Lens System for Simulating the Large Synoptic Survey Telescope Optical Train for the Case of a Single Star

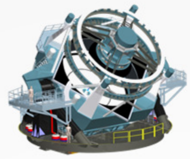
J. Haupt   Brookhaven National Laboratory

Introduction:

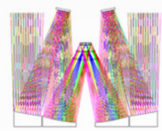
The design of a lens is described capable of simulating the optical system of the Large Synoptic Survey Telescope (LSST) to first order for the purpose of testing prototype CCDs for the telescope's camera. The need was acknowledged for creating a beam that matches the telescope's f-ratio and obstruction, and which would have sufficient back-focal distance to allow imaging onto a sensor at least 50mm away.

Background:

The LSST optical design is based on the three-mirror Paul-Baker configuration and the LSST camera will be the sole observing instrument with a field of view of ~3.5° and sensitivity from ~300-1100nm. The system focal ratio is f/1.23 with an obstruction of 65% by diameter. The telescope is telecentric n image space and 80% encircled energy (EE80) without atmospheric contribution will vary from 25µm to 35µm across the ø64cm focal plane, which will be populated by an array of 189 square 42mm 16MP CCDs for a total resolution of 2.4GP. The work of characterizing these sensors and developing the supporting hardware and electronics is being carried out at Brookhaven National Laboratory and Harvard University in collaboration with IN2P3 (Paris).



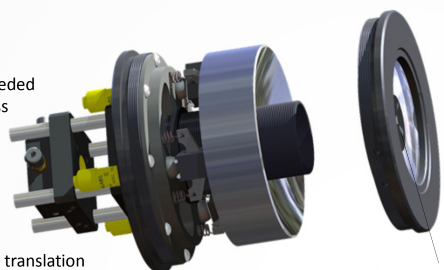
LSST



LSST ray trace

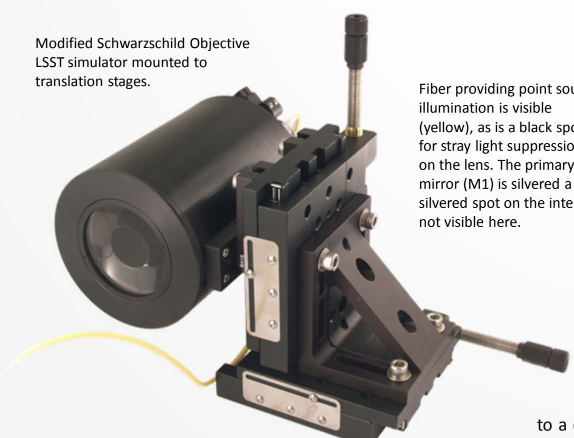
Optical Design:

Considering the minimum size of a lens needed to produce a telecentric f/1.23 beam across a 42mm sensor for a given back focal distance, the decision was made in the interest of cost to instead create an optic capable of projecting a single point (i.e. synthesizing a star). The optic could then be positioned laterally for full coverage of a CCD by means of an external translation stage. The first order design objectives were to create a diffraction-limited f/1.2 spot with LSST's 65% obstruction and a flange focal distance of ~50mm, with the ability to project through plane parallel vacuum chamber windows of various thickness without performance degradation.



Blackened spot

The Schwarzschild Objective is a simple design capable of creating a very fast beam. Traditionally used as a microscope objective, it consists of two spherical mirrors located concentrically whereby the convex surface is the primary mirror (M1) and the larger concave surface is the secondary mirror (M2). Inserting a plane parallel window in front of an otherwise perfect spherical wavefront as is nearly the case with a Schwarzschild Objective introduces spherical aberration which increases in proportion with numerical aperture.



Modified Schwarzschild Objective LSST simulator mounted to translation stages.

Fiber providing point source illumination is visible (yellow), as is a black spot for stray light suppression on the lens. The primary mirror (M1) is silvered a silvered spot on the interior, not visible here.

Performance:

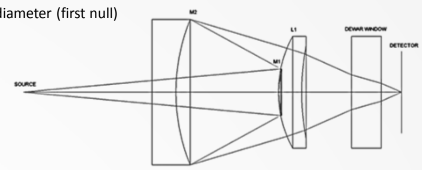
The as-measured performance of the optic is consistent with the expected performance. Shown here, the wings of the measured PSF extend somewhat beyond those of the prediction for a perfect system. This PSF was measured by reimaging the point in open space with a microscope objective and taking a cross-section of the magnified spot, so it is expected that an unknown amount of additional broadening has been introduced by the measurement method. Also shown here are the measured v. predicted encircled energy extracted from the same measurement as well as the actual image, in which the diffraction rings are clearly visible.

Optical Design, continued:

It was found that a variation on the Schwarzschild Objective in which a meniscus is placed before focus, called here a **Modified Schwarzschild Objective,** provides the necessary correction for positive spherical aberration to yield diffraction-limited performance of an on-axis spot through a range of optical window thicknesses, at the expense of polychromatic performance. Shown below, it was possible to simplify the design by combining the primary mirror with the inner surface of the meniscus.

With this arrangement either the object-M1 or the M1-M2 spacing can be used as compensators for windows of varying thickness. Two common window thicknesses encountered in our lab setting are 16mm and 19mm, for which object-M1 spacings of 172.2mm and 130mm (respectively) are used. A spot diagram with the Airy diameter overlaid shows the diffraction-limited nature of the design.

Modified Schwarzschild Objective spot diagram

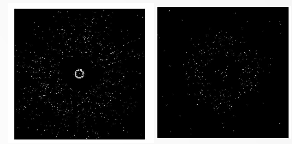


Modified Schwarzschild Objective ray trace

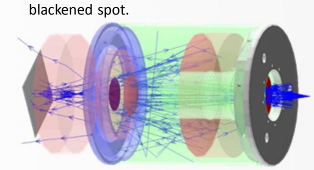
Stray Light:

Non-sequential analysis revealed a halo ghost resulting from multiple reflections within the meniscus corrector. After considering AR coating options it was found that the ghost could be eliminated by blackening the outer surface of the meniscus within the diameter of M1. This black spot can be seen clearly in the bottom photograph and is indicated on the left graphic.

Adding a Cassegrain-style central baffle was effective in reducing other scatter issues.



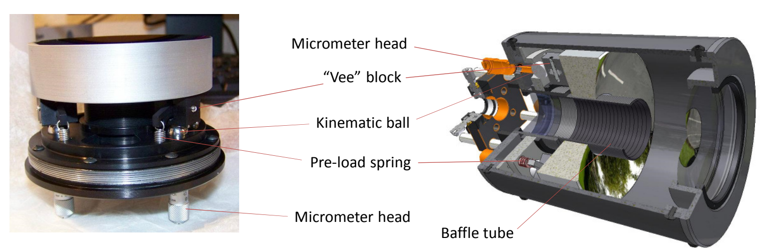
LEFT: Analysis of detector without ghost-suppressing blackened spot on lens. RIGHT: Analysis of detector with blackened spot.



Stray light analysis model

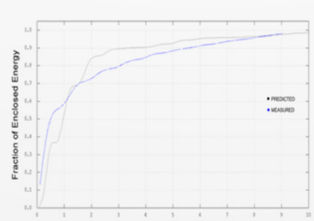
Mechanical Design:

The very fast f/.67 large secondary mirror was the most natural choice for the movable element (for vacuum window thickness compensation). The ability to manually align the system was also deemed necessary. A kinematic support mechanism was designed which allows precision adjustment of translation and tip/tilt via three micrometer heads. The micrometer head tips contact the kinematic balls which slide freely in circular holes that constrain the balls laterally. Three "vee" blocks cemented to the back of the secondary mirror mate kinematically to the balls. The blocks contain rocker mechanisms to which tension springs attach, holding the secondary mirror assembly against the balls.

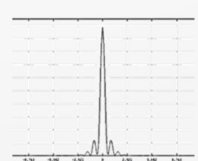


Usage:

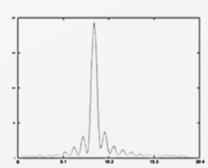
In the normal operating mode a single on-axis point is projected, illuminated by a single-mode fiber mounted to a cage on the rear flange. There is some ability to project or image extended objects but spherical aberration quickly starts to dominate off-axis. Because LSST is not diffraction limited (even without considering the atmosphere), intentional detuning of the M1-M2 spacing is necessary to simulate its PSF.



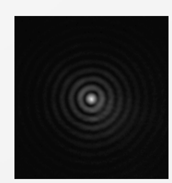
Measured and predicted encircled energy



Predicted PSF



Measured PSF



Imaged point, magnified by reimaging with a microscope objective

BROOKHAVEN NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY | Office of Science
NSF