Zwicky Transient Facility (ZTF)

Flat Field Screen Requirements

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# Revision History

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| **Version** | **Date** | **Author** | **Revision Description** |
| 0.0 | 2016-01-20 | TK | Initial draft |
| 0.1 | 2016-02-12 | ECB | Revised throughout |
| 0.2 | 2016-08-23 | R.Smith | Revised heavily: more specific & quantitative. |
| 0.3 | 2016-09-27 | ECB | Added Performance Requirements and improved flowdown |

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# Introduction

## Purpose

This document presents the rationale behind requirements for a flat field screen and screen illuminator for the Zwicky Transient Facility. It includes functional and performance requirements.

Using stable dome flat images will improve the photometric accuracy of the survey.

## Scope

The Flat field element provides the following elements:

* A flat field screen mounted in the dome
* Screen illuminator
* Additional TCS elements if needed

## Acronyms and abbreviations

* DS – Data System (the data processing and archiving portion of the ZTF project)
* FITS – Flexible Image Transport System.
* FoV – Field of View
* GUI – Graphical User Interface
* MTBF – Mean Time Between Failure
* OS – Observing System (the data acquisition portion of the ZTF project)
* PBS – Product Breakdown Structure
* TBD – To Be Determined.
* TBC – To Be Confirmed.
* TBR – To Be Revised.
* TCS – Telescope Control System.
* WaSP – Wafer-Scale camera for Prime, a large-format CCD camera for the Palomar 200” prime focus.
* ZTF – Zwicky Transit Facility.

## Definitions

In the requirements specifications, the following verbs are defined:

* Shall – denotes a requirement that is mandatory whenever the criterion for conformance with the specification requires that there be no deviation. It implies obligation.
* Should – denotes a guideline or recommendation whenever noncompliance with the specification is permissible. It expresses a contingent or conditional act or state, or a moral obligation.
* Will – denotes a simple statement of fact.

## Related Documents

* ZTF Science Requirements Document
* ZTF Photometric Requirements Document

## Document Organization

The rest of this document consists of an overall description flat fielding infrastructure – its functions, interfaces and constraints - followed by individual requirements including functionality, performance, reliability, implementation, design and documentation requirements.

## Points of Contact

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# Background

“Flat fields” are camera exposures of structureless scenes of (nearly) uniform brightness. They are used to calibrate CCD images for differences in throughput and gain on short spatial scales: between CCDs by comparing intensities across nearby boundaries, and from pixel to pixel within a CCD. Stable, accurate flatfields are one of the prerequisites for achieving high photometric precision.

PTF and iPTF use so-called superflats to calibrate the images. This superflat is constructed from sky images taken throughout the night (Laher et al. 2014). Stars and other contaminants are excluded by outlier rejection. The ZTF science requirements document sets a goal of 1% absolute photometric precision, driven by supernova Ia cosmology. Analysis of the PTF flats shows night-to-night variations of several percent, far larger than expected due to intrinsic throughput variations (F. Masci, priv. comm.). The PTF flat field calibration method is accordingly insufficient to reach this photometric goal.

Night-to-night variations in superflats (or twilight flats, another alternative) are inevitable due to changing sky conditions. In particular, the presence of high cirrus clouds, changes in scattered light from the moon at different phases and distances, and (for twilight flats) changes in the color of the sky with time will all modify the observed flat field.

Seeking greater stability and control, modern supernova cosmology surveys have (re)turned to dome flats (e.g., Marshall et al. 2013, PASP 125, 1277; Marshall et al. 2013 arXiv:1302.5720v1). As the relevant photometric precision requirements and science use cases are quite similar, we adopt a similar design approach.

## Connection to absolute calibration

Relative photometric stability—the repeatability of photometric measurements across the camera field and over time—is a necessary prerequisite for accurate absolute calibration. The latter requires use of fundamental standards (whether laboratory or astrophysical) to determine the absolute throughput of the camera, telescope, and atmosphere. Stable flat fields corrected for the effects of scattered light are vital to the former.

## Tracking temporal trends in gain and sensitivity

If flats are to be used to crosscheck long-term throughput or gain changes then the illumination must have greater stability than the telescope coatings, sensor QE, and gain.

## Short spatial scales

Dome flats are principally useful for measuring sensitivity variations on short spatial scales. Accuracy on medium to large spatial scales will be compromised not only by illumination non-uniformity at the screen, but the fact that returning light is not collimated so that baffling to reduce scattered light is ineffective.

## Long spatial scales

To achieve the desired photometric precision, it will be necessary to calibrate throughput variations on long spatial scales by performing aperture photometry on the same stars placed at different locations across the field. This measurement should be relatively immune to scattered light effect (because of the background subtraction).

## Shutter timing dependence

Even though the shutter is very close to the pupil plane there will be some field dependence of throughput on exposure time since beam obstructions are caused by three dimensional objects whose beam footprint differs with viewing angle and thus pixel location on the focal plane. The vignetting at the edge of the field if view is caused by portions of the beam falling beyond the edge of the primary mirror. These edges of the beam see a shorter exposure time than the center of the beam causing the vignetting function to be a strong contributor to the exposure time error.

As a consequence, one must either calibrate low to mid spatial scale variations in throughput using the *same exposure timing* or be prepared to measure the exposure time dependence and correct for this explicitly.

## Wavelength dependence

Flat field structure depends quite strongly on wavelength, particularly in the blue. Some causes are:

* “Brick wall” pattern due to laser annealing of the Boron implant at the back surface. This pattern has the highest spatial frequency and strongest wavelength dependence.
* AR coating non-uniformity (usually slowly varying and small amplitude).
* CCD thickness variation (changes red response; mid spatial scales)
* Contaminants (absorption and modulation of AR coating performance)
* Dust (short spatial scales)
* Pixel boundary effects due to lithography, dopant/donor density variations etc. Very short spatial scales.
* Filter throughput nonuniformity (mid to low spatial scales).

The photometric response is of course not only a function of the CCD and filter characteristics but also the spectral energy distribution (SED) of the astronomical source and sky. The interaction between SED of the source and the sensor, sets a limit on photometric precision since in practice we average the response over the pass band and make simplifying assumptions about the source SED which is often not accurately known (if at all).

As a general rule, an illumination source which is flat across the filter pass band or at least samples it over a wide range, will bias the photometric measurement less than narrow band illumination.

## Scattered Light

Scattered light, whether from light sources in the dome or from reflections of the illumination sources off material outside of the flat field screen, may compromise the accuracy of the resulting flats. In particular, it may introduce spatial or temporal nonuniformities in the illumination. Further, while the rays from a dome screen are necessarily different in nature from those of astrophysical sources (near-field diffuse rays vs. plane parallel rays), off-axis rays from scattered light create further complications in correcting the dome flat images for these effects. Accordingly, we use modeling as well as pragmatic design based on best practices in order to minimize scattered light from the dome flat system.

# Performance Requirements

**ZTFOS-FS-001 Illumination Uniformity**

The surface brightness of the illuminated flat field screen shall be spatially uniform to 10% or better. As described in Stubbs and Tonry (2006), this is a necessary (but not sufficient) condition for 1% photometry. This requirement may be verified either by appropriate raytracing or by direct measurement in the laboratory using a collimated photodiode that rasters over the flat screen area.

**ZTFOS-FS-002 Illumination Stability**

To aid in absolute calibration, the integrated intensity of the illuminated flat screen shall not vary by more than 2% (TBC) over the course of the anticipated 3-year ZTF survey and less than **0.2% peak to peak over any 24 hour period** (TBC) within the allowed operating temperatures range specified below.

# Functional Requirements

## Flat field screen

**ZTFOS-FS-010 Screen Size and Shape**

The screen shall have a circular, white, diffusing area. The diameter of the reflecting area shall exceed the beam footprint the chosen axial distance by 10 cm (TBC) to accommodate dome positioning errors. (Telescope pointing error will be negligible by comparison.)

**ZTFOS-FS-011 Screen Orientation**

The screen surface shall be normal to the telescope axis. Quantification **TBD**, based on modeling from the illumination uniformity requirement.

**ZTFOS-FS-012 Screen Flatness**

The reflective material shall be attached to or deposited on a stiff, flat substrate. Quantification **TBD** , based on modeling from the illumination uniformity requirement.

**ZTFOS-FS-013 Screen Location**

The flat field screen shall be located at a fixed location inside the telescope dome, external to the telescope shutter.

The screen shall be mounted no more than 45 degrees from zenith in order to minimize dust accumulation. (TBC)

**ZTFOS-FS-014 Screen Positioning**

The dome-telescope system shall position the center of the flat screen to within 10 cm (TBC) of the telescope optical axis. Tests shall verify if misalignments of this scale produce variations of the obtained flat field greater than 0.1% RMS. If so, an active alignment system may be used to reduce the misalignment to achieve that 0.1% RMS repeatability in the flats.

**ZTFOS-FS-015 Screen Material**

To maximize illumination uniformity and minimize sensitivity of the illumination on alignment variations, the screen material shall generate highly isotropic (near-Lambertian) luminance in response to illumination in ZTF’s g, r, and i filter bands~~.~~

Labsphere’s Spectralon material and Spectraflect and Duraflect coatings are commercially available near-Lambertian surfaces that meet these requirements and may be used.

## Stray light

**ZTFOS-FS-020 Light leaks**

Exposures acquired with flat field illuminator off and dome lights on shall produce no more than 1 photon per pixel per second (TBC: should be <0.1% of count rate at the camera from the illuminated screen, derived from the uniformity requirement.).

**ZTFOS-FS-021 Masking and Baffling**

The reflective screen shall be surrounded by a nonreflective surface or baffling in order to reduce scattered light from the illuminators as well as other light sources in the dome.

The nonreflective surfaces or baffles shall reflect less than 5% (**TBC**) of the incident light in the wavelengths of interest. Based on the work of Marshall et. al 2014 (SPIE 9147, 4), several commercially available black felts and fabrics meet this specification.

In order to minimize stray light from dome sources and off-axis reflections, the space between the screen and the telescope may be surrounded by black baffles with black flocking on interior sides and downward facing surfaces, having baffle depth greater or equal to baffle spacing, and less than 2% (baffle edge) area that is susceptible to grazing incidence reflection. The diameter of the baffle opening may exceed the beam foot print by at least 10 cm (matching the white area) and no more than 15 cm.

## Illumination

**ZTFOS-FS-030 Illuminator location**

The illuminators shall be mounted in a location that not impede the range of motion of the telescope or dome, yet deliver the light leak and illumination uniformity specified above.

The illumination system shall be designed to permit laboratory testing of the flat field assembly away from the telescope.

**ZTFOS-FS-031 Illumination Monitoring**

During flat field measurements, the intensity at selected portions of the screen shall be measured by means of calibrated photodiode(s) to an accuracy better than 0.1% (TBC) and the measurement(s) logged.

**ZTFOS-FS-032 Operating temperature**

The illuminator shall meet intensity and wavelength stability and over an operating temperature from -10 C to 25 C.

**ZTFOS-FS-033 Intensity variation with wavelength**

Intensity shall not vary with wavelength by more than 10% within any of the g, r, or I filter band passes, though band to band intensity, or more steeply than 1% for every 10 nm. (TBC)

**ZTFOS-FS-034 Power dissipation**

The surface temperature of the illuminators and structure to which they are attached shall not exceed 1 K above ambient, when measured 5 minutes after operation for 20 minutes..

**ZTFOS-FS-035 Peak intensity**

Peak intensity shall be between 10,000 e-/s/pixel and 20,000 e-/s/pixel on the central four ZTF CCDs.

**ZTFOS-FS-036 Wavelength coverage**

Illuminators shall be chosen or filtered to provide illumination across the g, r, and i bands. As a goal, there may be separate illumination sources to cover the center of the filter bandpass as well as both the blue and red edges of each bandpass in order to aid in color calibration.

**ZTFOS-FS-037 Intensity range (goal)**

Brightness of the illuminators should be adjustable by remote control in 0.02% increments or finer up to the peak intensity.

**ZTFOS-FS-038 Minimum intensity (goal)**

When the illuminator is switched off, it should produce <0.01 e-/s/pixel, for an exposure taken pointing at the flat field screen at night with dome lights off, commencing 200 seconds after 10s at peak illumination.

**ZTFOS-FS-039 Intensity linearity (goal)**

Intensity settings should be linear to 0.01% or better. (goal only)

## Control functions and interfaces

**ZTFOS-FS-040 Remote operation**

The illumination system shall be remotely controllable to permit automated calibrations and diagnostics.