# Direct measurement of cyclotron resonance in a high-temperature superconductor: Ultrafast THz spectroscopy in pulsed magnetic fields

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*The renormalization of effective electronic masses in materials is a well-established consequence of electron-electron (e-e) and electron-lattice interactions*. However, precisely *how* this renormalization manifests depends on the measurement. Angle-resolved photoemission, quantum oscillations (e.g., Shubnikov-de Haas) in high magnetic fields (*B*), and heat capacity all measure masses that reflect the underlying renormalized quasiparticle dispersion. *In this regard, cyclotron resonance (CR) merits special consideration, as it provides an especially direct measure of carrier mass via $m_c = eB/\omega_c$, where $\omega_c$ is the cyclotron frequency of the charge carriers*.

In high-Tc superconducting cuprate (HTSC) materials, CR studies complement other methods; however, due to large masses and scattering rates, very high *B* and broad (THz) bandwidth is needed. MagLab users coupled a time-domain THz spectrometer to a purpose-built 31T pulsed magnet to measure the broadband THz optical conductivity of $La_{2-x}Sr_xCuO_4$ (LSCO) thin films that ranged from slightly underdoped to highly overdoped ($p$=0.13-0.26). Systematic changes in the circularly-polarized complex conductivity reveal CR of *p*-type charge carriers (holes) with masses ranging from $m_c \approx 4 - 14 m_0$.

*Besides providing the first direct measurement of cyclotron mass in a HTSC, these data reveal an unexpected monotonic increase of $m_c$ with doping and a scattering rate that increases with B. These results open the door to characterizing the influence of e-e interactions in cuprate superconductors.*

**Facilities and instrumentation used:** Pulsed 31T free-space optics magnet and time-domain THz spectrometer at the MagLab's Pulsed Field Facility.

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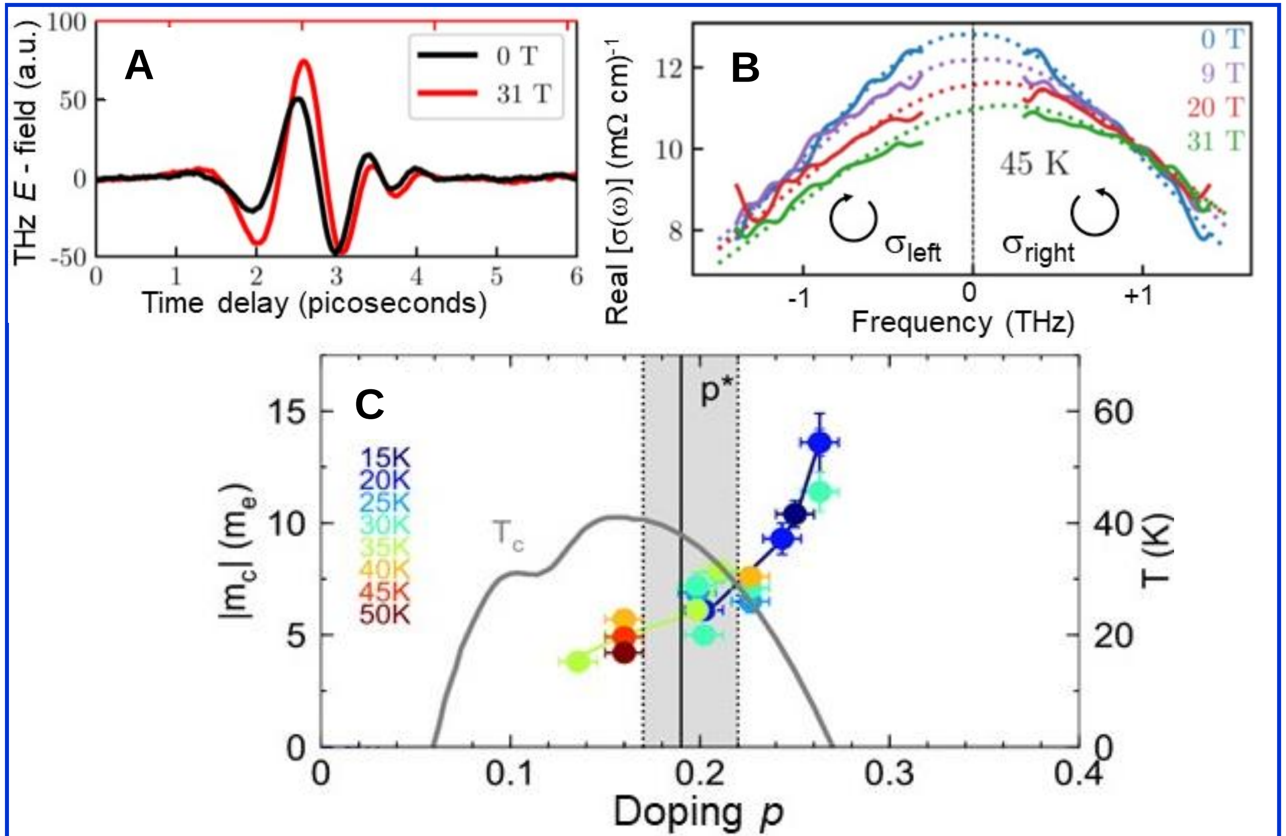
**[2]** Post, K.W.; Legros, A.; Rickel, D.G.; Singleton, J.; McDonald, R.; He, X.; Bozovic, I.; Xu, X.; Shi, X.; Armitage, N. P.; Crooker, S., *Observation of cyclotron resonance and measurement of the hole mass in optimally doped LaSrCuO,* **Physical Review B103**, 134515 (2021) **doi.org/10.1103/PhysRevB.103.134515**




**(A)** Time-domain transmission signals through the high-Tc superconducting sample of LSCO at zero field and 31T, resulting from electronically-controlled terahertz optical sampling, coupled to a tabletop 31T pulsed magnet with free-space optical access. **(B)** Optical conductivity $\sigma(\omega)$ of LSCO for right and left circularly polarized THz light. The very broad Drude conductivity peak from the charge carriers shifts by the magnetic-field-dependent cyclotron frequency $\omega_c$. Dashed lines are fits to the data. **(C)** Carrier cyclotron mass ($m_c = Be/\omega_c$) determined from the cyclotron frequency, plotted versus hole doping for a series of LSCO thin films. $m_c$ increases monotonically with *p*, right through the critical doping *p**~0.19.