LSST Wavefront and Alignment Sensing

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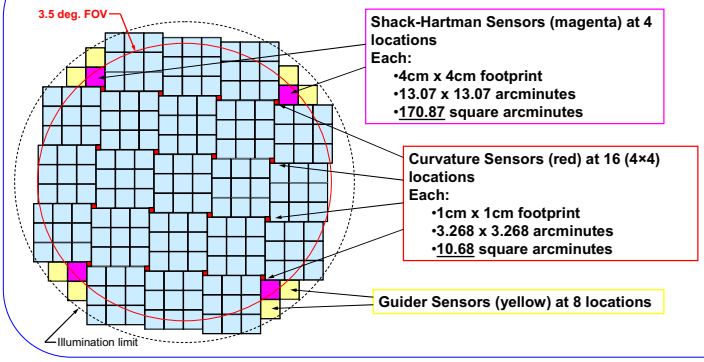
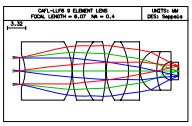
Large Synoptic Survey Telescope

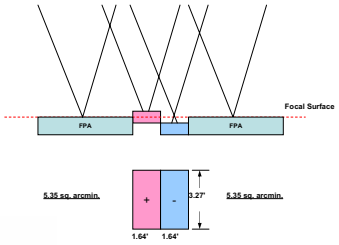
The proposed Large Synoptic Survey Telescope (LSST) has developed a concept for optical wavefront and system alignment control that includes direct wavefront sensing and separate rigid body position sensing. The telescope optical system has three reflective surfaces based on a Paul-Baker three element design and three refractive lenses feeding the single flat focal plane in the dedicated instrument. The large mirrors, an 8.4 m diameter primary, 3.4 m secondary, and 5.0 m tertiary, require active control of figure and all the optics and camera assembly must be actively positioned in rigid body to maintain performance of this 3.5 degree field of view system. The LSST concept uses a distributed set of wavefront sensors in the 65cm diameter focal plane with adequate spatial frequency to resolve the wavefront control for each of the three reflective surfaces. Optical reconstruction analysis, wavefront sensor performance, and star density statistics have been used to define the necessary field dependent sensing to meet the LSST requirements. An active alignment system using laser tracker technology has been defined to address the rigid body position control. The 30 second cadence of the LSST and the wavefront sensing intermittency associated with full camera exposures demands a separate system to keep the optical elements and camera within alignment specification. These two systems, working in concert with each other, sense the LSST wavefront and alignment at spatial and temporal rates necessary to support the LSST science mission.

PROPOSED BASELINE FPA CONFIGURATION



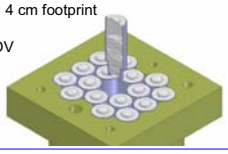
WAVEFRONT SENSORS





Shack Hartmann Sensor

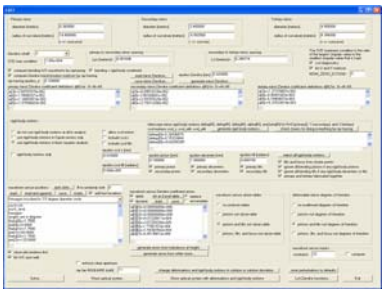
- •9 element lens (above) reimages the pupil onto a Shack-Hartmann lenslet array.
- •37.5 Arcsec diameter FOV on the sky, 0.31' sq.
- •Lens diameter is 6.8 mm.
- •17 SH cluster (left) fits in 4 cm × 4 cm footprint
- •5.22 sq. arcmin. Effective FOV
- •~3% efficiency in footprint vs FOV



Curvature Sensor

- •2 side-by-side detector arrays (above)
- •5.35 sq. arcmin. effective area
- •~50% efficiency in footprint use

RECONSTRUCTION SIMULATION



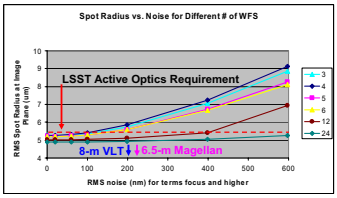
Reconstruction Simulation Tool: A software tool (the gui is shown above) is being developed to analyze the transformation of wavefront errors to specific corrective actions. The simulator has a multitude of configurable options, including:

- •Initial mirror bending and rigid body perturbations
- •Allowable mirror bending and rigid body modes for correction
- •The number of wavefront sensors and their positions
- •Can choose to randomly omit a number of wavefront sensors to simulate not having an available star in the field of view
- •Zernike terms measured by wavefront sensors
- •Noise in wavefront sensor measurements
- •User specified noise distribution for each measured Zernike coefficient
- •Atmospheric turbulence model
- •Wavefront test locations
- •Field positions, other than wavefront sensor locations, where wavefront is evaluated in order to determine system performance

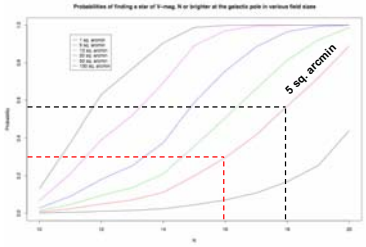
The simulator has yet to be fully exercised to determine the optimum wavefront sensing configuration. However, initial studies have provided guidance on how to develop the best strategy.

In the example below the performance of the reconstruction is evaluated as a function of total RMS noise in the wavefront and number of sensors. The horizontal red dashed line indicates the allowed performance for LSST for the base optical design + active optics system (RSS'd together) as currently partitioned in the image error budget. We need to be at or below this line for what ever curve we are on.

Data from 6.5m Magellan telescope indicates 200-250 nm RMS noise is typical in the wavefront (magenta arrow). Similar data from the VLT shows 200 nm RMS noise in 30 second wavefront exposures (blue arrow). We expect the LSST RMS wavefront error to be similar to those in the Magellan and VLT telescopes. At this level of noise the curve for 6 sensors is above our allowed image requirement while the curve for 12 sensors is below. An estimated ~8 wavefront samples (sensors) in the FOV will therefore be required in order to achieve the performance in the reconstruction that is desired.



STAR COUNT ANALYSIS



Stellar Probabilities

- •Assume Poisson distribution
- •For λN = average no. stars with $m_v \leq N$ per unit area, then the probability of finding k objects is

$$P(k) = 1 - \frac{e^{-\lambda_N}\lambda^k}{k!}$$

- •The probability of finding at least one star brighter than m_v is

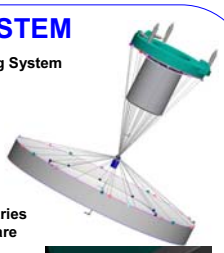
$$P(k \geq 1) = 1 - P(k=0) = 1 - e^{-\lambda_N}$$

The galactic poles represent the worse case in terms of stellar density. The cumulative probabilities for various areas derived from the USNOB catalog are shown above for the North Galactic Pole. Depending on the type of wavefront sensing used and signal-to-noise needed for reconstruction the LSST will require a star between V=16-18. For a 5 square arcminute FOV there is a ~30-55% probability of one of the LSST wavefront sensors having an acceptable reference star. The proposed FPA configuration will have an average of ~8 "active" wavefront sensors suitable for reconstructing the alignment and surface control.

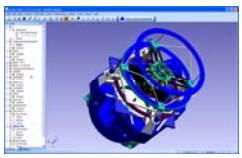
ACTIVE ALIGNMENT SYSTEM

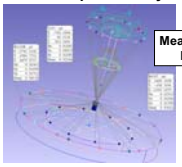
- **Narrow/Eliminate Rigid Body Measurements from Wavefront Sensing System**
- **Establish First-Order Look-up Tables for Basic Alignment**
- **Start of Night Operational Setup**
  - **Maintain Alignment (M1/M3, M2, & Camera) During Operation**

System Performance	Tilt	Lateral	Focus	Measurement Speed	Measurement Wavelength
Baseline Goals	< 5 arcsec	< 10μm	< 10μm	< 30sec	IR Only

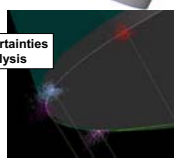


- **Use Laser Tracker Technology to Measure System Fiducials/Geometries**
- **Model Performance in New River Kinematics Spatial Analyzer Software**





Measurement Uncertainties Included in Analysis



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