The Cather in the Rye of Deconfinement

ZI YANG MENG
孟子杨
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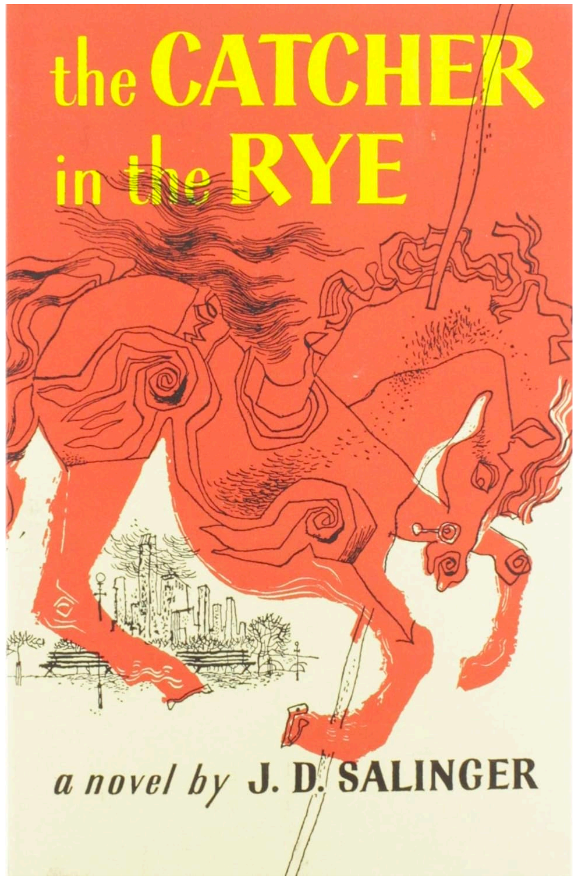

A coming of age story, themes of angst and alienation, and a critique of superficiality in society (phonies). Holden Caulfield, J. D. Salinger's adolescent antihero, has become an icon for teenage rebellion.

“I keep picturing all these little kids playing some game in this big field of rye and all. … And I'm standing on the edge of some crazy cliff. I have to catch everybody if they start to go over the cliff - I mean if they're running and they don't look where they're going I have to come out from somewhere and catch them. **That's all I do all day. I'd just be the catcher in the rye and all. I know it's crazy, but that's the only thing I'd really like to be.”**

Holden admires in children attributes that he often struggles to find in adults, like innocence, kindness, spontaneity, and generosity. Falling off the cliff could be a progression into the adult world that surrounds him and that he strongly criticizes.

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Jing Guo

Liling Sun

Shiliang Li

Anders Sandvik

PHYSICAL REVIEW LETTERS **124**, 206602 (2020)

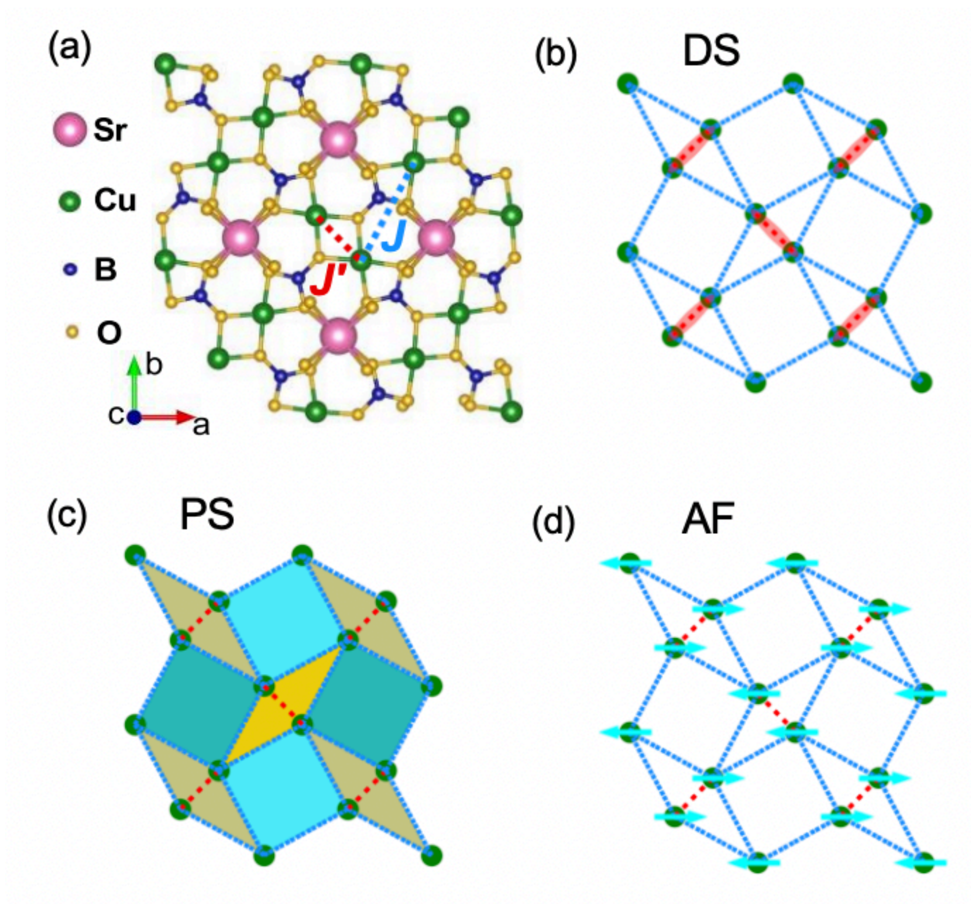
Quantum Phases of $SrCu_2(BO_3)_2$ from High-Pressure Thermodynamics

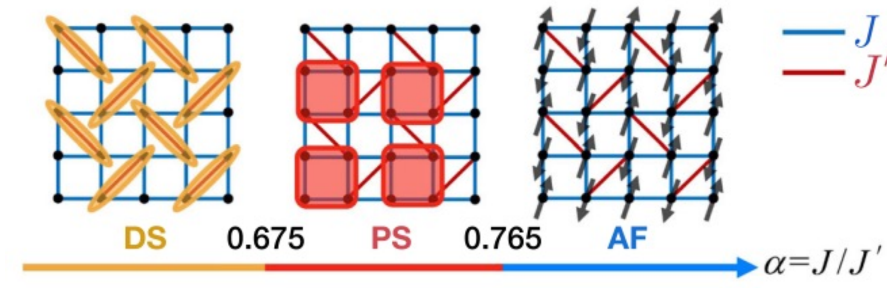
Jing Guo,[1] Guangyu Sun,[1,2] Bowen Zhao,[3] Ling Wang,[4,5] Wenshan Hong,[1,2] Vladimir A. Sidorov,[6] Nvsen Ma,[1] Qi Wu,[1] Shiliang Li,[1,2,7] Zi Yang Meng,[1,8,7,*] Anders W. Sandvik,[3,1,†] and Liling Sun[1,2,7,‡]

arXiv:2310.20128

Deconfined quantum critical point lost in pressurized $SrCu_2(BO_3)_2$

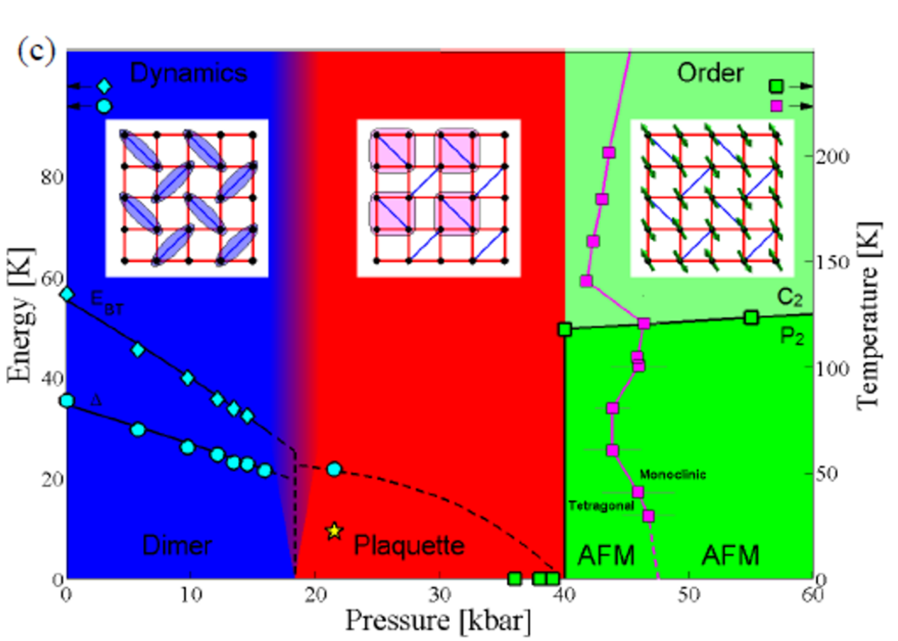
Jing Guo,[1,5,*] Pengyu Wang,[1,2,*] Cheng Huang,[3,*] Bin-Bin Chen,[3] Wenshan Hong,[1,2] Shu Cai,[4] Jinyu Zhao,[1,2] Jinyu Han,[1,2] Xintian Chen,[1,2] Yazhou Zhou,[1] Shiliang Li,[1,2,5] Qi Wu,[1] Zi Yang Meng,[3,†] and Liling Sun[1,2,4,5,‡]



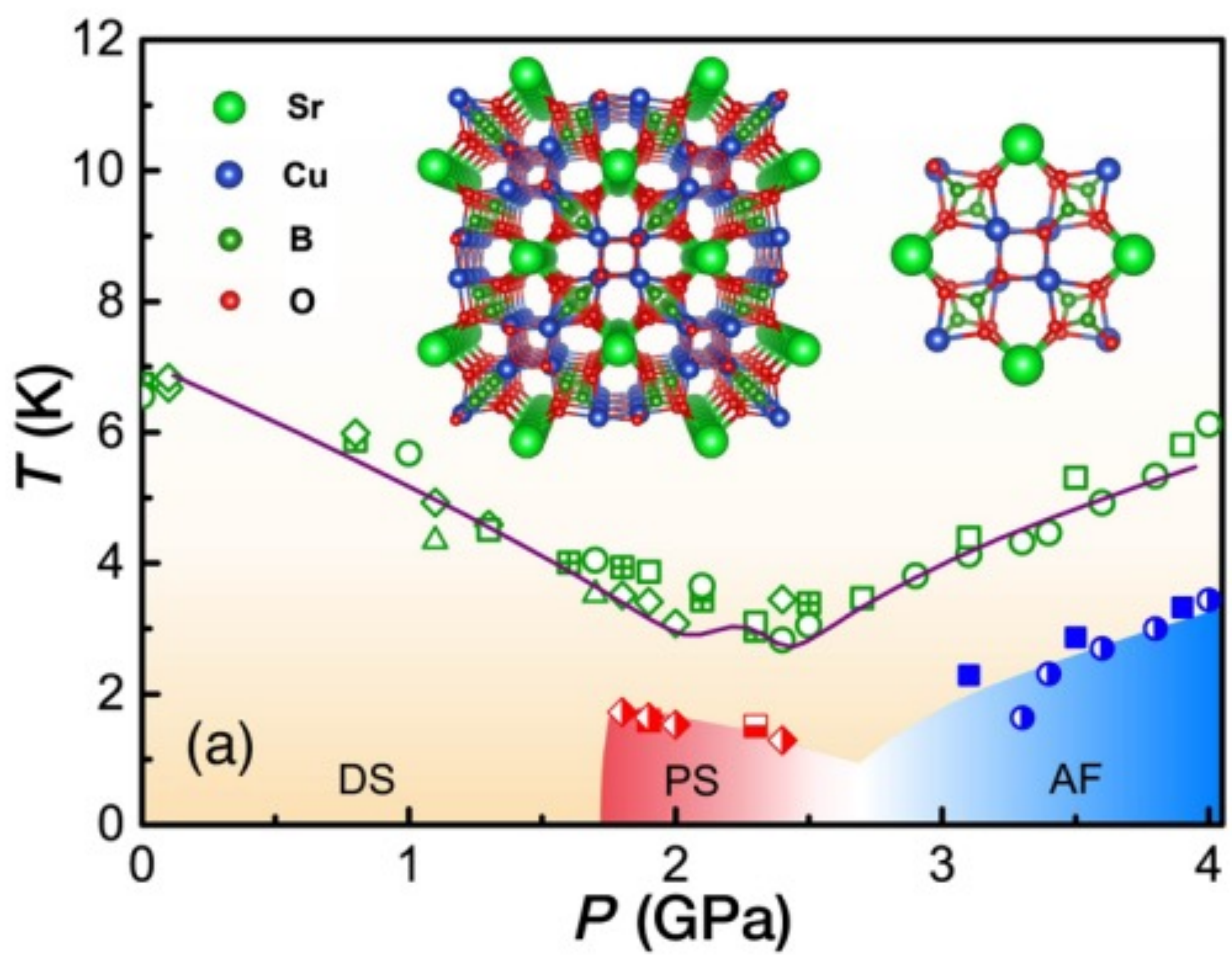


$$H = J \sum_{\langle i,j \rangle} S_i \cdot S_j + J' \sum_{\langle\langle i,j \rangle\rangle} S_i \cdot S_j$$

- Koga, Kawakami, PRL 84, 4461 (2000)
- Corboz, Mila, PRB 87, 115144 (2013)
- Wang, Sandvik, PRB 105, L060409 (2022)
- Viteritti, Rende, Parola, Goldt, Becca, arXiv: 2311.16889
- ......

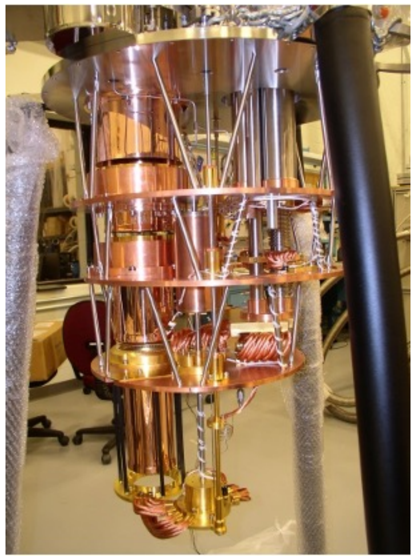


- M. E. Zayed et al. Nat. Phys. 13 962 (2017)

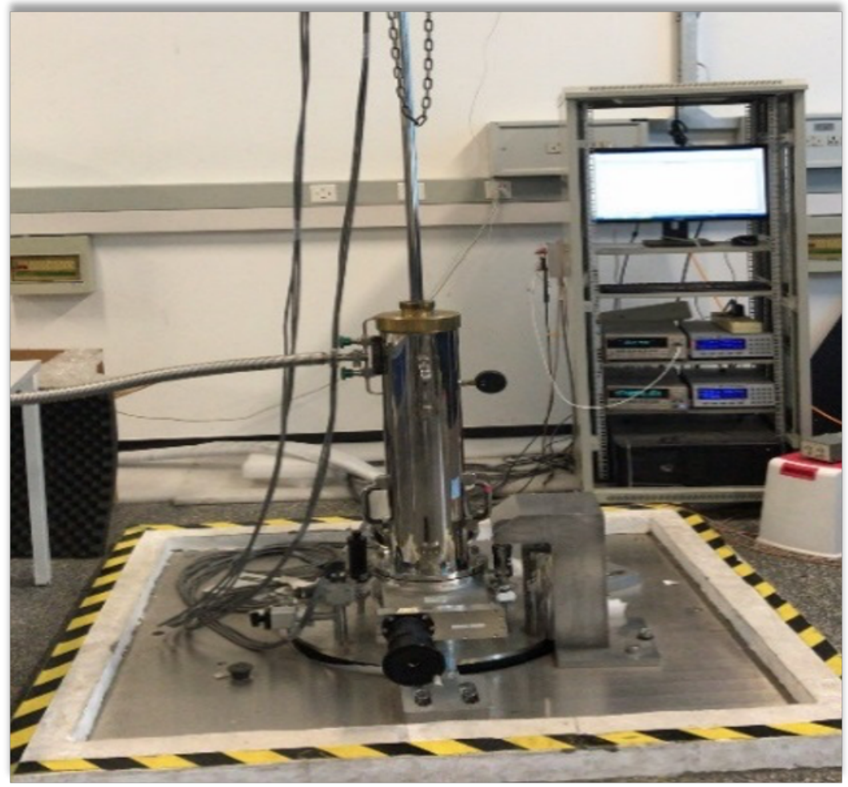


- Jing Guo, et al., PRL 124, 206602 (2020)

Equipments used for HP heat capacity measurements

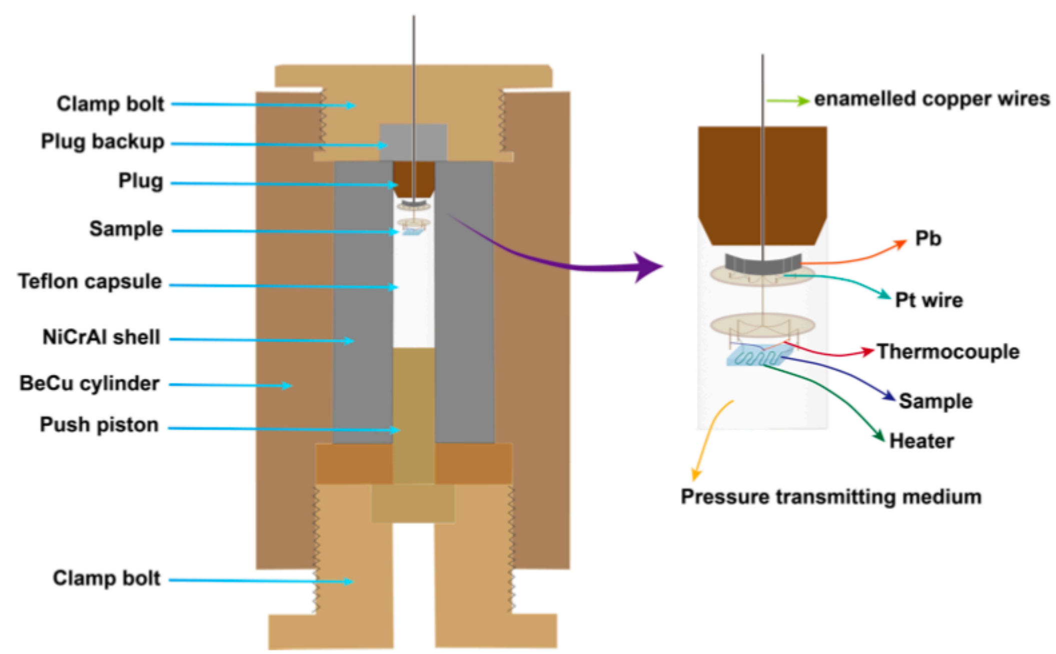


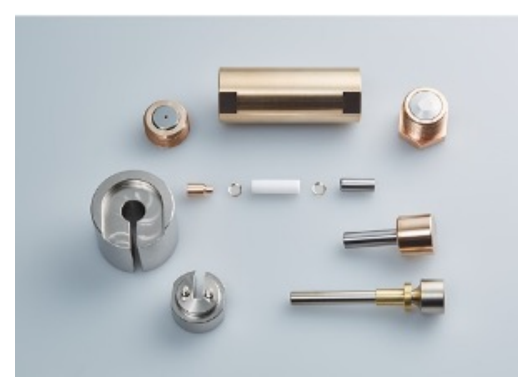
Three-stage cooling with He3 exchange



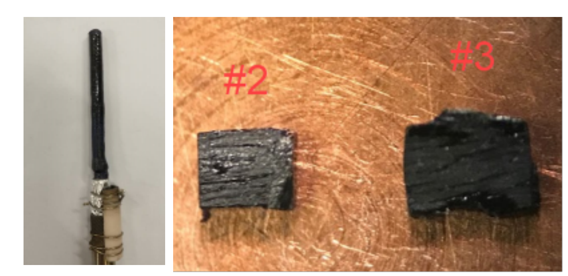
Integrated facility with HP and LT (0.3K)

Integrated facility with HP/LT(0.3K)/MF(14T)



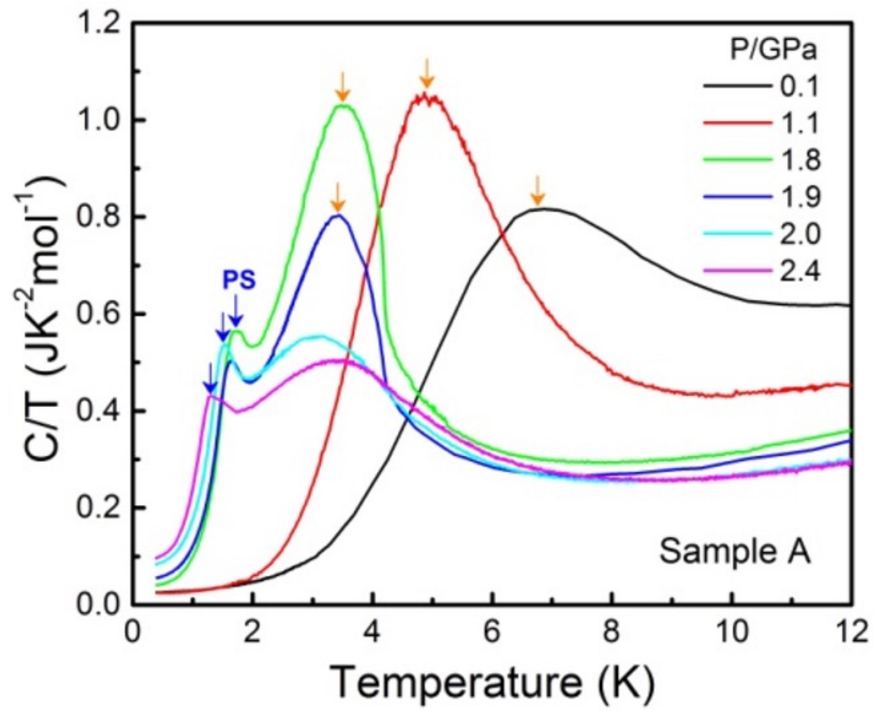


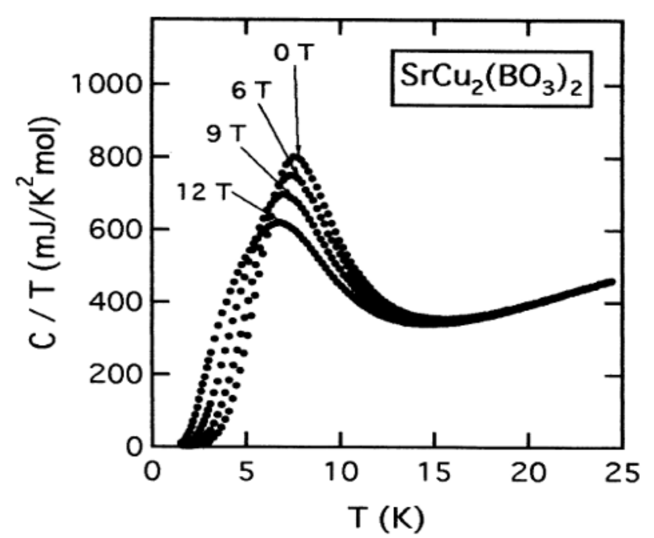
piston/cylinder cell



Single crystal SCBO

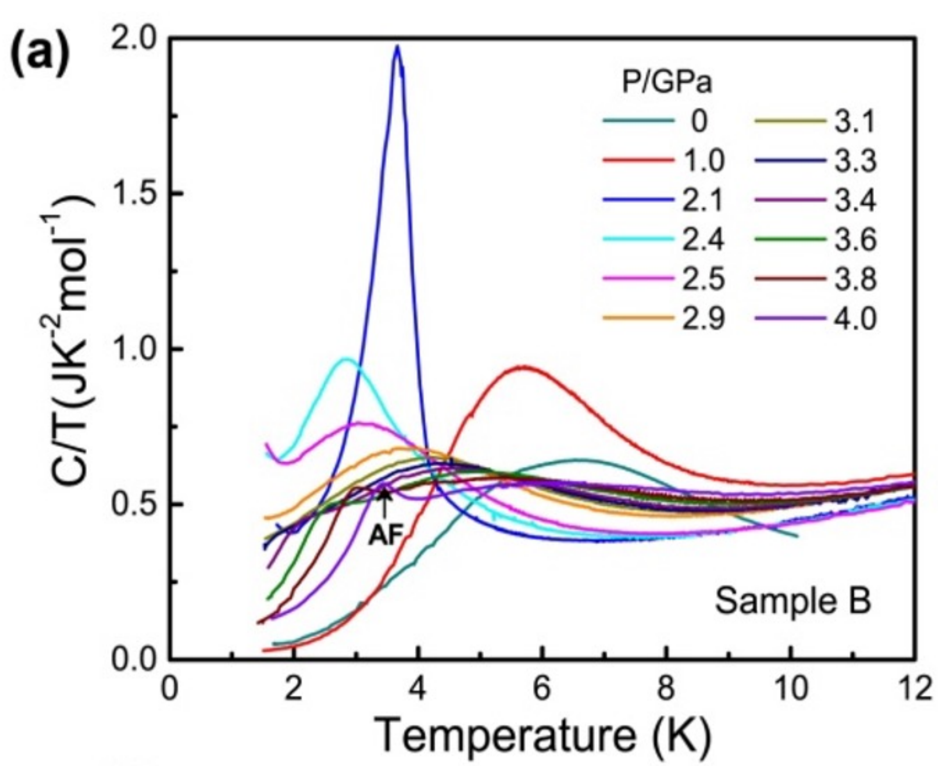
- Jing Guo, et al., PRL 124, 206602 (2020)
- Jing Guo, et al., arXiv:2310.20128

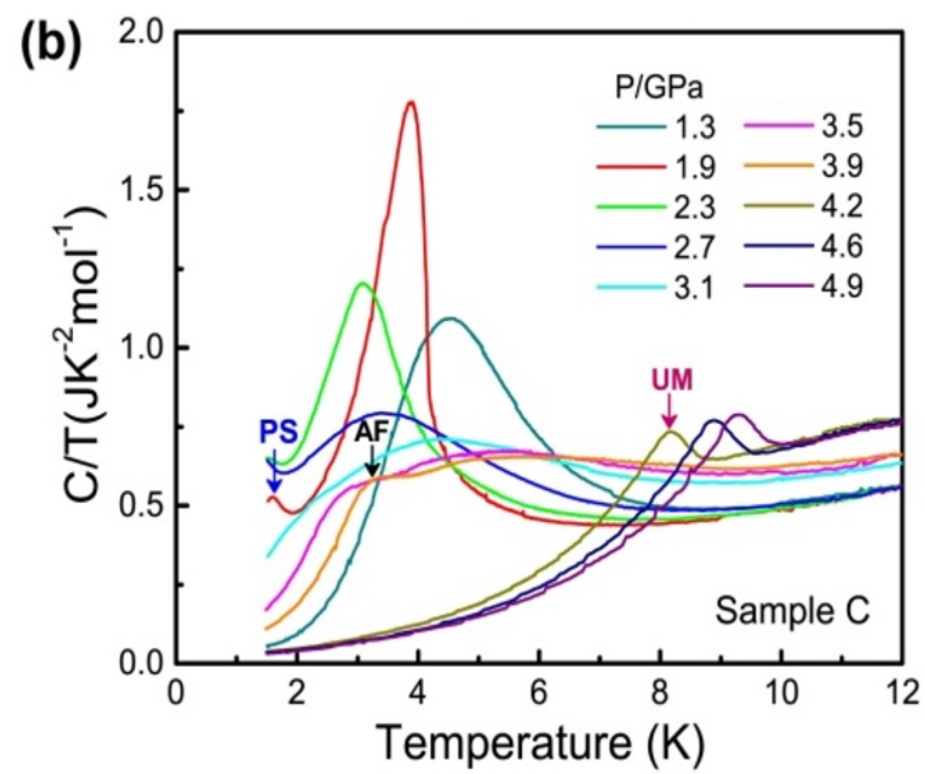




H. Kageyama et al. Physica B 667 281 (2000)

- A peak emerges at lower T at 1.8 GPa and prevails up to 2.4 GPa — the Plaquette phase.

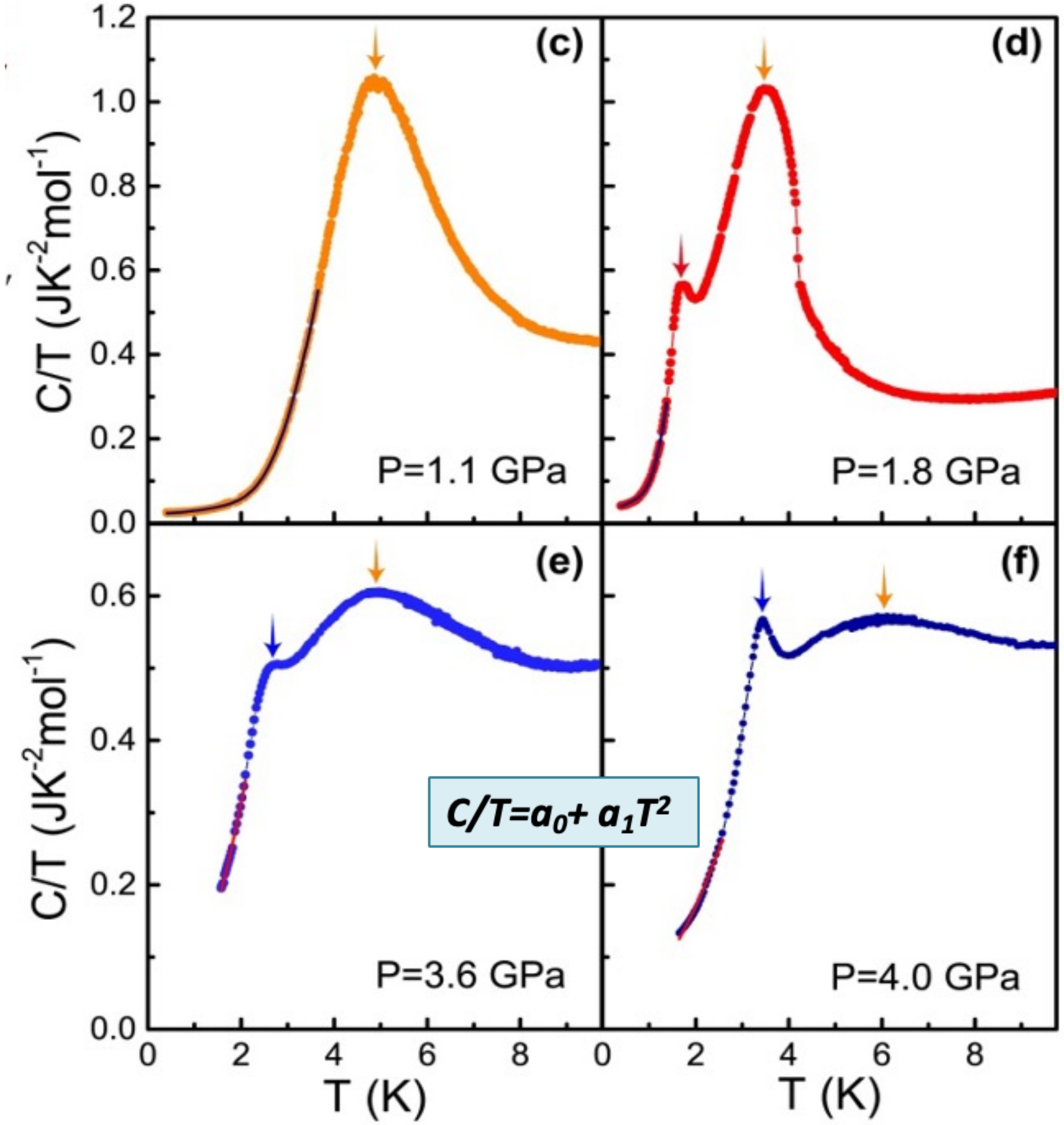




- At P>3 GPa, a new transition was observed at 1.7 − 3.5 K — the Antiferromagnet phase.

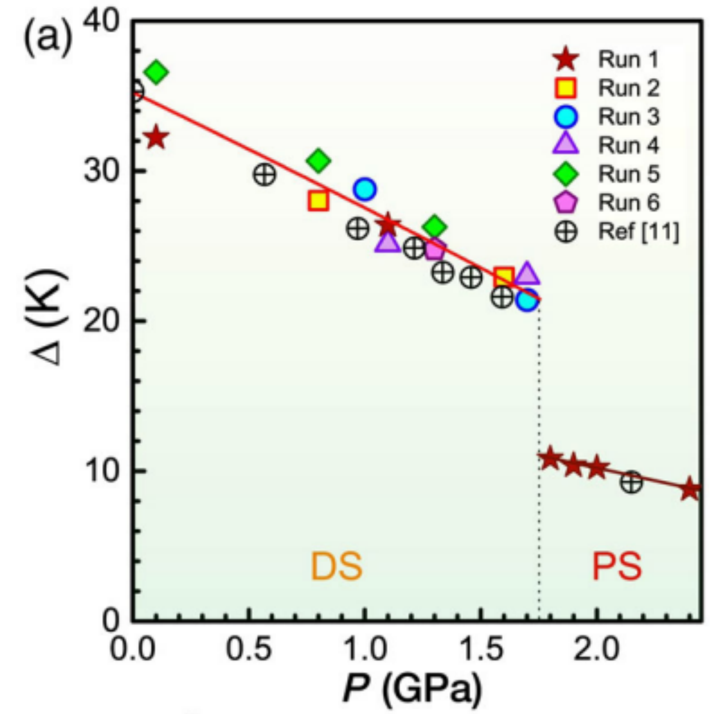
Jing Guo, et al., PRL 124, 206602 (2020)

$C/T = a_0 + a_1 T^2 + (a_3/T_3) e^{-\Delta/T}$

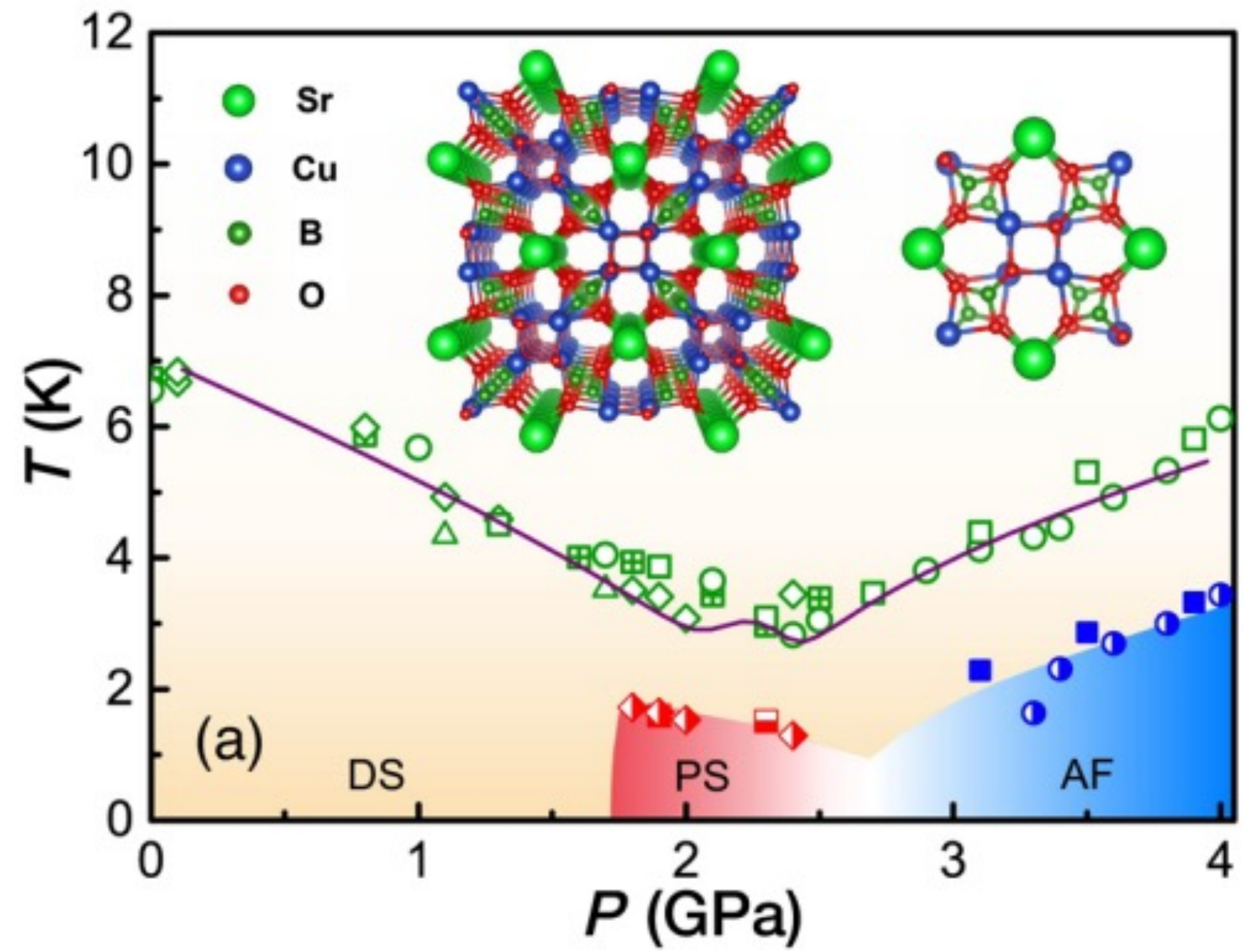


$C/T = a_0 + a_1 T^2$

Ref [11]: M. E. Zayed et al. Nat. Phys. 13 962 (2017)



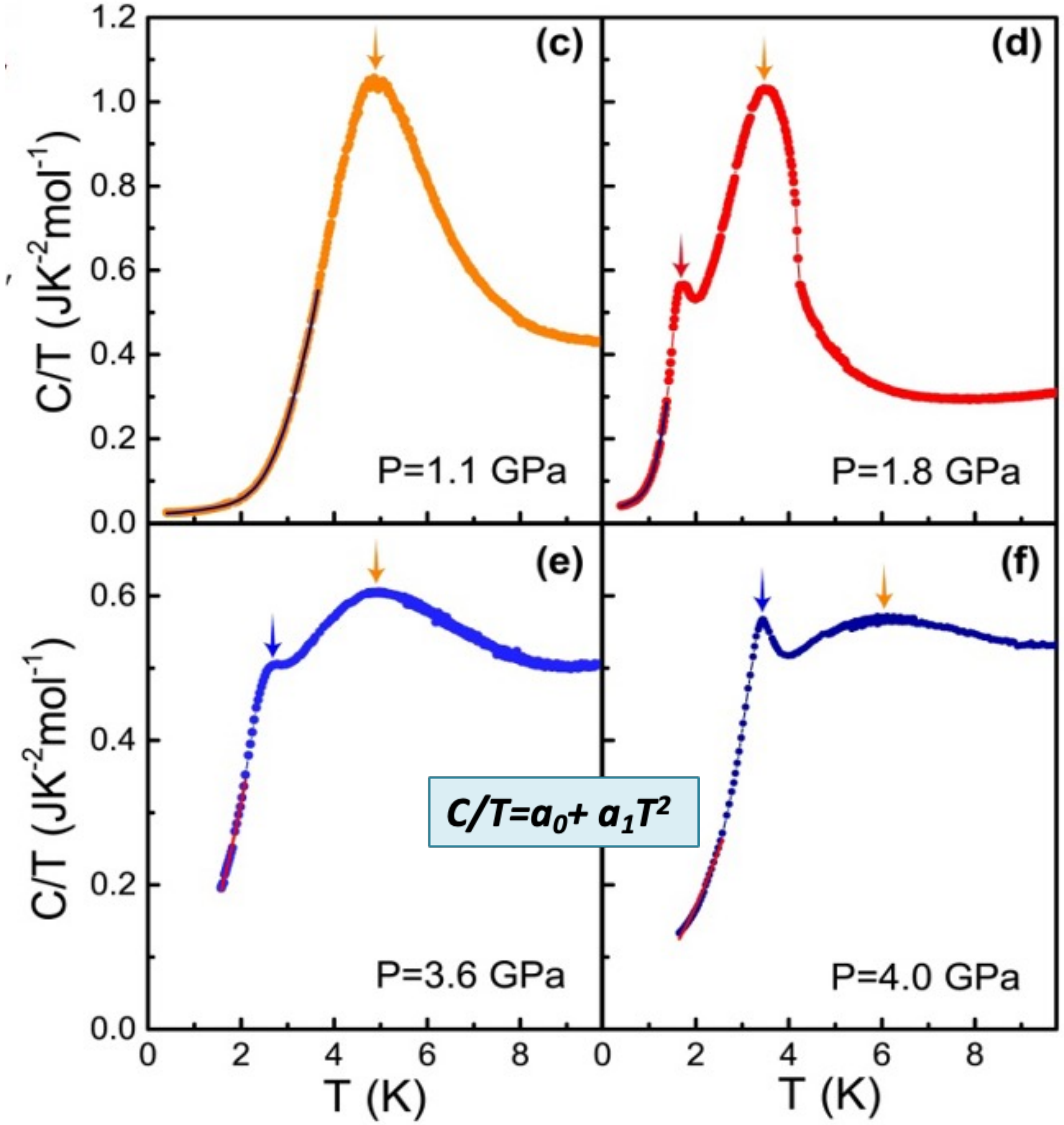
- Gaps are in agreement with previous report.
- The gap is suddenly reduced at 1.7 GPa, showing that the DS-PS transition is first order.



- **P < 1.8 GPa: Dimer-singlet state**
- **P < 2.5GPa: Plaquette-singlet state**
- **3 GPa < P < 4 GPa: AF state**

Jing Guo, et al., PRL 124, 206602 (2020)

$C/T = a_0 + a_1 T^2 + (a_3/T_3) e^{-\Delta/T}$



$C/T = a_0 + a_1 T^2$

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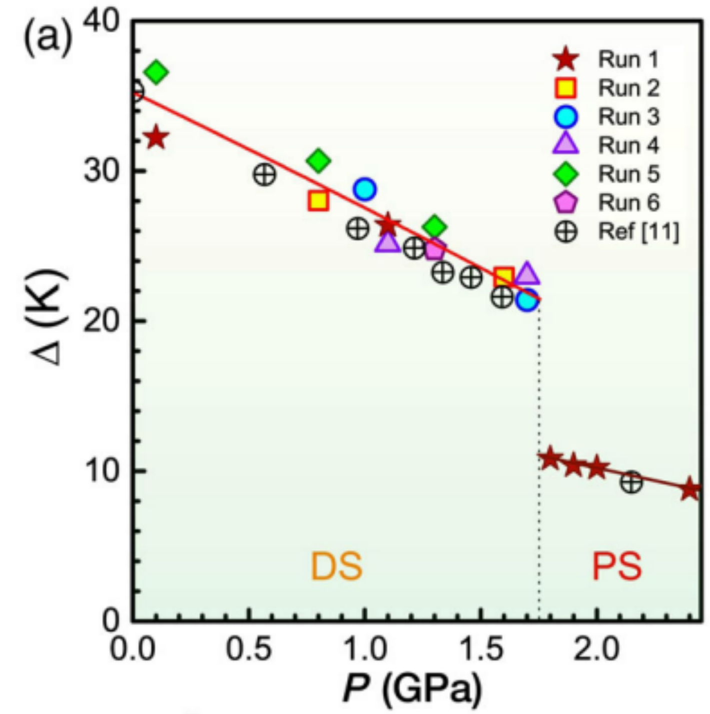

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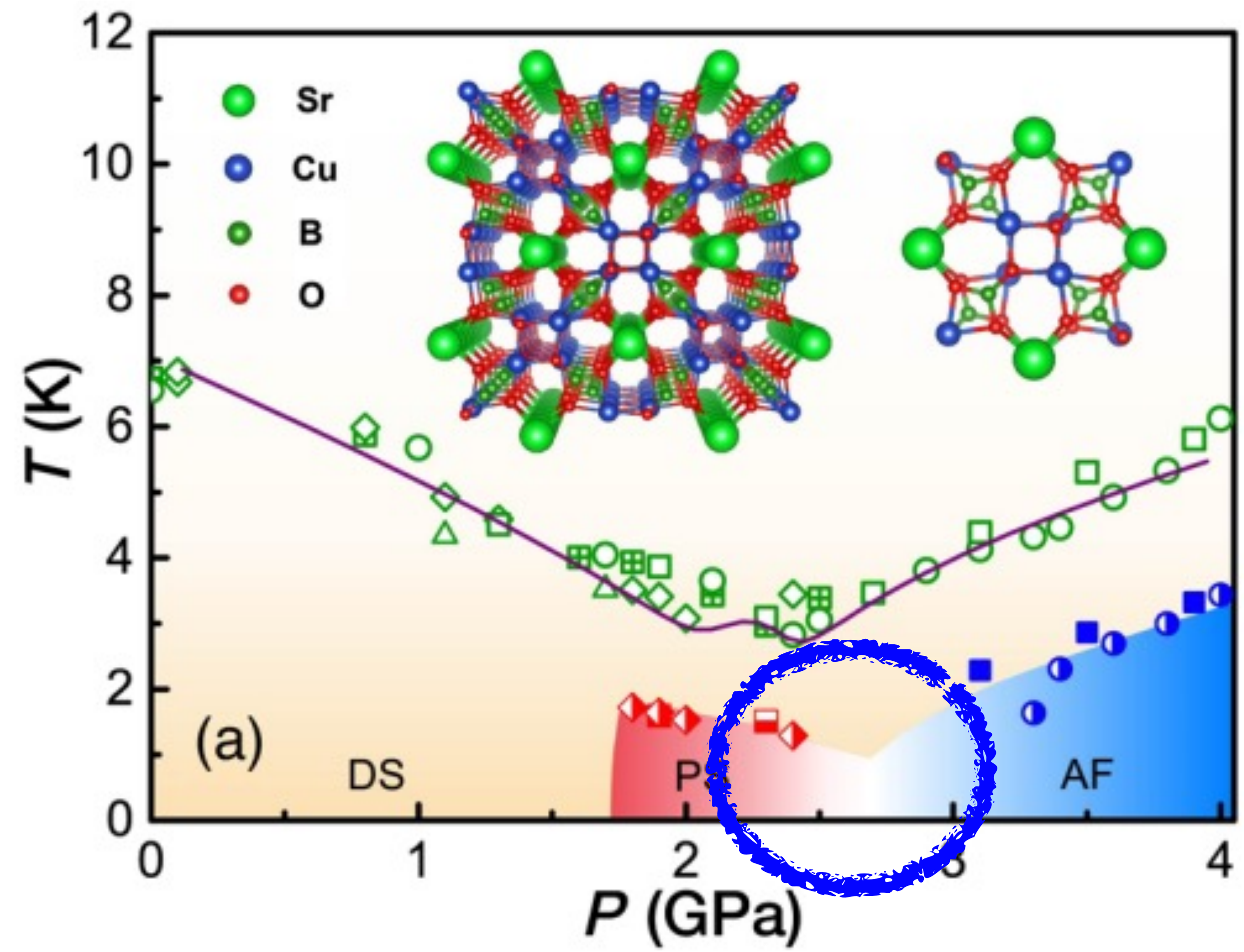

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Jing Guo, et al., PRL 124, 206602 (2020)

Deconfined quantum critical point lost in pressurized $SrCu_2(BO_3)_2$

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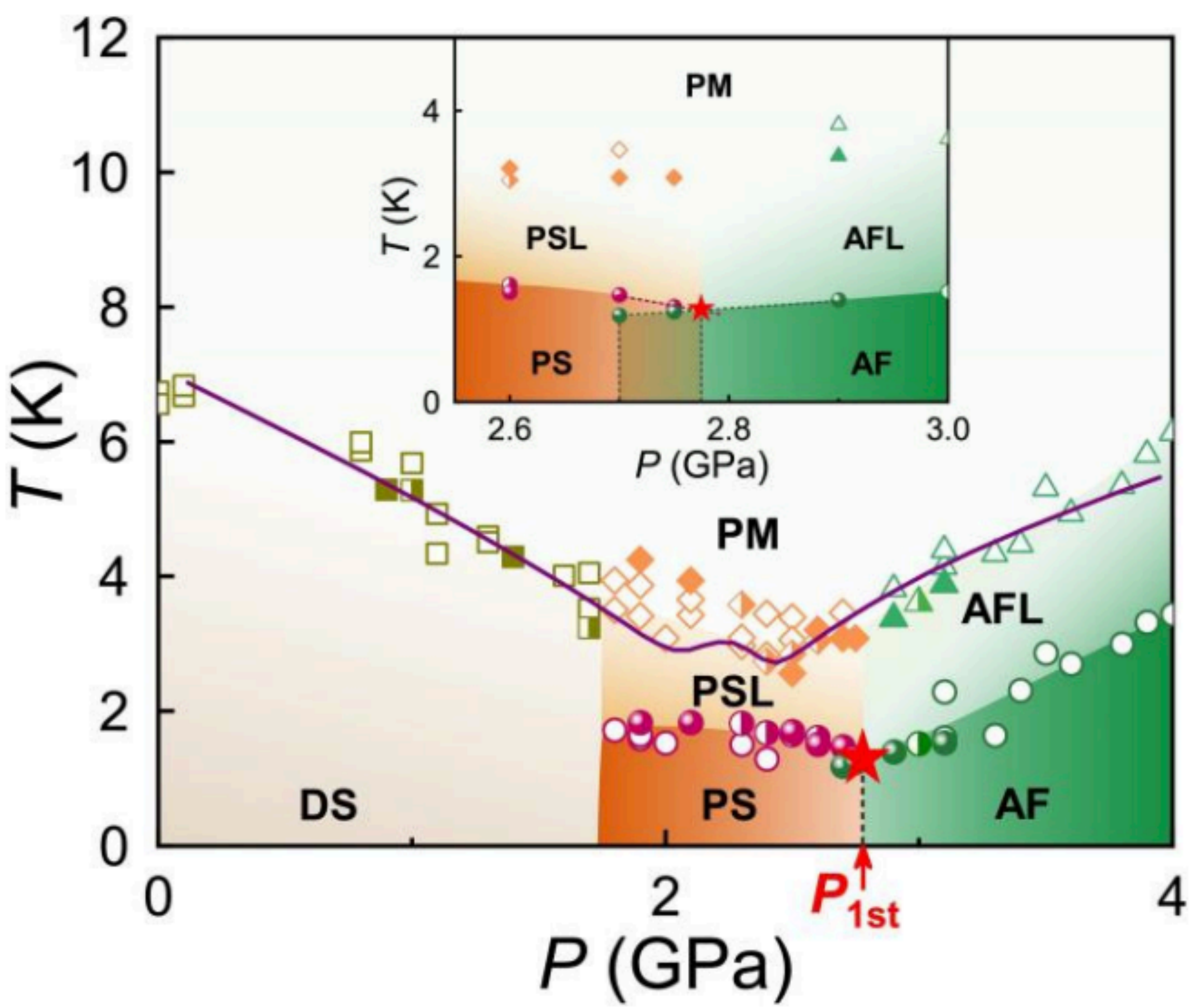

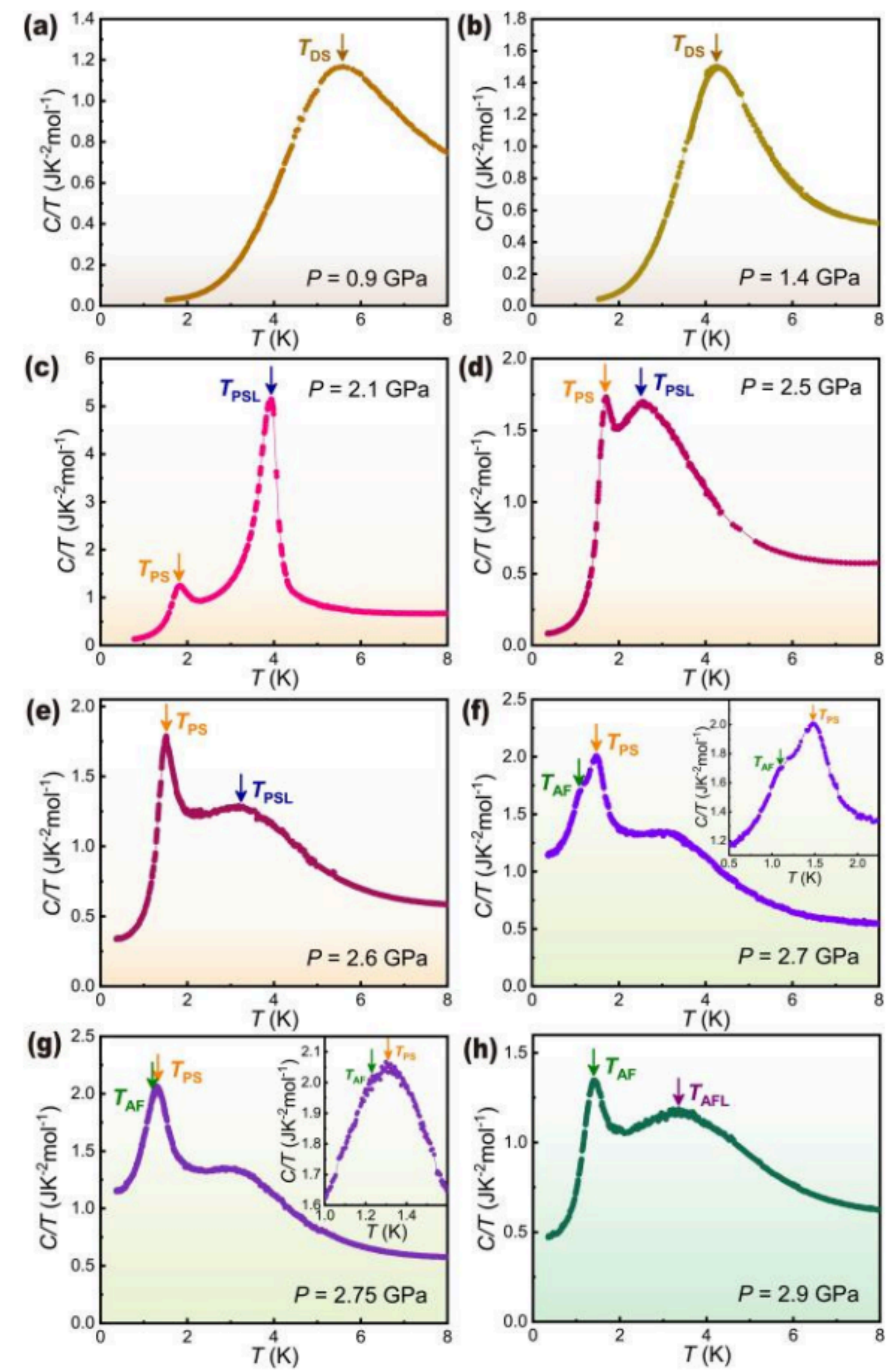

arXiv:2310.20128

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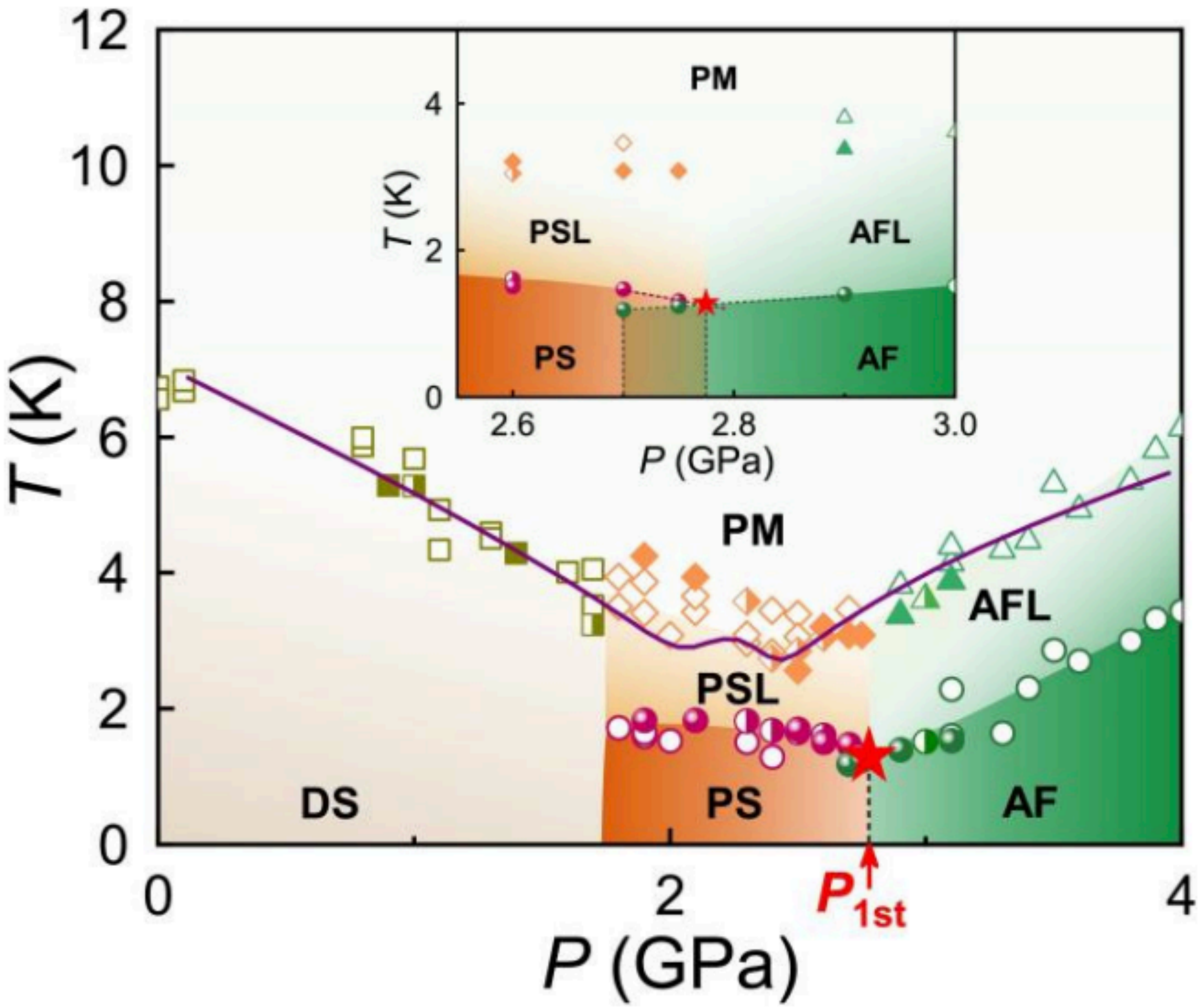
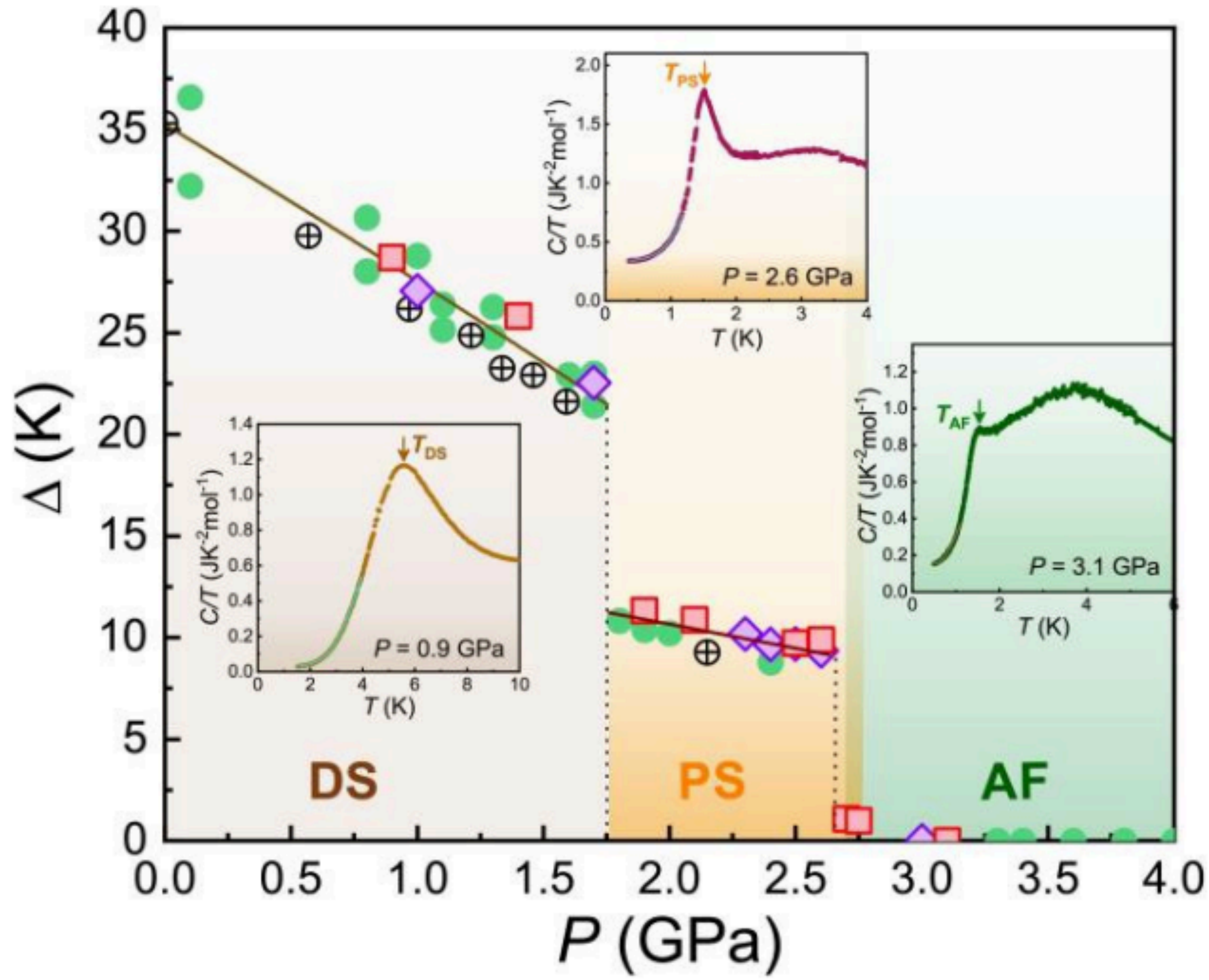
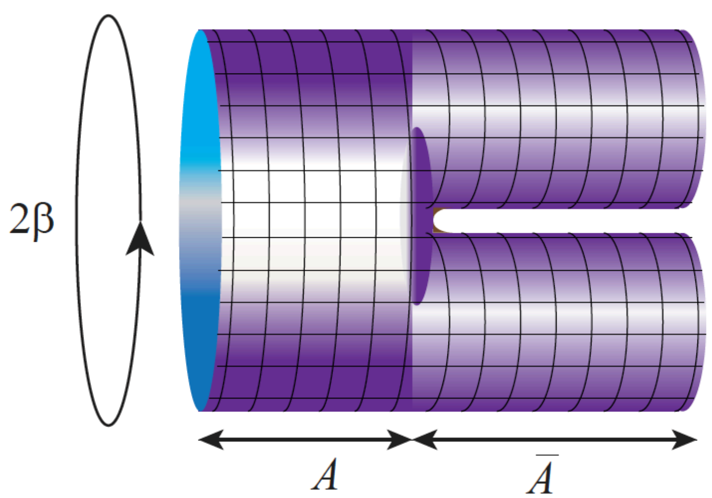




The learning of entanglement on deconfined quantum critical points



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Yuan Da Liao (Fudan)	Juncheng Rong (IHES)	William W. Krempa (Montreal)
Zheng Yan (Westlake)	Jonathan D'Emidio (DIPC)	Chaoming Jian (Cornell)
Yan-Cheng Wang (Beihang)	Fakher Assaad (Würzburg)	Yi-Zhuang You (UCSD)

PHYSICAL REVIEW LETTERS **128,** 010601 (2022)

Scaling of Entanglement Entropy at Deconfined Quantum Criticality

Jiarui Zhao,[1] Yan-Cheng Wang,[2] Zheng Yan,[1,3] Meng Cheng,[4,*] and Zi Yang Meng[1,†]

arXiv:2312.?????

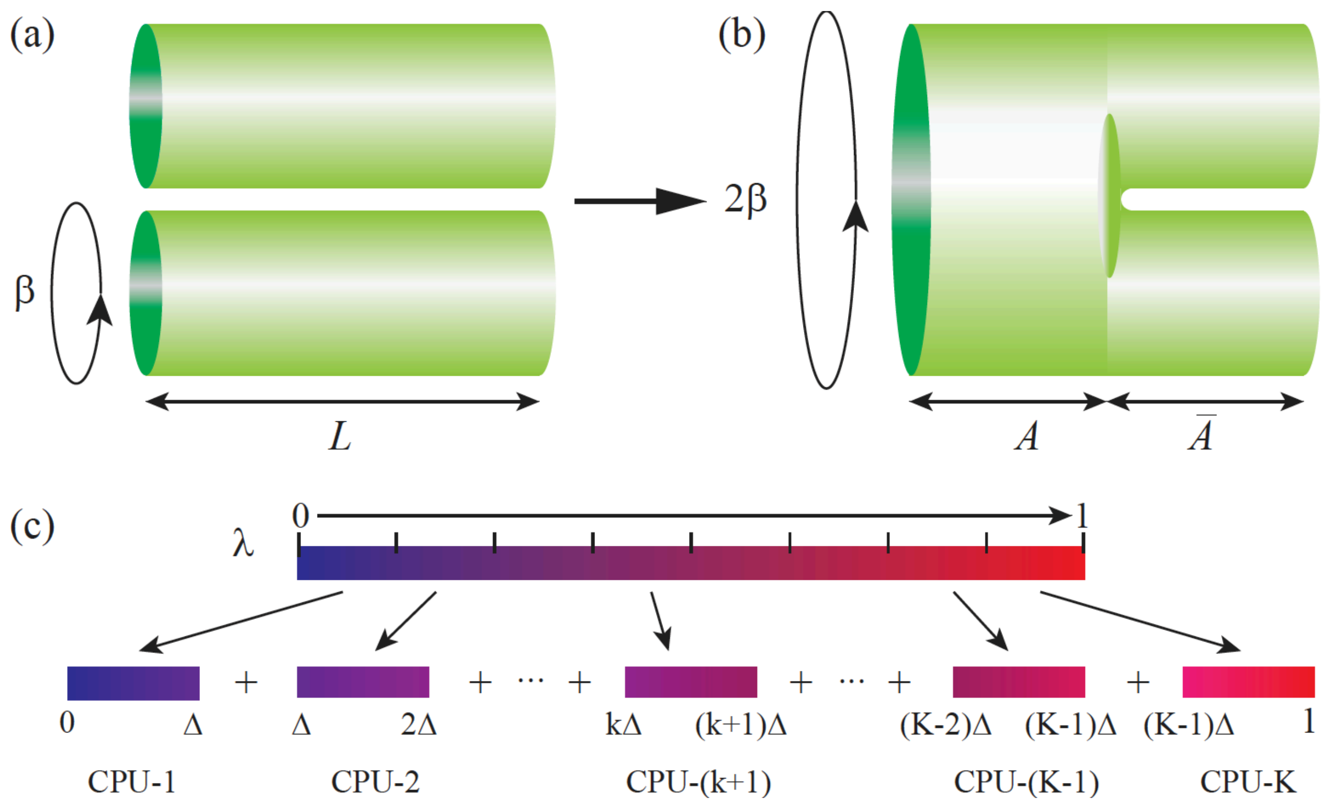
Extracting subleading corrections in entanglement entropy at quantum phase transitions

Menghan Song,[1,*] Jiarui Zhao,[1,*] Zi Yang Meng,[1,†] Cenke Xu,[2,‡] and Meng Cheng[3,§]

Entanglement entropy with incremental (Qiu Ku) method

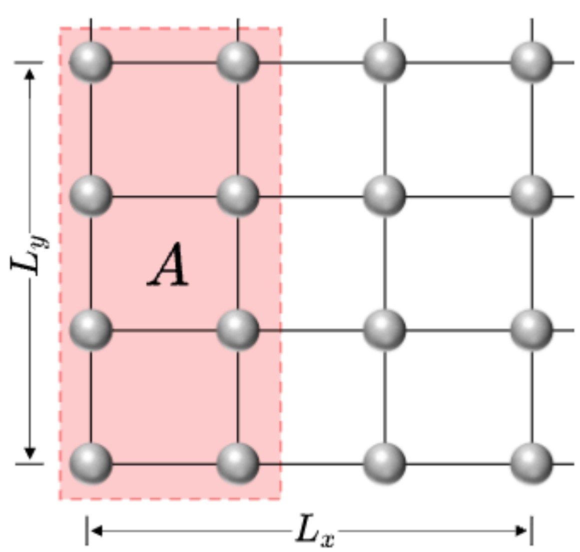
$$S_A^{(2)} = -\ln(Tr_A(\rho_A^2)) = -\ln\left(\frac{Z_A^{(2)}}{Z_\varnothing^{(2)}}\right) = \beta(F(Z_A^{(2)}) - F(Z_\varnothing^{(2)}))$$

- Calabrese & Cardy, J. Stat. Mech. (2004) P06002
- V. Alba, PRE 95, 062132 (2017)
- J. D'Emidio, PRL 124, 110602 (2020)
- J. Zhao, …, M. Cheng, ZYM, PRL 128, 010601 (2022)
- J. Zhao, …, M. Cheng, ZYM, npj Quantum Materials 7, 69 (2022)



$$e^{-S_A^{(2)}} = \frac{Z(1)}{Z(0)} := \frac{Z(\lambda_1)}{Z(0)}\frac{Z(\lambda_2)}{Z(\lambda_1)}\cdots\frac{Z(\lambda_k)}{Z(\lambda_{k-1})}\cdots\frac{Z(1)}{Z(\lambda_{N_\lambda-1})}$$

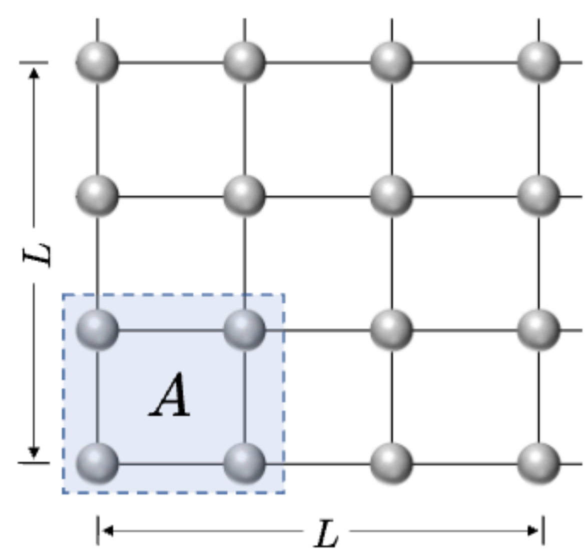
- J. D'Emidio, et al., arXiv:2211.04334
- G. Pan, Y. D. Liao, J. D'Emidio, ZYM, PRB 108, L081123 (2023)
- Y. D. Liao, arXiv:2307.10602
- X. Zhang, G. Pan, B.-B, Chen, K. Sun, ZYM, arXiv:2311.03448



Smooth boundary

$$S_A^{(2)}(l) = al + s_G \ln(l) + c$$

$$s_G = \frac{N_G}{2}$$



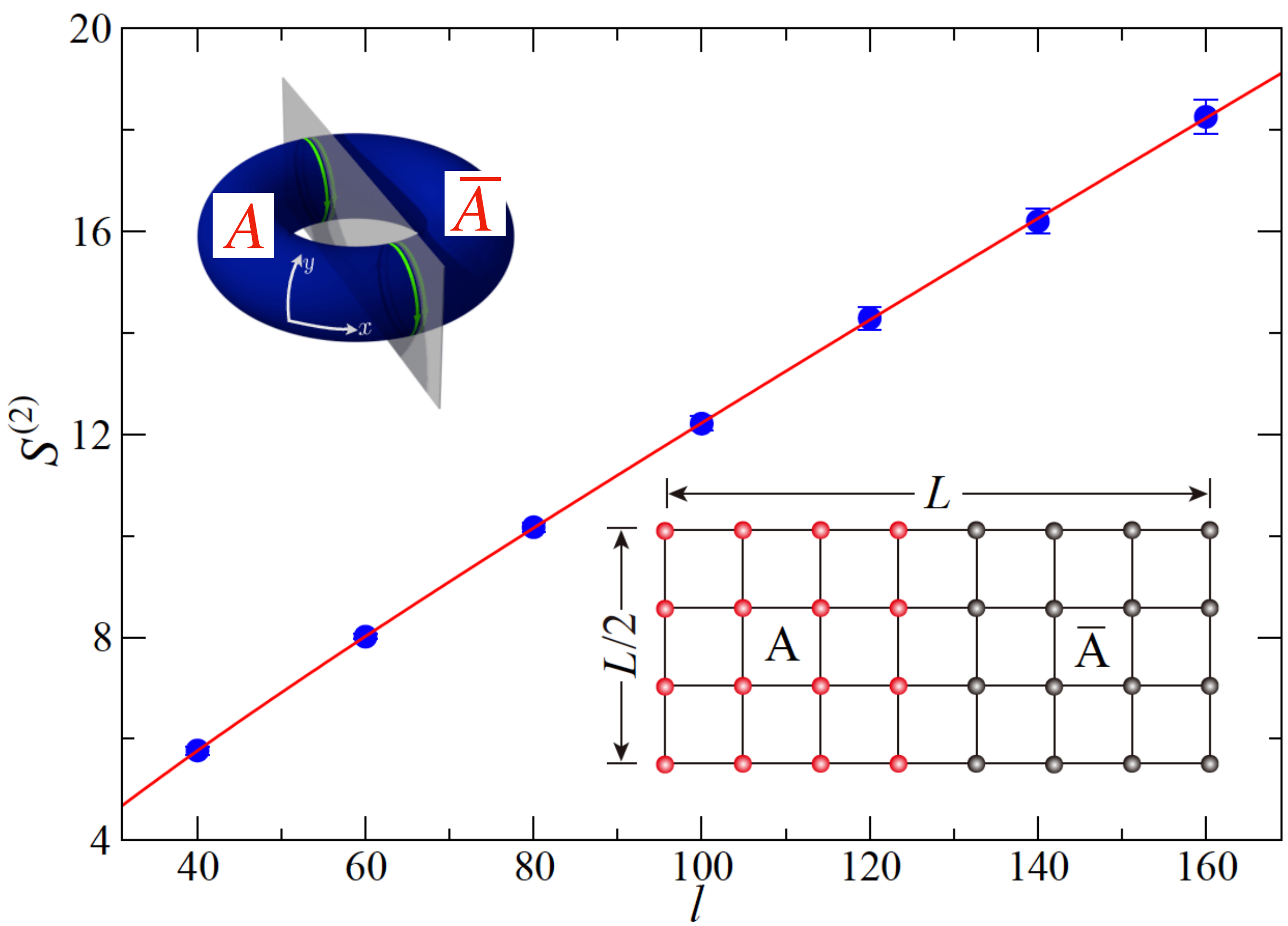
Corner

$$S_A^{(2)}(l) = al - s_C \ln(l) + c$$

(2+1)d SSB, O(3) QCP, Topological order Z2 QSL, GNY, FL, DQCP, SMG, …

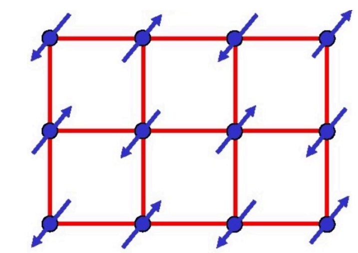
Spontaneous symmetry breaking phases: smooth boundary

- J. Zhao, B.-B Chen, Y.-C. Wang, Z. Yan, M. Cheng, ZYM, npj Quantum Materials 7, 69 (2022)
- M. Song, J. Zhao, ZYM, C. Xu, M. Cheng, arXiv:2312.?????



Square lattice Heisenberg model

$$H = J \sum_{\langle i,j \rangle} \mathbf{S}_i \cdot \mathbf{S}_j$$



Smooth boundary

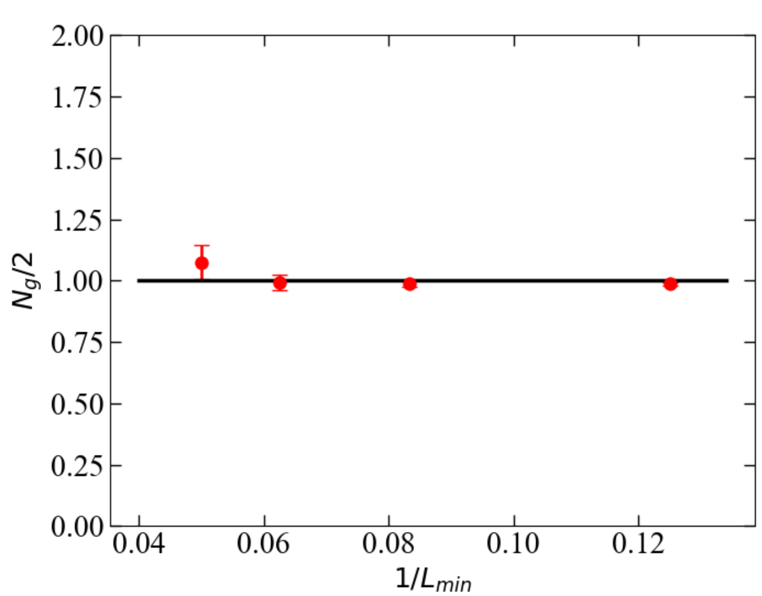
$$S_A^{(2)}(l) = al + s_G \ln(l) + c$$

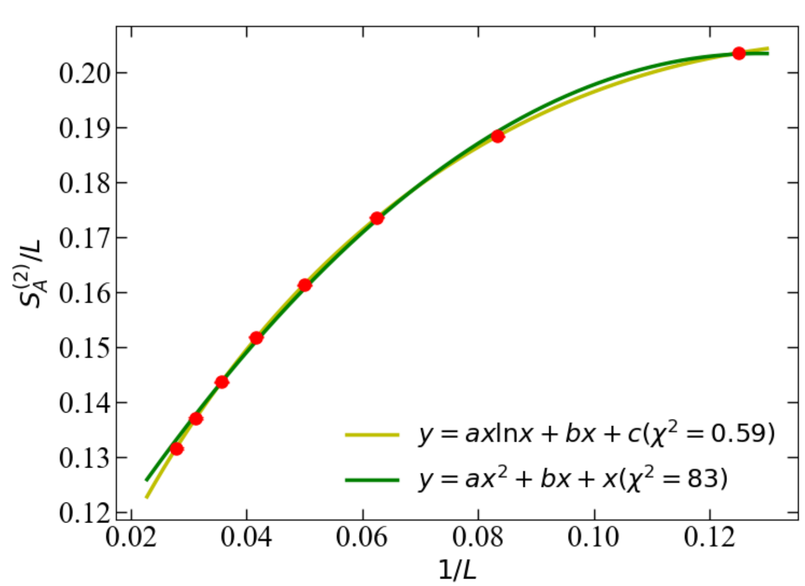
$$S_A^{(2)}(l) = 0.092(1)l + 1.0(1)\ln(l) - 1.63(3)$$

$$s_G = \frac{N_G}{2}$$

$$l \in [40,\ 160]$$

- Metlitski & Grover, arXiv:1112.5166





$$\frac{S_A^{(2)}(l)}{l} = s_G \frac{\ln(l)}{l} + \frac{c}{l} + a$$

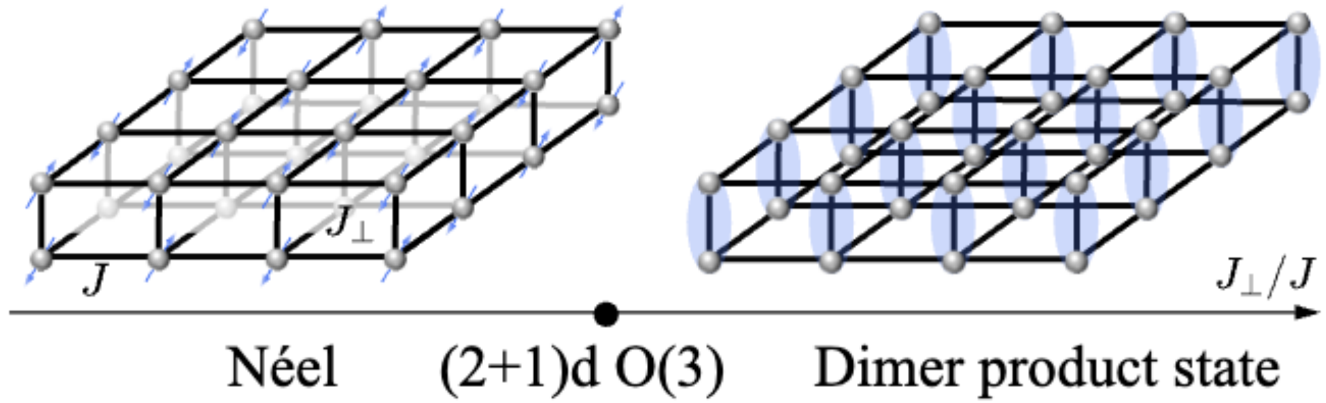
$$\frac{S_A^{(2)}(l)}{l} = \frac{b}{l^2} + \frac{c}{l} + a$$

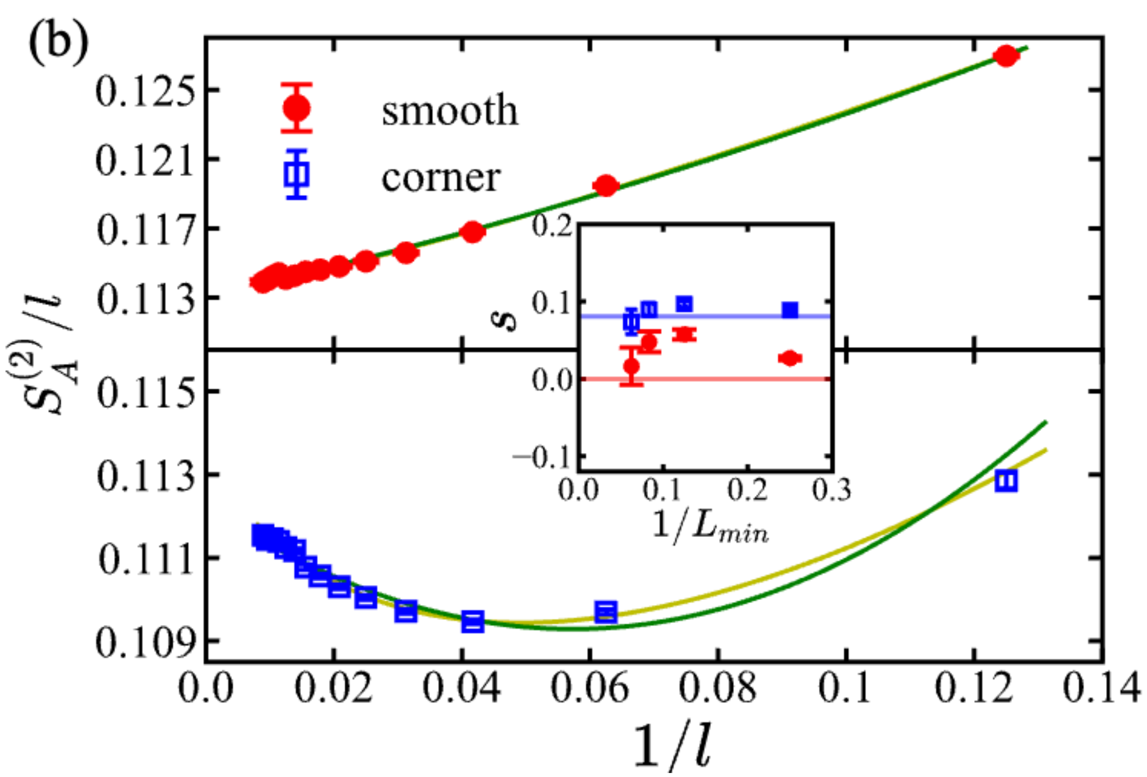
$\frac{1}{l}$ finite size correction

(2+1)d O(3) quantum critical points: smooth & corner

- J. Zhao, Y.-C. Wang, Z. Yan, M. Cheng, ZYM, PRL 128, 010601 (2022)
- M. Song, J. Zhao, ZYM, C. Xu, M. Cheng, arXiv:2312.?????

$$H = J\sum_{\langle i,j\rangle}(\mathbf{S}_{i,1}\cdot\mathbf{S}_{j,1}+\mathbf{S}_{i,2}\cdot\mathbf{S}_{i,2}) + J_\perp \sum_i \mathbf{S}_{i,1}\cdot\mathbf{S}_{i,2}$$





$$\frac{S_A^{(2)}(l)}{l} = a + \frac{c}{l} + \frac{b}{l^2} \qquad \frac{1}{l} \text{ finite size correction}$$

$$\frac{S_A^{(2)}(l)}{l} = a - s_c\frac{\ln l}{l} + \frac{c}{l}$$

	Fitted s from	χ^2/k	
	S/l vs $1/l$	$\ln l$	$1/l$
O(3), smooth	0.016±0.024	3.509	5.251
O(3), corner	0.074±0.015	2.217	11.41

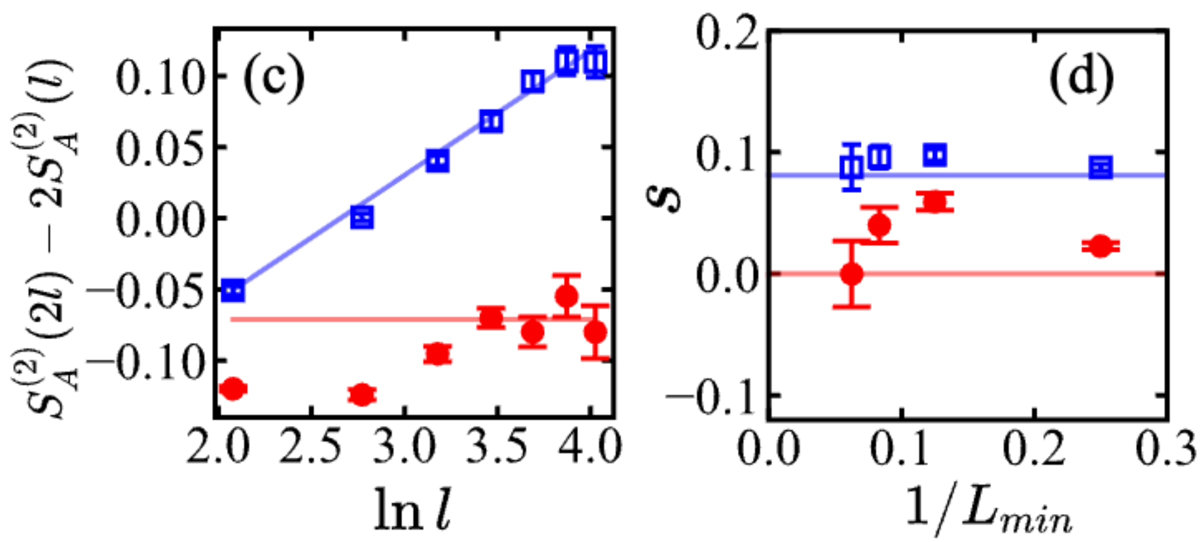
Substracted EE

$$S^S(l) = S_A(2l) - 2S_A(l)$$

$$S^s(l) = s\ln(l) - c$$

$$S^s(l) = b'/l - c$$

	Fitted s from	χ^2/k	
	$S(2l) - 2S(l)$	$\ln l$	$1/l$
O(3), smooth	0.000± 0.027	7.769	10.96
O(3), corner	0.088±0.018	1.938	22.44



$$s_G = 0.07(2)$$

- A. Kallin, et. al, J. Stat. Mech. P06009 (2014)
- J. Helmes, S. Wessel, Phys. Rev. B 89, 245120 (2014)

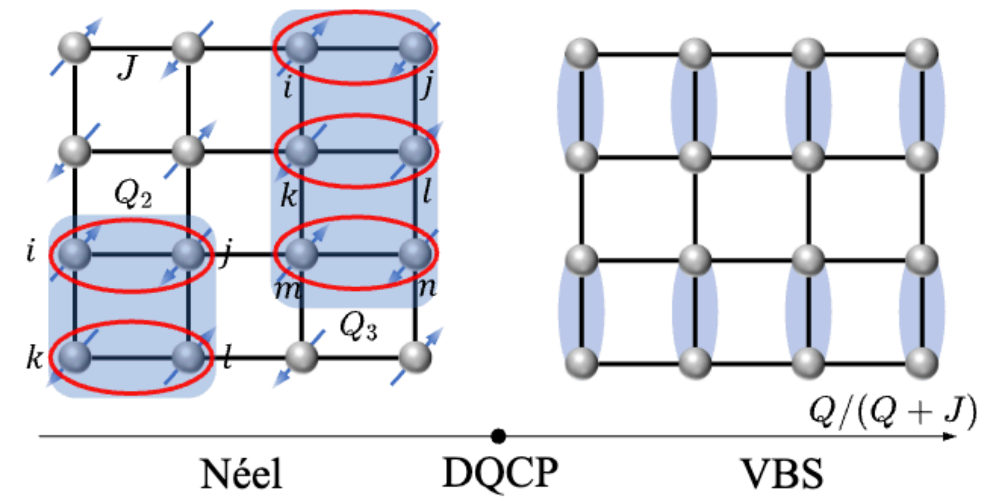
Deconfined quantum critical points: Corner

J. Zhao, Y.-C. Wang, Z. Yan, M. Cheng, ZYM, PRL 128, 010601 (2022)

JQ3 model $H = -J\sum_{\langle i,j \rangle} P_{i,j} - Q \sum_{\langle ijklmn \rangle} P_{ij}P_{kl}P_{mn}$

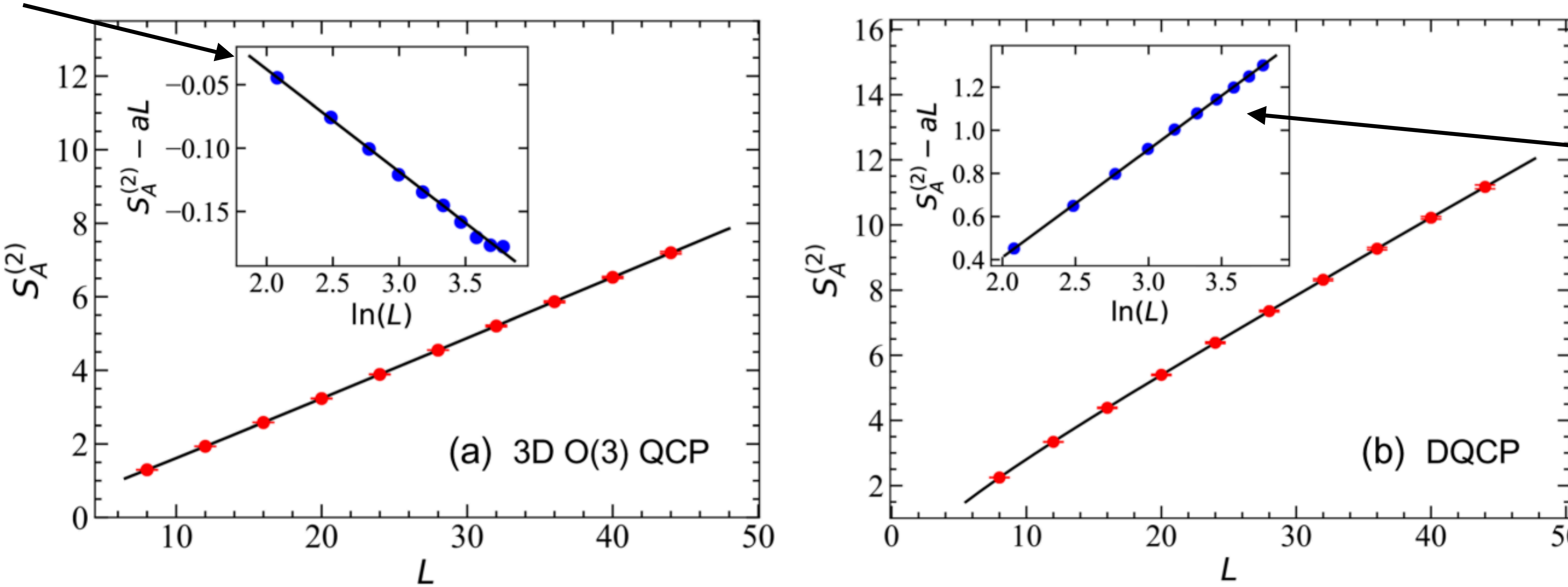
$$P_{ij} = \frac{1}{4} - \mathbf{S}_i \cdot \mathbf{S}_j$$

Deconfined QCP: $(Q/(J+Q))_c = 0.59864(4)$



$$S_A^{(2)}(l) = al - s_C \ln(l) + c$$

$s_C = 0.08 > 0$



$s_C < 0$

not a unitary CFT

Corner corrections for Renyi EE must be positive for unitary CFTs

H. Casini, M. Huerta, Journal of High Energy Physics 2012, 87 (2012)

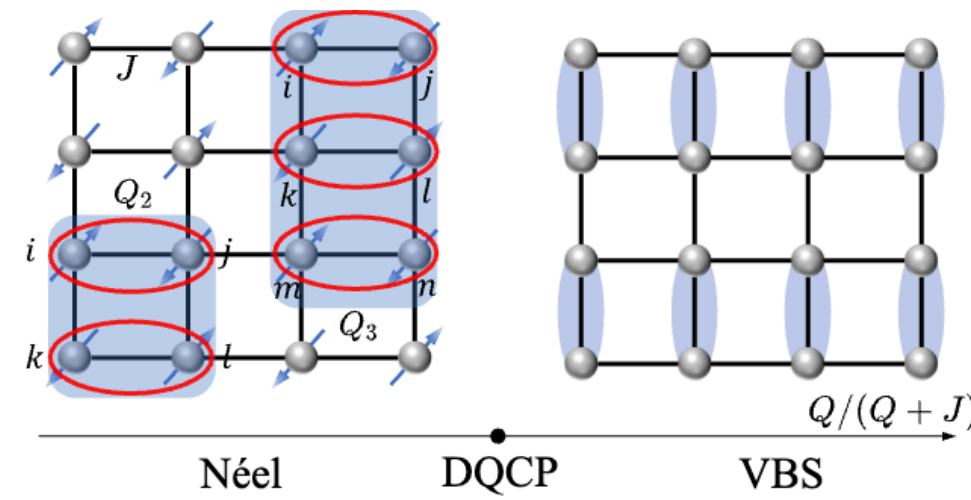
P. Bueno and W. Witczak-Krempa, PRB 93, 045131 (2016)

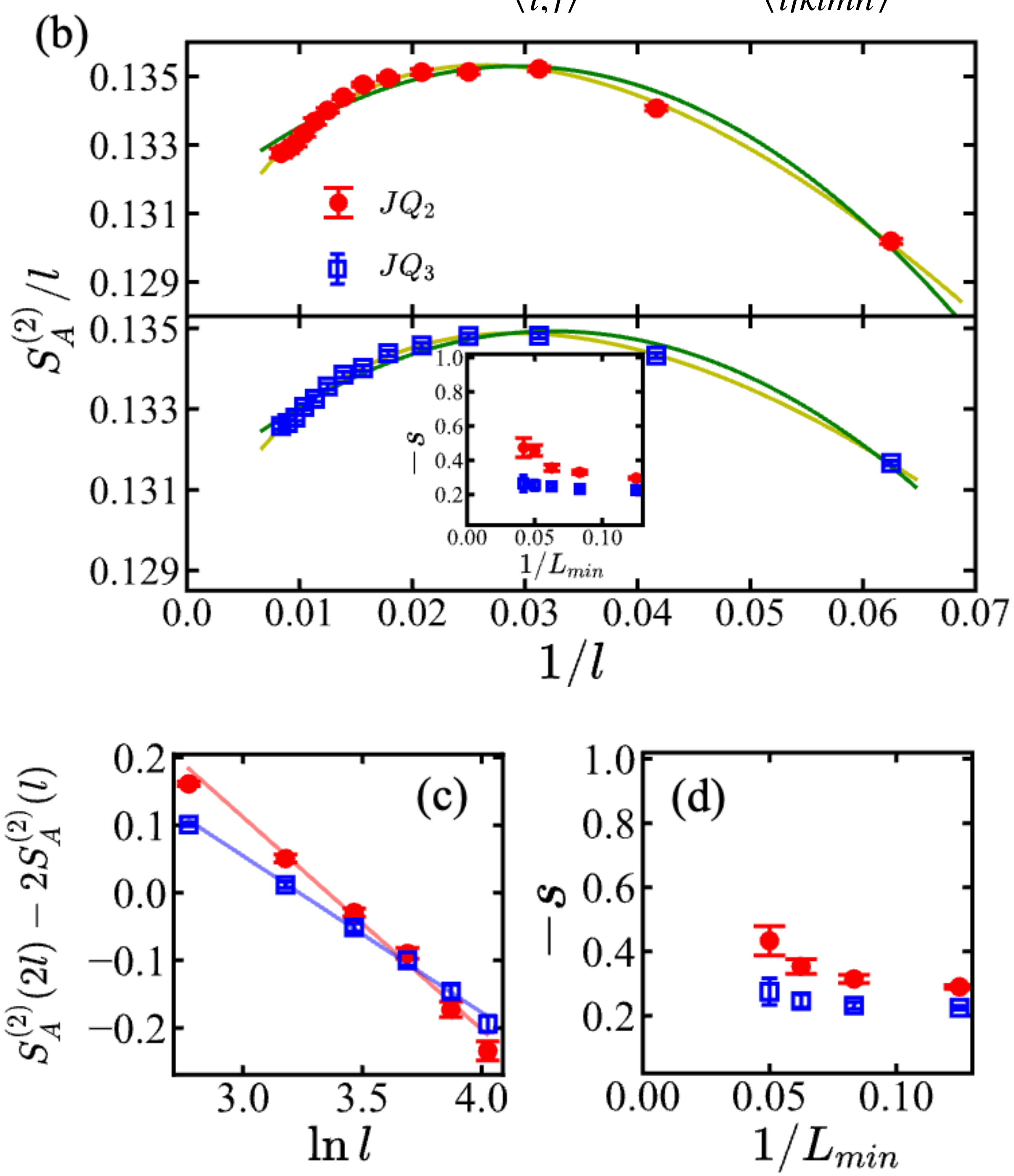
Deconfined quantum critical points: Smooth boundary

M. Song, J. Zhao, ZYM, C. Xu, M. Cheng, arXiv:2312.?????

JQ2 model: $H = -J\sum_{\langle i,j\rangle} P_{i,j} - Q\sum_{\langle ijkl\rangle} P_{ij}P_{kl}$

JQ3 model: $H = -J\sum_{\langle i,j\rangle} P_{i,j} - Q\sum_{\langle ijklmn\rangle} P_{ij}P_{kl}P_{mn}$





$$\frac{S_A^{(2)}(l)}{l} = a + \frac{c}{l} + \frac{b}{l^2}$$

$\frac{1}{l}$ finite size correction

$$\frac{S_A^{(2)}(l)}{l} = a - s\frac{\ln l}{l} + \frac{c}{l}$$

	Fitted s from S/l vs $1/l$	χ^2/k	
		$\ln l$	$1/l$
DQCP, JQ$_2$, smooth	-0.47±0.05	3.487	16.60
DQCP, JQ$_3$, smooth	-0.26±0.05	0.519	6.770

Substracted EE $S^S(l) = S_A(2l) - 2S_A(l)$

	Fitted s from $S(2l)-2S(l)$	χ^2/k	
		$\ln l$	$1/l$
DQCP, JQ$_2$, smooth	-0.43± 0.04	2.858	25.15
DQCP, JQ$_3$, smooth	-0.27± 0.04	0.478	13.1

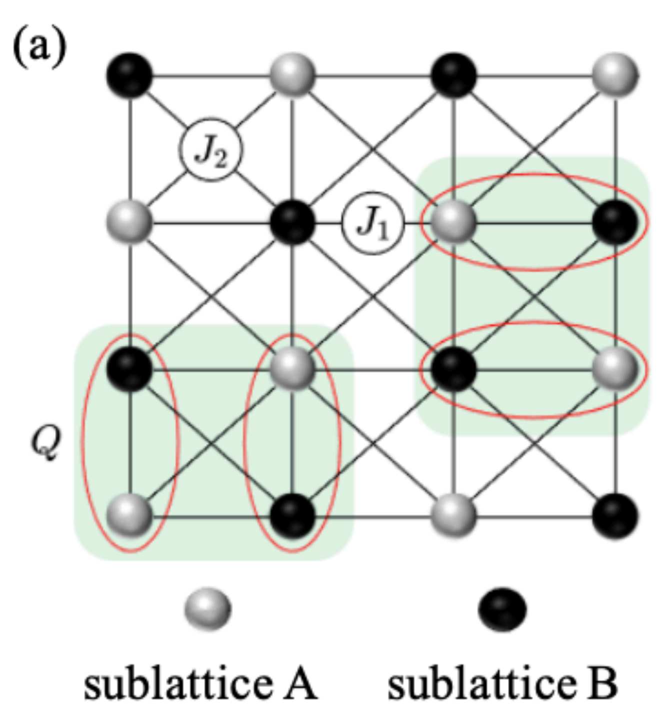
$-s > 0$ **Not a CFT, behave like Goldstone mode.**

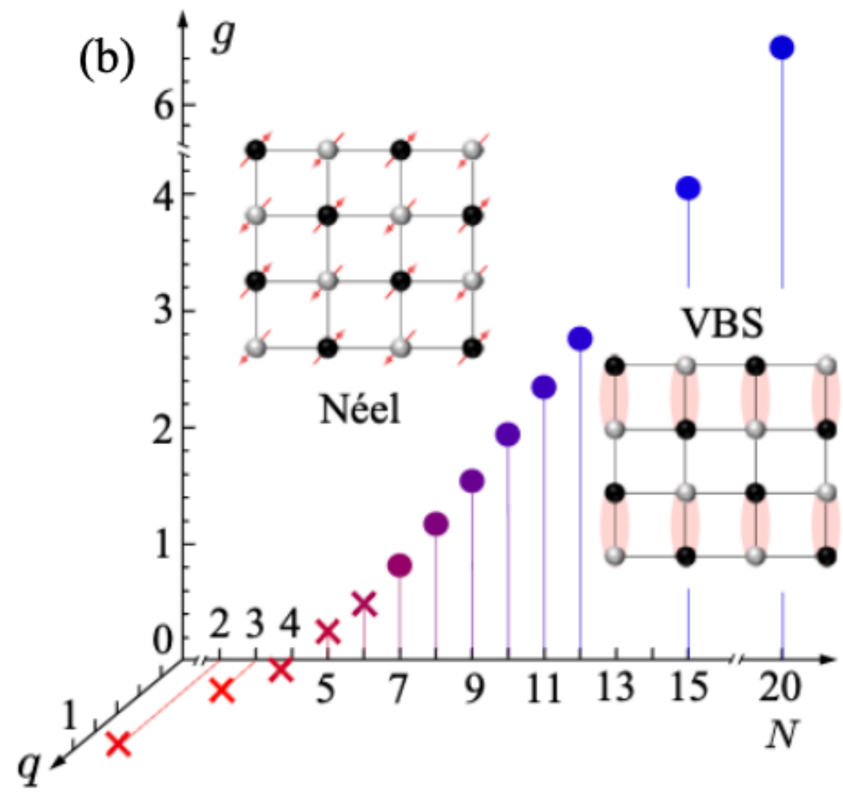
Smooth boundary $S_A^{(2)}(l) = al + s_G\ln(l) + c$

Deconfined quantum criticality lost

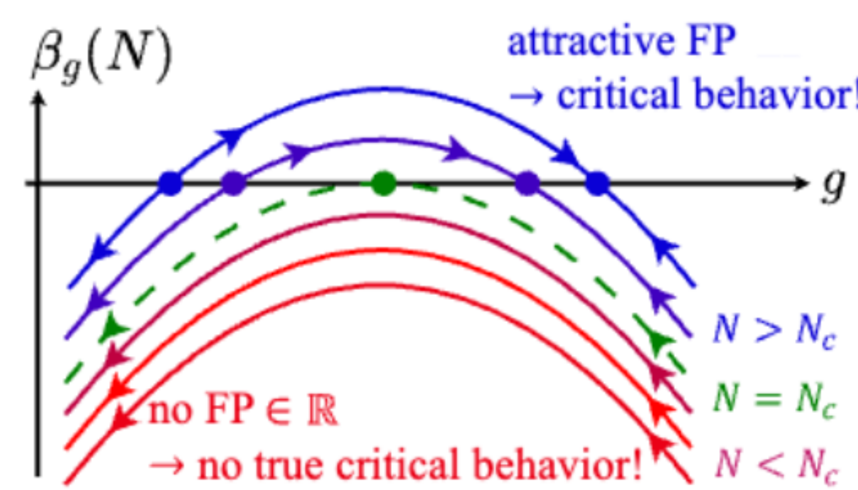
Menghan Song,[1] Jiarui Zhao,[1] Lukas Janssen,[2] Michael M. Scherer,[3] and Zi Yang Meng[1]

arXiv: 2307.02547





$$S_A^{(2)} = al - s\ln(l) - b$$



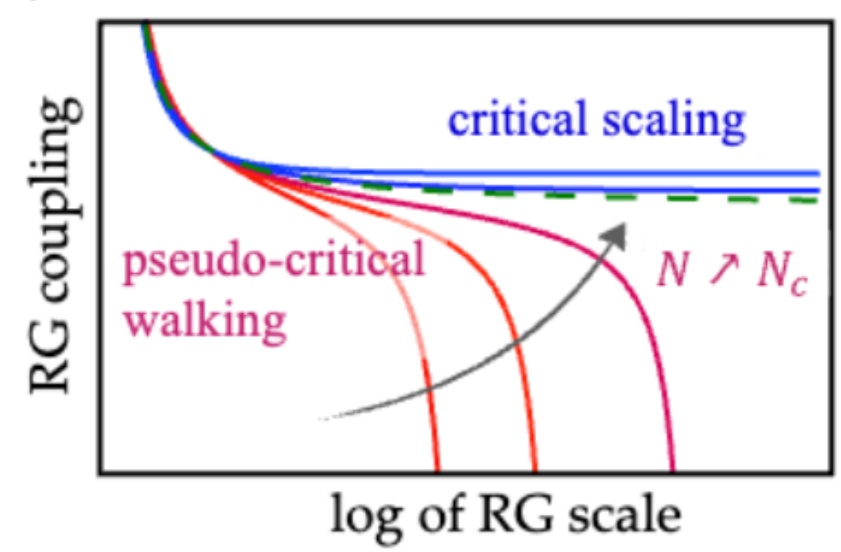
$$H = -\frac{J_1}{N}\sum_{\langle ij\rangle} P_{ij} - \frac{J_2}{N}\sum_{\langle\langle ij\rangle\rangle} \Pi_{ij} - \frac{Q}{N}\sum_{\langle ij\rangle,\langle kl\rangle} P_{ij}P_{kl}$$

SU(N) fundamental rep. $|\alpha\rangle_A \rightarrow U_{\alpha,\beta}|\beta\rangle_A$

SU(N) conjugate rep. $|\alpha\rangle_B \rightarrow U^*_{\alpha,\beta}|\beta\rangle_B$

P_{ij} SU(N) singlet projection

$\Pi_{ij}|\alpha\beta\rangle = |\beta\alpha\rangle$ SU(N) permutation with the same rep



Deconfined quantum criticality lost

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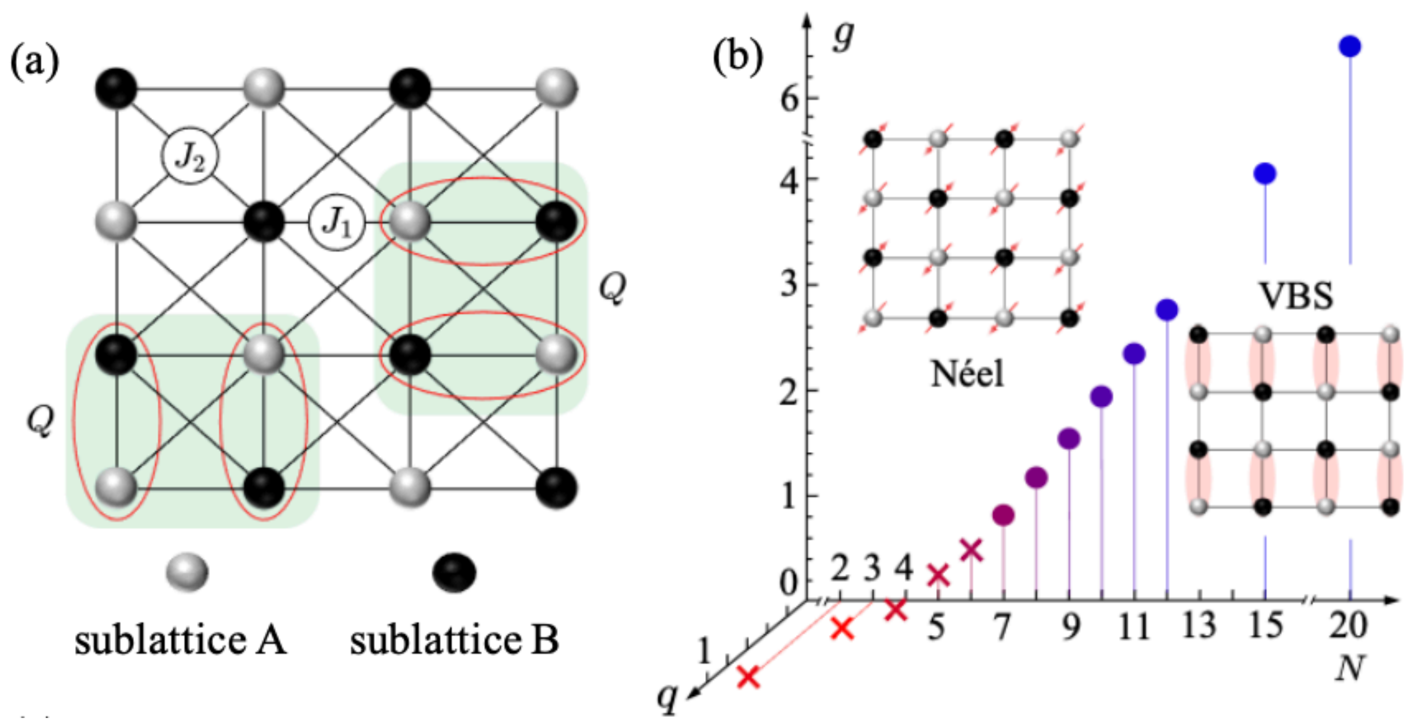
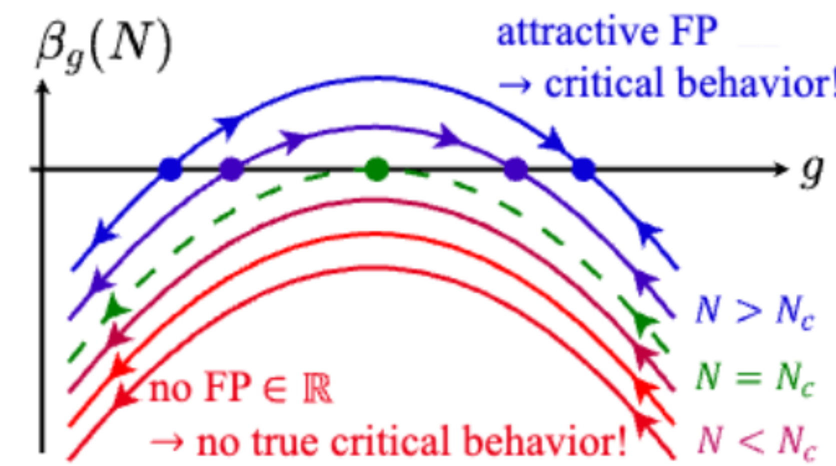
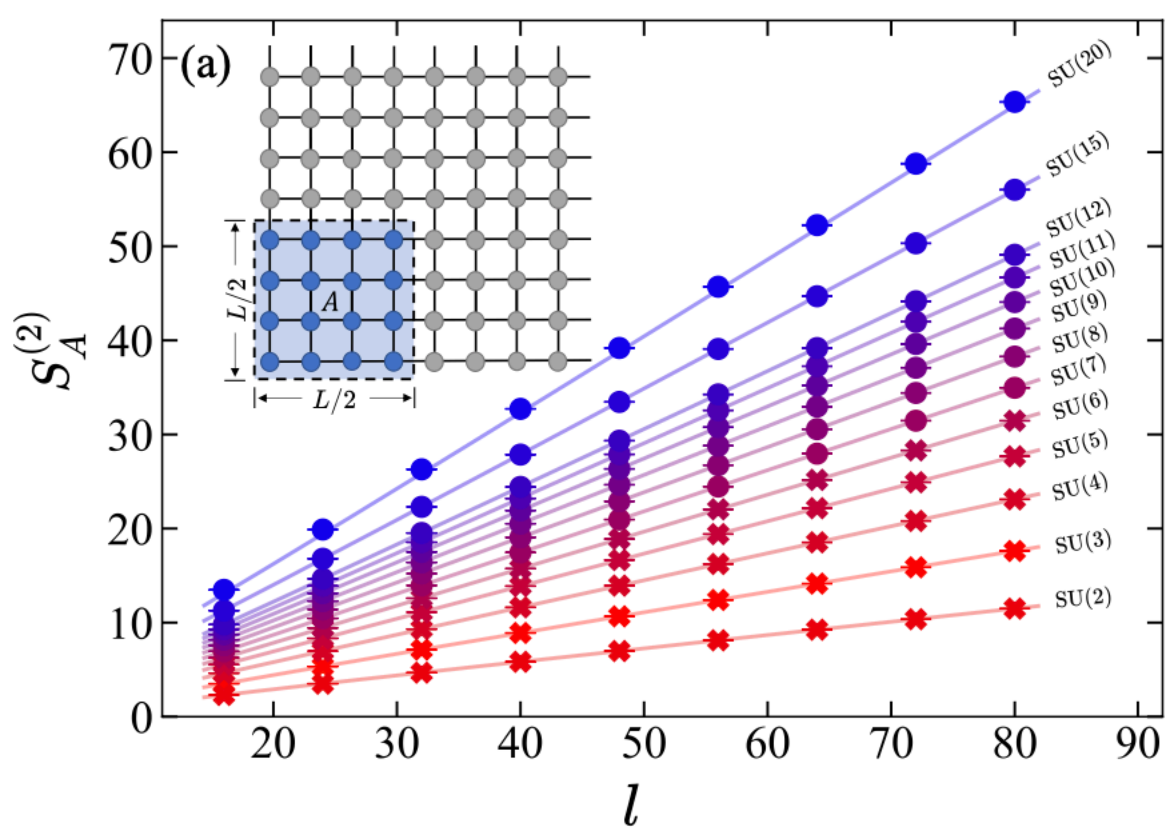
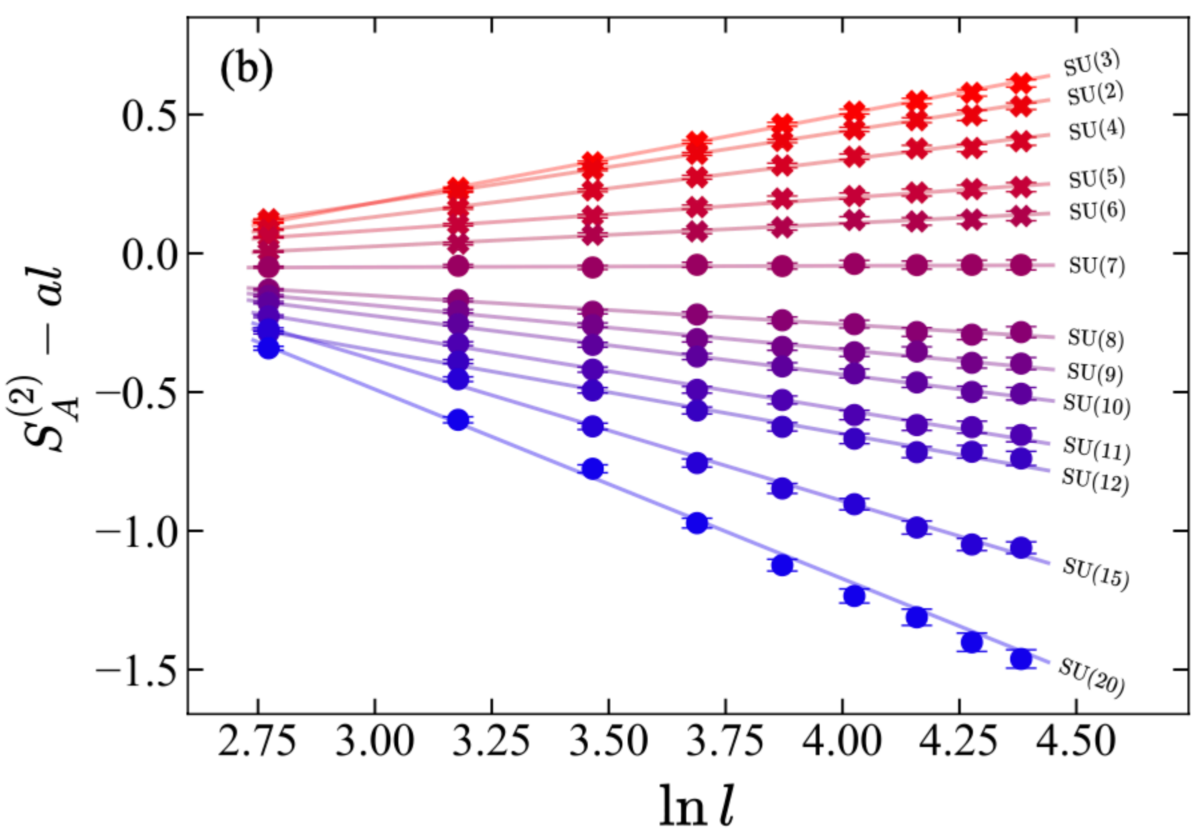




$$S_A^{(2)} = al - s\ln(l) - b$$





Deconfined quantum criticality lost

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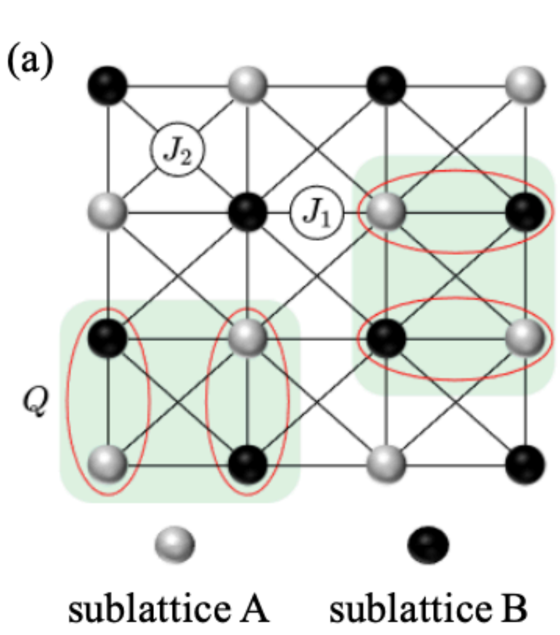
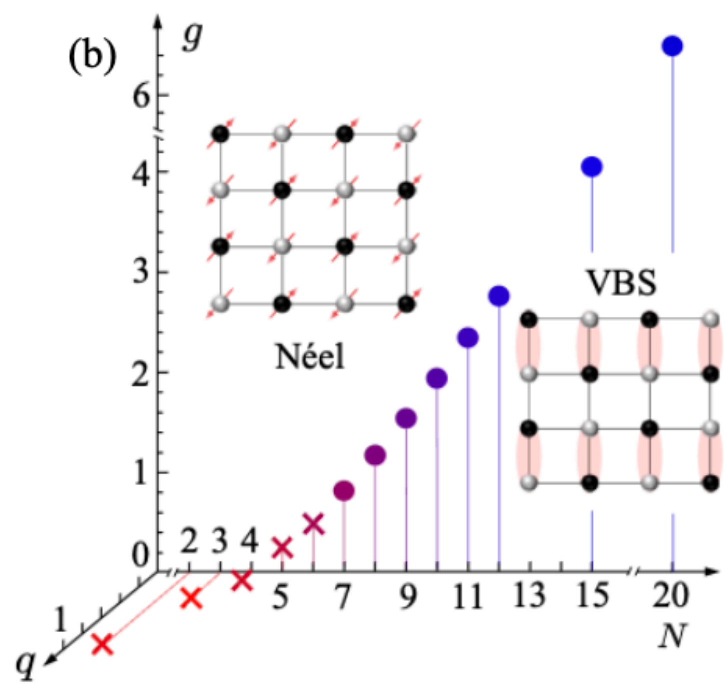
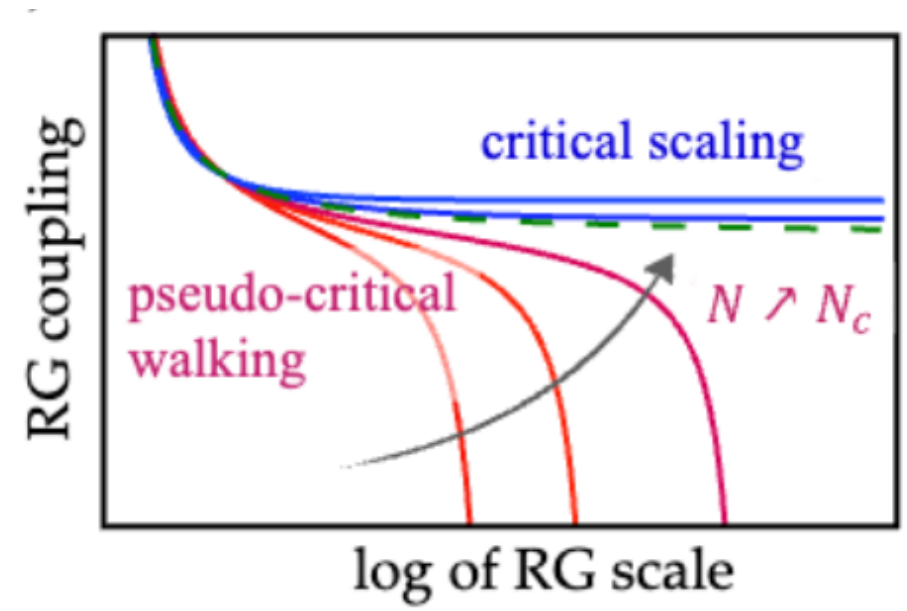
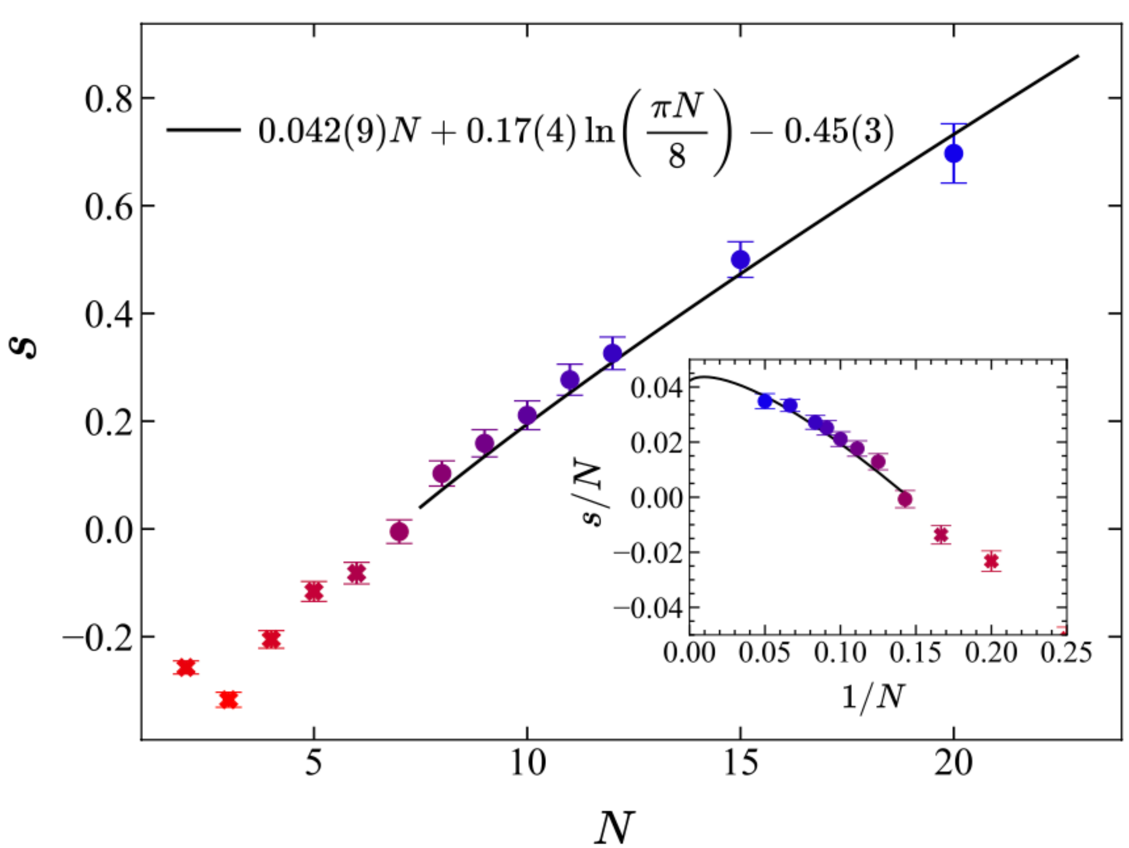
arXiv: 2307.02547

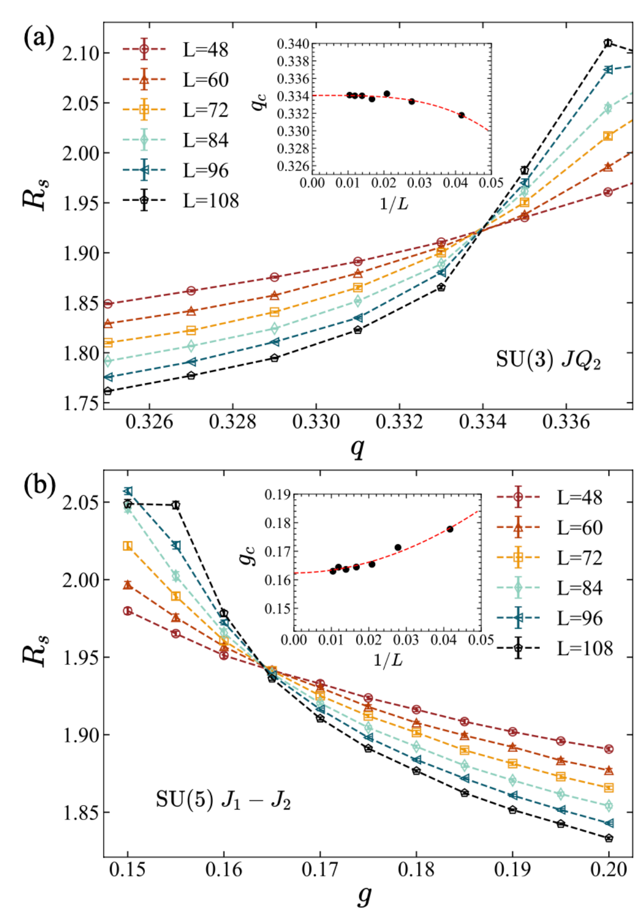


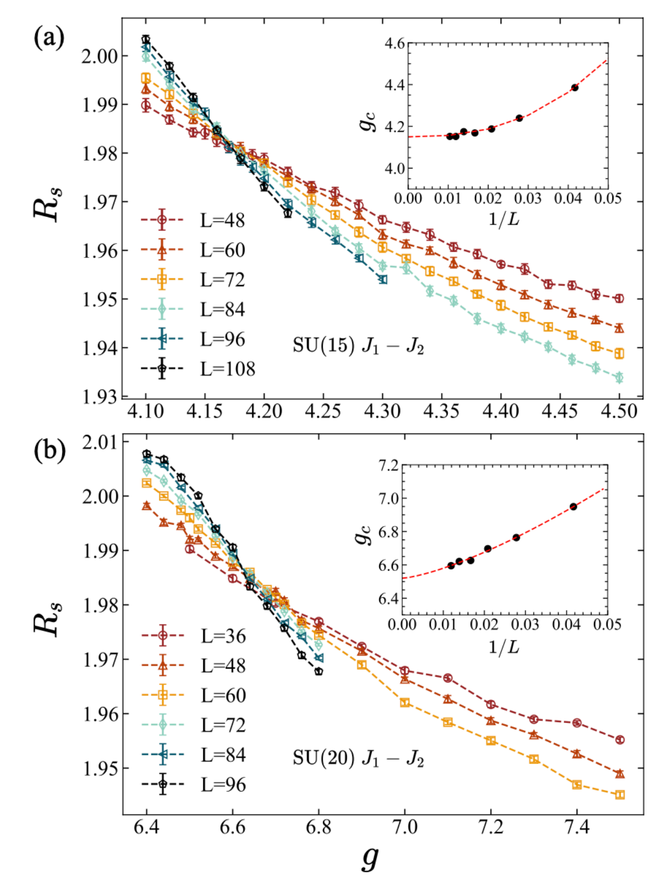




$$s(N) = a_s N + b_s \ln\left(\frac{\pi N}{8}\right) + c_s + \mathcal{O}(1/N)$$







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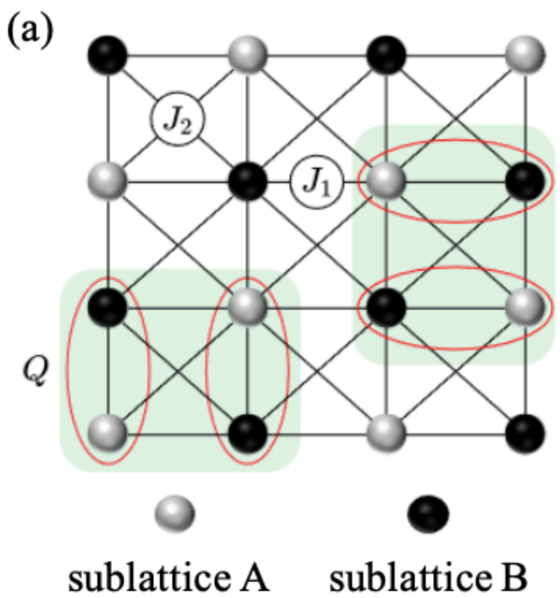
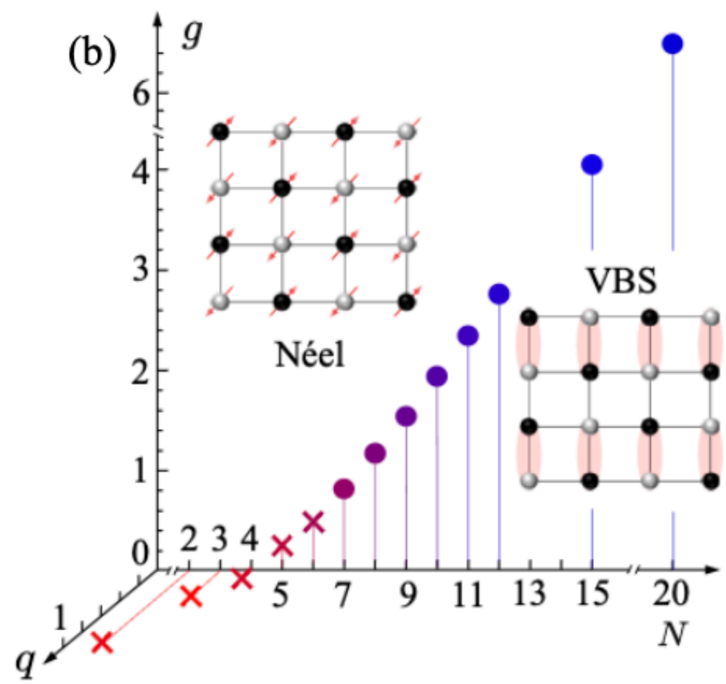
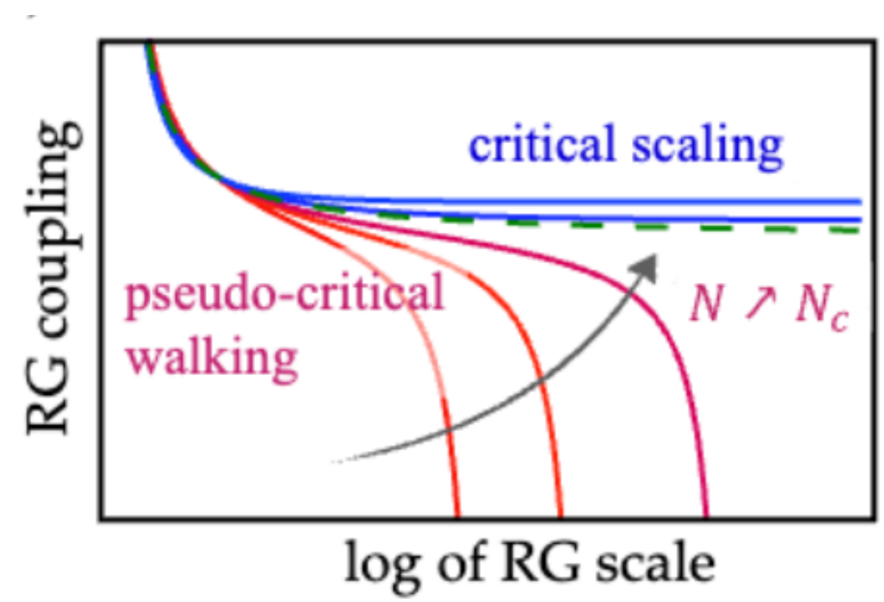
arXiv: 2307.02547







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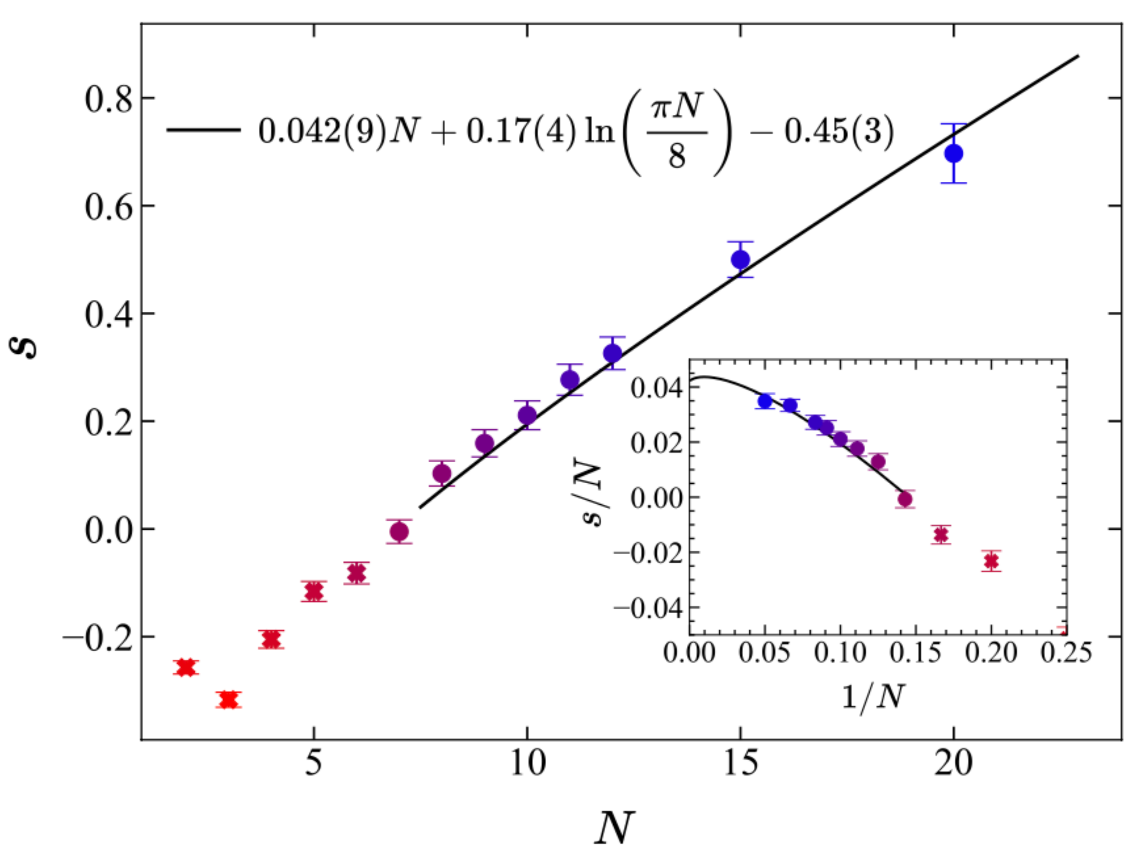
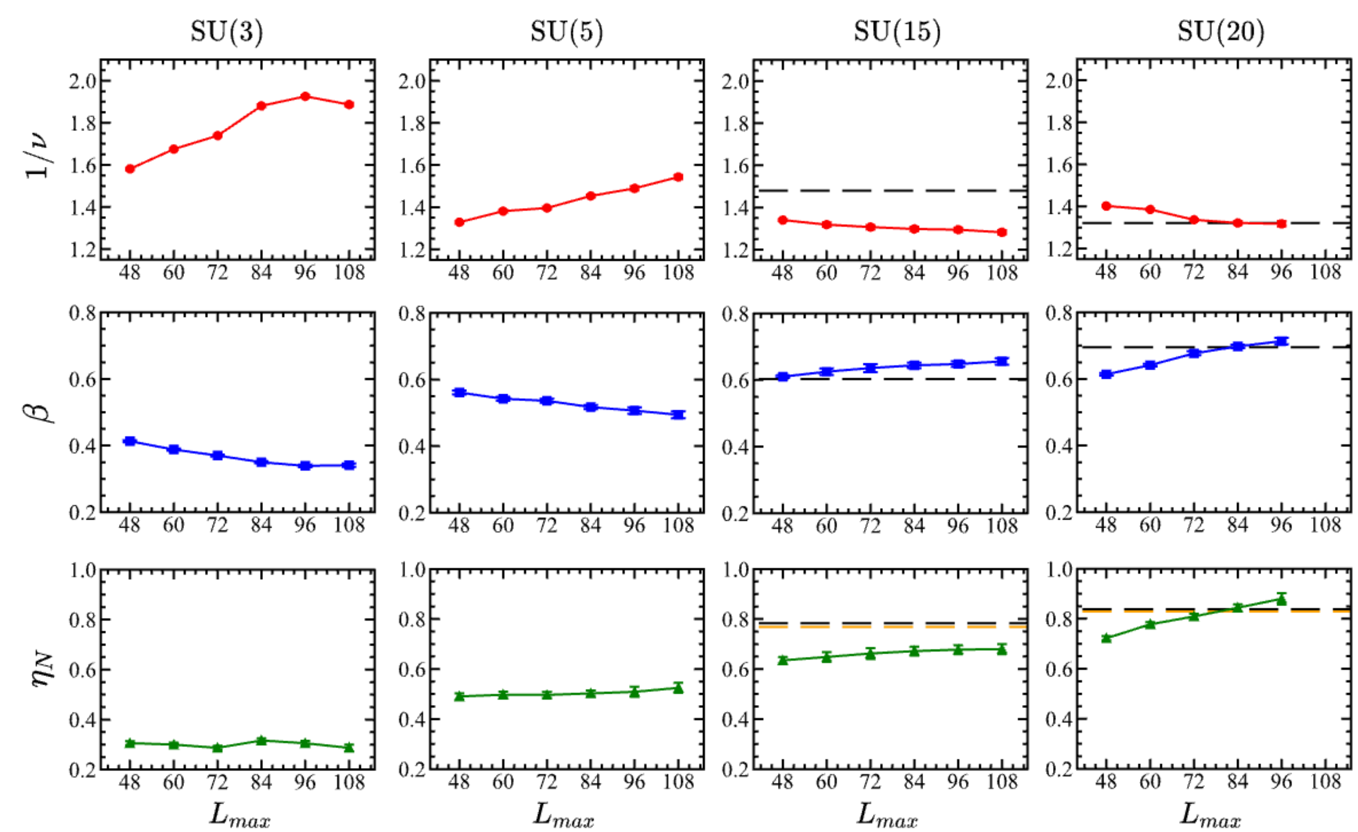




Phases of (2+1)D SO(5) non-linear sigma model with a topological term on a sphere: multicritical point and disorder phase

Bin-Bin Chen,[1] Xu Zhang,[1] Yuxuan Wang,[2,*] Kai Sun,[3,†] and Zi Yang Meng[1,‡]

- M. Ippoliti, R. Mong, F. Assaad, M. Zaletel, PRB 98, 235108 (2018)
- Z. Wang, M. Zaletel, R. Mong, F. Assaad, PRL 126, 045701 (2021)

arXiv: 2307.05307

$$S = \frac{1}{g}\int d^3x(\nabla\hat{\boldsymbol{\varphi}})^2 + S_{\mathrm{WZW}} + \cdots$$

$$H = \frac{1}{2}\int d\Omega\{U_0[\psi^\dagger(\Omega)\psi(\Omega) - 2]^2 - \sum_{i=1}^{5} u_i[\psi^\dagger(\Omega)\Gamma^i\psi(\Omega)]^2\}$$

$\psi_{\tau\sigma}(\Omega)$ $\quad$ $\Gamma^i = \{\tau_x \otimes \mathbb{I}, \tau_y \otimes \mathbb{I}, \tau_z \otimes \sigma_x, \tau_z \otimes \sigma_y, \tau_z \otimes \sigma_z\}$

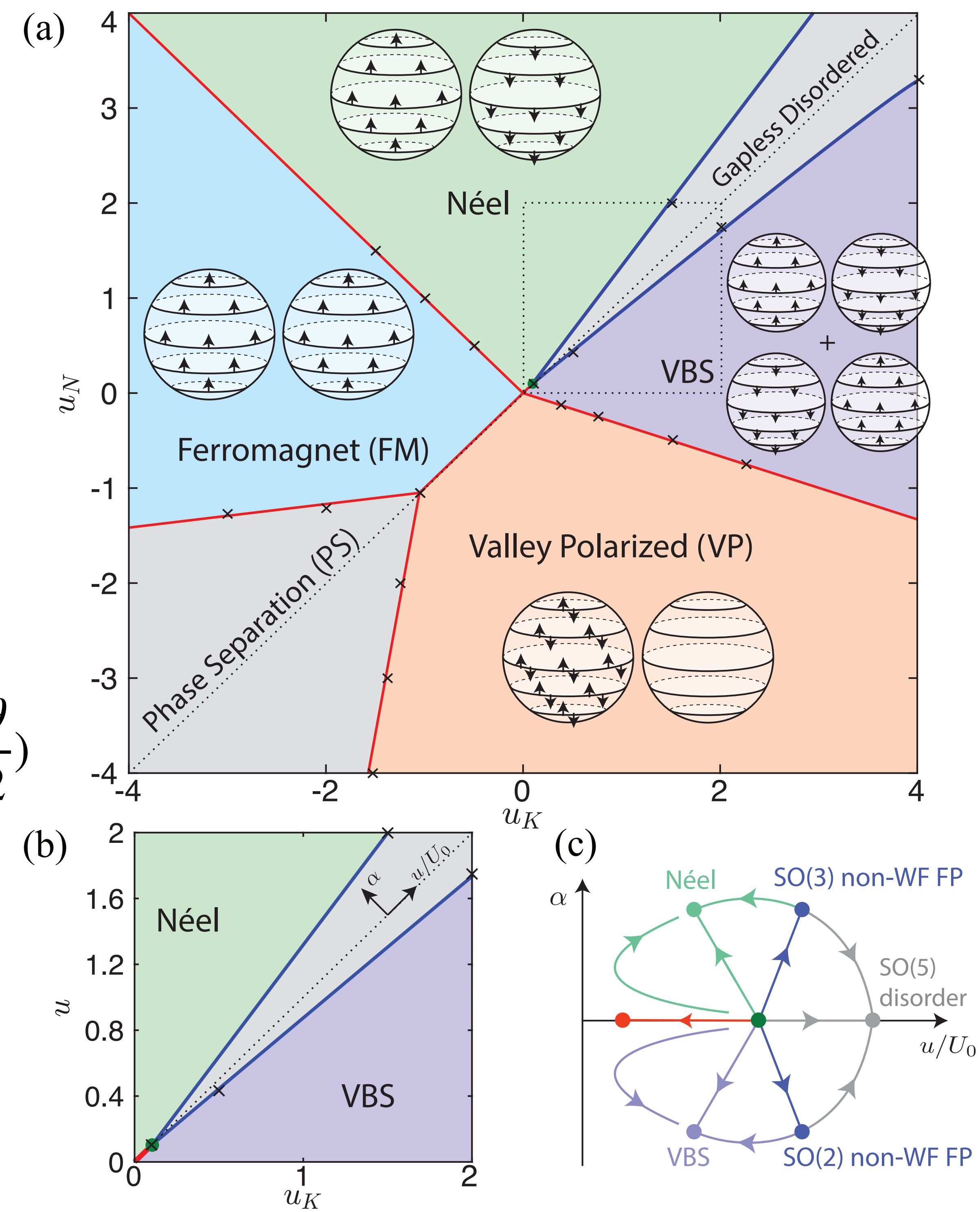
magnet monopole inside a sphere $\quad 4\pi s$

Projected to the LLL with degeneracy $\quad N = 2s + 1$

$$\psi(\Omega) = \sum_{m=-s}^{s} \Phi_m(\Omega)c_m \qquad \Phi_m(\Omega) \propto e^{im\phi}\cos^{s+m}(\frac{\theta}{2})\sin^{s-m}(\frac{\theta}{2})$$

$$\hat{H}_\Gamma = U_0\hat{H}_0 - \sum_i u_i\hat{H}_i, \text{with}$$

$$\hat{H}_i = \sum_{m_1,m_2,m} V_{m_1,m_2,m_2-m,m_1+m} \times \left(c^\dagger_{m_1}\Gamma^i c_{m_1+m} - 2\delta_{i0}\delta_{m0}\right)\left(c^\dagger_{m_2}\Gamma^i c_{m_2-m} - 2\delta_{i0}\delta_{m0}\right)$$



Phases of (2+1)D SO(5) non-linear sigma model with a topological term on a sphere: multicritical point and disorder phase

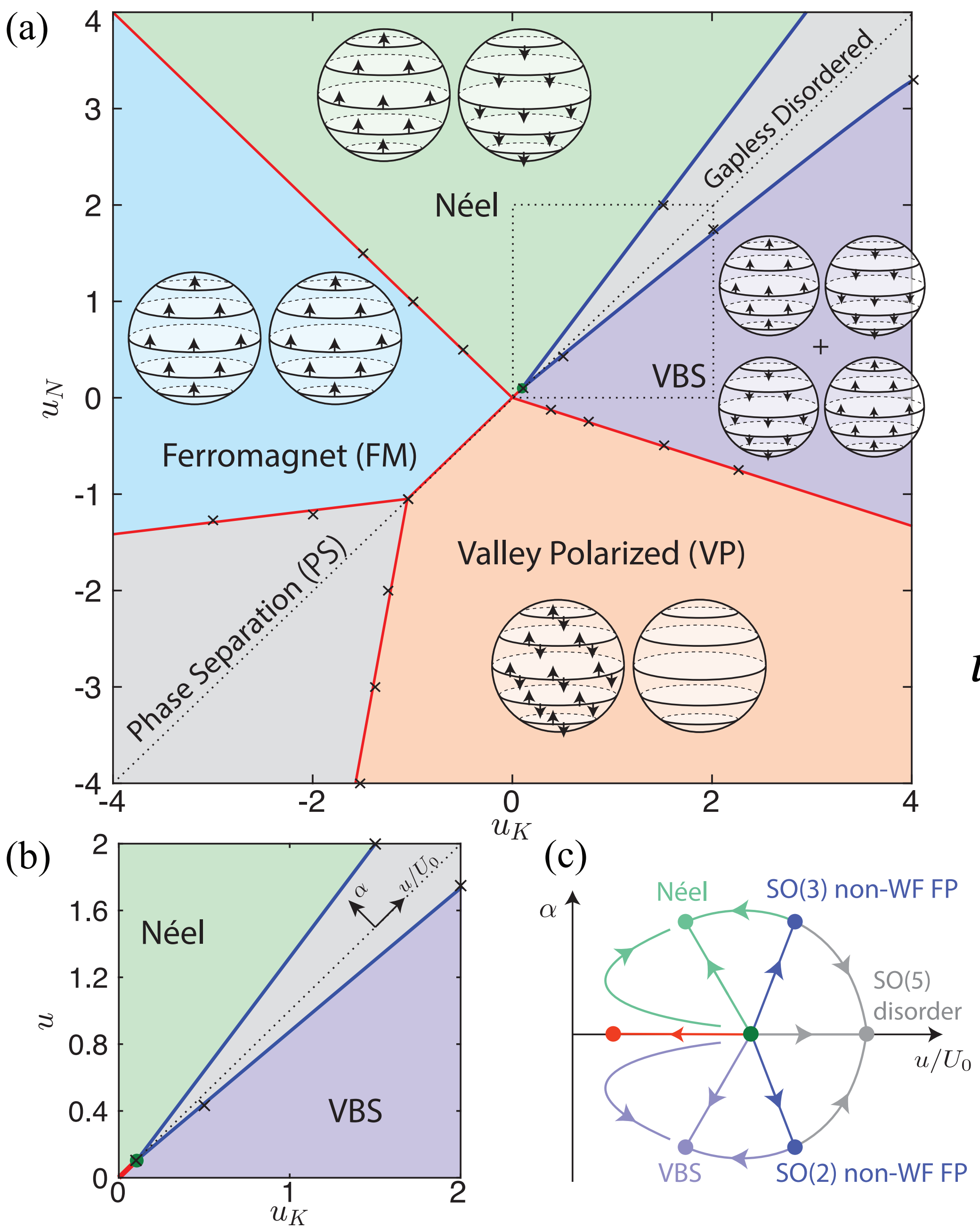
Bin-Bin Chen,[1] Xu Zhang,[1] Yuxuan Wang,[2,*] Kai Sun,[3,†] and Zi Yang Meng[1,‡]

arXiv: 2307.05307

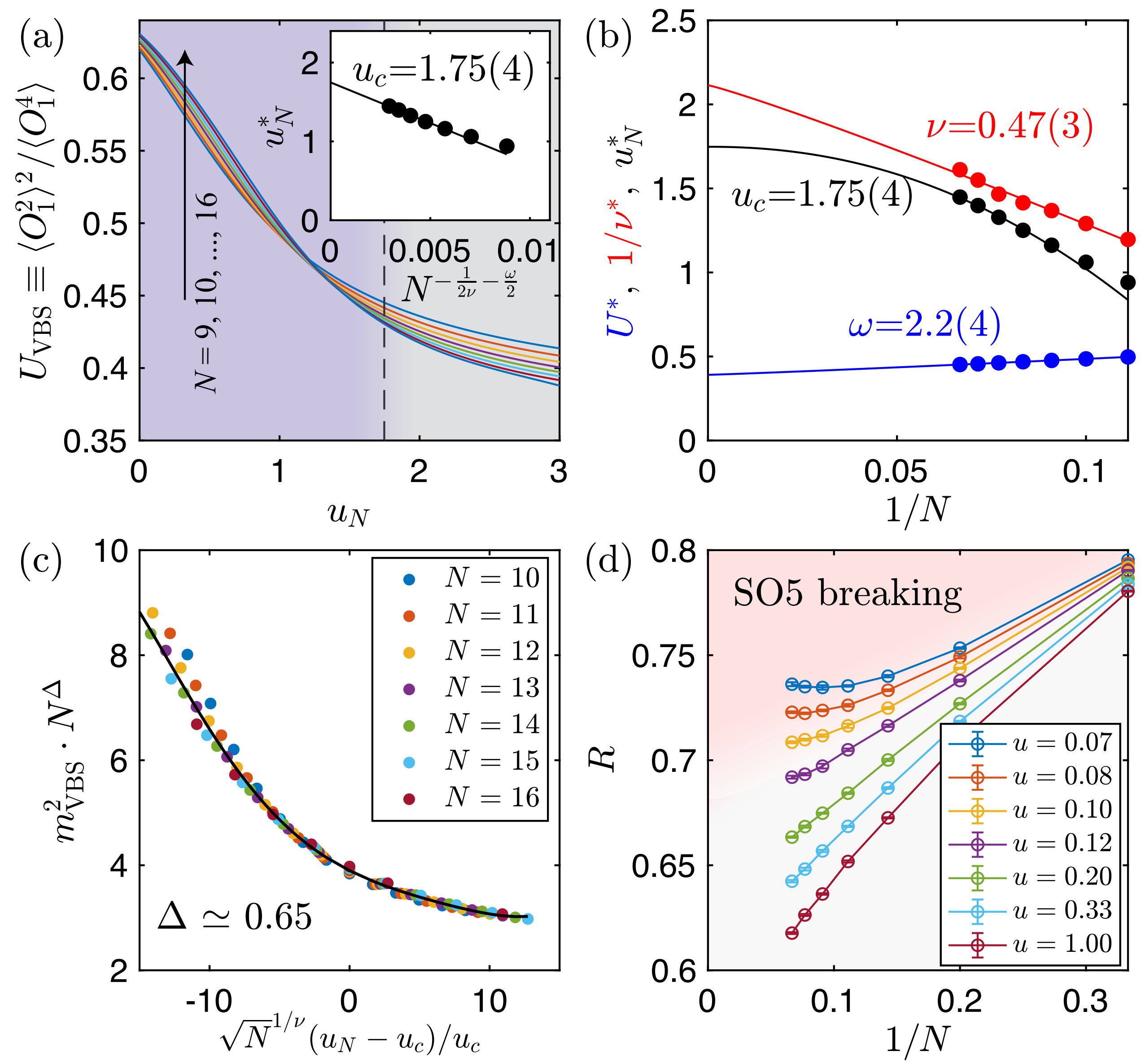
$$U_0 = 1,\ u_1 = u_2 = u_K, u_3 = u_4 = u_5 = u_N$$

$$\langle O_i \rangle = \int d\Omega \psi^\dagger(\Omega)\Gamma^i \psi(\Omega) = \sum_{m=-s}^{s} c_m^\dagger \Gamma^i c_m$$

$$m^2_{VBS} = \frac{1}{2N^2}\langle (O_1^2 + O_2^2)\rangle \qquad m^2_{Neel} = \frac{1}{3N^2}\langle (O_3^2 + O_4^2 + O_5^2)\rangle$$



$$u_K = 2$$



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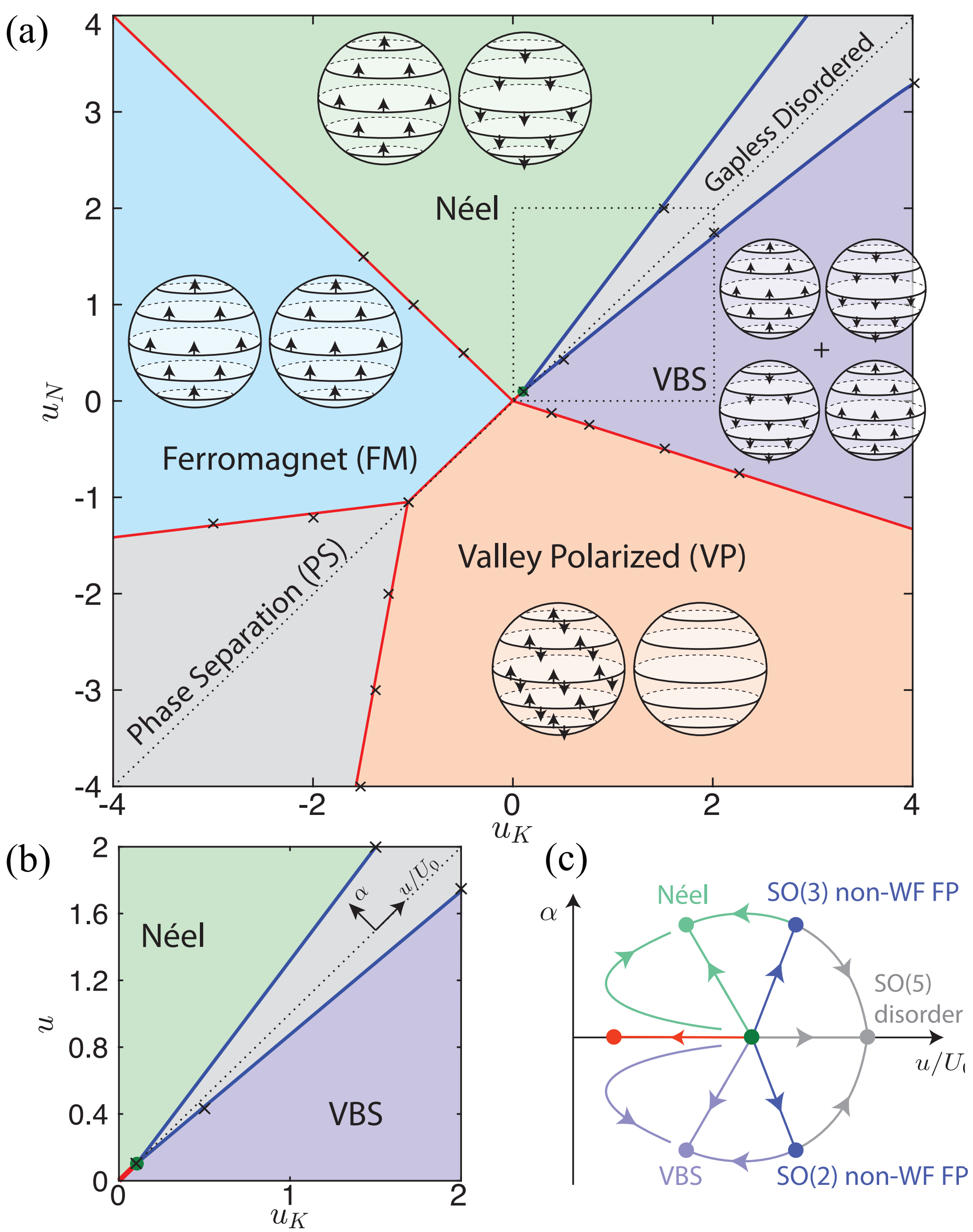

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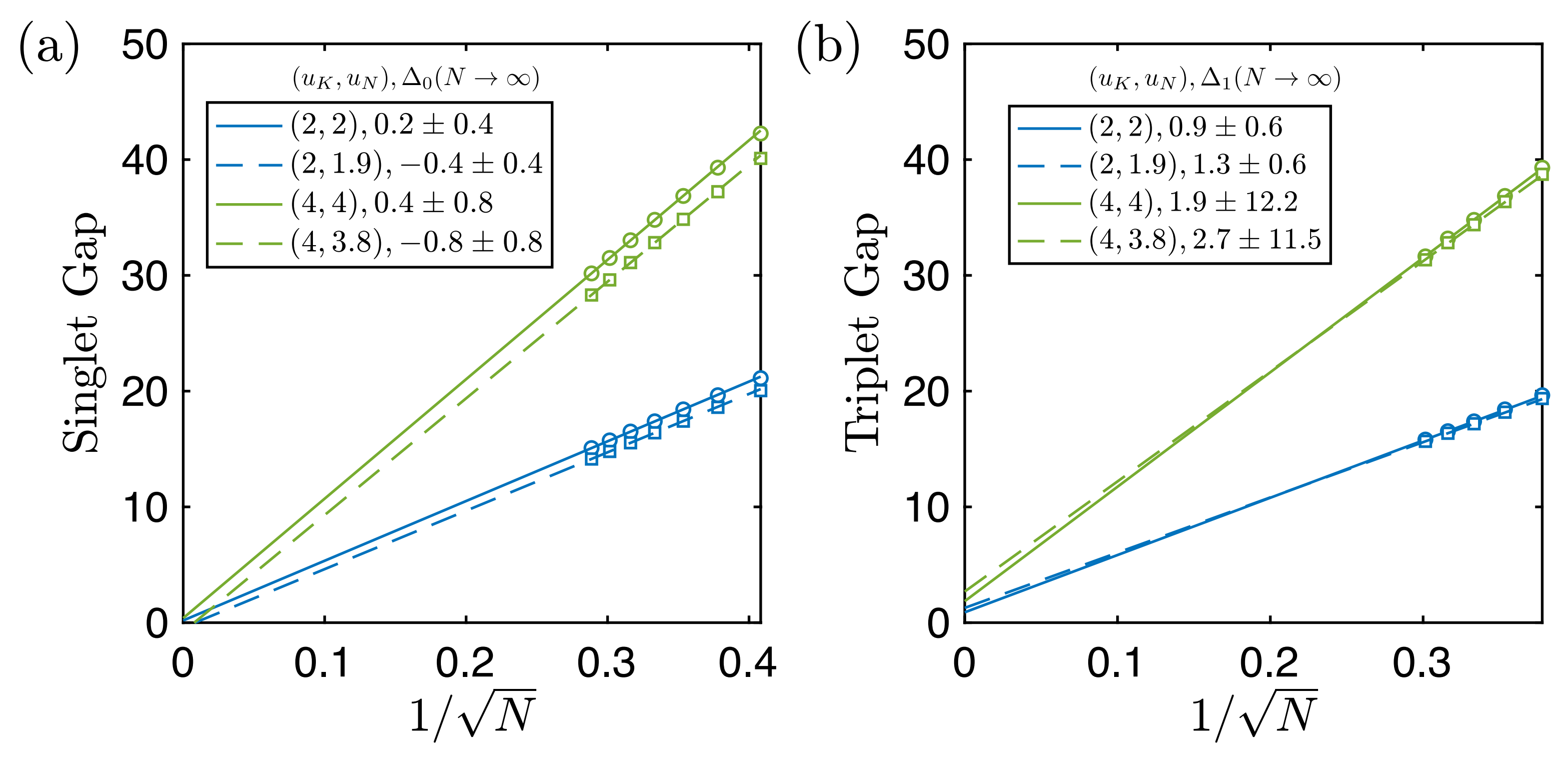

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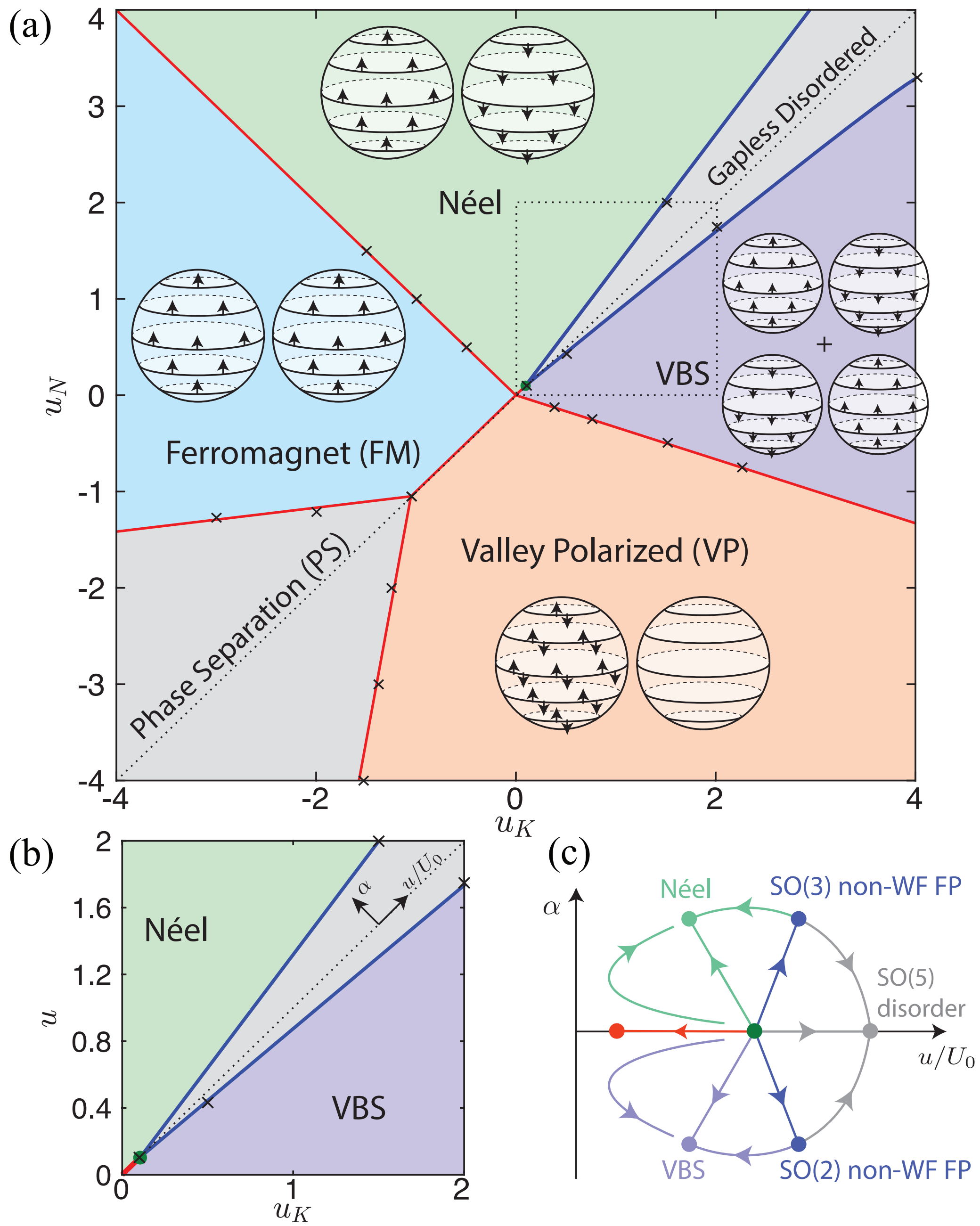
arXiv: 2307.05307



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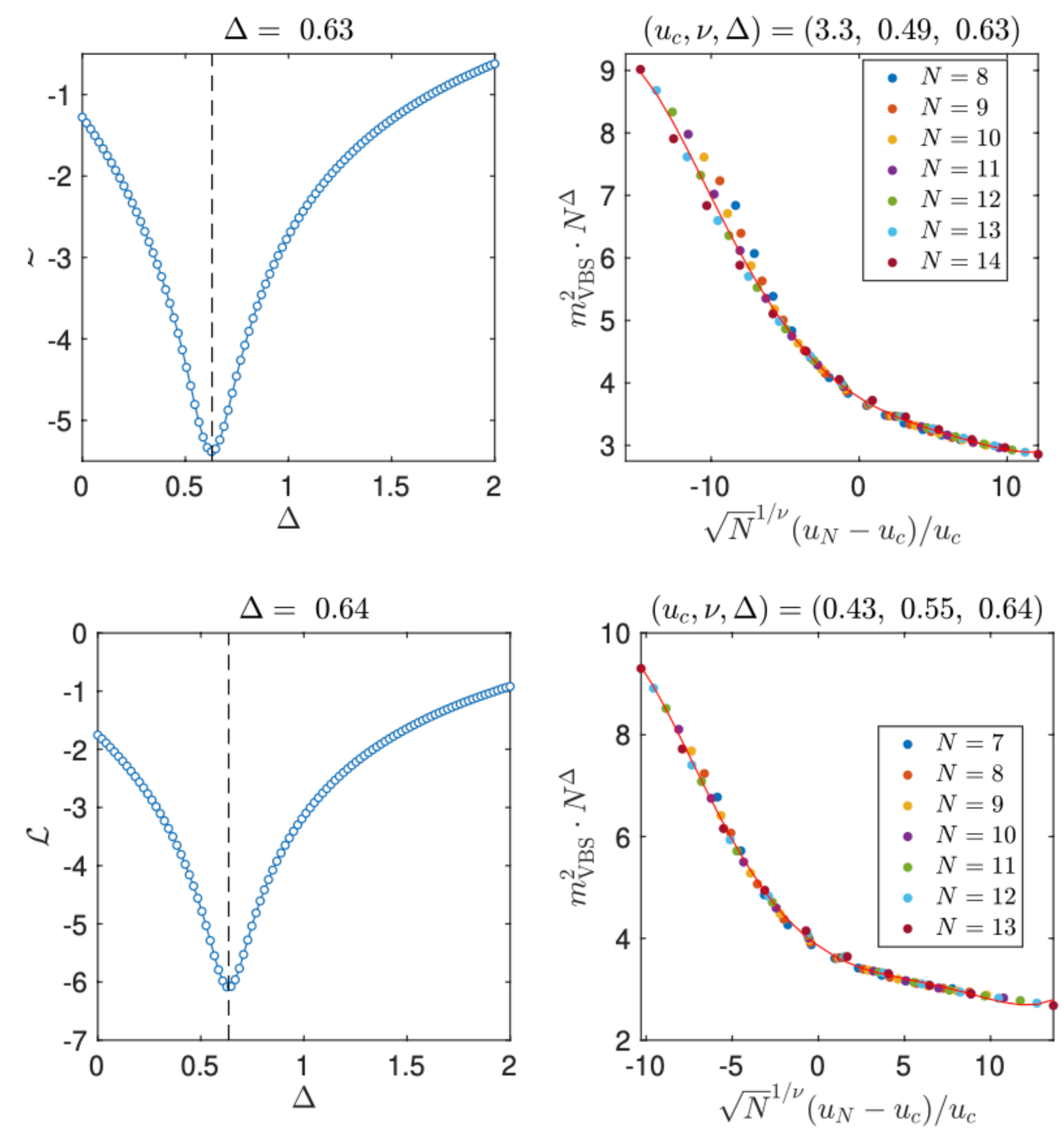
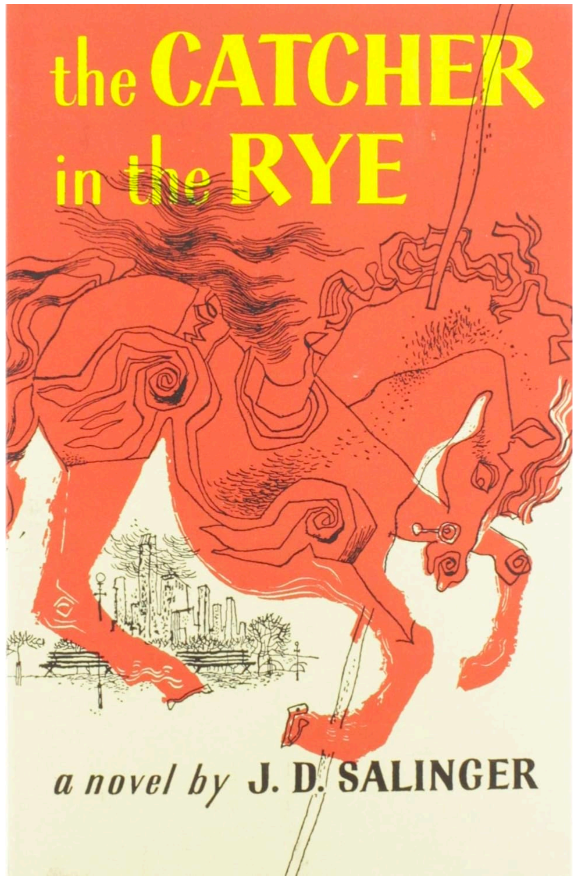
$u_K = 4$

$u_K = 0.5$





A coming of age story, themes of angst and alienation, and a critique of superficiality in society (phonies). Holden Caulfield, J. D. Salinger's adolescent antihero, has become an icon for teenage rebellion.

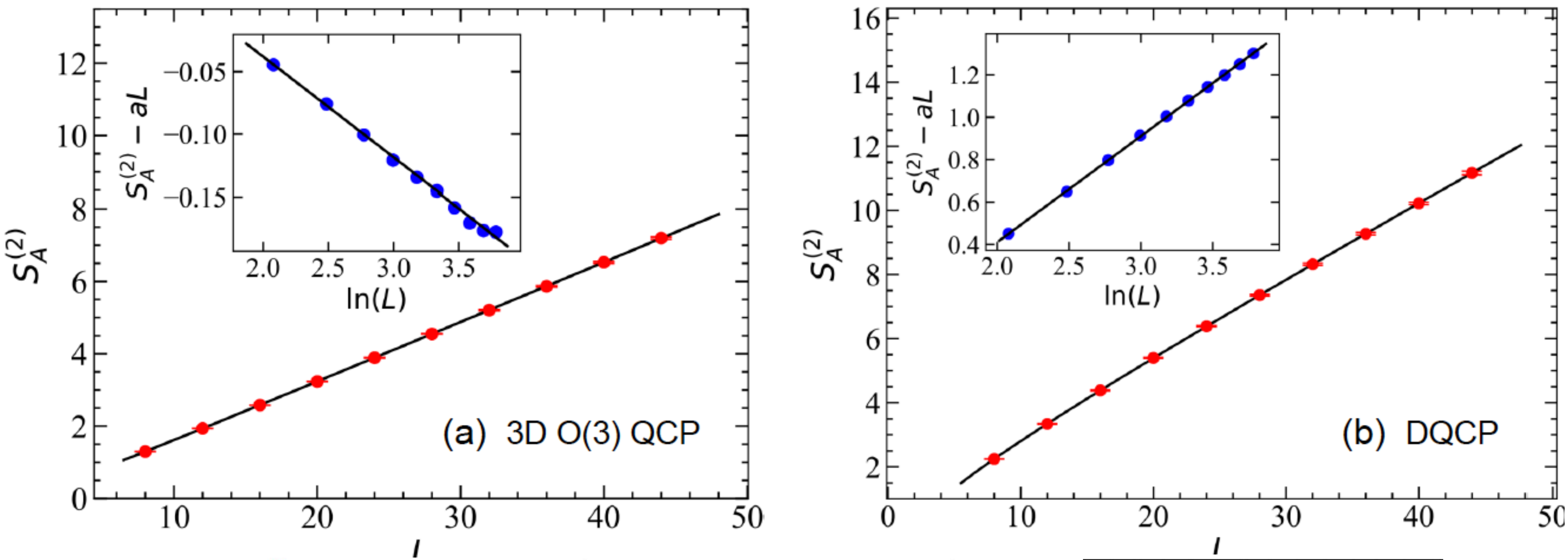
“I keep picturing all these little kids playing some game in this big field of rye and all. … And I'm standing on the edge of some crazy cliff. I have to catch everybody if they start to go over the cliff - I mean if they're running and they don't look where they're going I have to come out from somewhere and catch them. **That's all I do all day. I'd just be the catcher in the rye and all. I know it's crazy, but that's the only thing I'd really like to be.”**

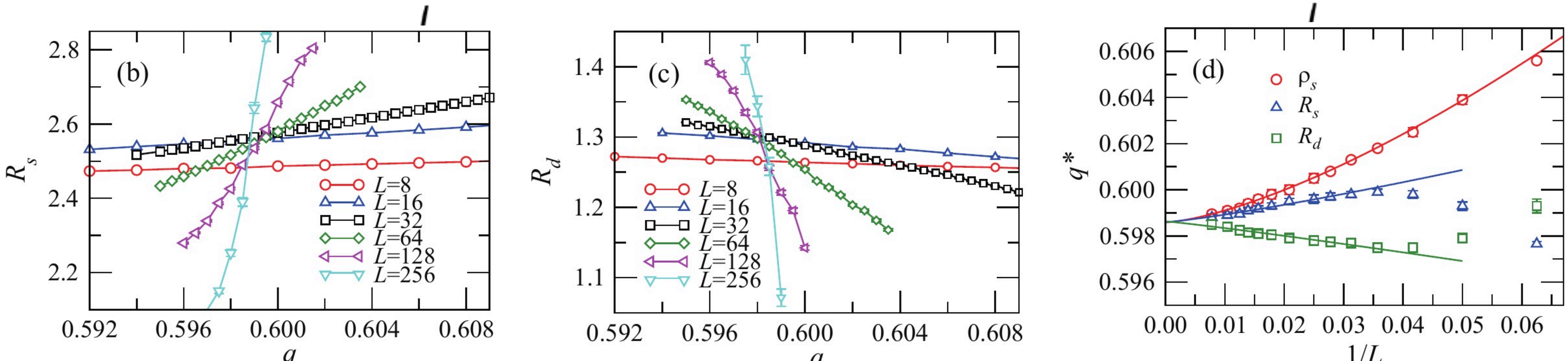
“I’m quite illiterate, but I read a lot.”

The enigma of DQCP

Jiarui Zhao, Yan-Cheng Wang, Zheng Yan, Meng Cheng, ZYM, PRL 128, 010601 (2022)

$$S_A^{(2)}(l) = al - s \ln l - b$$



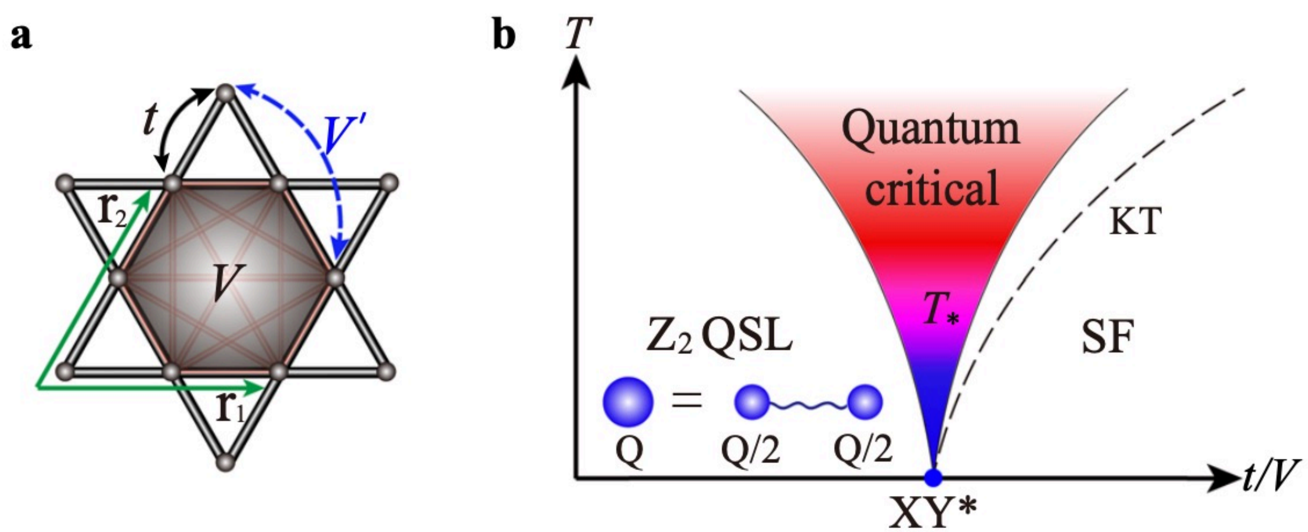


Entanglement entropy with Qiu Ku method

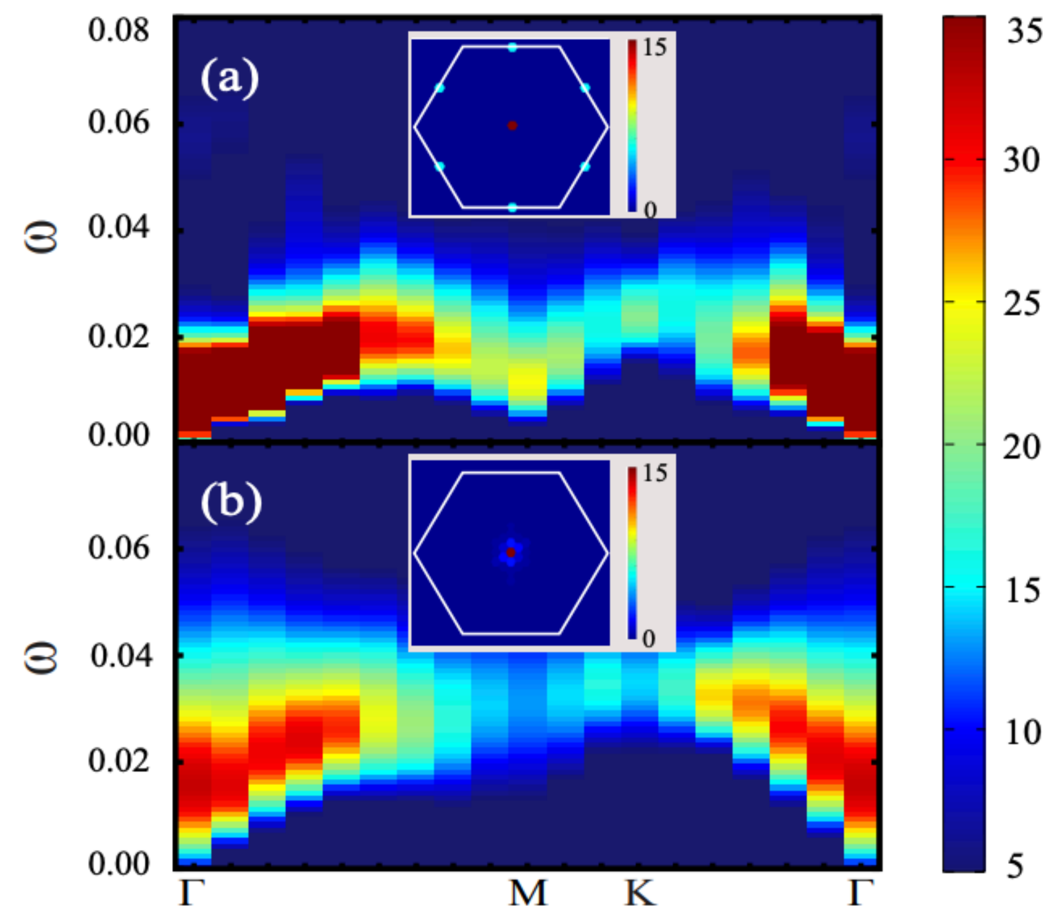
Topological order

- Yan-Cheng Wang, Meng Cheng, William Witczak-Krempa, ZYM, Nat Commun 12, 5347 (2021)

Kagome lattice frustrated spin model

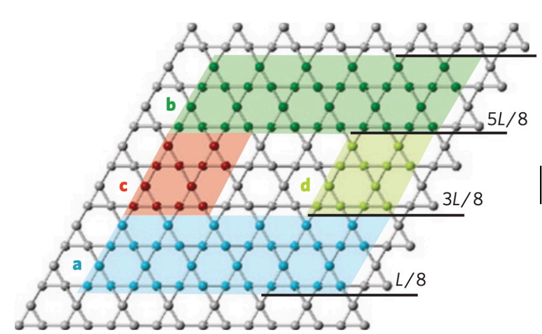


$$H = -t\sum_{\langle ij\rangle}\left(b_i^\dagger b_j + \mathrm{h.c.}\right) - \mu\sum_i n_i$$
$$+ V\left(\sum_{\langle ij\rangle} n_i n_j + \sum_{\langle\langle ij\rangle\rangle} n_i n_j + \sum_{\langle\langle\langle ij\rangle\rangle\rangle} n_i n_j\right)$$



Spinon and vison
Conductivity fractionalisation
Translational symmetry fractionalisation
……

- S. Isakov, Y.B. Kim, A. Paramekanti, PRL 97, 207204 (2006)
- Y.-C. Wang, et al., PRL 121, 057202 (2018)
- G.-Y. Sun, et al., PRL 121, 077201 (2018)
- J. Becker, S. Wessel, PRL 121, 077202 (2018)
- ……



$$S(l) = al - \underline{\gamma}$$

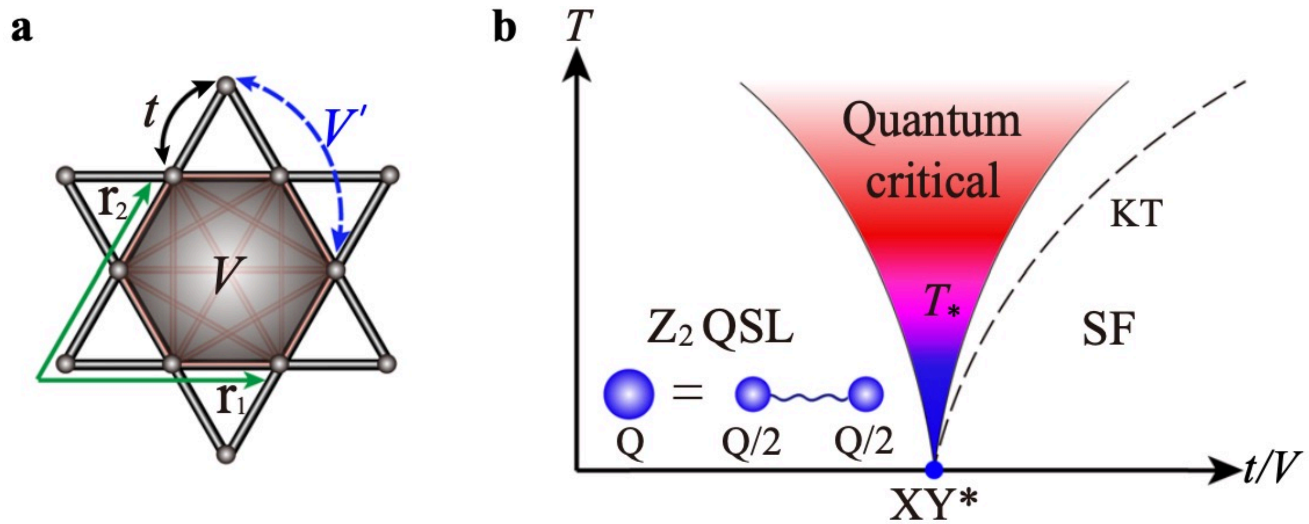
logical entanglement entropy (TEE)

$$\gamma = \ln(\mathscr{D}) = \ln\left(\sqrt{\sum_{a\in\mathscr{C}} d_a^2}\right)$$

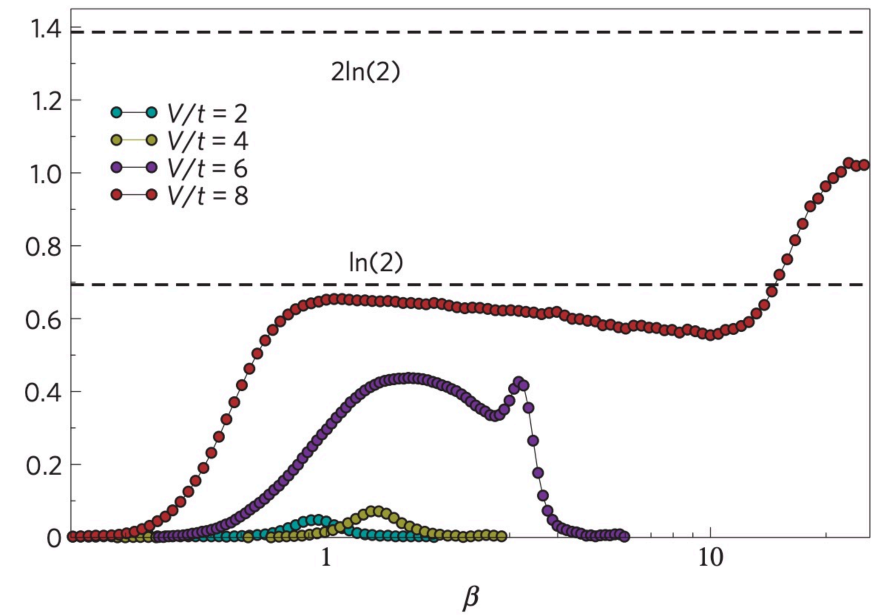
Entanglement entropy with Qiu Ku method

Topological order

Kagome lattice frustrated spin model



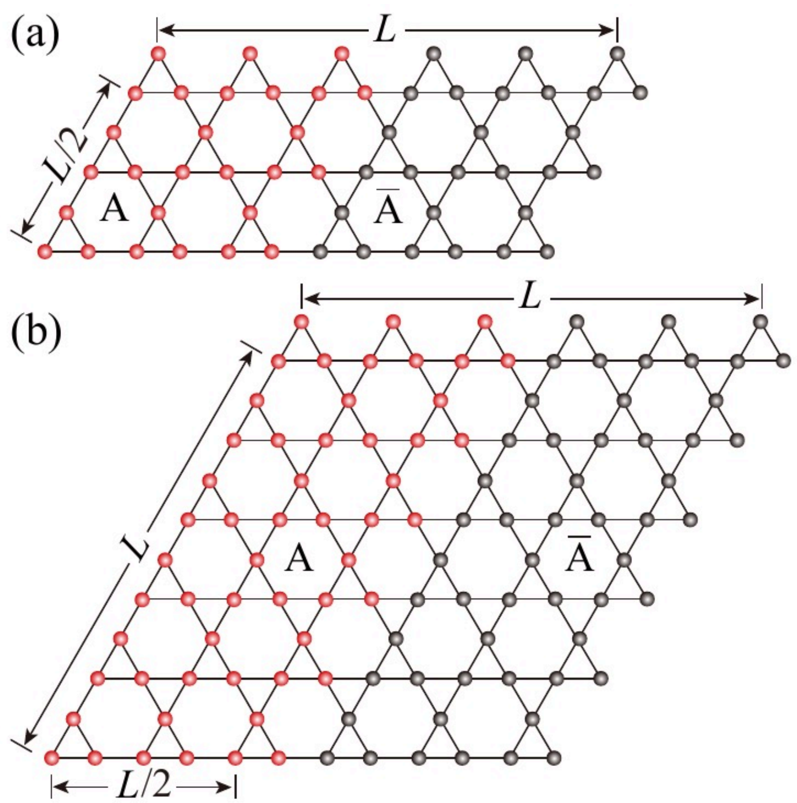
$L = 8$

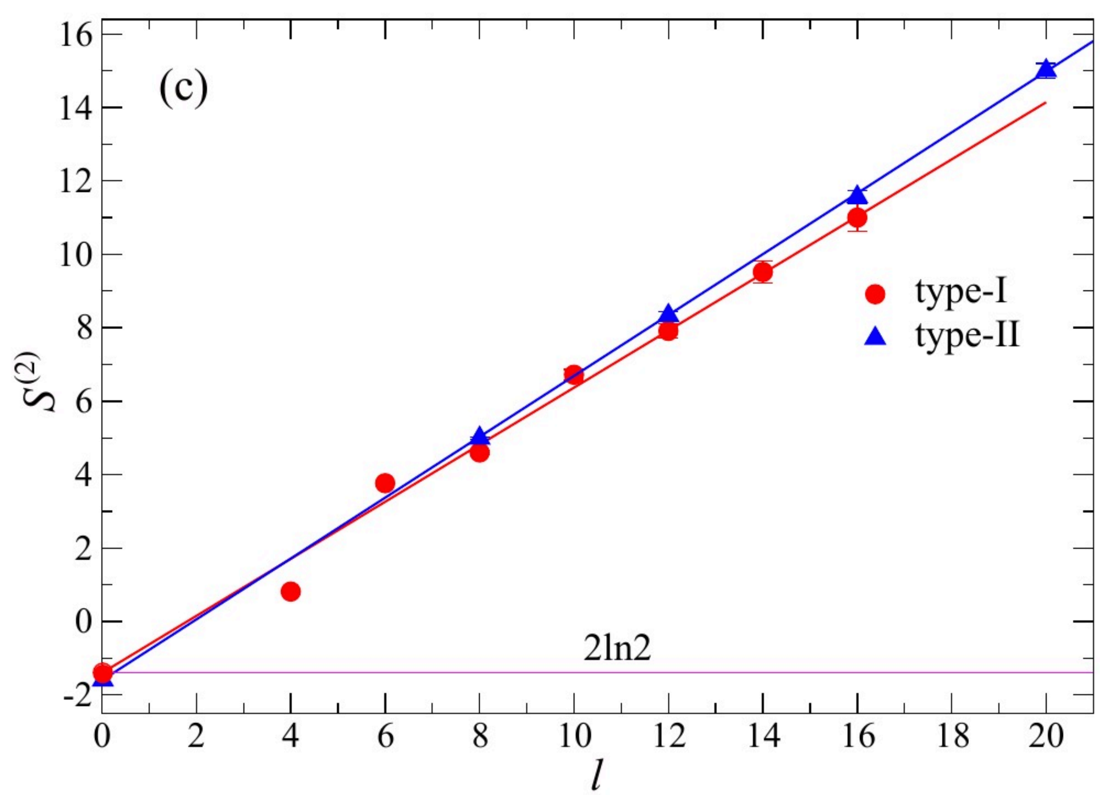


S. Isakov, M. Hastings, R. Melko, Nature Phys 7, 772 (2011)

$L = 12,14,16$

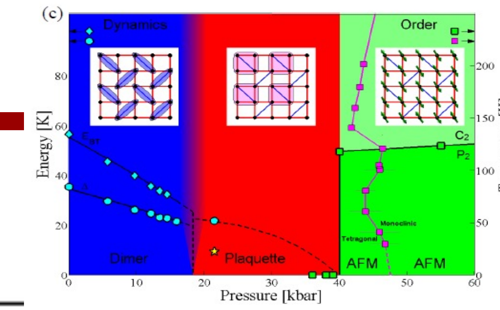
$L = 6,8,10$

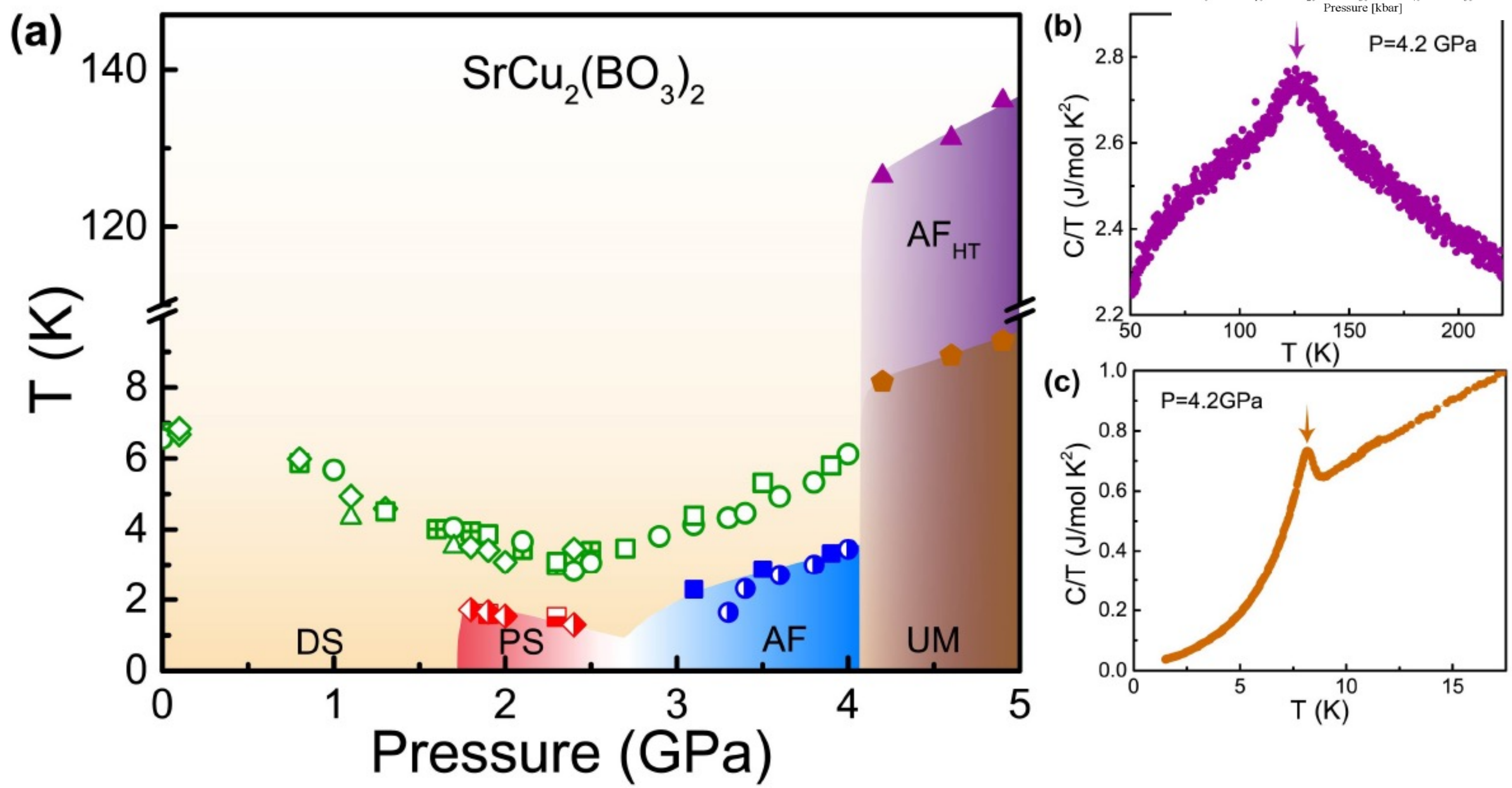




Jiarui Zhao, Bin-Bin Chen, Yan-Cheng Wang, Zheng Yan, Meng Cheng, ZYM, npj Quantum Materials 7, 69 (2022)

Extended pressure-temperature phase diagram





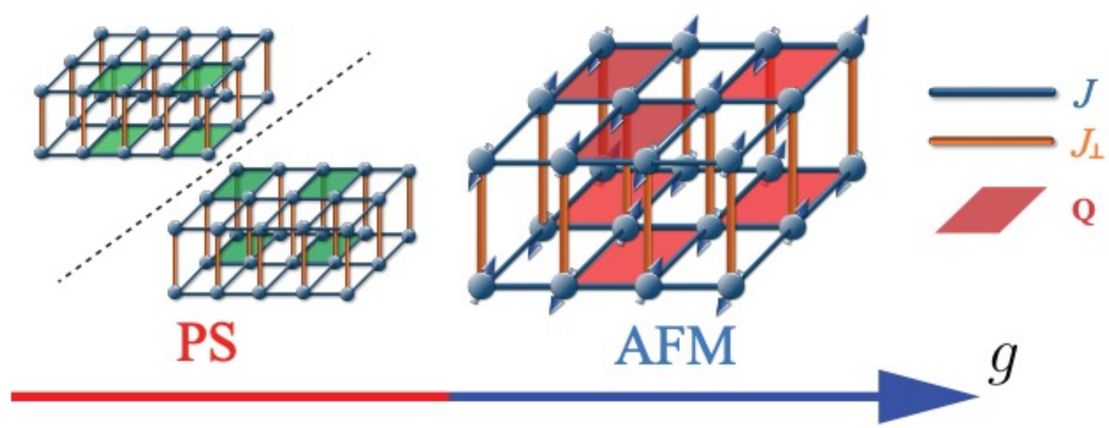
At P> 4GPa, an AFM transition at ~ 120 K and another previously not observed phase transition at T~ 8-9K were observed.

Jing Guo, et al., PRL 124, 206602 (2020)

Emergent O(4) symmetry at the phase transition from plaquette-singlet to antiferromagnetic order in quasi-two-dimensional quantum magnets

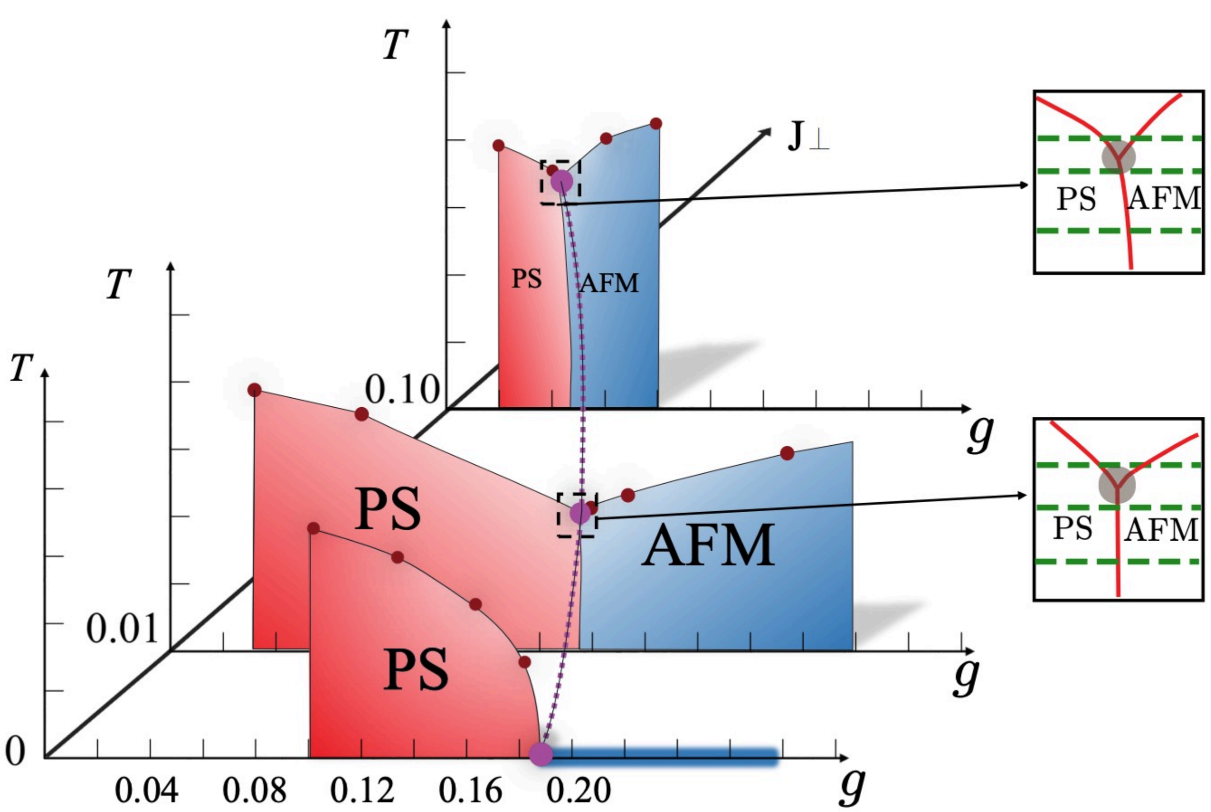
Guangyu Sun,[1,2] Nvsen Ma,[3,1] Bowen Zhao,[4] Anders W. Sandvik,[4,1,*] and Zi Yang Meng[1,5,†]

CPB 30, 067505 (2021) Cover Story



- Triple point: $J_\perp = 0.01 \quad T_c = 0.088(2), g_c = 0.16$

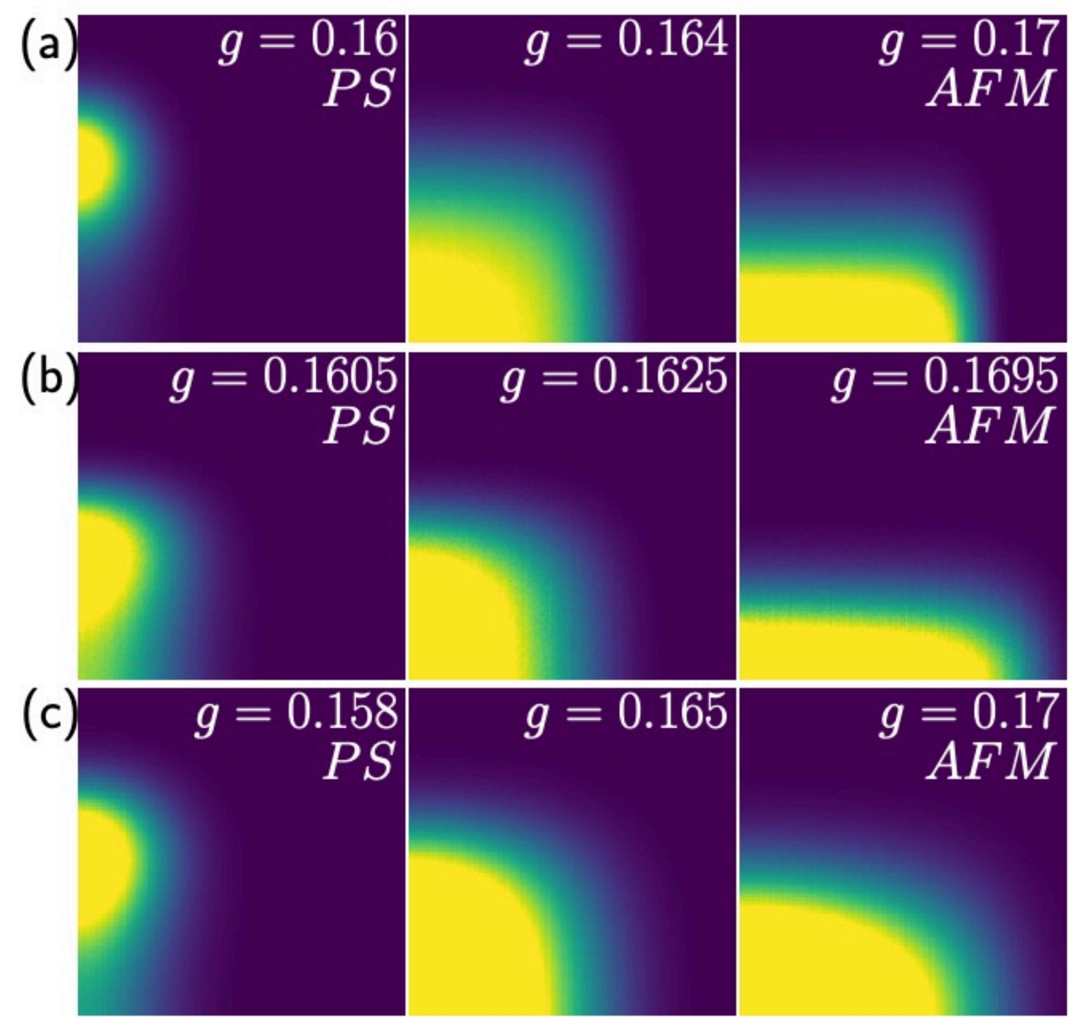
$$P(|m_p|, |m_z|)$$



$T = 0.06$

$T = 0.085$

$T = 0.09$



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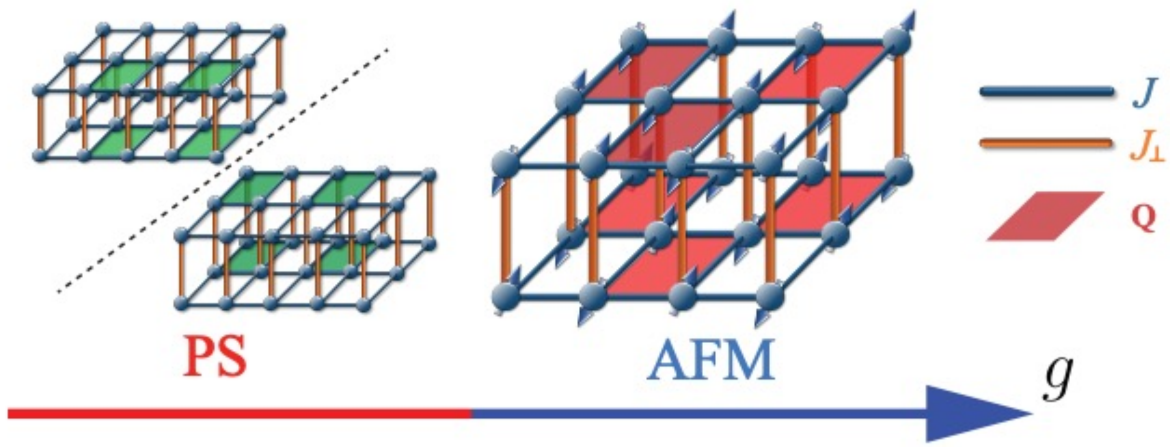
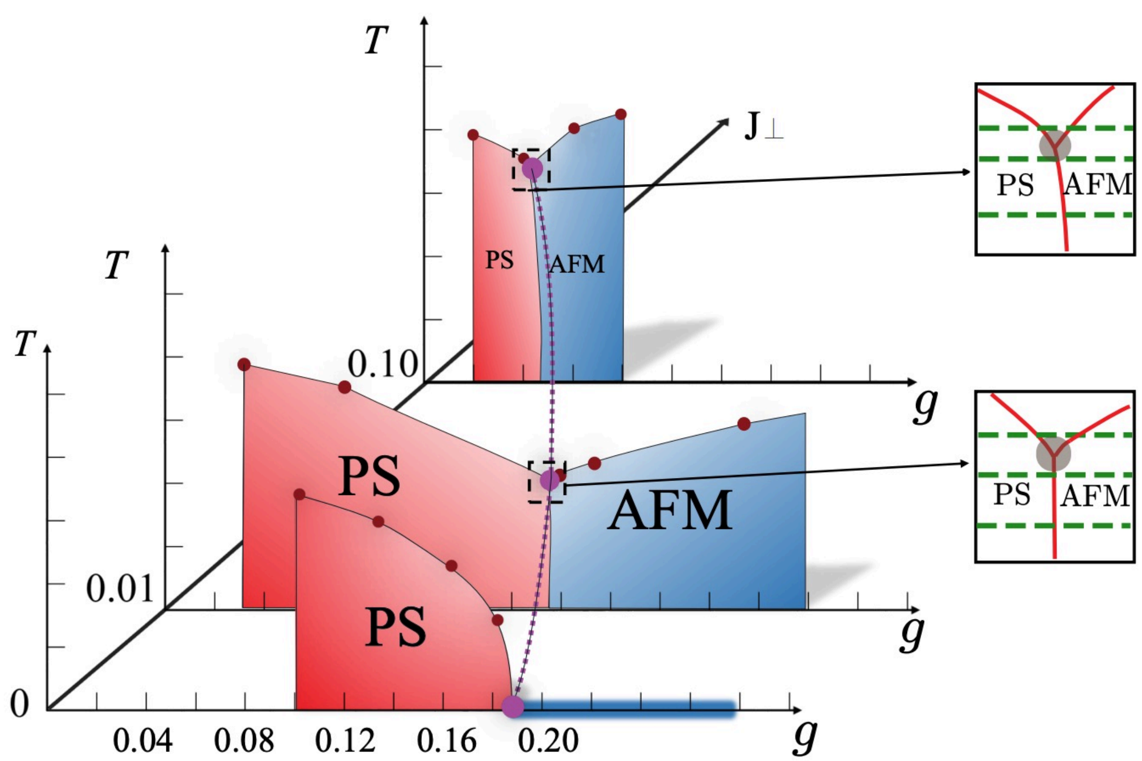


- Triple point: $J_\perp = 0.1 \quad T_c = 0.165(2), g_c = 0.041$

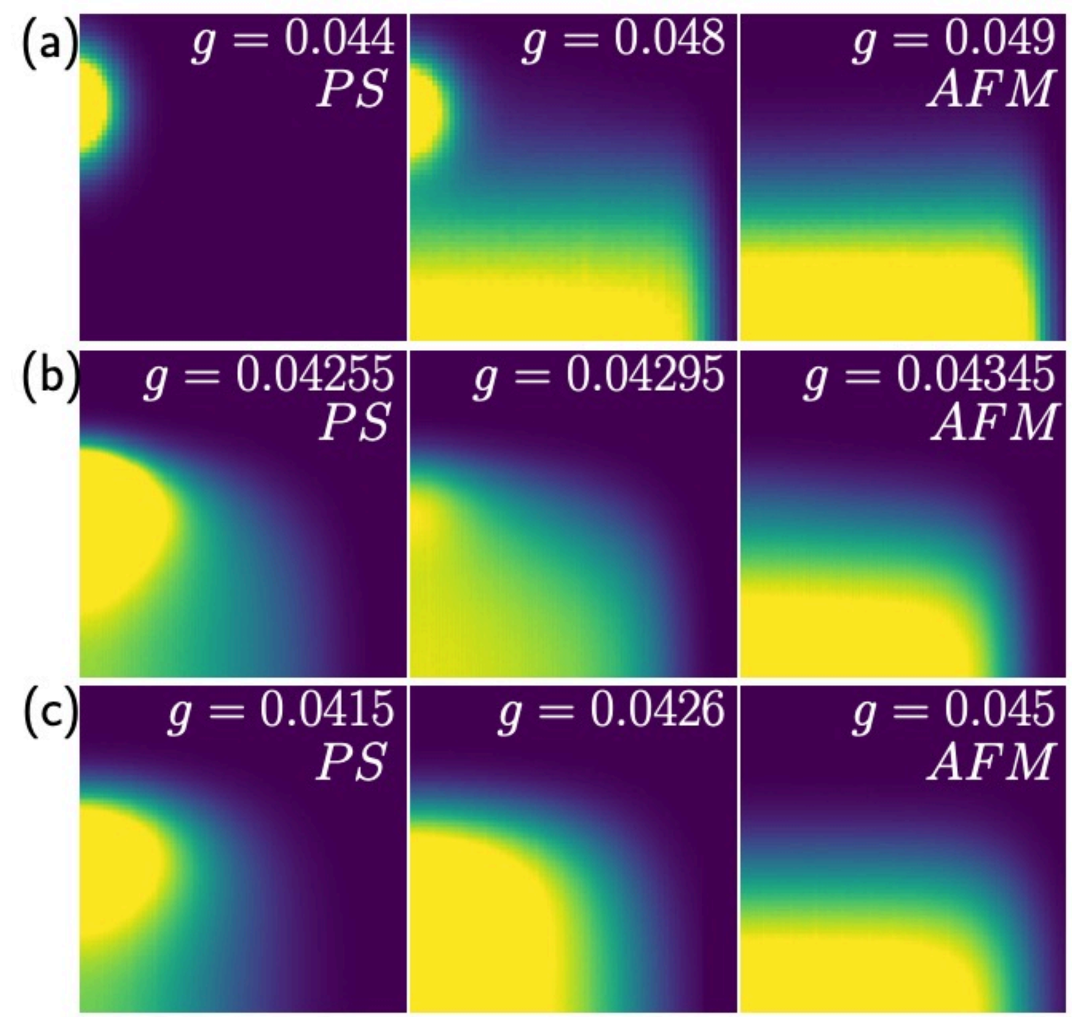
$$P(|m_p|, |m_z|)$$



$T = 0.1$

$T = 0.162$

$T = 0.168$



What is Qiu Ku (秋裤)

How can you tell winter is coming?

In Chinese: I need to put my Qiu Ku on.

- long underwear, looks similar to leggings
- normally made of cotton
- most popular colors are grey, blue, white and beige
- nothing to do with fashion or style
- The only reason for its existence is to keep you warm. When jeans can no longer resist the freezing air, just wear Qiu Ku under your jeans. Problem solved!

A pair of (stretchy) pants

long johns

Photo: Hulton Archive/Getty Images