Lecture 4

Supervised ML for Hypothesis Test on Real, position space Data

Machine learning in electronic-quantum-matter imaging experiments

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High Tc Superconductivity

Mysteries of HTSC

The Complex Phase Diagram

Simple PD of conventional SC

T

Superconductor

T_c

Fermi Liquid Metal

Complex PD of high T_c SC

- Multiple "phases"
- Unidentifiable regions

Density Wave and Nematic Order

Hoffman et al, Science (2002)
Howald et al, PRB (2003)
Abbamonte et al , Nature Phys (2005)
Hinkov et al, Science (2008)
Daou et al, Nature (2010)
Lawler et al, Nature (2010)
Ghiringhelli et al, Science (2012)
Blackburn et al PRL (2013)
Comin et al, Science (2014)
de Silva Neto et al, Science (2014)
Fujita et al, PNAS (2014)
Wu et al , Nat. Comm (2015)
Achkar et al, Science (2016)

Density Wave and Nematic

Glassy Order

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Achkar et al, Science (2016)

Comin *et al.* (2014)

Density Wave and Nematic

Glassy Order

Local Motif!

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Fujita et al, PNAS (2014)
Wu et al , Nat. Comm (2015)
Achkar et al, Science (2016)

R(r,150mV)

UD45K
Bi2212 6.2nmx6.2nm

Learn Local Motifs in Pseudogap State of HTSC

r-space
or
k-space?

The function $h(\vec{x})$?

Strong Coupling Mechanism

- Frustration of AFM order upon doping

Zaanen, Gunnarson, PRB (1989)
Low, Emery, Fabricious, Kivelson (1994)
Vojta, Sachdev(1999)
White, Scalapino,PRL(1998)
Capponi, Poilblanc (2002)
Corboz, Rice, Troyer, PRL (2014)
Fischer, EAK *et al.*, NJP (2014)

Commensurate Charge Modulation,
$\lambda = 4a$ at $p=1/8$

Weak Coupling Mechnism

- Nesting driven Fermi surface instability

Efitov et al, Nature Physics (2013)
Pepin et al, PRB (2014)
Wang, Chubukov, PRB (2014)
Loder et al, PRL (2011)

Incommensurate,
Q decrease with *p*

Conventional Approach

1. Fourier Transfrom
2. Compress FT down to the peak location of a line cut

UD45K
Bi2212

R(r,150mV)

6.2nmx6.2nm 0.68 1.55

Linecut through (0,0)-(1,0)

Robertson et al (2006),
Del Maestro et al (2006)
declared defeat within manual schemes!

3-stage protocol: I

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3-stage protocol: II

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3-stage protocol: III

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Training Set Generation

$$A_d(\boldsymbol{x}) = \prod_{i=1}^{n_d} (1 - exp(-|\boldsymbol{x} - \boldsymbol{x}_i|/\xi_d))$$

$$\varphi_d(x,y) = \sum_{j=1}^{n_d} Arg\left[sgn(w_j)(x - x_j) + i(y - y_j)\right],$$

$$I_{C,f,d}^{DFF}(x,y) = A_{DFF}\left[1 + \varepsilon_A\, A_f(x,y)\right] A_d(x,y)\, Cos\left(Q_C x + \varepsilon_\varphi \varphi_f(x,y) + \varphi_d(x,y) + \varphi_{DFF}\right)$$

Training Set generation demo

https://github.com/iamc/ML-CM-2019/blob/master/Eun-Ah_Kim/Train_2disl_DEMO.nb

Four Candidate Wave Vectors

Experimental Data Preprocessing

Size: {400, 400}; Min/Max: {0.217257, 2.74965}

Size: {355, 352}; Min/Max: {0.217257, 2.74965}

Data preprocessing

Experimental Data Preprocessing

Size: {400, 400}; Min/Max: {−1, 1}

Size: {365, 362}; Min/Max: {−1, 1}

Doping Dependence

Doping Dependence

Doping Dependence

Doping Dependence

Energy Dependence

Energy Dependence

Hypothesis test

Unidirectional, lattice commensurate, period 4 charge modulations.

Hypothesis test

Unidirectional, lattice commensurate, period 4 charge modulations.

FIN