The Pan-STARRS Wide Field Imaging System

Nick Kaiser
Institute for Astronomy, University of Hawaii
William Burgett
Institute for Astronomy, University of Hawaii
Jeffrey S. Morgan
Institute for Astronomy, University of Hawaii

ABSTRACT

Pan-STARRS is a distributed aperture system with unprecedented light collecting power, resolution and field of view. One telescope now operational and another is shortly to join it on Haleakala. We describe the design philosophy and some of the challenges that have been faced and overcome in development of this system.

1. Pan-STARRS DESIGN

The Pan-STARRS distributed aperture design is based on 2 observations: 1) that detector technology is a rapidly evolving field, with the cost per pixel falling at about the same rate as consumer compute power, whereas telescope technology is relatively static, and 2) if the goal is to perform wide field imaging from the ground then there is no gain to be had from building a large aperture system rather than obtaining the same collecting area with a number of smaller aperture telescopes.

One significant advantage of the multi-telescope approach is that lessons can be learned from deployment of the first system and incorporated in subsequent systems, and the first telescope can serve as a test-bed for shaking out the control systems and data pipelines. Another is that the deployment time is greatly reduced as compared to a single large-aperture system, allowing early scientific results; a significant bonus since the science goals tend to be fluid and evolving.

The Pan-STARRS project has capitalized on these advantages with the development and deployment on Haleakala of the first telescope PS1. This is currently the world's most powerful astronomical survey system, and has been in full-time operation, relentlessly surveying the sky for nearly 3 years. The scientific return from PS1 is already impressive and is increasing rapidly and is covered in more detail in Dr. Ken Chambers' presentation in these proceedings[1]. The gigapixel camera (GPC1) has been listed as one of the "20 Marvels of Modern Engineering" (http://www.gizmowatch.com/entry/20-marvels-of-modern-engineering/). Pan-STARRS will create the largest ever astronomical survey and database. More importantly, it will create a motion picture of regions of the sky so objects variable in space or time can be easily discovered and followed up. The 2000 Decadal Review report, "Astronomy and Astrophysics in the New Millennium" (AANM), reviewed the status and priorities for astronomy for the first decade of the 21st century, and highlighted the need for a new survey telescope for a modern survey system utilizing state-of-the-art imaging technologies[2]. While the ANNM proposal is for a telescope much larger than PS1, the survey science goals are the same as those for for Pan-STARRS, including the following:

- A census of the solar system with emphasis on finding potentially hazardous asteroids and comets, and a greatly increased inventory of objects in the outer solar system,
- Detailed studies of the content and formation history of the Milky Way,
- Dark energy (DE) and dark matter (DM) from studies of the large scale structure (LSS) of the Universe,
- Cosmology from "time-domain" observations of Type Ia supernovae that provide measurements of the expansion history of the Universe.

In these areas, the Pan-STARRS system will serve as a powerful precursor for the still more powerful LSST to become operational in the next decade and to be deployed in Chile. In the meantime other wide-field imaging systems are coming on line - these include the Dark Energy Camera and Sky-mapper in the South and Hypersuprimecam on the Subaru Telescope in the North.

The Pan-STARRS project will shortly be deploying the second telescope PS2 on Haleakala to operate in tandem with PS1.

2. LESSONS LEARNED FROM PS1 AND BEING INCORPORATED IN PS2

While PS1 has been a considerable success and has demonstrated that the fundamental design philosophy is sound, several important lessons have been learned.

Regarding the optics, we have found from wave-front sensing measurements (with out-of-focus images) that the optical system delivers FWHM of 0.6”, considerably worse than the design goal of 0.4” (the median site seeing on Haleakala being 0.8”). We believe that this is primarily due to figure errors in one of the corrector lenses L2 (see figure 1). We also discovered that the focal surface at the very center of the field is significantly distorted, as shown in figure 2, and we have tracked down the cause of this to another of the corrector lenses L3. Further lessons were learned regarding the baffling of the telescope against stray light which was considerably harder than anticipated owing to the very wide field and also the wide range of wavelengths. As well as the image quality degradation from the figuring errors we have found evidence for “dome seeing” coming in part from sources of heat in the primary mirror control system.

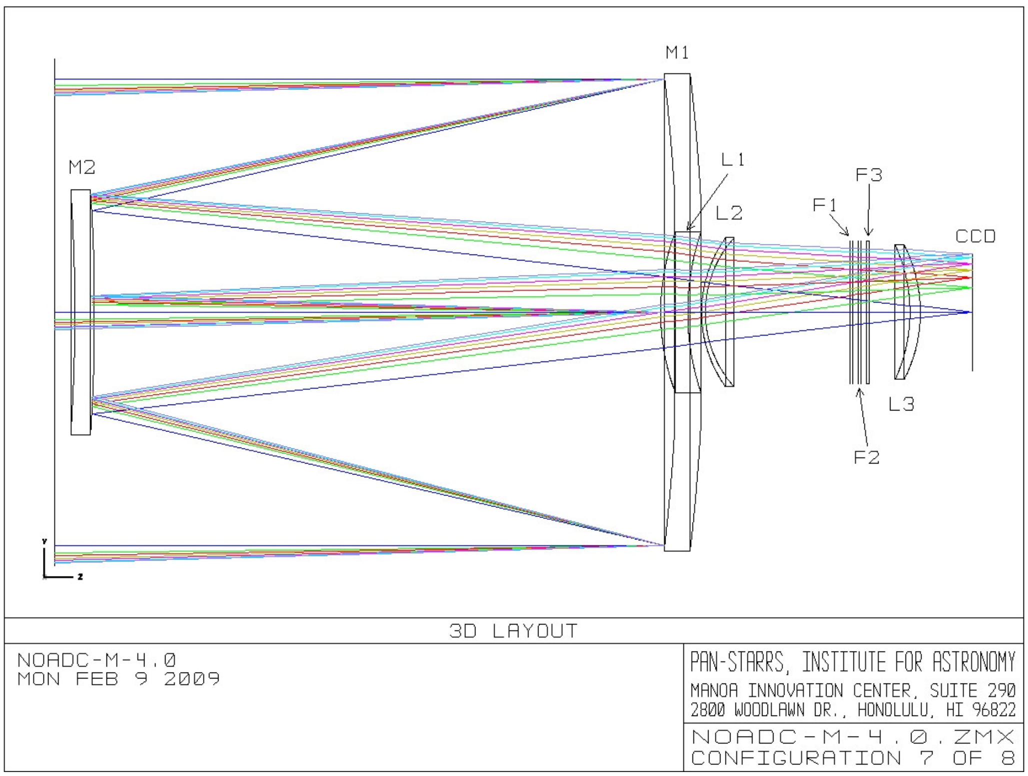
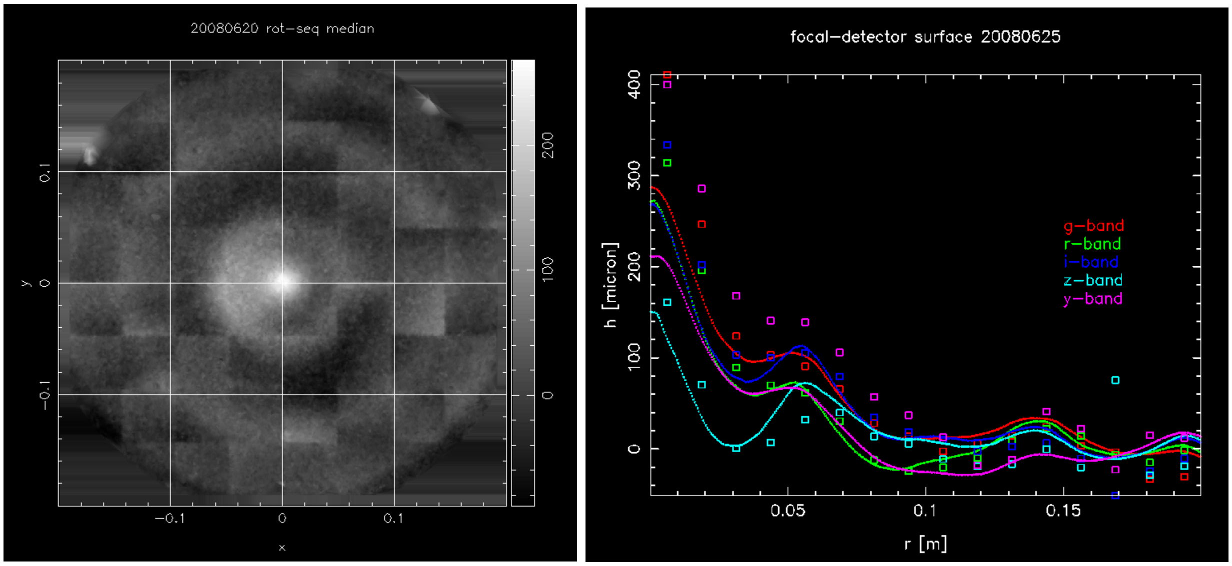


Fig 1. The optical layout of the PS telescope.

Collimation and alignment of a very wide field telescope like PS1 is very challenging, with tolerances on positioning of elements of order tens of microns (less that the width of a human hair). This is achievable using out-of-focus images. Developing the analysis software to accomplish this was a major effort for PS1. Similar techniques were also used to develop a model to control the figure of the primary mirror, which for PS1 floats on a bed of 36 pneumatic supports, 12 of which are actively adjustable. These analysis tools will carry over for use on PS2, and indeed can be used for other telescopes. Based on the experience with PS1 it was decided to upgrade the control system for PS2 by making all 36 supports actively adjustable.

Another feature of the optics that we felt we could improve on for PS2 was ghost images of bright stars coming from light reflected off the detector surface and bouncing off the first corrector lens to make a distorted out-of-focus image on the other side of the detector from the primary image.



a b

Figure 2. Measured focal plane distortions in the PS1 telescope obtained from measurements of the size of out-of-focus images of stars. Much of the large-scale deviations were corrected for by adjustment of the supports of the detector elements, but the spike in the very center remains and causes image degradation there.

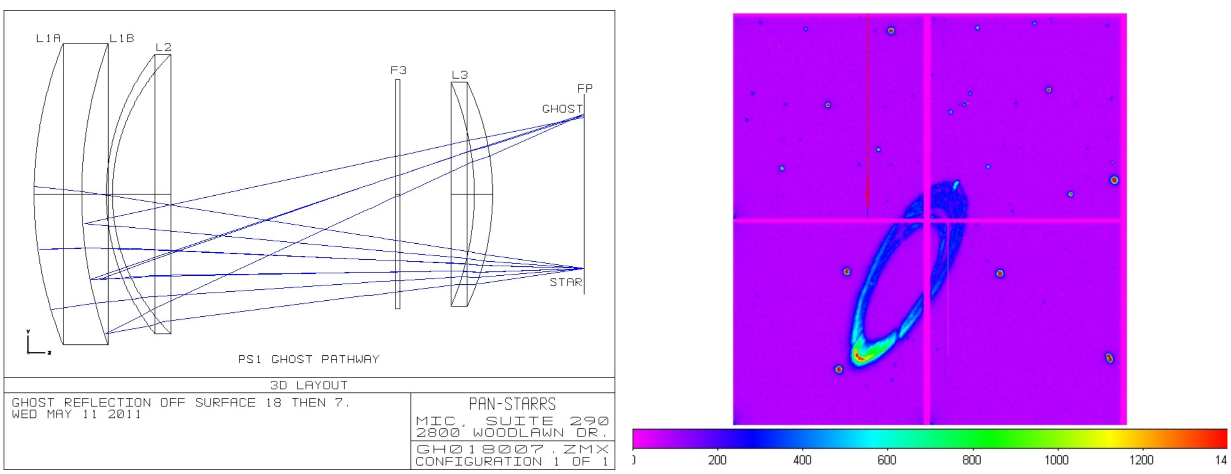


Figure 3. A typical CCD-L1b ghost in the PS1 telescope

The main problem we have had with the mechanical design of the telescope structure concerns the support for the secondary mirror. In the original design M2 was supported by an 18 point wiffle-tree system with 2-D flexures at each of the support points. This was rapidly found to be quite susceptible to wind-shake. Moreover, after about 9 months of operation with the original flexures, one of the flexures broke. It was discovered that there were design flaws which allowed the axial flexures to be over-stressed during assembly and that there were fabrication errors in the flexures themselves. The most critical fabrication error was found to be the failure to have had the steel in the flexures properly heat-treated. This resulted in a drastically reduced flexure lifetime and ultimately, the on-sky failure of one of the flexures. Because of that critical flaw, all of the support structure flexures had to be replaced and we took that opportunity to re-design the flexure arrangement in order to stiffen up the structure. The current PS1 secondary support flexure design utilizes 1-dimensional flexures that have been oriented in a manner so as to minimize the impact of thermal stress on the mirror. The current PS1 M2 support flexures are significantly stiffer than the original design and allow the telescope to operate in winds close to 10 m/s, but they are still marginal in performance. For PS2 we are using an improved design in which the support of the weight of the mirror is decoupled from the control of the figure via a wiffle-tree, as shown in figure 2.

Development of the giga-pixel detectors required to properly sample the excellent seeing on Halaekala presented a number of challenges, and, not surprisingly, several important lessons have been learned from the PS1 experience. The design adopted was an array of arrays comprising 3840 independently addressable 600x600 pixel "cells". This design allows massively parallel read-out as required by our goal of detecting hazardous asteroids. It also allows a small subset of cells to be used to monitor motions of stars at ~30 Hz video rate which is used to guide the telescope and will ultimately be used to drive the "on-chip" fast-guiding allowed by the orthogonal-transfer structure.

The detectors for PS2, which, like those for PS1, are being fabricated by Lincoln Labs at MIT, will be broadly similar to the PS1 detectors, but the system will incorporate some design modifications. One improvement will be a reduction in cross-talk between the detectors by a redesign of the cabling for the control and signal flow. Another will be better thermal control by repositioning of read-out electronics. As mentioned, bright stars in PS1 cause ghost images from light reflected off the focal surface. PS2 will feature improved AR coating which will reduce the intensity these ghosts and will also give better uniformity of quantum efficiency across the detector plane. Further hoped for incremental improvements for PS2 will be increased full-well depth and linearity range; reduction in residual charge from bright sources in previous exposures which currently requires masking in software; and reduction in glows from amplifiers which again has to be masked in PS1 images resulting in a reduction in the usable area for science.

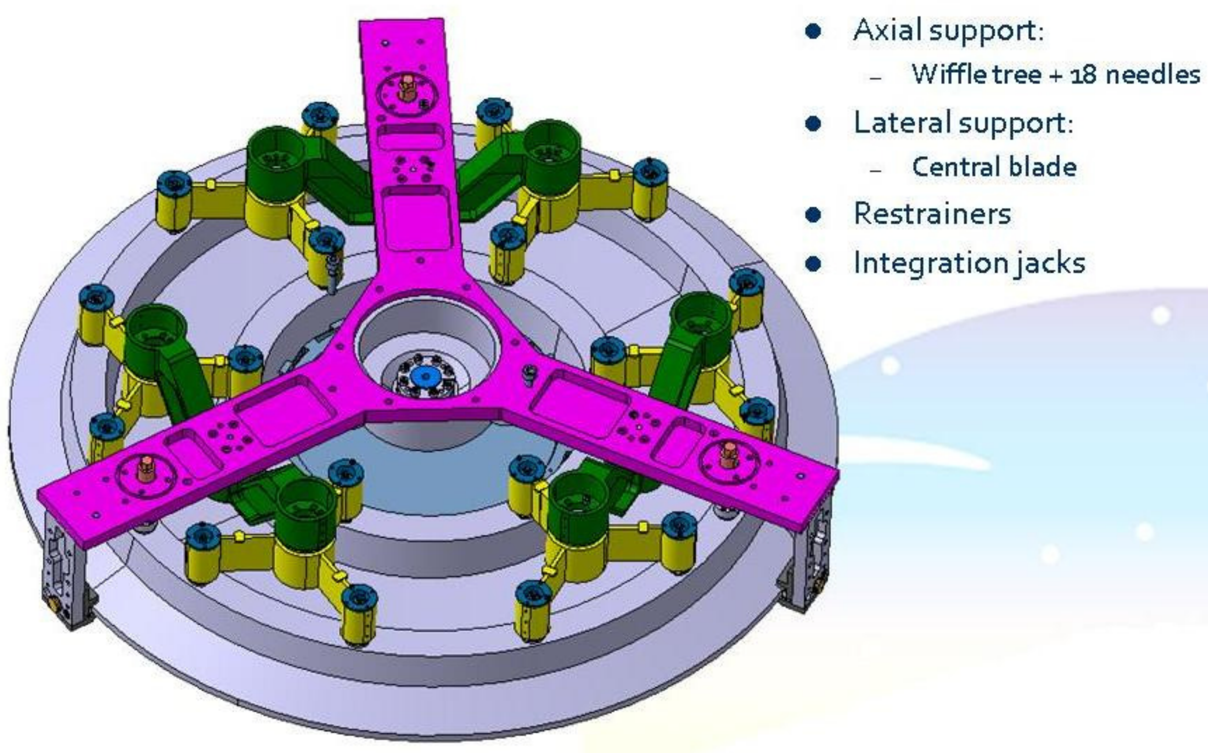


Figure 1. The PS2 secondary support (figure courtesy of AMOS)

3. SUMMARY

Three years of continuous on-sky survey operations with PS1 have resulted in an astronomically powerful data set that is now being applied to a broad range of science goals. It has demonstrated the soundness of the fundamental Pan-STARRS design, but has also revealed some areas where improvements can be made and these are being incorporated in the PS2 telescope that is scheduled to arrive on Haleakala early in 2013.

The key differences between the design and fabrication of PS2 and PS1 include the following items:

1. A change in the design of the secondary (M2) support structure.
2. Improved polishing of all of the optics (in particular, the L2 corrector)
3. Changes in the anti-reflection (AR) coatings of the corrector optics.
4. Removal of heat sources inside the primary (M1) mirror cell.
5. Improvements in the cable wrap design.
6. Changes in the M1 figure control actuators.
7. Improved baffling.
8. Improvements in the detector system.

REFERENCES

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