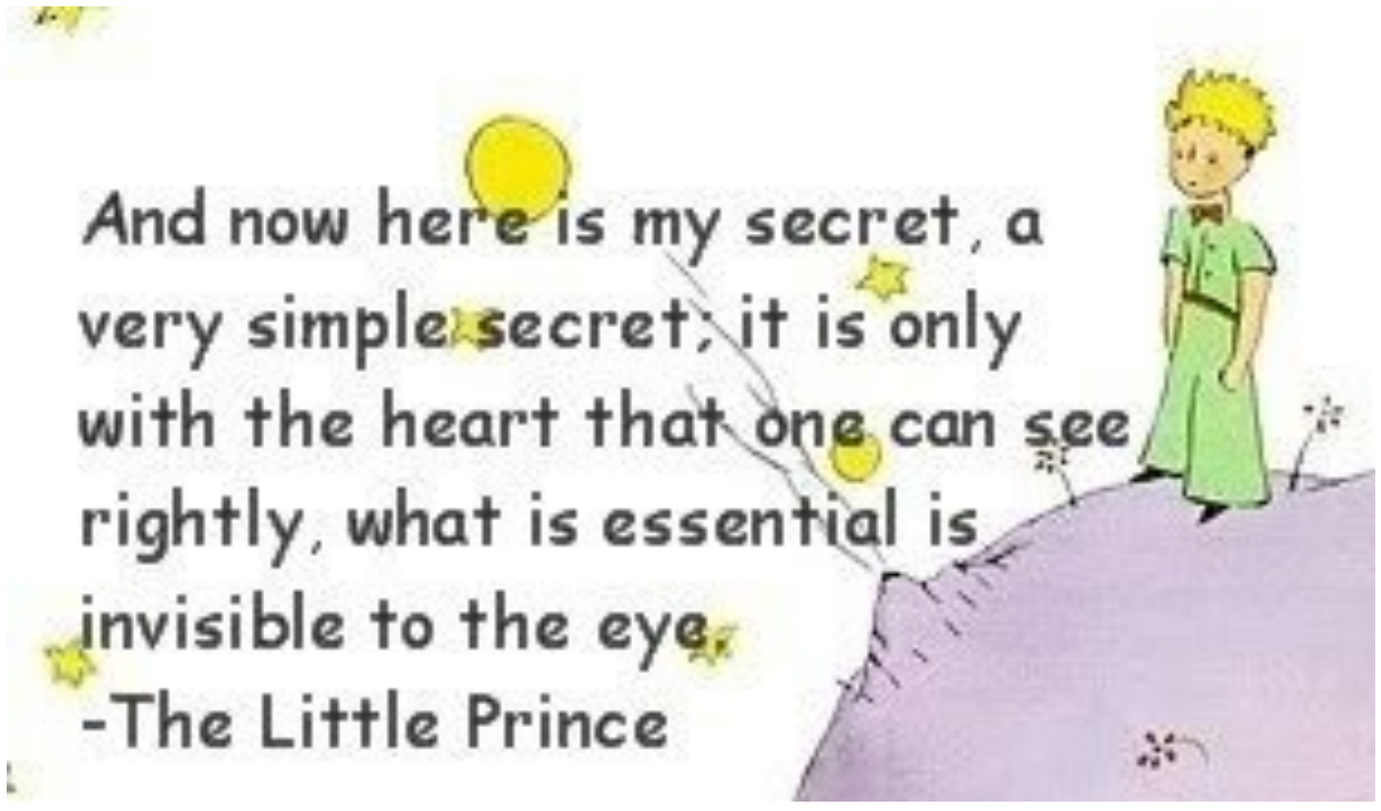
Revealing the Invisible

Frédo Durand
MIT CSAIL



Sound camera http://gizmodo.com/this-portable-sound-camera-shows-you-where-its-loud-498524262







http://www.youtube.com/watch?v=rKvXvkV16-U

https://www.youtube.com/watch?v=MoUQdcLmz5g

http://www.youtube.com/watch?v=wdggA-Qc7f4

https://www.youtube.com/watch?v=2awbKQ2DLRE&feature=youtu.be

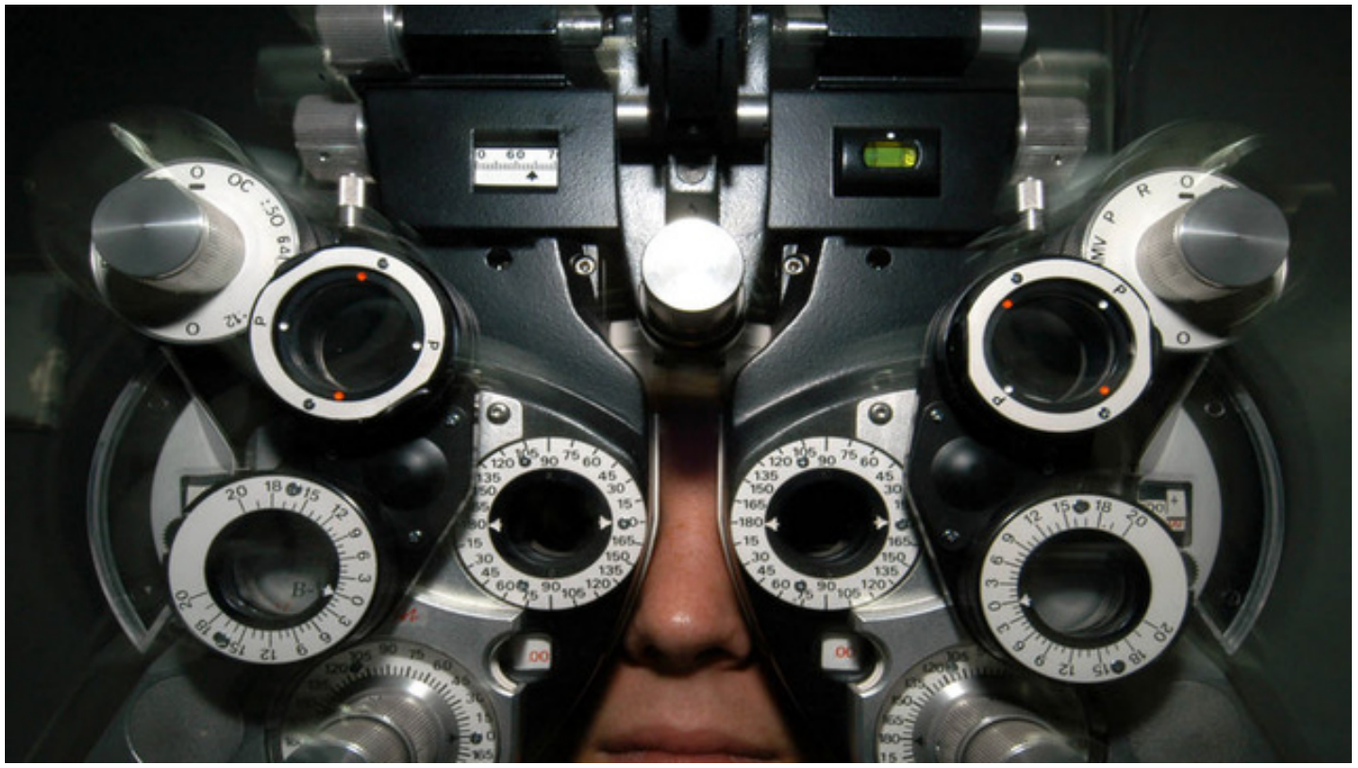
Chrysalid transformation

http://gizmodo.com/watch-a-caterpillar-transform-into-a-butterfly-from-ins-506894053

Motivations

- The human visual system is awesome
- But we should go beyond what is visible
- Graphics and imaging allow us
  to understand and reveal the visual world

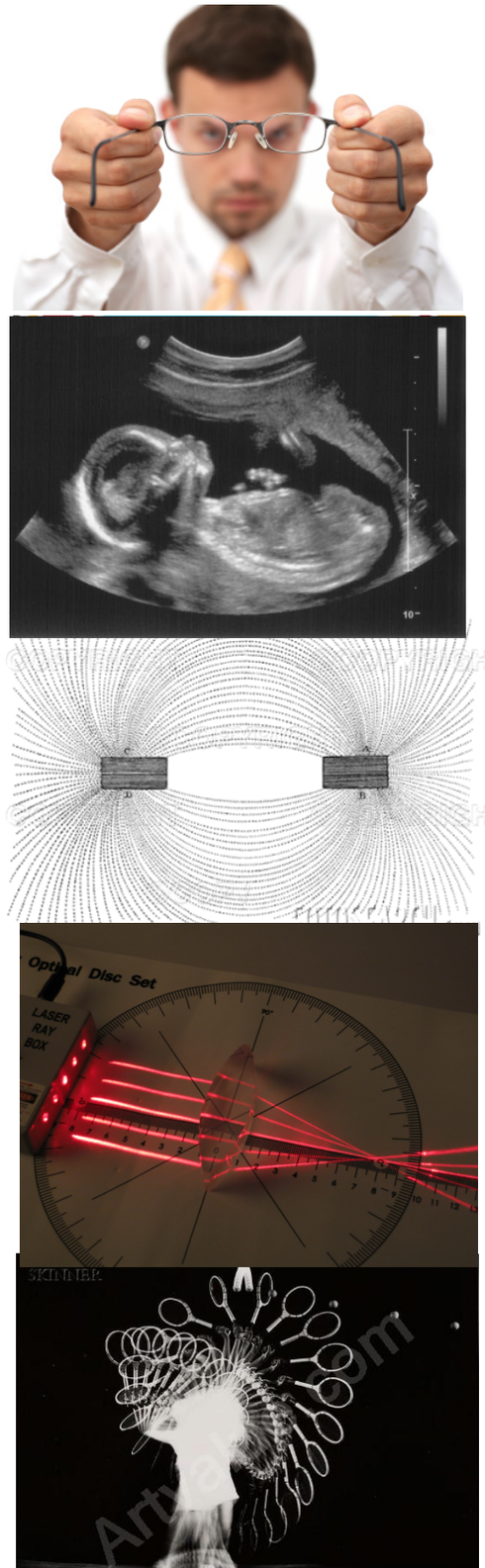




http://gizmodo.com/5945268/15-ophthalmological-marvels-that-make-your-eyesight-as-clear-as-your-hindsight/gallery/1

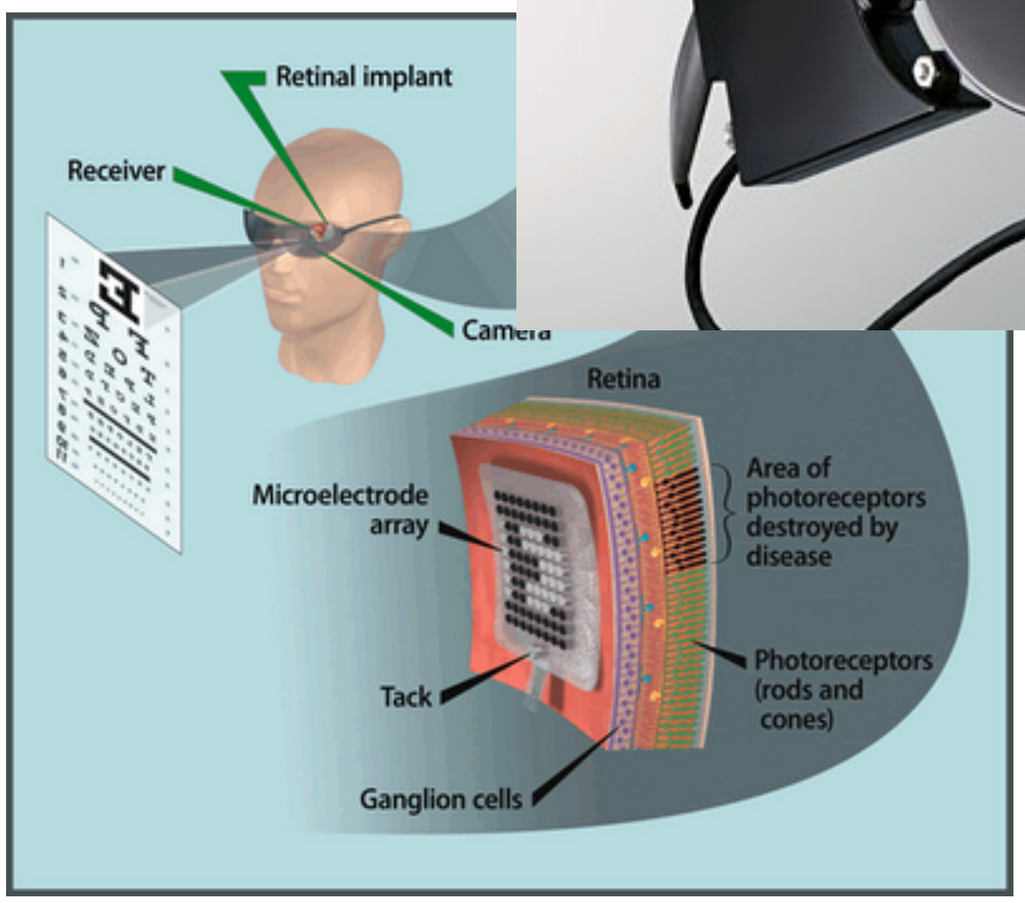
Overview

- Limits of human vision
- Occlusion
- Non-visual phenomena
- Non-visible visual phenomena
- Change and motion



Vision aid





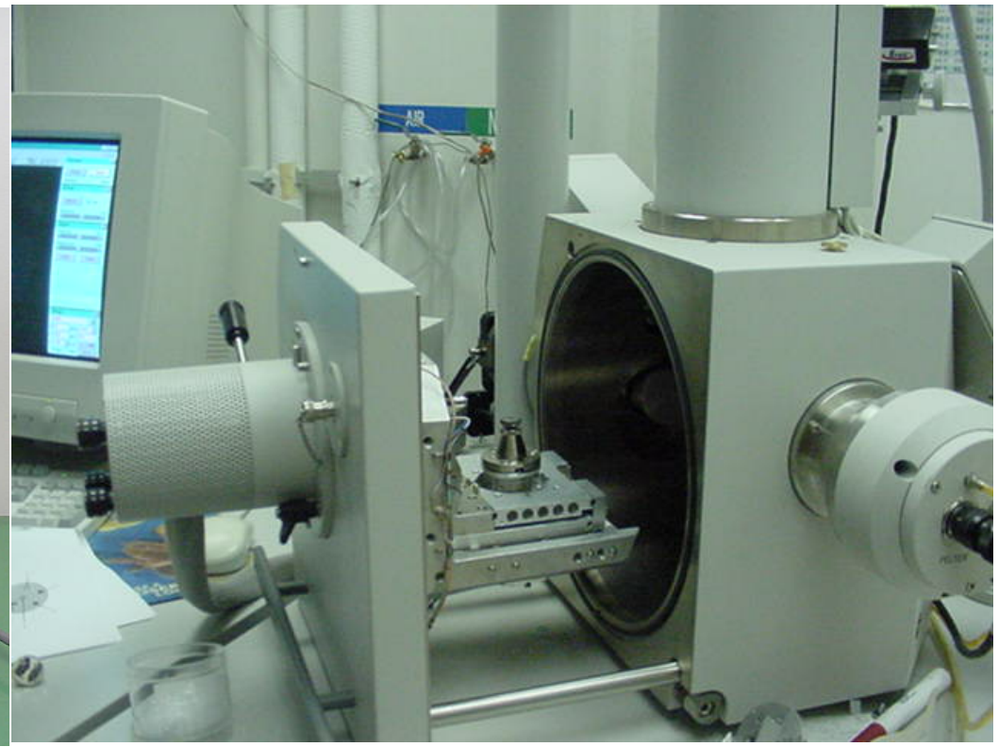


http://www.nytimes.com/2008/05/25/technology/25novel.html
See also http://www.freedomvision.net/ http://www.gwmicro.com/

Too small: microscopy

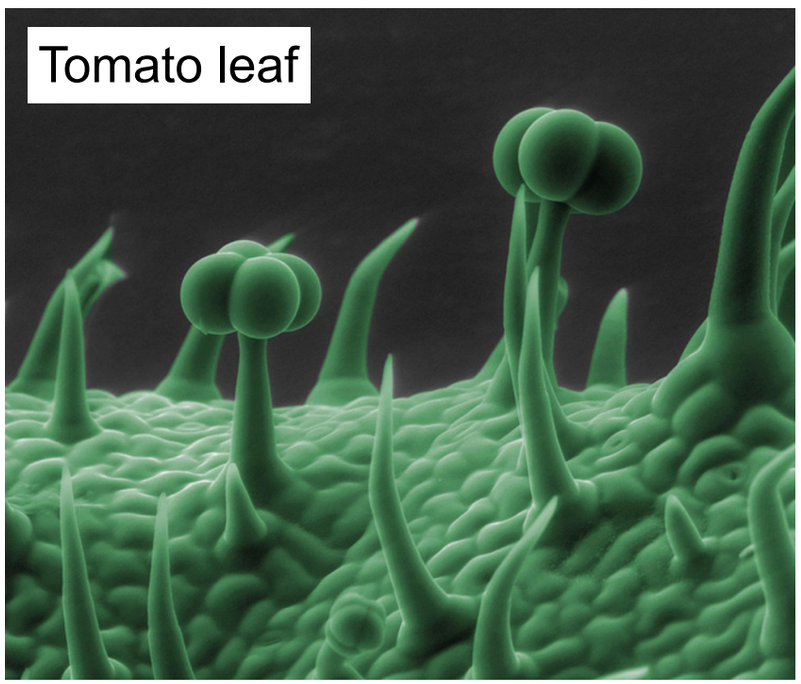


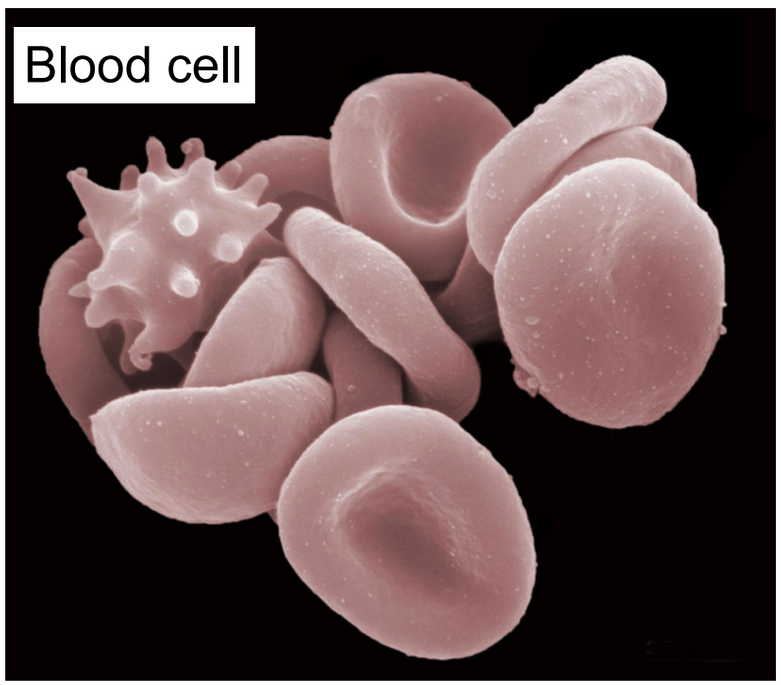




http://en.wikipedia.org/wiki/Microscope

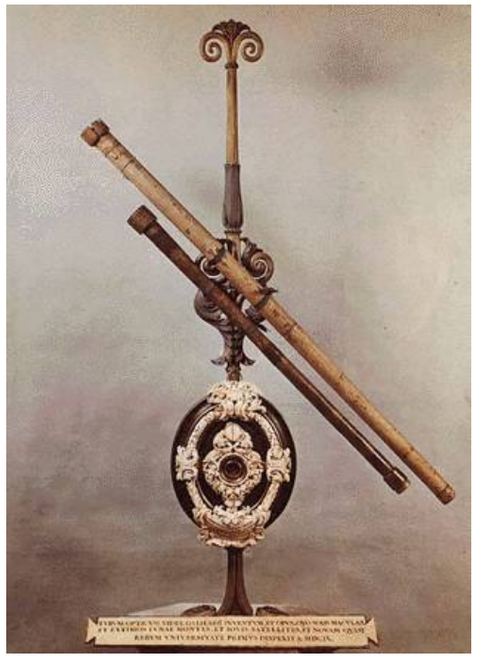


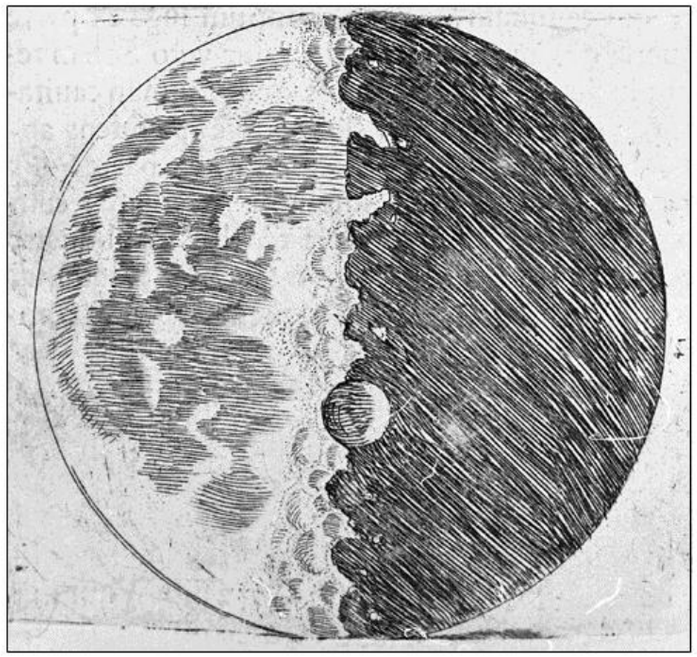




http://www.flickr.com/photos/fei_company/

Too far: telescope



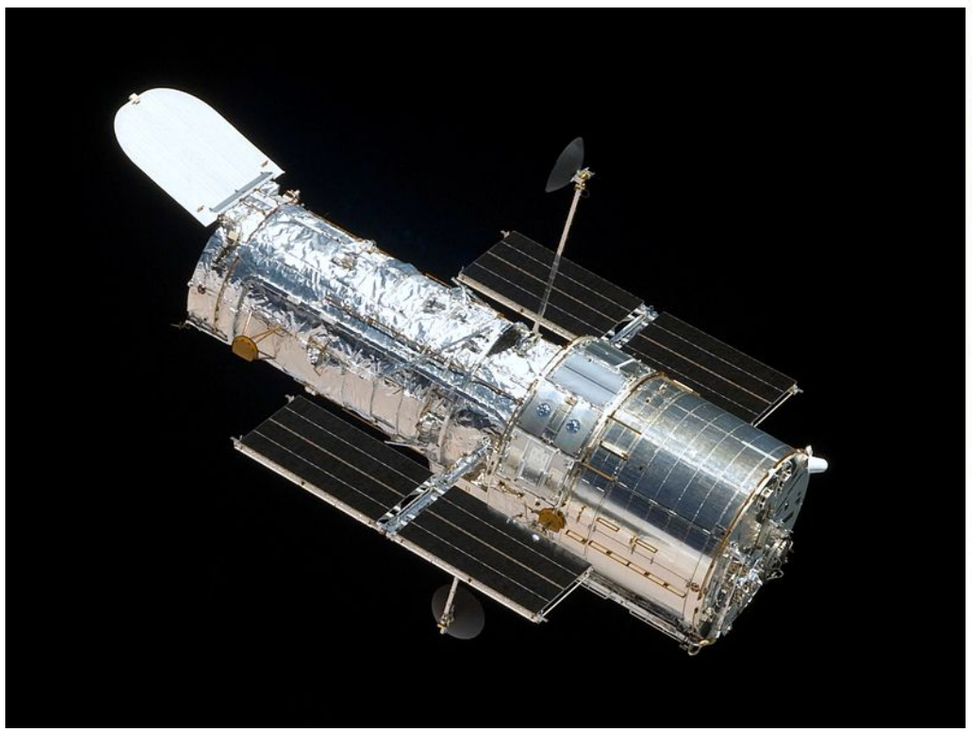






http://www.mhhe.com/physsci/astronomy/fix/student/chapter9/09f18.html

http://en.wikipedia.org/wiki/Telescope







Wide Field Planetary Camera 1

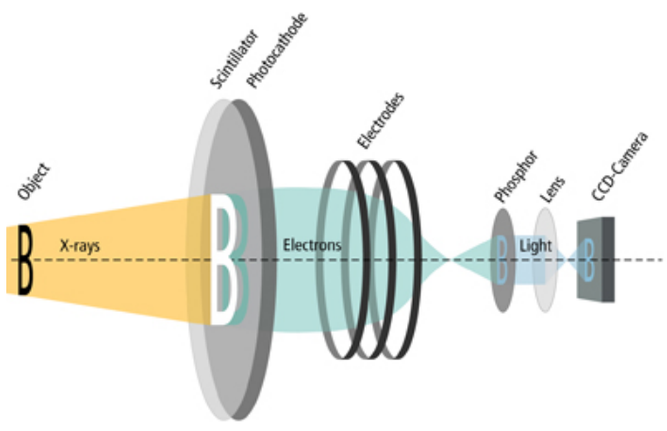
Wide Field Planetary Camera 2

http://en.wikipedia.org/wiki/Hubble_Space_Telescope

Too dark: Night vision

- **Image intensifier**
  - convert low levels of light from various wavelengths into visible quantities of light at a single wavelength.
- **Also active solutions**







http://www.phoenix-xray.com/en/company/technology/principles_of_operation/principle_050.htmlhttp://en.wikipedia.org/wiki/Night_vision

Too dark: Night photography

- The sensitivity of Digital sensors is revolutionizing night photography

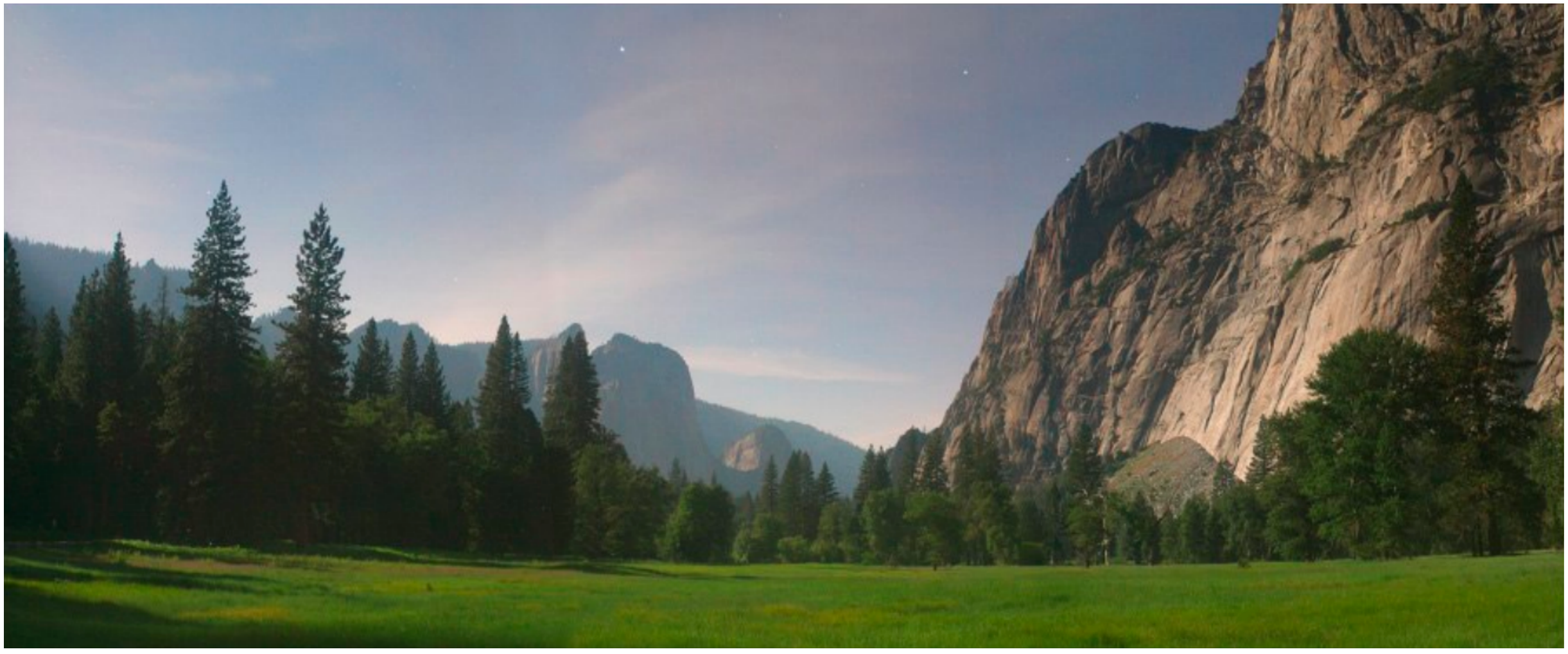
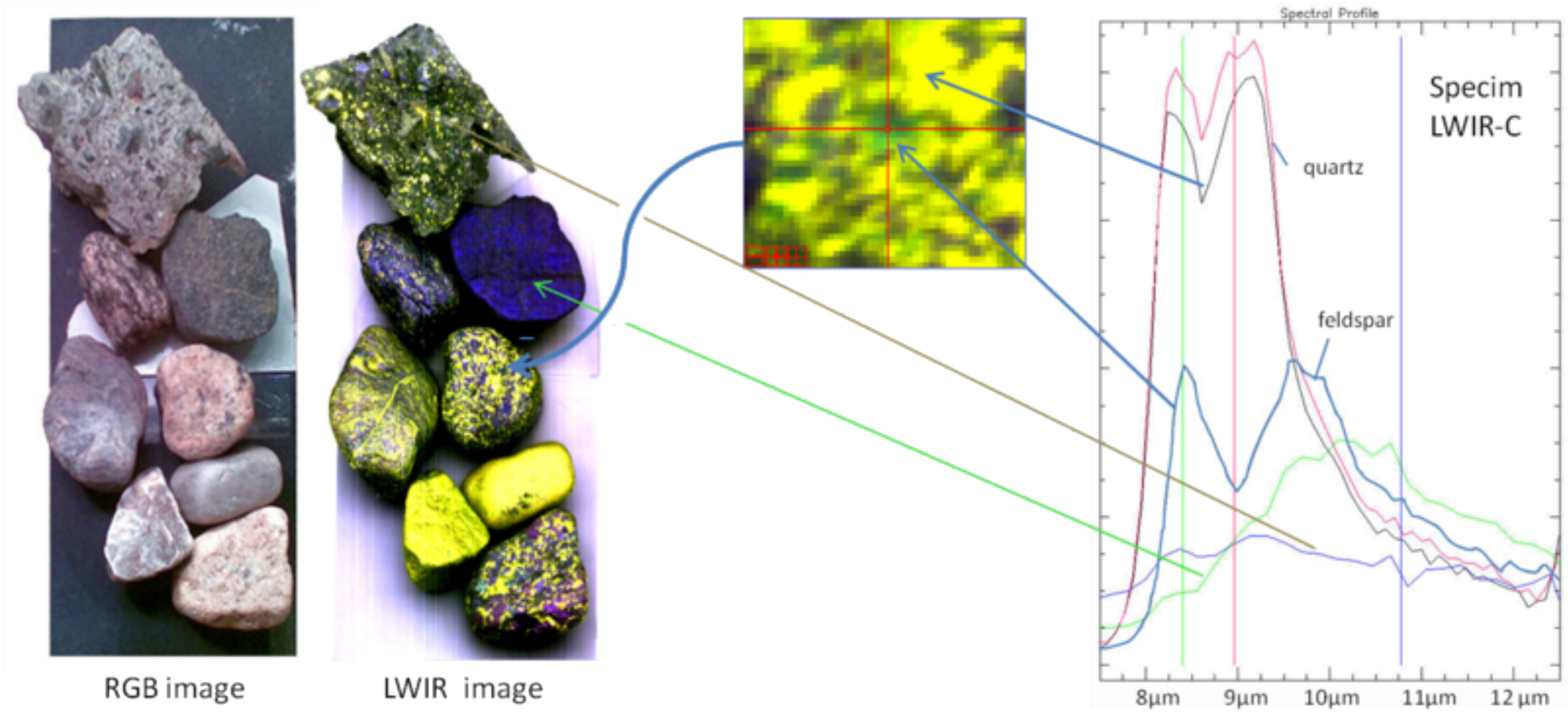


Image Jesse Levinson
Canon 10D, 28mm f/4, 3 min, ISO 100, 4 image pano

http://graphics.stanford.edu/courses/cs178-10/lectures/astrophotography-27apr10-150dpi-med.pdf

Hyperspectral

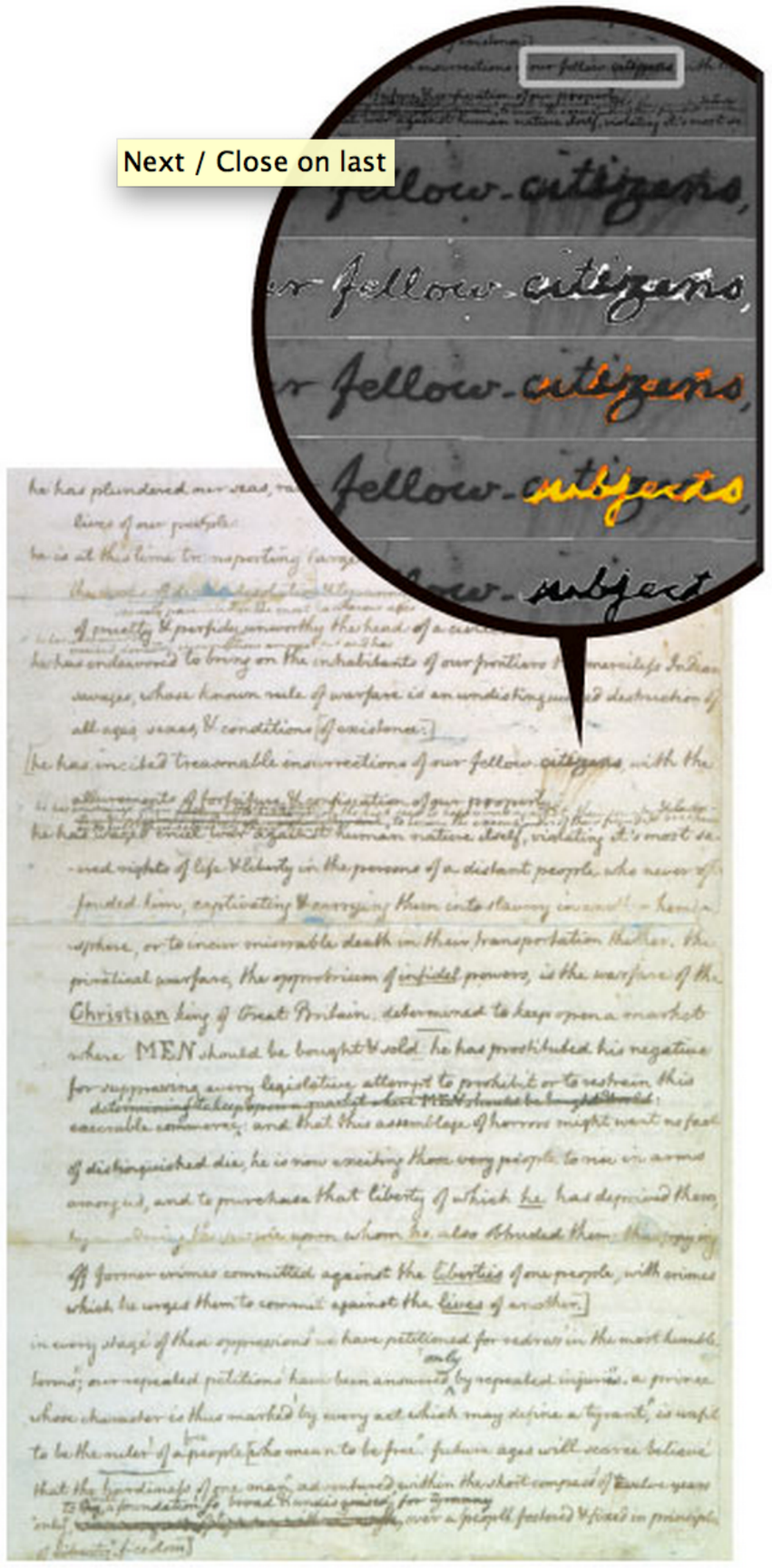


A set of stones is scanned with a Specim LWIR-C imager in the thermal infrared range from 7.7 µm to 12.4 µm. The quartz and feldsparspectra are clearly recognizable.

http://en.wikipedia.org/wiki/Hyperspectral_imaging

Hyperspectral

- Jefferson's revision of "subjects" to "citizens" in the Declaration of Independence is revealed through hyperspectral imaging

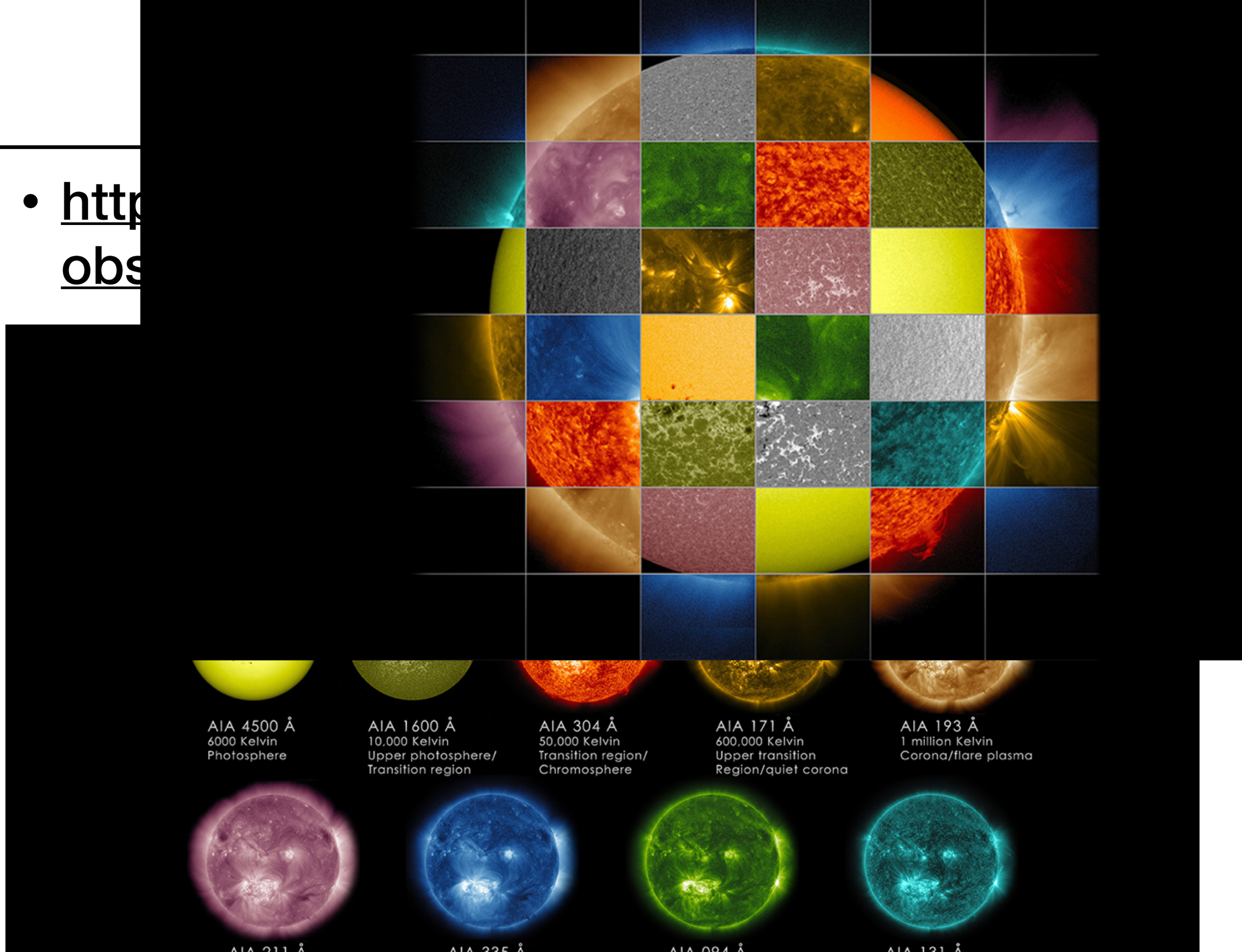




http://megavision-international.com/

http://www.americanphotomag.com/article/2012/07/chasing-invis

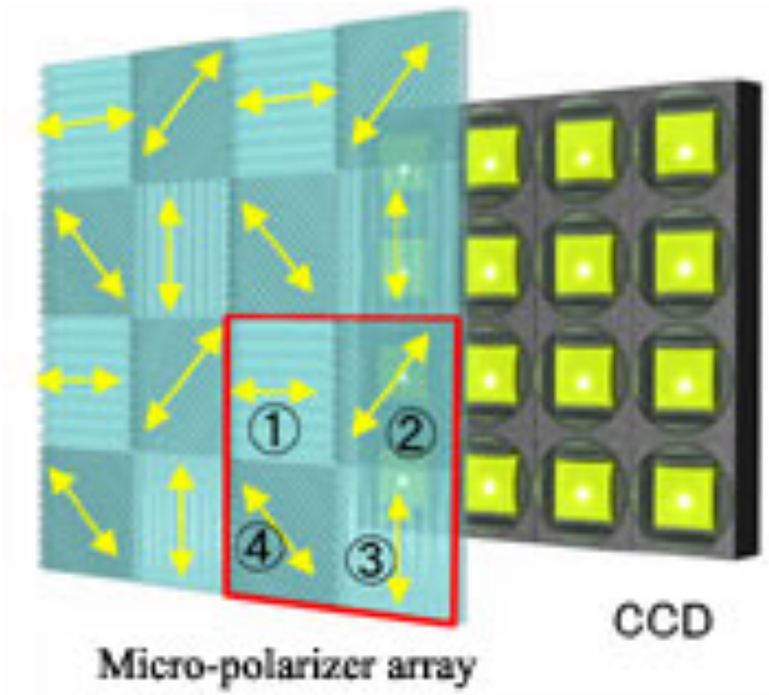
- http
obs

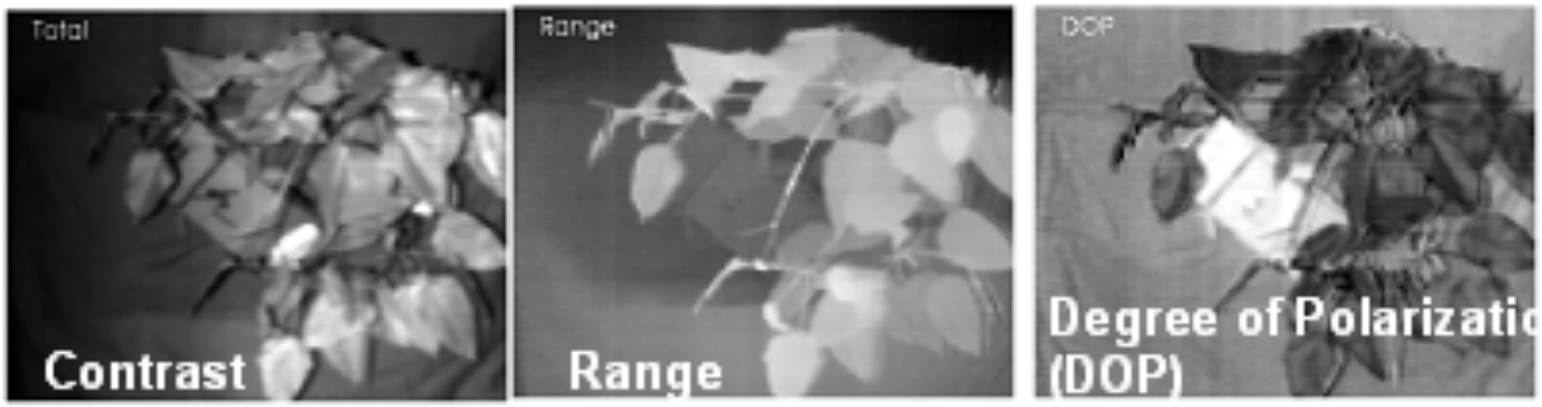

AIA 4500 Å
6000 Kelvin
Photosphere
AIA 1600 Å
10,000 Kelvin
Upper photosphere/
Transition region
AIA 304 Å
50,000 Kelvin
Transition region/
Chromosphere
AIA 171 Å
600,000 Kelvin
Upper transition
Region/quiet corona
AIA 193 Å
1 million Kelvin
Corona/flare plasma
AIA 211 Å
AIA 335 Å
AIA 094 Å
AIA 131 Å

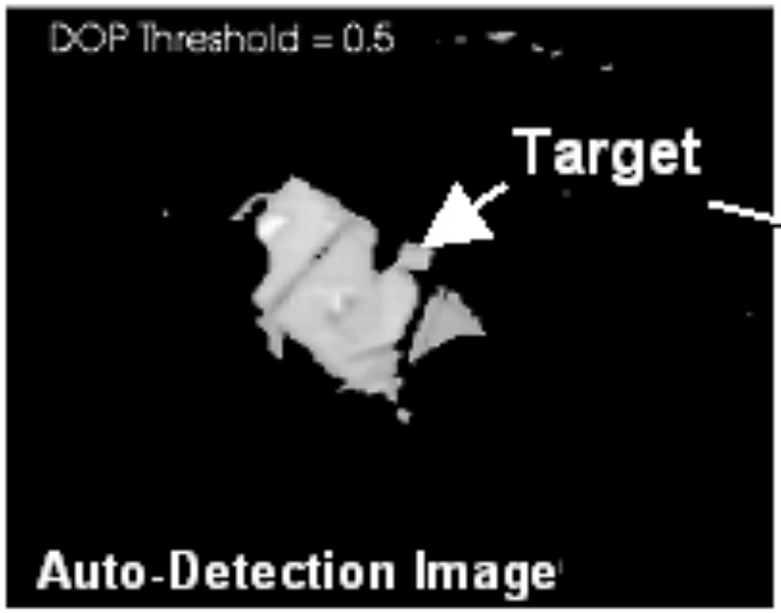
- http://o2amp.com/

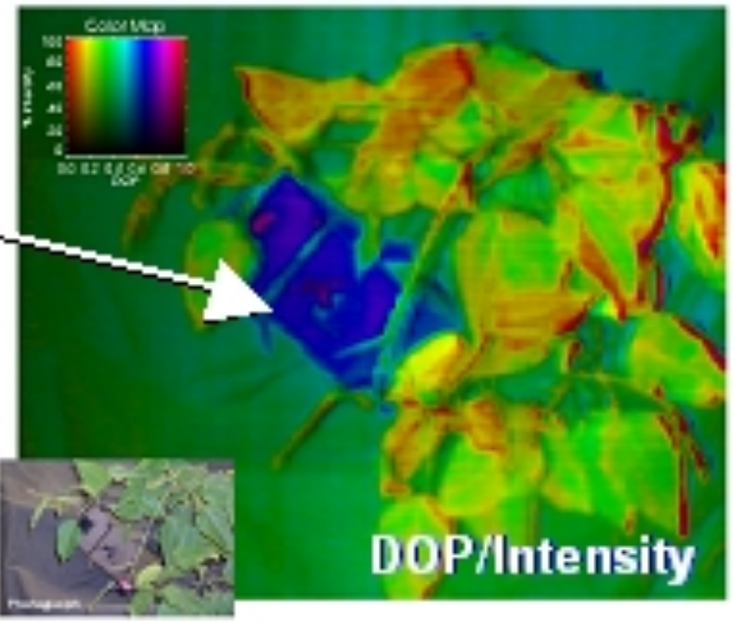


Polarization









http://www.photonic-lattice.com/en/Pol_Camera1.html

http://www.arete.com/arete_innovation/multislit_stil.aspx

Polarization

Segmentation with Invisible Keying Signal. Moshe Ben-Ezra

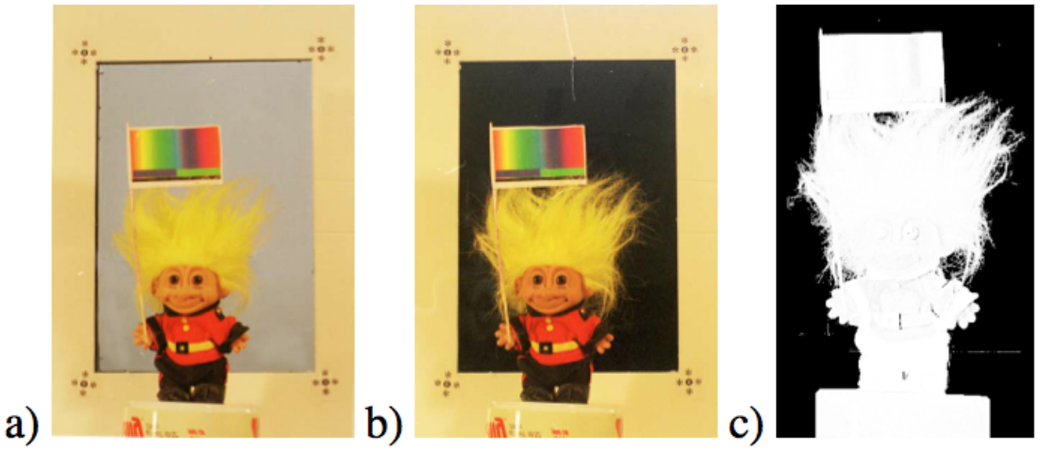




Figure 9. Object with fine details test. (The markers at the corners of the frame were used for alignment). a) "In-phase image" the background appear as light gray. a) "Out-of-phase image" the background appear as black. c) Produced matte. d) Compositing the doll image over a scenic image - fine details like hairs are visible and integrate well into the background.

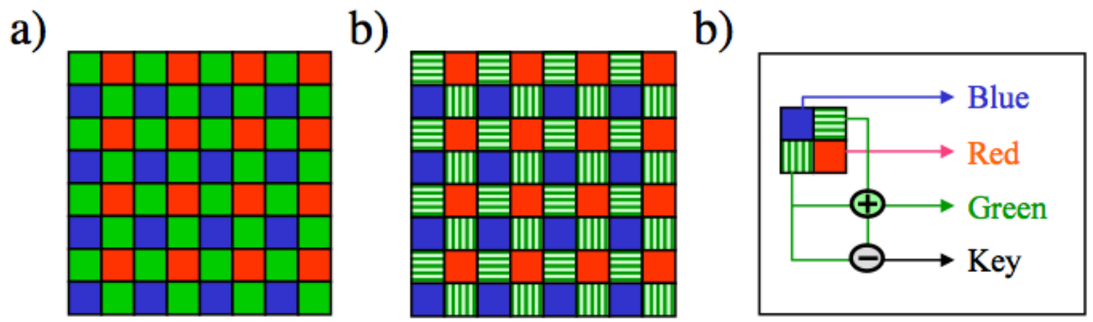


Figure 10. Proposed single chip sensor layout a) Conventional CCD/CMOS sensor layout. Pixels are covered with micro-filters. The Green channel which is the most visible to the human eye has twice as much sub-pixels as the blue and red channels. b) Proposed layout - The green pixels have complement pair of filters. c) Channel setup - The foreground image is generated as usual, for example average of the two green sub-pixels. The keying channel is produces by taking the absolute difference between the two green sub-pixels. This design is symmetric and it is orientation (landscape / portrait) invariant for polarized filters and rotation invariant for IR/UV filters.

Revealing relief that is too small

- Gel Sight, Johnson & Adelson



(a)



(b)

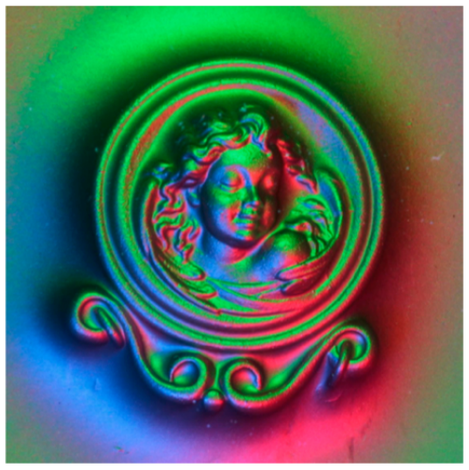


(c)

Figure 1. (a) A cookie is pressed against the skin of an elastomer block. (b) The skin is distorted, as shown in this view from beneath. (c) The cookie's shape can be measured using photometric stereo and rendered at a novel viewpoint.



(a)



(b)

Figure 2. (a) This decorative pin consists of a glass bas-relief portrait mounted in a shiny gold setting. (b) The RGB image provided by the retrographic sensor. The pin is pressed into the elastomer skin, and colored lights illuminate it from three directions.



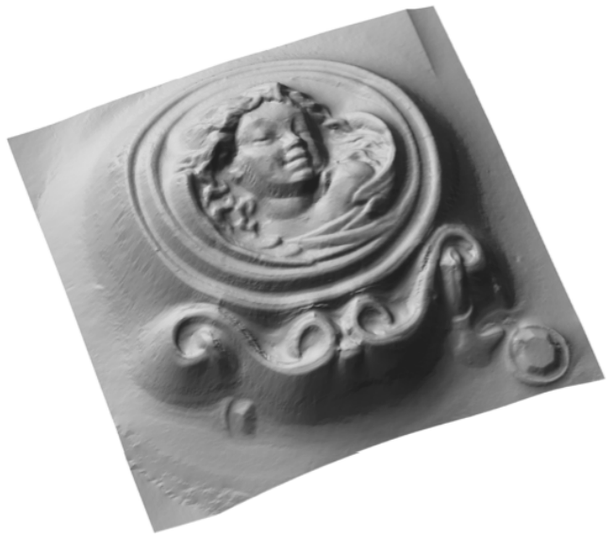


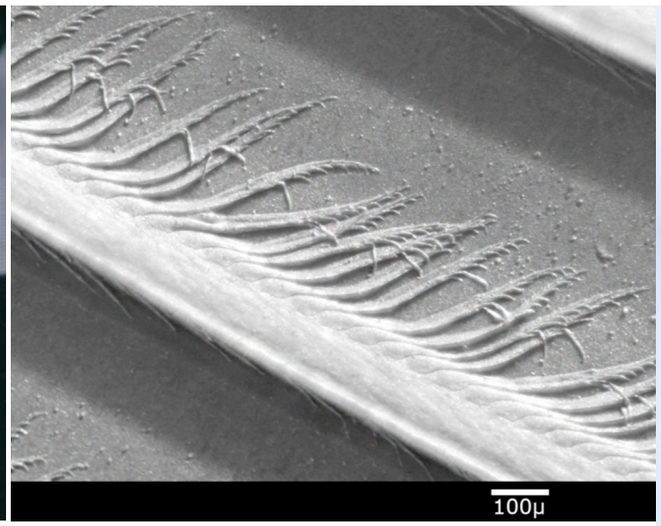
Figure 6. Two renderings of the acquired shape of a 1 cm decorative glass pin (see Fig. 2(a)).

http://www.mit.edu/~kimo/gelsight/

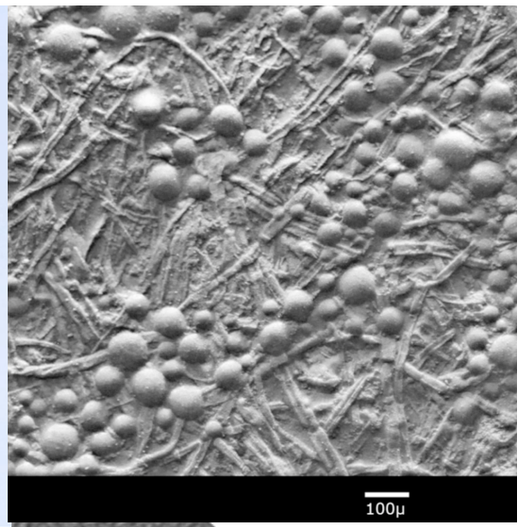
Revealing relief that is too small

- Gel Sight, Johnson & Adelson











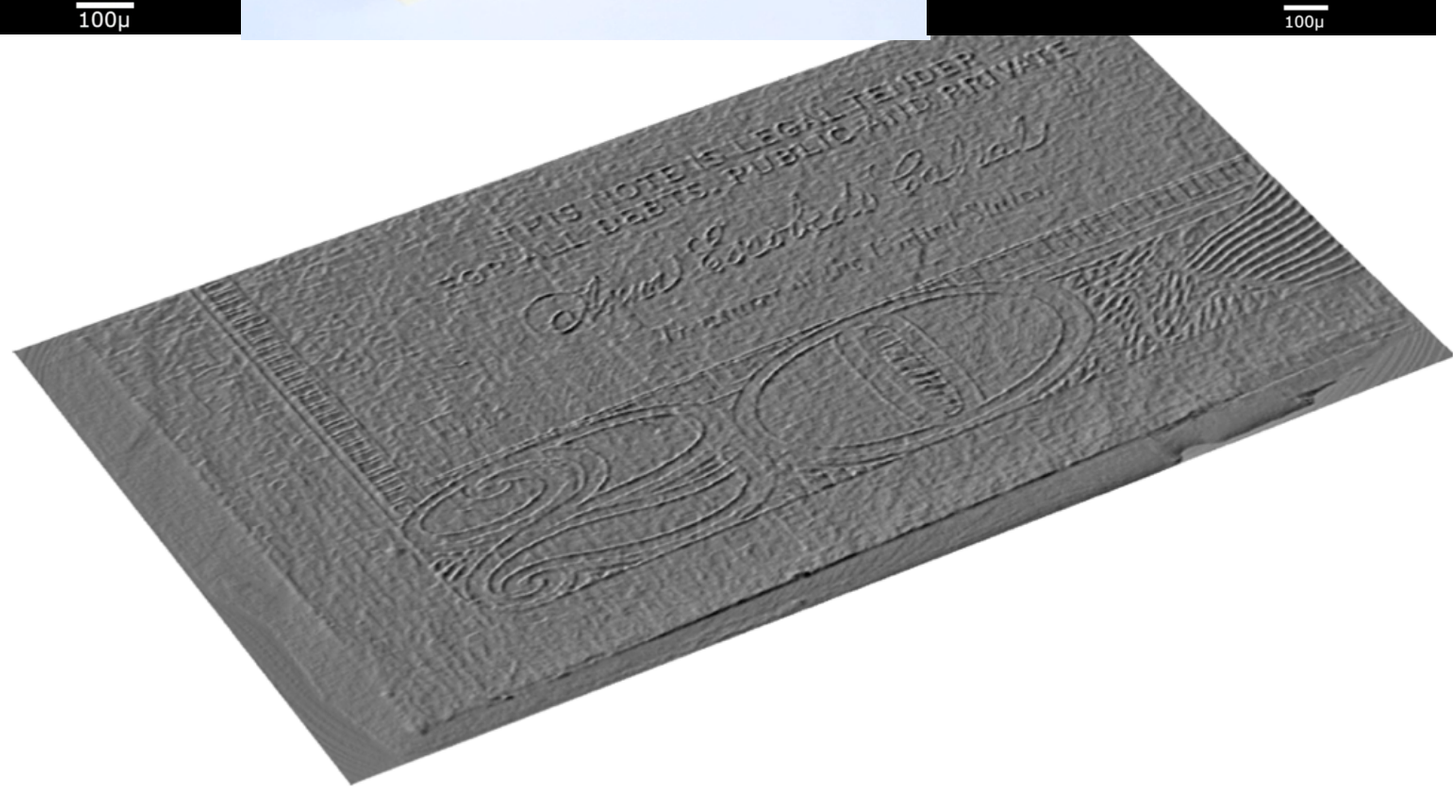


Figure 8. The corner of a twenty dollar bill. The ink is slightly raised, and the sensor is able to resolve this small difference in height, as shown by the reconstruction on the right.

http://www.mit.edu/~kimo/gelsight/

Revealing relief that is too small

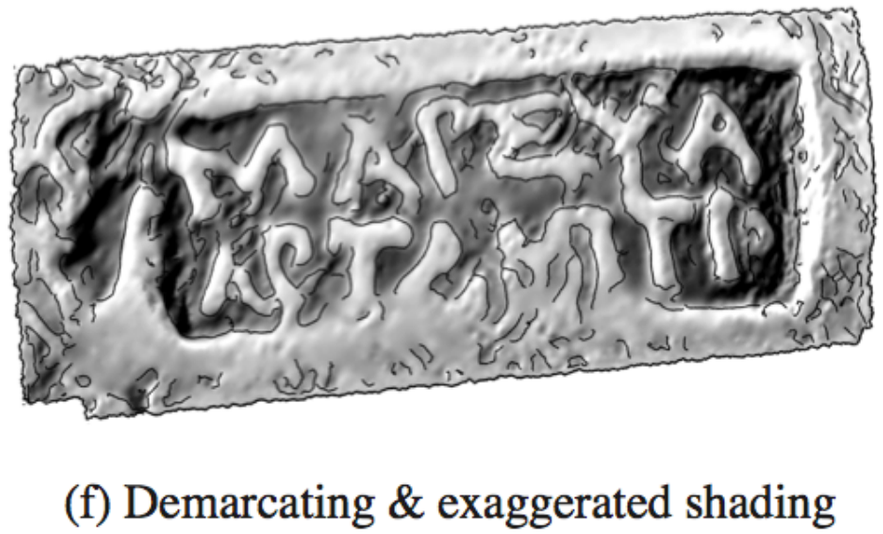
- Demarcating curves, Kolomenkin, Shimshoni, Tal



Original object



Demarcating (with mean curv. shading)



(f) Demarcating & exaggerated shading



Figure 10: A scanned Hellenistic stamped amphora handle from the first century BCE.

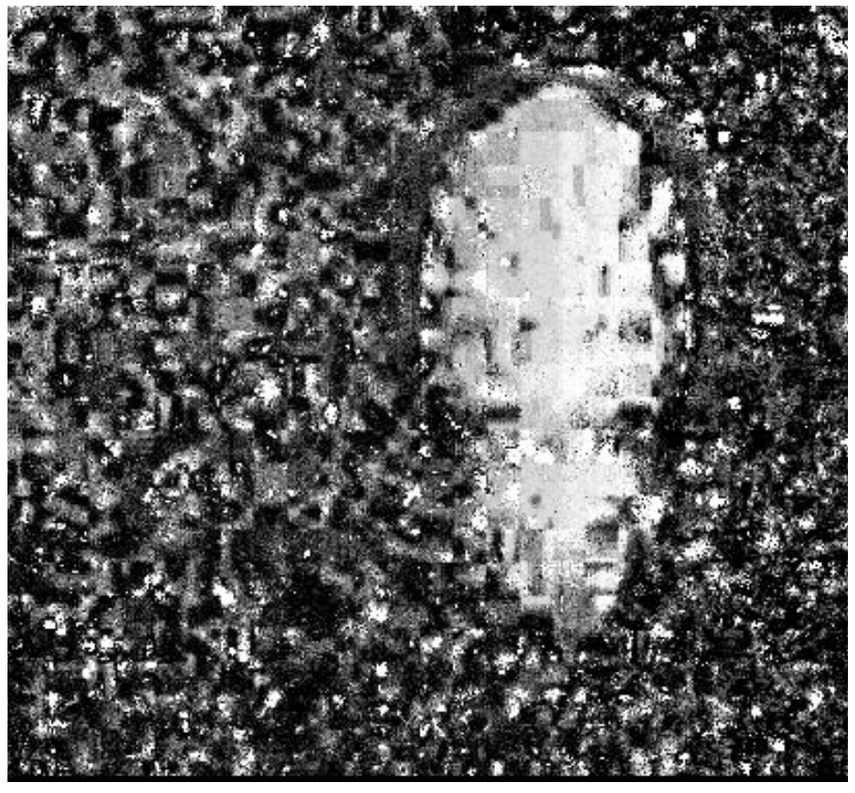
http://webee.technion.ac.il/~ayellet/Ps/08-KST.pdf

Too camouflaged

- Work by Derya Akkaynak Yellin (WHOI), in collaboration with Dr. Charlie Chubb (UCI)
- A camouflage breaking algorithm that requires no priors about the shape, shape, whereabouts of the camouflaged target

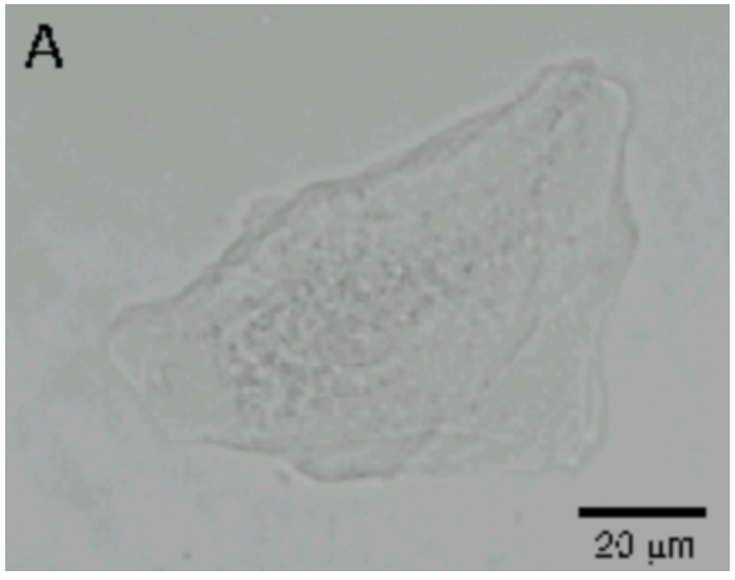


CATCH algorithm (based on color histograms)



Phase

- We see the amplitude of the EM field
- But some objects are mostly transparent and only affect phase (index of refraction)
- Especially small biological samples



Bright field image of human buccal epithelial cell
http://aups.org.au/Proceedings/34/121-127/

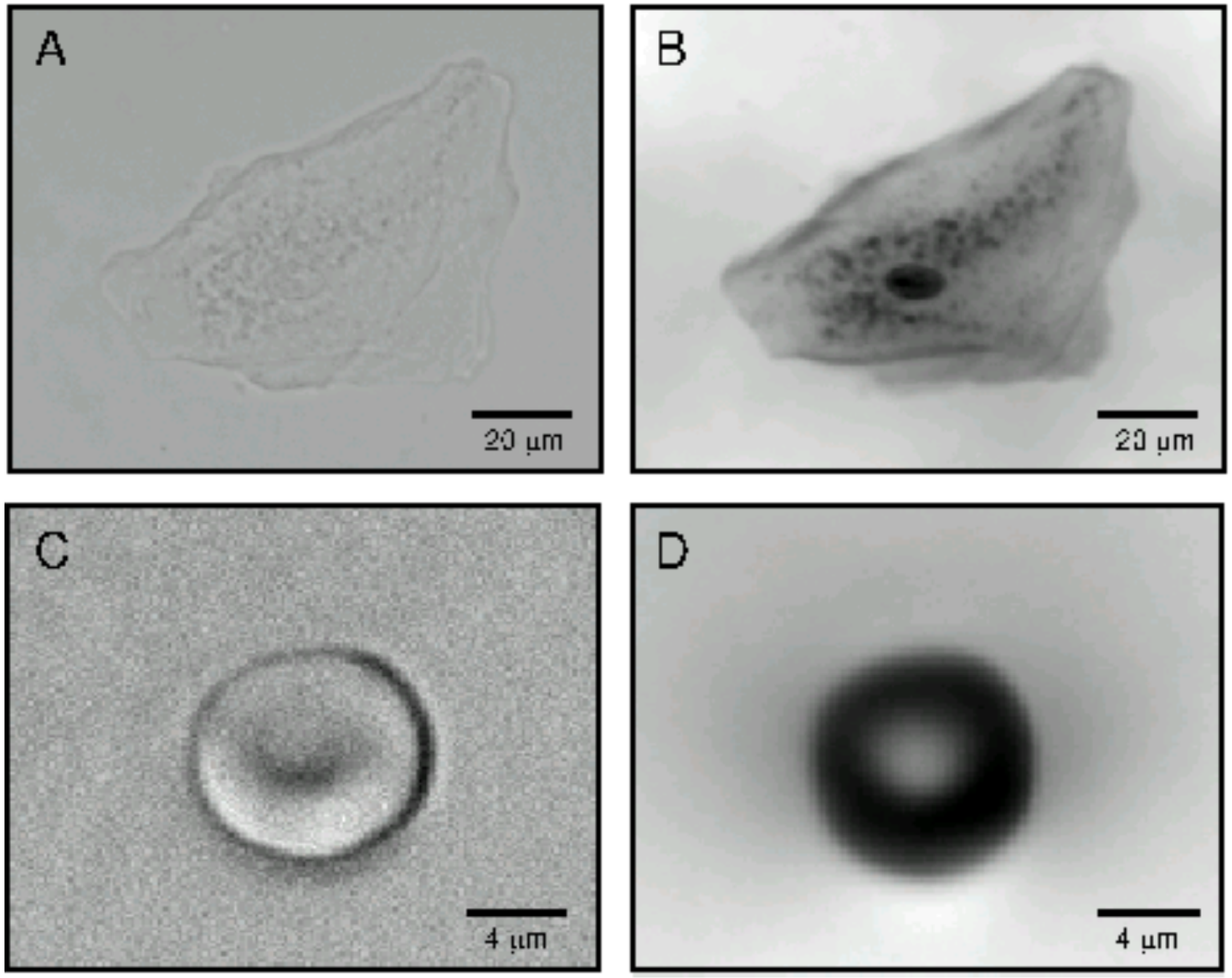
- Solution: exploit destructive interference when phase is shifted

Phase contrast microscope

- Zernike, (Nobel 1953)

Amplitude

Phase



Nobelprize.org
The Official Web Site of the Nobel Prize

MICROSCOPES BACK



The Phase Contrast Microscope

The phase contrast microscope is widely used for examining such specimens as biological tissues. It is a type of light microscopy that enhances contrasts of transparent and colorless objects by influencing the optical path of light. The phase contrast microscope is able to show components in a cell or bacteria, which would be very difficult to see in an ordinary light microscope.



Preparation of Specimen »

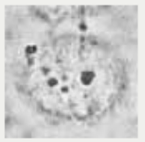


Photo Gallery »



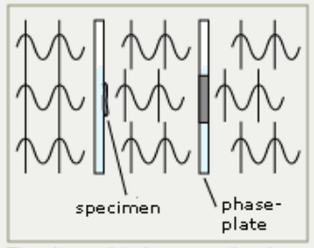
Try the Simulator! »
You need Macromedia Shockwave Player 8.5 to drive the microscope. Go to the help page to download the plug-in.

Altering the Light Waves

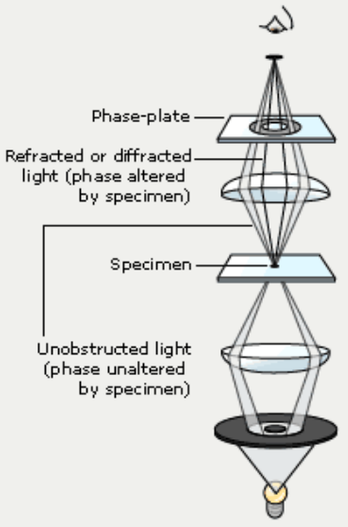
The phase contrast microscope uses the fact that the light passing trough a transparent part of the specimen travels slower and, due to this is shifted compared to the uninfluenced light. This difference in phase is not visible to the human eye. However, the change in phase can be increased to half a wavelength by a transparent phase-plate in the microscope and thereby causing a difference in brightness. This makes the transparent object shine out in contrast to its surroundings.

The Invisible Can Be Seen

The phase contrast microscope is a vital instrument in biological and medical research. When dealing with transparent and colorless components in a cell, dyeing is an alternative but at the same time stops all processes in it. The phase contrast microscope has made it possible to study living cells, and cell division is an example of a process that has been examined in detail with it. The phase contrast microscope was awarded with the Nobel Prize in Physics, 1953.



The phase-plate increases the phase difference to half a wavelength. Destructive interference between the two sorts of light when the image is projected results in the specimen appearing as a dark object.





Related Laureate:
The Nobel Prize in Physics, 1953
- Frits (Frederik) Zernike »

Light field camera for phase

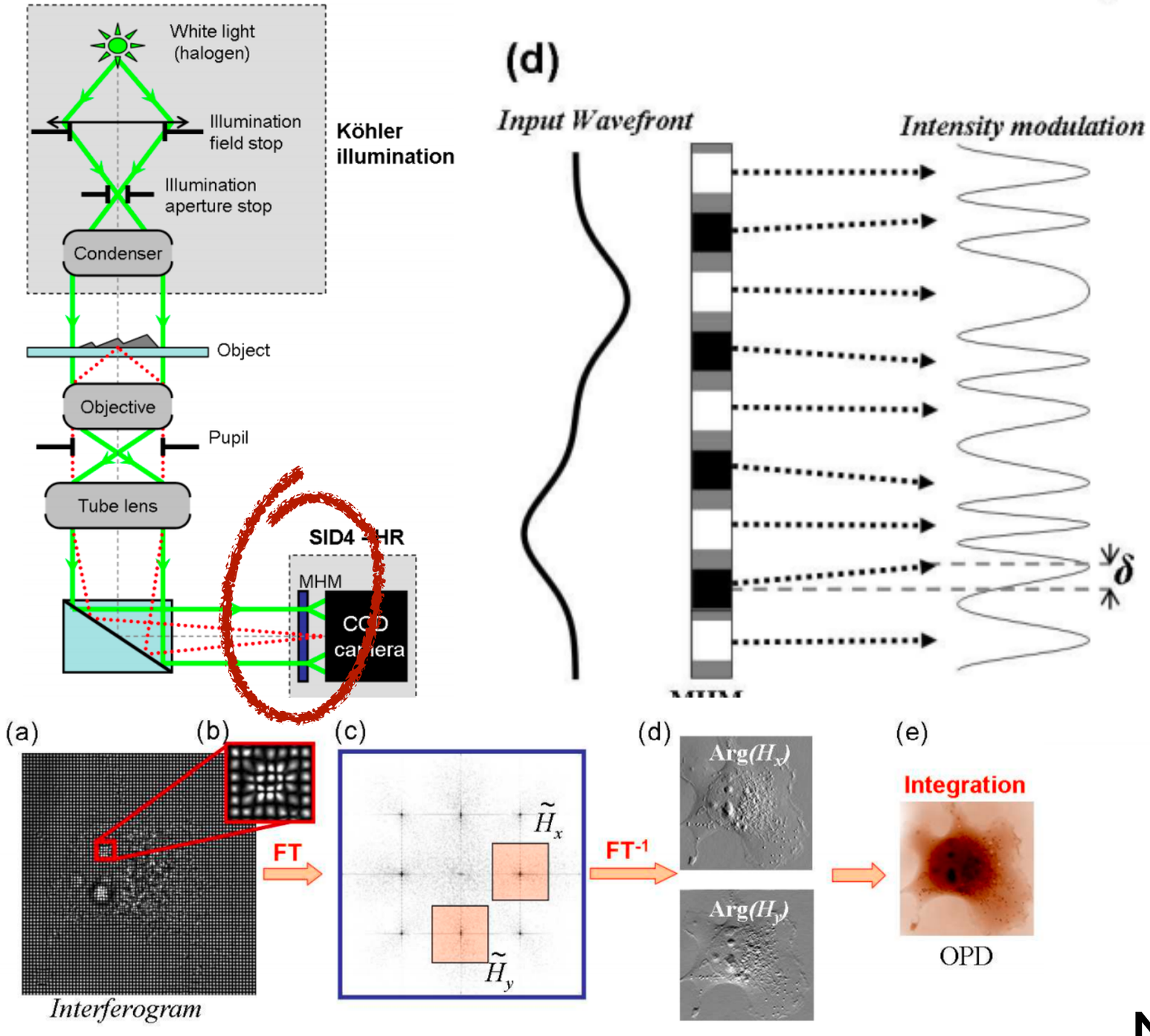


Fig. 3. (a) Interferogram obtained with an aberrant wavefront. (b) Zoom on a part of (*a*), visualization of the local frequency modulations. (c) Fourier Transform of (*a*). (d) Obtaining of 2 OPD orthogonal gradients by Inverse Fourier Transform of 2 sub-images of (*b*). (e) 2D Integration of the gradients to reconstruct the OPD.

Quadriwave lateral shearing interferometry for quantitative phase microscopy of living cells Pierre Bon. Guillaume Maucort. Benoit Wattellier and Serge Monneret

Revealing Ghosts and Spirits



One of Mumler's most famous images, purportedly showing Mary Todd Lincoln with the ghost of her husband,Abraham Lincoln.

http://en.wikipedia.org/wiki/Spirit_photography



The Ghost in the Stereoscope
Inspired by Brewster

http://www.photographymuseum.com/believe1.html

Revealing the undead

- Abe Davis

Digital Photography with Vampire and No-Vampire Image Pairs



Figure 1: *A vampire/no-vampire image pair taken using the proposed optical arrangement. One image with undead entities (left) and one without (middle) are obtained at the same time. We use the difference between these images to compute an approximate "vampire map." (right)*

http://people.csail.mit.edu/abedavis/Vamp.pdf

Revealing the undead

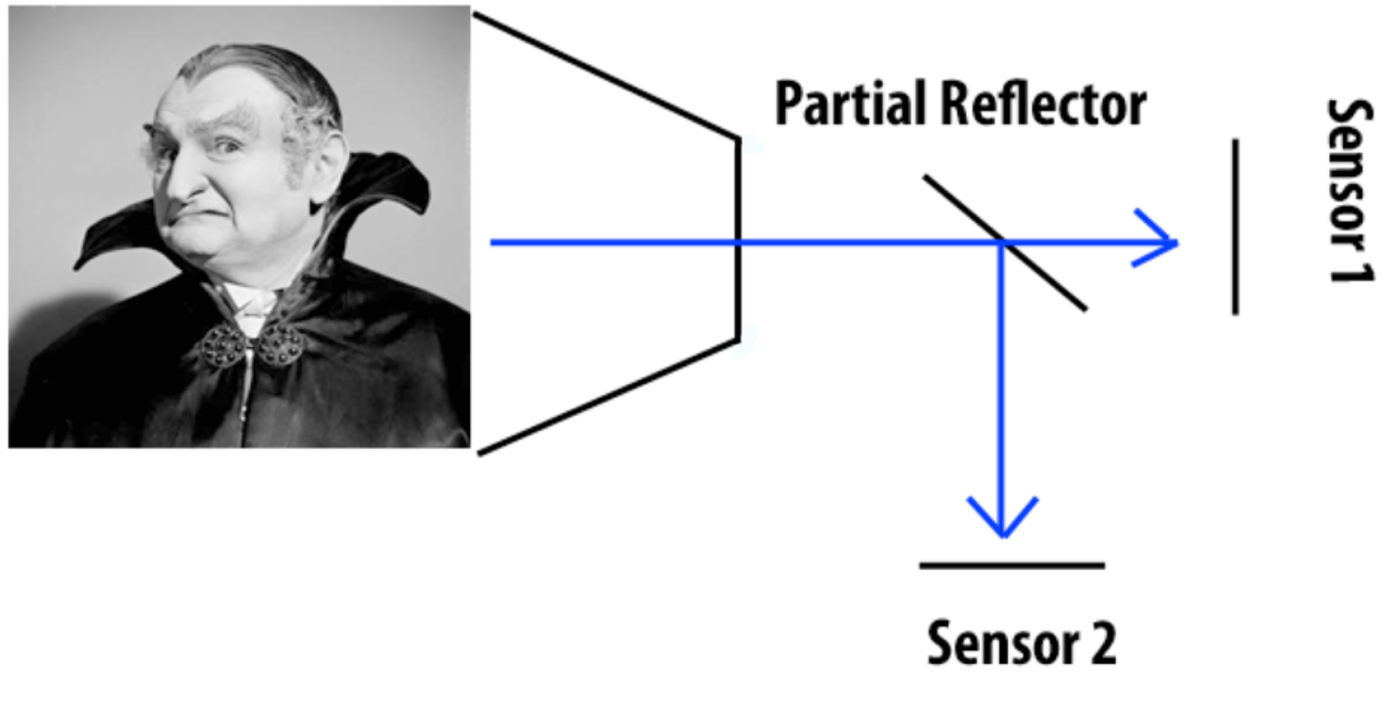
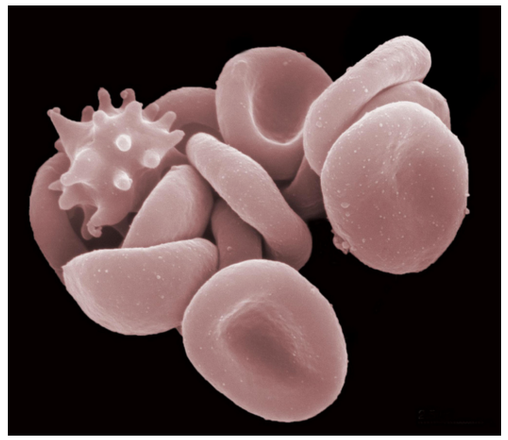


Figure 2: *Two Sensors are used to capture the same scene. One captures a reflected image of the other. The reflected light does not carry any image of undead entities.*



Recap: Beyond human capabilities

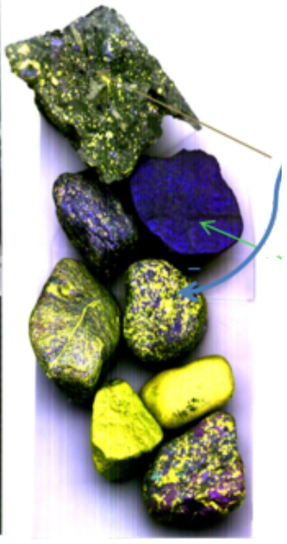
- Too small
- Too far
- Too dark
- Camouflaged
- Not RGB
- Polarized
- Too transparent

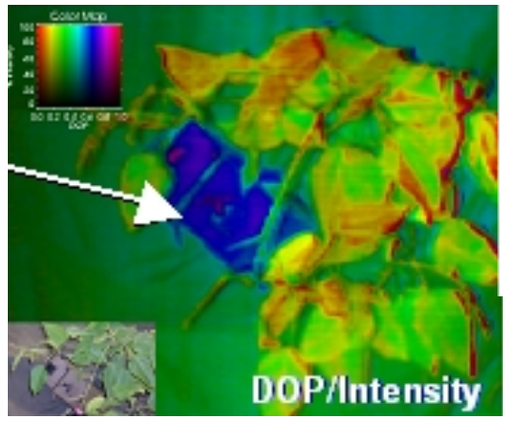




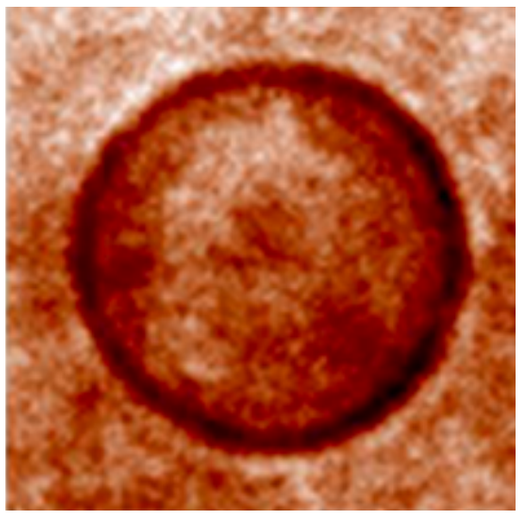










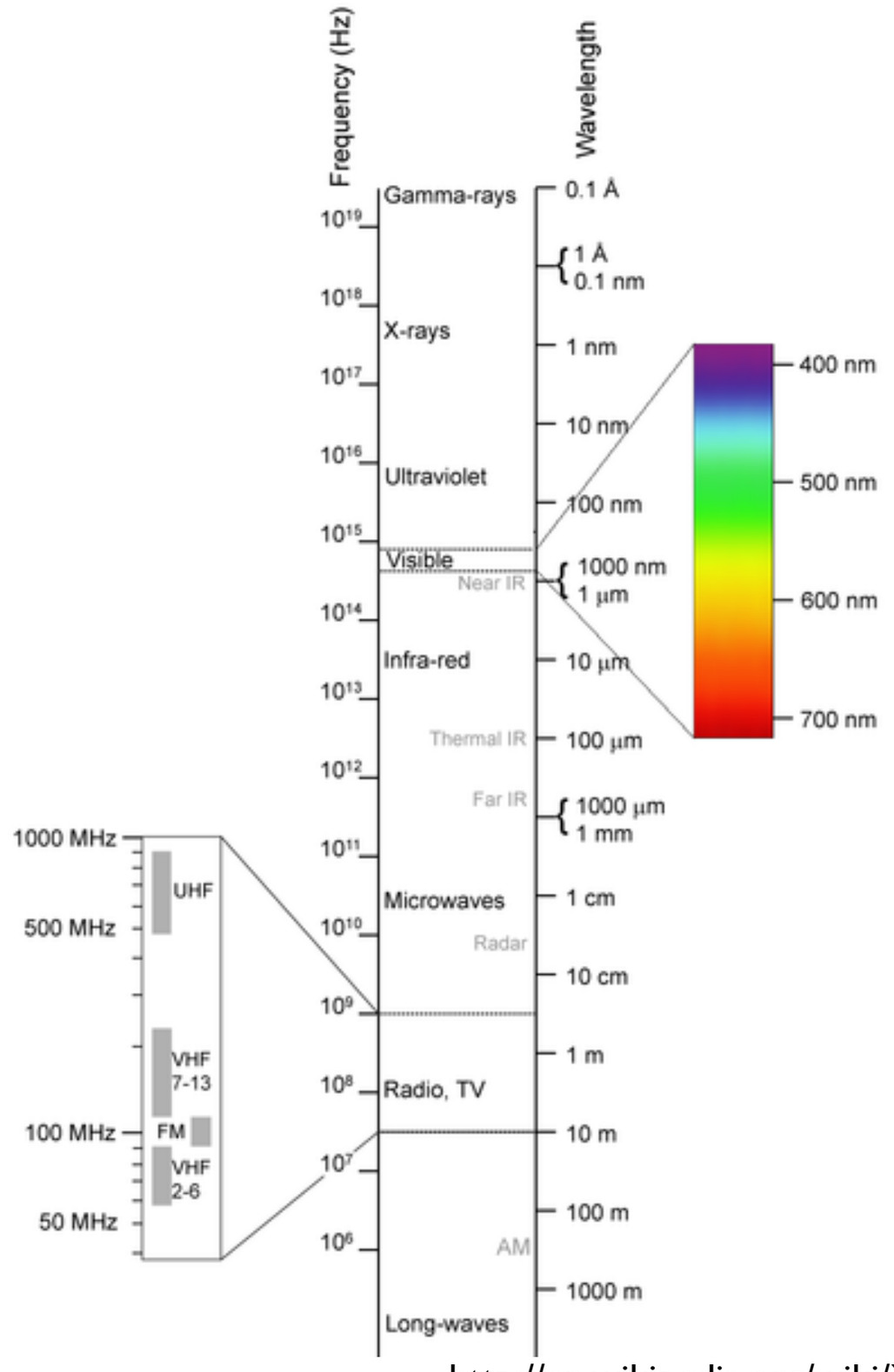


Overview

- Limits of human vision
- **Occlusion**
- Non-visual phenomena
- Non-visible visual phenomena
- Change and motion

X Ray

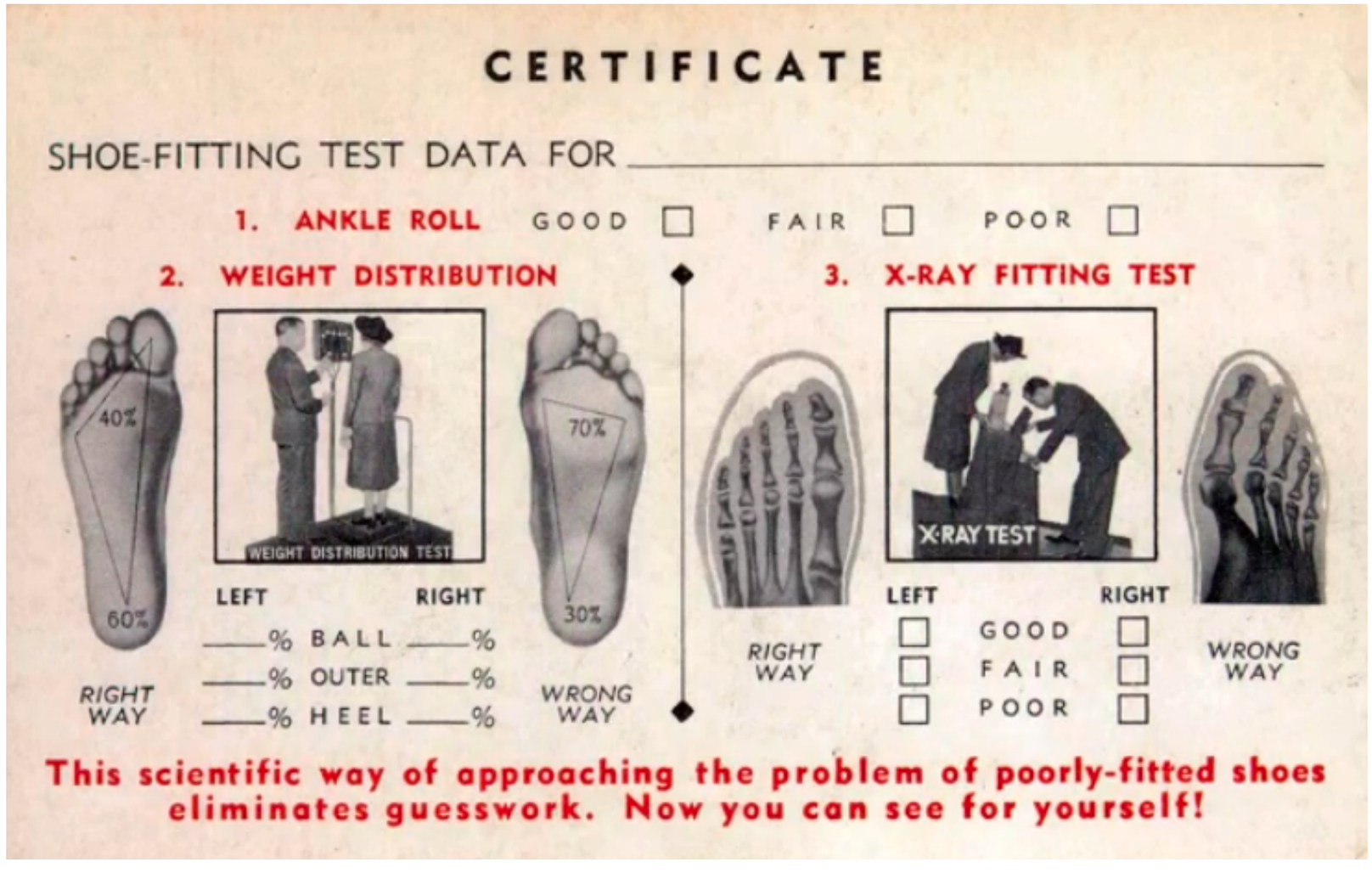




http://en.wikipedia.org/wiki/X-ray

Shoe fitting





http://en.wikipedia.org/wiki/Shoe-fitting_fluoroscope

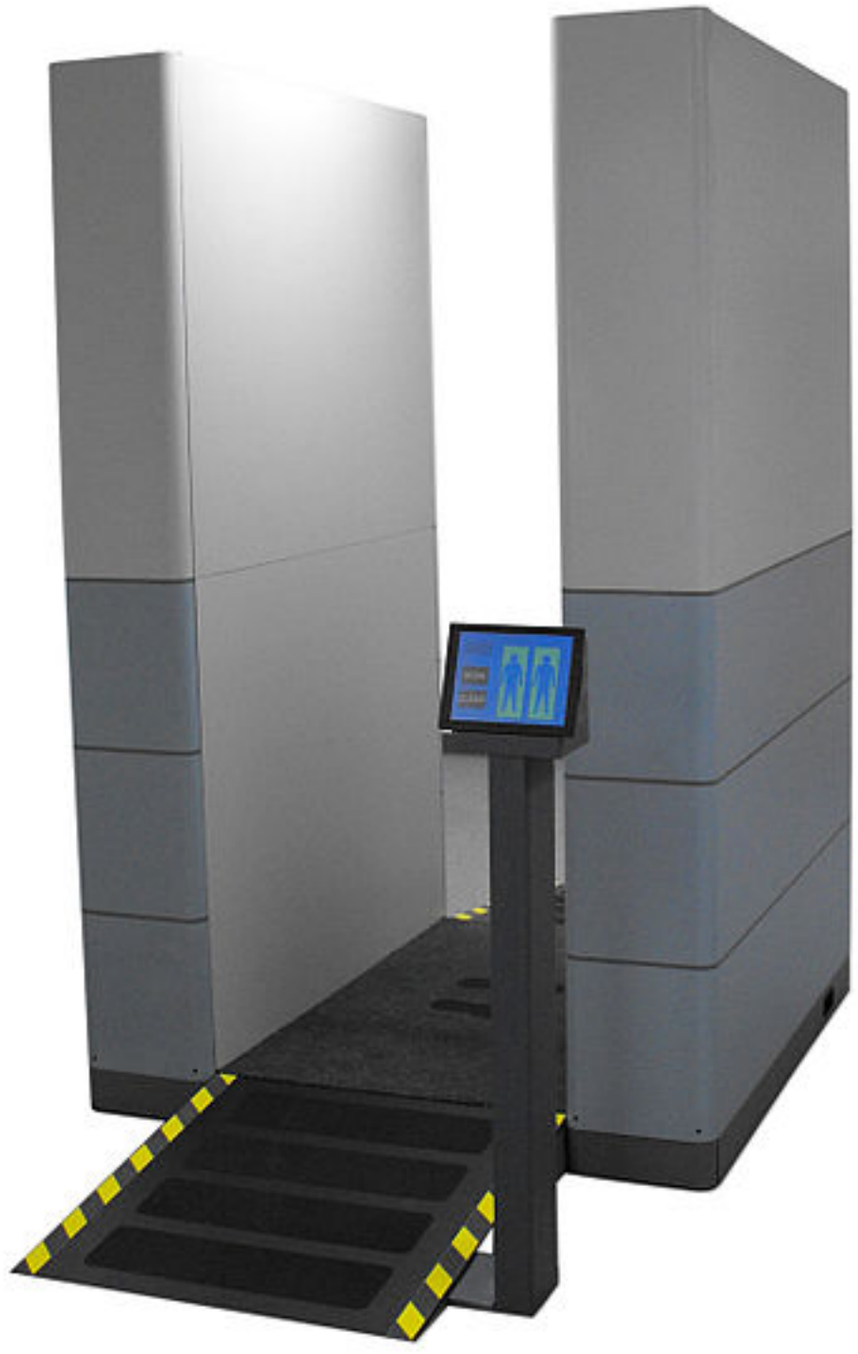
https://www.youtube.com/watch?feature=player_embedded&v=QVIEXd9w7vk#at=73

Sonogram

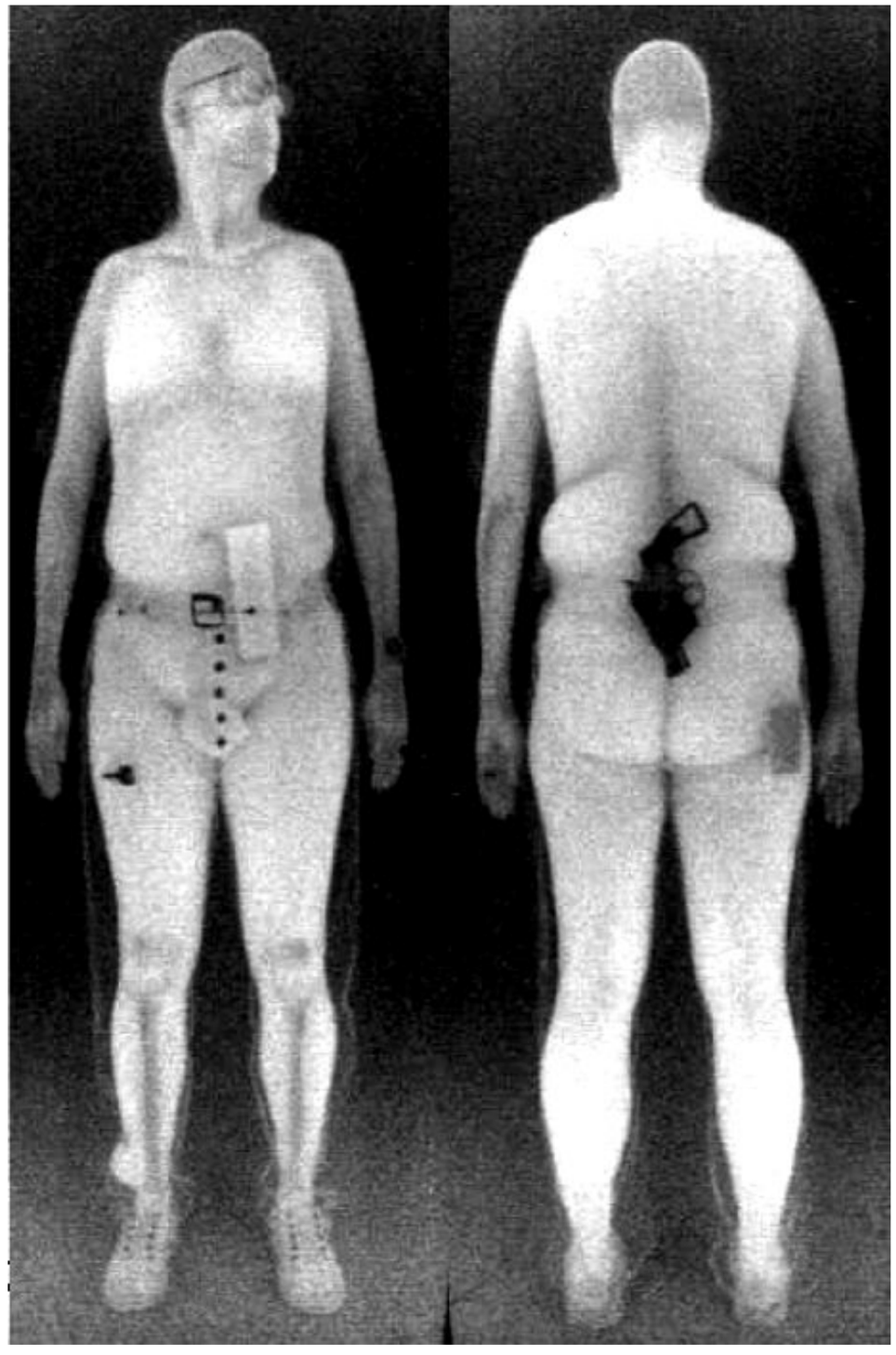


http://www.cbs19.tv/story/16897021/new-sonogram

Backscatter x ray



http://en.wikipedia.org/wiki/Backscatter_X-ray



http://compilerbitch.livejournal.com/218216.html

Analysis of paintings

- Scanning Macro X ray Fluorescence Spectrometry

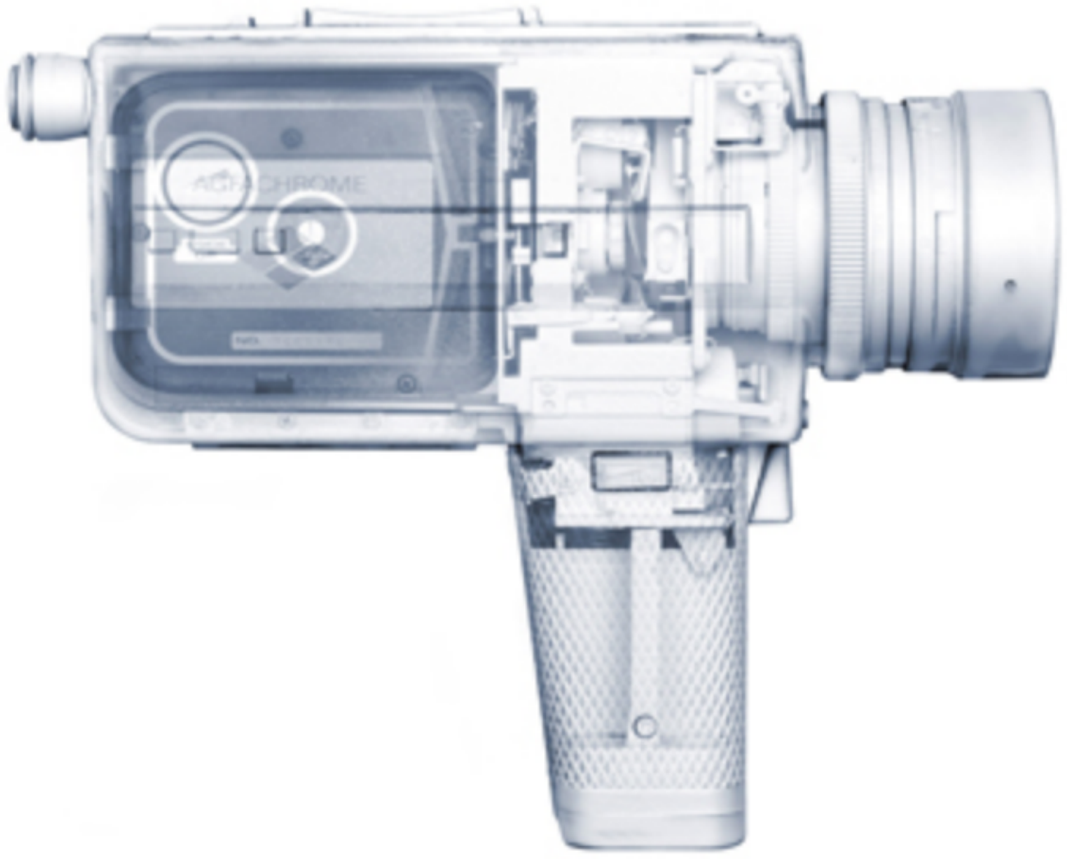


Francisco de Goya's Portrait of Don Ramon Statue (left) and the painting discovered underneath it

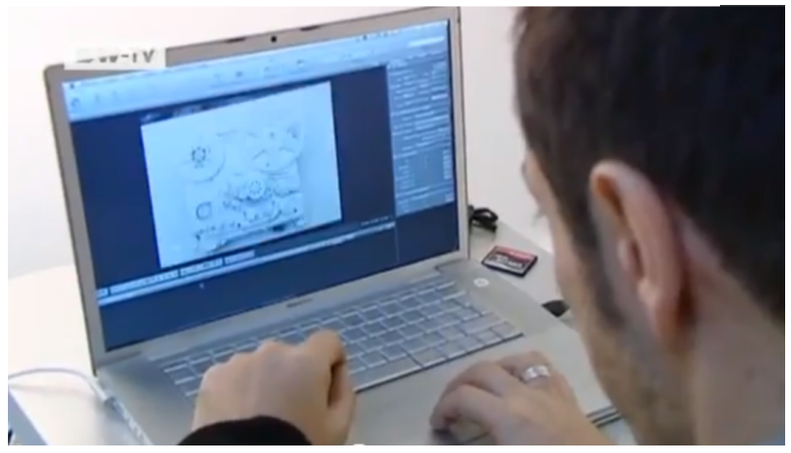
http://tudelft.nl/en/current/latest-news/article/detail/onbekend-portret-ontdekt-onder-meesterwerk-van-goya/

Fake Xray

- Max de Esteban's Proposition One
- Disassembled, spray-painted, multiple photos, layers in Photoshop







http://www.youtube.com/watch?feature=player_embedded&v=3NewEh0YQwk

http://www.maxphotos.es/

Synthetic aperture





(a) (b) (c)

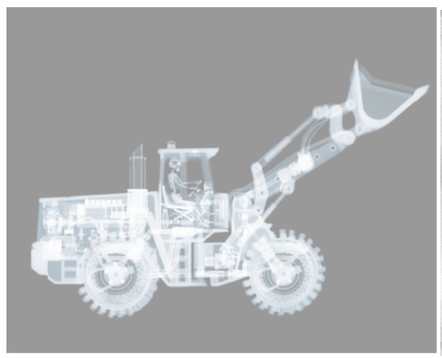
Figure 11: Matted synthetic aperture photography. (a) A sample image from one of 90 cameras used for this experiment. (b) The synthetic aperture image focused on the plane of the people, computed by aligning and averaging images from all 90 cameras as described in the text. (c) Suppressing contributions from static pixels in each camera yields a more vivid view of the scene behind the occluder. The person and stuffed toy are more clearly visible.

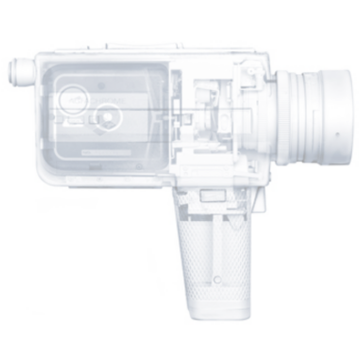
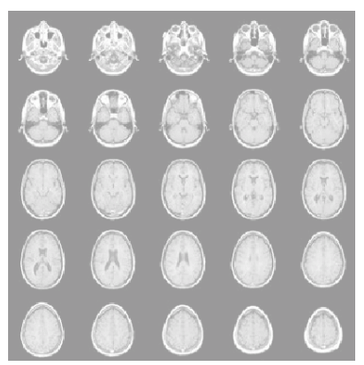
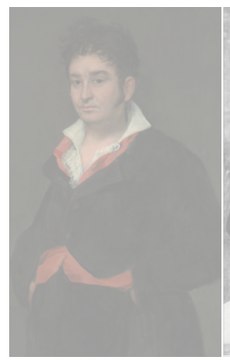
http://graphics.stanford.edu/papers/CameraArray/

Wire removal

Hidden things & occlusion

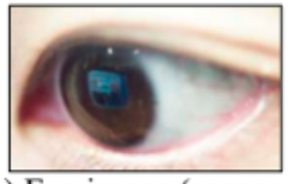
- Seeing inside objects



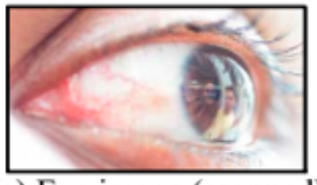






- Seeing beyond the field of view

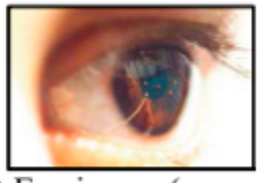
Reflection in an eye



(a) Eye image (cropped)



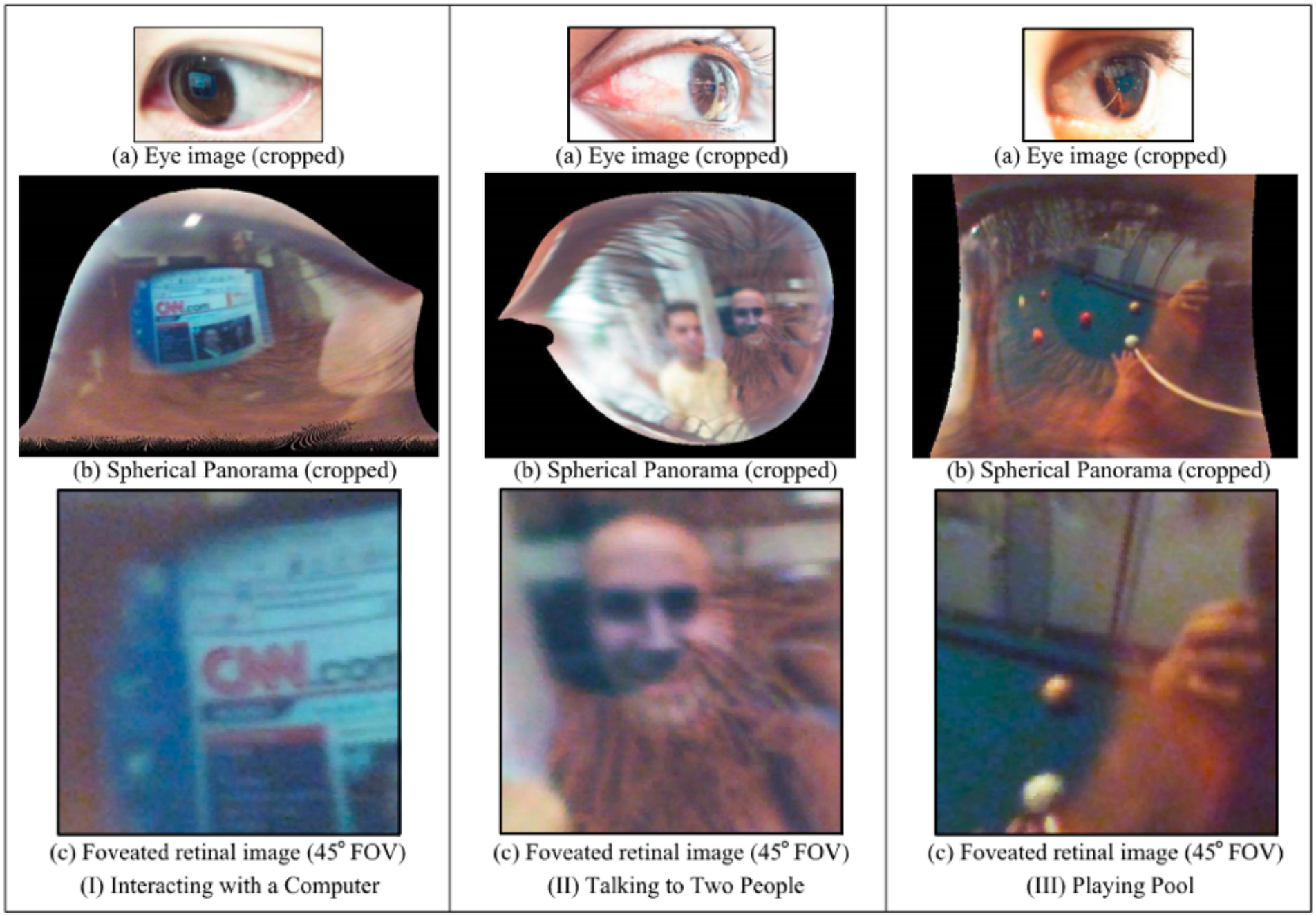
(a) Eye image (cropped)



(a) Eye image (cropped)

"The World in an Eye,"
K. Nishino and S.K. Nayar,
IEEE Conference on Computer Vision and Pattern Recognition (CVPR),
Vol.I, pp.444-451,
Jun, 2004.

Reflection in an eye

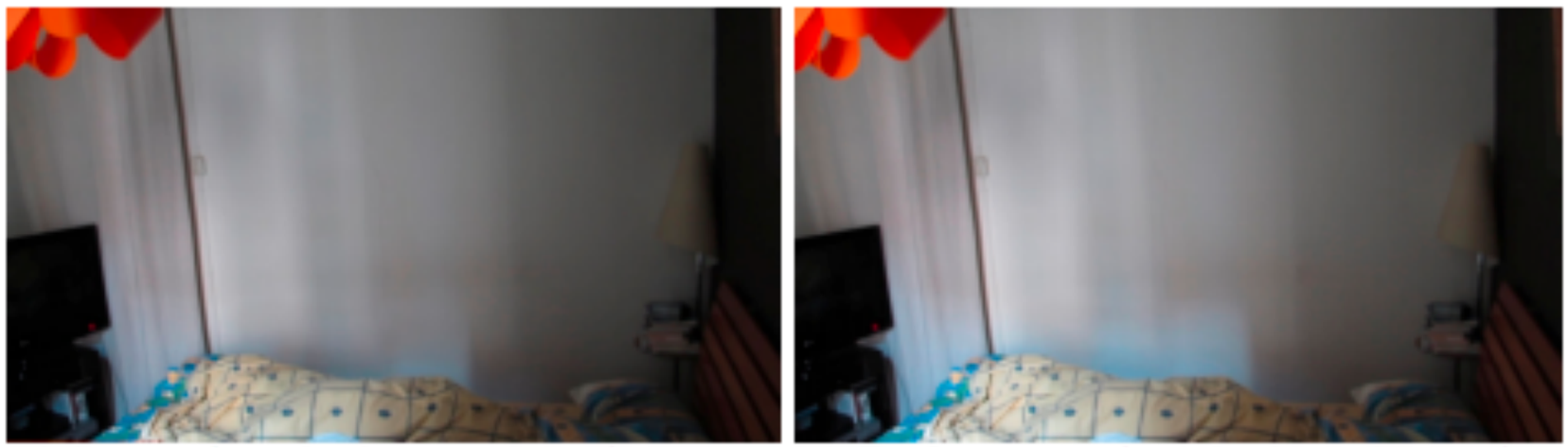


"The World in an Eye,"
K. Nishino and S.K. Nayar,
IEEE Conference on Computer Vision and Pattern Recognition (CVPR),
Vol.I, pp.444-451,
Jun, 2004.

Figure 10: Examples of spherical panoramas and foveated retinal images computed from images of eyes. Three different examples are shown. Each example includes (a) a cropped image of the eye, (b) a cropped image of the computed spherical panorama and (c) a foveated retinal image with a 45° field of view. The spherical panoramas and foveated retinal images clearly convey the world surrounding the person and what and where the person is looking at. This information can be used to infer the person's circumstance and intent.

Accidental pinhole and pinspeck cameras

- Torralba and Freeman, CVPR 2012



a) Input (occluder present) b) Reference (occluder absent)

- reconstruct scene outside field of view from multiple images with different occluders



Accidental pinhole and pinspeck cameras

- Torralba and Freeman, CVPR 2012

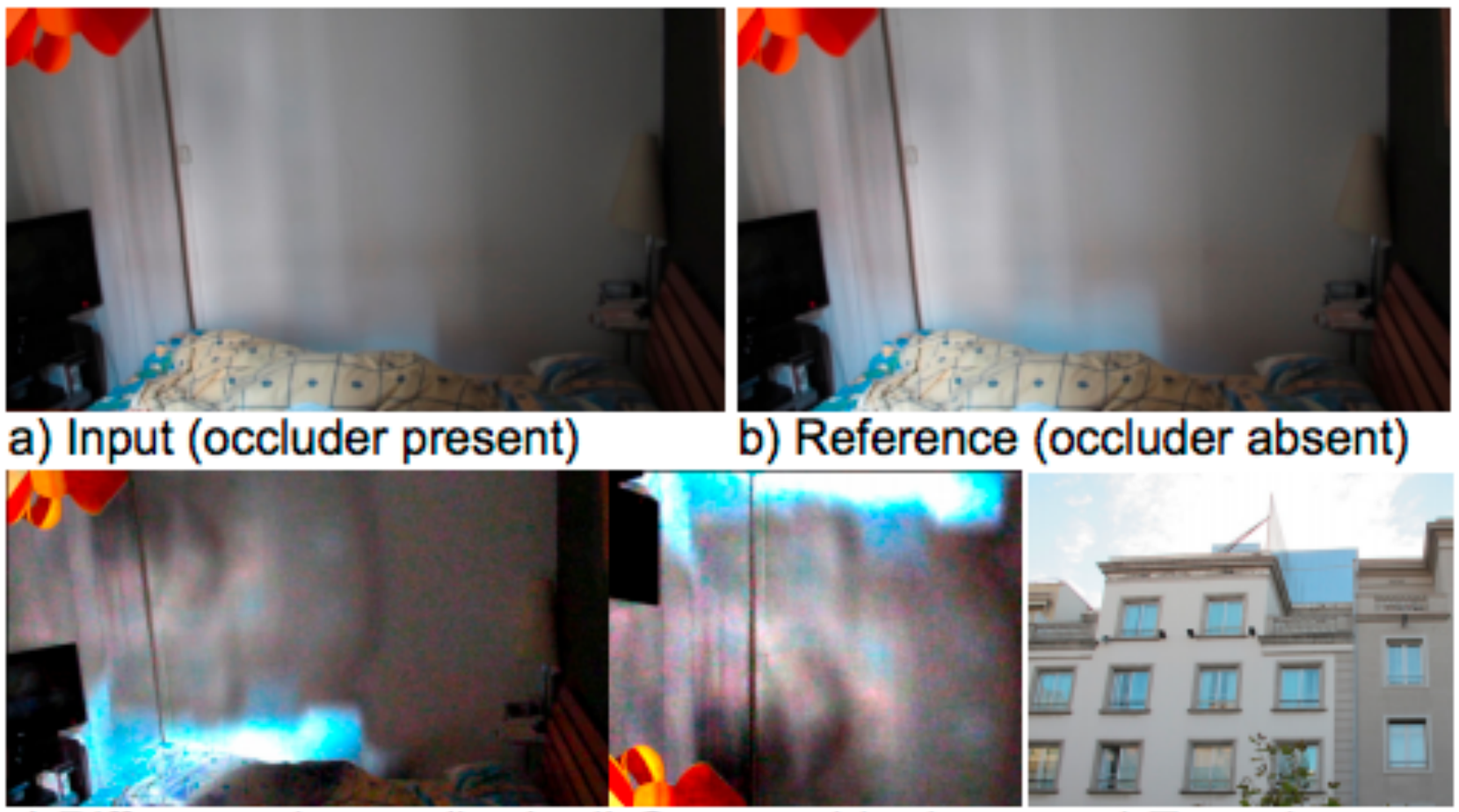
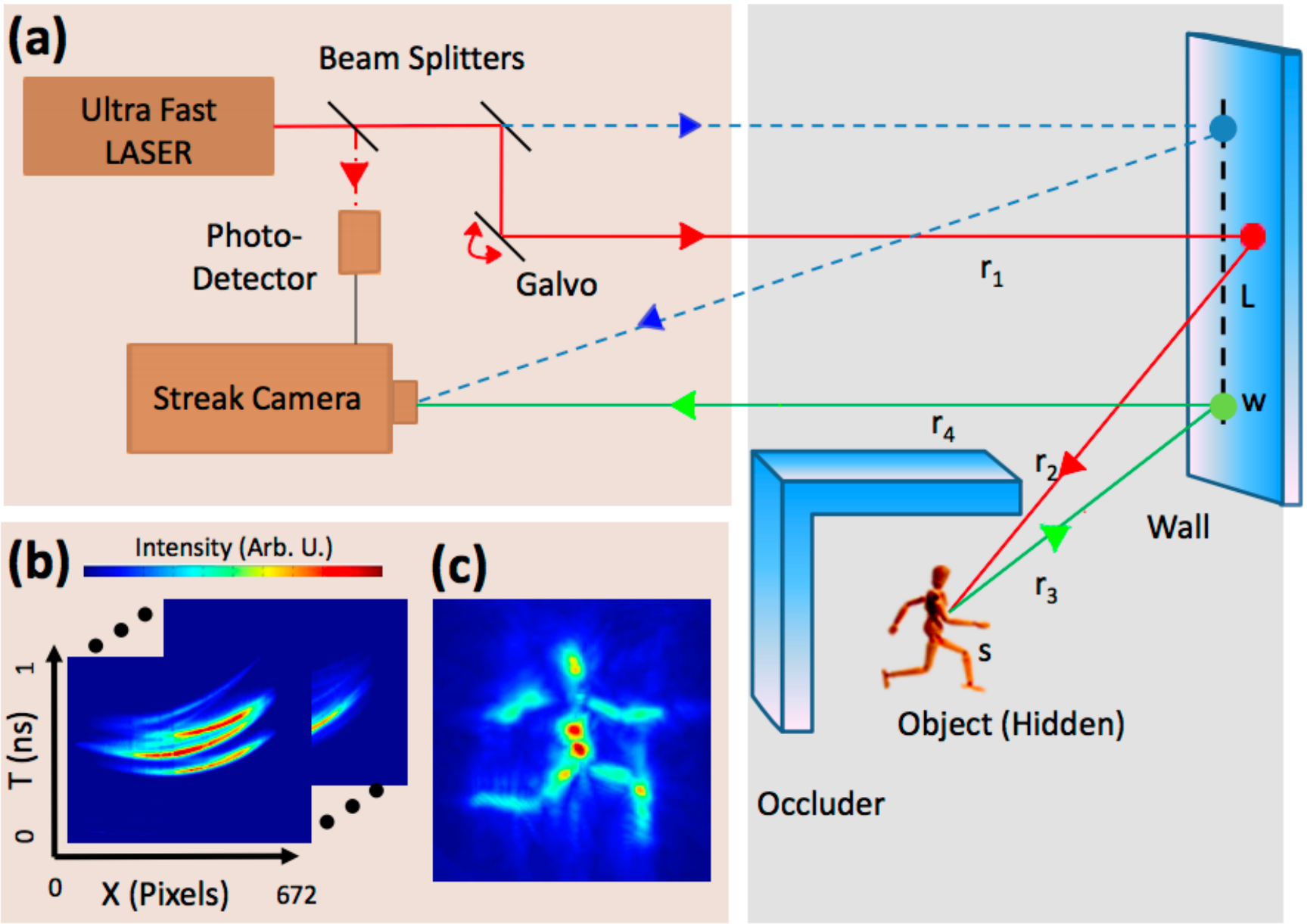
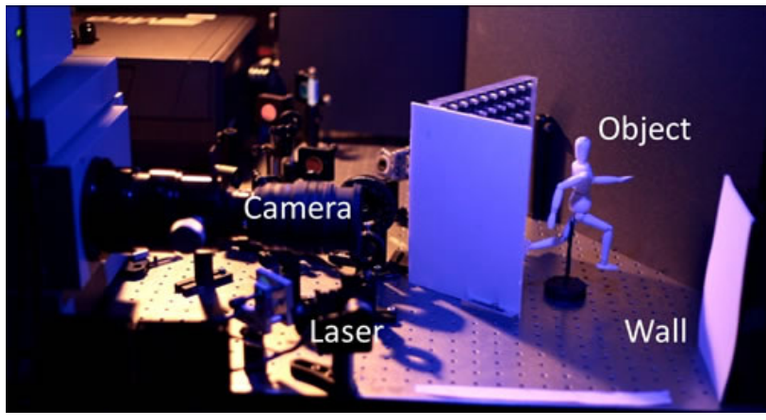


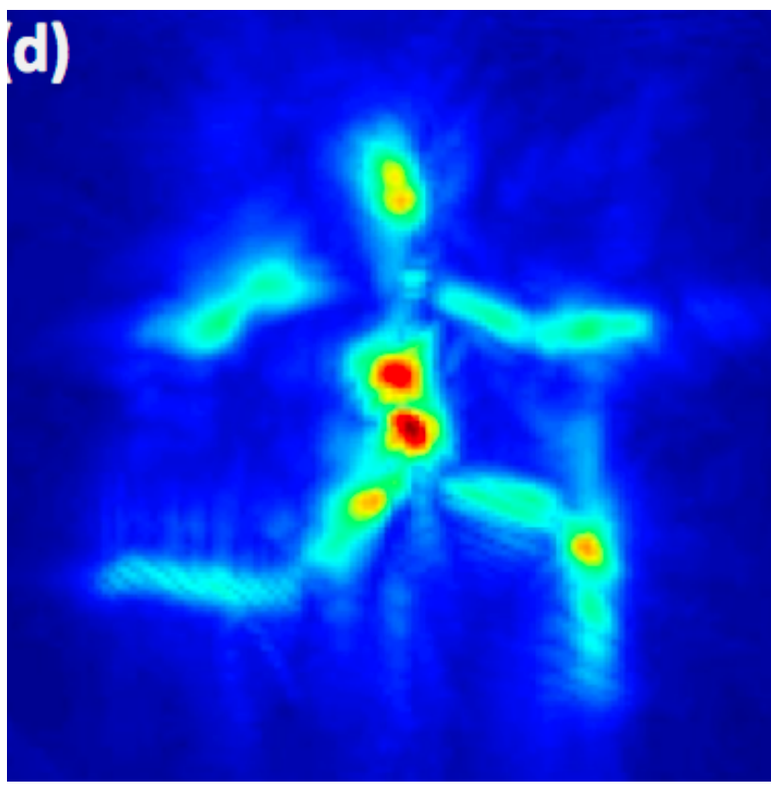
Figure 7. A second example of finding a picture of what is outside a room (d) from two pictures (a) and (b). The true view (e) is shown for comparison with the recovered image (d).

Seeing behind corners

- Velten et al. :
- Time of flight with 3rd bounce of light

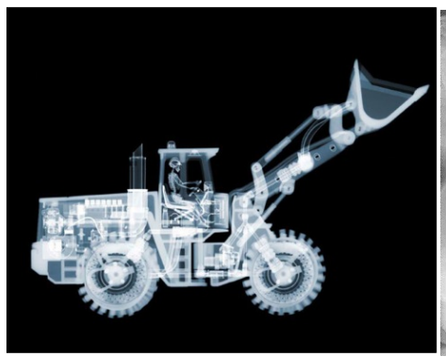
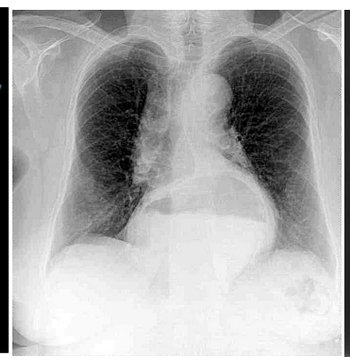


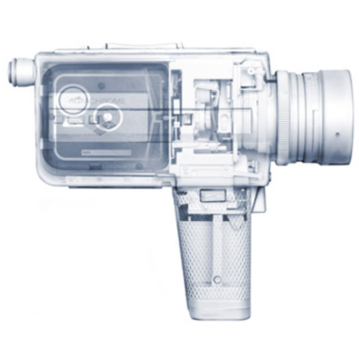
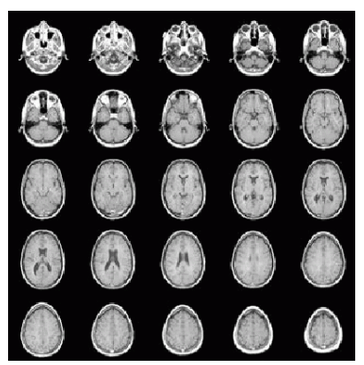




Recap: hidden things & occlusion

- Seeing inside objects

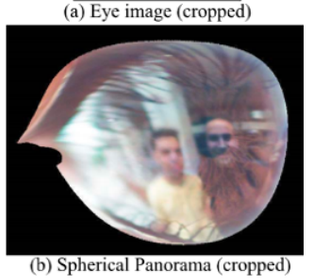



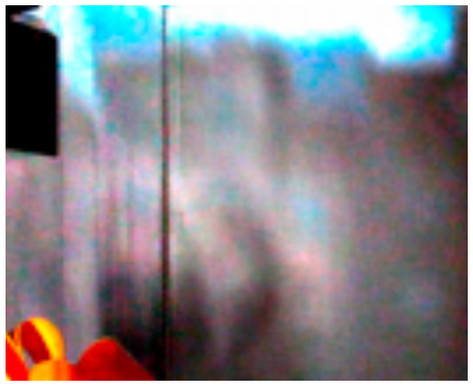
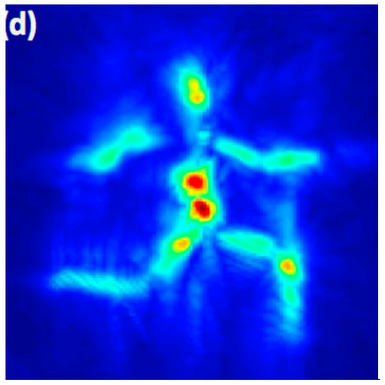



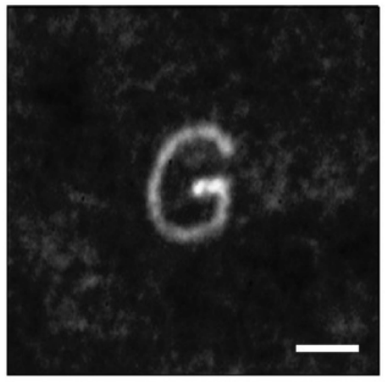


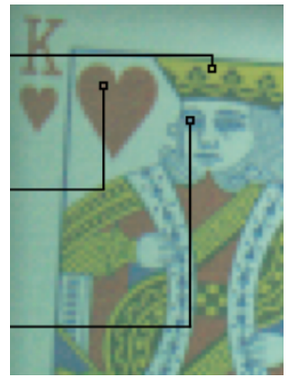
- Seeing beyond the field of view


(a) Eye image (cropped)


(b) Spherical Panorama (cropped)



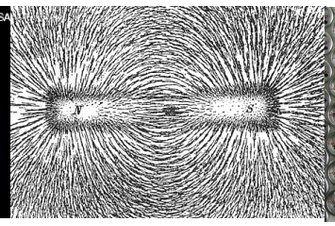
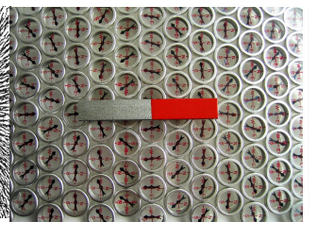
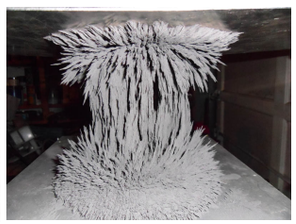
Overview

- Limits of human vision
- Occlusion
- **Non-visual phenomena**
- Non-visible visual phenomena
- Change and motion

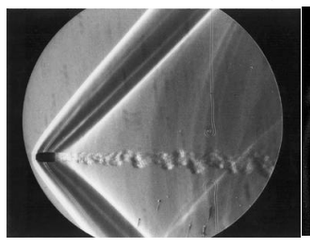
Non visual phenomena

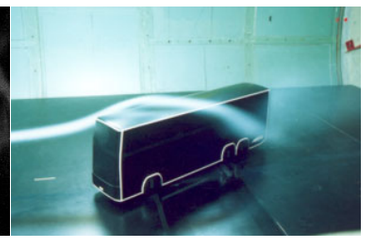
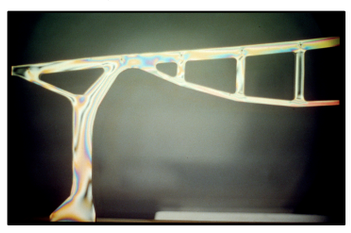
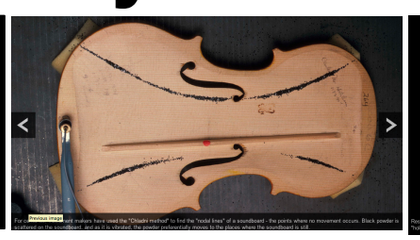
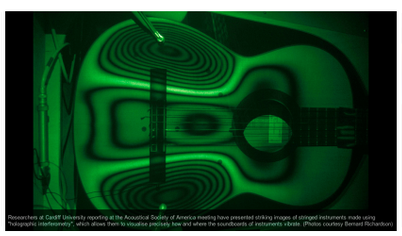
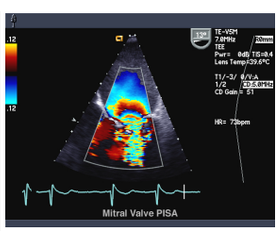
- Temperature, EM field, wifi



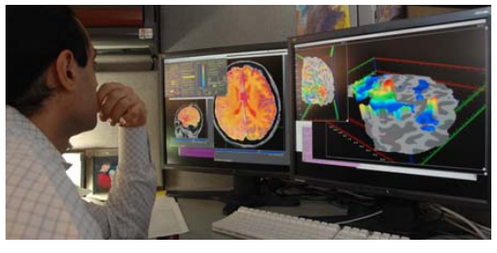





- Sound, air flow, particle trajectories, material stress, vibration modes, velocity

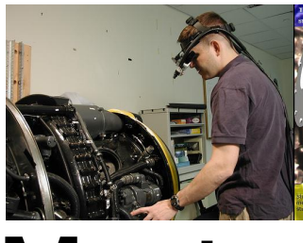


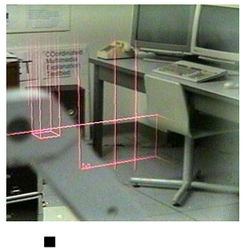






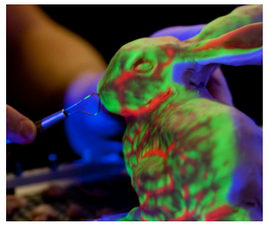
- Brain function



- Augmented reality, spatial AR



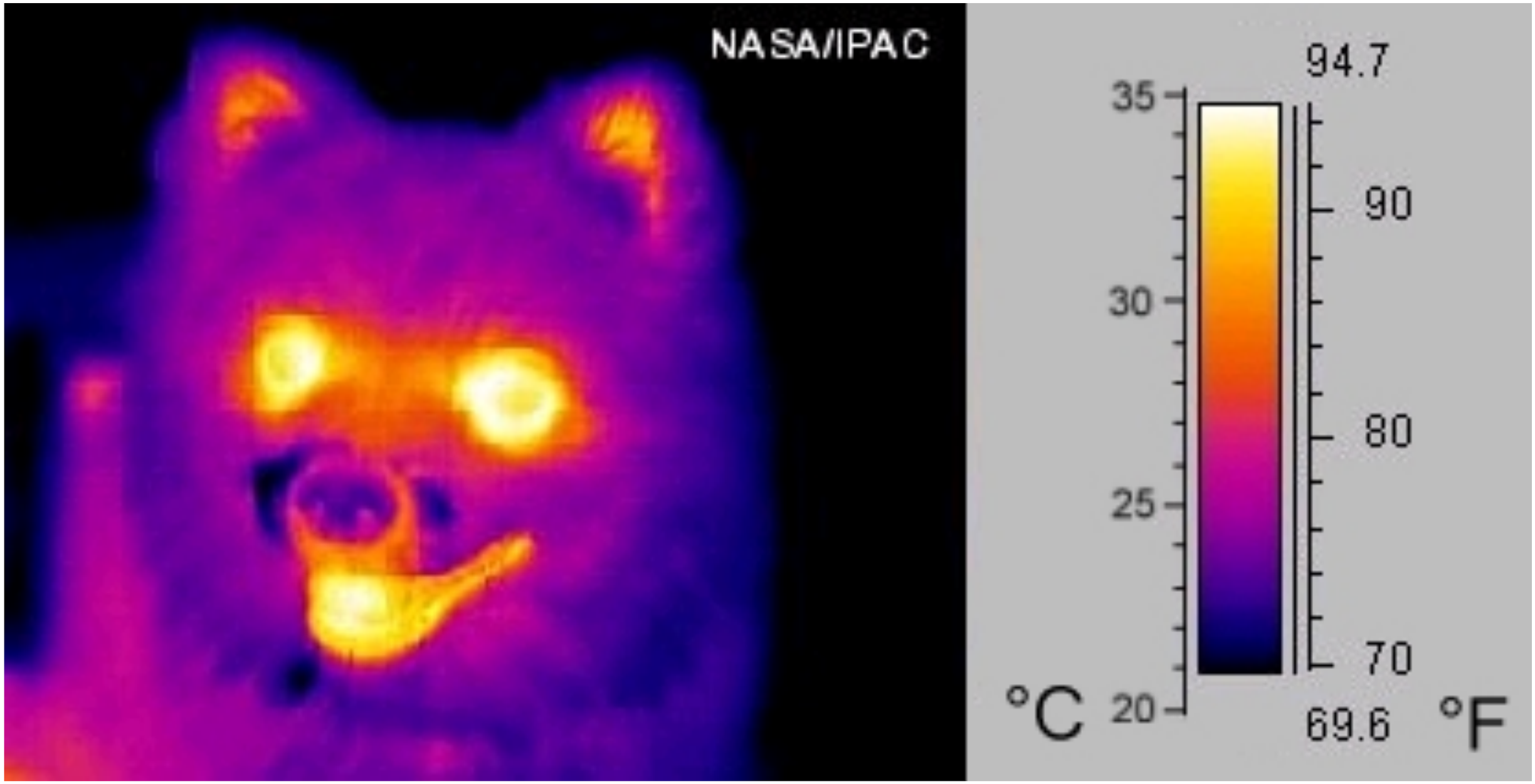




- Most sensing is optical!

Main ideas

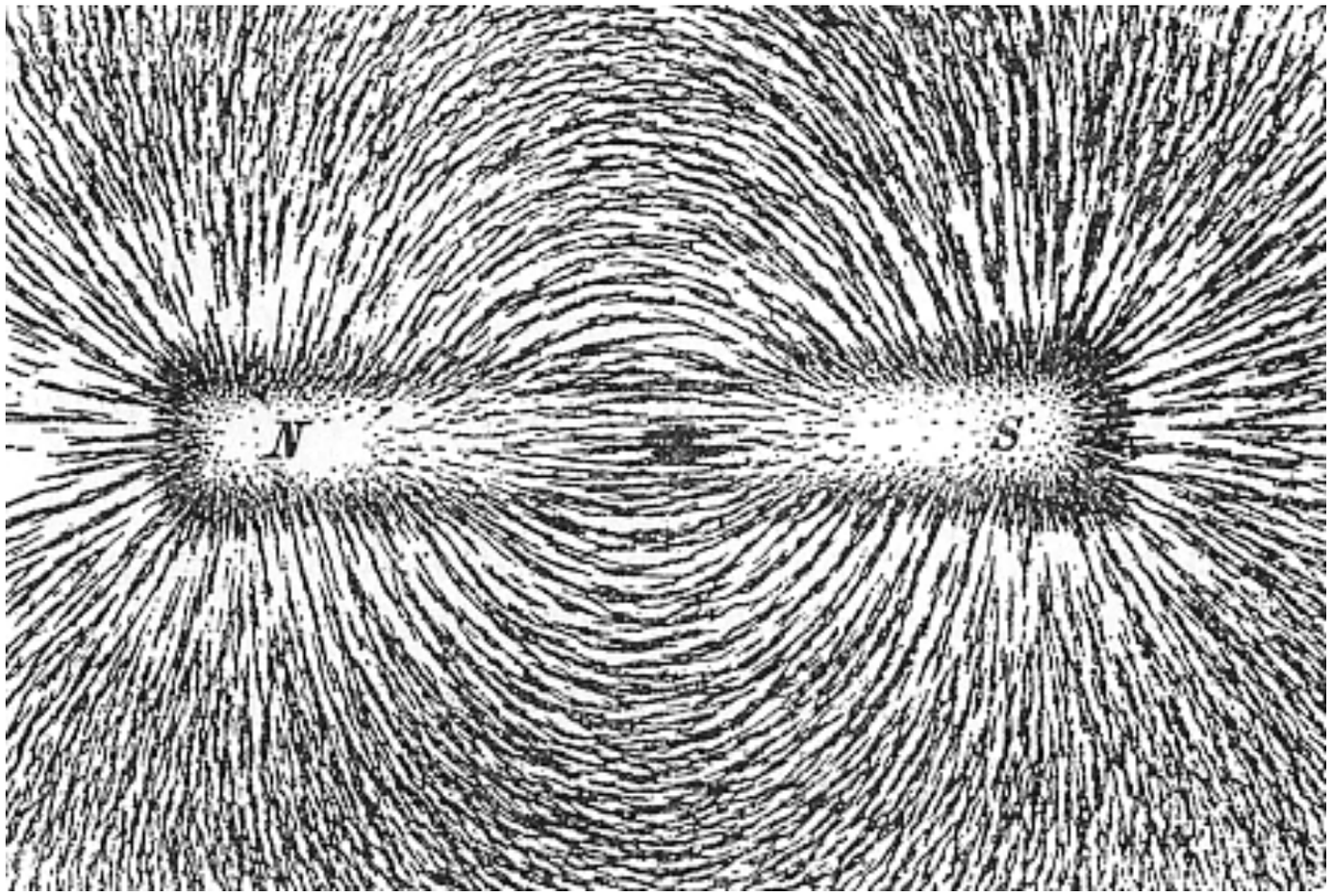
- The phenomenon modifies visual properties (phase & refraction, polarization)
- Add visual elements that are affected by the phenomenon (powder, smoke, etc.)
  - Attach visible stuff (fluorescent dye, light emitting enzymes)
- Convert to visible wavelengths (fluorescence)
- Interferences
- Augmented Reality

Thermal Infrared

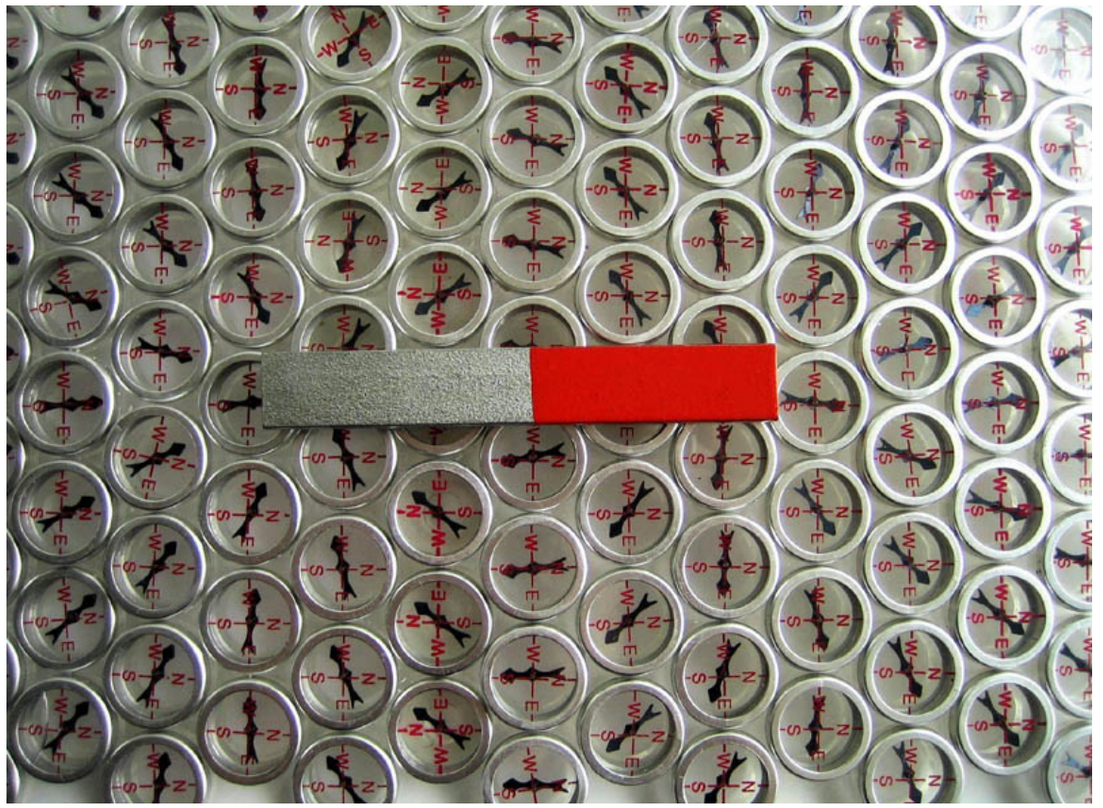


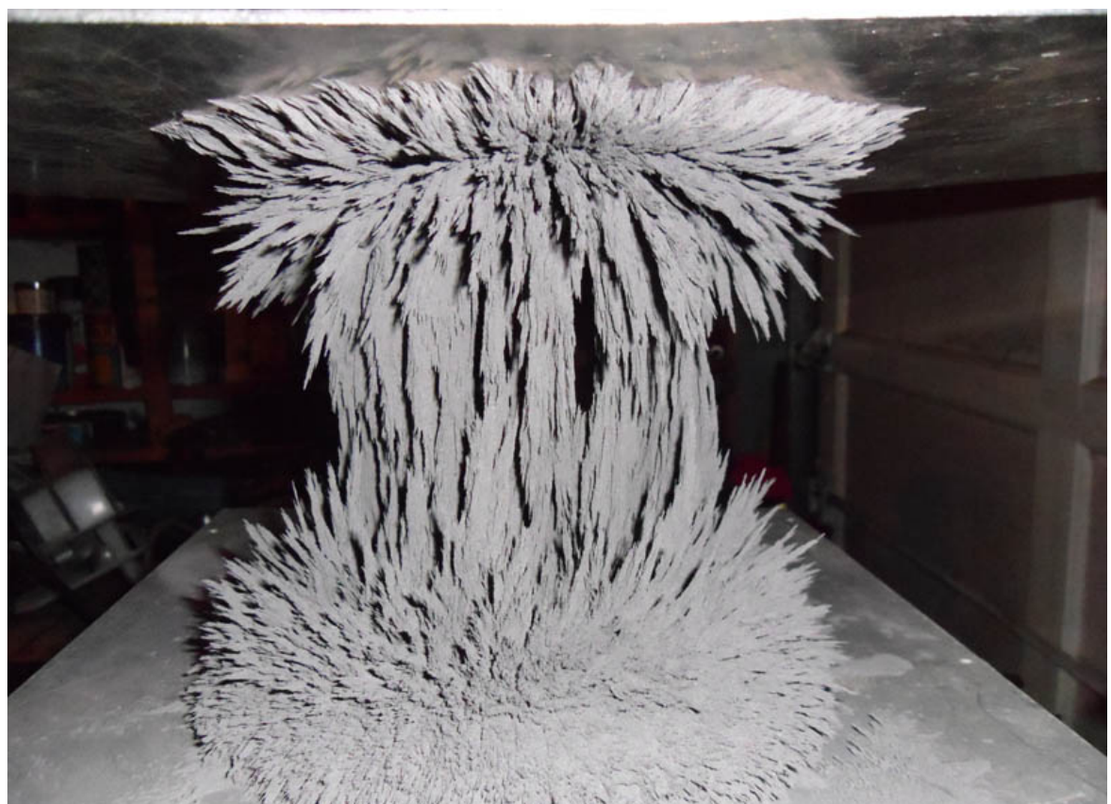
http://en.wikipedia.org/wiki/Thermographic_camera

Electromagnetic fields



Iron filings showing the direction of the magnetic field of a permanent magnet

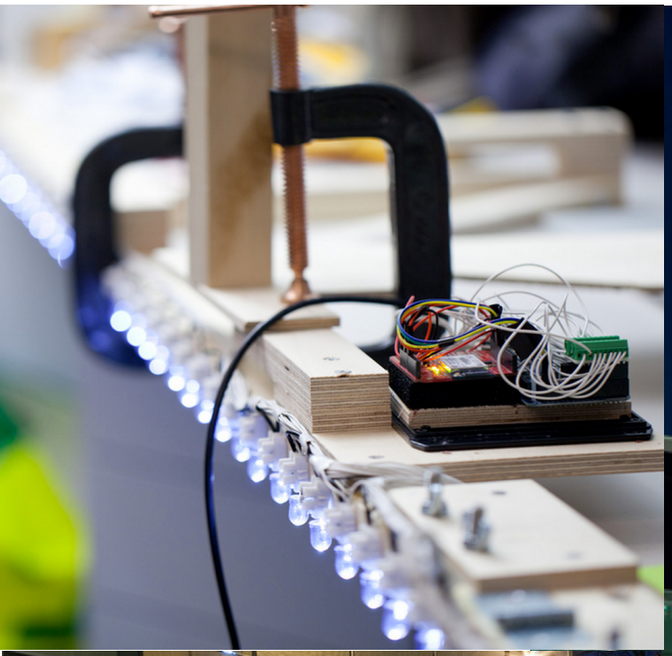




- http://en.wikipedia.org/wiki/Iron_filings
- http://www.fotopedia.com/items/flickr-3776988868
- http://www.christies.com/LotFinder/lot_details.aspx?intObjectID=5275958
- http://twistedsifter.com/2012/05/visualizing-magnetic-fields-compasses-iron-filings/
- http://en.wikipedia.org/wiki/Magnetic_field_viewing_film

Wifi signal

- Wifi sensor + rod with LEDs + long exposure

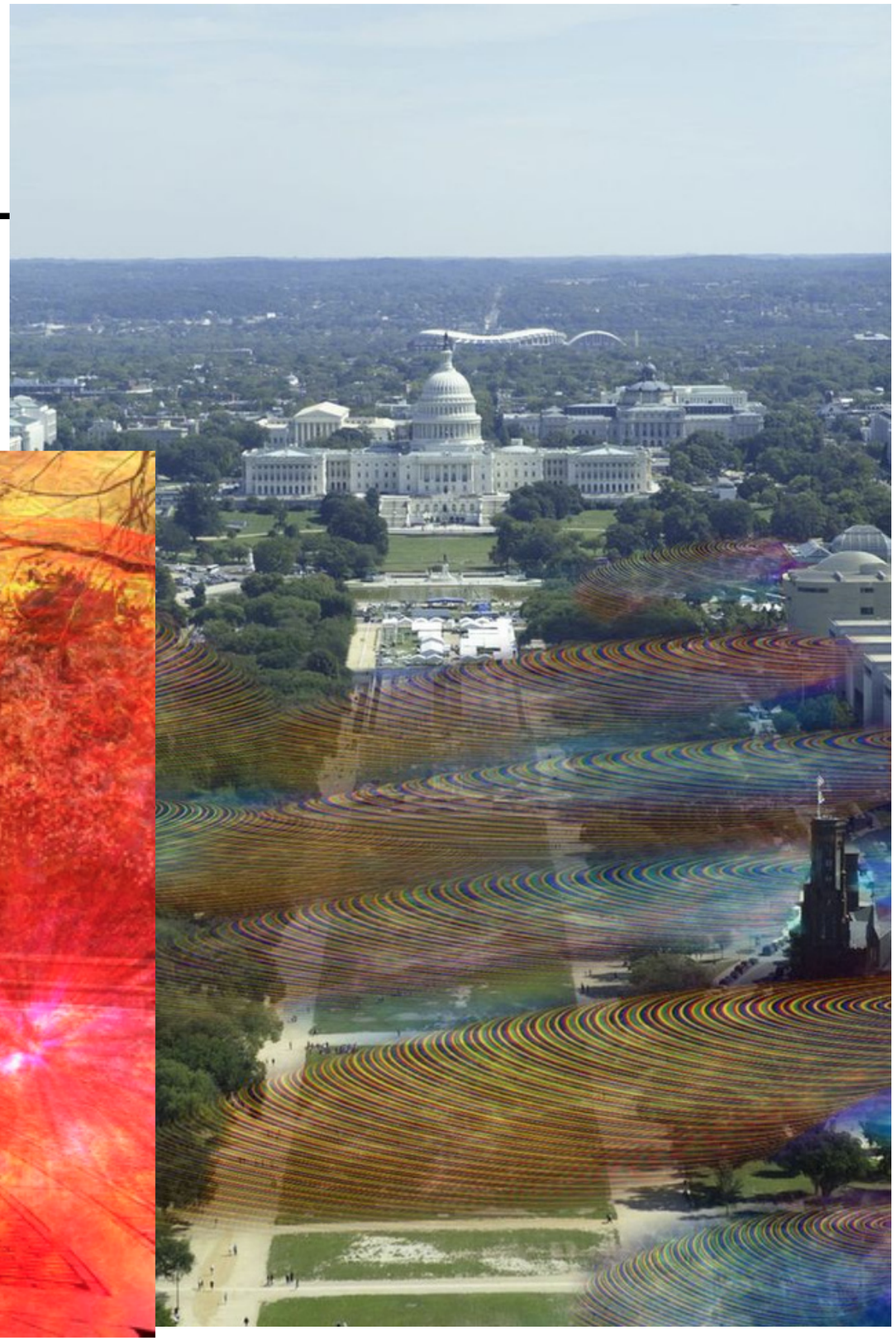






http://www.nearfield.org/2011/02/wifi-light-painting

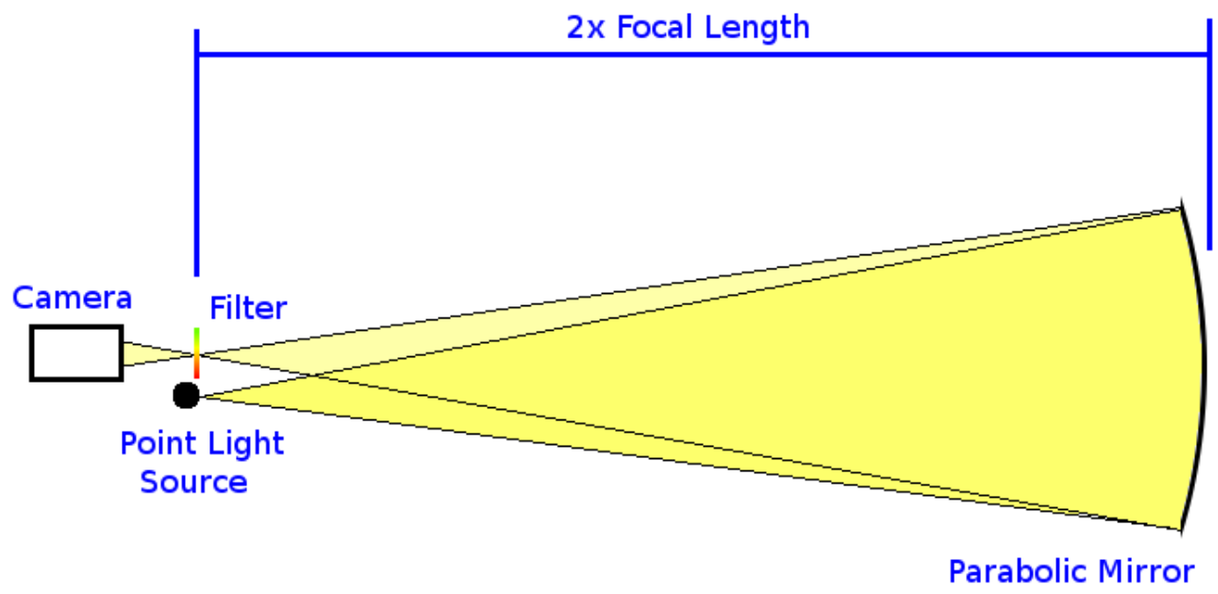




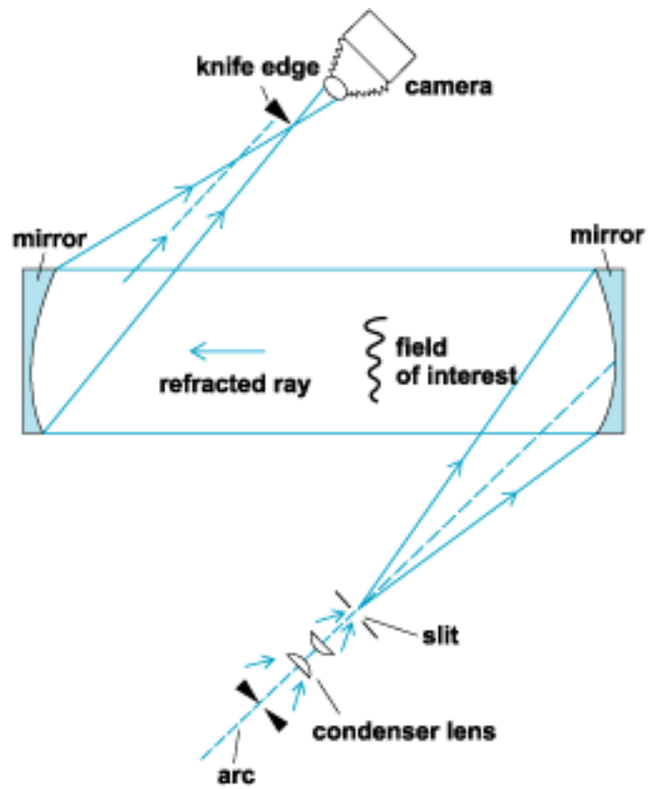
http://gizmodo.com/what-the-world-would-look-like-if-you-could-actually-se-846030448

http://gizmodo.com/5977490/what-wi+fi-looks-like-as-a-physical-object

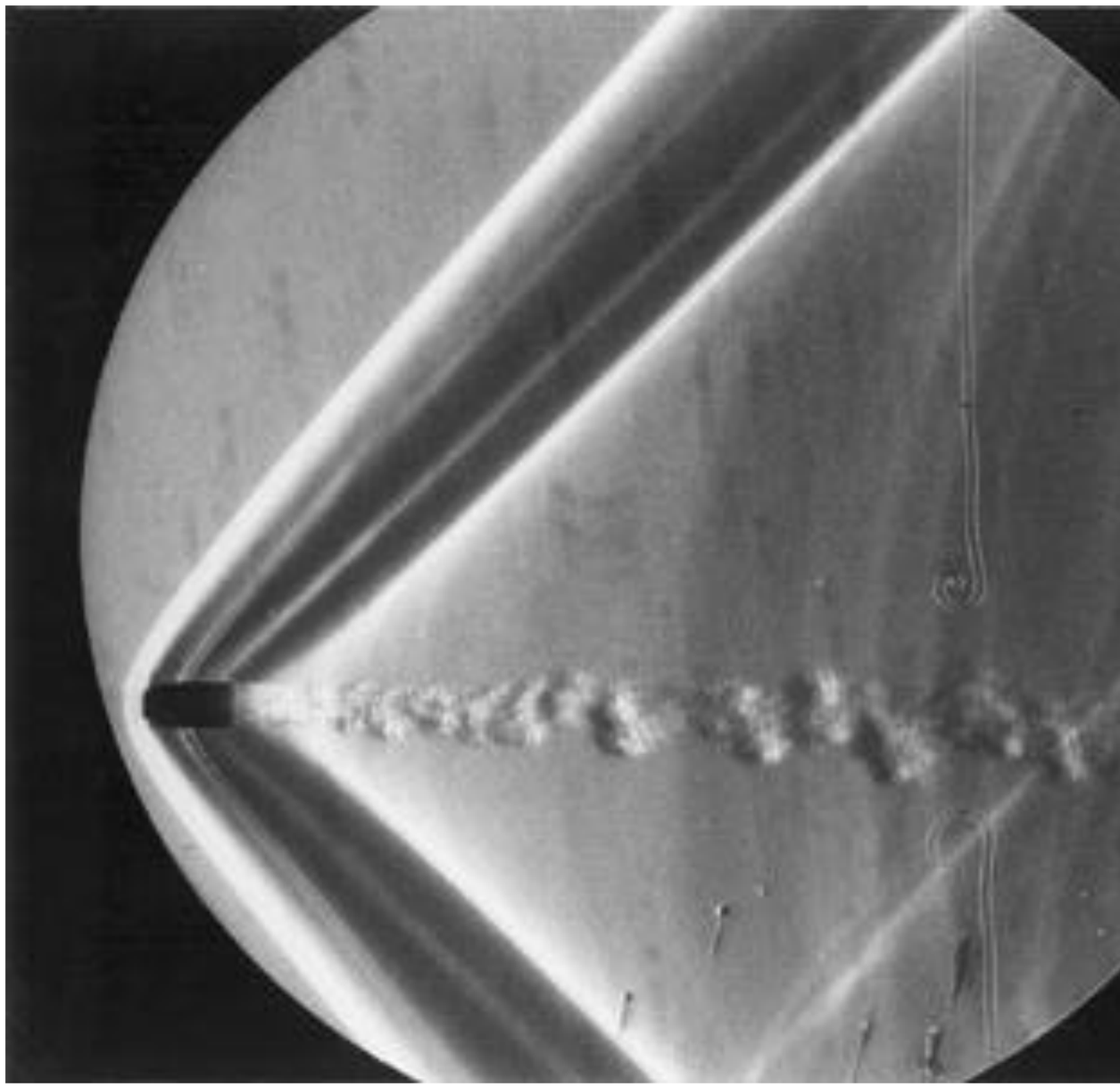
Sound, pressure: Schlieren



http://www.ian.org/Schlieren/HowTo.html



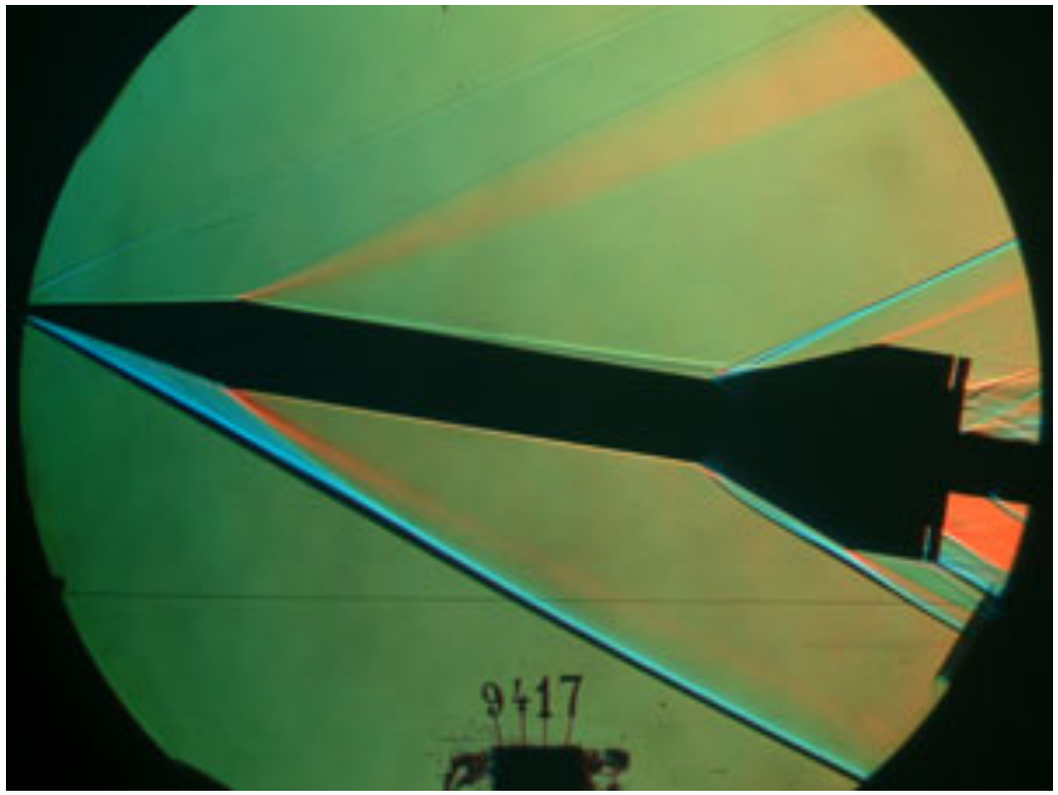
http://www.answers.com/topic/schlieren-photography



Sound wave of a bullet

http://people.rit.edu/andpph/schlieren-2.jpg

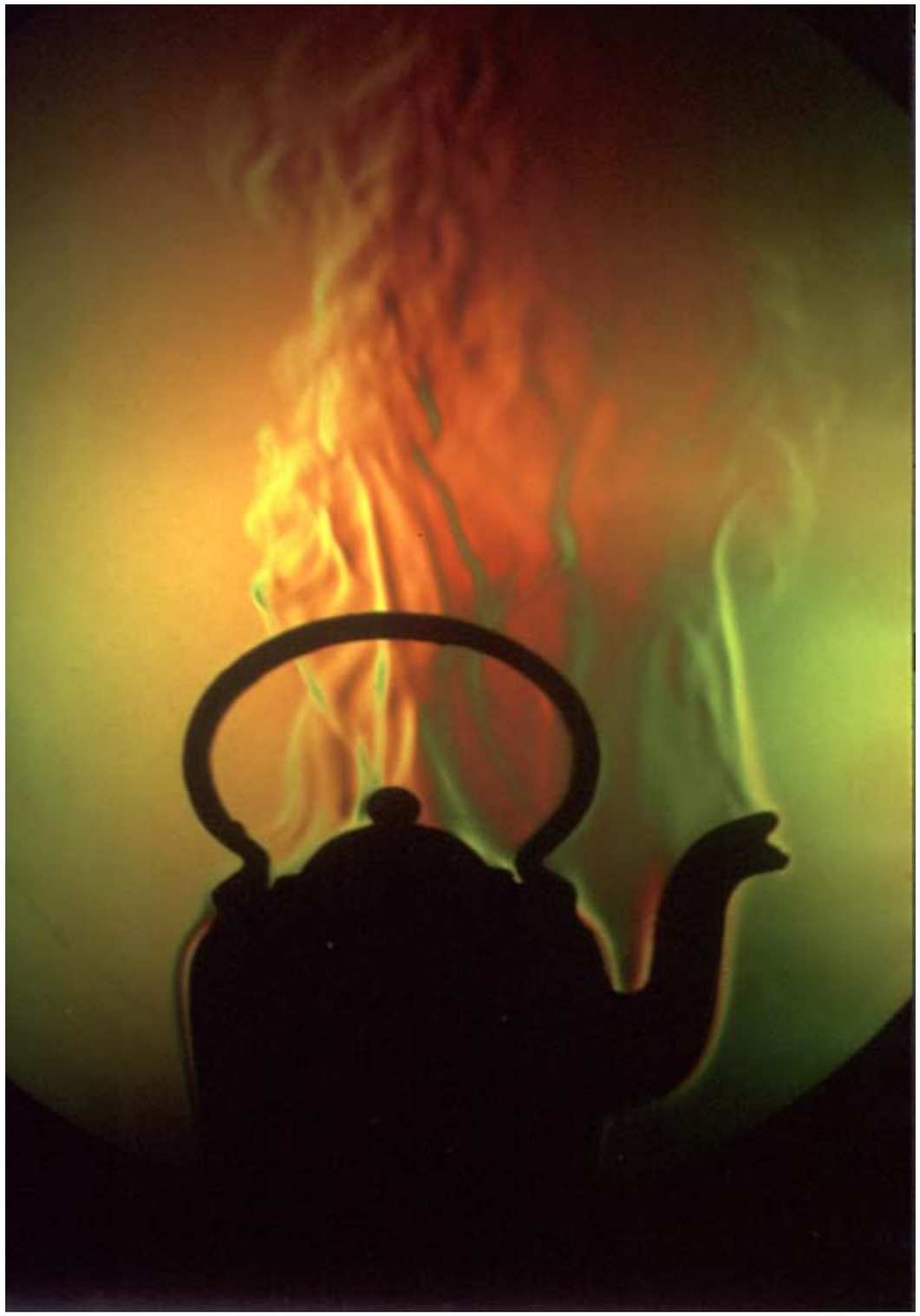
See also http://web.mit.edu/Edgerton/www/schlieren5.html



http://www.starcs.se/classical_methods.aspx



http://rainbowboys.blogspot.hk/2010/11/schlieren-photography.html

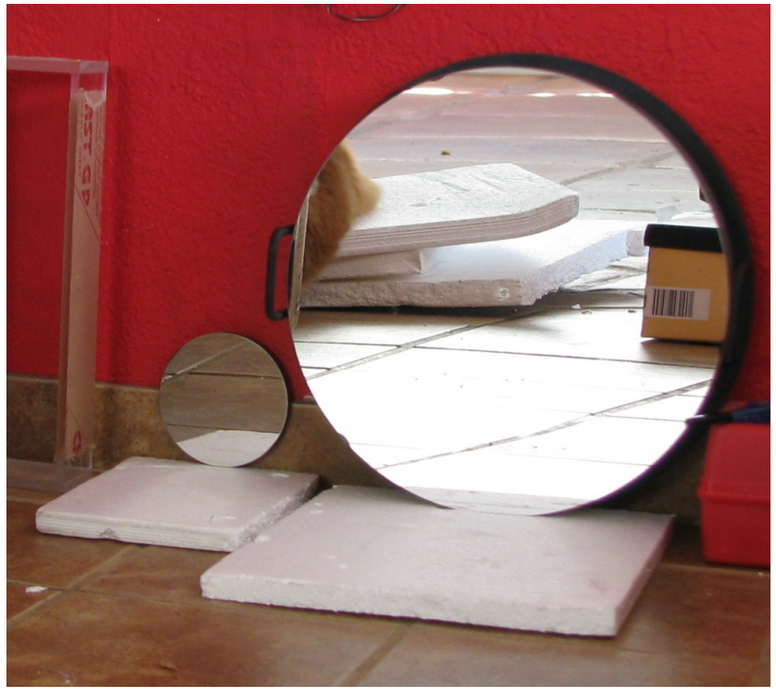


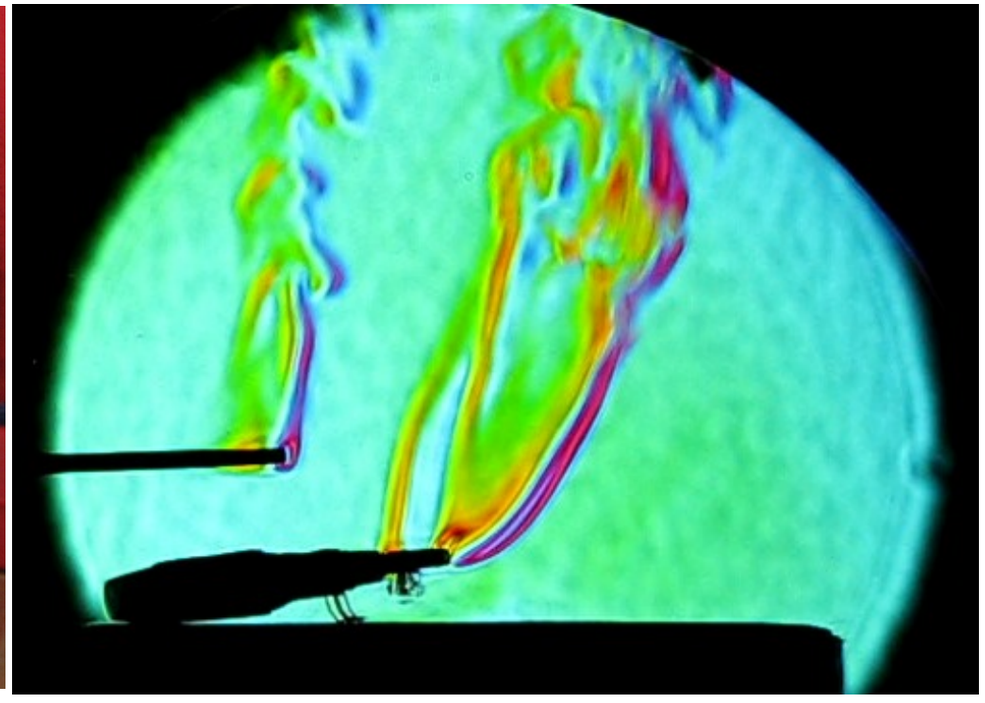
http://www.cloudshillimaging.com/schlieren-imaging-system.html

Try it at home

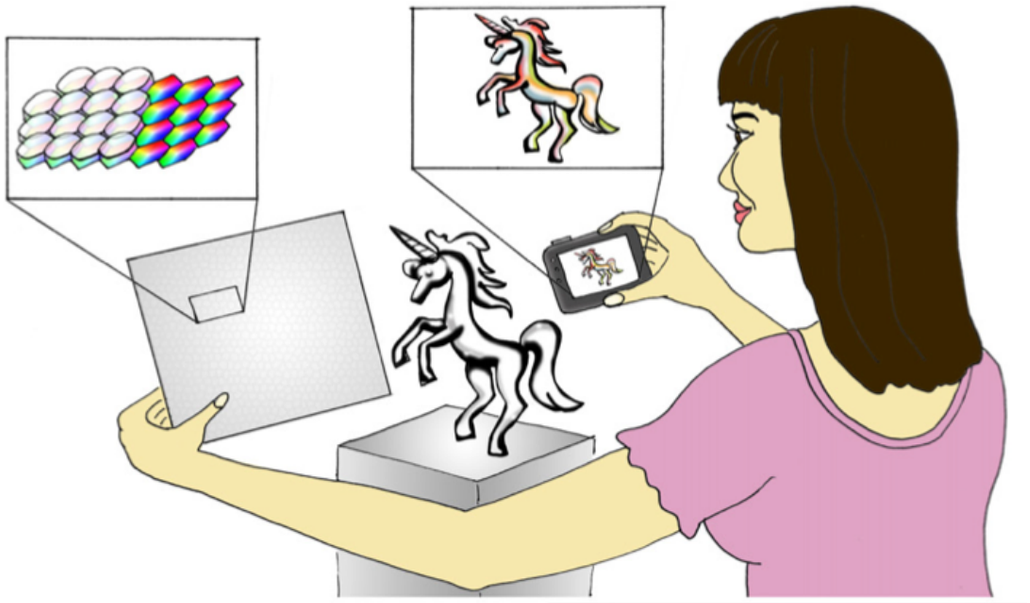
- http://content.photojojo.com/guides/schlieren-photography-guide/
- http://www.ian.org/Schlieren/HowTo.html

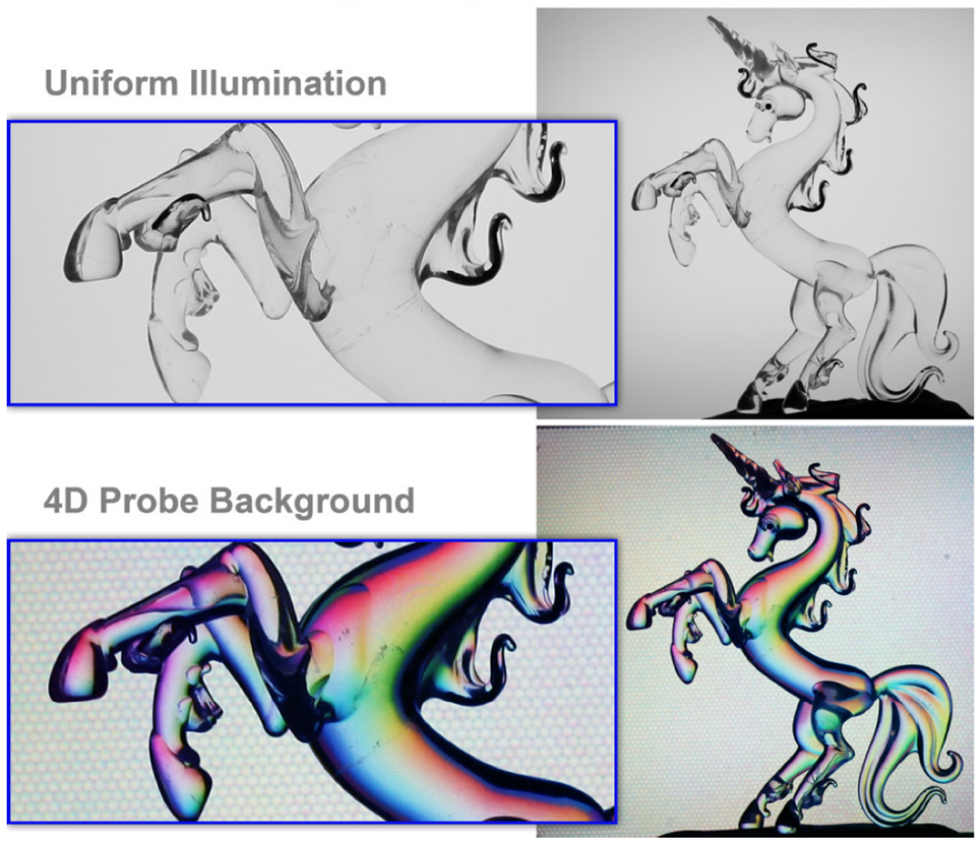


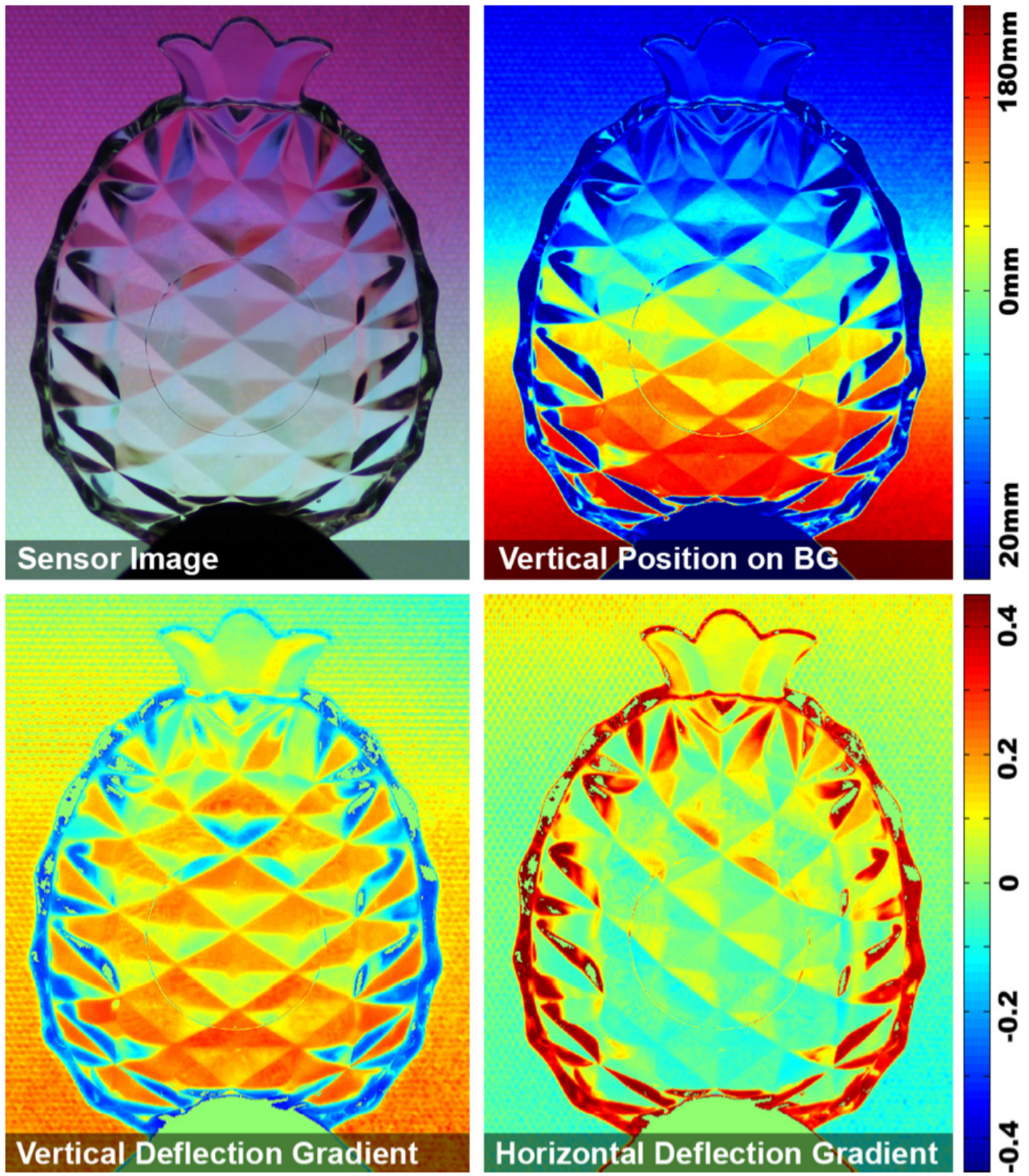




Schlieren with Light Field Probes

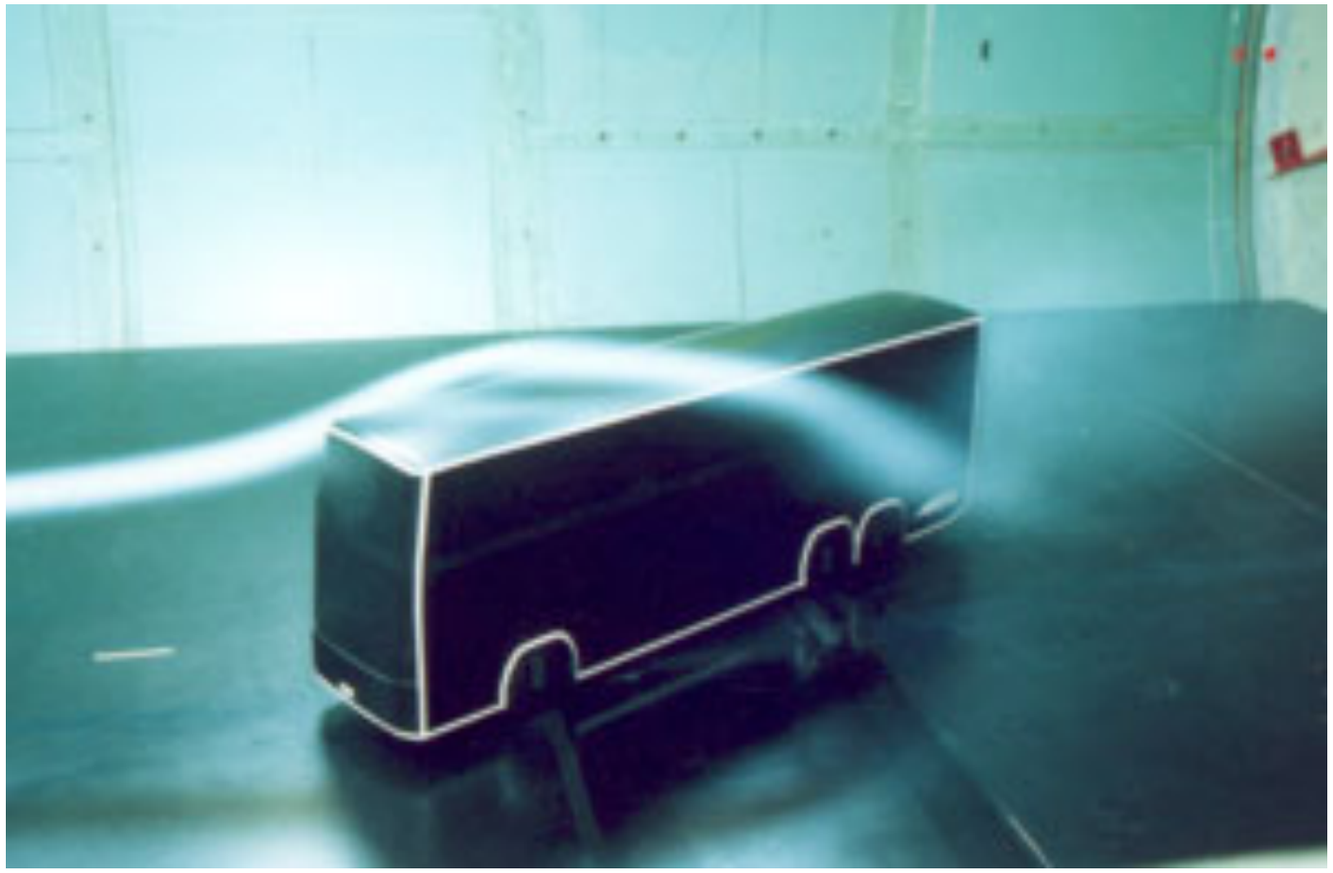






Wetzstein et al. ICCP 11 http://www.cs.ubc.ca/~heidrich/Papers/ICCP.11.pdf

Air flow: Smoke, sublimation

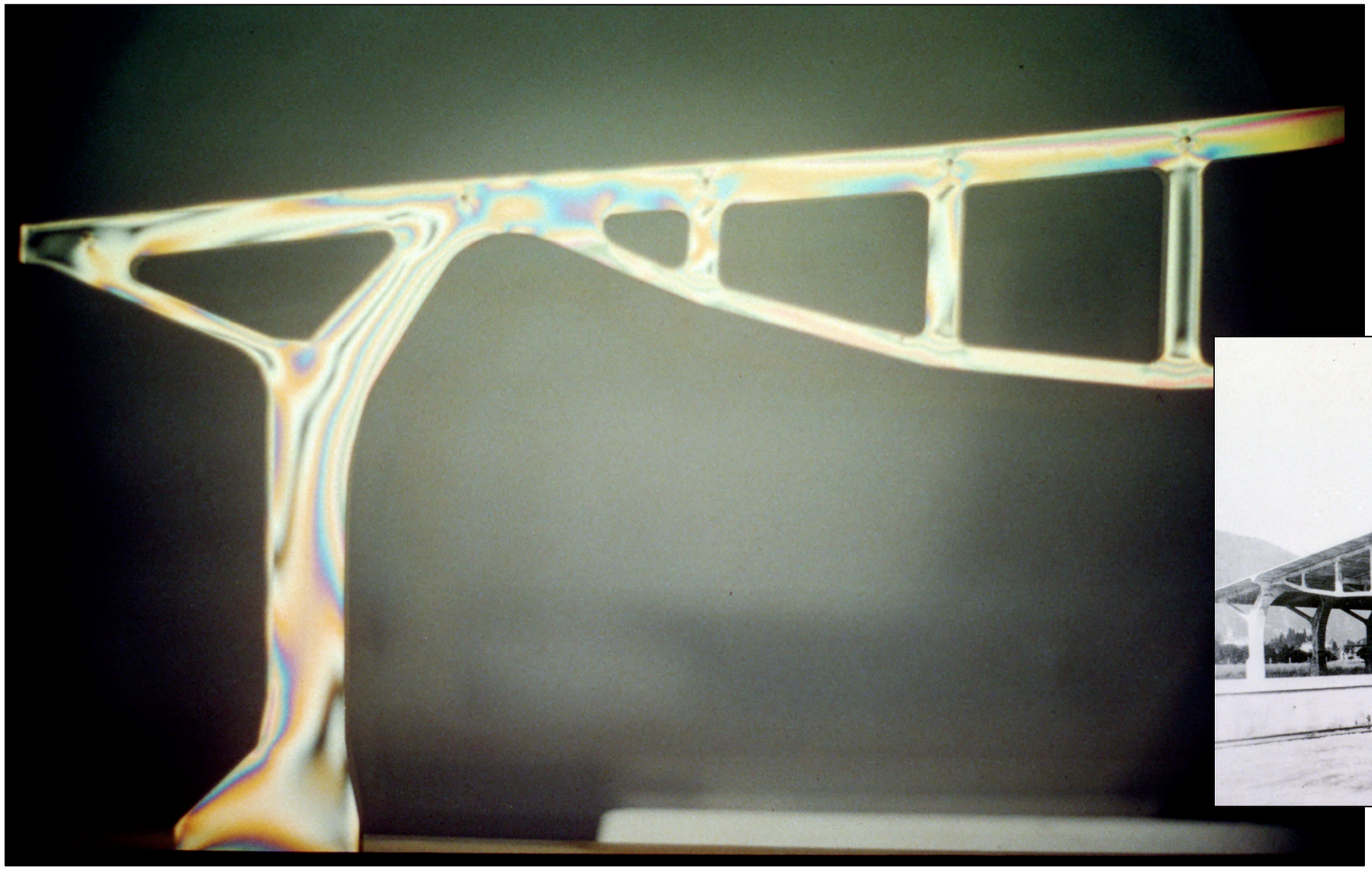




http://www.starcs.se/classical_methods.aspx

Material stress: Photoelasticity

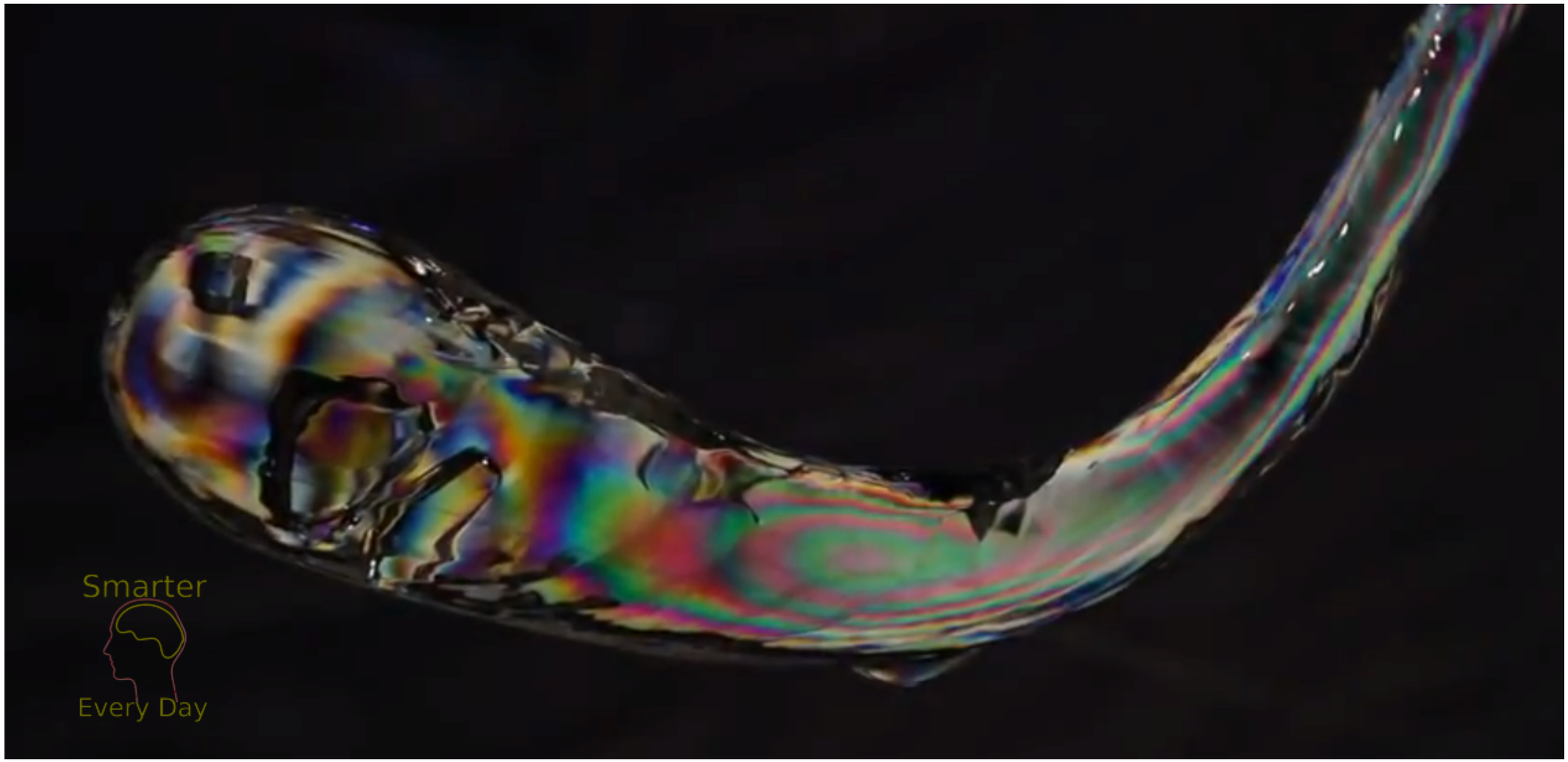
- First proposed by Brewster
- Birefrigence due to stress+interference





Photoelastic analysis of Maillart's Chiasso Roof, by Robert Mark

- https://www.youtube.com/watch?feature=player_embedded&v=xe-f4gokRBs#!

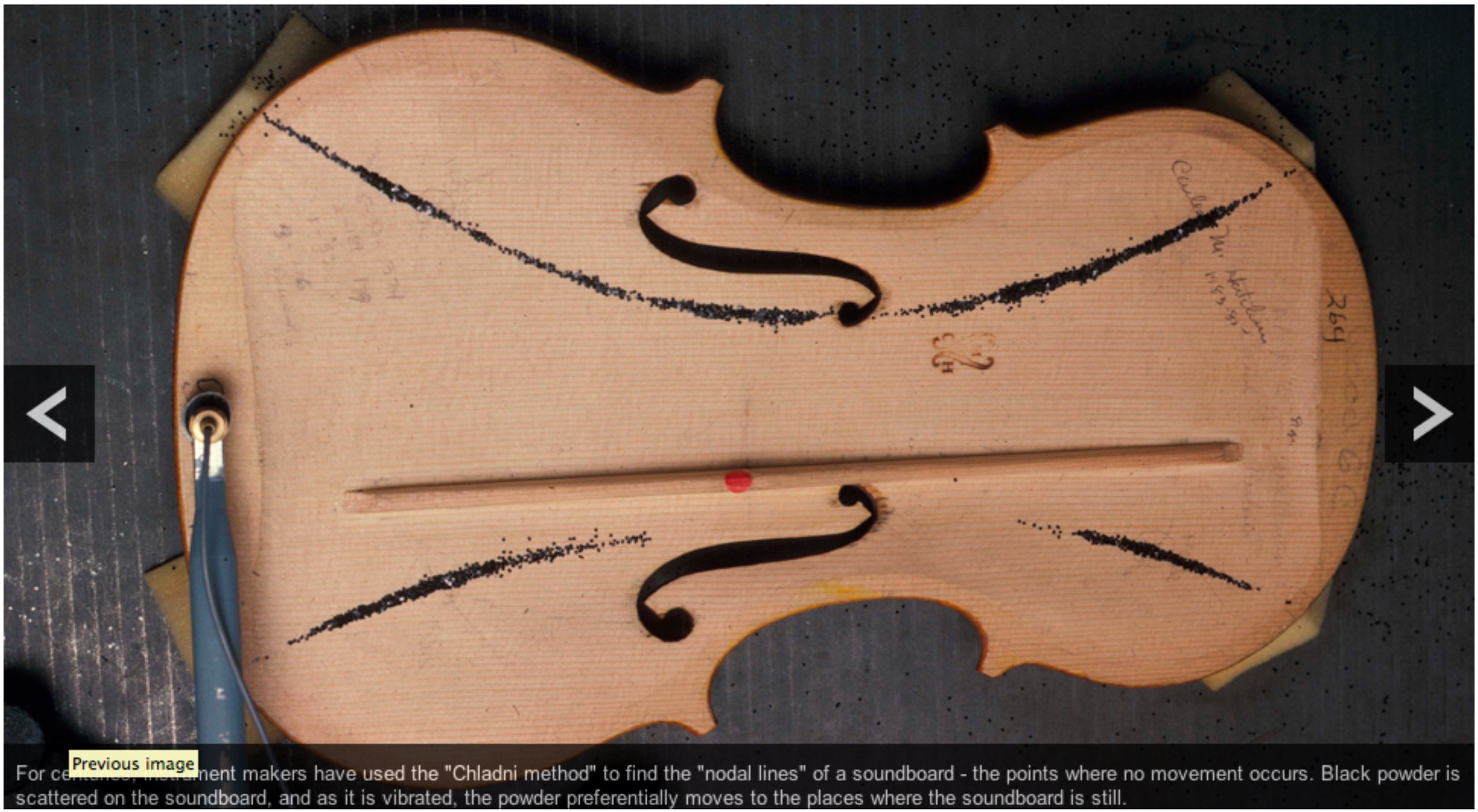


Vibration modes (Chladni)



- https://www.youtube.com/watch?feature=player_embedded&v=wvJAgrUBF4w#!

Vibration modes (Chladni)



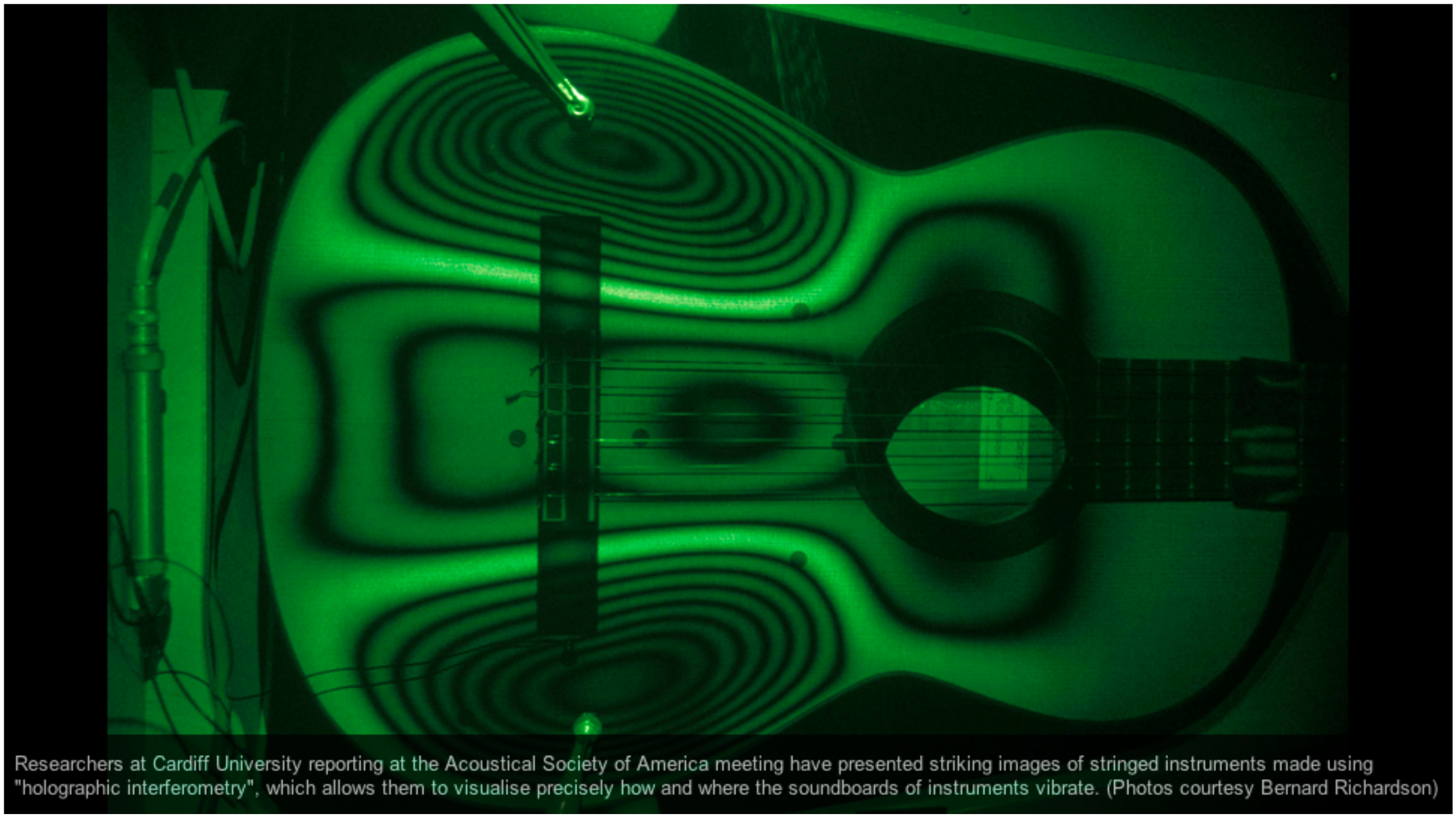
http://www.bbc.co.uk/news/science-environment-13573631

Vibration modes: Interferometry



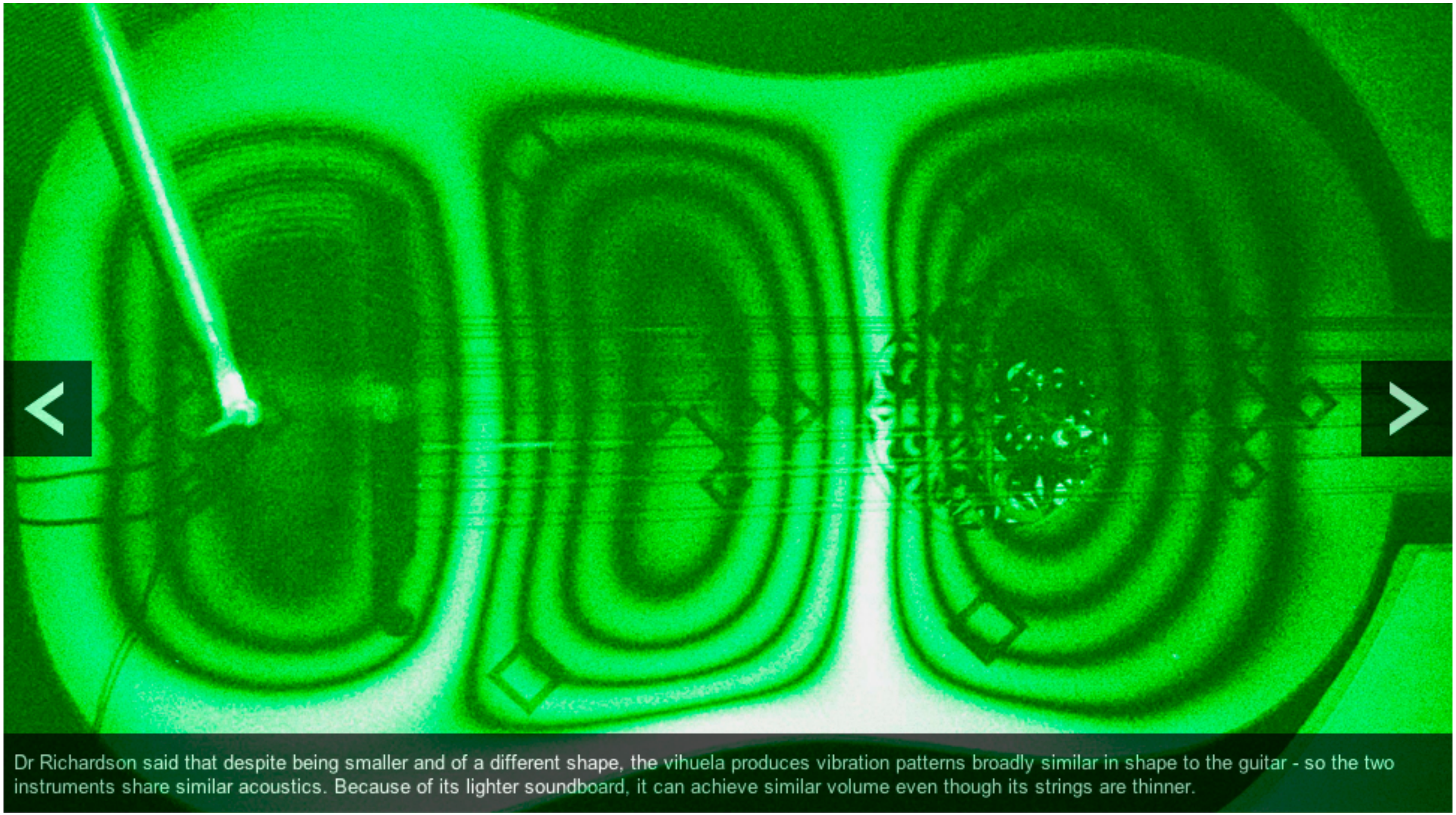
First, a laser beam is scattered off the instrument when it is still. That pattern, along with another laser beam, are cast back onto the instrument as it is actively vibrated. The contour lines appear where tiny movements of the soundboard - less than a millionth of a metre - cause interference between the two beams.

Vibration modes: Interferometry



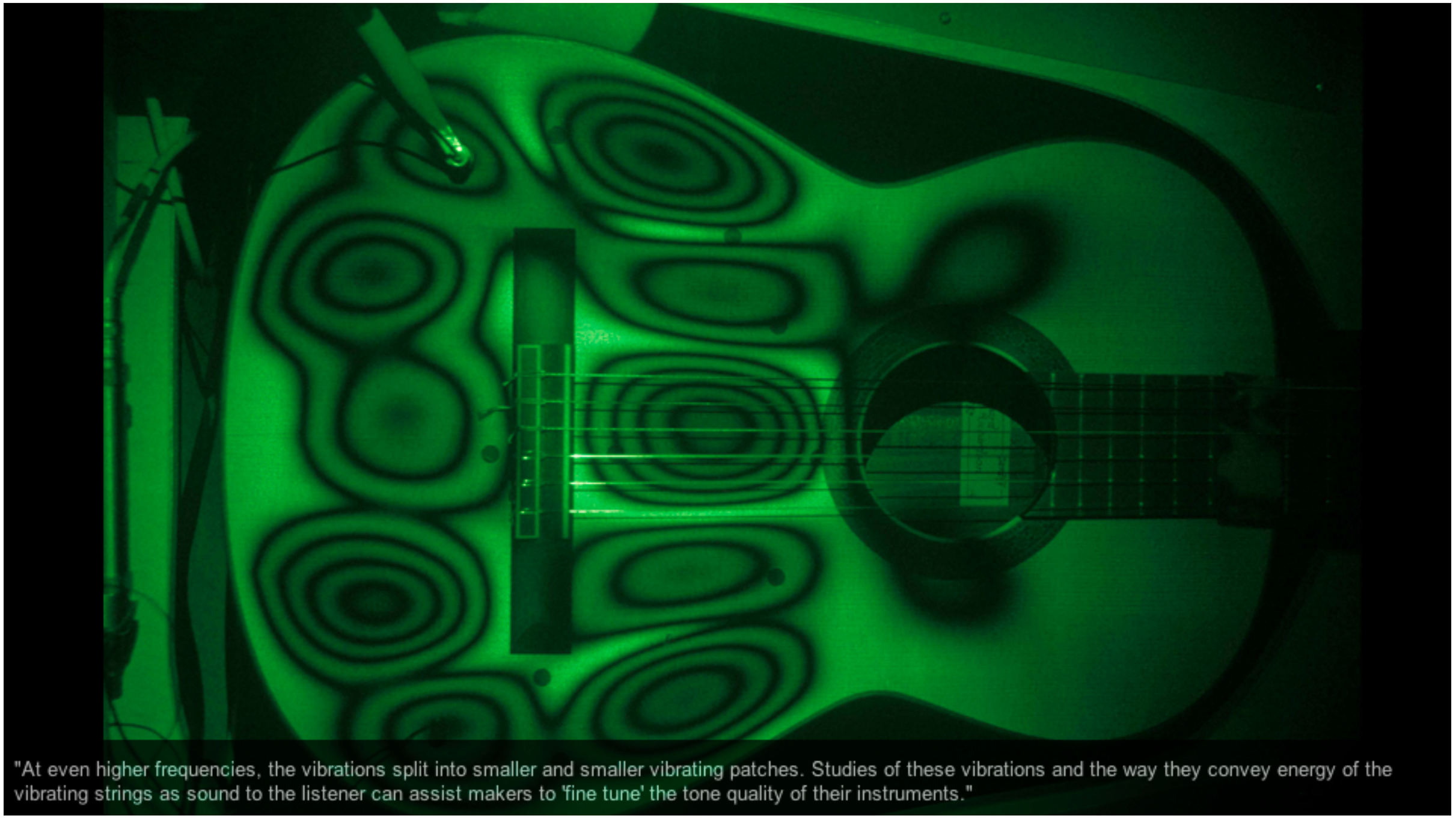
Researchers at Cardiff University reporting at the Acoustical Society of America meeting have presented striking images of stringed instruments made using "holographic interferometry", which allows them to visualise precisely how and where the soundboards of instruments vibrate. (Photos courtesy Bernard Richardson)

Vibration modes: Interferometry



Dr Richardson said that despite being smaller and of a different shape, the vihuela produces vibration patterns broadly similar in shape to the guitar - so the two instruments share similar acoustics. Because of its lighter soundboard, it can achieve similar volume even though its strings are thinner.

Vibration modes: Interferometry



"At even higher frequencies, the vibrations split into smaller and smaller vibrating patches. Studies of these vibrations and the way they convey energy of the vibrating strings as sound to the listener can assist makers to 'fine tune' the tone quality of their instruments."

Rolling shutter and waves

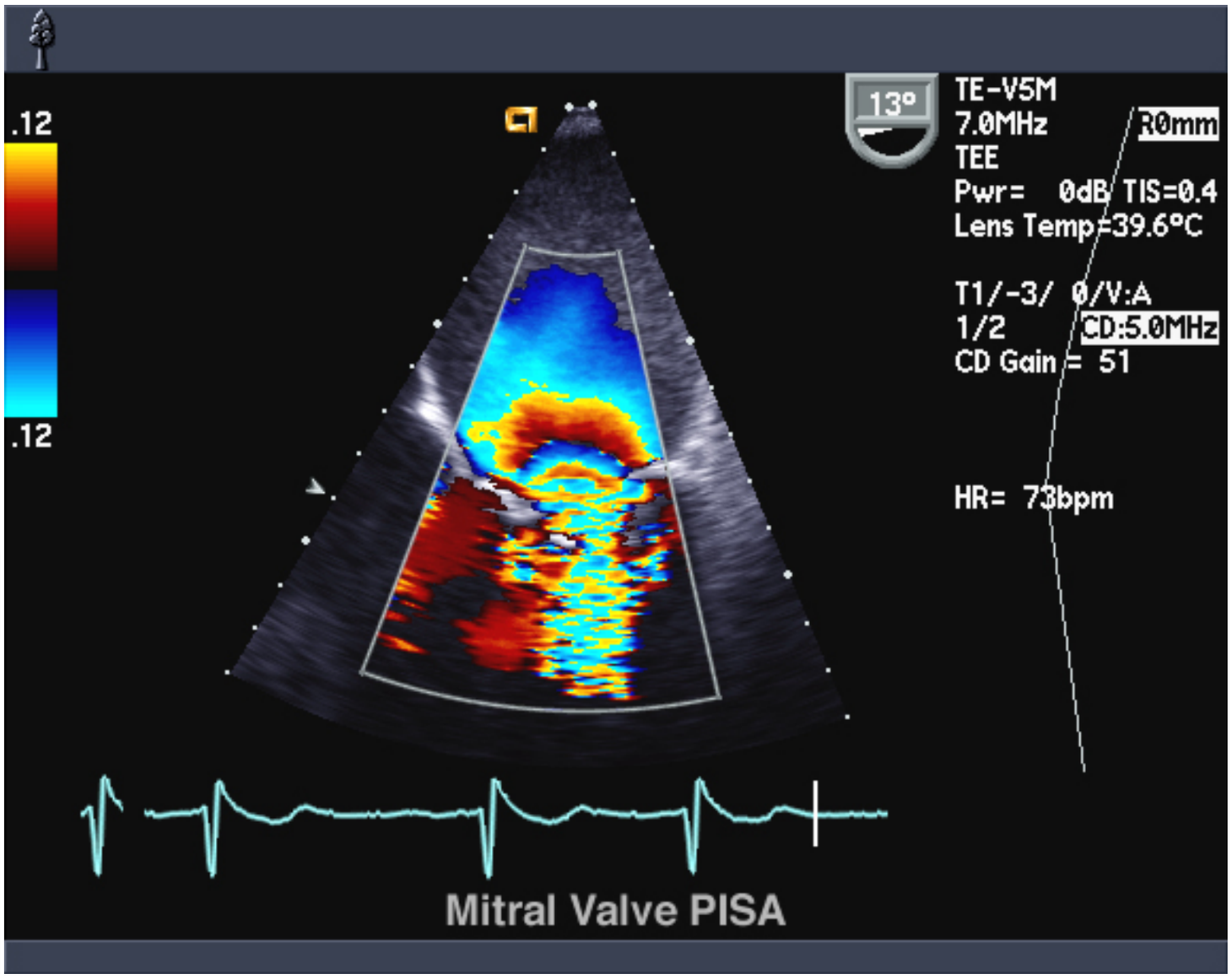
- by justkylevids http://www.youtube.com/watch?v=TKF6nFzpHBU



Revealing velocity

- Doppler imaging





http://www.satyakiranhealthcare.com/ColorDoppler.aspx

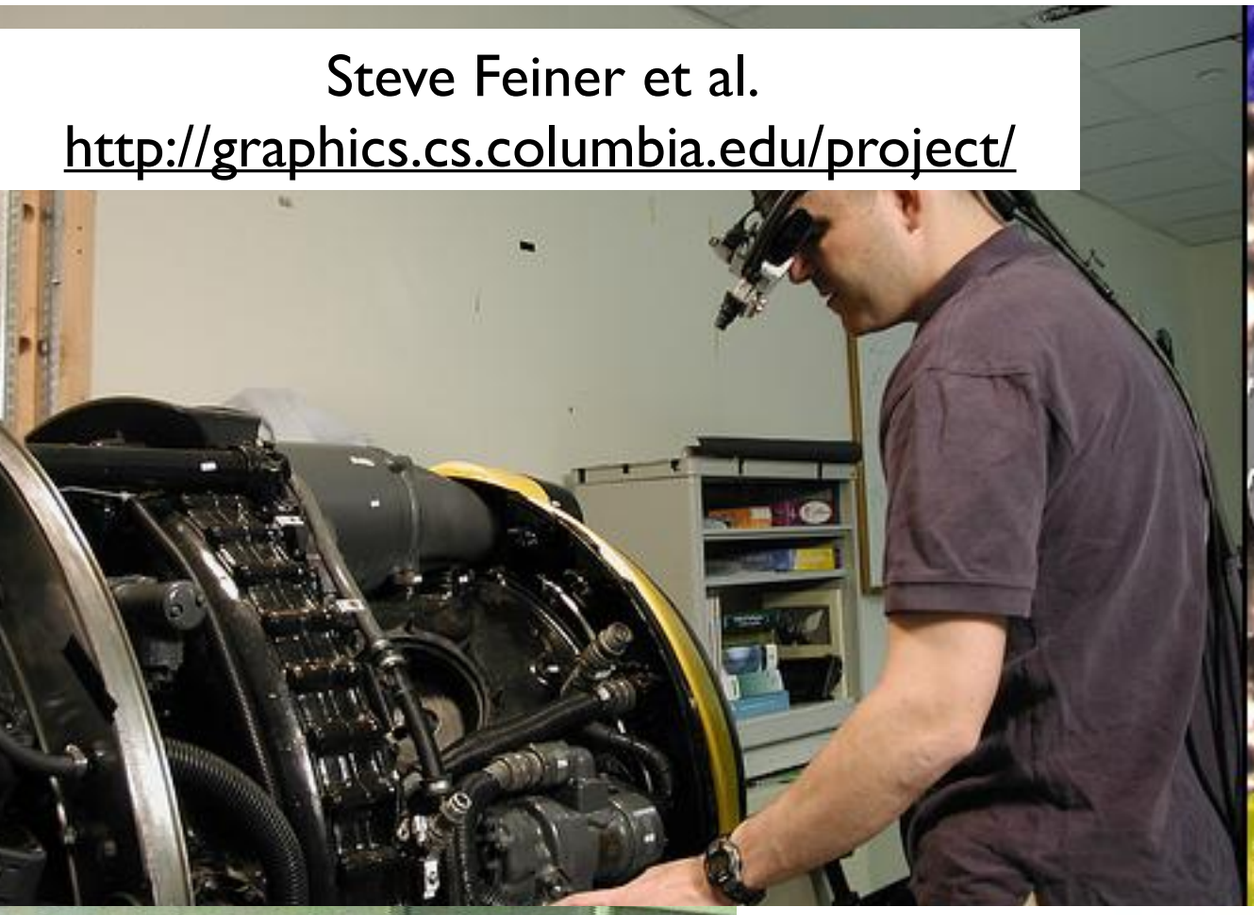
Brain function

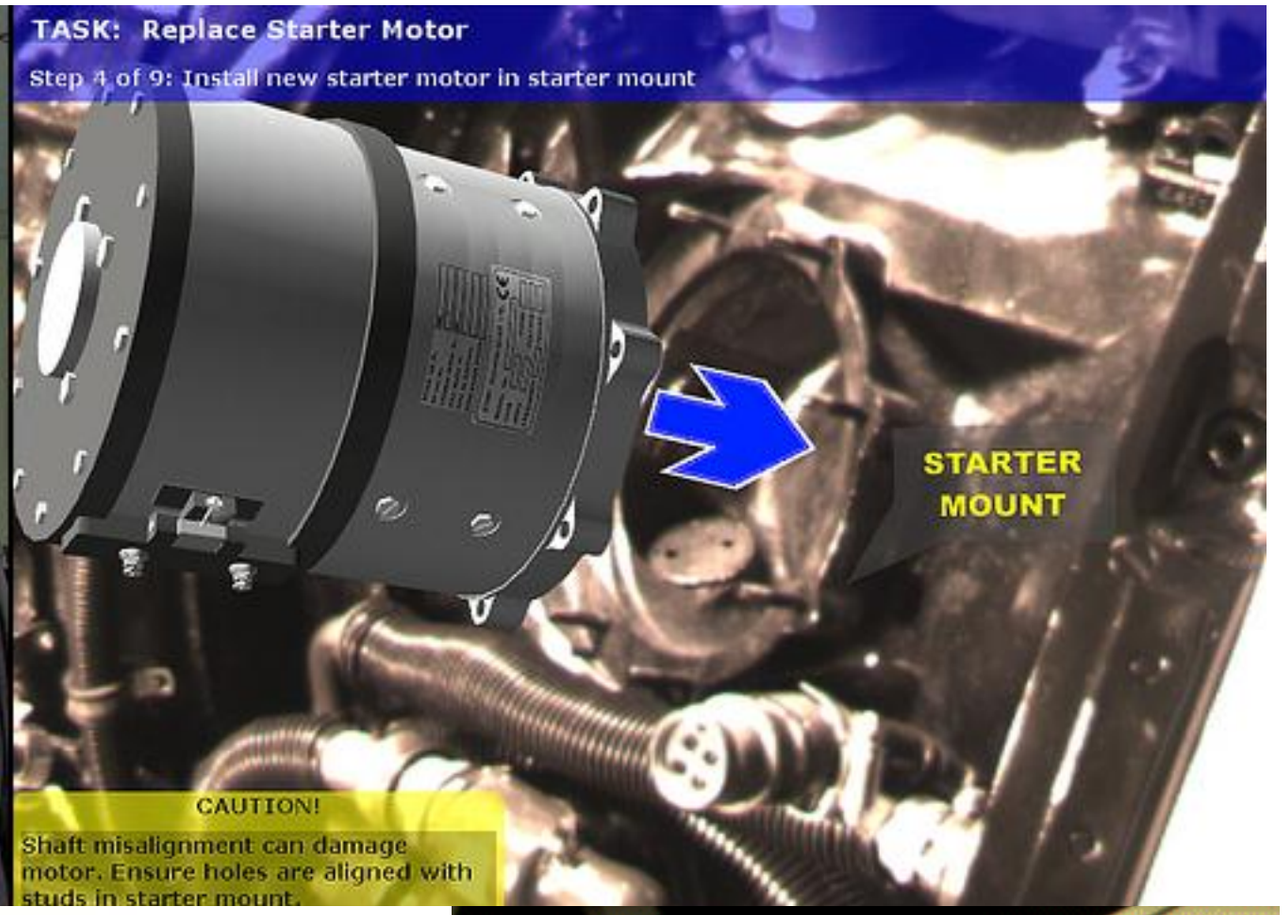
- Functional MRI
- Blood concentration correlates with brain activity

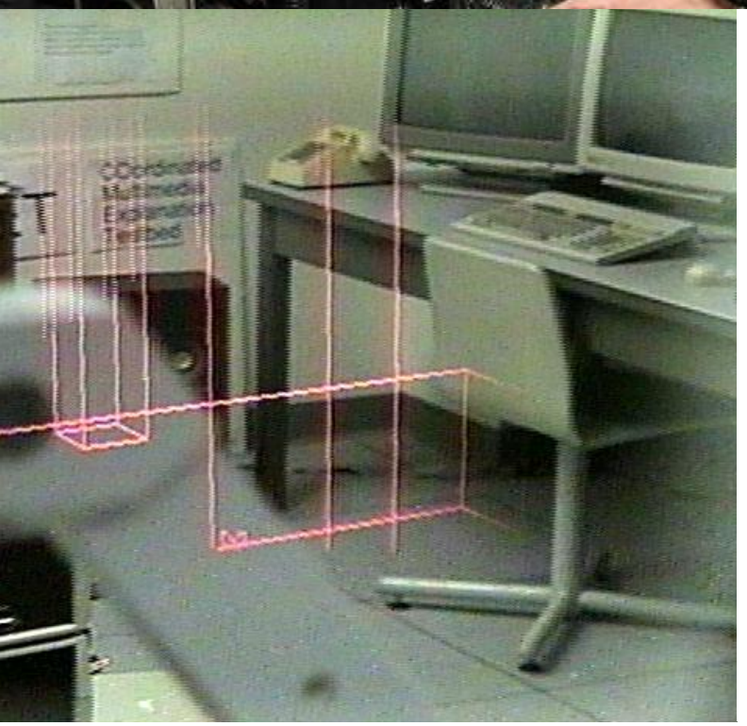


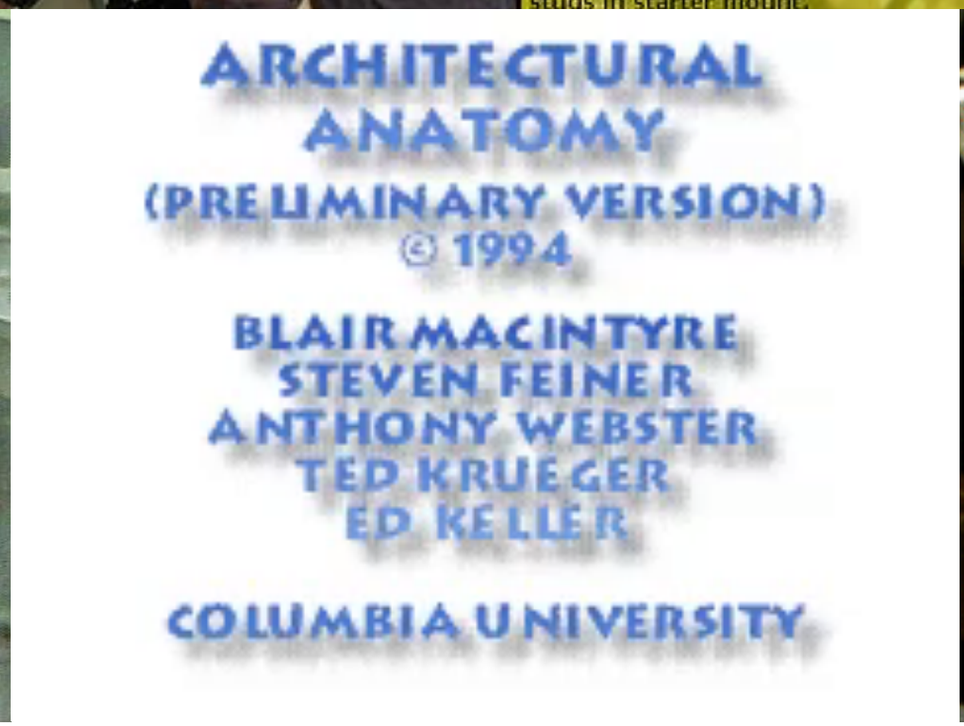
Augmented reality

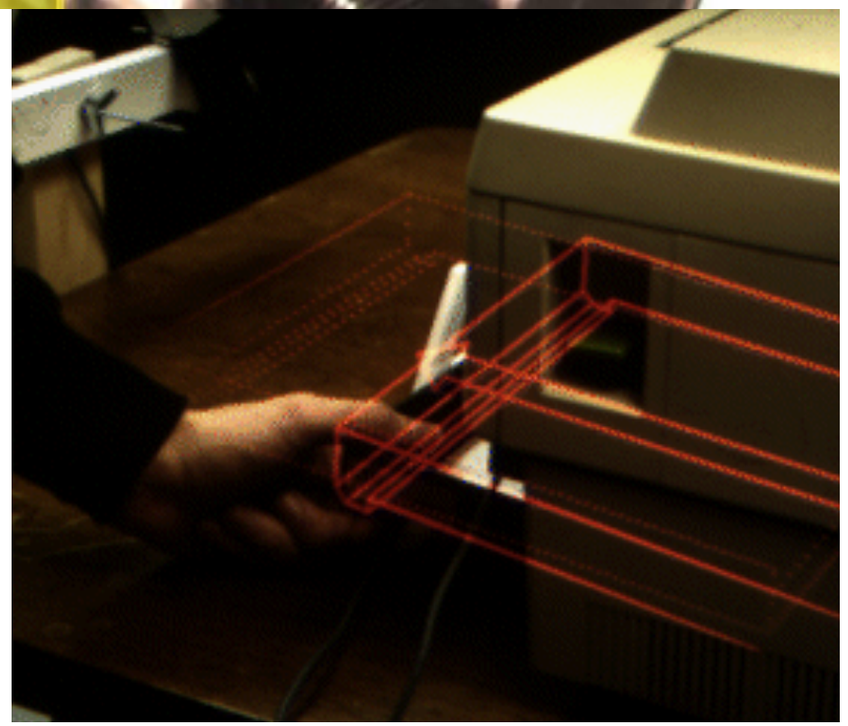
Steve Feiner et al.
http://graphics.cs.columbia.edu/project/











Augmented reality in sports

First Down line in American Football



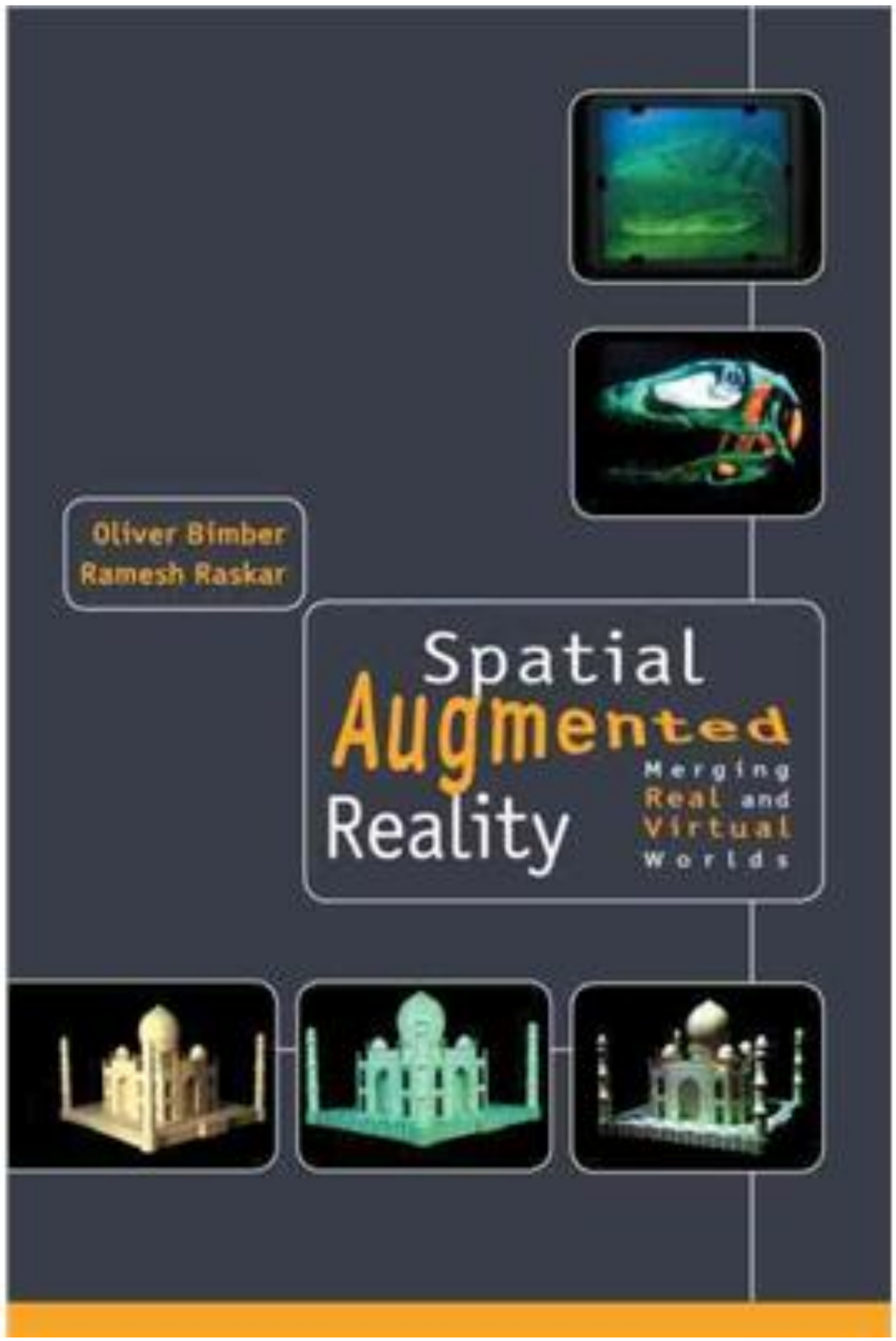
http://www.howstuffworks.com/first-down-line.htm
http://www.youtube.com/watch?v=UyPU2I9rdvo

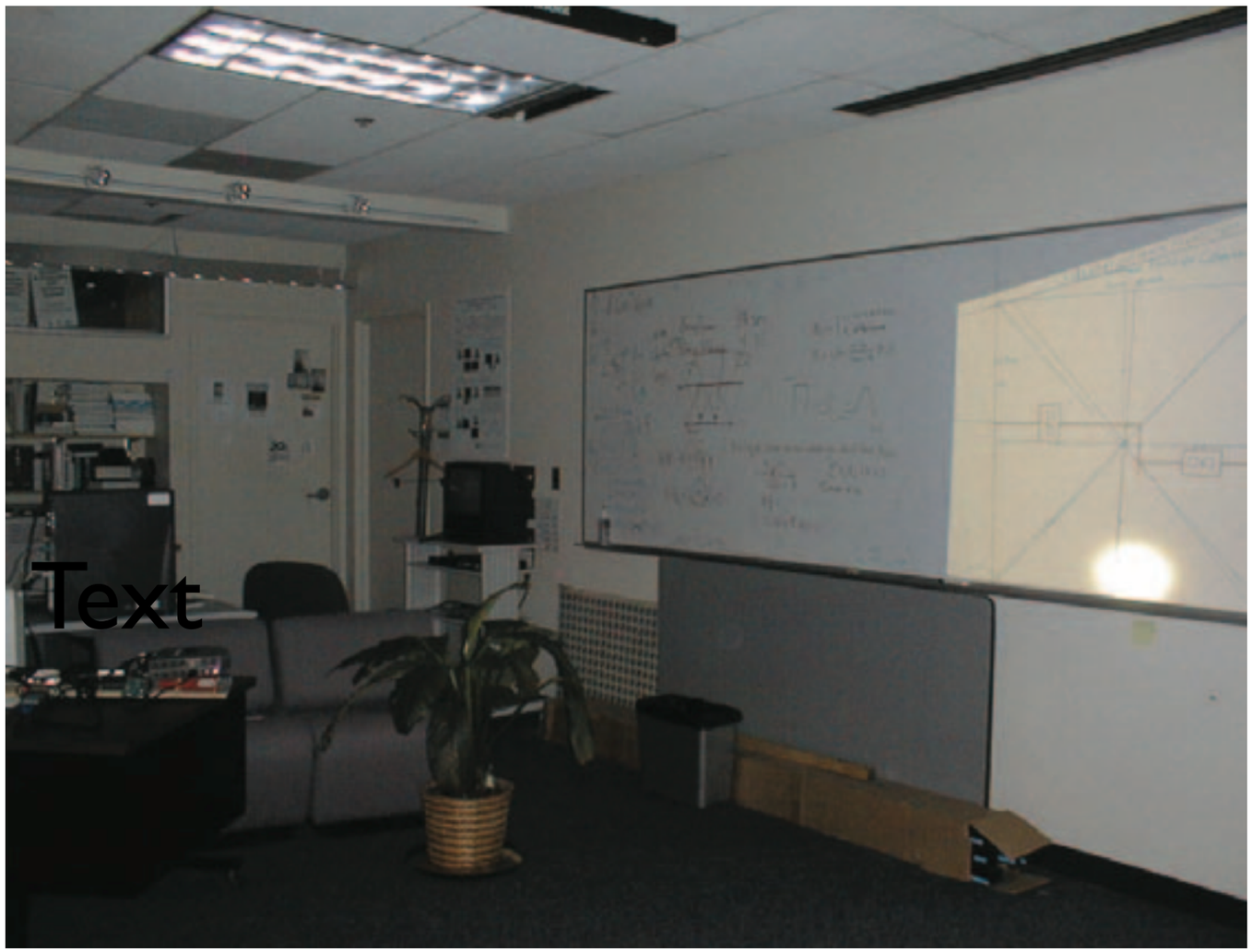
FoxTrax in Hockey



http://ictvictor.wordpress.com/tag/foxtrax/

Spatial augmented reality





An electrical diagram is projected onto the wall
Teller et al.

http://people.csail.mit.edu/jiawen/cgna03/IEEECGApervasive.pdf

Sculpting by numbers

- [Rivers, Adams & Durand, Siggraph Asia 2012, Skeels & Rehg 2007]
- Goal: sculpt a given 3D shape
- projector + camera scan the current artifact and project feedback



(a) Target 3D model



(b) Guidance projected onto material

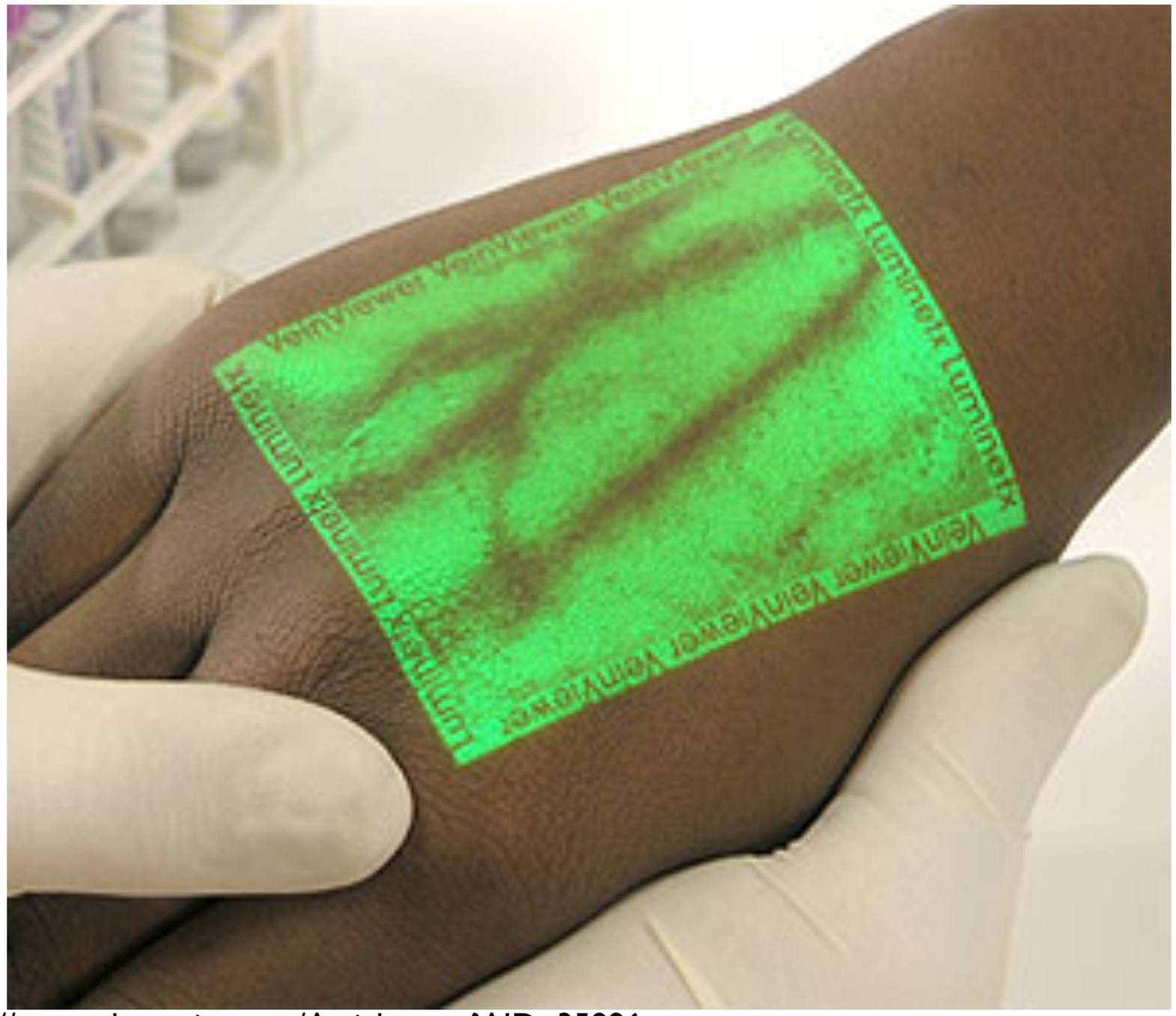


(c) Sculpted physical replica

Lumitex VeinViewer

- and AccuVein



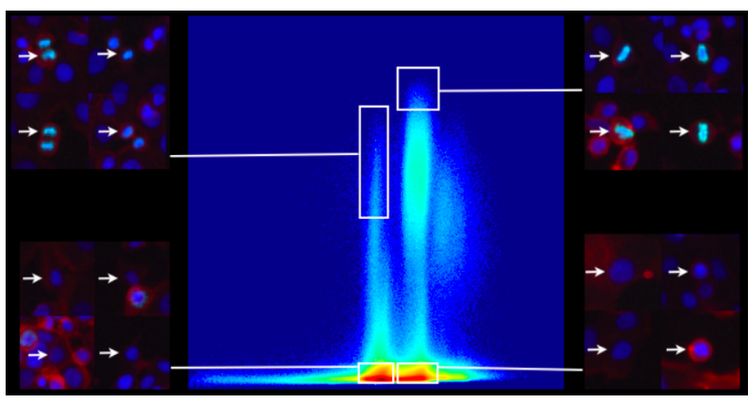


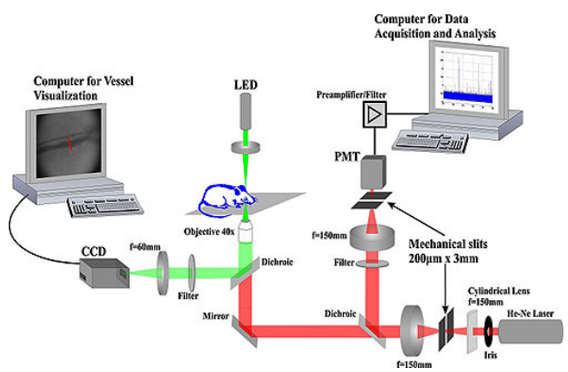
http://www.photonics.com/Article.aspx?AID=35886

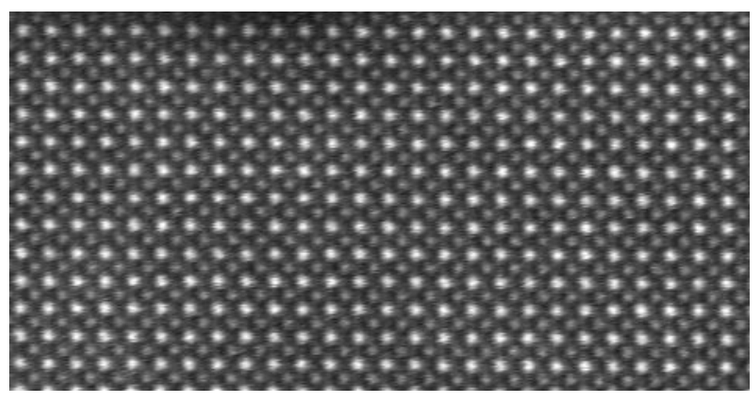
http://txch.org/news/news-archives/stanford-financial-donates-luminetx-vein-viewer-to-cancer-center/

Most sensing is optical

- X-ray diffraction crystallography
- Spectroscopy
- Fluorescent dyes, light-emitting enzymes
- DNA Sequencing
- Flow cytometry (cell classification)
- High-throughput cell screening

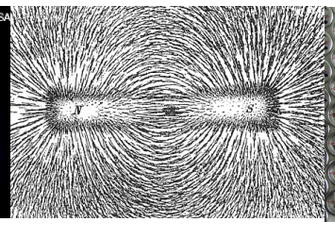
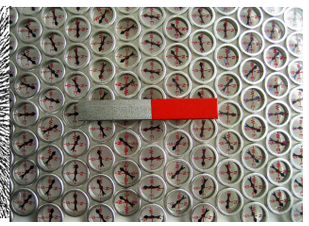
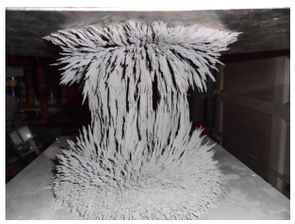




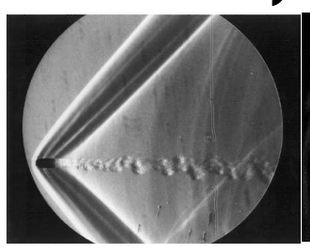


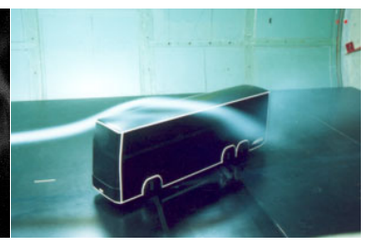
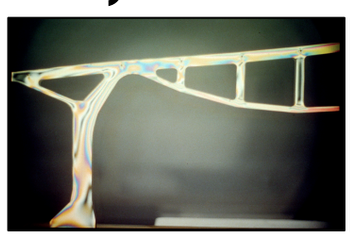
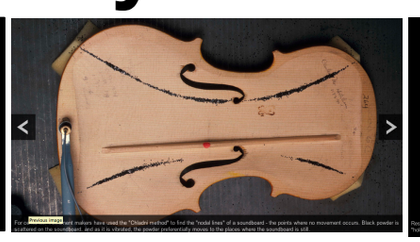
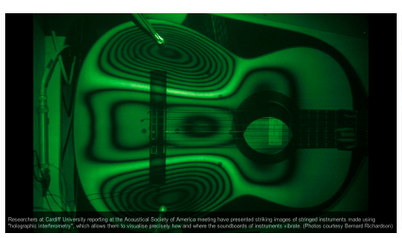
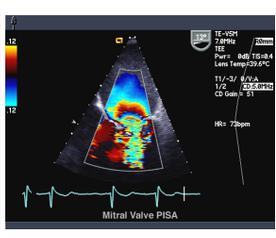
Recap: non visual phenomena

- Temperature, EM field, wifi

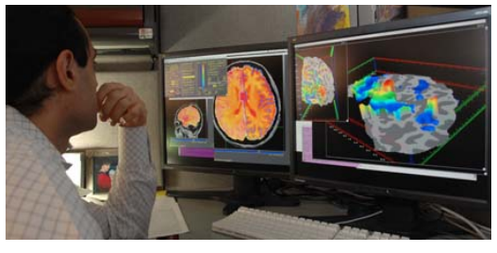






- Sound, air flow, particle trajectories, material stress, vibration modes, velocity



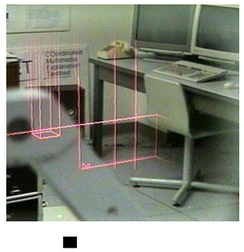






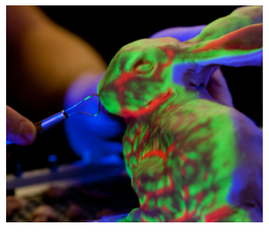
- Brain function



- Augmented reality, spatial AR




- **Most sensing is optical!**

Main ideas

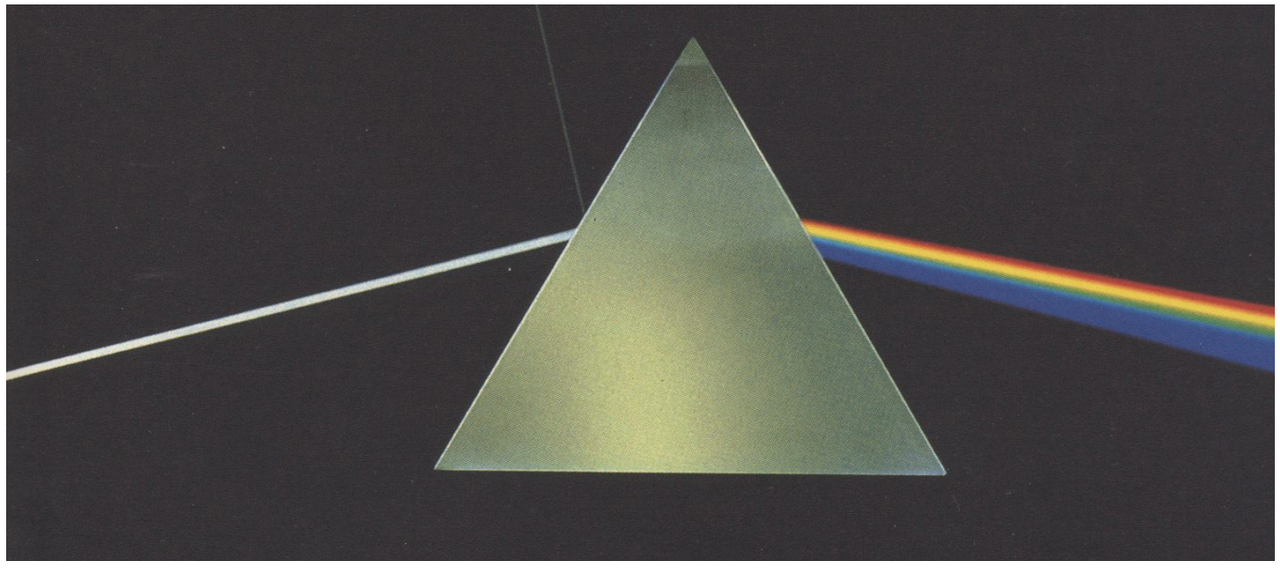
- The phenomenon modifies visual properties (phase & refraction, polarization)
- Add visual elements that are affected by the phenomenon (powder, smoke, etc.)
  - Attach visible stuff (fluorescent dye, light emitting enzymes)
- Convert to visible wavelengths (fluorescence)
- Interferences
- Augmented Reality

Overview

- Limits of human vision
- Occlusion
- Non-visual phenomena
- **Non-visible visual phenomena**
- Change and motion

Newton’s demo





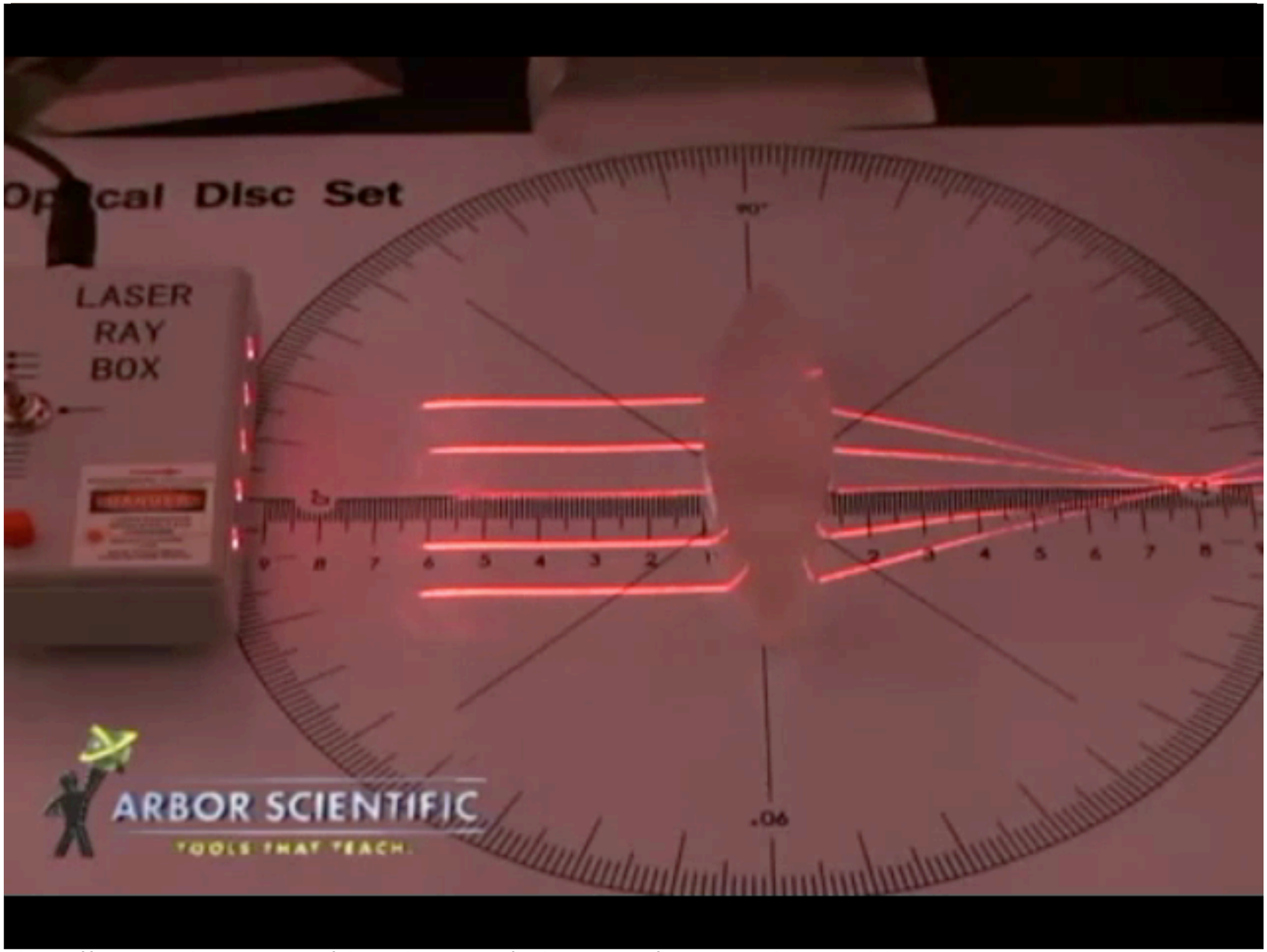
Pink Floyd, *The Dark Side of the Moon*



Pittoni, 1725, Allegory to Newton

Optics demo

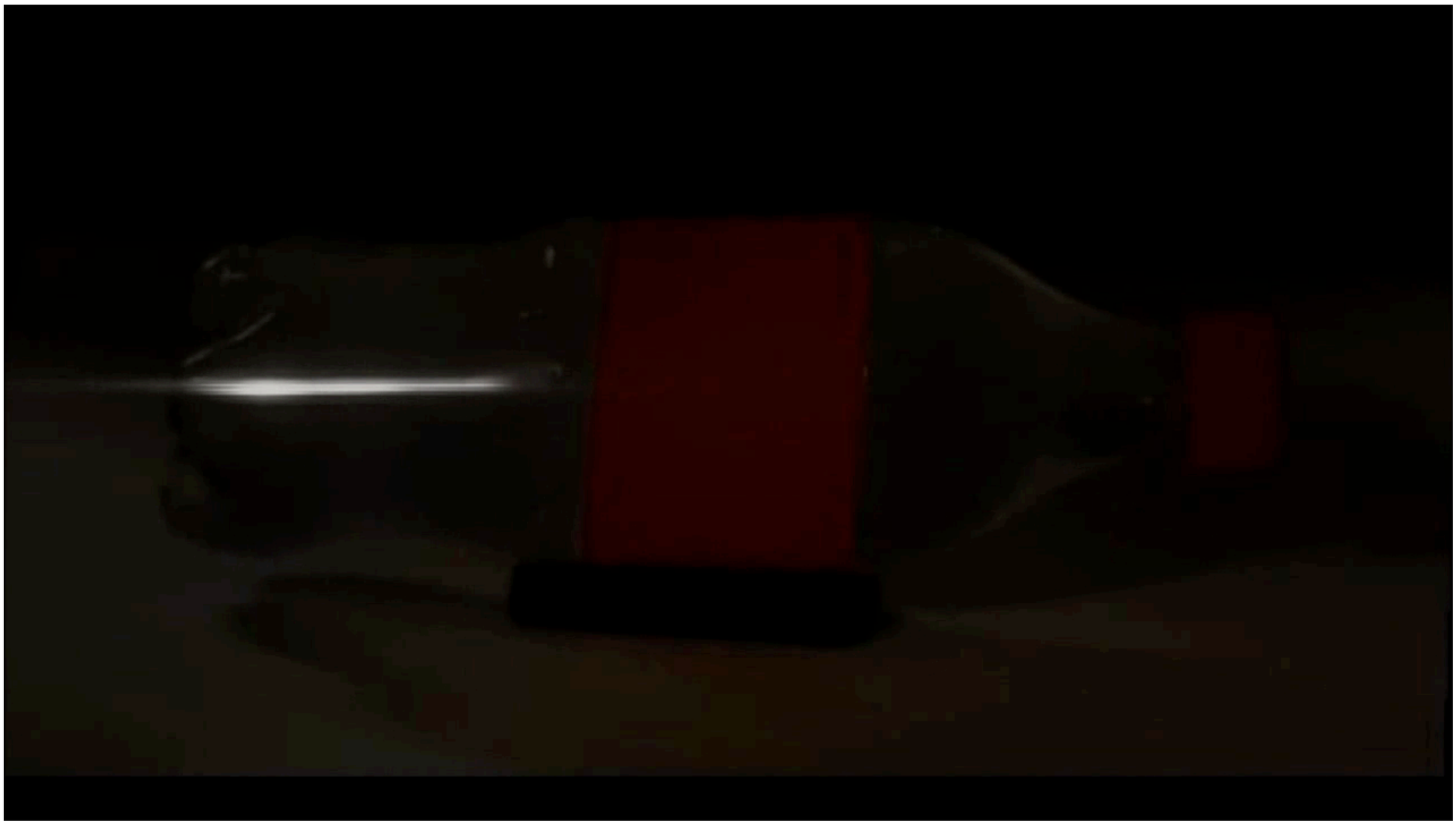
- Light box, smoke



http://www.arborsci.com/shop-by-topic/light-optics/laser-ray-box-and-lenses

Light propagation

- Raskar, Velten et al.



http://web.media.mit.edu/~raskar/trillionfps/

Direct vs indirect

Fast Separation of Direct and Global Components of a Scene using High Frequency Illumination

Shree K. Nayar* Columbia University

Gurunandan Krishnan† Columbia University

Michael D. Grossberg‡ City University of New York

Ramesh Raskar§ MERL



(a) Scene



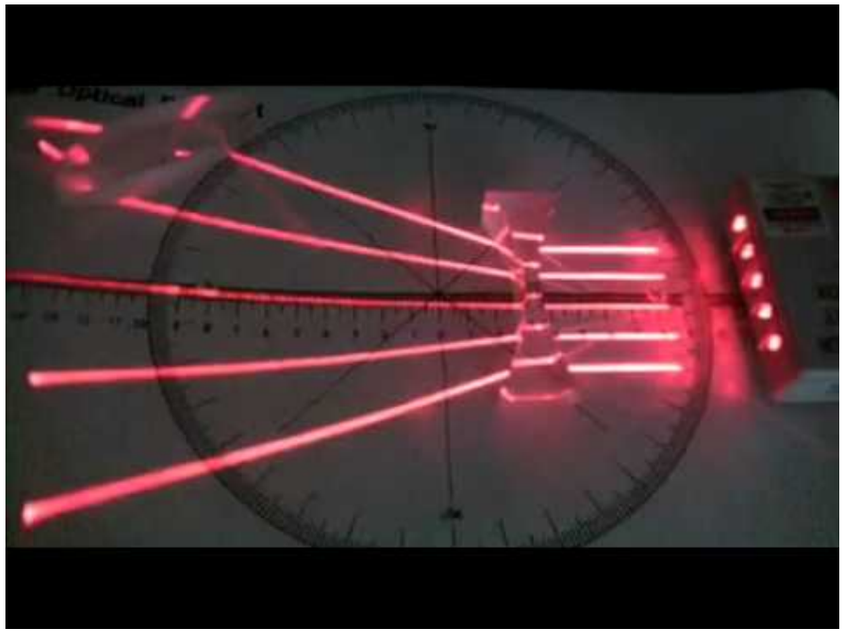
(b) Direct Component

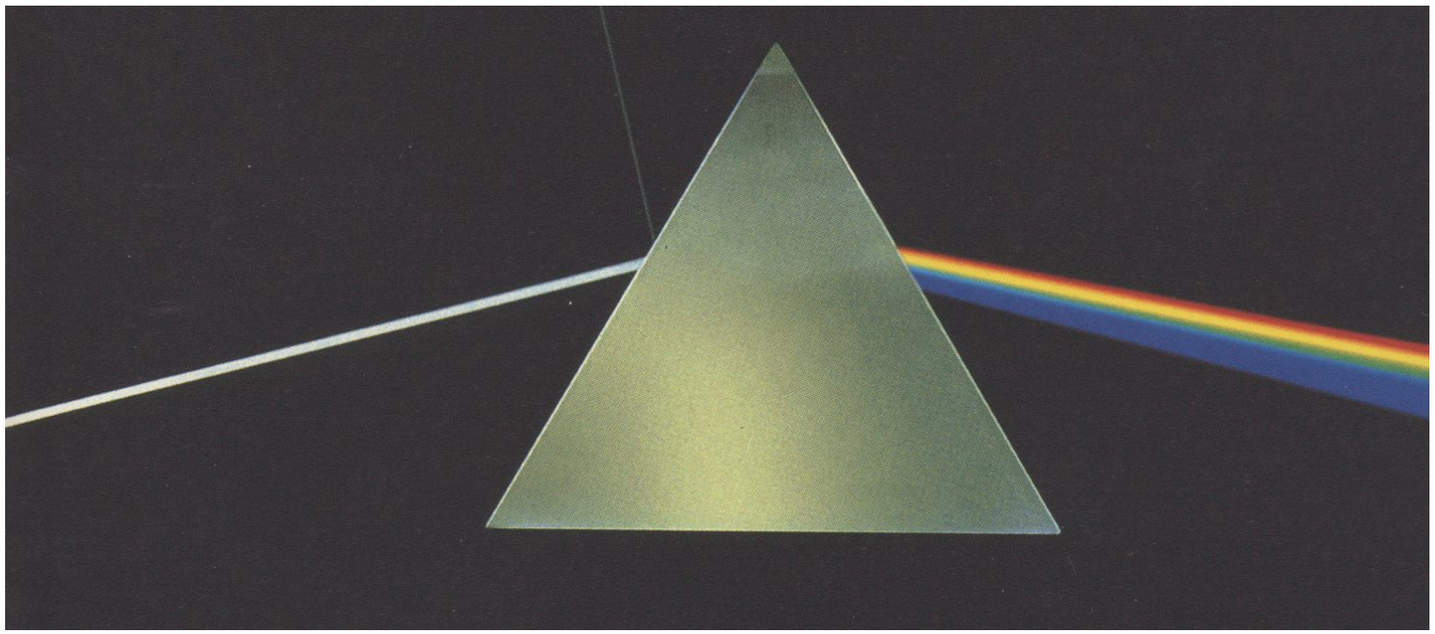


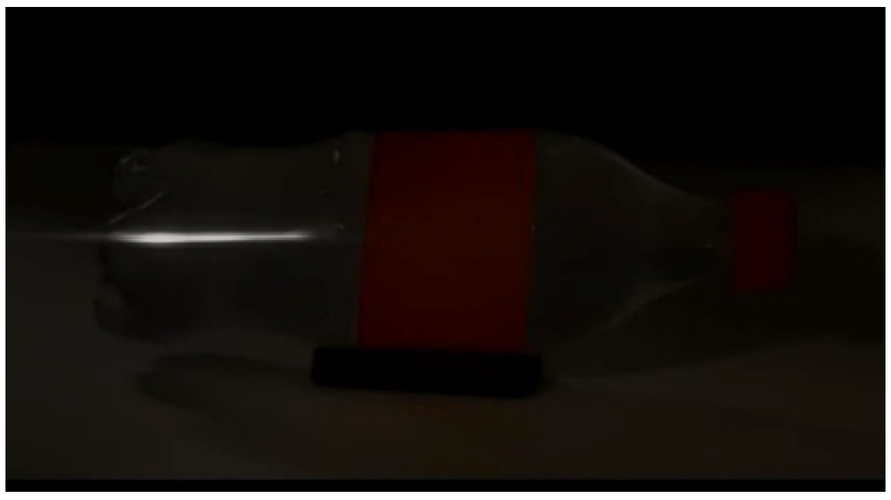
(c) Global Component

Recap: non-visible visual

- Reveal optics!









(b) Direct Component



(c) Global Component

Overview

- Limits of human vision
- Occlusion
- Non-visual phenomena
- Non-visible visual phenomena
- **Change and motion**

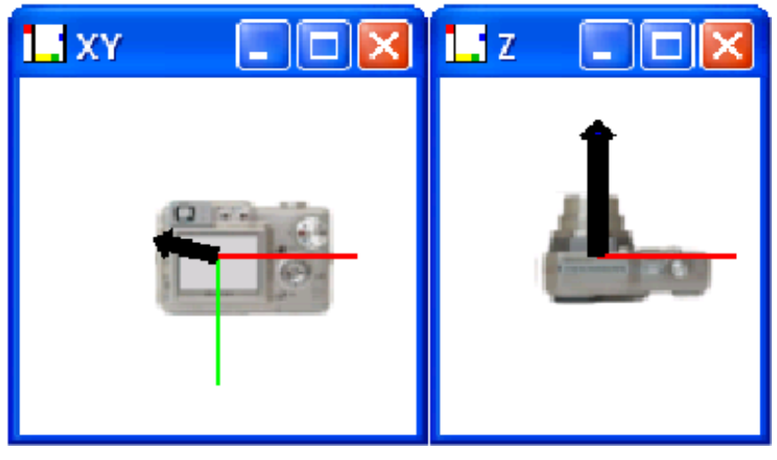
Rephotography

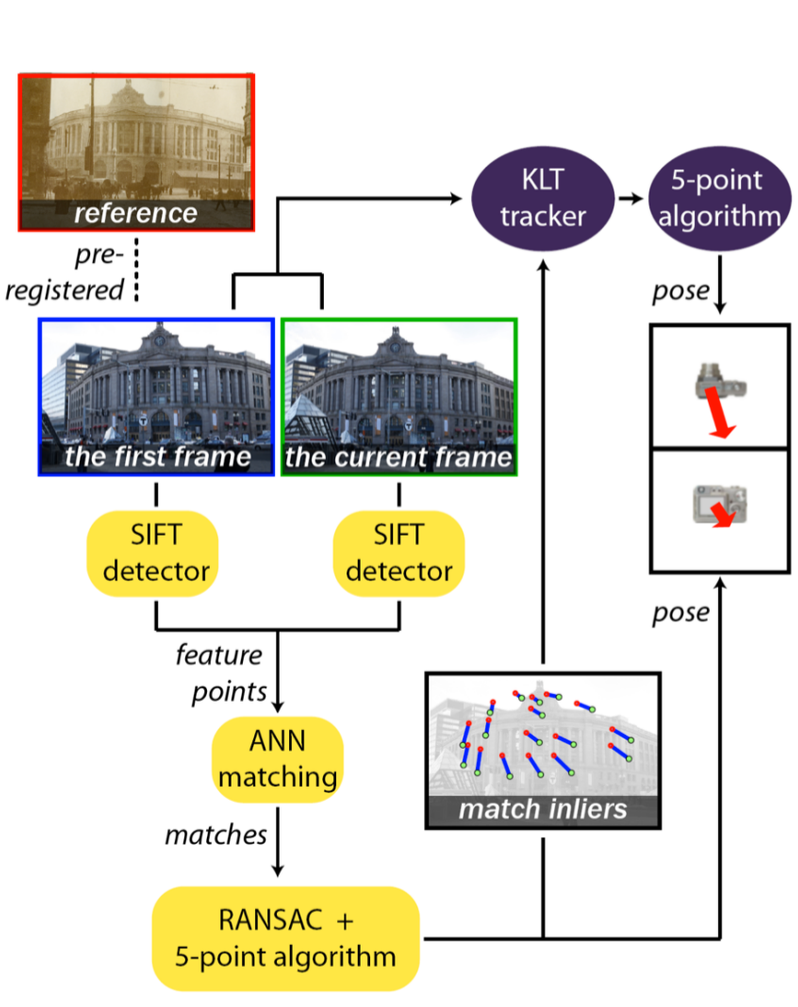


Computational Re-Photography

- *With Soonmin Bae and Aseem Agarwala*
- Given reference (old) photograph
- Take new photo at the exact same viewpoint
- Our method: the camera guides the user
  - camera tethered to a laptop
  - pose estimation
  - visualization







Results after Style Transfer



Results after Style Transfer



Web rephotography



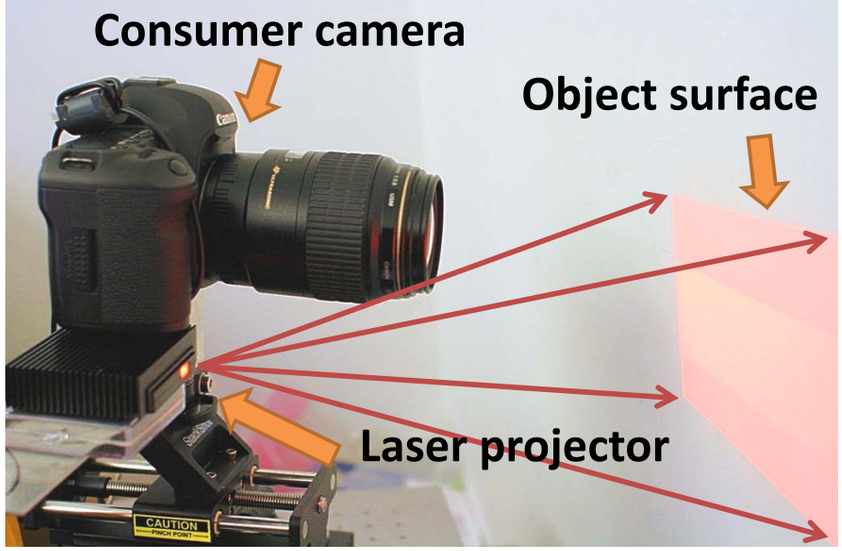
Shrivastava, Malisiewicz, Gupta & Efros 2011

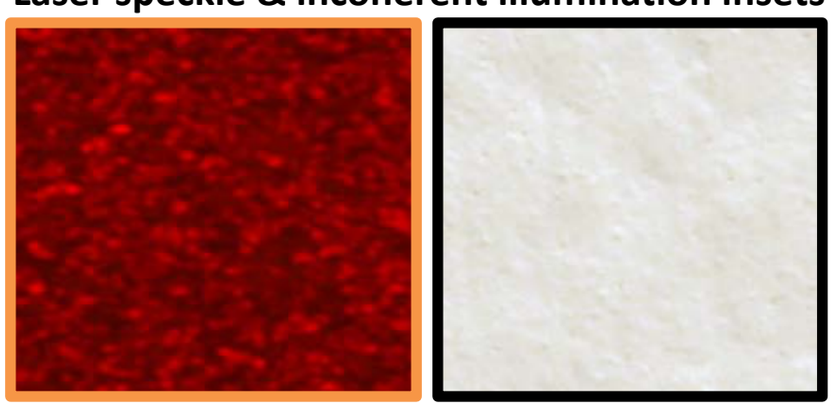
Speckle Imaging to reveal surface tampering

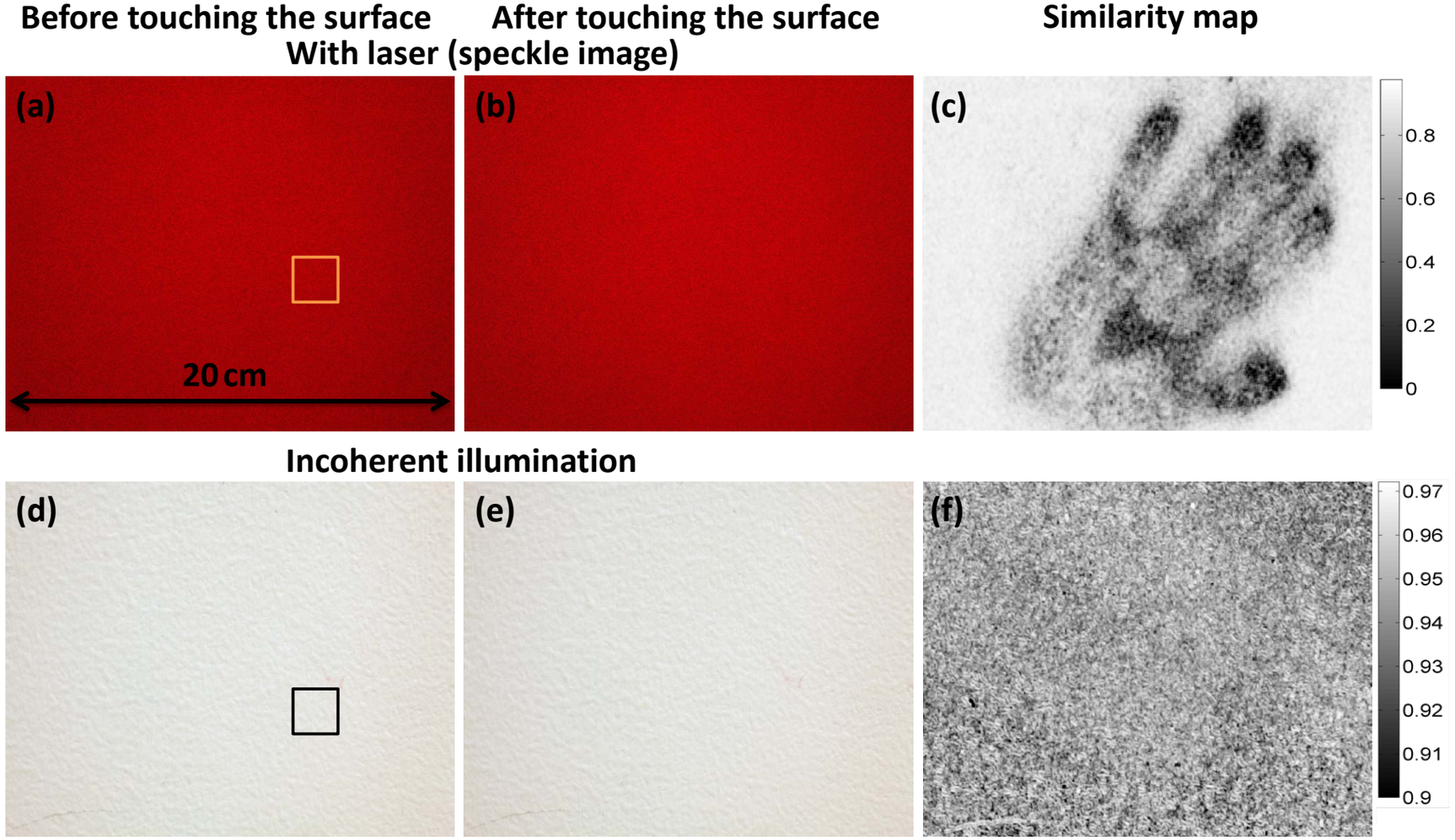
Yichang Shih, Abe Davis, Samuel Hasinoff, Bill Freeman, Fredo Durand

Speckle imaging

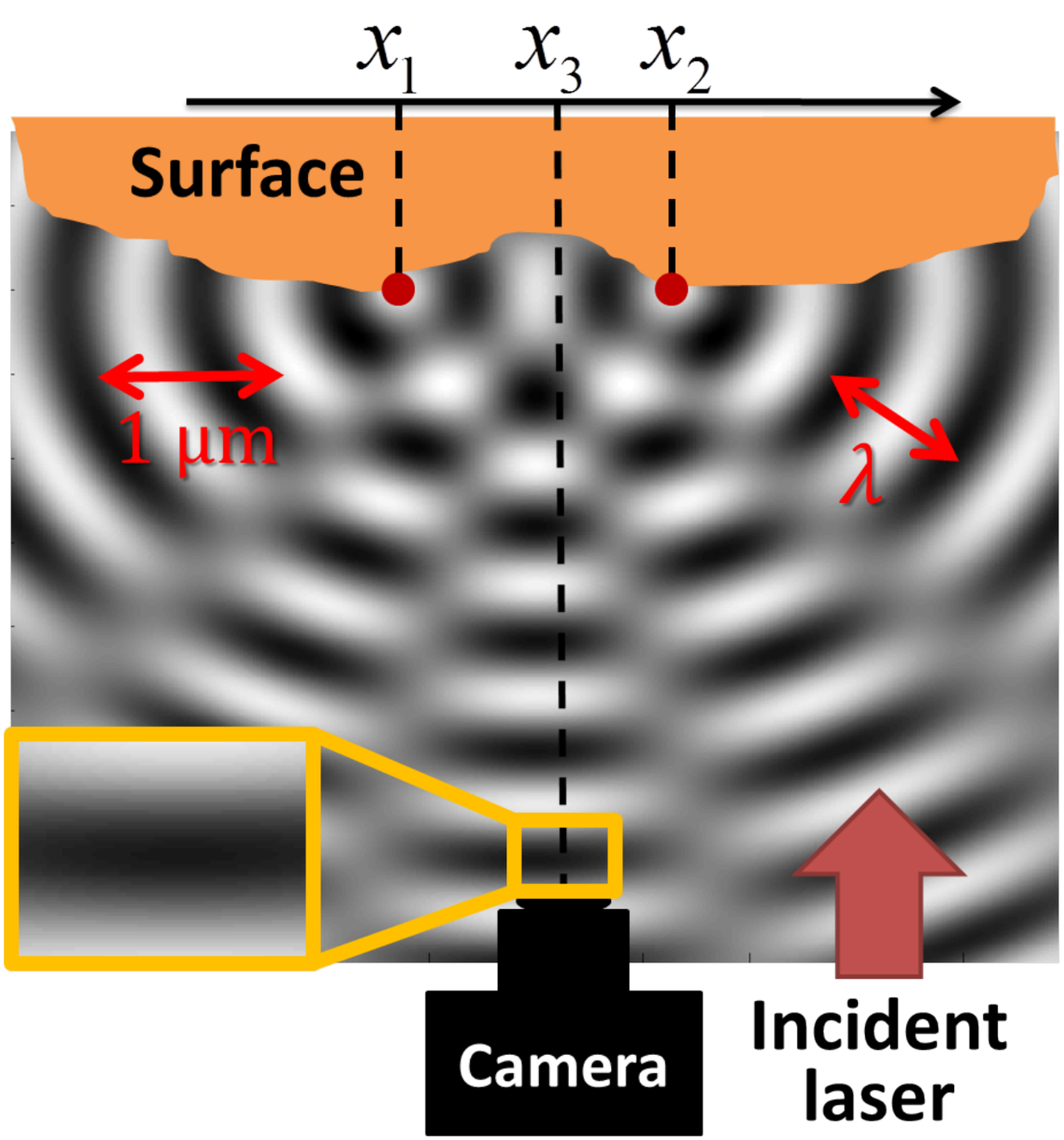
- **Reveal invisible tampering**
  - use difference in speckle pattern
  - small surface alterations affect the phase of the laser
  - change interference pattern
  - challenge: reposition the camera at the same location

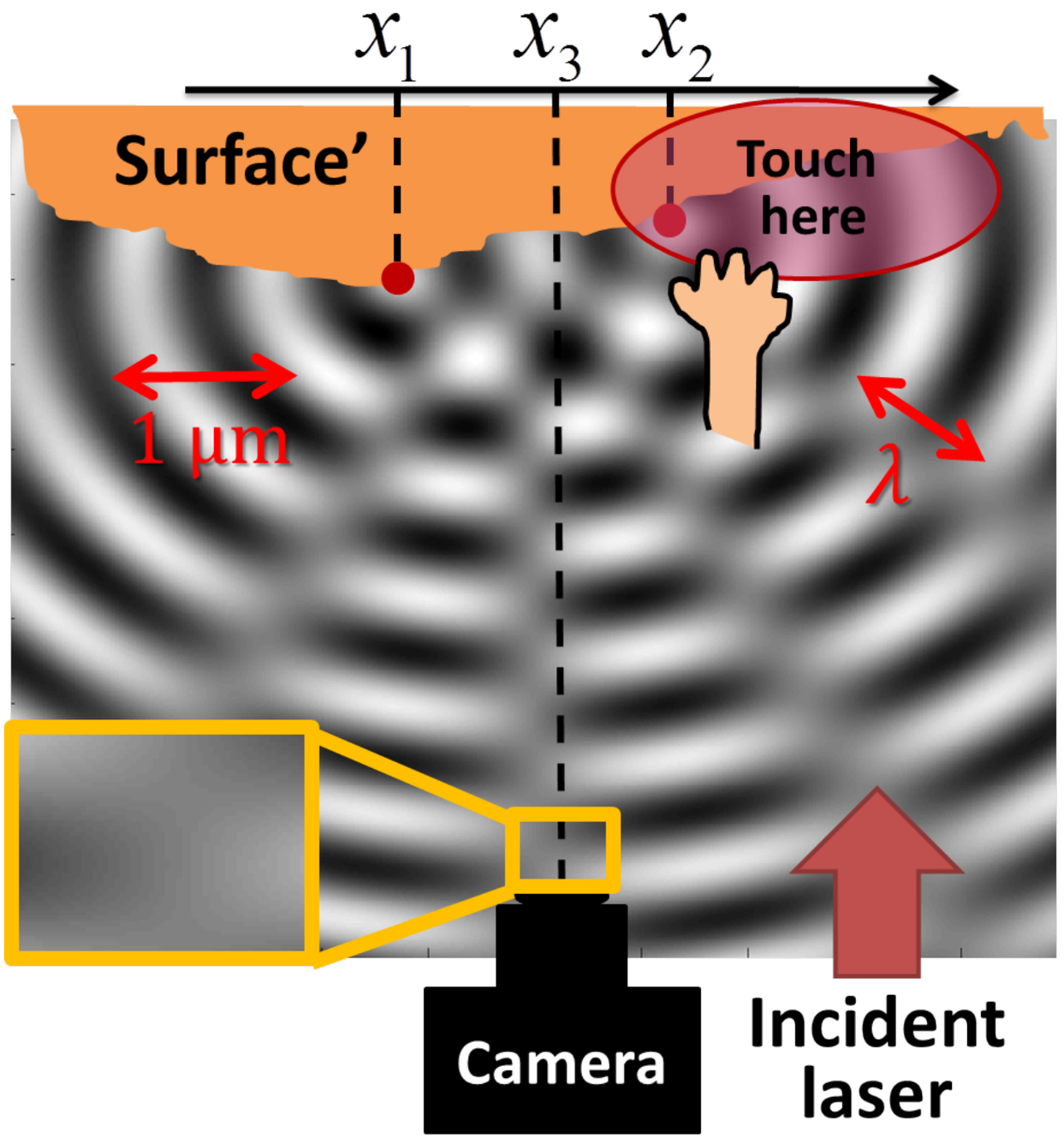




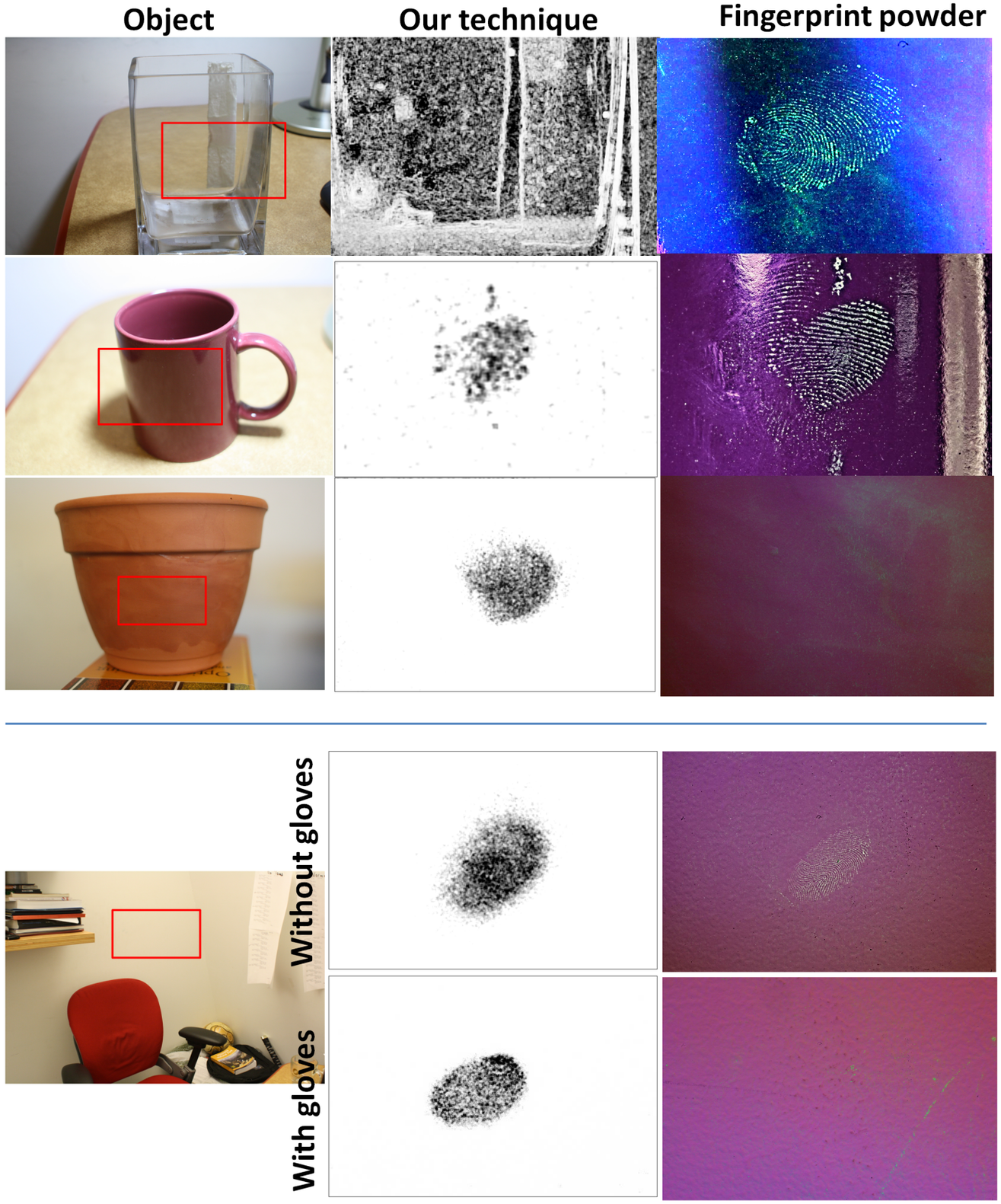


Principle

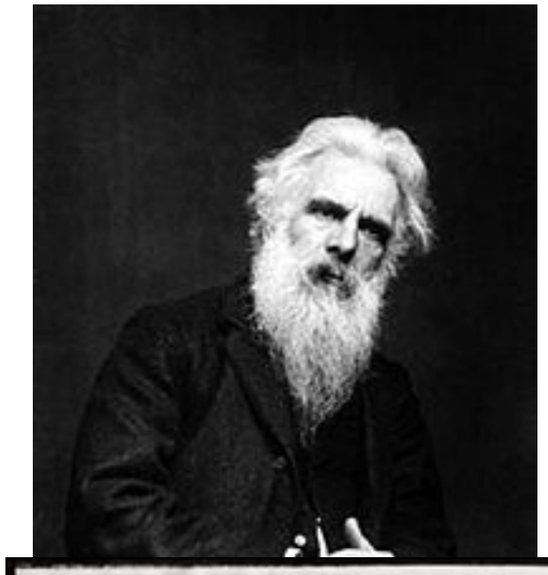

x_1
x_3
x_2
Surface
1 µm
λ
Camera
Incident laser


x_1
x_3
x_2
Surface'
Touch here
1 µm
λ
Camera
Incident laser

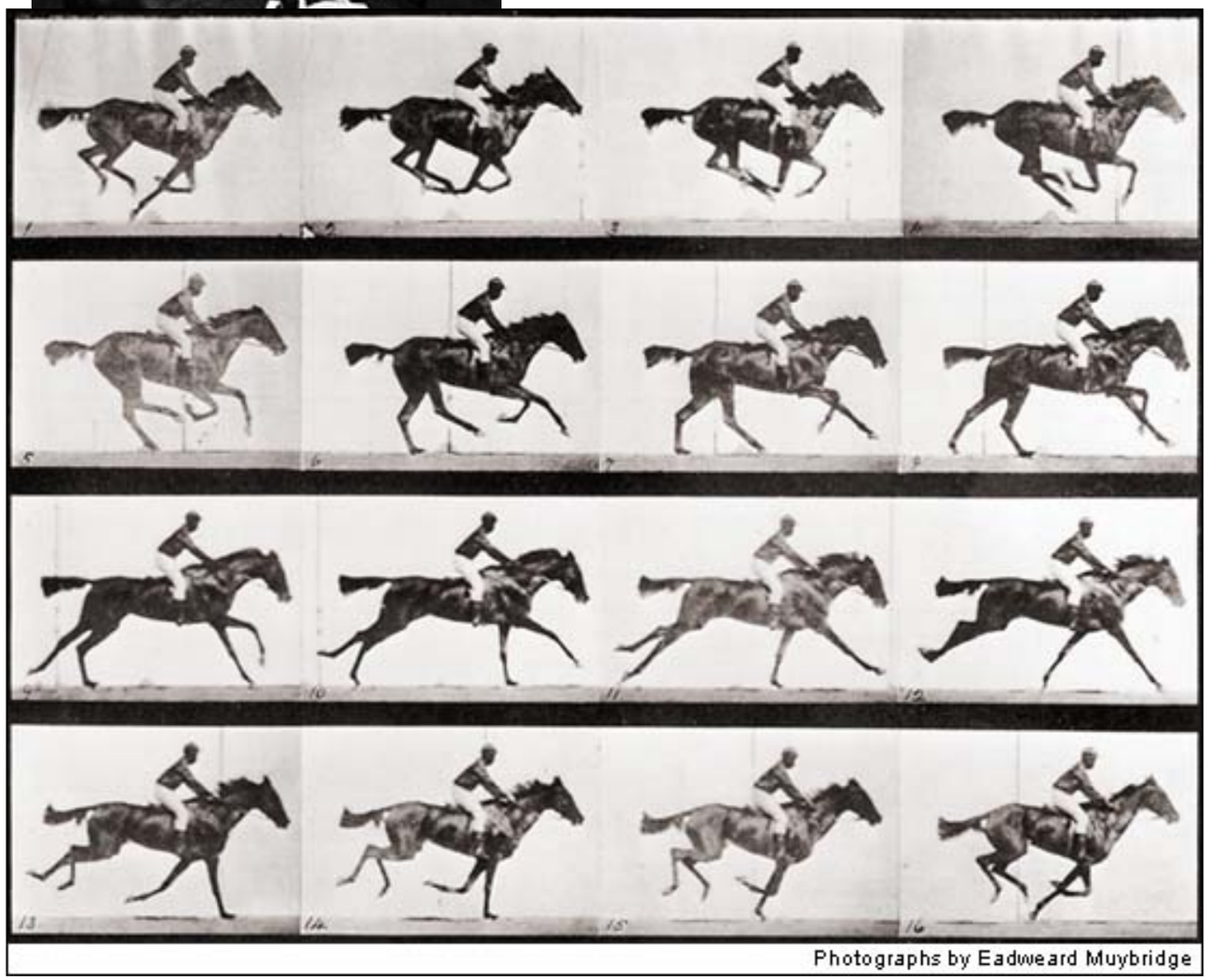
Comparison with fingerprint powder



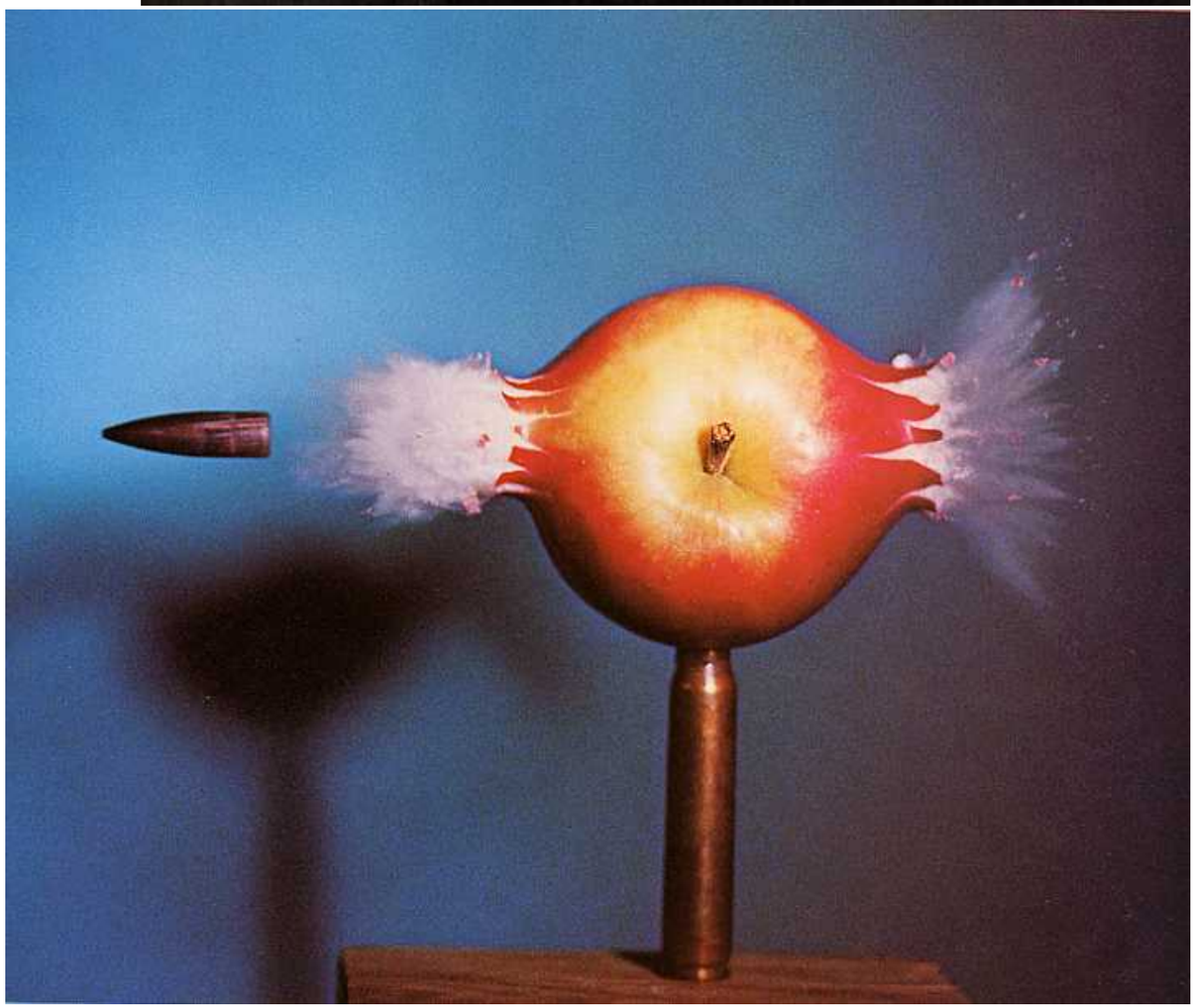
Too fast



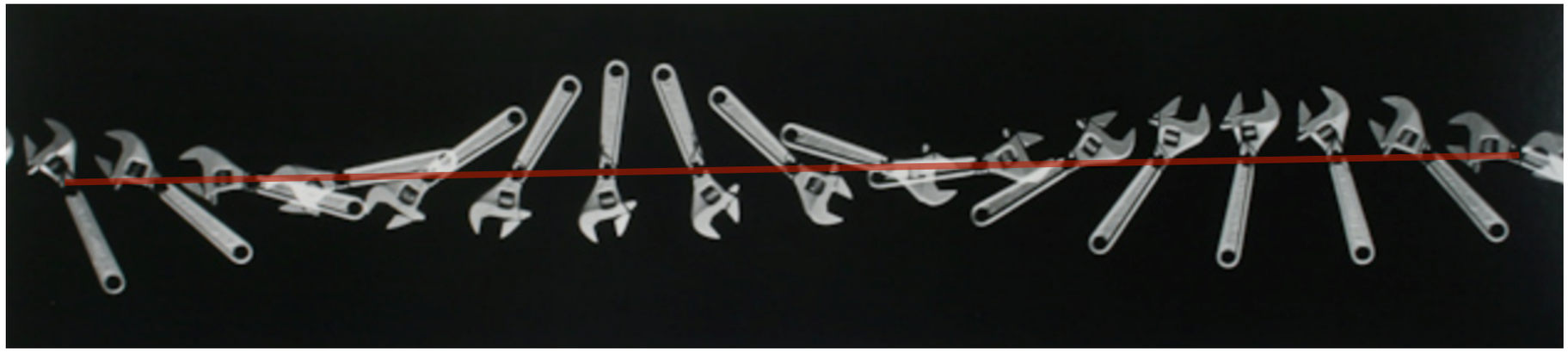




Photographs by Eadweard Muybridge



Trajectories



Abbott

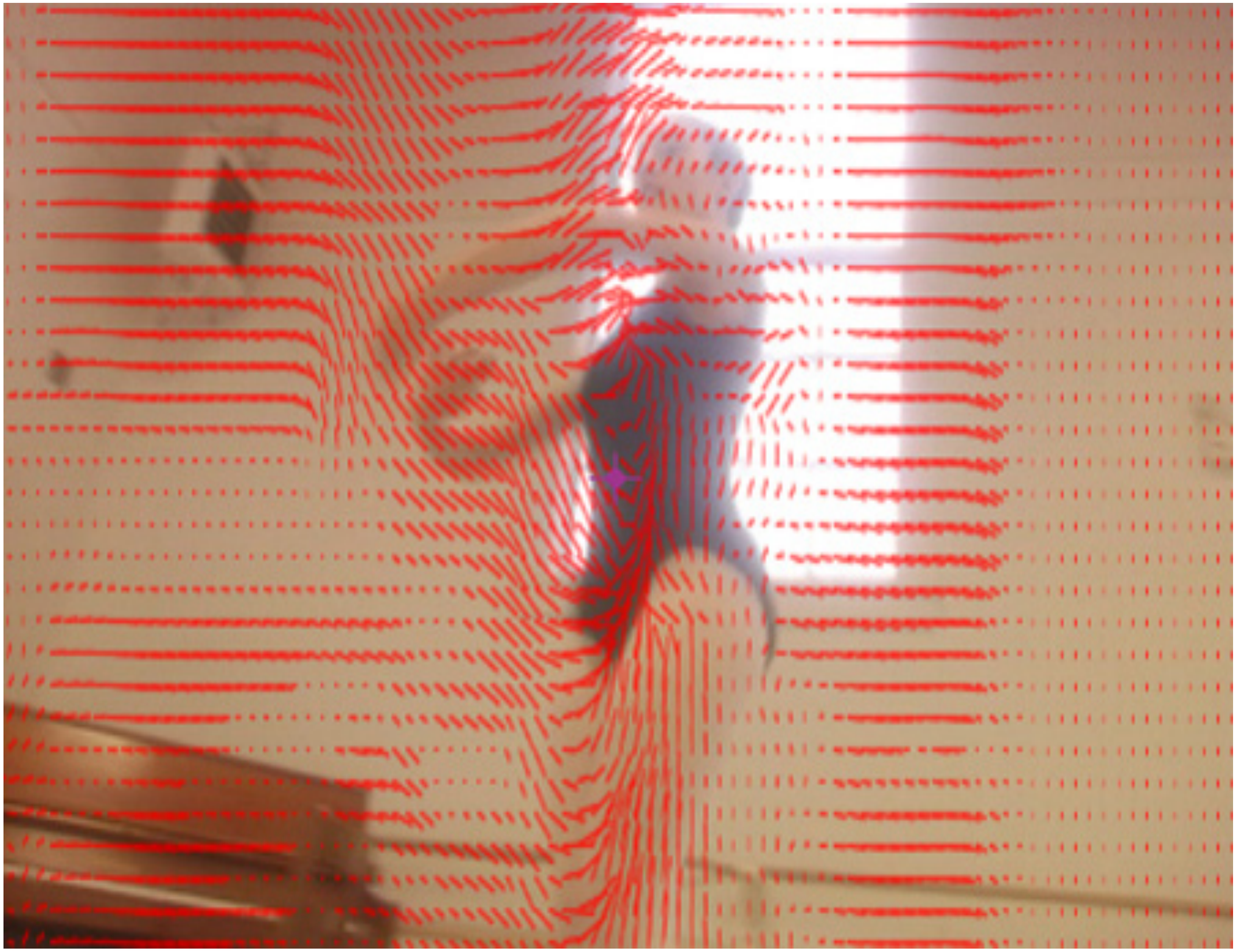


Edgerton



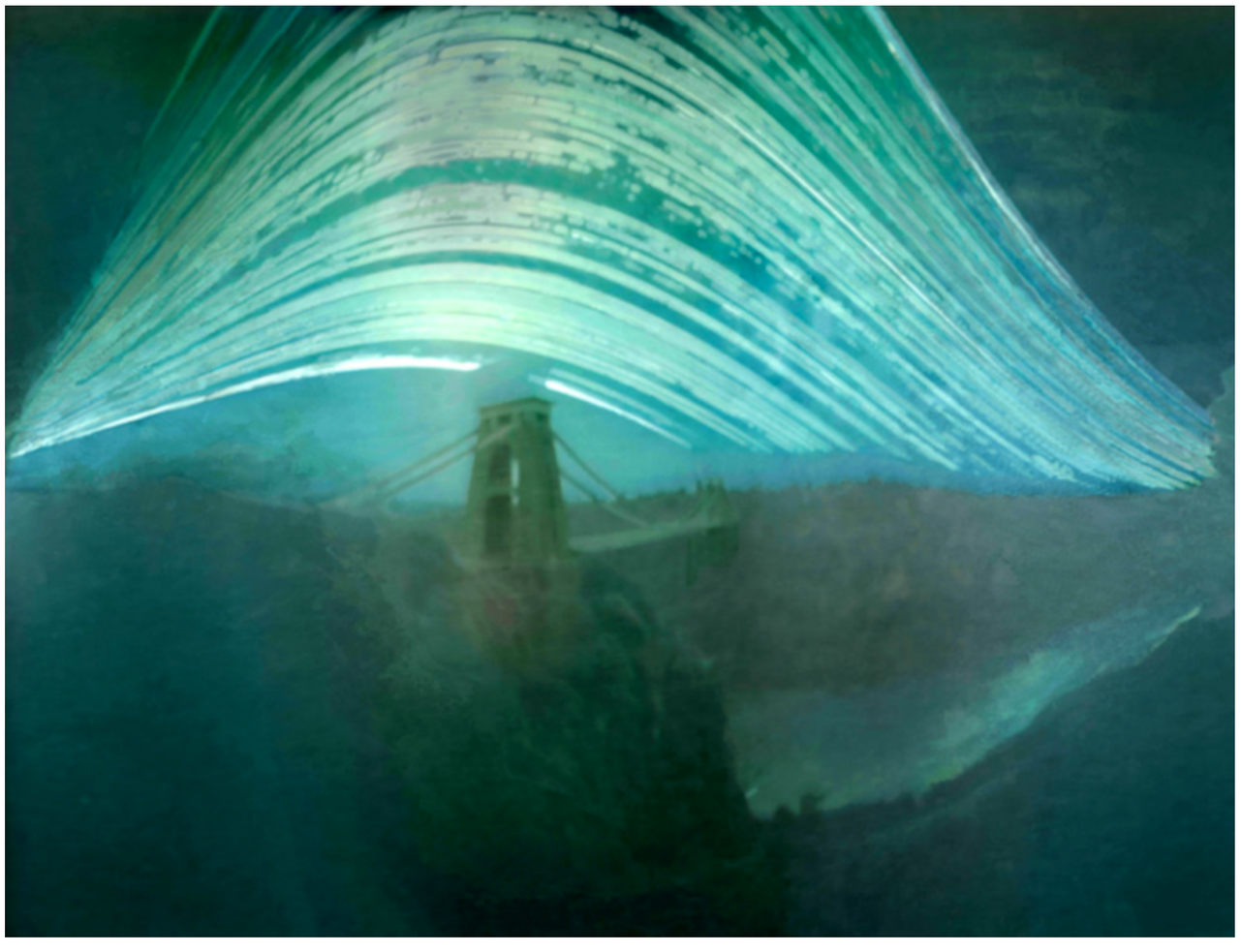
Freeman & Zhang Shape time photography

Optical flow vectors



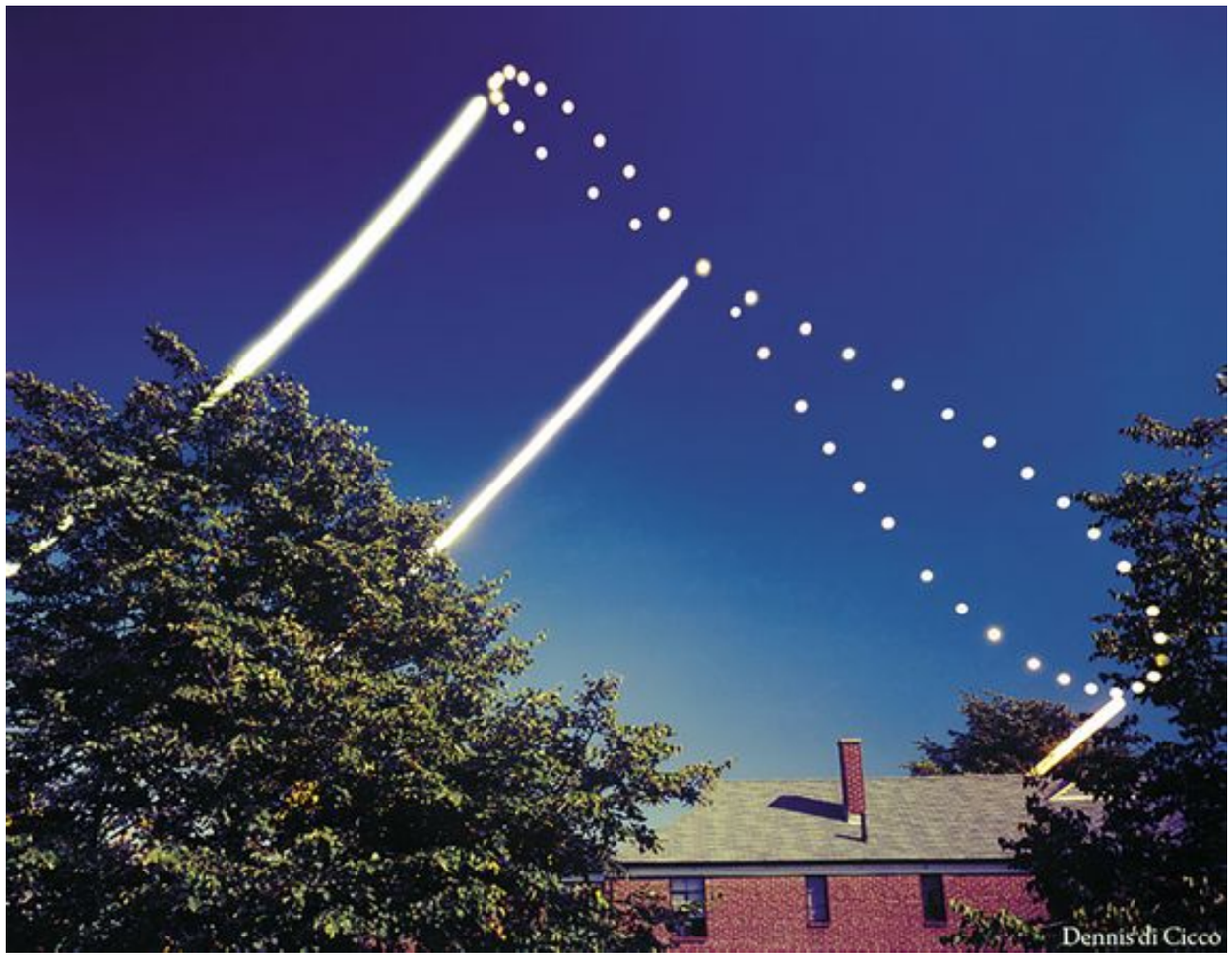
http://www.borisfx.com/avid/bccavx/classic_features.php

Sun over a year



6-month exposure
by Justin Quinnell

http://www.pinholephotography.org/gallery/slow/index.html



First ever analemma picture
by Dennis di Cicco, 1978-1979

http://news.nationalgeographic.com/news/2010/12/photogalleries/101228-sun-end-year-analemmas-solstice-eclipse-pictures/#/year-in-picture-analemma-sun-path-first_30693_600x450.jpg

Motion magnification

- With Ce Liu et al. [Siggraph 2005]
- Analyze motion in video (robust to occlusion)
- Magnify motion that is hard to see



Motion magnification

- With Ce Liu et al. [Siggraph 2005]
- Analyze motion in video (robust to occlusion)
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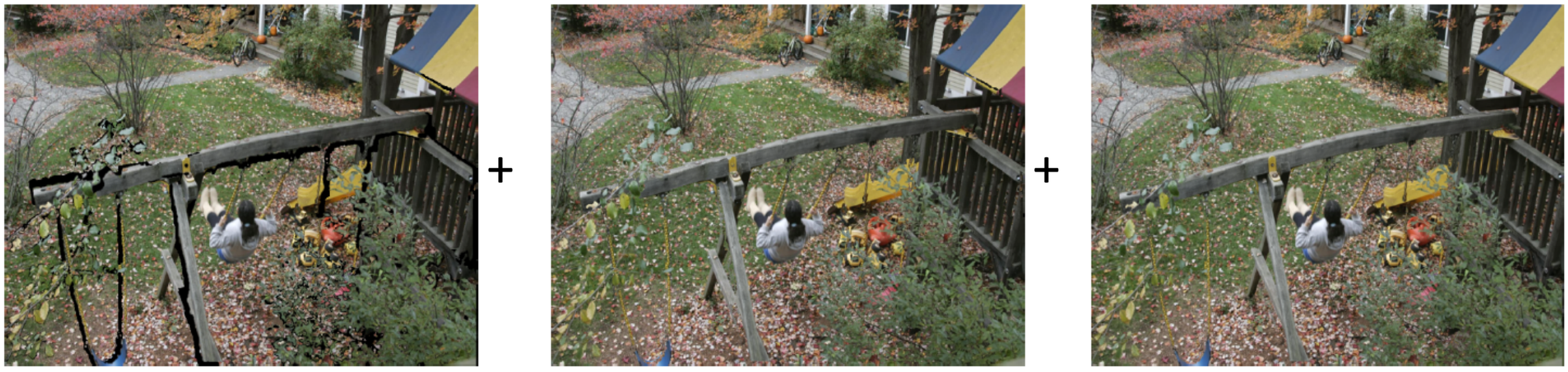




Related Work: Motion Magnification [Liu 2005]



(a) Registered input frame (b) Clustered trajectories of tracked features (c) Layers of related motion and appearance



(d) Motion magnified, showing holes (e) After texture in-painting to fill holes (f) After user's modifications to segmentation map in (c)

Liu et al. ***Motion Magnification***, 2005

Eulerian Video Magnification

for Revealing Subtle Changes in the World

Hao-Yu Wu[1] **Michael Rubinstein[1]** **Eugene Shih[2]** **John Guttag[1]**

Fredo Durand[1] **William T. Freeman[1]**

[1] MIT Computer Science and Artificial Intelligence Lab (CSAIL)

[2] Quanta Research Cambridge, Inc.

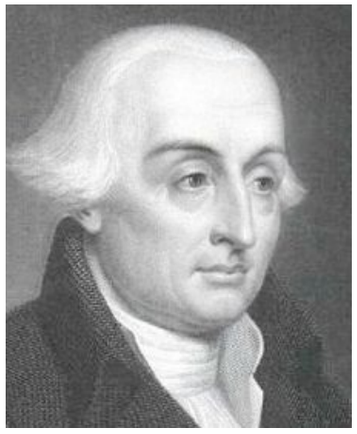
Massachusetts Institute of Technology

CSAIL

Revealing Invisible Changes In The World

Created for the NSF International Science & Engineering Visualization Challenge 2012

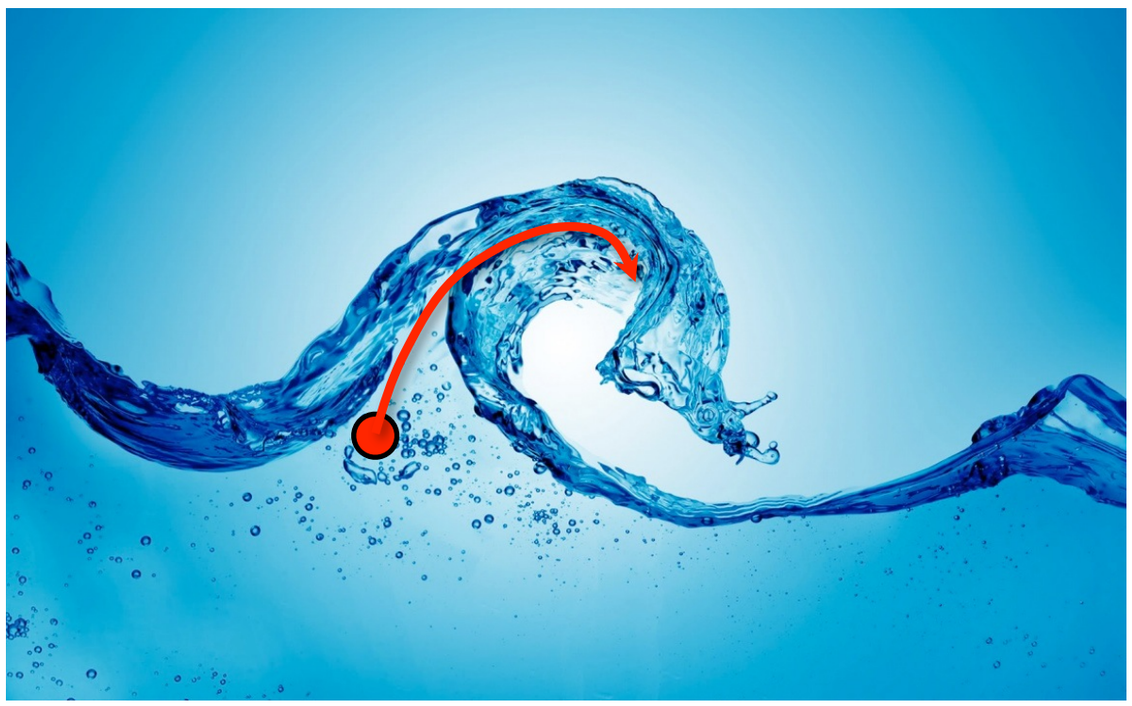
Lagrangian and Eulerian Perspectives: Fluid Dynamics

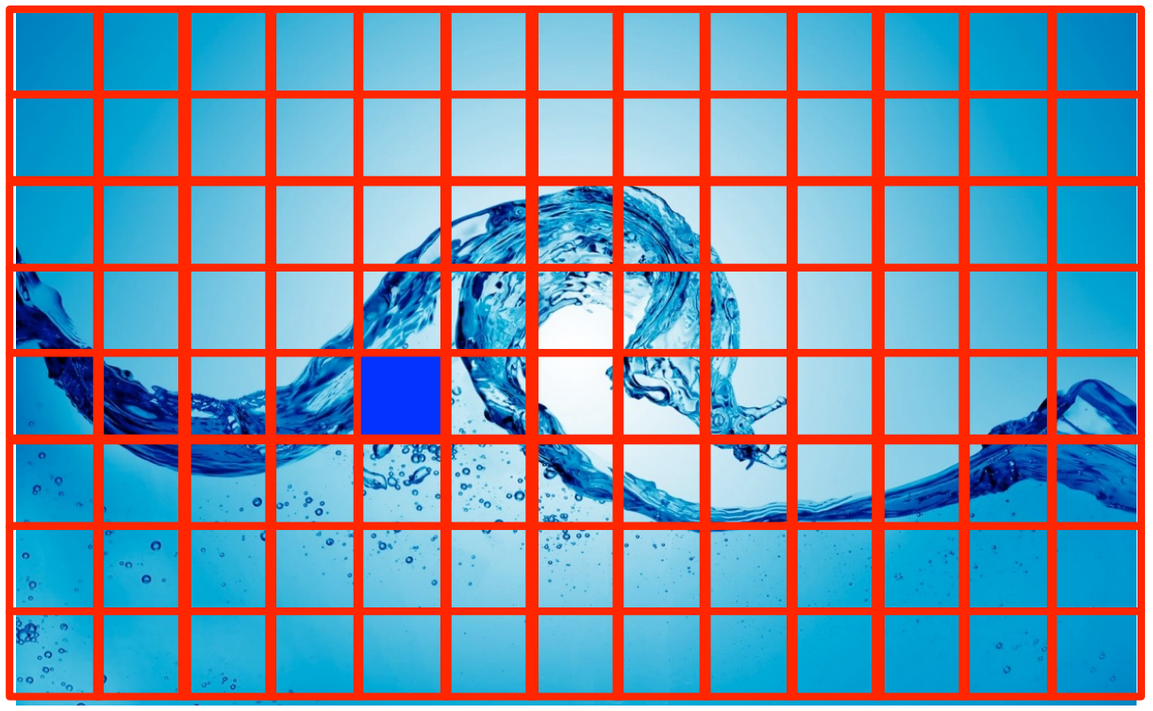


Lagrangian

Eulerian





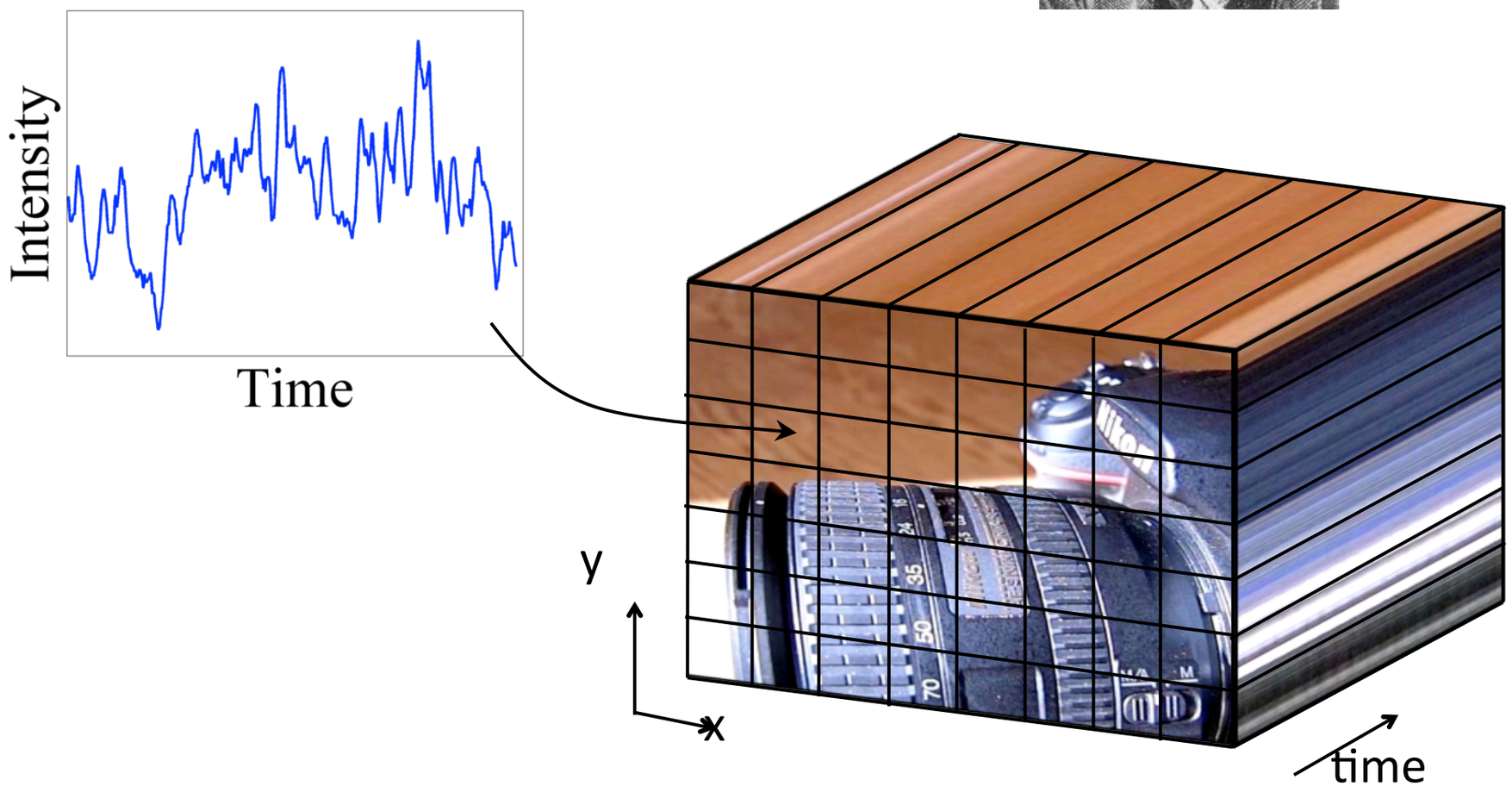


Eulerian Perspective: Videos

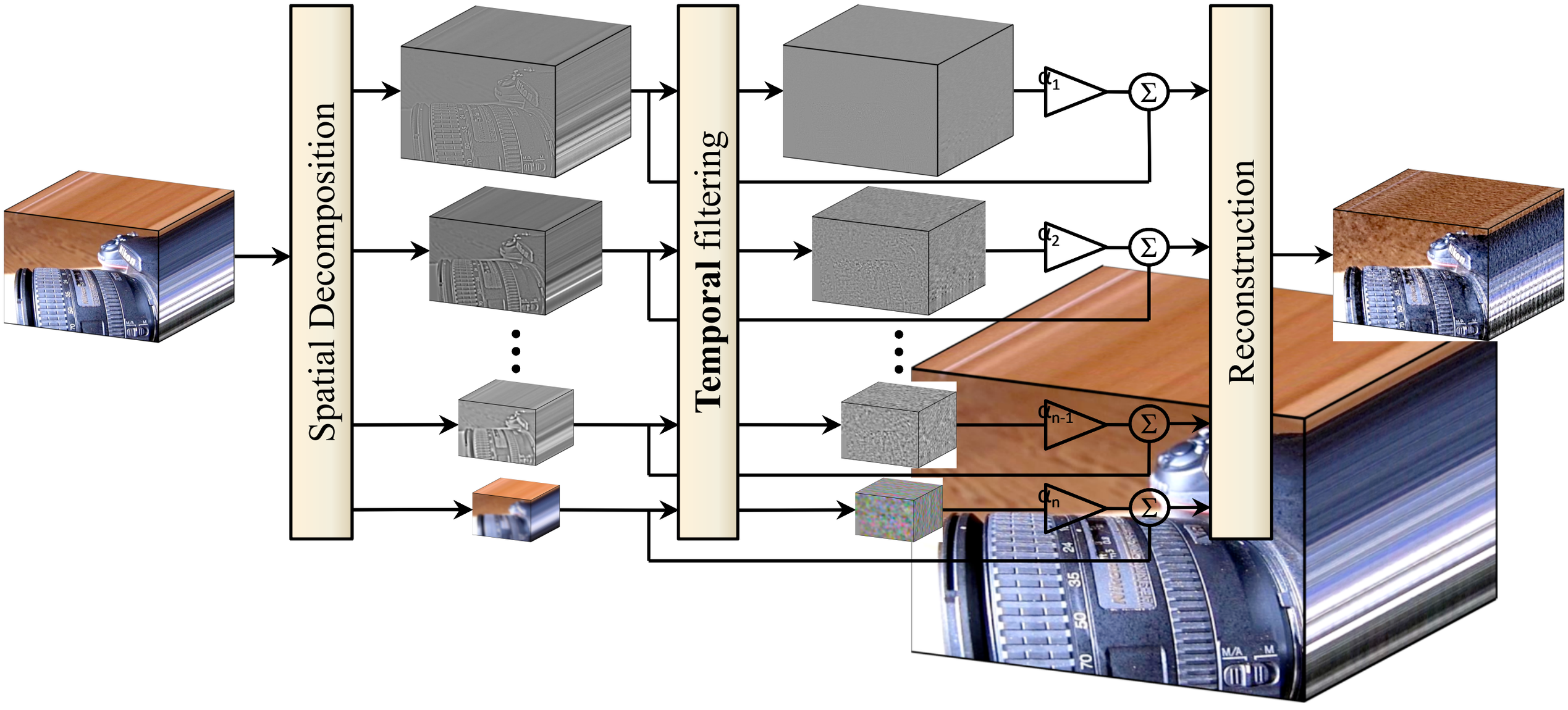
- Each pixel is processed independently
- We treat each pixel as a time series and apply signal processing to it

Eulerian





Method Overview



Talk Overview

- **Eulerian video magnification**
- Why it amplifies motion
- Results



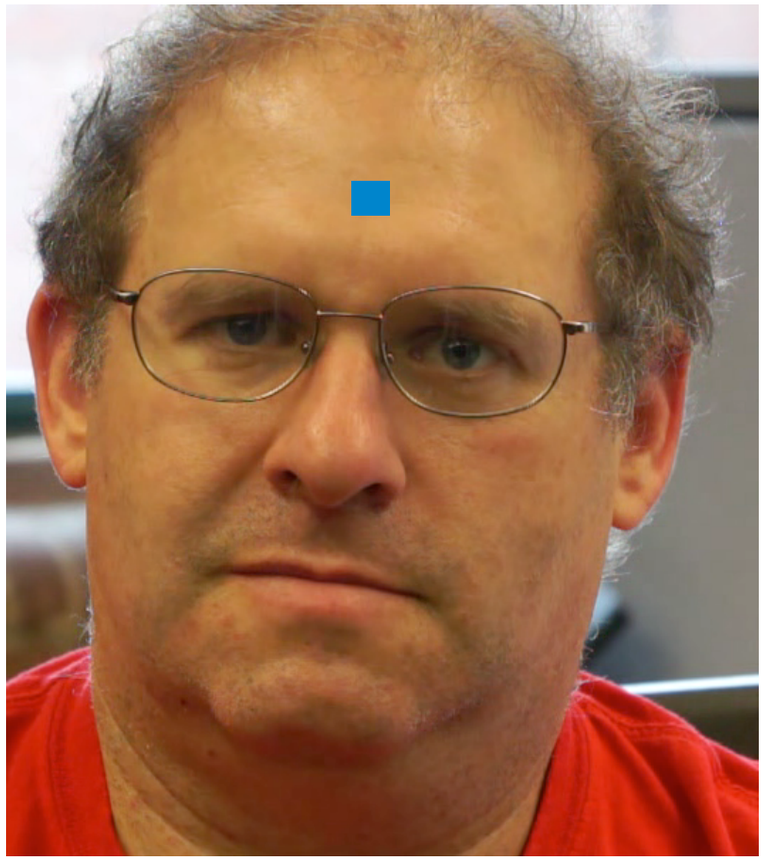


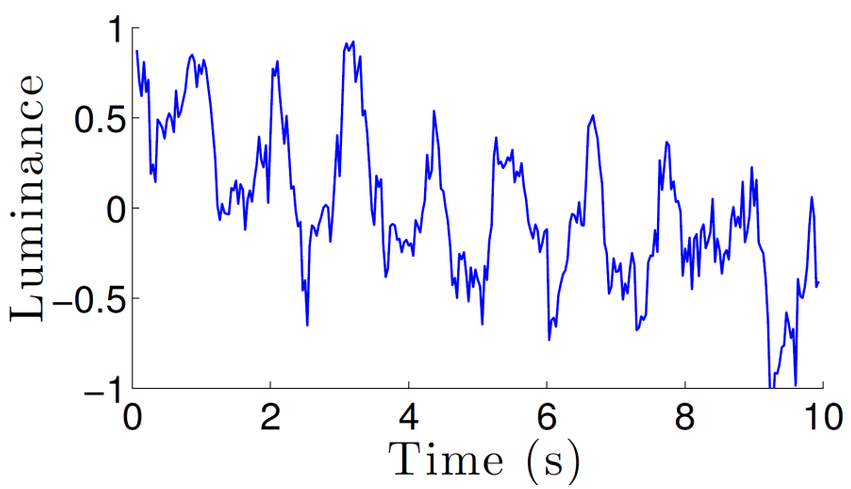


Amplifying Subtle Color Variations

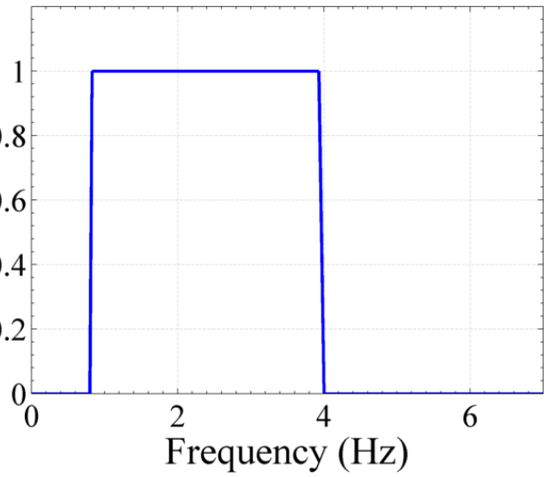
Filter spatially to reduce noise

Filter temporally to extract the signal of interest





Spatially averaged luminance trace



Temporal filter

Color Amplification Results

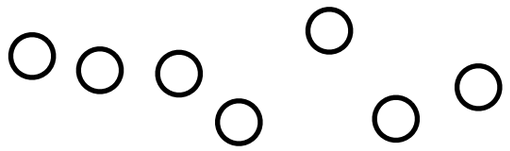


Source

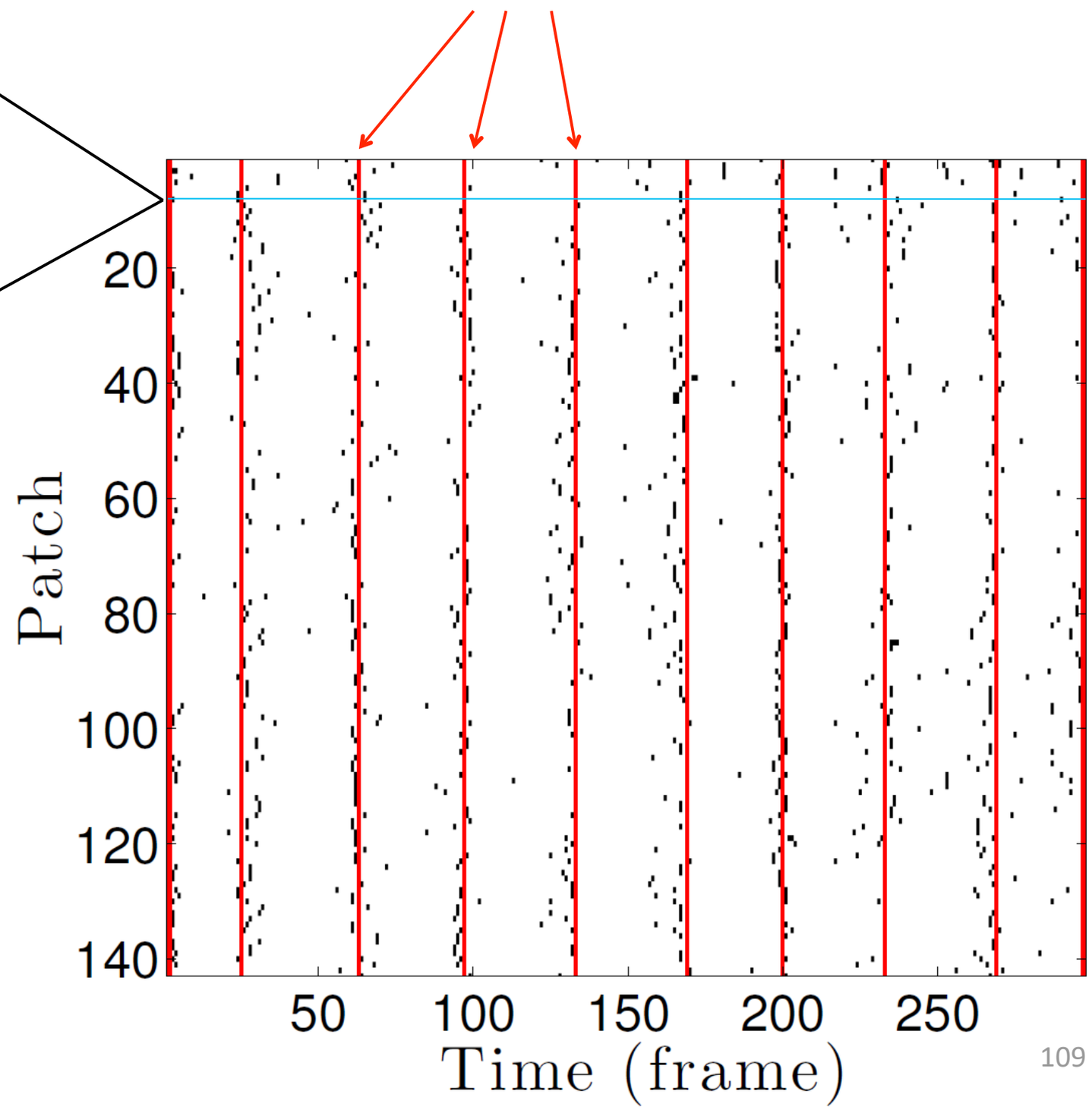
Color-amplified (x100)
0.83-1 Hz (50-60 bpm)

Heart Rate Extraction

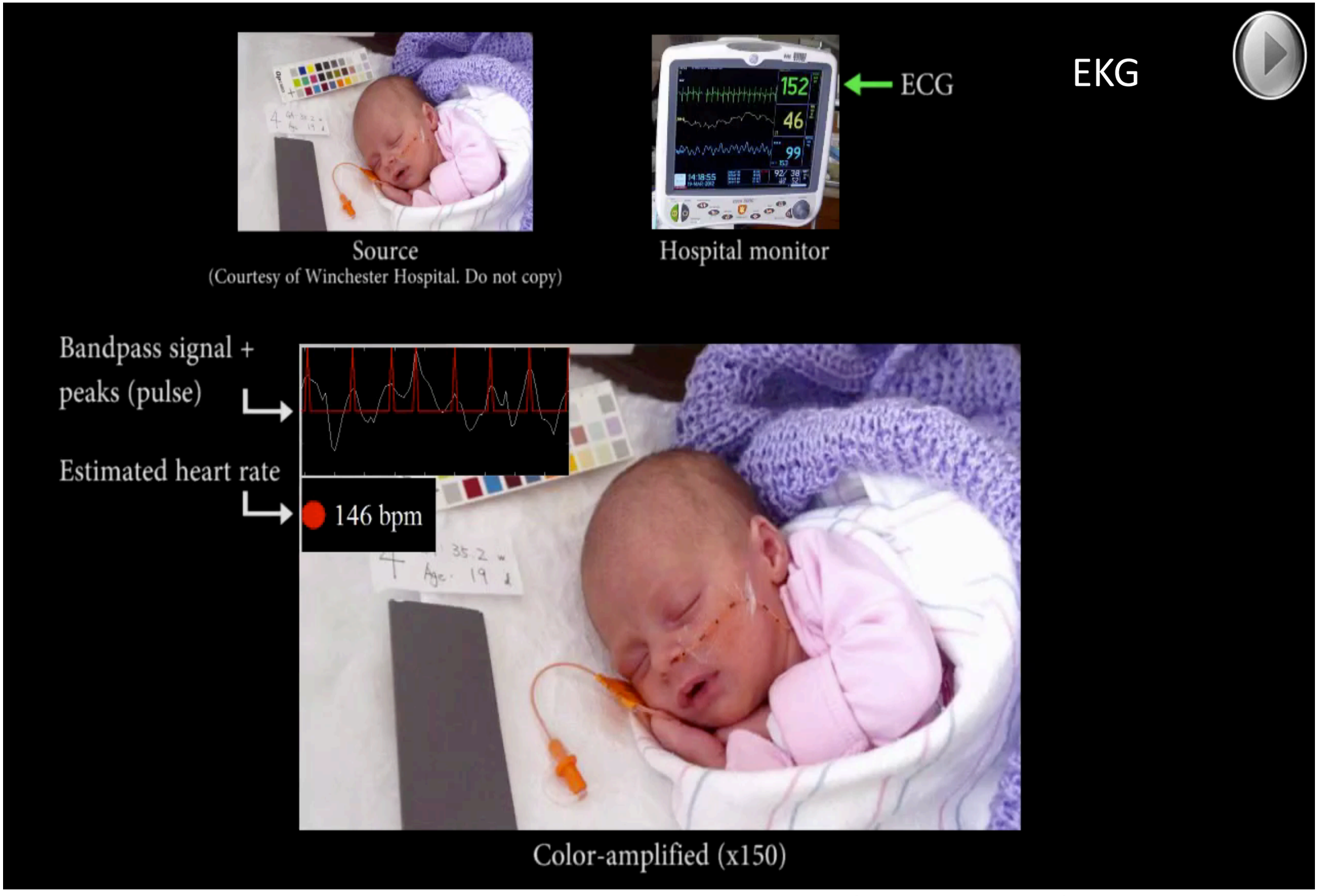
Peak detection



Temporally bandpassed trace (one pixel)



Heart Rate Extraction



Thanks to Dr. Donna Brezinski and the Winchester Hospital staff

2.33-2.67 Hz (140-160 bpm)

Overview

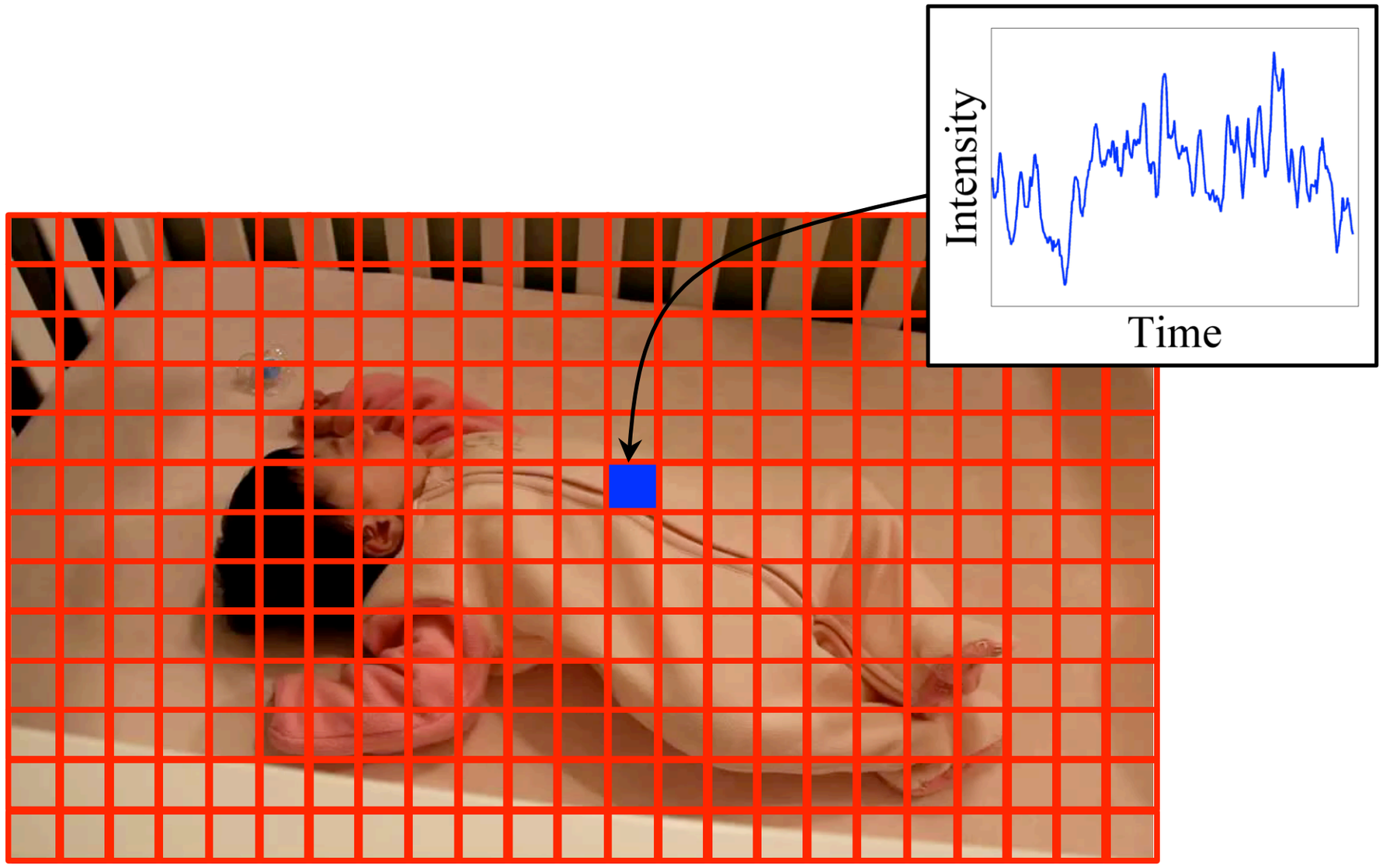
- Eulerian video magnification
- **Why it amplifies motion**
- Results



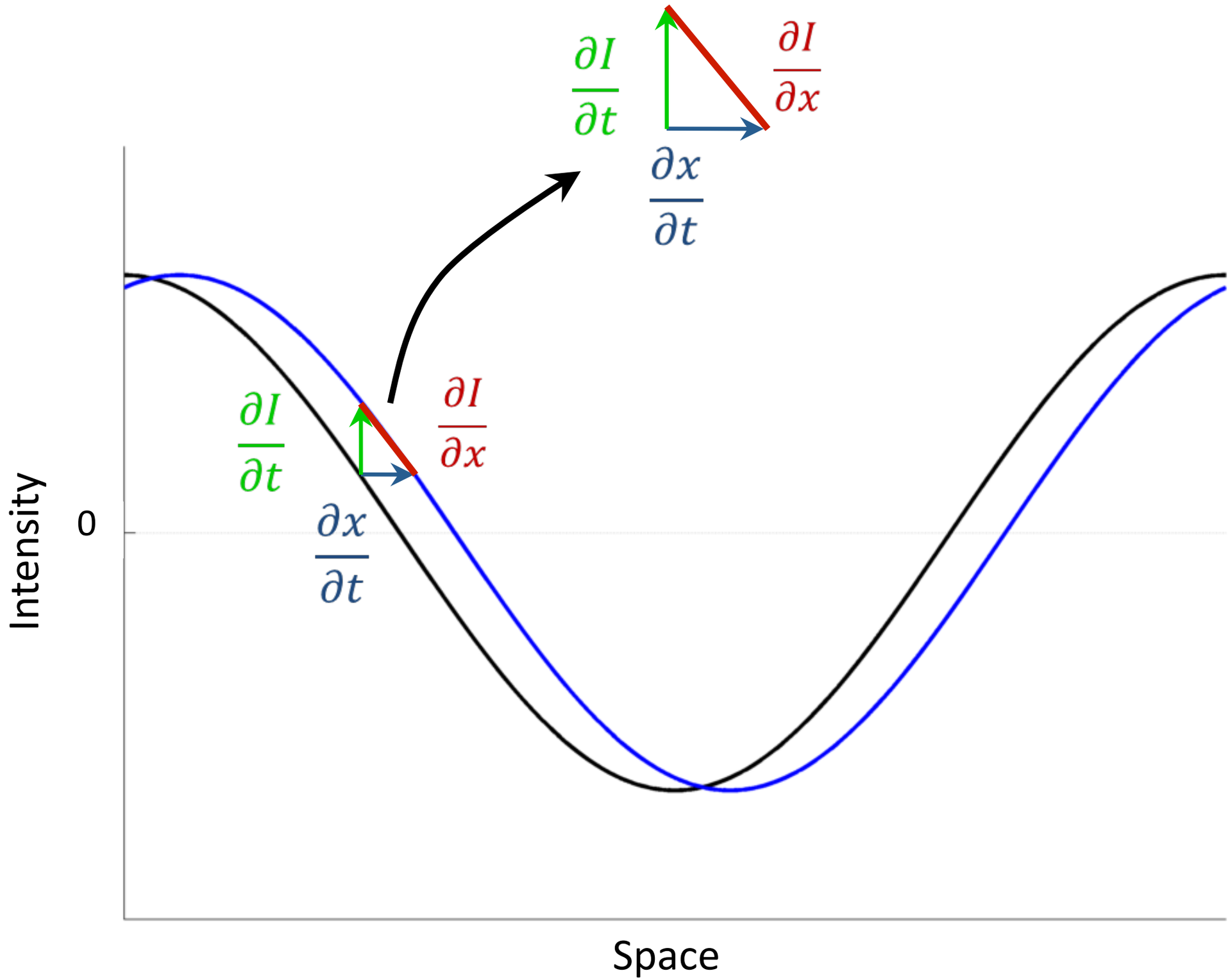




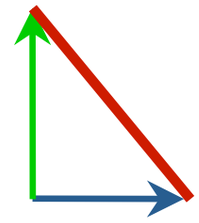
Why It Amplifies Motion



Differential Brightness Constancy

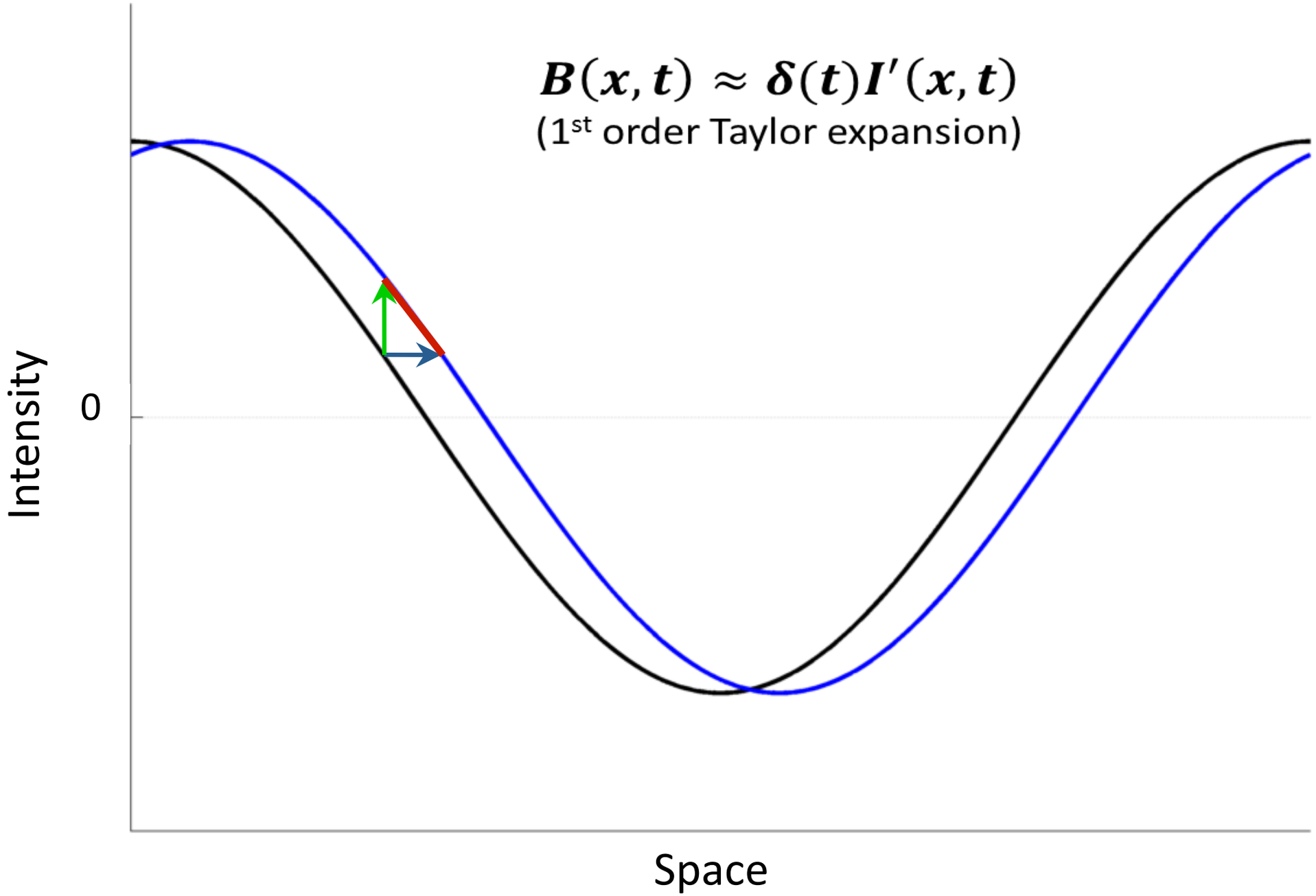


Relating Temporal and Spatial Changes

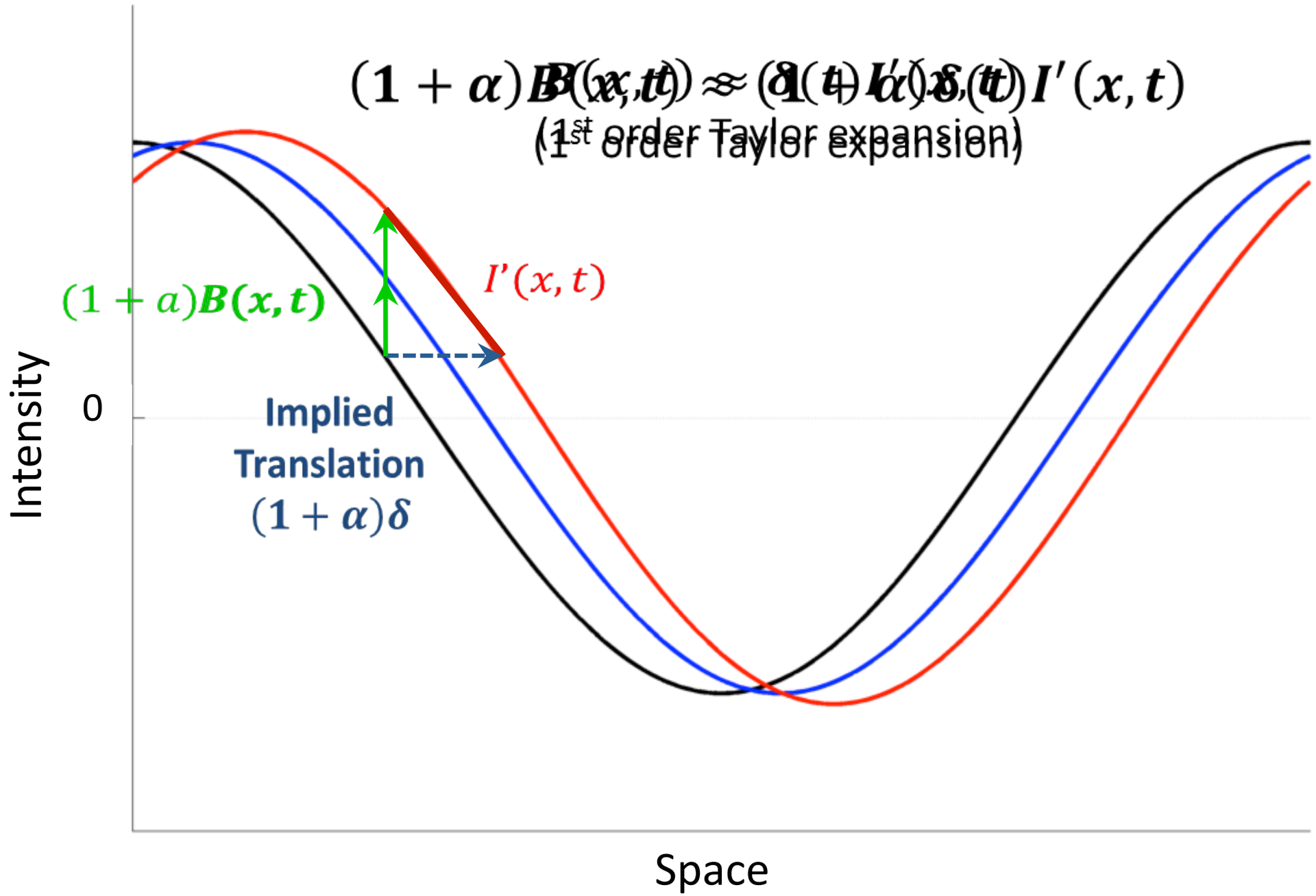


$$\boldsymbol{B}(\boldsymbol{x},\boldsymbol{t}) \approx \boldsymbol{\delta}(\boldsymbol{t})\boldsymbol{I}'(\boldsymbol{x},\boldsymbol{t})$$

(1st order Taylor expansion)

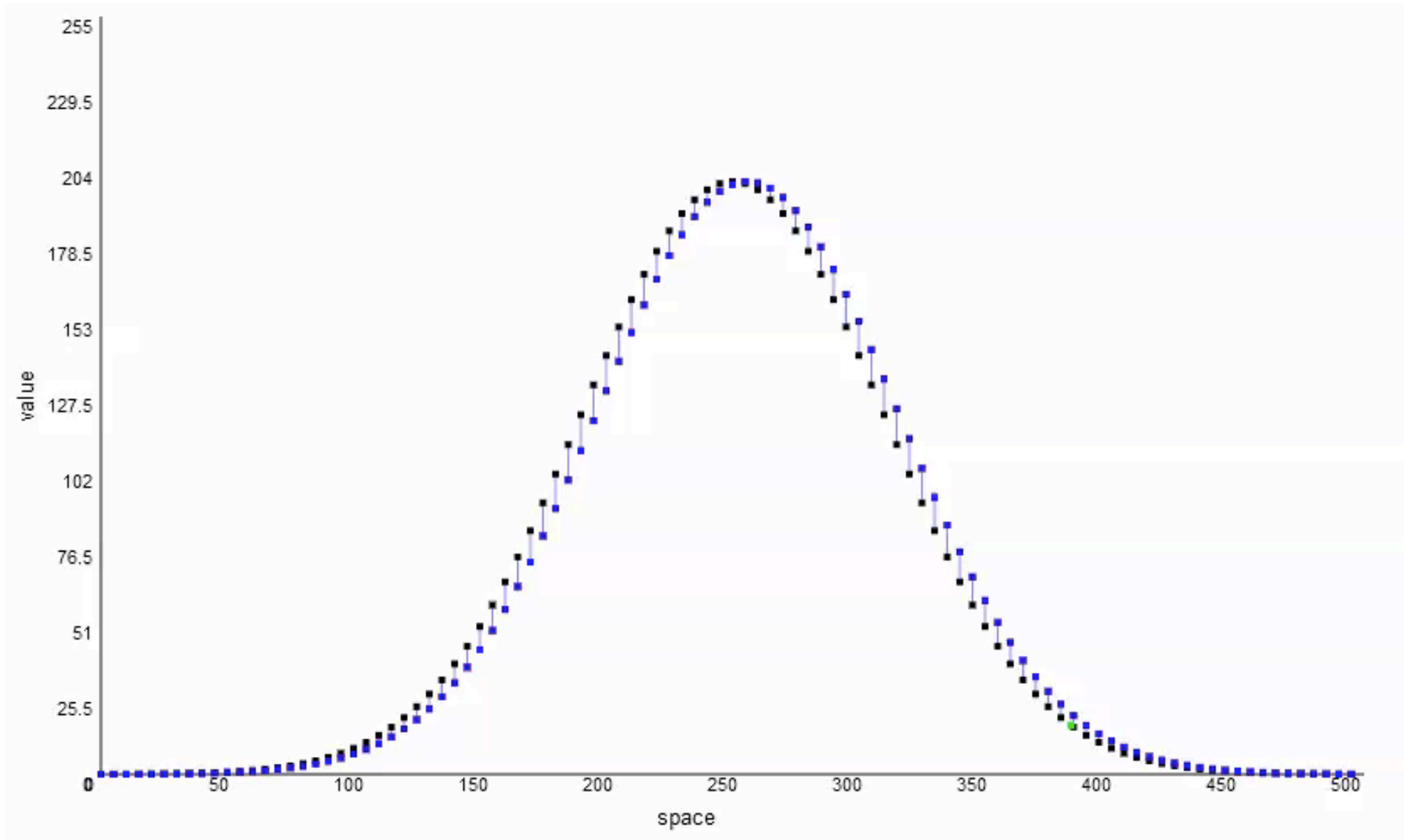


Relating Temporal and Spatial Changes



Relating Temporal and Spatial Changes

Motion-magnified



Courtesy of Lili Sun

Overview

- Eulerian video magnification
- Why it amplifies motion
- **Results**



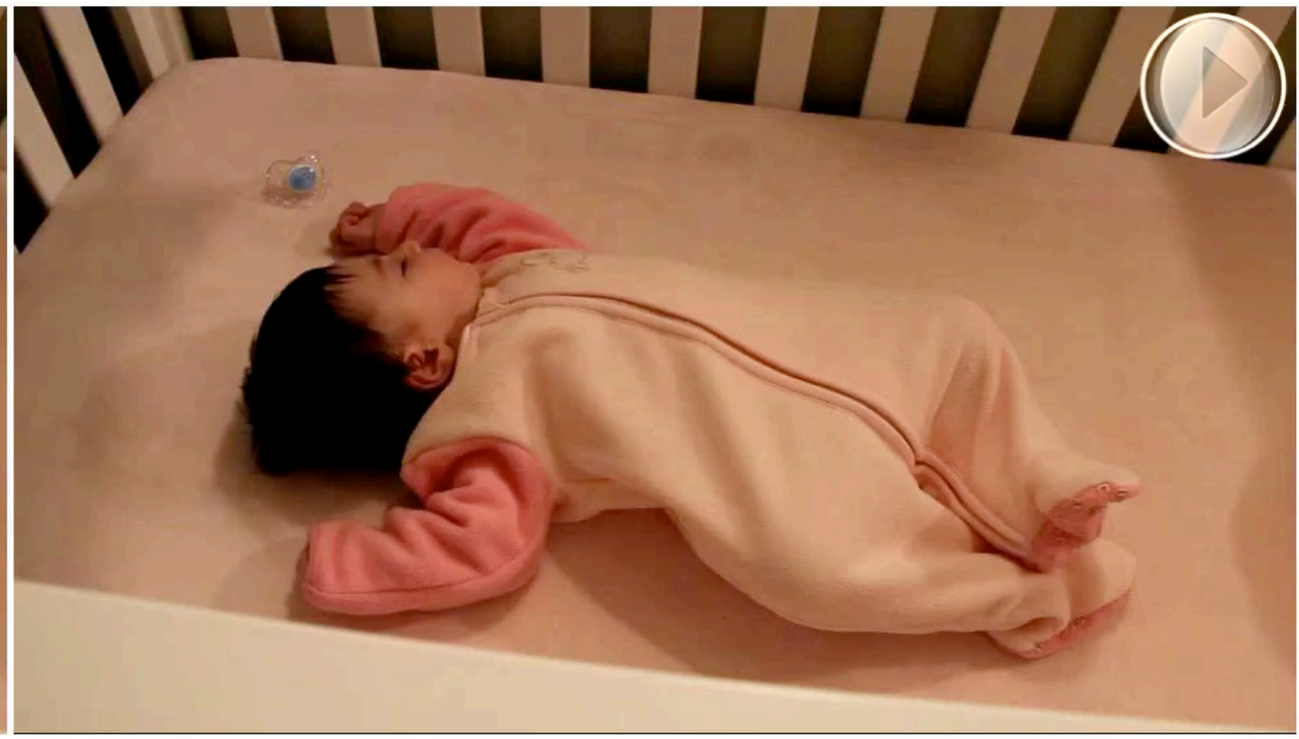




Motion Magnification Results



Source

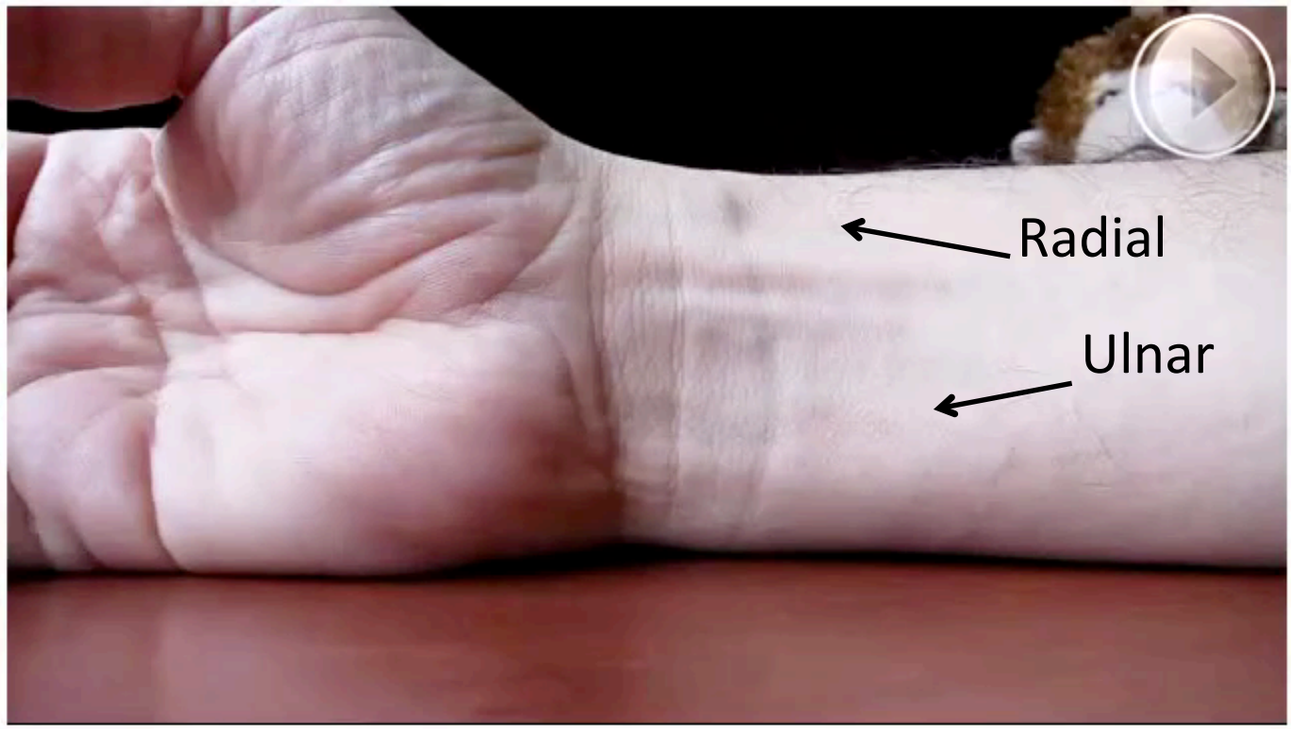


Motion-magnified (0.4-3 Hz, x10)

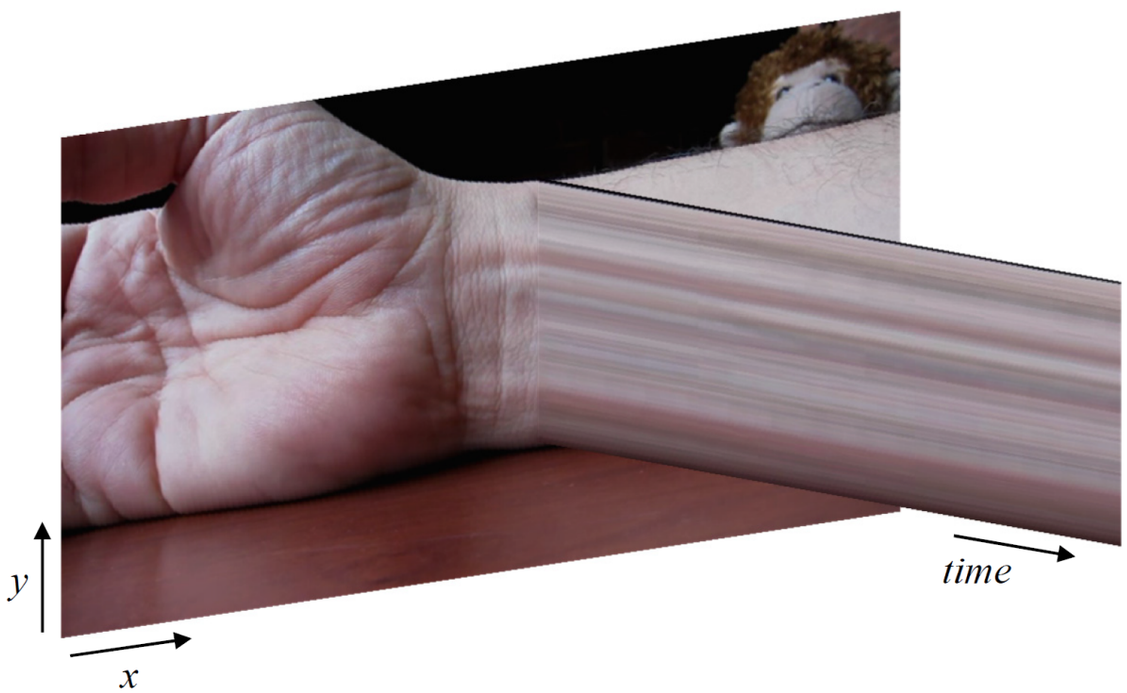
Motion Magnification

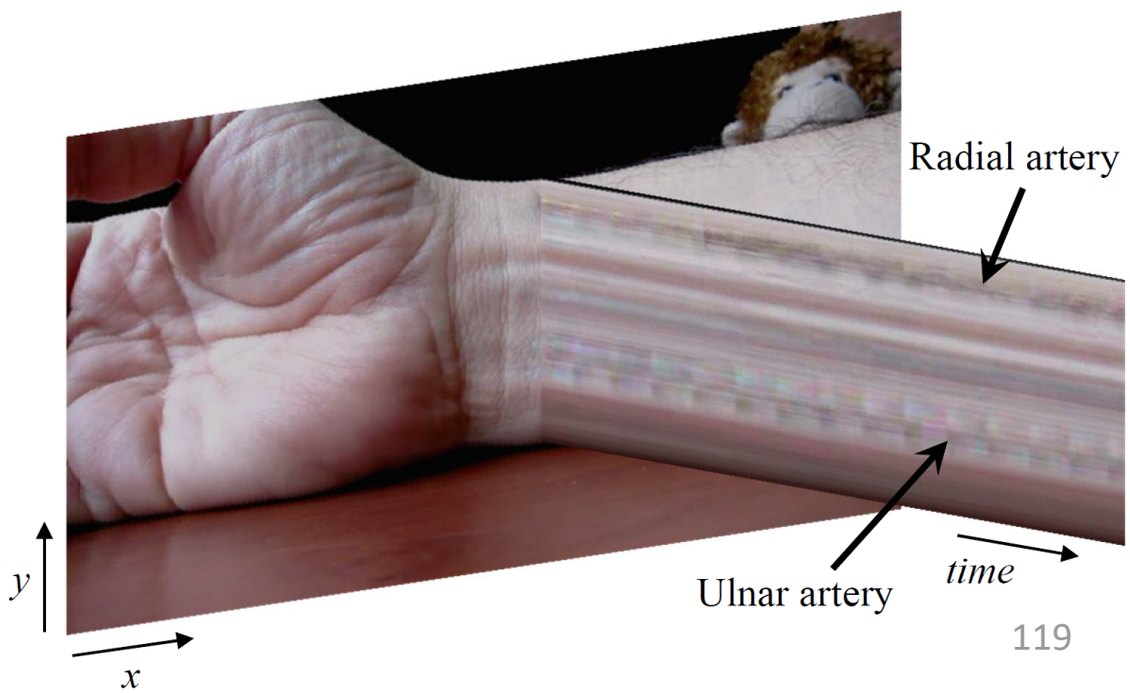


Source



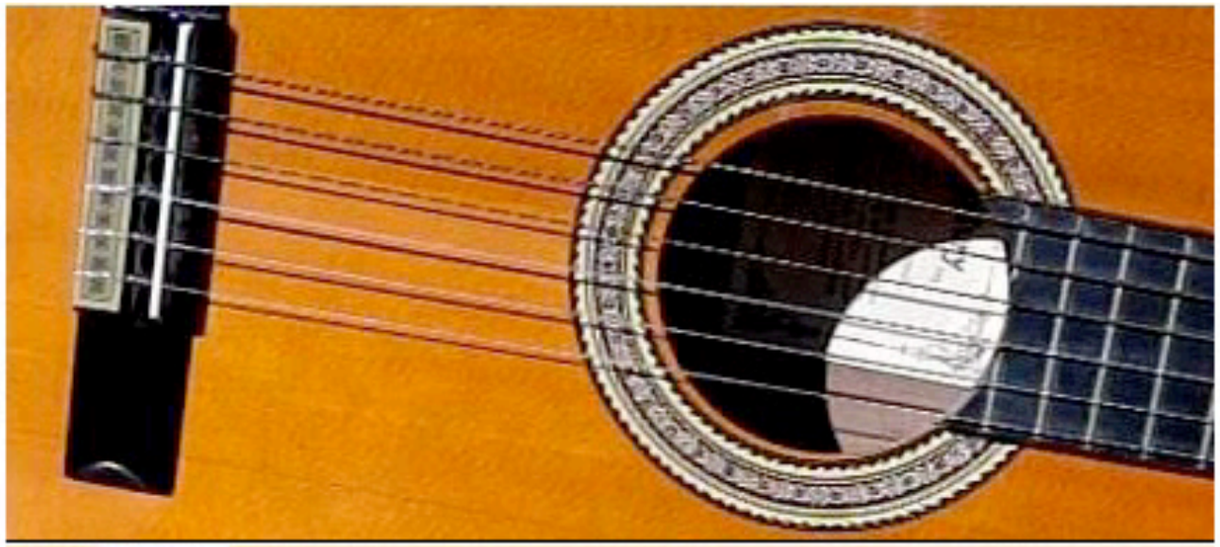
Motion-magnified (0.4-3 Hz, x10)



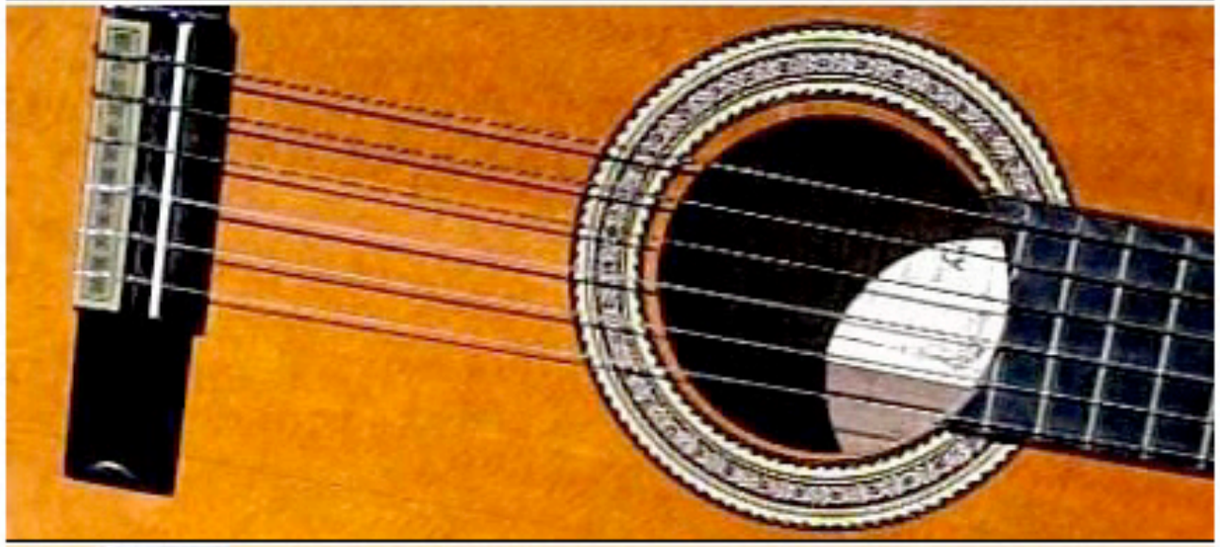


Selective Motion Magnification in Natural Videos

Source
(**600 fps**)

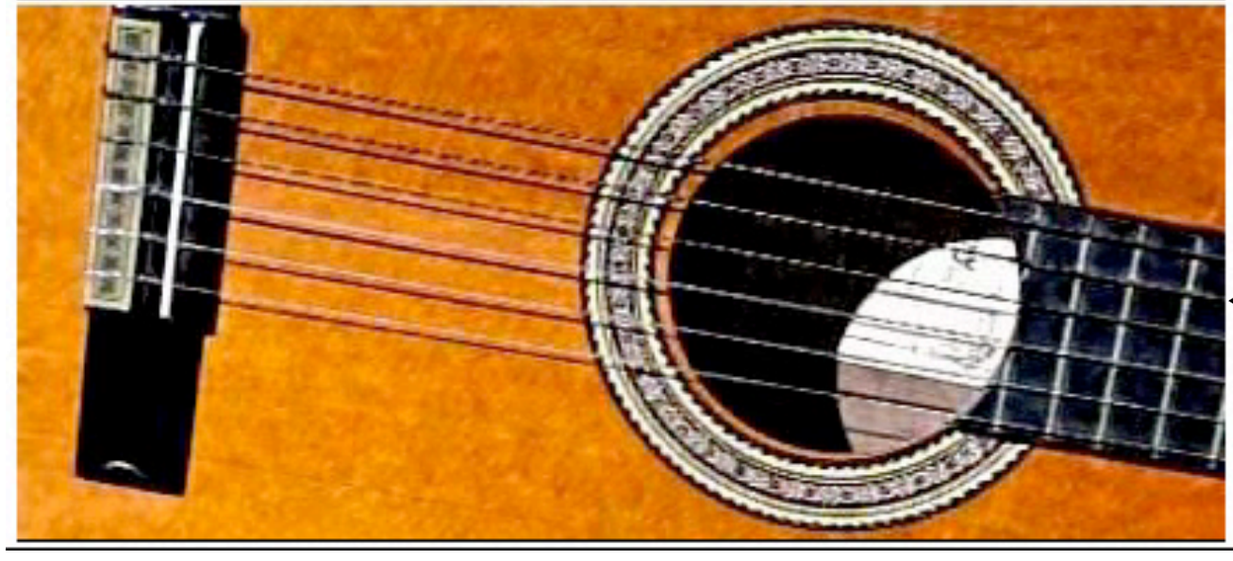


72-92 Hz
Amplified



← Low E (82.4 Hz)

100-120 Hz
Amplified



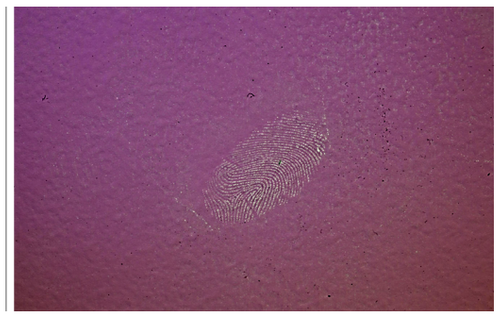
← A (110 Hz)

Motion and change

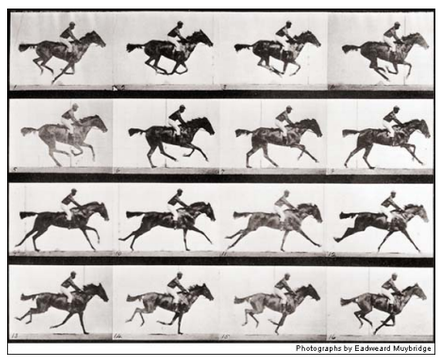
- Change

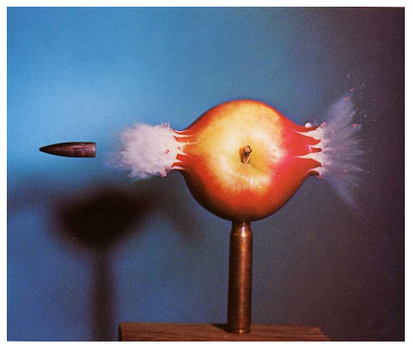






- Fast motion

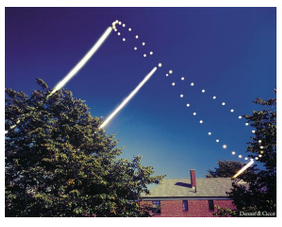


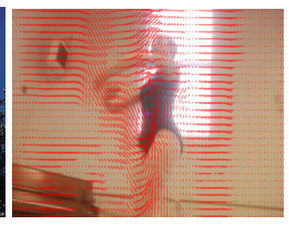




- Trajectories, video summaries

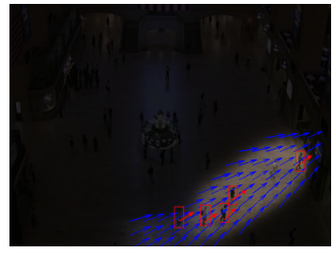




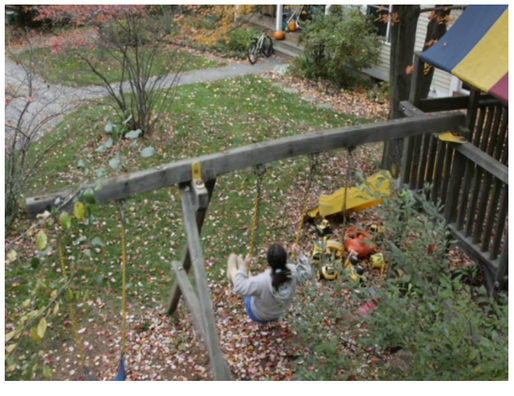








- Reveal small motion





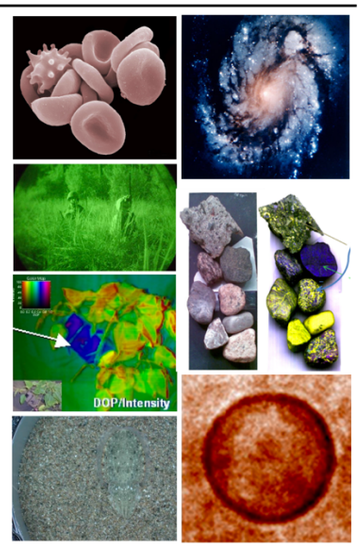




What do you want to reveal?

Recap: Beyond human capabilities

- Too small
- Too far
- Too dark
- Camouflaged
- Not RGB
- Polarized
- Too transparent

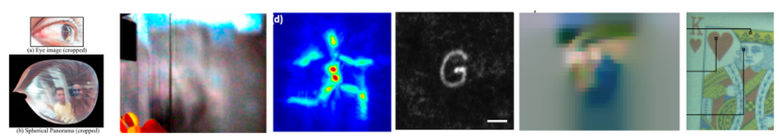


Recap: hidden things & occlusion

- Seeing inside objects

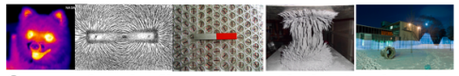


- Seeing beyond the field of view



Recap: non visual phenomena

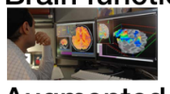
- Temperature, EM field, wifi



- Sound, air flow, particle trajectories, material stress, vibration modes, velocity



- Brain function



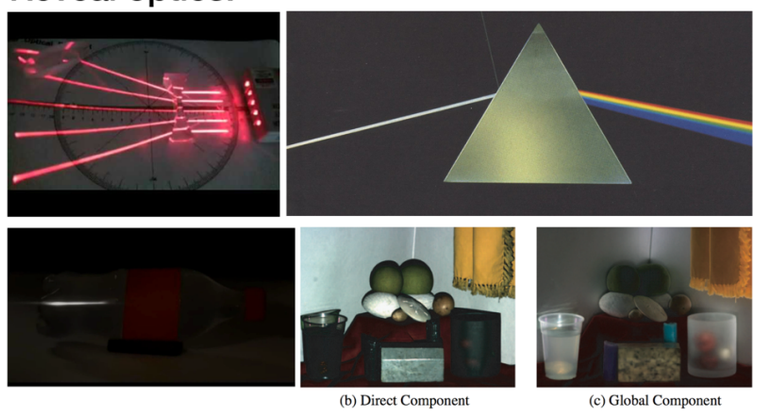
- Augmented reality, spatial AR



- Most sensing is optical!

Recap: non-visible visual

- Reveal optics!

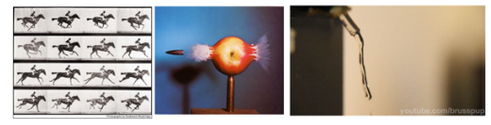


Motion and change

- Change



- Fast motion



- Trajectories, video summaries



- Reveal small motion

