Superconductivity, pseudo-gap, and stripe correlations in high- T_c cuprates

Zailan Zhang^a, Sylvain Denis^b, Blair W. Lebert^a, Francois Bertran^c, Patrick Le Fèvre^c, Amina Taleb-Ibrahimi^c, John-Paul Castellan^{d,e}, David Le Bolloc'h^f, Vincent Jacques^f, Yvan Sidis^d, Benoît Baptiste^a, Claudia Decorse^b, Patrick Berthet^b, Luca Perfetti^g, Matteo d'Astuto^a

^a*Institut de Minéralogie, de Physique des Matériaux, et de Cosmochimie (IMPMC)
Sorbonne Universités - UPMC Univ Paris 06, UMR CNRS 7590, MNHN, IRD, 4 Place
Jussieu, F-75005 Paris, France*

^b*ICMMO, Université Paris Sud and CNRS, Université Paris Saclay, 91405 Orsay cedex,
France*

^c*Synchrotron SOLEIL, L'Orme des merisiers, 91192 Gif sur Yvette Cedex, France*

^d*Laboratoire Léon Brillouin (CEA-CNRS), CEA-Saclay, F-91191 Gif-sur-Yvette, France*

^e*Institute for Solid State Physics, Karlsruhe Institute of Technology, D-76021 Karlsruhe,
Germany*

^f*Laboratoire de Physique des Solides, Université Paris-Sud, CNRS UMR 8502, F-91405
Orsay, France*

^g*Laboratoire des Solides Irradiés, CNRS UMR 7642, CEA-DSM-IRAMIS, Ecole
polytechnique, Université Paris-Saclay, 91128 PALAISEAU cedex, France*

Abstract

Under-doped La-214 cuprates show a charge- and spin-modulation known as “stripes” [1]. These stripe modulations are (quasi)-static close to 1/8 hole doping where superconductivity is suppressed. The pseudo-gap phase of other cuprate compounds recently also revealed charge modulation, but interpreted rather as a charge density wave (CDW) [2, 3, 4], that possibly competes with superconductivity. In this context, to better understand the interplay between the stripe phase and the superconductivity, we use angle-resolved photoemission spectroscopy to study the electronic band structure and gap in La-214 cuprates near 1/8 doping ($\text{La}_{2-x-y}\text{Nd}_y\text{Sr}_x\text{CuO}_4$ ($x = 0.12$; $y = 0.0$ & 0.4)) and compare with the previous results in the same system [5] and $\text{La}_{1.86}\text{Ba}_{0.14}\text{CuO}_4$ [6]. Our data shows a loss of spectral intensity towards the end of the Fermi arcs, that is possibly due to a strong renormalisation, as already pointed out elsewhere

*matteo.dastuto@neel.cnrs.fr - Institut Néel CNRS - 25, av des Martyrs - 38042 Grenoble cedex 9; tel: (+33)(0)4 76 88 12 84

[5], with a noisy but still measurable gap. On the nodal direction no gap is observed within our statistics, but a sizeable decrease in intensity with temperature. Moreover, we do not see any shadow band, but our Fermi surface can be well modelled with a single electron band calculation in the tight binding approximation, even very close to the 1/8 doping $\text{La}_{2-x-y}\text{Nd}_y\text{Sr}_x\text{CuO}_4$ with and without Nd substitution.

Keywords: cuprates, superconductivity, pseudo-gap, ARPES, stripes, Fermi surface

1. Introduction

The nature of the normal-state gap (pseudo-gap) and its relationship with superconductivity are believed to hold the key for understanding the mechanism of high- T_c superconductivity. In cuprates, the pseudo-gap opens well above
5 the superconducting critical temperature at moderate doping. Many previous experiments suggest that the pseudo-gap is distinct from superconducting gap and that it opens towards the anti-nodal direction, similar to a d -wave symmetry. A large body of experimental evidence now suggests that, at least in a small region of the under-doped phase diagram, there is a broken-symmetry state that
10 is distinct from homogeneous superconductivity. In the “214 family”, the low temperature phase is accompanied by the ordering of charge and spin in a stripe form, where a fraction of carriers forms a charge modulation coexistent with spin modulation in a configuration which is referred to as stripes [7, 8]. Charge-modulations have been proposed as a possible origin of the broken-symmetry
15 state, either in the stripes [1] or the CDW [9] form. In the region of the phase diagram where these charge-modulations are static, scattering experiments have suggested that they compete with superconductivity [2, 3, 4], although a possible different role of the fluctuating stripes is still debated [1]. We can pin the fluctuating stripes in $\text{La}_{2-x}\text{Sr}_x\text{CuO}_{4+\delta}$ (LSCO) at $x = 1/8$ doping, by replacing
20 Sr with Ba in $\text{La}_{2-x}\text{Ba}_x\text{CuO}_{4+\delta}$ (LBCO), or with partial substitution of Nd on the La site in $\text{La}_{2-x-y}\text{Nd}_y\text{Sr}_x\text{CuO}_{4+\delta}$ (LNSCO). Then the charge ordering

in LBCO or LNSCO is static and suppresses superconductivity in a narrow doping region around $x = 1/8$ [10]. When lowering the temperature, the pinning first appears for the charge component, accompanied by a structural transition
 25 from the low temperature orthorhombic (LTO) phase to the low temperature tetragonal (LTT) phase below T_{LTT} . Lowering the temperature even further, the magnetic component is pinned as well below T_{stripe} . In LSCO, as the charge/spin modulation static component is null [7] or much weaker [11], the impact of the density modulation is mitigated, causing only a slight depression
 30 in T_c in the vicinity of $x = 1/8$ [12] doping.

The link between the anti-nodal pseudo-gap and charge modulations (CDW/stripe phase) is explored by C. Matt and co-workers with an angle-resolved photoemission spectroscopy (ARPES) study of the charge stripe ordered system $\text{La}_{1.6-x}\text{Nd}_{0.4}\text{Sr}_x\text{CuO}_4$ at $1/8$ doping [5]. More recently, the nature of the
 35 pseudo-gap close to the node has been investigated in the 214 LSCO system, but without charge modulation pinning and for low doping [13]. The authors show a link between a spin density wave and the nodal gap. In this work, we report ARPES results for the nearly $1/8$ doped $\text{La}_{1.88}\text{Sr}_{0.12}\text{CuO}_4$ and $\text{La}_{1.48}\text{Nd}_{0.4}\text{Sr}_{0.12}\text{CuO}_4$ in order to study the nature of the pseudo-gap and its re-
 40 lationship with superconductivity, as well as its possible link to the spin/charge modulations.

2. Methods and experimental details

High-quality single crystals of nearly $1/8$ doped $\text{La}_{1.88}\text{Sr}_{0.12}\text{CuO}_4$ and $\text{La}_{1.48}\text{Nd}_{0.4}\text{Sr}_{0.12}\text{CuO}_4$ were grown from the melt in an image furnace by the travelling
 45 solvent floating zone (TSFZ) method under a pressure of 3 bar oxygen at the ICMMO, Orsay. The T_c were measured and determined from the susceptibility measurement by the MPMS (QuantumDesign) SQUID magnetometer available at the MPBT facility of the UPMC University (Paris, France), shown in Figure 1 (a) and 1 (b). The onset temperatures of the superconducting transition T_c are
 50 31 K for LSCO and 4.6 K for LNSCO, respectively. The structural and magnetic

Figure 1: (Color online). The magnetisation measurements of (a) $\text{La}_{1.88}\text{Sr}_{0.12}\text{CuO}_4$ (sample C13) and (b) $\text{La}_{1.48}\text{Nd}_{0.4}\text{Sr}_{0.12}\text{CuO}_4$ (sample C20). Temperature dependence of the magnetisation under a field of 50 Oe for the zero-field cooled condition. (c) Phase diagram of $\text{La}_{1.48}\text{Nd}_{0.4}\text{Sr}_{0.12}\text{CuO}_4$ determined by neutron scattering data: the temperature dependence of the super-lattice peak intensities. Blue filled circles: magnetic superlattice peak at the $(1/2, 1/2 + \delta, 0)$, $\delta \sim x \sim 0.111$; Black filled circles: $(1, 0, 0)$ structural peak allowed only in the LTT phase.

stripes characterisation was made using the 1T 3-axes spectrometer, run by KIT
 (Karlsruhe, Germany) and the LLB laboratory (Ce-Saclay, France) available at
 the Orphee neutron source (CE-Saclay, France), in particular to measure T_{LTT}
 and T_{stripe} . In Figure 1 (c), we also show the neutron scattering data on the
 55 LNSCO sample. We observe the intensity of the Bragg reflection $(1, 0, 0)$, which
 is forbidden in the LTO phase yet allowed in the LTT phase, increases at ~ 80 K
 and saturates at ~ 70 K. At this temperature, the charge modulations (stripes)
 are known to appear [7]. Below 35 K, we observe additional intensity on the
 satellite of the magnetic Bragg reflection at $(1/2, 1/2+\delta, 0)$ due to scattering
 60 from the magnetic stripes. Therefore, we can identify four different phases in
 this LNSCO composition with three transition temperatures: a superconducting
 state below $T_c \sim 4.6$ K, magnetic stripes state below $T_{stripe} \sim 35$ K, LTT phase
 below $T_{LTT} \sim 70$ –80 K and finally an LTO phase above T_{LTT} .

The ARPES measurements were performed on the CASSIOPEE-B-ARPES
 65 beamline of the Synchrotron SOLEIL (Ormes de Merisier, France). This beam-
 line has the necessary energy and momentum resolution, photon energy, and
 temperature ranges to allow a fast and systematic exploration of the experimen-
 tal phase space. The crystals were cut from a larger bar, at a given orientation
 determined by Laue diffraction in order to fit the cryostat holder. A notch was
 70 added to guide the cleave parallel to the ab -plane as much as possible. The
 crystals were mounted on the rotating head of the cryostat and cleaved in-situ
 at 10^{-11} mbar and 9 K. In this work, we performed our ARPES measurements
 of the LNSCO sample at three different temperatures ($T = 9$ K, 55 K and
 90 K), to investigate the magnetic stripe phase, charge-only stripe phase, and
 75 the normal phase.

3. Results and discussion

Figure 2 (a) shows a well-defined Fermi surface of LSCO for the compound
 $x = 0.12$ obtained at $T = 5$ K in the superconducting states reconstructed from
 experimental ARPES data measured at 5 K with a photon energy of $\hbar\omega = 55$ eV,

Figure 2: (Color online). Angle-resolved photoemission spectra and the Fermi surface of LSCO and LNSCO. (a) The Fermi surface of $\text{La}_{1.88}\text{Sr}_{0.12}\text{CuO}_4$ (LSCO) with a large momentum coverage measured at a photon energy of $\hbar\omega = 55$ eV at $T = 5$ K (below T_c). The dashed curves represent the tight binding Fermi surface results from a global fit to the data as guide to the eye. (b) The same as (a) but at $T = 55$ K (above T_c) (c) The Fermi surface of $\text{La}_{1.48}\text{Nd}_{0.4}\text{Sr}_{0.12}\text{CuO}_4$ at $T = 9$ K. (d) Zoom of the section marked in red in pane (b) showing the dispersion cuts along the Fermi surface.

80 which represents the integrated photoelectron intensity of spectra over a small
 energy window $E = E_F \pm 10$ meV, normalised using the intensity well above
 E_F . The normal states Fermi surface are shown in Figure 2 (b) for LSCO and 2
 (c) for LNSCO. The Brillouin zone guidelines shown in Figure 2 (a) are drawn by
 ignoring the finite k_z dispersion in the system, as this is indiscernible within the
 85 experimental accuracy for the photon energies used. We see a hole-like Fermi
 surface with a large pocket centred at M (π, π), which is consistent with previous
 observations in under-doped cuprates. Similar to the Ref. [14], we do not see the
 shadow bands previously reported in 1/8 doping, which potentially represents
 additional ingredients in the band structure that goes beyond the single-band
 90 picture. Indeed, it has been suggested that the shadow band intensity could be
 even enhanced at $x = 1/8$ compared with both its lower and higher doping sides
 [15]. Our data roughly corresponds to what expected from single electron bands
 calculations in the tight binding approximation (white, dashed line in Figure 2
 (a)).

95 In Figure 3, we compare the spectral line shapes of the nodal and off-nodal
 cuts (depicted in Figure 2 (d)) on LSCO samples in the superconducting states
 and in the normal states. In panel (a), the energy distribution curves (EDCs)
 integrated over a small interval of 0.02 Å around k_F were obtained along the
 nodal and off-nodal directions, both below and above $T_c = 31$ K. We can see
 100 a discernible quasi-particle peak in the superconducting state as well as in the
 normal state in the nodal region. In the off-nodal region, in contrast, the spectral
 weight near E_F is suppressed both below and above T_c , as already reported in
 the region where the pseudo-gap is open [5, 14]. There is no measurable spectral
 weight difference between data below and above T_c . In order to estimate the
 105 size of the energy gap at each k_F , we symmetrised the ARPES spectrum with
 respect to E_F to eliminate the effect from the Fermi-Dirac function [16], and the
 E_F -symmetrised EDCs are shown in panel (b) and (c). We can observe that, for
 the LSCO ($x=1/8$) sample, the superconducting gap is opening when we move
 from the nodal to the off-nodal region at $T = 5$ K, and persists at $T = 55$ K,
 110 well above T_c , where an almost comparable gap at the off-nodal region is clearly

Figure 3: Superconducting gap and pseudo-gap measured by ARPES. (a) Comparison of energy distribution curves (EDCs) at k_F along the nodal/off-nodal directions below and above T_c for $\text{La}_{1.88}\text{Sr}_{0.12}\text{CuO}_4$. (b) and (c) The E_F -symmetrised EDCs from the nodal to off-nodal region obtained at $T = 5 \text{ K}$ and $T = 55 \text{ K}$, respectively.

Figure 4: (a) Temperature and momentum dependence of EDCs at 9 K. (b) EDCs of panel (a) symmetrised.

visible, as expected for a pseudo-gap. The spectral evolution with temperature, shown in Figure 3 (c), indicates that the off-nodal pseudo-gap persists deep into the LTO phase. Our observation is consistent with the report of Ref. [17], which also shows that a off-nodal pseudo-gap exists at the 1/8 doping.

115 In order to see the pseudo-gap in the 1/8 doped LNSCO, we show in Figure 4 (a) the EDCs for several cuts in the reciprocal space at $T = 9$ K, from nodal region to off-nodal region. The EDCs show a fairly weak quasi-particle peak with a high background level along the off-nodal direction. When moving towards the nodal direction, the quasi-particle peak intensity evolves and gets sharp. This
120 evolution of the quasi-particle peak as function of k-momentum is consistent with general observations: the spectral weight has a maximum near the node and drops off rapidly when approaching the antinode where it is suppressed and finally vanishes, resulting in a broad line-shape with a weak shoulder near E_F . Despite the evolution of the low-energy spectral weight along the Fermi

Figure 5: (Color online). Temperature evolution of the nodal pseudo-gap (a) and off-nodal pseudo-gap (b) on 1/8 doped LNSCO shown as symmetrised EDCs.

surface, the quasi-particle peak maintains a distinct structure in momentum space, which gives the possibility to determine the peak position. For example, as shown in Figure 4 (a), we easily see that the peak position tends to move towards higher binding energy indicating an opening of the pseudo-gap with a maximum at the off-node. The raw symmetrised EDCs of LNSCO are shown in Figure 4(b). We can see the opening of the pseudo-gap as the momentum cut goes from the nodal direction towards the off-nodal region at the end of the Fermi arc.

The temperature evolution of the two momentum cuts along the nodal and off-nodal direction are shown in Figure 5, in symmetrised EDCs. In Figure 5 panel (a), despite the very noisy data, a small gap could be seen above 55 K, which would confirm the data shown by Matt and coworkers [5]. This suggests that the pseudo-gap can exist in the nodal region, but would require further measurements in order to have sufficient statistics to confirm the result.

4. Conclusions

Our data shows a loss of spectral intensity towards the end of the Fermi arcs, that is possibly due to a strong renormalisation, as already pointed out elsewhere [5], with a noisy but still measurable gap. On the nodal direction no gap is observed within our statistics, but a sizeable decrease in intensity with temperature. Moreover, we do not see any shadow band, but our Fermi surface can be well modelled with a single electron band calculation in the tight binding approximation, even very close to the 1/8 doping, both for LSCO and Nd substituted LNSCO.

Acknowledgments

We are very grateful to all the CASSIOPEE staff at the synchrotron SOLEIL and to V. Brouet, for the help with the data interpretation and the kind use of their Igor procedures for the ARPES data analysis. This work was supported by SOLEIL through experiment No. 20150289 and No. 20140068. We acknowledge the support of China Scholarship Council (CSC, Grant No. 201308070040).

References

- [1] S. A. Kivelson, I. P. Bindloss, E. Fradkin, V. Oganessian, J. M. Tranquada, A. Kapitulnik, C. Howald, How to detect fluctuating stripes in the high-temperature superconductors, *Rev. Mod. Phys.* 75 (2003) 1201–1241. doi: 10.1103/RevModPhys.75.1201.
URL <https://link.aps.org/doi/10.1103/RevModPhys.75.1201>
- [2] J. Chang, E. Blackburn, A. T. Holmes, N. B. Christensen, J. Larsen, J. Mesot, R. Liang, D. A. Bonn, W. N. Hardy, A. Watenphul, M. v. Zimmermann, E. M. Forgan, S. M. Hayden, Direct observation of competition between superconductivity and charge density wave order in $\text{YBa}_2\text{Cu}_3\text{O}_{6.67}$, *Nat Phys* 8 (12) (2012) 871–876.
URL <http://dx.doi.org/10.1038/nphys2456>

- [3] R. Comin, A. Frano, M. M. Yee, Y. Yoshida, H. Eisaki, E. Schierle, E. Weschke, R. Sutarto, F. He, A. Soumyanarayanan, Y. He, M. Le Tacon, I. S. Elfimov, J. E. Hoffman, G. A. Sawatzky, B. Keimer, A. Damascelli, Charge order driven by fermi-arc instability in $\text{Bi}_2\text{Sr}_{2-x}\text{La}_x\text{CuO}_{6+\delta}$, Science 343 (6169) (2014) 390–392. [arXiv:http://science.sciencemag.org/content/343/6169/390.full.pdf](http://science.sciencemag.org/content/343/6169/390.full.pdf), doi:10.1126/science.1242996. URL <http://science.sciencemag.org/content/343/6169/390>
- [4] E. H. da Silva Neto, P. Aynajian, A. Frano, R. Comin, E. Schierle, E. Weschke, A. Gyenis, J. Wen, J. Schneeloch, Z. Xu, S. Ono, G. Gu, M. Le Tacon, A. Yazdani, Ubiquitous interplay between charge ordering and high-temperature superconductivity in cuprates, Science 343 (6169) (2014) 393. URL <http://science.sciencemag.org/content/343/6169/393>
- [5] C. E. Matt, C. G. Fatuzzo, Y. Sassa, M. Månsson, S. Fatale, V. Bitetta, X. Shi, S. Pailhès, M. H. Berntsen, T. Kurosawa, M. Oda, N. Momono, O. J. Lipscombe, S. M. Hayden, J.-Q. Yan, J.-S. Zhou, J. B. Goodenough, S. Pyon, T. Takayama, H. Takagi, L. Patthey, A. Bendounan, E. Razzoli, M. Shi, N. C. Plumb, M. Radovic, M. Grioni, J. Mesot, O. Tjernberg, J. Chang, Electron scattering, charge order, and pseudogap physics in $\text{La}_{0.16-x}\text{Nd}_{0.4}\text{Sr}_x\text{CuO}_4$, Phys. Rev. B 92 (2015) 134524. doi:10.1103/PhysRevB.92.134524. URL <https://link.aps.org/doi/10.1103/PhysRevB.92.134524>
- [6] Z. Zhang, D. R. Garcia, S. Denis, G. Dhalenne, P. L. Fèvre, A. Taleb-Ibrahimi, C. Decorse, P. B. A. Lanzara, M. d’Astuto, Relation between nodal pseudogap, stripe correlations and structural phase transition in $\text{La}_{1.86}\text{Ba}_{0.14}\text{CuO}_{4+\delta}$ superconductor, unpublished results, article in preparation.
- [7] J. M. Tranquada, B. J. Sternlieb, J. D. Axe, Y. Nakamura, S. Uchida, Evidence for stripe correlations of spins and holes in copper oxide super-

- 195 conductors, *Nature* 375 (6532) (1995) 561–563.
 URL <http://dx.doi.org/10.1038/375561a0>
- [8] J. Zaanen, O. Gunnarsson, Charged magnetic domain lines and the magnetism of high- T_c oxides, *Phys. Rev. B* 40 (1989) 7391–7394. doi:10.1103/PhysRevB.40.7391.
 200 URL <https://link.aps.org/doi/10.1103/PhysRevB.40.7391>
- [9] D. H. Torchinsky, F. Mahmood, A. T. Bollinger, I. Božović, N. Gedik, Fluctuating charge-density waves in a cuprate superconductor, *Nat Mater* 12 (5) (2013) 387–391.
 URL <http://dx.doi.org/10.1038/nmat3571>
- 205 [10] J. D. Axe, A. H. Moudden, D. Hohlwein, D. E. Cox, K. M. Mohanty, A. R. Moodenbaugh, Y. Xu, Structural phase transformations and superconductivity in $\text{La}_{2-x}\text{Ba}_x\text{CuO}_4$, *Phys. Rev. Lett.* 62 (1989) 2751–2754. doi:10.1103/PhysRevLett.62.2751.
 URL <https://link.aps.org/doi/10.1103/PhysRevLett.62.2751>
- 210 [11] V. Thampy, M. P. M. Dean, N. B. Christensen, L. Steinke, Z. Islam, M. Oda, M. Ido, N. Momono, S. B. Wilkins, J. P. Hill, Rotated stripe order and its competition with superconductivity in $\text{La}_{1.88}\text{Ba}_{0.12}\text{CuO}_4$, *Phys. Rev. B* 90 (2014) 100510. doi:10.1103/PhysRevB.90.100510.
 URL <https://link.aps.org/doi/10.1103/PhysRevB.90.100510>
- 215 [12] L. S. Bilbro, R. V. Aguilar, G. Logvenov, O. Pelleg, I. Bozovic, N. P. Armitage, Temporal correlations of superconductivity above the transition temperature in $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ probed by terahertz spectroscopy, *Nat Phys* 7 (4) (2011) 298–302.
 URL <http://dx.doi.org/10.1038/nphys1912>
- 220 [13] G. Drachuck, E. Razzoli, G. Bazalitski, A. Kanigel, C. Niedermayer, M. Shi, A. Keren, Comprehensive study of the spin-charge interplay in antiferromagnetic $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$, *Nature Communications* 5 (2014) 3390.
 URL <http://dx.doi.org/10.1038/ncomms4390>

- [14] R.-H. He, M. Hashimoto, H. Karapetyan, J. D. Koralek, J. P. Hinton, J. P.
 225 Testaud, V. Nathan, Y. Yoshida, H. Yao, K. Tanaka, W. Meevasana, R. G.
 Moore, D. H. Lu, S.-K. Mo, M. Ishikado, H. Eisaki, Z. Hussain, T. P. De-
 vereaux, S. A. Kivelson, J. Orenstein, A. Kapitulnik, Z.-X. Shen, From a
 single-band metal to a high-temperature superconductor via two thermal
 phase transitions, *Science* 331 (6024) (2011) 1579–1583. `arXiv:http://`
 230 `science.sciencemag.org/content/331/6024/1579.full.pdf`, `doi:10.`
`1126/science.1198415`.
 URL `http://science.sciencemag.org/content/331/6024/1579`
- [15] J. Chang, Y. Sassa, S. Guerrero, M. Mnsson, M. Shi, S. Pailhs, A. Ben-
 dounan, R. Mottl, T. Claesson, O. Tjernberg, L. Patthey, M. Ido, M. Oda,
 235 N. Momono, C. Mudry, J. Mesot, Electronic structure near the 1/8-anomaly
 in la-based cuprates, *New Journal of Physics* 10 (10) (2008) 103016.
 URL `http://stacks.iop.org/1367-2630/10/i=10/a=103016`
- [16] M. R. Norman, H. Ding, M. Randeria, J. C. Campuzano, T. Yokoya,
 T. Takeuchi, T. Takahashi, T. Mochiku, K. Kadowaki, P. Guptasarma,
 240 D. G. Hinks, Destruction of the fermi surface in underdoped high- T_c super-
 conductors, *Nature* 392 (6672) (1998) 157–160.
 URL `http://dx.doi.org/10.1038/32366`
- [17] T. Yoshida, W. Malaeb, S. Ideta, D. H. Lu, R. G. Moor, Z.-X. Shen,
 M. Okawa, T. Kiss, K. Ishizaka, S. Shin, S. Komiya, Y. Ando, H. Eisaki,
 245 S. Uchida, A. Fujimori, Coexistence of a pseudogap and a supercon-
 ducting gap for the high – T_c superconductor $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ studied by
 angle-resolved photoemission spectroscopy, *Phys. Rev. B* 93 (2016) 014513.
`doi:10.1103/PhysRevB.93.014513`.
 URL `https://link.aps.org/doi/10.1103/PhysRevB.93.014513`