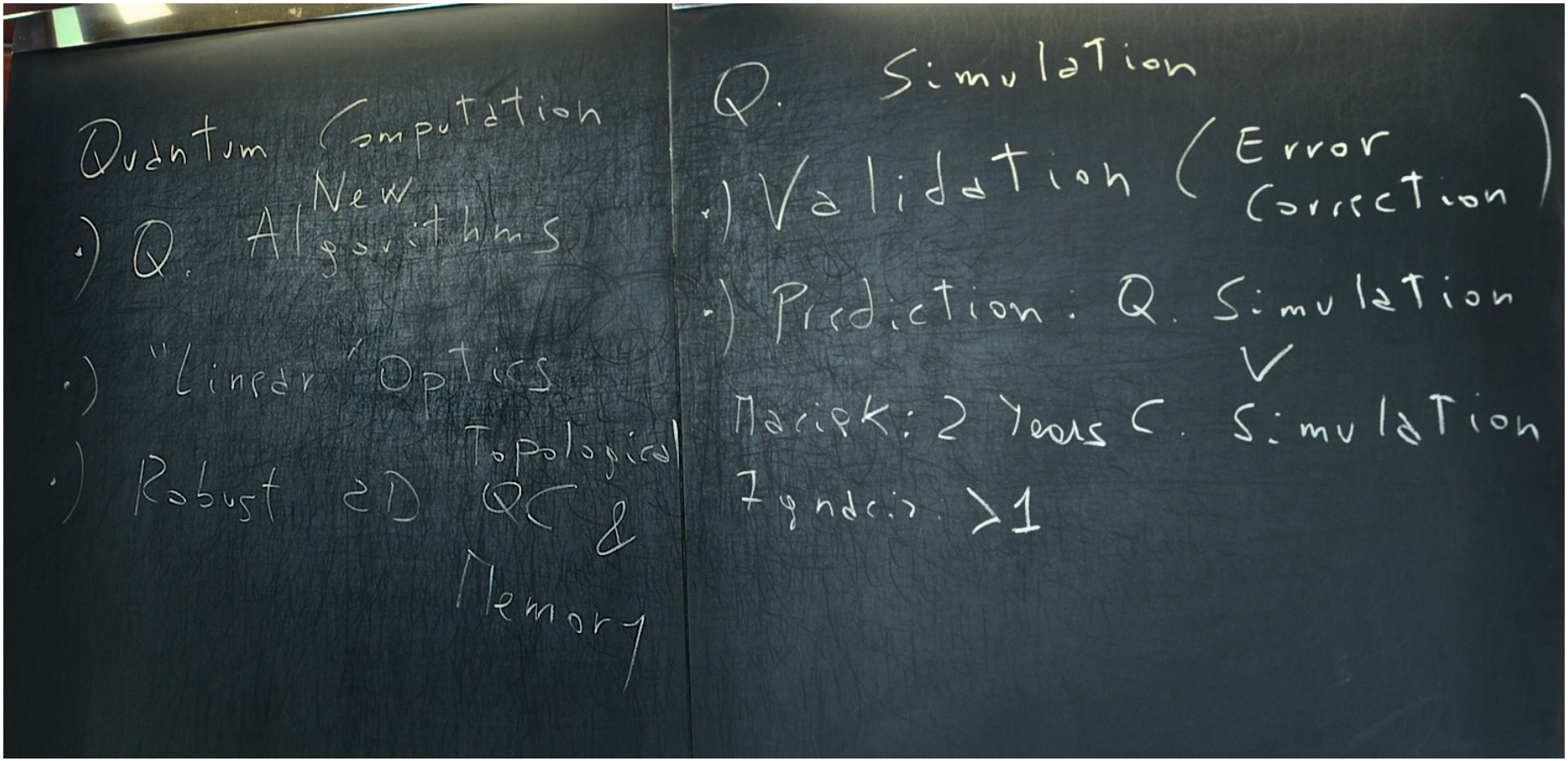
Future of QI

Benasque Quantum Informtion Workshops
2011 – 2019

July 2019

2011


Quantum Computation
New
) Q. Algorithms
) "Linear" Optics
Topological
) Robust 2D QC &
Memory
Q. Simulation
) Validation (Error
Correction)
) Prediction: Q. Simulation
V
Nanick: 2 years C. Simulation
Zyndex: >1

+5 more...

2013

QUANTUM INFORMATION THEORY

- NPT BOUND ENTANGLEMENT (PPTC ⇒ UNDIST)
- Quantum violate Ingleton ≥ 0
- Characterization M-part. entanglement + apps
- Q. Discord ??
* Unw. Q.c. with Q. Walks
* Unifying Q. Correlt. ⇐ Discord
* Q.C. with little entang.
- Charact. LOCC + POVM (measurements) LOSR
- Rôle ent. in Q.C
* Security Device-indep QKD
- General framework security dev.indep
- Certification Space-like separation dev-ind
- Example non-zero C.C. Channels
- $PPT^2 \Rightarrow$ E. Breaking

NEMTIAR VS NESSI

FOUNDATIONS OF QUANTUM PHYSICS

* PBR THEOREM
* Activation Q. non-locality
- B.E.S violate B. ineq
- Beyond B. ineq.
- PRINCIPLES FOR Q CORRELATIONS
* Q. Thermod: Landauer pple + 2nd law
- RELATIVITY & QIT IN LOW. ENERGY PHYSICS
- Firewall in B.H.
- ARE LEGGETT-GARG INEQUALITIES USEFUL?
- Decidability in QIT
- NON-LOCALITY IN MANY-BODY PHYSICS
- MULT. PRINCIPLES ENOUGH?
- LIFE AFTER LOOPHOLE-FREE BI?
- TSIRELSON'S PROBLEM

MANY-BODY PHYSICS

* TIME-DEPENDENT VARIATIONAL PRINCIPLE
* CRITICALITY IN OPEN Q SYSTEMS
- EFFICIENT SIMULATION OF Q DYNAMICS
- CLASS. PHASES HIGHER-D
- Approxs. (truncation) TN
- Thermalization physical Syst.
- Non-eq. inequalities (Quantum)
- Simulation TN HET
- TN $\overset{?}{\Longleftrightarrow}$ AdS/CFT
- Relations fluct-entanglement
- LOW-ENERGY EFFECTIVE THEORIES
- $\exists$ Self protecting Q.M. in D<4

QUANTUM OPTICS & IMPLEMENTATIONS

* GROUND STATE OF NANOMECHANICAL RESONATOR
- What is D-wave doing?
- IMPLEMENTATIONS OF DI STUFF
* DETECTION-LOOPHOLE FREE PHOTONIC EXPERIMENT
- Def. entang. bosons/fermions
- LIMITATIONS OF Q SIMULATION
- Boson sampling (Limitations)
* SUPERCONDUCTING QUBITS
* SIMULATION OF HIGH-ENERGY PHYSICS IN OPTICAL LATTICES
- CHEAP QKD
- SATELLITE-BASED Q COMM.
- CERTIFICATION OF Q SIMULATION
- LONG-DISTANCE ENT. BASED QC
- EXP IMPL. OF PBL-LIKE THEOREMS?
- STATE [illegible]

2013: Achievements in the last few years

Quantum Info

- Universal qc w/ q walk
- Unifying q correlations
- QC w/ little entanglement
- security device-indep QKD

Foundations QP

- PBR Theorem
- activation of q nonlocality
- Q thermo: Landauer's principle & 2nd Laws

Q Optics & Implementations

- ground state nanomech syst
- detection-loophole-free photonic exp
- superconducting qubits
- q sim.: high-energy physics in opt lattices
- q sim.: beating class comp

Many-Body Physics

- complexity of Hamiltonians
- criticality in open systems
- time-dependent variational principle

2013: Open Problems I

Quantum Info

- NPT bound entanglement
- Q violation Ingleton ineq
- m-partite entanglement: characterization & applic
- Q discord ??
- LOCC: characterization
- rôle of entanglement in QC
- device-indep: general framework security; certification of spacelike sep
- non-additivity of EOF/class capacity: examples
- QC more powerful than CC?
- $\text{PPT}^2 \Rightarrow$ ent breaking

Foundations QP

- bound ent violate Bell Ineq?
- beyond Bell Ineq
- principles for Q correlations
- relativity & QM in low-energy physics
- QI + relativity
- B.H. info paradox / firewall
- are Leggett-Garg Ineq useful?
- decidability in QIT
- non-locality in many-body phys
- life after loophole-free Bell Exp
- Tsirelson's Problem
- Q chaos & entanglement

2013: Open Problems II

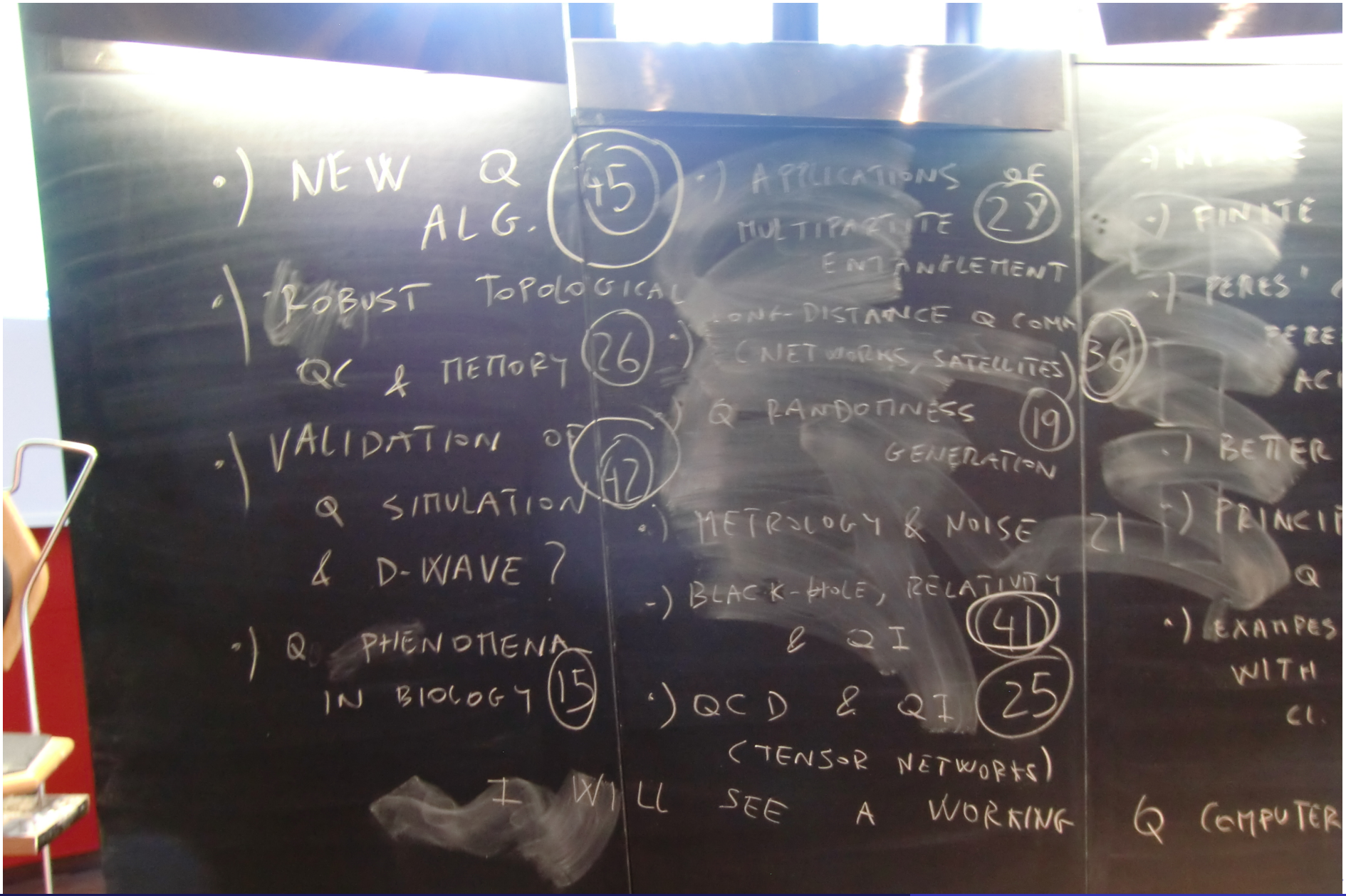
Many-Body Physics

- efficient sim of Q Dynamics
- classific phases higher D
- approx TN
- thermalization
- non-equilib inequalities (quantum)
- simulation TN HEP
- TN $\stackrel{?}{\Leftrightarrow}$ AdS/CFT
- relation fluctuat $\leftrightarrow$ entang.
- low-energy effective theories
- self-protect. Q Mem. $D < 4$?
- robustness topolog memories

Q Optics & Implementations

- what is D-Wave doing?
- implementations of QI stuff
- Q networks
- cheap QKD
- satellite-based Q Comm
- certification of Q Sim
- long-distance ent-based QC
- exp test of PBR-like theorems
- many-body state prep
- def ent of bosons/fermions
- limitations of Q simulations
- Boson Sampling (limitations)

2013 – Concluding Session



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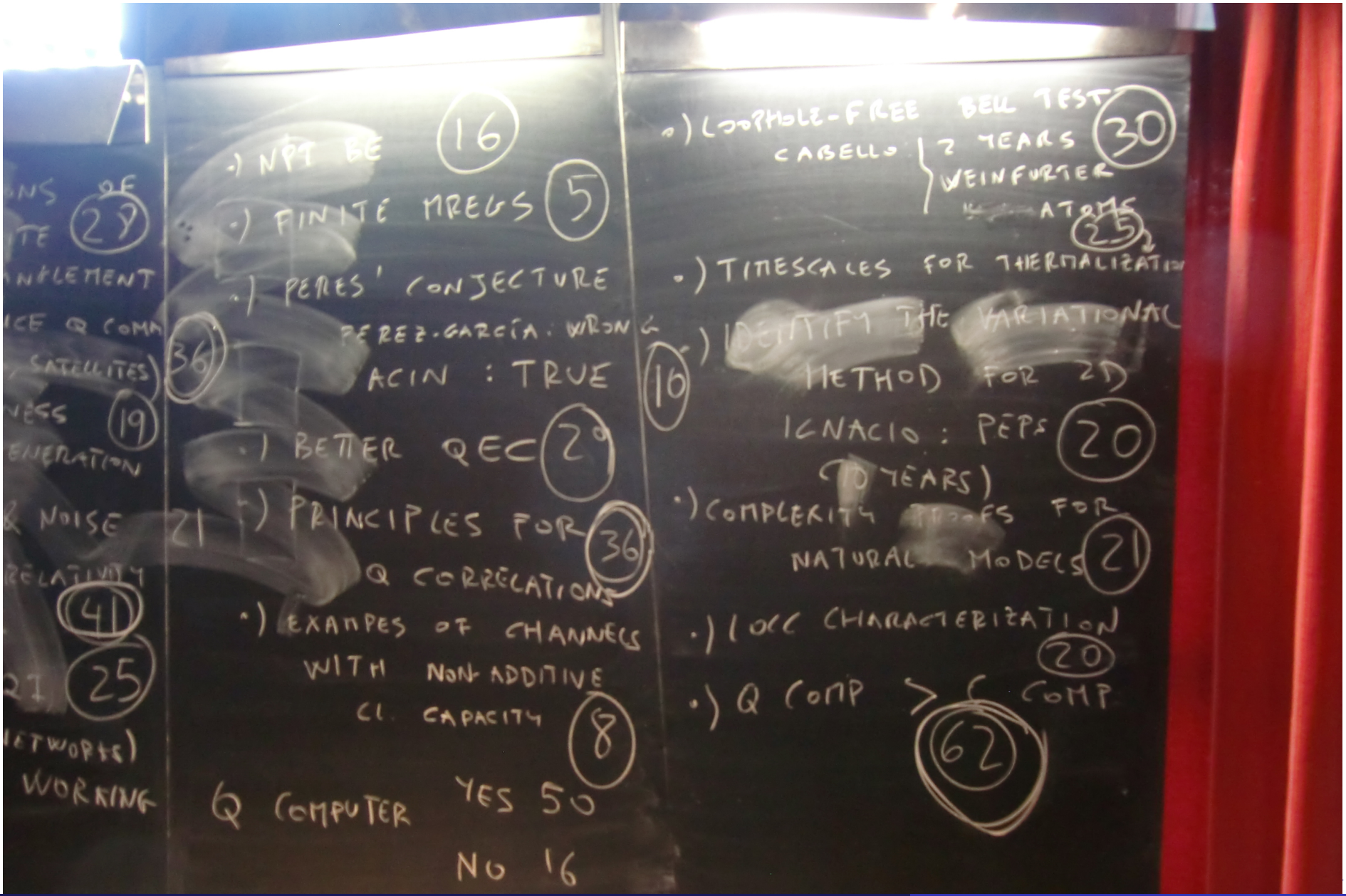

The Top 10 of Open QIS Challenges 2013

1. Q computation more powerful than classical? **(62)**
2. New q algorithms **(45)**
3. Certification of q simulation **(42)**
4. Black Holes, general relativity & q information (black hole information paradox) **(41)**
6. Long-distance q communication (networks, satellites) **(36)**
6. Principles for q correlations **(36)**
7. Loophole-free Bell test (30)
8. better QECC (29)
9. robust topological QC & QMemory (26)
10. timescales for thermalization (25)
10. high-energy physics and QI (tensor networks) (25)

2015

2015 Open Problems

OPEN PROBLEMS SESSION Benasque 2015 *Adán Cabello & Géza Giedke* July 8th, 2015

208	INFORMATION/COMPUTATION
30	**black holes & holography**
30	**demonstrate supremacy/speedup of QC**
28	**better quantum error correcting codes**
21	**multipartite entanglement**
16	**QFT and tensor networks**
10	macroscopic qubits/QI
10	quantum artificial intelligence (machine learning, etc.)
10	the existence of NPT bound entanglement

176	FOUNDATIONS
28	**principles for quantum correlations**
26	**encorporating time into the foundations of QT**
19	**quantum mechanics and relativity at low energies**
17	**experiment to rule out realist interpretation**
15	**role of causality**
13	quantum thermo: work and heat?
12	are all states useful?
11	protocols using QT + relativity

178	MANY-BODY PHYSICS
32	**better numerical algorithms for simulation**
24	**Quantum PCP conjecture**
19	**understanding the interplay of equilibration/transport/localization**
18	**entanglement detection**
18	**variational methods/tensor networks for field theories/continuous models in >= 2D**
14	uses for many-body phases
13	classifying topological phases in D=2 or higher
12	timescales of equlibration (also thermalization)

170	IMPLEMENTATIONS
25	**experimental demonstration of a protocol enhanced by quantum error correction**
25	**a 2D topological (e.g. surface) code**
24	**a quantum computer**
23	**long-distance quantum teleportation**
23	**q. chemistry simulation**
22	gravity tested in the lab
20	quantum repeaters
8	more efficient process tomography

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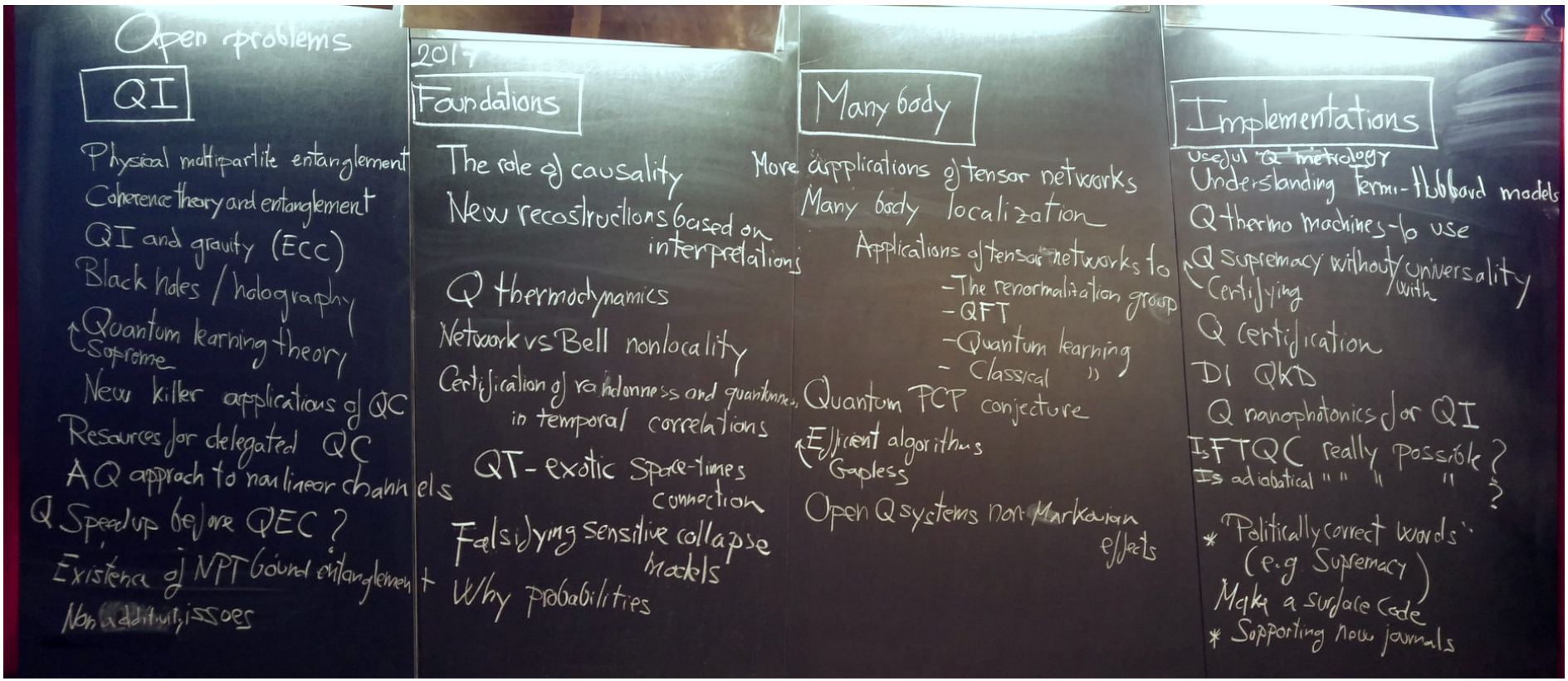
2017


Open problems
QI
Physical multipartite entanglement
Coherence theory and entanglement
QI and gravity (ECC)
Black holes / holography
Quantum learning theory
Supreme
New killer applications of QC
Resources for delegated QC
AQ approach to non linear channels
Q Speedup before QEC ?
Existence of NPT bound entanglement
Non additivity issues
2017
Foundations
The role of causality
New reconstructions based on interpretations
Q thermodynamics
Network vs Bell nonlocality
Certification of randomness and quantumness in temporal correlations
QT - exotic Space-times connection
Falsifying sensitive collapse models
+ Why probabilities
Many body
More applications of tensor networks
Many body localization
Applications of tensor networks to
- The renormalization group
- QFT
- Quantum learning
- Classical "
Quantum PCP conjecture
Efficient algorithms
Gapless
Open Q systems non Markovian effects
Implementations
Useful Q metrology
Understanding Fermi-Hubbard models
Q thermo machines - to use
Q supremacy without universality
Certifying
with
Q certification
DI QKD
Q nanophotonics for QI
IsFTQC really possible ?
Is adiabatical " " " " ?
* "Politically correct words"
(e.g. Supremacy)
Make a surface code
* Supporting new journals

2017 Open Problems I

QI

- physical multipartite entanglement
- coherence theory and entanglement
- QI and gravity (ECC)
- Black Holes / holography
- (supreme) quantum machine learning
- new killer applications for QC
- resources for delegated QC
- q approach to nonlinear channels
- q speedup before QECC?
- NPT bound entanglement?

Foundations

- role of causality
- new reconstructions based on interpretations
- q thermodynamics
- network vs Bell nonlocality
- certification of randomness and quantumness in temporal correlations
- QT–exotic space-times connection
- falsifying sensitve collapse models
- why probabilities?

2017 Open Problems I

Many-body

- more applications tensor networks
- many-body localization
- applications of TN to: RNG, QFT, q learning, c learning
- quantum PCP conjecture
- efficient algorithms for gapless systems
- open q systems w non-Markovian effects

Implementations

- useful q metrology
- understanding Fermi-Hubbard model
- q thermo machines to use
- certifying q supremacy without (or with) universality
- q certification
- device-independent QKD
- q nanophotonics for QIP
- is FTQC really possible?
- is adiabatic QC really possible?
- make a surface code

Bets over the years

- NPT bound entanglement? 2011 Ruskai: No
- general composable security proof for DI-QKD 2011 Winter: yes; Acín: 2 yrs
- Peres' Conjecture? 2011 Perez-García: False ✓
  Vertesi and Brunner 2014
- optimal states for 1-mode Gaussian channels? 2011 García-Patrón: vacuum (✓)
- loophole-free Bell test
  2011 Kleinmann: $>$ 2y ✓2013 Cabello: 2y, Weinfurter (✓)
  2015: Hensen et al; Giustina et al; Shalm et al
- D-wave QC? 2011 Cirac: No (2y) ✓
- q repeater better than direct transmission 2011 Brask Bohr: 3y
- q sim better than c sim Lewenstein: 2y; Cirac: $>$ 1y
- **the** variational method? 2013 Cirac: PEPS (10y)
- business interest in QC will increase 2015 Latorre: yes (2y) ✓

Voted predictions

- a universal quantum computer within our lifetimes?

  in 2013: **YES: 50**; NO: 16 in 2015: **YES: 60**; NO: 11; ABS: 5.

- predictions 2017 (for 2019):

  • quantum computers with X qubits and 10^3 gates:
  (A) $>$ 100 qubits (3; 4%) (B) $50-100$ (**37; 58%**) (C) <50 (24; 46%)

  • device-independent QKD:
  (A) $<$ 1km (3; 6%) (B) $1-10$km (**35; 71%**) (C) $>$ 10k (11, 23%)

  • reliable phase diagram Hubbard model:
  (A) Yes (9; 29%) (B) NO (22; 71%)

  • q metrology: commercial device using
  (A) only entanglement (24; 61%) (B) entanglement and (Q?)EC (2; 5%) (C) none (13, 33%)

2019

recent advances – major open problems – bets/predictions