

sCMOS

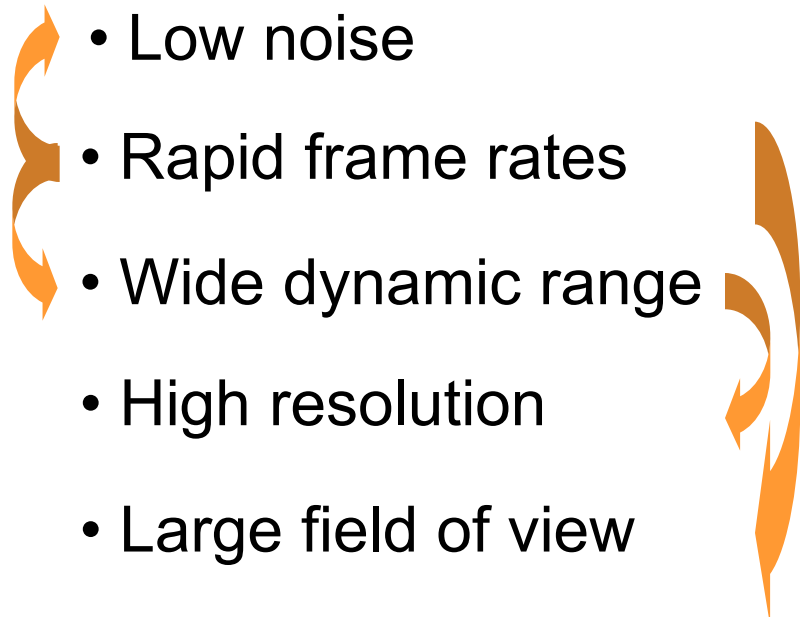
Orla Hanrahan, PhD

Application Specialist Life Science Imaging

discover new ways of seeing™

Scientific imaging trade-offs...

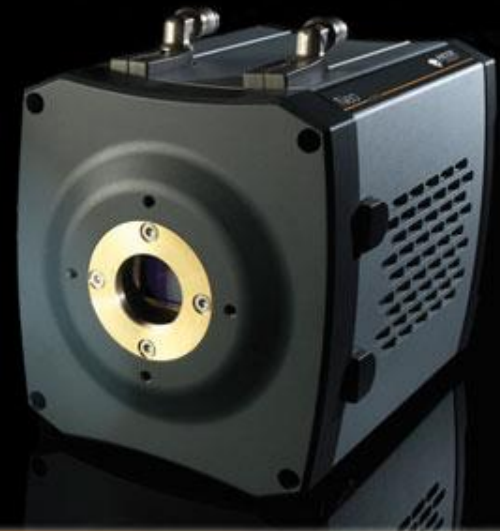
Today's imaging detectors exhibit trade-offs between key performance parameters...

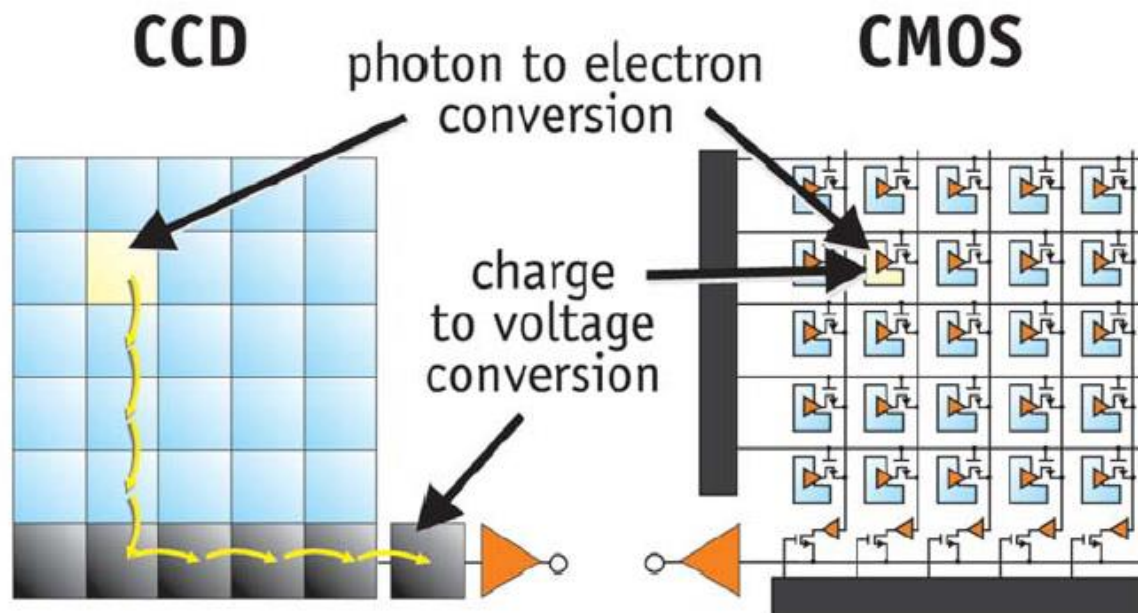
- 
- Low noise
 - Rapid frame rates
 - Wide dynamic range
 - High resolution
 - Large field of view

sCMOS technology overcomes trade-offs

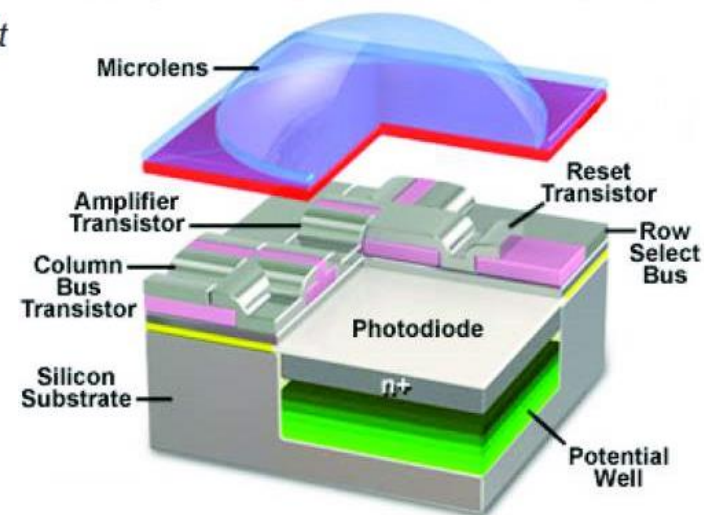
Scientific CMOS (sCMOS)
is *unique* in
simultaneously offering:

- Extremely low noise (without multiplication)
- Rapid frame rates
- Wide dynamic range
- High QE
- High resolution
- Large field of view





CCDs move photogenerated charge from pixel to pixel and convert it to voltage at an output node. CMOS imagers convert charge to voltage inside each pixel.

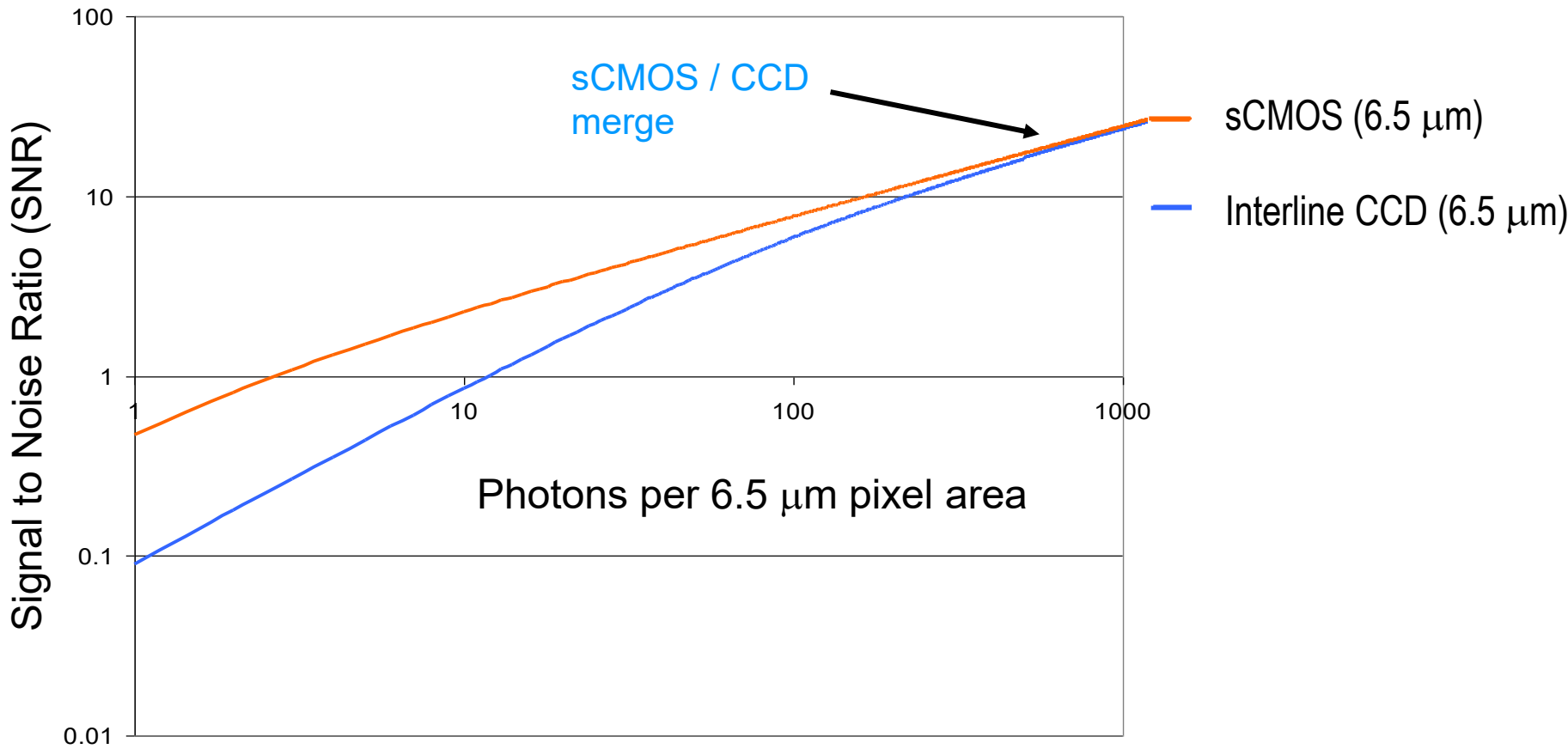


sCMOS vs other imaging technologies...

	Sony interline	EMCCD	sCMOS
Sensor format	1.4 MP	1 MP (max.)	5.5 MP
Pixel size	6.45 μm	8 to 24 μm	6.5 μm
Max. frame rate	12 fps @ 20MHz	> 30 fps	100 fps
Read noise	4 – 8 e^-	Negligible (<1 e^-)	1 e^- @ 30 fps 1.3 e^- @ 100 fps
QE	~ 60% (FI)	65% (FI) / >90% (BI)	~ 57% (FI) (excellent red response)
Dynamic range	~ 3,000:1 (@ 11 frames/sec)	~ 8,500:1 (@ 30 frames/sec)	30,000:1 (@ 30 frames/sec)
Darkcurrent (TE cooled)	0.0003 $\text{e}/\text{pix}/\text{sec}$ @ -55 $^{\circ}\text{C}$	0.001 $\text{e}/\text{pix}/\text{sec}$ @ -85 $^{\circ}\text{C}$	0.07 $\text{e}/\text{pix}/\text{sec}$ @ -30 $^{\circ}\text{C}$

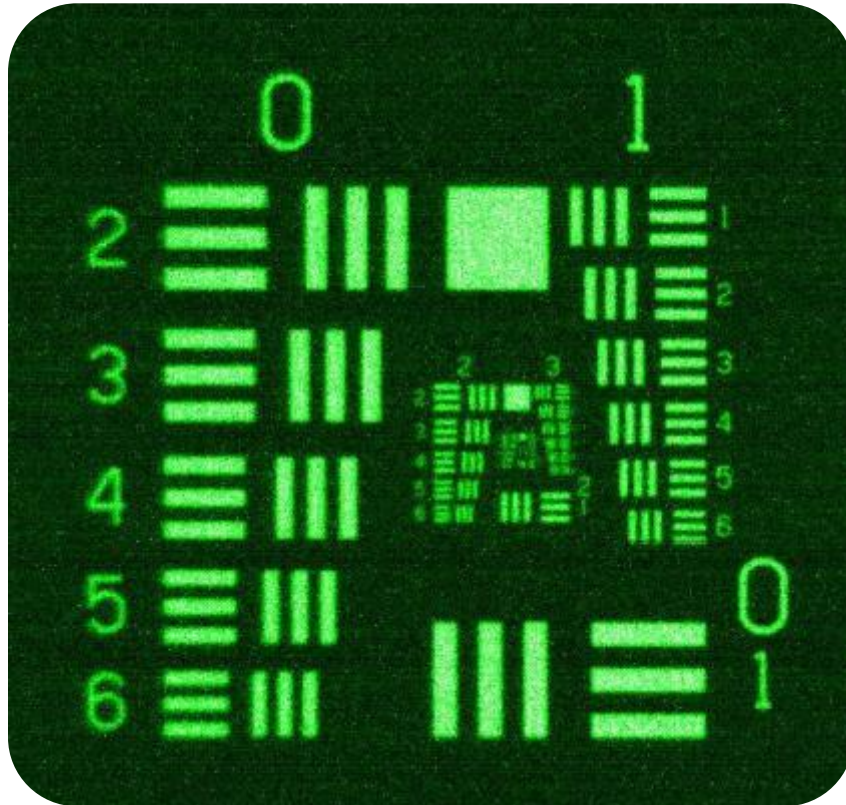
sCMOS vs interline CCD ...

sCMOS vs Interline CCD...
(no binning)

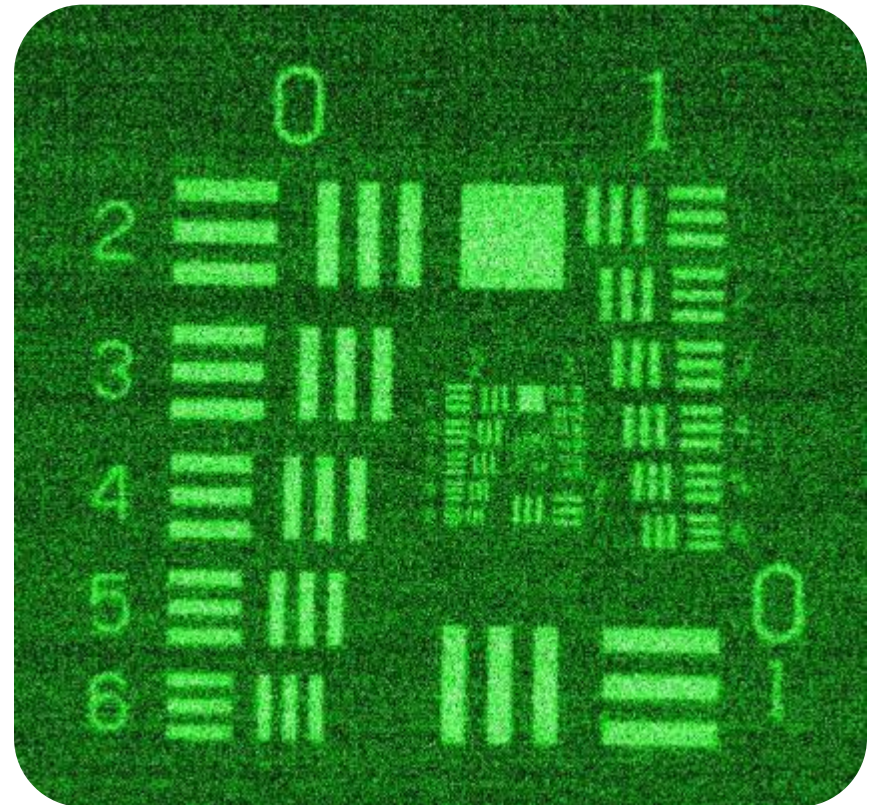


sCMOS vs interline CCD image comparison...

**sCMOS –
1.2 e^- noise**

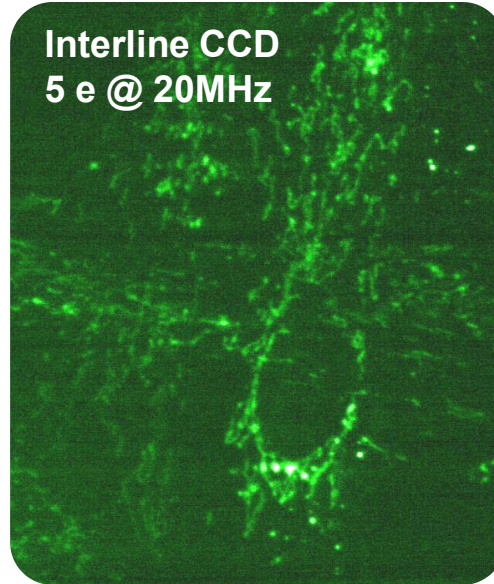
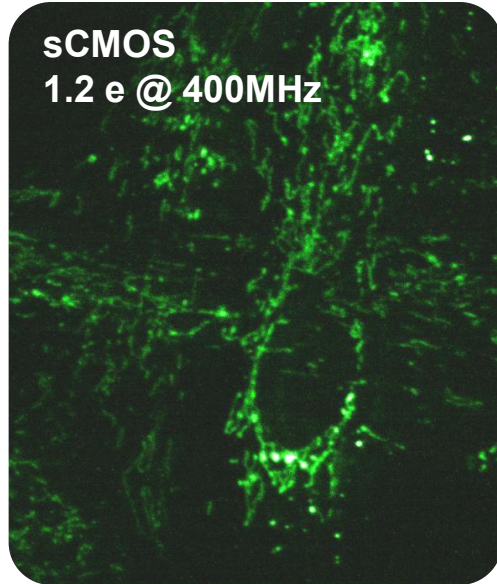


**Sony ICX285 Interline CCD –
5 e^- noise**



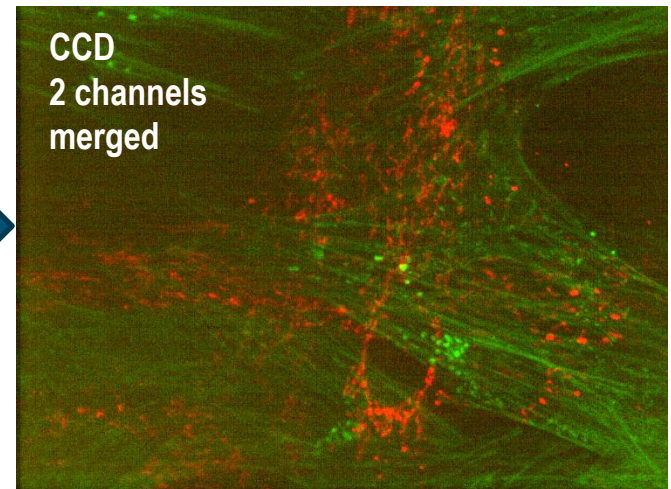
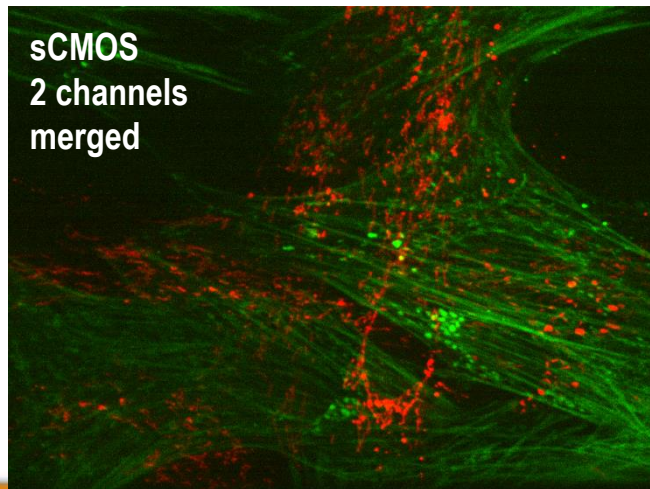
~ 30 ph/pix
622nm

sCMOS vs interline CCD image comparison...

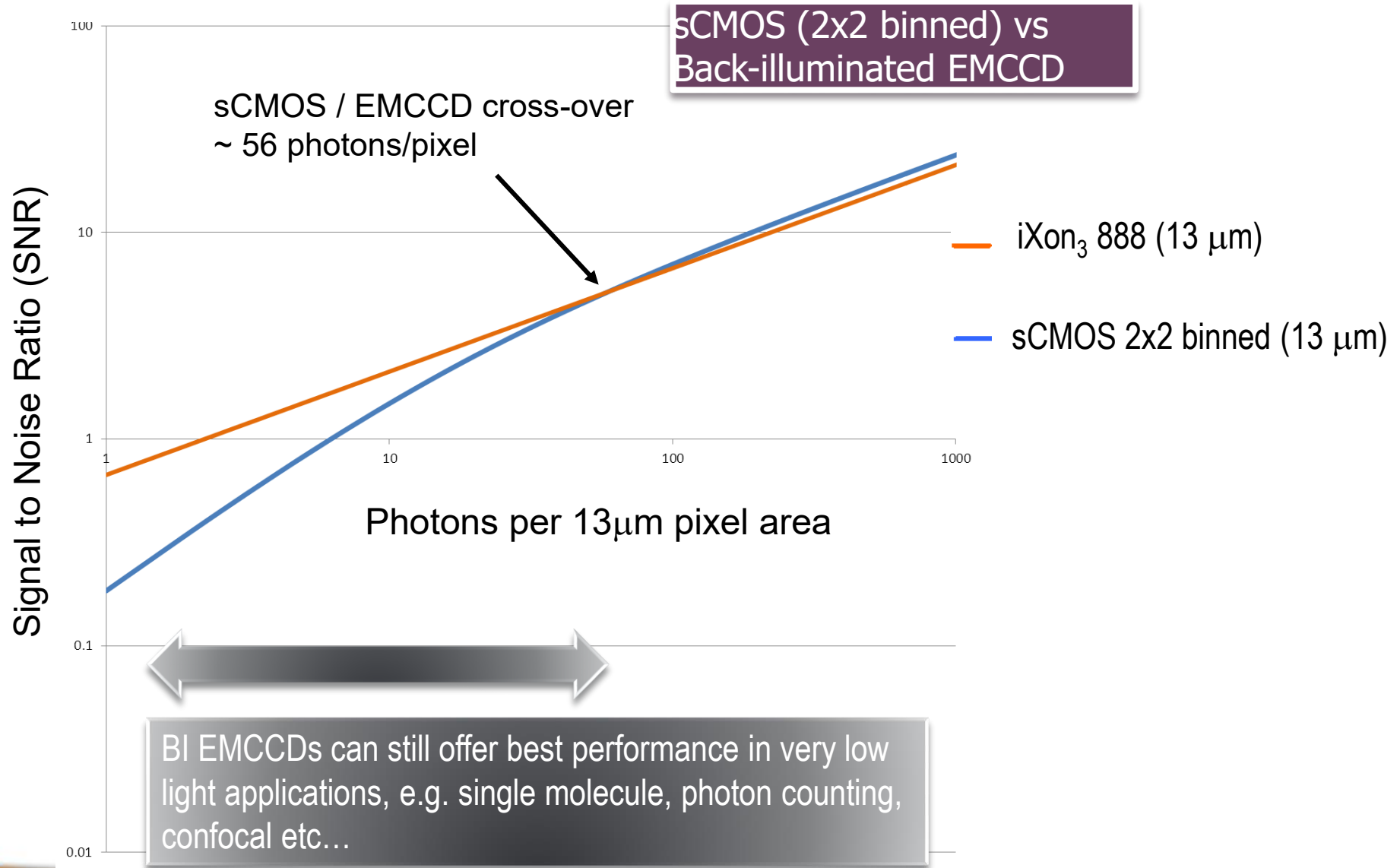


sCMOS (400MHz; 1.2 e⁻ read noise) vs Interline ICX285 sensor (20MHz; 5 e⁻ read noise)

- CSU-X spinning disk confocal microscope (x60 oil objective)
- each 100ms exposure
- same laser power
- displayed with same relative intensity scaling.



sCMOS vs EMCCD ...



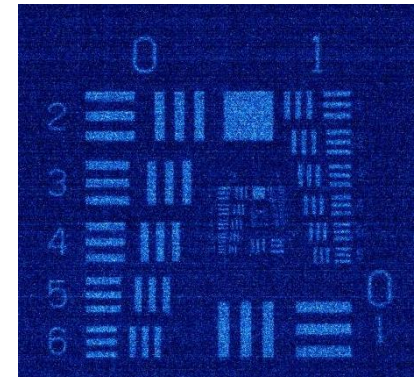
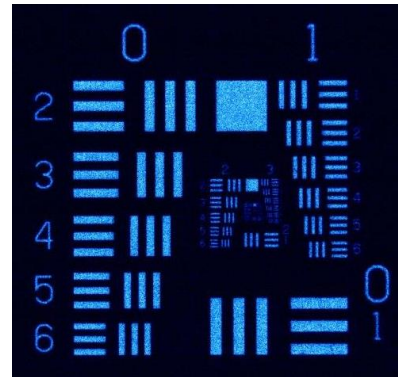
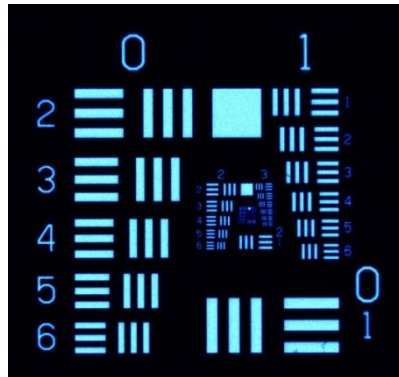
sCMOS vs EMCCD image comparison...

490
photons
per pixel

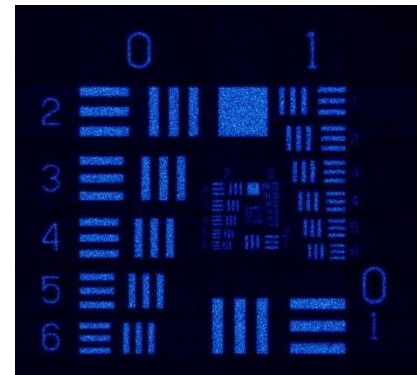
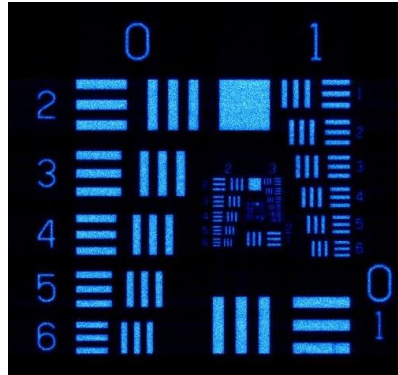
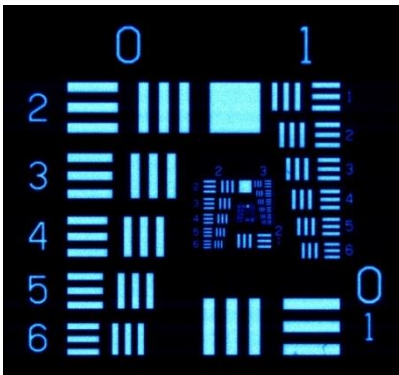
68
photons
per pixel

8
photons
per pixel

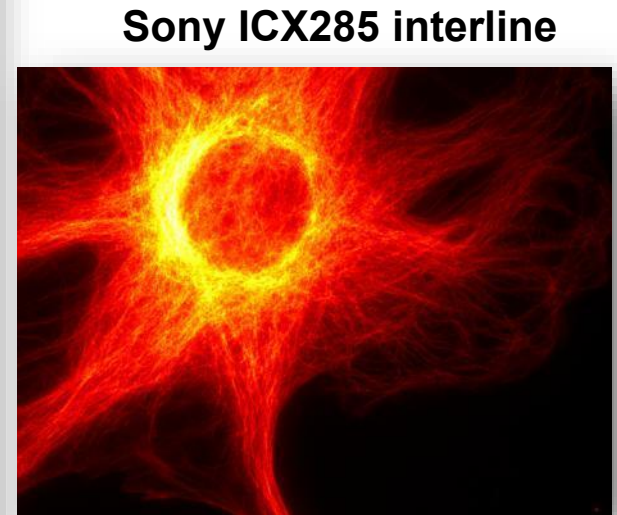
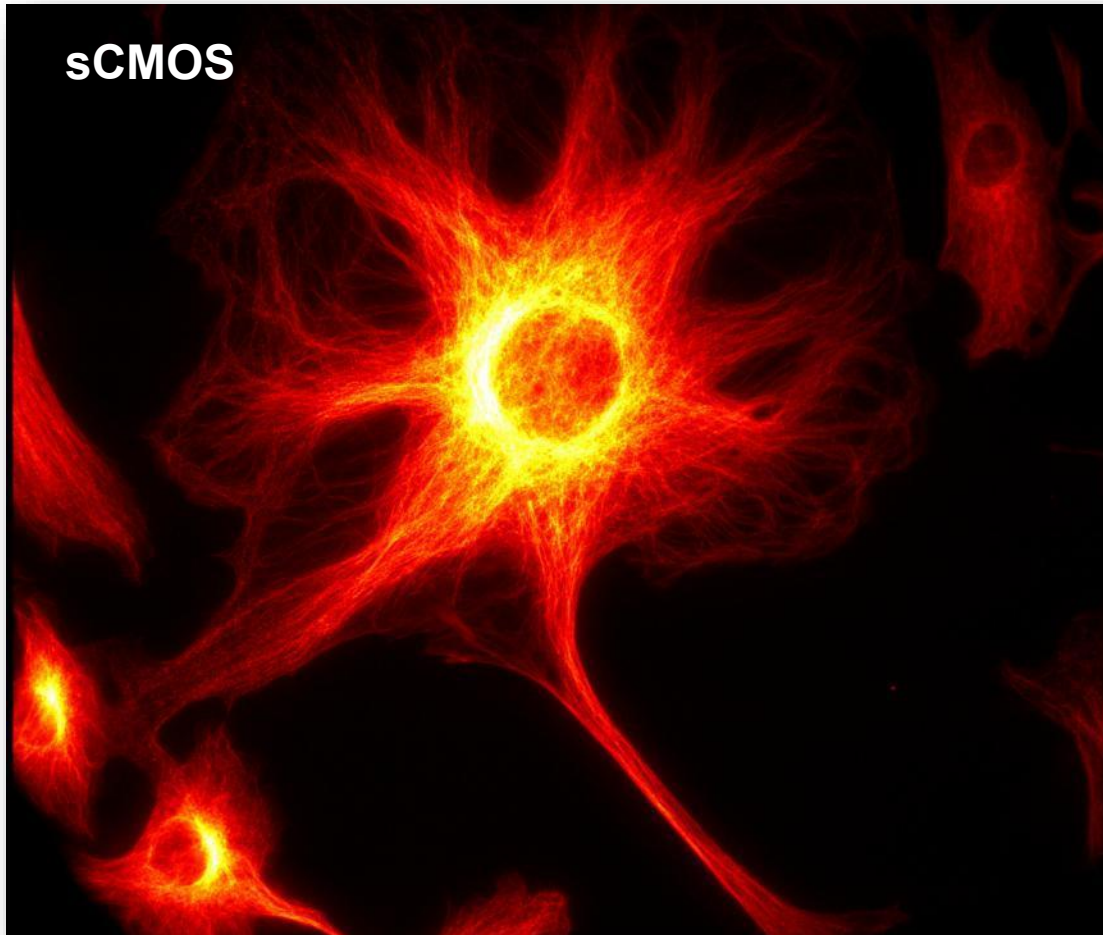
sCMOS
2x2 binned
(13 μm)



EMCCD
(13 μm)



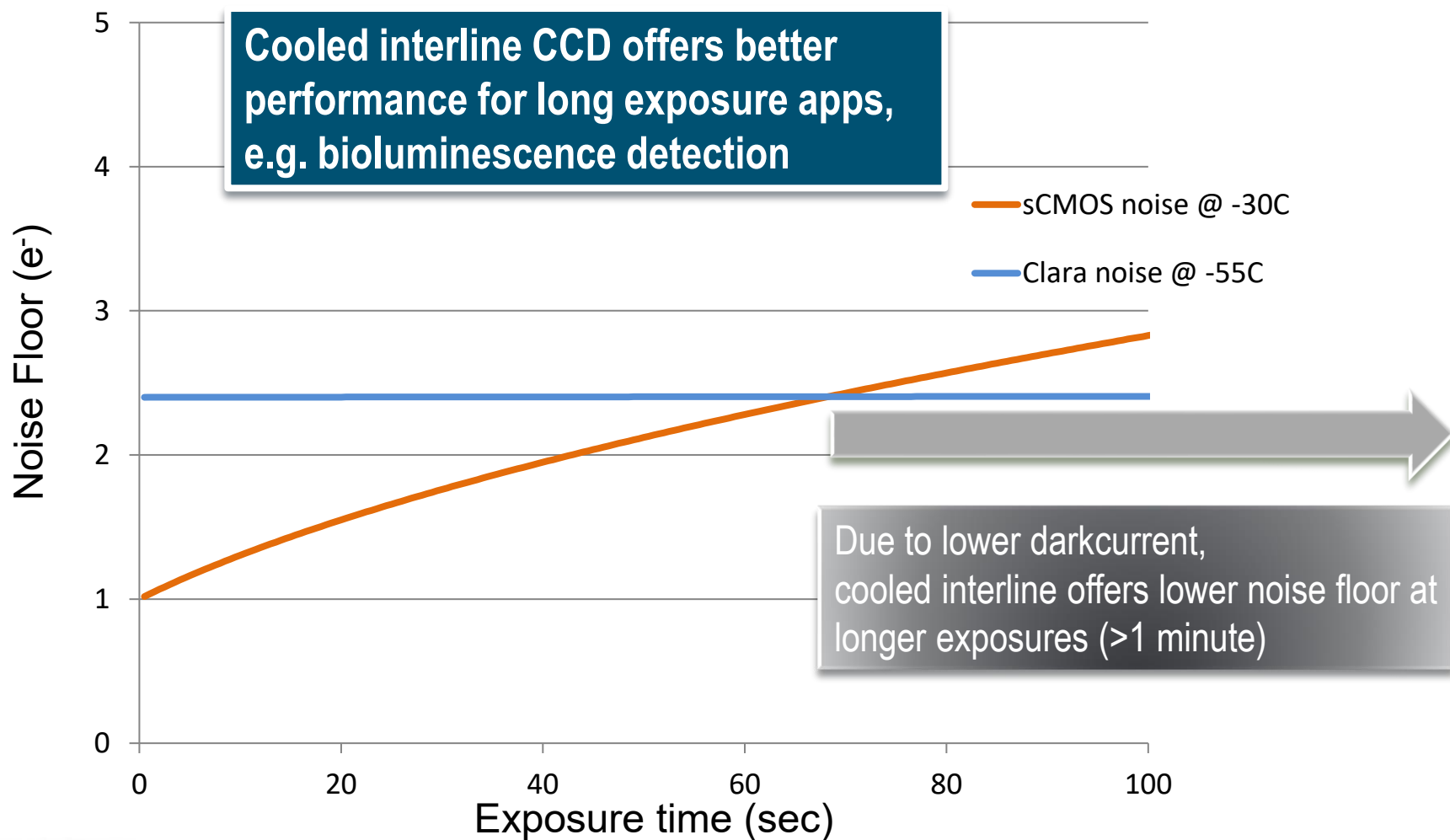
Field of View comparisons....



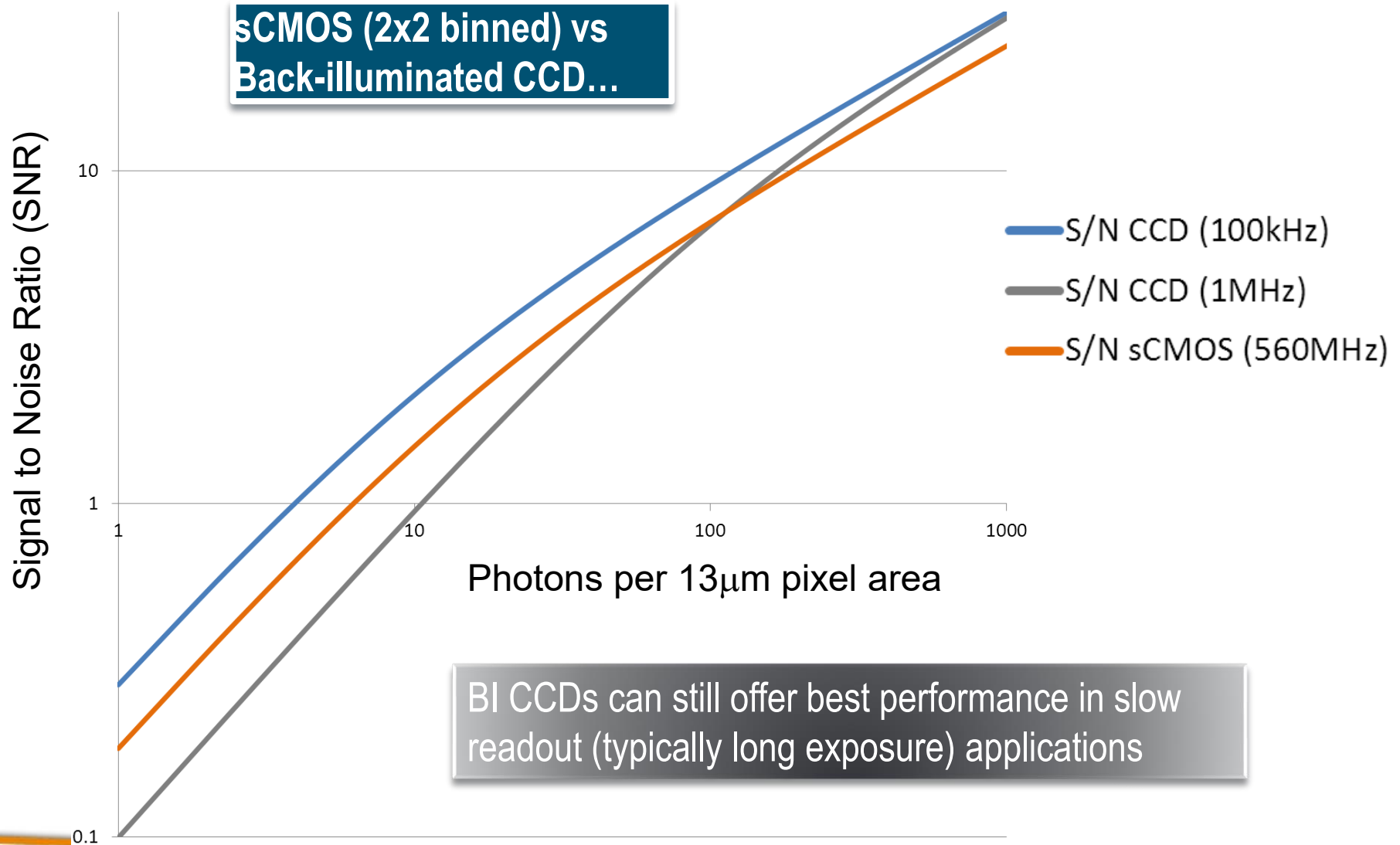
Field of view comparison of two technologies; x60 magnification; 1.25 NA; 5.5 megapixel sCMOS vs 1.4 megapixel interline CCD (each have ~ 6.5 μm pixel pitch).

sCMOS vs interline CCD

Noise Floor (read noise and dark noise) vs exposure



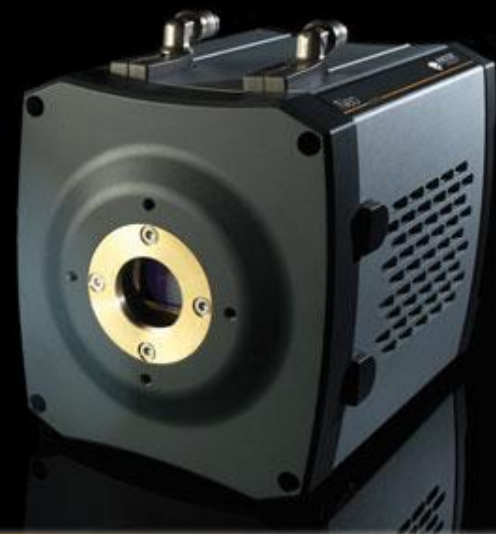
sCMOS vs back-illuminated CCD...



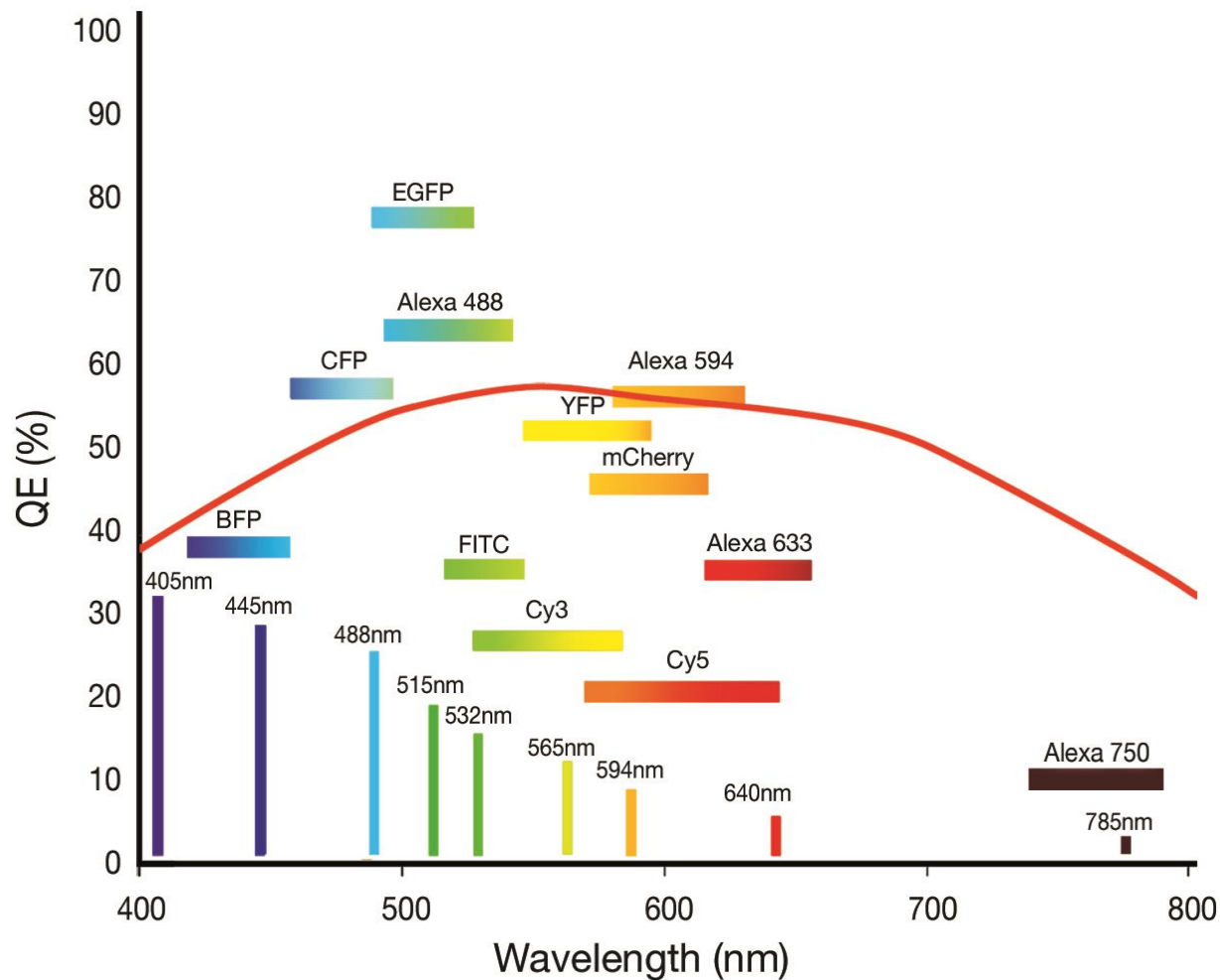
sCMOS was conceptualised to become the 'new interline'

How to achieve this?

Interline	sCMOS	
4 to 8 e ⁻	More Sensitive	1e ⁻
11-16 fps	Faster	30 fps sustained
< 12-bit	Wider Dynamic Range	> 14-bit
1.4 MP	Larger FoV / Resolution	5.5 MP
'Snapshot' exposure	Rolling & Global exposure	✓
Decent image quality		Price

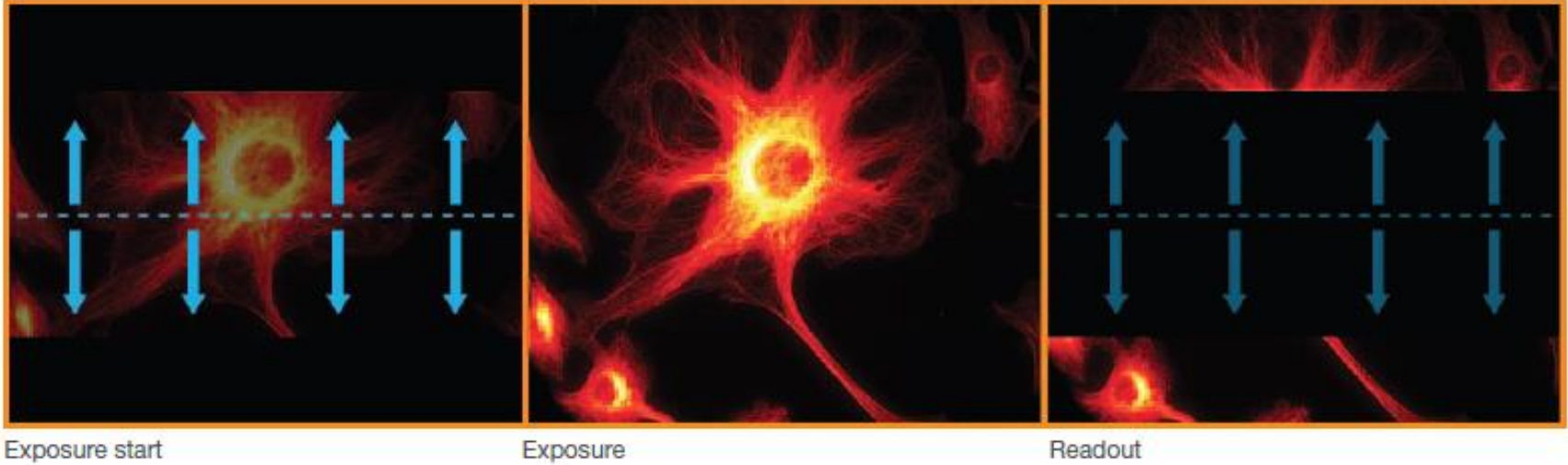


sCMOS QE curve



Rolling and Global exposure modes

Rolling Shutter exposure and readout



Global Shutter exposure and readout



Rolling or Global?

Rolling shutter

- Use when do **not** require exact correlation in time between two separated regions of the image, e.g. vesicle tracking, calcium waves
- Use when no danger of spatial distortion in 'large' fast moving objects
- To achieve lowest possible read noise (1 to 1.3 e⁻)
- To achieve fastest possible frame rates

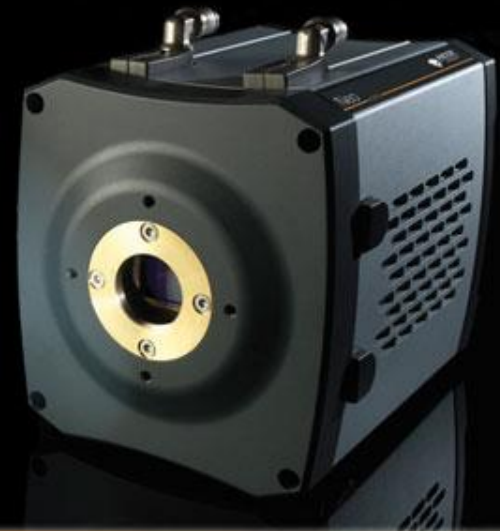
Global (Snapshot) shutter

- This mode is analogous to 'interline CCD' snapshot mode of exposure and readout
- Use when time correlation between separate regions of image is required
- Read noise compromised slightly (2.3 to 2.5 e⁻)

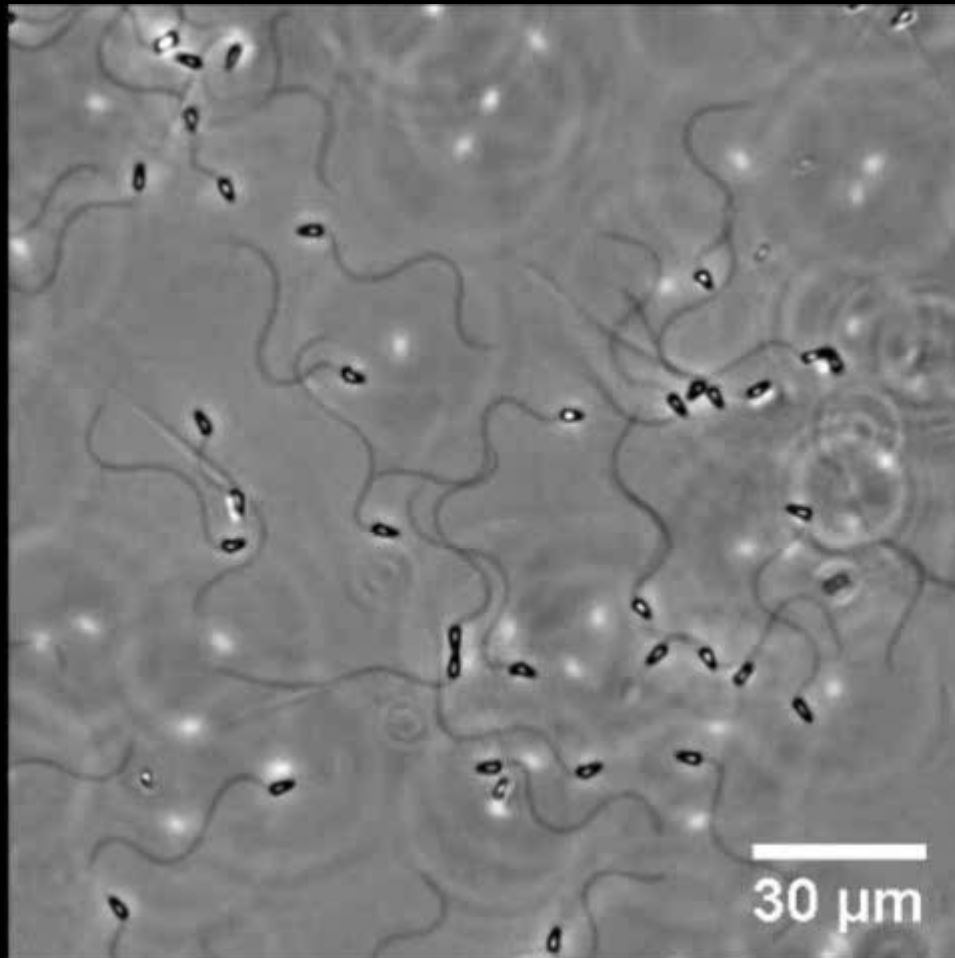
Applications of the sCMOS

Some uses of the sCMOS so far...

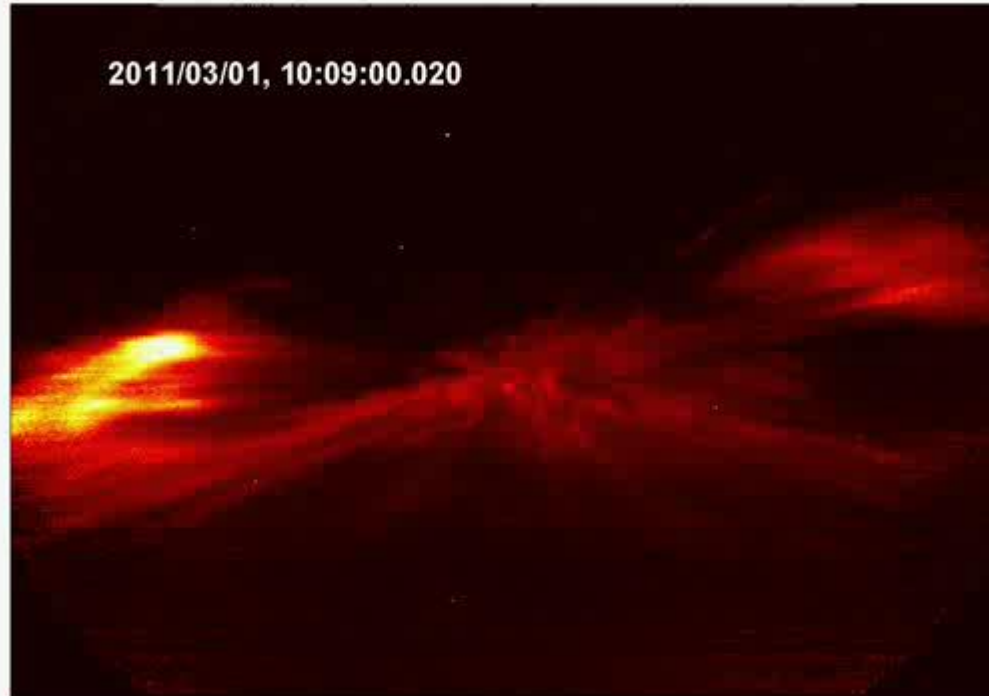
- SPIM
- Vesicle transport
- Cell motility
- Astronomy
- Motor proteins (myosin)
- Laser speckle imaging – blood flow
- Neural circuits
- Calcium signalling



Dr. Jeffrey Guasto, Dept. Of Civil & Environmental engineering, MIT-understanding the biomechanics of sperm cell movement-important for fertilization.

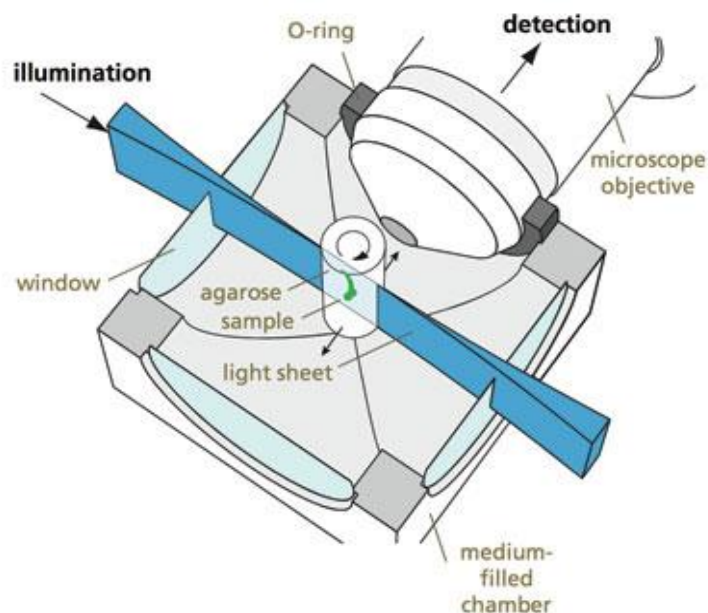


Dr. Robert Marshall, Centre for Space Physics, Boston University - Aurora
Breakup event captured with the Neo at 50 fps, full frame



“This data will allow us to make unprecedented measurements of morphology of small-scale auroral structures”

SPIM (Selective Plane Illumination Microscopy)



Recommendation: Neo sCMOS

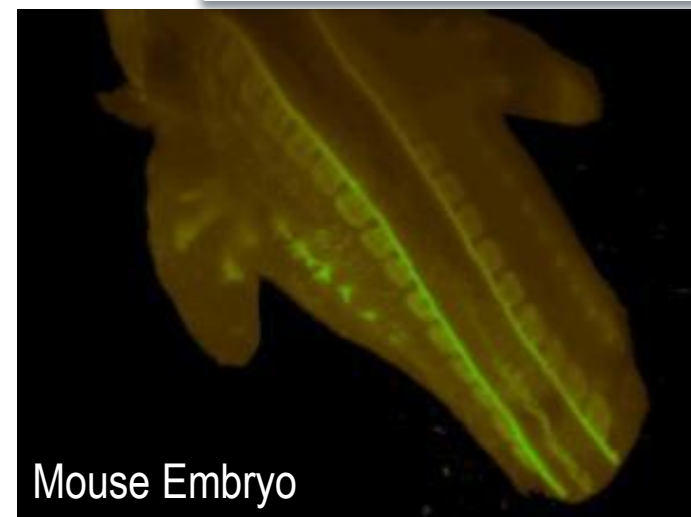
- ✓ Resolution
- ✓ Field of View
- ✓ Speed



Dr. Lars Hufnagel,
Developmental Biology
Unit, EMBL Heidelberg.

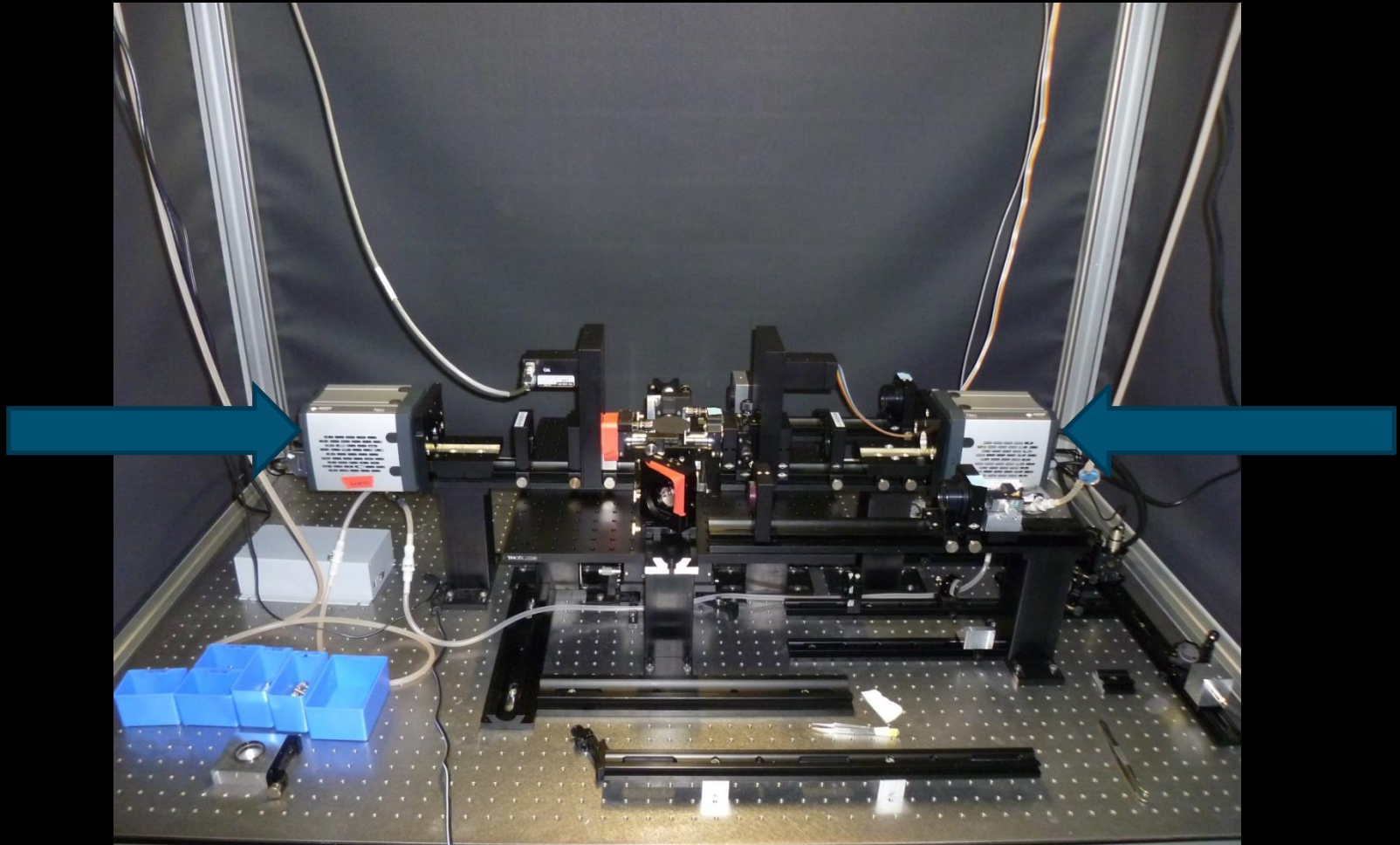
'Without pushing it to the limit we managed to take 131 planes of the drosophila embryo in just 4 seconds (5.5 megapixels mode), which is practically instantaneous compared to the morphogenetic processes and out-performs by far everything we have tried before. **The camera is made for SPIM microscopy!**

- Optical sectioning even with lenses that have a large working distance and a relatively low numerical aperture
- Especially well suited for the investigation of large samples (e.g. embryos) to study features such as growth, migration, morphological changes and gene expression patterns, that require high resolution, while being extended over a large volume.
- Single plane illumination significantly reduces photobleaching/phototoxicity



Mouse Embryo

A photograph of a state-of-the-art 4-lens SPIM, courtesy of Uros Krizic of the Hufnagel Lab, EMBL, Heidelberg



Optical cross-sections through a developing *Drosophila melanogaster* embryo in stage 5/6. Two Neos are used to capture this 3-D structure and one of these can be captured every 20 seconds.



50 μm -12 μm deep

Movie of the motor protein myosin (fluorescently tagged with GFP) in the nematode *C. Elegans* immediately after Fertilization – movie courtesy of Sundar Naganathan (Grill research group, MPI, Dresden)

