LECTURE 9
Advanced Widefield Microscopy
Ilan Davis, March 2011

Image formation and airy rings

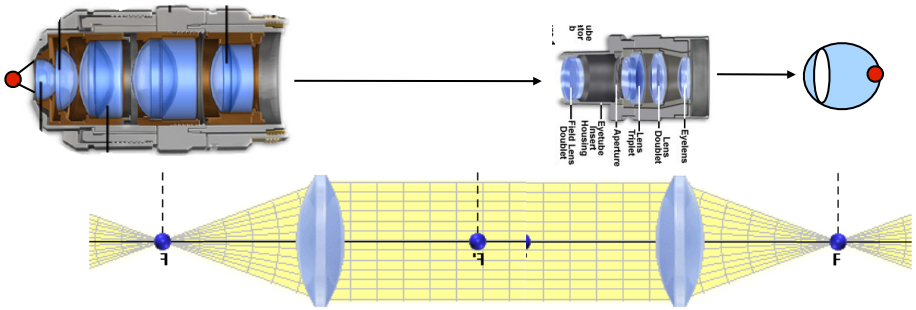
How deconvolution works

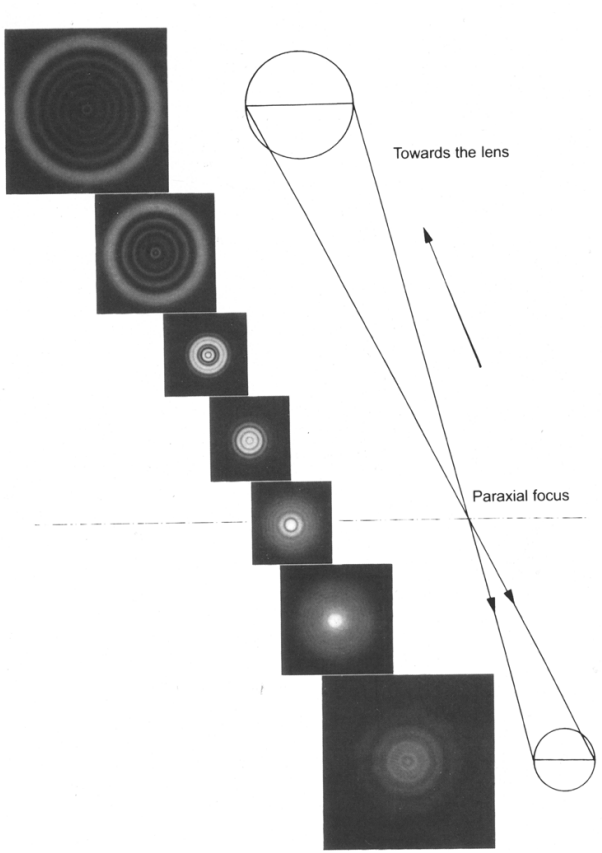
Design of a modern widefield digital acquisition system

OMX

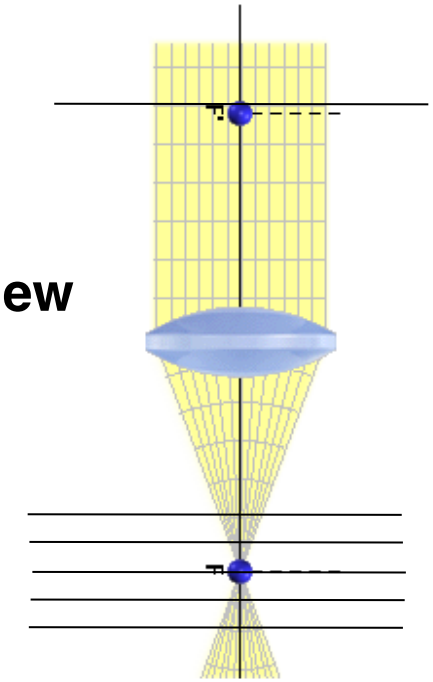
Structured Illumination

Image formation





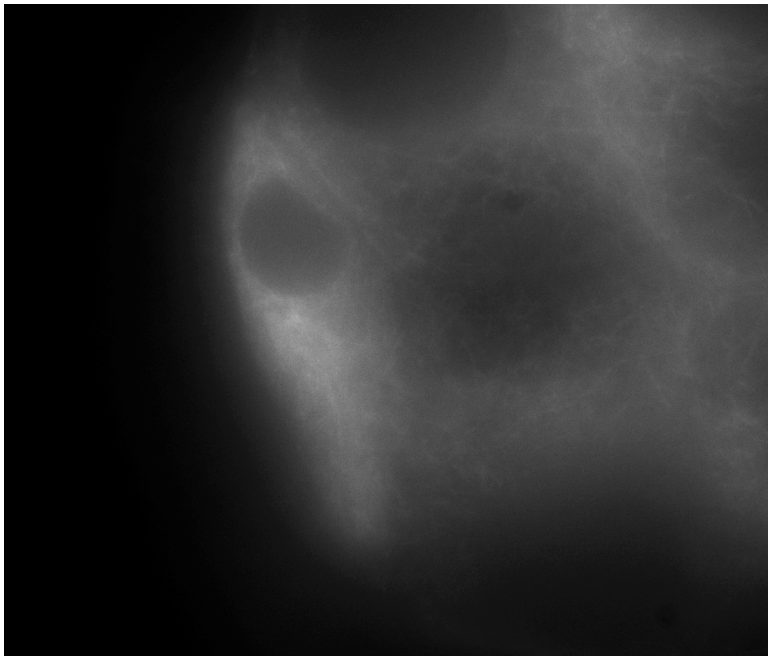
Out of focus light
-Airy rings in 3D view



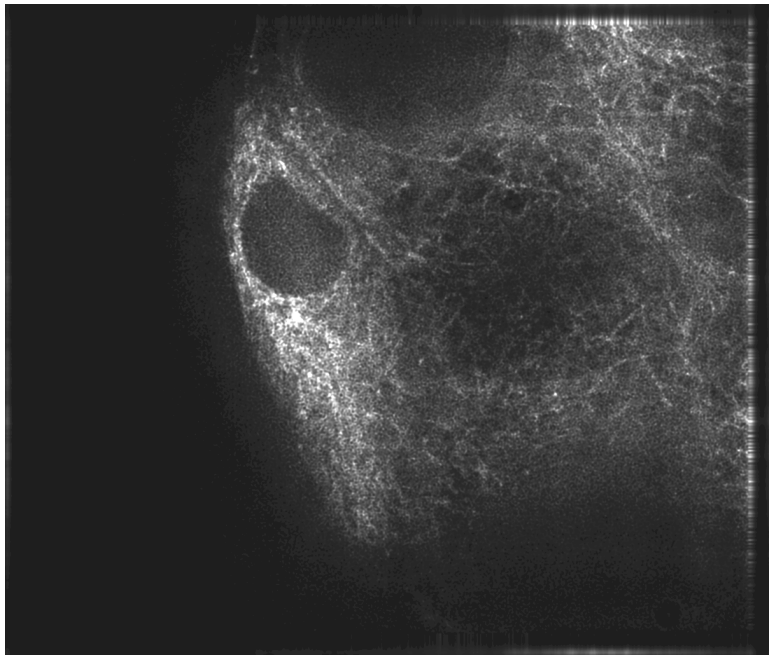
Different Focal plains

How does Widefield Deconvolution Work
(restoring out of focus light to its point of origin

Before Deconvolution



After Deconvolution



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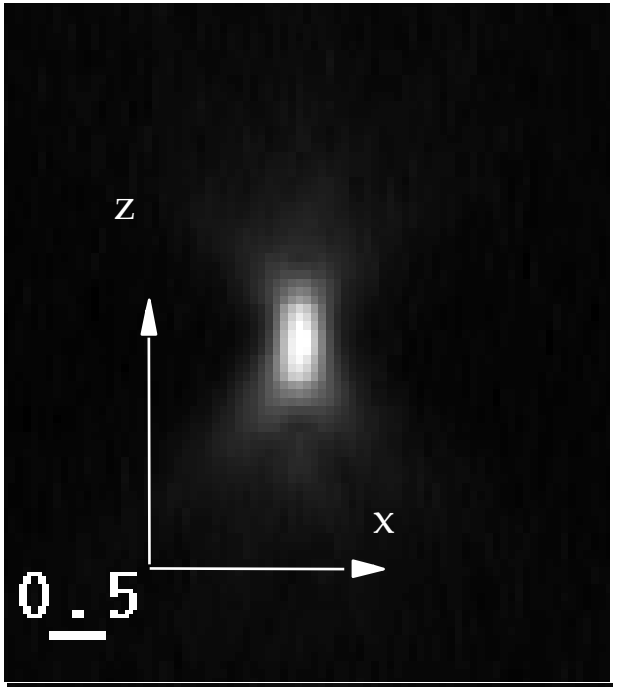

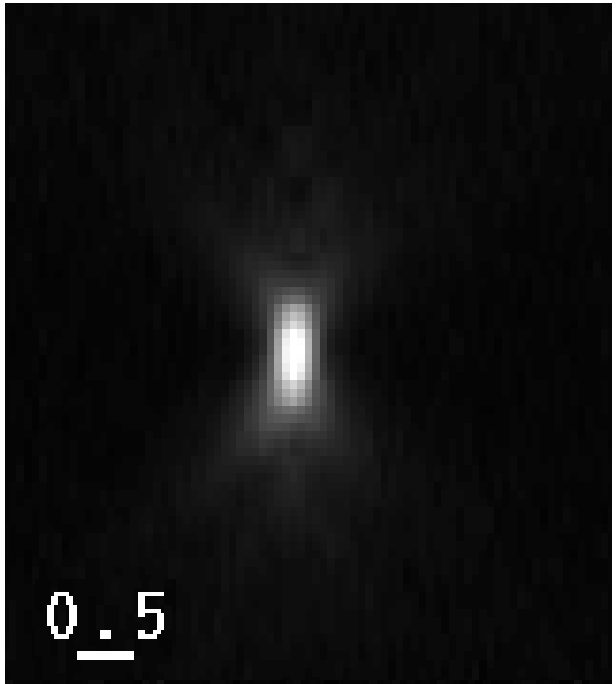

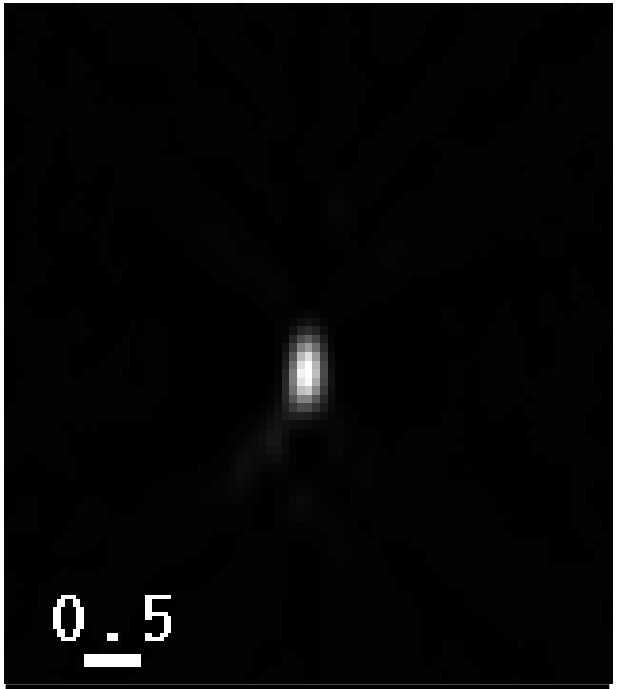

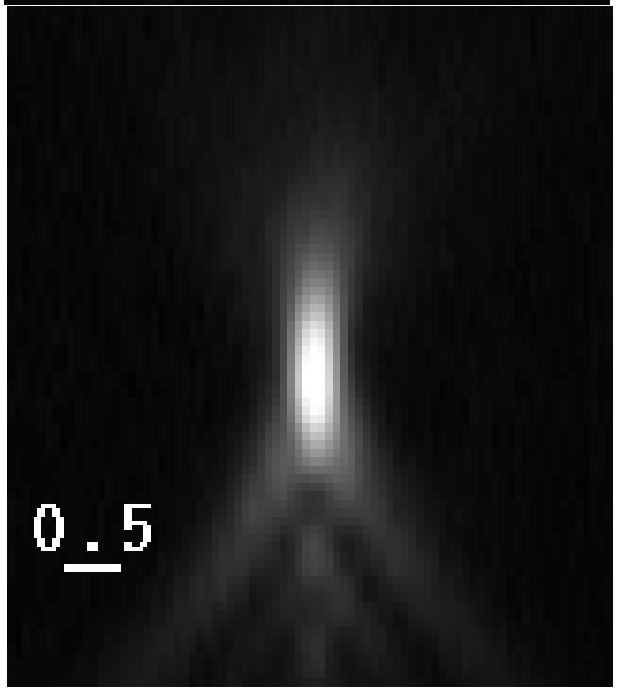

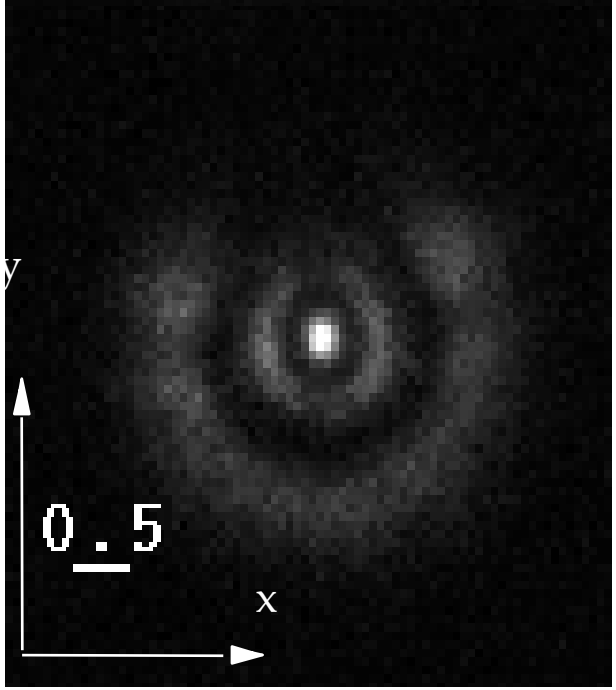

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171	167	159	133	119	118	124	148	164
194	199	192	173	156	151	158	175	193
216	237	237	235	221	217	208	214	223
256	290	288	288	281	283	259	271	259
268	328	365	420	440	434	359	324	282
271	362	460	600	663	636	490	378	297
256	396	643	954	1140	1058	760	477	313
246	420	752	1171	1419	1296	903	520	310
233	439	857	1379	1691	1522	1027	551	296
197	483	1057	1801	2226	1937	1253	614	271
195	497	1126	1928	2386	2066	1311	622	257
208	510	1162	1982	2437	2111	1323	619	253
258	544	1193	1969	2370	2063	1301	613	263
286	562	1173	1893	2251	1959	1241	596	278
313	585	1129	1760	2073	1791	1156	577	300
365	622	1000	1407	1630	1378	930	514	357
386	629	916	1215	1388	1154	819	491	373
401	613	819	1026	1148	946	709	467	372
411	526	613	678	704	614	518	420	328
406	477	511	523	509	458	425	387	307
387	419	420	405	364	340	349	345	284
321	327	307	320	268	260	271	261	245
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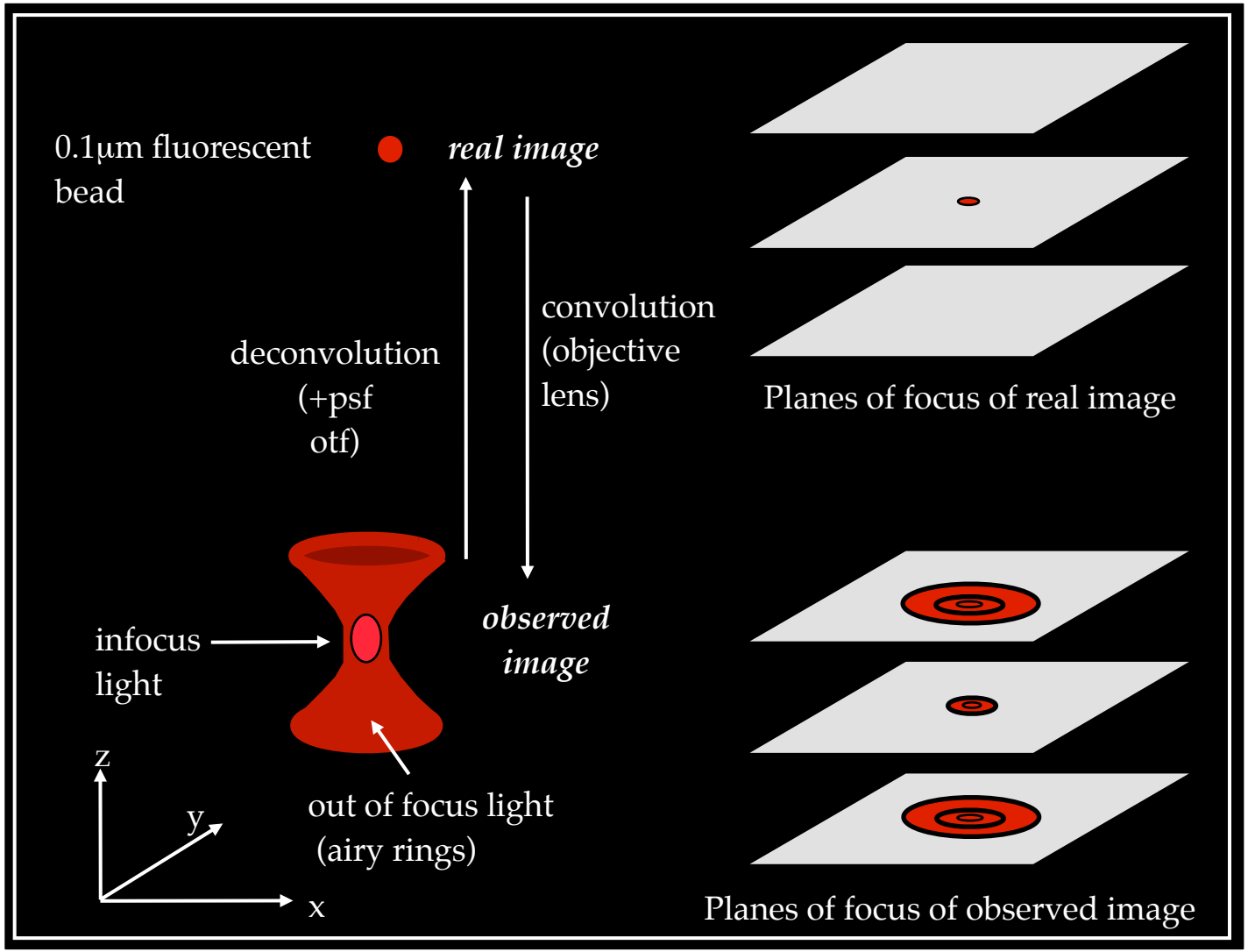
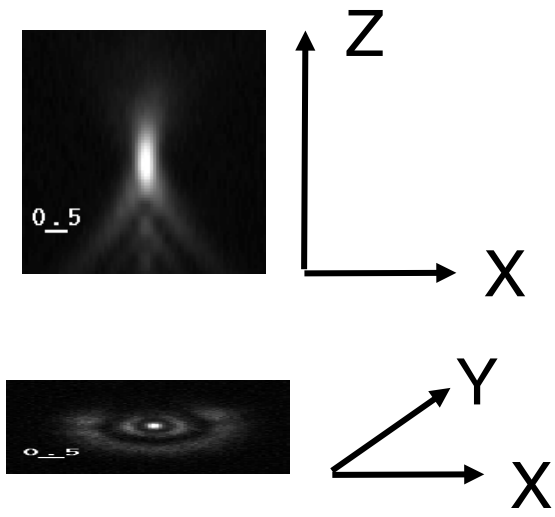
238	216	193	205	163	165	185	177	186


0.1µm fluorescent bead
real image
deconvolution (+psf otf)
convolution (objective lens)
Planes of focus of real image
observed image
infocus light
out of focus light (airy rings)
z
y
x
Planes of focus of observed image

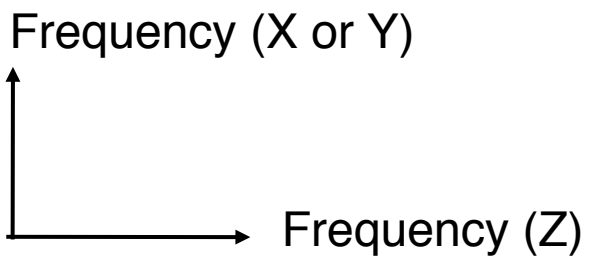
Deconvolution

Calculations done in Fourier (frequency) space not XYZ space.
Uses Fast Fourier Transforms - much faster algorithm (developed in the 1960s)
Psf is converted to optical transfer function (only information in X and Z)
Several methods that vary in their implementation

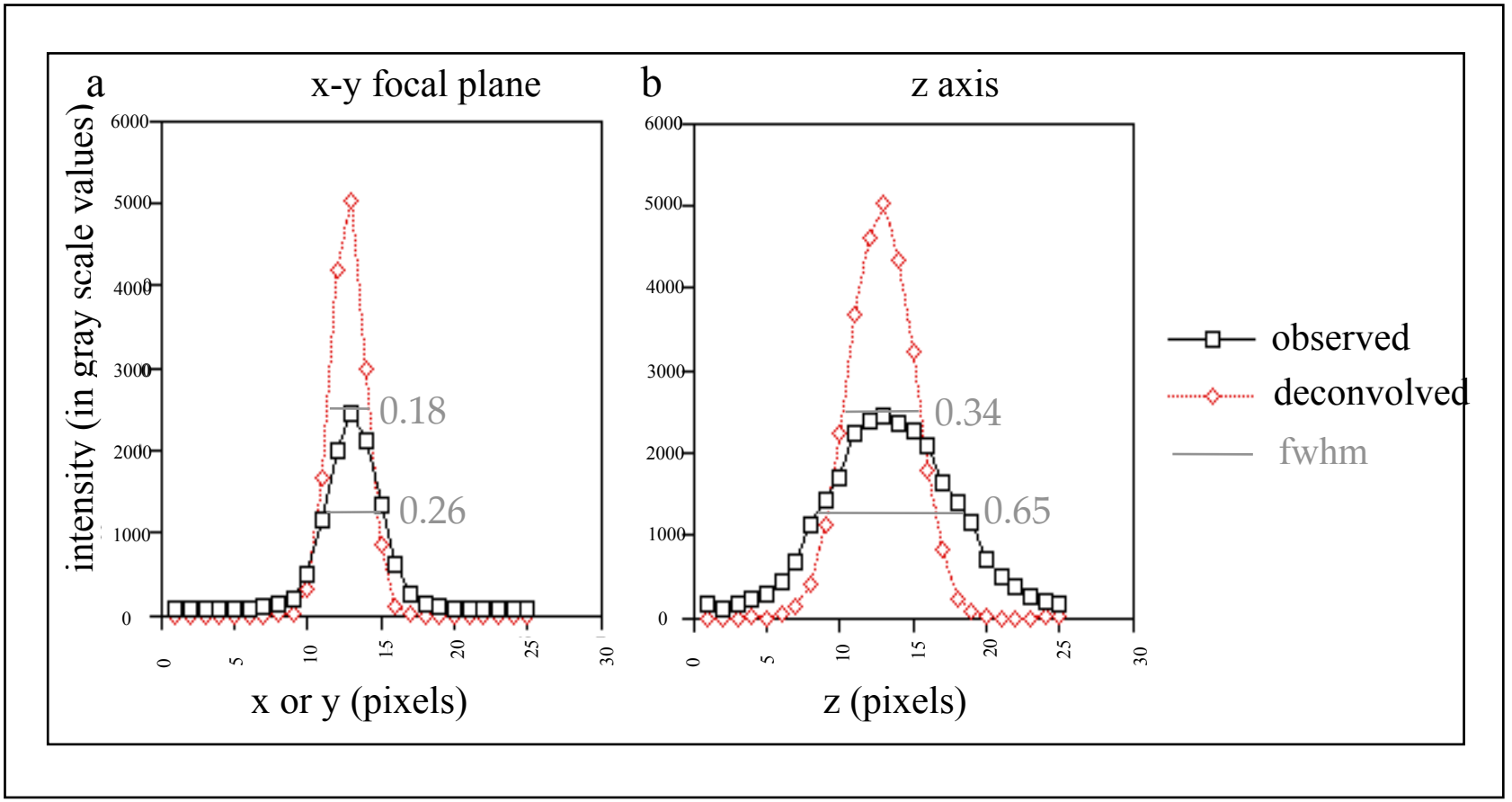
Point Spread Function
PSF (XYZ space)



Optical Transfer Function
OTF (XZ frequency space)



Increase in resolution (XY and Z) after deconvolution



Types of Deconvolution

•No neighbour, nearest neighbour - poor substitute

•2D deconvolution - Not as good

•3D constrained iterative approaches

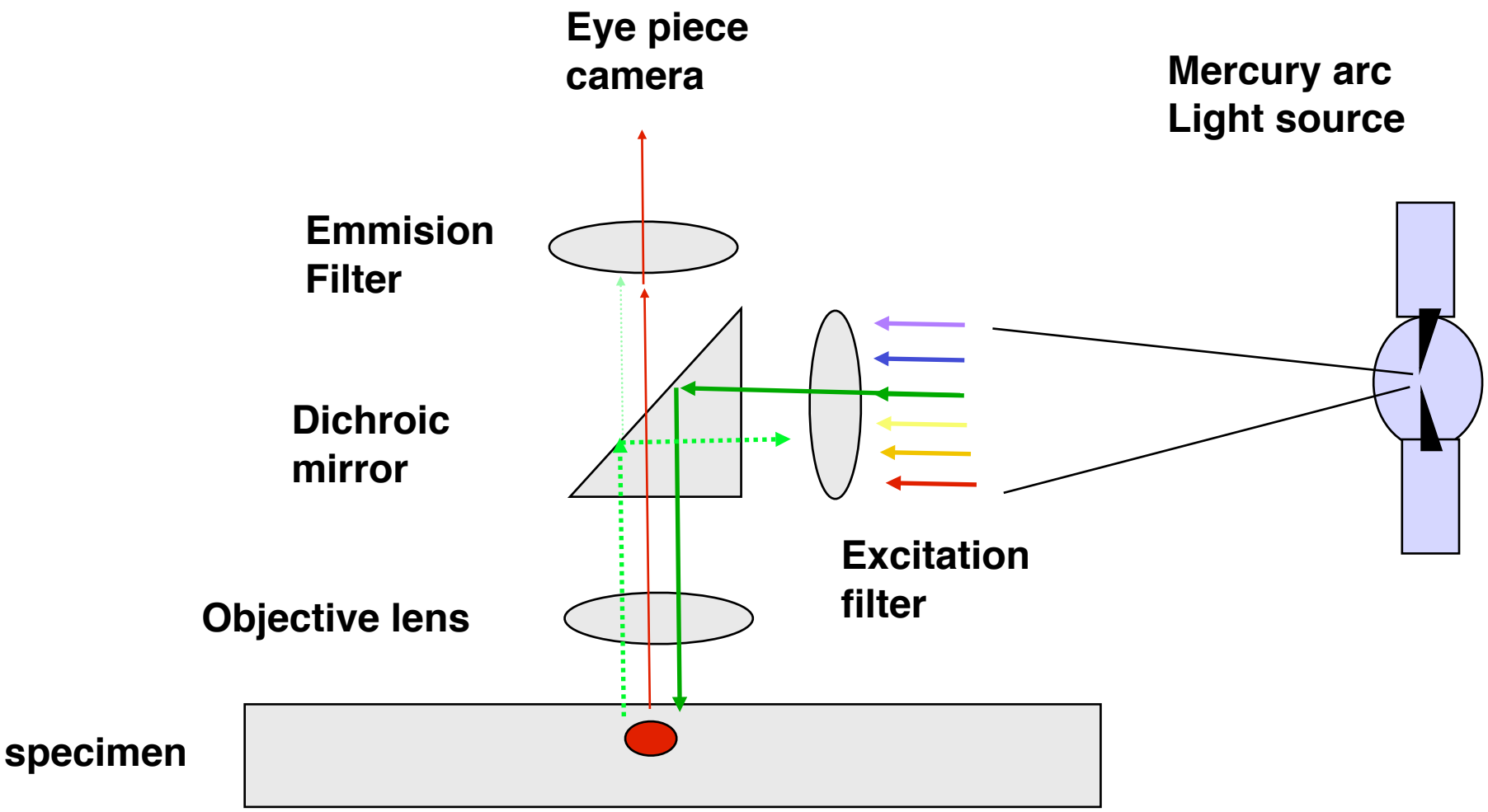
•Sedat/Agard ; Hoygens ; blind deconvolution

New methods (Sedat)

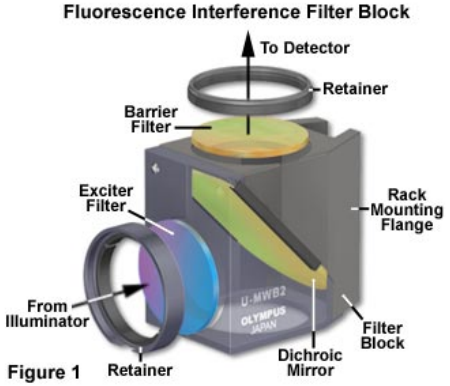
•Pupal functions (used to sharpen Hubble telescope) include information in otf in X, Y and Z and phase. Phase retrieval

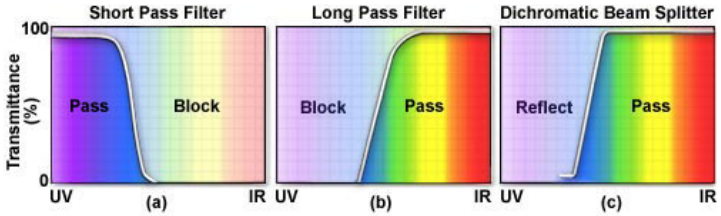
•Myopic deconvolution

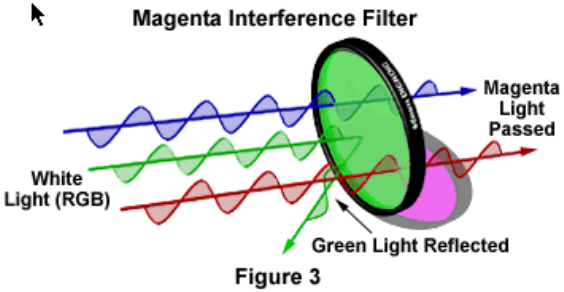
Reminder
How do fluorescence microscopes work ?

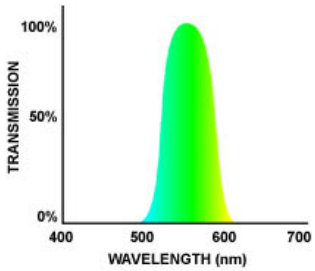


Filter cubes





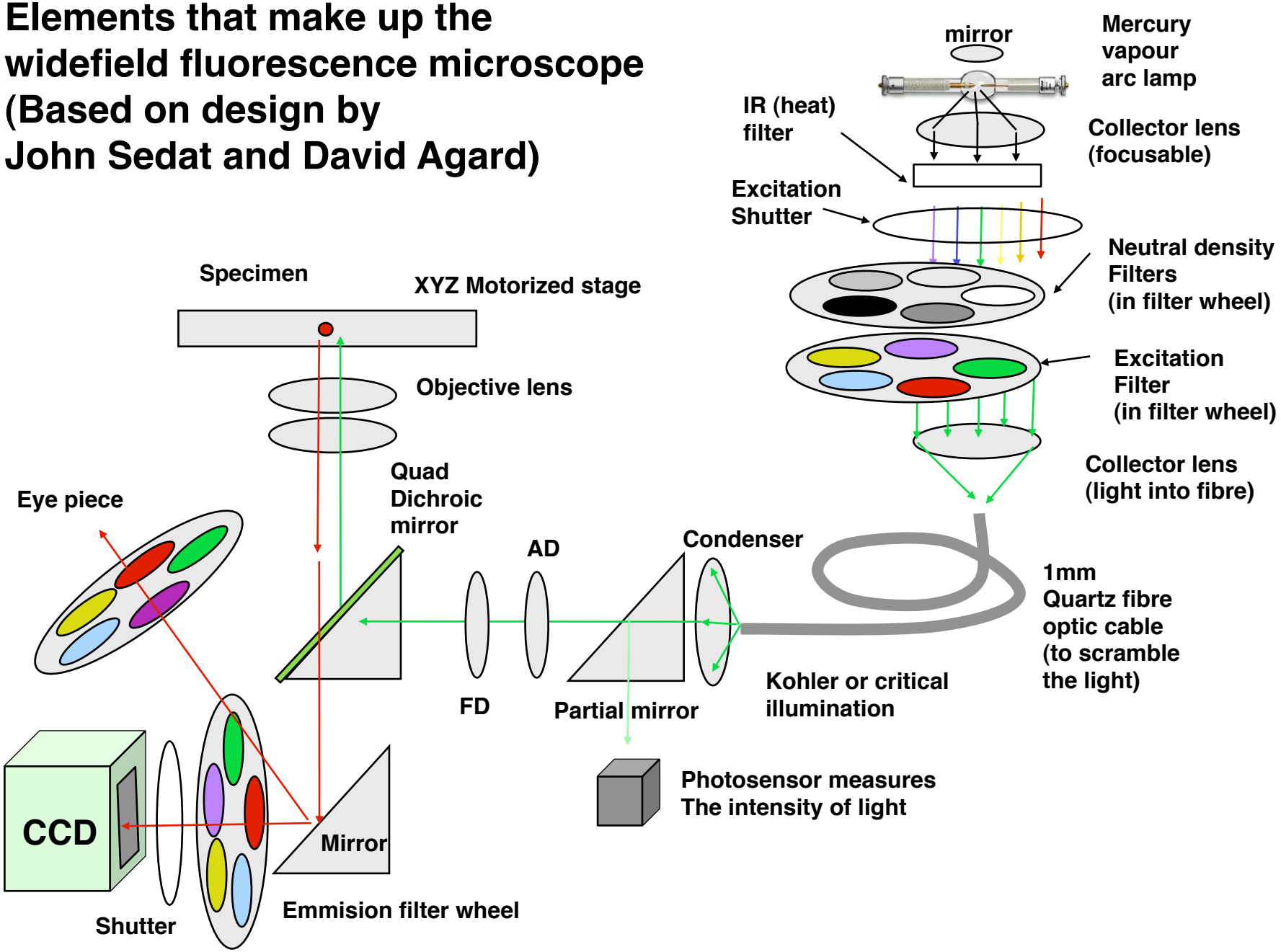




http://www.chroma.com/pdf/handbook4.pdf

Widefield Fluorescence microscopy (Olympus + Sedat/Agard DeltaVision)

Elements that make up the widefield fluorescence microscope (Based on design by John Sedat and David Agard)



How can we improve the basic design of widefield microscopes ?

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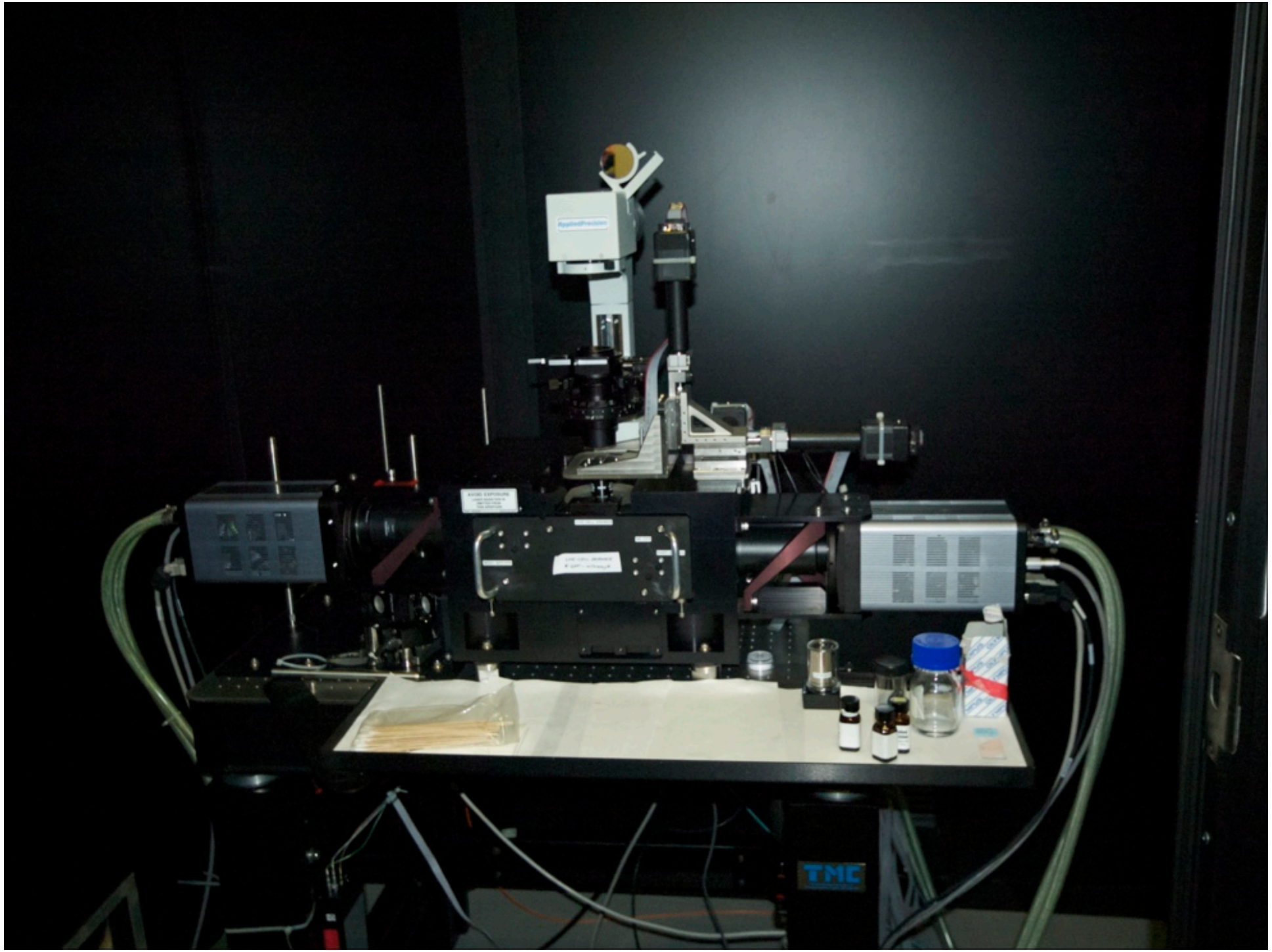
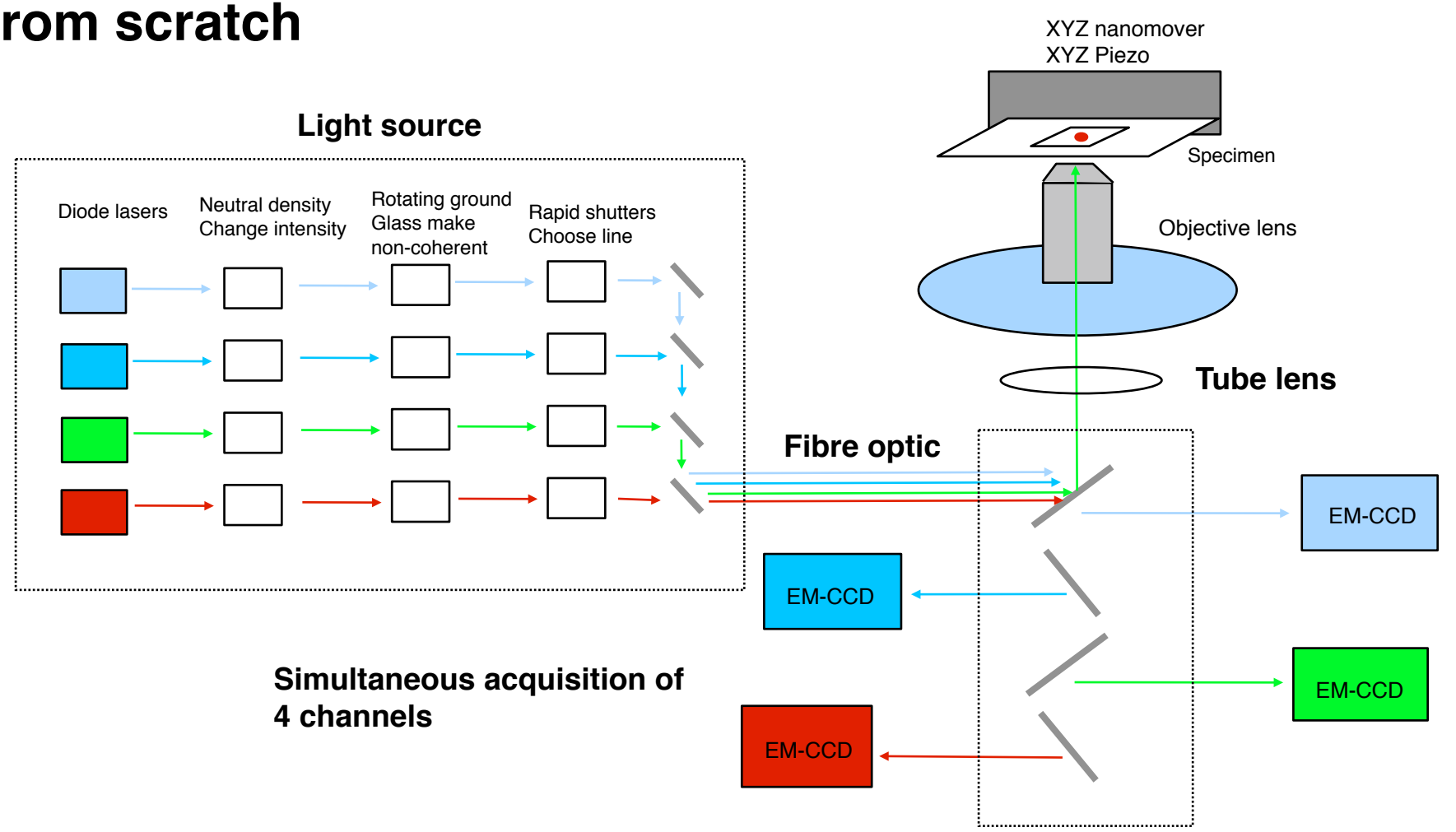
John Sedat and Ian Dobbie


TMC

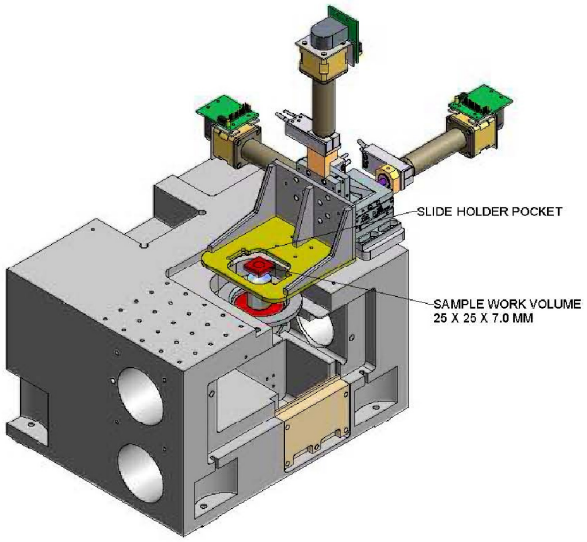
OMX - Redesigning widefield microscopy from scratch



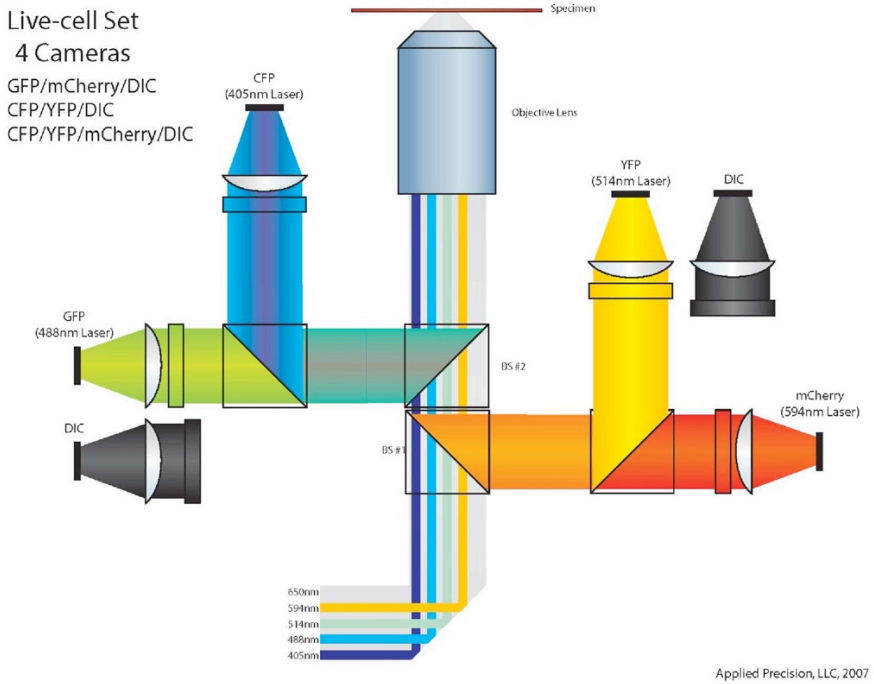
Simultaneous acquisition of 4 channels

Precisely machined
Metal block with internal sculpturing
That absorbs stray light.

OMX (John Sedat, David Agard and Mats Gustafsson)

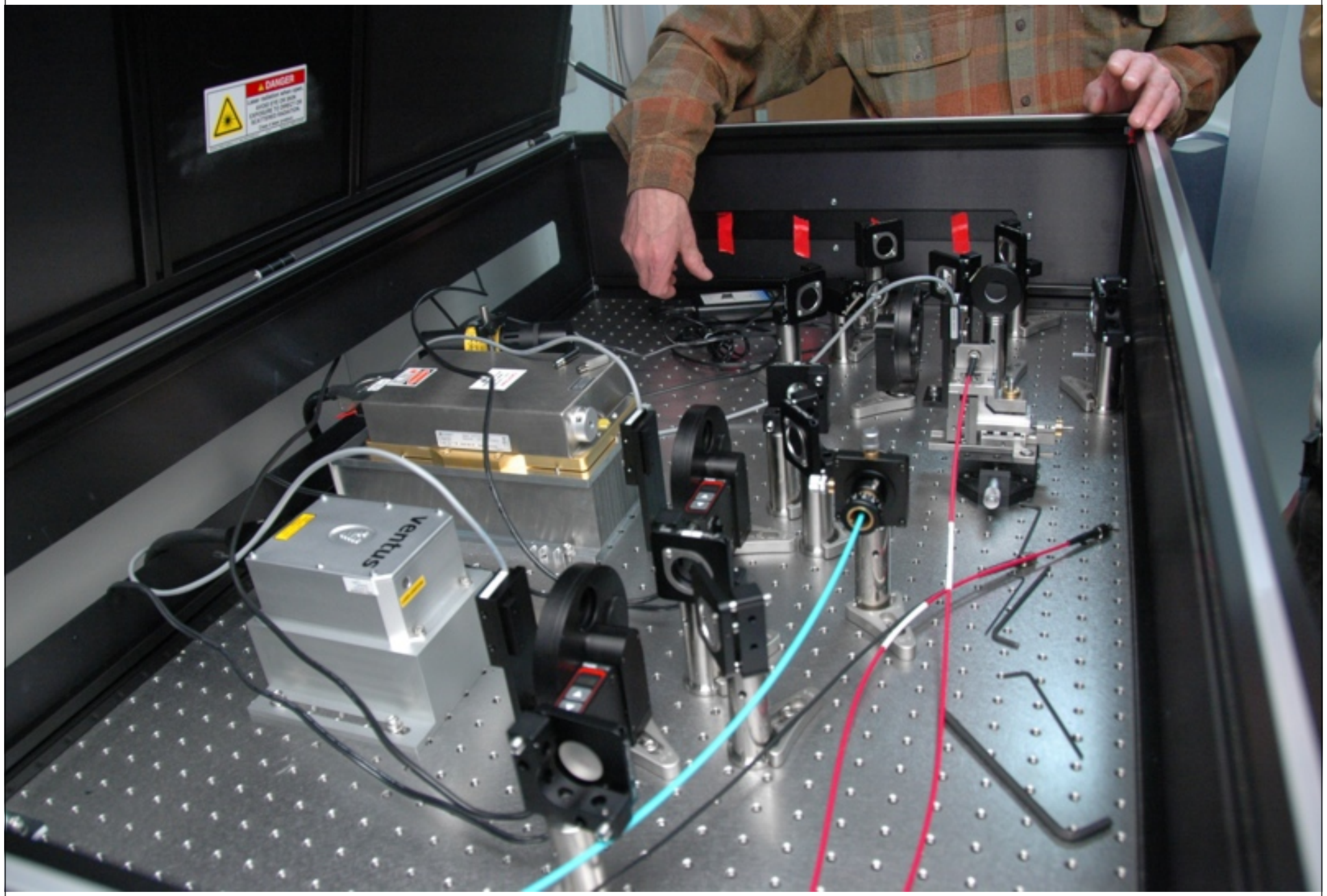


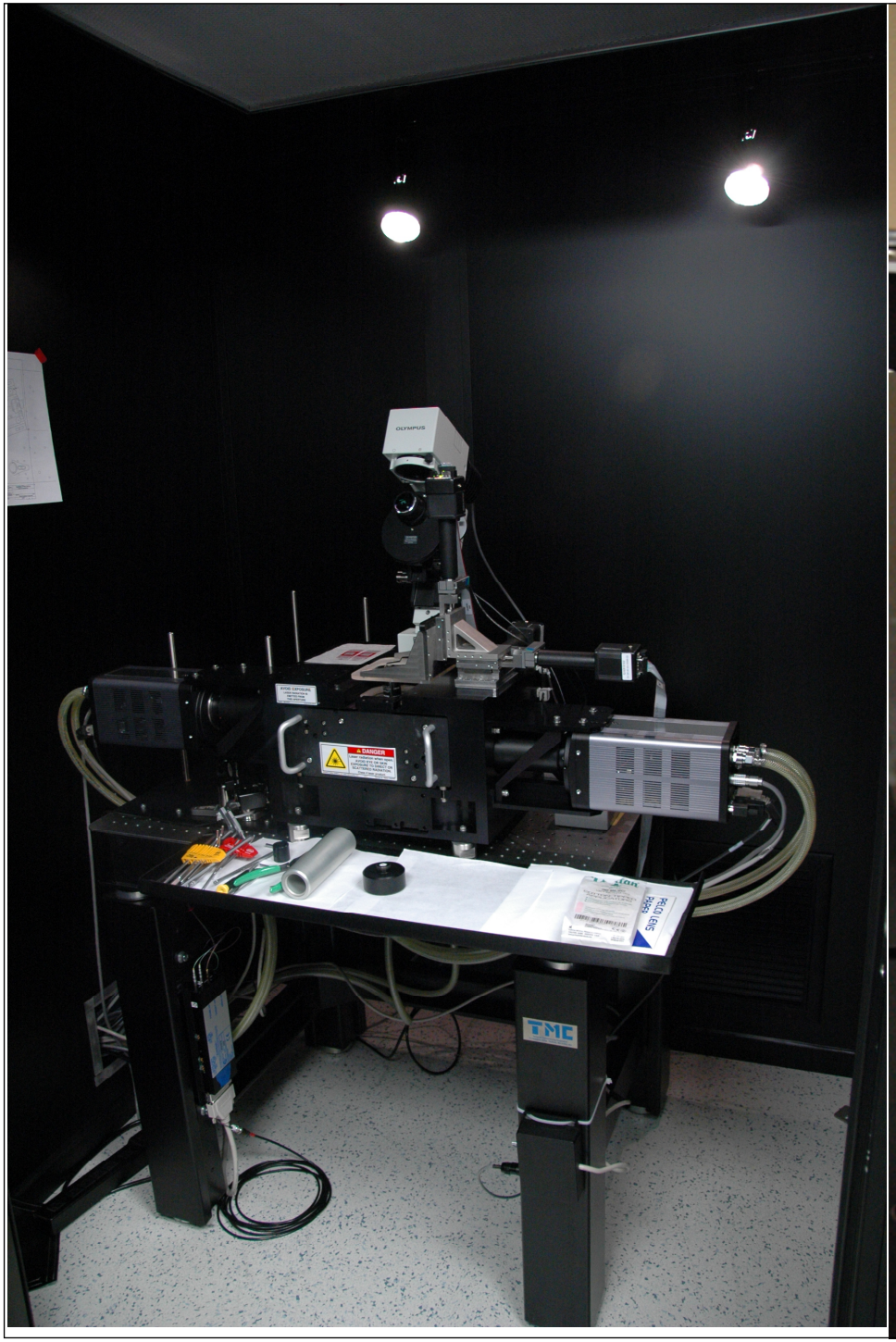
Precisely machined
Metal block with internal sculpturing
That absorbs stray light
Maximized emission light efficiency

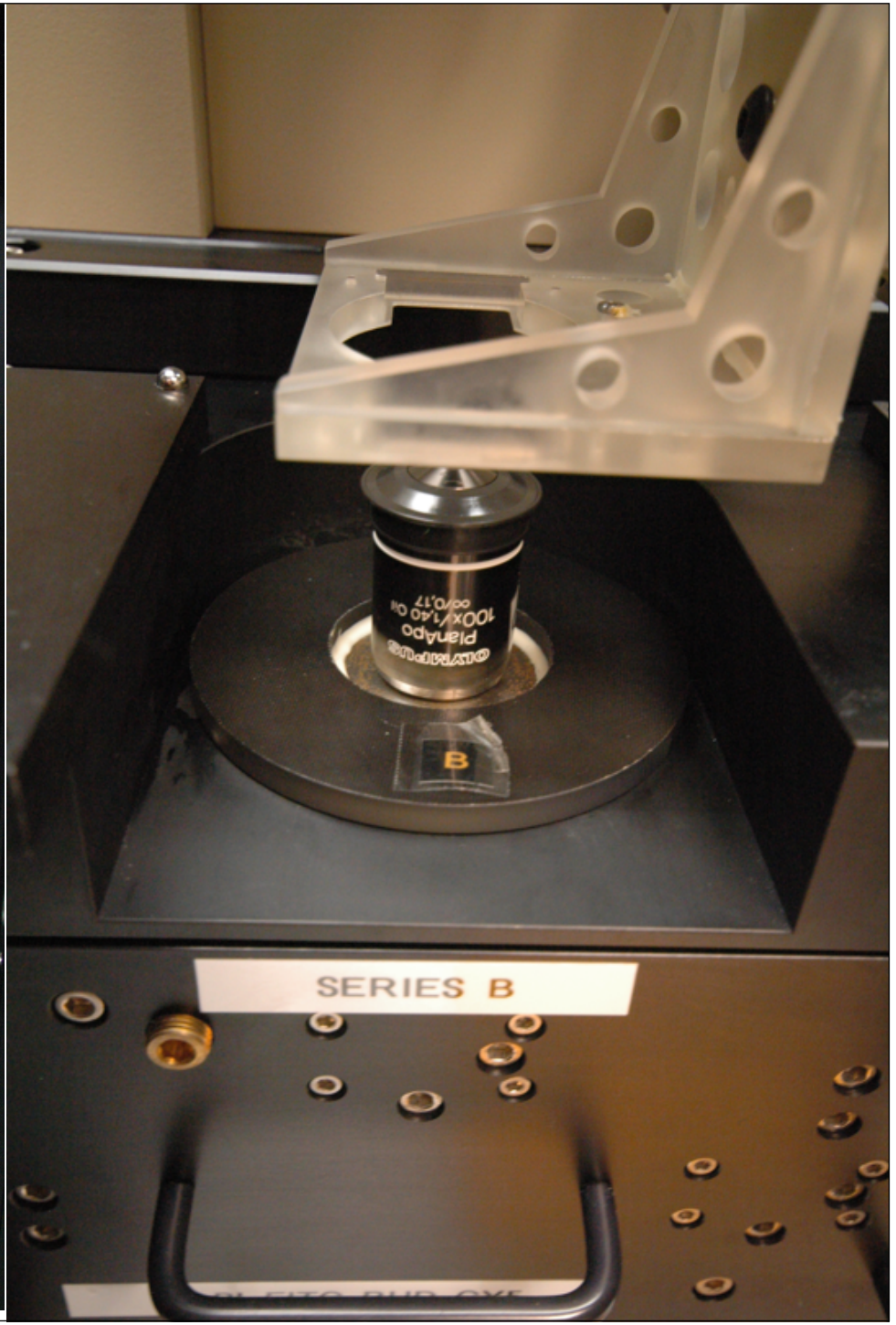


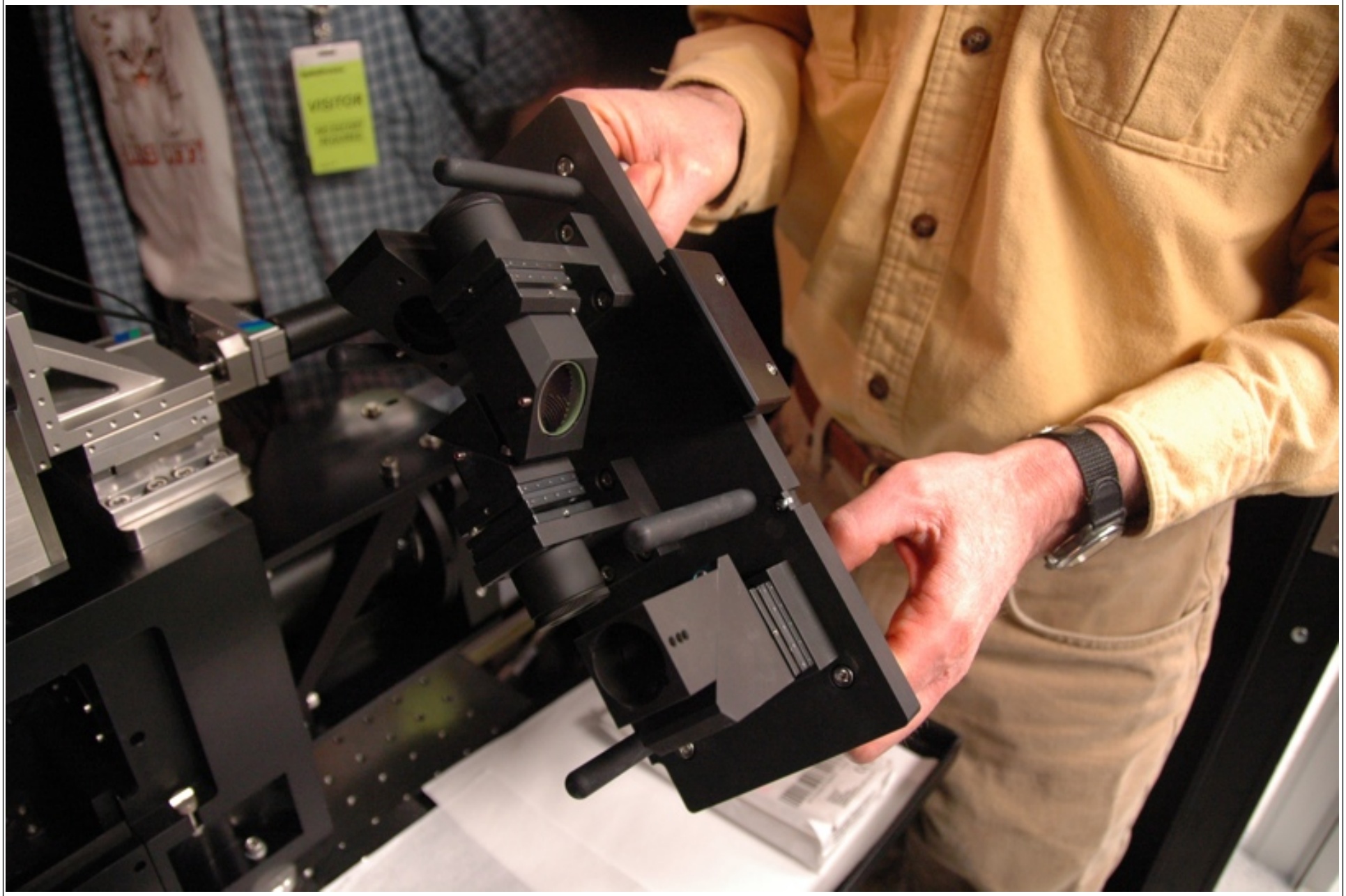
4 laser excitation lines
4 simultaneous acquisition lines CCDs

We have the second replica of the prototype instrument - 7 manufactured so far worlwide.

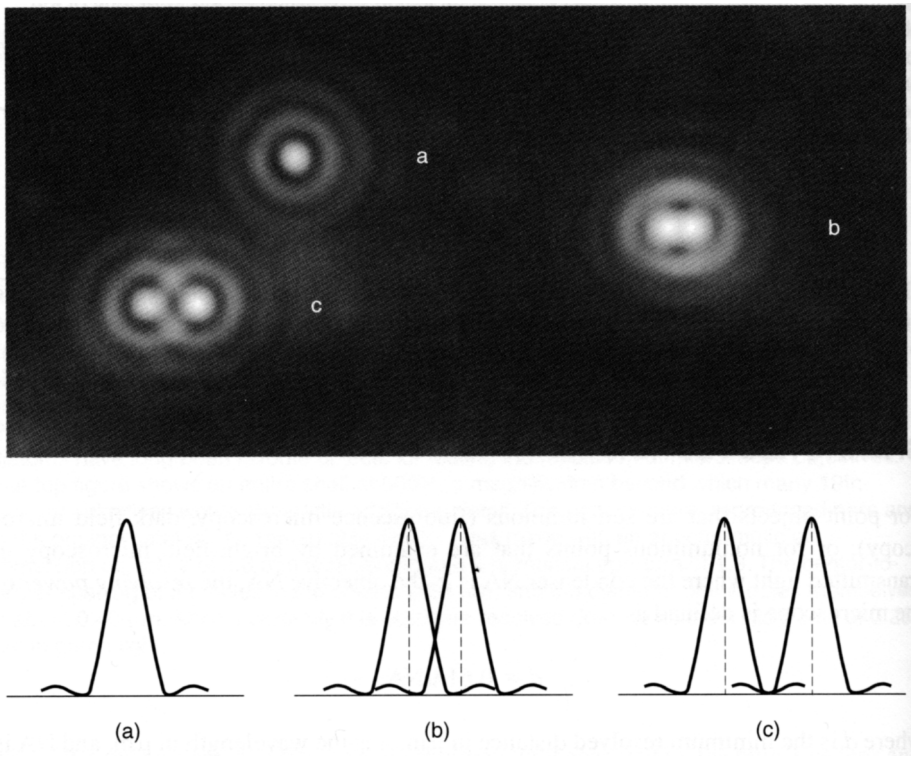

DANGER
Vantus

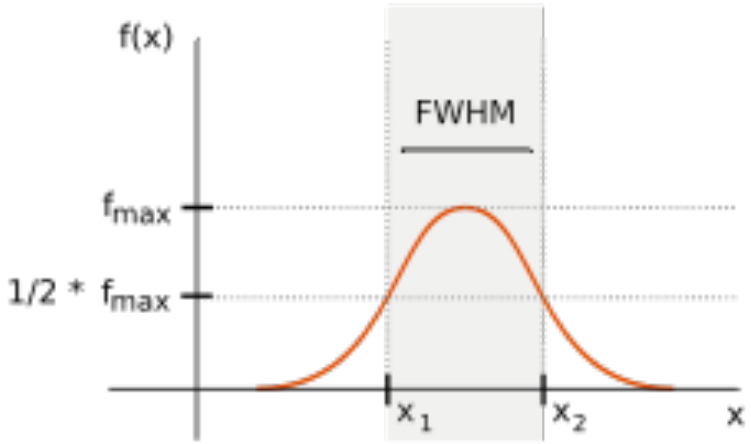

OLYMPUS
DANGER
TMC


OLYMPUS
PlanApo
100X/1.40 Oil
oo/0.17
B
SERIES B


VISITOR

Approximate resolution limit of light microscope
250nm in XY and 500nm in Z





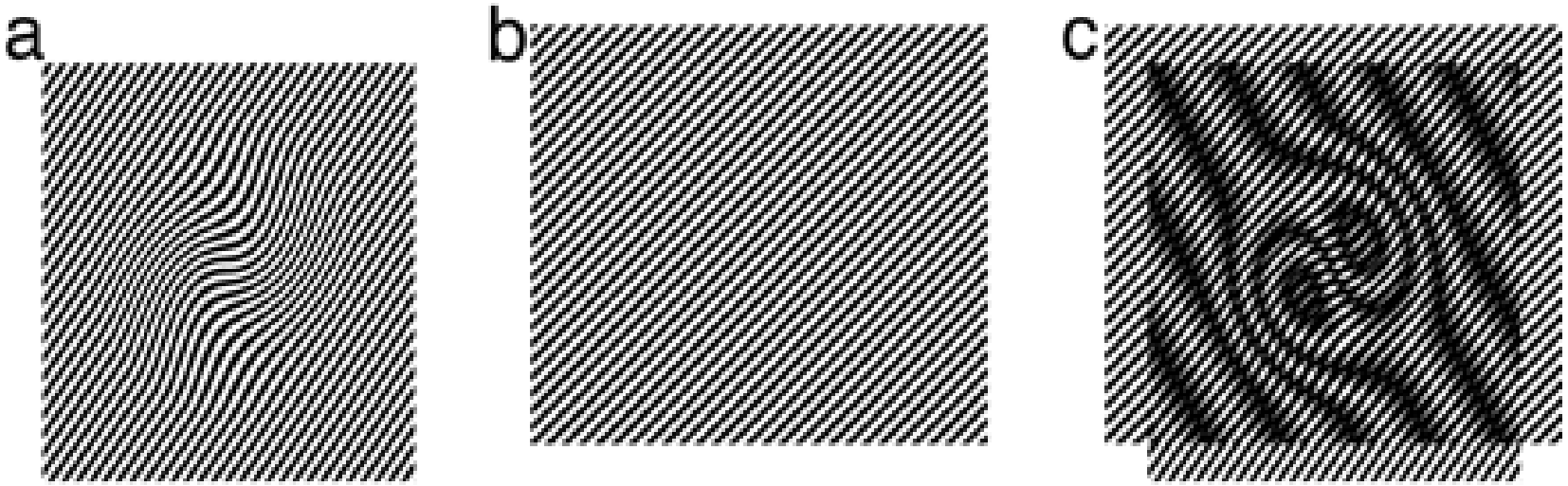
How can we overcome this limit ?

Structured Illumination

Surpassing the lateral resolution limit by a factor of two using structured illumination. Journal of microscopy Gustafsson, G.L., (2000) 198, 82.

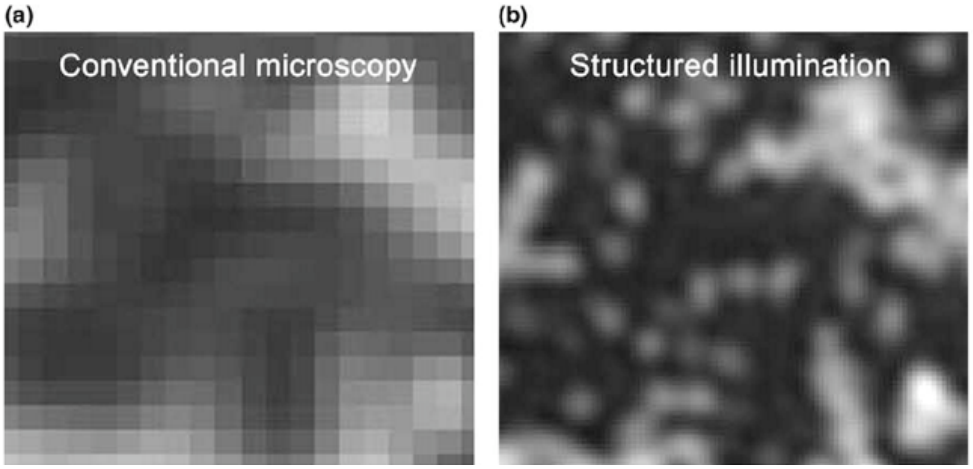
http://www.blackwell-synergy.com/links/doi/10.1046/j.1365-2818.2000.00710.x

Resolution extension through Moire effect

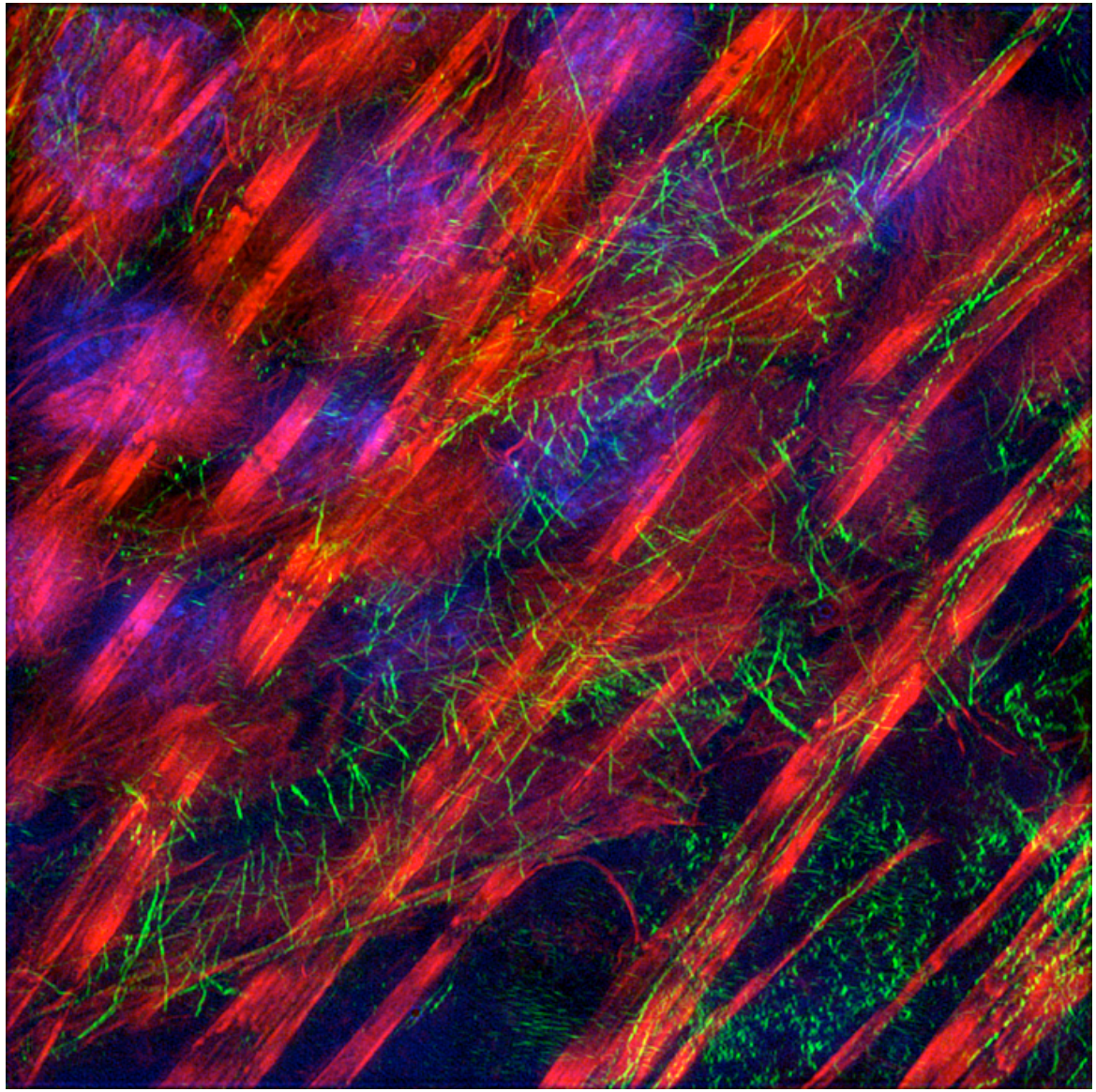


Sine wave pattern generated by a laser illumination
Captured at 5 phases and 3 angles and multiple Z sections

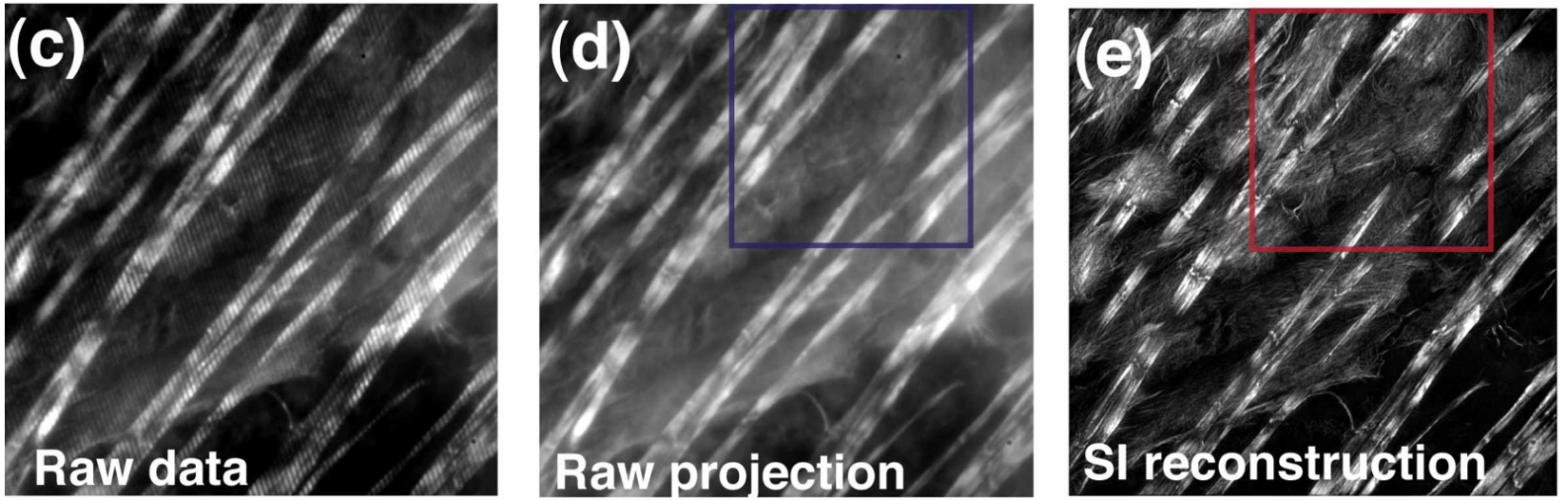
Fluorescent Beads

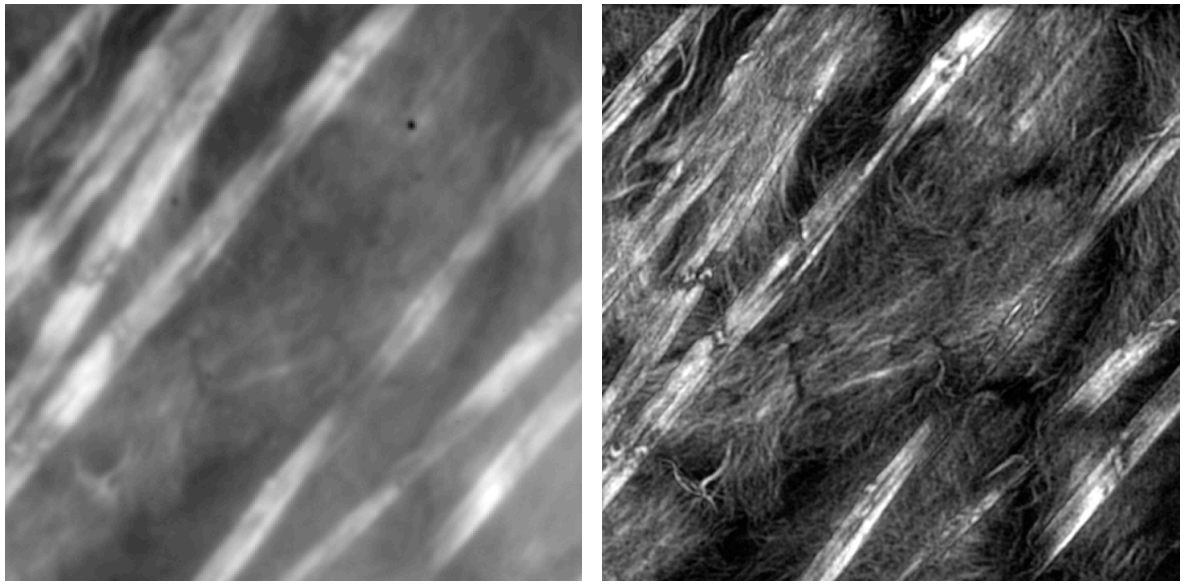


SI on *Drosophila* oocytes



How much better is it than conventional widefield ?





Structured Illumination imaging of living cells ?

Rapid Structured Illumination acquisition (e.g. <1Hz) is certainly possible

Structured Illumination increasing resolution beyond x2 ?

Non linear pattern (by saturation): no resolution limit

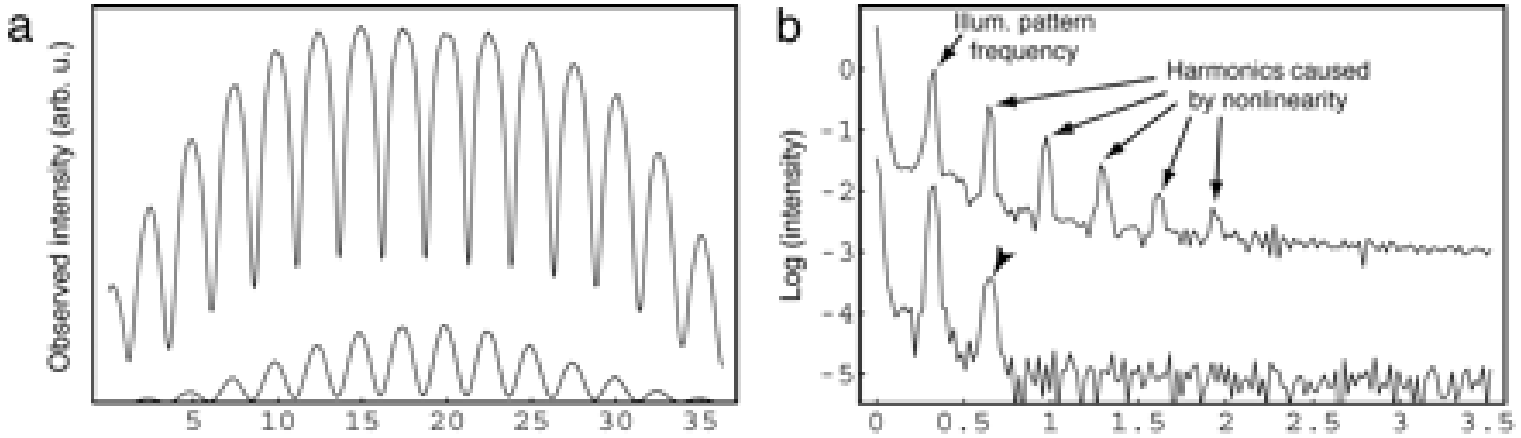
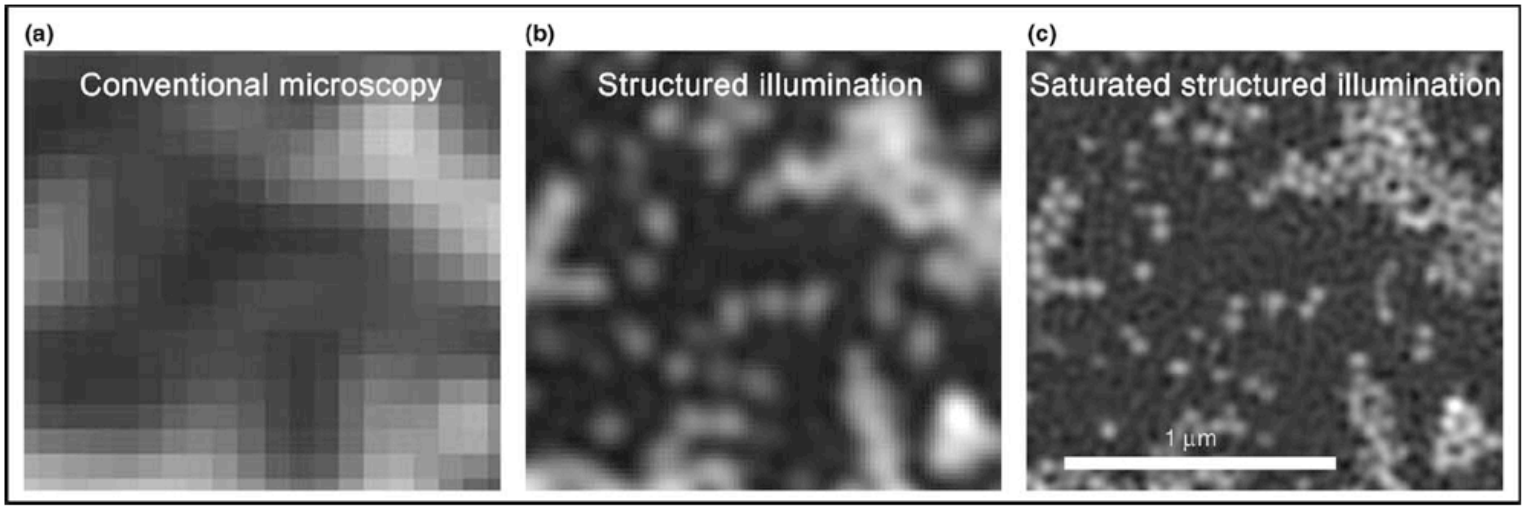


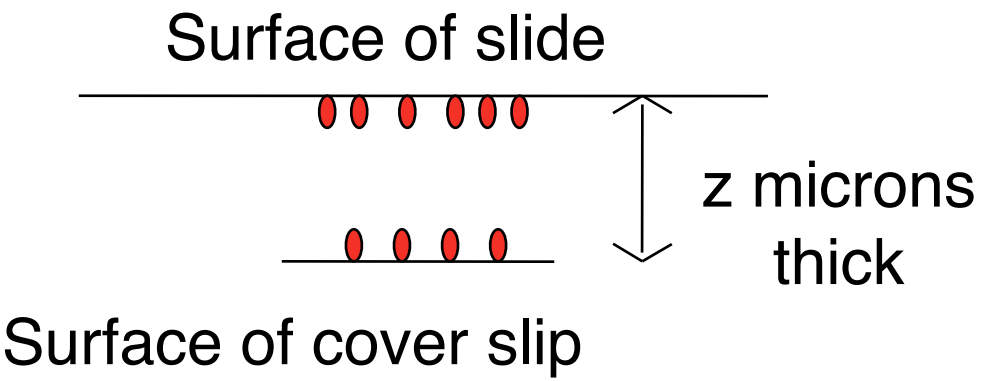
Figure 8



Improvement of resolution by structured illumination microscopy and nonlinear saturated structured illumination microscopy (SSIM). **(a)** Conventional microscope image, **(b)** structured illumination microscopy and **(c)** SSIM. The sample consists of fluorescent polystyrene beads with a nominal diameter of 51 nm [35]. (Figure reproduced with kind permission of M Gustafsson).

The End

Bead slide: 0.1micron and 0.5 micron

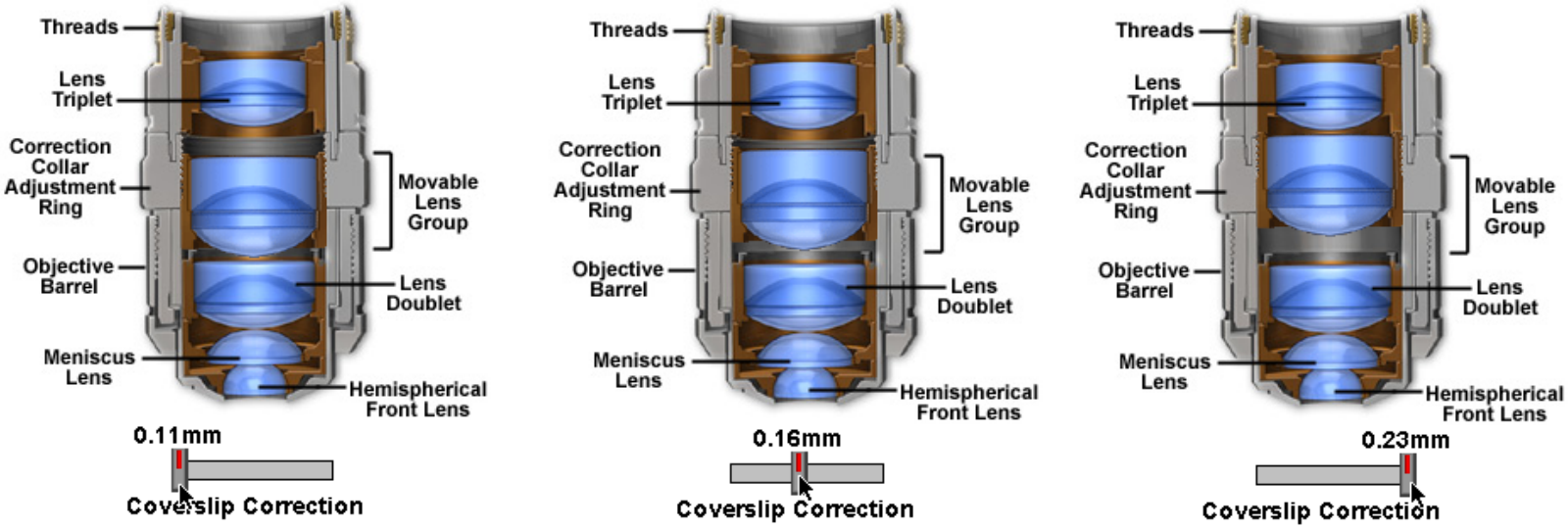


Tetraspeck beads: chromatic registration
DAPI/FITC/Rhodamine/Cy5

Beads (PS Spec): Single fluorochrome
Brighter -better for generating
point spread functions for deconvolution

Inspec Intensity beads: Measure dynamic range

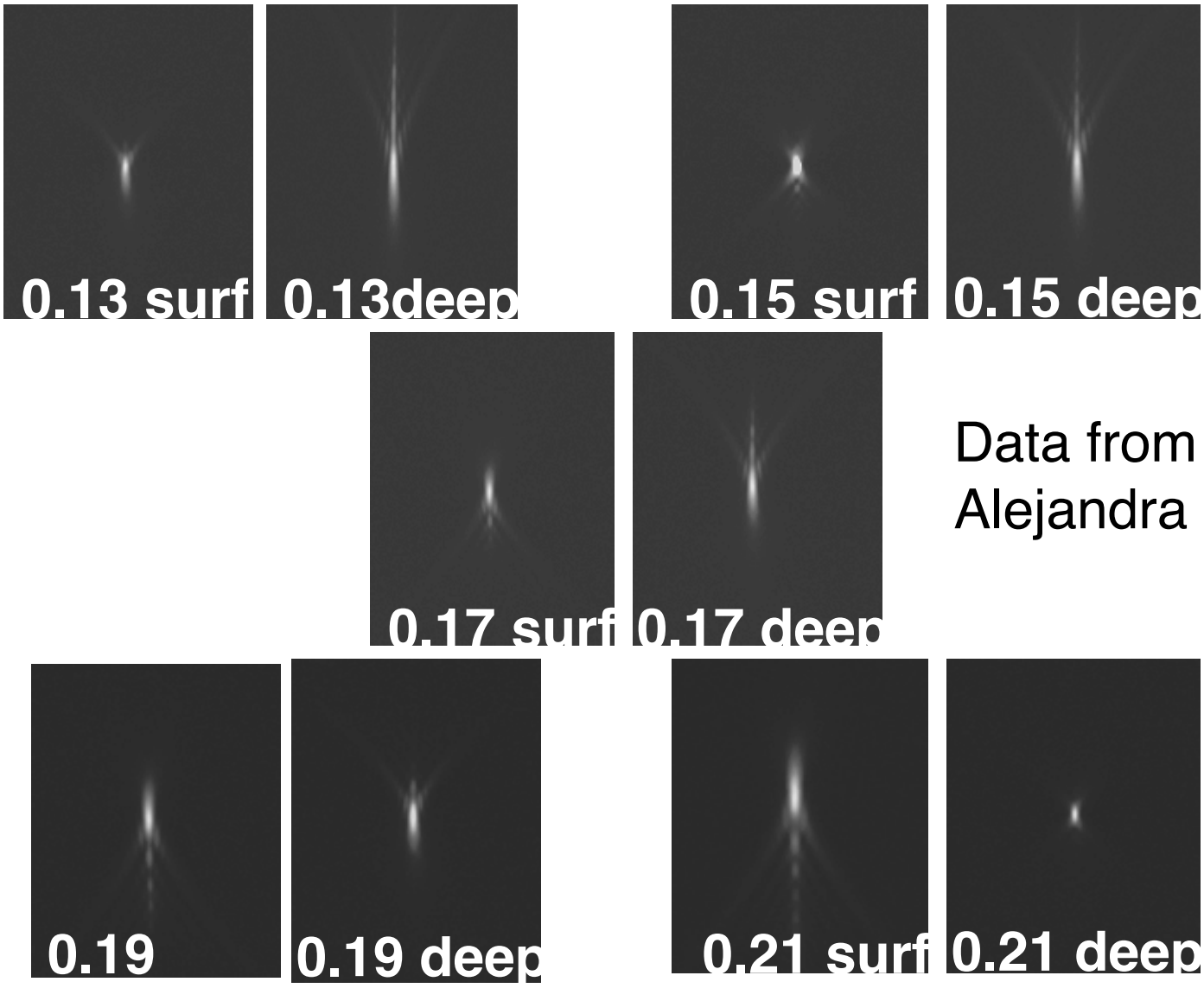
Using (coverslip thickness) correction collars of water immersion objectives to correct spherical aberration When imaging deep sections in thick specimens



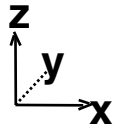
Alternatives:

1) Motorized lens inside microscope (Intelligent imaging-3I).
2) Can use immersion oils of varying refractive indices for oil immersion lenses (RI=1.515 to 1.534 from Cargil).
3) Use total immersion lenses / dipping lenses (no cover slip).
4) Adaptive Optics

Affects of deep imaging (90μm) and collar settings on spherical aberration and psf of 60X/NA1.2w

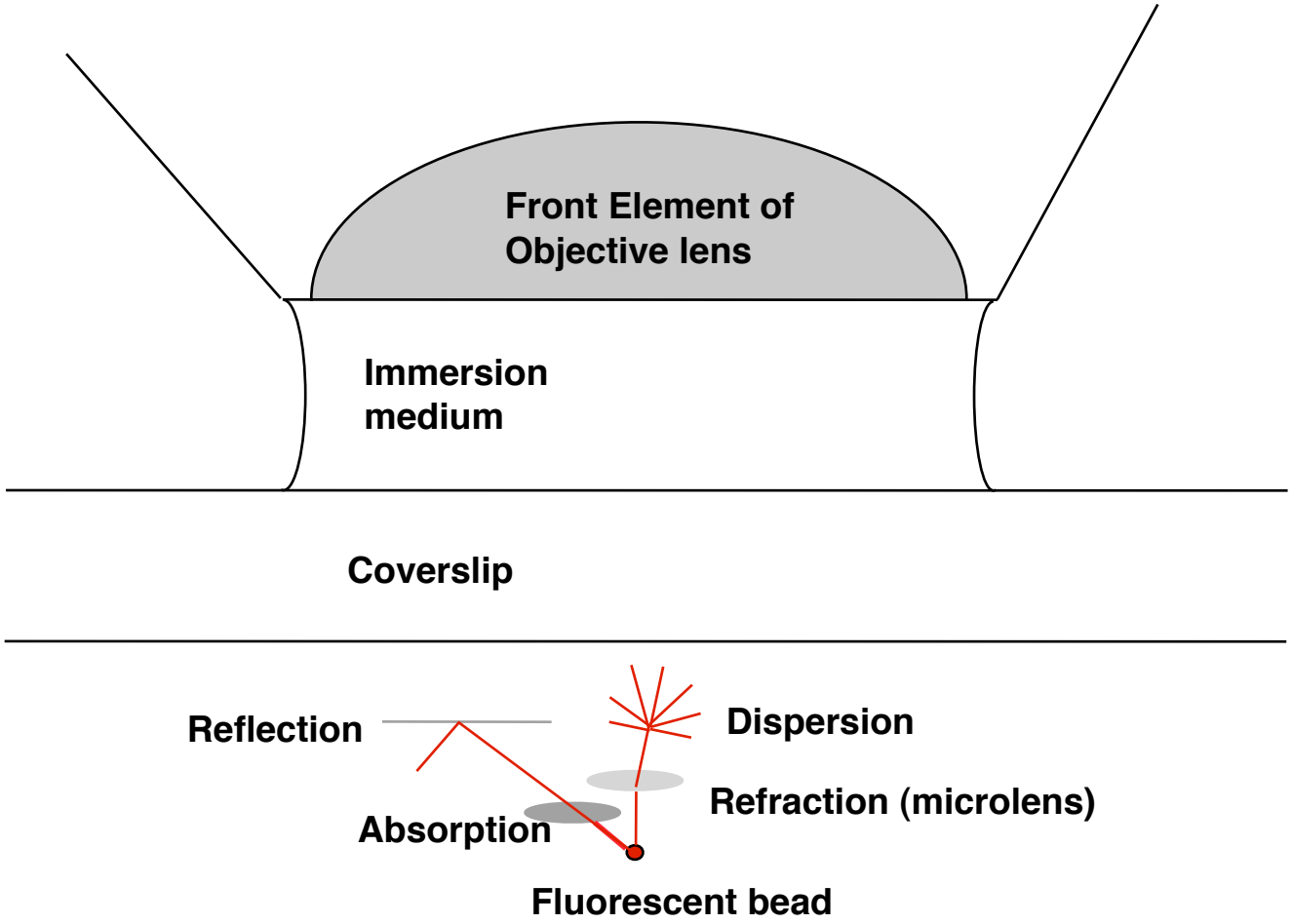


Data from
Alejandra Clark



Problems other than spherical aberration

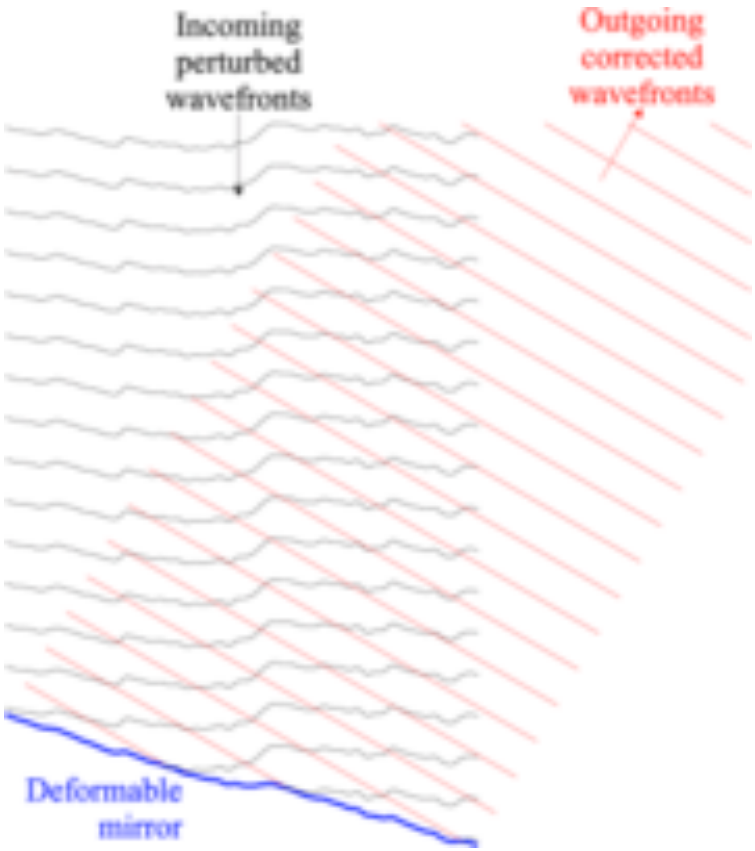
(imaging deep in thick specimens)



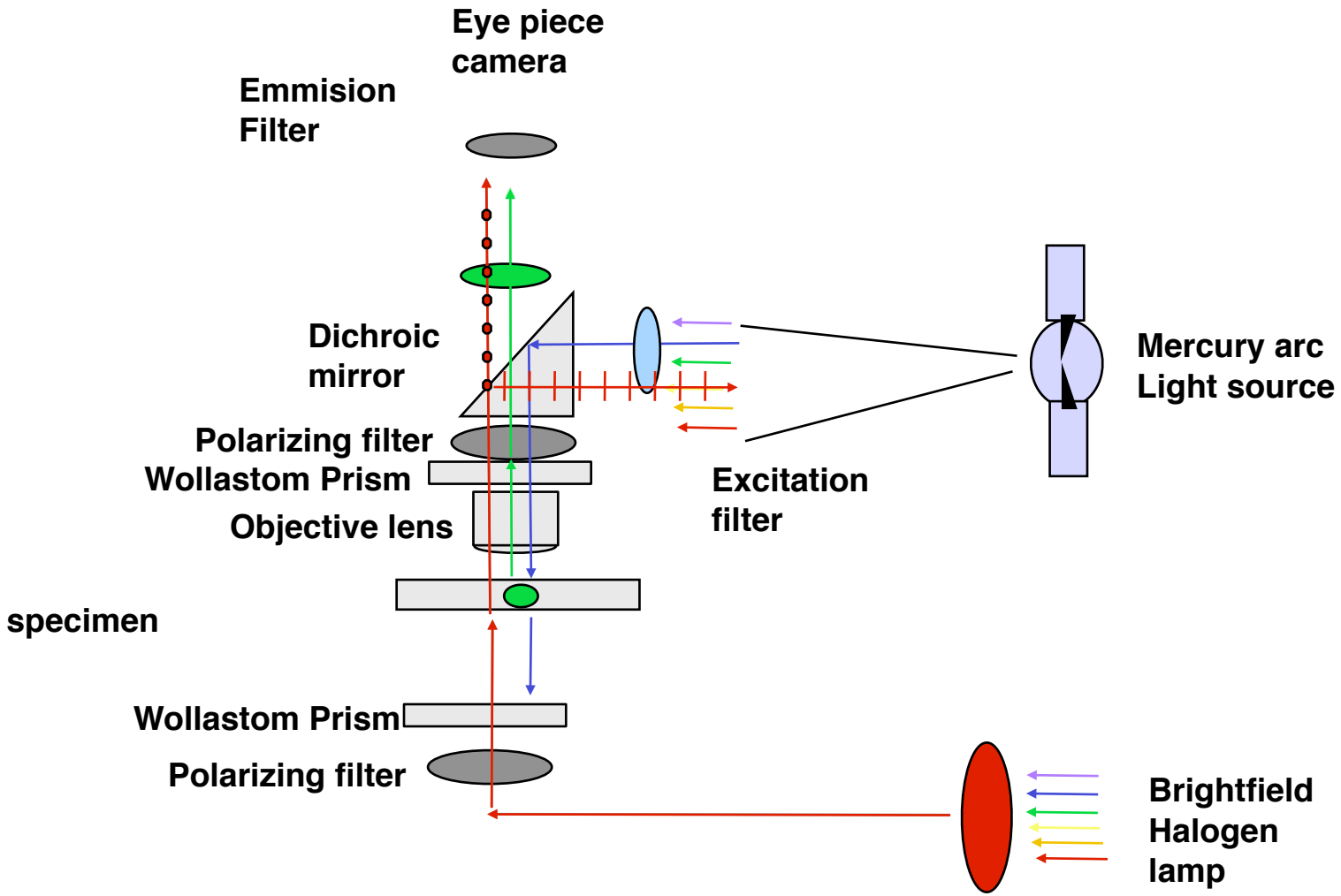
Partly overcome using far red / infrared excitation or multiphoton excitation

Adaptive Optics

Zam K, Hanser B, Gustafsson MGL, Agard DA, Sedat JW. Computational adaptive optics for live three-dimensional biological imaging. Proc. Natl. Acad. Sci. USA 98: 3790-3795, 2000.



How to use DIC and Fluorescence without loss of signal by polarizing filter?



Simultaneous DIC and fluorescence imaging with no loss of fluorescence intensity

DIC/FITC cube where dichroic mirror acts as polariser only in red light instead of the analyser.
Originally only for FITC now available for FITC/rhodamine/DIC and other flavours
Analyser removed to emission filter wheel (poorer quality DIC)

High resolution DIC

Critical bright field illumination (image of magnified central part of UV bulb focused directly onto specimen, opposite to Kohler).

- UV and IR filters used.
- Condenser with oil immersion lens.
- High resolution (low contrast) Wollaston prism