SLR tracking

Basic requirements and aids to success.

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Introduction and objectives

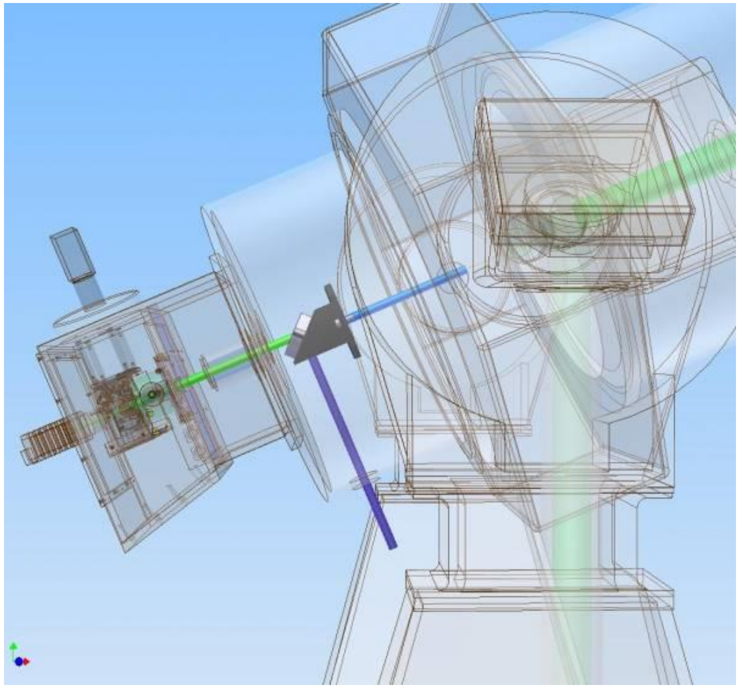
- The basic requirements of a functioning SLR system are obvious. A telescope that can track a satellite, illuminate the target with a laser and detect returning photons.
- But beyond this there are a wealth of factors that should be considered.
- I plan to cover the most fundamental of these, as well as some less essential but nonetheless useful systems that can be used.
- Hopefully illustrating how these aspects of system design and operation directly enhance acquisition and productivity.

Telescope pointing

- To get us started we need a telescope that can accurately track satellites at a range of altitudes.
- The exact pointing accuracy requirement will depend somewhat on your laser energy and divergence. But typically systems will track to a few arc sec.
- In reality unless you have a sealed and air conditioned dome (a good idea) then variation in the pointing model through the day will create larger offsets than this ideal tracking situation.
- It should be possible to build a temperature dependant pointing model, however real time corrections to the telescope pointing are almost certain to be required.

Pointing Aids

- To be able to build your pointing model you need a camera that lets you view stars.
- At Herstmonceux the telescope has a dichroic mirror that sends all non green light to a sensitive camera which allows simultaneous SLR and viewing to take place.
- In daytime a suitable red filter in front of the camera allows very bright stars to be observed.
- This lets you either build a full daytime model, or provides a guide to an observer, or the starting point of an automated search pattern.



Beam Alignment

- In both monostatic and bistatic systems a series of coude mirrors deliver the laser beam aligned perfectly with the optical axis.
- These mirrors must be adjusted to keep the beam static in the centre of the field while the telescope moves around the sky.
- Again, this alignment can vary with temperature and therefore the ability to see the beam in daylight as well as at night is very useful.
- Ideally you then want to be able to make rapid corrections to the beam pointing. For example at Herstmonceux the final emitting mirror is steerable so beam and target can be centred.

Beam Divergence

- One challenge of SLR comes from the different problems posed by targets over a wide range of altitudes.
- At LEO signal strength is less likely to be an issue, but tracking accuracy and prediction quality potentially are.
- While at GNSS and higher tracking is relatively simple, but obtaining sufficient signal strength more difficult.
- Being able to vary your laser divergence enables you to use the most appropriate beam setting for the situation. A wider angular divergence to give more tracking tolerance for LEO or the minimum possible for GNSS to maximise energy at the target.
- This also gives you some control of laser intensity at the satellite for missions with a maximum energy limit i.e. Sentinels.

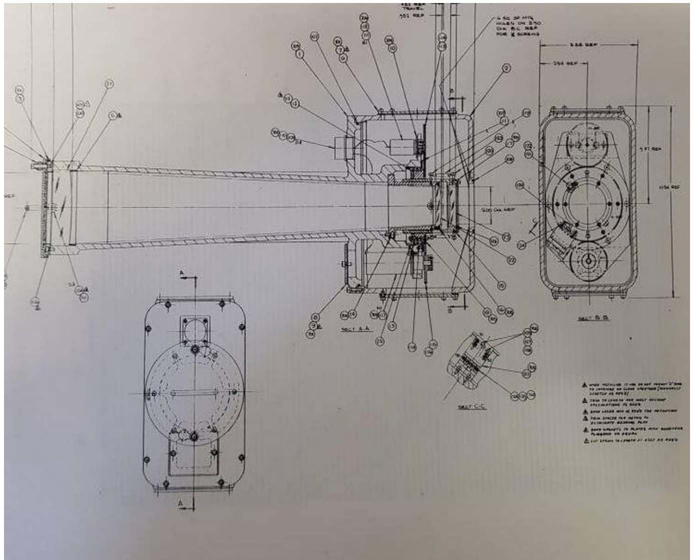


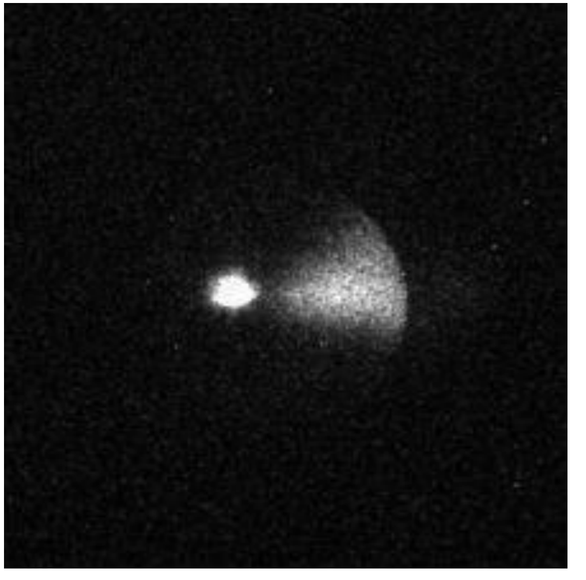
Figure 2-10. Beam Expander Assembly (Drawing E501716, Sheet 1)

Predictions

- Predictions as cpfs (xyz positions) are made available for all ILRS SLR targets, normally once a day.
- For the majority of targets most of the time these are of sufficient quality that data can be obtained day and night.
- However there are still occasionally problems post manoeuvre or with some very low orbiting satellites.
- The fastest accumulating error is in the along track direction.
- An SLR system therefore needs to be able to apply a correction to its tracking in real time by shifting position within the prediction by altering the epoch.
- Since this Time Bias offset is an error in the prediction set itself, it is possible to predict once some data has been obtained from any station. See http://slr.gfz-potsdam.de:5000/tb/v1/lists/leo for a useful current implementation.

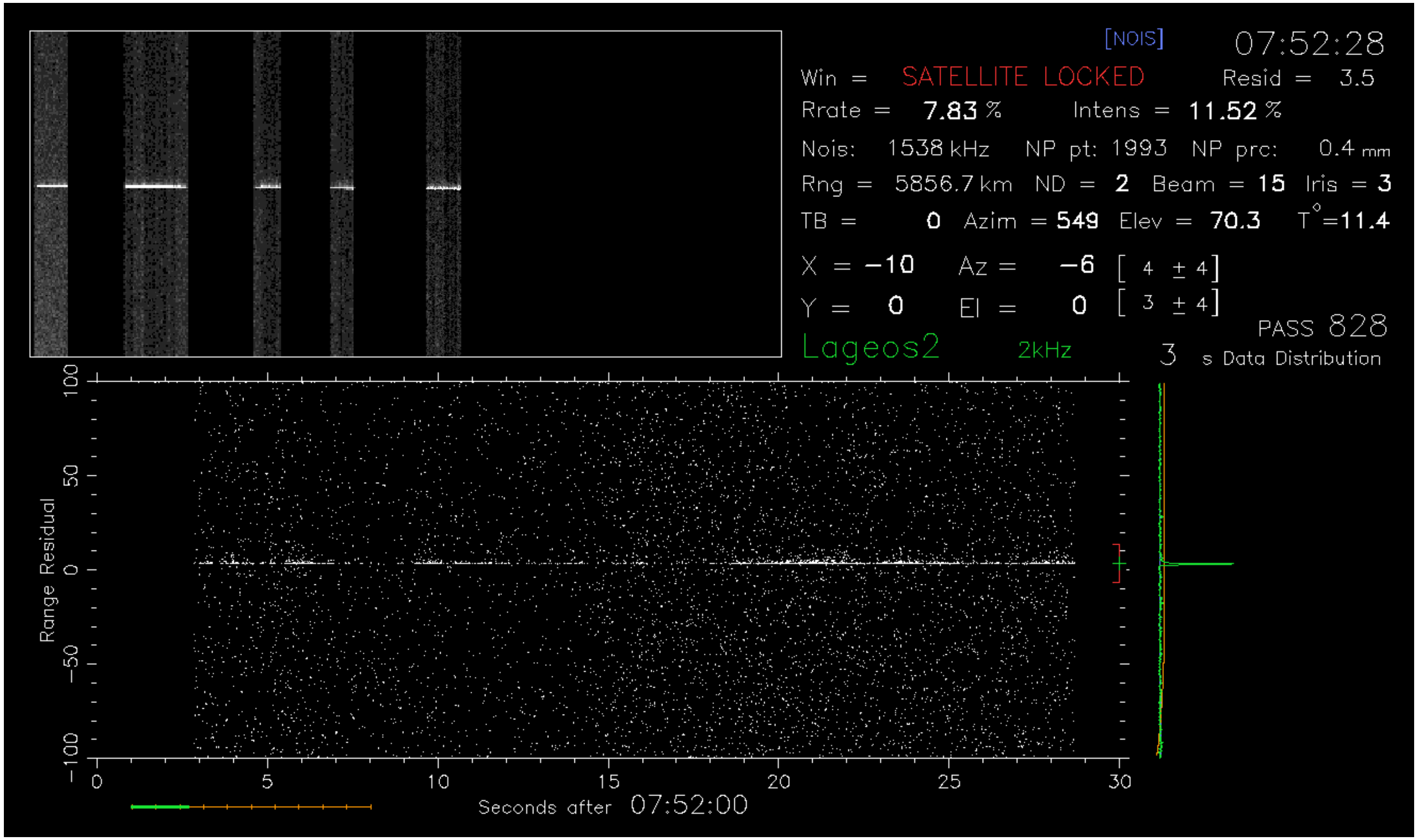
Obtaining returns

- So far we're tracking a satellite while firing our laser and we've got both target and beam aligned in the field of view.
- Now we need to make a time of flight measurement by detecting and timing the outgoing and returning laser pulse.
- The challenge here is the detection and identification of photons reflected by the satellite retro reflectors.
- This is achieved by a combination of temporal and spectral filtering.



Gating

- An SLR measurement begins with the recording of a firing time, normally a signal from a diode in the beam providing a start pulse to an interval timer or more typically recorded on an epoch timer.
- This is used to compute an estimated range from the prediction and generate a gating signal for a detector.
- How far ahead of any return you want to gate will depend on detector type, sky conditions and anticipated prediction quality. It is also useful to be able to alter this in real time.
- A successful detection will trigger a stop pulse and complete the measurement.
- Without this gating any real detections would be swamped by noise.



Real time tracking display

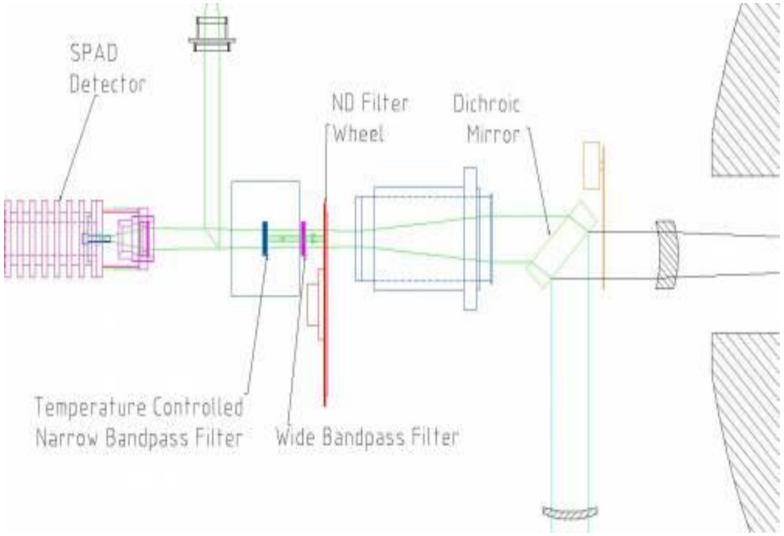
Note: x/y (beam) and Az/El (pointing) offsets

Gate at 100ns below track

Daytime noise (single photon detection)

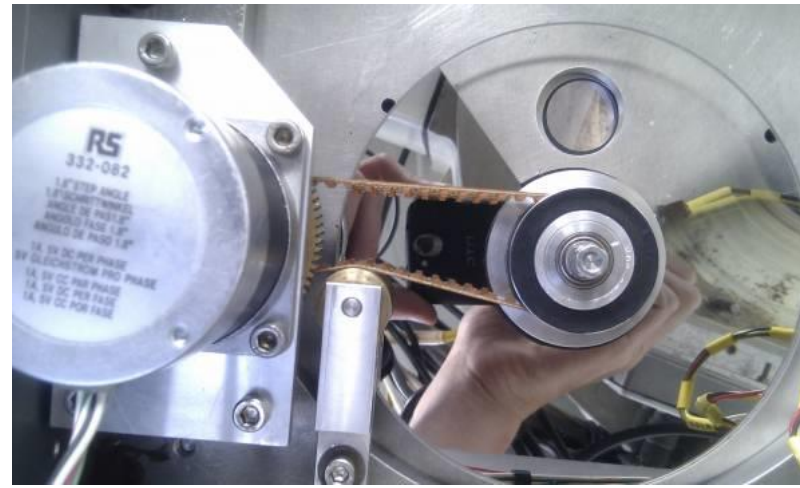
Spectral filtering

- It is critically important to set up your return optical path to filter out as much non laser wavelength light as possible.
- Many systems will have a permanent filter installed, for example a dichroic mirror filtering at a few nm.
- For daytime ranging a narrower filter will be needed, typically 0.1 – 0.2 nm width. There have been recent improvements in the efficiency of this type of filter and consequent daytime ranging improvements at several stations.
- Making this additional filter removable at night maximises return energy, but care must be taken to account for the additional glass in the return path.



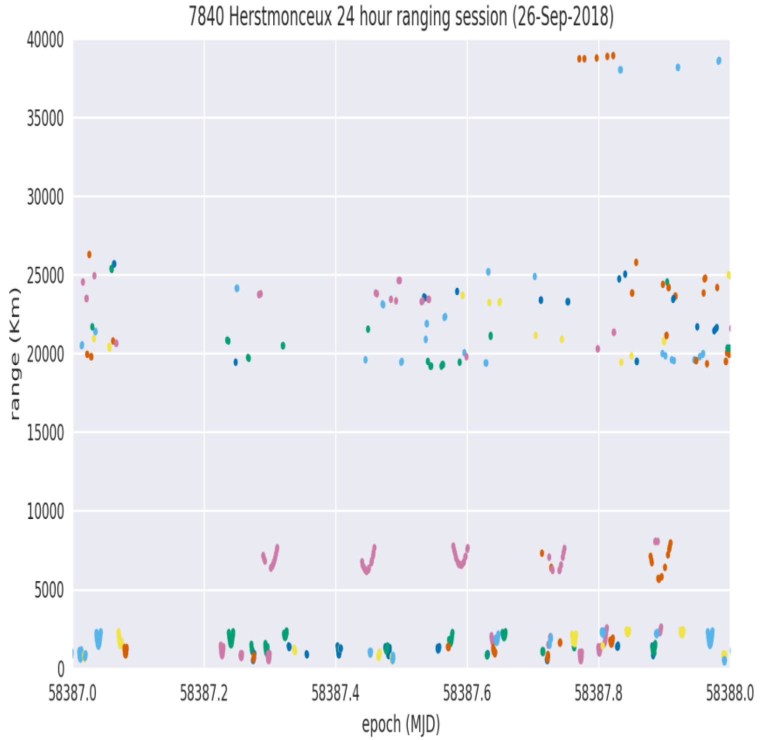
Return energy control

- Providing the ability to control return energy should be considered.
- Divergence control gives you a simple way of varying the return energy as well as smoothing out any tracking inaccuracies for LEO satellites.
- But the main control mechanism at Herstmonceux consists of an ND filter wedge that is controlled automatically in response to the computed return rate.
- This aims to maintain 8-10% return rate at all times. Providing a statistical approximation of single photon energy levels at the SPAD detector.
- Data with return rates >20% are then rejected at the processing stage.



Tracking strategies

- We have large numbers of satellites at a range of altitudes, this translates into observable passes of variable length.
- This creates a natural priority, where LEO targets of short pass duration are observed when available and longer passes fitted around them.
- On top of this is the science priority which acts to provide an order within these broad groups and for some classes of satellite a dynamic priority based on recent observations.
- The ability to quickly obtain sufficient returns for an accurate normal point with a high repetition rate system allows for faster switching between targets.



Thank you