Friday Materials Science Colloquia #4

Thursday, December 22th, 2022, 11:00 a.m.
Seminar room, U5 Building – via Roberto Cozzi 55, Milano

Lecturer: **Prof. Giorgio Benedek**

FROM EARTHQUAKES TO TOPOLOGICAL INSULATORS: What do we learn about surface dynamical processes from helium atom scattering spectroscopy

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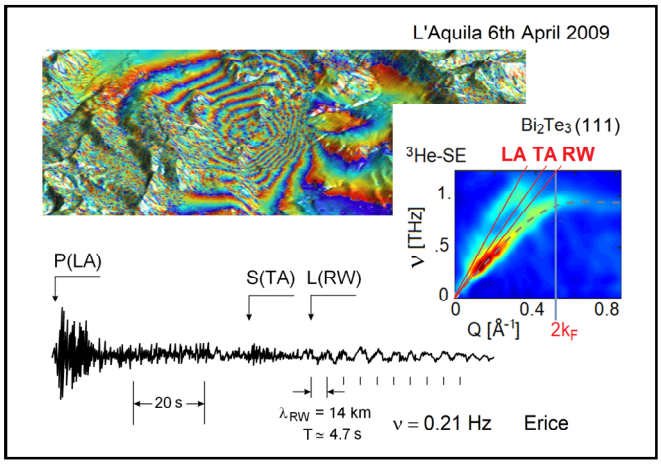

Figure: Scale invariance of surface acoustic waves over 12 orders of magnitude. Learning about the internal planet structure as well as about inter-atomic forces and electron-phonon interaction.

Lord Rayleigh's explanation (1885) of the seismic long-wave component as due to waves travelling at the surface of an elastic solid is viewed as a founding step in surface science. Otto Stern in 1929 with his helium-atom scattering (HAS) experiments from a crystal surface filled two needs with one deed: proving the quantum particle-wave duality for atoms and the ordered structure of crystal surfaces. The development of supersonic monocromatic ($\Delta E < 0.5$ meV) He-beam and of ^{3}He spin-echo (3He-SE, $\Delta E < 0.5$ μeV) spectrometers has paved the way to high-resolution momentum resolved spectroscopy of surface dynamics on the atomic scale. More needs fulfilled than envisaged by Stern! Unlike thermal neutrons and X-rays, thermal neutral He atoms only tickle the surface ~0.3 nm away from the first atomic plane, and exchange energy and momentum with the solid atoms only via the interposed electrons. Thus, phonons are detected via the electron-phonon (e-ph) interaction, and not just at the surface, but possibly as deep below the surface as the range of that interaction. This sort of *quantum sonar* allows for the direct measurement of the e-ph coupling strength for each individual phonon (*mode-λ spectroscopy*), and for ultimately answering the question about phonon-mediated pairing in (2D-) superconductors: who's doing the job? The venerable concept of Debye-Waller (DW) factor, by which Piet Debye (1913) and Ivar Waller (in his 1923 thesis) correctly attributed to thermal vibrations the attenuation of Roentgen rays, in the case of HAS and 3He-SE from conducting surfaces presently allows for a direct measurement of the e-ph mass-enhancement factor λ - a basic parameter for conducting materials. In particular much can be learnt with HAS and 3He-SE about topological insulators (TIs), their peculiar surface electronic structure and related e-ph coupling, as it will be shown with a few recent examples. Selfish surface electrons, when hit by a He atom, may however decide to keep for themselves the received energy and momentum, rather than delivering them to phonons. Thus, HAS is also qualifying as a possible probe of surface electron excitations in the THz domain, such as acoustic surface plasmons (ASPs), CDW phasons and Fermi-surface inter-pocket transitions in semimetal topological insulators. The basic concepts, developments and recent advances in He-atom spectroscopies of surface phonon and other excitations have now been collected with a vast literature in [1].

[1] G. Benedek and J. P. Toennies, *Atomic-Scale Dynamics at Surfaces* (Springer 2018).