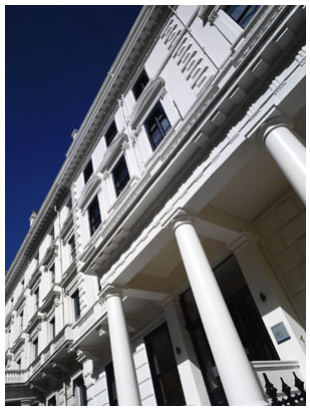
Imperial College London

Noise, Secrets and Photosynthesis

Martin B Plenio



Institute for Mathematical Sciences
&
Quantum Optics and Laser Science Group
Blackett Laboratory

Imperial College London

http://www.imperial.ac.uk/quantuminformation

Institute for Mathematical Sciences

Quantum Information @ Imperial College London

Exponential Growth in Technology

Space/Time Measurement precision

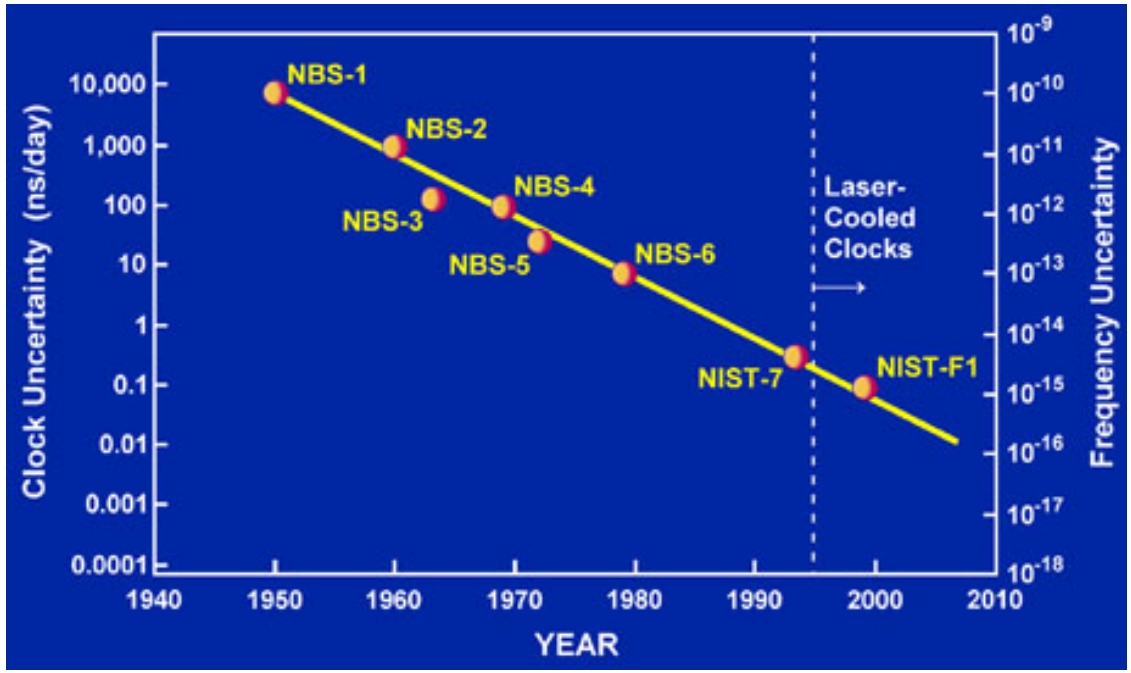
Communication capacity

Computational power

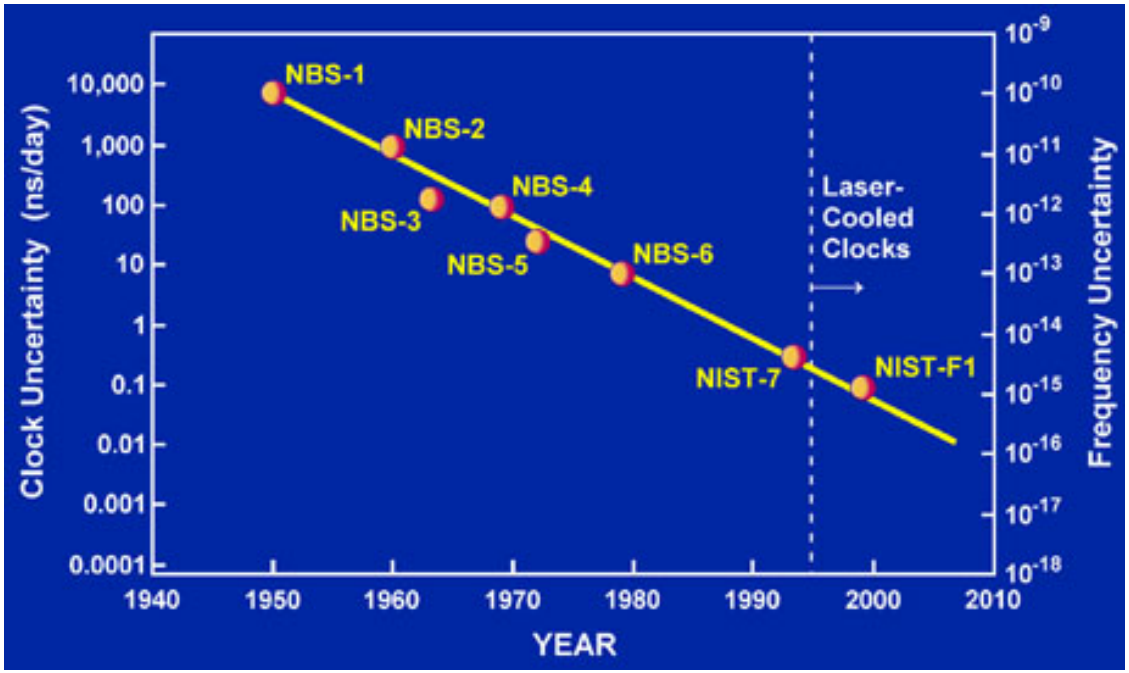
Energy efficiency

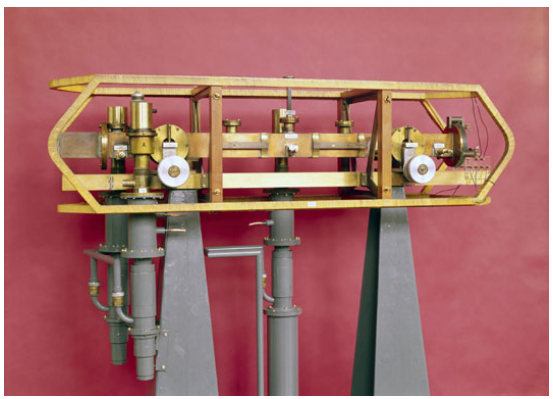
Energy consumption

Measurement of time gains in precision exponentially



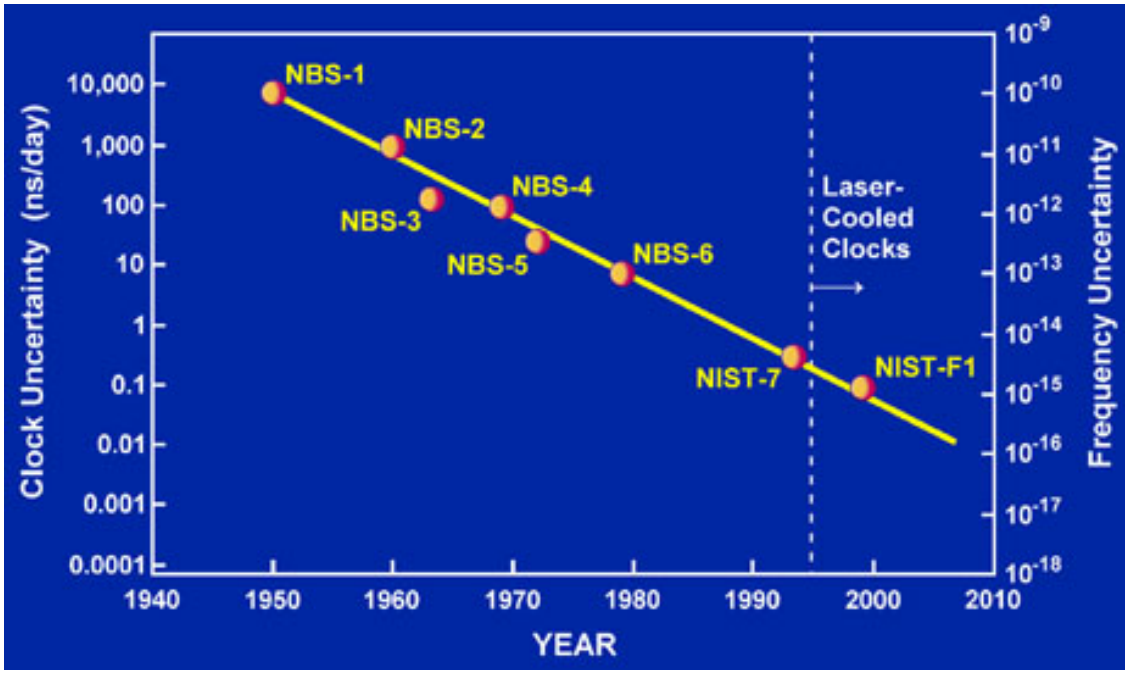
Measurement of time gains in precision exponentially

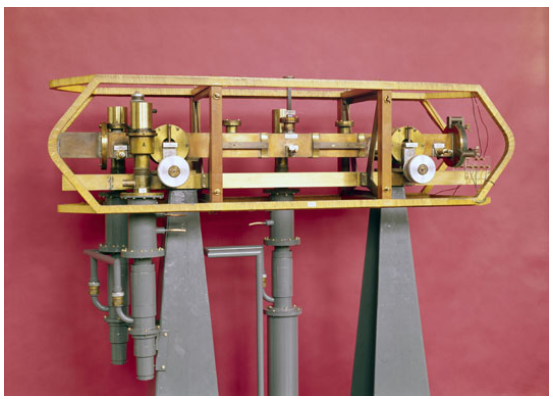




Essen & Parry @ National Physical Laboratory 1955

Measurement of time gains in precision exponentially





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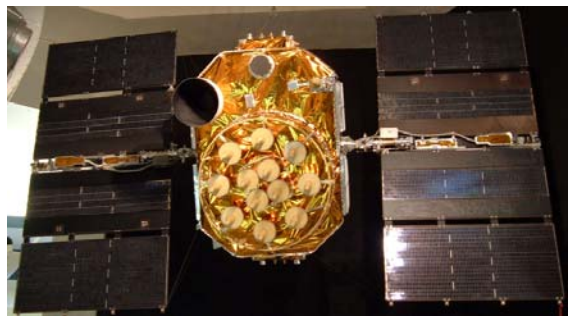

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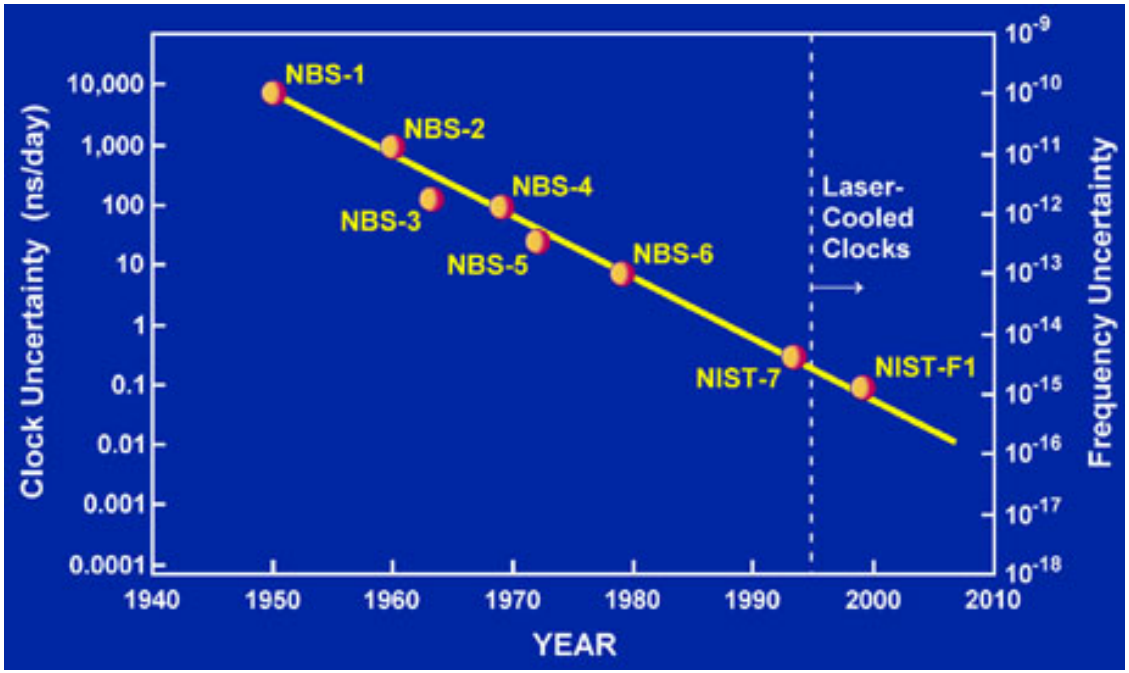

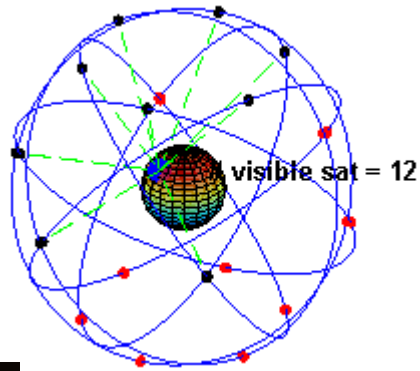

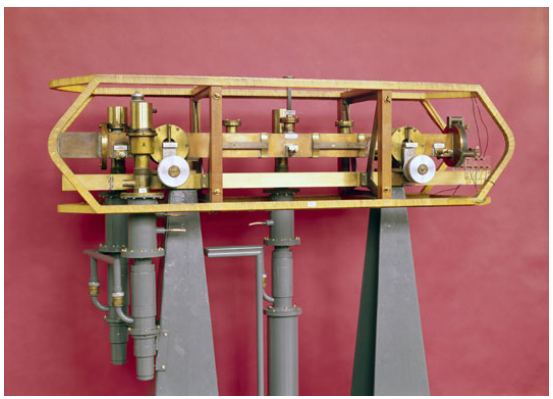

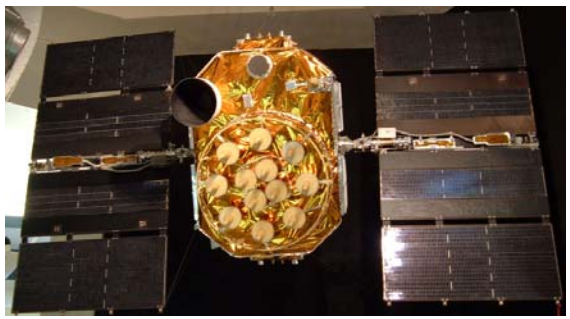

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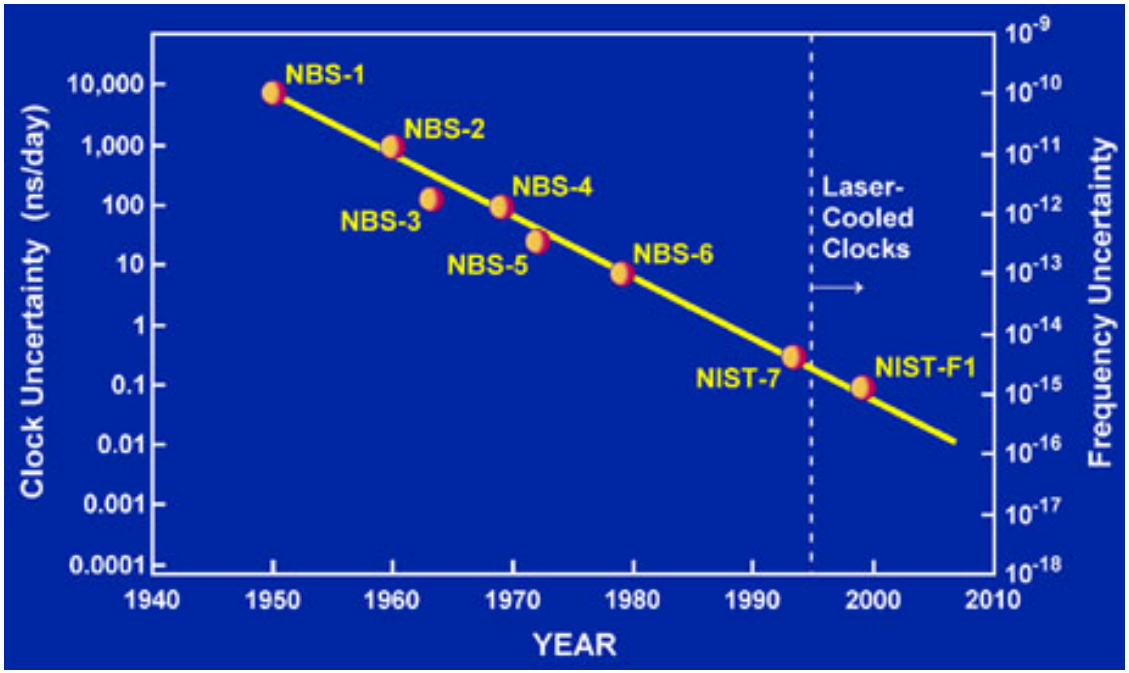
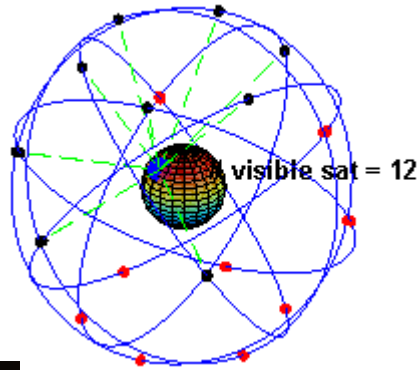
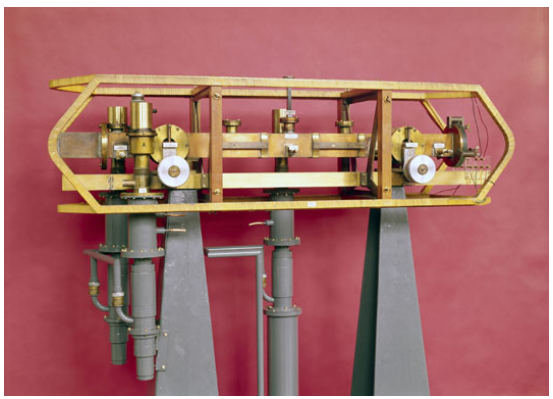
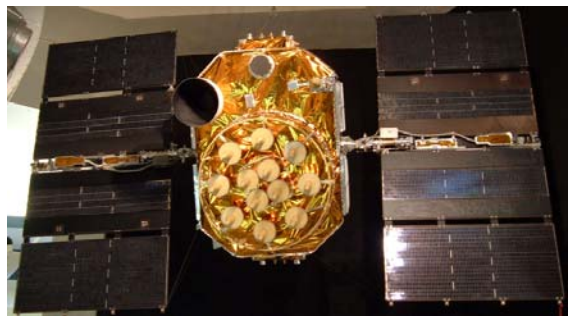


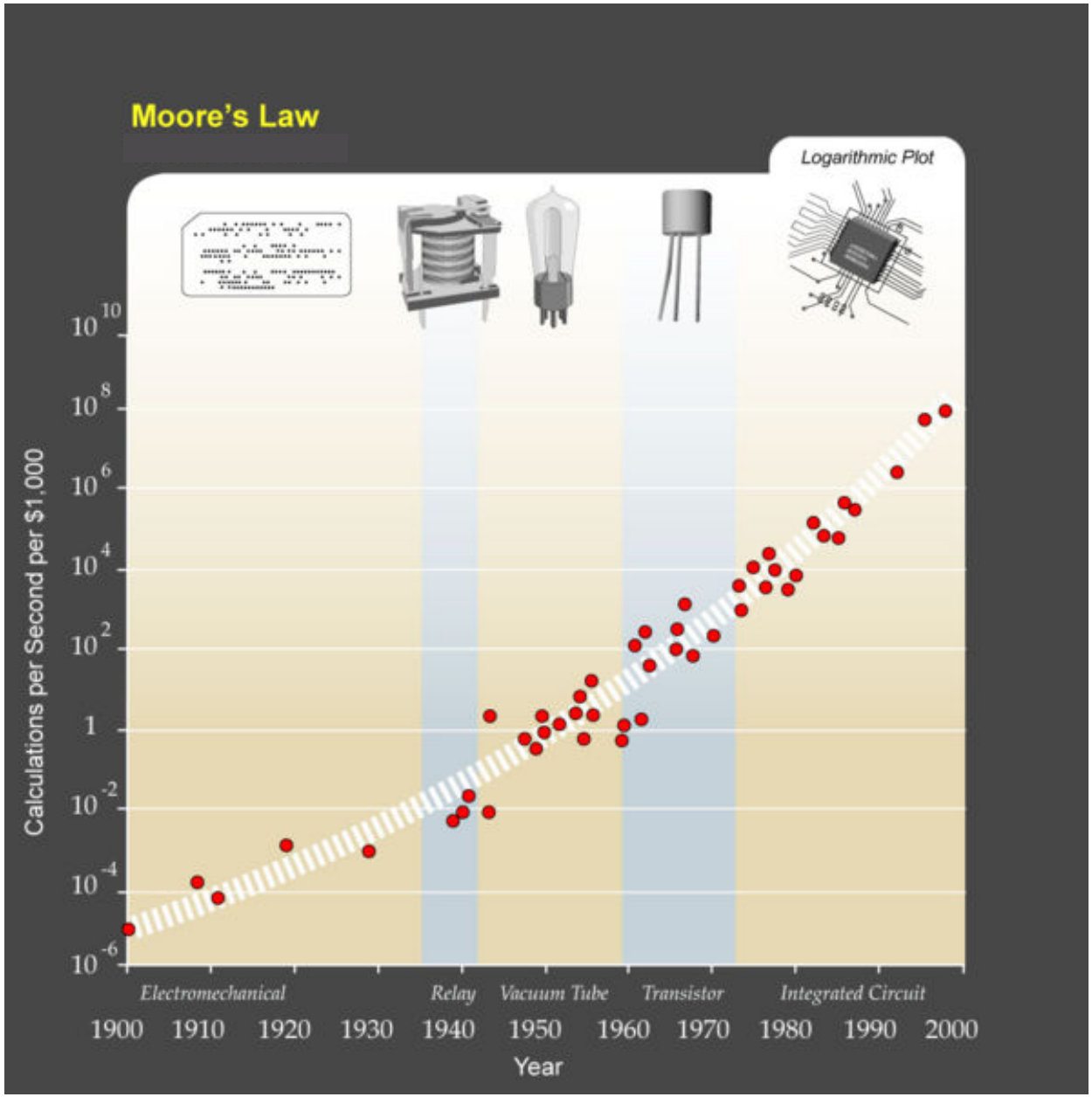




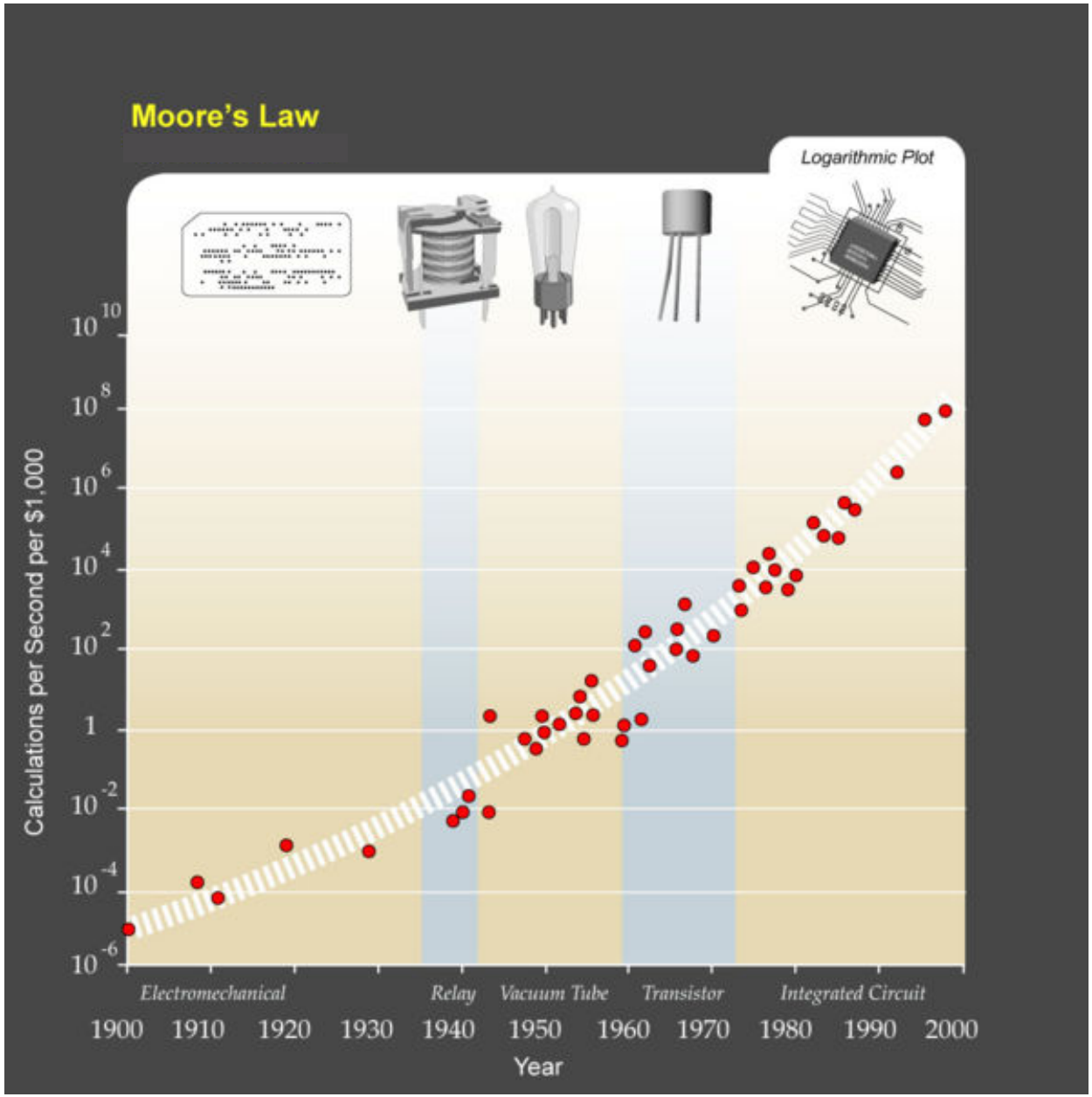


Essen & Parry @ National Physical Laboratory 1955

Computer grow faster exponentially

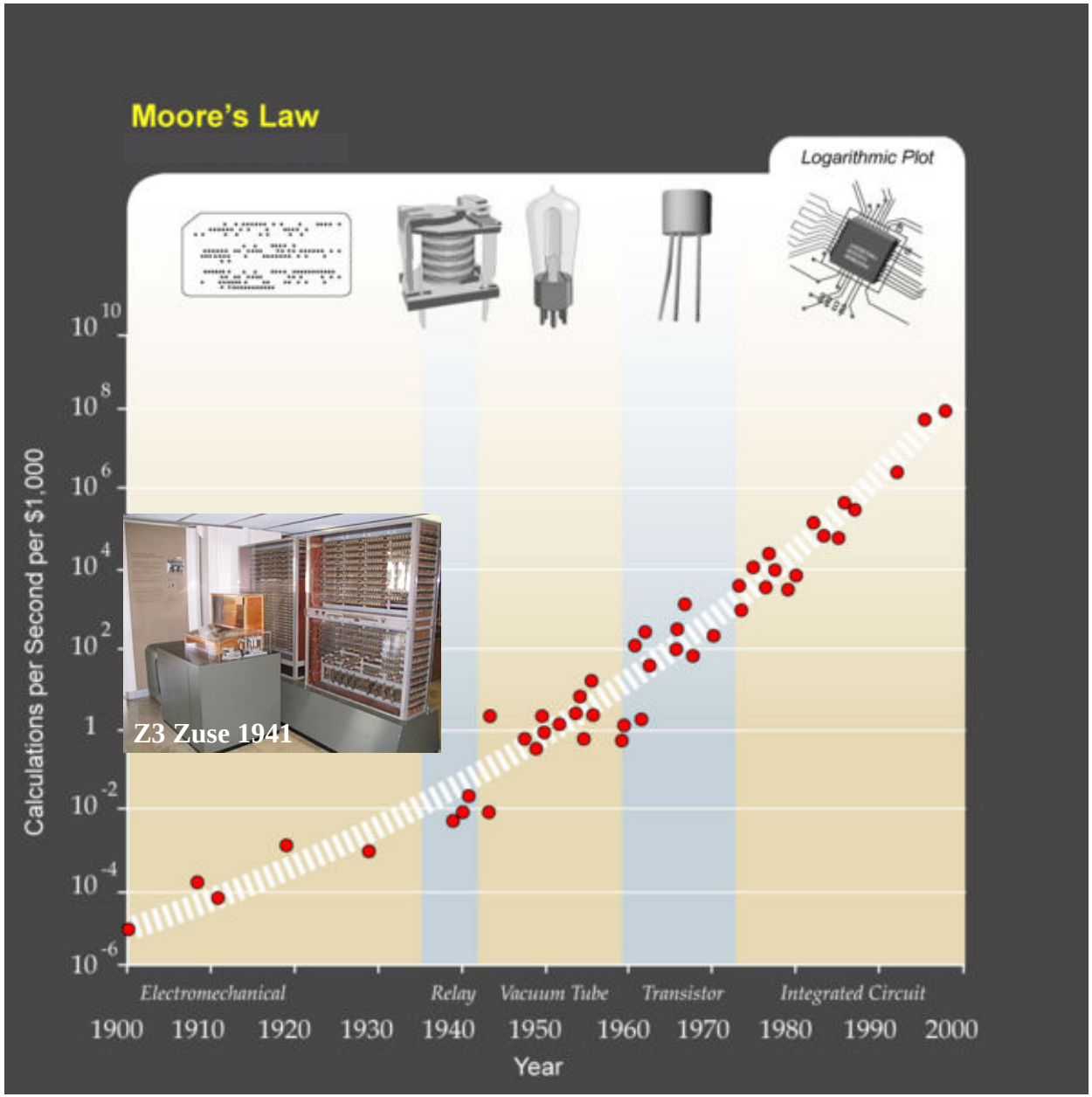


Computer grow faster exponentially



Kelvin's tide predictor 1872

Computer grow faster exponentially



Kelvin's tide predictor 1872

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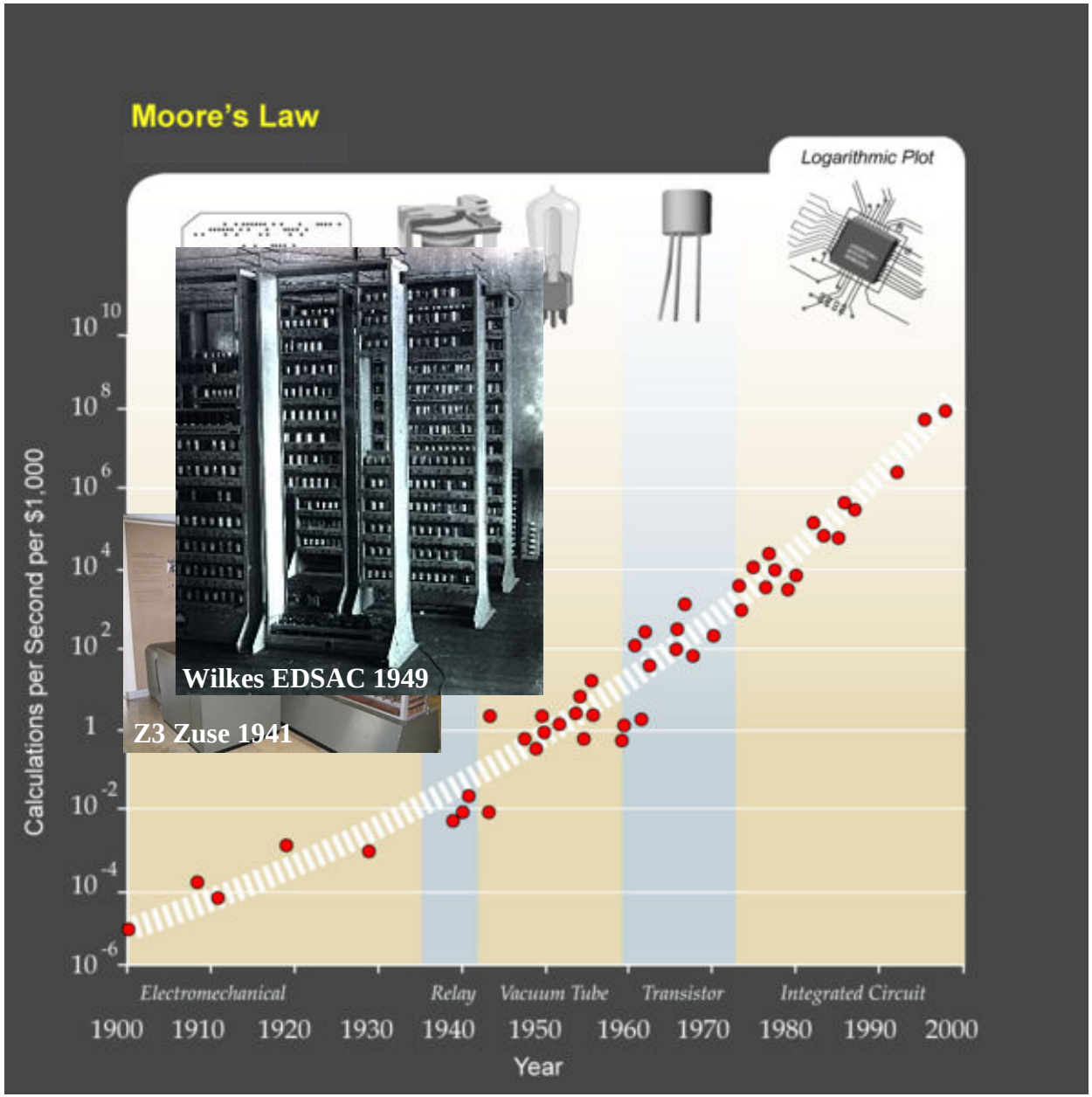

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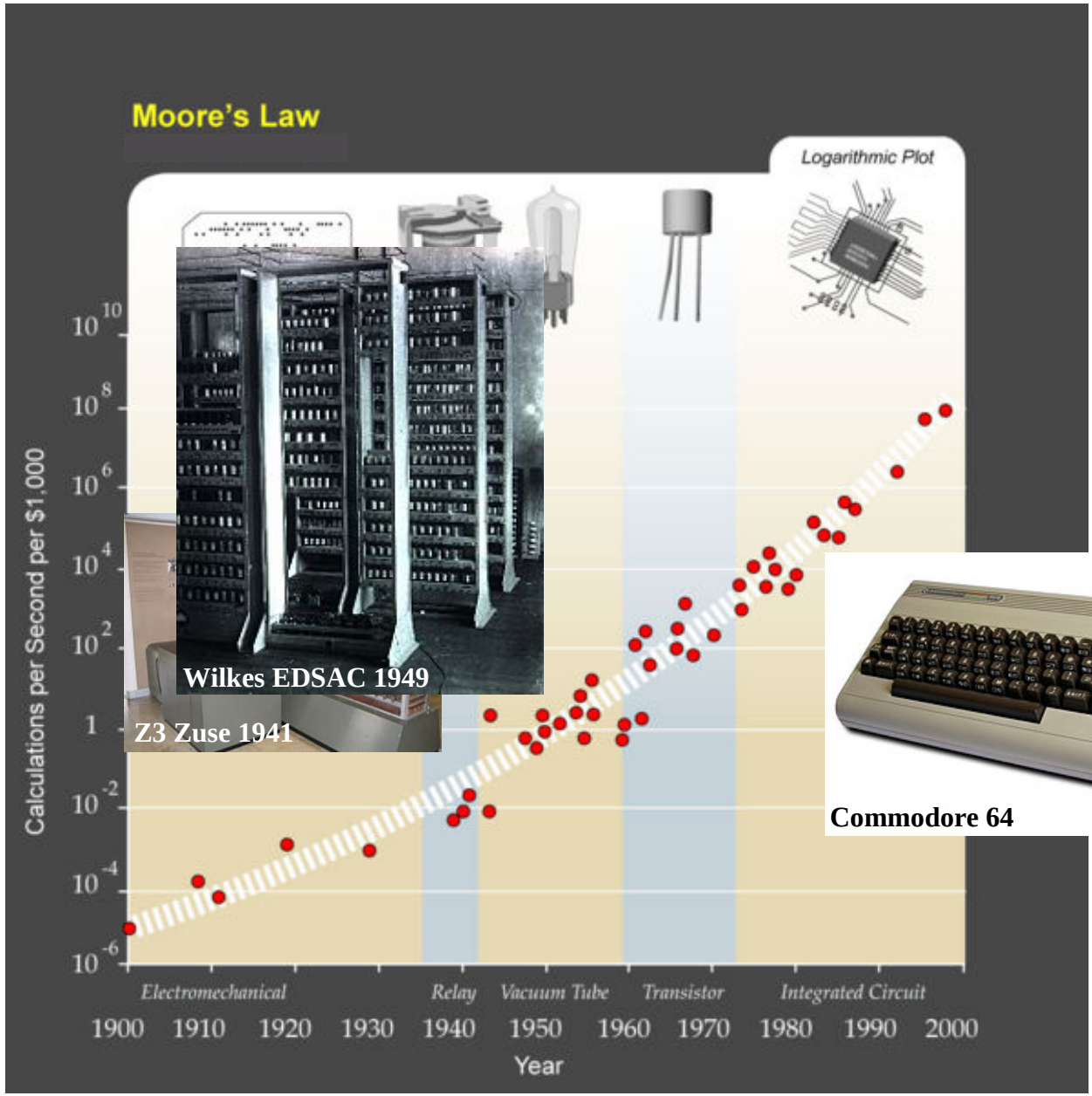

Kelvin's tide predictor 1872

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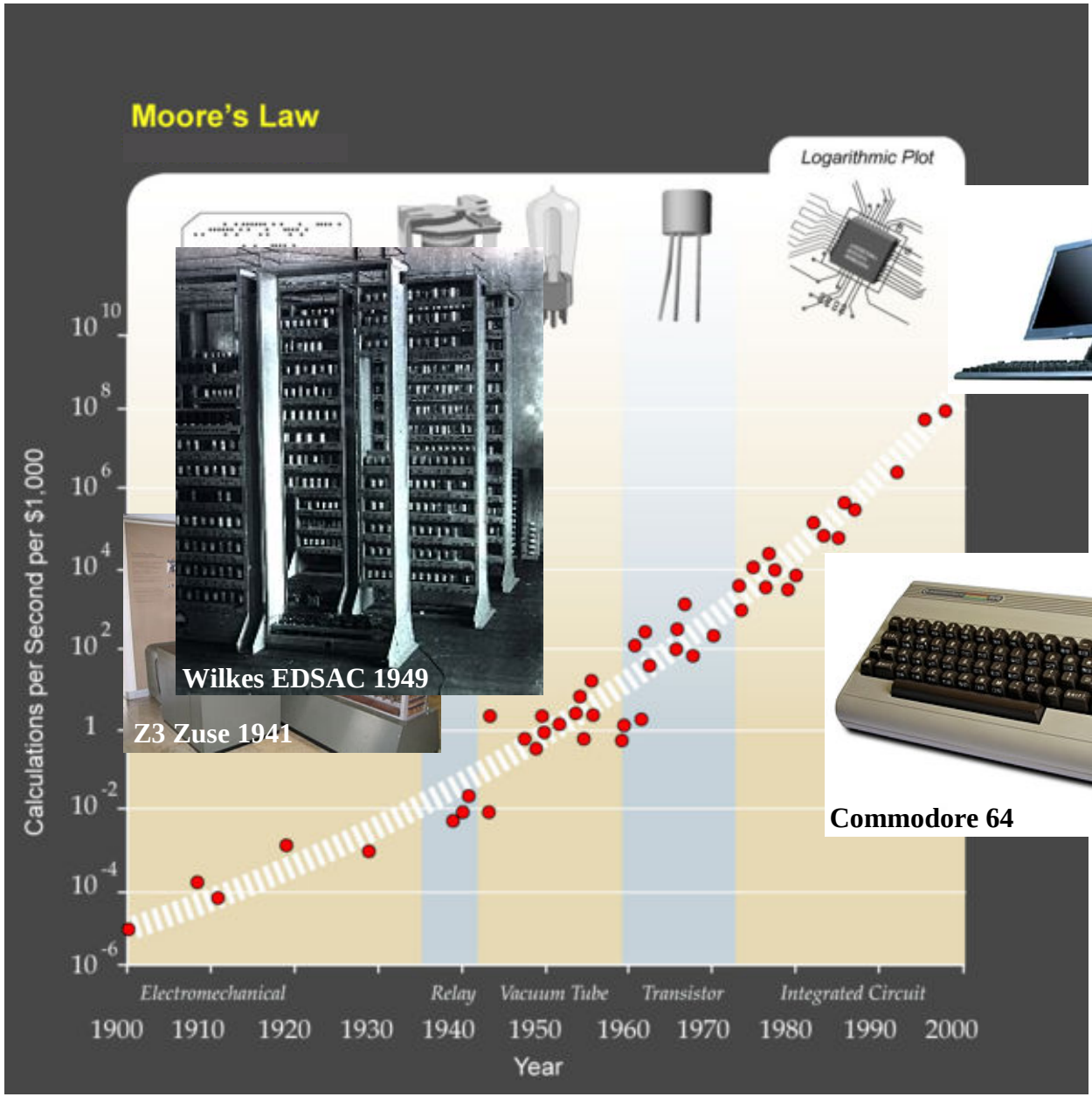
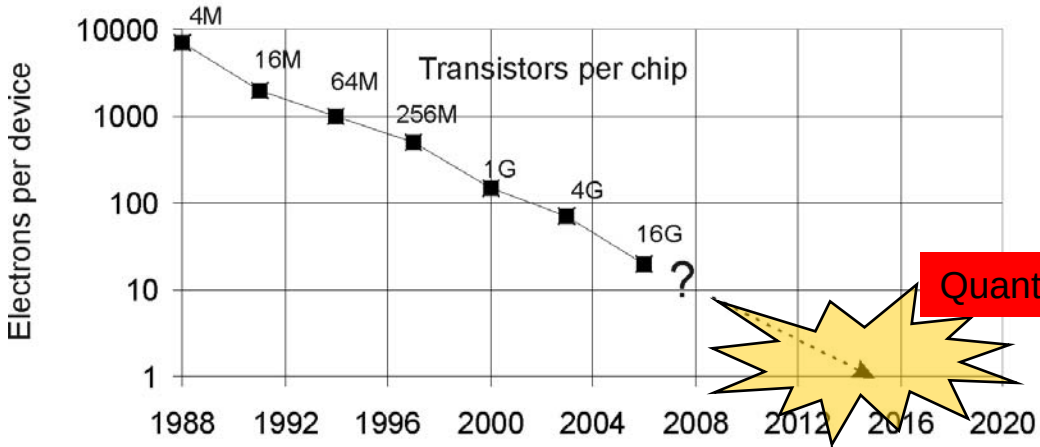


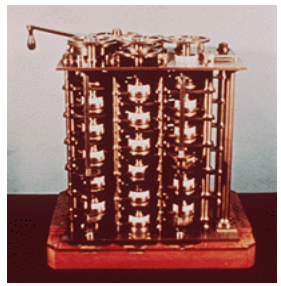
Kelvin's tide predictor 1872

Components grow smaller exponentially

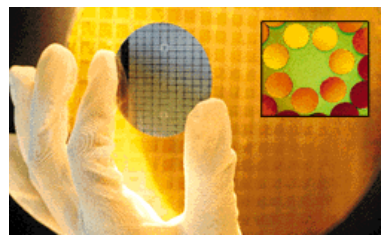


Quantum Noise

cm

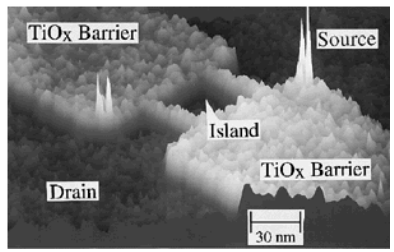


µm



Quantum technology

nm



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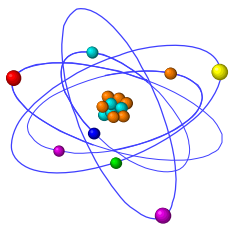
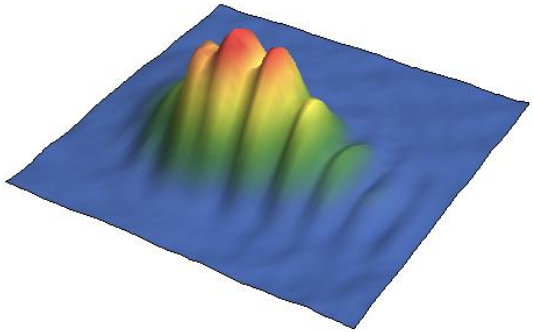
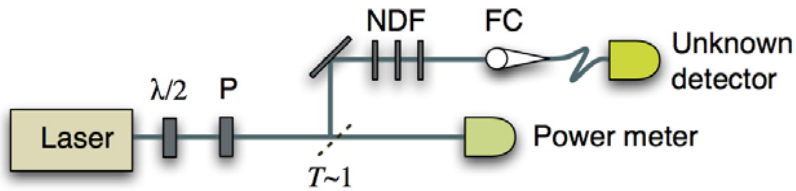


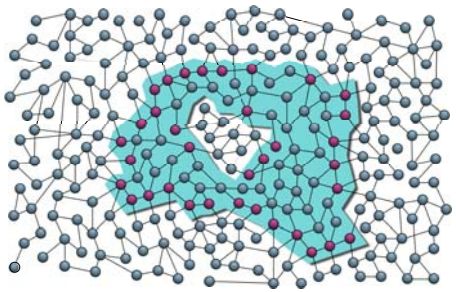
Observation: Technological progress will drive engineering towards the quantum regime

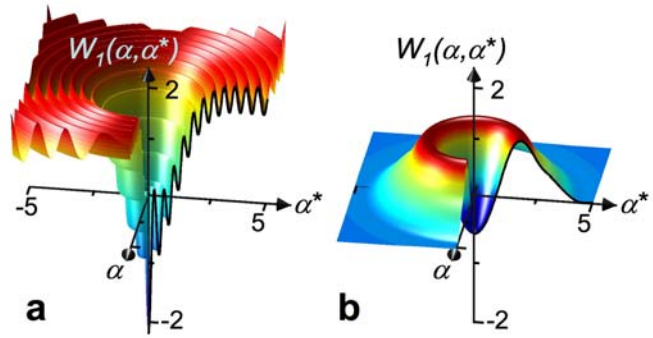
Threat: Noise from quantum fluctuations disrupts devices

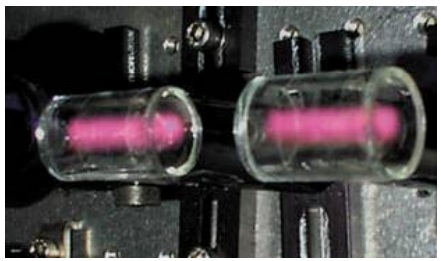
Controlled Quantum Dynamics

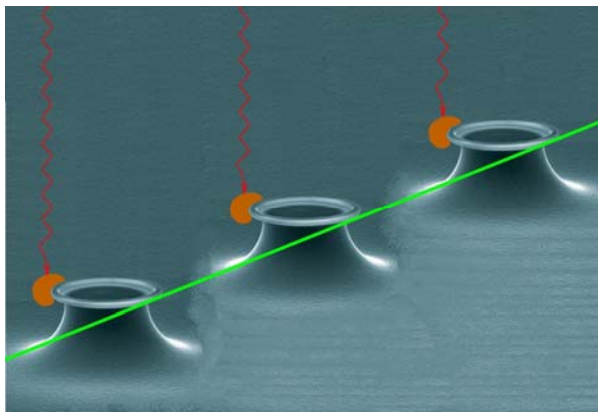


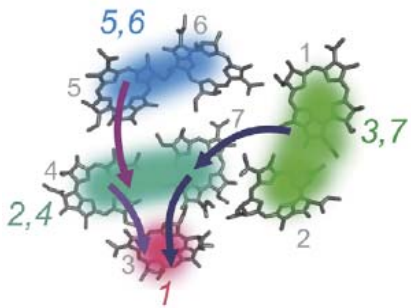


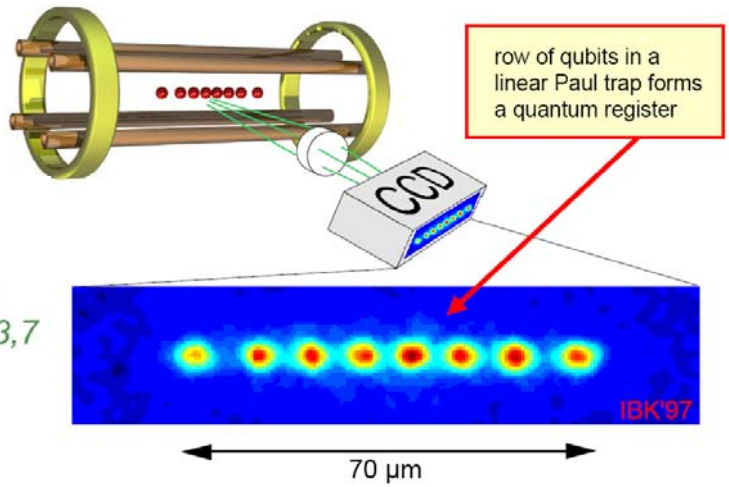












Observation: Technological progress will drive engineering towards the quantum regime

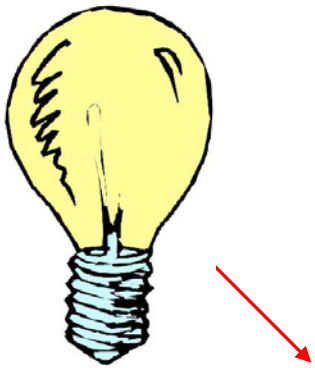
Threat: Noise from quantum fluctuations disrupts devices

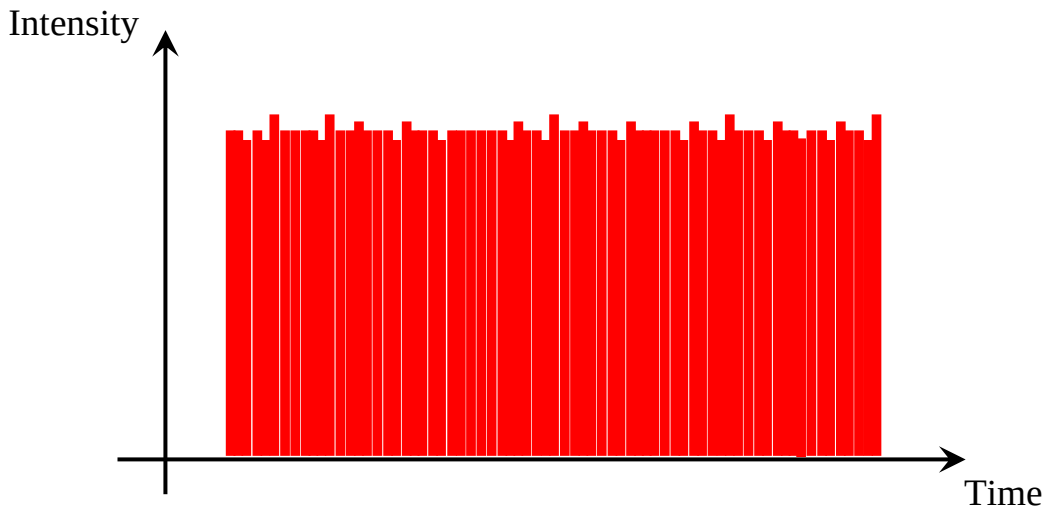
Opportunity: Use Quantum Properties to our Advantage

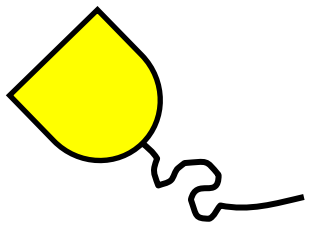
Challenge: Develop atom scale quantum technologies

Quantum vs Classical: Some key differences

High intensity:







Quantum vs Classical: Some key differences

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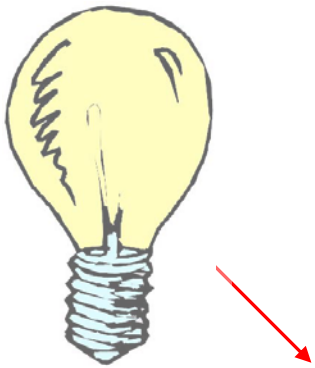

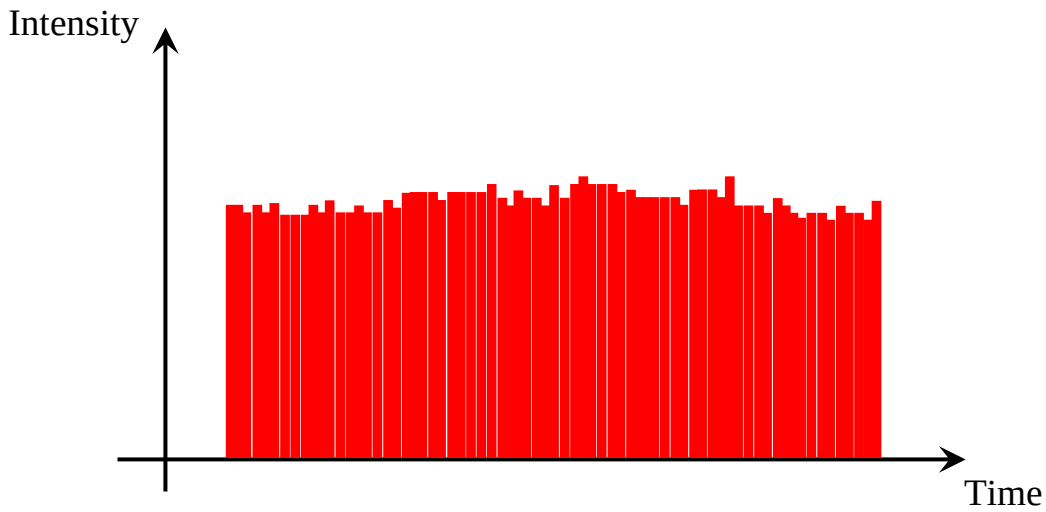

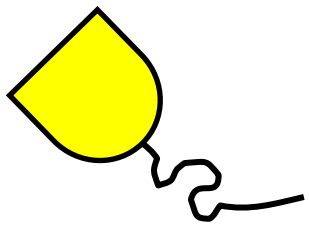

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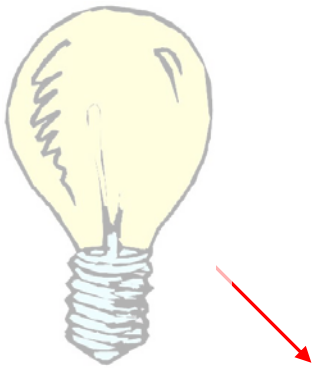

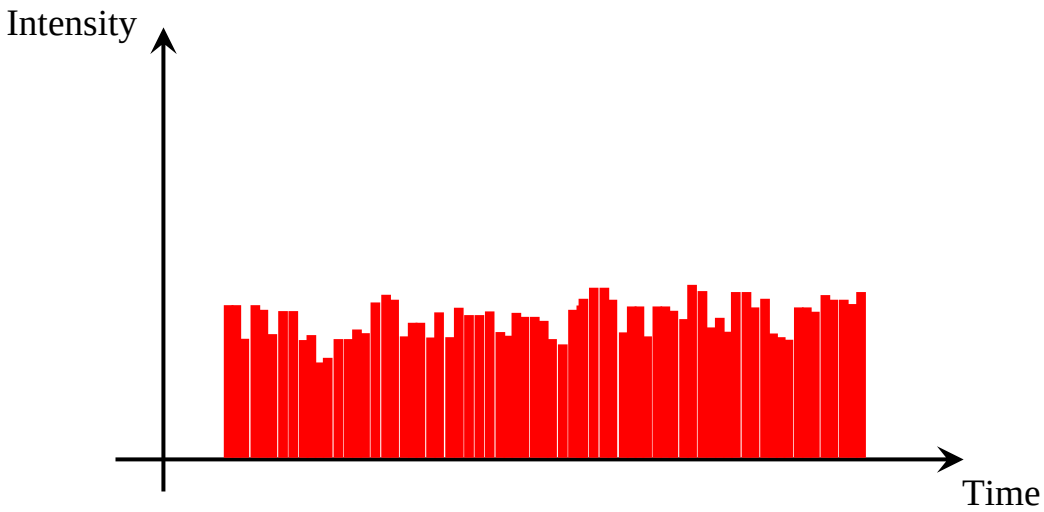

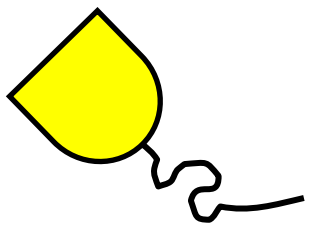

Quantum vs Classical: Some key differences

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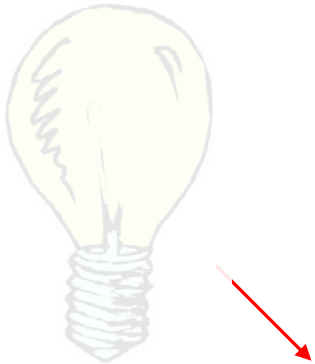
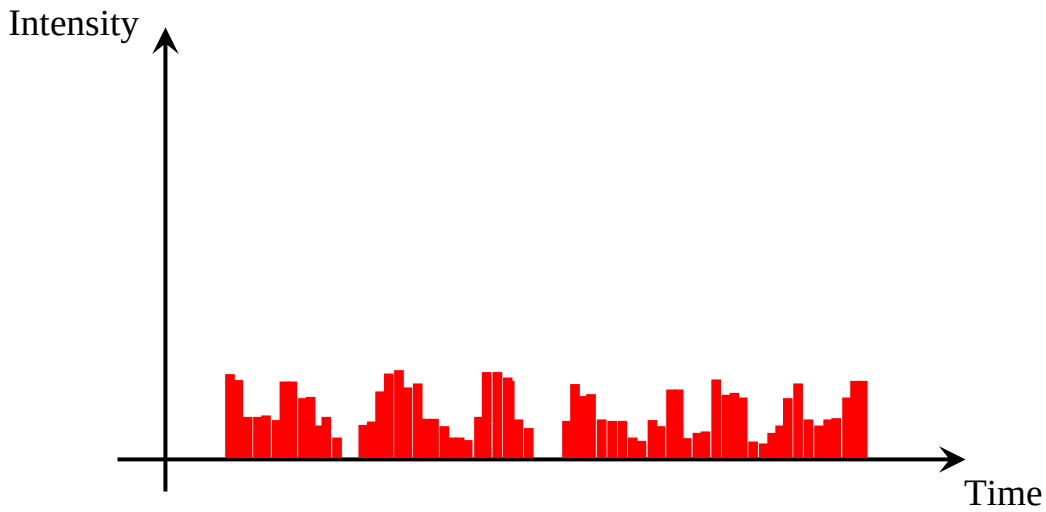
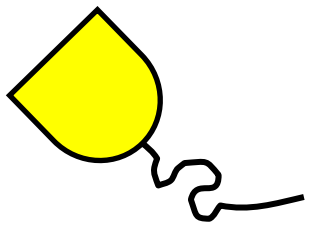
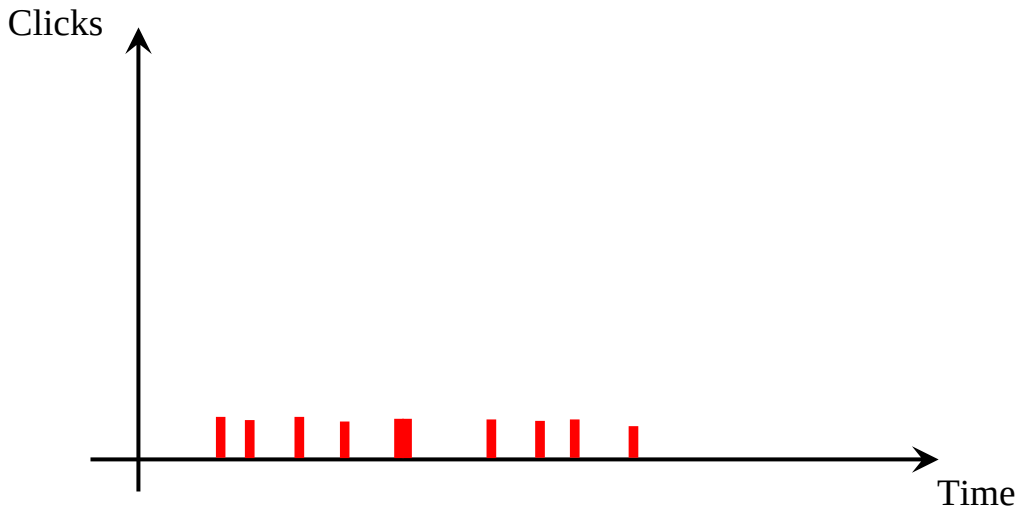


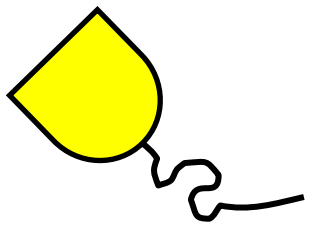




Quantum vs Classical: Some key differences

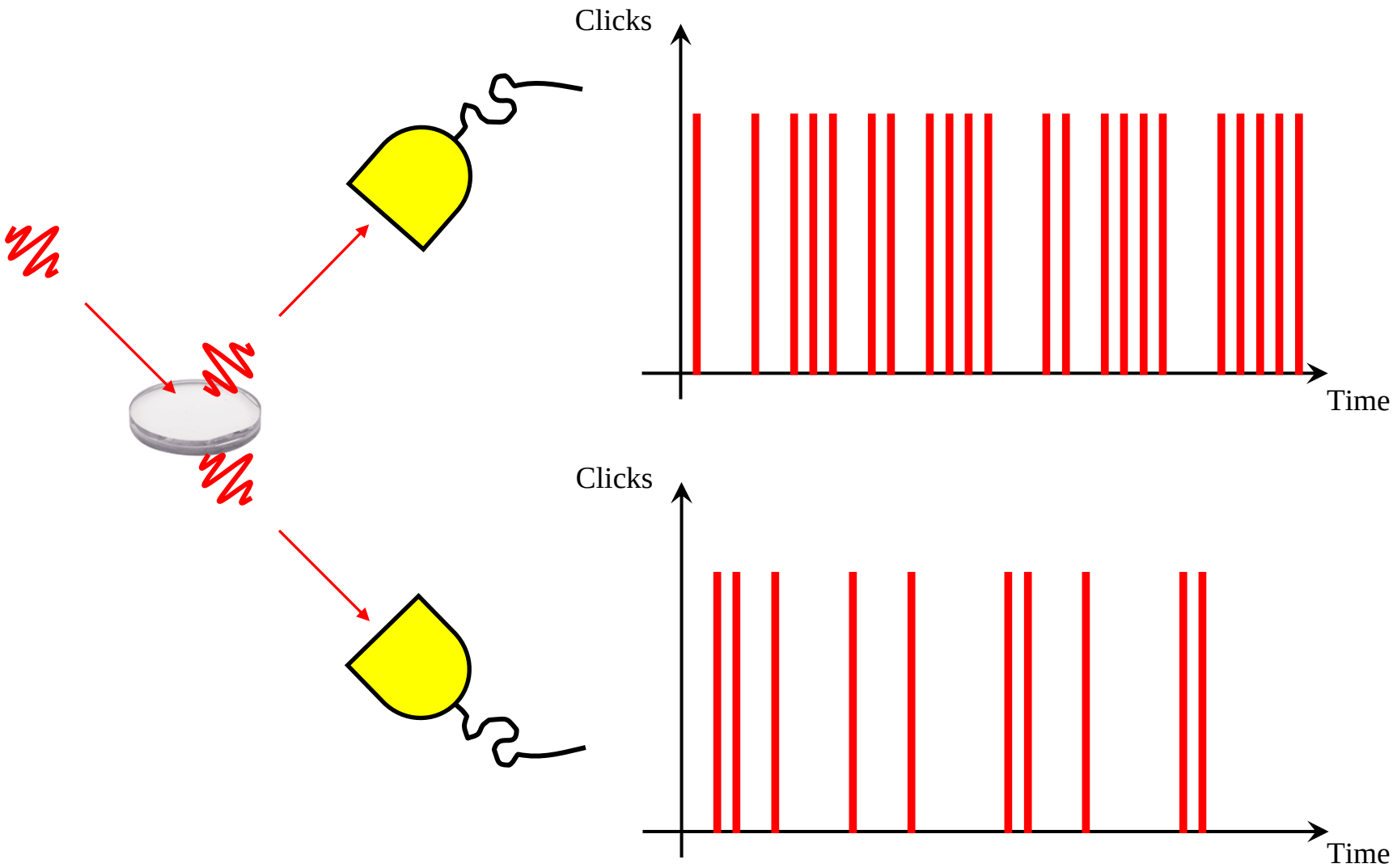
Low intensity:



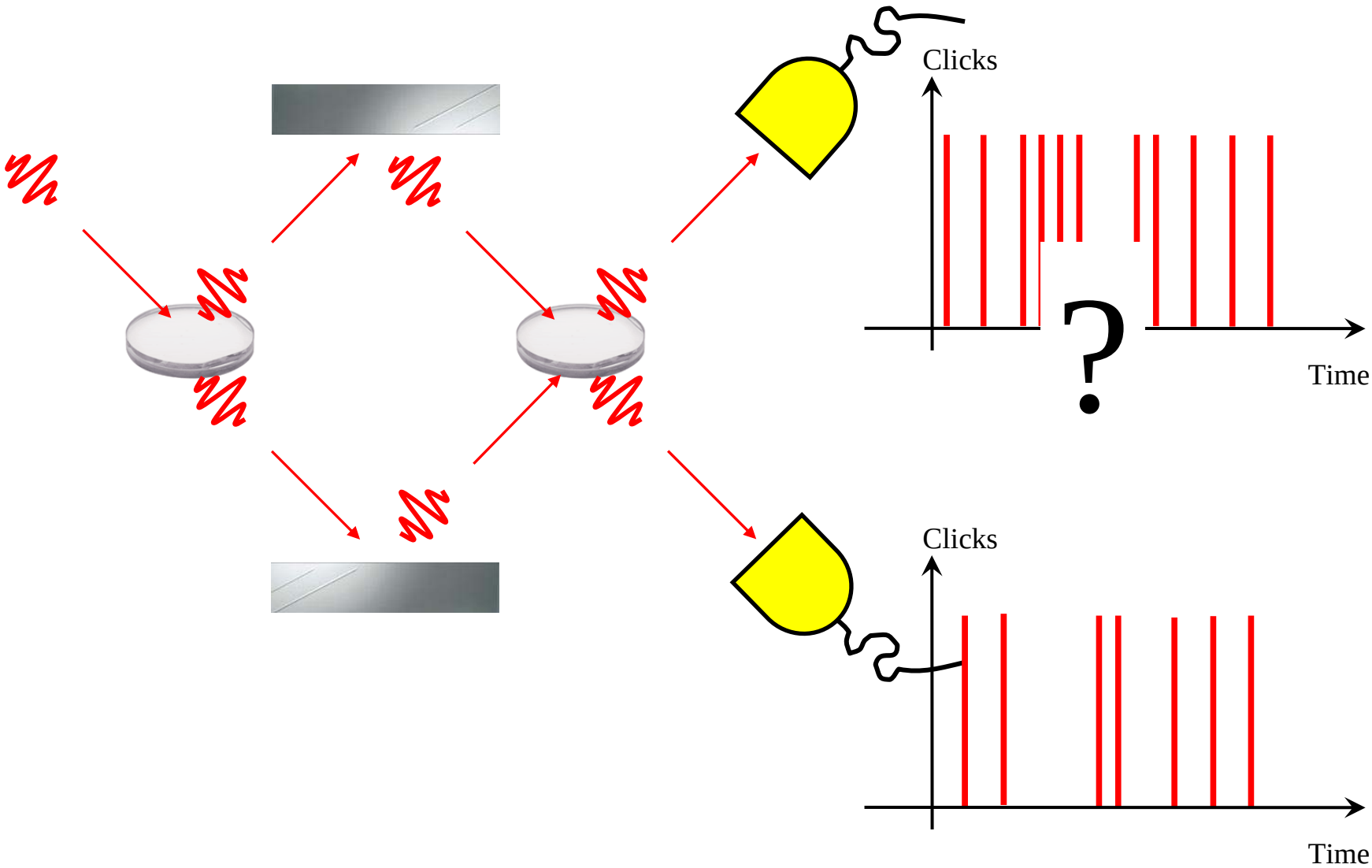


Light comes in little portions → Photons

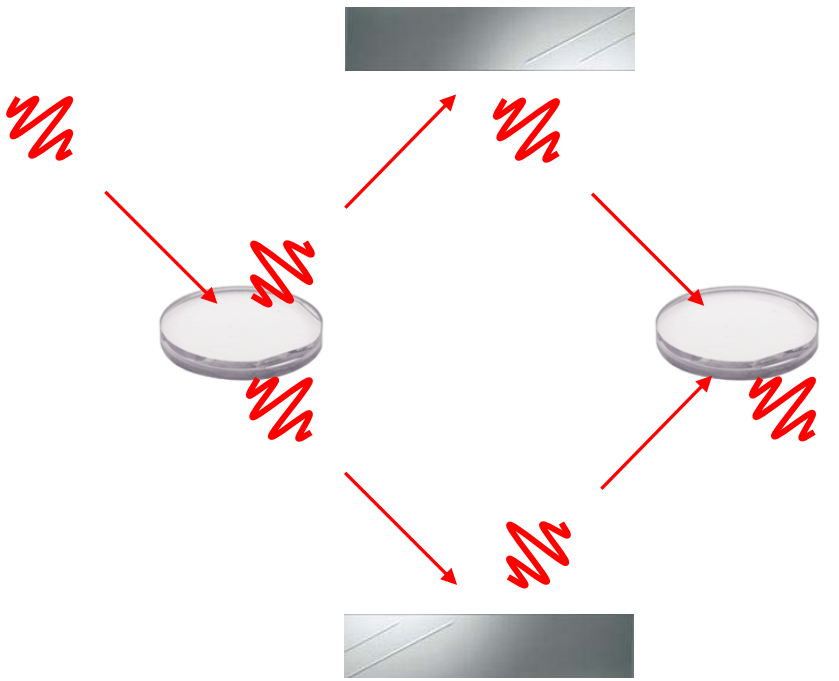
Quantum vs Classical: Some key differences

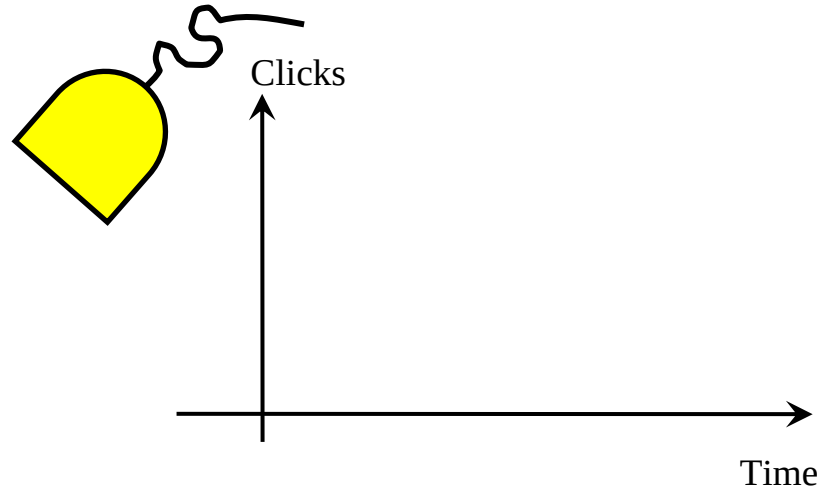


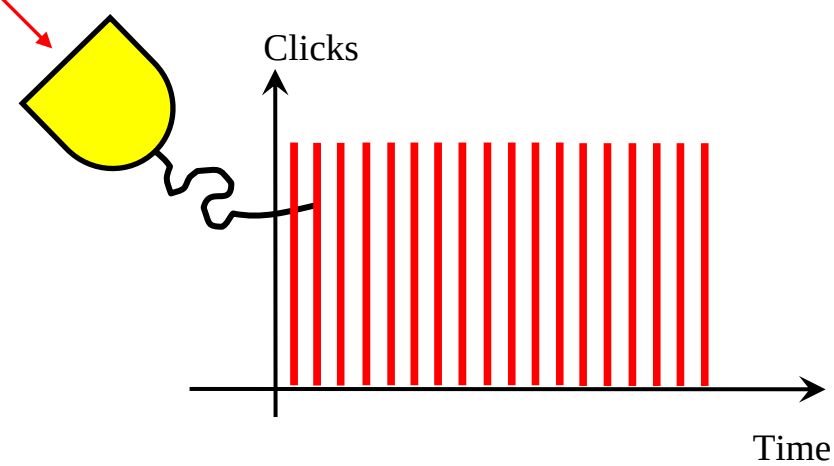
Quantum vs Classical: Some key differences



Quantum vs Classical: Some key differences



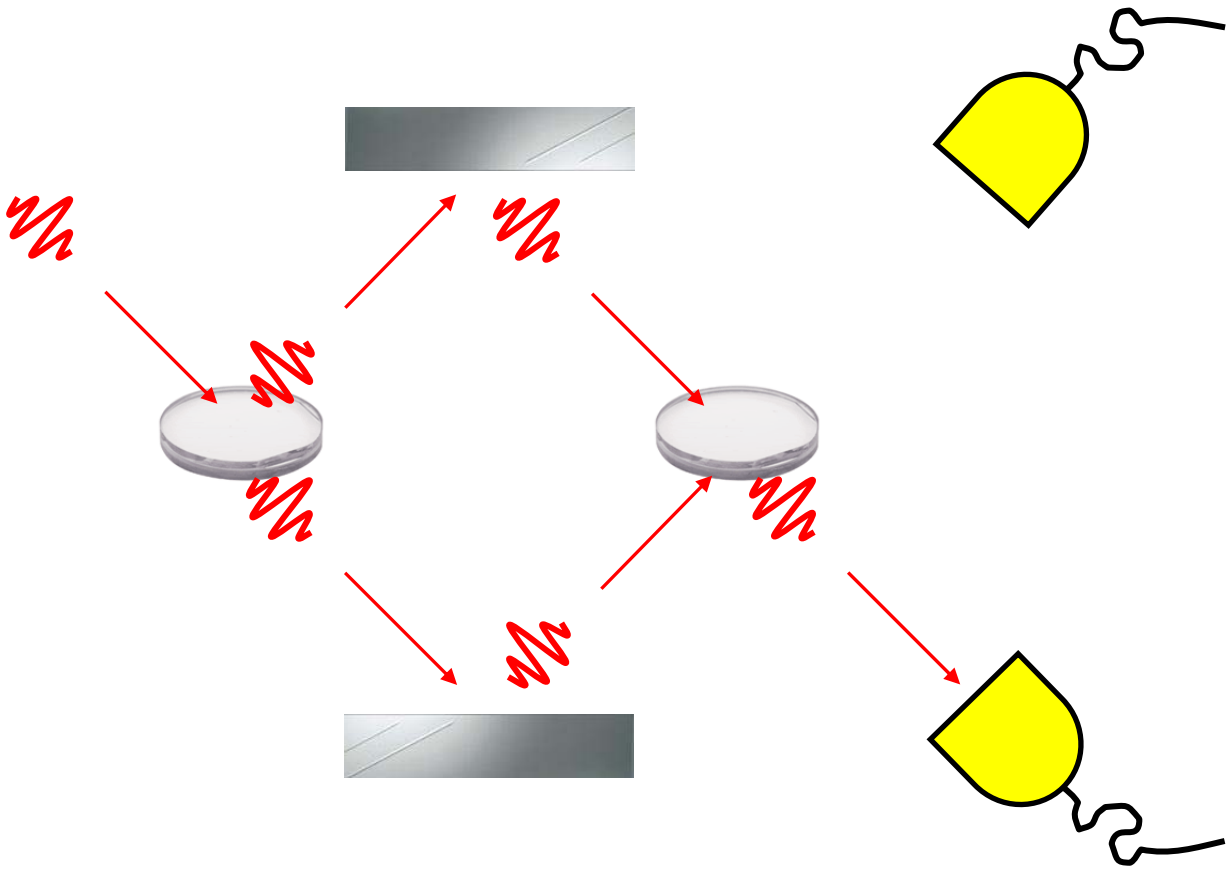




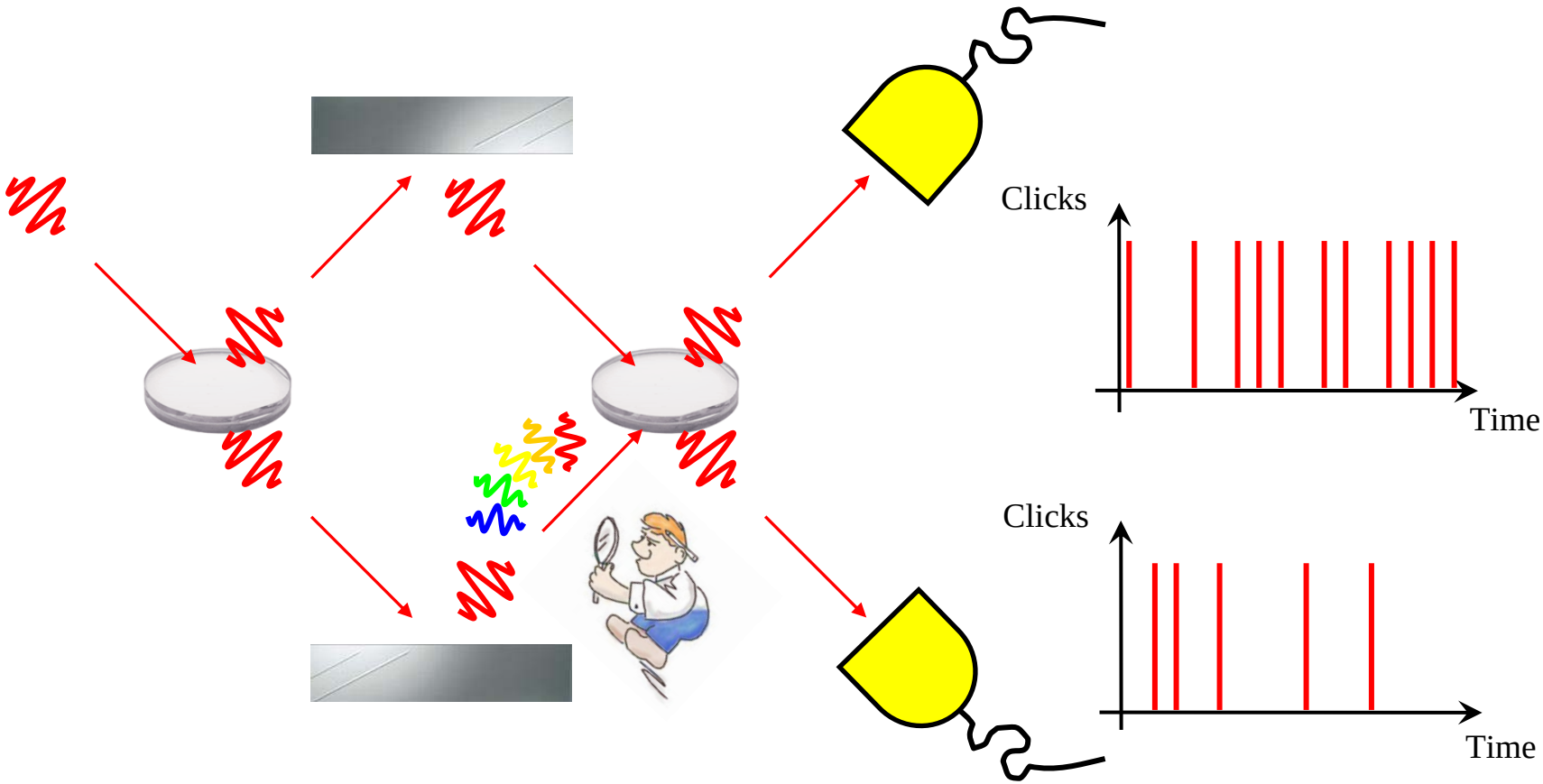
Photons can be in superposition

→ Interference

Quantum vs Classical: Some key differences



Quantum vs Classical: Some key differences



Quantum vs Classical: Some key differences

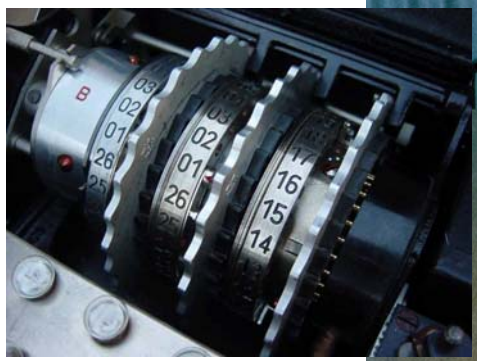
Take home messages:

- When evolving freely quantum systems exhibit wave character
- When measured quantum systems exhibit particle character

- Measurements that acquire information, inevitably destroy coherence and perturb the quantum systems.

Secrets and Noise

Secret Communication



Secret Communication

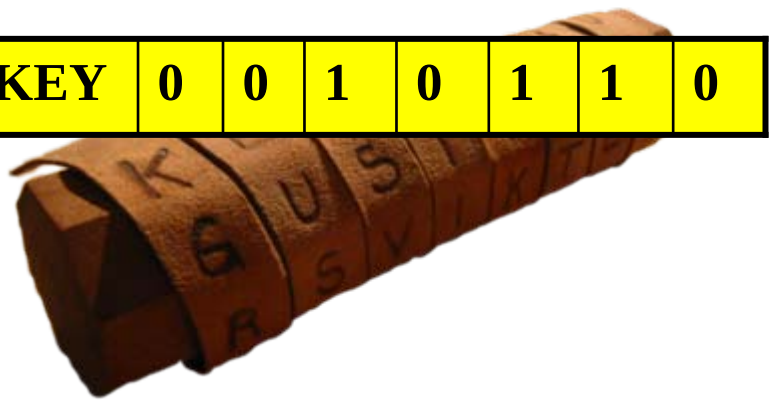
Alice

?

miles away

Bob

KEY	0	0	1	0	1	1	0



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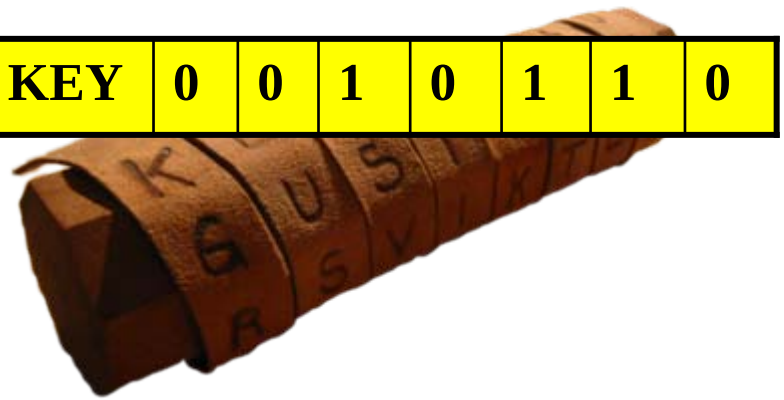


How to establish key that only Alice and Bob know ?

Secret Communication

Alice

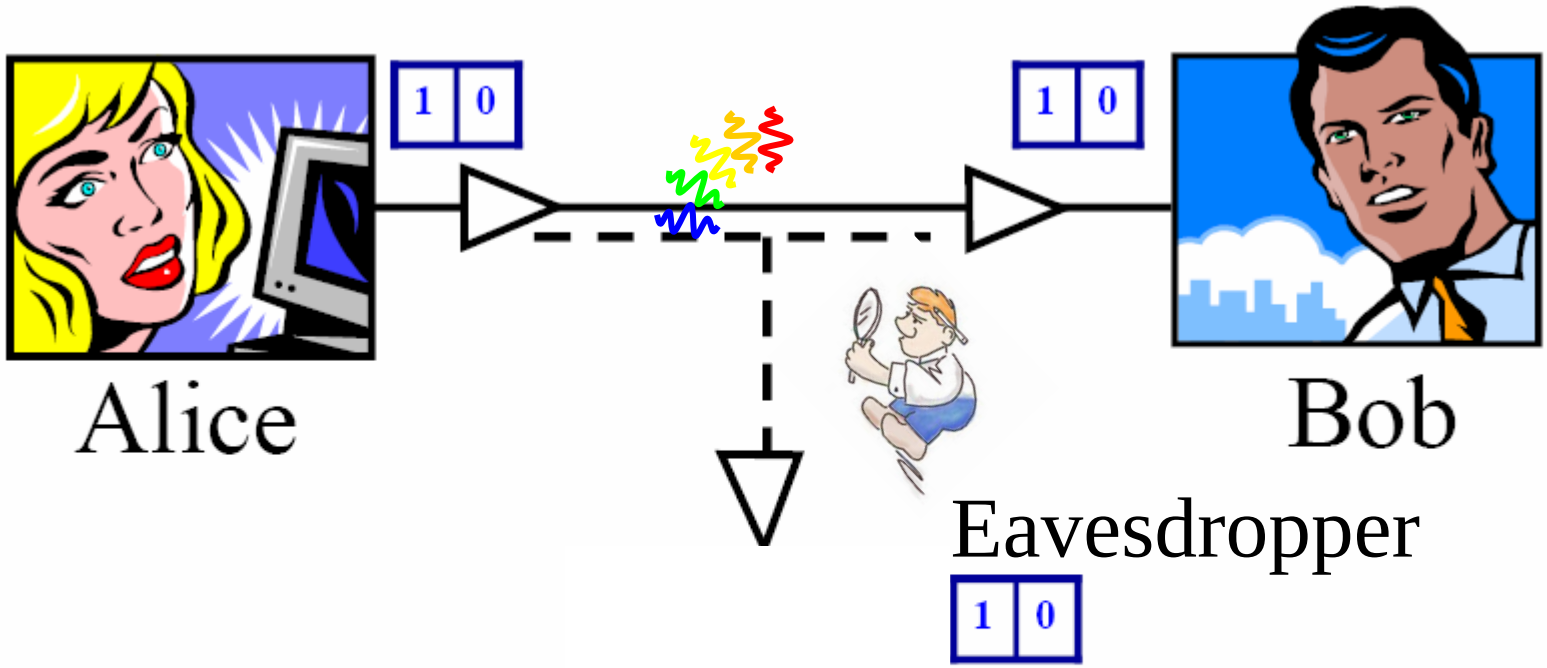
?

miles away

Bob

- **Information carried by physical objects such as Sound waves, photons, electrons**
- **An eavesdropper obtains information by measuring carrier of information**

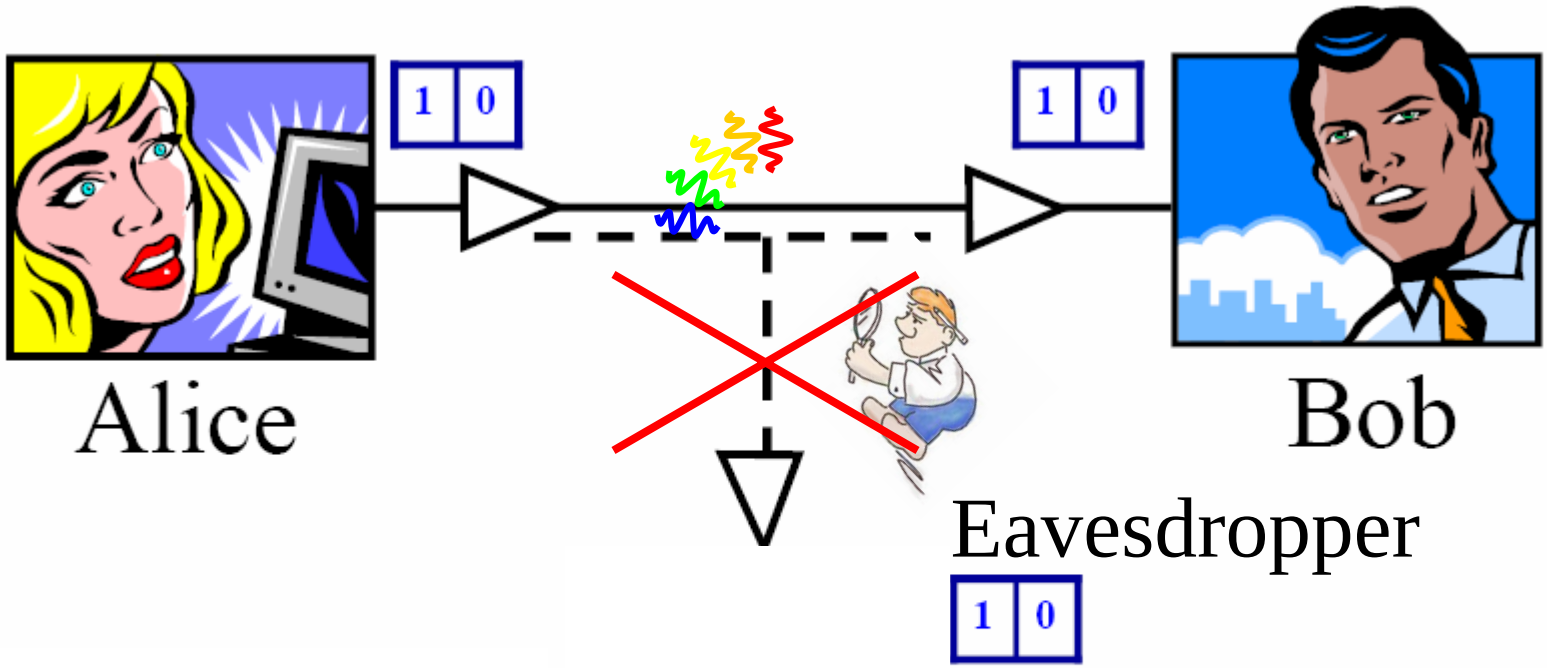
Secret Communication



Eve may measure classical signal without perturbation and hence without detection.

We do not know how much Eve has learnt about the key!

Secret Communication

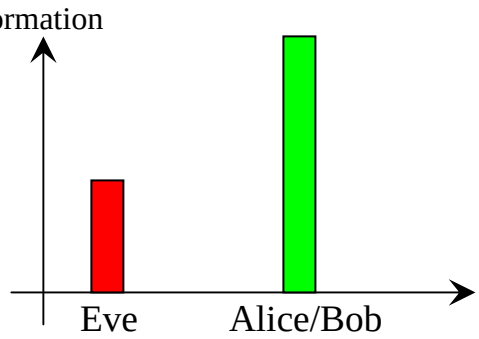


Quantum World:

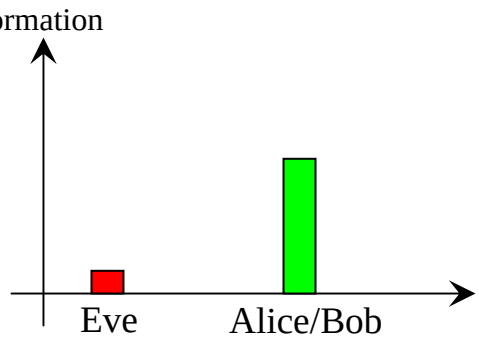
Eve's measurement of quantum signal causes perturbation and can be detected.

⇒ Noise level provides bounds on information leaked to Eve !

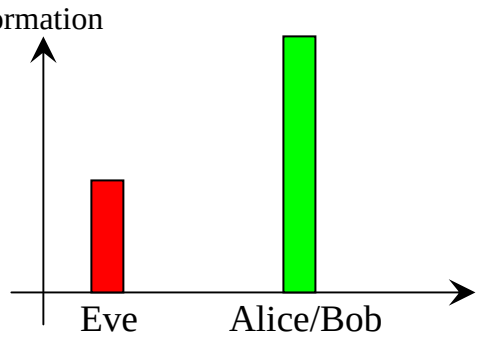
Secret Communication



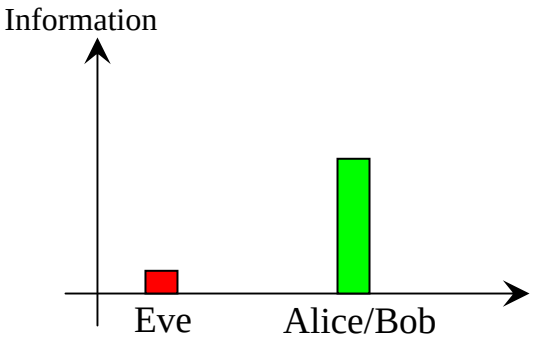
Privacy Amplification

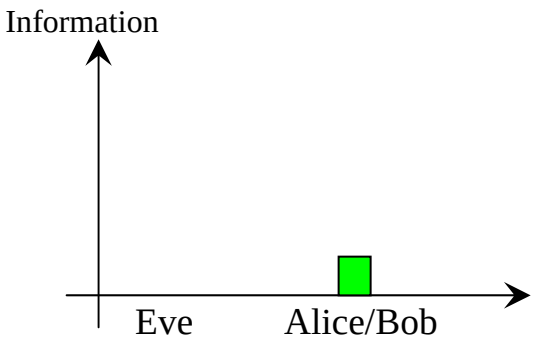


Secret Communication

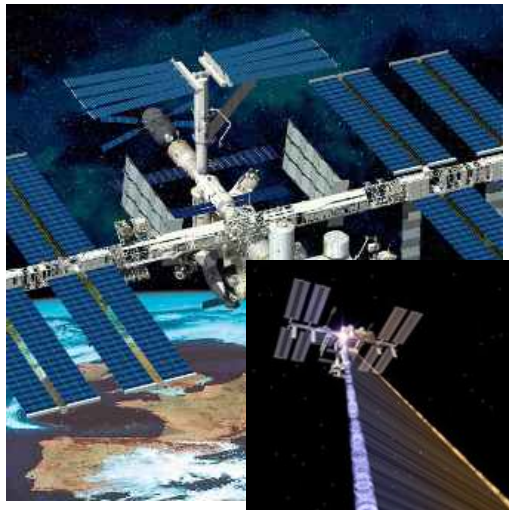


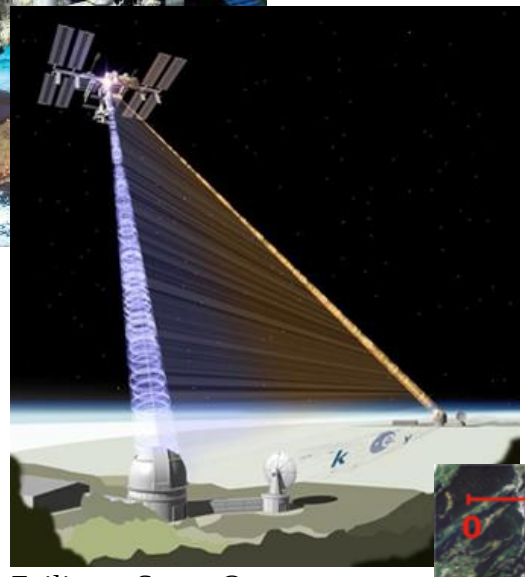
Privacy Amplification





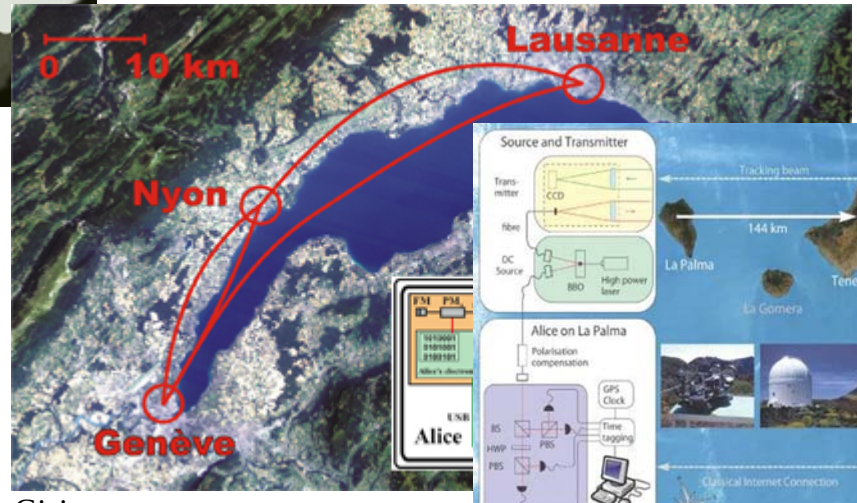
Secret Communication





Zeilinger Space Quest

id Quantique



Gisin

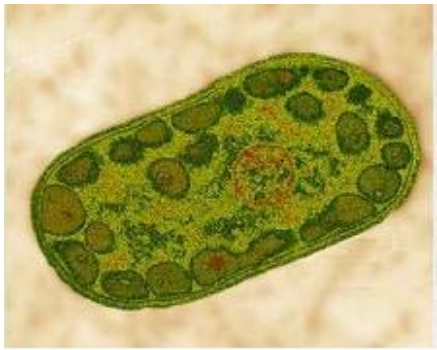
Noise Assisted Transport and Photosynthesis

Noise Assisted Transport and Photosynthesis

Noise Assisted Transport and Photosynthesis

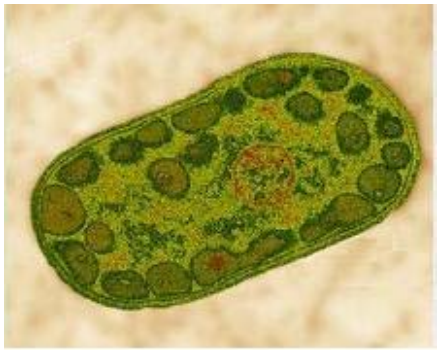
Noise Assisted Transport and Photosynthesis

Photosynthesis

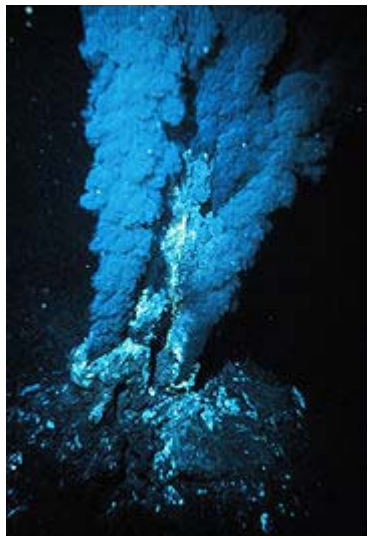


Green sulphur Bacteria

Photosynthesis

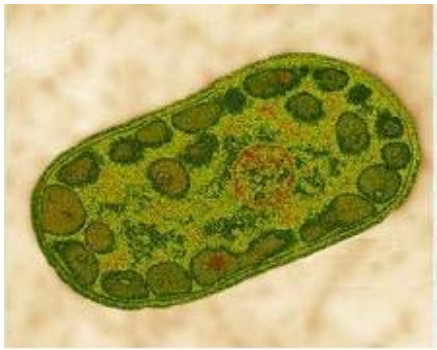


Green sulphur Bacteria

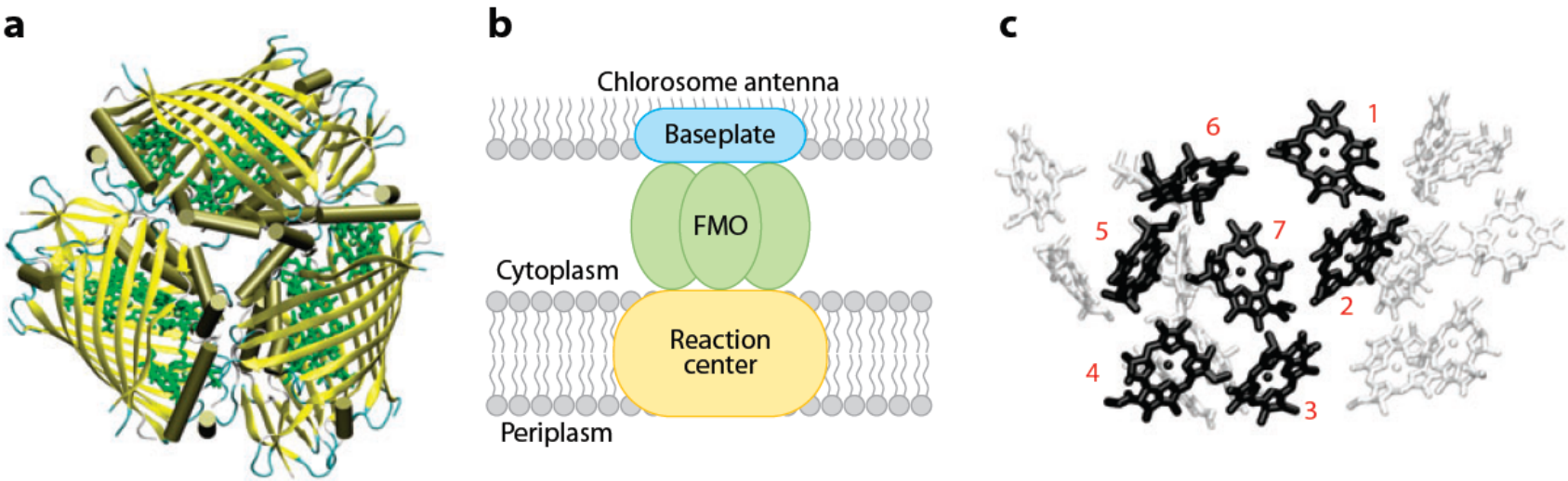


A black smoker in the Atlantic Ocean ~ 2000m deep

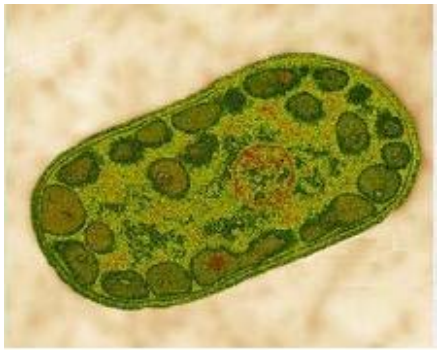
Photosynthesis



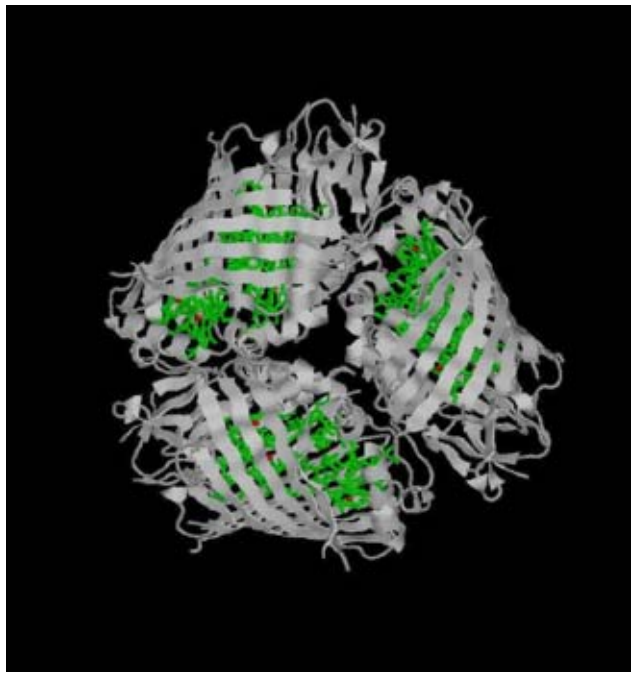
Green sulphur Bacteria



Noise Assisted Transport and Photosynthesis

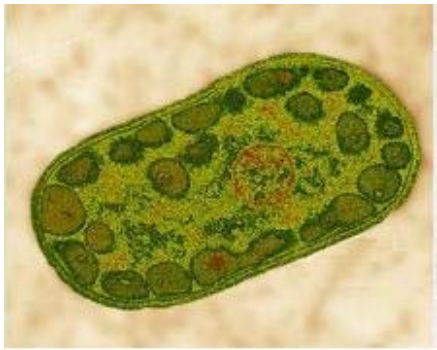


Green sulphur Bacteria

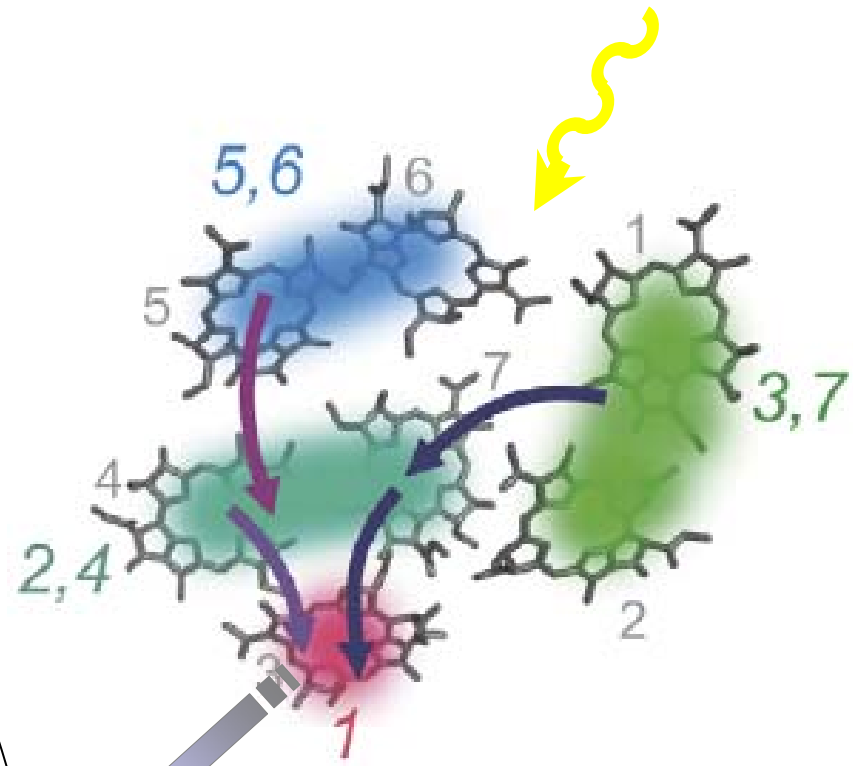


FMO protein trimer, BChl a molecules in green
© Protein data bank, structure by Tronrud et al 1986

Exciton Transport in Photosynthesis



Green sulphur Bacteria



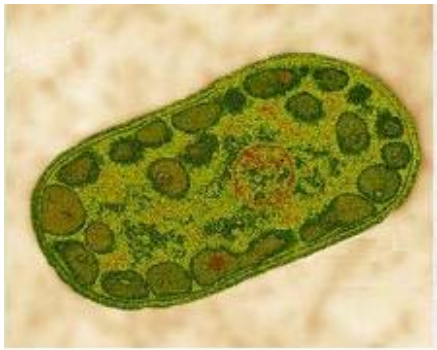
Reaction Centre

$CO_2 + 2\,H_2S$

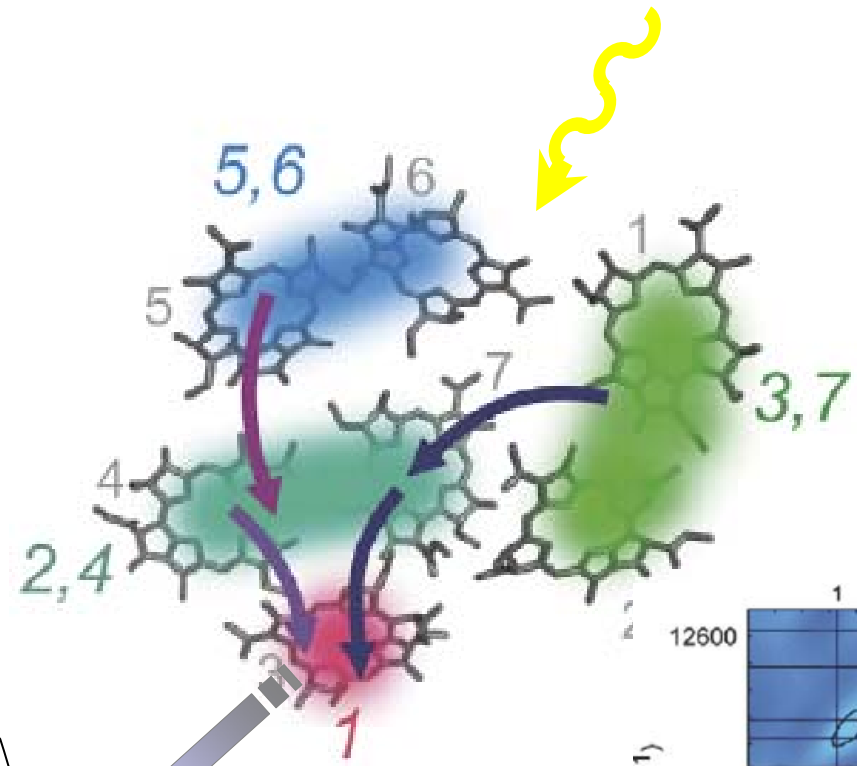
+ energy

$CH_2O + 2\,S + H_2O$

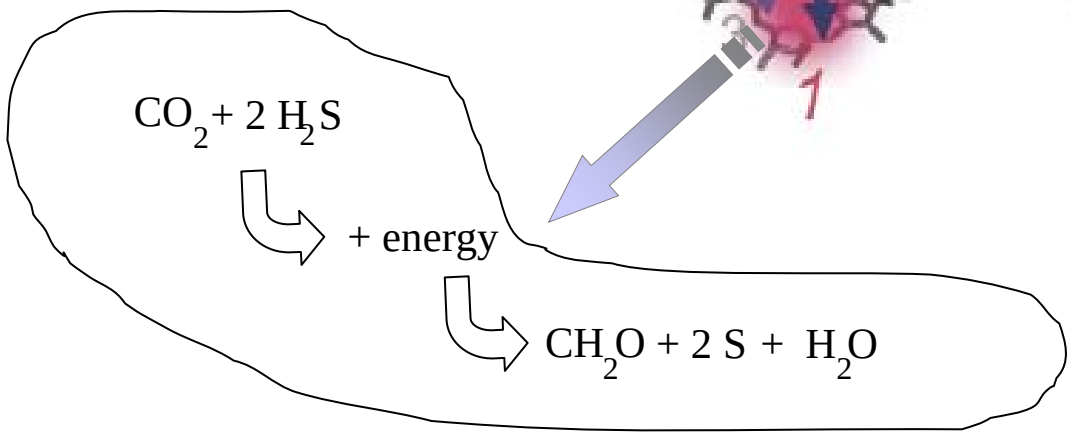
Noise Assisted Transport and Photosynthesis

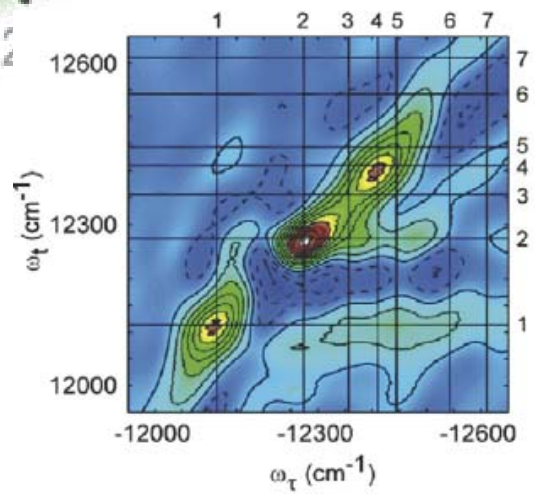


Green sulphur Bacteria



Reaction Centre





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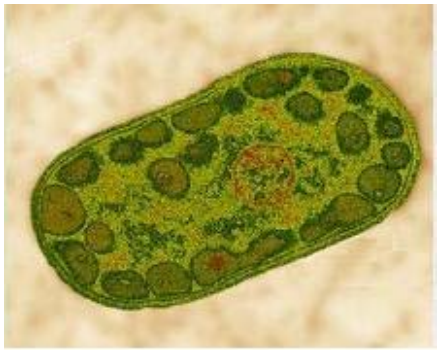
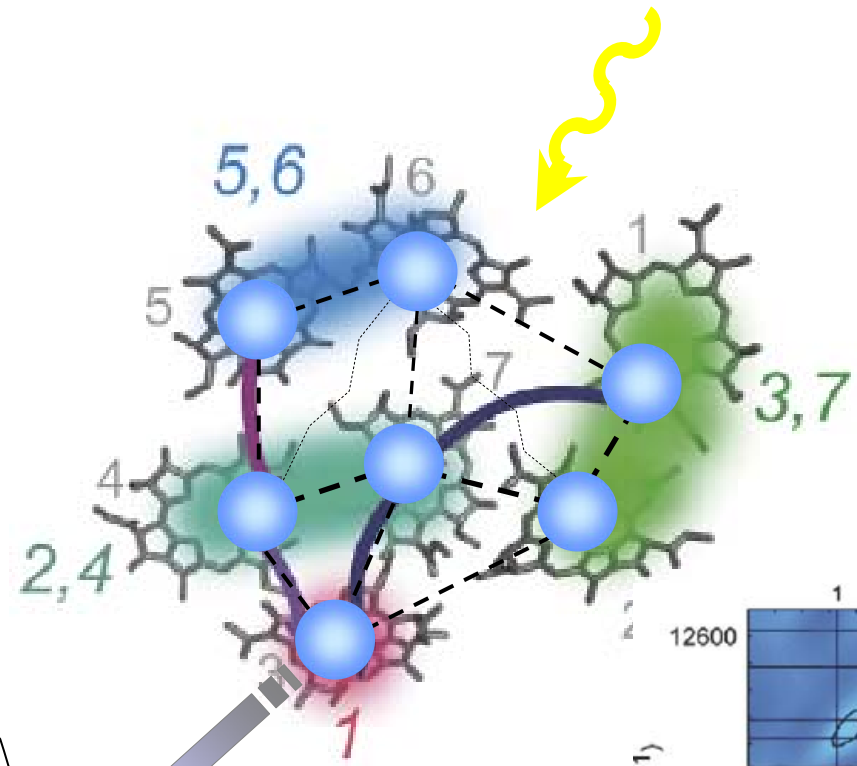


Green sulphur Bacteria



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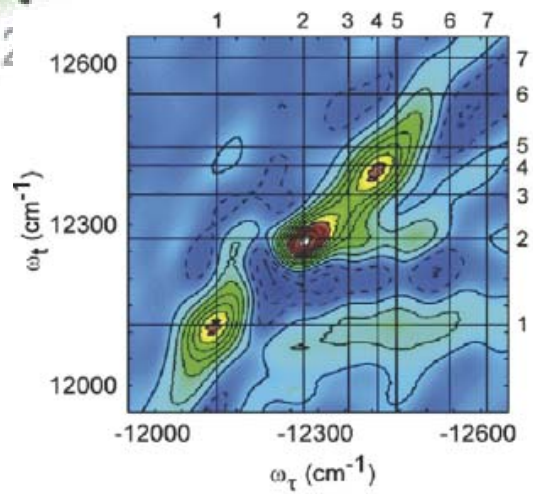
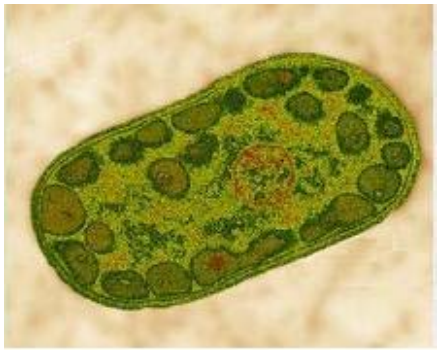
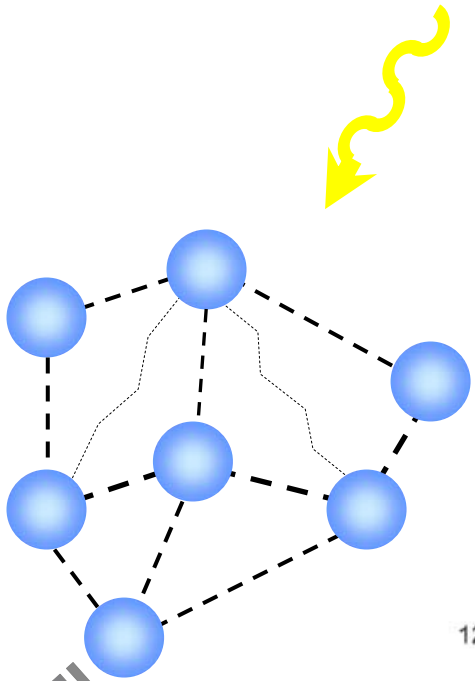


Noise Assisted Transport and Photosynthesis



Green sulphur Bacteria



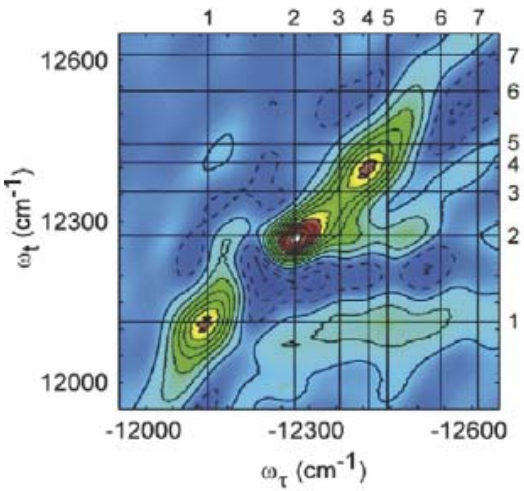
Reaction Centre

$CO_2 + 2\,H_2S$

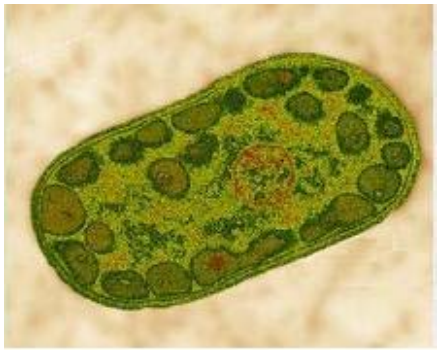
+ energy

$CH_2O + 2\,S + H_2O$

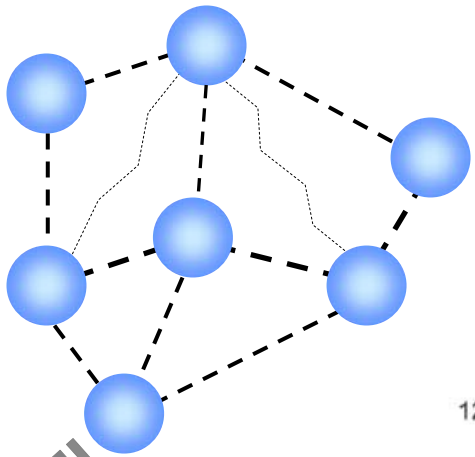
Transfer to reaction centre



Noise Assisted Transport and Photosynthesis



Green sulphur Bacteria



Reaction Centre

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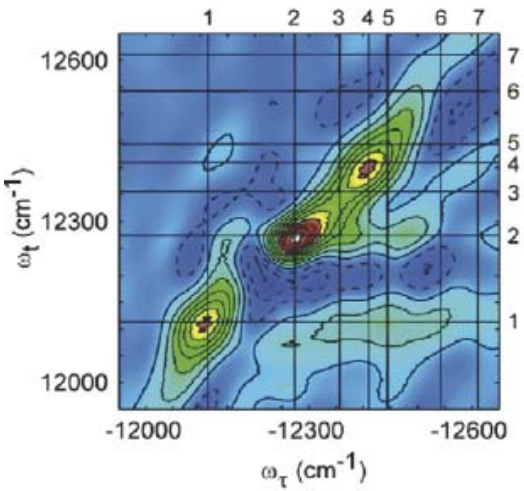
Transfer to reaction centre



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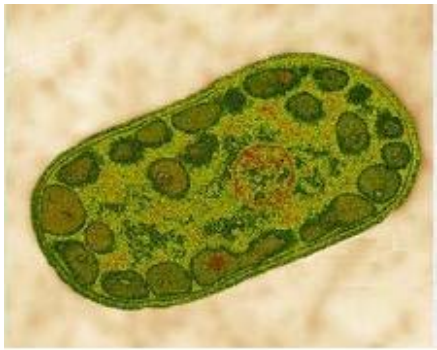
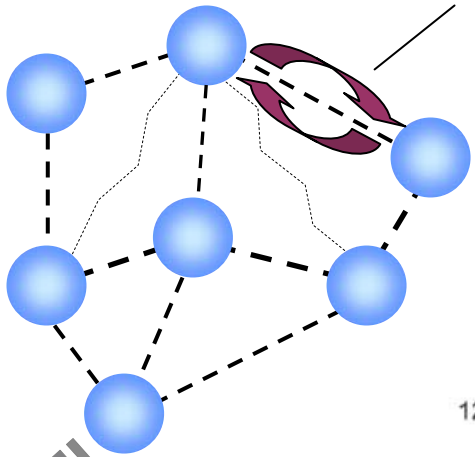


Green sulphur Bacteria

Exchange of excitation



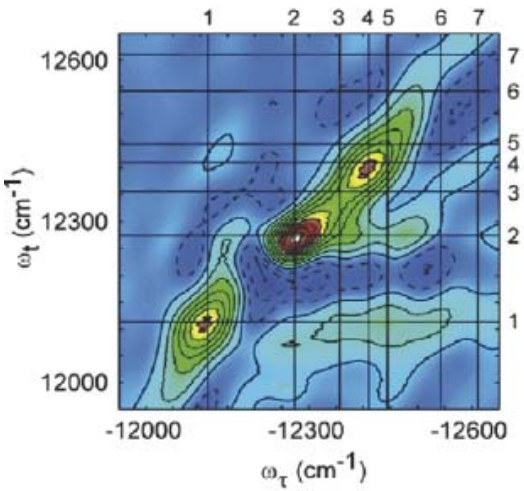
Reaction Centre

Transfer to reaction centre

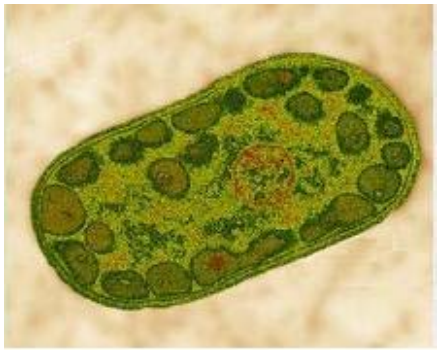
$CO_2 + 2\,H_2S$

+ energy

$CH_2O + 2\,S + H_2O$



Noise Assisted Transport and Photosynthesis



Green sulphur Bacteria

Loss of excitation

Exchange of excitation

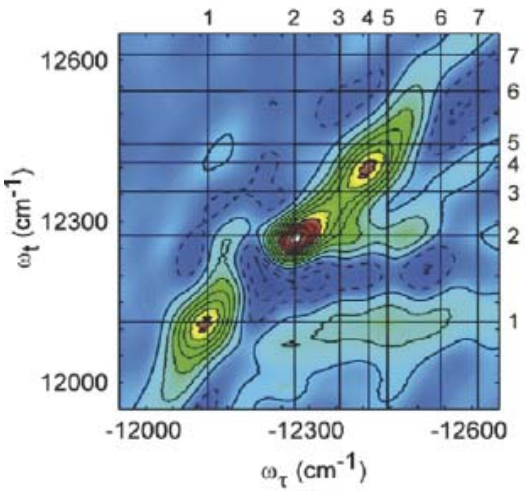
Reaction Centre

$CO_2 + 2\,H_2S$

+ energy

$CH_2O + 2\,S + H_2O$

Transfer to reaction centre



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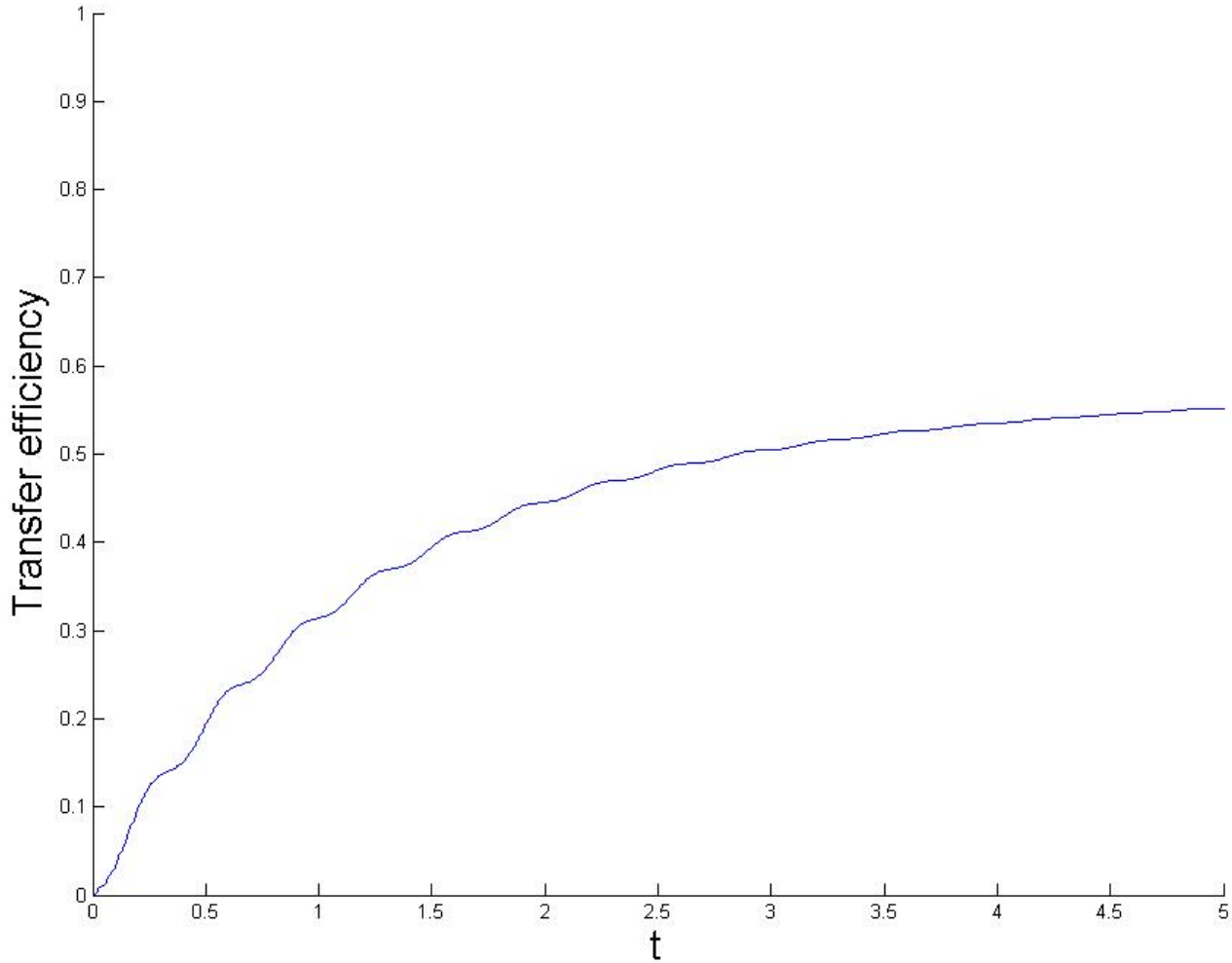
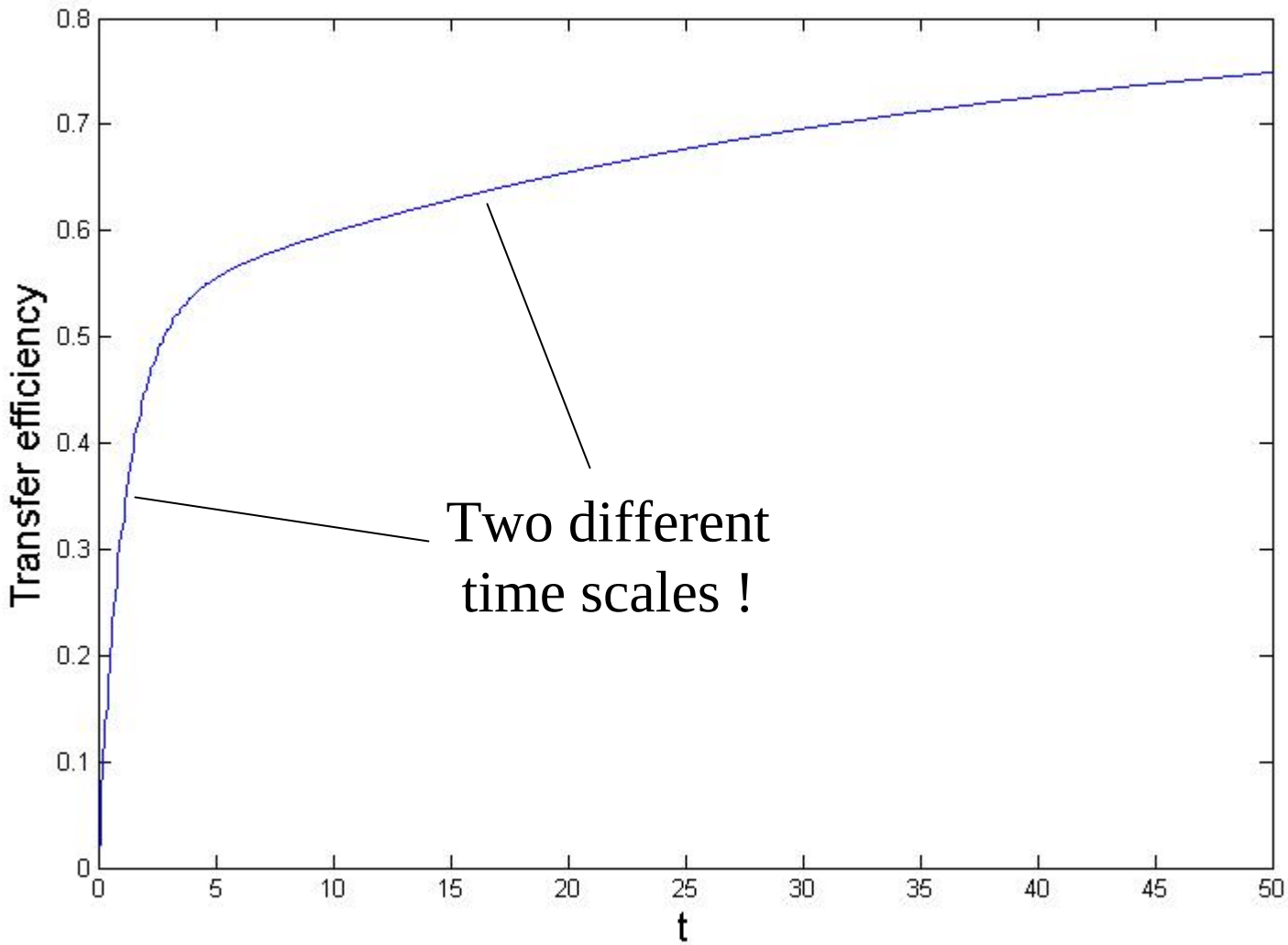


Plenio & Huelga, New J. Phys. 2008

Mohseni, Rebentrost, Lloyd, Aspuru-Guzik, J. Phys. Chem. 2008

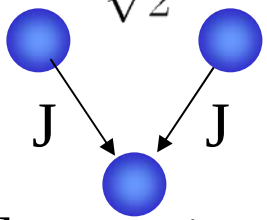
Exciton Transport in Photosynthesis



Caruso, Chin, Datta, Huelga, Plenio, arxiv:0901.4454 [quant-ph]

Destructive Interference and Invariant States

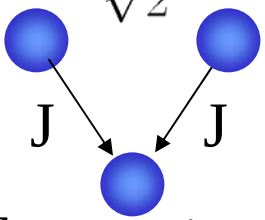
$$\frac{|01\rangle - |10\rangle}{\sqrt{2}}$$



destructive interference

Destructive Interference and Invariant States

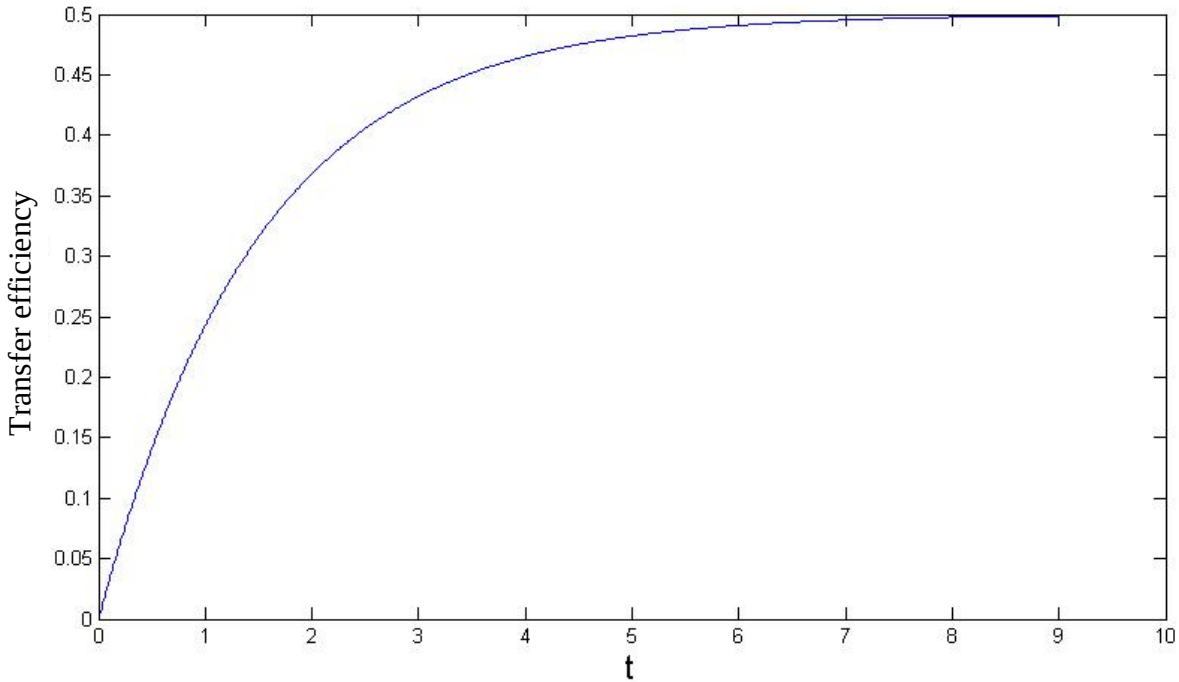
$$\frac{|01\rangle - |10\rangle}{\sqrt{2}}$$



destructive interference

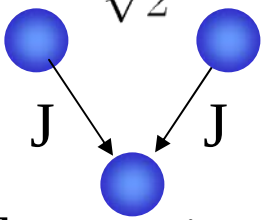
$$|01\rangle = \frac{1}{\sqrt{2}}\left[\frac{|01\rangle - |10\rangle}{\sqrt{2}} + \frac{|01\rangle + |10\rangle}{\sqrt{2}}\right]$$

$$\rho = \frac{1}{2}|\psi^-\rangle\langle\psi^-| + \frac{1}{2}|00\rangle\langle 00|$$

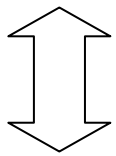


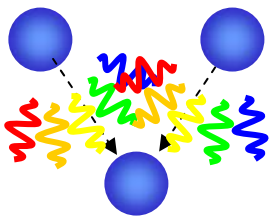
Noise Inhibits Destructive Interference

$$\frac{|01\rangle - |10\rangle}{\sqrt{2}}$$



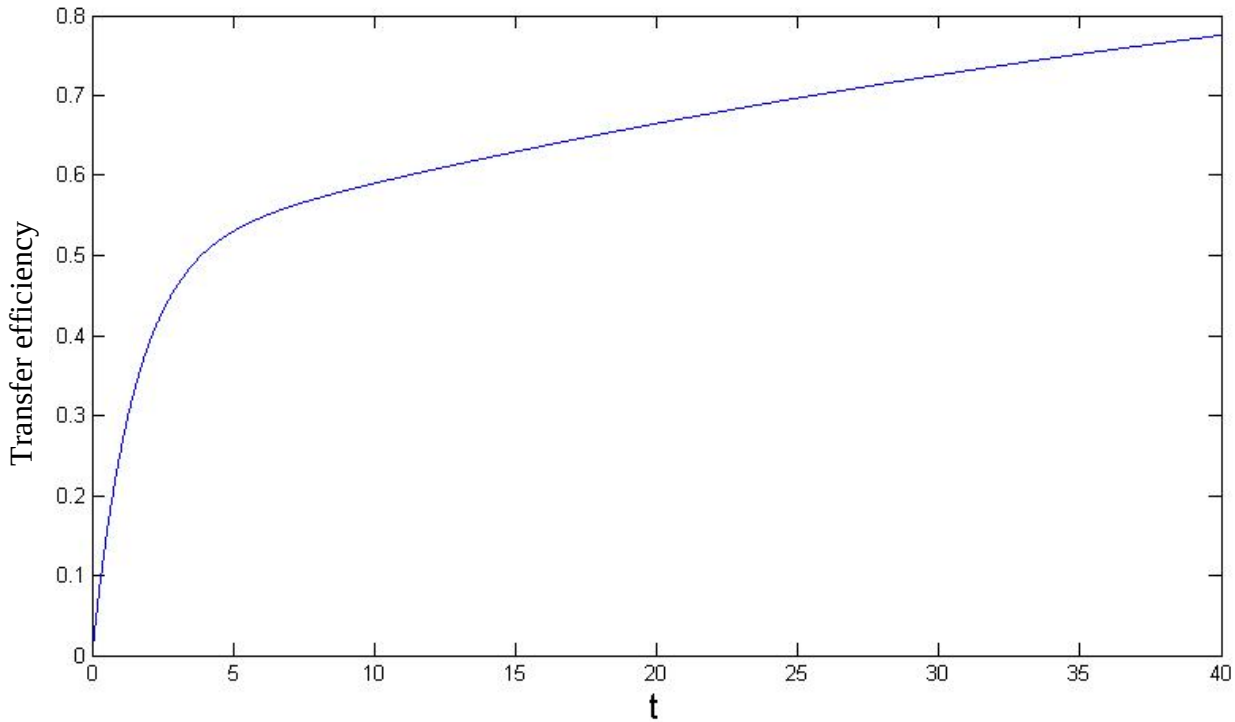
destructive interference



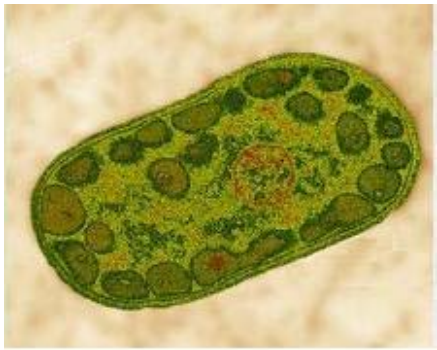


reduced destructive interference

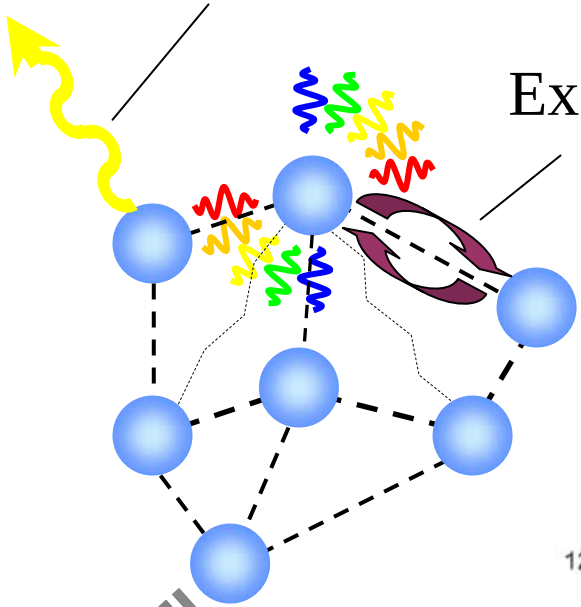
Decoherence inhibits destructive interference !



Noise Assisted Transport and Photosynthesis



Green sulphur Bacteria



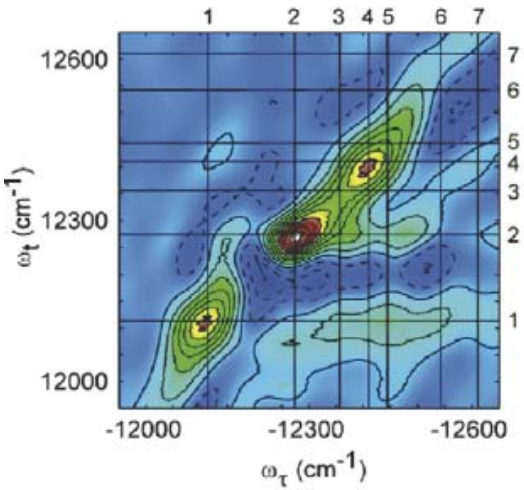
Reaction Centre

$CO_2 + 2\,H\,S_2$

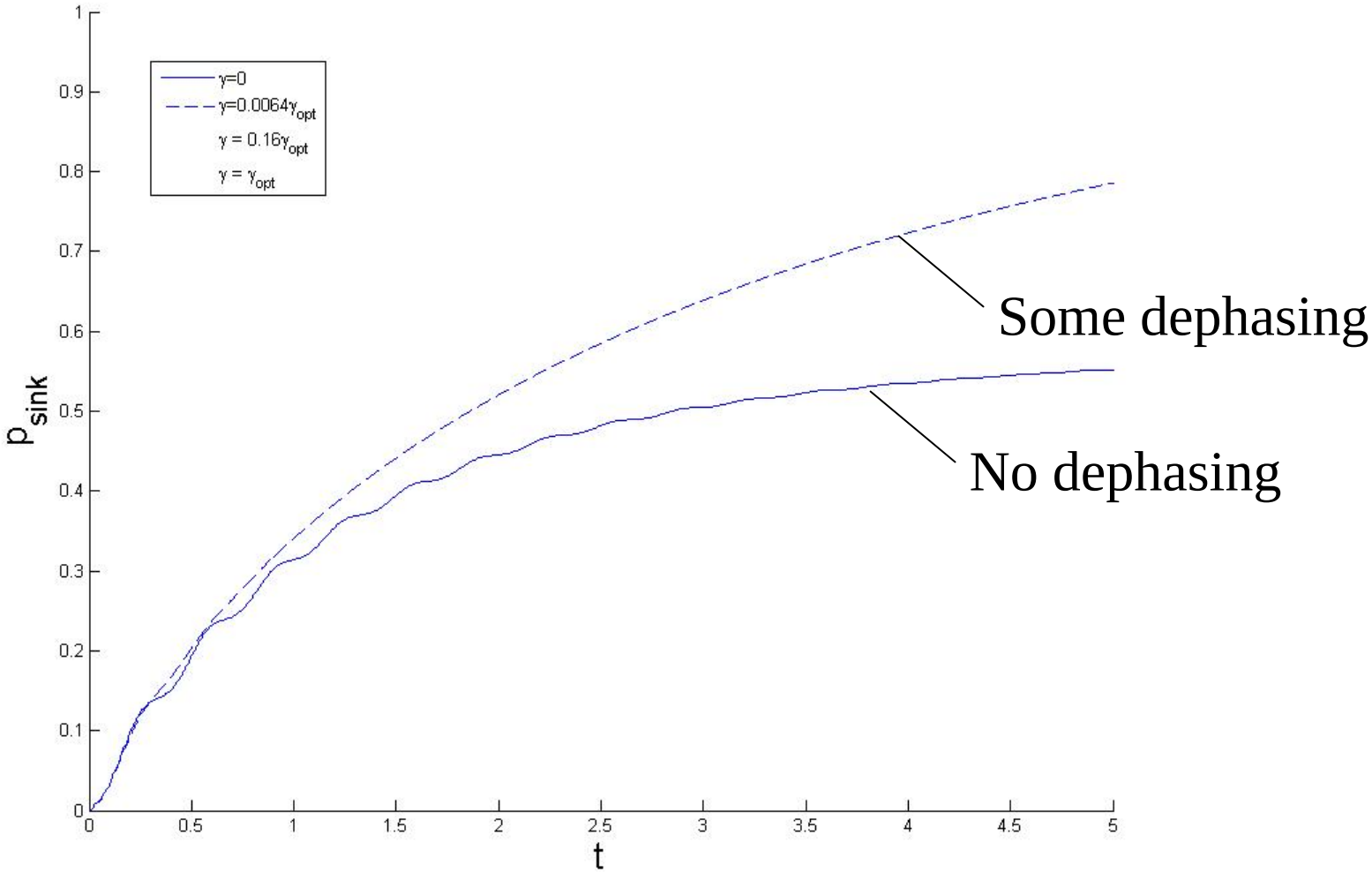
+ energy

$CH_2O + 2\,S + H_2O$

Transfer to reaction centre



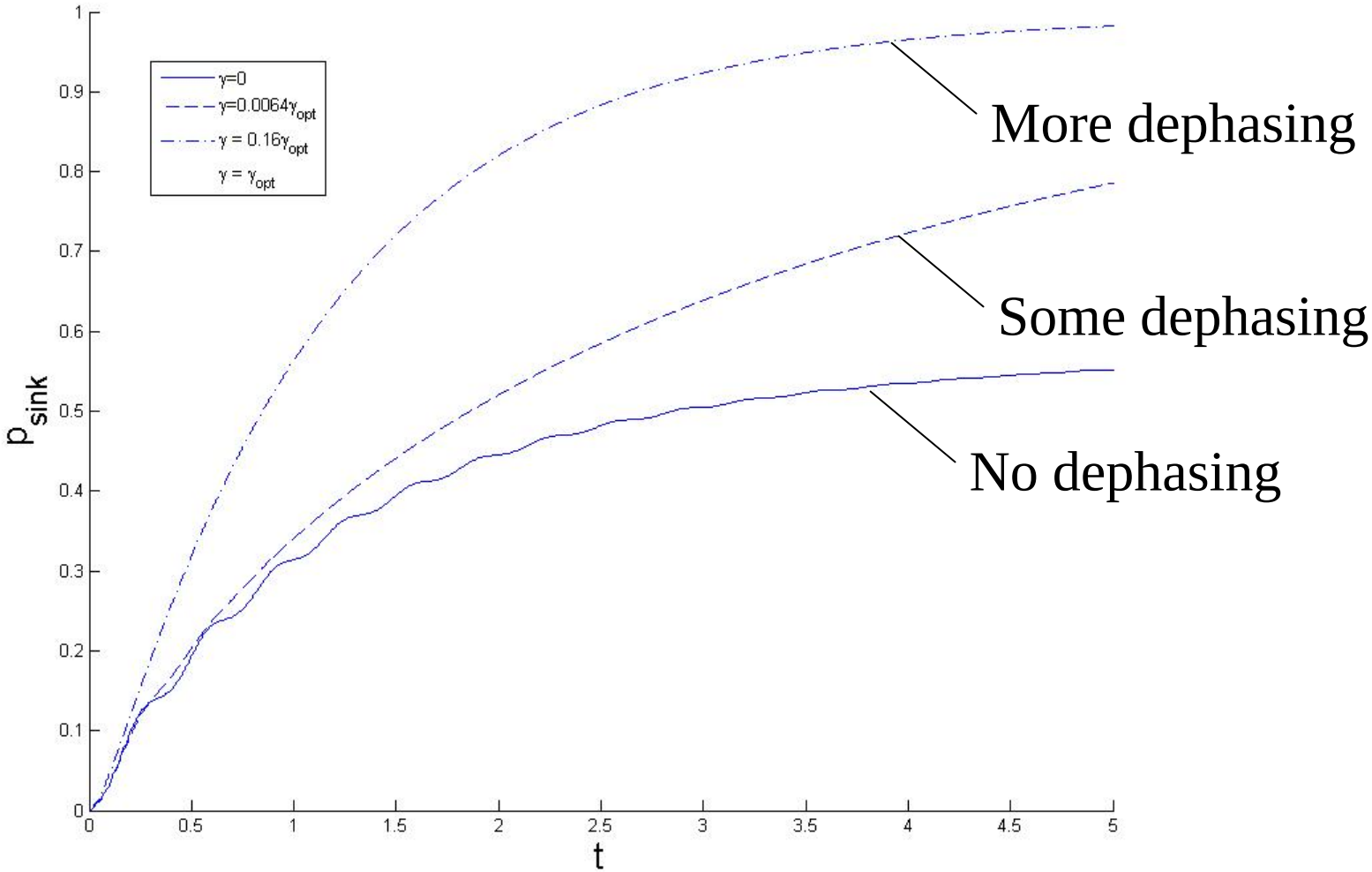
Noise Assisted Transport and Photosynthesis



Plenio & Huelga, New J. Phys. 2008

Mohseni, Rebentrost, Lloyd, Aspuru-Guzik, J. Phys. Chem. 2008

Noise Assisted Transport and Photosynthesis



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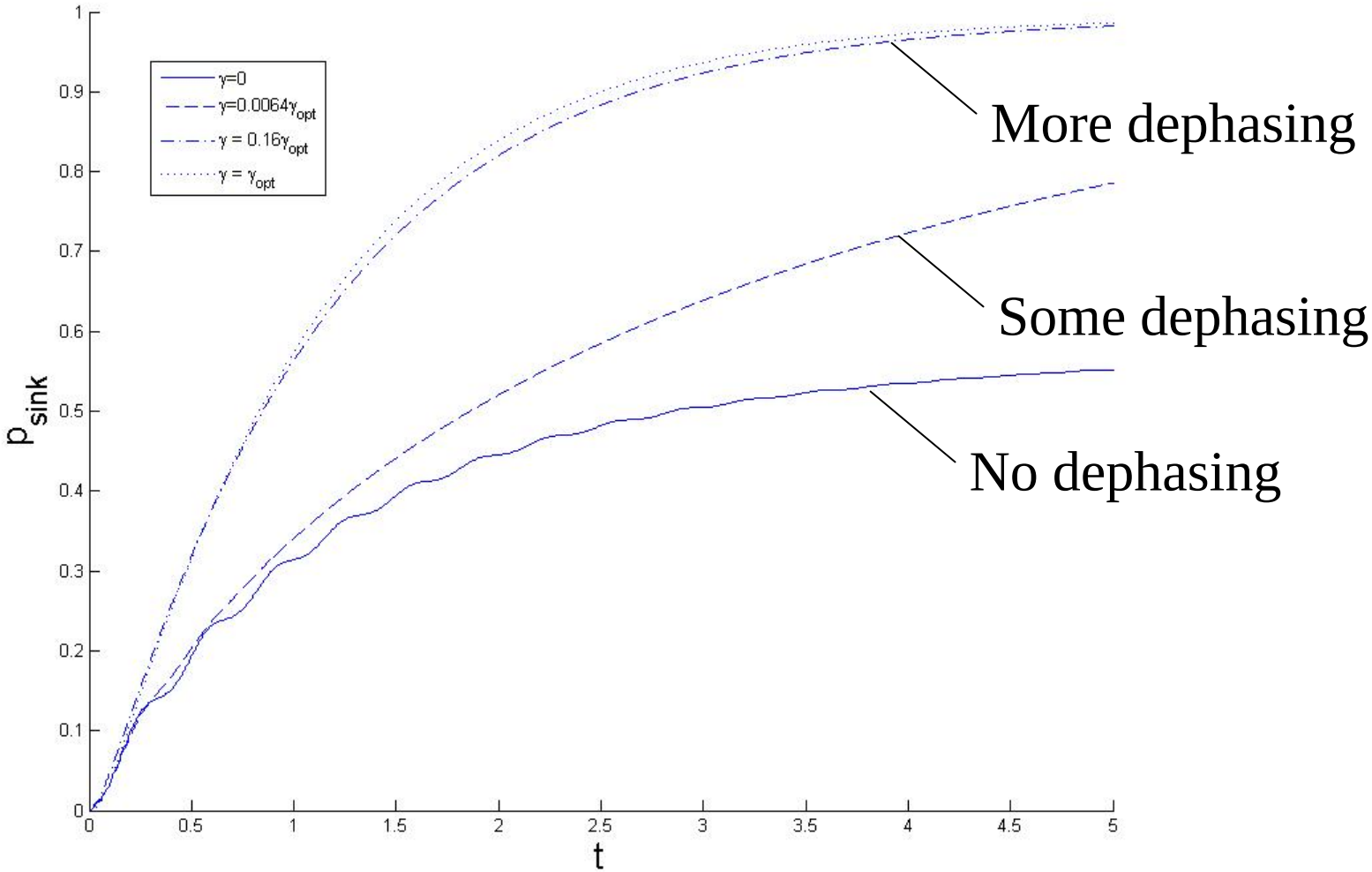
Noise Assisted Transport and Photosynthesis



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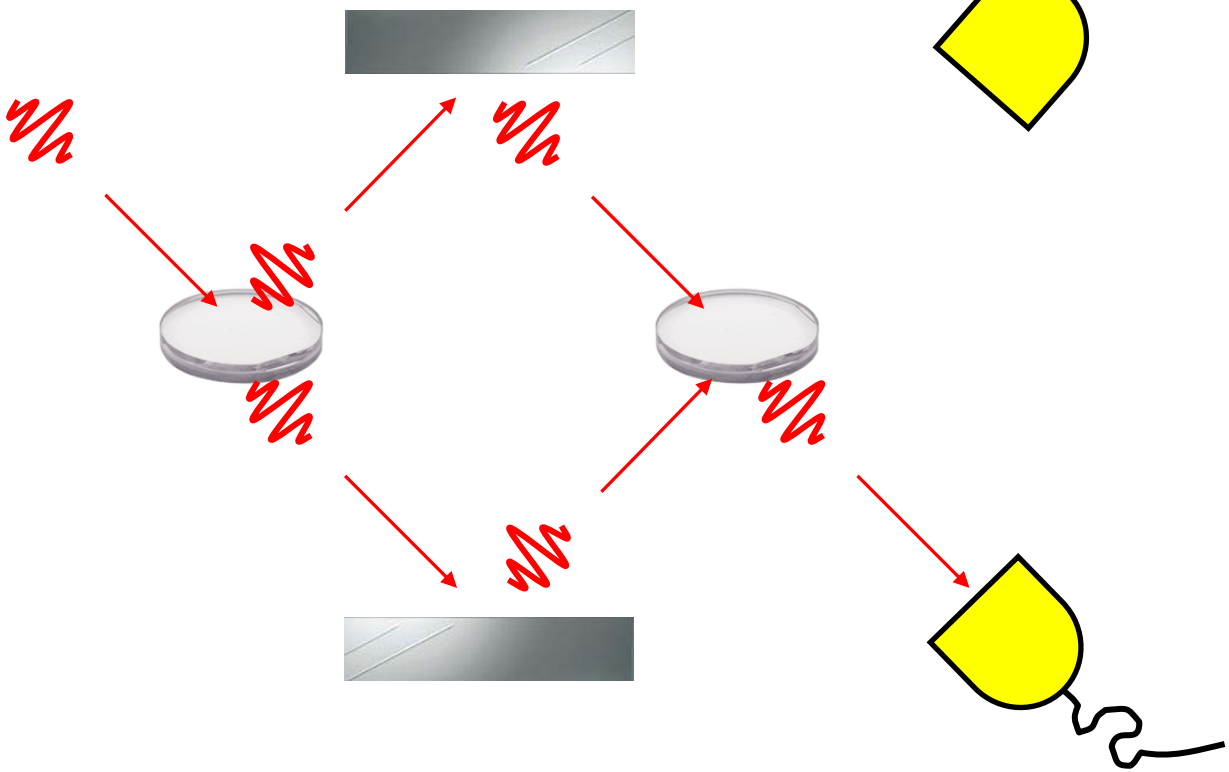
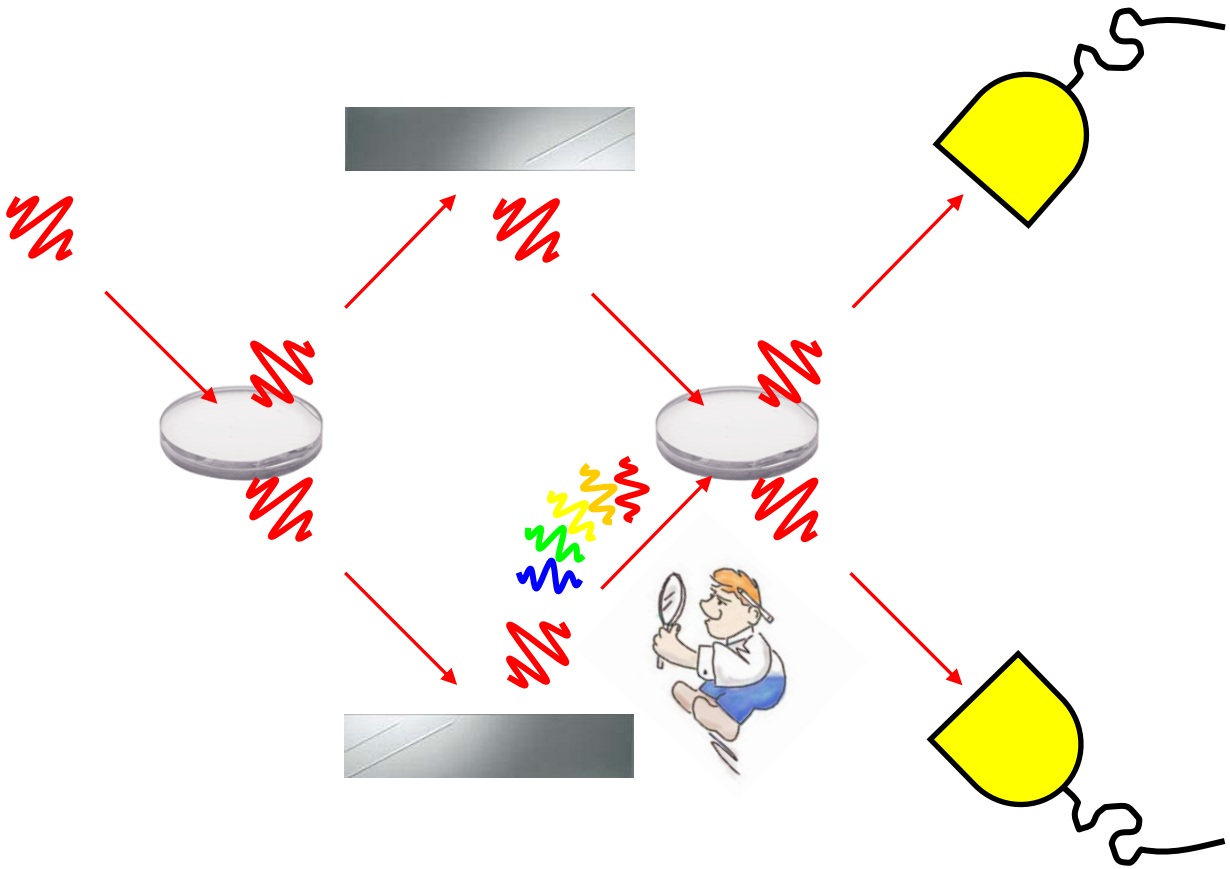
Mohseni, Rebentrost, Lloyd, Aspuru-Guzik, J. Phys. Chem. 2008

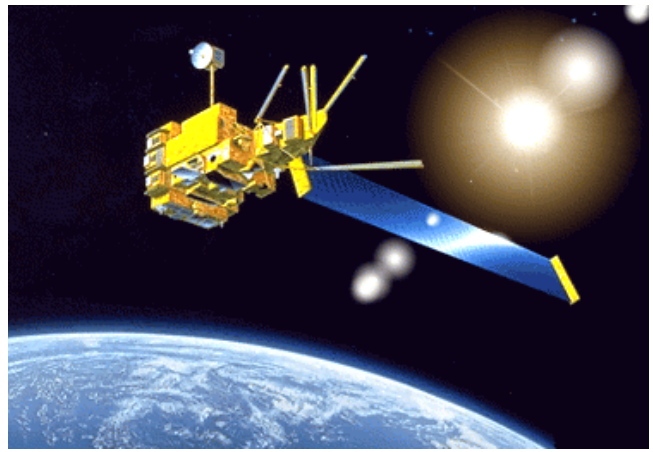
No photons: Destructive interference !



Noise kills destructive interference !

Photons arrive thanks to noise !





Can we improve solar cells based on this idea ?

More generally: Adding the right kind of noise, to the right kind of nano-structure can improve its performance.

Engineer system to generate constructive interplay between quantum dynamics and noise

Quantum particles are very fragile to noise

Tradition states:

Need to struggle with noise to stabilize quantum systems

Quantum particles are very fragile to noise

Modern view states:

Employ fragility as a resource