The Pan-STARRS Imaging Sky Probe

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Abstract

Photometric performance is limited by systematic errors introduced by uncertainty in the transparency of the Earth's atmosphere. Precision photometry required for programs including the characterization of supernovae and photometric redshifts can especially benefit from independent knowledge of the atmospheric transmission. In particular, multicolor near-simultaneous observations are able to constrain the impact of aerosol, dust, and water vapor on the atmospheric transparency.

To measure the atmospheric transmission function in real time, the Pan-STARRS PS1 prototype system will utilize auxiliary instruments: imaging, spectroscopic, and potentially u-band sky probes. These instruments will act synchronously with the primary survey camera to provide calibration data for the Image Processing Pipeline (IPP), and will also generate significant all-sky science data. For the Imaging Sky Probe (ISP), the broad-band transparency of the atmosphere will be measured in five survey bands matched to the Pan-STARRS *grizy* filter set. Atmospheric absorption and emission models will then be generated to produce a best-fit characterization of the atmosphere at the time of observation. Armed with measurements of the atmospheric transmission from the sky probe instruments, the Pan-STARRS IPP can precisely solve for the intrinsic source photometry. Such a system is unprecedented, and the Pan-STARRS PS1 system will act as the test bed for future development. The intent of this talk is to describe in detail the design and testing of the ISP which is the first Pan-STARRS sky probe, and we will present ISP images collected during the early commissioning of PS1.

1 A photometric probe for Pan-STARRS

The success of an all sky survey project such as Pan-STARRS (Panoramic Survey Telescope and Rapid Response System, [1]) depends upon its ability to produce uniform, high quality data over many years. Astronomical photometry is plagued by systematic errors introduced not only by the poorly characterized transmission properties of the telescope, but by the dynamic transmission properties of Earth's atmosphere as well [2]. For Pan-STARRS we have developed the Imaging Sky Probe, a prototype five color imaging camera, to measure the wavelength dependent atmospheric attenuation in conjunction with the survey.

The modest camera is designed to image each Pan-STARRS field in five survey bandpasses (*grizy*) in synchrony with the survey telescope to provide photometric calibration. The Sky Probe's 9 square degree field of view encompasses the entire 7 square degree survey field, hence, it will provide a real-time measurement of the atmospheric attenuation in each bandpass over the entire survey field. The Imaging Sky Probe will begin measuring standard fields, and, over the first year of survey operations, build up an all-sky, internal five color photometric catalog to 17th magnitude. As of this conference, we have only begun characterizing the instrument. Here we introduce the design of the Imaging Sky Probe and its basic performance characteristics.

2 Motivations – atmospheric extinction

The attenuation of visible light in the atmosphere is the result of a combination of aerosol and Rayleigh scattering and line absorption by molecular species, namely water and oxygen (see fig. 1). Additionally, emission in the optical is produced by water vapor, hydroxyl and forbidden transitions, most prominently of atomic oxygen. These contributions vary over a range of time scales from minutes with local weather conditions, pressure and humidity, to days and months with seasonal changes. Atmospheric attenuation introduces fluctuations in the zero point magnitude, but more seriously, it produces color dependent shifts that vary with the shape of the source spectral energy distribution (SED).

Systematic errors in photometry arise because the attenuation properties of the atmosphere vary over a wide bandpass and reshape the total telescope detection efficiency function. Consider observations made of a star as it sets, the effective bandpass becomes *redder* as airmass increases and blue light is increasingly filtered out. These second order effects depend on the SED of the source and the shape of the instrument

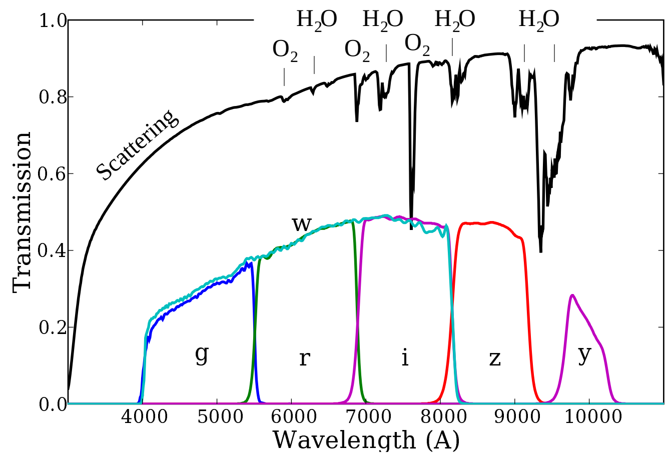

Figure 1: The Imaging Sky Probe has five filters, *grizy*, to monitor the atmospheric attenuation. The atmospheric attenuation is a smooth function of wavelength imprinted with deep atomic and molecular line absorption. The smooth trend is the result of Rayleigh and aerosol scattering. The dominant lines are produced by oxygen and water. Most bandpasses are placed to avoid strong atmospheric lines. The i band is an exception: the 7600Å molecular oxygen line falls in the middle of the band.

response, and are not easily comparable between observatories, or even between observations taken over a single night as photometric conditions change. Color transformations are typically used to convert between photometric systems, but these color terms depend on the SED and are only good to the few percent level at best.

Our goal is to precisely measure the atmospheric attenuation as a function of wavelength in real-time. The Imaging Sky Probe will be the first step by providing broad band photometric measurements. In addition, we are planning a dispersive instrument to measure the attenuation function (and sky emission spectrum) to moderate spectral resolution. With additional atmosphere modeling techniques in development, these observations will allow a precise characterization of the instantaneous atmosphere that the Pan-STARRS telescope is looking through. [3, 4].

3 The Imaging Sky Probe

The Imaging Sky Probe is designed as an off-the-shelf instrument. Only the filter wheel system and enclosure were designed in-house. It runs autonomously with an on-board mini computer, and is fully integrated into the observatory control system (OTIS). The components are listed in table 2. The Sky Probe mates to a frame bolted to the PS1 telescope mirror cell. It floats on a ball joint at the top of the frame allowing fine adjustments of pitch and yaw, before being bolted into place, see fig 4.

3.1 Camera

The Sky Probe is equipped with an Apogee 4Mpixel CCD camera with a commercial 500mm focal length F/4 Nikon camera lens. The field of view is 9 square degrees with a 5 arc second pixel size. The camera has an integrated thermoelectric cooler which we have modified for glycol cooling. We have carried out basic linearity and gain tests (fig. 2). The device characteristics are summarized in table 2.

We are in the initial stages of characterizing the camera performance. Preliminary zero points are listed in table 1. Further work must be completed to characterize the reproducibility of the shutter. The shutter is an iris integrated into the Apogee CCD. We find that the nonuniform illumination effects dominate over flat field artifacts for exposure times under 0.5 seconds. In addition, the Nikon lens shows astigmatism that is strongest in g band and improves towards the red. The impact on photometry has yet to be determined.

Table 1: Initial Imaging Sky Probe zero points

g	19
r	19
i	18.5
z	17.5
y	14

3.2 Focus

The filter set is not par-focal. We use a stepper motor to control the focus ring on the lens. High and low limit switches on the focus ring are enforced with magnets and hall switches.

3.3 Filter wheel

The filter wheel was designed in-house to position the 140 mm diameter filters in front of the camera lens. It carries five survey filters: *grizy*. The wheel was designed in a folded five petal form to conserve space. It is driven by an Animatics Smart Motor which includes an integrated position encoder and brake to hold the wheel in position. It is homed by a single hall switch. We experience systematic offsets in the filter position on the order of 0.1% due to stretch of the drive train, that appear when the wheel is driven over multiple revolutions. The periodic effect may be avoided by simply limiting the travel of the wheel to one revolution. The positioning error due to the servo motor is a factor of 10 smaller, or roughly $1\mu m$. Additionally, because the filter wheel is conical, there is a rotational offset produced by a transverse error. The error in the orientation of the normal vector of the filter is 0.04 degrees.

3.4 Cooling

Glycol cooling is used throughout the Sky Probe enclosure to draw heat away from the telescope mirror cell. We use three RTD temperature probes to measure the temperature in the enclosure.

4 Sky Probe science

The Imaging Sky Probe will not only be an excellent monitor of atmospheric attenuation, but has great potential in providing science results on its own. Over the survey life time, the camera will generate an independent five color all-sky survey. The large pixel size of the instrument makes it well suited for a low surface brightness survey. In addition, It will provide variability data for bright sources in cadence with the Pan-STARRS survey.

References

[1] Kaiser, N., & Pan-STARRS Team 2005, American Astronomical Society Meeting Abstracts, 207,

[2] Stubbs, C. W., & Tonry, J. L., Toward 1% Photometry: End-to-end Calibration of Astronomical Telescopes and Detectors, *Astrophysical Journal*, 646, 1436, 2006.

[3] Granett, B. R., Chambers, K. C., & Magnier, E. 2005, American Astronomical Society Meeting Abstracts, 207,

[4] Granett, B. R., DeRose, K., Chambers, K. C. *in prep.*

Table 2: Sky probe components

CCD	Model	Apogee U42
	Interface	USB 2.0
	Shutter	integrated iris
	Array size	2048x2048
	Pixel size	13.5μm
	Gain	1.0 e/ADU
	Read noise	10 e
	Dark current	2 e/sec
	Depth	16 bits/pixel
	Read out time	10 sec
	Cooler	Thermoelectric w/ glycol
Lens	Nikon	500 mm F/4
	Aperture	12.5 cm
	Field of view	9 sqr deg
	Pixel scale	5 arcsec/pixel
Computer	LittlePC 1.5GHz	
	Operating system	Redhat
Filter wheel	5 filters	*grizy*
	Filter size	140 mm diameter
	Encoder drive	Animatics Smart Motor
	Counts / rev	19200
	Positioning error	1 μm
Focus drive	Stepper motor	

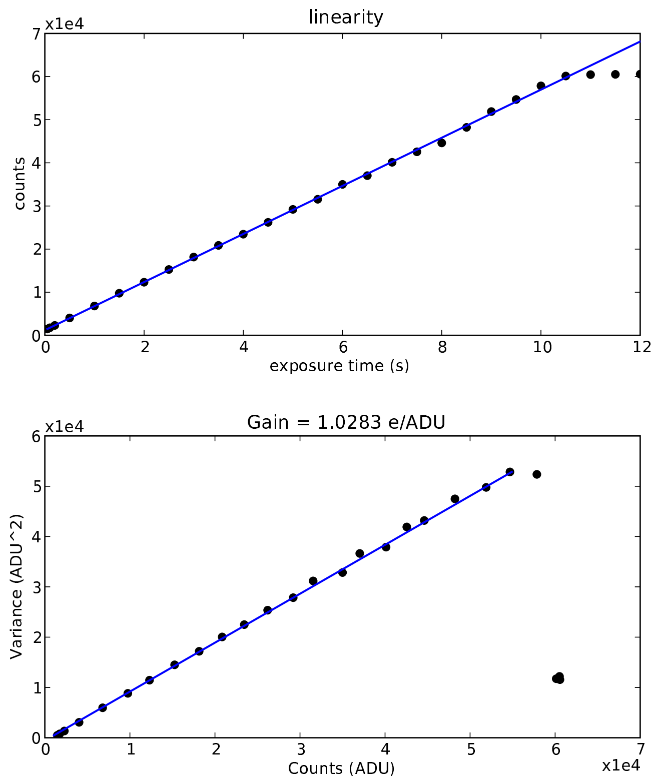

Figure 2: Linearity and gain performance tests of the Apogee CCD detector. The top plot shows the response of the detector to a constant flat field lamp over a range of exposure times. The line shows the best fit linear relation. The dark current is unimportant at just 2 electrons/sec. The detector saturates at 55000 counts, but the response remains linear to this limit. The lower plot, demonstrates the signal to noise properties of the detector. The slope of the relation gives the gain of 1.0 electrons/ADU.

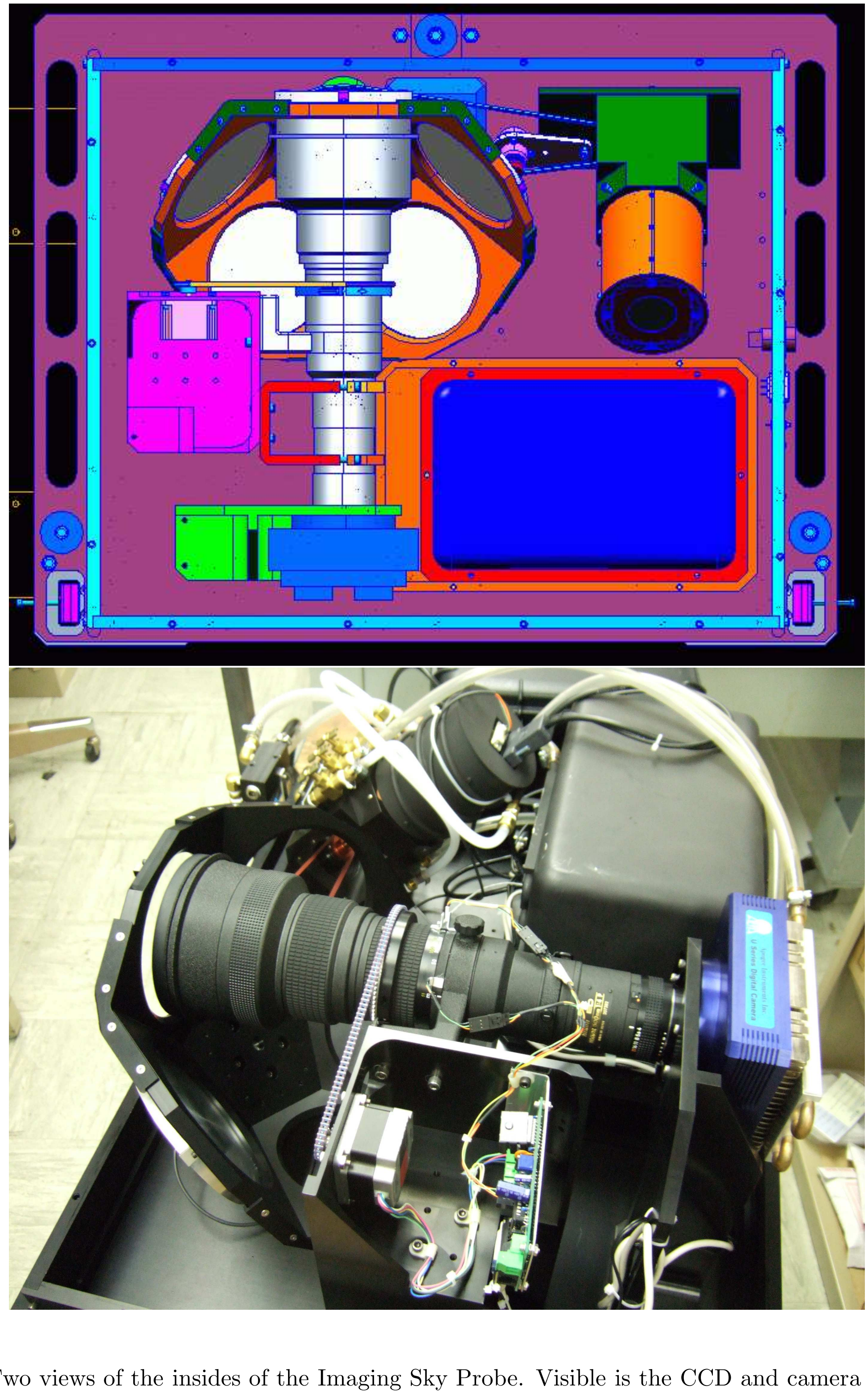

Figure 3: Two views of the insides of the Imaging Sky Probe. Visible is the CCD and camera lens, as well as the five-petal filter wheel.

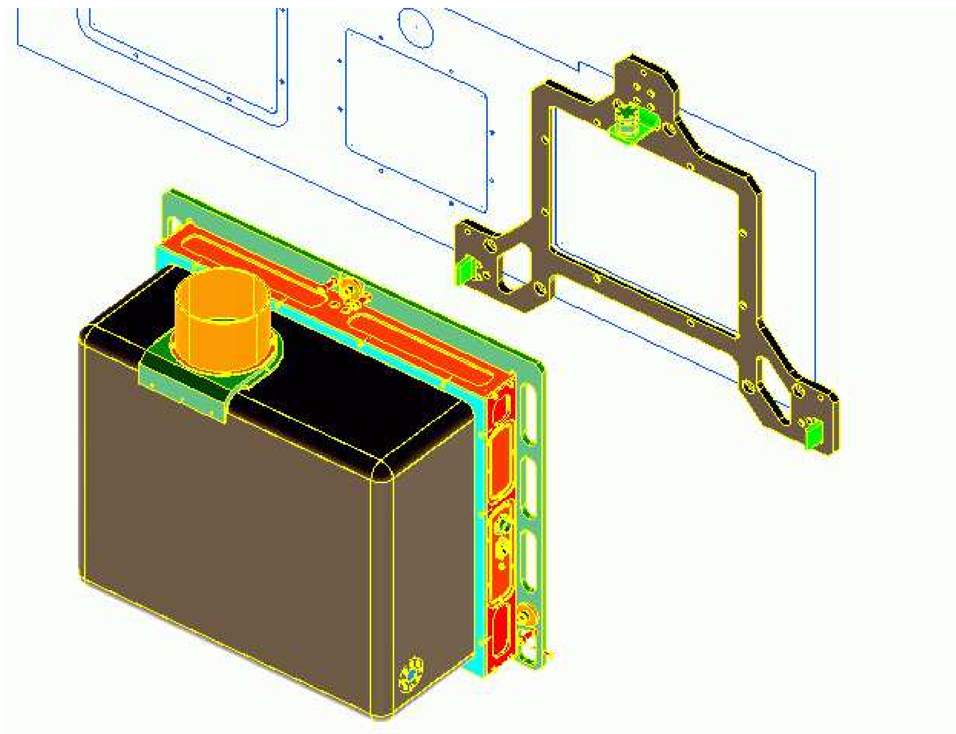

Figure 4: The Imaging Sky Probe mates to a mounting frame on the PS1 mirror cell. Before being locked down, the platform floats on a ball joint, at the top, to facilitate alignment.