Photometric Calibration Plan for the Pan-STARRS AP Survey

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ABSTRACT

The Pan-STARRS project will perform an initial Astrometric and Photometric (AP) Survey beginning in mid-2006 using the prototype telescope PS-1 to be located on Haleakala. The goal of this survey is to provide a calibration reference grid for observations from the main Pan-STARRS survey which is expected to begin in the 2008-2009 timeframe. We have been working with the Canada-France-Hawaii Telescope (CFHT) Legacy Survey / MegaPrime photometric standards team to guide the design of the photometric calibration procedures and to assess the likely sources of systematic errors. The current photometry from the CFHT MegaPrime standard star analysis demonstrates relative photometric residuals of better than 10 millimagnitudes. The Pan-STARRS AP Survey will implement the lessons learned from CFHT and in addition make use of additional external atmospheric transparency measurements as well as an innovative flat-field screen in an attempt to push the photometric accuracy below the 10 millimagnitude level. We discuss the plans for the Pan-STARRS AP Survey photometry calibration. The resulting photometric reference catalog will provide a highly accurate and dense reference system for future science observations in the entire 3 steradians accessible from Maui.

1. BACKGROUND

The Reference Mission for Pan-STARRS Telescope #1 (PS-1) on Haleakala is designed to act as a test-bed for the commissioning, testing, and calibration of the Pan-STARRS hardware and software in anticipation of the full Pan-STARRS array. The Reference Mission consists of three observing programs including an Astrometric and Photometric (AP) pre-survey over 3 steradians in 5 passbands, grizy. The photometric accuracy goal of this survey is 10 millimagnitude scatter within the internal system across the sky. In this article, we discuss the plan for analysis and calibration of the data from this survey in order to achieve the stringent photometry goals.

The PS-1 Reference Mission is expected to take two to three years, from PS-1 First Light - scheduled in January 2006 - to the deployment of the full Pan-STARRS array in approximately 2008. The AP Survey discussed here will have priority for photometric weather up to a maximum of 40 percent of the total time per lunation until the AP survey observations are completed.

Given the expected sensitivity of PS-1, the resulting observations should have a Poisson Signal-to-Noise ratio > 100 for stars between $8 < r < 20$ magnitude using a combination of long and short exposure times as well as a bright star video mode available to the PS-1 camera. The resulting grid of photometric references will consist of roughly 1 billion stars across the 30,000 square degrees, or an average density of 8 per square arcminute. This reference grid will allow observers of the future, including the surveys performed with the full Pan-STARRS 4-telescope array, to perform accurate photometric calibrations using *in-situ* standards.

In order to achieve the stated astrometric and photometric precision, the AP Survey must be performed in such a manner to maximize the chances of calibrating the data and demonstrating the quality of the calibration. The PS-1 telescope system will dynamically schedule the AP Survey observations when the observing conditions are judged to be photometric. In addition, the Pan-STARRS project will employ a variety of new technologies to monitor the conditions, perform the unique observations, and determine the data calibration necessary to achieve the photometric and astrometric accuracy goals. These new technologies, discussed in greater detail below, include an atmospheric transparency monitor (SkyProbe), an atmospheric emission and absorption line monitor (SpecProbe), orthogonal transfer array detectors with selectable video-rate readouts for individual cells, continuous wave-front sensing, and a unique fiber-fed calibration screen for flat fields that will measure system throughput. Combining these technologies with detailed system monitoring will allow an unprecedented control over the data quality assurance and calibration process.

2. SOURCES OF PHOTOMETRIC UNCERTAINTY

We have experience from the Canada-France-Hawaii Telescope (CFHT) wide field imagers, CFH12K & MegaPrime, and from the Sloan-Digital Sky Survey (SDSS) of the many sources of error encountered by photometric observations with wide-field, multi-detector cameras. We discuss these issues, roughly in the order in which they are encountered in the data analysis.

2.1. Sky Transparency

The photometric reference catalog will ultimately be limited by the sky transparency. Spatial variations in the sky transparency will limit our ability to perform relative photometry within a single image. Temporal variations in the sky transparency, even in the absence of spatial variations, will limit our ability to tie spatially separated images to the same photometric system. Spectral variations in the sky transparency will limit our ability to compare photometry of the same star with the same detector and filter set. Reference [1] has examined the amplitude of these types of variations for Mauna Kea from the MegaPrime and CFH12K standards observations, as well as other data sets such as the CFHT SkyProbe camera.

2.1.1. Spatial vs Temporal Transparency Variations

Using the MegaPrime and CFH12K standards observations, [1] has summarized the spatial and temporal variations in the sky transparency. This study used queued/service observing (QSO) standard star observations, which are generally biased to times when the observers judged the sky to be photometric on the basis of either SkyProbe (the CFHT atmospheric transparency monitor) or the appearance of the twilight sky before sunset. Thus the data do not sample cloudy times very significantly.

Table 1. Statistics of MegaPrime Standards Zero-Point Offsets

Filter	# of images	Percent with zero-point offset of			Percent with scatter of	
		< 20 mmag	< 10 mmag	< 5mmag	< 7 mmag	< 3.5mmag
u	151	58.3	36.4	15.2	95.4	24.8
g	276	71.7	46.4	26.8	98.6	46.9
r	350	72	44.3	25.4	92	45.6
i	294	74.1	46.3	25.5	95.3	35.8
z	249	65.5	38.6	18.1	96.4	12.8

The study demonstrates that, when the sky is apparently photometric, uniform transparency variations dominate over small-scale transparency variations: *i.e.,* haze dominates over structured clouds in these circumstances. This can be seen in Table 1 taken from [1] which lists the percent of images for which the mean transparency of the image differed from the mean transparency of the lunation by less than 5, 10, and 20 millimagnitudes. It also lists the percent of images for which the relative photometry scatter of the bright stars was less than 7 and 3.5 milli-magnitudes. The offsets represent a measure of the temporal variation in the average sky transparency, while the scatter values represent a measure of the per-image spatial variations in the transparency. Note that either of these values may be inflated by other aspects of the measurement errors, so they must be taken as upper limits on what can be expected only from the atmosphere under photometric conditions.

Table 2. Zero-point scatter as a function of delay

filter	Scatter (mmag) for images in delay range		
	T < 1hr	1h < T < 1day	1day < T < 10day
u	20.9	27.4	30.9
g	10.7	17.9	25.2
r	19.7	17.9	26.3
i	12.6	15.8	21.5
z	7.6	15.4	30

Reference [1] also shows that the average measured atmospheric transparency offset between two observations grows as a function of time between the two observations. Table 2 from [1] shows the scatter of this difference as a function of filter for image pairs obtained within 1 hour and within 1 night (0.5 day), and over the course of several nights, excluding pairs which are extremely deviant (>0.1 mag), representing clouds. The values given in this table show that the atmosphere transparency is more consistent over short timescales than over long timescales. Thus, the transparency at any moment in time is not simply a random variable drawn from a population. Rather, the transparency drifts in a fashion more akin to Brownian motion: the change in transparency between two points in time can be considered a random variable drawn from a population with a standard deviation which depends on the time between the two measurements. Note that the numbers in the table have had a nominal zero-point for each run subtracted, which removes an even longer-term and larger-amplitude transparency variation.

This examination of the sky transparency shows the expected limitations of the Pan-STARRS AP Survey and illustrates what is needed in order to achieve the maximum accuracy possible. First, it is necessary to limit observations to periods when the sky transparency is stable. Transparency stability should be determined from multiple sources to ensure it is correctly measured. Second, the actual zero-point should be measured at least once per hour, possibly more frequently for Haleakala. Third, periods which are judged to be photometric apparently may have minimal spatial transparency variations, but may still have uniform transparency variations on timescales of hours. Finally, the sky transparency can be stable at the 10 millimagnitude level on hour-long timescales, and may possibly be more stable if more stringent restrictions are placed on the selection of photometric weather.

PS-1 will have the PS-1 Imaging Sky Probe which will provide 5 band photometry of Tycho stars in the PS-1 field during every 30 second exposure. The Tycho stars all have accurate *B* and *V* magnitudes, so once the color terms are calibrated, this should provide an excellent, independent measure of sky transparency and stability. PS-1 will also use an all-sky IR camera to judge the conditions on larger spatial scales than are possible with the SkyProbe camera. In addition, the observing strategy ensures frequent visits to calibration fields to further pin-down the zero-points on timescales of roughly 1 hour.

2.1.2. Sky Transparency Spectral Variations

We have only limited information on the spectral variations of the atmospheric transmission function. We have a suspicion that the extinction terms for the redder bands (*izy*) may vary significantly since some of the atmospheric absorption lines in this region are saturated and may vary their absorption state as a function of the environmental conditions. It is likely that at high airmass or in the reddest bands, the extinction terms will not be well represented by a simple airmass term.

PS-1 will also have the PS-1 SpecProbe atmospheric spectral monitor which will obtain a 30-second long-slit low-resolution spectrum of one early-type star per field. Using standard atmospheric models, we will model the high-resolution atmospheric absorption, constrained by the observed low-resolution absorption spectrum. For standards and objects of special interest, use of the spectral sky probe will provide a powerful tool for understanding sky transparency spectral variations.

2.2. Shutter Linearity

The shutter provides an exposure of a requested interval. The design requirements of the shutter state that the exposure time shall be accurate to 0.5% across the full field for exposure times as short as 0.1 seconds. We will test the shutter upon delivery to demonstrate the accuracy and repeatability of the shutter exposure time. This measurement may be performed in a variety of ways. The shutter will be tested using the video-rate readouts of the camera to demonstrate the consistency of the shutter motion at a variety of gravity vectors. The shutter consistency is clearly of greatest concern for the shortest exposures: the 5 second exposures of the AP Survey or the potentially much shorter flat-field exposures.

2.3. Detector Linearity

Since a goal of the AP Survey is to generate photometry of stars in a single photometric system spanning the widest possible range of magnitudes, it will be necessary to measure and correct (if necessary) the detector linearity as a function of flux. The linearity must corrected to a level of better than 0.5% over a range from 100 DN to near the saturation limit. The linearity may be a function of the amplifier or detector in question. During the commissioning stage of PS-1, the detector linearity curves will be measured and applied to the data in the analysis process.

2.4. Bias / Dark Correction

The bias correction is unlikely to have a significant impact on the quality of the photometry. First, modern detectors and readout electronics rarely suffer from serious bias errors. Second, it is easy to model and subtract the typical residual bias variations. Finally, small errors in the bias correction couple to the photometry only as a second order error in the flat-field correction. Bias corrections good to 1-2 DN will be more than adequate for the photometry needs, and these levels are trivial to achieve.

2.5. Flat-field corrections

The challenges involved in flat-fielding wide-field imagers are now fairly well understood, if not trivial to correct. It is clear [2] that a simple flat-field image is insufficient to correct the photometry across the full field of a wide-field camera. Aside from the basic geometric distortion errors, the flat-field image is typically contaminated by some large-scale structures, which can be attributed to scattered light. In the CFHT wide-field cameras, this scattered light term is quite stable from run to run and flat-field image to flat-field image. In the case of twilight flat-field images, even as the sky brightness changes by two orders of magnitude, the fractional scattered light contribution does not change at more than the 0.1% level. This is easily seen in the consistency between flat-field images taken at the beginning and end of twilight.

For PS-1 we are constructing a unique flat-field calibration screen which will consist of ~1000 illuminated fiber optics pin-point sources [3]. The density of fibers is chosen to ensure stability across the field at the 0.1% level despite small positioning errors. The major advantages of the calibration screen include: 1) the capability to obtain high-quality flat-field images on demand, 2) the ability to illuminate the detectors with sources of different spectral energy distributions, 3) the ability shutter the light-source and thus obtain true light-dark flat-field images, and 4) the potentially higher level of repeatability of the illumination pattern.

The resulting flat-field images will have to be corrected (or at least tested) for large-scale variations on the basis of stellar photometry. This has been done at CFHT on the basis of a dither sequence in which the camera is offset in both the East-West and the North-South directions. These sequences start from very small offsets (50 pixels), doubling the offset until the offset is the full size of the mosaic. To generate the flat-field correction image, the images are processed with the basic flat-field image and photometry is performed on the images. The photometry is then used to construct a correction model as a function of position on the mosaic which minimizes the scatter for each individual star: any single photometry measurement is corrected by the offset appropriate to the portion of the mosaic from which the measurement was obtained. The correction model is used to generate a new flat-field images with the appropriate correction applied. This flat-field image should thus flatten a science image so that the stellar photometry across the entire field is consistent: *i.e.,* all parts of the mosaic have the same zero points.

For PS-1, we will use a dither pattern with more samples and with a complete set of two dimensional offsets. The dither pattern will consist of a single image followed by a sequence of at least 5 - 2 x 2 offset positions with increasing separation, ranging from 50 pixels to 50% of the mosaic width. These observations will be performed in three regions of high stellar density (Galactic Plane fields) widely spaced on the sky. These dither patterns will be performed several times during the AP Survey, resulting in fields with a high density of well-measured astrometric and photometric references. These fields may also be used throughout the AP Survey to test and verify the quality of the astrometric and photometric calibrations with single quick snap-shot images.

2.6. Photometry Linearity

The photometry process must return magnitudes which are consistent to better than 5 millimagnitudes across the 3.5 magnitudes between saturation and the 2% photometry limit. To demonstrate the photometric response, we can use a sequence of exposure with exposure times ranging from 1 second to ~1000 seconds to demonstrate the photometric linearity of the measurement algorithms. These types of observations will also act as full-system tests of the linearity resulting from the shutter, detector, and measurement techniques.

2.7. Chip-to-Chip Color Response

Photometry from stars on individual chips need to be brought to a common system before they may be compared. Small differences in the detector spectral response translate to color terms between detectors. In the CFHT MegaPrime standards, we have addressed this by defining an internal photometry system in which each detector has a color correction which places the photometry from that detector in the internal system. We use the dithered images used to construct the flat-field correction frame to determine the chip-by-chip color terms. Every possible measurement of a star on two different detectors can be used to determine the specific chip-to-chip color term. The collection of color terms between chips can then be used to generate a consistent set of per-chip color terms that are consistent with the chip-to-chip color terms. The observed color terms for MegaPrime are well represented by a linear trend and have slopes with a range of *ugriz* = (41, 22, 23, 40, 14) millimag/mag (though note the *z* slope is only weakly constrained in this dataset). In order to make such a measurement, it is necessary to have a large enough number of stars with sufficient signal-to-noise and a range of colors. The three Galactic plane fields proposed for the flat-field correction images should have a wide range of colors as a result of the range of extinction values in these regions.

2.8. Atmospheric extinction

During the AP Survey, it is necessary to connect observations on one field with observations of the reference fields at a different airmass. Many of the AP Survey field may be observed within a narrow airmass range. However, since the survey is required to reach both the pole and -50° south declination, it will be necessary to obtain some observations at high airmass (up to 3.0). In order to connect these observations at high airmass, it will be necessary to determine airmass extinction coefficients with sufficient accuracy. We will assign the Celestial Pole as a reference field, and will assign additional reference fields spaced in Declination between the Pole and the Landolt Equatorial fields to limit the range of airmasses between the standard fields and the survey fields. The necessary spacing and the observing strategy will be guided by measurements of variations in the extinction coefficients.

We can constrain the variations in the extinction coefficients with the SkyProbe measurements. Having the simultaneous multicolor SkyProbe camera will allow us to constrain both color independent and color dependent extinction terms. The former are likely to be haze and clouds while the latter are likely to be related to dust and Raleigh scattering. On Mauna Kea, the extinction terms are generally quite stable. In data from the CFHT SkyProbe camera, we find that the 90% of nights which are apparently photometric have airmass slopes in the range -18 to +18 millimags per airmass for V band. If we only need to extrapolate over 0.5 airmasses, this range would allow us to use a single airmass slope for all photometric nights and still only introduce an offset of 9 millimagnitudes. If we measure and apply the nightly airmass trend, then our introduced bias should be substantially smaller.

2.9. Color / Flux Calibration

As a reference catalog, it will be useful to provide the AP Survey data in the form of both internal system magnitudes and color-corrected magnitudes on an external photometric system. Future Pan-STARRS observations would be better calibrated by comparing with the internal photometry system rather than the color-corrected system, as they will be using very similar detectors and filters. However, physical quantities require calibrated flux measurements.

The color correction needed to bring the AP Survey data from an isolated system to an external reference can be determined from several sources. First, the SDSS fields will be contained by the AP Survey and will provide an invaluable reference. Second, the SDSS Secondary standards, which in principal have a higher accuracy than the SDSS objects, will also be available in the entire AP Survey. Finally, we will have the luxury of observing bright stars up to 8th magnitude with the guide star cells and the bright-star video mode. These stars can be chosen to include many Northern Hemisphere spectrophotometric standards. The measured spectra of these stars can be convolved with the measured filter transmission function to provide the calibration of AP Survey photometry in flux units.

3. PS-1 AP SURVEY STRATEGY

3.1. Observing Sequence

The basic imaging data for the AP Survey will consist of: 2 exposures of 30 seconds and 1 exposure of 5 seconds for each filter, along with 4 additional 30-second exposures in *i* (see Table 3). The 5-second and one of the 30-second exposures will be scheduled in immediate succession, in photometric conditions. The two sets of 30-second exposures in the each filter will be offset relative to one another by half of the mosaic field-of-view in both X and Y directions. In addition, adjacent to the 5-second exposure, the same pointing will be targeted for bright star observations by performing targeted video readouts for all stars brighter than 14th magnitude in the filter. The minimum effective exposure times in the video mode will be in the vicinity of 10 ms, with multiple integrations to average out the seeing motion. This procedure will give the complete dynamic range for the 5 band photometric catalog.

The observations will performed so that fields are observed with at least two filters within a short time period, sweeping over several fields in one filter, followed by the same fields in the second filter. The interval between passes will be short, possibly no more that 5-10 minutes. A likely pattern will consist of a north-south sequence of roughly 8-10 fields. The length will be chosen so that, including the overheads, a complete pass in two filters takes roughly as long as the sidereal motion of the sky to cover one FPA width at the selected declination (e.g., about 10 minutes at the equator). After performing a series of these sweeps, a nearby standard star field will be visited. Standard fields will be visited at least once per hour. During a series of patches, standards will be observed both at lower and higher airmasses. With the 25 proposed standard fields (see below), the observing strategy above results in all science fields being observed within 30 minutes and ~ 0.3 airmasses of a standard field. Such frequent re-observations of the standard fields are necessary to detect changes in the atmospheric transparency and to constrain the photometry under variations in the extinction curve. It is insufficient to rely only on the image overlaps to provide the connection between survey fields. The large number of links needed to traverse large distances across the sky result in random-walk errors which are excessive. The frequent standard star observations allows us to pin down a subset of the overlapping fields and minimize these drifts.

Table 3. AP Survey Exposures Per Position

Filter	Bandpass (nm)	Limiting Mag (5)	Exposure (sec)	Total
g	410 - 552	23.7	5 (video), 5, 2x30	70
r	550 - 694	23.3	5 (video), 5, 2x30	70
i	694 - 847	22.6	5 (video), 5, 6x30	190
z	847 - 930	21.5	5 (video), 5, 2x30	70
y	960 - 1028	19.7	5 (video), 5, 2x30	70

Thus for the 5,500 pointings that make up 3 steradians of accessible sky, the time required for the AP survey is 2,585,000 sec of on-source time. The CFHT-LS MegaPrime survey achieves an average observing efficiency of about 65%, with some observing programs reaching a high of 85%. Assuming we achieve a 75% observing efficiency (likely given our readout and slew times), this program will require 136 observing sessions of 7 hours each, all photometric. With an expected 40% of the nights photometric, this implies nearly a year (340 nights) for all data to be obtained. In practice, the AP Survey will compete with engineering and the other PS-1 survey programs in that first year, so the data collection period is likely to take somewhat longer than a year. This is actually desirable since spreading out the observations over 1.5 years will improve the measurement of parallax and proper motion.

3.2. Bright Stars in Video Mode

PS-1 has a unique opportunity to obtain photometry of all stars in the 3 survey region as bright as 8th magnitude by using the guide star cells. The value of such observations would be the ability to directly relate properties of stars in the Tycho, Hipparchos, and Bright Stars catalogs with the objects in the survey down to a depth of 22 or 23 magnitudes. Only photometry is required of these stars since Tycho provides excellent astrometry. Stars brighter than ~14 magnitude are saturated in even the 5 second exposures. The number of stars on the sky brighter than this limit is in the vicinity of 40 million, corresponding to roughly 5500 stars per AP Survey field. These stars can be observed by using the video guide star mode to measure them. The bright star mode will read out different star cells at different rates depending on their brightness. This could allow all stars to be observed with effective integration times of 5 seconds.

3.3. Standards Observations

Frequent standard star observations are required to detect and compensate for short-term changes in the atmospheric transparency and the airmass extinction curve. The observing strategy discussed above results in at least 8 standards observations per night in two filters. With full 30 second exposures in each filter, this would account for only 2.3% of the survey field observations. An open option would be to use shorter standard observations more frequently (ie, 15 second images every 30 minutes). This option increases the total overhead in exchange for a denser calibration dataset. The standard fields need not all correspond to existing standards, though some would. Rather, these are simply fields which are re-visited frequently to pin down the system zero point. We propose to define a collection of 25 standard fields scattered across the sky. Table 4 lists the characteristics of the 2 fields. They would distributed across the sky to minimize the amount of airmass range required to traverse the distance between them. The goal is to allow the survey fields to be observed as close as possible, both in time and in airmass, to a standard field. Observation of the standard fields would be performed in such a way that any sequence of survey observations would be bounded by standards observations at both higher and lower airmass. Special attention must be paid to the North Pole Cap fields since, at 70 degrees zenith angle, the airmass changes quite rapidly across these fields. Care should be taken to detect and remove any changes in the effective airmass trend.

Table 4. Standard Star Fields

Declination Range (deg)	# of fields	airmass range
90 - 88 North	1	2.67 - 2.92
78 - 81 North	4	1.89 - 2.06
65 - 68 North	6	1.41 - 1.49
0 - 3 South	8	1.06 - 1.09
20 - 23 South	6	1.31 - 1.37

In addition to the basic photometric reference fields, before the AP Survey proper is started, a limited number of fields will be observed in sufficient detail to define a dense, precise photometric and astrometric reference grid. These observations will also provide the needed data to construct the flat-field correction frames. Construction of these high density reference fields will involve many dithered observations, repeated over multiple nights to ensure photometric consistency. In the case of MegaPrime and CFH12K photometry, a dither pattern was used to construct the flat-field correction frame, which also served as a test of the photometry consistency across the mosaic FOV. These dither patterns only moved the camera in north-south and east-west directions from a starting position, and are not quite sufficient for the level of precision desired for the AP Survey. We can observe each field with 40 pointings per filter: a 2x2 grid with logarithmically increasing scale from 60 arcsecond initial offsets up to 10000 arcsec separation for the final set (e.g., offset spacings of 0, 60, 120, 240, 400, 800, 1600, 3000, 6000, 10000).

At least three complete sequences should be performed during the course of the AP Survey to test the calibration stability. The exposures for these grids must be sufficiently long to allow for a sufficiently high density of reference stars of at a sufficient signal-to-noise. These fields will thus use Galactic plane regions to increase the stellar density. With 100 second exposures and 9 dither spacings of a 2x2 pattern (and one center field), these observations account for a total of 3700 seconds of exposure time per filter per field, plus an additional 185 seconds of readout and other overhead time. Performing these observations for all 5 filters, three times over the course of the survey, will require a total of 21.3 hours, or 0.85% of the survey mission at 75% observing efficiency.

3.4. Existing Reference Data

The AP Survey needs to observe roughly 30,000 square degrees in the five photometry filters (*grizy*). Most of these fields have no internal photometric reference data. A large fraction of the sky (several thousand square degrees) encompasses the SDSS fields, which may be considered a reference with a high level of precision. However, we prefer not to be limited to the accuracy of SDSS nor require the SDSS photometry to determine the calibration, instead allowing the two surveys to act as in independent measurements of the photometry. Additional calibration fields are available from the MegaPrime QSO standards fields. These fields correspond to the 8 main Landolt equatorial fields, and may be used as an additional test of photometry accuracy. The SDSS Secondary standards are isolated stars scattered throughout the SDSS region, but have limited utility by virtue of being limited in number and color range. Finally, spectrophotometry standards may potentially be used to determine final flux calibrations. This is especially valid since even the brighter spectrophotometric standards will be observed in the Bright Star video mode. In addition, our SkyProbe camera will observe a collection of bright spectrophotometric standards across the sky to further tie down the calibration.

4. SUMMARY

We present our strategy for achieving the high-precision photometry goals of the Pan-STARRS PS-1 AP Survey. We employ a large number of interesting techniques to ensure the photometric accuracy of the survey, including: carefully controlling the construction of calibration images, frequent observations of reference fields, massive overlap of the survey images, at least triple coverage in each filter, and various external indicators of the atmospheric conditions. With these techniques and the care involved in the observation and analysis of the dataset, we expect to achieve 10 millimagnitude photometry in our system across the entire sky. The resulting reference catalog will have 1% photometric observations for stars as faint as 20th magnitude and will revolutionize ground-based astronomical photometry.

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6. REFERENCES

1. Magnier, E.A., *CFHT MegaPrime & CFH12K Standards Analysis,* in prep., 2005.

2. Magnier, E.A., Cuillandre, J.-C., *The Elixir System: Data Characterization and Calibration at the Canada-France-Hawaii Telescope,* PASP, 116, 449, 2004.

3. Tonry, J., Stubbs ,C., *Pan-STARRS Calibration Screen,* in prep., 2005.