External-fields induced novel phenomena in “Mott insulator Ca_2RuO_4”

Fumihiko NAKAMURA

ADSM, Hiroshima University

Ⅰ. Pressure induced Superconductivity

Ⅱ. *E* induced Ins.-Metal transition

>> Collaborators <<

>> Pressure works <<

Hiroshima: Y.Senoo,Y.Nakai, T.Suzuki, T.Fujita

Cambridge: P.L.Alireza, S.K.Goh, Y.T.C.Ko,
M.Sutherland, G.G.Lonzarich,
S.R.Julian (Toronto)

Kyoto: Y.Maeno, S.Nakatsuji (ISSP),
H.Fukazawa (Chiba)

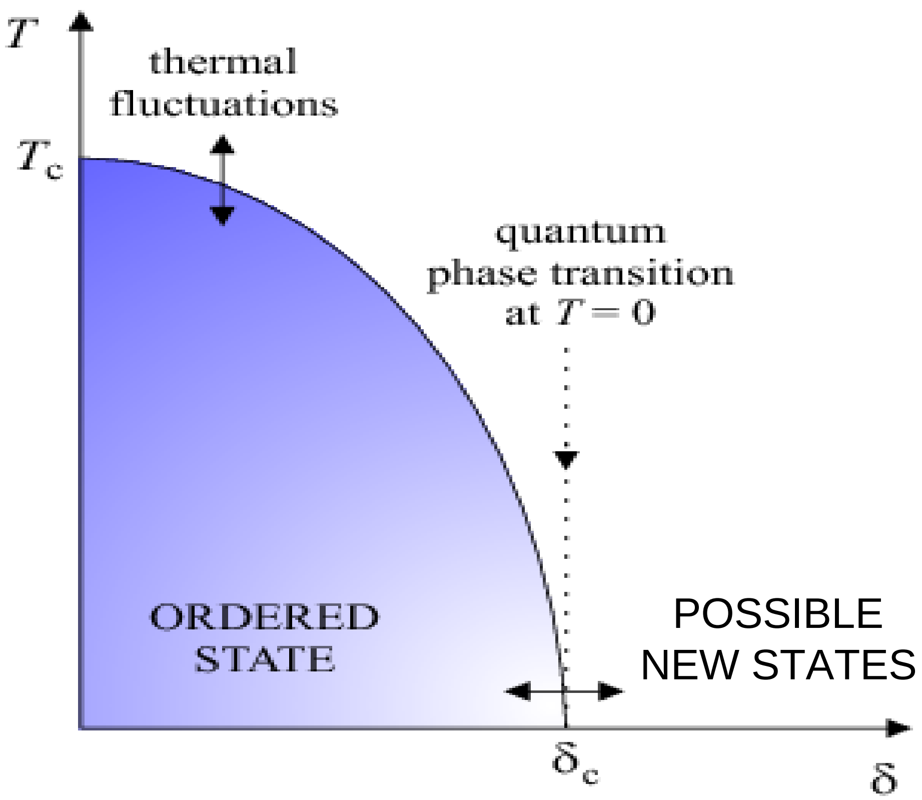
>> Dielectric breakdown <<

Hiroshima: T.Takemoto, M.Sakaki, Y.Yamauchi

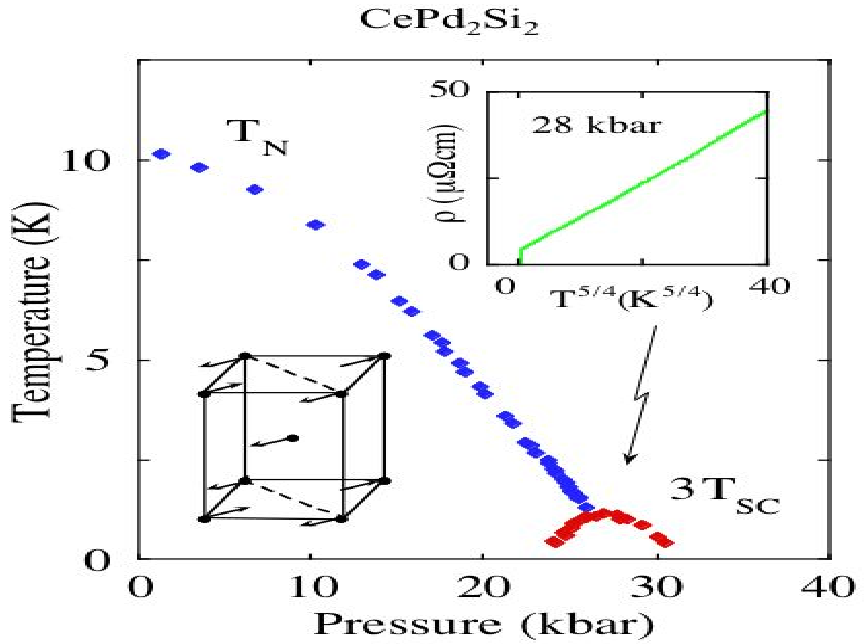
Kyoto: Y.Maeno, S.Yonezawa,T.Yamagishi

I. Quantum Critical natures in the vicinity of magnetic ordered state

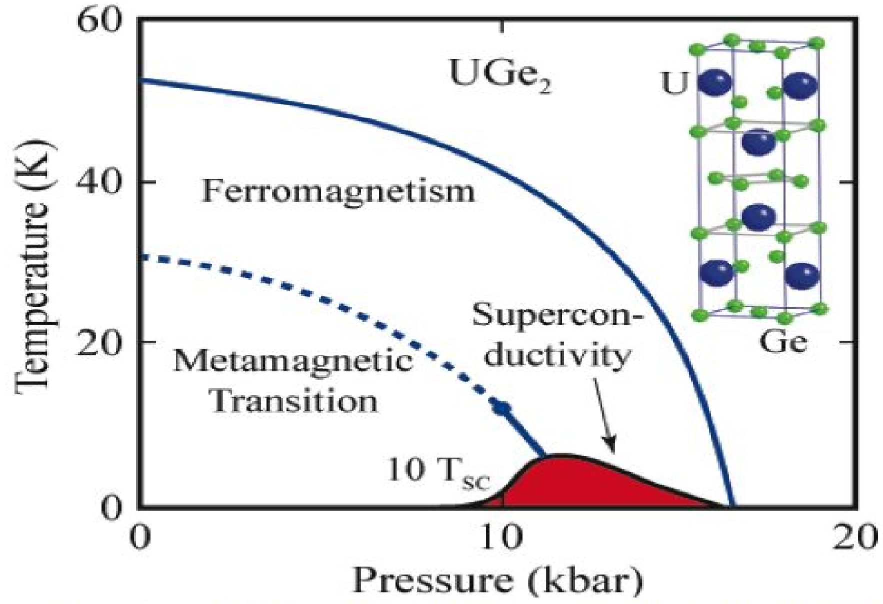
3D system



from P. L. Alireza, G.G.Lonzerich



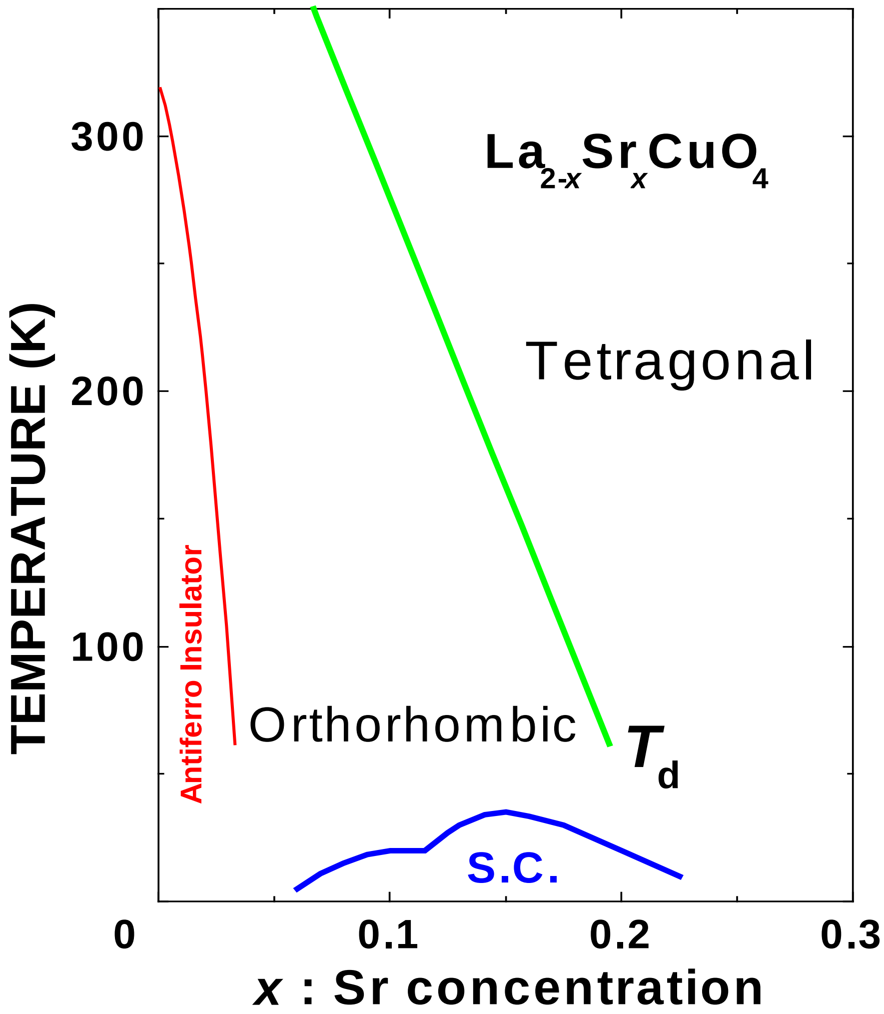
ND Mathur, FM Grosche, SR Julian, IR Walker, DM Freye, RKW



Saxena *et al.*, *Nature* (2000); Huxley *et al.*, *Phys. Rev. B* (2001); Tateiwa *et al.*, *J. Phys: Condens. Matter* (2001)

How about "2D system"?

2D system AFM



2D system FM

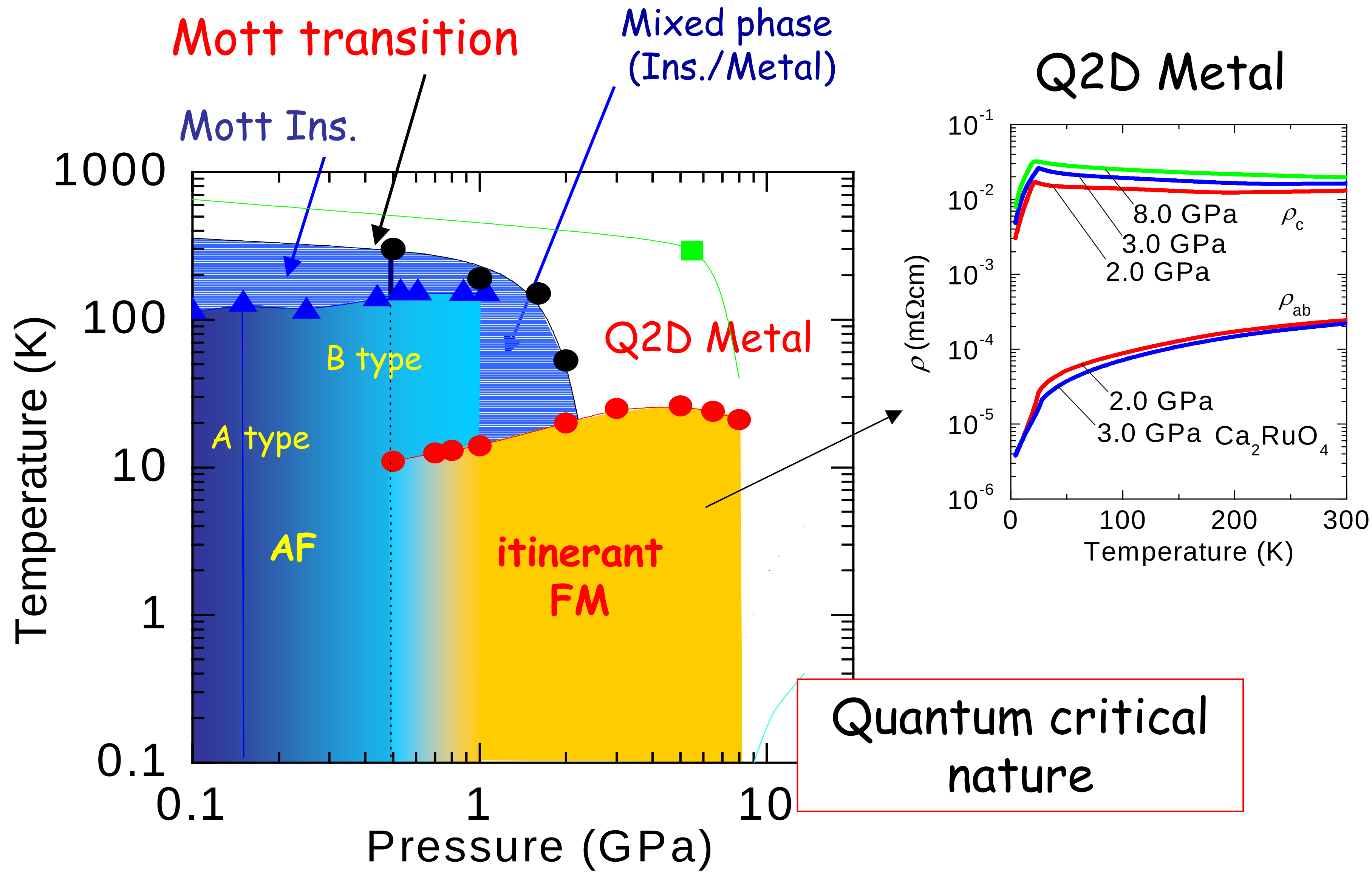
?

Theoretical prediction only

Hatatani and Moriya,
JPSJ, 64 (1995) 3434

"Ca_2RuO_4" was a candidate.

Rich variety of pressure phase diagram from Mott insulator to Q2D FM metal



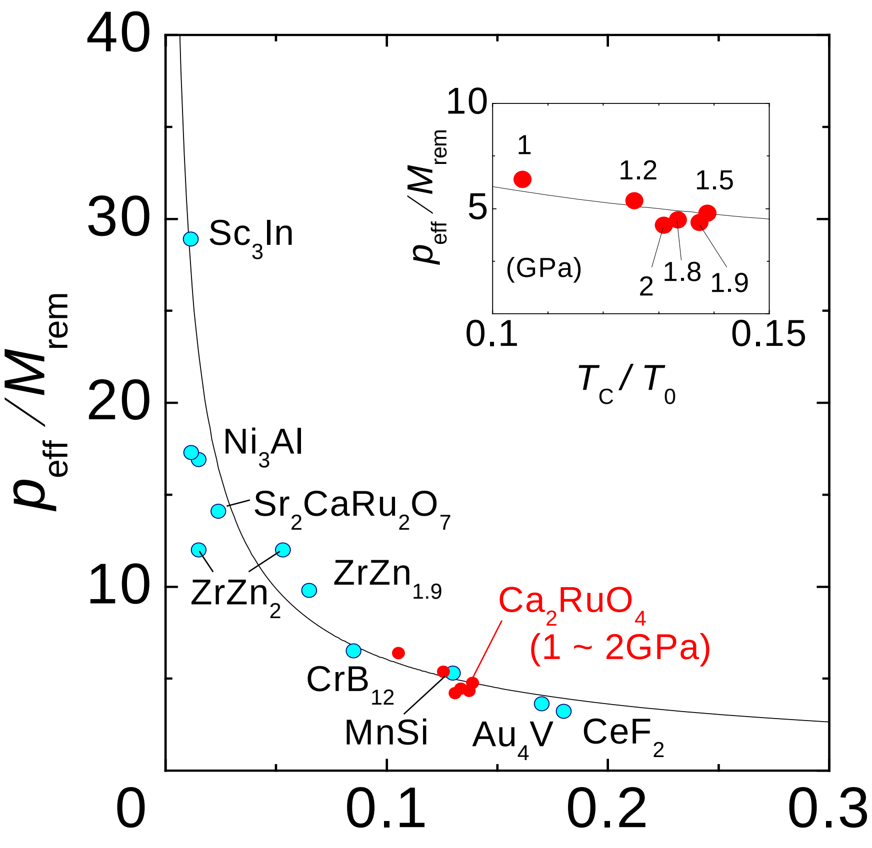
Quantum critical nature

F.Nakamura, PRB65 (2002)220402, JPSJ (2007).

Itinerant and Anisotropic FM in Ca_2RuO_4

Generalized Rhodes-Wohlfarth Plot

the scale for itinerant FM

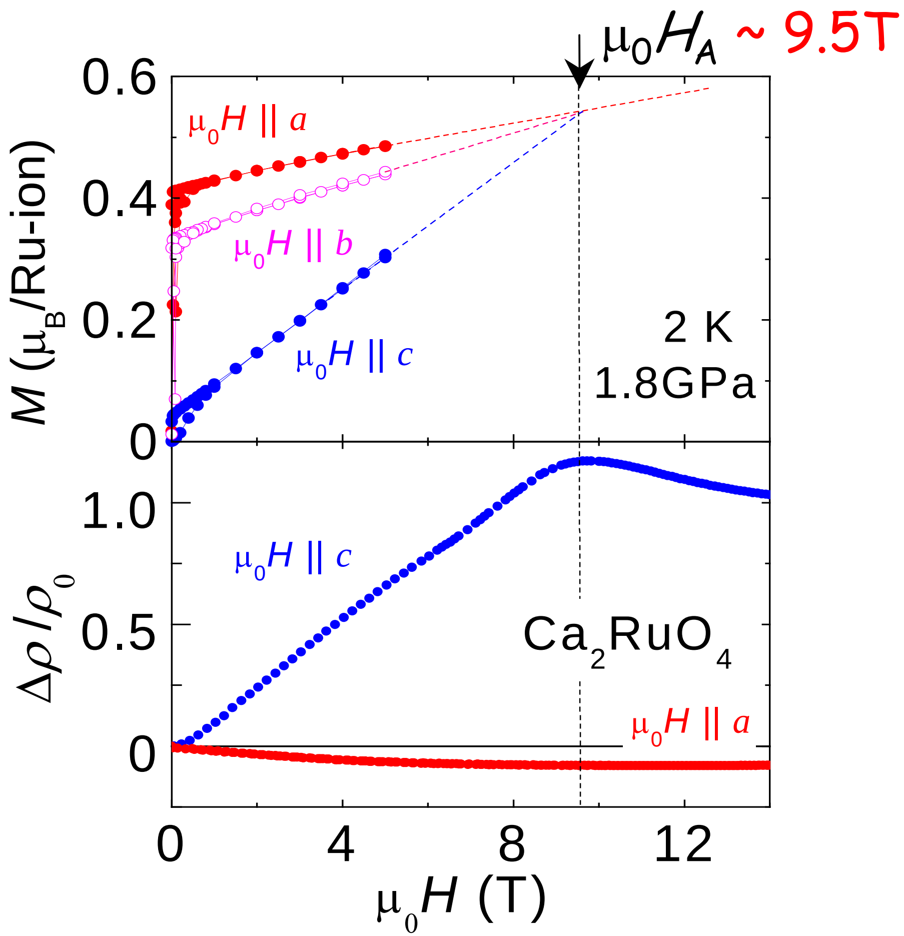


itinerant $\leftarrow$ T_C / T_0 $\rightarrow$ localize (up to 1)

Y.Yamauchi, et al., Physica C (2010).

Strongly anisotropic FM

due to Spin-orbit coupling

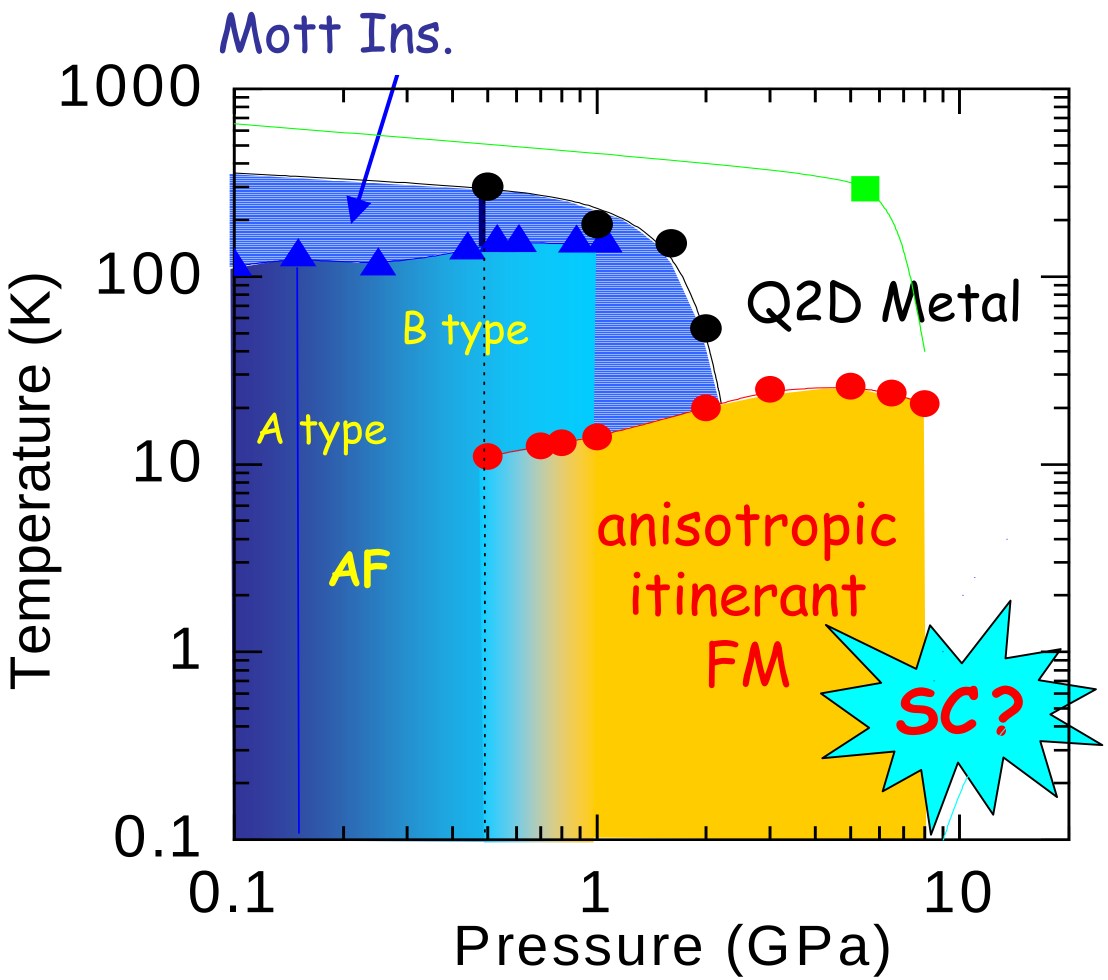


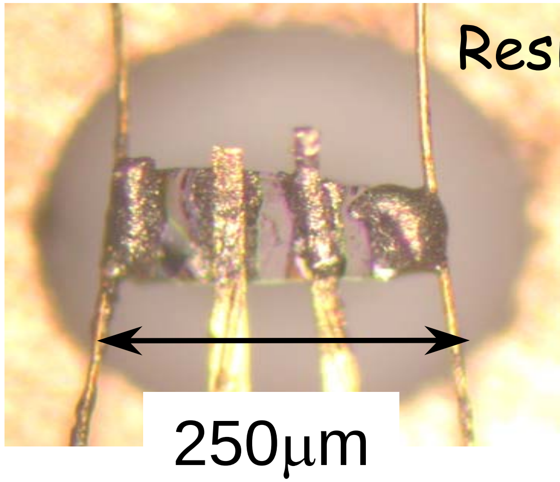
	Ni	Fe	Co
$\mu_0 H_A$	0.14T	0.049T	1.04T

To explore superconductivity in a Mott ins. Ca_2RuO_4

Our project started in 1999. >>> One decade after

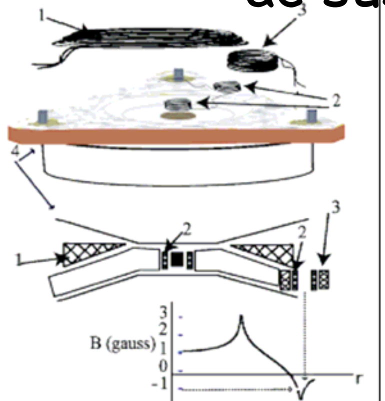
Over 10GPa: Very hard work !!

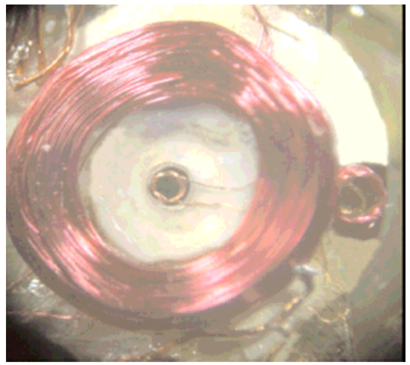




Resistance

ac susceptibility

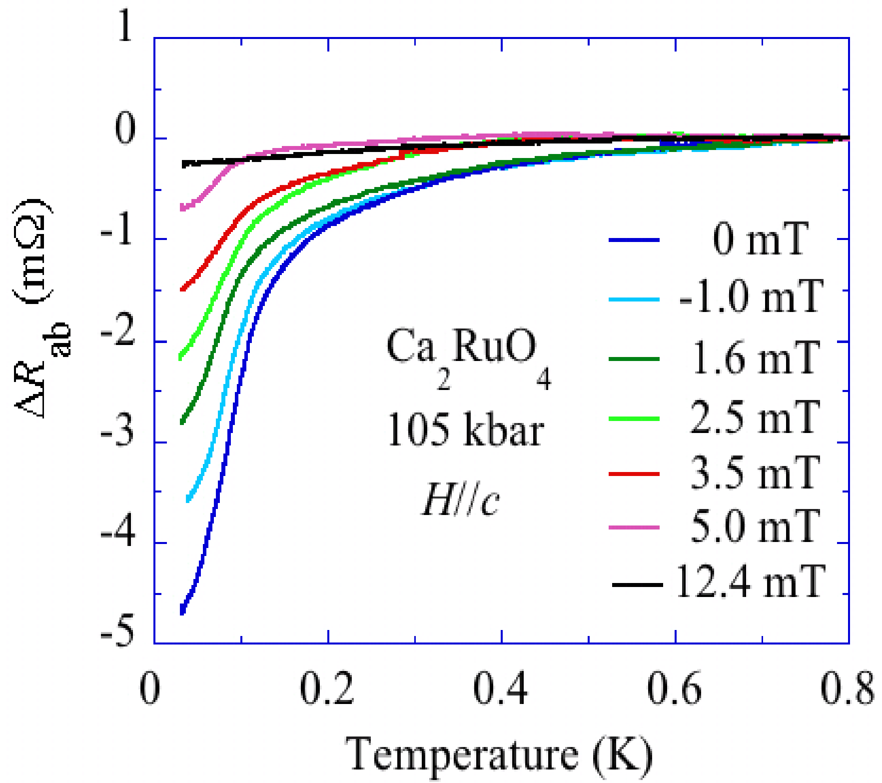




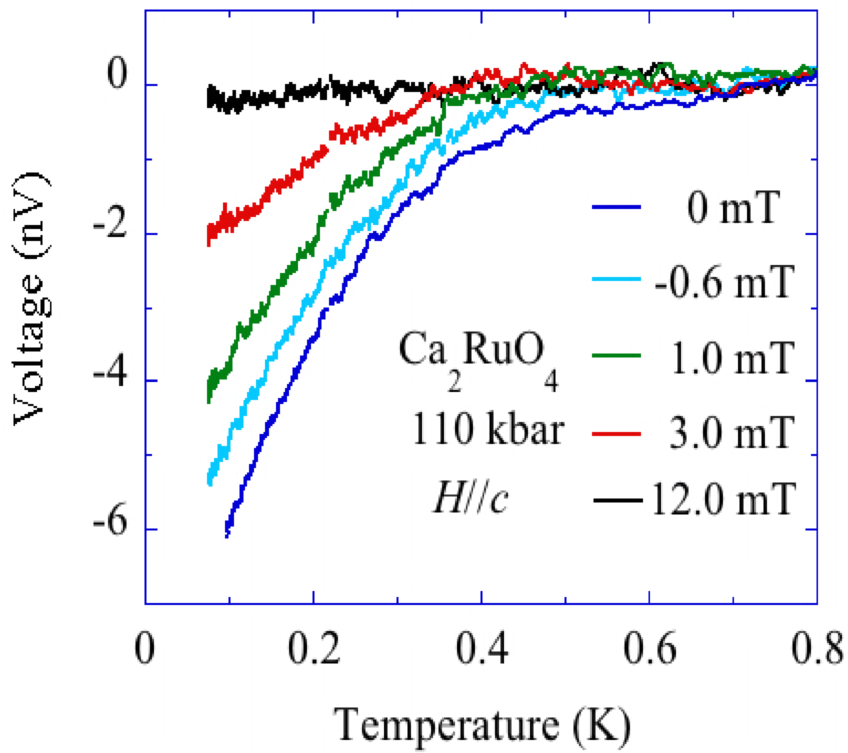
Alireza. Rev.Sci.Ins.**74**, 4728 (2003).

We found pressure induced SC at ~10 GPa

Resistance (2-terminal)

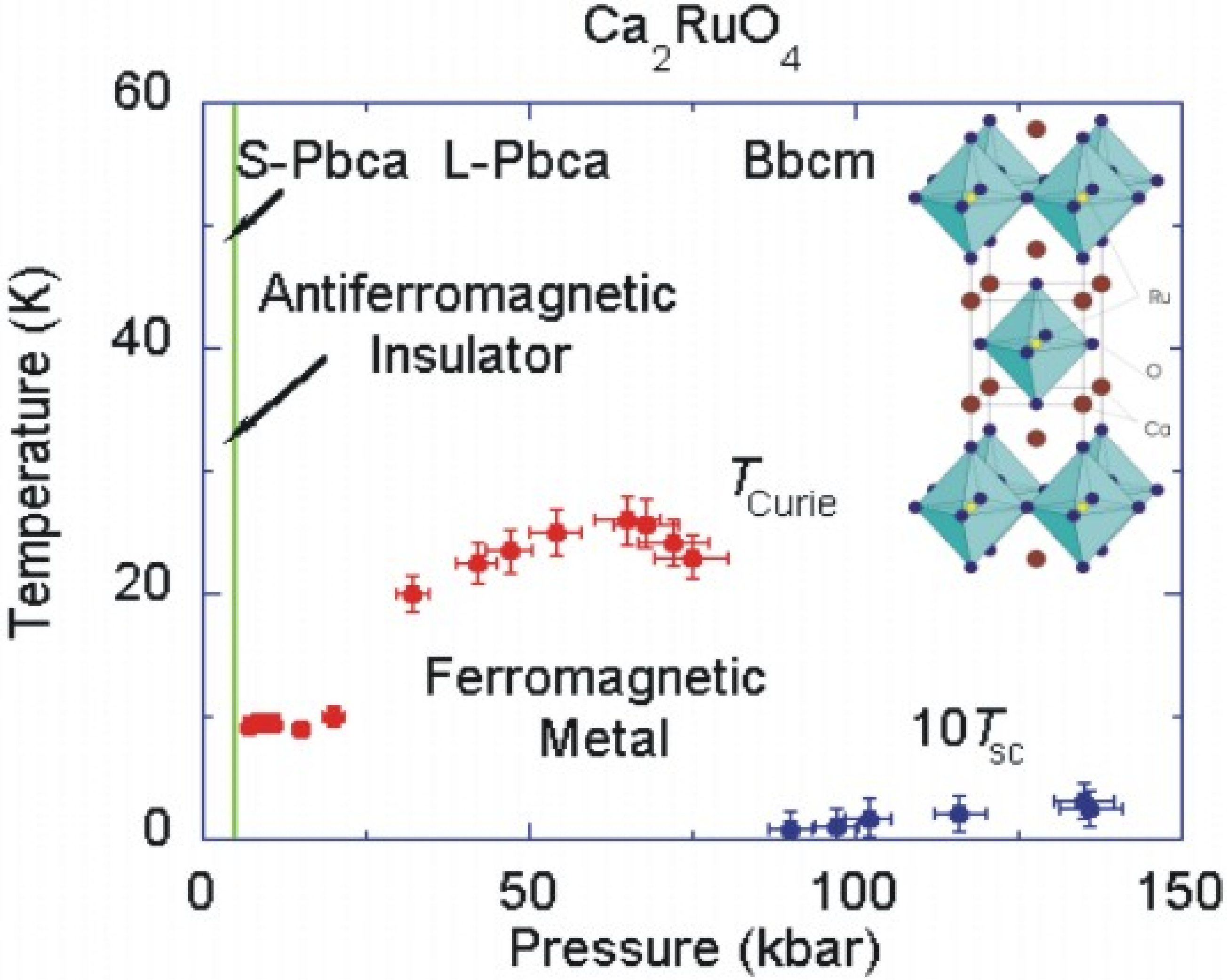


ac susceptibility



P. L. Alireza, et al., Journal of Physics: Condensed Matter **22** (2010) 052202.
arXiv:0912.1513 [cond-mat.supr-con]

From Mott insulator to " SC " via itinerant FM



$T_c \sim 0.4$ K at $P \sim 14$ GPa

P. L. Alireza, et al., Journal of Physics: Condensed Matter **22** (2010) 052202.
arXiv:0912.1513 [cond-mat.supr-con]

New SC phase in pressurised CRO

Pressurisation above ~8 GPa turns CRO

from FM metal to SC (T_c ~ 0.4 K and ~14 GPa).

1. How about relation between FM and SC ?

2. How about difference in SC between
SRO and CRO ? (*p* or *s*-wave SC ?)

3. Ru214 is 2D Fermi liquid metal
but what is difference ?

Quantum oscillation data is required.

Ⅱ. "Electric-field" induced Mott transition

"Electric field" has higher potential than *P*

Reported breakdown in Mott insulator

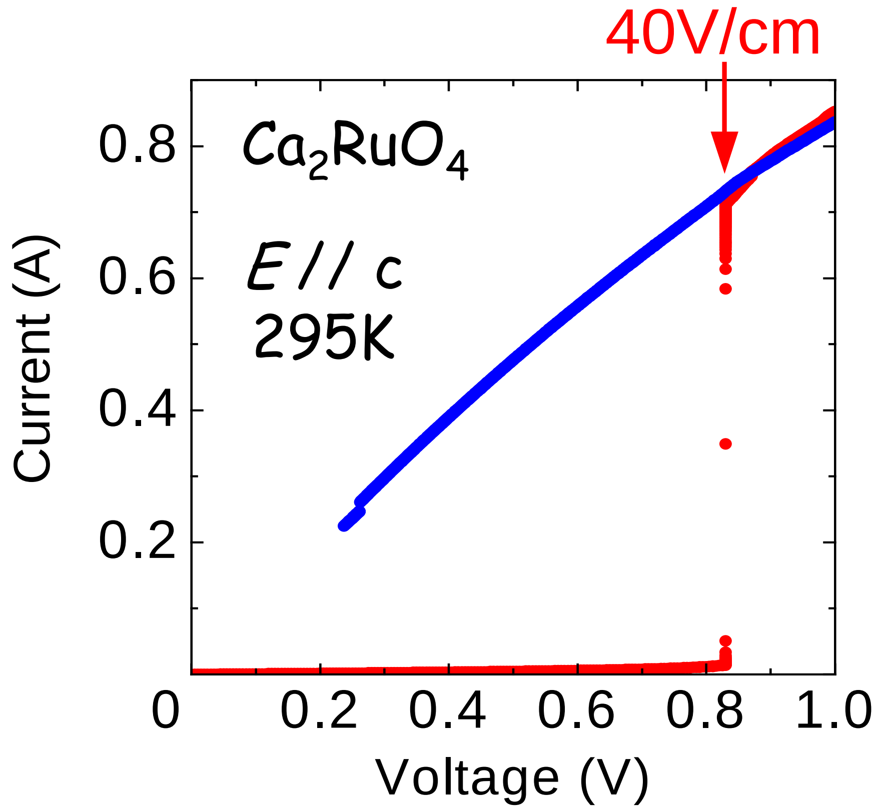
	E_{th} (kV/cm)	E_{gap} (eV)
$La_{2-x}Sr_xNiO_4$ [1)]	1~10	0.26
Sr_2CuO_3 [2)]	1~3	
$SrCuO_2$ [2)]	0.3~1	
(TTeC1TTF)-TCNQ [3)]	0.3~1.2	
Ca_2RuO_4	?	0.2 / 0.05 (@RT)

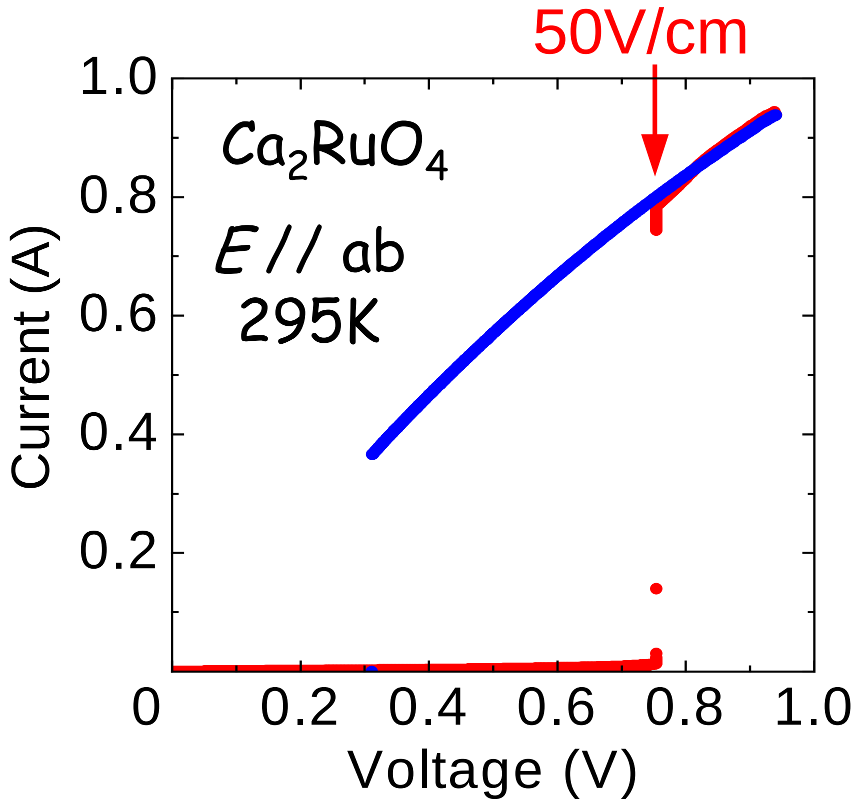
1) M.Imada, Rev.Mod.Phys. **70** 4 (1998).
2) Y.Taguchi., PRB. **62** 11 (1999).
3) Y. Iwasa ., APL. **39**, 10441 (1989).

We expect "E_{th} ~3kV/cm" @RT for Ca_2RuO_4 based on Zener breakdown model.

$$E_{th} = \frac{\varepsilon_{gap}^2}{e^2 \varepsilon_0 a}$$

Breakdown in 4d Mott insulator Ca_2RuO_4 occurs at "Surprisingly weak E_{th}~40V/cm"





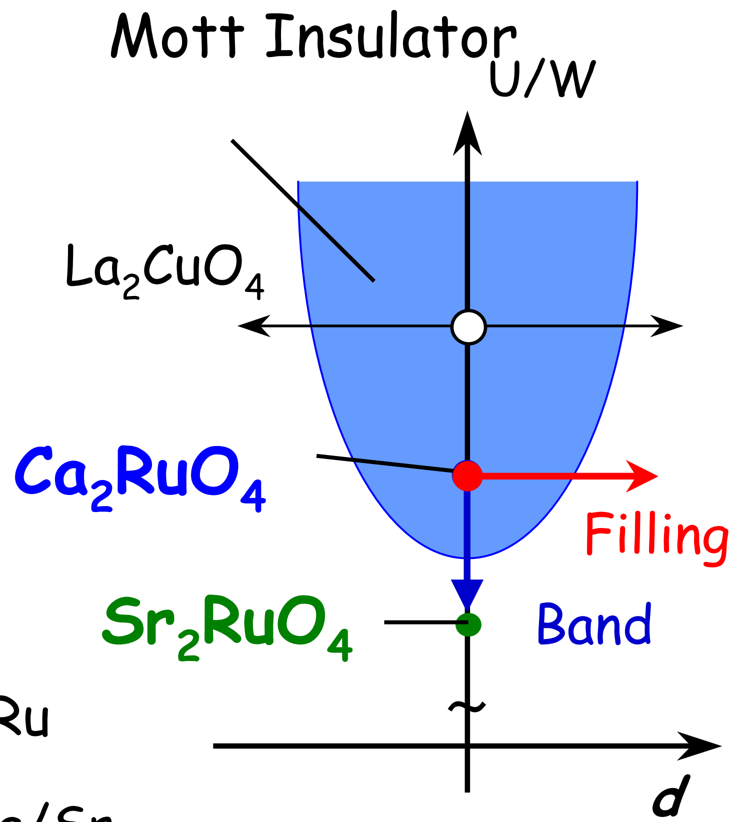
Zener Breakdown No !

Why is E_{th} ~ 40V/cm so weak in Ca_2RuO_4 ?

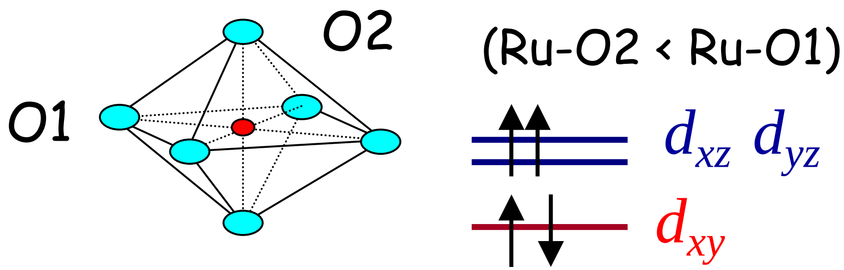
Avalanche Breakdown ?

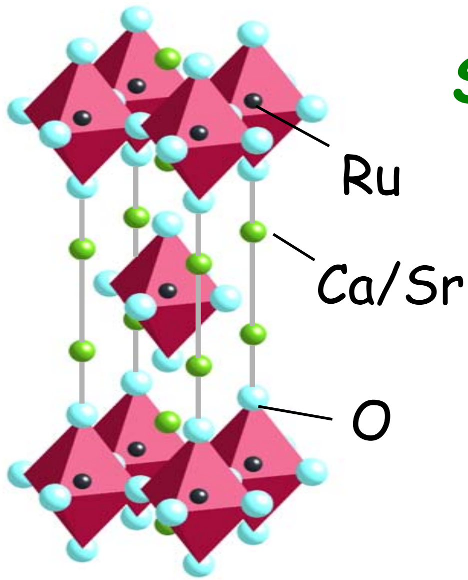
Metal-Insulator transition in Ca_2RuO_4 accompanied by structural change

1. Substitution ($(Sr/Ca)_2RuO_4$)
2. Heating (temperature)
3. **Pressure**
4. **Electric field**

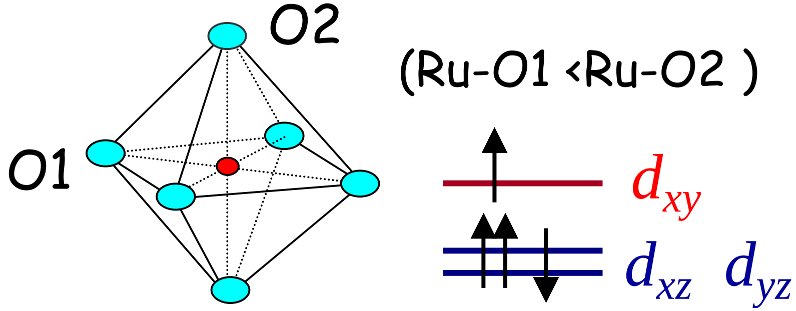


Insulator (S-Pbca flatted)





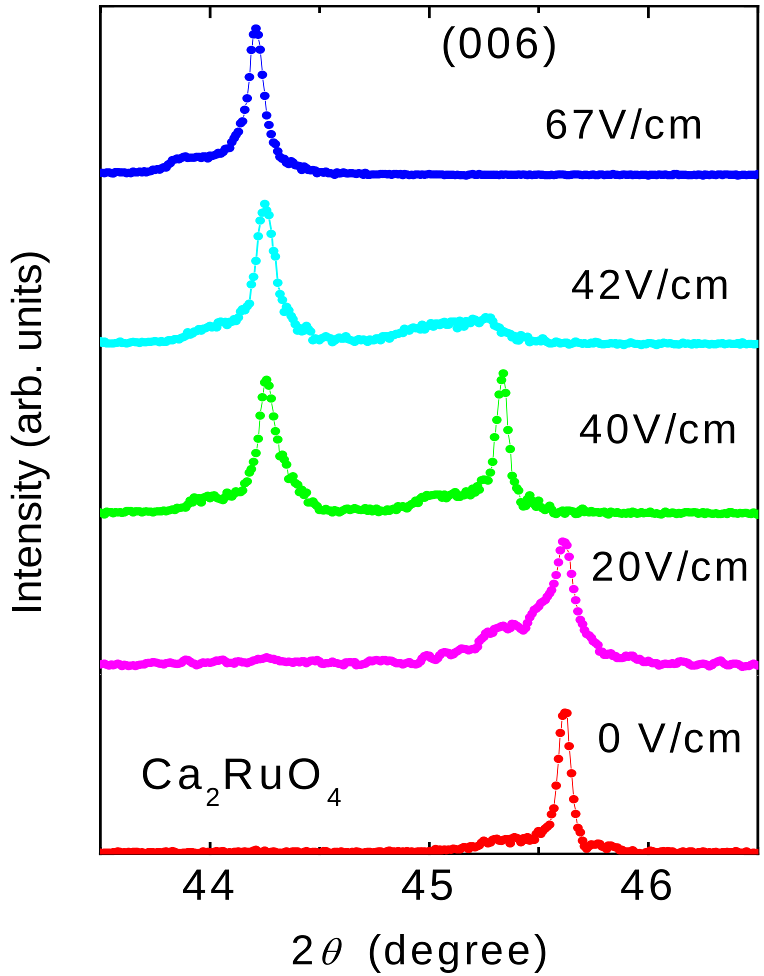
Metal (L-Pbca)

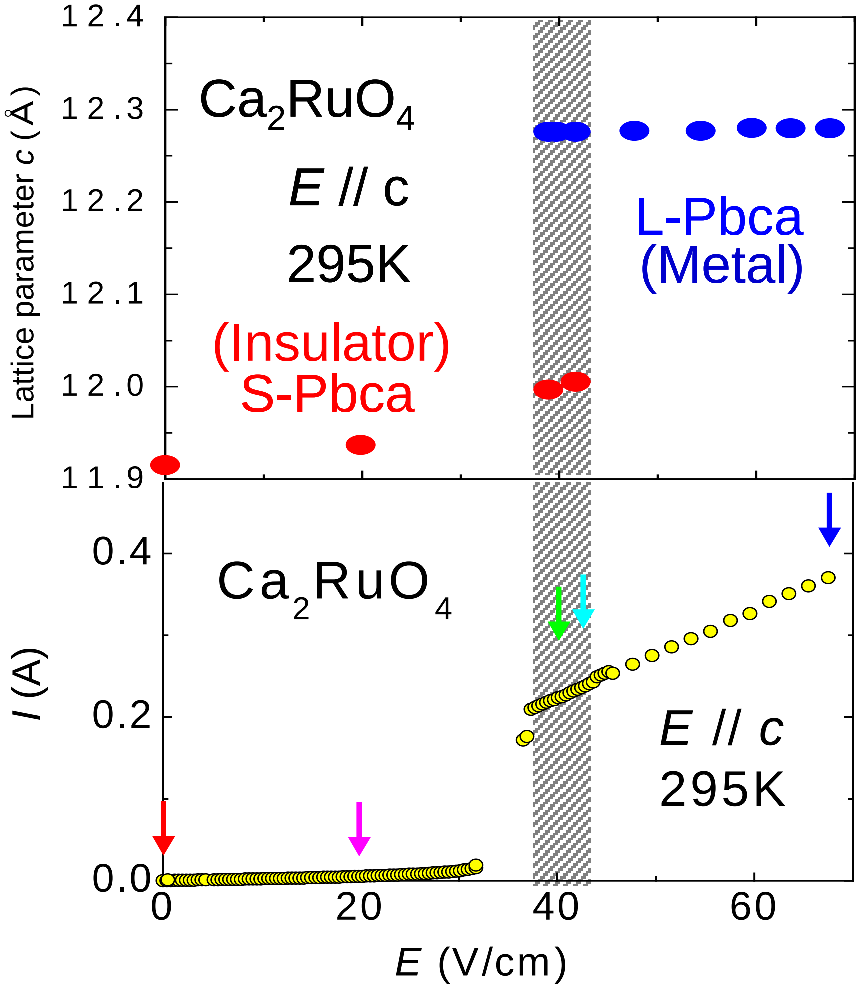


The breakdown accompanied by structural transition from S- to L-Pbca

Breakdown in CRO is "Bulk transition".

Avalanche Breakdown NO !





Summary

Dielectric Breakdown in Mott insulator Ca_2RuO_4 occurs

at "Superisingly weak E_{th}~40V/cm"

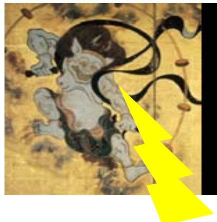
accompanying with structural transition

c axis: 11.9 Å (insulator) → 12.3 Å (metal)

DB in CRO → Bulk transition

1. Zener Breakdown — No
2. Joule heating — No
3. Avalanche Breakdown — No

What is the possible mechanism for weak E_{th} ?

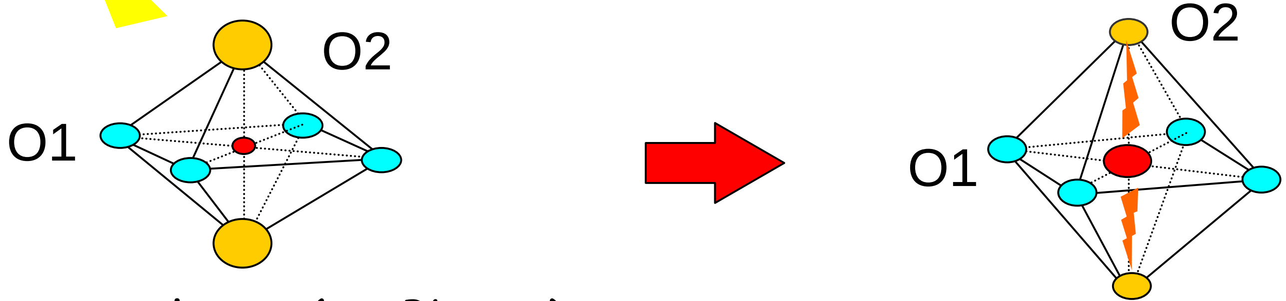


How about possible mechanism for Dielectric breakdown in Ca_2RuO_4 ?

<u>Change of the internal charge distribution.</u>

Enough amount of charge for the metalisation is internally stored in the apical oxygen (O2) of CRO, and then it can be poured into the RuO_2 plane only by quite weak field of E_{th}~40V/cm.

E_{th}~ 40V/cm



Insulator (S-Pbca)

Metal (L-Pbca)

Other possible mechanism