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The Pan-STARRS Search for Near-Earth Objects

Richard Wainscoat[1], Robert Weryk[2], Yudish Ramanjooloo[3], John Fairlamb[4], Mark Huber[5], Kenneth Chambers[6], Eugene Magnier[7], Thomas de Boer[8], Chien-Cheng Lin[9], and Hua Gao[10]

[1]*University of Hawaii, Institute for Astronomy, 2680 Woodlawn Drive, Honolulu, HI 96822, USA, rjw@hawaii.edu*
[2]*University of Western Ontario, Physics and Astronomy, 1151 Richmond Street, London ON N6A 3K7, Canada, weryk@hawaii.edu*
[3]*University of Hawaii, yudish@hawaii.edu*
[4]*University of Hawaii, fairlamb@hawaii.edu*
[5]*University of Hawaii, mhuber@ifa.hawaii.edu*
[6]*University of Hawaii, chambers@ifa.hawaii.edu*
[7]*University of Hawaii, eugene@ifa.hawaii.edu*
[8]*University of Hawaii, tdeboer@hawaii.edu*
[9]*University of Hawaii, cclin33@hawaii.edu*
[10]*University of Hawaii, hgao@hawaii.edu*

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Extended Abstract—

Pan-STARRS consists of two 1.8-meter diameter telescopes located near the summit of Haleakala, Maui, Hawaii. Each telescope is equipped with a very large camera at the Cassegrain focus that images an area that is approximately 3 degrees in diameter, and 7 square degrees in area. The first telescope, Pan-STARRS1 (PS1), started operations in 2010, and since 2014 has spent much of its time in a dedicated search for Near-Earth Objects (NEOs). Pan-STARRS2 (PS2) started surveying for NEOs in 2018. The initial discovery rate for NEOs from PS2 lagged PS1 — this was caused by degradation of the silver secondary mirror coating, which we believe was caused by volcanic gases from the eruption of Kilauea on the adjacent Island of Hawaii. The secondary mirror was recoated in 2021, and since then, PS1 and PS2 have similar sensitivities and NEO discovery rates.

Each telescope images approximately 1,000 square degrees per night, obtaining a sequence of four 45-second exposures spaced over approximately 1 hour. A wide filter spanning 400–820 nm is used when the moon is down or only partially illuminated, and an *i*-band filter is used when the moon is bright. The typical limiting magnitude in dark conditions is approximately V=22. The limiting magnitude is strongly seeing dependent — nights with light winds usually deliver the sharpest images, allowing NEO candidates as faint as V=22.5 to be reported. Pan-STARRS delivers excellent astrometry of moving objects, with positional errors typically less than 0.05 arc seconds, increasing to approximately 0.2 arc seconds at the limiting magnitude. Pan-STARRS has established itself as one of the leading surveys for Near-Earth Objects. A strength of Pan-STARRS is discovery of larger NEOs. Pan-STARRS presently discovers approximately 55% of NEOs with diameter >140 meters, and since it started operation, has discovered 11% of the estimated population of 25,500 NEOs with diameter >140 meters. The excellent image quality of Pan-STARRS has also made Pan-STARRS efficient at discovering comets.

Recent improvements made by Pan-STARRS include rapid reporting of NEO candidates, and self-follow up. NEO candidates are reported to the Minor Planet Center during the night, and objects that post to the NEO Confirmation Page are immediately followed up by Pan-STARRS whenever possible. This same-night follow up extends the orbital arc of newly discovered NEO candidates from ~1 hour to 3–4 hours. This arc extension provides strong constraints on the distance of the NEO candidate (due to Earth's rotation), and makes recovery easier. Same night follow up is not possible for NEO candidates discovered late in the night, because the brightening sky prevents follow up observations.

Unfortunately, NEO confirmation assets immediately to the west of Honolulu are sparse — this underscores the importance of the self-follow observations. The self-follow up has improved the discovery of smaller nearby Near-Earth objects by Pan-STARRS. These objects may have otherwise have been lost due to rapidly increasing positional error caused by their proximity.

Pan-STARRS has faced increasing challenges from severe weather during the last few years. Unlike Maunakea, where utilities such as communication and power are buried in a well-designed conduit, the power is delivered to the summit of Haleakala via overhead cables, and these cables traverse the adjacent Haleakala National Park, crossing sensitive areas where endangered birds nest. There has been an increasing occurrence of ice storms, which are usually accompanied by strong winds. Ice coats the electric lines, which become heavy, and their weight, together with the strong winds causes their support to fail. Because of the environmental sensitivity, repair is usually slow, since permits must be obtained, and work supervised by a biologist.. Ice storms on Haleakala used to be rare, but now seem to occur every year. An optical fiber is used to transmit data from the summit. Although the fiber is in a conduit, the conduit traverses a gully, and the conduit and fiber were cut in 2022 by erosion caused by extended heavy rain. This led to extended down time, which was temporarily mitigated by morning transport of the night's data (stored on disks), by vehicle to lower altitude where there was network access. The data rate from Pan-STARRS is too high for data to be sent from the telescope using radio links. In 2023, a lightning strike on Haleakala entered the utility power system, and from there, made its way into each of the telescopes on Haleakala (including Pan-STARRS), producing widespread damage to all telescopes on Haleakala.

Pan-STARRS continues to find detection of fast-moving objects challenging. This is because of the CCDs in each camera are Orthogonal Transfer Arrays (OTAs), which have a cell structure consisting of an 8x8 grid of 600x600 active pixels. Unfortunately, each cell is surrounded by an area that is not sensitive to light. Fast-moving objects are more likely to cross these cell boundaries, and have their detections corrupted. Pan-STARRS requires a minimum of three detections to form a tracklet for a moving object. Fast-moving objects may be nearby Near-Earth Objects, Atens, or interstellar objects.

It is clear that a new camera for Pan-STARRS could make a dramatic increase in the survey power. A new camera would have the following benefits:

- Improve the fill factor — the present cameras have a fill factor of 70%; part of this low fill factor comes from cosmetically poor areas of the CCDs, and part comes the OTA structure
- Improve the quantum efficiency — the present CCDs have excellent quantum efficiency in the near-IR, but is less good at visible wavelengths. Modern CCDs have excellent quantum efficiency at visible wavelengths, which are the most important wavelengths for asteroid detection
- Increase the area imaged — the present cameras do not image the entire image circle of the telescope
- Improve the noise characteristics of the camera — the present cameras have non-Gaussian noise characteristics, and as a result, a higher than ideal signal-to-noise ration threshold must be used for detection, and as a result, some faint detections are missed
- Allow longer exposure times — longer exposure times will allow Pan-STARRS to find fainter slow-moving Near-Earth Objects. Exposure times on Pan-STARRS1 are presently effectively limited to 45 seconds in the w-band filter due to image persistence problems from bright, saturated stars.
- Reducing overhead by reading the camera out faster

Together (and ignoring the noise issue), the improvements listed above would yield an increase in survey power by a factor of 1.8. A new camera would make Pan-STARRS a more effective northern hemisphere complement to the larger aperture Rubin Observatory in the south.

The structure and noise characteristics of the Pan-STARRS detectors means that the archival images from Pan-STARRS contain many unreported moving objects. The archival images have provided many arc extensions for newly discovered NEOs, and their value will continue into the future.