Light field photography

CS 178, Spring 2014

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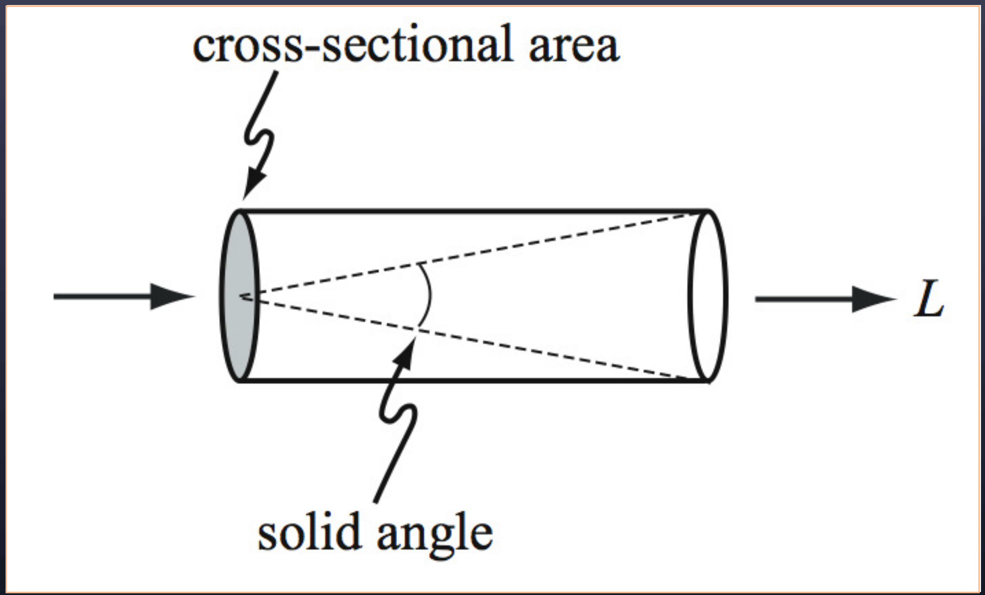
The light field
(in geometrical optics)

Radiance as a function of position and direction in a static scene with fixed illumination

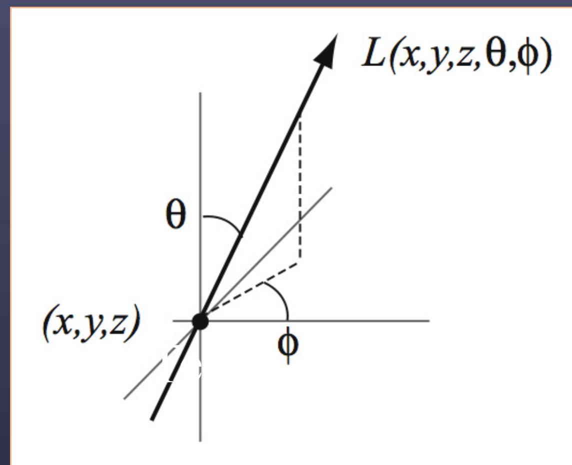


L is radiance in watts / (m^2 steradians)

Dimensionality of the light field

- for general scenes

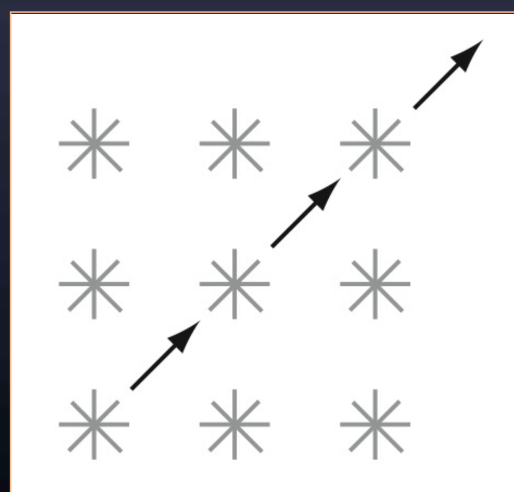
  ⇒ 5D function



$L(x, y, z, \theta, \phi)$

- in free space

  ⇒ 4D function

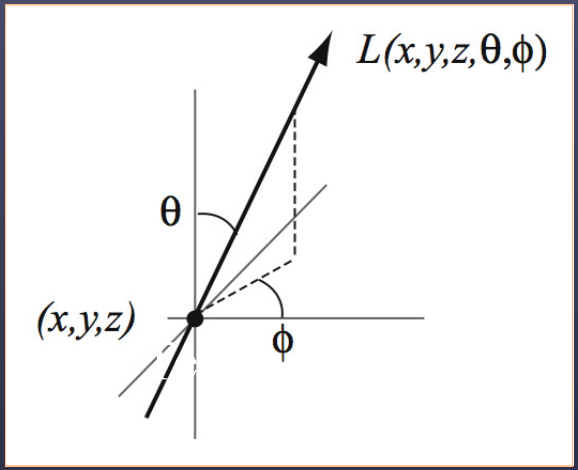


L (?)

Dimensionality of the light field

- for general scenes

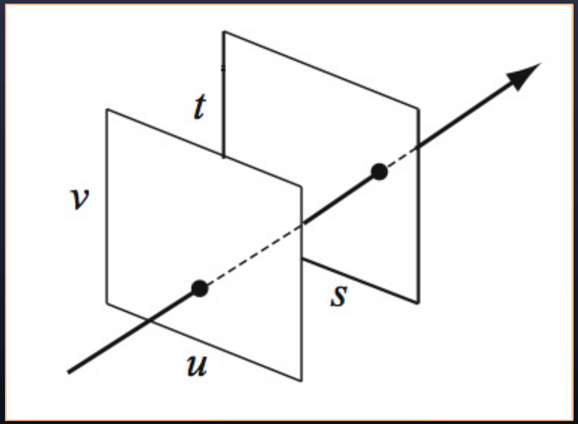
  $\Rightarrow$ 5D function



$L(x, y, z, \theta, \phi)$

- in free space

  $\Rightarrow$ 4D function



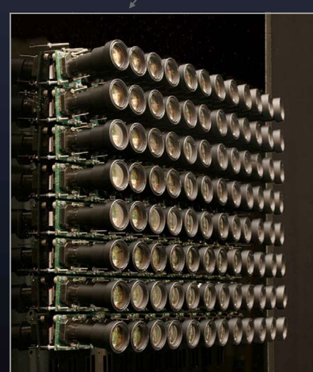
$L(u, v, s, t)$

two-plane parametrization

Devices for recording light fields

big scenes ↕ small scenes

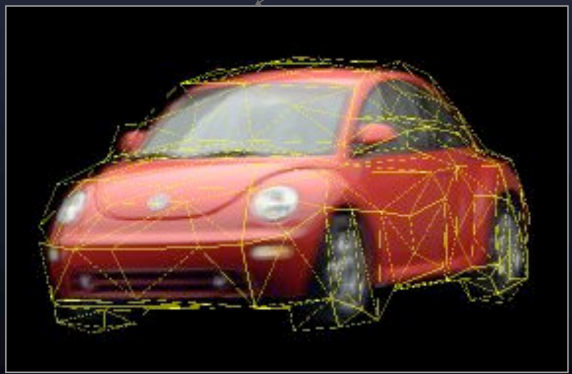
- handheld camera [Buehler 2001]
- array of cameras [Wilburn 2005]
- plenoptic camera [Ng 2005]
- light field microscope [Levoy 2006]

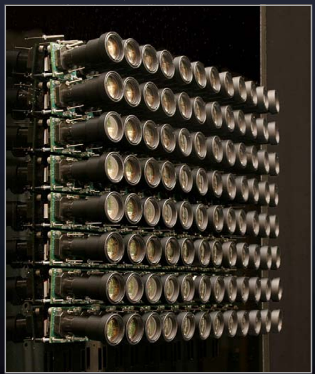



Devices for recording and creating light fields

big scenes ↕ small scenes

- handheld camera [Buehler 2001]
- → array of cameras [Wilburn 2005]
- → plenoptic camera [Ng 2005]
- → light field microscope [Levoy 2006]
- → light field illumination



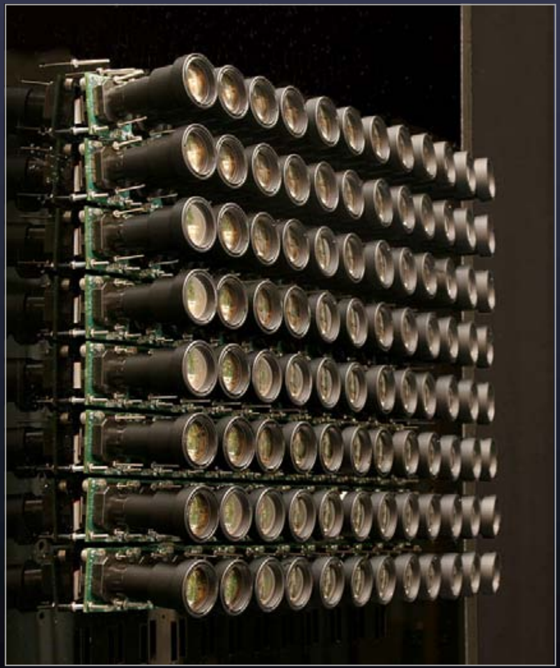


Stanford Multi-Camera Array

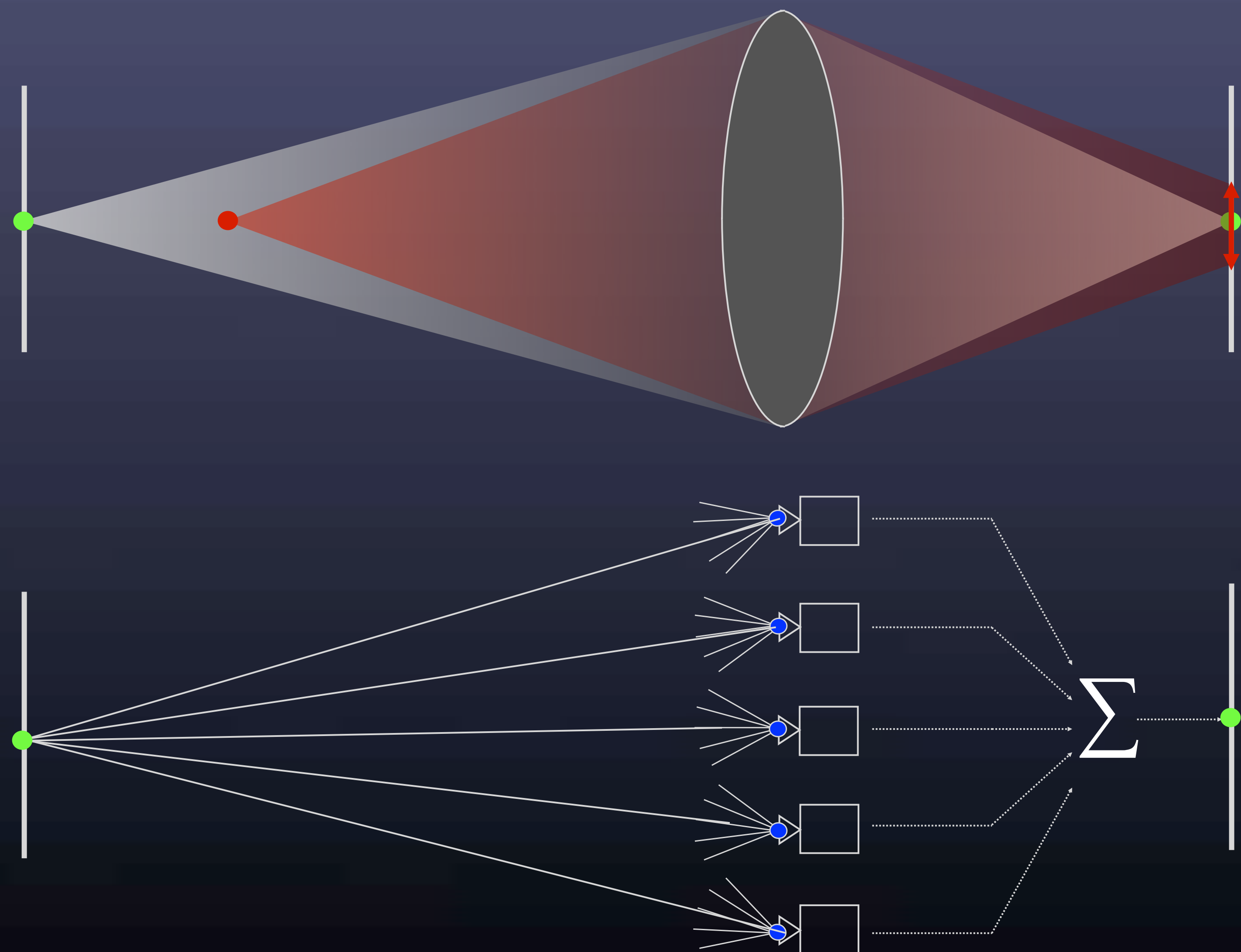
[Wilburn SIGGRAPH 2005]

- 640 × 480 pixels × 30 fps × 128 cameras

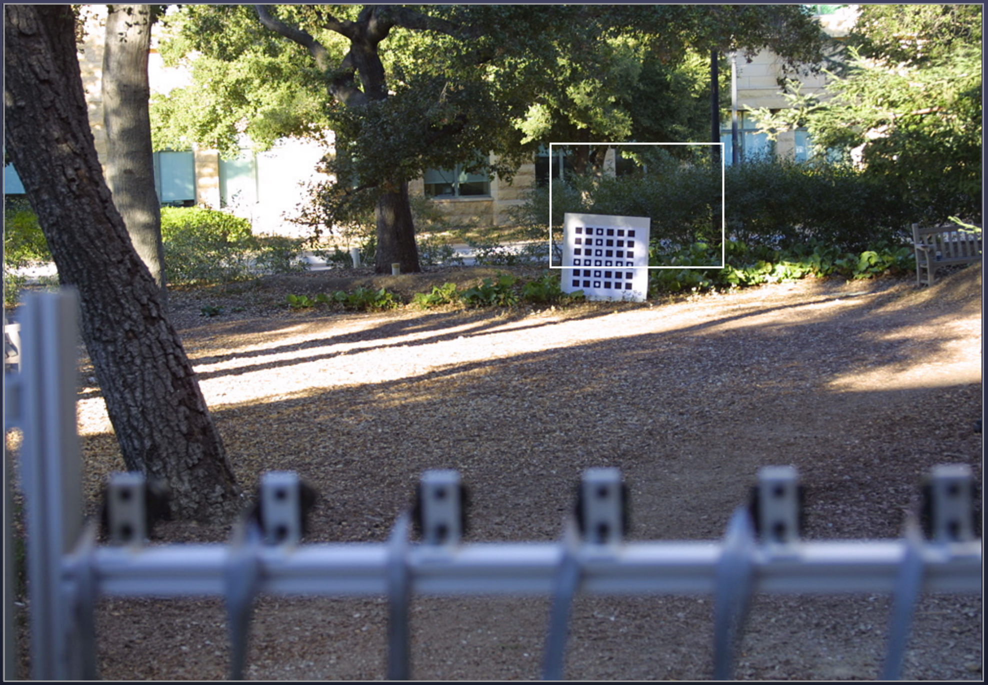
- synchronized timing
- continuous streaming
- flexible arrangement



Synthetic aperture photography



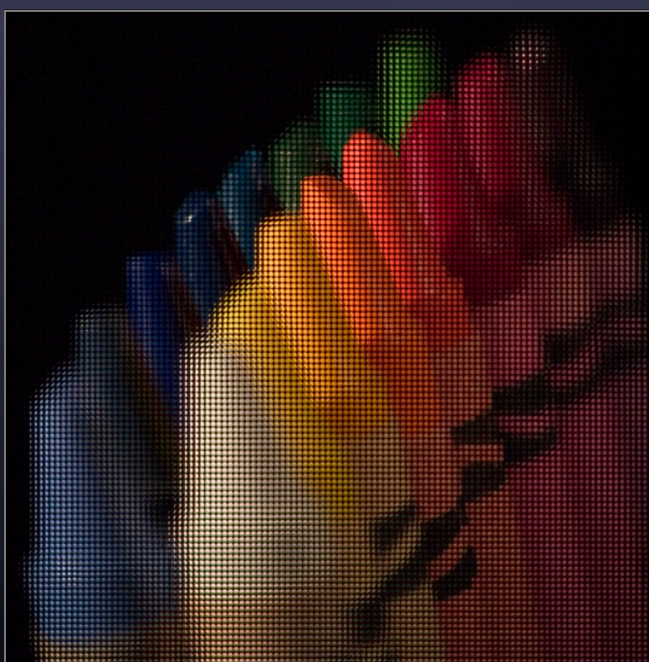
Example using 45 cameras
[Vaish CVPR 2004]



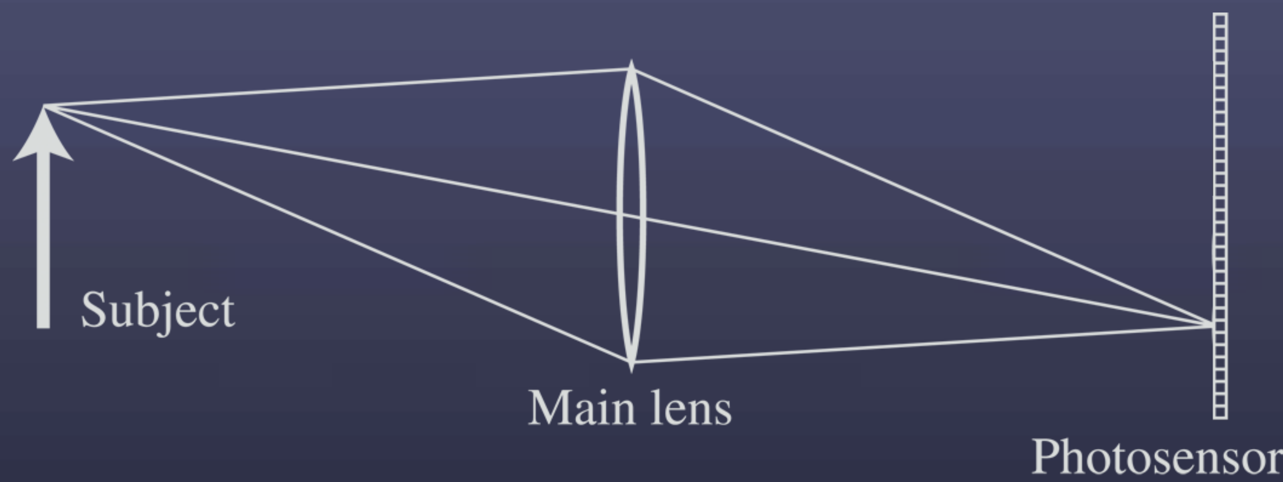

Light field photography using a handheld plenoptic camera

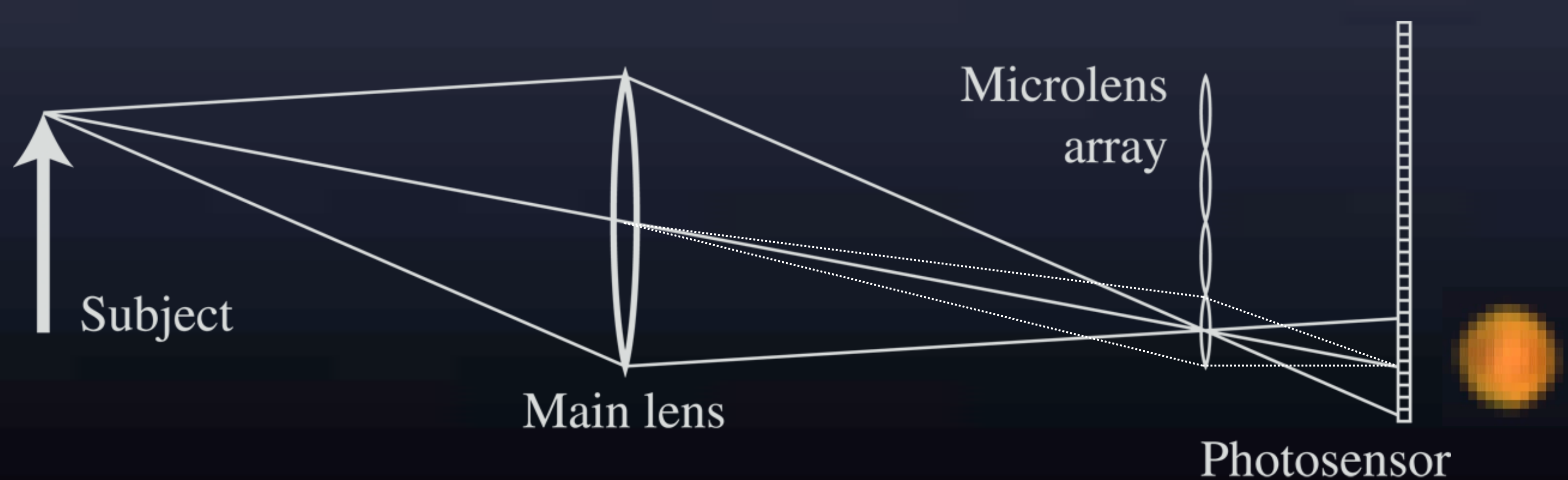
Ren Ng, Marc Levoy, Mathieu Brédif,
Gene Duval, Mark Horowitz and Pat Hanrahan

(Proc. SIGGRAPH 2005
and TR 2005-02)

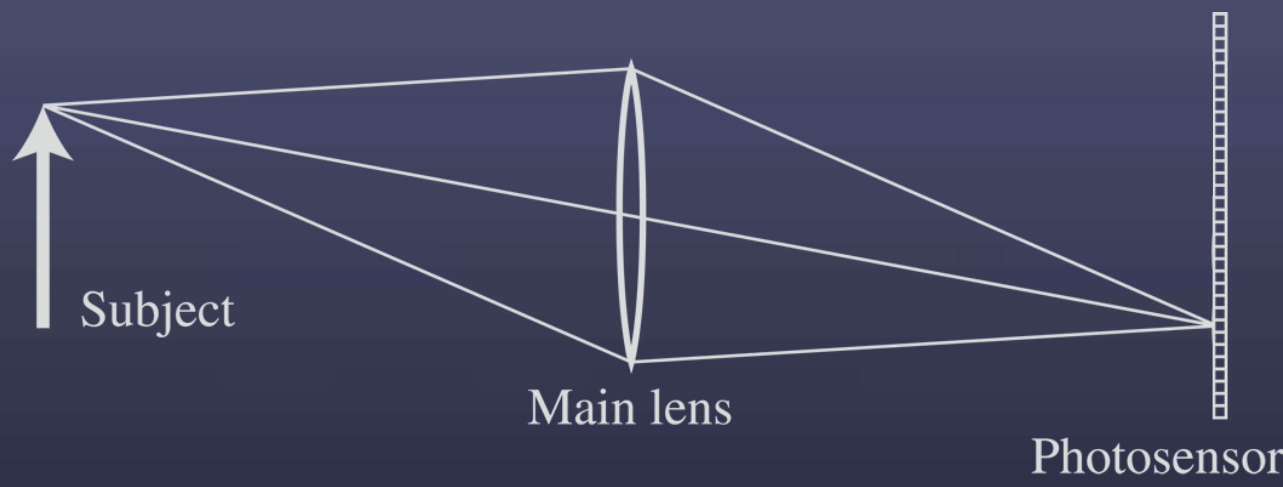


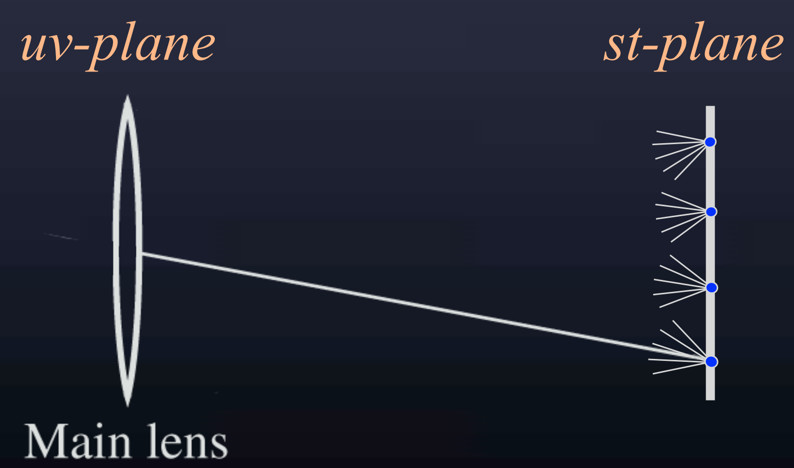
Conventional versus light field camera





Conventional versus light field camera

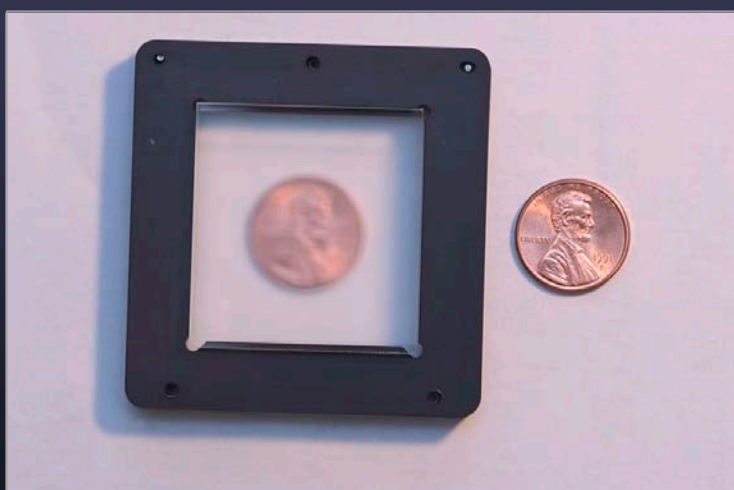




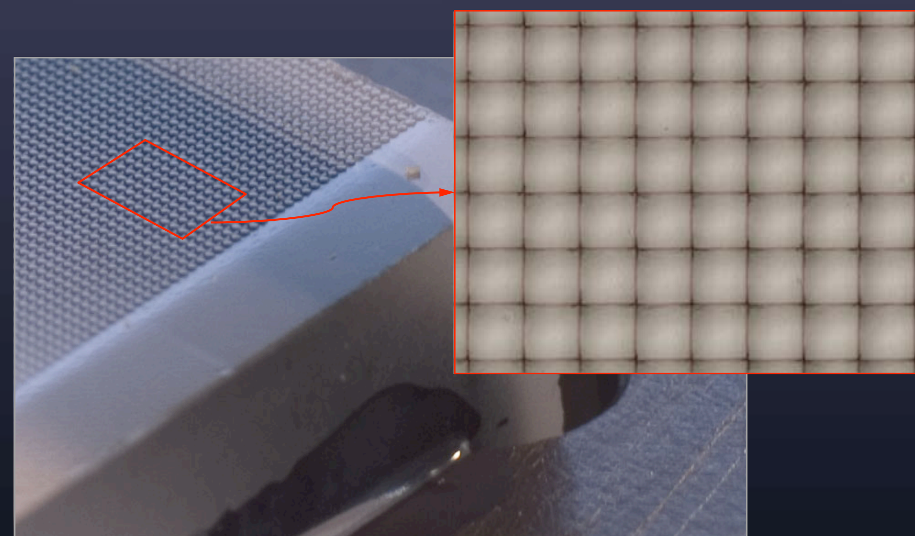
Prototype camera

Contax medium format camera

Kodak 16-megapixel sensor

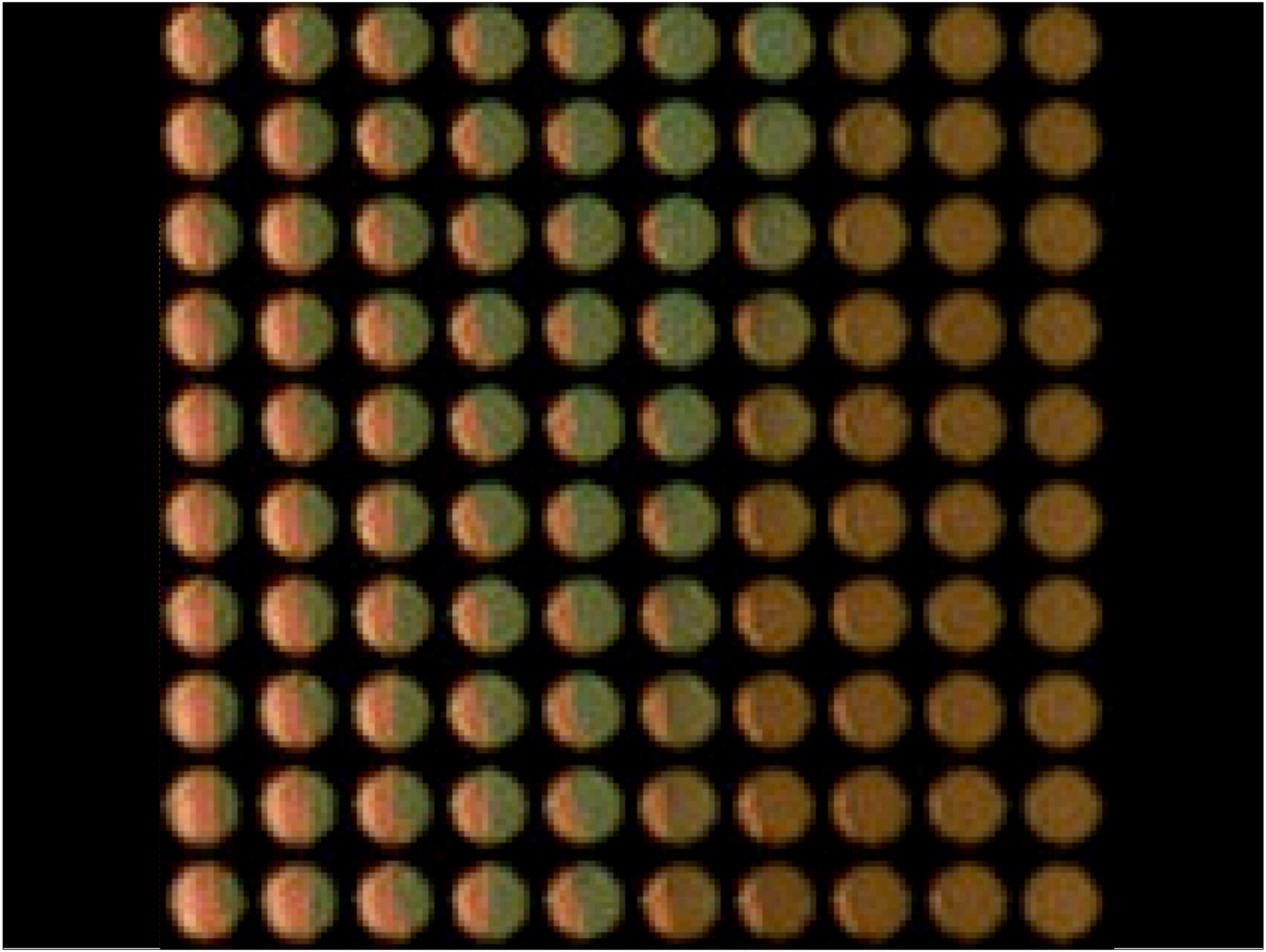


Adaptive Optics microlens array

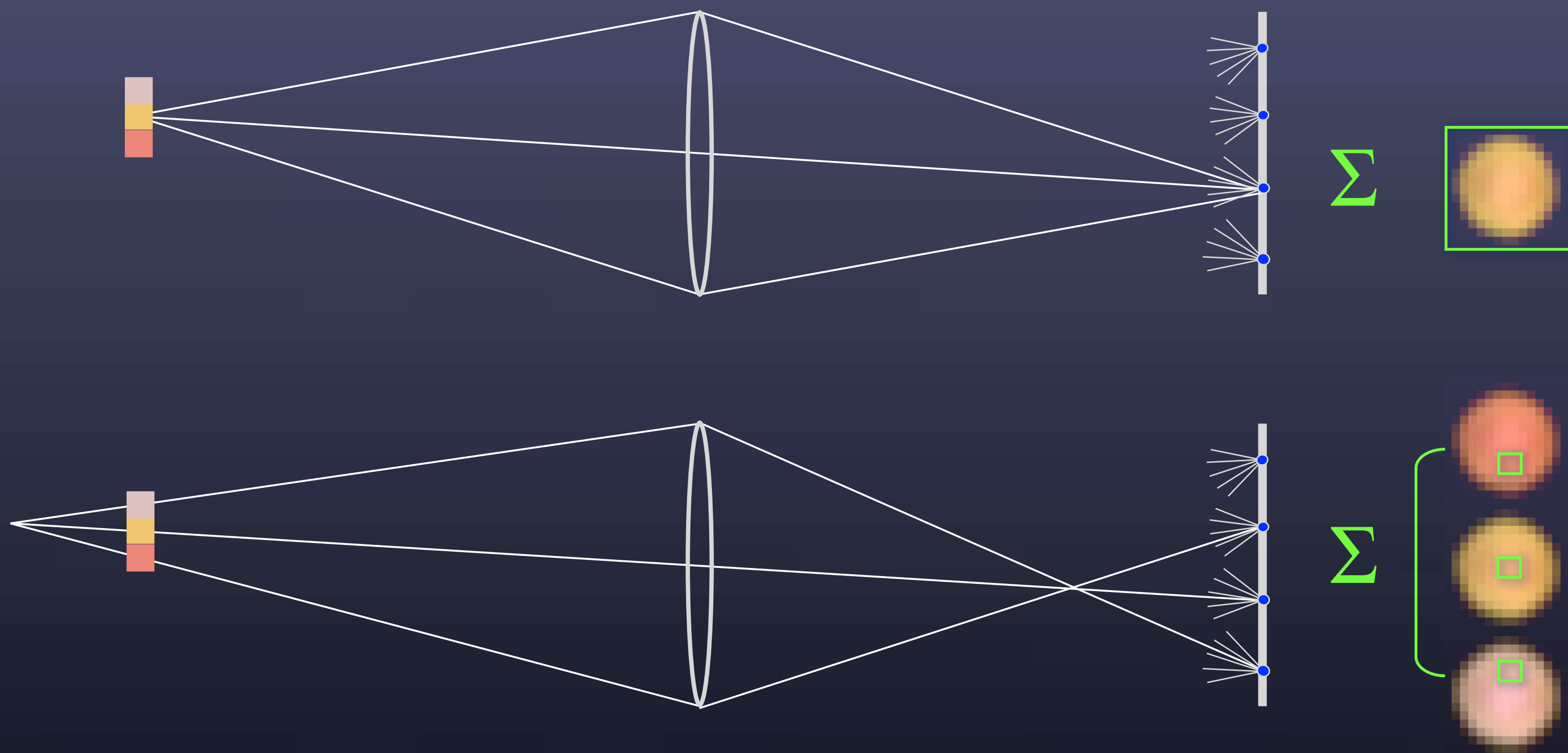


125μ square-sided microlenses

$$4000 \times 4000 \text{ pixels} \div 292 \times 292 \text{ lenses} = 14 \times 14 \text{ pixels per lens}$$

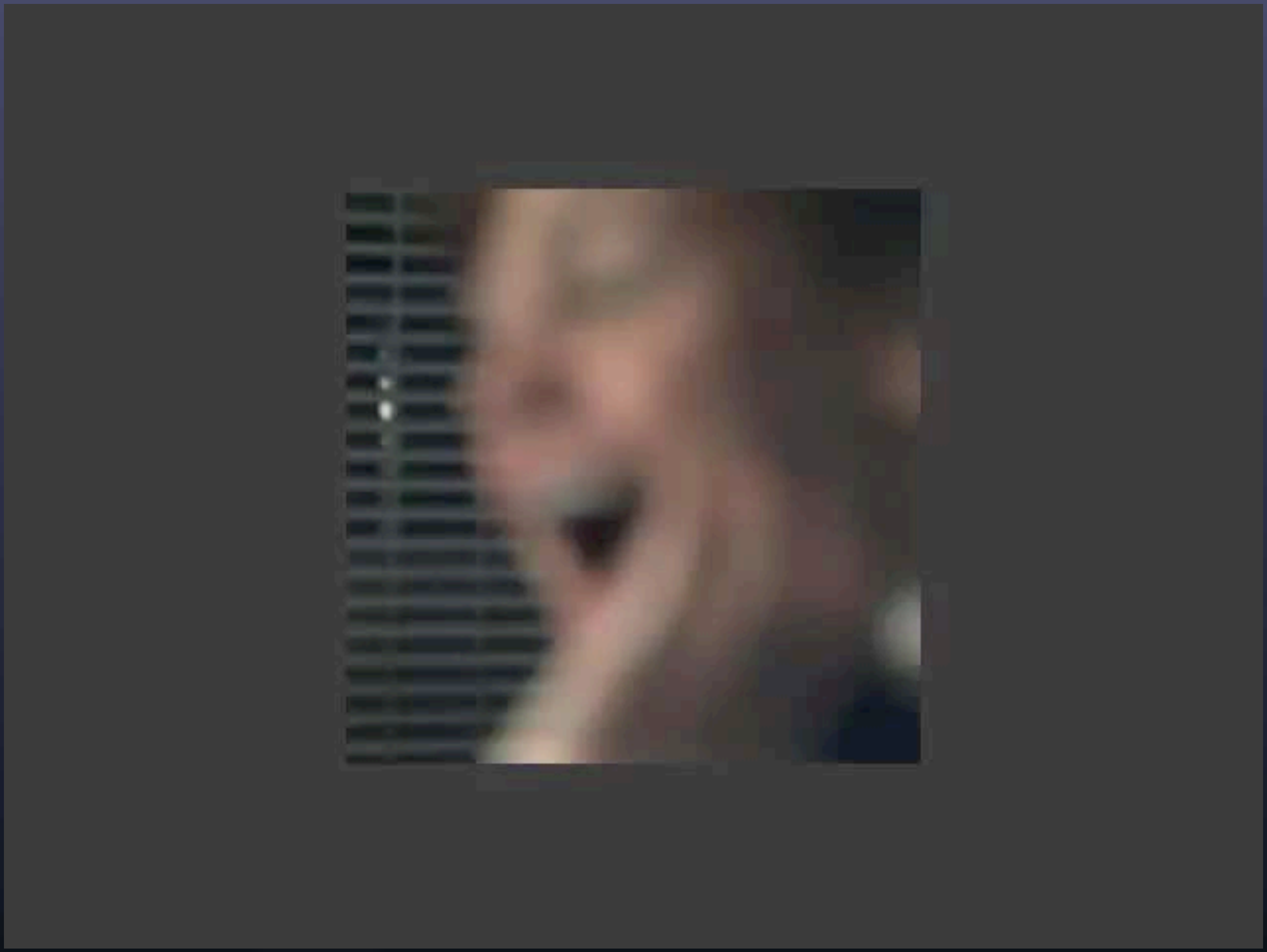


Digital refocusing



Example of digital refocusing

Refocusing portraits



Light field photography

(FLASH DEMO)

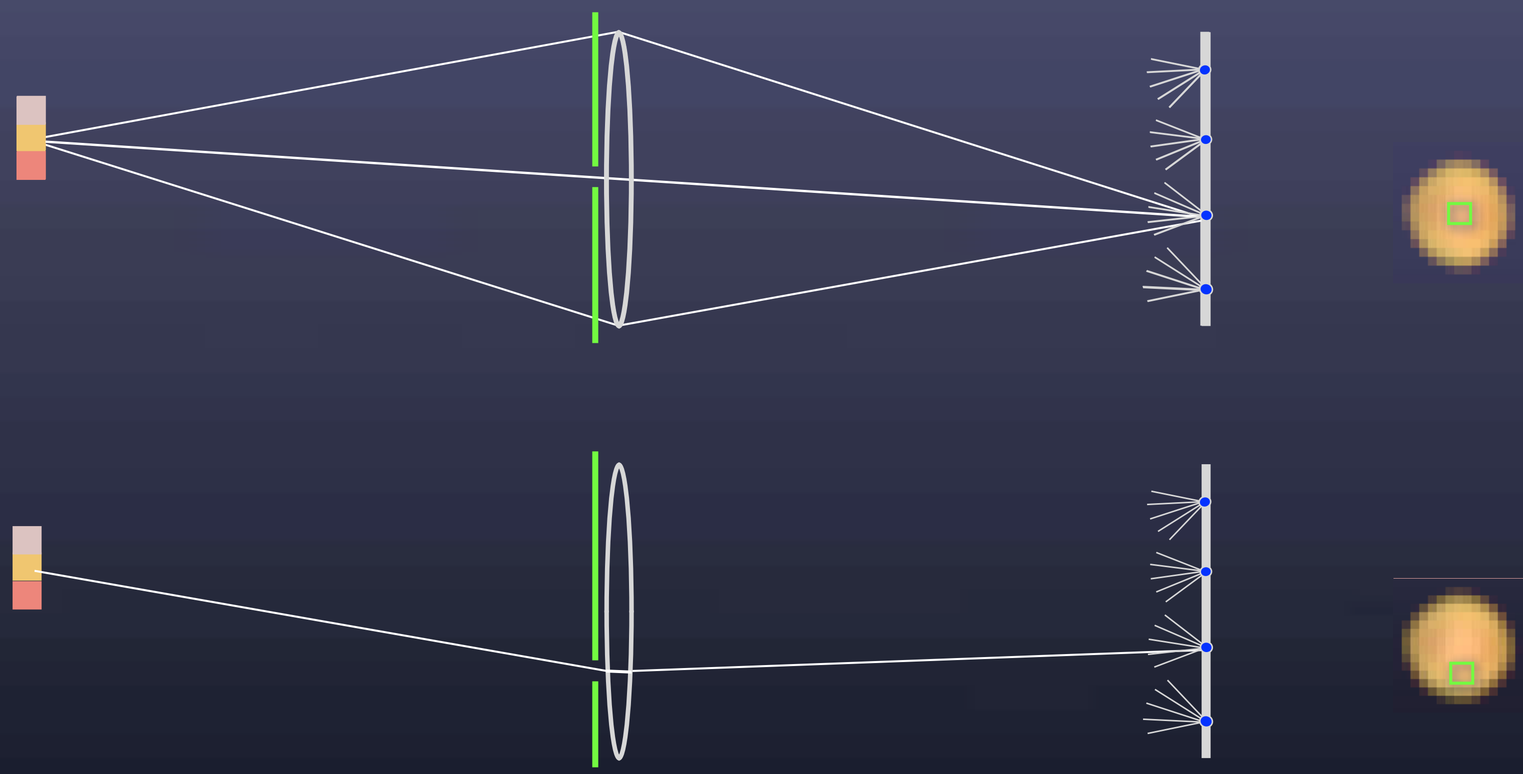
Extending the depth of field

conventional photograph, main lens at *f* / 4

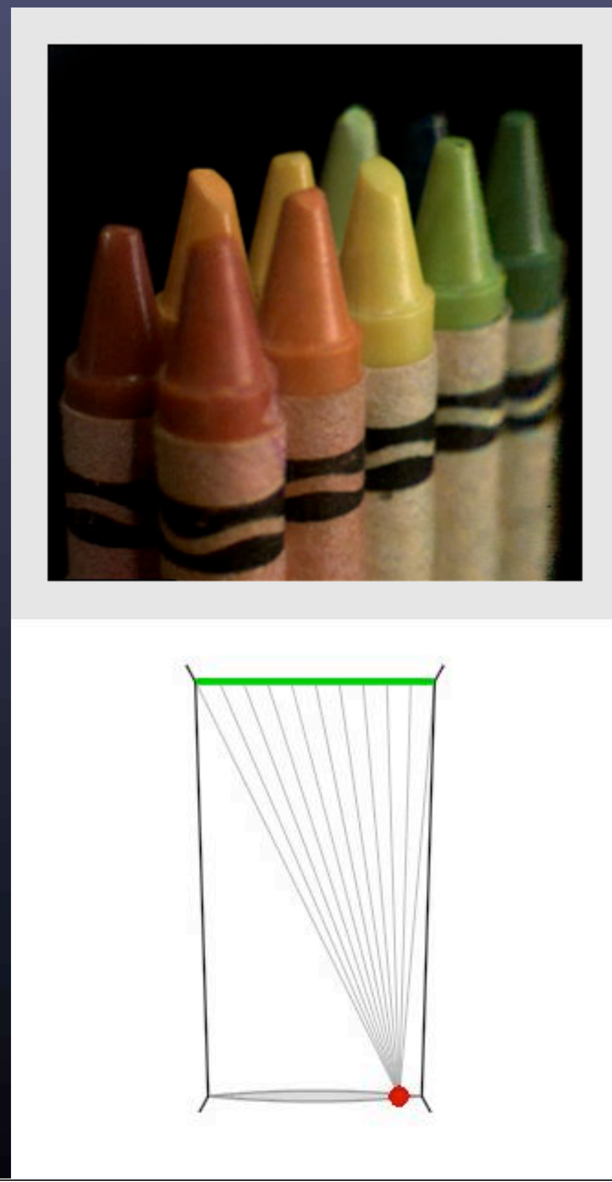
conventional photograph, main lens at *f* / 22

light field, main lens at *f* / 4, after all-focus algorithm [Agarwala 2004]

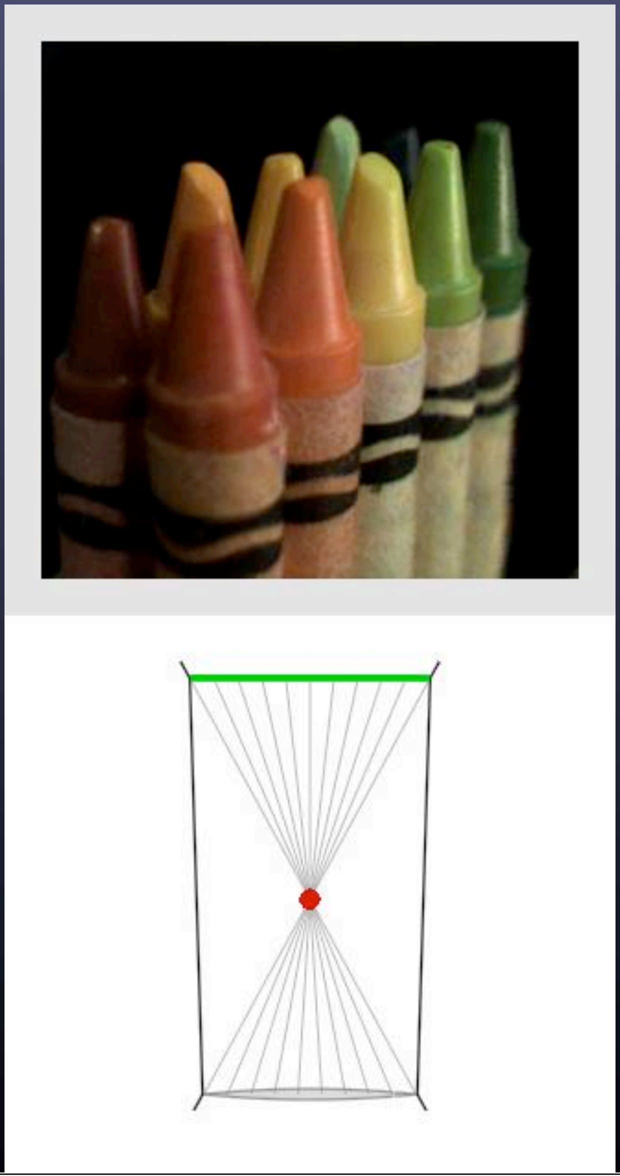
Digitally moving the observer



Example of moving the observer



Moving backward and forward



Commercialization

LYTRO

- trades off spatial resolution for ability to refocus and adjust the perspective

- use the largest possible sensor, and the smallest possible pixels:

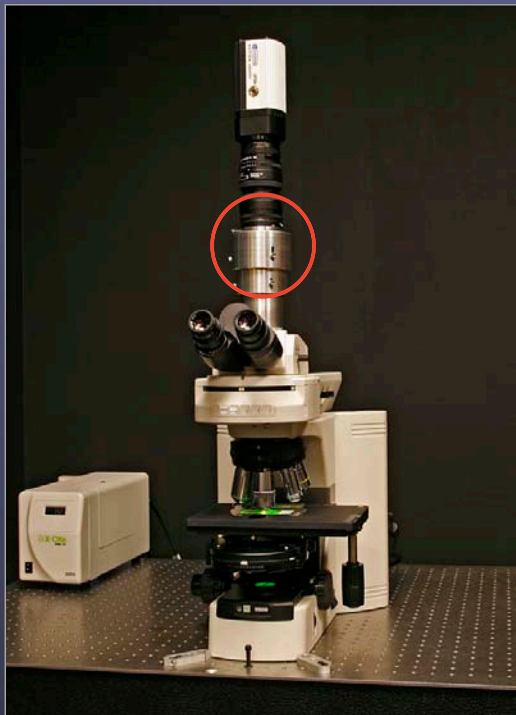
  36mm × 24mm ÷ 1.4μ pixels = 440 Mpix

  26K × 17K pixels

  2600 × 1700 pixels × 10 × 10 rays per pixel

  or

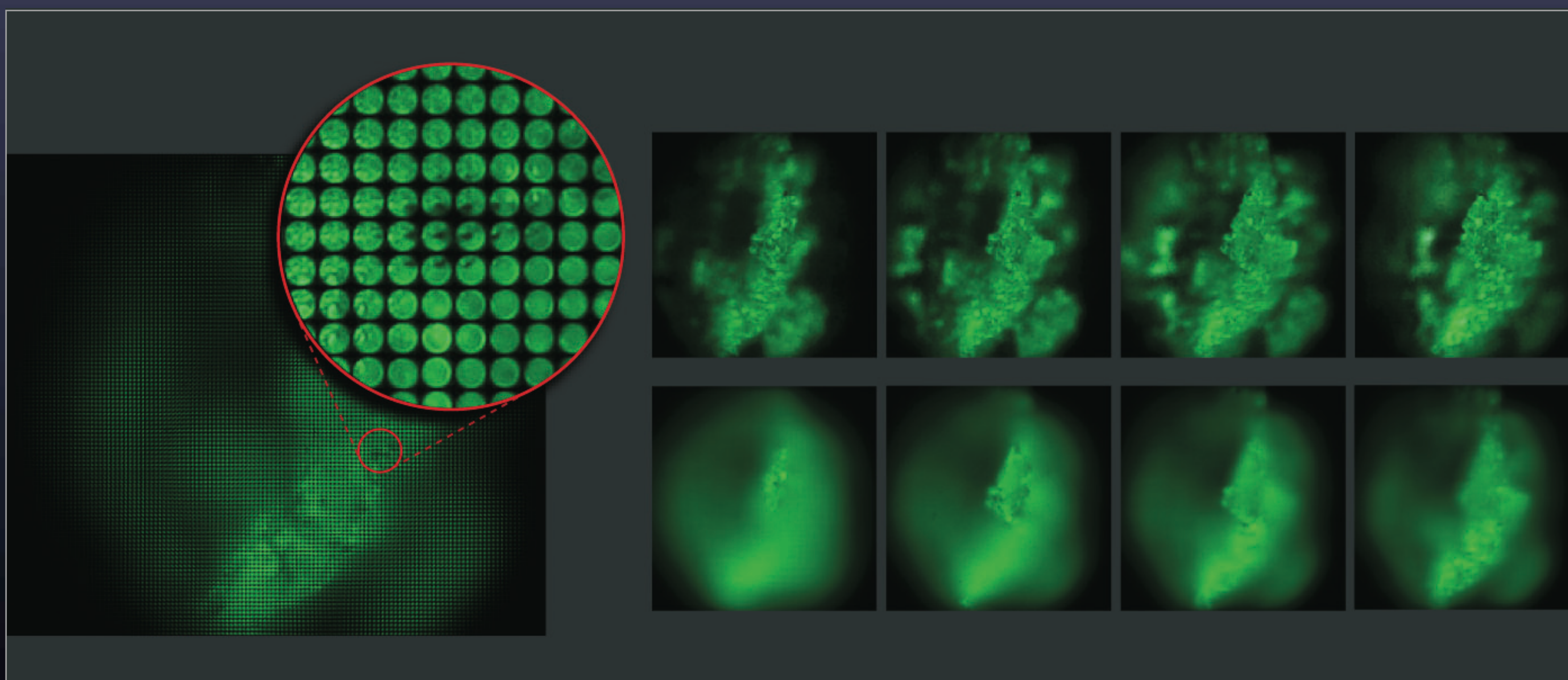
  5200 × 3400 pixels × 5 × 5 rays per pixel



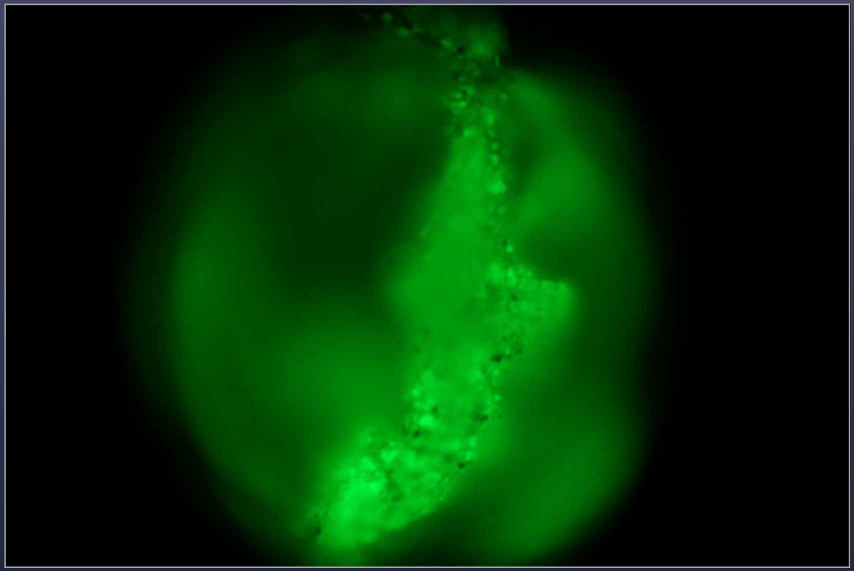
Light Field Microscopy

Marc Levoy, Ren Ng, Andrew Adams, Matthew Footer, and Mark Horowitz

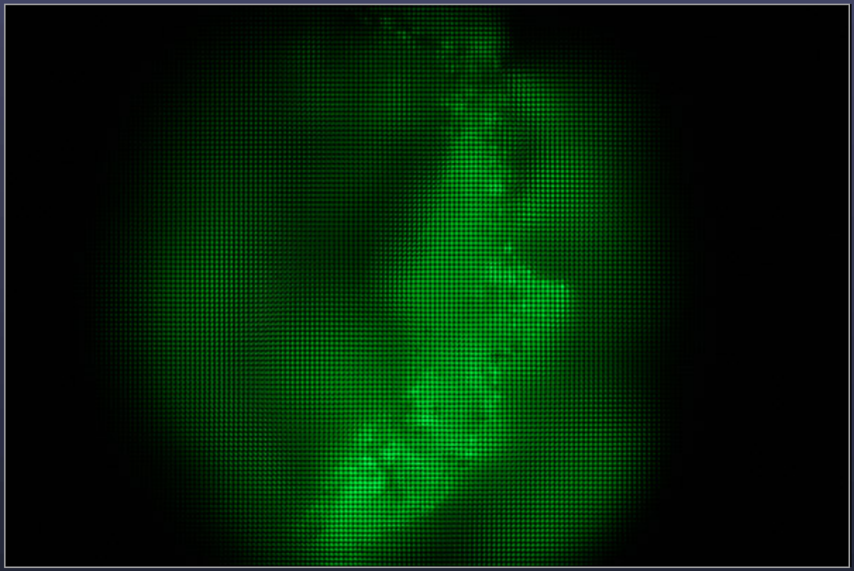
(Proc. SIGGRAPH 2006)



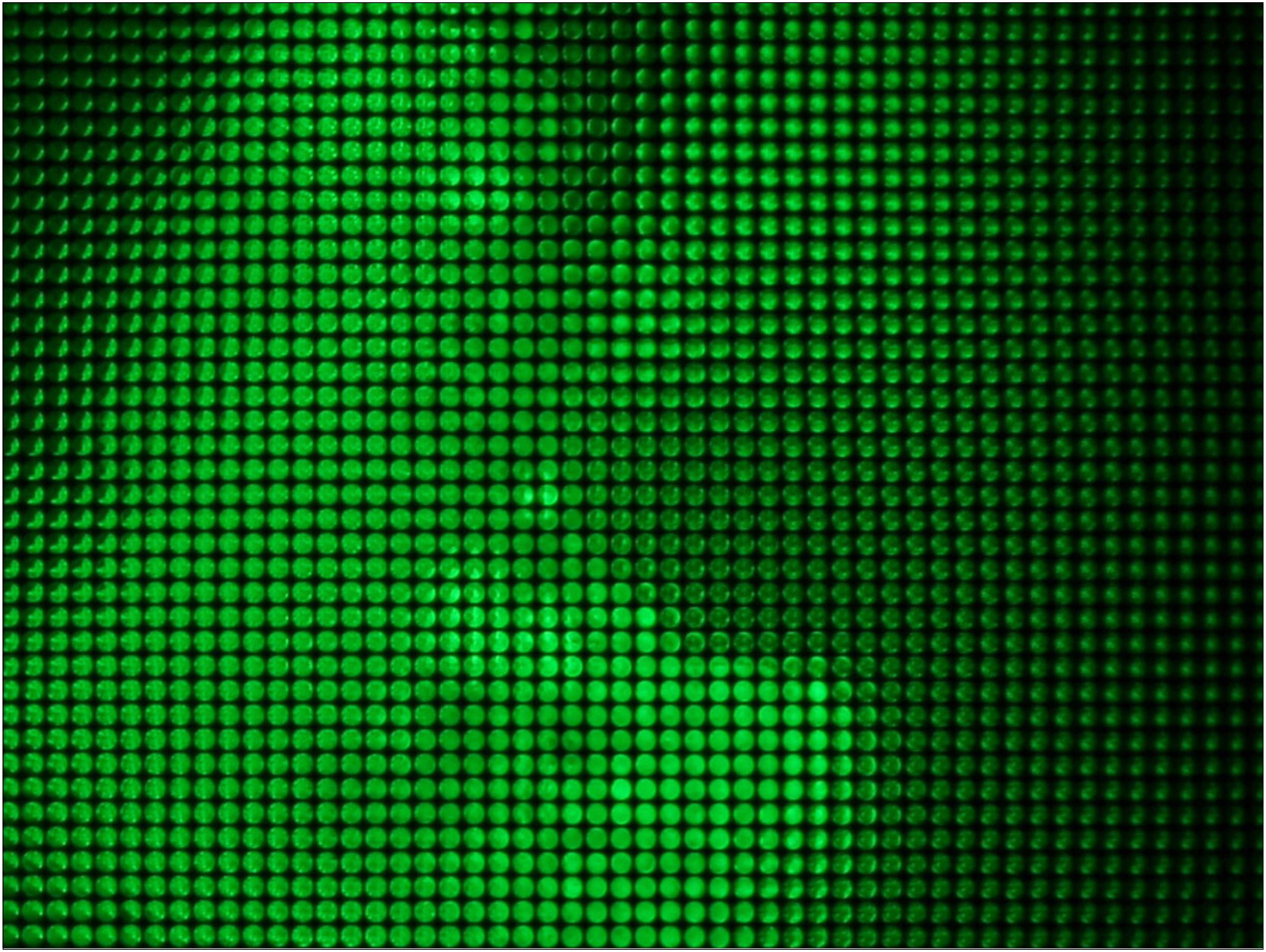
Example light field micrograph

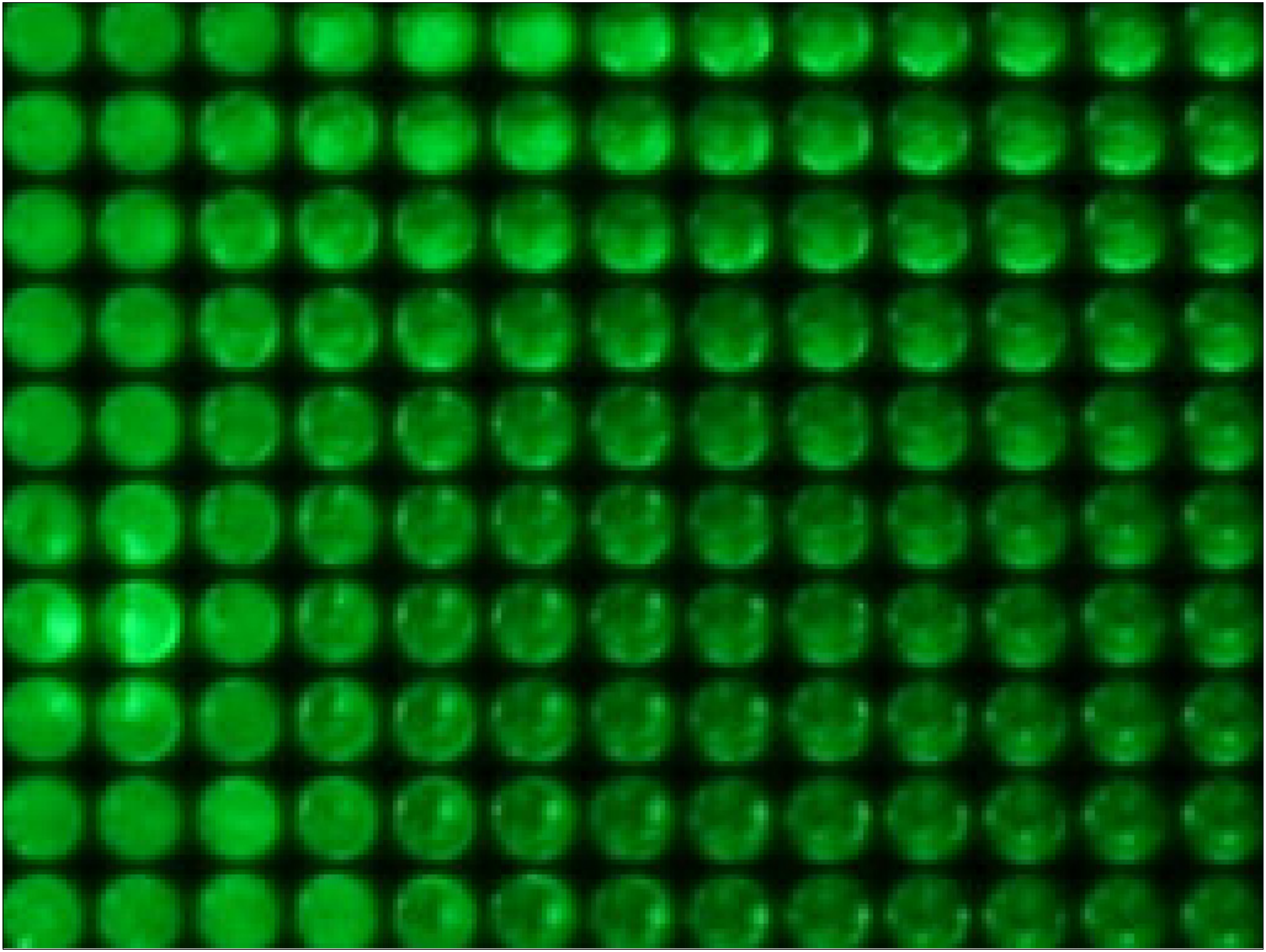


ordinary microscope

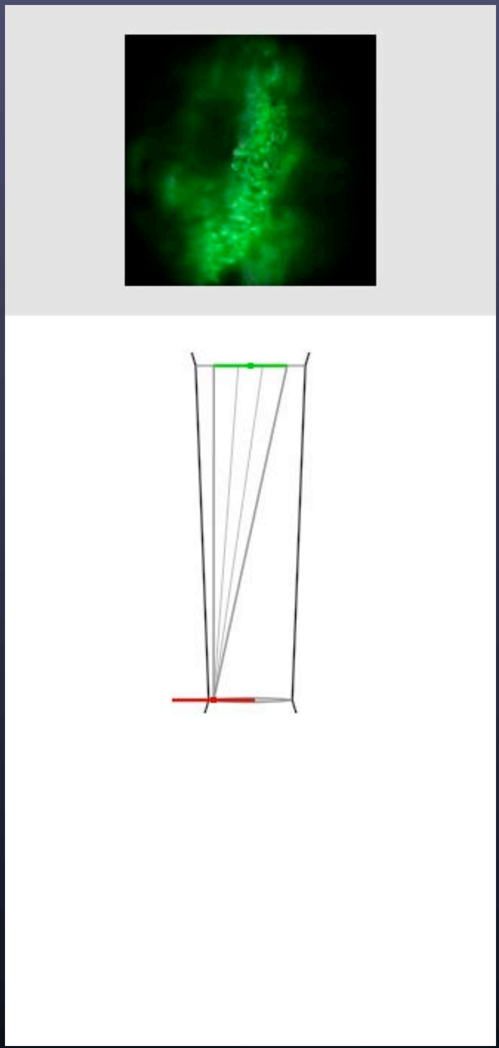


light field microscope

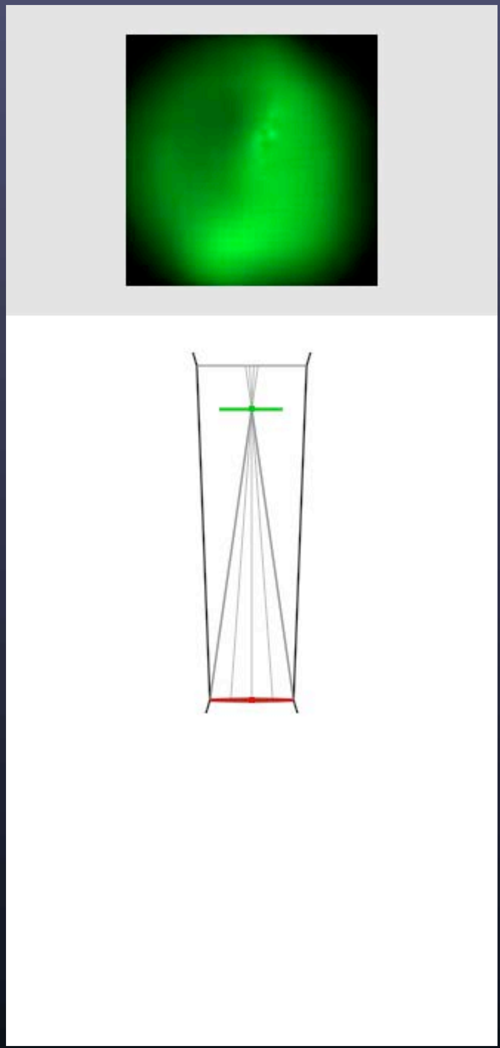




Example light field micrograph

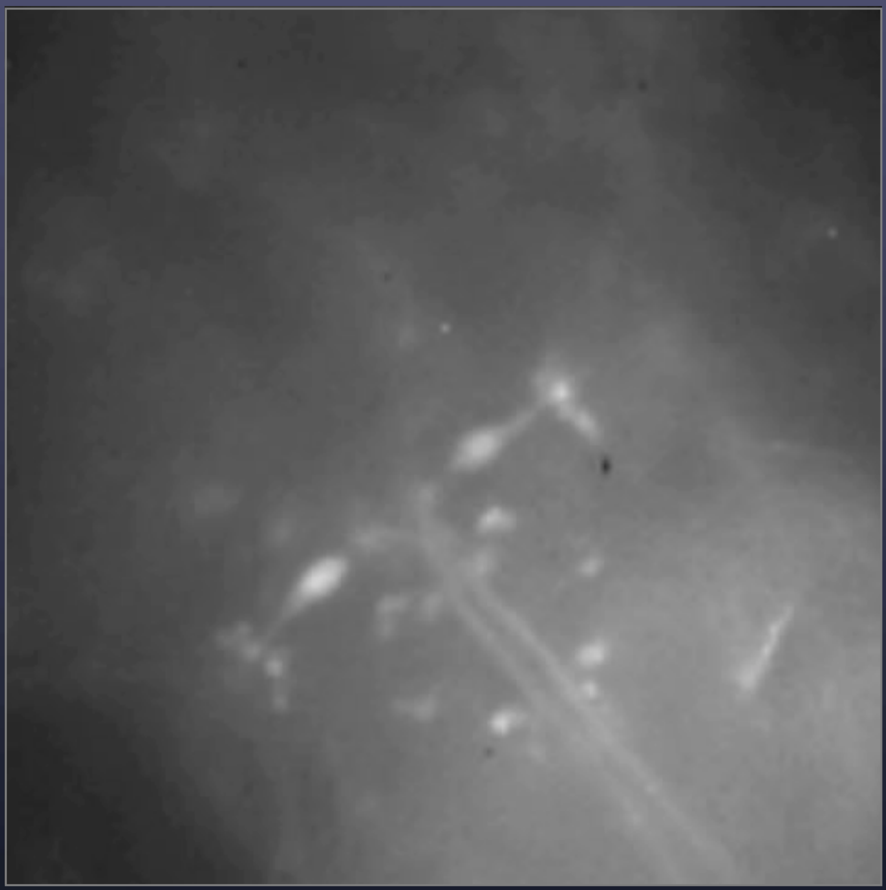


panning sequence



focal stack

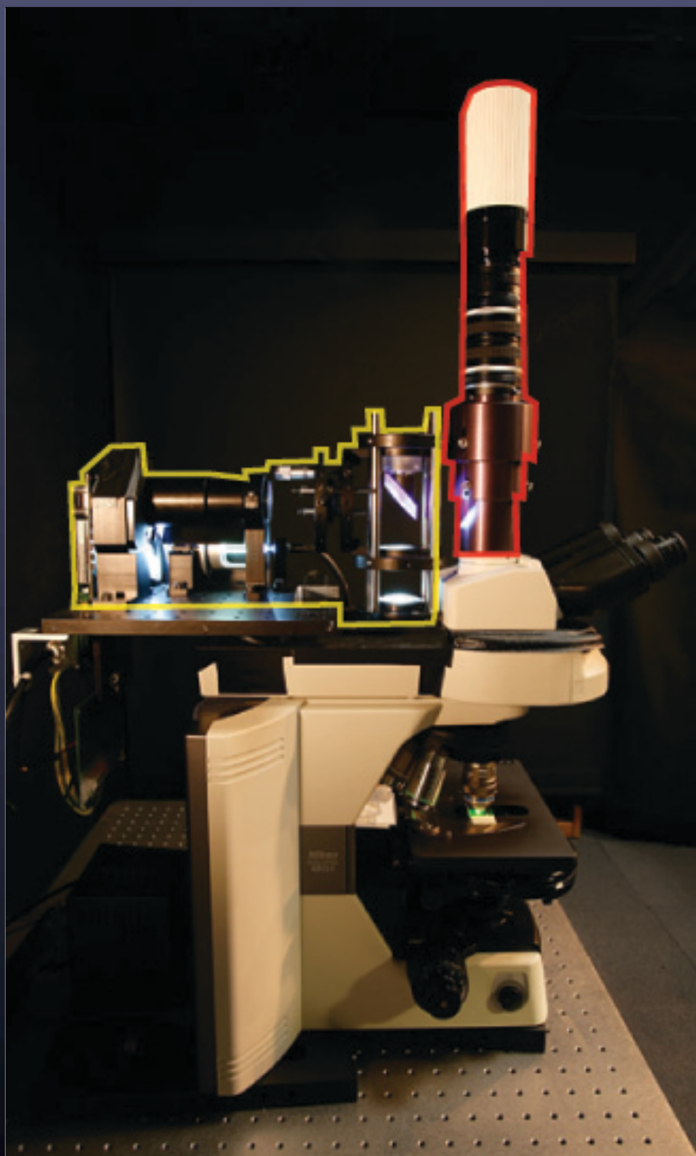
Zebrafish optic tectum
(Florian Engert / Ruben Portugues)



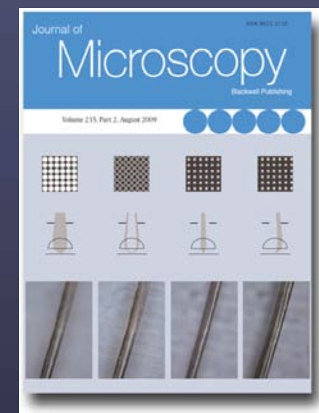
genetically modified
to express GFP
(40x)

calcium imaging
of neural activity
(40x)

Combined light field microscope (LFM) and light field illuminator (LFI)



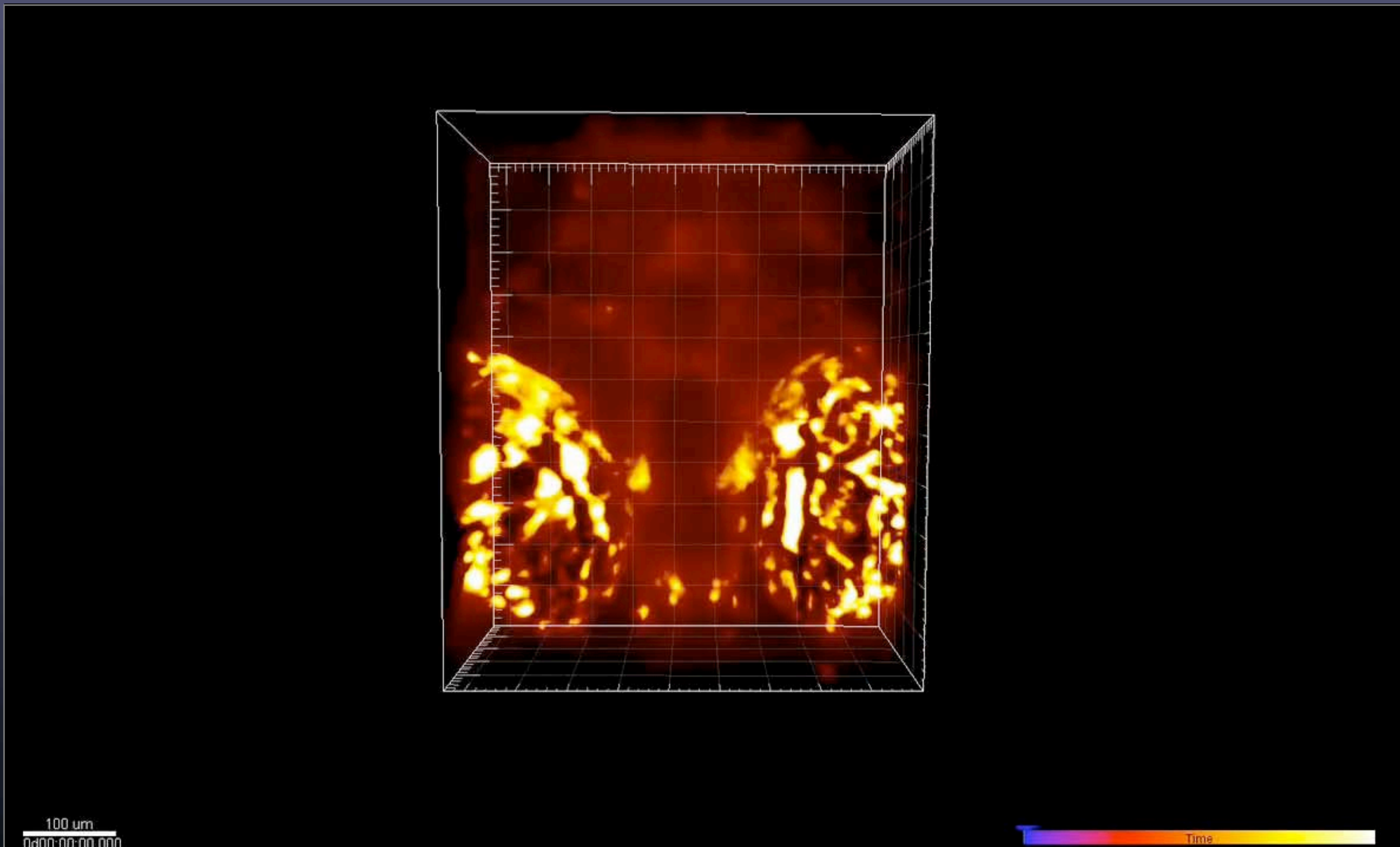
Marc Levoy,
Zhengyun Zhang,
Ian McDowall
(Journal of Microscopy, 2009)



Applications

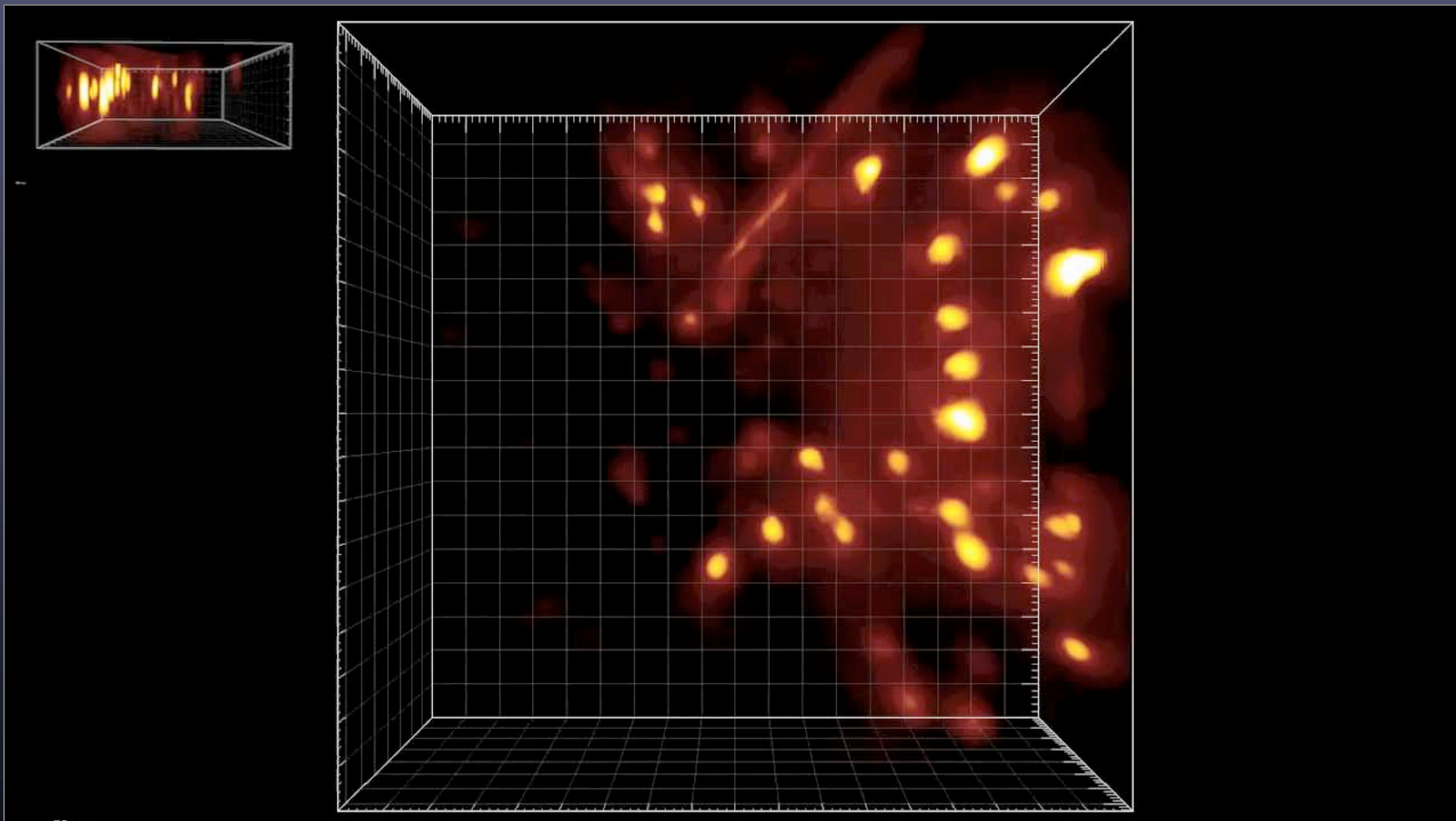
- exotic microscope illumination
- reducing scattering using 3D “follow spots”
- characterizing and correcting for aberrations
- microscopic structured light rangefinding
- gonioreflectometer for opaque surfaces
- **optical stimulation of neural tissues in 3D**

Zebrafish whole brain
(Logan Grosenick)



calcium imaging of neural activity
(40x)

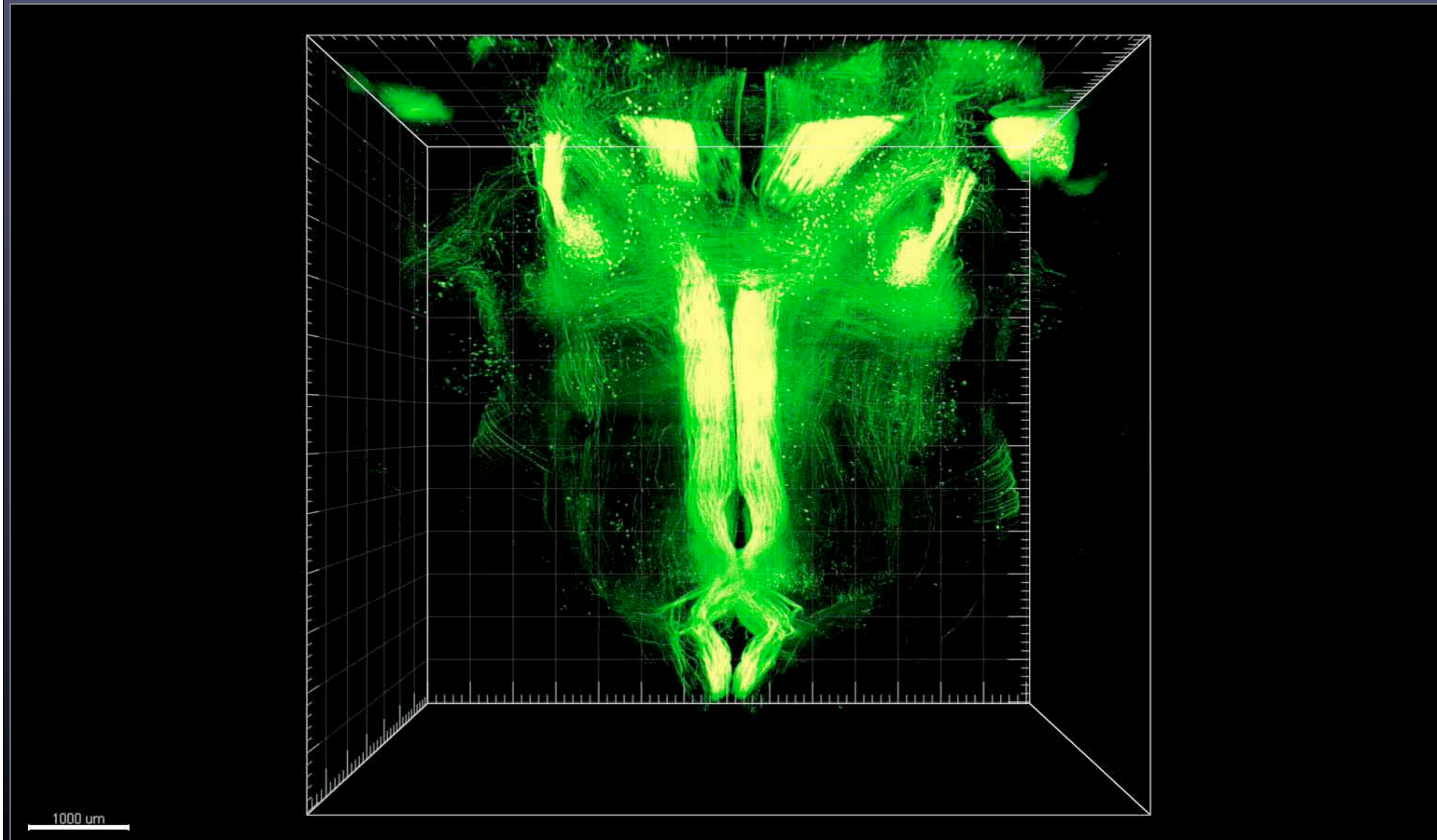
Mouse slice
(Logan Grosenick)



calcium imaging of neural activity

(40x)

Anatomical structure
(Karl Diesseroth)



Anatomical structure
(Karl Diesseroth)