Potential Future Uses of the Rubin Observatory Facility After Completion of the Ten-Year Legacy Survey of Space and Time

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1. Introduction

The Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST) will be a large-aperture, wide-field imaging survey of the entire southern hemisphere in six optical color bands (u, g, r, i, z, y). The Rubin Observatory will make more than 825 visits to every part of the southern sky, where each visit will be roughly 30 s in duration. Single visit limiting magnitudes range from 23.9 in the u-band to 22.1 in the y-band, yielding roughly 3 magnitudes greater depth for coadded images over the full ten years.

The nominal duration of the LSST will be ten years. The science goals and requirements for the technical design assumed this duration, and the construction project is currently on track to achieve them. However, given the very significant investment in Rubin Observatory construction (~ $700M), it makes sense to consider the fate of this world-unique facility after that nominal program has been completed. The purpose of this LOI is to address that question from the viewpoint of the Rubin Observatory/LSST Project Science Team. In connection with the Snowmass process, we concentrate on potential uses of the facility for improved constraints on the nature of dark energy, dark matter, and other cosmological issues.

2. Extended Running with Existing Hardware

The Dark Energy Task Force (DETF) figure of merit (FOM) can be used as a proxy for dark energy capability. The precision for cosmological parameters from an LSST-like survey is a strong function of time, reflecting both decreasing random errors in galaxy photometry and shape measurements, as well as a reduction in various systematic errors due to a combination of multiple cosmological probes (baryon acoustic oscillations, weak lensing correlations, and supernovae). We find that the DETF error product continues to decrease approximately linearly with t^{-1} as a function of time, even in the last two years of the survey. This is driven by weak lensing and BAO signal-to-noise ratios. The errors of the two quantities that enter the DETF FOM as a product each decrease proportionally to $t^{-1/2}$. This is driven by random shear errors, assuming that systematic shear errors can be reduced to an essentially negligible level.

3. Replacement of the Filter Complement

Calibration of photometric redshifts is likely to remain an important source of systematic error for dark energy science, even after ten years. One possible modification to the system could involve a new filter complement to aid in these determinations for the sources that have already been surveyed. Given the cost of the original filters, we estimate that such a replacement will be in the range $5-10M, depending on how many new filters are produced, and whether the existing filter blanks are made available for recoating, or whether new blanks would have to be fabricated. A modified set of wideband filters – shifted by up to half the single filter bandwidth – would produce better SED information on faint galaxies at the same high S/N as the original set. The photo-z degeneracies produced by the existing five inter-filter transitions would be partially broken, resulting in a decreased outlier fraction. Keeping the same detectors, the optimal deployment of the 350-1000 nm high-QE region would be filters interspersed between the ugrizy bands. An example 5 filter set would be shifted filters centered on the 5 transition wavelengths: ug, gr, ri, iz, zy. That full depth survey would take 8 years. However, there are attractive alternatives ranging from one additional filter to several.

4. Replacement of the Camera with a Multi-Object Spectrograph

The etendue of the Rubin optical system is potentially attractive for spectroscopy, but only if the full field is populated with optical fibers at high packing density. The spatial density of objects with $20 < i_{AB} < 23{:}5$ is 14 per square arcminute, or ~ 450,000 per Rubin Observatory field of view. It would be ideal to capture all of these in a single pointing, with a half-million object spectrograph. That would require a tremendous investment in the instrument, with a short data collection period. Taking a rough estimate of $50M/yr for Rubin operating costs and an instrument investment of $500M implies a ten-year spectroscopic survey. This means that each field can be revisited multiple times, adopting 10 pointings as a goal. One could then have ten fiber configurations with which to observe the targets of interest, which in turn implies about 40k optical fibers in the focal plane. With a resolving power ~ 10,000, however, the spectrograph would require ~ 20 Gigapixels, an order of magnitude larger than the LSST camera!

The comparatively short focal length of LSST provides a plate scale that is more compact than is typical on most other large-aperture telescopes. That fact, in conjunction with the strategy of having ~ 10 distinct pointings per field, means that the full-range-of-motion required for the fiber positioner is of order 1mm, about a factor of 5-10 smaller than current practice. As the objects of interest for spectroscopy push to fainter levels, the tolerable fractional error in sky subtraction also becomes more demanding.
Another challenge is the lack of an atmospheric dispersion corrector. Although the distortion of the spectrum due to differential chromatic refraction (DCR) can be ameliorated somewhat using the broadband imaging data, for fiber diameters smaller than the refracted footprint the photons are lost, and the signal-to-noise ratio suffers. Making the fiber large enough to capture the entire DCR-displaced footprint introduces unwanted shot noise from the sky.

5. Other Considerations

We have discussed some options that could be considered for an extended Rubin Observatory mission beyond the ten years of LSST. In all cases, there will be continued operational costs that would remain as a major component of the NSF and DOE annual budgets. If international partners can be recruited, some of the operational costs could potentially be mitigated, although at the expense of added complication.

It should be emphasized that decommissioning Rubin is also not without significant cost. Simply mothballing the facility could present safety hazards, so this would have to be carefully studied. We do not presently have estimates of what it would take to dismantle the facility and return the site to an alternate state, but we expect those costs to be very considerable.

We recognize that the full scientific benefits of any of these plans will be much better understood once Rubin is operating, and we have a more complete understanding of its performance and programmatic characteristics. In addition, we are expecting the nominal LSST program to profoundly affect the scientific landscape over the next ten years, and it is likely that the unexpected discoveries that it will make may drive its future scientific program. This is an uncertain process, but we hope that the comments above are useful for the Snowmass deliberations.