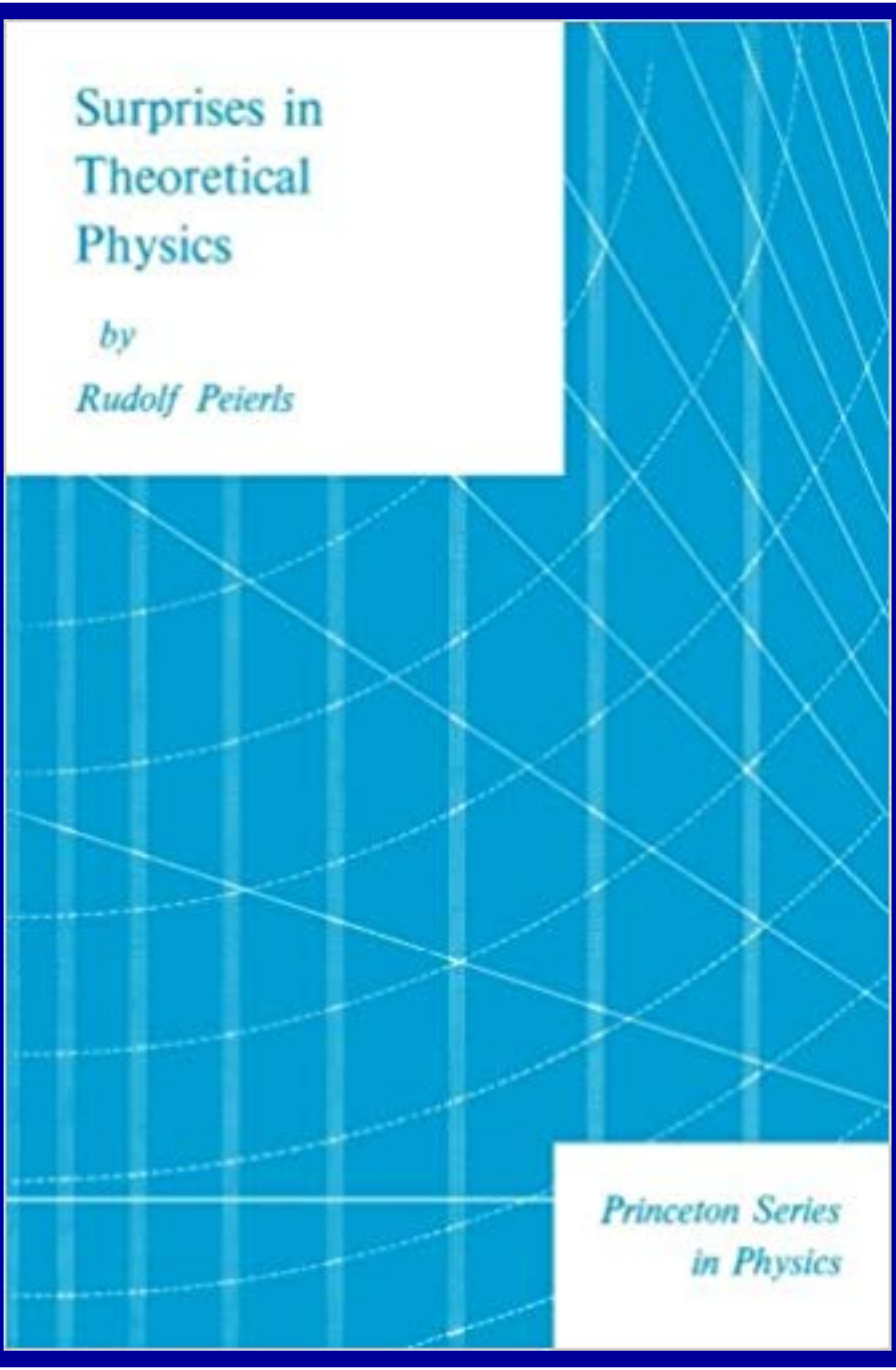
Suprises in Theoretical Physics !

Antoine Georges
CPHT@61
March 2019

CPHT
Centre de
Physique
Théorique



Surprises in
Theoretical
Physics

by

Rudolf Peierls

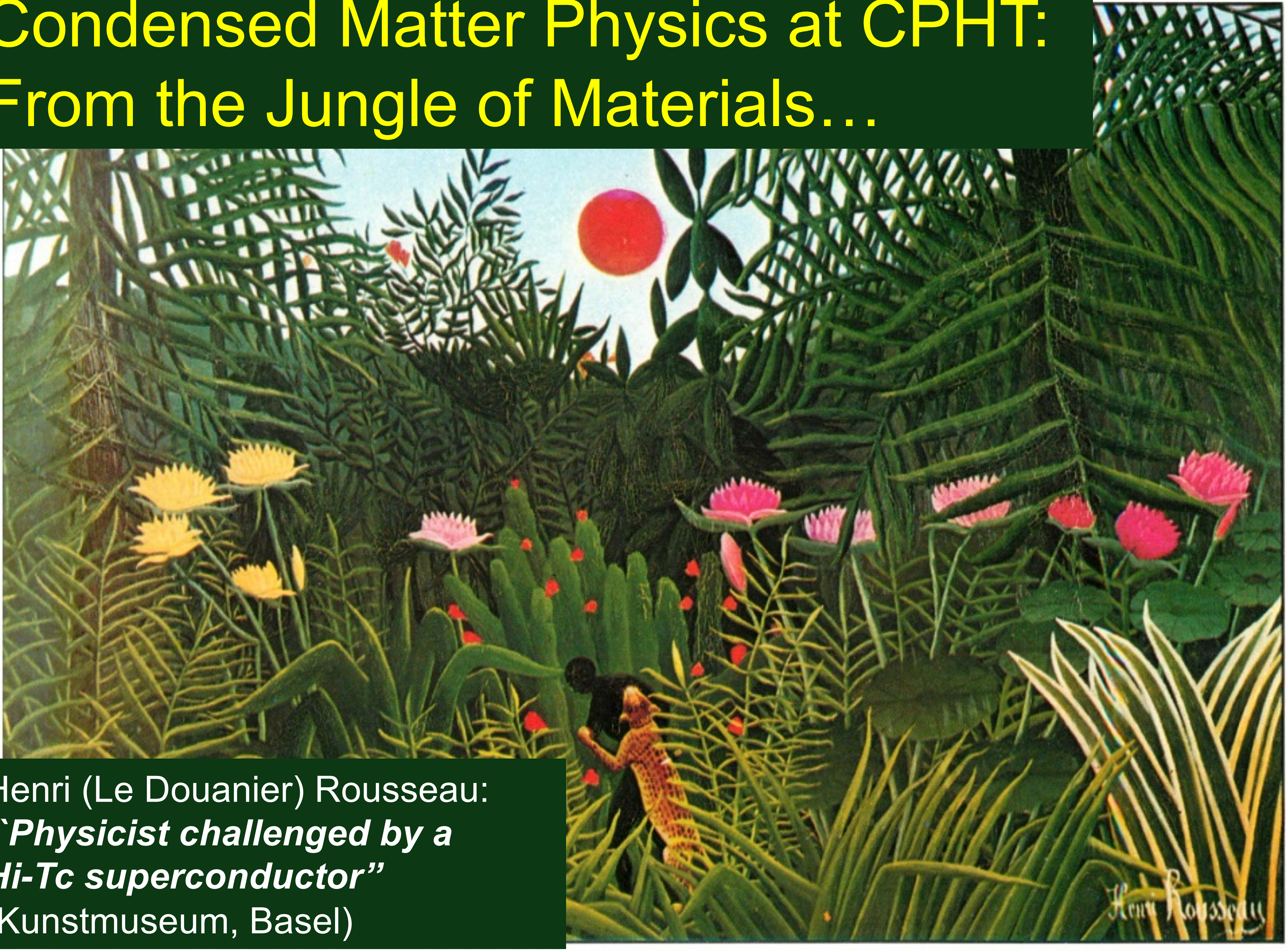
Princeton Series
in Physics

Sir Rudolf Peierls
Lectures
at U.Washington
and IPN – Orsay
1977-1978

Surprises in Theoretical Physics:

One of the fascinating aspects
of Theoretical Physics
is that unexpected connections
between seemingly unrelated
questions or fields emerge,
sometimes across
many decades of research

Condensed Matter Physics at CPHT: From the Jungle of Materials…

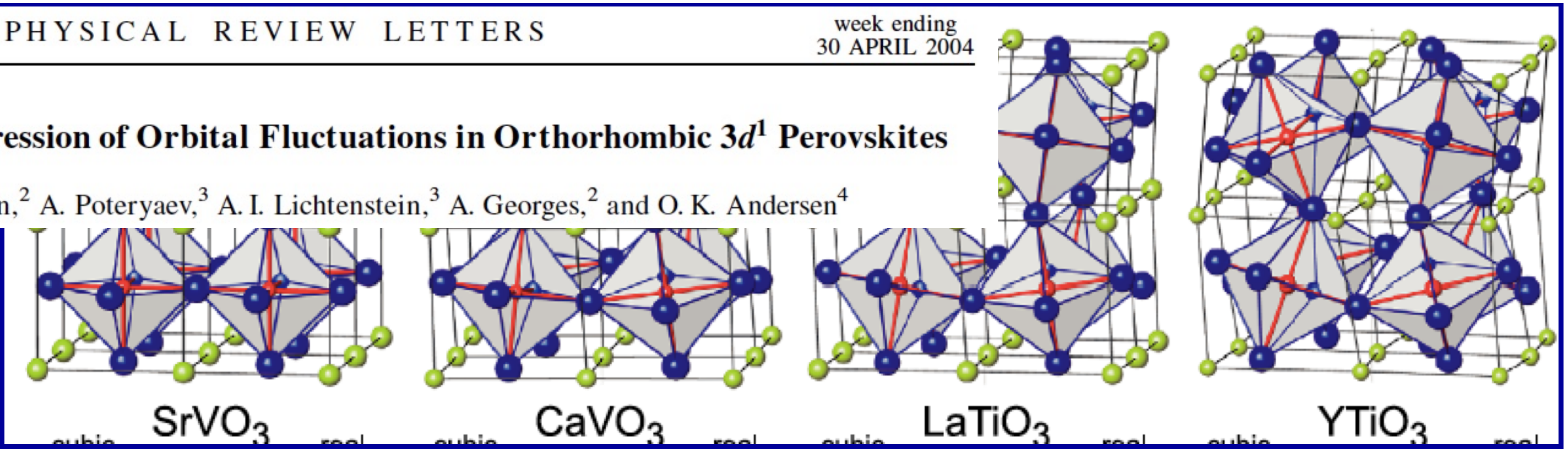


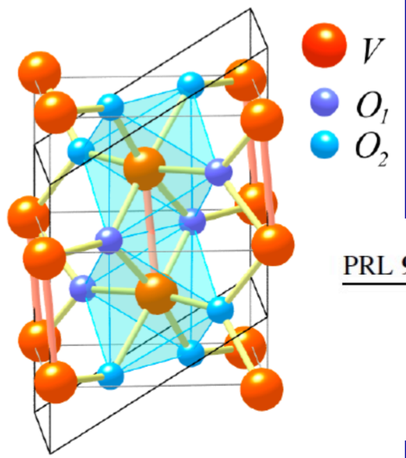
Henri (Le Douanier) Rousseau:
``Physicist challenged by a Hi-Tc superconductor”
(Kunstmuseum, Basel)

VOLUME 92, NUMBER 17 PHYSICAL REVIEW LETTERS week ending 30 APRIL 2004

Mott Transition and Suppression of Orbital Fluctuations in Orthorhombic $3d^1$ Perovskites

E. Pavarini,[1] S. Biermann,[2] A. Poteryaev,[3] A. I. Lichtenstein,[3] A. Georges,[2] and O. K. Andersen[4]

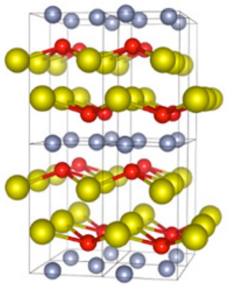


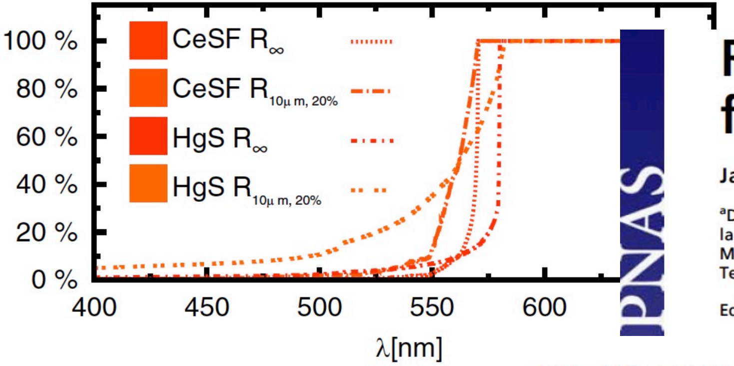


PRL 94, 026404 (2005) PHYSICAL REVIEW LETTERS week ending 21 JANUARY 2005

Dynamical Singlets and Correlation-Assisted Peierls Transition in VO_2

S. Biermann,[1,2] A. Poteryaev,[3,1] A. I. Lichtenstein,[4] and A. Georges[1,2]





Rare-earth vs. heavy metal pigments and their colors from first principles

Jan M. Tomczak[a,1], Leonid V. Pourovskii[b], Loig Vaugier[b], Antoine Georges[b,c,d,e], and Silke Biermann[b,e]

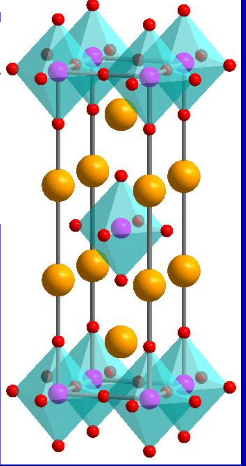
[a]Department of Physics and Astronomy, Rutgers University, Piscataway, NJ 08854; [b]Centre de Physique Théorique, Ecole Polytechnique, Centre National de la Recherche Scientifique Unité Mixte de Recherche 7644, 91128 Palaiseau, France; [c]Collège de France, 75005 Paris, France; [d]Département de Physique de la Matière Condensée–Materials with Novel Electronic Properties (DPMC-MaNEP), Université de Genève, CH-1211 Geneva, Switzerland; and [e]Japan Science and Technology Agency, Core Research for Evolutional Science and Technology (CREST), Kawaguchi 332-0012, Japan

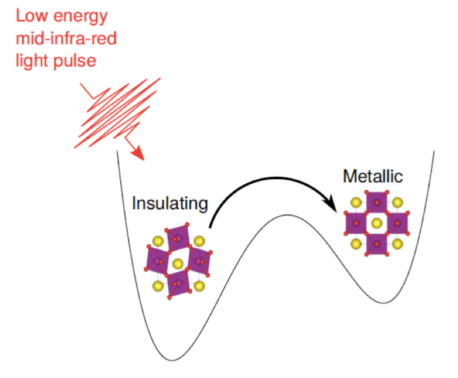
Edited* by Elihu Abrahams, University of California, Los Angeles, CA, and approved November 27, 2012 (received for review August 31, 2012)

PRL 117, 036401 (2016) PHYSICAL REVIEW LETTERS

Thermopower and Entropy: Lessons from Sr_2RuO_4

Jernej Mravlje[1] and Antoine Georges[2,3,4]





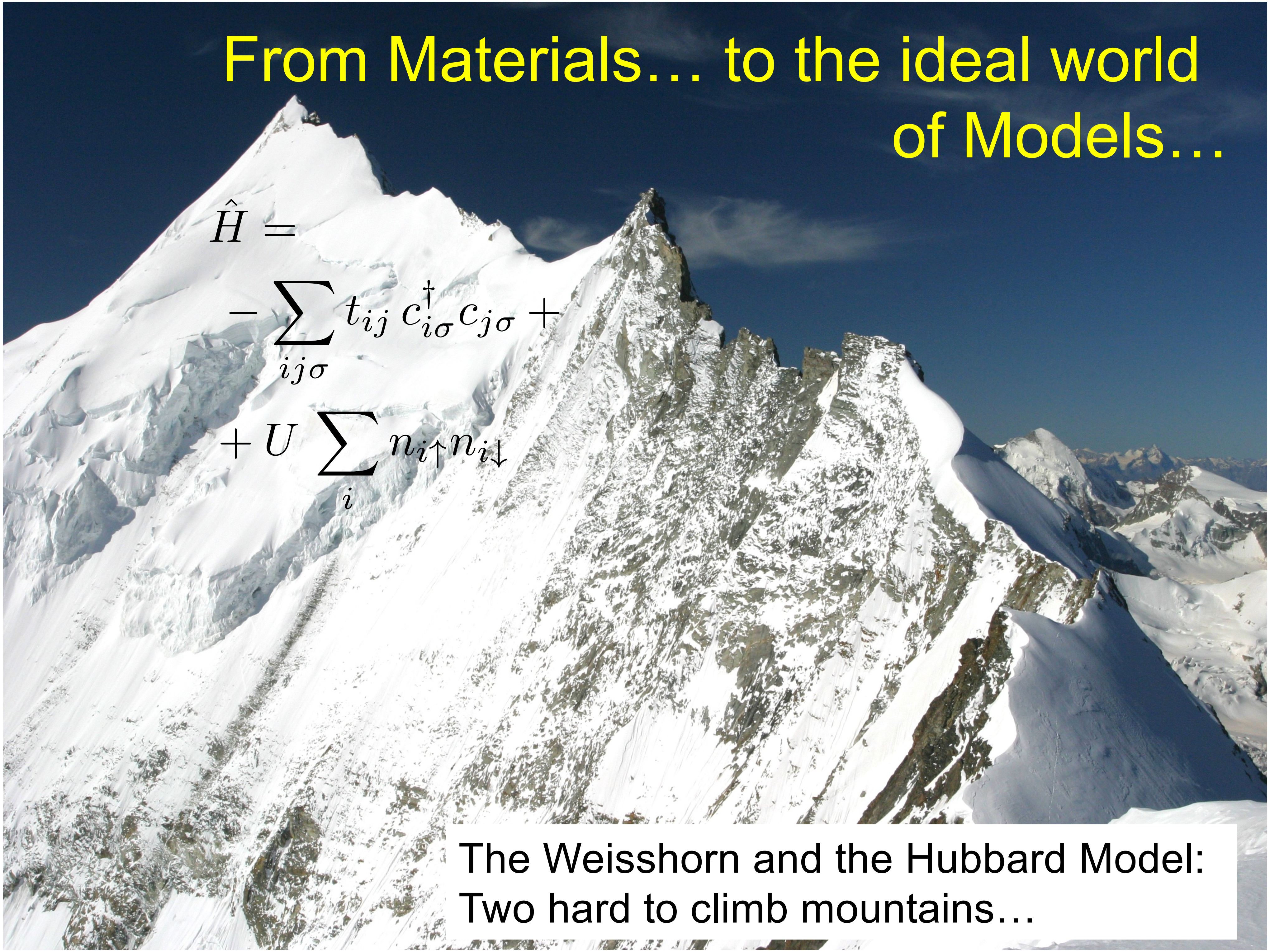
PHYSICAL REVIEW B 89, 220301(R) (2014)

Theory of nonlinear phononics for coherent light control of solids

Alaska Subedi,[1] Andrea Cavalleri,[2,3] and Antoine Georges[1,4,5]

2006: Visit of Ole and Sanne Andersen

2004 : Our first cluster !
THANK YOU, Computer and Admin team !

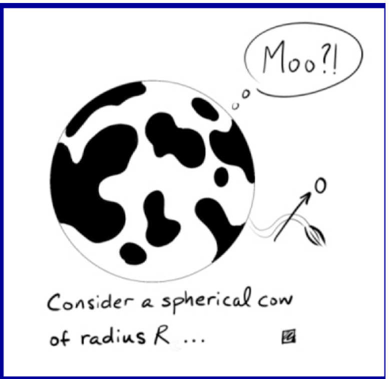


From Materials… to the ideal world of Models…

$$\begin{aligned}\hat{H} = \\ -\sum_{ij\sigma} t_{ij}\, c^{\dagger}_{i\sigma} c_{j\sigma} + \\ + U \sum_{i} n_{i\uparrow} n_{i\downarrow}\end{aligned}$$

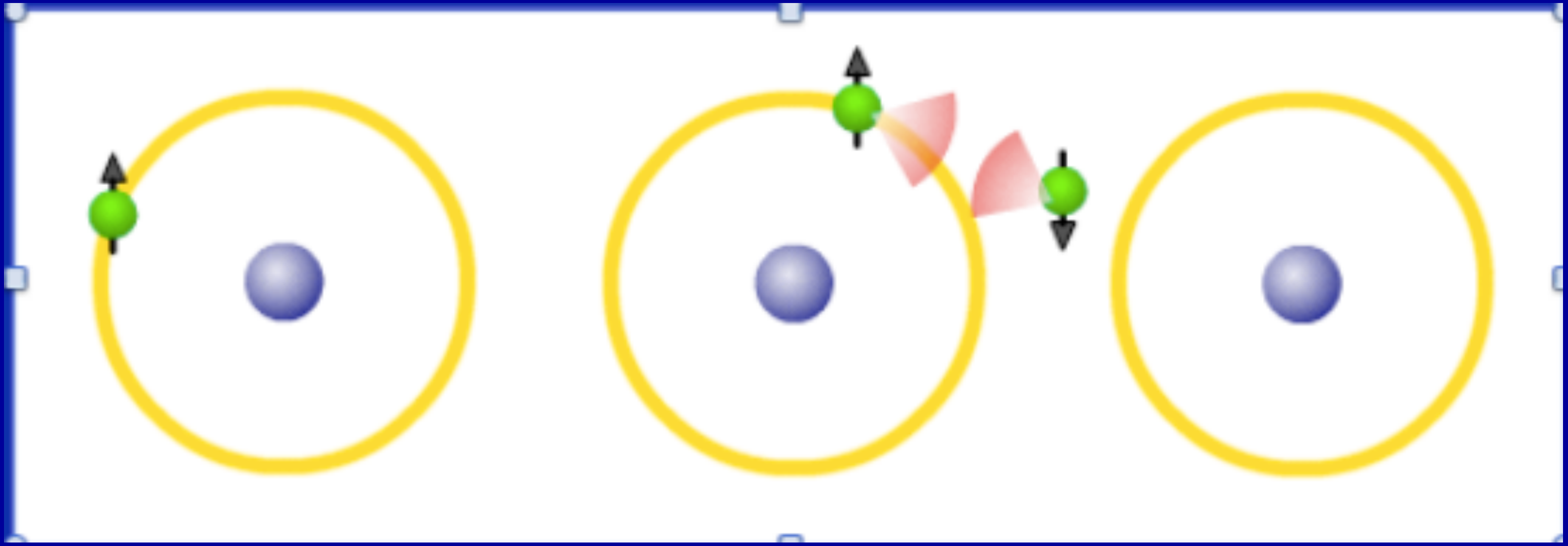
The Weisshorn and the Hubbard Model:
Two hard to climb mountains…

Simplest « toy model »: The Hubbard model



$$H = -t \sum_{\langle ij \rangle} (c_i^\dagger c_j + h.c.) + U \sum_i n_{i\uparrow} n_{i\downarrow}$$

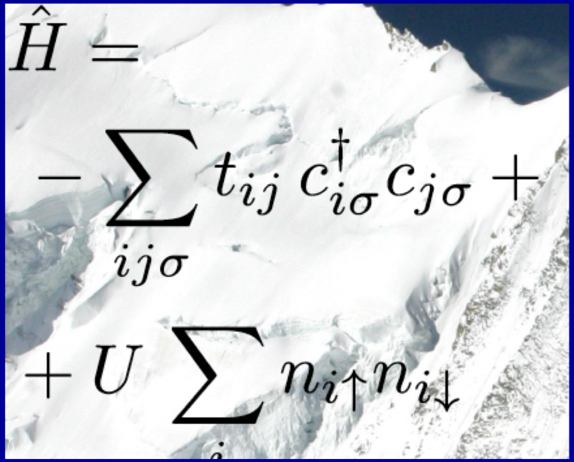
4^N states !



t: Tunnel amplitude → bandwidth

U: On-site matrix element of screened Coulomb interaction

In 2002 , the Hubbard model stops being `just a toy model’ !



$$\hat{H} = -\sum_{ij\sigma} t_{ij}\, c^{\dagger}_{i\sigma} c_{j\sigma} + U \sum n_{i\uparrow} n_{i\downarrow}$$

Ultra-Cold Atomic Gases
in Optical Lattices

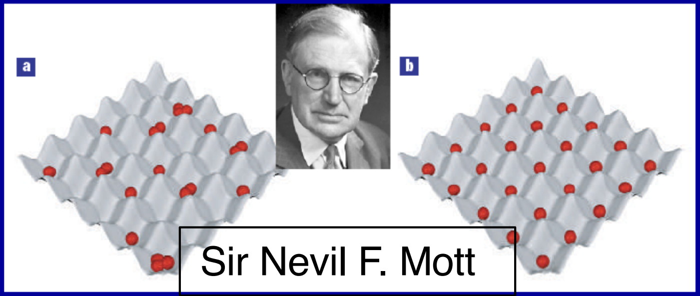
A `new’ (now ~ 20 years old)
field at the interface
of Condensed Matter Physics and
Quantum Optics.

Experimental observation of the Mott transition (cold bosonic atoms)

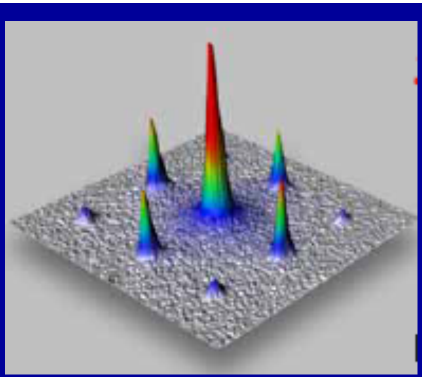
Quantum phase transition from a superfluid to a Mott insulator in a gas of ultracold atoms

NATURE | VOL 415 | 3 JANUARY 2002

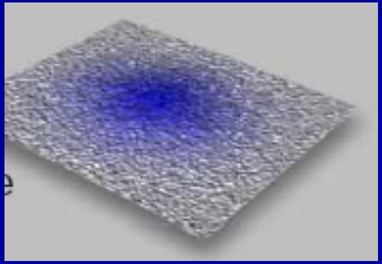
Markus Greiner*, Olaf Mandel*, Tilman Esslinger†, Theodor W. Hänsch* & Immanuel Bloch*

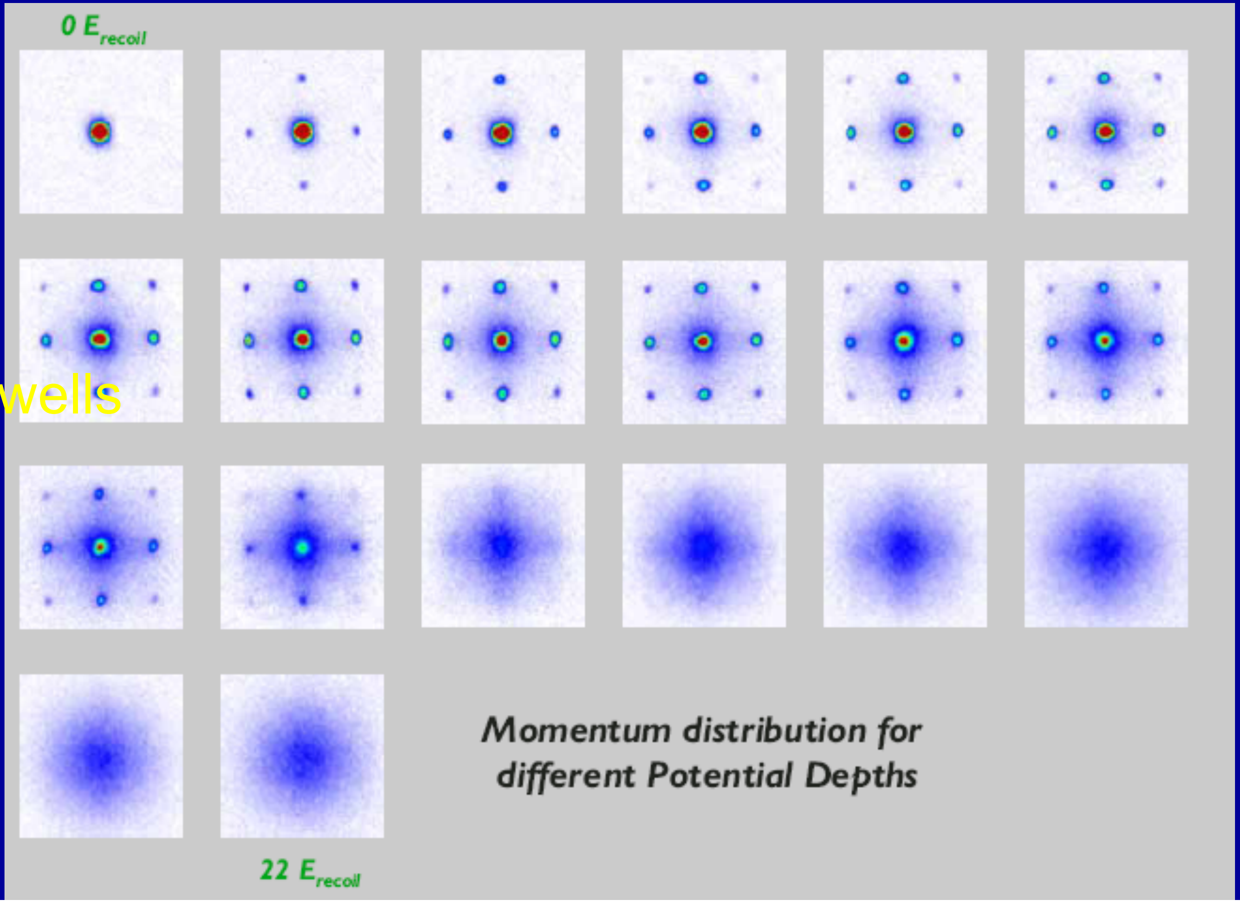


Sir Nevil F. Mott



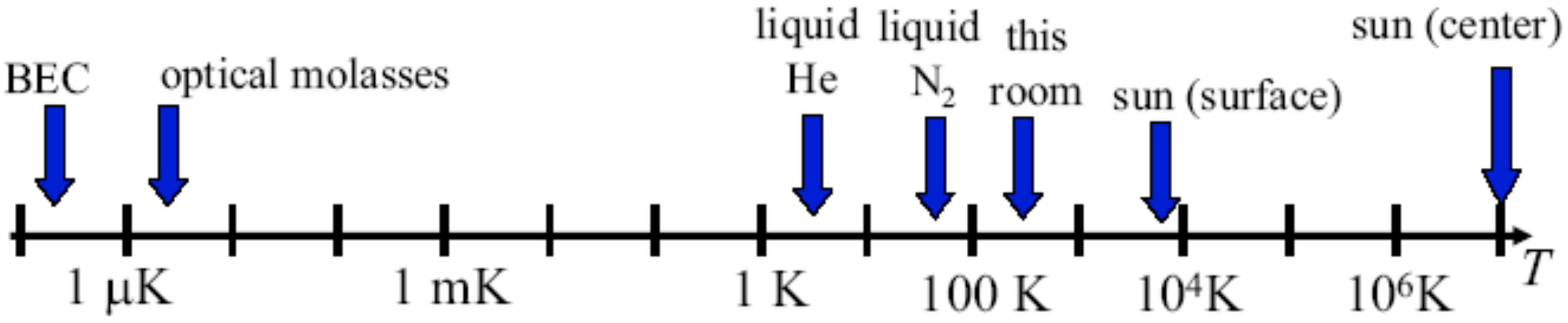
Phase coherence between wells
in superfluid phase
>interference pattern





Momentum distribution for different Potential Depths

Ultra-Cold Atomic Gases



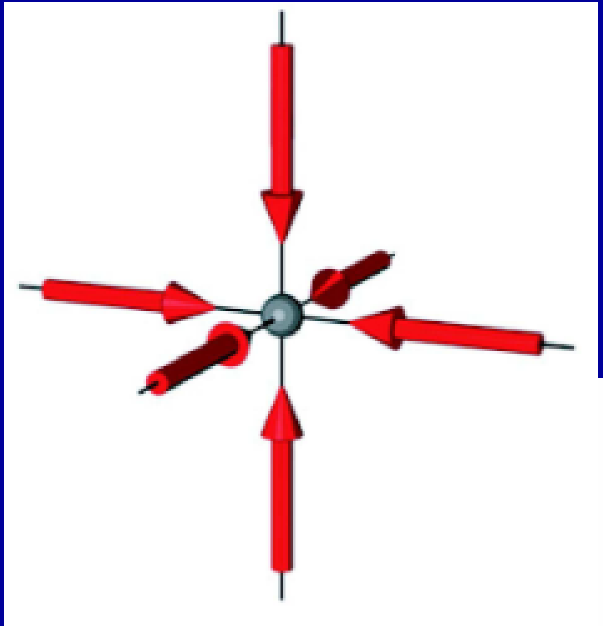
BEC

Nobel 2001
E. Cornell , W. Ketterle , C. Wieman

COOLING

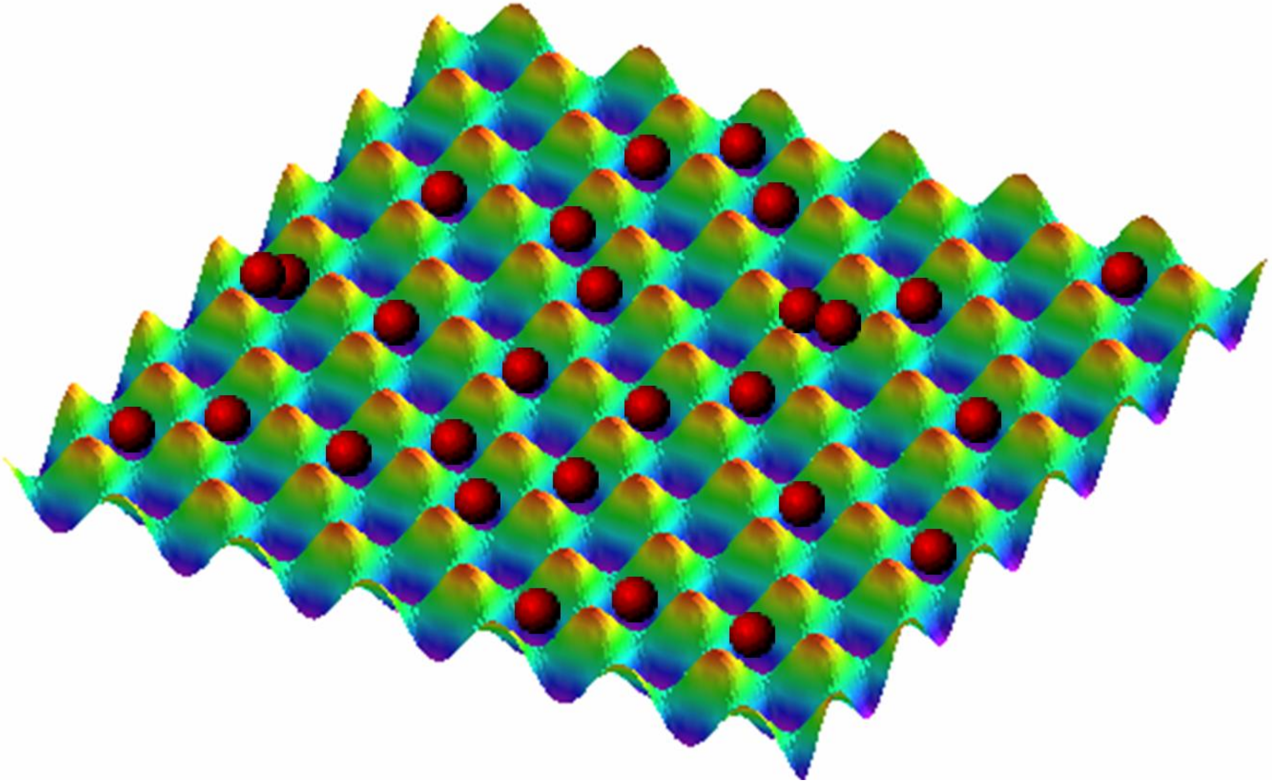
Nobel 1997
S. Chu, C. Cohen-Tannoudji, W. Phillips

The Hubbard model can be realized using quantum optics techniques



Gas of cold atoms in optical lattices:
«artificial crystals of atoms and light »

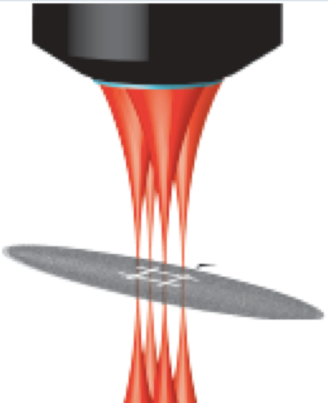
D.Jaksch et al.
PRL, 1998



Cold Atoms and Condensed Matter Physics:

very different characteristic scales, but similar `big questions'

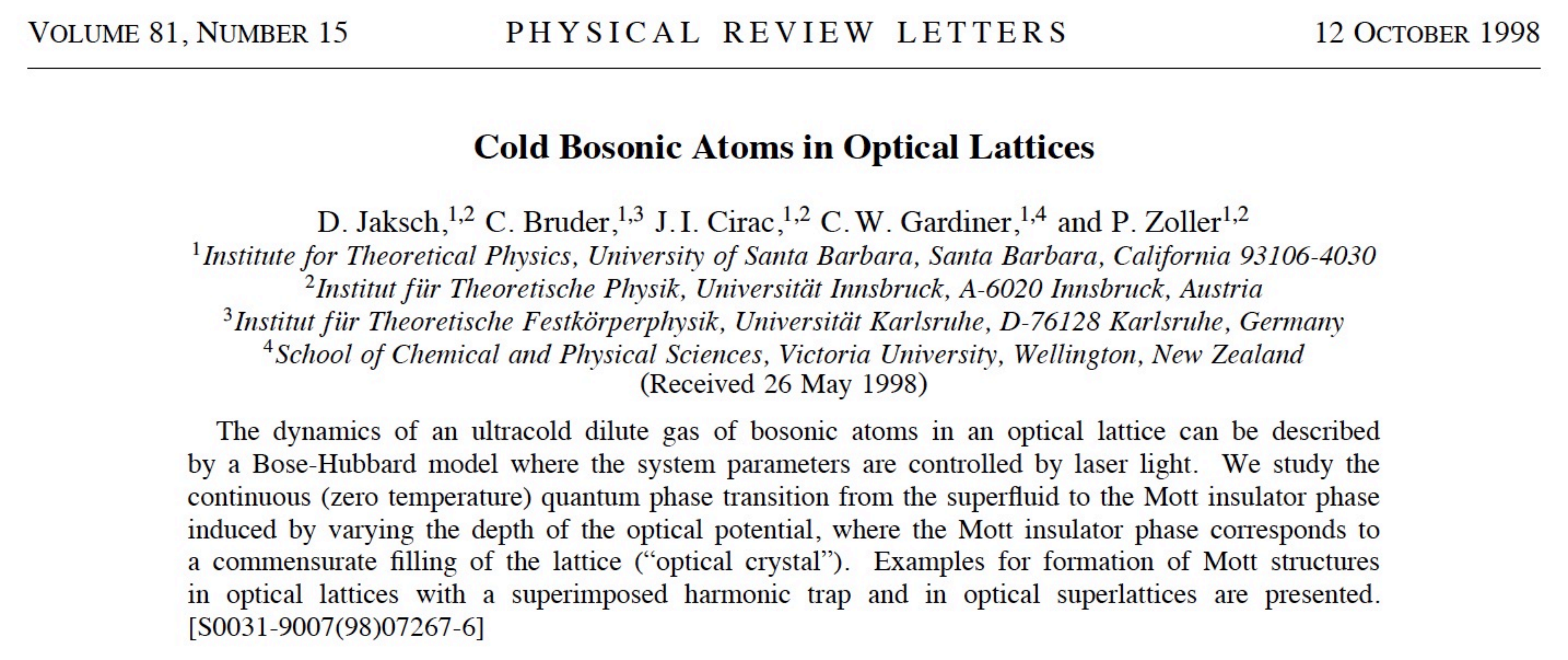
	Cold Fermionic atoms	Electrons in a solid
Density	10^{12} cm^{-3}	10^{22} cm^{-3} (Metals)
Mass	6 (Li), 40 (K)	$5.4\ 10^{-4}$
Fermi Temperature	µK	10^4 K
Temperature	100 nK	10 mK
Charge	0	-1
Interactions	Contact, *tunable*	Coulomb, material dep.
Potential shaping	Laser light	growing, lithography



Slide: courtesy
J-P Brantut

A most influential theory paper

(Google scholar as of yesterday: 3960 citations)



VOLUME 81, NUMBER 15 PHYSICAL REVIEW LETTERS 12 OCTOBER 1998

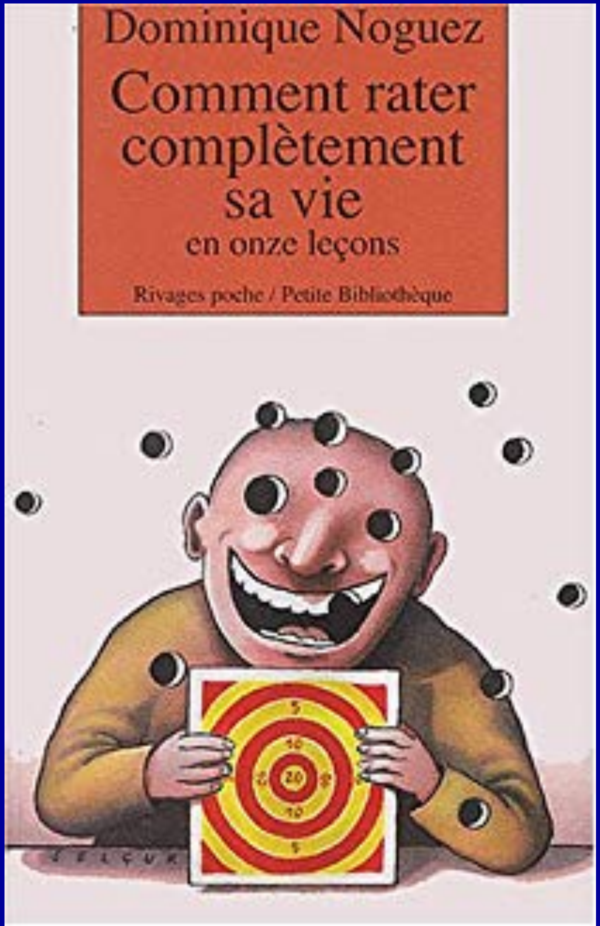
Cold Bosonic Atoms in Optical Lattices

D. Jaksch,[1,2] C. Bruder,[1,3] J. I. Cirac,[1,2] C. W. Gardiner,[1,4] and P. Zoller[1,2]
[1] *Institute for Theoretical Physics, University of Santa Barbara, Santa Barbara, California 93106-4030*
[2] *Institut für Theoretische Physik, Universität Innsbruck, A-6020 Innsbruck, Austria*
[3] *Institut für Theoretische Festkörperphysik, Universität Karlsruhe, D-76128 Karlsruhe, Germany*
[4] *School of Chemical and Physical Sciences, Victoria University, Wellington, New Zealand*

(Received 26 May 1998)

The dynamics of an ultracold dilute gas of bosonic atoms in an optical lattice can be described by a Bose-Hubbard model where the system parameters are controlled by laser light. We study the continuous (zero temperature) quantum phase transition from the superfluid to the Mott insulator phase induced by varying the depth of the optical potential, where the Mott insulator phase corresponds to a commensurate filling of the lattice ("optical crystal"). Examples for formation of Mott structures in optical lattices with a superimposed harmonic trap and in optical superlattices are presented. [S0031-9007(98)07267-6]

Reflecting on missed opportunities (*suprises I couldn't see*) …


Dominique Noguez

Comment rater complètement sa vie

en onze leçons

Rivages poche / Petite Bibliothèque

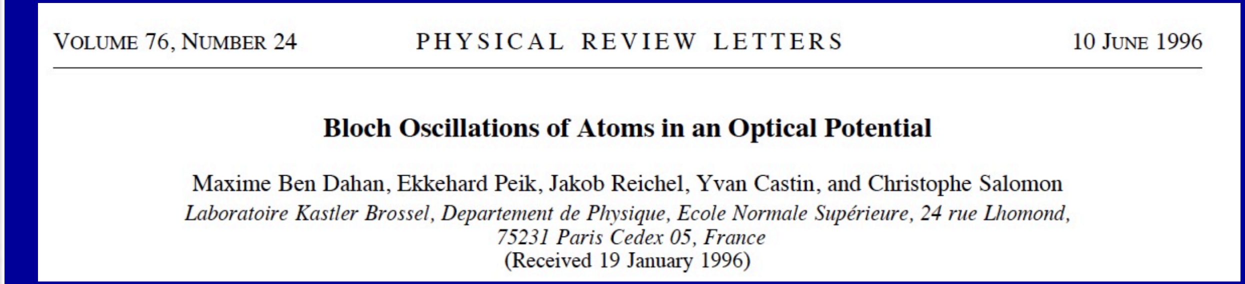
Ecole Normale, 0/1st floor, Late 80's→ Nobel prize 1997


Manipulating atoms with photons*

Claude N. Cohen-Tannoudji

Collège de France et Laboratoire Kastler Brossel[†] de l'Ecole Normale Supérieure, 75231 Paris Cedex 05, France

Ecole Normale, 1st floor, 1996:


VOLUME 76, NUMBER 24 PHYSICAL REVIEW LETTERS 10 JUNE 1996

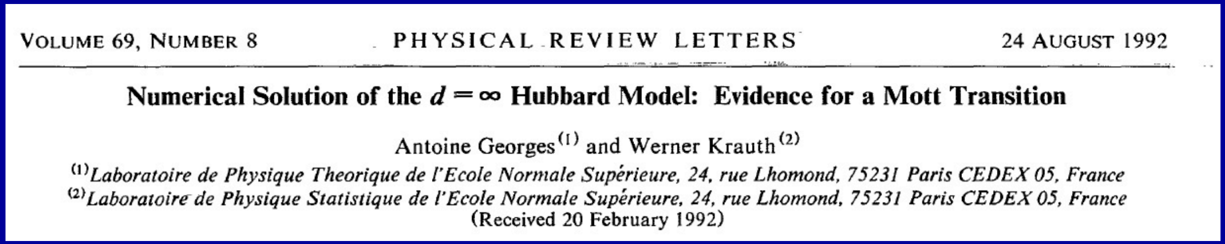
Bloch Oscillations of Atoms in an Optical Potential

Maxime Ben Dahan, Ekkehard Peik, Jakob Reichel, Yvan Castin, and Christophe Salomon

Laboratoire Kastler Brossel, Departement de Physique, Ecole Normale Supérieure, 24 rue Lhomond, 75231 Paris Cedex 05, France

(Received 19 January 1996)

Ecole Normale, 2nd floor, 1992:


VOLUME 69, NUMBER 8 PHYSICAL REVIEW LETTERS 24 AUGUST 1992

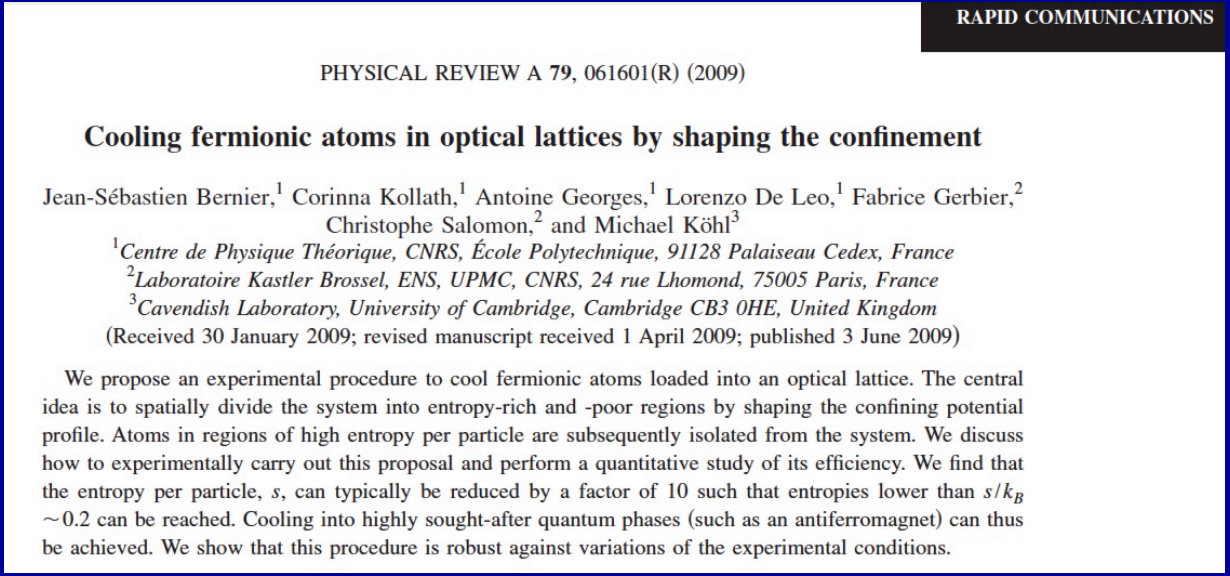
Numerical Solution of the $d = \infty$ Hubbard Model: Evidence for a Mott Transition

Antoine Georges(1) and Werner Krauth(2)

(1)*Laboratoire de Physique Theorique de l'Ecole Normale Supérieure, 24, rue Lhomond, 75231 Paris CEDEX 05, France*
(2)*Laboratoire de Physique Statistique de l'Ecole Normale Supérieure, 24, rue Lhomond, 75231 Paris CEDEX 05, France*

(Received 20 February 1992)

Some nice consolating successes …
… at CPHT !



RAPID COMMUNICATIONS

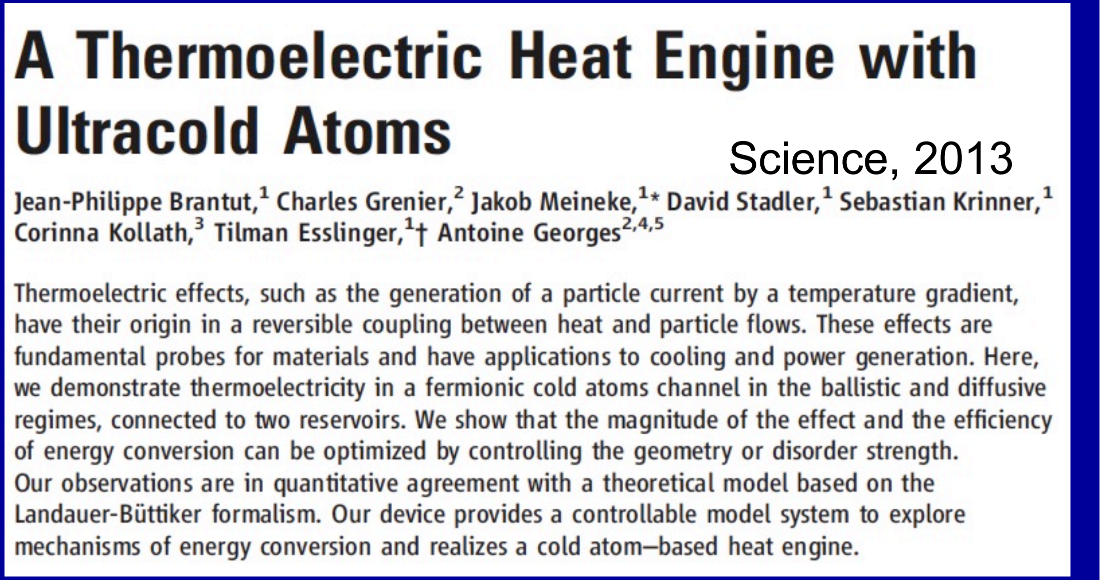
PHYSICAL REVIEW A **79**, 061601(R) (2009)

Cooling fermionic atoms in optical lattices by shaping the confinement

Jean-Sébastien Bernier,[1] Corinna Kollath,[1] Antoine Georges,[1] Lorenzo De Leo,[1] Fabrice Gerbier,[2]
Christophe Salomon,[2] and Michael Köhl[3]
[1]*Centre de Physique Théorique, CNRS, École Polytechnique, 91128 Palaiseau Cedex, France*
[2]*Laboratoire Kastler Brossel, ENS, UPMC, CNRS, 24 rue Lhomond, 75005 Paris, France*
[3]*Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, United Kingdom*
(Received 30 January 2009; revised manuscript received 1 April 2009; published 3 June 2009)

We propose an experimental procedure to cool fermionic atoms loaded into an optical lattice. The central idea is to spatially divide the system into entropy-rich and -poor regions by shaping the confining potential profile. Atoms in regions of high entropy per particle are subsequently isolated from the system. We discuss how to experimentally carry out this proposal and perform a quantitative study of its efficiency. We find that the entropy per particle, s, can typically be reduced by a factor of 10 such that entropies lower than $s/k_B \sim 0.2$ can be reached. Cooling into highly sought-after quantum phases (such as an antiferromagnet) can thus be achieved. We show that this procedure is robust against variations of the experimental conditions.

Corinna, Michel (and Petra)
@ group BBQ, 2009

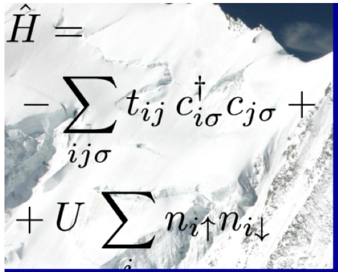


A Thermoelectric Heat Engine with Ultracold Atoms

Science, 2013

Jean-Philippe Brantut,[1] Charles Grenier,[2] Jakob Meineke,[1]* David Stadler,[1] Sebastian Krinner,[1]
Corinna Kollath,[3] Tilman Esslinger,[1]† Antoine Georges[2,4,5]

Thermoelectric effects, such as the generation of a particle current by a temperature gradient, have their origin in a reversible coupling between heat and particle flows. These effects are fundamental probes for materials and have applications to cooling and power generation. Here, we demonstrate thermoelectricity in a fermionic cold atoms channel in the ballistic and diffusive regimes, connected to two reservoirs. We show that the magnitude of the effect and the efficiency of energy conversion can be optimized by controlling the geometry or disorder strength. Our observations are in quantitative agreement with a theoretical model based on the Landauer-Büttiker formalism. Our device provides a controllable model system to explore mechanisms of energy conversion and realizes a cold atom–based heat engine.



$$\hat{H} = -\sum_{ij\sigma} t_{ij}\, c^{\dagger}_{i\sigma} c_{j\sigma} + U \sum n_{i\uparrow} n_{i\downarrow}$$

The Hubbard model: simple as it stands, still a very challenging problem !

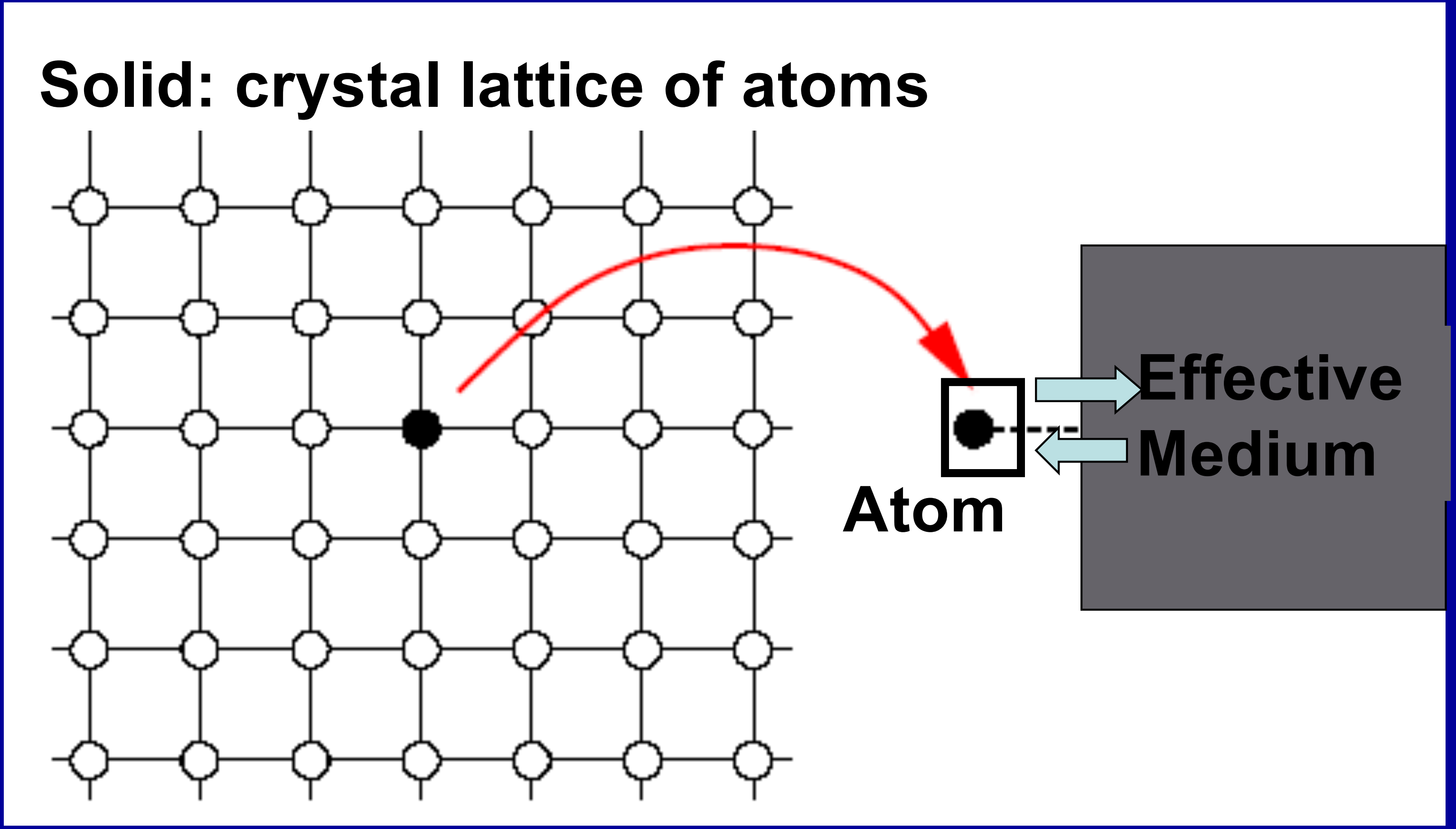
One of the routes to try climbing this mountain:

Dynamical Mean-Field Theory

(and its extensions/generalisations)

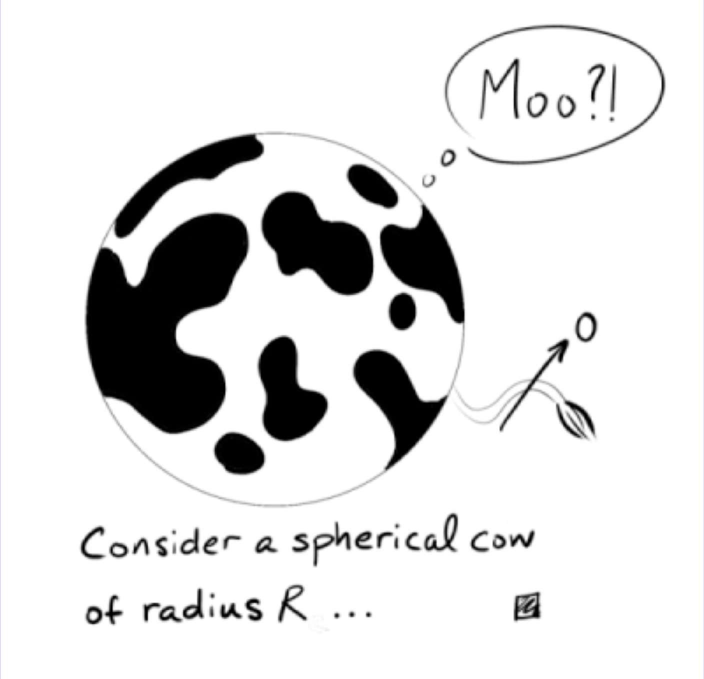
Dynamical Mean-Field Theory:

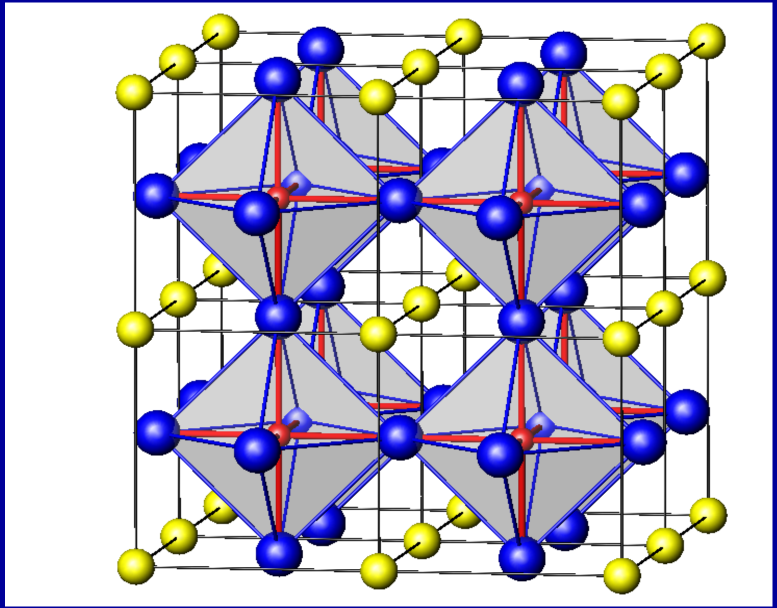
viewing a material as an (ensemble of) atoms coupled to a self-consistent medium



From spherical cow models…

… to real materials

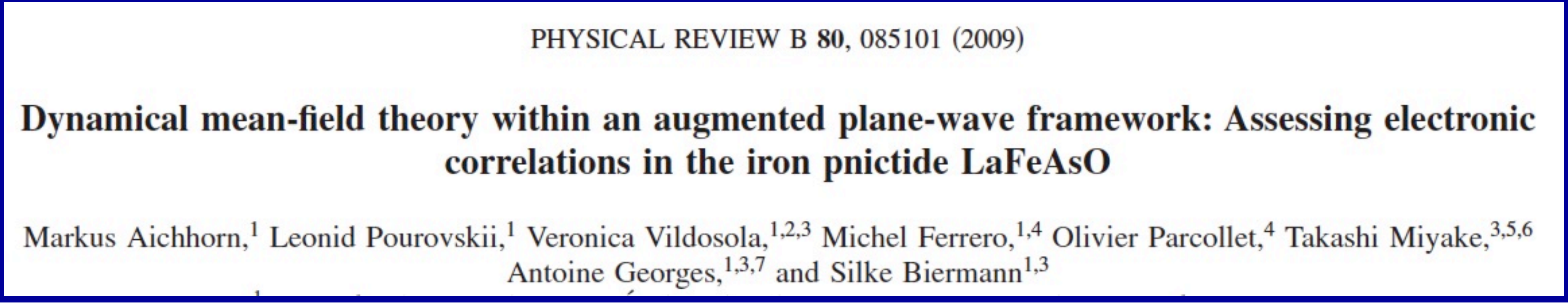




$\mathbf{SrVO_3}$

Happy marriage of DMFT and first-principles electronic structure based on DFT or GW !

CPHT Implementation (part of the TRIQS library):

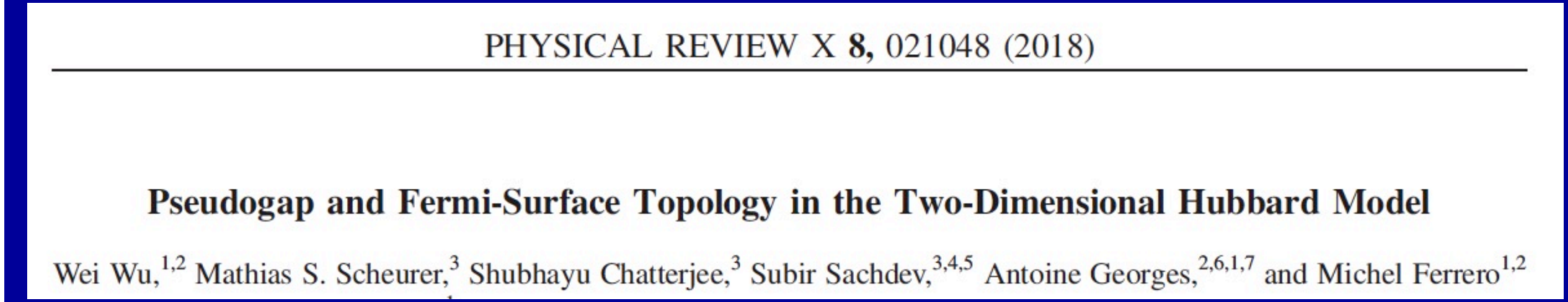


PHYSICAL REVIEW B **80**, 085101 (2009)

Dynamical mean-field theory within an augmented plane-wave framework: Assessing electronic correlations in the iron pnictide LaFeAsO

Markus Aichhorn,[1] Leonid Pourovskii,[1] Veronica Vildosola,[1,2,3] Michel Ferrero,[1,4] Olivier Parcollet,[4] Takashi Miyake,[3,5,6] Antoine Georges,[1,3,7] and Silke Biermann[1,3]

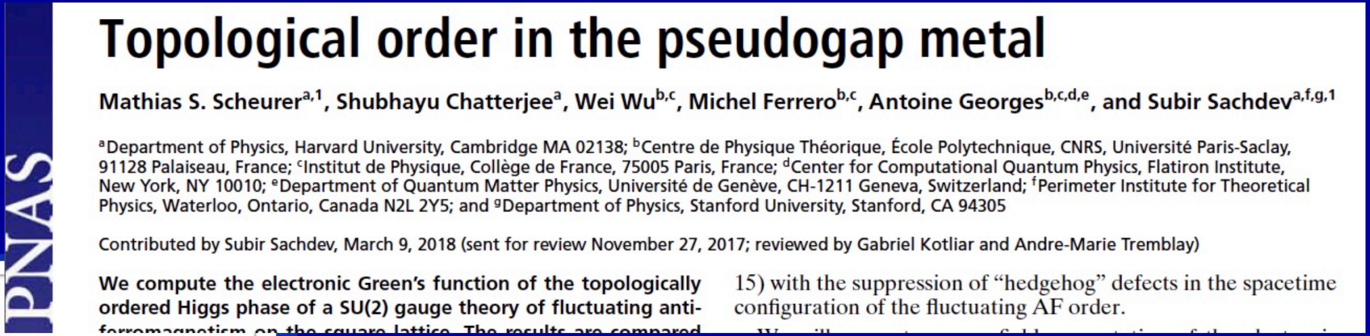
Cluster extensions of DMFT and the `pseudogap' of the 2D Hubbard model



PHYSICAL REVIEW X **8,** 021048 (2018)

Pseudogap and Fermi-Surface Topology in the Two-Dimensional Hubbard Model

Wei Wu,[1,2] Mathias S. Scheurer,[3] Shubhayu Chatterjee,[3] Subir Sachdev,[3,4,5] Antoine Georges,[2,6,1,7] and Michel Ferrero[1,2]



PNAS

Topological order in the pseudogap metal

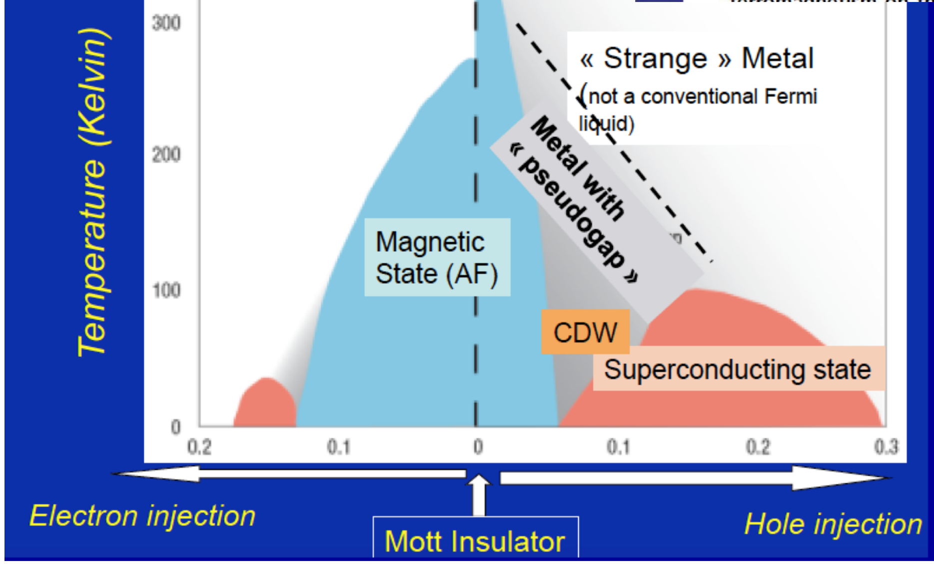
Mathias S. Scheurer[a,1], Shubhayu Chatterjee[a], Wei Wu[b,c], Michel Ferrero[b,c], Antoine Georges[b,c,d,e], and Subir Sachdev[a,f,g,1]

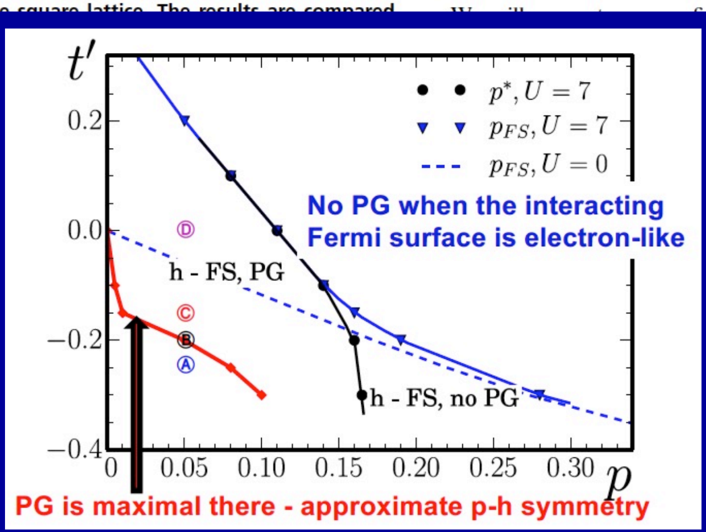
[a]Department of Physics, Harvard University, Cambridge MA 02138; [b]Centre de Physique Théorique, École Polytechnique, CNRS, Université Paris-Saclay, 91128 Palaiseau, France; [c]Institut de Physique, Collège de France, 75005 Paris, France; [d]Center for Computational Quantum Physics, Flatiron Institute, New York, NY 10010; [e]Department of Quantum Matter Physics, Université de Genève, CH-1211 Geneva, Switzerland; [f]Perimeter Institute for Theoretical Physics, Waterloo, Ontario, Canada N2L 2Y5; and [g]Department of Physics, Stanford University, Stanford, CA 94305

Contributed by Subir Sachdev, March 9, 2018 (sent for review November 27, 2017; reviewed by Gabriel Kotliar and Andre-Marie Tremblay)

We compute the electronic Green's function of the topologically ordered Higgs phase of a SU(2) gauge theory of fluctuating anti-

15) with the suppression of "hedgehog" defects in the spacetime configuration of the fluctuating AF order.

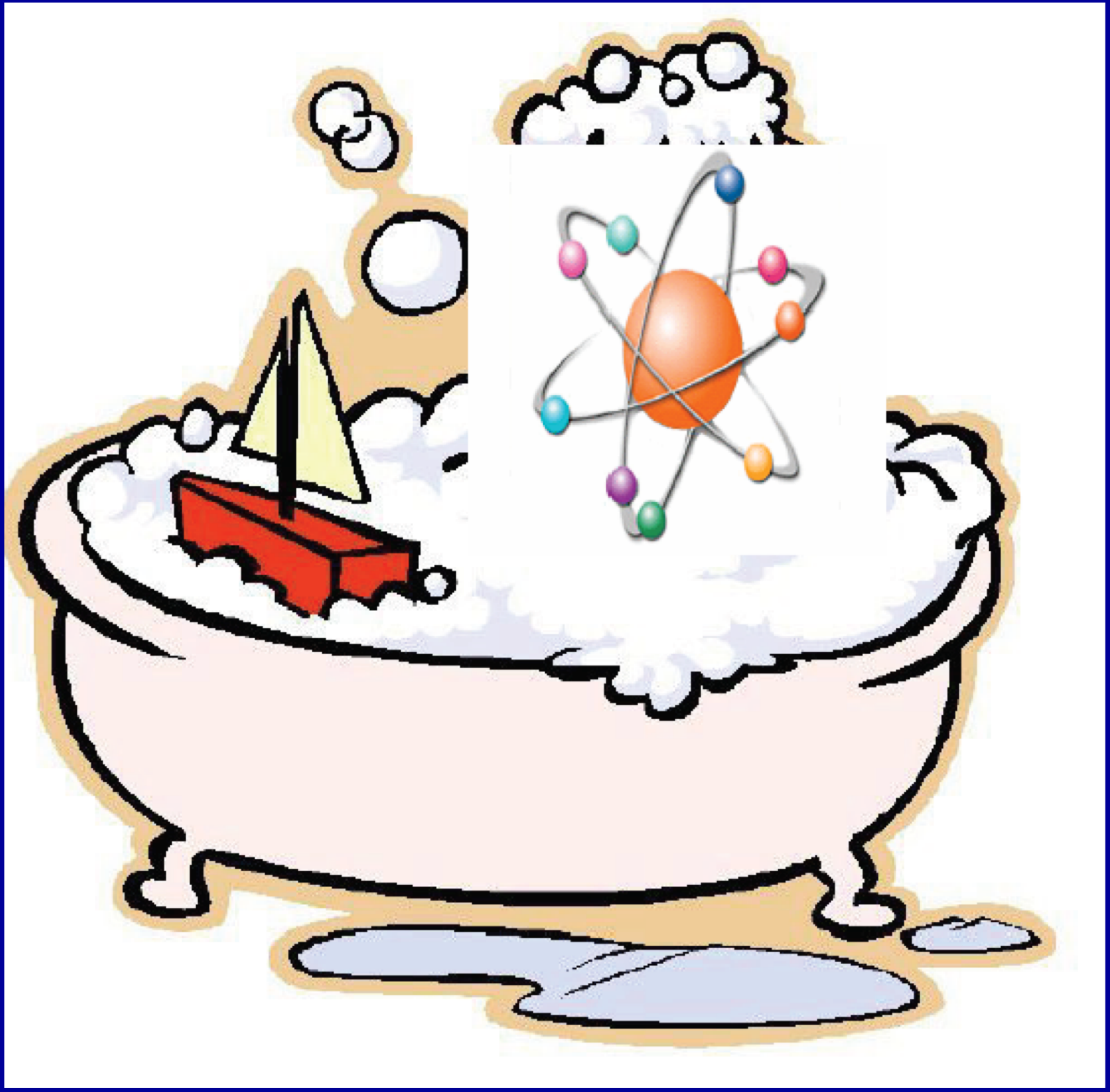




No PG when the interacting Fermi surface is electron-like

PG is maximal there - approximate p-h symmetry

``Atom in a bath''

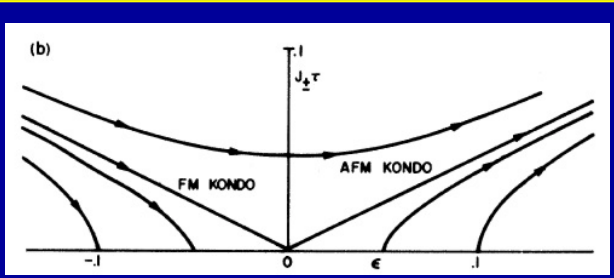


Atom in a bath: the amazingly fertile Kondo problem

$$H = \sum_k \varepsilon_k c^+_{k\alpha} c_{k\alpha} + J_K \vec{S} \cdot c^+_\alpha(0) \frac{\vec{\sigma}_{\alpha\beta}}{2} c_\beta(0)$$

Magnetic impurities
In Metals
(60's, 70's: Friedel, Anderson, Kondo and many others)

First application of RG
To condensed matter physics !
(Anderson,Yuval,Hamann, 1970)



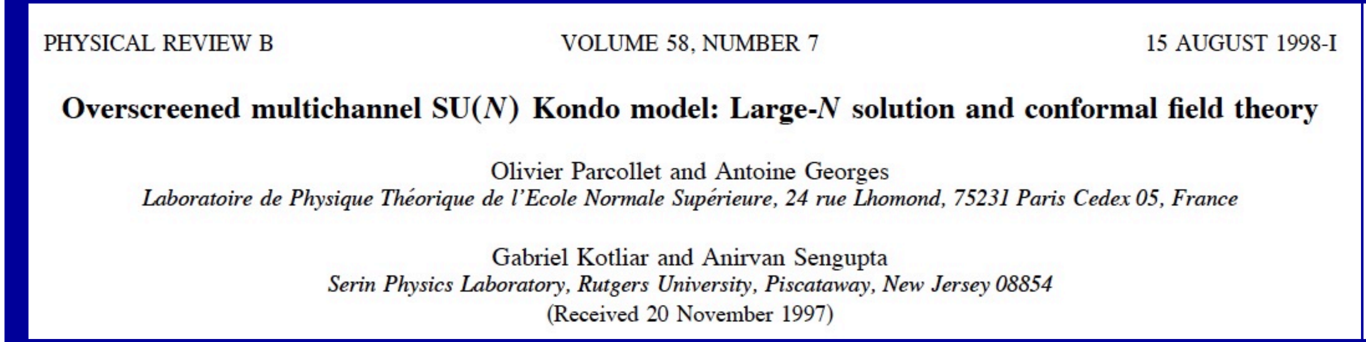
Suppression of Coulomb Blockade in Quantum Dots
(Glazman&Raikh; Ng&Lee 1988
Goldhaber-Gordon, 1998)

First Non-Perturbative Numerical RG
(K.G.Wilson, 1975)

First `non Fermi liquid' fixed points
Nozieres and Blandin 1981

Conformal Field Theory
Affleck and Ludwig's
`fusion principle' 1995

Building blocks of DMFT
(AG & G.Kotliar, 1992)



PHYSICAL REVIEW B VOLUME 58, NUMBER 7 15 AUGUST 1998-I

Overscreened multichannel SU(N) Kondo model: Large-N solution and conformal field theory

Olivier Parcollet and Antoine Georges
Laboratoire de Physique Théorique de l'Ecole Normale Supérieure, 24 rue Lhomond, 75231 Paris Cedex 05, France

Gabriel Kotliar and Anirvan Sengupta
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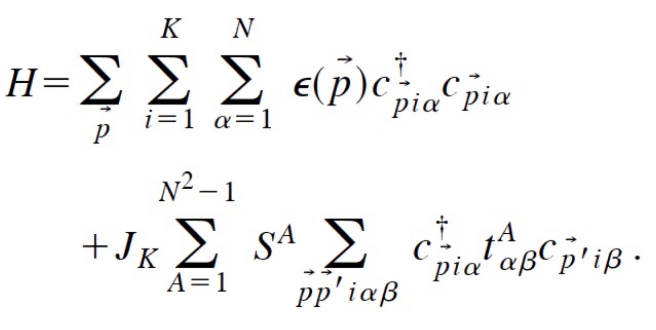
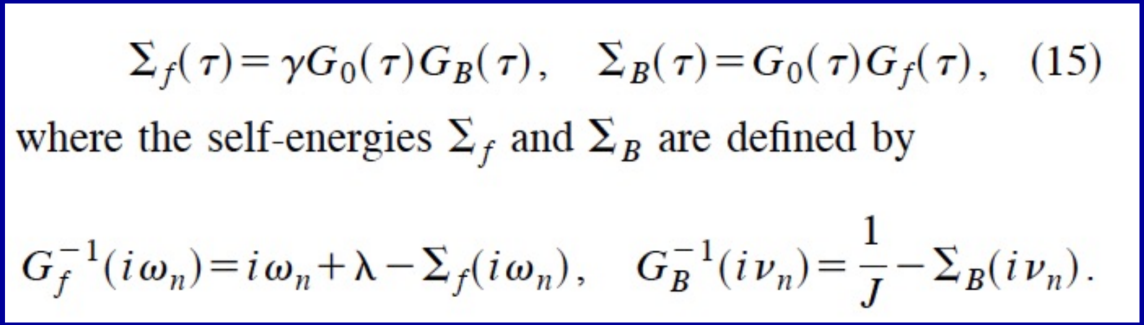
(Received 20 November 1997)



$$H=\sum_{\vec{p}}\sum_{i=1}^{K}\sum_{\alpha=1}^{N}\epsilon(\vec{p})c^{\dagger}_{\vec{p}i\alpha}c_{\vec{p}i\alpha}+J_K\sum_{A=1}^{N^2-1}S^A\sum_{\vec{p}\vec{p}'i\alpha\beta}c^{\dagger}_{\vec{p}i\alpha}t^A_{\alpha\beta}c_{\vec{p}'i\beta}.$$



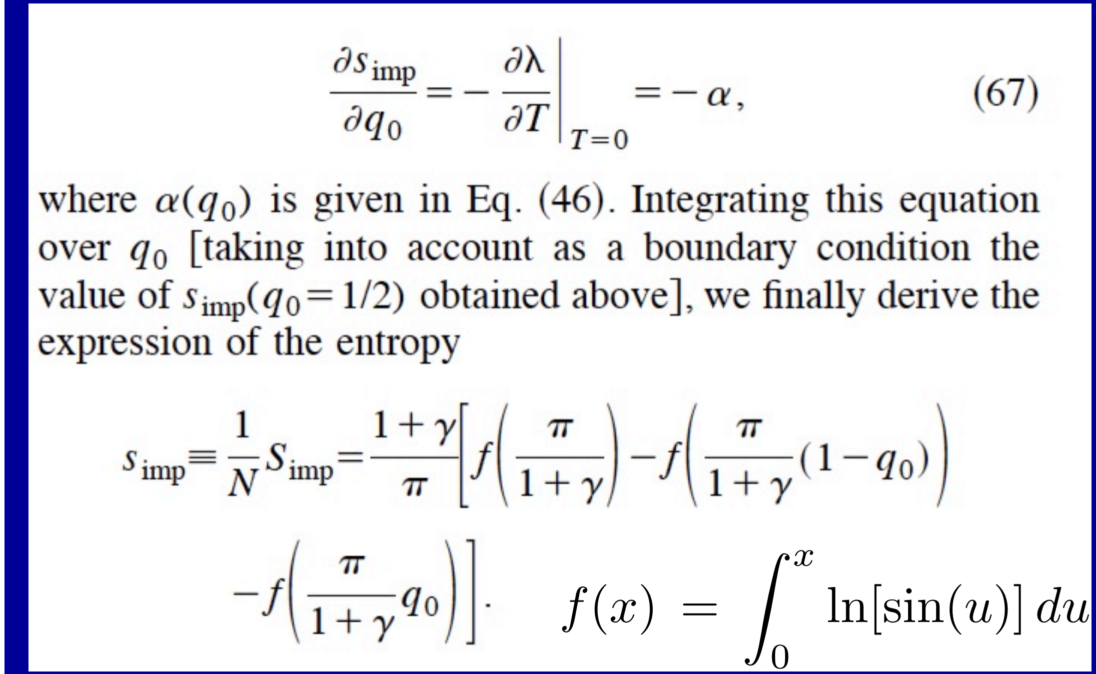
$$\Sigma_f(\tau)=\gamma G_0(\tau)G_B(\tau),\quad \Sigma_B(\tau)=G_0(\tau)G_f(\tau), \qquad (15)$$

where the self-energies Σ_f and Σ_B are defined by

$$G_f^{-1}(i\omega_n)=i\omega_n+\lambda-\Sigma_f(i\omega_n),\quad G_B^{-1}(i\nu_n)=\frac{1}{J}-\Sigma_B(i\nu_n).$$

$$K,N\to\infty\ ,$$

$$\gamma=\frac{K}{N}\ \text{fixed}$$

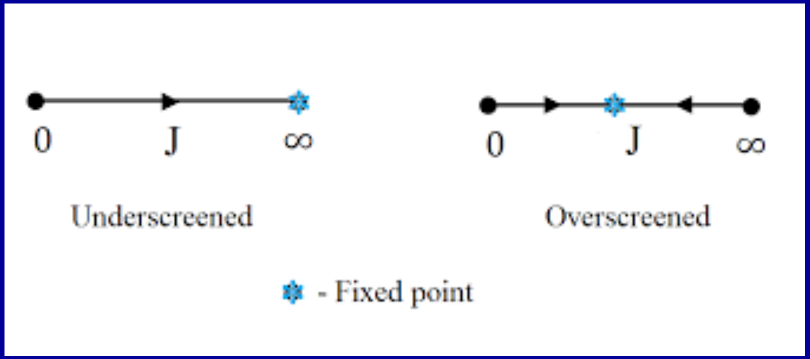


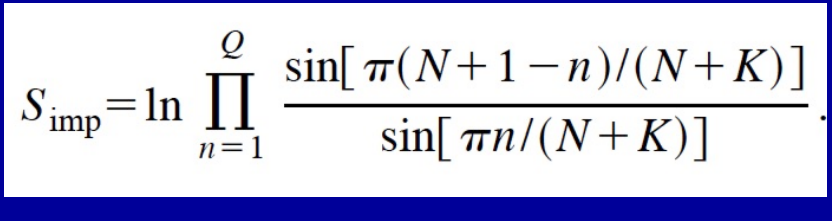
$$\frac{\partial s_{\mathrm{imp}}}{\partial q_0}=-\left.\frac{\partial\lambda}{\partial T}\right|_{T=0}=-\alpha, \qquad (67)$$

where $\alpha(q_0)$ is given in Eq. (46). Integrating this equation over q_0 [taking into account as a boundary condition the value of $s_{\mathrm{imp}}(q_0=1/2)$ obtained above], we finally derive the expression of the entropy

$$s_{\mathrm{imp}}\equiv\frac{1}{N}S_{\mathrm{imp}}=\frac{1+\gamma}{\pi}\left[f\left(\frac{\pi}{1+\gamma}\right)-f\left(\frac{\pi}{1+\gamma}(1-q_0)\right)-f\left(\frac{\pi}{1+\gamma}q_0\right)\right].$$

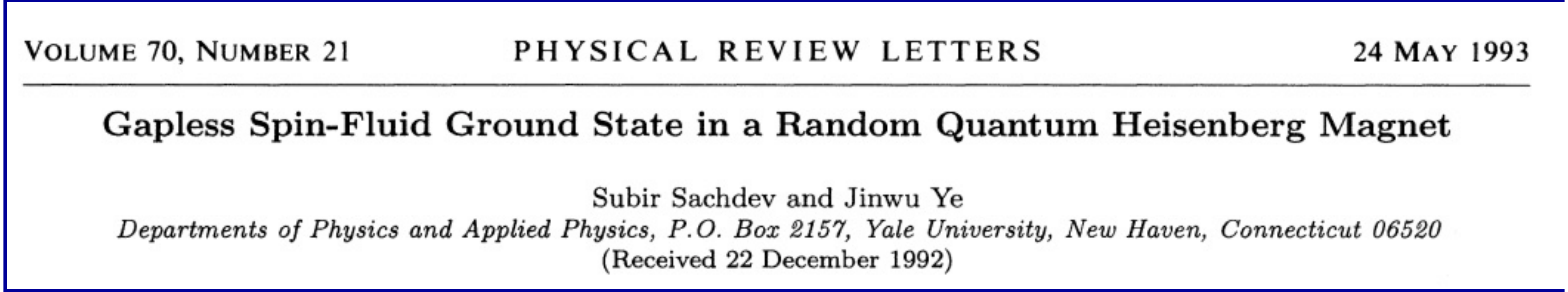
$$f(x)=\int_0^x\ln[\sin(u)]\,du$$





$$S_{\mathrm{imp}}=\ln\prod_{n=1}^{Q}\frac{\sin[\pi(N+1-n)/(N+K)]}{\sin[\pi n/(N+K)]}.$$

The Sachdev-Ye model (ancestor of SYK)
Large-N Kondo inspired early derivation of Entropy



VOLUME 70, NUMBER 21 PHYSICAL REVIEW LETTERS 24 MAY 1993

Gapless Spin-Fluid Ground State in a Random Quantum Heisenberg Magnet

Subir Sachdev and Jinwu Ye
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(Received 22 December 1992)

$$H = \sum_{ij} J_{ij}\, \vec{S}_i \cdot \vec{S}_j = \sum_{ij,\alpha\beta} J_{ij}\, f^{+}_{i\alpha} f_{i\beta} f_{j\beta} f^{+}_{j\alpha}$$

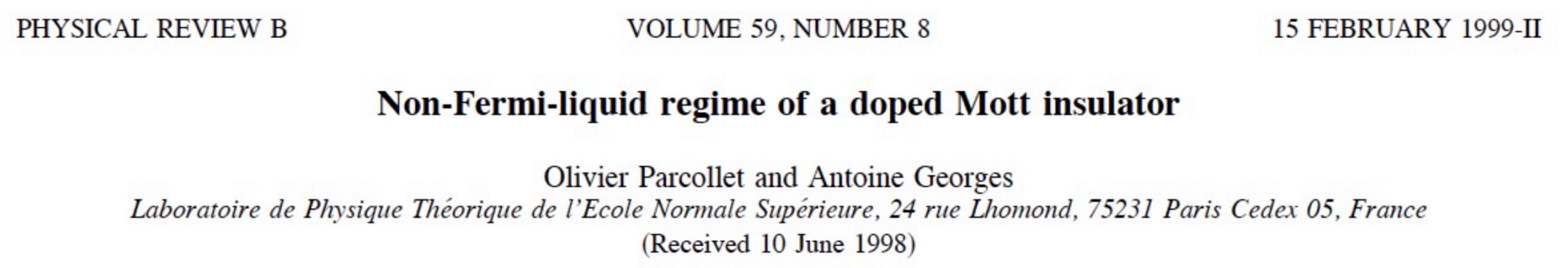
SU(N) spins, Large-N, Random Jij

SYK model: $H = \sum_{ijkl} J_{ij;kl}\, \chi_i \chi_j \chi_k \chi_l$

cf. work by R.Gurau at CPHT - Large-N

The Sachdev-Ye model (ancestor of SYK)

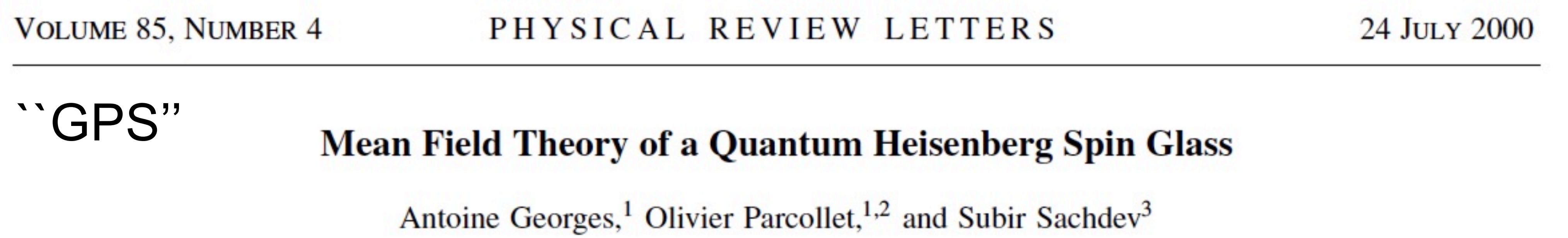
Large-N Kondo inspired early derivation of Conformal Invariance and Entropy



PHYSICAL REVIEW B VOLUME 59, NUMBER 8 15 FEBRUARY 1999-II

Non-Fermi-liquid regime of a doped Mott insulator

Olivier Parcollet and Antoine Georges
Laboratoire de Physique Théorique de l'Ecole Normale Supérieure, 24 rue Lhomond, 75231 Paris Cedex 05, France
(Received 10 June 1998)

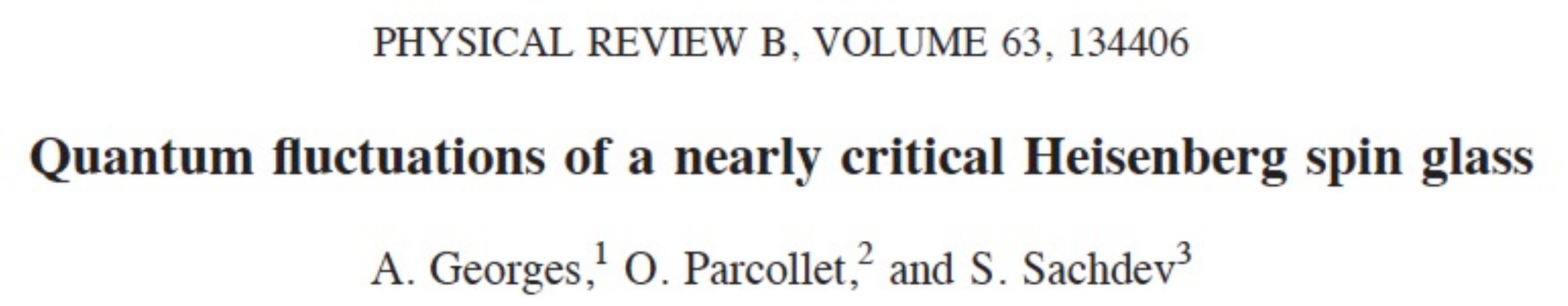


VOLUME 85, NUMBER 4 PHYSICAL REVIEW LETTERS 24 JULY 2000

``GPS''

Mean Field Theory of a Quantum Heisenberg Spin Glass

Antoine Georges,[1] Olivier Parcollet,[1,2] and Subir Sachdev[3]



PHYSICAL REVIEW B, VOLUME 63, 134406

Quantum fluctuations of a nearly critical Heisenberg spin glass

A. Georges,[1] O. Parcollet,[2] and S. Sachdev[3]

$$(G_f^{-1})^{ab}(i\omega_n) = i\omega_n \delta_{ab} + \lambda^a \delta_{ab} - \Sigma_f^{ab}(i\omega_n),$$

$$\Sigma_f^{ab}(\tau) = -J^2 (G_f^{ab}(\tau))^2 G_f^{ab}(-\tau),$$

$$G_f^{aa}(\tau = 0^{-1}) = q_0 .$$

$$G_f(\tau) \sim -\frac{1}{\sqrt{2J}\,\pi^{1/4}} \left(\frac{\pi/\beta}{\sin \pi\tau/\beta} \right)^{1/2} . \qquad (50)$$

Remarkably, Eq. (50) has the form that would hold in a model having *conformal invariance*, for example, a quantum impurity model of a spin interacting with a structureless bath of conduction electrons. In that case, a conformal mapping

low-frequency behavior $\chi''_{\mathrm{loc}}(\omega) \sim \mathrm{const}$. For this reason, our effective single-site model does obey conformal invariance properties in the low-energy limit, which explains the result above. This remark actually applies in a broader context than the specific model considered here, as will be discussed in more detail elsewhere.

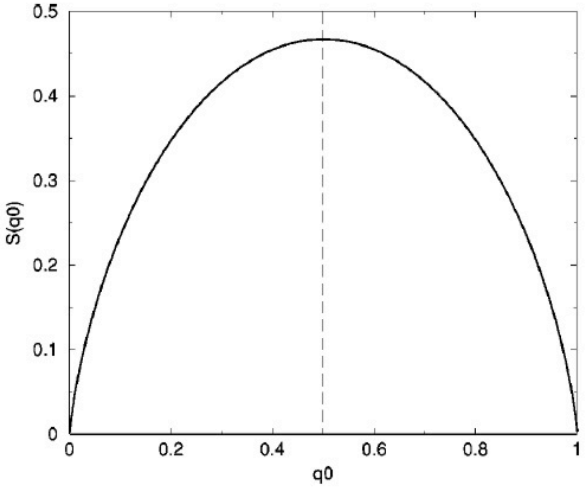


FIG. 3. Entropy as a function of the size of the spin (q_0) in the ermionic model.

$$\frac{\partial S}{\partial q_0} = -\left.\frac{\partial \lambda}{\partial T}\right|_{T=0} . \qquad (11)$$

Then a low-temperature expansion is used which allows one to relate the slope of $\lambda(T)$ to the spectral asymmetry parameter θ above, so that one finally gets (in the fermionic case)

$$\frac{\partial S}{\partial q_0} = \ln \frac{\sin(\pi/4 - \theta)}{\sin(\theta + \pi/4)} . \qquad (12)$$

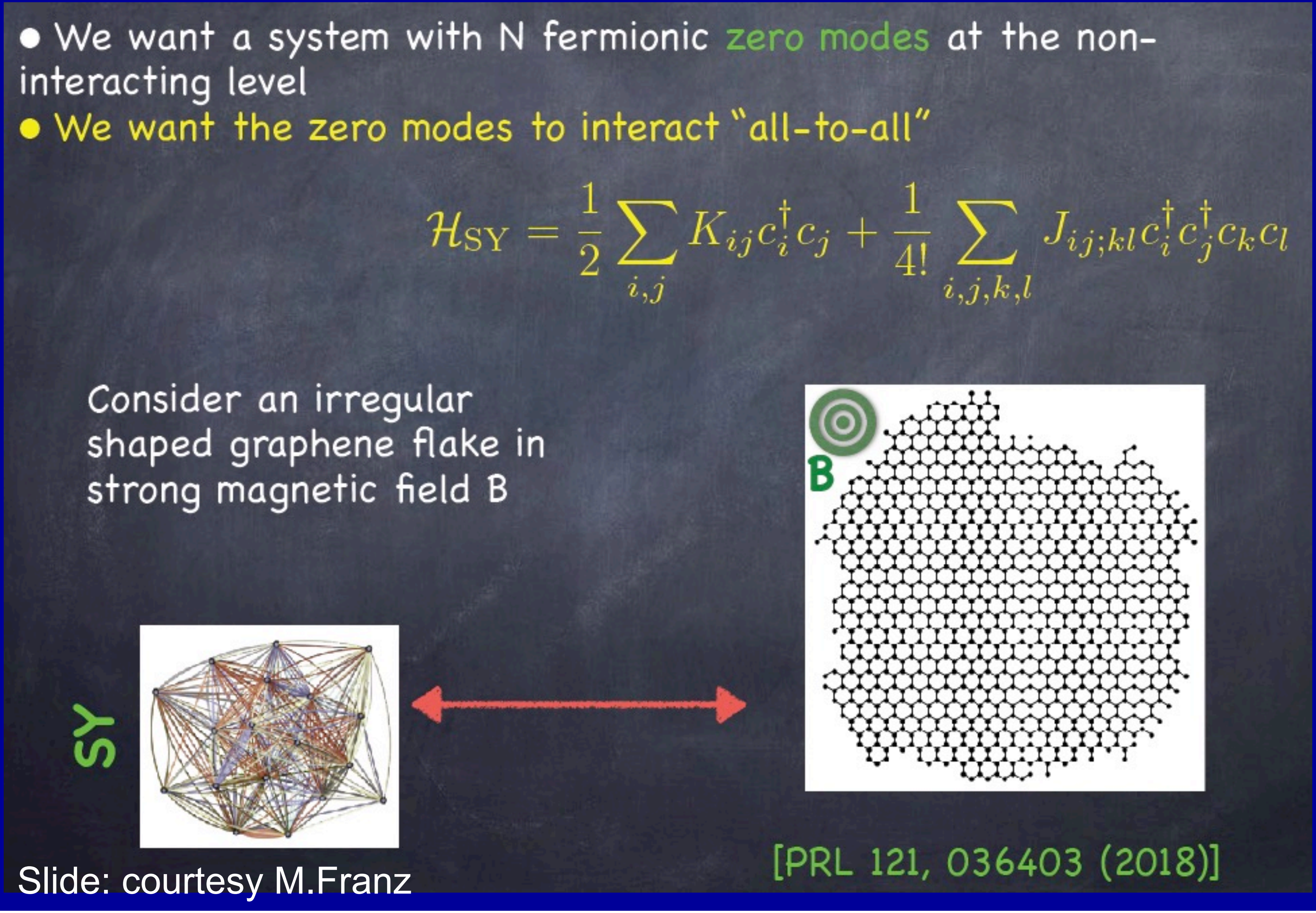
$$\frac{\theta}{\pi} + \frac{\sin 2\theta}{4} = \begin{cases} \frac{1}{2} + S & \text{in the bosonic model} \\ \frac{1}{2} - q_0 & \text{in the fermionic model.} \end{cases}$$

The surprise: SYK is the holographic dual of a black hole with AdS_2 geometry !

- Extensive Entropy at T=0 → Beckenstein-Hawking Entropy ! $S_{GPS}=S_{BH}$
- Emergent conformal invariance at low energies
- SYK model thermalizes in shortest possible time $\sim \hbar/k_B T$
- S.Sachdev, PRX 6, 041025 (2015)
- Maldacena and Stanford, PRD 94, 106002 (2016)

Materials ? The graphene flake proposal

(M.Franz, PRL 2018)



- We want a system with N fermionic zero modes at the non-interacting level
- We want the zero modes to interact "all-to-all"

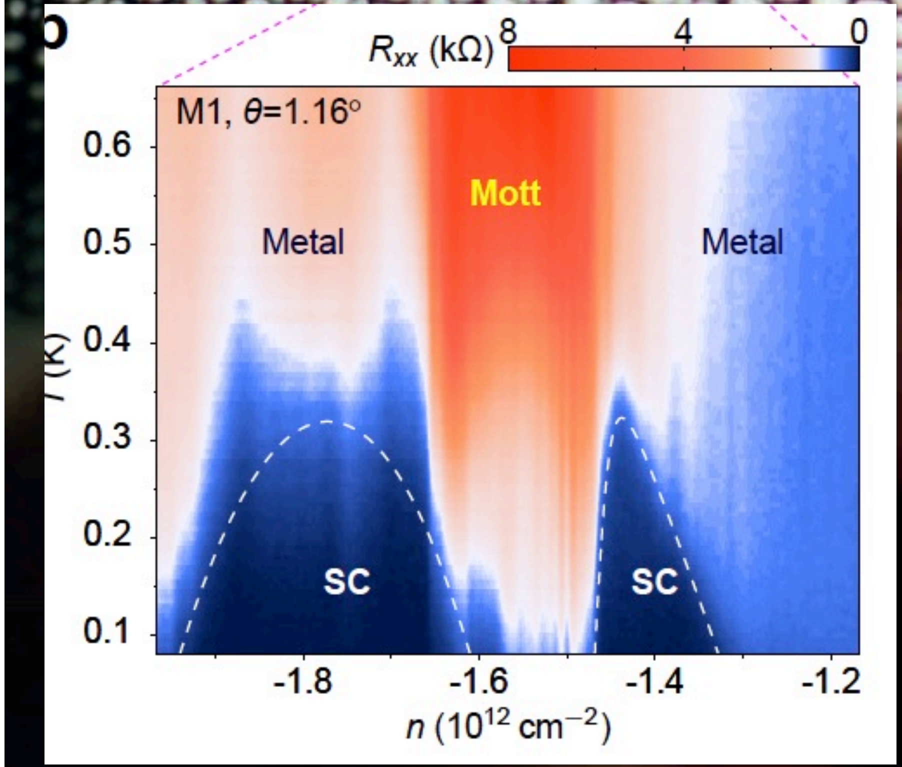
$$\mathcal{H}_{\rm SY} = \frac{1}{2}\sum_{i,j} K_{ij} c_i^\dagger c_j + \frac{1}{4!}\sum_{i,j,k,l} J_{ij;kl} c_i^\dagger c_j^\dagger c_k c_l$$

Consider an irregular shaped graphene flake in strong magnetic field B

[PRL 121, 036403 (2018)]

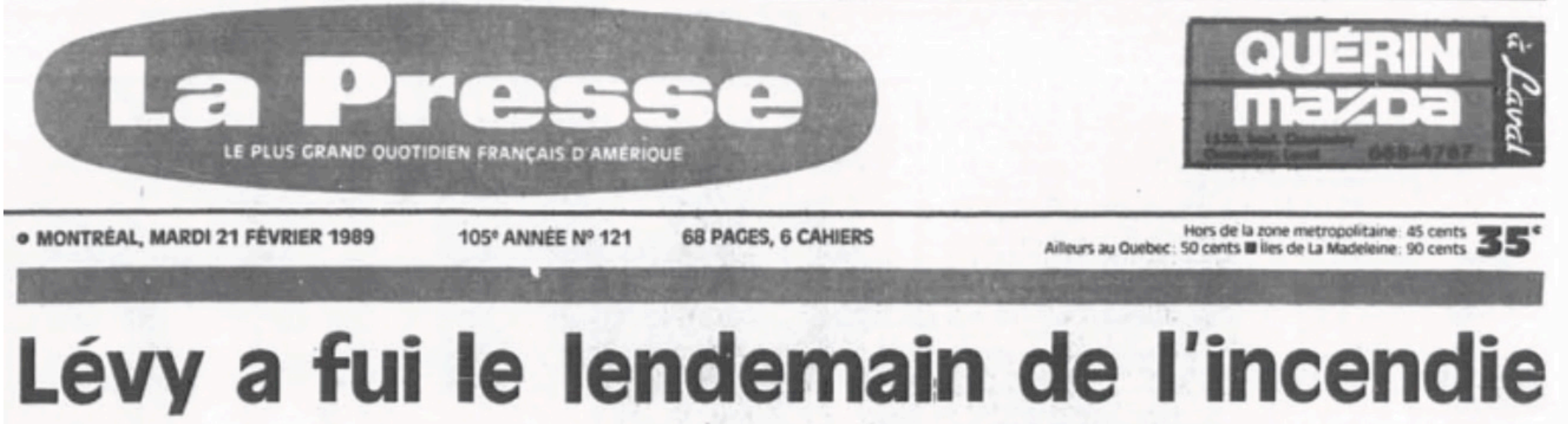
Slide: courtesy M.Franz

Graphene also continues to surprise us…



Twisted Bilayer Graphene:
`The new kid on the block’
Pablo Jarillo-Herrero’s group
@MIT - 2018

Theoretical Physics at CPHT: Even More Surprises !



La Presse

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Lévy a fui le lendemain de l'incendie

April 4, 2012… The Levy building catches fire !

The PMC group is (temporarily) homeless…

CPHT Centre de Physique Théorique

THANK YOU CPHT !

To P.Mora, B.Pire, J-R. Chazottes

for trying to shepherd theoretical physicists (impossible !)

To all staff, admin and computer teams

without whom we couldn't do any work

To the colleagues, postdocs, students [and former ones] who make Condensed/Quantum Matter Physics at CPHT more alive than ever

S.Backes, S.Biermann, M.Ferrero, K. Le Hur,
L. Poyurovskii, L.Sanchez-Palencia, A.Subedi

To all CPHT colleagues