Measuring Atmospheric Seeing with kHz SLR

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Abstract

During night-time kHz SLR operation in Graz, we use an ISIT camera to see satellites, stars, and also the backscatter of the transmitted kHz laser beam (Fig. 1). This backscatter image of the laser beam shows a beam pointing jitter in the order of several arcseconds, caused by the actual atmospheric conditions ("Seeing").

Using real time image processing, we determine the area of this beam pointing jitter, and derive the actual astronomical seeing values. These values depend not only – as usual for optical astronomy - on actual atmospheric conditions and on elevation of telescope, but also on the angular speed of telescope motion. In addition, the seeing values are considerably bigger (worse) during winter time, when – due to heating and poor isolation of the Graz observatory - the air above the observatory roof is significantly more turbulent than during the other seasons.

This beam pointing jitter due to atmospheric turbulence can reach a similar magnitude as the laser beam divergence; it spoils our pointing accuracy, affecting our return rate especially from higher satellites. To reduce these effects, we are planning to use a fast steering mirror, which is controlled by the ISIT image derived laser beam pointing offsets.

Introduction

The ISIT camera observes the backscatter of the transmitted laser beam; the image is transferred into the PC via a standard frame grabber. The software (written in C++) now uses the brightness of each pixel, to find out the borders of the laser beam image, and to determine the coordinates of the peak. The offset of the peak from the center (as defined by the illuminated reticle, visible in Fig. 1), is kept as a result for each processed image. This image processing at present is running with 25 Hz, and can handle each ISIT image.

The offsets of the laser beam pointing show variations in the several arcsecond range, and with frequencies between few Hz up to 25 Hz.

Possible reasons for the Laser Beam Pointing Jitter (other than atmosphere)

To verify that this jitter in laser beam pointing is NOT caused by the laser itself, we installed a Laser Beam Monitor at the exit window of the laser box (Fig. 2).

A mirror reflects a small portion of the laser beam (<< 1%) on a CCD chip; the CCD image is monitored by a PC, with up to 30 fps; for each image, the PC calculates the center coordinates (X/Y) of the laser beam, and stores single frame center coordinates and / or averaged values. This data sets (Fig. 3) show that the pointing stability of the laser at the output window of the laser box is in the order of a few microrad (<< 1", more or less within the measurement accuracy); there is no indication of a laser beam induced pointing jitter, as seen in the atmospheric backscatter images. The only visible effect is a very fast (few seconds) warm-up time at start of firing (Fig. 3)

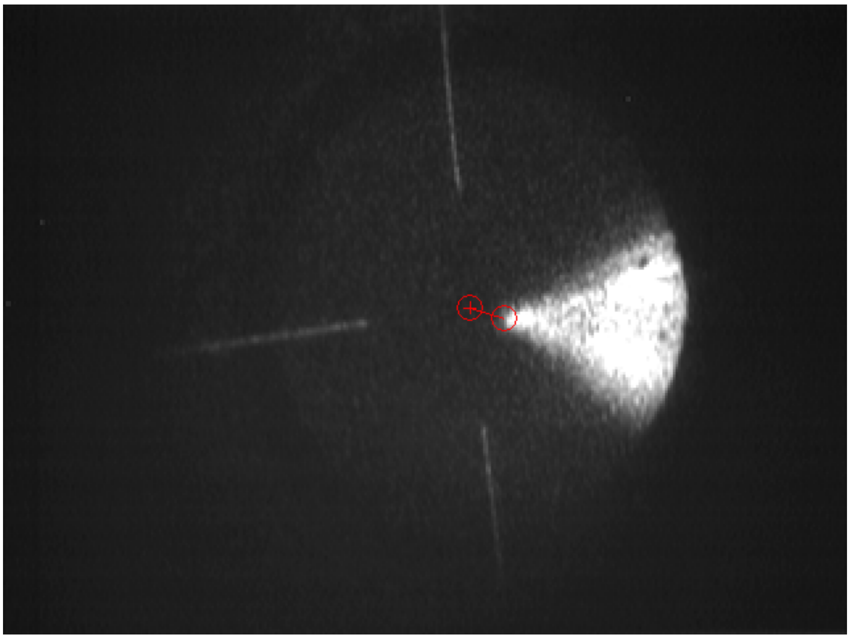

***Fig. 1:** ISIT image, with laser beam backscatter, laser beam peak as determined by image processing, and its offset from the center. This offset shows a pointing jitter due to atmospheric turbulence*

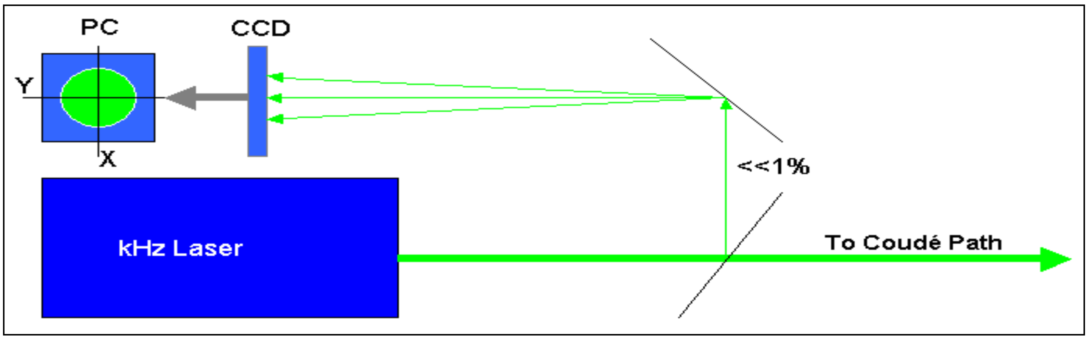

***Fig. 2:** Laser Beam Monitor*

Another possibility for the observed laser beam pointing wobble is the mount itself; but tests with fixed mount showed the same wobble of the laser beam pointing.

Laser Beam Pointing Jitter: It is due to atmosphere !

We concluded that the Laser Beam Pointing Jitter is caused by atmospheric micro-turbulences (atmospheric "seeing"); after talking with astronomers working in Graz, we expected seeing values of about 2-4 arcseconds as an average, with expected frequencies from a few Hz up to a few 10 Hz.

However, our measurements usually showed higher seeing values, ranging from about 3" up to more than 8"; there are several reasons for that:

- The fast moving SLR telescope, instead of a more or less constant pointing (or only slow moving) astronomy telescopes; the atmospheric conditions during SLR tracking are therefore changing much faster;
- Heating of the – almost NON-isolated – observatory in cold winter nights; the leakage causes heating of the surrounding air, which heavily degrades seeing; and most astronomy work at the Graz observatory is done usually in autumn, with almost NO heating of the rooms;

- SLR in Graz is usually done down to 10° elevation and lower, where seeing values are increasing.

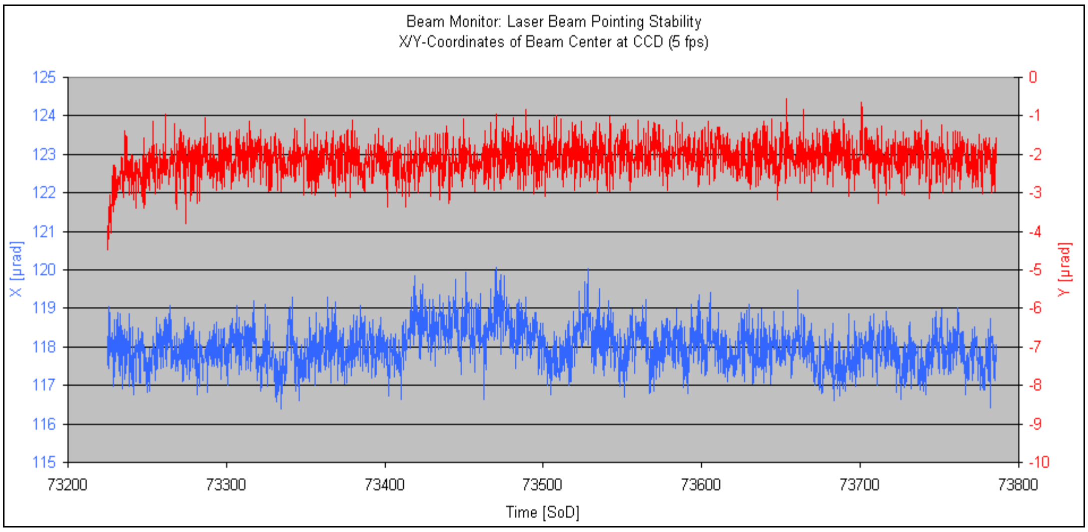

***Fig. 3:** X/Y coordinates of Laser Beam Center, 10 minutes of routine SLR operation.*

What are the effects for SLR ?

The minimum laser beam divergence of SLR Graz is about 5"; with a pointing jitter caused by seeing values up to 3" to 8" (and sometimes worse) the "hit rate" or pointing accuracy will decrease (Fig. 4), reducing the return rate.

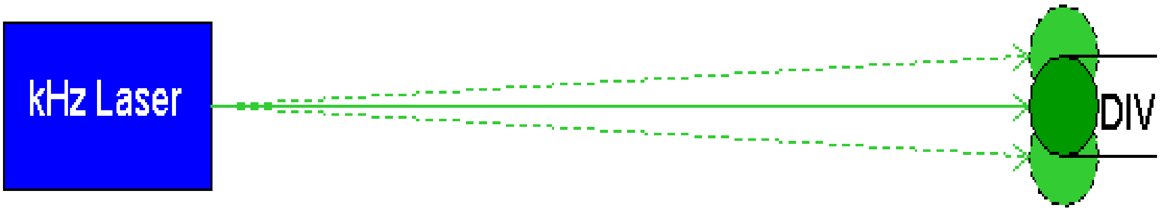

***Fig. 4:** Atmospheric turbulences cause laser beam jumping*

Verifying the Seeing Values

To check and verify the seeing values, as measured by the beam pointing jitter, we used the standard DIMM (Differential Image Motion Monitor; Hartmann – Shack) method: With an additional, standard telescope we observed e.g. the polar star; a mask with 2 small holes at a specified distance is placed at the entrance pupil of the telescope (Fig. 5); a CCD (defocused; placed with some offset from the focal plane) monitors the 2 spots created from the star light and the two holes; all images are stored on the PC.

The atmospheric turbulences cause the dual star images to move relatively to each other; this relative motion is measured in the PC, and allows calculation of the atmospheric seeing values.

A typical result of such seeing measurements is shown in Fig. 6; showing an average seeing value of 3" to 4"; it was made in summer time (no heating), at 45° elevation (polar star) and with constant pointing (star).

Seeing Values Derived from kHz Laser

Using the ISIT-Camera and the image processing programs- as described at the beginning - we monitored the atmospheric seeing values automatically during routine

SLR operation for several months; due to the method, we were able to collect seeing values along each tracked pass, and to correlate it with azimuth and elevation of each pass. As an example, an AJISAI pass with about 50° maximum elevation is shown in Fig. 7; tracking started / stopped at about 10° elevation; the correlation between elevation and seeing is obvious for this pass; however, other passes showed sometimes completely different values. Such a different pass is shown in Fig. 8: an ENVISAT pass, with a maximum elevation of <30°, starts with the usual decrease of the seeing value with increasing elevation; however, it then shows a significant INCREASE.

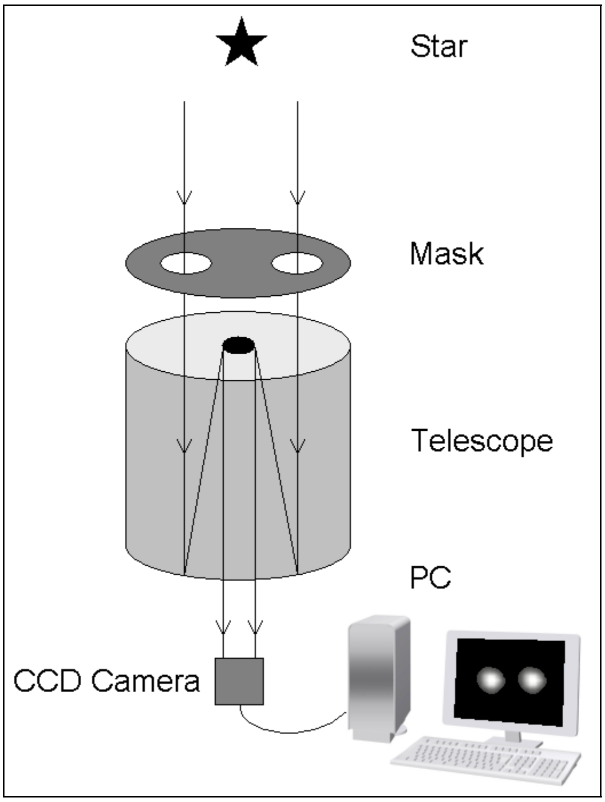

Fig. 5: *Differential Image Motion Monitor (DIMM) / Hartmann – Shack method.*

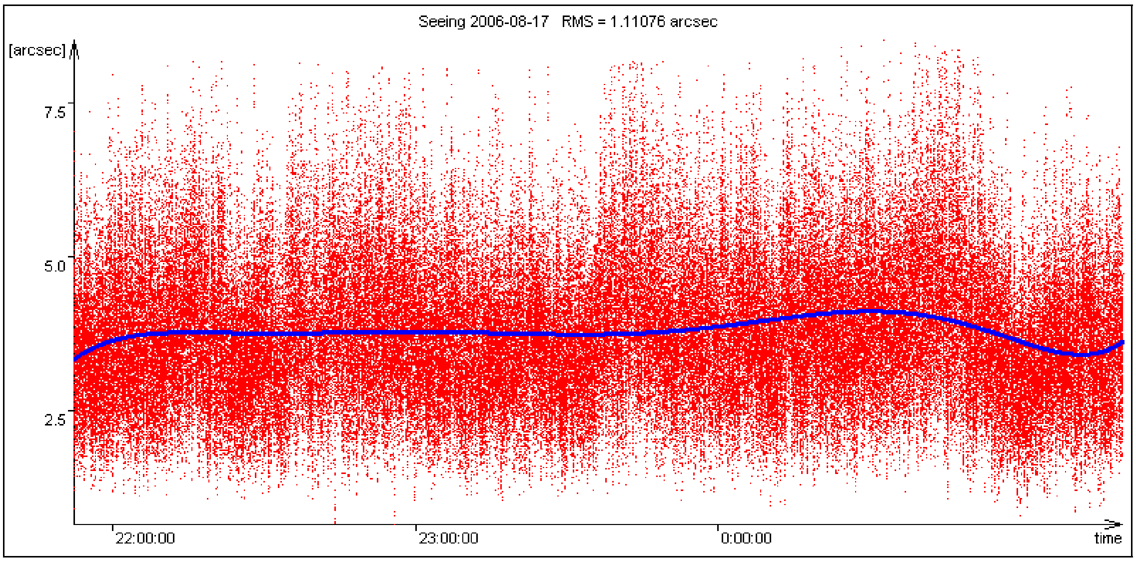

Fig. 6: *Seeing Values measured with DIMM: Summer night, polar star used.*

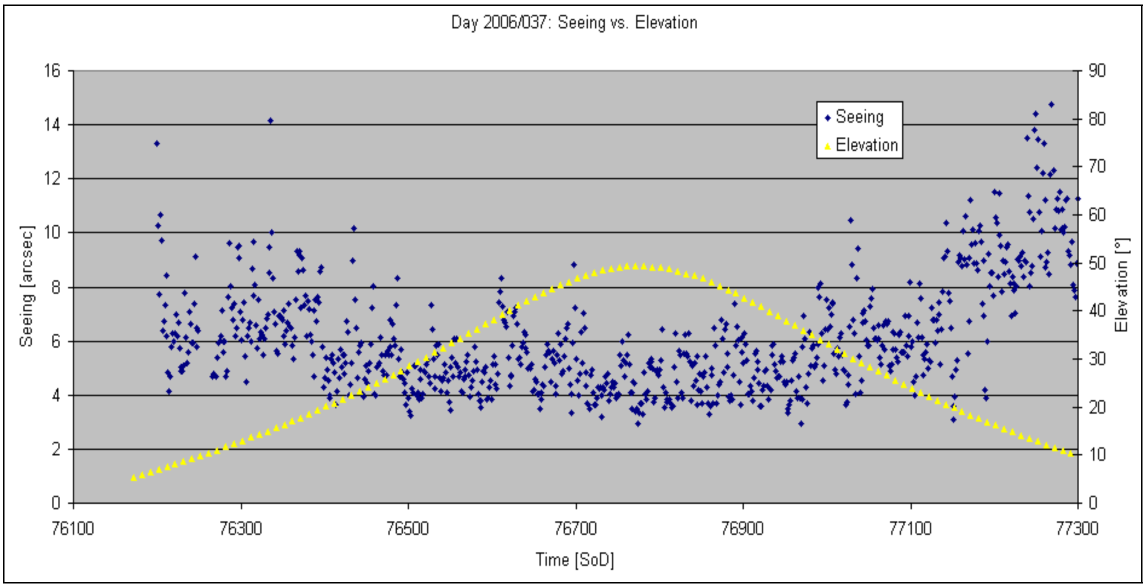

***Fig. 7.** Ajisai: day of year 2006 / Day 037: Seeing changes with elevation.*

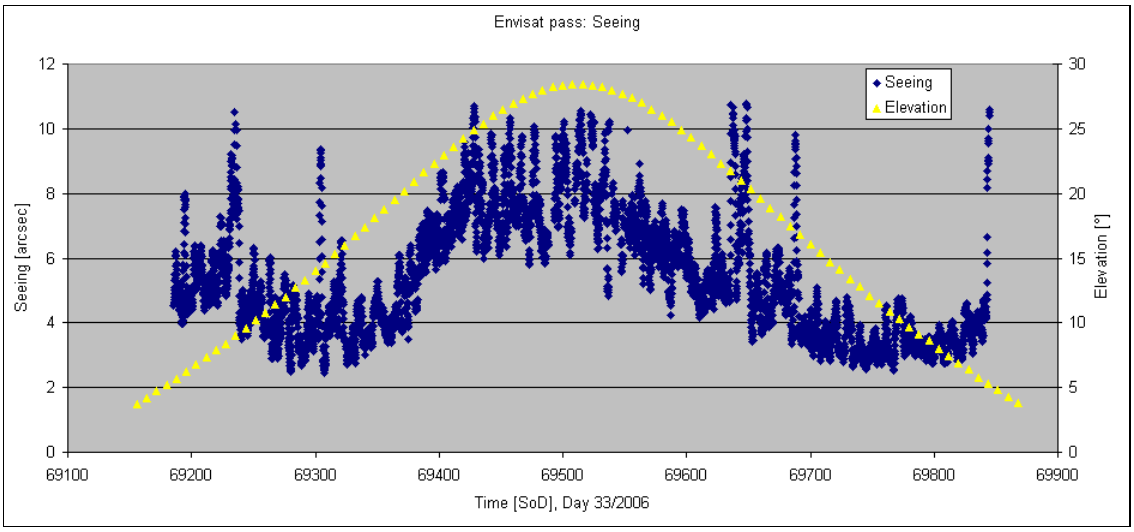

***Fig. 8:** Envisat: day of year: 33, < 30° Elevation*

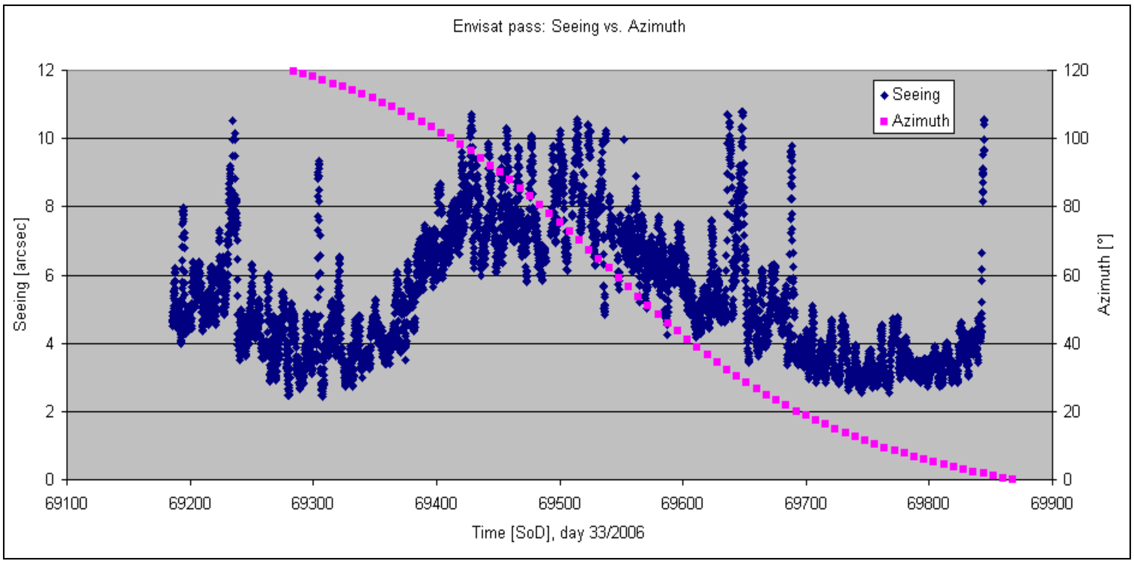

***Fig. 9:** At 90° Azimuth: => Obs. Roof, Heating Influence*

The explanation for such a strange behaviour: At this time we started to track (at 90° azimuth) along / above the observatory, where the leakage of the heated building caused increasing turbulence, and hence increasing seeing values (Fig. 9).

Future plans:

We will continue to monitor atmospheric seeing values along the laser beam path during routine SLR operation at night; at least we should get some valuable statistics about the seeing values at the observatory (no such records exist here up to now). In addition, there are plans to install a Fast Steering Mirror (FSM) at the laser bench, to be able to compensate at least partially the beam pointing jitter, using the actual pointing offsets of the laser beam as derived from the ISIT images as control input to the FSM. The goal is to increase return rate from high satellites, like GPS, Giove etc.