Title: Gong Show

Date: Aug 19, 2015 04:30 PM

URL: http://pirsa.org/15080073

Abstract:

Analogue Gravity

towards dynamics in analogue systems

or

Emergent gravity from relativistic Bose-Einstein condensate

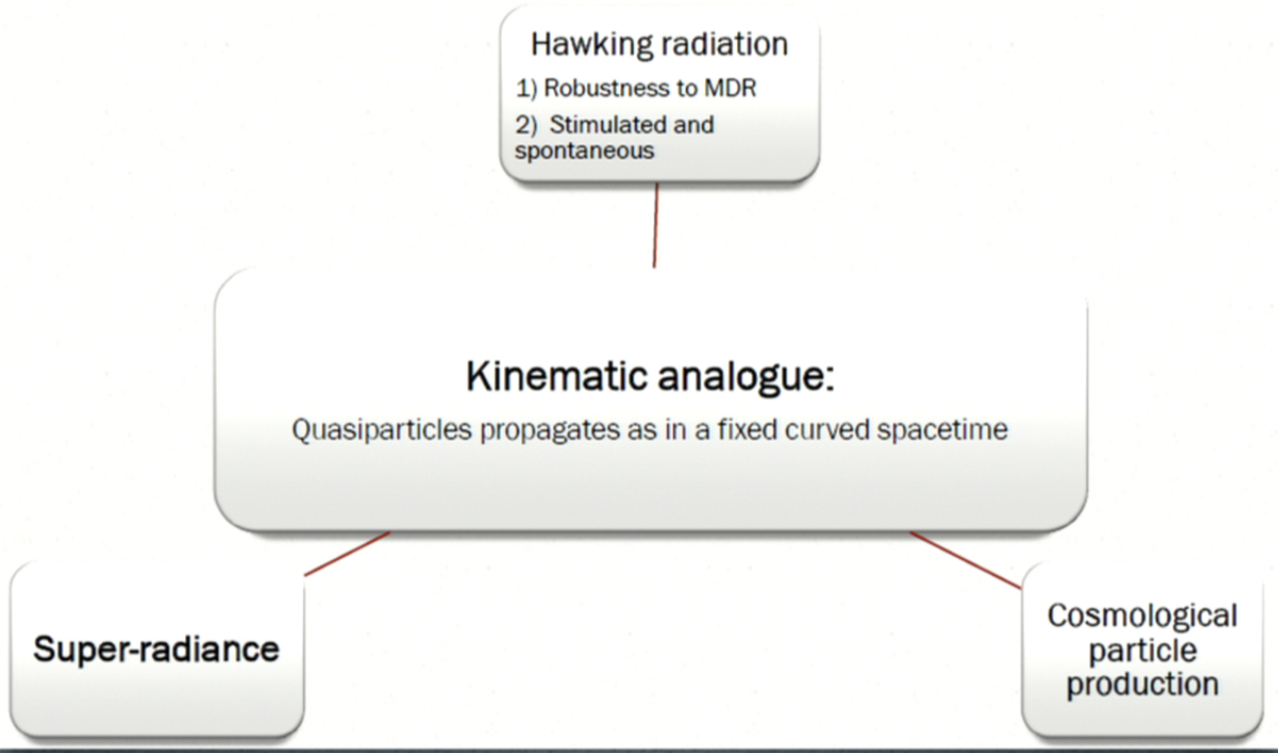
Alessio Belenchia

Based on *A.B., Liberati, Mohd, Phys.Rev. D90 (2014)*

Quantum Information in Quantum Gravity II
Gong Show
19/08/2015

Analogue....What???

Analogue Gravity studies condensed matter systems that share properties of gravitational theories



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Analogue....What???

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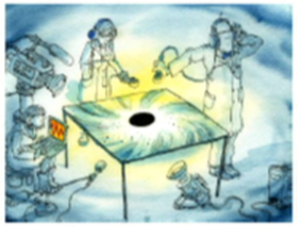
Hawking radiation

1) Robustness to MDR

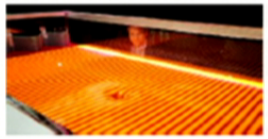
2) Stimulated and spontaneous



Kinematic analogue:

Quasiparticles propagates as in a fixed curved spacetime

Super-radiance



Cosmological particle production

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Towards dynamics in analogue systems

AIM:

Take into account the back-reaction of quasiparticles propagation on the analogue spacetime and see if and when the dynamics of the latter resemble some gravity theories

- *Easier to say than to do*
- *BEC are good candidates for the scope*
- *Previous studies with non-relativistic BEC were successfull*

Girelli, S.Liberati, L.Sindoni, *Phys.Rev.D78,2008*

$$(\nabla^2 - \frac{1}{L^2})\phi_{grav} = 4\pi G_N \rho_{matter} + \Lambda$$

$\phi_{grav} \propto VEV$

Back-reaction of quasi-particles

- *Relativistic BEC (complex scalar field with U(1) SSB) offer good analogue models ,* S.Fagnocchi et al., *New J. Phys.,2010*

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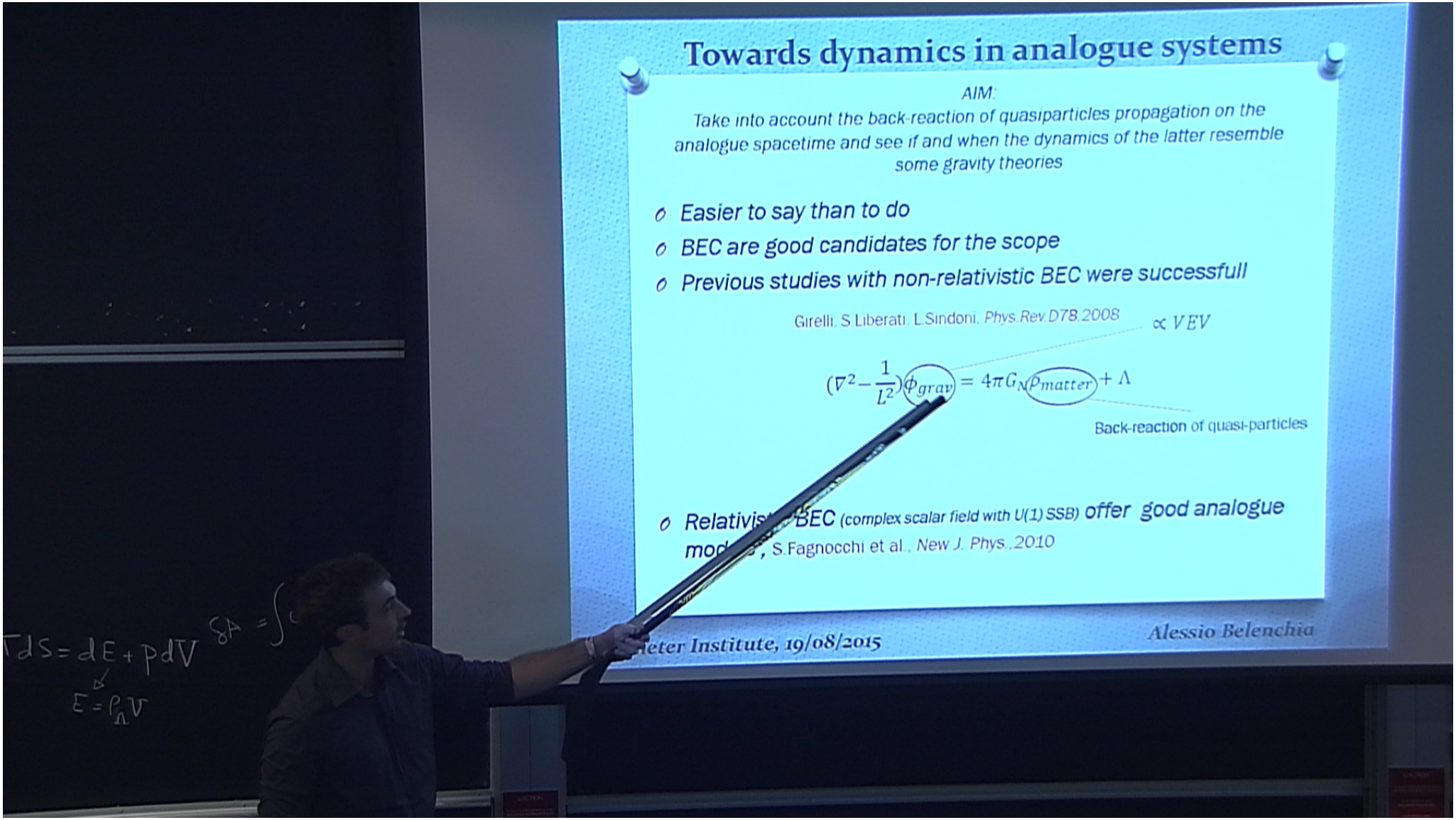
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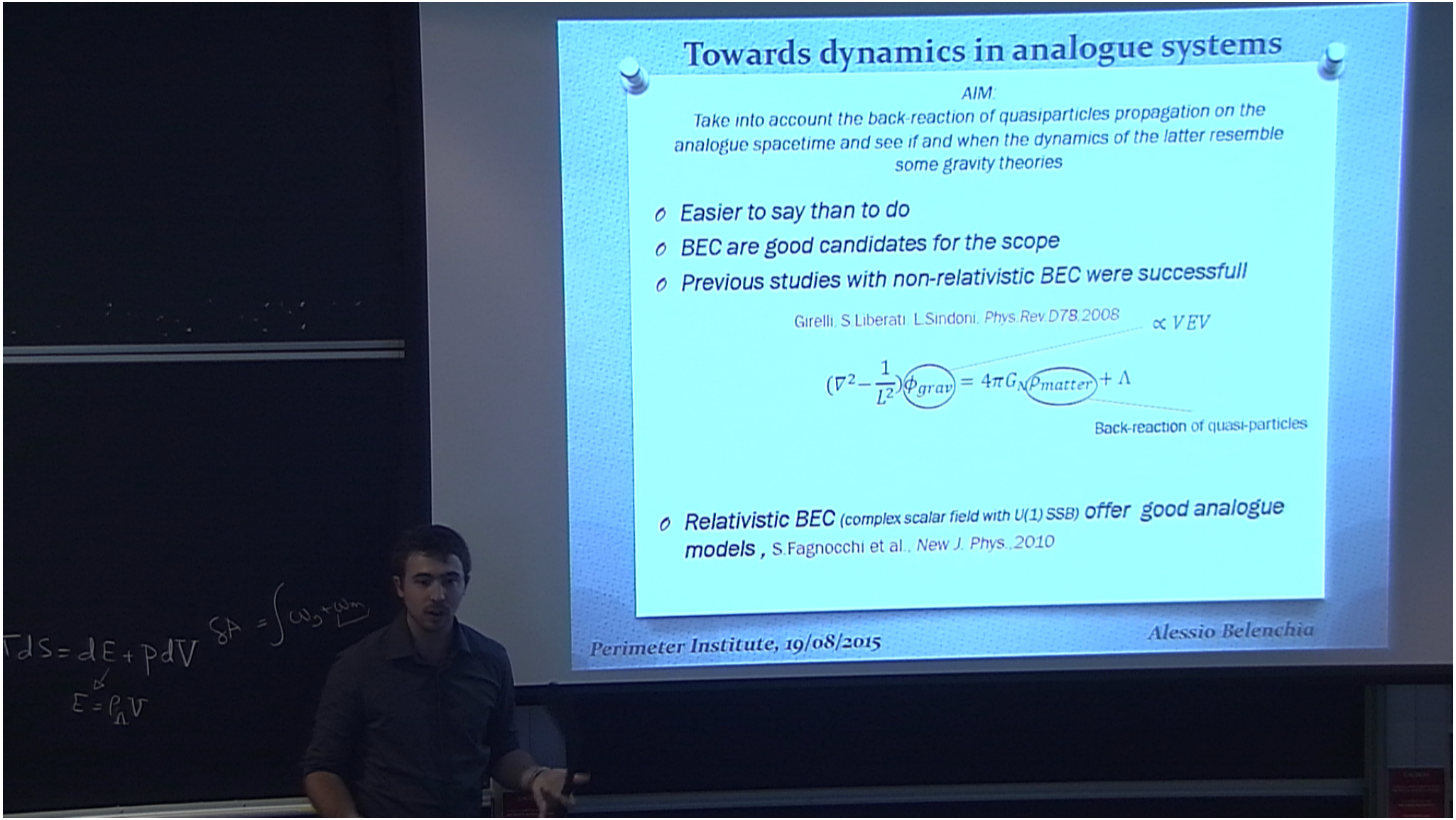
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Emergent Nordström Gravity I

Starting equation: $(\Box - m^2)\varphi - 2\lambda|\varphi|^2\varphi = 0$

Mean field plus fractional fluctuations splitting: $\varphi = \varphi_0(1 + \psi_1 + i\,\psi_2)$

- Assuming the VEV (φ_0) to be real we restrict ourselves to a particular corner of the theory

Relativistic BdG equation

$$(\Box - m^2)\varphi_0 - 2\lambda\varphi_0^3 - 2\lambda\varphi_0^3\,[3\langle\psi_1^2\rangle + \langle\psi_2^2\rangle] = 0$$

$$\Box\psi_1 + 2\eta^{\mu\nu}\partial_\mu(\log\varphi_0)\partial_\nu\psi_1 - 4\lambda\varphi_0^2\,\psi_1 = 0 \quad \Rightarrow \quad \Box_g\psi_1 - 4\lambda\psi_1 = 0$$

$$\Box\psi_2 + 2\eta^{\mu\nu}\partial_\mu(\log\varphi_0)\partial_\nu\psi_2 = 0 \quad \Rightarrow \quad \Box_g\psi_2 = 0$$


Semiclassical
Et
S
TdS = dE + pdV
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$(\square - m^2)\varphi_0 - 2\lambda\varphi_0^3 -$
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Emergent Nordström Gravity II

Analogue metric is conformally flat

$$g_{\mu\nu} = \varphi_0^2 \eta_{\mu\nu}$$

and its Ricci scalar is

$$R = -6\frac{\Box\varphi_0}{\varphi_0^3}$$

- The BdG equation assume an (almost) geometrical form reminiscent of Einstein-Fokker equation for Nordström gravity
- After re-introducing the dimensional constant and matching the RHS with the SET of perturbations we end up with

$$\boxed{R + \Lambda = 24\pi\frac{G_{eff}}{c^4}\langle T\rangle}$$

$$\Lambda = 12\lambda\frac{\mu^2}{c\hbar}$$

$$G_{eff} = \frac{\hbar c^5}{4\pi\mu^4}$$

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Conclusions and outlook

- Analogue gravity models are important tools to test effects of QFT in CS in condensed matter systems
- In order to go beyond «Semiclassical gravity» we need to get dynamical analogue models
- First steps in this direction are the toy models of BEC that constitute (simple) dynamical analogues

---

- Investigate more complex systems
- Understand the «formation» of the analogue spacetime (geometrogenesis)
- Inspire/be inspired by QG ideas (e.g. GFT)
- Tackle problems like Information-loss


Semiclassical
Et
S
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Perimeter Institute, 19/08/2015


thank you
danke
謝謝
ngiyabonga
teşekkür ederim
gracias
merci
obrigado
спасибо
bedankt
dziękuję
sukriya
kop khun krap
go raibh maith agat
mochchakkeram
tapadh leat
dank je
arigatō
dakujem
grazie
terima kasih
sagolun
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mauruuru
takk
taiku
мерси
감사합니다
ευχαριστώ
ありがとう
Баярлалаа
рахмат
хвала

Consistency Conditions for an AdS/MERA Correspondence

Ning Bao (that's him), ChunJun Cao, Sean M. Carroll,
Aidan Chatwin-Davies (that's me), Nicholas Hunter-Jones (that's him),
Jason Pollack, and Grant N. Remmen

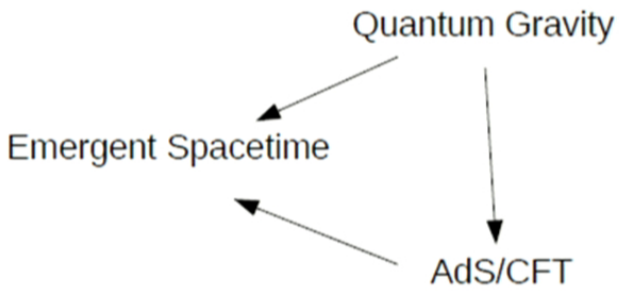
arXiv: 1504.06632

August 19, 2015
Quantum Information in Quantum Gravity II
Perimeter Institute for Theoretical Physics

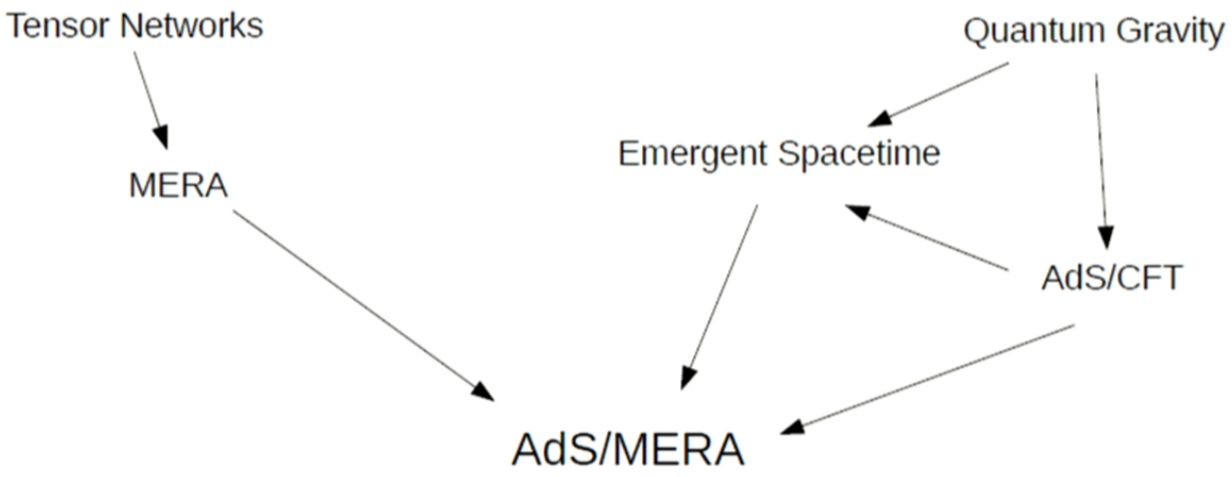
Introduction

Quantum Gravity

Introduction



Introduction



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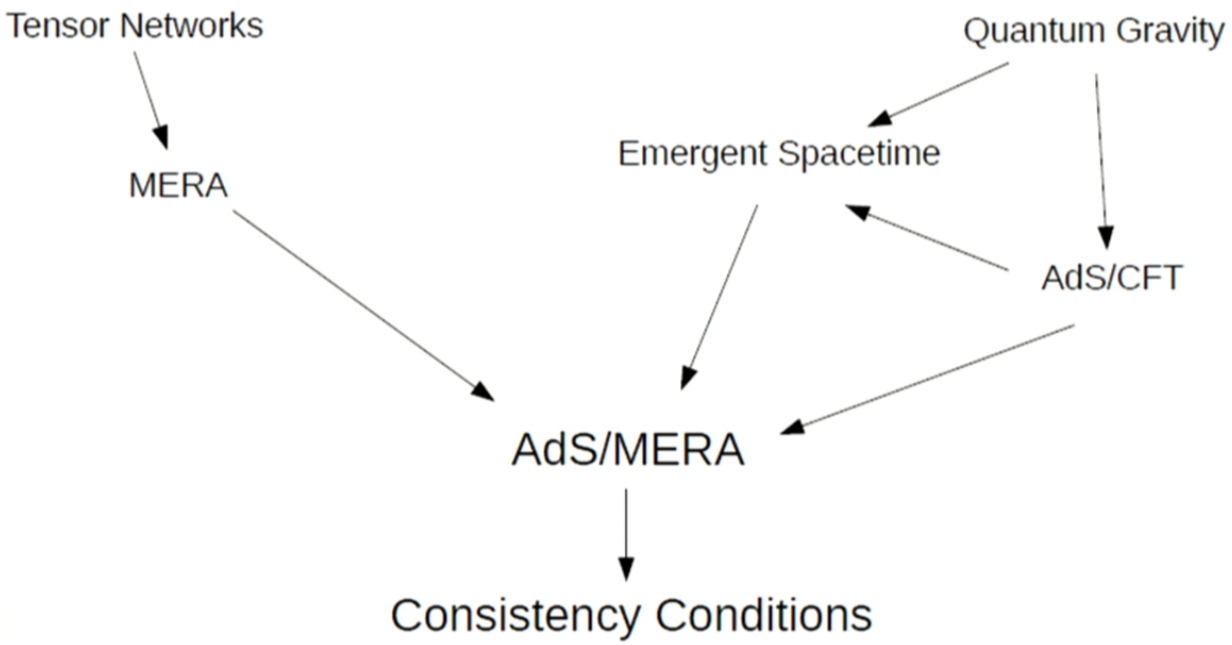
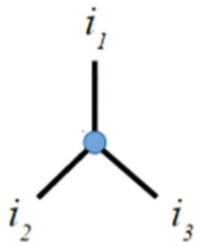


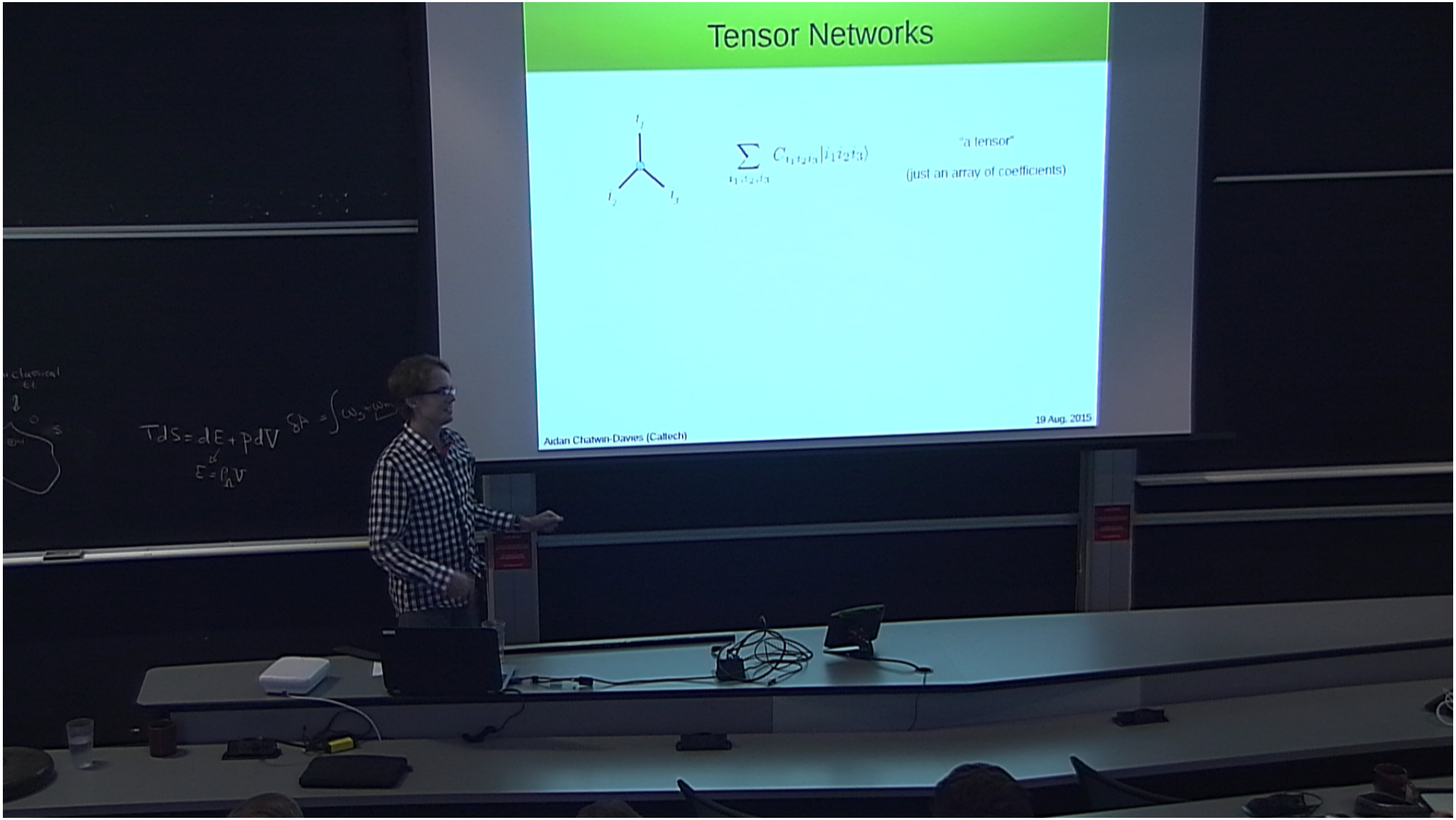
Tensor Networks



$$\sum_{i_1,i_2,i_3} C_{i_1 i_2 i_3} |i_1 i_2 i_3\rangle$$

"a tensor"

(just an array of coefficients)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19 Aug. 2015

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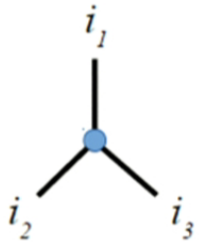

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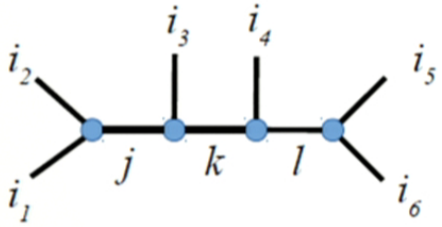
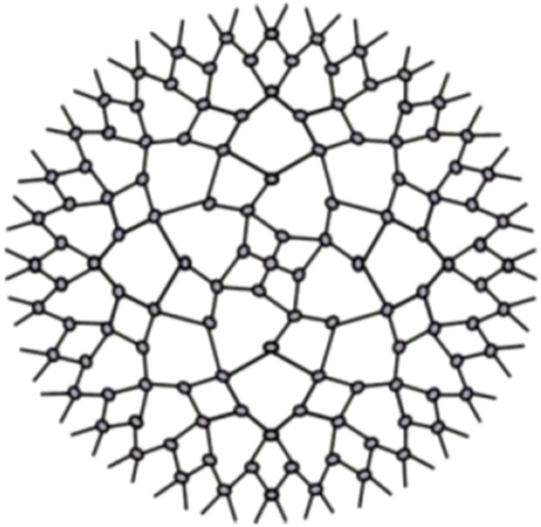


$$T_{i_1 i_2 i_3 i_4 i_5 i_6} = \sum_{j,k,l} C_{i_1 i_2 j} C_{j i_3 k} C_{k i_4 l} C_{l i_5 i_6}$$

"a tensor network"

(a contraction of many tensors)

The MERA and AdS_{1+1}



Source: www.perimeterinstitute.ca/research/research-initiatives/tensor-networks-initiative

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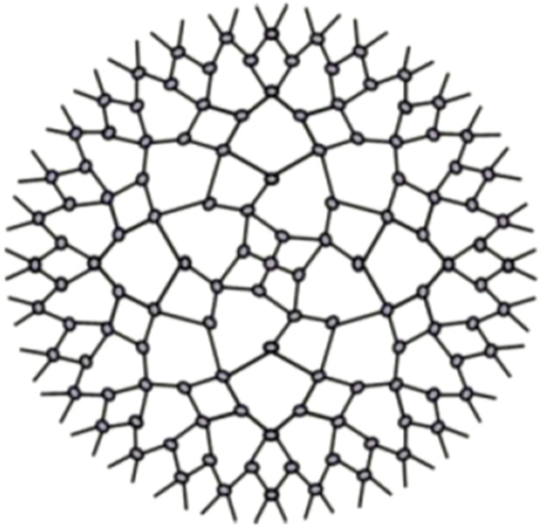

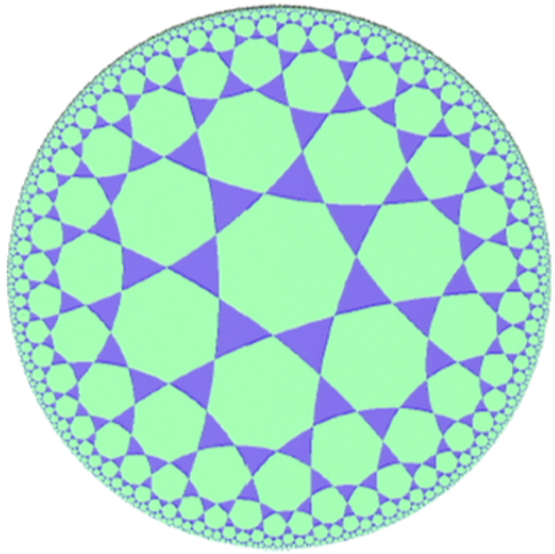

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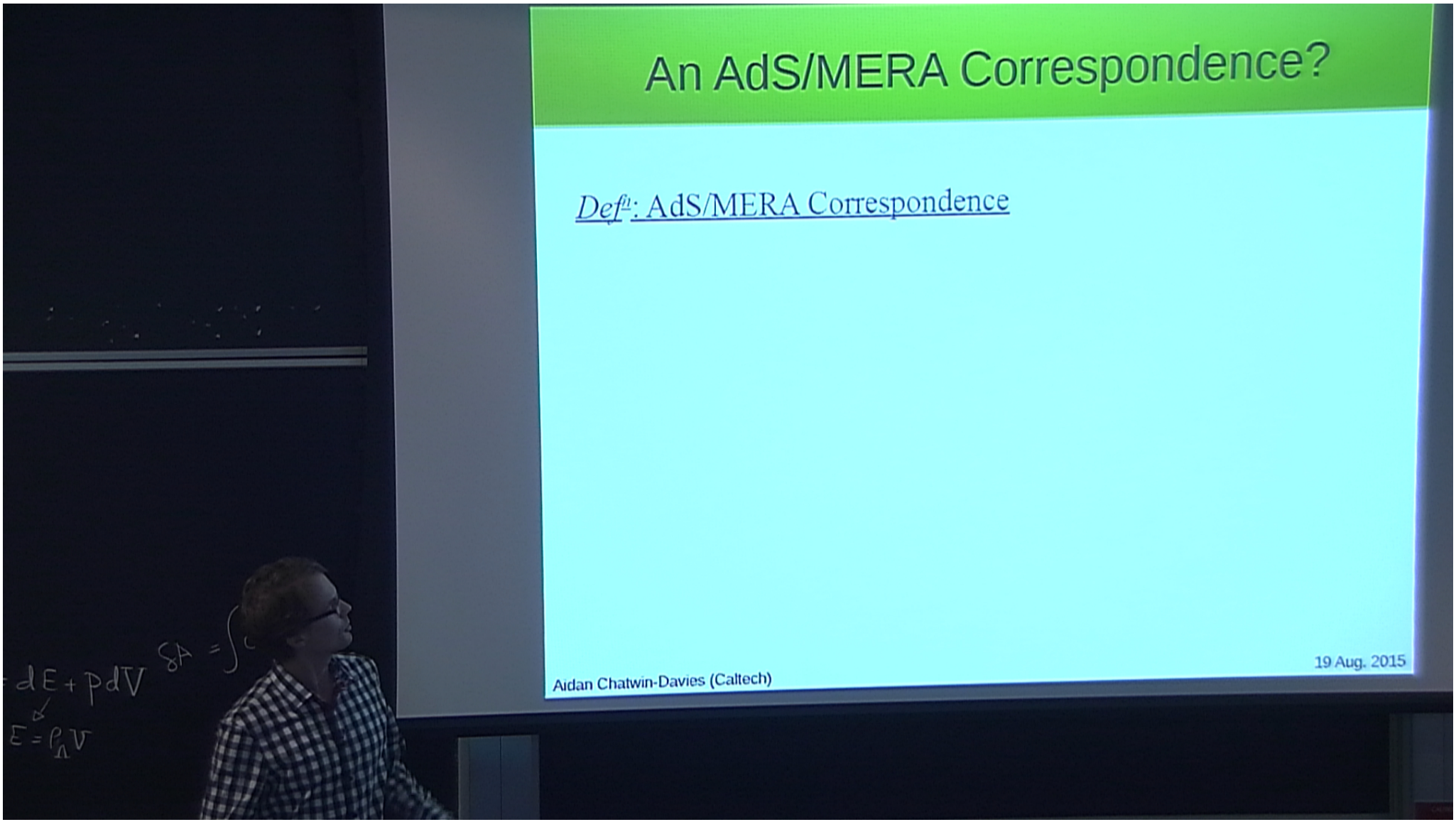
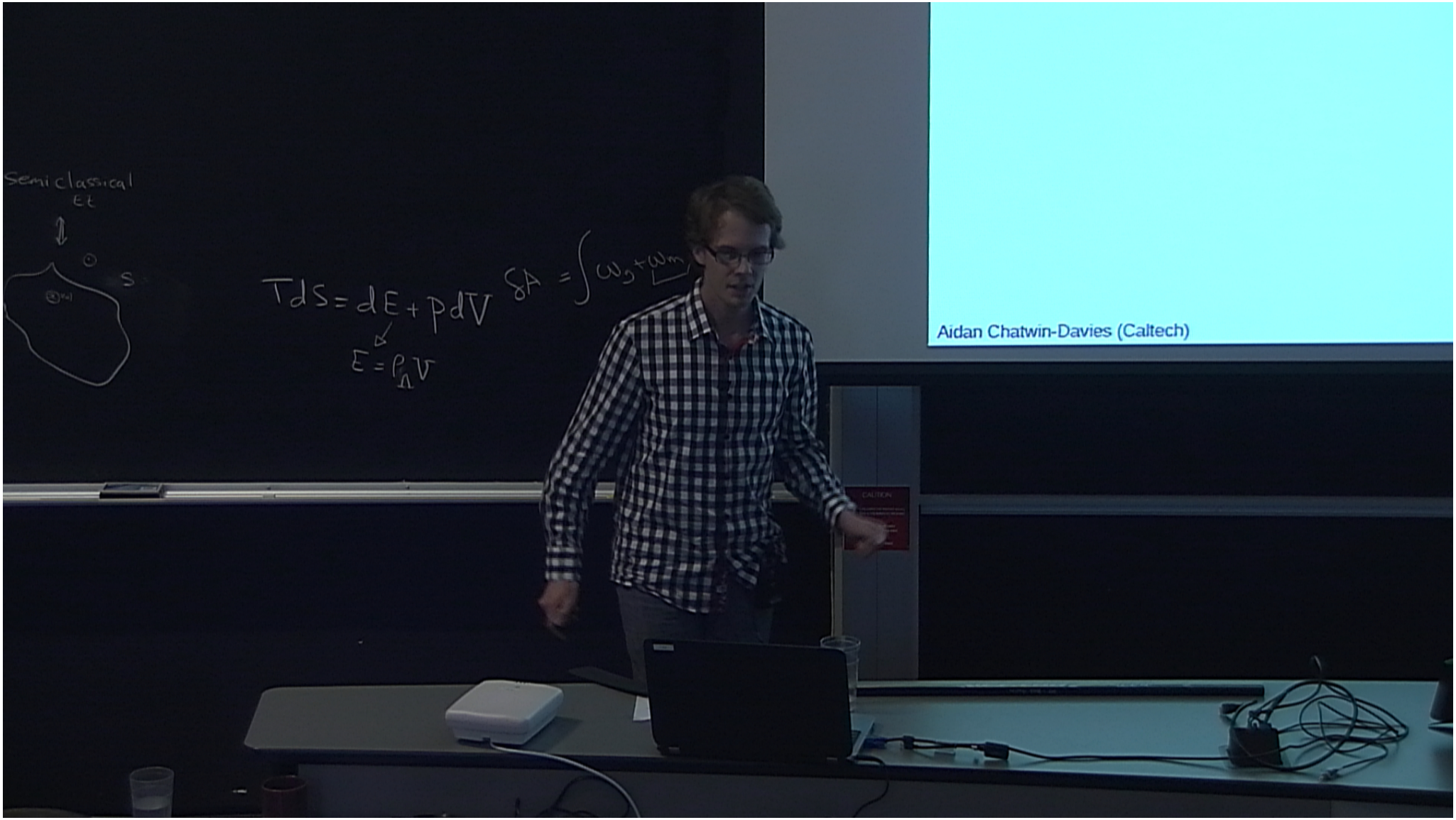

An AdS/MERA Correspondence?
Def[n]: AdS/MERA Correspondence
Aidan Chatwin-Davies (Caltech)
19 Aug. 2015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Def[n]: AdS/MERA Correspondence

- MERA fills out spatial slice of AdS_{1+1}
- Physics described by $\mathcal{H}_{\text{boundary}}$, $\mathcal{H}_{\text{bulk}}$, with $|\mathcal{H}_{\text{boundary}}| = |\mathcal{H}_{\text{bulk}}|$
- $\mathcal{H}_{\text{bulk}} = (V_{\text{bulk}})^{\otimes N}$

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- $\mathcal{H}_{\text{bulk}} = (V_{\text{bulk}})^{\otimes N}$
- Each V_{bulk} localized about a MERA lattice site (to preserve locality)
- MERA can be used to define a map $\mathcal{H}_{\text{boundary}} \leftrightarrow \mathcal{H}_{\text{bulk}}$

What We Did

AdS/MERA

↓

Consistency Conditions

What We Did

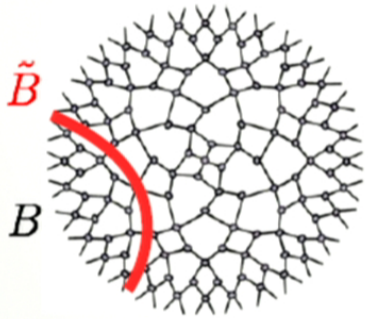
AdS/MERA

↓

Consistency Conditions

↙

Geodesics



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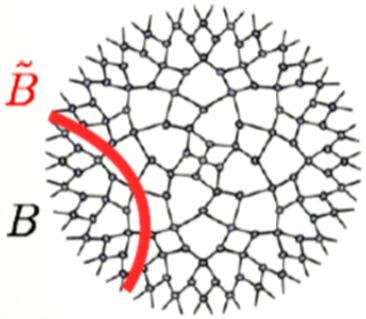

Boundary
Entanglement Entropy

$$S(B) = \frac{\mathrm{Area}(\tilde{B})}{4G}$$

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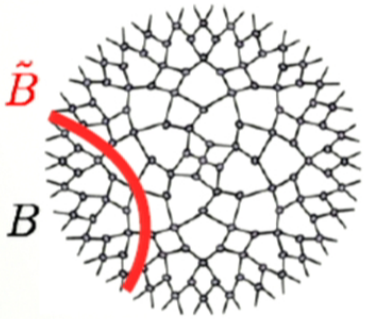

Boundary
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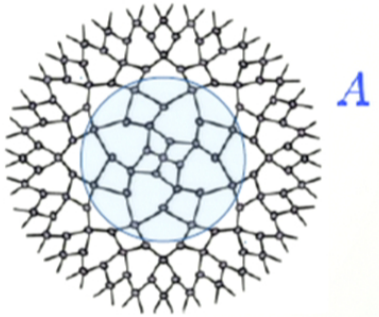
Bulk
Entanglement Entropy

$$S_{\text{bulk}}(A) \leq \frac{A}{4G}$$



Conclusion

Not for vanilla MERA!

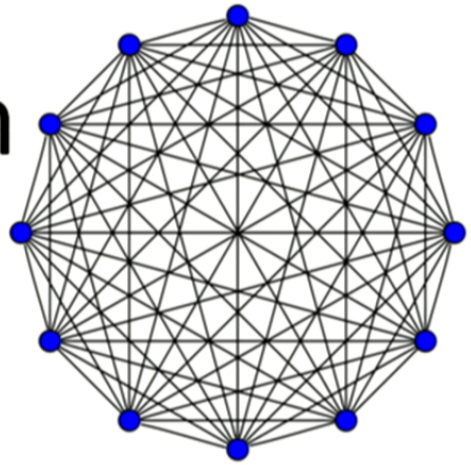

Conclusion
MERA
Correspondence?
AdS
Not for vanilla MERA!
Modify your MERA
Change your defn of AdS/MERA
Aidan Chatwin-Davies (Caltech)
19 Aug. 2015

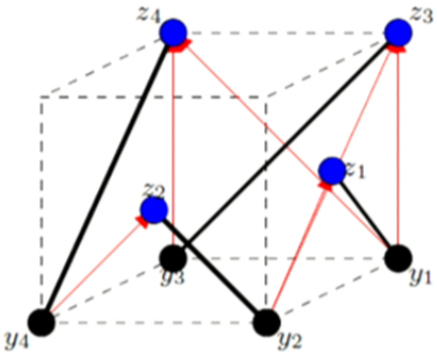
Conclusion

Not for vanilla MERA!

- Modify your MERA
- Change your defn of AdS/MERA
- Other holographic tensor network

Replicating Quantum Information in Spacetime





Grant Salton
Stanford University

With: Patrick Hayden, Sepehr Nezami, and Barry Sanders

arXiv: 1508.#####

Perimeter Institute, August 19, 2015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With: Patrick Ha
arXiv: 1508.#####

Quantum Information Bedrock

Information cannot propagate faster than light – *no signaling*

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Quantum information *cannot be cloned.*

$$|\varphi\rangle \not\to |\varphi\rangle|\varphi\rangle$$

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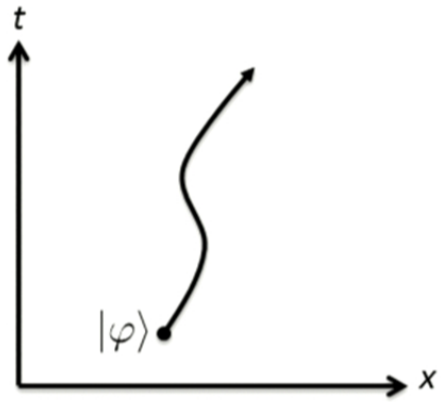
And yet…



Quantum Information Bedrock

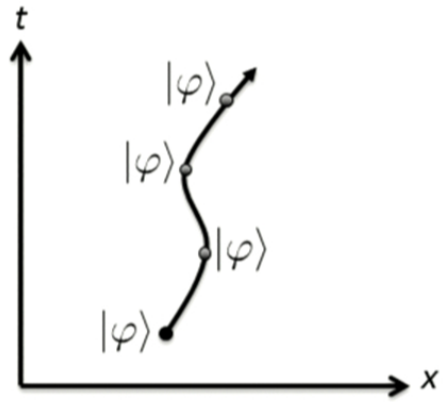
Information cannot propagate faster than light – *no signaling*

Quantum information *cannot be cloned*.

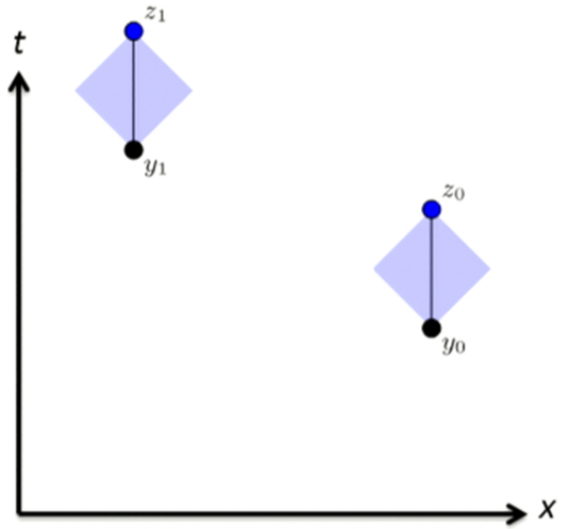
$$|\varphi\rangle \not\to |\varphi\rangle|\varphi\rangle$$

Quantum information **must** be widely replicated in space*time*.

And yet…



Replicating info in causal diamonds



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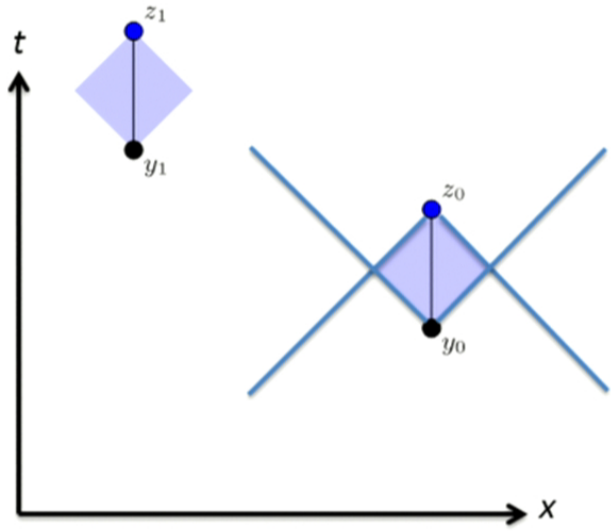
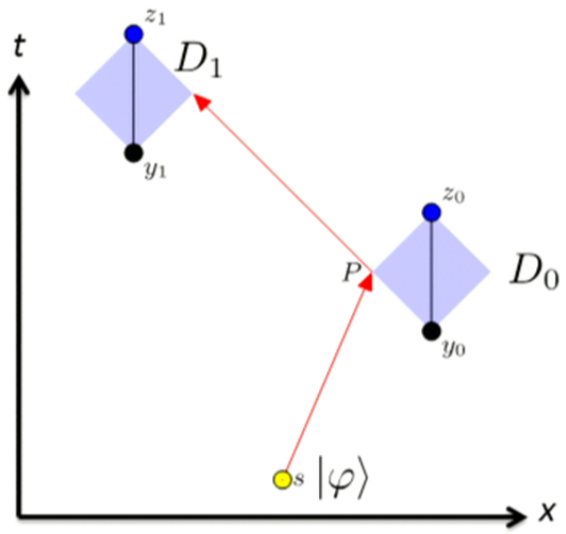


Define *causal diamond* D_j to be the intersection of the future of y_j and the past of z_j.

Replicating info in causal diamonds



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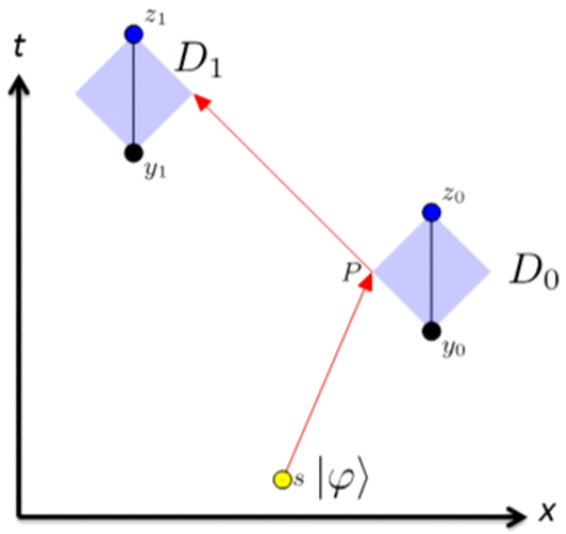
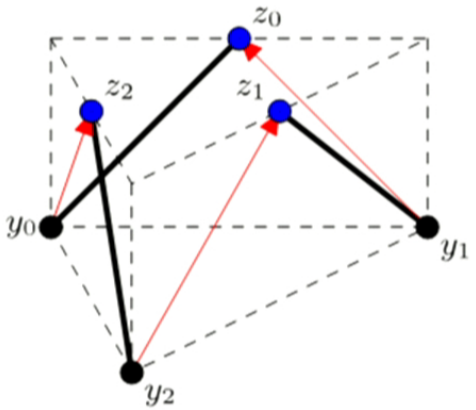
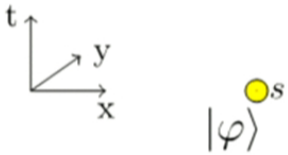


Define *causal diamond* D_j to be the intersection of the future of y_j and the past of z_j.

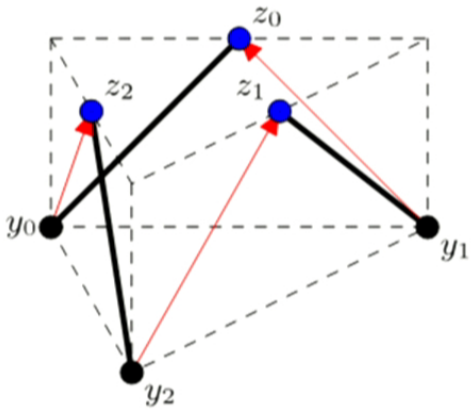
Hayden and May: Replication is possible iff every pair of causal diamonds is *causally related*: *i.e.*, there exists a causal curve from D_i to D_j or vice-versa.

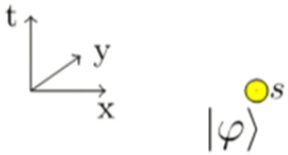
The causal merry-go-round





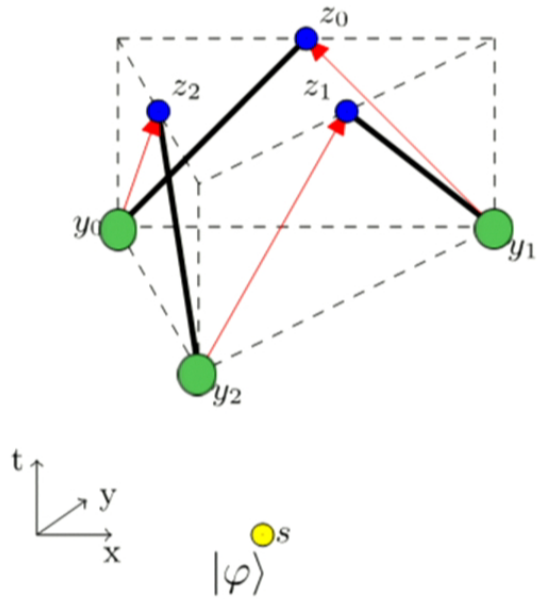
The causal merry-go-round





φ is encoded into ((2,3)) threshold quantum error correcting code at *s*

The causal merry-go-round

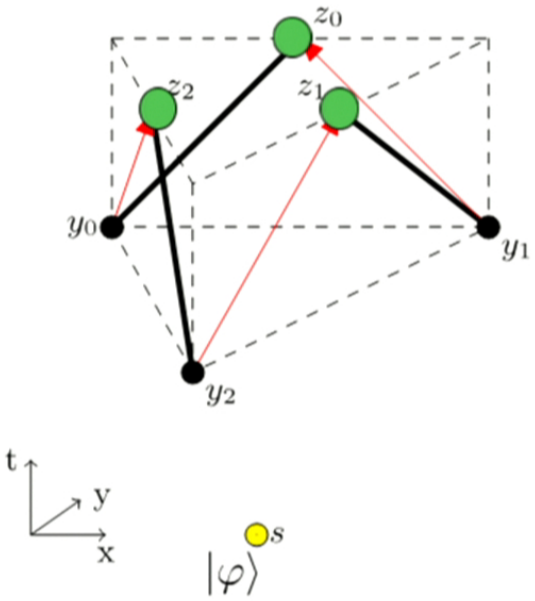


φ is encoded into ((2,3)) threshold quantum error correcting code at s

One share sent to each of y_j

Each share is then sent at the speed of light along a red ray

The causal merry-go-round



φ is encoded into ((2,3)) threshold quantum error correcting code at s

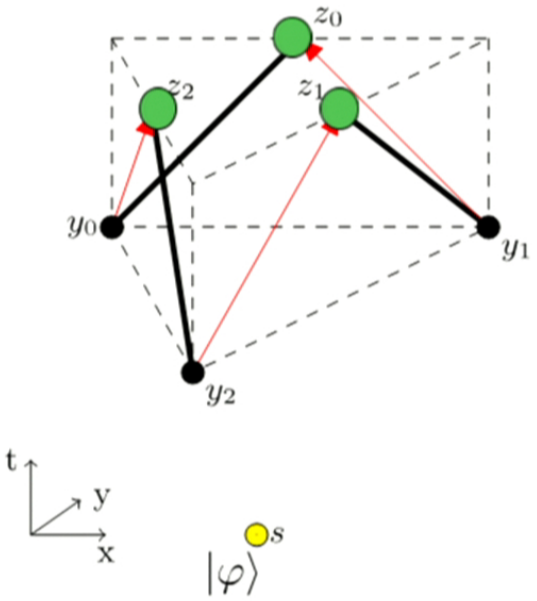
One share sent to each of y_j

Each share is then sent at the speed of light along a red ray

2 shares pass through each causal diamond yz_j

The same quantum information is replicated in each causal diamond

The causal merry-go-round



φ is encoded into ((2,3)) threshold quantum error correcting code at s

One share sent to each of y_j

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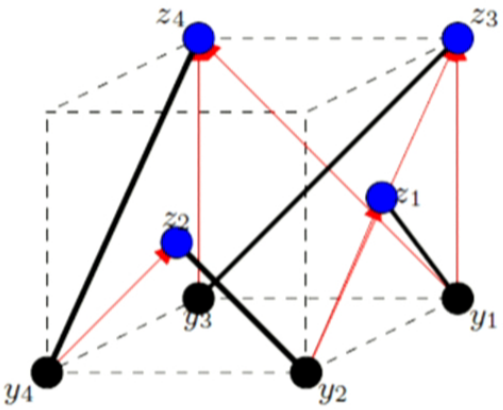
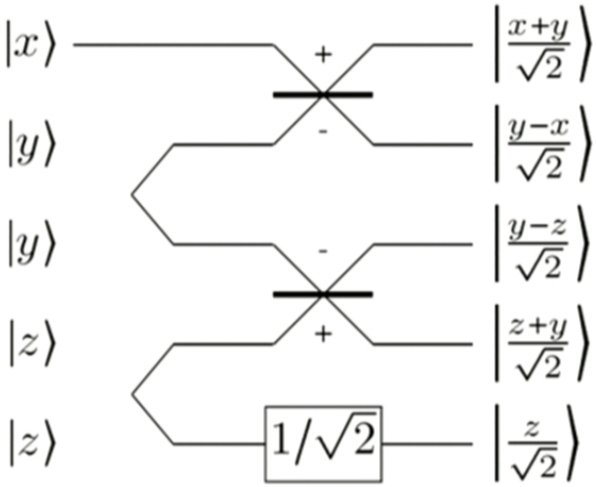
Four region example





Encoding

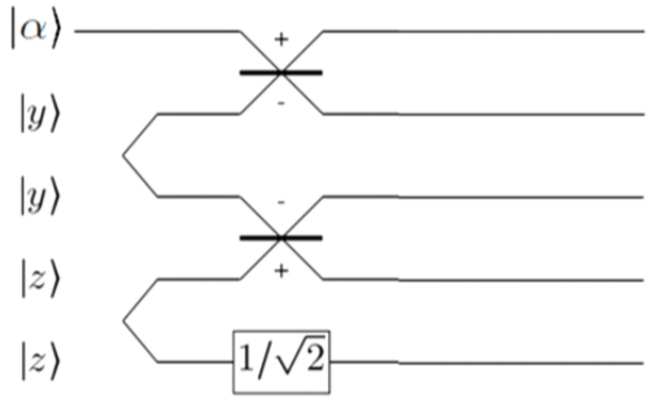
Encoding: two sets of entangled photons, passive beam splitters, single mode squeezer

We encode a coherent state $|\alpha\rangle$ since they form a basis

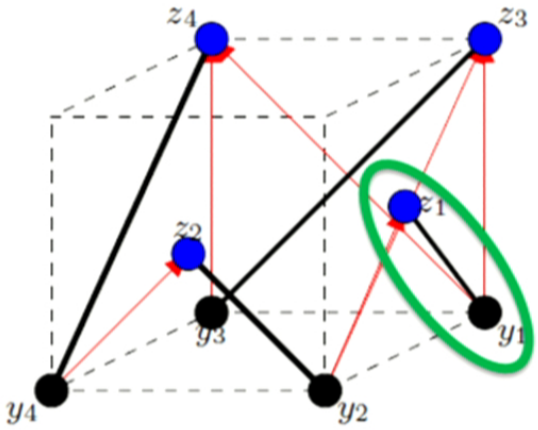
Decoding: recover from a loss of a known subset of modes

Optical implementation

Decoding to reconstruct the state in diamond D_1

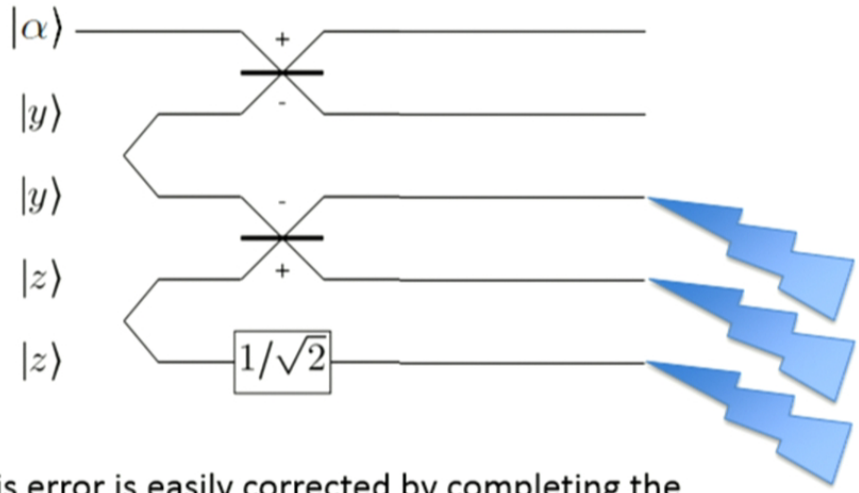


This error is easily corrected by completing the interferometer on modes 1 and 2



Optical implementation

Decoding to reconstruct the state in diamond D_1



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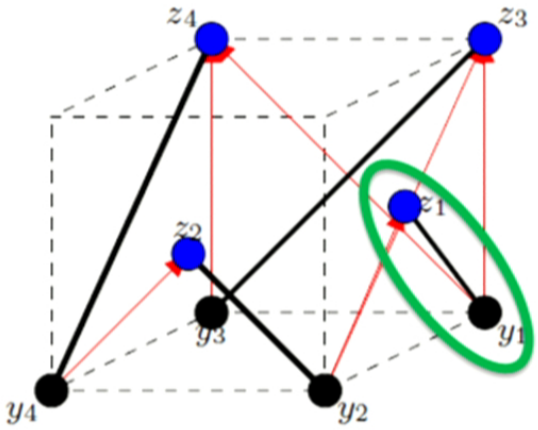

Optical implementation

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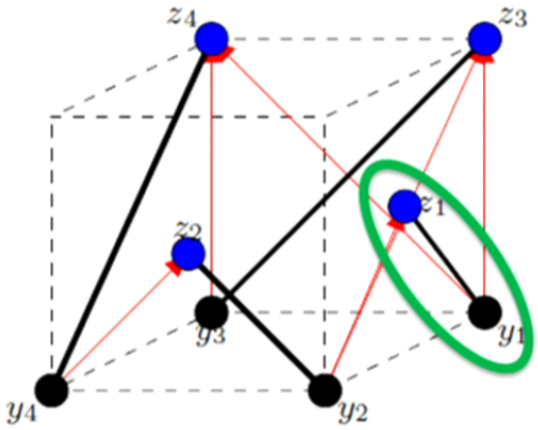
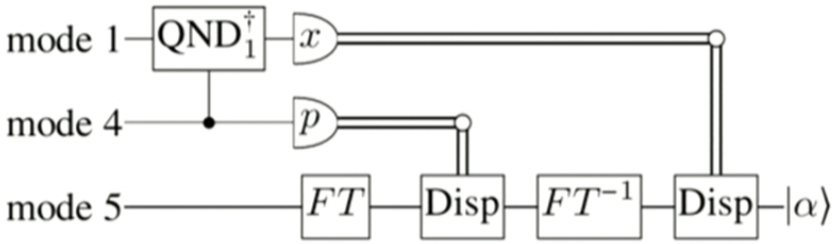
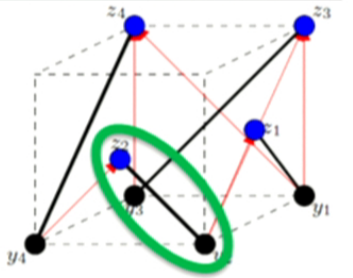
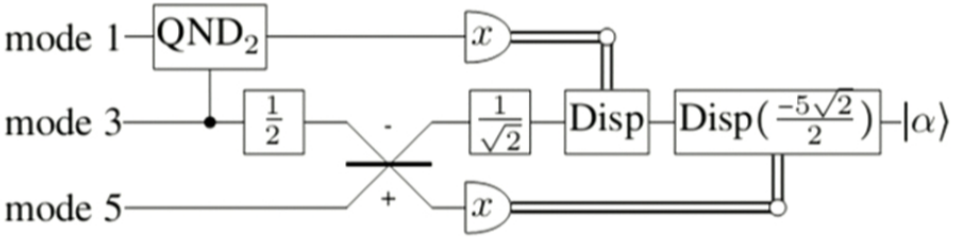
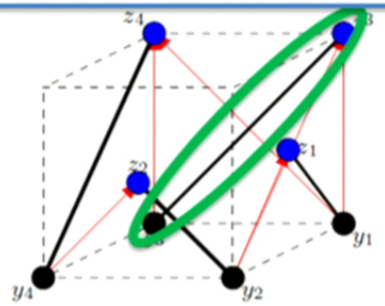


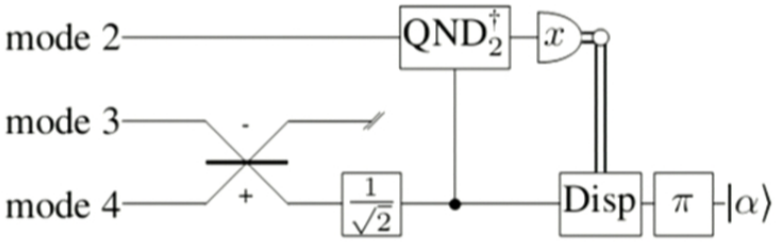
Optical implementation

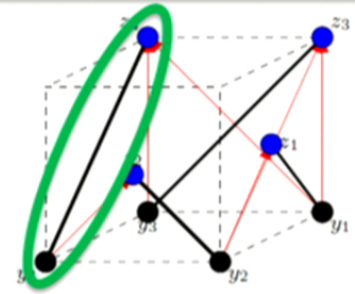


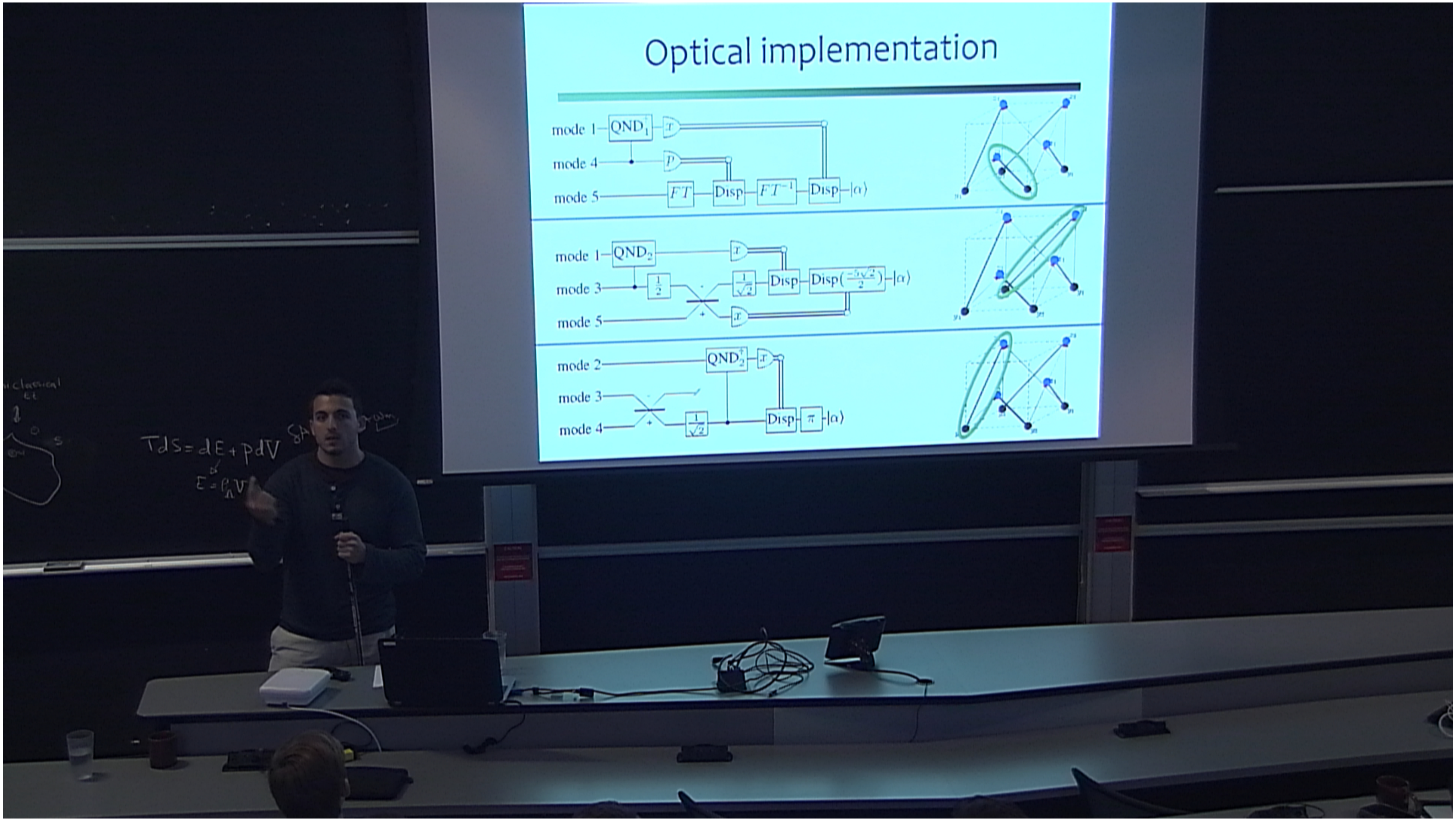




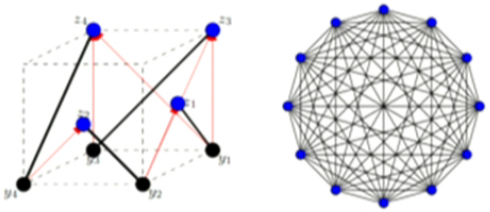




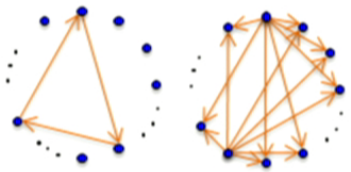


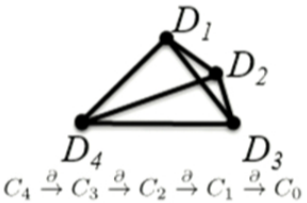

Optical implementation
mode 1
mode 4
mode 5
FT
Disp
FT^{-1}
Disp
$|\alpha\rangle$
mode 1
mode 3
mode 5
QND_2
Disp
mode 2
mode 3
mode 4
Disp
π
$|\alpha\rangle$
TdS = dE + pdV

Summary

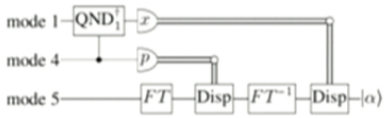


- Information replication
  - Complete characterization of the allowed configurations
  - Only constrained by no-cloning & no-signaling
  - **Realized with QEC!**

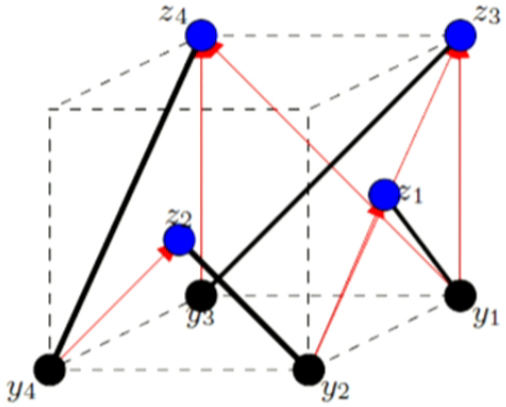




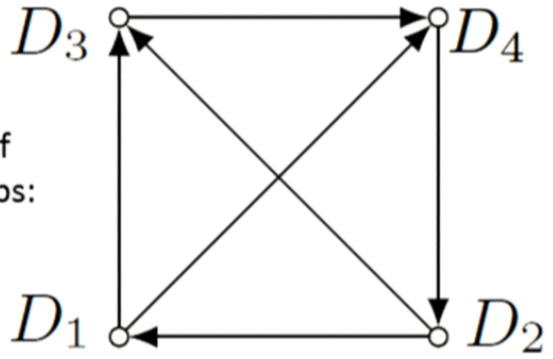
- Continuous variables
  - General solution in terms of CV codes *based on homology*
  - Specific 5 mode code complete with optical implementation



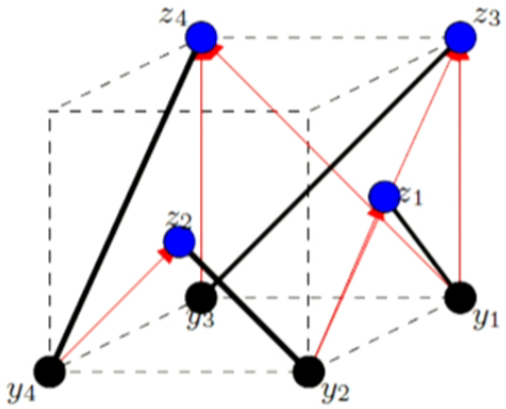
General procedure



$G = (V,E)$ graph of causal relationships:



General procedure



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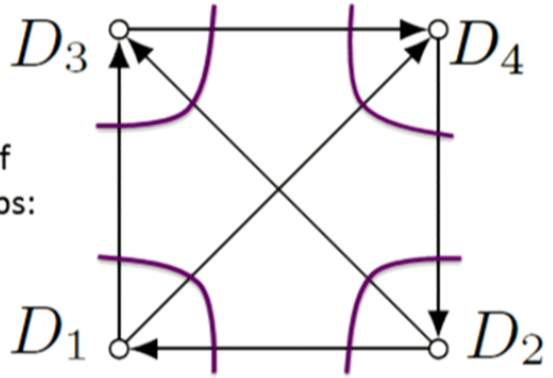


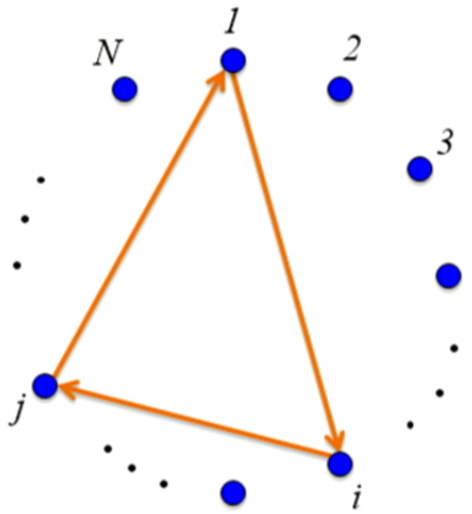
Encode φ into a quantum error correcting code with one share for each edge.

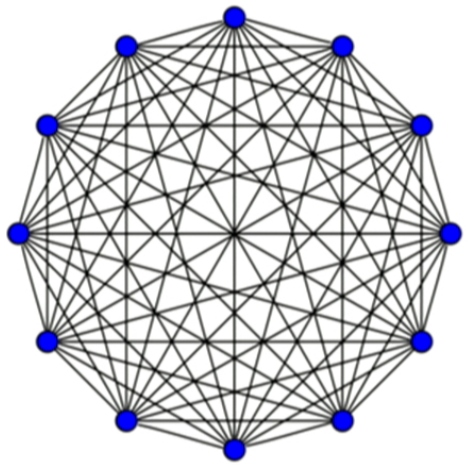
Transport each share according to directed edge in the graph

Code property: φ can be recovered provided all the shares associated to any D_j

CV Code for general replication

X-type stabilizer generators are triangular subgraphs including vertex 1:

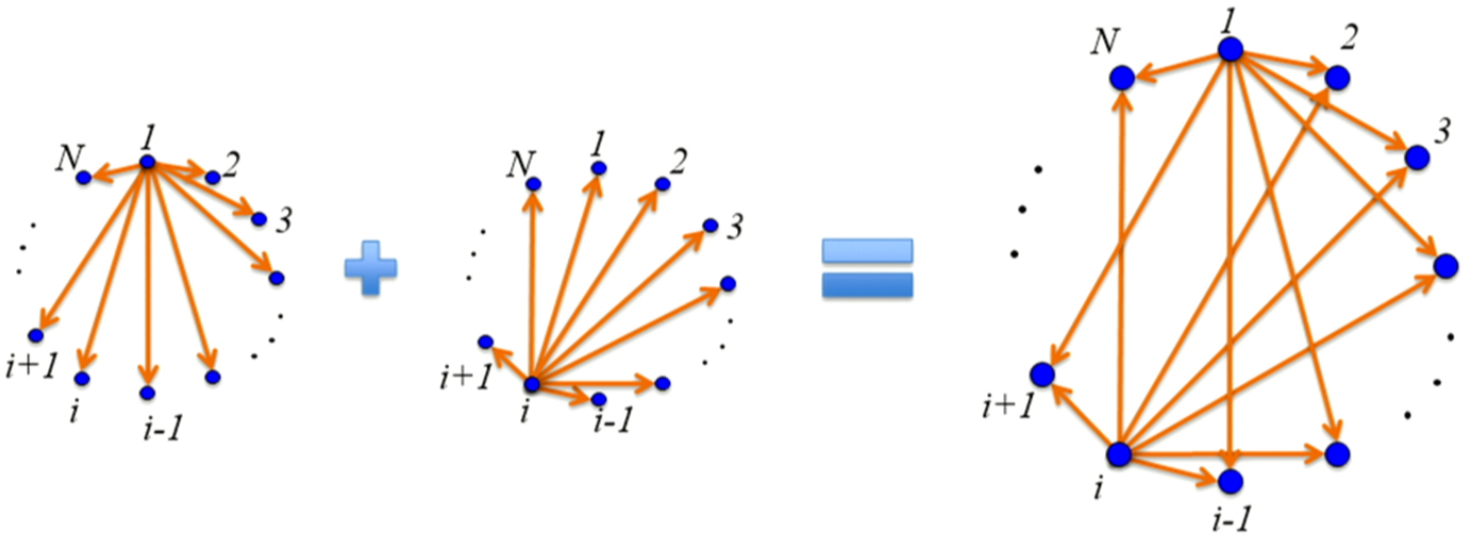




$$g_{ij} = \exp(i\boldsymbol{v_{ij}} \cdot \boldsymbol{X}), \quad (2 \le i < j \le N).$$

CV Code for general replication

P-type stabilizer generators are also subgraphs:



$$h_i = \exp(i\boldsymbol{w_i} \cdot \boldsymbol{P}), \quad (2 \le i \le N-1)$$