Coordinating Strategies for LSST Follow-Up

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Following guidance from the NSF, NOAO is developing the LSST Community Science Center (LCSC) to provide support and infrastructure for community science with LSST. The LCSC Working Group (WG) was formed to study the goals, requirements, and aspirations for community science with LSST, and to recommend priorities for the essential functions of the LCSC. This white paper outlines examples of coordination strategies for LSST follow-up (particularly in the area of time domain science) that NOAO (NCOA) should continue to develop in the LSST era. Additional information can be found in the October 2017 NOAO Newsletter (https://www.noao.edu/noao/noaonews/oct17/116news.pdf), "Preparing for Community Science with LSST" on page 11.

One of the primary goals of LSST is the study of the transient sky. Both hardware and software are being optimized to identify changing objects on a variety of timescales and to announce those changes. The standard estimate is that there will be about 10^4 detected (signal-to-noise ratio ≥ 5) changes with every readout and about 10^7 events per night. LSST will release one alert for each detection in a constant, public stream in a yet-to-be-determined format (e.g., VOEvent, Apache Avro), provide one "mini-broker" with basic filtering capabilities, and deliver this stream to at least 4 other independent, user-built alert brokers. The astronomical community will be responsible for all of the analysis and science with these alerts. This includes classification, complex filtering, and the organization of all follow-up observations. In many cases it will not be possible to classify variable or new objects based only on LSST photometry. Other observations, especially spectra, will be required, often on very short timescales after the initial discovery.

The sheer volume of alerts means that existing methods which rely on human review for filtering and responding to alert streams will not be able to keep up with LSST and many interesting targets will be missed. The most efficient use of scarce astronomer and telescope time will be attained if access to all available facilities can be streamlined, especially since many projects will want to take advantage of multiple facilities (aperture sizes and instruments). Therefore, it is imperative that the community develop systems that can handle the volume of LSST alerts and organize the use of the available follow-up resources. This issue and its potential solutions have also been explored in Chapter 9 of the working group document Maximizing Science in the Era of LSST, but we have prepared the following text independently.

There will also be a need to plan efficient strategies for static source follow-up. Spectroscopic characterization and imaging with non-LSST imaging cadences or alternate filter sets will enhance the scientific return for many types of static objects. Large spectroscopic surveys to complement the LSST data set will add further pressure to the community for new policies and data reduction pipelines to optimize the available facilities.

To illustrate one example of a possible strategy for effective follow-up, we outline a new collaboration between NOAO, SOAR Telescope, Gemini Observatory, and the Las Cumbres Observatory that is attempting to coordinate their follow-up resources in order to enable more efficient science as the LSST era approaches, especially regarding time-domain astrophysics. In the following Sections 5.2 - 5.6, we describe the diversity of challenges facing the scientific community regarding source follow-up and propose how the LCSC might play a role in the solutions. In most cases, we propose that the LCSC's main role will be to advocate for community involvement in the solutions as opposed to solving these problems directly (although supporting new tools and web platforms could be part of the solutions). The broader NOAO+LCSC structure should lead the community in developing policies and procedures for the solutions.

Follow-up Organization: a Case Study of a New Collaboration

Many aspects of alert follow-up systems were discussed at the May 2017 workshop on Building the Infrastructure for Time-Domain Alert Science in the LSST Era. Currently a system is being designed by a collaboration between NOAO, SOAR, Gemini Observatory, and Las Cumbres Observatory (LCO). The main components of the network are shown in Figure 1 below.

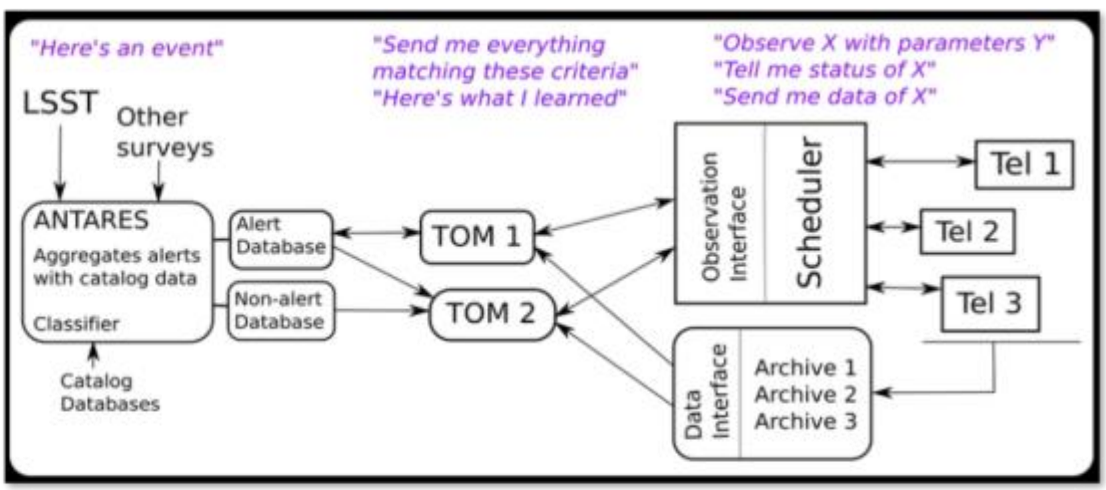

Figure 1: The first component is an alert "broker" or "aggregator" that collects alerts from LSST and other surveys. An example that is under development is the ANTARES system from NOAO and the University of Arizona. Events are classified based on cross-matches with existing catalogs and with photometric properties (colors, brightness changes, and light curves). The characterized events can then be filtered for objects of interest and the results send to new alert streams and databases. (Credit: Rachel Street)

After the alert broker, a science layer is needed so that research teams can match the events of interest from the brokers with telescope resources. These Target Observation

Managers (TOMs, https://www.noao.edu/meetings/lsst-tds/presentations/Street_TOMintro.pdf) present the known information about the objects of interest and aid the science teams with prioritization, managing telescope allocations and observations, collecting and even processing of data, and information access. Several TOMs are already being used by groups studying supernovae, microlensing, AGN, and solar system objects with the LCO network. The AURA/LCO project hopes to develop a simple TOM and a toolkit so that any team can create their own system relatively easily.

Currently the communication of "target-of-opportunity" (ToO) observations that need rapid reaction times ranges from phone calls to observers, web-page lists of targets, and electronic "messages" or observation submissions to observatory systems. The AURA/LCO project aims to develop a set of common interfaces (APIs) for the transmission of observations to telescopes as well as announcements of availability, conditions, and data back from observatories to the network.

The scheduling of observations with a TOM can be done either internally by a given facility or globally over the entire network. Scheduling is complicated by different observing modes ("visitor" or "classical" time versus queue time) and observatory policies for interrupts. Internal scheduling is only concerned with a specific facility. This allows the process to be tuned for a specific observatory and reduces complexity due to external constraints. A global scheduler optimizes the observations over an entire network of potentially heterogeneous facilities. The AURA/LCO project plans to connect first SOAR and then Gemini to a generalized version of the LCO network scheduler. Initial tests will be done on dedicated "ToO network" nights. The goal is that the scheduler will eventually be able to schedule all of Gemini's queue observations, updating it as necessary to accommodate new triggers and changing conditions. Rapid and preferably automated data reduction and archiving is the final part of the system that helps close the loop with the TOMs. Efforts to develop automated reduction pipelines are underway at SOAR and Gemini.

Further references for this new collaborative follow-up system include these slides from the "Building the Infrastructure for Time-Domain Alert Science in the LSST Era" (LSST-TDS) workshop:
LSST-TDS: Workshop Report
LSST-TDS: A LSST Follow-up System (Blum)
LSST-TDS: Community Development (Boroson)

Supporting Observing Modes for Networked Follow-Up

Although the time-sensitive nature of transient source follow-up prompted the demand for TOM systems, we note that TOMs can be a valuable management tool for static source follow-up as well. The efficiency of a global scheduler will benefit large survey programs and/or multiwavelength observing campaigns for static sources, and it will reduce the chance of duplicate observations from multiple facilities.

Joining facilities with different observing styles, policies, and allocation processes into a common network for follow-up observations is a significant challenge. While common communication interfaces (e.g. software APIs) are required and must be documented, this is relatively straightforward. The larger challenge is negotiating the politics and sociology of the different organizations, especially because the envisioned follow-up network will be a new observing paradigm for many observers.

The facilities that will join the AURA/LCO network described in Section 5.1 currently operate in very different ways, and these differences will have to be resolved to move forward. For example, SOAR and the CTIO Blanco 4m time is scheduled to projects in fixed blocks of time. Project teams are then responsible for taking the data themselves. ToOs are handled somewhat ad hoc, often at the discretion of the observers, or via requests to the directors (e.g. the NOAO ToO policies). Compensation to interrupted programs can be hard to accommodate. On the other hand, Gemini and LCO operate mostly or exclusively in queue mode in which observations are executed by the observatories based on science rankings, visibility, and various observing constraints (times, conditions, etc). ToOs are handled naturally since observing plans can be updated quickly and any interrupted observations just return to the queue to be scheduled again. Gemini is mostly queue scheduled but some time is blocked off for "classical" observing, visitor instruments, large science campaigns, and laser guide star observing. Thinking about how the differences for these particular observatories participating in this particular new network leads us to the following suggestions.

First and foremost, ToO policies will need to be clearly explained and documented. The following questions will need to be addressed:

- What are the best practices for ToO observing modes
- What are important requirements for Telescope Observation Managers (TOMs)
- Are there new metrics that must be developed to evaluate surveys (e.g., urgency *vs.* importance in scheduling) and priorities observations

Modifying Time Allocation Policies for ToO Follow-Up

As observatories change their observing modes to meet the future anticipated demand for more streamlined ToO follow-up, a thorough consideration should also be given to whether the time allocation process also needs to be modified. What are the time allocation policies that best meet community needs?

Reducing Redundancy in Follow-Up Observations

Follow-up resources will be limited in the LSST era, unable to cover the total number of scientifically valuable targets, and it is in the astronomical community's best interest to develop policies that reduce (or better, eliminate) targets being observed multiple times. It is conceivable that multiple parties may have similar accepted programs to follow-up sources with a given facility, and request to follow-up the same target. Whether or not the community undertakes a major effort to share such data, individual telescope facilities will likely want to enact policies that define and govern the cases in which requested observations constitute a duplication, and in which scenarios the telescope might refuse to take new observations.

New infrastructure could enable productive cooperation among the user community for astronomers create TOMs in which people can share their follow-up schedules or announce the metadata for completed follow-up observations, and possibly even share their non-proprietary data.

Automated Pipeline Reduction (Closing the Loop)

In time domain astronomy, rapid feedback from observed targets helps to optimize the use of oversubscribed follow-up resources and can enable new science. The overall strategy for coordinating follow-up networks may change with the addition of automated pipeline reductions that close the loop with schedulers. For example, consider a transient with rapidly evolving spectral emission lines but a relatively constant photometric color: the prioritization of such a transient for additional spectroscopic follow-up hinges on the rapid (automated) reduction and analysis of initial follow-up. Automated reduction and analysis would allow for the machine classification of such targets of interest and for the automated submission for further monitoring and/or changes in the instrument configurations. Large follow-up surveys of static sources will also benefit from automated reduction pipelines.