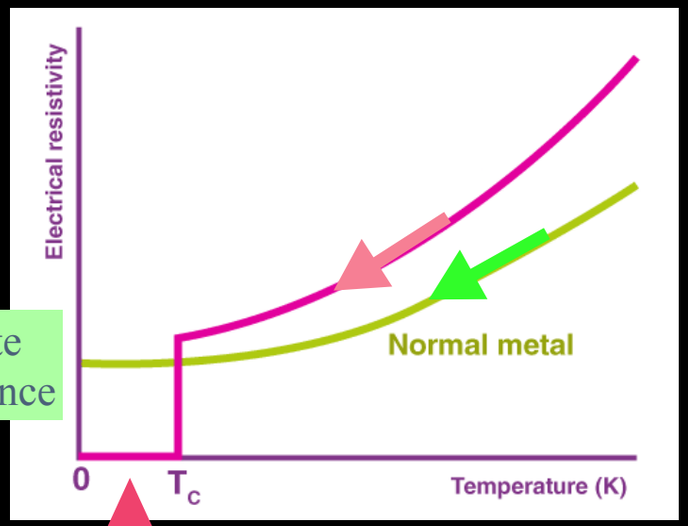
New Model to Represent Characteristics of Unique High-Temperature Superconductors

Speaker: Zhiyan

Research Article:

Phillips P W, Yeo L, Huang E W. Exact theory for superconductivity in a doped Mott insulator[J]. *Nature Physics, 2020, 16(12): 1175-1180.*

Introduction: Superconductor



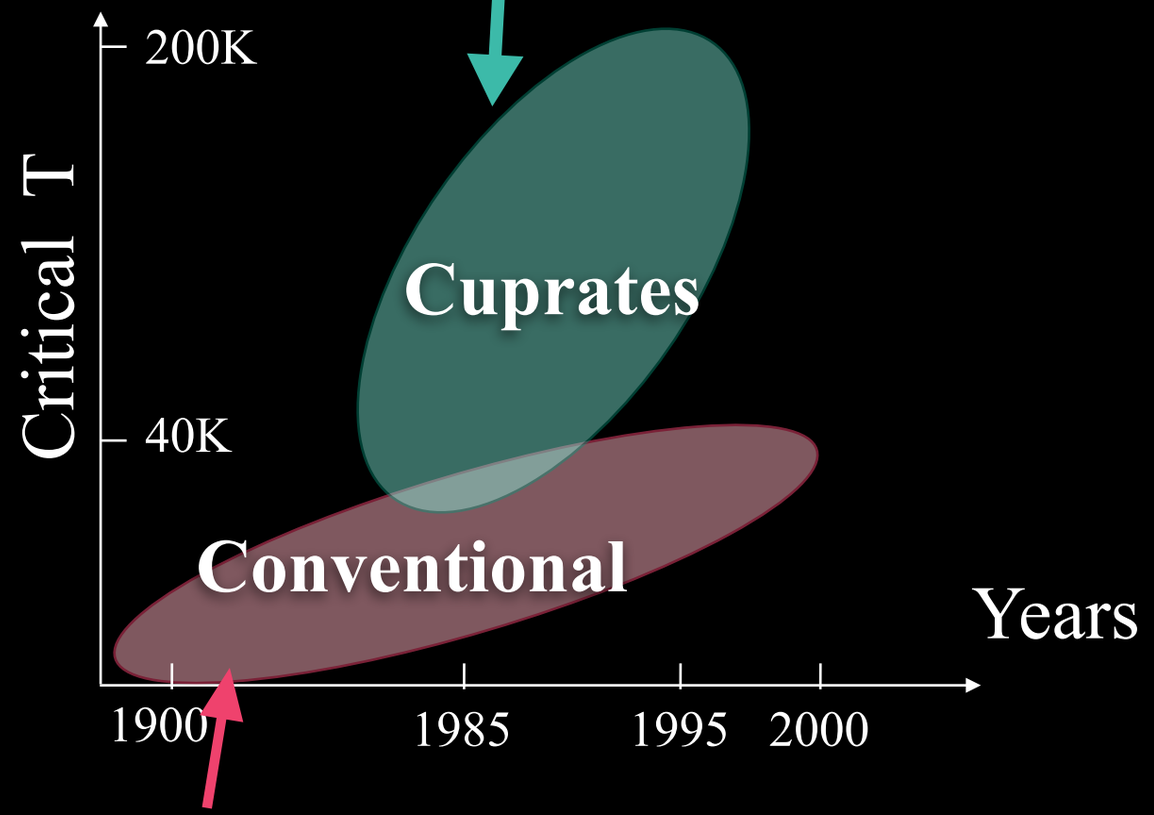
Finite resistance

No resistivity, no energy lost

Zero resistivity region ($T < T_c$)

Exploring the Superconductors Journey

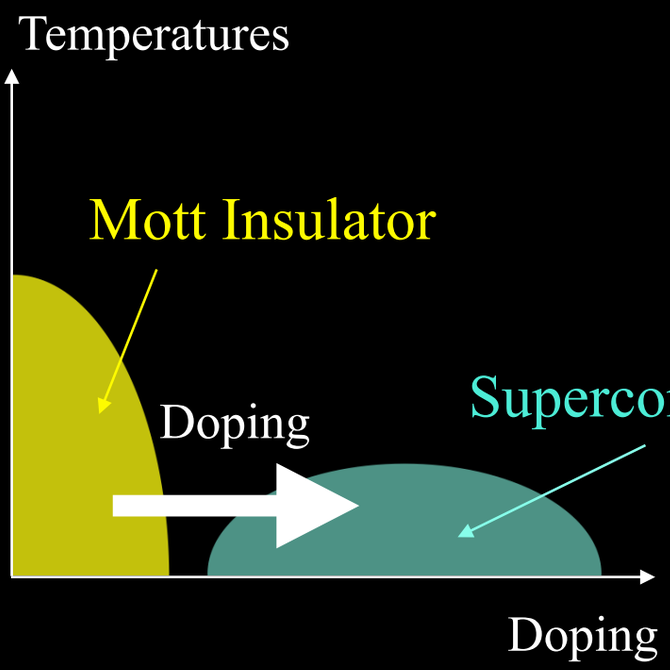
High-T superconductors, T_c : 30 ~ 200K



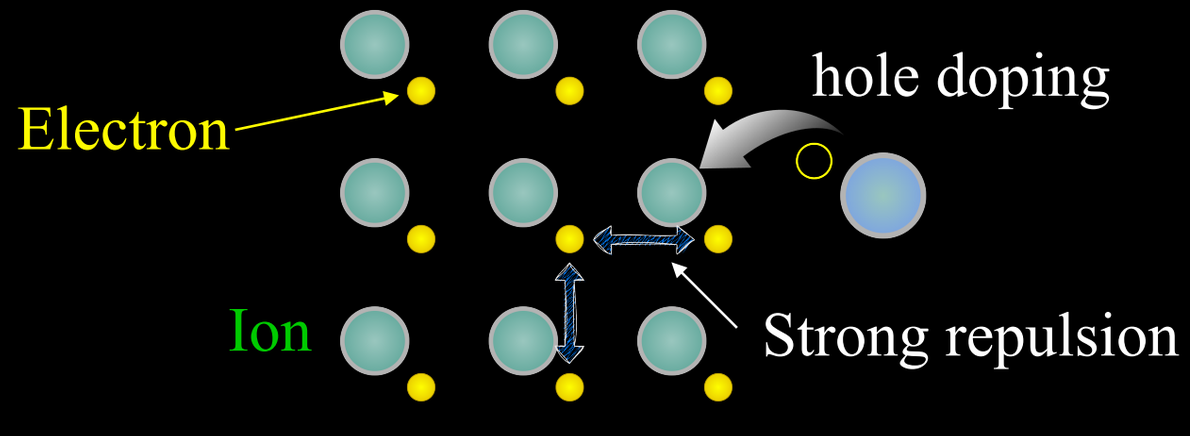
Low-T superconductors, $T_c < 40$K

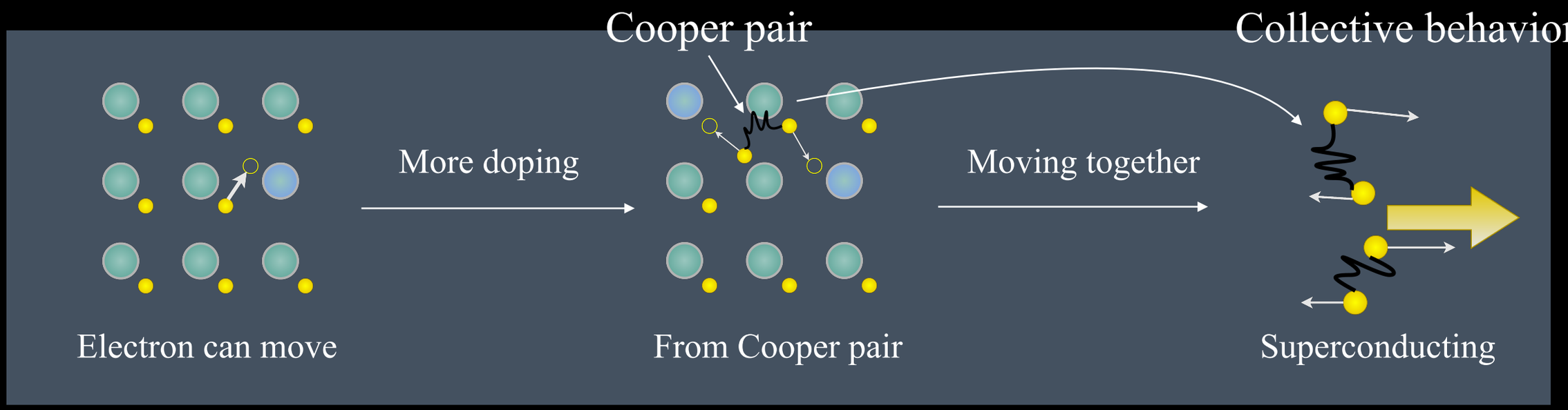
Introduction: High-temperature Superconductor

Cuprates phase diagram



Mott Insulator





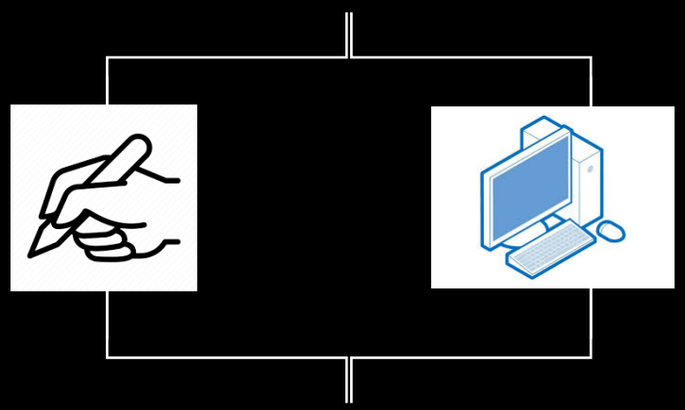
What is unknown

Mott Insulator + Cooper pair?

Mott Insulator ..... Superconductor

Transition?

Model ← Total energy



Physical quantities

HK-BCS Model

HK model

Hatsugai, Y., & Kohmoto, M. (1992)

$W \sim$ hopping

$U \sim$ localization

Cooper pair

$g \sim$ Cooper pair

When U < W

Mottness:
localizated tendency

When U > W

Mott Insulator

Superconducting

Parameters: W, U, g

Aim 1: Method

New Model

HK-BCS model —Aim 1 / Prove→ Superconductivity

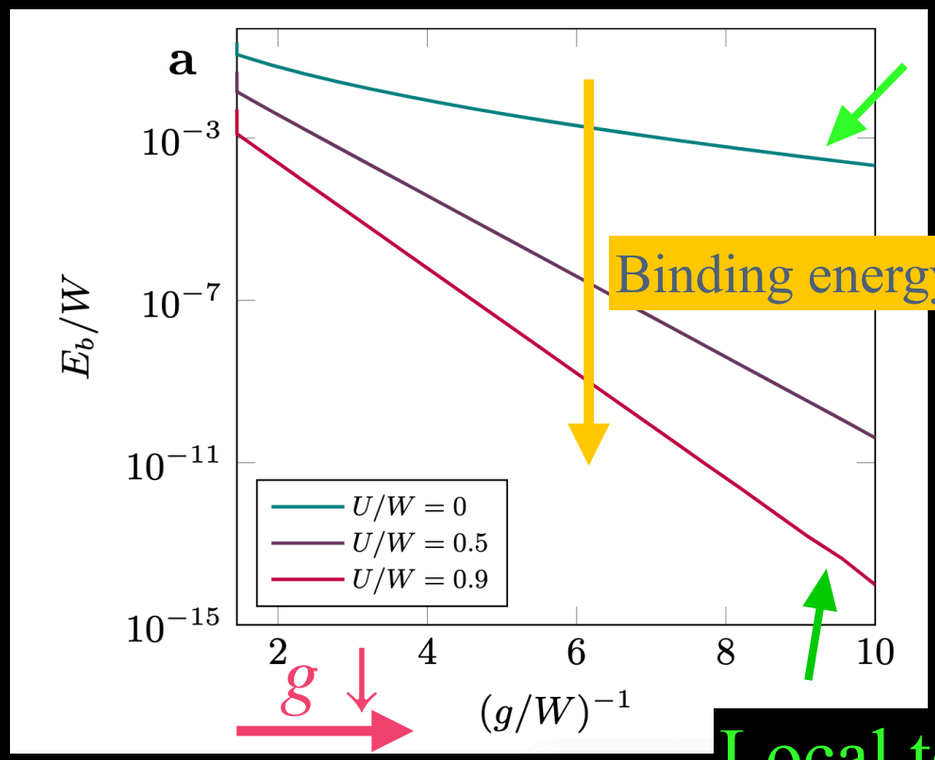
How to prove it has superconducting state?

One pair state —break a pair→ $g = 0$ case

Binding energy

$$E_b = \Delta E$$

Aim 1: Result



No repulsion,
Conventional

Binding energy suppressed

Local tendency
Mottness VS Cooper pair

- For any g exists, $E_b > 0$ which means breaking a pair needs to pay energy.
- Local repulsion **reduces the tendency to pair**, but **cannot eliminate it**.

Aim 1: Conclusion

Can Pairing Happen? Yes

New Model

HK-BCS model ⋯⋯▸ Superconductivity

Aim 1

Proved

The system is **always unstable to forming pairs**,
no matter how weak the Cooper-pair strength is.

Research Study

New Model

HK-BCS model ⋯⋯➤ Superconductivity

Conventional Superconductors

Doesn't explain

Aim 2

Describe

Aim 3

Describe

Superfluid stiffness

Spectral weight transfer

Experimental signatures of superconductivity in the cuprates

Aim 2

New Model

HK-BCS model ⋯⋯➤ Superconductivity

Aim 2

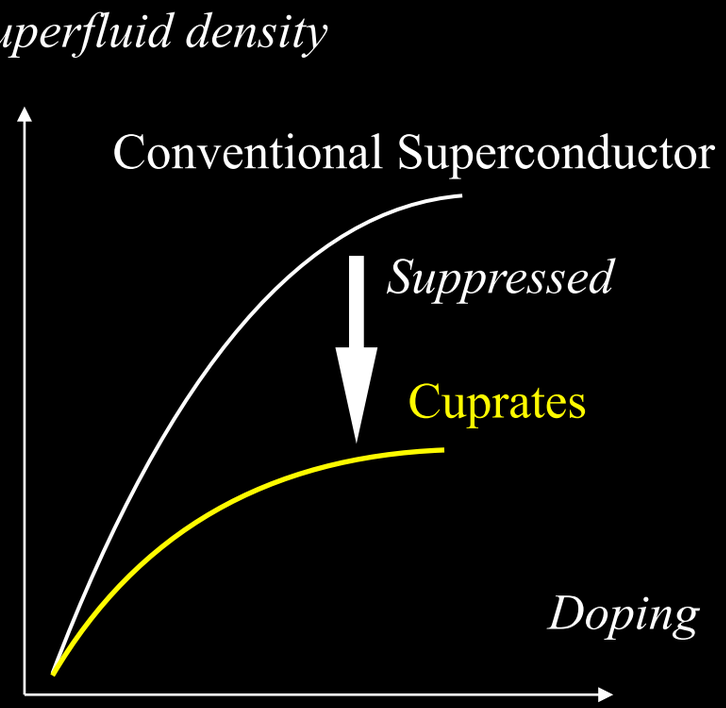
Describe

Superfluid stiffness

Experimental conclusion:

Božović et al., Nature 536, 309 (2016)

Unlike conventional Superconductor,
The superfluid stiffness in Cuprate is suppressed.



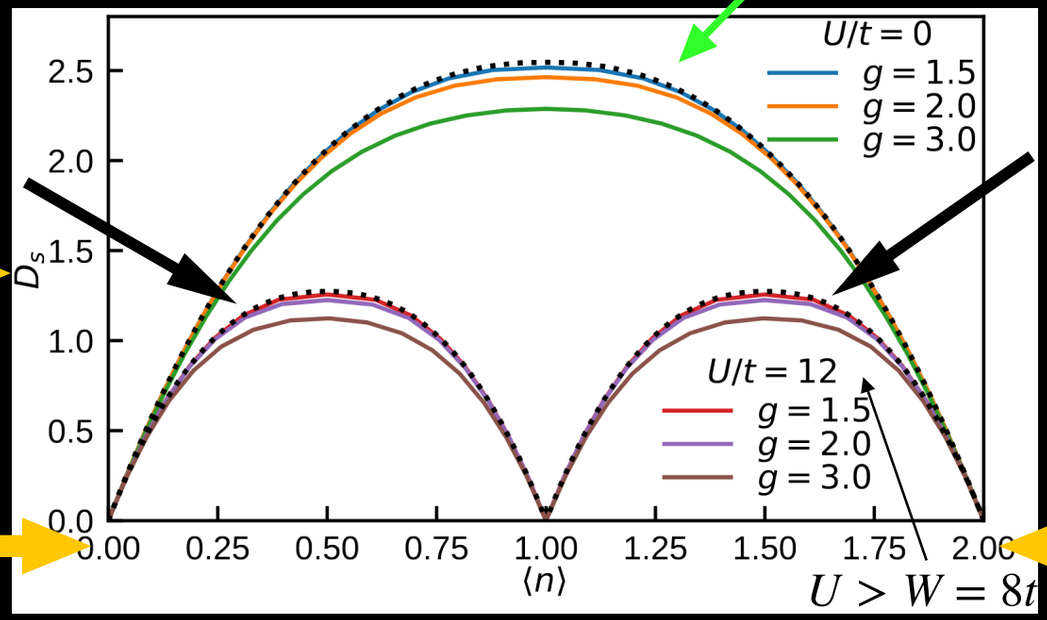
Aim 2: Result

Conventional superconducting

HK-BCS

HK-BCS

Cooper pair density



Doping level

Doping level

Mott insulator

Near the Mott insulator, stiffness collapses

Aim 2: Conclusion

New Model

HK-BCS model ⋯⋯▸ Superconductivity

↓

Superfluid stiffness

The system still forms Cooper pairs — but they don't flow easily.
This captures the same behavior seen in experiments on cuprates.

Research Study

New Model

HK-BCS model ⋯⋯➤ Superconductivity

Aim 3

Describe

Superfluid stiffness

Spectral weight transfer

Experimental signatures of superconductivity in the cuprates

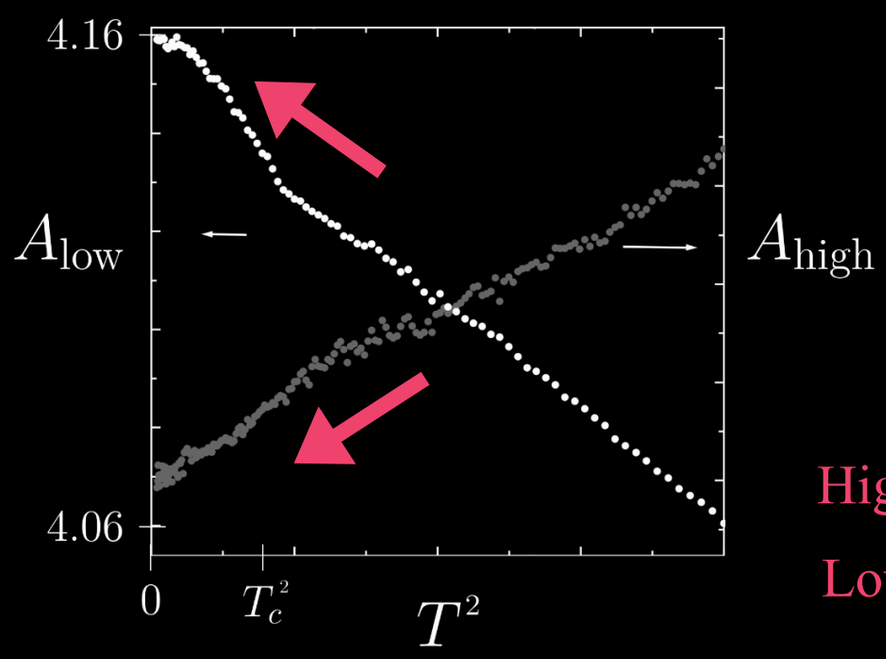
Aim 3

New Model

HK-BCS model ⋯⋯➤ Superconductivity

Experimental conclusion:

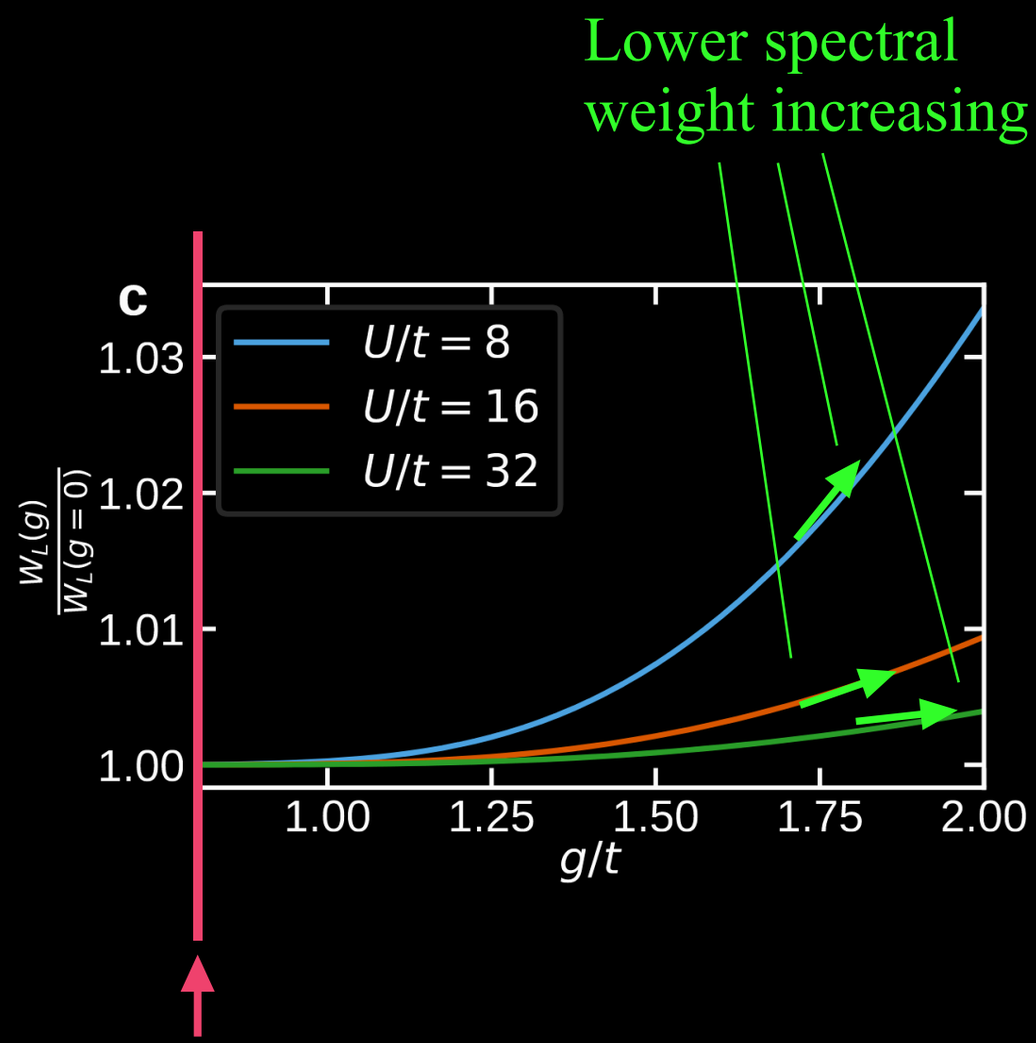
Molegraaf et al. (Science 66, 2239 (2002))



High frequency weight ↓

Low frequency weight ↑

Aim 3: Result



The lower spectral weight is increasing while g growing.

Aim 3: Conclusion

New Model

HK-BCS model ⇢ Superconductivity

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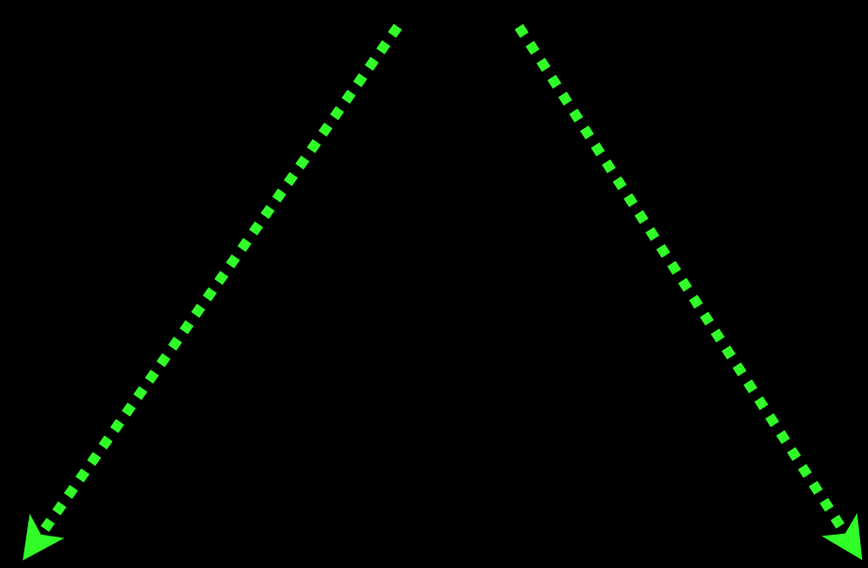
Spectral weight transfer

Dynamical spectral weight transfer (DSWT)
is a **general consequence of Mottness**

Research Study

New Model

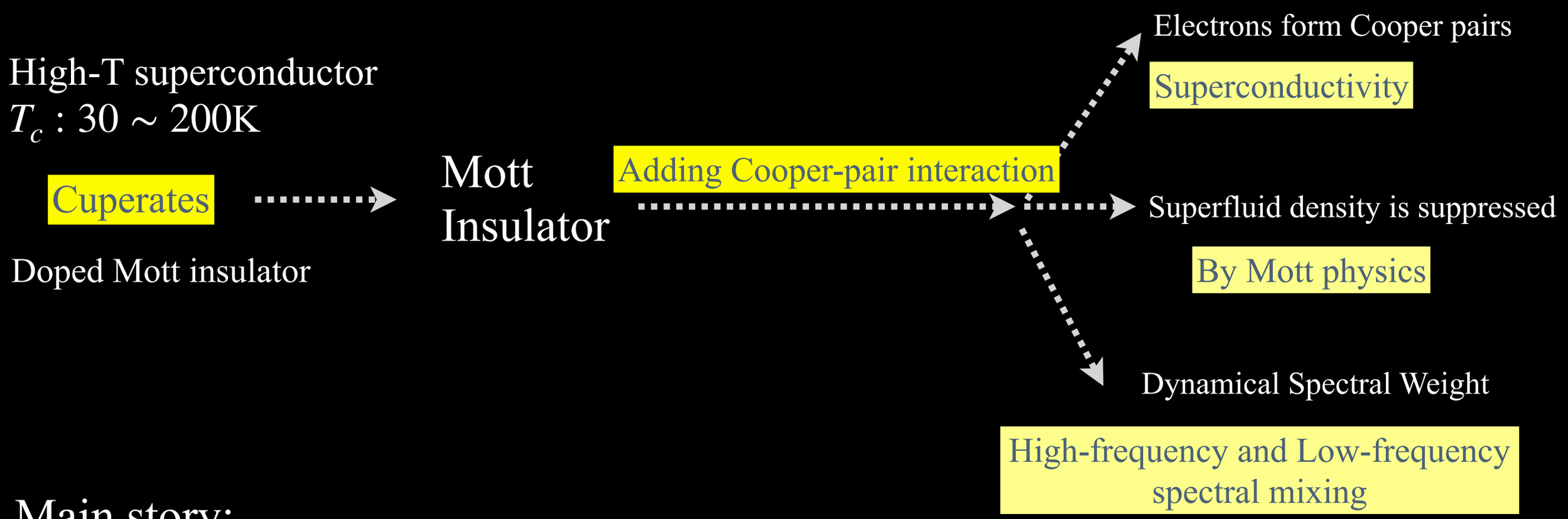
HK-BCS model ⇢ Superconductivity



Superfluid stiffness Spectral weight transfer

Experimental signatures of superconductivity in the cuprates

Summary for Research Idea Story



Main story:

A family of high-temperature superconductors is Cuprates, they start from a very different place: a Mott insulator. Now, a new model is proposed to represent the transition from Mott Insulator to Superconductor, and simulate the unique behaviors of superconducting state. So, this new model can successfully describe Cuprates.

Importance of the Study

Cuprates

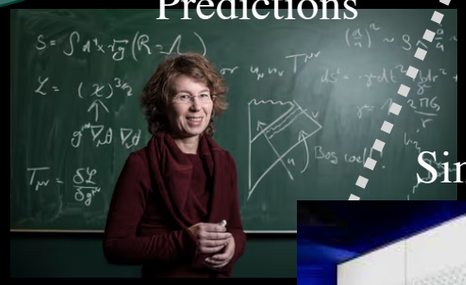
Mott Insulator

Superconductor

Organized

New model

Predictions



Simulations

Test Ideas

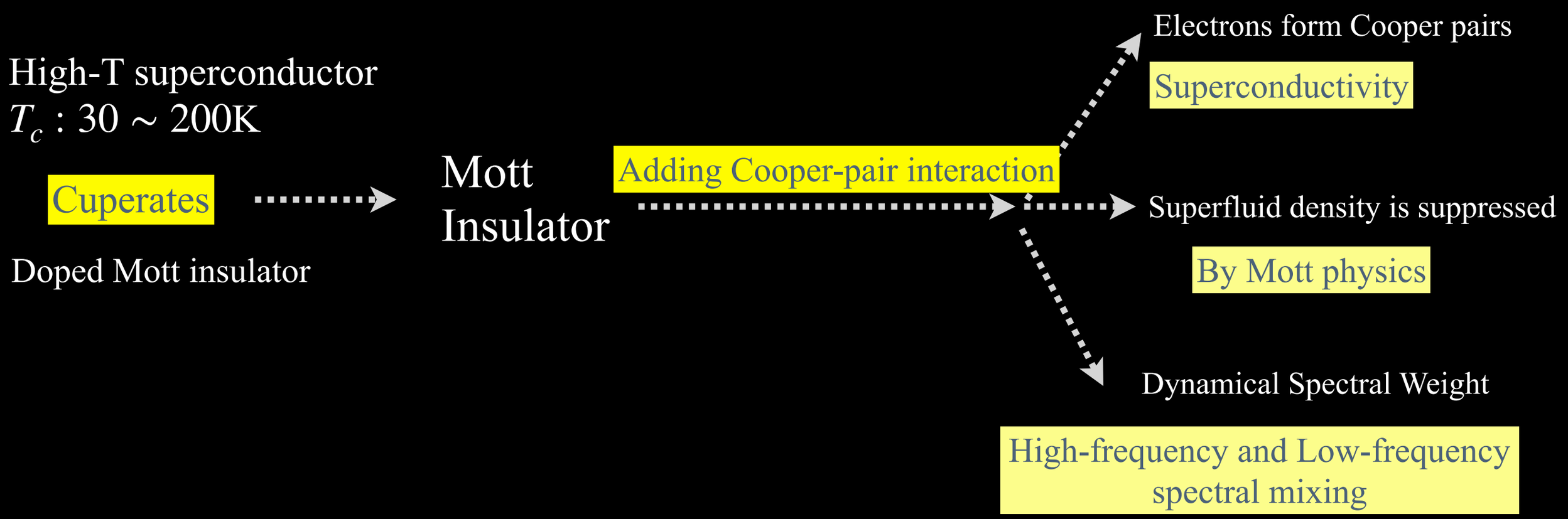
Understanding

Superconductors

Developing the critical temperature

Benefit Society

Final Page



Thank you!

References

[1] Phillips P W, Yeo L, Huang E W. Exact theory for superconductivity in a doped Mott insulator[J]. *Nature Physics, 2020, 16(12): 1175-1180.*

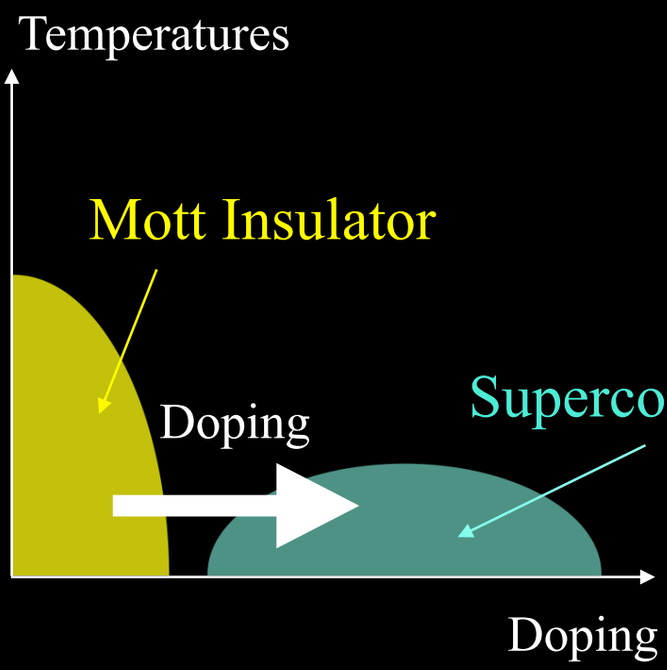
[2] Hatsugai, Y., & Kohmoto, M. (1992). Exactly Solvable Model of Correlated Lattice Electrons in Any Dimensions. *Journal of the Physical Society of Japan, 61*, 2056-2069.

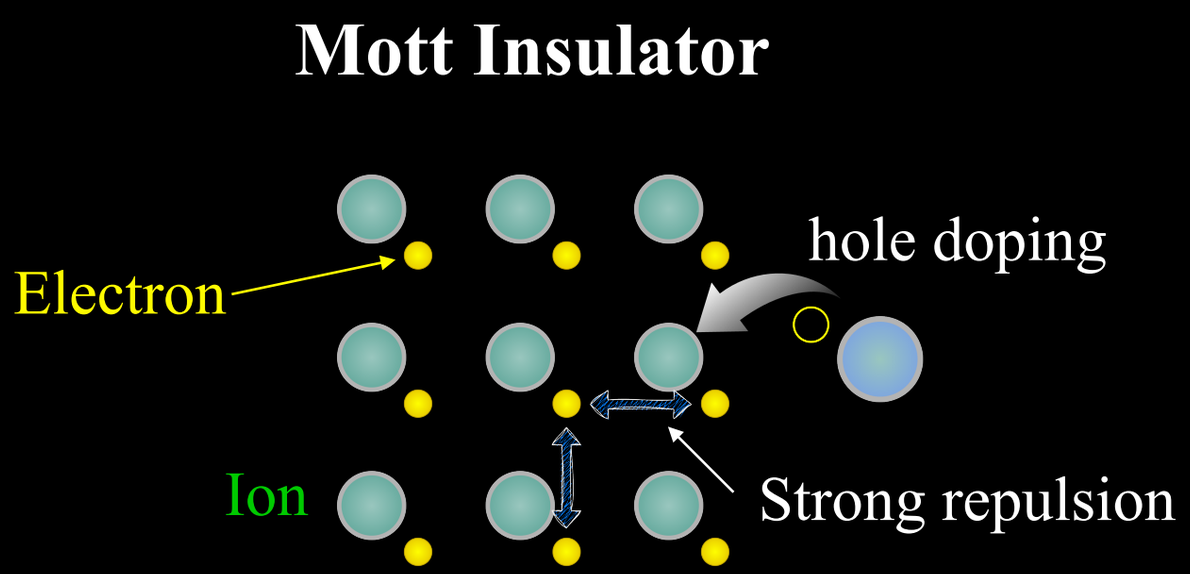
[3] Božović, I., He, X., Wu, J., & Bollinger, A. T. (2016). Dependence of the critical temperature in overdoped copper oxides on superfluid density. *Nature*, *536*(7616), 309-311.

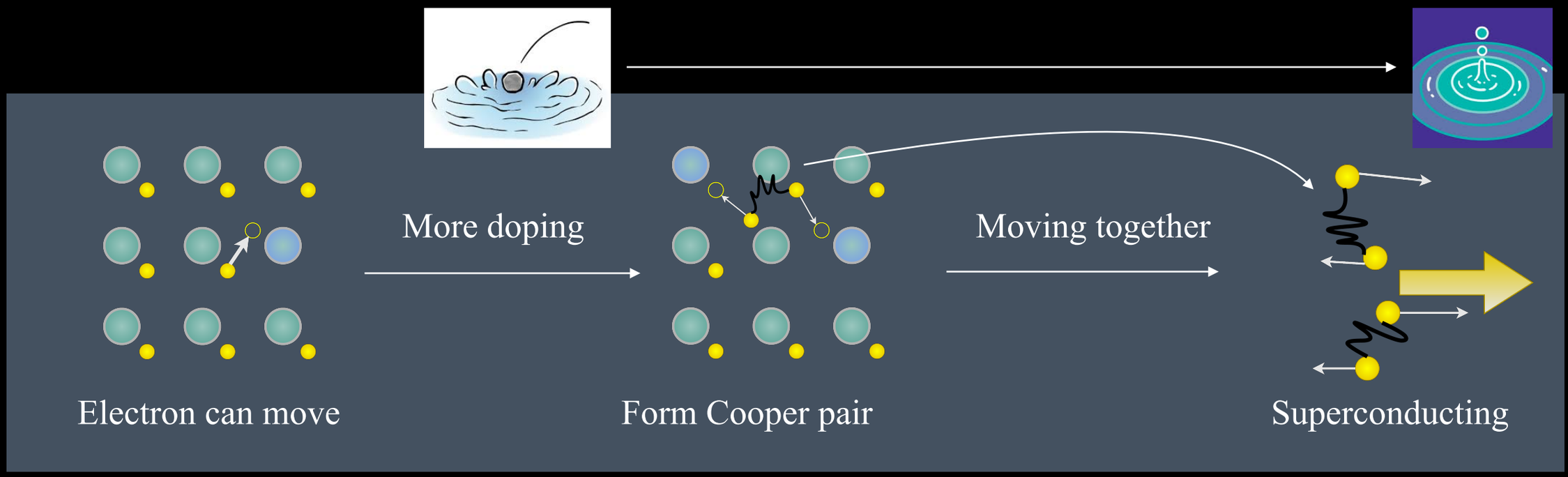
Appendix

Introduction: High-temperature Superconductor

Cuprates states diagram







HK-BCS Model

HK model

Hatsugai, Y., & Kohmoto, M. (1992)

$$H = \underbrace{W(\text{hopping})}_{\text{Electron can freely move}} + \underbrace{U(\text{local})}_{\text{Electron cannot move}}$$

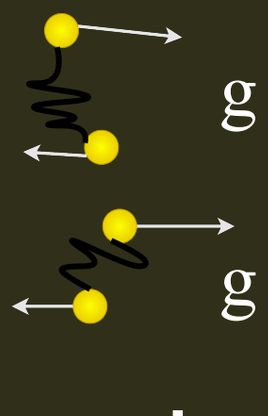
When U > W

Mott Insulator

+

Cooper pair

g(Cooper pair)



Superconducting