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# Programming Matter

Smart Surfaces, Molecular Machines,  
and Invisibility Cloaks

Lauren Zarzar  
**Nicholas Schade**  
Adam Marblestone

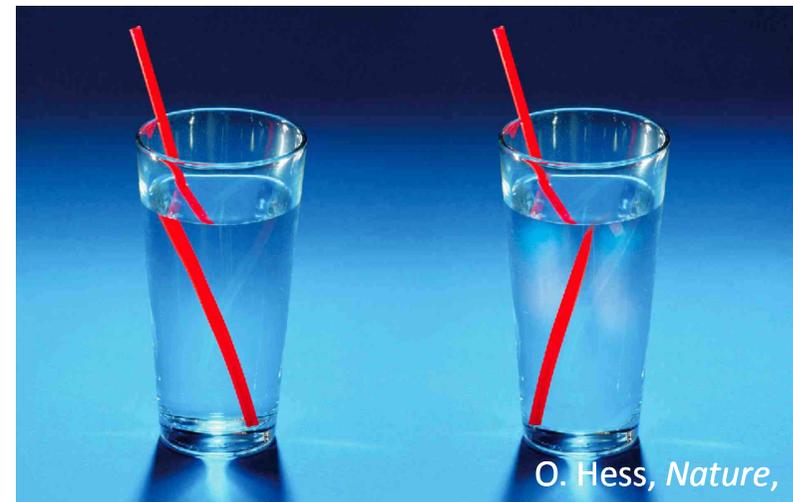
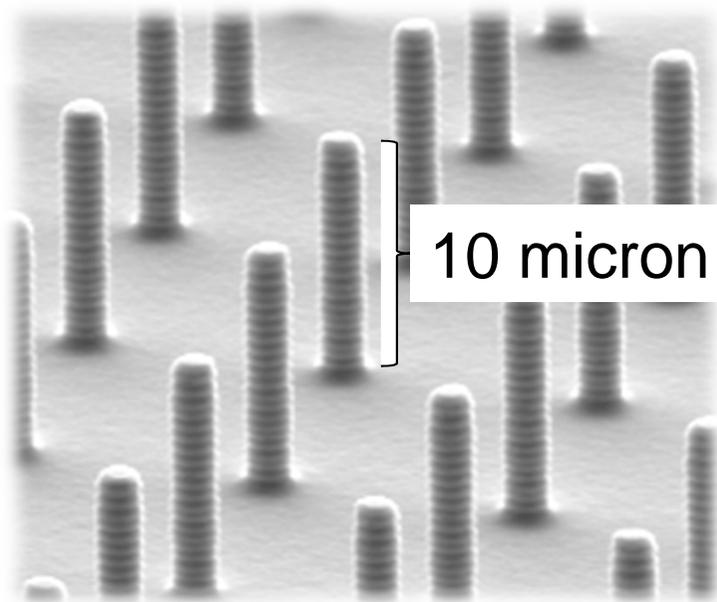
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# Outline for the Evening

- Lauren Zarzar – Programming smart surfaces with hydrogels
- Nicholas Schade – Controlling the way matter interacts with light
- Adam Marblestone – Building tiny molecular machines using DNA

# Programming Matter

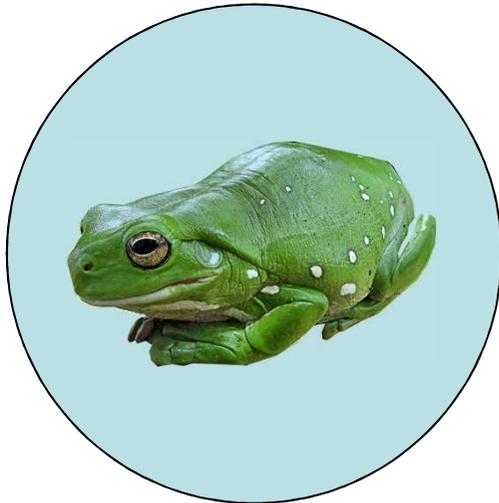
- Programming smart surfaces with hydrogels
- Guiding the path taken by light



Why does the straw look bent?  
Which picture shows real water?

# How can we program matter to be an invisibility cloak?

“Cloak”



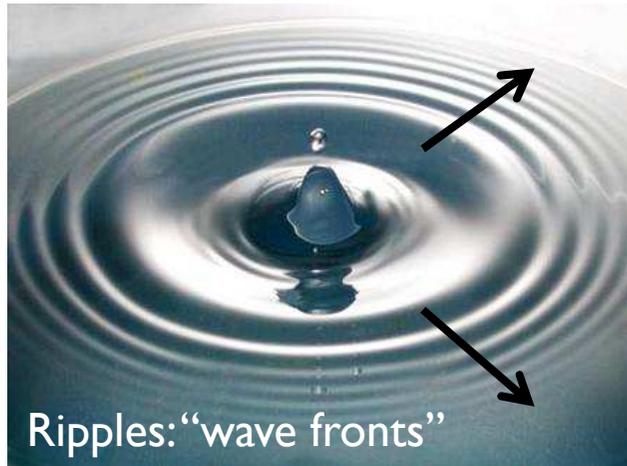
LiquidGhoul – Wikimedia Commons



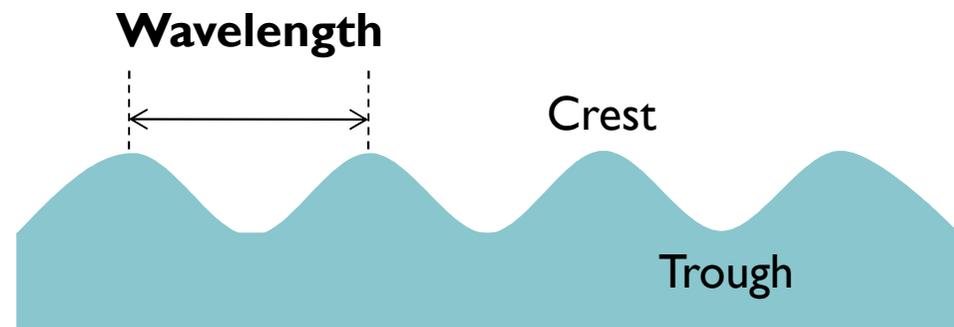
Sundae2Sundae – Wikimedia Commons

Goal: invisible from all viewing angles; no shadow

# Light travels as a wave



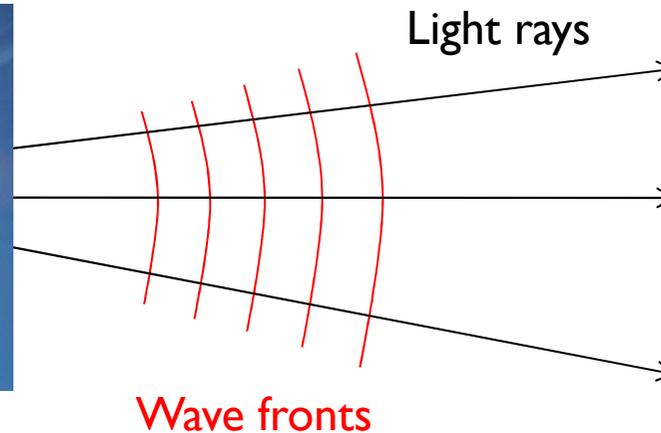
Courtesy of Prof. Andrew Davidhazy  
School of Photo Arts and Sciences/RIT – Rochester, NY 14623

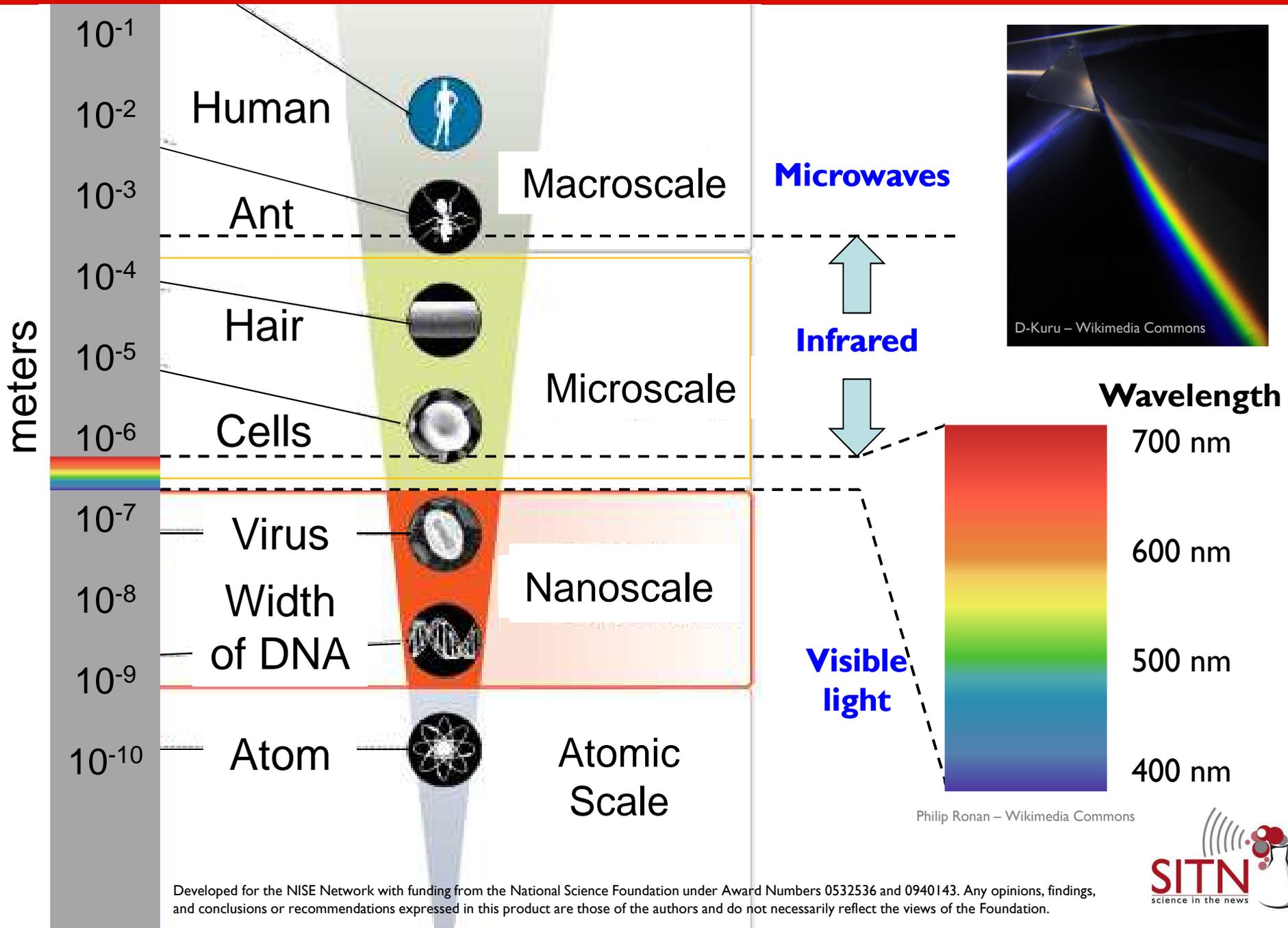


Wavelength determines color of light



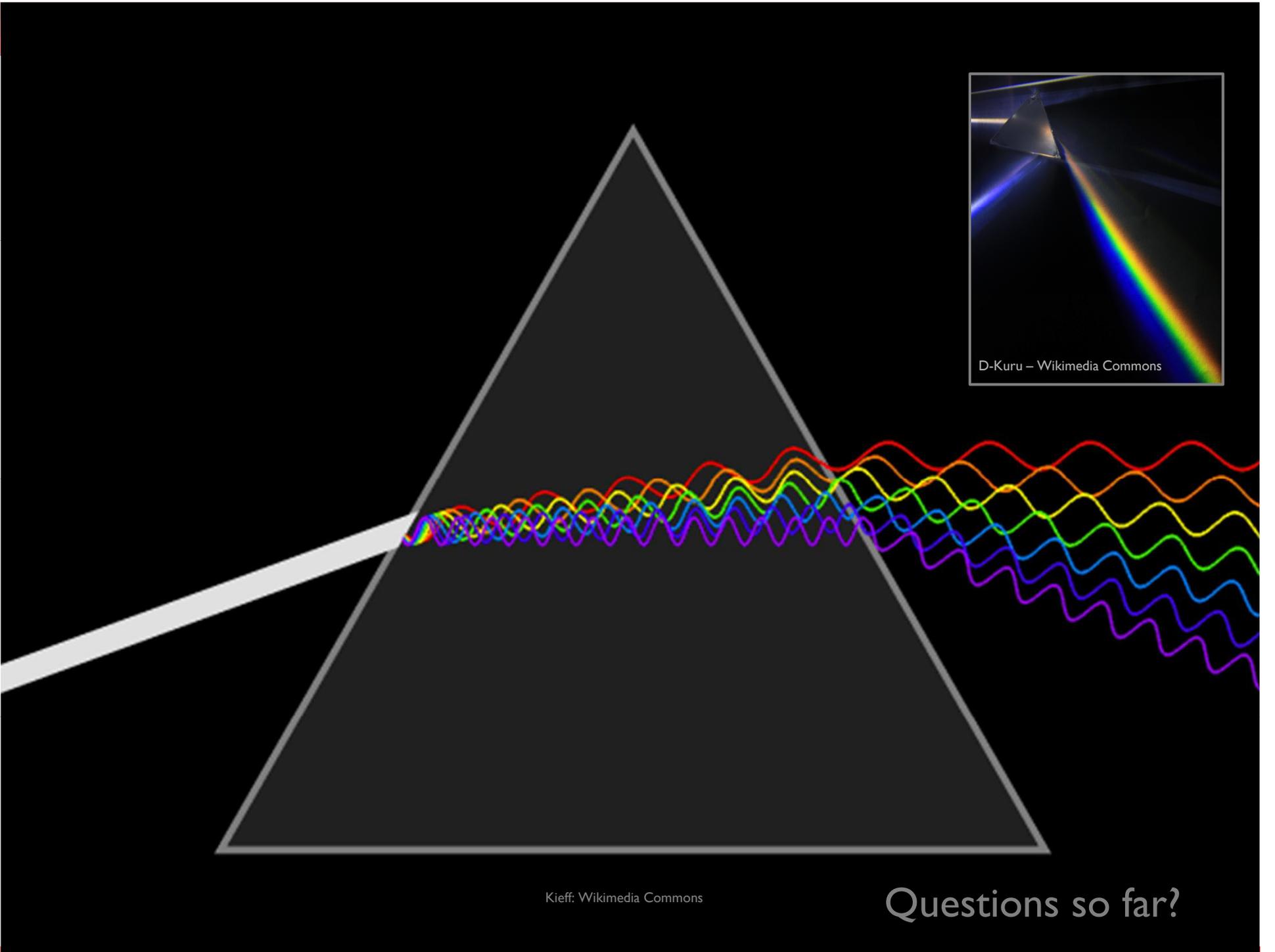
Lykaestria: Wikimedia Commons





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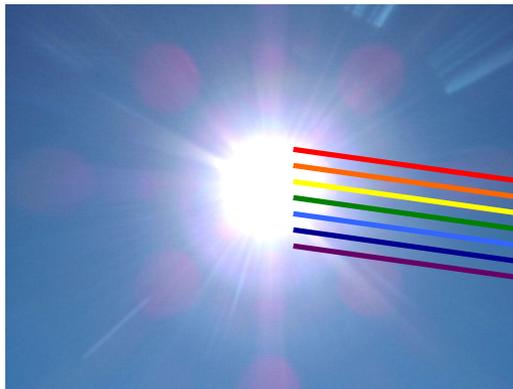


Kieff: Wikimedia Commons

Questions so far?

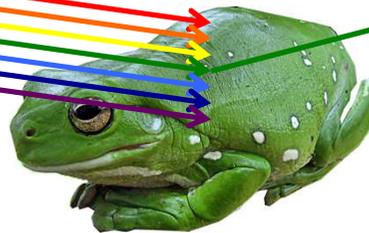
# How do we see objects?

**Light source**



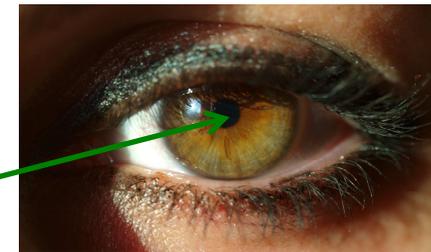
Lykaestria: Wikimedia Commons

**Object**



LiquidGhoul – Wikimedia Commons

**Observer**

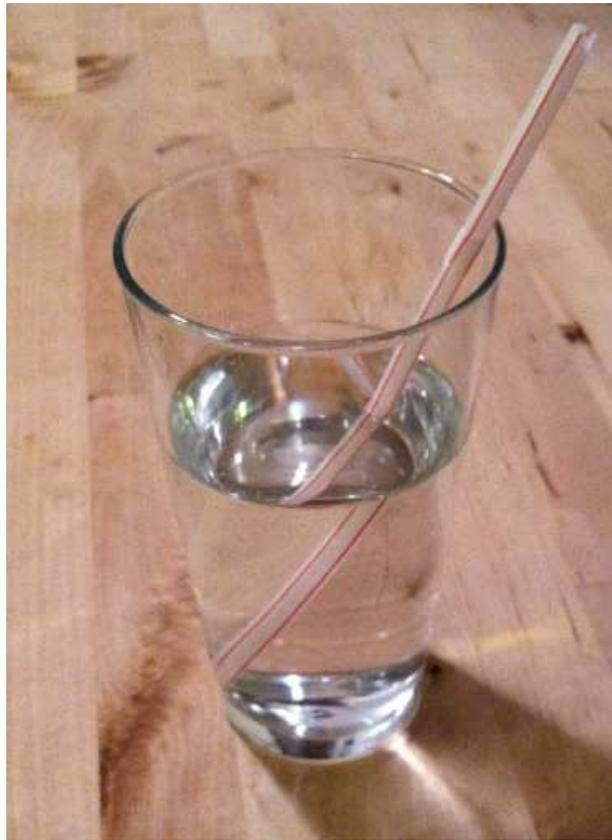


Petar Milošević – Wikimedia Commons

Opaque objects **absorb** some colors of light and **reflect** others

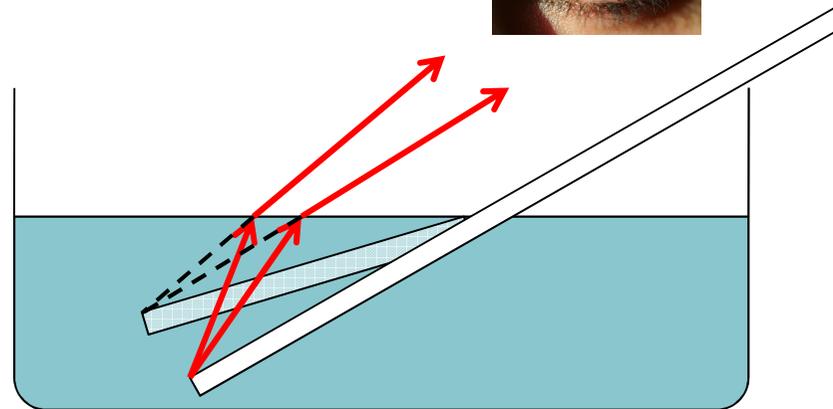
What about transparent objects that light can pass through?

# We can see transparent objects easily if they bend light



Light may change direction at surfaces between materials, creating distorted images

Petar Milošević – Wikimedia Commons



The straw looks bent but we know it isn't, so we can tell there is water in the glass

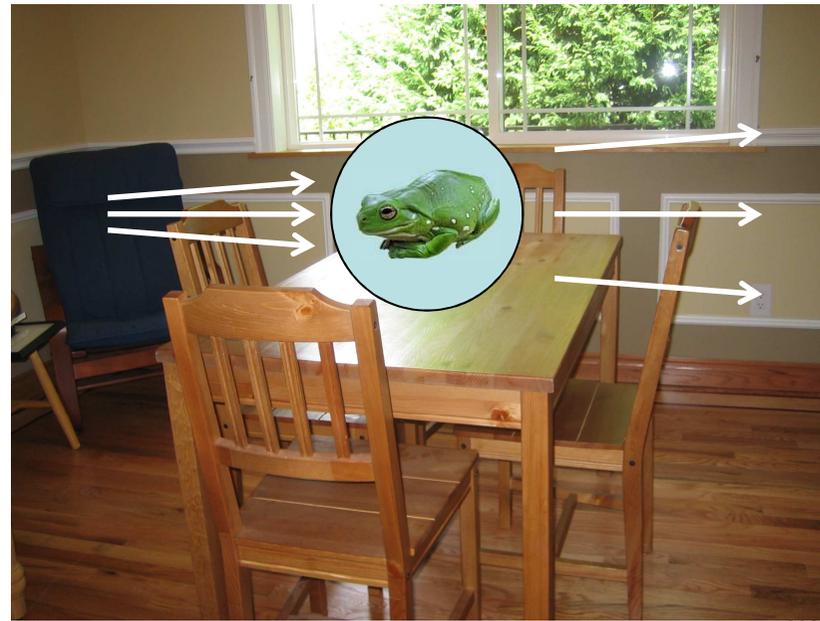
# What's the difference between transparency and invisibility?

Transparent objects bend light, creating distorted images



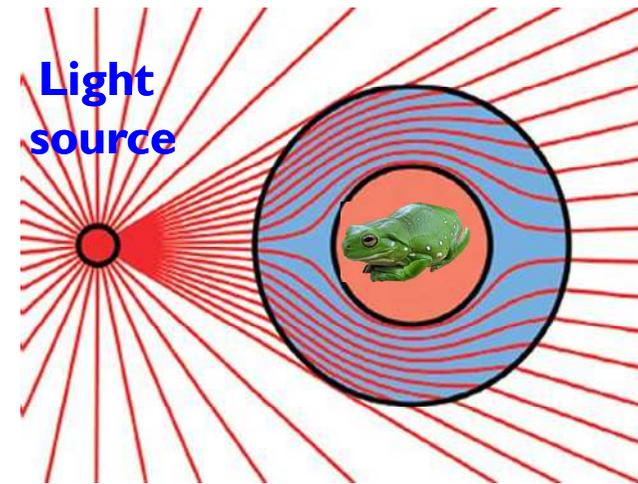
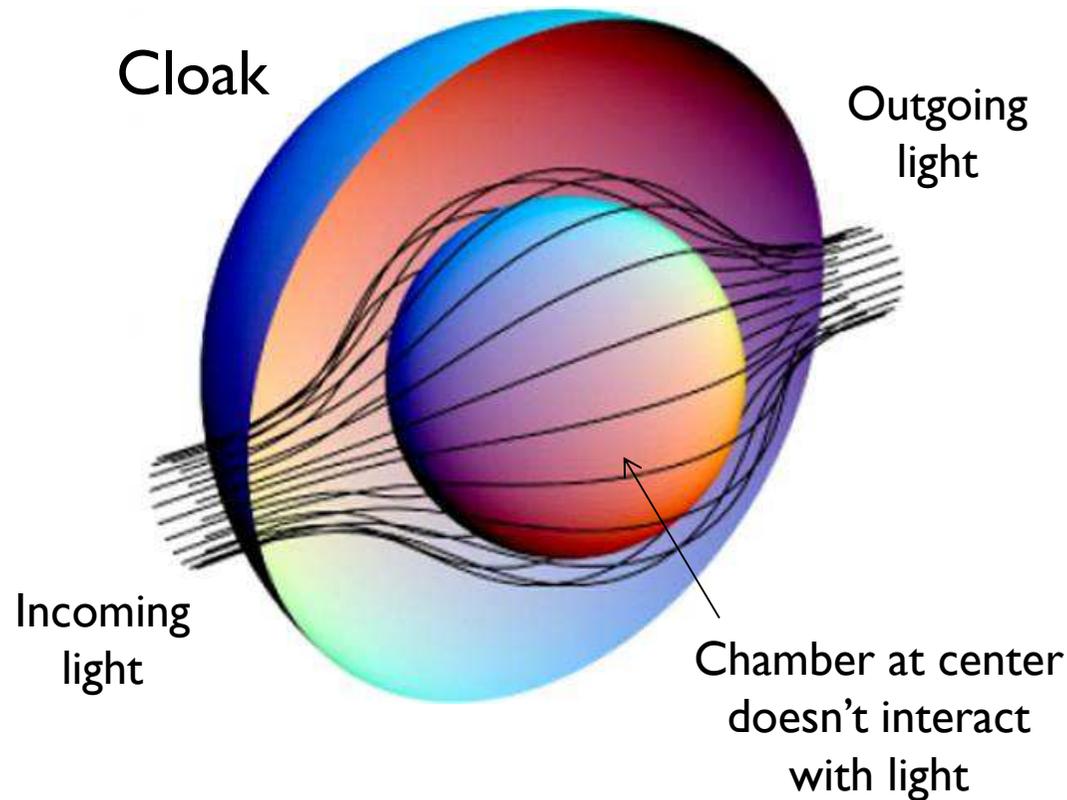
Mila Zincova – Wikimedia Commons

For invisibility, all light rays should resume their original directions



LiquidGhoul, Sundae2Sundae – Wikimedia Commons

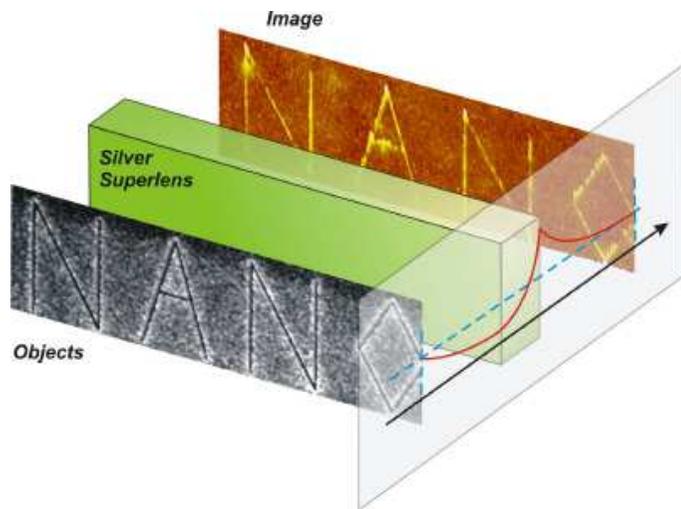
# Invisibility requires guiding light around an object



J. Pendry, et al., *Science*, 2006

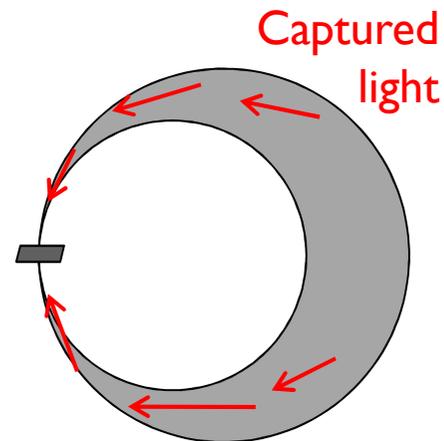
# What else could we do if we could guide waves arbitrarily?

## “Super lens” for perfect imaging



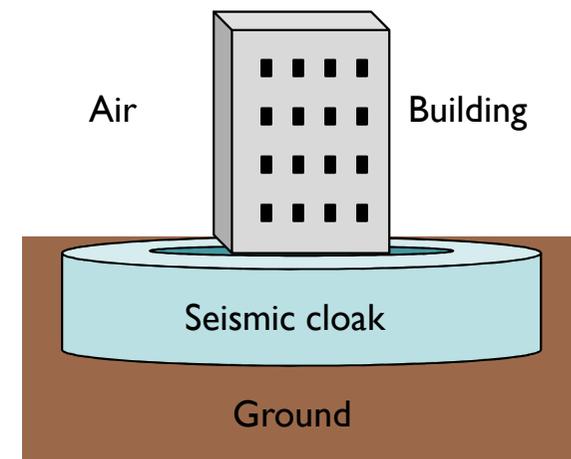
N. Fang, et al.,  
*Science*, 2005

## Light harvesting



A. Aubry, et al.,  
*Nano Letters*, 2007

## Other types of cloaking



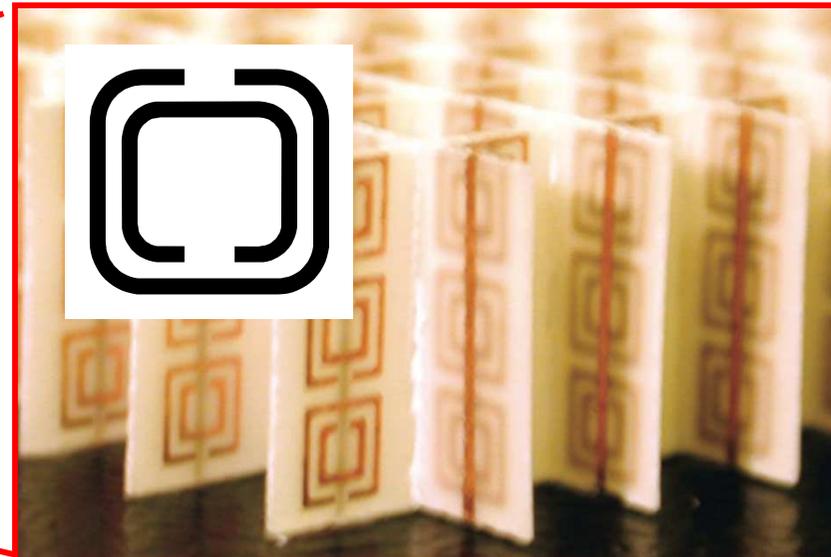
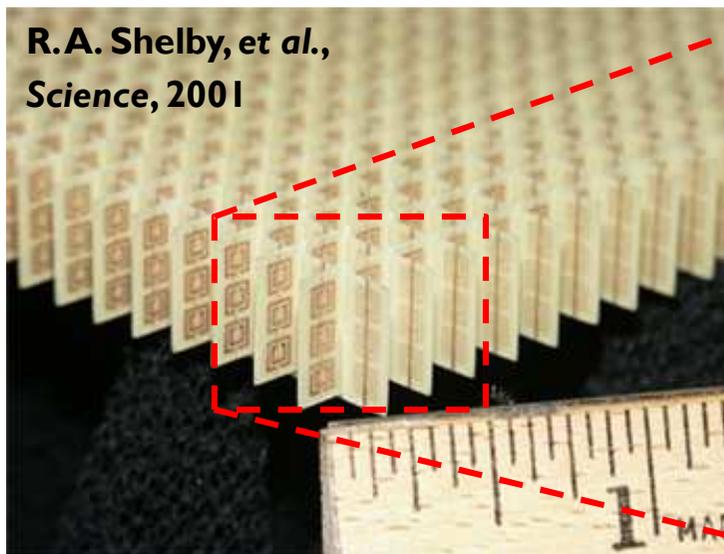
S. Kim & M. P. Das, in  
preparation

Questions so far?

# How do we program the way light and matter interact?

**Meta-material:** a synthetic substance programmed to interact with waves differently than natural materials

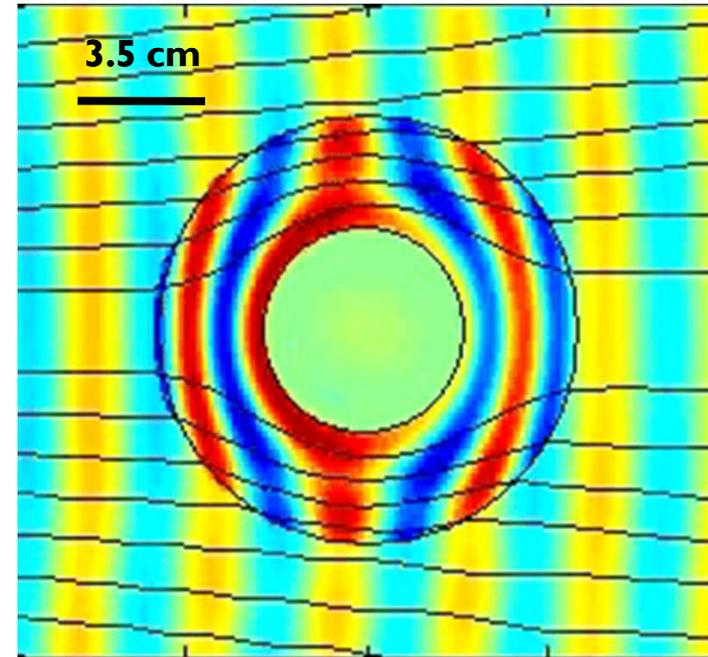
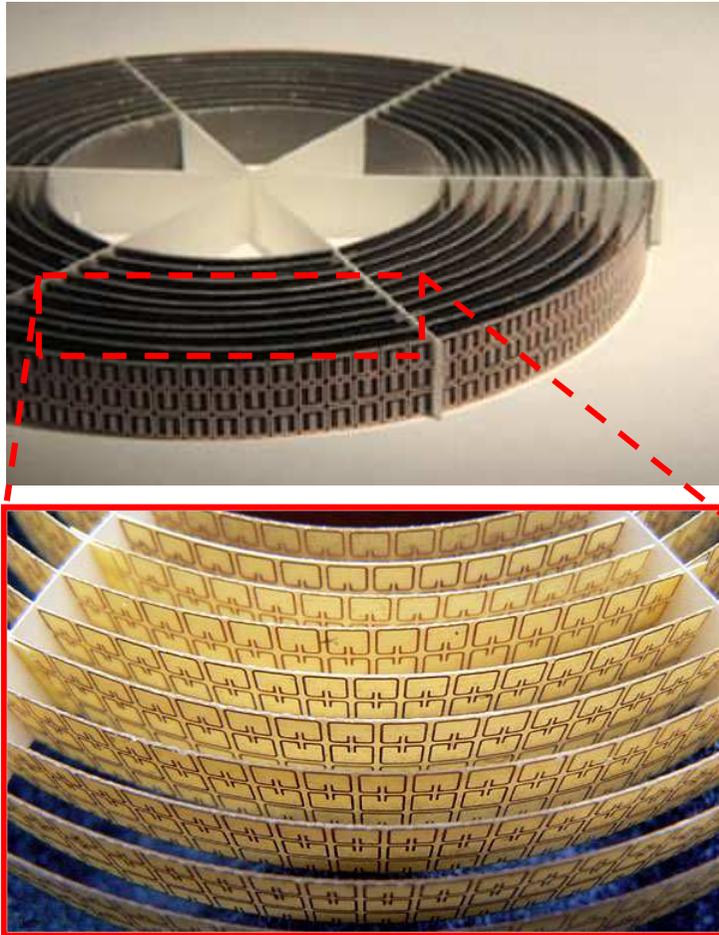
“meta” = “beyond”      **beyond the properties of natural materials!**



The structures in a meta-material must be *smaller than the wavelength* of light that you want to manipulate

# The world's first invisibility cloak!

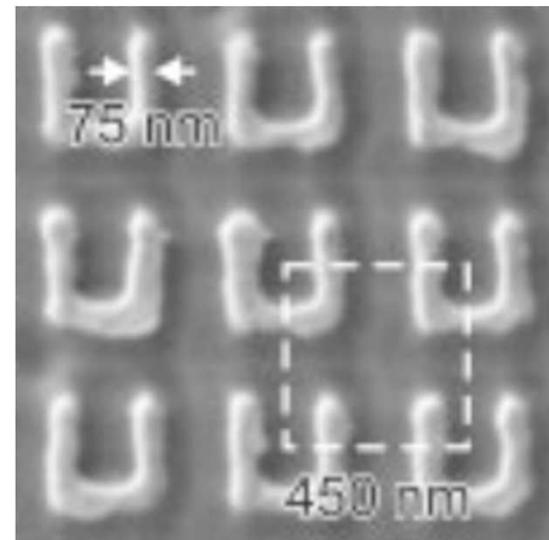
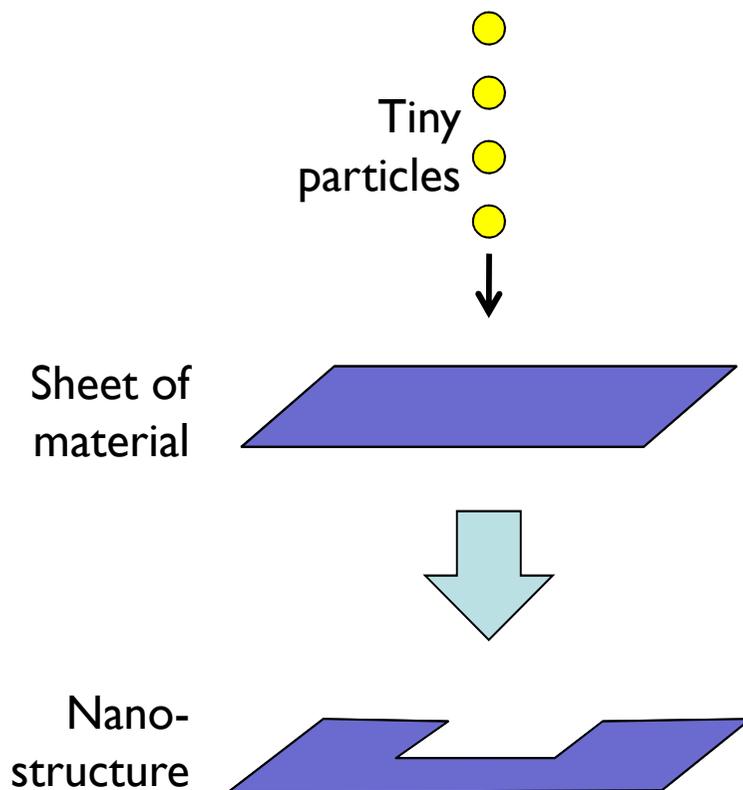
D. Schurig, *et al.*, *Science*, 2006



Designed for 3.5 cm wavelength  
(microwaves)!

# Can we do this for visible light?

Need structures smaller than 100 nm!  
How would we make them?

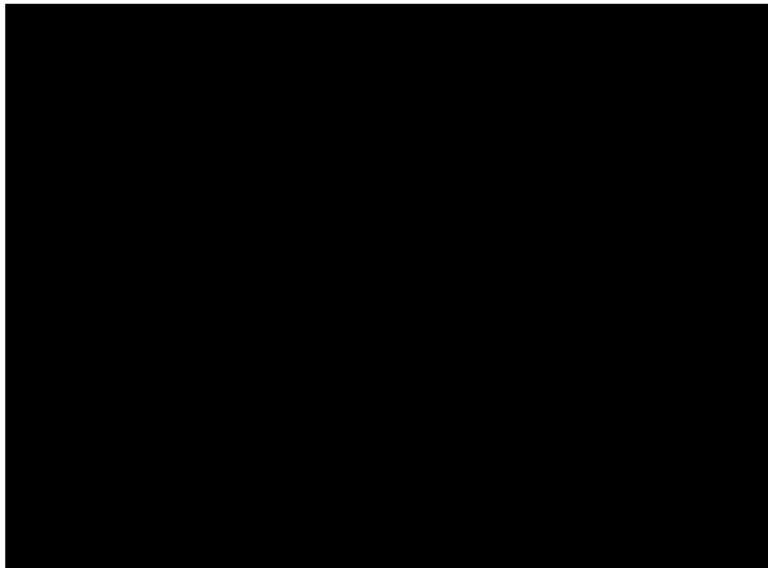


Enkrich, et al., *Advanced Materials*, 2005

- **Flat**
- **Expensive**
- **Limited precision**

# Self-assembly: designing things that build themselves

**Soup of building blocks**

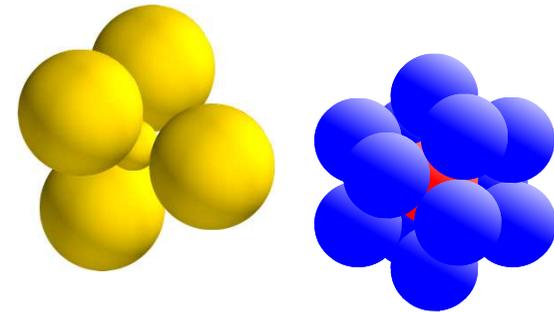


1.2  $\mu\text{m}$  (diameter) spherical particles

Mix, wait

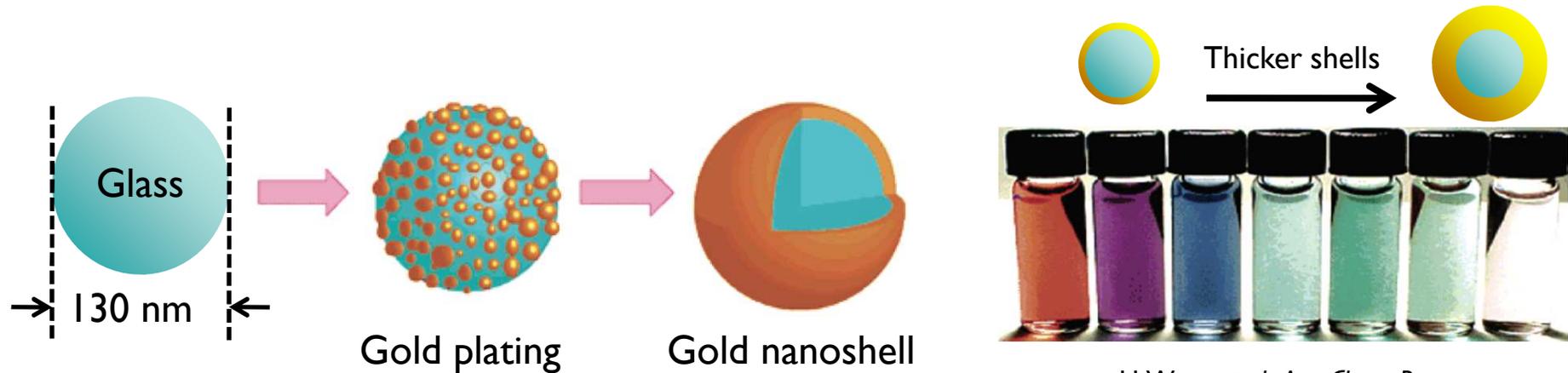


**Arbitrary  
3D structures**

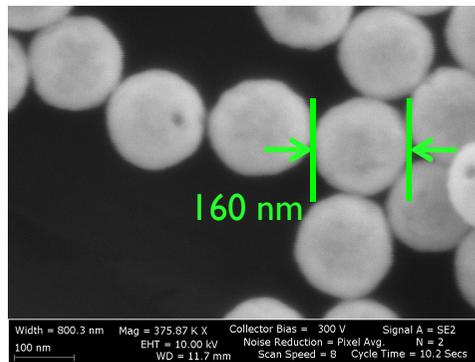


Questions?

# Building structures for meta-materials using self-assembly

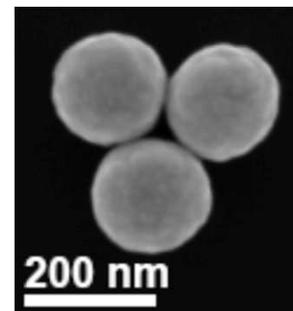


H.Wang, et al., *Acc. Chem. Res.*,  
© 2007 American Chemical Society



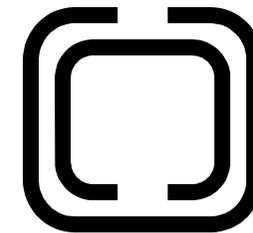
Gold nanoshells

Self-assembly

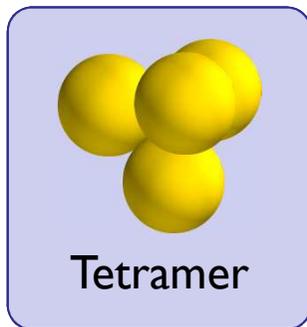


Trimer

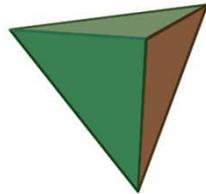
J.A. Fan, et al., *Science*, 2010



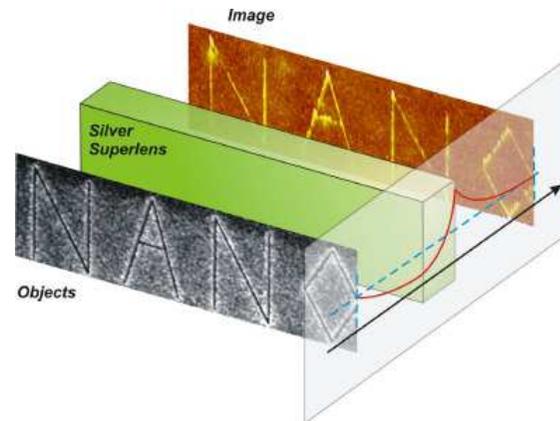
# Can we find a way to self-assemble tetramers in bulk?



DTR: Wikimedia Commons

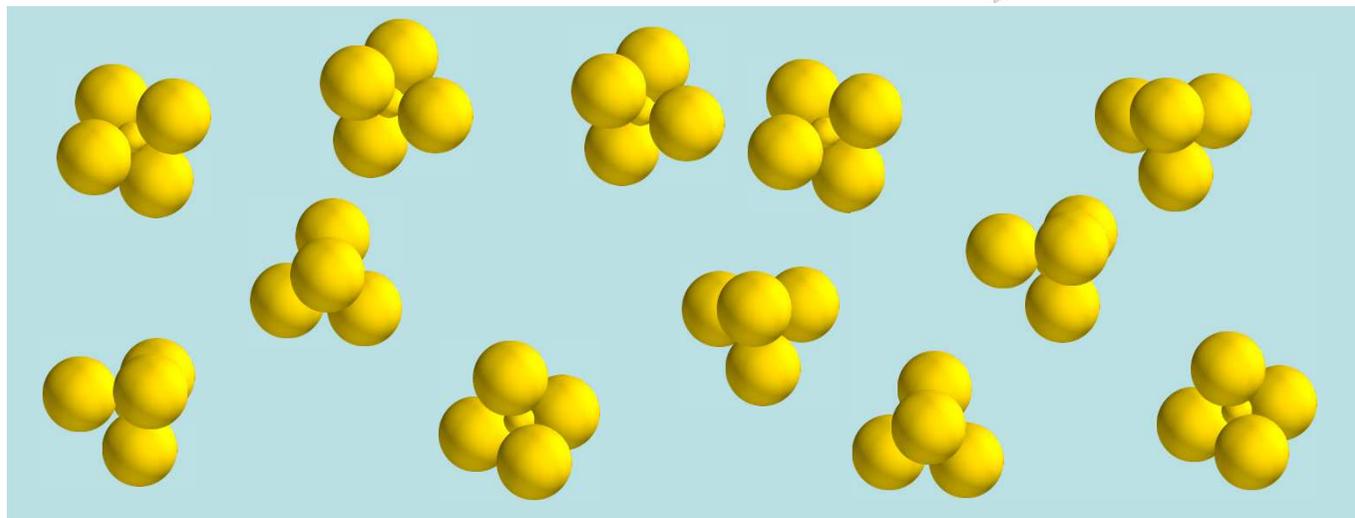


Tetrahedron  
“Tetra” = 4



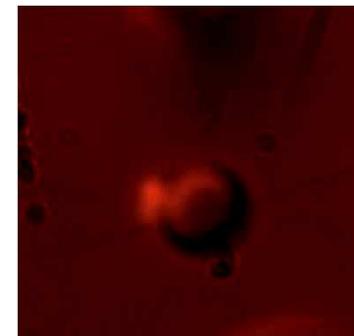
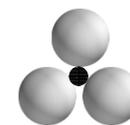
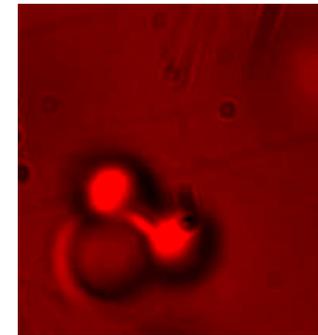
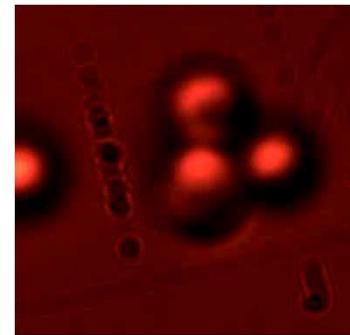
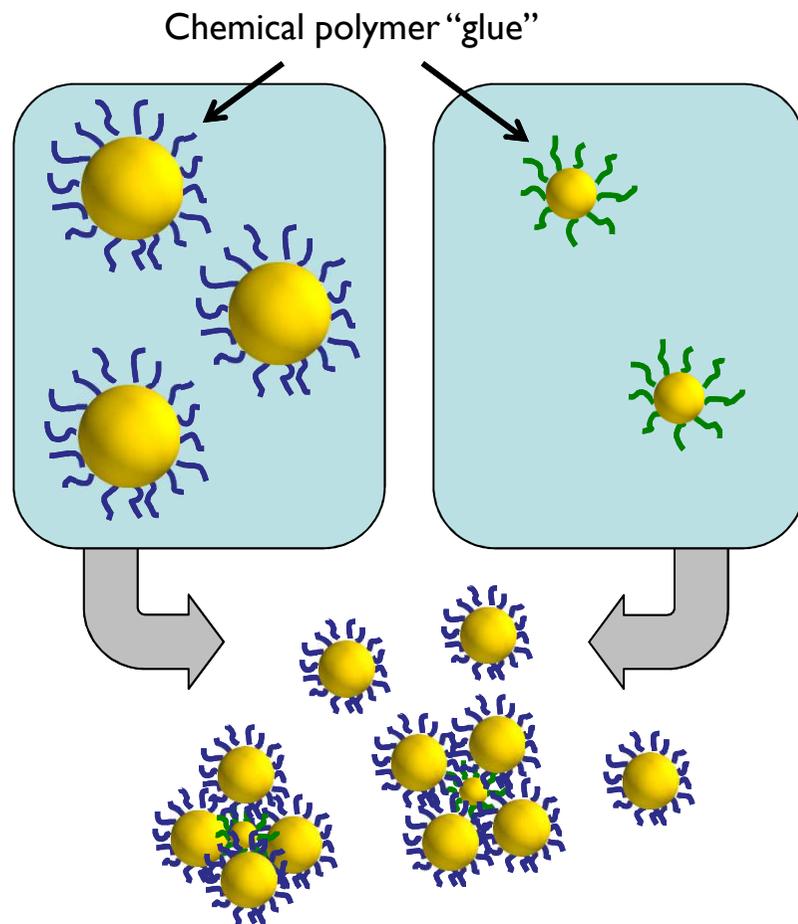
N. Fang, et al.,  
*Science*, 2005

Ideal for  
super lens!

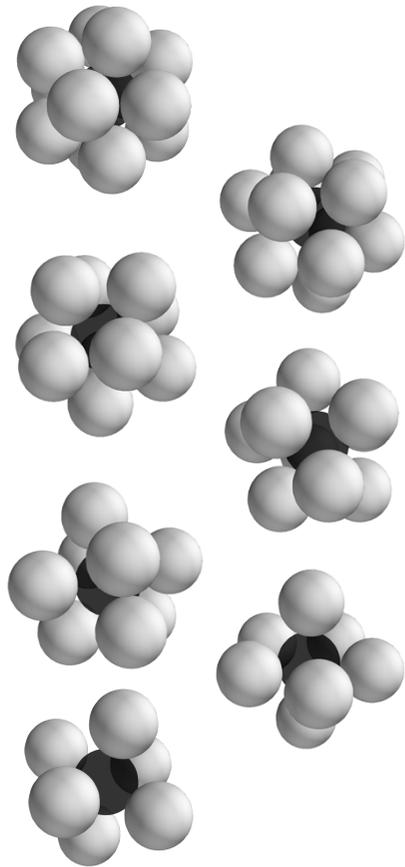


**How can we make this?**

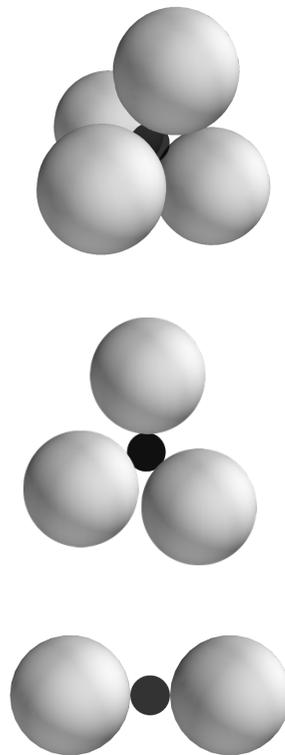
# Assembly using big and small particles that stick to each other



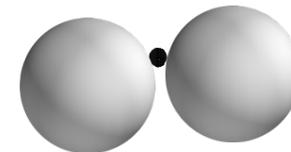
# Sphere size ratio determines cluster sizes



$$x = 1$$

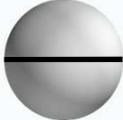


$$x = 3$$



$$x = 7$$

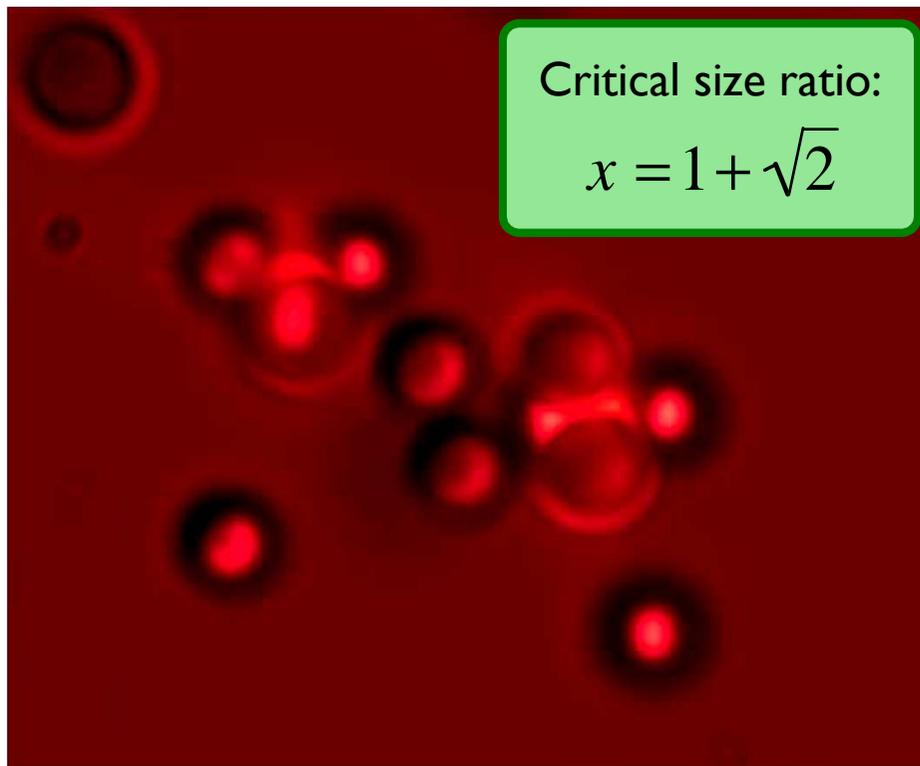
  $D_{small}$

  $D_{big}$

$$x = \frac{D_{big}}{D_{small}}$$

Big sphere is  $x$  times wider than small sphere

# With the right sphere sizes, nearly all clusters are tetramers!



## Collaborators:

Miranda C. Holmes-Cerfon

Elizabeth R. Chen

Dina Aronzon

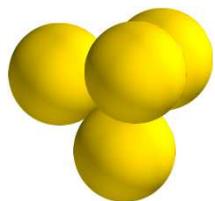
Jesse W. Collins

Jonathan A. Fan

Federico Capasso

Vinothan N. Manoharan

## Acknowledgments

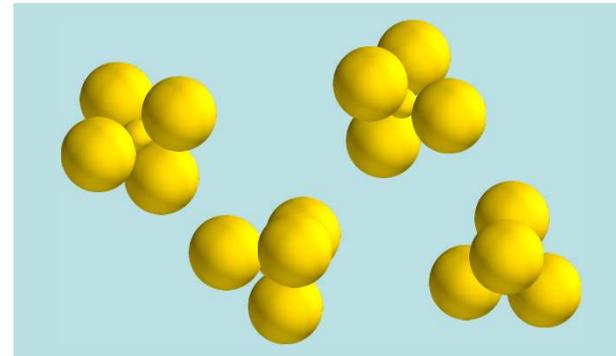
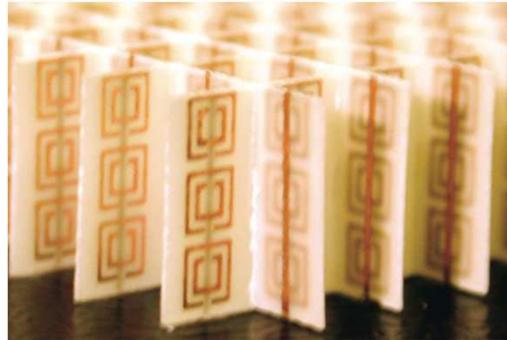
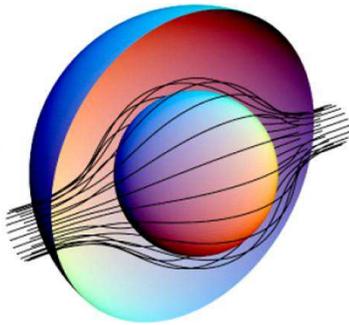


Next challenge is to do this with gold nanoparticles to build useful meta-materials

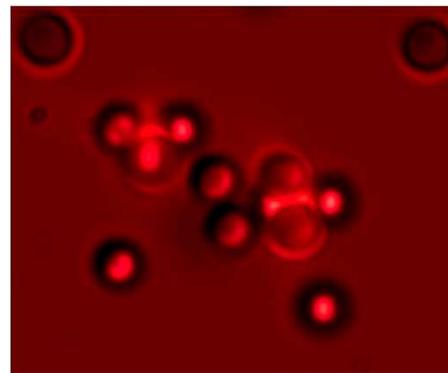
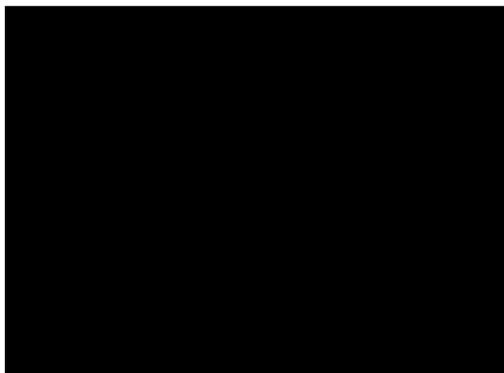


# Recap

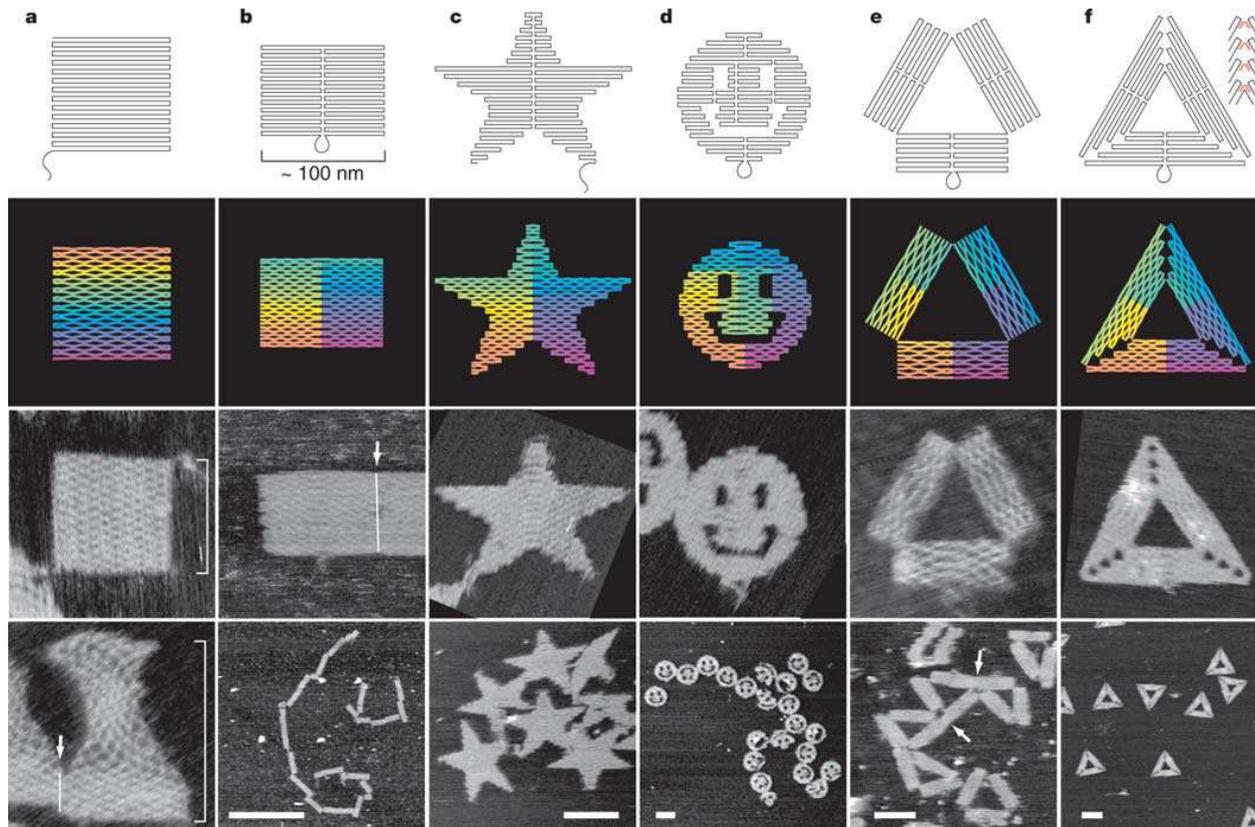
Controlling the path taken by light requires new materials containing tiny synthetic structures



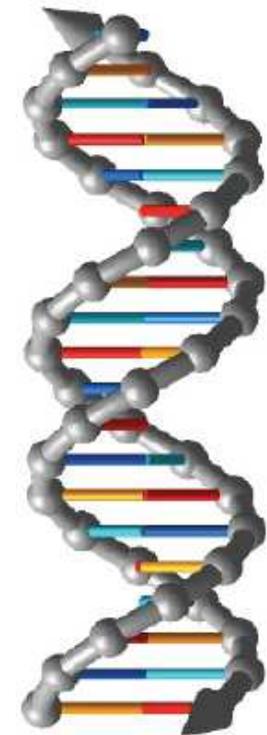
Self-assembly is one way we are trying to build such a material for visible light



# Coming up after the break



DNA



**Adam Marblestone**

Building tiny molecular machines using DNA