Title: Resource theories of communication

Speakers: HlÃ©r KristjÃ¡nsson

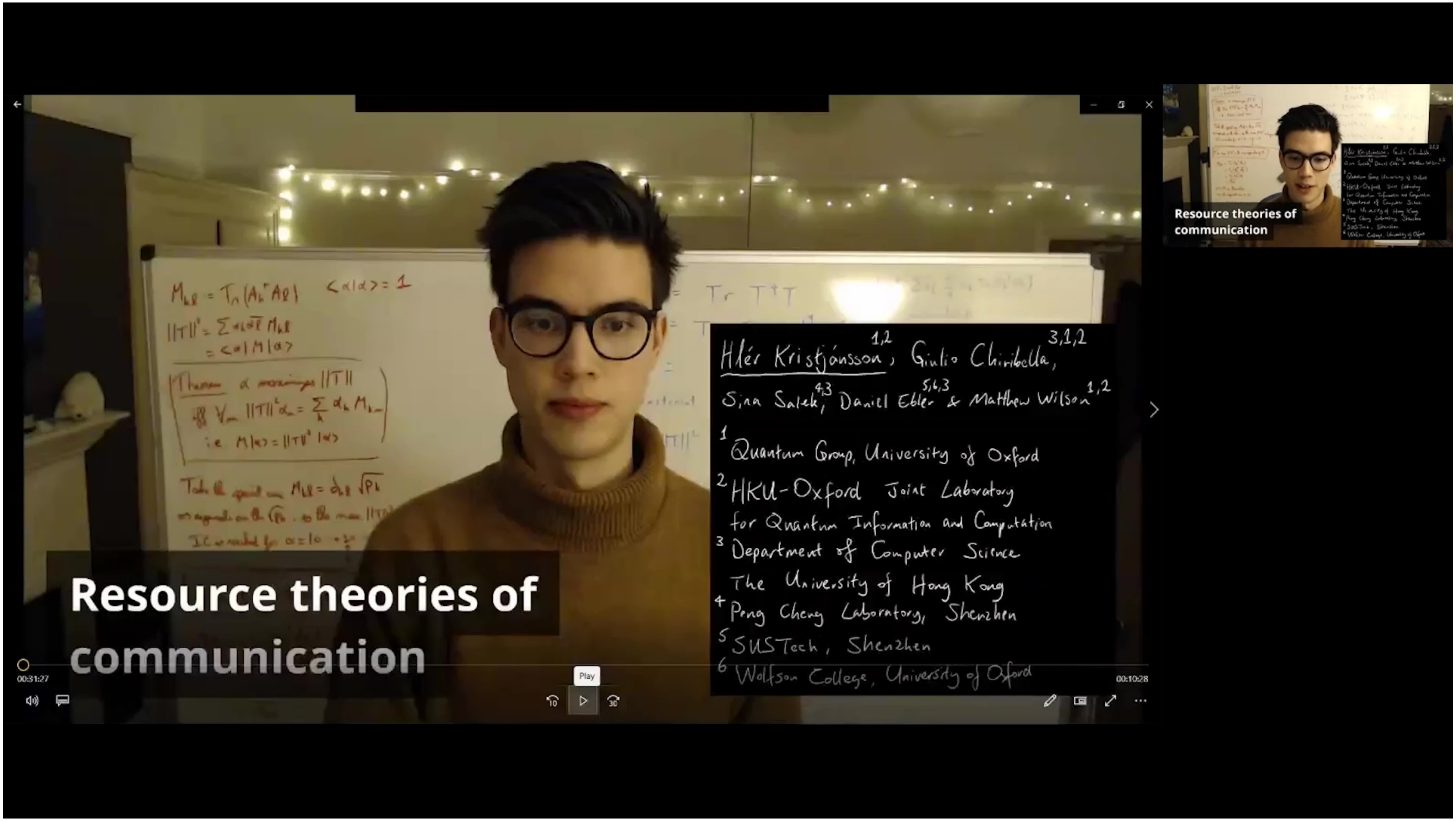
Series: Quantum Foundations

Date: January 29, 2021 - 12:00 PM

URL: http://pirsa.org/21010022

Abstract: A series of recent works has shown that placing communication channels in a coherent superposition of alternative configurations can boost their ability to transmit information. Instances of this phenomenon are the advantages arising from the use of communication devices in a superposition of alternative causal orders, and those arising from the transmission of information along a superposition of alternative trajectories. The relation among these advantages has been the subject of recent debate, with some authors claiming that the advantages of the superposition of orders could be reproduced, and even surpassed, by other forms of superpositions. To shed light on this debate, we develop a general framework of resource theories of communication. In this framework, the resources are communication devices, and the allowed operations are (a) the placement of communication devices between the communicating parties, and (b) the connection of communication devices with local devices in the parties' laboratories. The allowed operations are required to satisfy the minimal condition that they do not enable communication independently of the devices representing the initial resources. The resource-theoretic analysis reveals that the aforementioned criticisms on the superposition of causal orders were based on an uneven comparison between different types of quantum superpositions, exhibiting different operational features.

Ref. https://iopscience.iop.org/article/10.1088/1367-2630/ab8ef7



Resource theories of communication
Hlér Kristjánsson[1,2], Giulio Chiribella[3,1,2],
Sina Salek[4,3], Daniel Ebler[5,6,3] & Matthew Wilson[1,2]
1 Quantum Group, University of Oxford
2 HKU-Oxford Joint Laboratory for Quantum Information and Computation
3 Department of Computer Science The University of Hong Kong
4 Peng Cheng Laboratory, Shenzhen
5 SUSTech, Shenzhen
6 Wolfson College, University of Oxford
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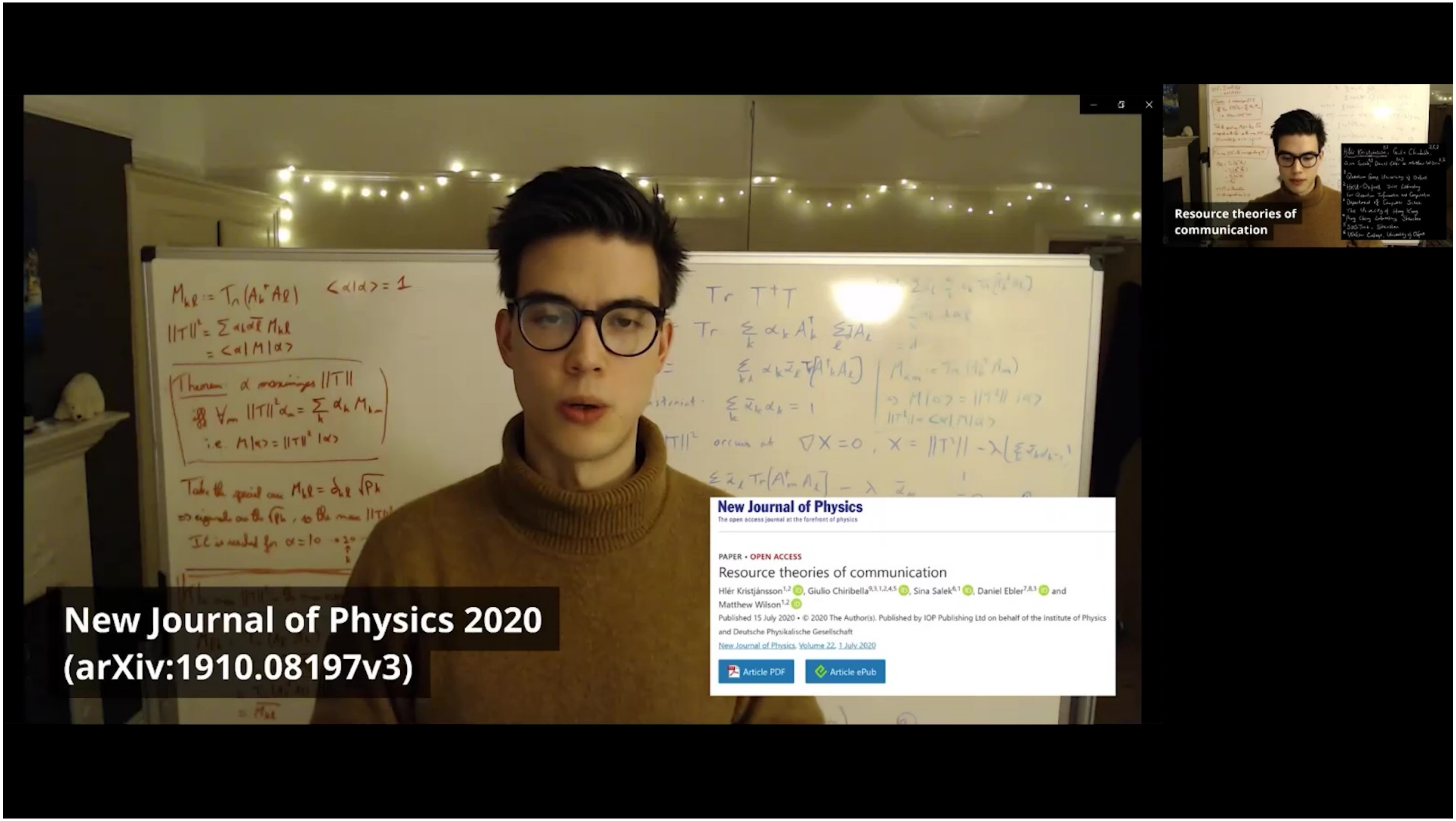
Resource theories of communication
New Journal of Physics 2020
(arXiv:1910.08197v3)
New Journal of Physics
PAPER • OPEN ACCESS
Resource theories of communication
Hlér Kristjánsson, Giulio Chiribella, Sina Salek, Daniel Ebler and Matthew Wilson
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New Journal of Physics, Volume 22, 1 July 2020
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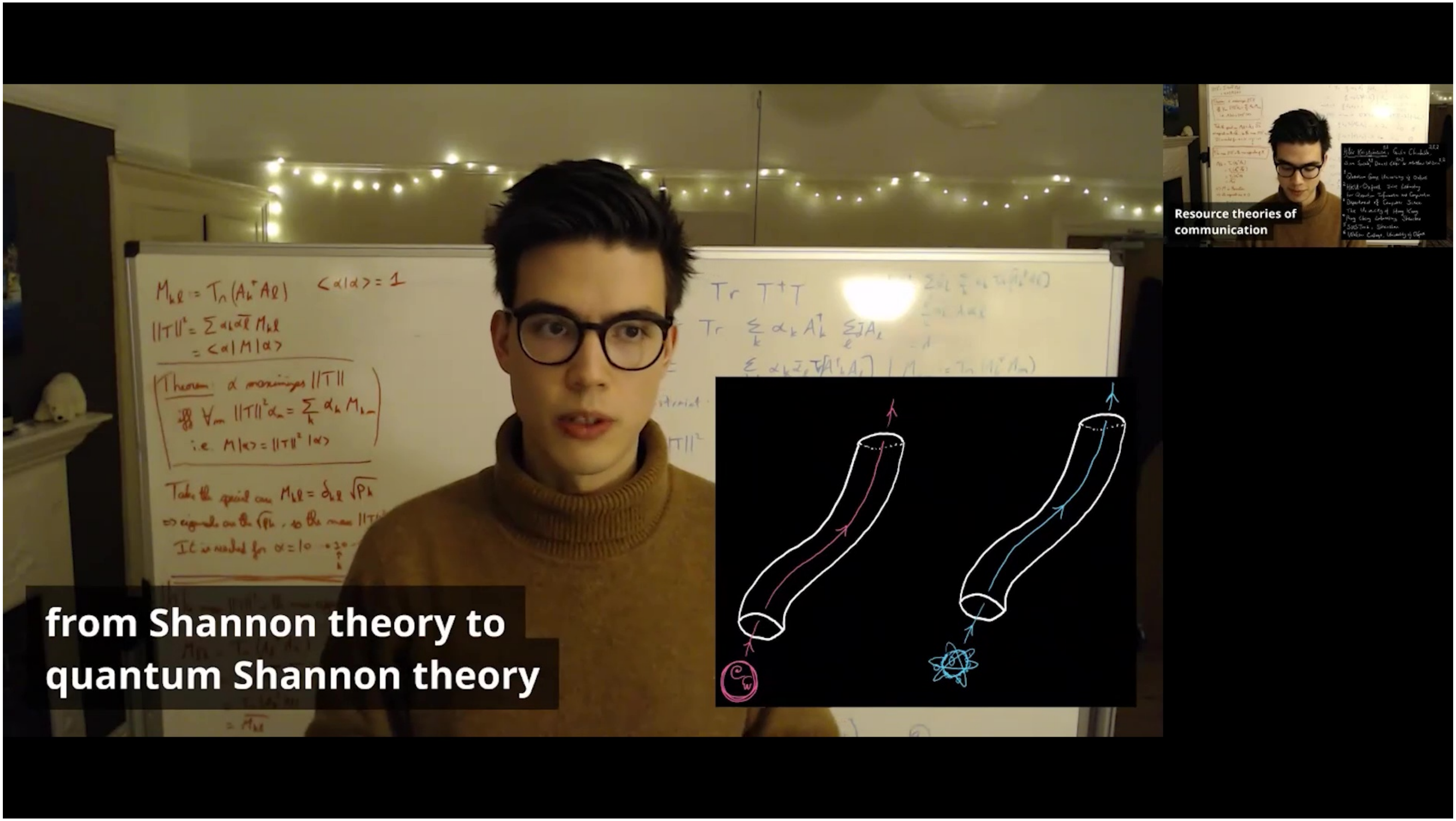
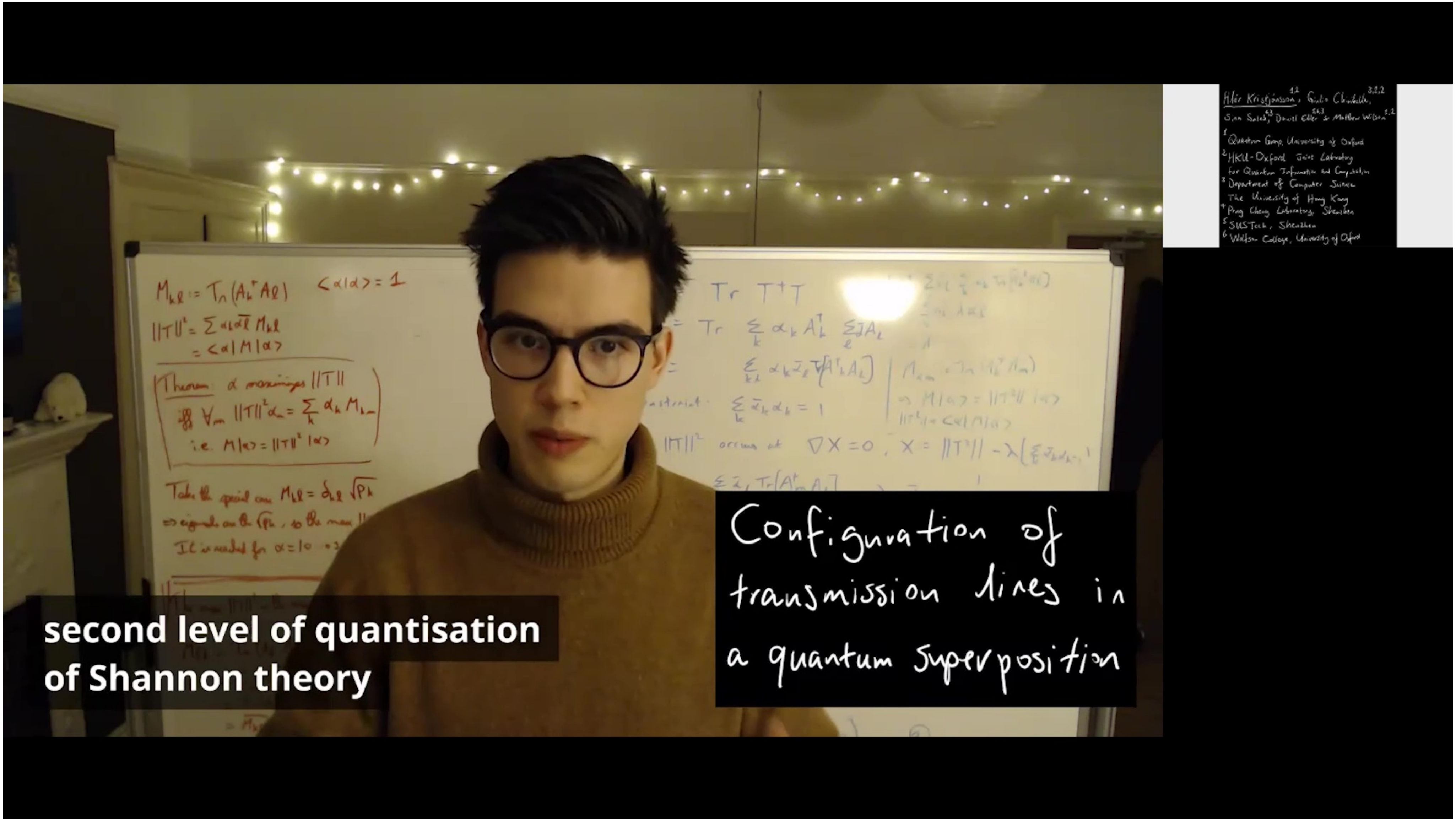
Plan:
• Second-quantised Shannon theory
• New: resource-theoretic formulation
• Applications
• Taster: routed quantum circuits
Resource theories of communication


Resource theories of communication
from Shannon theory to quantum Shannon theory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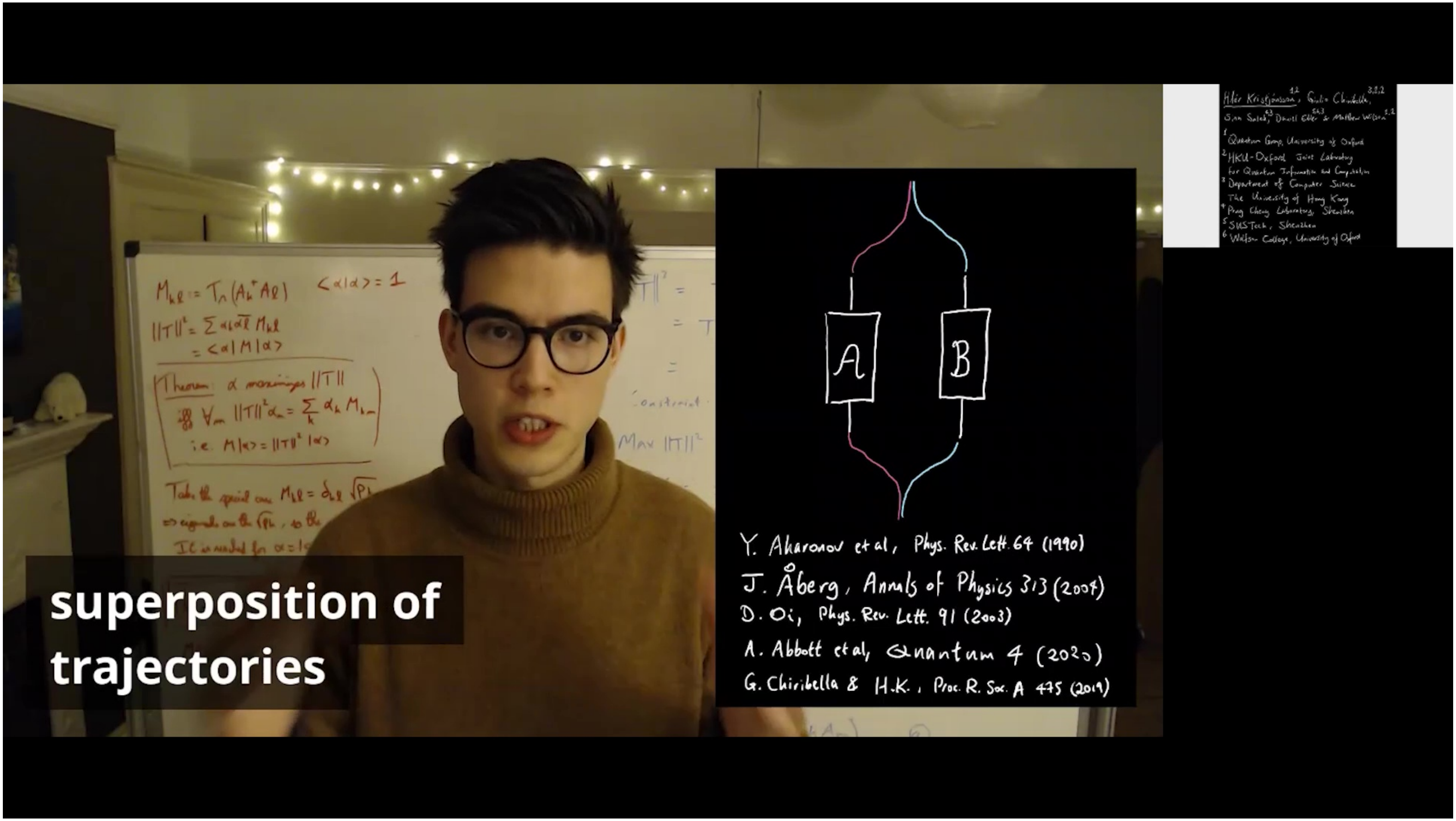
second level of quantisation of Shannon theory
Configuration of transmission lines in a quantum superposition


superposition of trajectories
A
B
Y. Aharonov et al, Phys. Rev. Lett. 64 (1990)
J. Åberg, Annals of Physics 313 (2004)
D. Oi, Phys. Rev. Lett. 91 (2003)
A. Abbott et al, Quantum 4 (2020)
G. Chiribella & H.K., Proc. R. Soc. A 475 (2019)
1 Quantum Group, University of Oxford
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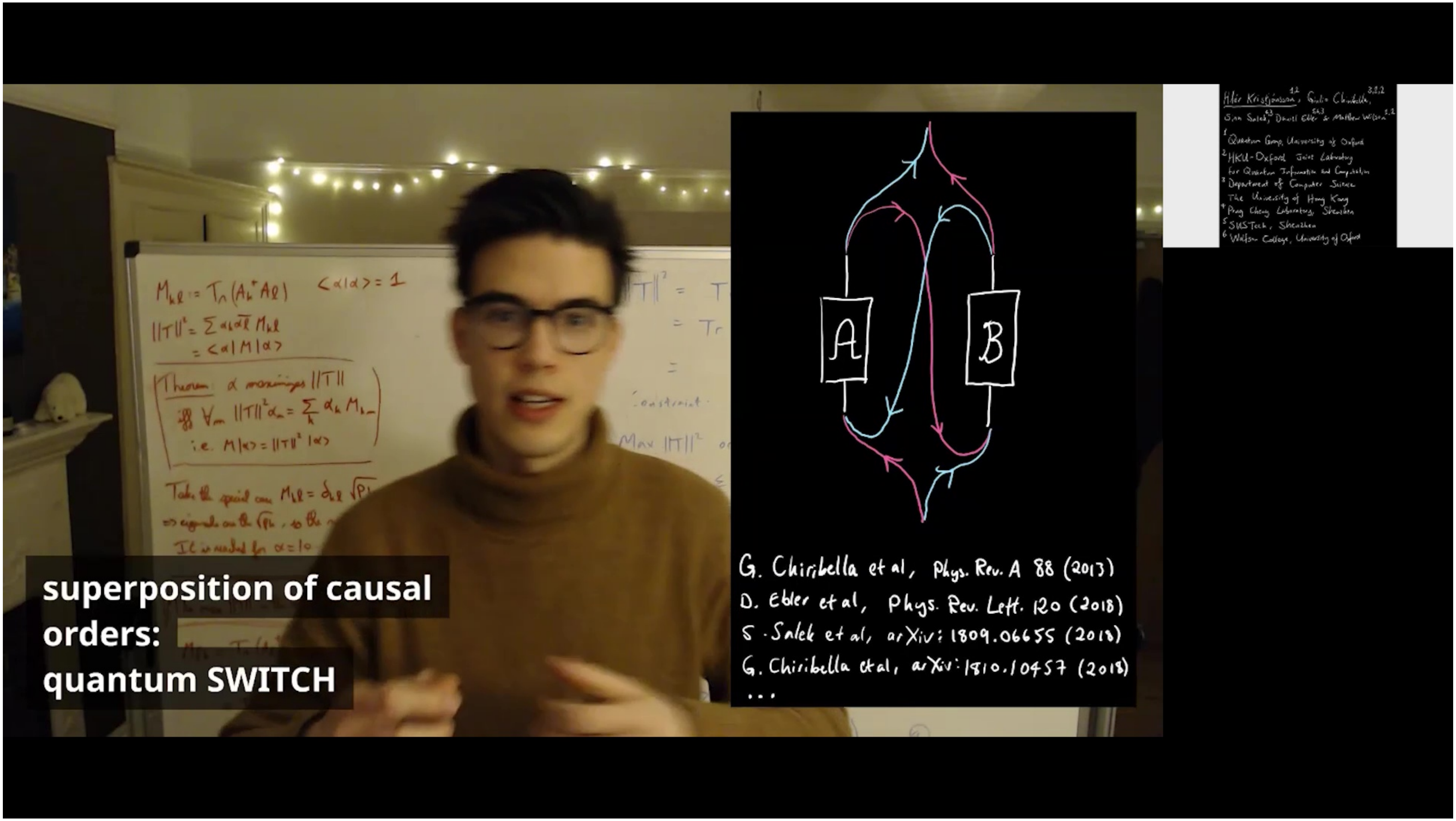
superposition of causal orders:
quantum SWITCH
A
B
G. Chiribella et al, Phys. Rev. A 88 (2013)
D. Ebler et al, Phys. Rev. Lett. 120 (2018)
S. Salek et al, arXiv: 1809.06655 (2018)
G. Chiribella et al, arXiv: 1810.10457 (2018)
...
Hlér Kristjánsson, Giulio Chiribella,
Sina Salek, Daniel Ebler & Matthew Wilson
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2 HKU-Oxford Joint Laboratory for Quantum Information and Computation
3 Department of Computer Science The University of Hong Kong
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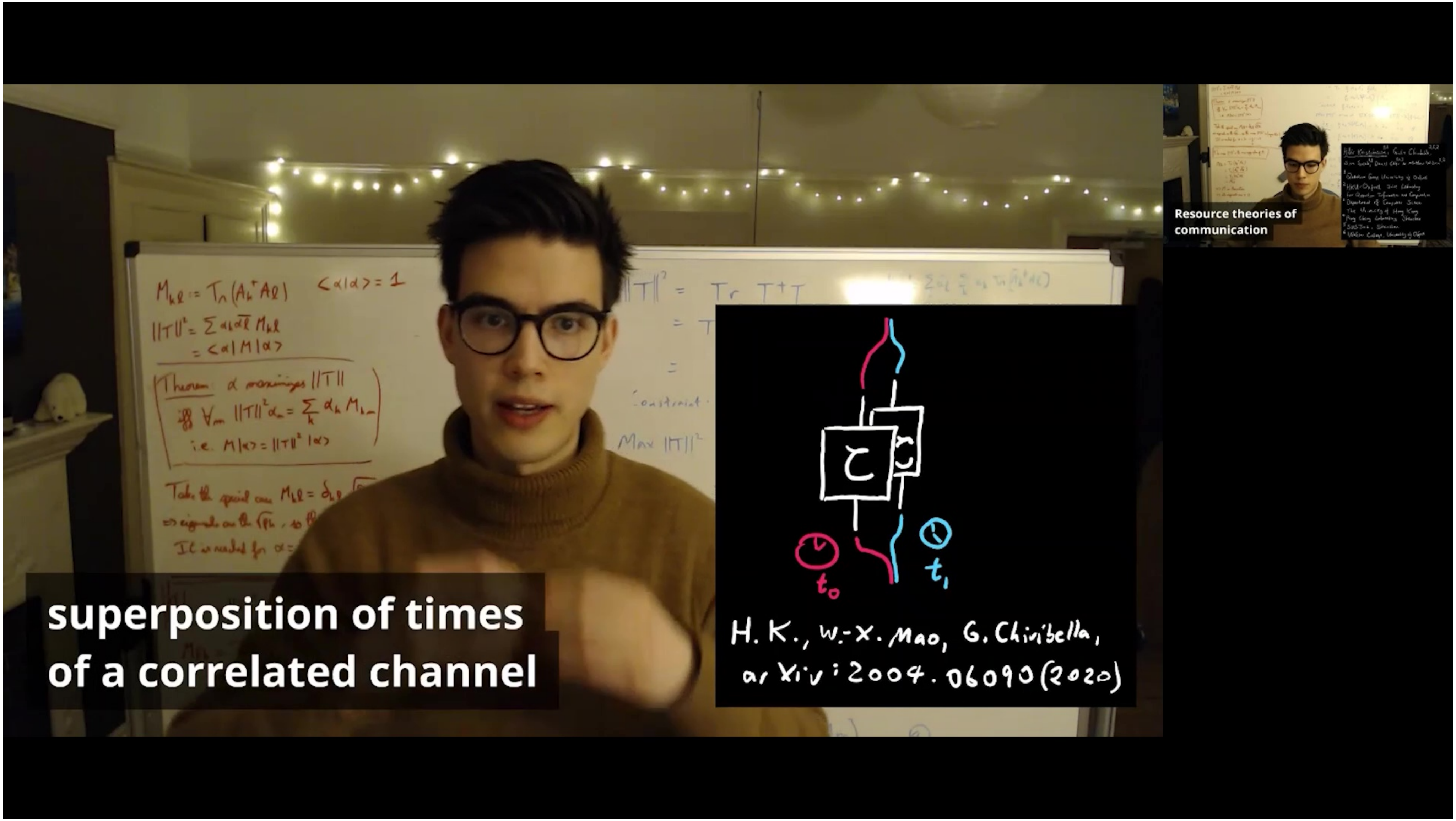
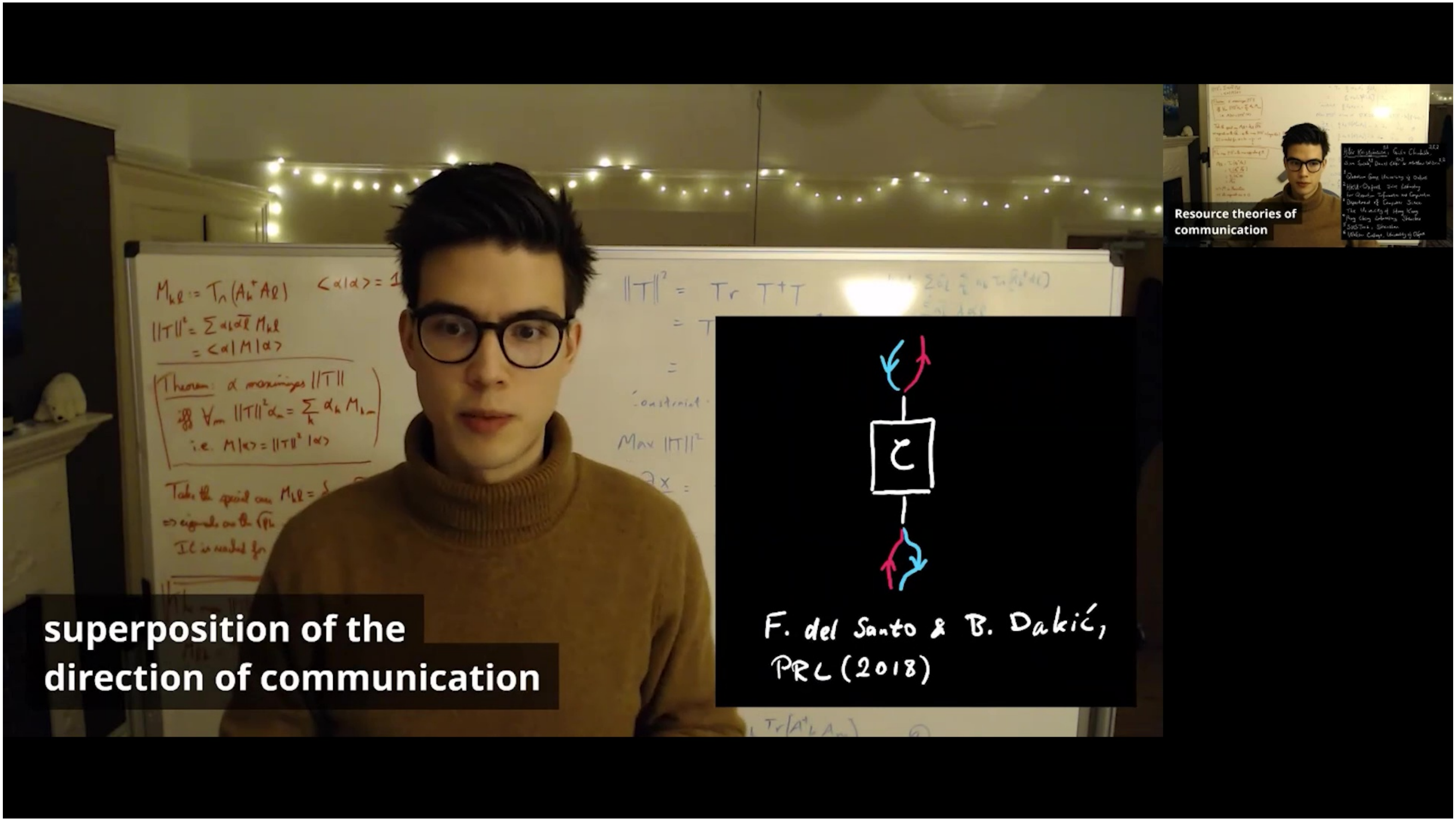
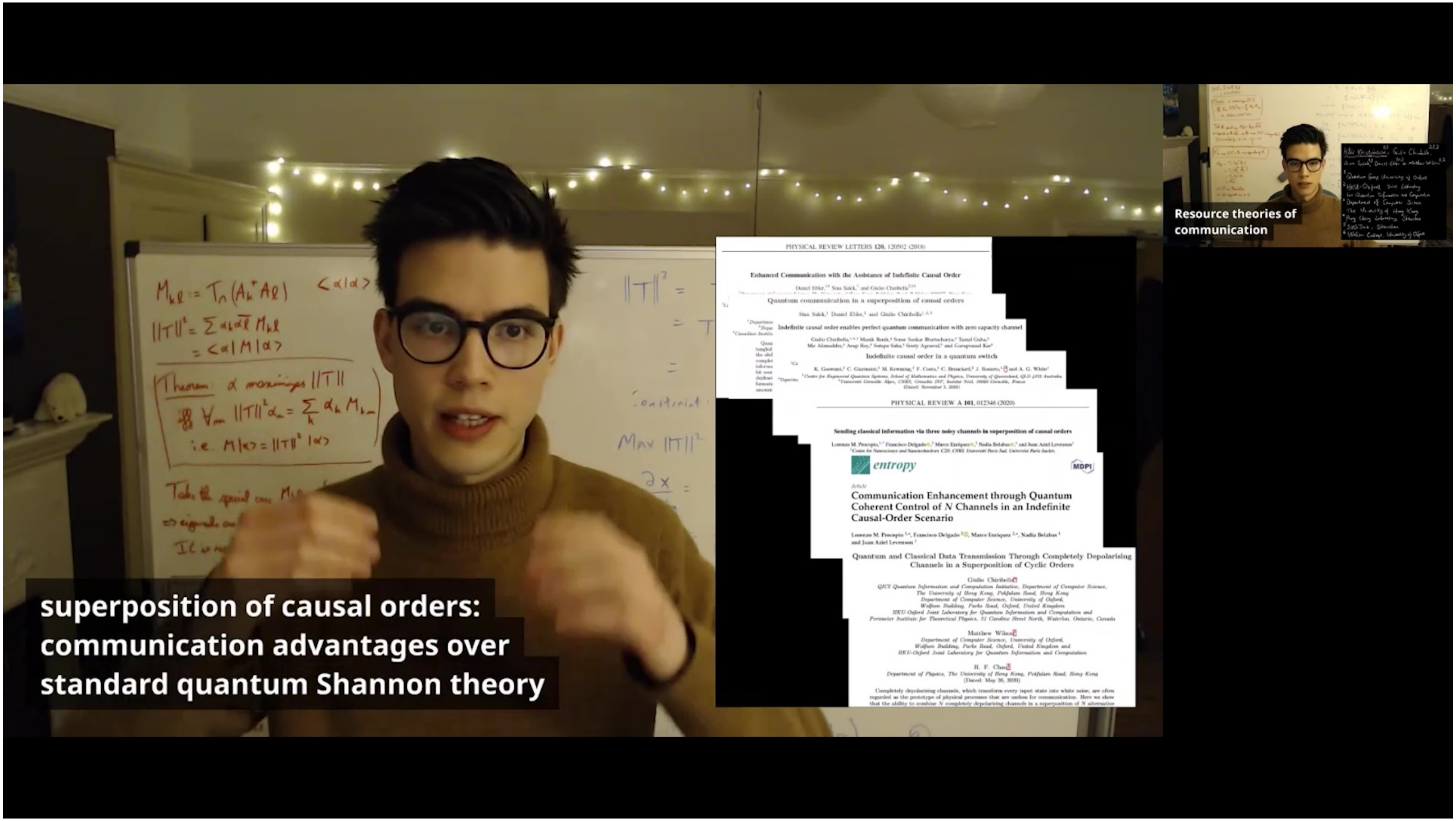
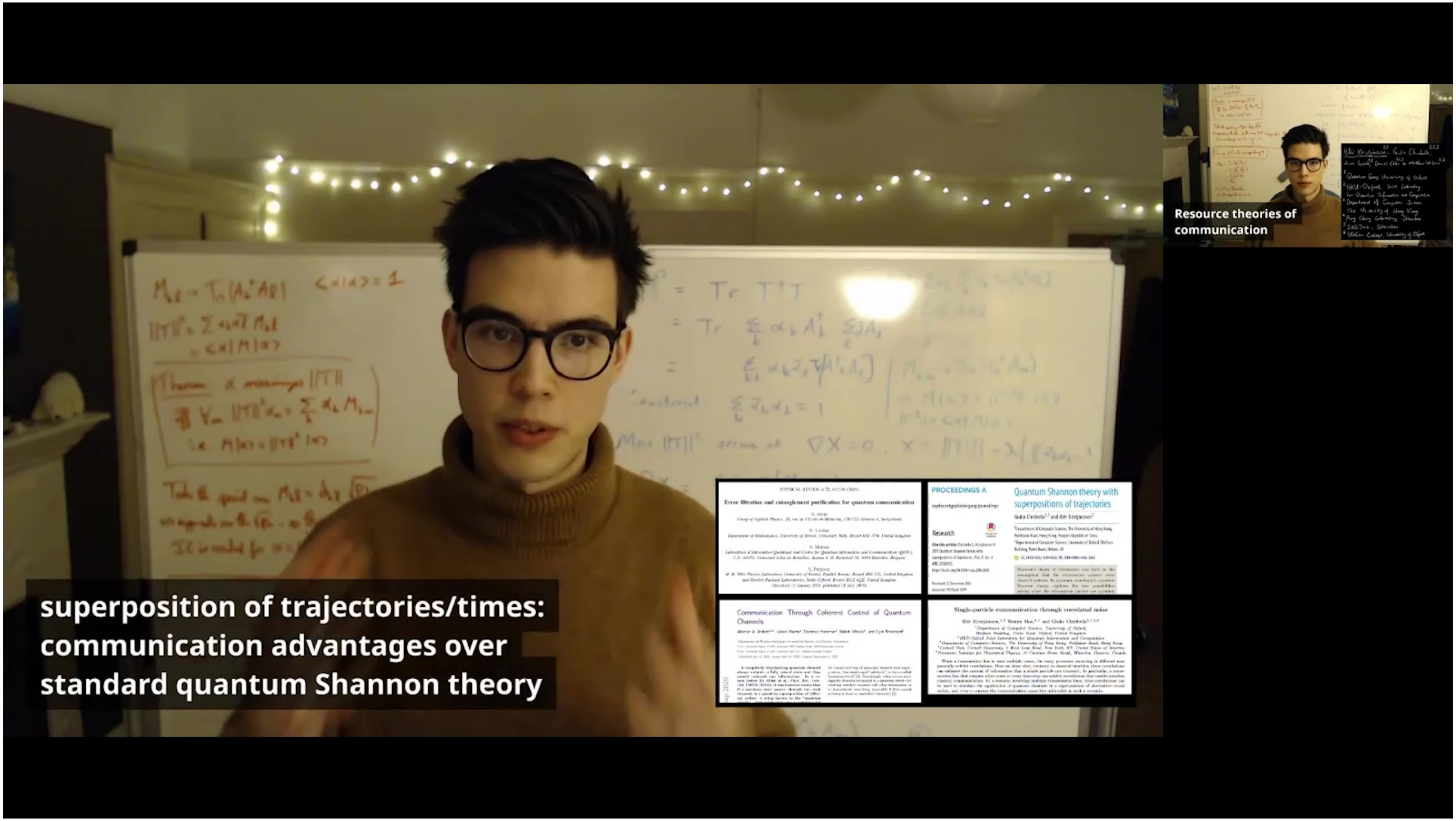
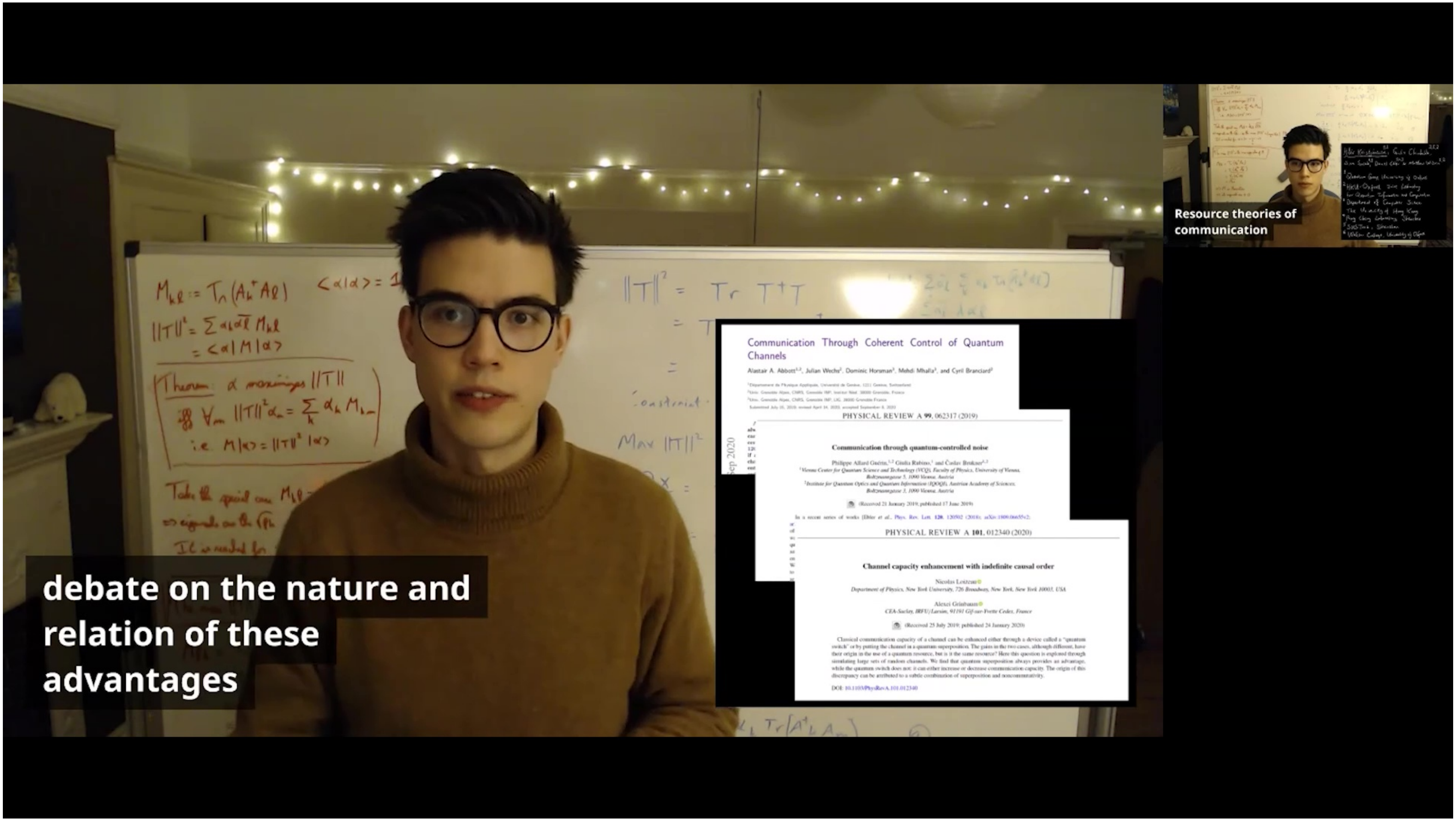
5 SUSTech, Shenzhen
6 Wolfson College, University of Oxford

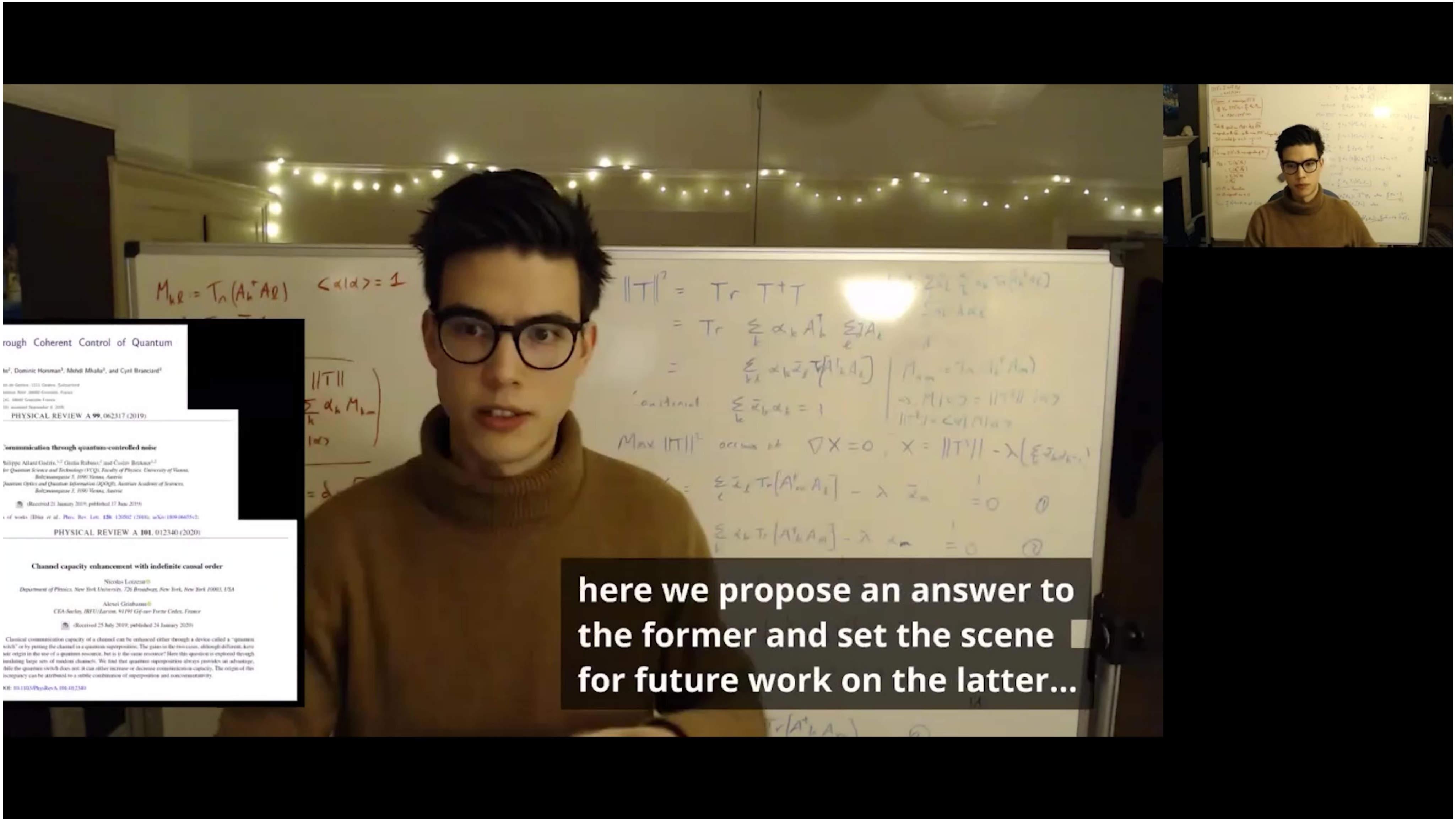

superposition of times
of a correlated channel
H. K., W.-X. Mao, G. Chiribella,
arXiv:2004.06090(2020)
Resource theories of
communication

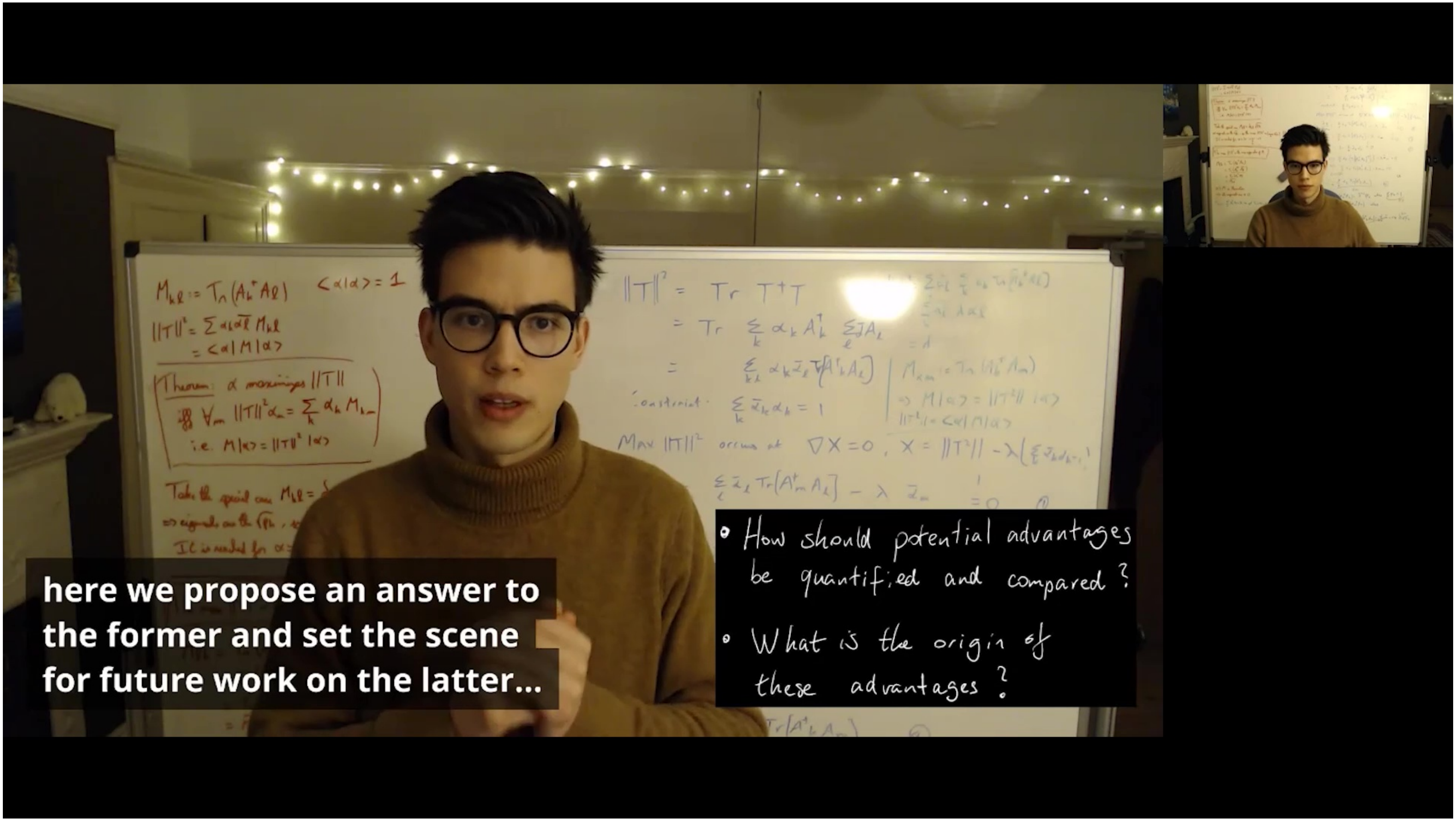

Resource theories of communication
superposition of the direction of communication
F. del Santo & B. Dakić, PRL (2018)

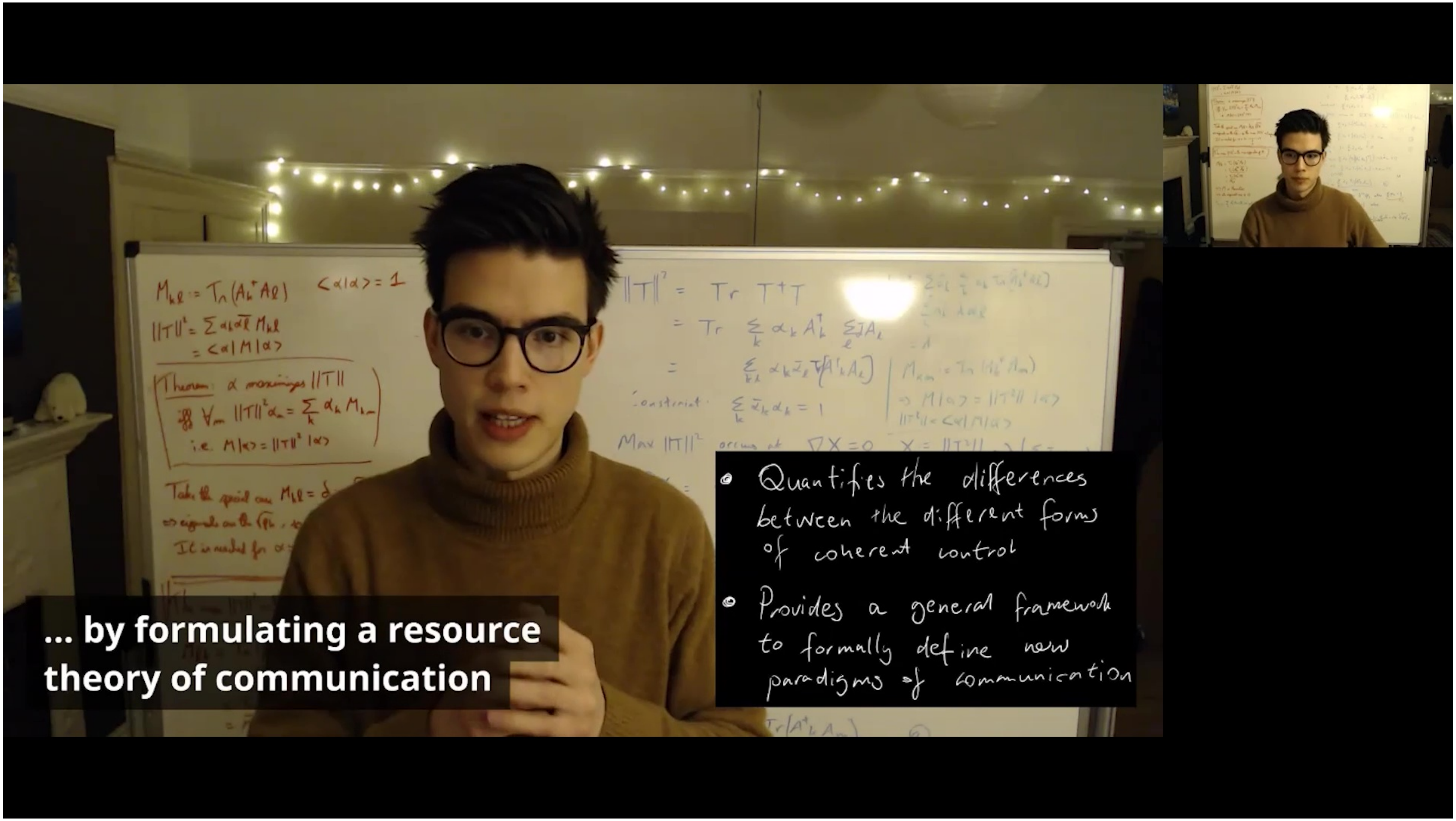

superposition of causal orders:
communication advantages over
standard quantum Shannon theory
Resource theories of communication
PHYSICAL REVIEW LETTERS 120, 120502 (2018)
Enhanced Communication with the Assistance of Indefinite Causal Order
Quantum communication in a superposition of causal orders
Indefinite causal order enables perfect quantum communication with zero capacity channel
Indefinite causal order in a quantum switch
PHYSICAL REVIEW A 101, 012346 (2020)
Sending classical information via three noisy channels in superposition of causal orders
entropy
MDPI
Communication Enhancement through Quantum Coherent Control of N Channels in an Indefinite Causal-Order Scenario
Quantum and Classical Data Transmission Through Completely Depolarising Channels in a Superposition of Cyclic Orders

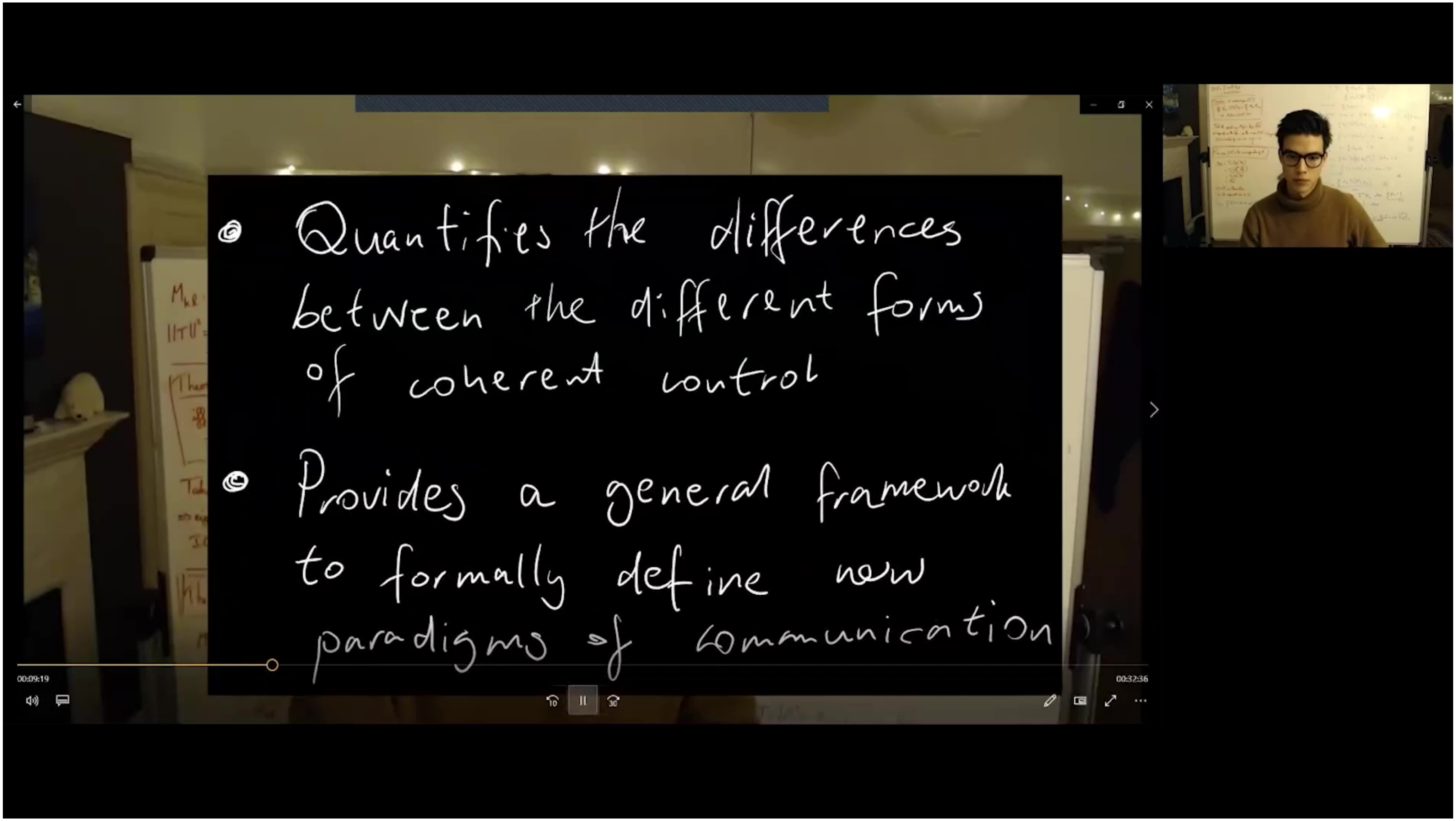

superposition of trajectories/times:
communication advantages over
standard quantum Shannon theory
Resource theories of
communication
PROCEEDINGS A
Quantum Shannon theory with superpositions of trajectories
Research
Error filtration and entanglement purification for quantum communication
Communication Through Coherent Control of Quantum Channels
Single-particle communication through correlated noise


Communication Through Coherent Control of Quantum Channels
PHYSICAL REVIEW A 99, 062317 (2019)
Communication through quantum-controlled noise
PHYSICAL REVIEW A 101, 012340 (2020)
Channel capacity enhancement with indefinite causal order
Nicolas Loizeau
Alexei Grinbaum
Resource theories of communication
debate on the nature and relation of these advantages


PHYSICAL REVIEW A 99, 062317 (2019)
PHYSICAL REVIEW A 101, 012340 (2020)
Channel capacity enhancement with indefinite causal order
here we propose an answer to the former and set the scene for future work on the latter...


here we propose an answer to the former and set the scene for future work on the latter...
• How should potential advantages be quantified and compared?
• What is the origin of these advantages?


... by formulating a resource theory of communication
Quantifies the differences between the different forms of coherent control
Provides a general framework to formally define new paradigms of communication


Quantifies the differences between the different forms of coherent control
Provides a general framework to formally define new paradigms of communication
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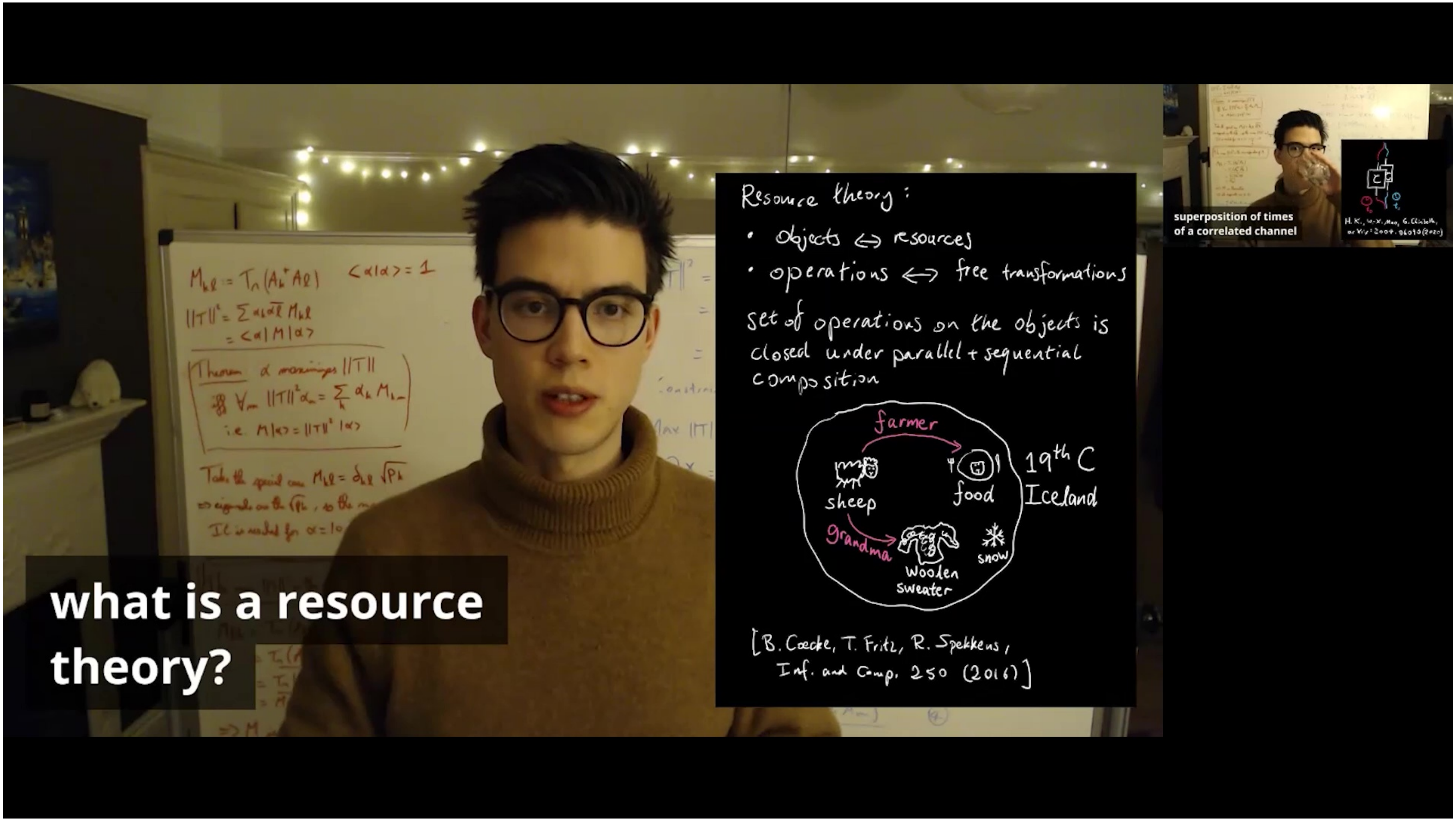
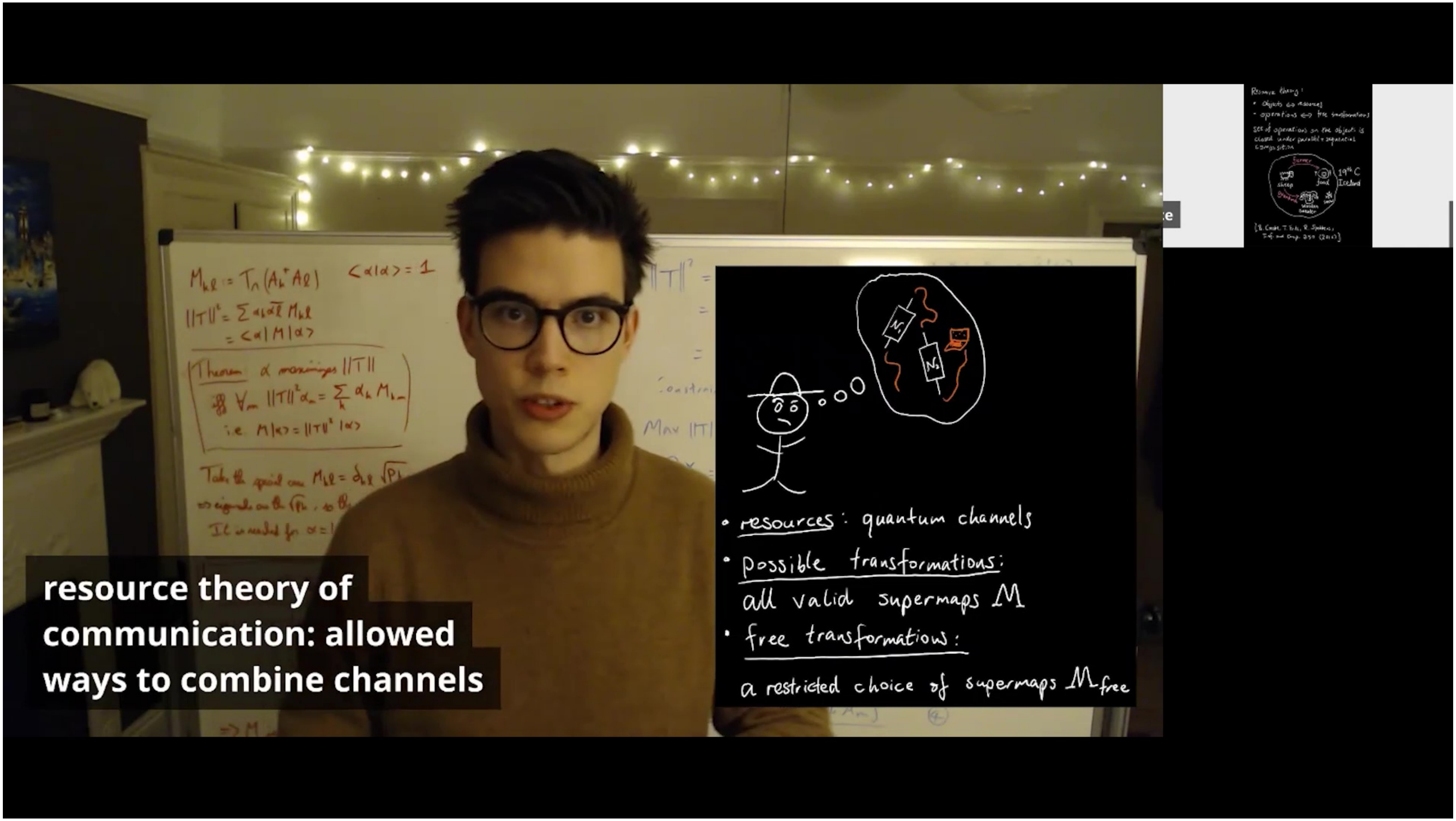
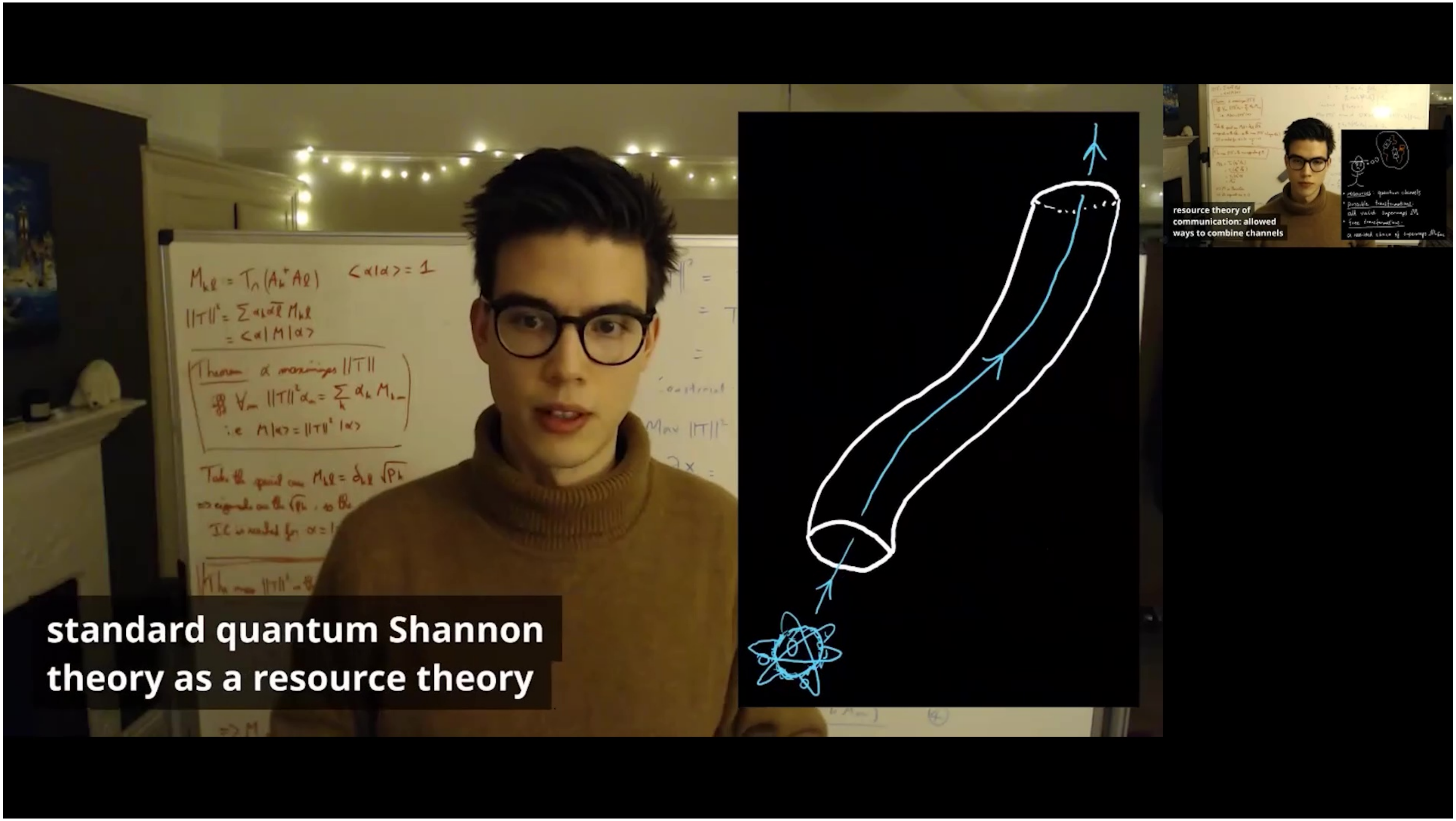
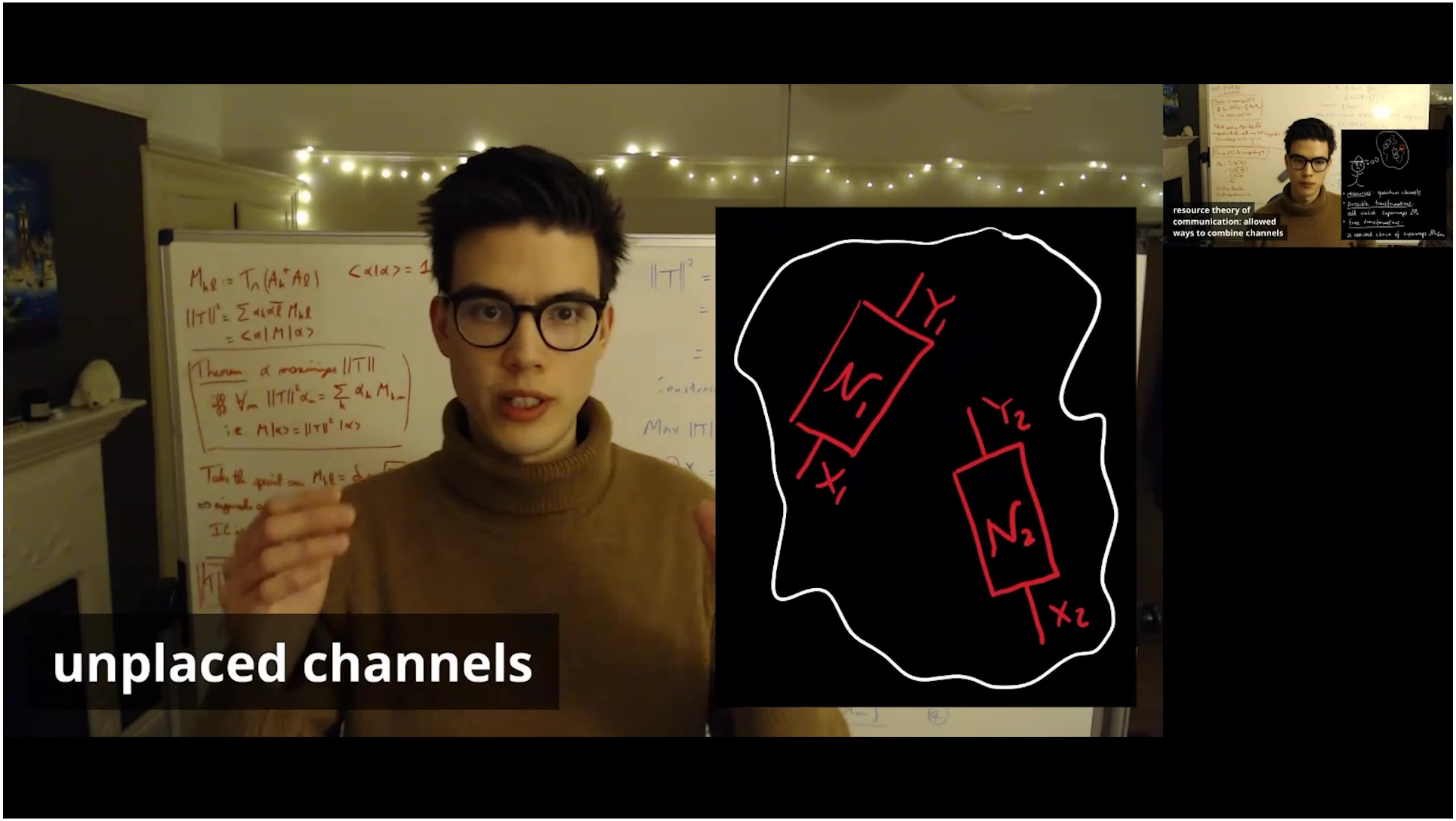
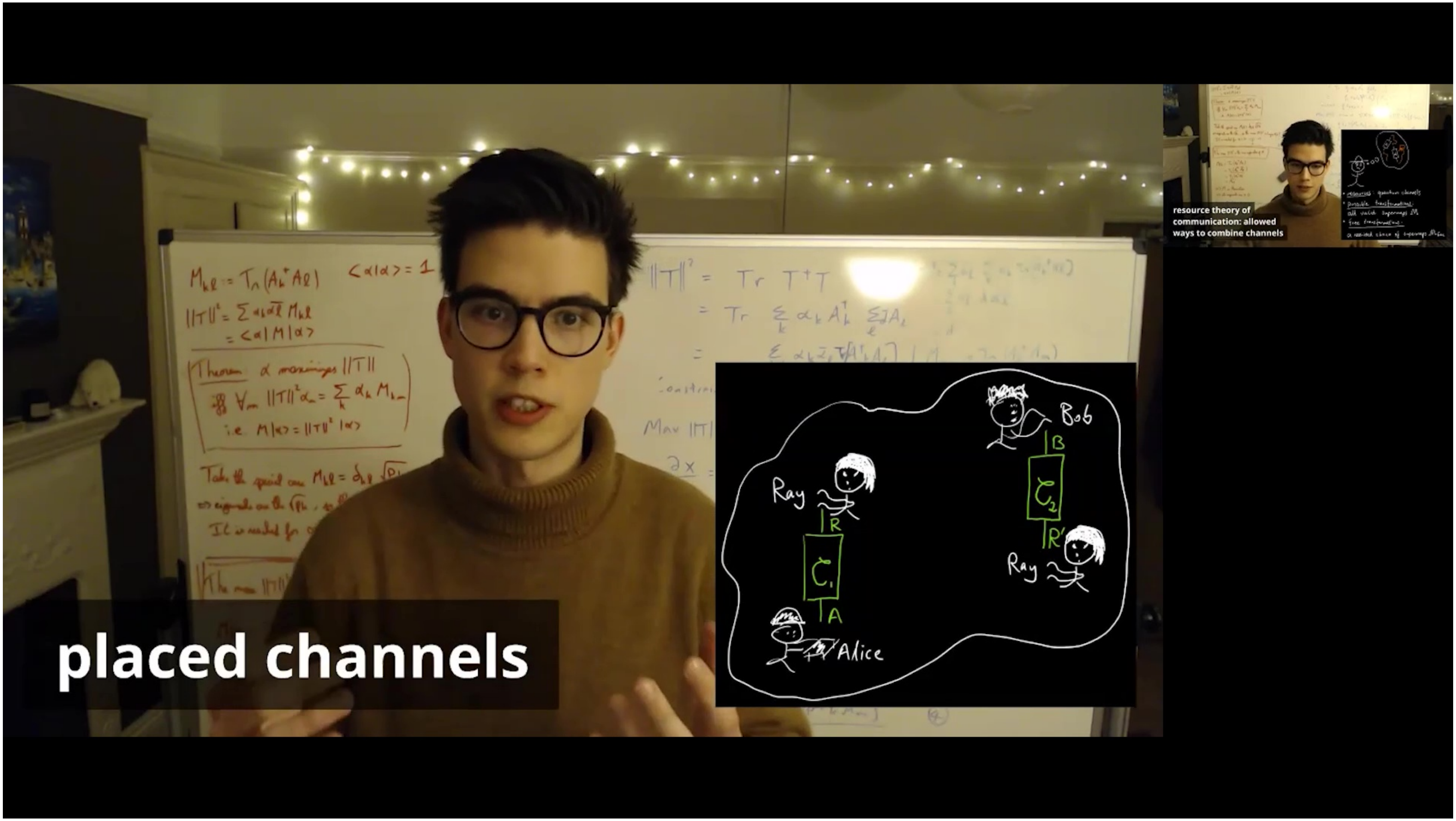
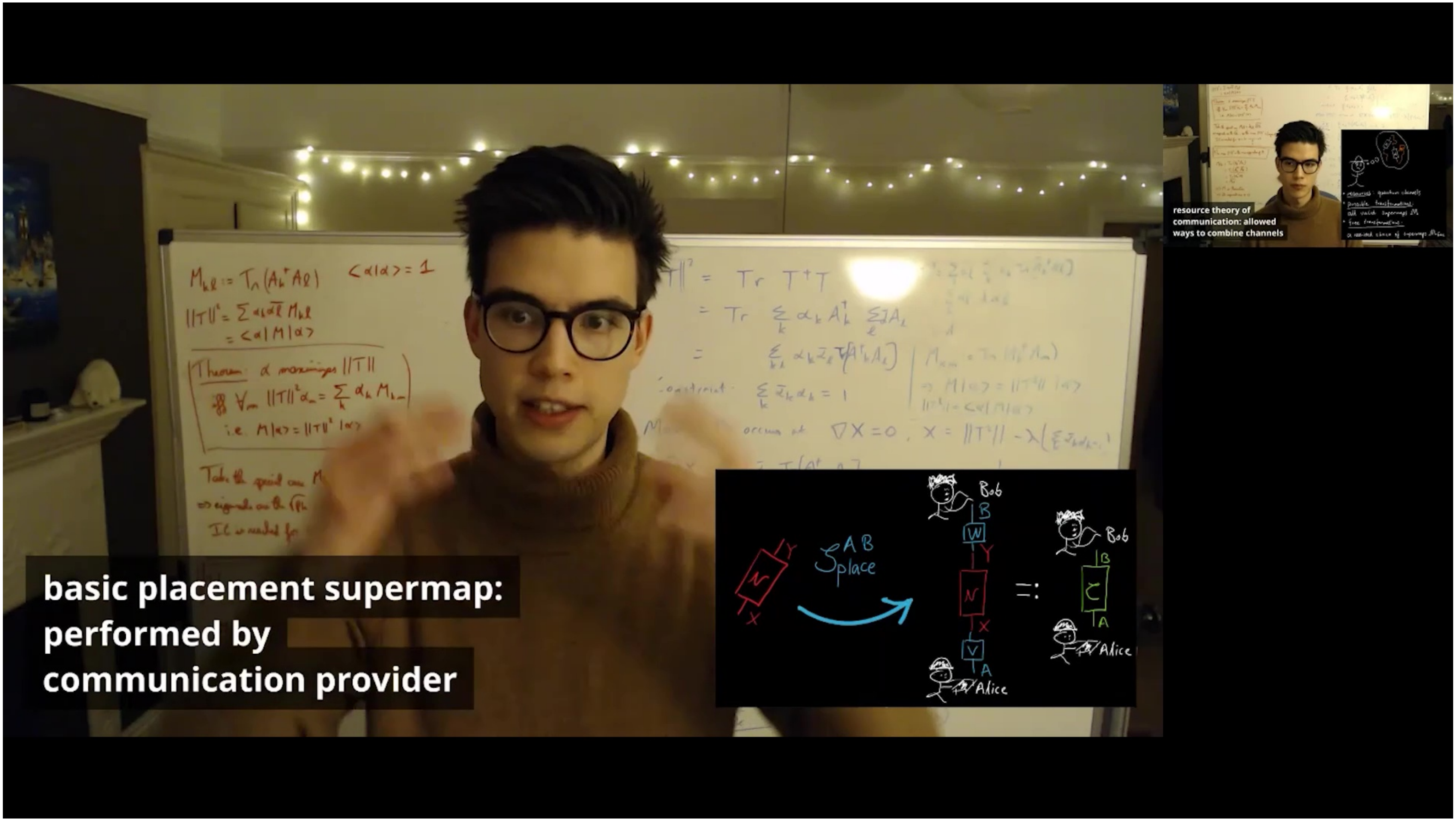

what is a resource theory?
Resource theory:
• objects ⇔ resources
• operations ⇔ free transformations
set of operations on the objects is closed under parallel + sequential composition
farmer
sheep
food
grandma
wooden sweater
snow
19th C Iceland
[B. Coecke, T. Fritz, R. Spekkens, Inf. and Comp. 250 (2016)]
superposition of times of a correlated channel

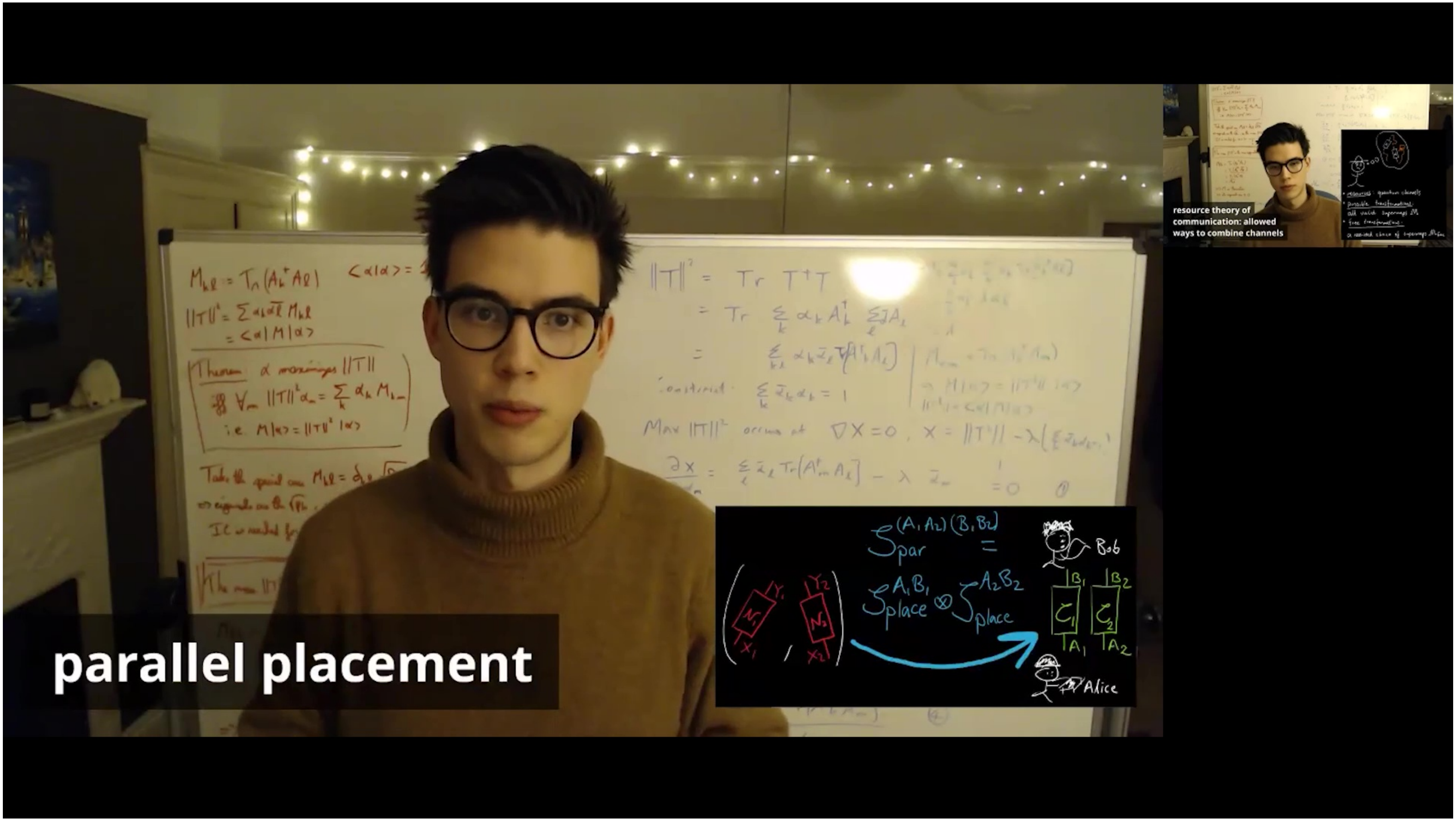

resource theory of
communication: allowed
ways to combine channels
• resources: quantum channels
• possible transformations:
all valid supermaps $\mathcal{M}$
• free transformations:
a restricted choice of supermaps $\mathcal{M}_{free}$

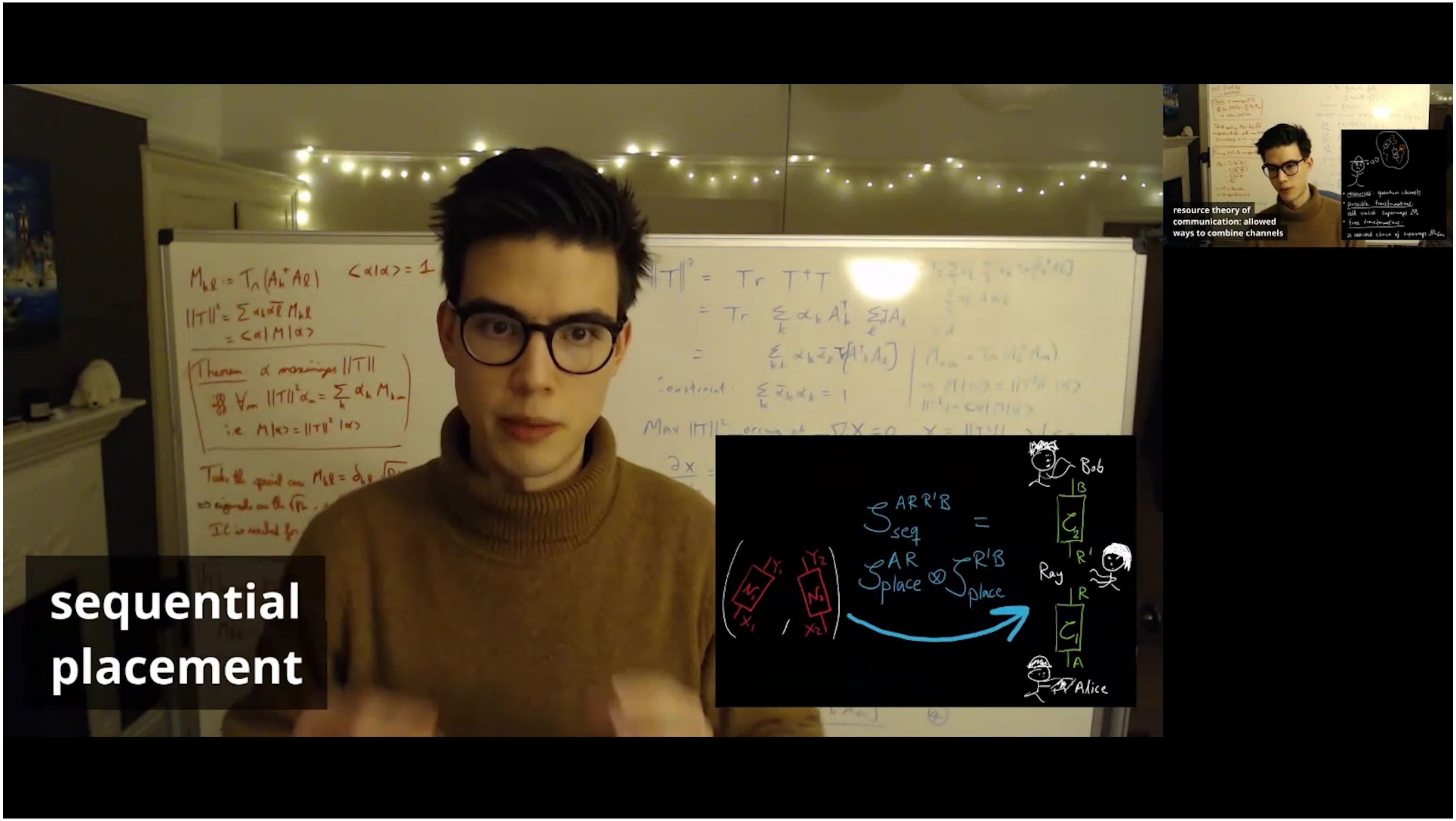

standard quantum Shannon
theory as a resource theory
resource theory of
communication: allowed
ways to combine channels

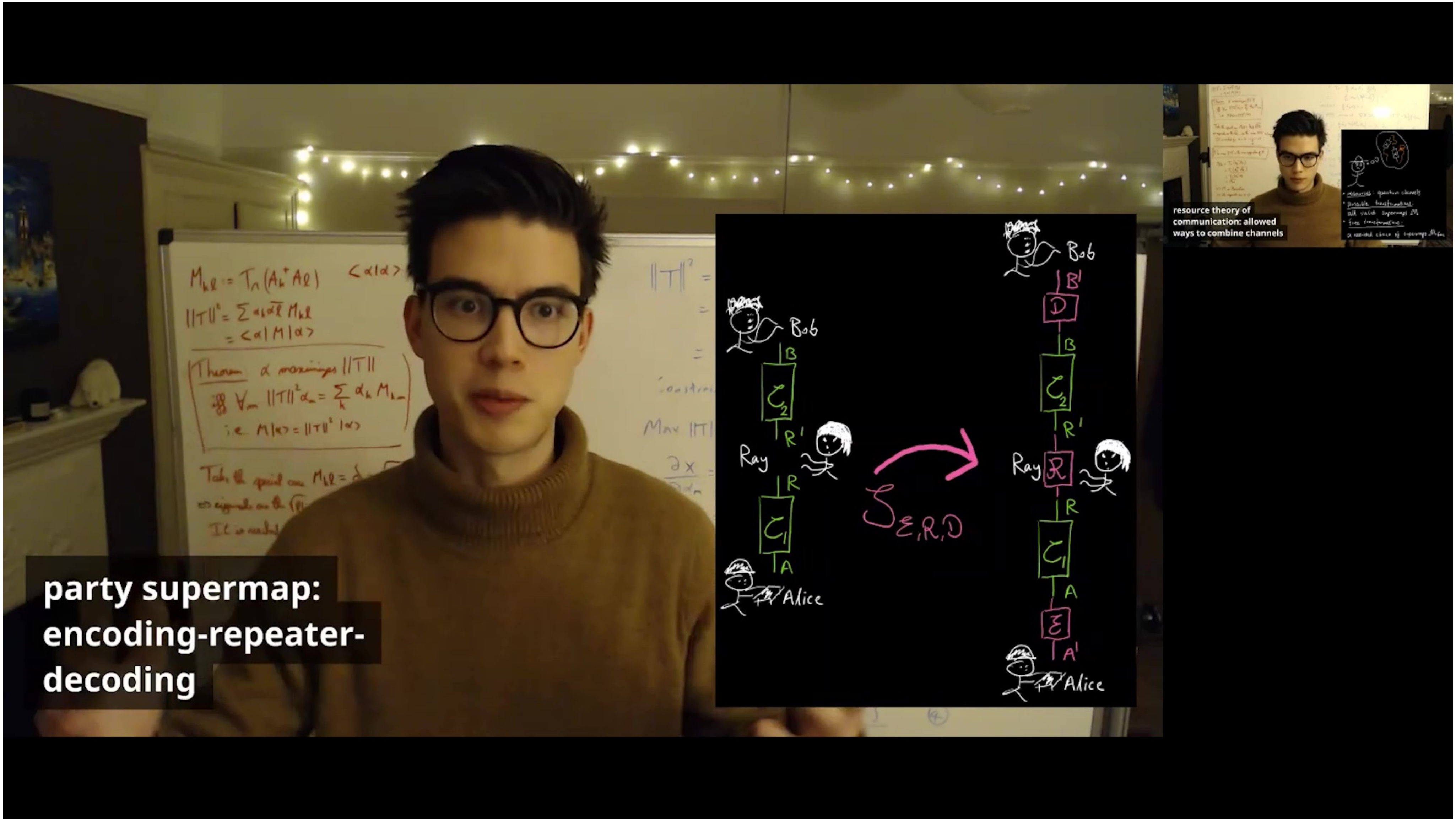

unplaced channels
resource theory of communication: allowed ways to combine channels

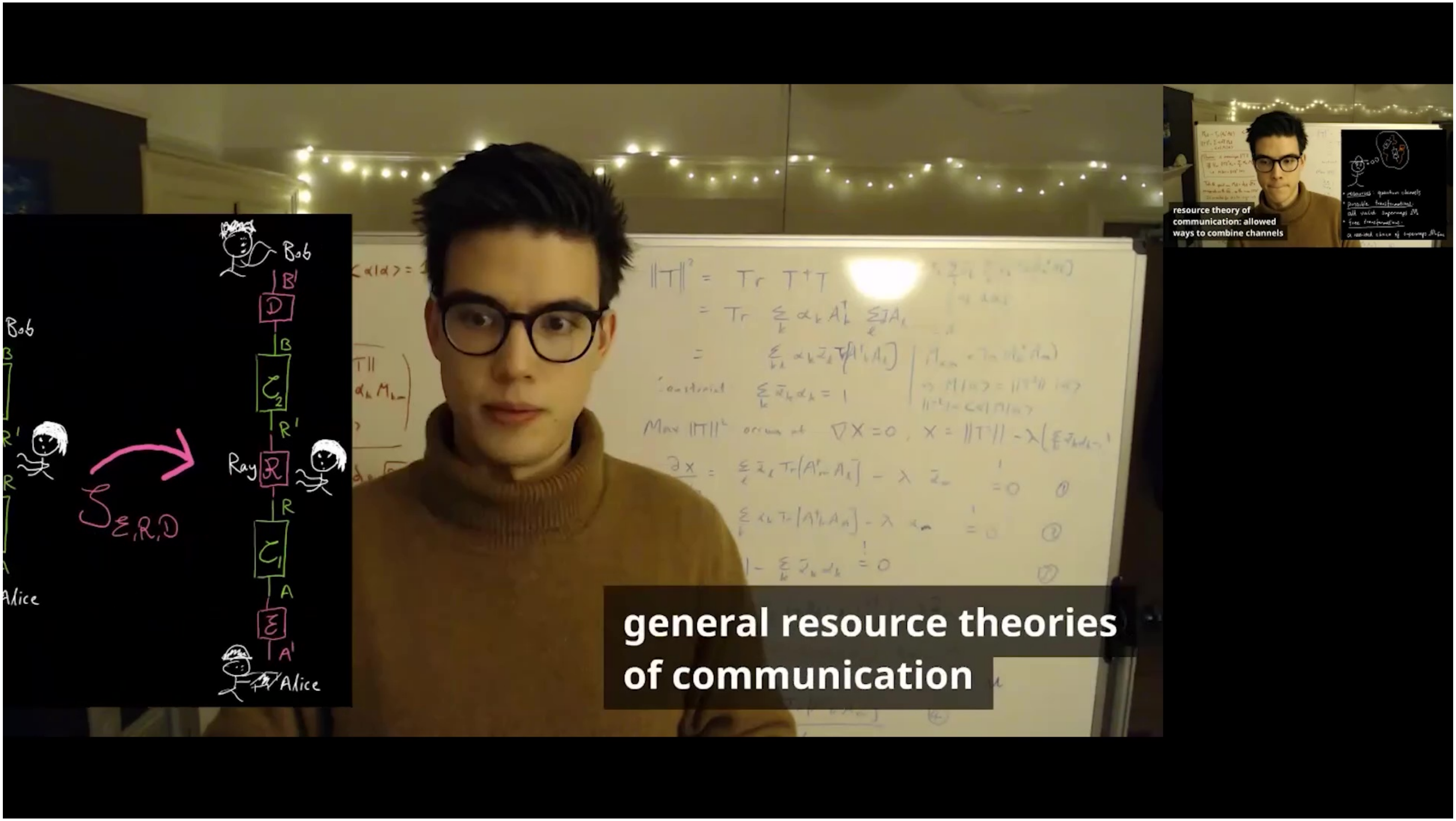

placed channels
Bob
B
C_2
R'
Ray
Ray
R
C_1
A
Alice
resource theory of communication: allowed ways to combine channels


basic placement supermap:
performed by
communication provider
resource theory of
communication: allowed
ways to combine channels
Bob
Alice
AB
place

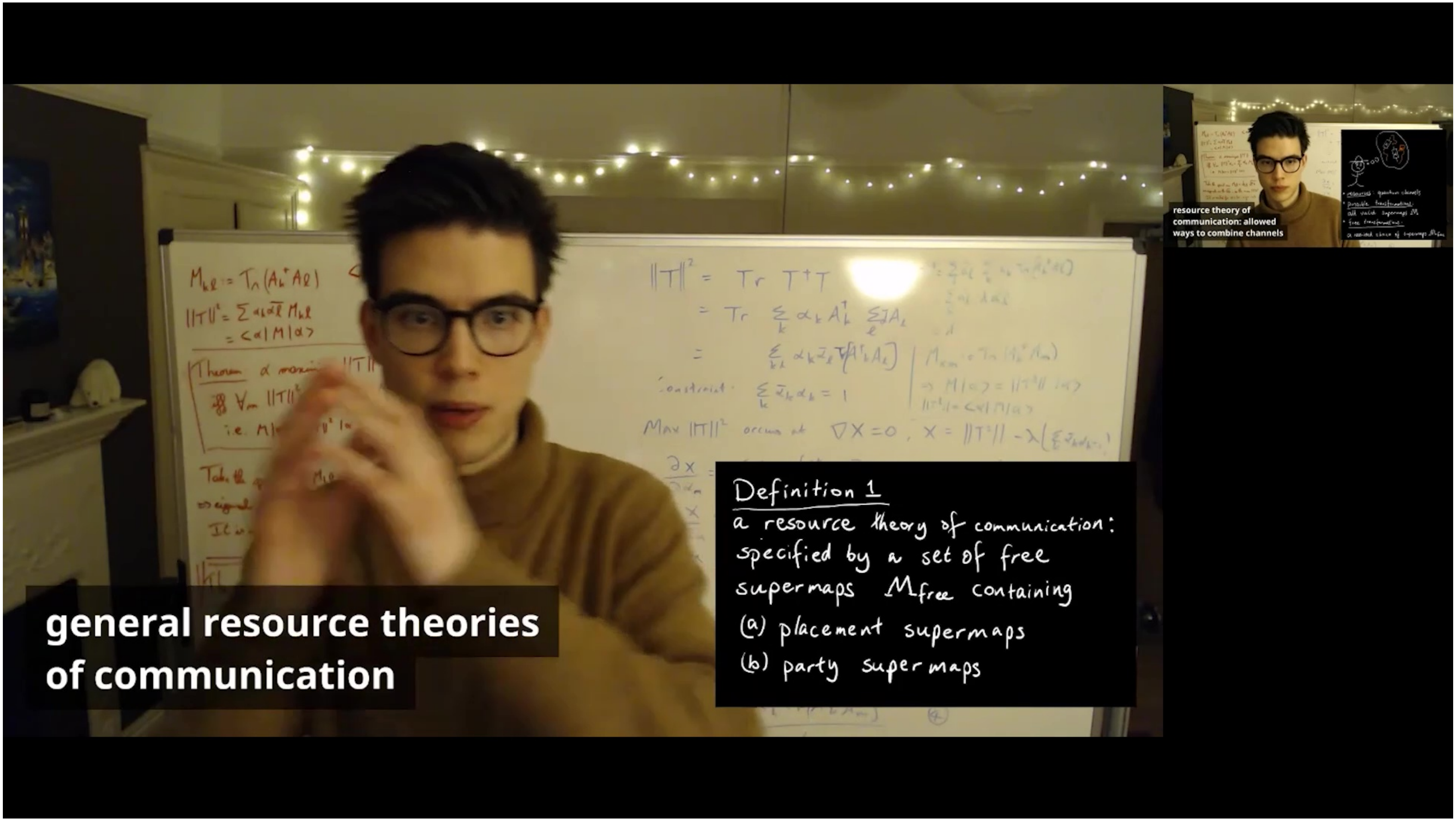

parallel placement
resource theory of communication: allowed ways to combine channels
Bob
Alice


sequential
placement
resource theory of
communication: allowed
ways to combine channels
Bob
Ray
Alice


party supermap:
encoding-repeater-
decoding
Bob
B'
D
B
C_2
R'
Ray
R
C_1
A
E
A'
Alice
$S_{E,R,D}$
resource theory of
communication: allowed
ways to combine channels



general resource theories
of communication
resource theory of
communication: allowed
ways to combine channels
Bob
Ray
Alice

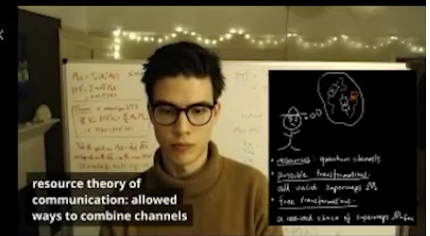

general resource theories of communication
Definition 1
a resource theory of communication: specified by a set of free supermaps $\mathcal{M}_{free}$ containing
(a) placement supermaps
(b) party supermaps
resource theory of communication: allowed ways to combine channels

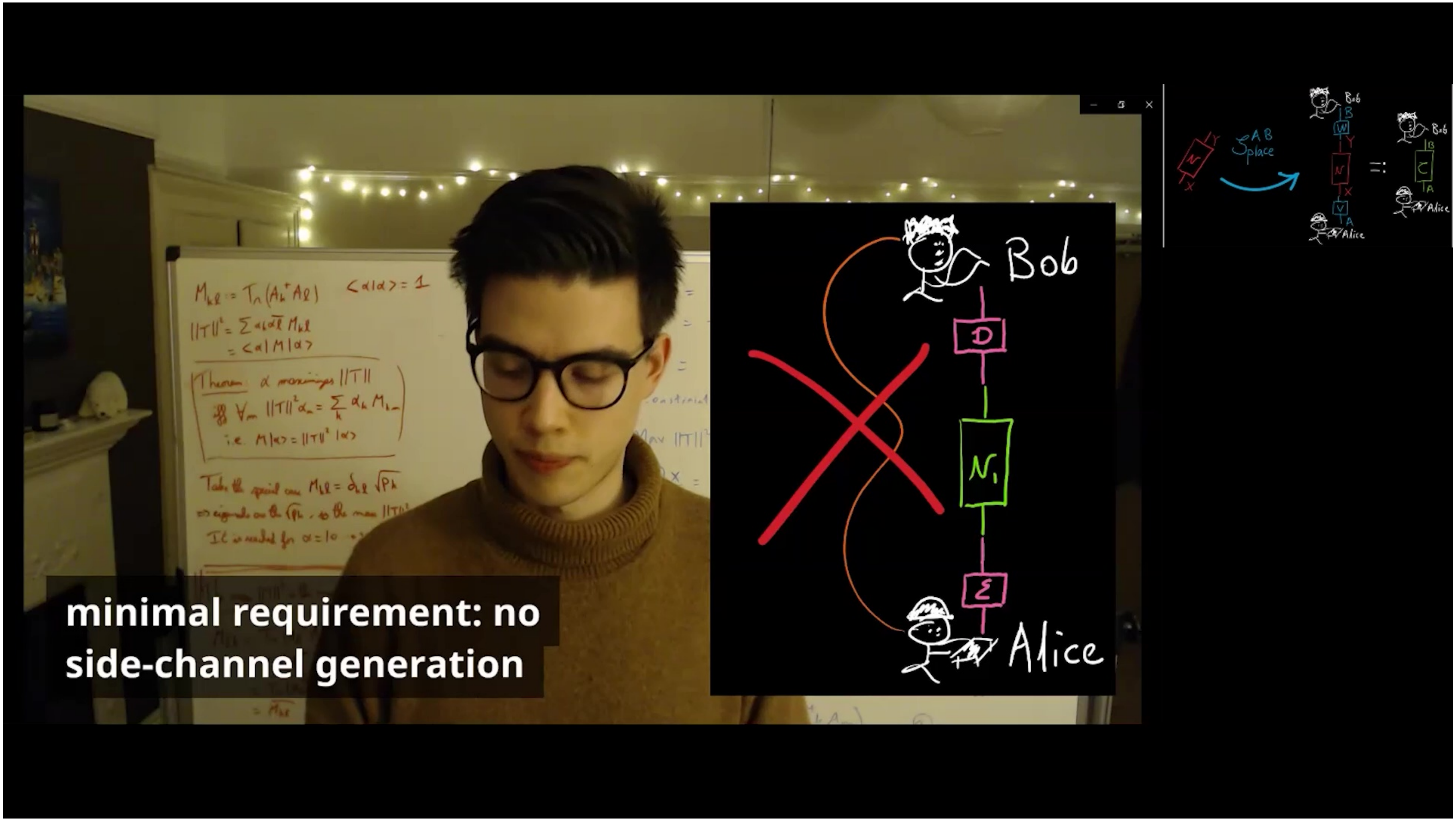
Definition 1

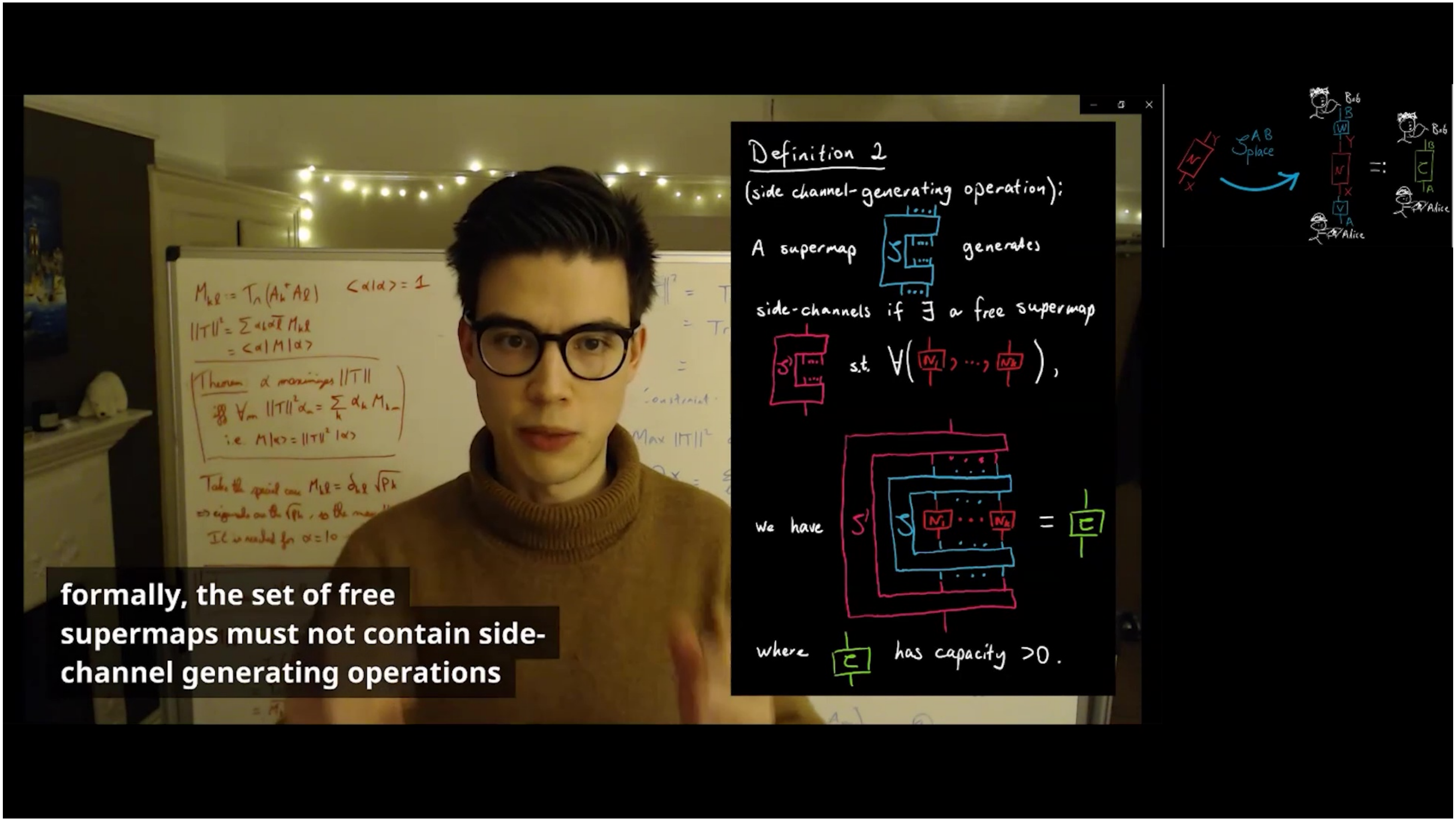
a resource theory of communication: specified by a set of free supermaps $\mathcal{M}_{free}$ containing

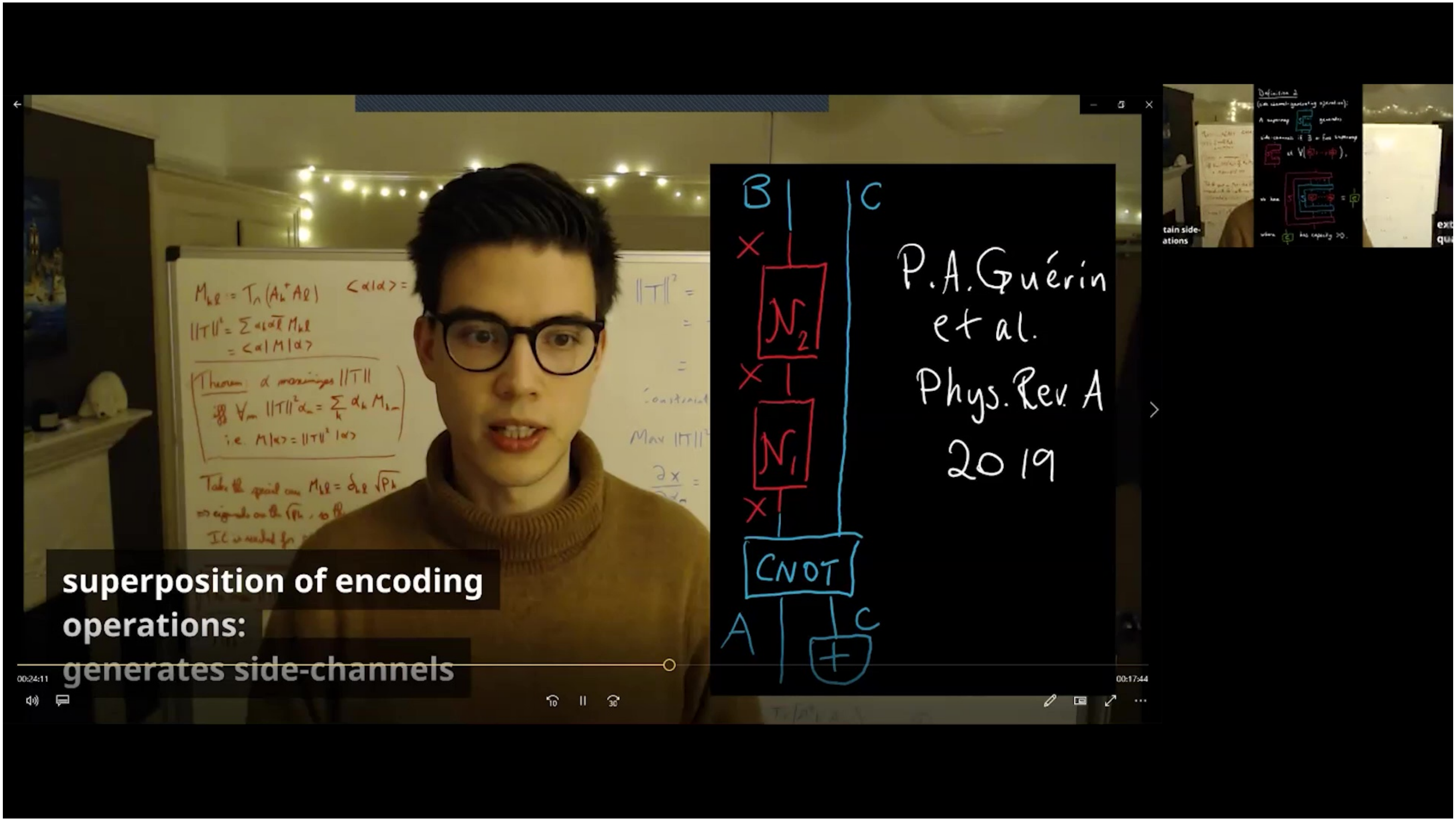
(a) placement supermaps

(b) party supermaps




minimal requirement: no
side-channel generation
Bob
D
N1
E
Alice


formally, the set of free supermaps must not contain side-channel generating operations
Definition 2
(side channel-generating operation):
A supermap S generates side-channels if ∃ a free supermap S' s.t. ∀(N1, ..., Nk),
we have
where C has capacity >0.
Bob
Alice


superposition of encoding
operations:
generates side-channels
B
C
CNOT
A
C
P.A.Guérin
et al.
Phys. Rev A
2019
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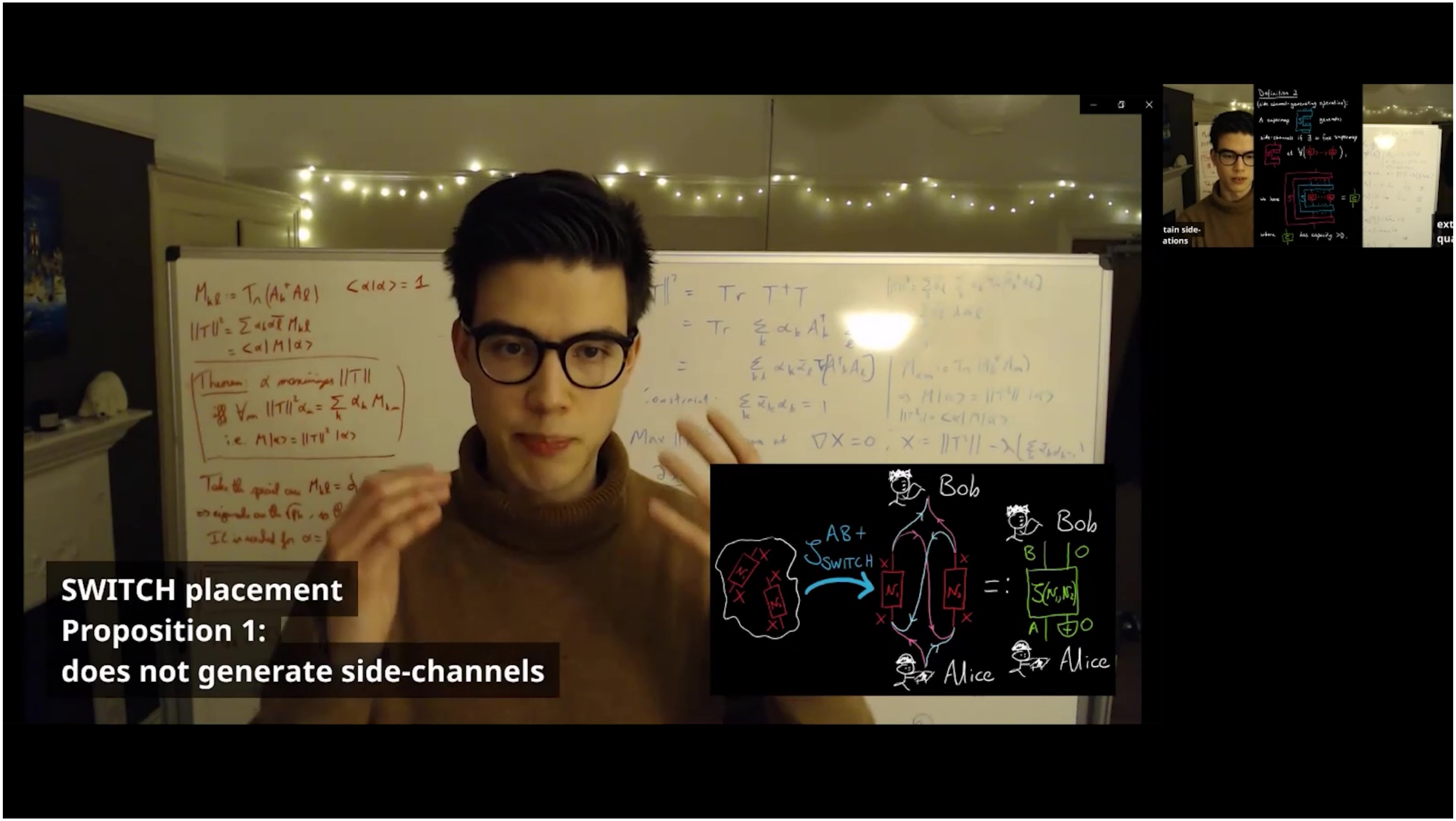
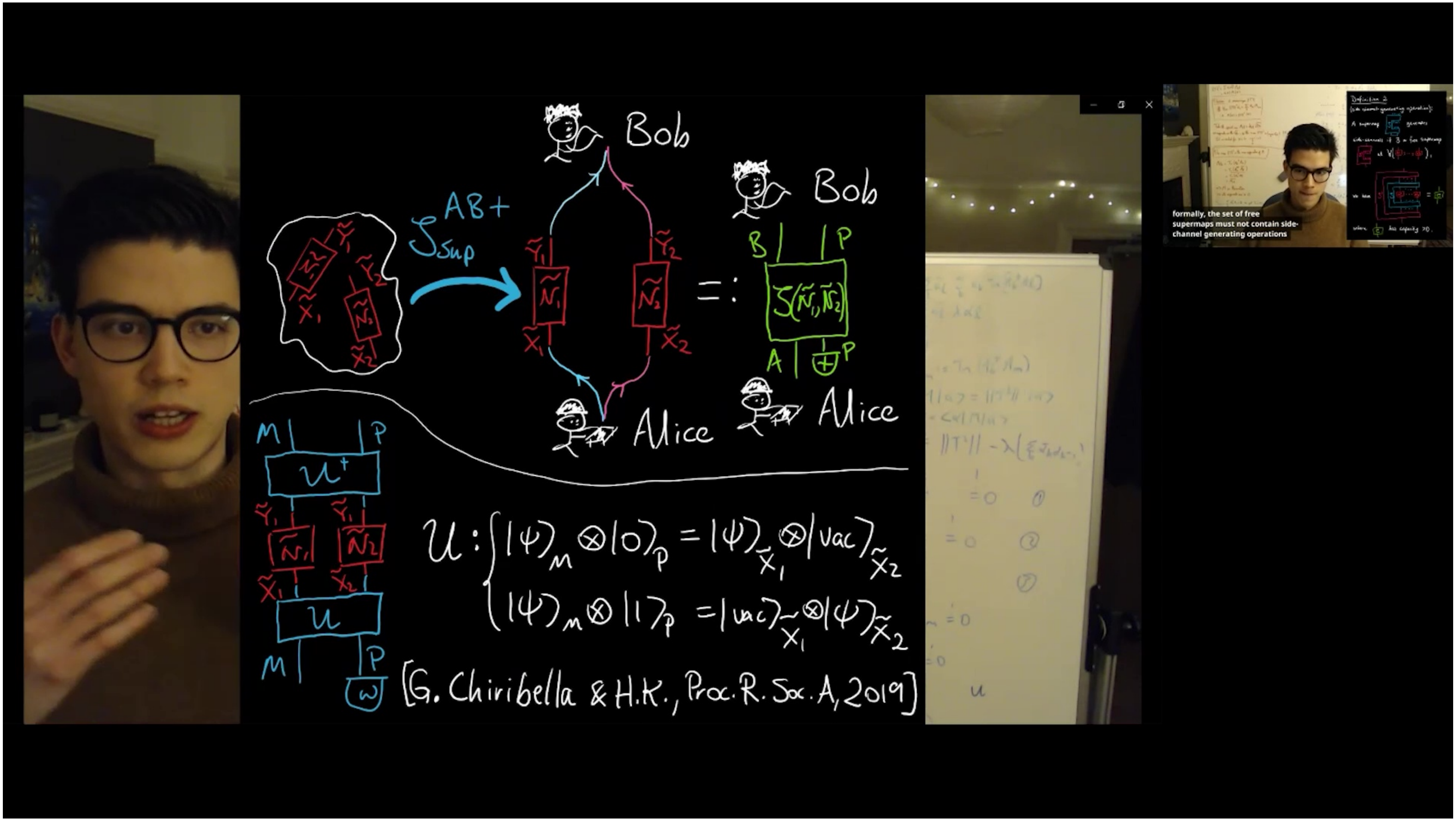
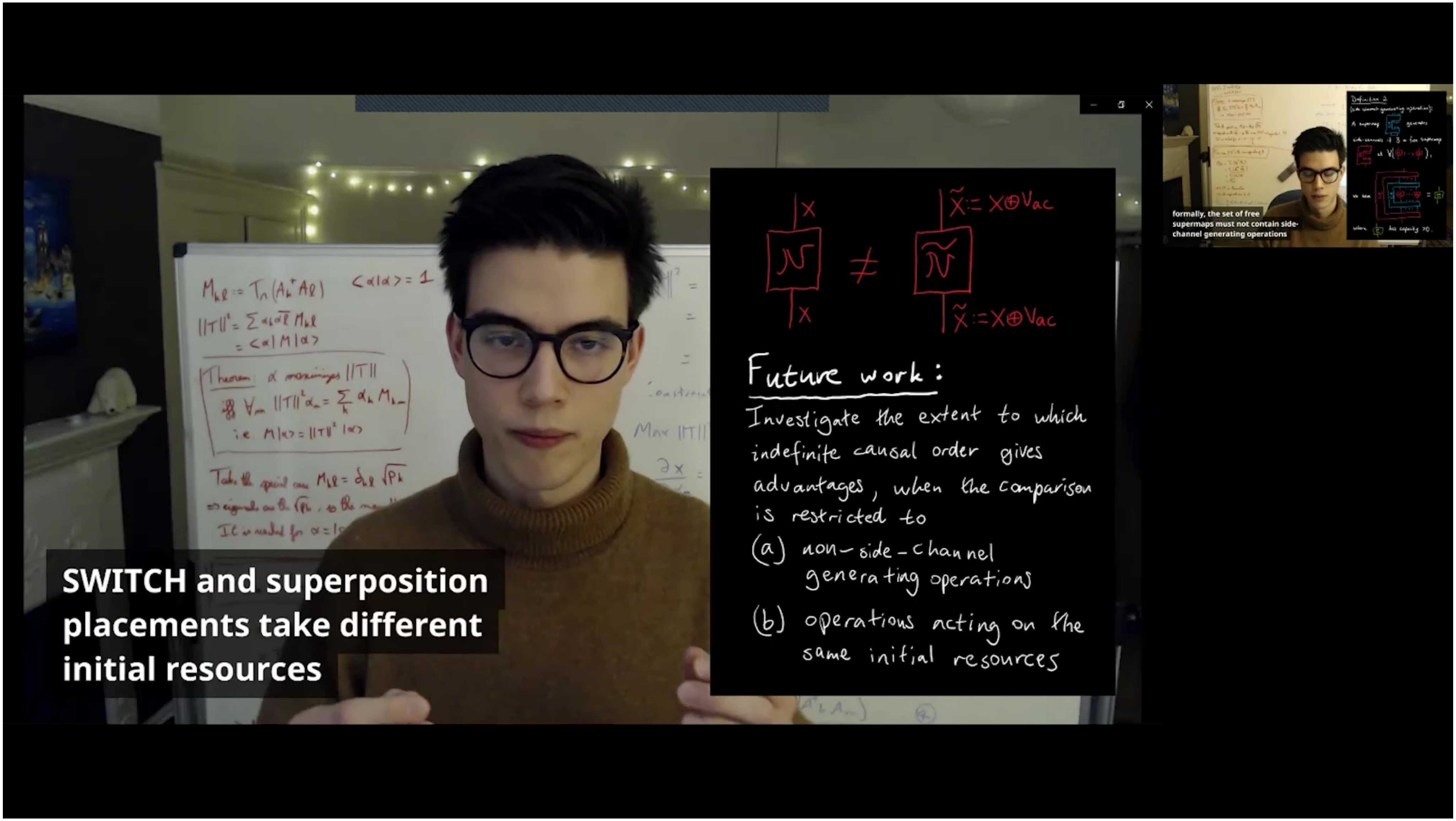
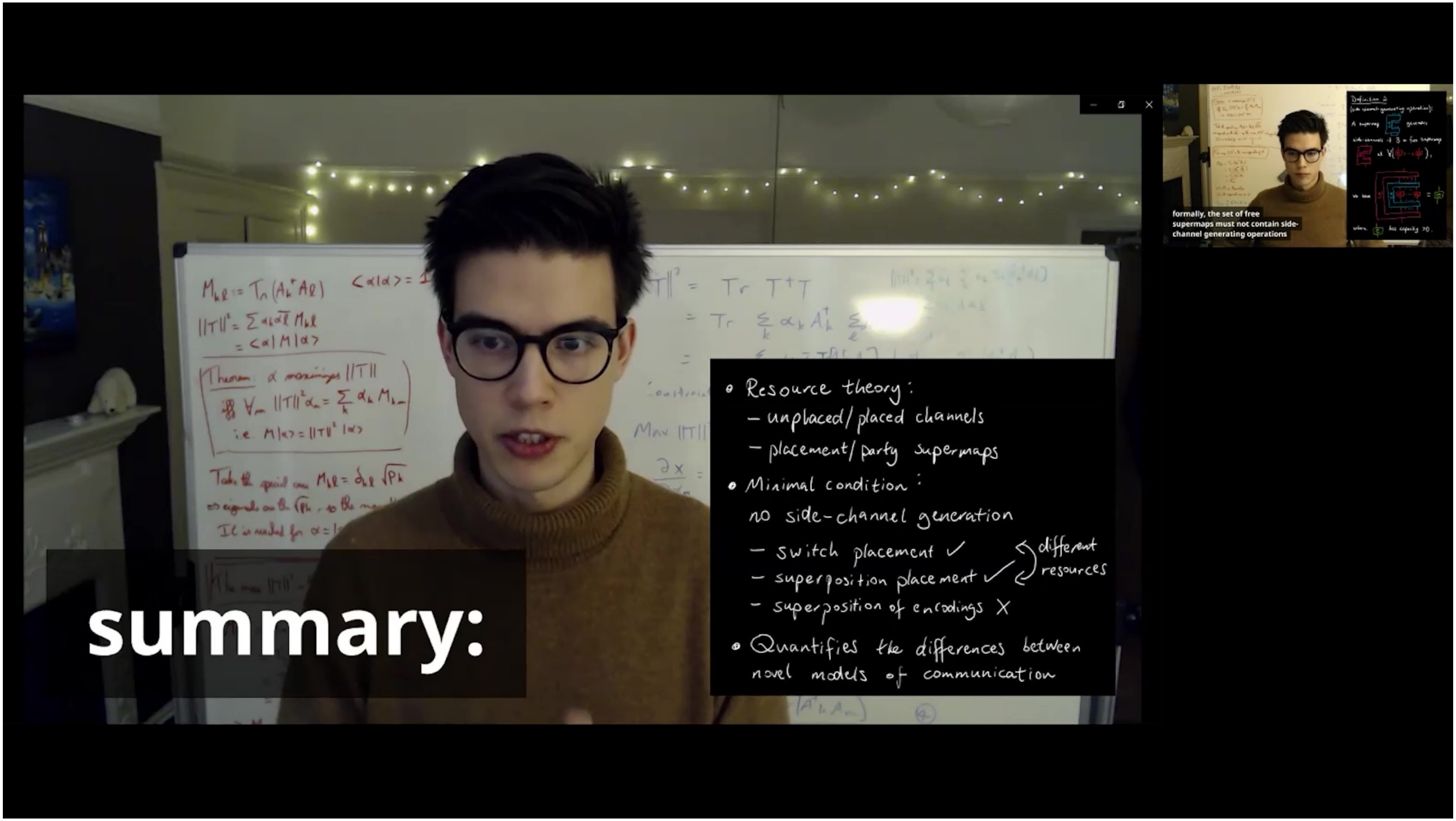
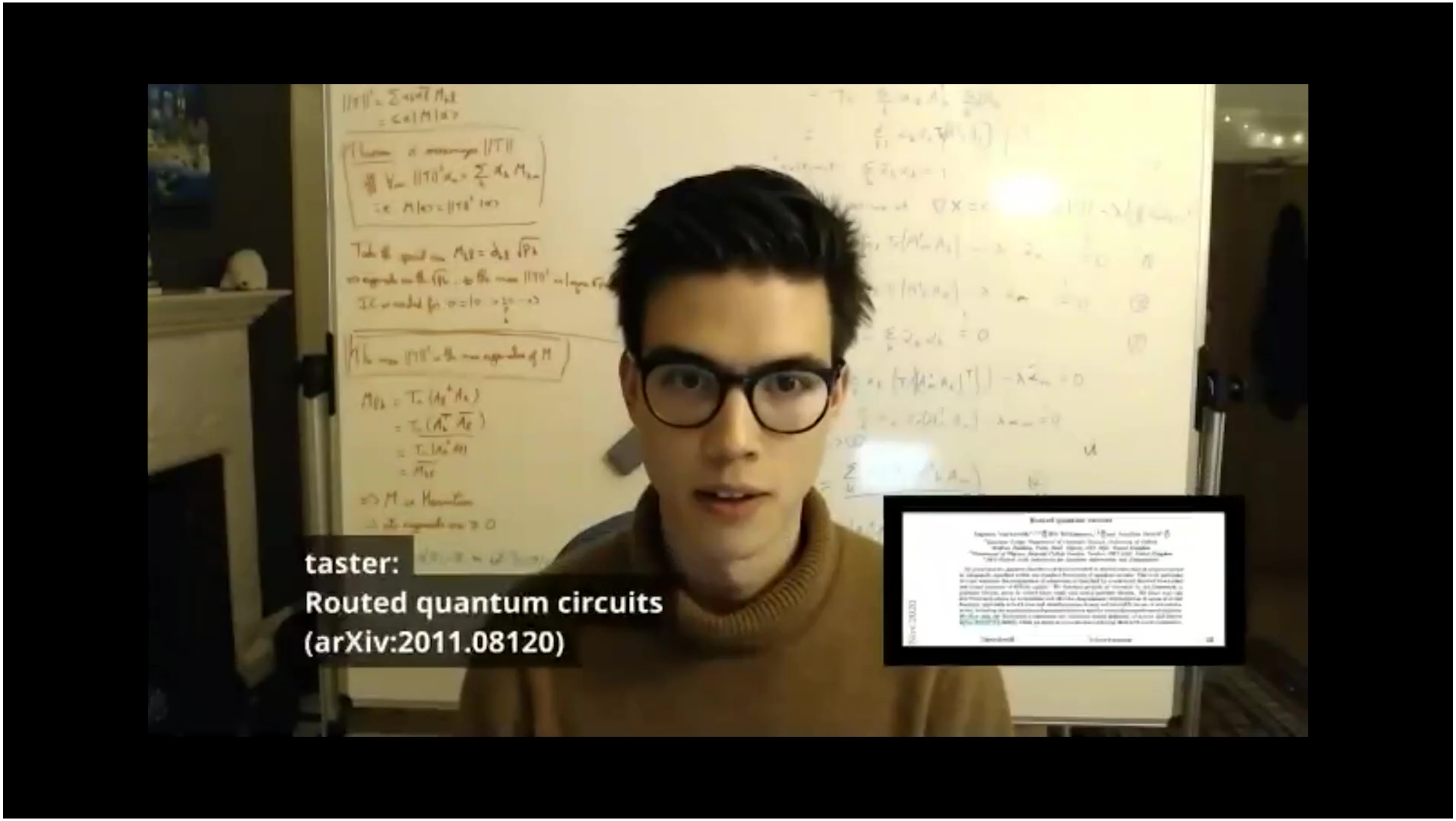

SWITCH placement
Proposition 1:
does not generate side-channels
Bob
Bob
AB+
SWITCH
Alice
Alice

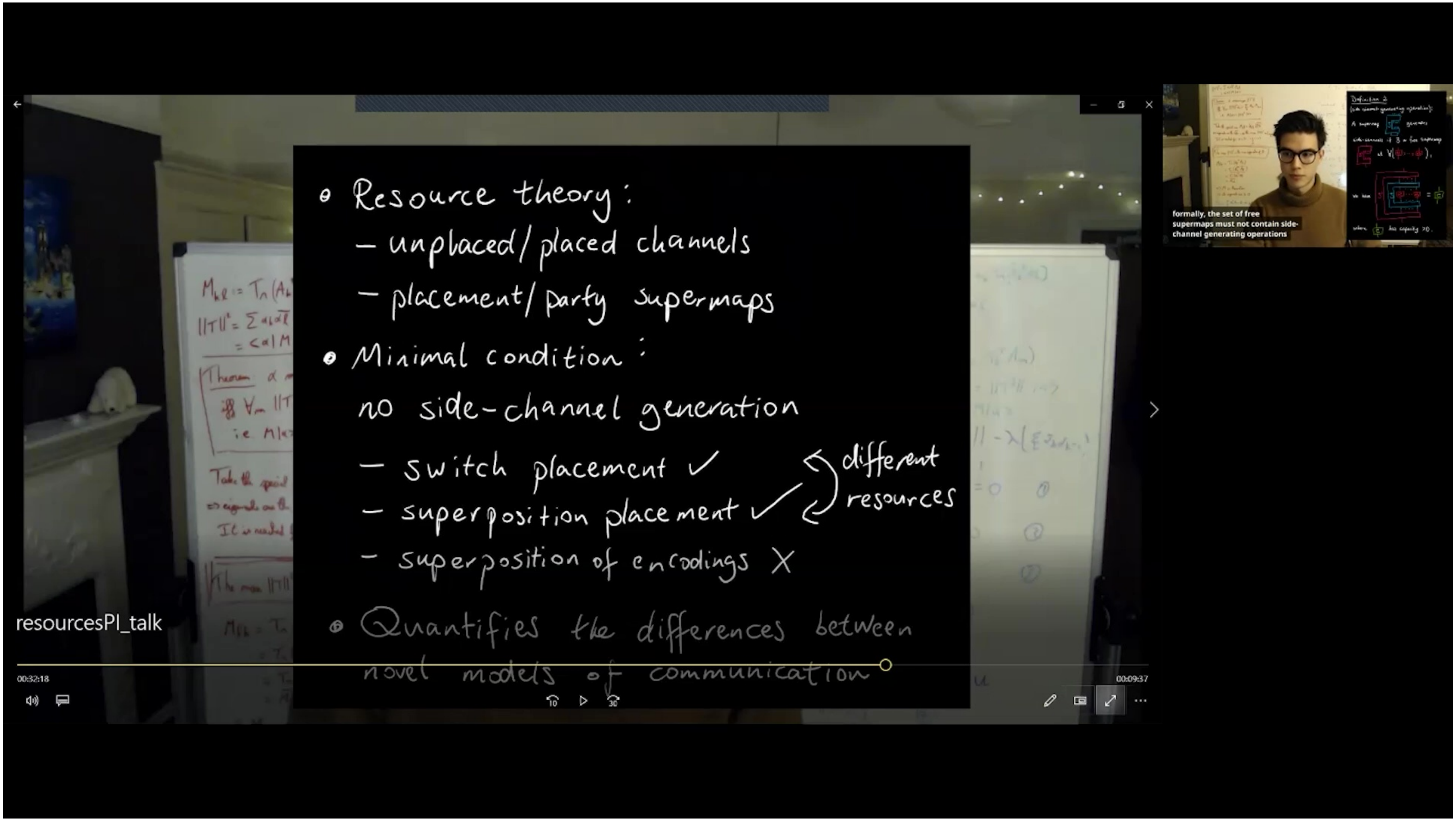

Bob
Bob
AB+
Alice
Alice
U: |ψ⟩_M ⊗ |0⟩_P = |ψ⟩_X̃1 ⊗ |vac⟩_X̃2
|ψ⟩_M ⊗ |1⟩_P = |vac⟩_X̃1 ⊗ |ψ⟩_X̃2
[G. Chiribella & H.K., Proc. R. Soc. A, 2019]
formally, the set of free supermaps must not contain side-channel generating operations

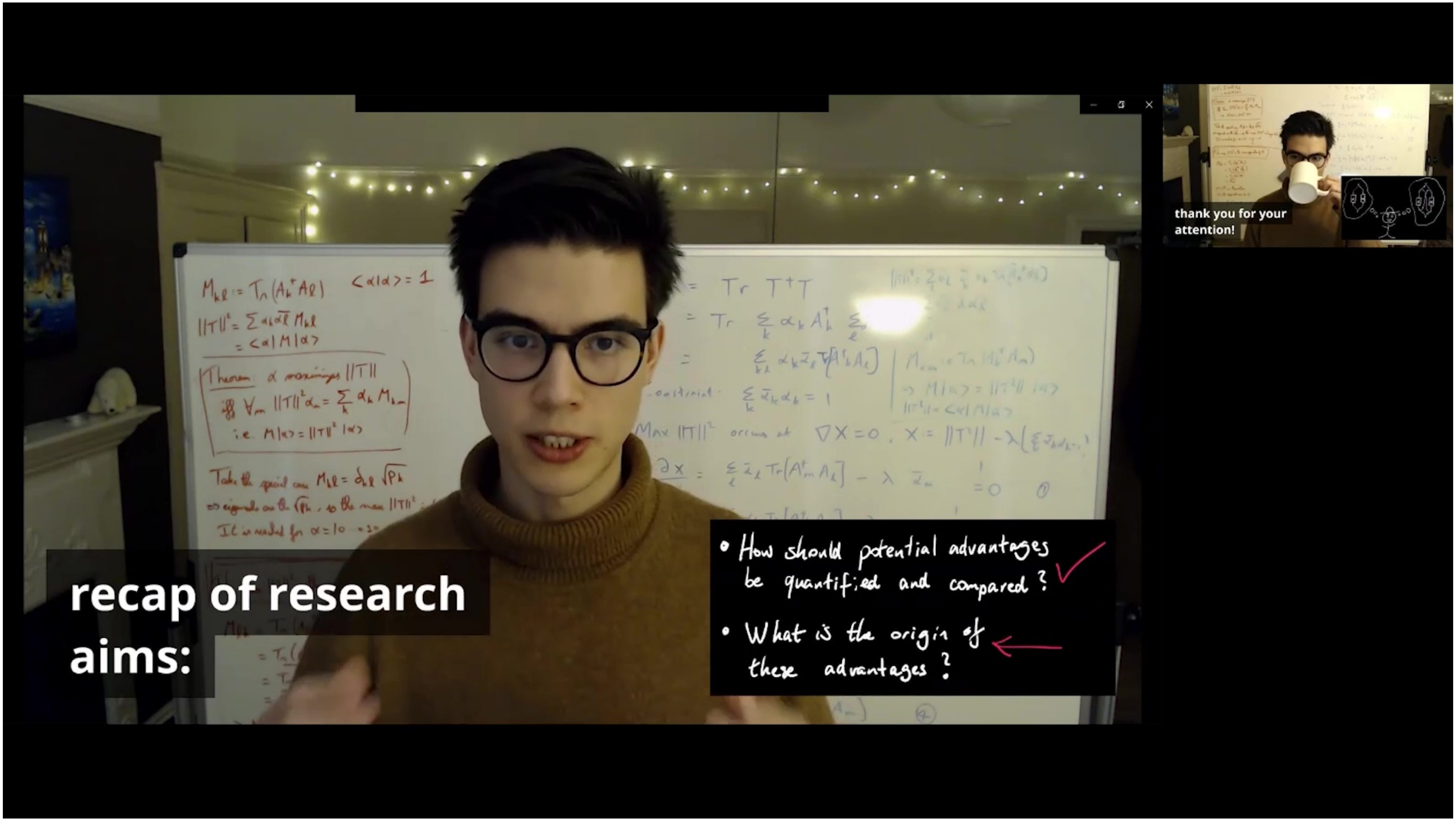

SWITCH and superposition placements take different initial resources
Future work:
Investigate the extent to which indefinite causal order gives advantages, when the comparison is restricted to
(a) non-side-channel generating operations
(b) operations acting on the same initial resources
formally, the set of free supermaps must not contain side-channel generating operations

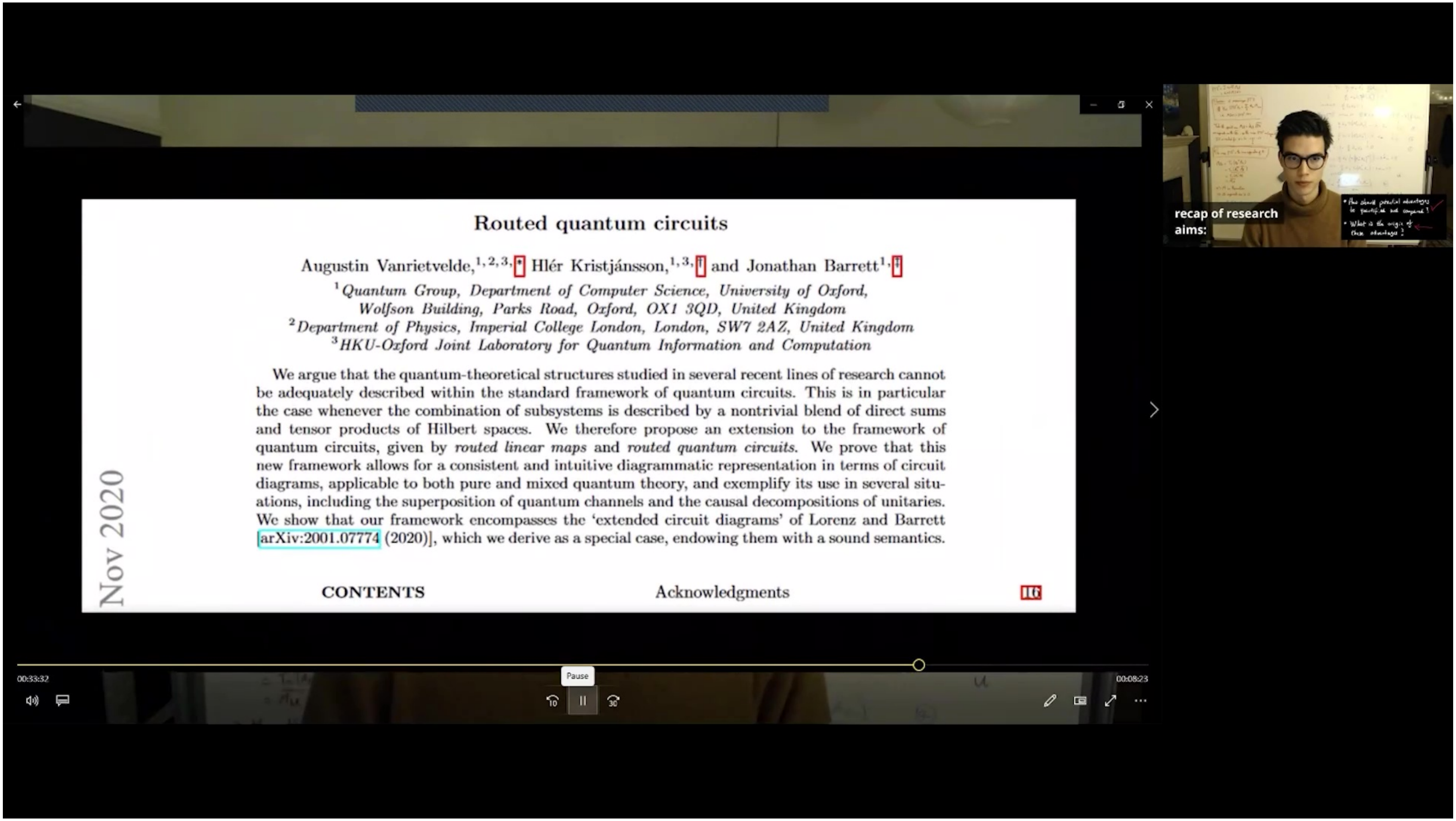

summary:
• Resource theory:
– unplaced/placed channels
– placement/party supermaps
• Minimal condition:
no side-channel generation
– switch placement ✓
– superposition placement ✓
– superposition of encodings X
different resources
• Quantifies the differences between novel models of communication
formally, the set of free supermaps must not contain side-channel generating operations



taster:
Routed quantum circuits
(arXiv:2011.08120)


• Resource theory:
– unplaced/placed channels
– placement/party supermaps
• Minimal condition:
no side-channel generation
– switch placement ✓
– superposition placement ✓
– superposition of encodings X
different resources
• Quantifies the differences between novel models of communication
resourcesPI_talk
00:32:18
00:09:37
formally, the set of free supermaps must not contain side-channel generating operations


recap of research aims:
• How should potential advantages be quantified and compared?
• What is the origin of these advantages?
thank you for your attention!



Routed quantum circuits

Augustin Vanrietvelde,[1,2,3,*] Hlér Kristjánsson,[1,3,†] and Jonathan Barrett[1,‡]

[1] *Quantum Group, Department of Computer Science, University of Oxford, Wolfson Building, Parks Road, Oxford, OX1 3QD, United Kingdom*
[2] *Department of Physics, Imperial College London, London, SW7 2AZ, United Kingdom*
[3] *HKU-Oxford Joint Laboratory for Quantum Information and Computation*

We argue that the quantum-theoretical structures studied in several recent lines of research cannot be adequately described within the standard framework of quantum circuits. This is in particular the case whenever the combination of subsystems is described by a nontrivial blend of direct sums and tensor products of Hilbert spaces. We therefore propose an extension to the framework of quantum circuits, given by *routed linear maps* and *routed quantum circuits*. We prove that this new framework allows for a consistent and intuitive diagrammatic representation in terms of circuit diagrams, applicable to both pure and mixed quantum theory, and exemplify its use in several situations, including the superposition of quantum channels and the causal decompositions of unitaries. We show that our framework encompasses the 'extended circuit diagrams' of Lorenz and Barrett [arXiv:2001.07774 (2020)], which we derive as a special case, endowing them with a sound semantics.

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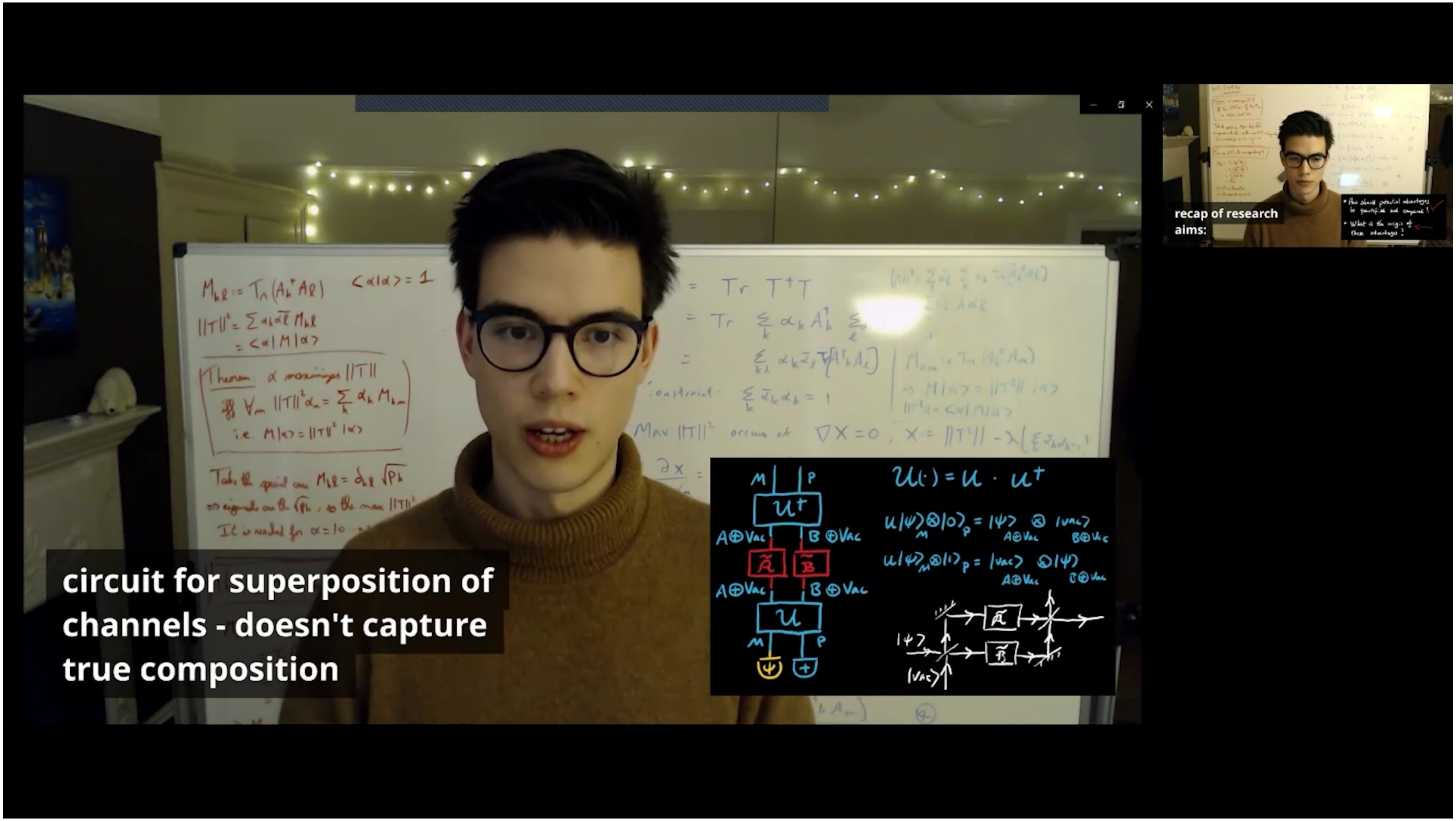
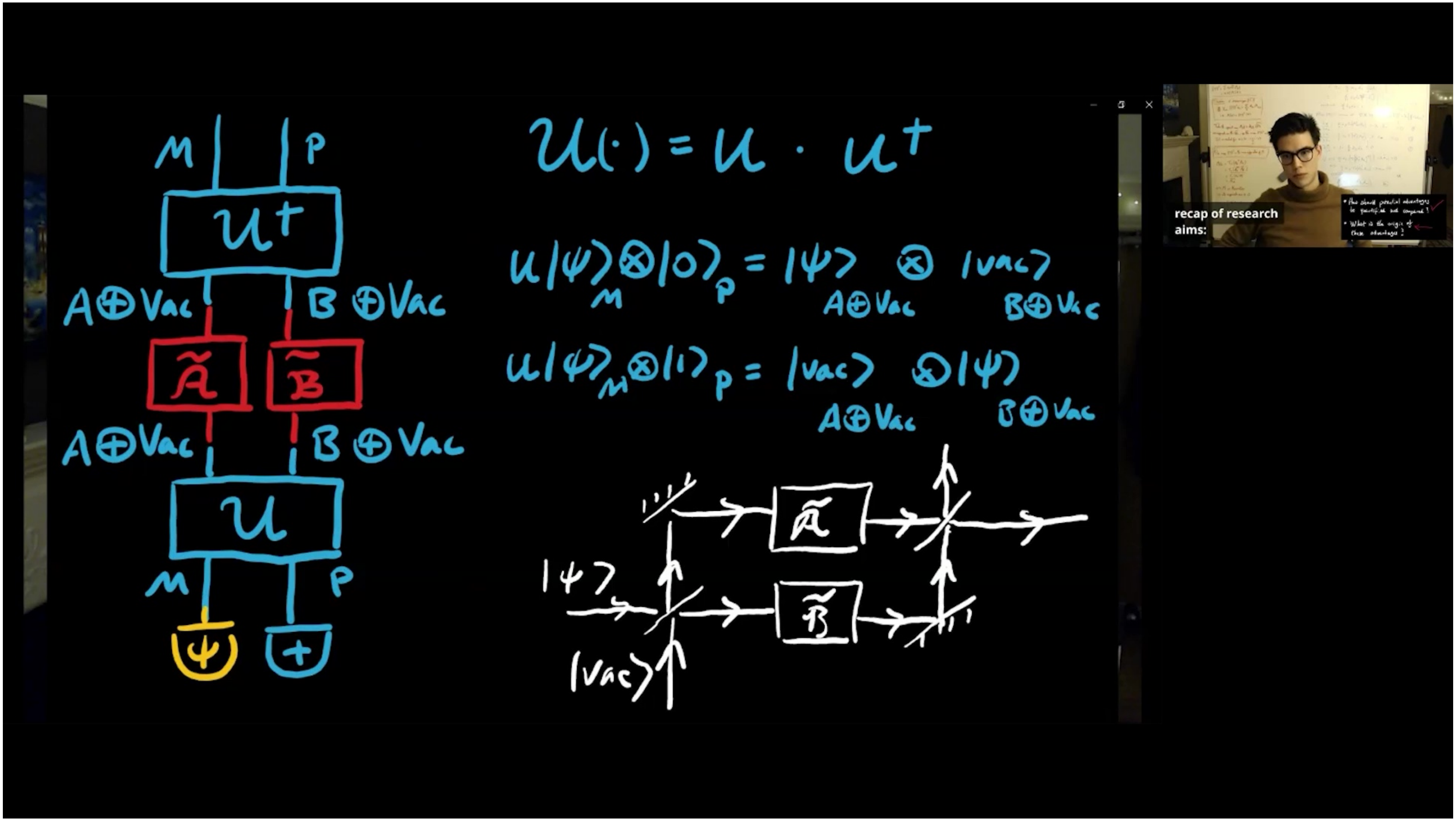

circuit for superposition of channels - doesn't capture true composition
recap of research aims:


M
P
U†
A ⊕ Vac
B ⊕ Vac
Ã
B̃
A ⊕ Vac
B ⊕ Vac
U
M
P
ψ
+
U(·) = U · U†
U|ψ⟩_M ⊗ |0⟩_P = |ψ⟩ ⊗ |vac⟩
A⊕Vac
B⊕Vac
U|ψ⟩_M ⊗ |1⟩_P = |vac⟩ ⊗ |ψ⟩
A⊕Vac
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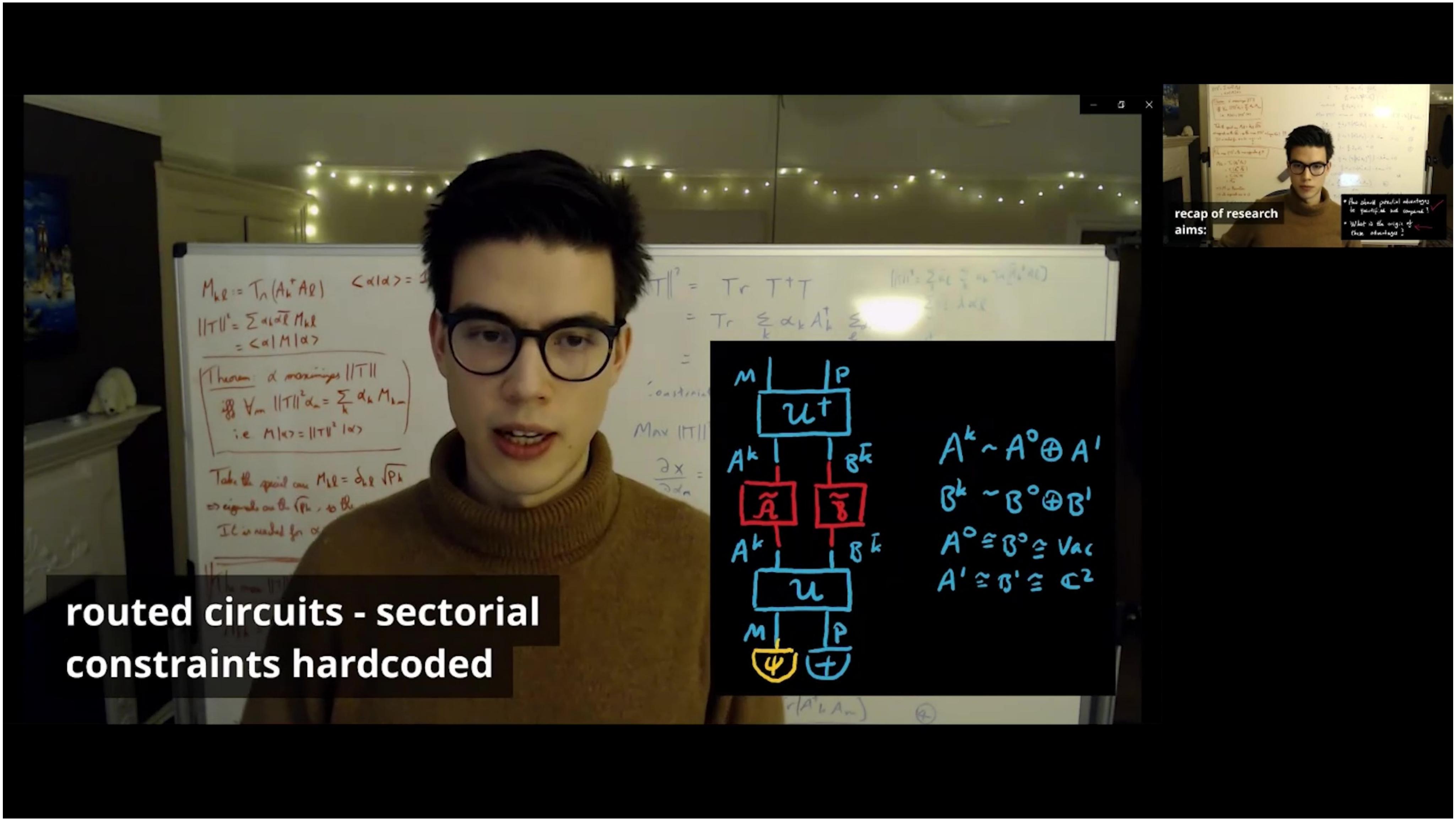
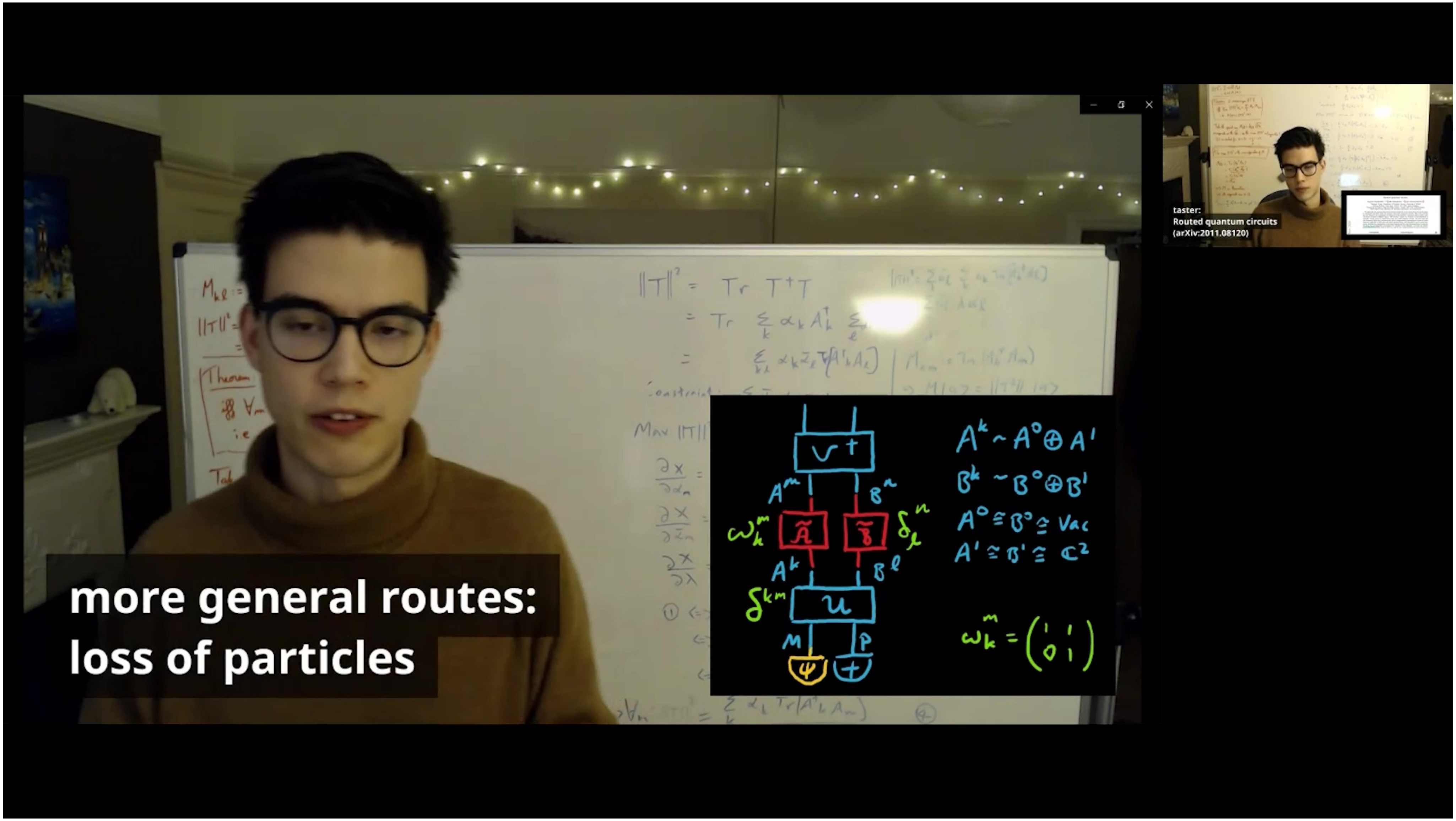
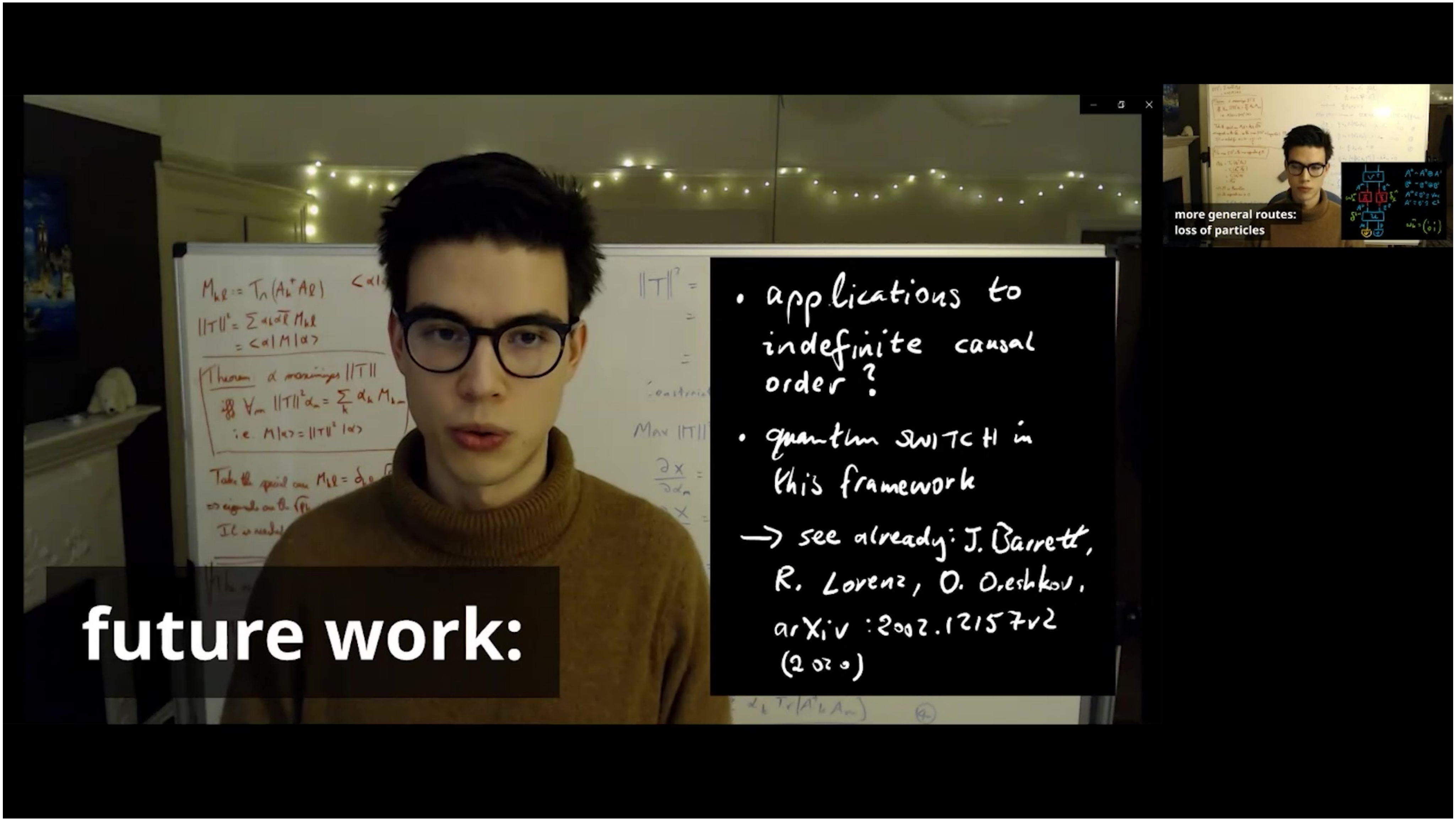
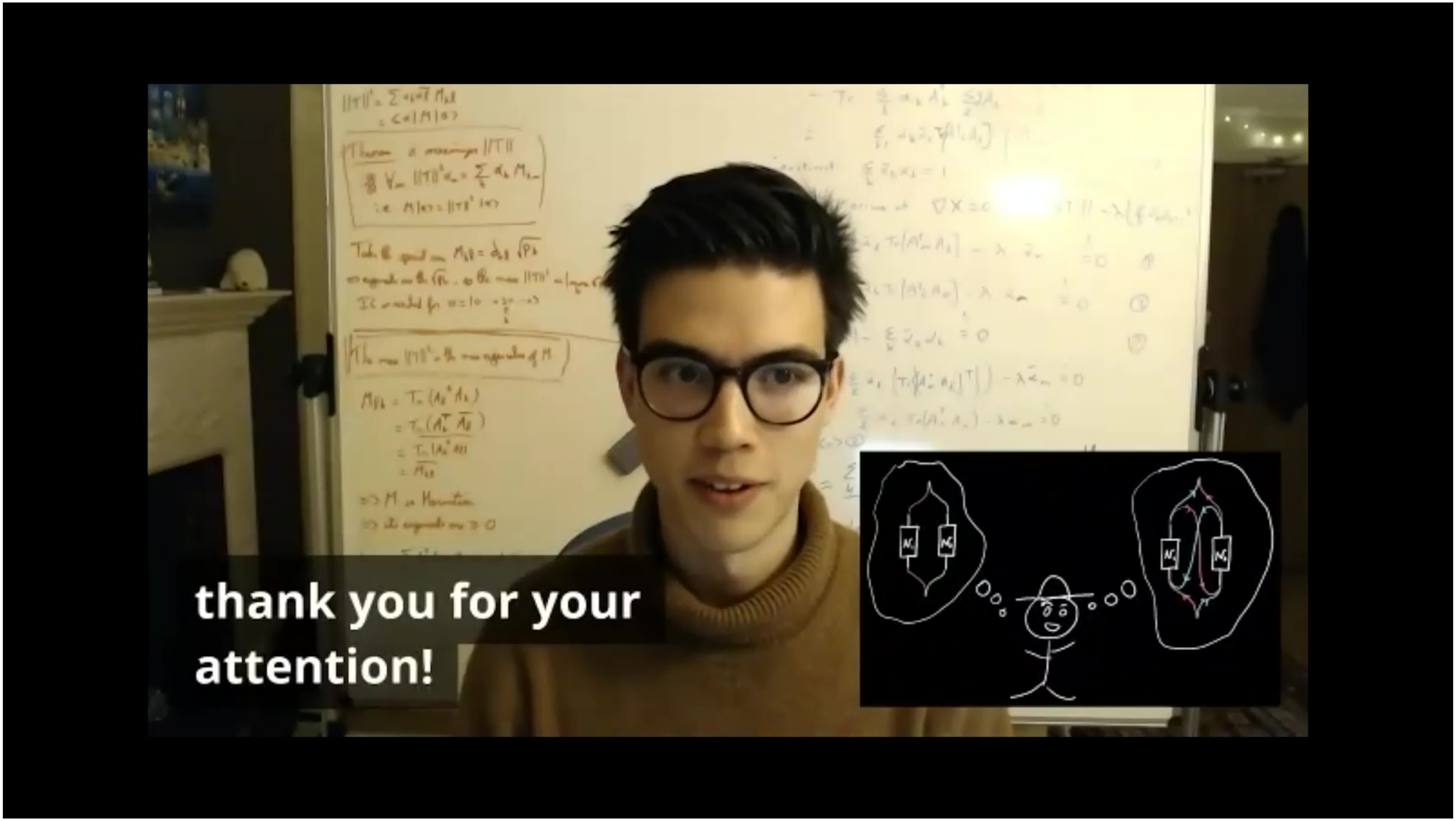
|ψ⟩
|vac⟩
Ã
B̃
recap of research aims:


routed circuits - sectorial constraints hardcoded
recap of research aims:
M
P
$\mathcal{U}^\dagger$
A^k
$B^{\bar{k}}$
$\tilde{A}$
$\tilde{B}$
$\mathcal{U}$
ψ
$A^k \sim A^0 \oplus A^1$
$B^k \sim B^0 \oplus B^1$
$A^0 \cong B^0 \cong Vac$
$A^1 \cong B^1 \cong \mathbb{C}^2$


more general routes:
loss of particles
taster:
Routed quantum circuits
(arXiv:2011.08120)


future work:
• applications to indefinite causal order ?
• quantum SWITCH in this framework
→ see already: J. Barrett, R. Lorenz, O. Oreshkov, arXiv:2002.12157v2 (2020)
more general routes: loss of particles


thank you for your
attention!