Pan-STARRS GPC1, Calibration, Medium Deep, and ATLAS
Orthogonal Transfer Image Correction

- Orthogonal Transfer CCD
  - Pixel design which can noiselessly remove image motion at high speed

- Independently Addressable Cell
- OTA: 8x8 Array of Cells

- Pixel structure
- 512x512 pixel OTCCD
- Video output lines
- Analog out
- Digital control in
- Clock control lines

- Channels stop
- 1
- 2
- 3
- 4

- Dead cells
- Science cells
- Guide star cells
- Bad columns
Orthogonal Transfer Arrays

- Orthogonal Transfer Array: A new pixel/CCD chip design to noiselessly remove image motion at high speed (~10 usec)
- Current use on PS1 to simultaneously track stars and multiple GEO satellites

Normal guiding (0.73")
OT tracking (0.50")

PS Seminar 120907
Pan-STARRS Gigapixel Camera
Pan-STARRS Photometry

• The AB magnitude system
  – Defined as a monochromatic flux density:
    \[ m_{\text{AB}} = 0 \text{ at } 3631 \text{ Jy} = 3631 \times 10^{-26} \text{ W/m}^2/\text{Hz} \]
  – Over a bandpass, AB magnitude is defined as the ratio of a detector’s response to an SED relative to its response to 3631 Jy.
  – Defined to match the Vega system (boo, hiss) at 548 nm

• Three main issues:
  – What are the Pan-STARRS bandpasses? (Cal screen)
  – What is the zeropoint on the AB system for all these stars? (HST spectrophotometric standard stars)
  – What is the relative photometry in the Pan-STARRS bandpasses of stars all around the sky? (Uber-calibration.)
Calibration Screen
(Chris Stubbs, John Tonry, Keith Lykke)

- Illuminate a screen with monochromatic light from NIST laser that can be tuned over the entire 400nm-1020nm wavelength range of PS1
- Measure the system throughput as a function of wavelength for every pixel.
- Monitor system throughput with white light flats.
- Also use a projection telescope to put a beam through the optics that avoids all scatterers.
Spectroscopic Sky Probe

• 14cm telescope with a diffraction grating over the aperture that takes pictures of Polaris every 30 sec.
• Useful for determining water content of the atmosphere (now), and aerosol content (someday).
Bandpasses

• Components to the Pan-STARRS zeropoint
  – Aperture (1.8m diameter)
  – Atmosphere (0.9)
  – Vignetting (0.62)
  – Mirror losses (0.8)
  – AR coating losses (0.9)
  – Dirt (0.9)
  – Filter transmission (0.9 and bandpass)
  – Detector QE (0.5-0.9)

• ~70% of photons on 1.8m diameter are lost!
Avoid Stray Light!

- Avoid scattered light by using a projection telescope
- Avoid ghosts by measuring them and subtracting
Filter Transmission

- Filter transmission depends on radius (a lot)
- Manufacturer’s (Barr) curves seem accurate.
Filter Transmission for f/4.4 Beam

- The Barr (and projection telescope) measurements were done in nearly parallel light. Pan-STARRS has an f/4.4 beam, spread over a 4” diameter on filters.
- Ray-trace and use a fit to interference filter transmission as a function of angle of incidence to get the final filter transmission function.
CCD QE

Red QE as a function of temperature

Blue QE depends on AR coating
Components of System Throughput
Atmosphere

Atmospheric extinction

Extinction as a fn of airmass

Modtran and Polaris

One month of water
Spectrophotometric Standards

- Eight HST “Calspec” spectrophotometric standards
- AB compliance largely from models of dA WD
- Accuracy
  2% very likely
  1% some stars, some wavelengths
  <1% probably not yet
Lots and lots of spectrophotometric standards, integrated against PS1 bandpasses

Observed stellar colors in one of the Calspec standard star fields
SDSS (we believe) has ~0.02 mag errors
PS1 Effective Area

The Pan-STARRS1 Photometric System
JT MD Ongoing Projects

• Partners: Flewelling, Heasley
• Papers and work underway
  – Supernova templates and photometry (Scolnic, Rodney, Rest, Huber, Foley, …)
  – SNIa host galaxies (Tonry, Rodney)
  – Photometric redshifts (Saglia)
  – PS white dwarfs (Tonry)
  – Variable stars (Flewelling)
  – Brown dwarfs (Aller, Liu)
  – Weak lensing (Dixon, Kaiser)
  – QSO variability (Suh, Hasinger)
  – Various TOO (e.g. Gezari)
SNIIa Hosts (Huber)

- Large range in host properties!
Objects in MD Fields

0.5M bright stars

10M all objects
MD proper motion: high $\mu$

- PS1 astrometric residuals $\sim$25mas
- Baseline 2 years and growing, USNO-B, SDSS, or 2MASS can provide a first epoch for bright $m$
- $\sim$4800 proper motions >6 sigma, >40mas/yr

(Known) $m=18$ WD moving at 1.8″/yr
Reduced proper motion

- \( \sim 65,000 \) proper motions at 3\( \sigma \)

4,800 objects, 6\( \sigma \)
Brown Dwarfs (Aller)

- Extremely fast, faint, red star
  - 711 mas/yr
  - $g < 26$
  - $r \sim 25$
  - $i = 23.0$
  - $z = 20.81$
  - $y = 19.86$
  - $w_1 = 17.08 \pm 0.14$
  - $w_2 = 16.04 \pm 0.20$

- L or T dwarf? Very fast halo M star? No spectroscopy yet...
  - M: 800 - 2000 km/s,
  - L: 200 - 800 km/s,
  - T: 80 - 200 km/s.
**MD proper motions: white dwarf**

- Binary white dwarf
  - $366$ mas/yr, $H_r=21.97$
  - $g=19.74$ 19.74
  - $r=19.13$ 19.18
  - $i=18.54$ 18.64
  - $z=18.71$ 18.81
  - $(g-r)=0.59$, $(r-i)=0.56$
  - ~30pc?  5.4” separation ~150AU
White Dwarf Planets

- Eric Agol has suggested that WD planets might host life
  - Duration of eclipse: ~2 min
  - Probability of habitable planet’s orbit causing eclipse: 0.01
  - Probability of being in eclipse in any 2 min interval: 0.001

- Search MD observations of WD for planetary eclipses
  - 3215 WD chosen by PM or color: 7738995 observations
  - OK data: 4635187 observations
  - IPP magnitude error < 0.2 mag: 4355900 observations
  - Drop by >4σ only once: 374 candidates
  - At least 20 pixels from CCD edge: 49 candidates
  - Delete flaws, patchy clouds, telescope moved: 0 planets

- Therefore frequency of habitable planets around WD is <0.03.
High-z QSOs

- Many point objects in MD fields with high accuracy, non-stellar colors
- Variability and color selection
z>6 QSO Searches (Suh)
MD Field variables
Variable Stars (Flewelling)
Weak Lensing (Dixon)
ATLAS
Asteroid Terrestrial-impact Last Alert System
(www.fallingstar.com)
Survey Merit

Point size proportional to solid angle surveyed within $t_{\text{cad}}$

Tonry 2011, PASP 123, 58
Survey Merit

Point size proportional to solid angle surveyed within $t_{\text{cad}}$

Tonry 2011, PASP 123, 58
ATLAS Unit Telescope

• Hardware (expect to build 2 units)
  – Houghton optics: 0.5m aperture, 10° field of view
  – CCD: 100 Mpixel, 2.4” pixel camera, 50 sq deg

• Nominal observing plan
  – 30 sec exposure
  – r+i and g+r filter for two units
  – $5\sigma$ at AB=20 per exposure
  – 100,000 sq deg per night with two units. 4-5 visits to each point in the sky each night.
  – Same volume as PS1-MD or PTF2, but 4 mag brighter…
ATLAS Science

• Solar system
  – \( \sim 10^3 \) NEO/yr, \( \sim 10^4 \) asteroid rotation, etc.
• Stars
  – \( \sim \) hr resolution light curve of all stars to \( m < 19 \)
• Planets: habitable planets
  – search WD for planetary transits, \( \eta_{\text{Earth}} < 0.01 \)
• Gravitational lensing: dark matter, \( H_0 \)
  – near field microlensing; AGN time delays
• Supernovae: SN properties and large scale flows
  – \( \sim 10^4 \) SNIa/yr, many CCSN, \( \sim 10 \) bright ultraSN/yr
• AGN and black holes: AGN properties and evolution
  – \( \sim \) hr resolution of \( \sim 10^5 \) AGN to \( m < 19 \)
• Gravity waves: because it’s there (\textit{surely!})
  – E&M counterparts to events creating gravity waves