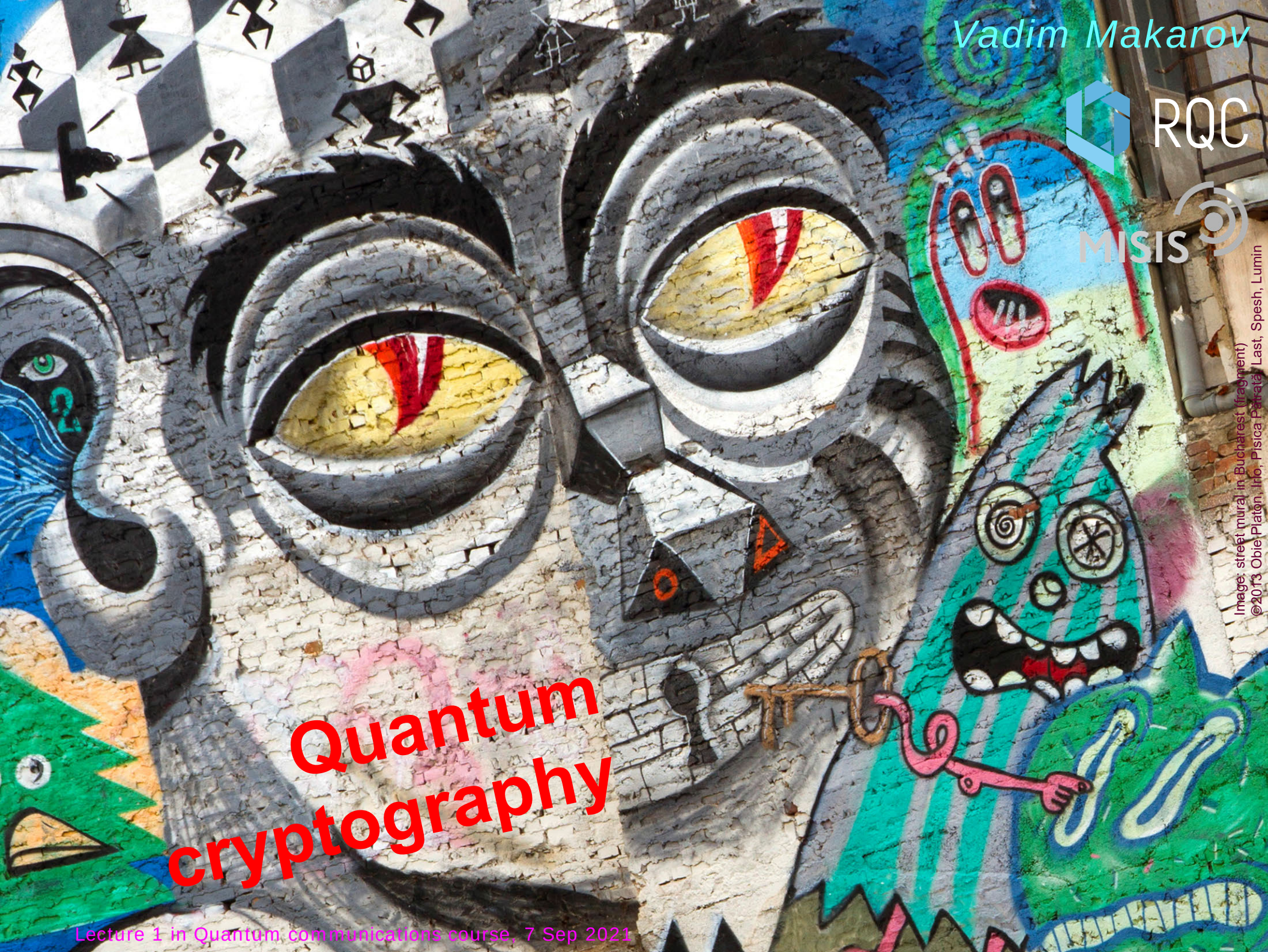

Quantum cryptography

Vadim Makarov

RQC

MISIS

Lecture 1 in Quantum communications course, 7 Sep 2021

Image: street mural in Bucharest (fragment)
©2013 Obie Platon, Info, Pisica Pătată, Last, Spesh, Lumin

A (very) brief history of cryptography

		Broken?
Monoalphabetic cipher	invented ~50 BC (J. Caesar)	~850 (Al-Kindi)
Nomenclators (code books)	~1400 – ~1800	✓
Polyalphabetic (Vigenère)	1553 – ~1900	1863 (F. W. Kasiski)
…		
Polyalphabetic electromechanical (Enigma, Purple, etc.)	1920s – 1970s	✓
…		
DES	1977 – 2005	1998: 56 h (EFF)
Public-key crypto (RSA, elliptic-curve)	1977 –	will be once we have q. computer (P. Shor 1994)
AES	2001 –	?
Public-key crypto ('quantum-safe')	in development	?

Breaking cryptography retroactively

Photo ©2013 AP / Rick Bowmer

Mosca theorem

y (re-tool infrastructure)

x (encryption needs be secure)

z (time to build large quantum computer)

Time

If $x + y > z$, then worry.

M. Mosca, http://eprint.iacr.org/2015/1075

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Quantum cryptography	invented 1984, in development	**impossible***
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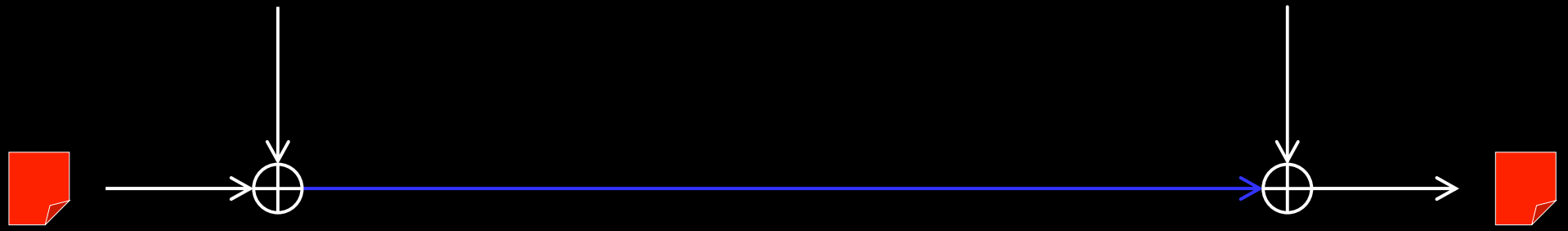
One-time pad

Alice

Bob

Random
secret key of same length as message

Random
secret key



Message

Message

α	β	α⊕β
0	0	0
0	1	1
1	0	1
1	1	0

G. Vernam, U.S. patent 1310719 (filed in 1918, granted 1919)
C. E. Shannon, Bell Syst. Tech. J. **28**, 656 (1949)

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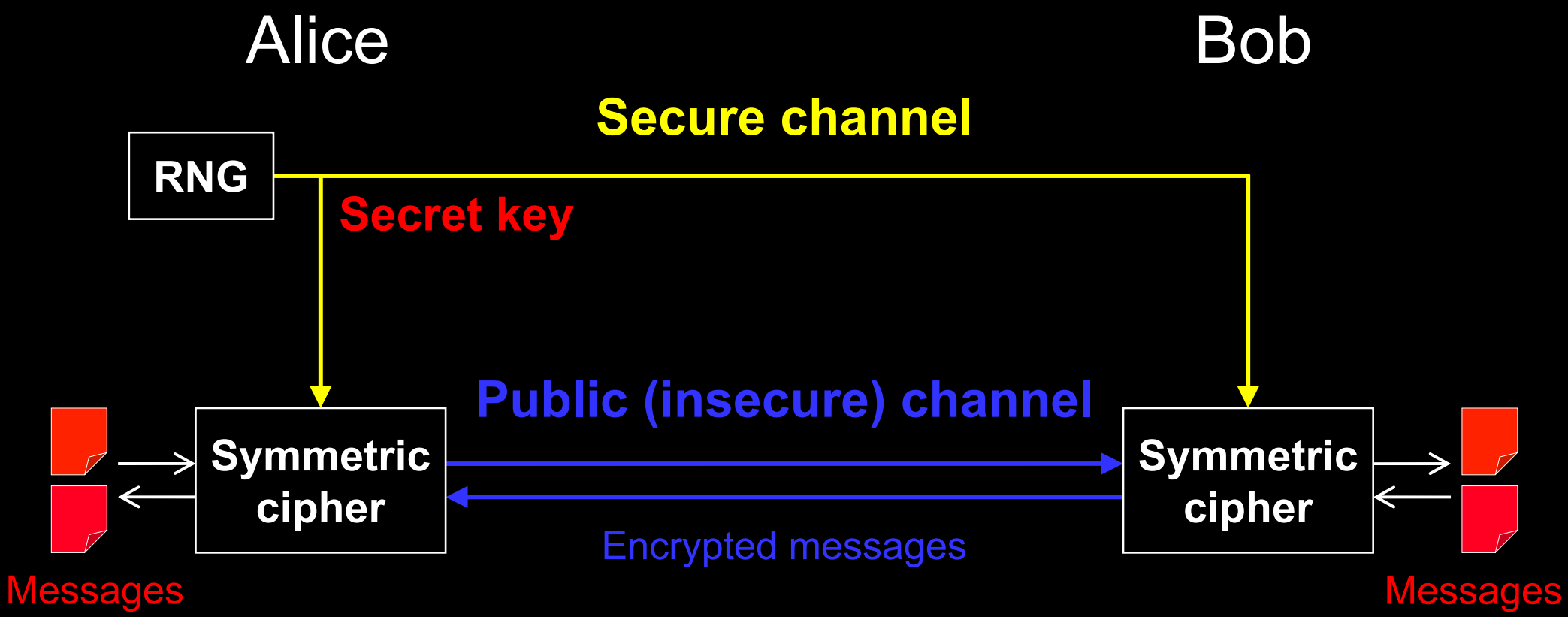
Quantum communication primitives

	Advantages over classical primitives: Unconditionally secure?	Less resources?	Other quantum advantages?
Money	●		
Key distribution	●		
Secret sharing	●		
Digital signatures	●	●	
Superdense coding		●	
Fingerprinting		●	
Oblivious transfer	Impossible		●
Bit commitment	Impossible		●
Coin-tossing	●		
Cloud computing	●		
Software leasing	●		
Bitcoin		●	
Bell inequality testing	(no classical equivalent)		
Teleportation			
Entanglement swapping			
Interaction-free measurement			
Random number generators	●		

Quantum communication primitives

Money	S. Wiesner, unpublished circa 1970, Sigact News **15**, 78 (1983); S. Aaronson, P. Christiano, Proc. STOC'12, 41 (2012)
Key distribution	idquantique.com, quantum-info.com, qasky.com, goqrate.com
Secret sharing	W. P. Grice *et al.,* Opt. Express **23**, 7300 (2015).
Digital signatures	R. Collins *et al.,* Phys. Rev. Lett. **113**, 040502 (2014)
Superdense coding	C. H. Bennett, S. J. Wiesner, Phys. Rev. Lett. **69**, 2881 (1992)
Fingerprinting	J.-Y. Guan *et al.,* Phys. Rev. Lett. **116**, 240502 (2016)
Oblivious transfer	C. Erven *et al.,* Nat. Commun. **5**, 3418 (2014)
Bit commitment	T. Lunghi *et al.,* Phys. Rev. Lett. **111**, 180504 (2013)
Coin-tossing	A. Pappa *et al.,* Nat. Commun. **5**, 3717 (2014)
Cloud computing	S. Barz *et al.,* Science **335**, 303 (2012)
Software leasing	A. Broadbent *et al.,* arXiv:2101.12739
Bitcoin	J. Jogenfors, Proc. IEEE ICBC 2019, 245 (2019)
Bell inequality testing	B. Hensen *et al.,* Nature **526**, 682 (2015)
Teleportation	X.-S. Ma *et al.*, Nature **489**, 269 (2012)
Entanglement swapping	M. Żukowski *et al.,* Phys. Rev. Lett. **71**, 4287 (1993)
Interaction-free measurement	A. C. Elitzur, L. Vaidman, Found. Phys. **23**, 987 (1993)
Random number generators	idquantique.com, picoquant.com

Key distribution for encryption

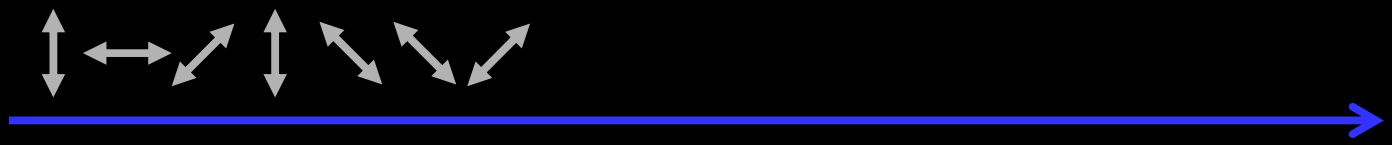


Quantum key distribution transmits secret key by sending quantum states over *open channel.*

Quantum key distribution (QKD)

Alice

Bob



Prepares photons

or ?

Measures photons

(0), (1)

(0), (1)

Eavesdropping introduces errors

C. H. Bennett, G. Brassard (1984)

Post-processing in QKD

Alice ⟷ **Classical channel** (e.g., internet) ⟷ Bob

Raw photon detection data

↓

Sifting (discard bits Bob failed to detect or detected in incompatible basis)

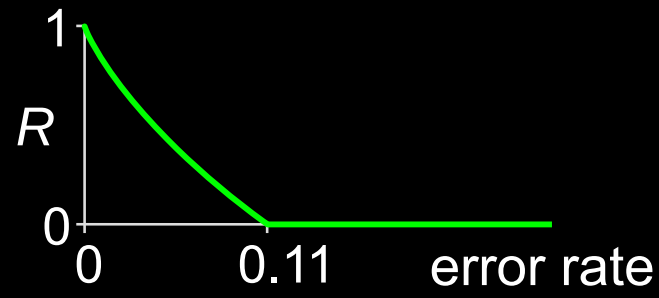
↓

Error correction

↓ error rate

Secret key rate estimation

↓ R



Privacy amplification (compress key using a hash function)

↓

Authentication Alice–Bob ← 1st time: initial short key, or public-key infrastructure

↓

Secret key — small fraction → **Authentication Alice–Bob**

C. H. Bennett *et al.*, J. Cryptology **5**, 3 (1992); N. Lütkenhaus, Phys. Rev. A **59**, 3301 (1999)

Commercial QKD

Classical encryptors:

L2, 2 Gbit/s
L2, 10 Gbit/s
L3 VPN, 100 Mbit/s

WDMs

Key manager

QKD to another node
(4 km)

QKD to another node
(14 km)

www.swissquantum.com
ID Quantique *Cerberis* system (2010)

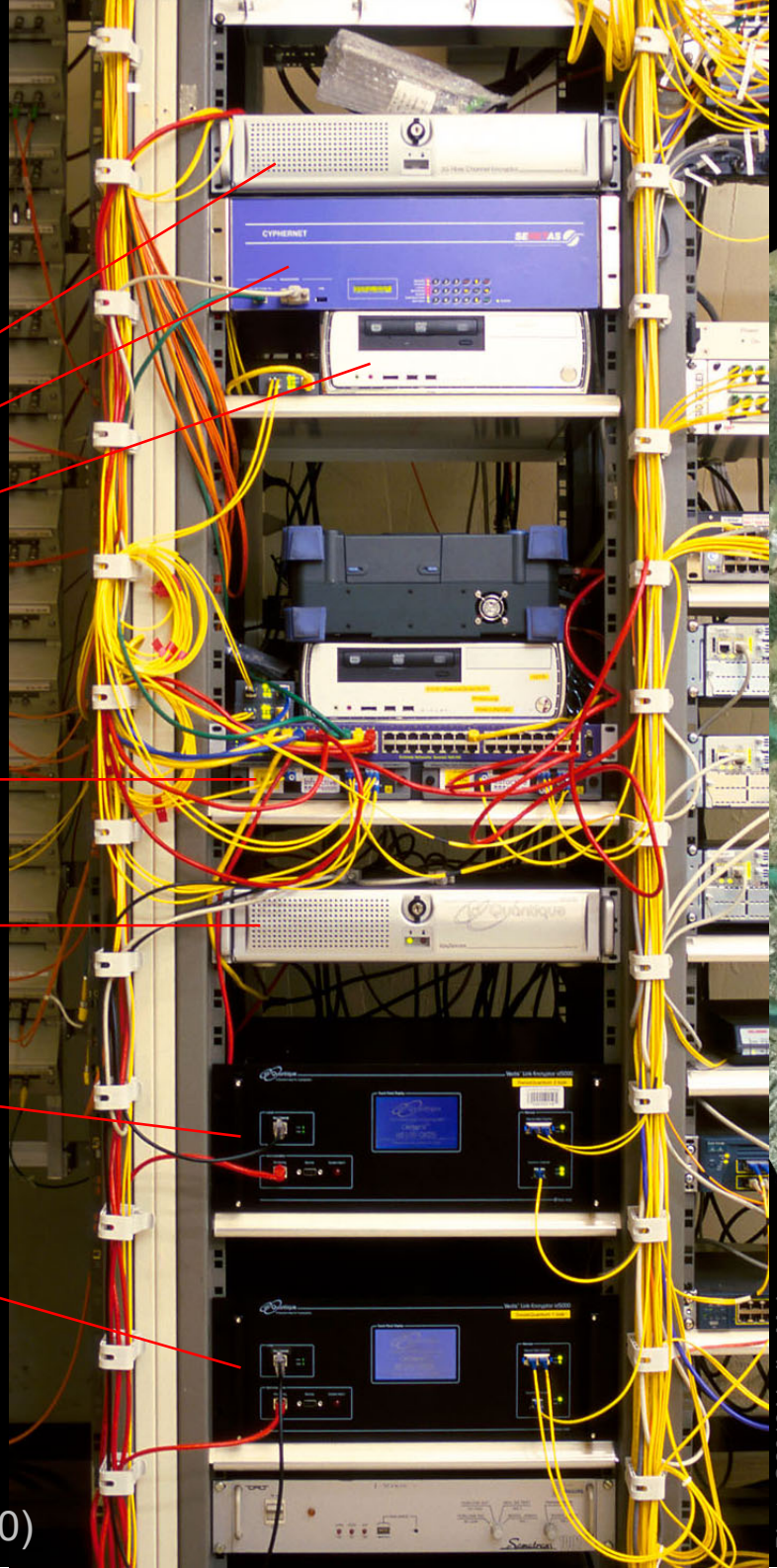
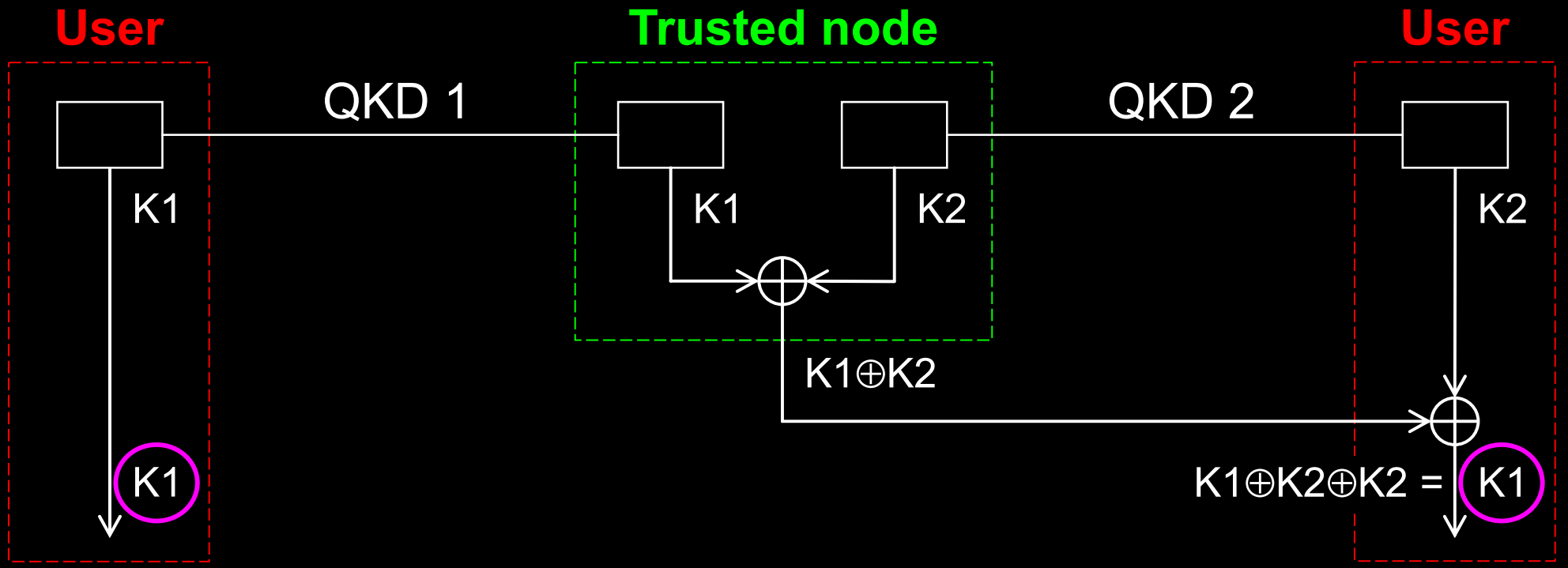
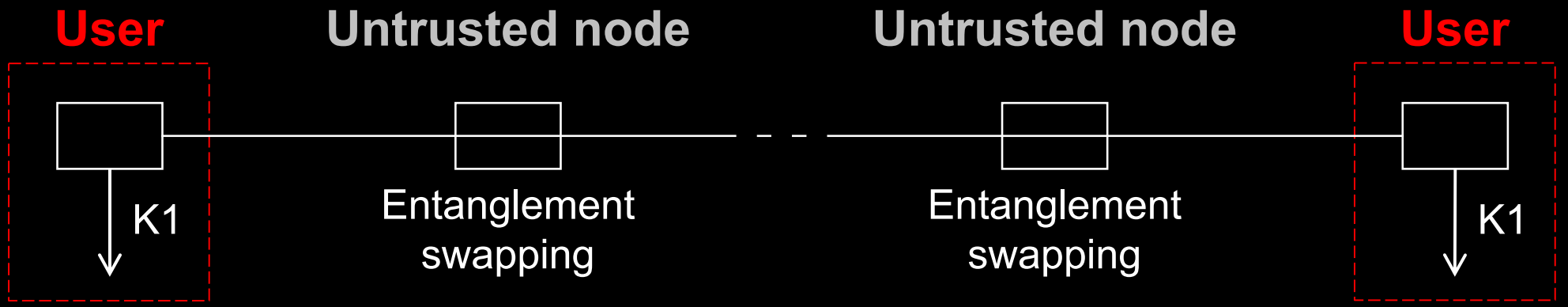


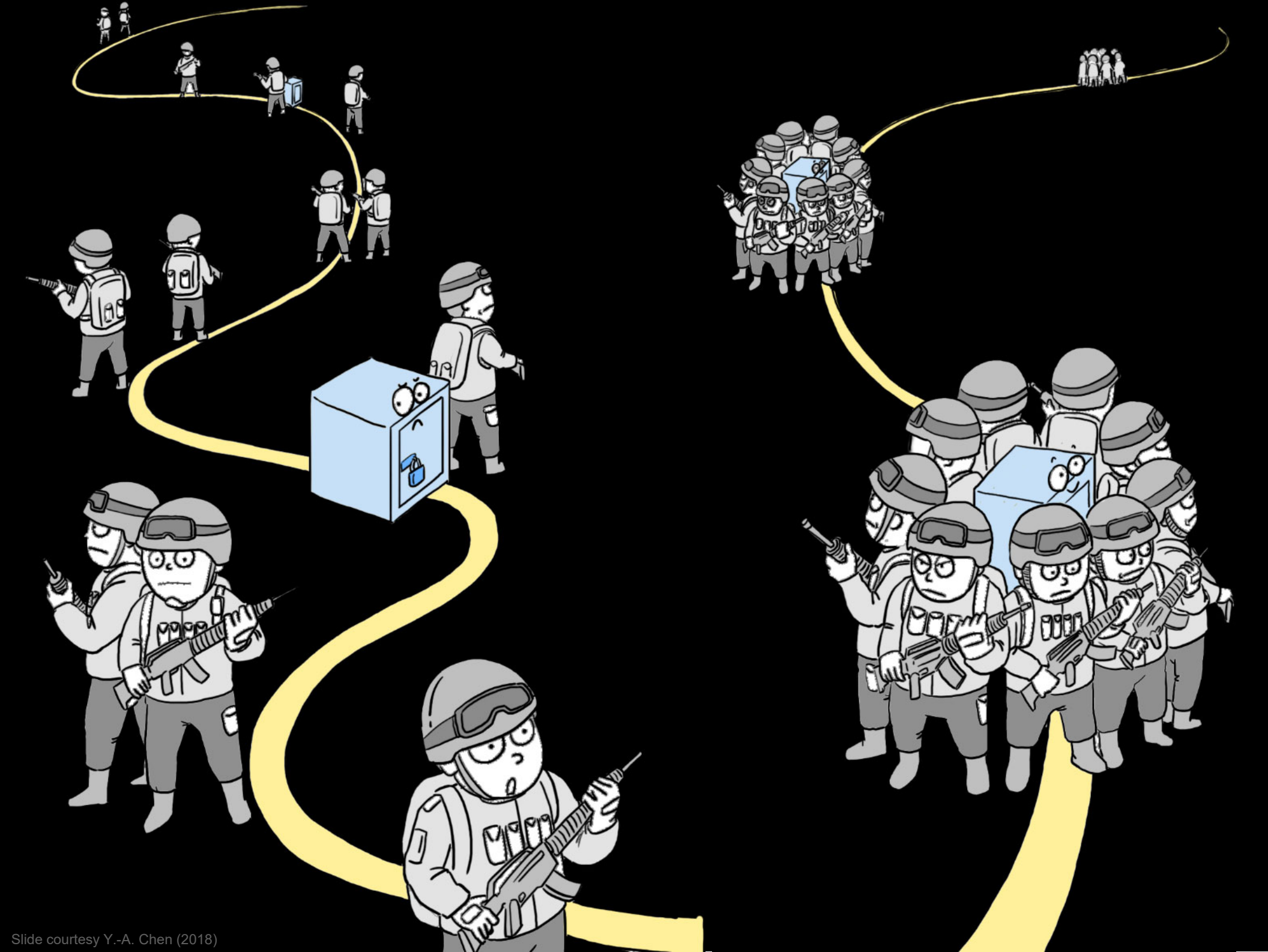
Photo ©2010 Vadim Makarov

Today: trusted-node repeater



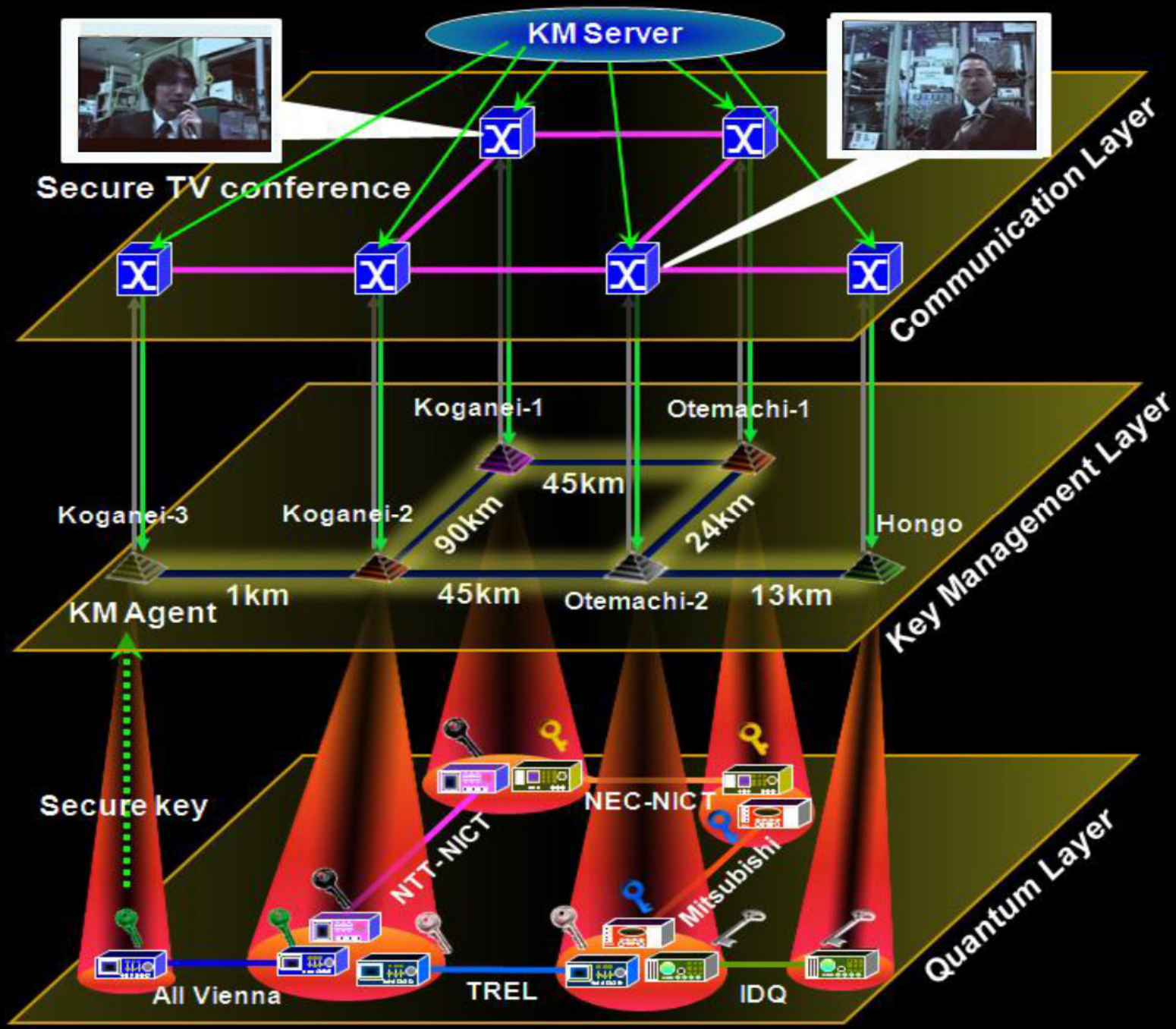
Future: quantum repeater





Slide courtesy Y.-A. Chen (2018)

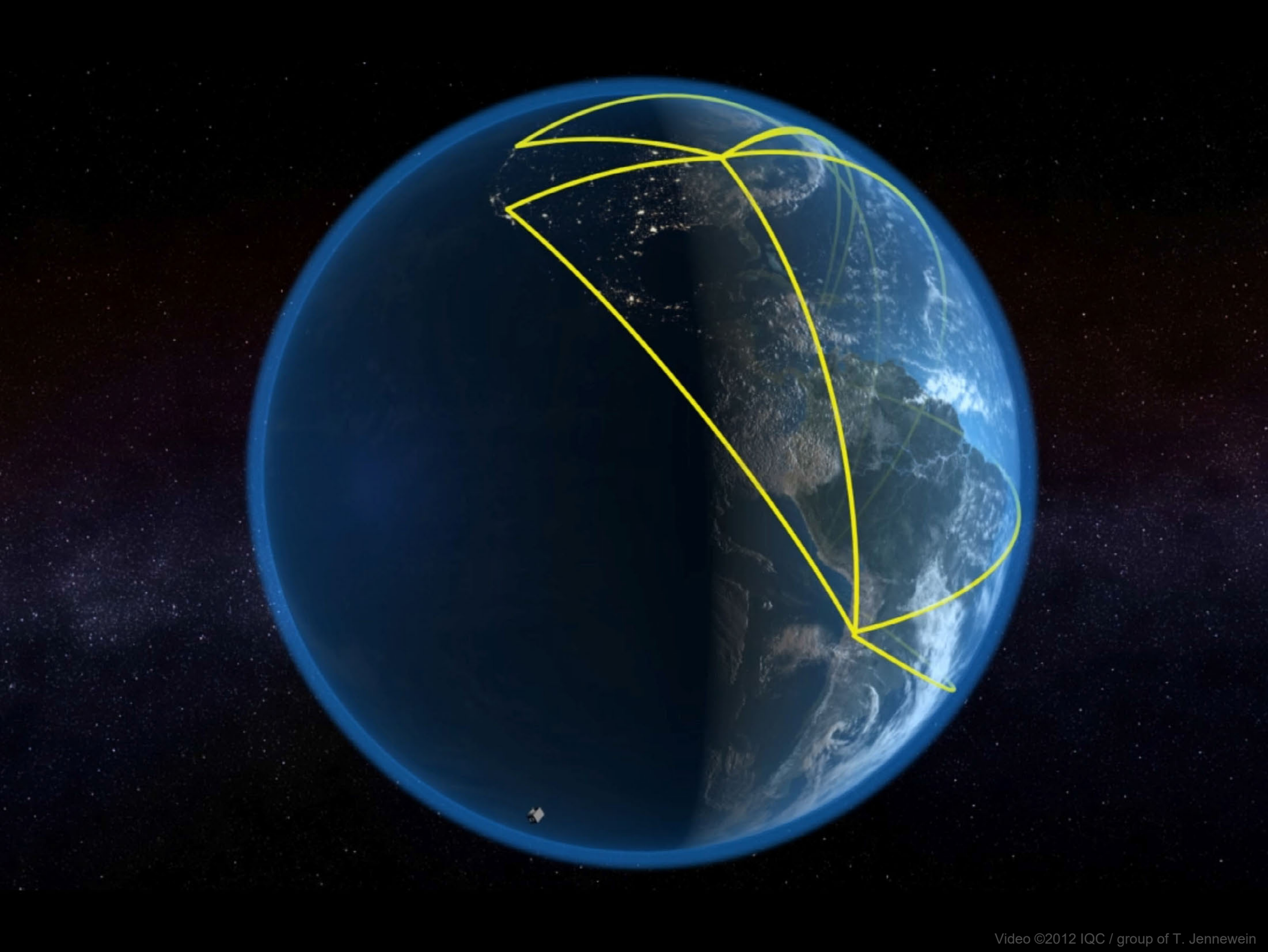
Trusted-node network



M. Sasaki *et al.*, Opt. Express **19**, 10387 (2011)

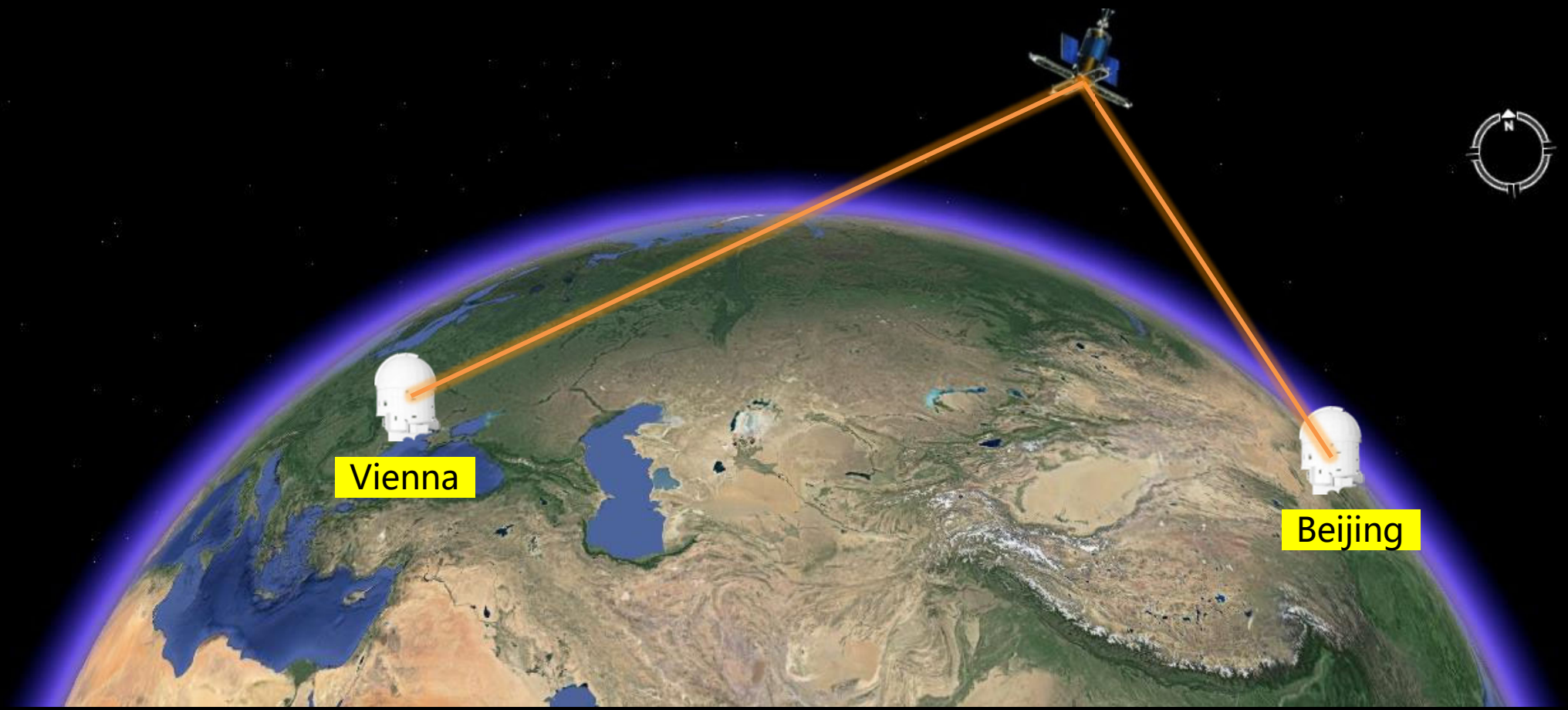
Shanghai control center of the Chinese quantum key distribution network and satellite

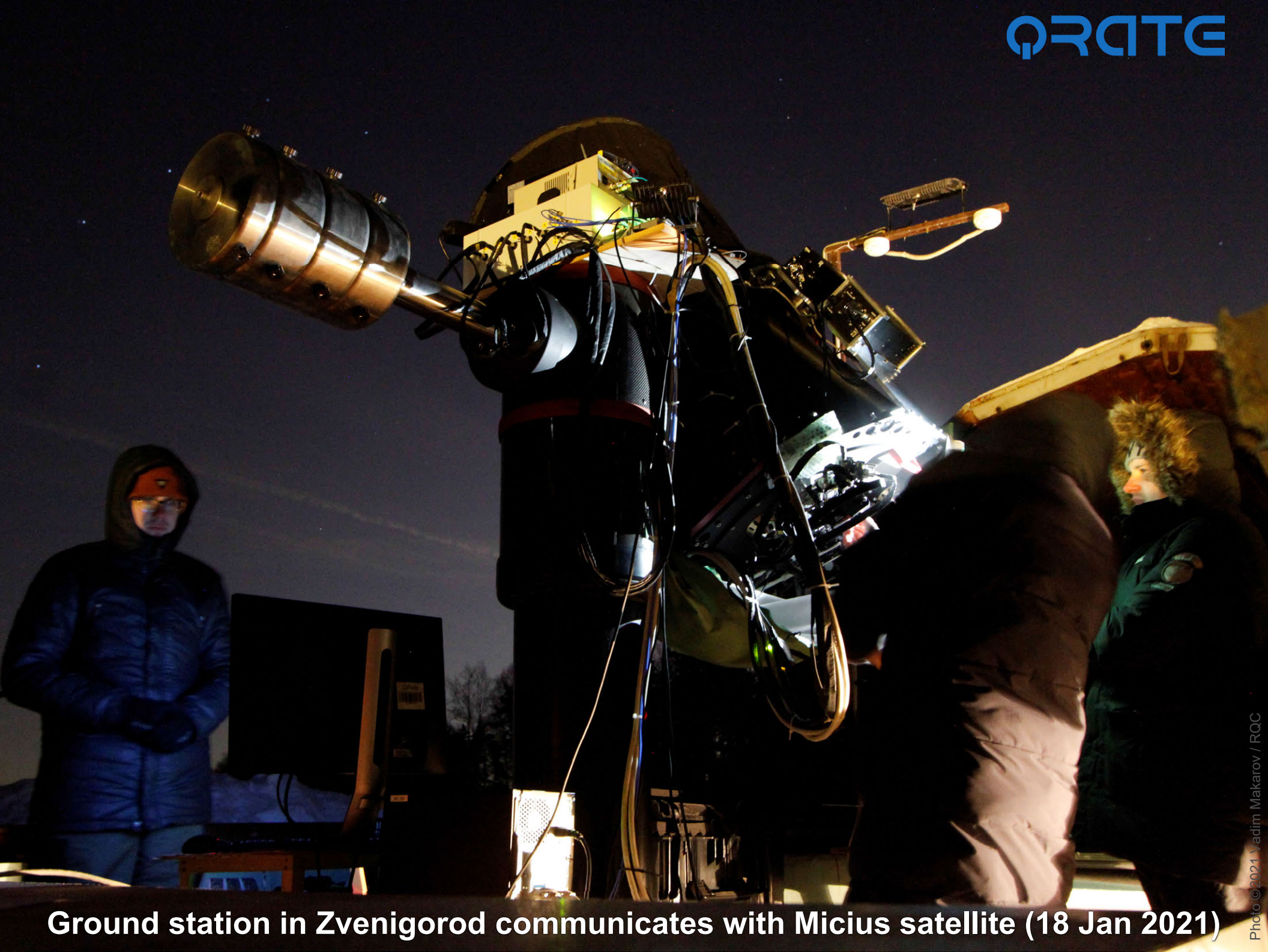

Global
quantum key distribution
Video ©2012 IQC / group of T. Jennewein



CAS Strategic Priority Research Program: Quantum Satellite

- Intercontinental quantum key distribution





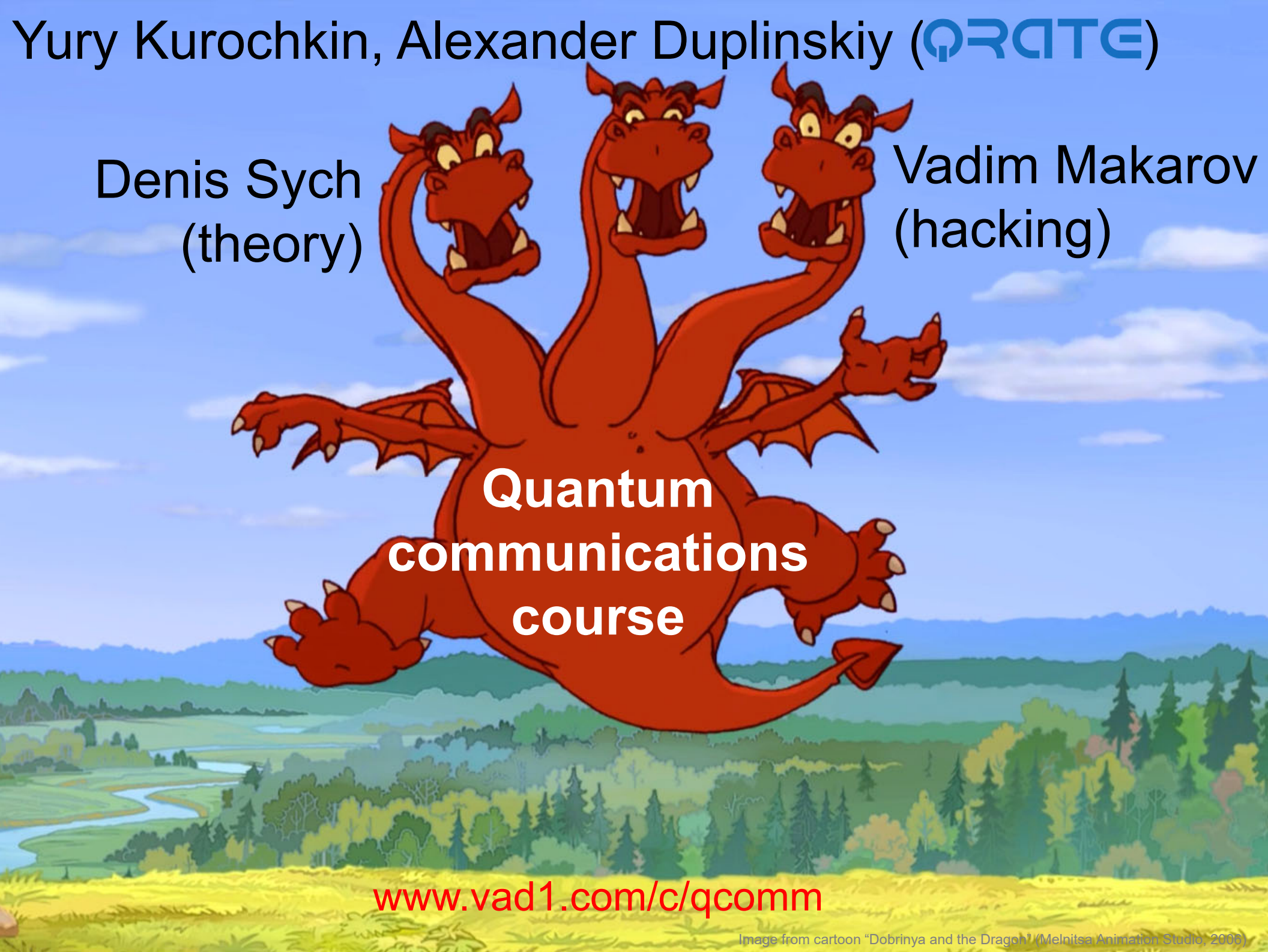
Ground station in Zvenigorod communicates with Micius satellite (18 Jan 2021)

Ground station in Zvenigorod communicates with Micius satellite (18 Jan 2021)

Yury Kurochkin, Alexander Duplinskiy (QRATE)

Denis Sych
(theory)

Vadim Makarov
(hacking)



Quantum communications course

www.vad1.com/c/qcomm

Image from cartoon “Dobrinya and the Dragon” (Melnitsa Animation Studio, 2006)

Labs in quantum photonics and cryptography

THORLABS

Discovery

EDU-QCRY1
EDU-QCRY1/M
Quantum Cryptography Demonstration Kit

Manual

www.vad1.com/c/lqpc/7/lab-manual.pdf