A Peculiar Natural Resonance of the Earth at 46.265 µHz

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Abstract: By carefully choosing the filter methods, the noise level of geophysical data could be reduced sufficiently to detect a hitherto unknown spectral line whose modulation is phase-locked to the duration of the year. The origin is enigmatic.

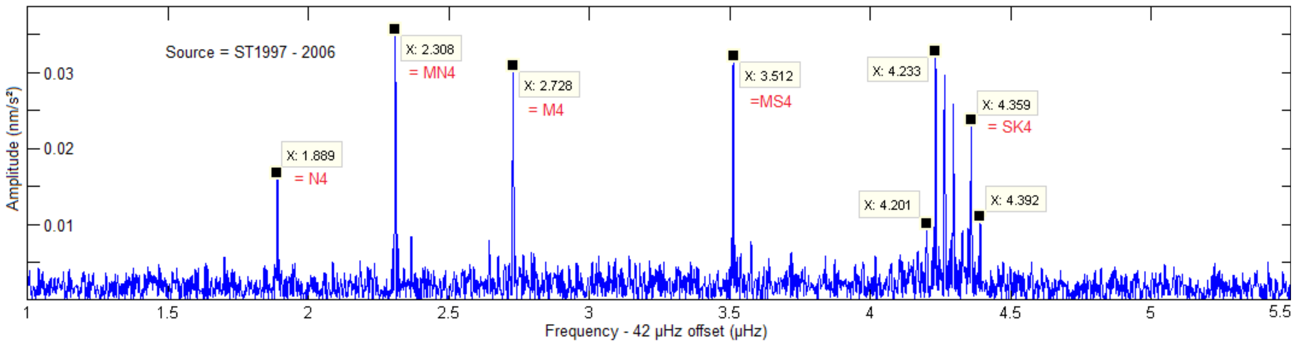
Introduction

All calculations, which concern the legendary *Slichter triplet*[1], predict on the basis of the previously known data that the earth core oscillates at a frequency between 32 µHz and 85 µHz around its rest position near the center of the earth[2]. The rotation of the earth causes three different natural resonances of the 1S1 translational mode to exist. Despite multiple, intense search, the vibration has not been proven beyond doubt. One reason could be that the measurable amplitude disappears here on the earth's surface in the background noise of the many earthquakes.

The extremely strong tide signals also hinder the search in the lower frequency range. Extensive research has shown that most methods of suppressing tidal signals generate additional noise and must be avoided. Therefore, a novel method has been developed which deletes selectively the tide signals and does *not* increase the noise level. The biggest advantage of this method is that it is now possible to search for previously unknown spectral lines in the immediate vicinity of strong signals.

Data of SG Strasbourg

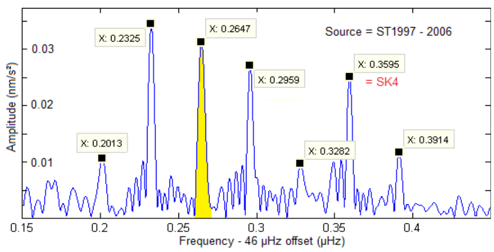
The investigation started with the low-noise data sets of the superconducting gravimeter ST during the years 1997 to 2006. Immediately and without further post-processing, a group of closely adjacent spectral lines near 46.26 µHz appeared, that can not be found in any table of known geophysical resonances[3][4]. Since the same group also appears in the data sets of the stations CA, CB, S1 and S2 with very good signal-to-noise ratio, they can not be equipment malfunctions.



The figure above shows part of the spectrum of data recorded by the gravimeter ST. To improve the frequency resolution, all frequencies were reduced by the value 42 µHz before the FFT was carried out (Superhet method). Known tide frequencies are marked in red.

A Strange Quintet

To determine further details of the peculiar group of spectral lines, the frequency offset was increased to 46 µHz. The spectrum can be broken down into a quintet, which may be examined more closely and two lines to the right (SK4 and a line of unknown origin),who are unlikely to have anything to do with the quintet.



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The spectral line at f = 46.3 µHz is asymmetric and apparently consists of two lines of different origin: a strong component at 46.2958 µHz and a weaker (S4) at 46.2963 µHz. According to Tide catalog, the S4 line should be negligible because its amplitude is only 11% of the adjacent line MS4. Below we will deal exclusively with the strong component at 46.2958 µHz. The S4 component can not be eliminated due to a lack of exact knowledge of amplitude and phase, and the resulting interference must be accepted.

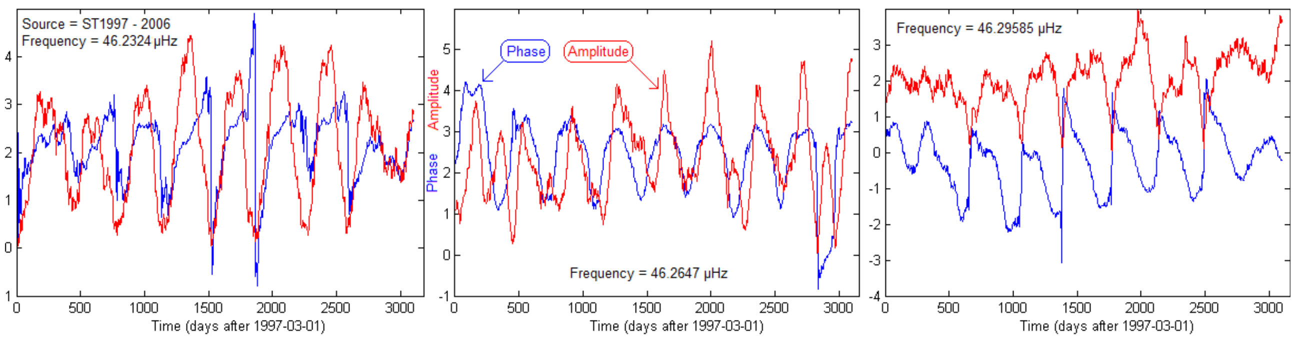
The exact values of the five spectral lines and their distances from the putative center frequency (yellow) are summarized in the following table.

Frequency (µHz)	46.20133	46.23248	46.26469	46.29585	46.32817
f-Deviation (µHz)	0.06337	0.03221	0	0.03115	0.06347
Period (days)	182.65	359.30	See below	371.52	182.35
Amplitude (pm/s²)	11	34	31	28	10

The period lengths calculated in the third row of the table suggest the following interpretation:

- There is an oscillator generating the central frequency 46.2647 µHz. Since all SGs are located on the rotating earth surface, it remains unclear whether the oscillator itself is amplitude-modulated or whether the fluctuations are a consequence of the motion of the earth's crust. This question will not be further elaborated here.
- If the sidebands are *not* suppressed, the measured total amplitude changes periodically over the course of one year. See below.
- The small percentage of double frequency (Period ≈ 182 days) means that the envelope of the oscillation is not sinusoidal. To determine the exact waveform, the relative phases must also be determined.

Therefore, the next goal is to check this time dependence of amplitude and phase. The usual type of FFT is unsuitable for determining these two physical quantities as a function of time. By contrast, the Vector-FFT[5] method is designed so that the necessary time dependencies can be displayed well.



In all three measured phases as well as in the individual amplitudes the annual rhythm is obvious.

The preparation of the data

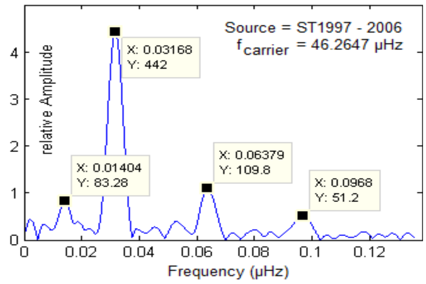
The preparation of the raw data generated by the SG has already been described several times, so a short summary is sufficient here. The influence of the fluctuating air pressure is taken into account with a factor of 3.74 and all data gaps are filled with the value zero. As digital filters will introduce noise to a signal, they must only be used when absolutely necessary.

- First, a comb filter with the notch frequency 800 µHz removes the lowest (tide-)frequencies and shifts some noise to higher frequencies.
- The annoying and extremely strong tide signals are selectively deleted without changing the noise level.

- Only before decimating by the factor 100, the data *must* pass through low-pass filters, whereby a slight increase in the noise level is inevitable.
- In order to minimize the time required for the subsequent vector FFT, all frequencies are reduced by 46 µHz and the sampling interval is extended to ten hours. Again, the crossover frequencies are chosen so that the noise increases as little as possible.

Here are the parameters used by the Vector-FFT:

NFFT = 2^{18} (=262144);
frame-length = 400 data points (=4000 hours), extended by zero-padding;
advance of the frame = 4 data points (=40 hours);
total number of frames = 1860;

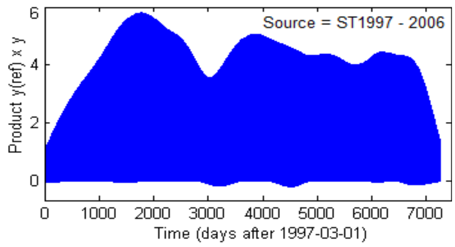


All three phases shown above show very regular fluctuations whose period can be determined quite accurately by FFT. The spectrum shows that the phase of the carrier frequency of 46.2647 µHz varies almost sinusoidally, the period being 365.3 days. The three smaller peaks indicate distortions of the sinusoidal modulation.

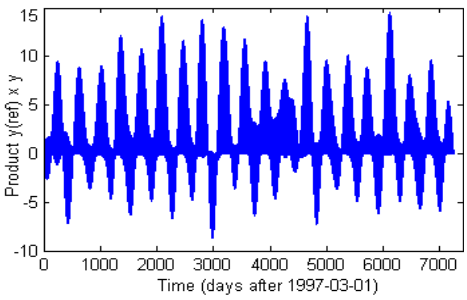
It must be emphasized that the phases of the tidal signals such as MN4, MS4 or SK4 fluctuate very irregularly, have much smaller amplitudes (± 0.1 radians) and have not the slightest resemblance to the phase modulation of the mysterious oscillation detected here at 46.2647 µHz.

Long-term measurements ST

The Strasbourg station has been measuring with the SG since 1997 and has been providing very low-noise data since then – with brief interruptions. If these are combined into a single data chain, interesting investigations can be carried out.

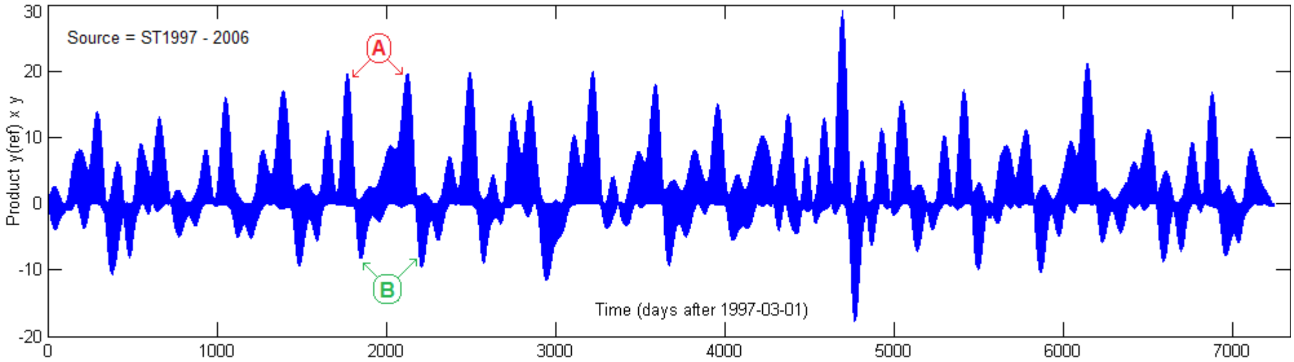


a) The carrier: After all sidebands of carrier frequency are suppressed with an extremely narrow-band filter (bandwidth 0.02 µHz), the long-term constancy of amplitude and phase gets visible. To show this, the signal is multiplied by the reference frequency of 46.26469 µHz (direct conversion). If the frequency and phase position are selected correctly, the product should show no sign change. The shows the result: the SG measures a signal that oscillates for at least twenty years at constant frequency and approximately constant amplitude. The amplitude decrease at both ends is caused by the transient response of the very narrow filter. The two major earthquakes in 2004 and 2011 seem to have no influence.



b) Carrier + two satellites: Widening the bandwidth to 0.1 µHz, the overall result is formed by only three spectral lines: 46.2325 µHz, 46.2647 µHz and 46.2959 µHz. A windowed sinc filter with a rectangular passband was used to avoid changing the mutual phase relationships. The adjoining figure shows periodic phase jumps of the overall signal, which occur exactly once a year. 2900 days after the start of the measurement, there appears to be a slight deviation from the strict regularity, which lasts several years. Cause could be the strong EQ 2004-12-26.

c) The whole signal: A further broadening of the bandwidth to 0.24 µHz shows finer details such as double peaks and also allows a better determination of events, but also contains more disturbing noise.

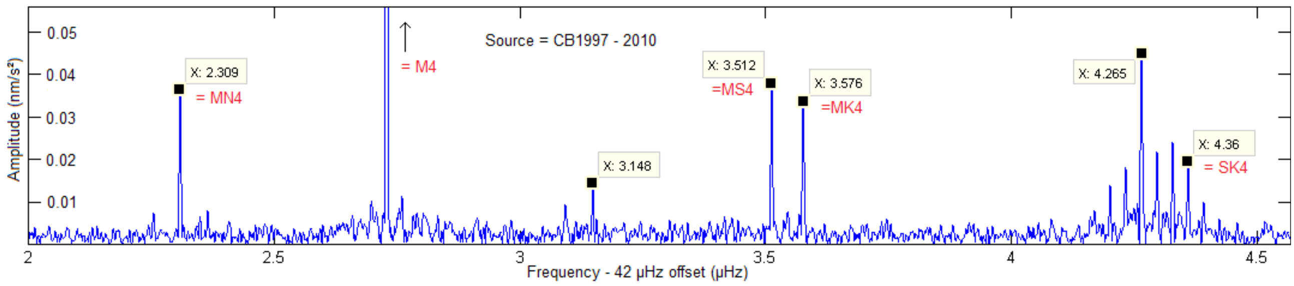


The figure above shows a peculiar signal structure over the course of each year: two in-phase pulses (small – large) are followed by two out-of-phase pulses (large – small). Since the delays of the low-pass filters and the start date of the records (1997-03-01) are known, the times of the maxima can be determined quite accurately. The big positive impulses (indicated in the figure with a red **A**) have their maximum value around the 20th of December each year. The big negative impulses (green **B** in the figure) have their maximum value *exactly* 91 ± 1 days later, ie around March 20 of each year. Are these dates fixed by the Earth's axial tilt?

The times of the smaller pulses can not be reliably determined because the signal-to-noise ratio is insufficient.

Data of SG Canberra

The spectrum recorded in Canberra differs in some details from the spectrum of the Strasbourg data, the enigmatic frequency 46.265 µHz is even more clearly visible. To improve the frequency resolution, all frequencies were reduced by the value 42 µHz before the FFT was carried out (Superhet method). Known tide frequencies are marked in red.



The exact values of the five spectral lines and their distances from the putative center frequency (yellow) are summarized in the following table.

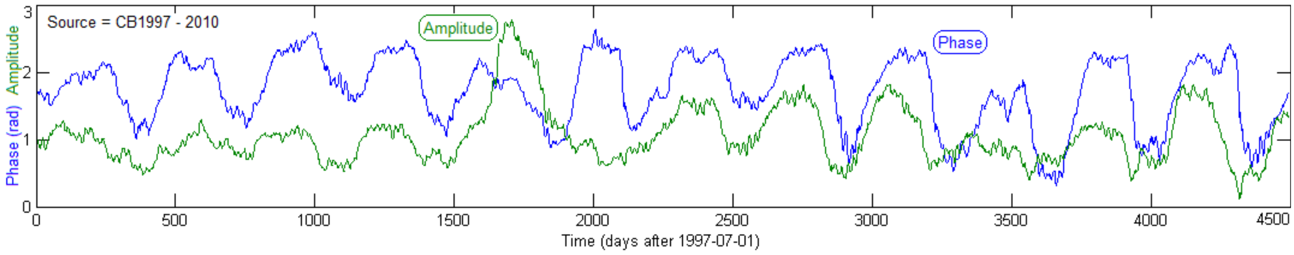
Frequency (µHz)	46.20112	46.23248	46.26470	46.29649	46.32806
f-Deviation (µHz)	0.06358	0.03221	0	0.03179	0.06337
Period (days)	182.04	359.3		364.09	182.65
Amplitude (pm/s²)	14	18	45	21	23

The time dependence of amplitude and phase was calculated with vector FFT. Here are the parameters used by the Vector-FFT:

NFFT = 2^{18} (=262144);
frame-length = 400 data points (=4000 hours), extended by zero-padding;
advance of the frame = 4 data points (=40 hours);
total number of frames = 2696;

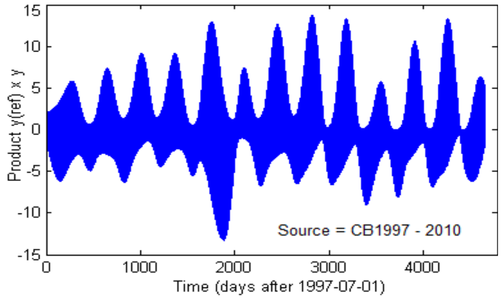
Long-term measurements CB

In order to determine the time of the striking amplitude maximum, the frame duration of the FFT must be taken into account. The increase in amplitude begins 1630 days after the start of the recordings. For this, the duration of a frame (167 days) must be added. As a result, this increase in amplitude begins 4.9 years after 1997-07-01.

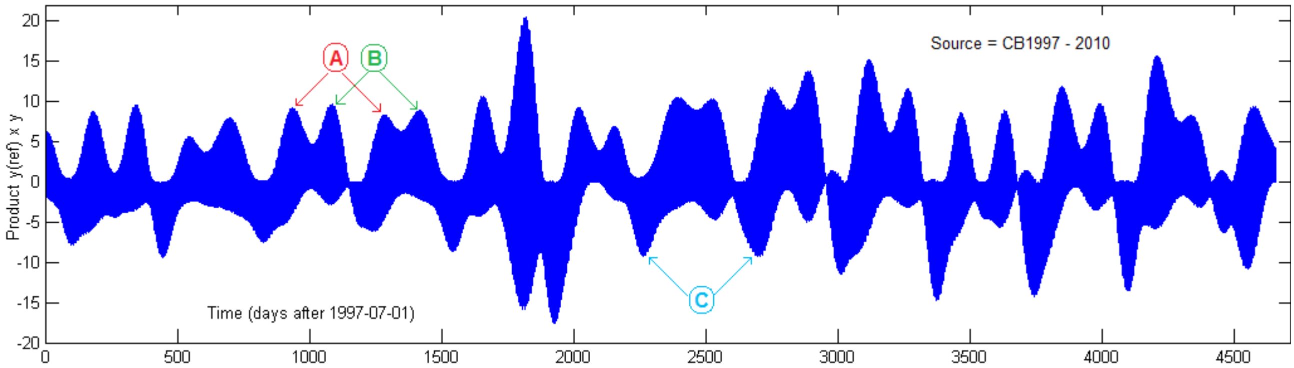


The further investigations are carried out with the method of direct conversion: To measure the phase constancy and the amplitude of the signal, this is multiplied by a computer-generated sinusoid of the same frequency.

a) Carrier + two satellites: Chosing the bandwidth of 0.1 µHz, the overall result is formed by only three spectral lines: 46.2325 µHz, 46.2647 µHz and 46.2965 µHz. A windowed sinc filter with a rectangular passband was used to avoid changing the mutual phase relationships. The figure on the right shows the envelope.



b) Carrier + four satellites: A further broadening of the bandwidth to 0.2 µHz shows finer details such as double peaks and also allows a better determination of events.



The figure above shows a peculiar signal structure over the course of each year: two in-phase pulses (A – B) are followed by a single out-of-phase pulse (C). Since the delays of the low-pass filters and the start date of the records (1997-07-01) are known, the times of the maxima can be determined quite accurately. The leading positive impulses (indicated in the figure with a red **A**) have their maximum value around the 20th of December each year. The second positive impulses (green **B** in the figure) have their maximum value 149 ± 2 days later, ie around May 20 of each year. The negative maximum (blue **C**) follows 249 days after (A), about the 17th of September each year.

Acknowledge

Thanks to all operators for gathering SG data and thanks the IGETS data base at GFZ Potsdam for storing the data.

[1] L. Slichter, The fundamental free mode of the Earth's inner core, Proc. Natl. Acad. Sci., 47, 186-19, (1961)
[2] S. Rosat, Y. Rogister, D. Crossley, J. Hinderer, A search for the Slichter triplet with superconducting gravimeters: Impact of the density jump at the inner core boundary, Journal of Geodynamics 41 (2006) 296–306
[3] Severine Rosat, ondes_non_lineaires, personal communication
[4] Hartmann, Wenzel, Tidal potential catalogue, (1995)
[5] H. Weidner, Frequency Measurements in Noisy Records using Vector-FFT, 2019