Predicting received power in satellite laser ranging

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The Big Question

If we fire a laser at a reflector on a satellite in low or medium earth orbit, how much light can we expect to receive?

Background

The Next Generation Satellite Laser Ranging (NGSLR) station is used to track satellite distances to millimeter precision by recording the time of flight of photons from a ground station reflected off of a satellite retroreflector array back to the station. Using the time of flight, satellite distance to the station can be acurately determined over thousands of kilometers.

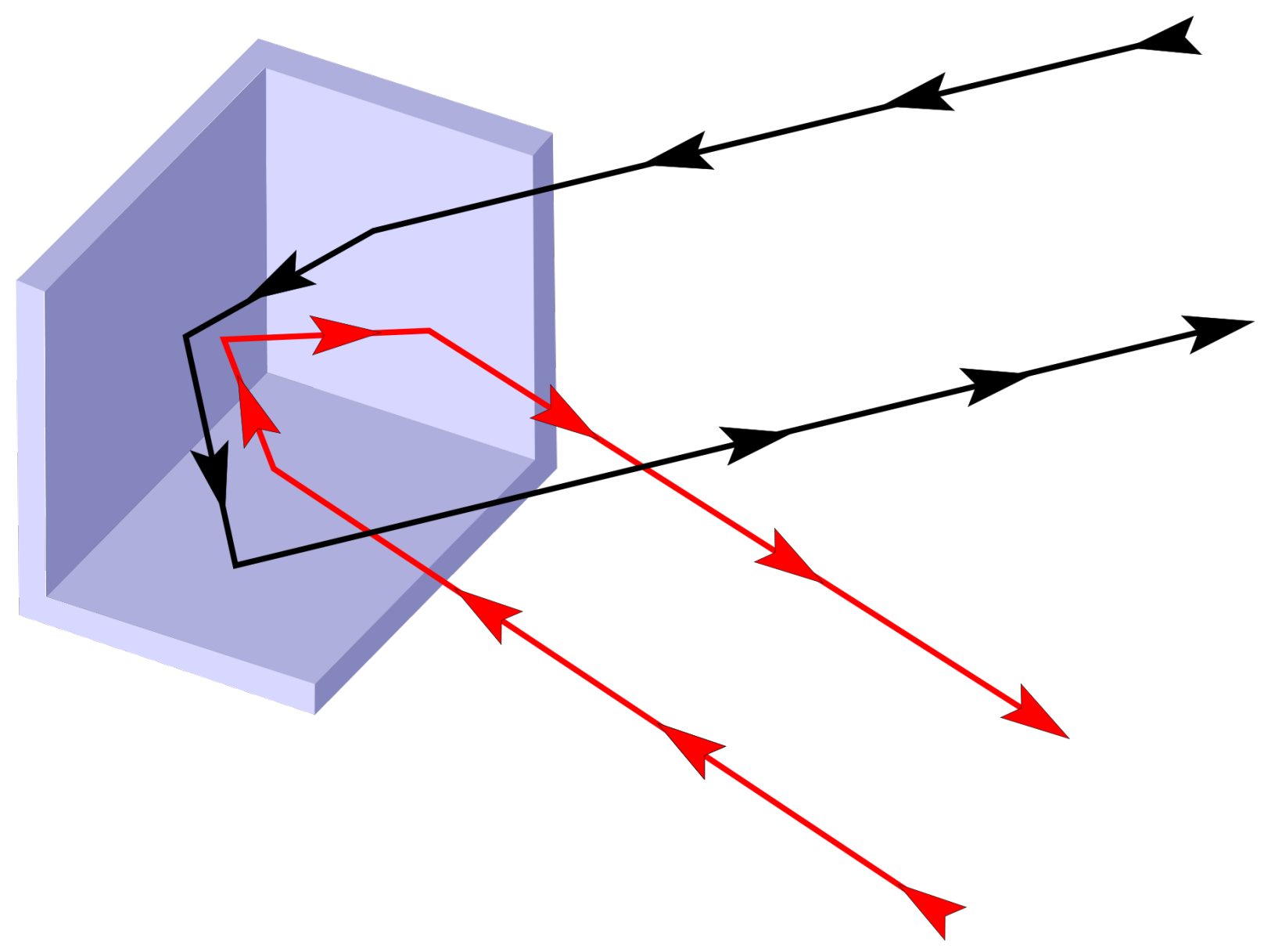

Figure 1: Corner cube retroreflector diagram

Introduction

Because the satellite orbit is already known with some accuracy, the station uses a range gate to only observe photons within an expected time window for a given pulse. Further, the event timer has a 60 ns dead time after a photon has been detected. As a result, signal photons arriving within 60 ns of prior noise are not detected. The filtering mechanisms affect signal and noise impartially, however noise photons following a poisson distribution would be increasingly likely to be detected first as the total number of photons returned increased. As a result, the optimum signal return rate is less than 100%.

$$n_{pe} = \eta_e \left(E_T \frac{\lambda}{hc} \right) \eta_t G_t \sigma \left(\frac{1}{4\pi R^2} \right)^2 A_r \eta_r T_a^{2sec(\theta_{zen})} T_c^2$$

The goal of this project was to determine the strength of the signal detected using the link equation above ([2], [3]). Having an accurate and reliable estimate of signal strength could be used to optimize the return rate.

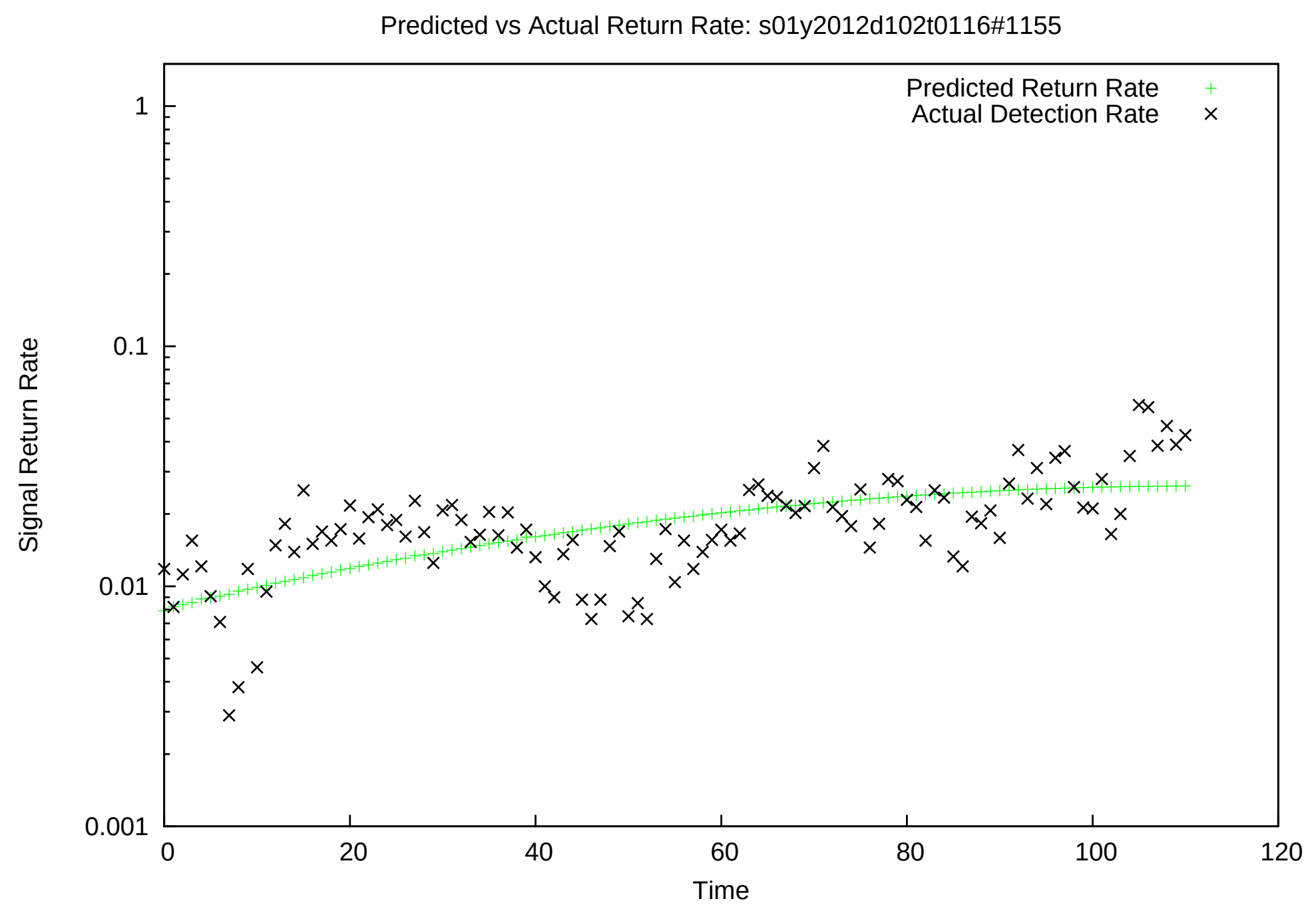

Figure 2: LAGEOS pass fit to average pointing error = 1.76 mdeg

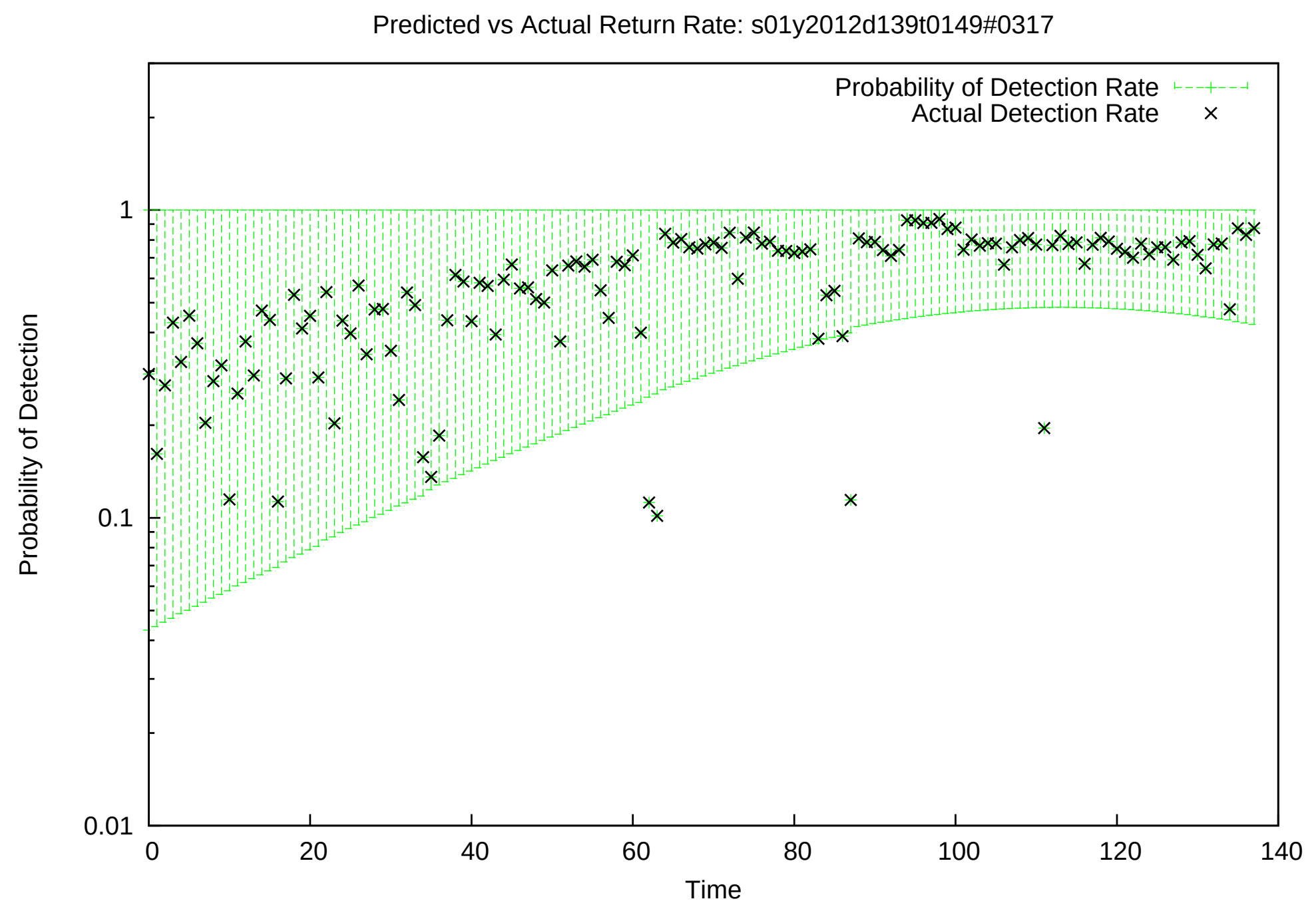

Figure 3: Probability of detection: Beacon-C pass w/ < 0.7 mdeg mount jitter and $\sqrt{2}$ mdeg pointing bias error

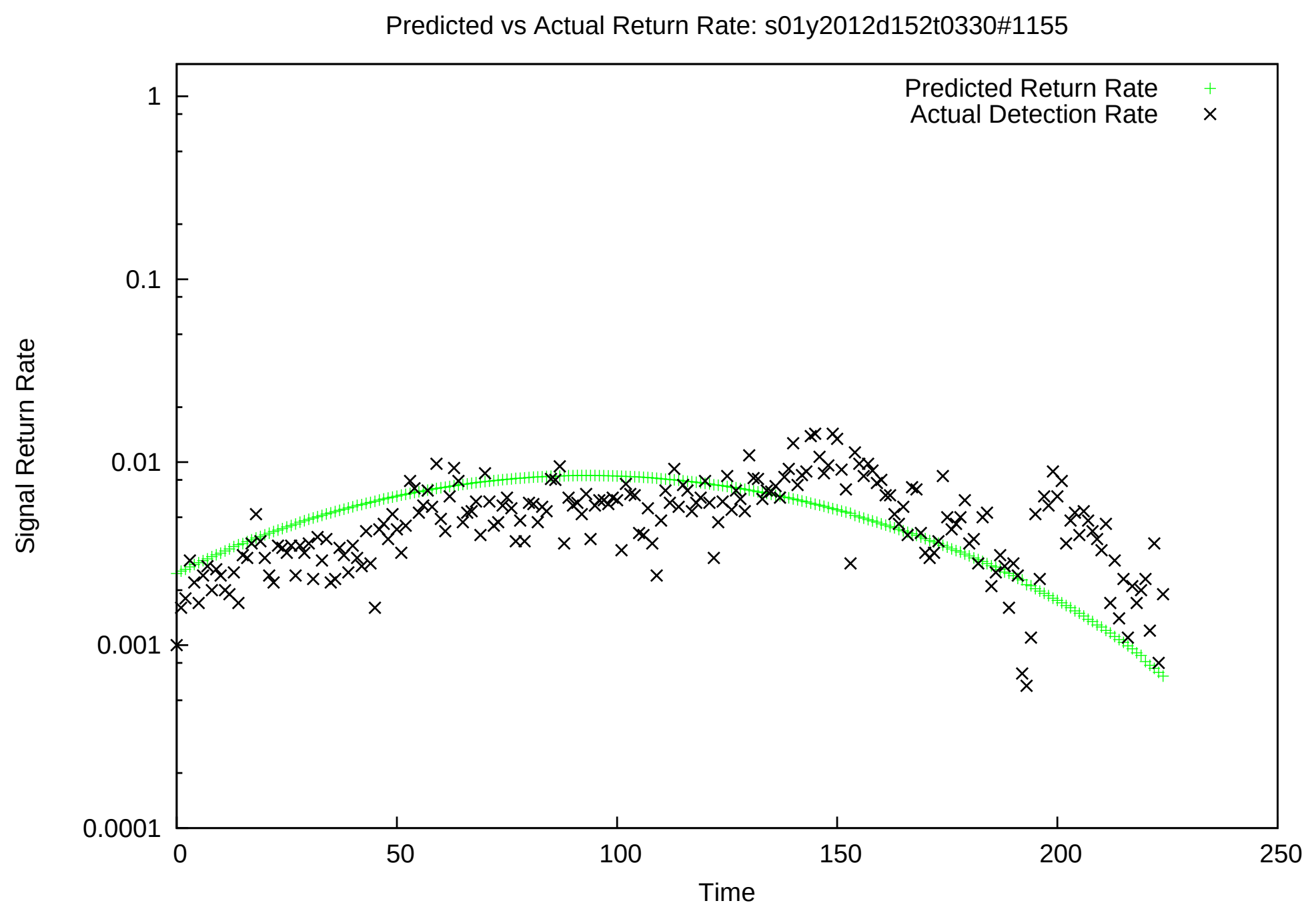

Figure 4: Low visibility LAGEOS pass fit to pointing error = 1.87 mdeg

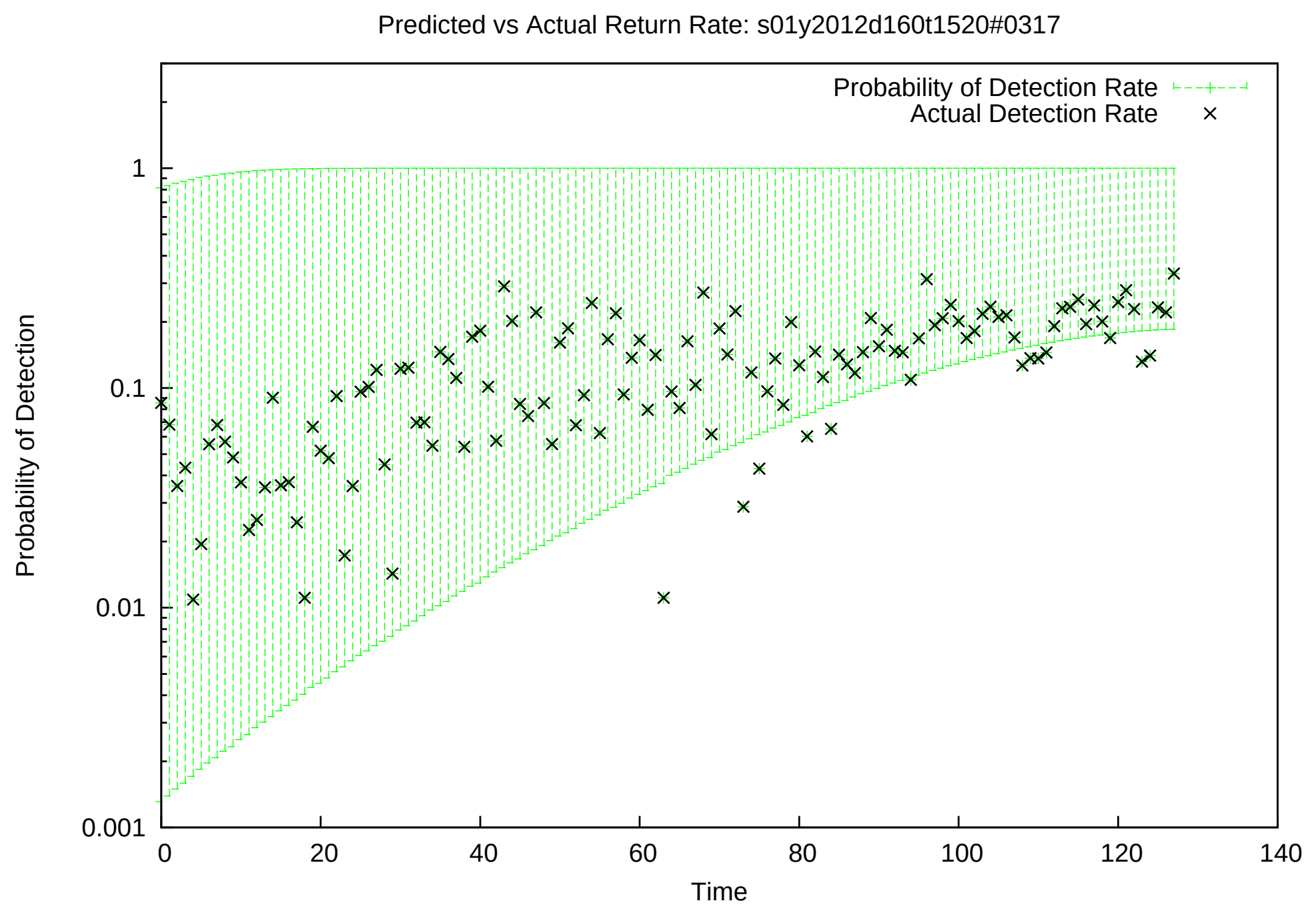

Figure 5: Low visiblity probability of detection: Beacon-C, day pass

Summary

The power received by a satellite laser ranging detector is approximated by the link equation and is proportional to $\frac{T_a^{2sec(\theta_{zen})}}{R^4}$, where T_a is atmospheric transmissivity and R is the satellite slant range. The atmospheric transmissivity can be estimated from the ground-level visibility.

Methodology

We examined a number of low and medium earth orbit satellites (LAGEOS, Beacon-C, Starlette, Jason, Cryosat-II, and Ajisai) and calculated signal rates for passes from April-June 2012. The first method (shown top) solved for the average pointing error within a pass. The second method (shown bottom) assumed a pointing bias error of $<$ 2 mdeg in both azimuth and elevation and a random mount jitter $<$ 1" in both directions to determine the mean return rate, $< n_s >$, and probability of detection, P, shown right.

The atmospheric transmission coefficient, T_a, was taken from [2]. Visibility data were collected at a weather station by a Vaisala FD12P sensor. The receive optics coefficient, η_r, was multiplied by 0.7 for passes beginning within 30 minutes of sunrise/sunset or midday due to additional optical losses in the daylight spectral filter. Time since the last star calibration was also examined. Satellite cross-sectional areas were gathered from [1].

$$< n_s >= n_s \frac{\sigma_{r\alpha}\sigma_{r\beta}}{\sigma_\alpha \sigma_\beta} exp\left[-2 \left(\frac{\alpha^2+\beta^2}{\sigma_t^2} \right) \right] exp\left[\frac{2}{\sigma_t^4} (\alpha^2 \sigma_{r\alpha}^2 + \beta^2 \sigma_{r_\beta}^2) \right]$$
$$P \ = \ 1 - e^{-<n_s>}$$

Results

The experimetal values for power received by the ranging station fell within the expected range for most passes. Additionally, the curvature of the graph matched passes with consistent returns, as indicated by the upper graphs demonstrating predictions fit to an average pointing error. Passes with greater visibility not only demonstrated stronger returns, but less dependence on the zenith angle or elevation.

Return rates on some passes were extremely erratic; these inconsistencies occurred with greater frequency during daylight passes. It was also found that the time since the last calibration did not have a significant effect on the quality of the return signal.

Conclusions

Experimental data fell within the predicted returns for the estimated range of pointing bias error and mount jitter. Further, the theoretical return rate matched the curvature of consistent passes. This result gives confidence that the dominating variables in return rate are the satellite elevation/zenith angle, transmissivity/attenuation, and pointing error. The elevation angle is known during ranging while attenuation can be estimated from the ground level visibility data provided by the Vaisala sensor. It was also determined that there is no correlation between the pointing error and the time since the last star calibration. Moreover, passes taken during the day were more likely to demonstrate inconsistent return rates.

Additional research could be conducted to examine other contributions to lost power to reduce the range of possible return rates. Some sources of power loss that were not accounted for in this project are downlink divergence due to retroreflector thermal gradients, satellite/beam incidence angle, noise interference, and atmospheric turbulence. Greater losses could also be attributed to less efficient optical components than assumed in this report.

References

[1] Arnold, David., "Cross section of ILRS satellites", ILRS Technical Workshop, Koetzting, Germany, October 2003,

[2] Degnan, John., "Millimeter Accuracy Satellite Laser Ranging: A Review", Contributions of Space Geodesy to Geodynamics: Technology **25**, 1993

[3] Degnan, John., ""Asynchronous laser transponders for precise interplanetary ranging and time transfer", Journal of Geodynamics **34** 551-594 (2002)

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Further information

Please contact me at *bhan@lbl.gov.* More information on the Space Geodesy Project can be obtained at *http://space-geodesy.nasa.gov/*