Has the plasma environment influence on spacecraft instruments? – A proposed experiment -

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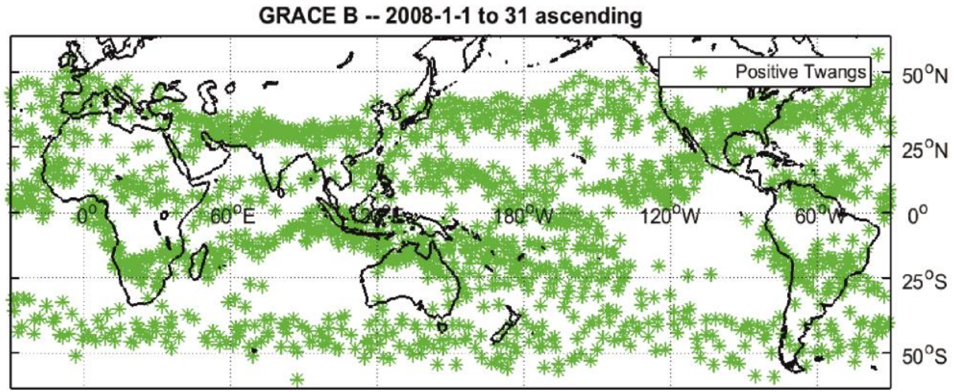
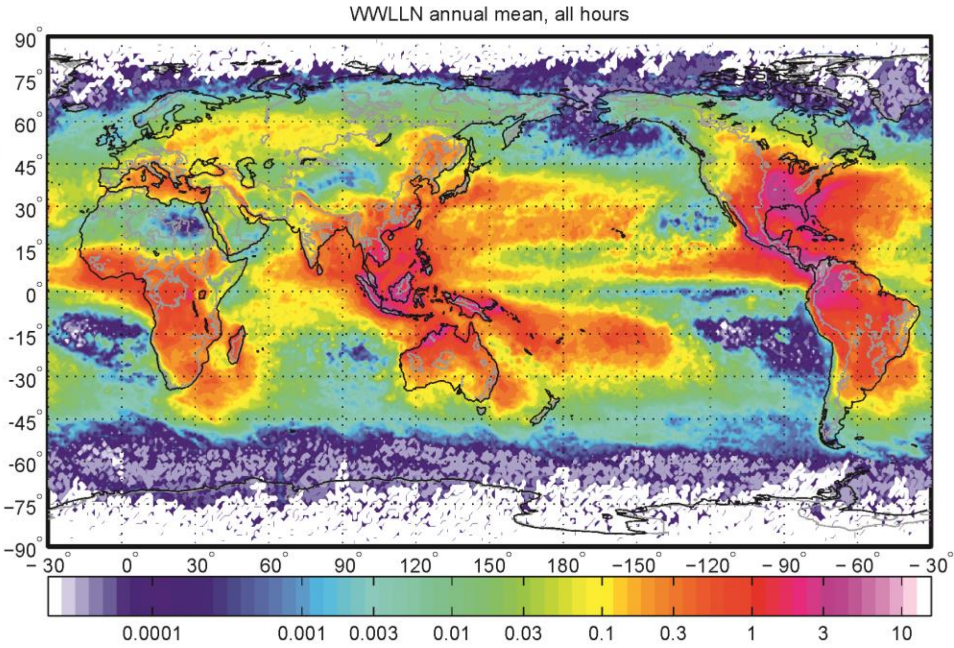
Motivation


GRACE B -- 2008-1-1 to 31 ascending


WWLLN annual mean, all hours

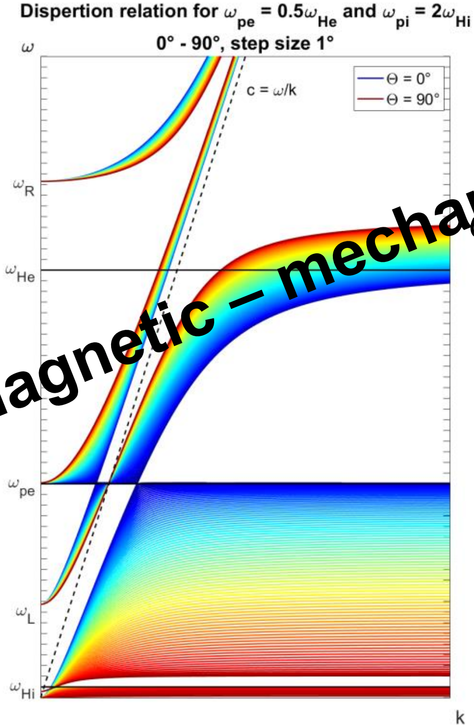
Overview

- THE HYPOTHESIS: excitaion of coherent phonons in space
- THE TRANSDUCER: electromagnetic generation of „sound“
- THE THEORY: excitation of coherent phonons in space
- THE CONSEQUENCES: Which disturbances can be seen on instruments in the ionosphere?
- THE EXPERIMENT: Outlook on the next activities
- THE CONCLUSIONS: What does a quartz oscillator do in space?

THE HYPOTHESIS:

electromagnetic waves in a magnetised plasma

At any oblique propagation direction in respect to the magnetic field the whistler modes are partly electrostatic in nature.



ω_{UHR}

ω_{LHR}

Electron whistler mode

Ion whistler mode

Coherent electromagnetic – mechanical coupled waves

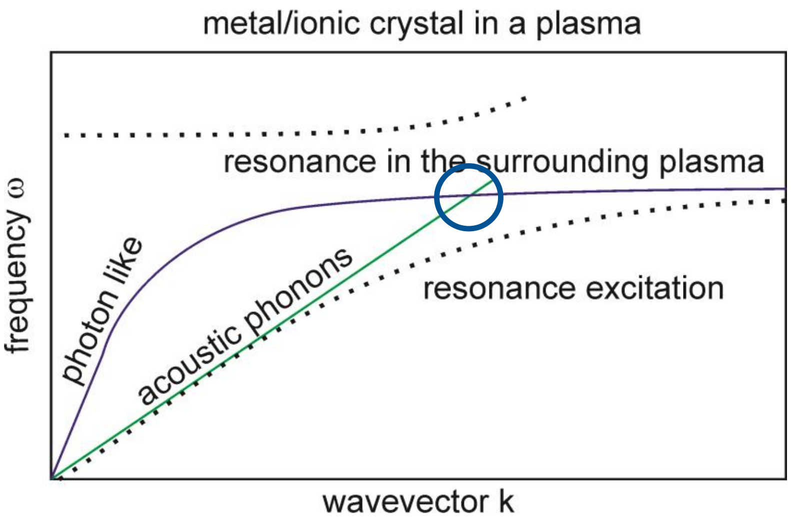
ω_{He} electron cyclotron frequency
ω_{pe} electron plasma frequency
ω_{Hi} ion cyclotron frequency
ω_{pi} ion plasma frequency

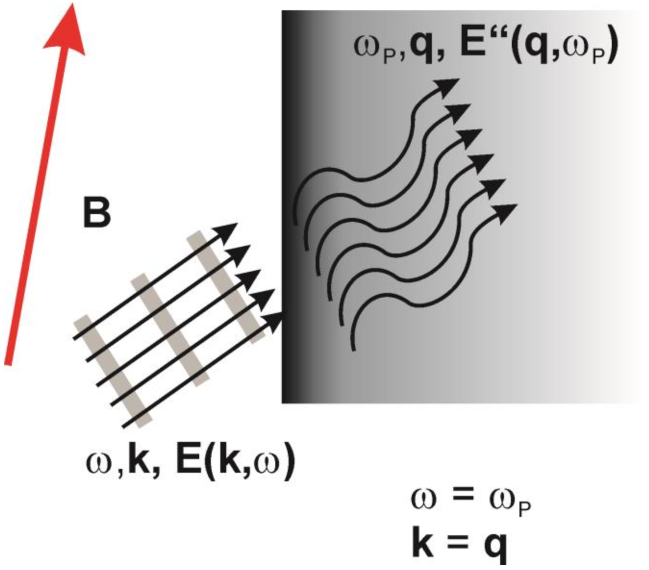
ω_{UHR} upper hybrid resonance (longitudinal oscillation of electrons)
ω_{LHR} lower hybrid resonance (longitudinal oscillation of ions and electrons)

According to:
Handbook of atmospheric electrodynamics

THE HYPOTHESIS:

excitation of coherent phonons in space



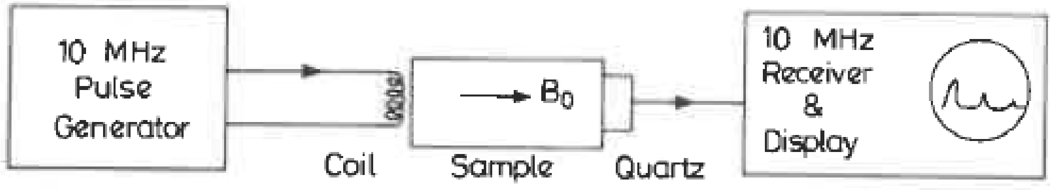


Longitudinal and transversal modes can be excited

THE TRANSDUCER:

electromagnetic generation of „sound“

According to Dobbs, „Physical Acoustics: Principles and Methods Vol X“, ed. Mason and Thurston, 1973



$$M\frac{\partial^2}{\partial t^2}\boldsymbol{\xi} - C_l\, grad\; div\; \boldsymbol{\xi} + C_t\, curl\; curl\; \boldsymbol{\xi} = \boxed{Ze\boldsymbol{E}(\boldsymbol{q}) + \boldsymbol{F}_C} + \frac{Ze}{c}\left(\xcancel{\frac{\partial}{\partial t}}\boldsymbol{\xi} \times \boldsymbol{B}_0\right)$$

In the limit $\omega\tau \ll 1$ within the penetration depth of the electric field
with τ scattering time of the electrons
ξ displacement of the ions, *M* mass of ion, $C_{l/t}$ longitudinal and transversal elastic moduls

In the limit $ql > 1$ coherent phonons can be excited without constant magnetic field B_0
with *l* the mean free path of the electrons

THE THEORY:

excitation of coherent phonons in space

$$M\frac{\partial^2}{\partial t^2}\boldsymbol{\xi} - C_l grad\, div\, \boldsymbol{\xi} + C_t curl\, curl\, \boldsymbol{\xi} = Ze\boldsymbol{E}(\boldsymbol{q}) + \boldsymbol{F}_C + \overset{\boldsymbol{F}_{NL}}{\cancel{\frac{Ze}{c}\left(\frac{\partial}{\partial t}\boldsymbol{\xi} \times \boldsymbol{B}_0\right)}}$$

Non-linear scattering mechanisms can break the symmetry (electron and ion propagation in the plasma)

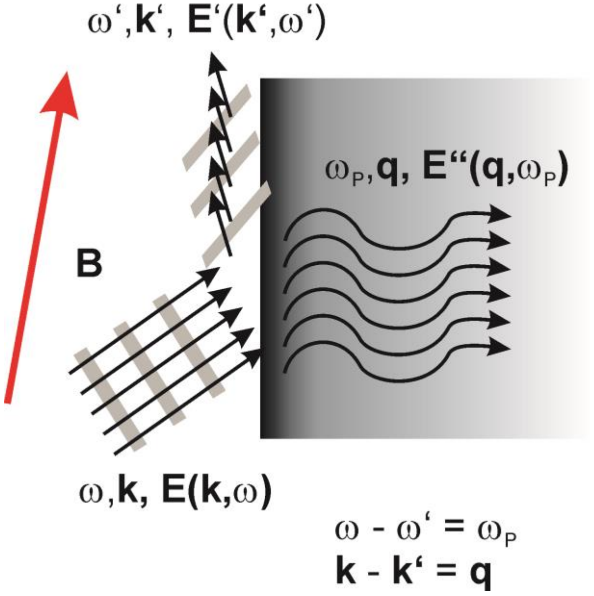
Electrons

$$F_C = \frac{Zm}{\tau}[\langle v\rangle - u] = \frac{Zm}{\tau}\frac{\partial}{\partial t}[\langle \eta\rangle - \xi] = \frac{Zm}{\tau^2}[\langle \eta\rangle - \xi]$$

η displacement of the „mean“ electron, m electron mass, v electron velocity, u ion velocity

THE THEORY:

excitation of coherent phonons in space



Step1: scattering of the „mechanical“ wave excites ions in metal

Step2: electrons need time τ and mean free path l to build „screening wave“

Step3: if $\lambda_{Phonon} \gg \delta \gg l$
electron wave and ion wave (phonon) react on the electric field
and a polarisation builds up
Within self-consistant field approximation (E^{ext} has to be taken self-consistantly)

$$\frac{\partial^2\xi}{\partial t^2} + \gamma_P \frac{\partial\xi}{\partial t} + \omega_P\xi = \frac{Ze}{M}\left(E^{ext} - 4\pi P\right) + F_{sc}\delta(x)$$

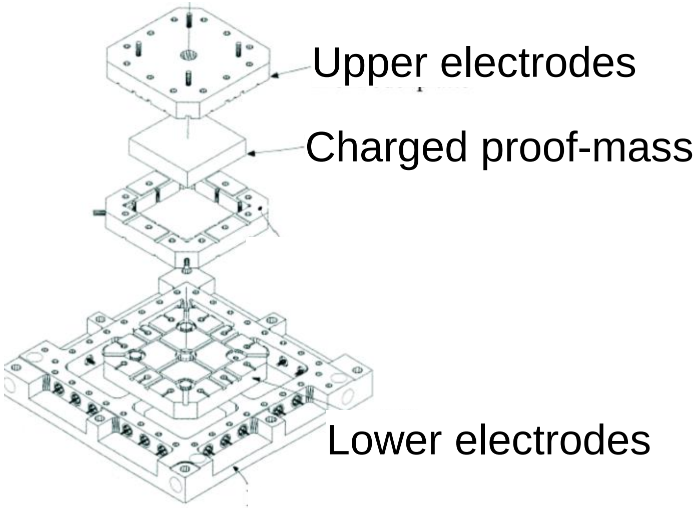
$$\frac{\partial^2 P}{\partial t^2} + \gamma_{el} \frac{\partial P}{\partial t} + \omega_{el} P = \frac{e^2 N^*}{m}\left(E^{ext} - 4\pi\gamma_{12}\xi\right)$$

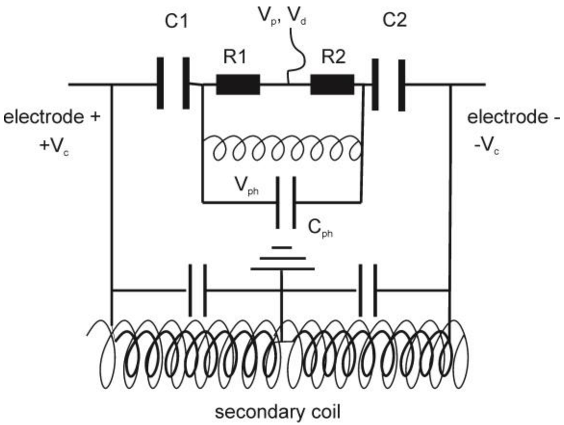
Polarisation of a phonon

THE CONSEQUENCES:

Which disturbances can be seen on instruments in the ionosphere?

1. Coherent phonons radiate back: Metals do not shield
2. Electric field causes acceleration of charges and polarization on „massive“ solids (metals, semiconductors, ion crystals, …) in instruments in space





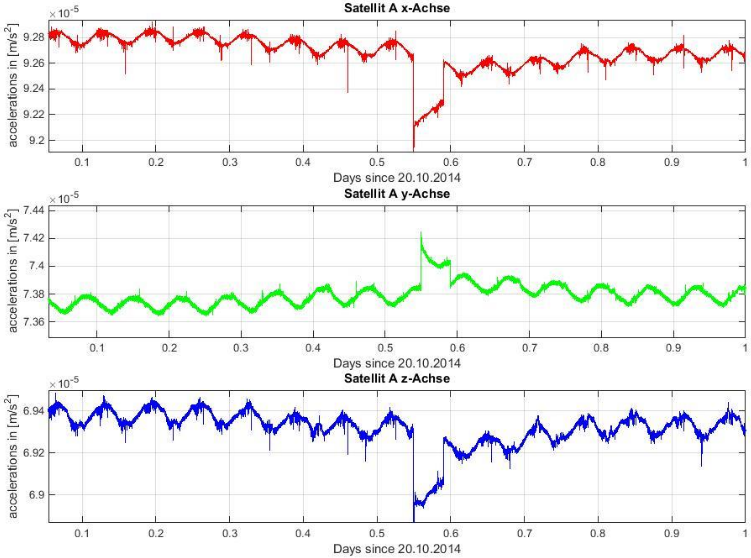
THE CONSEQUENCES:

Which disturbances can be seen on instruments in the ionosphere?

1. Coherent phonons radiate back: Metals do not shield!!!

2. Polarization on „massive“ solids (metals, semiconductors, ion crystals, …) in instruments in space

3. Electromagnetic – mechanical coupling



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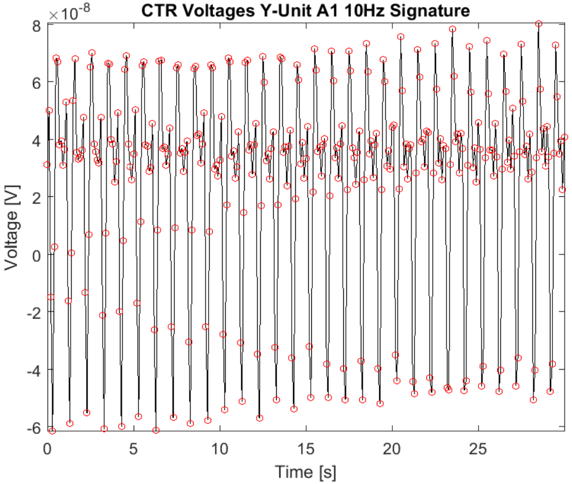


THE CONSEQUENCES:

Which disturbances can be seen on instruments in the ionosphere?

1. Coherent phonons radiate back: Metals do not shield!!!

2. Polarization on „massive“ solids (metals, semiconductors, ion crystals, …) in instruments in space

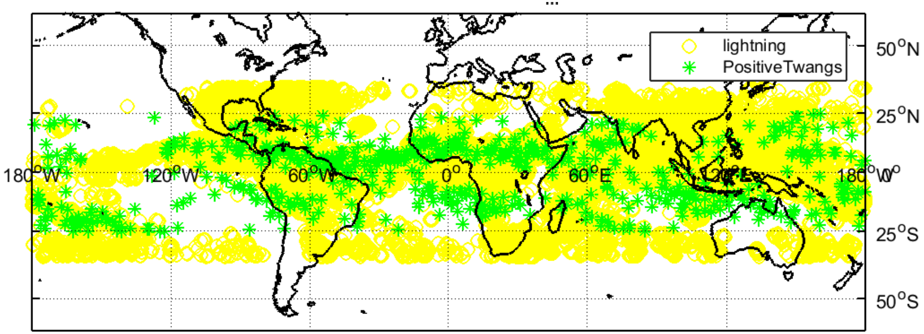
3. Electromagnetic – mechanical coupling

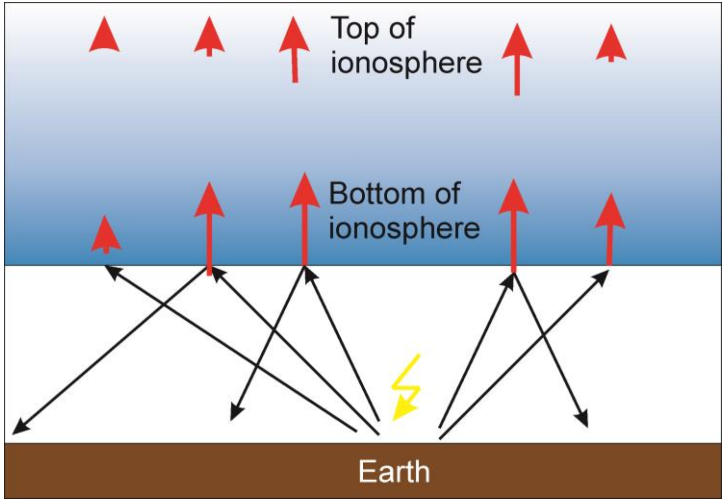
4. The lower hybrid frequency can be excited very easily: switching of currents, discharging events on the spacecraft, digital control, …

5. There are many natural whistler mode waves in the ionosphere, …

Oblique whistlers

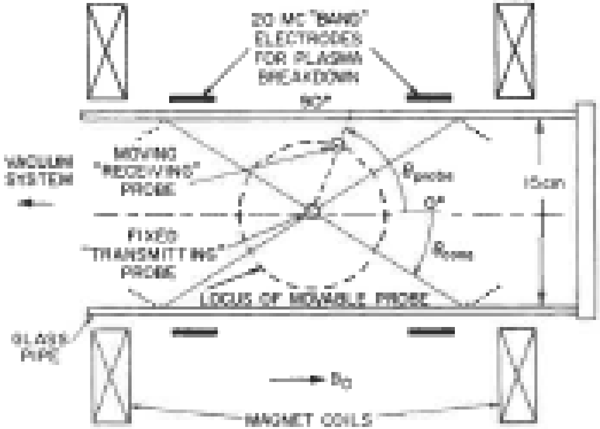
Match of lightning and twangs 5-2008 (30min/30°)



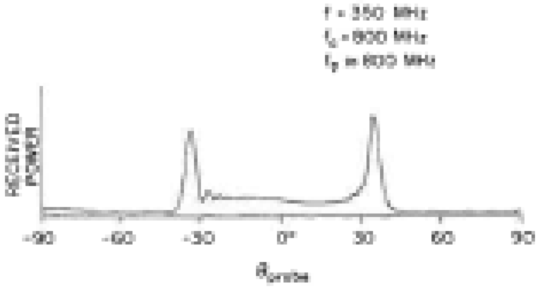


THE EXPERIMENT:

Antenna: 3.6mm unshielded co-axial cable driven by a delta pulse
same antenna for detection 3.5cm apart



Fisher and Gould 1969



Simonutti 1976

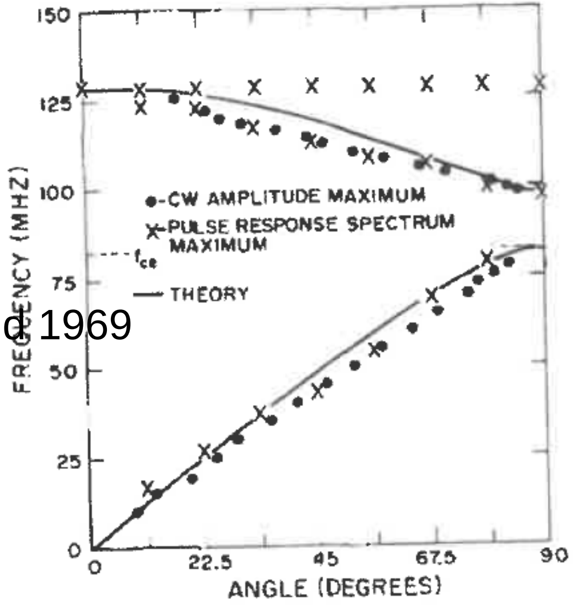
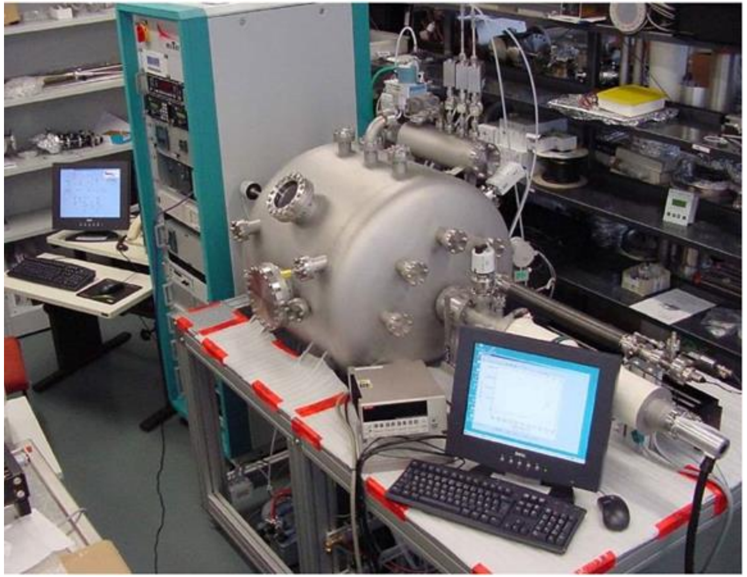


FIG. 3. Direct comparison of the location in frequency of the peaks in the spectrum of the pulse response versus angle, and the resonance cone angle versus frequency.

THE EXPERIMENT:



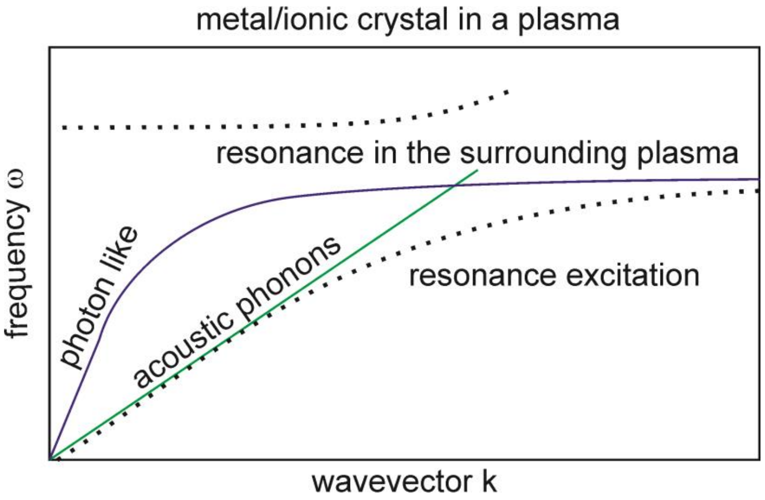
Stay to the conditions:

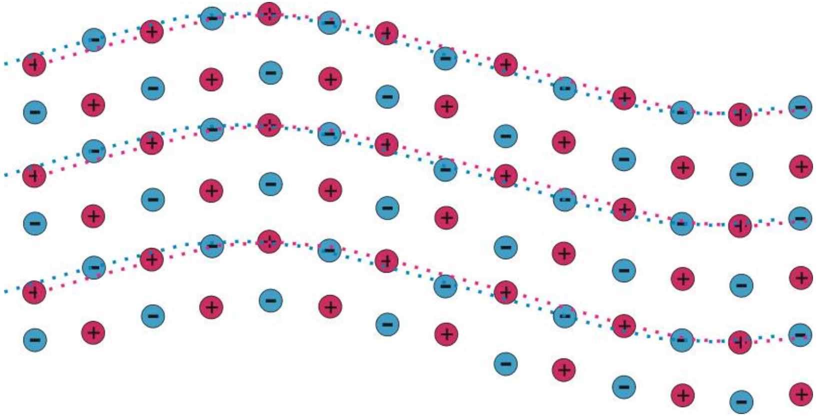
$$\omega\tau \gg 1,$$

$$\lambda_{Phonon} \gg \delta \gg l$$

THE CONCLUSION:

What does a quartz oscillator do in space?





Thank you very much!