Focal plane figure - knowledge and control for Rubin Observatory's LSST Camera (#38)

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INTRODUCTION

Rubin Observatory has a unique optical beam geometry. The large collecting area of the primary mirror, combined with atmospheric seeing-limited imaging across the wide (9.6 deg^2) field-of-view, enables the survey mission.

The combination drives a fast (F/1.2) beam geometry with unprecedented sensitivity to defocus driven, point spread function blur and shape transfer, even under operation (closed loop, active optic compensation).

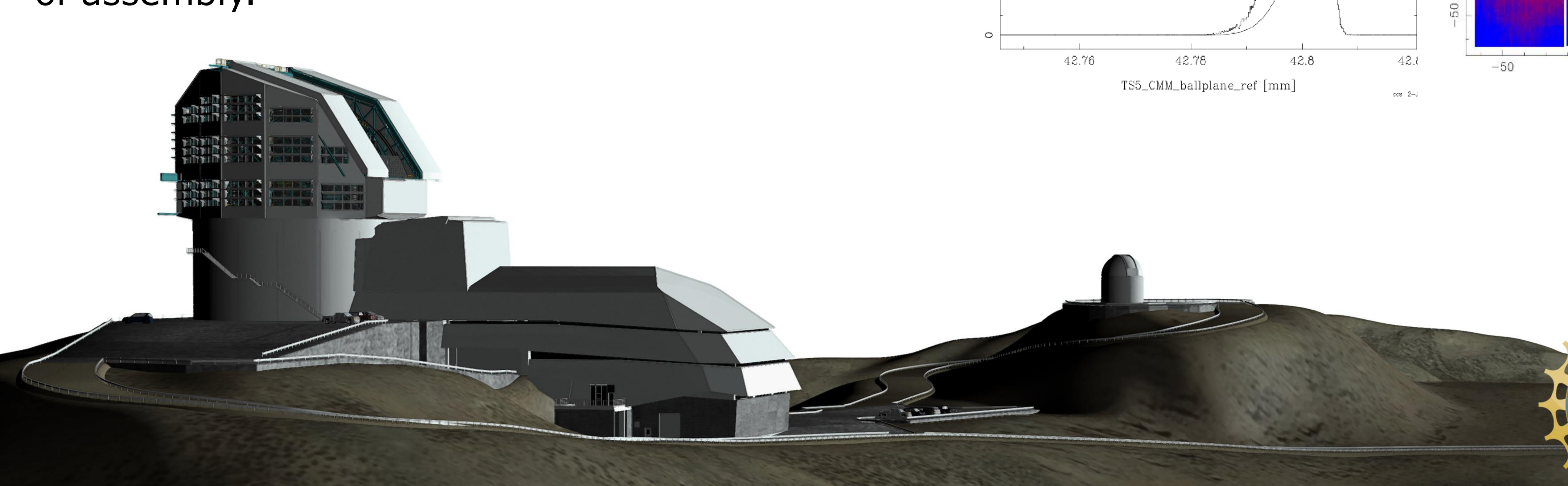
The LSST focal plane is constructed out of 205 individual sensor surfaces under passive alignment and operates at -100°C, within the cryostat vacuum. In this contribution we describe the Manufacturing, Integration and Testing effort that went toward assembly of the ultimate focal plane (achieving 4µm rms deviation from flat), as well as the detailed, underlying as-built characterization knowledge under operating conditions. We anticipate that these data will enable improved point spread function estimation/extrapolation in instances where its contribution may be ambiguous or inadequately quantified.

FAST OPTICAL BEAMS (AND WIDE FOV) REQUIRE PRECISE SENSOR SURFACE DEFINITION

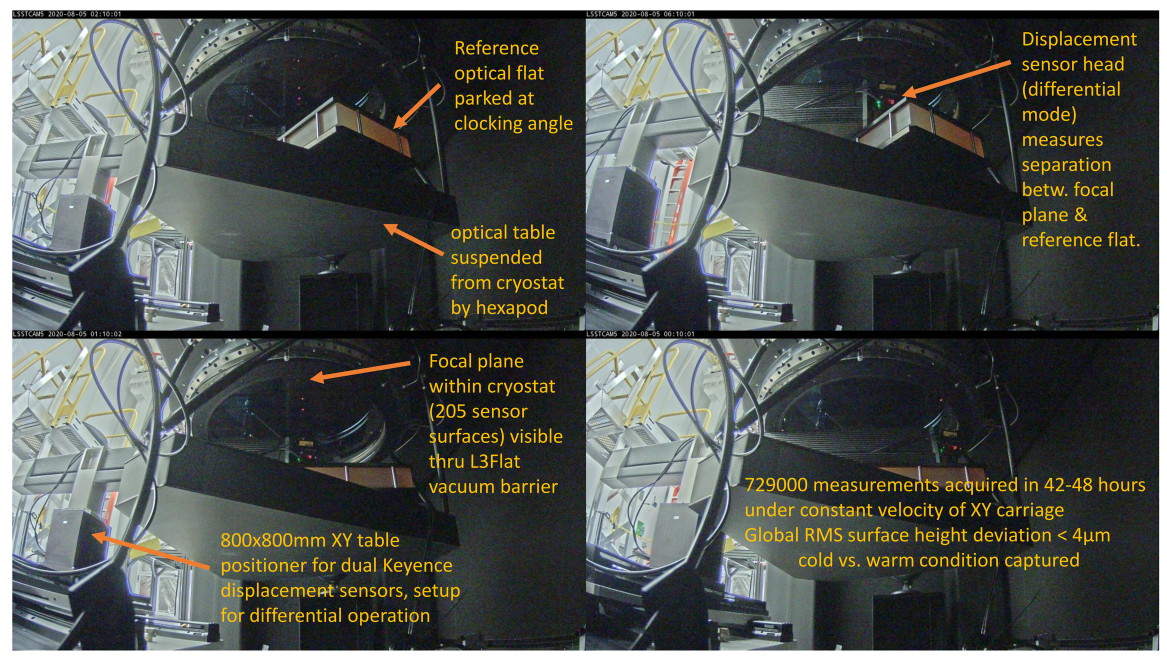
- Pixel scale was chosen to just oversample seeing limited image quality (FWHM/3). This provides economical pixel count (3.2E9) and read noise limited sensitivity in photon starved conditions.
- F/1.2 optics behave more like F/1.0 because of primary mirror's annular geometry.
- Pixel 3D geometry is 10x10x100µm – with depth driven by near-IR response and pitch driven by focal length and primary mirror diameter (8.4m).
- Only a small blur contribution due to focal plane figure may be tolerated. The Image Quality Error Budget specifies the following allocations, which sum in quadrature to **0.079" FWHM**:
  - Sensor flatness: 0.062" FWHM contrib
  - Raft assembly: 0.022" FWHM contrib
  - Detector plane assembly: 0.044" FWHM contrib
- Using a conservative, 95% distribution width of the measured Science array image height, as a peak-to-valley (PV) parameter in a uniform distribution, the image quality penalty works out to **0.053" FWHM**.

DESIGN AND E-MANUFACTURING STRATEGY FROM THE BOTTOM UP

The large focal plane (640mm across) maintains required flatness performance with a passive alignment strategy, using highly stable, stress-free configuration: very low CTE Cesic focal plane GRID, Cesic RSAs built specifically for each flavor of sensor (e2v & ITL) and strict screening of parts and assemblies at all levels of assembly.



IN-SITU MEASUREMENT OF 205 SENSOR SURFACES, OPERATING CONDITIONS



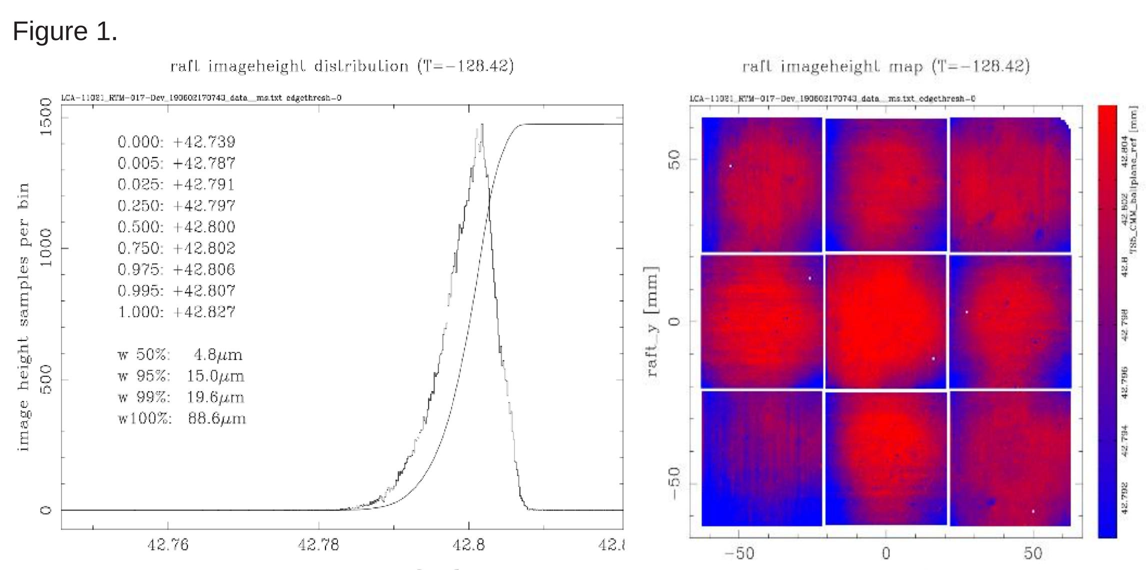
WORKING TOWARD FULL FOCAL PLANE MEASUREMENTS

The development program for the flat focal plane required detailed measurements and analysis at every level of construction. As the heart of the Camera is highly modular with many parts nominally identical, non-compliances were detected efficiently and parts were rejected (or remanufactured) so that when the ultimate assembly was integrated, performance of the whole part was also compliant with requirements.
Table 1 below summarizes the inspection, testing and metrology program executed over several years and across several locations. Figure 1 is an example of an RTM-level figure measurement, representing 4% of the focal plane.

Table 1.

Measurement type	Assembly level	Location	Purpose	Reference type	Env. conditions
Spot check	Sensor component level	E2v & ITL (vendor)	Pre-ship, screening	Absolute, against mounting interface	Ambient
Spot check	Sensor component level	BNL	Receiving, screening	Absolute, against mounting interface	Ambient
(C)RSA baseplate, WFS step plate spot check	Component leve	ECM (vendor)	Pre-ship screening	CMM, absolute, touch probe	Ambient
RSA baseplate spot check	Component level	BNL(TS2)	Receiving, screening	OGP, TTL laser probe, absolute	Ambient
RSA assembly spot check	Subassembly level	BNL (TS2)	Subassembly verification	OGP, TTL laser probe, absolute	Ambient
RSA assembly scan	Subassembly level	BNL (TS5)	Environmental verification	Differential Keyence, figure measurement	Operational, -100C
CRSA baseplate scan	Component level	SLAC (B084)	Parts combination	OGP, touch probe & video probe, absolute	Ambient
WFS step plate scan	Component level	SLAC (B084)	Parts combination	OGP, touch probe & video probe, absolute	Ambient
INVAR kinematic frame, 2 models RTM, 1 for CRTM.	Tooling characterization, also following re-work	SLAC (B025)	To achieve absolute measurements in TS5	CMM, absolute, touch probe	Ambient, unloaded
RTM assembly scan	Subassembly level	SLAC (TS5)	Receiving (from BNL), several reassembly verification, (SLAC)	Differential Keyence, absolute (against RTM INVAR kinematic frame fiducials)	Ambient & operational, -100C
CRTM assembly scan	Subassembly level	SLAC (TS5)	Receiving (from BNL), several reassembly verification, (SLAC)	Differential Keyence, absolute (against CRTM INVAR kinematic frame fiducials)	Ambient & operational, -100C
GRID ball nest measurement	Integrating structure level	ECM (vendor)	Pre-ship review	CMM, absolute, touch probe	Ambient, unloaded
GRID ball nest measurement	Integrating structure level	SLAC (B025)	Receiving (from ECM)	CMM, absolute, touch probe	Ambient, unloaded
In-situ GRID-to-cryostat measurement	Integrating structure within cryostat housing	SLAC (IR2)	Verify cryostat assembly	FARO arm & laser tracker GRID & GRID fiducials, referenced to L3 interface plane	Ambient, in BOT orientation
In-situ (cryostat) focal plane image height mapping	Focal plane assembly	SLAC (IR2 BOT)	Verify focal plane image quality performance	Differential keyence, common reference figure measurement	Ambient, loaded & Cold (-100C), nominal acceleration (zenith pointed)

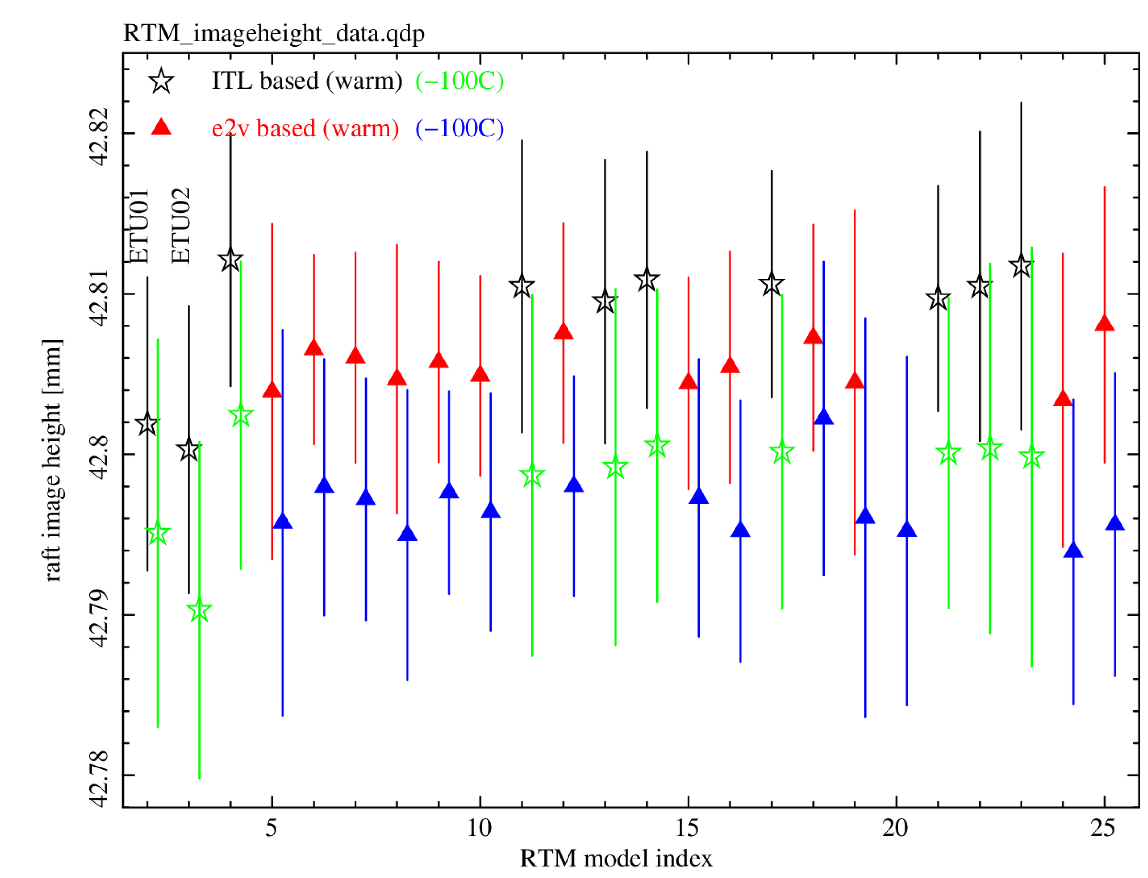
Figure 1.



RAFT TOWER MODULE LEVEL METROLOGY

Absolute height maps (e.g. Figure 1) were generated using the measurements made for each RTM and Corner Raft Tower Module. Figure 2 is a side-by-side comparison of all RTMs integrated in the focal plane. Combining these with metrology details of the manufactured Cryostatic GRID (integrating structure) we built confidence in the end result's flatness performance prior to focal plane integration. Error bars represent 99% widths of the available data.

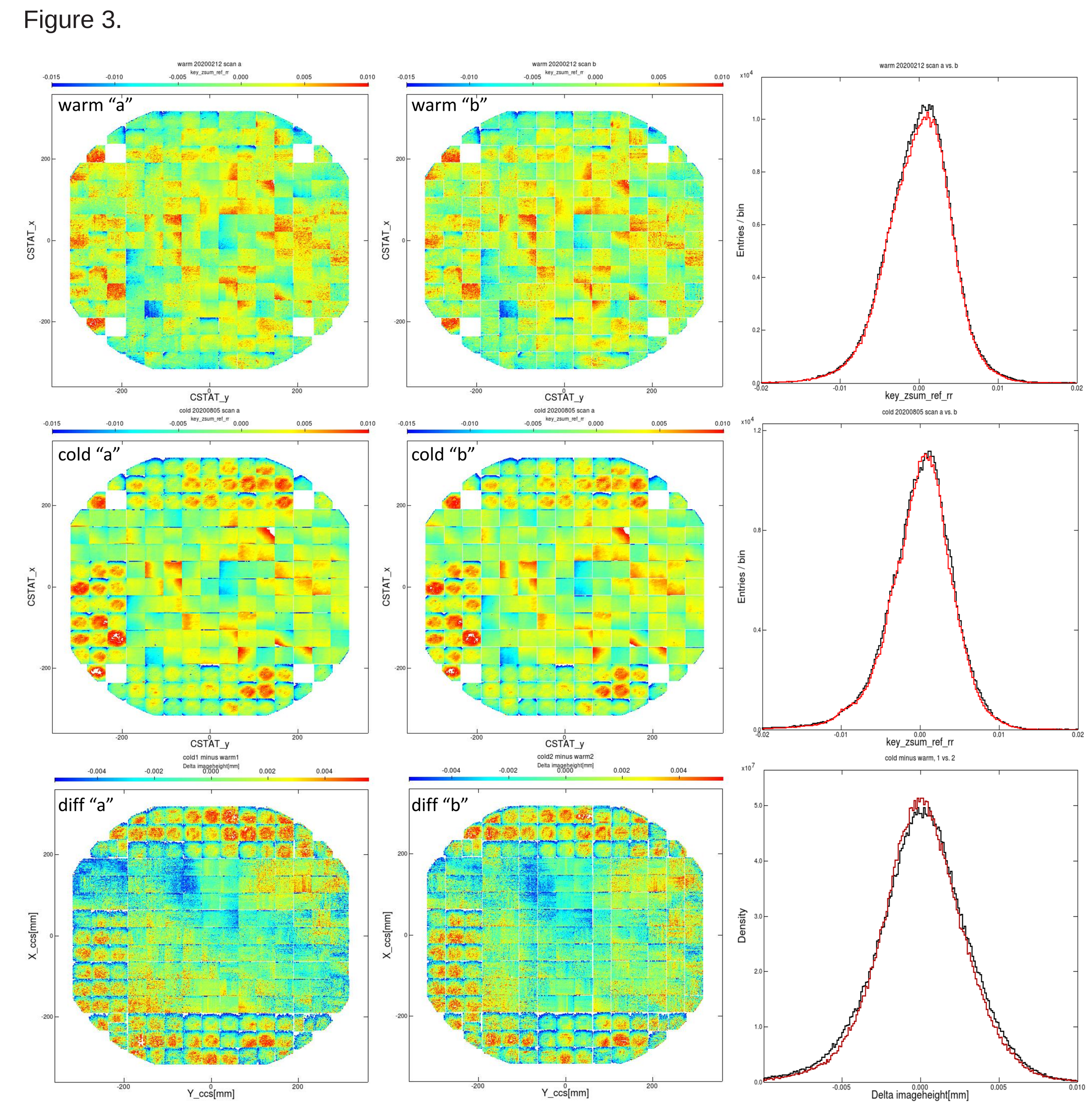
Figure 2.



FOCAL PLANE METROLOGY

Once all RTMs were integrated into the Cryostat, full focal plane scans were performed, re-referenced against drift and stitched - twice for each environmental conditions (ambient and -100C). These are displayed and compared in Figure 3. They show high repeatability and significant differences between environmental condition. Under operating conditions, the full focal plane maps are retained in detail but are characterized by the flatness parameters referenced above (RMS <4µm, w95 <16µm).

Figure 3.



Wavefront sensor requirements addressed:

All four Wavefront sensors have a step, or separation, of less than $\mathbf{10\ \mu m}$ from the nominal $3.0\ mm$. The average positions of the Wavefront sensors each lies within $\mathbf{2\ \mu m}$ of the best-fit Focal Plane height. The individual Wavefront sensor halves each lie at most $\mathbf{7\ \mu m}$ from their nominal position. Four of the wavefront sensors lie within P-V requirement of 10 microns, while the other 4/8 lie within a P-V of 15 microns.

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