

## **EELS in STEM: the “Swiss Army Knife” of Spectroscopy**

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Electron energy-loss spectroscopy (EELS) in scanning transmission electron microscopy (STEM) is arguably the most versatile spectroscopy technique to study materials at (sub)nanometer length scales. Successive improvements over decades has been possible to obtain chemical maps of composition, dielectric response and bonding information of materials [1] — to mention only a few examples. EELS measurements and mapping have been carried out in TEM/STEMs since the 1980s, and elemental mapping with atomic resolution ( $d \leq 2 \text{ \AA}$ ) became routinely possible with the advent aberration-corrected STEMs [2].

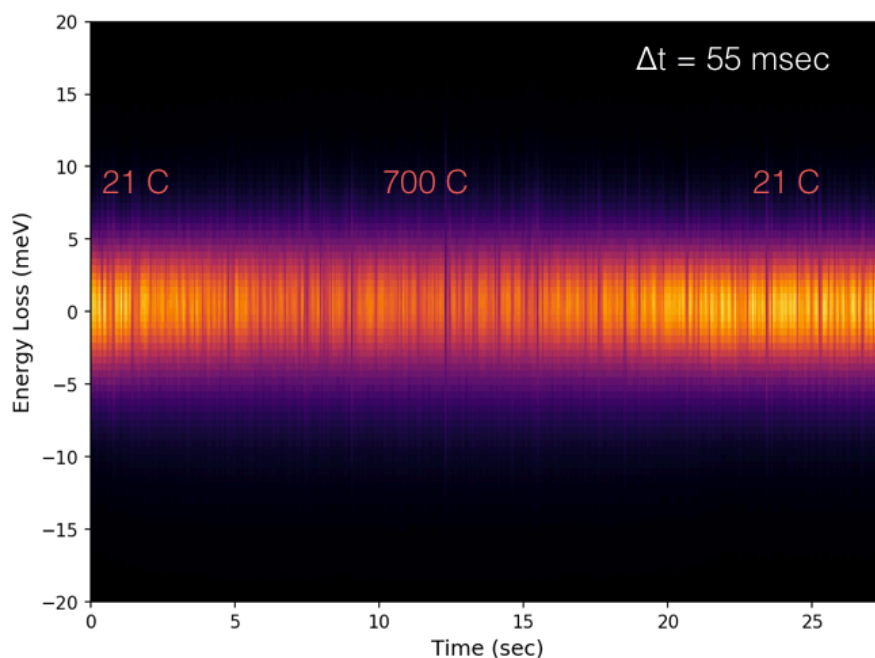
Improvements in the understanding of the scattering process involved in EELS have also resulted in the ability of EELS to measure and quantify ferromagnetic phases in materials, analogously to X-ray circular magnetic dichroism (XMCD) in synchrotrons, but with the phase of the electron playing the role of polarization of light [3].

The recent development of a new generation of monochromators [4] and spectrometers [5] has made EELS even more versatile. Phonon mapping with atomic resolution [6,7], primary temperature measurements at the nanoscale (without requiring any previous knowledge of the sample) [8], and the detection of isotopes in water [9] and amino acids [10] are now some of the new “*tools*” in this Swiss Army knife of spectroscopy that is EELS.

We will review the technical details of the aforementioned tools and discuss potentially relevant new “*blades*” that could be added to the EELS toolkit. In particular, is it possible to map orbitals with atomic resolution? Can we spectrally detect a superconducting transition? Can we measure cryogenic temperatures with 10s of mK precision? Can we measure specific heat and thermal conductivity of a material? Can we perform radiocarbon dating at the nanoscale? These questions will be addressed and further elaborated during the presentation [11].

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**Figure 1.** Zero-loss peak (ZLP) recorded during a ~27 seconds period at time intervals of 55 msec. The electron probe was in an aloof configuration next to a SiC membrane. The SiC membrane was cycled in temperature from 21 C to up 700 C. Variations in the ZLP, i.e., reduction of its intensity, as well as increment of its full-width-half maximum can be observed when the SiC membrane is heat 700 C. Brighter color means higher intensity. Changes of the ZLP at cryo temperatures (LN) should be also possible to be detected. Measurements as a function of time and temperature should, in principle, allow to extract specific heat and thermal conductivity of a material from spectral features.