DMD-based Compressive Imaging & Spectroscopy

A 1-Pixel Camera & Beyond

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New Acquisition Hardware

- CS changes the rules of the data acquisition game
  - exploits a priori signal/image *sparsity* information

- Same random projections / hardware can be used for *any* compressible signal class (*generic*)

- Simplifies hardware and algorithm design

- Random projections automatically *"encrypted"*

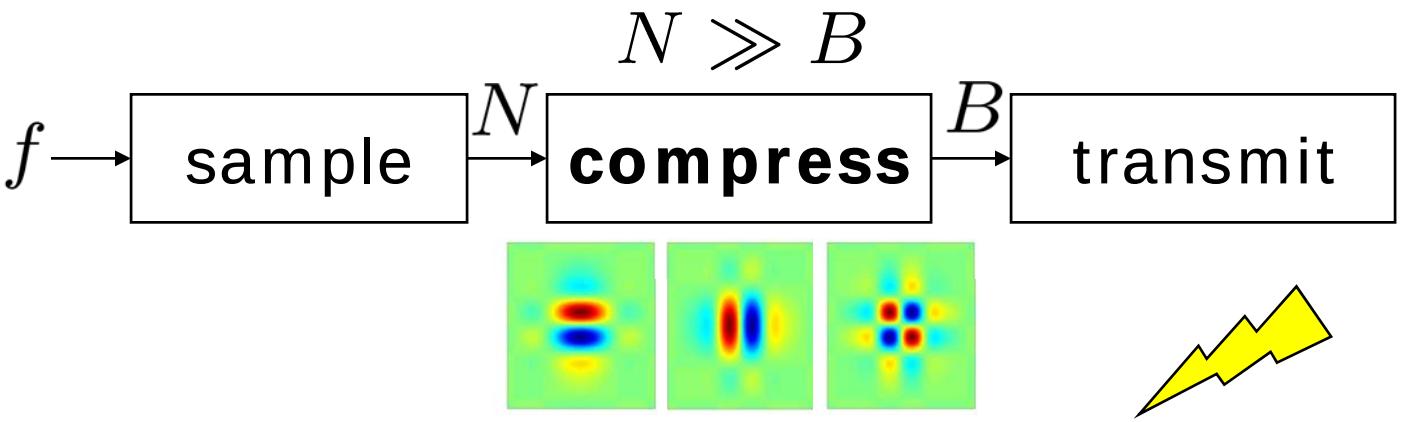
- Very simple encoding

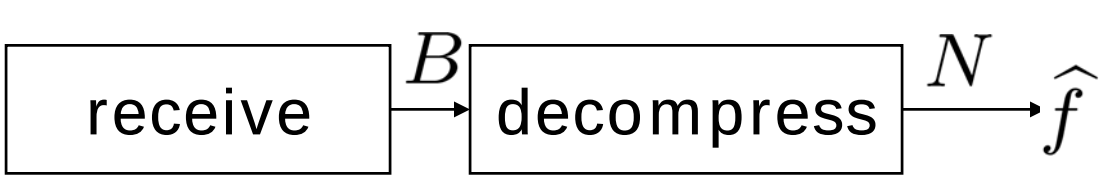
- Robust to measurement loss and quantization

- Asymmetrical processing (most at decoder)

Conventional Sensing

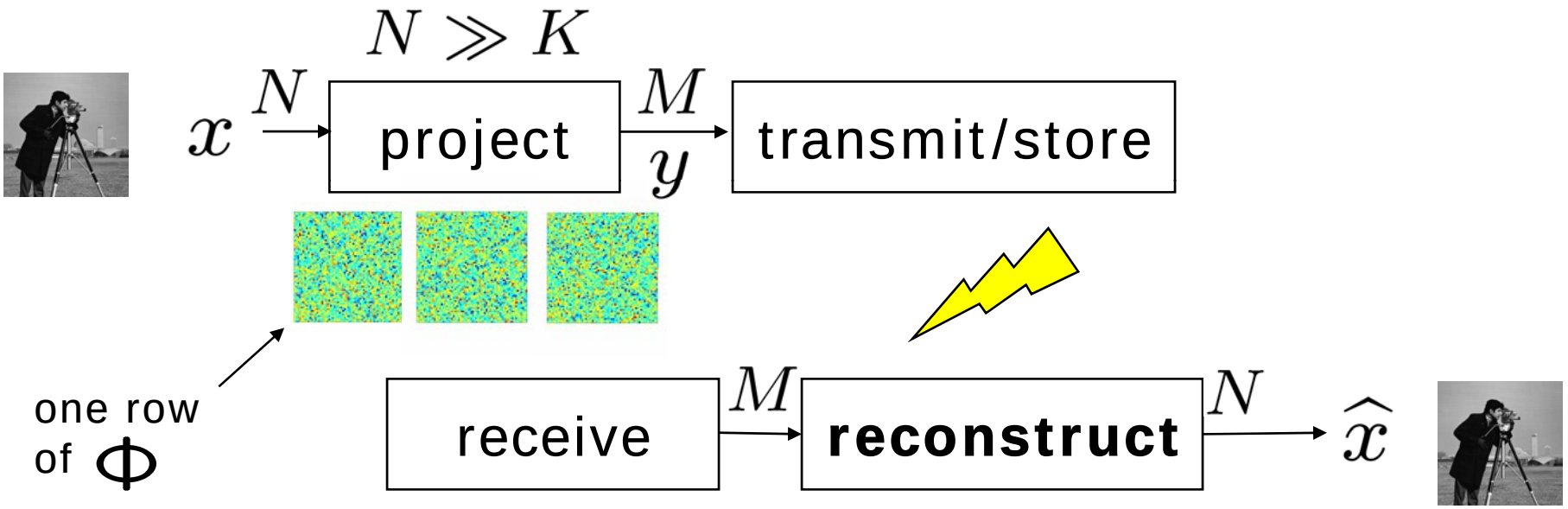
- The typical sensing/compression setup
  - compress = transform, sort coefficients, encode
  - most computation at *sensor* (asymmetrical)





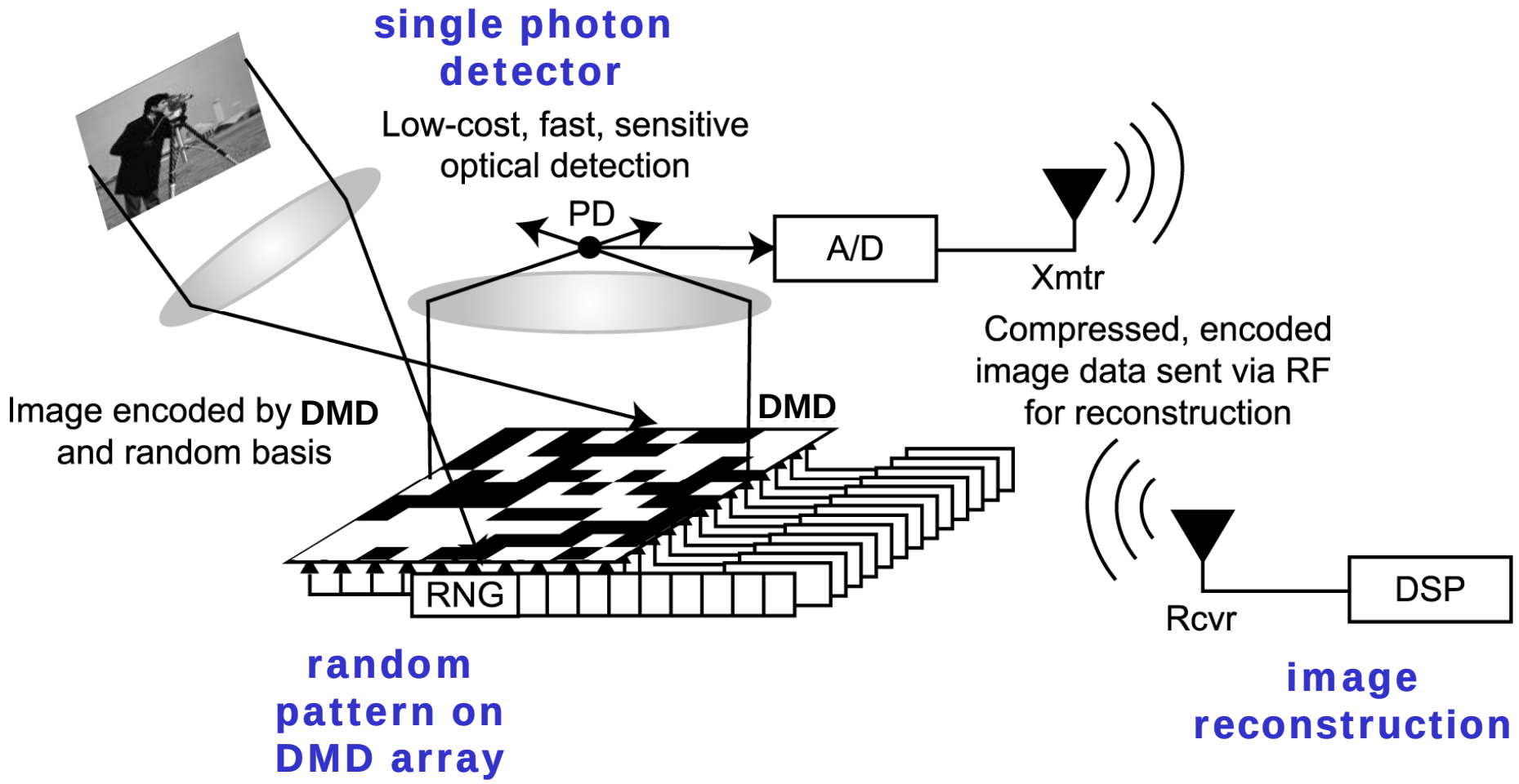
Compressive Sensing

- Measure linear projections onto *random* basis where data is *not sparse/compressible*

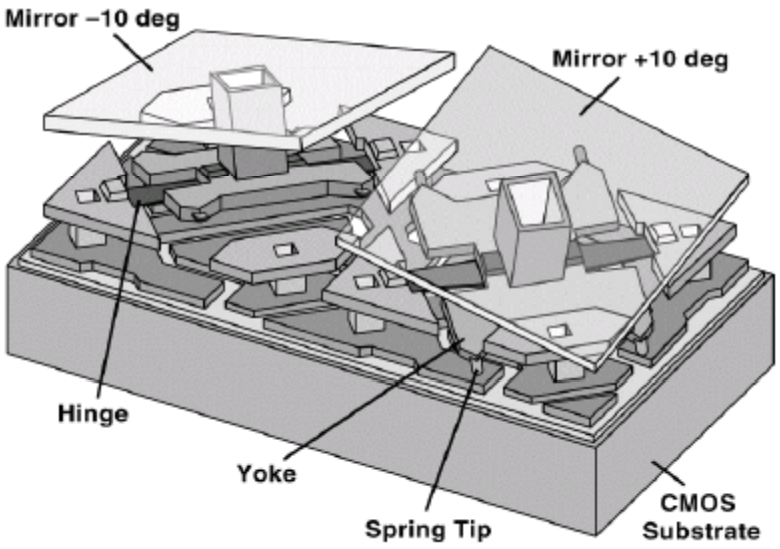


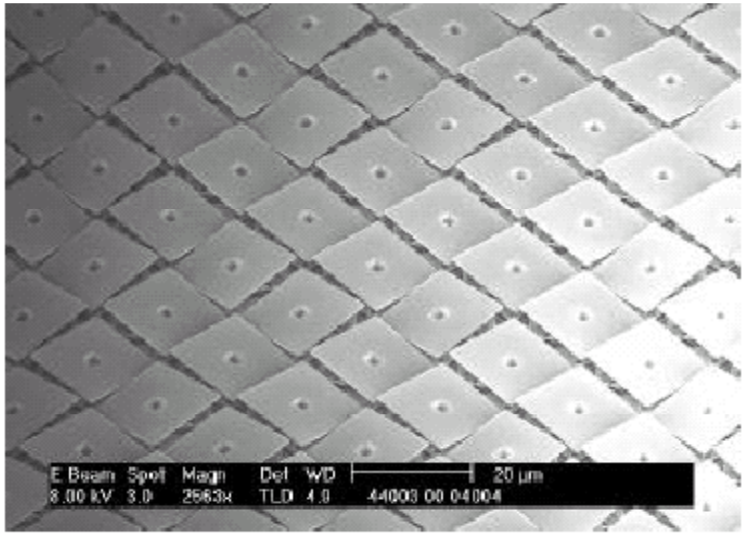
- Reconstruct via *nonlinear processing* (optimization)

Rice 1-Pixel Camera



TI Digital Micromirror Device (DMD)

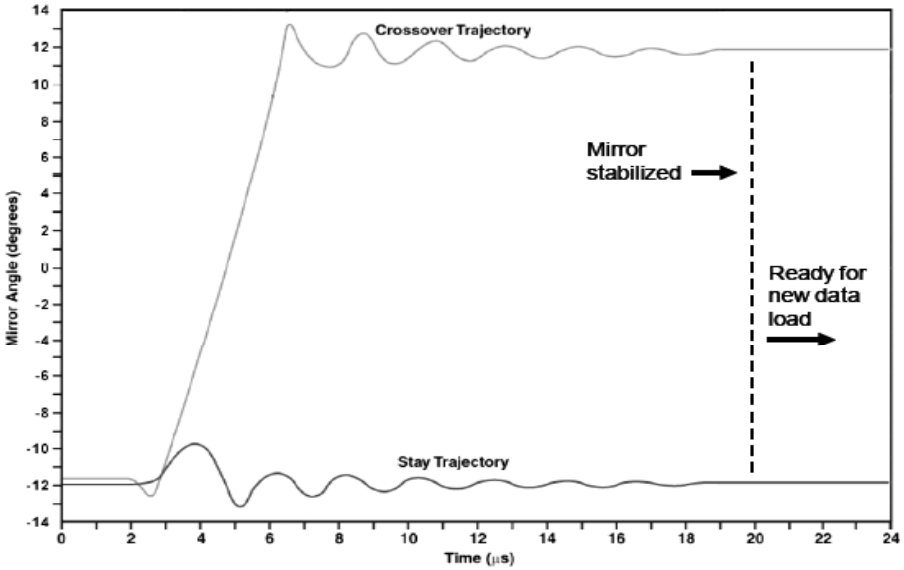




DLP 1080p --> 1920 x 1080 resolution

(Pseudo) Random Optical Projections

- Binary patterns are loaded into mirror array:
  - light reflected towards the lens/photodiode (1)
  - light reflected elsewhere (0)
  - pixel-wise products summed by lens



- Pseudorandom number generator outputs measurement basis vectors ...

Rice CI Camera

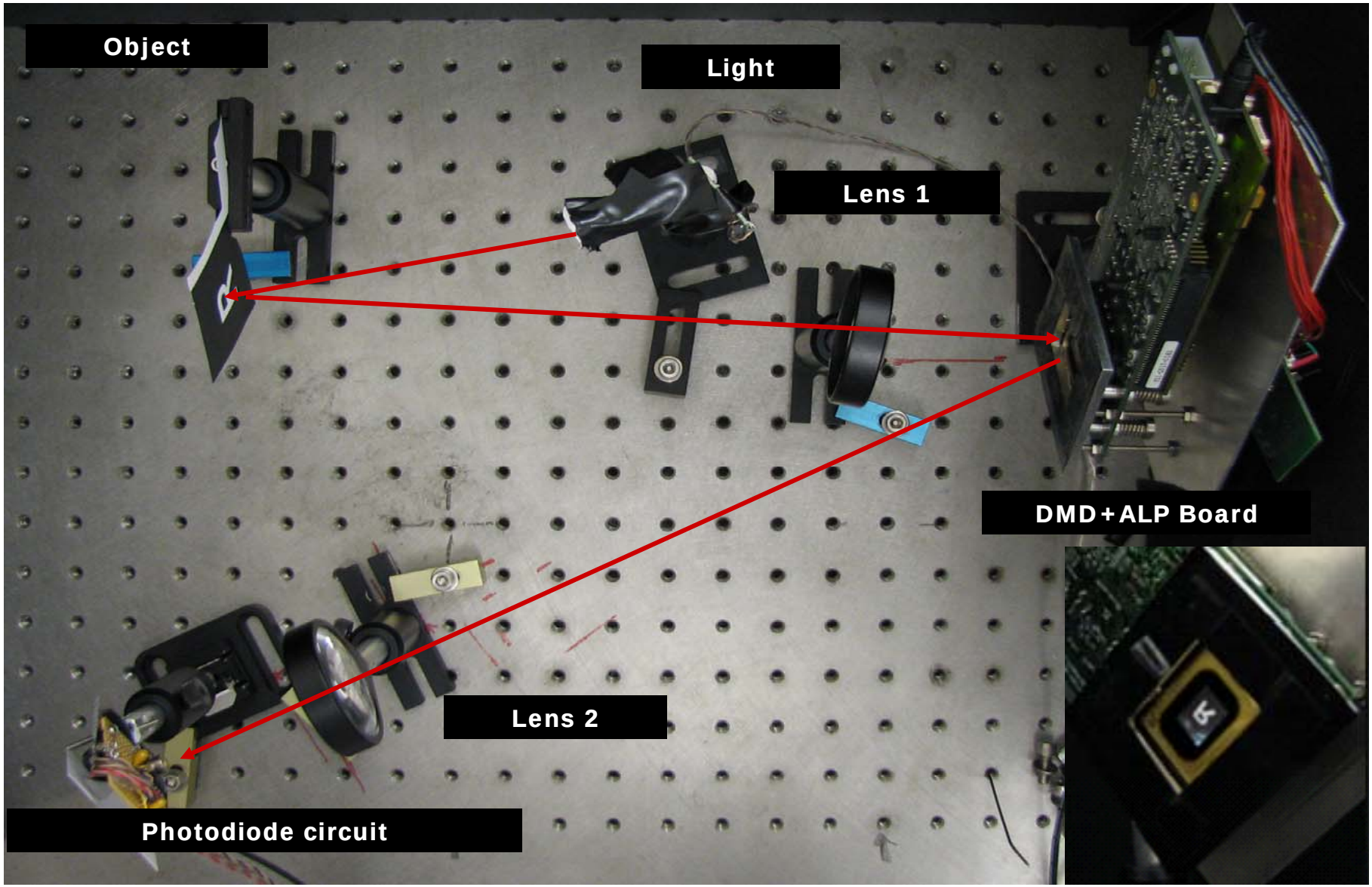


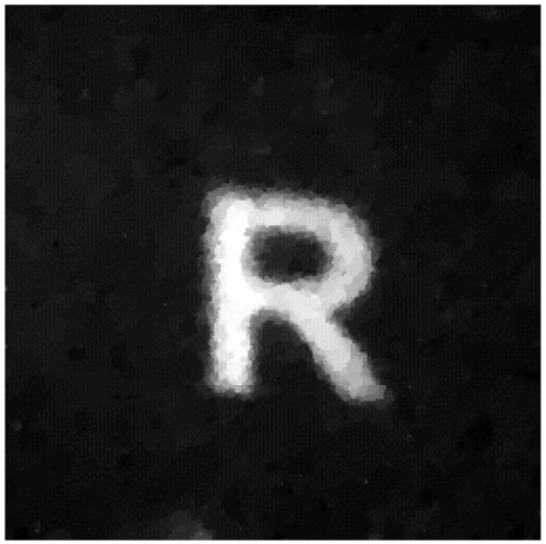
Image Acquisition

Original

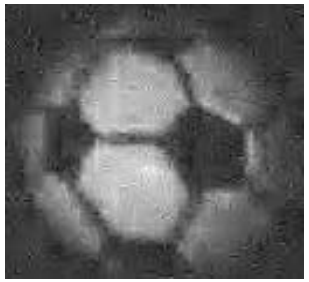
16384 Pixels
1600 Measurements
(10%)

16384 Pixels
3300 Measurements
(20%)

65536 Pixels
1300 Measurements
(2%)



65536 Pixels
3300 Measurements
(5%)



CS Low-Light Imaging with PMT

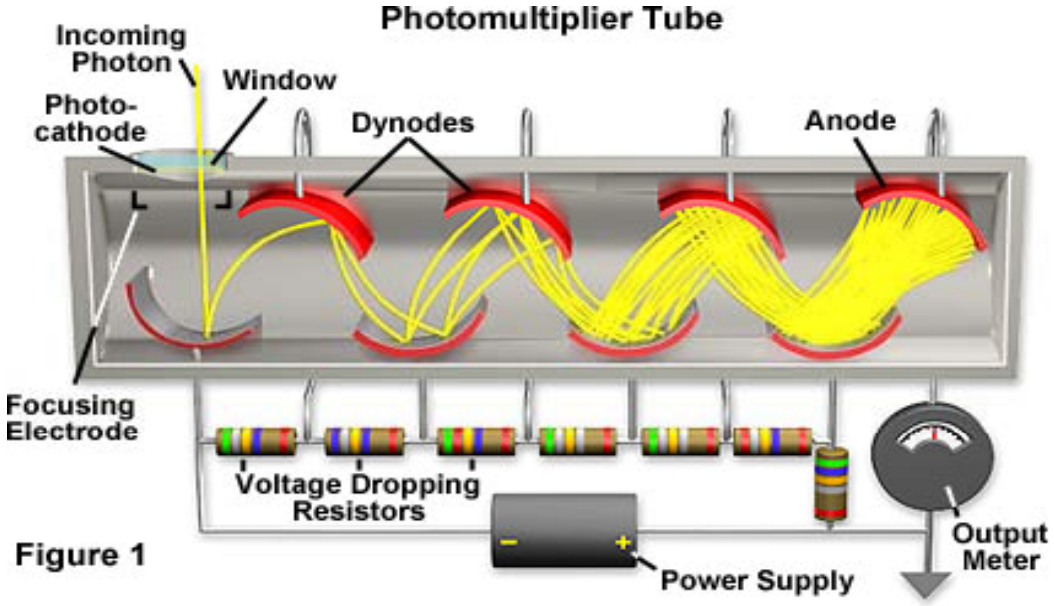
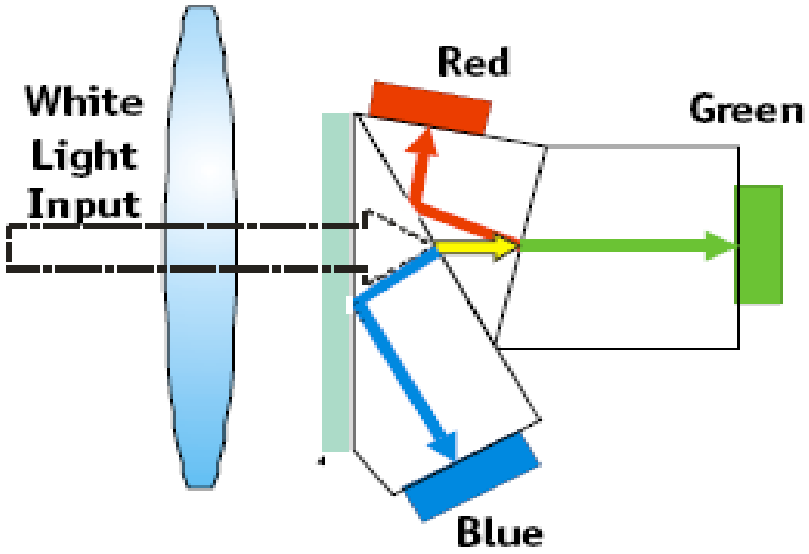


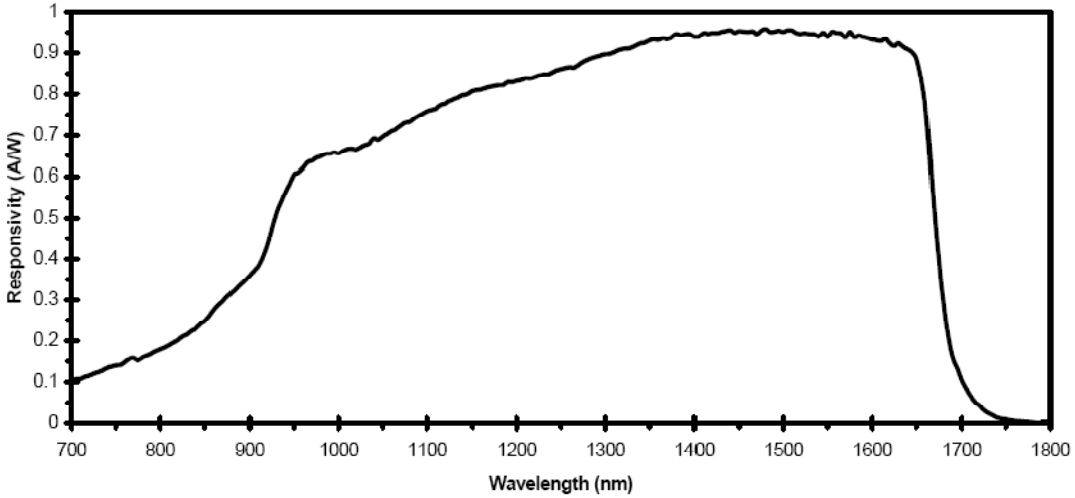
Figure 1

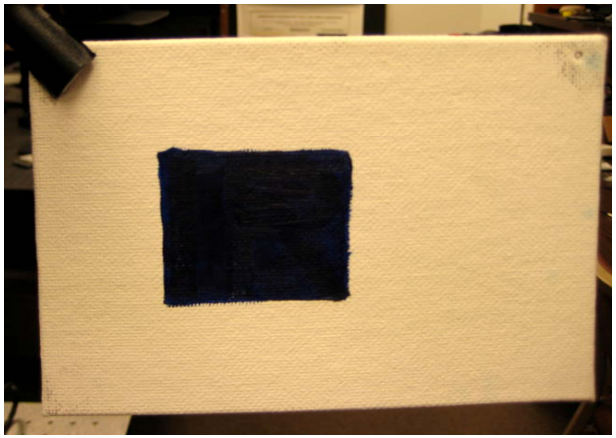


True color low-light imaging:

256 x 256 image with 10:1 compression

CS Imaging in the Infrared



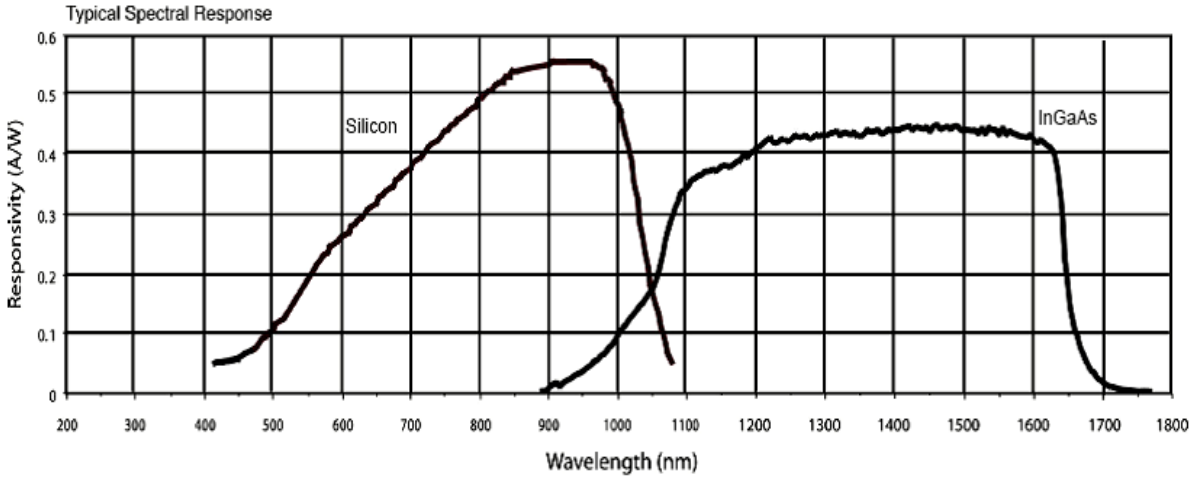


20%

5%

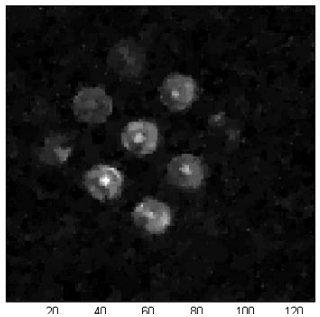
Dual Visible/Infrared Imaging

Detector: commercial dual-band sandwich photodetector with a Si substrate mounted above an InGaAs substrate



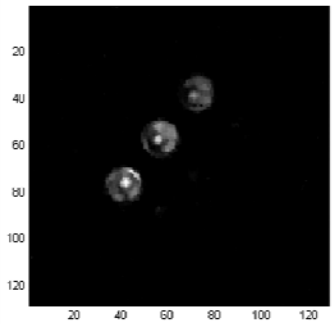
5%

Visible

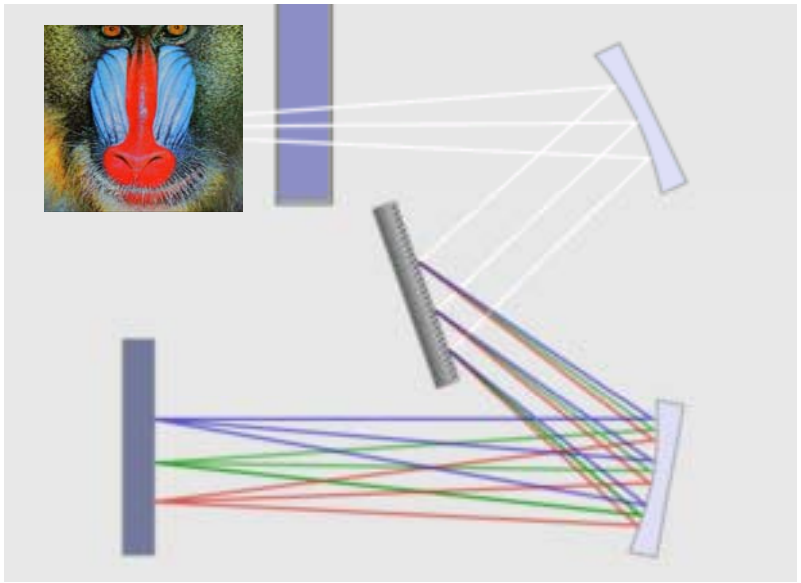


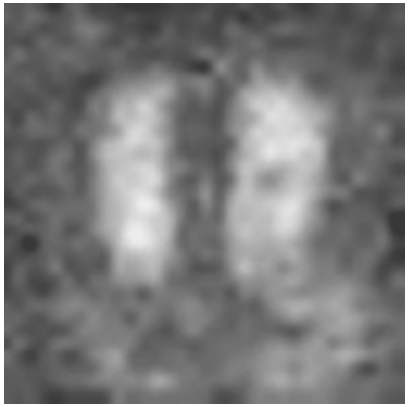
5%

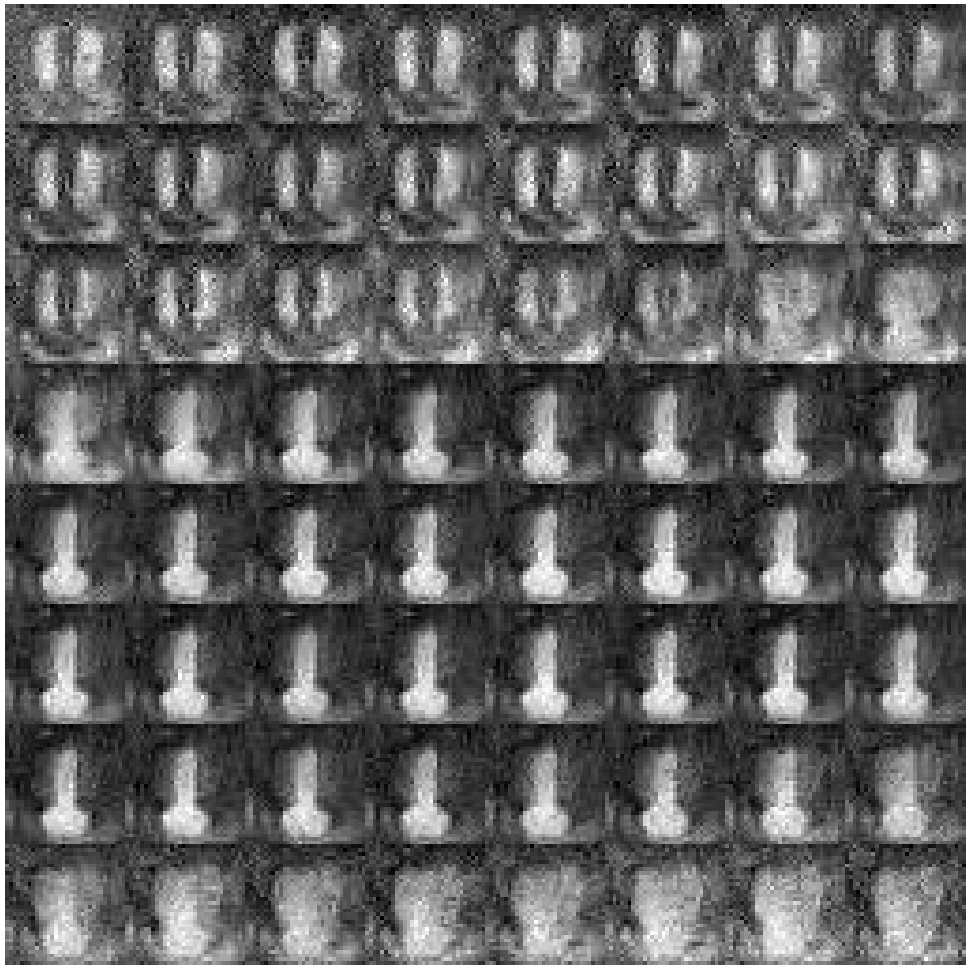
Infrared



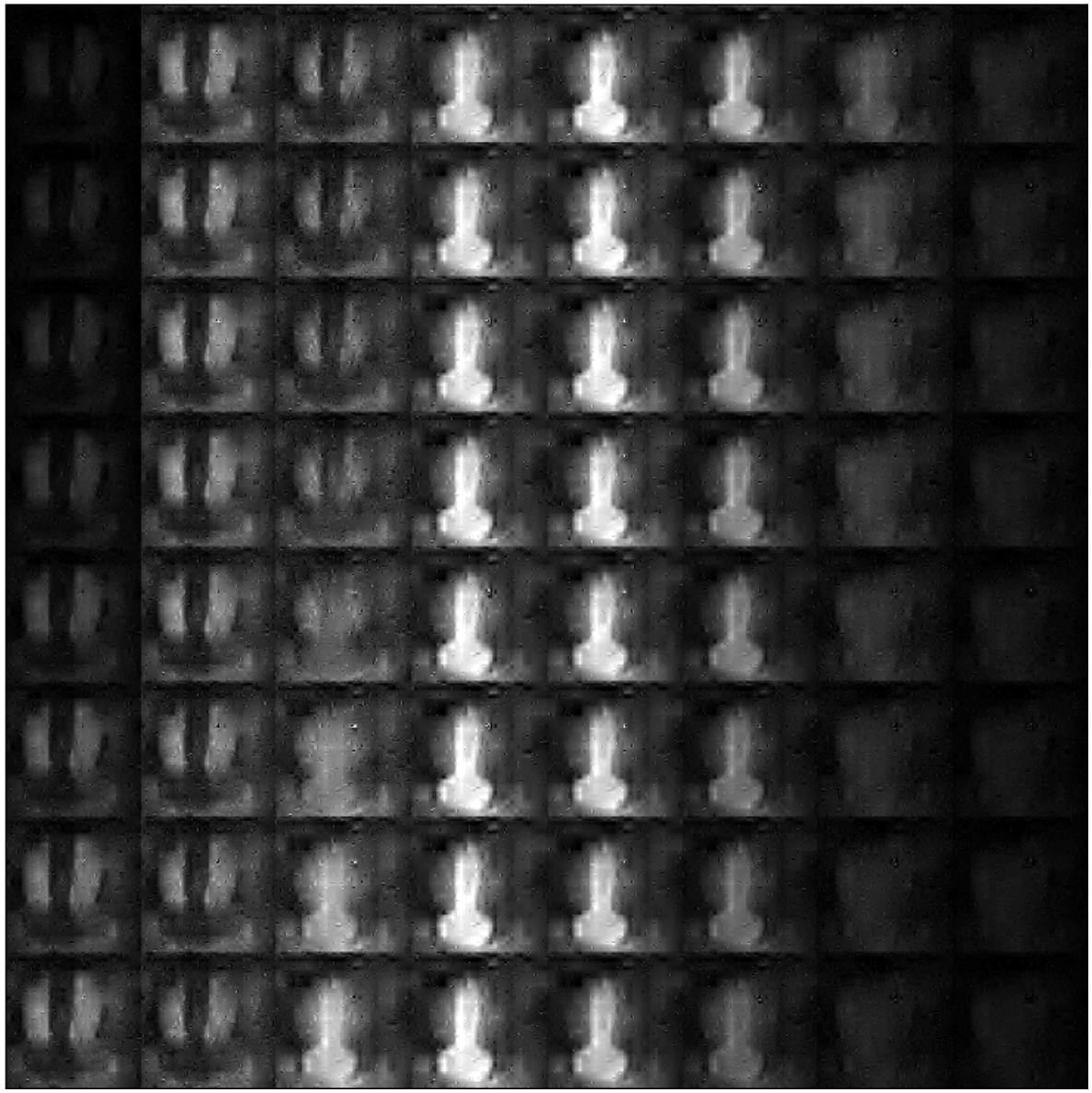
Hyperspectral Mandrill 32x32x64



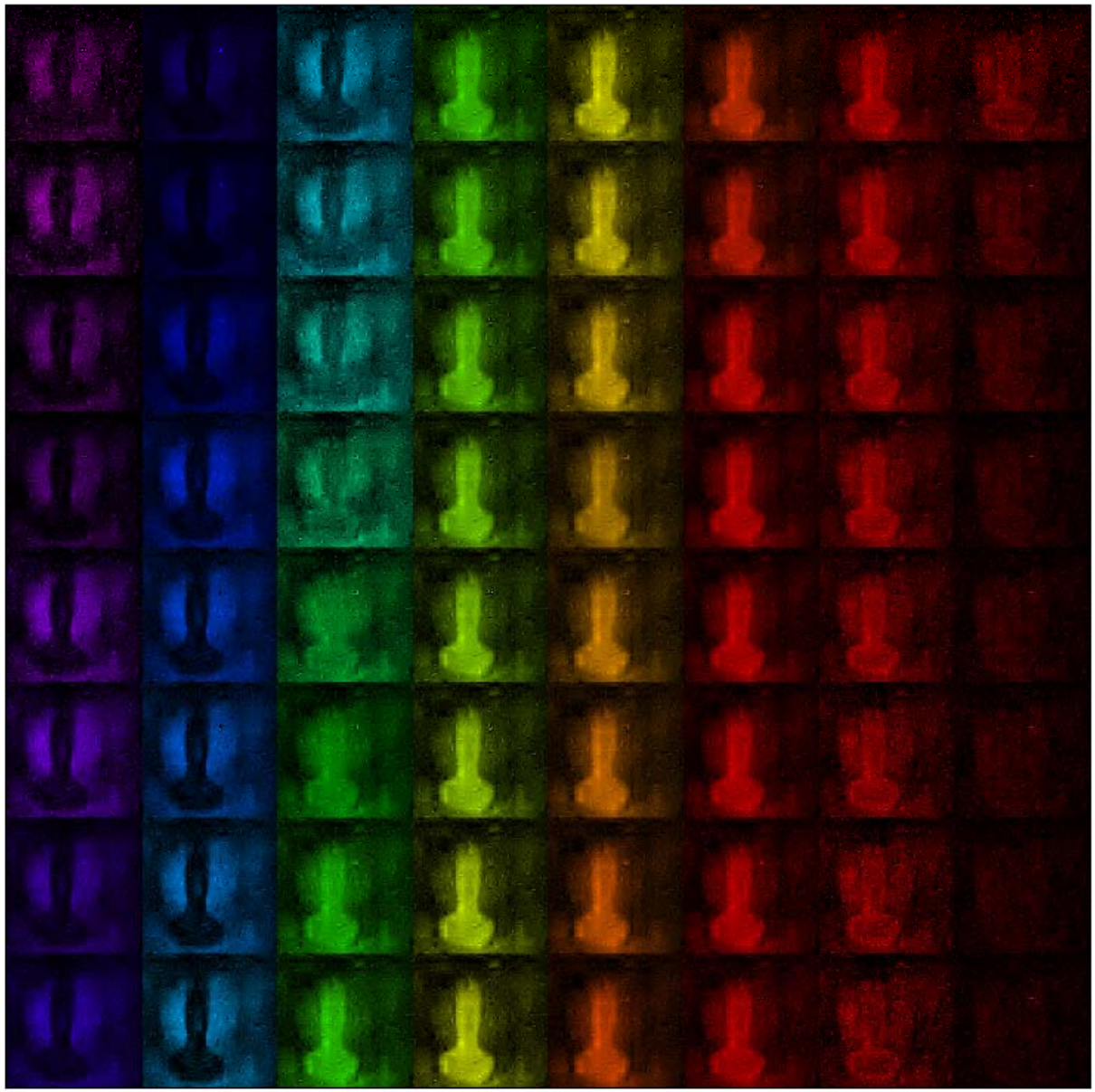




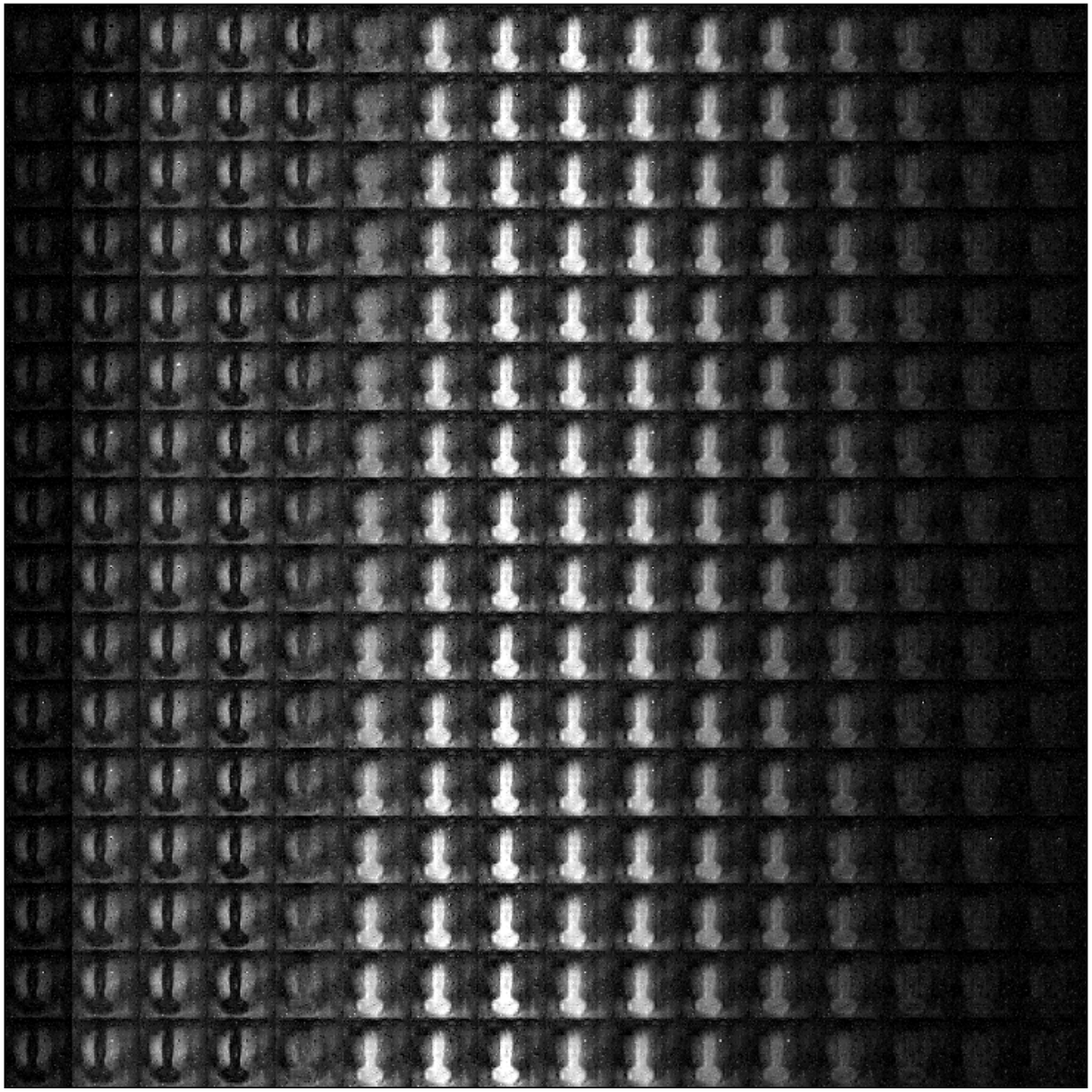
independent reconstruction of each band



joint reconstruction with a spatial wavelet / spectral Fourier tensor product sparsity basis

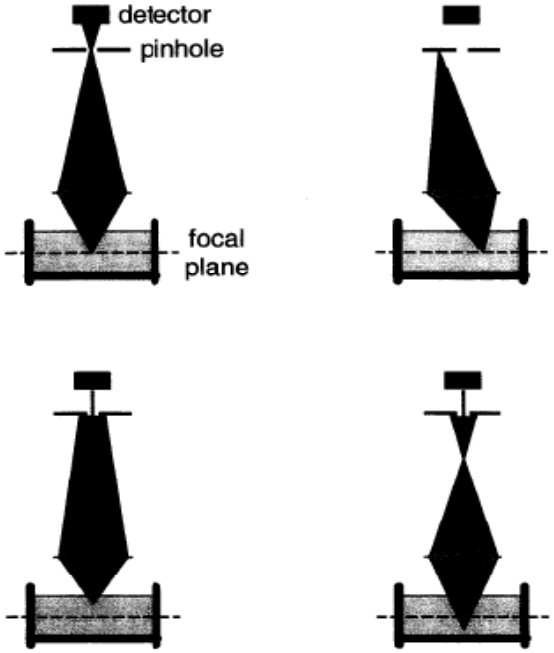


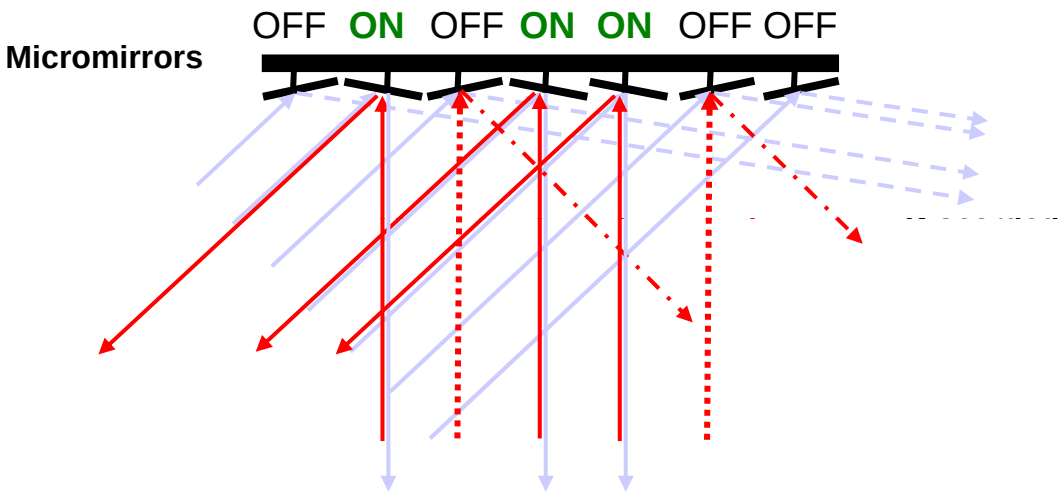
joint reconstruction with a spatial wavelet / spectral Fourier tensor product sparsity basis



CS Confocal Microscopy

An imaging technique used to increase contrast and/or to reconstruct 3-D images by using a pinhole to eliminate out-of-focus light

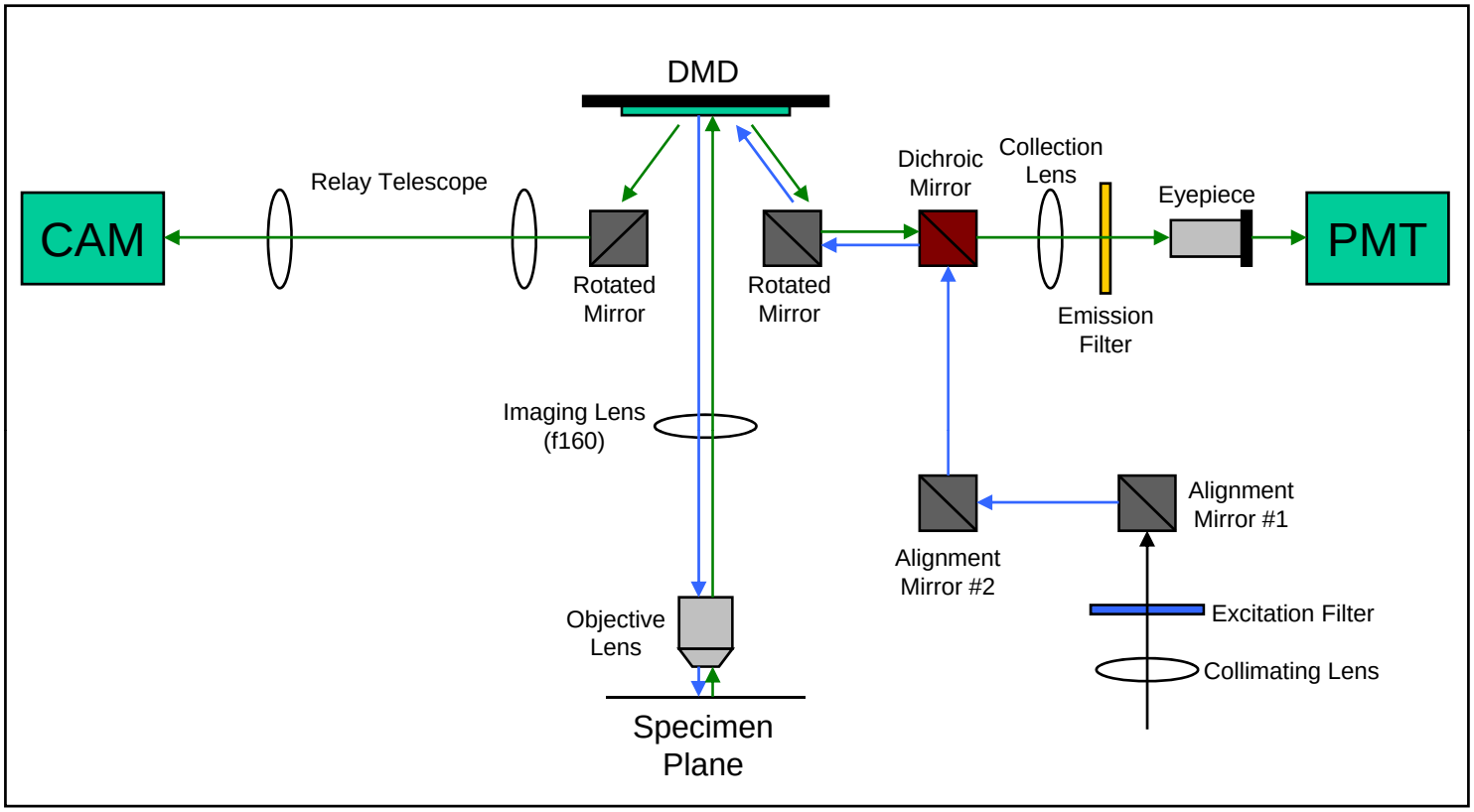


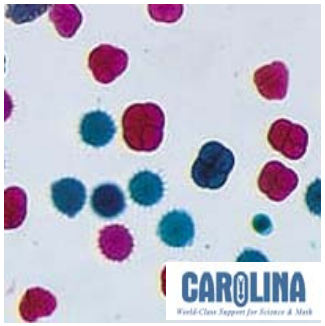


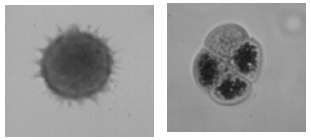
Compressive Sensing vs. Traditional Raster Scan

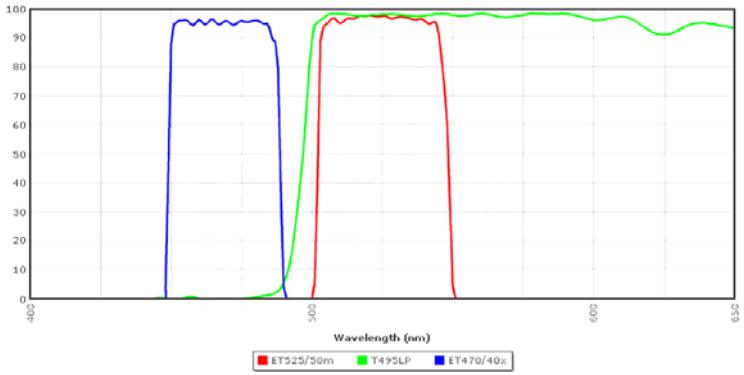
- **50% of the illumination used in the CS measurement compared to less than 1% used in a raster measurement**
- **Additionally, CS will make far fewer measurements but will still obtain the same size final image**

DMD-based CS Microscope Layout

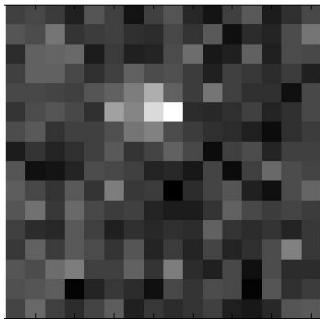




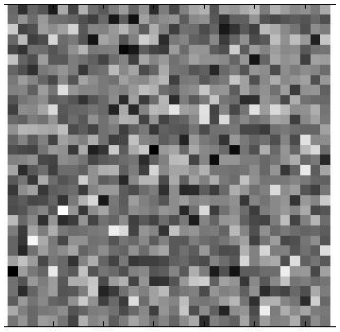




CS Fluorescence Microscopy



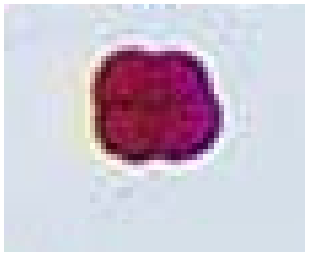
16 x 16 raster
(Gain: 2e6)

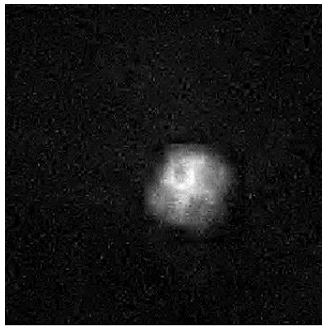


32 x 32 raster

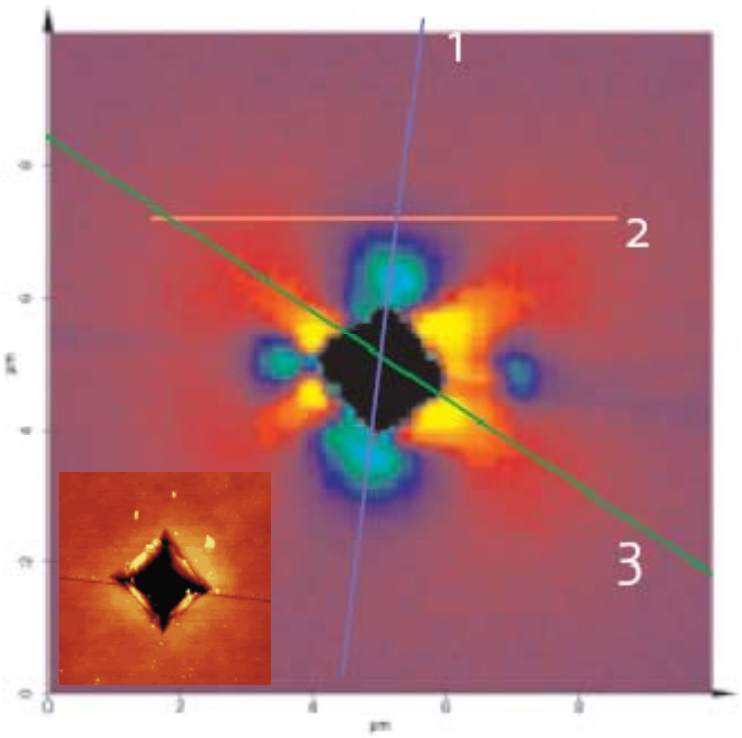
128 x 128 CS
1600 measurements
(Gain: 6e5)

- **Using the raster scan, the signal quickly drops below our detection limit.**
- **Compressive sensing we can obtain a high resolution even with decreased detector gain and without the threat of photobleaching.**





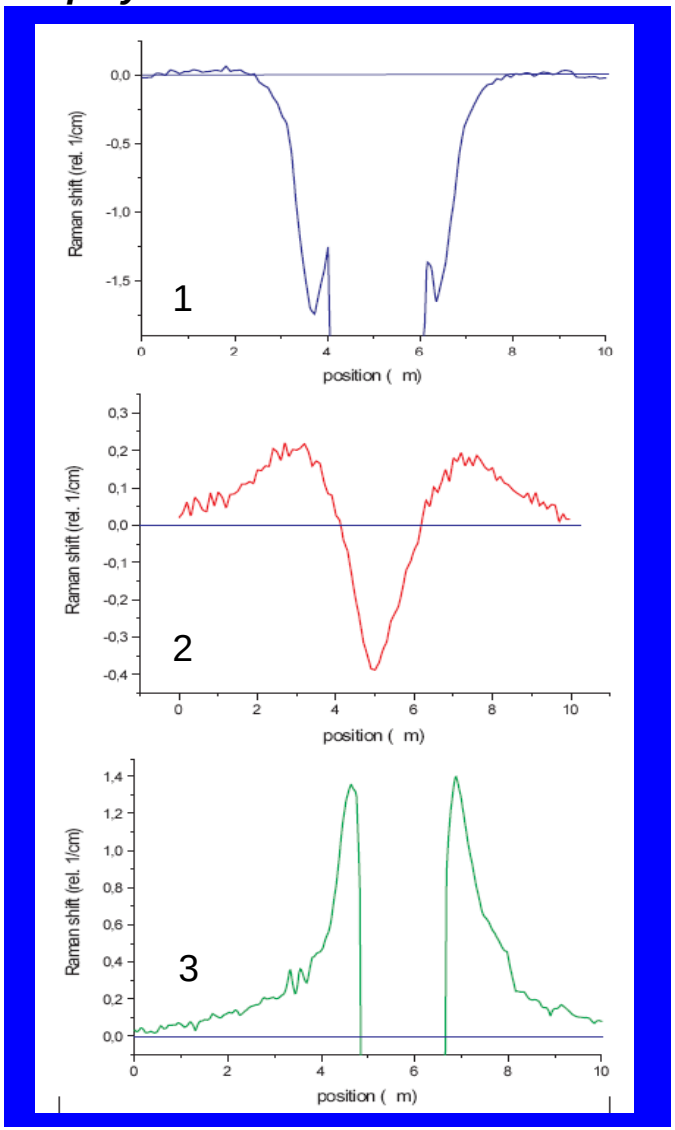
Confocal Measurement of Stress in Silicon



Confocal Raman image of a Vickers indent into silicon (10 x 10 μm). The image was calculated by determining the peak position of the Si-Raman line of each measured spectrum. Inset is the corresponding AFM image. (Data courtesy of Witec Instruments Gmbh.)

U. Schmidt et al., *Vibrational Spectroscopy* 42, 93 (2006).

Three cross-sections are marked in the stress image on the left and displayed below.



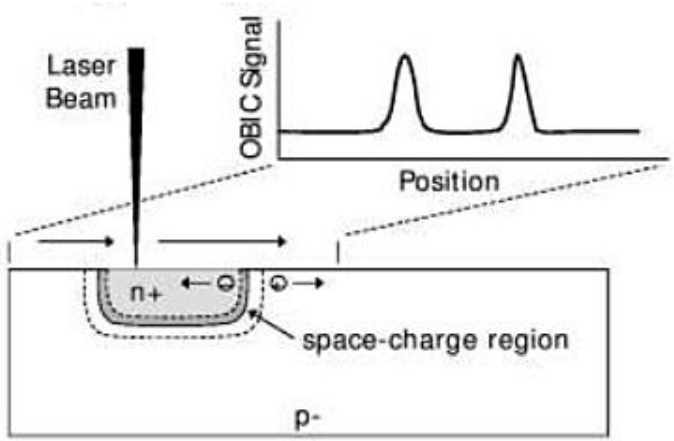
Optical Beam Induced Current Imaging

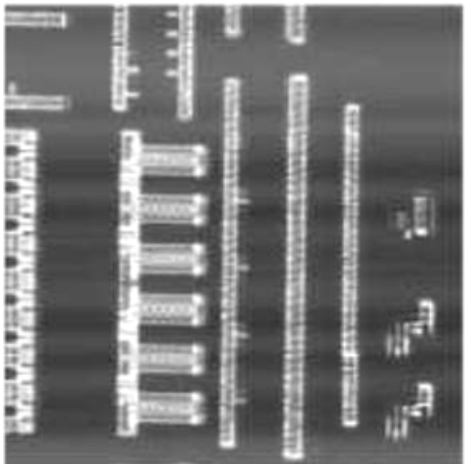
1. OBIC Theory

- failure analysis to locate electrically active defects such as diffusion, stacking faults, latch-up and leakage in integrated circuits (IC)

- monitor the nonrandom recombination current of the electron-hole pairs generated by a laser as it is scanned across the chip surface.

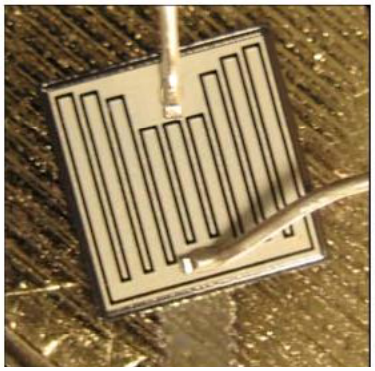
- variations in currents are converted into variations in contrast to form the OBIC image

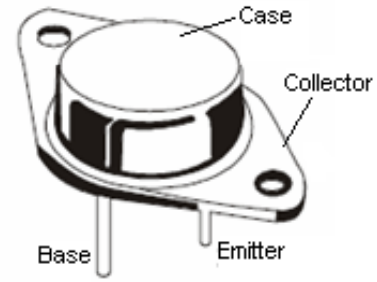


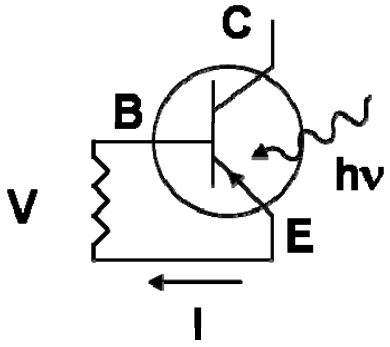


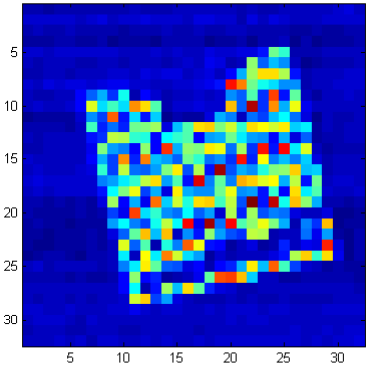
Optical Beam Induced Current Imaging

Target: NTE68 (PNP) is a complementary silicon power transistor designed for high power audio, disk head positioners

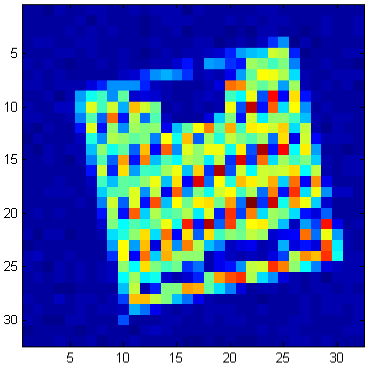




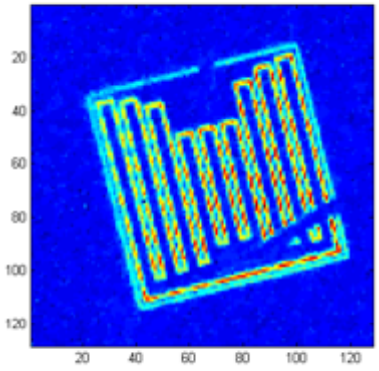




32 x 32 Raster

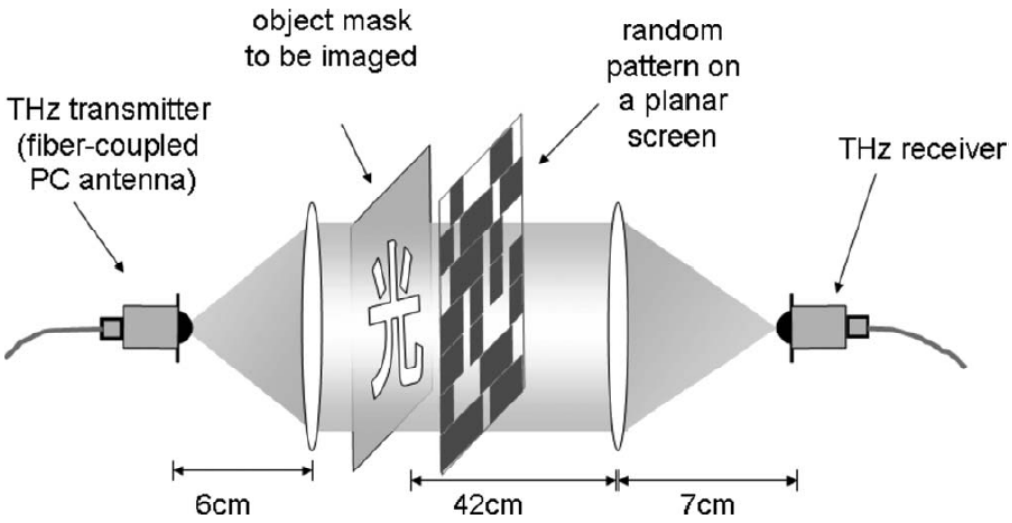


32 x 32 CS

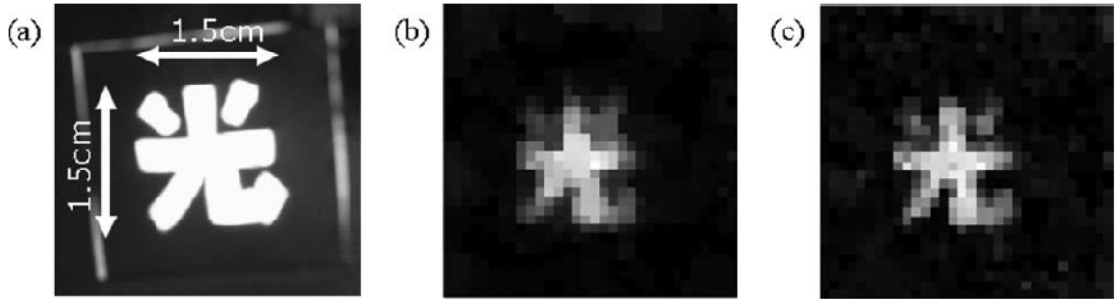


128 x 128 CS

CS THz Camera

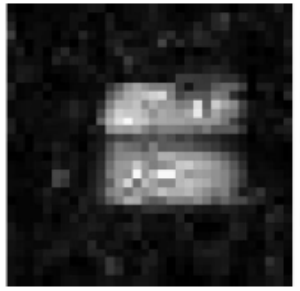


32 x 32 PCB masks



Object mask **CS recon 300 measurements** **CS recon 600 measurements**

THz Amplitude

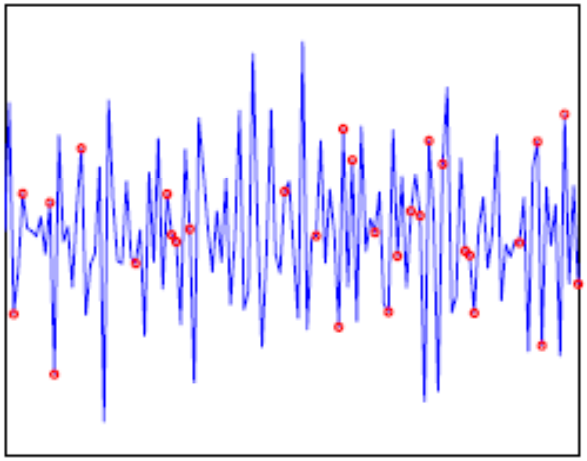


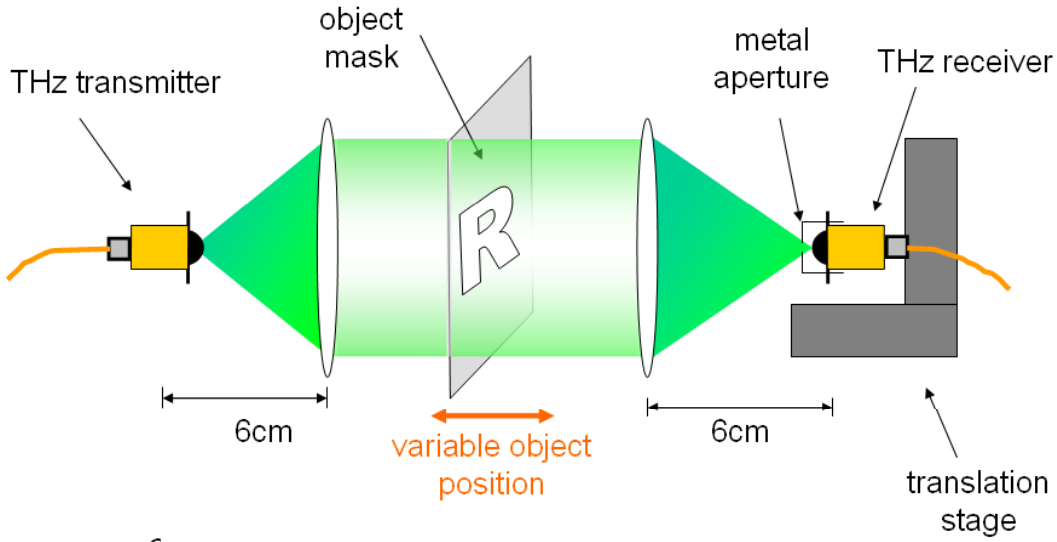
THz Phase

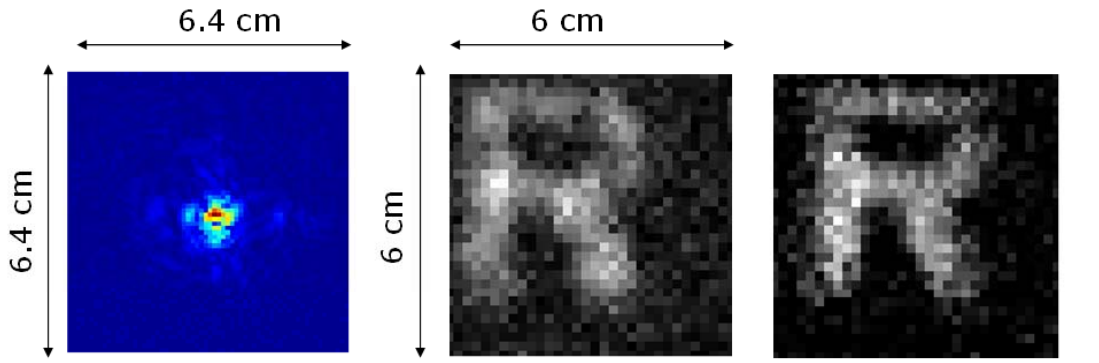
Mittleman Group, Rice University

APPLIED PHYSICS LETTERS 93, 121105 (2008)

THz Camera 2: Sampling in Fourier







Fourier Transform of object (Magnitude-only)

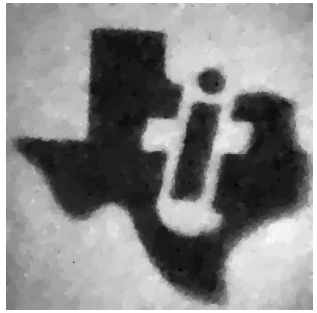
CPR Reconstruction (4096 measurements)

CSPR Reconstruction (1000 measurements)

Mittleman Group, Rice University

Conclusions

- Compressive imaging
  - a new imaging framework based on compressive sensing
  - exploit a priori image sparsity information
  - based on new uncertainty principles
- Proof of concept: CS camera
  - single sensor element
  - universal, simple, robust image coding
  - imaging beyond the visible
  - hyperspectral
  - confocal microscopy



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dsp.rice.edu/cs/camera