Nanotechnology in the Age of Information

Nathaniel Gabor
QMO Lab
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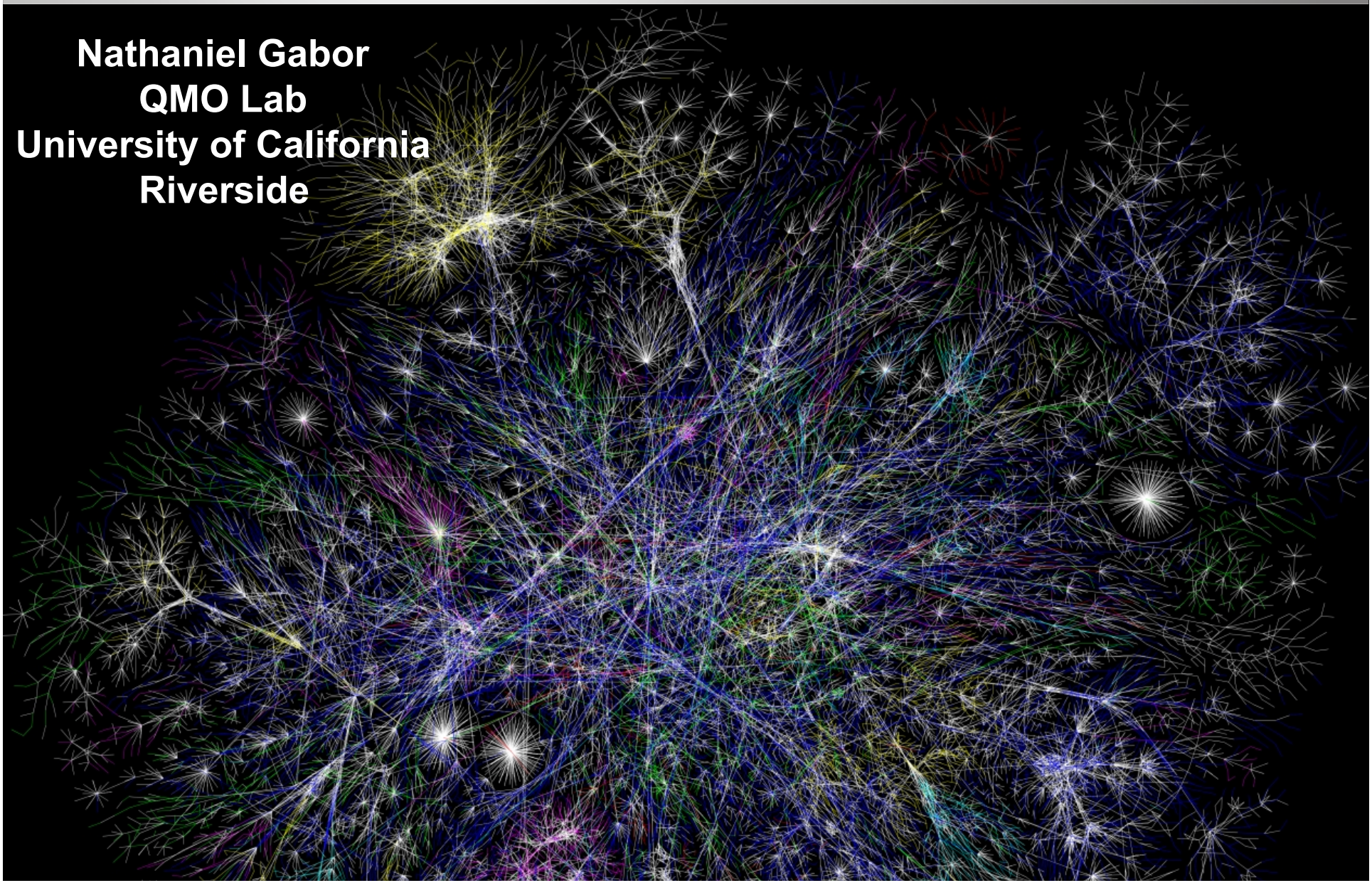

The Age of Information

Instant access to knowledge and the ability of individuals to transfer information freely

What is information?

“*…is tied up with our destiny…*”

. . . - - - . . .

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Digital Information Revolution

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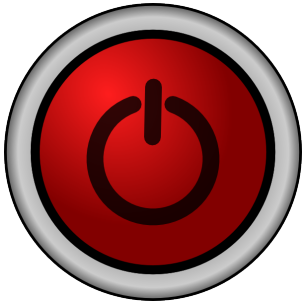
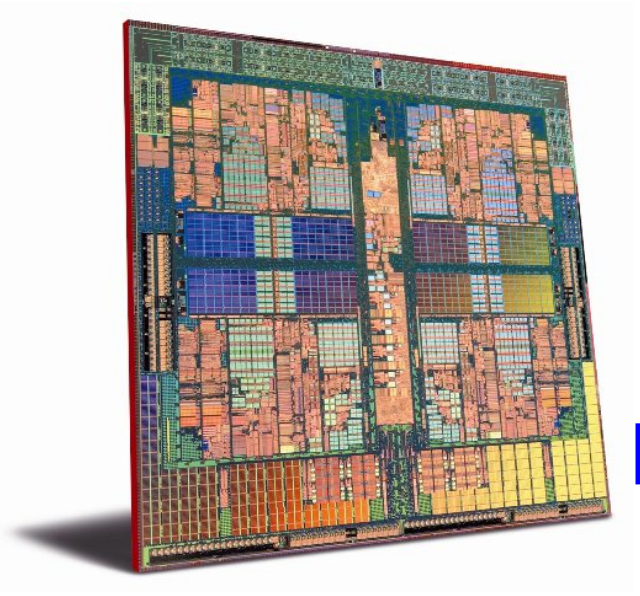
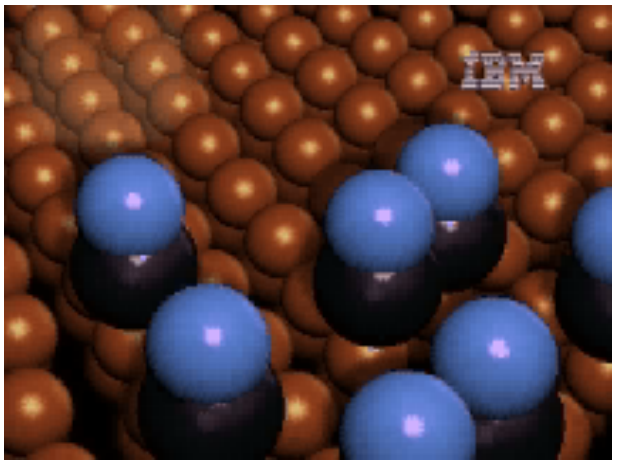


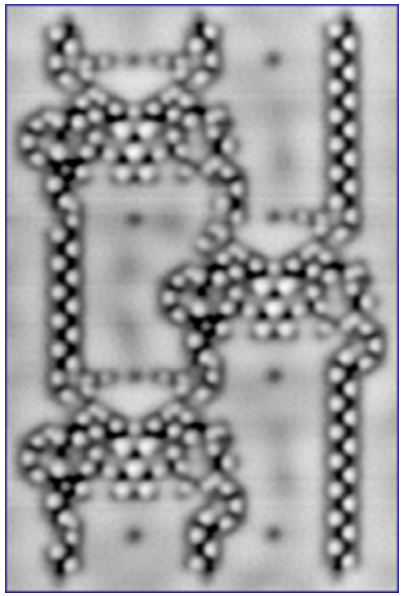


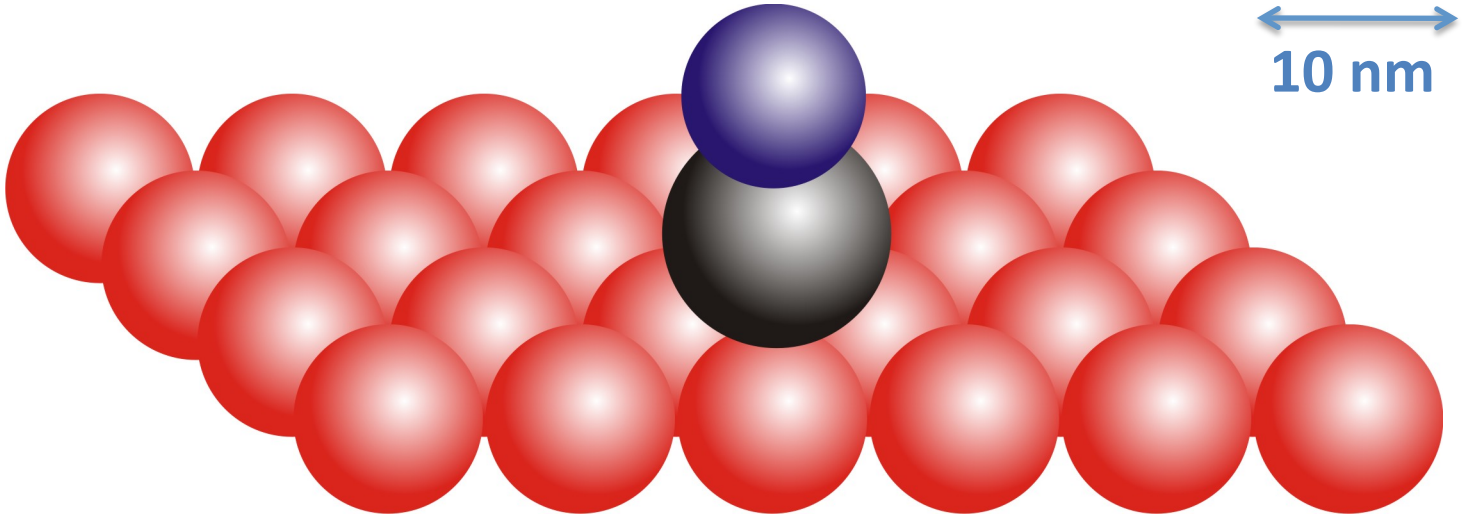
Goal:
Maximize the information per unit volume

How small can we go?

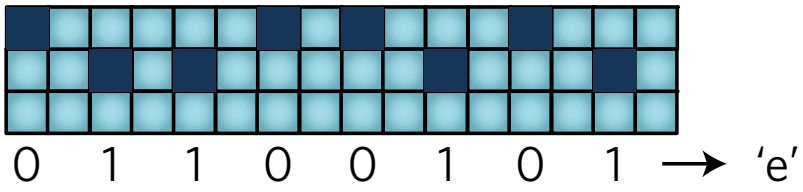
Goal:
Maximize the information per unit volume

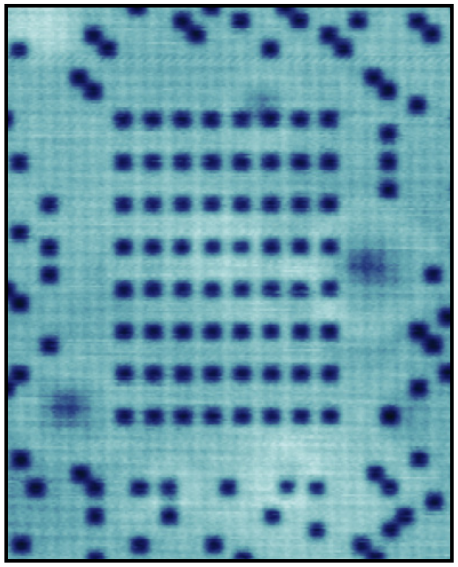


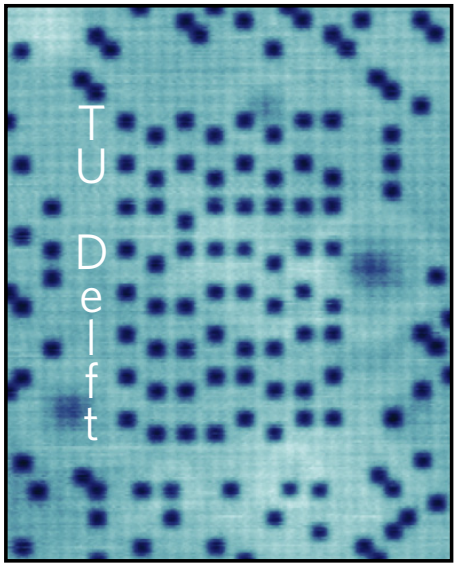


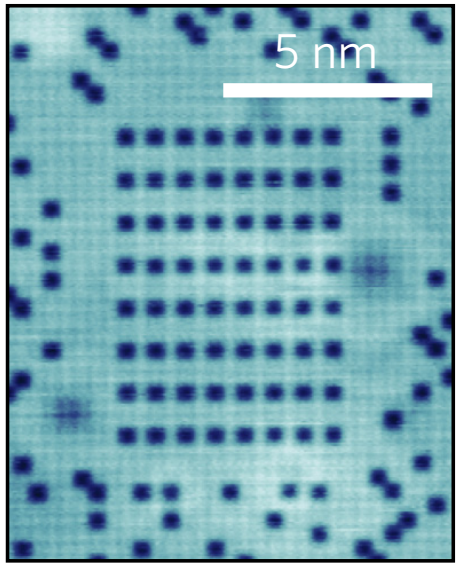


How small can we go?









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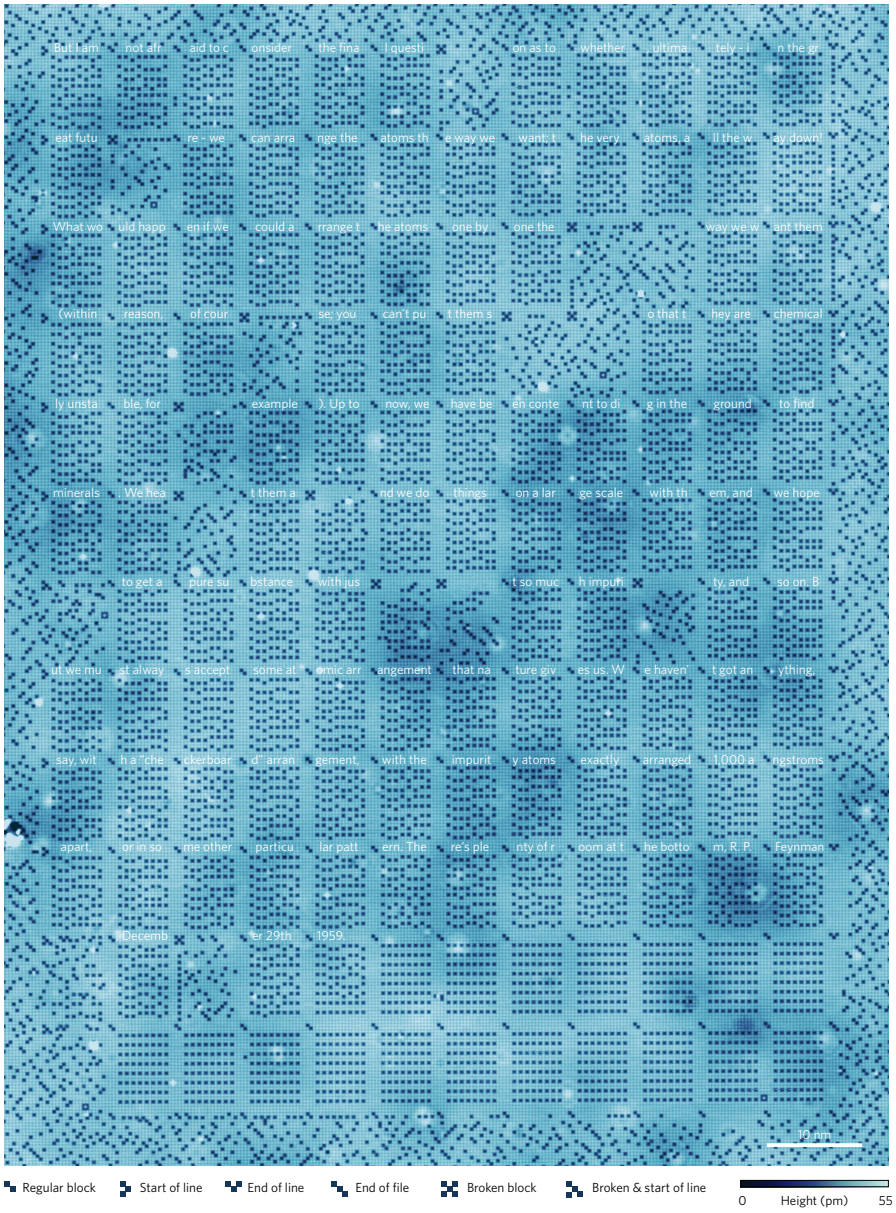
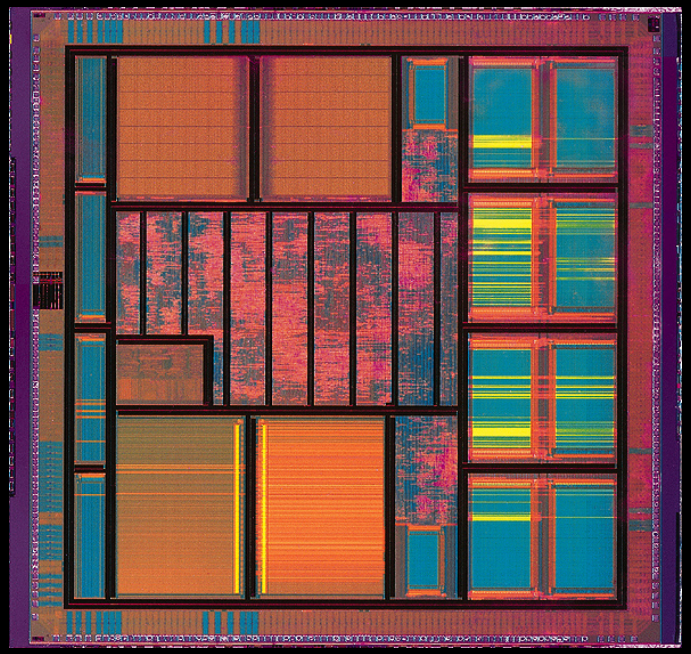


Kalff et al.
Nature Nano 2016

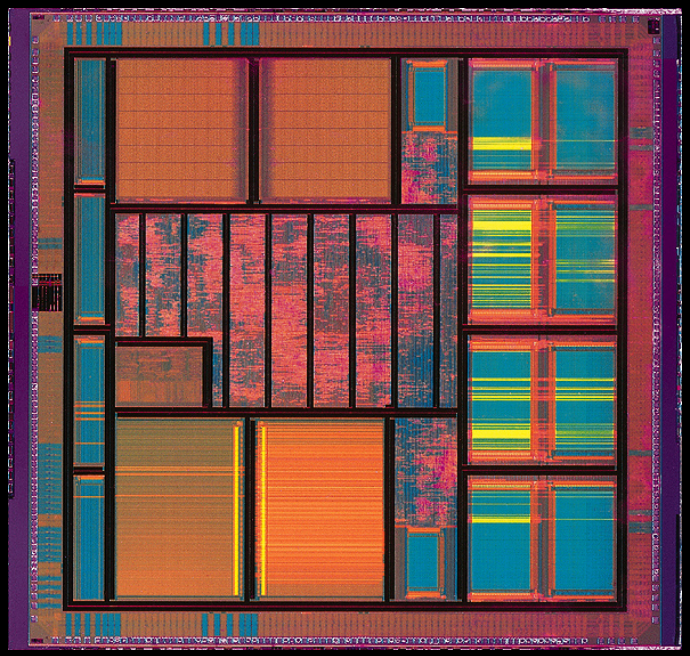
Technology in the Age of Information

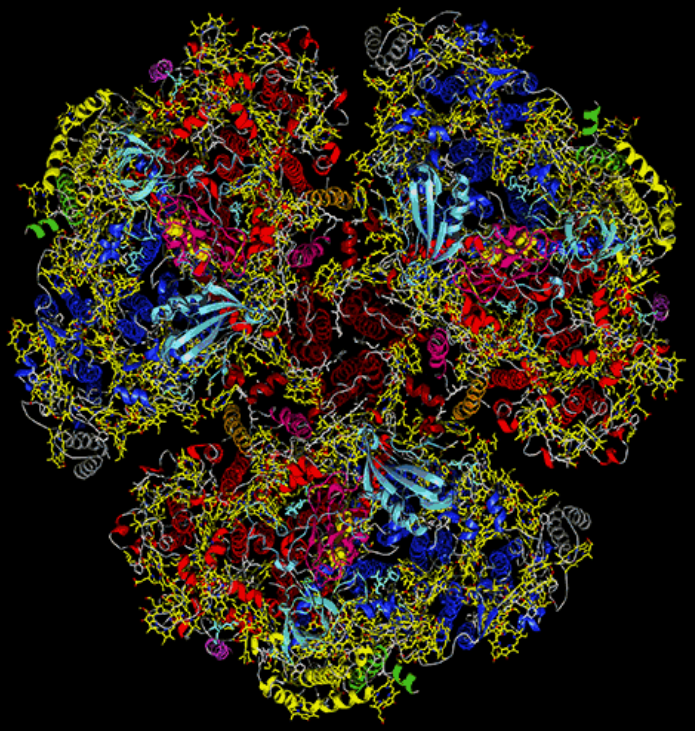
Condensed Matter drives the Information Age

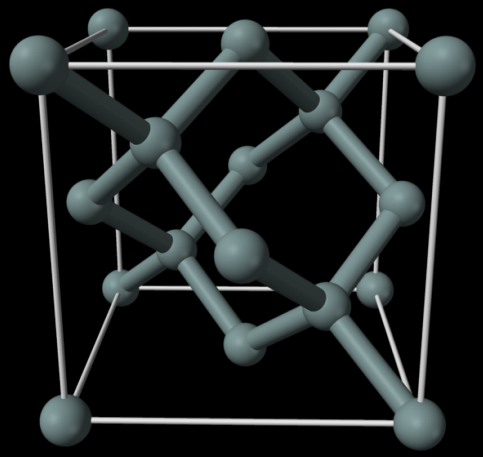
Condensed Matter: Nanotechnology

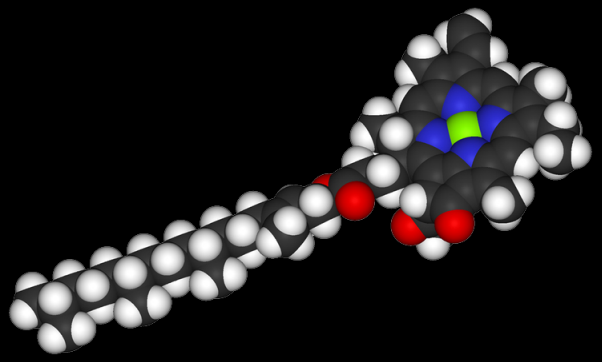


Nanotechnology

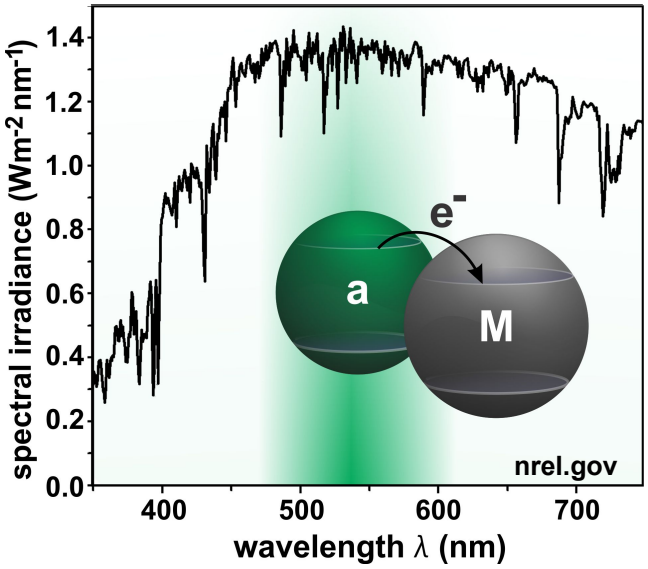








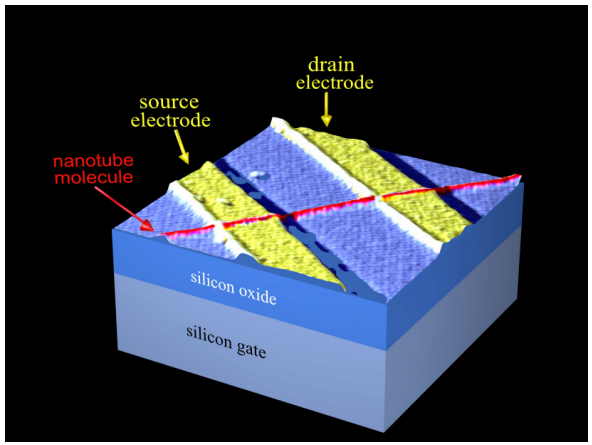
Designing a Quantum Material Solar Photocell



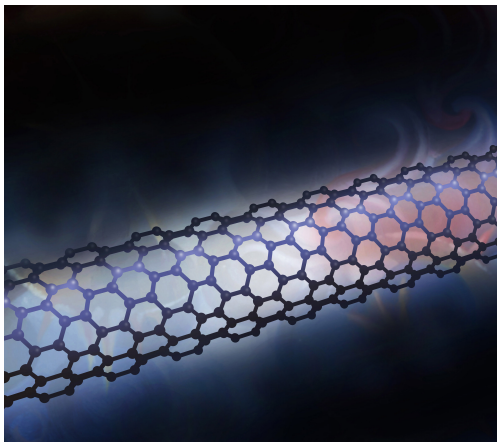
The ideal quantum material should exhibit:

1. **High absorption efficiency,**
2. **Efficient energy/charge transfer,**
3. **Quantum effects (e.g., multiple electron-hole pair production, FRET, entanglement)**

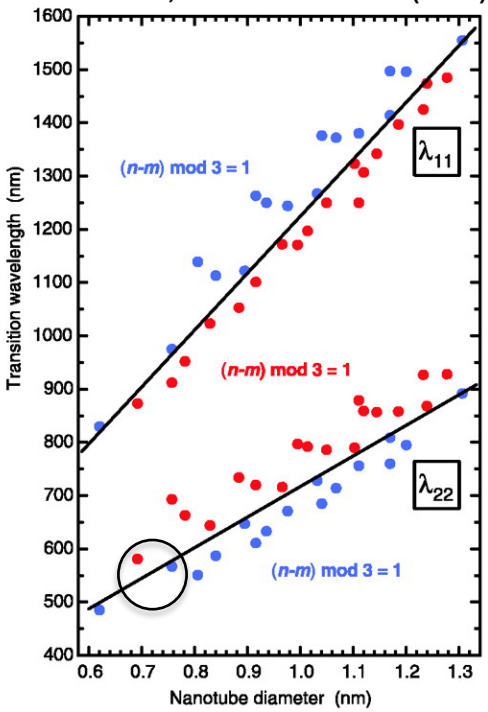
Tans, et al. *Nature* 393 (1998)



Gabor, et al. *Science* 325 (2009), *PRL* (2012)



Bachillo, et al. *Science* 298 (2002)



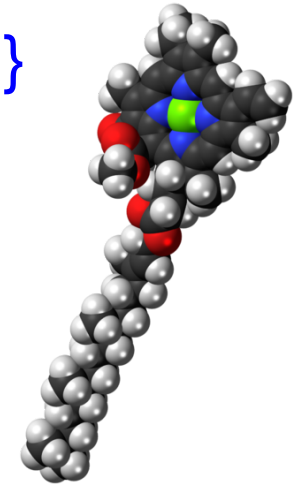
The simplest quantum solar photocell would absorb green light

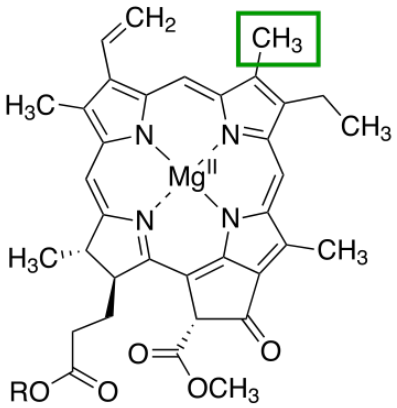
Why Are Terrestrial Plants Green?

Chlorophyll absorbs in the red and blue parts of the solar spectrum. When sunlight hits a plant, the blue and red portions of the light are absorbed by the chlorophyll, and the rejected green portion of light is reflected back.

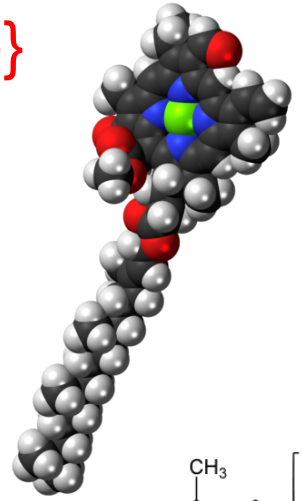
Chlorophyll: Structure and Absorption

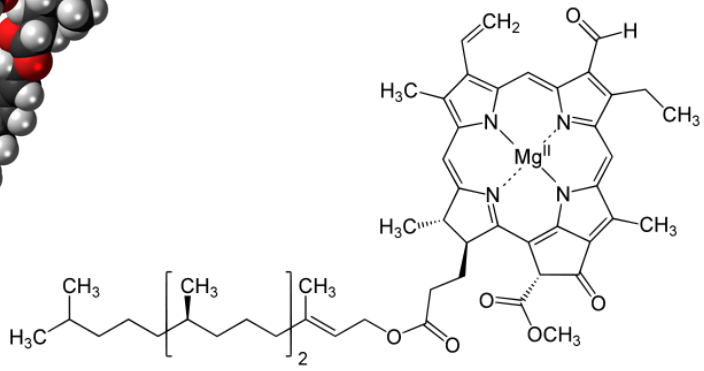
{a}

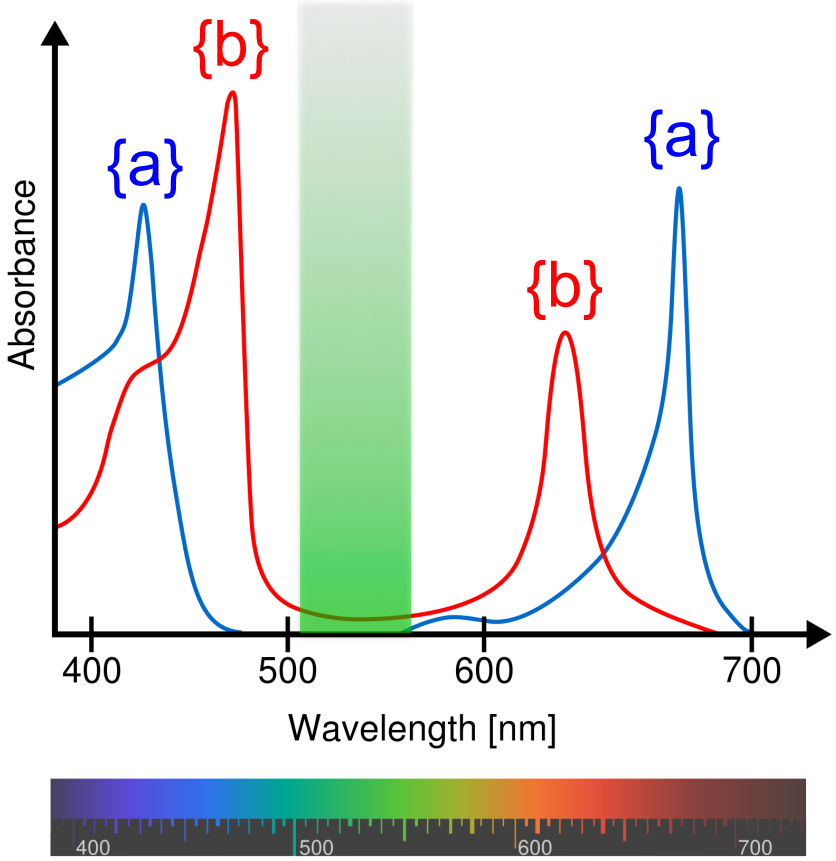




{b}







Nature's quantum photocell does *not* absorb green light

Astrobiological Perspective

Apparently the vegetable kingdom in Mars, instead of having green for a dominant colour, is of a vivid blood-red tint.

—H.G. Wells, *The War of the Worlds*, 1898

As photosynthesis on Earth produces the primary signatures of life that can be detected astronomically at the global scale, a strong focus of the search for extrasolar life will be photosynthesis, particularly photosynthesis that has evolved with a different parent star.

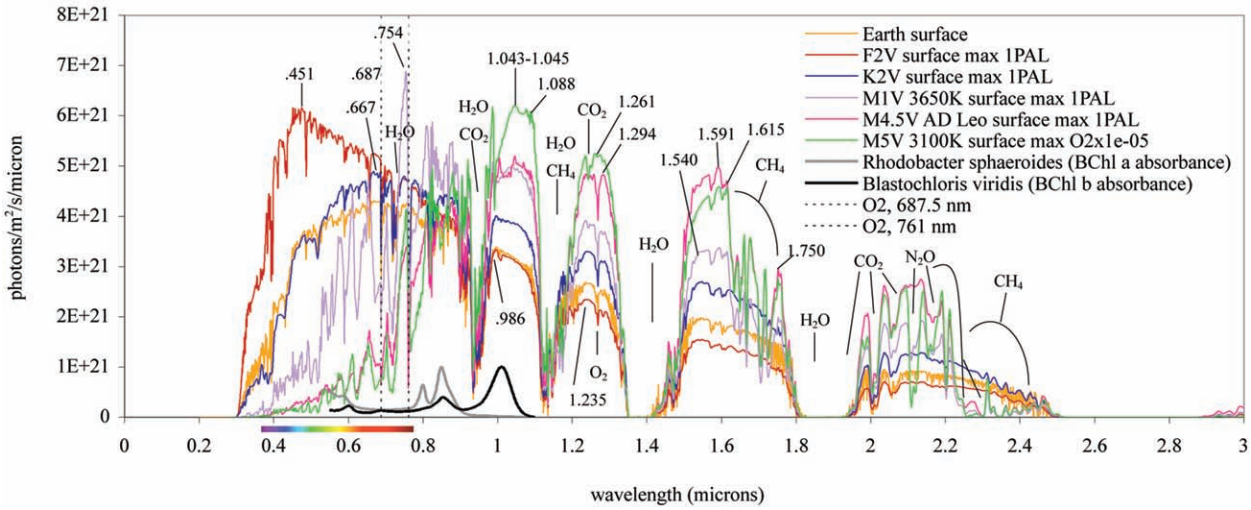
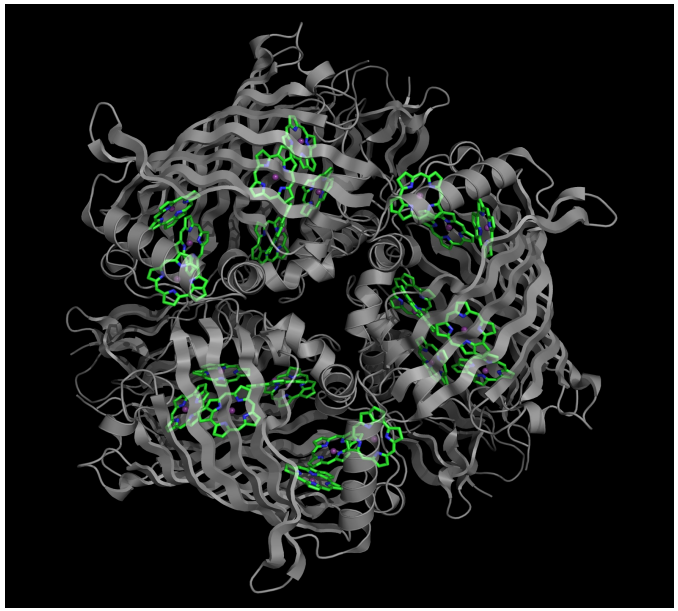
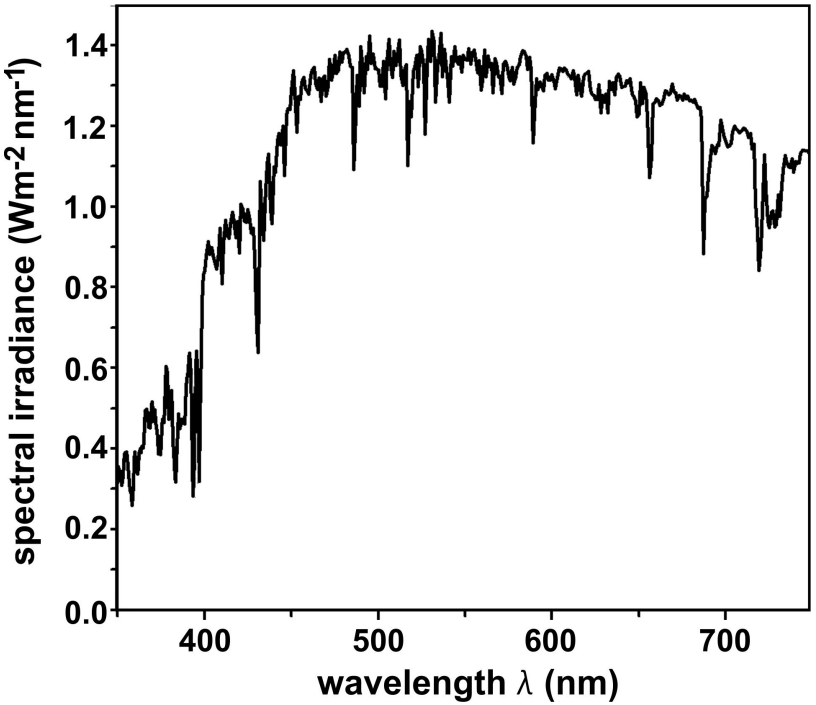


FIG. 3. Surface incident photon flux densities at solar noon for the Earth and for planets in the habitable zone of F, K, and M stars (temperatures of 3,650 K, 3,100 K, and measured AD Leo), as calculated from atmospheric composition in Segura *et al.* (2003, 2005) and the SMART radiative transfer model (Crisp, 1997). Wavelength of peak flux densities and transmittance window edges are indicated, as well as O_2 absorption lines. The absorbance spectra of bacteriochlorophyll (BChl) a and BChl b are included.

Kiang, et al., I, *Astrobiology* **7** (2007)
Kiang, et al., II, *Astrobiology* **7** (2007)

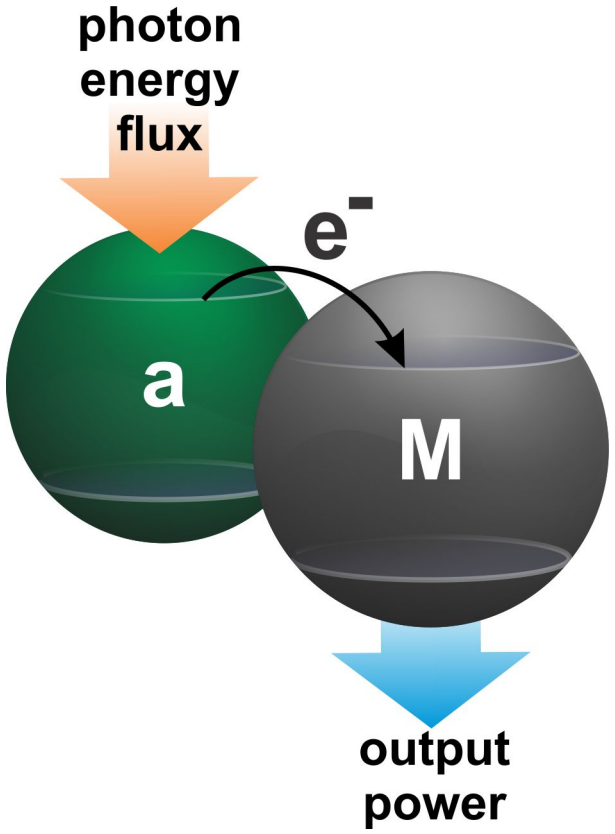
Natural Regulation of Energy Flow in a Quantum Photocell

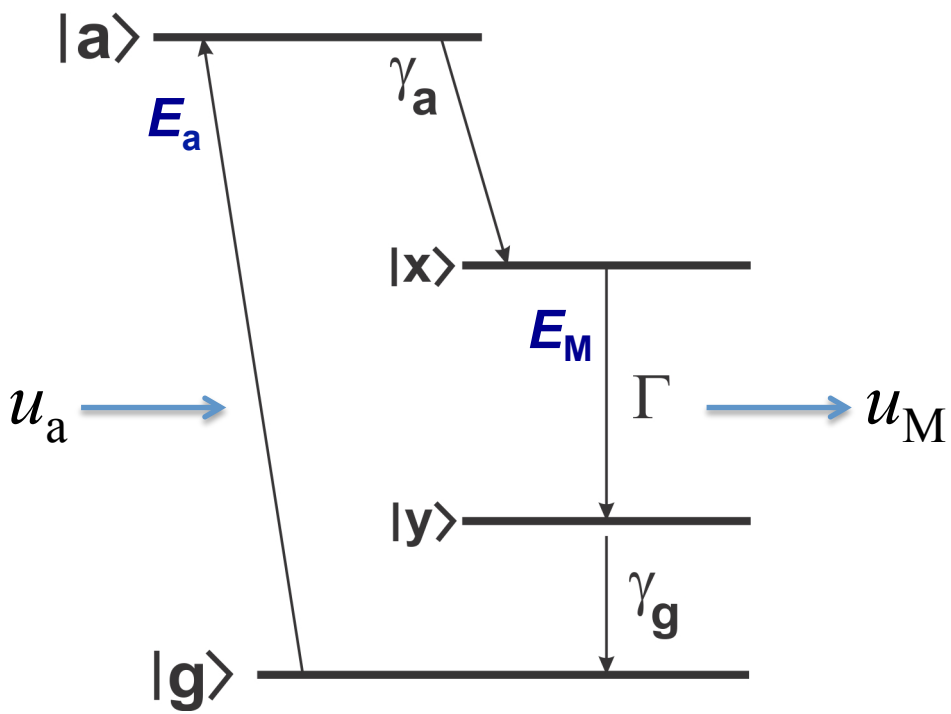




Does quantum structure give rise to emergent regulation against fluctuations?

Natural Regulation of Energy Flow in a Quantum Photocell

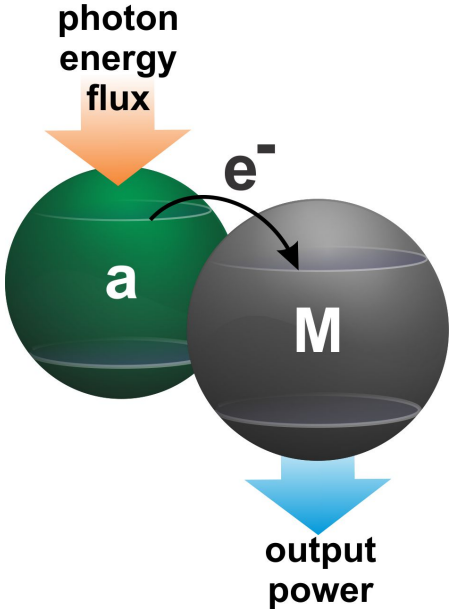


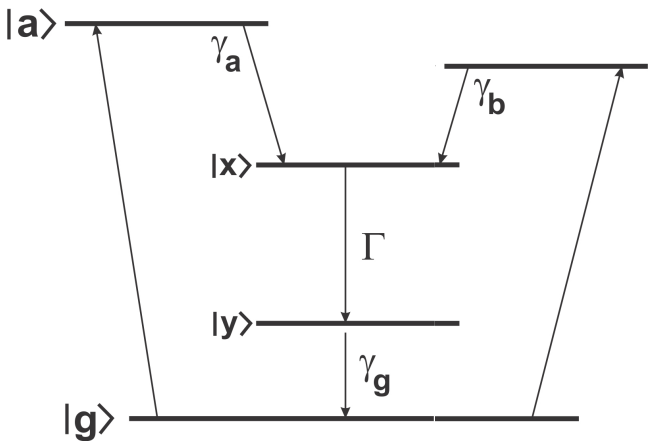


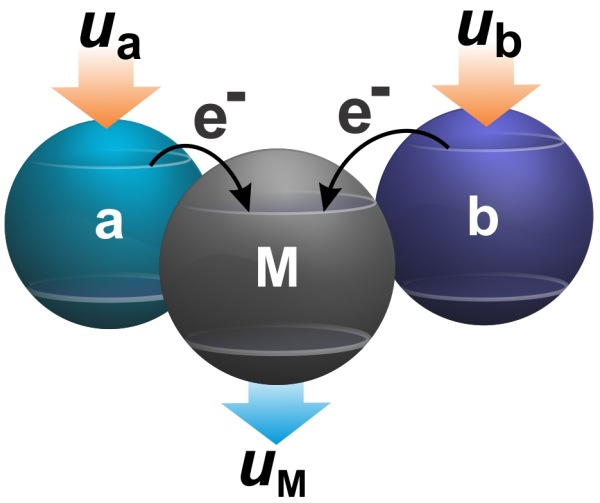
Regulation:

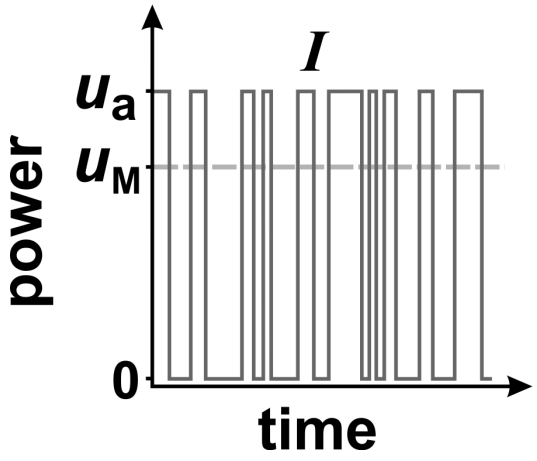
Efficient power conversion and energy storage requires that
1) the energy flux into the system matches the output demand, and
2) energy fluctuations (surplus or deficit) are suppressed.

Natural Regulation of Energy Flow in a Quantum Photocell

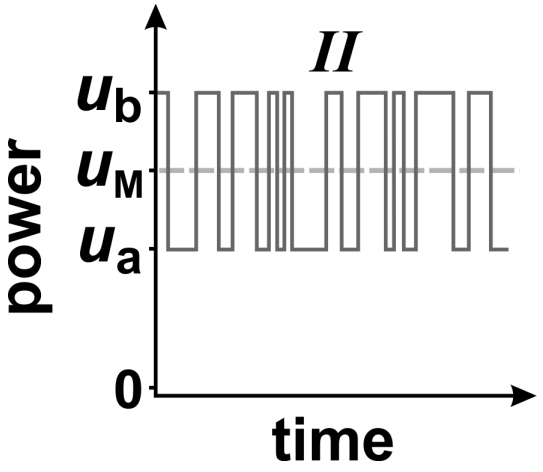




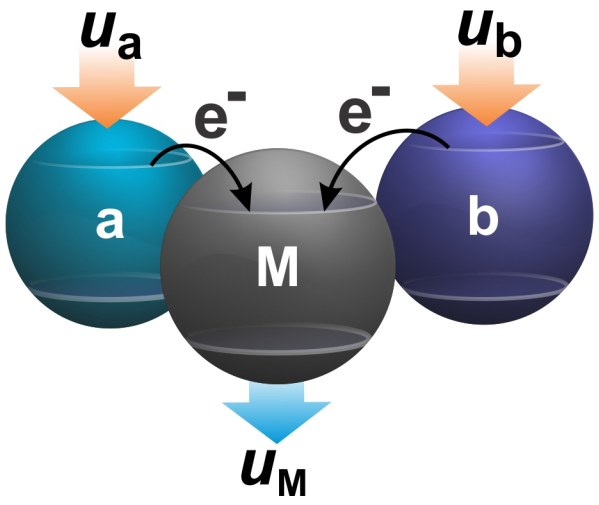


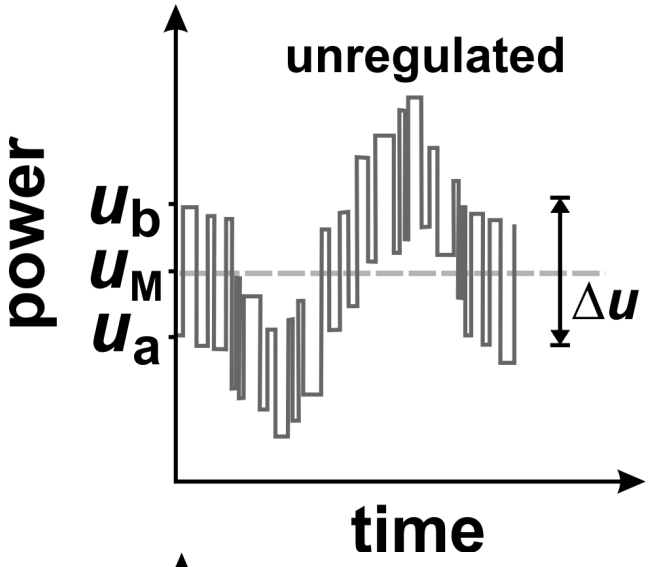


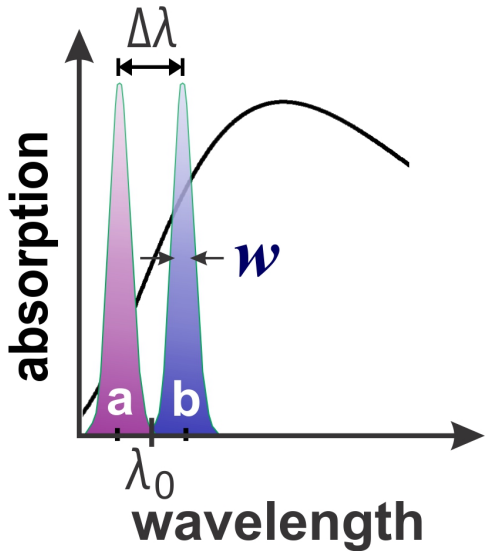
fluctuations are suppressed by introducing a second quantum channel

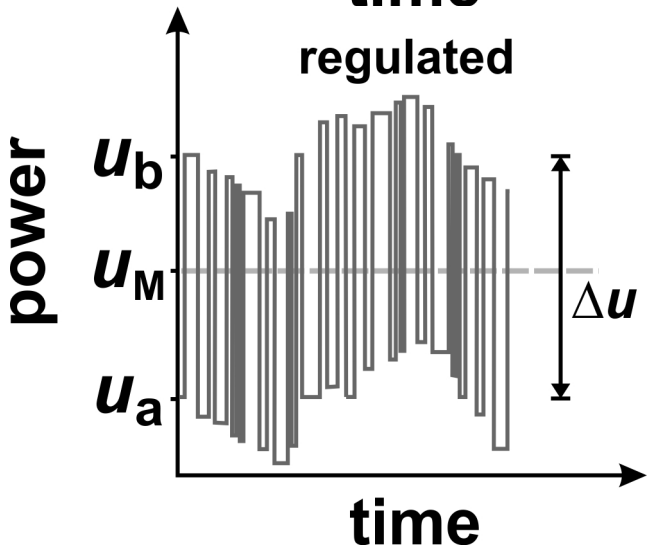


Natural Regulation of Energy Flow in a Quantum Photocell









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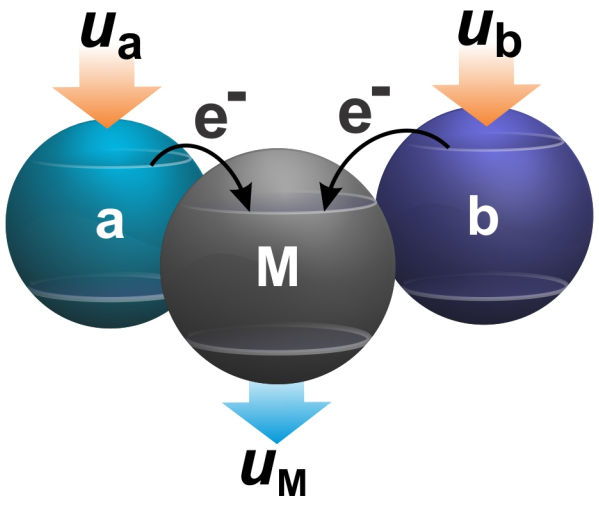

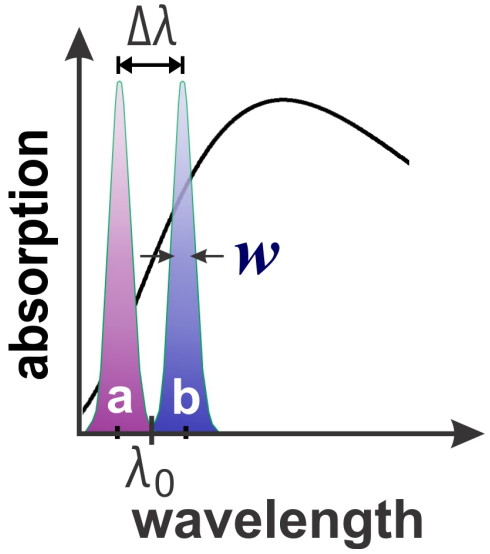

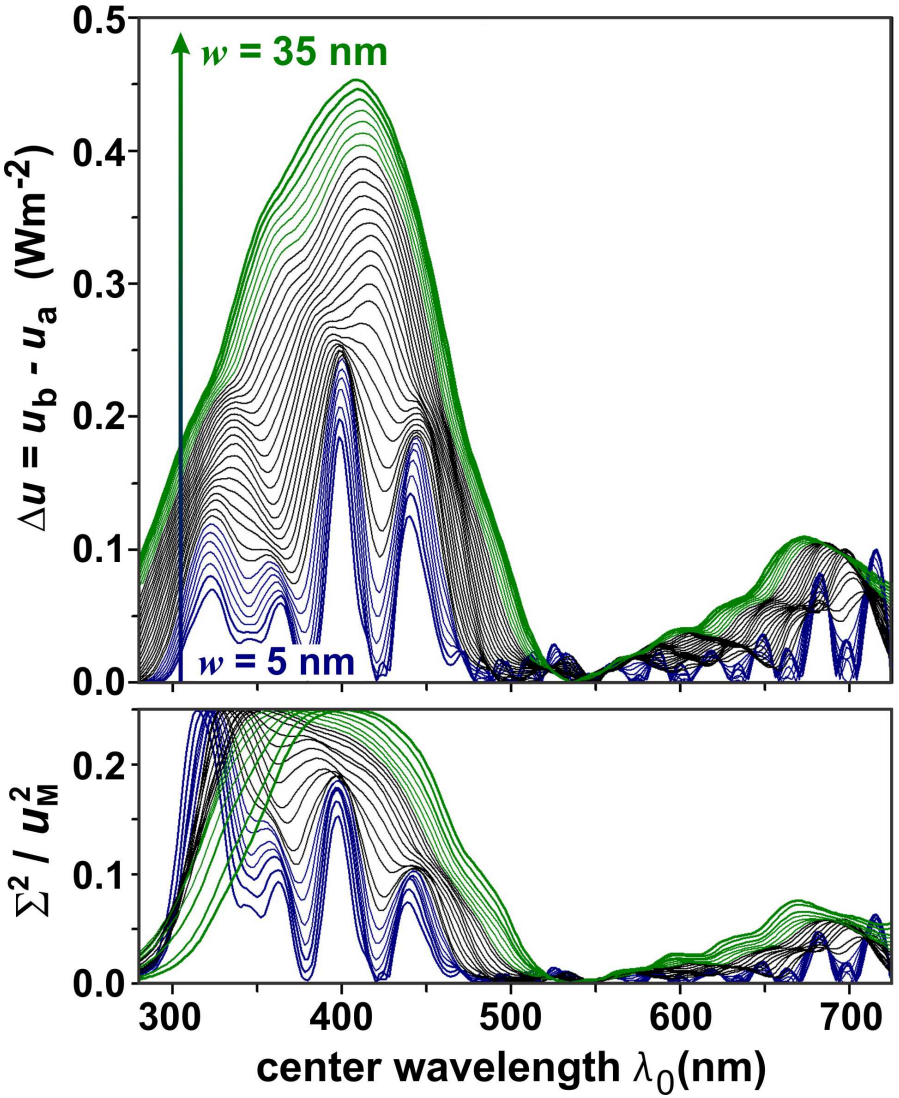

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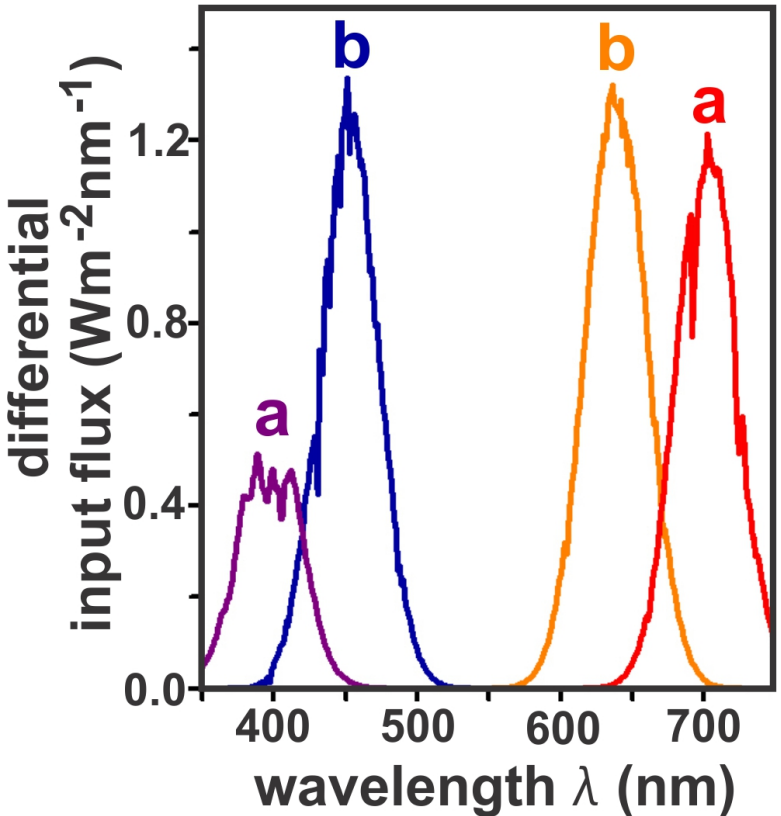
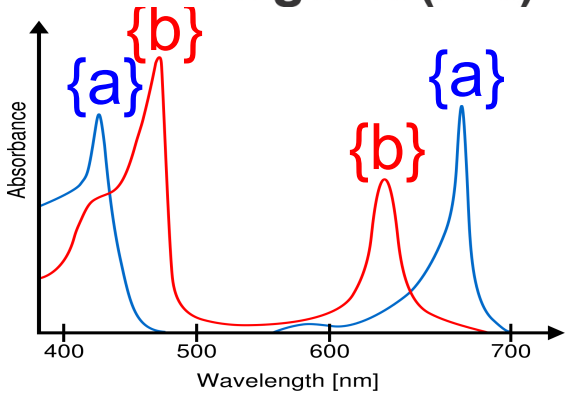
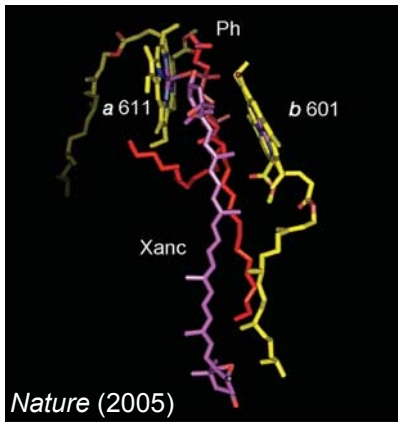
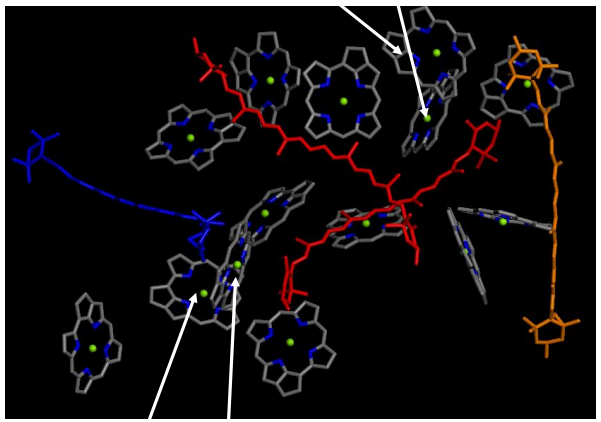






Molecular basis of photoprotection and control of photosynthetic light-harvesting

Andrew A. Pascal[1], Zhenfeng Liu[2], Koen Broess[3], Bart van Oort[3], Herbert van Amerongen[3], Chao Wang[2], Peter Horton[4], Bruno Robert[1], Wenrui Chang[2] & Alexander Ruban[4]



chl b606 – chl a604 (quasi H-type)

William Barford, Theoretical Chemistry Group, Oxford

Why Are Terrestrial Plants Green?

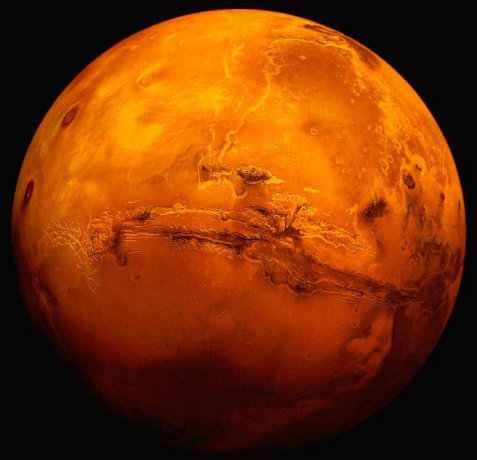
Chlorophyll absorbs in the red and blue parts of the solar spectrum. When sunlight hits a plant, the blue and red portions of the light are absorbed by the chlorophyll, and the rejected green portion of light is reflected back.

The Implications of Natural Regulation in Quantum Systems

Astrobiology

Could intrinsic regulation have relevance in exoplanet astronomy?

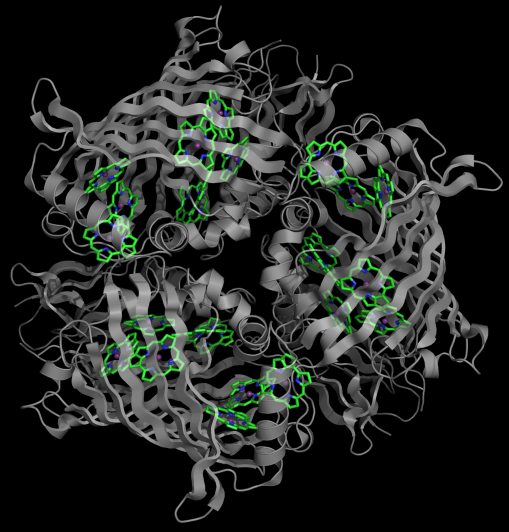
Does natural regulation relate exoplanetary life to a star's temperature?



Bionanoscience

Do biological energy harvesting complexes utilize intrinsic regulation?

Can the design of bionano systems benefit from intrinsic regulation?

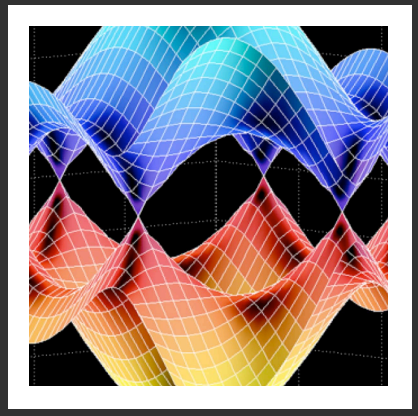


Quantum Nanoscience

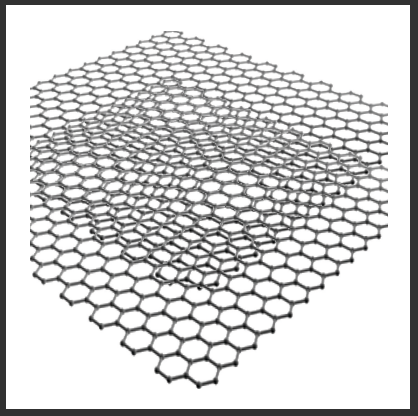
Can intrinsic regulation be utilized in efficient optimization algorithms?

Can we demonstrate it, and how?

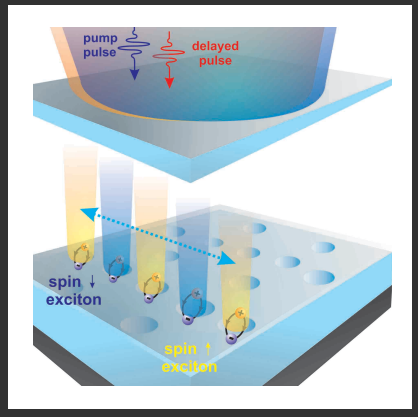
Quantum Materials Optoelectronics Lab



Photocurrent and optical properties of low-dimensional materials



Quantum photocells for next-generation quantum nanoscience



Ultrafast spatio-temporal probes of atomic layer semiconductors

Development and design of novel nanospectroscopy techniques

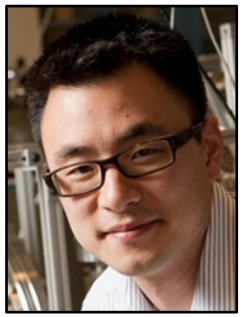
Acknowledgements

QMO Lab 2017

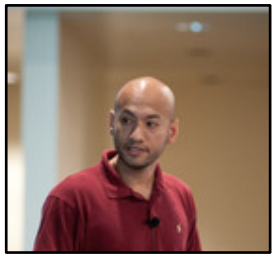
Nathaniel Gabor

Vivek Aji

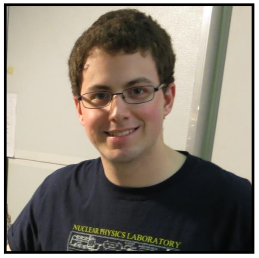
Paul McEeun



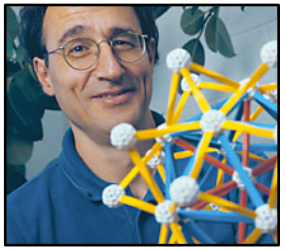
Kyle Shen



Yafis Barlas



Trevor Arp



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Quantum Materials Optoelectronics Lab

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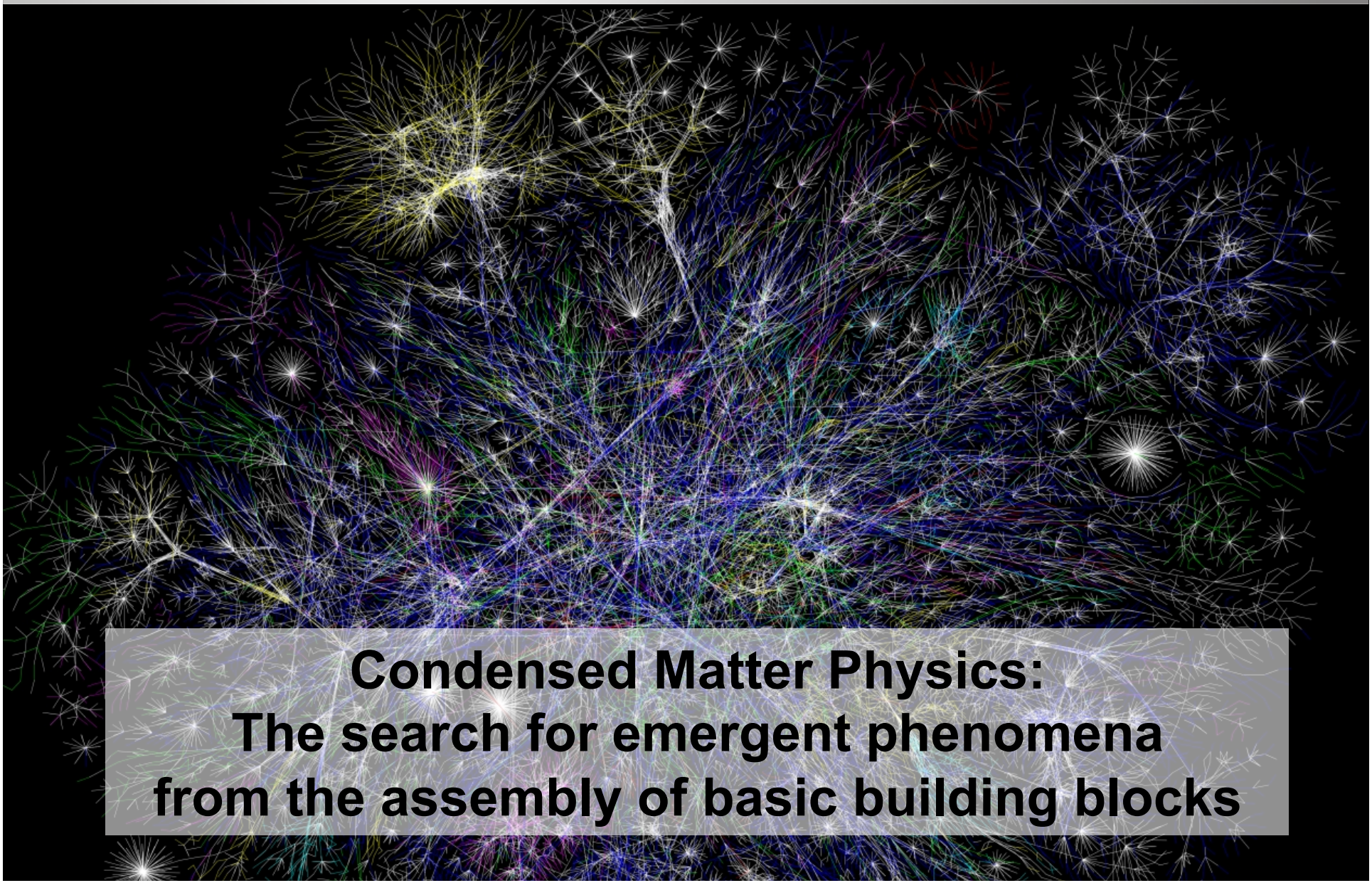

Condensed Matter Physics:
The search for emergent phenomena
from the assembly of basic building blocks