A Technique for a Self-Luminous Flatfield Calibration Screen

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Abstract. The use of flatfield illuminators shows great promise for calibrating telescopes to be used in the next generation of Ia supernova measurements. In order to meet the physical constraints of the PanSTARRS and LSST domes, we are developing a self-luminous flatfield calibration screen which can cover the entrance aperture of these telescopes while presenting a total thickness of only 13 cm. We expect to achieve illumination uniformity and passband flatness adequate for optical throughput calibration at the 1% level. The emitting element is a “side-emitting” optical fiber excited by a pulsed laser tunable over the bandpass of 400 to 1100 nm. The fiber is embedded in a sheet of acrylic the size of the telescope aperture. This radiating element is backed by a mirror. In front of the radiator is an acrylic lambertian diffusing screen, and in front of the diffuser is a baffle screen that occults much of the light that would have entered the telescope by way of scattering from telescope and dome structures. The baffle screen is a sheet of black acrylic drilled with a densely packed array of threaded holes.

1. Introduction

The next generation of Ia supernova studies will require photometric calibration of telescopes and cameras at the 1% level of precision into the near infrared. In an effort to refine the photometric calibration of telescopes to this level, Stubbs, Tonry, et al. (Stubbs & Tonry 2006) (Stubbs et al. 2007) have devised and demonstrated a very promising technique in which they perform an end-to-end calibration that relies upon a standard photodiode detector rather than upon a standard astronomical source as a photometric reference. Their approach is to illuminate a dome-mounted flat screen by projecting light from a tunable pulsed laser onto it. The illuminance due to the flat screen is then monitored at the entrance pupil of the telescope by a calibrated photodiode while the camera records a series of monochromatic flatfield images at wavelengths throughout the passband of the instrument.

Although this novel flatfield technique has proved workable at CTIO, projection onto a flat screen is not practical in other observatories simply because of the space required to accommodate the projection geometry. For example, a flat screen mounted in the PanSTARRS-1 enclosure (shown in Figure 1) would clear the top end by only a few cm, not nearly enough to accommodate projection. In order to overcome this limitation, we are developing a self-luminous flat screen
that will fit inside the PanSTARRS enclosure and which we hope will demonstrate the usefulness of the Stubbs-Tonry approach to precision calibration.

Figure 1. Cross section of the PanSTARRS-1 enclosure and telescope. There is barely enough space to install a flat screen without projection.

2. Design

2.1. Radiator Panel

The heart of the self-luminous screen is an array of optical fibers that have been specially manufactured to emit light along their lengths. These fibers, sometimes called “side emitting fibers,” “glowing fibers,” or “luminous fibers,” have been used in numerous consumer technologies, including decorative lighting. The fibers we have chosen are supplied by Z-Light, Ltd. of Litani, Latvia, for use in industrial and medical lighting systems. Z-Light supplied our fibers with a retroreflector at the unfed end. The fibers are drawn in such a way that the fraction of light scattered out of the fiber is a function of distance from the fed end thereby evening out the emission brightness of the fiber over its length. The fibers are 400 μm diameter step-index silica fibers, with a translucent plastic jacket. Each fiber is 60 m long, and we use an array of eight of them for a total active fiber length of 480 m. Testing indicates that the side emission property of the fibers is consistent over the wavelength bandpass of 400 to 1100 nm.
We construct a planar radiator employing luminous fibers by embedding them in a large sheet of clear acrylic plastic. The fibers are embedded in a series of parallel grooves milled into the surface of the plastic radiator panel. As shown in Figure 2, the radiator panel is backed by another sheet of acrylic with an aluminum mirror coating which reflects light out the front of the panel. Structurally, the mirror panel serves to capture the optical fibers in their grooves. The radiator panel is 2.21 m square with 176 parallel grooves spaced 12.4 mm apart. Each groove has a square cross section of 1.6 mm (1/16 inch) that loosely holds the fiber so as not to create any high-luminance “hot spots.”

Figure 2. Cross sections of the assembled panel showing the arrangements of the various components. The glowing fibers lie in the grooves that are seen end-on in the Side Edge View. The aluminized surface of the mirror panel is on the side away from the radiator panel. The textured surface of the diffuser panel faces the radiator. (Dimensions in inches.)

2.2. Diffuser Panel

In order for the screen to illuminate the primary mirror of the telescope evenly, it must radiate uniformly across its surface; and in order for each point on the screen to illuminate the entire focal plane evenly, it must radiate uniformly into the solid angle equivalent to the field of view of the camera. We therefore place in front of the radiator-mirror sandwich a third acrylic panel finished with a diffusing surface that scatters light in an approximately lambertian pattern. The diffuser serves both to smooth out the spatial pattern established by the
fiber layout and to provide an angular distribution that is within a fraction of a percent of being uniform over the angular field of view of the camera.

The amount of spatial smoothing achieved by the diffuser depends on its spacing from the plane of the luminous fibers. We have set this spacing at 8.9 cm largely for structural reasons (it accommodates a standard 4-inch aluminum U-channel), but testing indicates that surface brightness variation due to the fiber layout pattern is less than 1%.

The diffusing surface is a standard cell-cast matte finish called P-95. Assuming that this finish provides a lambertian distribution of scattered light, the variation in intensity over the 2-degree field of view of the PanSTARRS-1 telescope is only $1 - \cos^2 2^\circ = 0.06\%$. Even if the diffuser deviates quite dramatically from truly lambertian, it will still produce a uniform distribution over the required angle to well within 1%.

To increase the efficiency of the system and to suppress edge effects, we enclose the borders of the cavity formed by the radiator and the diffuser with side mirrors.

2.3. Baffle Screen

One drawback of the flatscreen calibration approach is that much of the light emitted by the screen emerges at angles much larger than the acceptance angle of the camera. Some of this stray light will inevitably scatter off the dome and telescope structure and will fall on the focal plane, thereby contaminating the signal that is due to light passing through the optical system of the telescope. We intend to remove the stray light signal from the calibration image by subtracting a flat taken with the secondary masked, but the system would still clearly benefit from suppression of stray light in the first place.

Since the only light to be used by the system is that which emerges from the screen in a cone of about 2 degrees opening angle, we will include a baffle screen directly in front of the diffuser. The baffle screen is a sheet of black ABS plastic 23 mm thick in which a close-packed array of small holes has been drilled. Each hole is machined with an entrance aperture and an exit aperture of different sizes so that the exposed area of diffuser seen from a position within 2 degrees of the normal appears unoccluded, but the visible luminous surface drops off rapidly at viewing angles greater than 2 degrees. The inside of the holes are threaded in order to suppress specular reflections of off-axis rays.

2.4. Mechanical Structure

The optical components are supported by a structure fabricated from aluminum honeycomb panels and additional bracketry. As shown in Figure 2, the radiator assembly is backed by a sheet of honeycomb paneling. A second panel placed in front of the diffuser has a circular aperture cut in it to mask the area of the diffuser that lies outside the aperture of the telescope. The backing panel and mask panel are connected by lengths of aluminum U-channel that also hold the plastic components in place. Overall thickness of the completed panel is 13 cm (5 inches). Figure 3 shows a plan view of the assembled device. The baffle screen fits directly over the diffuser and is captured in the circular aperture of the mask panel.
2.5. Light Source

The light source for the system is a tunable pulsed laser manufactured by Opotek, Inc. of Carlsbad, CA, USA. This is the same laser system that Stubbs used for the feasibility study at CTIO and is described in more detail elsewhere in this volume (Stubbs et al. 2007). The great difference with regard to the laser as used in the projection system as opposed to the self-luminous system is that in the self-luminous system the laser light must be divided evenly among the eight glowing fibers that span the radiator panel. We split the light using the straightforward expedient of an “octofurcated fiber” provided by Ocean Optics of Dunedin, FL, USA. This device consists of eight 400 µm fibers gathered into the ferrule of a single SMA connector. The common end is coupled directly to the laser output, while each of the eight arms is coupled to one of the eight glowing fibers by way of an adjustable attenuator. The attenuator (supplied by Ocean Optics) allows balancing of the light output across the array of fibers, and also provides a mode scrambling effect that improves the uniformity of the emissions along the length of the glowing fiber.

Although the glowing fiber is designed and manufactured to radiate uniformly over its entire length, the actual luminous flux per unit length does vary considerably from point to point. Figure 4 shows the results of our measure-
ments of relative light output. In order to even out the light distribution across the radiator, we divide the 176 fiber grooves into the radiator into eight “unit cells” of 22 channels each. We then weave a single 60-meter fiber back and forth across each unit cell following a pattern contrived to place brighter sections of fiber adjacent to dimmer sections. The result is a distribution of surface brightness that is as uniform as possible across the span of the entire radiator. The diffuser serves to even out short wavelength (groove-to-groove) variations, while adjustments to the fiber attenuators will serve to even out any long-wavelength (cell-to-cell) variations.

![Figure 4](image_url)

Figure 4. Relative emittance of a luminous fiber as a function of position along the fiber. The shape of this curve depends strongly on how the fiber is fed. In all cases, however, the profile is independent of wavelength. The solid curve corresponds to 500 nm; dotted, 600 nm; dashed, 650 nm; dash-dot, 700 nm; dash-dash-dot, 750 nm; and long-dash, 800 nm.

### 3. Current Status

As of this writing, we have all the components in hand to construct a prototype 2-meter diameter unit for installation in the PanSTARRS-1 enclosure. Machining the fiber-carrying grooves in the radiator has been performed using a router carried by a precision x-y stage mounted on a 3-meter square granite surface plate. We have completed several smaller test samples to verify the fiber weaving technique and to evaluate the system optical properties. We have also tested several approaches to the final design of the baffle screen, and expect to make a final evaluation in the near future. We expect to install the first unit on the
PanSTARRS-1 telescope in the spring of 2007. In the longer term, we intend to develop a system that will span the 8.4-meter aperture of the LSST.

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References