Pan-STARRRS status and Geo Observations Results

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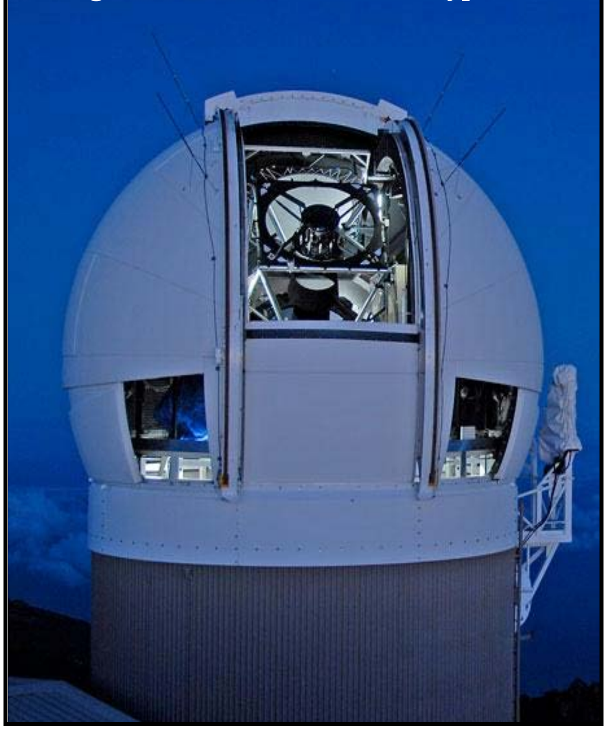
Abstract

Pan-STARRS, Panoramic Survey Telescope And Rapid Response System, is an astronomical telescope developed through a cooperative agreement between University of Hawaii/Institute for Astronomy and the Air Force Research Laboratory which utilizes MIT/LL-developed orthogonal transfer arrays. While its primary mission is investigating astronomical transient phenomena, 5% of the telescope time is allocated for AFRL Geo Research. The combination of its high sensitivity (>21st Magnitude), wide field of view (7 square degrees), and high metric accuracy (<1arcsec), provides AFRL a unique capability to assess the Faint Geo Population. In its survey mode, many of the faint objects are detected as they streak across the focal plane. For a significant portion of these objects, the streak will not be entirely detected due to gaps, masking, and low signal levels. This talk will discuss the various methodologies for computing detection magnitudes in these scenarios and present observation results.

Introduction

Since 2002, the Air Force Research Laboratory and the University of Hawaii Institute for Astronomy have been developing the Panoramic Survey Telescope And Rapid Response System (Pan-STARRS) to observe transient phenomena and detect Near Earth Orbiting asteroids which may pose a threat. The final design includes four 1.8m telescopes each equipped with a giga-pixel camera and is planned for the summit of Mauna Kea. As a prototype, one 1.8m telescope, PS1 was constructed on Haleakala. It began its operational mission in May 2010 and provides AFRL with 5% of the telescope time to survey GEO for Faint (>16th Visual Magnitude) Debris. Due to the unique capability combination of: wide field of view (7 square degrees), high metric accuracy (<1arcsec), and high sensitivity (>21st Magnitude), this system is well suited for the task.

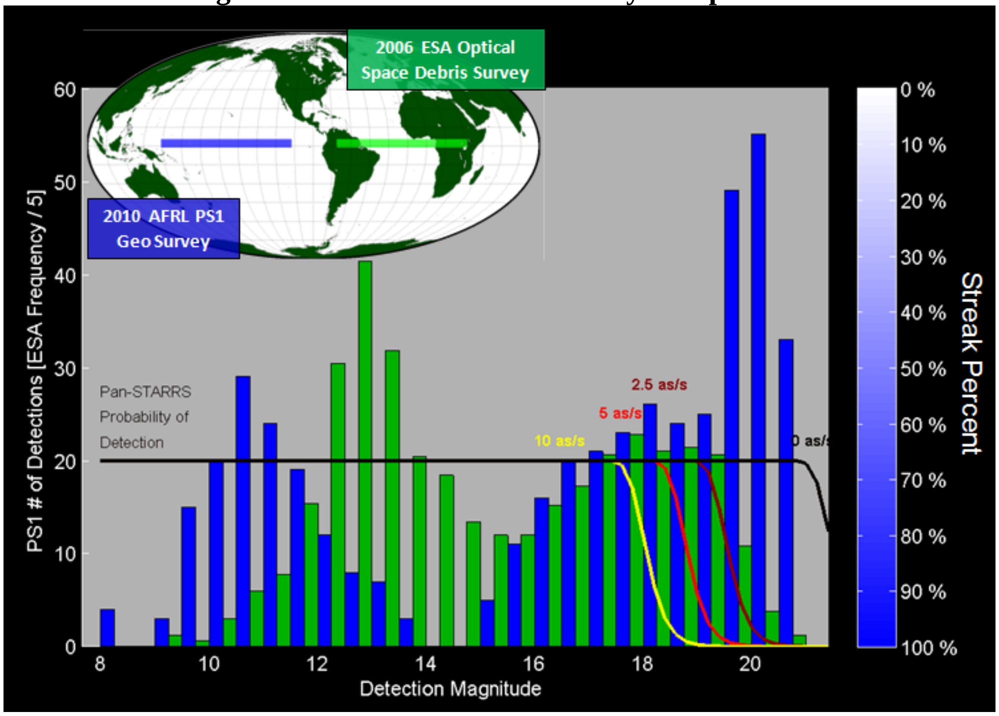
Figure 1: Pan-STARRS Prototype PS1



Discussion

In 2006 ESA performed an optical space debris survey of GEO which reported two dominant populations in GEO. The study indicated there was a bright object population and a faint object population. It has been theorized and widely accepted that the bright object population (<16th Visual Magnitudes) is dominated by artificial satellites both active and inactive, while the faint object population is composed of debris. In order to validate and push fainter, PS1 was utilized by AFRL for a GEO survey over two consecutive nights. In Figure 2 the results from the two surveys are plotted on the same axis with a relative scaling.

Figure 2: AFRL & ESA Geo Survey Comparison



Viewing the results comparison of these two surveys identifies three major differences. First, the bright object population detected by the AFRL survey appears to have a median value of approximately 2 visual magnitudes brighter than the bright population surveyed by ESA. Possible explanations include: differences in calibration procedures, different observed objects with substantial design differences, different viewing geometries, and/or different timescales. More investigation is required to understand true nature of the difference, and will not be discussed further in this paper. Second, as the number of faint objects detected decreases for the ESA survey, the number of faint objects detected by the AFRL survey increases. Since the probability of detection for PS1 extends out for fainter objects this is expected with current theory for Geo Debris. Third, past 19th visual magnitudes there is a sharp increase in the detected population for PS1. Possible explanations include: differences in ConOps, data types, sample size, or calibration procedures. This paper will analyze these possibilities and theorize that the observed sharp increase is most likely a result of a combination of ConOps, data type, and current calibration procedures.

PS1 Geo Survey Concept of Operations

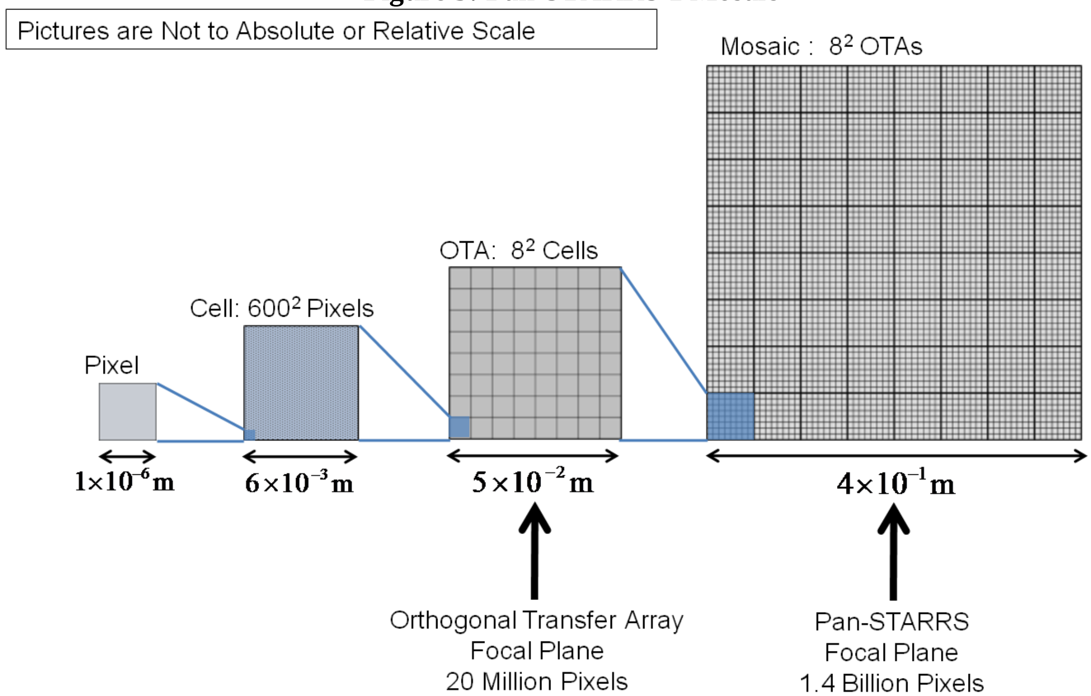
The PS1 Mount & associated software is currently capable of two modes of operation: sidereal tracking or "stare mode," where the telescope is simply parked and the stars streak during an exposure. Since geostationary object rates are relative to the rotation of the earth, the mount is commanded utilizing "stare mode" for all GEO observations. The belt is surveyed by revisiting a single Right Ascension and 3 Declinations parking the mount each time and letting the stars streak through. By choosing the appropriate integration time the geo belt is observed M number of times. In order to detect an object it must be observed N number of times out of the possible M observations. This type of tasking is necessary to decrease background noise, to filter false detections, and to mitigate missing objects which may fall into gaps in the array or masked areas of the focal plane.

PS1 Data Type

PS1 utilizes a giga-pixel camera which is composed of 60 Orthogonal Transfer Arrays, each compose of 64 600x600 pixel CCD's.

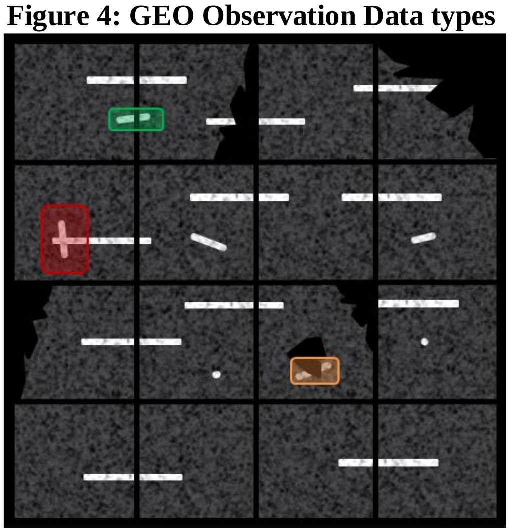
See Figure 3.

Figure 3: Pan-STARRS 1 Mosaic



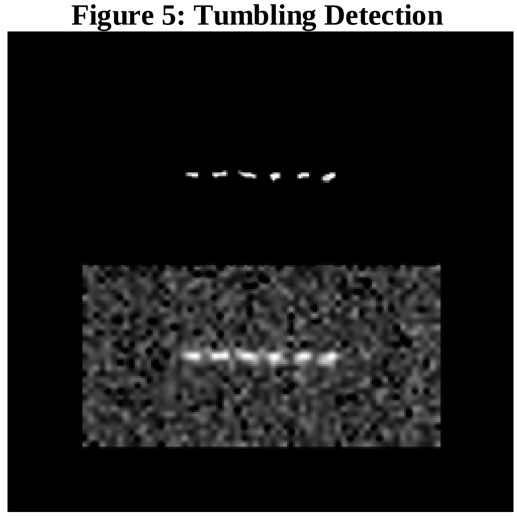
The gaps between CCD's and OTA's also create other obstacles. Under it's ConOps, PS1 detects a large number of objects which are near GEO but not Geostationary. Since these objects possess motion with respect to the FOV in stare mode, they streak over multiple pixels, gaps, masks, and stars. See Figure 4.

Figure 4: GEO Observation Data types



As a result only a partial streak is detected. This also can occur for objects which are tumbling and have signatures which fluctuate above and below the detection threshold as it streaks across the focal plane. See Figure 5.

Figure 5: Tumbling Detection



This can also result in partial streak detection for two reasons. One, the end points of the streak are not above the threshold. Two, not all partial detections are associated with a single detection.

PS1 Calibration Procedures

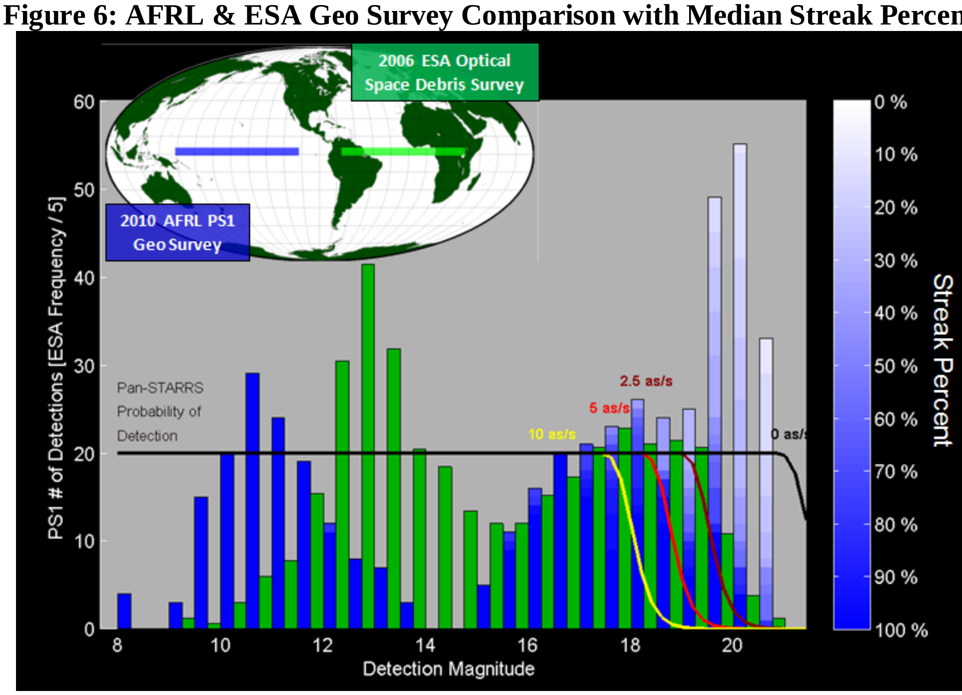
These three situations, star crossings, CCD gaps & masks, and tumbling objects, produce different effects when calculating the visual magnitudes. For the situation of an object which steaks through a star streak, there is little effect, unless the combined signals cause saturation. In such a case the visual magnitude would be reported fainter than its true signal. For objects which cross CCD gaps & masks the visual magnitude is reported fainter than it is in reality since the photons from that time were unobserved. In the case of a tumbling object the visual magnitude may be reported fainter since there may be signal beneath the threshold which extends beyond the detected end points. It may also be reported fainter if all partial streak detections are not associated with one another.

Due to this effect it is necessary to track streaks which have only been partially detected. This is done by using the metric Median Streak Percent. See Equation 1. We can combine this metric with our magnitude histogram by stacking the median streak percent in the vertical axis as a function of color. See Figure 6. This shows that the sharp increase in number objects as a function of magnitude is likely related to the small streak percentage of the detected objects.

Equation 1: Median Streak Percent

$$\boldsymbol{Median\ Streak\ Percent} = \frac{median(Streak\ Length)}{(Streak\ Rate * Exposure\ Time)/_{IFOV}}$$

Figure 6: AFRL & ESA Geo Survey Comparison with Median Streak Percent

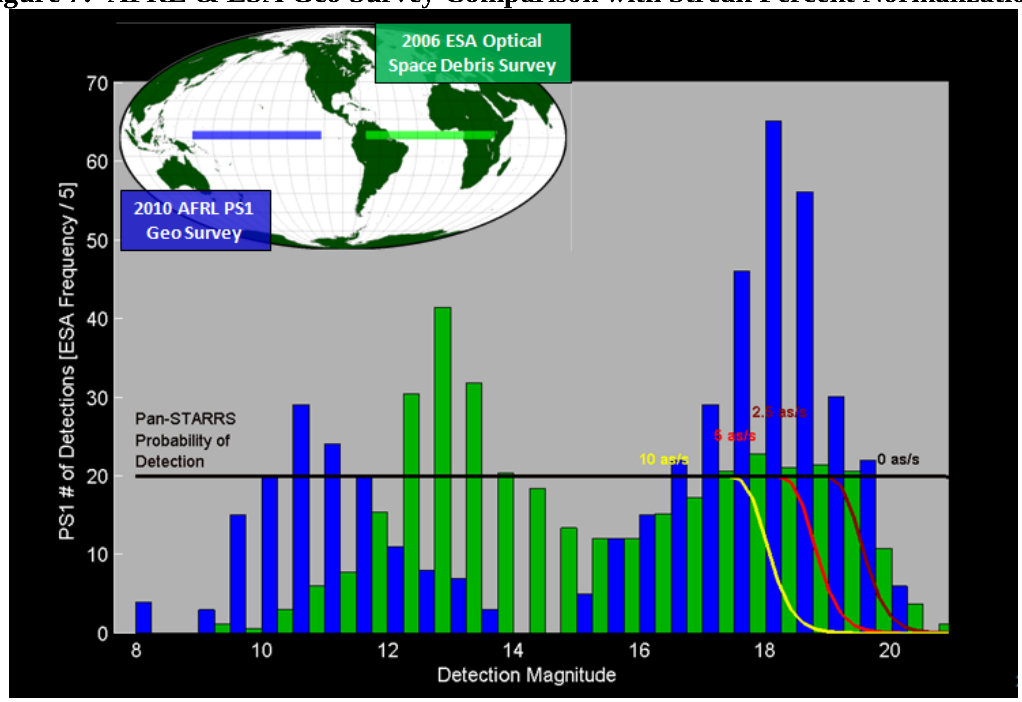


Due to these effects two new procedures have been developed for calibration. Objects which cross gaps & masks can be corrected by adjusting the effective integration time. Since objects are detected in multiple frames, the inferred streak rate can be used to calculate this value. To avoid partial streak detections due to low signal to noise, the streak rate can also be used to identify the expected pixel length associated with a given streak. The expected streak width is calculated by utilizing the widest pixel width detected. This is done to account for varying atmospheric seeing. Results utilizing these techniques are pending a global re-reduction of the PS1 Survey data. Since these results are not yet available the reported magnitude can be normalized utilized in equation 2 and plotted in figure 7.

Equation 2: Normalized Median Magnitude

$$\textbf{Normalized Median Magnitude} = Median\ Magnitude + 2.5 * log(Median\ Streak\ Percent)$$

Figure 7: AFRL & ESA Geo Survey Comparison with Streak Percent Normalization



Sample Size

In addition to the consecutive night GEO survey's PS1 has also regularly observed during smaller portions of the night distributed throughout the year. By plotting these collections in the same graph, a similar distribution is observed, indicating the effect is not likely related to the sample size. See Figure 8. In order to determine the dominate cause for the partial streak detections the data is plotted as a function of visual magnitude and Streak Rate with respect to geostationary. See Figure 9.

Figure 8: All AFRL PS1 Detections with Streak Percent

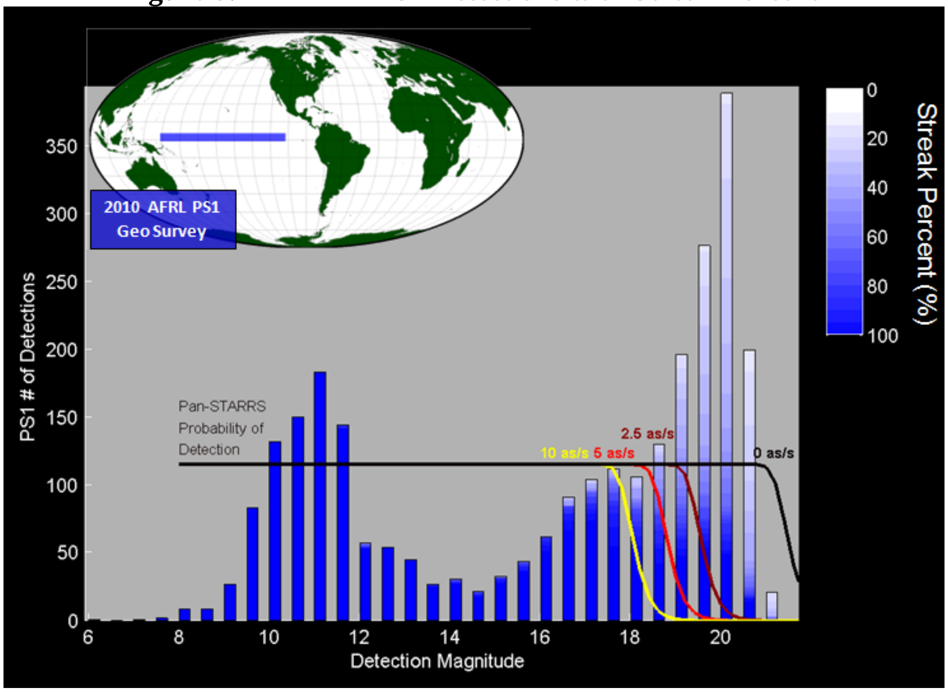


Figure 9: All AFRL PS1 Detections with Streak Percent & Rate

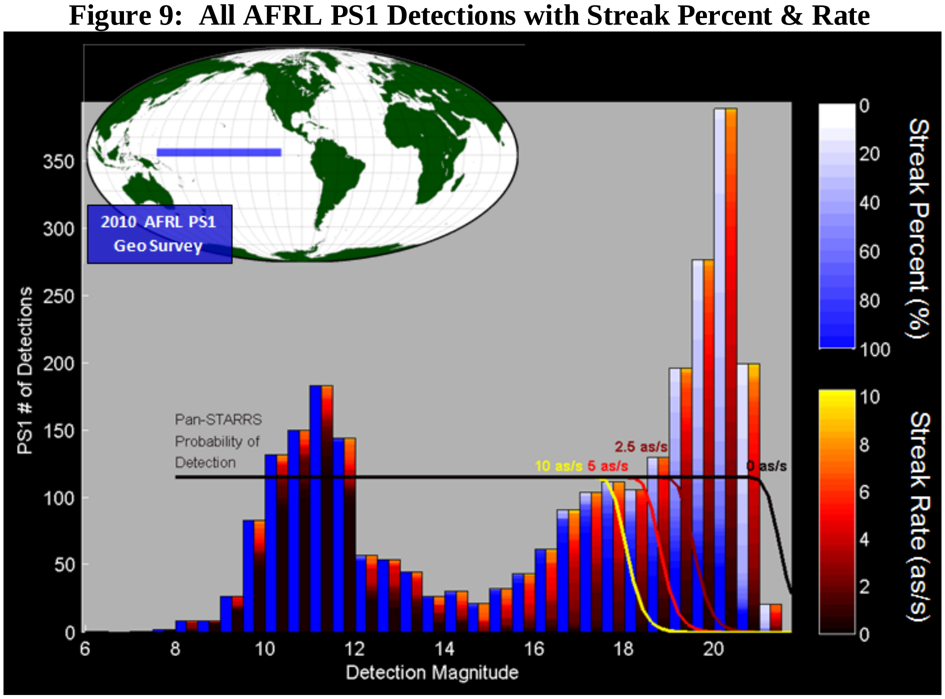
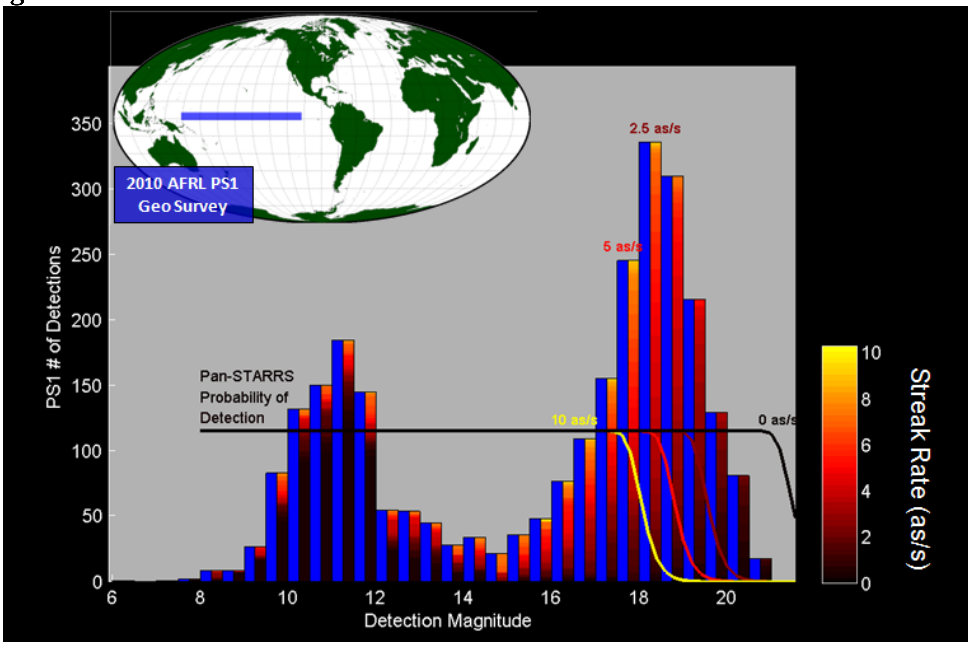


Figure 8 indicates that the plateau effect in the magnitude distribution is not representative of the faint object population. It represents an effect caused by partial streak observations. Figure 9 indicates that while there are objects with high streak rates at almost all magnitude bins, only the faint objects exhibit low median streak percentages. This supports the theory that the plateau effect in the faint object population is a result of tumbling objects which have fluctuating signal levels above and below the detection threshold. If the crossing of CCD gaps or masks were the cause, this effect would be distributed across all magnitude bins.

This has ramifications on the streak percent normalization process. Normalizing the magnitude based on median magnitude, for objects crossing gaps and masks introduces noise but no significant biases. The same procedure for tumbling objects with signal below the detection threshold causes a significant bias. With this correction tumbling objects are reported brighter than reality. This can be seen in Figure 10. In reality, the population exhibits characteristics within the bounds of Figures 9 & 10. This will be demonstrated as the new calibration procedures are applied.

Figure 10: All AFRL PS1 Detections with Rate & Streak Percent Normalization



Conclusion

The Pan-STARRS Prototype, PS1, is operational and collecting valuable data on the characteristics of the GEO debris population. It is important to identify and report calibration procedures which can introduce biases. PS1's GEO survey contains a bias due to the variability in visual magnitude for non-geostationary objects which streak over multiple pixels. As a result, the entire signal is not always detected when the signal fluctuates below the threshold. This can potentially cause the visual magnitude of objects to be reported at fainter visual magnitudes. Thus, it is important for survey's to either report the streak percentage detected in combination with an objects visual magnitude for objects which are not rate tracked or develop ConOps & calibration methods to compensate.