Present and Future
Dark Energy Probes (II)

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Next Generation of Galaxy Surveys

Ground

Rubin Observatory

Space

Euclid

Nancy Roman Space Telescope
Vera C. Rubin Observatory

LSST: Legacy Survey of Space & Time

a Color Movie of the Sky:
an Optical/NIR survey of the entire Southern Sky to a depth
of 27th Magnitude, imaged 825 times in 6 bands over 10 years
Wide, Deep, Fast
Vera C. Rubin

compelling evidence for Dark Matter
Rubin Observatory & LSST Design Optimization

Galaxy Surveys should maximize the product of Etendue = $A\Omega$ and Observing Time

- **Rubin Observatory:** $A\Omega = 340 \, [m^2 \, deg^2]$
- vs. Blanco & Dark Energy Camera ~ 40
- **Rubin Observatory:** Dedicated Telescope & only 1 instrument
- vs. Subaru & HyperSuprimeCam, shared facility
- **Maximize Image Quality and Optical Throughput**
- Cerro Pachon
- Three Mirror Design
- Deep Depletion CCDs
LSST: **Wide, Fast, Deep**

will image the Entire Southern Sky in 6 Bands
LSST: Wide, Fast, Deep
LSST: Wide, Fast, Deep
Figure 0.2: The coadded 5\text{mag} depth for point sources in the \textit{r} band across the sky for simulated survey minion_1016. The red line shows the Ecliptic and the blue line shows the Galactic equator (it bifurcates around the so-called “Galactic confusion zone”). The median value across the WFD area is 27.1, with rms scatter of only 0.04 mag. The small dark dots are deep drilling fields, with a median 5\text{mag} depth of 28.6.

For the 2,293 (overlapping) fields from the WFD area, the median number of visits in the \textit{ugrizy} bands is (62, 88, 199, 201, 180, 180), respectively. Not only that these medians exceed the requested number of visits (design specification from the SRD) of 56, 80, 184, 184, 160, 160 in the \textit{ugrizy} bands, but the minimum number of visits per field over this area does so, too. This result is quite encouraging given that only 85% of observing time was spent on the WFD proposal.

The median coadded 5\text{mag} depth for point sources in the \textit{ugrizy} bands is 25.4, 27.0, 27.1, 26.4, 25.2, 24.4, respectively, for the WFD area. The distribution of coadded depth across the sky is fairly uniform, as illustrated in Figure 0.2.

For the 2,293 fields from the WFD area, the median geometric FWHM for seeing is 0.78 arcsec in the \textit{r} band and 0.77 arcsec in the \textit{i} band. The median airmass in the \textit{urz} bands is 1.25, 1.20 and 1.26 (the maximum allowed airmass for the WFD area was set to 1.5). The median sky brightness in the \textit{ury} bands is 22.0 mag/arcsec$^2$, 21.1 mag/arcsec$^2$, and 17.3 mag/arcsec$^2$, respectively (for comparison, assumed dark sky brightness in the \textit{ury} bands is 5...
Telescope: Large Aperture

8.4m Primary
Optical System & Focal Plane: Field of View

9.6° Field of View
Optical System: Fast system with $F=1.23$

- Three Mirror Paul-Baker
- Fast Optical Design with $F\# 1.23$
  - combined primary-tertiary mirror
  - small optical aberrations over $9.6^\circ$ FOV
  - squat structure for rapid slewing: $\sim5$ sec for $3.5^\circ$ slew
Combined Primary-Tertiary Mirror
LSST Camera
LSST Camera Design Rationale

- Focal Plane 64cm Diameter with 3.5° Field of View
  - Nominal PSF of 0.7"
    - 0.2”/10μm pixel
  - 3.2 Giga-Pixels: 189 4k x 4k CCDs
- Image Entire Available Sky in 3-4 nights
- Pairs of Short Exposures: two 15sec exposures in a visit
  - 2sec readout to minimize deadtime
  - 16 channel CCDs
  - 3 metric tons: light-weight for fast slewing
- 189×16 Channels total
  - electronics in the Cryostat
- Fast Optics F# 1.23
  - Shallow Depth of Focus
  - very flat focal plane
Contributions to Image Quality

- Point Spread Function from Camera < 0.3”
- largest contribution is diffusion in CCD ≈ 0.2”
- focal plane needs to be flat to within ±11 μm
Optical throughput close to maximum possible given:
- CCD Quantum Efficiency from 100μm thick Si
- AR coatings on 3 Refractive elements
- Interference Filter band-passes

<table>
<thead>
<tr>
<th>Waveband</th>
<th>5 sigma point source detection per visit</th>
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<tbody>
<tr>
<td>u</td>
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<tr>
<td>g</td>
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Rubin Observatory Construction
Rubin Observatory Telescope Mount
LSST Camera Focal Plane
LSST Camera Charged Coupled Devices

Figure 1: Optical micrograph of the output device chain on the ITL STA3800 device. This shows the serial chain with the 45 degree bend of the pre-scan pixels, the single-stage output transistor, and the reset gate.

Lage (2019)

Burke (2006)
A Question:

What has been the biggest challenge in building the LSST Camera?

- CCDs (A)
- Lenses (B)
- Limited Space Constraints (C)
- Fasteners (ie. Screws & Bolts) (D)
- All of the Above (E)

Respond at PollEv.com/aaronroodman286
Text AARONROODMAN286 to 22333 once to join, then A, B, C, D, or E
LSST Predicted Cosmology Constraints

Figure H2: The forecast dark energy constraints at Y1 (top left) and Y10 (top right; bottom) from each probe individually and the joint forecast including Stage III priors. For consistency, the same axes are used on the Y1 and the top Y10 plot, while the bottom Y10 plot is zoomed in further. Note that the supernova contours appear to be tilted clockwise with respect to typical forecasts shown in the literature, because most papers include a Stage III prior when generating the contour for SN. 68% confidence intervals are shown in all cases; the plotted quantities $w_0$ and $w_a$ are the difference between $w_0$ and $w_a$ and their fiducial values of -1 and 0. The contours in this figure for individual probes do not include Stage III priors, so they should only be compared with the individual probe FoM values in Table 6.1 that have no Stage III prior included.
Dark Energy Spectroscopic Instrument

Five target classes:
- **35 million** redshifts
  (SDSS x20)

**2.4 million QSOs**
- Lyα $z > 2.1$
- **Tracers** $1.0 < z < 2.1$

**17 million ELGs**
- $0.6 < z < 1.6$

**6 million LRGs**
- $0.4 < z < 1.0$

**10 million**
- **Brightest galaxies**
  $0.0 < z < 0.4$

DESI (2020-2025)

Palanque-Delabrouille for DESI Collab.
DESI Instrument at Kitt Peak
DESI First Light Spectra
DESI Hubble Diagram

$H(z)/(1+z)$ [km s$^{-1}$/Mpc]

DESI (2016)
Vera Rubin Observatory Schedule

- LSST Camera scheduled for shipment to Chile in 2021
- First light with a Commissioning Camera (9 CCDs) 2021
- Camera Installed on the Telescope 2021-2
- Start of 10 year LSST survey in 2022-3