WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Wisconsin Summer School for Quantum Science

scientific organization: Ilya Esterlis, Elio J. König, Tiancheng Song

University of Wisconsin-Madison | Aug 27-29, 2024

Wisconsin Summer School for Quantum Science

Lab tours:

	Tuesday	*Wednesday*	*Thursday*
3:30 PM	Lab Tour: Eriksson Lab /Yavuz Lab	Lab Tour: Song Lab /Brar Lab	Lab Tour: Choy Lab /Kats Lab (Engineering)
4:00 PM	Lab Tour: McDermott Lab /Kuzmin Lab	Lab Tour: Saffman Lab	Lab Tour: Wang Lab (Engineering)
Meeting point	3 30pm 4 00pm *by elevator* *5th floor Chamberlin*	3 30pm *Chamberlin lobby* *(University Av exit)*	3 30pm *Chamberlin lobby* *(University Av exit)*

Wifi: eduroam

Lunch and Coffee: Hallway behind lecture hall 8 45 am

Dinner for registered participants:
Steenbock's on Orchard, today, reception at 5 45 pm

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Wisconsin Summer School for Quantum Science

Lectures (@ Chamberlin 2223, backup Sterling 1310)

	Tuesday	*Wednesday*	*Thursday*
9am	**König** Overview	**Song** Quantum LEGO	**Kuzmin** Superconducting qbits (exp)
11am	**Perkins** Quantum spin liquids	**Esterlis** Quantum sensing	**Vavilov** Superconducting qbits (th)
2pm	**Perkins** Kitaev Materials	**Levchenko** Quantum transport	

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Wisconsin Summer School for Quantum Science

Elio J. König
University of Wisconsin-Madison | Aug 27, 2024

the era of the 2nd quantum revolution

What is quantum science good for?

2nd
quantum revolution
=
domestication of
quantum physics

the era of the 2nd quantum revolution

What is quantum science good for?

2nd
quantum revolution
=
domestication of
quantum physics

the era of the 2nd quantum revolution

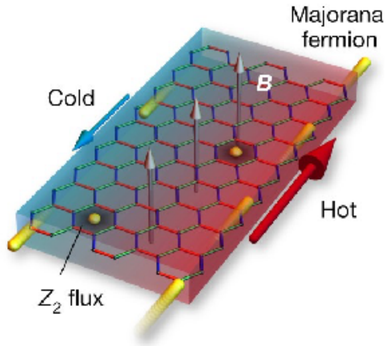
What is quantum science good for?

2nd
quantum revolution
=
domestication of
quantum physics

the era of the 2nd quantum revolution

What is quantum science good for?

quantum materials



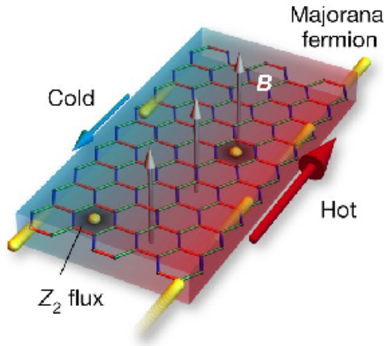
$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

2nd
quantum revolution
=
domestication of
quantum physics

the era of the 2nd quantum revolution

What is quantum science good for?

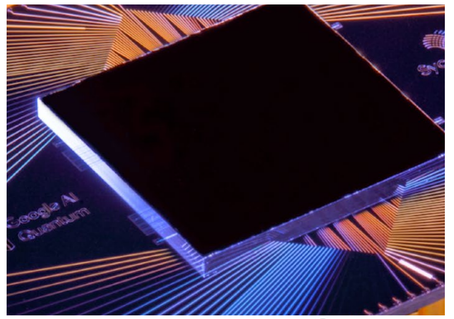
quantum materials



$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

2nd
quantum revolution
=
domestication of
quantum physics

quantum computing

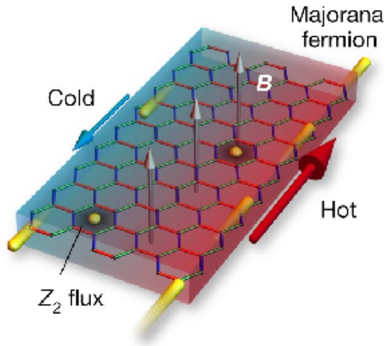


Quantum chip:
Google Quantum, Science (2021)

the era of the 2nd quantum revolution

What is quantum science good for?

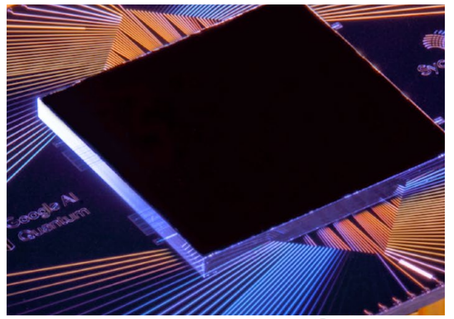
quantum materials



$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

2nd
quantum revolution
=
domestication of
quantum physics

quantum computing



Quantum chip:
Google Quantum, Science (2021)

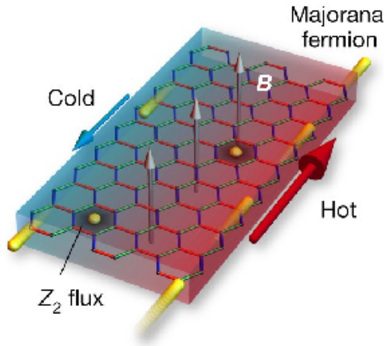
the era of the 2nd quantum revolution

What is quantum science good for?

1st Agricultural
Revolution 10000 BCE

take control of biosphere
adapt it to human needs

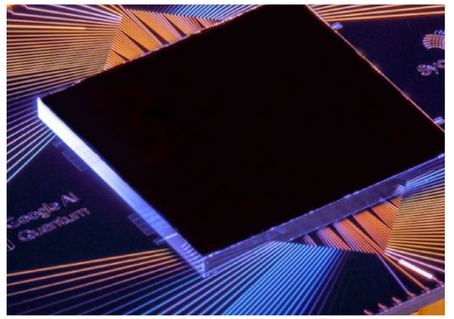
quantum materials



$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

natural occurrence
inspires / is emulated by
man-made system

quantum computing



Quantum chip:
Google Quantum, Science (2021)

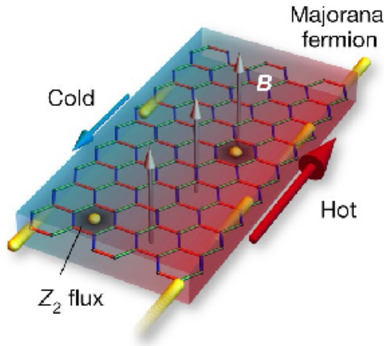
the era of the 2nd quantum revolution

What is quantum science good for?

1st Agricultural
Revolution 10000 BCE

take control of biosphere
adapt it to human needs

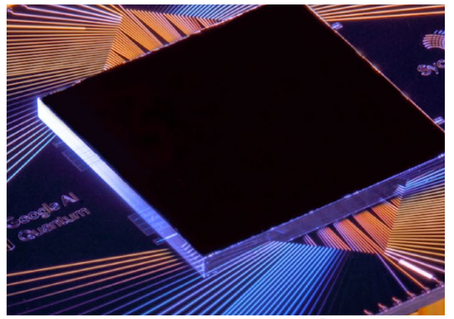
quantum materials



$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

natural occurrence
inspires / is emulated by
man-made system

quantum computing



Quantum chip:
Google Quantum, Science (2021)

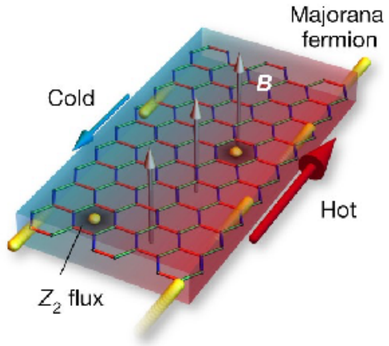
the era of the 2nd quantum revolution

What is quantum science good for?

1st Agricultural
Revolution 10000 BCE

take control of biosphere
adapt it to human needs

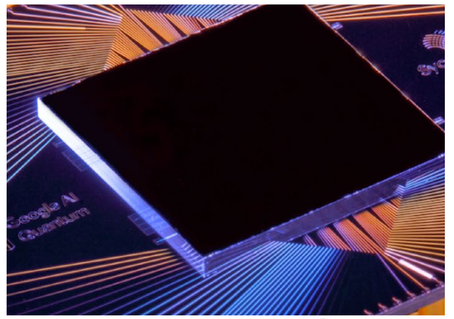
quantum materials



$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

natural occurrence
inspires / is emulated by
man-made system

quantum computing



Quantum chip:
Google Quantum, Science (2021)

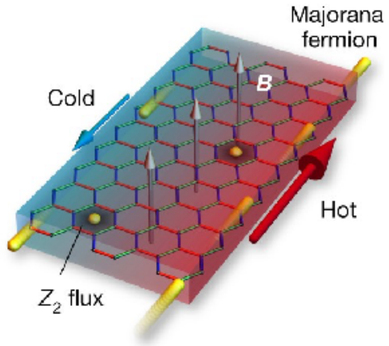
the era of the 2nd quantum revolution

What is quantum science good for?

"Quantum technology seeks to harness the peculiar laws of quantum mechanics for processing information, to develop new kinds of computers, communications networks, and sensors."

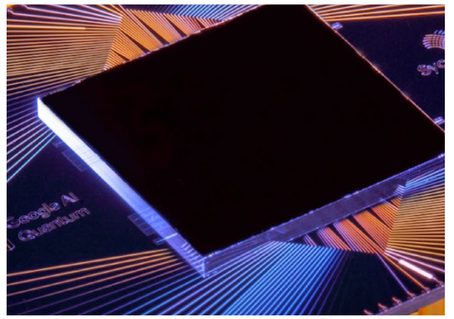
(The Washington Post, Aug 18th, 2019)

quantum materials



$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

quantum computing and communication



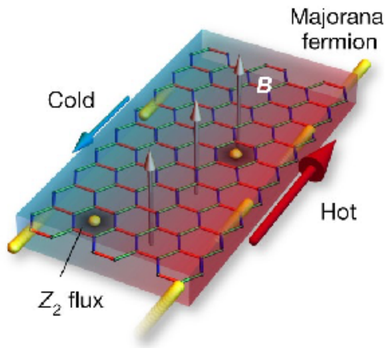
Quantum chip:
Google Quantum, Science (2021)

Aspects of quantum science

"Quantum technology seeks to harness the peculiar laws of quantum mechanics for processing information, to develop new kinds of computers, communications networks, and sensors."

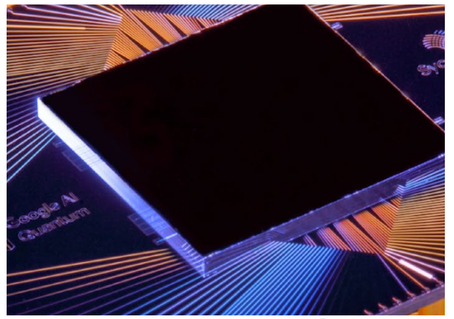
(The Washington Post, Aug 18th, 2019)

quantum materials



$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

quantum computing and communication



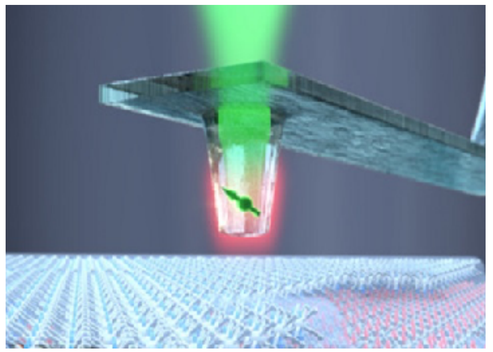
Quantum chip:
Google Quantum, Science (2021)

Aspects of quantum science

"Quantum technology seeks to harness the peculiar laws of quantum mechanics for processing information, to develop new kinds of computers, communications networks, and sensors."

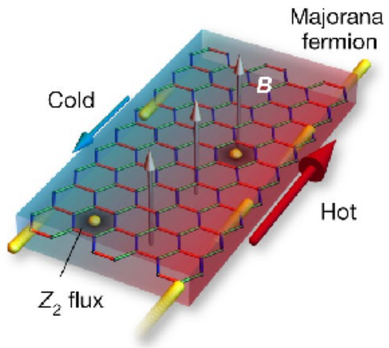
(The Washington Post, Aug 18th, 2019)

quantum sensing



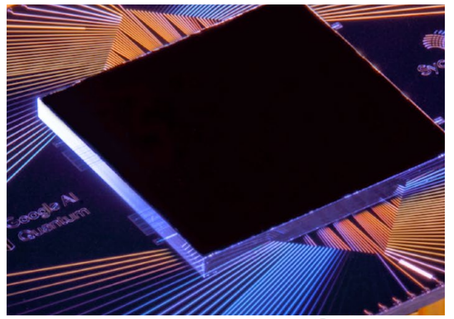
Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

quantum materials



$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

quantum computing and communication



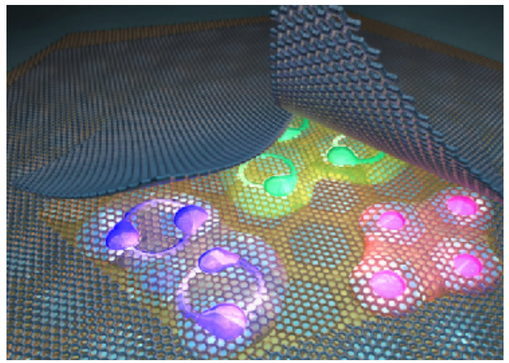
Quantum chip:
Google Quantum, Science (2021)

Aspects of quantum science

"Quantum technology seeks to harness the peculiar laws of quantum mechanics for processing information, to develop new kinds of computers, communications networks, and sensors."

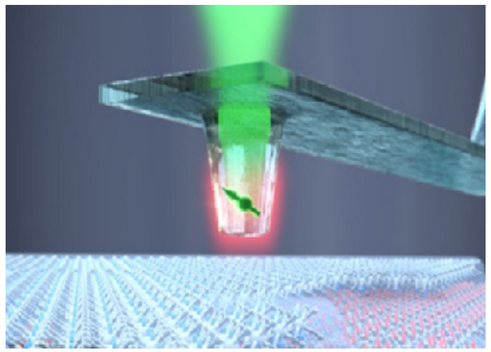
(The Washington Post, Aug 18th, 2019)

quantum design



2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

quantum sensing



Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

quantum materials

$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

quantum computing and communication

Quantum chip:
Google Quantum, Science (2021)

Aspects of quantum science

quantum design

2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

quantum sensing

Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

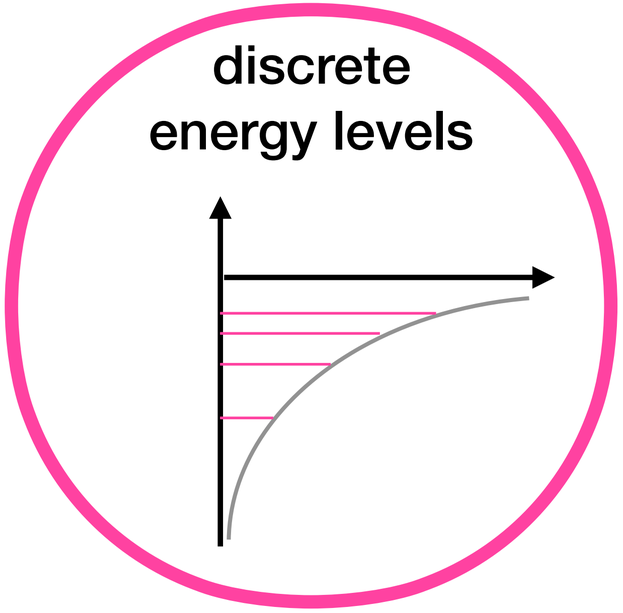
quantum materials

$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

quantum computing and communication

Quantum chip:
Google Quantum, Science (2021)

Aspects of quantum science



quantum design

2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

quantum sensing

Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

quantum materials

$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

quantum computing and communication

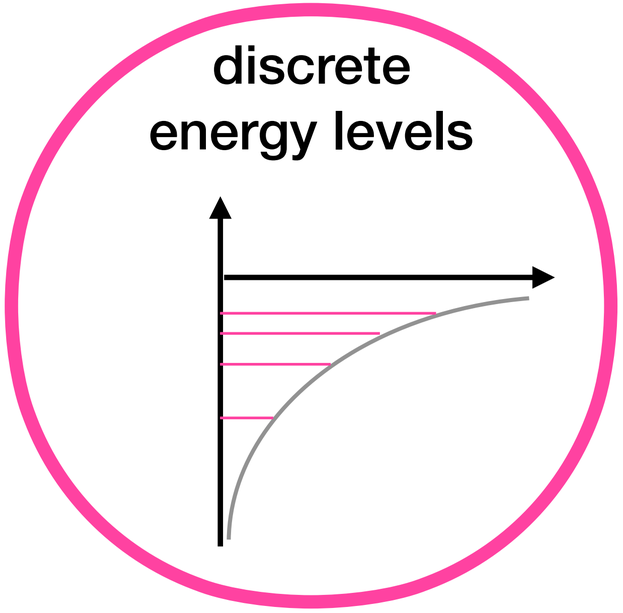
Quantum chip:
Google Quantum, Science (2021)

Aspects of quantum science

quantum design

allows to build
0D, 1D, 2D
quantum systems

2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).



quantum sensing

Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

quantum materials

$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

quantum computing and communication

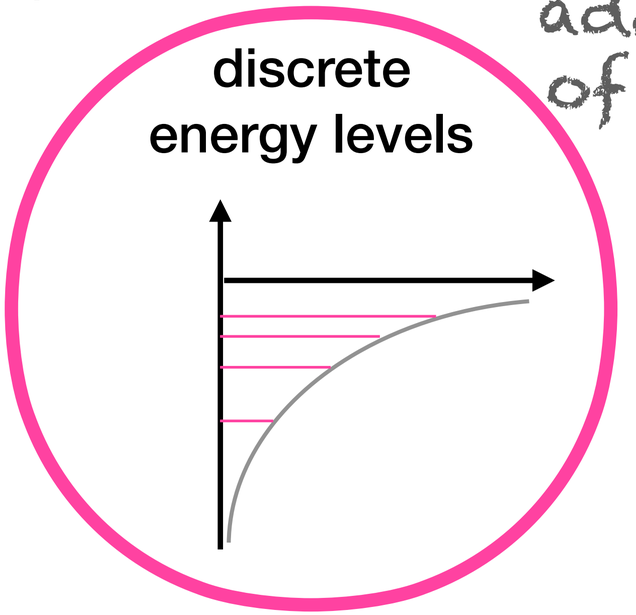
Quantum chip:
Google Quantum, Science (2021)

Aspects of quantum science

quantum design

allows to build
0D, 1D, 2D
quantum systems

2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).



addressing a pair
of levels defines
a qubit

quantum sensing

Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

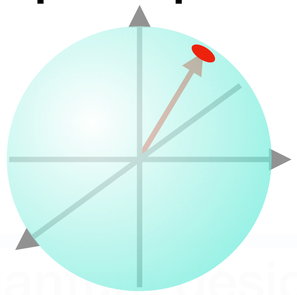
quantum materials

$RuCl_3$: candidate Quantum Spin Liquid:
2018).

quantum computing
and communication

Quantum chip:
Google Quantum, Science (2021)

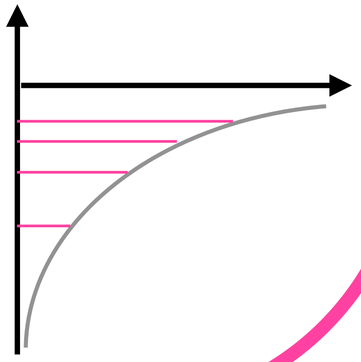
superposition
principle



$|0\rangle + |1\rangle$

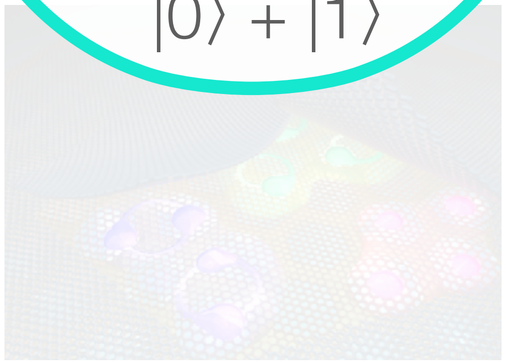
Aspects of quantum science

discrete
energy levels



quantum sensing

Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)



2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

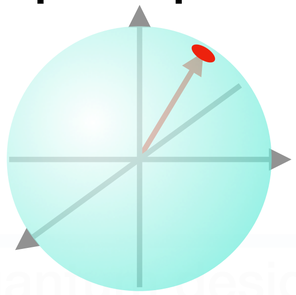
quantum materials

$RuCl_3$: candidate Quantum Spin Liquid:
2018).

quantum computing
and communication

Quantum chip:
Google Quantum, Science (2021)

superposition
principle



$|0\rangle + |1\rangle$

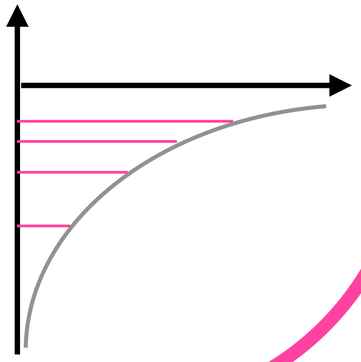
quantum design

probabilistic
nature of quantum
mechanics

2D materials (twisted bilayer graphene):
Efetov *et al*, Physics World (2019).

Aspects of quantum science

discrete
energy levels



quantum sensing

Color center magnetometry:
Maletinsky *et al*., Physics World (2019)

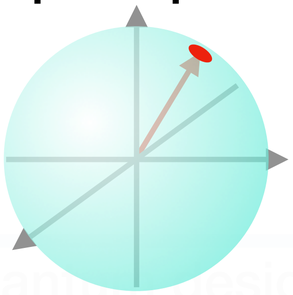
quantum materials

$RuCl_3$: candidate Quantum Spin Liquid:

quantum computing
and communication

Quantum chip:
Google Quantum, Science (2021)

superposition
principle

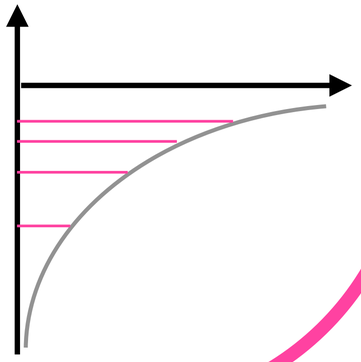


$|0\rangle + |1\rangle$

is a resource for
"parallelization"

Aspects of
quantum science

discrete
energy levels



quantum design

probabilistic
nature of quantum
mechanics

2D materials (twisted bilayer graphene):
Efetov *et al*, Physics World (2019).

quantum sensing

Color center magnetometry:
Maletinsky *et al*., Physics World (2019)

quantum materials

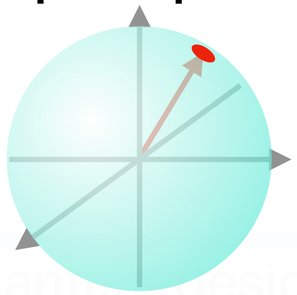
quantum coherence

$RuCl_3$: candidate Quantum Spin Liquid:

quantum computing and communication

Quantum chip:
Google Quantum, Science (2021)

superposition principle

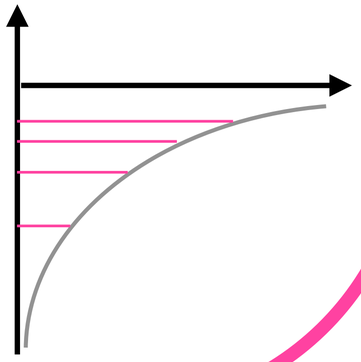


$|0\rangle + |1\rangle$

is a resource for "parallelization"

Aspects of quantum science

discrete energy levels



quantum sensing

Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

quantum design

probabilistic nature of quantum mechanics

2D materials (twisted bilayer graphene):
Efetov *et al*, Physics World (2019).

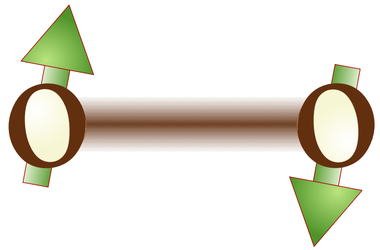
quantum materials

$RuCl_3$: candidate Quantum Spin Liquid:
(2018).

quantum computing
and communication

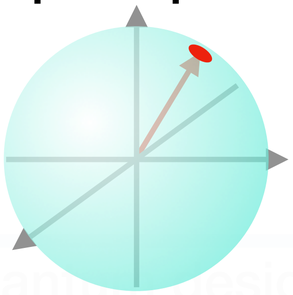
Quantum chip:
Google Quantum, Science (2021)

entanglement



$|0\rangle|1\rangle - |1\rangle|0\rangle$

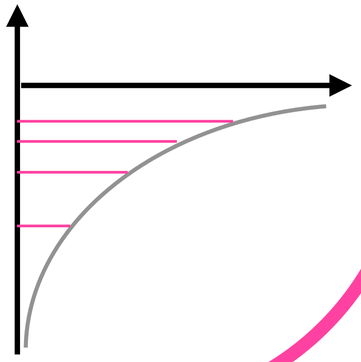
superposition principle



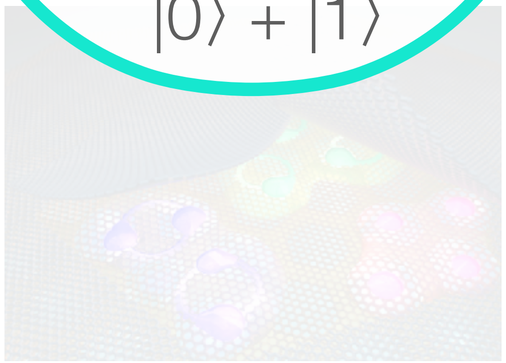
$|0\rangle + |1\rangle$

Aspects of quantum science

discrete energy levels



quantum design



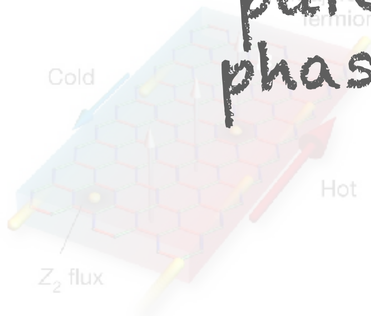
2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

quantum sensing

Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

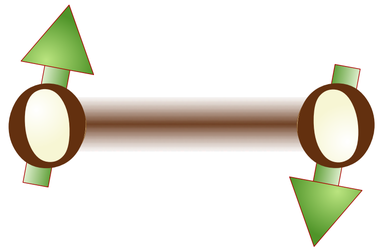
quantum materials

purely quantum phases of matter



$RuCl_3$: candidate Quantum Spin Liquid: [illegible] (2018).

entanglement

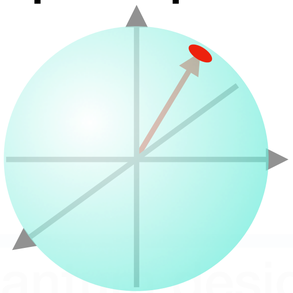


$|0\rangle|1\rangle - |1\rangle|0\rangle$

quantum computing and communication

Quantum chip: Google Quantum, Science (2021)

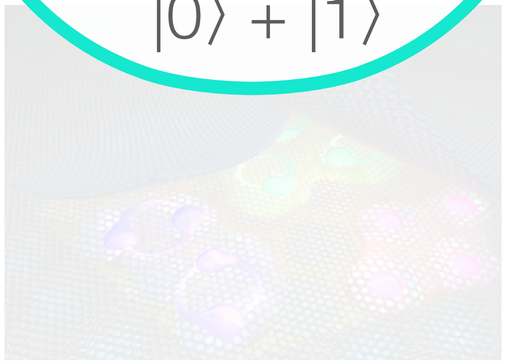
superposition principle



$|0\rangle + |1\rangle$

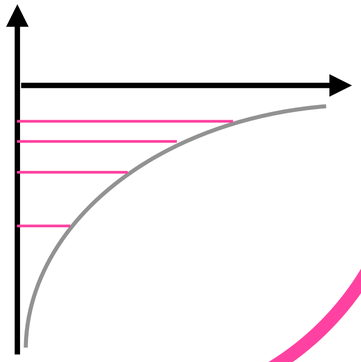
Aspects of quantum science

quantum design



2D materials (twisted bilayer graphene): Efetov *et al,* Physics World (2019).

discrete energy levels



quantum sensing

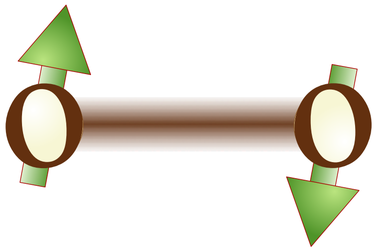
Color center magnetometry: Maletinsky *et al.*, Physics World (2019)

quantum materials

purely quantum phases of matter

$RuCl_3$: candidate Quantum Spin Liquid:
2018).

entanglement



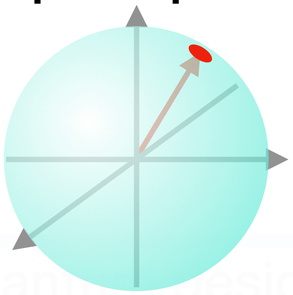
$|0\rangle|1\rangle - |1\rangle|0\rangle$

resource for error correction and quantum communication

quantum computing and communication

Quantum chip:
Google Quantum, Science (2021)

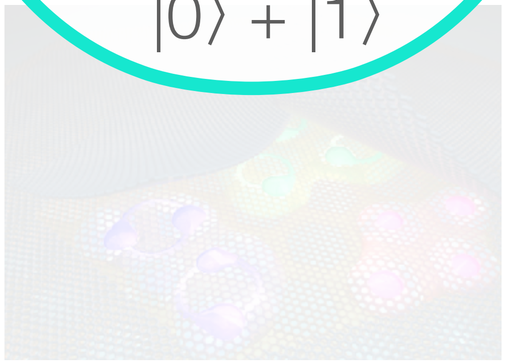
superposition principle



$|0\rangle + |1\rangle$

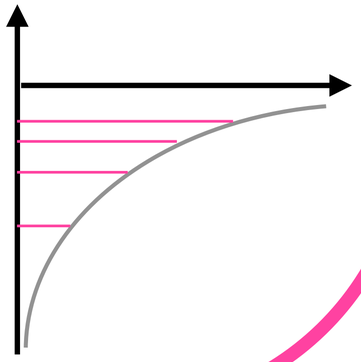
Aspects of quantum science

quantum design



2D materials (twisted bilayer graphene):
Efetov *et al*, Physics World (2019).

discrete energy levels



quantum sensing

Color center magnetometry:
Maletinsky *et al*., Physics World (2019)

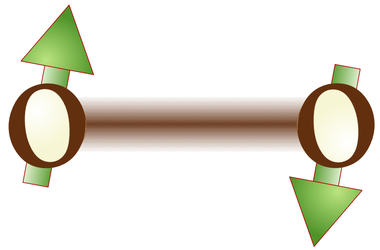
quantum materials

$RuCl_3$: candidate Quantum Spin Liquid:
2018).

quantum computing
and communication

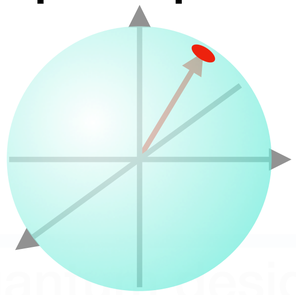
um chip:
2021)

entanglement



$|0\rangle|1\rangle - |1\rangle|0\rangle$

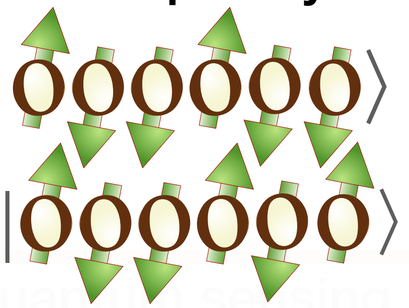
superposition
principle



$|0\rangle + |1\rangle$

Aspects of
quantum science

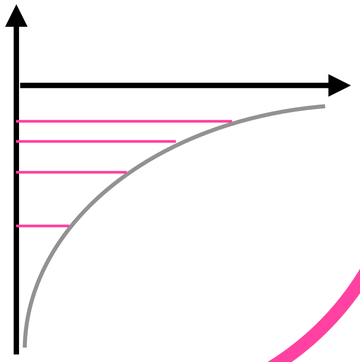
exponential
complexity



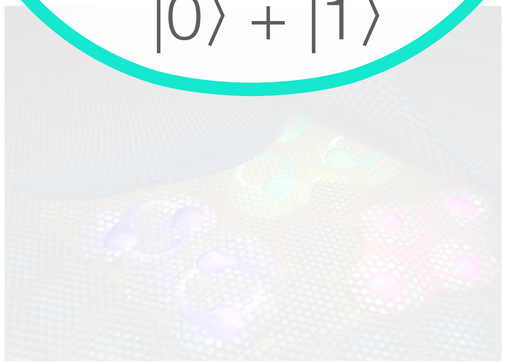
$|0000000\rangle$
$+|0000000\rangle$

$\dim(H) = 2^N$

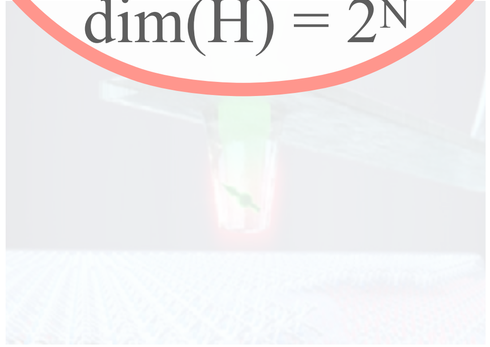
discrete
energy levels



quantum sensing



2D materials (twisted bilayer graphene):
Efetov *et al*, Physics World (2019).



Color center magnetometry:
Maletinsky *et al*., Physics World (2019)

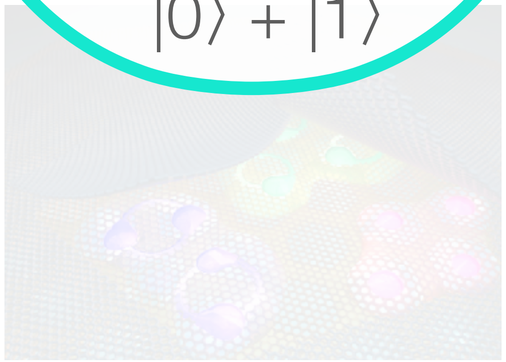
quantum materials

$RuCl_3$: candidate Quantum Spin Liquid:
(2018).

quantum computing
and communication

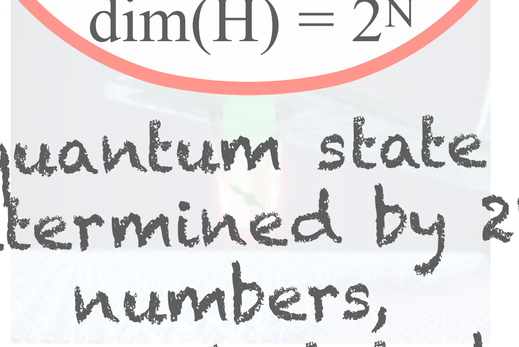
um chip:
2021)

quantum design



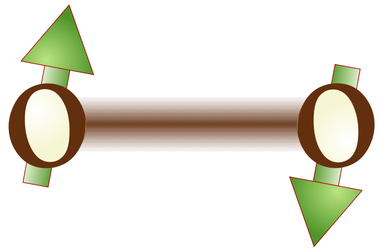
2D materials (twisted bilayer graphene):
Efetov *et al*, Physics World (2019).

quantum sensing



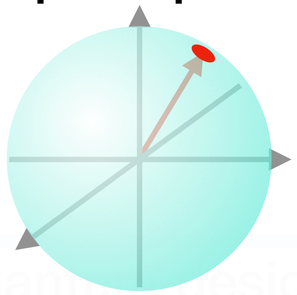
Maletinsky *et al*, Physics World (2019)

entanglement



$|0\rangle|1\rangle - |1\rangle|0\rangle$

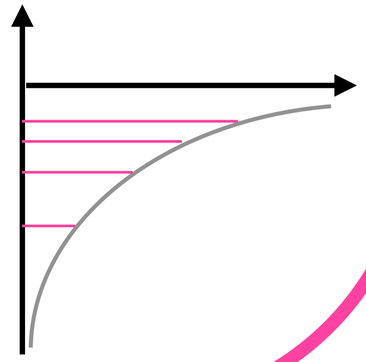
superposition
principle



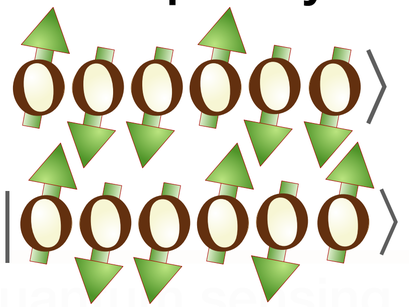
$|0\rangle + |1\rangle$

Aspects of
quantum science

discrete
energy levels



exponential
complexity



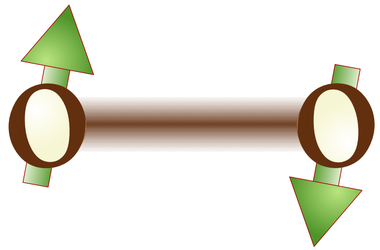
$|0000000\rangle$
$+|0000000\rangle$

$\dim(H) = 2^N$

quantum state
determined by 2^N
numbers,
classical state by
N numbers

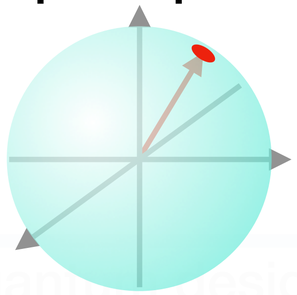
Aspects of quantum science

entanglement



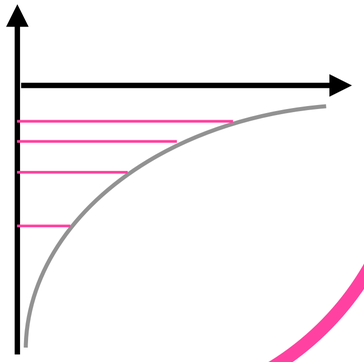
$|0\rangle|1\rangle - |1\rangle|0\rangle$

superposition principle

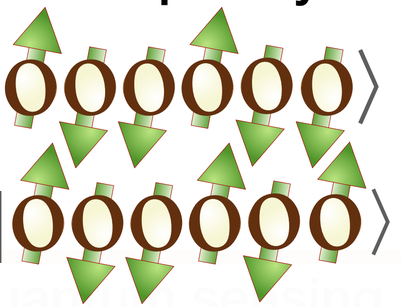


$|0\rangle + |1\rangle$

discrete energy levels



exponential complexity

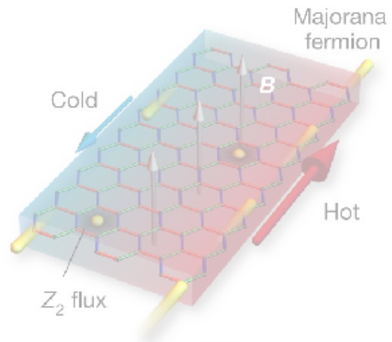


$|0000000\rangle + |0000000\rangle$

$\dim(H) = 2^N$

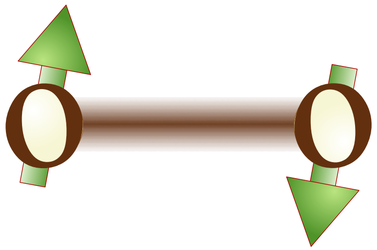
quantum state determined by 2^N numbers, classical state by N numbers

quantum materials



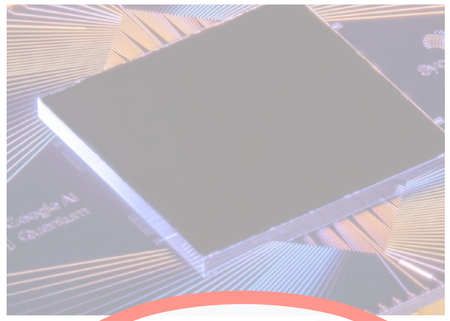
$RuCl_3$: candidate Quantum Spin Liquid: (2018).

entanglement



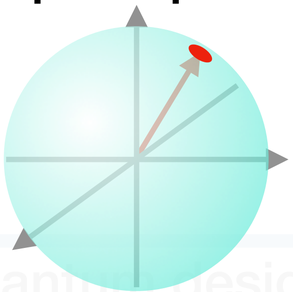
$|0\rangle|1\rangle - |1\rangle|0\rangle$

quantum computing and communication



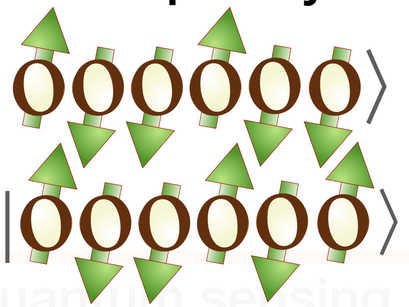
Qu tum chip: (2021)

superposition principle



$|0\rangle + |1\rangle$

exponential complexity

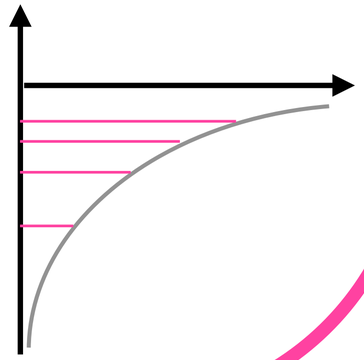


$|0000000\rangle$
$+|0000000\rangle$

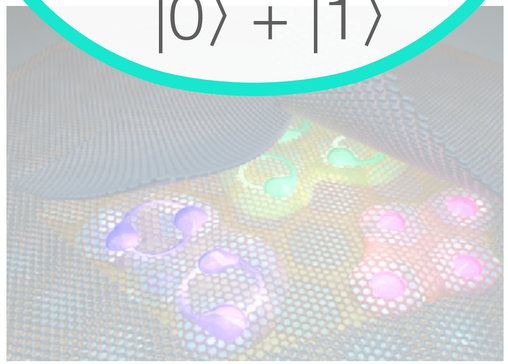
$\dim(H) = 2^N$

Aspects of quantum science

discrete energy levels

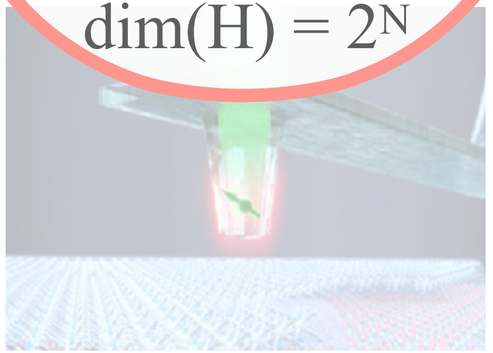


quantum design



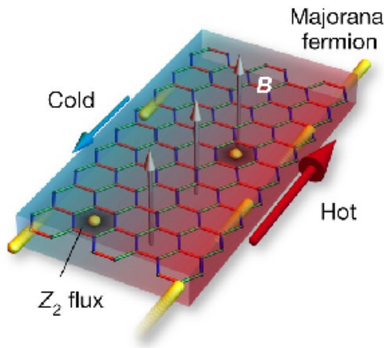
2D materials (twisted bilayer graphene): Efetov *et al,* Physics World (2019).

quantum sensing



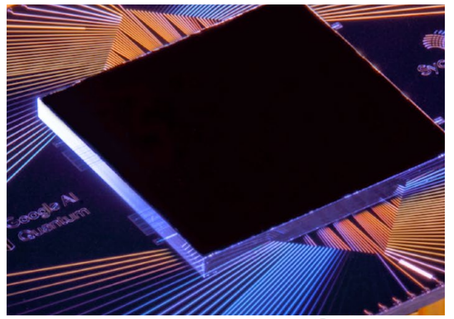
Color center magnetometry: Maletinsky *et al.*, Physics World (2019)

quantum materials



$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

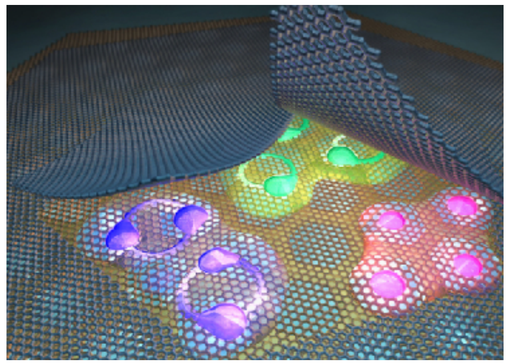
quantum computing and communication



Quantum chip:
Google Quantum, Science (2021)

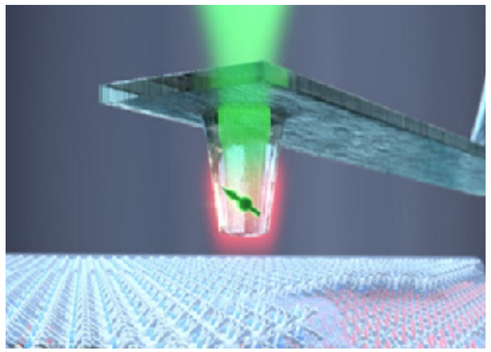
Aspects of quantum science

quantum design



2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

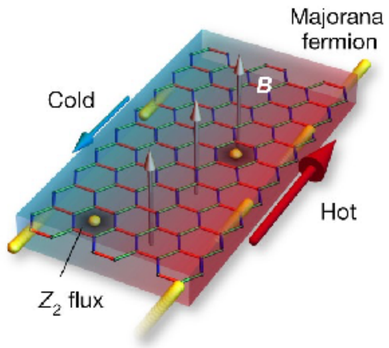
quantum sensing



Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

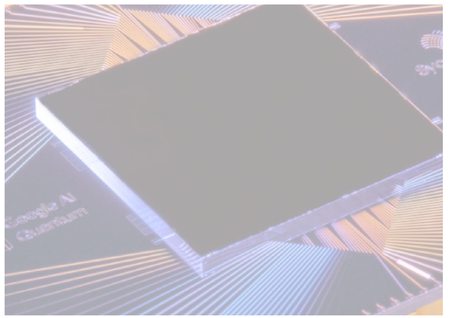
Aspects of quantum science

quantum materials



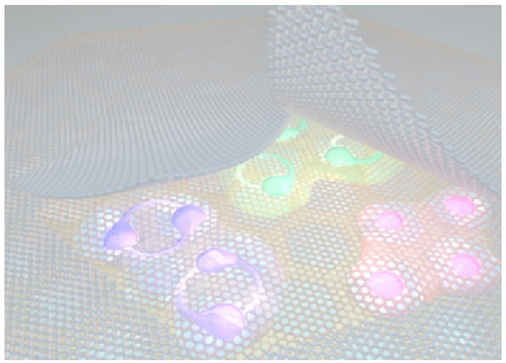
$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

quantum computing and communication



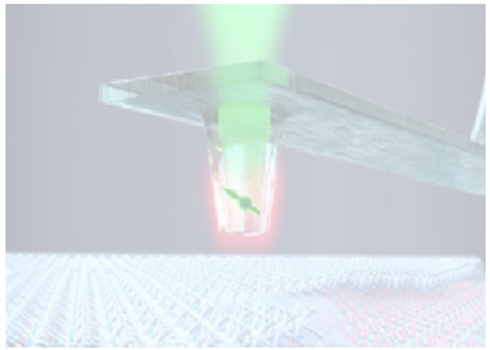
Quantum chip:
Google Quantum, Science (2021)

quantum design



2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

quantum sensing



Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

Quantum Materials & forms of order

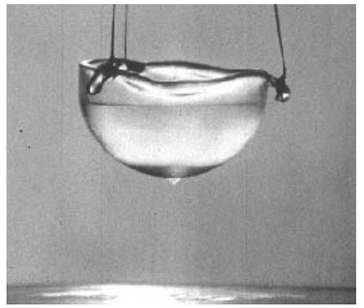
Quantum Materials & forms of order

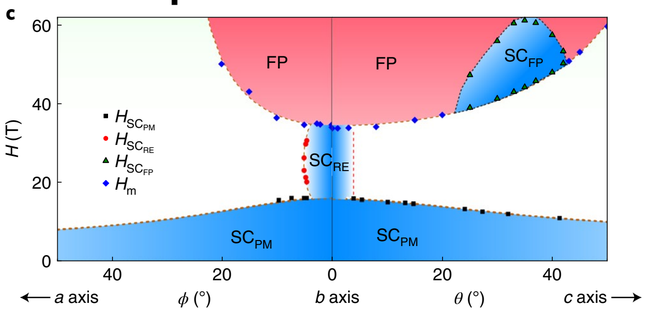
"the simplest of definitions is that a quantum material is one whose electronic or magnetic properties are best described as having a nontrivial quantum mechanical origin" [R Cava, *et al.* "Introduction: Quantum Materials", Chem. Rev. (2021)]

Quantum Materials & forms of order

"the simplest of definitions is that a quantum material is one whose electronic or magnetic properties are best described as having a nontrivial quantum mechanical origin" [R Cava, *et al.* "Introduction: Quantum Materials", Chem. Rev. (2021)]

superfluids and superconductors



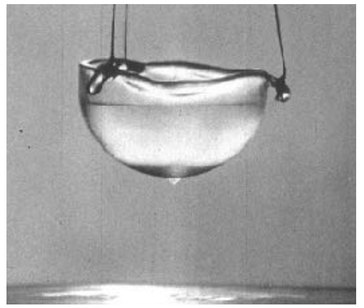


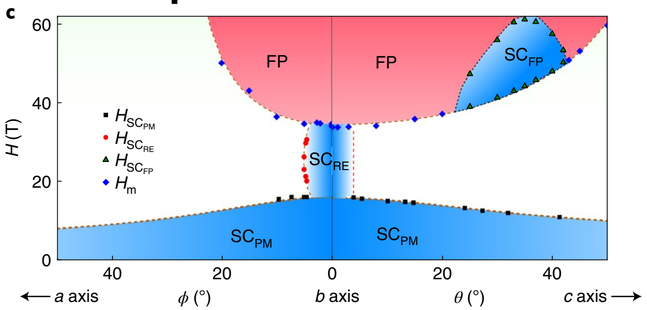
[Superfluid He: A Leitner (BBC).
UTe_2: S Ran, …, N Butch, Nature Phys (2019)]

Quantum Materials & forms of order

"the simplest of definitions is that a quantum material is one whose electronic or magnetic properties are best described as having a nontrivial quantum mechanical origin" [R Cava, *et al.* "Introduction: Quantum Materials", Chem. Rev. (2021)]

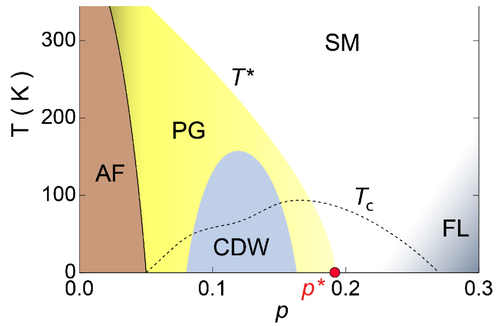
superfluids and superconductors

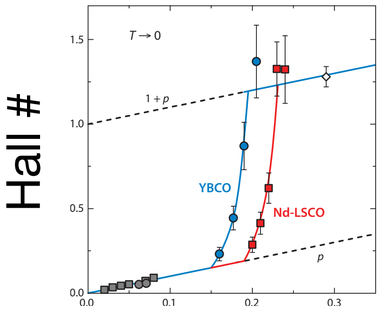




[Superfluid He: A Leitner (BBC).
UTe_2: S Ran, …, N Butch, Nature Phys (2019)]

strange & bad metals & pseudogap



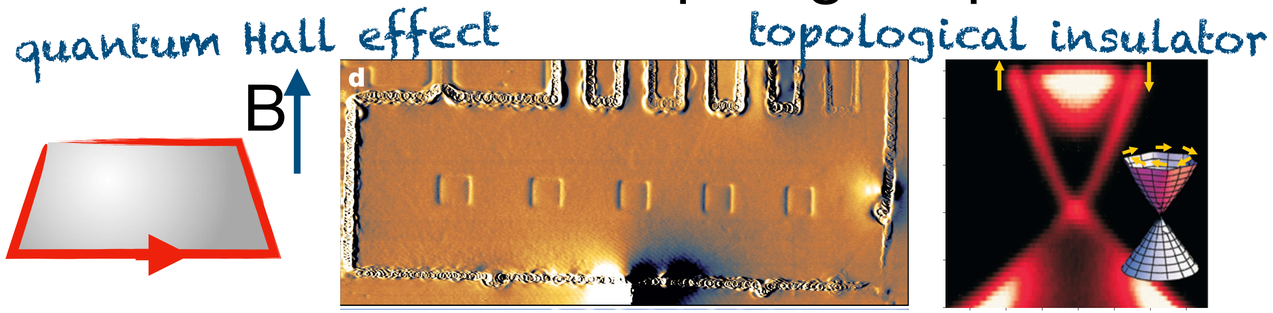


[cuprates: Proust, Taillefer, Annu. Rev. of CM Phys. (2019)]

Quantum Materials & forms of order

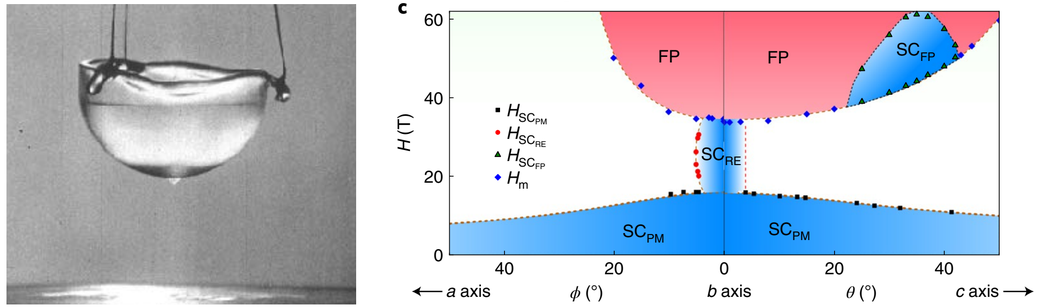
> "the simplest of definitions is that a quantum material is one whose electronic or magnetic properties are best described as having a nontrivial quantum mechanical origin" [R Cava, *et al.* "Introduction: Quantum Materials", Chem. Rev. (2021)]

topological phases



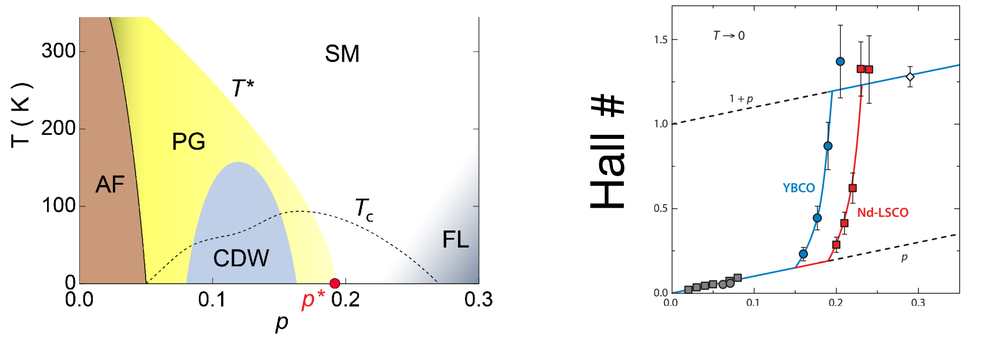
[scanning SQUID on graphene: Marguerite,…, Zeldov, Nature (2019)
ARPES on Bi_2Se_3: Wray, …, Hasan, Nat Phys (2010)]

superfluids and superconductors



[Superfluid He: A Leitner (BBC).
UTe_2: S Ran, …, N Butch, Nature Phys (2019)]

strange & bad metals & pseudogap

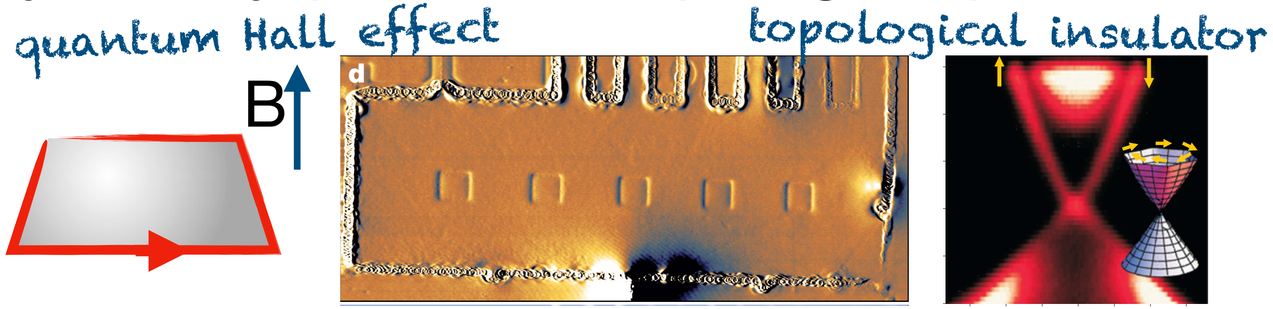


[cuprates: Proust, Taillefer, Annu. Rev. of CM Phys. (2019)]

Quantum Materials & forms of order

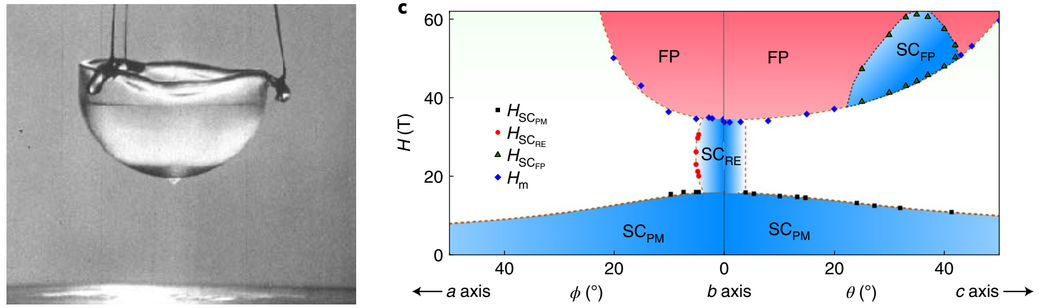
> “the simplest of definitions is that a quantum material is one whose electronic or magnetic properties are best described as having a nontrivial quantum mechanical origin” [R Cava, *et al.* "Introduction: Quantum Materials”, Chem. Rev. (2021)]

symmetry-protected topological phases



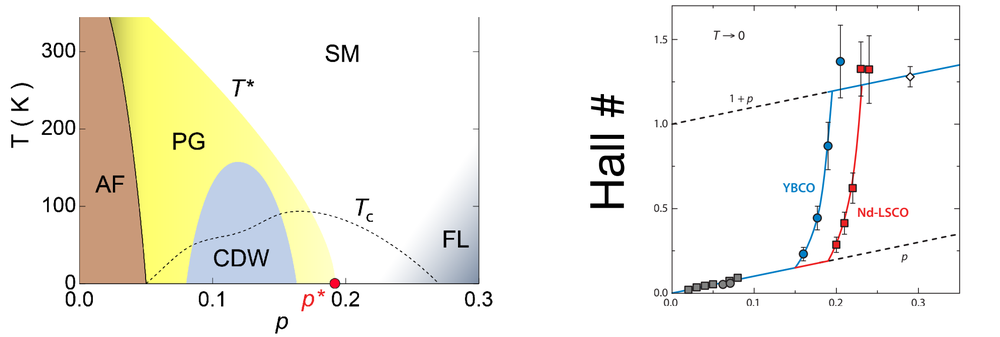
[scanning SQUID on graphene: Marguerite,…, Zeldov, Nature (2019)
ARPES on Bi_2Se_3: Wray, …, Hasan, Nat Phys (2010)]

superfluids and superconductors



[Superfluid He: A Leitner (BBC).
UTe_2: S Ran, …, N Butch, Nature Phys (2019)]

strange & bad metals & pseudogap



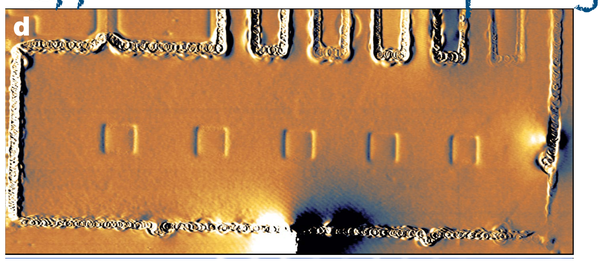
[cuprates: Proust, Taillefer, Annu. Rev. of CM Phys. (2019)]

Quantum Materials & forms of order

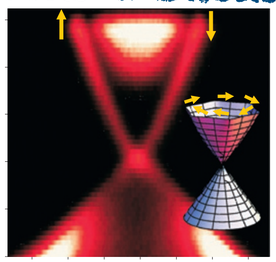
> "the simplest of definitions is that a quantum material is one whose electronic or magnetic properties are best described as having a nontrivial quantum mechanical origin" [R Cava, *et al.* "Introduction: Quantum Materials", Chem. Rev. (2021)]

symmetry-protected topological phases

quantum Hall effect

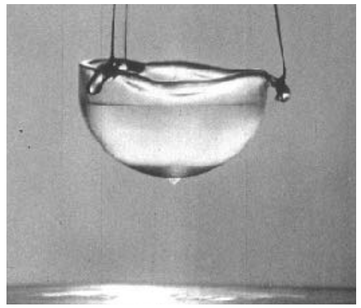


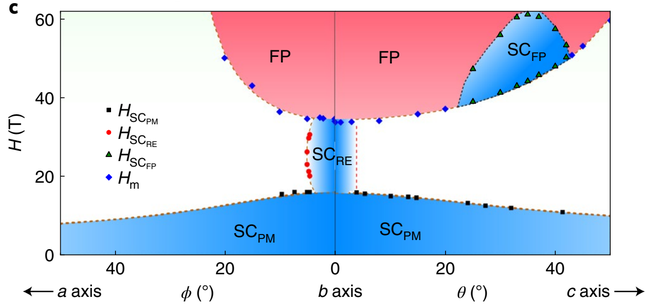
topological insulator



[scanning SQUID on graphene: Marguerite,…, Zeldov, Nature (2019)
ARPES on Bi_2Se_3: Wray, …, Hasan, Nat Phys (2010)]

superfluids and superconductors

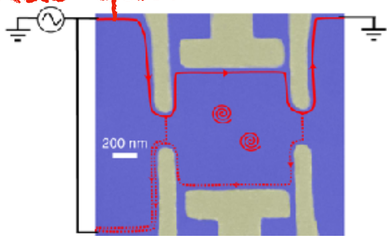




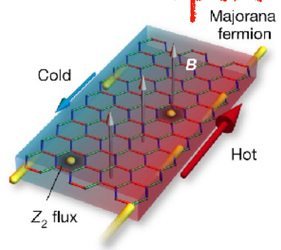
[Superfluid He: A Leitner (BBC).
UTe_2: S Ran, …, N Butch, Nature Phys (2019)]

topological order

fractional quantum Hall

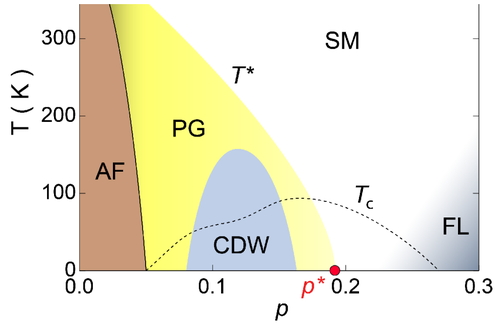


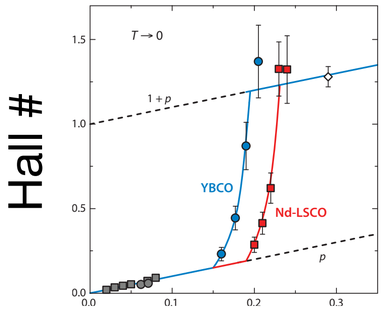
quantum spin liquid



[FQH: Nakamura *et al*, Nature (2020)
$RuCl_3$: Kasahara *et al* Nature (2018)]

strange & bad metals & pseudogap





[cuprates: Proust, Taillefer, Annu. Rev. of CM Phys. (2019)]

Quantum Materials & forms of order

symmetry-protected topological phases

quantum Hall effect

topological insulator

[scanning SQUID on graphene: Marguerite,…, Zeldov, Nature (2019)
ARPES on Bi_2Se_3: Wray, …, Hasan, Nat Phys (2010)]

topological order

fractional quantum Hall

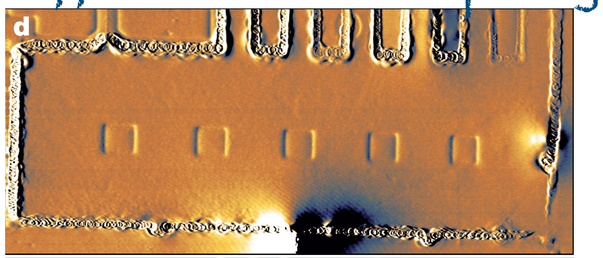
quantum spin liquid

[FQH: Nakamura *et al*, Nature (2020)
$RuCl_3$: Kasahara *et al* Nature (2018)]

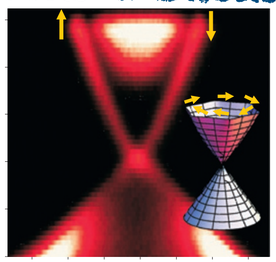
Quantum Materials & forms of order

symmetry-protected topological phases

quantum Hall effect



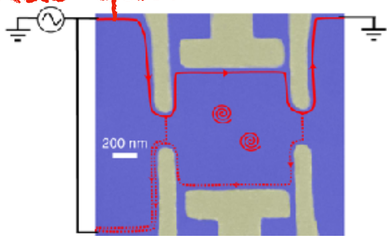
topological insulator



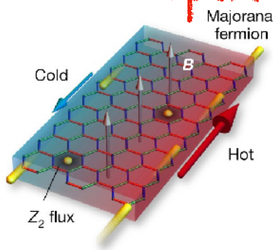
[scanning SQUID on graphene: Marguerite,…, Zeldov, Nature (2019)
ARPES on Bi_2Se_3: Wray, …, Hasan, Nat Phys (2010)]

topological order

fractional quantum Hall



quantum spin liquid



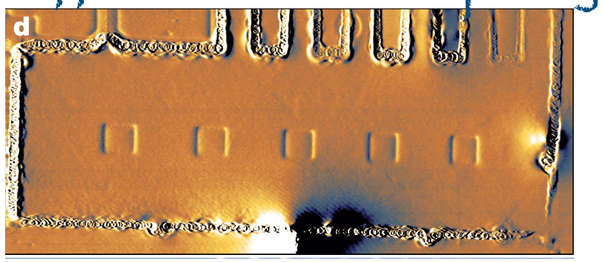
[FQH: Nakamura *et al*, Nature (2020)
$RuCl_3$: Kasahara *et al* Nature (2018)]

Quantum Materials & forms of order

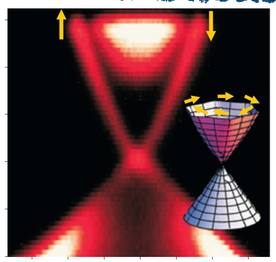
What is winding?
phase of Bloch wavefunction

symmetry-protected topological phases

quantum Hall effect



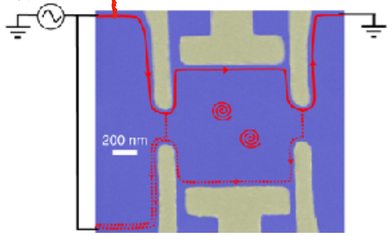
topological insulator



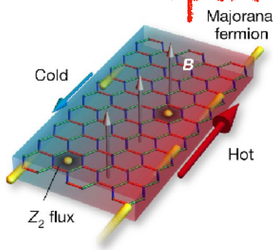
[scanning SQUID on graphene: Marguerite,…, Zeldov, Nature (2019)
ARPES on Bi_2Se_3: Wray, …, Hasan, Nat Phys (2010)]

topological order

fractional quantum Hall



quantum spin liquid



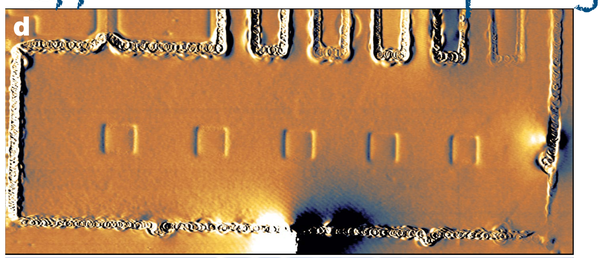
[FQH: Nakamura *et al*, Nature (2020)
$RuCl_3$: Kasahara *et al* Nature (2018)]

Quantum Materials & forms of order

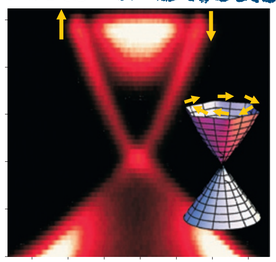
What is winding?
phase of Bloch wavefunction

symmetry-protected topological phases

quantum Hall effect



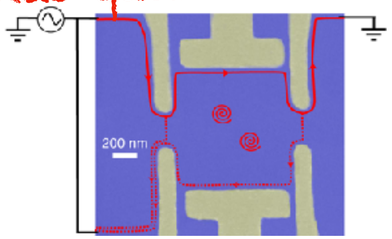
topological insulator



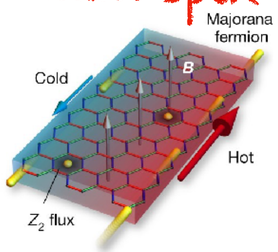
[scanning SQUID on graphene: Marguerite,…, Zeldov, Nature (2019)
ARPES on Bi_2Se_3: Wray, …, Hasan, Nat Phys (2010)]

topological order

fractional quantum Hall



quantum spin liquid



[FQH: Nakamura *et al*, Nature (2020)
$RuCl_3$: Kasahara *et al* Nature (2018)]

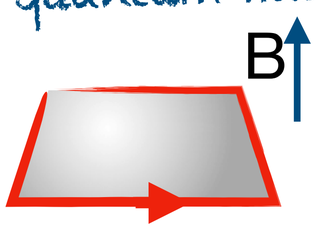
What is winding?
phase of many-body wavefunction with point-like excitations

Quantum Materials & forms of order

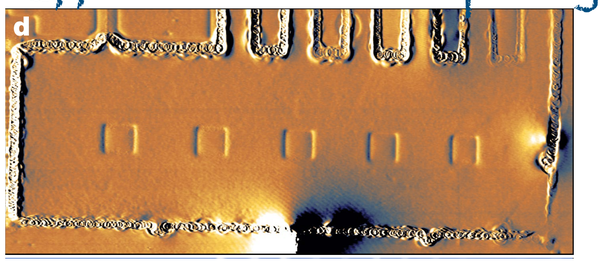
What is winding?
phase of Bloch wavefunction

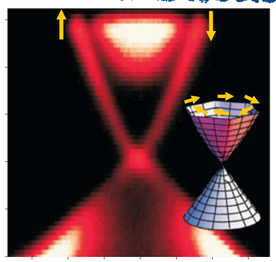
symmetry-protected topological phases

quantum Hall effect



topological insulator





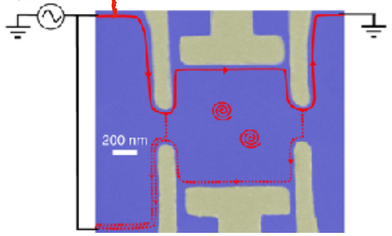
[scanning SQUID on graphene: Marguerite,…, Zeldov, Nature (2019)
ARPES on Bi_2Se_3: Wray, …, Hasan, Nat Phys (2010)]

(unless symmetries are broken)

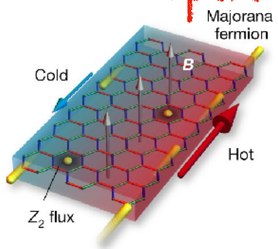
For both:
many-body quantum state
can't be created from product state
with finite depth unitary circuit

topological order

fractional quantum Hall



quantum spin liquid



[FQH: Nakamura *et al*, Nature (2020)
$RuCl_3$: Kasahara *et al* Nature (2018)]

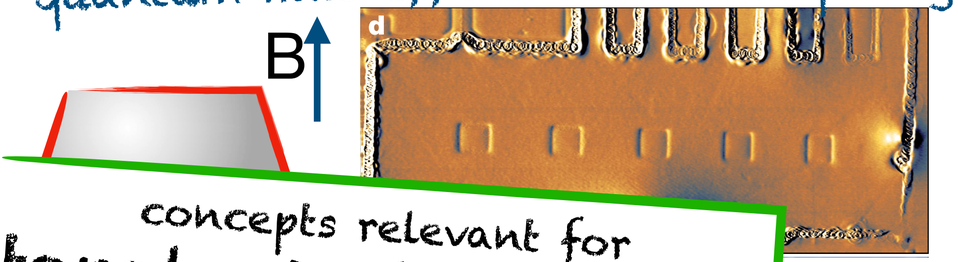
What is winding?
phase of many-body wavefunction with point-like excitations

Quantum Materials & forms of order

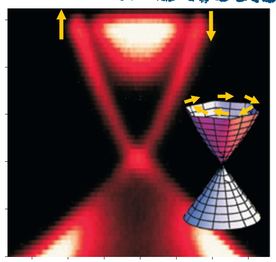
What is winding?
phase of Bloch wavefunction

symmetry-protected topological phases

quantum Hall effect



topological insulator



…, Zeldov, Nature (2019)
Hasan, Nat Phys (2010)]

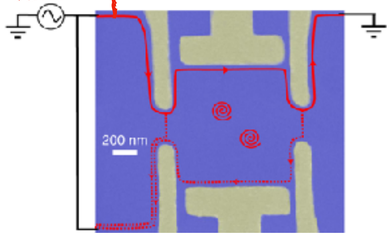
(unless symmetries are broken)

For both:
many-body quantum state
can't be created from product state
with finite depth unitary circuit

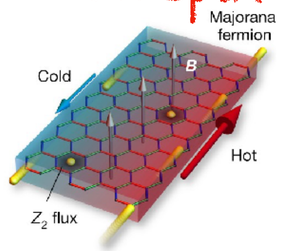
concepts relevant for
topological quantum computation

topological order

fractional quantum Hall



quantum spin liquid



[FQH: Nakamura *et al*, Nature (2020)
$RuCl_3$: Kasahara *et al* Nature (2018)]

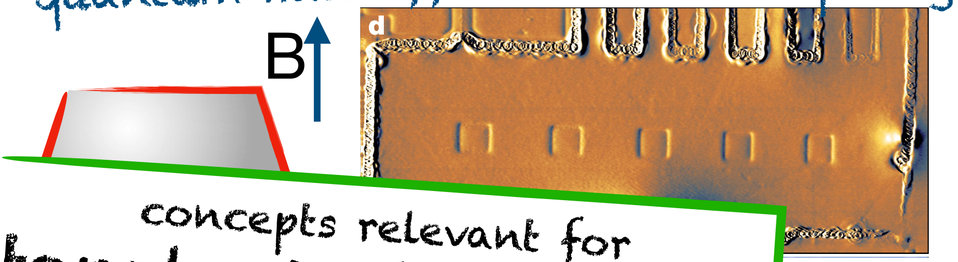
What is winding?
phase of many-body wavefunction with point-like excitations

Quantum Materials & forms of order

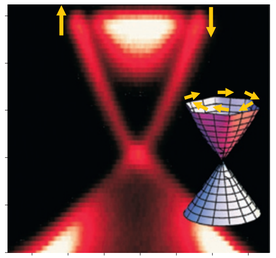
What is winding?
phase of Bloch wavefunction

symmetry-protected topological phases

quantum Hall effect



topological insulator



…, Zeldov, Nature (2019)
Hasan, Nat Phys (2010)]

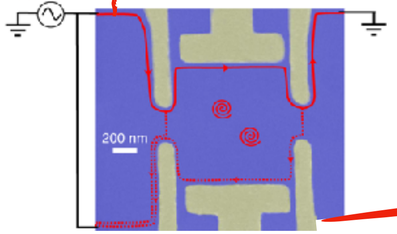
(unless symmetries are broken)

For both:
many-body quantum state
can't be created from product state
with finite depth unitary circuit

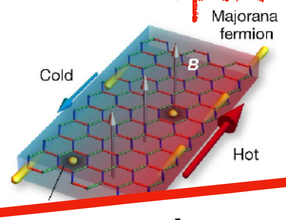
concepts relevant for
topological quantum computation

topological order

fractional quantum Hall



quantum spin liquid

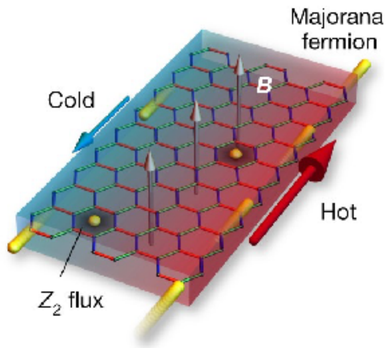


talks by Natasha Perkins

(2020)
Kasahara *et al* Nature (2018)]

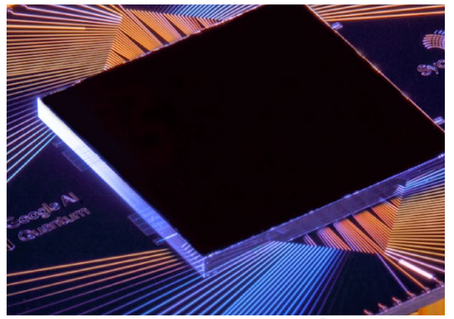
What is winding?
phase of many-body wavefunction with point-like excitations

quantum materials



$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

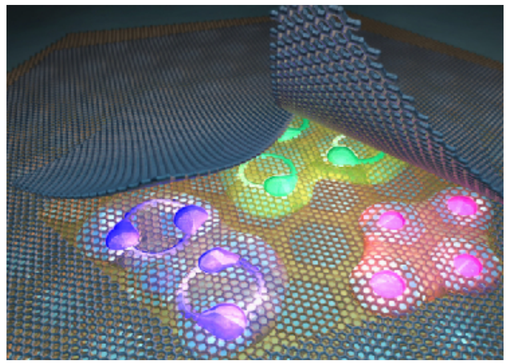
quantum computing and communication



Quantum chip:
Google Quantum, Science (2021)

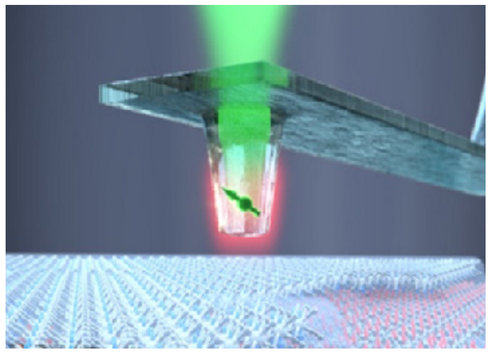
Aspects of quantum science

quantum design



2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

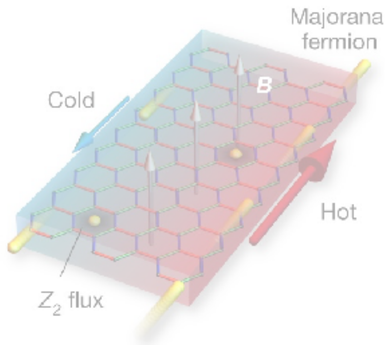
quantum sensing



Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

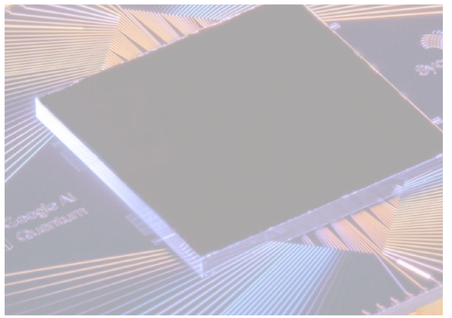
Aspects of quantum science

quantum materials



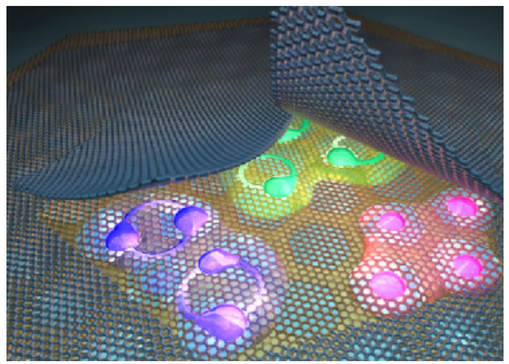
$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

quantum computing and communication



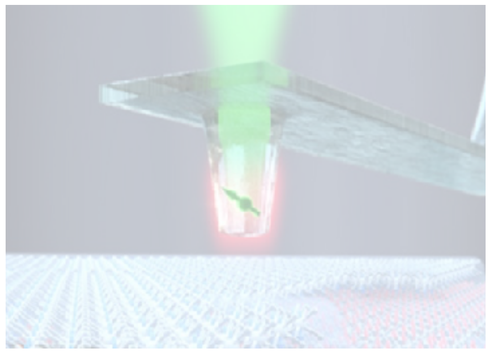
Quantum chip:
Google Quantum, Science (2021)

quantum design



2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

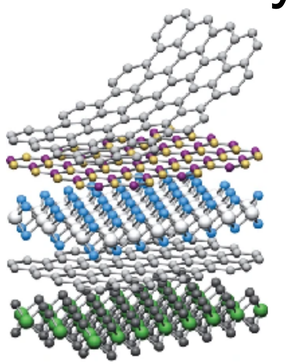
quantum sensing



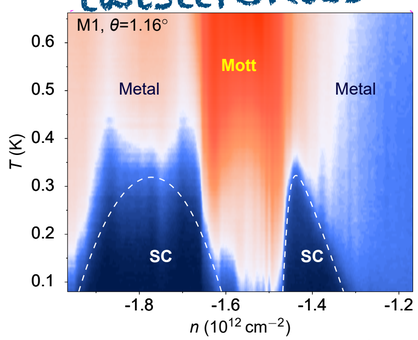
Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

Quantum Design

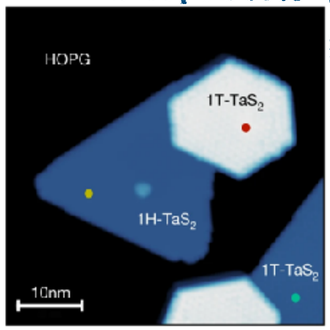
Materials by design: van der Waals LEGO



twisttronics



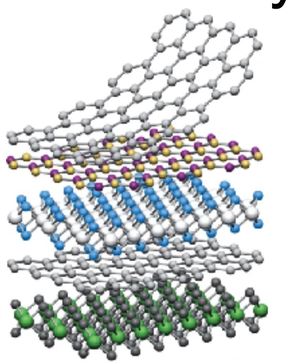
artificial Kondo lattice



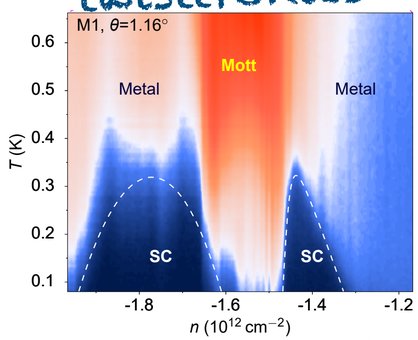
[van der Waals Lego: Geim & Grigorieva, Nature (2013)
twisted bilayer graphene: Jarillo-Herrero *et al* Nature (2018)
STM on TaS_2: Liljeroth *et al* Nature (2021)]

Quantum Design

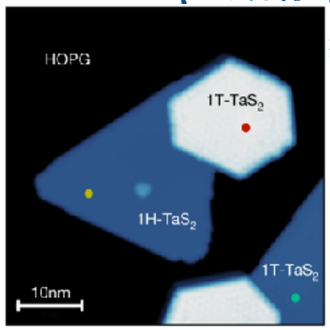
Materials by design: van der Waals LEGO



twisttronics



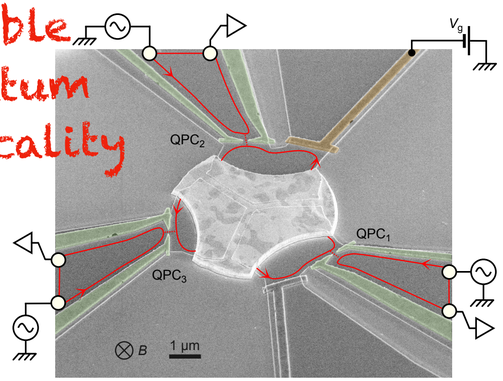
artificial Kondo lattice



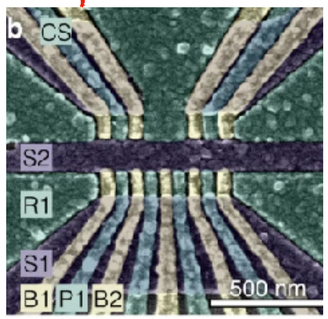
[van der Waals Lego: Geim & Grigorieva, Nature (2013)
twisted bilayer graphene: Jarillo-Herrero *et al* Nature (2018)
STM on TaS_2: Liljeroth *et al* Nature (2021)]

Quantum dots

Tunable quantum criticality



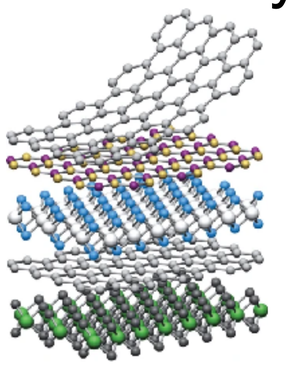
wiggle well quantum dot



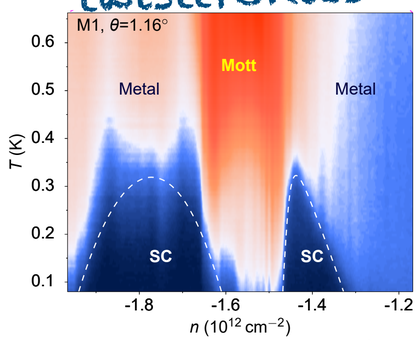
[3-channel Kondo device: Pierre *et al*, Science (2018)
Si quantum dot: Eriksson, Joynt, Friesen *et al* Nat Comm (2022)]

Quantum Design

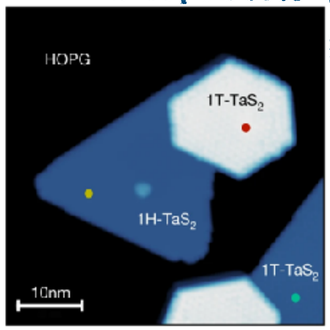
Materials by design: van der Waals LEGO



twisttronics



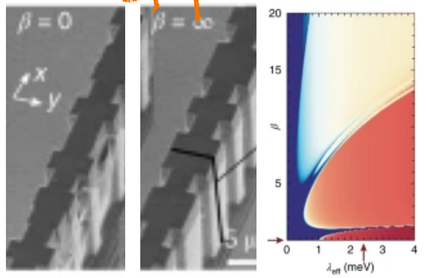
artificial Kondo lattice



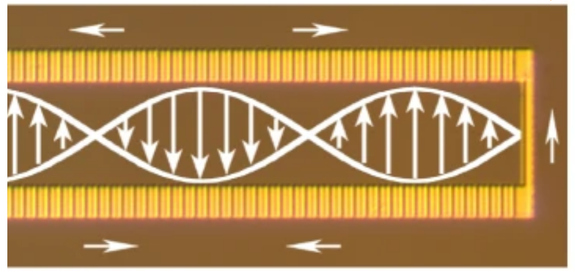
[van der Waals Lego: Geim & Grigorieva, Nature (2013)
twisted bilayer graphene: Jarillo-Herrero *et al* Nature (2018)
STM on TaS_2: Liljeroth *et al* Nature (2021)]

Artificial materials

Anderson localization of polaritons



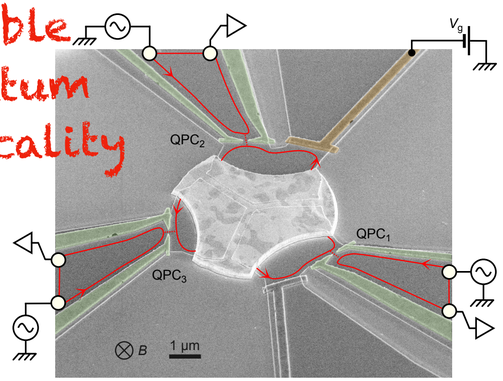
superconductor-insulator transition



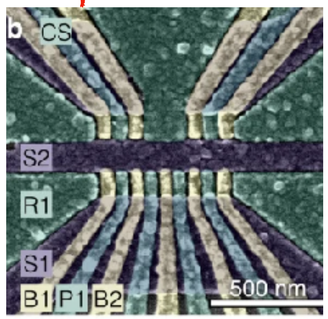
[Polariton waveguides: J Bloch *et al*, Nat Phys (2020)
Josephson junction chain: Kuzmin *et al* Nat Phys (2019)]

Quantum dots

Tunable quantum criticality



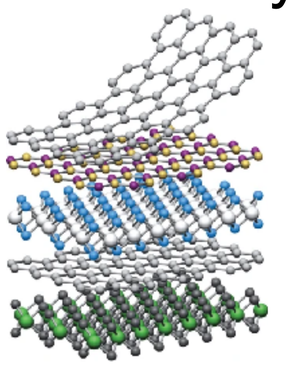
wiggle well quantum dot



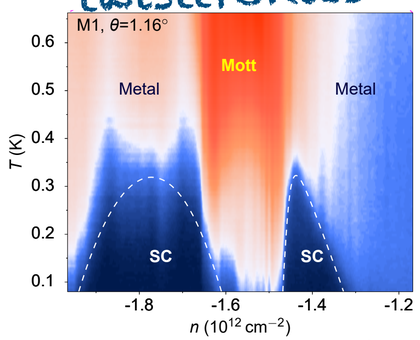
[3-channel Kondo device: Pierre *et al*, Science (2018)
Si quantum dot: Eriksson, Joynt, Friesen *et al* Nat Comm (2022)]

Quantum Design

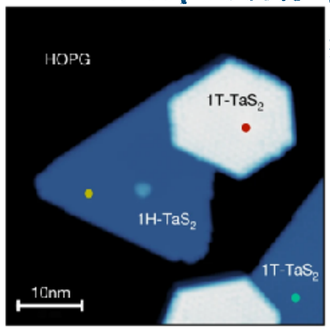
Materials by design: van der Waals LEGO



twisttronics



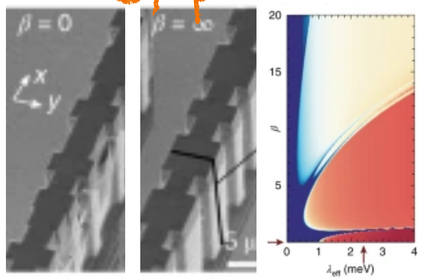
artificial Kondo lattice



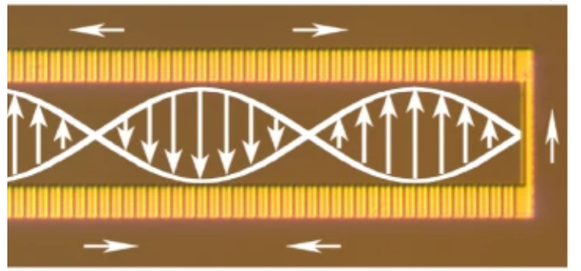
[van der Waals Lego: Geim & Grigorieva, Nature (2013)
twisted bilayer graphene: Jarillo-Herrero *et al* Nature (2018)
STM on TaS_2: Liljeroth *et al* Nature (2021)]

Artificial materials

Anderson localization of polaritons



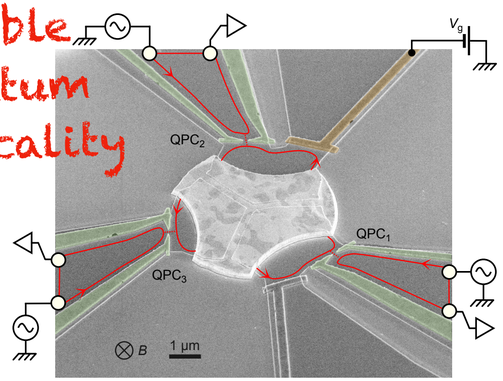
superconductor-insulator transition



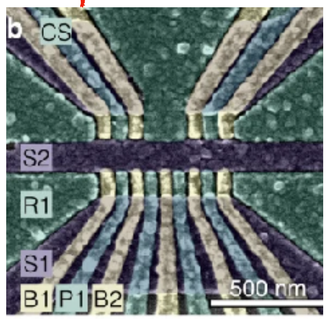
[Polariton waveguides: J Bloch *et al*, Nat Phys (2020)
Josephson junction chain: Kuzmin *et al* Nat Phys (2019)]

Quantum dots

Tunable quantum criticality



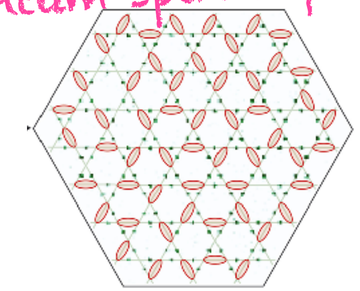
wiggle well quantum dot



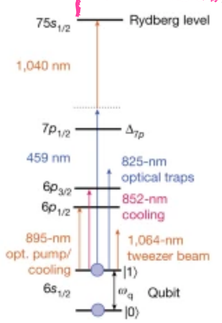
[3-channel Kondo device: Pierre *et al*, Science (2018)
Si quantum dot: Eriksson, Joynt, Friesen *et al* Nat Comm (2022)]

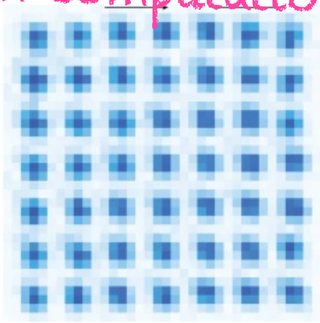
Cold atoms, trapped ions, etc.

Rydberg simulation of quantum spin liquid



Neutral atom gate-based quantum computation

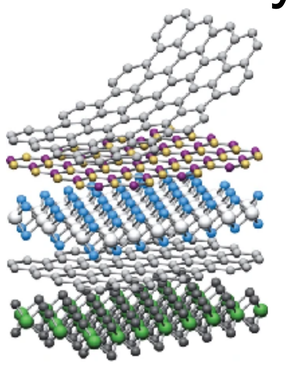




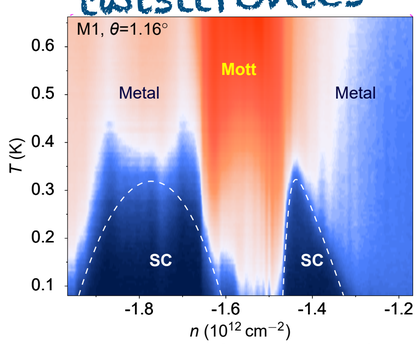
[^{87}Rb Rydberg states: Lukin et al, Science (2021)
Cs quantum gates: Saffmann *et al*, Nature (2022)]

Quantum Design

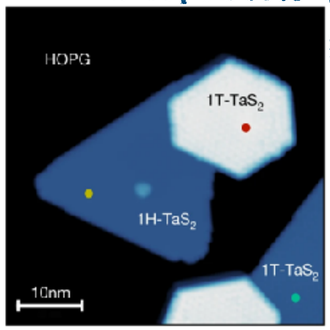
Materials by design: van der Waals LEGO



twisttronics



artificial Kondo lattice

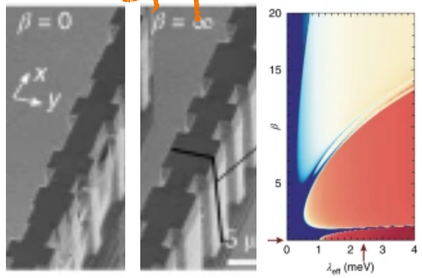


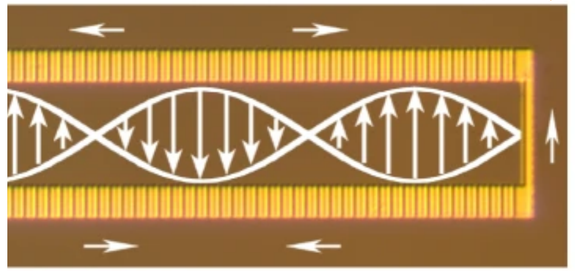
[van der Waals Lego: Geim & Grigorieva, Nature (2013)
twisted bilayer graphene: Jarillo-Herrero *et al* Nature (2018)
STM on TaS_2: Liljeroth *et al* Nature (2021)]

Artificial materials

Anderson localization of polaritons

superconductor-insulator transition

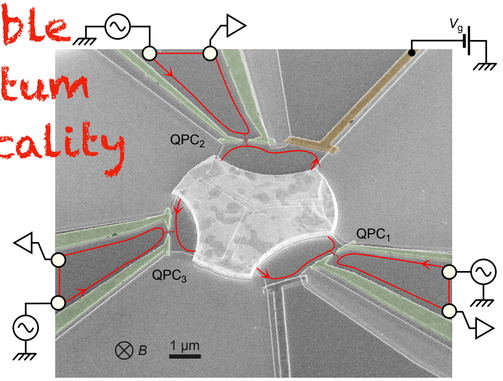




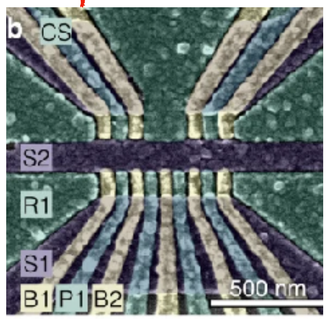
[Polariton waveguides: J Bloch *et al*, Nat Phys (2020)
Josephson junction chain: Kuzmin *et al* Nat Phys (2019)]

Quantum dots

Tunable quantum criticality



wiggle well quantum dot

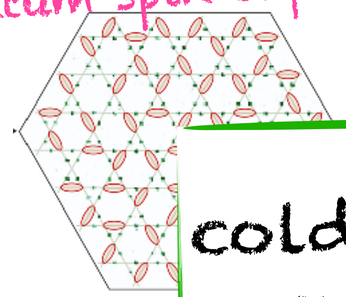


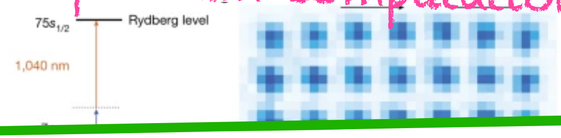
[3-channel Kondo device: Pierre *et al*, Science (2018)
Si quantum dot: Eriksson, Joynt, Friesen *et al* Nat Comm (2022)]

Cold atoms, trapped ions, etc.

Rydberg simulation of quantum spin liquid

Neutral atom gate-based quantum computation





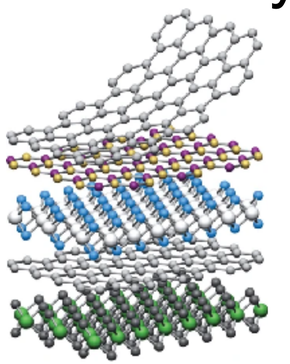
basis for cold atom/trapped ion quantum computer

[8

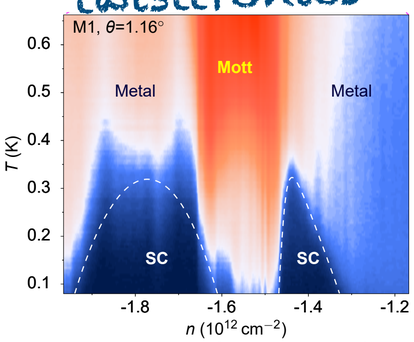
Cs quantum gates: Saffmann *et al*, Nature (2022)]

Quantum Design

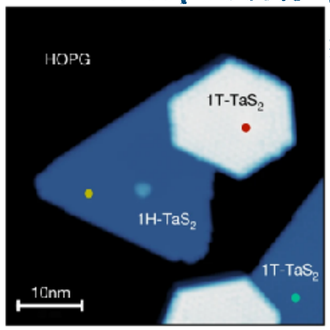
Materials by design: van der Waals LEGO



twisttronics



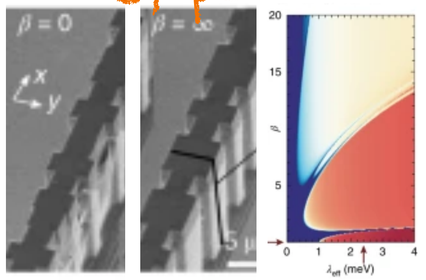
artificial Kondo lattice



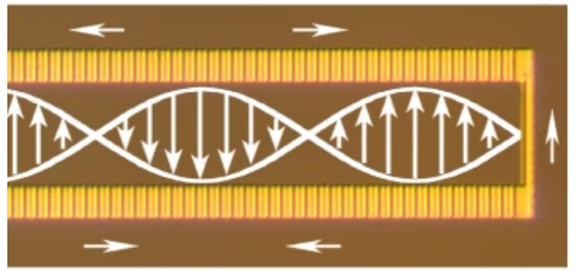
[van der Waals Lego: Geim & Grigorieva, Nature (2013)
twisted bilayer graphene: Jarillo-Herrero *et al* Nature (2018)
STM on TaS_2: Liljeroth *et al* Nature (2021)]

Artificial materials

Anderson localization of polaritons



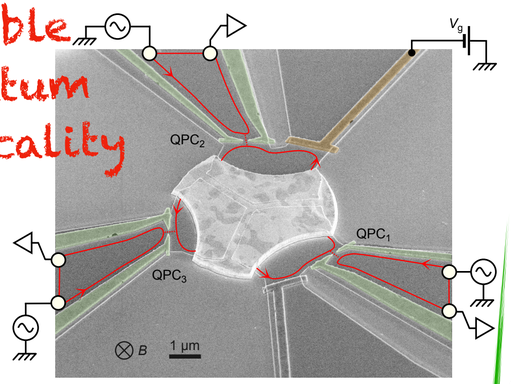
superconductor-insulator transition



[Polariton waveguides: J Bloch *et al*, Nat Phys (2020)
Josephson junction chain: Kuzmin *et al* Nat Phys (2019)]

Quantum dots

Tunable quantum criticality



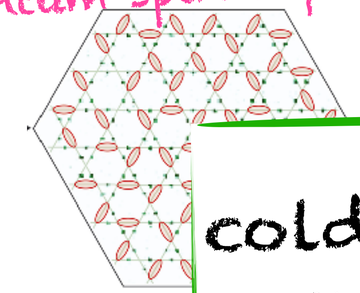
wiggle well quantum dot

basis for spin qubit quantum computer

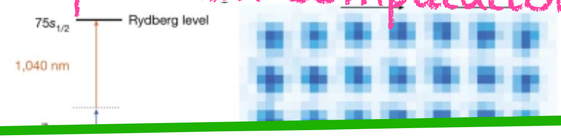
[3-channel Kondo device
Si quantum dot: Eriksson, Joynt, Friesen *et al* Nat Comm (2022)]

Cold atoms, trapped ions, etc.

Rydberg simulation of quantum spin liquid



Neutral atom gate-based quantum computation

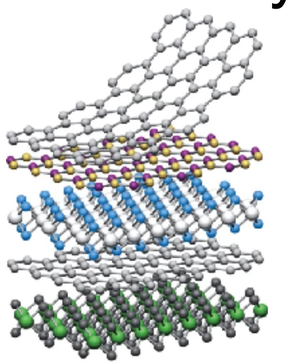


basis for cold atom/trapped ion quantum computer

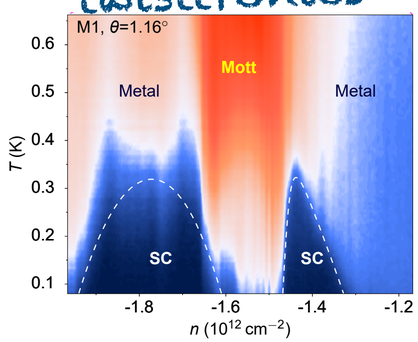
[8
Cs quantum gates: Saffmann *et al*, Nature (2022)]

Quantum Design

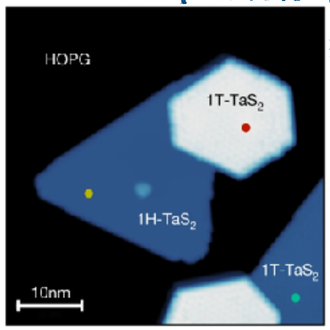
Materials by design: van der Waals LEGO



twisttronics



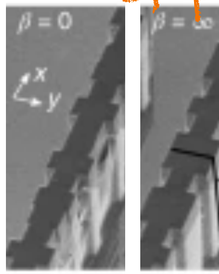
artificial Kondo lattice

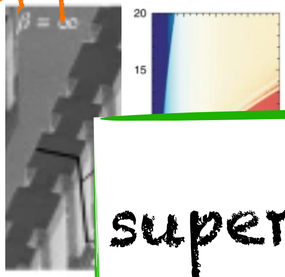


[van der Waals Lego: Geim & Grigorieva, Nature (2013)
twisted bilayer graphene: Jarillo-Herrero *et al* Nature (2018)
STM on TaS_2: Liljeroth *et al* Nature (2021)]

Artificial materials

Anderson localization of polaritons





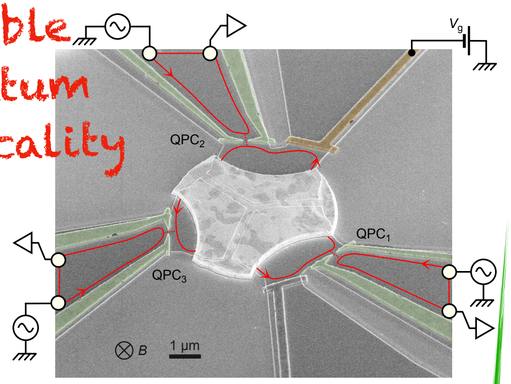
superconductor-insulator transition

basis for superconducting qubit quantum computer

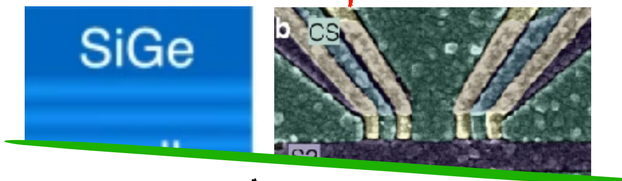
[Polariton
Josephson junction chain: Kuzmin *et al* Nat Phys (2019)]

Quantum dots

Tunable quantum criticality



wiggle well quantum dot

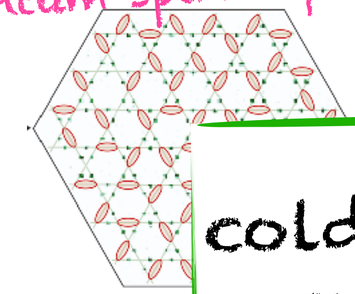


basis for spin qubit quantum computer

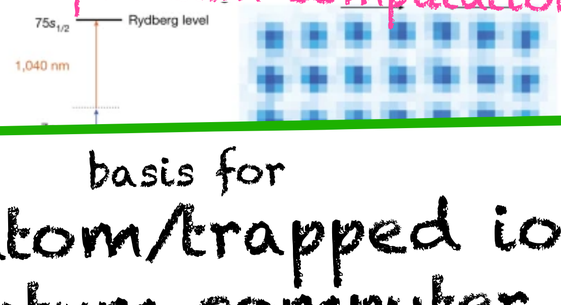
[3-channel Kondo de
Si quantum dot: Eriksson, Joynt, Friesen *et al* Nat Comm (2022)]

Cold atoms, trapped ions, etc.

Rydberg simulation of quantum spin liquid



Neutral atom gate-based quantum computation

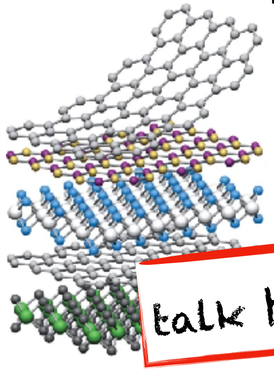


basis for cold atom/trapped ion quantum computer

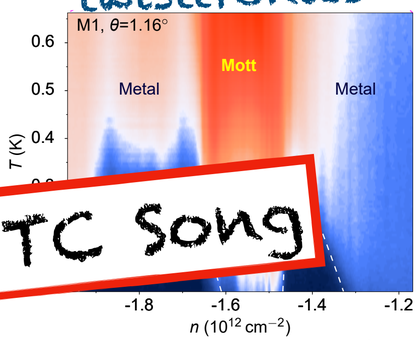
[8
Cs quantum gates: Saffmann *et al*, Nature (2022)]

Quantum Design

Materials by design: van der Waals LEGO

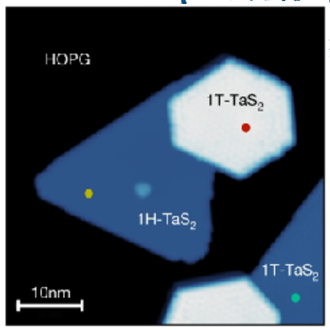


twisttronics



talk by TC Song

artificial Kondo lattice

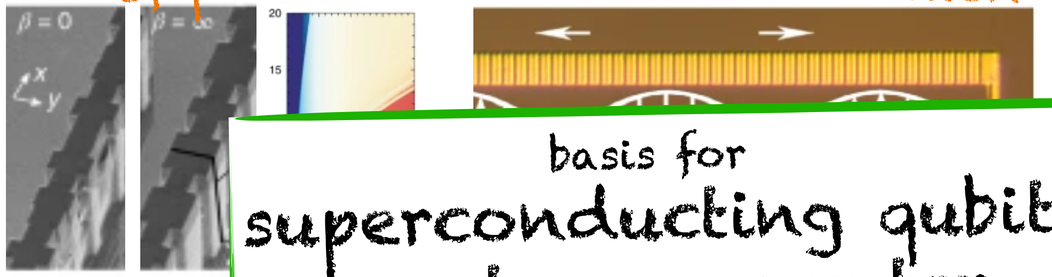


[van der Waals Lego: Geim & Grigorieva, Nature (2013)
twisted bilayer graphene: Jarillo-Herrero *et al* Nature (2018)
STM on TaS_2: Liljeroth *et al* Nature (2021)]

Artificial materials

Anderson localization of polaritons

superconductor-insulator transition

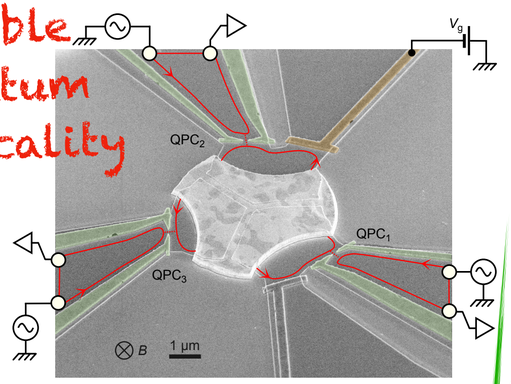


basis for superconducting qubit quantum computer

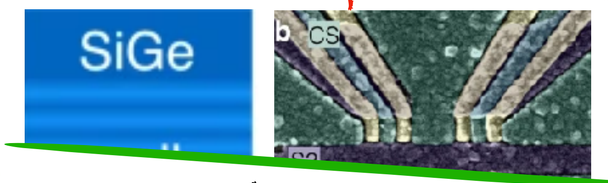
[Polariton
Josephson junction chain: Kuzmin *et al* Nat Phys (2019)]

Quantum dots

Tunable quantum criticality



wiggle well quantum dot

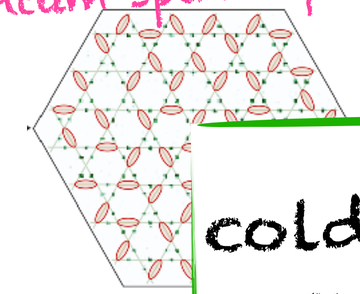


basis for spin qubit quantum computer

[3-channel Kondo d
Si quantum dot: Eriksson, Joynt, Friesen *et al* Nat Comm (2022)]

Cold atoms, trapped ions, etc.

Rydberg simulation of quantum spin liquid



Neutral atom gate-based quantum computation

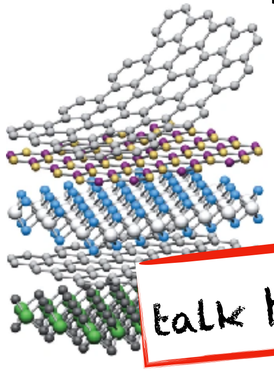
basis for cold atom/trapped ion quantum computer

[8
Cs quantum gates: Saffmann *et al*, Nature (2022)]

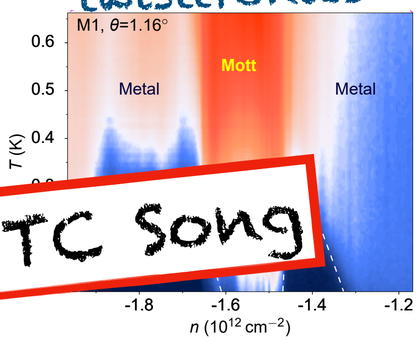
Quantum Design

talks by
Maxim Vavilov
Roman Kuzmin

Materials by design: van der Waals LEGO

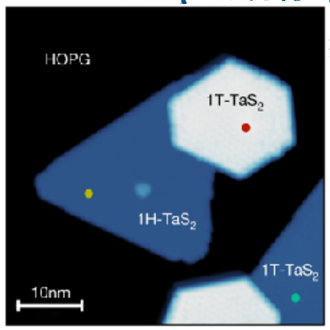


twisttronics



talk by TC Song

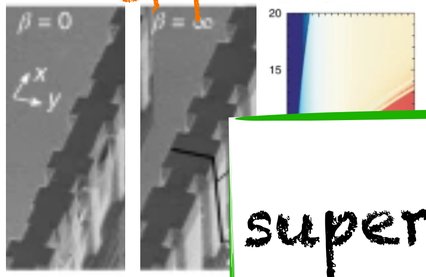
artificial Kondo lattice



[van der Waals Lego: Geim & Grigorieva, Nature (2013)
twisted bilayer graphene: Jarillo-Herrero *et al* Nature (2018)
STM on TaS_2: Liljeroth *et al* Nature (2021)]

Artificial materials

Anderson localization of polaritons



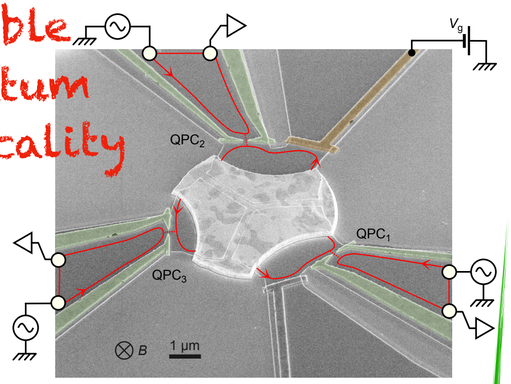
superconductor-insulator transition

basis for
superconducting qubit
quantum computer

[Polariton
Josephson junction chain: Kuzmin *et al* Nat Phys (2019)]

Quantum dots

Tunable quantum criticality



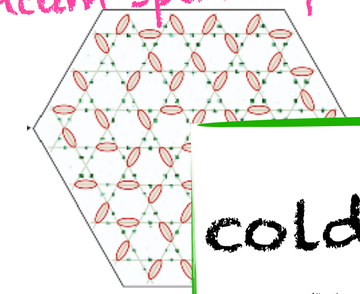
wiggle well quantum dot

basis for
spin qubit
quantum computer

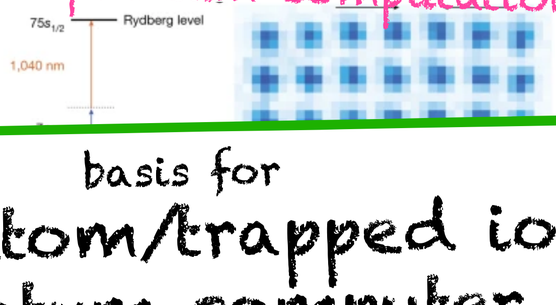
[3-channel Kondo de
Si quantum dot: Eriksson, Joynt, Friesen *et al* Nat Comm (2022)]

Cold atoms, trapped ions, etc.

Rydberg simulation of quantum spin liquid



Neutral atom gate-based quantum computation



basis for
cold atom/trapped ion
quantum computer

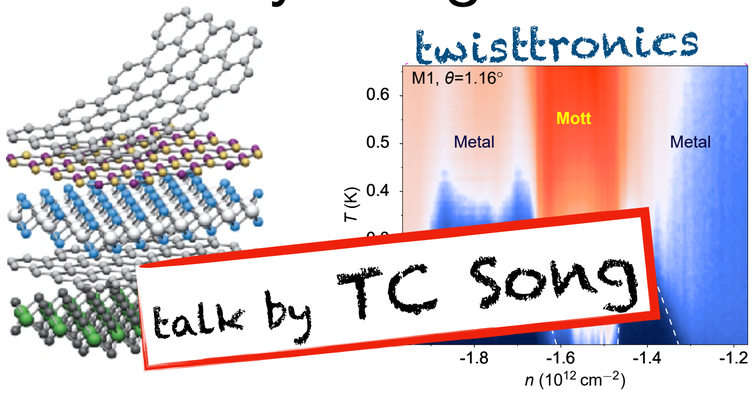
[8
Cs quantum gates: Saffmann *et al*, Nature (2022)]

Quantum Design

talks by
Maxim Vavilov
Roman Kuzmin

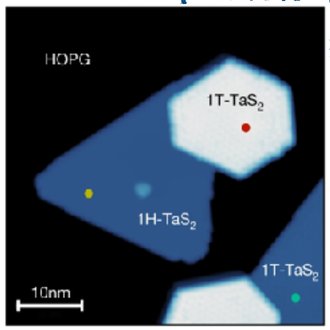
Materials by design: van der Waals LEGO

twisttronics



talk by TC Song

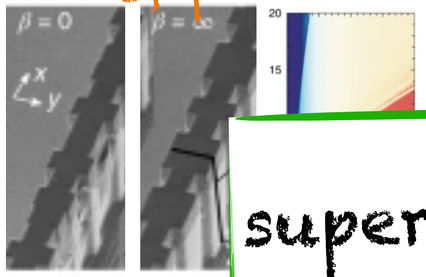
artificial Kondo lattice



[van der Waals Lego: Geim & Grigorieva, Nature (2013)
twisted bilayer graphene: Jarillo-Herrero *et al* Nature (2018)
STM on TaS_2: Liljeroth *et al* Nature (2021)]

Artificial materials

Anderson localization of polaritons



superconductor-insulator transition

basis for
superconducting qubit
quantum computer

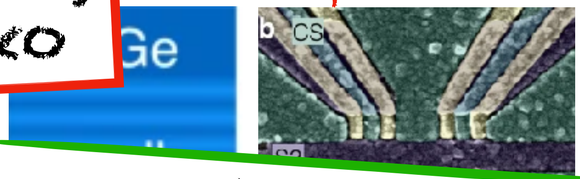
[Polariton
Josephson junction chain: Kuzmin *et al* Nat Phys (2019)]

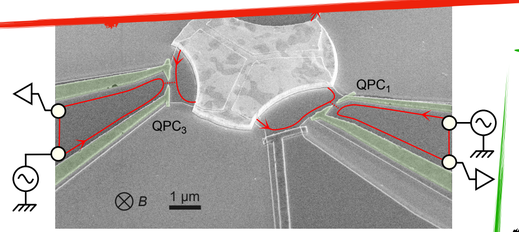
Quantum dots

Tun
qua
crit

Quantum transport: talk by
Alex Levchenko

le well quantum dot



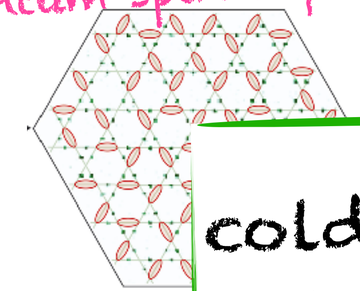


basis for
spin qubit
quantum computer

[3-channel Kondo de
Si quantum dot: Eriksson, Joynt, Friesen *et al* Nat Comm (2022)]

Cold atoms, trapped ions, etc.

Rydberg simulation of quantum spin liquid

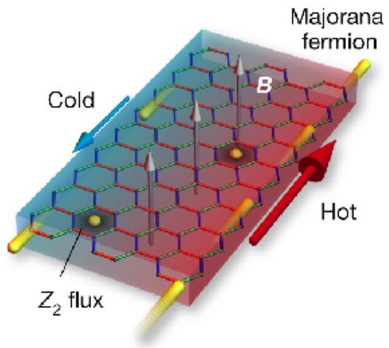


Neutral atom gate-based quantum computation

basis for
cold atom/trapped ion
quantum computer

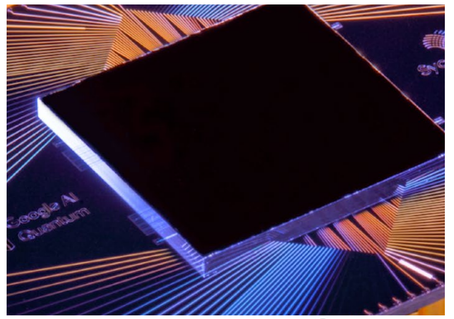
[8
Cs quantum gates: Saffmann *et al*, Nature (2022)]

quantum materials



$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

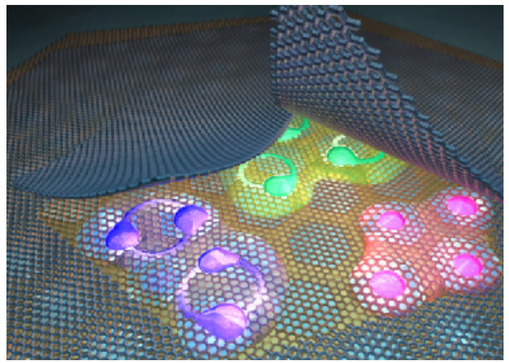
quantum computing and communication



Quantum chip:
Google Quantum, Science (2021)

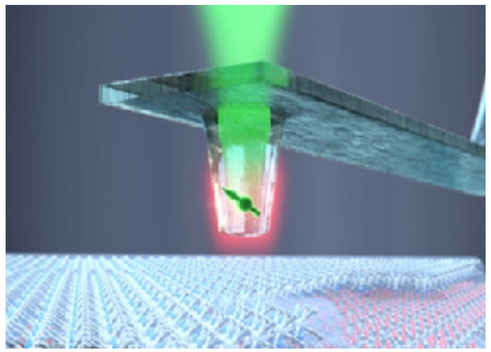
Aspects of quantum science

quantum design



2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

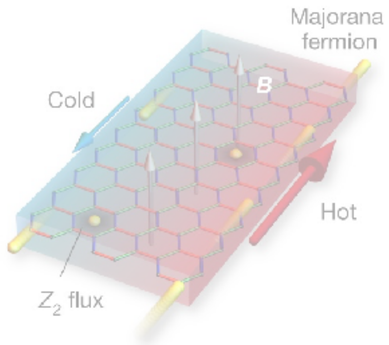
quantum sensing



Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

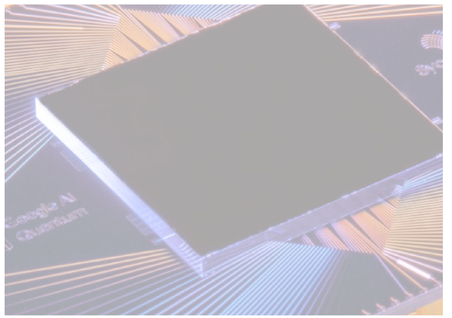
Aspects of quantum science

quantum materials



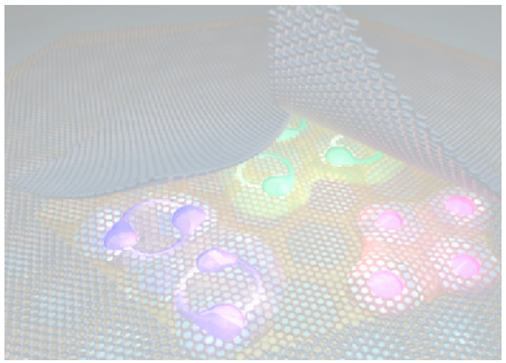
$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

quantum computing and communication



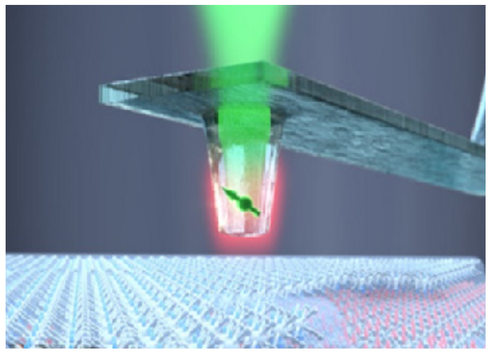
Quantum chip:
Google Quantum, Science (2021)

quantum design



2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

quantum sensing

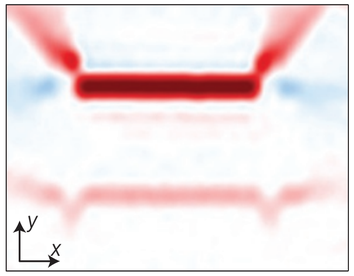


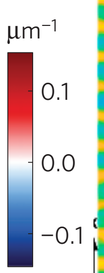
Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

Quantum Sensing

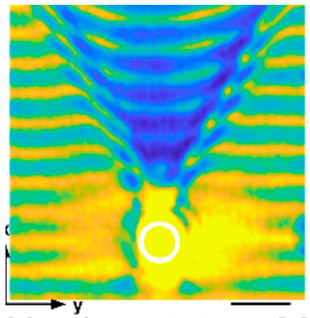
Local magnetometry

Scanning SQUID

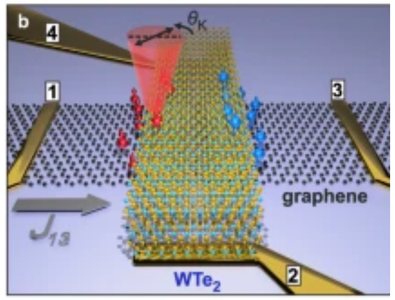




NV centers



Local Kerr

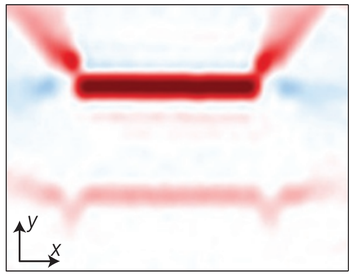


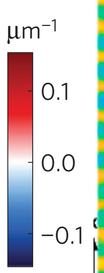
[QSH edge states: Moler *et al*, Nat Mat (2013)
Local magnetization in YIG: Yacoby *et al* PNAS (2021)
current induced Kerr: König, Burghard *et al* Nat Comm (2022)]

Quantum Sensing

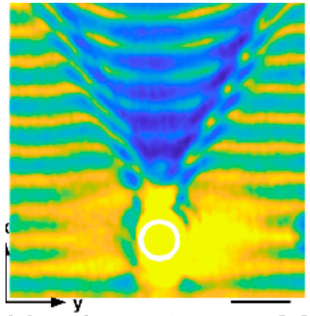
Local magnetometry

Scanning SQUID

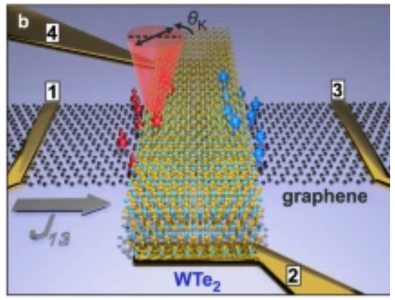




NV centers



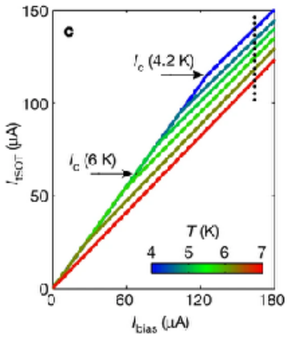
Local Kerr

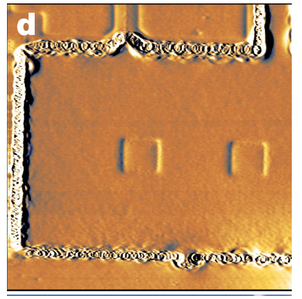


[QSH edge states: Moler *et al*, Nat Mat (2013)
Local magnetization in YIG: Yacoby *et al* PNAS (2021)
current induced Kerr: König, Burghard *et al* Nat Comm (2022)]

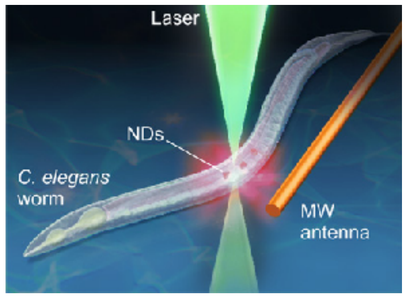
Local thermometry

SQUID on tip





Frequency shift in NV centers

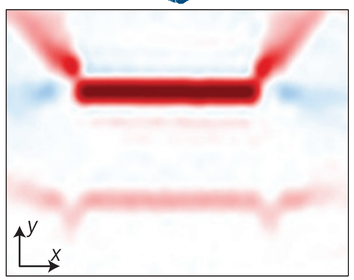


[Squid on tip: Zeldov *et al*, Nature (2016)
Real time NV thermometry: Kage-Nakagai *et al,* Sci Adv (2020)]

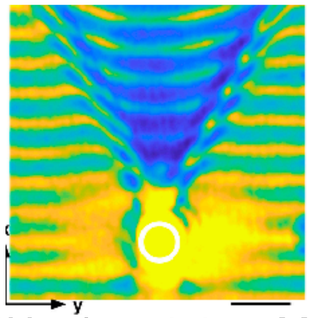
Quantum Sensing

Local magnetometry

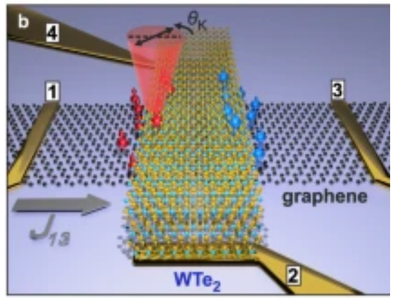
Scanning SQUID



NV centers



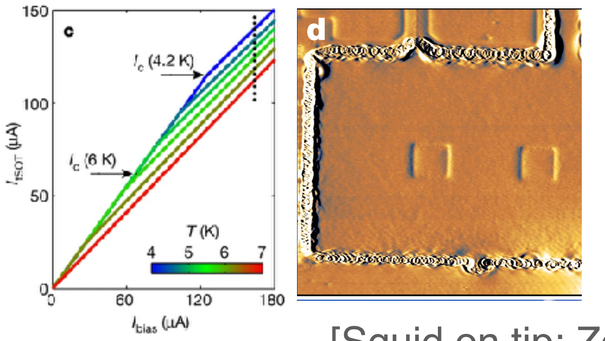
Local Kerr



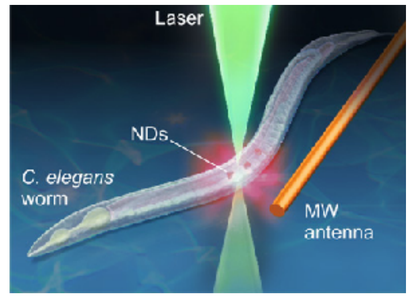
[QSH edge states: Moler *et al*, Nat Mat (2013)
Local magnetization in YIG: Yacoby *et al* PNAS (2021)
current induced Kerr: König, Burghard *et al* Nat Comm (2022)]

Local thermometry

SQUID on tip



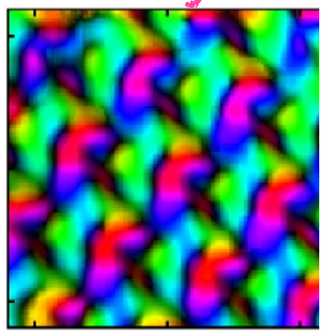
Frequency shift in NV centers

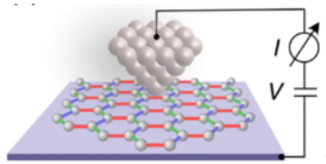


[Squid on tip: Zeldov *et al*, Nature (2016)
Real time NV thermometry: Kage-Nakagai *et al,* Sci Adv (2020)]

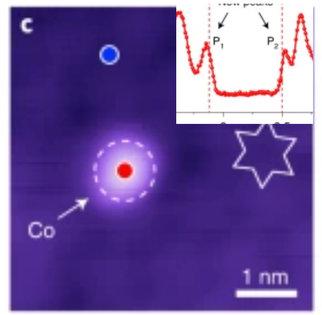
Scanning tunneling microscopy

Twisted bilayer graphene





Spinon Kondo

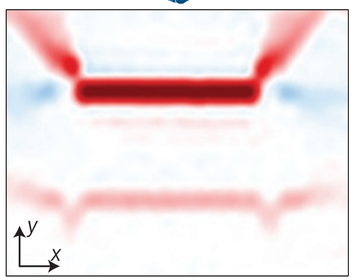


[IVC in twisted bilayer graphene: Yazdani *et al*, Nature (2023)
Spinon Kondo in TaS_2: Crommie *et al*, Nature (2022)]

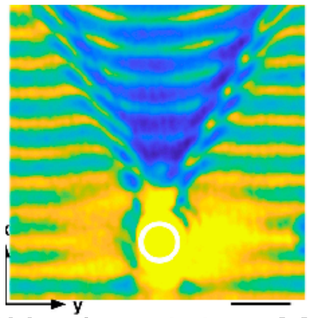
Quantum Sensing

Local magnetometry

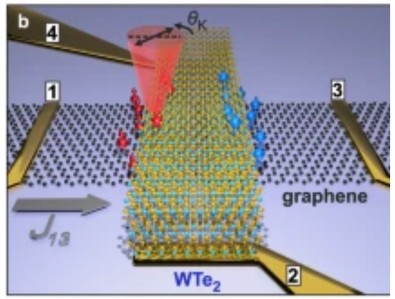
Scanning SQUID



NV centers



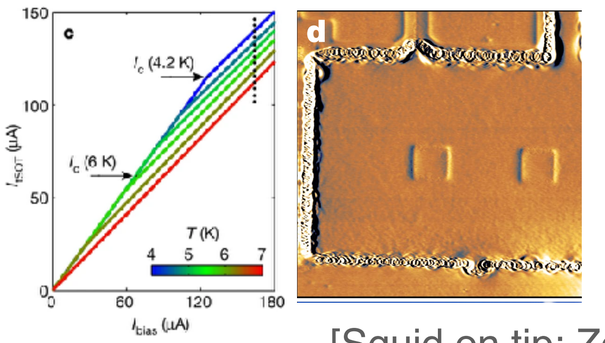
Local Kerr



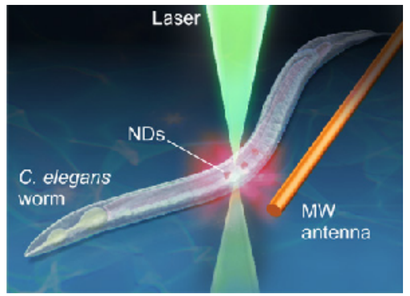
[QSH edge states: Moler *et al*, Nat Mat (2013)
Local magnetization in YIG: Yacoby *et al* PNAS (2021)
current induced Kerr: König, Burghard *et al* Nat Comm (2022)]

Local thermometry

SQUID on tip



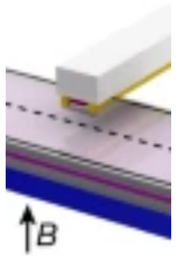
Frequency shift in NV centers

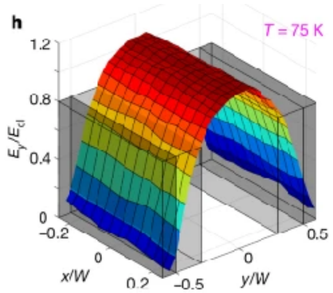


[Squid on tip: Zeldov *et al*, Nature (2016)
Real time NV thermometry: Kage-Nakagai *et al,* Sci Adv (2020)]

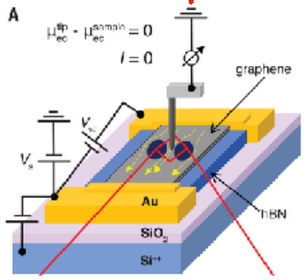
Local potentiometry

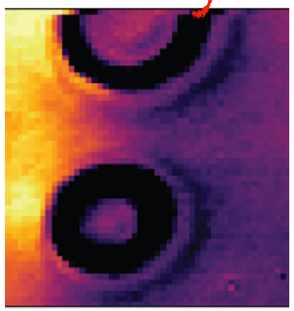
Scanning single electron transistor





Scanning tunneling potentiometry

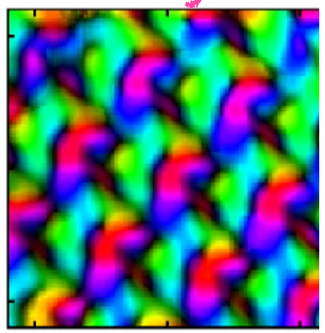


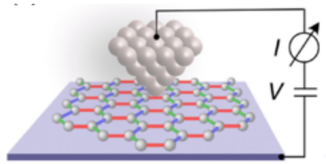


[Poiseuille profile in graphene: Ilani *et al*, Nature (2019)
dams in graphene: Levchenko, Brar *et al* Science (2023)]

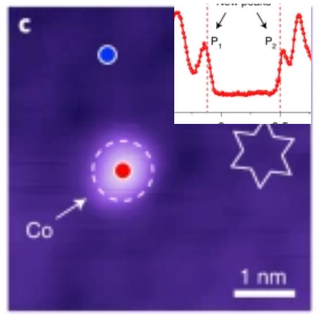
Scanning tunneling microscopy

Twisted bilayer graphene





Spinon Kondo

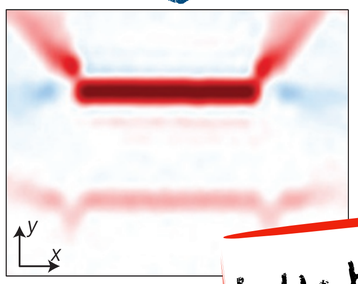


[IVC in twisted bilayer graphene: Yazdani *et al*, Nature (2023)
Spinon Kondo in TaS_2: Crommie *et al*, Nature (2022)]

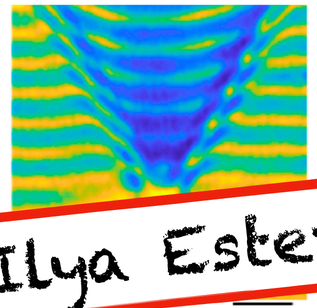
Quantum Sensing

Local magnetometry

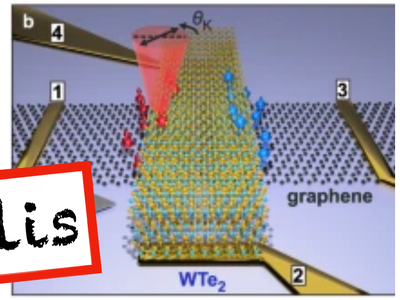
Scanning SQUID



NV centers



Local Kerr

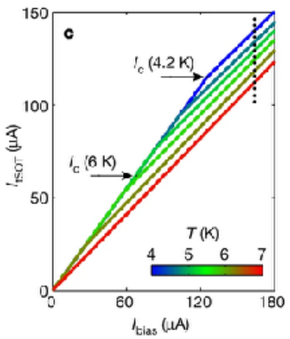


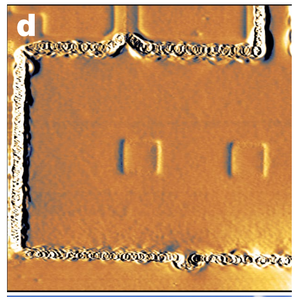
talk by Ilya Esterlis

[QSH edge states: Moler *et al*, Nat Mat (2013)
Local magnetization in YIG: Yacoby *et al* PNAS (2021)
current induced Kerr: König, Burghard *et al* Nat Comm (2022)]

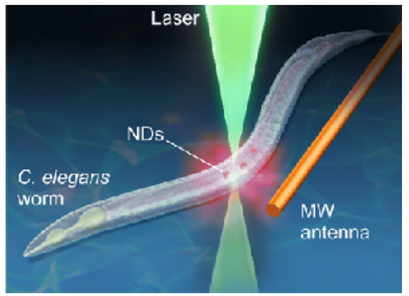
Local thermometry

SQUID on tip





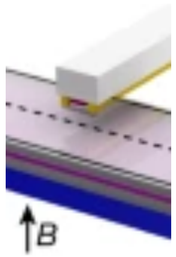
Frequency shift in NV centers

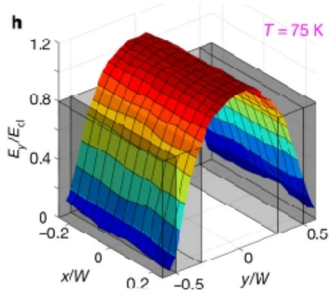


[Squid on tip: Zeldov *et al*, Nature (2016)
Real time NV thermometry: Kage-Nakagai *et al,* Sci Adv (2020)]

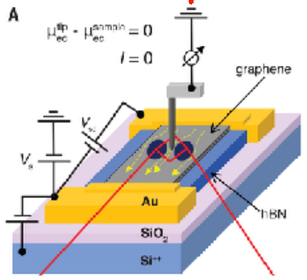
Local potentiometry

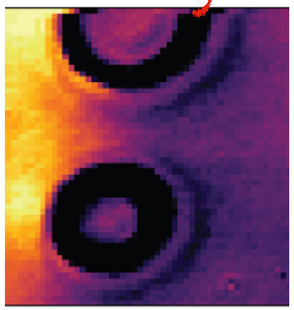
Scanning single electron transistor





Scanning tunneling potentiometry

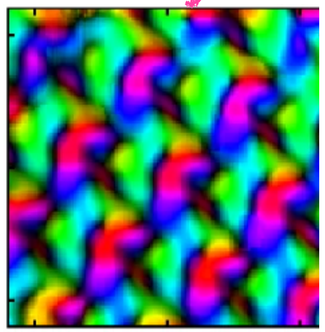


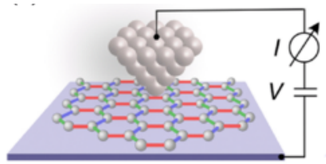


[Poiseuille profile in graphene: Ilani *et al*, Nature (2019)
dams in graphene: Levchenko, Brar *et al* Science (2023)]

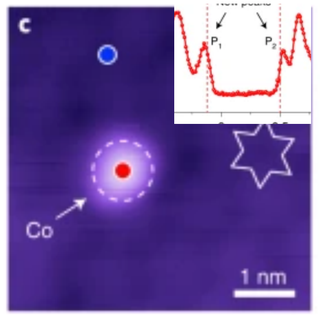
Scanning tunneling microscopy

Twisted bilayer graphene



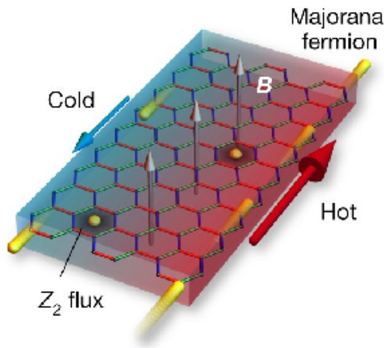


Spinon Kondo



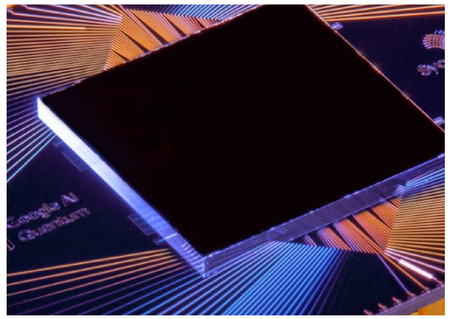
[IVC in twisted bilayer graphene: Yazdani *et al*, Nature (2023)
Spinon Kondo in TaS_2: Crommie *et al*, Nature (2022)]

quantum materials



$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

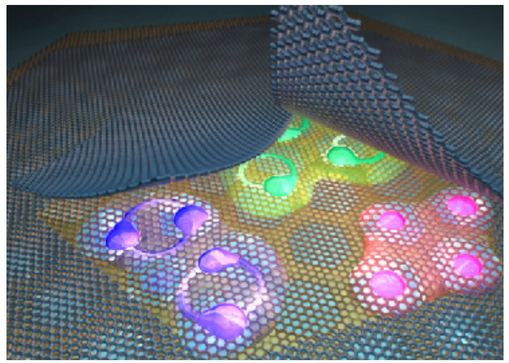
quantum computing and communication



Quantum chip:
Google Quantum, Science (2021)

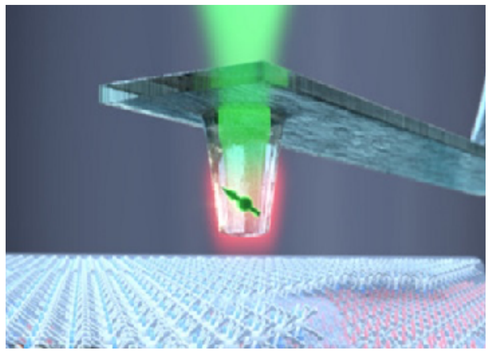
Aspects of quantum science

quantum design



2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

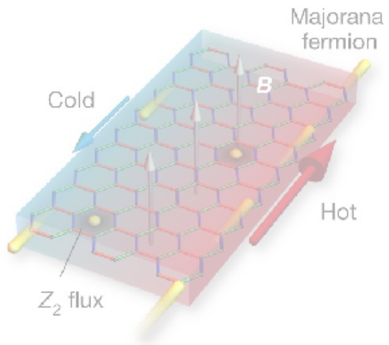
quantum sensing



Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

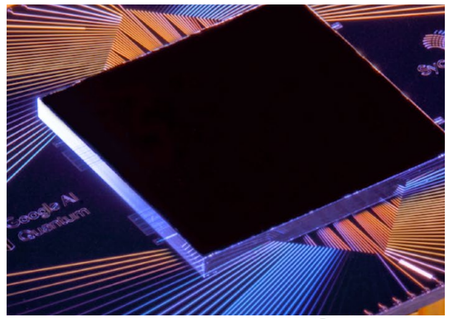
Aspects of quantum science

quantum materials



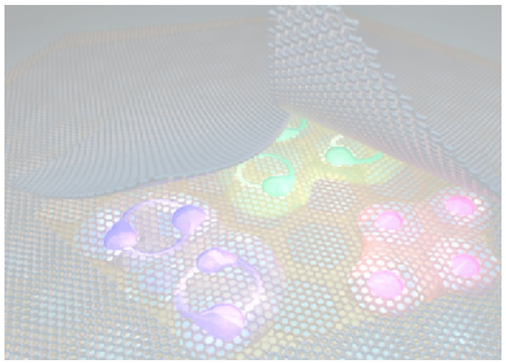
$RuCl_3$: candidate Quantum Spin Liquid:
Matsuda *et al,* Nature (2018).

quantum computing and communication



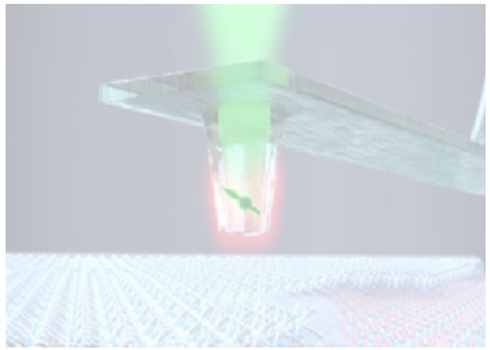
Quantum chip:
Google Quantum, Science (2021)

quantum design



2D materials (twisted bilayer graphene):
Efetov *et al,* Physics World (2019).

quantum sensing

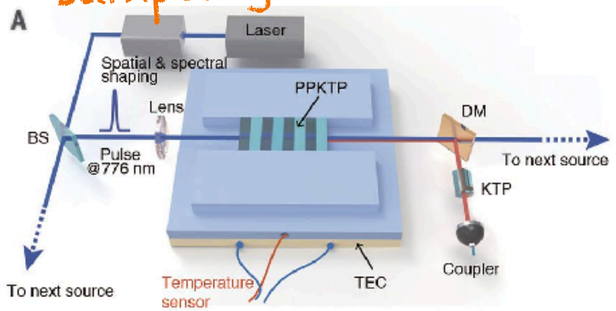


Color center magnetometry:
Maletinsky *et al.*, Physics World (2019)

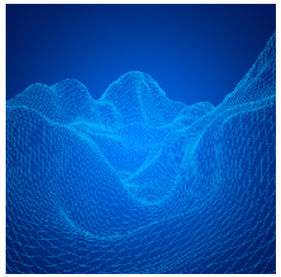
Quantum Computing

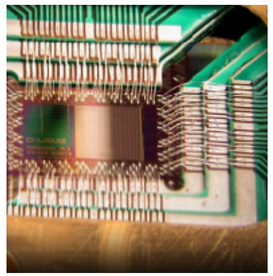
Analog and Non-Universal

Gaussian boson sampling



Quantum annealing



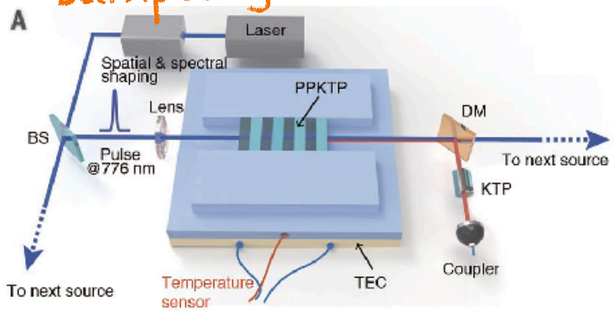


[Photonic Jiuzhang q computer: Pan *et al,* Science (2020)
Quantum Annealer: D-Wave Quantum Systems Inc]

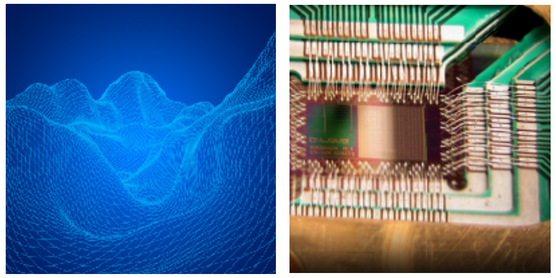
Quantum Computing

Analog and Non-Universal

Gaussian boson sampling



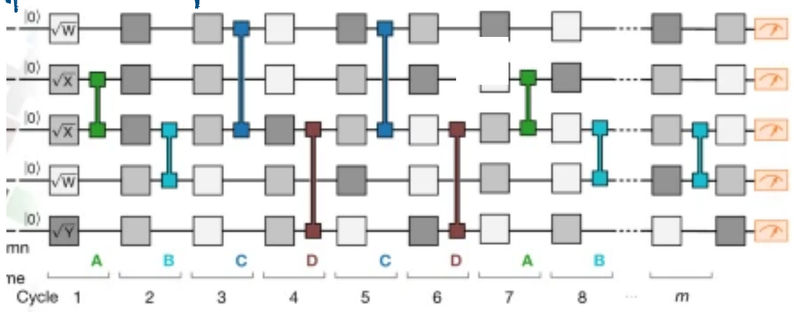
Quantum annealing

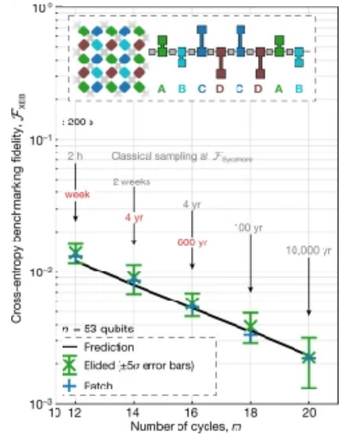


[Photonic Jiuzhang q computer: Pan *et al,* Science (2020)
Quantum Annealer: D-Wave Quantum Systems Inc]

Digital and Universal

(putative) quantum advantage



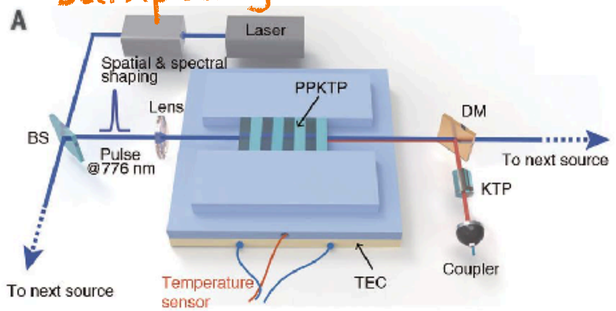


[X entropy benchmarking, random circuits: Google AI, Nature (2018)]

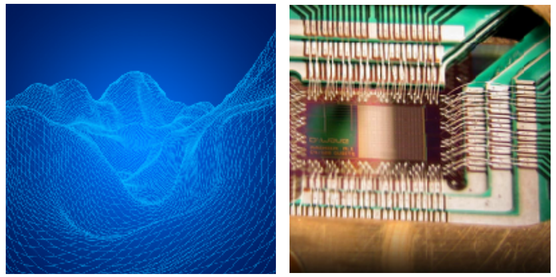
Quantum Computing

Analog and Non-Universal

Gaussian boson sampling



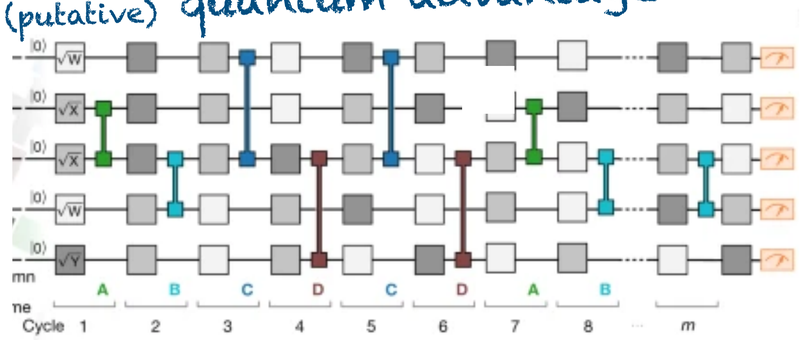
Quantum annealing

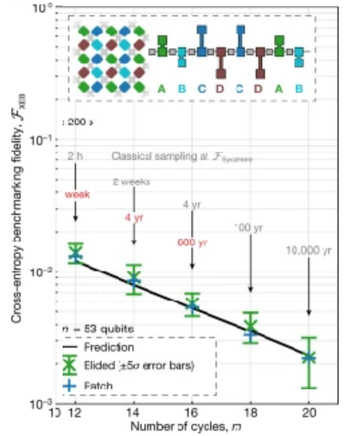


[Photonic Jiuzhang q computer: Pan *et al,* Science (2020)
Quantum Annealer: D-Wave Quantum Systems Inc]

Digital and Universal

(putative) quantum advantage

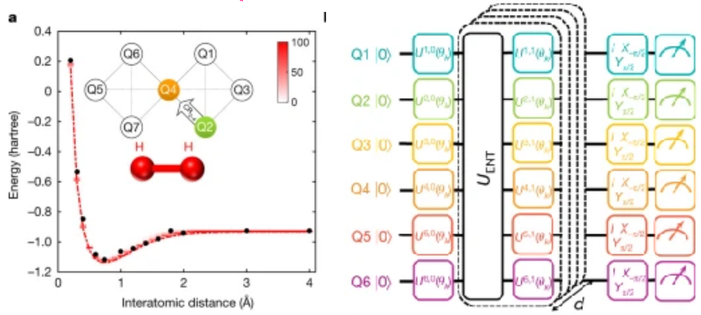




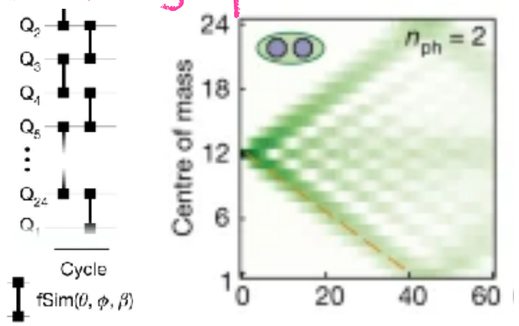
[X entropy benchmarking, random circuits: Google AI, Nature (2018)]

Noisy, Intermediate Scale Quantum (NISQ) era: gate based simulators

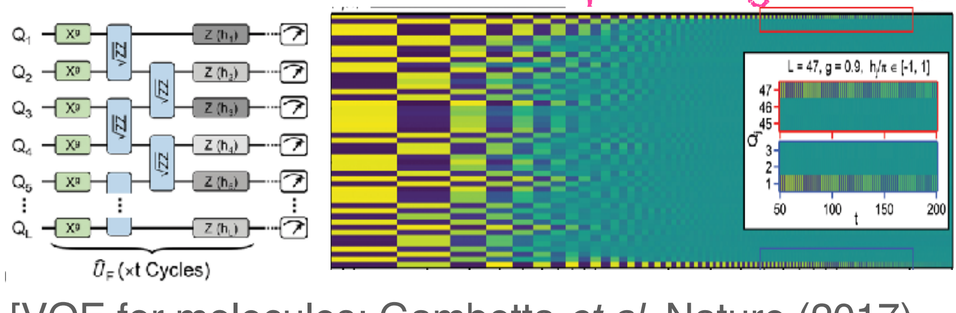
variational quantum eigensolvers



Heisenberg spin chain circuit



Noise resilient Floquet Majoranas



[VQE for molecules: Gambetta *et al*, Nature (2017),
Bound states of XXZ chain: Roushan *et al*, Nature (2022),
One-dimensional kicked Ising model: Abanin *et al* (2022)]

The König-group at UW

PhD projects available!

Max-Planck-Institute for Solid State Research
Stuttgart, Germany

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Research in the König group

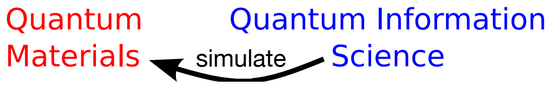
Quantum Materials as a blueprint for Quantum Information Theory

Quantum Materials

Quantum Information Science

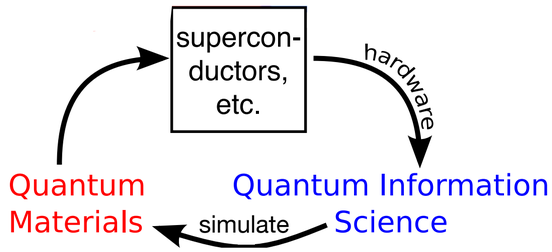
Research in the König group

Quantum Materials as a blueprint for Quantum Information Theory



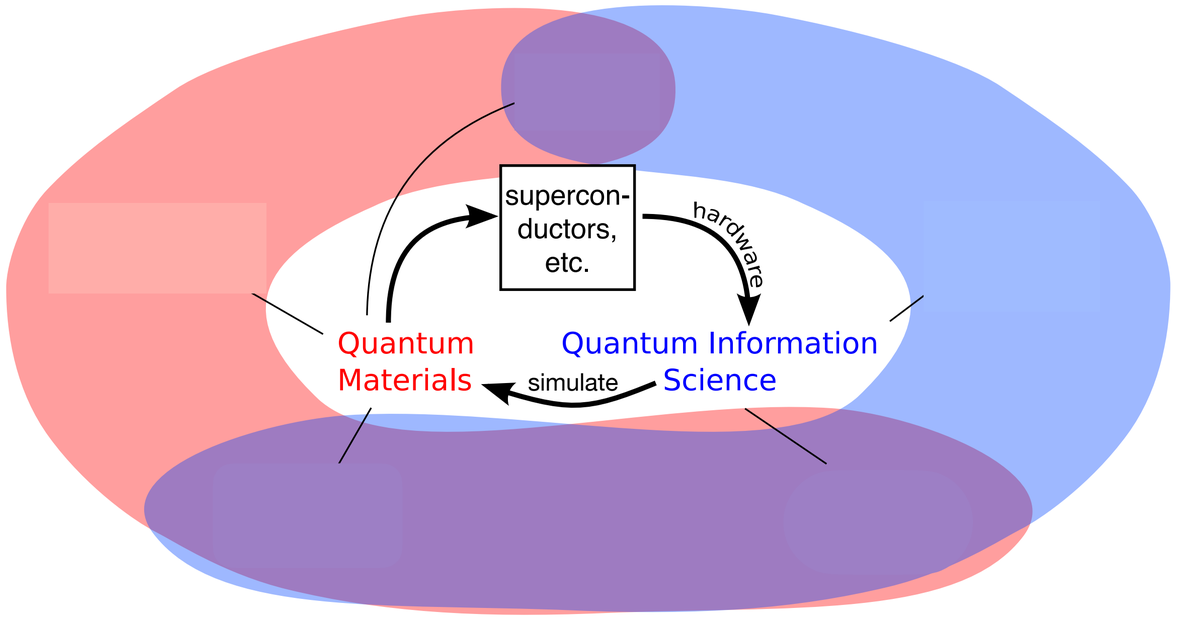
Research in the König group

Quantum Materials as a blueprint for Quantum Information Theory



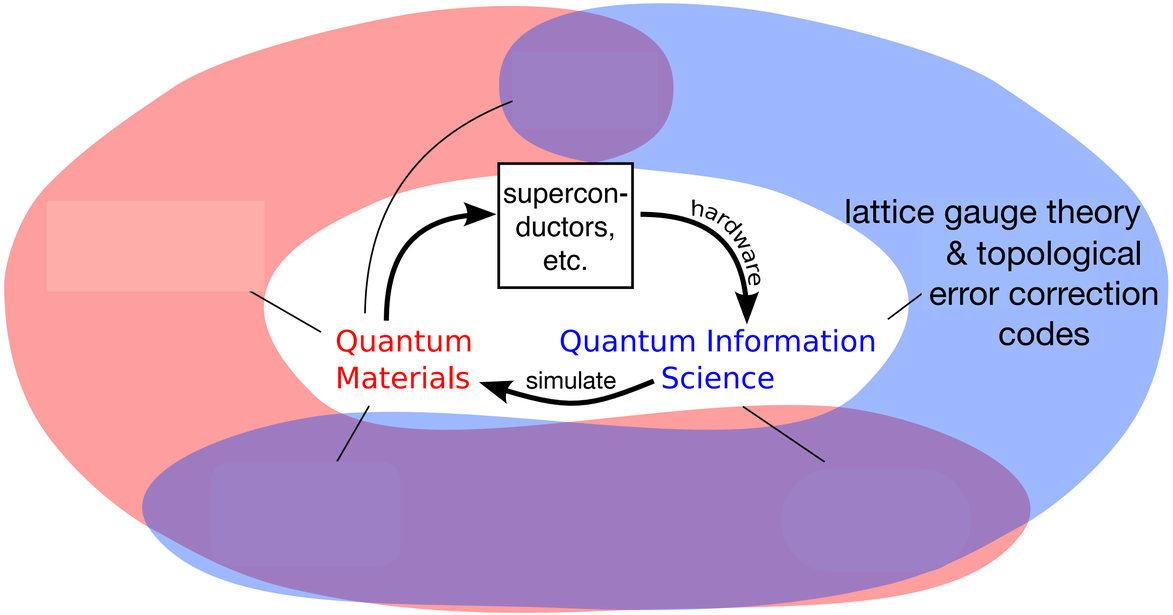
Research in the König group

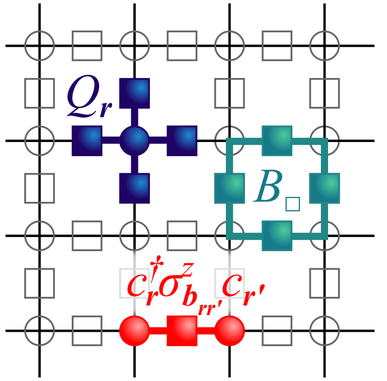
Quantum Materials as a blueprint for Quantum Information Theory



Research in the König group

Quantum Materials as a blueprint for Quantum Information Theory

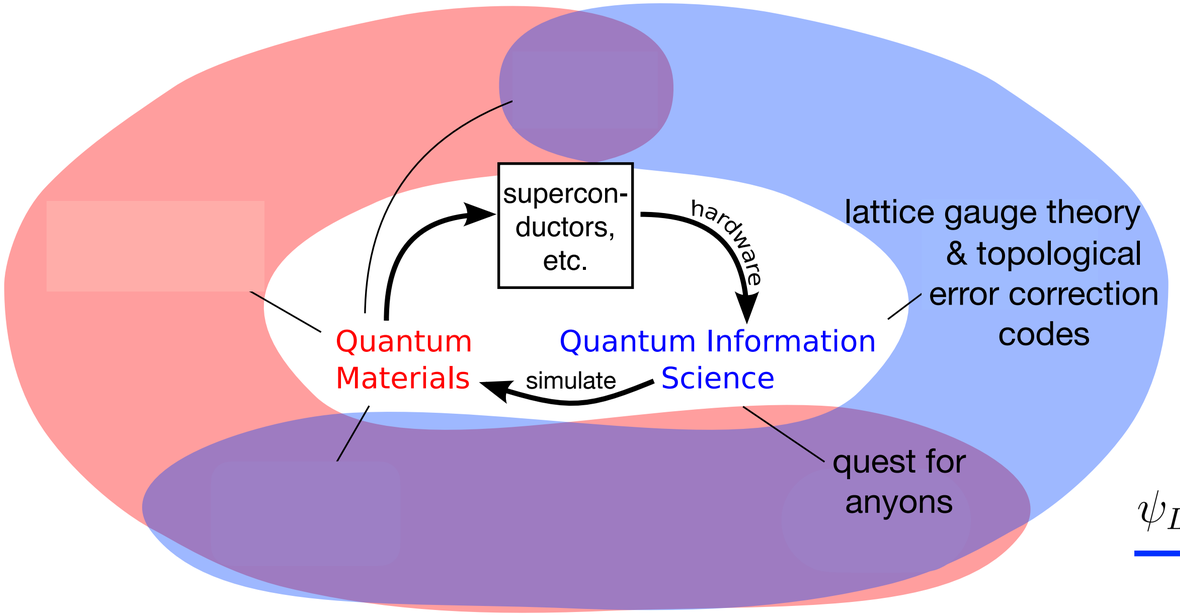


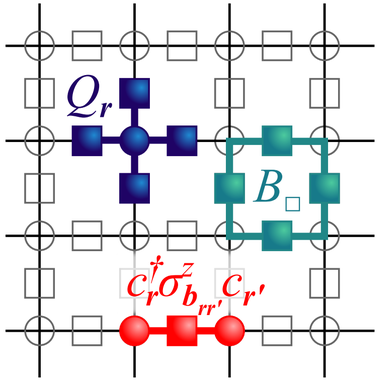


[EJK, Coleman, Tsvelik, PRB 2020,
Roy & EJK, PRB 2023]

Research in the König group

Quantum Materials as a blueprint for Quantum Information Theory



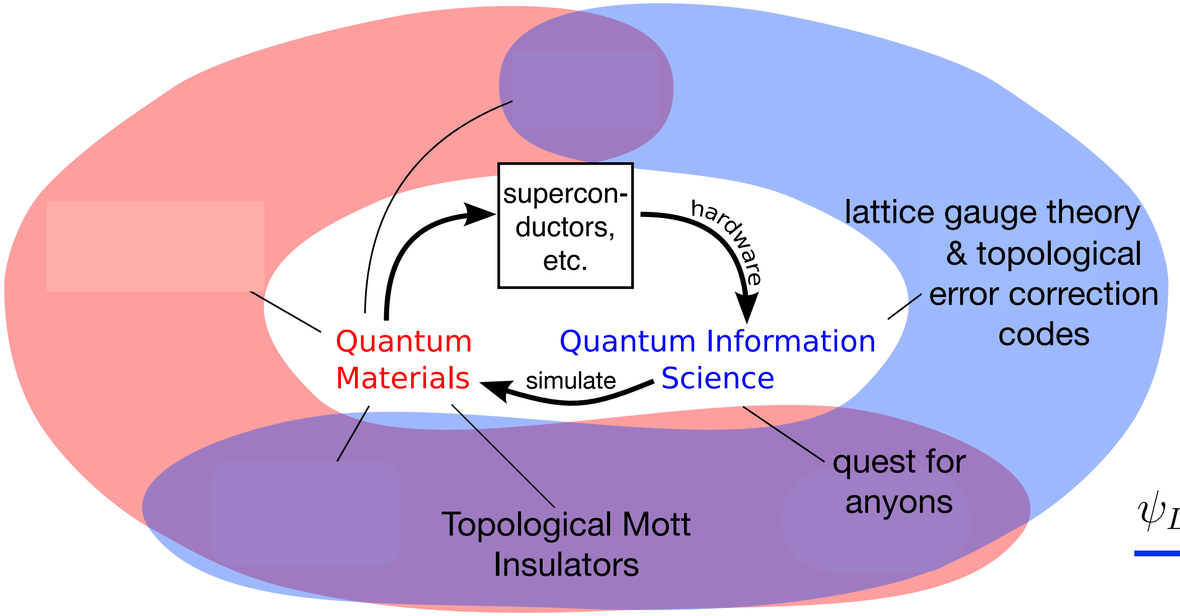


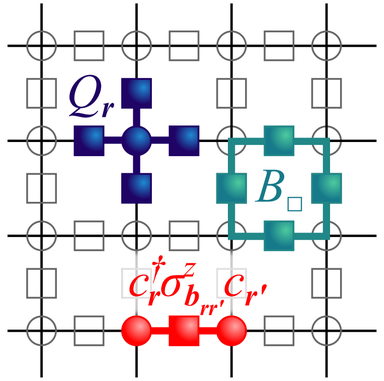
[EJK, Coleman, Tsvelik, PRB 2020,
Roy & EJK, PRB 2023]

[EJK, Komijani, Coleman, PRB 2020,
EJK, Coleman, Tsvelik, PRB 2020,
Li, EJK*, Väyrynen*, PRB (L) 2023,
EJK, Tsvelik, Ann Phys 2023,
Ren, EJK, Tsvelik PRB 2024,
Bollmann, Väyrynen, EJK PRB 2024]

Research in the König group

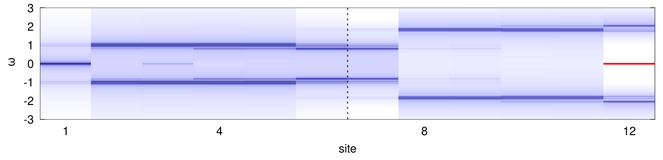
Quantum Materials as a blueprint for Quantum Information Theory





[EJK, Coleman, Tsvelik, PRB 2020,
Roy & EJK, PRB 2023]

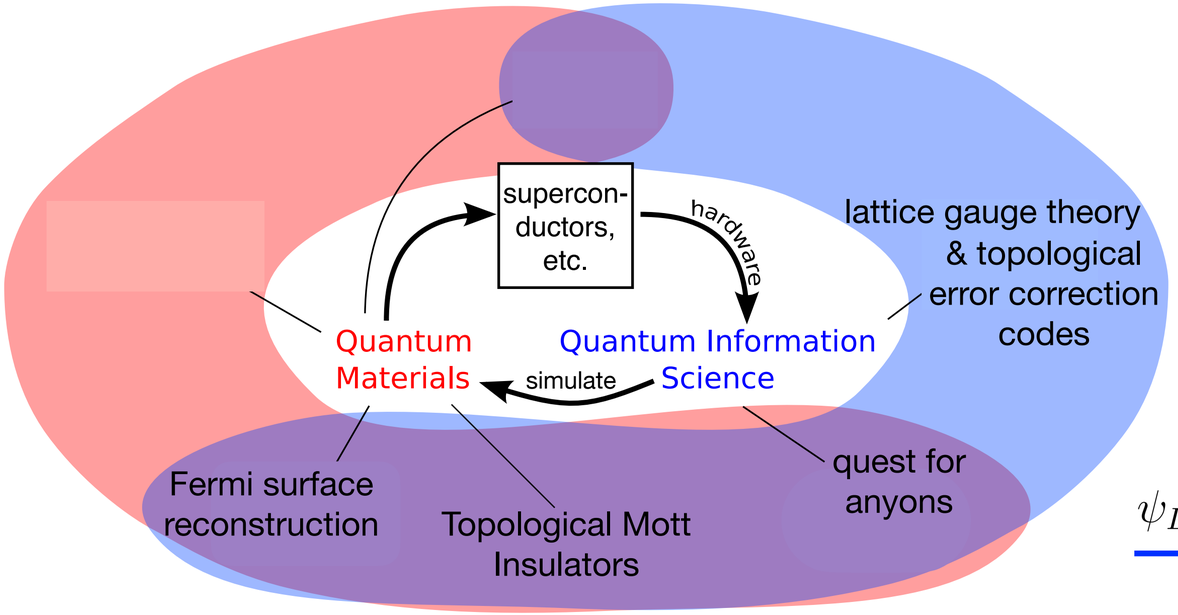
[EJK, Komijani, Coleman, PRB 2020,
EJK, Coleman, Tsvelik, PRB 2020,
Li, EJK*, Väyrynen*, PRB (L) 2023,
EJK, Tsvelik, Ann Phys 2023,
Ren, EJK, Tsvelik PRB 2024,
Bollmann, Väyrynen, EJK PRB 2024]

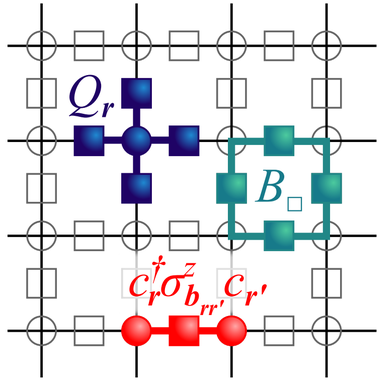


[Wagner, …,EJK, …, Sangiovanni, Nat Comm 2023,
Bollmann,…,EJK , PRL 2024 (in press)]

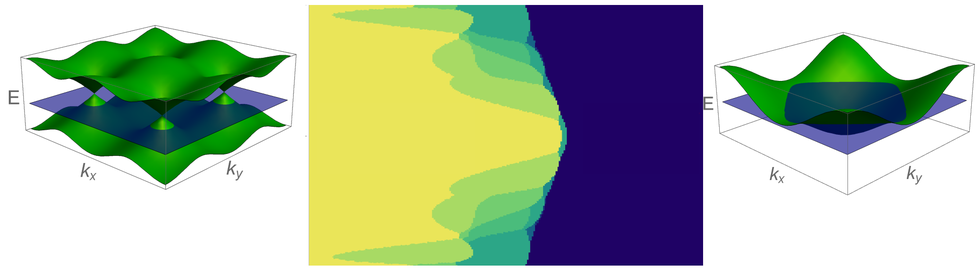
Research in the König group

Quantum Materials as a blueprint for Quantum Information Theory

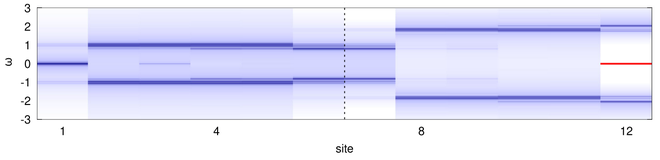




[EJK, Coleman, Tsvelik, PRB 2020,
Roy & EJK, PRB 2023]



[EJK, Coleman, Tsvelik, PRB 2020]

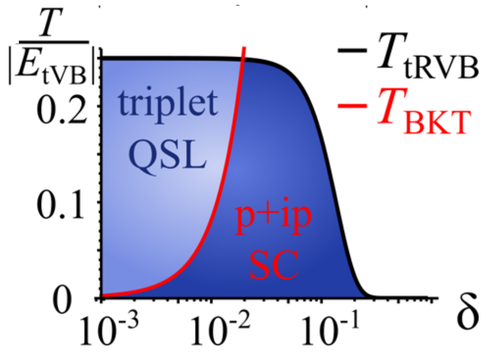


[Wagner, …,EJK, …, Sangiovanni, Nat Comm 2023,
Bollmann,…,EJK , PRL 2024 (in press)]

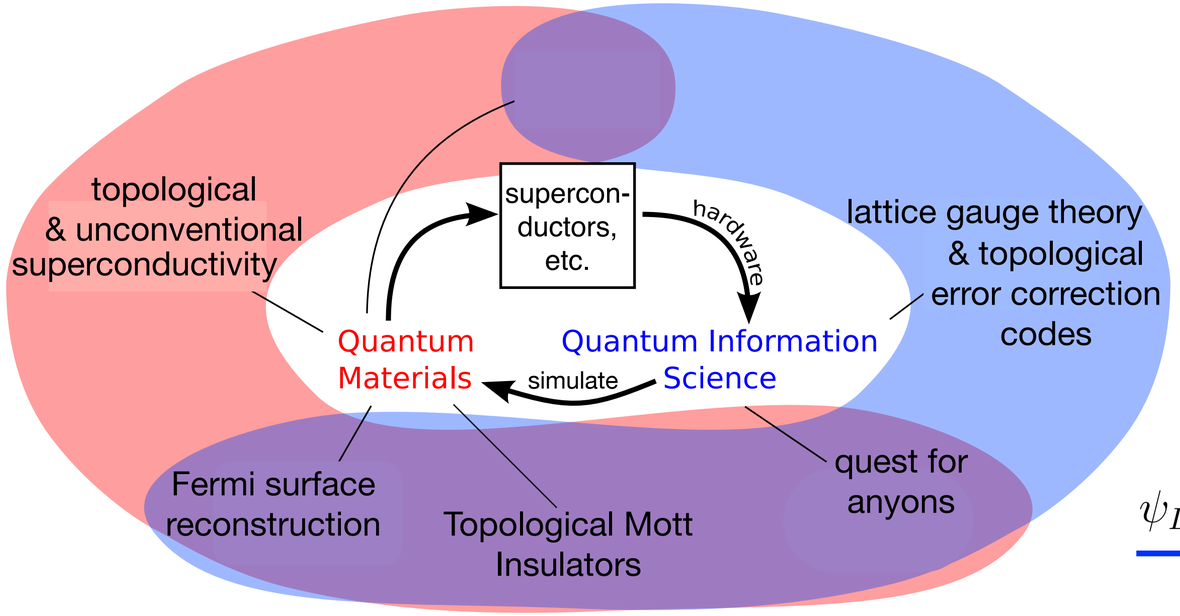
[EJK, Komijani, Coleman, PRB 2020,
EJK, Coleman, Tsvelik, PRB 2020,
Li, EJK*, Väyrynen*, PRB (L) 2023,
EJK, Tsvelik, Ann Phys 2023,
Ren, EJK, Tsvelik PRB 2024,
Bollmann, Väyrynen, EJK PRB 2024]

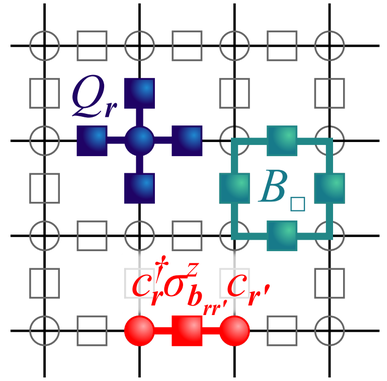
Research in the König group

Quantum Materials as a blueprint for Quantum Information Theory

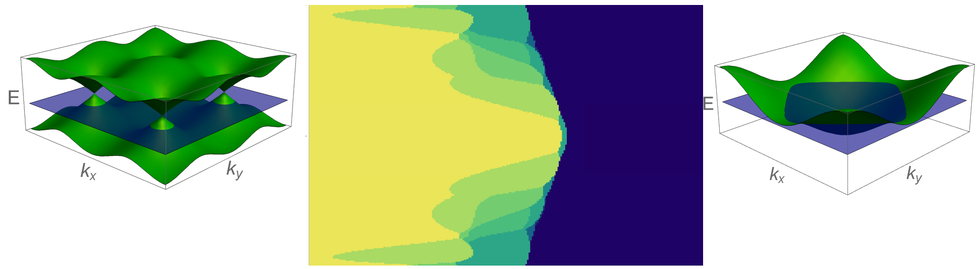


[Coleman, Komijani, EJK, PRL 2020 & PRB 2021,
Drouin-Touchette, EJK, *et al.*, PRB 2021 & PRR (L) 2022,
EJK & Coleman, PRL 2019,
Rampp, EJK, Schmalian, PRL 2022]

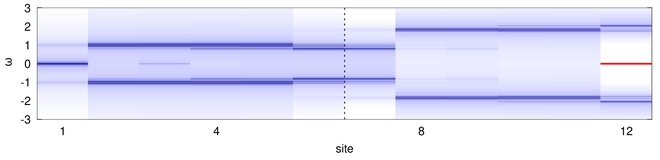




[EJK, Coleman, Tsvelik, PRB 2020,
Roy & EJK, PRB 2023]



[EJK, Coleman, Tsvelik, PRB 2020]

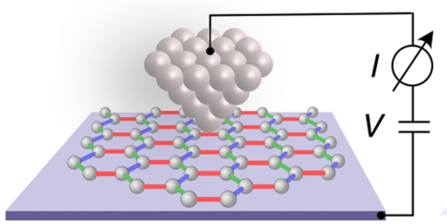


[Wagner, …,EJK, …, Sangiovanni, Nat Comm 2023,
Bollmann,…,EJK , PRL 2024 (in press)]

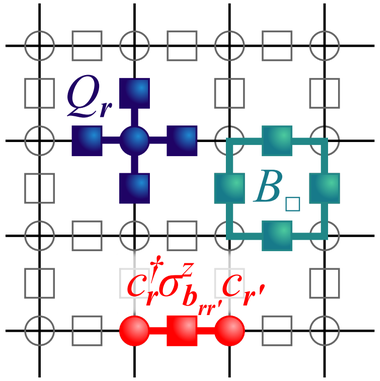
[EJK, Komijani, Coleman, PRB 2020,
EJK, Coleman, Tsvelik, PRB 2020,
Li, EJK*, Väyrynen*, PRB (L) 2023,
EJK, Tsvelik, Ann Phys 2023,
Ren, EJK, Tsvelik PRB 2024,
Bollmann, Väyrynen, EJK PRB 2024]

Research in the König group

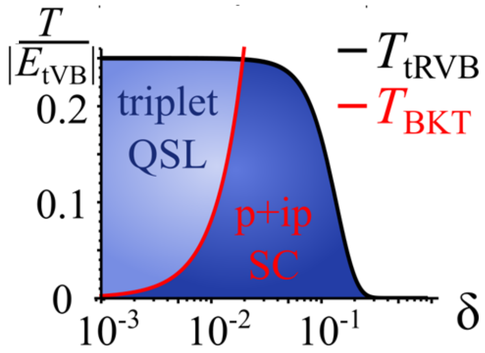
Quantum Materials as a blueprint for Quantum Information Theory



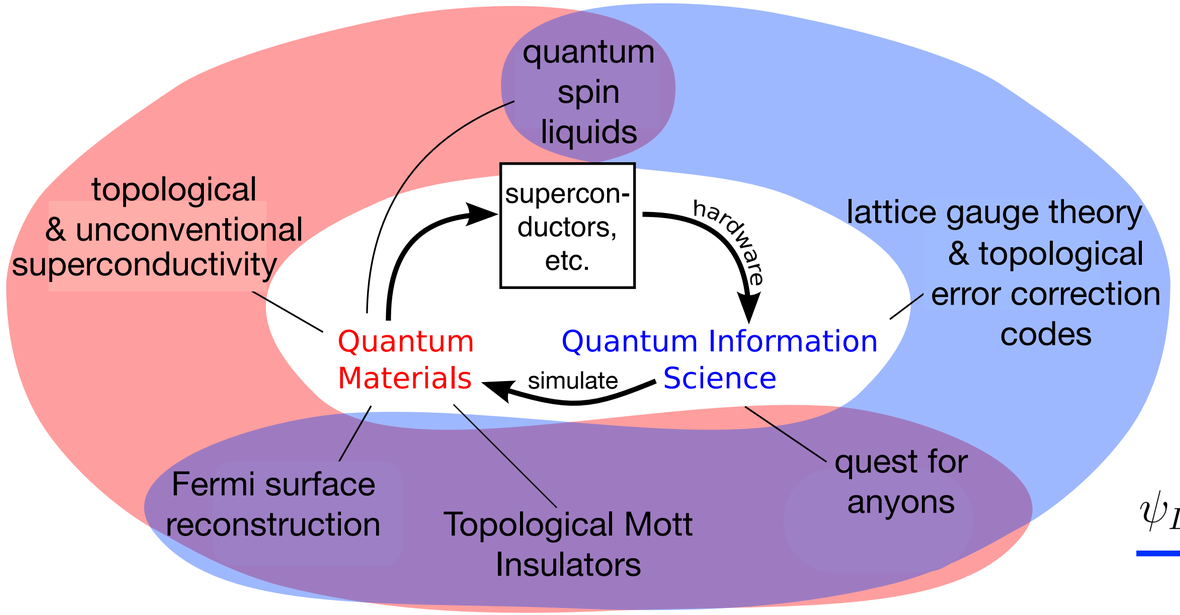
[EJK, MT Randeria, B Jäck, PRL 2020,
Mazzilli, Levchenko, EJK, PRB 2023]

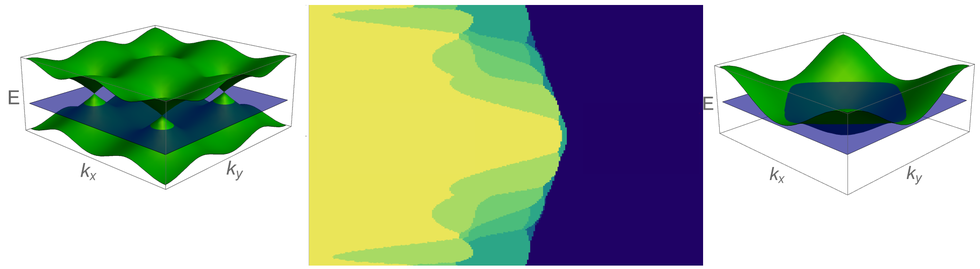


[EJK, Coleman, Tsvelik, PRB 2020,
Roy & EJK, PRB 2023]

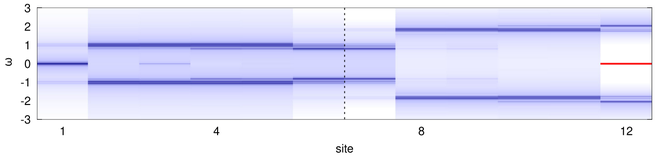


[Coleman, Komijani, EJK, PRL 2020 & PRB 2021,
Drouin-Touchette, EJK, *et al.*, PRB 2021 & PRR (L) 2022,
EJK & Coleman, PRL 2019,
Rampp, EJK, Schmalian, PRL 2022]





[EJK, Coleman, Tsvelik, PRB 2020]

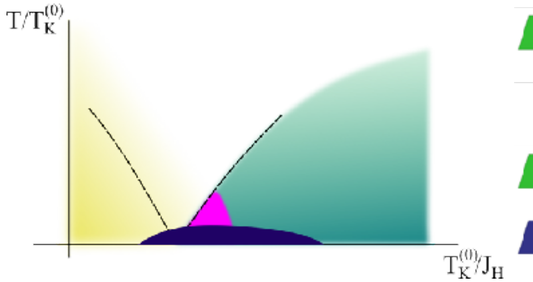


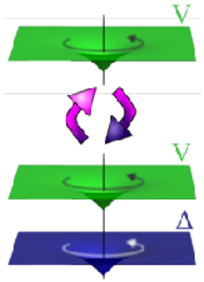
[Wagner, …,EJK, …, Sangiovanni, Nat Comm 2023,
Bollmann,…,EJK , PRL 2024 (in press)]

[EJK, Komijani, Coleman, PRB 2020,
EJK, Coleman, Tsvelik, PRB 2020,
Li, EJK*, Väyrynen*, PRB (L) 2023,
EJK, Tsvelik, Ann Phys 2023,
Ren, EJK, Tsvelik PRB 2024,
Bollmann, Väyrynen, EJK PRB 2024]

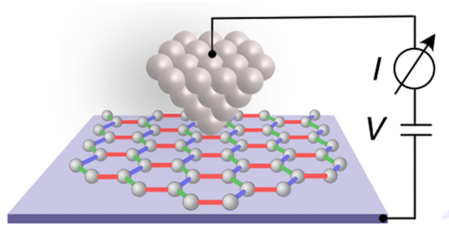
Research in the König group

Quantum Materials as a blueprint for Quantum Information Theory

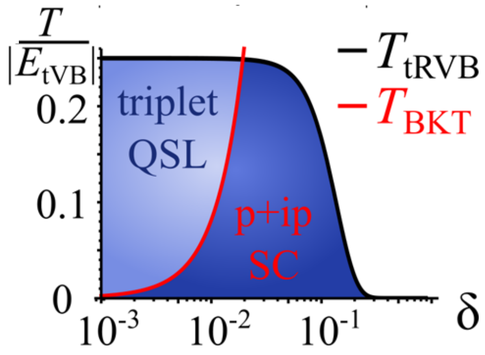




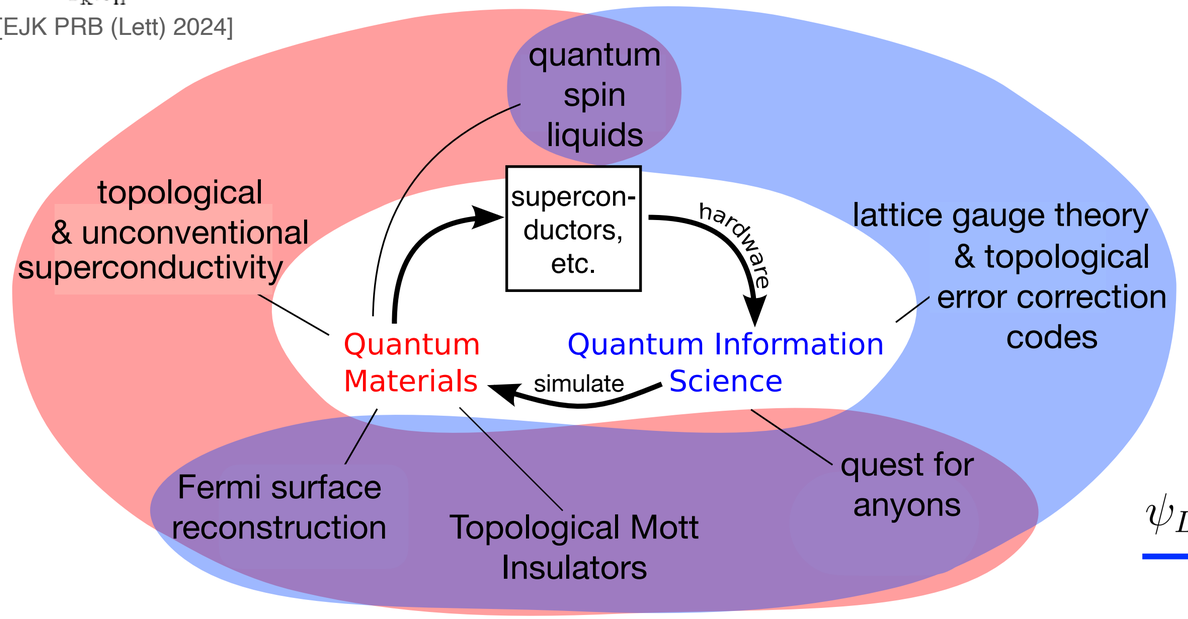
[EJK PRB (Lett) 2024]

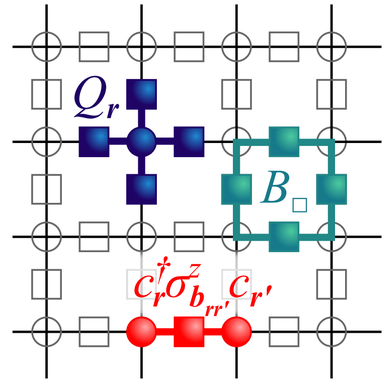


[EJK, MT Randeria, B Jäck, PRL 2020,
Mazzilli, Levchenko, EJK, PRB 2023]



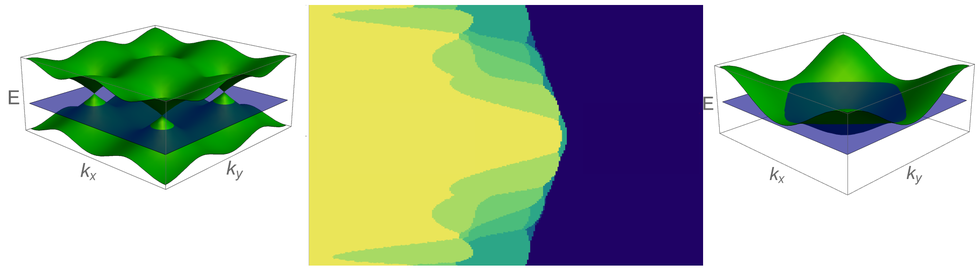
[Coleman, Komijani, EJK, PRL 2020 & PRB 2021,
Drouin-Touchette, EJK, *et al.*, PRB 2021 & PRR (L) 2022,
EJK & Coleman, PRL 2019,
Rampp, EJK, Schmalian, PRL 2022]



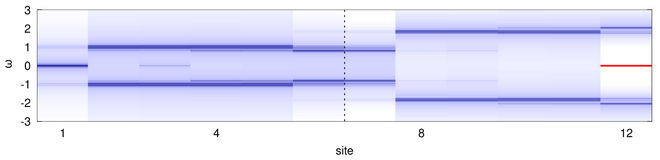


[EJK, Coleman, Tsvelik, PRB 2020,
Roy & EJK, PRB 2023]

[EJK, Komijani, Coleman, PRB 2020,
EJK, Coleman, Tsvelik, PRB 2020,
Li, EJK*, Väyrynen*, PRB (L) 2023,
EJK, Tsvelik, Ann Phys 2023,
Ren, EJK, Tsvelik PRB 2024,
Bollmann, Väyrynen, EJK PRB 2024]



[EJK, Coleman, Tsvelik, PRB 2020]

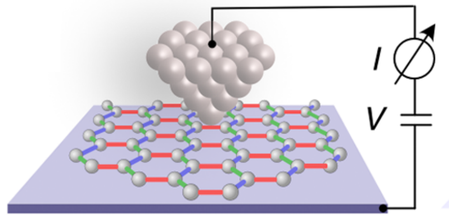


[Wagner, …,EJK, …, Sangiovanni, Nat Comm 2023,
Bollmann,…,EJK , PRL 2024 (in press)]

Research in the König group

Quantum Materials as a blueprint for Quantum Information Theory

[EJK PRB (Lett) 2024]



[EJK, MT Randeria, B Jäck, PRL 2020,
Mazzilli, Levchenko, EJK, PRB 2023]

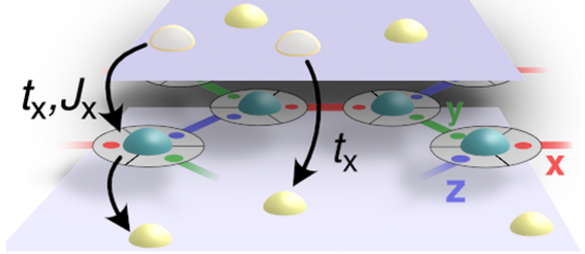
[EJK, Coleman, Tsvelik, PRB 2020,
Roy & EJK, PRB 2023]

[Coleman, Komijani, EJK, PRL 2020 & PRB 2021,
Drouin-Touchette, EJK, *et al.*, PRB 2021 & PRR (L) 2022,
EJK & Coleman, PRL 2019,
Rampp, EJK, Schmalian, PRL 2022]

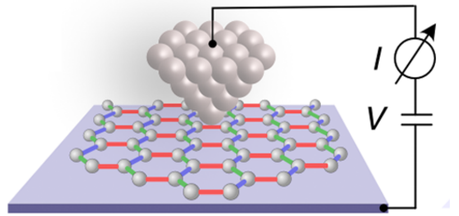
[EJK, Komijani, Coleman, PRB 2020,
EJK, Coleman, Tsvelik, PRB 2020,
Li, EJK*, Väyrynen*, PRB (L) 2023,
EJK, Tsvelik, Ann Phys 2023,
Ren, EJK, Tsvelik PRB 2024,
Bollmann, Väyrynen, EJK PRB 2024]

[EJK, Coleman, Tsvelik, PRB 2020]

[Wagner, …,EJK, …, Sangiovanni, Nat Comm 2023,
Bollmann,…,EJK , PRL 2024 (in press)]

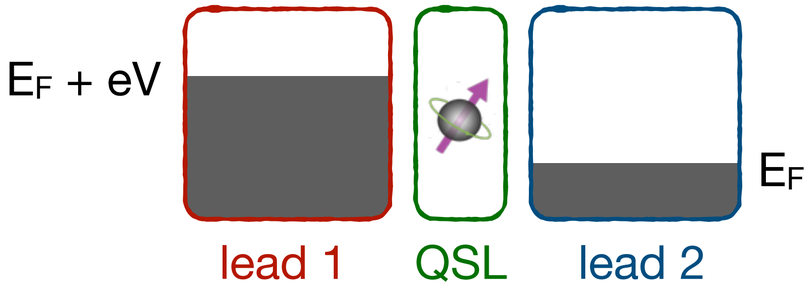


Tunneling current

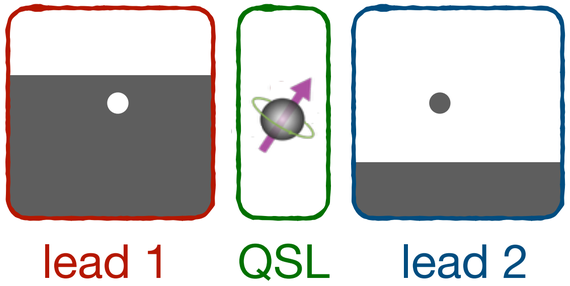


[EJK, MT Randeria, B Jäck, PRL 2020, Mazzilli, Levchenko, EJK, PRB 2023]

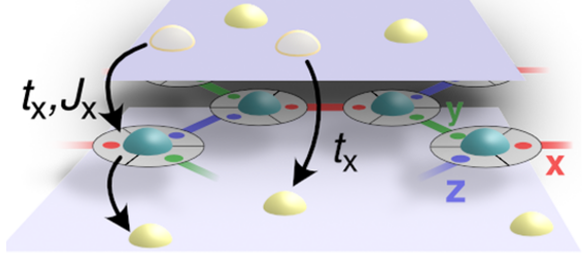
initial state



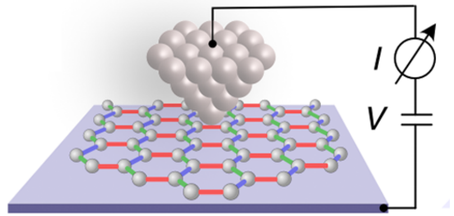
final state
(elastic tunneling)



[J. Fernández-Rossier, PRL **102**, 256802 (2009), J. Fransson *et al.*, PRB **81**, 115454 (2010)]

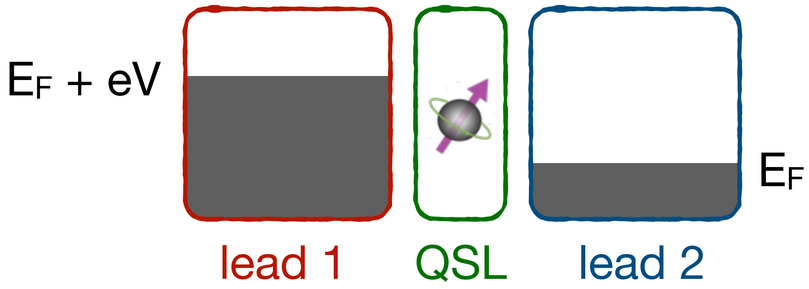


Tunneling current

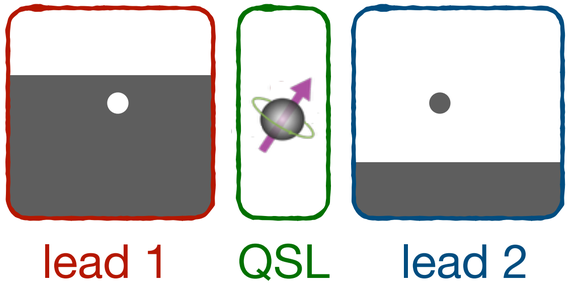


[EJK, MT Randeria, B Jäck, PRL 2020, Mazzilli, Levchenko, EJK, PRB 2023]

initial state

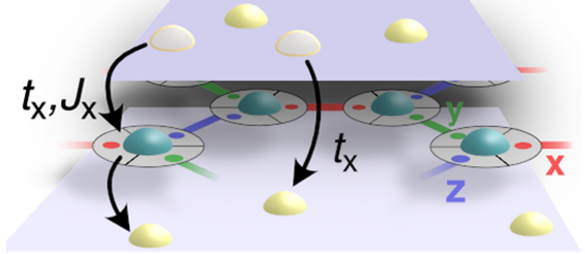


final state
(elastic tunneling)

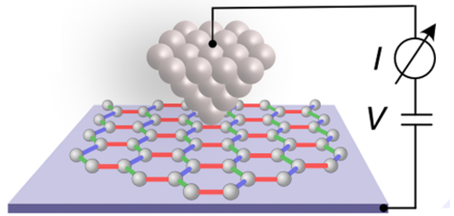


$$I^{\mathrm{el}} = 2\pi \frac{e}{h} \sum_{\mathbf{x},\mathbf{x}'} t_{\mathbf{x}} t_{\mathbf{x}'} [\mathcal{A}^{1^\dagger 2}_{\mathbf{x},\mathbf{x}'}(eV) - 1 \leftrightarrow 2].$$

[J. Fernández-Rossier, PRL **102**, 256802 (2009), J. Fransson *et al.*, PRB **81**, 115454 (2010)]

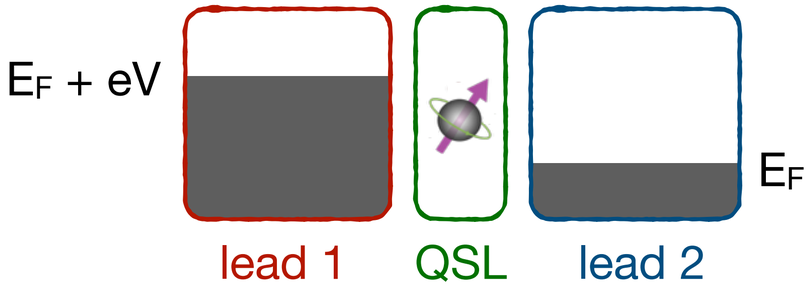


Tunneling current

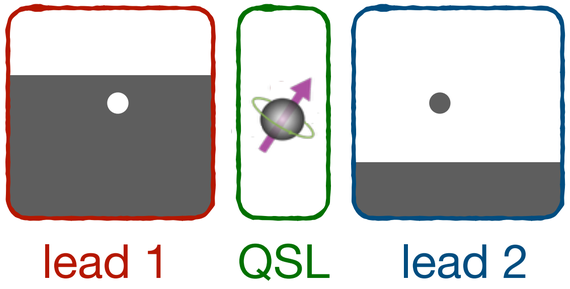


[EJK, MT Randeria, B Jäck, PRL 2020, Mazzilli, Levchenko, EJK, PRB 2023]

initial state



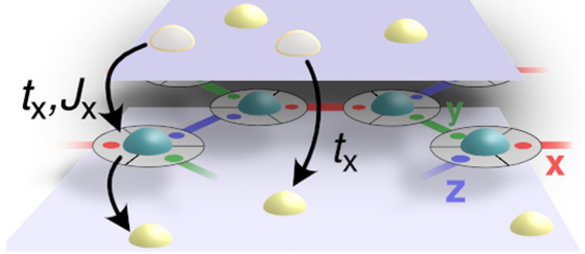
final state
(elastic tunneling)



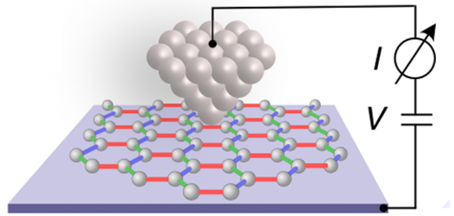
$$I^{\rm el} = 2\pi \frac{e}{h} \sum_{\mathbf{x},\mathbf{x}'} t_{\mathbf{x}} t_{\mathbf{x}'} [\mathcal{A}^{1^\dagger 2}_{\mathbf{x},\mathbf{x}'}(eV) - 1 \leftrightarrow 2].$$

Spectral weight of electron-hole pair

[J. Fernández-Rossier, PRL **102**, 256802 (2009), J. Fransson *et al.*, PRB **81**, 115454 (2010)]

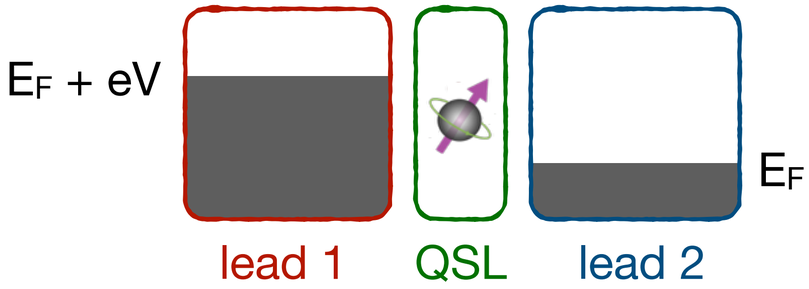


Tunneling current

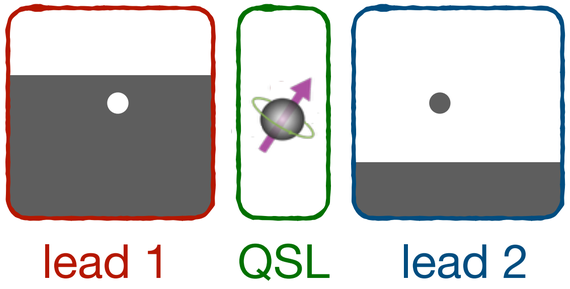


[EJK, MT Randeria, B Jäck, PRL 2020, Mazzilli, Levchenko, EJK, PRB 2023]

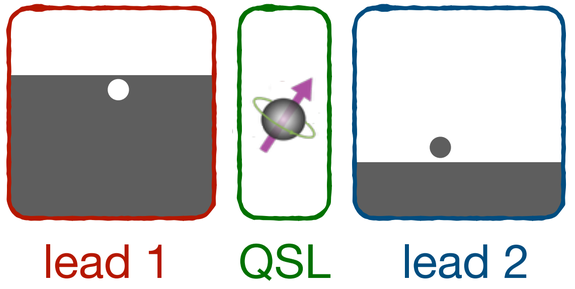
initial state



final state
(elastic tunneling)



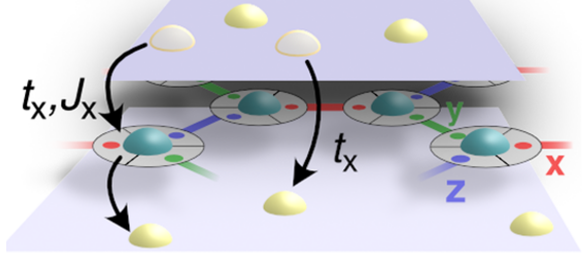
final state
(inelastic tunneling)



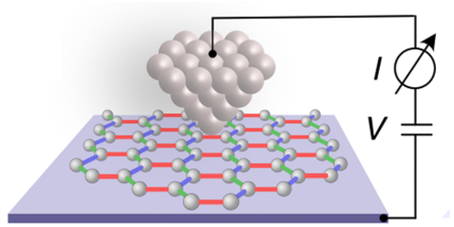
$$I^{\mathrm{el}} = 2\pi \frac{e}{h} \sum_{\mathbf{x},\mathbf{x}'} t_{\mathbf{x}} t_{\mathbf{x}'} [\mathcal{A}^{1^\dagger 2}_{\mathbf{x},\mathbf{x}'}(eV) + 1 \leftrightarrow 2].$$

Spectral weight of electron-hole pair

[J. Fernández-Rossier, PRL **102**, 256802 (2009), J. Fransson *et al.*, PRB **81**, 115454 (2010)]

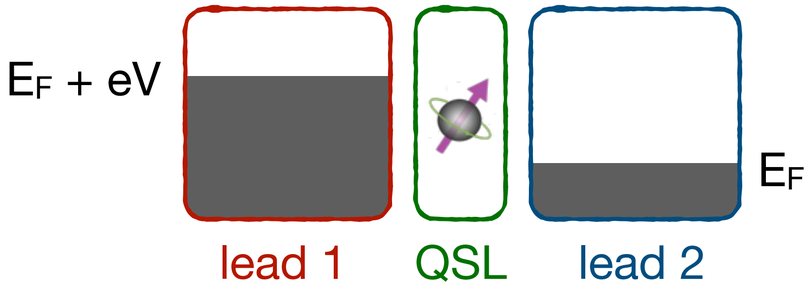


Tunneling current

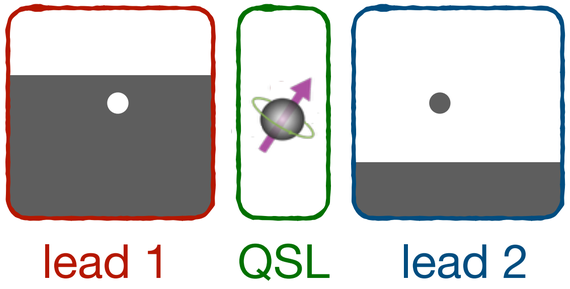


[EJK, MT Randeria, B Jäck, PRL 2020, Mazzilli, Levchenko, EJK, PRB 2023]

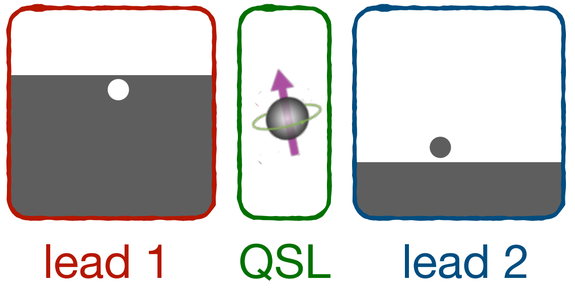
initial state



final state
(elastic tunneling)



final state
(inelastic tunneling)

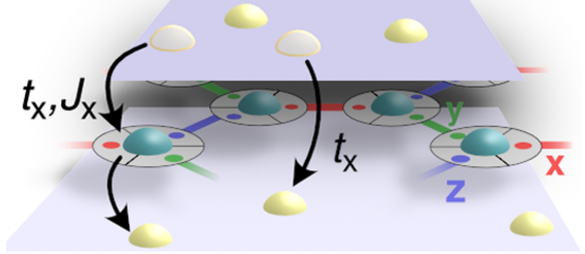


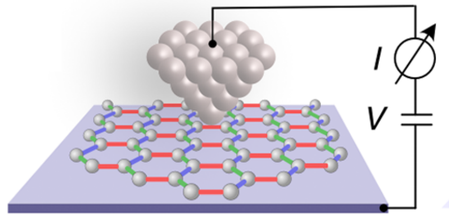
$$I^{\mathrm{el}} = 2\pi \frac{e}{h} \sum_{\mathbf{x},\mathbf{x}'} t_{\mathbf{x}} t_{\mathbf{x}'} [\mathcal{A}^{1^\dagger 2}_{\mathbf{x},\mathbf{x}'}(eV) + 1 \leftrightarrow 2].$$

Spectral weight of electron-hole pair

[J. Fernández-Rossier, PRL **102**, 256802 (2009), J. Fransson *et al.*, PRB **81**, 115454 (2010)]

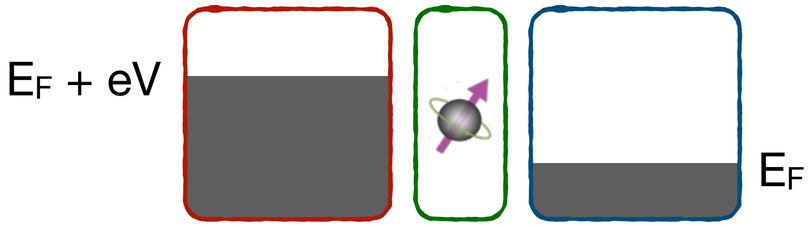
Tunneling current



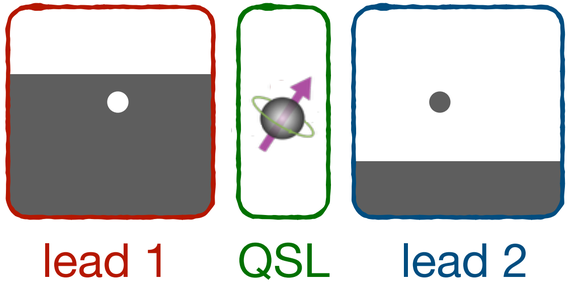


[EJK, MT Randeria, B Jäck, PRL 2020, Mazzilli, Levchenko, EJK, PRB 2023]

initial state



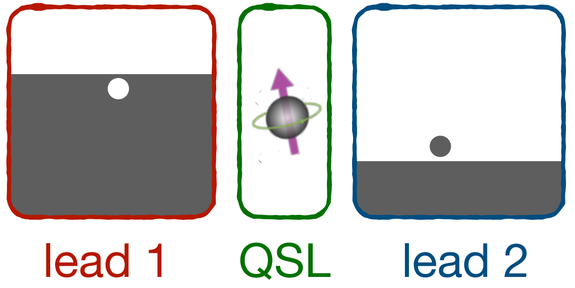
final state
(elastic tunneling)



$$I^{\rm el} = 2\pi \frac{e}{h} \sum_{\mathbf{x},\mathbf{x}'} t_{\mathbf{x}} t_{\mathbf{x}'} \mathcal{A}^{1^\dagger 2}_{\mathbf{x},\mathbf{x}'}(eV) - 1 \leftrightarrow 2].$$

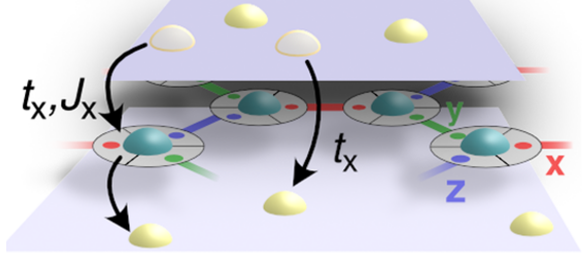
Spectral weight of electron-hole pair

final state
(inelastic tunneling)

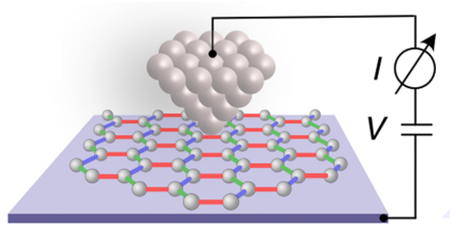


$$I^{\rm inel} = \frac{e}{h} \sum_{\mathbf{x},\mathbf{x}'} \int dE J_{\mathbf{x}} J_{\mathbf{x}'} \{ \mathcal{A}^{\rm spin}_{\mathbf{x},\mathbf{x}'}(eV - E) \mathcal{A}^{1^\dagger 2}_{\mathbf{x},\mathbf{x}'}(E) \times [n(eV - E) - n(E)] - 1 \leftrightarrow 2 \}.$$

[J. Fernández-Rossier, PRL **102**, 256802 (2009), J. Fransson *et al.*, PRB **81**, 115454 (2010)]

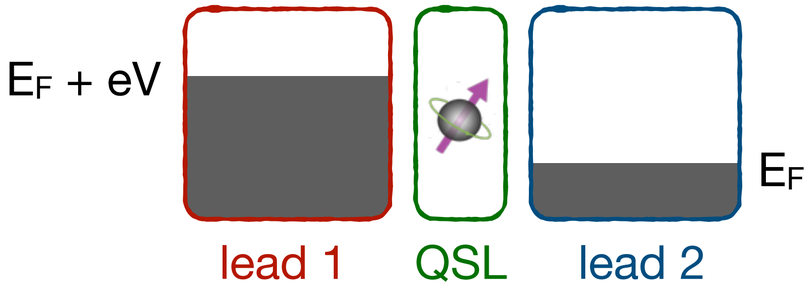


Tunneling current

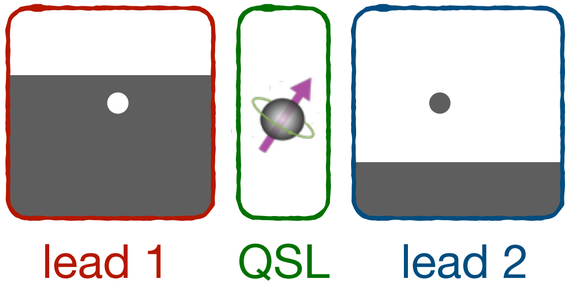


[EJK, MT Randeria, B Jäck, PRL 2020, Mazzilli, Levchenko, EJK, PRB 2023]

initial state



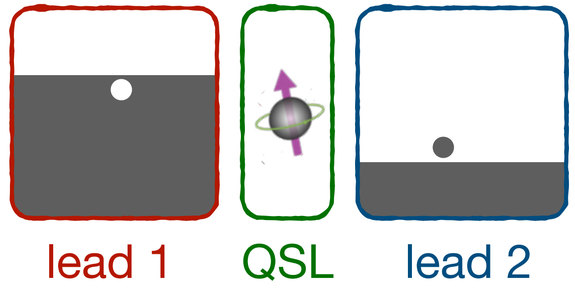
final state (elastic tunneling)



$$I^{\rm el} = 2\pi \frac{e}{h} \sum_{\mathbf{x},\mathbf{x}'} t_{\mathbf{x}} t_{\mathbf{x}'} \mathcal{A}^{1^\dagger 2}_{\mathbf{x},\mathbf{x}'}(eV) - 1 \leftrightarrow 2].$$

Spectral weight of electron-hole pair

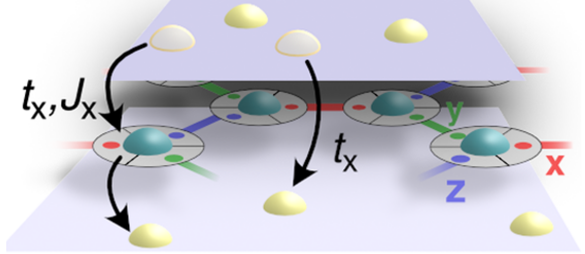
final state (inelastic tunneling)



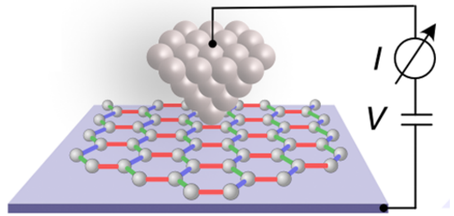
$$I^{\rm inel} = \frac{e}{h} \sum_{\mathbf{x},\mathbf{x}'} \int dE J_{\mathbf{x}} J_{\mathbf{x}'} \mathcal{A}^{\rm spin}_{\mathbf{x},\mathbf{x}'}(eV - E) \mathcal{A}^{1^\dagger 2}_{\mathbf{x},\mathbf{x}'}(E) \times [n(eV - E) - n(E)] - 1 \leftrightarrow 2\}.$$

Dynamical structure factor

[J. Fernández-Rossier, PRL **102**, 256802 (2009), J. Fransson *et al.*, PRB **81**, 115454 (2010)]

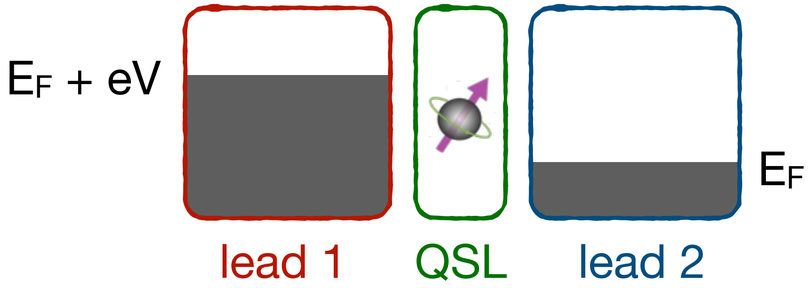


Tunneling current

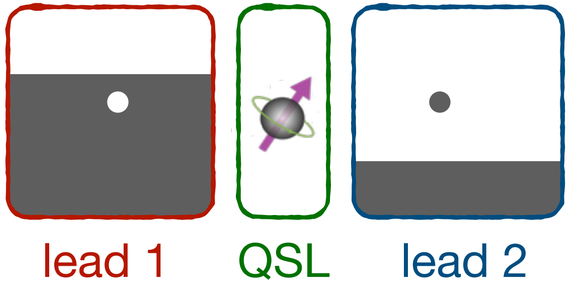


[EJK, MT Randeria, B Jäck, PRL 2020, Mazzilli, Levchenko, EJK, PRB 2023]

initial state



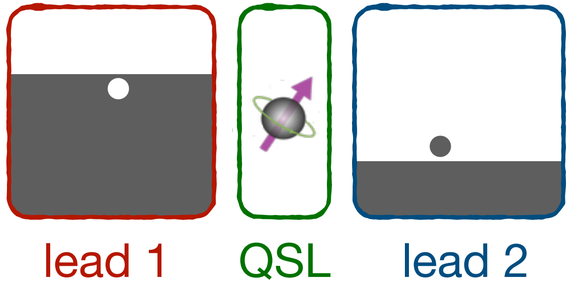
final state
(elastic tunneling)



$$I^{\rm el} = 2\pi \frac{e}{h} \sum_{\mathbf{x},\mathbf{x}'} t_{\mathbf{x}} t_{\mathbf{x}'} [\mathcal{A}^{1^\dagger 2}_{\mathbf{x},\mathbf{x}'}(eV) - 1 \leftrightarrow 2].$$

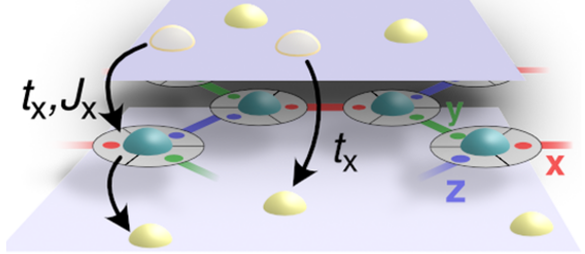
Spectral weight of electron-hole pair

final state
(inelastic tunneling)

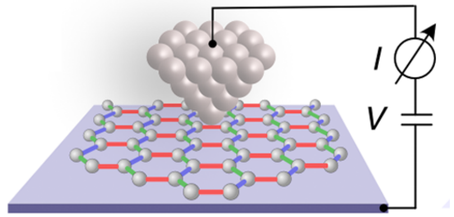


(short range correlations)

$$\frac{dI^{\rm inel}}{dV} = 2G_0 \sum_{\mathbf{x},\mathbf{x}'} \frac{J_{\mathbf{x}} J_{\mathbf{x}'}}{t_0^2} \int_0^{\rm eV} \frac{dE}{2\pi} \mathcal{A}^{\rm spin}_{\mathbf{x},\mathbf{x}'}(E)$$

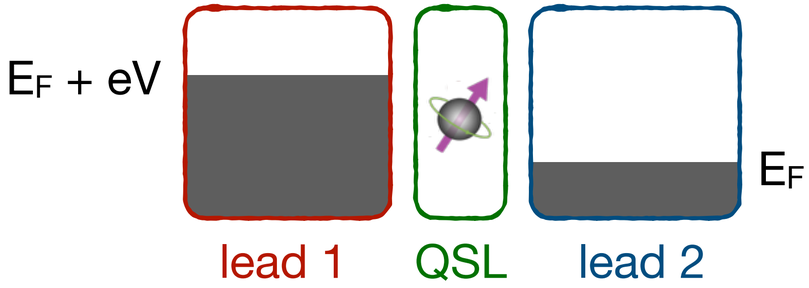


Tunneling current

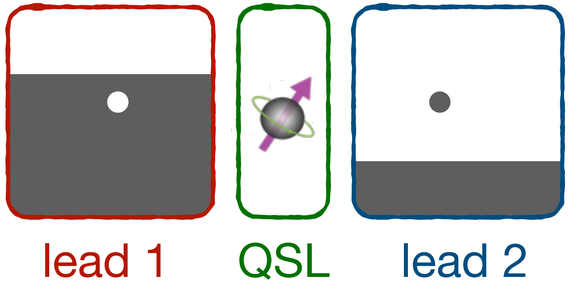


[EJK, MT Randeria, B Jäck, PRL 2020, Mazzilli, Levchenko, EJK, PRB 2023]

initial state



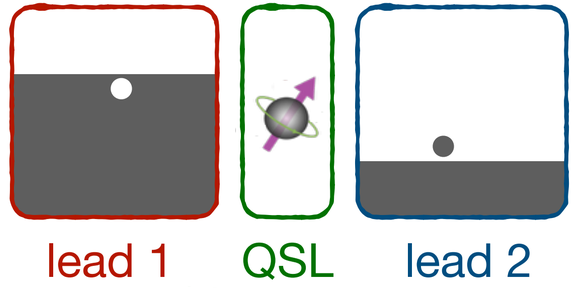
final state
(elastic tunneling)



$$I^{\rm el} = 2\pi \frac{e}{h} \sum_{\mathbf{x},\mathbf{x}'} t_{\mathbf{x}} t_{\mathbf{x}'} [\mathcal{A}^{1^\dagger 2}_{\mathbf{x},\mathbf{x}'}(eV) - 1 \leftrightarrow 2].$$

Spectral weight of electron-hole pair

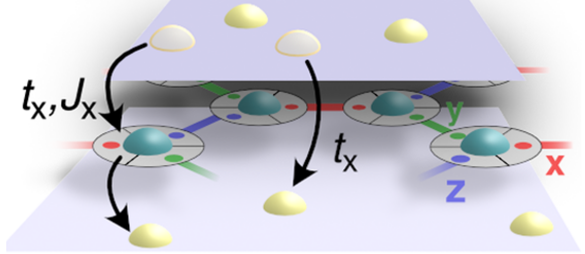
final state
(inelastic tunneling)



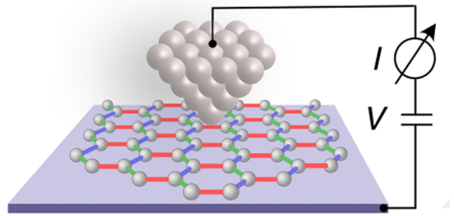
(short range correlations)

$$\frac{dI^{\rm inel}}{dV} = 2G_0 \sum_{\mathbf{x},\mathbf{x}'} \frac{J_{\mathbf{x}} J_{\mathbf{x}'}}{t_0^2} \int_0^{\rm eV} \frac{dE}{2\pi} \mathcal{A}^{\rm spin}_{\mathbf{x},\mathbf{x}'}(E)$$

Dynamical structure factor

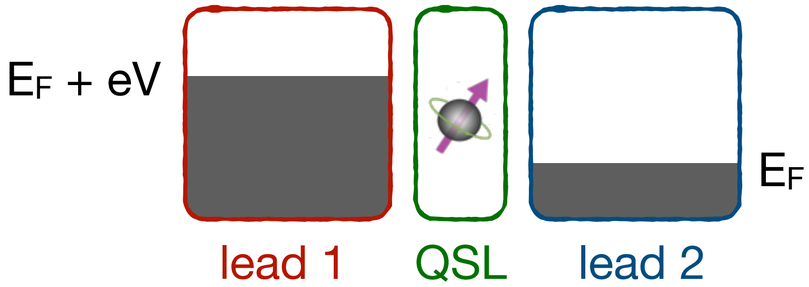


Tunneling current

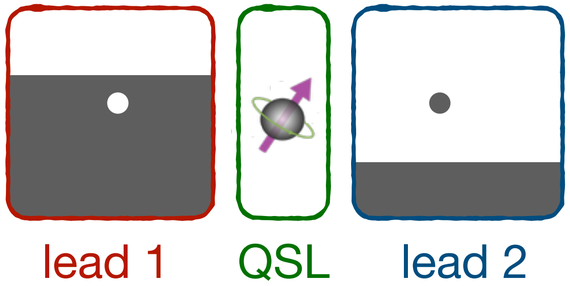


[EJK, MT Randeria, B Jäck, PRL 2020, Mazzilli, Levchenko, EJK, PRB 2023]

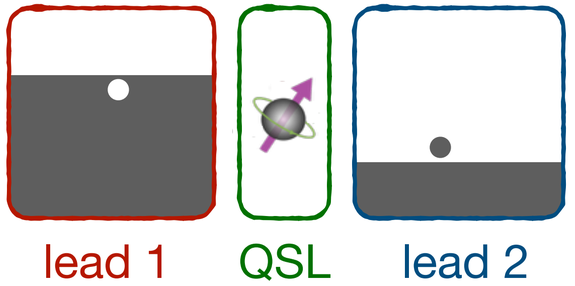
initial state



final state
(elastic tunneling)



final state
(inelastic tunneling)



(short range correlations)

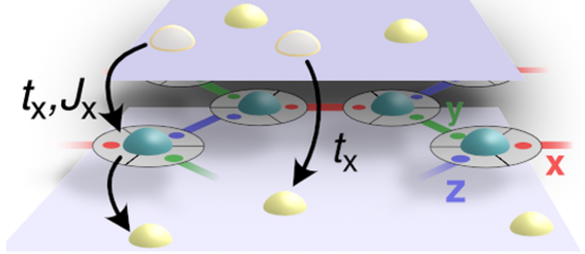
$$I^{\rm el} = 2\pi \frac{e}{h} \sum_{\mathbf{x},\mathbf{x}'} t_{\mathbf{x}} t_{\mathbf{x}'} [\mathcal{A}^{1^\dagger 2}_{\mathbf{x},\mathbf{x}'}(eV) - 1 \leftrightarrow 2].$$

$$\frac{dI^{\rm inel}}{dV} = 2G_0 \sum_{\mathbf{x},\mathbf{x}'} \frac{J_{\mathbf{x}} J_{\mathbf{x}'}}{t_0^2} \int_0^{\rm eV} \frac{dE}{2\pi} \mathcal{A}^{\rm spin}_{\mathbf{x},\mathbf{x}'}(E)$$

Spectral weight of electron-hole pair

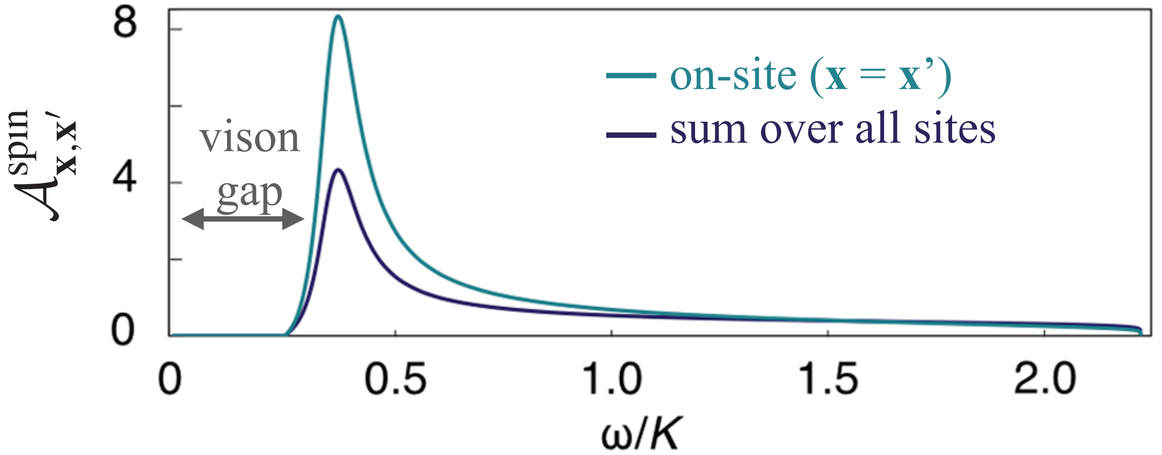
conductance of 0D junction

Dynamical structure factor



Tunneling current

Isotropic Kitaev model

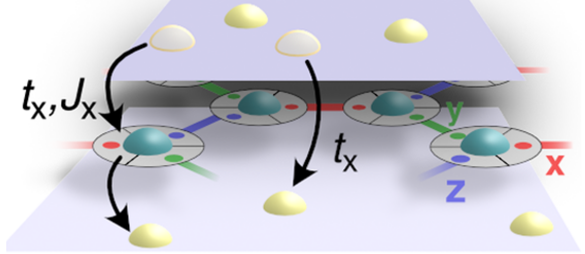


[J. Knolle *et al.*, PRL **112**, 207203 (2014)]

$$\frac{dI^{\text{inel}}}{dV} = 2G_0 \sum_{\mathbf{x},\mathbf{x}'} \frac{J_{\mathbf{x}} J_{\mathbf{x}'}}{t_0^2} \int_0^{\text{eV}} \frac{dE}{2\pi} \mathcal{A}^{\text{spin}}_{\mathbf{x},\mathbf{x}'}(E)$$

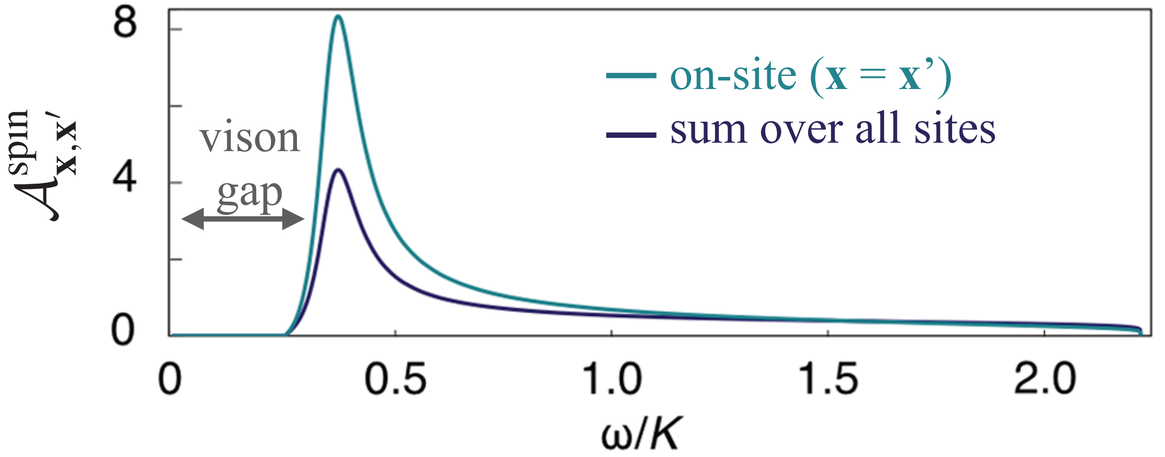
conductance of 0D junction

Dynamical structure factor

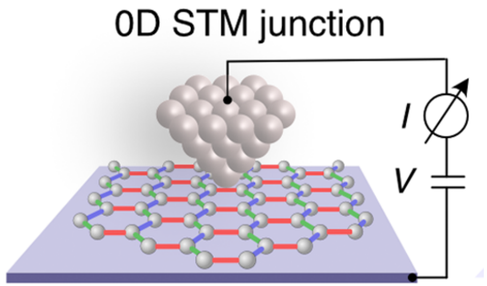


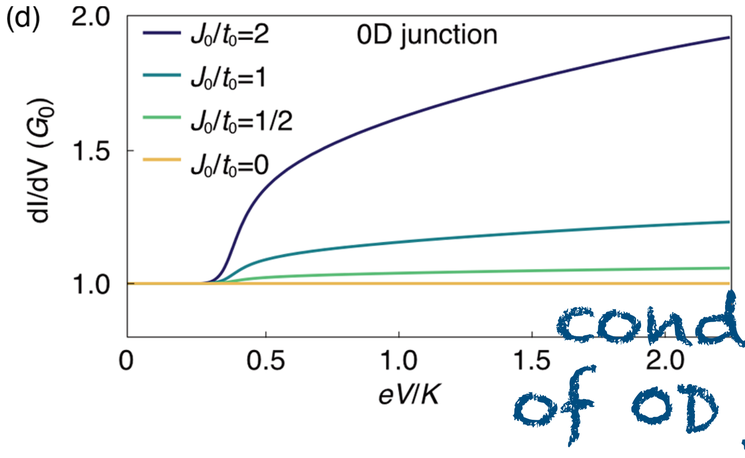
Tunneling current

Isotropic Kitaev model



[J. Knolle *et al.*, PRL **112**, 207203 (2014)]

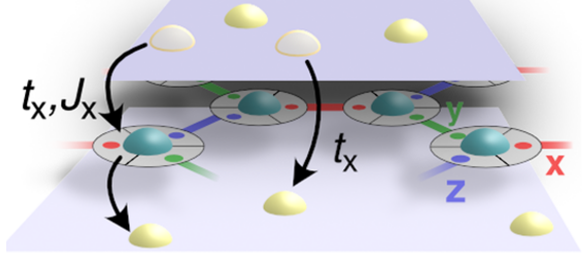




$$\frac{dI^{\mathrm{inel}}}{dV} = 2G_0 \sum_{\mathbf{x},\mathbf{x}'} \frac{J_{\mathbf{x}} J_{\mathbf{x}'}}{t_0^2} \int_0^{\mathrm{eV}} \frac{dE}{2\pi} \mathcal{A}^{\mathrm{spin}}_{\mathbf{x},\mathbf{x}'}(E)$$

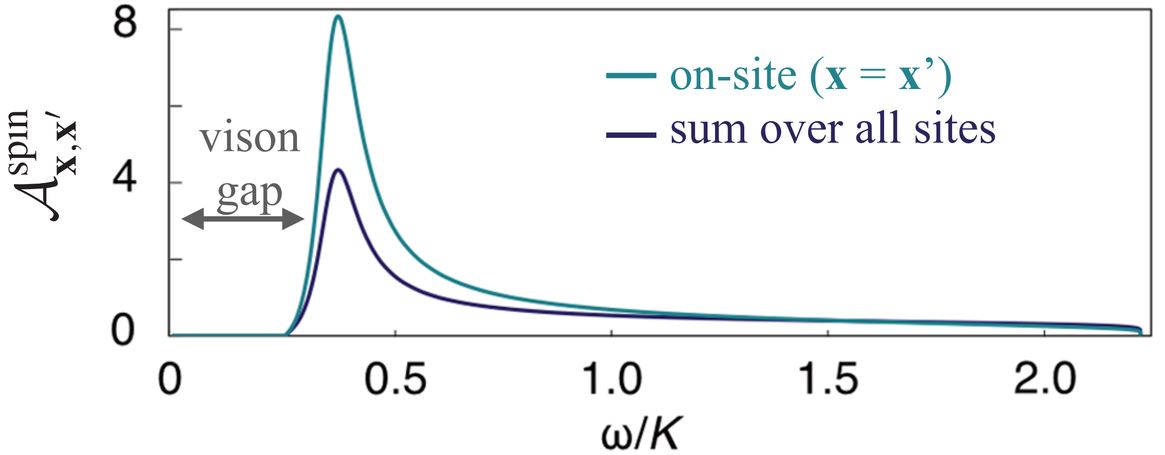
conductance of 0D junction

Dynamical structure factor

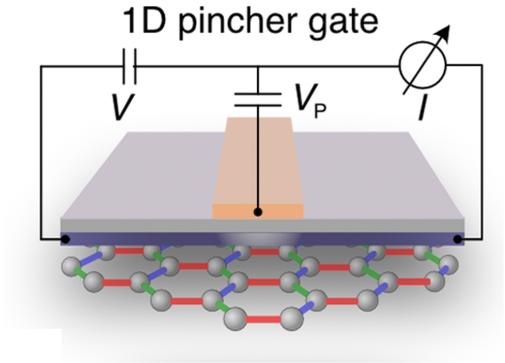


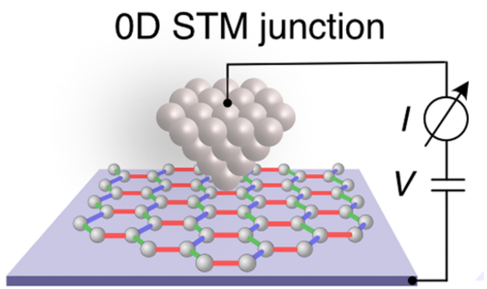
Tunneling current

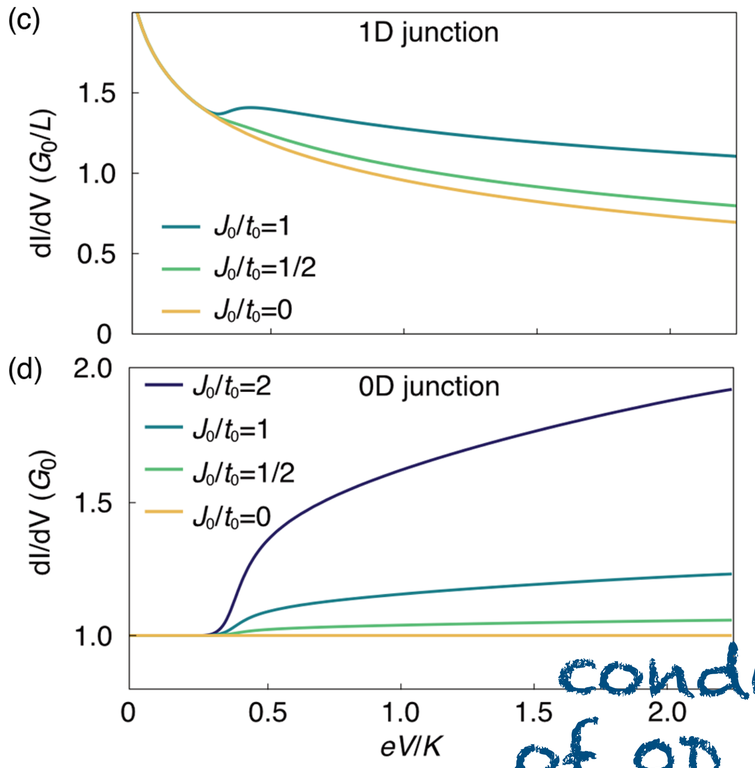
Isotropic Kitaev model



[J. Knolle *et al.*, PRL **112**, 207203 (2014)]





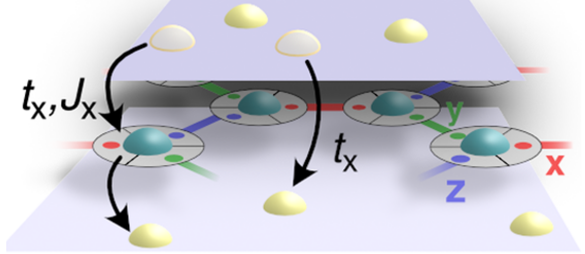


$$\frac{dI^{\text{inel}}}{dV} = 2G_0 \sum_{\mathbf{x},\mathbf{x}'} \frac{J_{\mathbf{x}} J_{\mathbf{x}'}}{t_0^2} \int_0^{\text{eV}} \frac{dE}{2\pi} \mathcal{A}^{\text{spin}}_{\mathbf{x},\mathbf{x}'}(E)$$

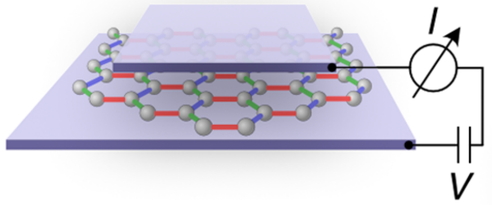
conductance of 0D junction

Dynamical structure factor

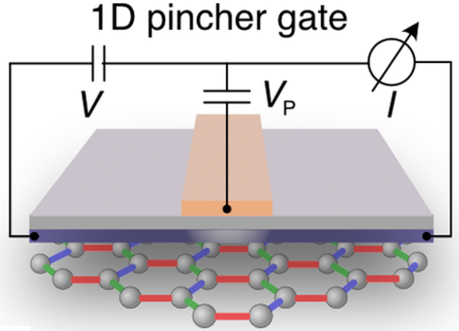
Tunneling current



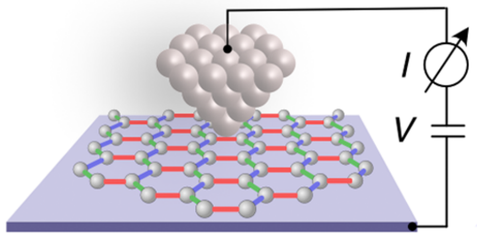
2D planar

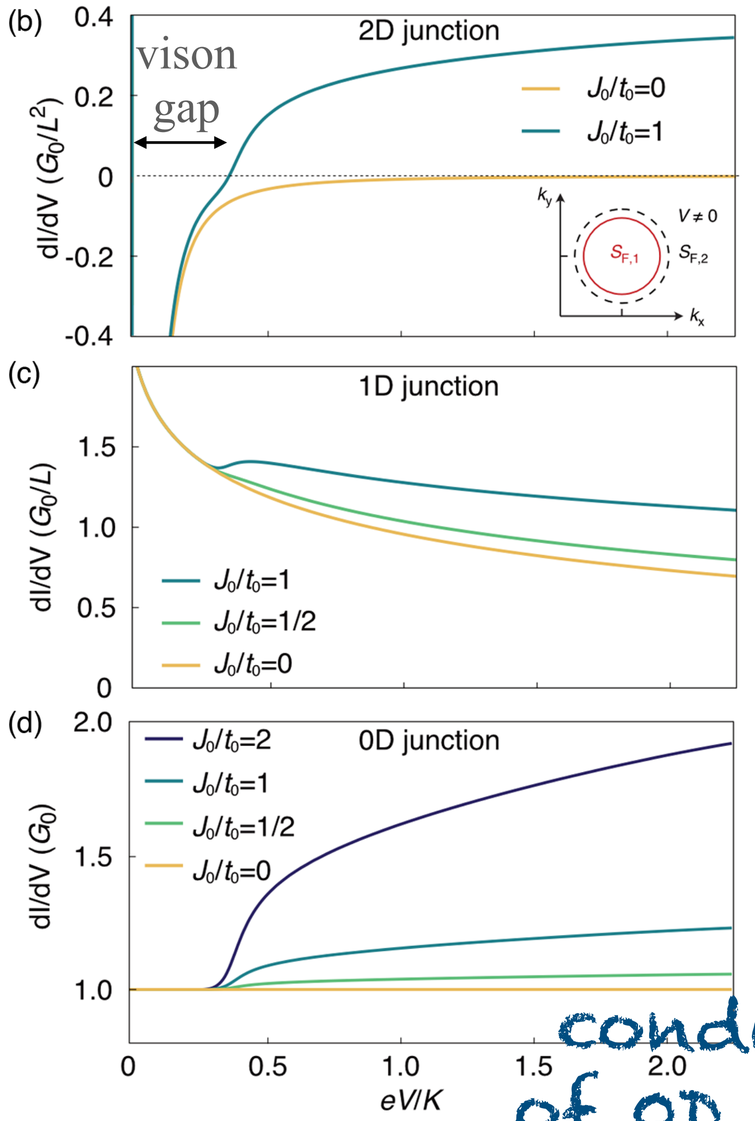


1D pincher gate

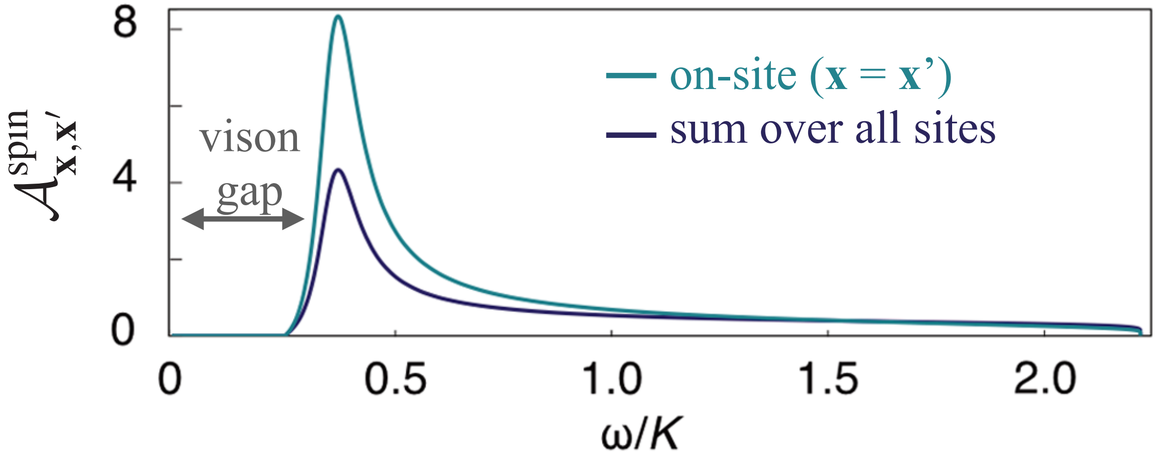


0D STM junction





Isotropic Kitaev model



[J. Knolle *et al.*, PRL **112**, 207203 (2014)]

$$\frac{dI^{inel}}{dV} = 2G_0 \sum_{x,x'} \frac{J_x J_{x'}}{t_0^2} \int_0^{eV} \frac{dE}{2\pi} \mathcal{A}^{spin}_{x,x'}(E)$$

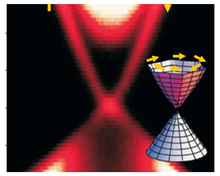
conductance of 0D junction

Dynamical structure factor

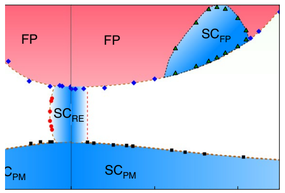
Summary
quantum science

quantum materials

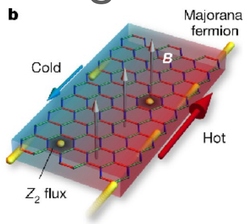
band topology



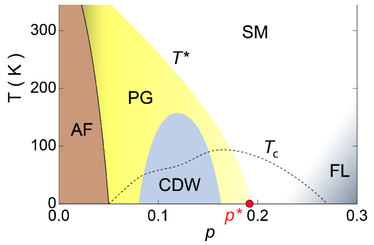
superconductors



topological order

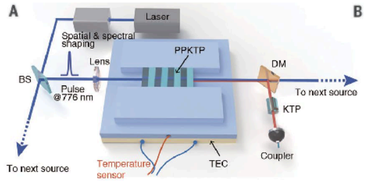


strange metals

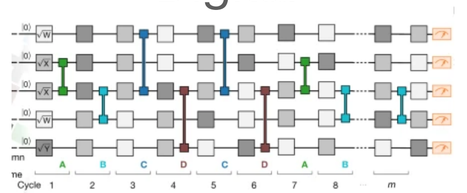


quantum computing

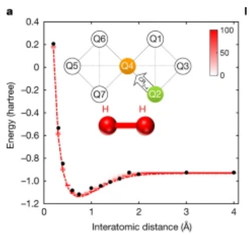
Analog

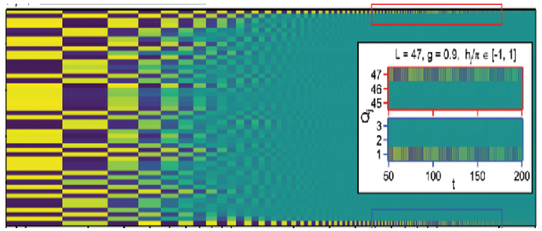


Digital



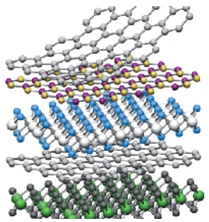
NISQ



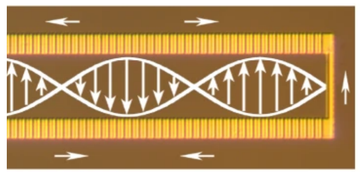


quantum design

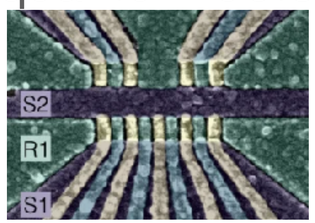
2D LEGO



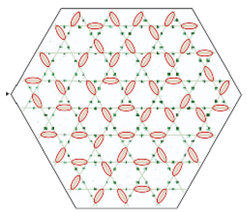
artificial materials



quantum dots

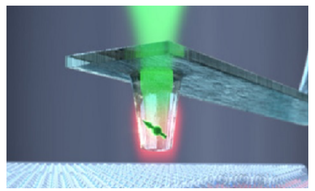


cold atoms

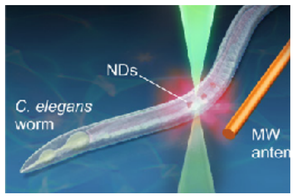


quantum sensing

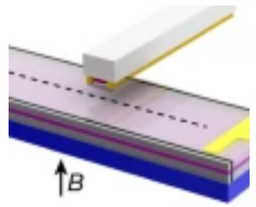
Magnetometry



Thermometry



Potentiometry



STM