optotune

Optotune

Liquid lenses for microscopy

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Summary

Liquid lenses enable compact and reliable focusing in microscopy:

- Fast Z stacking
- No vibrations
- Large working distance range
- No chromatic aberrations
- Long life-time (>1B cycles)

Agenda

- Company presentation
- Tunable lens technology in microscopy
- Non telecentric vs telecentric configuration
- Techniques overview & examples
- Further application examples

Optotune on a page

Established in 2008

Leader in light controlling components

28 sales partners in 30 countries

200 employees
- 95 in Switzerland
- 100 in Slovakia
- 5 in sales offices in Taiwan and Korea

Key markets
- Medical
- Industrial
- AR/VR
- Automotive

Privately owned

SIQT Innovations Award 2020 >
InVision Top Innovations 2017 >
Vision Systems Innovator Award 2016 >
Swiss Economic Award 2014 >
No. 1 Startup in Switzerland 2011 >
Prism Award 2011 >
Swiss Technology Award 2010 >
Winner of Venture 2008 >
ETH Spin-off 2008 >

Certified System swiss TS ISO 9001

Our mission, vision and core values

Optotune’s mission is to enhance people’s lives through innovation in dynamic light control.

Optotune’s vision is to be the solution of choice for optical systems that need dynamic light control.

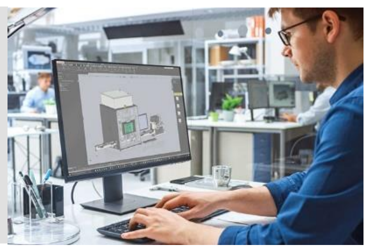
Optotune’s values are pioneership, positive mindset, respect, profitable growth and ownership.

Broad range of competences in-house

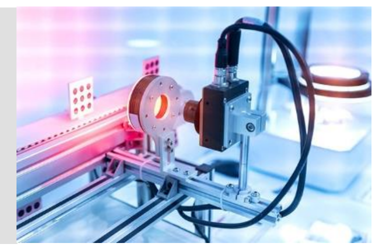
Materials Research
- Material characterization & testing
- Material processing

Optical Design
- Optics simulation using ZEMAX® ray tracing software
- Stray light analysis
- Tolerance analysis

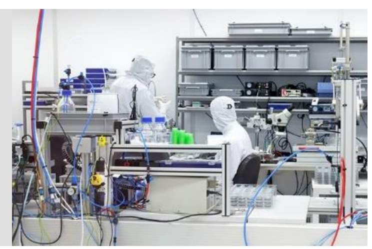
Mechanical Design
- Multiphysics FEM simulations (COMSOL)
- Complete system design
- CAD (Solidworks®)



Testing
- Optical characterization
- Environmental testing

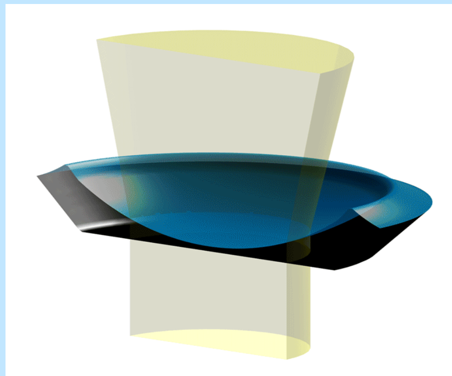


Production
- Semi-automated production
- Cleanroom class 1000
- Production facilities in Switzerland and Slovakia

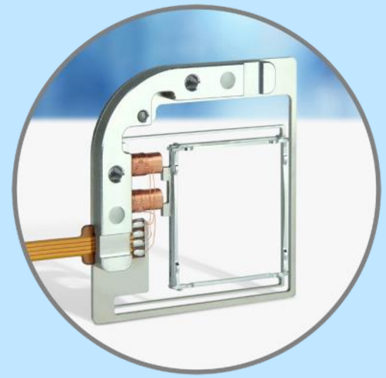


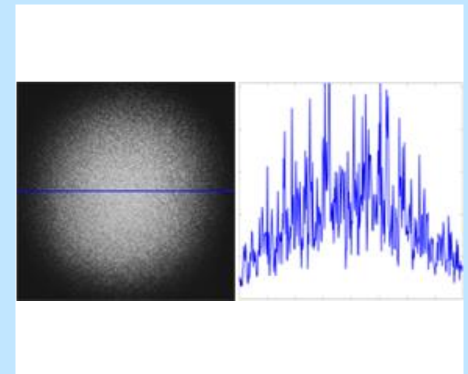
Optotune provides four core product lines

Focus tunable lenses

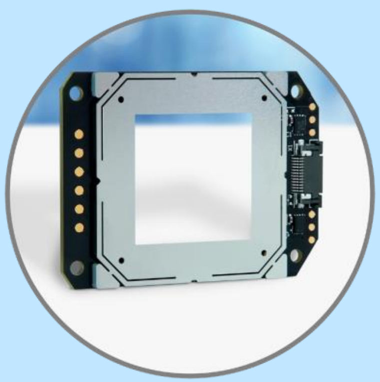


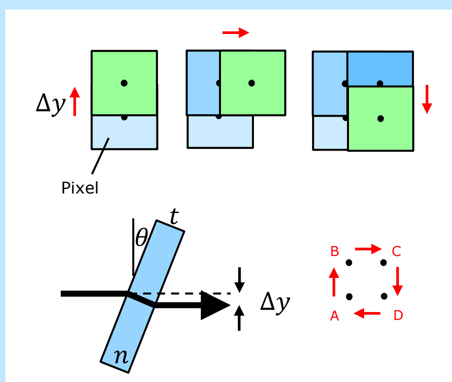
Laser speckle reducers



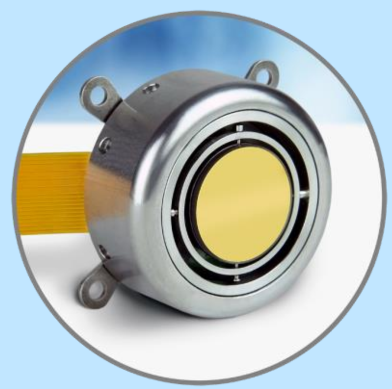


Beam shifting devices





Beam steering devices (2D mirrors)



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Current situation

How do we move from 2D to 3D

Goals

- Imaging of 3D cell cultures
- Imaging of whole embryos
- In-vivo imaging

Limitations

- Small depth of field
- Mechanical vibrations
- Focusing speed

Solution

- 3D microscope

Current solutions

To focus along Z-axis

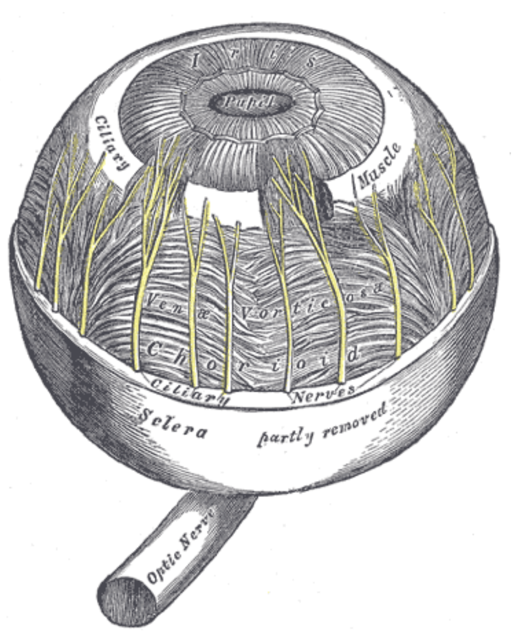
	Motorized Z	Piezo Z	Focus Tunable Lens	
Price	$$	$$$	$	3x cheaper than piezo's
Speed	+	+++	+++ (100Hz)	100x faster than motorized Z
Travel Range	+++	+	++	e.g. 600 µm with 40x objective
Compactness	+	++	+++	No table-top controller
Vibrations	+	+	+++	No vibrations
Thermal Drift	+	+	+++	Temp. comp. sensor

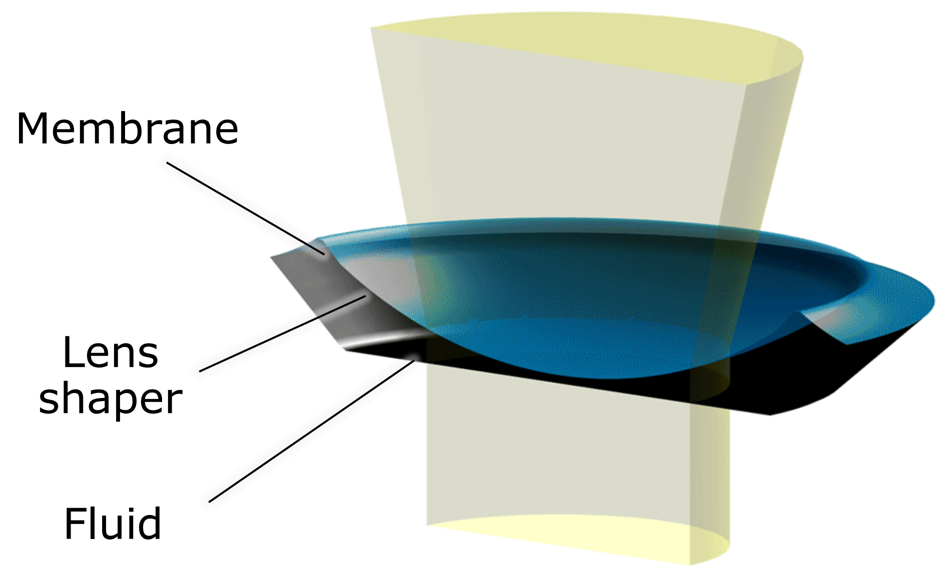
Working principle

Membrane with fluid and actuator

Human eye:
Ciliary muscle actuates
the lens curvature

Optotune lens:
Electromagnetic actuator
controls the lens curvature

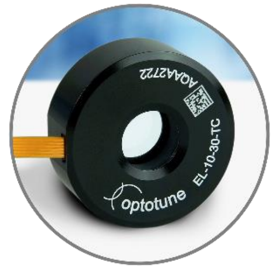




See also: https://www.optotune.com/tunable-lenses

Our product range

Liquid lenses for microscopy applications

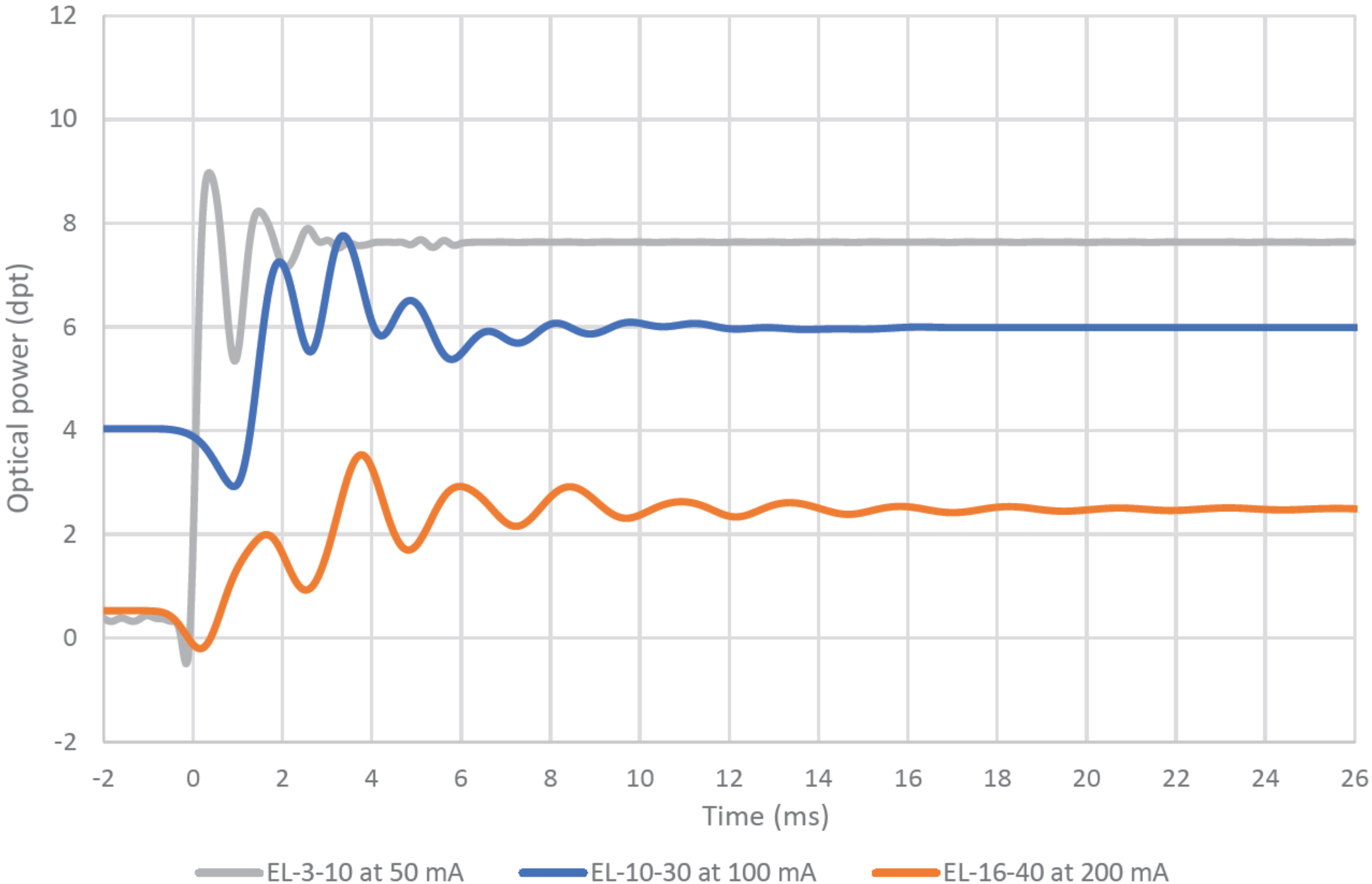


	EL-3-10-TC	EL-10-30-TC	EL-10-30-C(i)	EL-16-40-TC
Focal power range	-13 … +13 dpt	8 … 22 dpt	-1.5 … +3.5 dpt +5 … +10 dpt	-2 … +3 dpt -10 … +10 dpt
Clear aperture	3mm	10mm	10mm	16mm
Outer diameter	10mm	30mm	30mm	40mm
Response time*	1 / 3 ms	4 / 9 / 20 ms	2.5 / 6 / 15ms	5 / 12 / 25ms
Wavefront quality RMS @525nm**	<0.07 λ	<0.15 λ	<0.1 λ	<0.15 λ
Absolute focal power accuracy (typical)	N/A	< 0.1 dpt	< 0.1 dpt	< 0.05 dpt
Temperature compensation	No	Yes	Yes	Yes

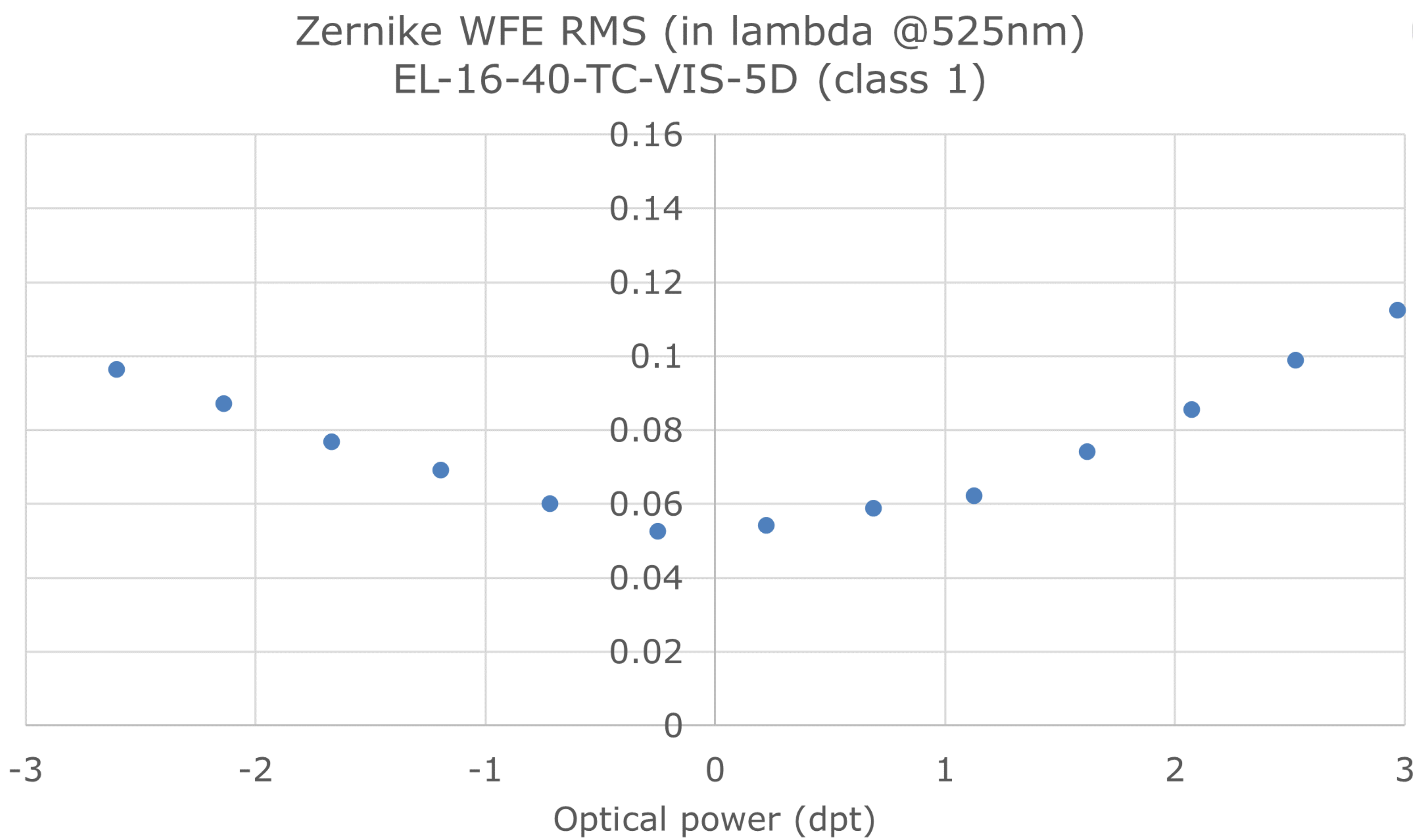
* 10-90% of step / settling time of a controlled step / settling time of rectangular step

** class 1 specification

Settling times from 4 to 25ms



EL-16-40 can provide excellent wavefront quality



Note: Measured with Shack-Hartmann sensor @80% of the 16mm clear aperture, optical axis vertical

EL series: a family of reliable products

Test	Test conditions	Result
Mechanical cycling	40 million full-range cycles (0 to 300 mA rectangular, at 10 Hz) 5 billion sinusoidal cycles at resonant frequency	Passed
High temperature	85±2°C; rel. hum. <6% for 168 hours, non-operational	Passed
Temperature cycling	-40°C / +85°C for 30 min each, 3 min transition time, 100 cycles	Passed
Damp heat cycling	25°C / 55°C at 90-100% relative humidity, 3 hour transition time, 24h per cycle (9h plus transition time each), 18 cycles	Passed
Shock	800g for 1ms duration, 5 pulses in each direction (30 pulses in total)	Passed
Solar radiation	1120 W per m2 (IEC 60068-2-5), 8 h irradiation & 16 h darkness, 10 cycles	Passed

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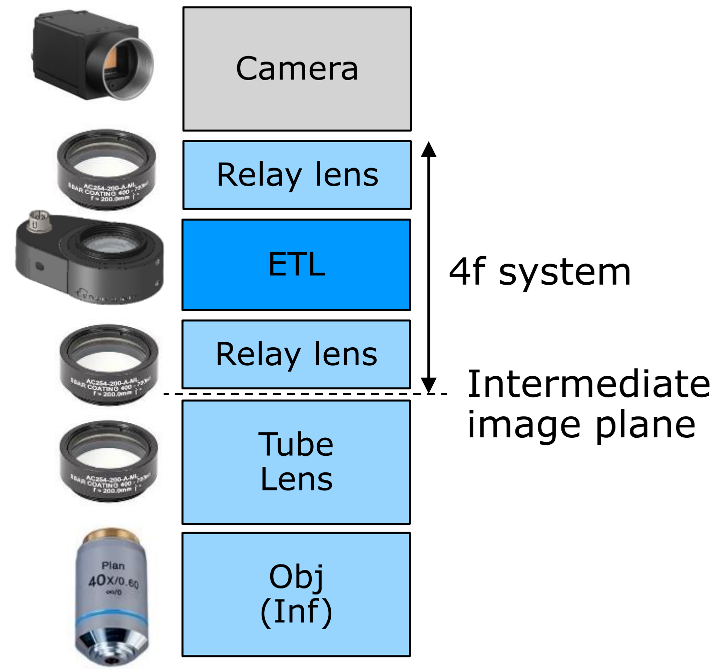
Microscopy configurations

How ETL impacts on the image magnification

Non-telecentric

	Z-range with 5D lens	Mag change*
10x	2560 µm	7.5%
20x	640 µm	12.2%
40x	160 µm	23.7%

Telecentric

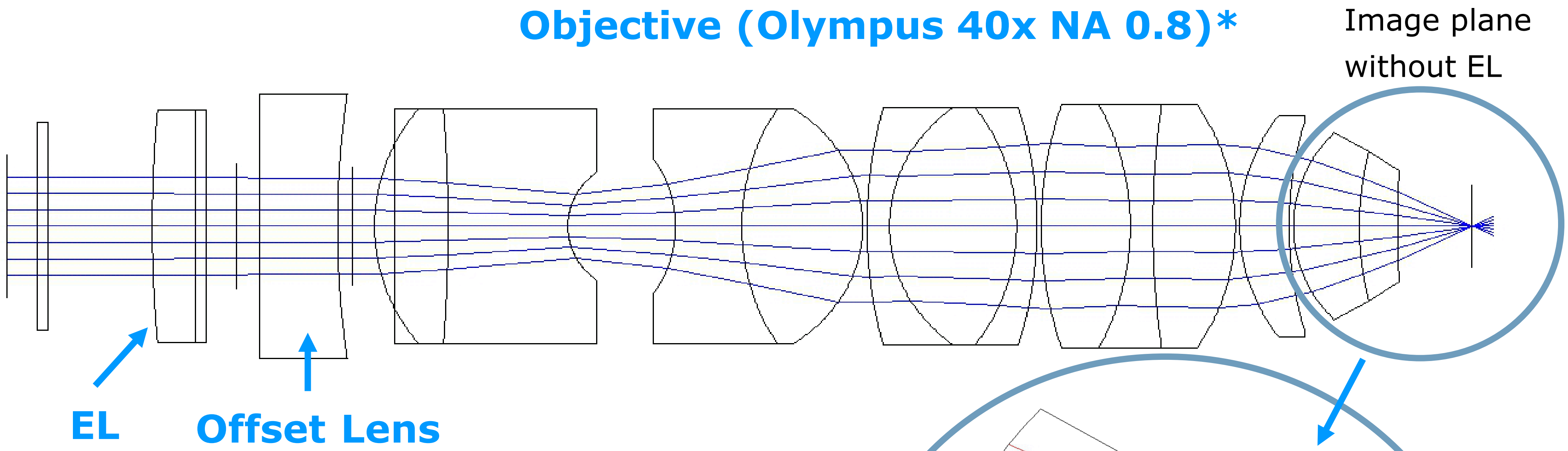


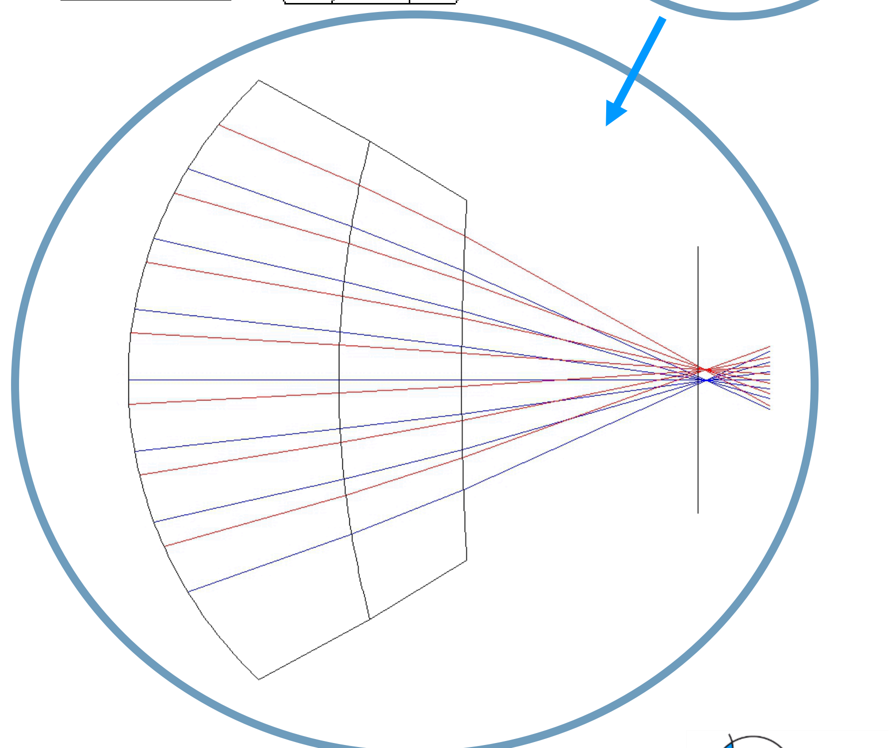
	Z-range with 5D lens	Mag change
10x	1000 µm	0%
20x	250 µm	0%
40x	60 µm	0%

* Magnification changes are linear, it is possible to compensate it via software

Non-telecentric configuration

Optical layout





- With the tunable lens on top of the objective, the FOV and NA changes while focusing (non-telecentric behavior)

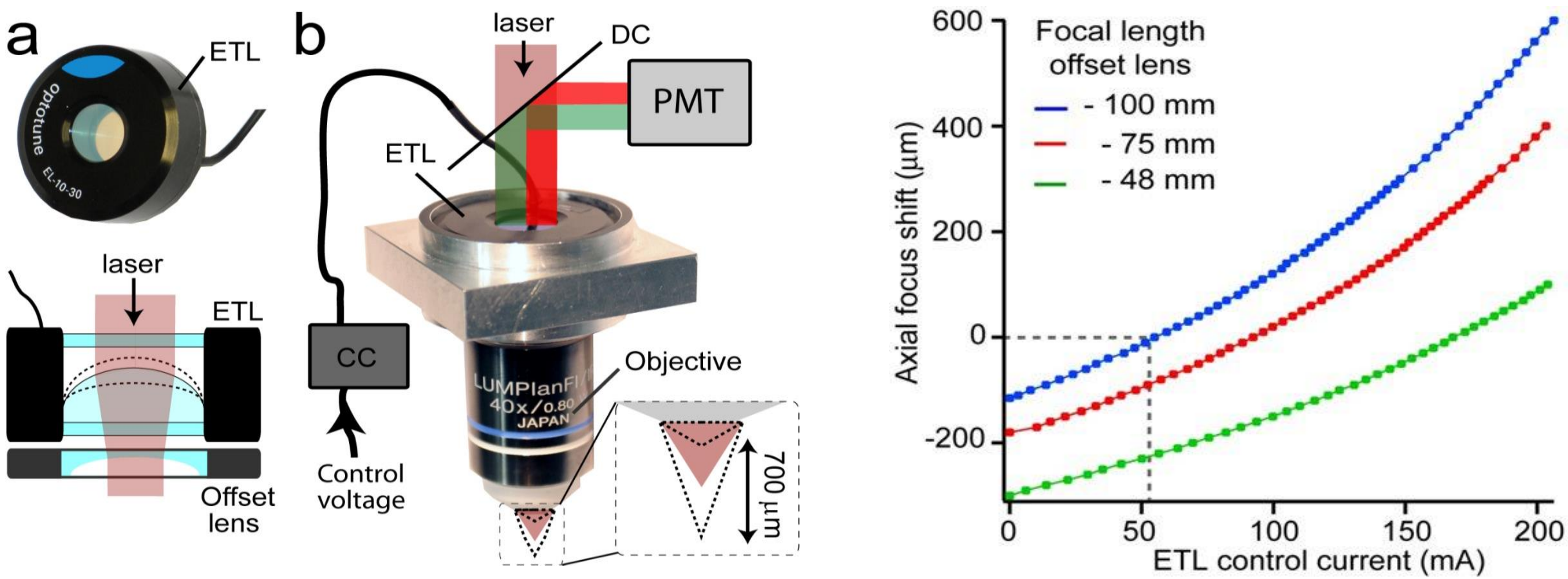
- The animation on the left shows this as an increasing distance between the blue (on-axis) and red (maximum FOV) foci

* Japanese patent 8-292374

Non-telecentric autofocus configuration

Tunable lens EL on top of objective

- A compact autofocus solution without the need of mechanical translation can be achieved by placing the tunable lens directly on top of the objective:

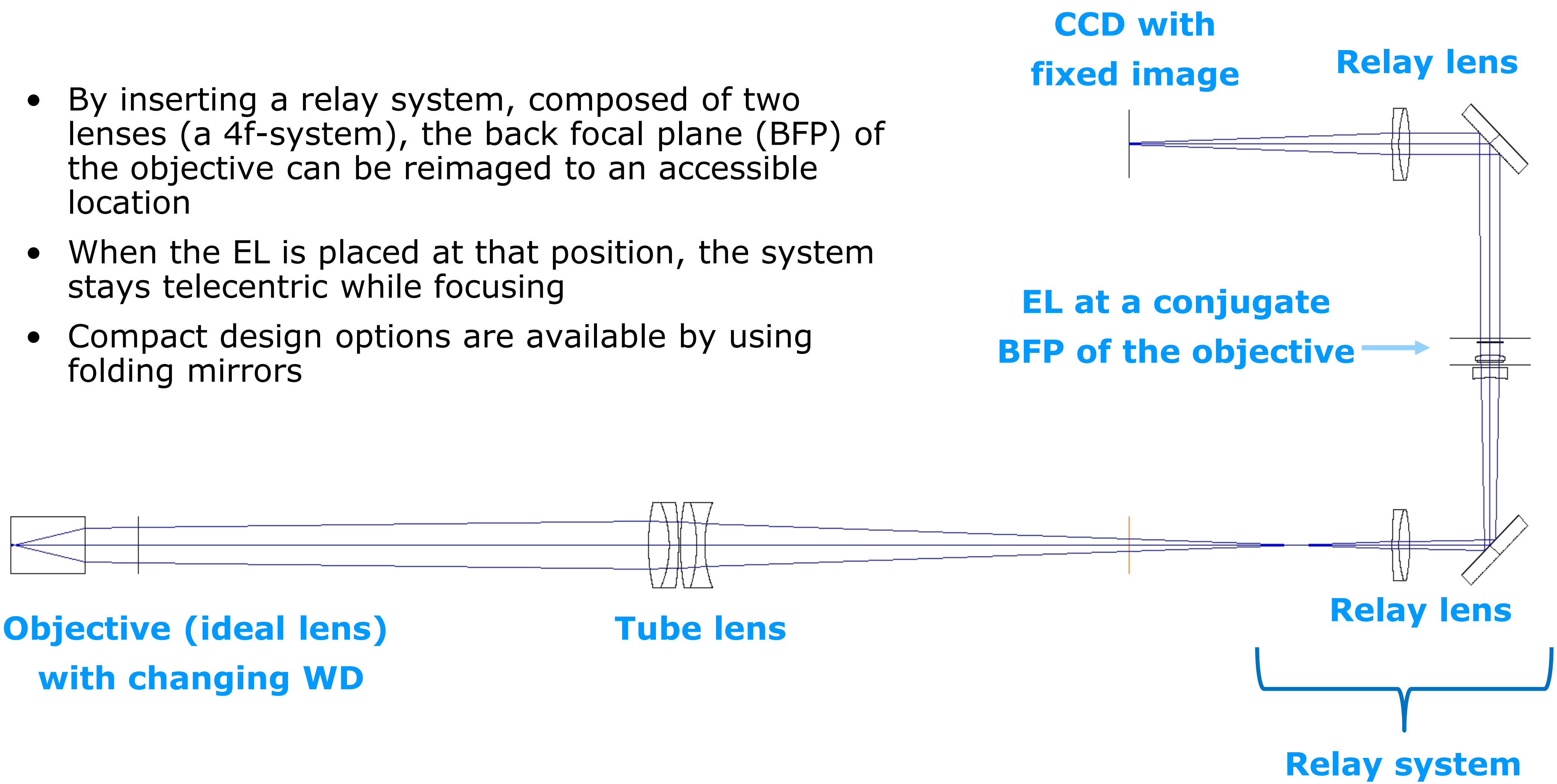


- However, in such a configuration, the field-of-view (FOV) and numerical aperture (NA) changes while focusing (non-telecentric behavior)

Telecentric configuration

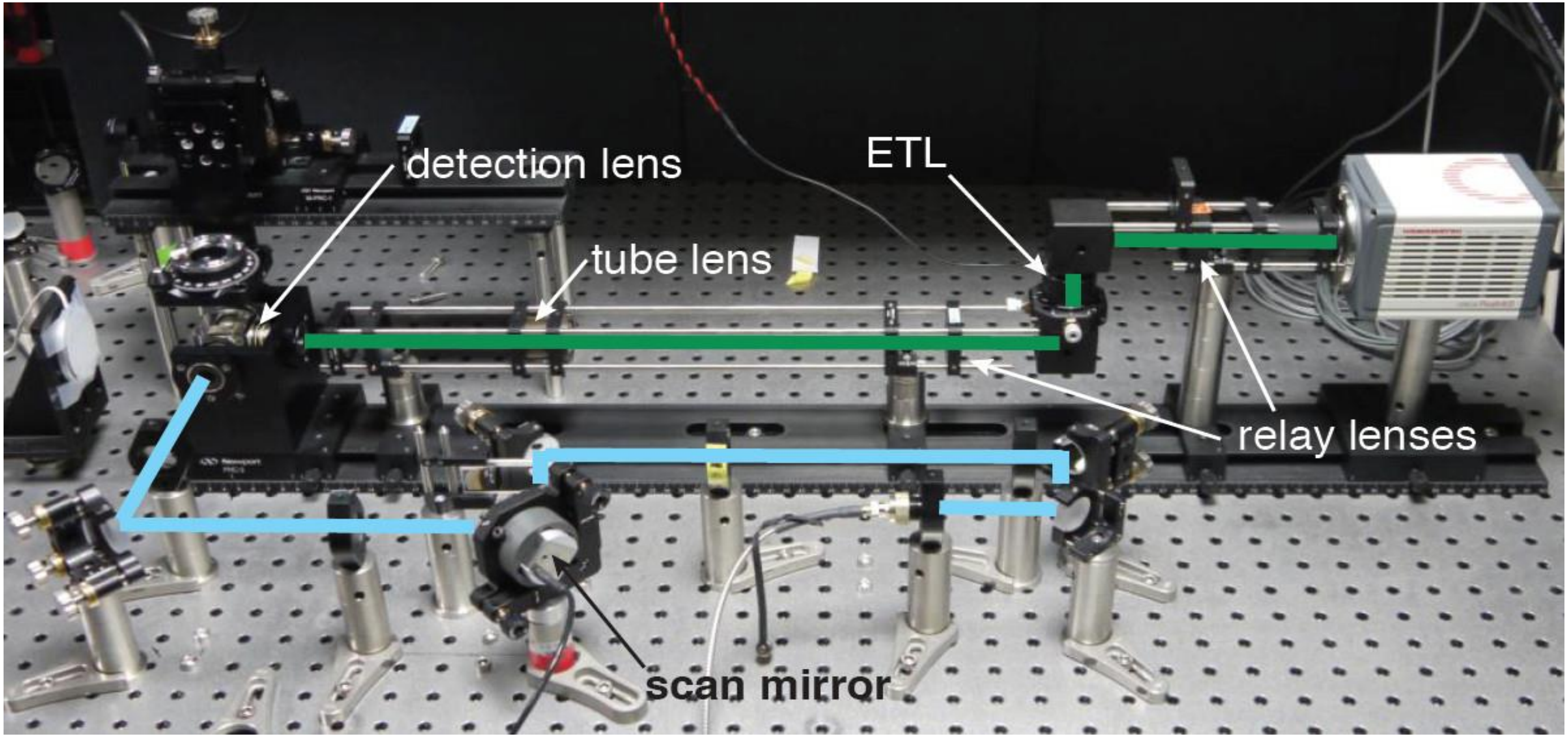
Optical layout with a relay system

- By inserting a relay system, composed of two lenses (a 4f-system), the back focal plane (BFP) of the objective can be reimaged to an accessible location
- When the EL is placed at that position, the system stays telecentric while focusing
- Compact design options are available by using folding mirrors



Telecentric configuration

Setup on an optical table



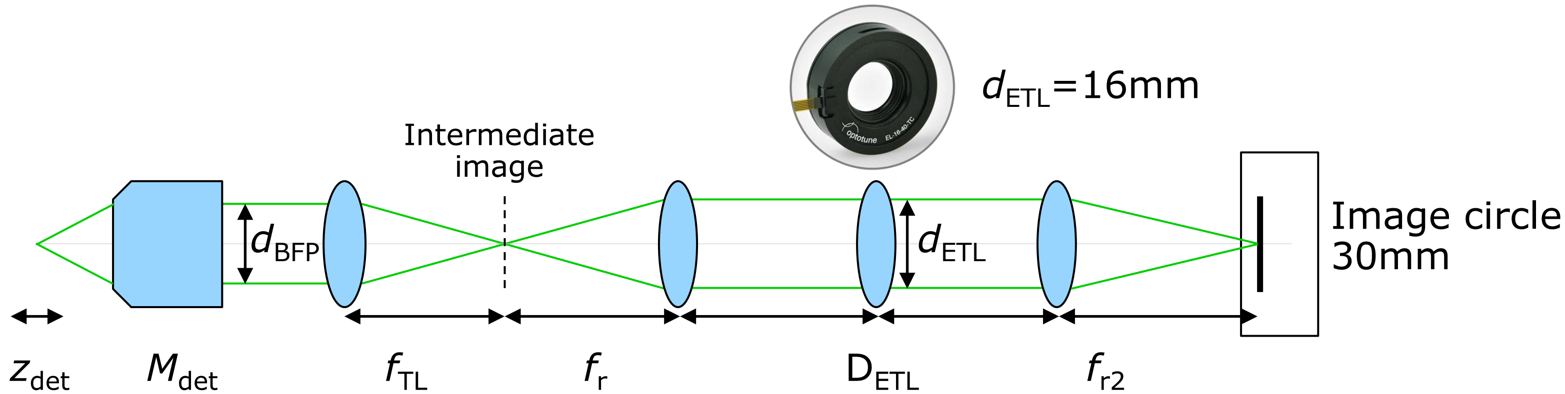
This design principle can be found in this EL-lightsheet microscope (Fahrbach et al., Optics Express 2013)

https://www.osapublishing.org/oe/fulltext.cfm?uri=oe-21-18-21010&id=260811

optotune

Relay system

The axial scan range



- The displacement of the image plane is given by

$$\delta z_{\mathrm{det}} = -\frac{1}{M_{\mathrm{det}}^2} \cdot \frac{n f_{\mathrm{r}}^2}{f_{\mathrm{ETL,eff}}}.$$

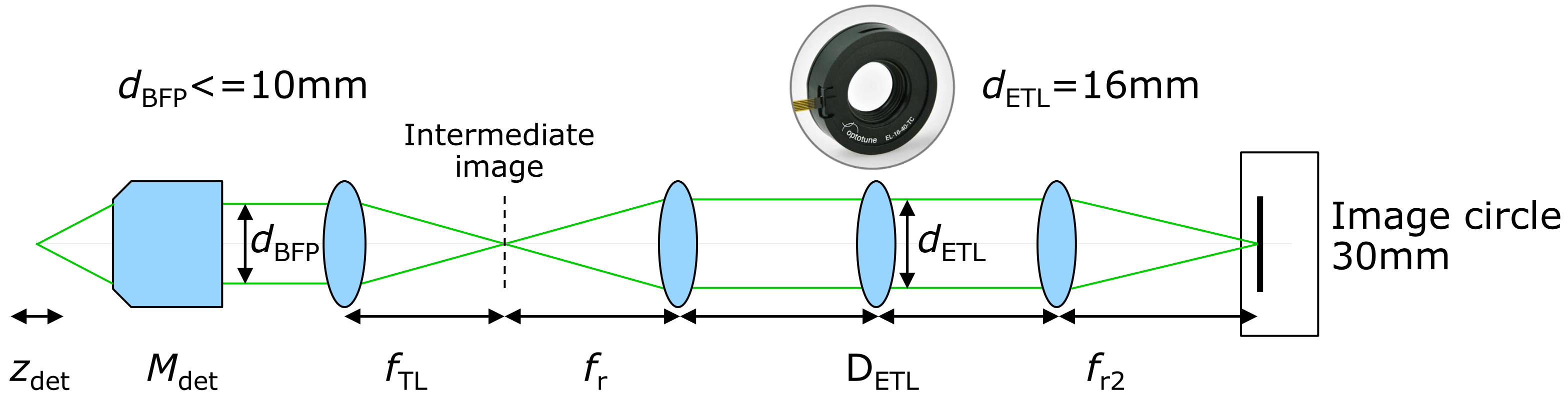
  where n is the refractive index of the immersion medium, M_{det} is the magnification of the microscope objective, f_r is the focal length of the relay lens and $f_{ETL,eff}$ is the effective focal length of the Optotune lens ($1/f_{ETL,eff} \approx 1/f_{ETL} + 1/f_{OL}$) and f_{OL} is the focal length of a possible offset lens.

- To maintain the full NA of the detection lens, the ratio of the focal lengths of the relay lens f_r and the tube lens f_{TL} must not be larger than the ratio of the aperture of the ETL d_{ETL} and the diameter of the BFP of the detection lens d_{BFP}, i.e.

$$f_{\mathrm{r}} \leq f_{\mathrm{TL}} \cdot \frac{d_{\mathrm{ETL}}}{d_{\mathrm{BFP}}}.$$

Relay system

Axial scan range examples



Scenarios:

							Mag Relay	Image circle	Total length
10x, long relay, 5D:	2000um	10x	200mm	200mm	5D	200mm	1X	30mm	1100mm
Shorter relay lenses:	1000um	10x	200mm	141mm	5D	141mm	1X	30mm	864mm
20X, long relay, 5D:	500um	20x	200mm	200mm	5D	200mm	1X	30mm	1100mm
Shorter relay lenses:	250um	20x	200mm	141mm	5D	141mm	1X	30mm	864mm
10D lens:	500um	20x	200mm	141mm	10D	141mm	1X	30mm	864mm
1″ sensor:	500um	20x	200mm	141mm	10D	70mm	0.5X	15mm	744mm
Microscopy adapter prototype (5D):	12um	40x	200mm	62mm	5D	31mm	0.5X	12mm	~450mm

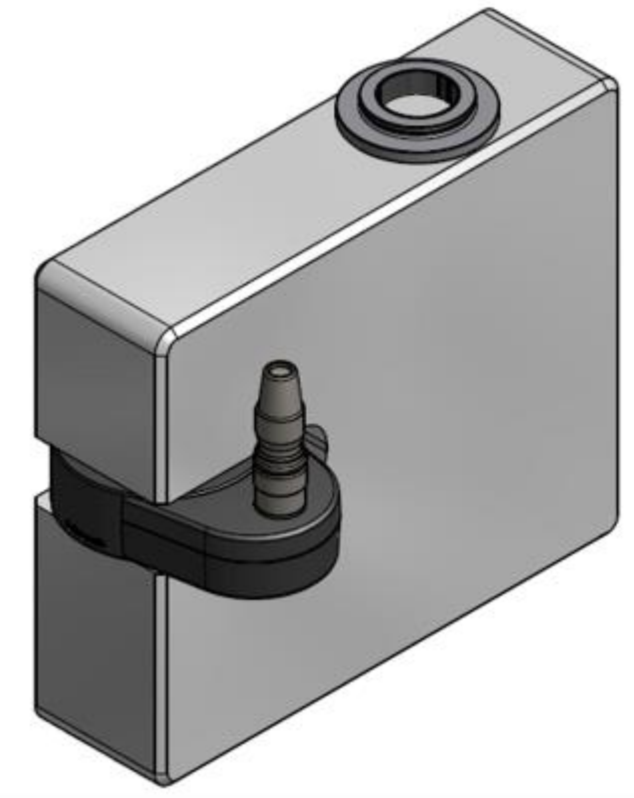
$$\delta z_{\mathrm{det}} = -\frac{1}{M_{\mathrm{det}}^2} \cdot \frac{n f_{\mathrm{r}}^2}{f_{\mathrm{ETL,eff}}}.$$

$$f_{\mathrm{r}} \leq f_{\mathrm{TL}} \cdot \frac{d_{\mathrm{ETL}}}{d_{\mathrm{BFP}}}.$$

$D_{ETL} = 1/f_{ETL}$ $\quad$ $Mag_{Relay} = f_r / f_{r2}$

Relay system

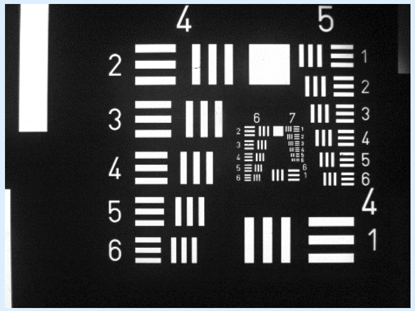
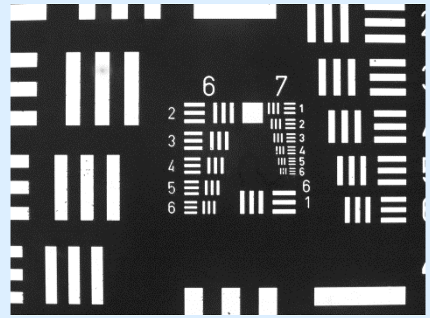
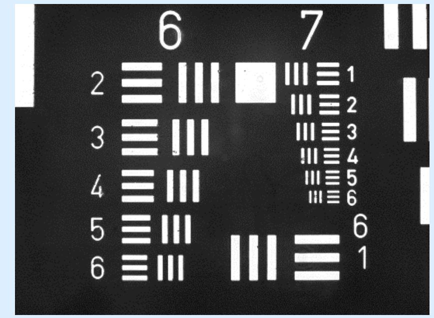
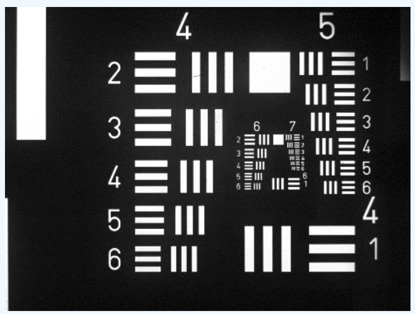
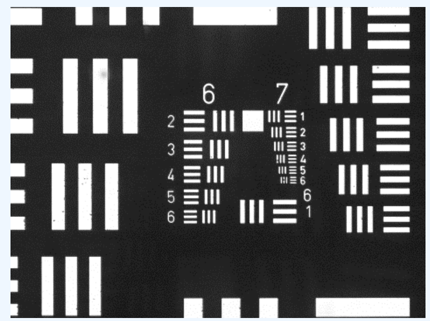
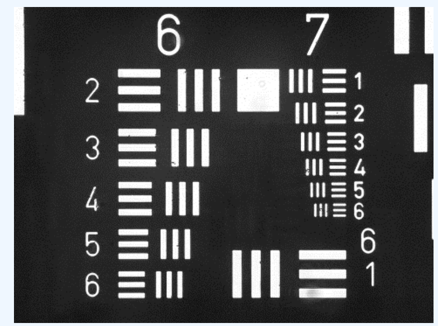
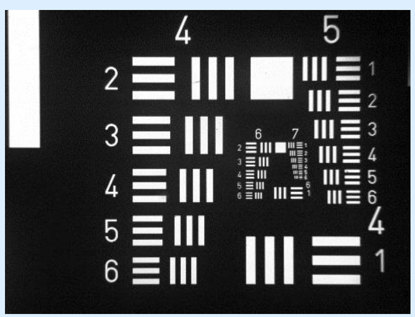
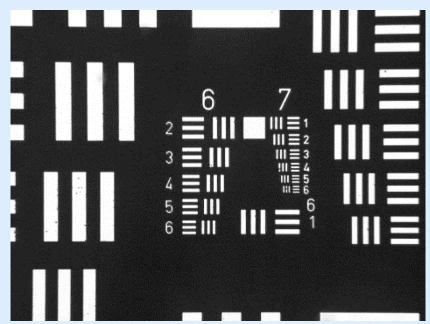
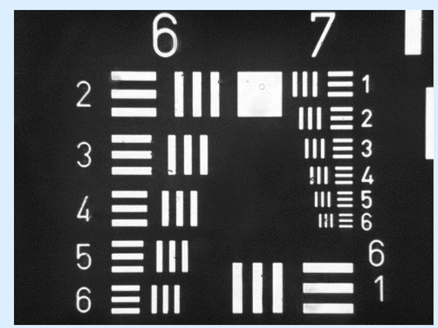
Off the shelf solution



- Folded relay system (240mm in total)
- Designed to support EL-16-40
- Fits commercial microscopes and other C-mount imaging optics

Telecentric configuration

No magnification change

	10x	20x	40x
10 dpt			
0 dpt			
-10 dpt			

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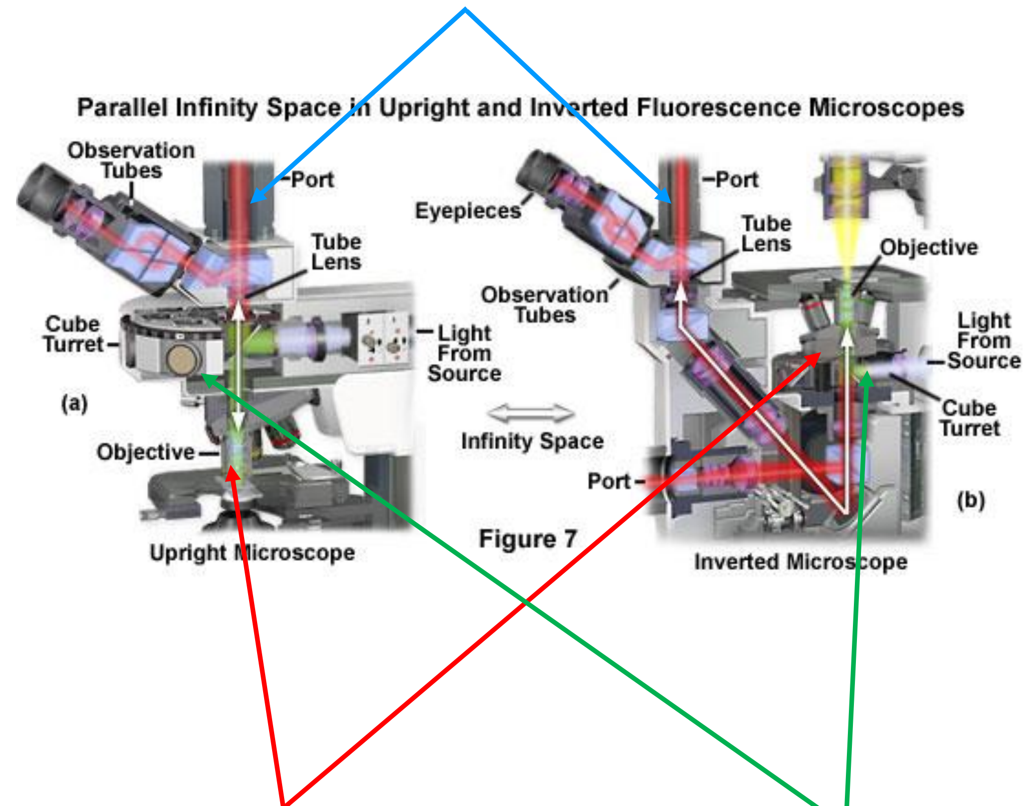
Integrations

How ETL can become part of your systems

Digital inspection microscope

Scientific microscope

ETL Pos.
(camera port)



ETL Pos.
(after objective)

ETL Pos.
(filter cube)

Techniques overview

Different techniques, different applications

3D Microscopy

Wide-Field

Two-Photon

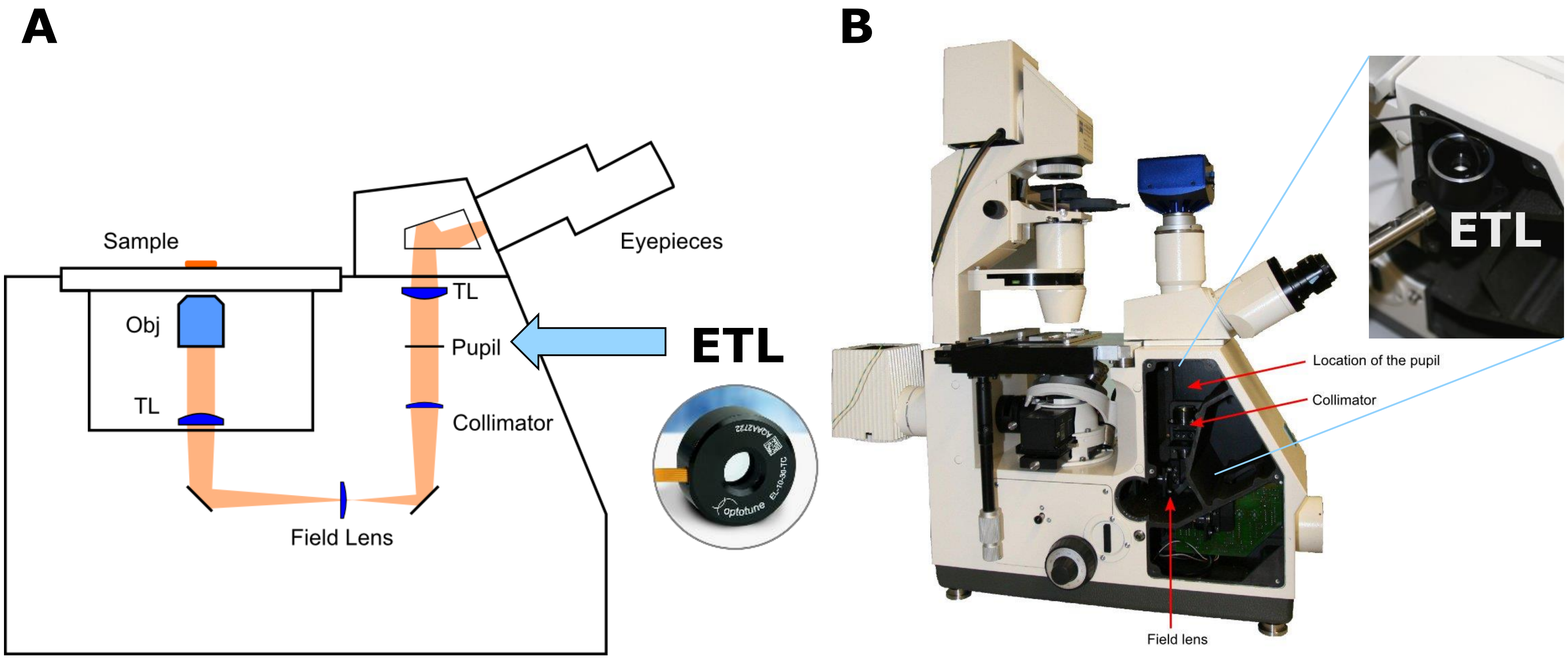
Digital Microscopy

Confocal

Light Sheet

Raman Spectroscopy

Techniques overview
Wide field microscopy

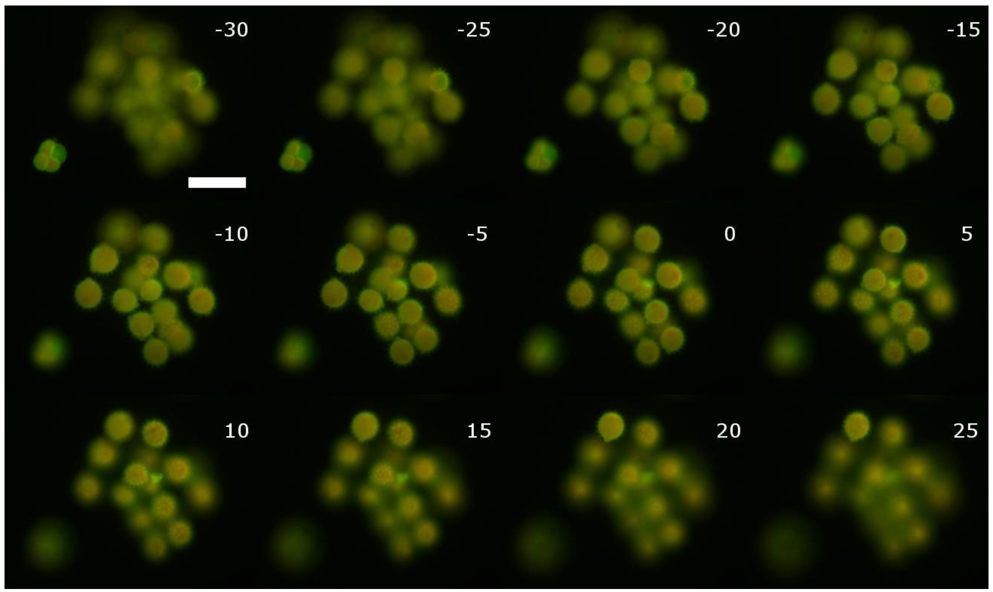


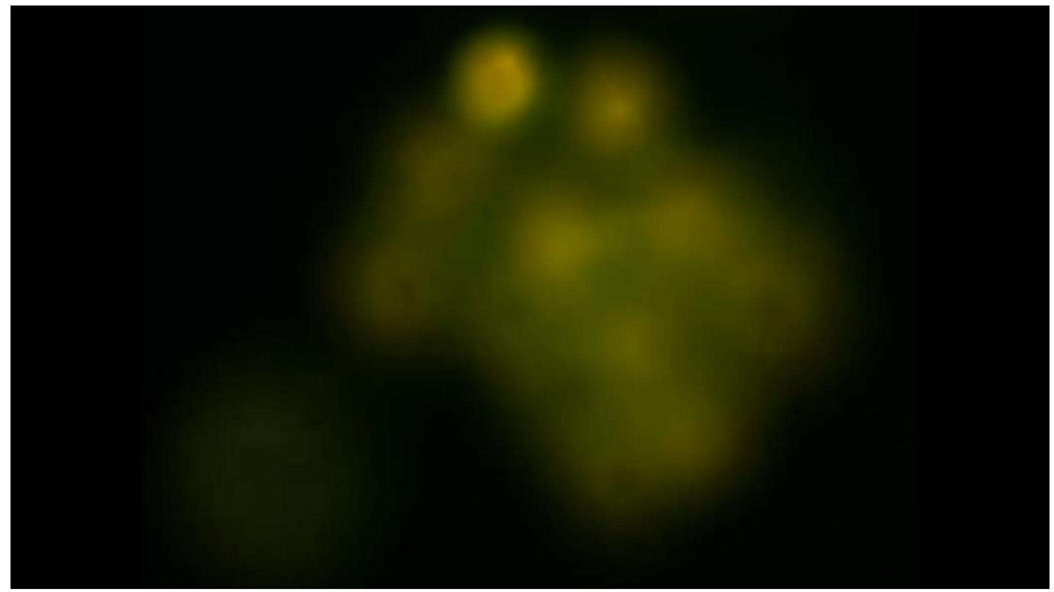
Optical path of the Axiovert 35 microscope. The ETL/OL assembly can be placed at the pupil without inserting an additional relay system. TL: Tube lens.

Images courtesy of F. F. Voigt, Department of Neurophysiology, Brain Research Institute, University of Zurich

Techniques overview

Wide field microscopy





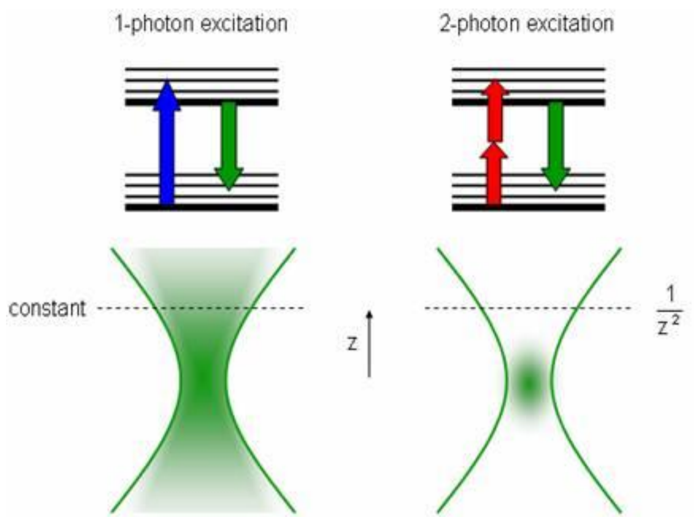
Video

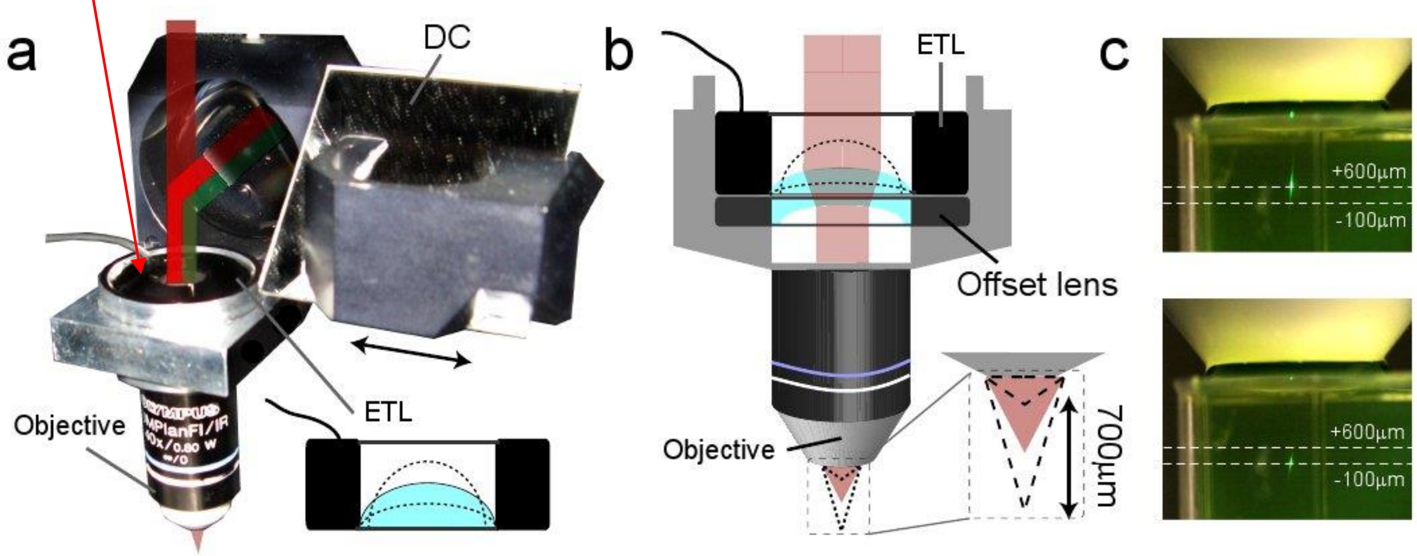
ETL-based focusing through a group of pollen grains.

Images courtesy of F. F. Voigt, Department of Neurophysiology, Brain Research Institute, University of Zurich

Techniques overview

Two-photon microscopy



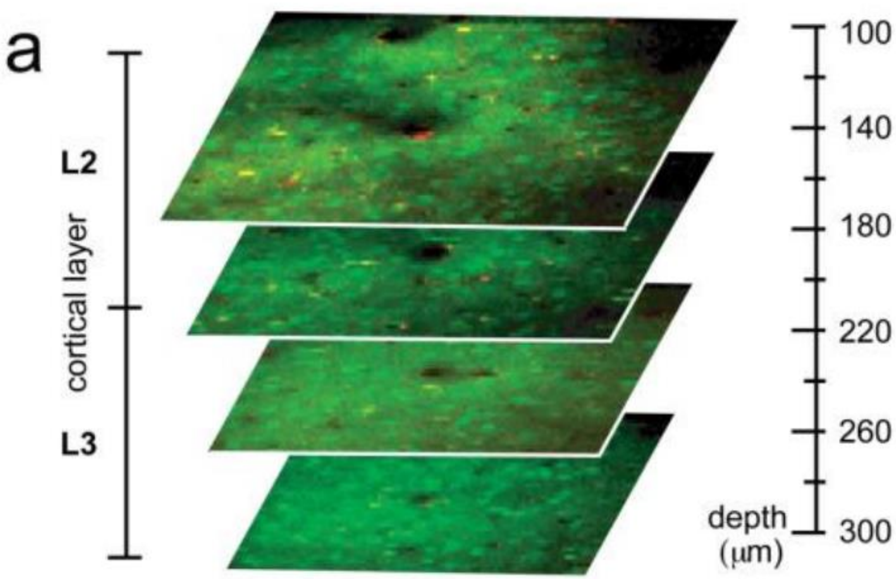


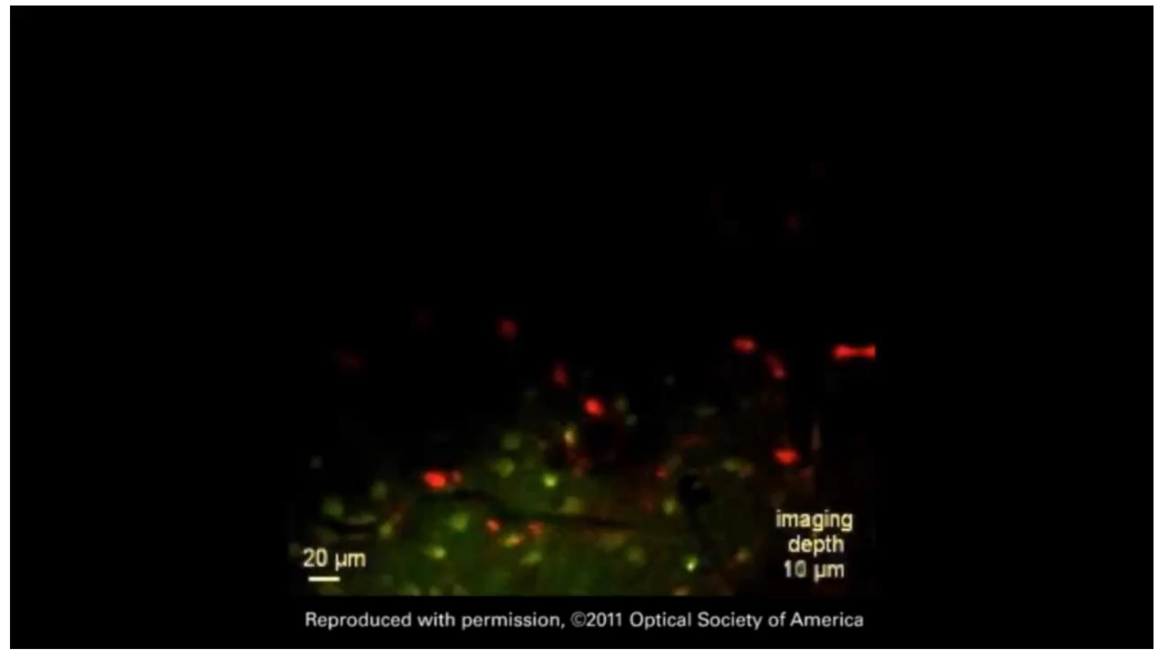
B.F Grewe *et al*., Biomedical Express (2011), **2**, (7), pp.2035

https://www.osapublishing.org/boe/fulltext.cfm?uri=boe-2-7-2035&id=219300

Techniques overview

Two-photon two-layer calcium imaging in mouse neocortex



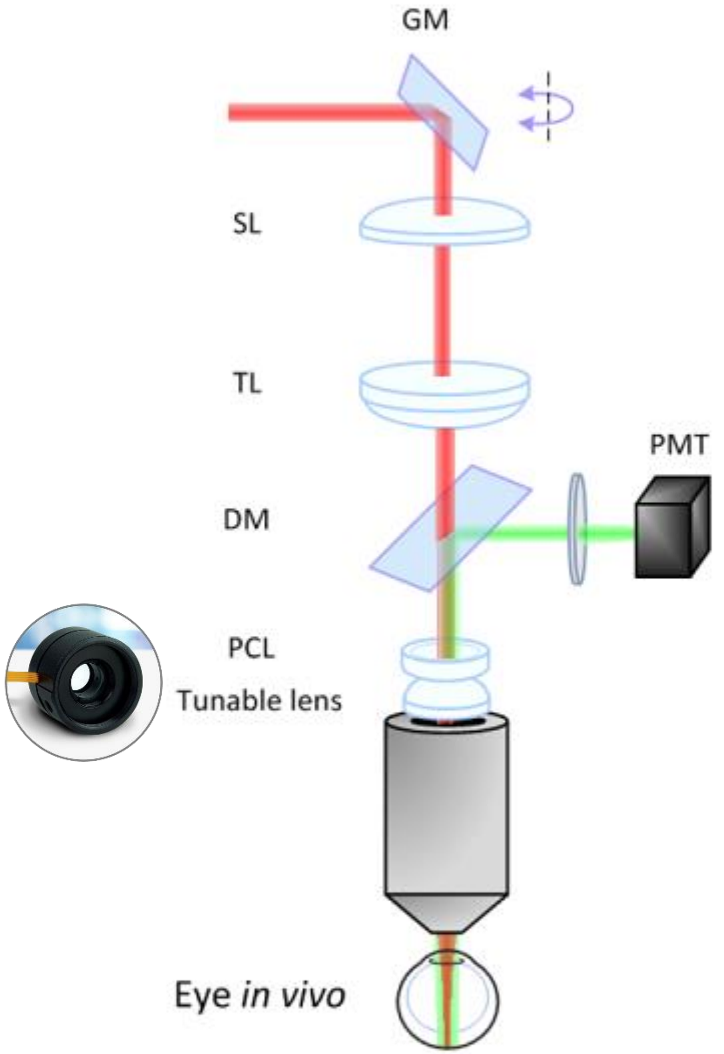


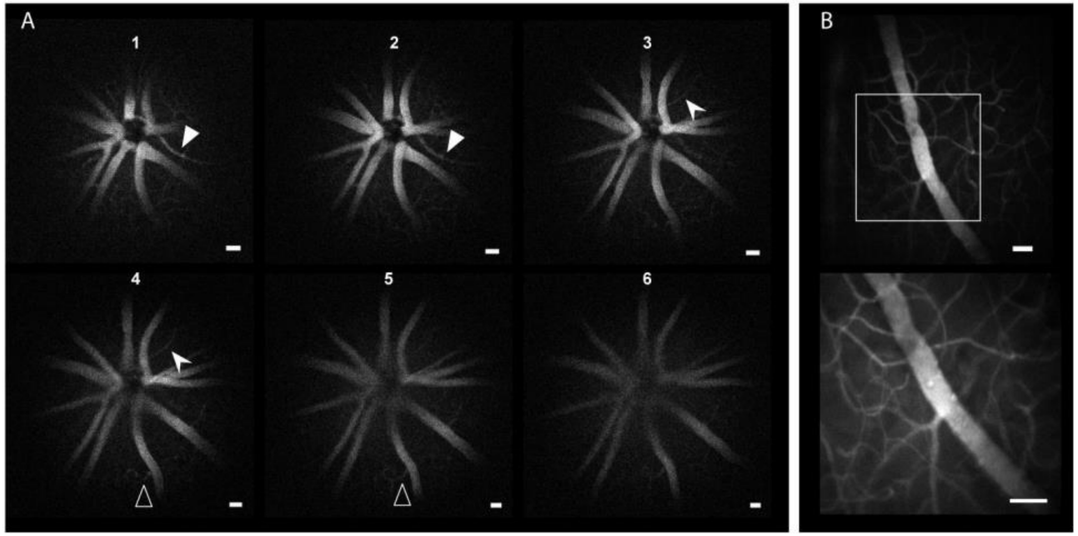
Two-photon images of a stained neuronal cell population (green)

Benjamin F. Grewe, BIOMEDICAL OPTICS EXPRESS (2011), **2**, (7), pp. 2035

Techniques overview

Two-photon microscopy example





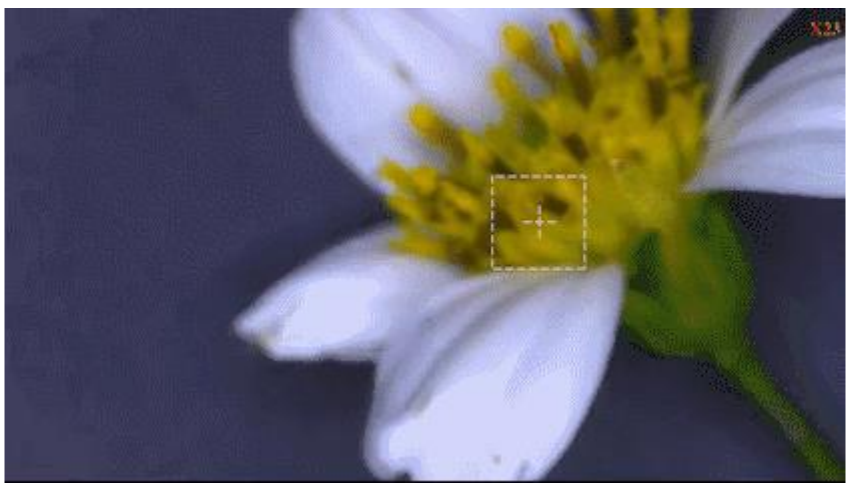
Optical sectioning in mouse 2P fluorescence angiography. A. Two-photon images of the optic disc. The microscope objective lens and mouse were held in place, and each image was acquired at different ETL currents (10mA interval between successive images; each image is an average over 30 frames acquired at 1 fps). Arrowheads point to blood vessels visible in only a few images, but not in others. B. Images of blood vessels outside the optic disc, acquired at different scan zooms (average over 100 and 200 frames; different animal than A). The FOV of the lower image is marked by a white box. Scale bars = 50 µm.

Adi Schejter, Proc. SPIE 8948, Multiphoton Microscopy in the Biomedical Sciences XIV, 894824 (February 28, 2014); doi:10.1117/12.2039375

Techniques overview

Tucsen digital microscopy

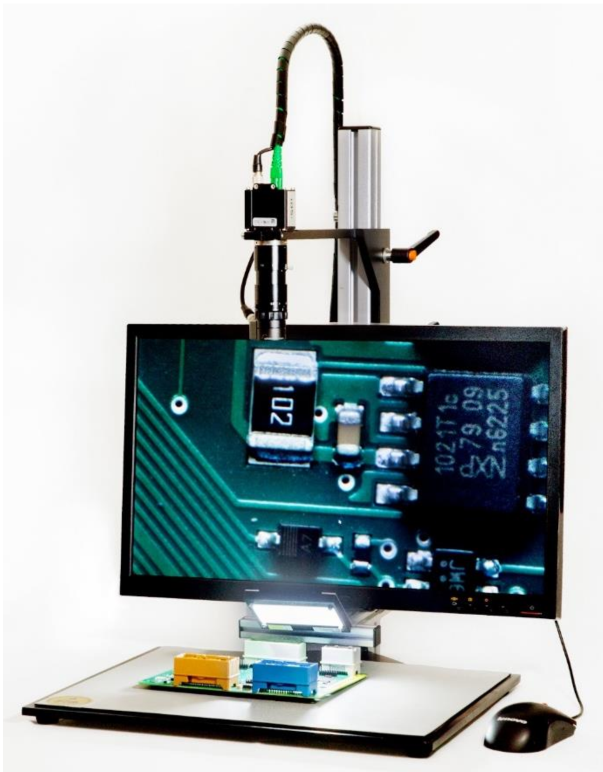
- Lens control fully integrated into system software
- Tunable lens: EL-10-30
- 3D measurement system
- Extended focus



- Video: https://youtu.be/5h5JyK8z_j8
- Website: http://www.tucsen.com/en.html

Techniques overview

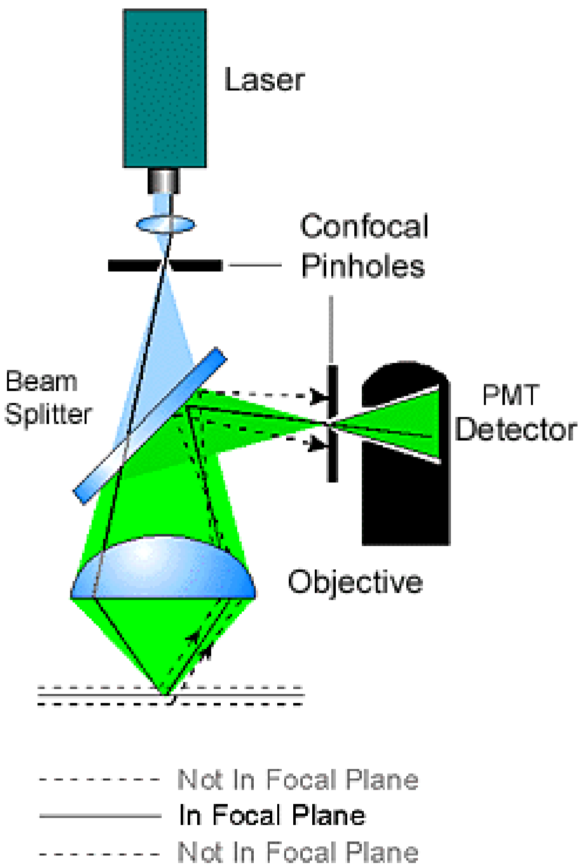
Sanxo digital microscopy

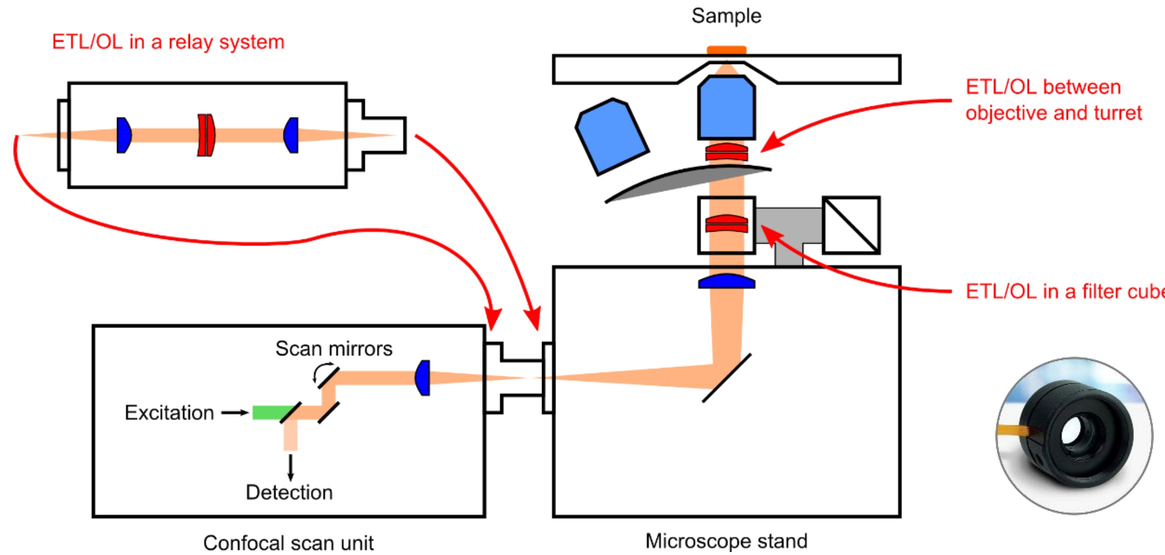


- Inspection station with 10MP camera
- Driver integrated in machine vision software “Modular X”
- Features:
  - Click to autofocus
  - Focal sweep with 3D rendering

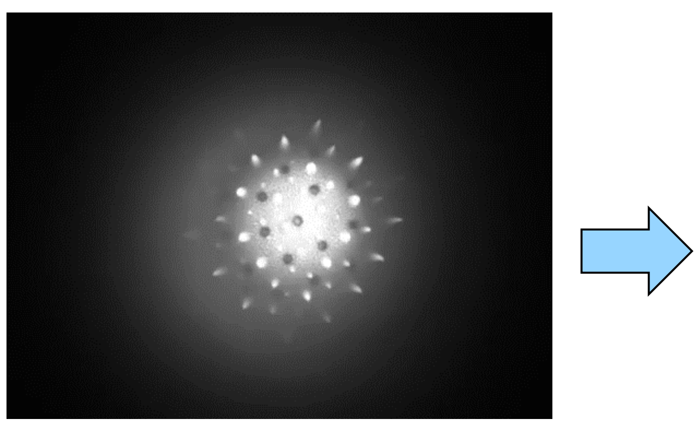
Techniques overview

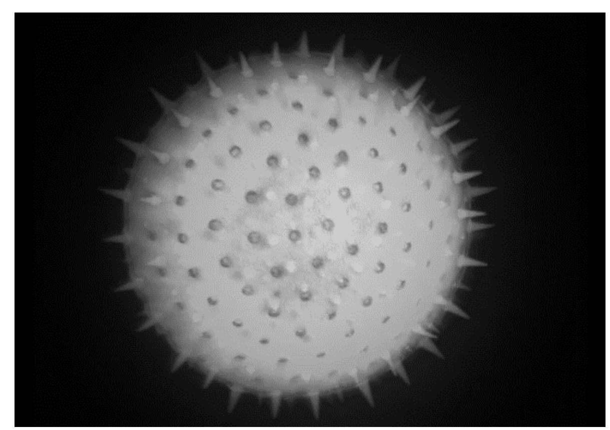
Confocal microscopy





Max. intensity projection of a pollen corn

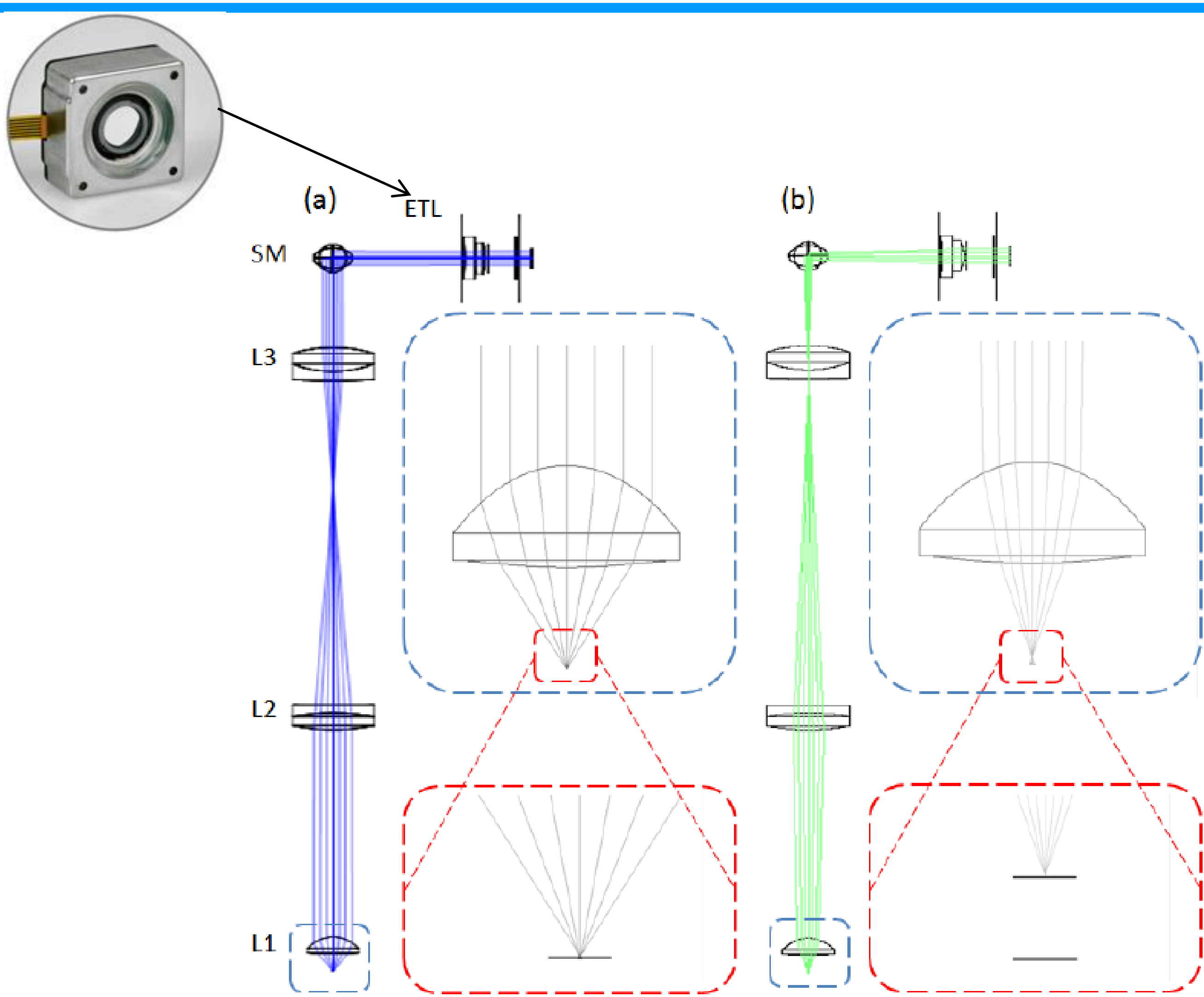




Images courtesy of F. F. Voigt, Department of Neurophysiology, Brain Research Institute, University of Zurich

Techniques overview

Confocal microscopy

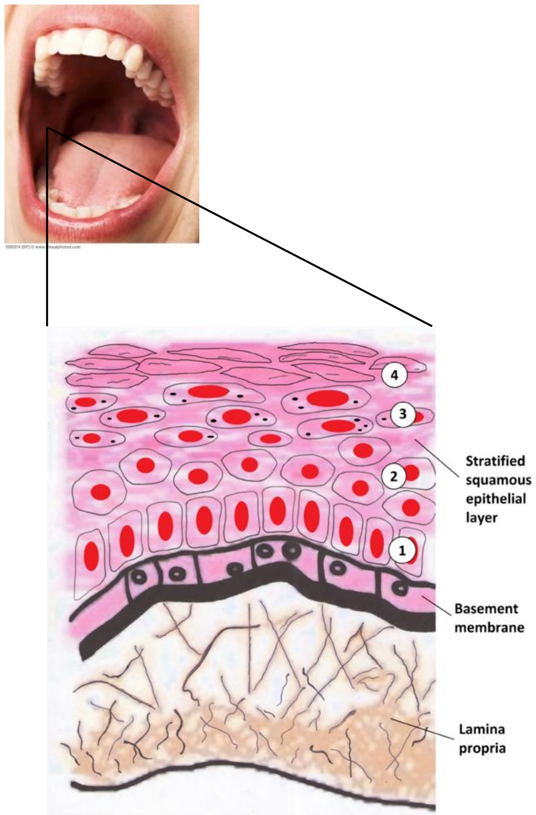


Focal power range	Axial scan range @ sample
-127 mm to +44.3 mm	700µm

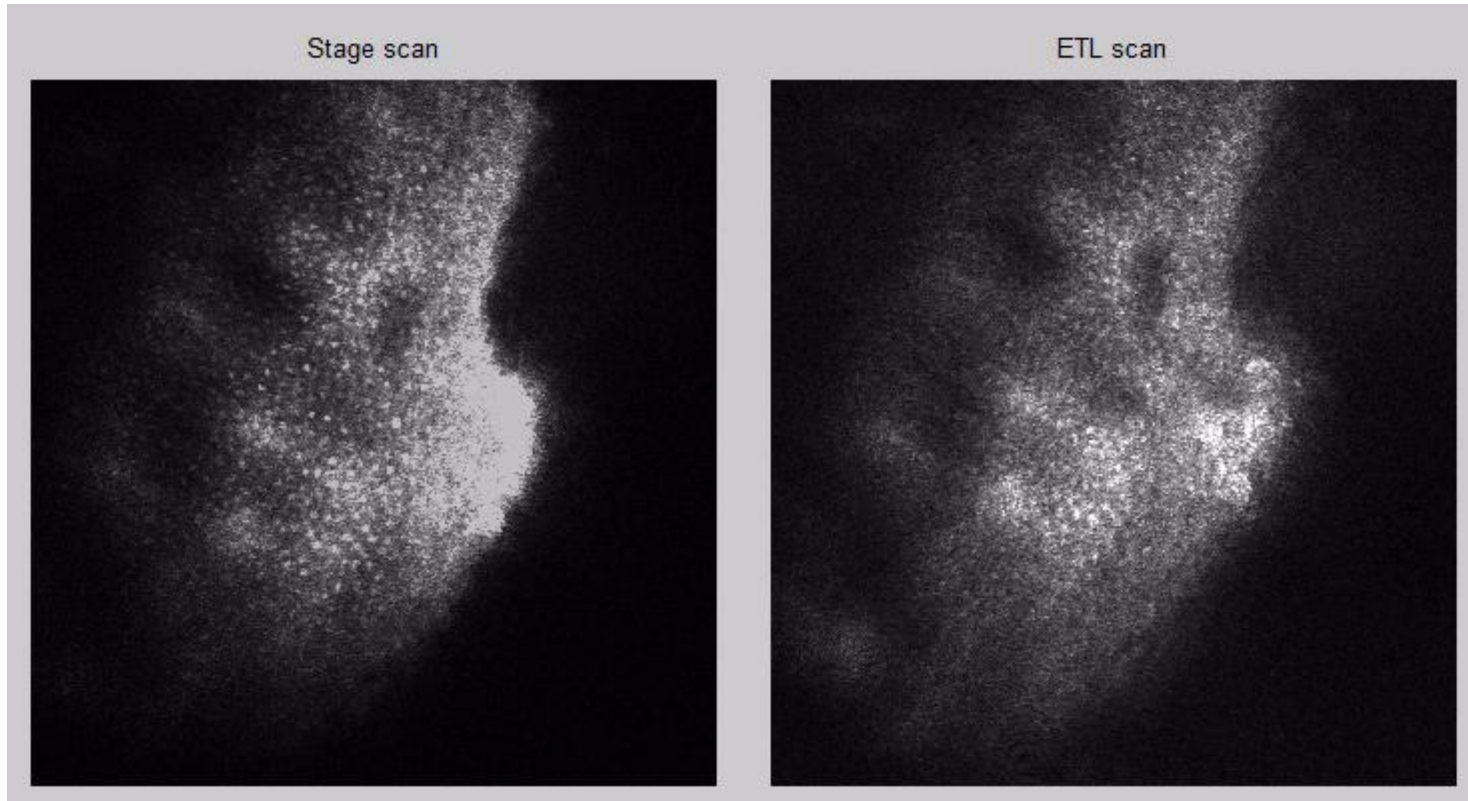
Ref: J.M. Jabbour et al., BIOMEDICAL OPTICS EXPRESS 2014, **5**, (2), pp. 645, 2014, “Optical axial scanning in confocal microscopy using an electrically tunable lens”

Techniques overview

Confocal endomicroscopy



Traditional approach **Optotune approach**

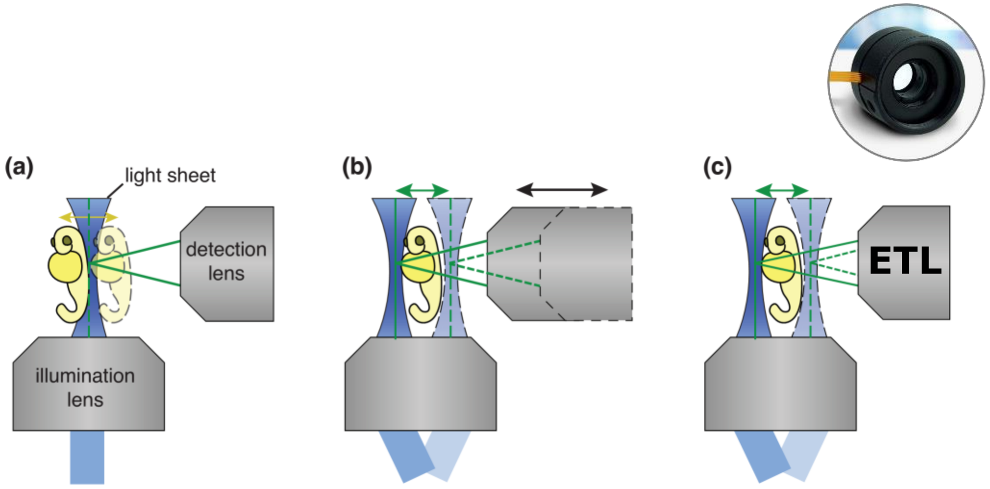


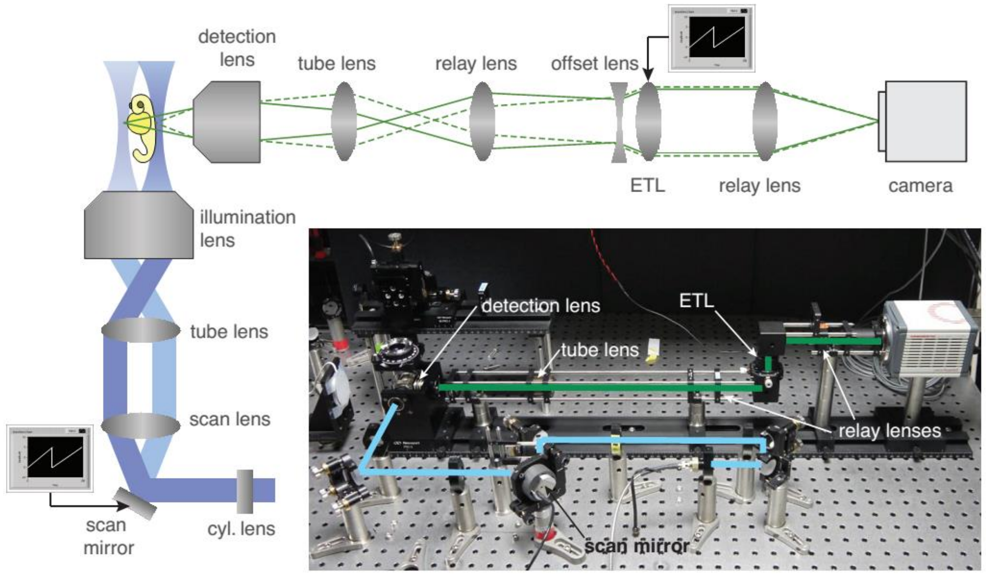
Scan through oral mucosa *ex vivo* [Video]

Ref: J.M. Jabbour et al., BIOMEDICAL OPTICS EXPRESS 2014, **5**, (2), pp. 645, 2014, "Optical axial scanning in confocal microscopy using an electrically tunable lens"

Techniques overview

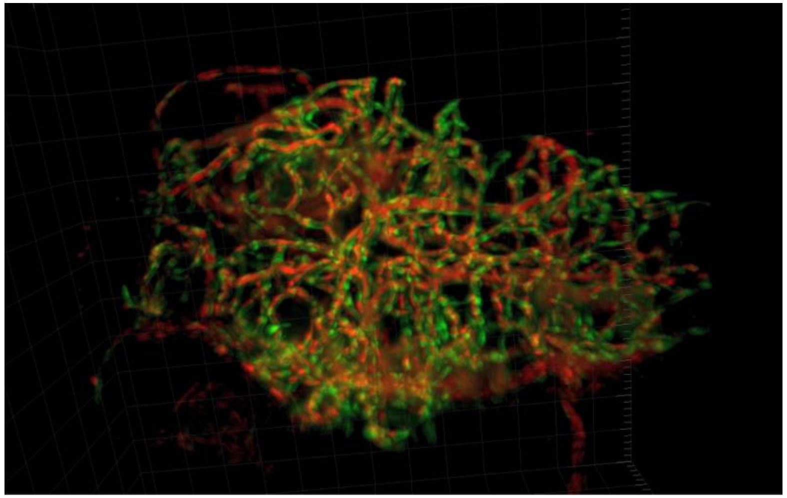
Light-sheet microscopy

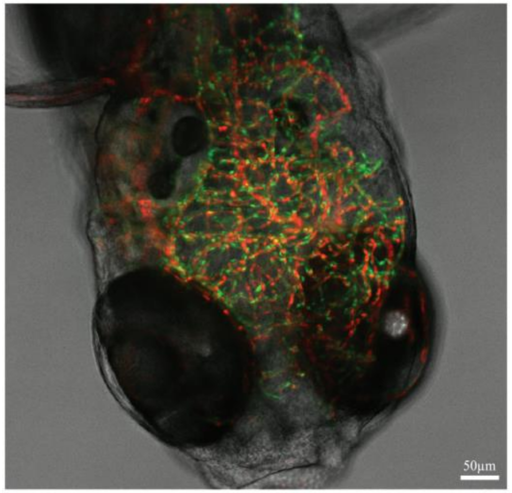




Vascular system in the brain of a zebrafish

Video



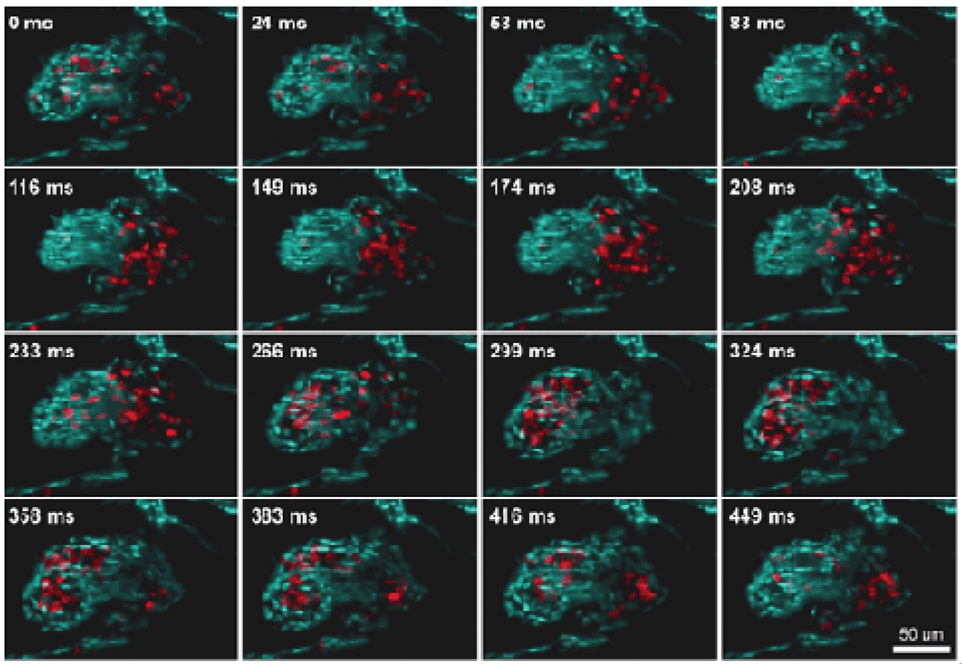


F. O. Fahrbach *et al.,* Opt. EXPRESS (2013), **21**, (18), pp. 21010.

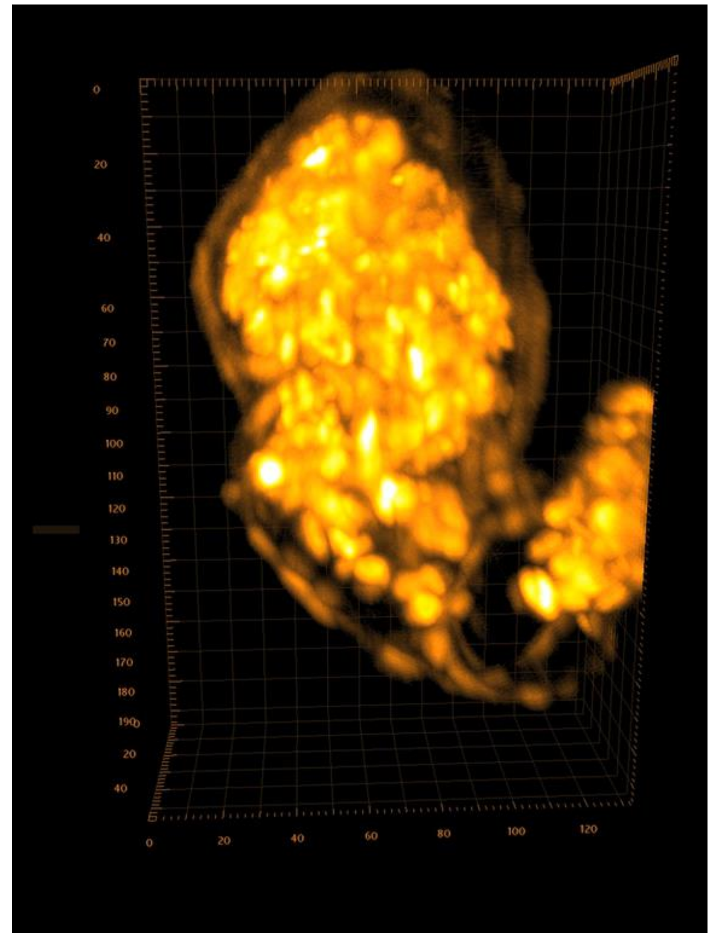
Techniques overview

Light-sheet microscopy with 10x objective

Large volume scan with an ETL through the heart of a zebrafish



Courtesy of Florian Fahrbach, Michaela Mickoleit and Jan Huisken.



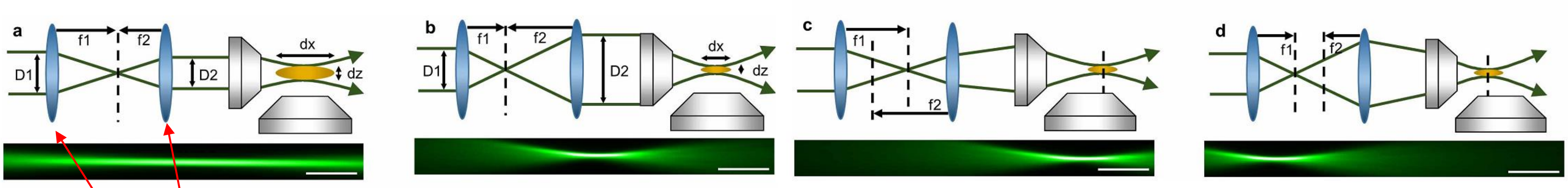
[Video](#)

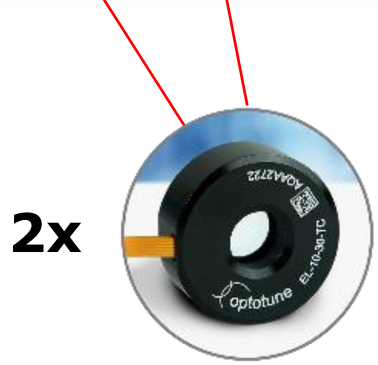
F. O. Fahrbach *et al.,* Opt. EXPRESS (2013), **21**, (18), pp. 21010.

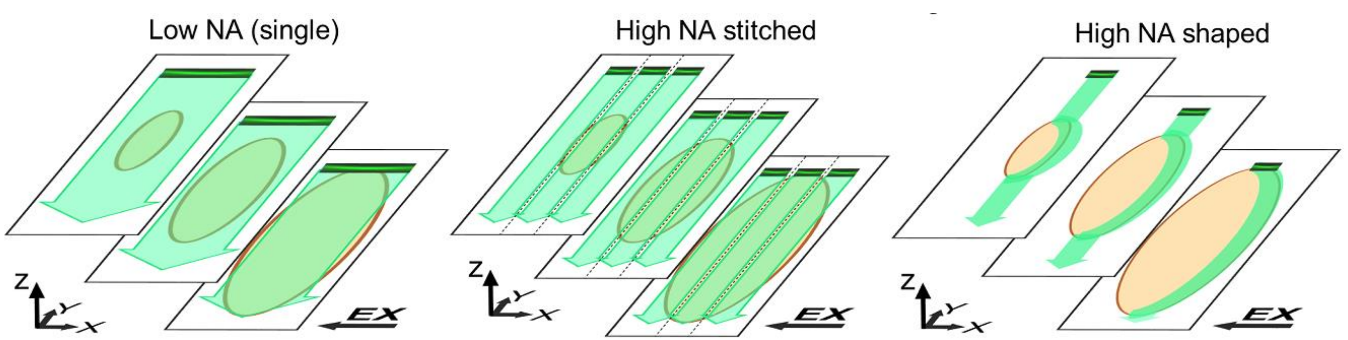
Techniques overview

Light-sheet microscopy

- Goal: *Optimize with help of tunable lenses the illumination light-sheet to the requirement at hand.*
- A telescope composed of two electrically tunable lenses enable to define thickness and position of the light-sheet independently but accurately within milliseconds, and therefore optimize image quality of the features of interest interactively.
- This technique proved compatible with confocal line scanning detection, further improving image contrast.







A. K. Chmielewski et al., Nature Scientific Reports 5, Article number: 9385 doi:10.1038/srep09385 (2015).

optotune

Preferred partner to develop new technologies

Publications using Optotune Lenses for Microscopy

Four-dimensional visualization of zebrafish cardiovascular and vessel dynamics by a structured illumination microscope with electrically tunable lens

Chen Chong, Li Simin, Wen Gang, Liang Yong, Wang Linbo, Yang Guang, Jin Xin, and Li Hui, Biomed. Opt. Express 11, 1203-1215 (2020) https://doi.org/10.1364/BOE.382114

Speeded-Up Focus Control of Electrically Tunable Lens by Sparse Optimization

Iwai, D., Izawa, H., Kashima, K. et al. Speeded-Up Focus Control of Electrically Tunable Lens by Sparse Optimization. Sci Rep 9, 12365 (2019). https://doi.org/10.1038/s41598-019-48900-z

Large depth-of-field 3D shape measurement using an electrically tunable lens

Xiaowei Hu, Guijin Wang, Yujin Zhang, Huazhong Yang, and Song Zhang, Opt. Express 27, 29697-29709 (2019) https://doi.org/10.1364/OE.27.029697

Experimental validations of a tunable-lens-based visual demonstrator of multifocal corrections

Vyas Akondi, Lucie Sawides, Yassine Marrakchi, Enrique Gambra, Susana Marcos, and Carlos Dorronsoro, Biomed. Opt. Express 9, 6302-6317 (2018) https://doi.org/10.1364/BOE.9.006302

Cell mechanotransduction with piconewton forces applied by optical tweezers

Fabio Falleroni, Vincent Torre, Dan Cojoc, Frontiers in cellular nanoscience (2018), https://doi.org/10.3389/fncel.2018.00130

All-optical microscope autofocus based on an electrically tunable lens and a totally internally reflected IR laser

M. Bathe-Peters, P. Annibale, and M. J. Lohse, Optics Express Vol. 26, Issue 3, pp. 2359-2368 (2018), https://doi.org/10.1364/OE.26.002359

Three-dimensional Two-photon Optogenetics and Imaging of Neural Circuits in vivo

B. W. Yang, L. Carrillo-Reid, Y. Bando, D.S. Peterka, R. Yuste, bioRxiv preprint (2017). https://doi.org/10.1101/132506

NeuBtracker—imaging neurobehavioral dynamics in freely behaving fish

B. P. Symvoulidis, A. Lauri, A. Stefanoiu, M. Cappetta, S. Schneider, H. Jia, A. Stelzl, M. Koch, C. C. Perez, A. Myklatun, S. Renninger, A. Chmyrov, T. Lasser, W. Wurst, V. Ntziachristos, G. G. Westmeyer, Nature Methods - Brief communication (2017). doi:10.1038/nmeth.4459

High-speed dual-layer scanning photoacoustic microscopy using focus tunable lens modulation at resonant frequency

B. K. Lee, E. Chung, S. Lee, T. J. Eom, Optics Express, Vol 22, pp. 26427 (2017). doi.org/10.1364/OE.25.026427

Quantifying three-dimensional rodent retina vascular development using optical tissue clearing and light-sheet microscopy

B. J. N. Singh, T. M. Nowlin, G. J. Seedorf, S. H. Abman, D. P. Shepherd, J. Biomed. Opt., Vol 22, Issue 7, (7), pp. 2035-2046 (2011). doi:10.1117/1.JBO.22.7.076011

Three-dimensional multiple-particle tracking with nanometric precision over tunable axial ranges

B. G. Sancataldo, L. Scipioni, T. Ravasenga, L. Lanzanò, A. Diaspro, A. Barberis, and M. Duocastella, Optica Vol. 4, Issue 3, pp. 367-373 (2017)

Reduction of coherent artefacts in super-resolution fluorescence localisation microscopy

A. P. Georgiades, V. J. Allan, M. Dickinson, T. A. Waight, Journal of Microscopy (2016); doi: 10.1111/jmi.12453

High-speed microscopy with an electrically tunable lens to image the dynamics of in vivo molecular complexes

Y. Nakai, M. Ozeki, T. Hiraiwa, R. Tanimoto, A. Funahashi, N. Hiroi, A. Taniguchi, S. Nonaka, V. Boilot, R. Shrestha, J. Clark, N. Tamura, V. M. Draviam and H. Oku, Rev. Sci. Instrum. 86, 013707 (2015)

Multi-depth photoacoustic microscopy with a focus tunable lens

Kiri Lee, Euiheon Chung, Tae Joong Eom, Proc. of SPIE Vol. 9323 93233O-1 (2015)

Calcium transient prevalence across the dendritic arbour predicts place field properties

M. E. J. Sheffield, D. A. Dombeck, Nature 517, 200–204 (2015)

3d high- and superresolution imaging using single-objective SPIM

Remi Galland et al., Nature Methods 3402, 1-4 (2015)

Fast imaging of live organisms with sculpted light sheets

A. K. Chmielewski, A. Kyrsting, P. Mahou, M. T. Wayland, L. Muresan, J. F. Evers & C. F. Kaminski, Scientific Reports 5, Article number: 9385 doi:10.1038/srep09385 (2015)

A rapid image acquisition method for focus stacking in microscopy

D. Clark, B. Brown, Microscopy Today, Volume 23, Issue 04, pp 18-25 (2015)

Rapid quantitative phase imaging for partially coherent light microscopy
B. José A. Rodrigo and Tatiana Alieva, Optics Express, Vol. 22, Issue 11, pp. 13472-13483 (2014)

Investigation of diffraction-based measurement errors in optical testing of aspheric optics with digital micromirror devices

Stephan Sturwald, Robert Schmitt, J. Micro/Nanolith. MEMS MOEMS 13(1), 1-8, (2014)

Agenda

- Company presentation
- Tunable lens technology in microscopy
- Non telecentric vs telecentric configuration
- Techniques overview & examples
- Further application examples

Application example

Z stack with an upright microscope,100x objective

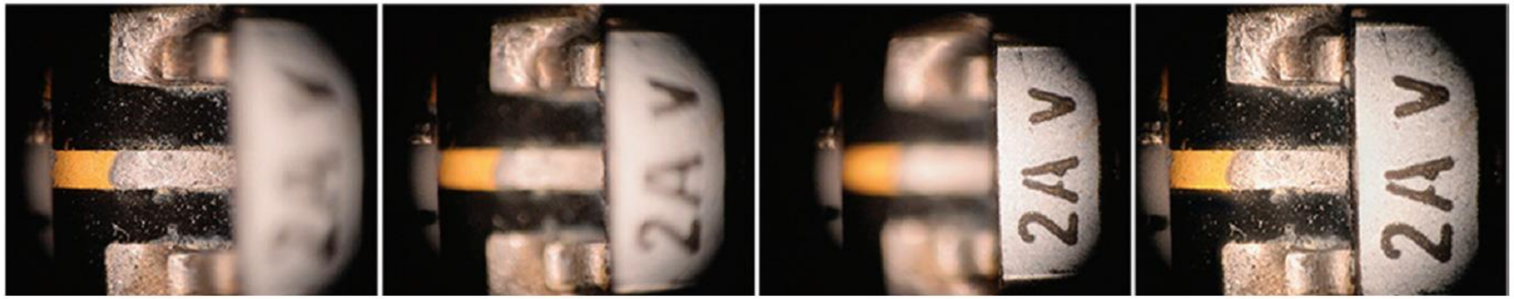
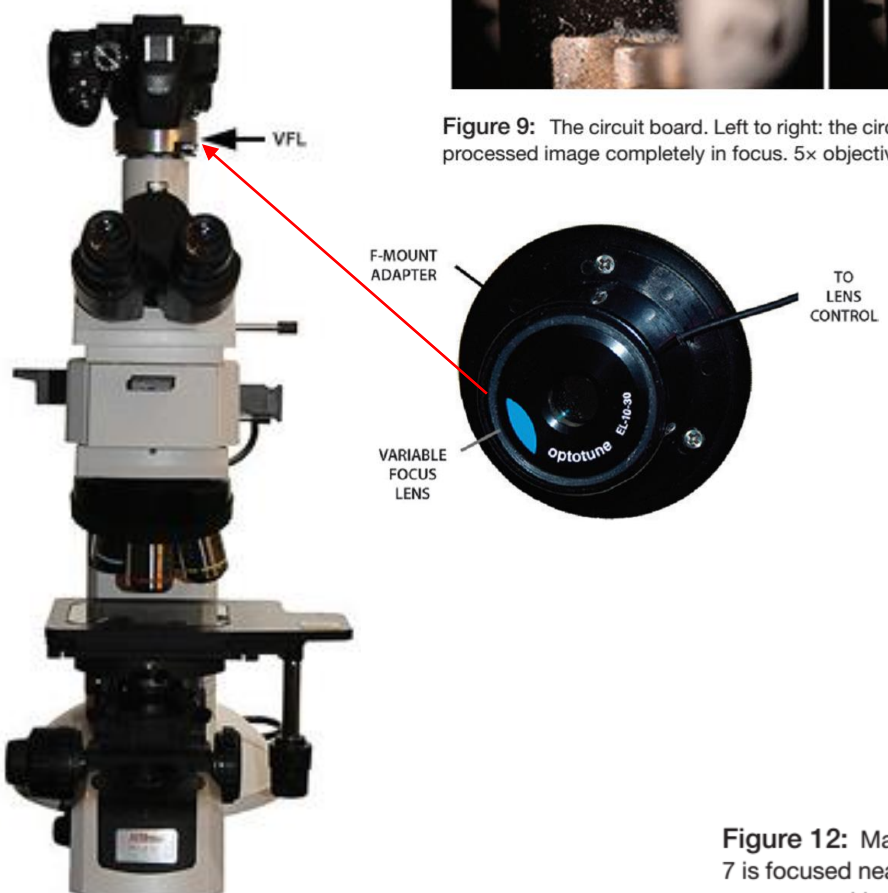
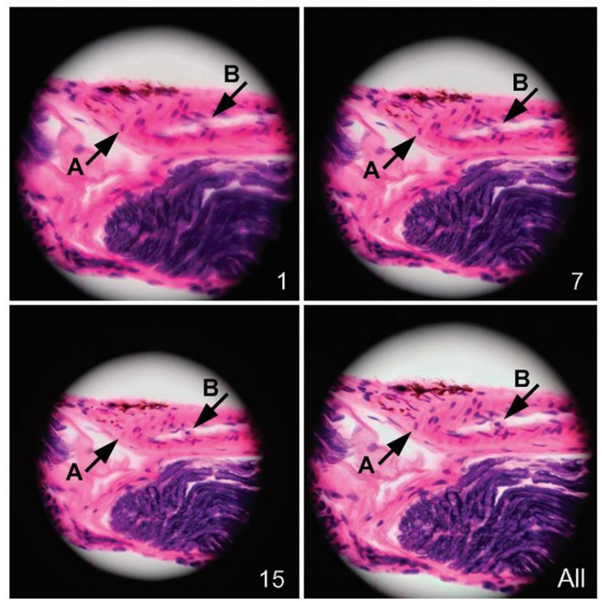


Figure 9: The circuit board. Left to right: the circuit board in focus, halfway between the circuit board and the top of the component, the top of the component, and the processed image completely in focus. 5× objective, stack of 27 images, final image diameter ≅3.0 mm, acquisition time = 0.45 sec.





D. Clark, Microscopy Today / Volume 23 / Issue 04 / July 2015, pp 18-25Copyright

DOI: http://dx.doi.org/10.1017/S1551929515000577

Figure 12: Mammalian tissue specimen. Image 1 is focused at the lowest level where feature A is in focus. Image 7 is focused near the center of the specimen. Image 15 is focused at the top where feature B is in focus. Image All is a processed image showing all features in focus. 50× objective, stack of 15 images, final image diameter ≅0.3 mm, acquisition time = 0.25 sec.

Application example

Microscopy adapter without mag change

Zeiss Axioskop

- Zeiss Neofluar, 10x/0.3 Inf./0.17
- Zeiss LD Achroplan 20x/0.4 Korr Ph2 Inf./0-1.5
- Zeiss Plan-Neofluar 40x/0.75 Inf/0.17

Camera

IDS UI-3580CP-C-HQ (1/2", 5MP)

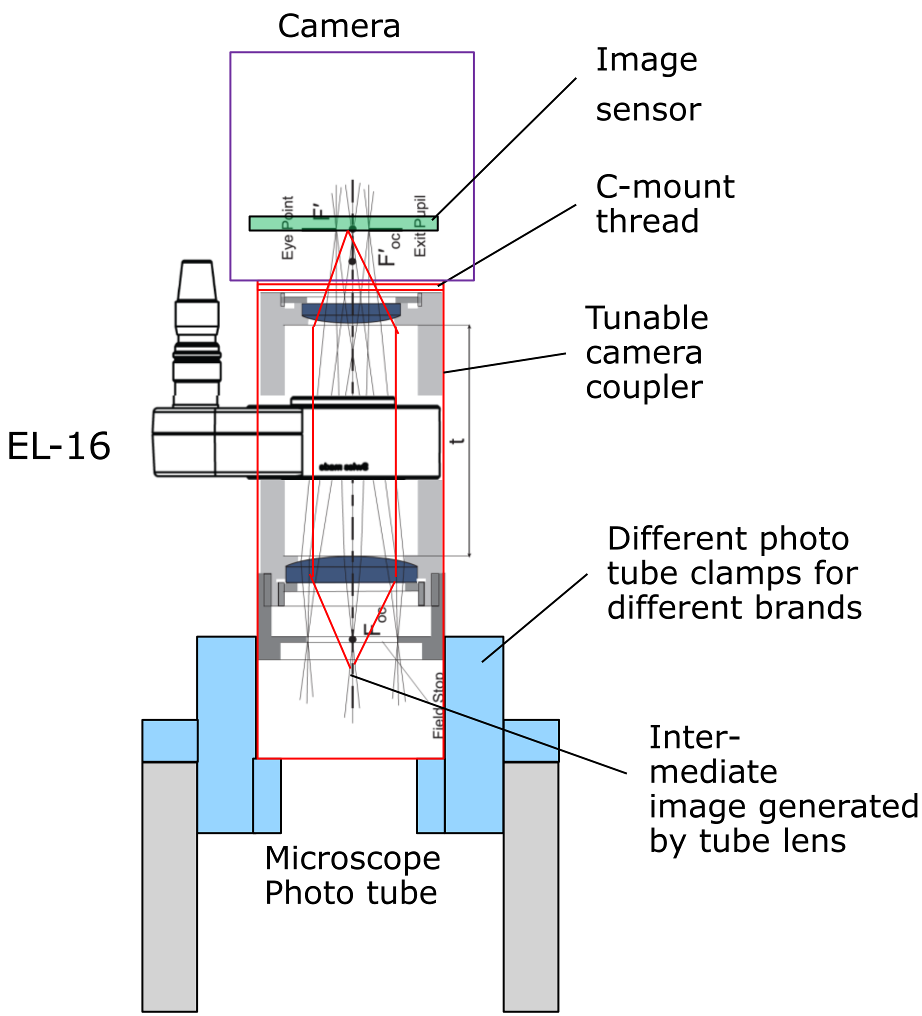
Optotune Lens

EL-16-40-TC-VIS-20D

Mag	EL-16-40-TC-VIS-5D	EL-16-40-TC-VIS-20D
10x	262um	980um
20x	64um	254um
40x	12um	56um

Application example

Tunable camera coupler retrofitted to microscope

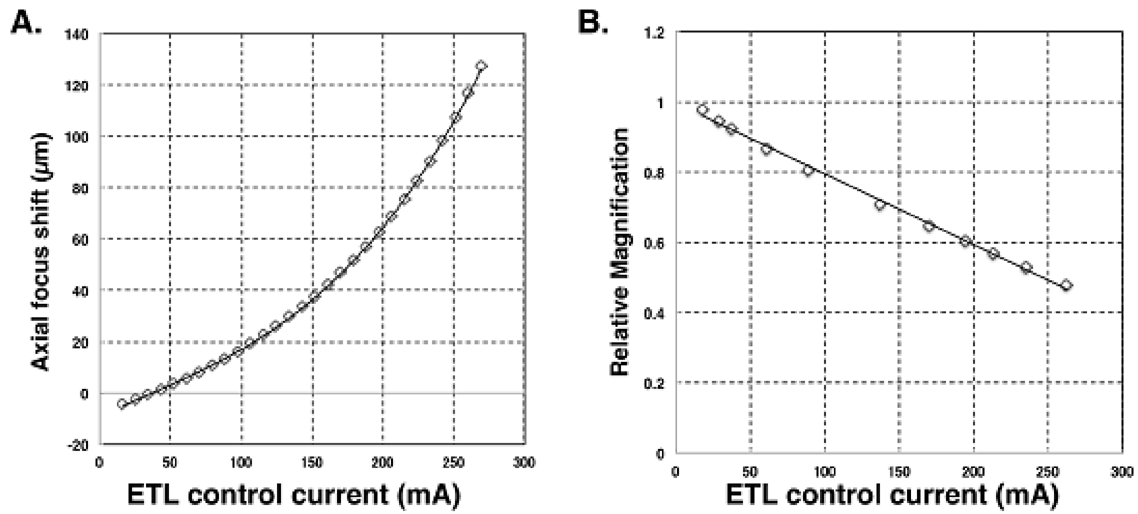


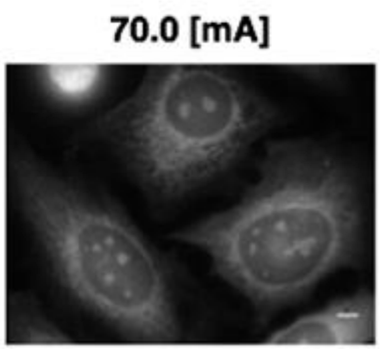
- Retrofit to existing microscope possible
- Automatic user independent parfocality between eye and camera port
- Fast autofocus
- Focus on region of interest by clicking into image
- Wide-field 3D imaging (image stacking)

Application example

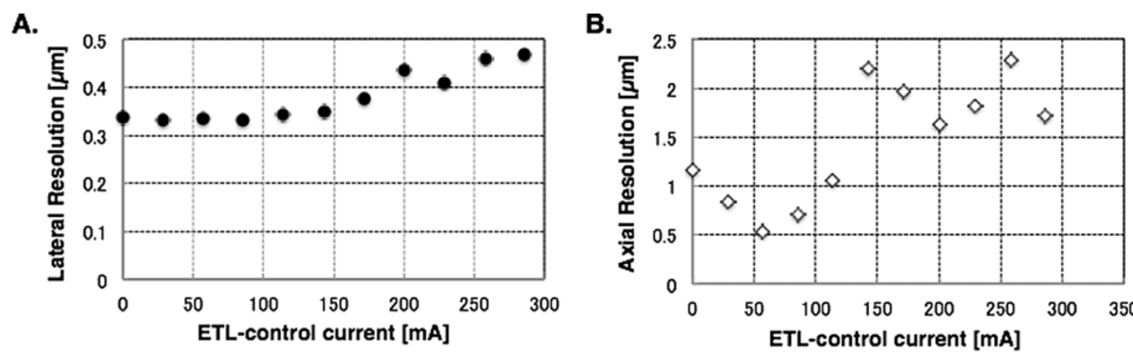
Z-stack with an inverted microscope,100x objective

Optotune
EL-10-30





microtubules in HeLa
cells



http://scitation.aip.org/content/aip/journal/rsi/86/1/10.1063/1.4905330

optotune

Application example

3D High- and super-resolution imaging using single-objective SPIM

- Single-objective selective-plane illumination microscopy (soSPIM) is achieved with micro-mirrored cavities combined with a laser beam–steering unit installed on a standard inverted microscope.
- Based on custom EL-C-10-30 focus-tunable lens (TL) from −80 mm to +1,000 mm.

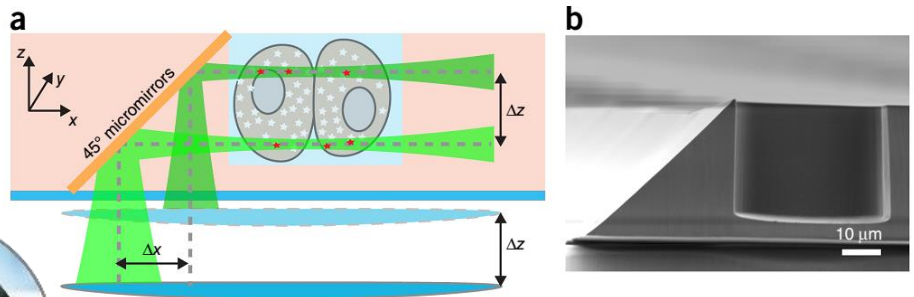


Figure 1 | Principle and 3D high-resolution capabilities of the soSPIM method. (**a**) Schematic representation of soSPIM. A light sheet is created by reflection from a 45° mirror. The excitation-beam displacement (Δ*x*) along the mirror combined with the axial positioning of the objective (Δ*z*) enables 3D-volume imaging.

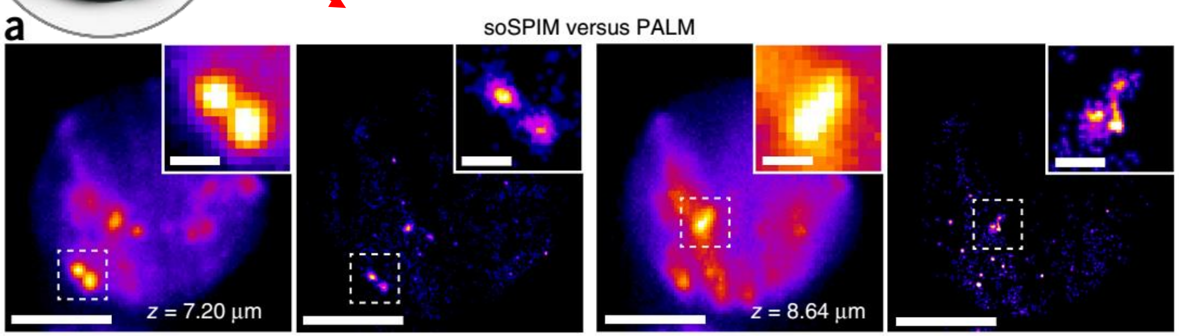


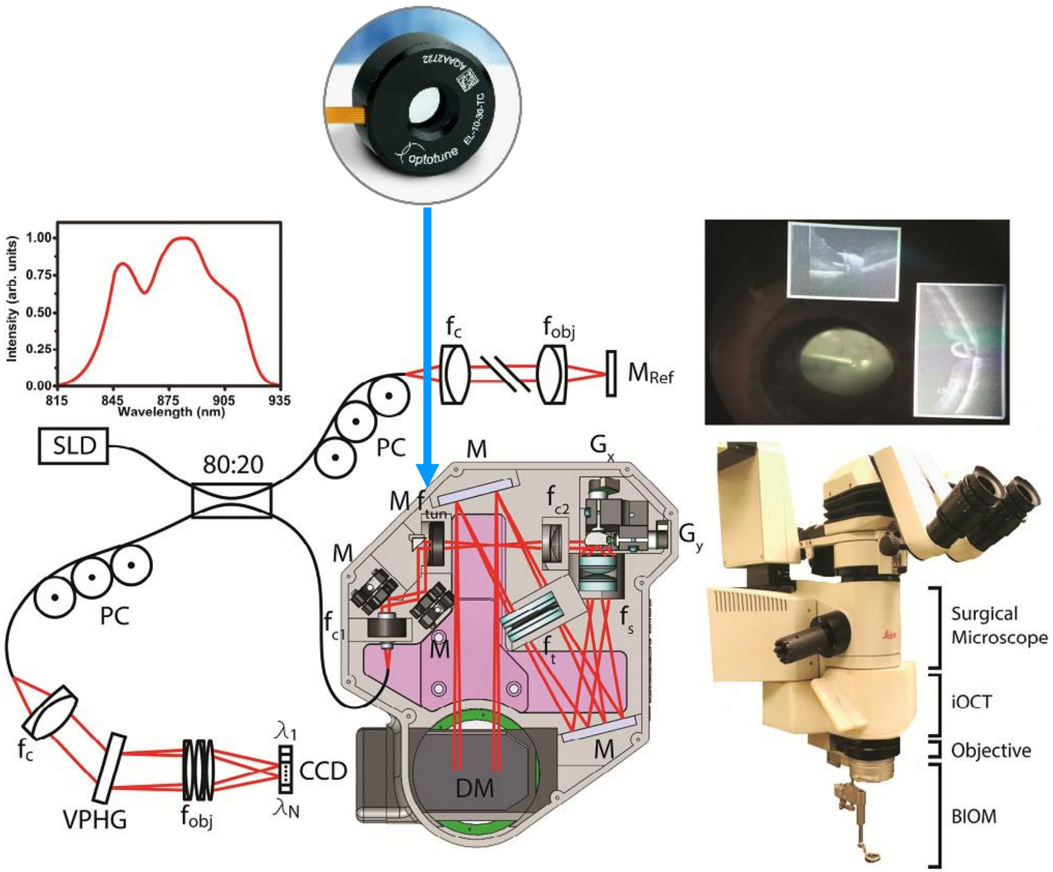
Figure 2 | 3D super-resolution capabilities of the soSPIM method. (**a**) High-resolution (two leftmost panels) and PALM super-resolution (two rightmost panels) images of a U2-OS cell nucleus expressing the nucleolus protein fibrillarin-Dendra2 at two different planes 1.44 μm apart (representative images; $n = 15$).

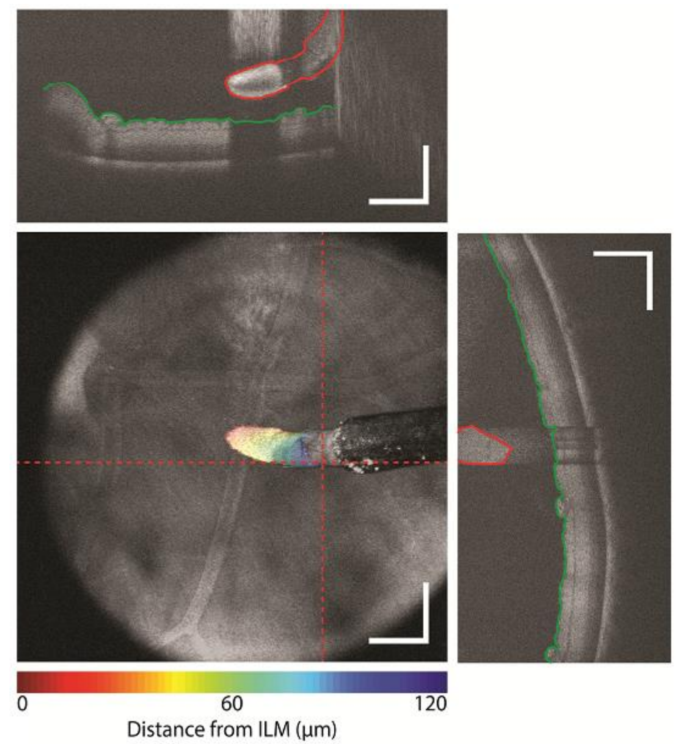
Remi Galland, Nature Methods, published online 11 May 2015DOI:10.1038/NMETH.3402

Application example

Microscope-integrated intraoperative OCT

- Optotune’s electrically tunable lens EL-10-30-NIR-LD allowed real-time adjustment of the OCT focal plane to maintain parfocality with the microscope view.
- Potential for iOCT-guided maneuvers and clinical decision-making in ophthalmic surgery

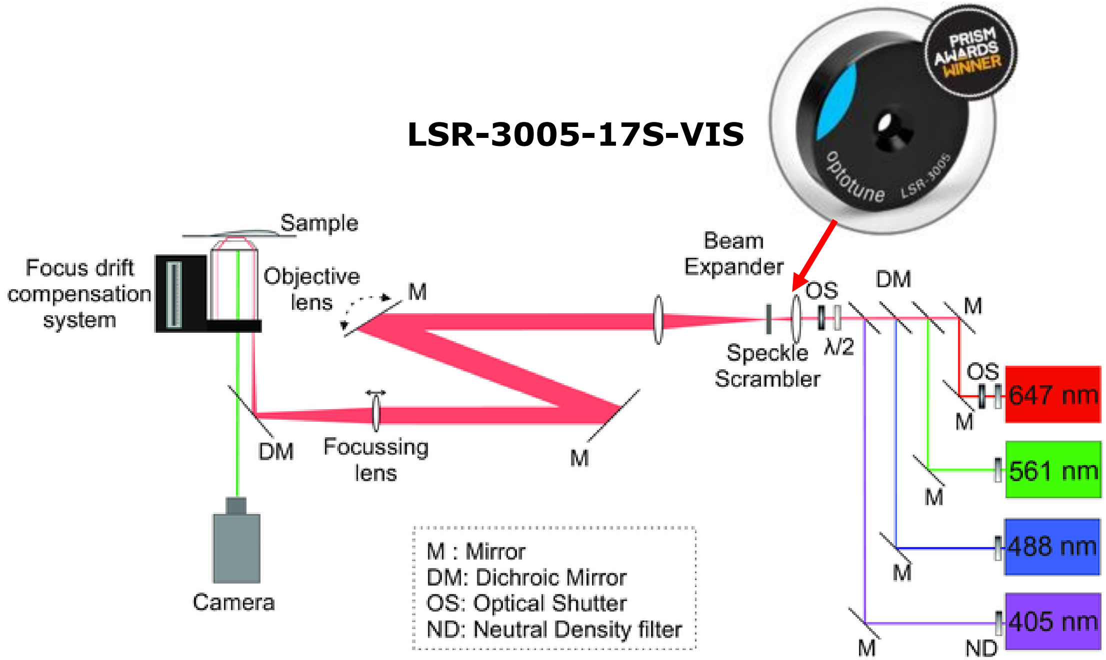




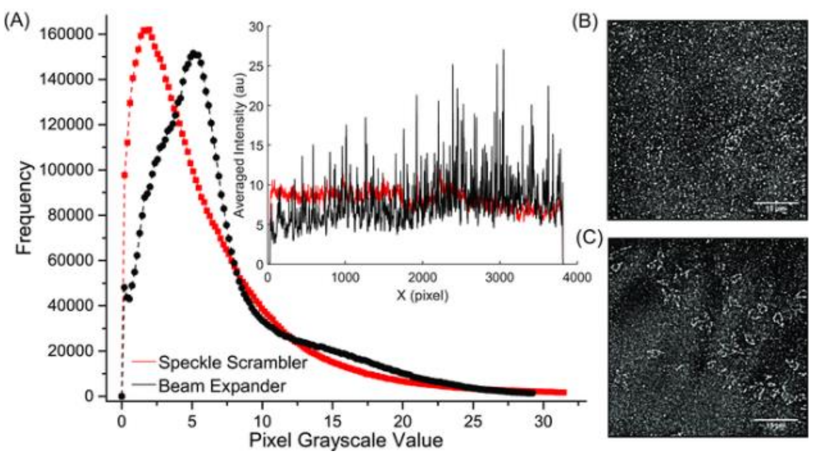
Y. K. Tao *et al.,* BIOMEDICAL OPTICS EXPRESS (2014), **5**, (6), pp. 1877.

Application example

STORM image quality boost with LSR

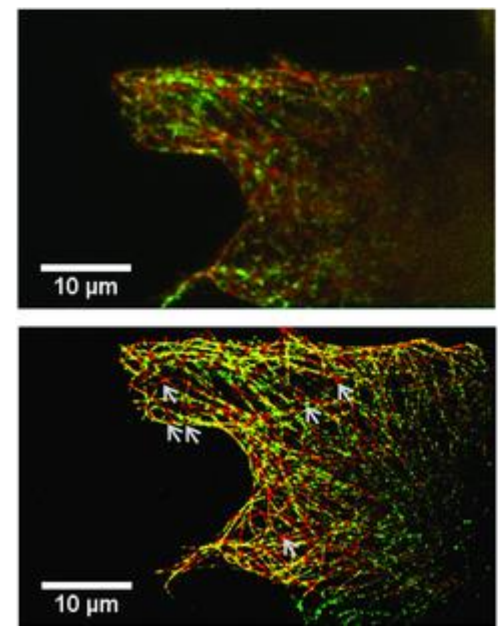


Distribution of pixel greyscale values:



LSR off

LSR on



MRC5 cells stained with Alexa Fluor 647

Ref: P. Georgiades et al., Journal of Microscopy (2016), http://onlinelibrary.wiley.com/doi/10.1111/jmi.12453/full

Integration example

Based on Optotune EL-10-30 and EL-16-40

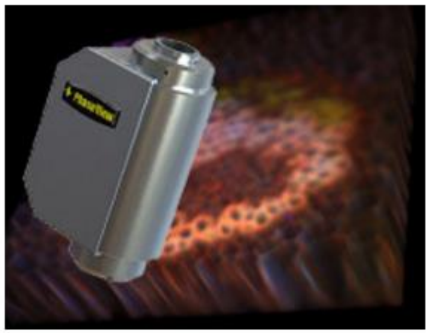
Life Sciences & Scientific Imaging

Microscopy Volume Imaging Solutions

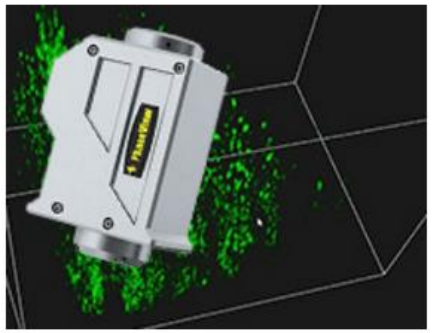
Industries & Quality Control

3D Solutions For Microscopes And Automated Vision Systems

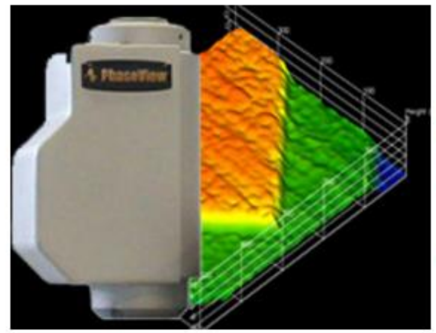
PhaseView®



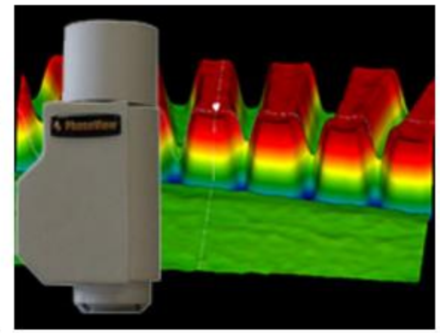
NeoScan
Fast Volume Scanning



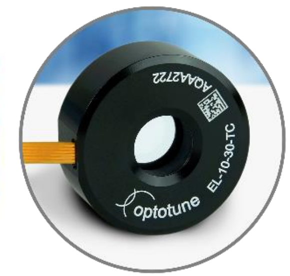
ThunderScan
Ultra High Speed Scanning

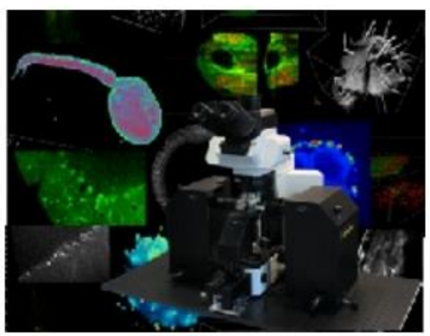


ZeeScan
3D Add-On for microscopes

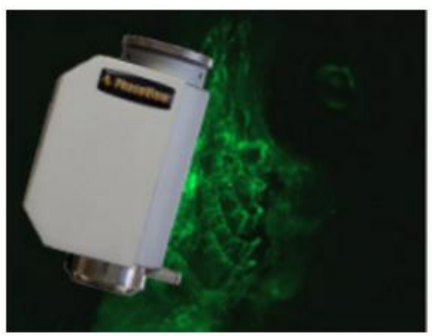


ZeeCam
3d microscope camera

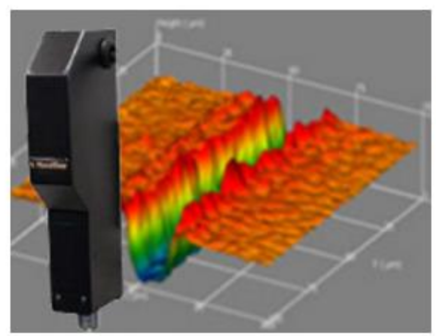




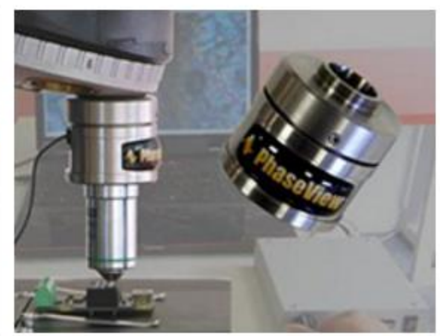
Alpha³
Light Sheet Microscope



InSight
Real Time 3D Acquisition



ZeeScope
3d measurement microscope



SmartScan
Motorless focus control

www.phaseview.com

Integration example

Edmund optics dynamic focus VZM with the EL-10-30

- Very large focus range as EL is placed close to aperture stop
- The zoom is NOT parfocal, however, as the EL is placed above the zoom

Magnification setting	0.75X	1X	2X	3X	4X	4.5X
Magnification range	0.65X - 1.15X	0.9X - 1.2X	1.5X - 2.0X	2.4X - 3.0X	3.2X - 4.0X	3.7X - 4.6X
Working distance (mm)	20 - 101	20 - 100	54 - 90	75 - 90	82 - 90	84 - 90
Horiz. FOV (1/2" sensor)	9.8 - 5.6	7.1 - 5.3	4.3 - 3.2	2.7 – 2.1	2.0 - 1.6	1.7 - 1.4

Integration example

Compact variable focus 2X and 5X lenses offered by Edmund Optics

- EL-10-30-Ci-VIS-LD-MV integrated

TECHSPEC® TUNABLE COMPACT OBJECTIVE LIQUID LENS ASSEMBLIES

Magnification:	2X	5X	Image
Numerical Aperture NA:	0.12	0.15	
Working Distance (mm):	31.3	16.2	
Focus Tunable Range (typical) (mm):	±2	±0.5	
Maximum Sensor Size:	⅔"	⅔"	
Field of View, ⅔" Sensor (mm):	4.4 x 3.3	1.8 x 1.32	
Field of View, ½" Sensor (mm):	3.2 x 2.4	1.28 x 0.96	
Mount:	C-Mount	C-Mount	
Liquid Lens Type:	10mm, VIS Coated, -1.5 - 3.5 diopter range	10mm, VIS Coated, -1.5 - 3.5 diopter range	
Stock No.	#34-712	#34-713	
1-5	$950.00	$1,050.00	
6-10	$875.00	$975.00	
+11	Call for OEM Quantity Pricing		

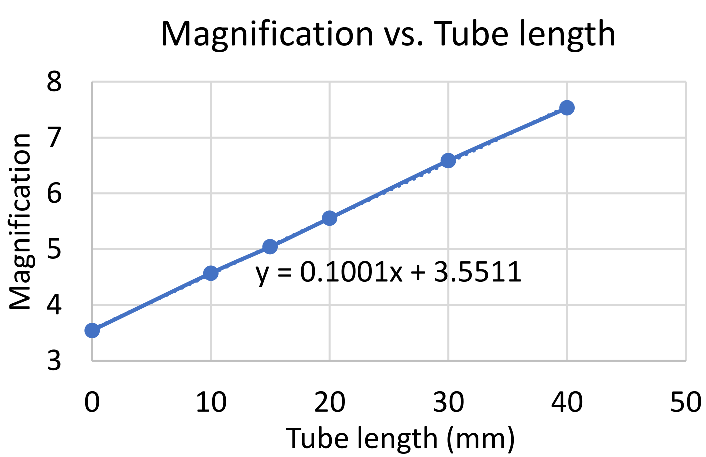
Webshop: https://www.edmundoptics.com/f/tunable-compact-objective-liquid-lens-assemblies/39544/

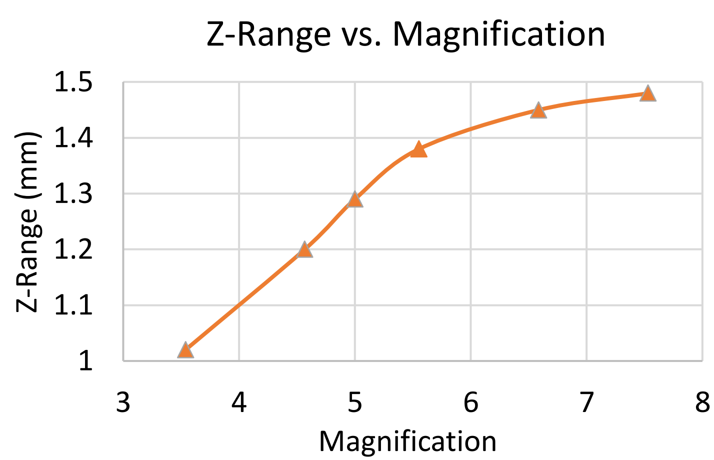
Integration example

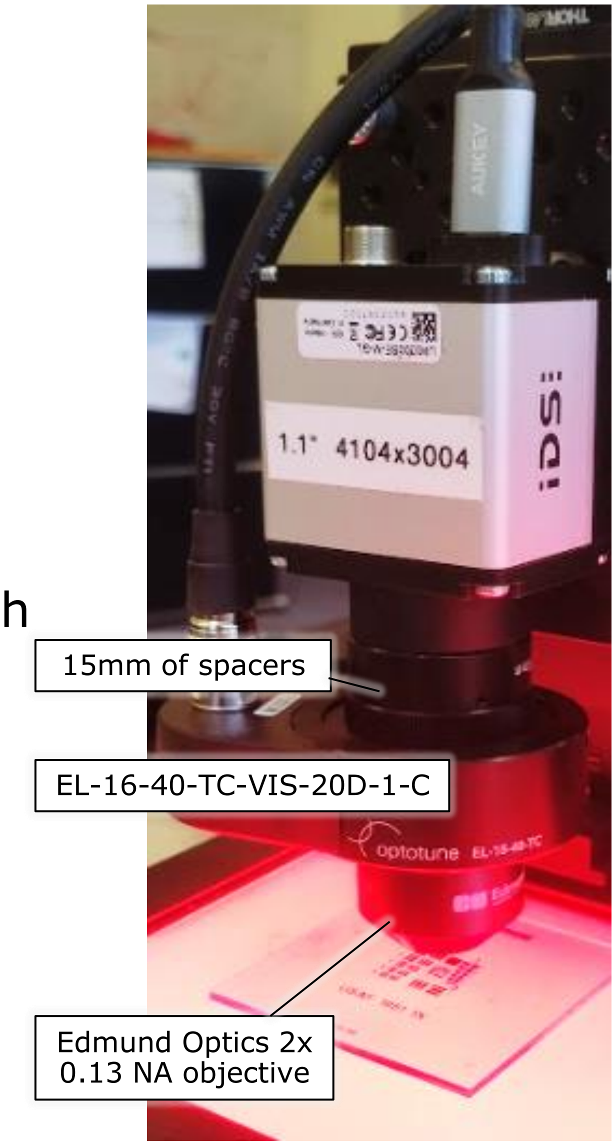
Compact focusing solution >11mm z-range with 5x objective

- FOV @ 0 dpt: 2.8 mm (PMAG = 5x)
- Sensor format: 1.1”
- WD @ 0 dpt: 6.9 mm
- Z-range: 1.29 mm (over 20 dpt tuning range)
- PMAG change: 1.3% per 100um of WD
- Optical leverage: 0.065 mm/dpt

Magnification can easily be adjusted by varying tube length







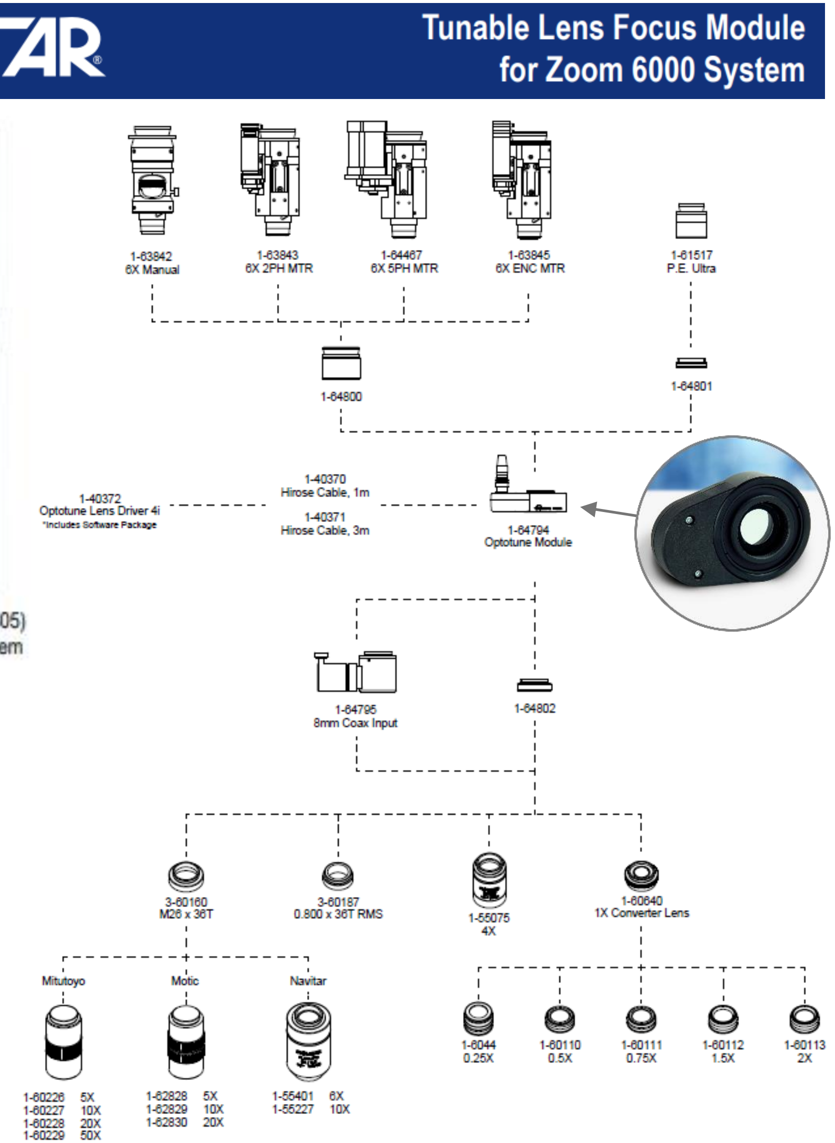
Test report: https://www.optotune.com/s/Optotune-EL-16-40-20D-C-Edmund-Optics-2x-013-NA-Objective.pdf

Integration example

Navitar industrial microscope with EL-16-40-TC autofocus module

- Modular system for zoom applications
  - Zoom is parfocal as the EL is placed below the zoom
- Also suitable for fixed mags
- Compatible with several microscope lenses up to 50X
- System diagram & detailed spec sheet available on Navitar website:
  https://navitar.com/products/imaging-optics/optotune-module/optotune-zoom-6000-system-components/

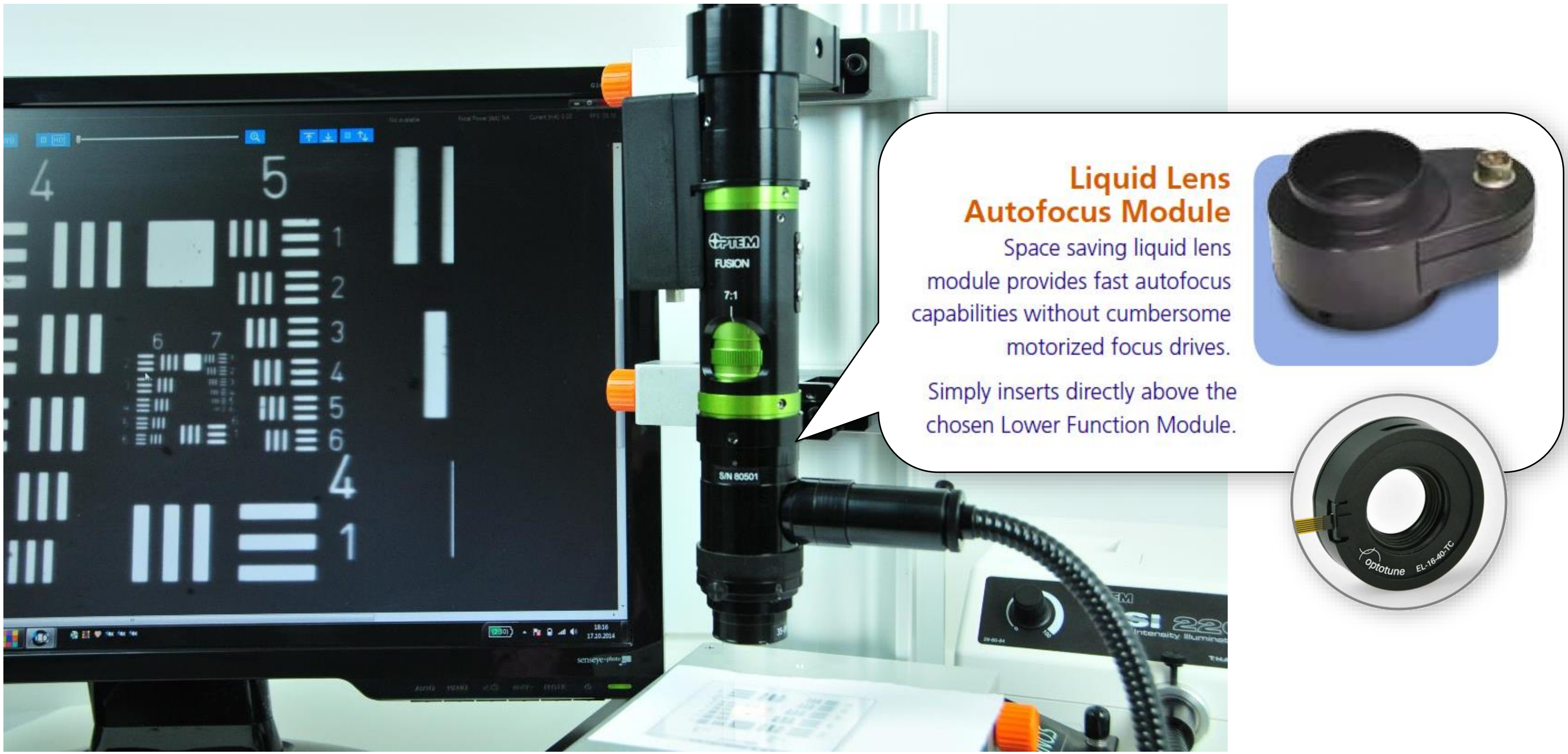
Optotune Module (Navitar 1-64805) with Zoom 6000 Motorized System



Integration example

Optem Fusion industrial microscope with EL-16-40 autofocus module

The zoom is parfocal as the EL is placed BELOW the zoom and above the coaxial illumination



http://www.qioptiq.com/optem-fusion-lens, Optem® is a registered trademark of Qioptiq, Inc

Integration example

Optem 70XL zoom with EL-10-30 autofocus module

C-mount camera
1/2.5” 5MP sensor

1.5x mini tube lens
P/N 29-90-28-000

Optotune lens
EL-10-30-Ci-VIS-LD-MV

Optem 70XL zoom (0.75x-5.25x)
P/N 399510-309

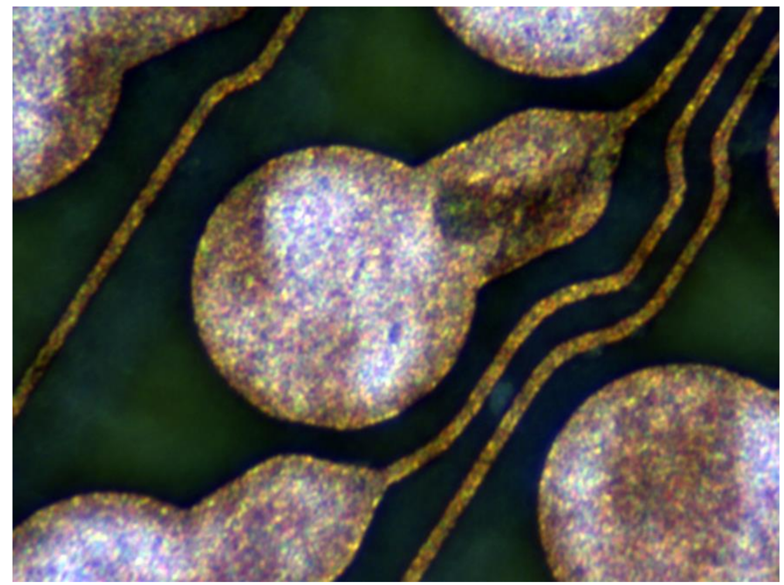
Coaxial lighting unit with lens
P/N 296515-310

LED ring light (used instead)

Working distance: ~90mm

Results:

Magnification	1.1x	3.5x	7.9x
Z range	400mm	40mm	8mm
Z resolution	100µm	10µm	2µm
DOF (approx.)	1mm	0.3mm	0.1mm
HFOV	4.5mm	1.4mm	0.65mm



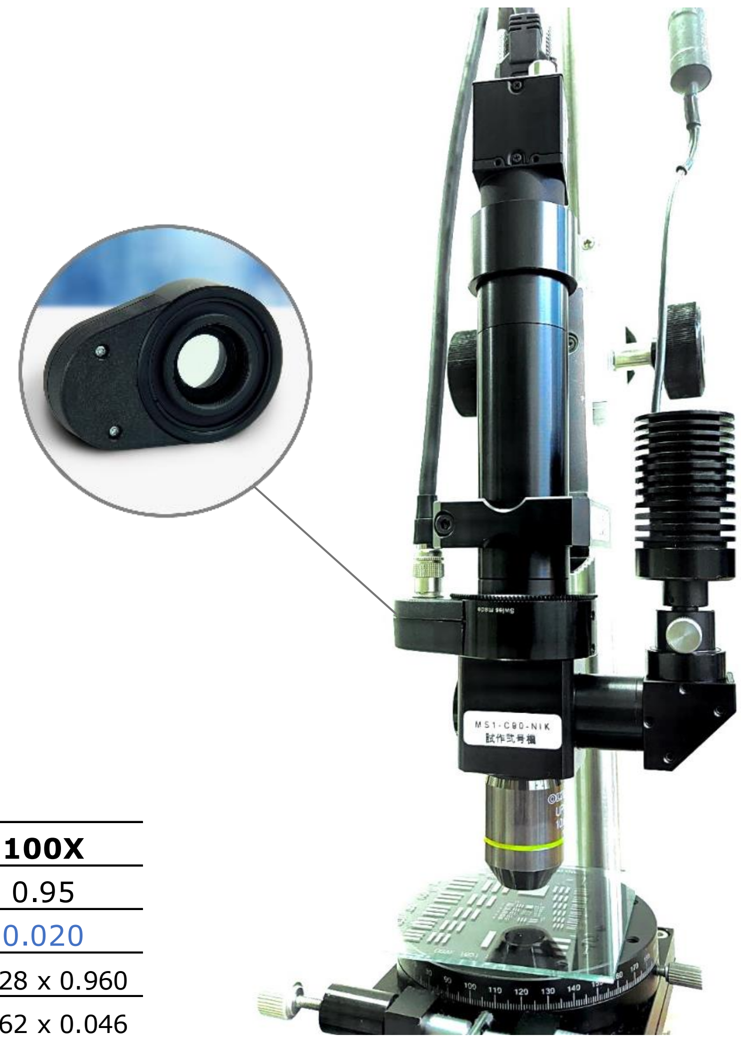
- No vignetting
- Off-the-shelf components

Integration example

Off-the shelf microscope for 10-100x with EL-16-40 autofocus module

- Non-telecentric setup
- Sensor: Up to 1.1"
- Tube lens: 1x/0.8x/0.6x
- Tunable lens: EL-16-40-TC-VIS-5D-1-C*

  *Additional adapters required for tube lens and objective
- Objective lens: 10X to 100X



- Performance (with 1X Tube lens)

Objective lens			**10X**	**20X**	**40X**	**100X**
NA			0.25	0.50	0.65	0.95
Tuning Z-range*	[mm]		2.80	0.51	0.13	0.020
FOV	[mm]	1" Sensor	1.28 x 0.96	0.64 x 0.48	0.32 x 0.24	0.128 x 0.960
		1/2.3" Sensor	0.62 x 0.46	0.31 x 0.24	0.16 x 0.12	0.062 x 0.046

* Black: Measured Value; Blue: Calculated value

shaping the future of optics

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