IRsweep

Understanding the noise of a measurement

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Contents

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Introduction

Signal to noise is an important topic when discussing the performance of a spectrometer and a convenient way to describe this is through Allan deviation, which provides a way to quantify the noise present in a system as a function of integration time. The Allan deviation is calculated by dividing the measurement data into overlapping groups of equal length and calculating the variance of the differences between the means of these groups. This application note describes the result of applying an Allan deviation analysis to the output of the IRis-F1 and what this means for a measurement.

Results

The plots in Figure 1 show the noise behavior of the IRis-F1 with a laser module spanning approximately 1200 to 1290 cm^{-1}. All measurements were done with an empty sample compartment and the absorbances are presented in log of base 10.

Allan deviation of absorbance | **Spectrum**
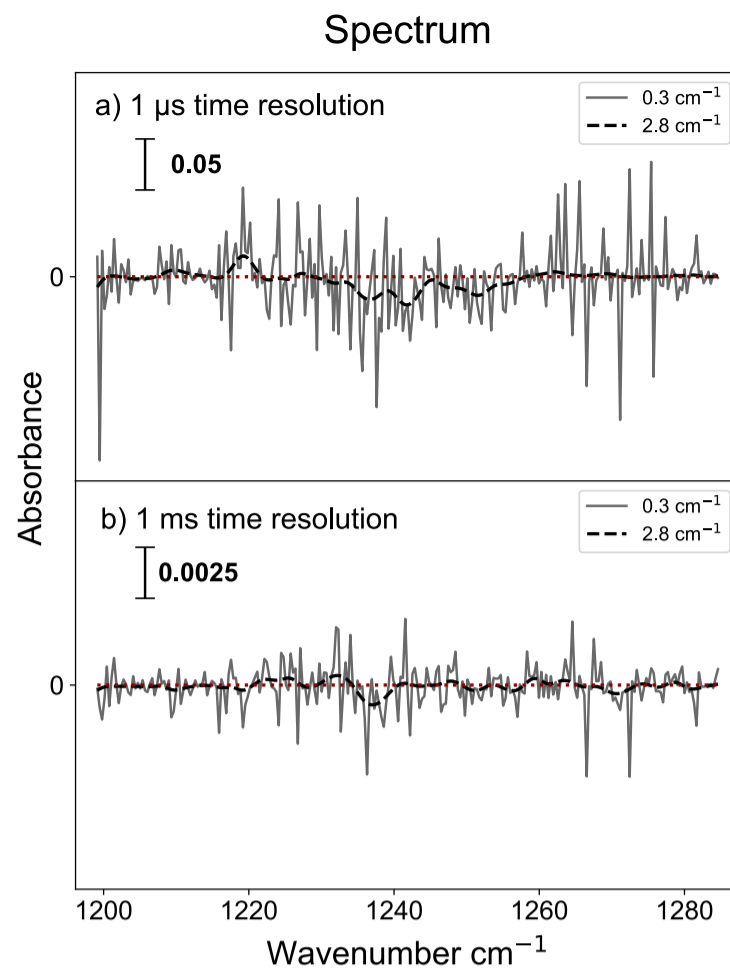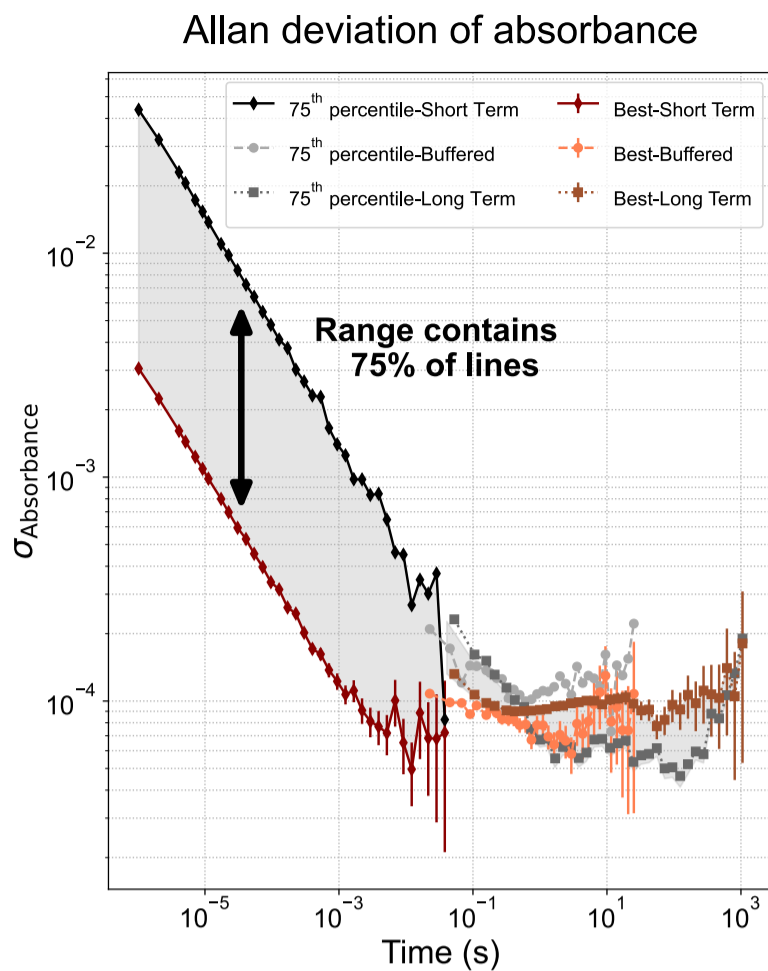
Allan deviation overview

The Allan deviation of two spectral points is shown on the left. It shows the standard deviation of a spectral line as a function of integration time. Since not all spectral points in a dual comb measurement are equal, two points are shown. The red and orange lines belong to the strongest heterodyne line, which has the lowest noise. The black and gray lines belong to the heterodyne line marking the 75th percentile. This means, 75% of the data points are better than this and lie in the range indicated.

The measurements span 1 µs to 1 hour. It's currently not possible to do this in a single continuous measurement (watch this space for developments!), which is why three separate measurements were taken, represented by the lines Short Term, Buffered, and Long Term. The different acquisition modes are described elsewhere.

There can be a small jump in the vertical dimension when the acquisition mode is changed, which is due to different levels of throughput achieved. The Short Term measurement has a throughput of 100%, meaning all of the measurement time can be co-averaged. In contrast, the Long Term mode currently reaches a maximum throughput of *ca.* 10%, meaning that for every second measured, only 100 ms are integrated.

At short times, the Allan deviation decreases linearly with a slope of 0.5, which shows a dependence of noise on integration time (τ) of $1/\sqrt{\tau}$. At longer times, the dominant source of noise is due to long-term drifts and further averaging does not change the noise level. Different spectral lines take a different amount of time to converge to this same level. To improve further, see the section "Spectra overview".

Spectra overview

The right side of the figure shows the spectral response of the IRis-F1 under several conditions. The top panel shows the noise at maximum time resolution of 1 µs, while the bottom panel shows the noise when integrated to 1 ms. From these plots, it's easy to see how the noise is different across the spectral range and how it scales with integration time.

In each case, the black dashed line shows how the noise level improves with spectral integration. These figures were generated from a single acquisition. For even lower noise levels, acquisition-averaging can be used, which scales well for many hundreds of acquisitions. Otherwise, stronger spectral and/or time averaging is also possible. For example, with

1000 averages, τ of 500 μs, and 4 cm^{-1} spectral averaging, noise levels approaching 1 x 10^{-6} across a spectrum can be achieved.

Looking at all spectral lines

Looking at all lines of the Allan deviation can quickly become overwhelming. To improve visibility, Figure 2 shows all lines for this measurement ordered from worst to best in a heatmap. The axis Spectral Index therefore represents the wavenumber points, but ordered by noise level.
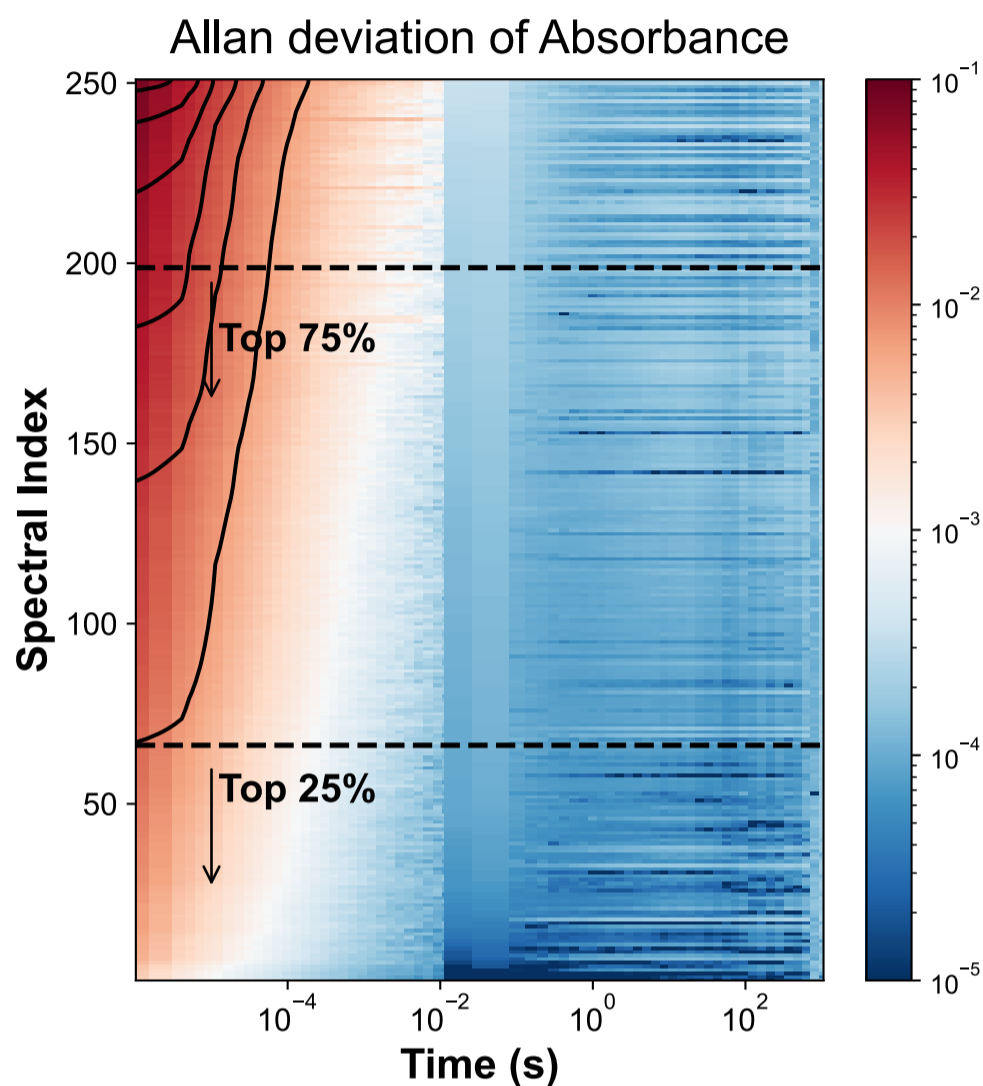
The break at 10^{-2} s once again represents a switch in acquisition modes (see above). Most of the spectral lines indicate outstanding noise for their integration times.

Related product

IRis-F1

The IRis-F1 spectrometer offers you an unmatched combination of speed, brightness and multi-color measurements. The quantum cascade laser frequency comb spectrometer is the first turn-key frequency comb spectroscopy system. As opposed to single-frequency operation, which necessitates tuning over your spectral range of interest, you will achieve a broad spectral coverage in a single-shot measurement.