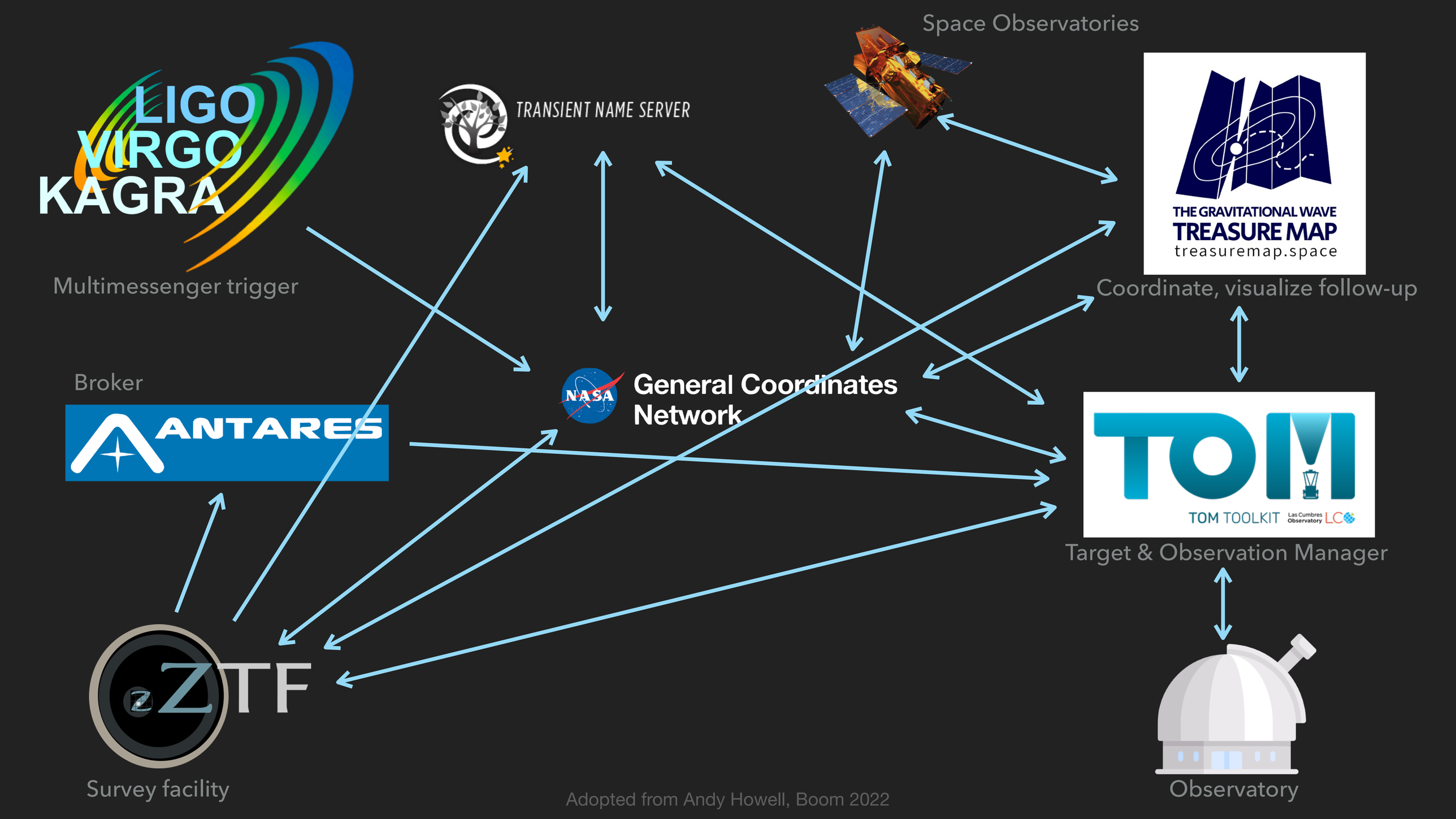
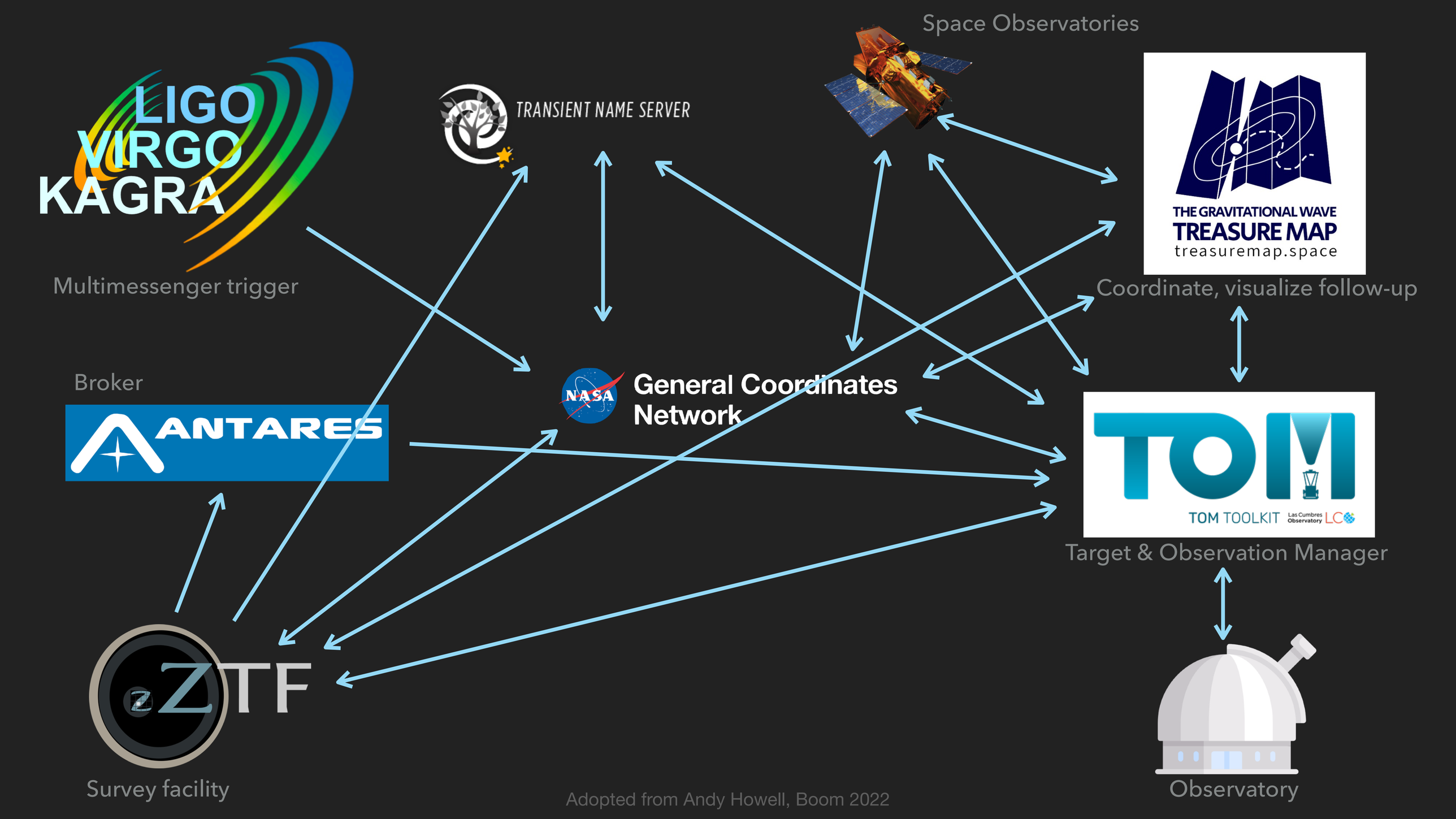



Adopted from Andy Howell, Boom 2022




Adopted from Andy Howell, Boom 2022

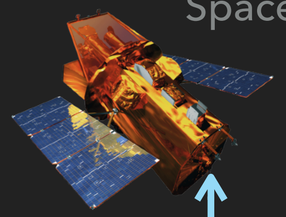
# SCIMMA HOPSKOTCH

- 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. This allows carrying much more information.
- 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 Kafka – will scale to LSST era.
- Cloud-based. Hosted by Amazon Web Services
- Integrated with Identity and Access Management system (currently COmanage).
- **Standards problem:** How do we all agree on how to make what we send machine readable?

Adopted from Andy Howell, Boom 2022


Multimessenger trigger

Space Observatories


General Coordinates Network


Coordinate, visualize follow-up

Kafka + Magic

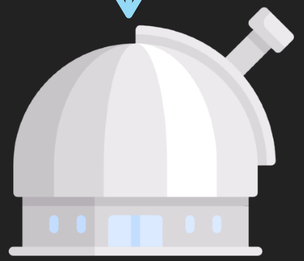
Broker



GUI + API + Protocol + Database


Target & Observation Manager


Survey facility



Observatory

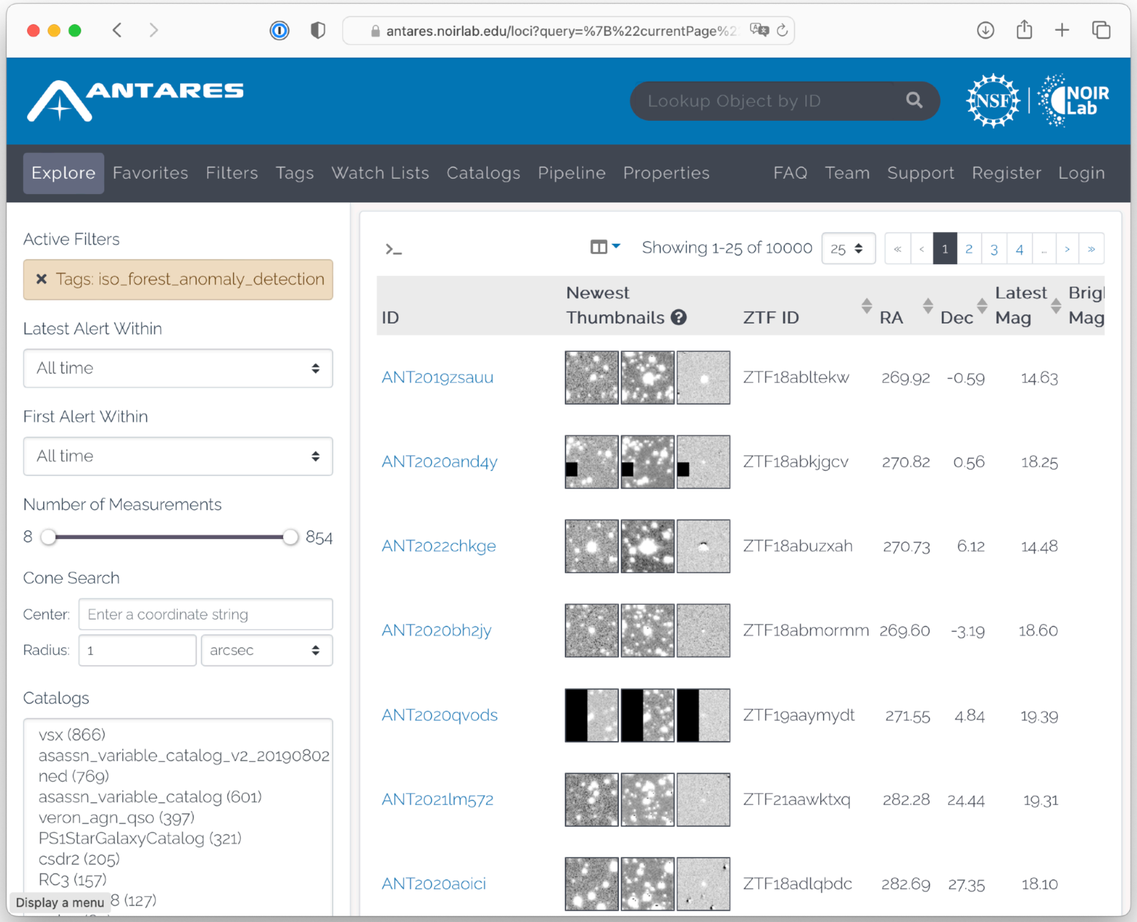
Adopted from Andy Howell, Boom 2022

# ANTARES alert broker

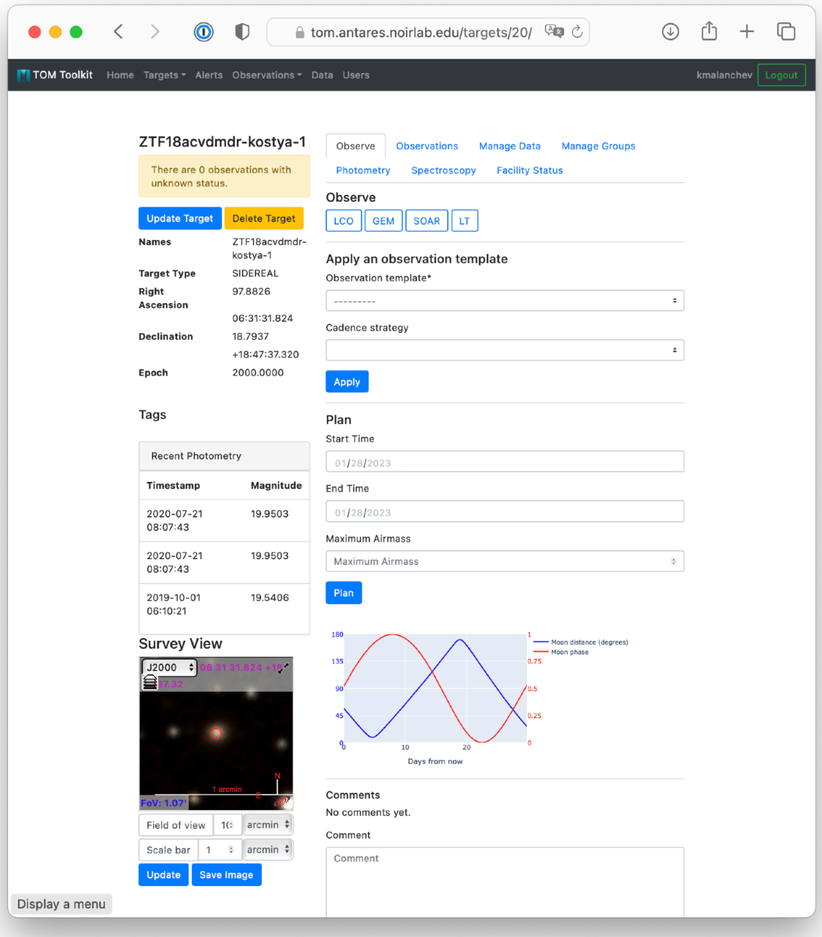
# Web-portal

## Broker for: ZTF, LSST, DECam, GW alerts.

### Main portal



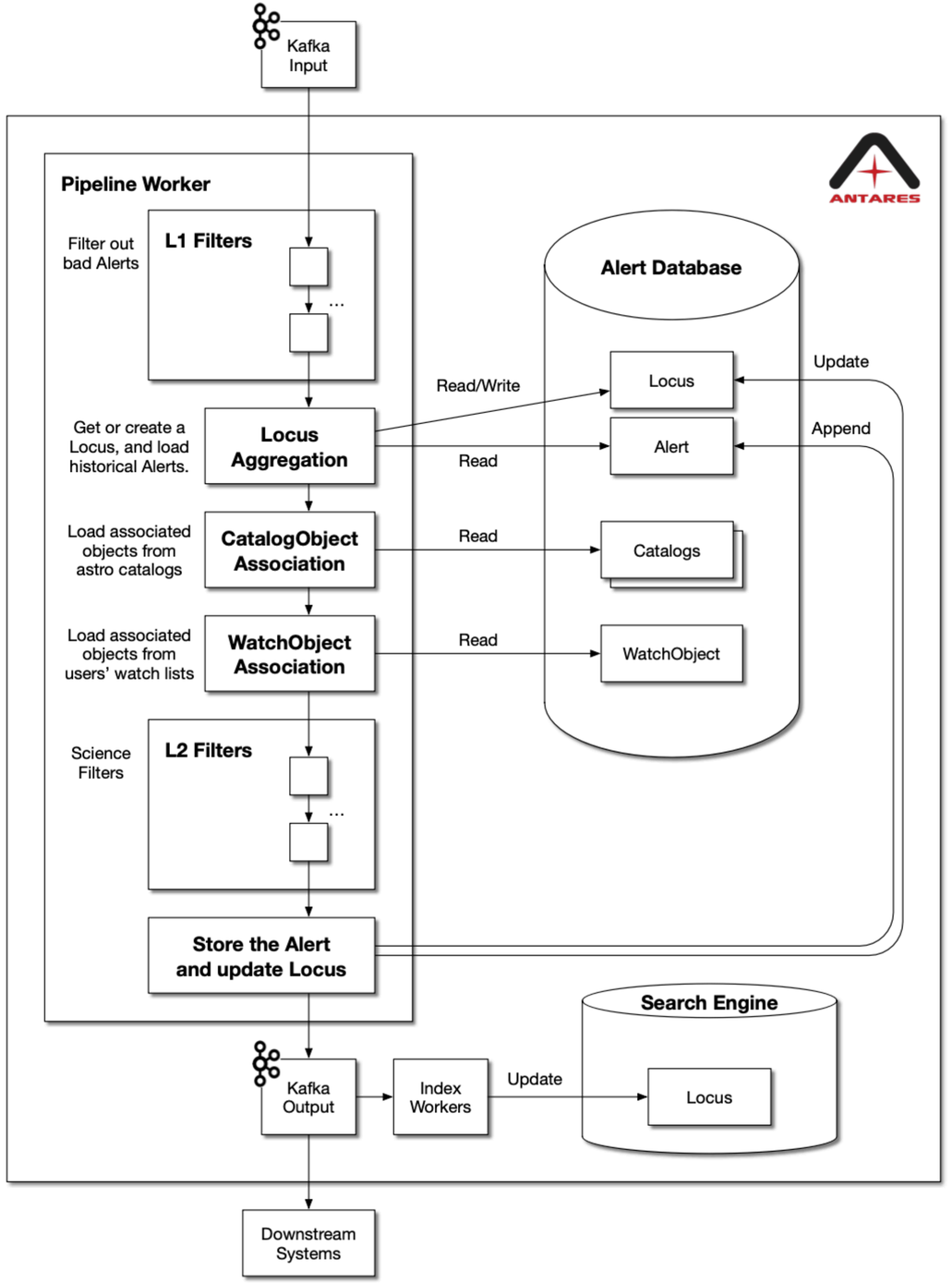

### Target & observation manager



# ANTARES and user filters

## Filters

- Easy to develop with NOIRLab Data Lab https://datalab.noirlab.edu/
- Submit and update via ANTARES portal https://antares.noirlab.edu/
- Communicate with the team for the further integration
- LSST simulations, ZTF data wait for your filters!



# ANT

## Filters

- Easy
  https
- Subr
  https
- Com
  integ
- LSS
  filter

gp12.datalab.noirlab.edu/user/kostya/lab/tree/feature_filter.ipynb

File Edit View Run Kernel Tabs Settings Help

Filter files by name

/ antares-anomaly-features /

Name Last Modified

feature_filter.ipynb

Code Python 3 (ANTARES)

```
[1]: from itertools import chain

     import antares.devkit as dk; dk.init()
     import light_curve as lc
     import numpy as np
     from astropy.table import MaskedColumn
```

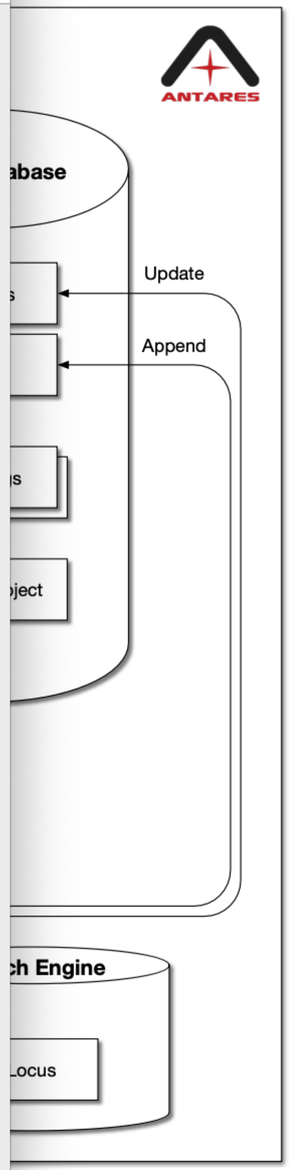
```
Loading ANTARES from /data0/sw/antares-kernel/lib/python3.9/site-packages/antares/__init__.py

      _    _   _ _____ _    ____  _____ ____
     / \  | \ | |_   _/ \  |  _ \| ____/ ___|
    / _ \ |  \| | | | / _ \ | |_| |  _| \___ \\
   / ___ \| |\  | | |/ ___ \|  _ /| |___ ___| |
  /_/   \_\_| \_| |_/_/   \_\_| \_\_____|____/   v2.3.0

2023-01-09 09:28:06,290 - WARNING MainThread settings.py:setup_prometheus:120 - Prometheus failed
to start with [Errno 98] Address already in use
Testing loading a random Locus with `dk.get_locus()`...
2023-01-09 09:28:09,431 - INFO MainThread settings.py:cassandra_session_factory:80 - Establishing
connection to Cassandra
2023-01-09 09:28:10,724 - INFO MainThread settings.py:cassandra_session_factory:84 - Connection t
o Cassandra established
2023-01-09 09:28:10,725 - INFO MainThread settings.py:cassandra_session_factory:80 - Establishing
connection to Cassandra
2023-01-09 09:28:12,026 - INFO MainThread settings.py:cassandra_session_factory:84 - Connection t
o Cassandra established
2023-01-09 09:28:12,028 - INFO MainThread settings.py:cassandra_session_factory:80 - Establishing
connection to Cassandra
2023-01-09 09:28:13,335 - INFO MainThread settings.py:cassandra_session_factory:84 - Connection t
o Cassandra established
2023-01-09 09:28:17,110 - WARNING MainThread cassandra.py:list_by_location:1170 - Catalog object
not found (catalog_id=19, object_id=816030436)

ANTARES v2.3.0 DevKit is ready!
Website: http://antares.noirlab.edu
Documentation: http://noao.gitlab.io/antares/filter-documentation/
```

Display a menu 0 4 Python 3 (ANTARES) | Idle Mem: 563.31 / 8192.00 MB Saving completed Mode: Command Ln 1, Col 1 feature_filter.ipynb



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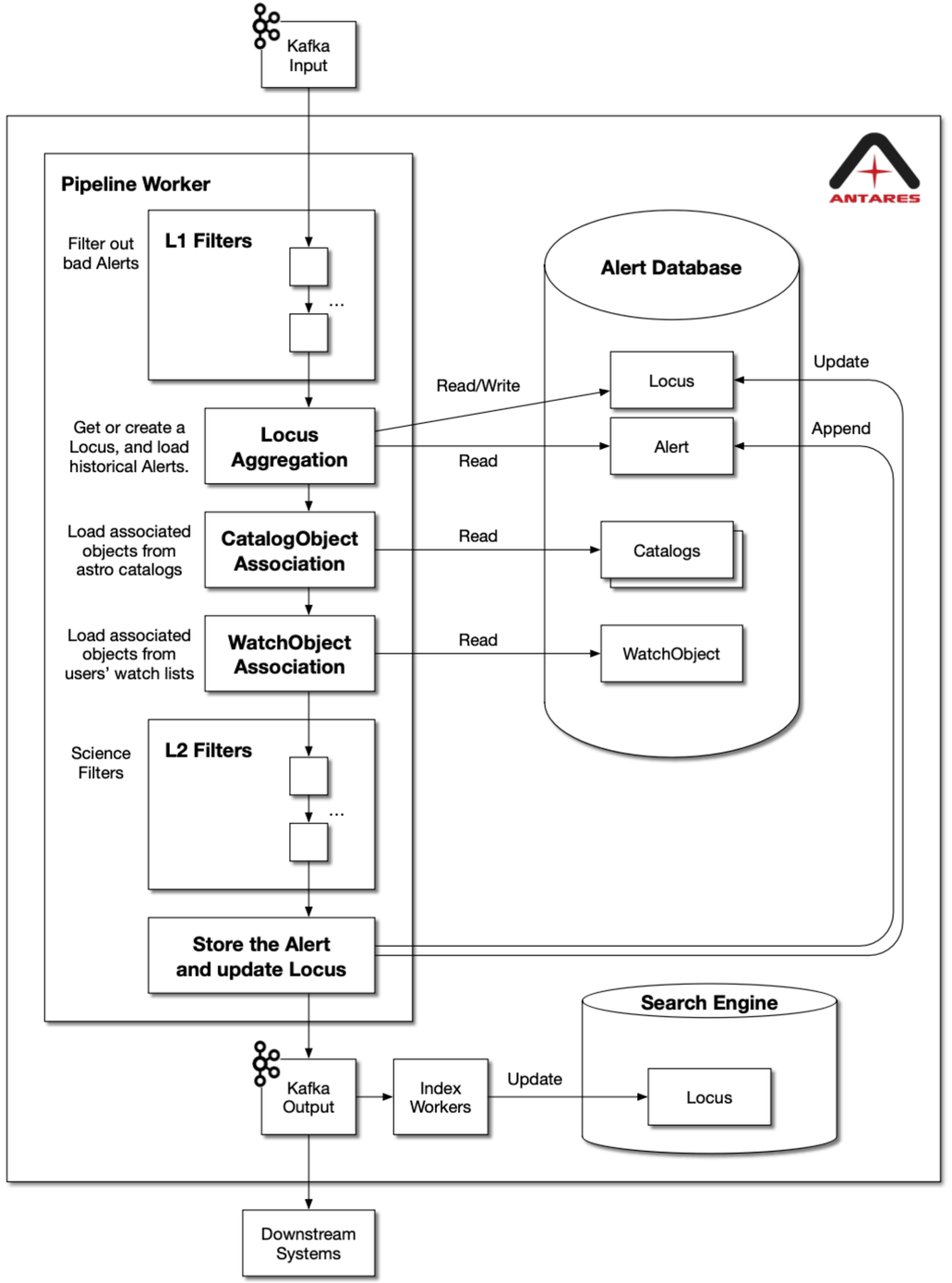

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antares.noirlab.edu/filters/create

ANTARES

Lookup Object by ID

NSF | NOIR Lab

Explore | Favorites | Filters | Tags | Watch Lists | Catalogs | Pipeline | Properties | FAQ | Team | Support | Konstantin Malanchev

### New Filter Submission

Thank you for your interest in submitting a filter to ANTARES.

Filter Name

Enter the name of your filter

Filter names must begin with a lowercase or uppercase letter and may contain up to 64 characters. They may contain letters, numbers, spaces, underscores, hyphens and periods.

Filter Description

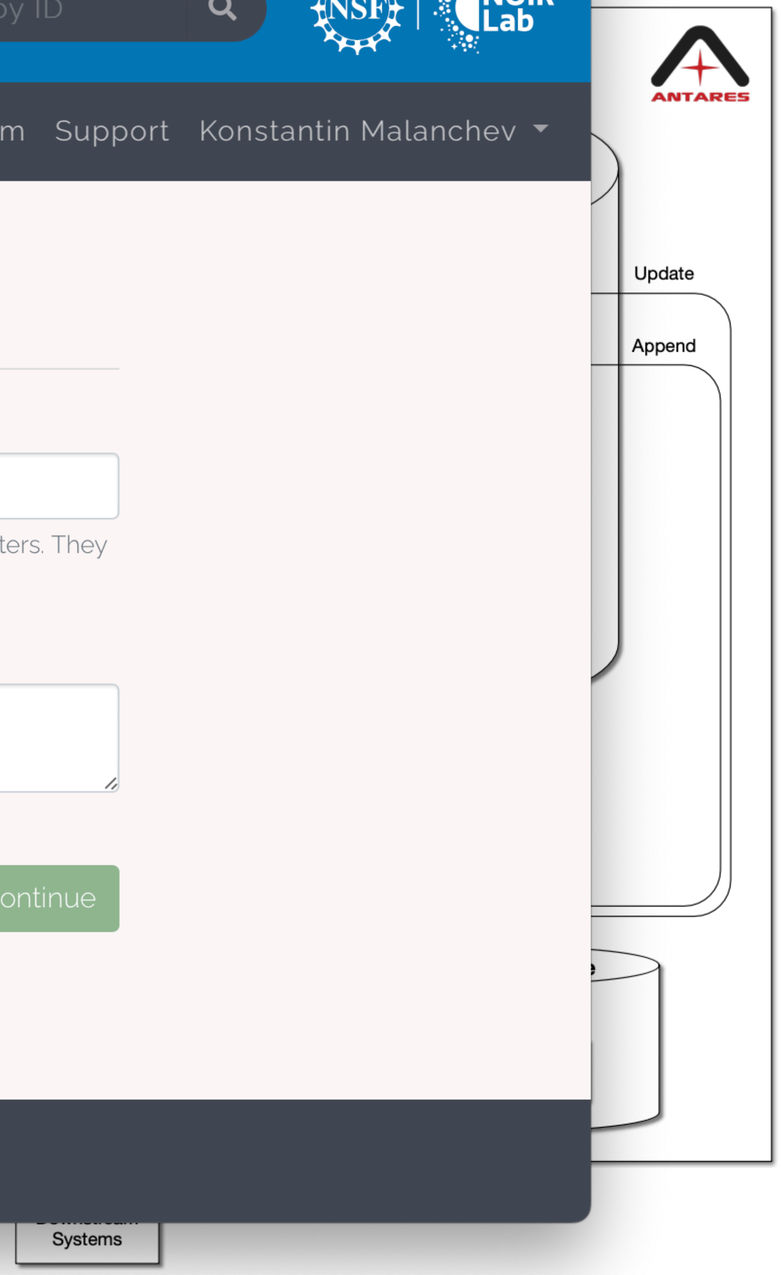
Enter a description for your filter

Enter up to 2048 characters describing this filter.

Cancel | Continue

AURA | HEISING-SIMONS FOUNDATION

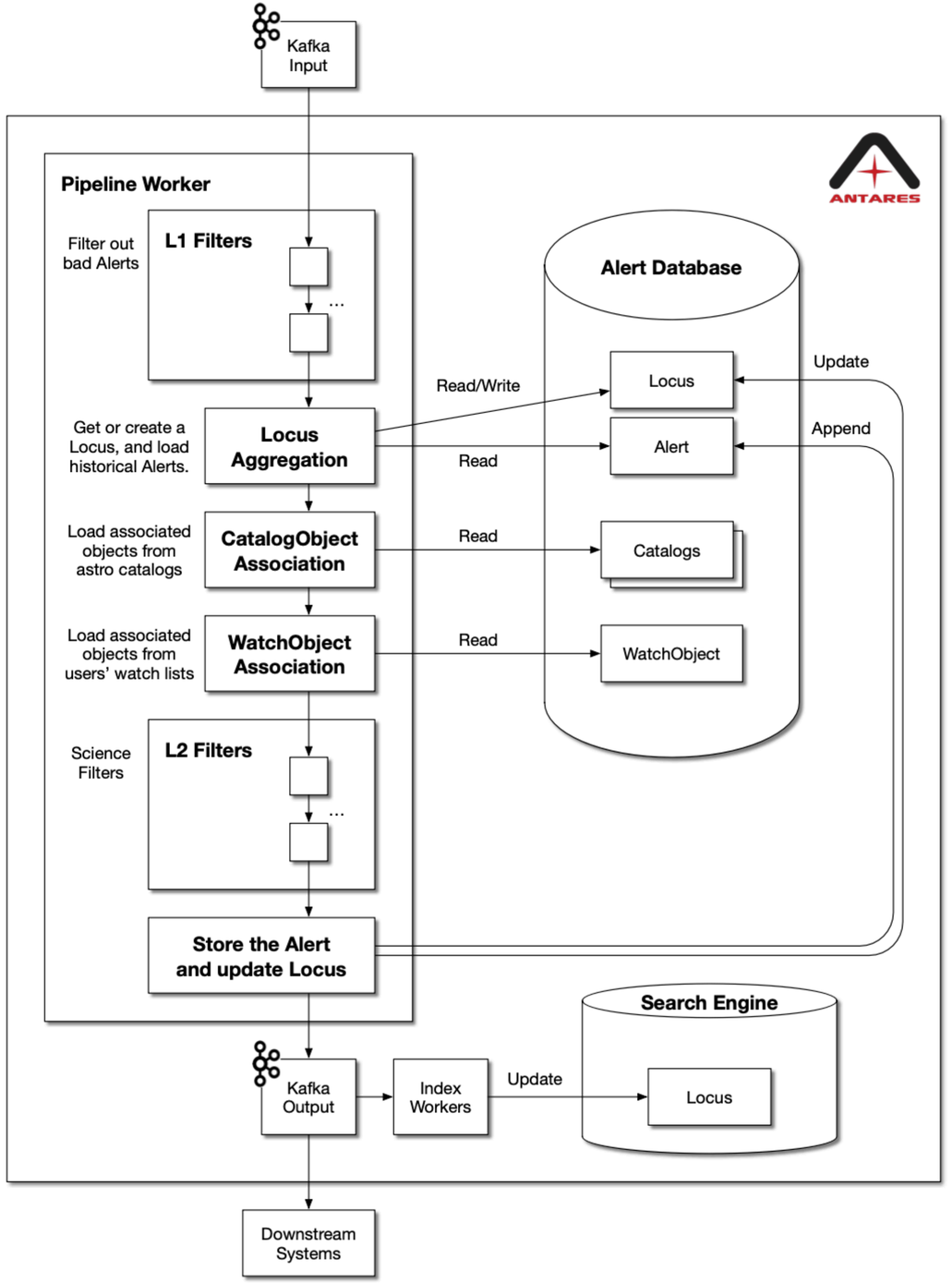
Display a menu



# ANTARES and user filters

## Filters

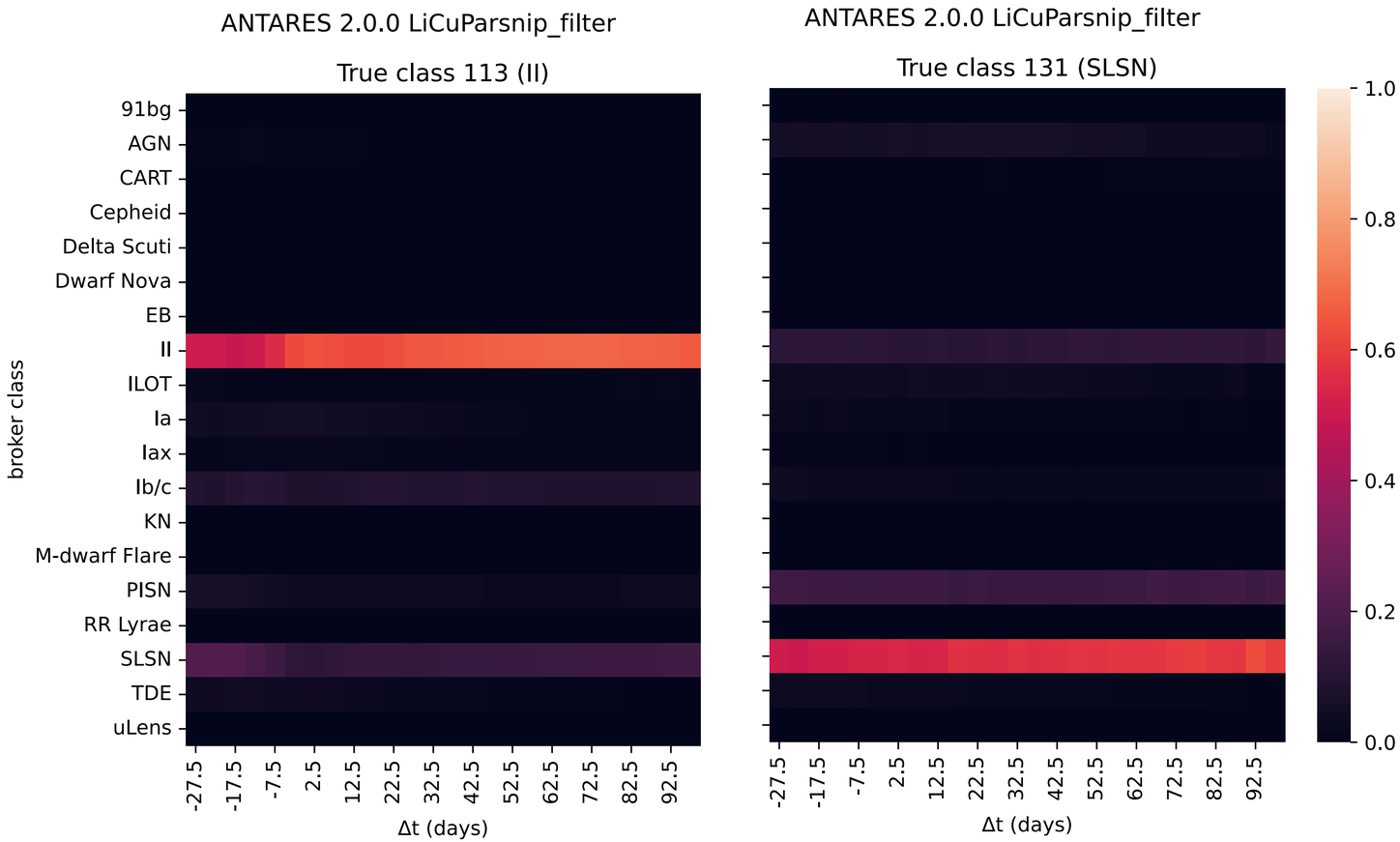
- Easy to develop with NOIRLab Data Lab https://datalab.noirlab.edu/
- Submit and update via ANTARES portal https://antares.noirlab.edu/
- Communicate with the team for the further integration
- LSST simulations, ZTF data wait for your filters!



# Filter example: light-curve classification

## WIP KM

- ParSNIP (Boone21) autoencoder on extragalactic transients
- Light-curve features (KM+22)
- Host separation, photometry and morphology
- XGBoost classifier

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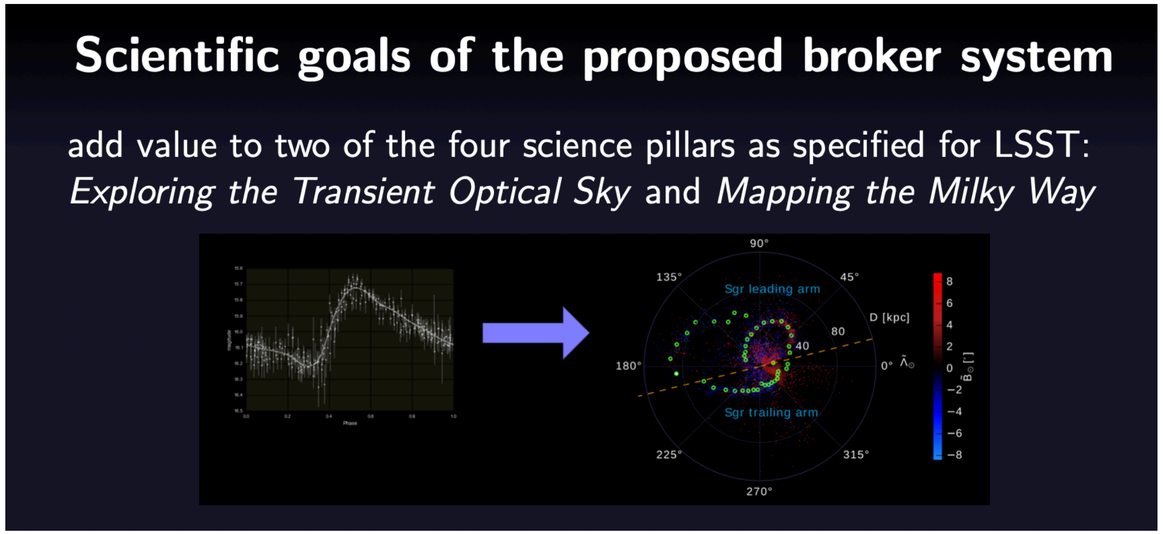
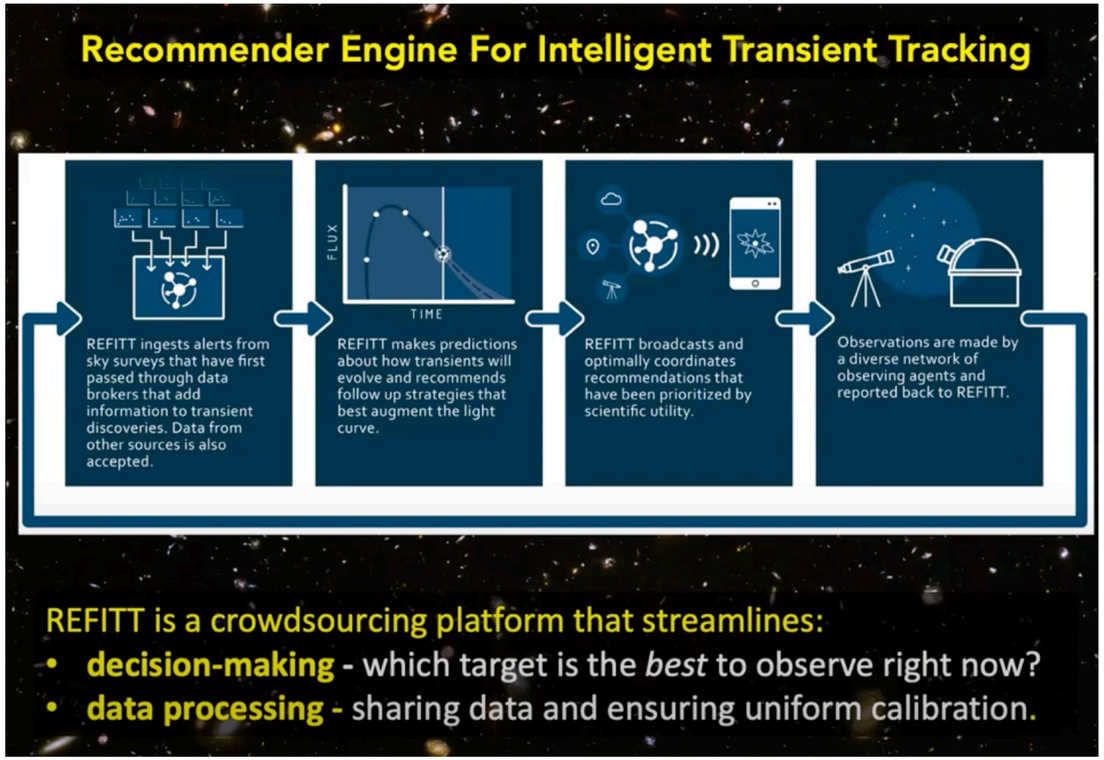
# Downstream systems

- "Point of Interest", PI Nina Hernitschek.




- Recommender Engine For Intelligent Transient Tracking (REFITT), PI Dan Milisavljevic



# Takeaways

- We need efficient strategy and ML algos for KN search
- SCiMMA HOPSKOTCH is present and future of message passing
- ML model deployment target is an alert broker
- Next run of ELAsTiCC is March-June, you can jump into
- Bring your ML to real ZTF, DECam, and future LSST, O5 data
- Contact ANTARES team or me directly kostya@illinois.edu