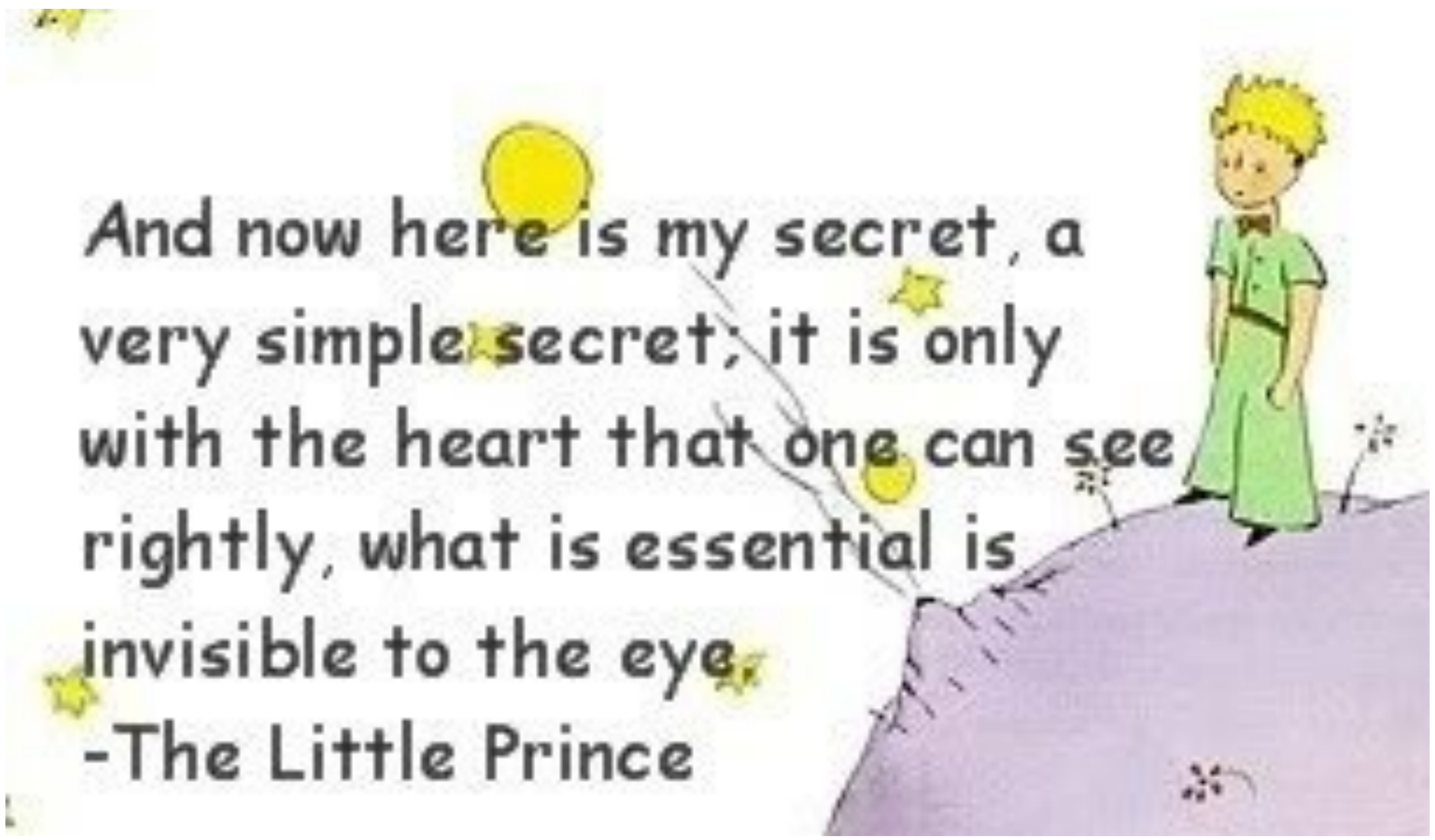
Revealing the Invisible

Frédo Durand
MIT CSAIL



Motivations

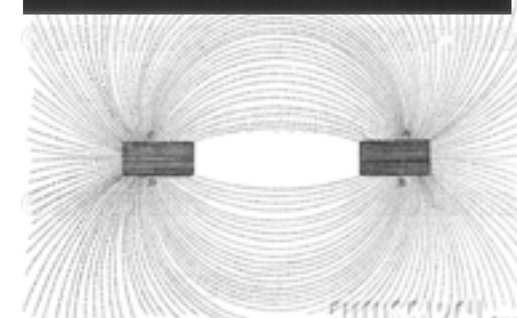
- The human visual system is awesome
- Go beyond what is visible
- Graphics and imaging allow us
  to understand and reveal the visual world

Overview

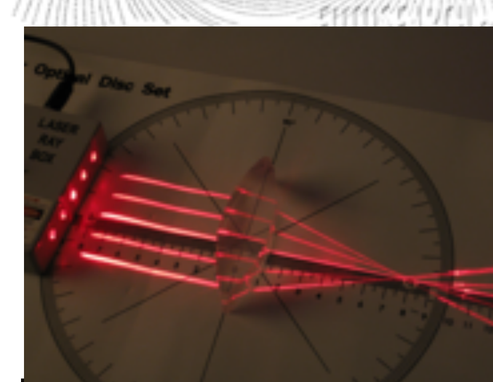
- Limits of human vision

- Occlusion

- Non-visual phenomena

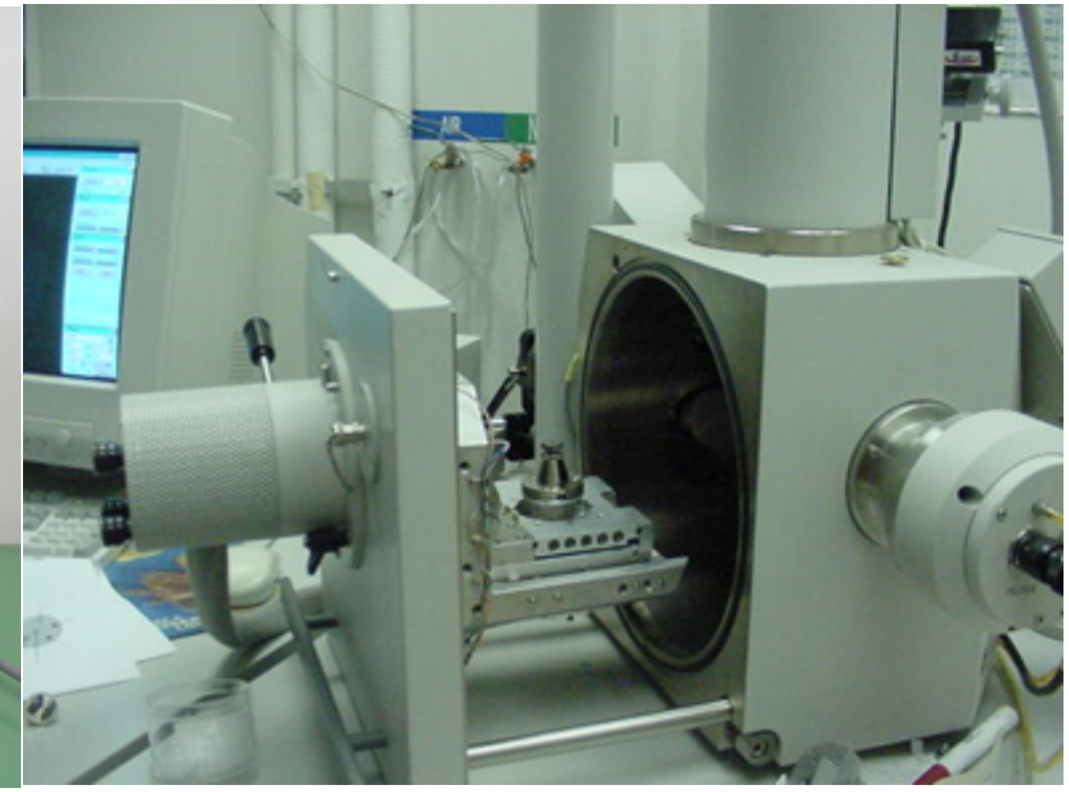


- Non-visible visual phenomena

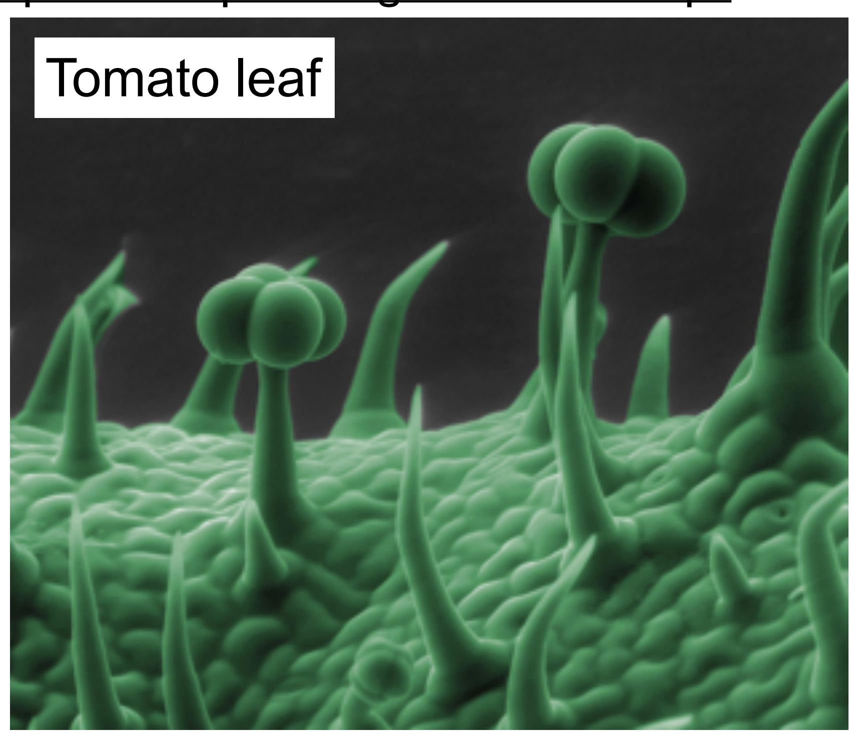


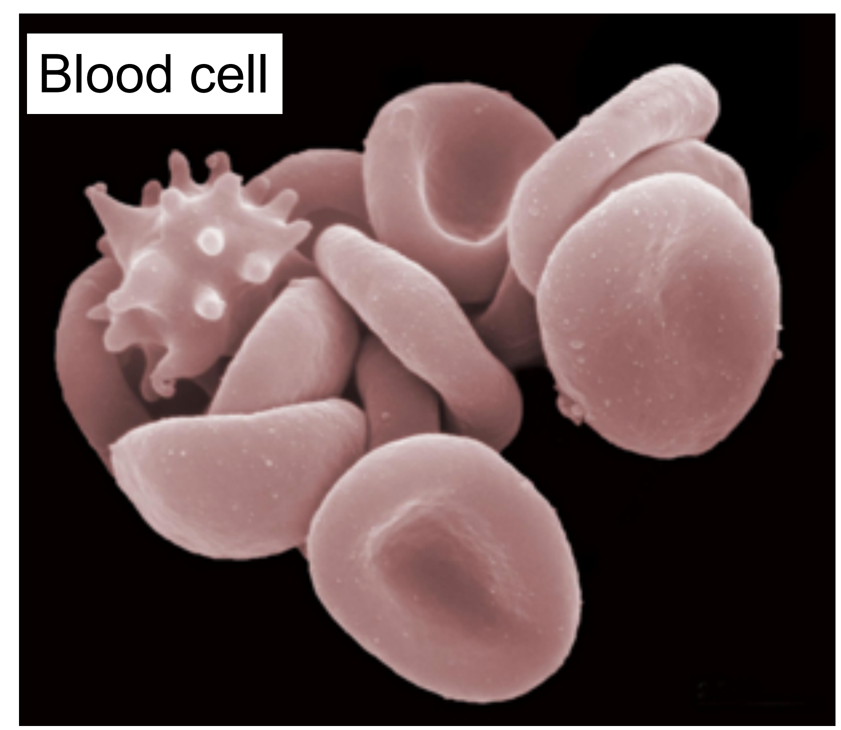
- Change and motion

Too small: microscopy



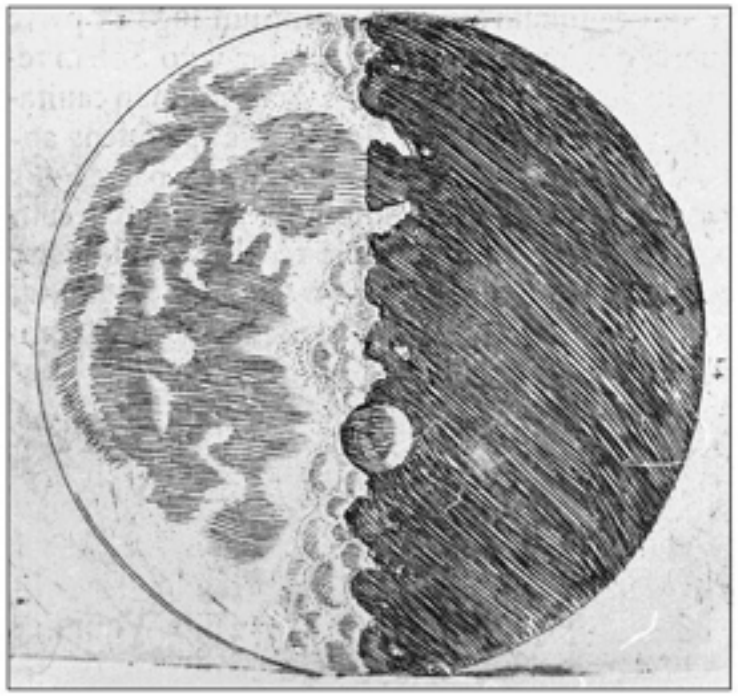
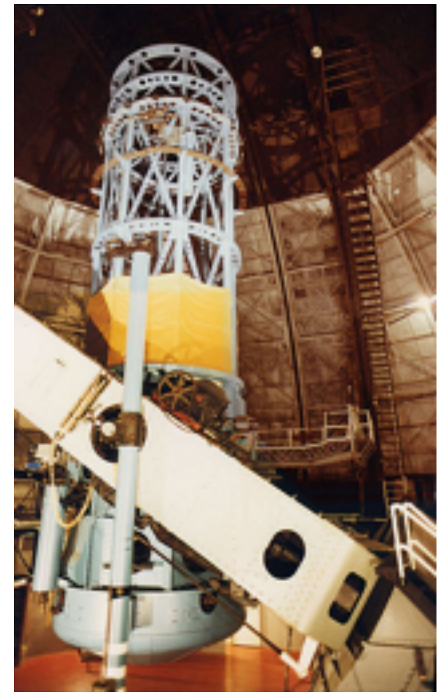
http://en.wikipedia.org/wiki/Microscope





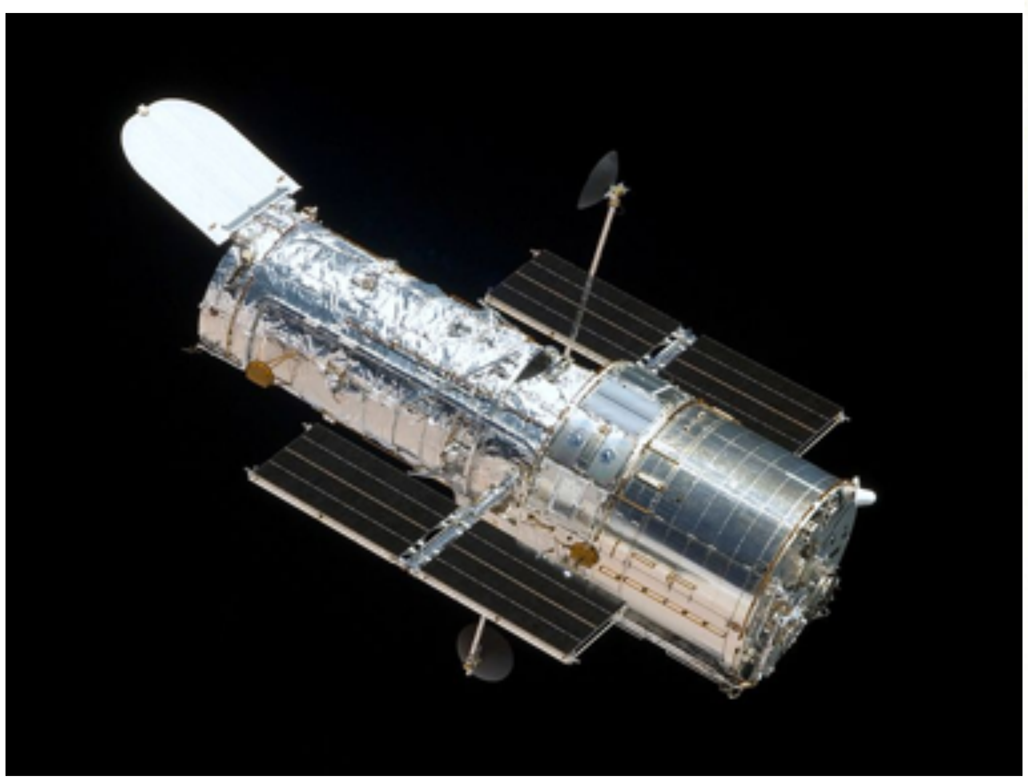
http://www.flickr.com/photos/fei_company/

Too far: telescope


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

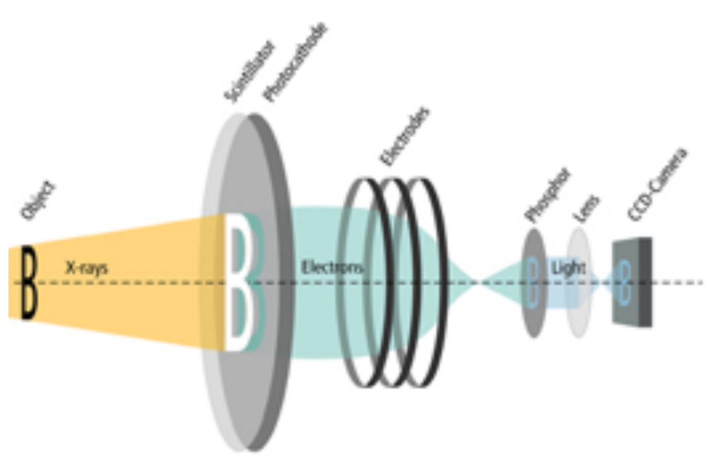
http://en.wikipedia.org/wiki/Telescope




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.html http://en.wikipedia.org/wiki/Night_vision

Too dark: Night photography

- The sensitivity of Digital sensors is revolutionizing night photography

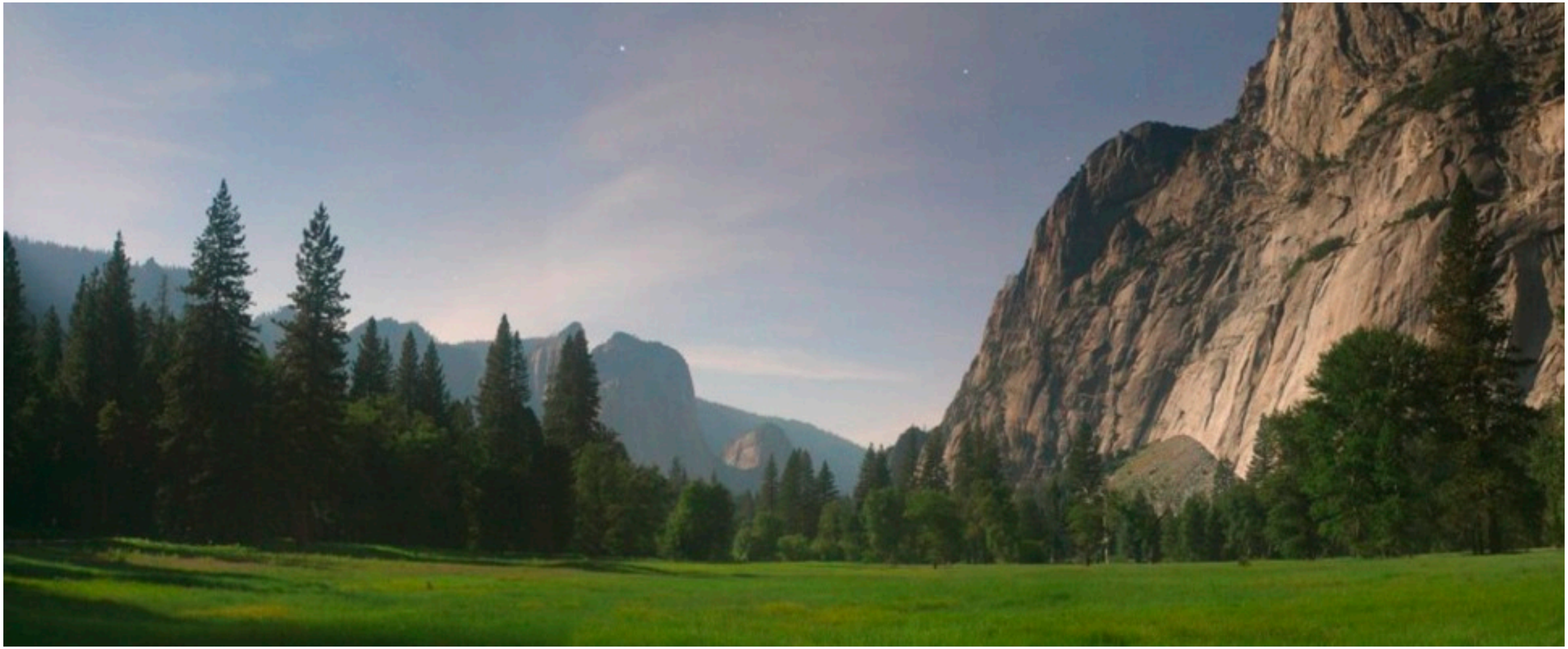


Image Jesse Levinson
Canon 10D, 28mm f/4, 3 min, ISO 100, 4 image pano

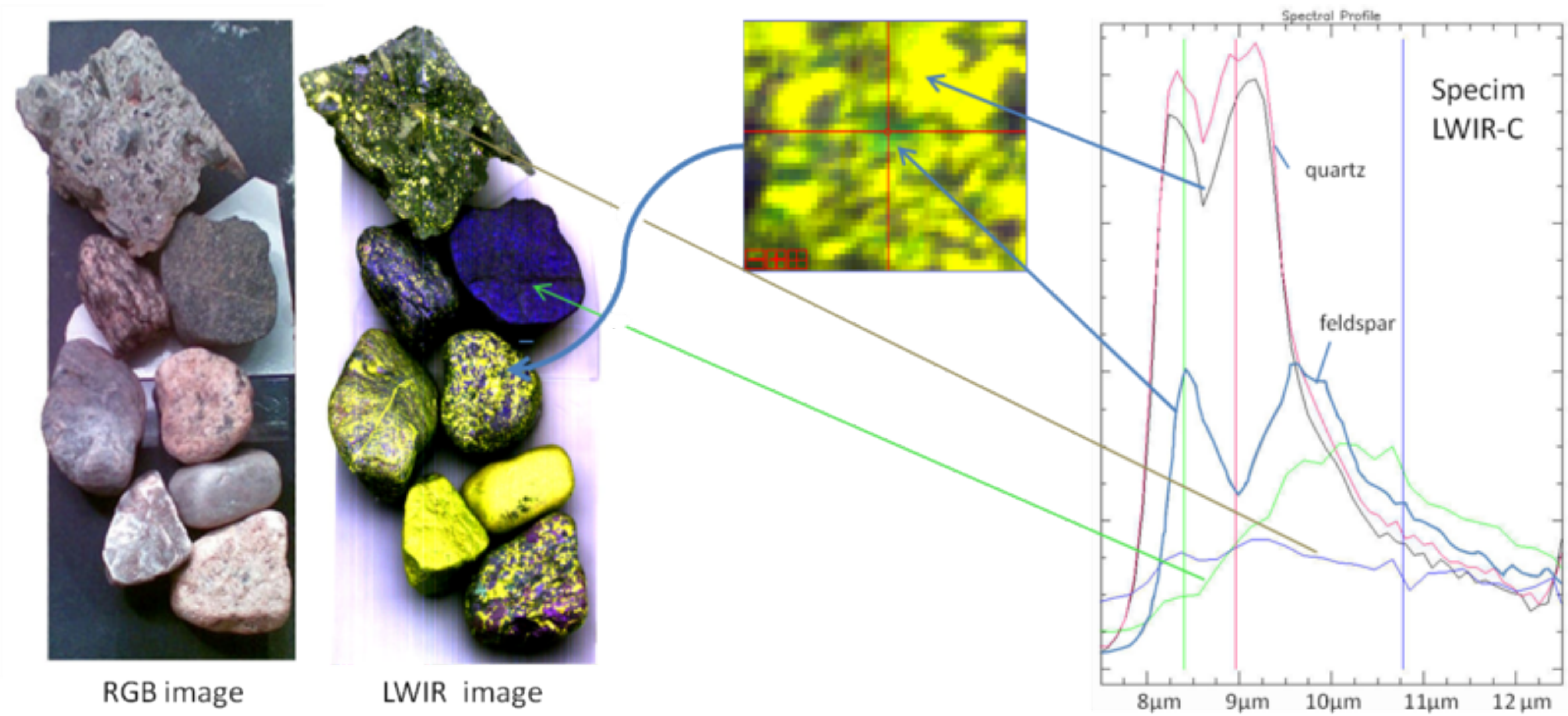
http://graphics.stanford.edu/courses/cs178-10/lectures/astrophotography-27apr10-150dpi-med.pdf

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)

Hyperspectral

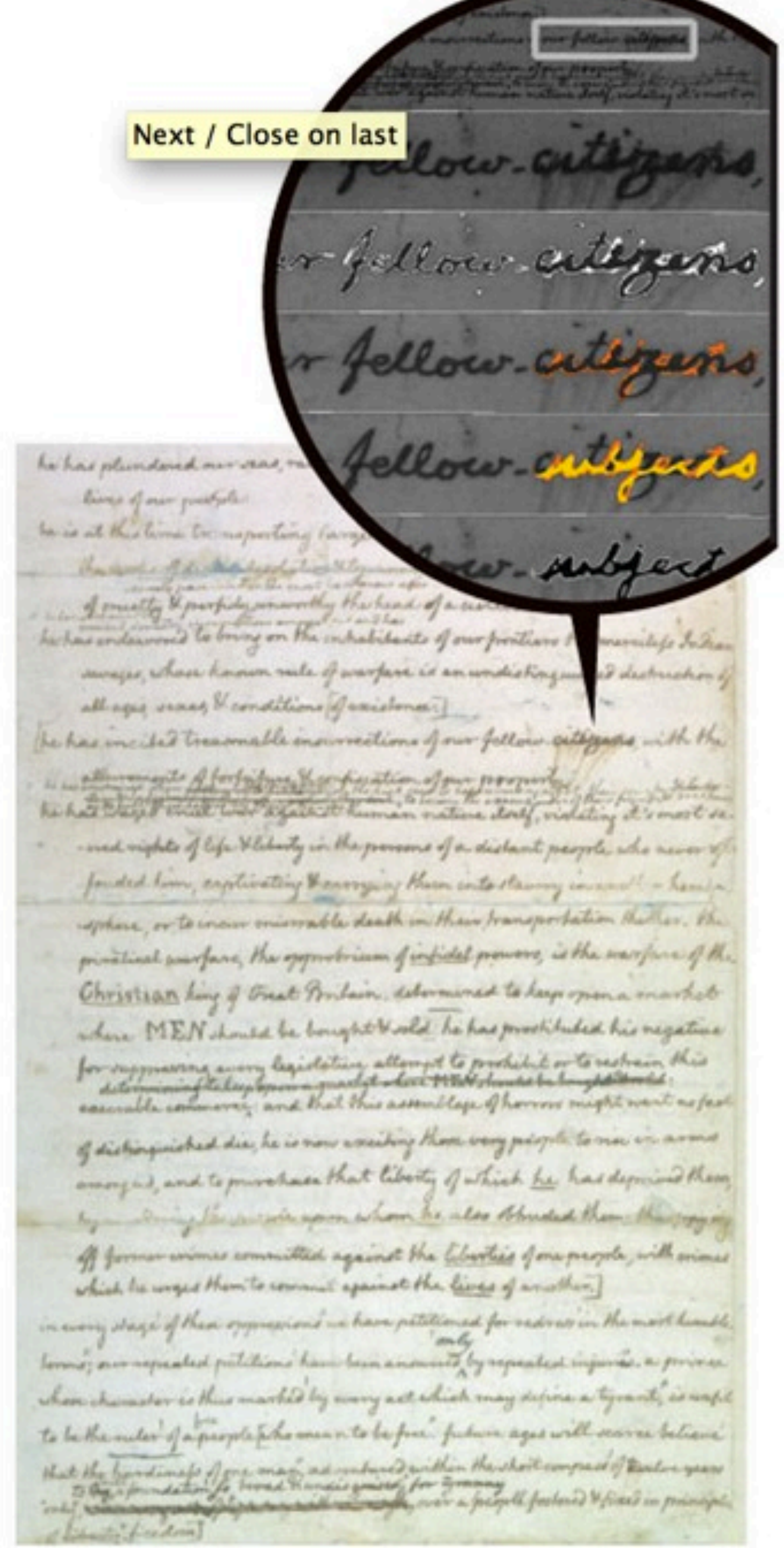


A set of stones is scanned with a Specim LWIR-C imager in the thermal infrared range from 7.7 µm to 12.4 µm. The quartz and feldsparspectra are clearly recognizable.

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

Hyperspectral

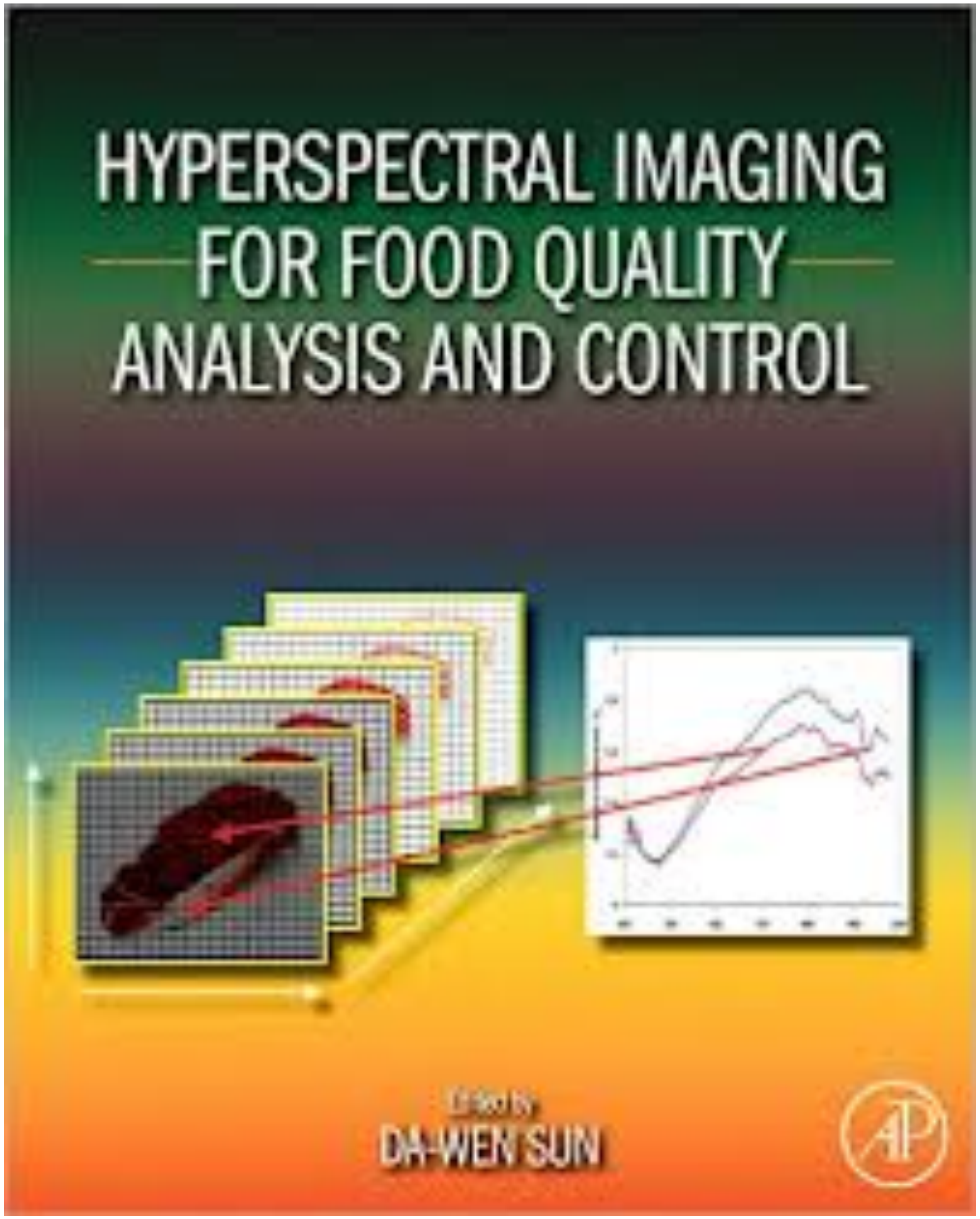
- Jefferson's revision of "subjects" to "citizens" in the Declaration of Independence is revealed through hyperspectral imaging

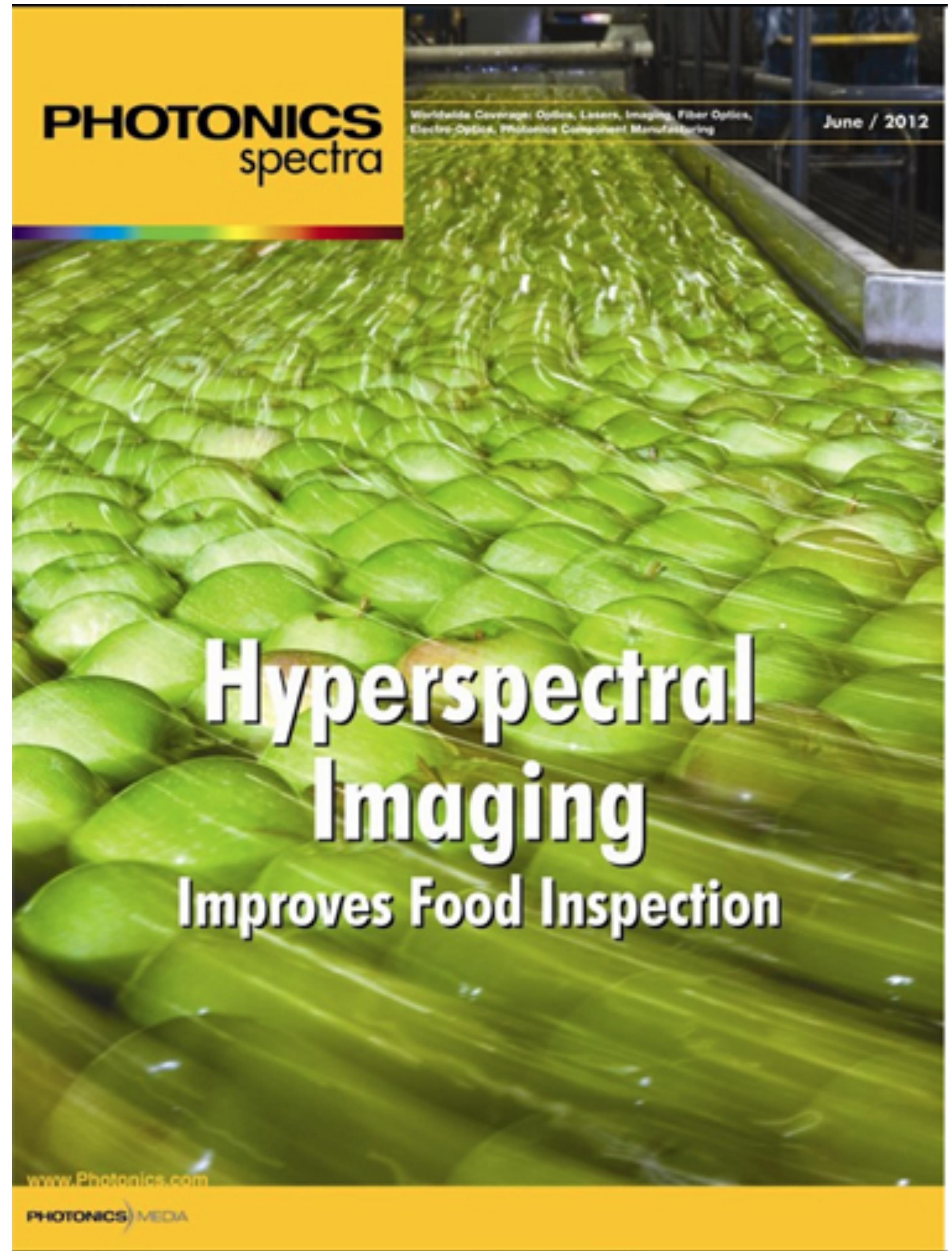


http://megavision-international.com/

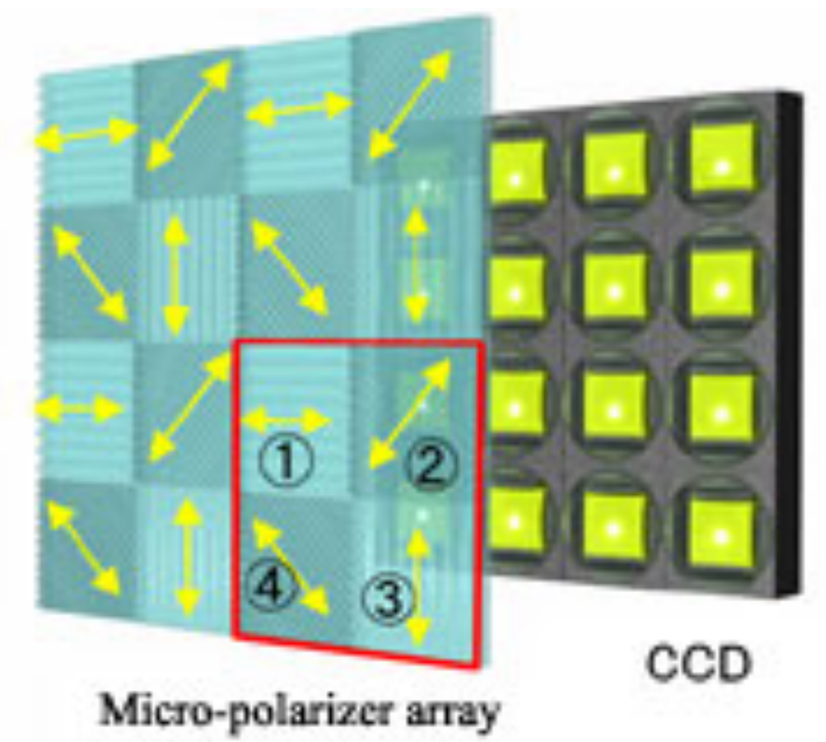
http://www.americanphotomag.com/article/2012/07/chasing-invis

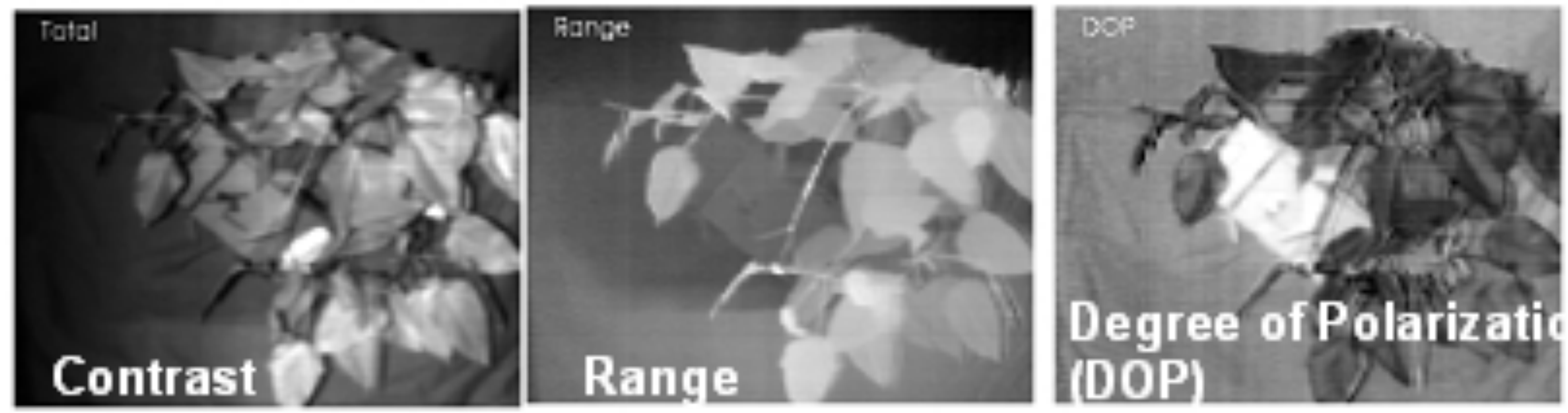
Hyperspectral & food analysis

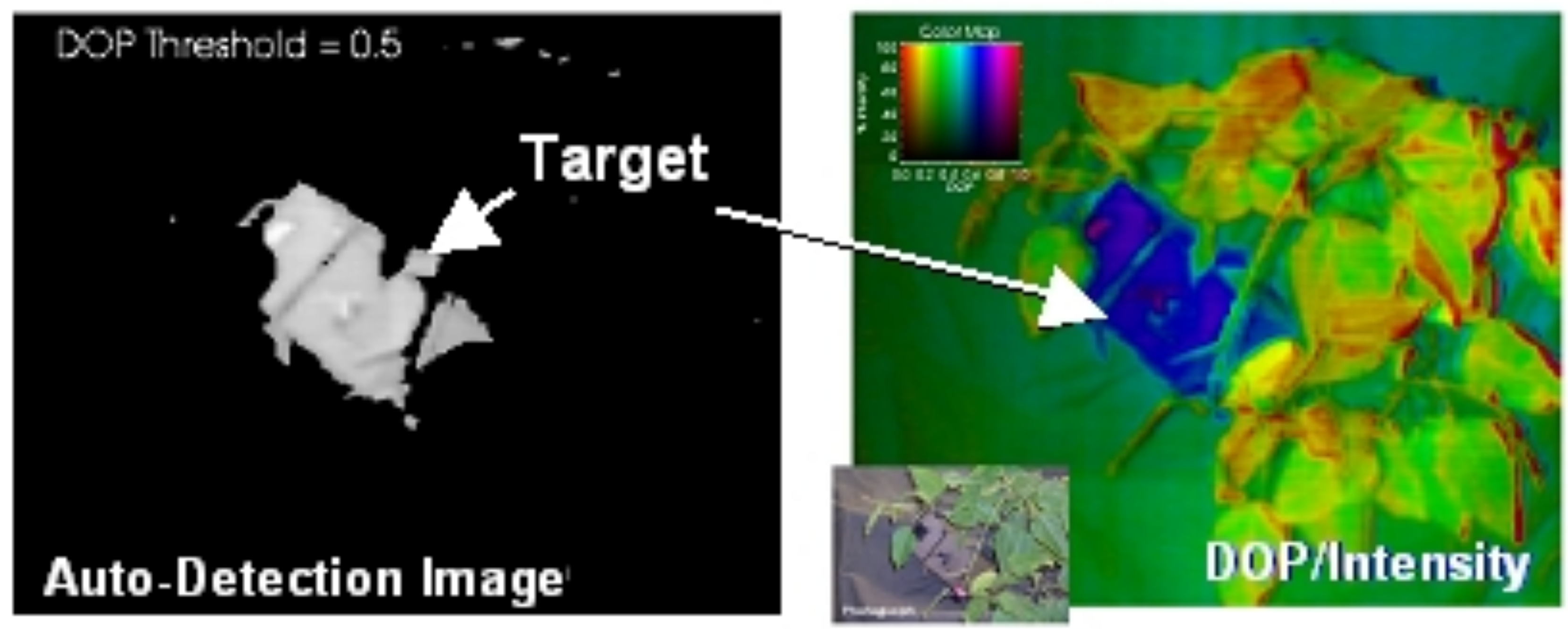




Polarization







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

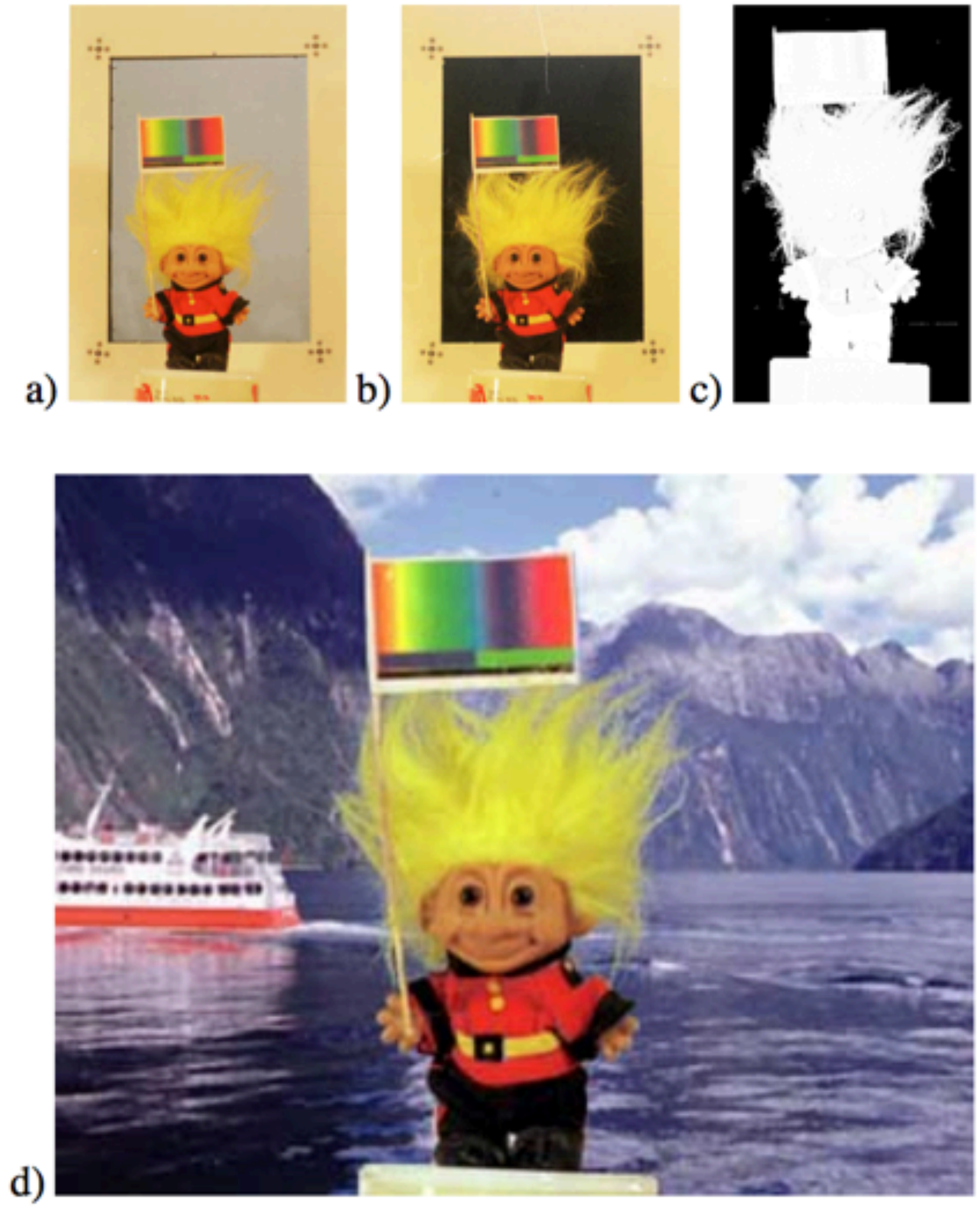


Figure 9. Object with fine details test. (The markers at the corners of the frame were used for alignment). a) "In-phase image" the background appear as light gray. a) "Out-of-phase image" the background appear as black. c) Produced matte. d) Compositing the doll image over a scenic image - fine details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

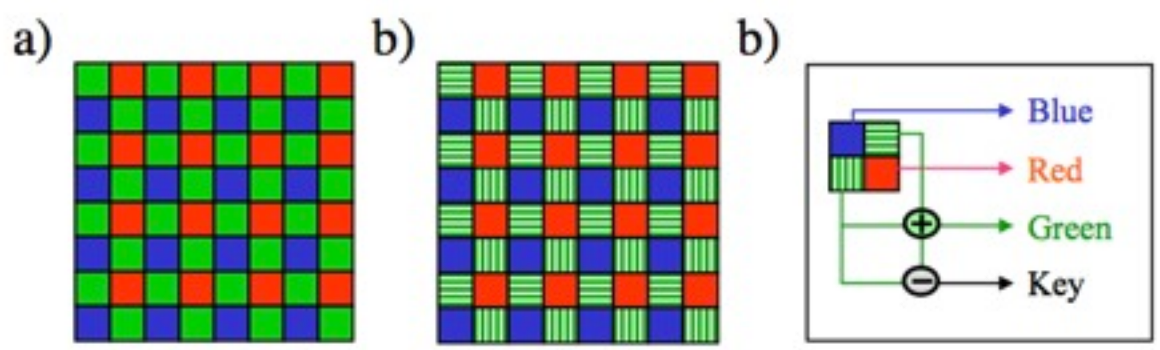


Figure 10. Proposed single chip sensor layout a) Conventional CCD/CMOS sensor layout. Pixels are covered with micro-filters. The Green channel which is the most visible to the human eye has twice as much sub-pixels as the blue and red channels. b) Proposed layout - The green pixels have complement pair 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.

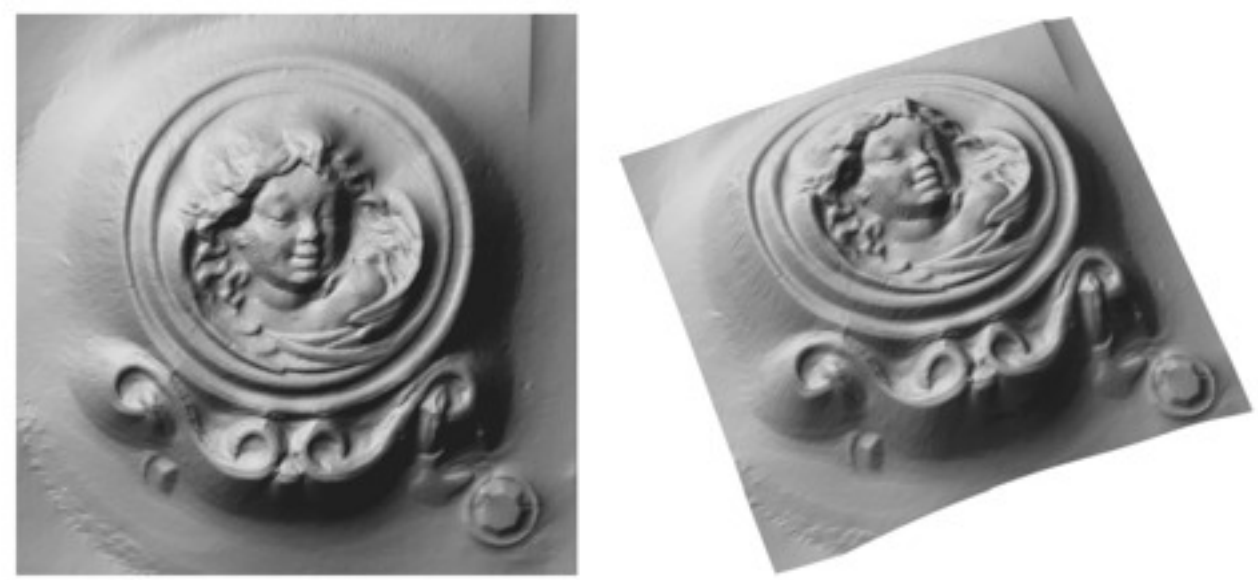
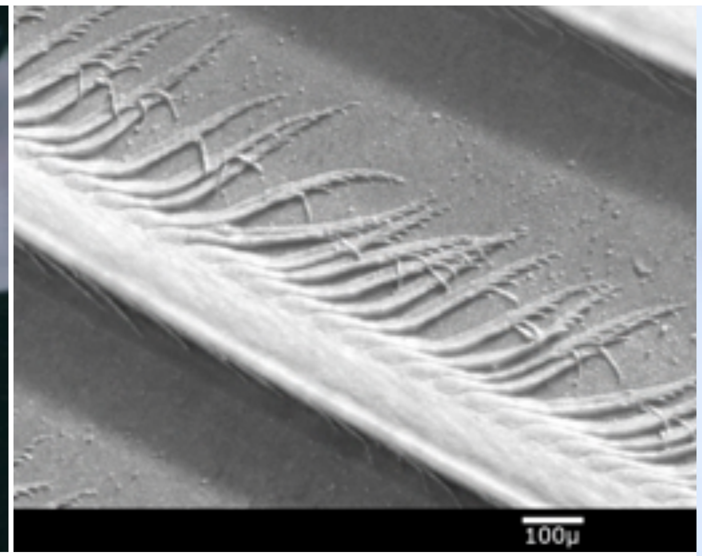


Figure 6. Two renderings of the acquired shape of a 1 cm decorative glass pin (see Fig. 2(a)).

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

Revealing relief that is too small

- Gel Sight, Johnson & Adelson

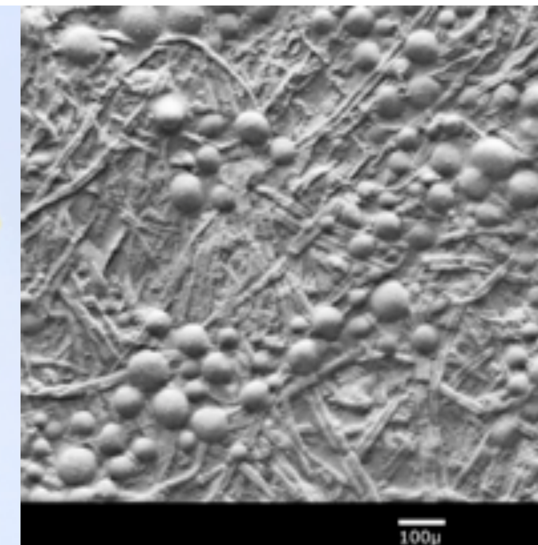


Figure 8. The corner of a twenty dollar bill. The ink is slightly raised, and the sensor is able to resolve this small difference in height, as shown by the reconstruction on the right.

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

Revealing relief that is too small

- Demarcating curves, Kolomenkin, Shimshoni, Tal

Original object

Demarcating (with mean curv. shading)

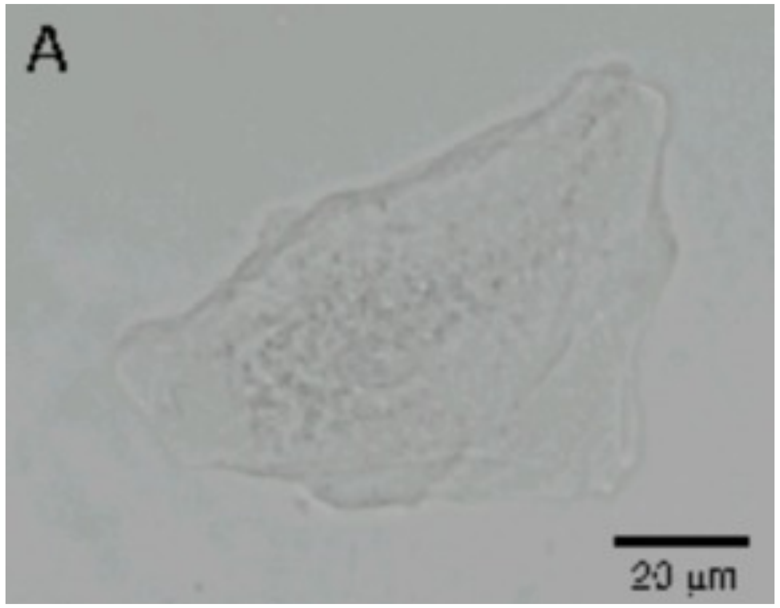
(f) Demarcating & exaggerated shading

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

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

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



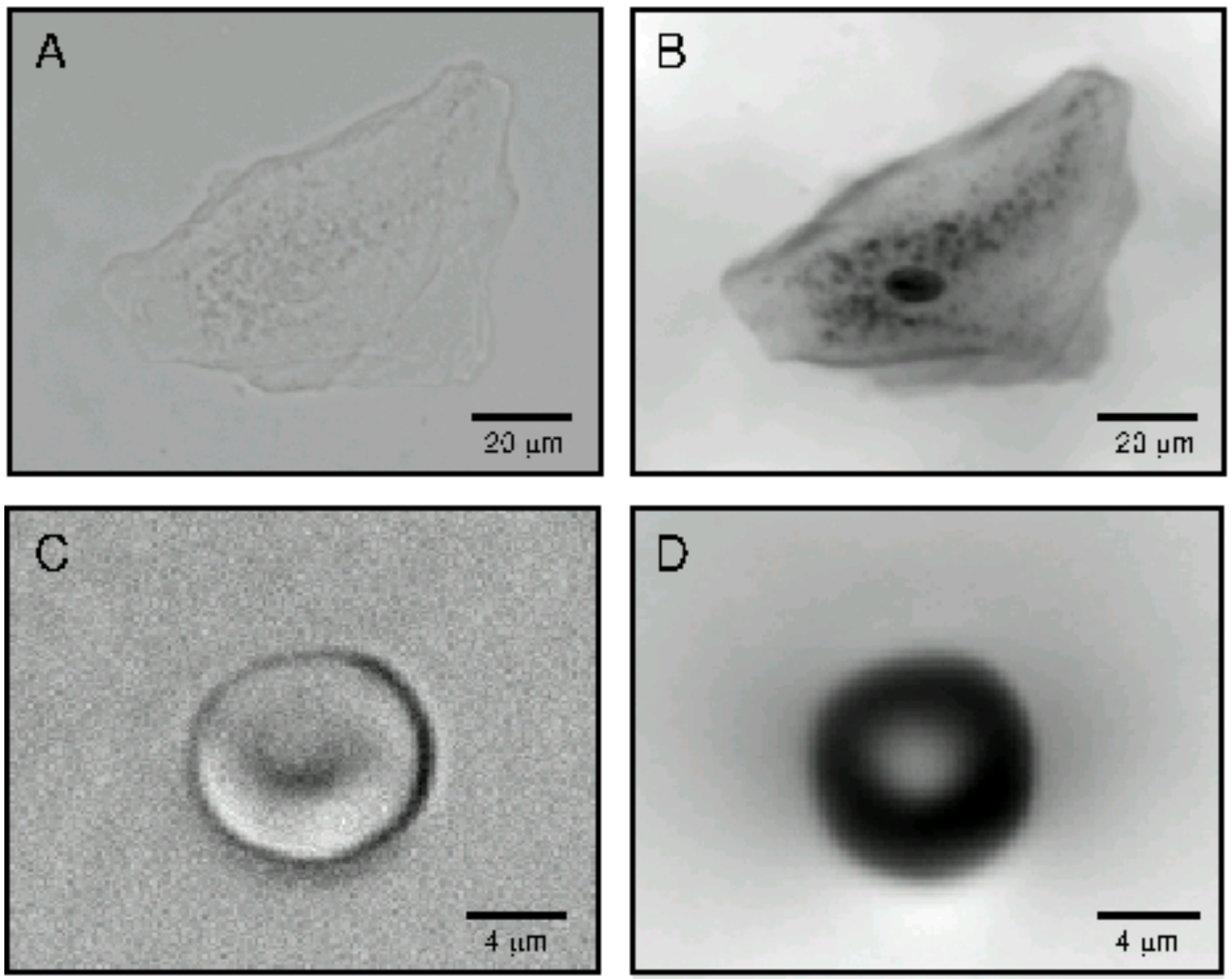
Bright field image of human buccal epithelial cell
http://aups.org.au/Proceedings/34/121-127/

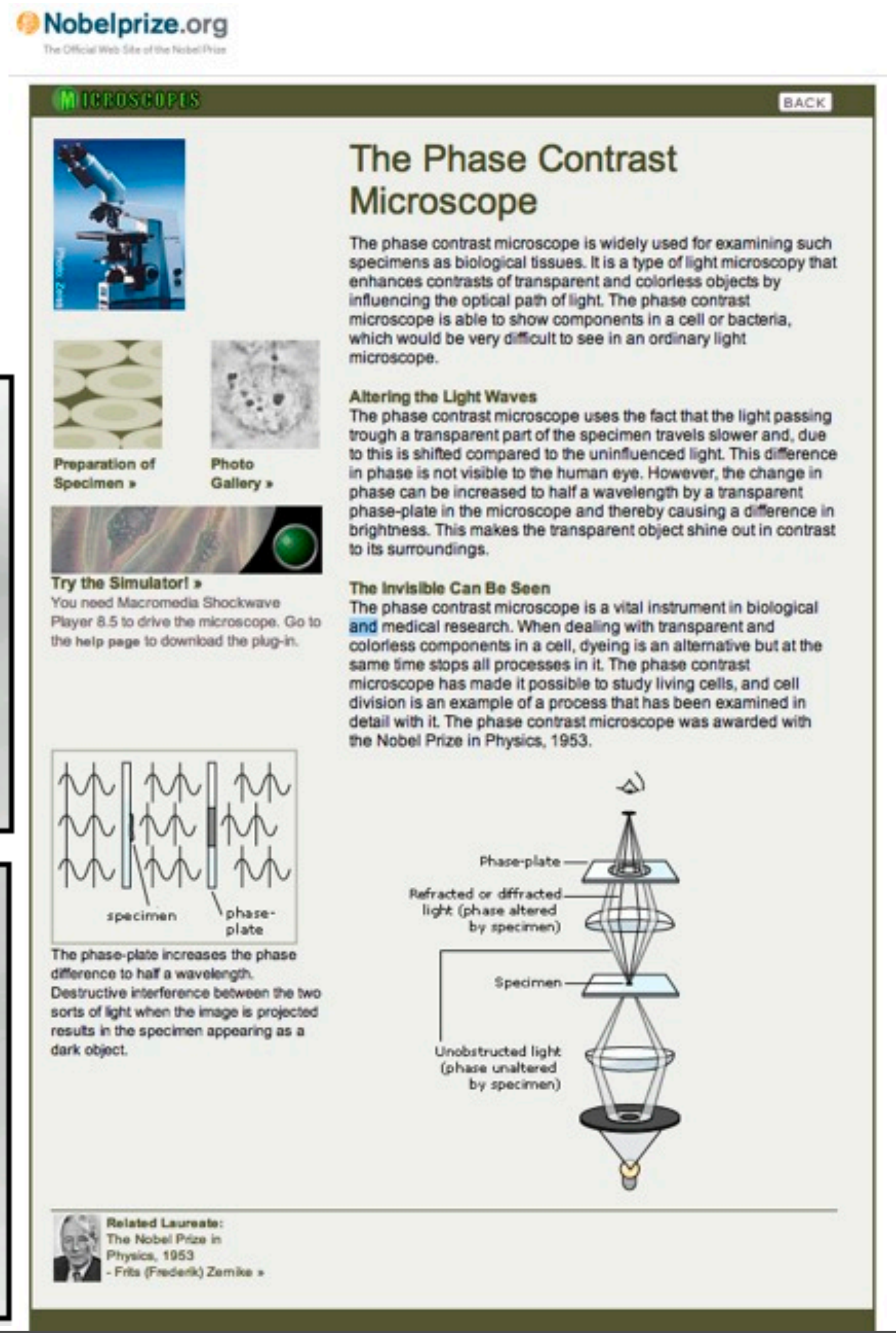
- Solution: exploit destructive interference when phase is shifted

Phase contrast microscope

- Zernike, (Nobel 1953)

Amplitude | Phase





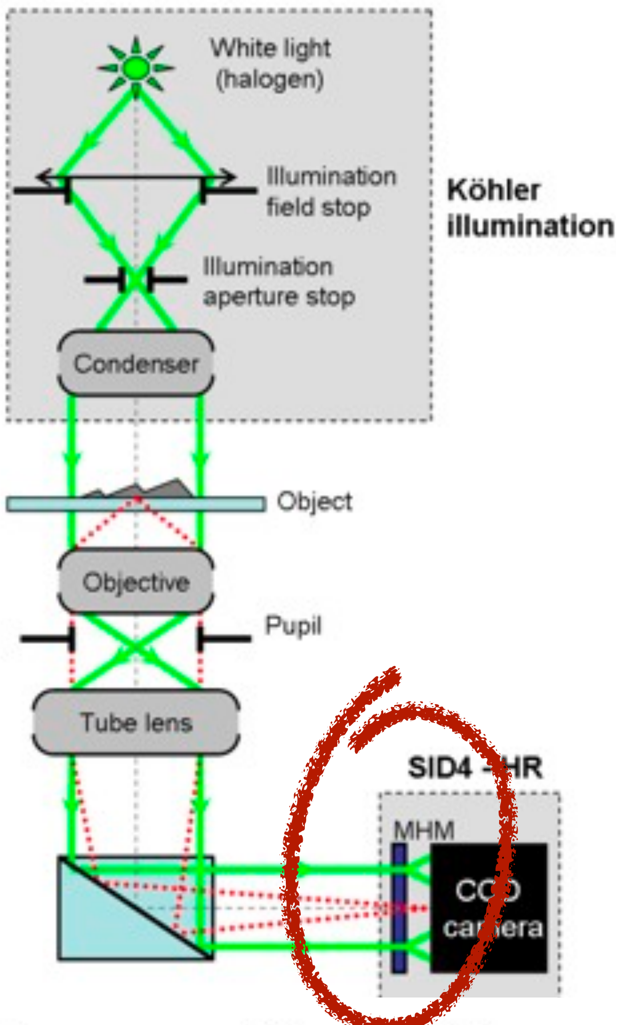
The Phase Contrast Microscope

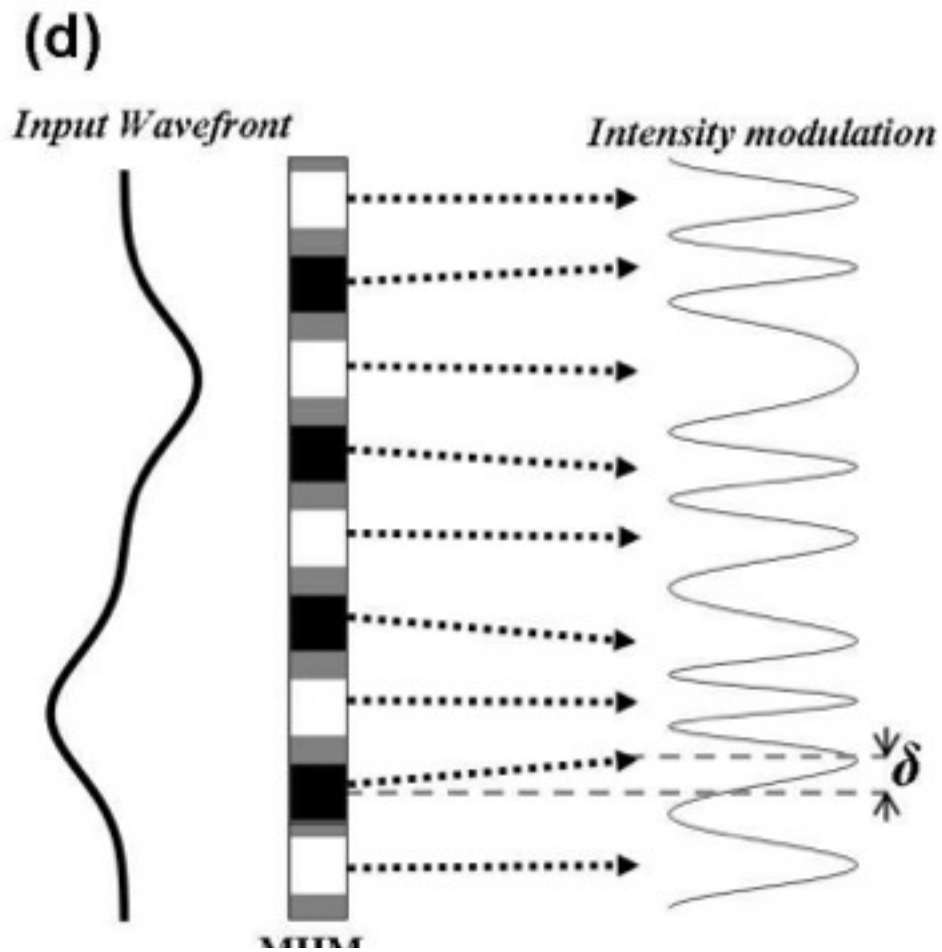
The phase contrast microscope is widely used for examining such specimens as biological tissues. It is a type of light microscopy that enhances contrasts of transparent and colorless objects by influencing the optical path of light. The phase contrast microscope is able to show components in a cell or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

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.

Light field camera for phase





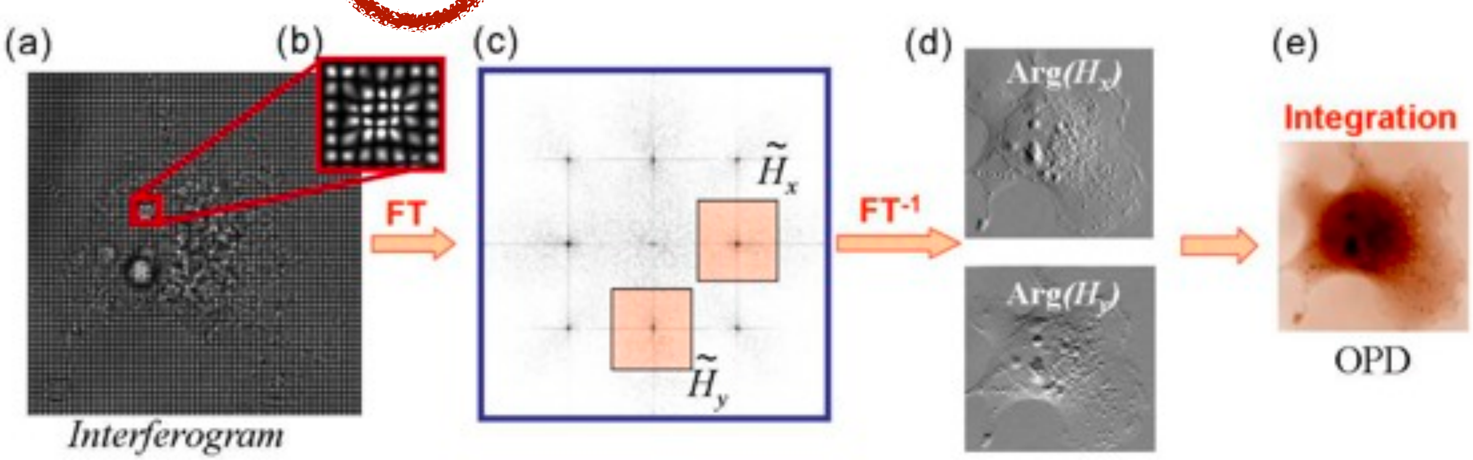


Fig. 3. (a) Interferogram obtained with an aberrant wavefront. (b) Zoom on a part of (*a*), visualization of the local frequency modulations. (c) Fourier Transform of (*a*). (d) Obtaining of 2 OPD orthogonal gradients by Inverse Fourier Transform of 2 sub-images of (*b*). (e) 2D Integration of the gradients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

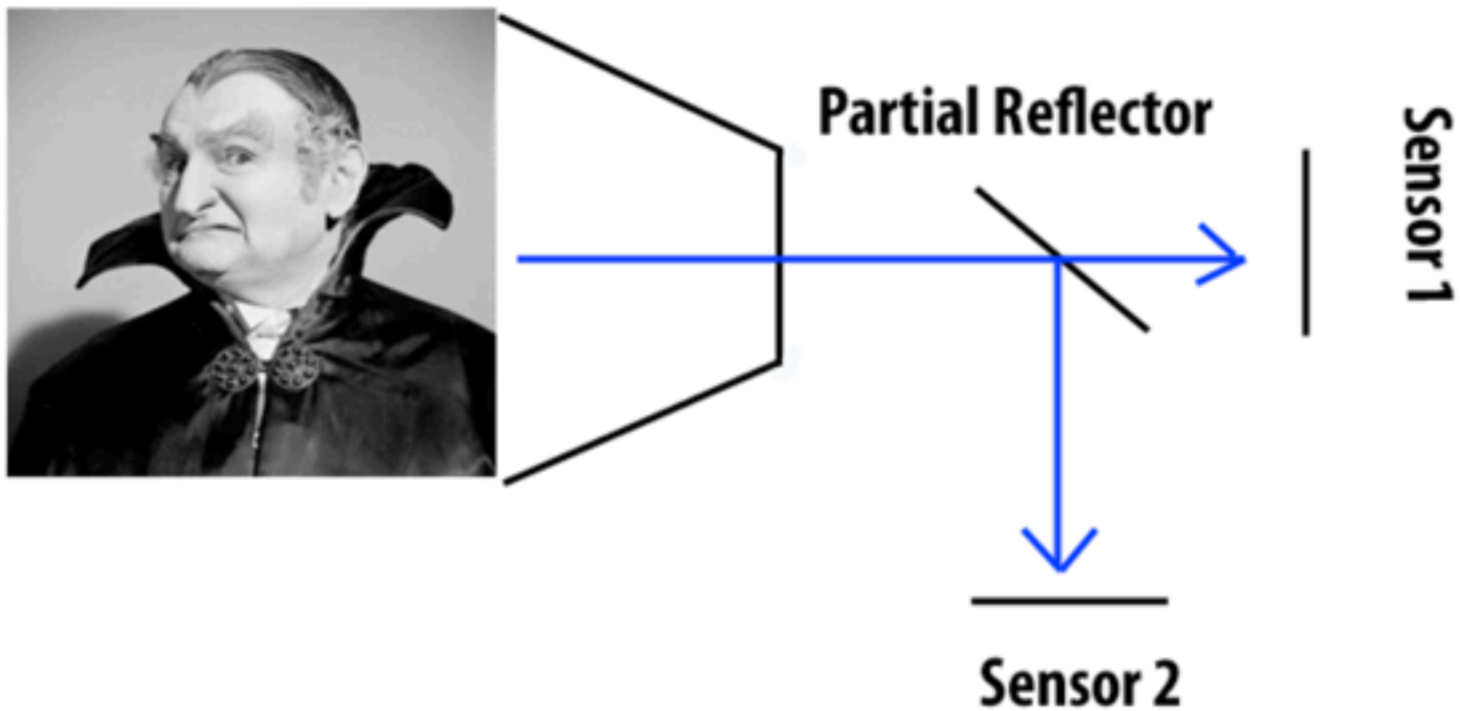
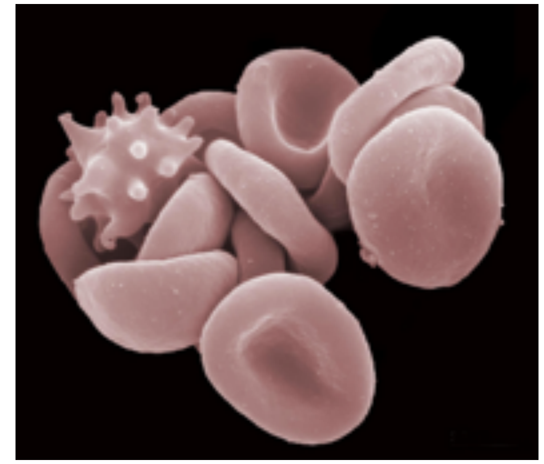
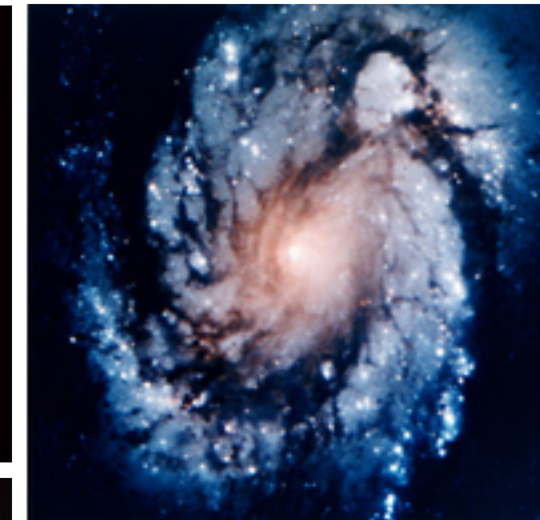
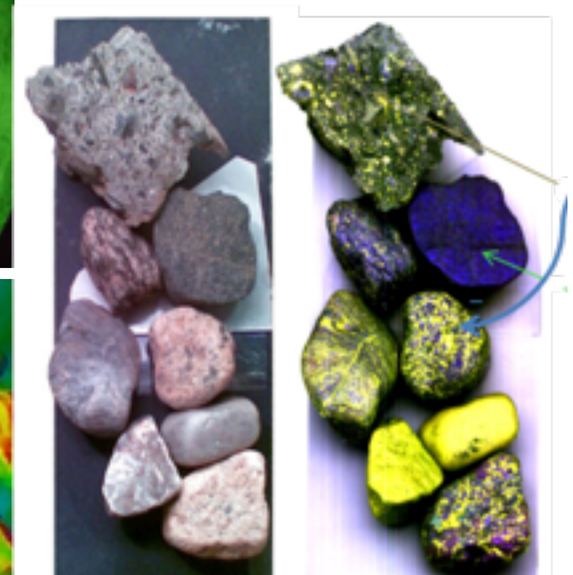
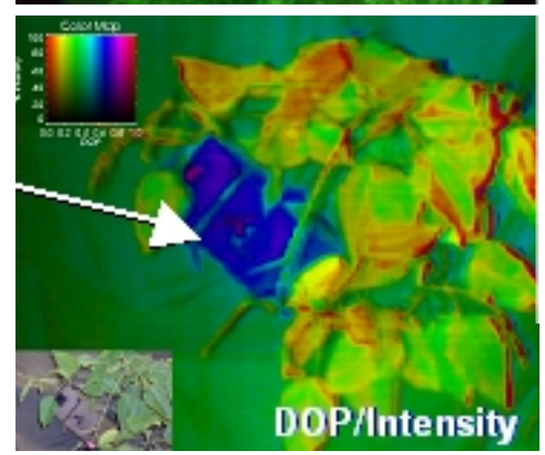


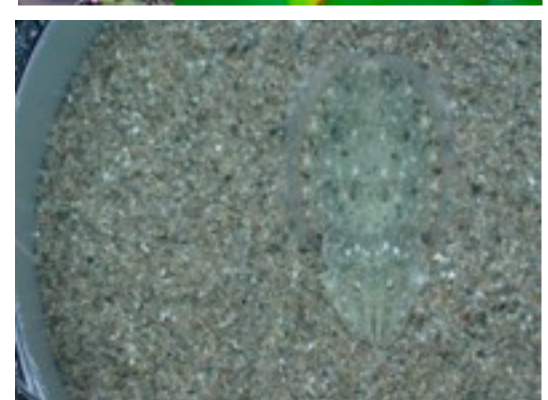
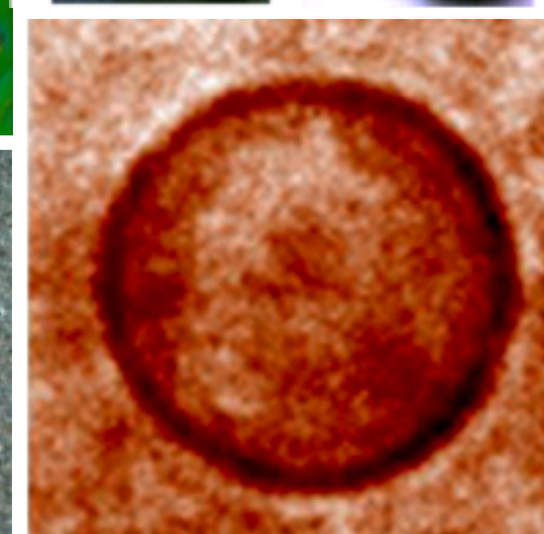
Figure 2: *Two Sensors are used to capture the same scene. One captures a reflected image of the other. The reflected light does not carry any image of undead entities.*

Recap: Beyond human capabilities

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

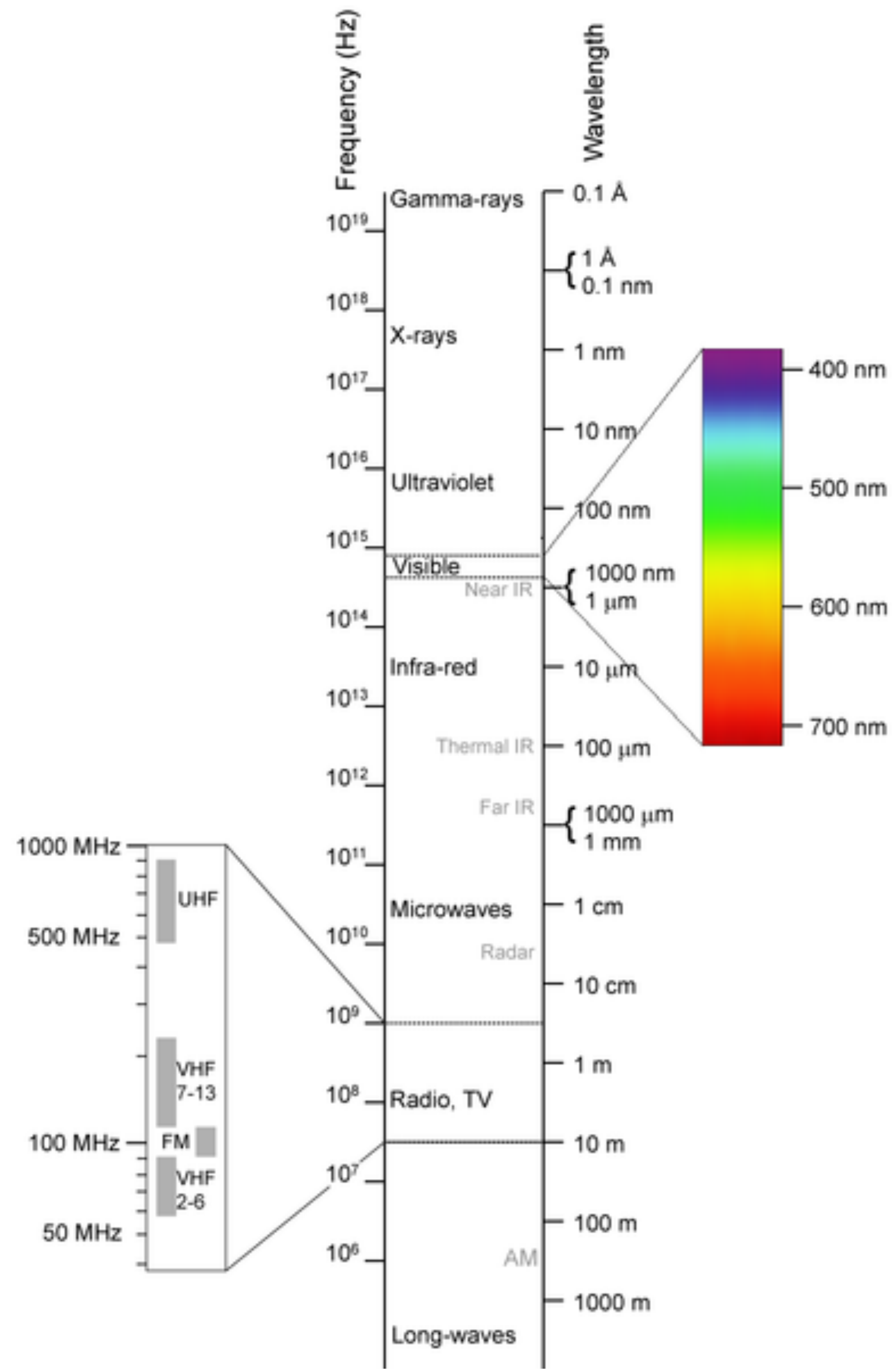



Overview

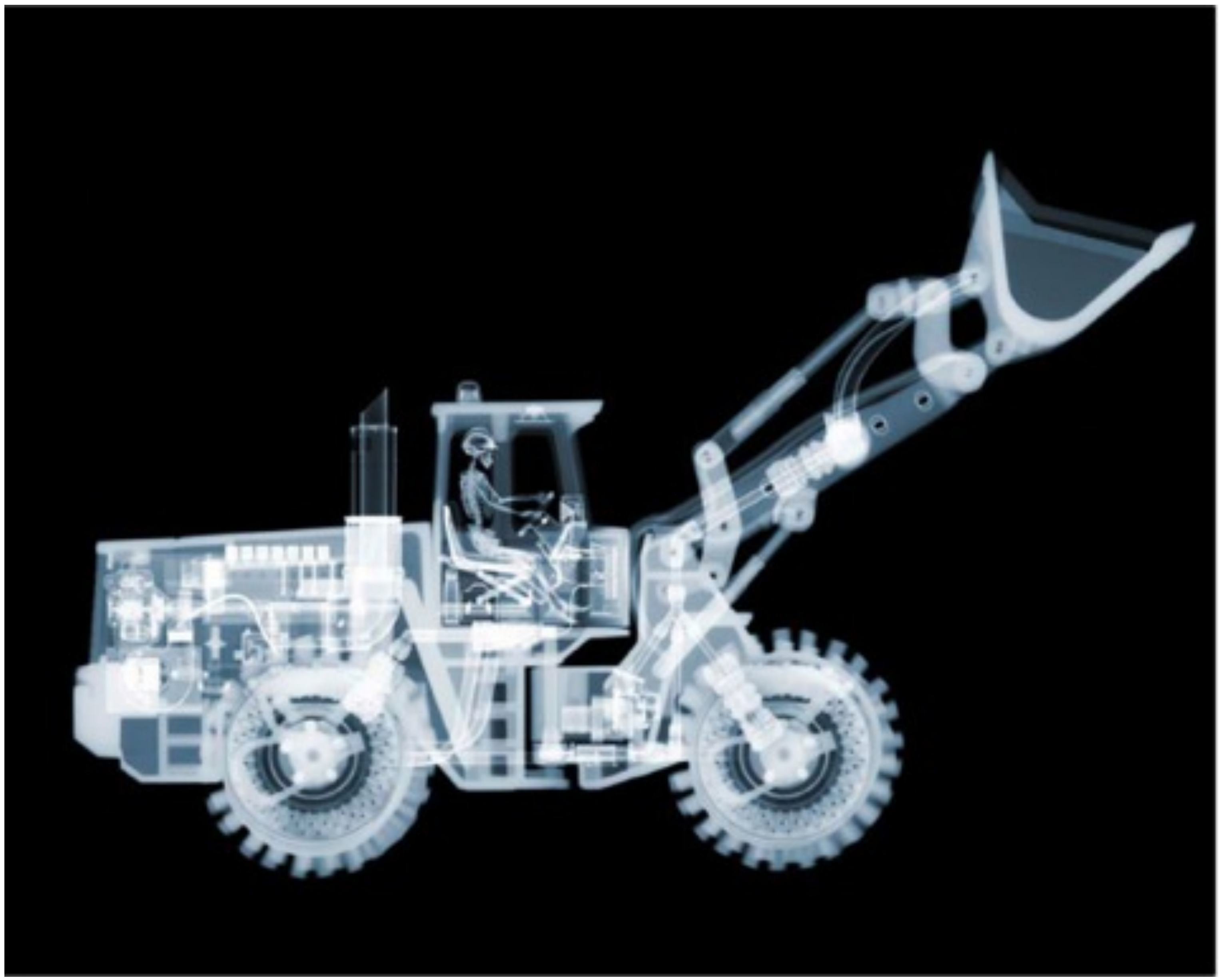
- Limits of human vision
- **Occlusion**
- Non-visual phenomena
- Non-visible visual phenomena
- Change and motion

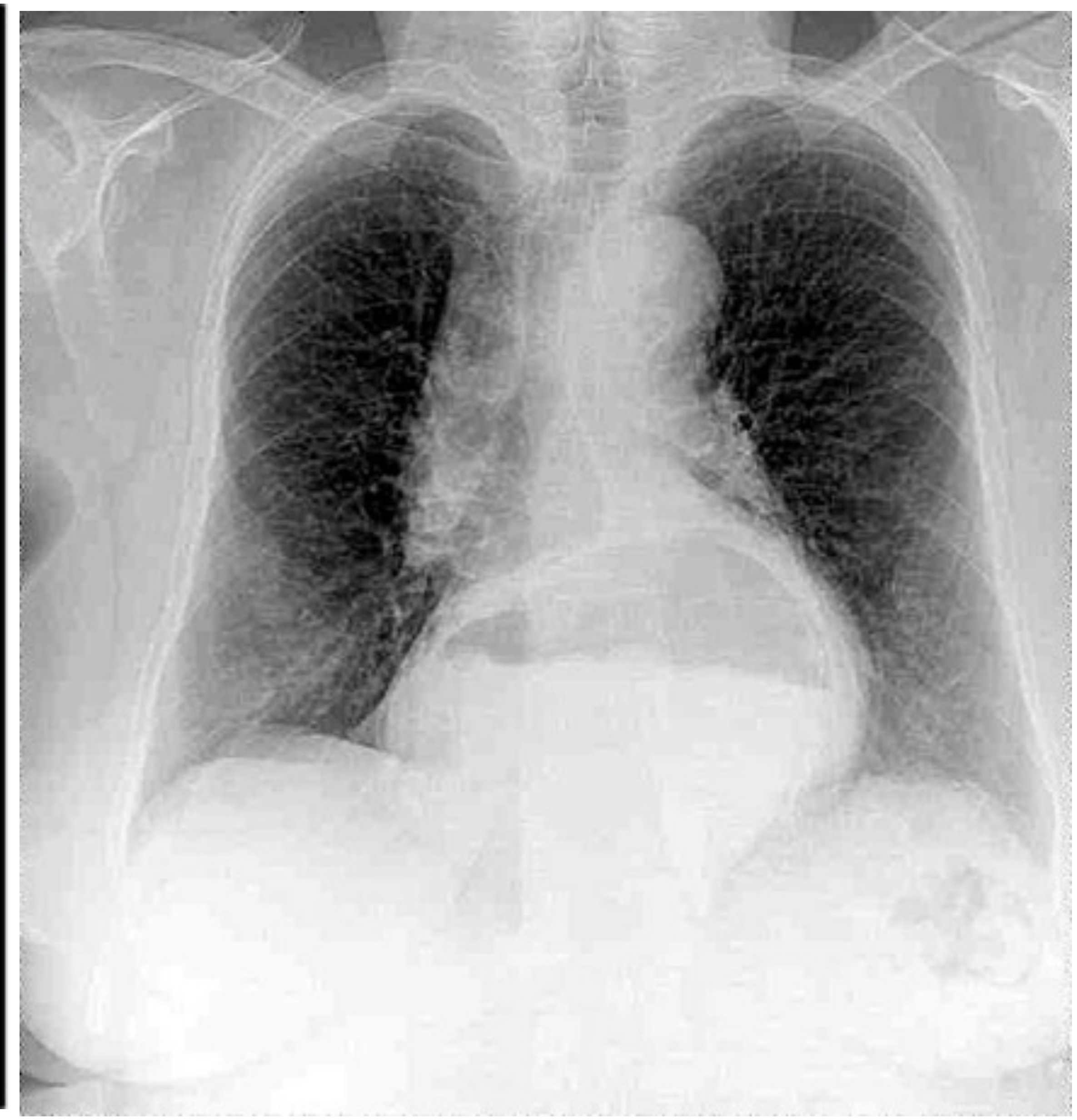
X Ray



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

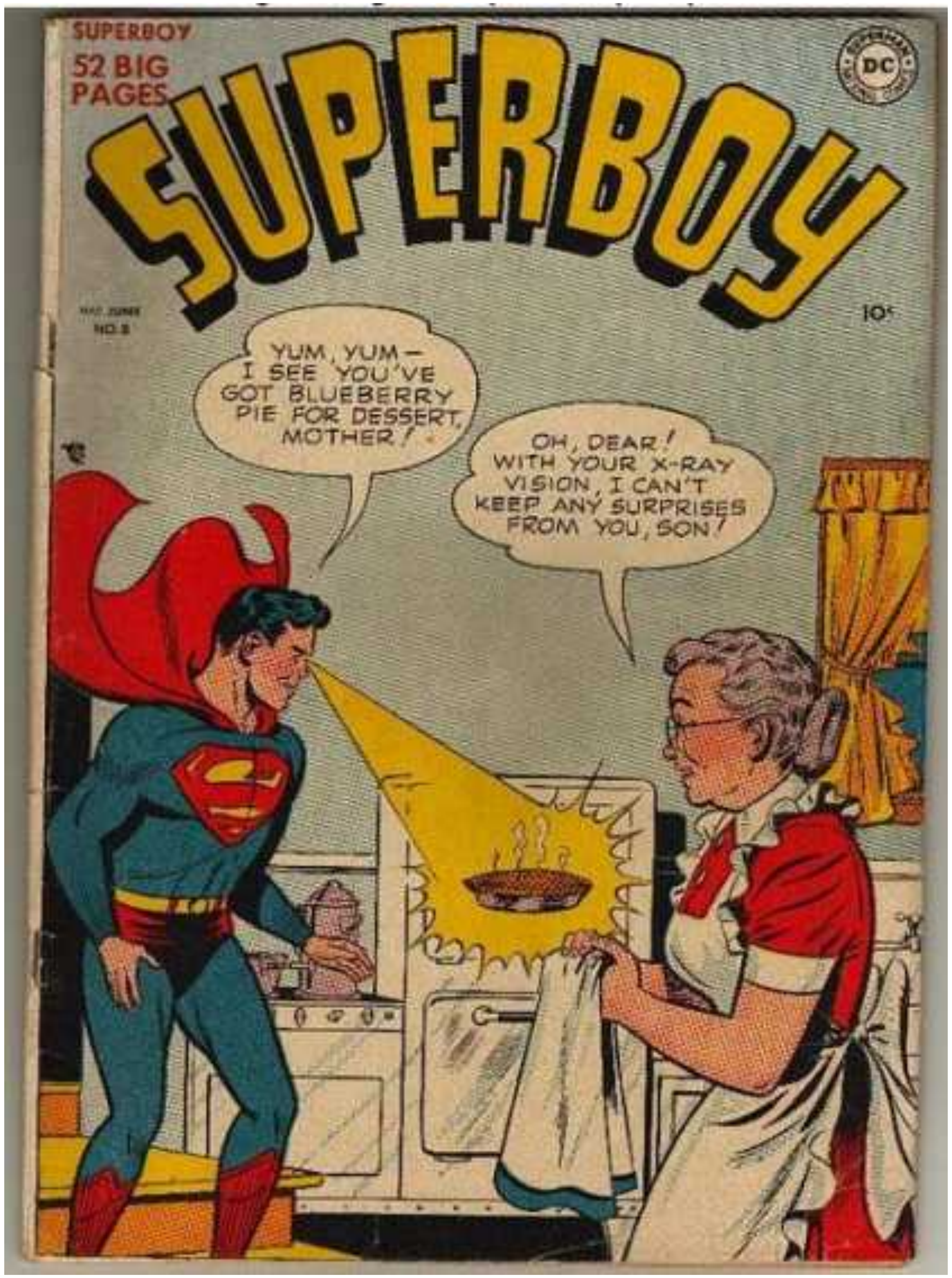
X Ray

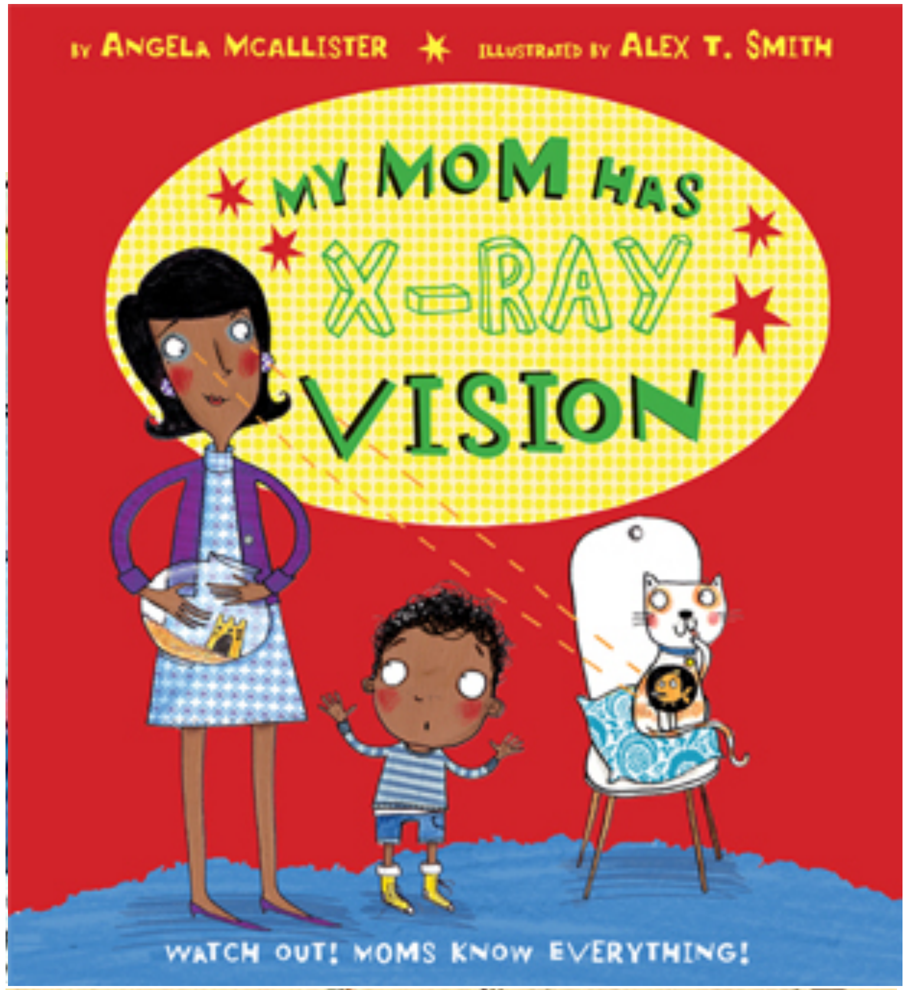




http://www.nickveasey.com/ http://en.wikipedia.org/wiki/X-ray

X ray vision!





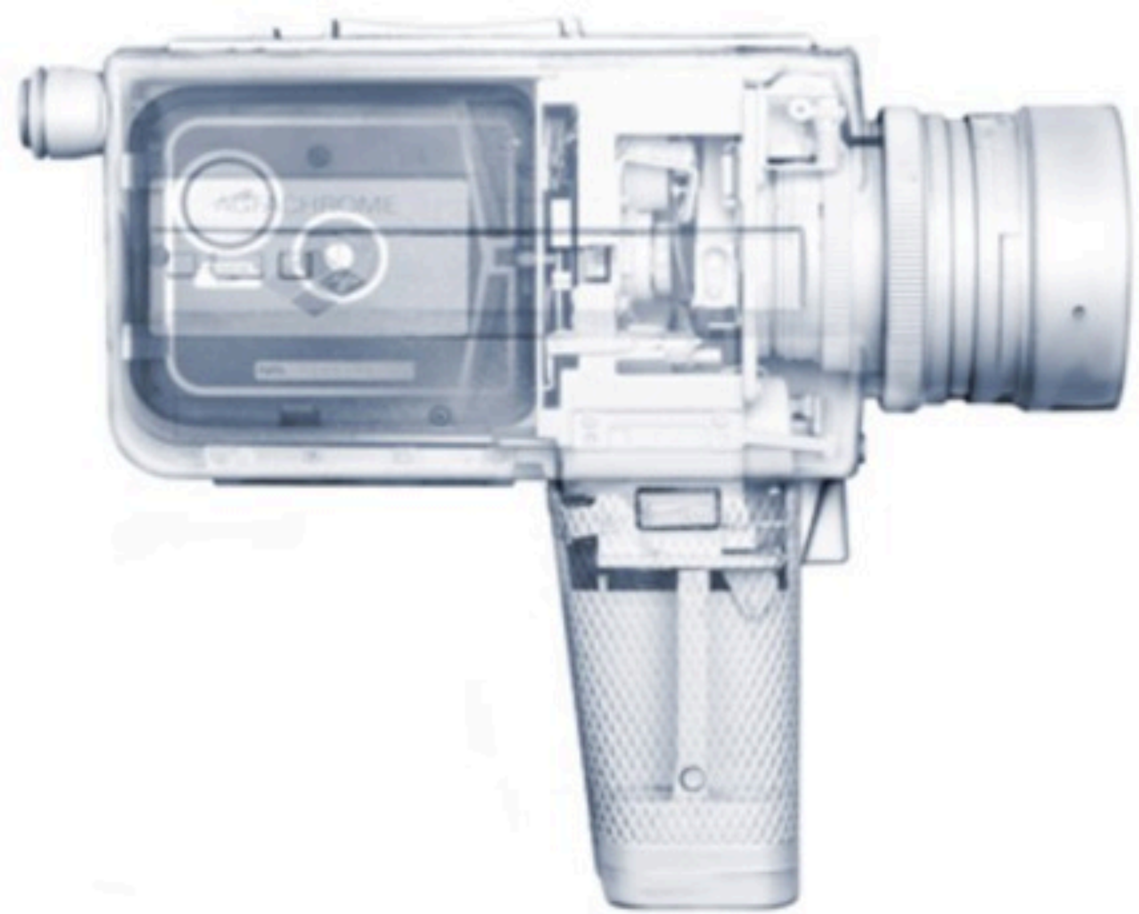
http://blubabalu.blogspot.hk/2012/01/x-ray-specs.html

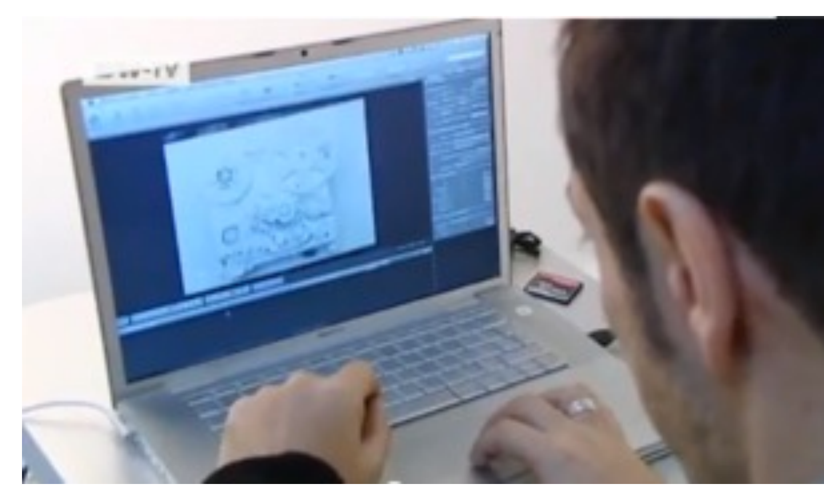
Sonogram

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

Fake Xray

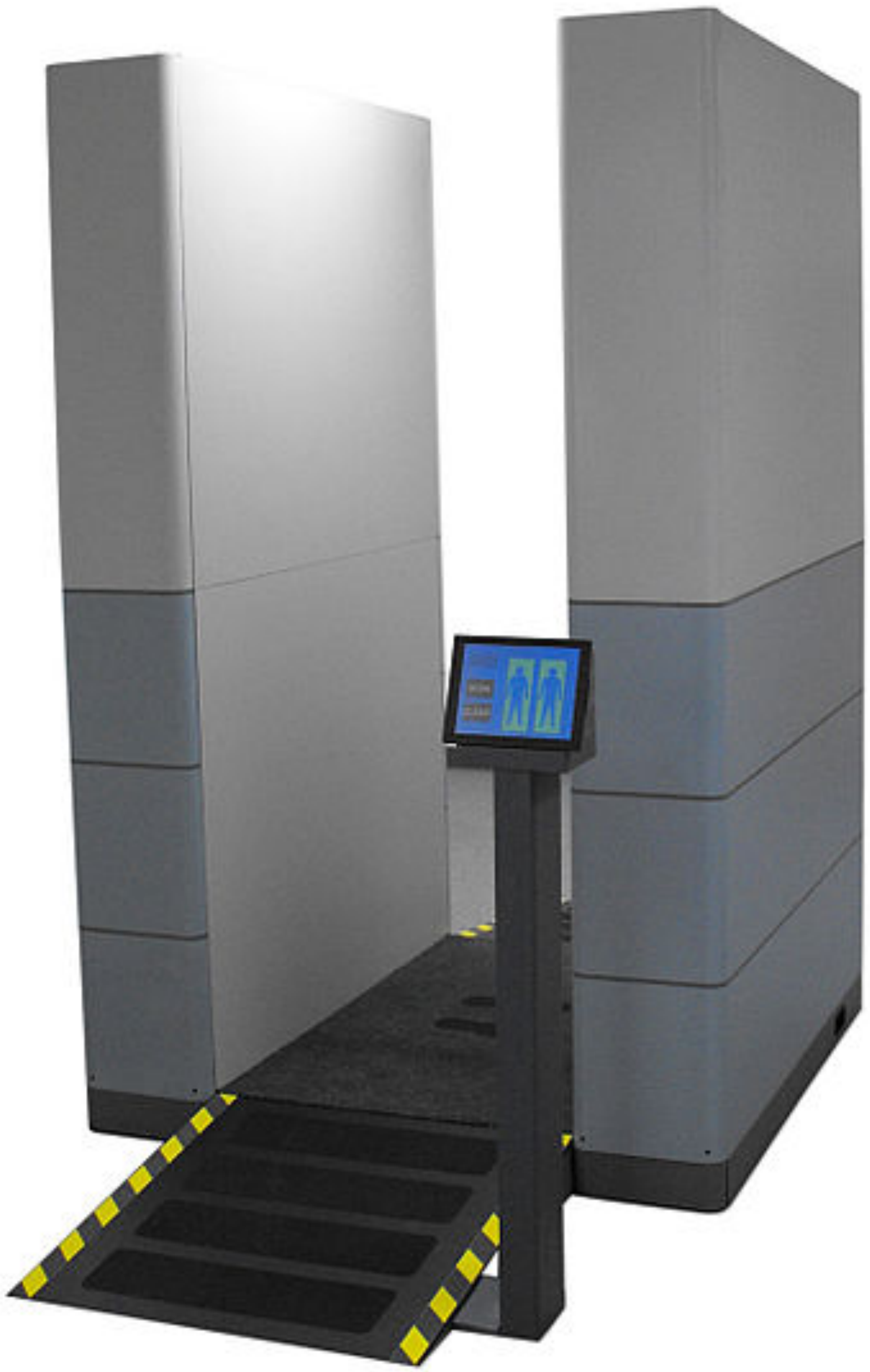
- Max de Esteban’s Proposition One
- Disassembled, spray-painted, multiple photos, layers in Photoshop



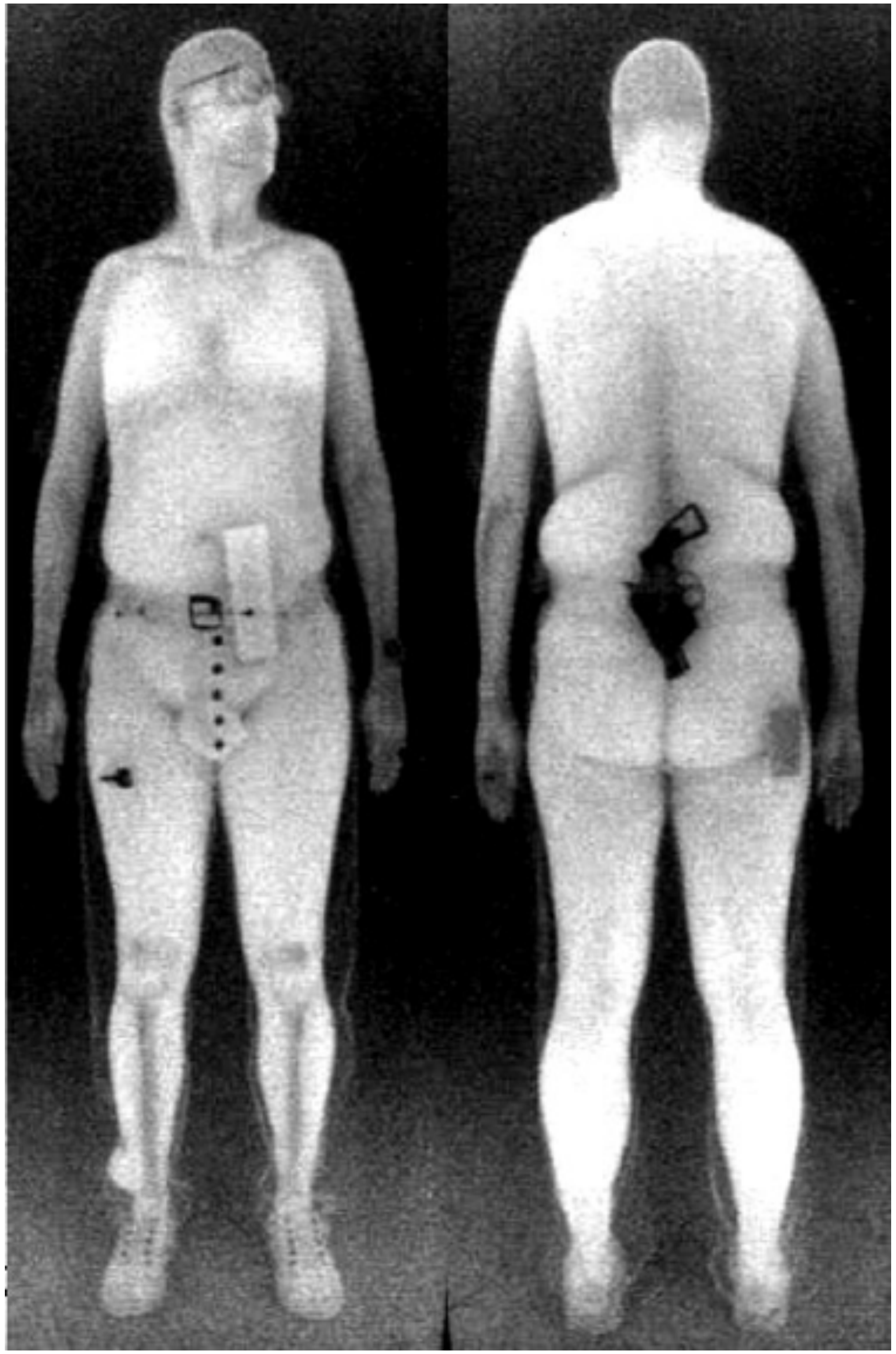


http://www.youtube.com/watch?feature=player_embedded&v=3NewEh0YQwk http://www.maxphotos.es/

Backscatter x ray

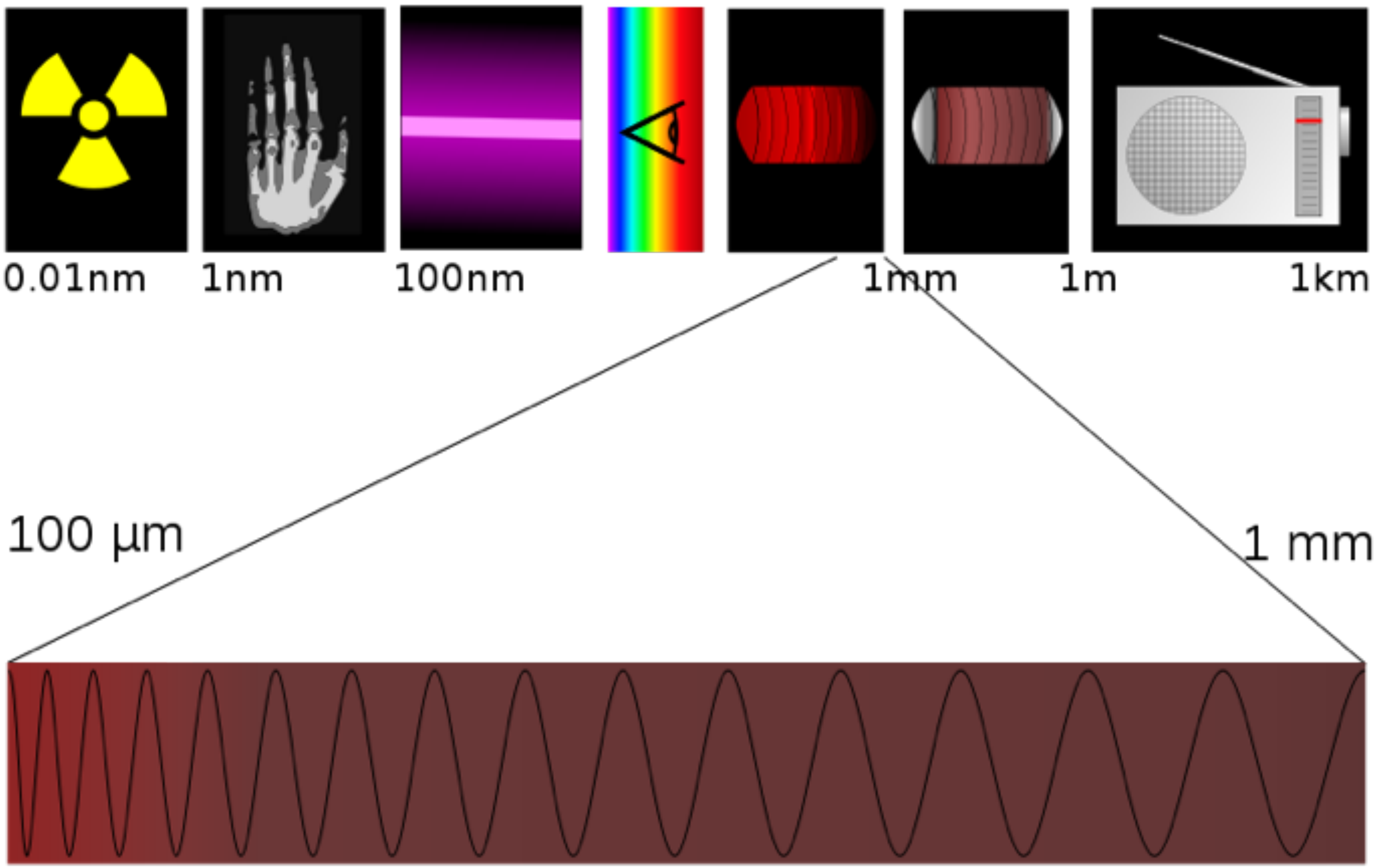


http://en.wikipedia.org/wiki/Backscatter_X-ray



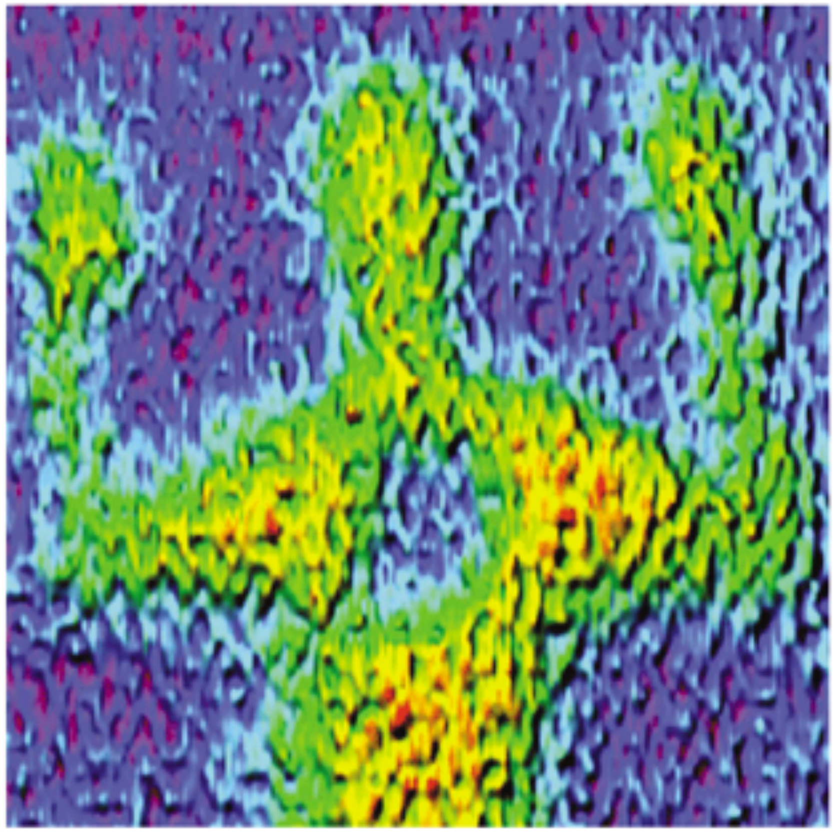
http://compilerbitch.livejournal.com/218216.html

Terahertz imaging



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

http://www.jlab.org/FEL/terahertz/



http://www.masazumifujiwara.net/source/thz.html

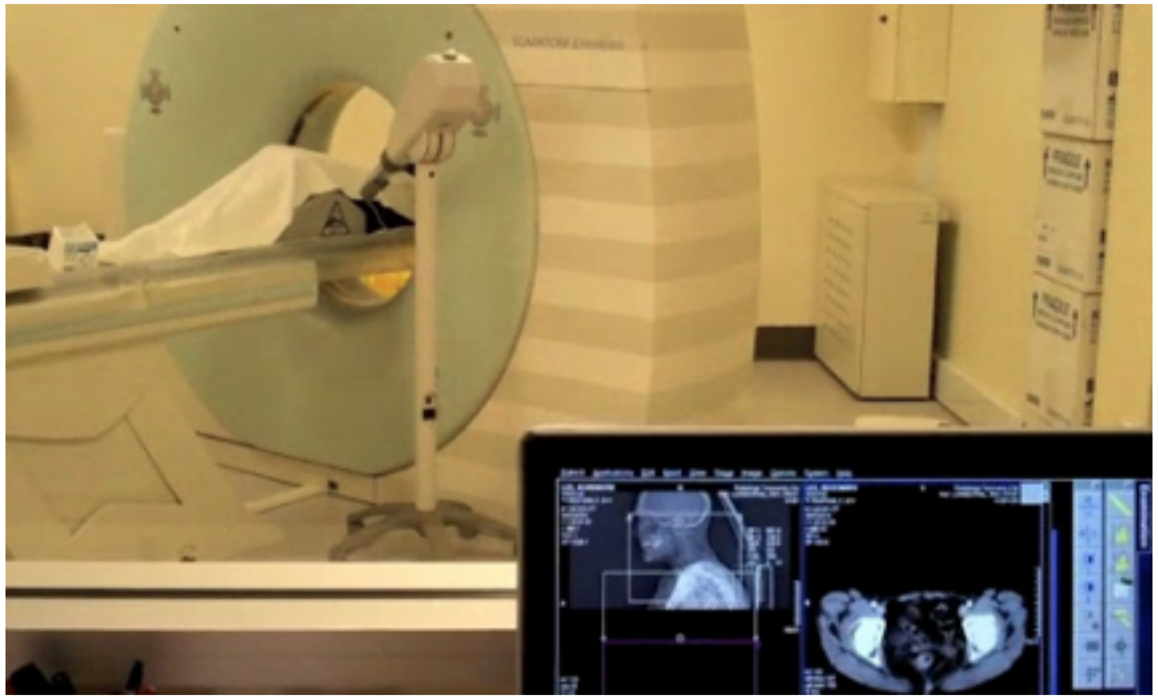
Analysis of paintings

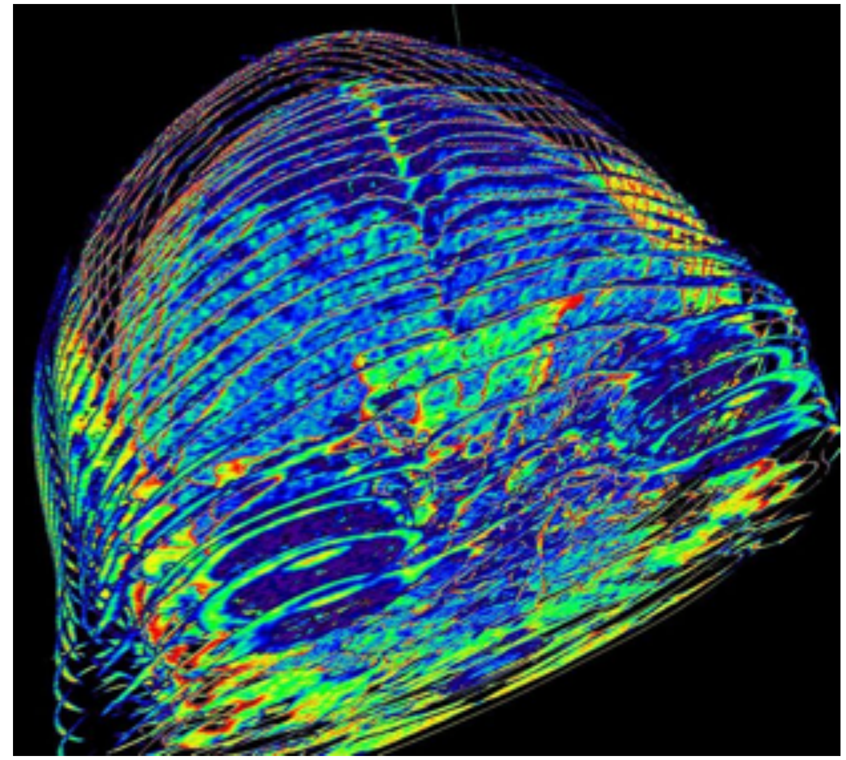
- Scanning Macro X ray Fluorescence Spectrometry

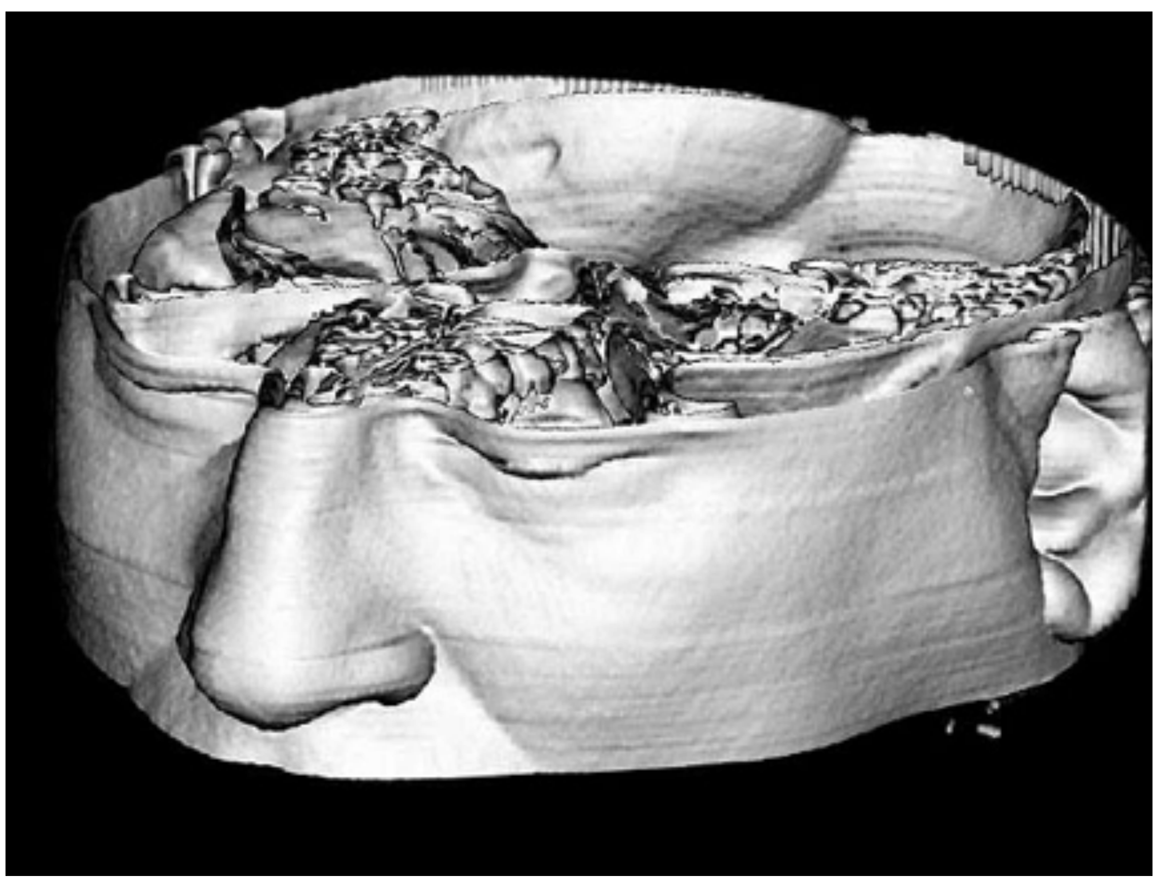
Francisco de Goya's Portrait of Don Ramon Statue (left) and the painting discovered underneath it

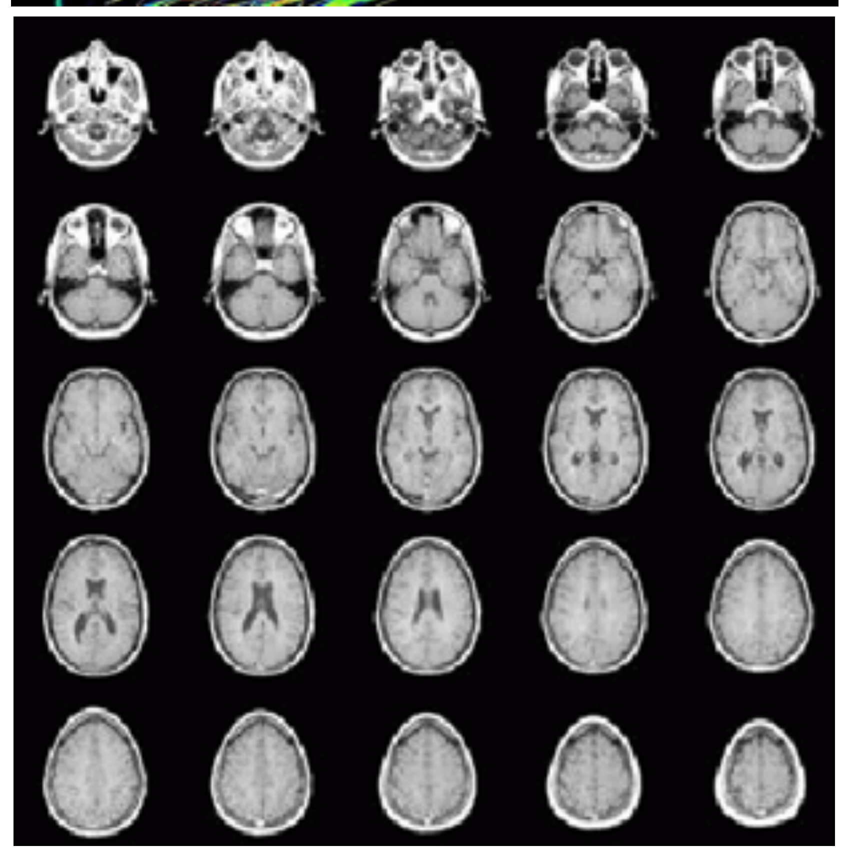
http://tudelft.nl/en/current/latest-news/article/detail/onbekend-portret-ontdekt-onder-meesterwerk-van-goya/

CT, MRI





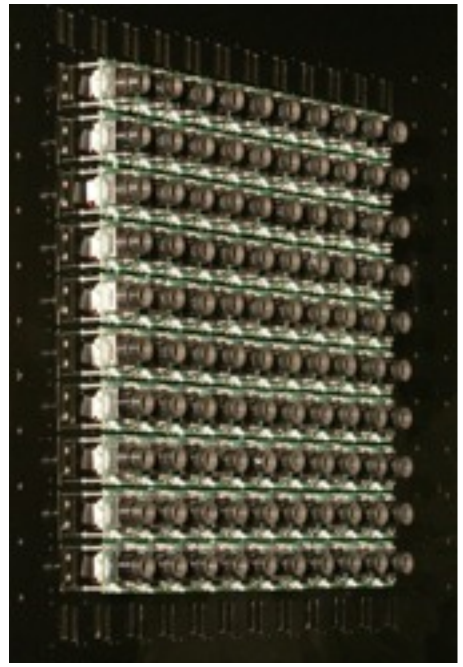




http://tomographymeetsmasochism.blogspot.hk/

http://www.mathworks.com/products/demos/image/3d_mri/tform3.html http://en.wikipedia.org/wiki/X-ray_computed_tomography

Synthetic aperture



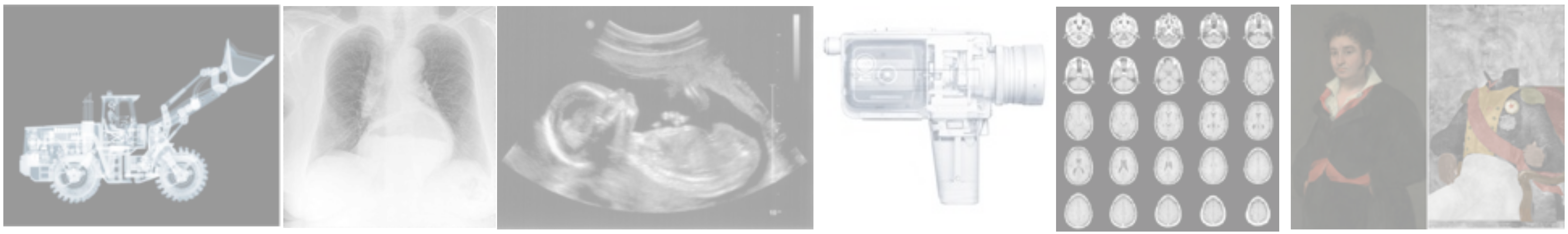
(a) (b) (c)

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/

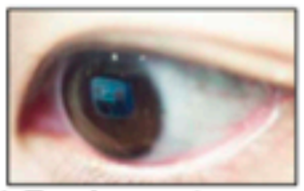
Hidden things & occlusion

- Seeing inside objects

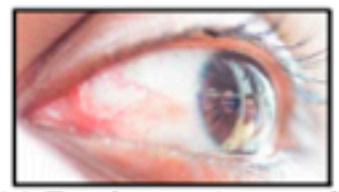


- Seeing beyond the field of view

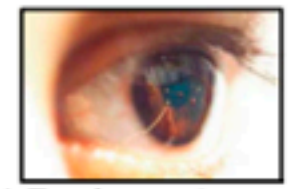
Reflection in an eye



(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

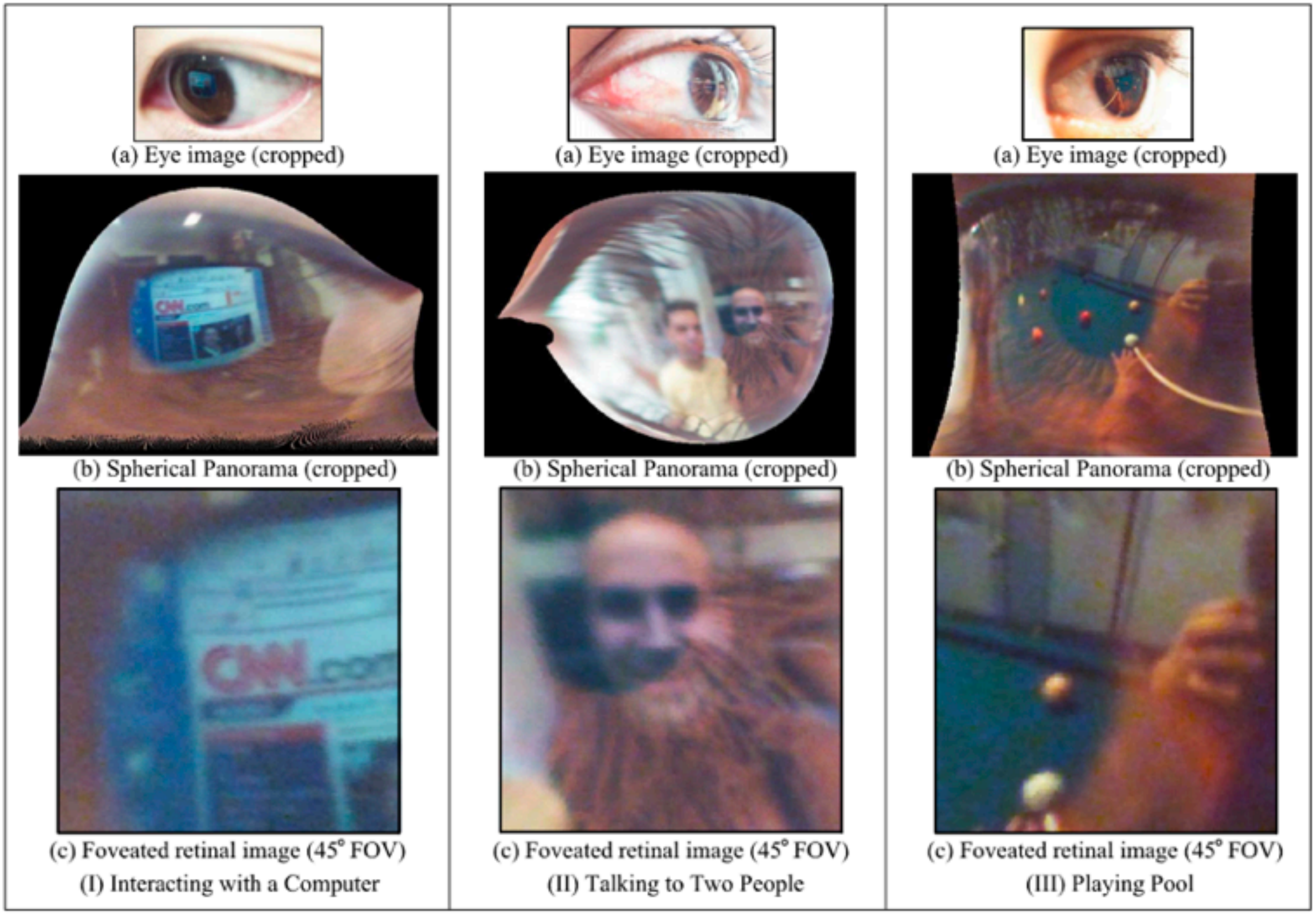
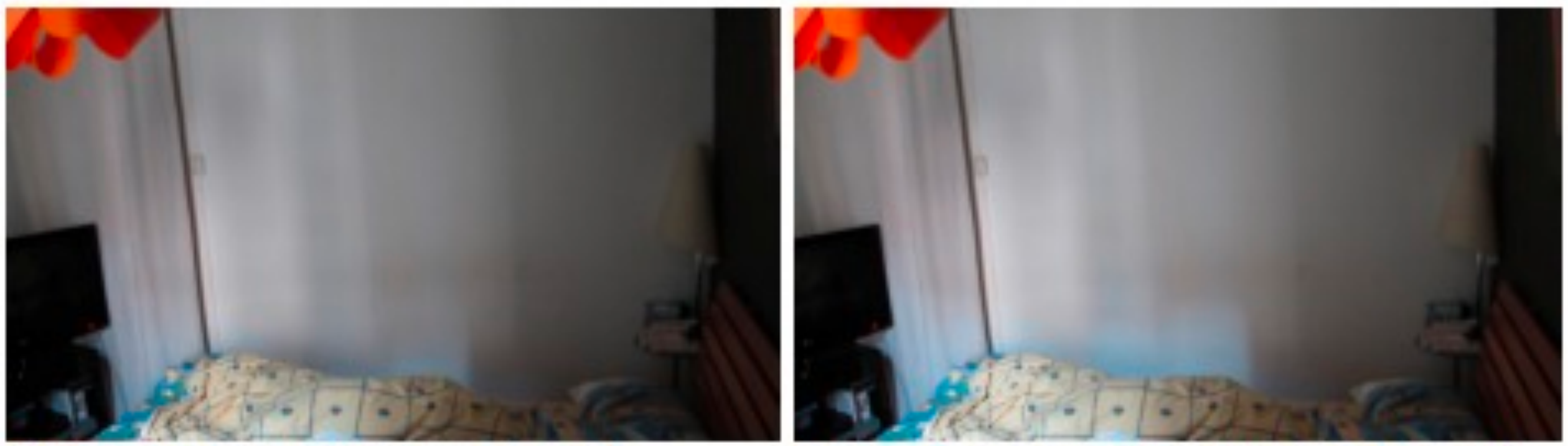


Figure 10: Examples of spherical panoramas and foveated retinal images computed from images of eyes. Three different examples are shown. Each example includes (a) a cropped image of the eye, (b) a cropped image of the computed spherical panorama and (c) a foveated retinal image with a 45° field of view. 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.

"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.

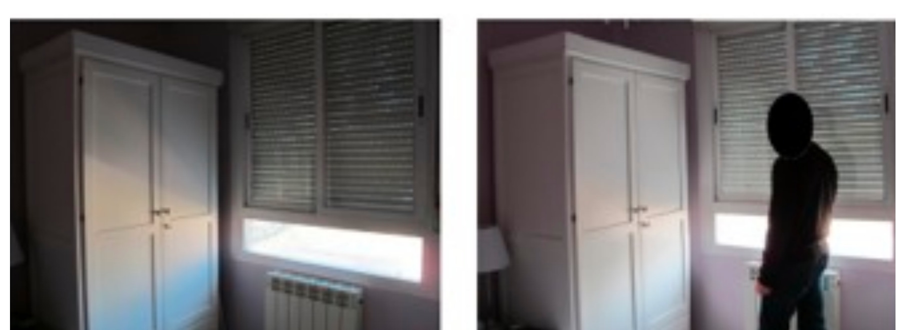
Accidental pinhole and pinspeck

- 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

- Torralba and Freeman, CVPR 2012

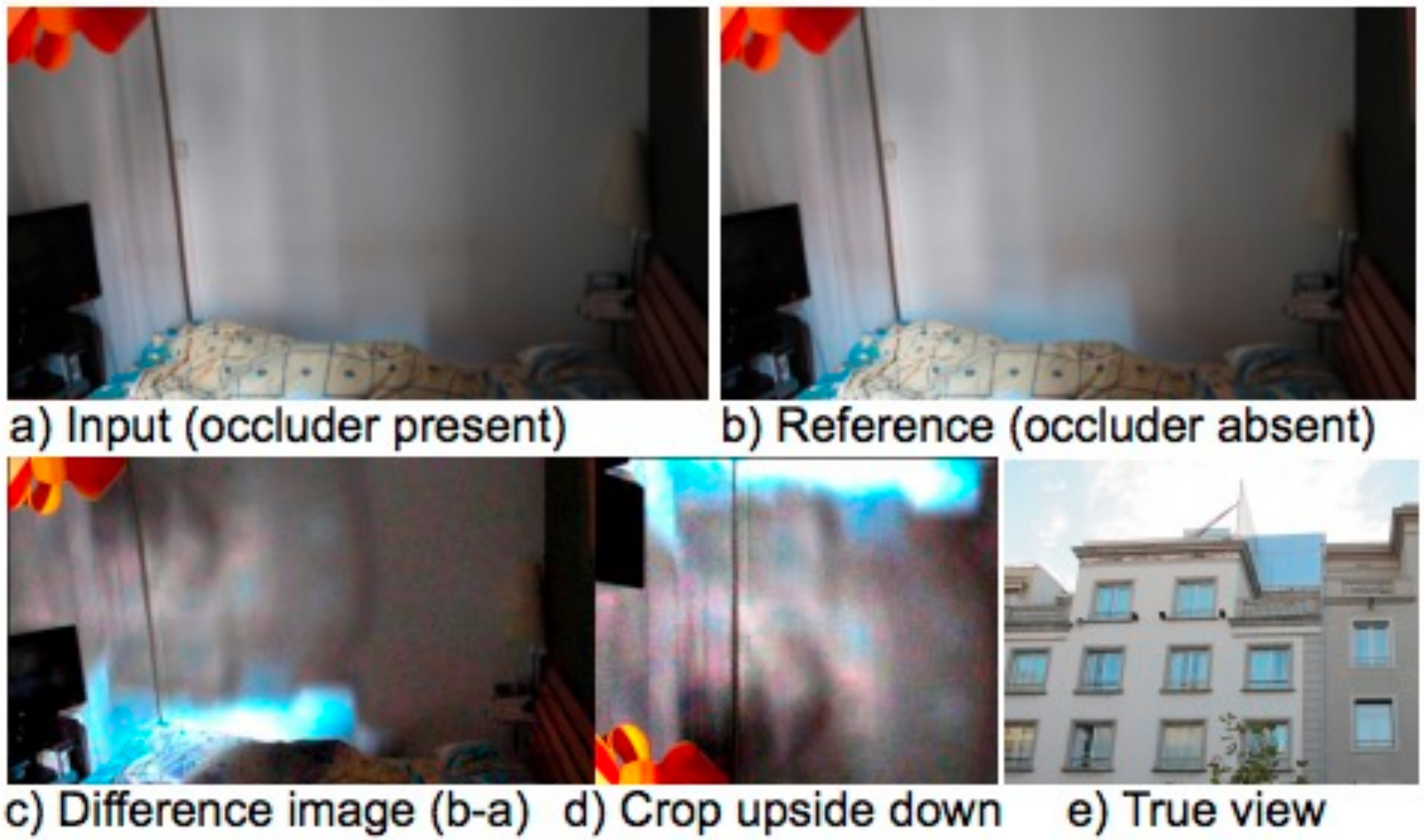
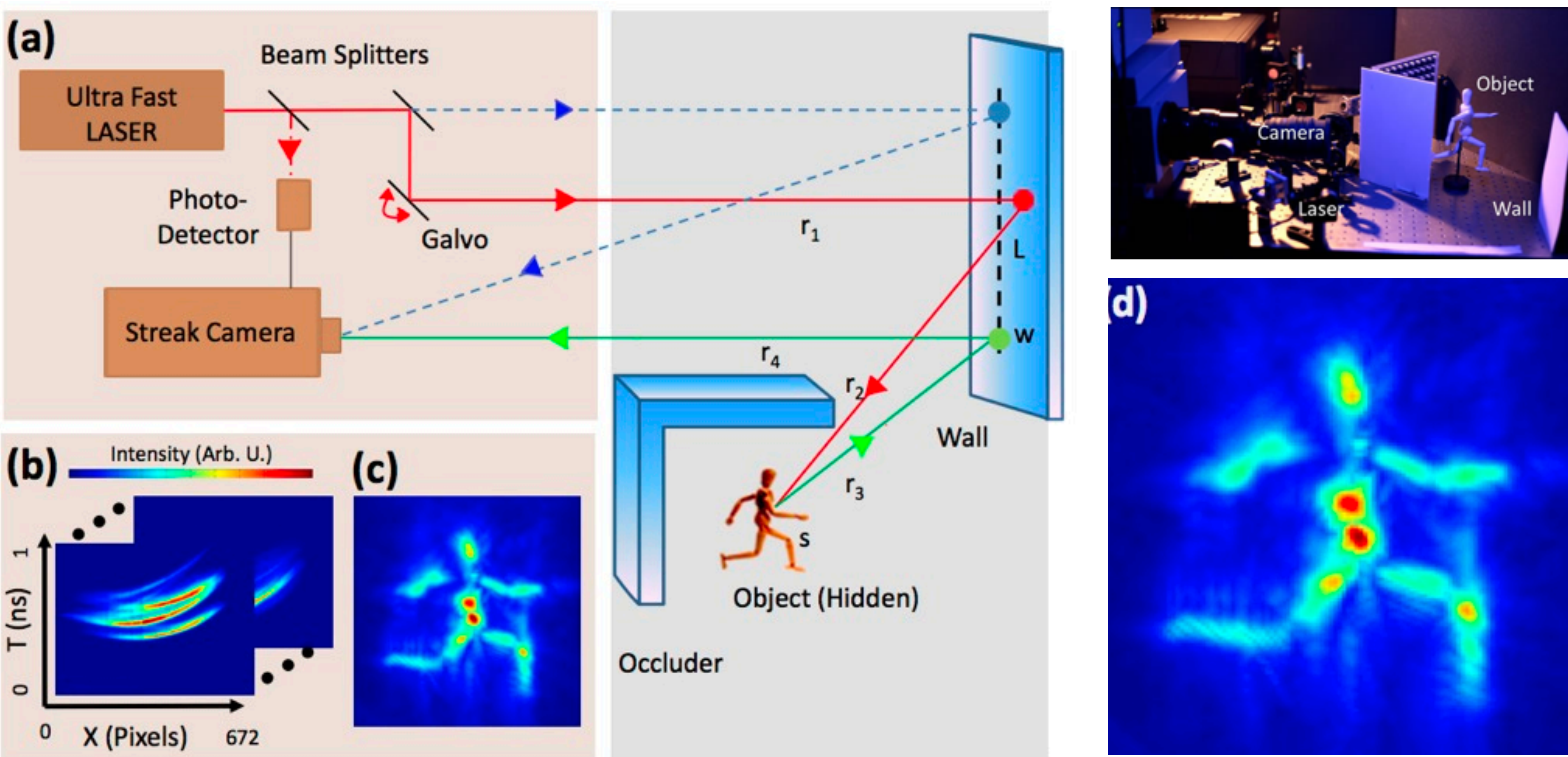


Figure 7. A second example of finding a picture of what is outside a room (d) from two pictures (a) and (b). The true view (e) is shown for comparison with the recovered image (d).

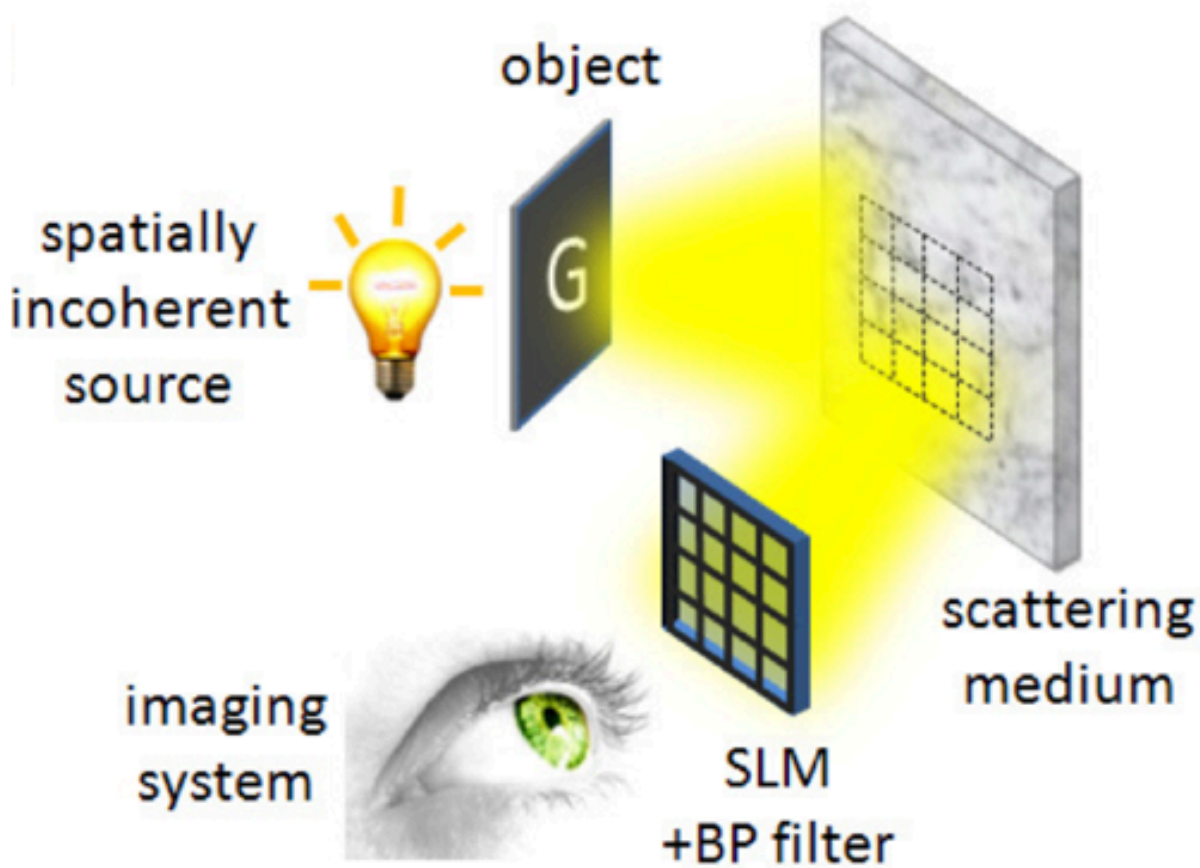
Seeing behind corners

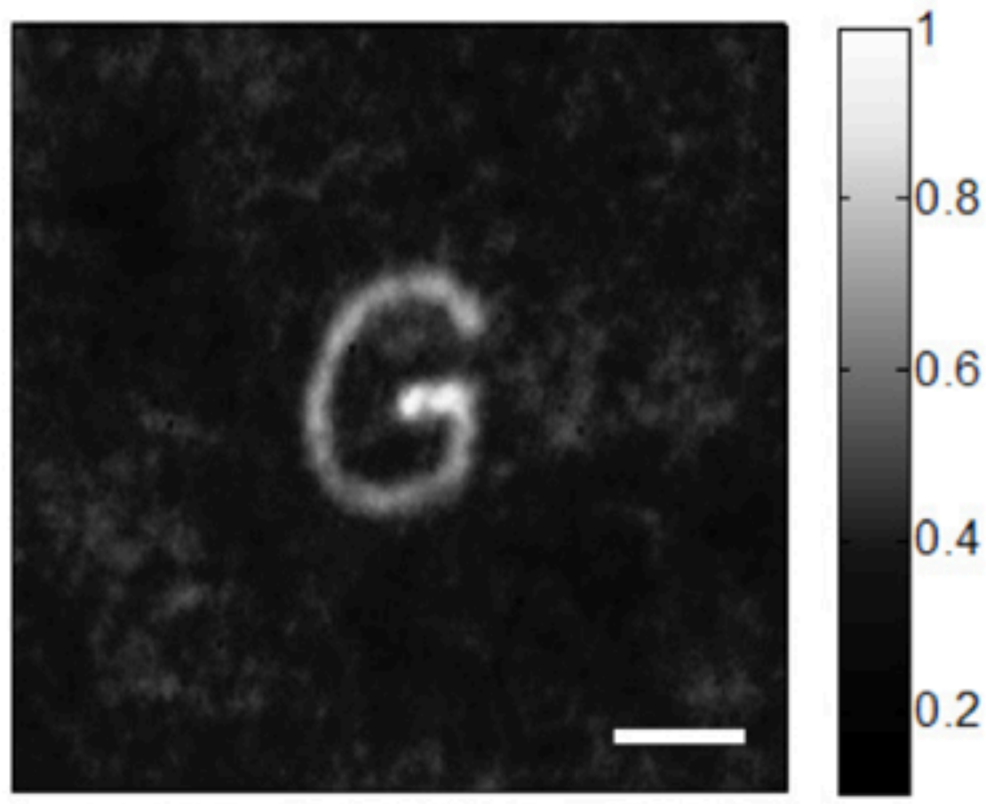
- Velten et al. :
- Time of flight with 3rd bounce of light



Seeing behind corners

- Katz et al.
- White light, direct imaging
- Spatial light modulator to focus light reflected by a diffuse reflector

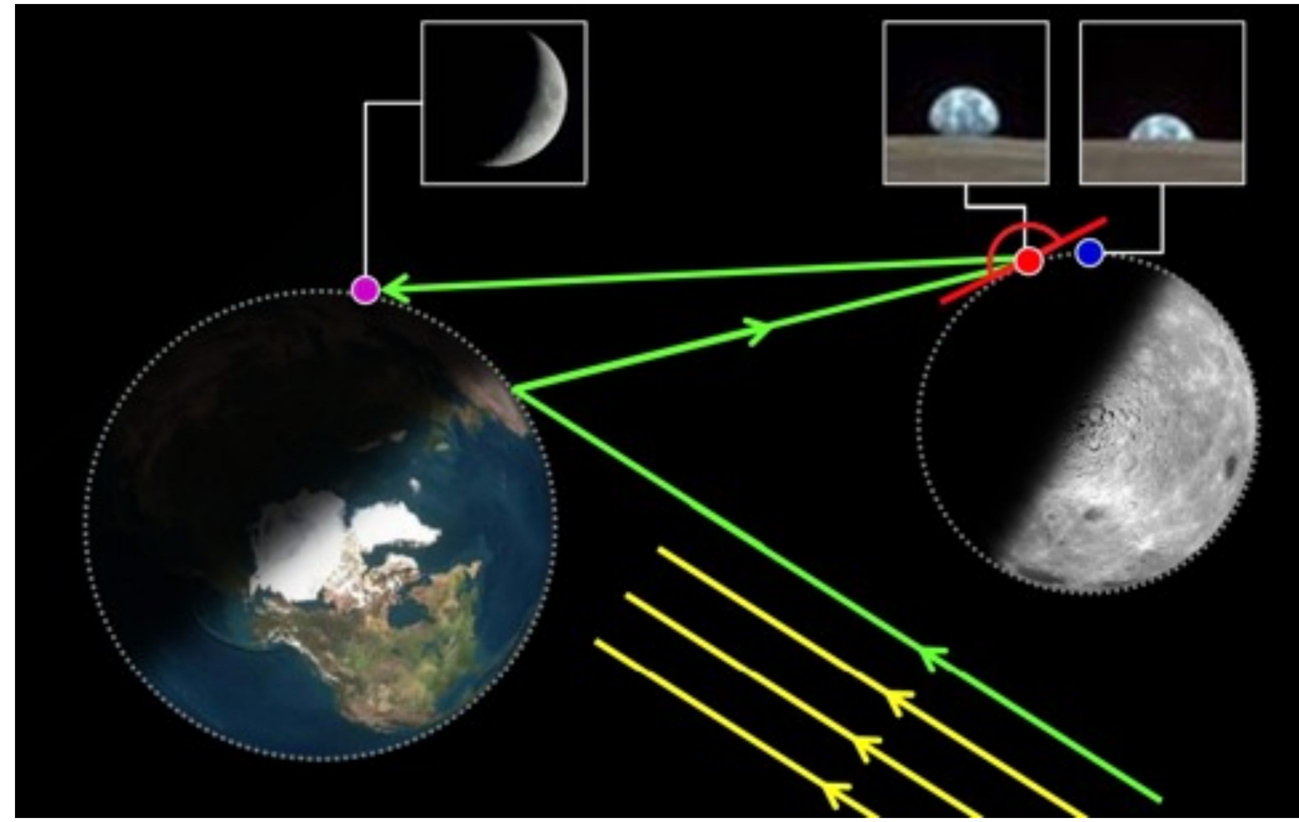


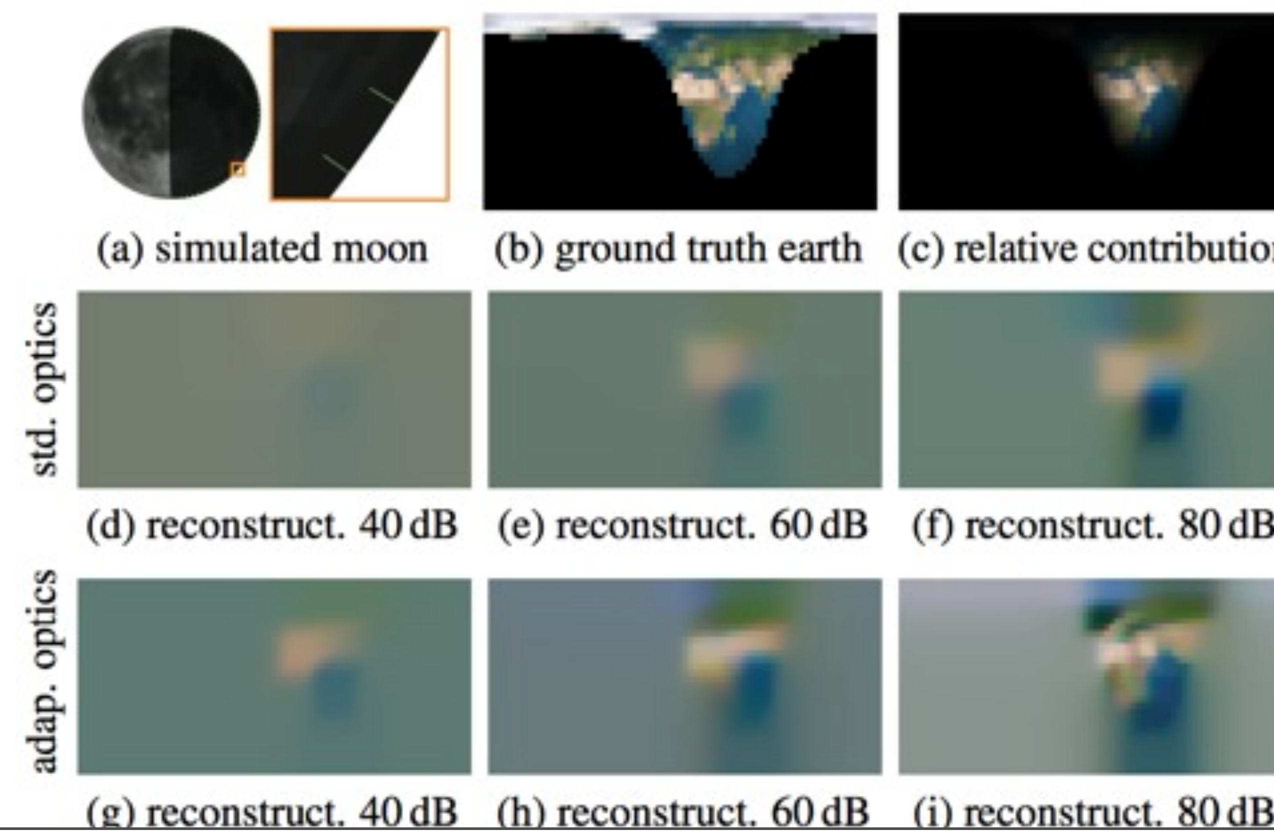


http://arxiv.org/ftp/arxiv/papers/1202/1202.2078.pdf

Diffuse imaging

- Hasinoff et al., CVPR 2012





Dual photography

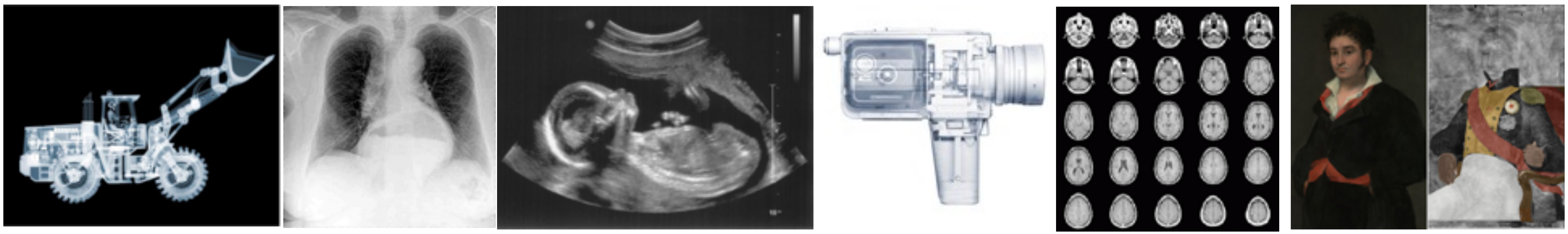
(a) (b) (c) (d)

Figure 16: Dual photography with indirect light transport. (a) A projector illuminates the front of a playing card while the camera sees only the back of the card and the diffuse page of the book. An aperture in front of the projector limits the illumination only onto the card. The card was adjusted so that its specular lobe from the projector did not land on the book. Thus, the only light that reached the camera underwent a diffuse bounce at the card and another at the book. (b) Complete camera view under room lighting. The back of the card and the page of the book are visible. It seems impossible to determine the identity of the card from this point of view simply by varying the incident illumination. To acquire the transport matrix, a 3×3 white pixel was scanned by the projector and 5742 images were acquired to produce a dual image of resolution 66×87. (c) Sample images acquired when the projector scanned the indicated points on the card. The dark level has been subtracted and the images gamma-corrected to amplify the contrast. We see that the diffuse reflection changes depending on the color of the card at the point of illumination. After acquiring the T matrix in this manner, we can reconstruct the floodlit dual image (d). It shows the playing card from the perspective of the projector being indirectly lit by the camera. No contrast enhancement has been applied. Note that the resulting image has been automatically antialiased over the area of each projector pixel.

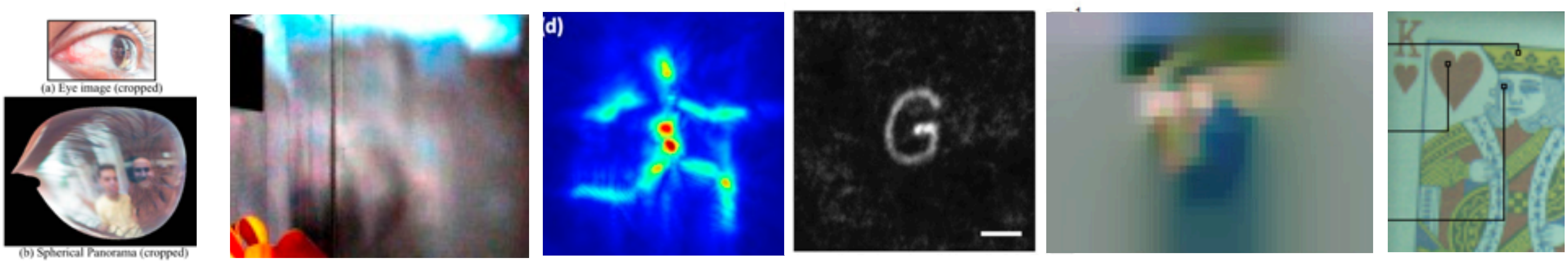
http://graphics.stanford.edu/papers/dual_photography/

Recap: hidden things & occlusion

- Seeing inside objects



- Seeing beyond the field of view



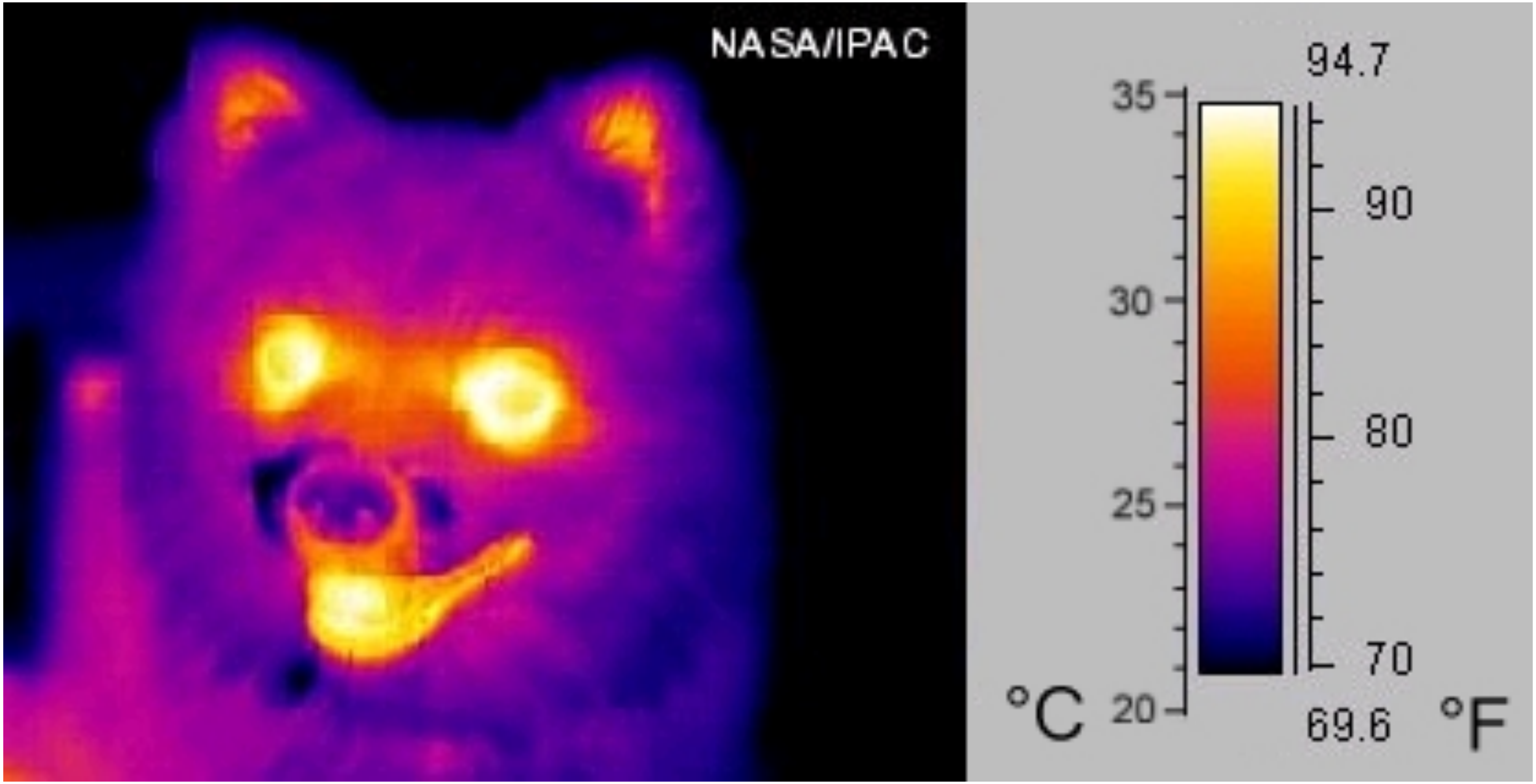
Overview

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

Main ideas

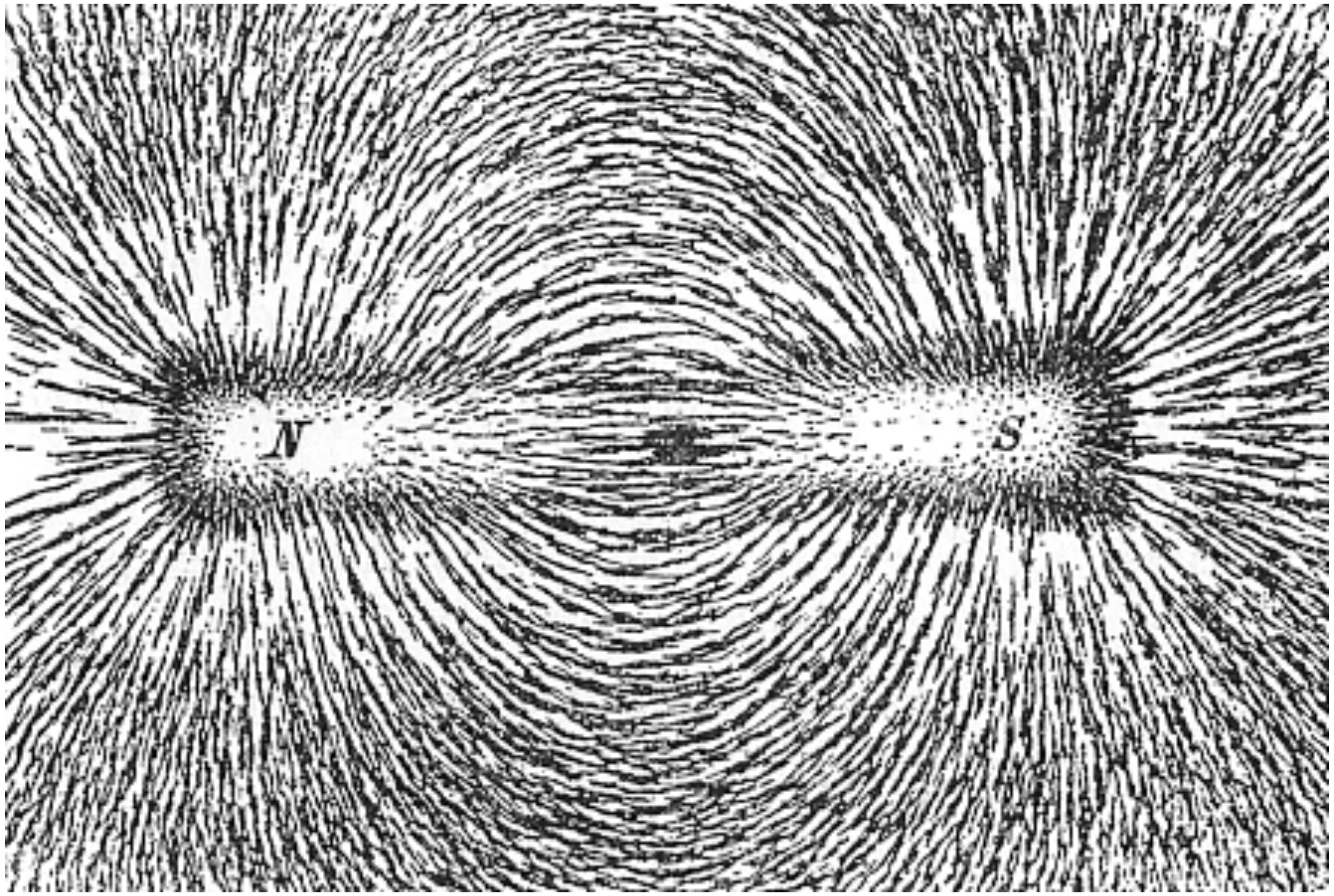
- The phenomenon modifies visual properties (phase & refraction, polarization)
- Add visual elements that are affected by the phenomenon (powder, smoke, etc.)
  - Attach visible stuff (fluorescent dye, light emitting enzymes)
- Convert to visible wavelengths (fluorescence)
- Interferences
- Augmented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

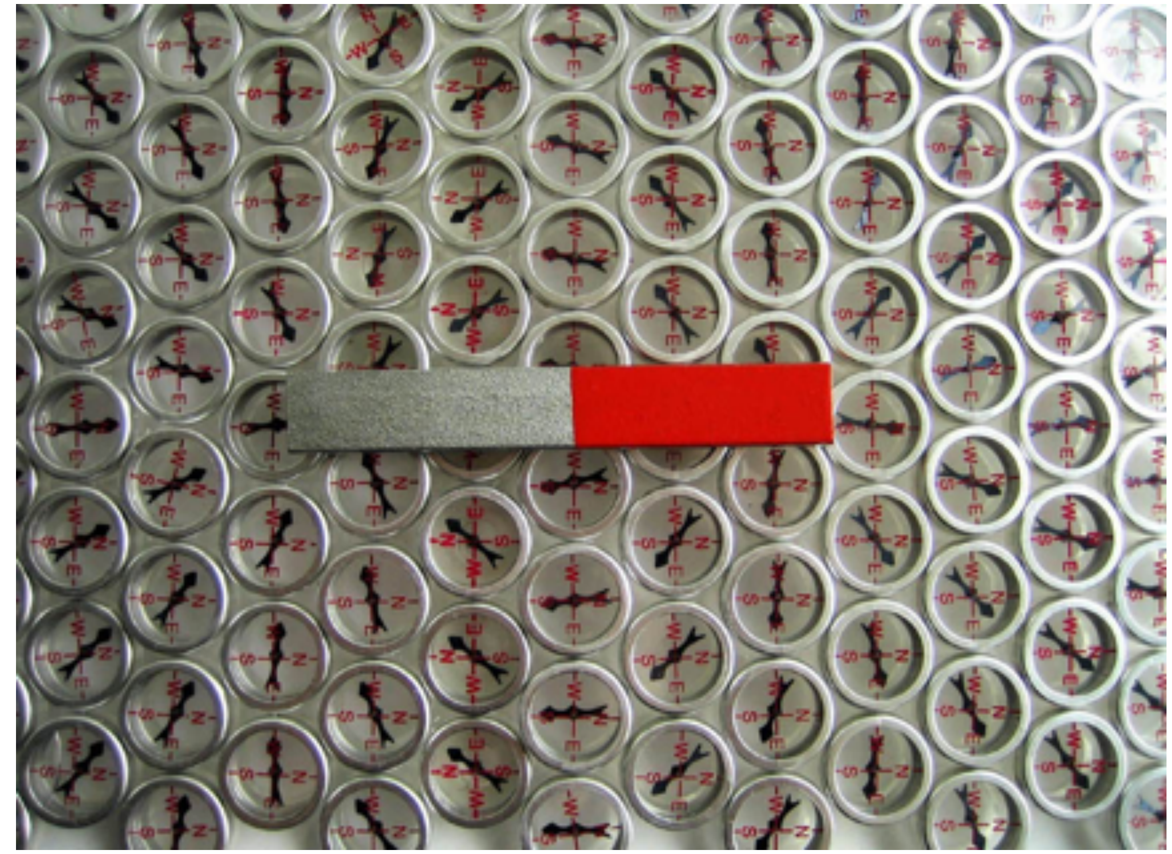
Thermal Infrared



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

Electromagnetic fields



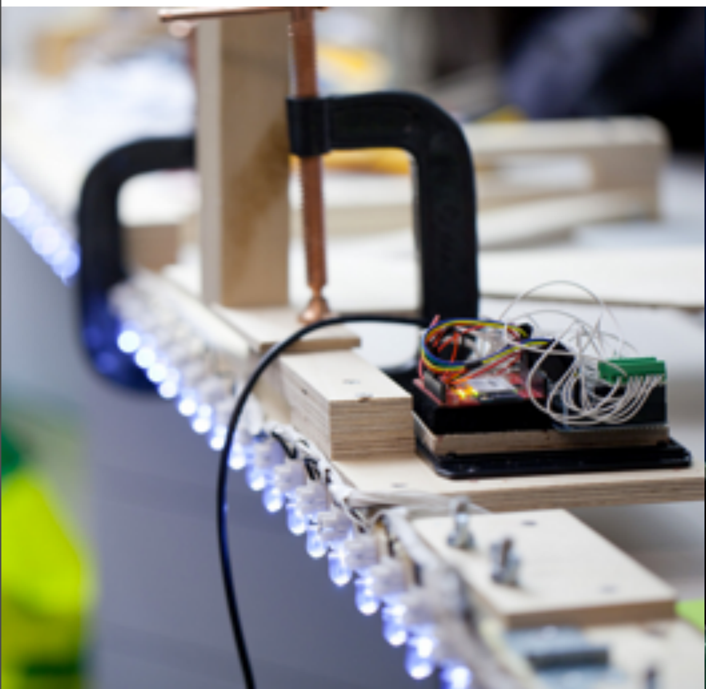


Iron filings showing the direction of the magnetic field of a permanent magnet

- 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

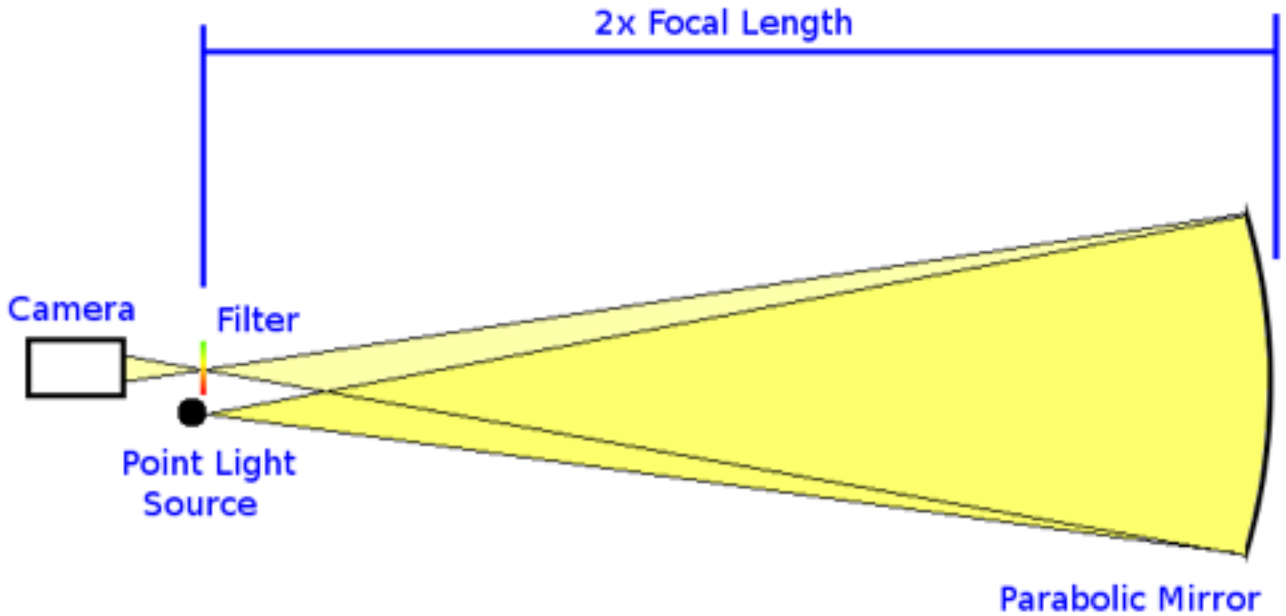
Wifi signal

- Wifi sensor + rod with LEDs + long exposure

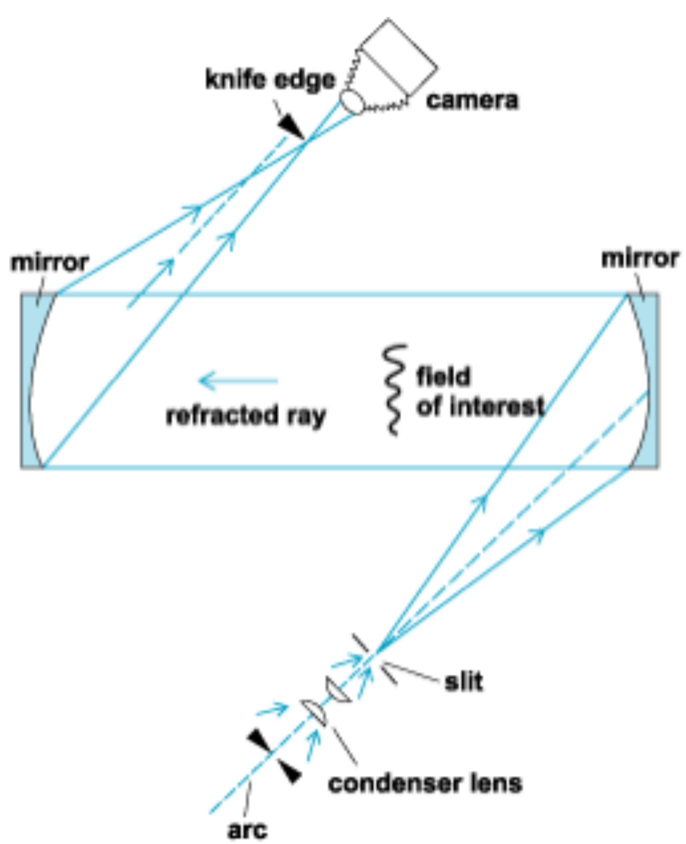


http://www.nearfield.org/2011/02/wifi-light-painting

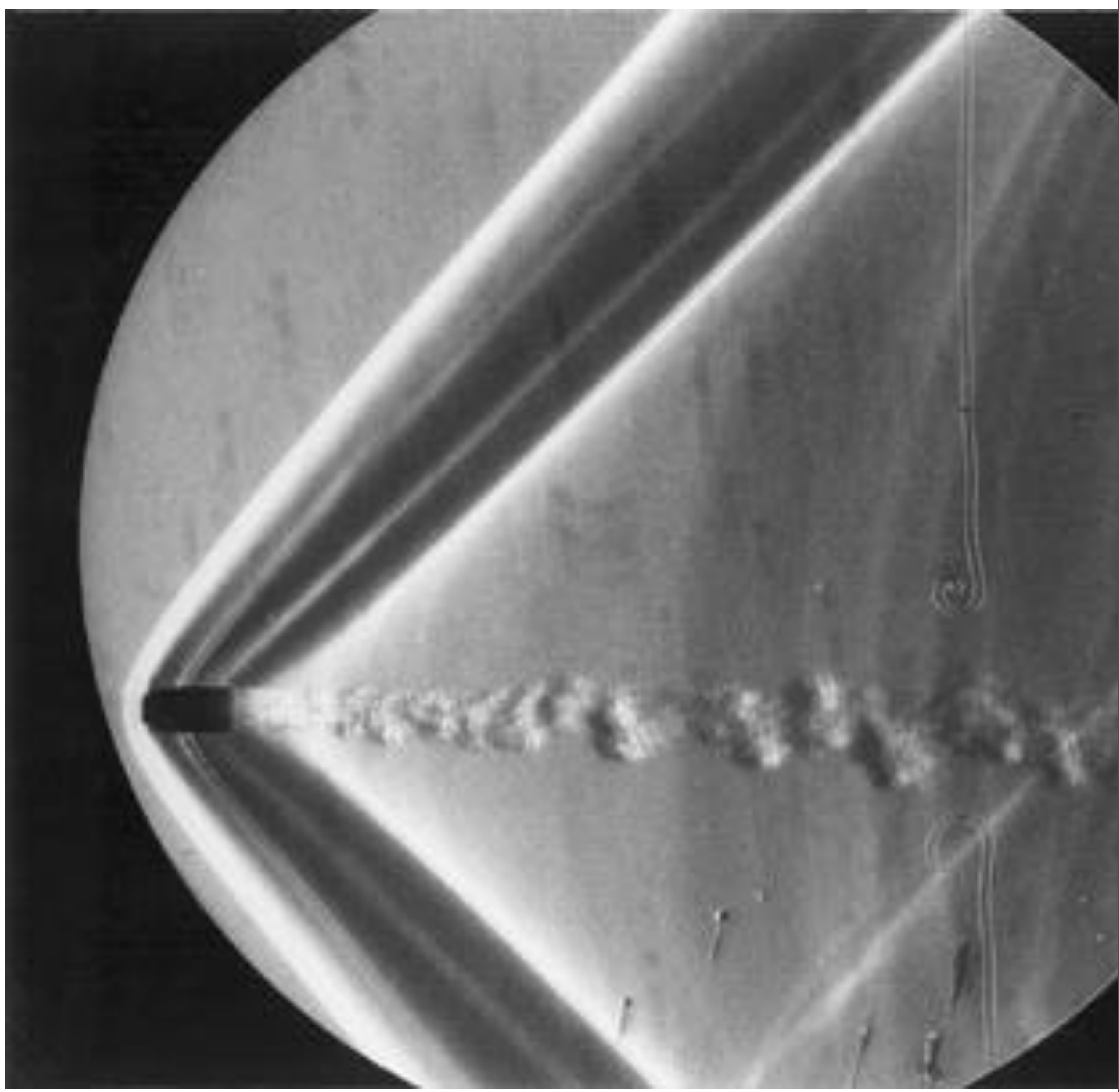
Sound, pressure: Schlieren



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



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

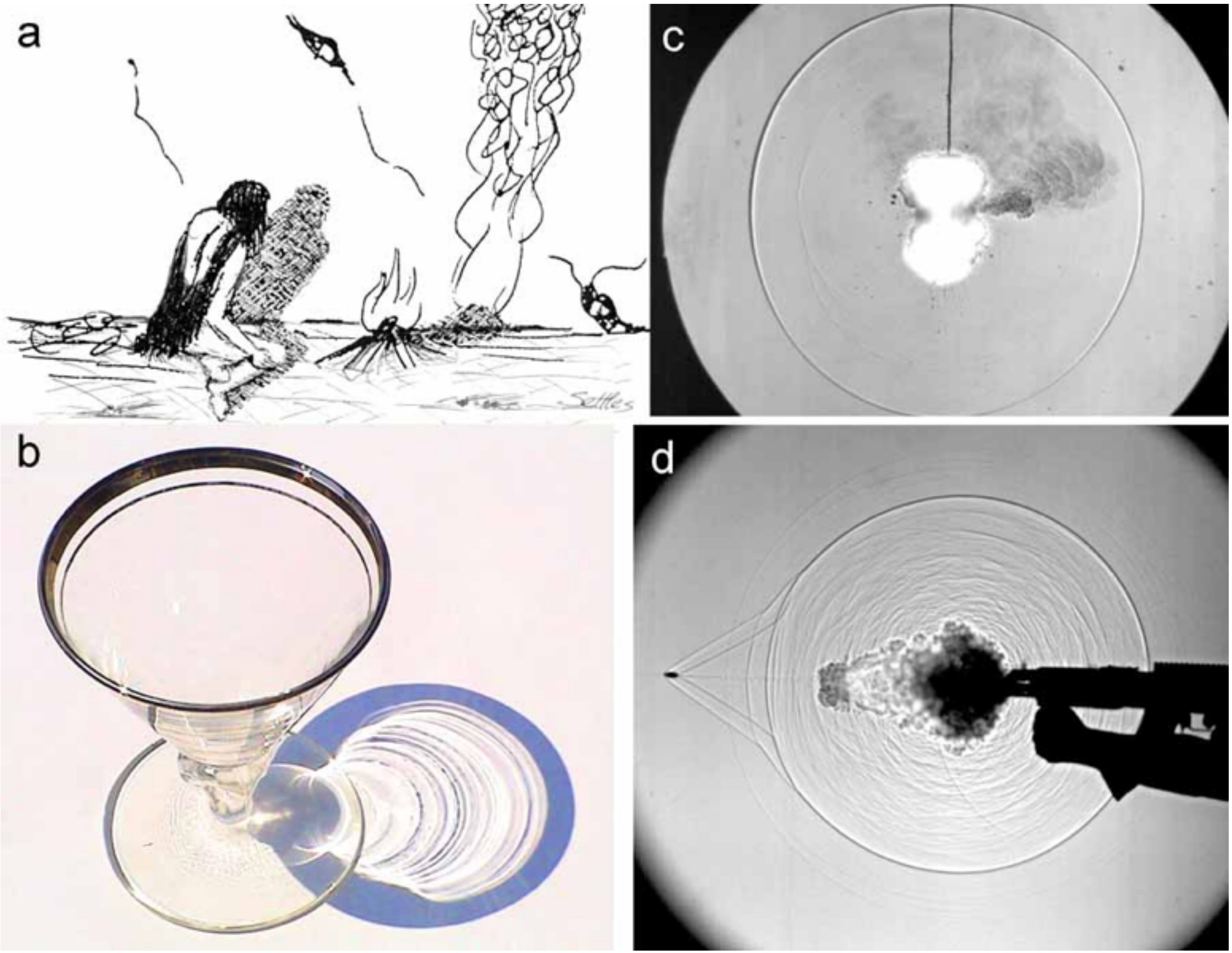


Sound wave of a bullet

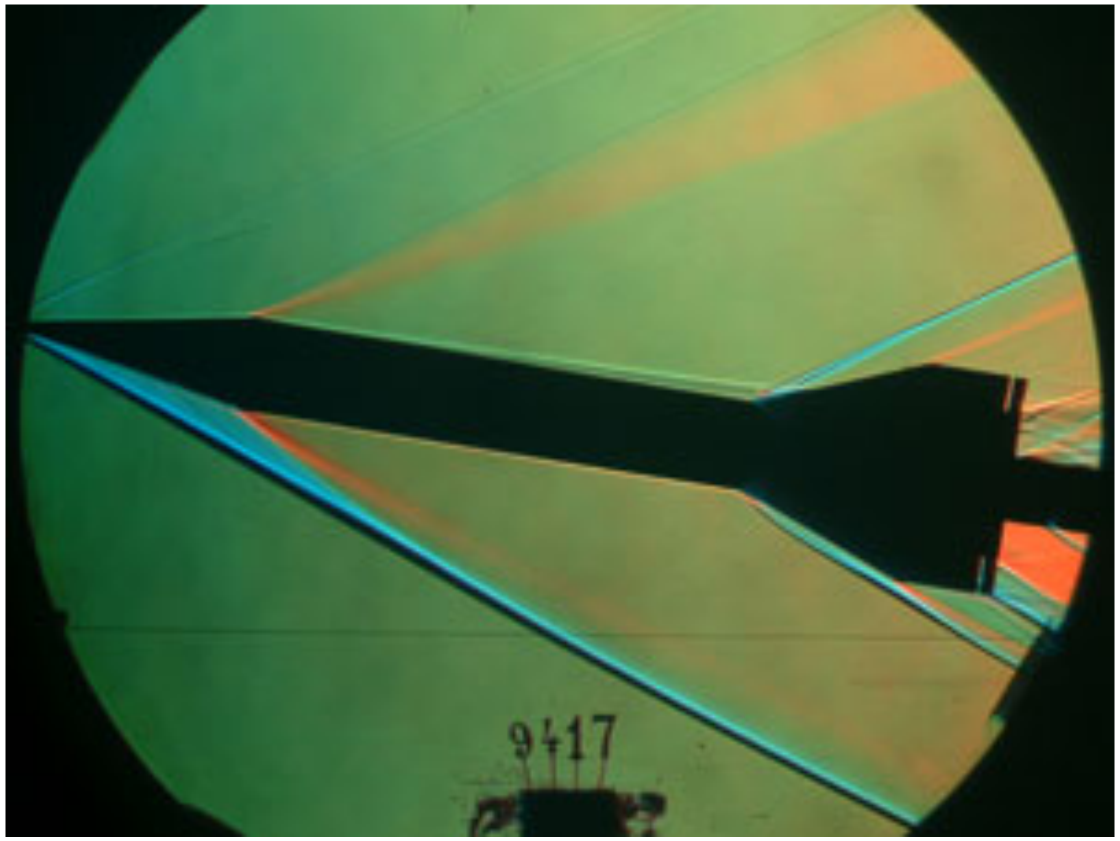
http://people.rit.edu/andpph/schlieren-2.jpg

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

Schlieren/Shadowgraphy

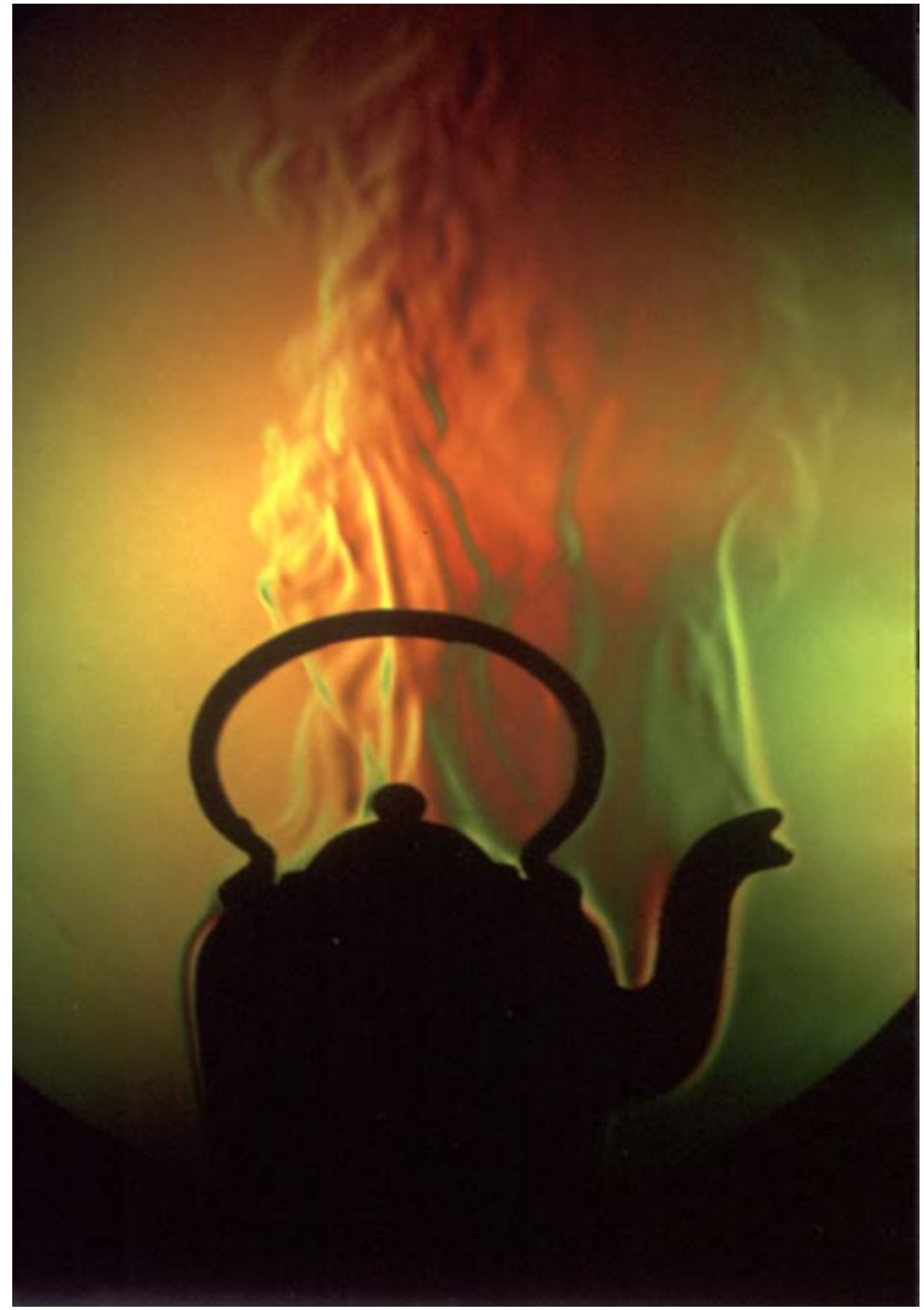


http://en.wikipedia.org/wiki/Shadowgraph



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

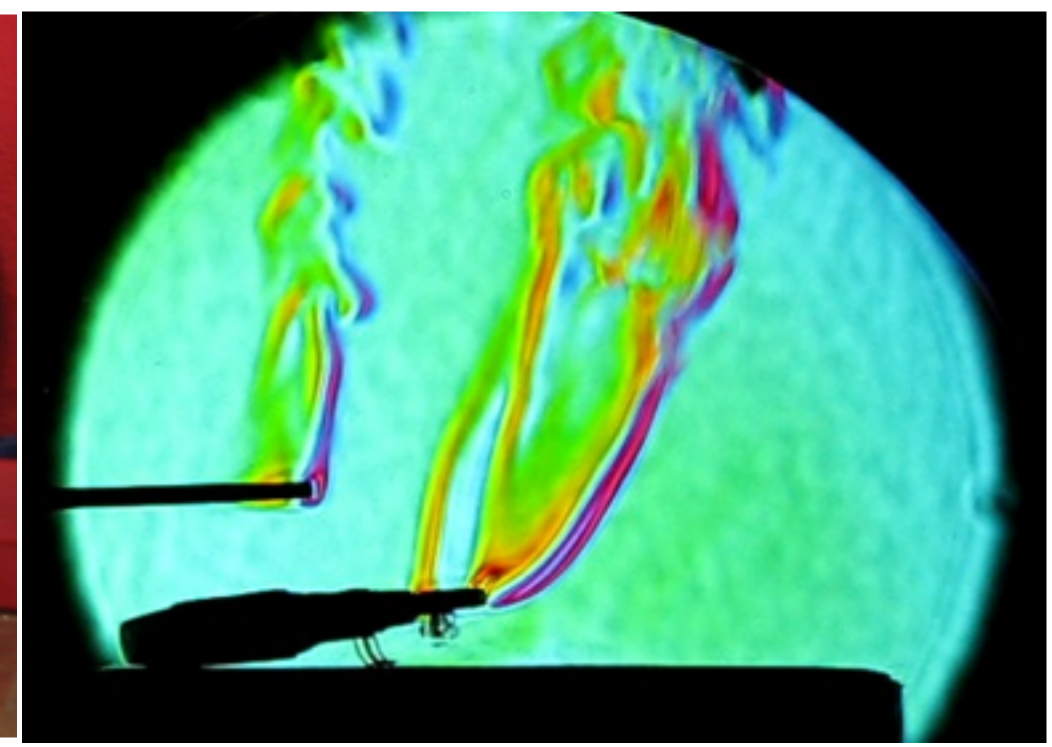
tp://rainbowboys.blogspot.hk/2010/11/schlieren-photography.html



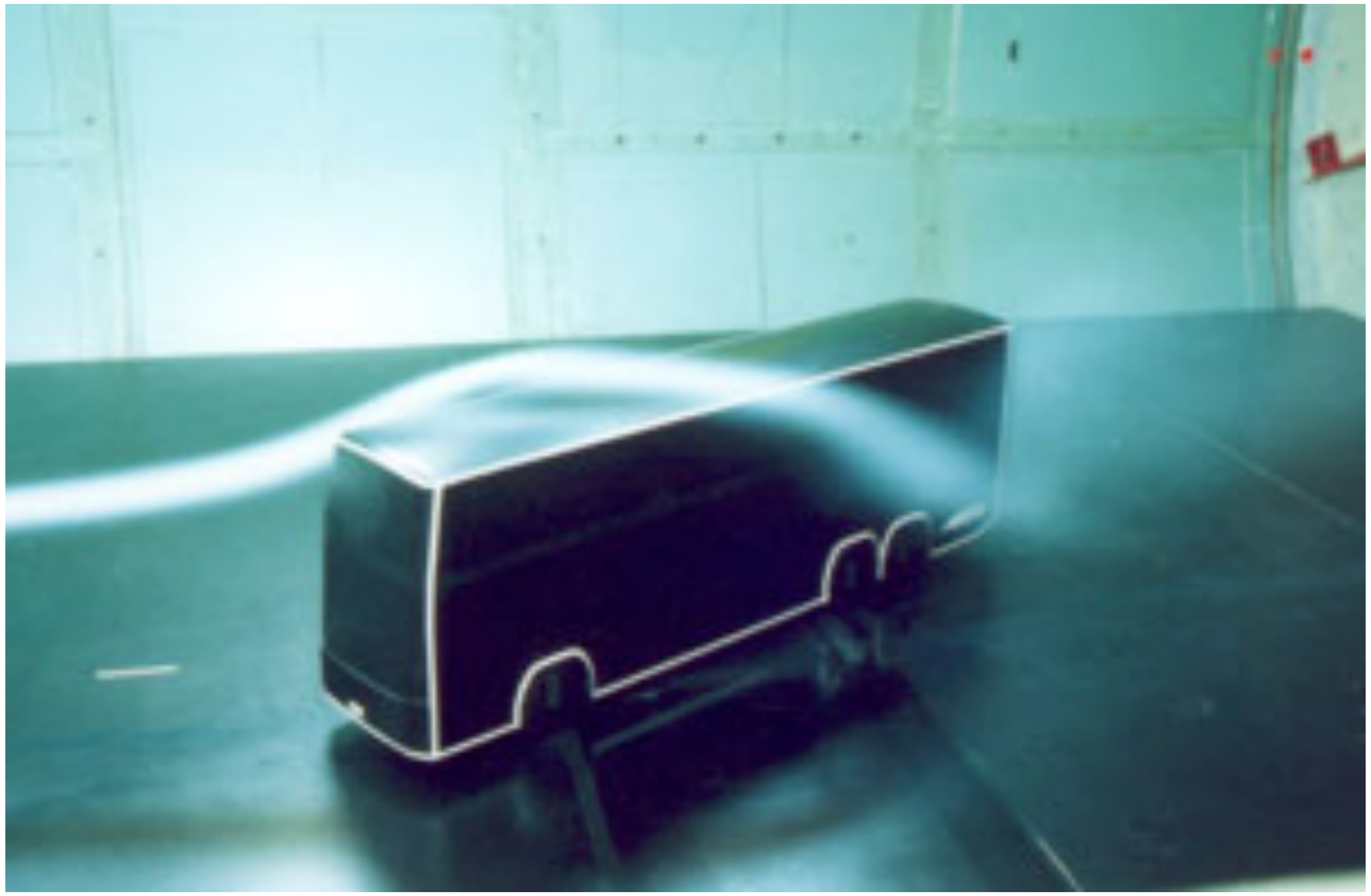
http://www.cloudshillimaging.com/schlieren-imaging-system.html

Try it at home

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

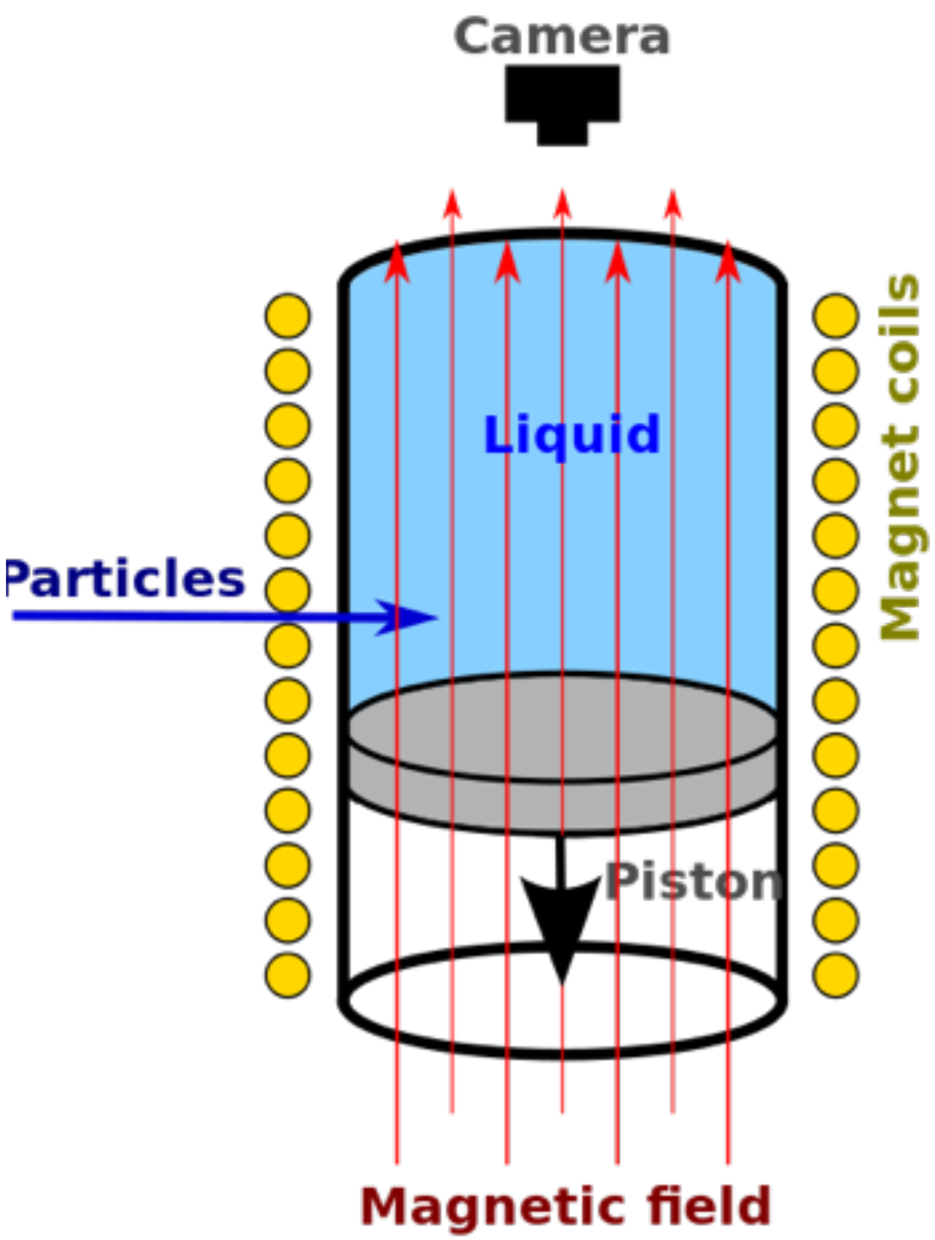
  

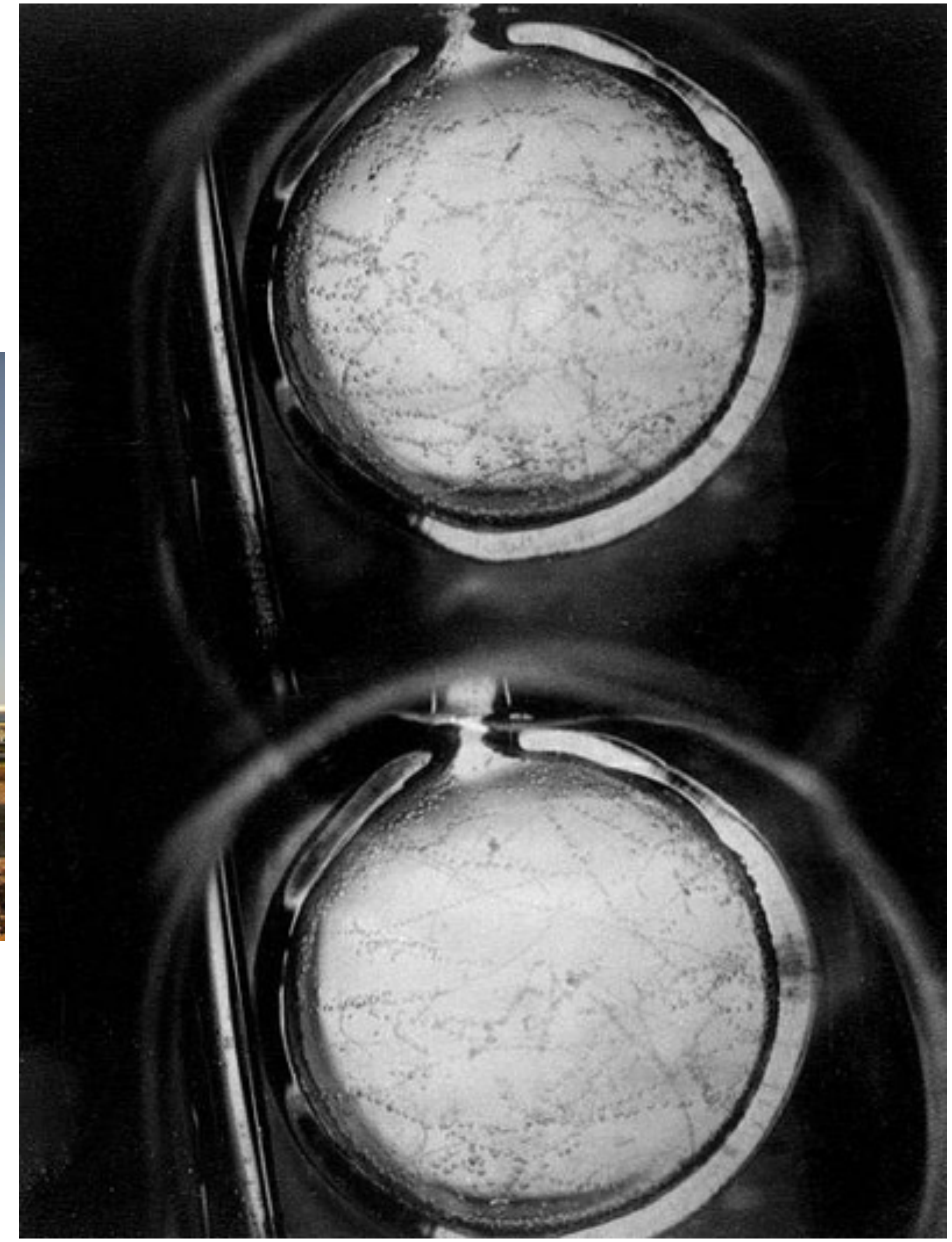
Air flow: Smoke, sublimation



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

Bubbles chambers

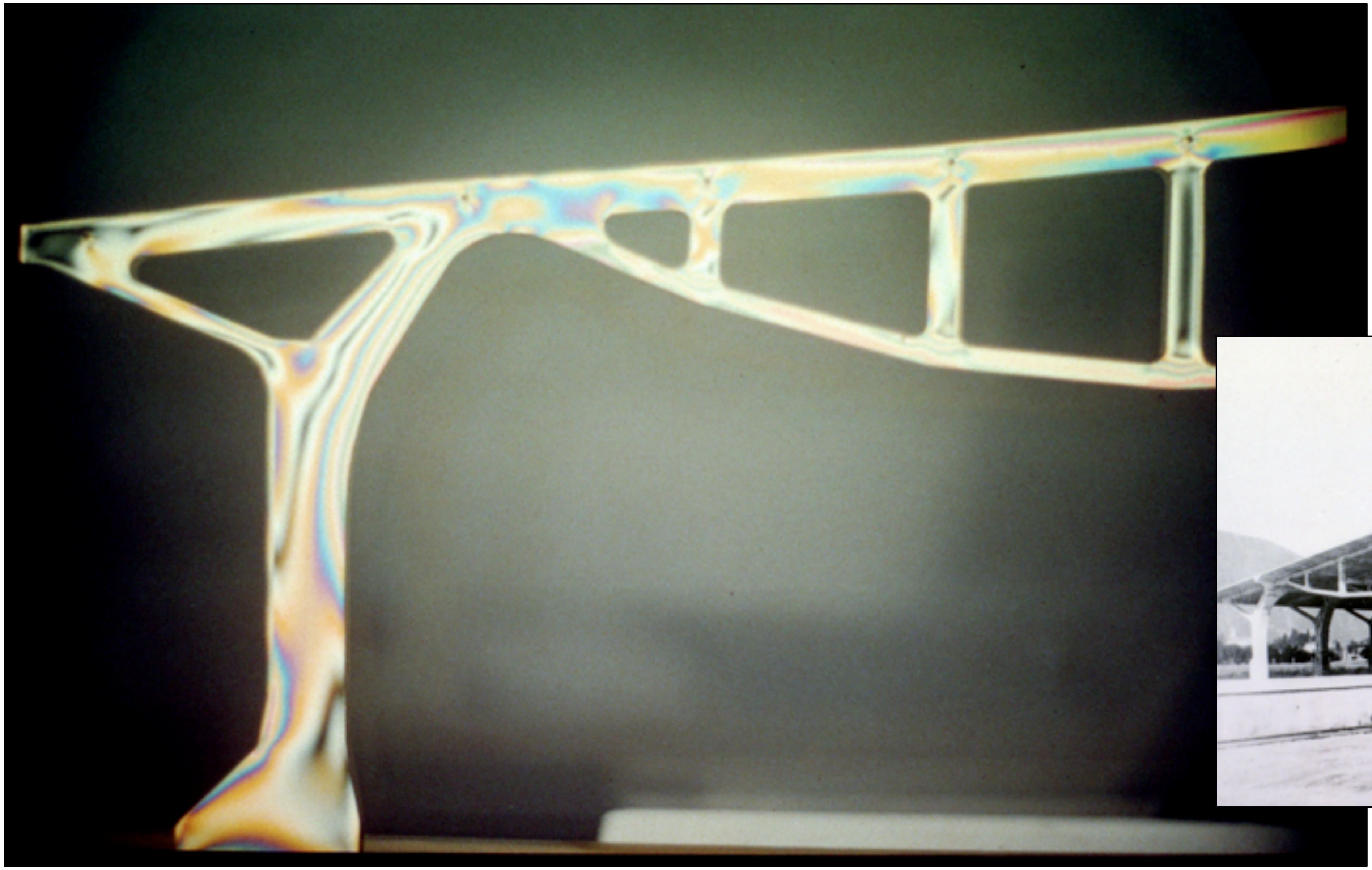




The first tracks observed in John Wood's 1.5-inch (~3.8 cm) liquid hydrogen bubble chamber, in 1954.
http://en.wikipedia.org/wiki/Bubble_chamber

Material stress: Photoelasticity

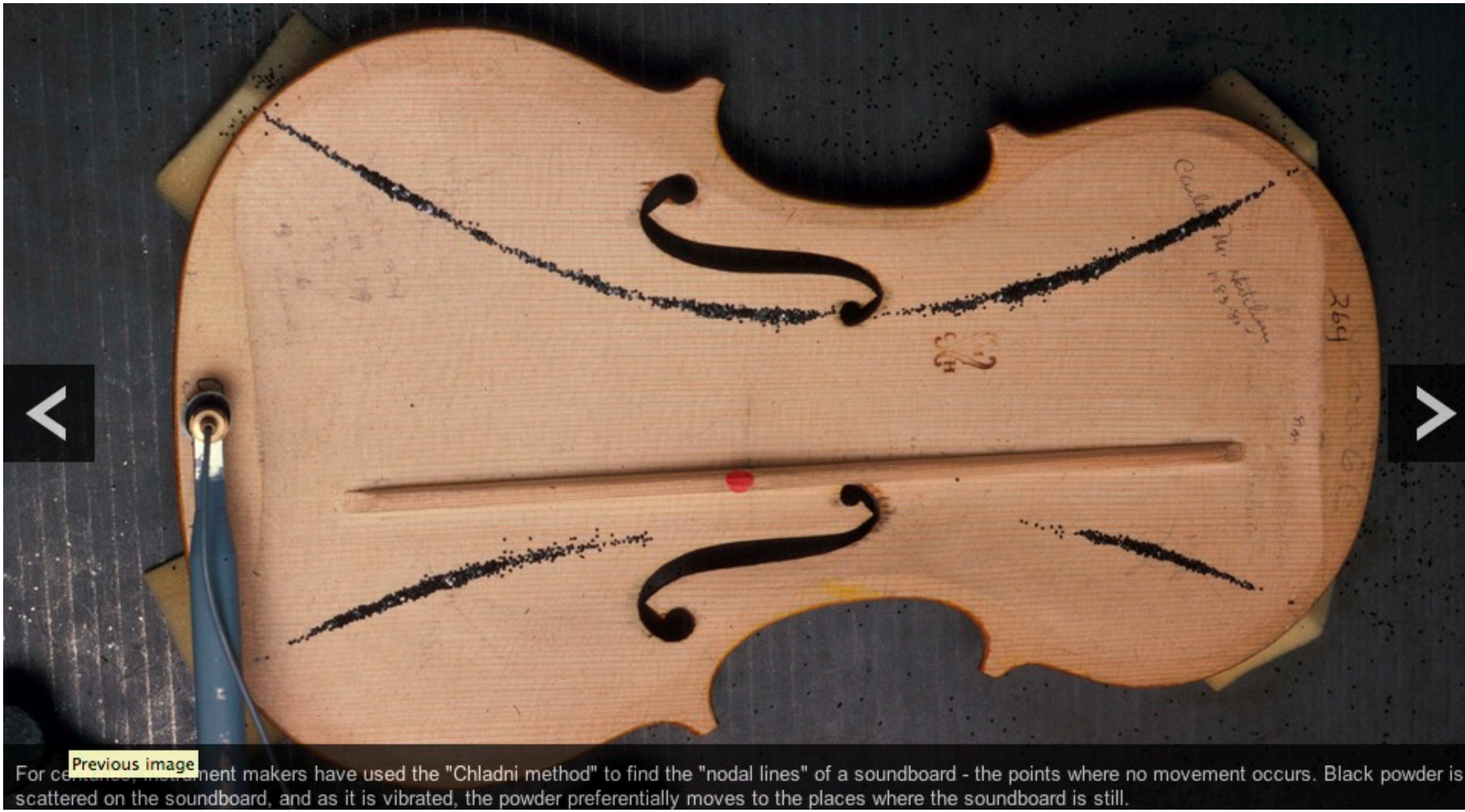
- First proposed by Brewster
- Birefrigence due to stress+interference



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

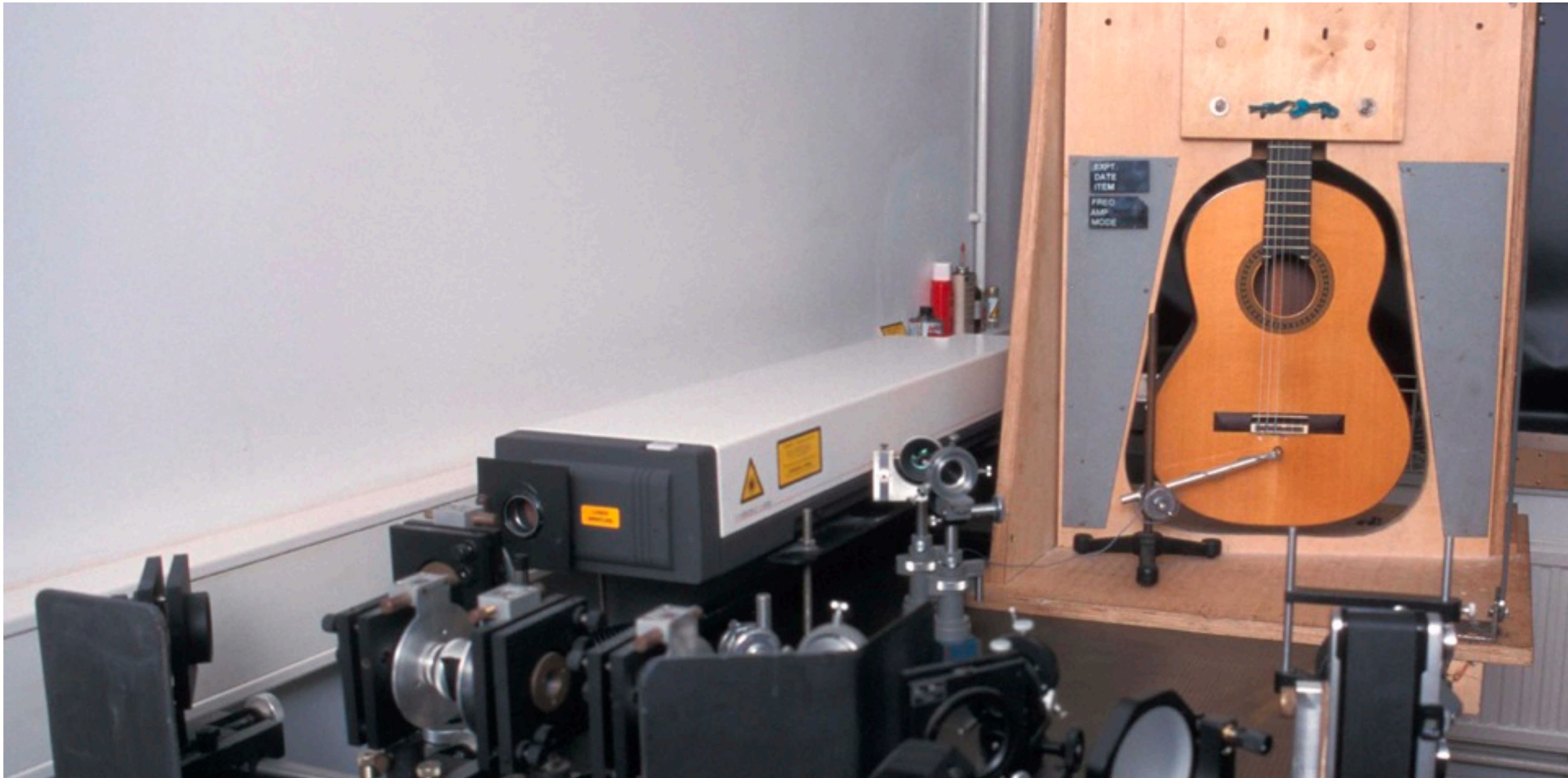
Vibration modes (Chladni)

Vibration modes (Chladni)



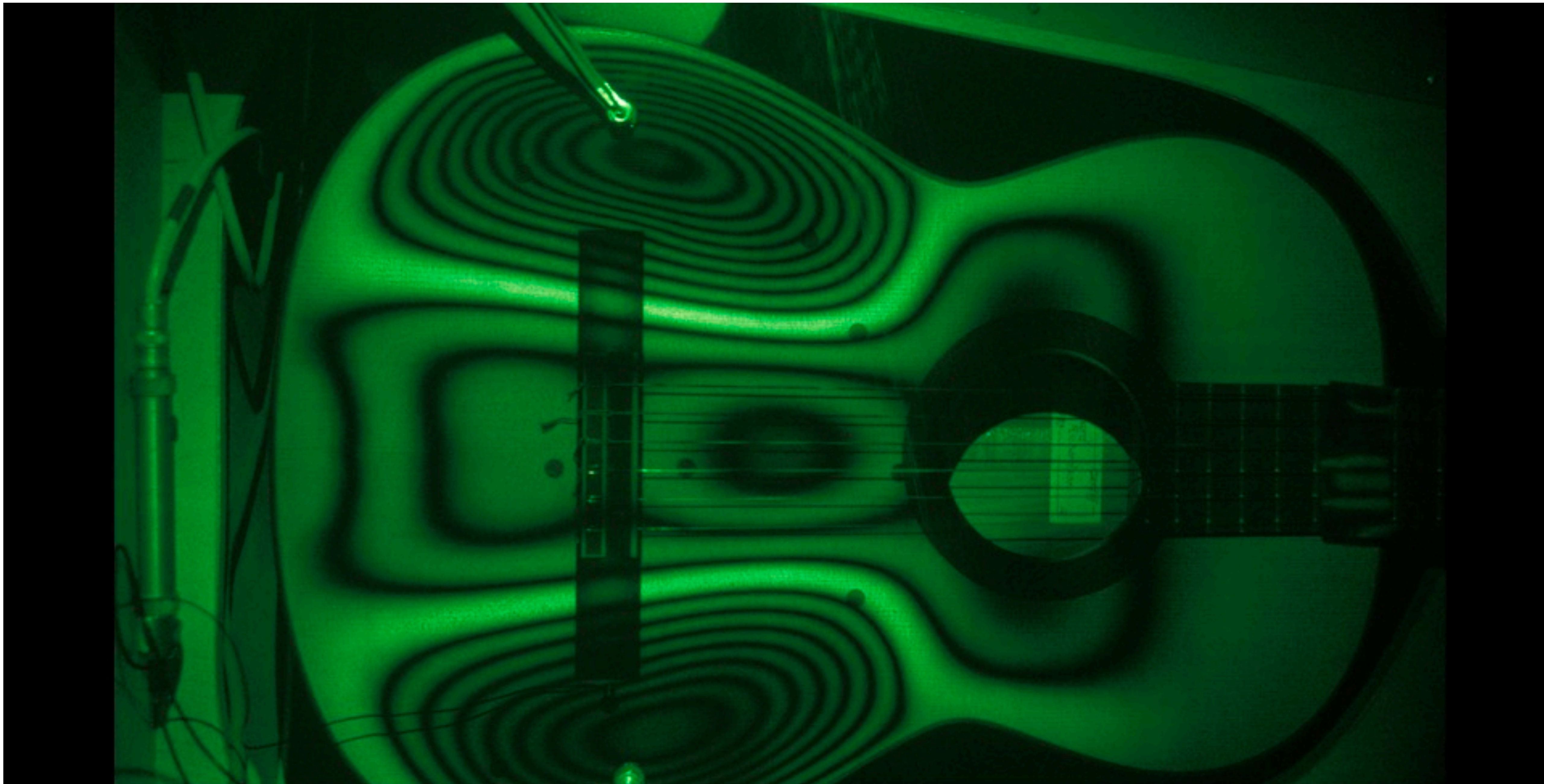
http://www.bbc.co.uk/news/science-environment-13573631

Vibration modes: Interferometry



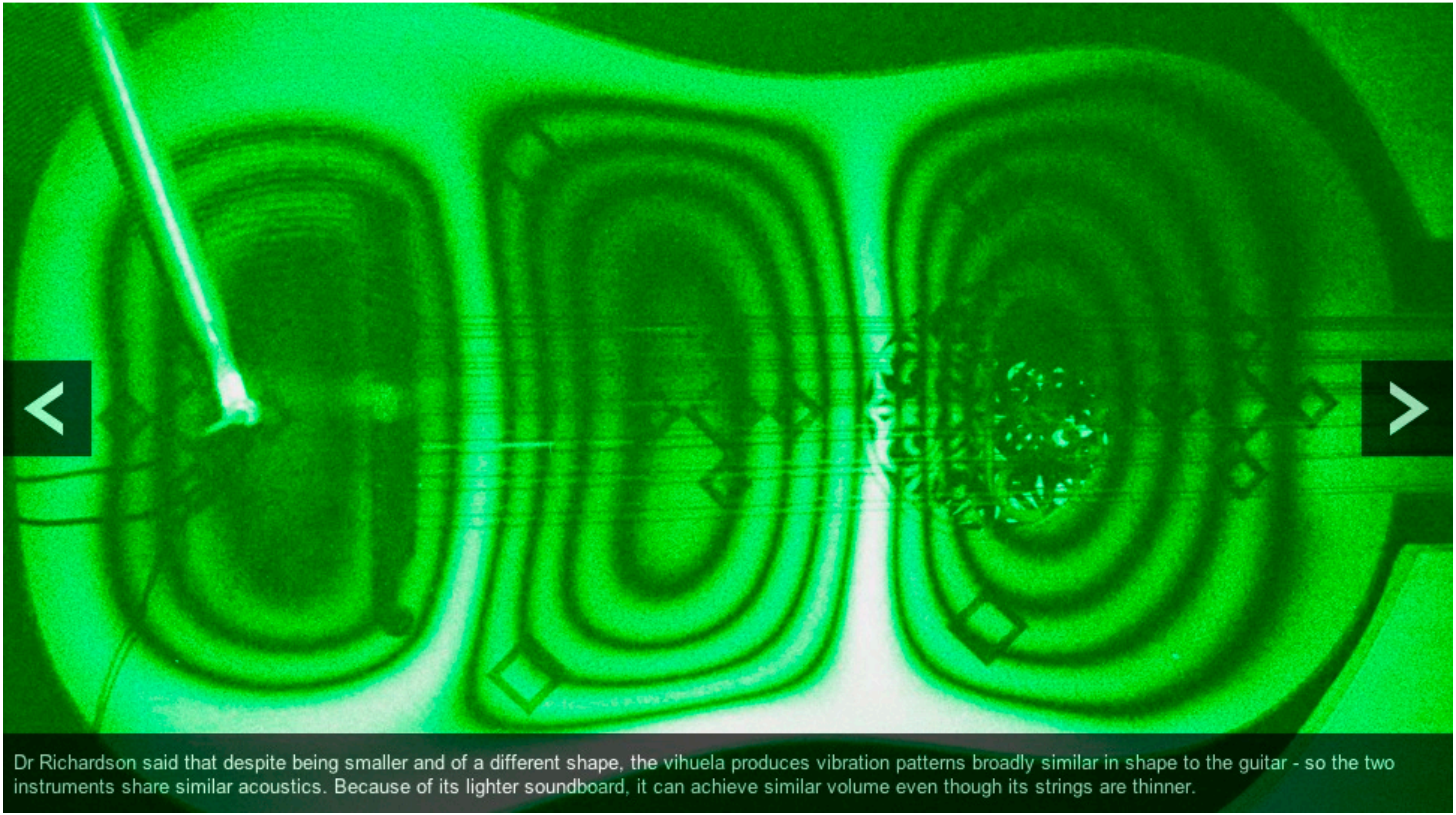
First, a laser beam is scattered off the instrument when it is still. That pattern, along with another laser beam, are cast back onto the instrument as it is actively vibrated. The contour lines appear where tiny movements of the soundboard - less than a millionth of a metre - cause interference between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

Vibration modes: Interferometry

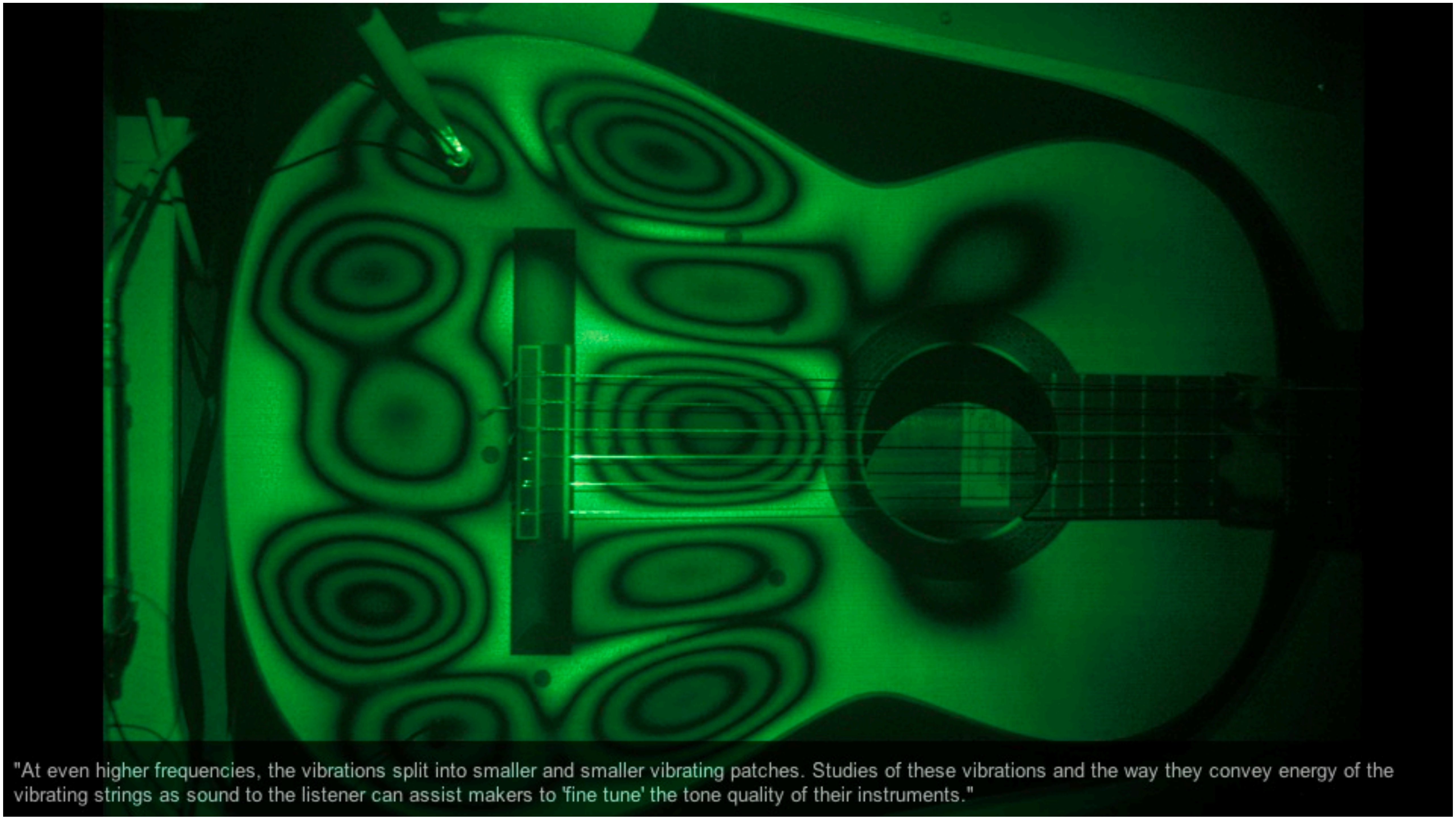


Researchers at Cardiff University reporting at the Acoustical Society of America meeting have presented striking images of stringed instruments made using "holographic interferometry", which allows them to visualise precisely how and where the soundboards of instruments vibrate. (Photos courtesy Bernard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

Vibration modes: Interferometry



Vibration modes: Interferometry

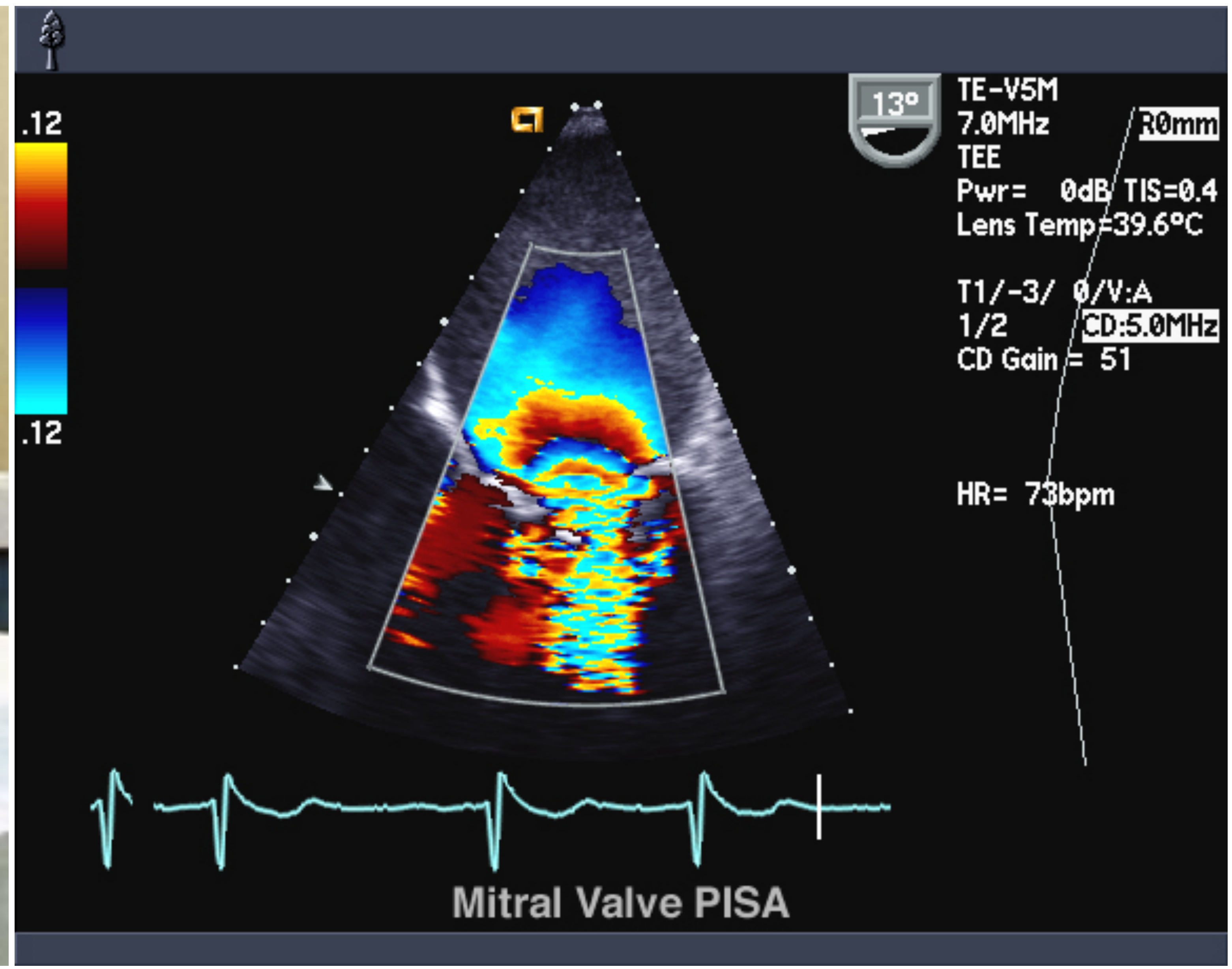


Rolling shutter and waves

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

Revealing velocity

- Doppler imaging



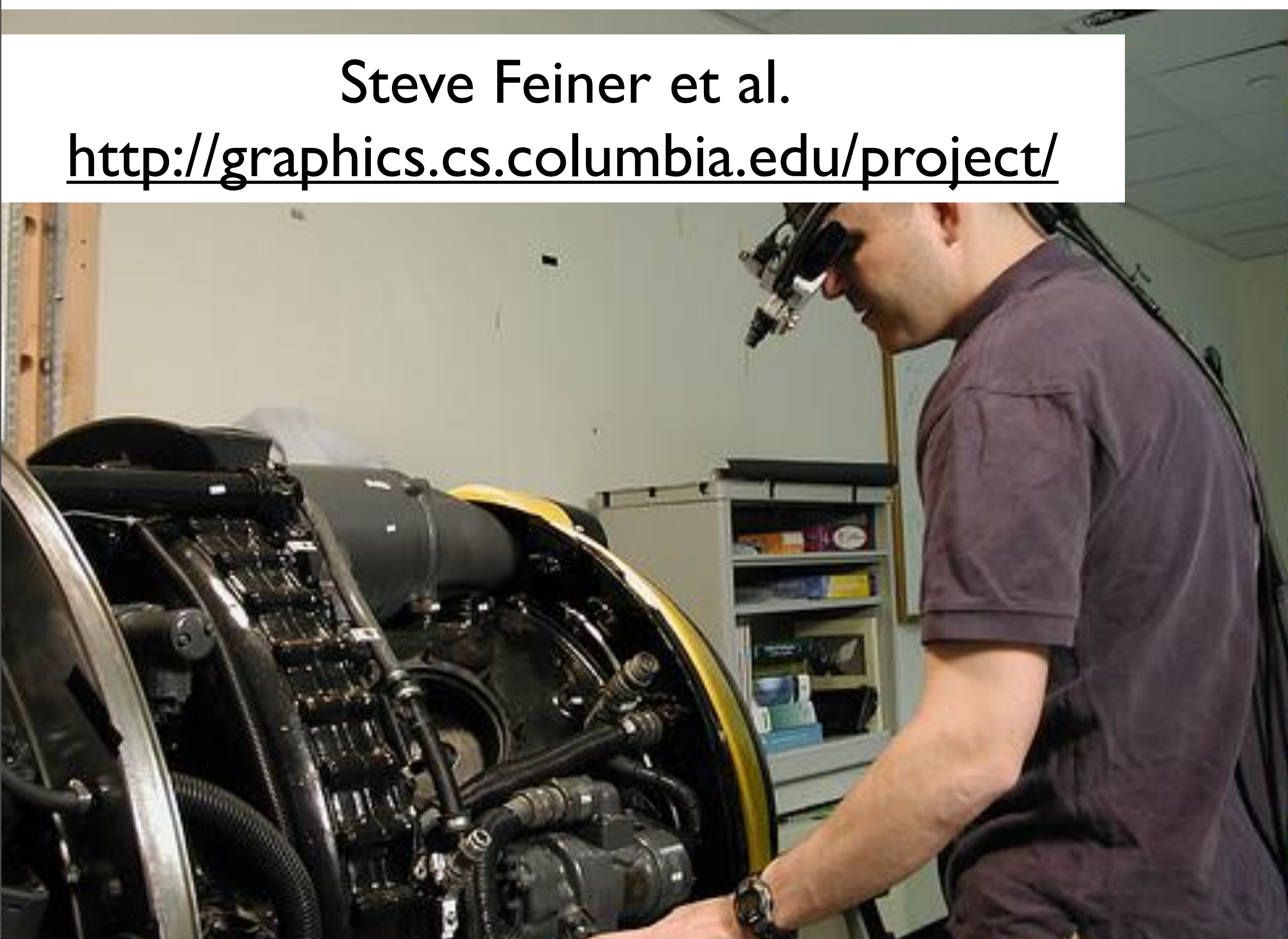
http://www.satyakiranhealthcare.com/ColorDoppler.aspx

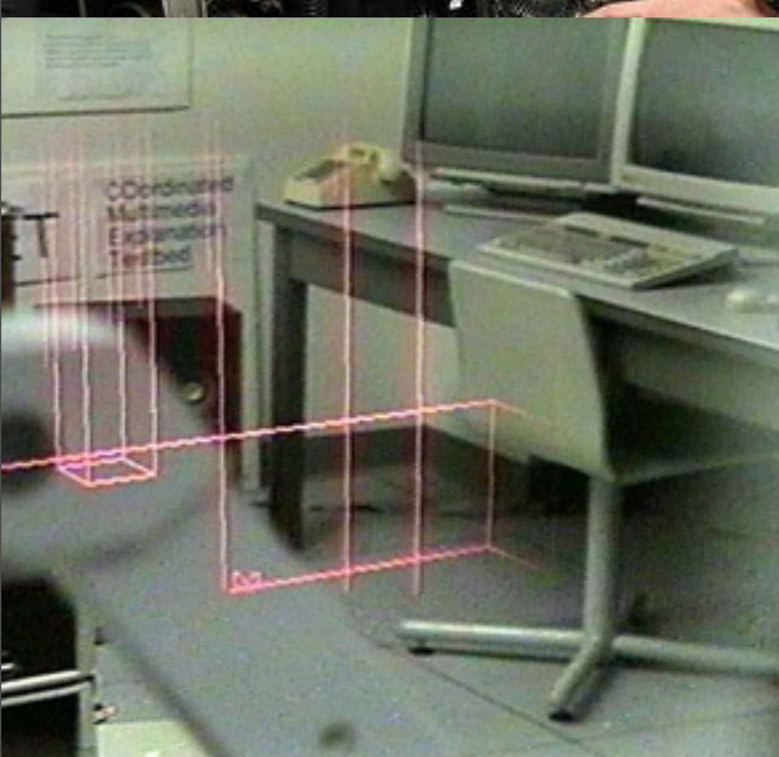
Brain function

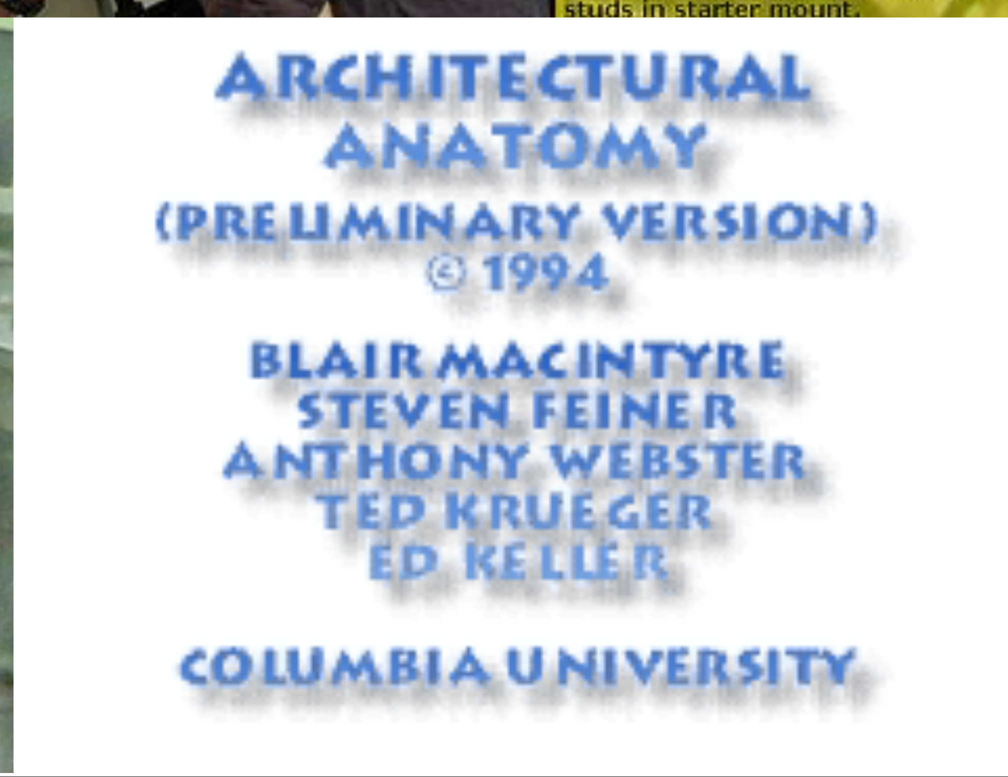
- Functional MRI
- Blood concentration correlates with brain activity

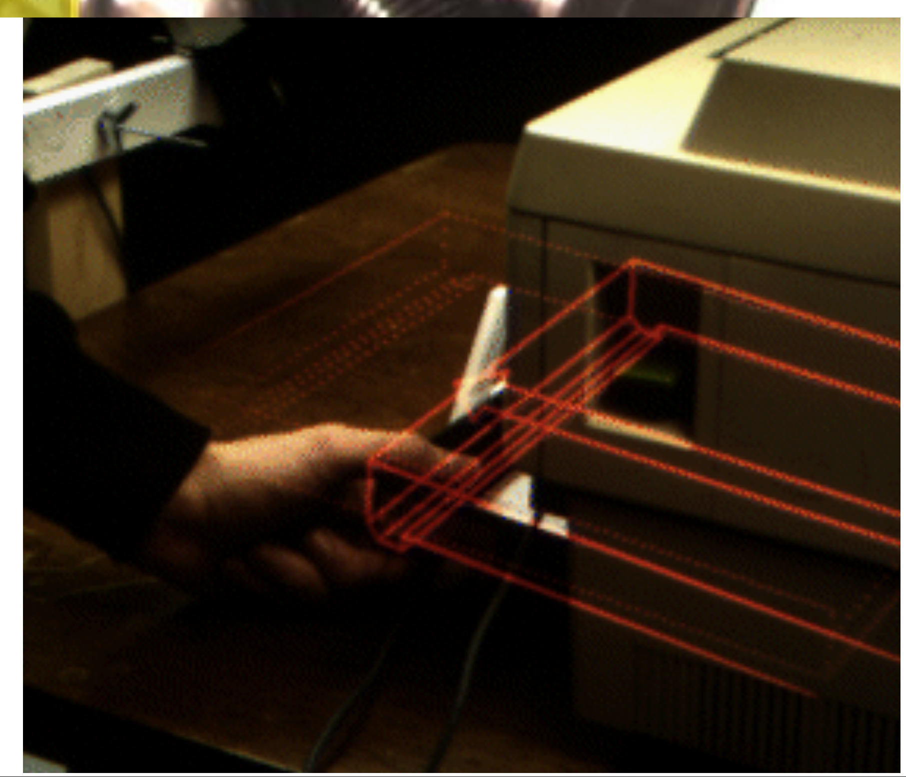
Augmented reality

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









Augmented reality in sports

First Down line in American Football

FoxTrax in Hockey

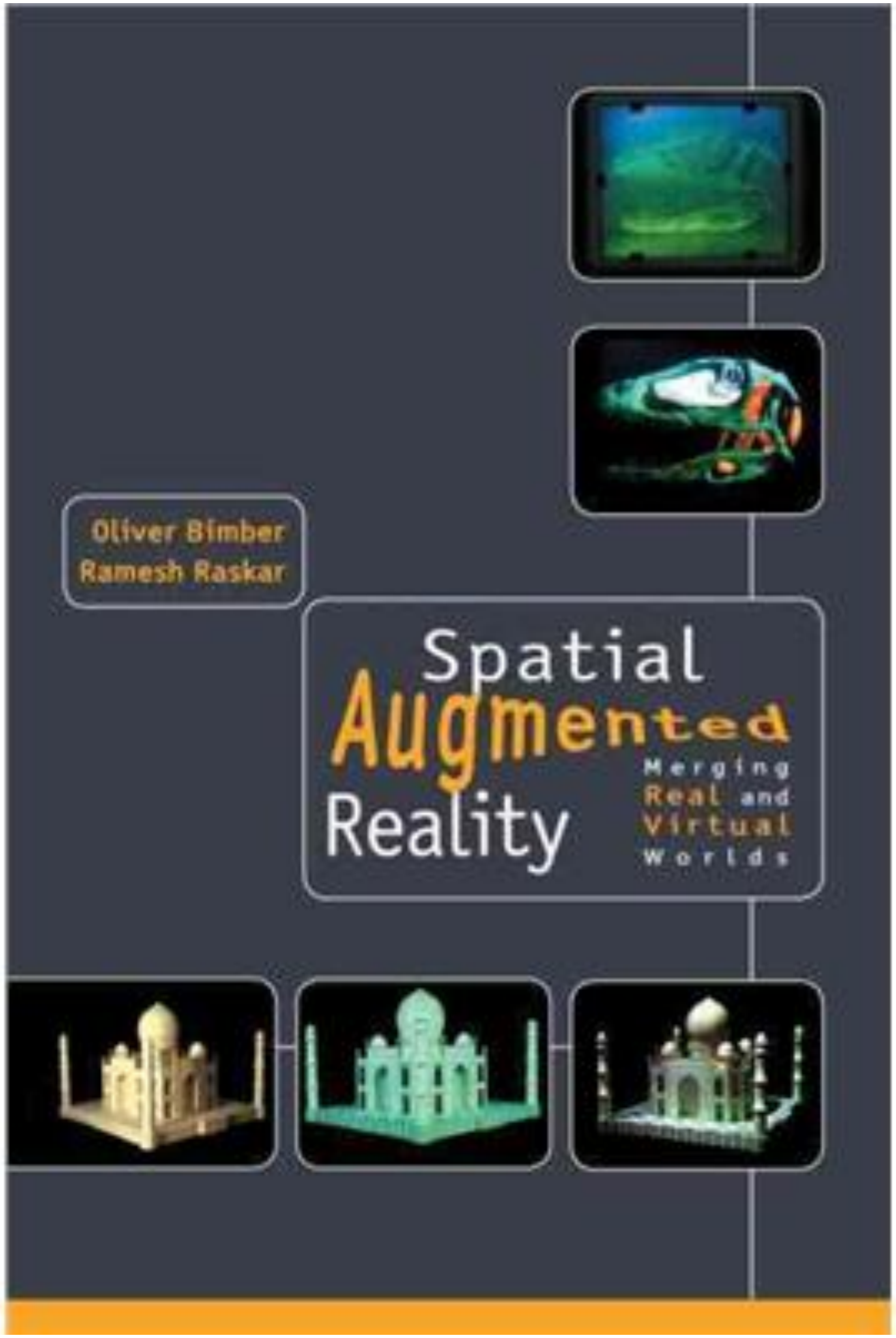
http://www.howstuffworks.com/first-down-line.htm
http://www.youtube.com/watch?v=UyPU2l9rdvo

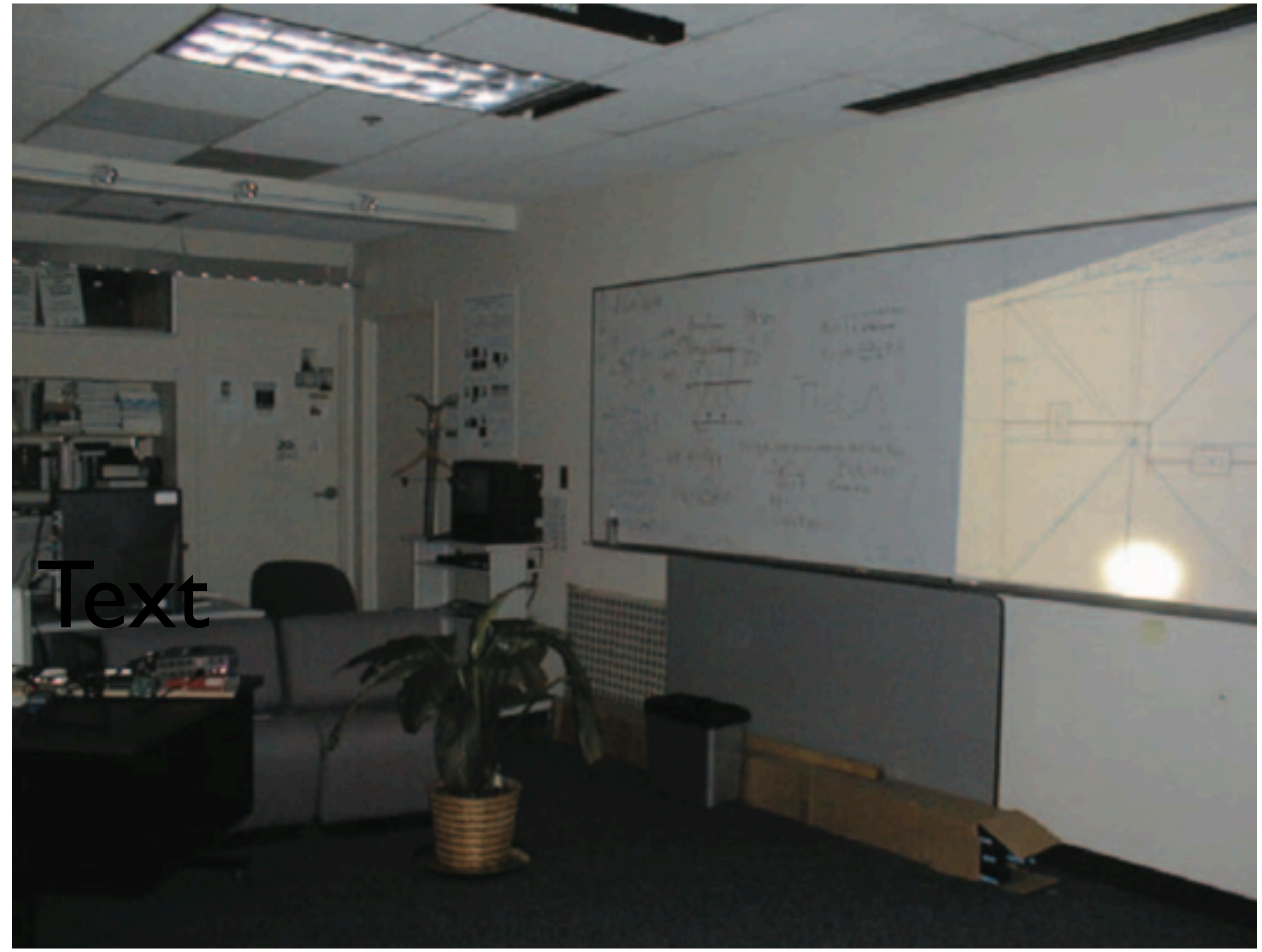
http://ictvictor.wordpress.com/tag/foxtrax/

Augmented reality

http://en.wikipedia.org/wiki/File:MediatedReality_on_iPhone2009_07_13_21_33_39.jpg

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

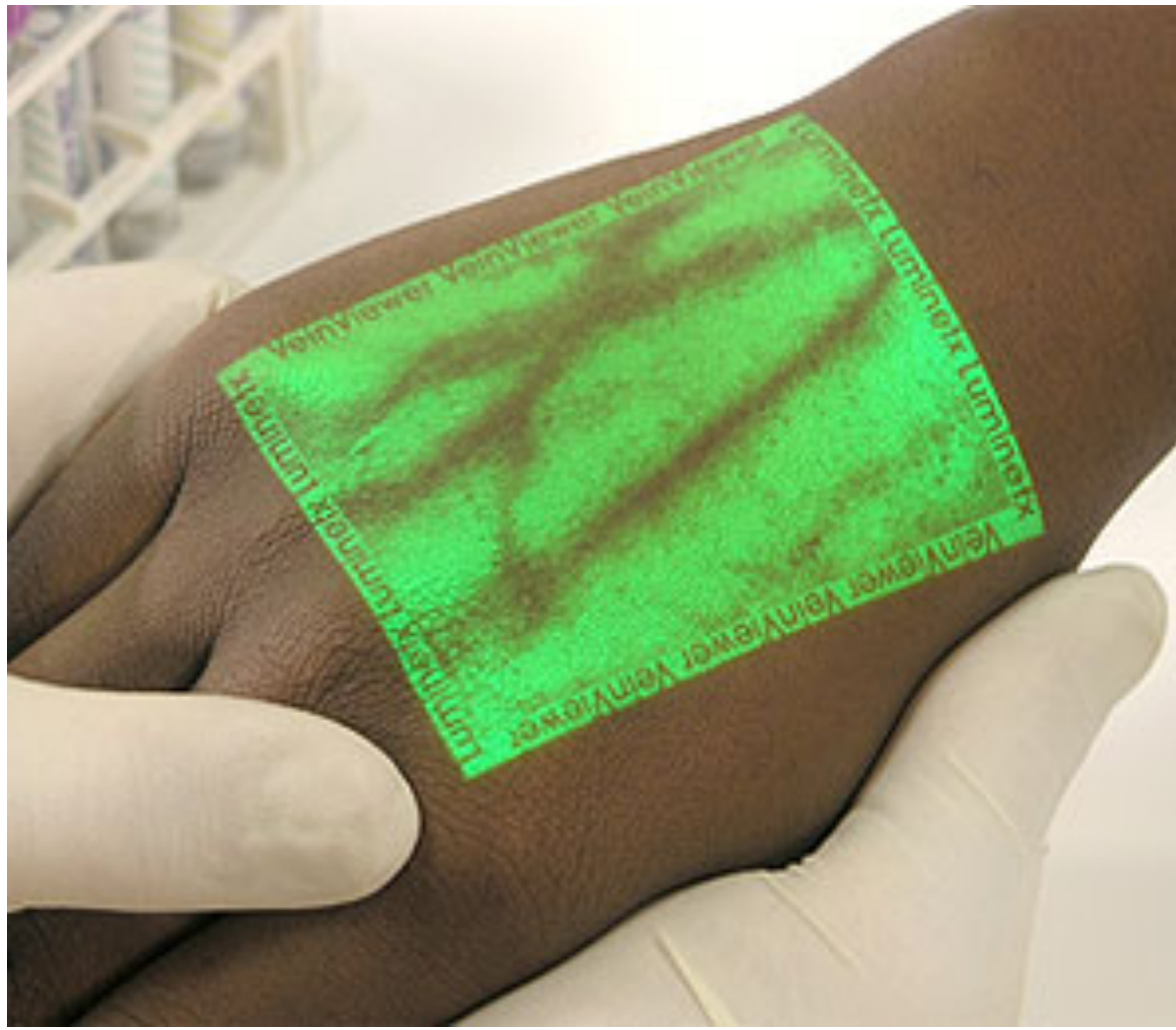
(a) Target 3D model

(b) Guidance projected onto material

(c) Sculpted physical replica

Lumitex VeinViewer

- and AccuVein

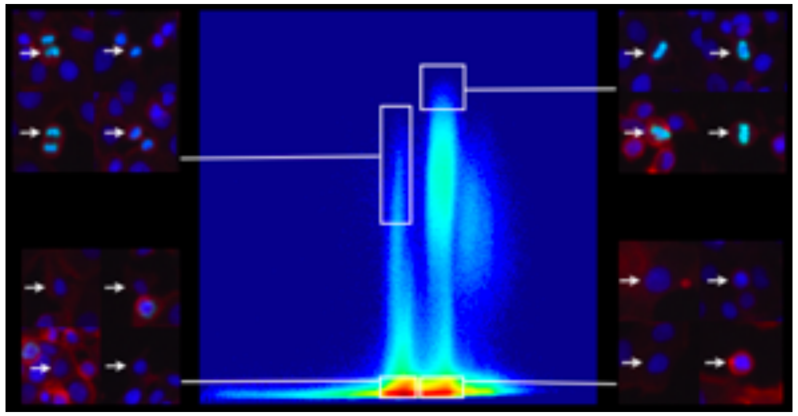


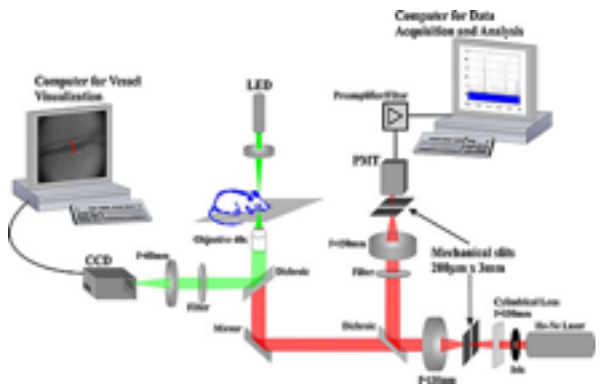
http://www.photonics.com/Article.aspx?AID=35886

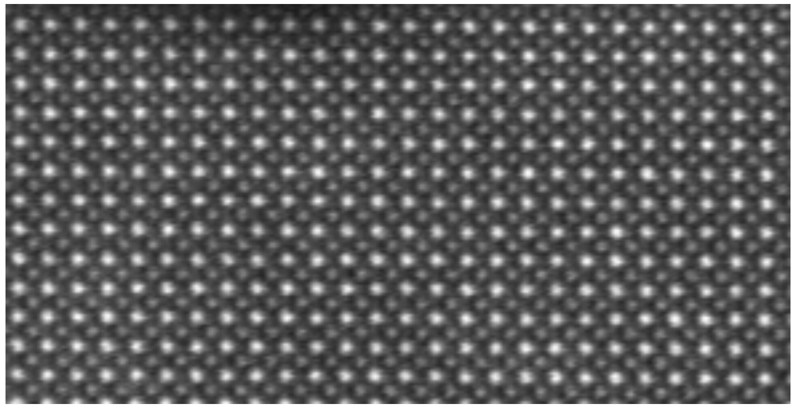
http://txch.org/news/news-archives/stanford-financial-donates-luminetx-vein-viewer-to-cancer-center/

Most sensing is optical

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

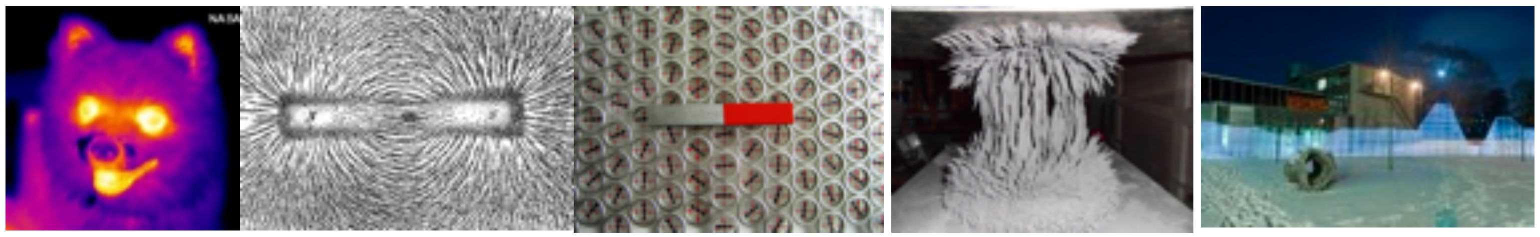




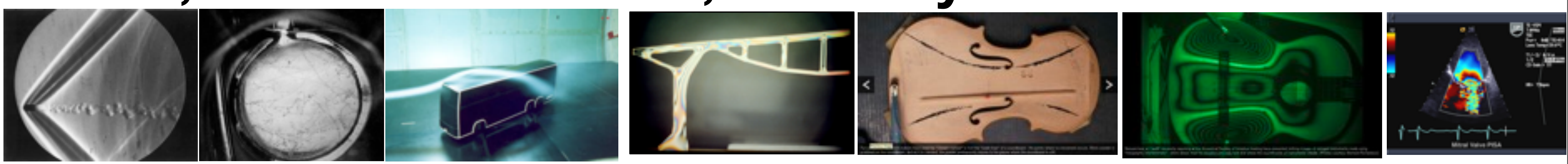


Recap: non visual phenomena

- Temperature, EM field, wifi



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



- Brain function

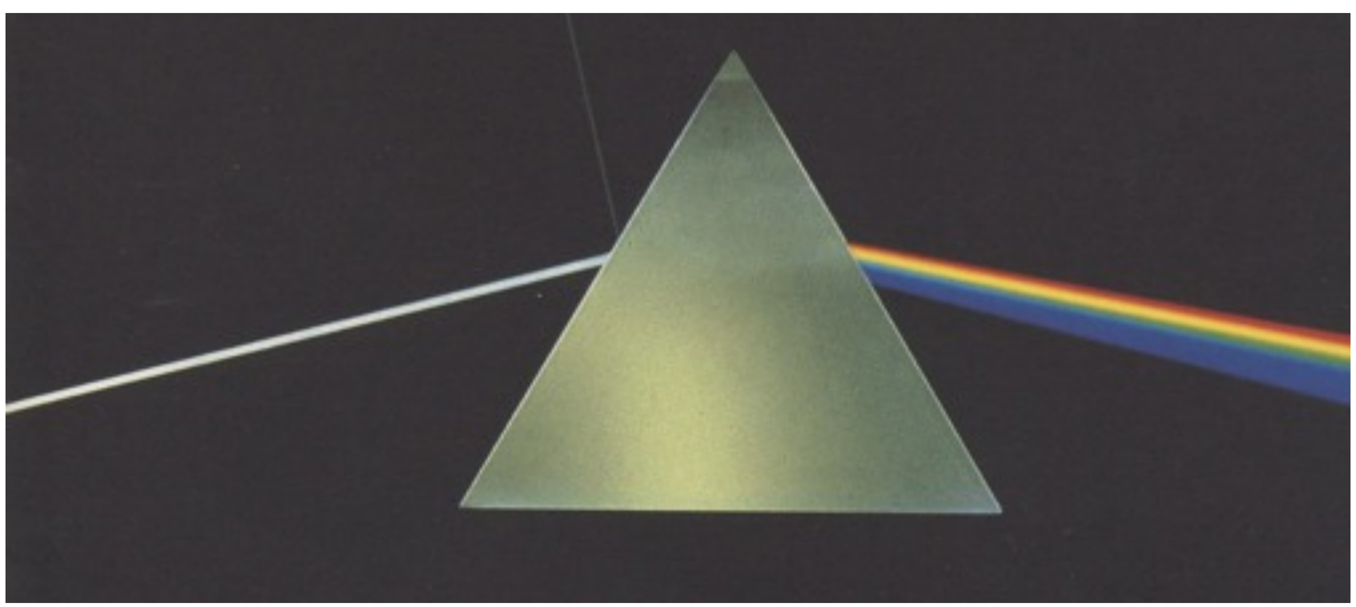
- Augmented reality, spatial AR

- **Most sensing is optical!**

Overview

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

Newton’s demo

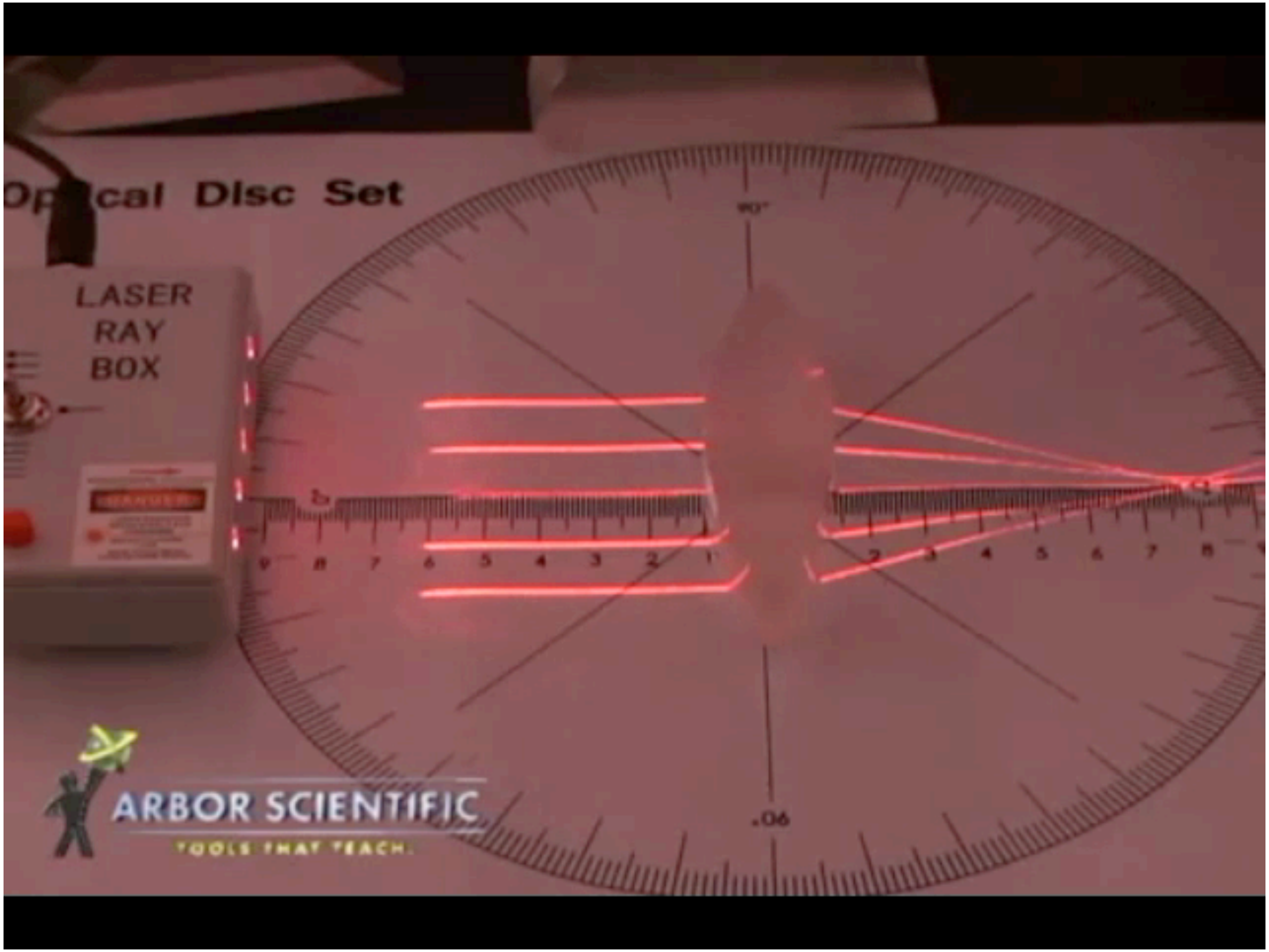


Pink Floyd, *The Dark Side of the Moon*

Pittoni, 1725, Allegory to Newton

Optics demo

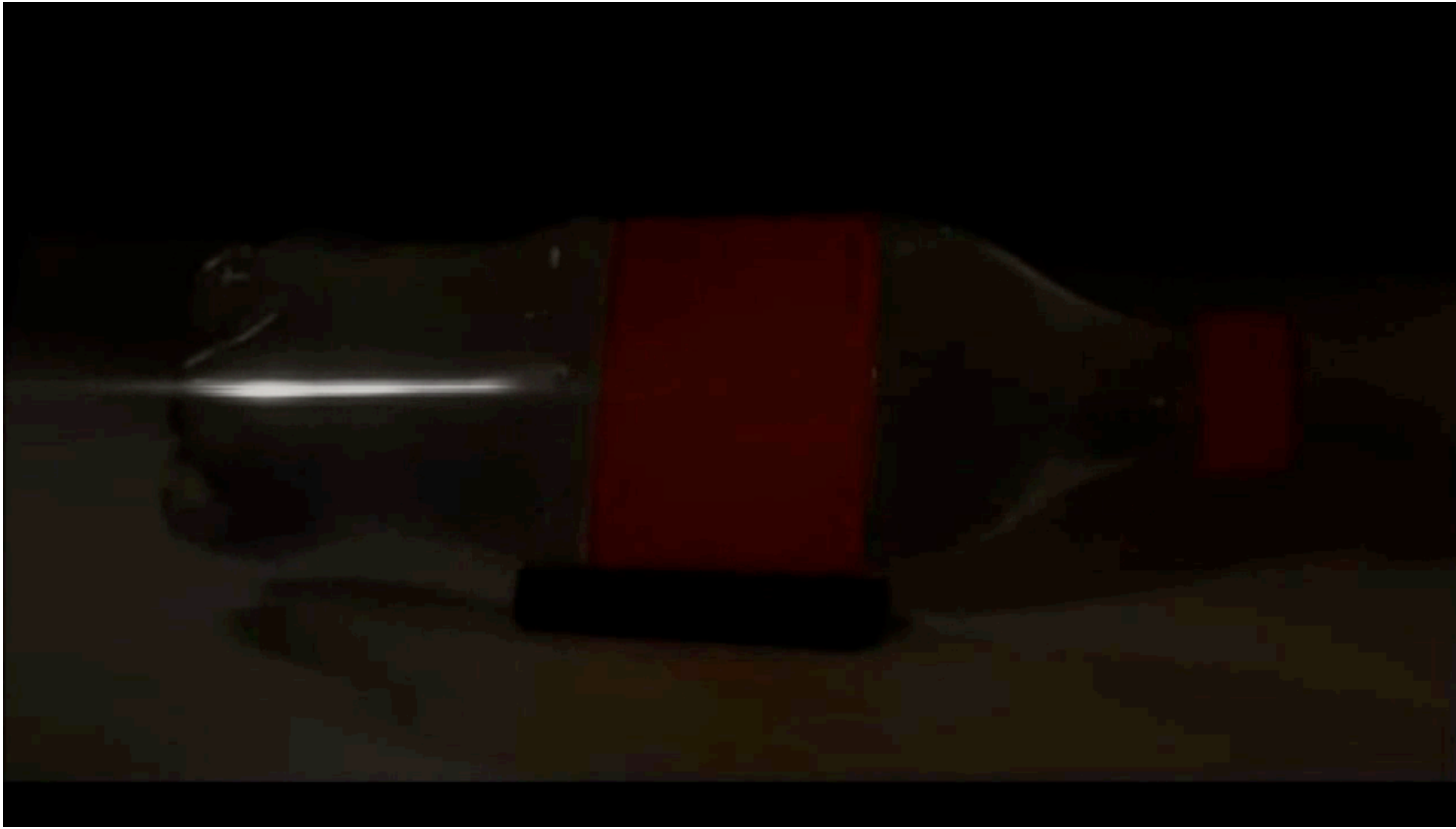
- Light box, smoke



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

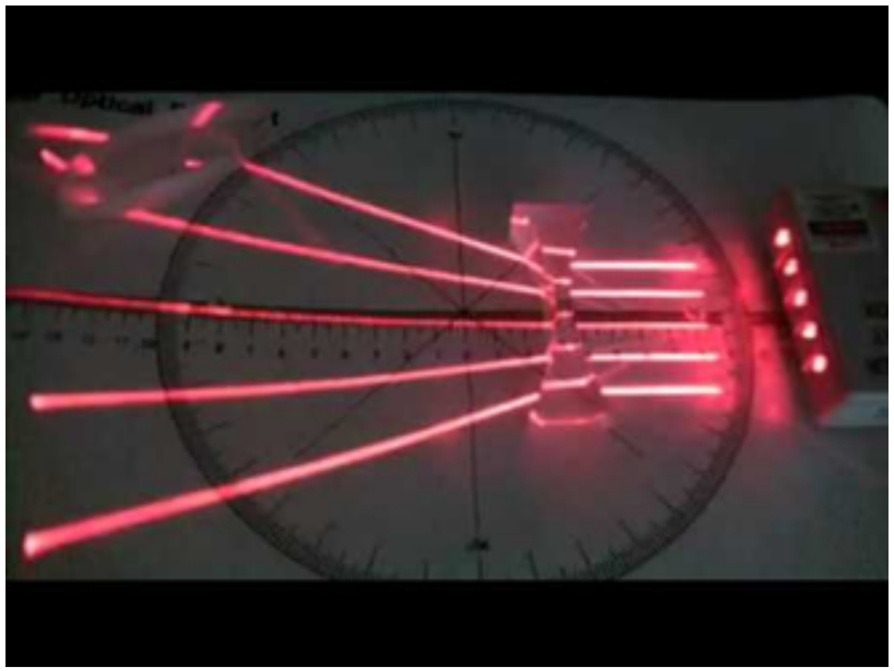
Fast Separation of Direct and Global Components of a Scene using High Frequency Illumination

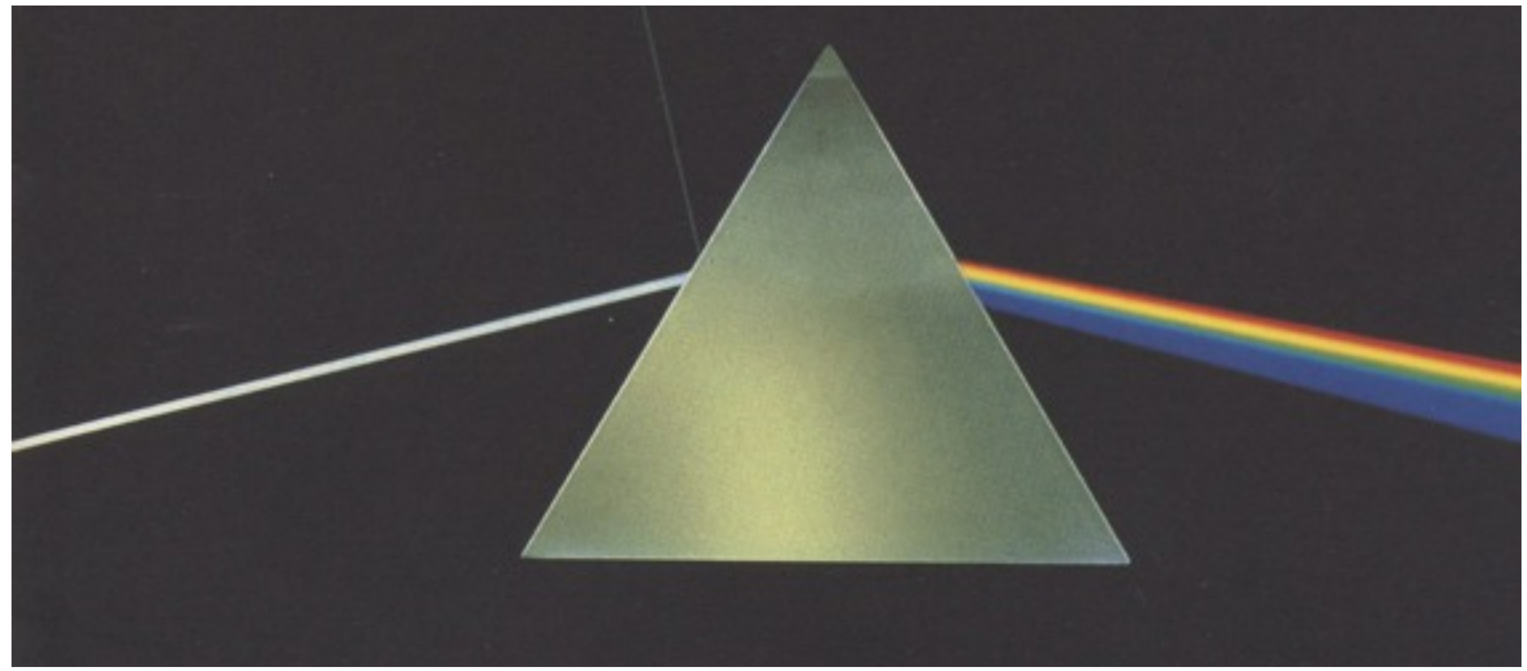
Shree K. Nayar* — Columbia University
Gurunandan Krishnan† — Columbia University
Michael D. Grossberg‡ — City University of New York
Ramesh Raskar§ — MERL

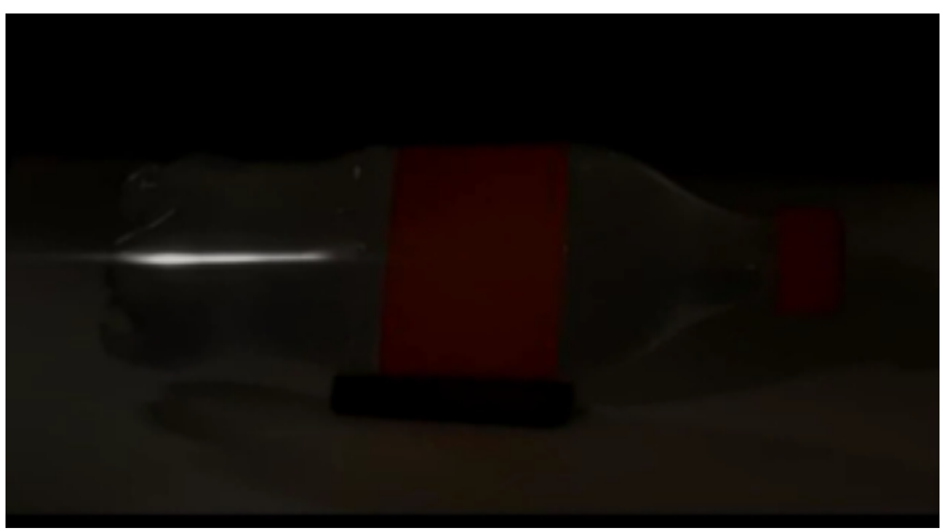
(a) Scene (b) Direct Component (c) Global Component

Recap: non-visible visual

- Reveal optics!







(b) Direct Component

(c) Global Component

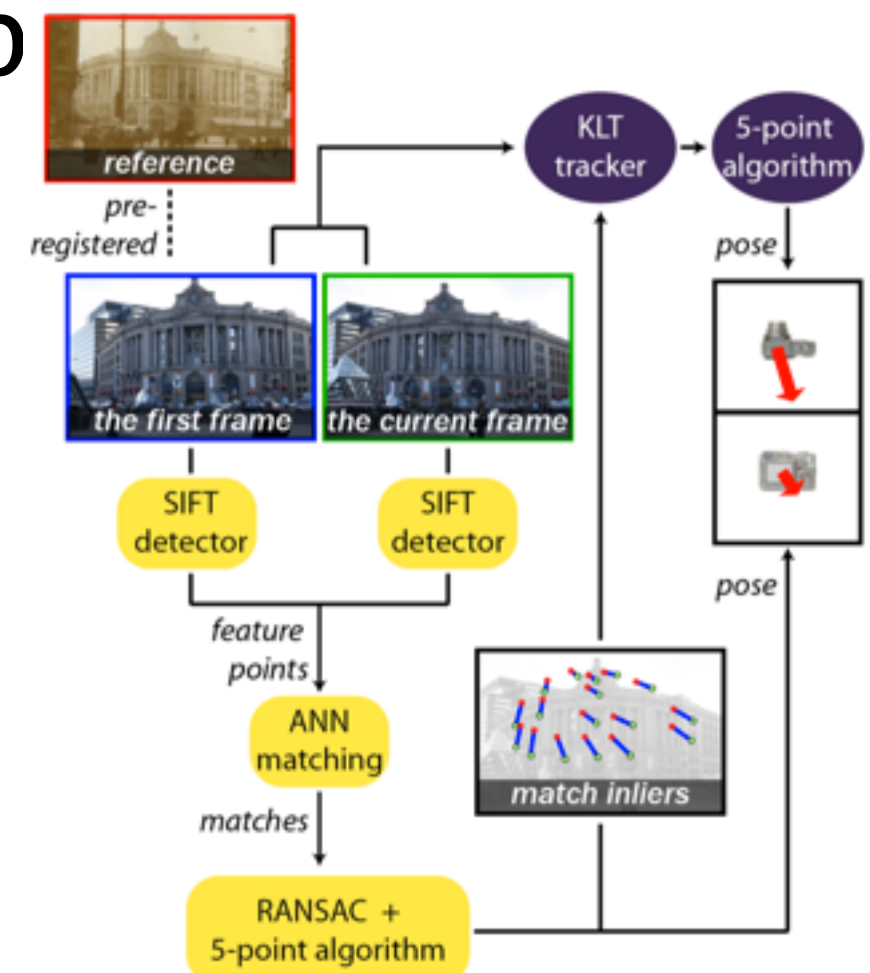
Overview

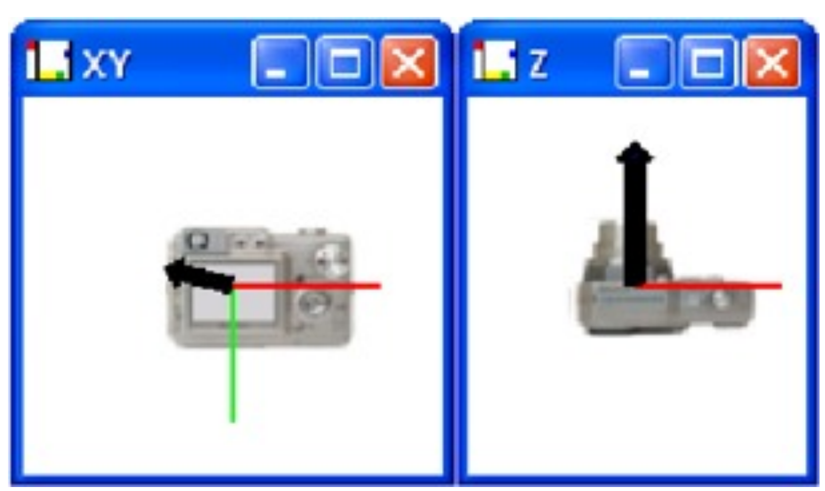
- Limits of human vision
- Occlusion
- Non-visual phenomena
- Non-visible visual phenomena
- **Change and motion**

Rephotography

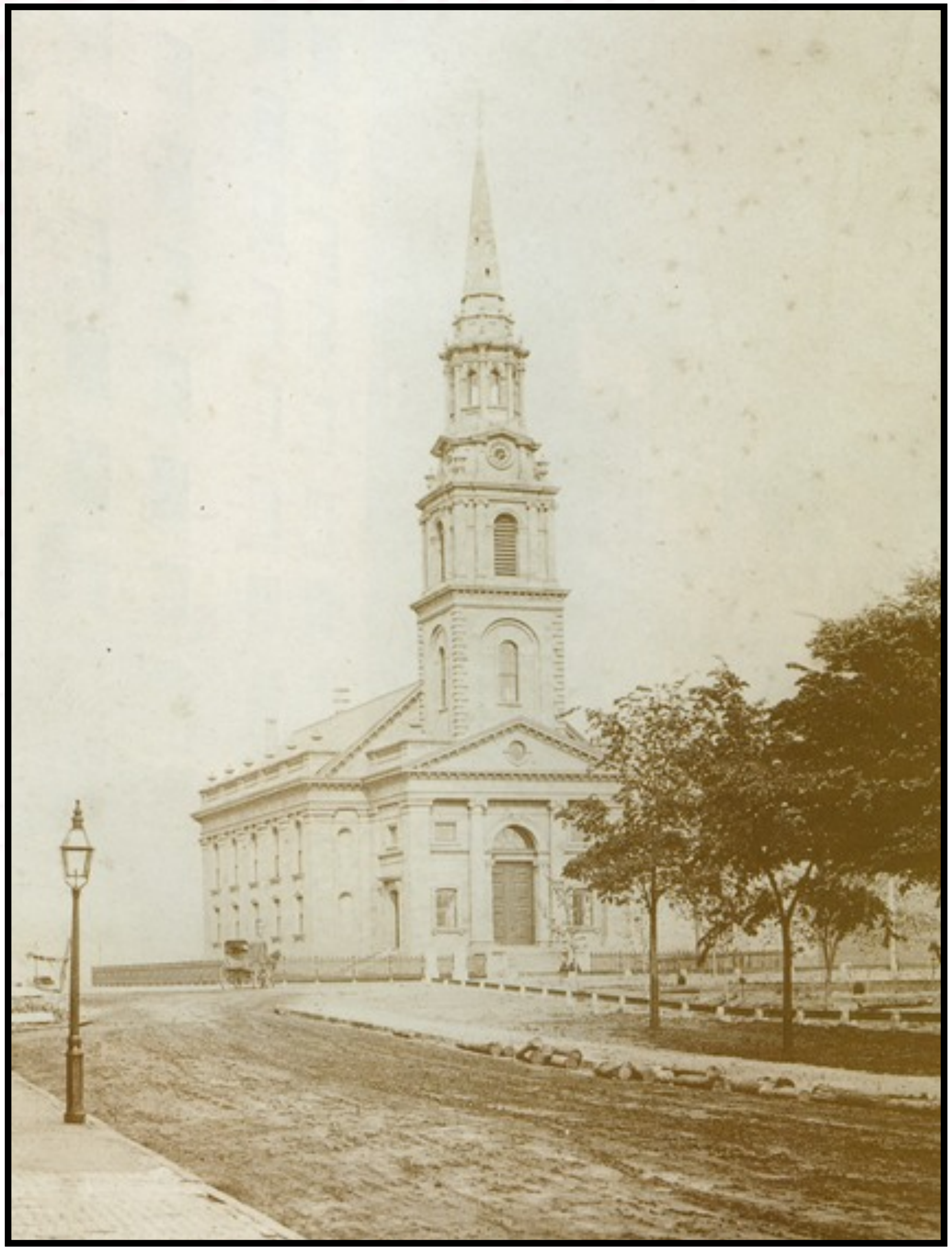
Computational Re-Photography

- *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

rephoto

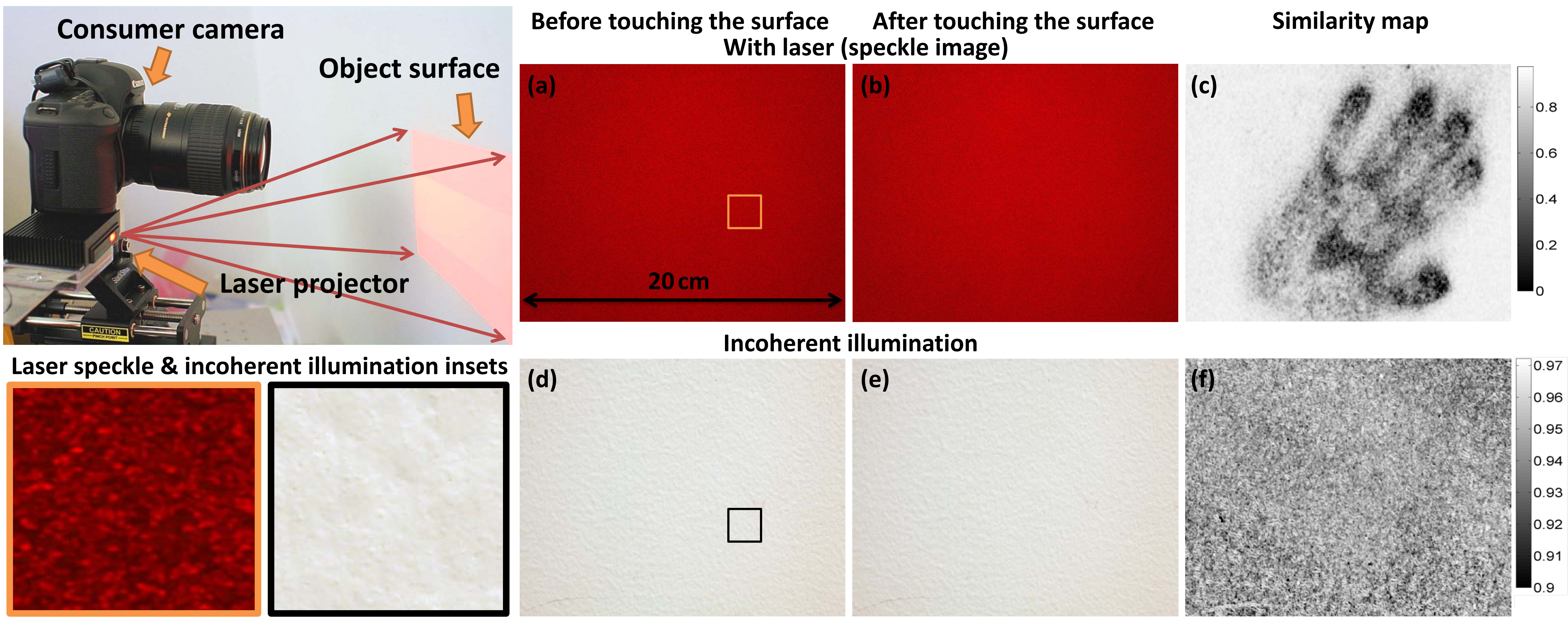
By Robert Pless http://itunes.apple.com/us/app/rephoto/id557209438?ls=1&mt=8

Speckle Imaging to reveal surface tampering

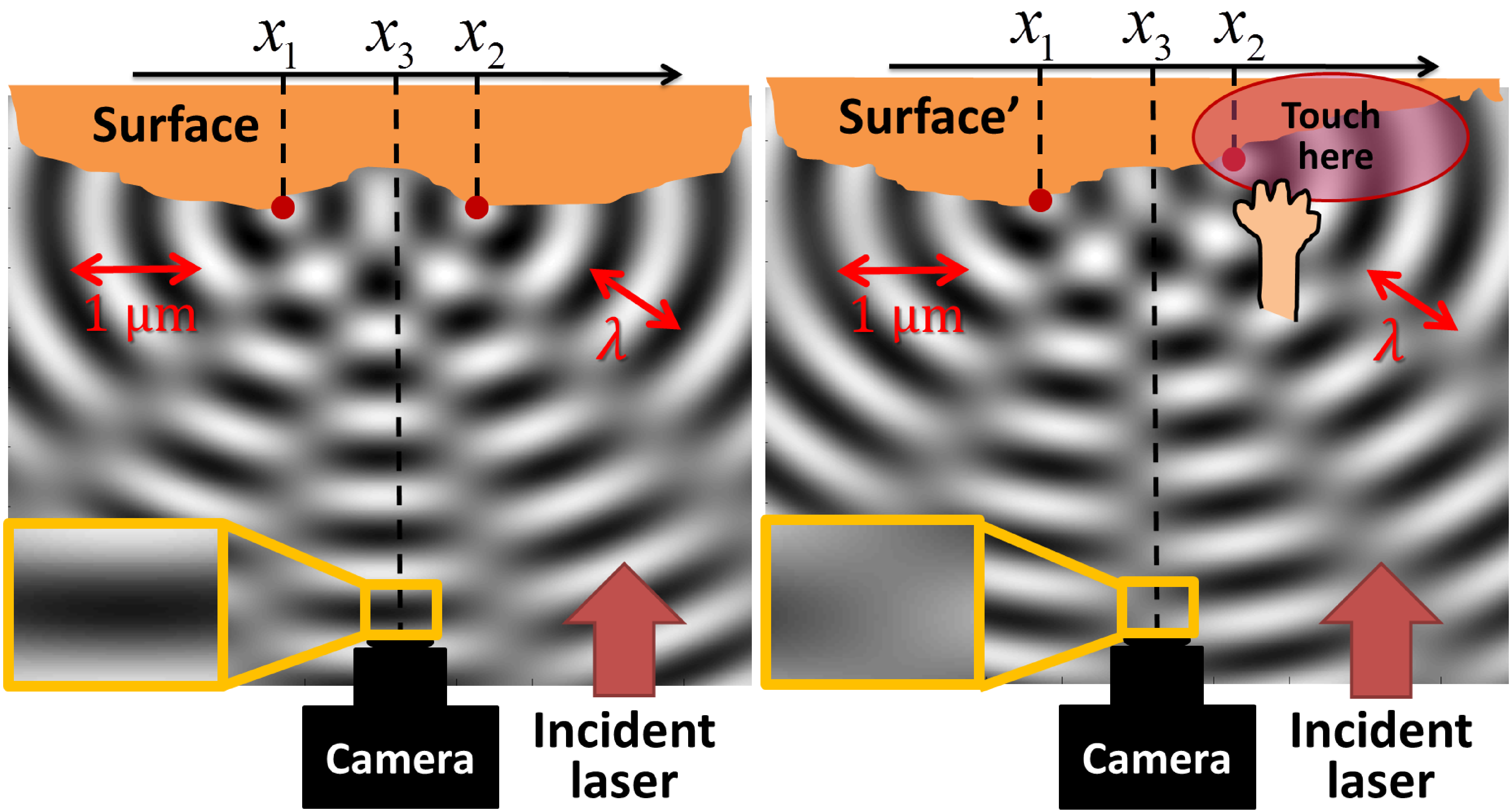
Yichang Shih, Abe Davis, Samuel Hasinoff, Bill Freeman, Fredo Durand

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

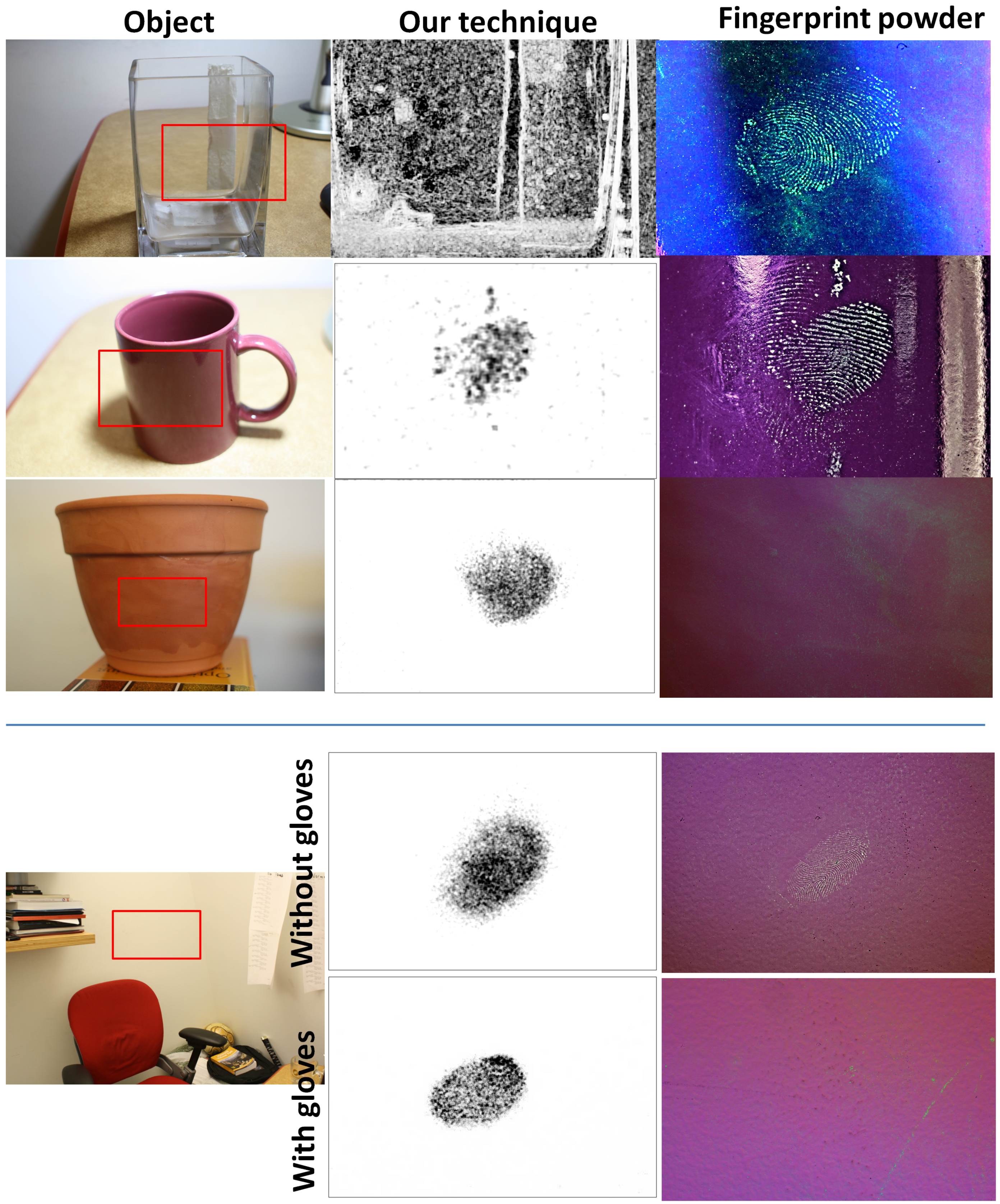


Principle

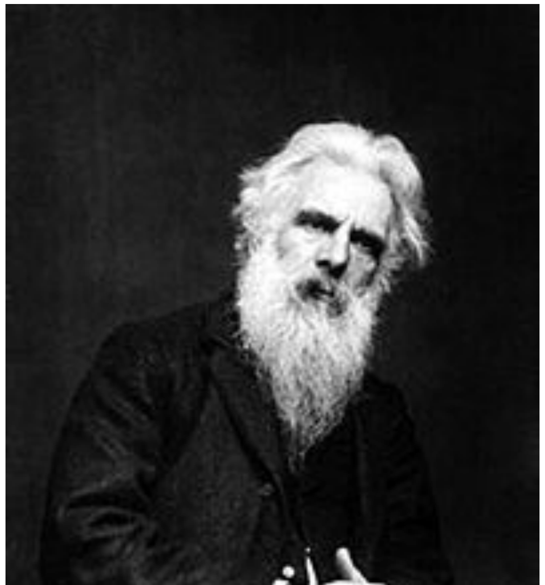


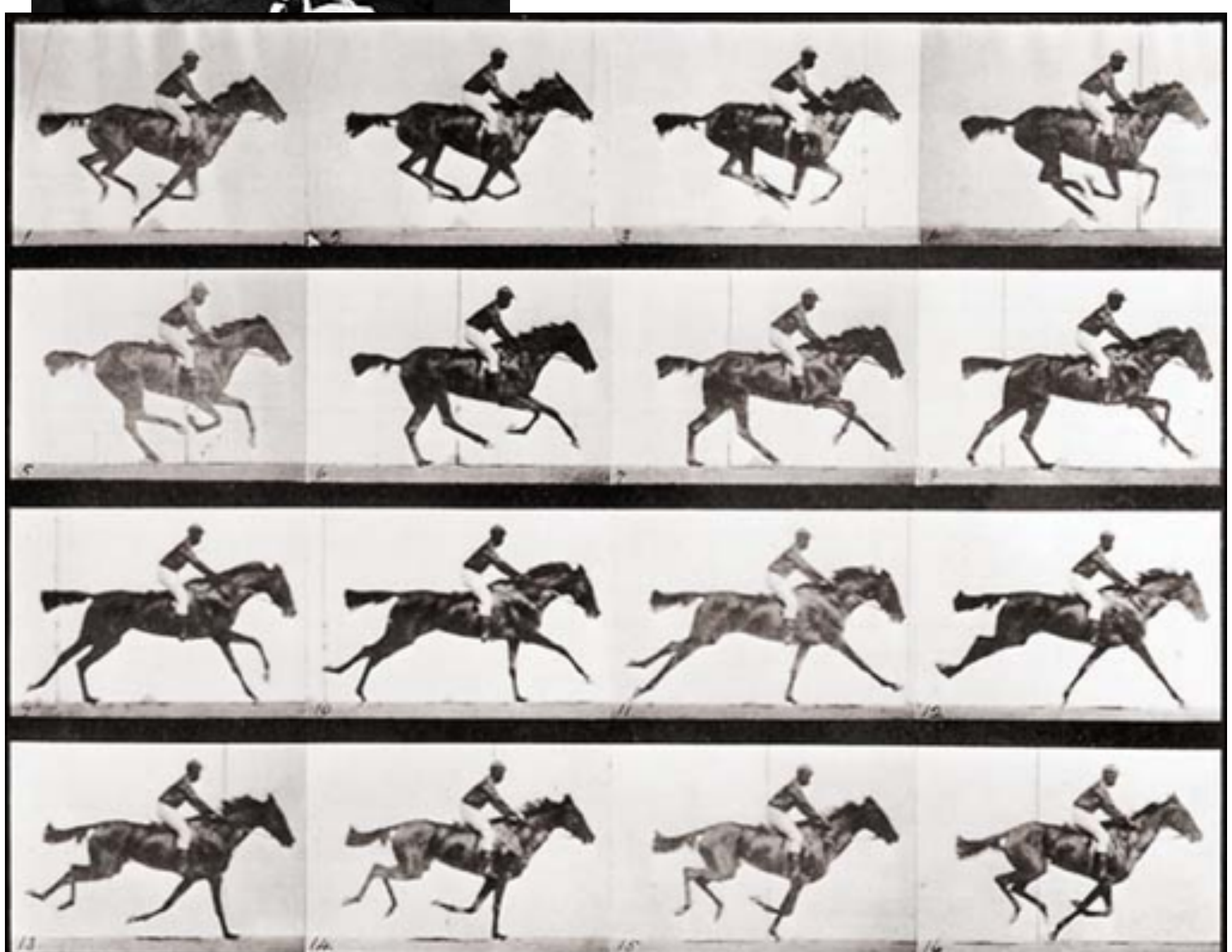
x_1
x_3
x_2
Surface
1 µm
λ
Camera
Incident laser
x_1
x_3
x_2
Surface'
Touch here
1 µm
λ
Camera
Incident laser

Comparison with fingerprint powder

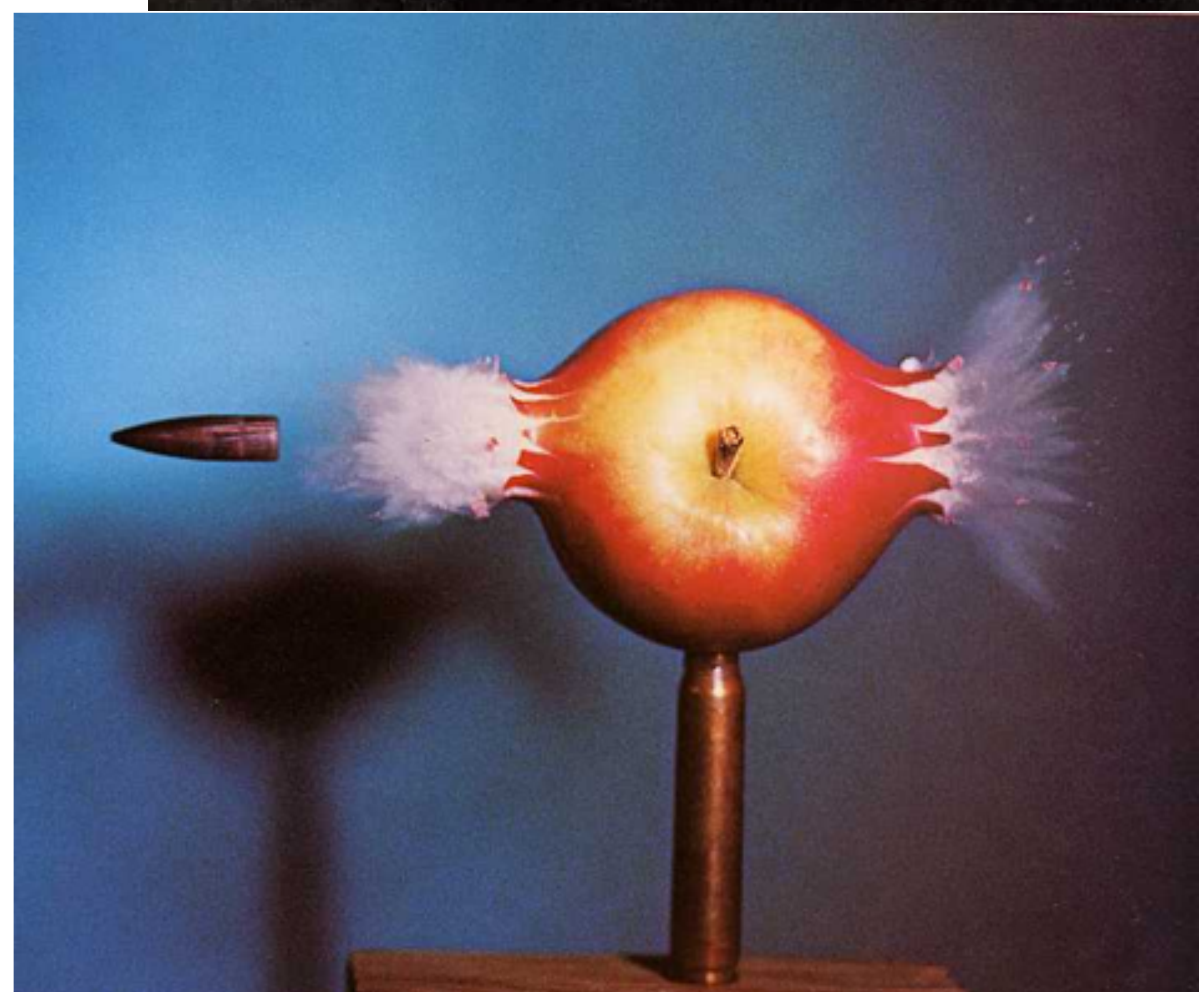


Too fast





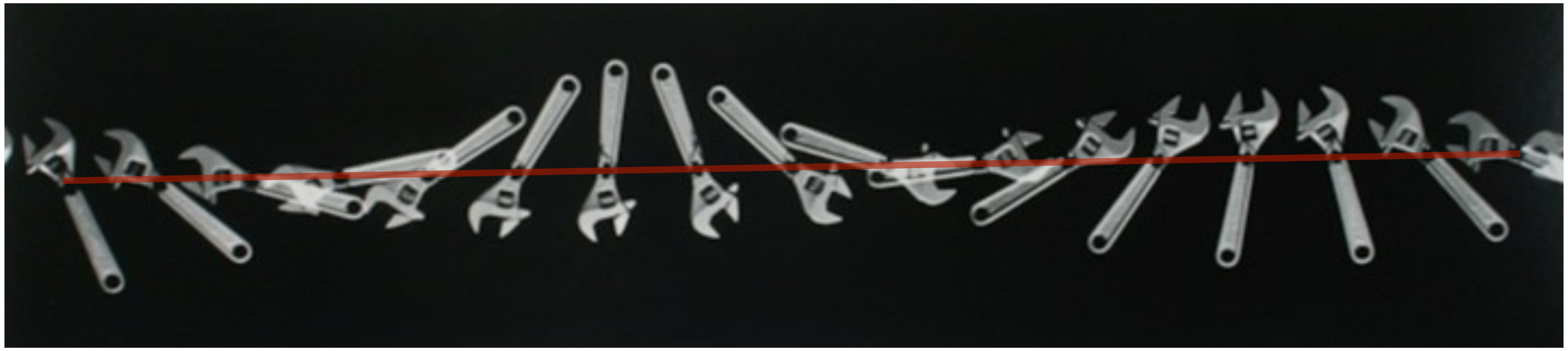
Photographs by Eadweard Muybridge



Strobe imaging

http://www.youtube.com/watch?v=mODqQvlrgIQ&list=UUeQEKFH31vvD-lnkTGSvCrA

Trajectories



Abbott

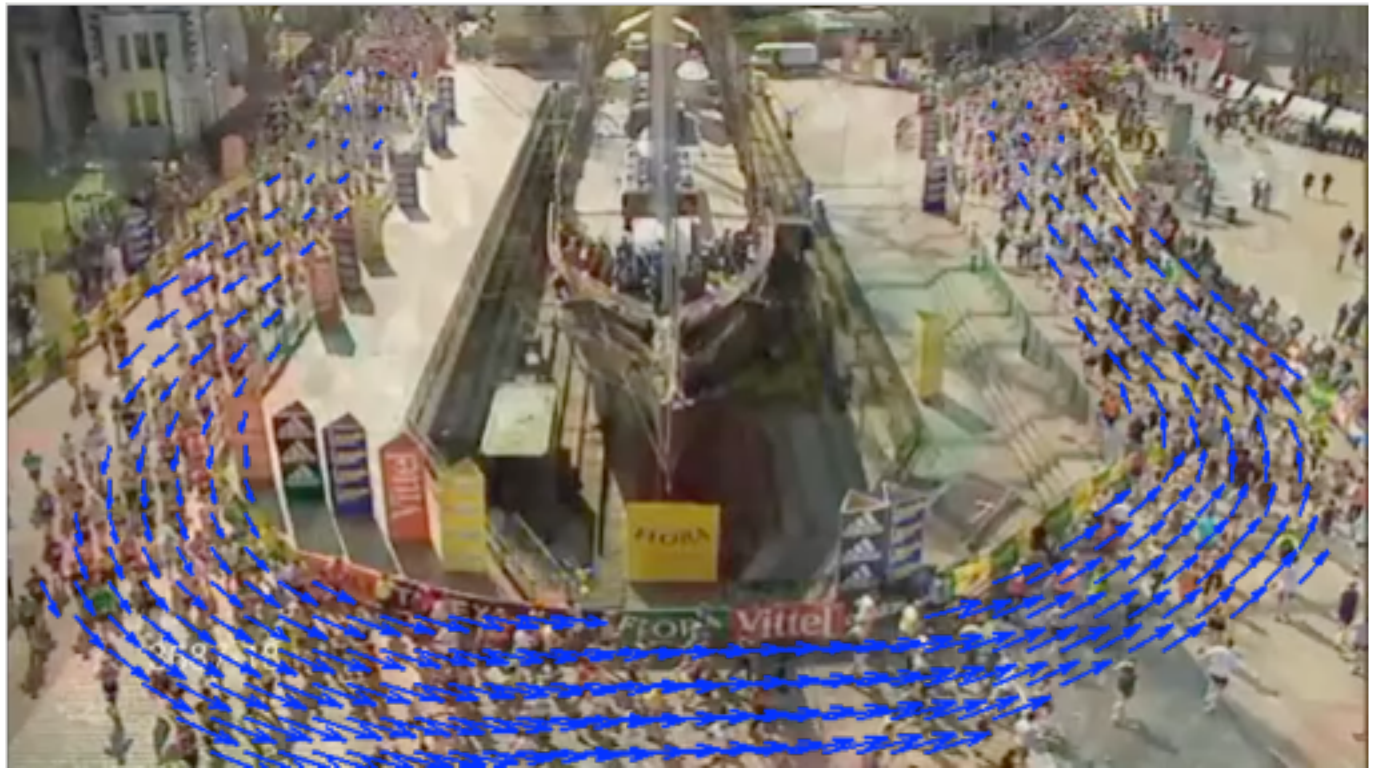
Edgerton

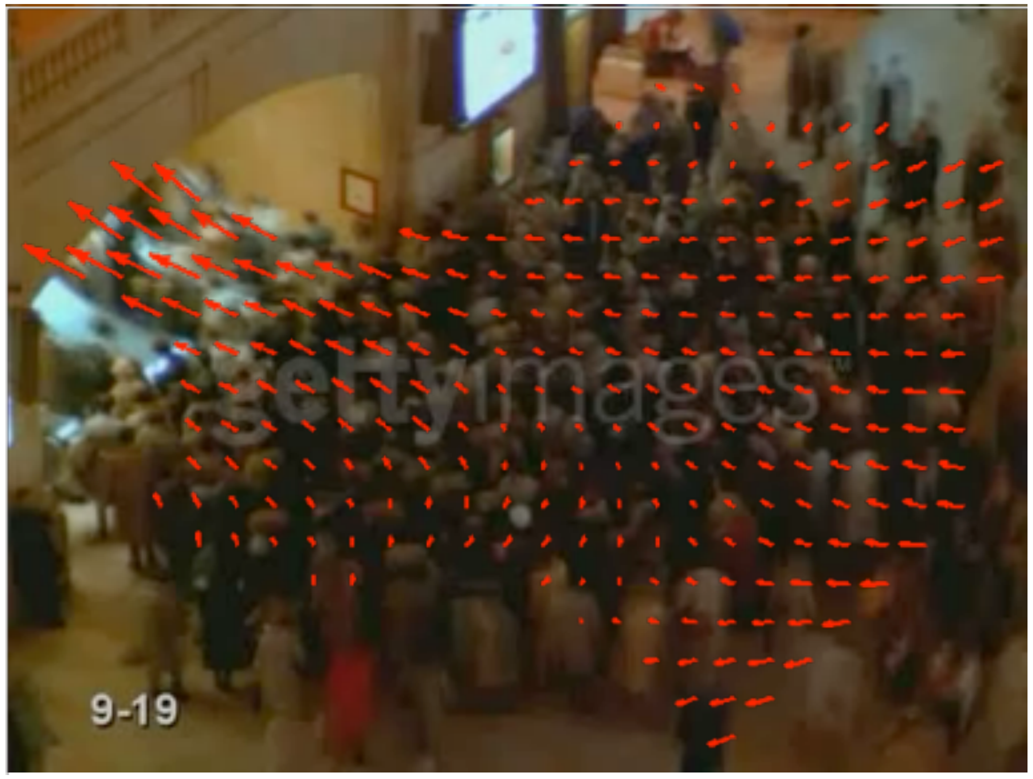
Freeman & Zhang Shape time photography

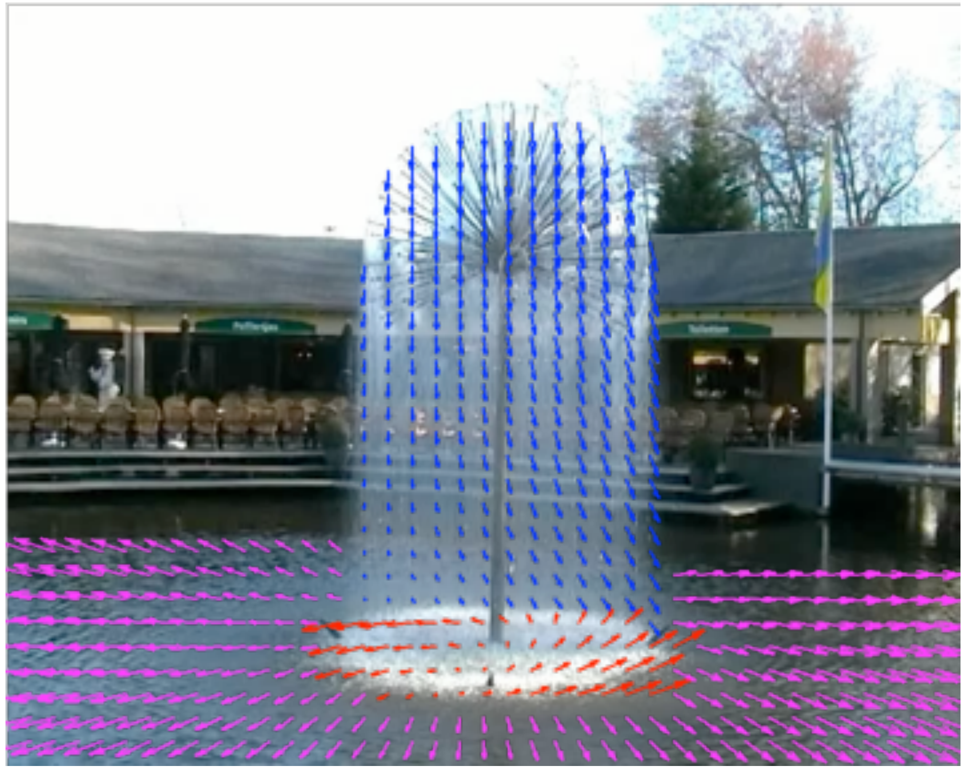
Optical flow vectors

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

Lie Algebra flows

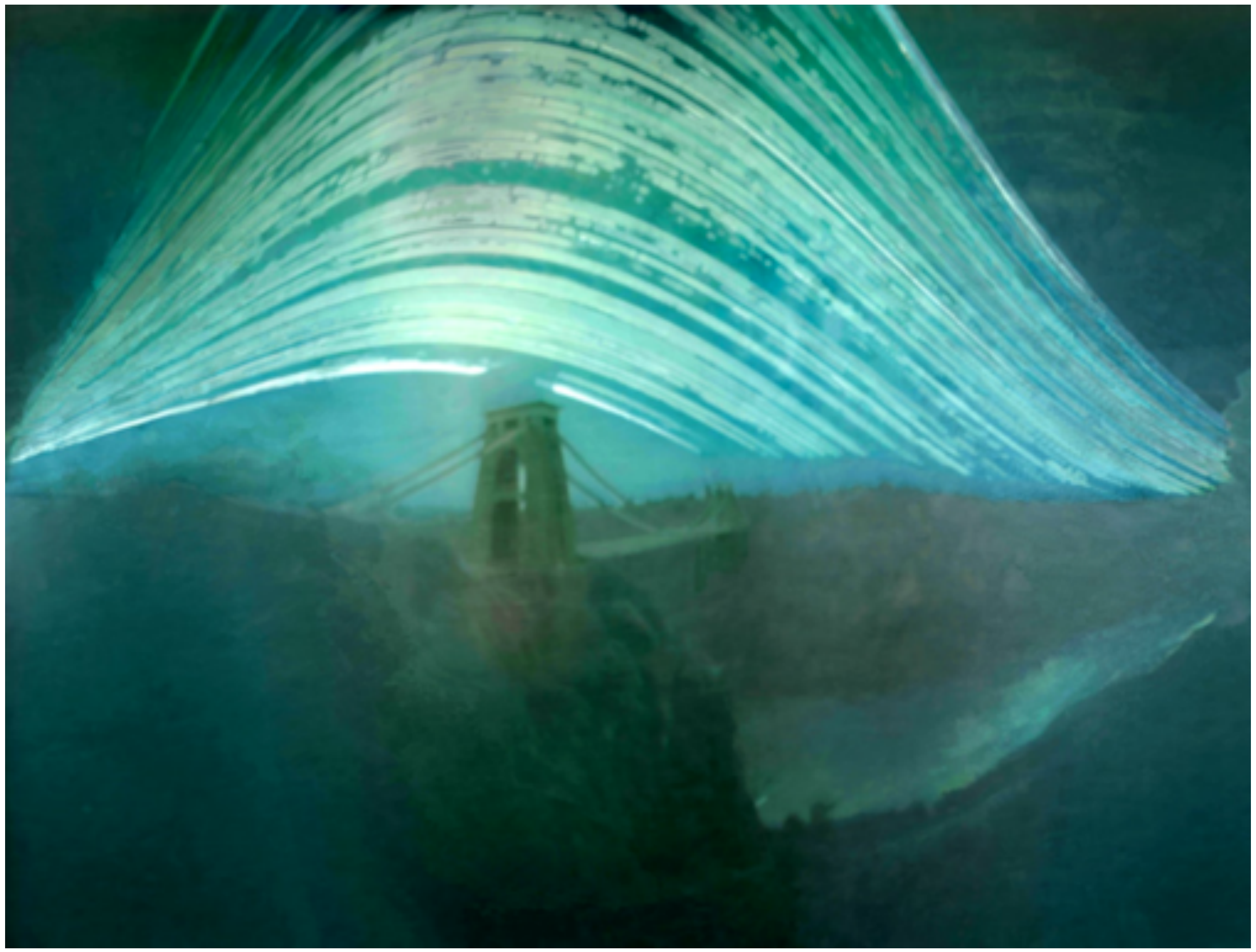




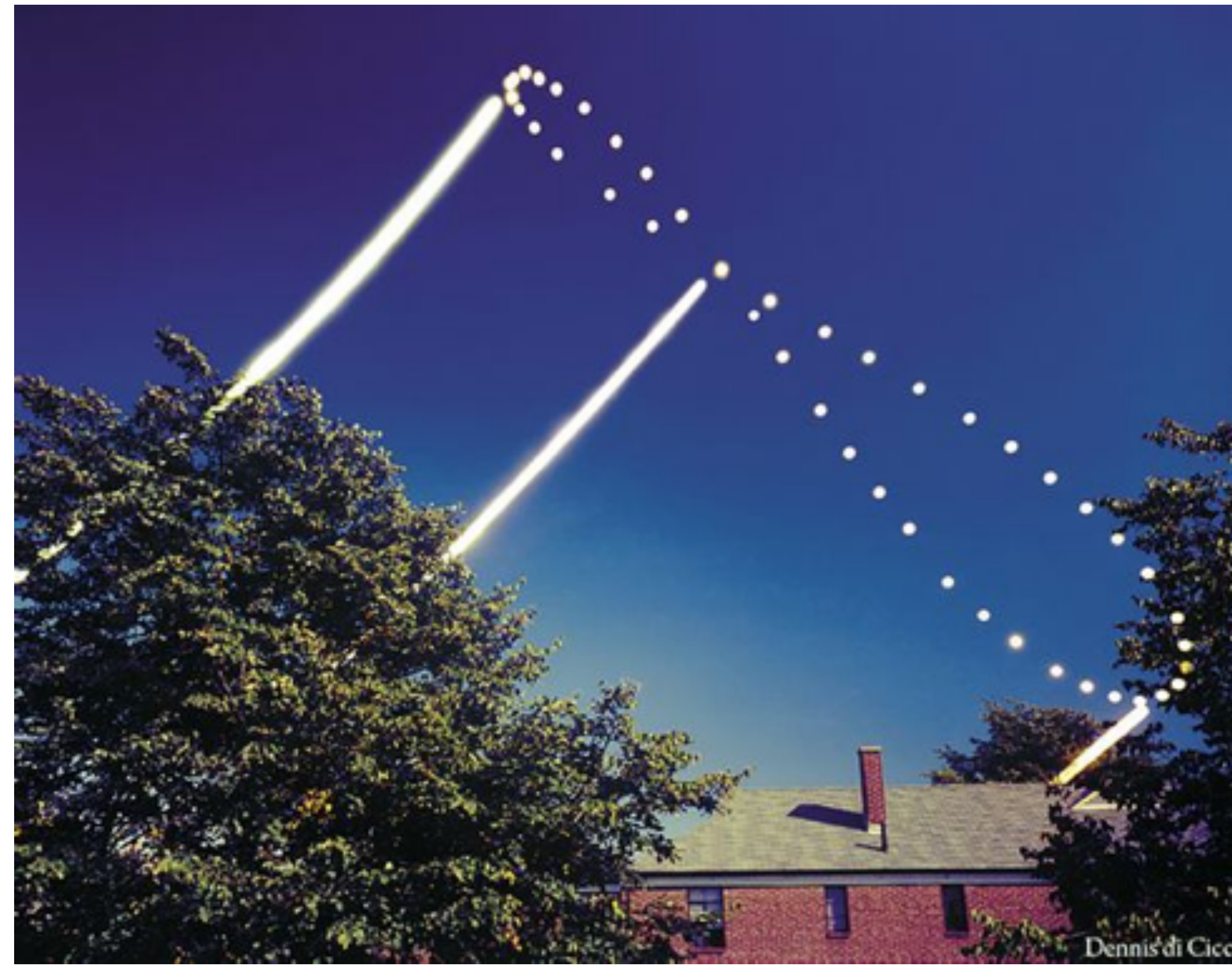


http://people.csail.mit.edu/fisher/publications/papers/dhlin09cvpr.pdf

Sun over a year



6-month exposure
by Justin Quinnell



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

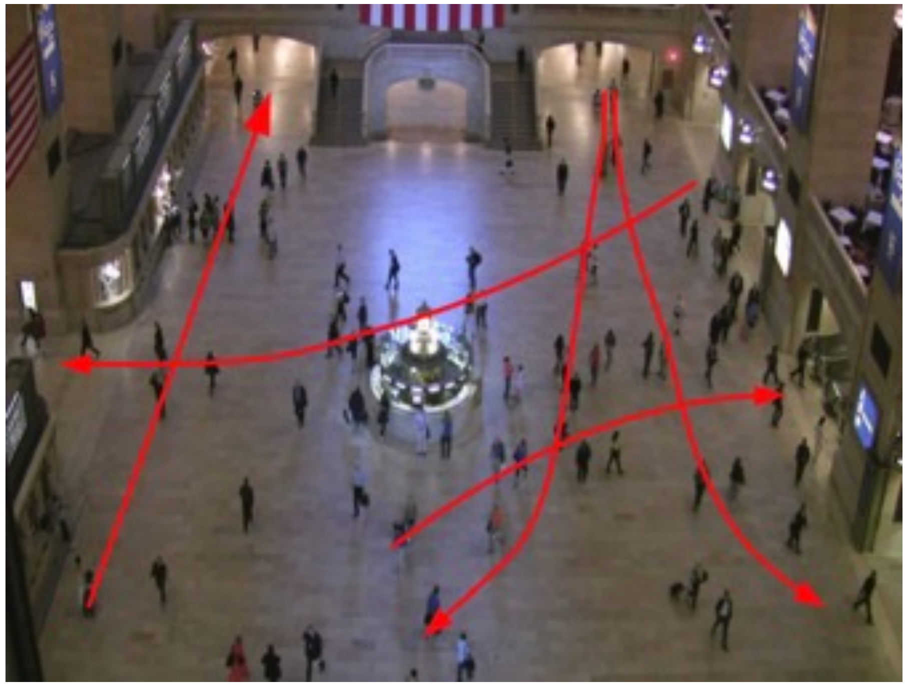
http://www.pinholephotography.org/gallery/slow/index.html

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

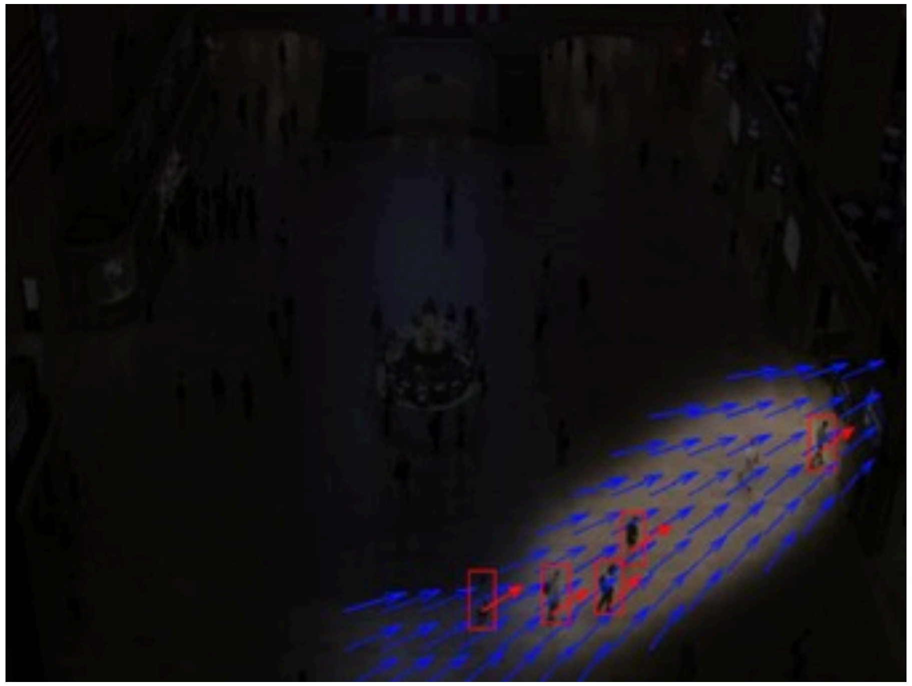
Motion/video summarization

- Goldman et al., Barnes et al. , Lin et al.

http://grail.cs.washington.edu/projects/storyboards/paper/boards.sig06.pdf



http://www.cs.princeton.edu/gfx/pubs/Barnes_2010_VTW/tapestry_electronic.pdf



http://people.csail.mit.edu/fisher/publications/papers/dhlin09cvpr.pdf

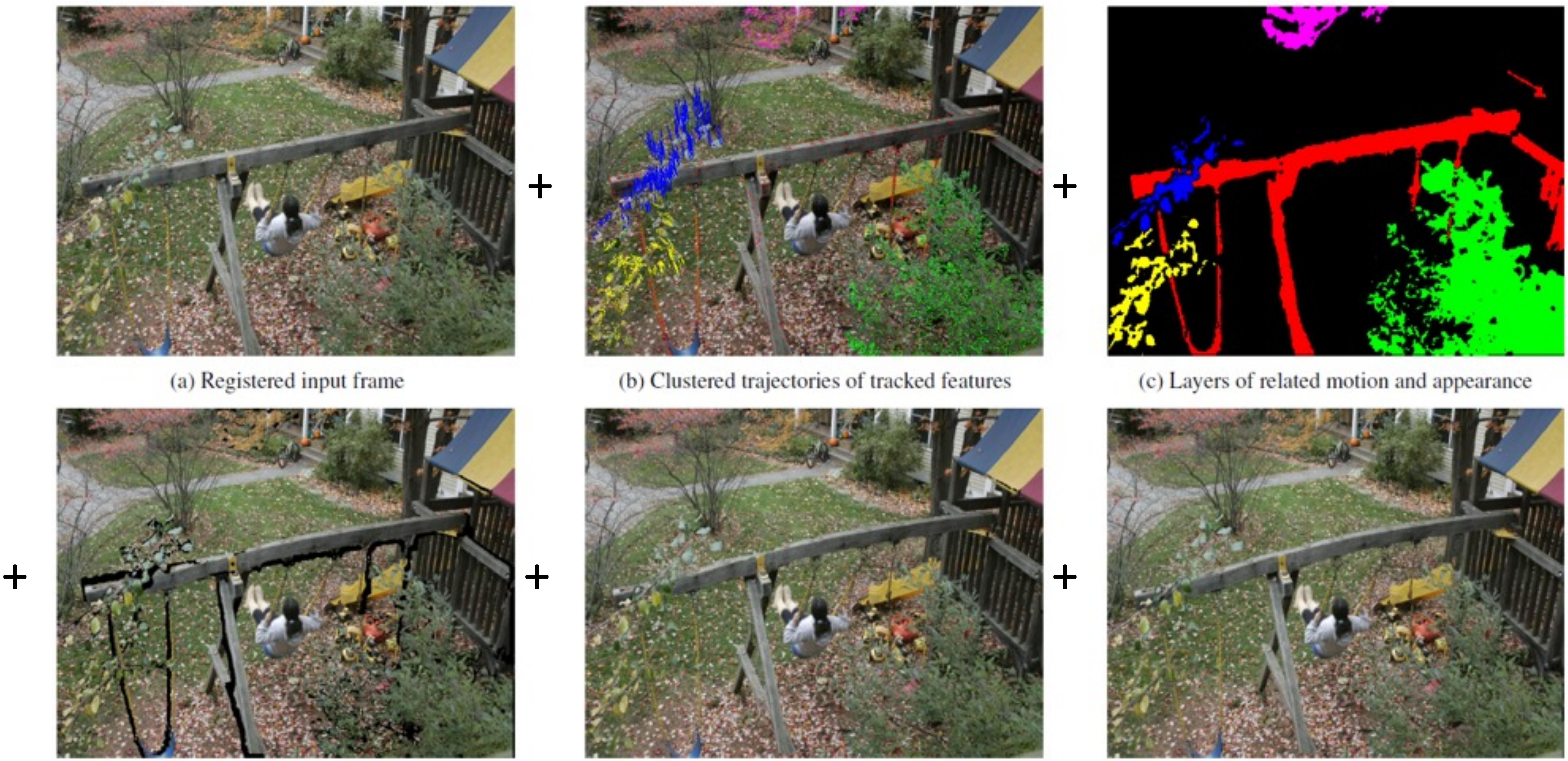
Motion magnification

- 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)
- Magnify motion that is hard to see

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

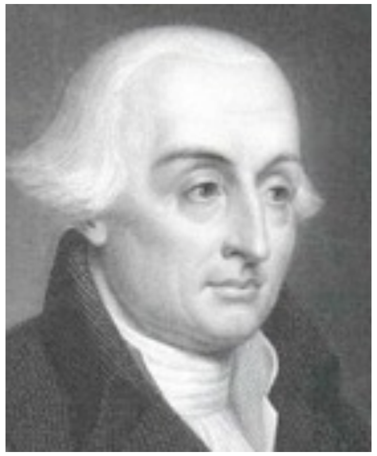
for Revealing Subtle Changes in the World

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.

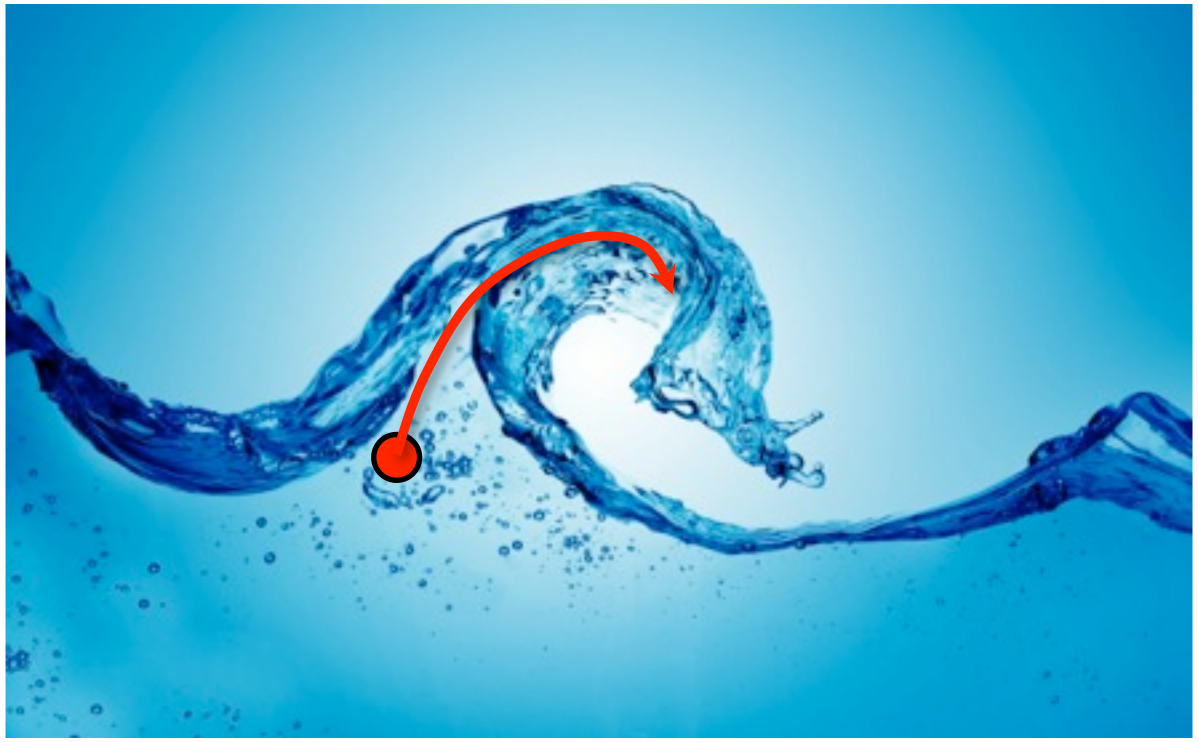
Lagrangian and Eulerian Perspectives: Fluid Dynamics

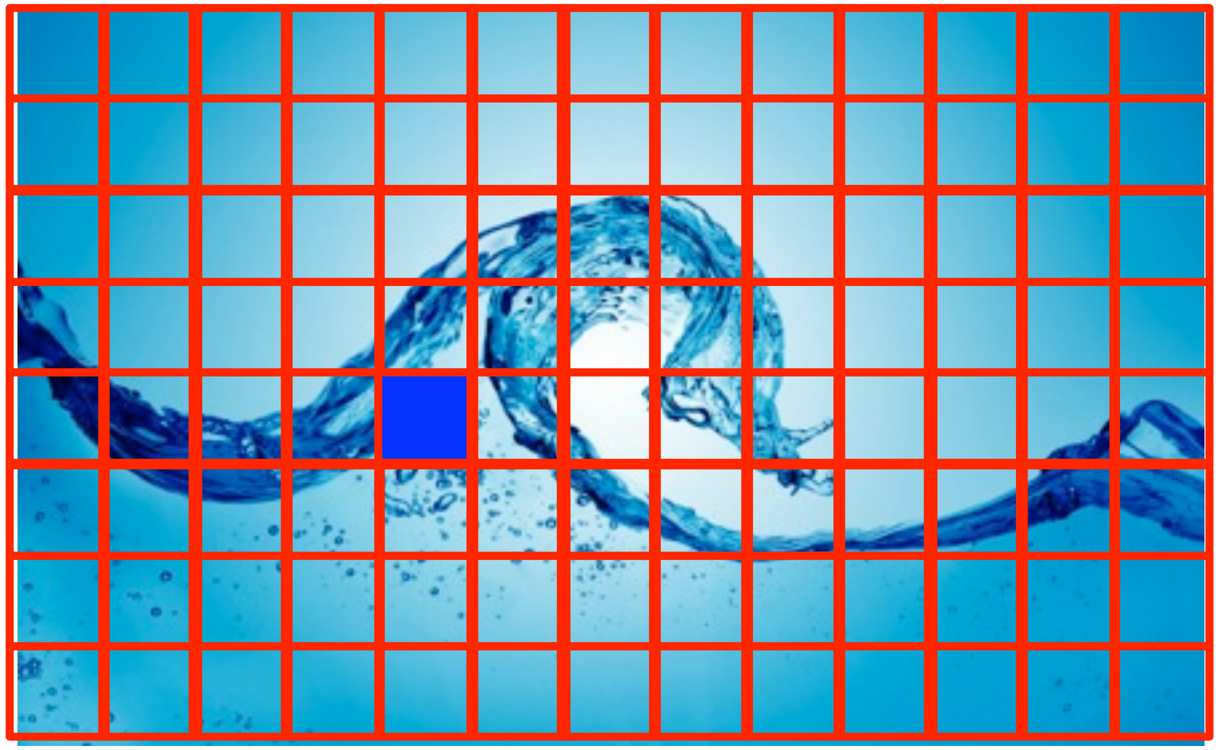
SIGGRAPH2012



Lagrangian

Eulerian

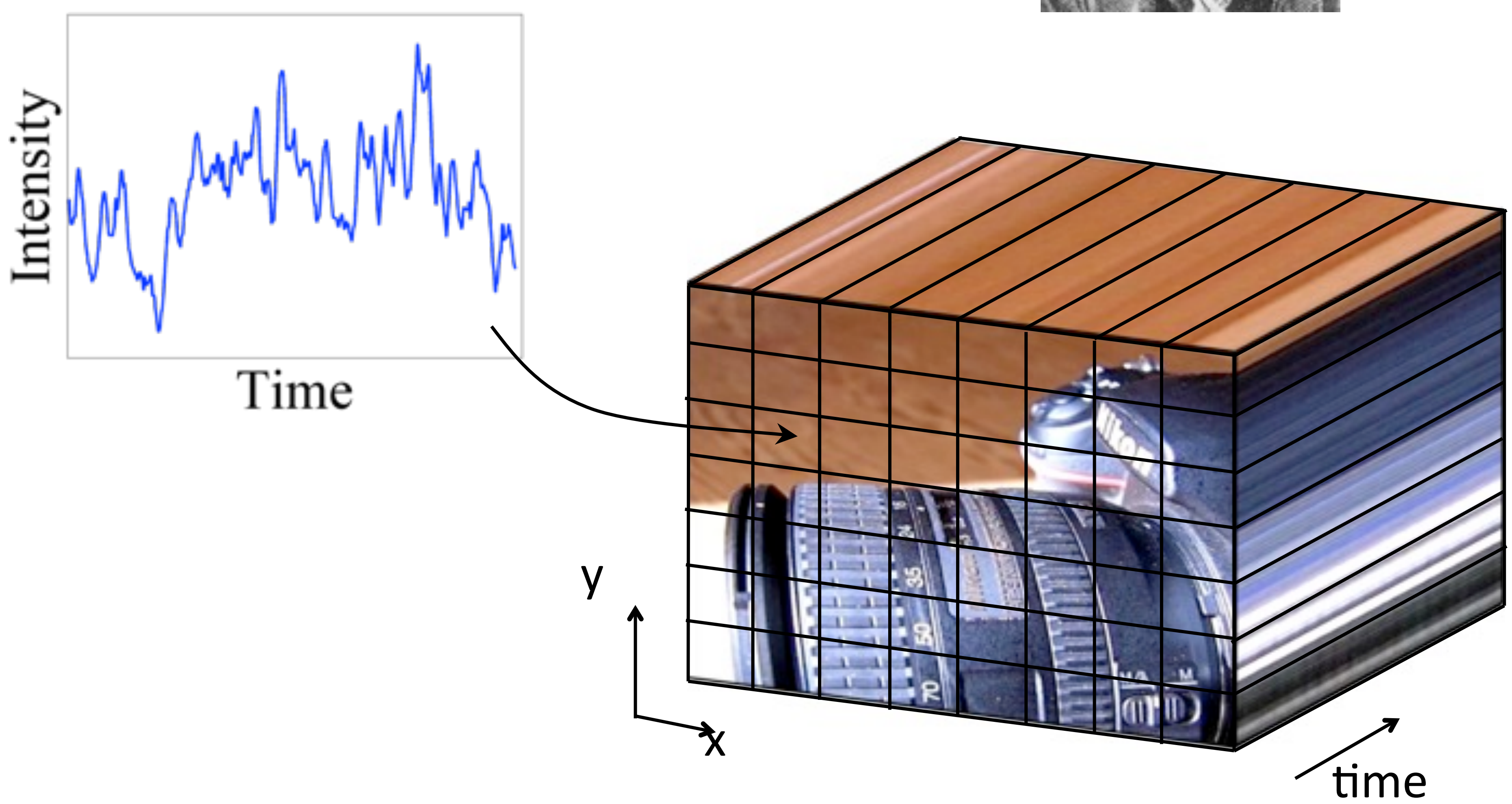




Eulerian Perspective: Videos

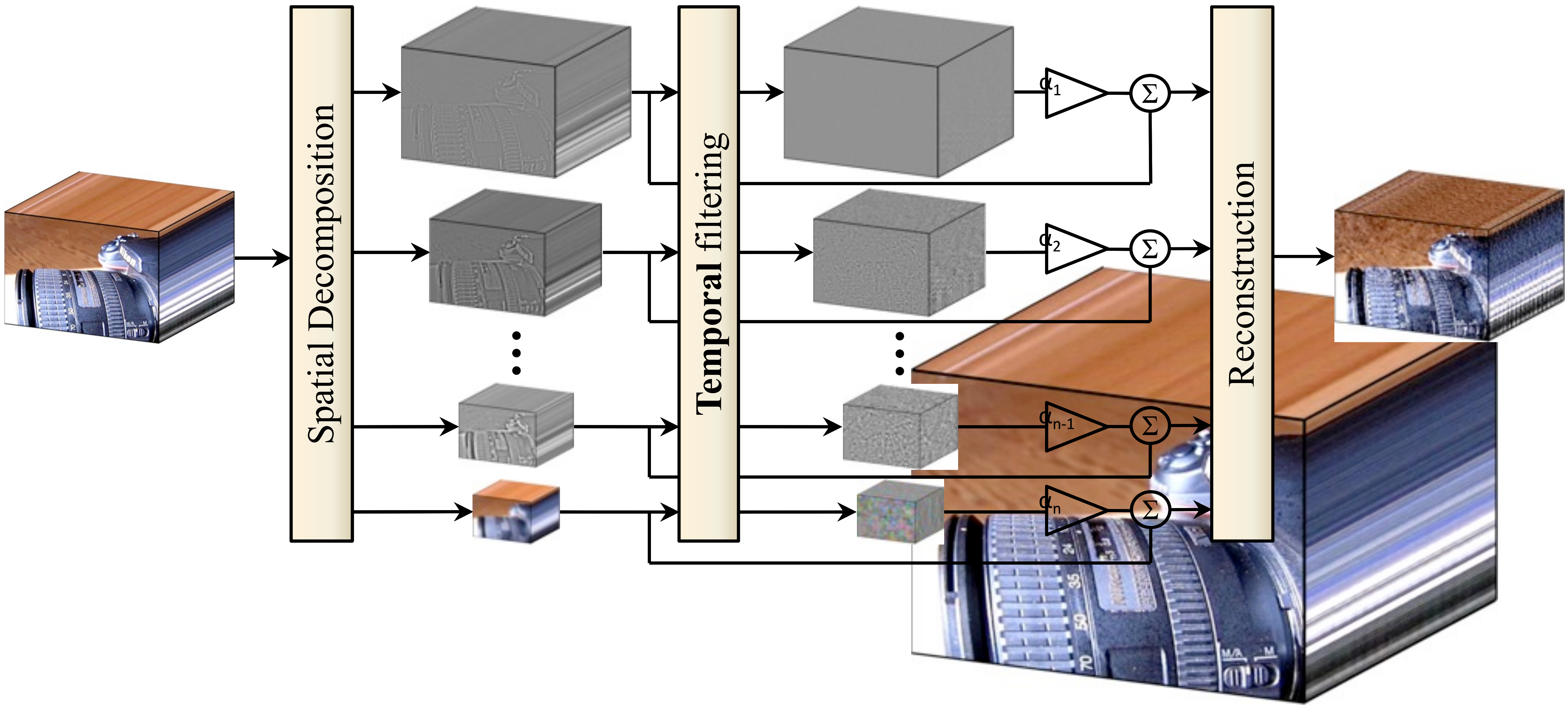
- Each pixel is processed independently
- We treat each pixel as a time series and apply signal processing to it

Eulerian



Method Overview

SIGGRAPH2012



Talk Overview

- **Eulerian video magnification**

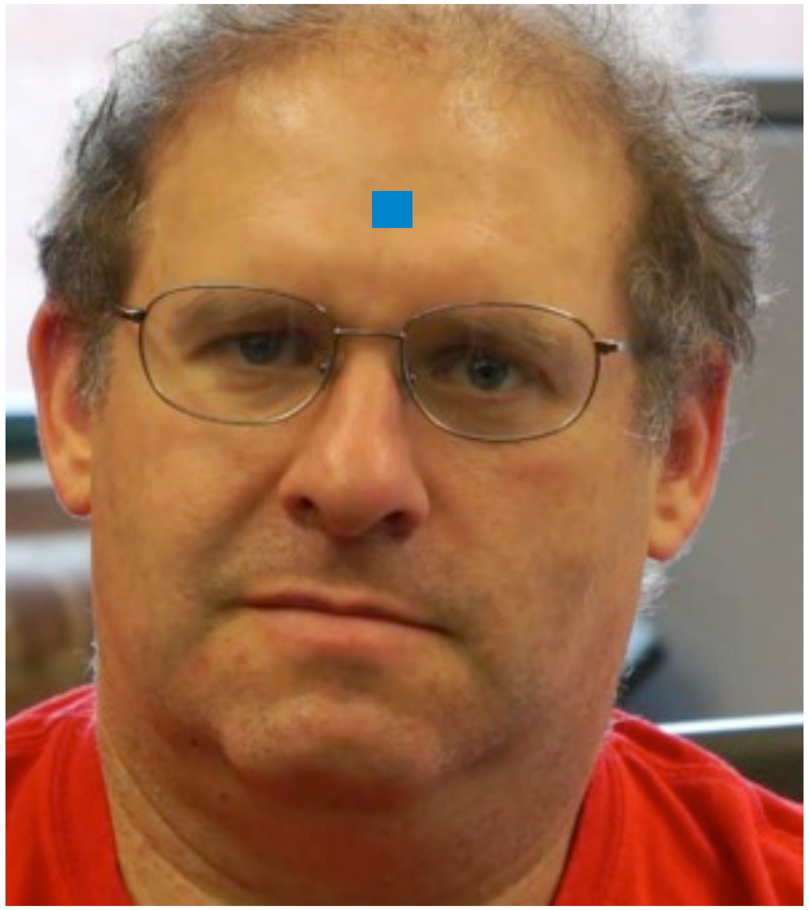
- Why it amplifies motion

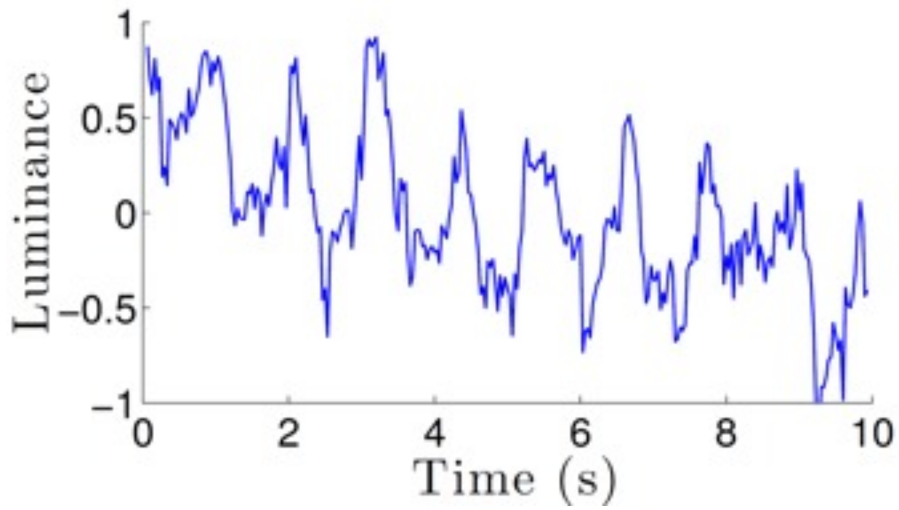
- Results

Amplifying Subtle Color Variations

Filter spatially to reduce noise

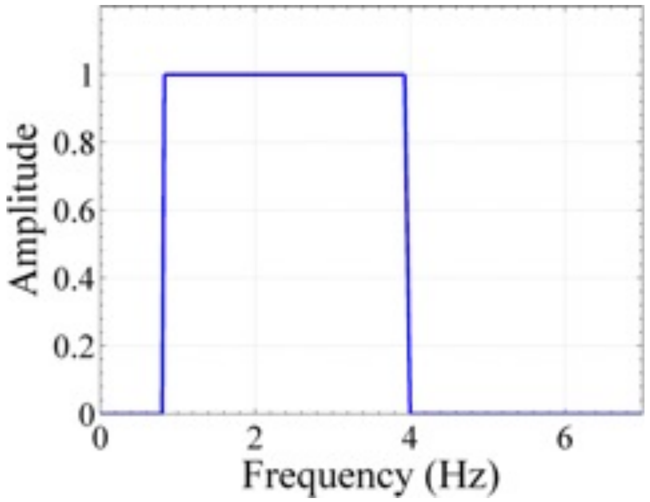
Filter temporally to extract the signal of interest





Spatially averaged luminance trace

⊗



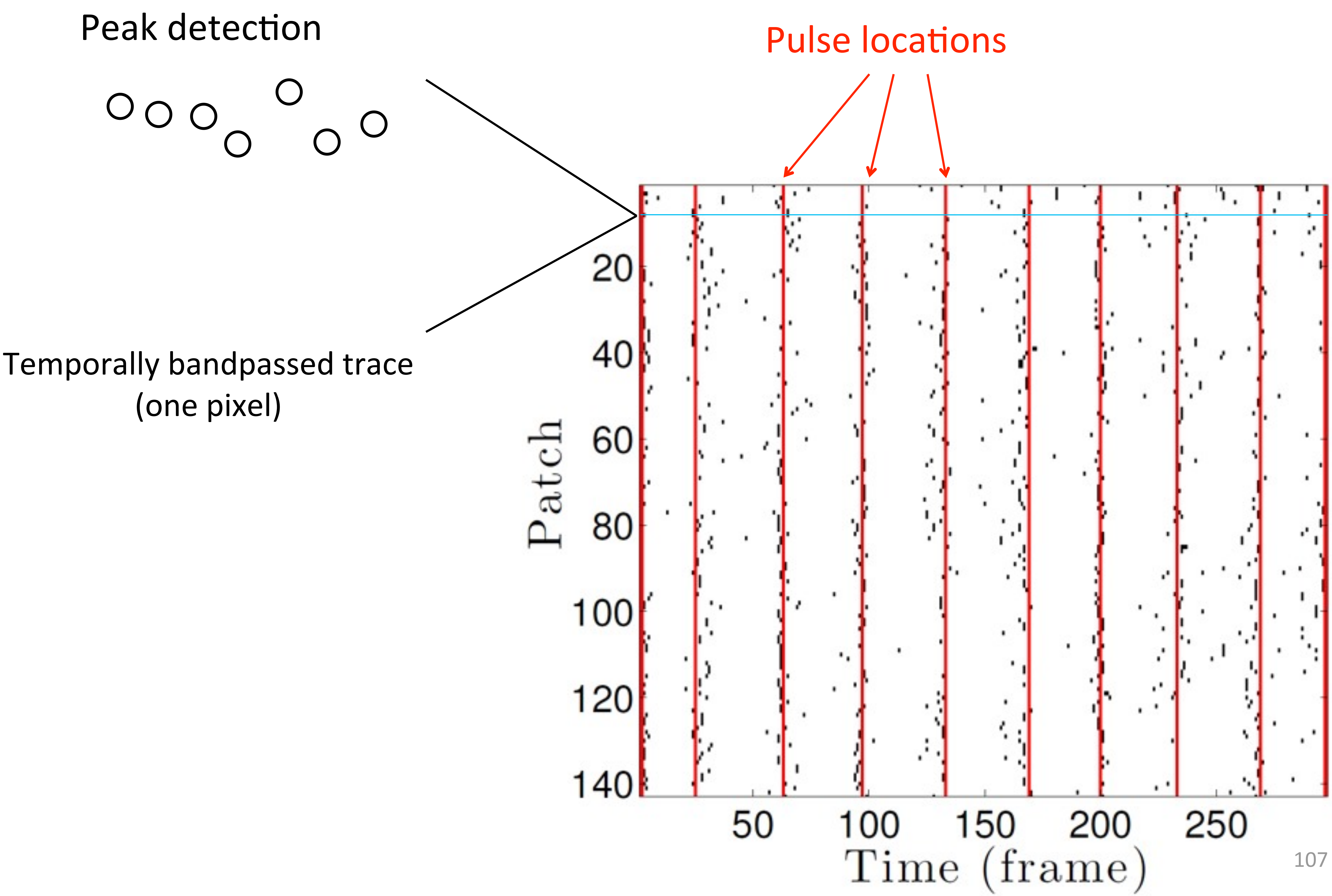
Temporal filter

Color Amplification Results

Source

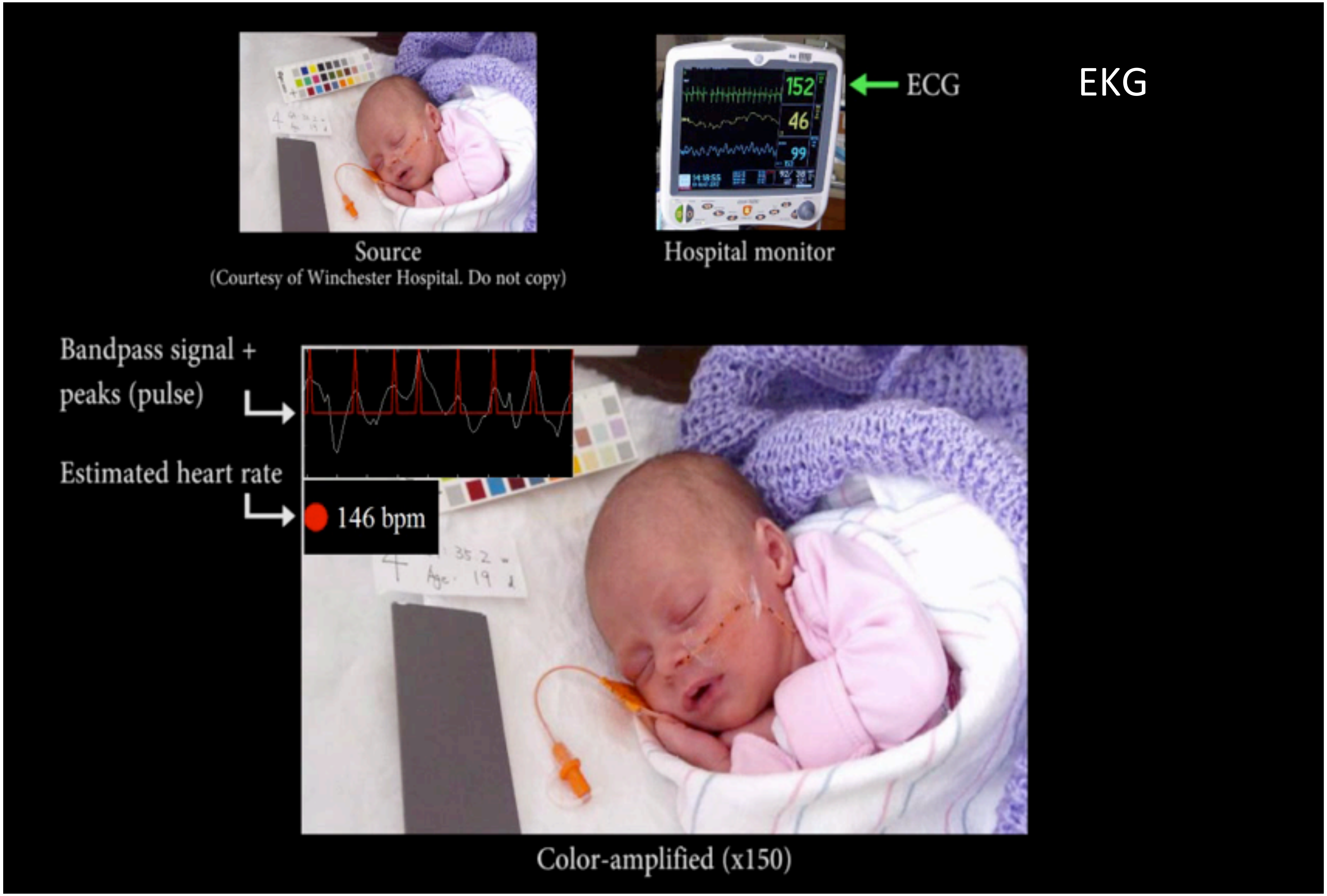
Color-amplified (x100)
0.83-1 Hz (50-60 bpm)

Heart Rate Extraction



Heart Rate Extraction

SIGGRAPH2012



EKG

Thanks to Dr. Donna Brezinski and the Winchester Hospital staff

2.33-2.67 Hz (140-160 bpm)

Overview

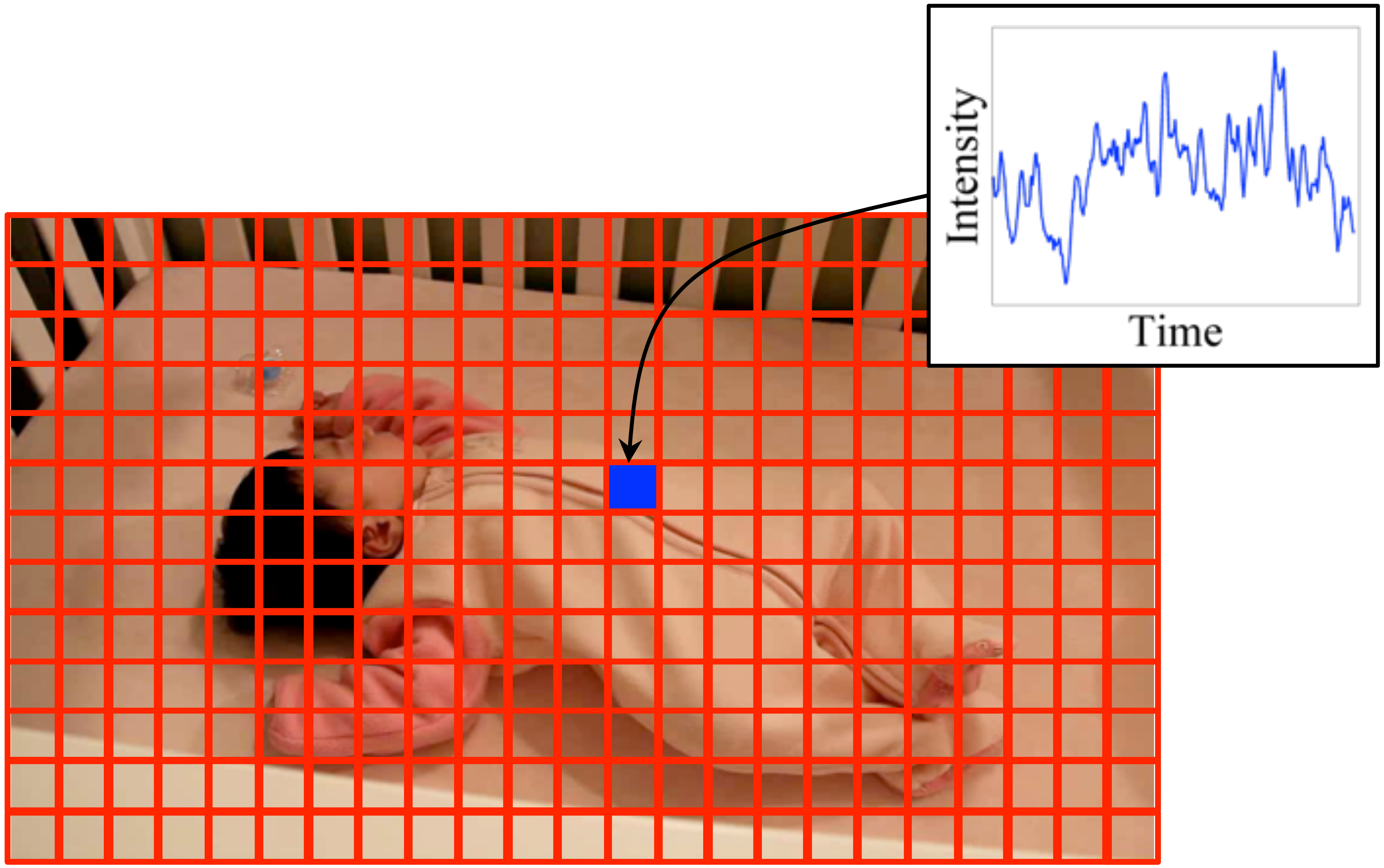
SIGGRAPH2012

- Eulerian video magnification

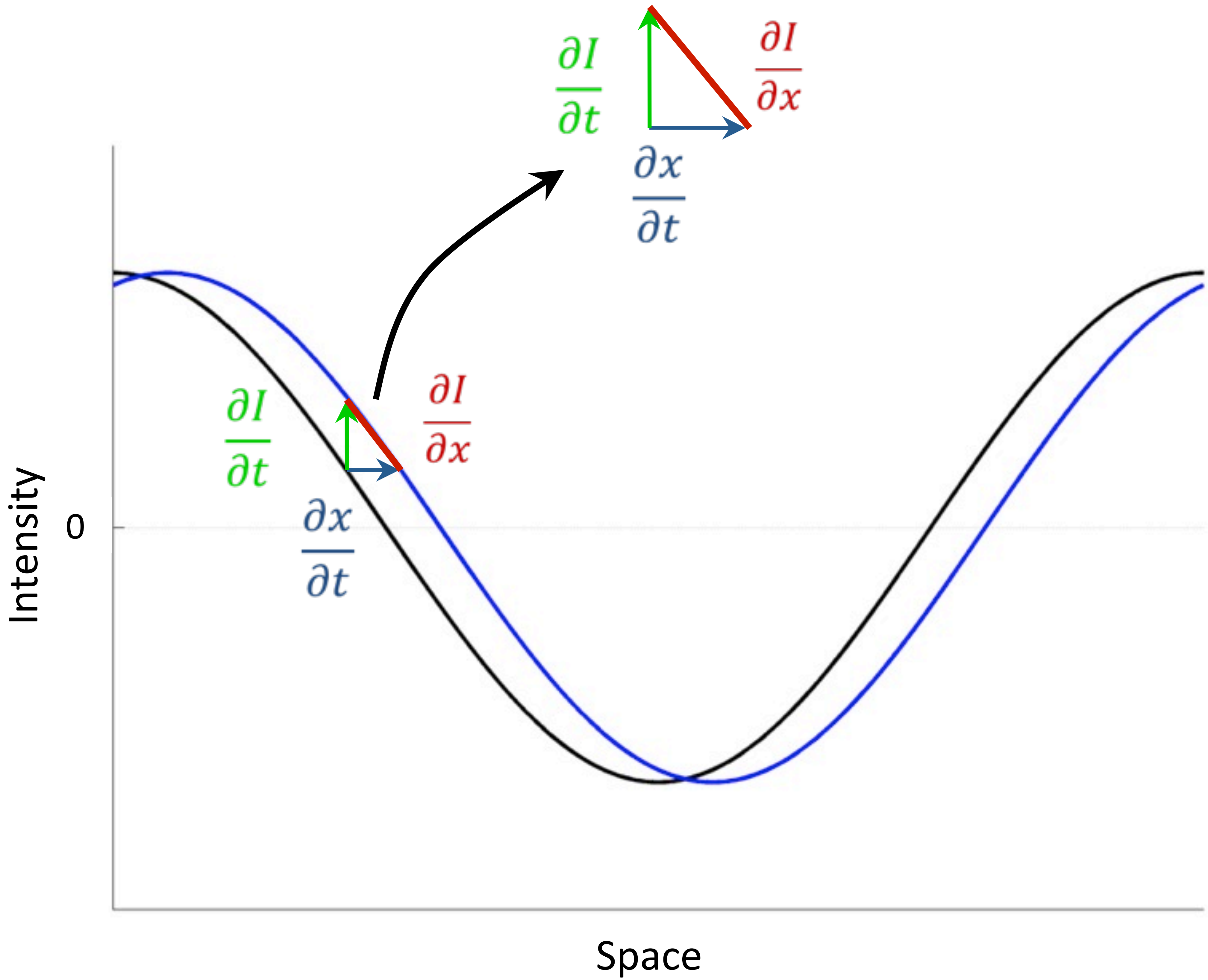
- **Why it amplifies motion**

- Results

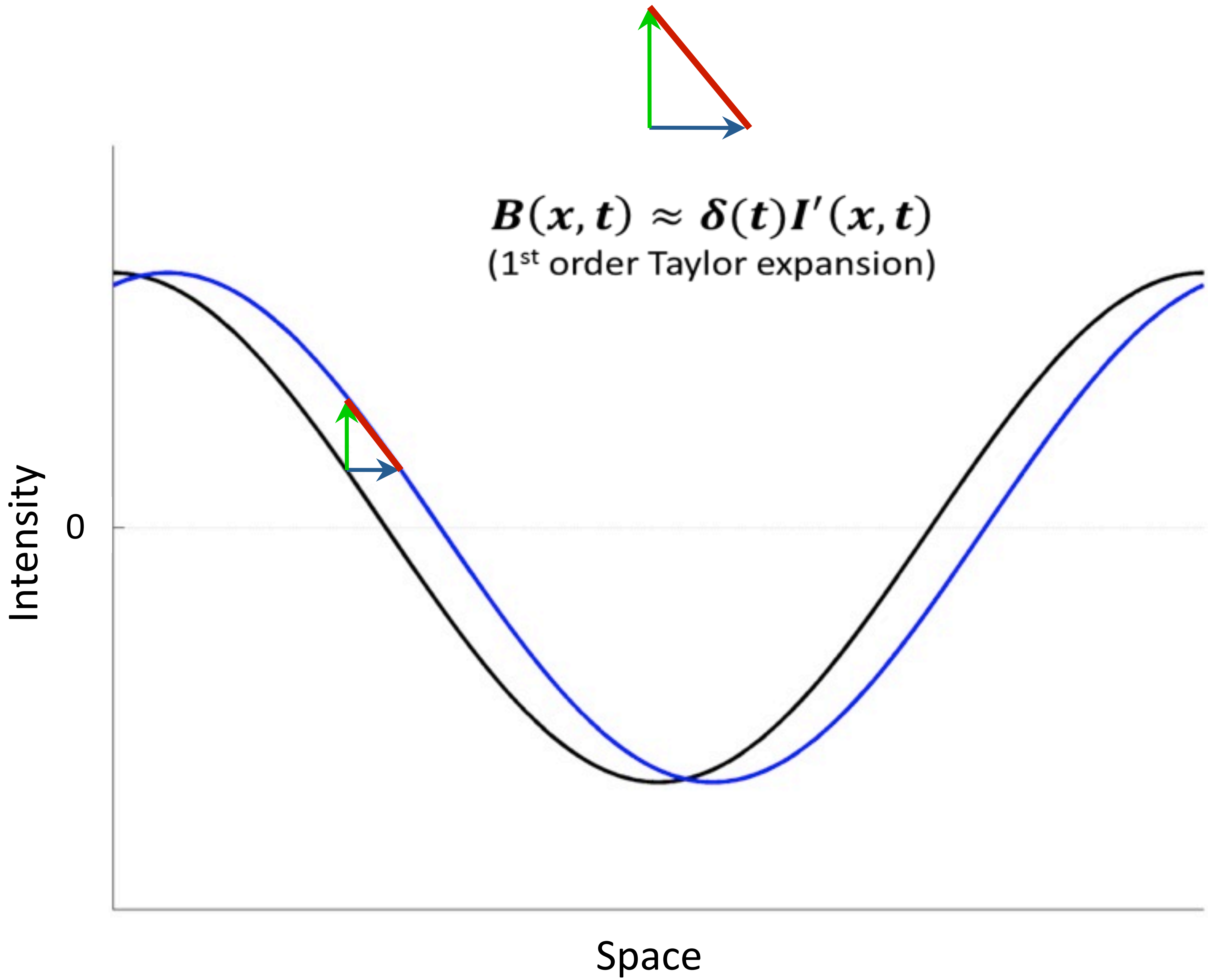
Why It Amplifies Motion



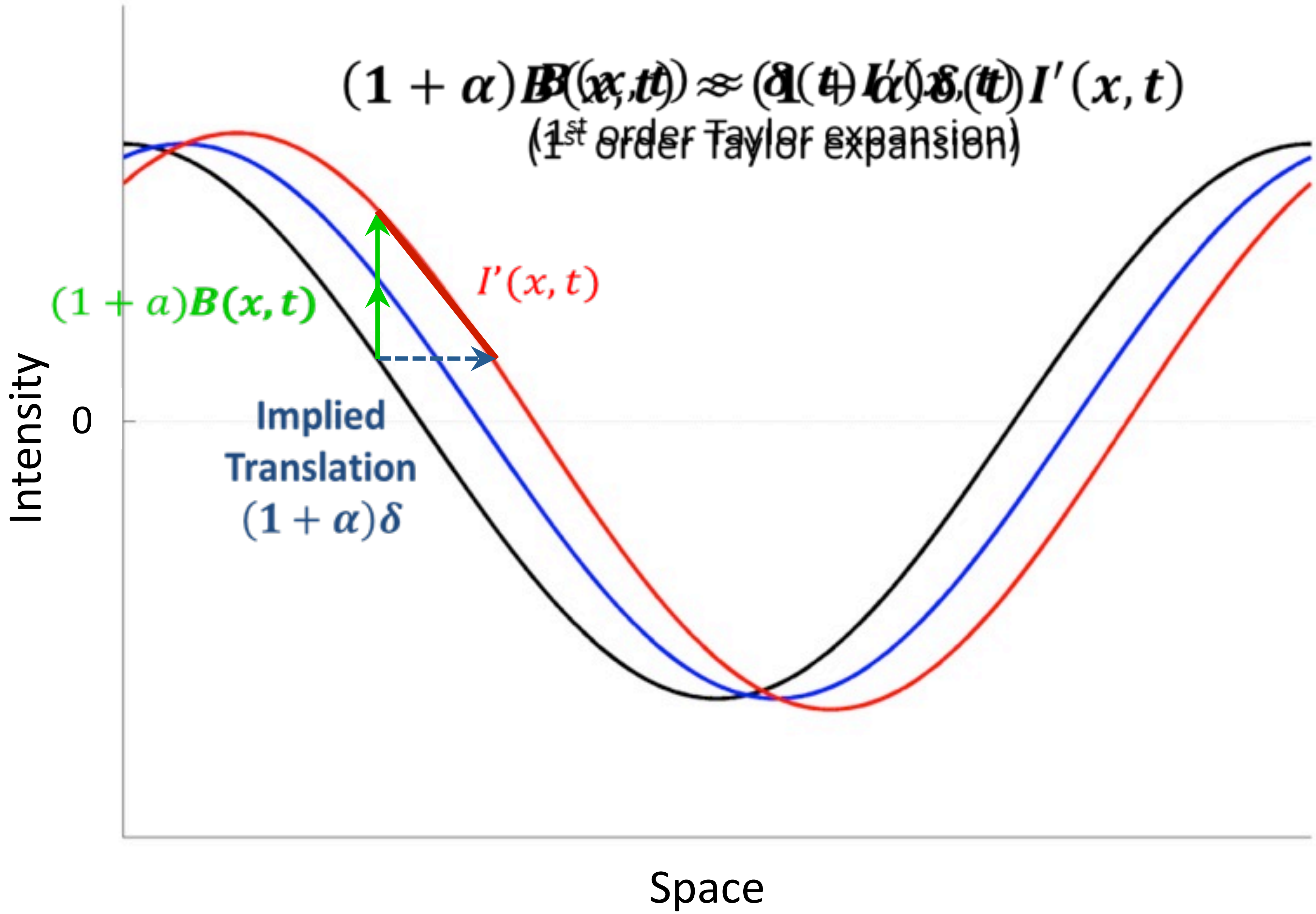
Differential Brightness Constancy



Relating Temporal and Spatial Changes



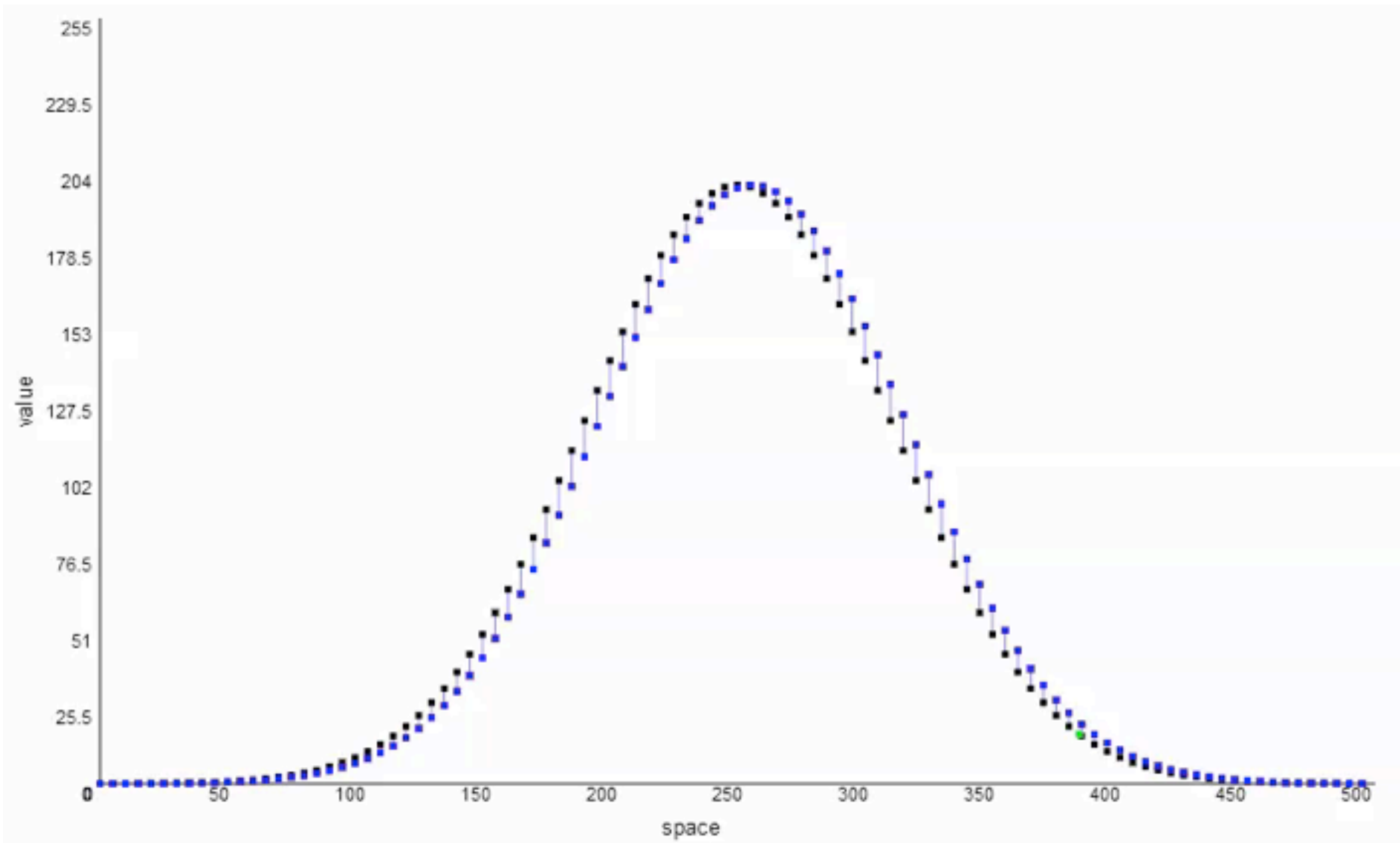
Relating Temporal and Spatial Changes



Relating Temporal and Spatial Changes

SIGGRAPH2012

Motion-magnified



Courtesy of Lili Sun

Overview

- Eulerian video magnification

- Why it amplifies motion

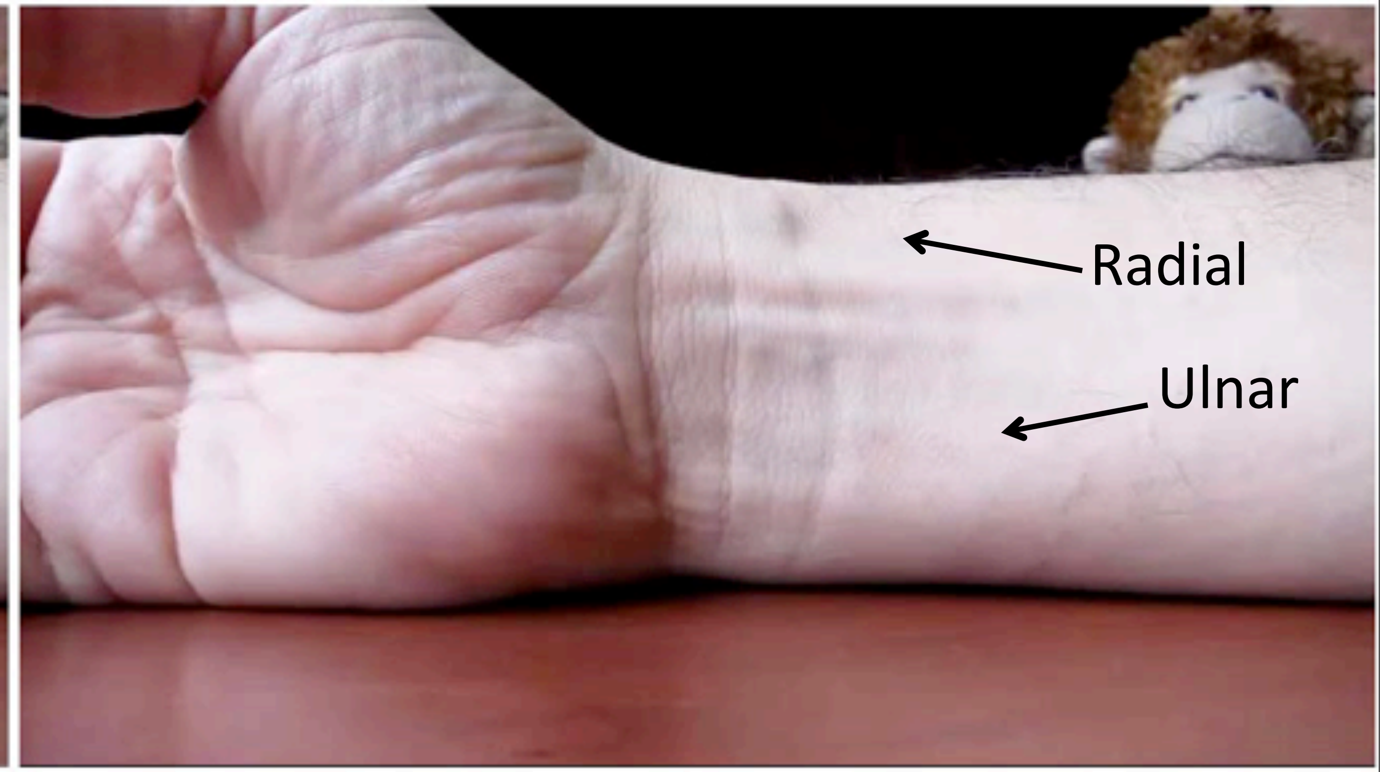
- **Results**

Motion Magnification Results

Source

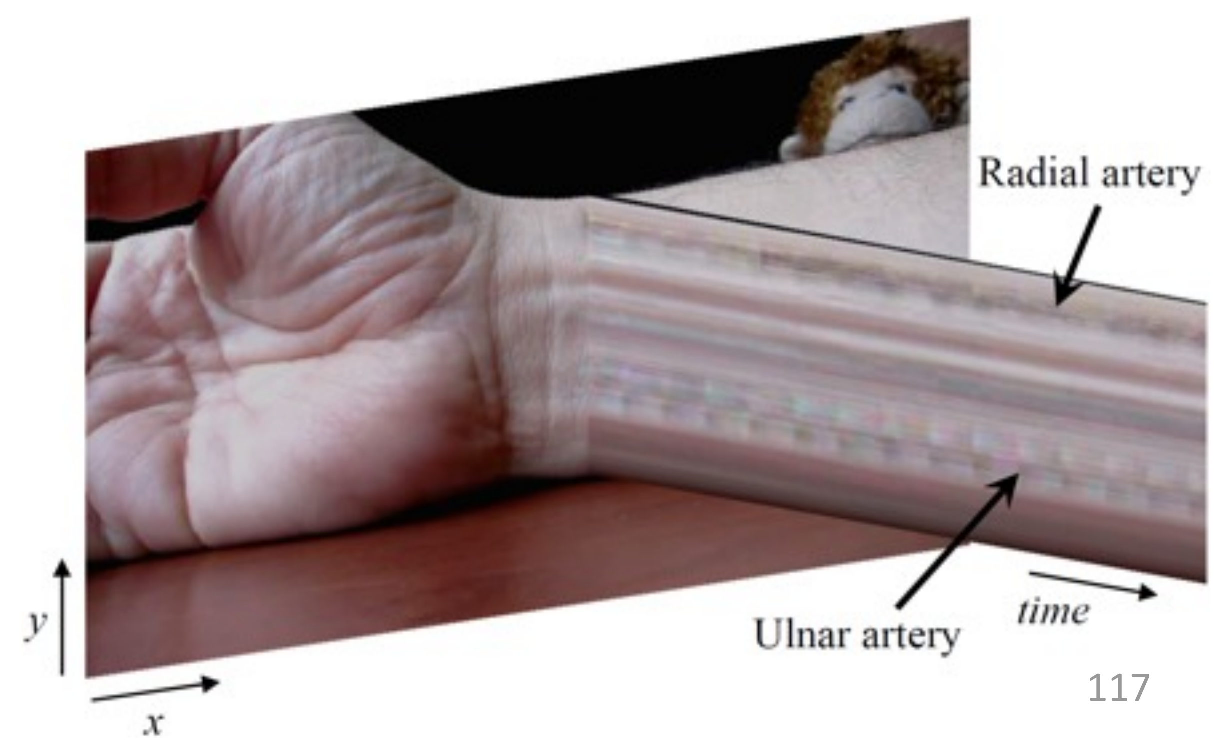
Motion-magnified (0.4-3 Hz, x10)

Motion Magnification



Source

Motion-magnified (0.4-3 Hz, x10)



Selective Motion Magnification in Natural Videos

SIGGRAPH2012

Source
(**600 fps**)

72-92 Hz
Amplified

100-120 Hz
Amplified

← Low E (82.4 Hz)

← A (110 Hz)

Motion and change

- Change



- Fast motion



- Trajectories, video summaries





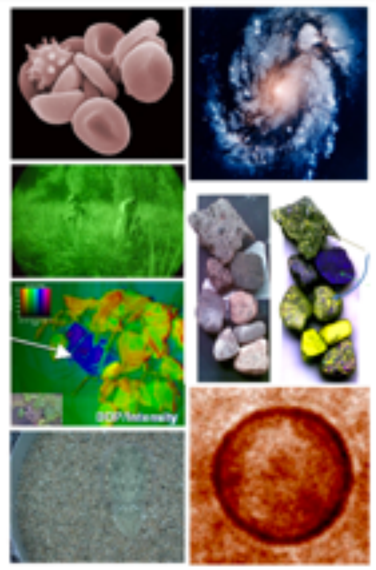

- Reveal small motion




What do you want to reveal?

Recap: Beyond human capabilities

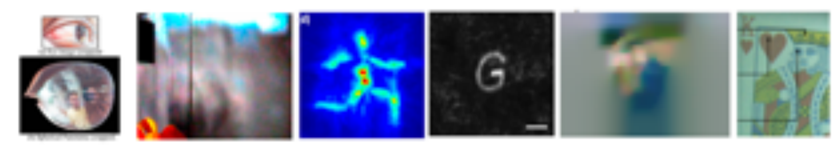
- Too small
- Too far
- Too dark
- Camouflaged
- Not RGB
- Polarized
- Too transparent



Recap: hidden things & occlusion

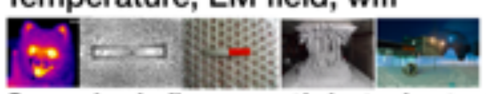
- Seeing inside objects

- Seeing beyond the field of view

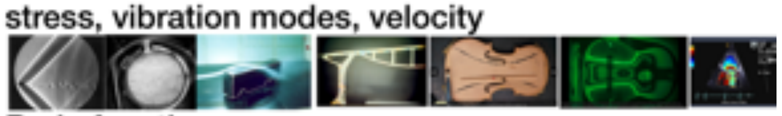


Recap: non visual phenomena

- Temperature, EM field, wifi



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



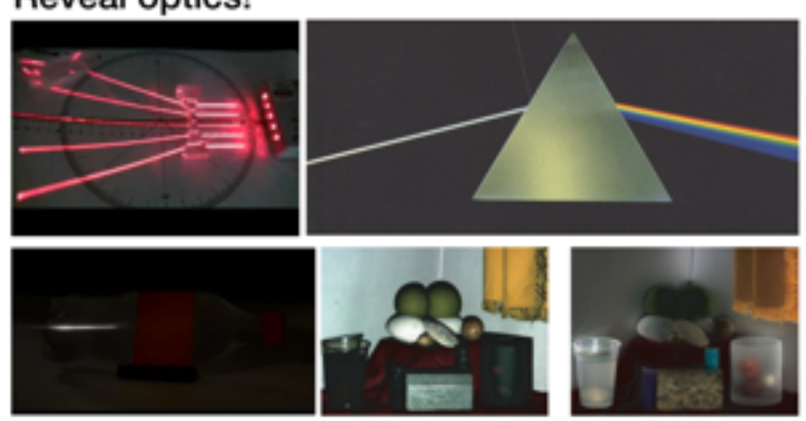
- Brain function

- Augmented reality, spatial AR

- Most sensing is optical!

Recap: non-visible visual

- Reveal optics!

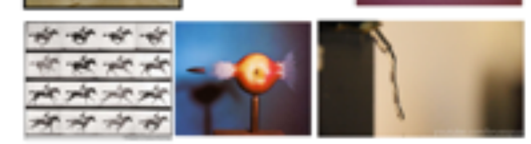


(b) Direct Component (c) Global Component

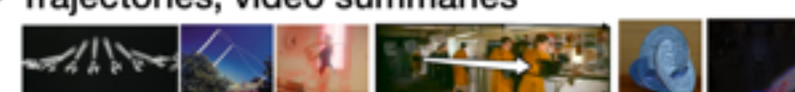
Motion and change

- Change

- Fast motion



- Trajectories, video summaries



- Reveal small motion