Snowmass2021 - Letter of Interest

La Silla Schmidt Southern Survey

Thematic Areas: (check all that apply □/■)

□ (CF1) Dark Matter: Particle Like
□ (CF2) Dark Matter: Wavelike
□ (CF3) Dark Matter: Cosmic Probes
■ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
□ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
■ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
□ (CF7) Cosmic Probes of Fundamental Physics
□ (Other) *[Please specify frontier/topical group]*

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Abstract: We are proposing a 5-year public, wide-field, optical survey using an upgraded 20 square degree QUEST Camera on the ESO Schmidt Telescope at the La Silla Observatory in Chile – The La Silla Schmidt Southern Survey (LS4). We will use LBNL fully-depleted CCDs to maximize the sensitivity in the optical up to 1 micron. This survey will complement the *Legacy Survey of Space and Time* (LSST) being conducted at the Vera C. Rubin Observatory in two ways. First, it will provide a higher cadence than the LSST over several thousand square degrees of sky each night, allowing a more accurate characterization of brighter and faster evolving transients to 21^{st} magnitude. Second, it will open up a new phase-space for discovery when coupled with the LSST by probing the sky between 12–16^{th} magnitude – a region where the Rubin Observatory saturates. In addition, a Target of Opportunity (ToO) program will be able to trigger on Multi-Messenger Astronomy (MMA) events with localization uncertainties up to several hundred deg^2 in multiple colors very quickly. This project has direct relevance to several cosmology and fundamental physics efforts including: peculiar velocity measurements, and hence fundamental constraints on general relativity, with supernova as standardized candles; gravitational wave standard sirens as probes of the expansion of the Universe and gravity; measurements of the Hubble constant through Type Ia and II-P supernovae; and probes of dark matter through low surface brightness galaxies and intra-cluster light.

Motivation. Why consider a shallow, optical survey in the south at a time during which it will not only overlap with the Rubin observatory, but also with the BlackGEM and DECam facilities? The answer can be broken down into several themes that form the basis of our proposal. The first notion one has to dispel is that the LSST is the do-all and end-all of surveys for transient cosmology and astrophysics. The design of the Rubin Observatory and the LSST is set to achieve several goals in astrophysics, transient science being just one of them.

- *The cadence of the LSST WFD survey is not optimal for many transients.* While the reach of the LSST Wide-Fast-Deep survey is impressive, **it will leave large gaps in the temporal-color light curves of cosmologically-valuable transients, including spotty early coverage when such transients need to be photometrically-screened as a precursor to spectroscopic follow-up, and gaps in the scientifically-important period around peak magnitude due to saturation.**
- *Not all volumes are created equally.* The follow-up capabilities of most of the world's telescopes can only handle the brighter sources discovered by the Rubin Observatory and there is a large swath of transient science in which a timely spectrum is the only path forward for new science. **Moreover, nearby peculiar velocity measurements are more accurate.** In addition, much of the local universe is inaccessible to the Rubin Observatory due to saturation.
- *One survey is not the path forward for cosmology and transient astrophysics.* What has become increasingly apparent in astronomy is the power of two or more overlapping surveys. **This now forms the backbone of MMA** as well as the desire to initiate collaborations between such surveys as Euclid and WFIRST with the LSST, or the DES and DECaLS imaging surveys paving the way for spectroscopy with DESI.

Science cases. The science goals of LS4 include several probes of cosmology, high energy astrophysics, and fundamental physics, that we describe in this section.
Hubble Constant: Several measurements of the Hubble constant H_0 have recently come into tension, and have reached a 4.4σ discrepancy. Nearby ($z \lesssim 0.1$) distance indicators are mostly sensitive to H_0 and can be used as probes of the expansion of the Universe close to today. For this reason, we design LS4 to be a discovery machine of nearby Supernovae (SNe) that can be used as standard candles, and of optical counterparts to gravitational wave events (GWs), which can be used as standard sirens[1] (StSs). Early follow-up observations by LS4 or other large FoV instruments are paramount to enable timely classification of GW counterpart candidates, and therefore to the use of StSs for cosmological measurements[2]. With the discovery of $\mathcal{O}(50)$ GW counterparts, the StS method will provide constraints competitive with current H_0 measurements from other probes[3,4]. The different measurements of H_0 we propose for LS4 will be sensitive to different sets of systematics, and will help to shed light on the observed tension.
Large scale structure and tests of gravity: Since SNe Ia and GW events are distance indicators, they can also be used to measure the peculiar velocity field of galaxies. A study of this kind will enable precision measurements of the growth of large scale structure and probes of gravity[5–8].
Dark Matter: The survey will make use of the ability of the QUEST2 camera, given the fast optics of the ESO Schmidt telescope and dark skies at La Silla, to carry out a survey of the low-surface brightness objects and features in order to constrain galaxy formation models and the properties of dark matter.
High-energy astrophysical events and unknown transients: We will follow up several multi-messenger astrophysical transients, other than GWs, including: IceCube high-energy (TeV-PeV) neutrinos, Gamma-Ray Bursts (GRBs) and Tidal Disruption Events (TDEs). We will also be able to improve our understanding of the physical processes behind high-energy astrophysical sources, including the first stages of SN explosions, Active Galactic Nuclei and quasar variability, and unexpected short duration transients.

To facilitate the dissemination of new transients discoveries, LS4 will stream its alerts, in near real-time, to all the major transient brokers. Coupled with the Rubin Observatory, the science of both is greatly enhanced. Examples of this include the recent detections of both pre-supernova[9] and post supernova outbursts[10,11], in a variety of both core-collapse and thermonuclear supernovae, likely due to mass loss and interaction. While at distances $< 100\,\mathrm{Mpc}$, such supernovae saturate for weeks with Rubin, LS4 will accurately observe their lightcurves. Prior to explosion and several years post explosion, Rubin will be sensitive to outbursts at $M_V \leq -11$. These measurements have implications for determining the progenitors of SNe, and hence can help the measurements of the cosmological parameters by removing systematic biases.

Survey design. The design of LS4 is set up to provide a unique impact in several areas of time-domain astronomy and cosmology while maximizing the scientific potential of several overlapping surveys (DESI, Rubin, 4MOST, etc.). The base strategy for the program is to have 90% of the time dedicated to a rolling, wide-field, public survey and 10% available for a ToO program. While the exact nature of each will be decided by the LS4 collaboration in advance of each semester (given the LSST schedule, location uncertainties for various MMA triggers, etc.), there are a few things that can be approximately defined now: a survey that can cover several thousand deg^2 per night; use one to four fixed filters from g-band to z-band; detect transients with $12 < \mathrm{mag} < 21$; and generate alerts in near real time to the global community.

In order to maximize the scientific outcomes from overlapping surveys, we will make the raw data, the code to process the data, and the final processed data available to the global community. The data processing pipeline is a modified version of the one developed for the Palomar Transient Factory[12]. The software is actively being used to process the ZTF Uniform Depth Survey since the start of 2020, and a previous version was used for the follow-up of LIGO/Virgo triggers on DECam[13]. The current version allows for the transmission of alerts (via Avro data packets) and the co-addition of the subtractions over days, weeks or months to increase the depth of the survey. The entire pipeline is run at NERSC. It has also been pushed to a Docker container, which allows it to be run on moderately sized clusters as well as AWS. 95% of the data can be processed from shutter closed to the issuing of alerts in <15 minutes.

The camera is located at the prime focus of the ESO Schmidt Telescope, with a curved focal plane. The camera window is a field flattener lens designed to produce a flat focal plane which can be populated by CCD detectors. The upgraded camera will contain 32 LBNL CCDs with Fermilab electronics, each 2K x 4K pixels, each pixel is 15 microns square yielding a 1-arcsec resolution[14]. Since these have a fast readout and are fully depleted, the sensitivity up to 1 micron is excellent and unique in current shallow, wide-field surveys.

An important part of this survey is rapid follow-up of new transients, for classification purposes, as well as a systematic measurement of their host galaxy redshifts. For the former, we have engaged with the Son of X-Shooter (SoXS) collaboration and will be providing them targets to screen during the night. Likewise opportunities are available at the CTIO 1.5-m, CTIO 1.3-m and the CAS 2-m telescope to be installed at the Ventarrones Observatory. For the latter, both the DESI/Transient Working Group and the 4MOST/TiDES projects will target, at least, the host galaxies of the majority of transients we discover.

There are three other surveys in which concurrent observations by LS4 has the potential to broaden and/or enable new science. *ULTRASAT*, scheduled to launch in 2023, is a scientific mini-satellite which will observe in the UV. The FoV of LS4 is is such that it can pave over a single ULTRASAT pointing in two filters in just over 22 minutes each night as part of the main survey. Early UV observations can unlock the explosion mechanisms of SNe Ia, and thus be used to improved the measurements of the cosmological parameters. *eROSITA*, successfully launched in 2019, will image the entire sky in the X-ray for the next 7 years, during which LS4 will operate. The goals of *eROSITA*'s transient program is filled with many of the same objectives as LS4 including: TDEs; AGN physics; GRBs and afterglows. *Euclid's* nominal mission will observe $\sim 1/3$ of the extragalactic sky. Each day, Euclid will cover 10 deg^2 which could easily be shadowed by LS4 to enable combined transient science with exquisite resolution.

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EUCLID: https://sci.esa.int/web/euclid
eROSITA: https://www.mpe.mpg.de/eROSITA