Vera C. Rubin Observatory
Systems Engineering

Investigation of the Scratched Tape Scattered Light Artifact at Rubin Observatory

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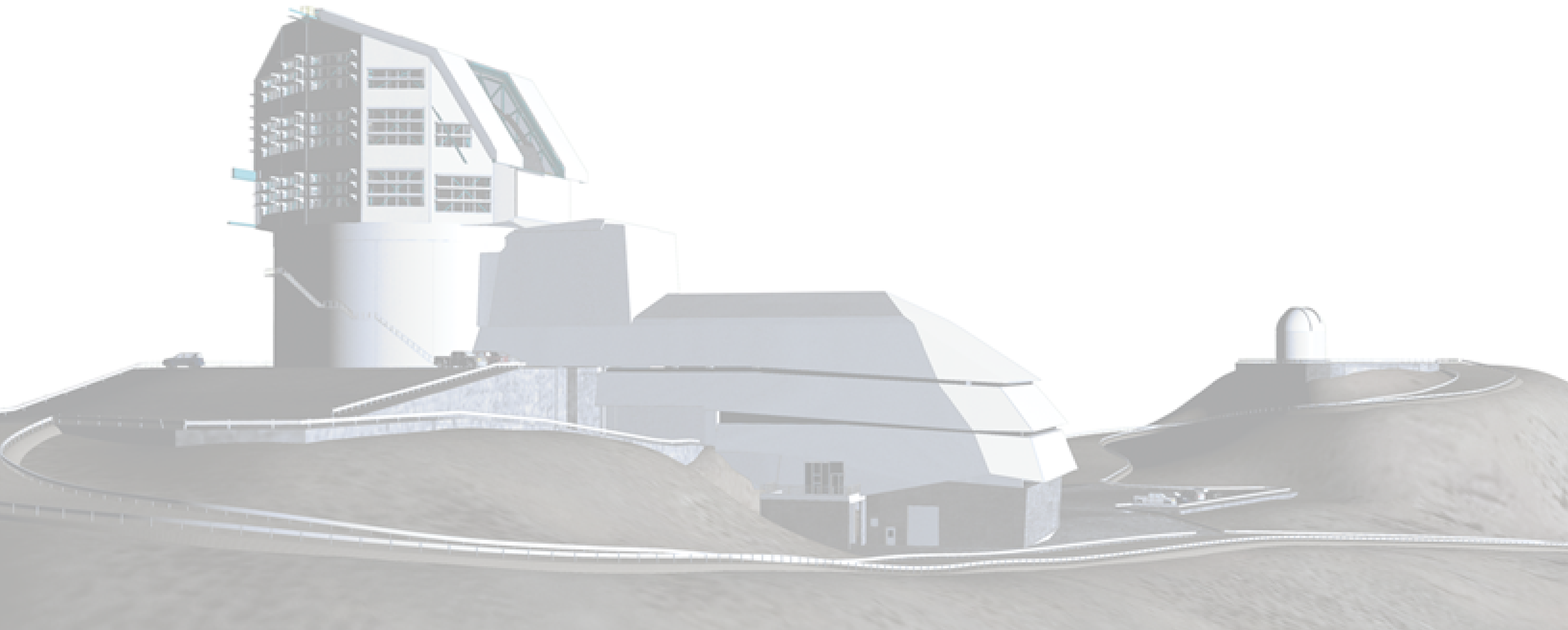

Abstract

The "scratched tape" stray light feature is the most prominent and prevalent stray light artifact identified during the commissioning of the Vera C. Rubin Observatory. This feature originates when light from large off-axis angles (∼20 deg) passes between the mid-level and center-section light baffles of the Simonyi Survey Telescope, reflects off of the primary mirror, and illuminates the LSST Camera. This scenario represented an unobstructed light path to the sky during Rubin commissioning that arose due to delays in the integration of the dome slit light–wind screen. Once identified and characterized, the scratched tape light path was successfully mitigated by extending the mid-level light baffle outward by ∼22 cm. This document describes the identification, modeling, characterization, and mitigation of the scratched tape stray light artifact.

Change Record

Version	Date	Description	Owner name
1	2026-04-28	Update after mitigation.	Alex Drlica-Wagner
1	2025-09-18	Draft for release.	Alex Drlica-Wagner
1	2025-08-07	Initial content.	Alex Drlica-Wagner
1	2025-07-09	Initial template.	Lee Kelvin

Document source location: `https://github.com/lsst-sitcom/sitcomtn-166`

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1 Introduction

The unique, wide-field design of the Simonyi Survey Telescope at the Vera C. Rubin Observatory makes it particularly susceptible to stray and scattered light. Since one of the primary goals of Rubin is to investigate the low-surface-brightness Universe (Ivezić et al., 2019), it is particularly important to identify, model, and mitigate stray-light artifacts. In particular, the delayed installation of the Rubin dome slit light–wind screen (LWS; Marchiori et al., 2024) has led to a large number of unanticipated stray light features that were identified during Rubin commissioning (Rodeghiero et al., SITCOMTN-160). In this note, we focus specifically on efforts related to the “scratched tape” stray light feature (Figure 1), which is the most prominent and prevalent stray light artifact identified during Rubin commissioning. We describe the discovery, origin, characterization, and successful mitigation of this stray light artifact.

The scratched tape artifact is a wide-area stray light feature that is present in at least 5% of images collected by the LSST Camera (LSSTCam) during the first year of on-sky commissioning and early operations. As described in Section 3, the scratched tape was found to originate from an unobstructed light path to the sky that passes between the center-section and mid-level light baffles on the Telescope Mount Assembly (TMA) of the Simonyi Survey Telescope (Thomas et al., 2022). The LWS is expected to block this path to the sky once it is installed and operating. However, the partially completed state of the Rubin dome during commissioning, science validation, and early operations makes it possible for astronomical sources located $\sim$20 deg off-axis to illuminate the primary mirror (M1) and reflect directly into LSSTCam (i.e., bypassing M2 and M3). The result is a sharp, several-degree-long, rectilinear feature with surface brightness that has been measured to be $\sim$20% of the dark-sky background for some bright sources (Figure 1). The scratched tape feature manifests in a variety of morphologies, brightnesses, and prominences, and several morphologically similar artifacts (e.g., the “pillow”, “muddy shoe”, etc.; Rodeghiero et al. SITCOMTN-160) are suspected to be connected to this same light path. In this document, we collectively use the term “scratched tape” to refer to all features that arise from the same off-axis stray light path. Figure 1 shows two common morphologies of the scratched tape feature sourced by light from the bright star Alpha Centauri (αCen; $V \sim -0.1$ mag) located $\sim$21 deg off-axis.

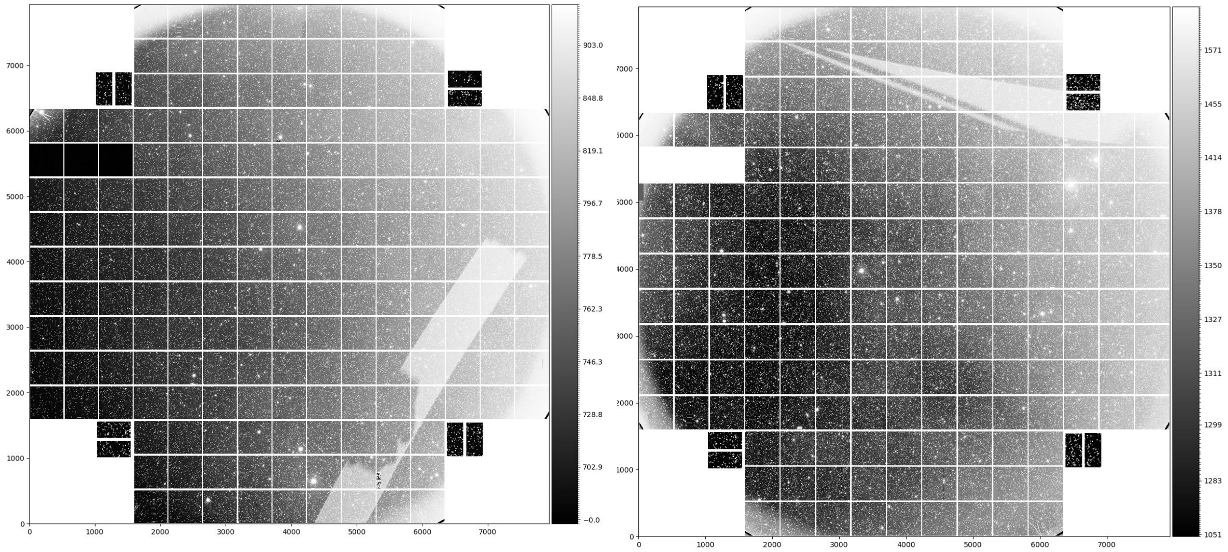

Figure 1: Examples of stray light features associated with the “scratched tape” stray light path in LSSTCam images from Rubin commissioning. These examples originate from the bright star αCen ($V \sim -0.1$ mag), which is located ~21 deg off-axis and illuminates the primary mirror (M1) through a gap between the mid-level and center-section light baffles. (Left) Prototypical “scratched tape” morphology (visit = 2025050500421). (Right) Prototypical “sail” morphology coming from a similar light path (visit = 2025051900402). The difference in morphology comes from physical obscurations on the TMA.

2 Identification of the Scratched Tape

The scratched tape artifact was identified in early commissioning images from LSSTCam (the first documented instance was on 17 April 2025). The origin of this feature was initially unclear, although it was found to consistently impact observations of specific commissioning fields (i.e., SV_225_-40). A visual inspection campaign was mounted to catalog and characterize the appearance of this and other stray-light features (see Rodeghiero et al. SITCOMTN-160). By correlating the appearance of the scratched tape with the locations of bright stars, it was determined that some of the brightest instances of the scratched tape appeared in observations taken when the bright star αCen ($V \sim -0.1$ mag) was located ~21 deg off-axis. Based on this analysis, observations were executed to reproduce the scratched-tape feature on 28 May 2025. While the ability to reproduce the feature strongly indicated that αCen was the light source, the large off-axis light path responsible for this feature was still unclear.

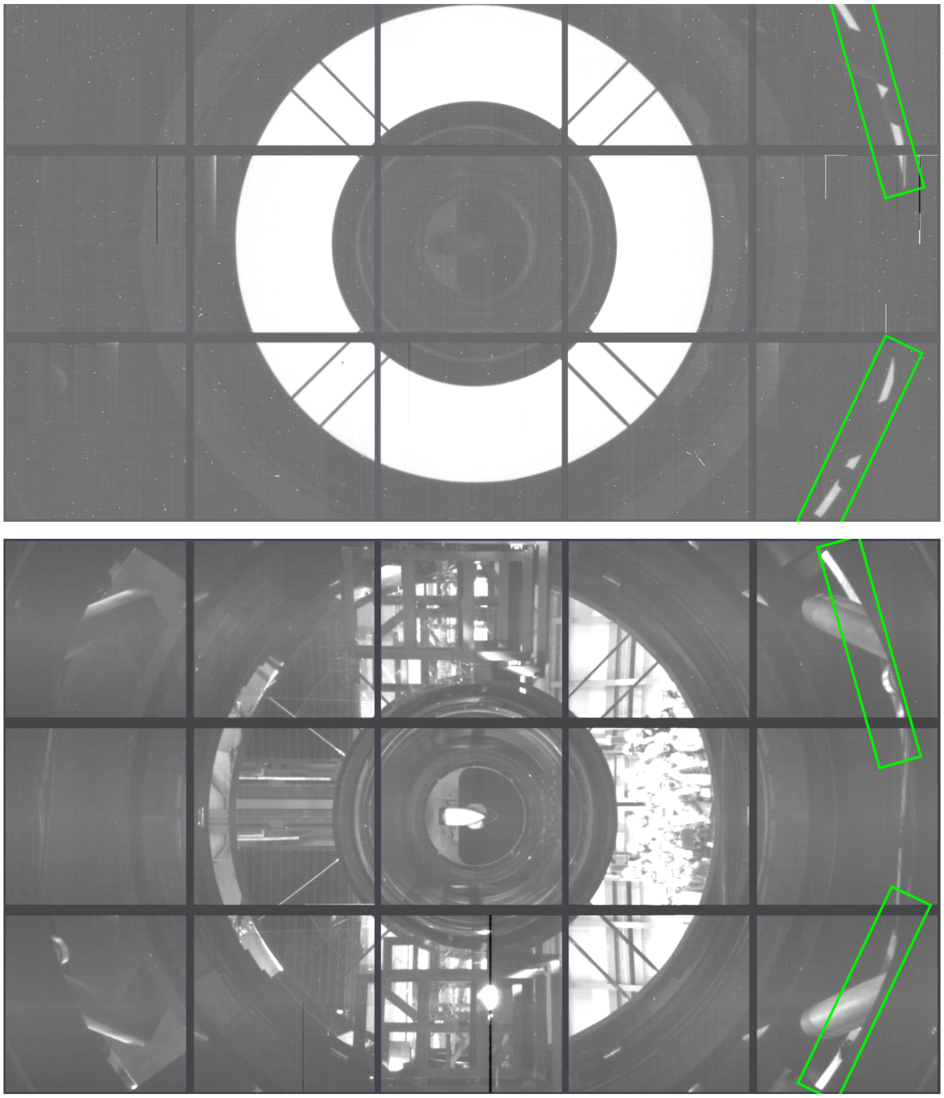

Figure 2: Images taken with the pinhole filter showing the gap between the mid-level and center-section light baffles that is responsible for the scratched tape feature (green rectangles). (Top) Twilight flat (visit = 2025070100103) showing scratched-tape-like morphology coming from large incident angle. (Bottom) In-dome image at higher illumination level (visit = 2025070200040) showing the scratched tape path in the context of the TMA geometry.

3 Physical Origin

After demonstrating the ability to reproduce the scratched tape feature on-sky, emphasis was placed on understanding the light path that allowed a bright star located >20 deg off-axis to impact LSSTCam images. Investigation of images taken with the pinhole filter during twilight in early May 2025 proved extremely useful. The pinhole filter is an opaque mask with a con-

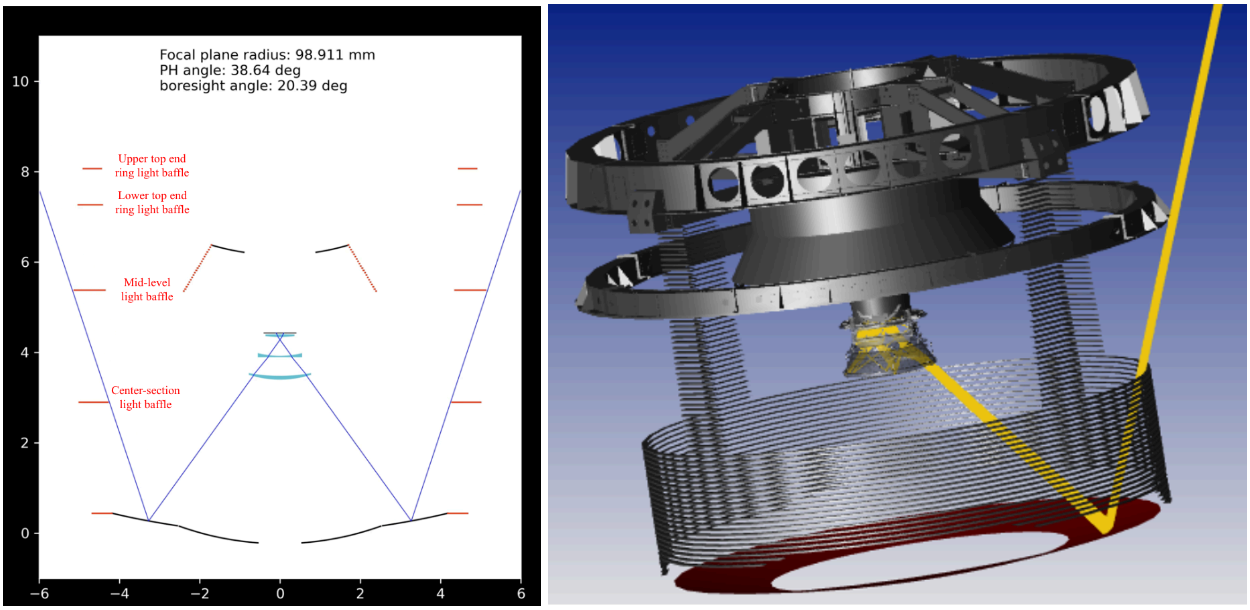

Figure 3: Ray tracing models showing the scratched tape light path between the mid-level and center-section light baffles. (Left) The `batoid` model showing a ray passing through the scratched tape gap and into the center pinhole. The projected radius on the focal plane (98.911 mm) corresponds to the position of the scratched tape seen in pinhole twilight flats. Baffles (red lines) are labeled following the nomenclature of LTS-213. (Right) The `Zemax` model showing the scratched tape light path with a more complete model of the TMA and LSSTCam. `Zemax` modeling indicated that it is possible for photons to reach the detectors for off-axis angles of $19.8 < \theta < 26$ deg due to secondary bounces off of surfaces within the camera.

figurable number of small pinholes that can be inserted into the LSSTCam filter changer to produce an image of the telescope pupil, including the mechanical structures that surround the system clear aperture. We reconstructed a direct connection between the appearance of the scratched-tape features observed on-sky and the light patterns revealed by the pinhole images. Morphologically similar bright features were observed at large angles from the central pinhole in twilight images. Additional pinhole observations were executed in July 2025, including both on-sky twilight images and illuminated in-dome images. Investigation of these images identified the stray light path as a gap between the mid-level and center-section light baffle (Figure 2). The existence of this gap was further experimentally verified by directed illumination with the collimated beam projector (Coughlin et al., 2016; Urbach et al., SITCOMTN-152) at large off-axis angles on 3 September 2025.

The scratched tape light path between the mid-level and center-section light baffles was reproduced with two independent ray-tracing models of the telescope and optical system, `batoid` (Meyers et al., 2019) and `Zemax` (Figure 3). Note that while this gap exists in each quadrant of the

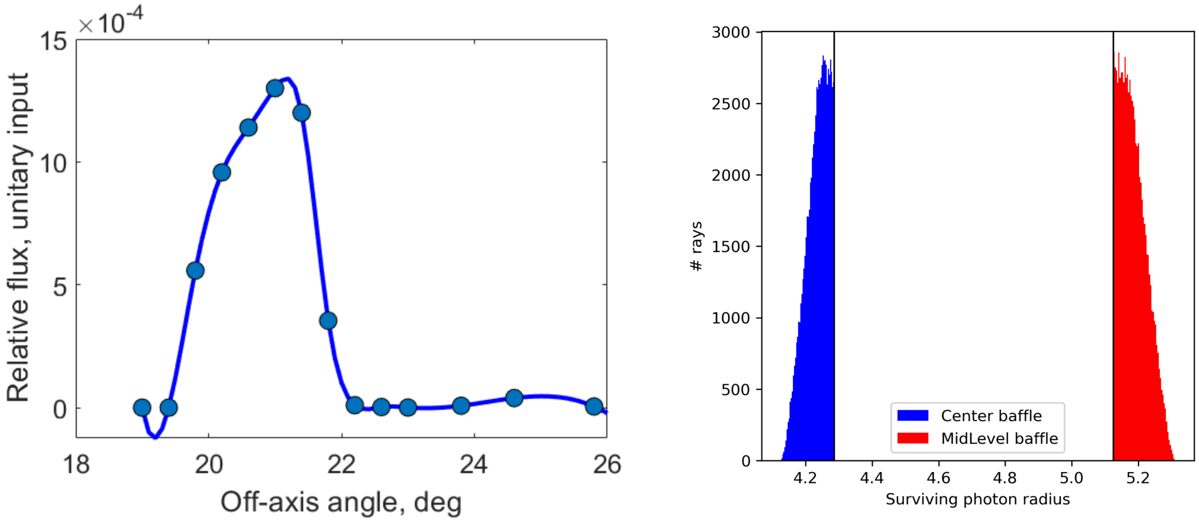

Figure 4: (Left) Ray-tracing simulations with `Zemax` show the relative flux on the LSSTCam focal plane via the scratched tape light path for a unitary flux injected into the telescope pupil. At off-axis angles >22 deg the relative flux reaching the LSSTCam focal plane is ∼10^{-6}. (Right) Ray-tracing simulations run with `batoid` show the distribution of $\sim 2 \times 10^7$ photons fired in the direction of the scratched tape gap between the mid-level and center-section light baffle. The simulation tracks those rays that survive the trip through the baffles off of M1 into the LSSTCam and reached the detectors. The radial distribution of the surviving rays at the heights of the mid-level baffle and the center-section baffle are shown in red and blue, respectively. To block all of these photons, the mid-level baffle would need to be extended outward by 185 mm. However, these simulations use design dimensions of the TEA (LTS-213) and do not account for 10 mm uncertainty on the TEA components.

mid-level ring, the dome slit blocks light from the sky at large off-axis angles in the azimuth direction (±X in TMA coordinates). Modeling shows that the LWS is expected to block this path in altitude as well once it is fully installed and operating. Based on non-sequential `Zemax` modeling that includes a representative mechanical model of the TMA baffles and structure, the range of incident angles where this light path could illuminate the LSSTCam focal plane was determined to be 19.8 deg $\lesssim \theta \lesssim$ 26 deg off-axis (Figure 4). The `Zemax` modeling suggests that the angular range for bright scratched-tape features is concentrated between 20 deg and 22 deg, where the illumination can reach $\gtrsim 10^{-3}$ of the flux injected into the telescope pupil. Beyond 22 deg, the illumination comes from secondary bounces off of structures internal to the camera, and the relative flux deposited onto the LSSTCam focal plane falls to ∼10^{-6}.

4 Characterization

Extensive visual inspection has led to a large database of images affected by scratched tape and other related stray light artifacts (see Rodeghiero et al. SITCOMTN-160 for details). During the period from 2025-04-17 to 2025-07-03, there were 1,093 documented examples of the scratched tape out of 22,308 exposures (~4.9%). However, much of the observing during commissioning was highly biased toward a small number of fields, and it can be argued that a more useful metric is the number of *fields* in which the scratched tape occurs. Grouping visits with boresight pointing (RA, Dec) within 0.2 deg of each other, it was found that there are 2,998 unique sky configurations, of which 188 show the scratched-tape artifact (~6.3%).

Due to our evolving knowledge of the scratched tape morphology and origin, early visual classifications split the scratched tape into several morphologically distinct features that were later determined to result from the same light path. Since the above analysis was performed only for features that were labeled “scratched tape”, it underestimates the true incidence of related features. Due to a variety of factors (i.e., the brightness and location of the aggressor light source), the scratched tape can take on a variety of sizes, morphologies, and focal plane coverage fractions. Furthermore, as flat fielding improved during commissioning, it became possible to identify fainter scratched tape artifacts. Due to these complexities, the above analysis makes no attempt to capture the relative impact of each scratched tape occurrence.

While the occurrence rate of the scratched tape was tracked through systematic visual inspection of LSSTCam images, analyses of the flux and surface brightness of this feature are more limited due to the additional human effort involved. Aperture photometry of the scratched tape feature associated with αCen (visit = 2025051900386) found a total flux of 1.4×10^{10} counts in r-band. This is approximately 0.2% (2×10^{-3}) of the flux expected from a direct on-axis image of αCen, which roughly agrees with the relative flux predicted by the `Zemax` model (Figure 4). The feature covered 10^8 pixels ($0.34\,\mathrm{deg}^2$) and had a surface brightness of $\sim$127 counts/pixel or a calibrated (top of the atmosphere) surface brightness of ~ 23.2 mag/arcsec^2.

A more extensive analysis was performed on $\sim$10 distinct instances of the scratched tape feature originating from αCen. This analysis involved identifying the bounding region of the scratched tape and obtaining the mean calibrated flux per pixel and surface brightness. In order to estimate the surface brightness of the feature, it is necessary to model and subtract a smooth sky background component. Estimating the background on small spatial scales, as is done in the standard data processing pipeline, results in a loss of intensity because the

Table 1: Surface brightness of scratched tape features originating from αCen computed from 10 images in comparison to the reference dark-sky background for LSST (Jones, SMTN-002).

Band	Scratched Tape (mag/arcsec^2)	Dark-Sky Background (mag/arcsec^2)
u	24.65 ± 0.13	23.05
g	23.97 ± 0.16	22.25
r	23.01 ± 0.27	21.20
i	22.93 ± 0.15	20.46
z	22.79 ± 0.16	19.61
y	21.53 ± 0.66	18.60

scratched-tape feature is often included in the background model. To avoid this misinterpretation, we performed our analysis on the `post_isr_image` data products, rather than the `visit_image` (or the `preliminary_visit_image`), and estimated the background over the entire focal plane using a low-order polynomial fit to avoid removing light associated with the scratched tape feature. Scratched tape features associated with αCen were identified in each band, and the mean surface brightness and standard deviations of 10 images are reported in Table 1.

Note that these surface brightness estimates were assembled from observations collected over several nights when the scratched tape feature could be associated with αCen. The reported standard deviation includes variations in the observing conditions, differences in the precise location of αCen with respect to the gap between the mid-level and center-section light baffles, and the exact geometry of the scratched tape feature on the focal plane. Furthermore, while the wavelength dependence of the scratched tape in this analysis is expected to follow the spectral energy distribution of αCen, this has not been explicitly verified. Despite these caveats, this analysis provides a rough quantitative assessment of the prominence of these features relative to the nominal dark-sky background (i.e., Jones, SMTN-002).

While the analysis in the section focuses on scratched tape originating from αCen, the scratched tape feature will occur for any light source offset from the boresight by $19.8 < \theta < 22$ deg at an appropriate altitude and azimuth to avoid obstruction by the dome and TMA. However, only bright sources (e.g., bright stars, planets, the Moon, the twilight sky, etc.) produce scratched tape features that can be easily identified in the LSSTCam images. There are some indications that fields with many repeated observations taken with similar telescope altitude and azimuth (i.e., the Deep Drilling Fields) may have lower surface-brightness scratched tape features that become apparent after image coaddition.

5 Mid-Level Baffle Extension

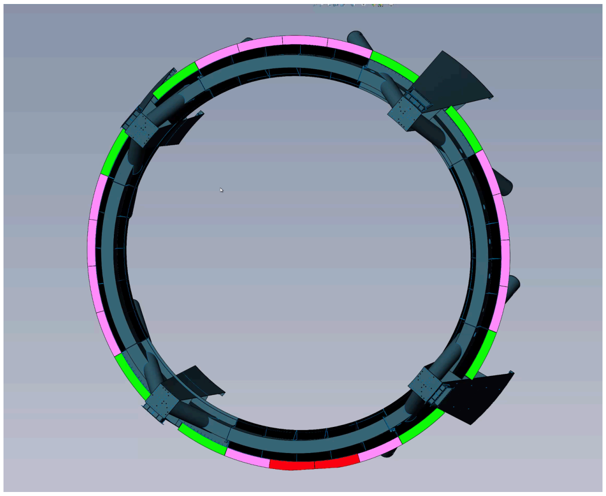

Figure 5: Initial design of a 220 mm outward extension to the mid-level light baffle to block the scratched tape light path. The mid-level baffle extension ring is composed of 24 individual panels that can be installed incrementally (colored green, pink, and red in this design drawing).

The ray tracing described in Section 3 indicated that the scratched tape light path could be effectively mitigated by extending the mid-level light baffle outward (Figure 6). This mitigation strategy has no impact on the clear aperture of the telescope. Ray-tracing simulation with `batoid` modeled the paths of $\sim 2 \times 10^7$ photons fired in the direction of the scratched tape gap between the mid-level and center-section light baffle. This simulation tracked rays that survived the trip through the baffles, reflected off of M1, entered LSSTCam, and reached the detectors. It was found that extending the mid-level baffle outward 185 mm would block all simulated photons from reaching the detectors. However, these simulations used the design dimensions of the TMA (LTS-213), did not account for uncertainty on the positions/dimensions of the as-built TMA, and did not account for reflections off of components inside the camera. Further modeling with `Zemax` showed that an extension of 200 mm would effectively block the primary scratched tape component out to ~23 deg. A small fraction of photons originating with off-axis angles >23 deg can enter the camera and reflect off of components internal to the camera (i.e., the L2 holder pads, autochanger, etc.) to reach the focal plane. However, the flux of these reflections is suppressed by a factor of $\sim 10^{-3}$ relative to the scratched tape itself (Figure 4). Given the tolerances on all large TMA components (~ 10 mm) and allowing for some margin of error, the recommended width of the mid-level baffle extension was 220 mm.

The mechanical design of the mid-level baffle extension was performed at NOIRLab. Consideration was given to a light-weight modular design that would allow installation to be staged during regular daytime engineering to avoid interrupting the observing schedule. The baffle extension is comprised of 24 panels, each measuring 120 cm × 27 cm, allowing for 5 cm of radial overlap with the existing mid-level baffle (Figure 6). The baffle extension panels were fabricated from 2-mm-thick low-carbon steel and painted with low-reflectivity Aeroglaze Z306. These panels were attached to the mid-level baffle using selftapping screws that were fixed in

Table 2: Mid-level baffle extension installation timeline.

Date	Baffle Extension Component	Completion Fraction
2026-02-19	−Y all panels	**(6/6)**
2026-02-20	+X lower panels	(4/6)
2026-02-24	−X lower panel	(1/6)
2026-02-25	−X lower panel	(2/6)
2026-02-26	+Y outer panels	(2/6)
2026-02-27	−X upper panels	**(6/6)**
2026-03-04	+Y inner panels	**(6/6)**
2026-03-06	+X upper panels	**(6/6)**
2026-04-02	Corner overlap panels	**(8/8)**

place with silicone sealant. Small overlap panels (22 cm × 5 cm) were attached to the extension panels to prevent gaps between the panels.

Installation of the mid-level baffle extension occurred over a period of ∼1.5 months between late February and early April, 2026 (Table 2). The ±Y quadrants have the largest scientific impact, since these quadrants provides a direct path to the sky, while the ±X quadrants are already blocked by the dome. In contrast, access to the −Y quadrant was the easiest, while access to the ±X quadrants required a lift, and installation of the +Y quadrant required a section of the mid-level baffle to be removed from the TMA. Installation generally progressed from the easiest sections to the most difficult, and installation of the main panels was completed in ∼2 weeks. Installation of small overlap panels at the corners where the mid-level baffle connects to the TMA pylons was completed about a month later.

6 Mitigation Results

The effectiveness of the mid-level baffle extension was validated with dedicated on-sky tests and with opportunistic on-sky data taking. Dedicated pre-observations on 2026-02-16 placed αCen in different radial and azimuthal positions in the scratched tape gap. Subsets of these observations were then repeated on 2026-02-19 (after the −Y extension was installed), 2026-02-26 (after the outer +Y panels were installed), 2026-03-06 (after the +Y panels were completed), and 2026-03-12 (after several corner overlap panels were installed). These tests demonstrated that the scratched tape light path had been blocked (Figure 7). A small residual feature (referred to as the “smudge”) was found to remain until 2026-03-19. This smudge has not been observed since installation of the corner overlap panels was completed. Anecdotally, the ap-

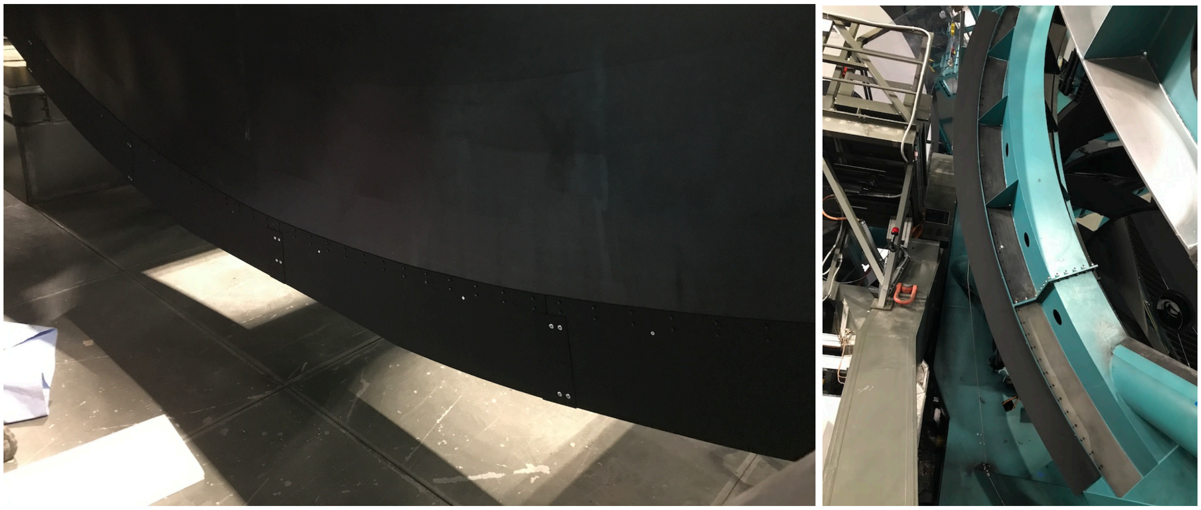

Figure 6: Installation of the mid-level baffle extension on the −Y (left) and +X (right) quadrants of the Rubin TMA.

pearance of the muddy shoe and pillow stray light artifacts have also decreased significantly since the installation of the mid-level baffle extension. However, these features occur more infrequently and are more poorly understood, thus requiring a longer observation span to confirm.

7 Conclusions

The scratched tape stray light feature was caused by illumination from astronomical sources at large ($19.8 \lesssim \theta \lesssim 26$ deg) off-axis angles. This light passed through a gap between the mid-level and center-section light baffles on the TMA, reflected off the primary mirror, and directly into the camera. These features were prominent during LSSTCam commissioning and early operations. Visual inspection determined that bright instances of the scratched tape feature contribute to at least 5% of on-sky science images during commissioning, science validation, and early operations. Instances of these features arising from bright stars were found to have a surface brightness comparable to ∼20% of the night sky. While the impact of this feature on high-level data products is mitigated through aggressive sky background modeling and subtraction, residual effects persist in Rubin DP2. Based on detailed analysis and modeling of the scratched tape feature, an outward extension of the TMA mid-level light baffle was proposed, designed, constructed, and installed. The mid-level baffle extension successfully blocks the scratched tape stray light path, considerably reducing stray light contamination in

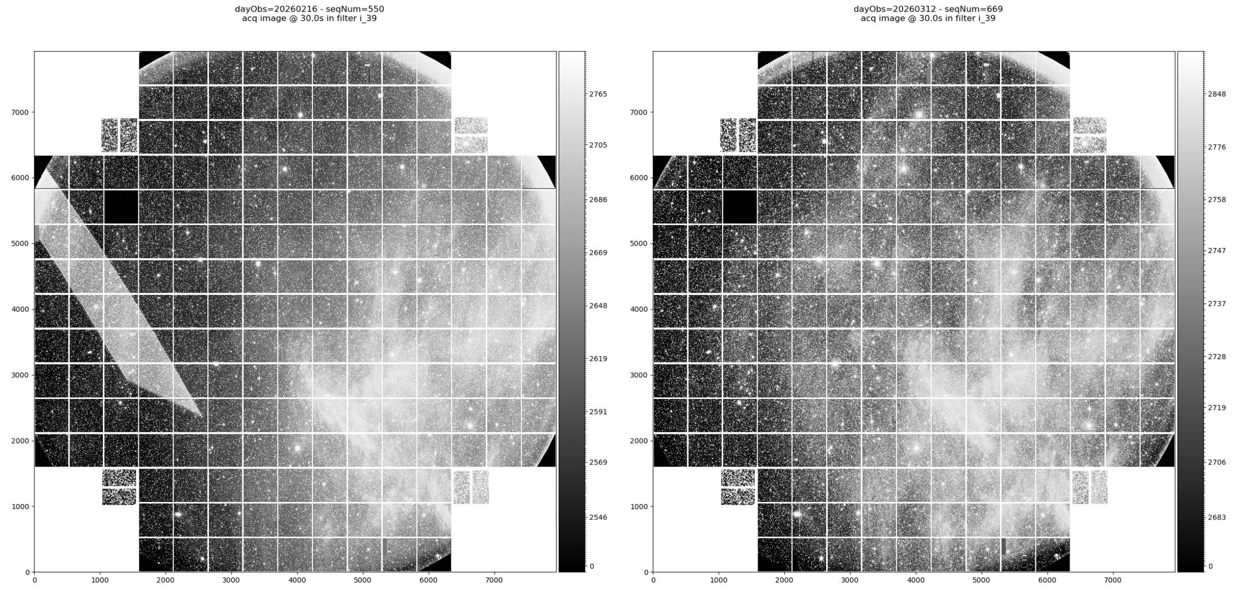

Figure 7: Mitigation of the prominent scratched tape stray light feature by the mid-level light baffle extension. (Left) Stray light originating from αCen located ~21 degrees off-axis prior to the installation of the mid-level baffle extension (visit = 2026021600550). (Right) Stray light is not present in an exposure taken after installation of the mid-level baffle extension (visit = 202603120000669). The relative position of αCen is similar to the image on the left.

the LSSTCam images prior to the start of LSST.

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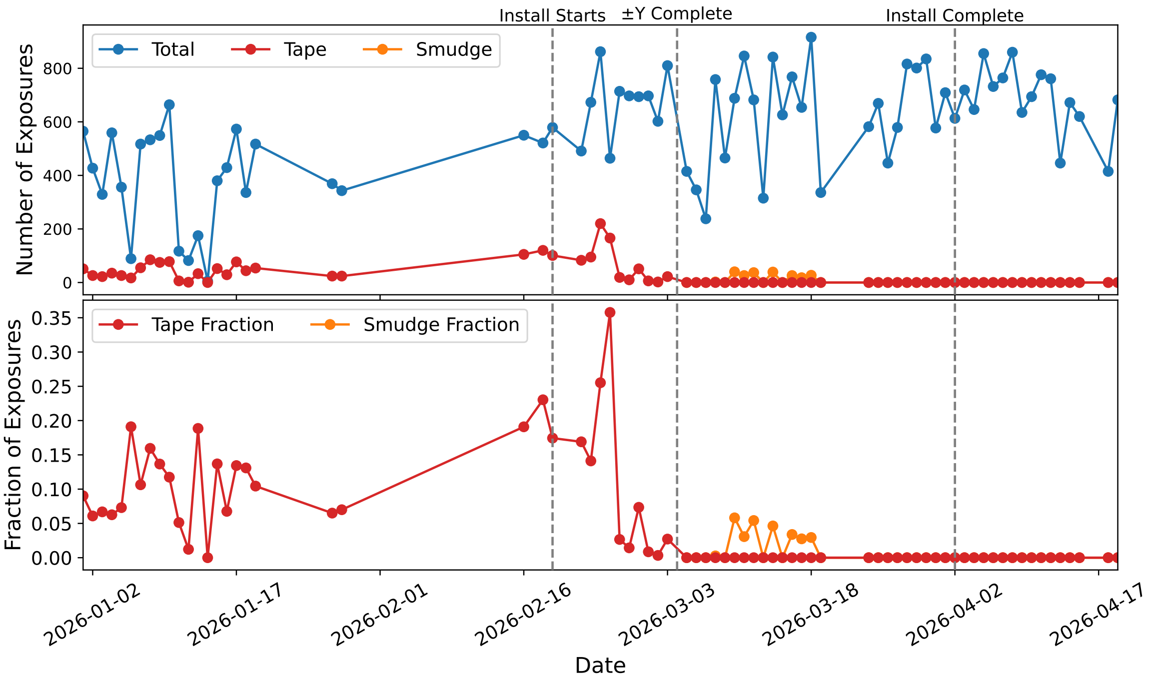

Figure 8: Installation of the mid-level light baffle extension effectively removed the scratched tape stray light feature. A small, residual feature (known as the "smudge") appeared briefly, and was attributed to a remaining gap between the extension panels. This feature has not been observed since installation was completed.

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B Acronyms

Acronym	Description
DP2	Data Preview 2
L2	Lens 2
LSST	Legacy Survey of Space and Time (formerly Large Synoptic Survey Telescope)
LSSTCam	LSST Science Camera
LTS	LSST Telescope and Site (Document Handle)
LWS	Light-Wind Screen
M1	Primary Mirror
M2	Secondary Mirror
M3	Tertiary Mirror
NOIRLab	NSF's National Optical-Infrared Astronomy Research Laboratory; `https://noirlab.edu`
RA	Rapid Analysis
SV	Science Validation
TEA	Top End Assembly
TMA	Telescope Mount Assembly