WiTricity:

non-radiative wireless power transfer

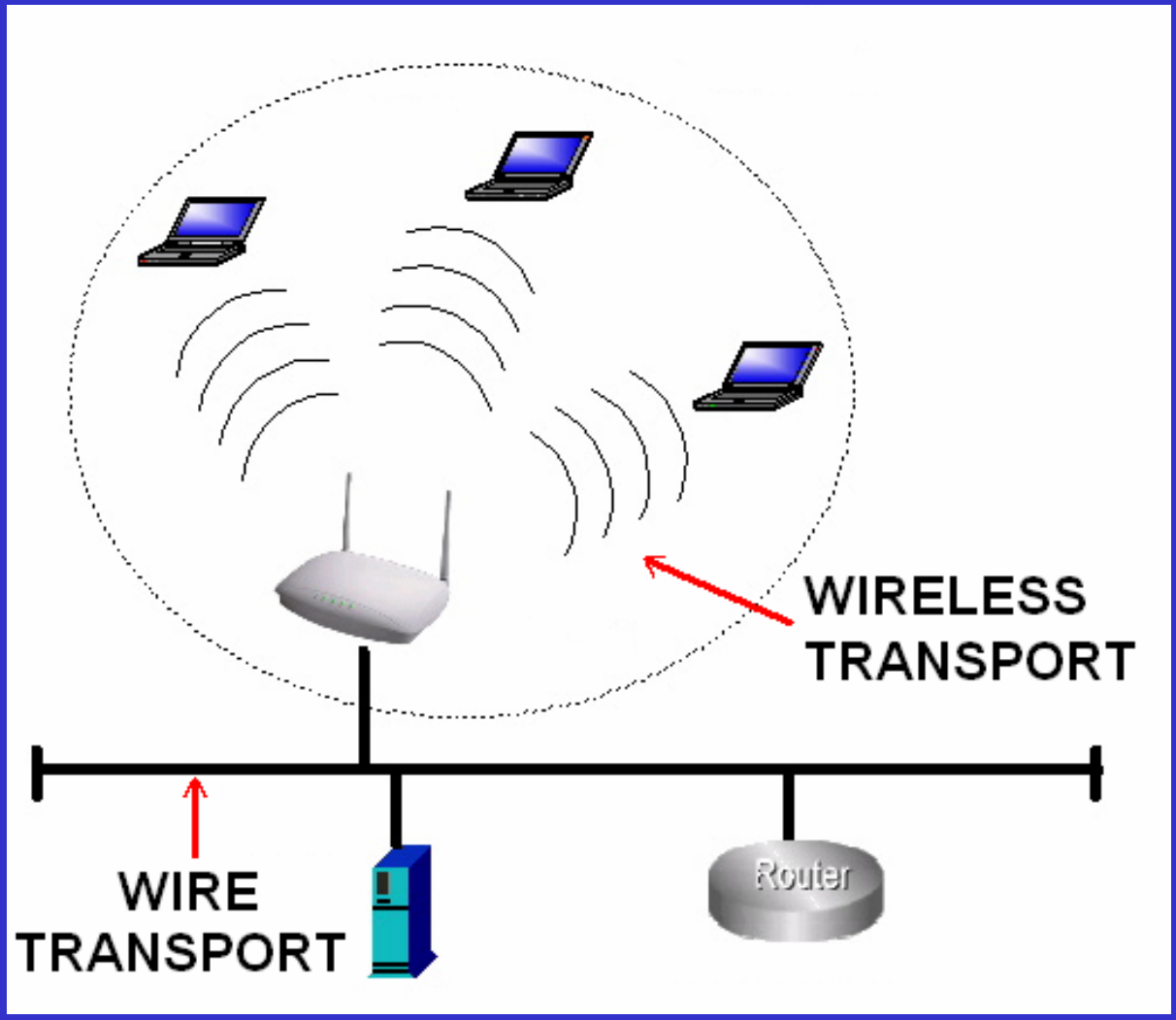
OUTLINE:

- Background and motivation
- Resonant coupling as energy transfer
- Magnetically coupled resonators
- Experimental results
- Path forward
- Potential applications

Motivation

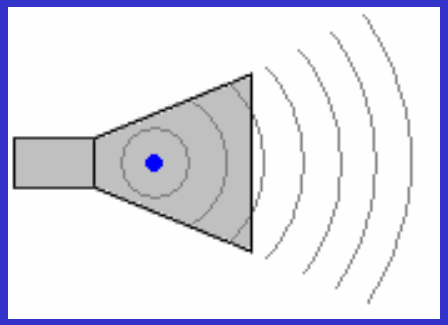
Tesla tower: cca. 1904

Wi-Fi (wireless internet) concept: radiation



Radiative energy transfer

Omni-directional radiation



Directed radiation

Resonant coupling as energy transfer

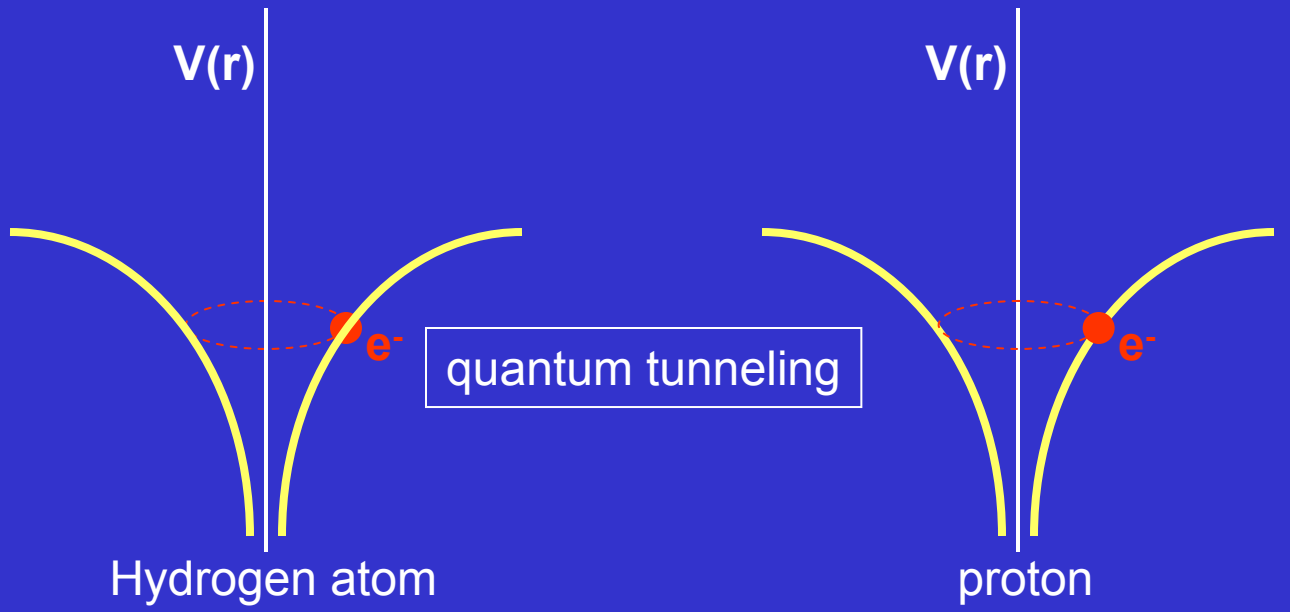
Resonances in quantum mechanics – nonradiative transfer

$$-\frac{\hbar^2}{2m}\nabla^2\psi = E\psi$$

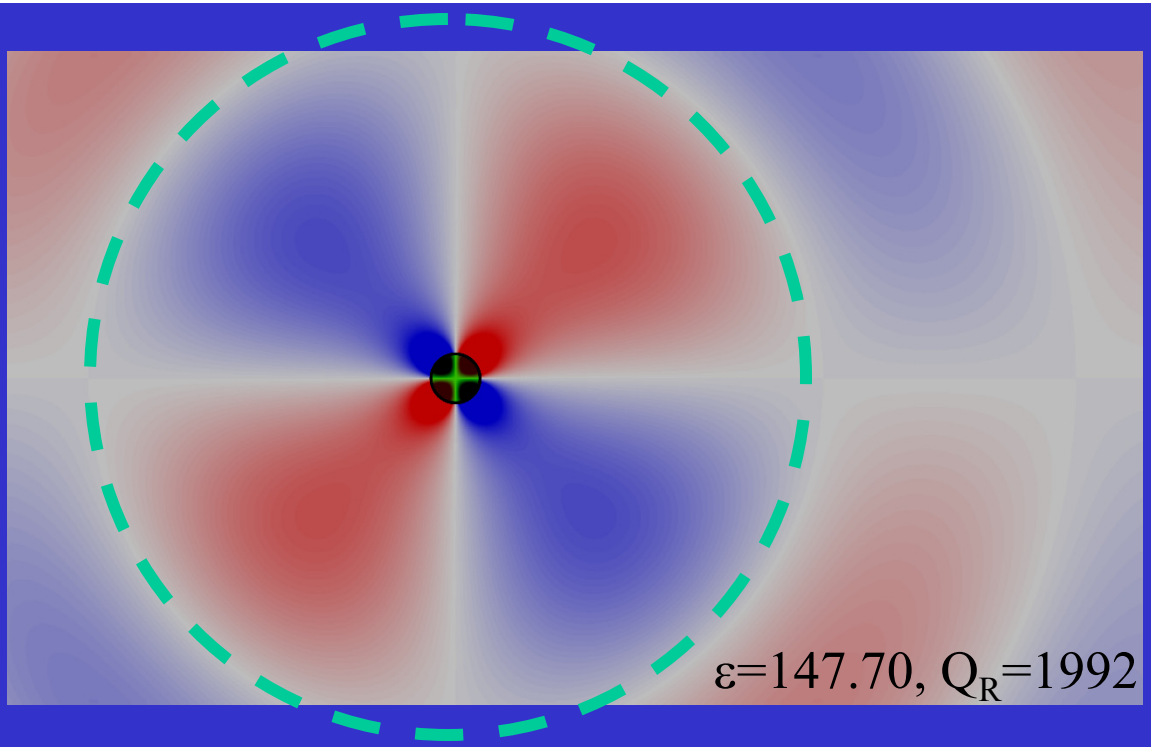
Schrödinger equation

$$-c^2\nabla^2\mathbf{E} = \omega^2\mathbf{E}$$

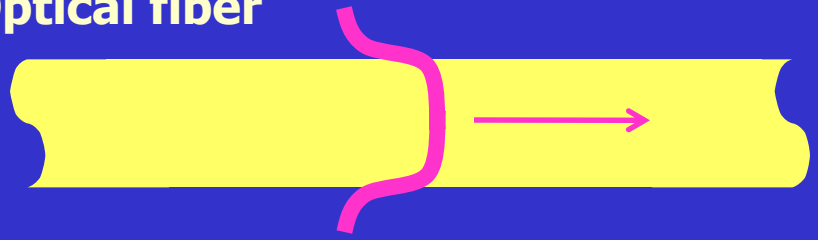
Maxwell equation

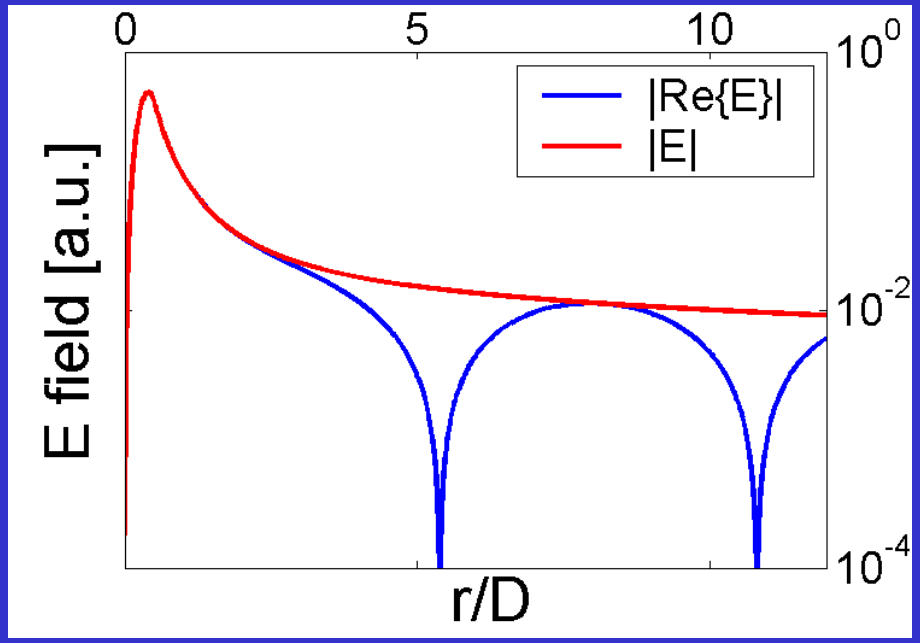


Electro-magnetic resonances

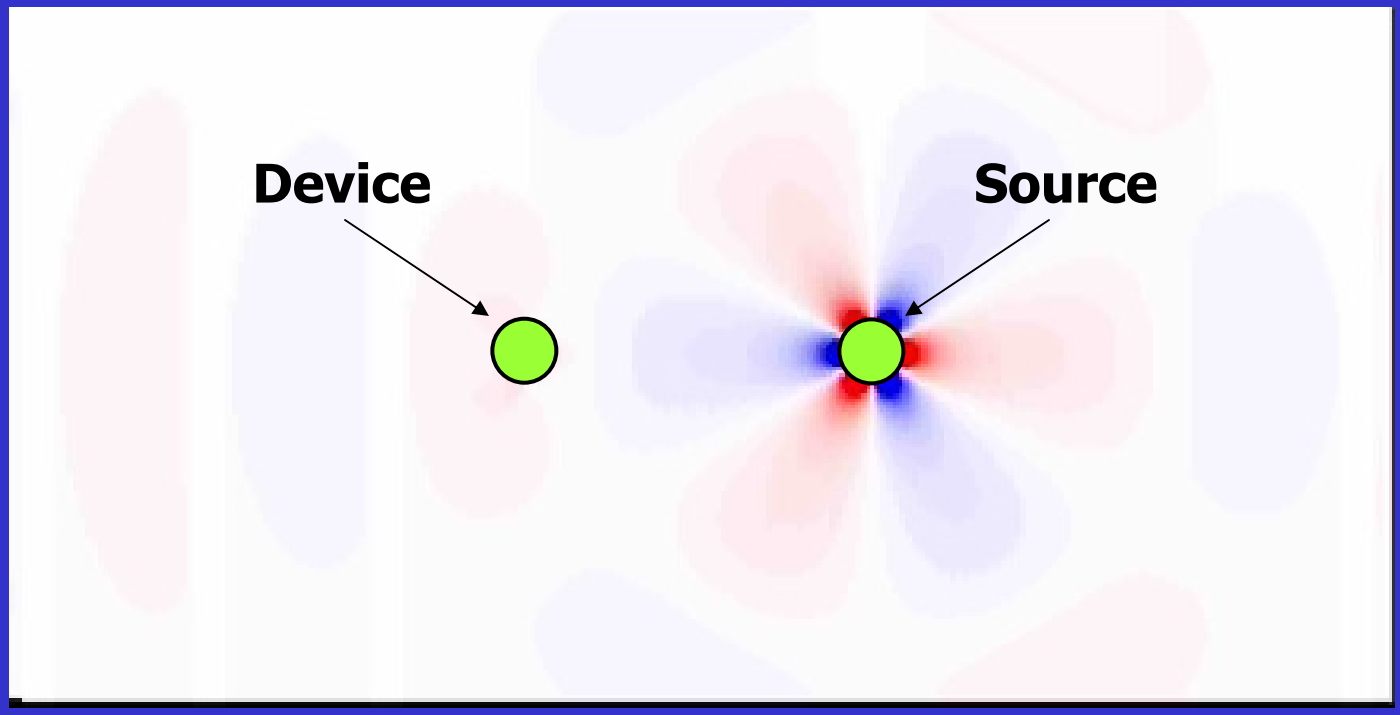


Optical fiber

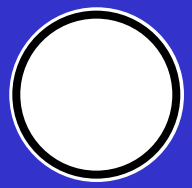




Example of resonant coupling

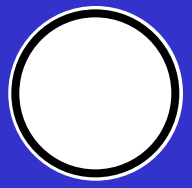


Coupled mode theory



resonant object (Source)

$$\frac{da_S}{dt} = -i(\omega - i\Gamma)a_S + i\kappa a_D$$



resonant object (Device)

$$\frac{da_D}{dt} = -i(\omega - i\Gamma)a_D + i\kappa a_S$$

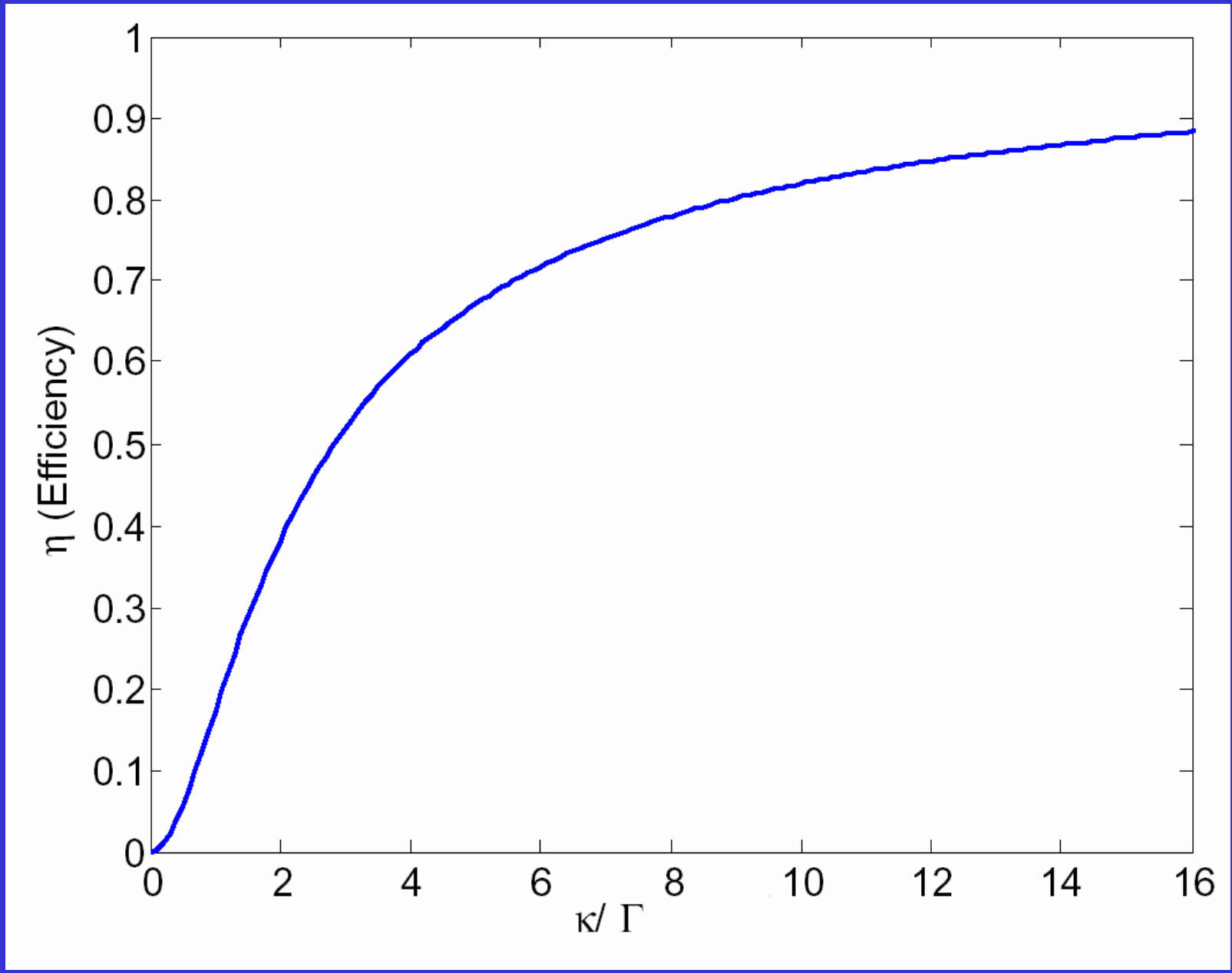
$$Q = \frac{\omega}{2\Gamma}$$

"Strong Coupling":

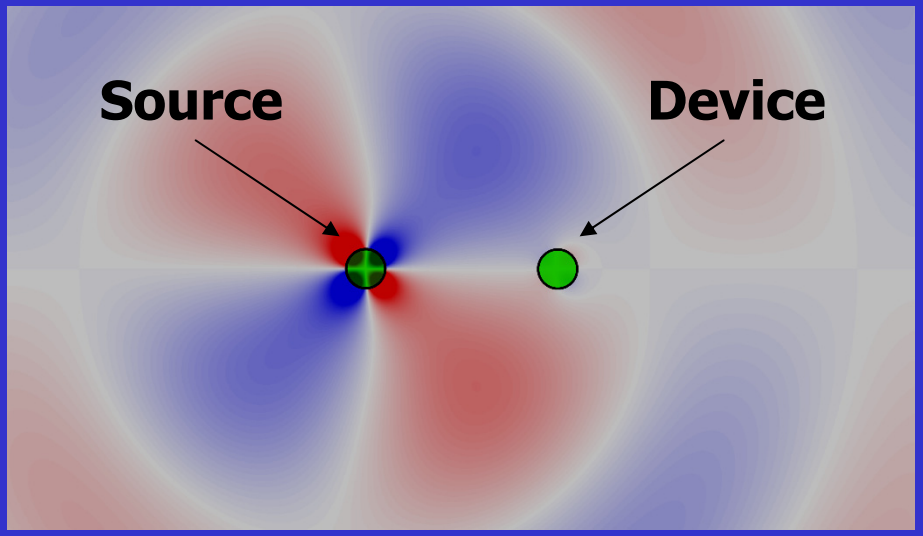
$$\kappa/\Gamma \gg 1$$

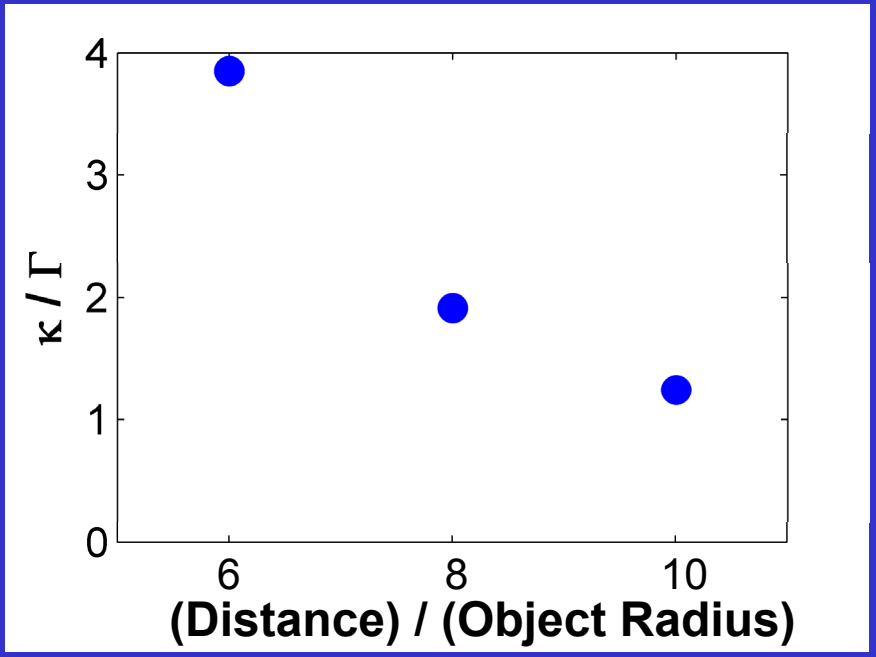
$\Rightarrow$ ***efficient*** energy transfer

"Strong Coupling" ⇒ efficient transfer

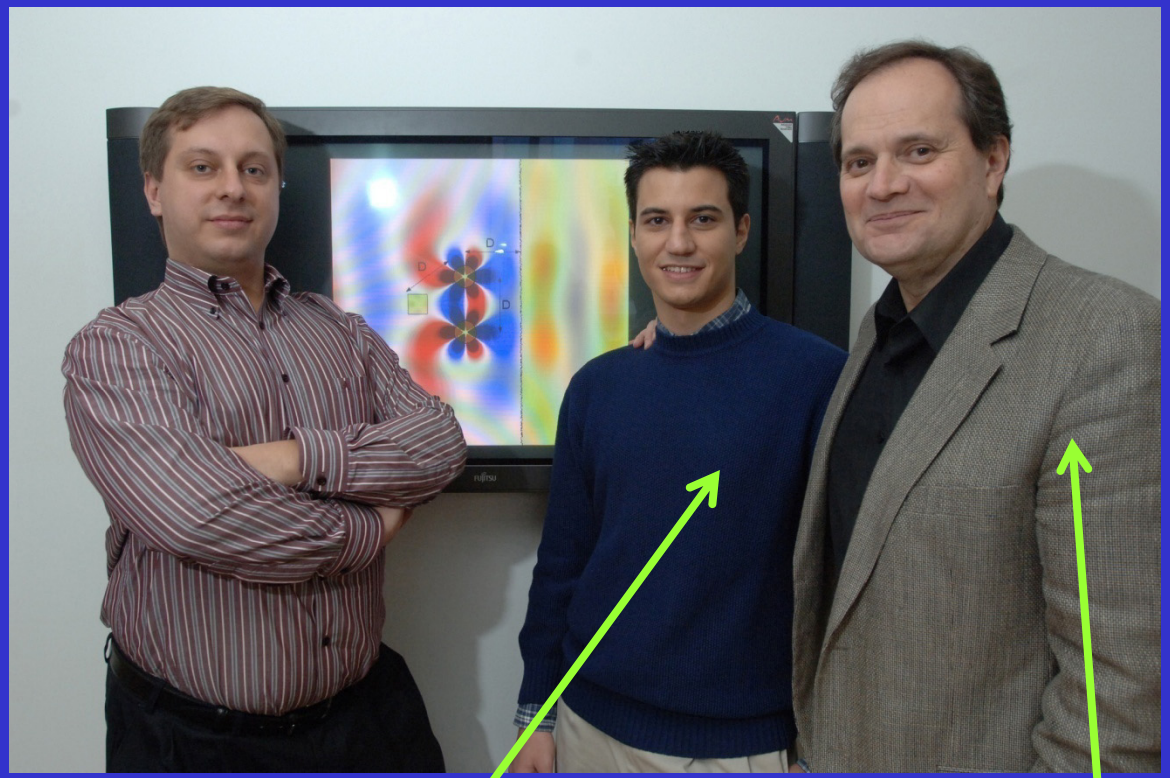


Resonant coupling vs. distance





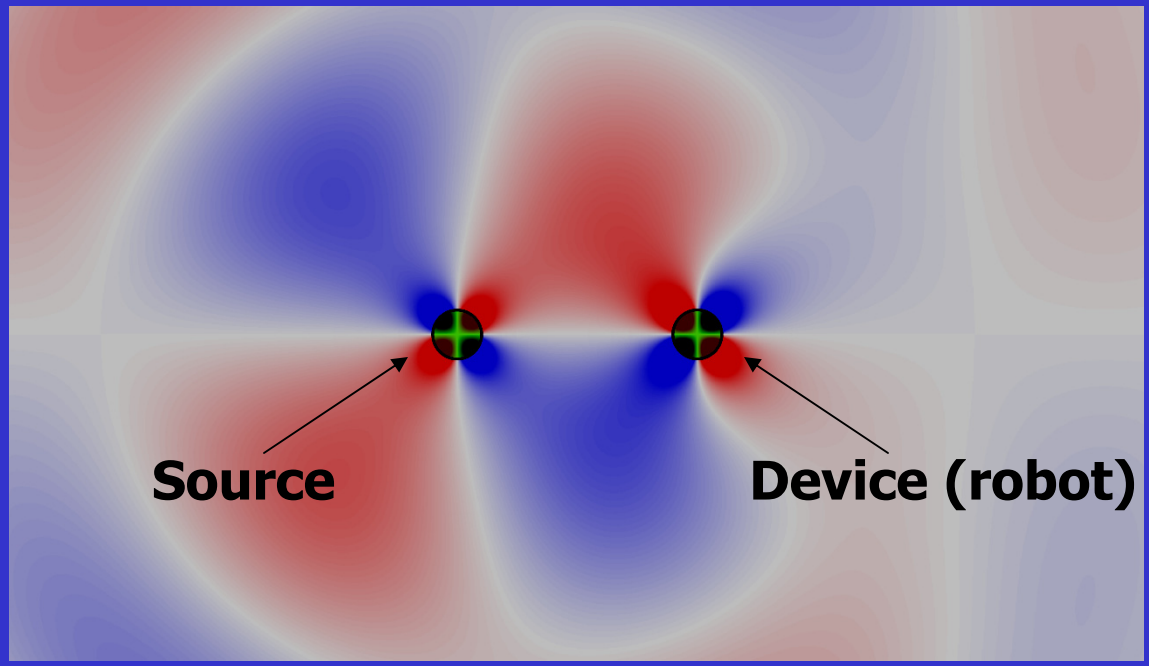
Aside: Paris Hilton connection



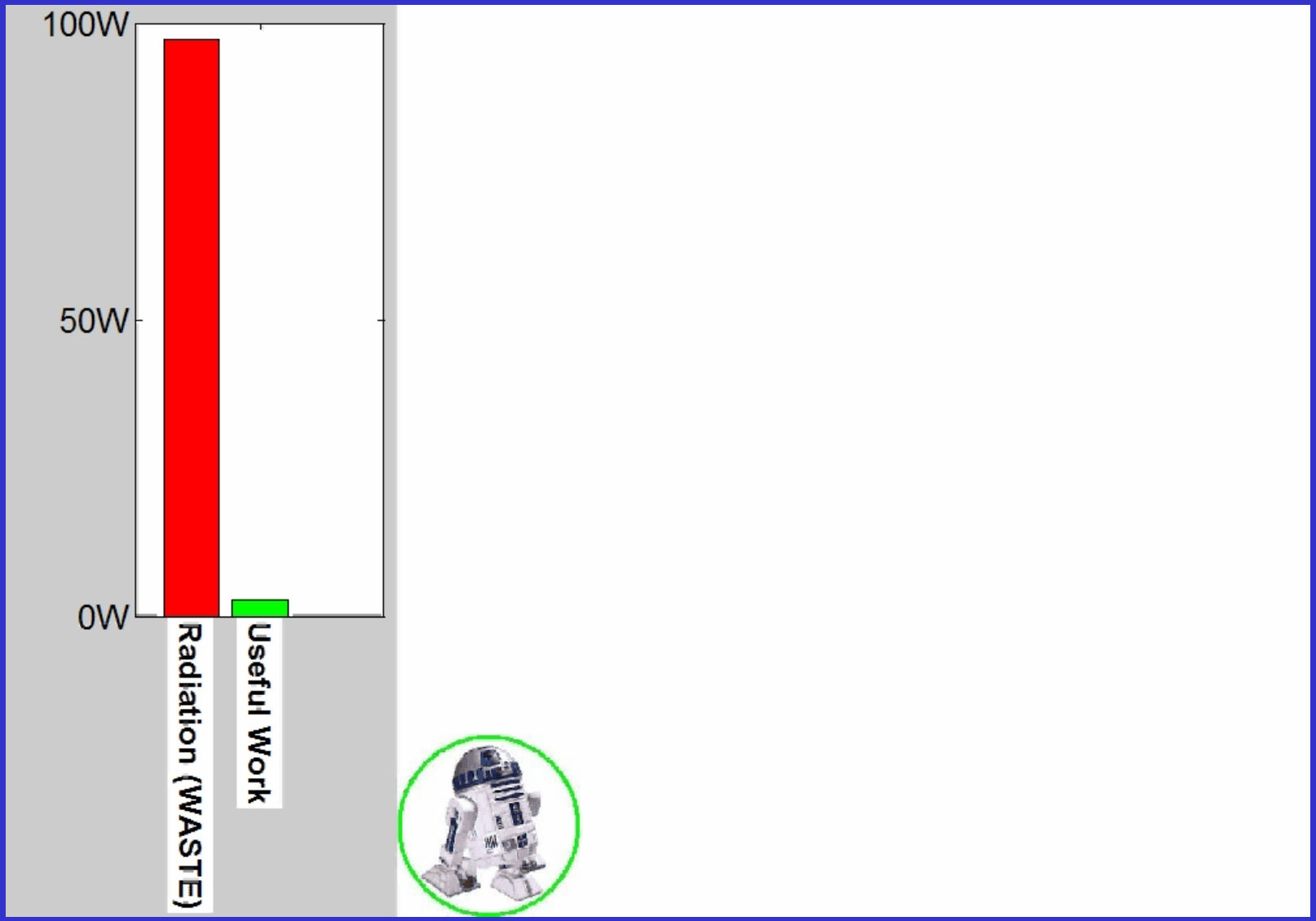
Aristeidis Karalis

Prof. J.D. Joannopoulos

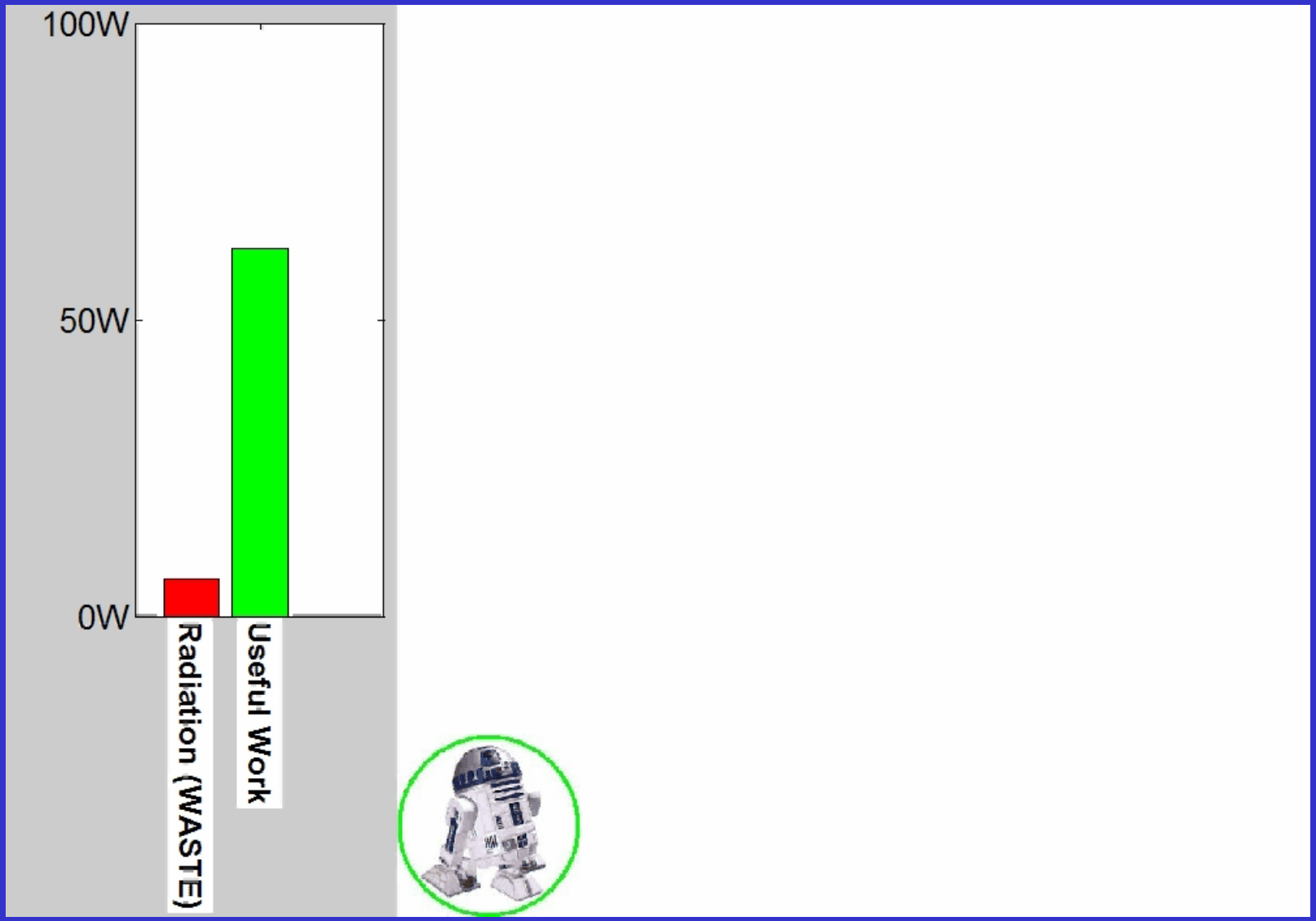
Robot & Office: simulation



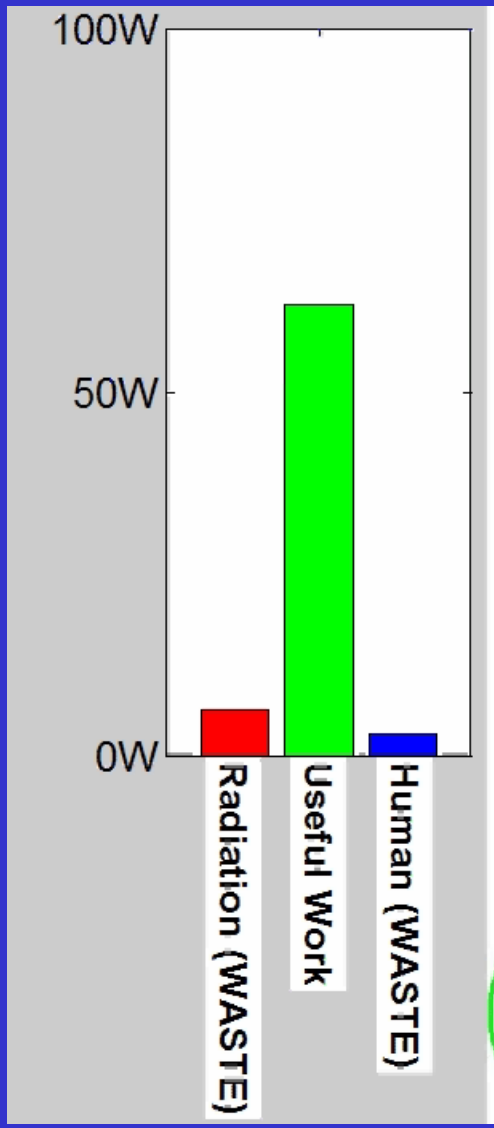
Robot & Office: *radiative* scheme

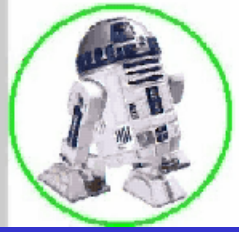


Robot & Office: *non-radiative* scheme



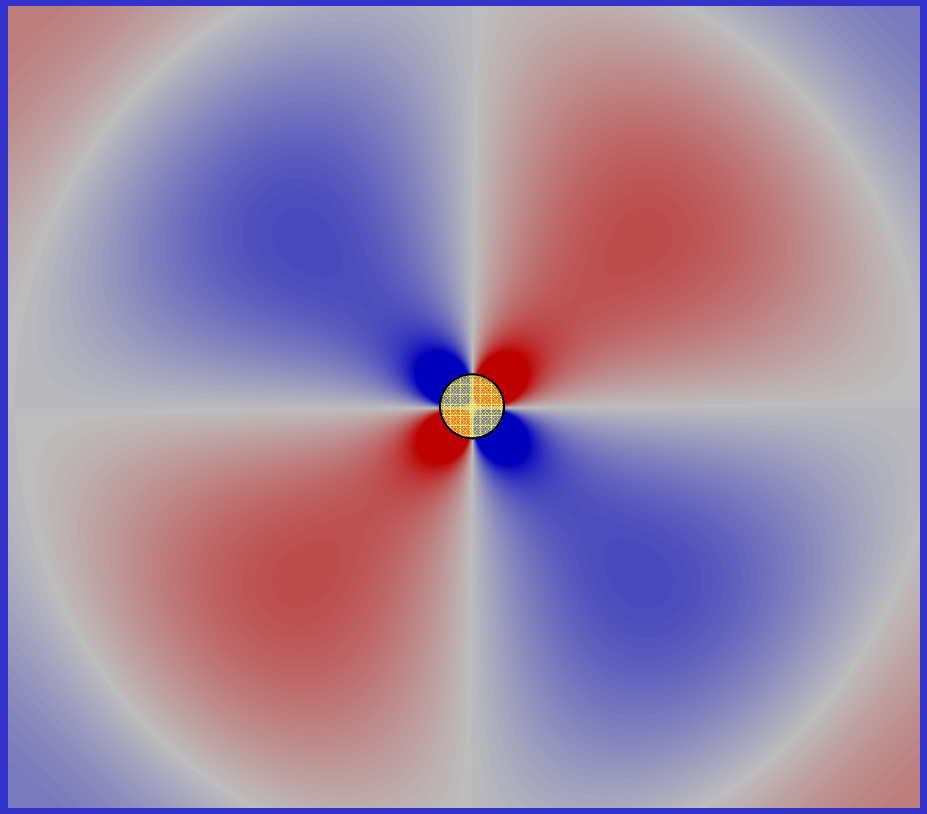
Robot & Office: *non-radiative* scheme



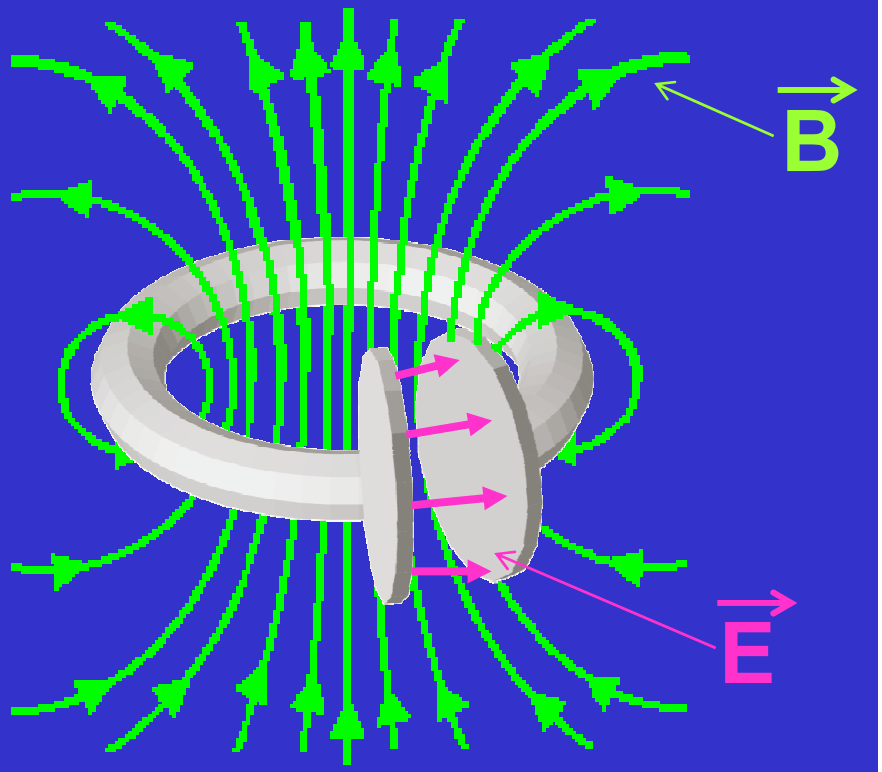


Magnetically coupled resonators

Magnetic resonances



Outside: $U_E \sim U_B$



Outside: $U_E \ll U_B$

Most materials: $\mu \sim \mu_{AIR}$

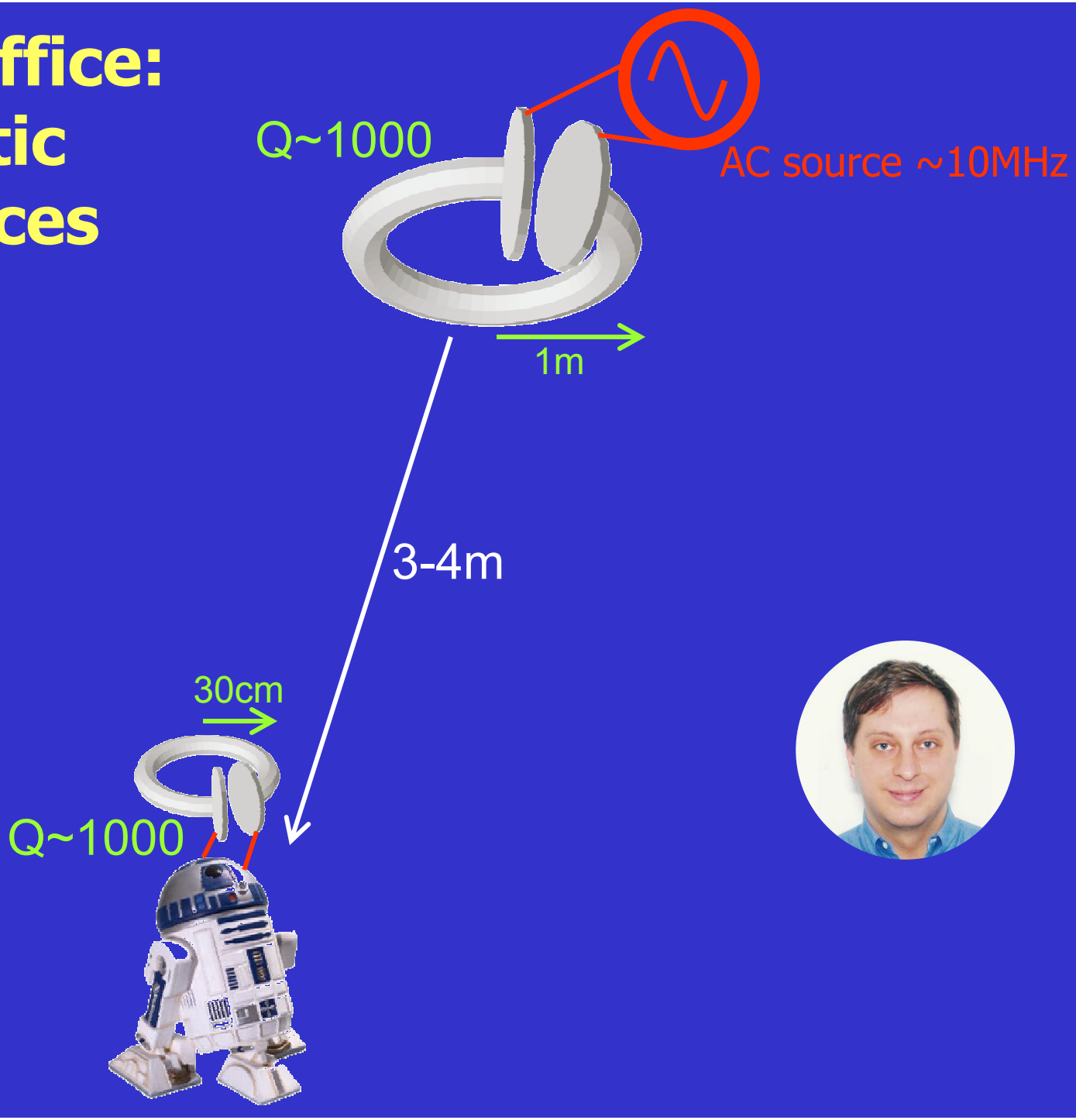
$\Rightarrow$ weak interaction with B-field!

Examples of "magnetic technology"

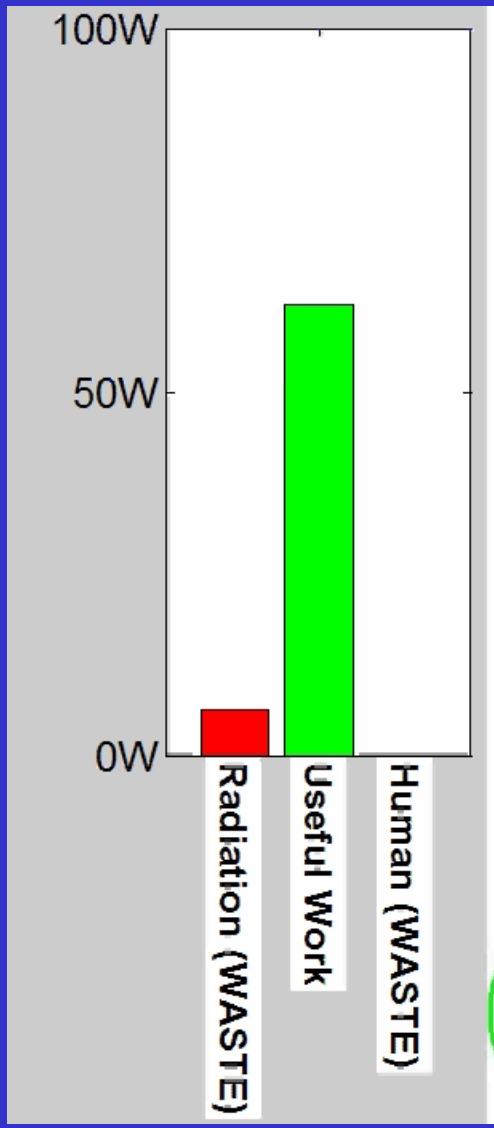
Maglev

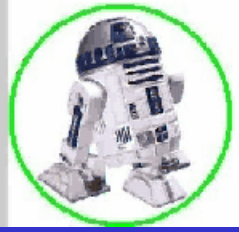
Magnetically levitating bed

Robot & Office: magnetic resonances

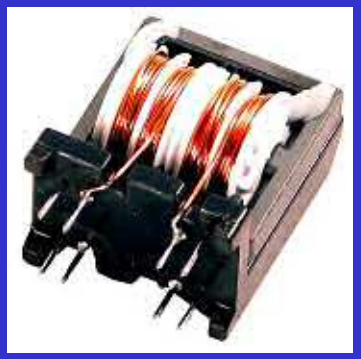


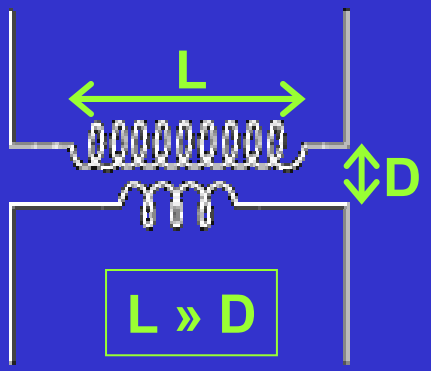
Robot & Office: *non-radiative* scheme

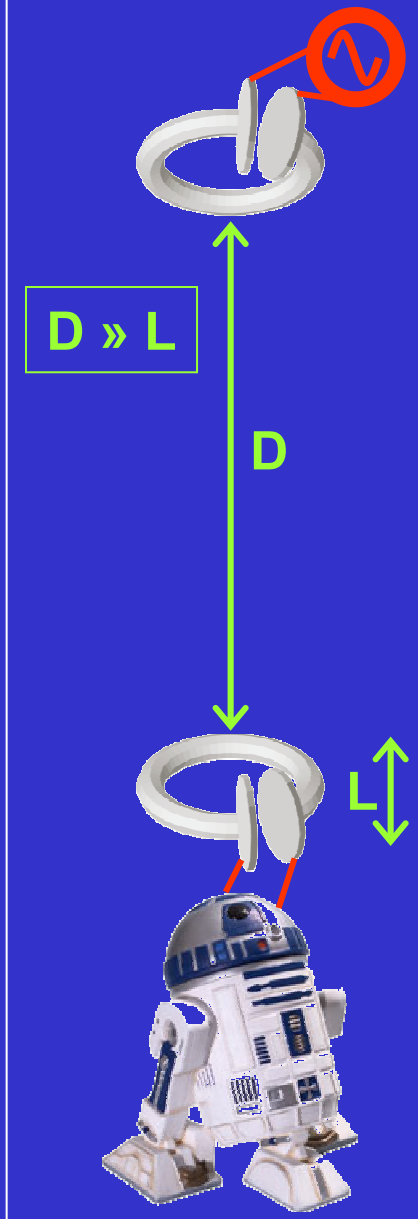




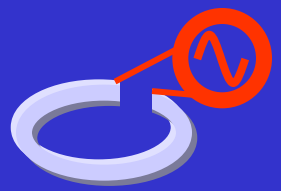
Comparison with inductive coupling





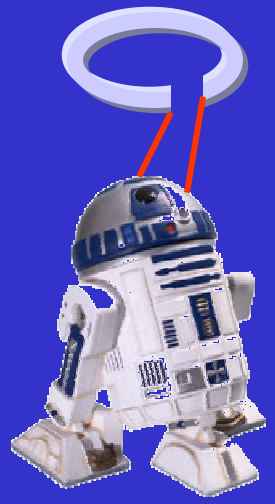


Efficiency $\equiv \eta_R$



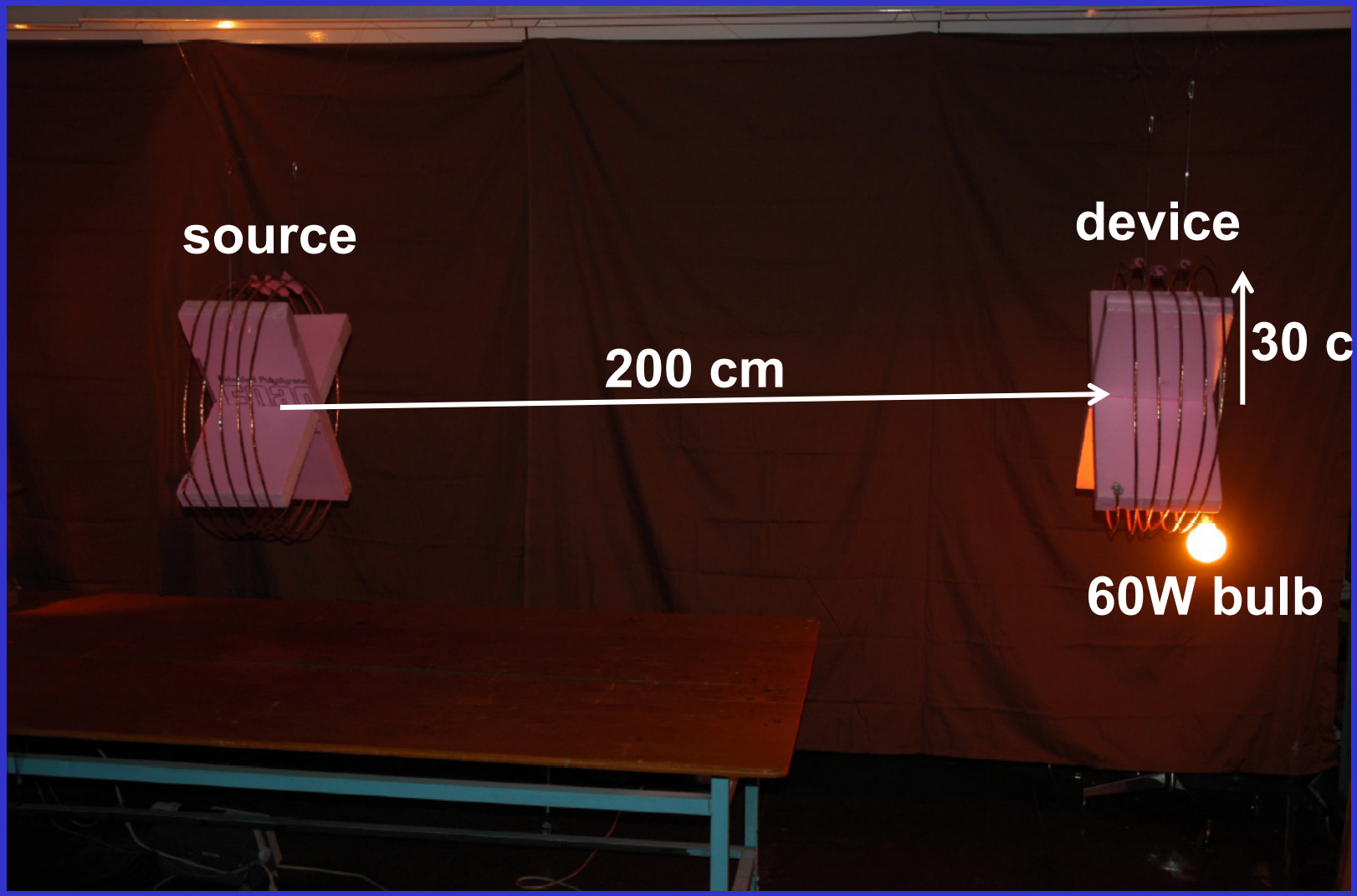
Efficiency $\approx \eta_R/Q^2$

$\sim \eta_R/1{,}000{,}000$



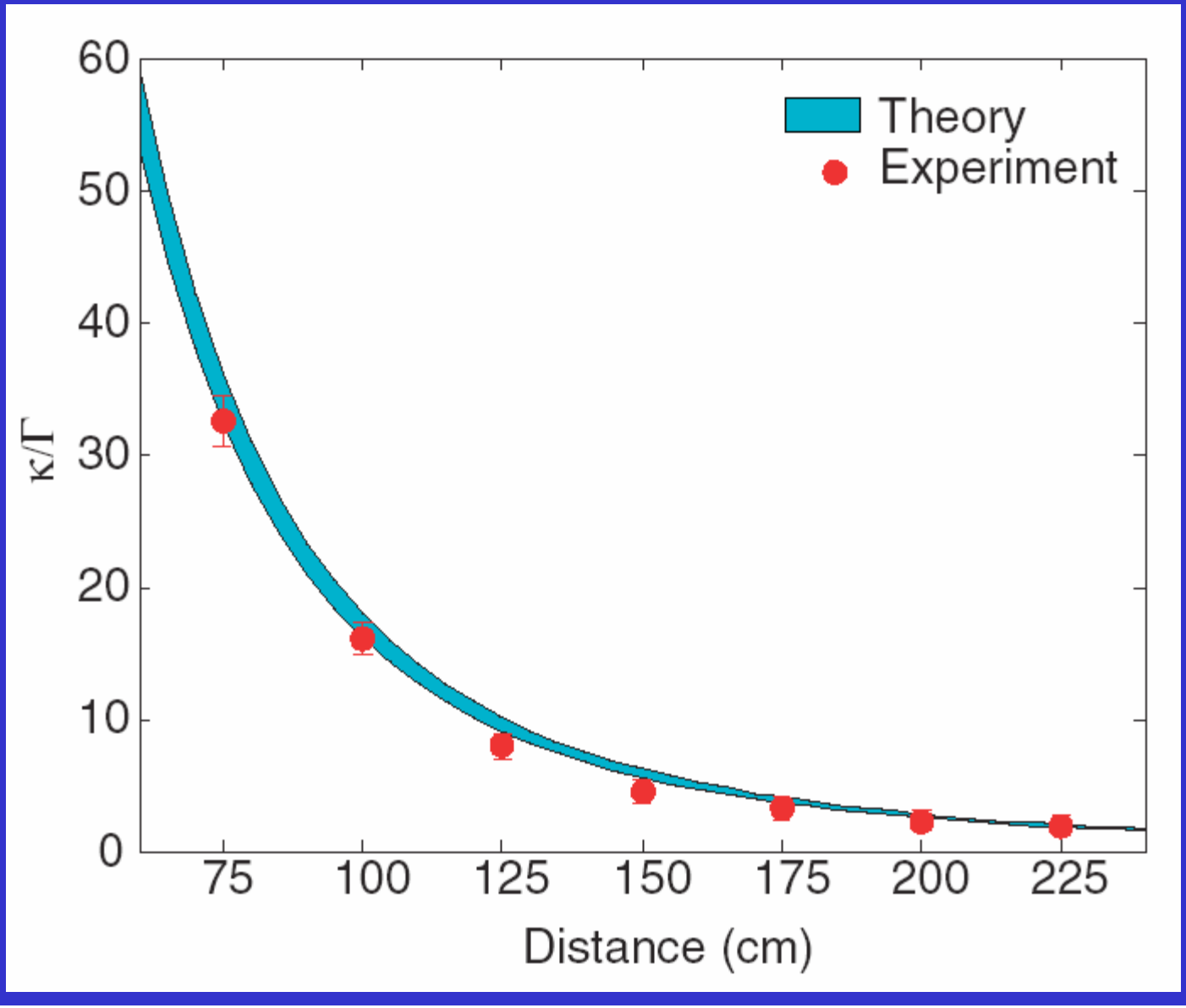
Experimental results

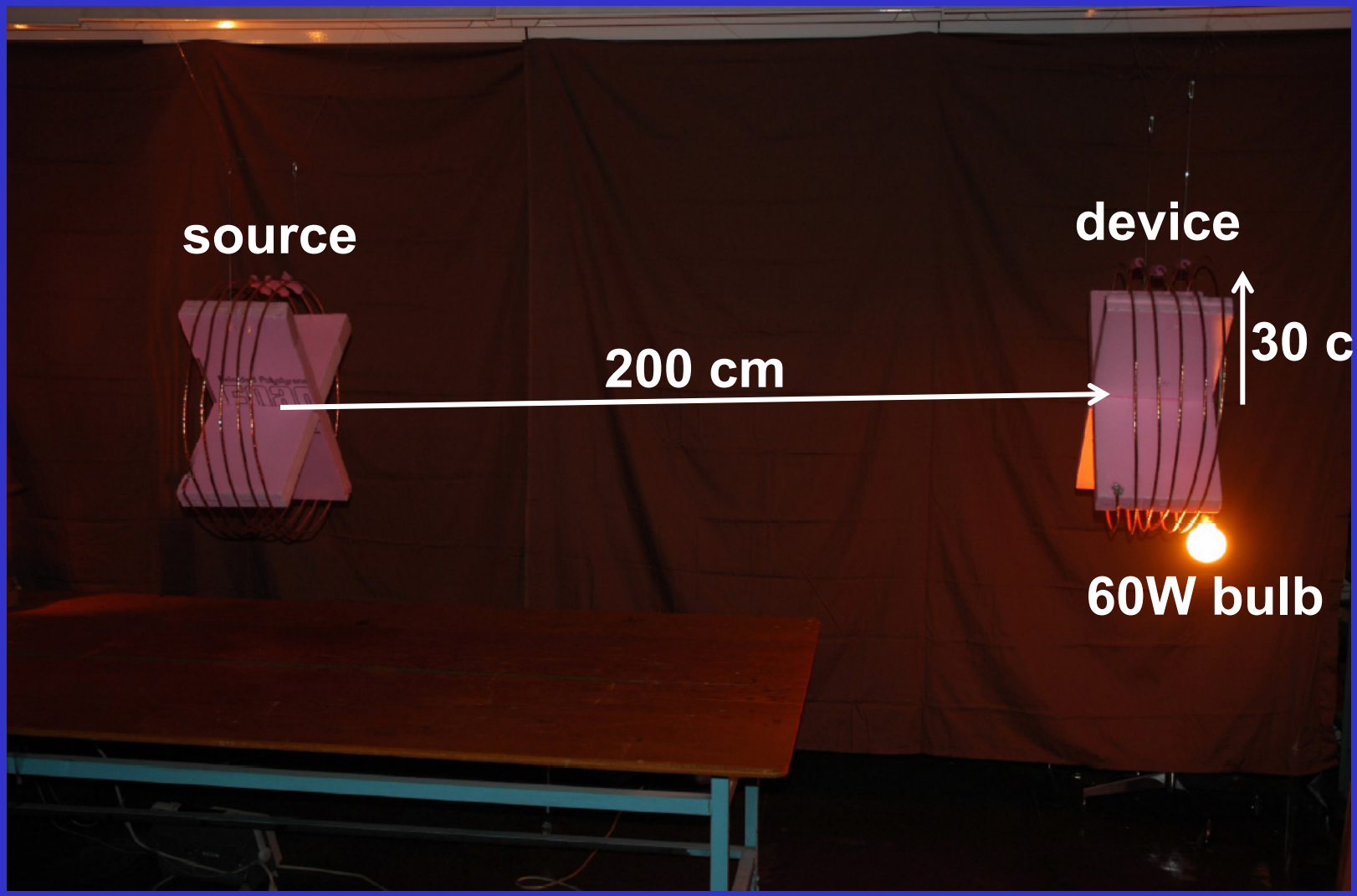
Science Magazine, 6th July 2007



same thing, different viewing angle

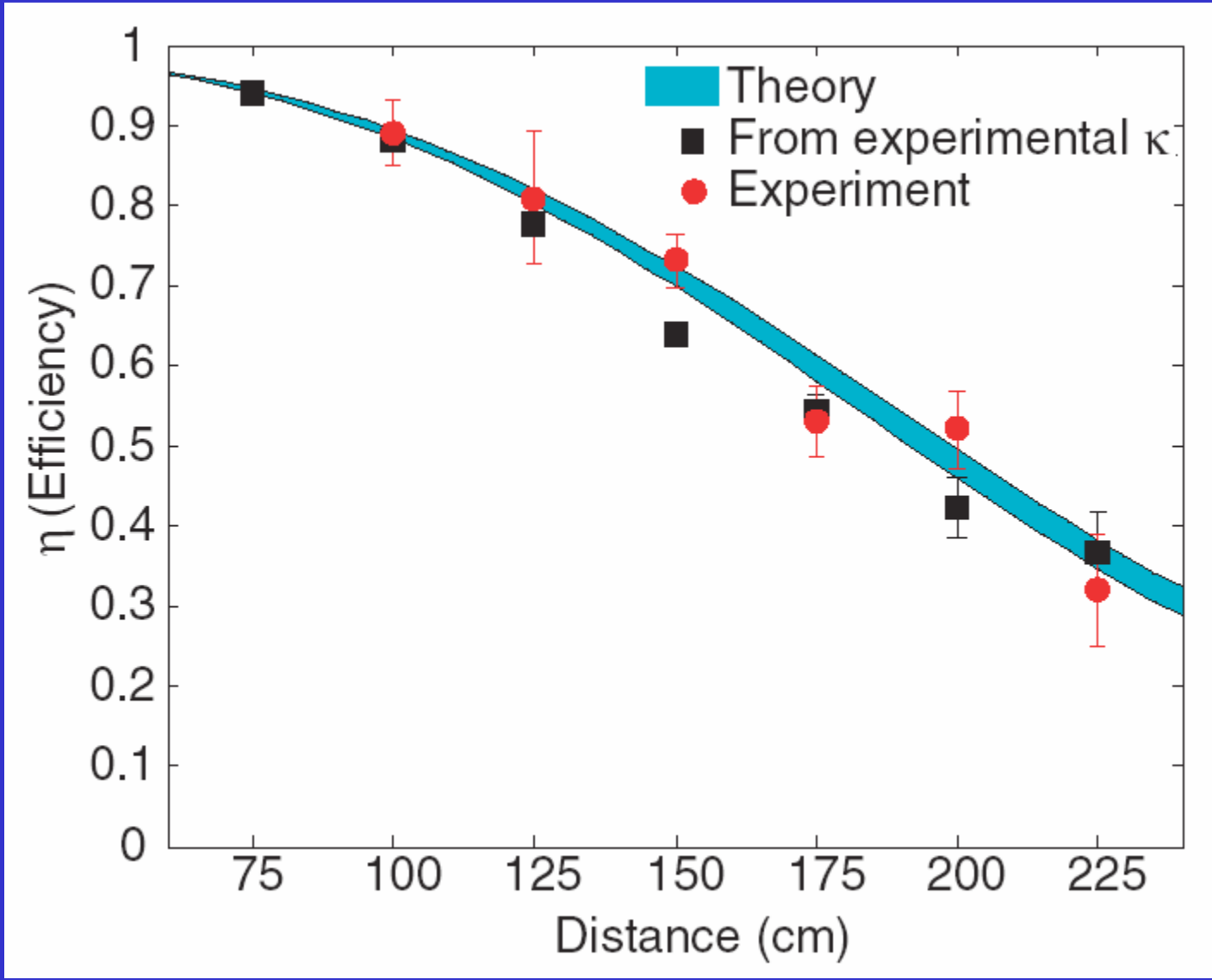
Experimental proof of strongly-coupled regime

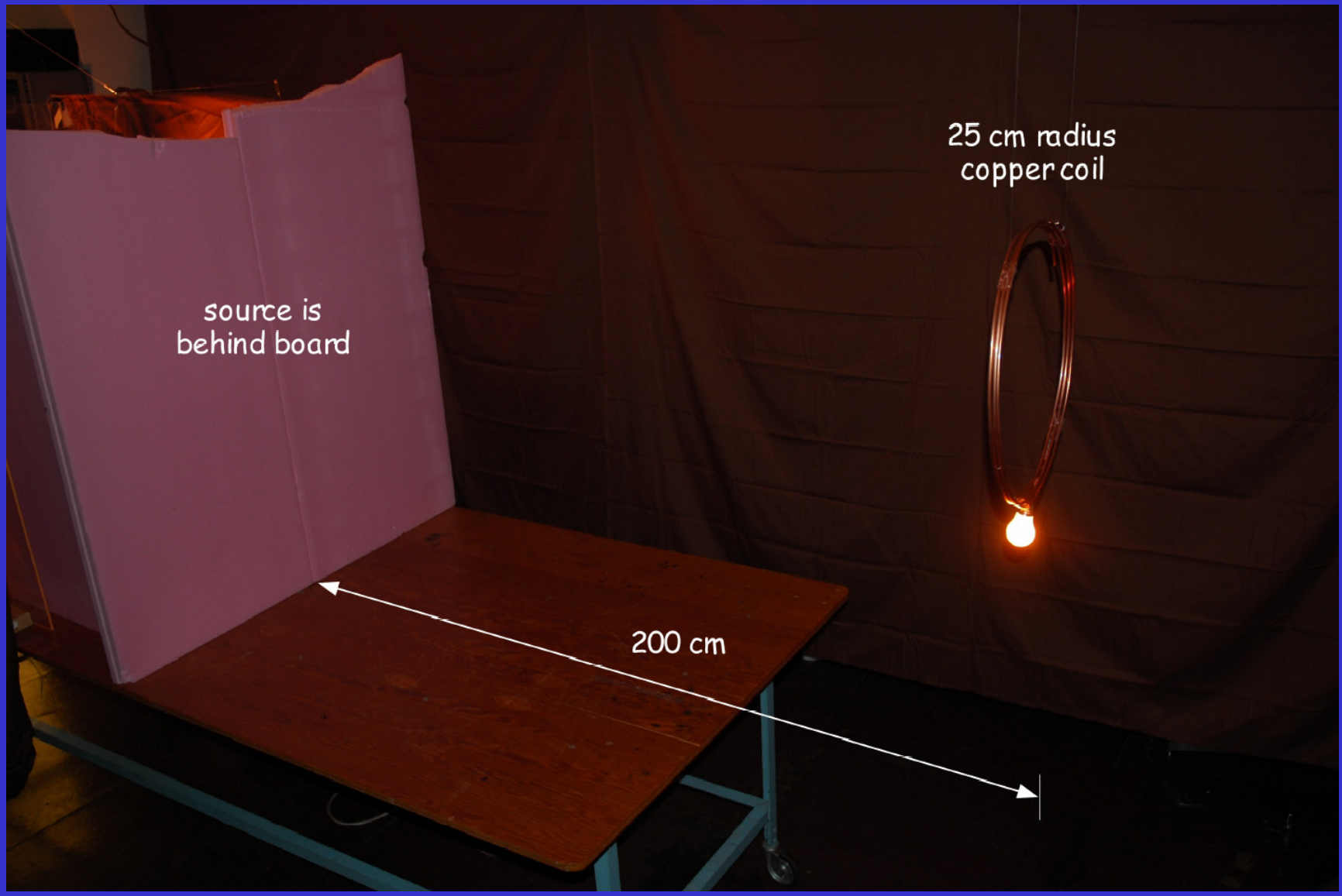




efficiency ~50%

Efficiency vs. distance



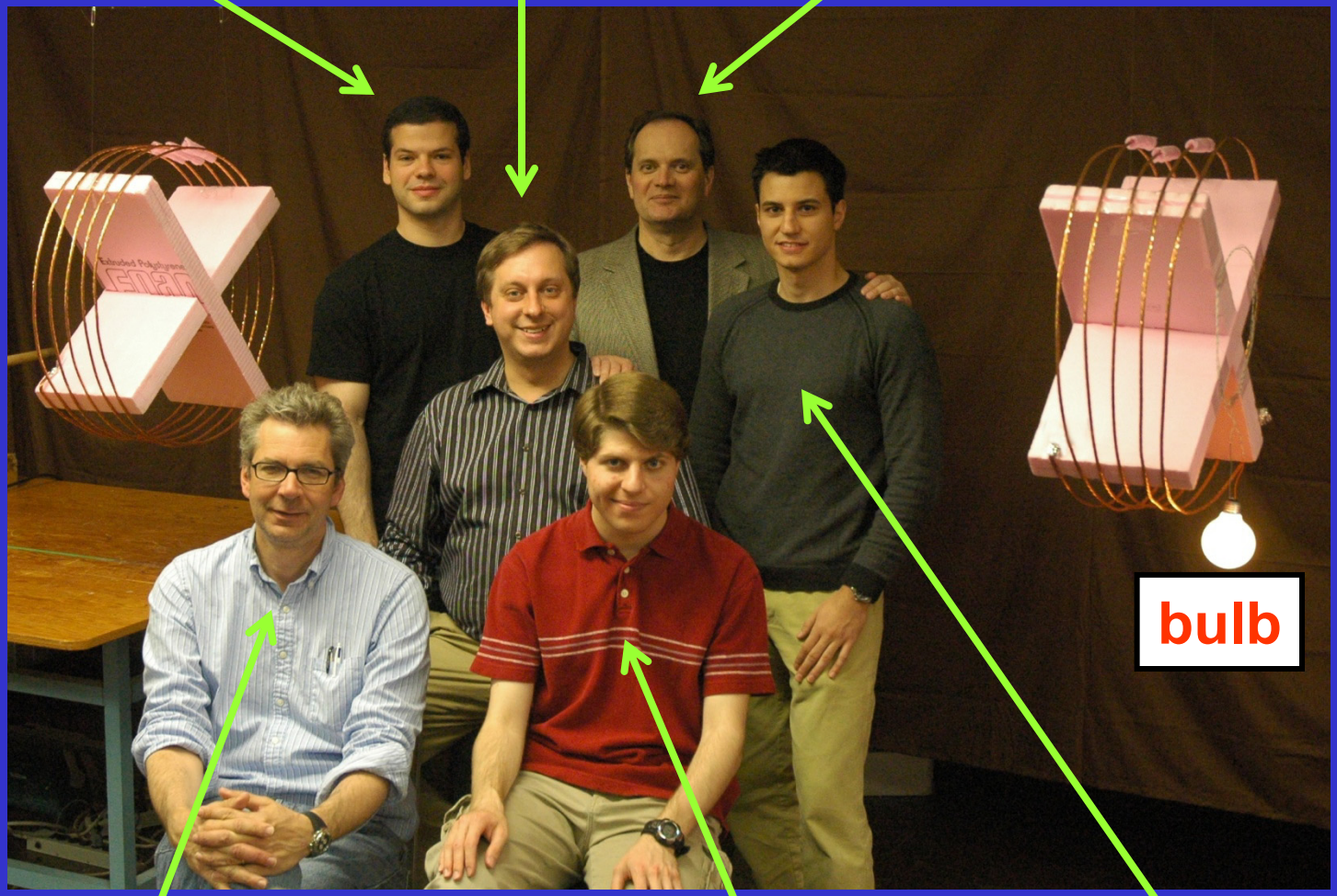


another geometry

Prof. Marin Soljačić

Andre Kurs

Prof. J.D.Joannopoulos



Prof. Peter Fisher

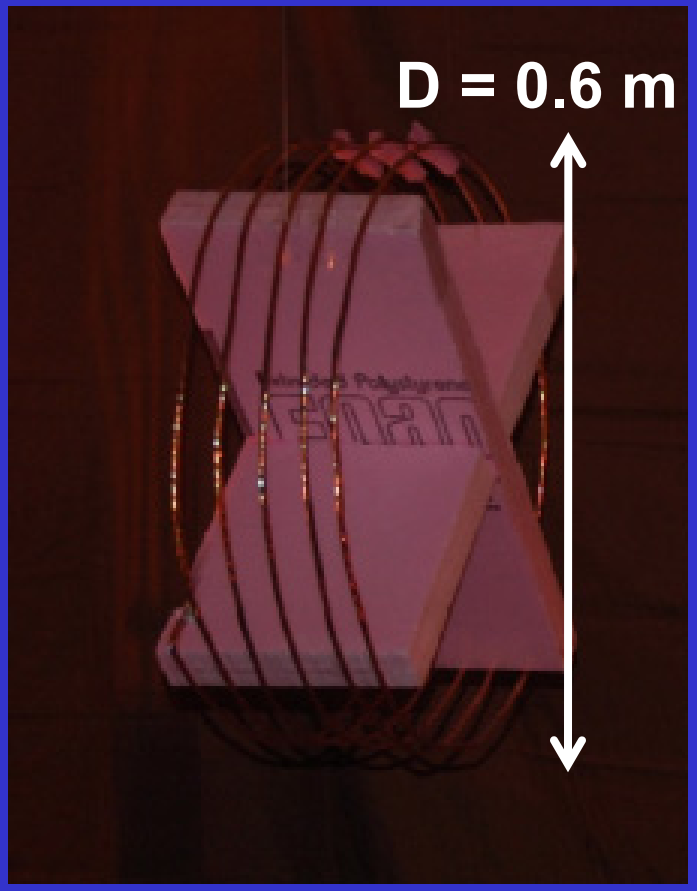
Robert Moffatt

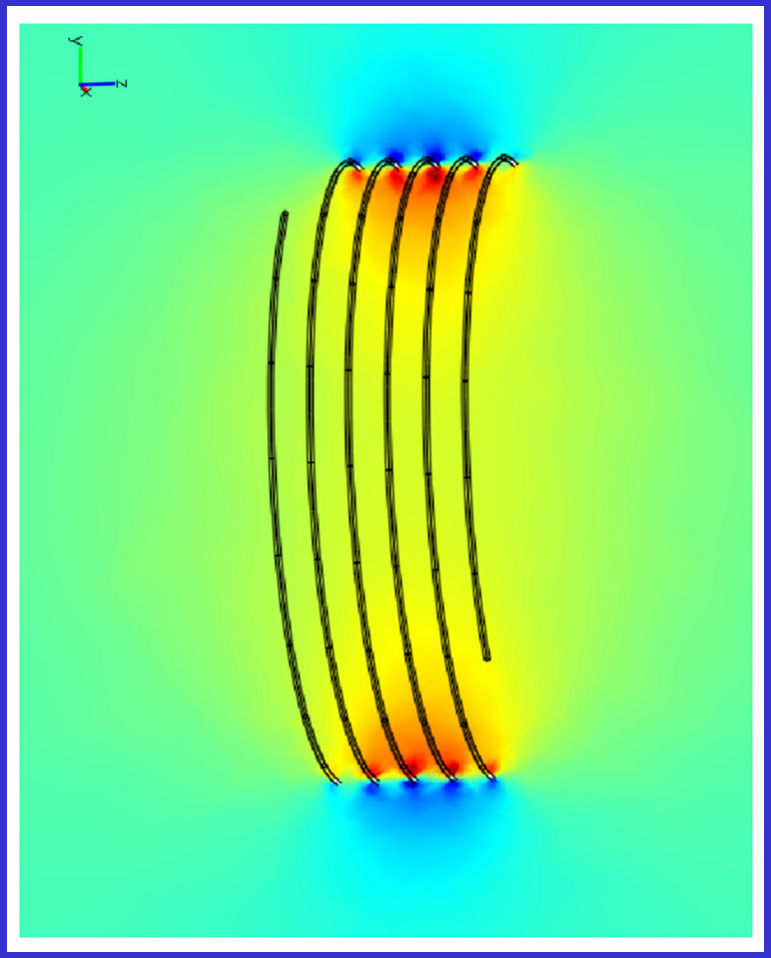
Dr. Aristeidis Karalis

Path forward: physics part

Learning from atomic physics

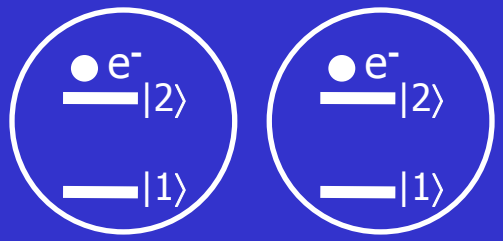
An oscillating resonator radiates a bit



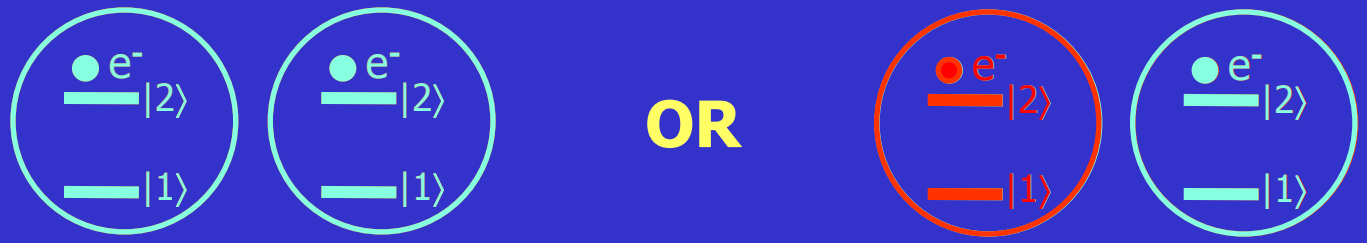


Much smaller than the wavelength: $\lambda_{RES} \approx$ **30 m**

"Dicke effect" – atomic physics

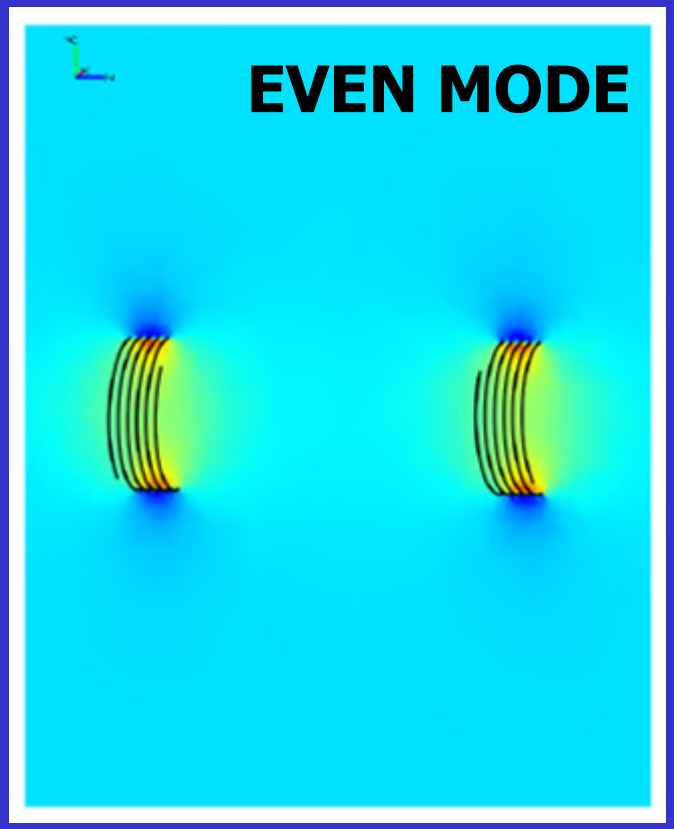


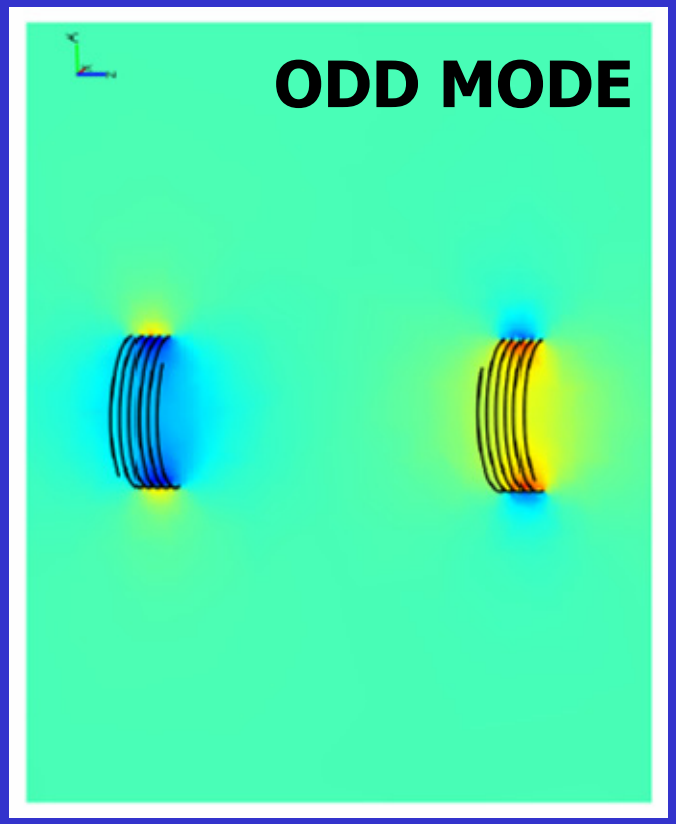
two excited, same atoms



strong radiation **NO radiation**

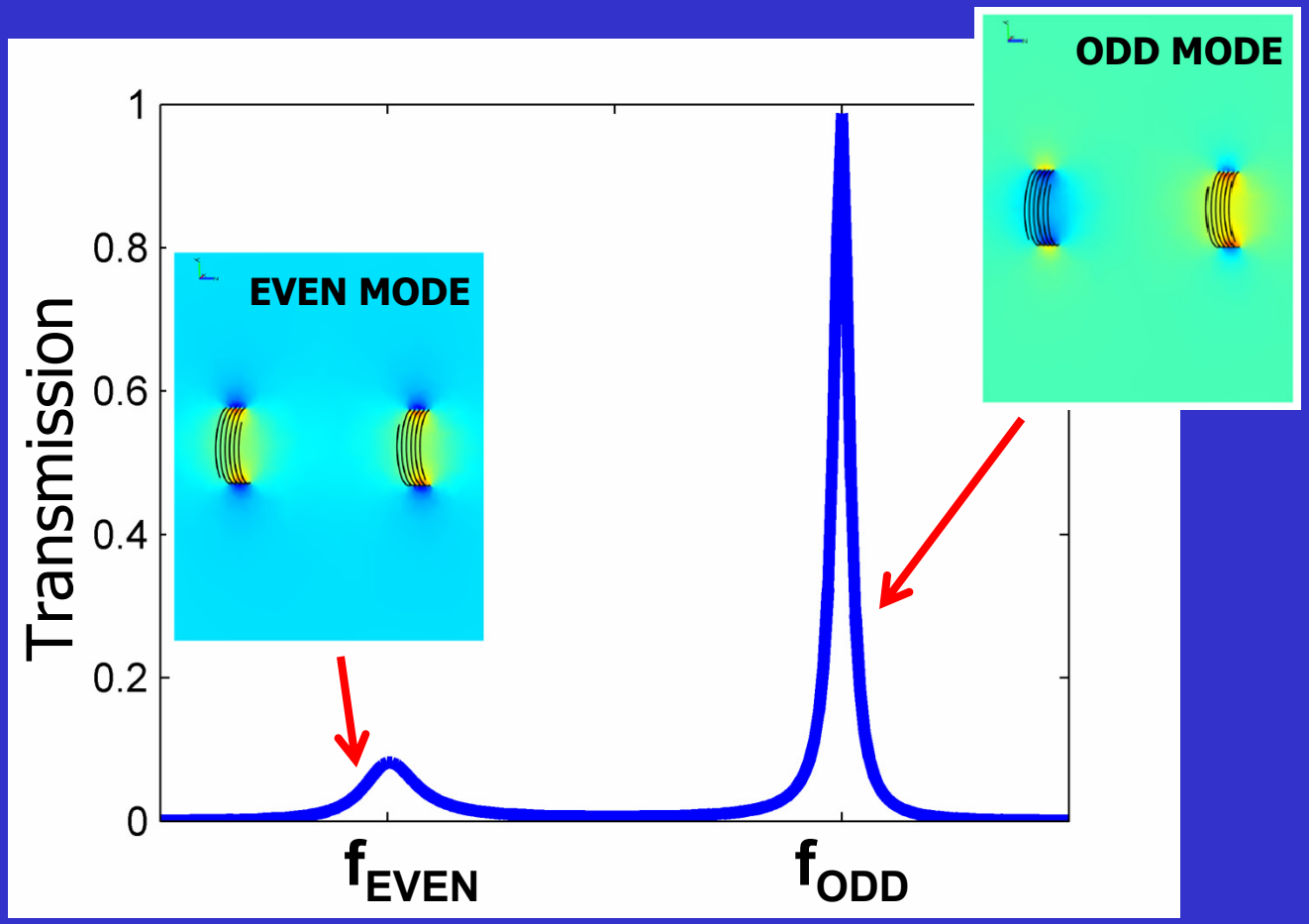
Coupling of resonators





Coupling $\Rightarrow$ $f_{EVEN} \neq f_{ODD}$

Transmission vs. frequency (gedanken system)

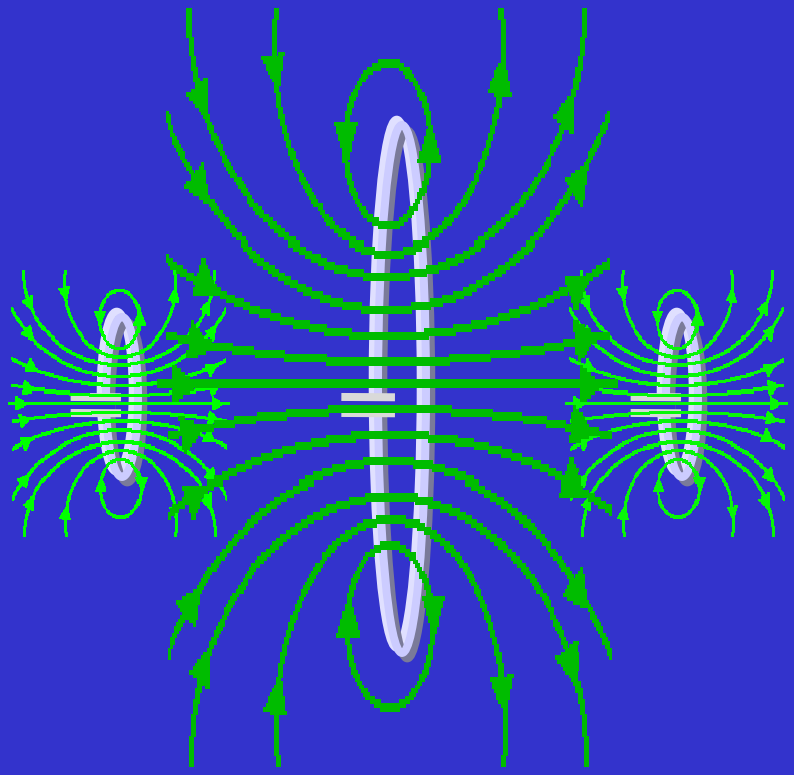


Collaborators:
A.Karalis, R.Hamam, and J.D.Joannopoulos

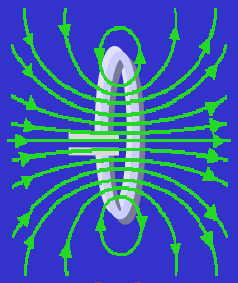
Playing David Copperfield with energy

Direct transfer

Mediated transfer

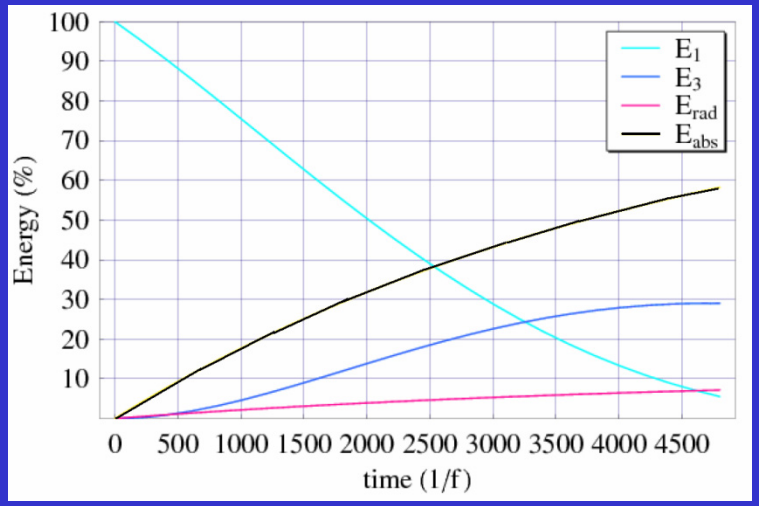


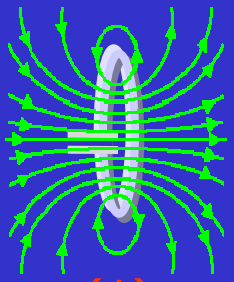
Comparison: direct vs. mediated



(1)

(3)

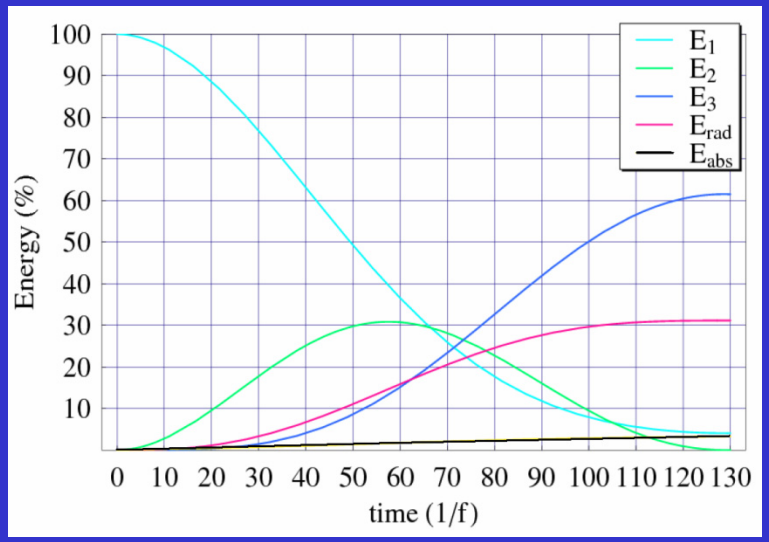




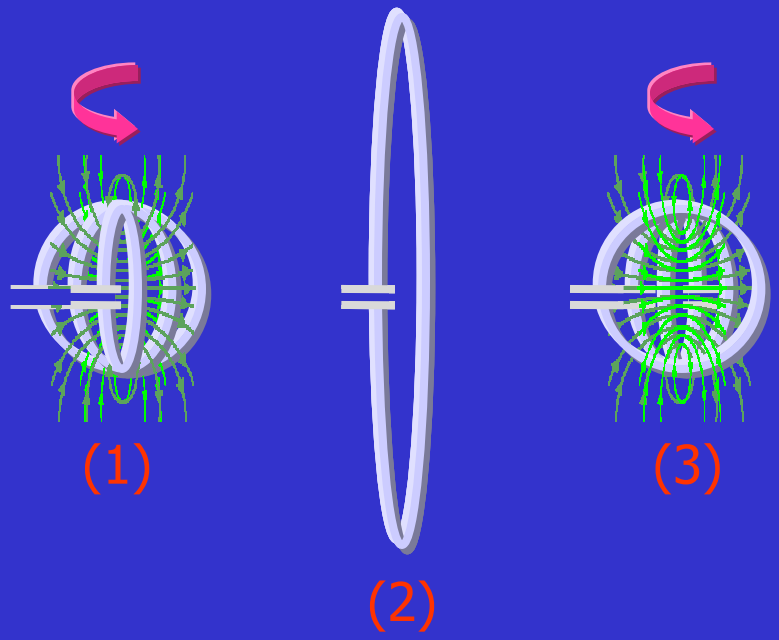
(1)

(2)

(3)

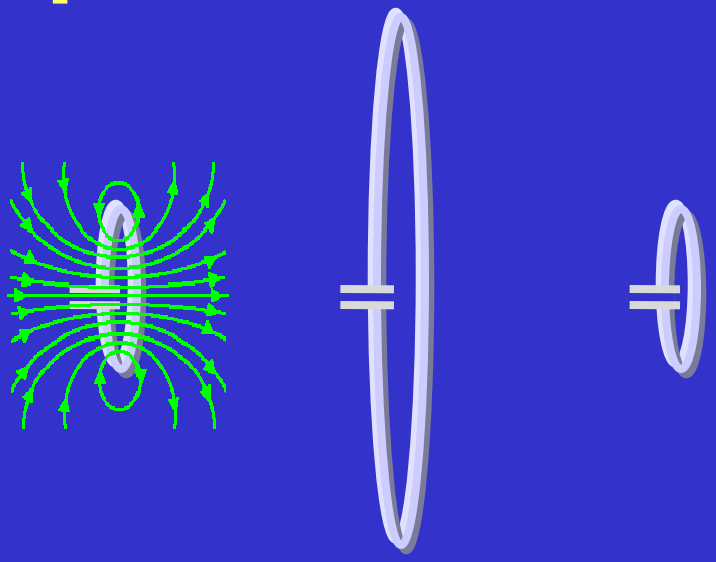


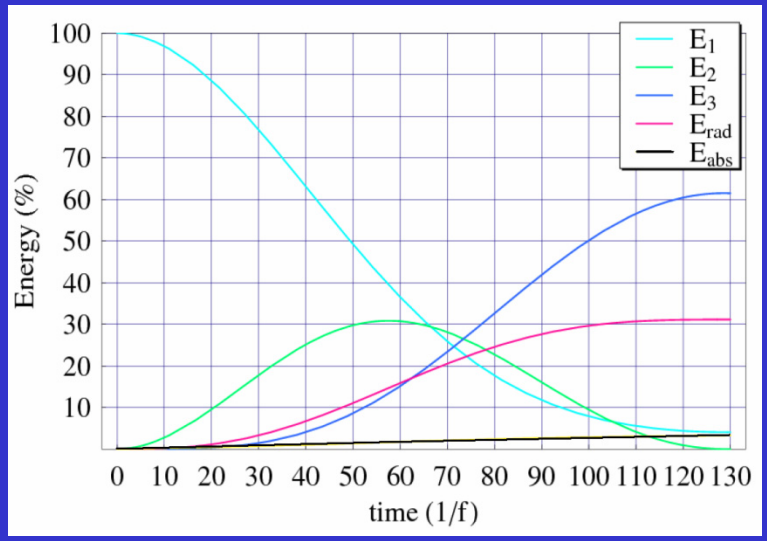
Time-dependent coupling strength

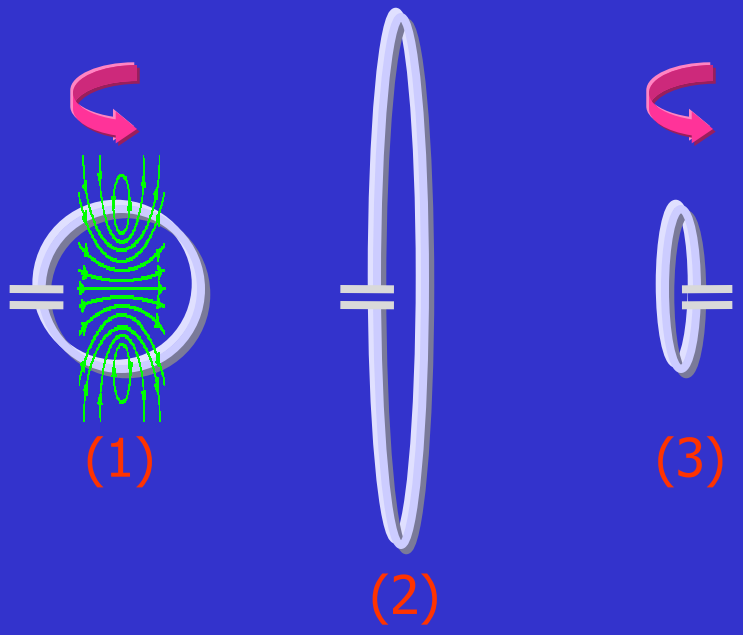


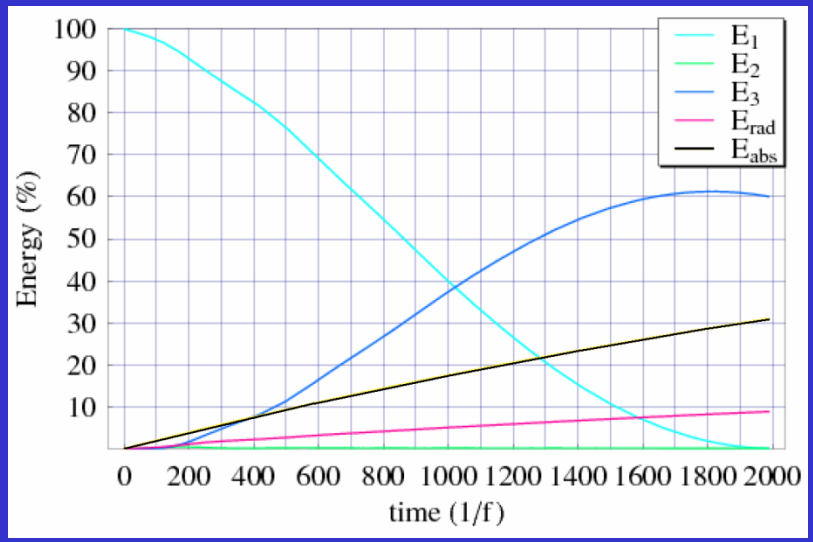
Collaborators:
R.Hamam, A.Karalis, and J.D.Joannopoulos

Comparison: mediated vs. time-dependent

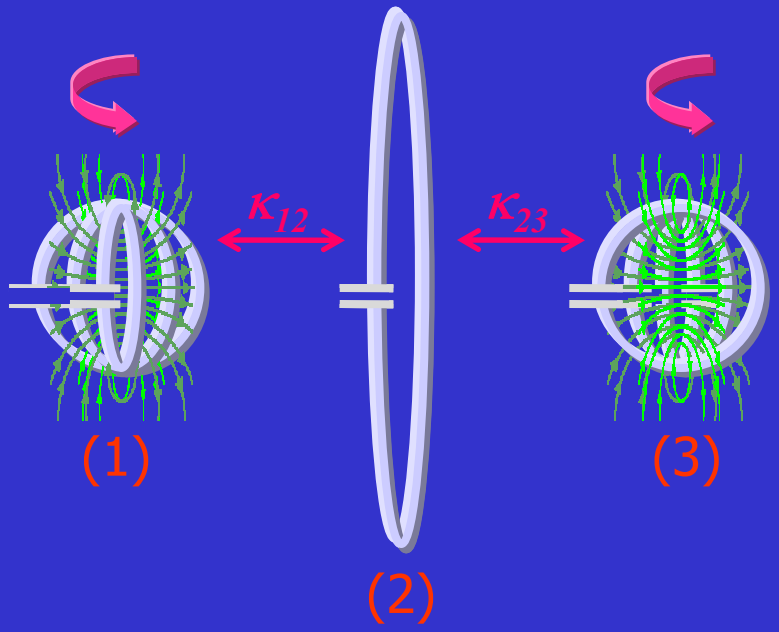








Time-dependent coupling strength

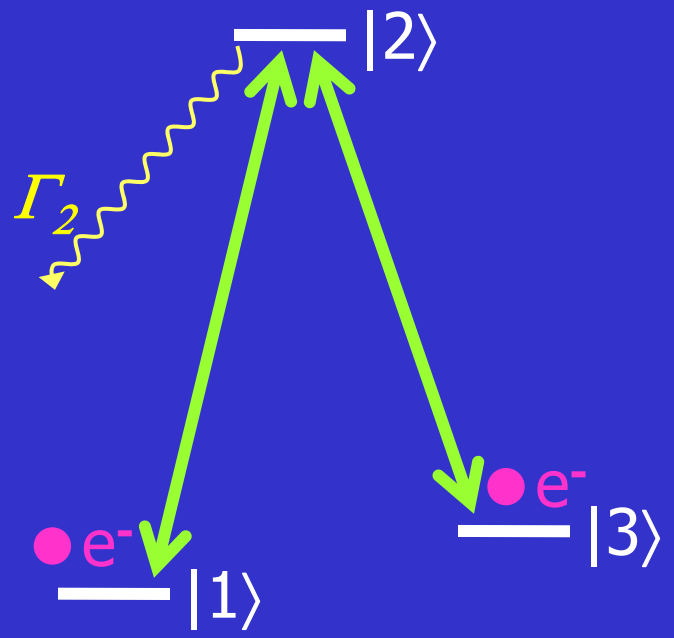


"Dark" state:

$$\vec{V}_1 = e^{-i\omega t-\Gamma_A t}\begin{pmatrix} \frac{-\kappa_{23}}{\sqrt{(\kappa_{12})^2+(\kappa_{23})^2}} \\ 0 \\ \frac{\kappa_{12}}{\sqrt{(\kappa_{12})^2+(\kappa_{23})^2}} \end{pmatrix}$$

$$\frac{d}{dt}\begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} = \begin{pmatrix} -(i\omega\ +\Gamma_A) & i\kappa_{12} & 0 \\ i\kappa_{12} & -(i\omega\ +\Gamma_B) & i\kappa_{23} \\ 0 & i\kappa_{23} & -(i\omega\ +\Gamma_A) \end{pmatrix}\begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix}$$

In atomic physics, this effect is known as STIRAP



STIRAP: "Stimulated Raman Adiabatic Passage"
…also happens in "Electromagnetically Induced Transparency" (EIT)

Potential applications

Some potential applications

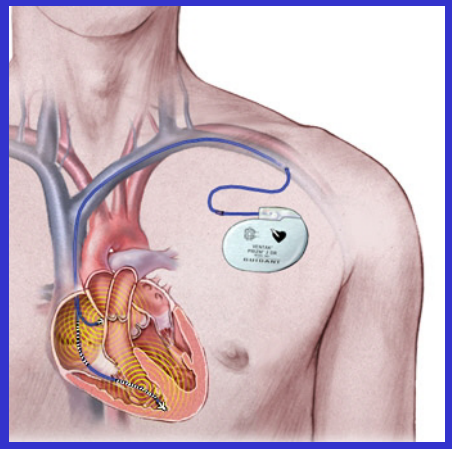
Industrial, military, and household robots

Portable personal electronics

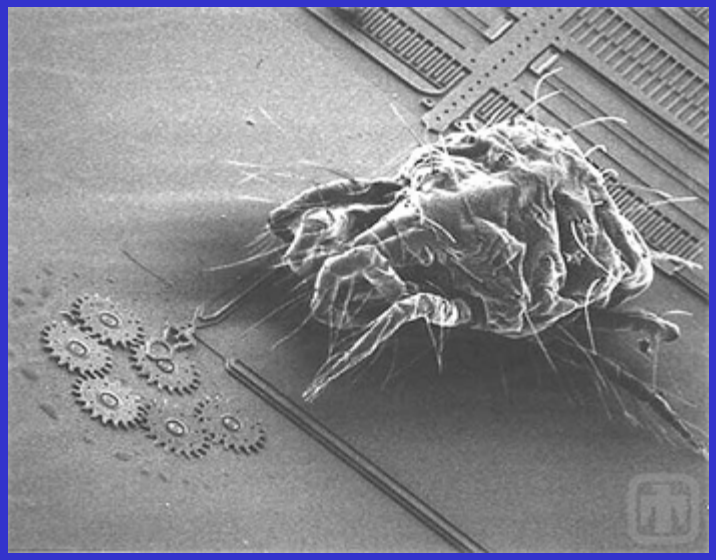
Electric vehicles

Vision: less dependence on batteries

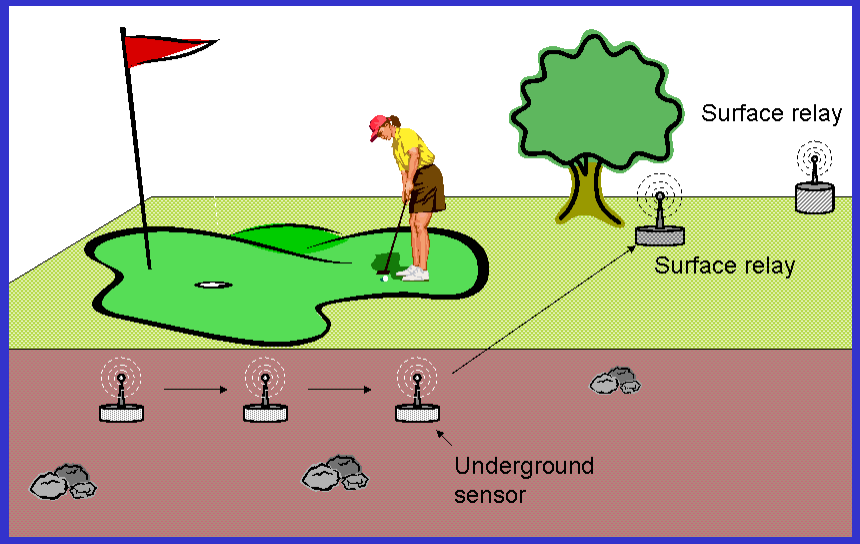
Other possible applications



Implanted medical devices



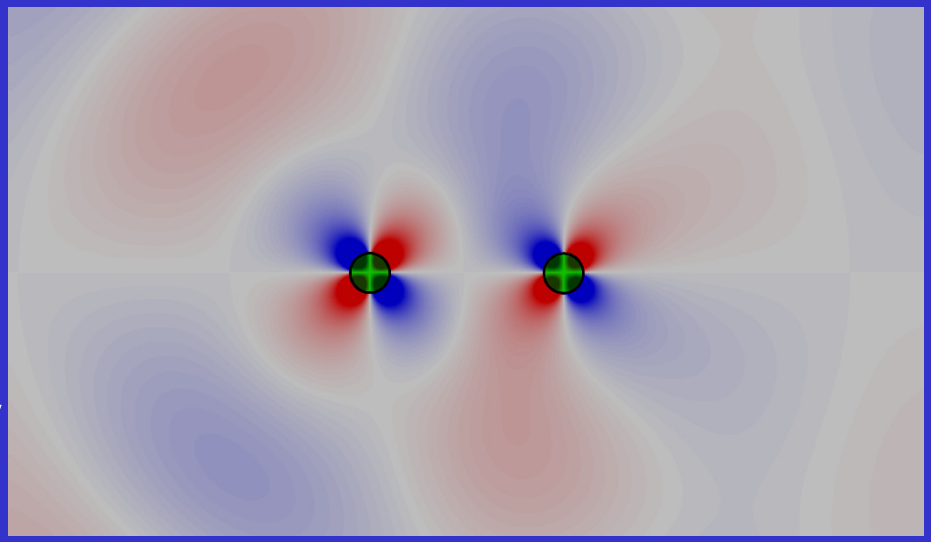
Power supply for MEMS or nano-robots



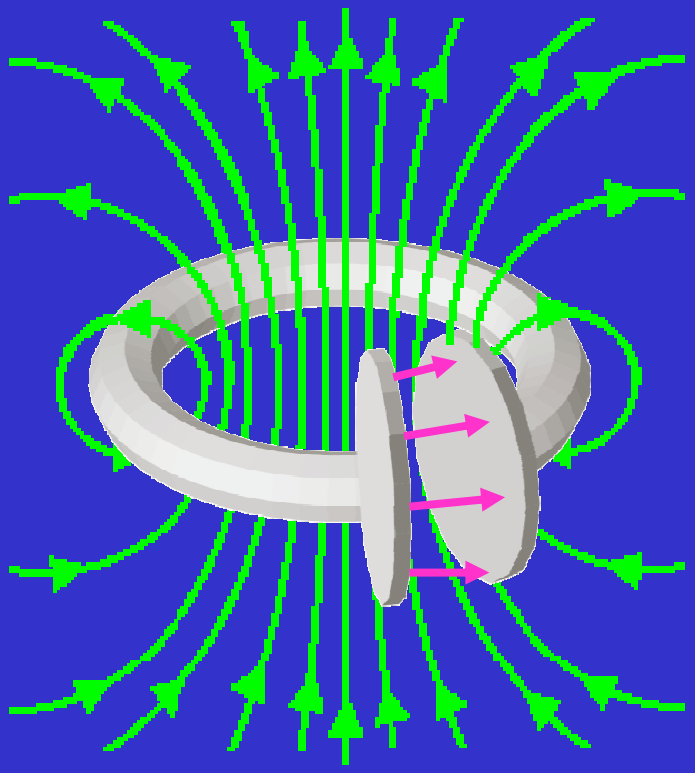
Sensors with difficult access

Electrically heated clothes

Conclusion



- mid-range ***non-radiative***
  energy transfer scheme
  based on ***strongly-coupled***
  resonances



- even very simple designs
  have promising performance

- as a powerful concept, it could
  enable a wide range of applications

Epilogue: what about Paris Hilton?

Press coverage of WiTricity

Wall Street Journal
New York Times
USA Today
BBC News: front page of news.bbc.co.uk *2
BBC World Service Radio *3
The Economist *2
Associated Press
NPR
…600 other newspapers, TVs, radio stations around the world

>2,000,000 hits for "WiTricity" on Google (~10th June 2007)

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Sports

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It's electric!

MIT team claims wireless power demo

BOSTON. Massachusetts Institute of Technology researchers made a 60-watt light bulb glow by sending it energy wirelessly — from a device 7 feet away — potentially heralding a future in which cell phones and other gadgets get juice without having to be plugged in.

The breakthrough, disclosed yesterday in Science Express, the online publication of the journal Science, is being called "WiTricity" by the scientists.

The concept of sending power wirelessly isn't new, but its wide-scale use has been dismissed as inefficient because electromagnetic energy generated by the charging device would radiate in all directions.

It's similar to how an opera star can break a wine glass that happens to resonate at the same frequency as her voice.

The truly new step, which is what was described in the paper in Science, was that the MIT team carried the concept out. The scientists were able to light up a 60-watt bulb that had "no physical connection" with the power-generating appliance. AP

Breakthrough step

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The innovation is being called "WiTricity" by the scientists.

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In pictures: G8 summit protests
Climate change: In graphics

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Moscow 'to cut migrant workers'

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Ok, but how come no one thought of this before?

"We explore. What path to explore is important, as well as what we notice along the path.

And there are always unturned stones along even well-trod paths.

Discovery awaits those who spot and take the trouble to turn the stones."

-- Charles H. Townes

Collaborators:

Robert Moffatt

Andre Kurs

Rafif Hamam

Dr. Aristeidis Karalis

Prof. Peter Fisher

Prof. John Joannopoulos

More info and reprints: www.mit.edu/~soljacic