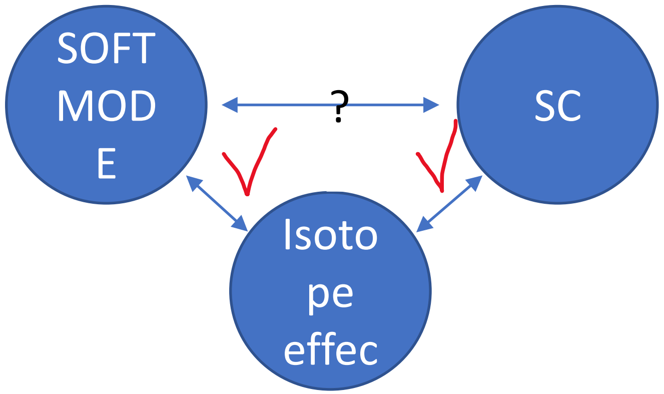
Puzzles of the soft mode and multiband superconductivity in STO

A.V. Balatsky

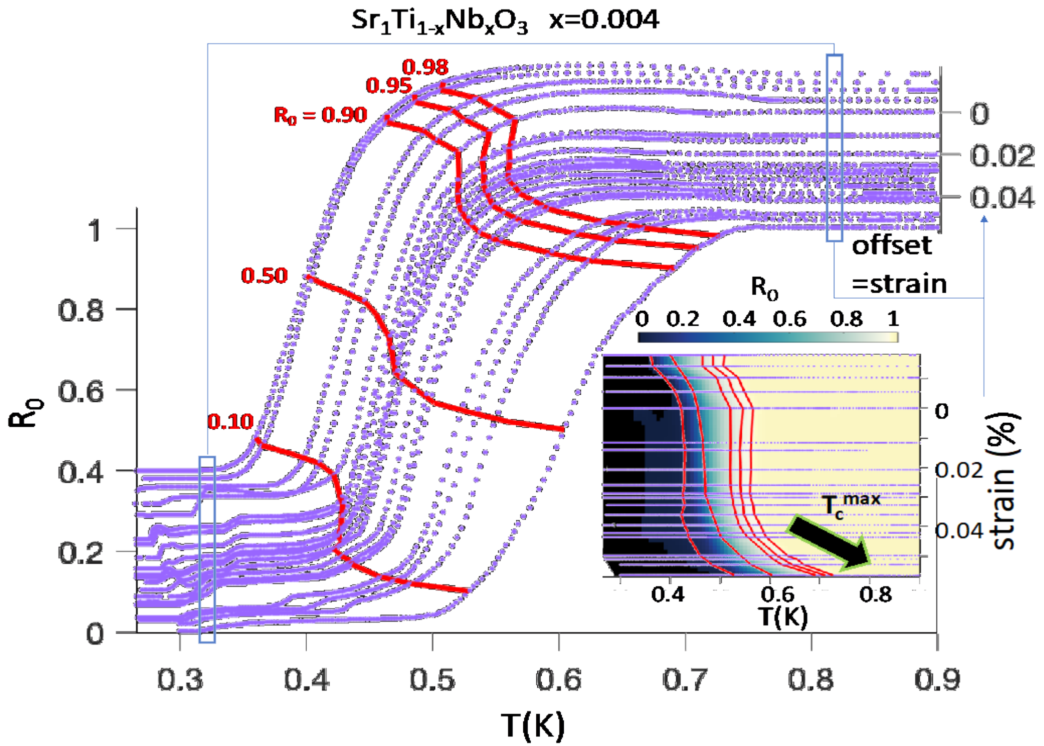
Work with P. Wolfle, J. Edge, Y.Kedem, N. Spaldin, U. Aschauer, K. Dunnett, J. Haraldsen, R. Fernandes, JX Zhu

* SC in STO is controlled by QCP and attendant TO soft mode: proofs by isotope effect, strain and Gruneisen.
* SC in STO is multiband.

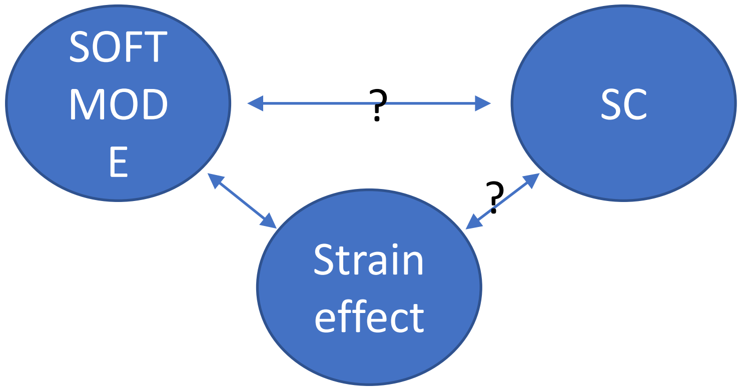
See earlier discussion on isotope effect (YK)



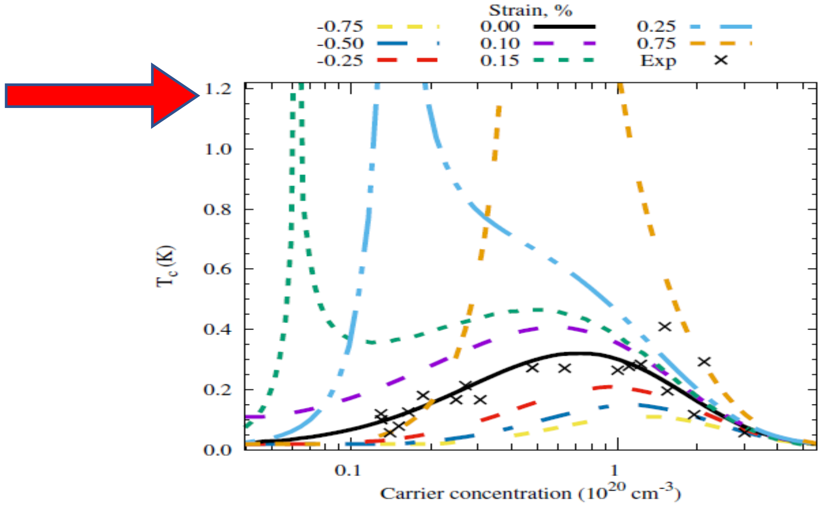
See also P Wölfle, Physical Review B 98 (10), 104505 (2018)



Test 2: Strain effects to tune to FE QCP



Ferroelectric phonons responsible for pairing; $\omega^2(u) = \omega^2(0) + bu$



- Tensile strain: large increase in T_c
- Sharp peak: $\omega(u, q = 0) = 0$. (model breakdown)
- Increasing T_c as nearing ferroelectric quantum critical point

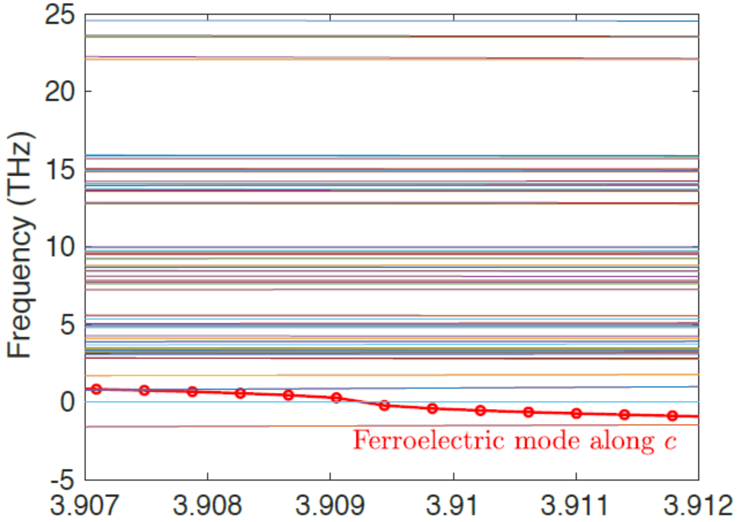
ArXiv:1712.08368 (2017, K. Dunnett et al.)

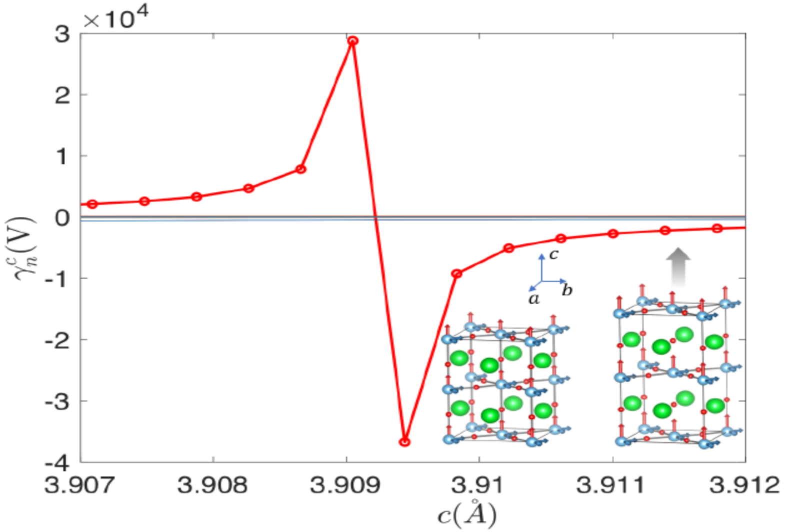
Test 3: Gruneisen parameter in STO QCP

Sochnikov, Aschauer, Arxiv 2003.07686.pdf

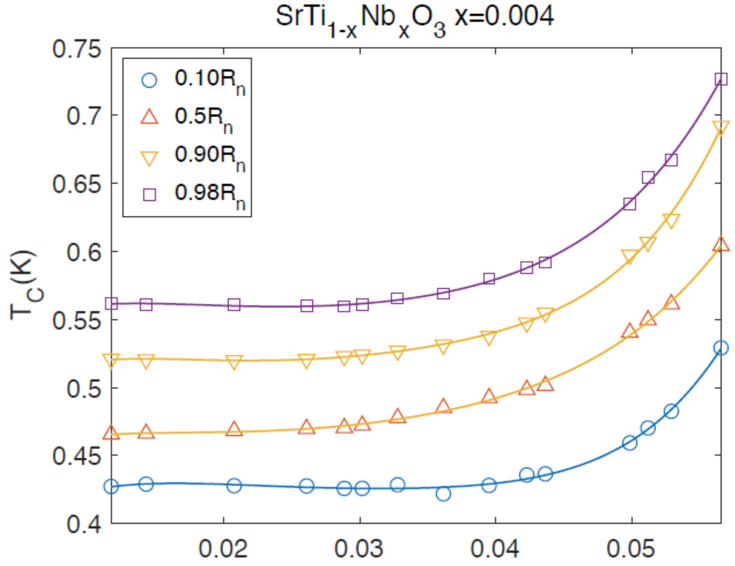
$$\gamma_{SC} = -\frac{d\ln(N_0\Delta^2)}{d\epsilon} \sim -\frac{d\ln(T_c)}{d\,\epsilon}$$

Lattice $\gamma_n^c(V) = -\frac{V}{\omega_n}\left(\frac{\partial\omega_n}{\partial V}\right)_c$



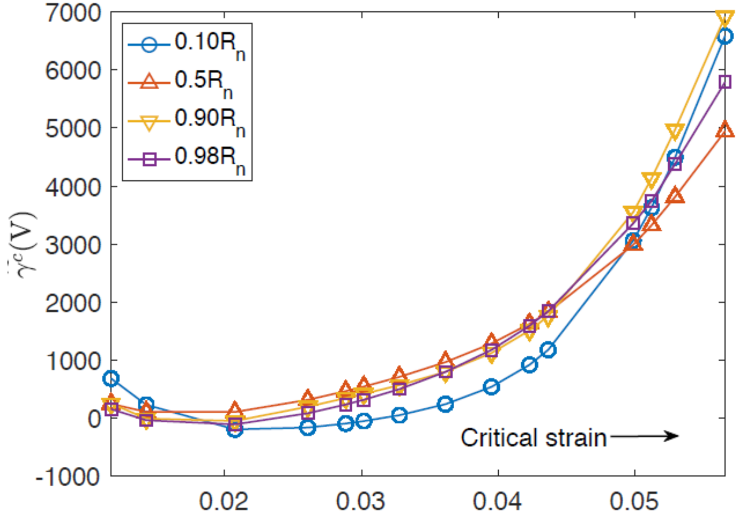


SC Gap:



Largest GP for any known QCP

TO SOFT MODE IS THE KEY PLAYER IN SC in STO

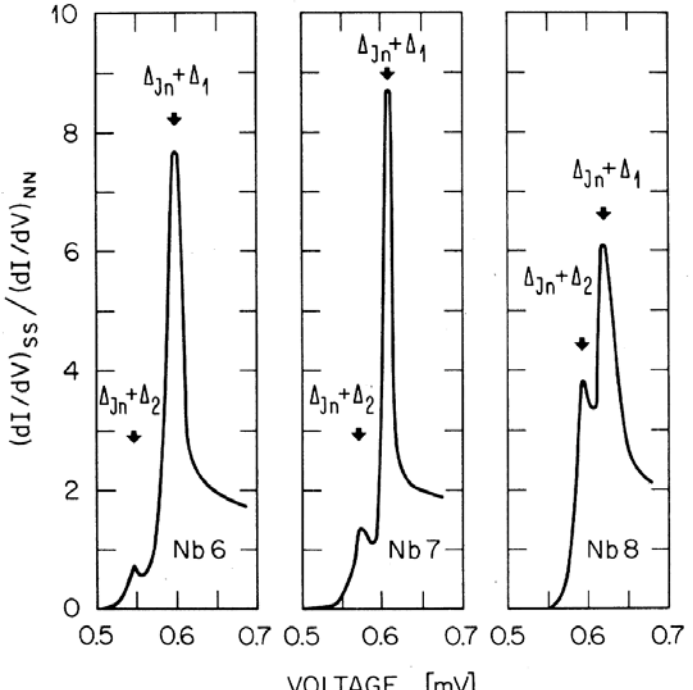


Nature of SC in STO: multiband SC in STO

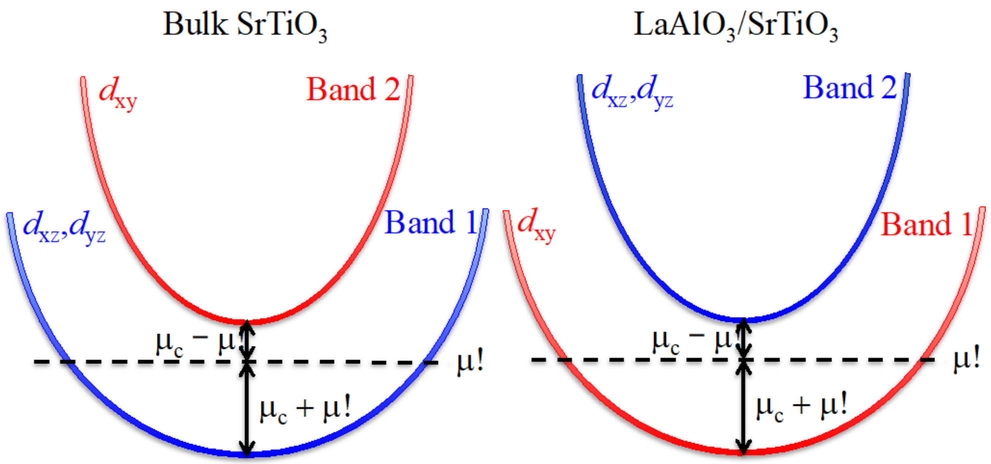
Strong correlations with Soft mode
Is SC conventional? Most likely NOT.
STO is a bona fide multiband SC

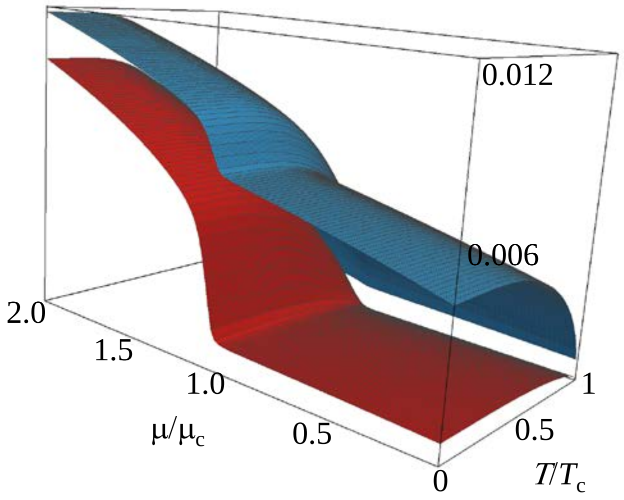
Binning,Manhart, Behnia –exp
Haraldsen, Fernandes, Yanase - theory

Binnig *et al.*, Phys. Rev. Lett. **45**, 1352 (1980)



Haraldsen *et al.*, Phys. Rev. B **84**, 020103(R) (2011),
Haraldsen *et al.*, Phys. Rev. B **85**, 134501 (2012),
Fernandes*et al.*, Phys. Rev. B **87**, 014510 (2013)



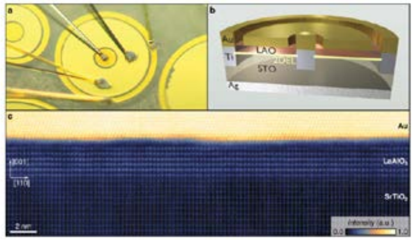


We find that the start of the second band produces a kink in T_c

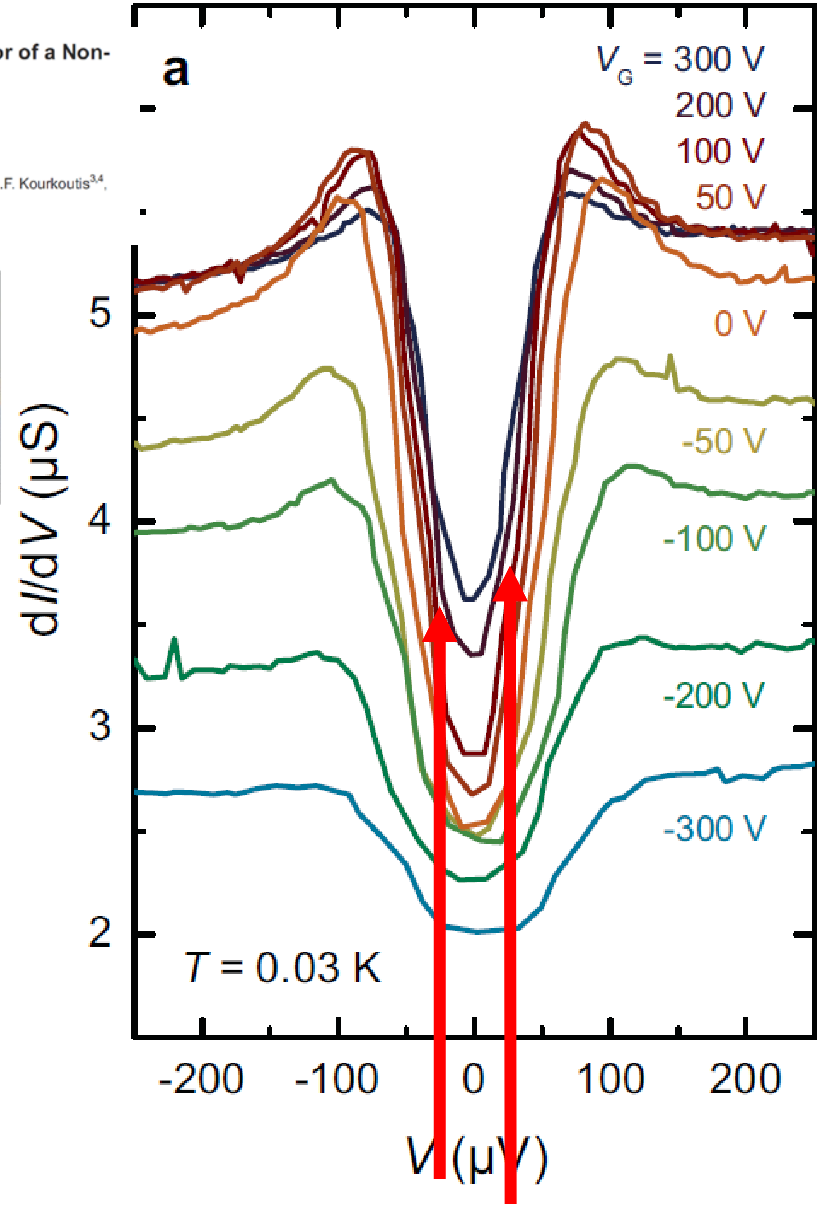
Dig here for multi bands evidence

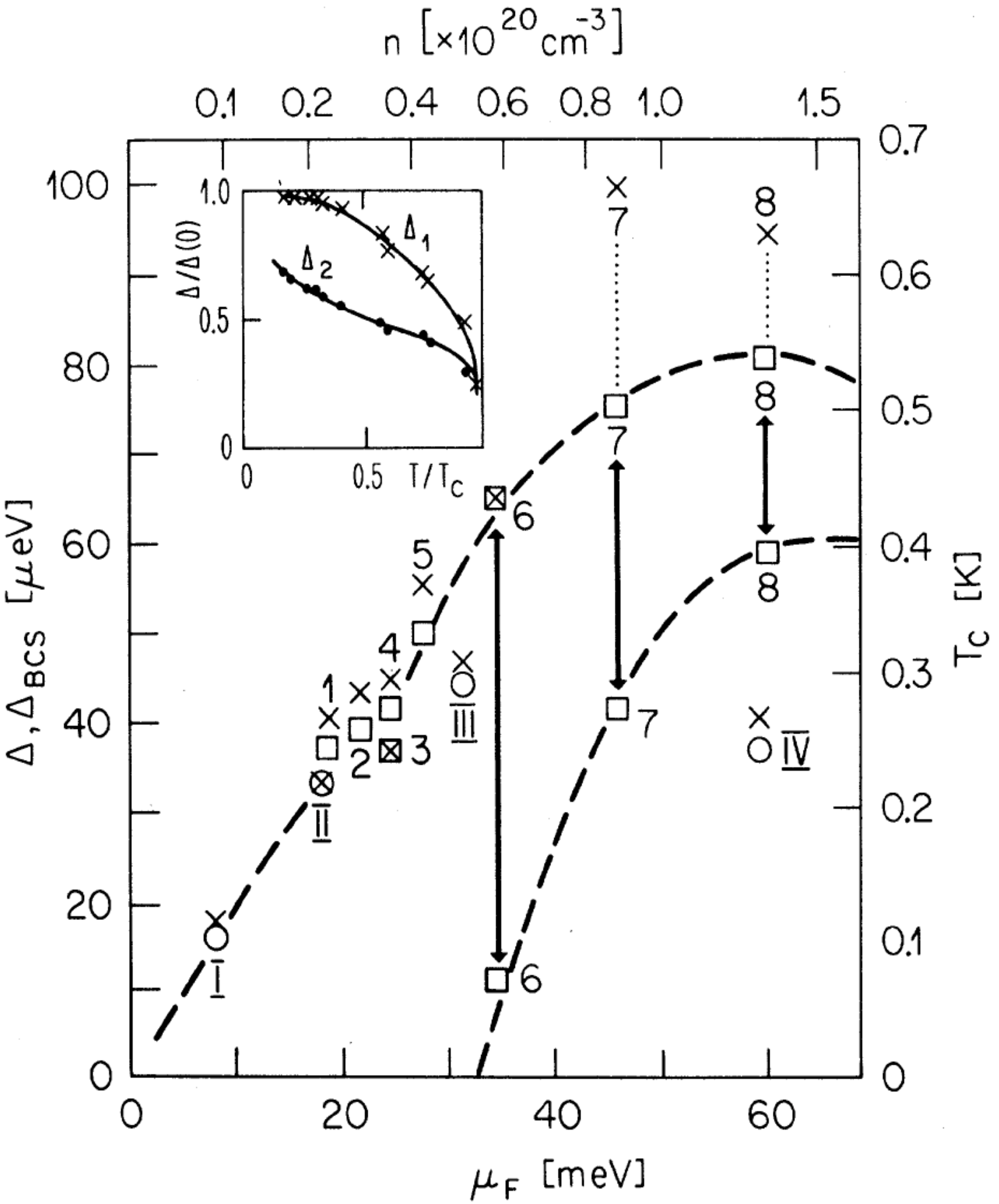
High-T_c-Superconductor-like Gap Behavior of a Non-Cuprate 2-D Interface Superconductor

C. Richter[1,2], H. Boschker[1], W. Dietsche[1], R. Jany[2], F. Loder[2], L.F. Kourkoutis[3,4], D.A. Muller[3,4], J.R. Kirtley[5], C.W. Schneider[6], J. Mannhart[1]



Nature 2013





Binnig *et al.*, Phys. Rev. Lett. **45**, 1352 (1980)

Hc2 in two band superconductors

Upper critical field as a probe for multiband superconductivity in bulk and interfacial STO

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Nordita, KTH Royal Institute of Technology and Stockholm University, Roslagstullsbacken 23 106 91 Stockholm, Sweden

Alexander V. Balatsky

Cond mat arxive 1401
Journal of Superconductivity 2015

Data-Behnia grp

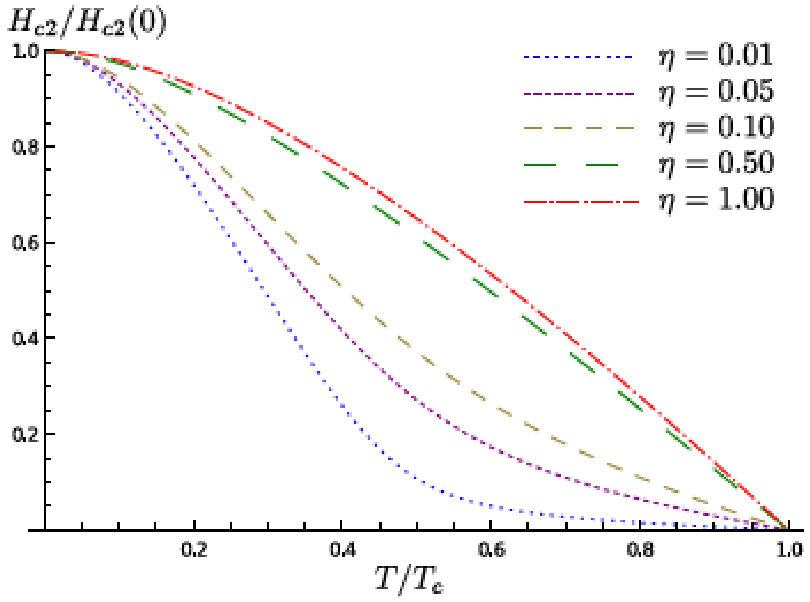
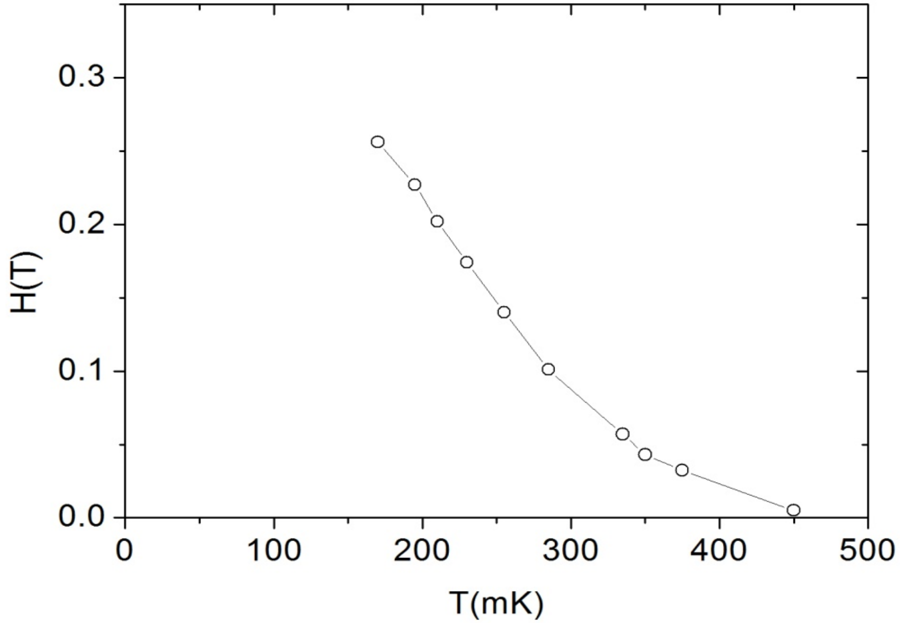


FIG. 1. (Color online) Temperature dependence of the upper critical field in the disordered limit for the coupling constants $\lambda_{11} = 0.14, \lambda_{22} = 0.13, \lambda_{12} = 0.02^{22}$. Different values of $\eta = D_2/D_1$ correspond to different ratios of the diffusivities.



One can get interesting behavior if bands are different enough: diffusivity

Conclusion

- SC in STO is controlled by QCP and attendant TO soft mode: proofs by isotope effect, strain and Gruneisen.
- SC in STO is multiband. Consequences?

High-T_c-Superconductor-like Gap Behavior of a Non-Cuprate 2-D Interface Superconductor

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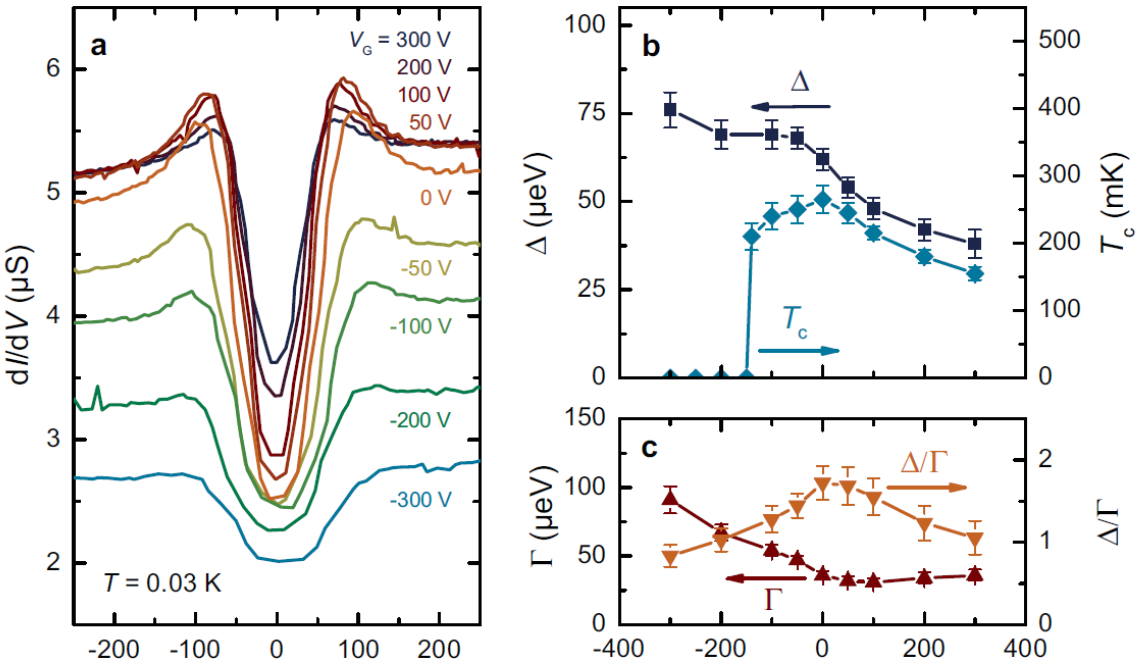
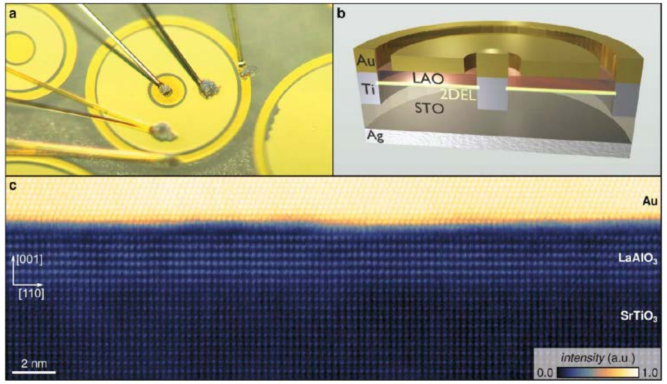


We did not observe signatures of a second superconducting gap as reported[24] for superconducting Nb-doped $SrTiO_3$.

Nature 2013



Gap 1 ~ 75 microeV

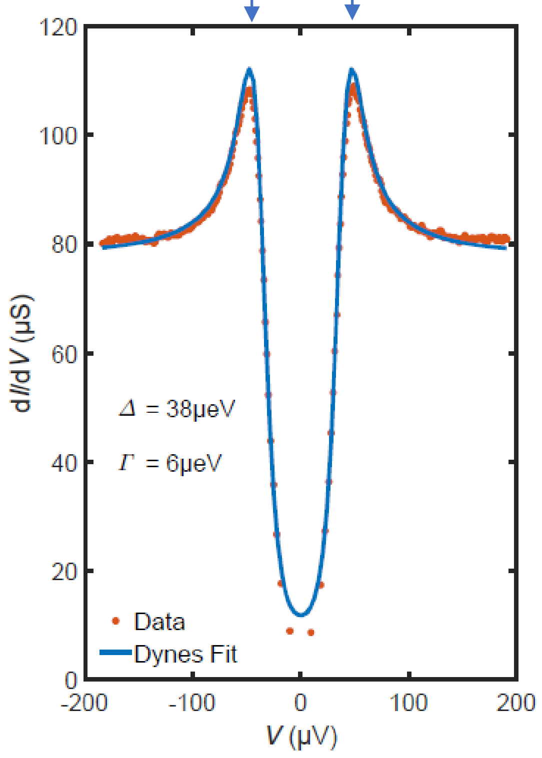
Gap 2 ~ 35 microeV

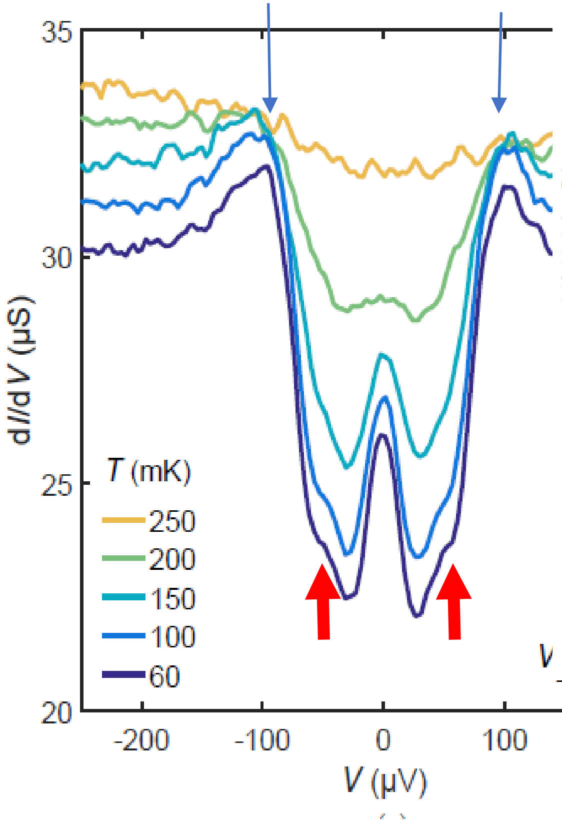
Gamma ~ 50 microeV

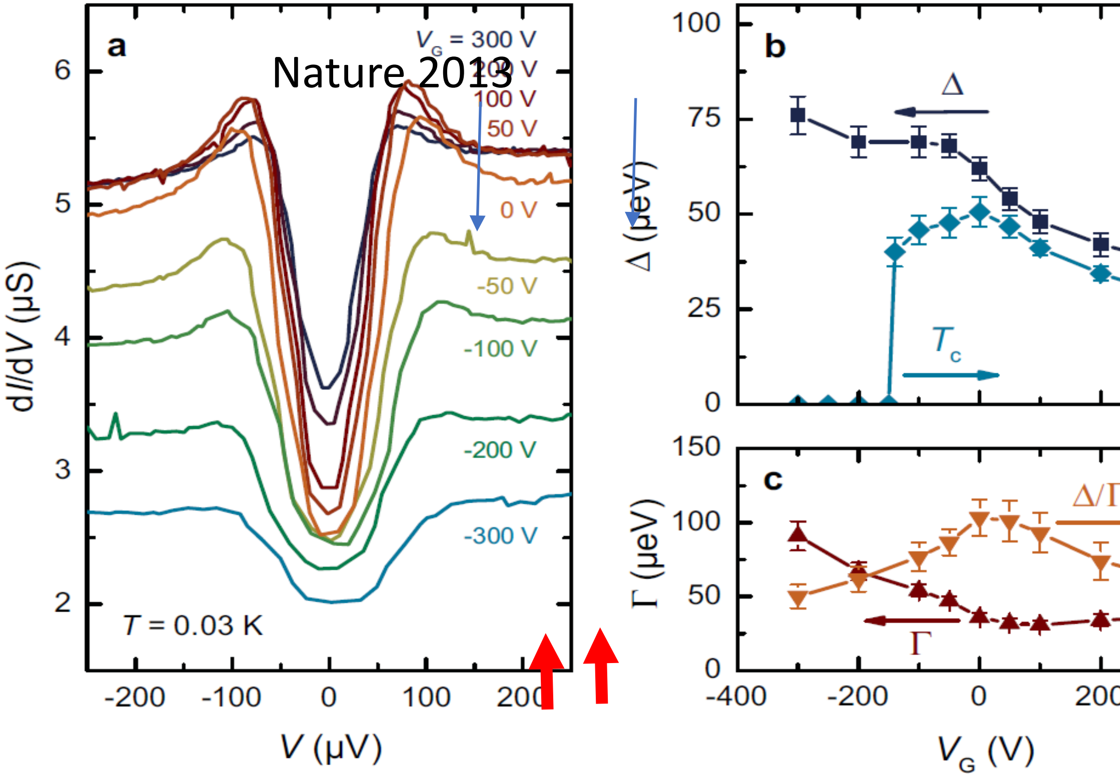
Seem not enough resolution to detect second gap

One gap vs two gaps in STO/LAO

17.03 arxiv







Typical spectra
One gap = 50 mV

Spectra with the resonance

Spectra without the resonance

same scape of gap 1 and gap 2
With or withour resonance