Compressive Imaging System for Mid-IR Microscopy: towards a novel diagnostic modality for disease detection

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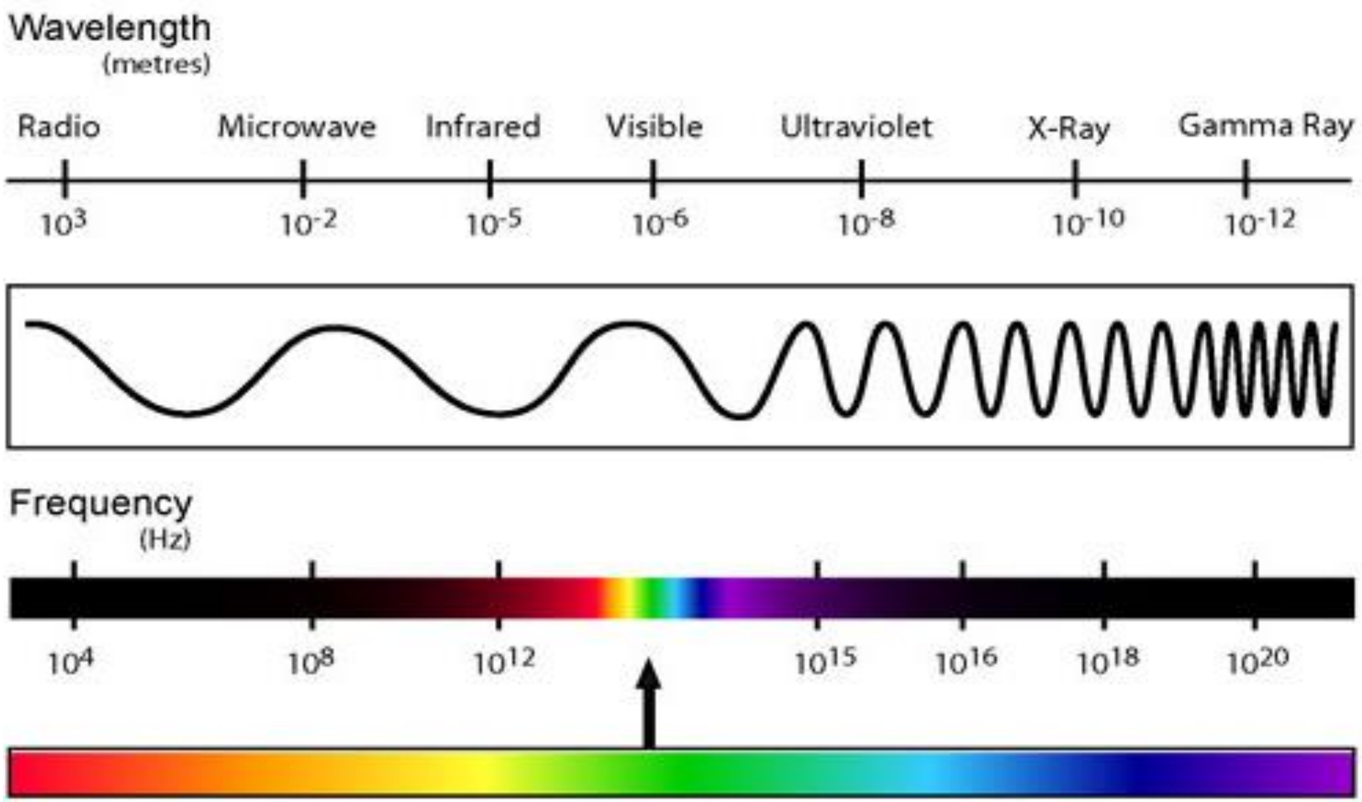
Outline

- Introduction
- An overview of Compressed Sensing(CS)
- Outline CS architecture at Rice
- Broad Examples of CS imaging
- Make a case for adapting CS for Mid-IR biological Imaging

Significant biomolecules

Absorption band (cm^{-1})	Corresponding biomolecules and their functional groups
1650	Amide I band arises from in plane C=O stretching vibration weakly coupled with C-N stretching and in plane N-H bending of the amide group in proteins
1540	Amide II band which arises from the N-H bending vibration strongly coupled to the C-N stretching vibration of protein
1400	Symmetric and asymmetric CH_3 bending modes respectively of the methyl groups of proteins
1338	Vibrations of collagen
1240	Asymmetric phosphate (PO^-_2) stretching modes (νas PO^-_2) of nucleic acids and the amide III/CH_2 wagging vibrations of collagen
1080	Vibrational modes of –CH2 OH groups and C-O stretching coupled with C-O bending of the C-OH groups of carbohydrates respectively
970	O-P–O antisymmetric stretching mode of DNA or to a phosphate monoester band of phosphorylated proteins and nucleic acids

THE ELECTROMAGNETIC SPECTRUM

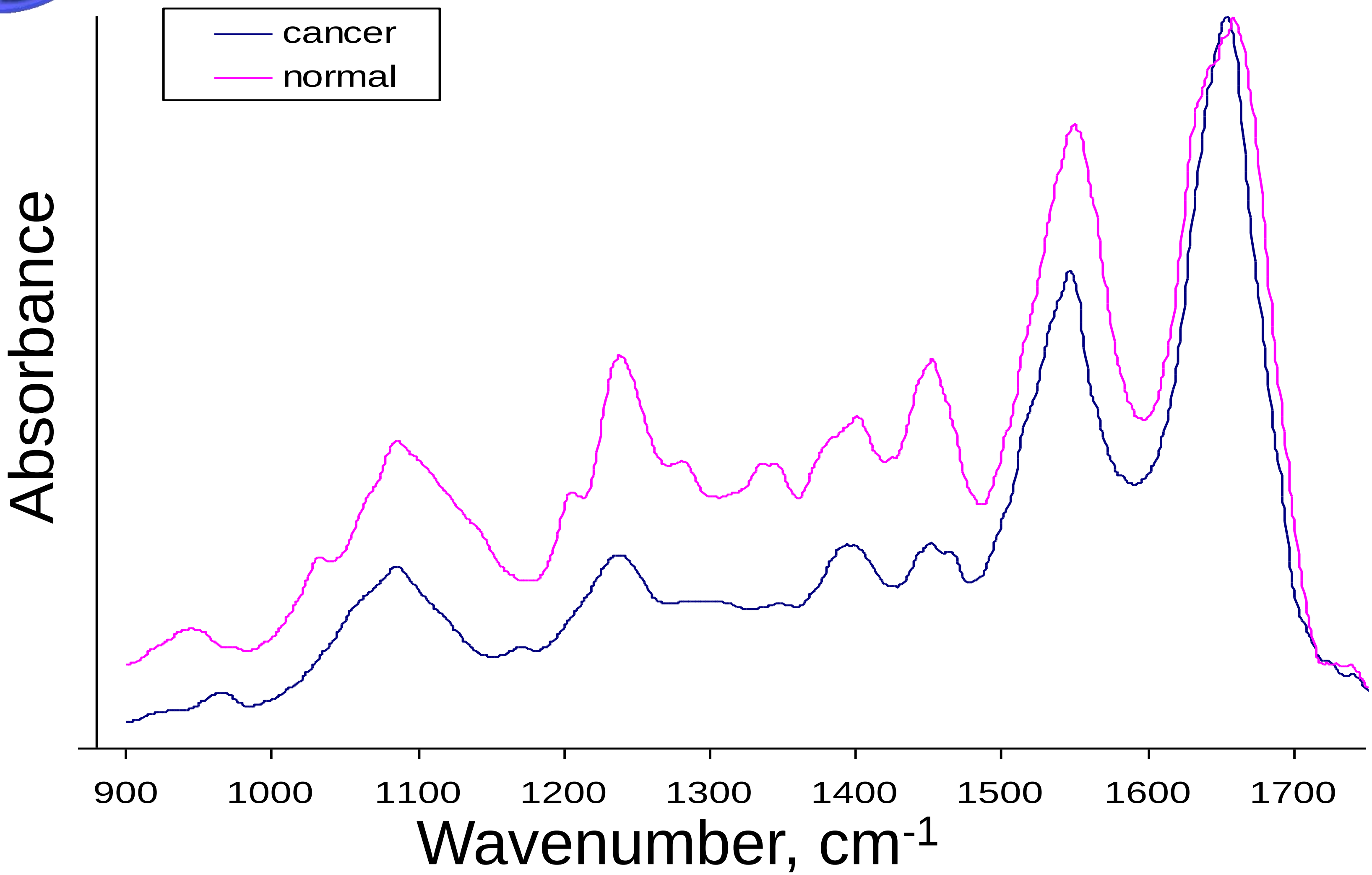


Diagnosis

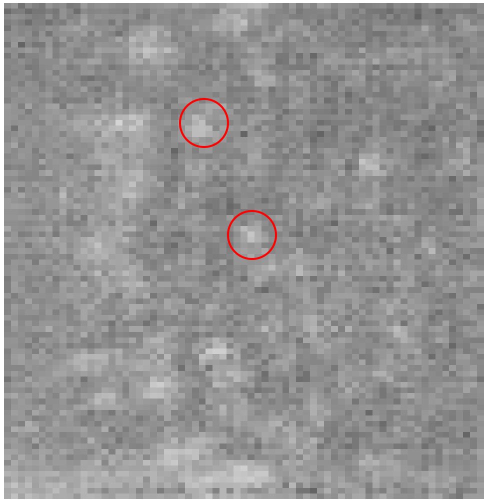
- Biopsy is gold standard
- Expensive stains
- Complex procedure
- Time intensive process

OUR APPROACH: Mid-IR Imaging

Normal/Cancer spectra



Microscopic Imaging



320 x 240 pixels

Noise equivalent Power (NEP): 1.5e^{-11} W

Uncooled ferreolectric material: BST

Compound microscopy

*Image of ovarian tissue biopsy section @30X

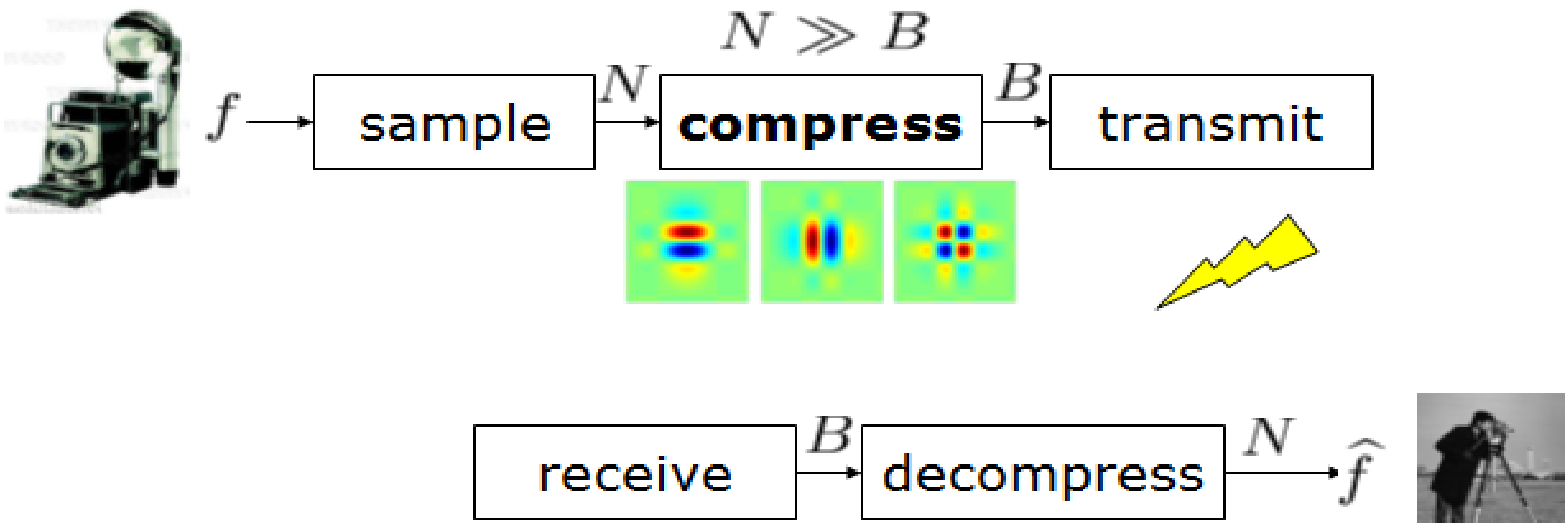
*Image is very ill-resolved, an improvement would be more sensitive camera

Would CS be useful? YES

-highly resolved images

Conventional Sensing

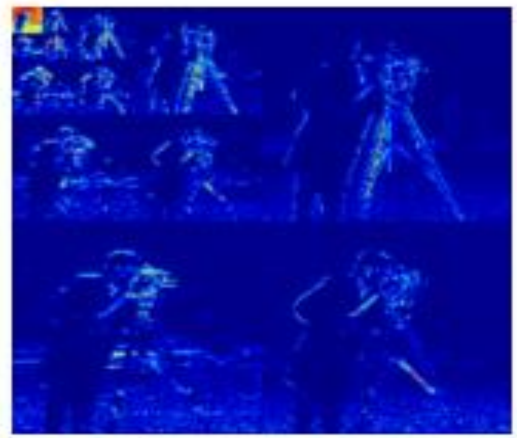
- The typical sensing/compression setup
  - compress = transform, sort coefficients, encode
  - most computation at *sensor* (asymmetrical)



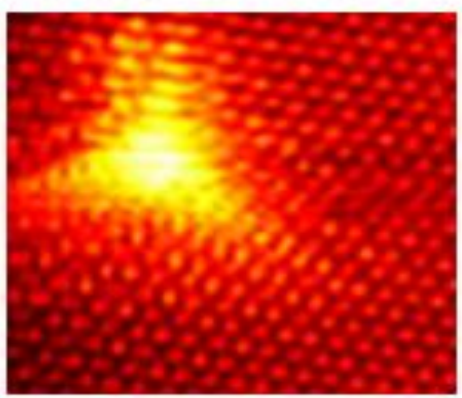
SPARSITY

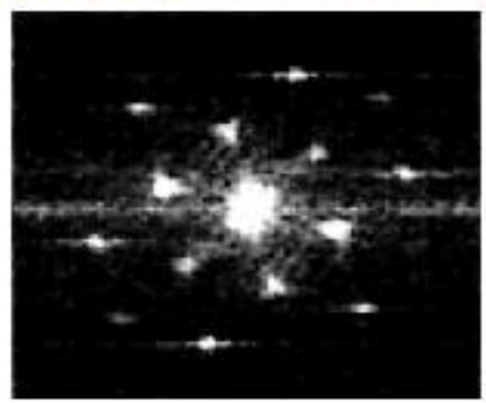
- Many images can be *sparsely represented* in some representation/basis (Fourier, wavelets, ...)

N
pixels



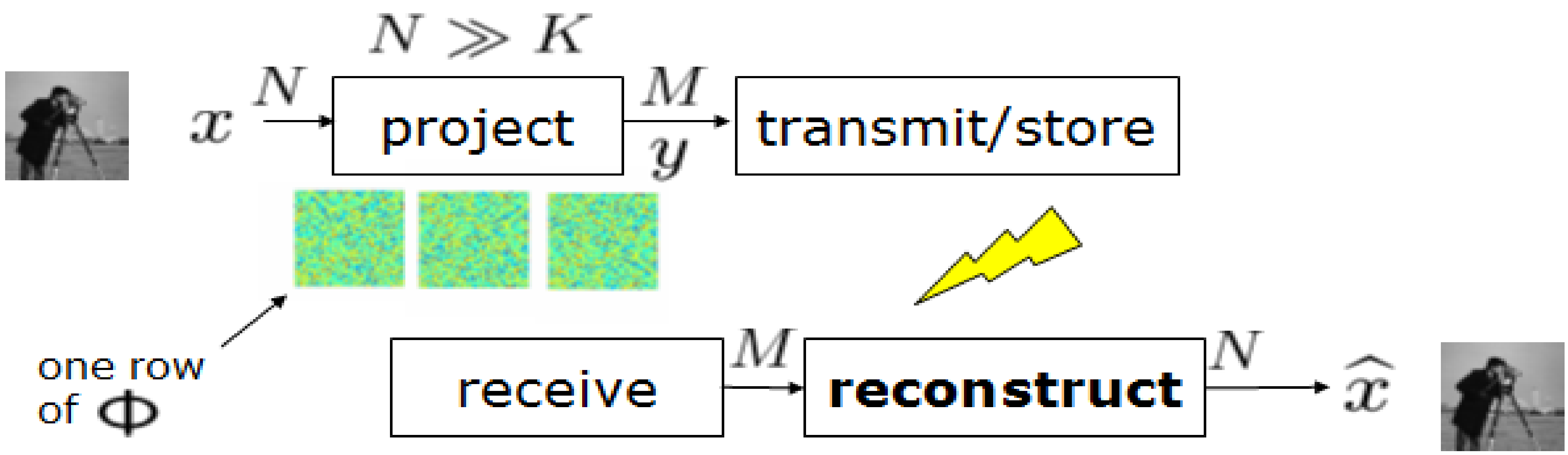
$K \ll N$
large
wavelet
coefficients





Compressive Sensing

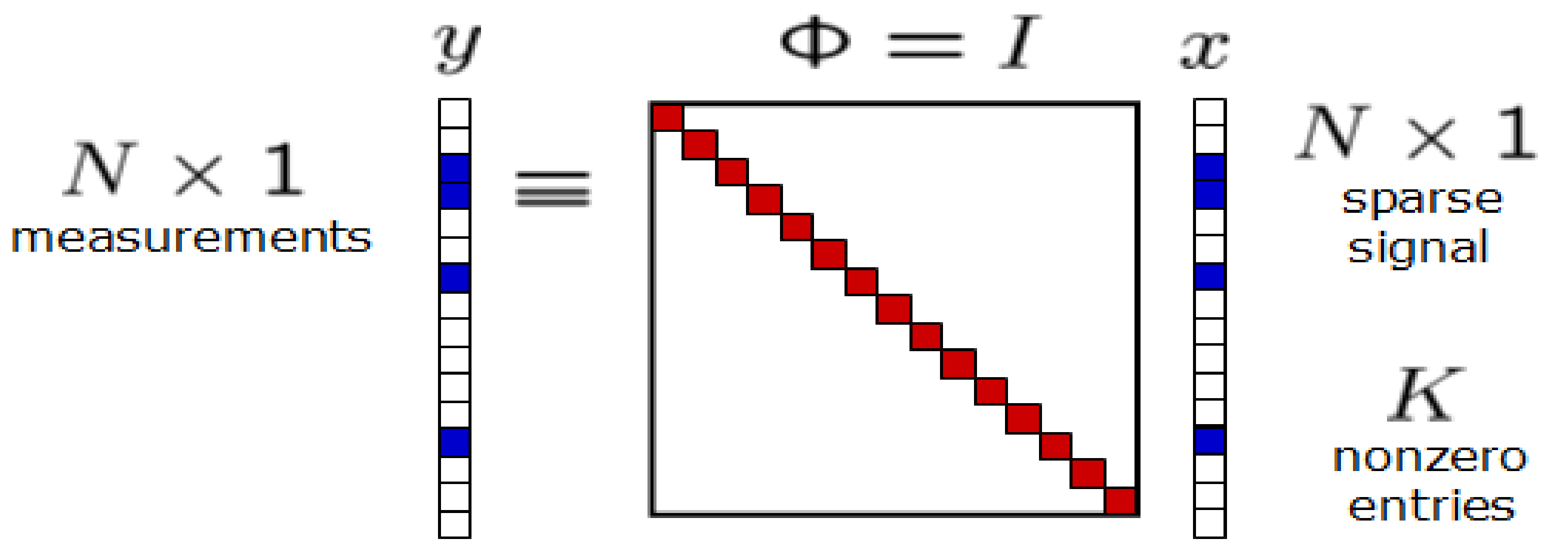
- Measure linear projections onto *random* basis where data is *not sparse/compressible*



- Reconstruct via *nonlinear processing* (optimization)

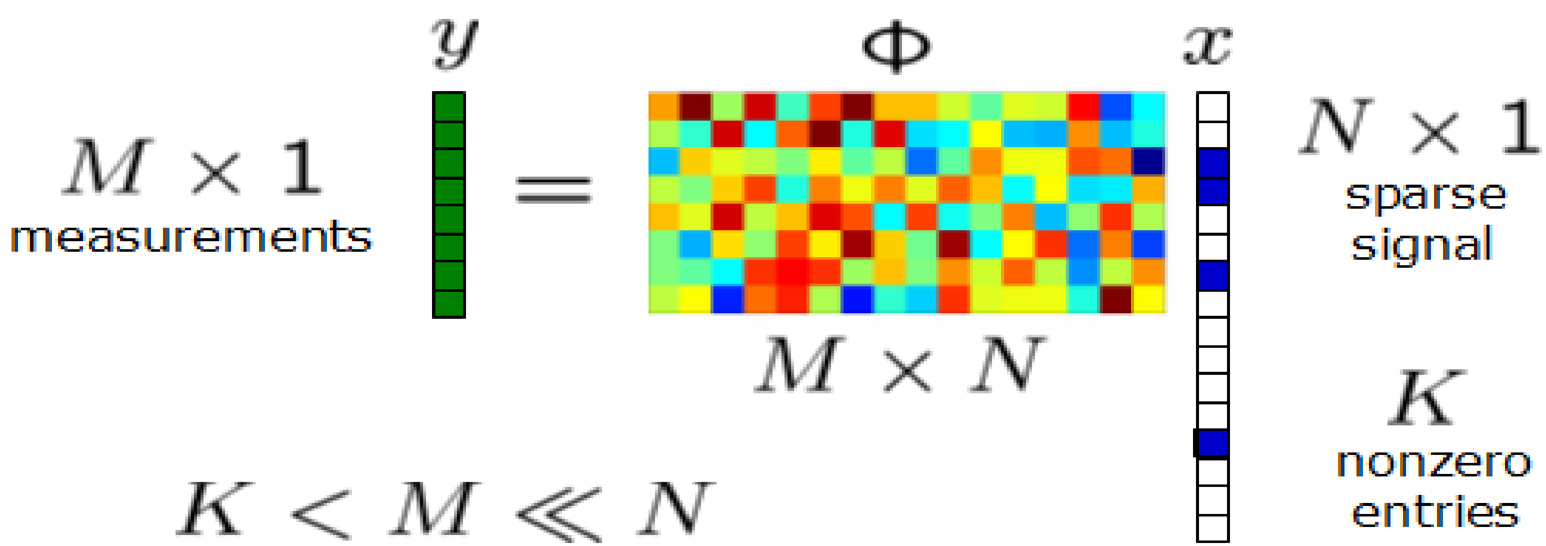
Sampling

- Signal x is K-*sparse* in basis/dictionary Ψ
  - WLOG assume sparse in space domain $\Psi = I$
- **Samples**



CS Signal Recovery

- Reconstruction/decoding: given $y = \Phi x$
  (ill-posed inverse problem) find x



$$K < M \ll N$$

CS Signal Recovery

- Reconstruction/decoding: given $y = \Phi x$
  (ill-posed inverse problem) find x

- L_2 fast, wrong $\widehat{x} = \arg\min_{y=\Phi x} \|x\|_2$

- L_0 correct, slow $\widehat{x} = \arg\min_{y=\Phi x} \|x\|_0$

- L_1 **correct,**
  mild oversampling $\widehat{x} = \arg\min_{y=\Phi x} \|x\|_1$
  [Candes, Tao, Romberg; Donoho] *linear program*

$$M = O(K \log(N/K)) \ll N$$

http://www.acm.caltech.edu/l1magic/

Progression in CS Imaging:

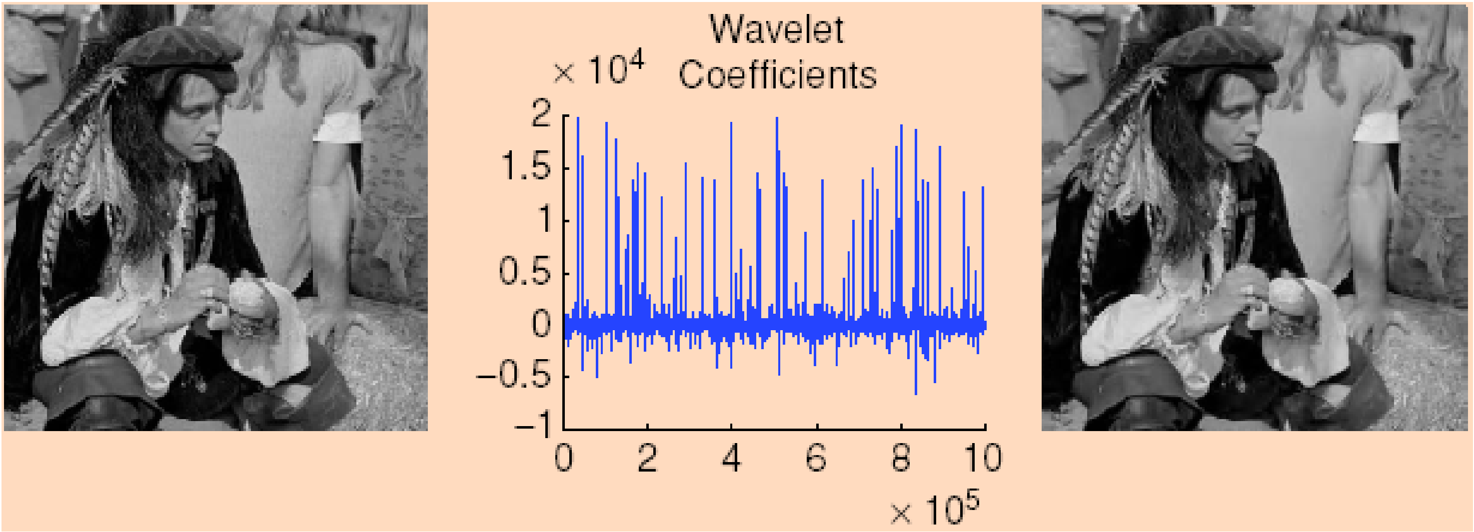
Minimize ||x*||

Ax*=Ax

Image gets progressively clearer

Jordan Ellenberg, Wired Magazine, March 2010

Further examples

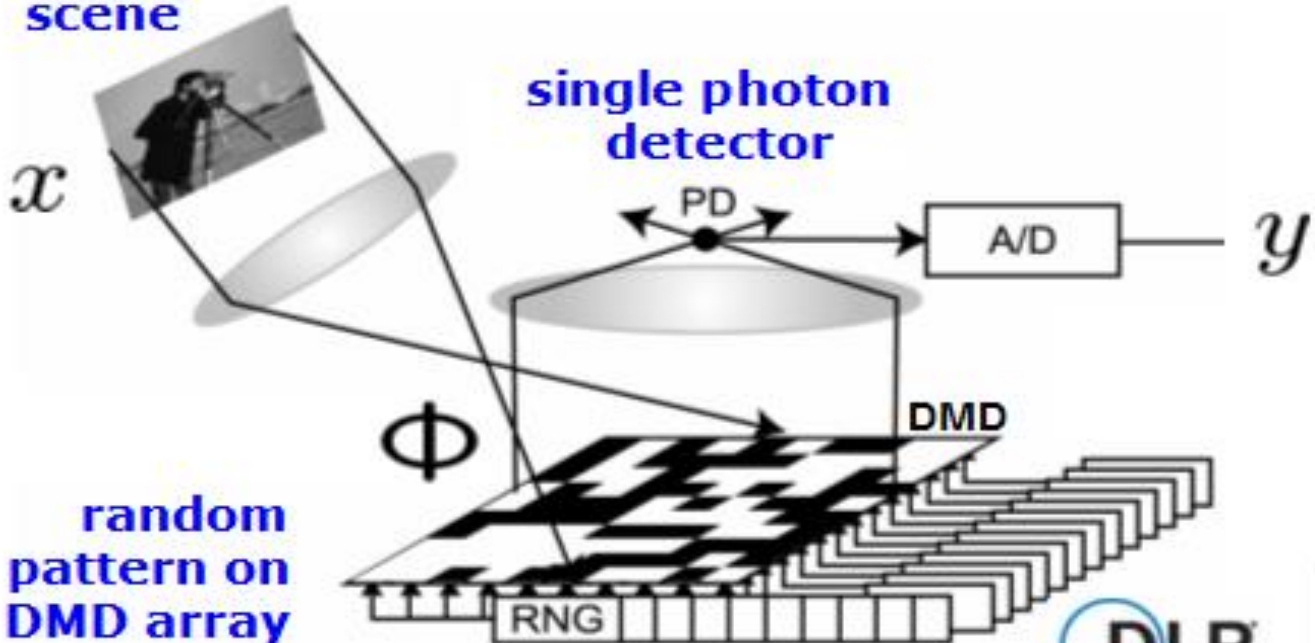


Sparse signal representation in Wavelet basis

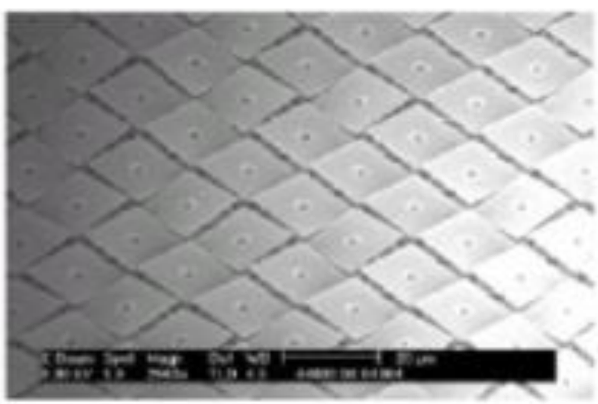
Original Image: 1MB

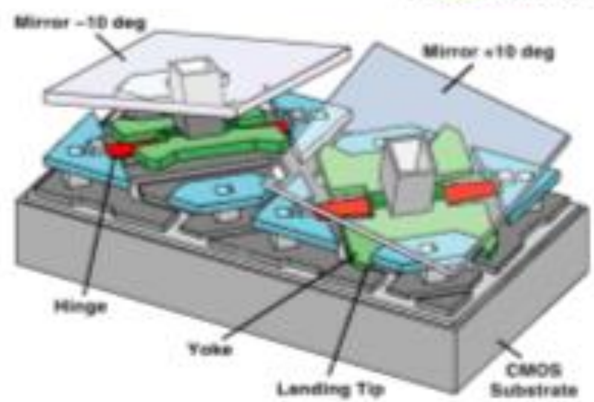
E. Candes, B Wakin, IEEE Signal Processing Magazine, March 2008

"Single-Pixel" CS Camera

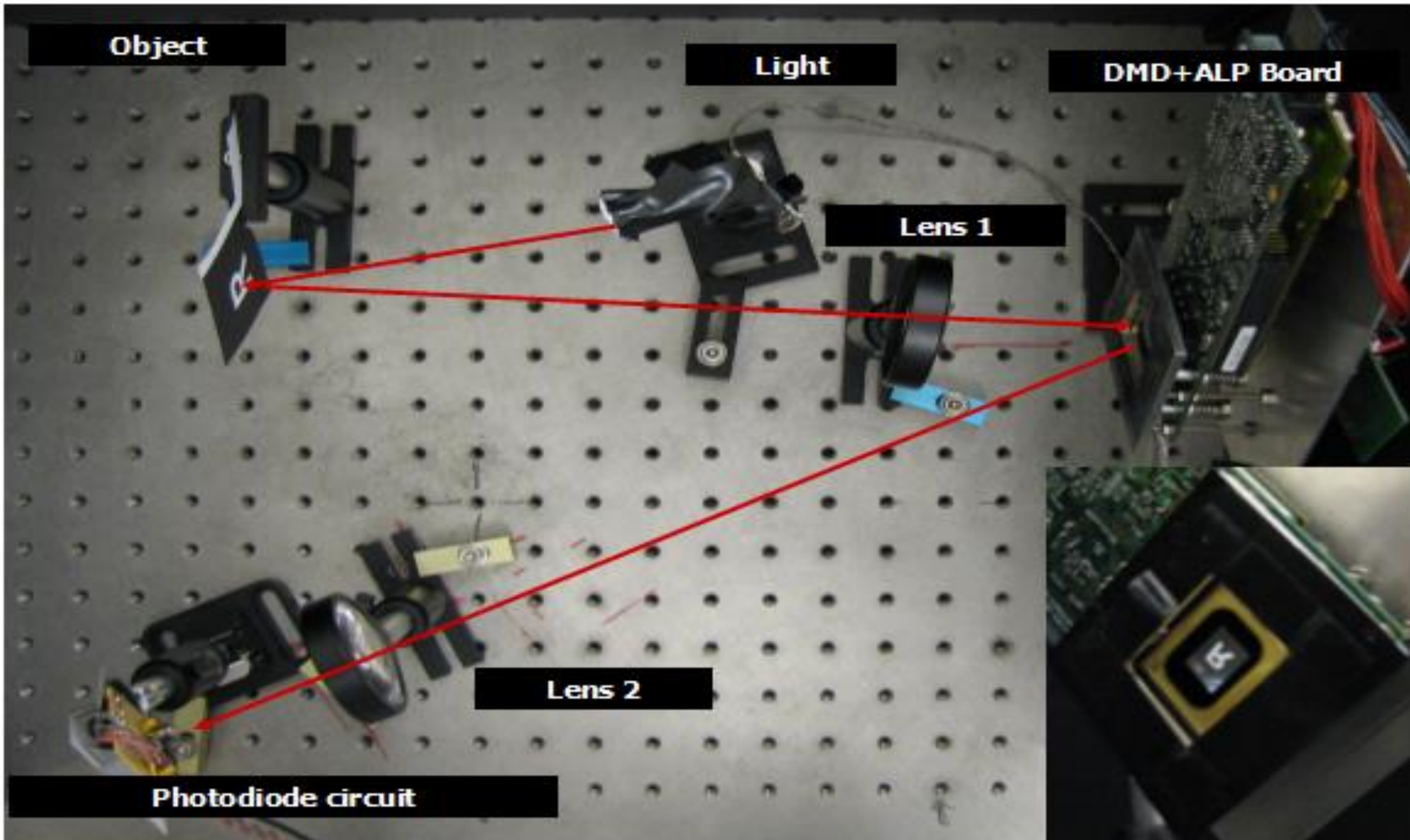


DLP
TEXAS INSTRUMENTS

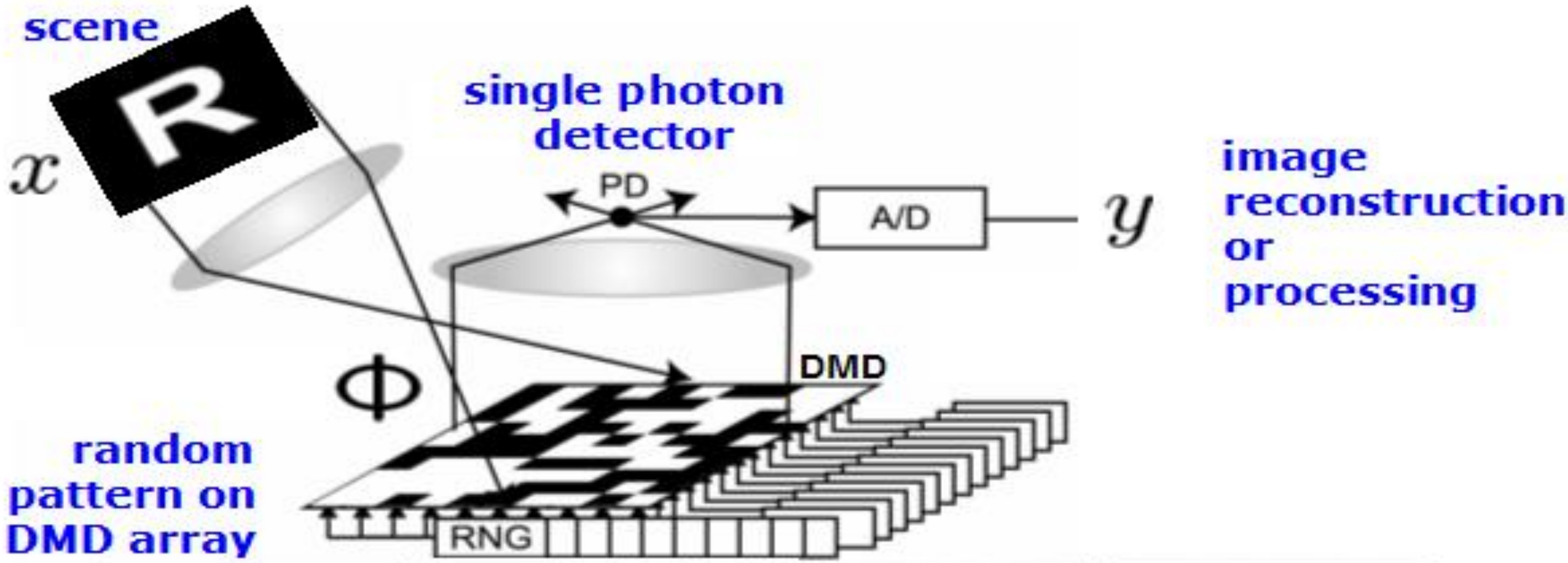




Rice CI Camera



“Single-Pixel” CS Camera



Original

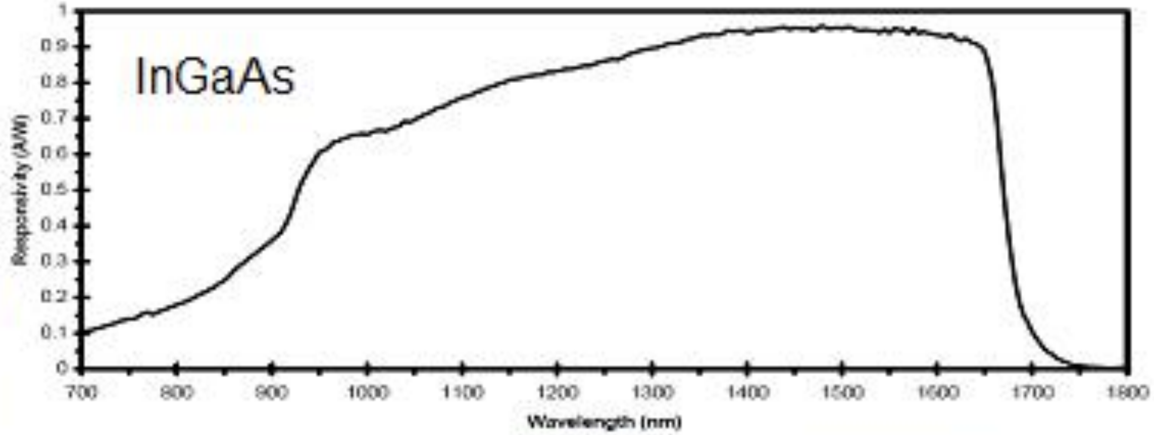
6600 measurements (10%)

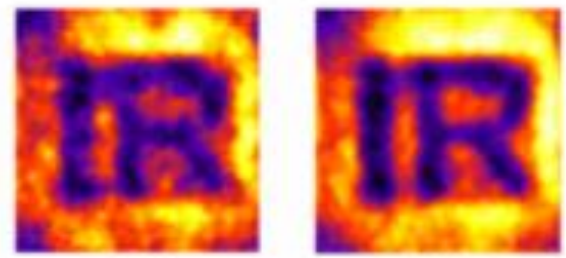
3300 measurements (5%)

1300 measurements (2%)

CS Imaging in the Infrared

A canvas board with a handwritten letter "IR" using charcoal pencil. On top of that is a layer of blue oil paint which completely covers the lettering.





(b) 1% (c) 2%

(d) 5% (e) 10% (f) 100%

CS reconstruction of 256×256 pixel image based on 1%, 2%, 5%, 10%, 100% measurements respectively. $(M \geq O(K \log(N/K)))$

Conclusions

– CS exploited to image beyond the visible into the infrared
– Ongoing research has adapted this technique for Mid-IR imaging
– CS is capable of high resolution imaging which make it particularly suitable for biological imaging
– Adapted to biological microcopies for disease detection
– CS and Mid-Infrared Imaging is a great match

Further Information:

* www.ece.rice.edu/~kkelly

*dsp.rice.edu/cs