Flat Field Calibrations for the AAVSO Photometric All Sky Survey (APASS)

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Abstract

In this paper the authors discuss the flat field systems utilized in the AAVSO Photometric All Sky Survey (APASS) to include the various stages of construction and details of the testing from each system studied and used. The need for well-calibrated images is obvious when conducting a photometric survey intended for use as a catalog of secondary standards covering the entire sky. Several systems for flat field calibration were investigated.

1. Introduction

Each CCD pixel acts as a unique detector; it has a different response to light than its neighbors. Some of this difference is intrinsic to the pixel, such as its quantum efficiency and spectral response; some of the difference is extrinsic, such as system vignetting or obstructions in the optical path. Correcting these effects, so that each pixel has the same normalized response as its neighbors, is a process called flat-fielding. In general, you present a uniform illumination pattern to the front of the telescope, see what the response is at the detector, and then divide this response into all science images so that weak pixels are boosted and over-bright pixels are reduced. There are a number of methods of producing that uniform front-end illumination, such as light boxes, projection screens (“dome flats”), or twilight (“sky”) flats.

The AAVSO Photometric All-Sky Survey is designed to provide calibrated photometry in five passbands over the entire sky, using a telescope system in the north at DRO (Dark Ridge Observatory, Weed, NM) and one in the south at CTIO (Cerro Tololo Inter-American Observatory, La Serena, Chile). The telescopes are very wide field (2.9x2.9 degrees) systems with KAF 16803 (4kx4k) detectors, so accurate calibration across the entire field is essential for the success of the survey.

We have investigated several methods of flat-fielding the APASS systems, and describe three of those methods (two projector flat systems and twilight flats) in this paper.

2. The Hardware

2.1 The Construction of the Dome Flat Screens

The advantage of using dome flats as opposed to sky flats is that the dome flat screen is always available. Since flats are taken after any significant change in the optical train of the scope [e.g. filter change or camera rotation], it is often necessary to take these flats at the *end* of the nights observing rather that at the beginning, when sky flats are available.

To properly illuminate the reflective surface, the illuminator for these dome flats must have a wide spectral output. Incandescent lamps offer the widest range of spectral output. When underpowered, they offer output mainly in the red and IR range. Then overpowered, they will produce a spectral output rich in the blue wavelengths of the spectrum (Figure 1).

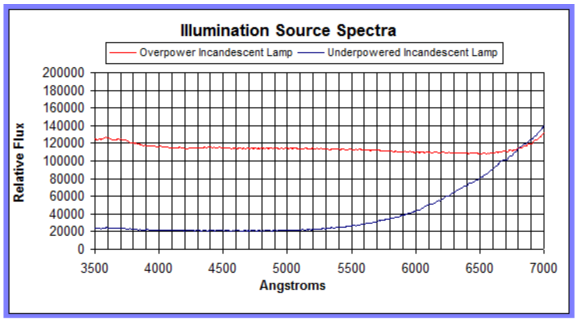

Figure 1. Spectra of incandescent lamps used to illuminate dome flat field screen [spectra taken by DRS]. Graph shows increased IR lamp spectra at low power while a nearly flat response in the visual range when used at over-power conditions

The reflective media itself is one variable that must be addressed when building the dome flat reflector. If the illuminator has a wide spectral output, but the reflector has a selective reflectivity, the CCD will not realize the full spectrum of the illuminator. Today, virtually all commercial white paints derive their pigmentation from titanium dioxide and zinc oxide. While the pigments look “white” to the human eye, their spectral response is much more red than blue (Massey & Jacoby, 1992). The answer for this is to coat the reflector using a pigment known to have a flat spectral response. Barium sulfate is such a pigment. CC Wu detailed the use of barium sulfate in his paper on sensitometer design (Wu et al., 1972). Wu derived a paint formula where barium sulfate was dispersed in vinyl alcohol binder as the vehicle. The paint formula was problematic for the reason that unmodified vinyl alcohol makes an inferior binder due to oxidation and poor long-term ultraviolet light stability. It also has poor adhesion to non-porous substrates.

One of the authors (DRS) has updated Wu’s formula by using precipitated barium sulfate, aka: Blanc fixe, as a pigment/filler and has replaced the vinyl alcohol with a modern aliphatic polyurethane polymer base as the coating vehicle. Blanc fixe, because of it purity, has a higher surface brightness than barium sulfate. The Blanc fixe is ground to a fine particle size using a three-roll paint mill. The milled media is let down into the aliphatic urethane polymer base. The aliphatic urethane polymer is a clear, film-forming coating that polymerized in the presence of air as the water evaporates from the coating. The coating also contains thixotropic agents and sufficient flow control agents to hold the filler in suspension and ensure an even coating the final product. The urethane polymer provides light fastness and outstanding adhesion to most clean porous and non-porous surfaces.

The Blanc fixe filled urethane coating was applied to twelve-inch diameter x 0.25” cutouts of high-density fiberboard substrate, aka: Masonite®. The coating was applied to the mill finish [smooth side] of the substrate. Four coats of the product were required to provide a coating that completely covered the dark surface of the Masonite®. It is important to use a dark surface substrate such as Masonite®. The dark substrate will reveal any inconsistency in the coating thickness at the time of coating. It will also absorb rather than reflect any light that might completely penetrate the reflective coating.

2.2 Target Installation

The mounting hardware was originally designed to place the flat field targets side-by-side as would be the case for the two optical telescope tube (OTA) orientation with the Paramount® ME German equatorial mount looking due north. It was quickly obvious that the flat screens would have to be mounted and tilted such that they would be perpendicular to the optical paths. This would introduce serious sky sight limitations. The final target orientation was that of an over-and-under configuration positioned at a convenient location and elevation to preclude sky obstructions. See Image 1.

Image 1. APASS-north in PARK configuration with flat field targets in their normal, permanent position.

The flat targets are illuminated using remotely switchable banks of tungsten incandescent, “grain-of-wheat” bulbs (see Image 2) and controlled through a Phidgets® I/O device with associated relays. The modified dew shields prevent internal OTA illumination with light rings mounted just behind the dew shield opening.

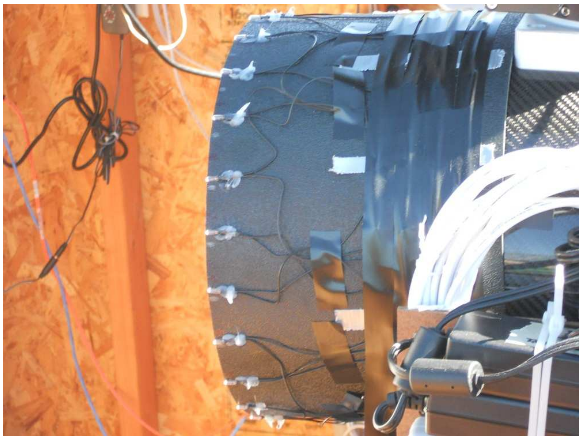

Image 2. One of the OTA flat-field target illumination bank systems with tungsten "grain of wheat" bulbs.

2.3 Alternative Screen Material

A simpler flat-fielding surface can also be used, though you must be careful: the surface needs to have Lambertian reflection properties (isotropic reflection that does not contain information about the angle of original illumination; that is, no reflected image of the illumination source); it must be uniform and flat; and it must have good reflection properties across a broad wavelength range. As mentioned above, standard paint does not work well in the blue/ultraviolet part of the spectrum.

Image 3. Styrofoam flat targets.

However, we have found an interesting alternative. Standard 1-inch insulation panels sold in most home improvement centers are made of Styrofoam®, with a foil covering on one side. The panels have a glossy foam surface, not ideal for a projection screen. If you peel the foil off of the other side, that foam surface is dull and works well as a projection screen. Image 3 shows one of these panels, where we have left two 14-inch circles bare and have painted the remainder of the background with a flat-black paint.

Surprisingly, this foam surface has good reflection properties in the ultraviolet and comes close to the performance of the painted surface described earlier. We use the Styrofoam® projection screen for APASS-south, as it was developed before the paint was available. We expect to take painted screens to APASS-south during the next maintenance trip so that both northern and southern systems use identical flat-fielding methods.

2.4 Twilight Flat System

The first flat attempts made were utilizing an incandescent bulb (dimmable using an X-10 lamp module) shining on four layers of cotton cloth stretched on an embroidery hoop acting as a diffuser (see image 4).

Image 4. One of the two light diffusers used in the early APASS flat system.

While this method was sufficient for initial operation, we re-used the hoop diffusers for tests of twilight flats. Twilight flats use the sunlit sky as the illumination source. For wide-field systems, traditional twilight flats, where the telescope points to a zenithal location and takes multiple exposures during twilight, dithering between exposures so that star images will be removed with a median combine of the stack, do not work well. The sky is not uniform over the telescope field of view (Chromey and Hasselbacher 1996), and there are many bright stars at any pointing, making even median combining difficult. Instead, using a diffuser such as shown in Image 4 removes both sky non-uniformity and any point source. Diffused twilight flats are common for many telescope systems, and can work at DRO where a human operator is present for startup and shutdown, but won't work for an automated system.

Twilight flats also have the problem of changing illumination as the sun gets farther below the horizon. You also need to avoid nights where the moon is near the pointed position, as this can cause gradients even in a diffuser flat. The download times (20 seconds) for the cameras made getting a sufficient number of flats in one evening very difficult. It was necessary to take flats over many evenings in order to cover the entire 5-filter set used in the survey.

3. Flat Analysis

There are two ways to test one flat system vs. another: ratio the images to see how well one compares with the other, and compare how well they do in providing reproducible photometry on the sky. The latter method is not possible at this time, as we have other corrections that must be applied to the images to account for optical distortions and scattered light, and they also correct for any deviations from uniformity of the flat-field. Therefore, we cannot separate flat-fielding differences between the various illumination systems. However, we can compare one set of flats vs. another, to at least highlight where differences occur and are likely to impact photometry.

Shown in Table 1 are the exposure differences between the painted screens and the Styrofoam® screens as a function of wavelength (using broadband Sloan filters from the ultraviolet to the far red).

Filter	wavelength	ratio (foam/paint)
u'	355.7	1.03
g'	482.5	1.14
r'	626.1	1.06
i'	767.2	1.02
z'	909.7	0.96

Table 1. Ratio of responses

Note that the Styrofoam® has higher reflectivity than the paint except in the far-red. There is a peak in the Sloan g', most likely due to fluorescence in the foam material. Because of this, even though the foam response is a cheap and simple screen material, we consider the paint to have a more uniform spectral response.

Comparing the flat images tells you whether there are gradients of one with respect to the other, or other features that are not common with all systems. Unfortunately, there are many affects besides flat-fielding on the APASS images. Most notably, scattered light is more prevalent in the blue than in the red. Shown in Image 5 is a typical r' flat using the painted targets. The center-to-edge vignetting is about 25%, with the corners being outside the 52mm corrected image circle of the astrograph and so being substantially weaker.

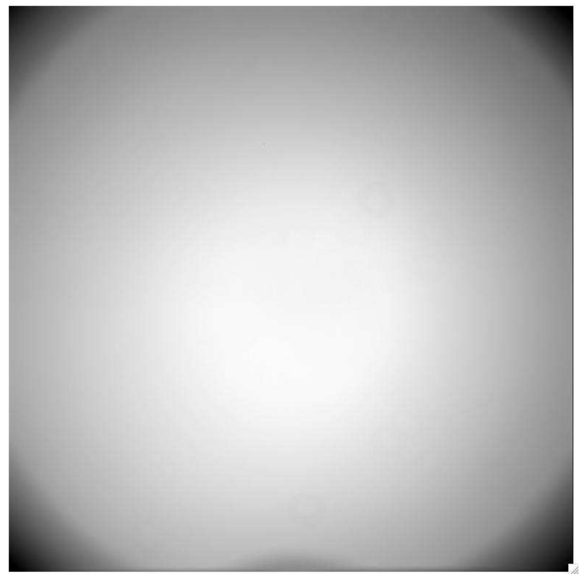

Image 5. Typical r' flat field using painted target.

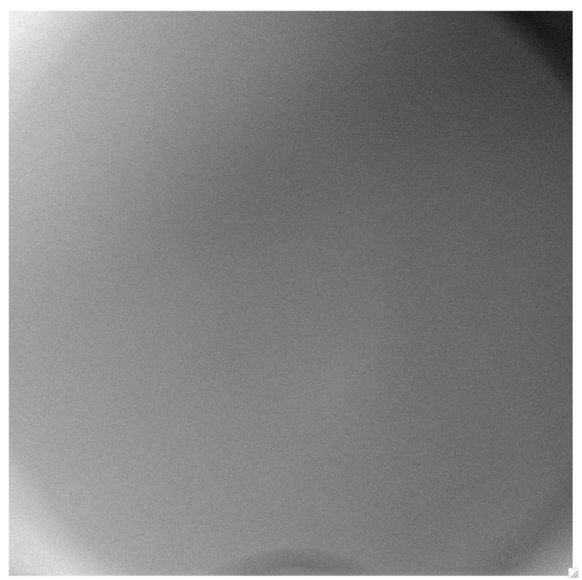

Image 6. r' foam flat divided by painted flat

Image 6 shows the ratio between the foam flat and the paint flat, with the scale such that from the left edge to the right edge is about 0.5%. At shorter wavelengths, the difference can be several percent due to scattered light.

4. The Current Systems in Use

After much testing of the various methods of flat field acquisition it was determined that the most repeatable and "flat" images came with the combination of tungsten bulbs ("grains-of-wheat") and the new Blanc fixe coated flat targets. The system is illuminated in banks as necessary to achieve a good flux level while keeping the flat image exposure times between 10 and 30 seconds. This system is in use at APASS-north and will be sent to APASS-south for installation on the next maintenance trip.

5. Conclusion

Many different methods of taking flat-field images are possible, especially for the typical narrow field imaging system. For wide-field systems, the choices are harder. Diffused twilight flats would probably be the best, if this could be automated and if sufficient flats could be taken to get high signal/noise in the flats. Failing this, some sort of projector flat is a logical alternative, and we present two possible setups for taking such flats. Based on preliminary photometric results and visual inspection of the flats, we feel that the Blanc fixe painted flat targets are the best choice for APASS.

6. Acknowledgements

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7. References

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