Arizona-NOAO Temporal Analysis and Response to Events System

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NOAO

ANTARES

What It Is and Why We Need It

- ANTARES is an astronomical time-domain event broker
- A broker is an intermediary that sits between the source of the alerts and the consumers of the alerts while adding value
- LSST will compare each image with a reference and issue an alert for any 5σ change (brightness or position)
- LSST will generate 1-10 million alerts each night for the ten-year duration of the survey
- We need a system to rapidly winnow that number down to something commensurate with follow-up resources
- Rate and volume will be unprecedented

Need for a Broker

- One of the primary recommendations from the 'Spectroscopy in the Era of LSST' workshop (Matheson et al. 2013, astro-ph 1311.2496)
- Also one of the primary recommendations from the NRC report "Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System" (Elmegreen report)
- Expected high-priority recommendation from 'Maximizing Science in the Era of LSST,' recent (May 2016) Kavli-funded workshop

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Computer Science/Astronomy

- LSST problem is one of scale and rate
- Multidisciplinary with computer science
- Collaboration between NOAO and UA Computer Science
- NSF INSPIRE proposal was successful (IIA-1344024)

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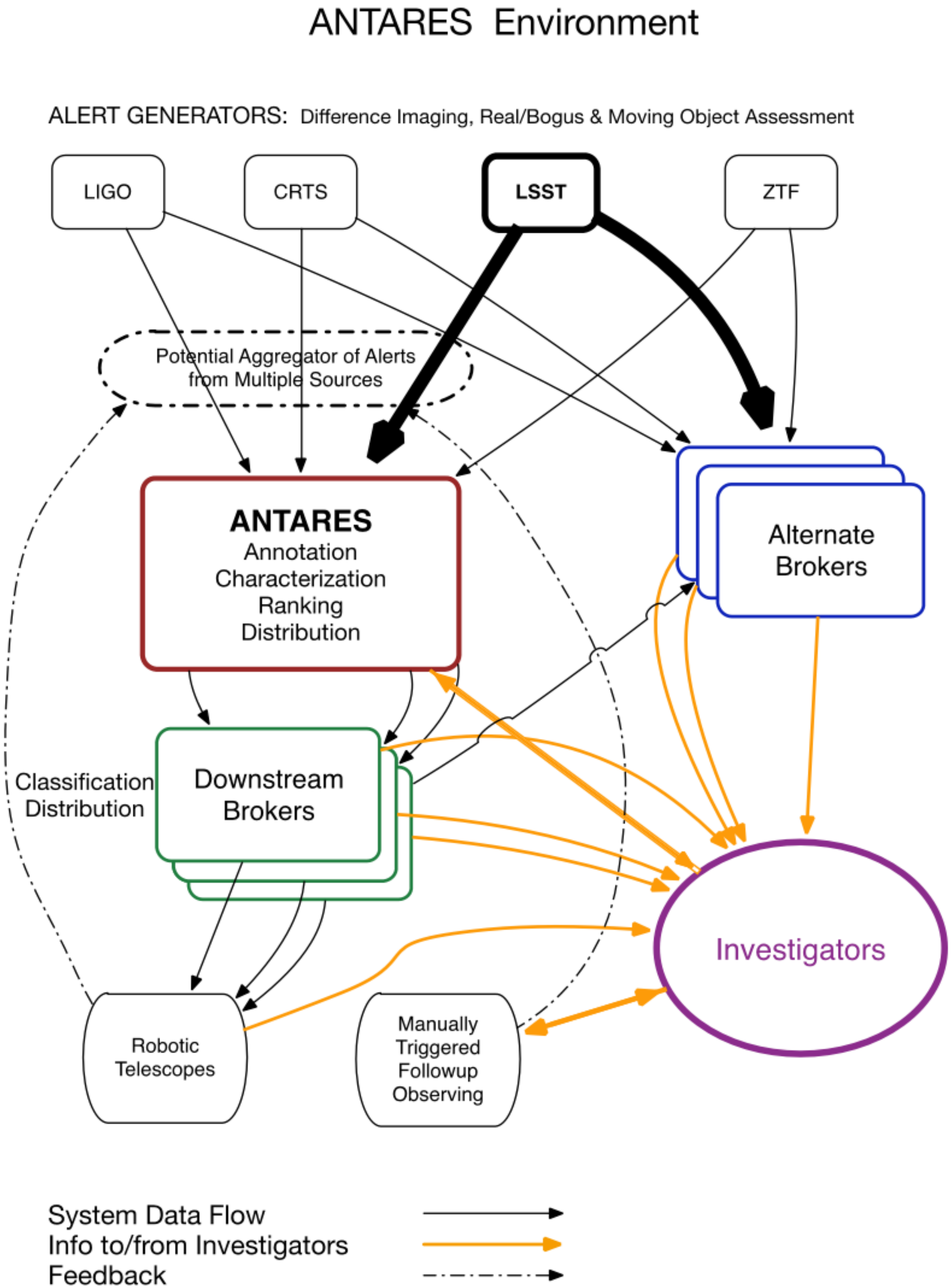
Where we are

- Functional prototype exists
- Expert external review
- Beginning transition from R&D to fully-realized product
- Start on live streams in 2017
- ZTF-scale in 2018
- Will depend on resource availability

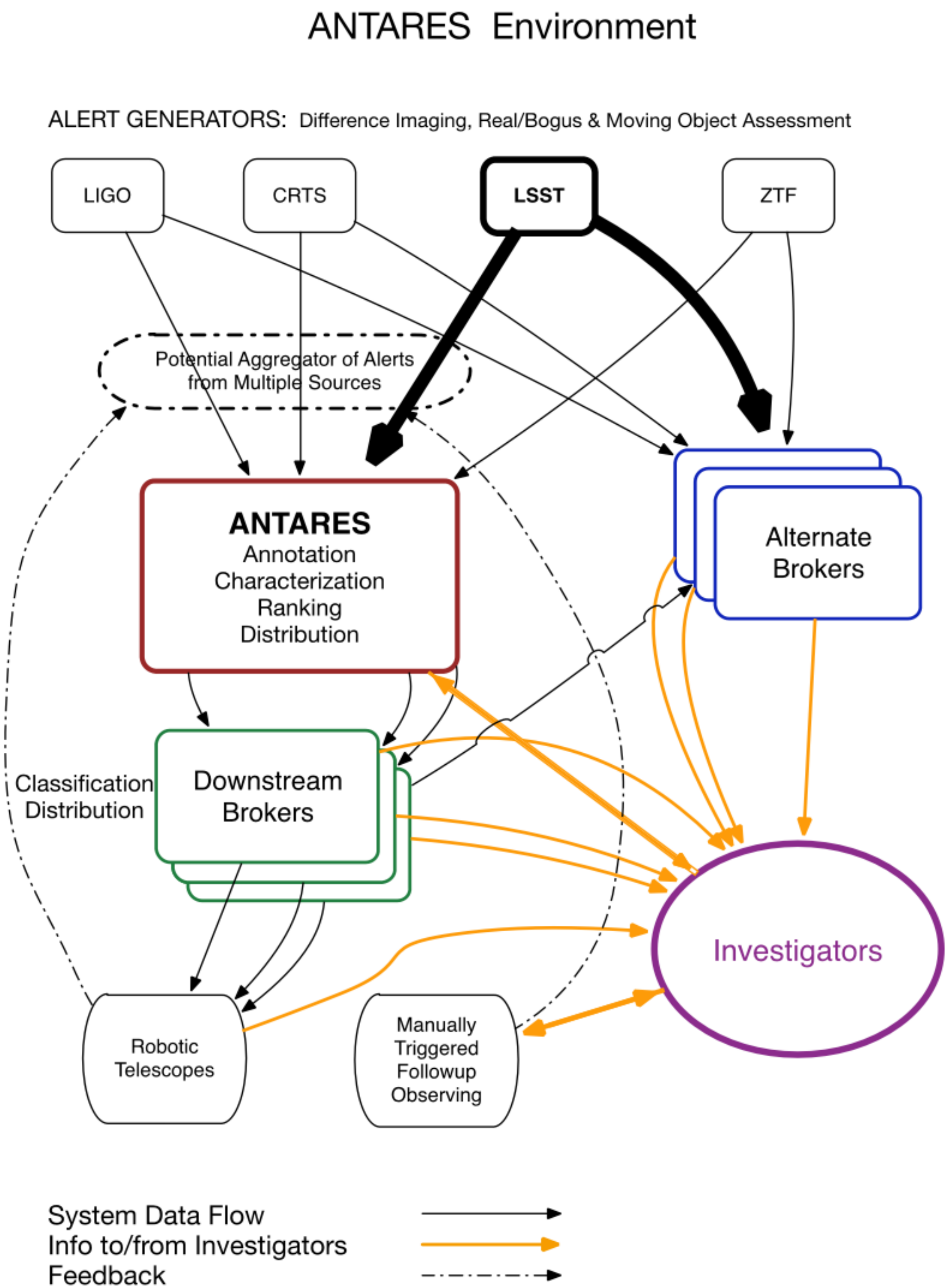


ANTARES and the Time-Domain Ecosystem

What it does, and does not, intend to do

Does Not:

- Perform image differencing
- Identify sources on images
- Assess validity of source
- Identify moving objects
- Coordinate follow up



ANTARES and the Time-Domain Ecosystem

What it does, and does not, intend to do

Does (after receiving alerts):

- Annotates alerts
- Characterizes alerts
- Ranks alerts
- Stores value-added alerts
- Distributes alerts

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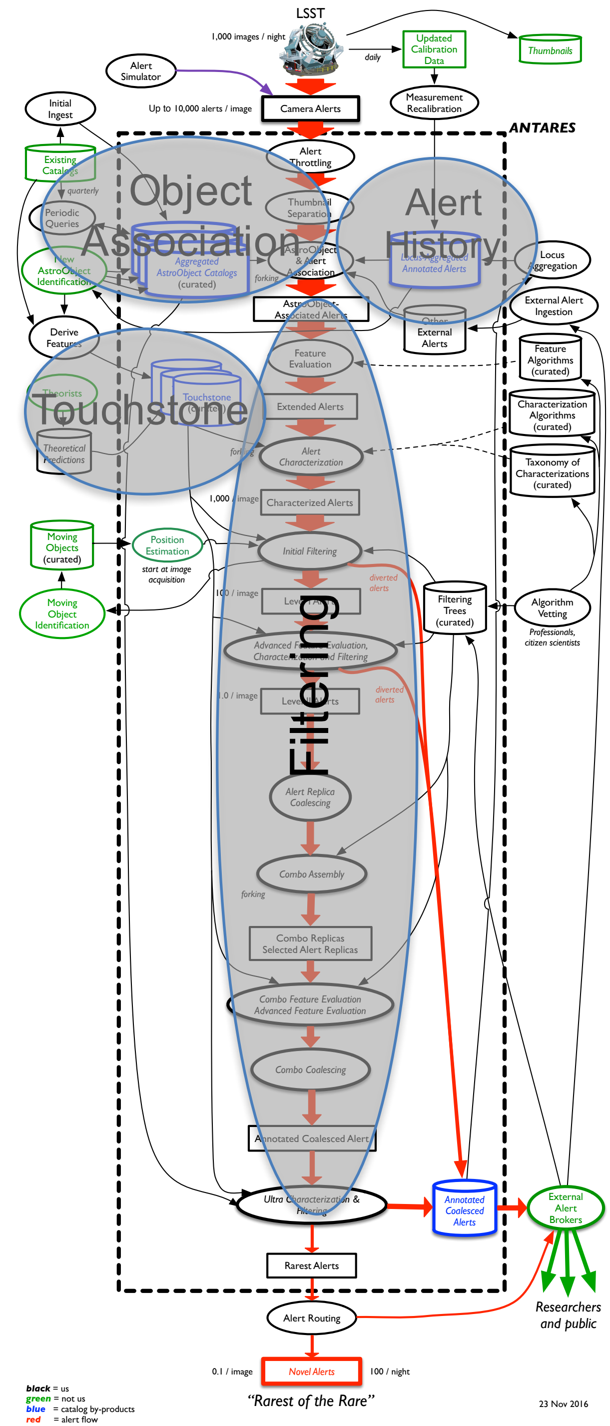
Overall Architecture

- Core flow for alerts
- Draws on local databases for annotation
- Various stages of filtering
- No alerts are lost, just diverted to other channels
- Prototype focuses on ‘rarest of the rare’
- Open source/open access



UC, Tucson, May 2017 (D1)

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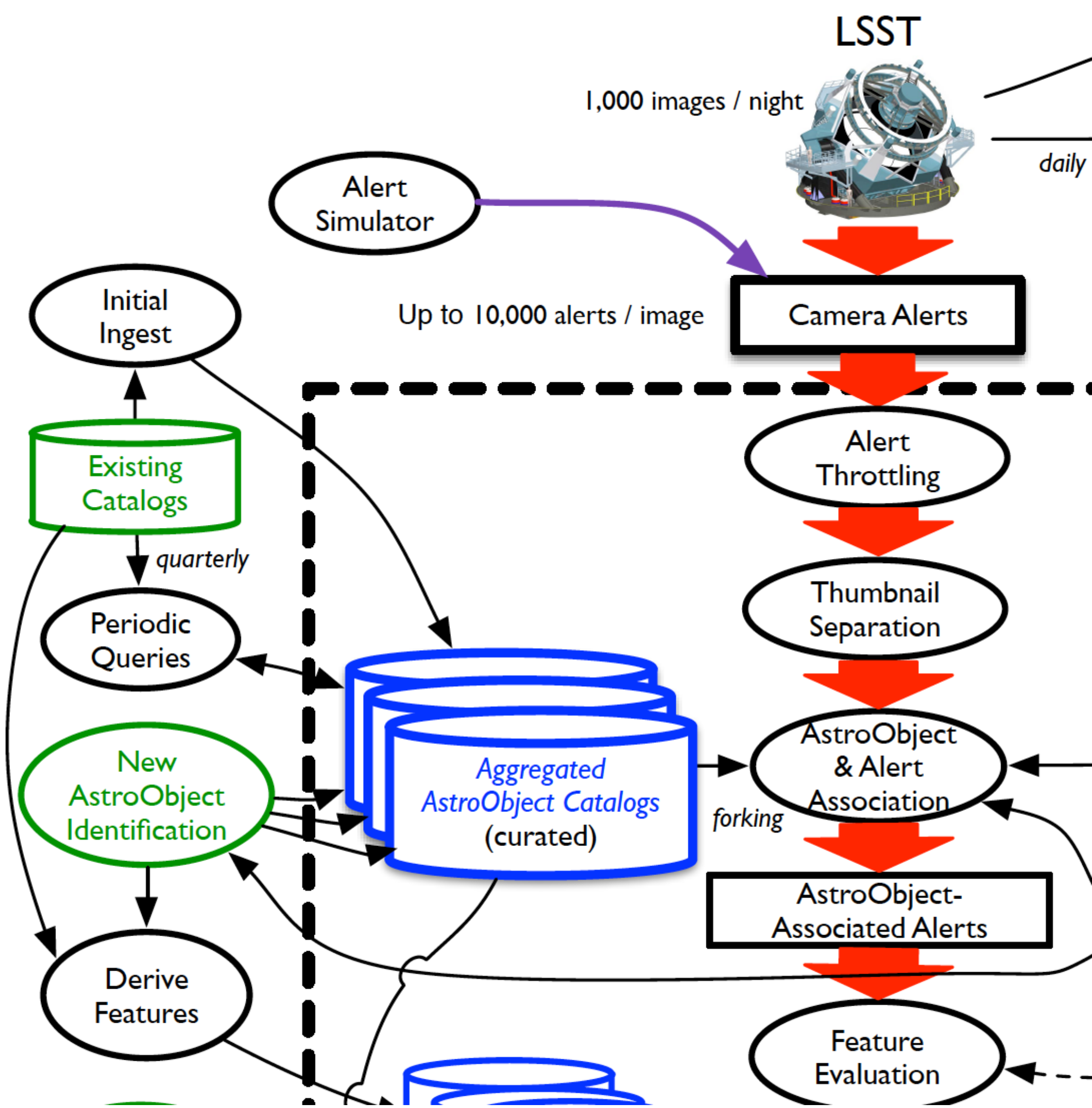
Annotation Architecture

- Added value is critical
- Multiwavelength catalogs including LSST itself
- Past history of alerts
- Other alert sources (e.g., LIGO)
- Theoretical predictions



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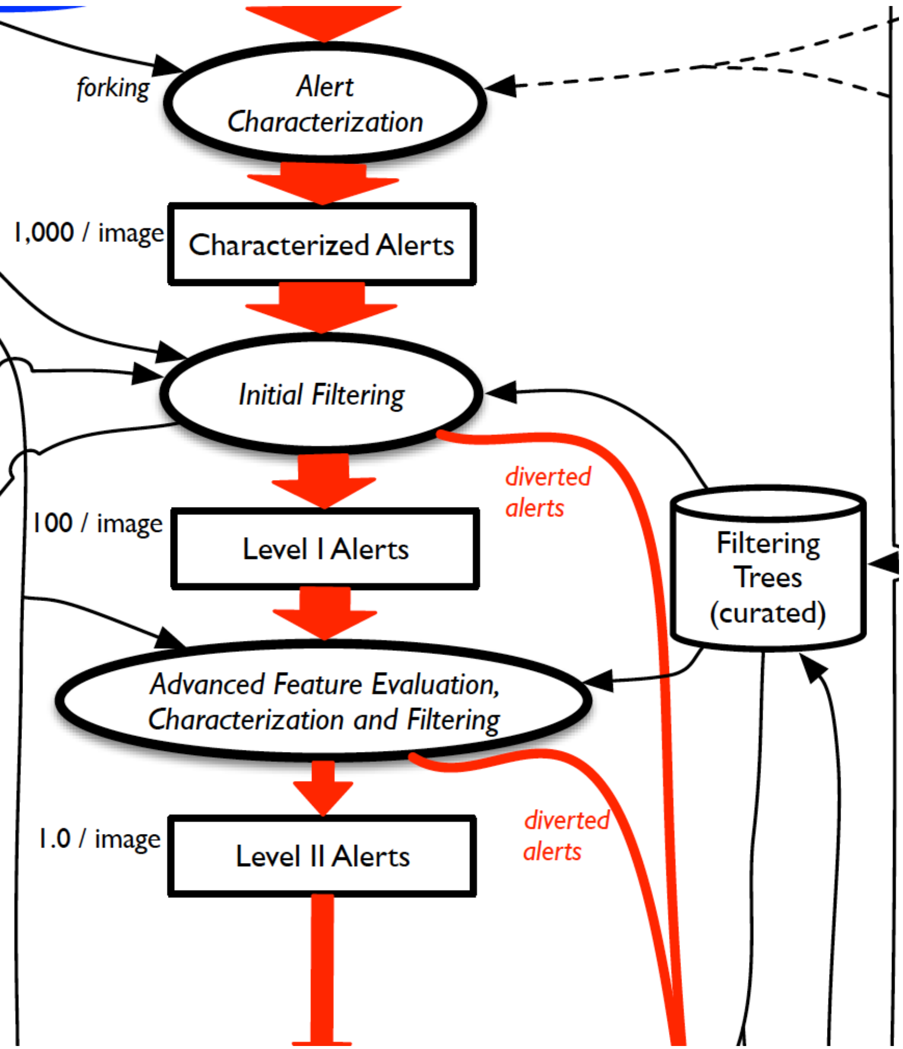
Filtering Architecture



Derive features from alert and annotation data

Use features to characterize (not classify) objects

Alerts can be forked if more than one possibility

Filter based on features/characterizations

As alert numbers drop, more complex processing can occur

ANTARES Filtering Features

- Information from alert itself
- Information from association
- Derived information

Description	Data location[a]	Quantity	Data Type	Why
Data quality information	A/I	x,y on array	float(s)	near edge/bad pixel?
Data quality, cosmic ray	A/I	x,y on array	boolean	If a c.r. is rejected, variance higher
Data quality information	I	Seeing (arcsec)	float	point source or not
Data quality information	I	Point Spread Function	float [0,1]	point source or not
Equatorial Coords. (RA/DEC)	A	Basic coordinates	floats	position on sky, AstroObject assoc.
Galactic (Milky Way) Coords.	D	Galactic lat/long	floats [0,1]	probability of Galactic origin
Ecliptic Coords.	D	Ecliptic lat/long	floats [0,1]	probability of Solar System origin
Measured brightness	A	mag	float	objects will have different potential brightness ranges
Change in brightness	A	Δmag	float	objects will have different potential Δmags
Prior amplitude range	D	min max range/filter	floats	Test deviation from known variation
Time scale	A/L/D	Δt	float	Different phenomena will have different time scaless
Known source (outside LSST)	C	$\mathrm{Flux}_{\mathrm{external\ filter}}$	various[b]	Different phenomena emit over different EM ranges
Nearest object on sky	C	distance in arcsec	various	Different phenomena associate with different objects
If galaxy	C	Type, redshift, pos. in gal.	various	type and distance will guide expected phenomena
If star	C	Type, mag, π	various	type and distance will guide expected phenomena
Periodic	D/C	P	float	sort known periodic phenomena
Fourier components [TBD]	D	First n components	floats	characterize variability
Color	D	$m_x - m_y$	foat	narrow range of possible objects
Light curve	D	mag vs. time	floats	different phenomena have different light curves
Light curves (multiband)	D	$[\mathrm{mag\ vs.\ time}]_{\mathrm{filter}}$	floats	correlate different bands ($\rho_{f_1 f_2}$)
Moving object	M	Prob. moving object, μ, π, PSF shape	floats	eliminate moving objects

[a] (I)mage-level data, (A)lert-level data, (L)ocus-aggregated alert information, (C)atalog information, (D)erived quantity, (M)oving object (from LSST/MOPS)
[b] In this context, various means that the associated object will have a name (string), and various measurements of flux, position, etc. (floats).

ANTARES Progress I

- Databases for object association in place
- Databases for annotation developed
- Can predict Galactic stellar variability
- Demonstration prototype operational
  - Increasingly complex test streams
  - Larger feature sets for comparison
  - Utilizes major stages of architecture
  - Modular components can become more complex
  - Visualization of feature spaces
  - Visualization of processes

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Progress II

- Demonstration prototype functional April 2015, v2 August 2015, v3 December 2015, v4 July 2016, v5 Dec 2016. Demos all week at the NSF booth at the AAS meeting in January, demo at LSST2016
- Community engagement at Hot-Wiring the Transient Universe III, IV, & V, SPIE 2014 & 2016, IAU, Aspen Center, GMT science meeting, LSST project science team, Air Force Research Lab, AAS 225 & 227
- Cluster installed at UA data center, provides realistic test bed
- Second postdoc hired September 1, 2016
- External expert review held December 5-6, 2016
  - Very positive endorsement of the project
  - Panel views current status as meeting the goal of the INSPIRE proposal (i.e., functional prototype)
  - Recognizes resource limitation and recommends augmentation for scaling up

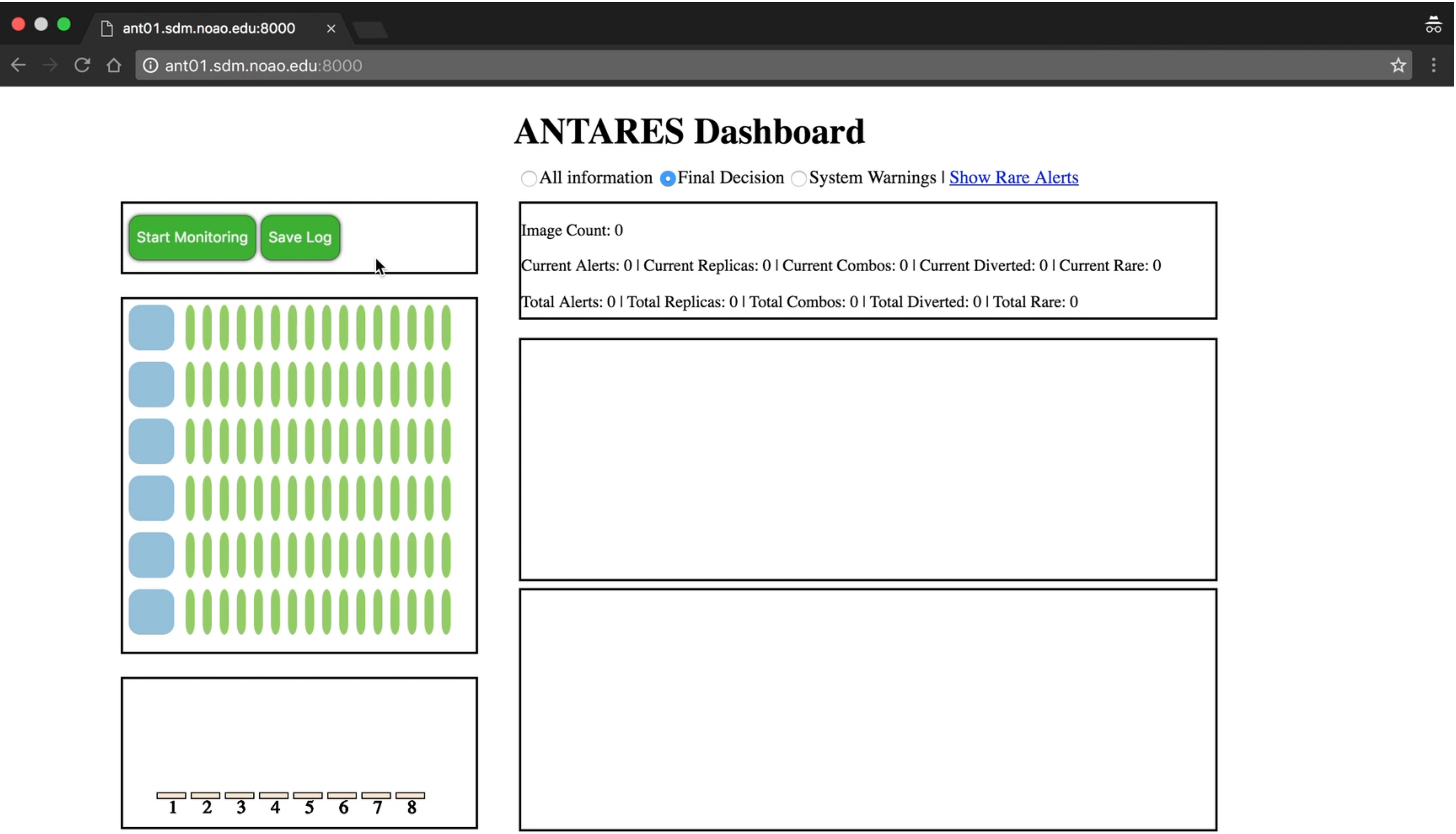
ANTARES: Next Steps

- Fully populate annotation databases
- Expand Touchstone
- Expand Filters
- Programmer/Database Support
- Program management
- Run on live alert streams in 2017
- Workshop for broker development in 2017
- Next proposal will be to make ANTARES generic to handle the full breadth of user interests (2018-?)
- During LSST operations, will likely include NCSA collaboration
  - Operations will require support

Demo

- Full run through of the entire system
- Input alerts are observations of real astrophysical objects (some selected as they are ‘rare’)
- Alert data is separate from Touchstone data
- Real-time cross matching
- Feature derivation and categorization
- Operating on a cluster at UA IT center
- Fault resiliency (Chaos Monkey)

Demo


ant01.sdm.noao.edu:8000
ant01.sdm.noao.edu:8000
ANTARES Dashboard
All information
Final Decision
System Warnings | Show Rare Alerts
Start Monitoring
Save Log
Image Count: 0
Current Alerts: 0 | Current Replicas: 0 | Current Combos: 0 | Current Diverted: 0 | Current Rare: 0
Total Alerts: 0 | Total Replicas: 0 | Total Combos: 0 | Total Diverted: 0 | Total Rare: 0
1 2 3 4 5 6 7 8

Detail Slides

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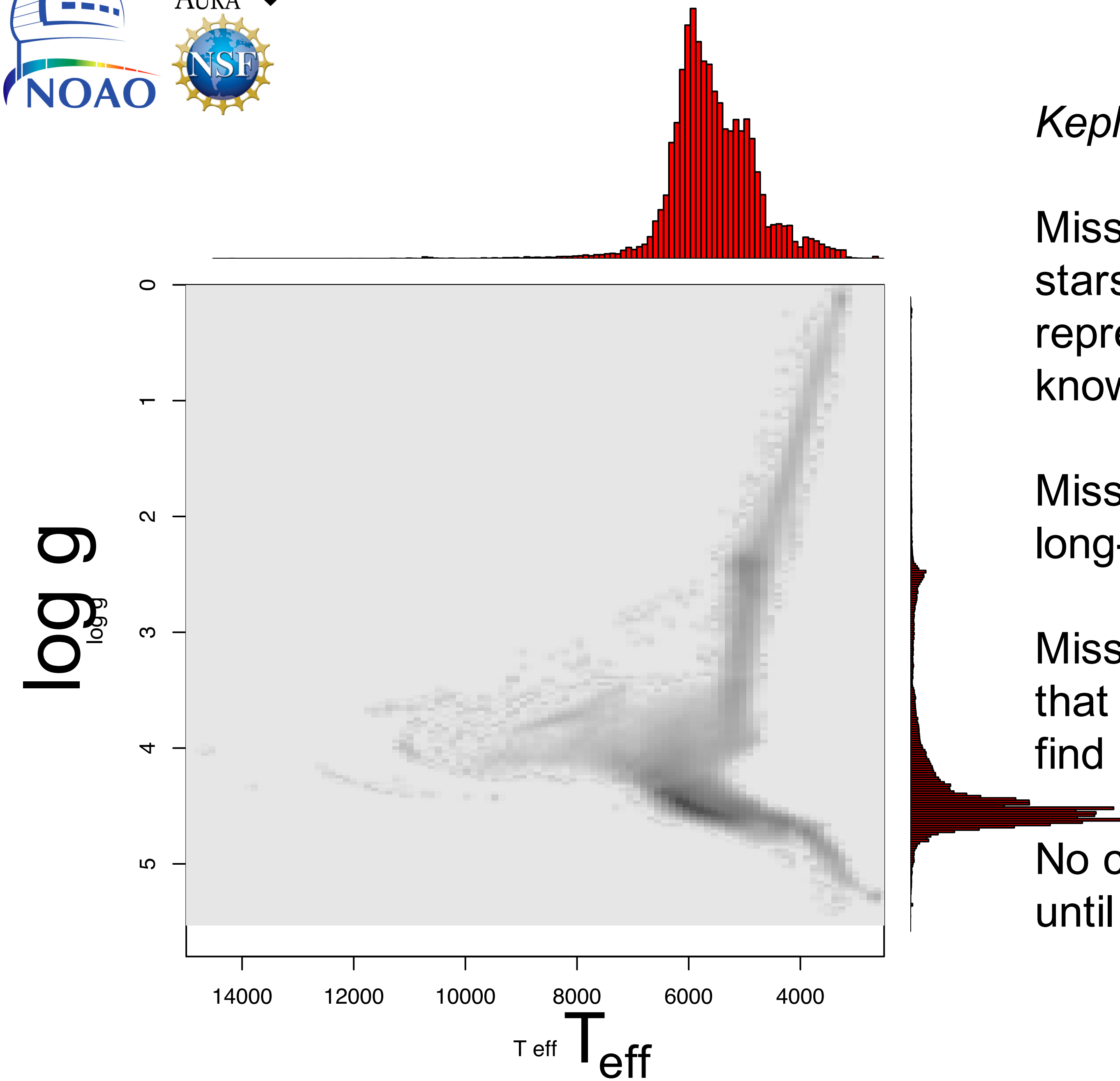
Filter Example

Kepler sample



Misses many classes of stars, but still broadly representative (and we know stellar parameters)

Missing white dwarfs, long-period variables

Missing rare objects, but that is what we want to find

No comparable sample until *GAIA* data release

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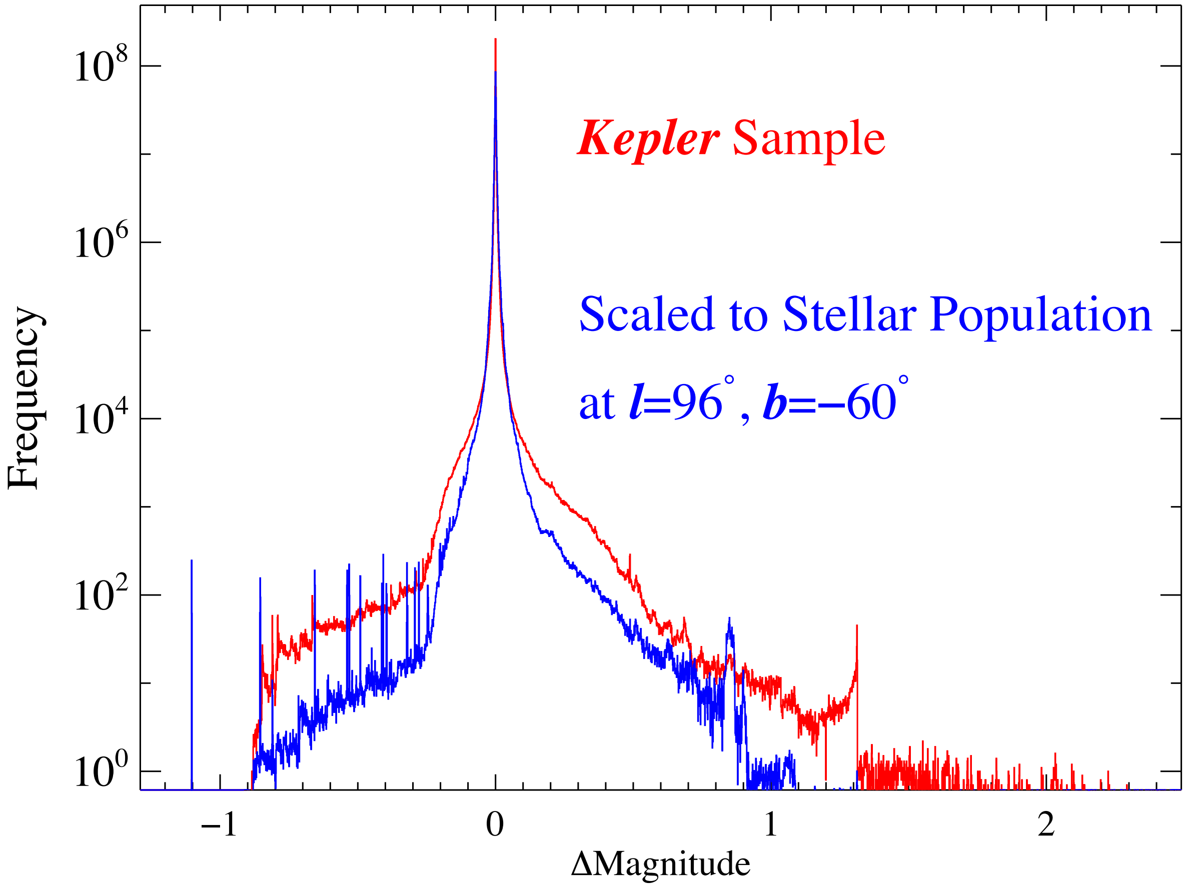
Filter Example



Distribution of variability from Q13 of Kepler (600 million observations)

For any position on the sky, can estimate stellar population and distribution from Besançon Galaxy model

Warp Kepler distribution to stellar content

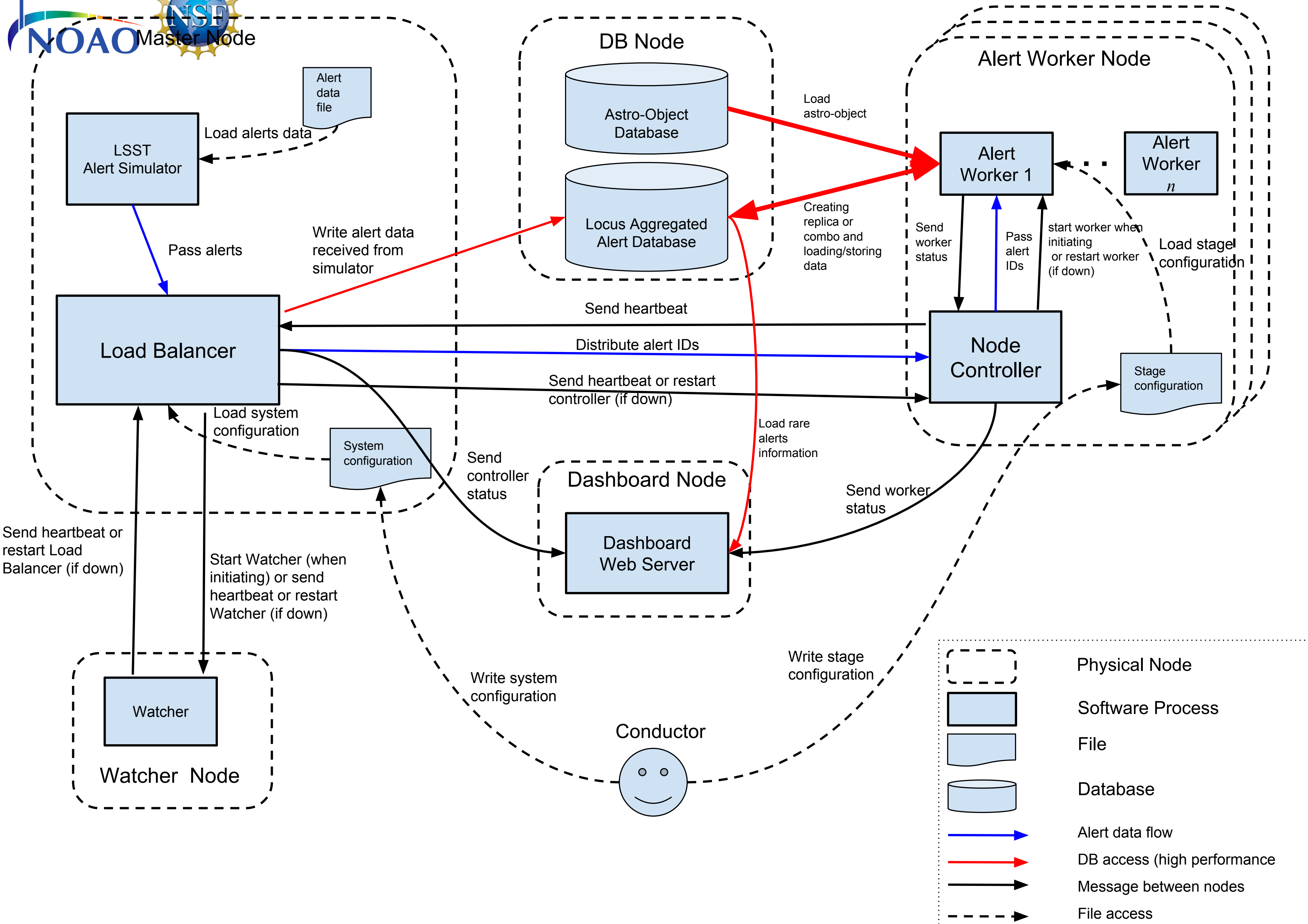
Quantifiable way to say how unusual any given excursion in brightness might be

Only helps with Galactic stellar variables (but these and Solar System objects will be the bulk of alerts)

ANTARES
Personnel

- Tom Matheson (NOAO)
- Abhijit Saha (NOAO)
- Richard Snodgrass (UA Computer Science; PI of NSF proposal; database expert)
- John Kececioglu (UA Computer Science; algorithm expert)
- Carlos Scheidegger (UA Computer Science; data visualization expert)
- Rob Maier (UA Mathematics; Statistics expert)
- Gautham Narayan (NOAO Postdoc)
- Monika Soraisam (NOAO Postdoc)
- Three UA CS grad students

ANTARES Architecture (10/9/2016)



Application Program Interface

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General Alert (`antares.alert.Alert`)

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Enter search terms or a module, class or function name.

Antares Documentation

Welcome to Antares documentation.

API reference¶

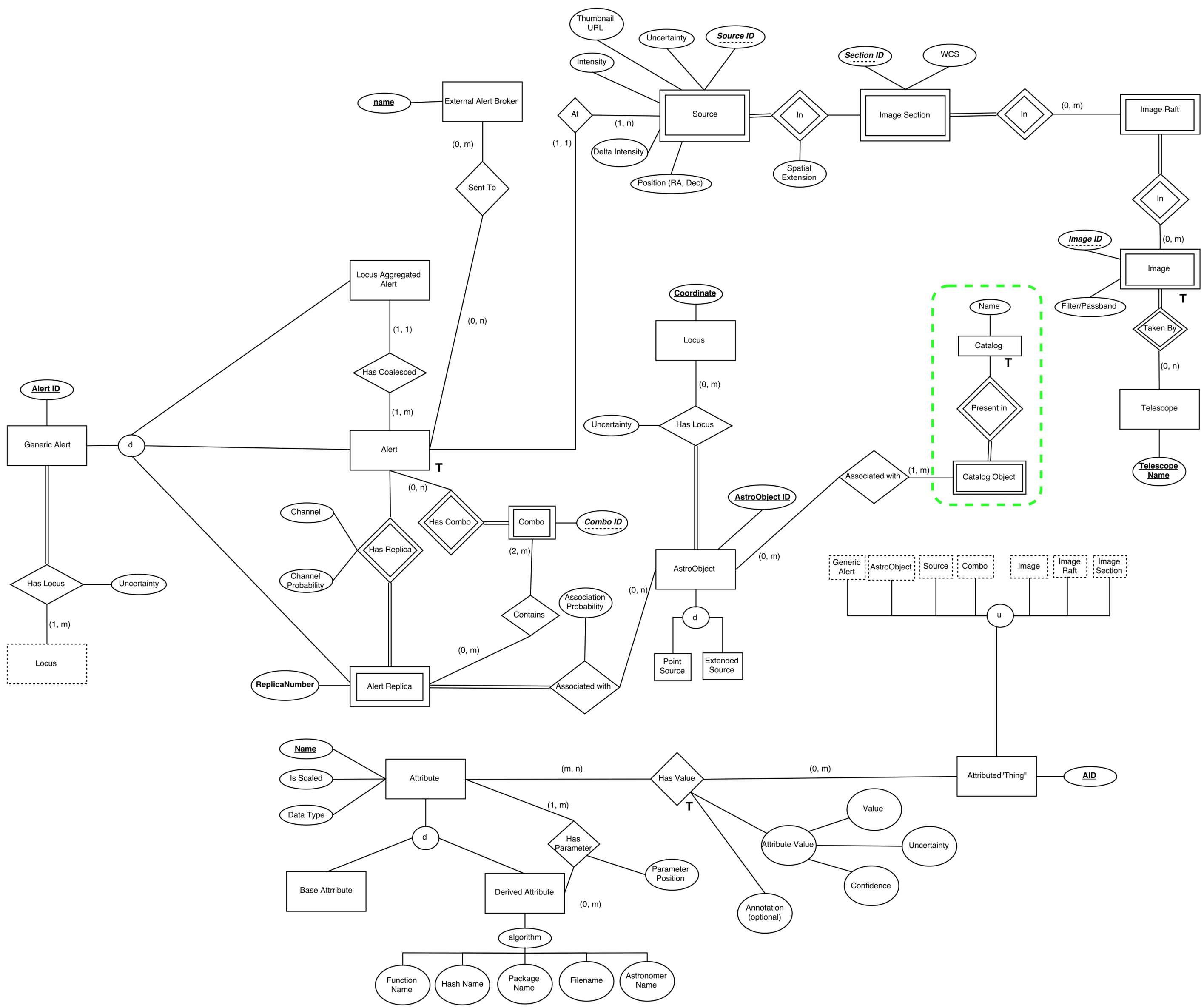
The Arizona-NOAO Temporal Analysis and Response to Events System (*ANTARES*), at its core, analyzes camera alert data generated by the Large Synoptic Survey Telescope (*LSST*) in order to present astronomically interesting phenomena to scientists. Thus, the system determines and filters regular activity from the more interesting data astronomers wish to investigate further. In order to do this, ANTARES allows astronomers to develop code for use in determining the rarity of the observations.

When the LSST completes and transmits an exposure to ANTARES, that exposure is XOR'd with previous exposures of the same segment of the sky; differences between exposures are entered into ANTARES as a set of *Camera Alerts* containing the data from the exposure. Those Camera Alerts (and subsequently generated Alerts as will be discussed) are sent by ANTARES through the code developed by astronomers in *stages* which are run in a distributed system concurrently. These code stages may determine that a Camera Alert is not sufficiently interesting to continue analysis and will then divert the alert, which instructs ANTARES to not continue further processing; Camera Alerts not diverted will proceed to further code stages for further processing. In addition, stages may generate *Alert Replicas*- copies of a given Camera Alert associated with different *Astro Objects* (known astrometric phenomena)- for parallel stage processing (each Replica Alert may be processed separately) or for use in *Combo Alerts*- a type of Alert which allows multiple Alerts to be

https://www.cs.arizona.edu/projects/antares/api_documentation/index.html

Entity-Relationship Diagram

2014-12-15
GN/RS



System Architecture

MySQL Cluster Hardware/Software Architecture for the cluster with 6 machines (11/19/2016)