DMDs
(time modulated imaging)

Gil Bub
University Research Lecturer, Med. Sci. Division
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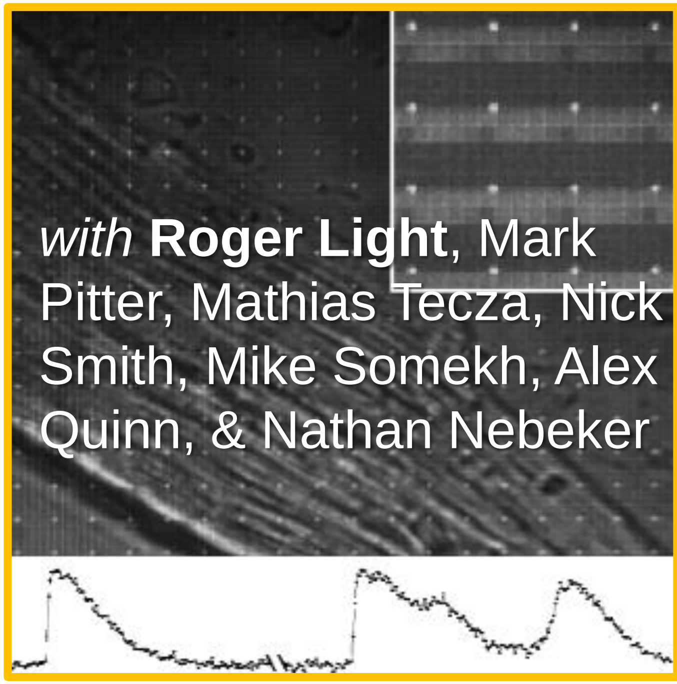
TPM

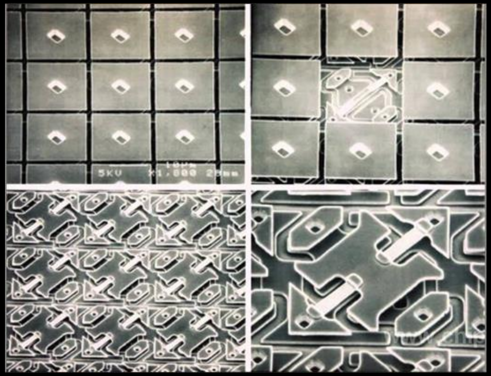


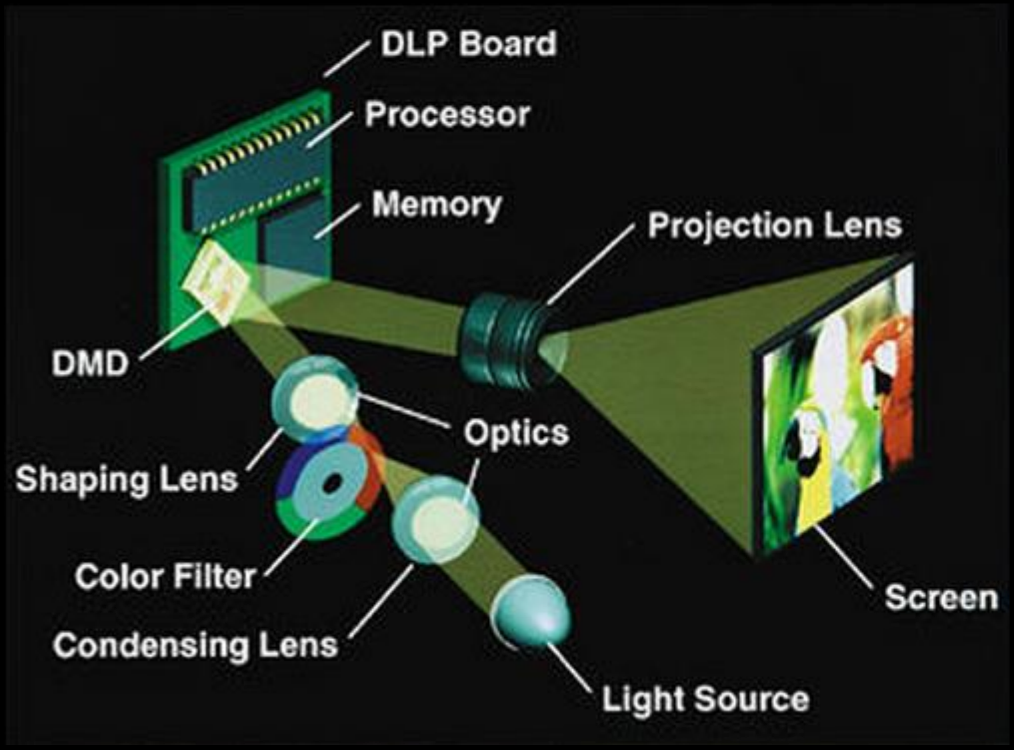
remote focusing

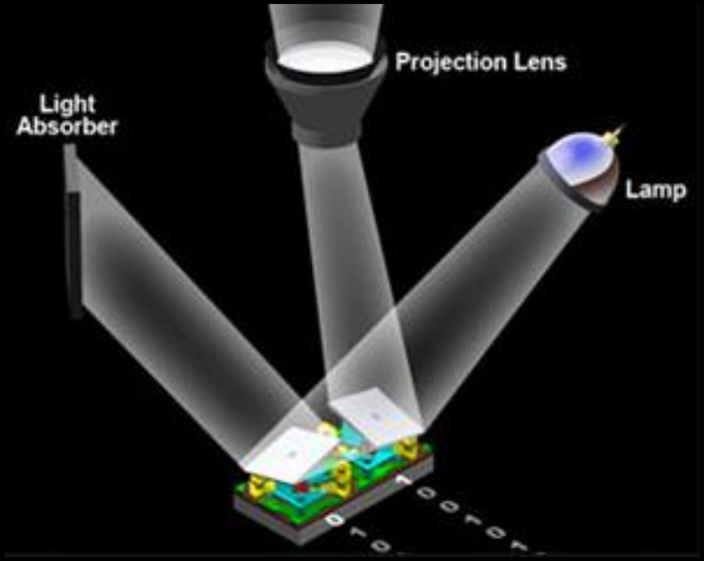
macro-imaging

Digital Micromirror Devices (DMDs)

- Projector technology
- Invented by TI in the 80's







nature International weekly journal of science

NATURE | LETTER

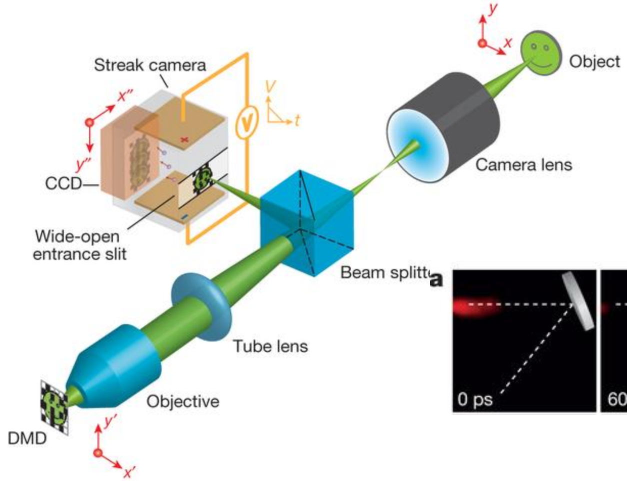
日本語要約

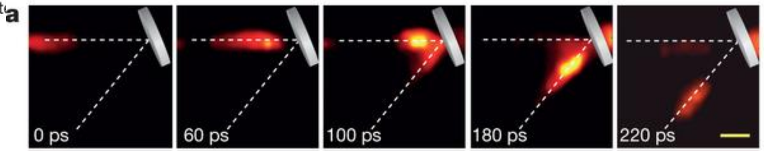
Single-shot compressed ultrafast photography at one hundred billion frames per second

Liang Gao, Jinyang Liang, Chiye Li & Lihong V. Wang

Affiliations | Contributions | Corresponding author

Nature **516**, 74–77 (04 December 2014) | doi:10.1038/nature14005





SCIENTIFIC REPORTS

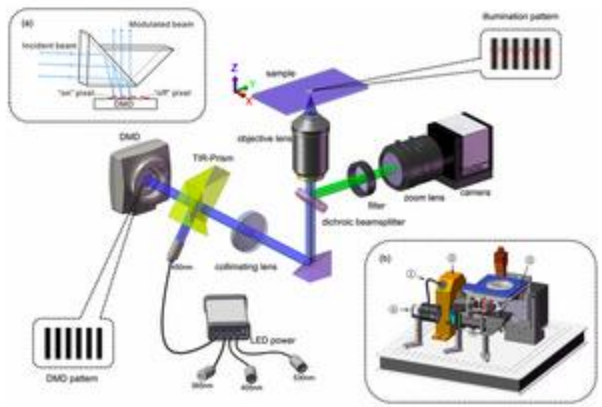
SCIENTIFIC REPORTS | ARTICLE OPEN

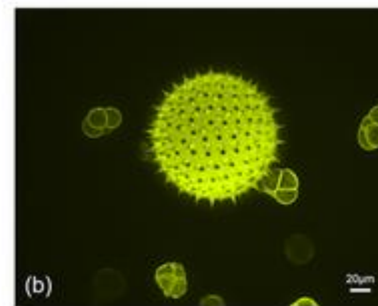
DMD-based LED-illumination Super-resolution and optical sectioning microscopy

Dan Dan, Ming Lei, Baoli Yao, Wen Wang, Martin Winterhalder, Andreas Zumbusch, Yujiao Qi, Liang Xia, Shaohui Yan, Yanlong Yang, Peng Gao, Tong Ye & Wei Zhao

Affiliations | Contributions | Corresponding authors

Scientific Reports **3**, Article number: 1116 | doi:10.1038/srep01116





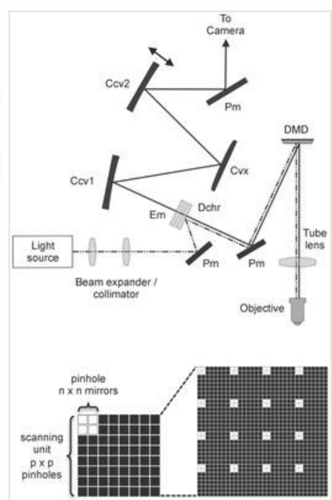
PLOS ONE

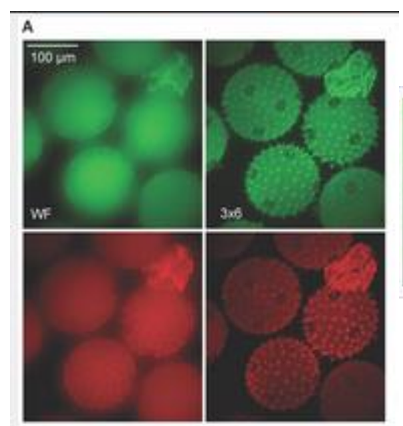
RESEARCH ARTICLE

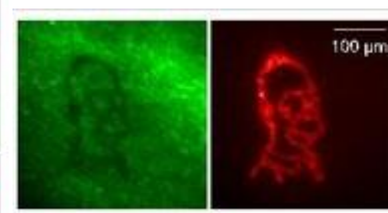
Programmable Illumination and High-Speed, Multi-Wavelength, Confocal Microscopy Using a Digital Micromirror

Franck P. Martial, Nicholas A. Hartell

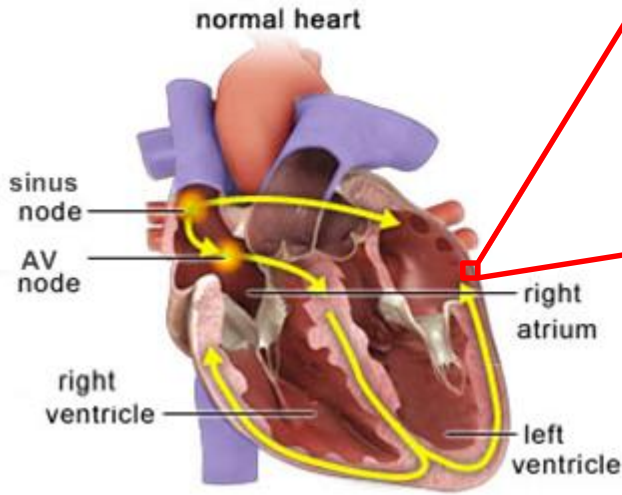
Published: August 24, 2012 • DOI: 10.1371/journal.pone.0043942

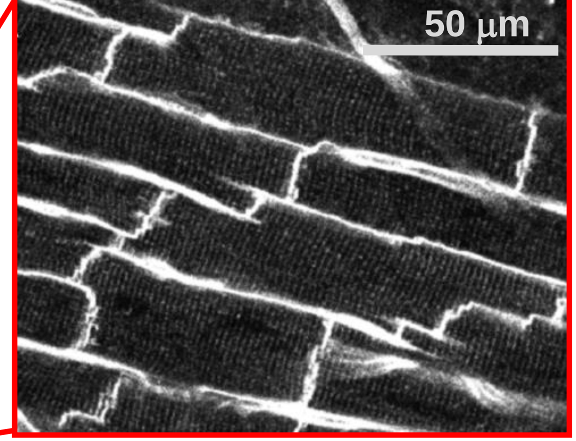




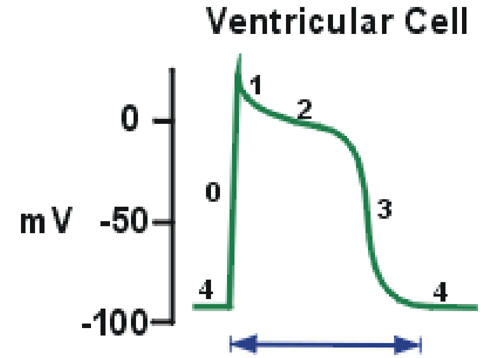


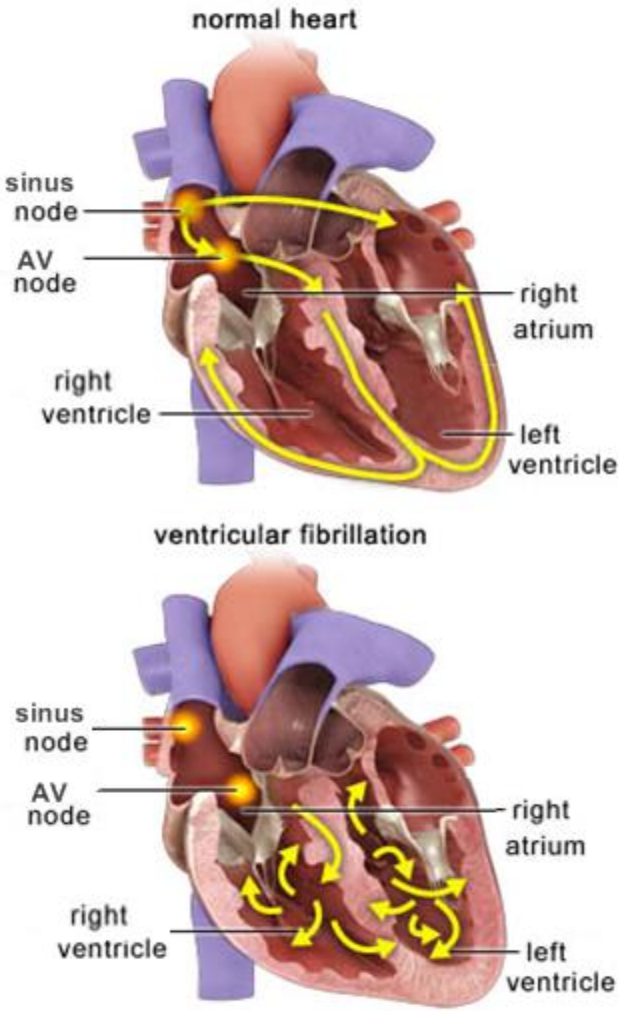
A brief intro into cardiac sciences (why imaging is important)

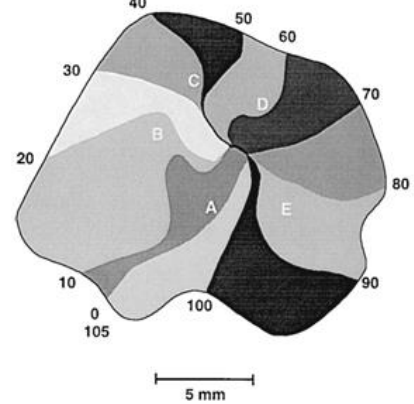




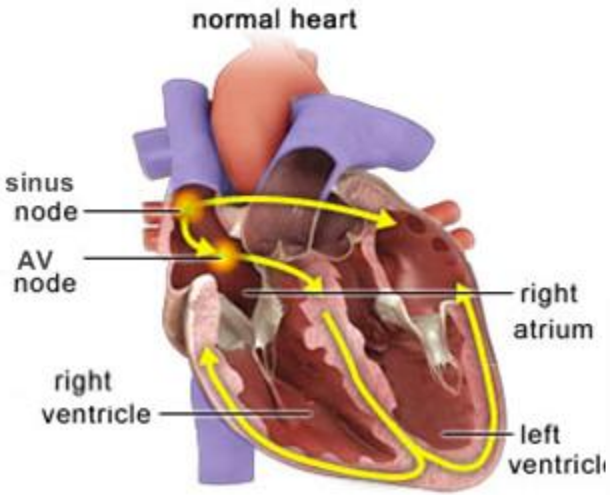
Bub *et al*. **AJP**, 2010.

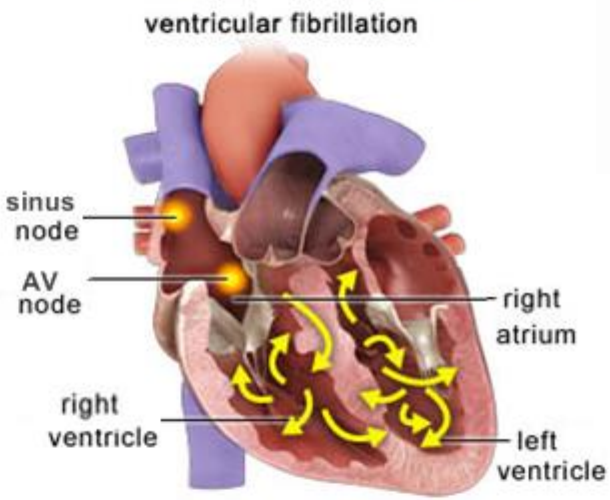


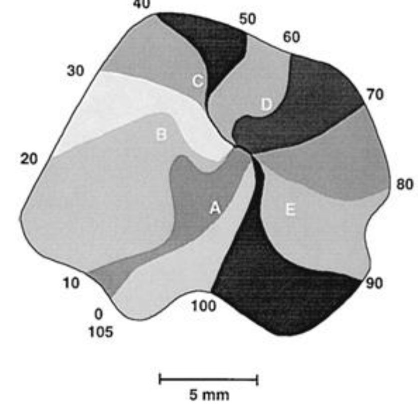




Allessie *et al.*, **Circ. Res.**, 1977

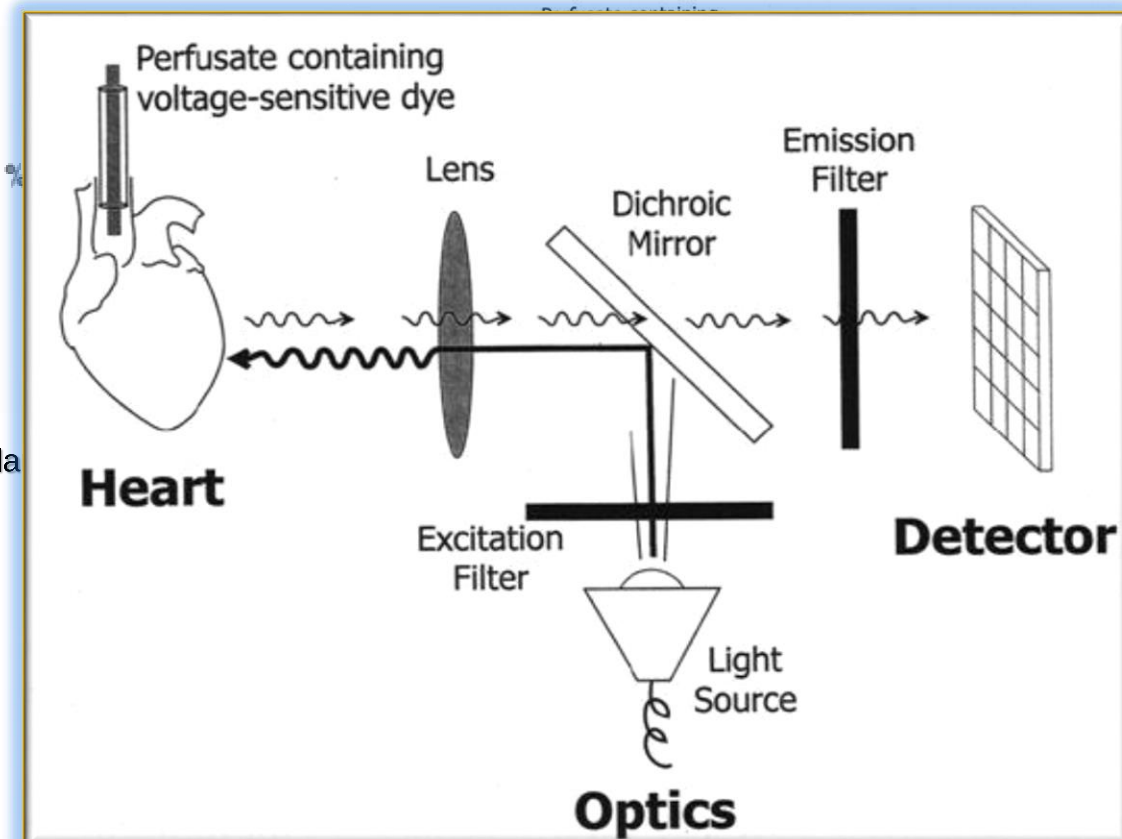


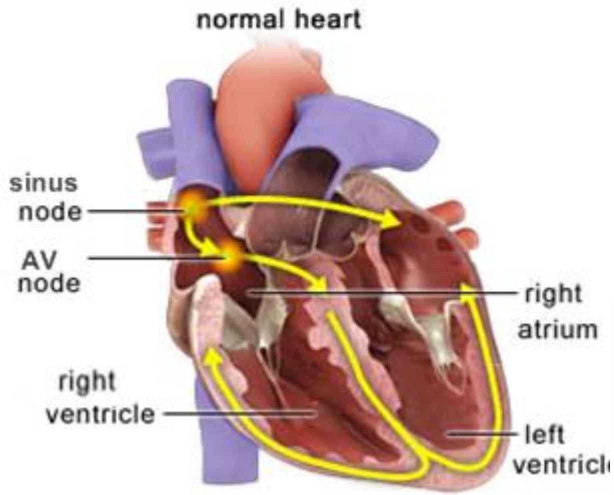


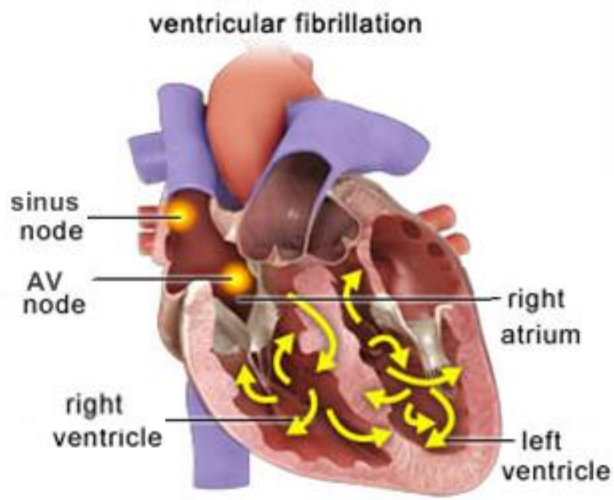


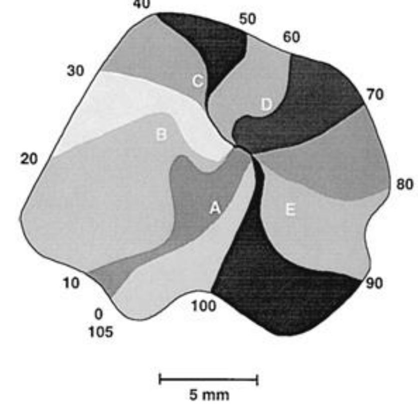
Allessie *et al.*, **Circ. Res.**, 1977

Sala

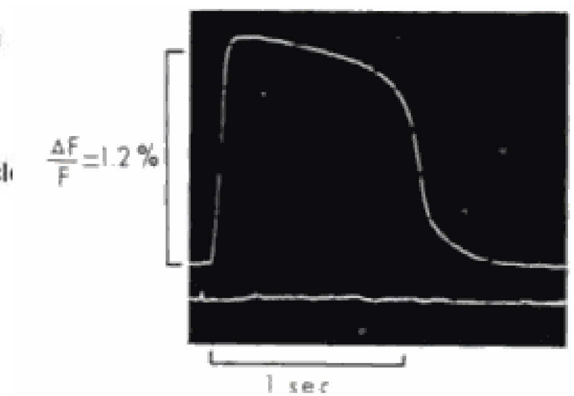


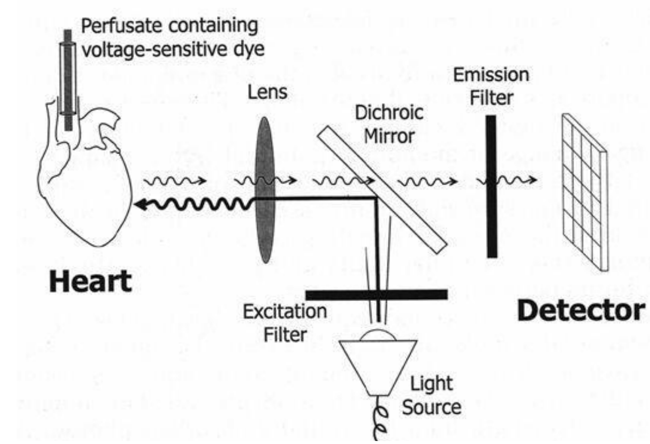






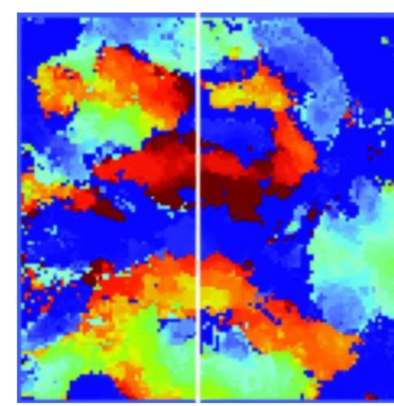
Allessie *et al.*, **Circ. Res.**, 1977



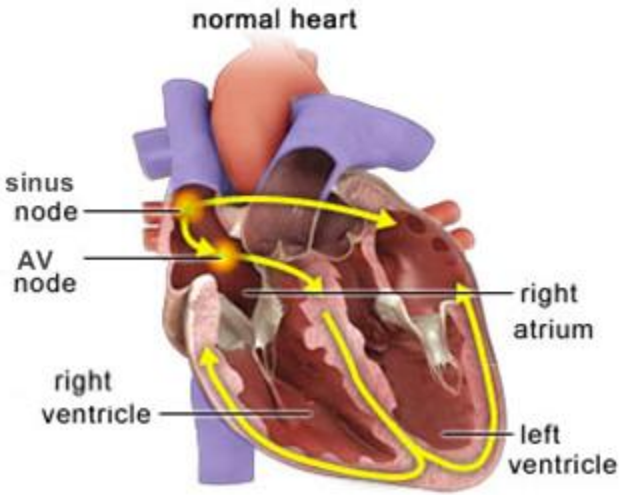


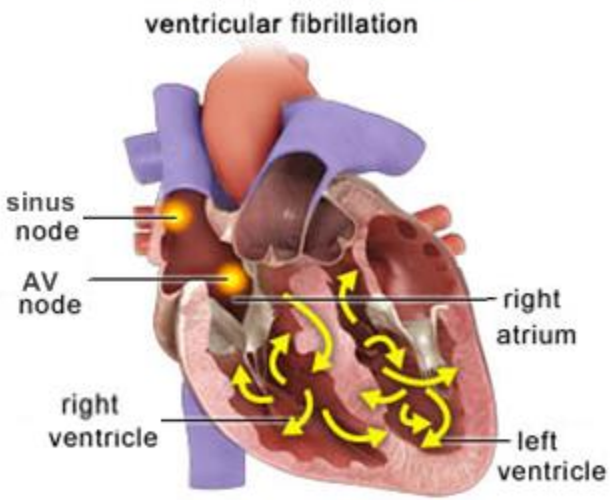
Salama, & Morad, **Science**, 1976; Salama, Sanger & Cohen, **Biol. Bull.**, 1981

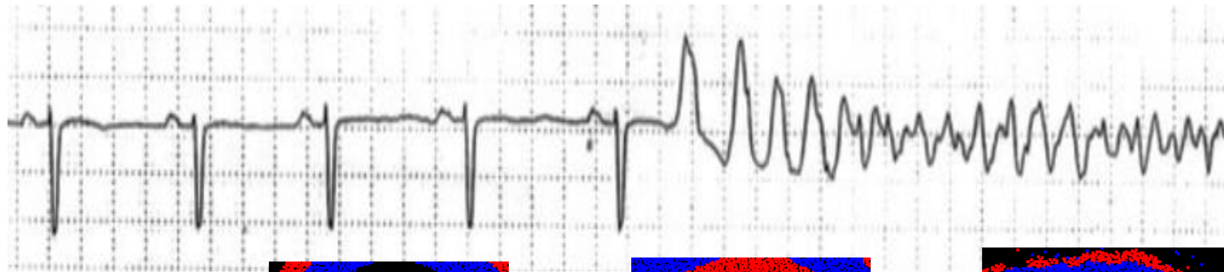
Davidenko *et al*. **Nature**,'92.



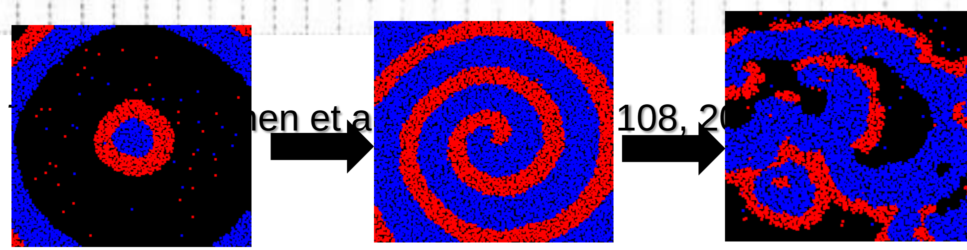
Witkowski *et al.* **Nature**,'98.







macro
(tissue)

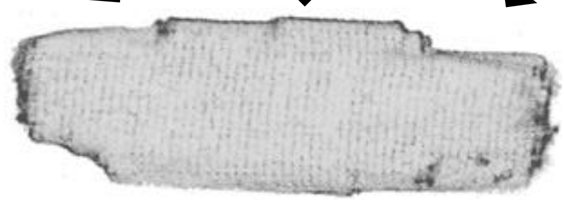


sinus
targets

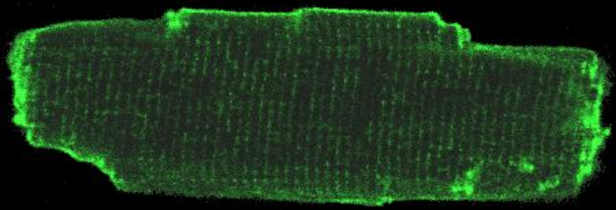
VT
spirals

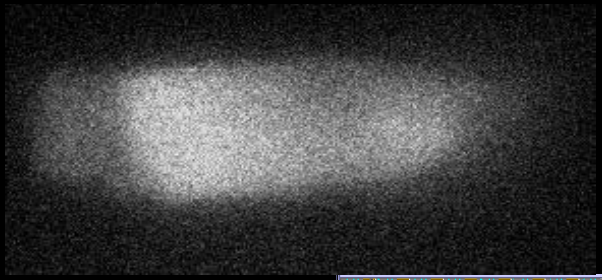
VF
‘wavelets’

micro
(cell)

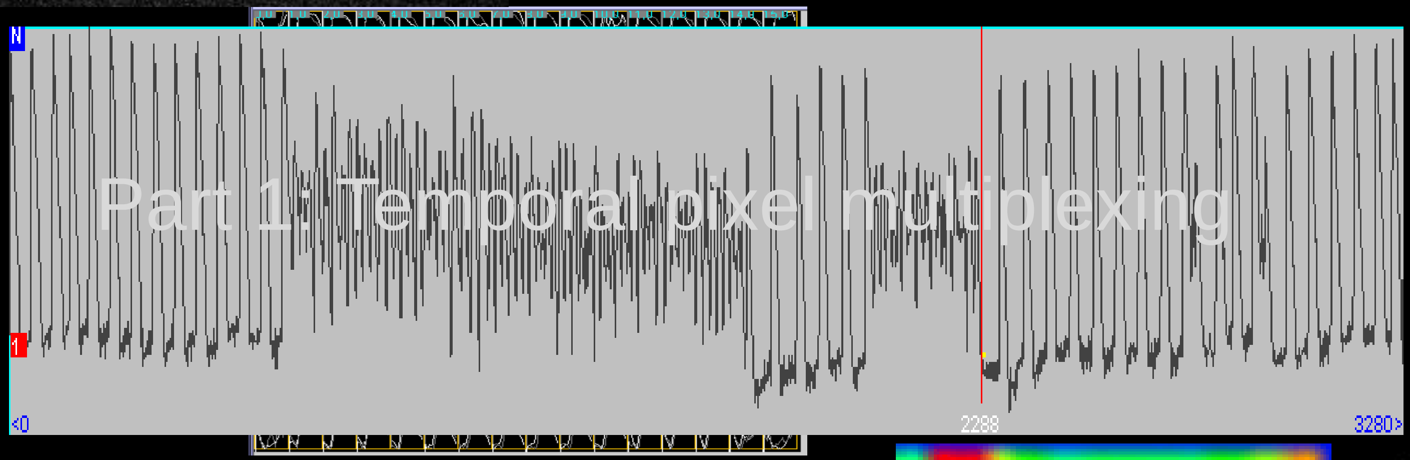


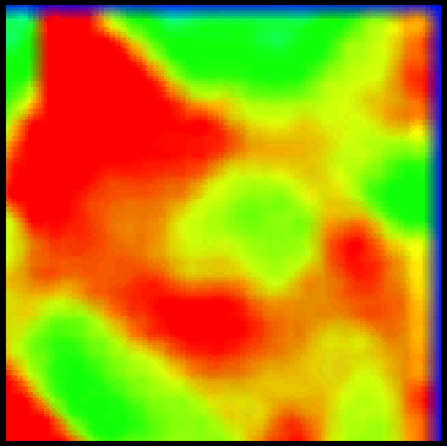
Lakirredy *et al.* JMCC 2008.
Bub *et al.* AJP 2010.
Bub *et al.* PNAS 1998.





Part 1: Temporal pixel multiplexing





MRI: Burton *et al.* Heart Rhythm 2006

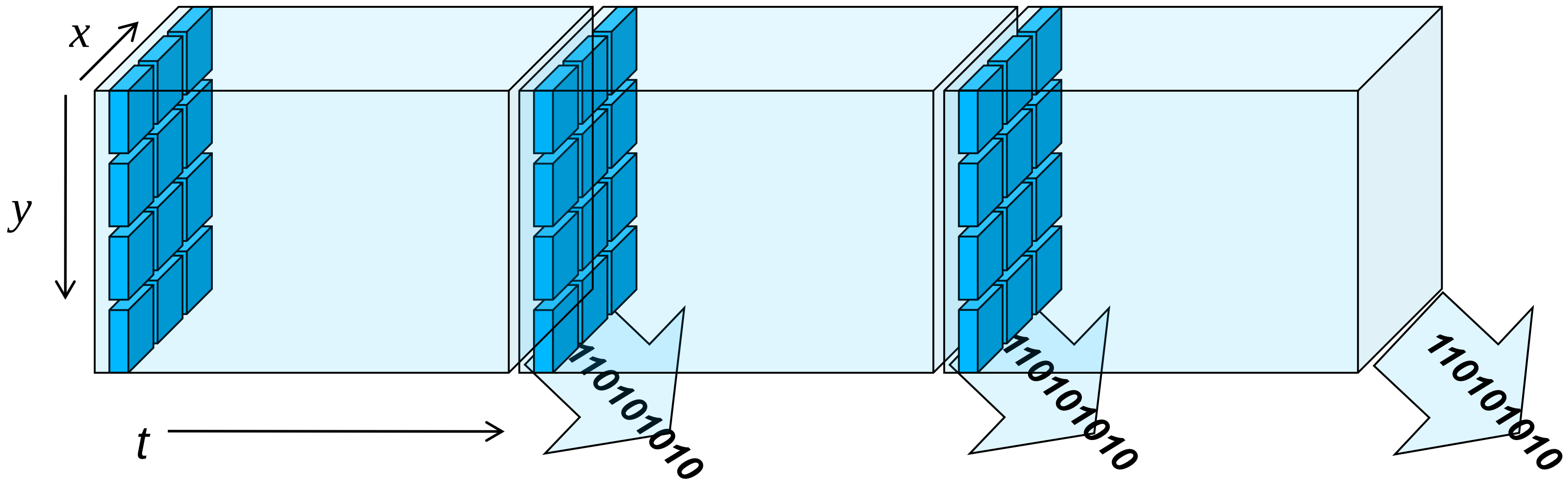
Imaging spatiotemporal dynamics

Challenges:

1. Function is related to structure
   - ***High spatial resolution***
2. Events are very rapid (ms)
   - ***High speed***
3. Events occur at varying time scales
   - ***Long record times***

Difficult to tackle with current technology...

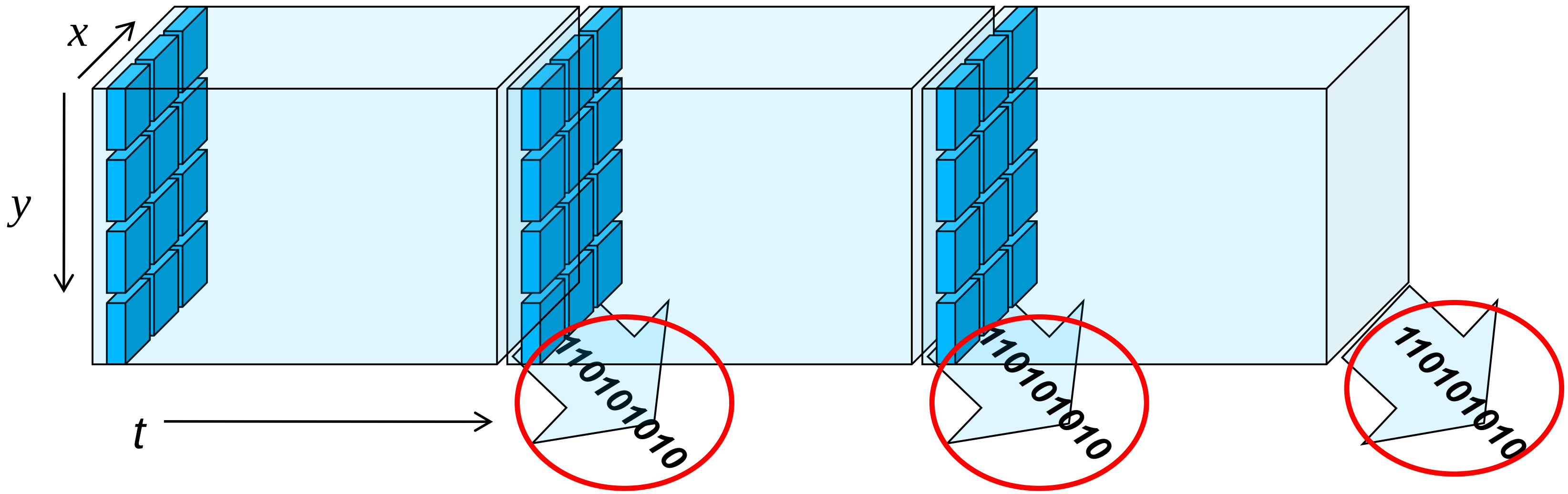
How cameras work



Conventional Imaging:

1) Take a snapshot to image a scene
2) Read out and store.
3) Repeat (as fast as possible).

How cameras work



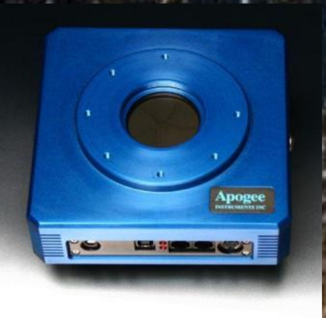
<u>Conventional Imaging Bottlenecks:</u>

1) Hardware read-out rates
2) Memory & storage
3) Read Noise

How cameras work

Low noise cameras typically have very slow readout speeds

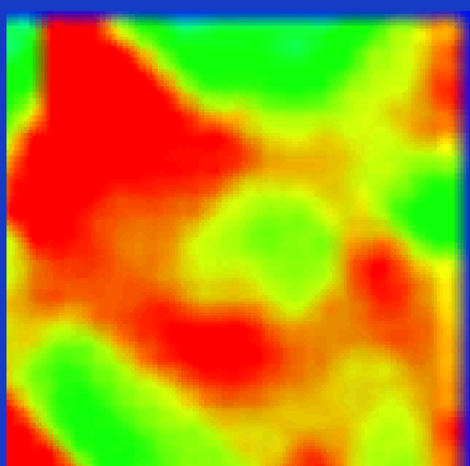
Low noise ≠ high speed.



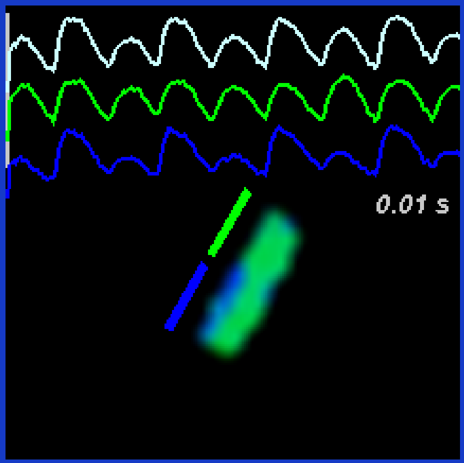
High speed imaging

Low pixel count: hardware

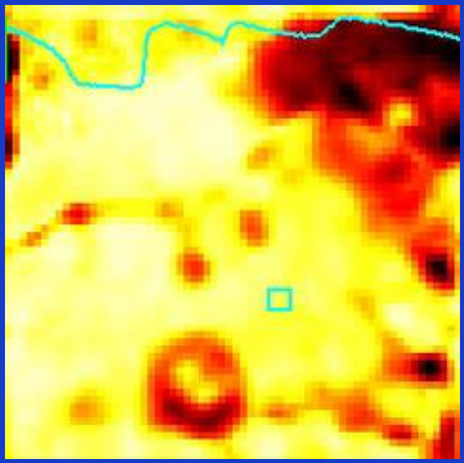
Manufacturer	Resolution	Speed
Hamamatsu	16x16	2,000 fps
Redshirt	80x80	2,000 fps
SciMedia	100x100	10,000 fps
Andor/PI	128x128	500 fps



Lakkireddy *et al.* **Am. J. Physiol. Heart Circ. Physiol.** 2006..



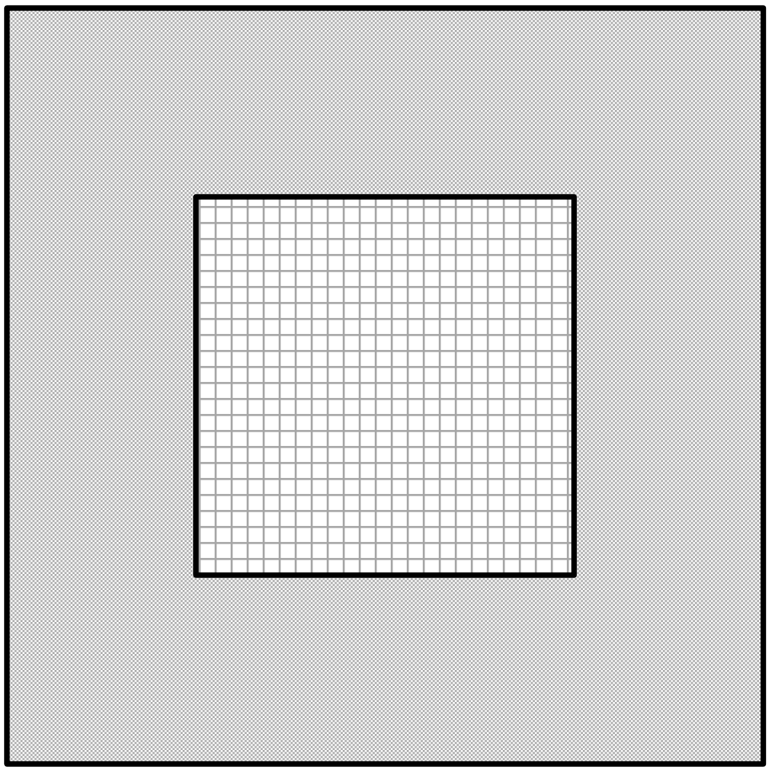
Gaeta *et al.* **Circ Res**. 2009.



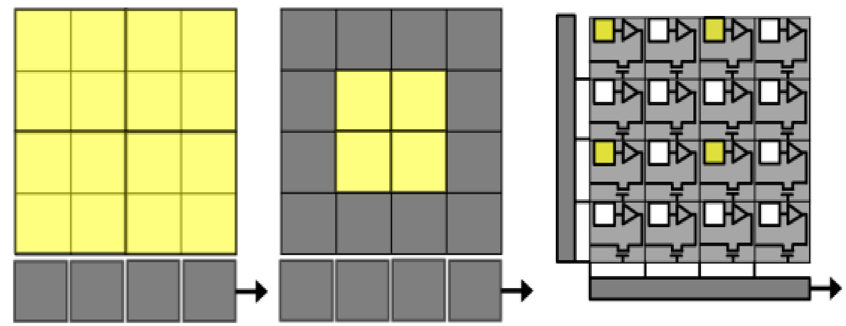
Bishop *et al.* **Am. J. Physiol. Heart Circ. Physiol.** 2014.

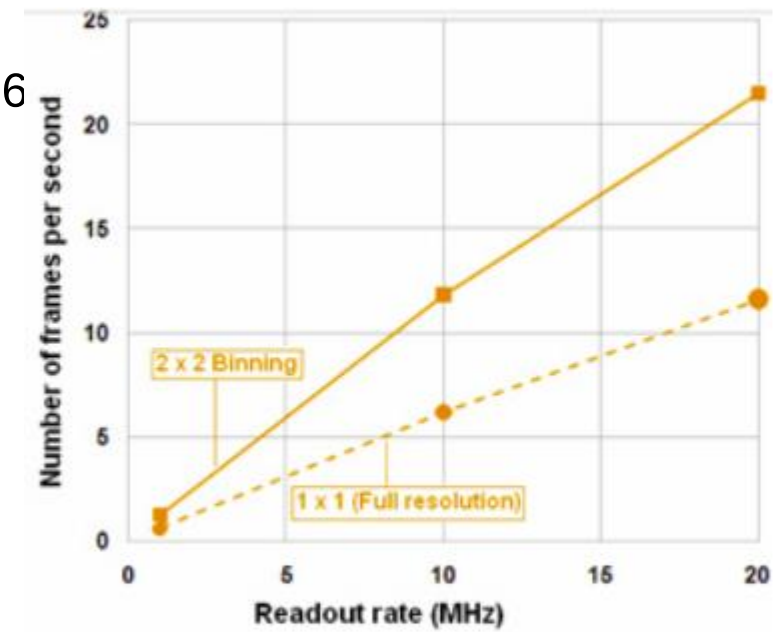
High speed imaging

Low pixel count: bandwidth reduction



binning roi skipping



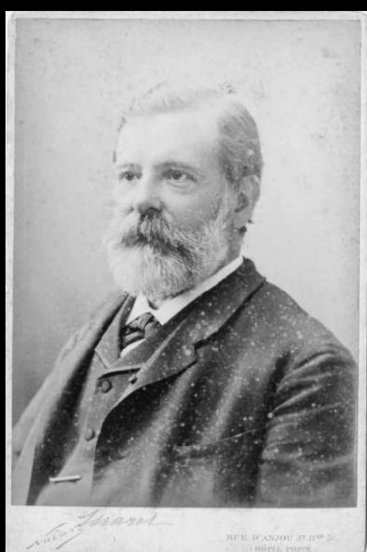


Simultaneous high speed/high res imaging

Eadweard Muybridge

Bio:
1830 - born (London, England)
Moved to San Francisco
1860 - Hit his head
…became a photographer
1872- high speed imaging
1880s -University of Pennsylvania
1904 - death (London)

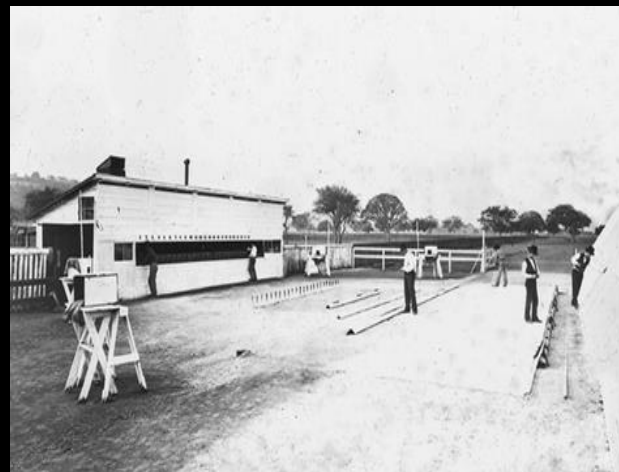
Étienne-Jules Marey



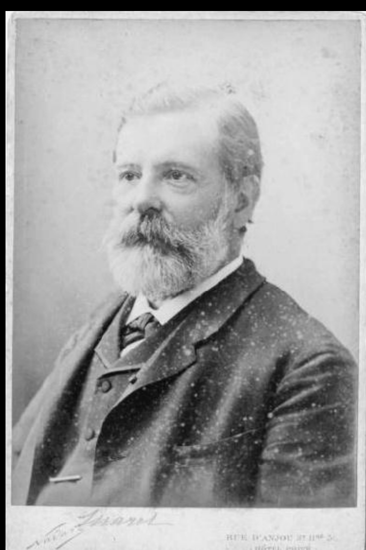
Bio:
1830- born in Beaune, France
Professor, Paris College de France
President French Academy of Sciences
Measure blood circulation
1882 - chronotropic gun
1901 - aerodynamics
1904 - death (Paris)

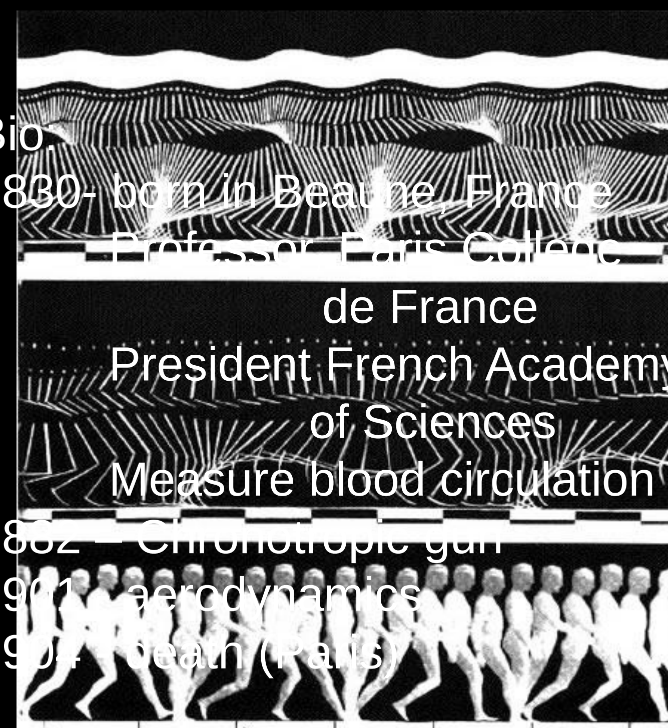
Simultaneous high speed/high res imaging

Eadweard Muybridge



Étienne-Jules Marey





Bio:
1830- born in Beaune, France
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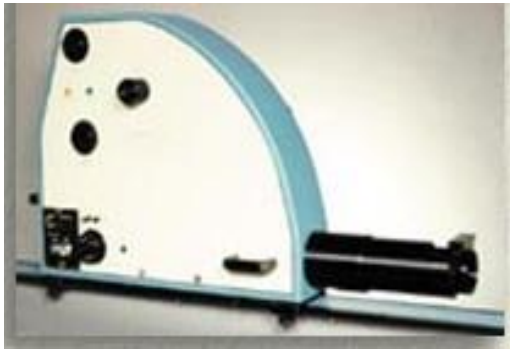
President French Academy of Sciences
Measure blood circulation

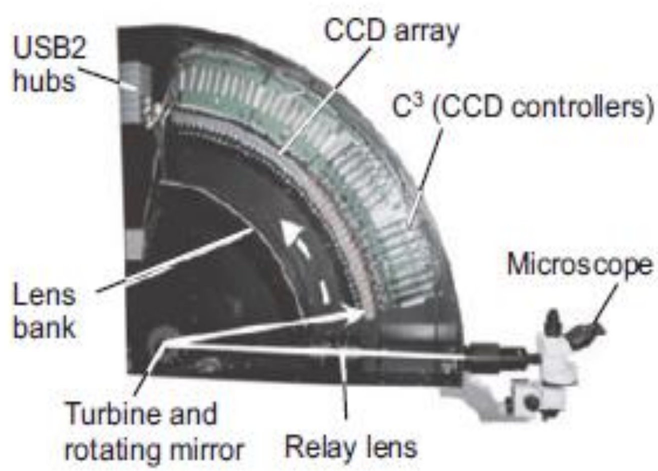
1882 – Chronotropic gun
1901 – aerodynamics
1904 – death (Paris)

High speed imaging

Rotating turbine cameras



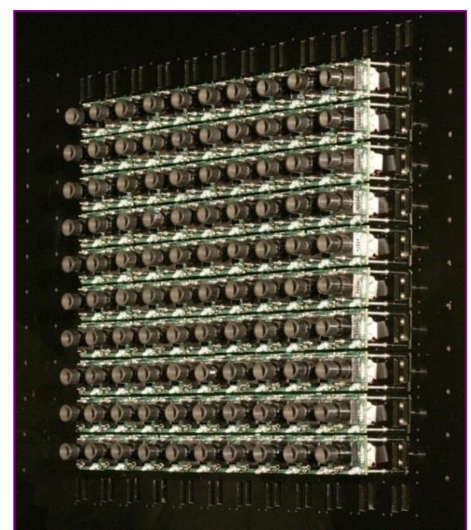
CORDIN
SCIENTIFIC IMAGING



Computational photography

Camera Array
Mark Levoy, Stanford

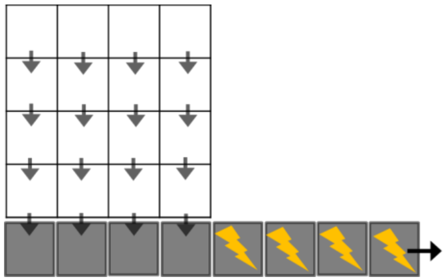
Wilbern *et.al.*, CVPR, 2004.



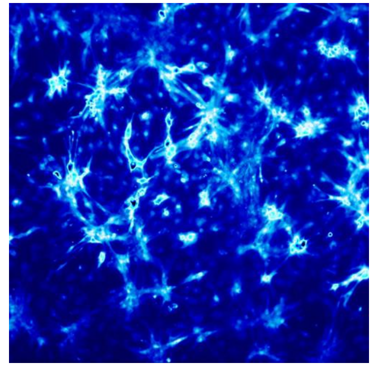
2: High speed imaging strategies – ccd and cmos architecture

High speed imaging

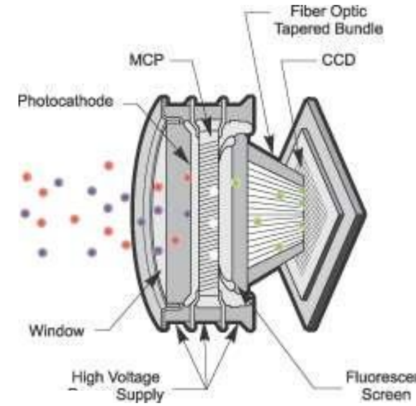
Intensified



emCCDs

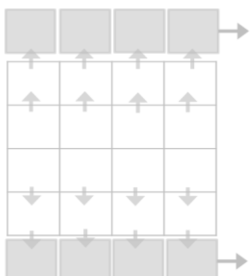


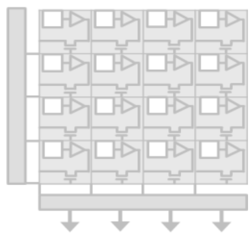
iCCDs



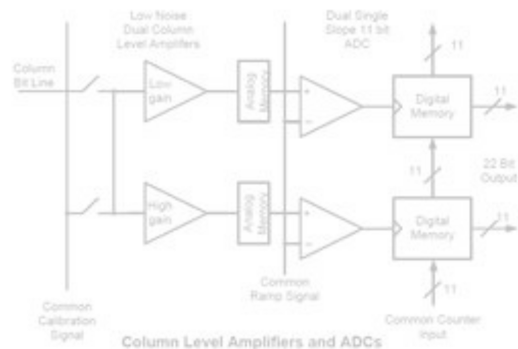
30fps

Parallelized

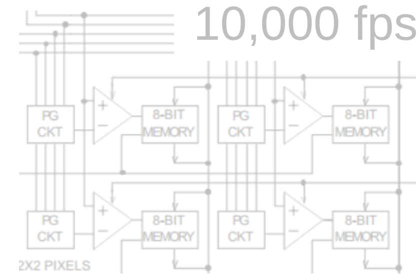




'sCMOS'



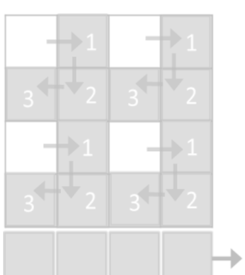
100 fps

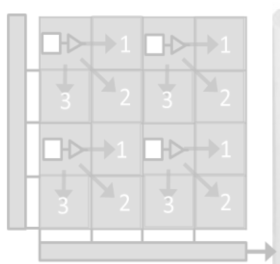


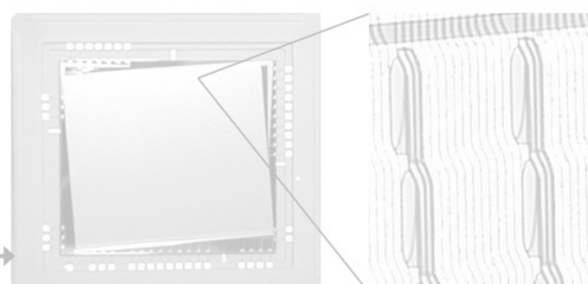
10,000 fps

Kleinfelder , ISSCC 2001.

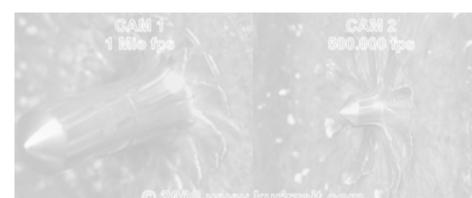
ISIS





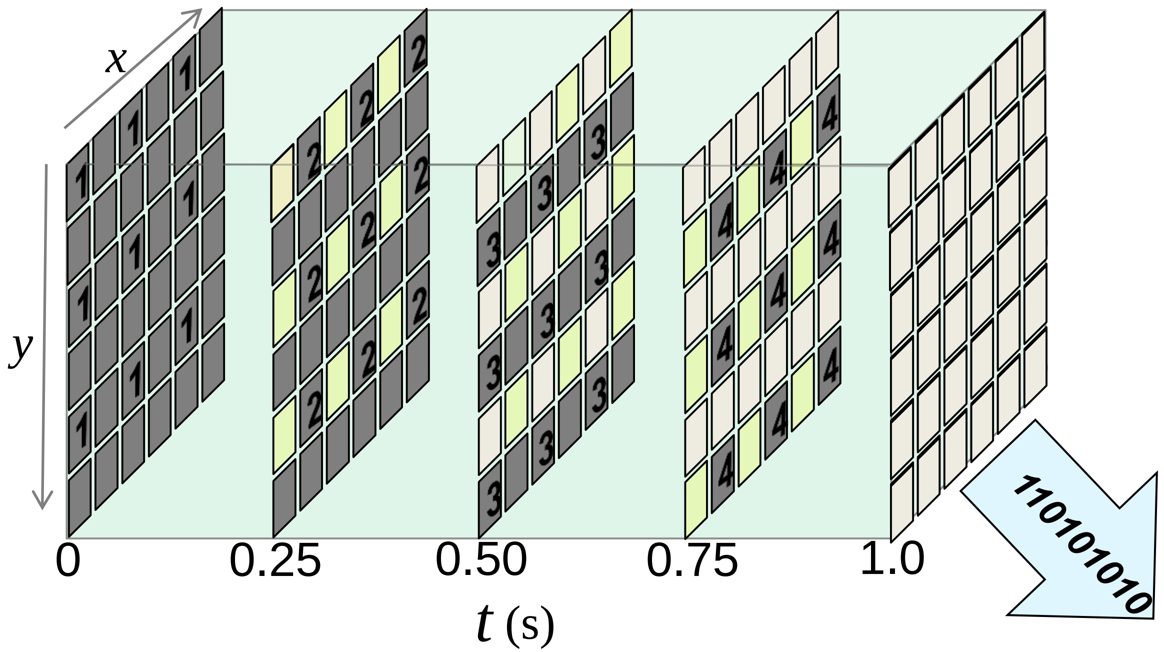


1,000,000 fps



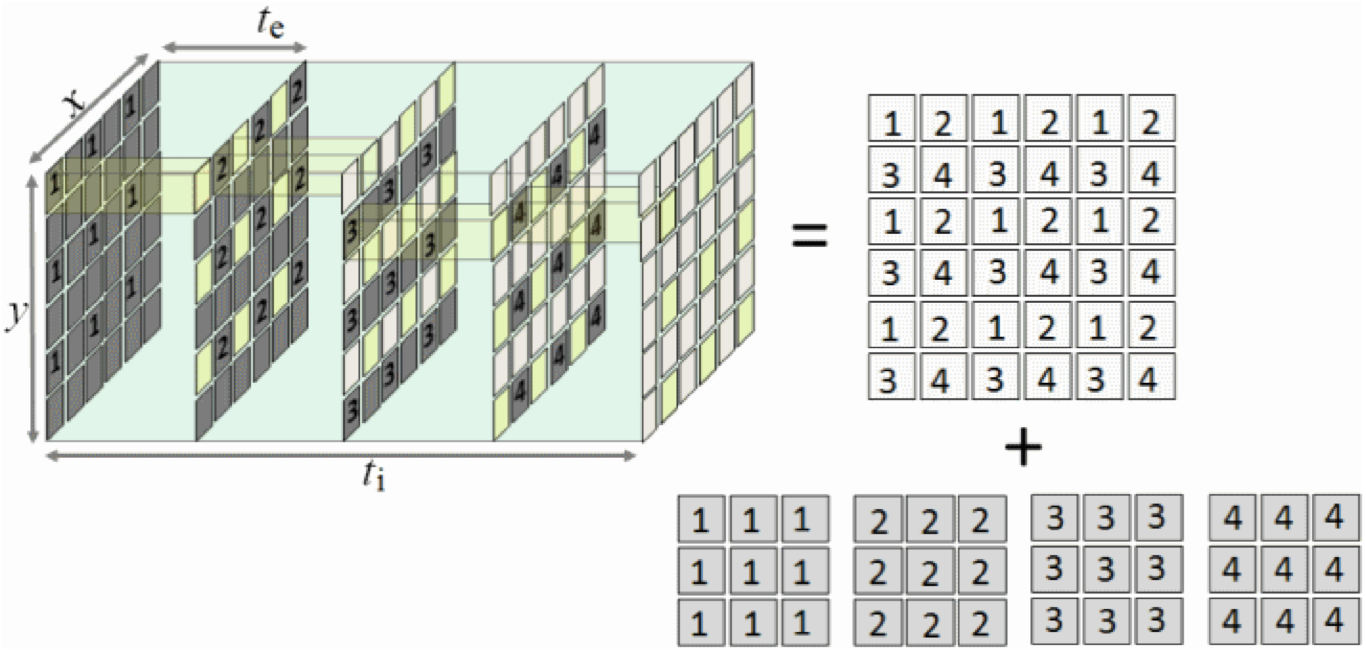
In Situ Image Sensor: Etoh, Ann Rev Fluid Mech 2008.

TPM – a new imaging modality



Temporal Pixel Multiplexing (TPM)

TPM – a new imaging modality



Gives a high resolution image & a high speed image sequence –

- ***in a single picture***
- ***with no added read noise***

TPM – a working prototype

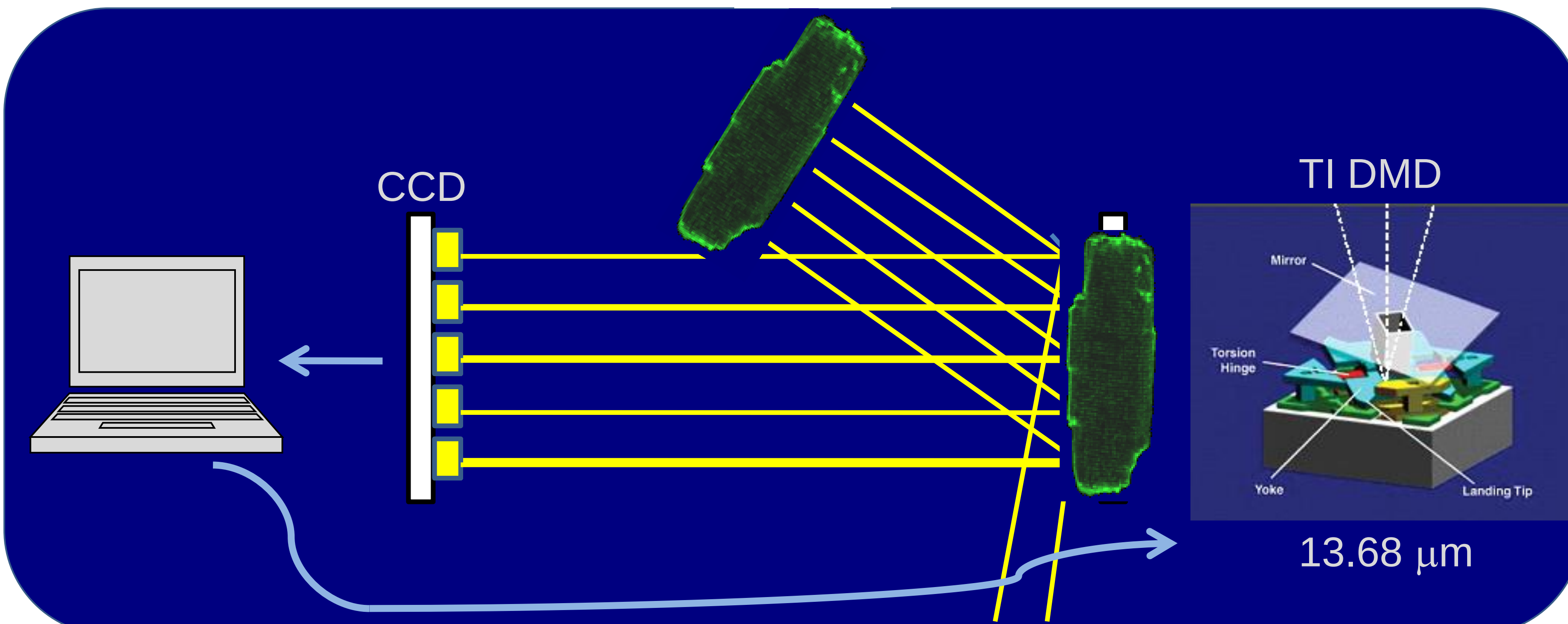
Challenge:

How do you control light at the pixel level?

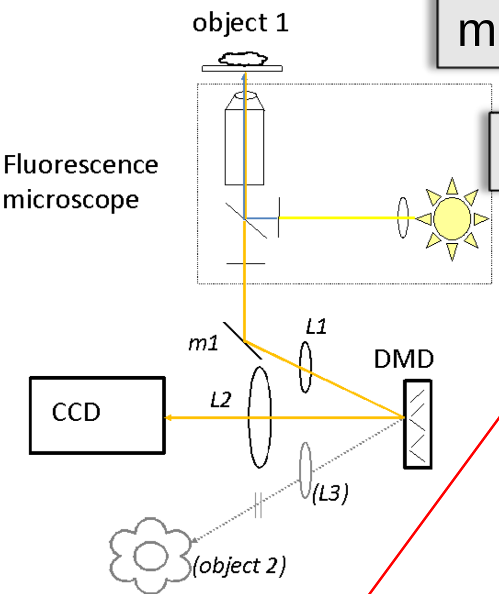
Approach:

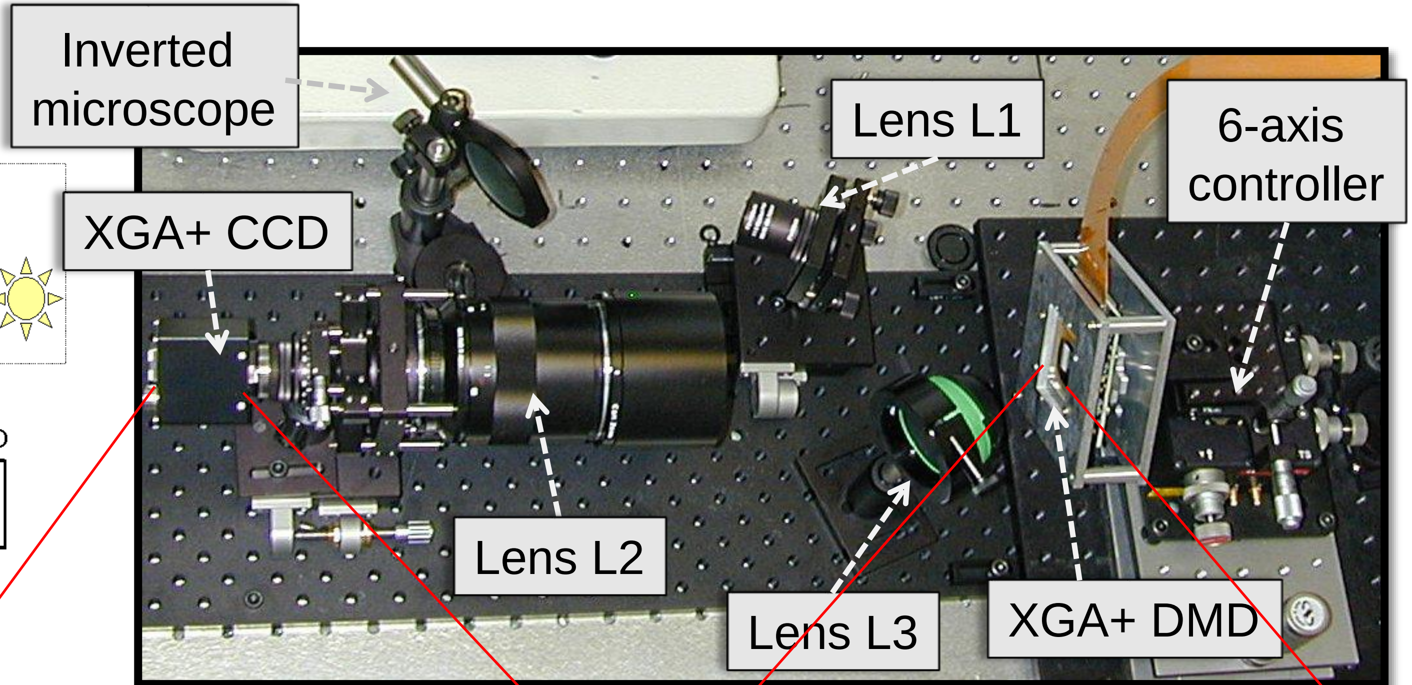
Use Digital Micromirror Device (DMD) array technology

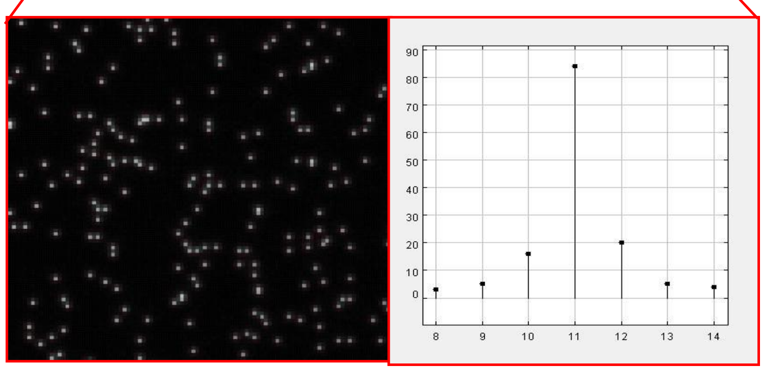
- TI DMD invented over 20 years ago... now ubiquitous.
- Used in many experimental microscopy/photography apps

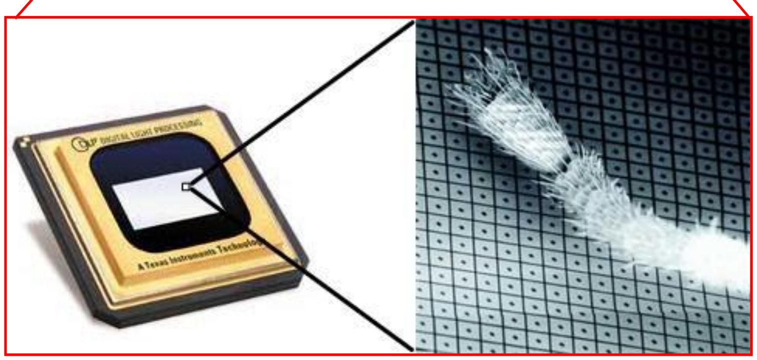


TPM – a working prototype

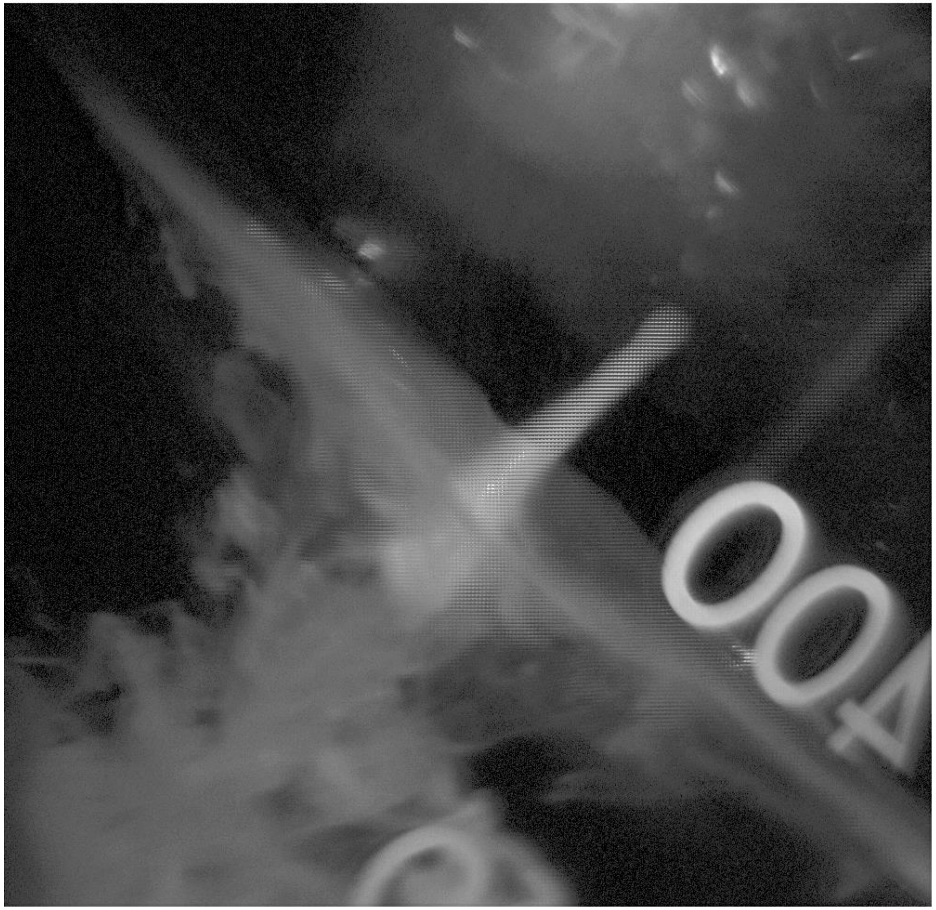








TPM in action



25 fps camera

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

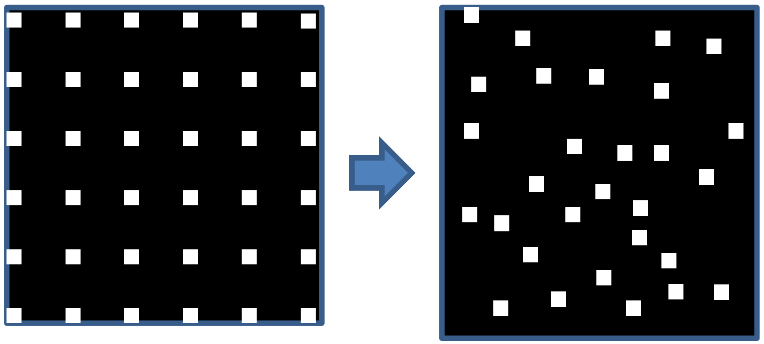
exposure group

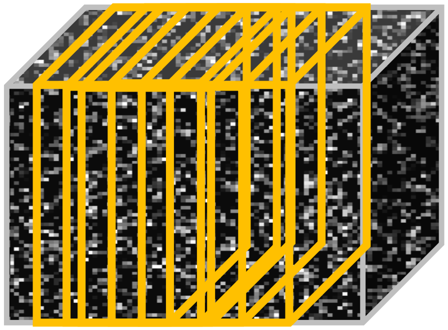
400 fps movie

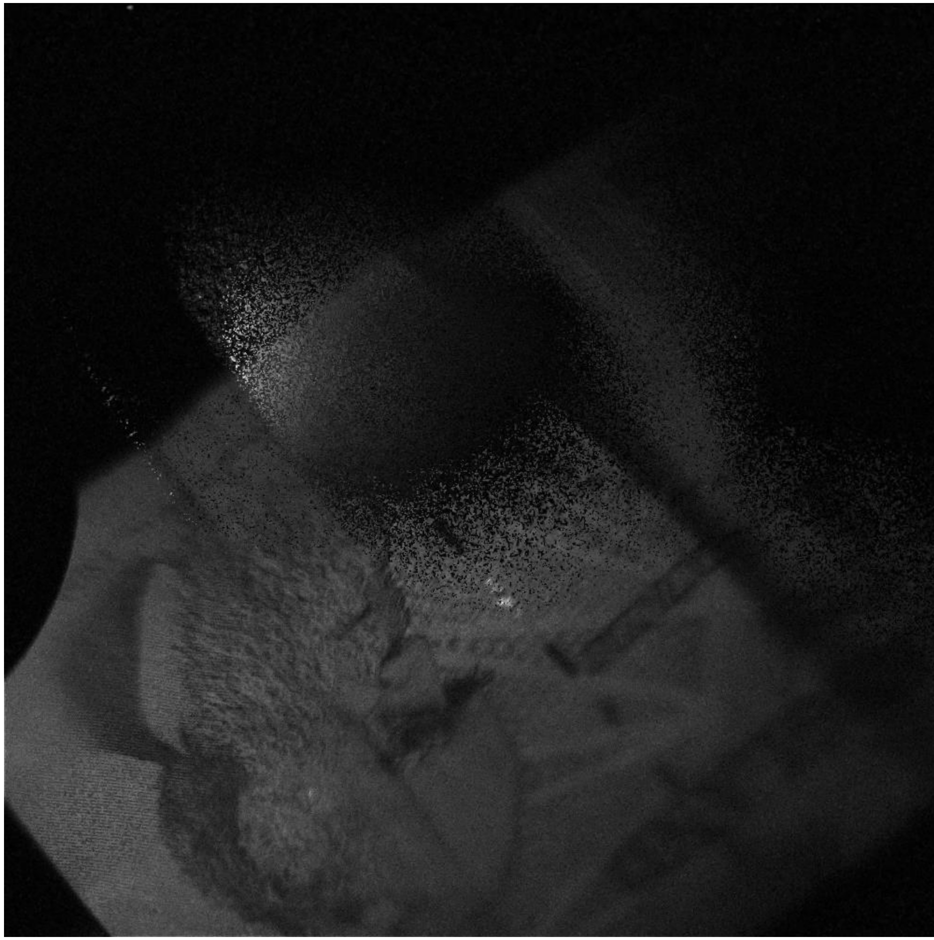
Bub *et al*., **Nature Methods** 2010.

Multiresolution imaging

Can we embed many resolutions in a image?





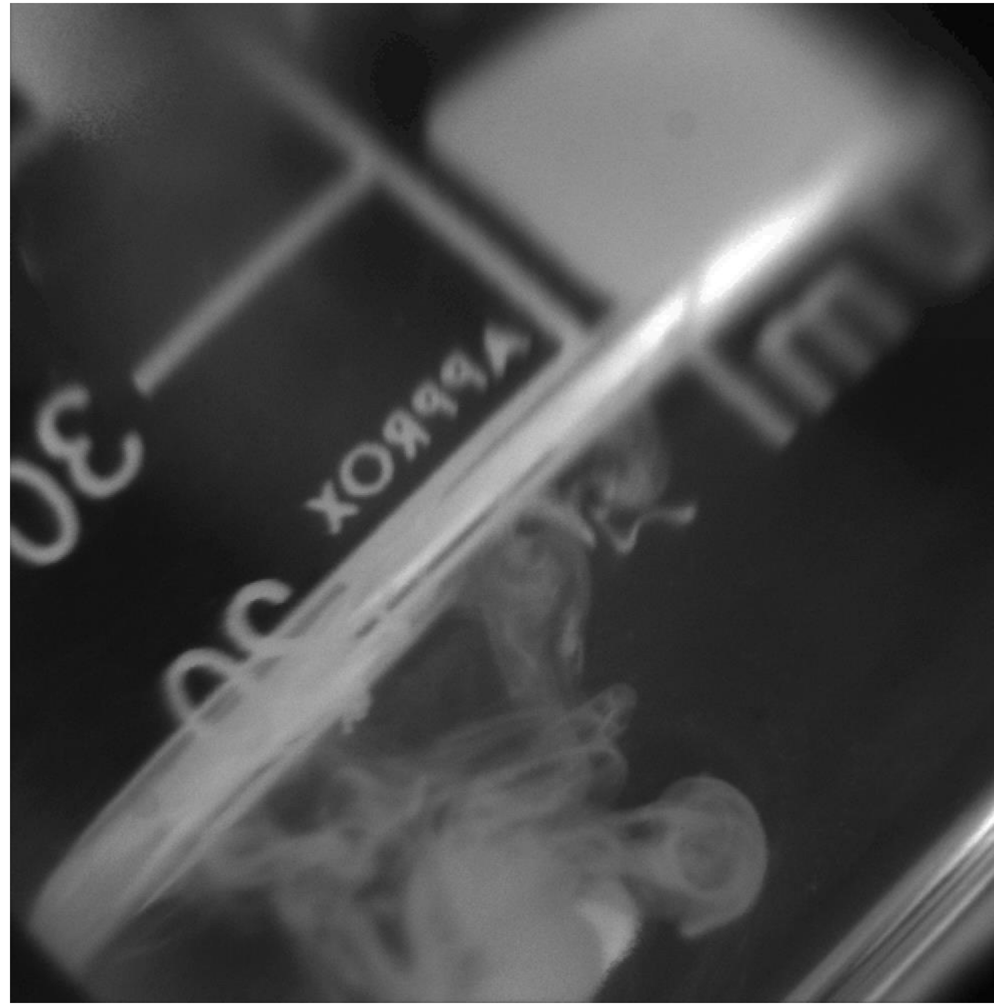


By varying the time window, embed *many* spatial/temporal resolutions in a *single* image....

work in progress

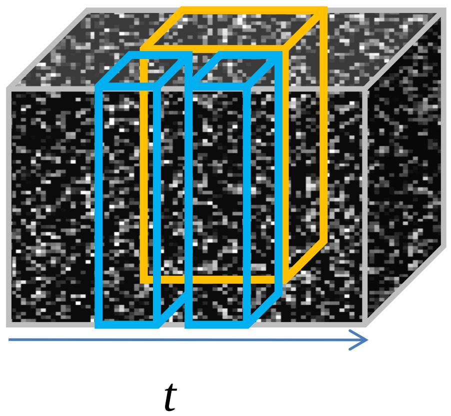
Multiresolution imaging

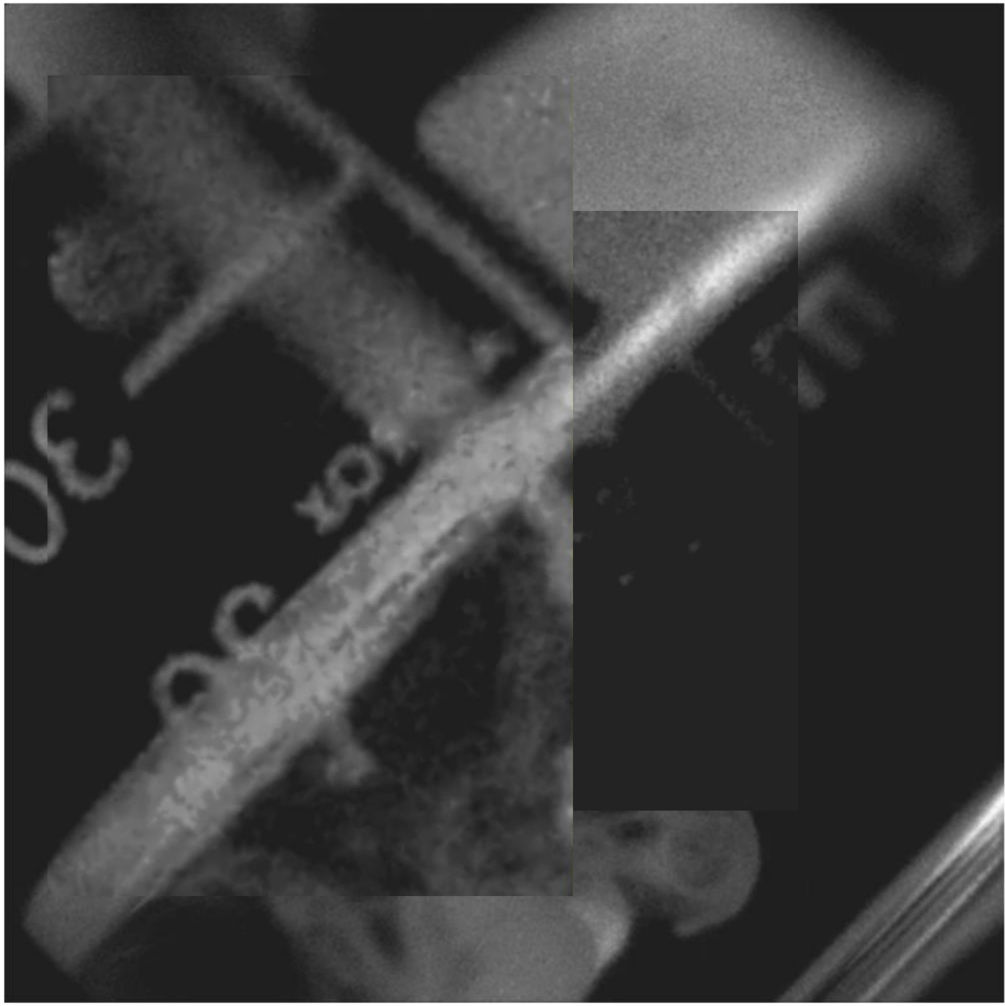
20 frames captured
at 25 fps



work in progress

Multiresolution imaging





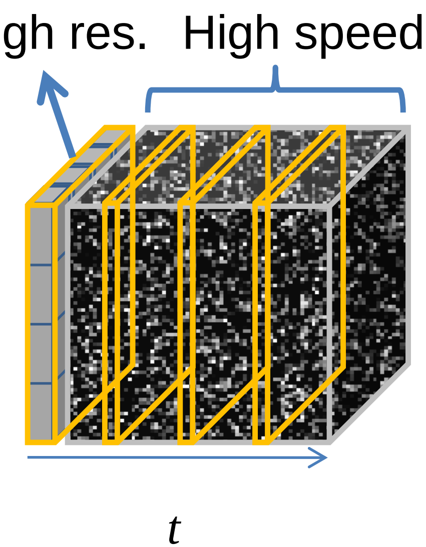
1250 fps 280 fps

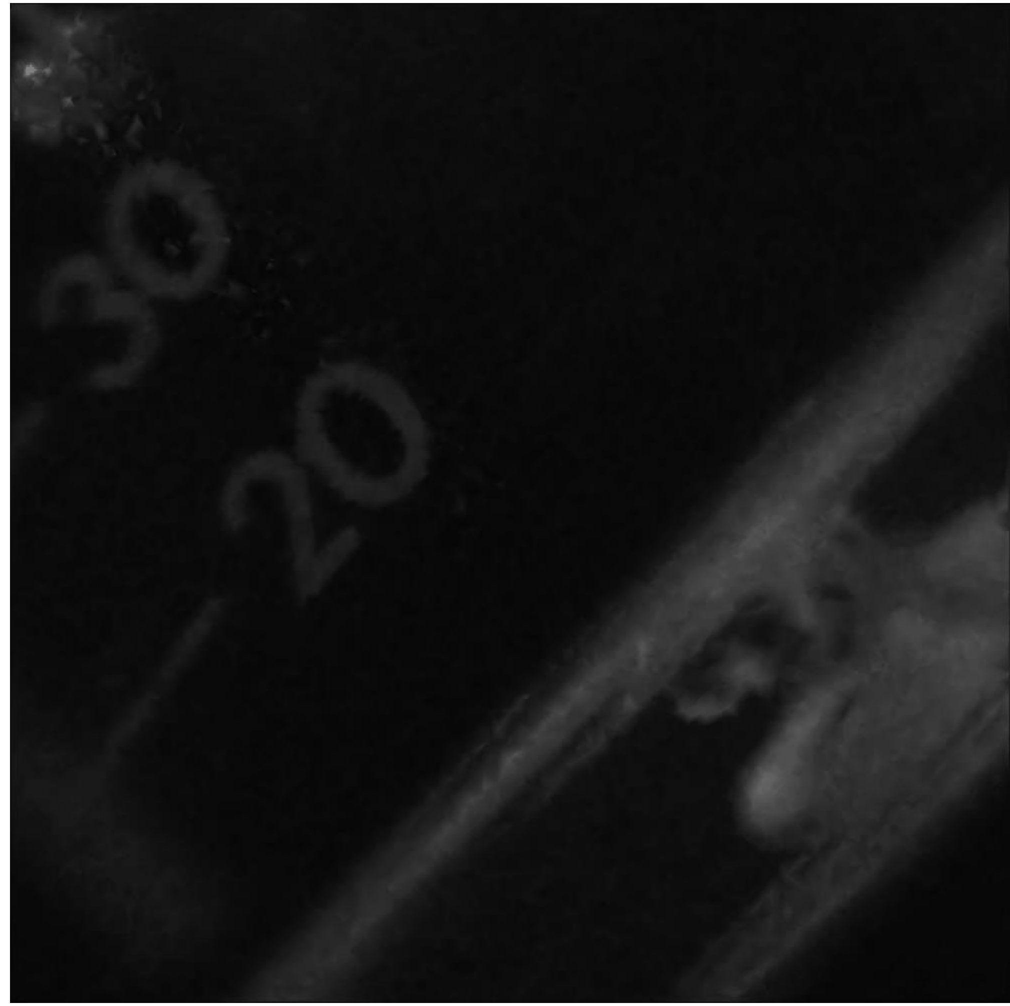
Able to ‘zoom in’ to ***any*** spatial and temporal resolution, ***after*** the picture is taken!

also see: Gupta et al, “Flexible Voxels for Motion-Aware Videography”, ECCV 2010

Multiresolution imaging

Can TPM acquire
sharp high-res images
& high speed video?

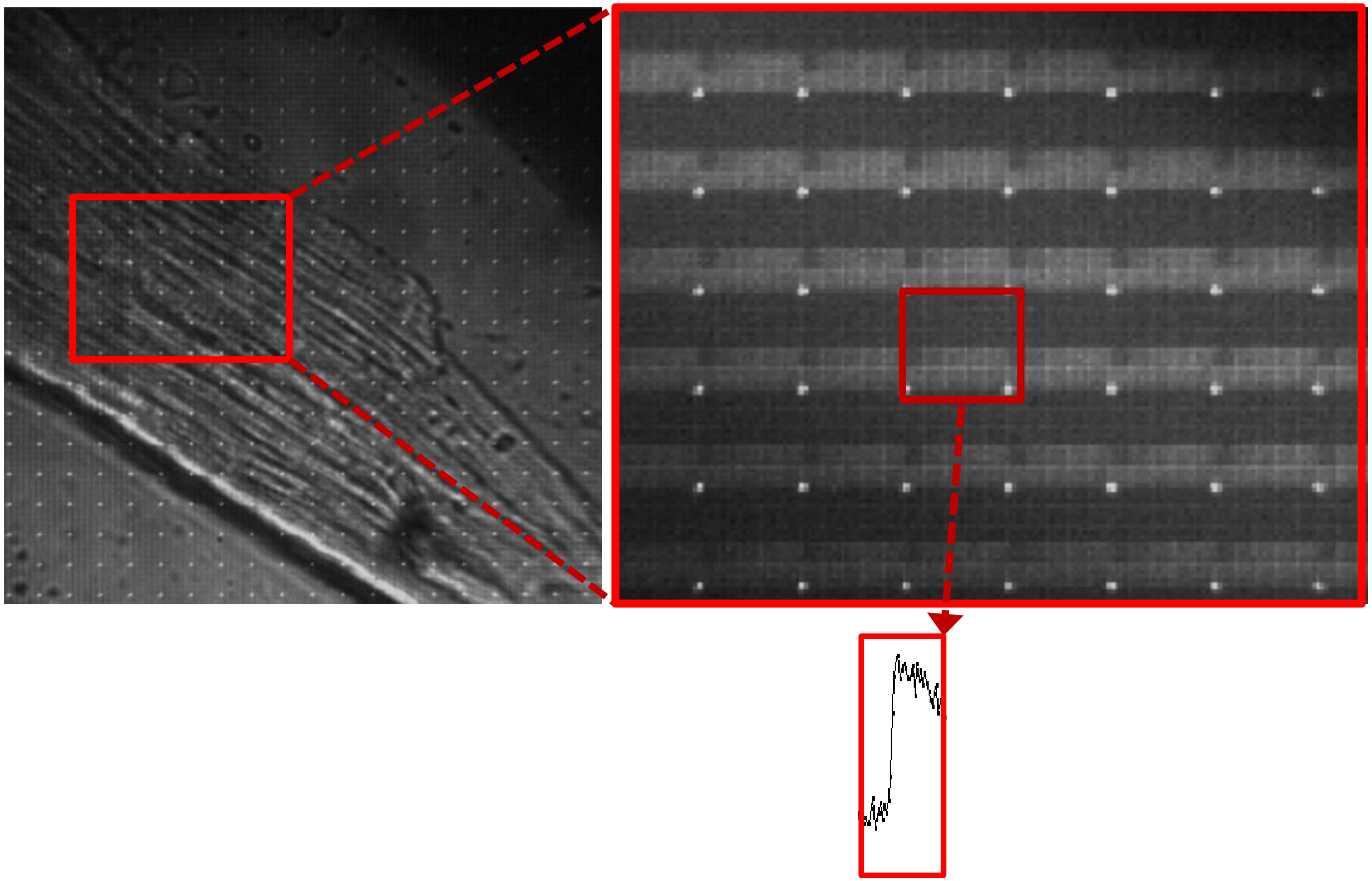




Flexibility: *One* Detector = *many* cameras

work in progress

Calcium transients

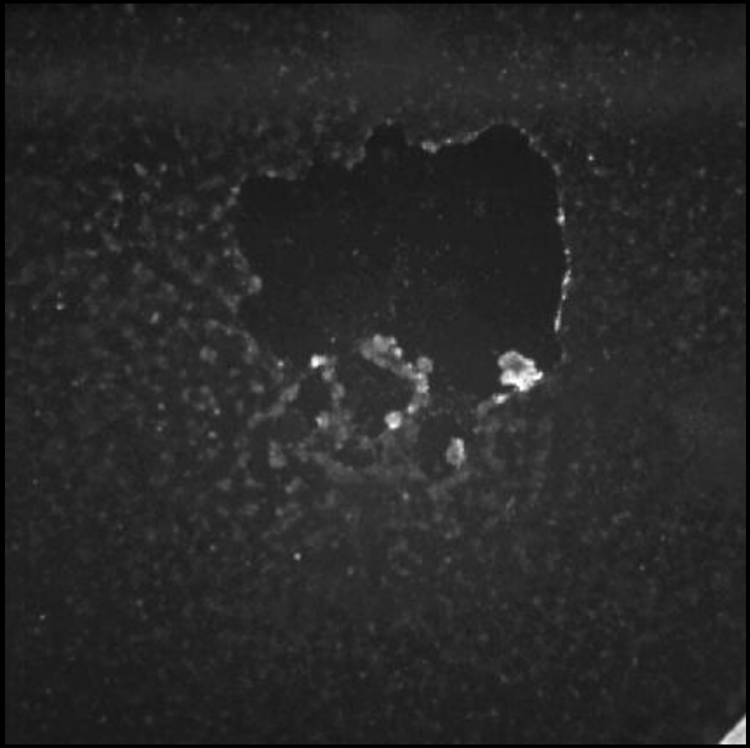


10 FPS camera

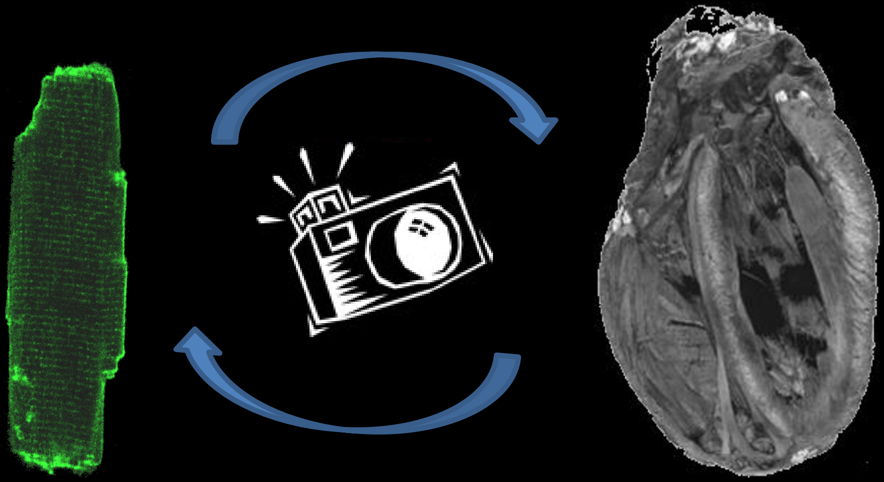
250 FPS Ca^{++} transient

Bub et al., Nature Methods 2010.

…what is it good for?



- Post capture zoom:
  see cause & effect
- Long term recording:
  image rare events
- Megapixel+ resolution:
  structure vs. function

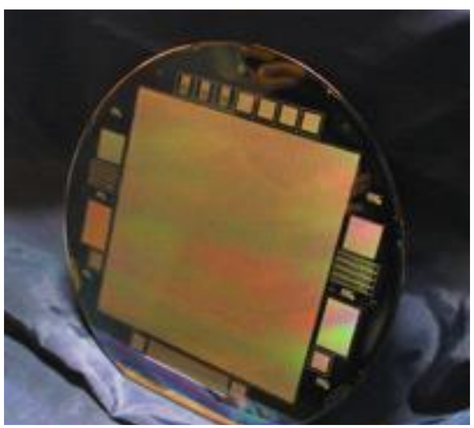


summary

TPM

... is a first step towards a multi-scale imaging modality for the life sciences:

- Combines speed, resolution and flexibility
- Takes advantage of emerging imaging paradigms
  - Sophisticated computational techniques
  - Increasing camera resolutions

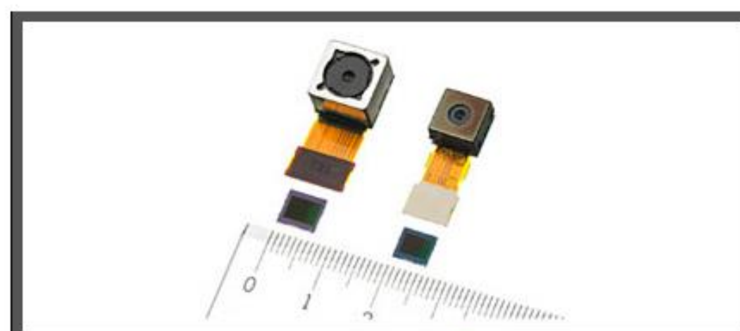


Press Releases

DALSA Semiconductor Delivers World's First 100+ Million Pixel CCD Image Sensor Chip to Semiconductor Technologies Associates (STA)

Posted 6/19/2006

Sony commercializes world's first*1 16.41 Megapixel "Exmor R™" back-illuminated CMOS image sensors for mobile phones



*Also announces industry's smallest and thinnest*1 lens module for mobile phones*

TPM on-a-chip...

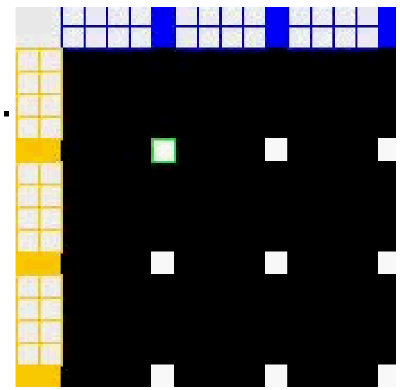
Why?

Increased resolution, dynamic range & speed.

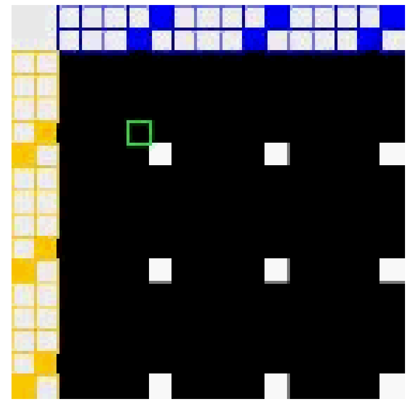
How?

Joint project between Oxford & Nottingham

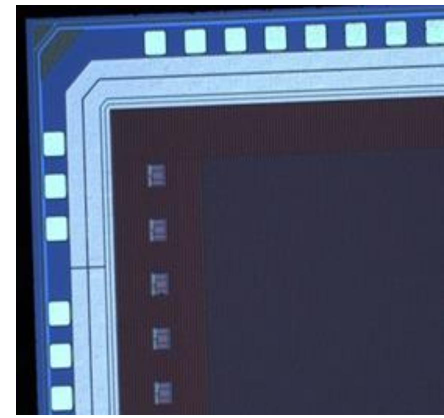
Roger Light
Mark Pitter
Mike Somekh



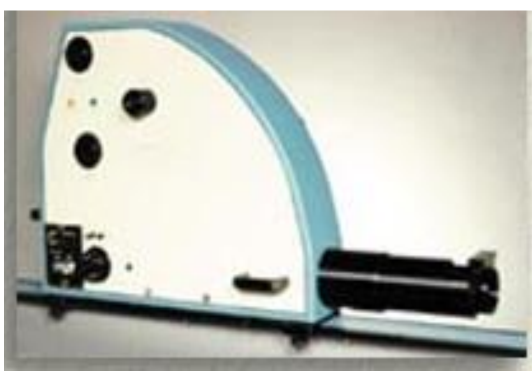
5x5 row by row



5x5 complex



200x200 prototype (first light - 3 months)



CORDIN
SCIENTIFIC IMAGING

High speed imaging (10,000 – 1,000,000 fps)

– To compete with Shimadzu camera.

– Cordin to fund & market final 4 megapixel TPM chip design.

TPM+: A general platform for computational photogra

What’s next: TPM on a chip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Published: 7:30AM GMT 15 Feb 2010
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Imaging at 1,000,000 fps

Joint project between


Lfoundry Rousset fab closes with loss of 600 jobs

January 02, 2014 // Peter Clarke

Lfoundry Rousset, the French chip manufacturing site of Lfoundry GmbH, has been declared bankrupt by the Commercial Court of Paris, with an immediate stop to activities on the site from Dec. 26 and the loss of 613 jobs, according to French reports.

Page 1 of 2

The move has prompted angry demonstrations by the workforce in Rousset and Marsaille as well as allegations that Lfoundry in Germany misappropriated 20 million (about $27.5 million) from Lfoundry in France. The German group is now the subject of a French criminal investigation, according to a report in *Le Figaro*.

Analog and mixed-signal chip maker Lfoundry bought the Rousset site from Atmel Corp. in 2010 for 1 together with a lengthy order book and Atmel was the main customer for Rousset until mid-2013.

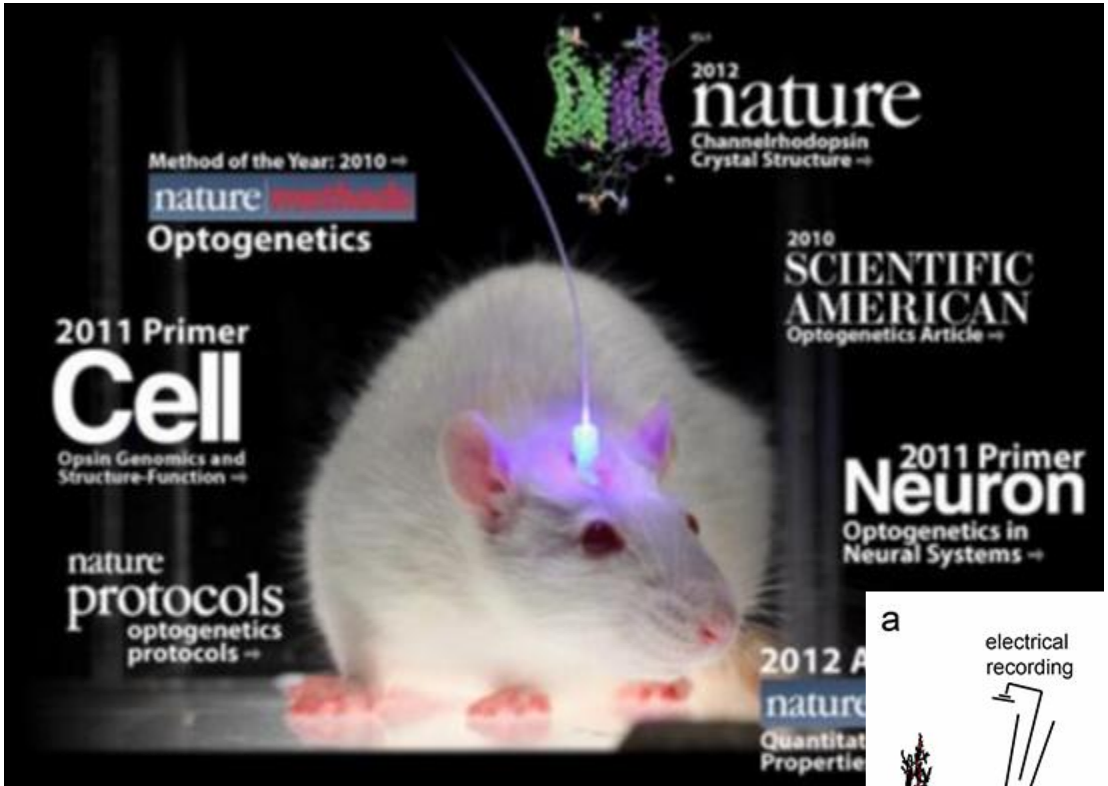
However, when Atmel’s requirement turned down suddenly in June 2013 the Commercial Court in Paris placed Lfoundry into receivership with a six-month observation period to give time to develop a continuation plan for the business.

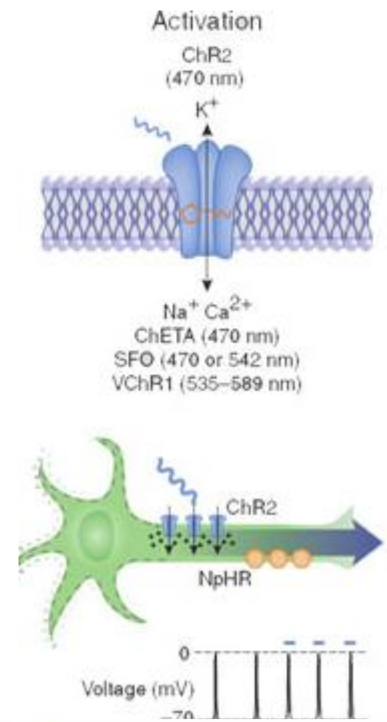
A voluntary redundancy plan was sketched out in November 2013 (see *Jobs to go at Lfoundry Rousset*) but it has failed to postpone the closure of the business.

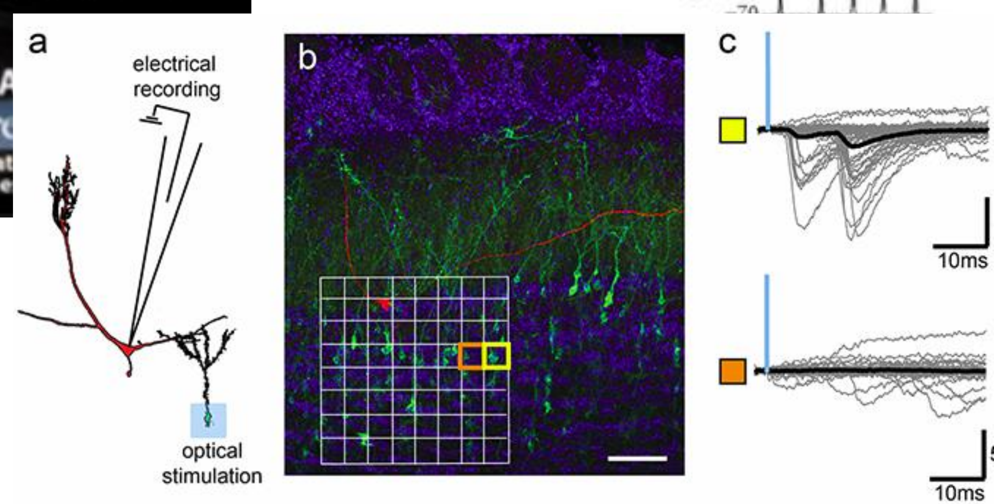
The Rousset site will be preserved for a further three months while efforts continue to try and find a buyer but this will be for the site and equipment rather than for the business as a going concern with employees.

CORDIN
SCIENTIFIC IMAGING

Part 2: optogenetics







Thank you!

TPM Experiments: Matthias Tecza, Michiel Helmes, Alex Quinn and Peter Kohl, with thanks to Martin Booth and Ramon Casero for discussions, and Richard Vaughan-Jones for isolated cells

CMOS development: Mark Pitter, Roger Light Mike Somekh, Nick Johnston & Nathan Nebeker

SL Experiments: Rebecca Burton, Alex Corbett, Ed Botcherby and Chris Smith, Martin Booth and Prof. Tony Wilson

Cell Culture: Rebecca Burton and David Paterson, with Ed Mann, Emilia Entcheva (Stonybrook), Harold Bien (Stonybrook), Aleks Klimas (Stonybrook), Kevin Webb (Nottingham), Hege Larsen, Sam Bilton, Guy Stevens, Dan Li, Chieh-Ju Lu, Julia Shanks, Amy Sharkey, Claudia Molina, Noah Evans, Richard Hall, Pok Tang, Joanna Lau, Jacub Tomek (DTC), Gary Mirams (Computer Science) and Blanca Rodriguez.

Proteomics: Rebecca Burton, Hege Larsen, Holger Kramer, Carla Schmidt, Profs Carol Robinson & David Paterson.

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