Large Synoptic Survey Telescope

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Exploring the Transient and Variable Universe with LSST

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LSST's real-time image processing pipeline is expected to release tens of thousands of variability alerts per night. Many of these alerts will be associated with previously known classes of Galactic and cosmological variables. However, with LSST's novel combination of areal coverage, photometric depth, and rapid time sampling, new classes of phenomena will be uncovered. To recognize them, we must first characterize the menagerie of known transient and variable phenomena as they will be seen by LSST. We report here on efforts to model the signatures of astrophysical variability using the operational and image simulation tools being developed by LSST. This includes the injection of variable flux, at the pixel level, into simulated LSST images, and the measurement of this signal using the LSST Data Management stack. We also address LSST's potential capability to serve as a localization resource for alerts issued by gravity wave experiments, whose effective beam size is well-matched to LSST's field of view. This opportunity for trans-spectral astrophysics requires interrupt and follow-up capabilities in the LSST scheduler, as well as well-defined conditions to trigger them.

Simulating Variability for LSST

To investigate the end-to-end impact of LSST's observing cadence on its multiple time-domain science goals, and to test the evolving Data Management software, we have begun a directed effort to incorporate time variability into the LSST image simulation effort (see poster by Krughoff et al.). In the simulation infrastructure, an object is represented by its position and spectral energy distribution (SED). For time-variable objects, this requires a time-variable SED. These ***spectro-temporal*** surfaces represent the evolution of the object's spectrum as a function of time. An ideal example of these surfaces comes from models of Type Ia supernovae, an example of which is shown in Figure 1. At each epoch/phase specified by the operations simulator, the instantaneous spectrum is evaluated from this surface and seeds the distribution from which photons are drawn and traced through the simulator. This allows high-fidelity representation of wavelength-dependent effects, such as redshift and color evolution.

To faithfully represent each type of phenomenology included in the simulations, we require the following attributes for the population:

- Spectro-temporal behavior
- Rates
- Luminosity distribution
- Spatial distribution

Such surfaces will also be useful for future efforts in event classification. An evolving event may be compared to an ensemble of surfaces to yield likelihoods the event is drawn from a given surface. An important initiative will be to build an ensemble of these surfaces for all major populations of time variability to enable classification efforts.

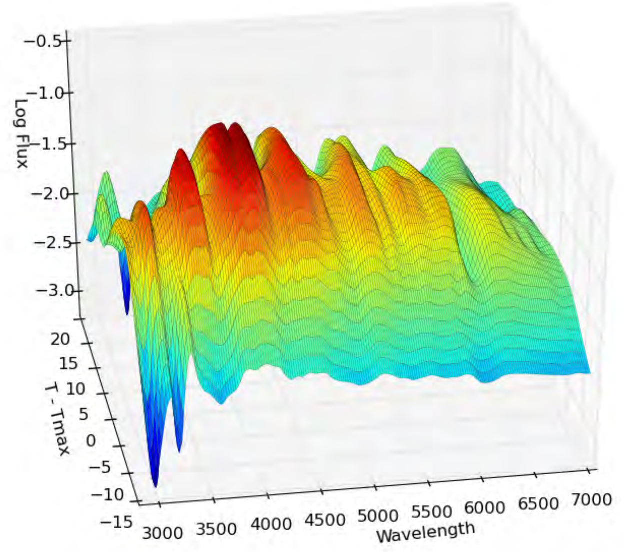


Figure 1: Example spectro-temporal surface, constructed from multiple photometric and spectroscopic observations of Type Ia supernovae (SALT 2; Guy et al., 2007, A&A, 466, 1). Such models are needed for ***all*** types of phenomenology to faithfully represent their time-variability in LSST image simulations, as well as to construct statistical models for event classification.

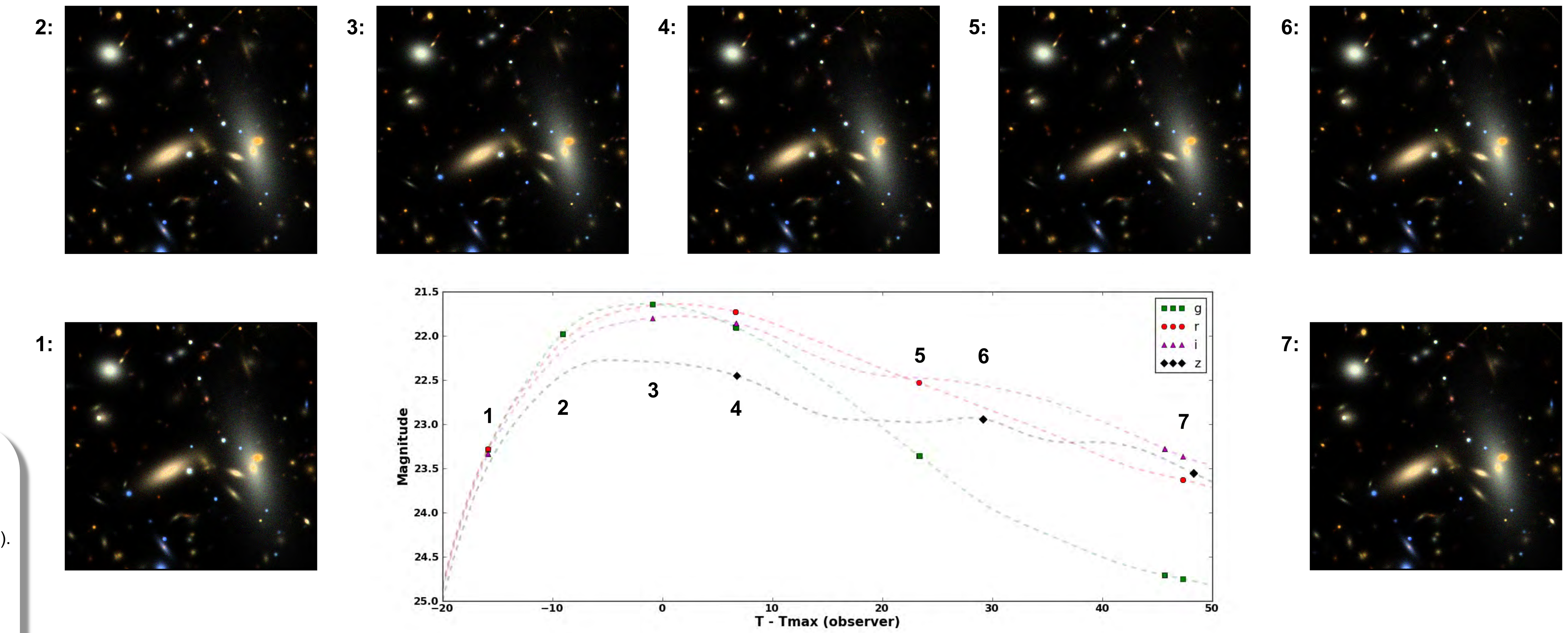


Figure 2: Lightcurve for a Type Ia supernova at z=0.2, generated using the SALT 2 surface in Figure 1, as sampled by the LSST Universal Cadence. Cropped (2' x 2') images have been generated for each epoch of observation, shown here as a g,r,i composite image. The images sample the expected seeing and transparency distribution of LSST at Cerro Pachon. There is no sky noise added to these images, meaning they appear deeper than a typical LSST exposure.

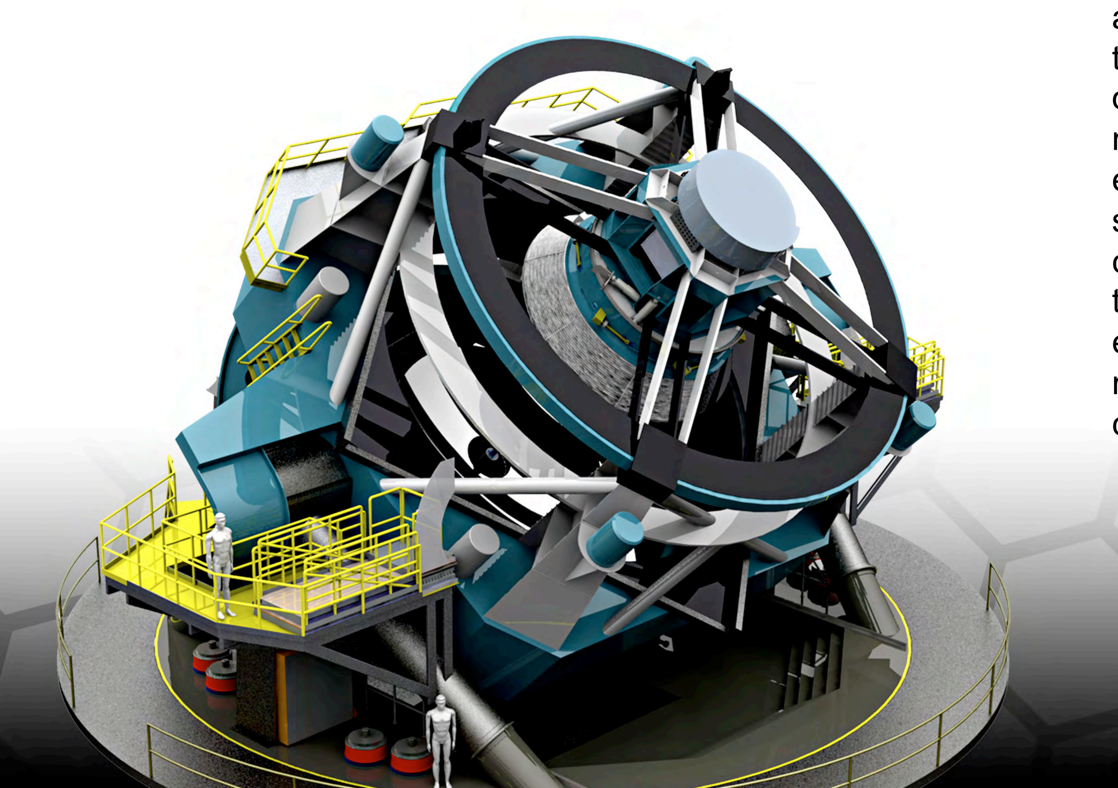
Optical Counterparts to Gravitational Wave Events

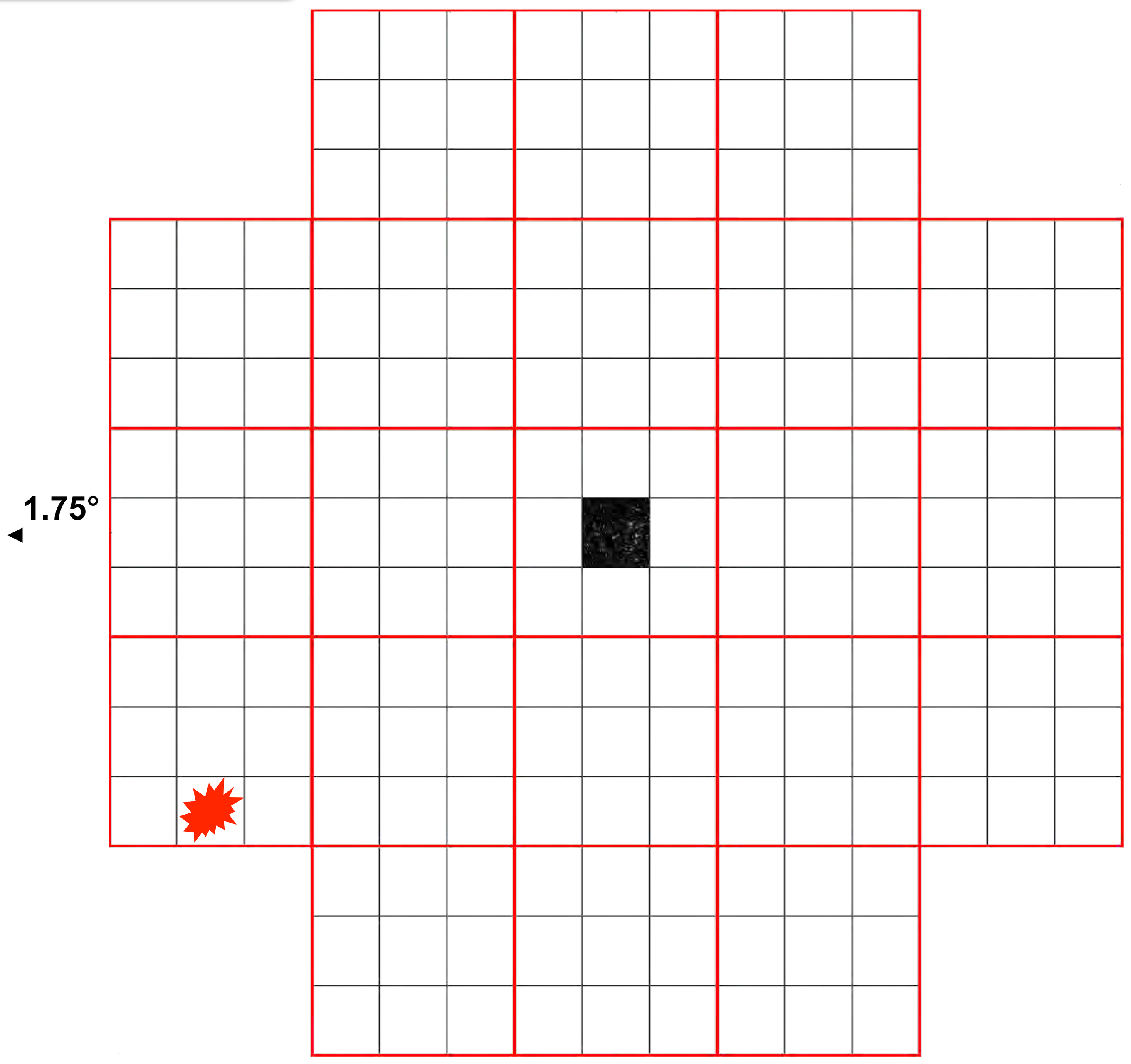
It is widely expected that the coming decade will witness the first direct detection of gravitational waves (GWs). The ground-based LIGO and Virgo detectors are being upgraded to "advanced" sensitivity, and are expected to observe a significant binary merger rate. The launch of the planned LISA antenna will extend the GW window to low frequencies, opening new vistas on dynamical processes involving massive ($M \geq 10^5 M_\odot$) black holes. GW events are likely to be accompanied by electromagnetic (EM) counterparts. Since information carried electromagnetically is complementary to that carried gravitationally, a great deal can be learned about an event and its environment if it becomes possible to measure both forms of radiation in concert. Measurements of this kind will mark the dawn of ***trans-spectral astrophysics***, bridging two distinct spectral bands of information.

The LIGO-Virgo network of antennae is expected to localize high signal-to-noise GW events with an uncertainty of 1.7° degrees over half the sky (Cavalier et al, 2006, Phys Rev D, 74, 8), comparable to LSST's 1.75° radius field of view. However, more common (lower signal-to-noise) events may only be localized to within several tens of square degrees (Fairhurst, 2009, New Journal of Physics, 11, 12), requiring a tiling of the sky for the detection of EM counterparts. The localization of LISA is expected to be far sharper, typically down to 0.3° before merger (Haiman et al., 2008, ASP Conf Series, 399, 20).

LSST is thus a unique resource for rapid, wide-field optical localization of GW events, given an alert trigger. The sharing of a common alert system such as VOEvent (http://voevent.org) should also enable efficient follow-up. However, the scheduler must be designed to respond to such an alert, and to decide on visibility given the airmass profile, moon phase, filters available, and time history of the field center.

The scheduler also needs to be able to recover from this alert, and to resume normal LSST observations immediately. Alerts must be responded to infrequently enough to not disrupt normal scheduling. Due to potential confusion with other "new" transients in the field, multiple epochs of observation with LSST may be needed to verify an EM counterpart to a GW trigger.





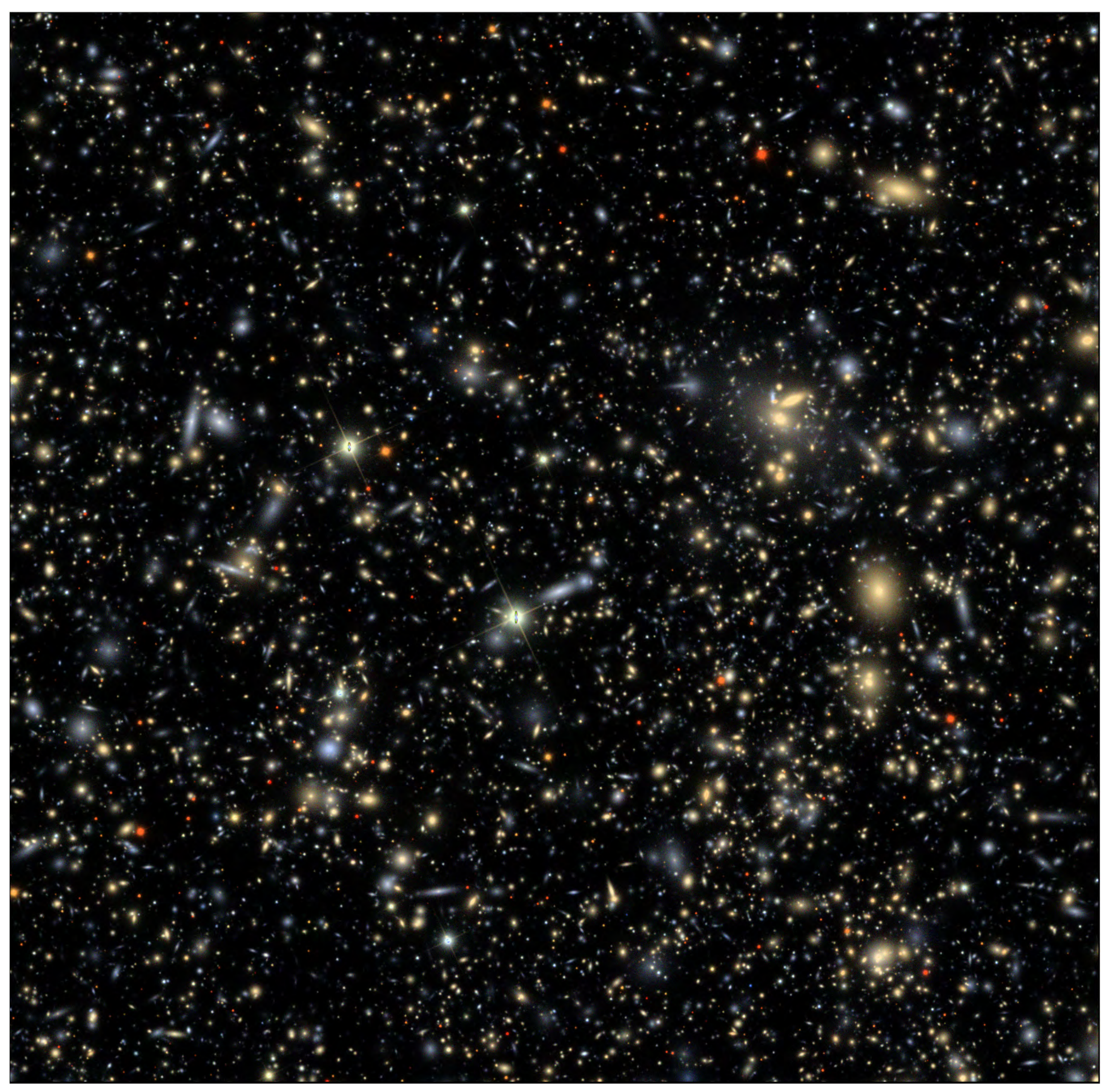


Figure 3: Simulated CCD-sized (13.3' x 13.3') g,r,i composite image, which is only 1/189th of the entire LSST focal plane. The positional uncertainty of LIGO-Virgo GW alerts is commensurate with the LSST field of view, 1.75° in radius, making LSST an optimal localization resource for GW alerts.

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