Disturbances on space borne accelerometers and the behavior of metal shields in a dilute plasma

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Introduction

On electrostatic accelerometers of the gravity field missions CHAMP, GRACE and GOCE many high frequency, and on GOCE also broad band noise, can be seen. Some are analyzed already: the heater switching spikes on GRACE (Flury et al. 2008), the magnetic torquer switching on GRACE (Peterseim et al. 2012) and so called twangs (Peterseim 2014). We now show the correlation of one type of twangs with the troposphere and the excitation of whistler waves (in VLF very low frequency range) injected by lightning strokes in the troposphere and propagating in the ionosphere-Earth waveguide as sferics and leaking into the ionosphere.

As it is not possible to explain all the observed similarities between twangs and whistlers as secondary effects (accelerations or magnetic disturbances) we hypothesize, that the accelerometer itself is sensitive to VLF and worked out two special frequencies which cause the problems, the lower-hybrid resonance and the ion cyclotron resonance. We classify the disturbances, show the correlation of whistlers and twangs and present the hypothesis.

Classification of disturbances

First class: Internal short pulsed disturbances
In this class belong all switching processes on the spacecraft, like heater switching, torque switching and discharging events (twangs type I and II)

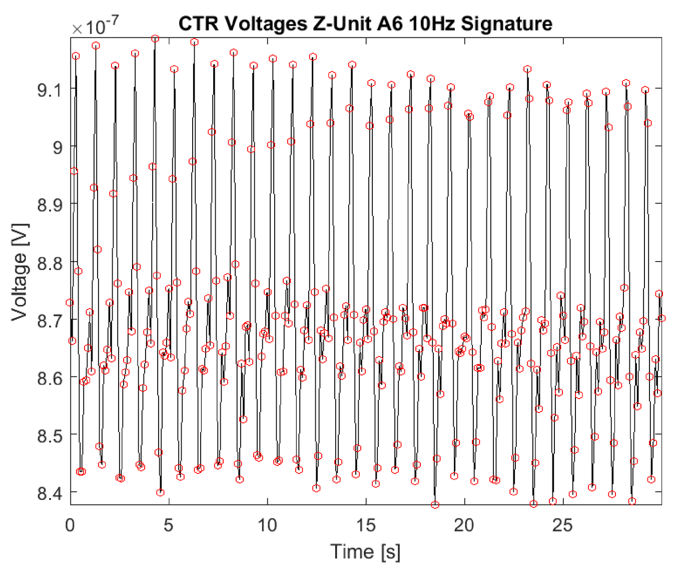

Fig.1:

Heater switching spikes on GOCE accelerometer.

Second class: Internal continuous disturbances
In GOCE accelerometer it is the first time that we se continuous disturbances. In all 6 accelerometers in axis a white noise structure is seen, which correlate between the two accelerometers of all axis. Correla ted to this noise is a permanent quadratic factor at least shown for the y-direction of accelerometer 2 a 5 (Siemes 2017)

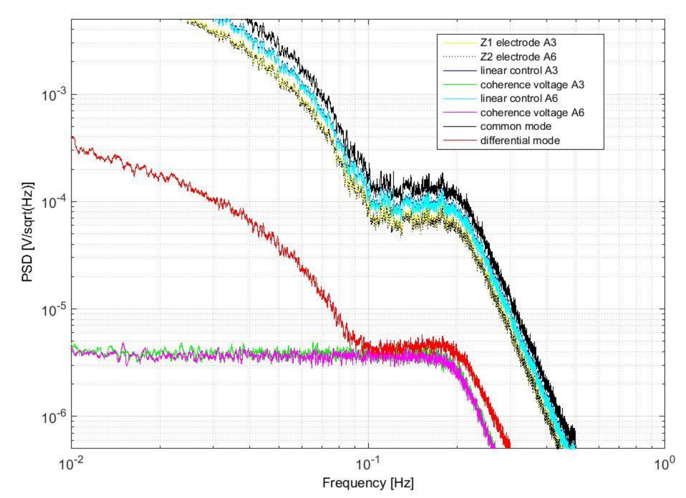

Fig.2:

Noise on the accelerometers 3 and 6 of the GOCE gradiometer.

Third class: External short pulsed disturbances
The type III twangs belong in this class. These signatures correlate with sferics caused by lightning strokes and high wind speed.

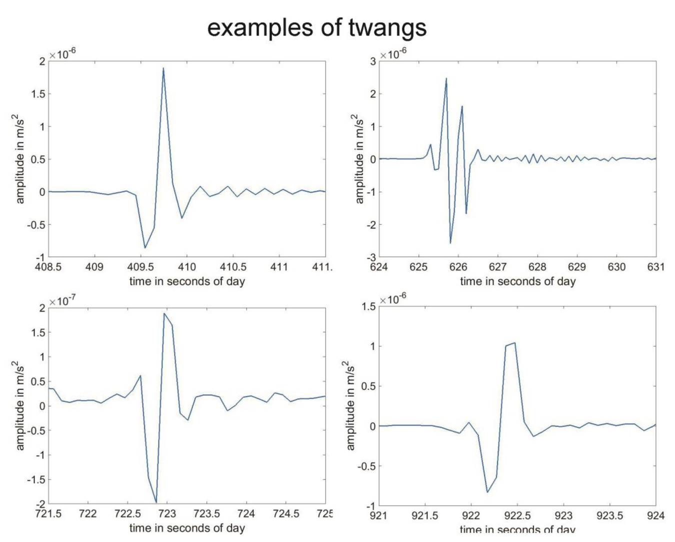

Fig.3:

Twangs have varying shapes. In most cases they consist of double or triple peaks but more peaks can be observed. A following oscillation is as common as a precursor peak or even precursor oscillation.

Acknowledgement

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Tropospheric twangs

These twangs correlate with the cloud coverage and with strong winds in the troposphere. They have a seasonal variability, a day and night asymmetry, and separate bands for first peak positive and negative. As figure 3 shows they have multiple shapes, but can be divided into a multiple peak and a following oscillation. They are dominantly observed in the radial direction of the accelerometer.

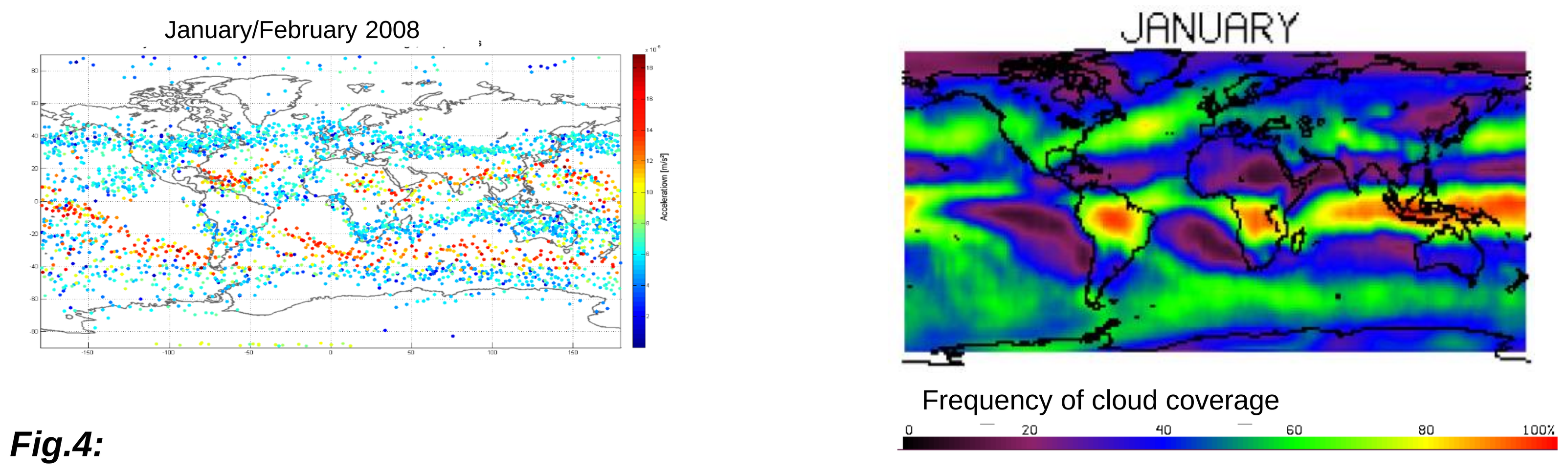


Fig.4:

Comparison of twangs and its amplitude with cloud coverage in the troposphere.

Sferics and Whistler-sferics

Sferics are injected short electromagnetic pulses in the Earth-ionosphere waveguide by lightning strokes in the troposphere. While propagating in this waveguide they disperse and when reflected at the ionosphere fractions of the energy can penetrate into the ionosphere and travel as whistler-sferics to the top side of the ionosphere and into the magnetosphere. Their propagation direction is perpendicular to the Earth surface. As whistler-sferics travel oblique to the magnetic field the electric field is tilted in the direction of propagation. So the electric field has a great component into the direction of propagation. Their frequency is in the order of some kHz.

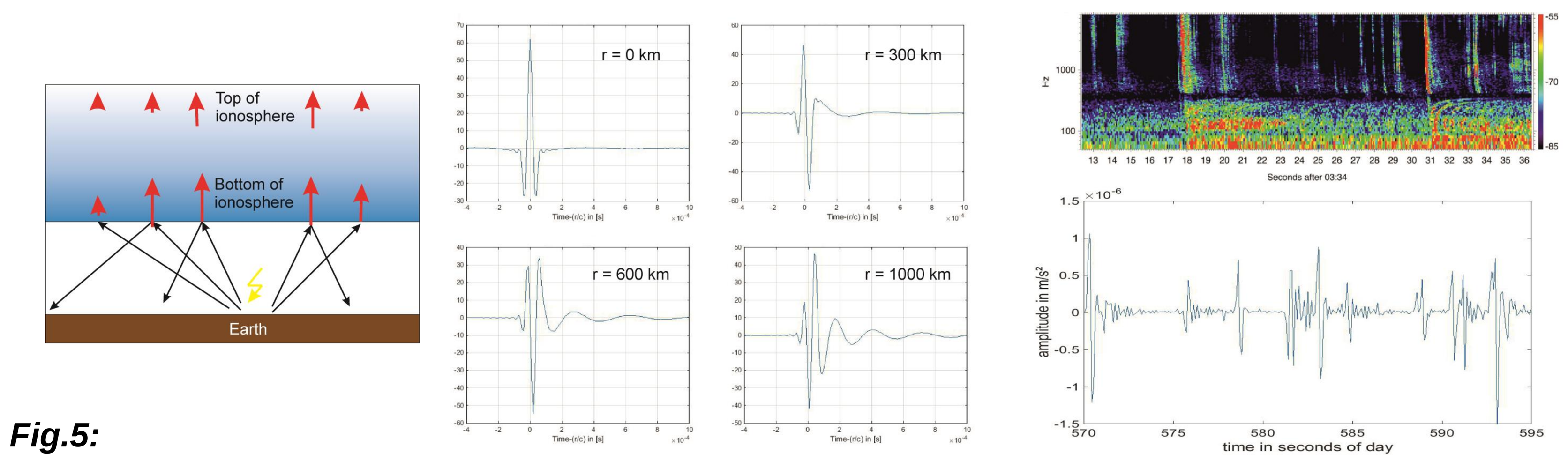


Fig.5:

Sferics are injected into the troposphere by lightning discharges (a). While propagating in the troposphere they disperse (b) and couple into the ionosphere as whistler-sferics (c). Figure c compares the rate of occurrence of twangs with observations of whistler-sferics on satellite height (Holzworth et al. 2011).

Comparison of tropospheric twangs and whistlers

- The occurrence of twangs with highest amplitude in the radial direction. This is the dominant direction of the electric field of whistler-sferics injected into the ionosphere by lightning strokes.
- The signal shape of the twangs is similar to dispersion effects on sferics even though the detection electronics of the accelerometer changes the frequency content of the signal. Some twang can be modelled as two parts of different shape and amplitude, in the same sense as a whistler can be a combination of an electron and an ion whistler.
- The seasonal dependency with an asymmetry between summer and winter on both hemispheres.
- The latitude dependency with less type three twangs at the poles.
- The sequence of twangs correlate to observations of whistlers on low-orbiting satellites.

Hypothesis

As other mechanisms causing this correlation can be excluded (magnetic shielded, mass movement small electric fields) we propose that accelerometers are sensitive to VLF.

1. Excitation of resonance frequency in the satellite-plasma-tube
2. Metal cannot shield
3. Absorption in metal proof-mass enhanced by potential stabilization
4. Change in equilibrium position of the proof-mass causing a quadratic factor
5. Force on proof-mass due to potential drop

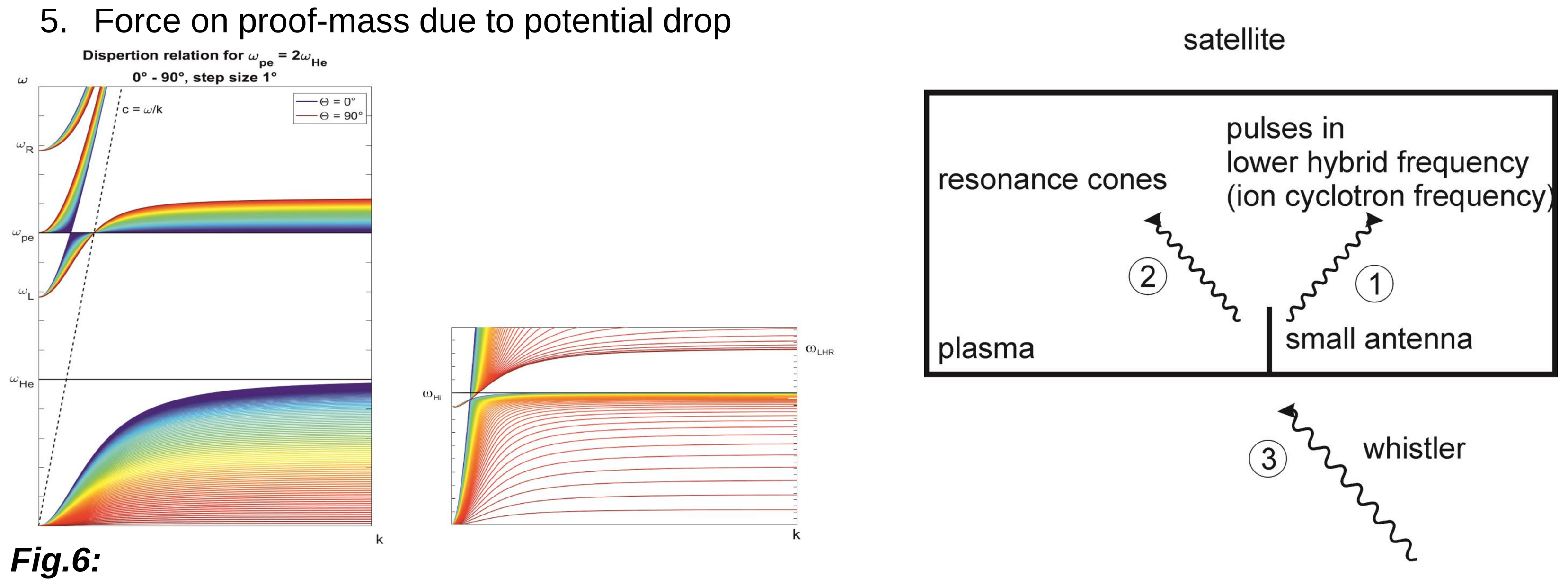
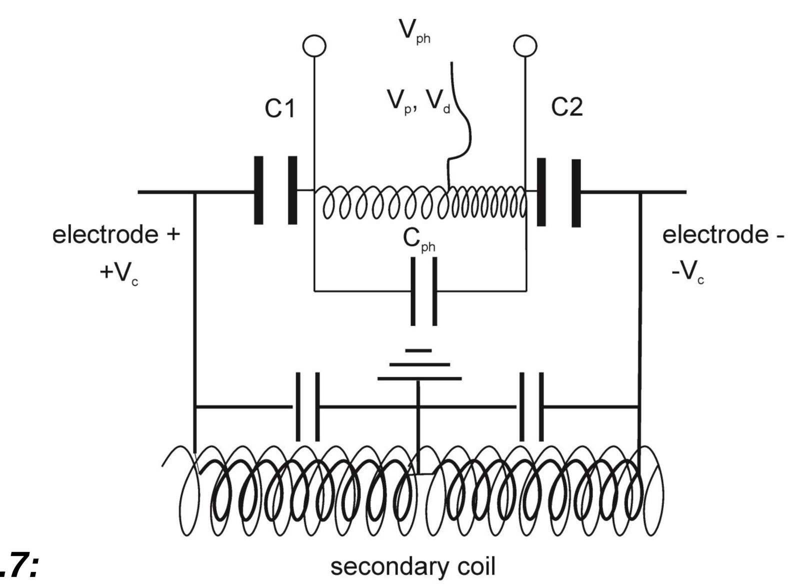


Fig.6:

Left: Dispersion relation of VLF in a magnetized plasma. Resonances occur due to the interaction with ions and electrons in the plasma (left). The enlargement (right) shows the bottom of the right figure with the lower-hybrid resonance LHR and ion cyclotron resonance Hi.

Right: The excitation of the satellite-plasma-tube can be manifold. 1 pulse on an antenna inside the satellite. 2 continuous signal on an antenna (no experimental hints up to now). 3 whistlers received by electric conducting surfaces and reemitted into the satellite interior. The excitation of the satellite interior is always in a resonance frequency (lower-hybrid frequency and ion cyclotron frequency).



$$F = \frac{1}{2}\left(\nabla C_1 (V_C - V_P)^2 + \nabla C_2 (V_C + V_p)^2\right)$$

$$F = \frac{1}{2}(\nabla C_2 + \nabla C_1)(V_C^2 + V_P^2) + V_C V_P (\nabla C_2 - \nabla C_1) = F_{quad} + F_{bias} + F_{meas}$$

$$F_{add\ bias} = \frac{1}{2}(\nabla C_2 + \nabla C_1) V_{Drms}^2$$

$$F = \frac{1}{2}\left(\nabla C_1 (V_C - V_P + \langle V_{dis} \rangle)^2 + \nabla C_2 (V_C + V_p + \langle V_{dis} \rangle)^2\right)$$

Fig.7:

Disturbance on the read-out side: The excitation of resonances in the proof-mass causes a shift in the equilibrium position of the proof-mass. This causes a quadratic factor. In GOCE permanent due to high frequent heater switching?

Disturbance on the force side: The voltage drop (direction of the electric field of the disturbance) leads to a force enhanced by the potential stabilization at the gold wire contact.

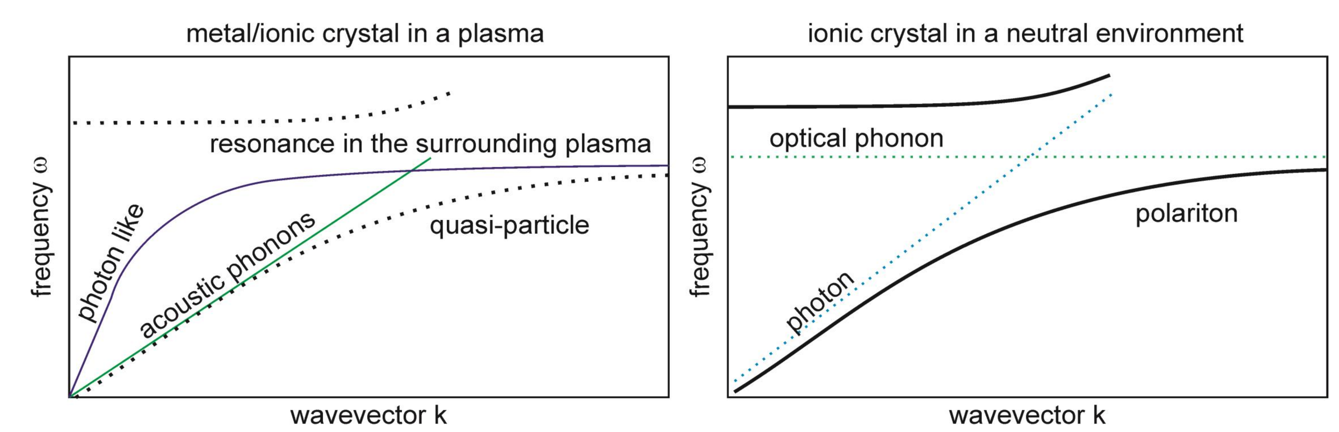


Fig.8:

We propose the excitation of resonances in crystalline materials in a plasma environment (left) comparable to polaritons in ionic crystals (right). An interesting feature is, that longitudinal and transversal quasi-particals will degenerate.