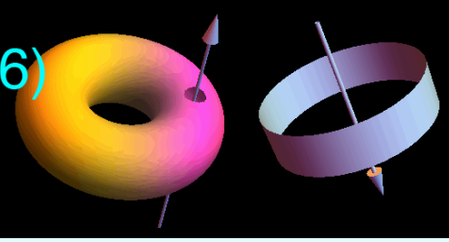
Physics of bulk-edge correspondence & its universality (BEC2016)
From solid state physics to cold atoms Workshop 2016, Sep 27-30



Kyoto, Sep.27 (2016)

Welcome everybody !

YITP international workshop "Physics of bulk-edge correspondence & its universality : From solid state physics to cold atoms" (BEC2016)

Devision of Physics, University of Tsukuba
Yasuhiro Hatsugai

京都大学 基礎物理学研究所
Yukawa Institute for Theoretical Physics Kyoto University

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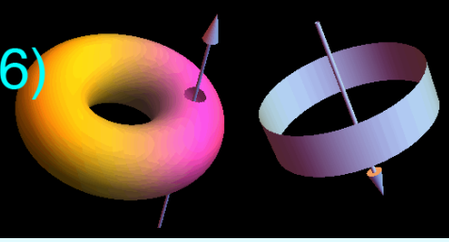

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This workshop is supported by
Yukawa Institute for Theoretical Physics (YITP)
& KAKEN-HI (JSPS)

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BEC

Bulk-Edge Correspondence

named by K.-I. Imura

Bose Einstein Condensation

well established

Bulk Edge Correspondence

not yet

Implying we have a dream

BEC 2015 Tokyo

Last year

Solid state, photonics & cold atoms

.....

BEC 2016 Kyoto

Solid state, photonics & cold atoms

+ Newton's + Maxwell's

+ Math

Exchange idea between different area !

Physics of bulk-edge correspondence & its universality (BEC2016)

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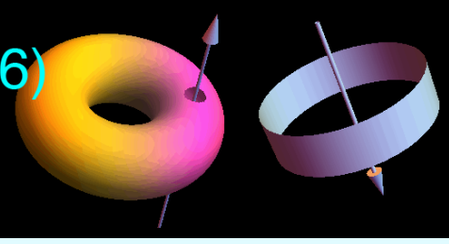

Kyoto, Sep.27 (2016)

Welcome everybody !

Thank you for joining us

Just a few words before the tight schedule

" Bulk-edge correspondence :
From math to physics & beyond "

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Yasuhiro Hatsugai

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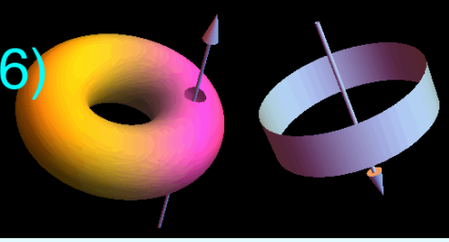

Welcome everybody !

Thank you for joining us

Solid states

Topological states

Photonics & Newton's !

Cold atoms

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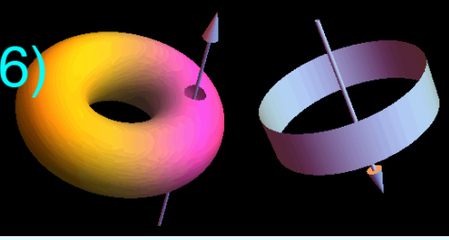

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Solid states

Topological states

Photonics & Newton's !

Cold atoms

As a bulk

- ☆ Hidden
- ☆ Can not be seen
- ☆ Gapped
- ☆ Unconventional

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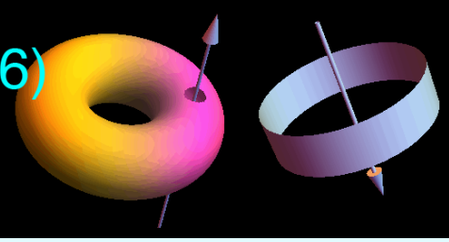

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With edges

- ☆ Observables
- ☆ In gap states
- ☆ Low energy modes

As a bulk

- ☆ Hidden
- ☆ Can not be seen
- ☆ Gapped
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Solid states

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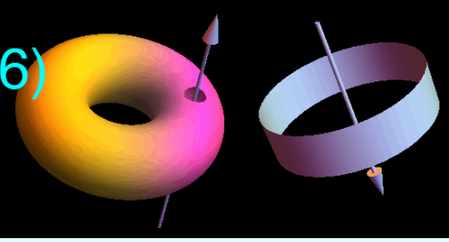

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bulk-edge correspondence

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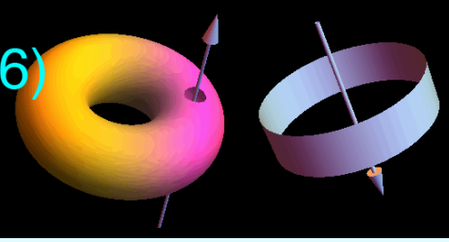

Solid states

- ☆ Graphene, Silicene, ... (Zigzag edge states:Fujita's)
- ☆ Solitons in polyacetylene
- ☆ Bound states of superconductors Andreev/Majorana
- ☆ Point/line nodes of superfluids/superconductors
- ☆ Weyl, Dirac semi-metals
- ☆ Photonic crystals
- ☆ Quantum Hall states, integer/fractional
- ☆ Quantum Spin Hall states (Topological insulators)
- ☆ Valence bond solid states (Haldane spin chains)
- ☆ Frustrated spins (spin liquids)
- ☆ Half filled Kondo lattice

bulk-edge correspondence

Photonics & Newton's !

- ☆ Photons: non-equilibrium
- ☆ Even Newton's law (classical mech.)

Cold atoms

- ☆ Synthetic gauge fields
- ☆ Hofstadter' problem
- ☆ Entanglement (entropy)

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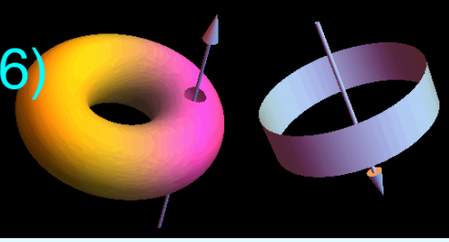

Diversity / Everywhere ? !

Lots of fun to play with

Solid states

bulk-edge correspondence

Photonics & Newton's !

Cold atoms

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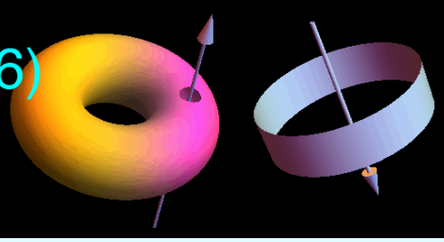

Learn something from examples !

From diversity to *UNIVERSALITY*

Solid states

bulk-edge correspondence

Photonics & Newton's !

Cold atoms

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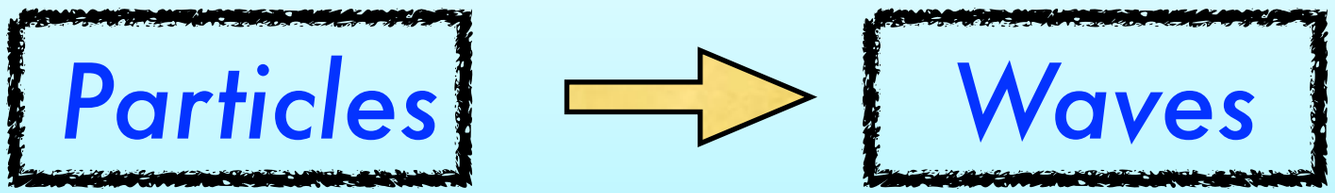
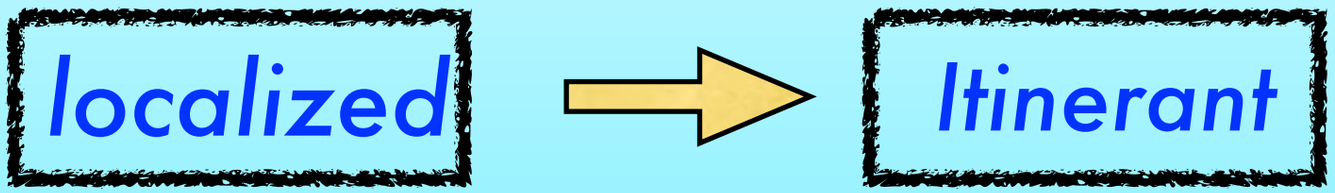
20-th century

Quantization:



photons, magnons, excitons, phonons, polaritons, spin wave…



gapless excitations

Before 80'

Quantization:

Particles → Waves

photons, magnons, excitons, phonons, polaritons, spin wave…

localized → Itinerant

gapless excitations

☑ *Metal is IMPORTANT and insulators are not !* Anderson

☑ *Thermodynamic limit is IMPORTANT* Nambu

More is different / Symmetry breaking

Huge success ! Universal idea over whole physics

From magnetism to superconductivity: Landau-Ginzburg-Wilson

After '80

Back to "classical world"

Particles ⟵ Waves

Q(S)HE, superconductivity, spin gap, Haldane gap,

localized ⟵ Itinerant

??

gapped

No Response

Anderson

Nambu

More is different / symmetry breaking

Huge success ! Universal idea over whole physics

But, but,....

We do have gapped systems everywhere!

NEED something for classification

- ☐ Topological order
- ☐ Berry connections
- ☑ Edge states

Now we are in the new millennium

Think different ! : topological phases

Particles ⟺ Waves

localized ⟺ Itinerant

related with each other

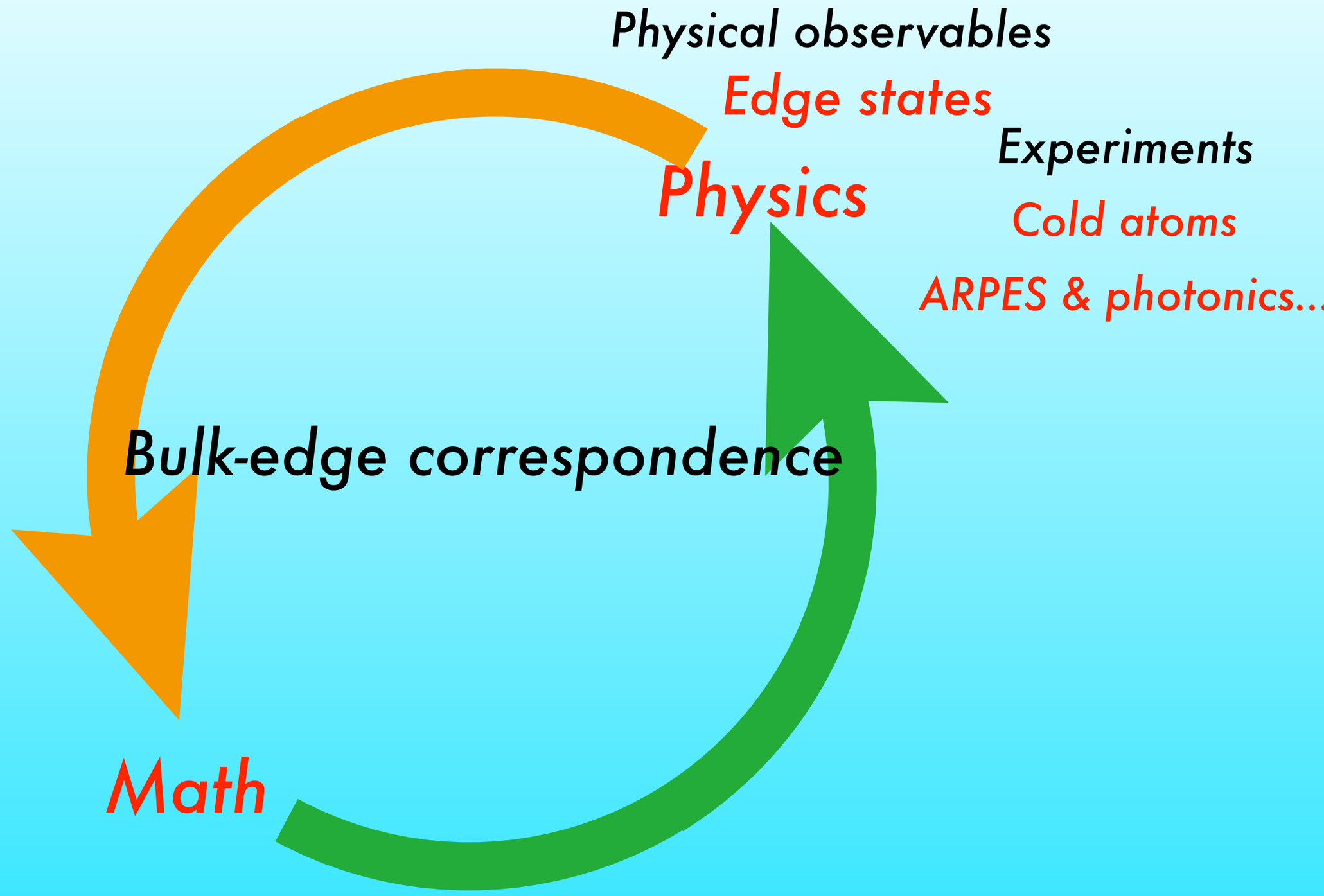
Lots of varieties for gapped systems (noticed just recently)

- ☑ Insulators (superconductors) can be of fun !
- ☑ Boundaries are not negligible

Bulk-edge correspondence

Math & physics :BEC2016

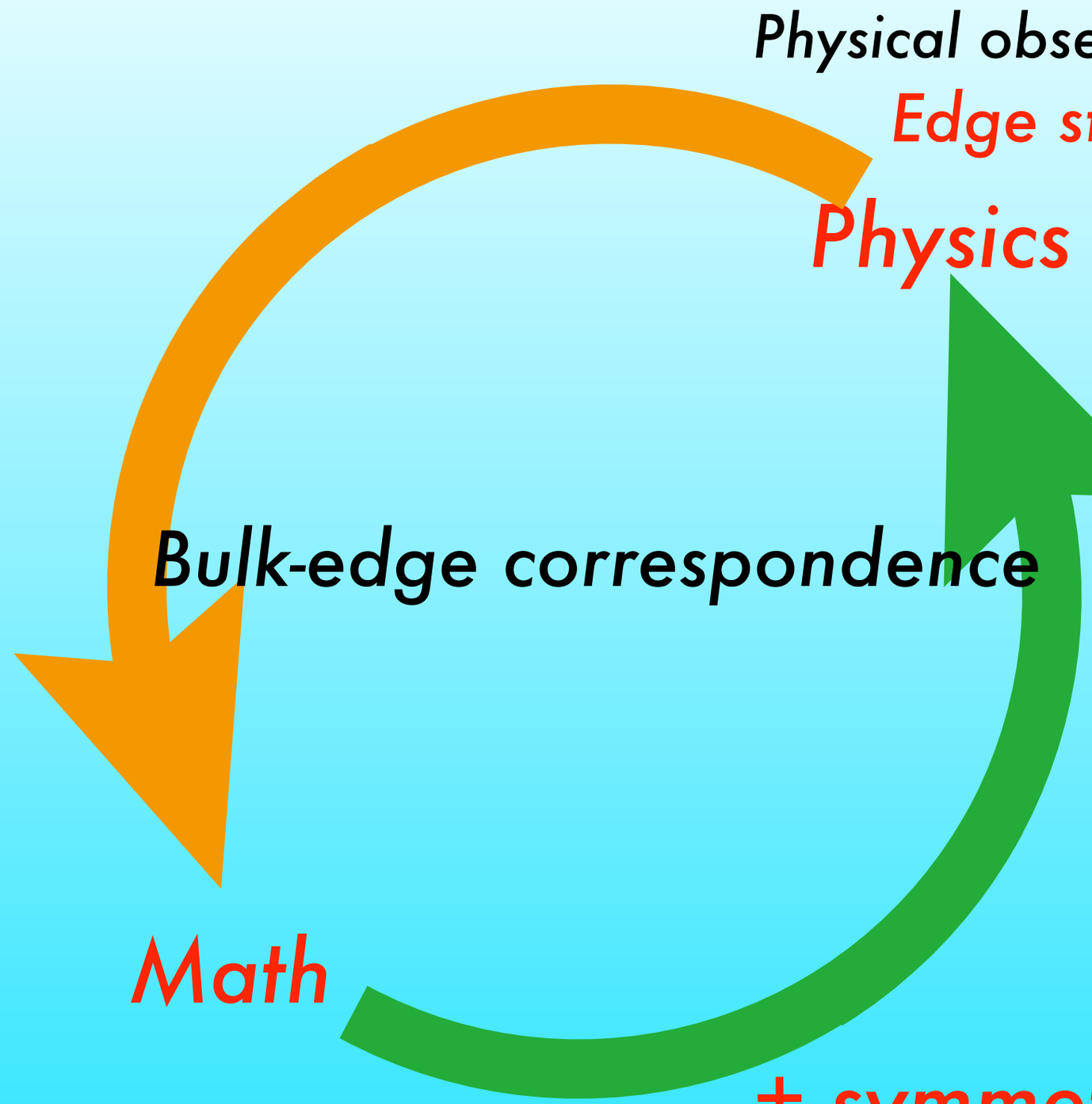
Exchange idea between different area !



New idea for better understanding of the matter

Math & physics :BEC2016

Exchange idea between different area !



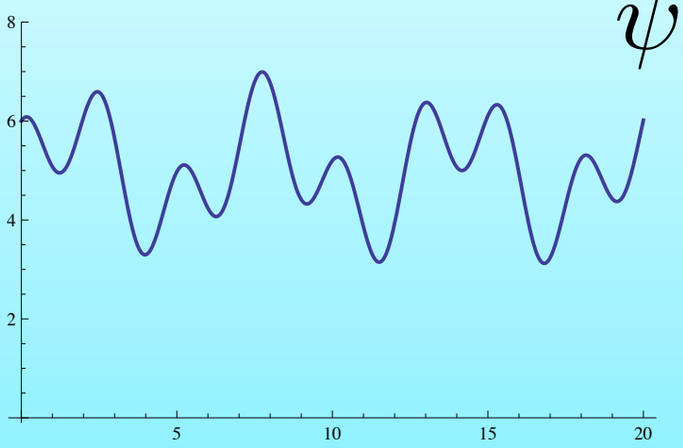
+ *symmetry protection*

New idea/phenomena : "adiabatic principle"

Edges states vs bulk states $(V \to \infty)$

Extended states / bulk states

unnormalizable

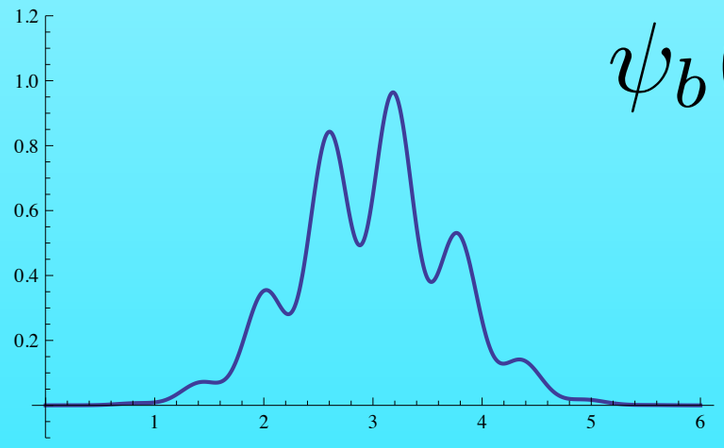


$$\psi_e(r) \sim \frac{1}{\sqrt{V}} e^{ikr} \longrightarrow 0 \quad (V \to \infty)$$

V: Volume of the whole system

Bound states / Edge states

normalizable



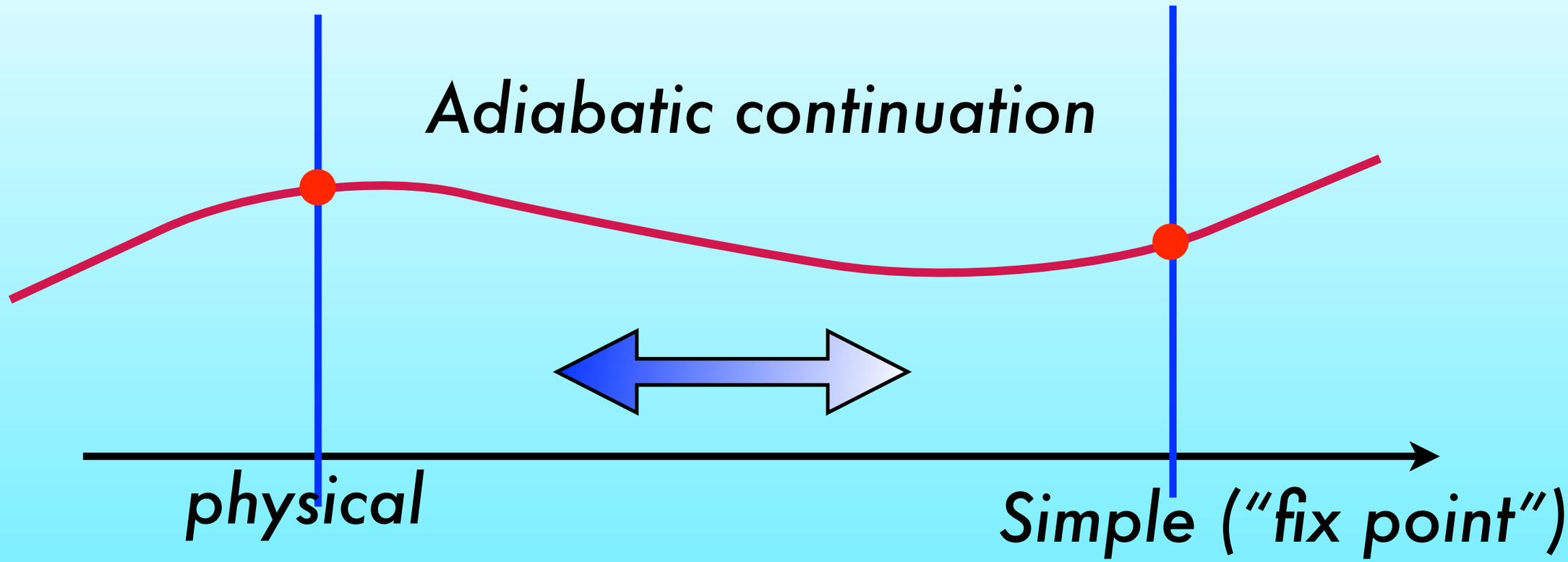
$$\psi_b(r) \sim \frac{1}{\sqrt{a_0^3}} e^{-r/a_0}$$

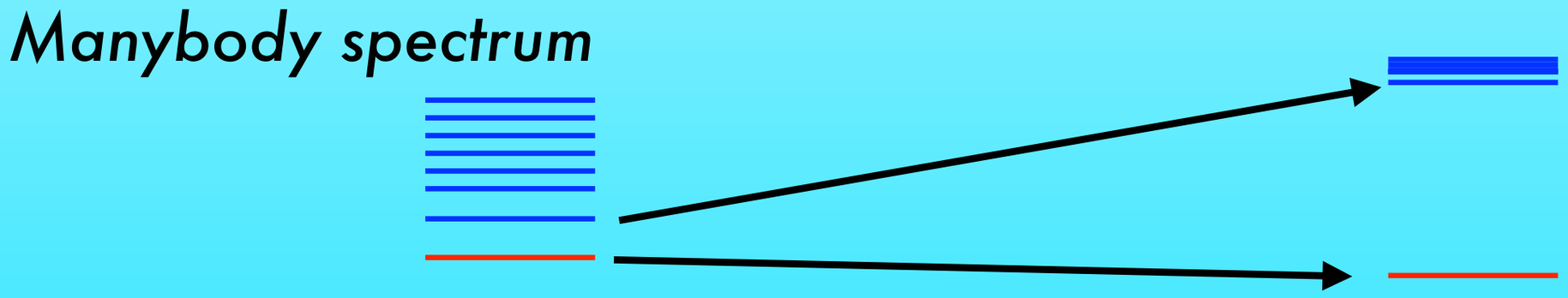
a_0 *:size of the bound state*

☑ *Clear difference only in the infinite system with boundaries !*

Adiabatic principle

For bulk



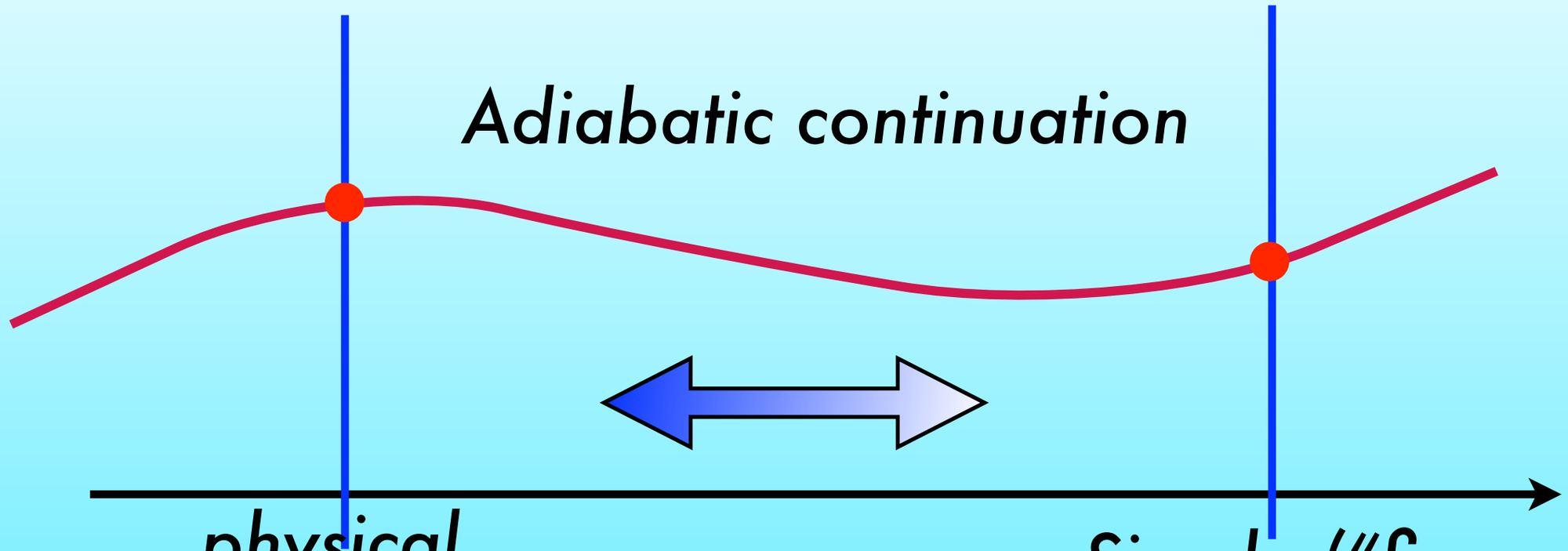


Quantized quantity (Chern #,..) : Adiabatic invariant

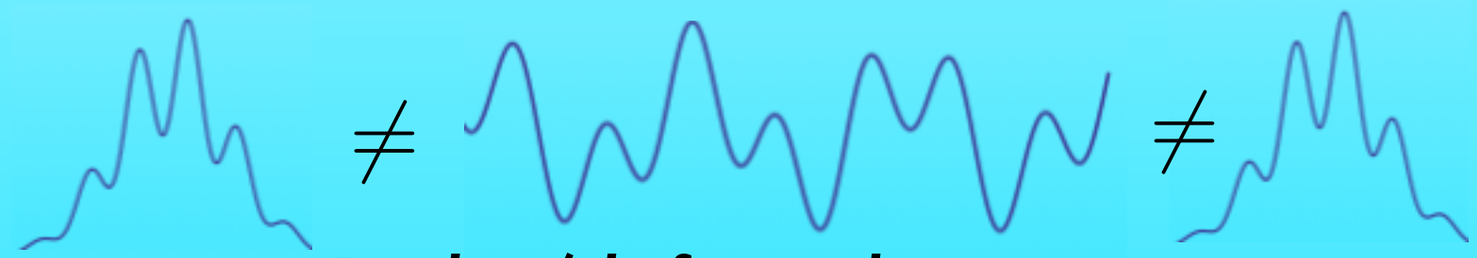
remains the same, unless the gap closes.

Adiabatic principle

For edges



left edges bulk right edges



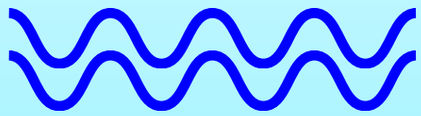
Right / left to the symmetry $(V \to \infty)$

Edge states (in the gap) can not disappear suddenly unless the gap closes

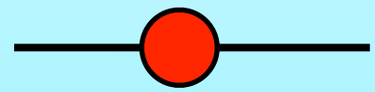
☑ Edge states are adiabatic invariants if the bulk is gapped !

Edge states: need some reasons to be there !
Not accidental !

Bulk-edge correspondence



Universality



Bulk state
"vacuum"

Control
with
each other

Edge state
"particles"

Edge state is a topological order parameter

Understand the bulk from edges

Edge determines the bulk

Summary

Learn physics/math from examples

Solid states

bulk-edge correspondence

Photonics & Newton's !

Cold atoms

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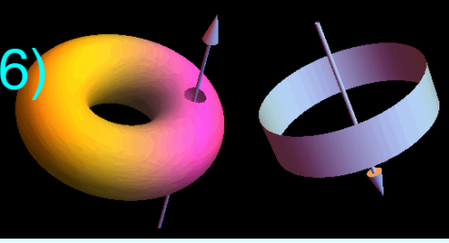
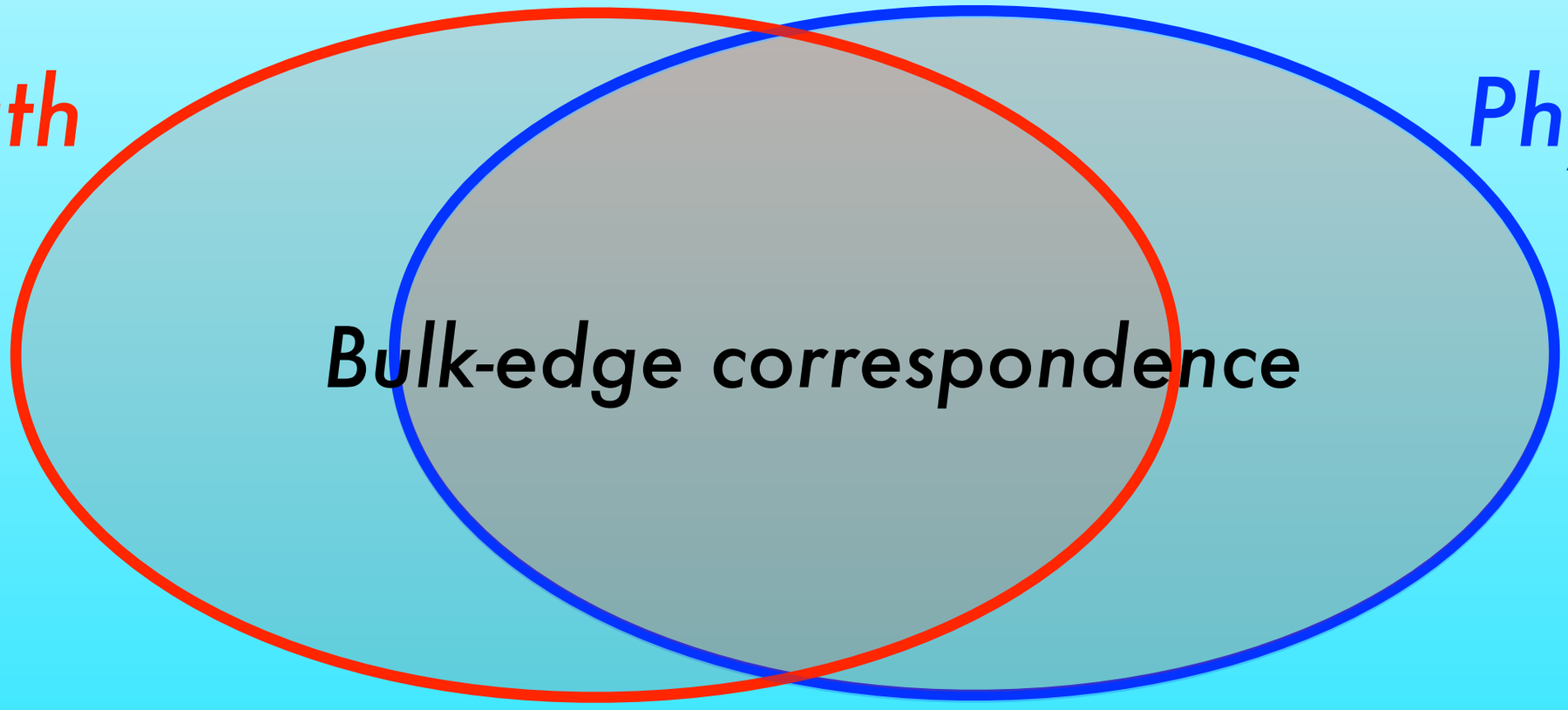


Enjoy this workshop!

Learn physics/math from examples

a common key word



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