Liquid crystal lens focusing in monocentric multiscale imagers

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SPIE Optics+Photonics

UCSD

August 14, 2012

Photo: Kevin Walsh, OLR

Wide field of view surveillance

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Standard approach:
- Mechanical sweep over full scene
- Time / resolution tradeoff

Reverse telephoto or Fisheye lens:
- Limited angular resolution / sensitivity

Multi aperture + image stitching system:
- Physical volume / resolution tradeoff

First monocentric panoramic lenses

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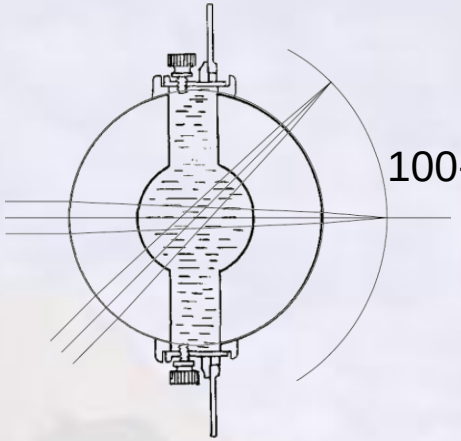
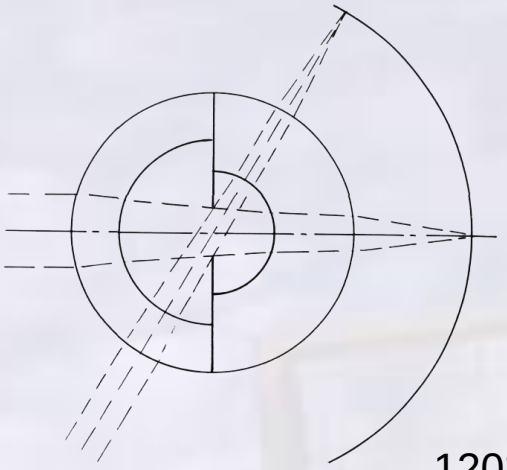
(1859) Thomas Sutton
Water filled Panoramic ball lens

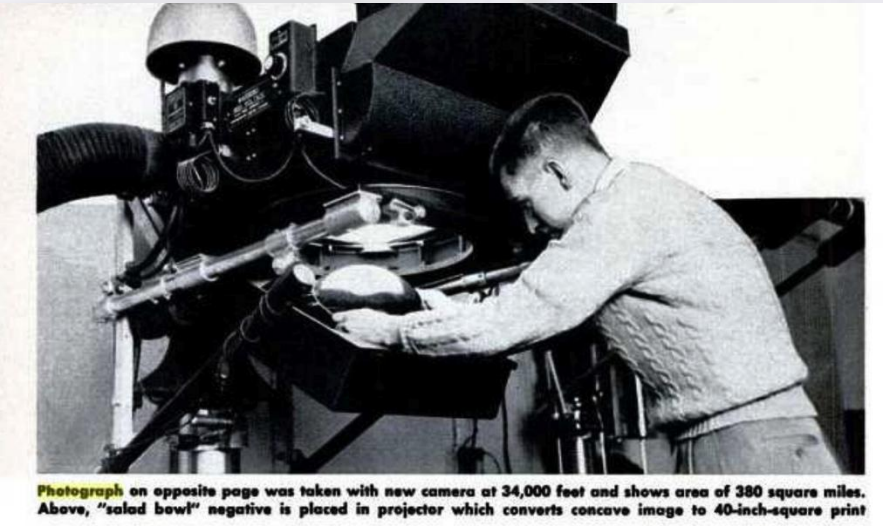


100-110° F#/10-30

(1942) Baker ball lens (U2 spy plane)



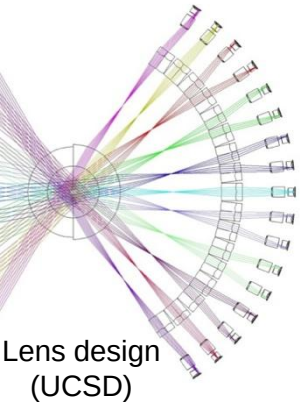
120° F#/3.5



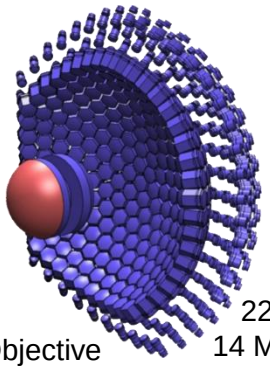
Rudolf Kingslake, "A History of the Photographic Lens," (1989); Museum Victoria, www.museum.vic.gov.au; Image, George Eastman House **22**, (Dec. 1979)

DARPA's "AWARE" Wide Field Imaging Project (MOSAIC)

Multi-scale monocentric imager: 2400 Gigapixels per image at up to 10 fps

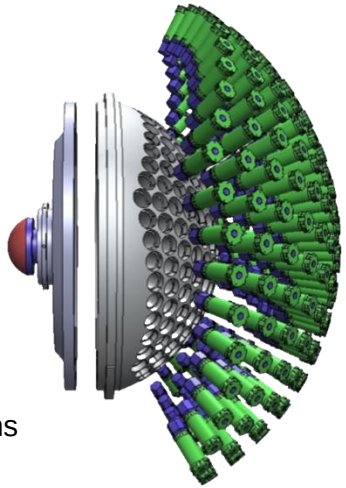


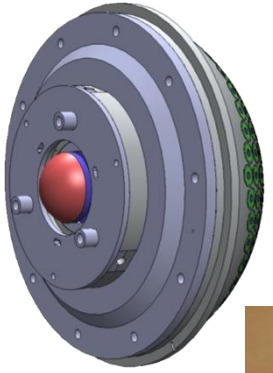
Lens design (UCSD)

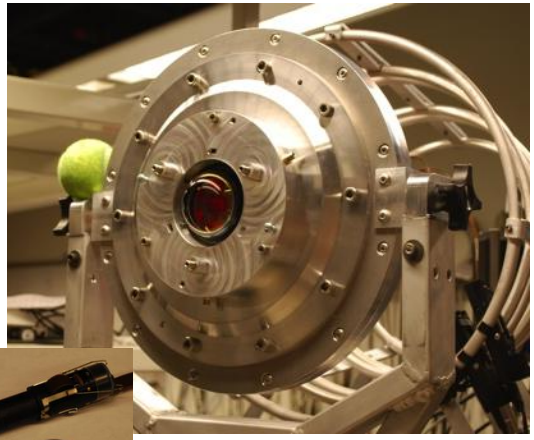


Objective Lens

226 14 MPix microcams



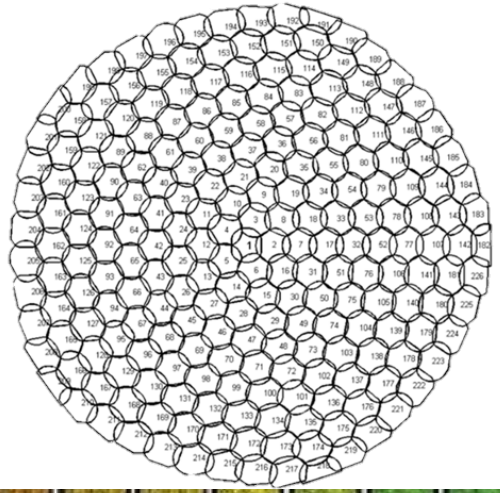




Optomechanics (Jungsang Kim)

Microcamera

David Brady (team lead)



1st (partial) image, August 2011

AWARE2 optical layout

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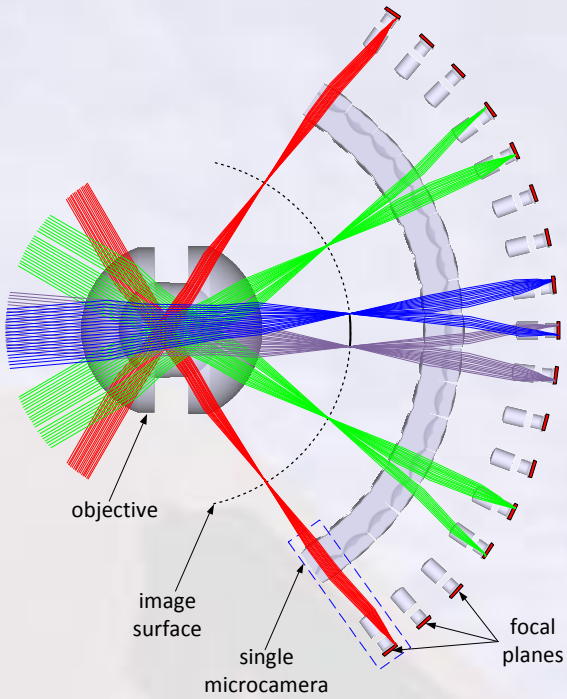
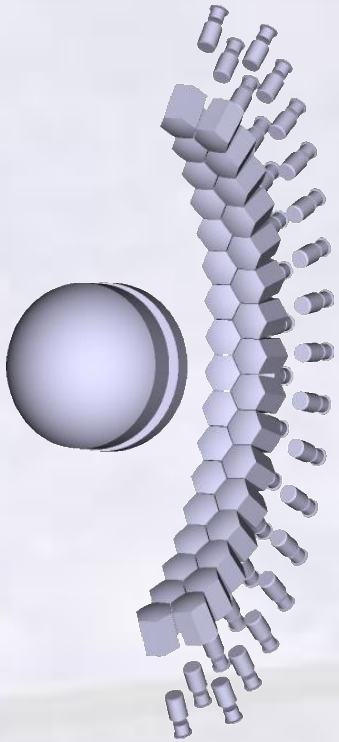
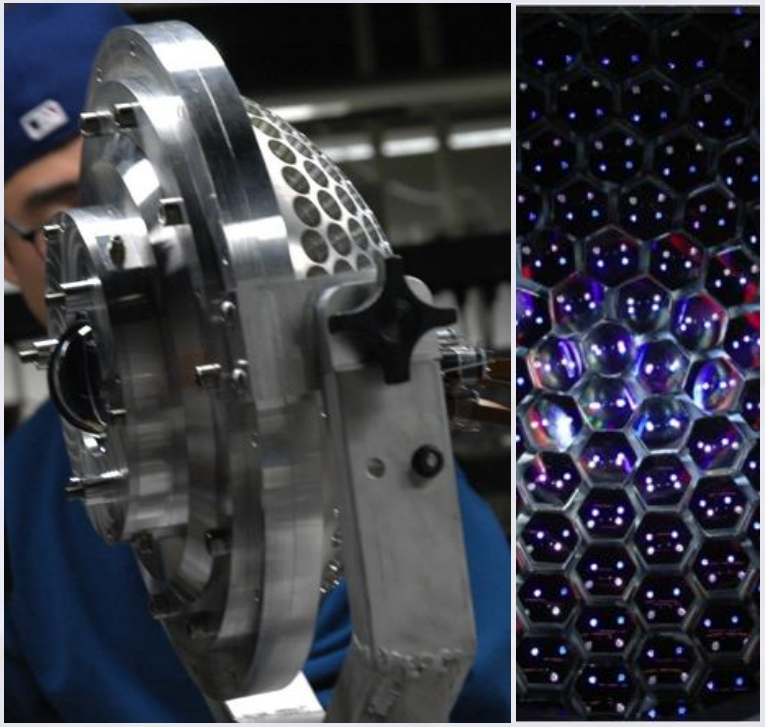
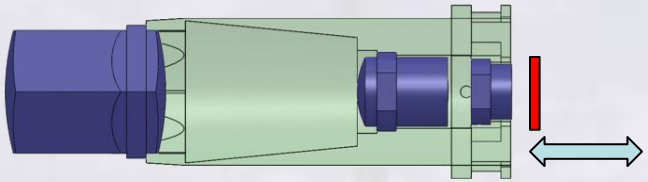






Monocentric objective & microcameras

- Up to 226 microcameras on a spherical image plane
- Each with a 14MPix focal plane, full scene is stitched
- Focusing via servo motor translation of sensor



Tremblay et al, "Design and Scaling of Monocentric Multiscale Imagers," Applied Optics 51(20), (2012)

AWARE2 – wide field of view surveillance

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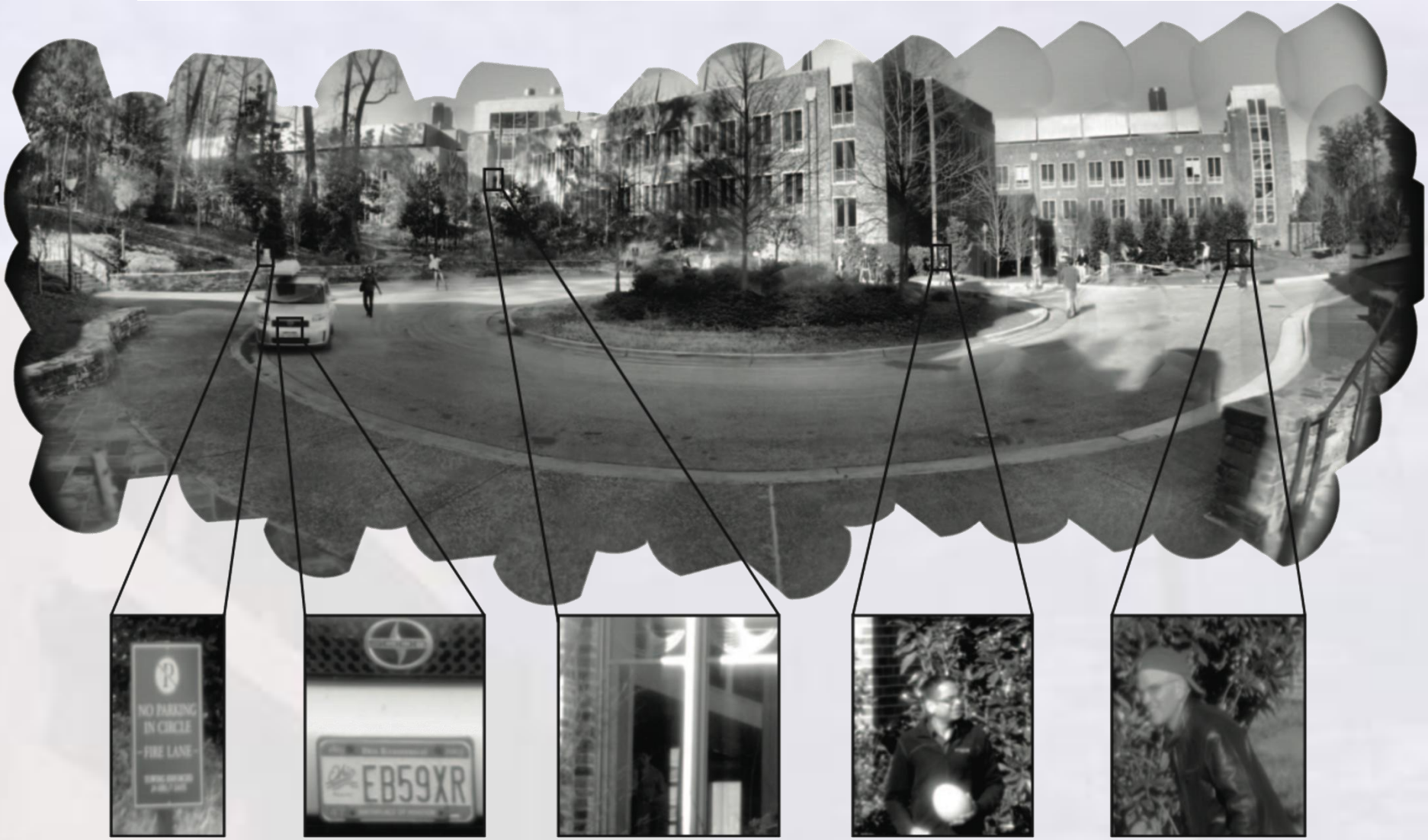
Independent focusing challenge



D. J. Brady, M. E. Gehm, R. A. Stack, D. L. Marks, D. S. Kittle, D. R. Golish, E. M. Vera and S. D. Feller, "Multiscale gigapixel photography," Nature 486, 386-389 , (2012)

AWARE2 focusing mechanism

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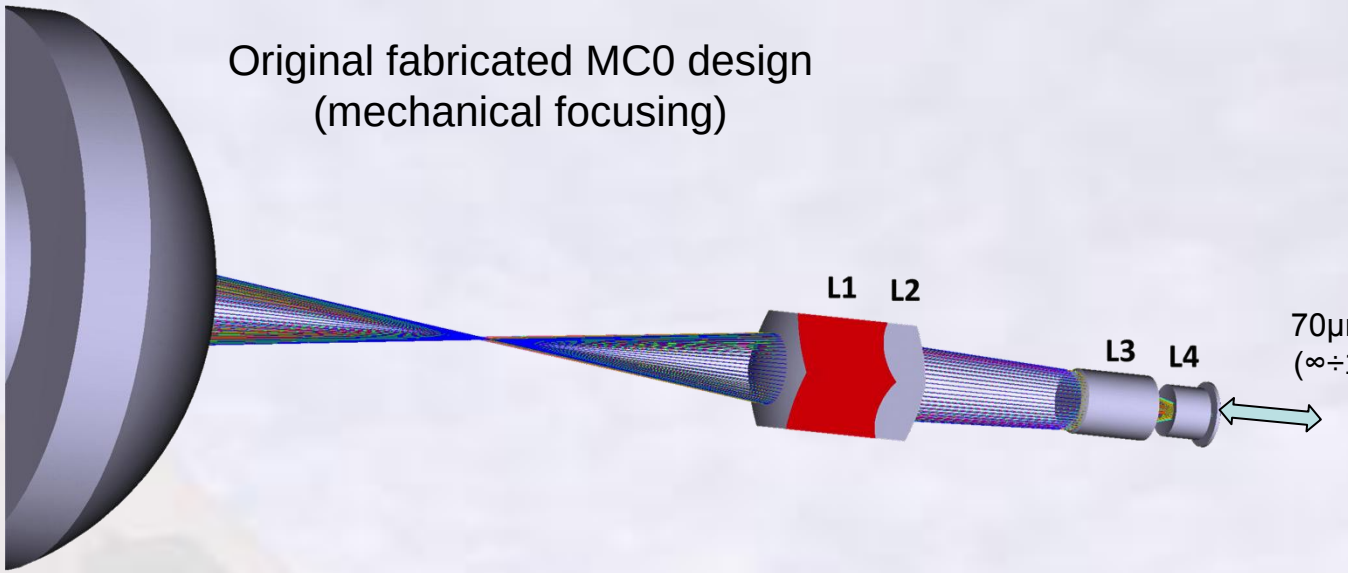
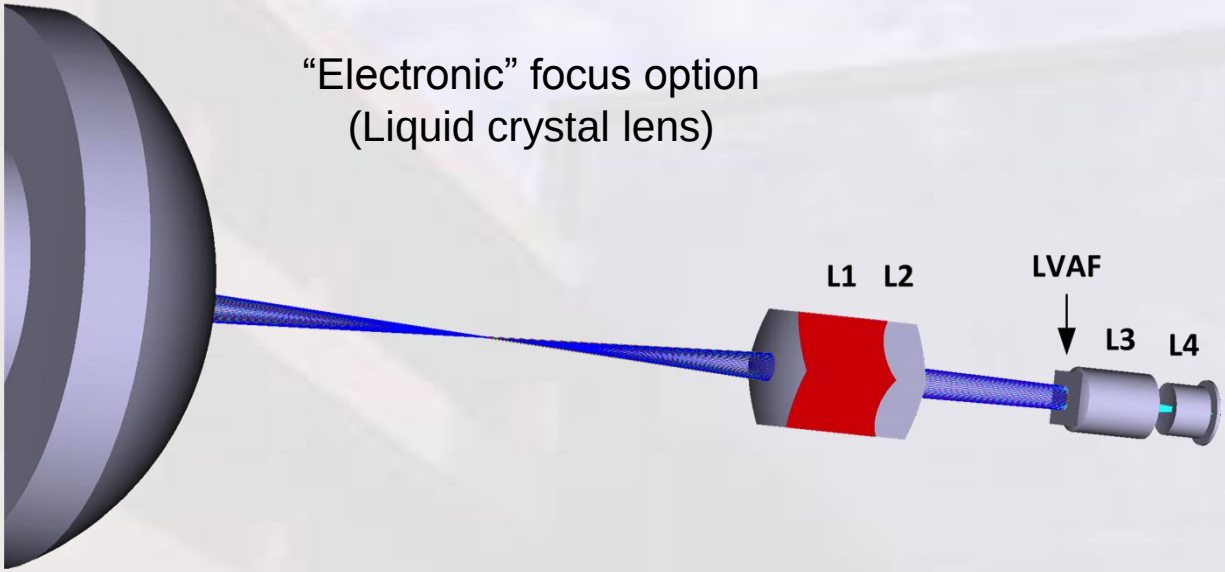
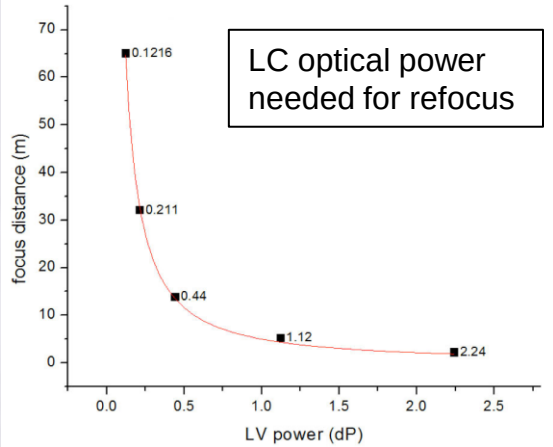
Original fabricated MC0 design
(mechanical focusing)



70µm sensor movement
(∞÷15m object distance)

"Electronic" focus option
(Liquid crystal lens)





“Electronic” focus options

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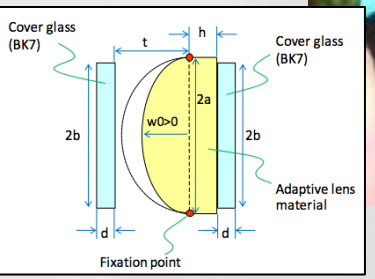
Liquid Lens

Membrane (e.g., Optotune):

Full 10 mm aperture in available products

Liquid reservoir adds bulk

Good option for larger microcameras



Liquid crystal

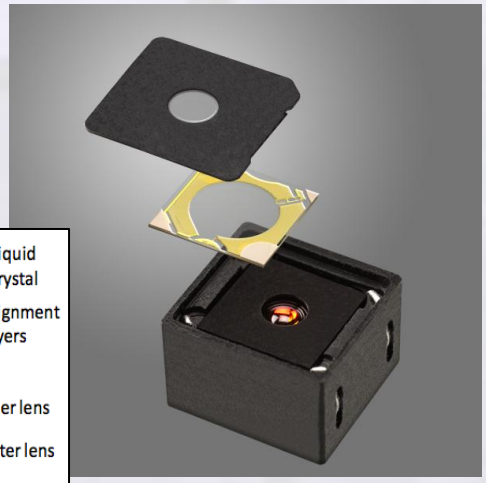
Liquid crystal (e.g., LensVector):

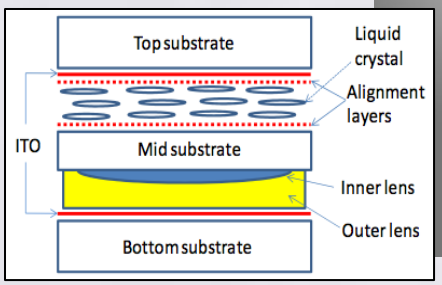
Dielectric layer over planar LC (E-field shaping)

Limited ~2.5mm aperture of available products

Ideal for wafer-scale integration

Potential for higher-level aberration correction





Integrated Monocentric Multiscale Imagers

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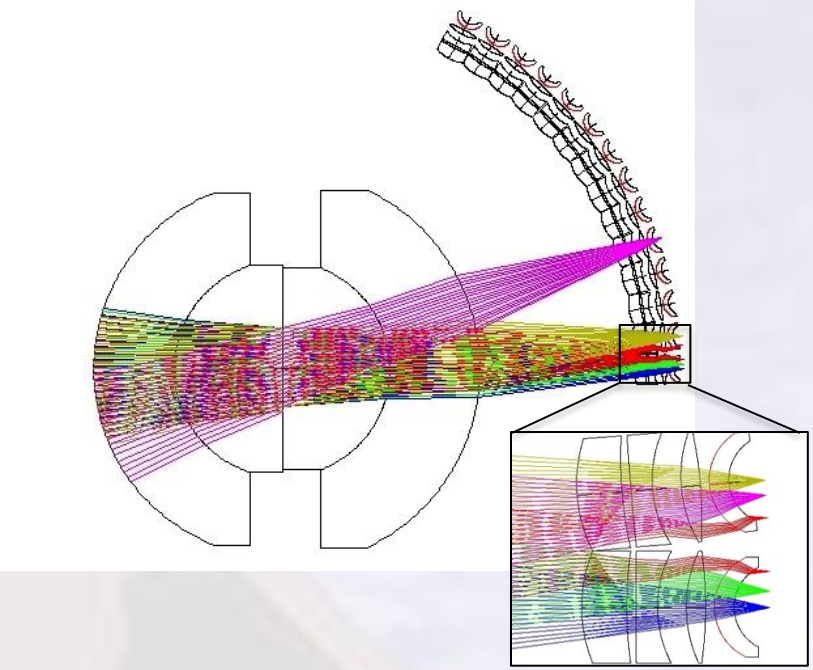
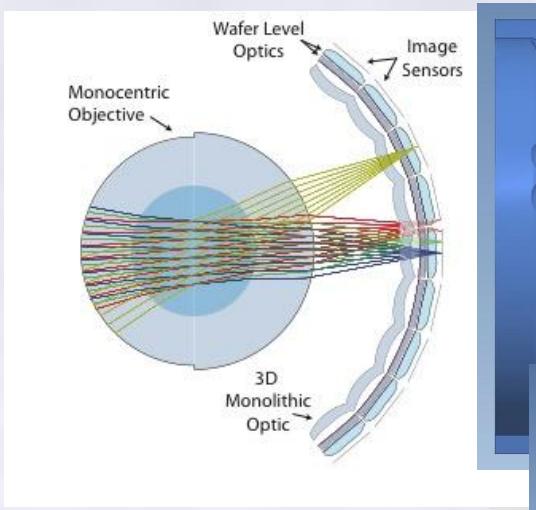
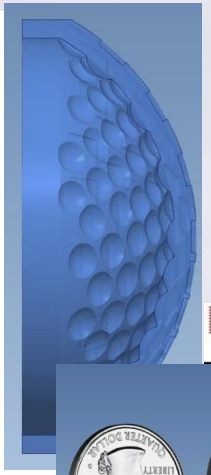
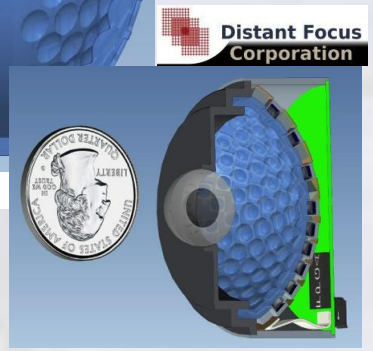
Large scale MMC, Galilean layout (no internal image plane)



Small scale multiscale lens, Galilean layout (no internal image plane)







Wafer level camera: Omnivision "cameracube"

Research goal is multiscale system integration

- Large scale MMC using thousands of (cheap) WLC: ~10GPix
- Miniaturized MMC hundreds of (small) WLC : ~100MPix

This talk:

- Characterization of wafer-level LC focus in monocentric multiscale optics

LensVector liquid crystal lens focusing

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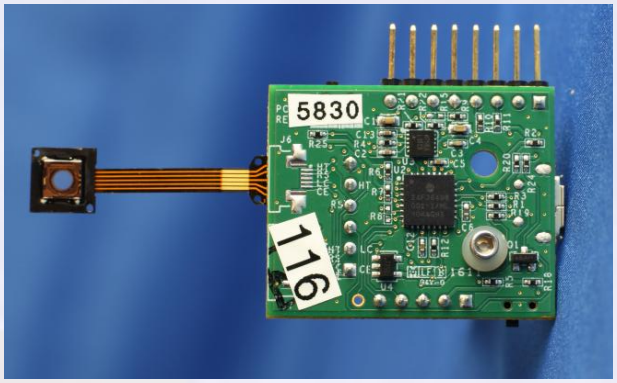
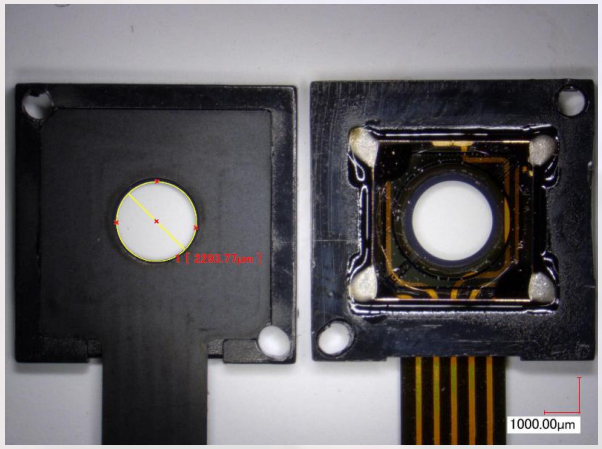
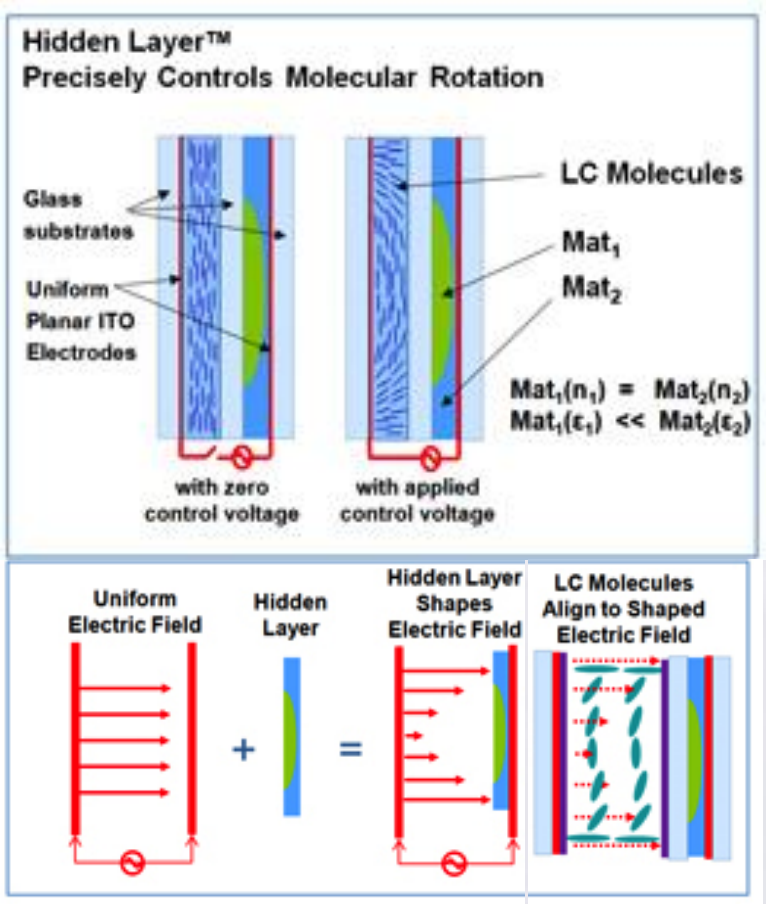


Lens
Vector
Auto
Focus
crystal lens



LV5830
with USB
controller
board
0-5dP
range
(1dP=1/m)

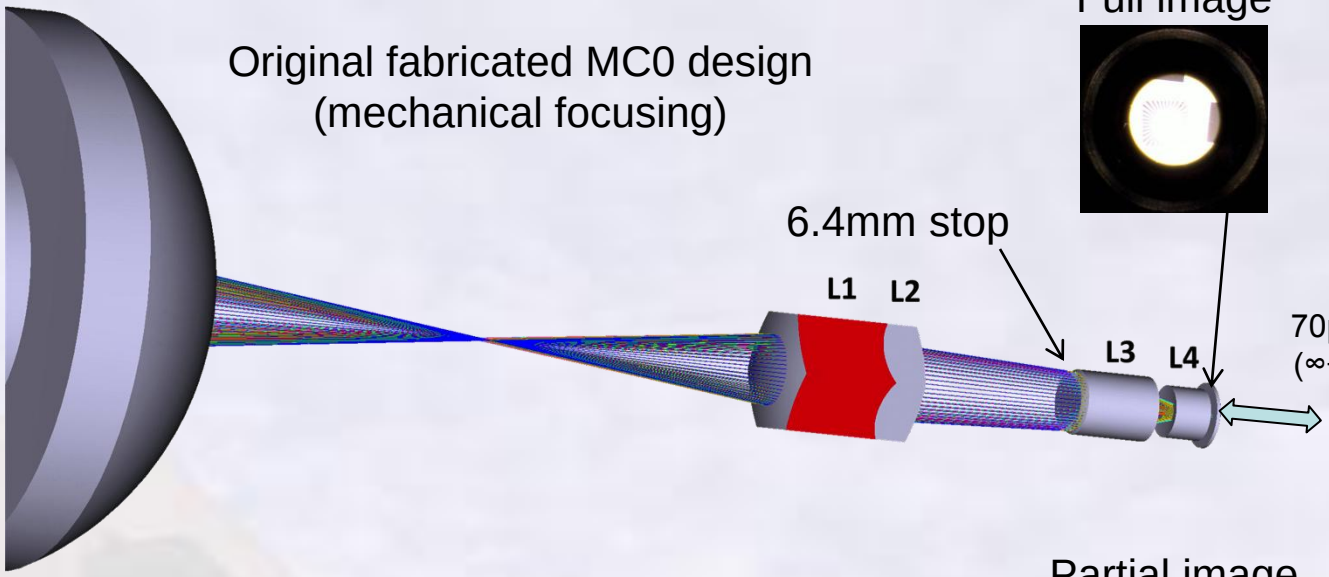


AWARE2 focusing mechanism

UCSD Photonics

Original fabricated MC0 design
(mechanical focusing)

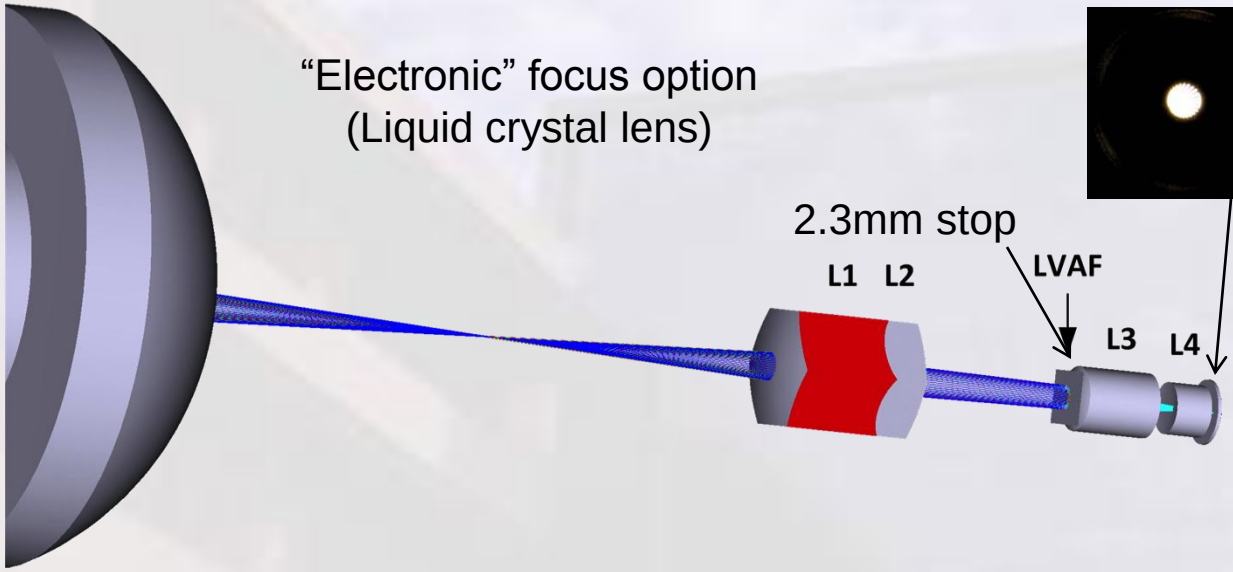
Full image



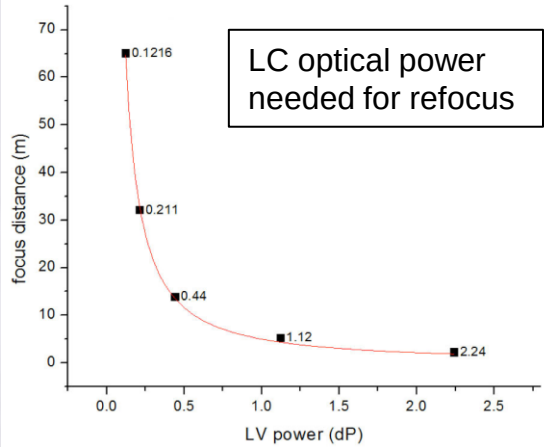
70µm sensor movement
(∞÷15m object distance)

"Electronic" focus option
(Liquid crystal lens)

Partial image



Vignetting from
2.3 mm LVAF aperture



LC lens alternative approach – OKO lenses

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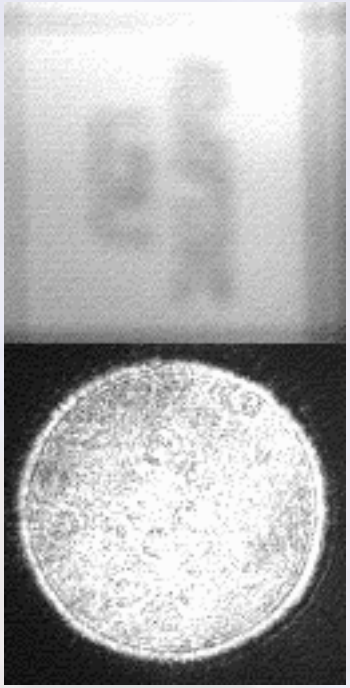
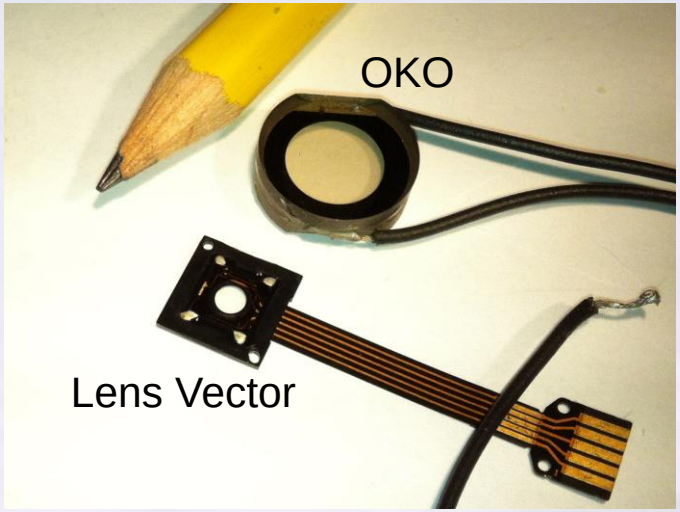


http://www.okotech.com/lclenses



Parameter	Value
Wavelength region	0.44…2 μm
Transmittance (without antireflection coatings)	about 70 %
Range of voltages	below 10 V, typically 3…5 V
Range of frequencies	1…50 kHz
Geometry	cylindrical or spherical
Switching speed (for $d = 25$ μm and $D = 5$ mm)	780 ms from 1 to 2 m focal distance, 860 ms from 2 to 1 m

Configuration	1	2	3	4
LC thickness (d), μm	40	50	50	50
Aperture diameter (D), mm	5	5	7.5	5
External diameter, mm	10	10	12	12
F_{min}, cm	27.9	22.3	50.2	22.3
Type	spherical	spherical	spherical	cylindrical

Various configurations availability

- For focal distances >2F_{min} spherical aberration can be compensated efficiently
- LC lens affects only one polarization component of light; combination of two LC lenses can be used to make a polarization-independent device.
- Calibrated lens with calibration data for a function generator driving is available

LVAF characterisation

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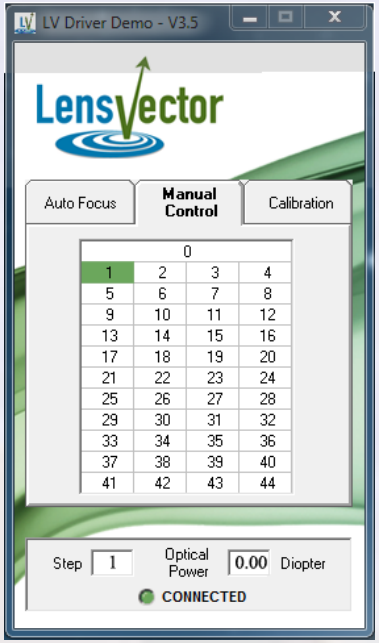
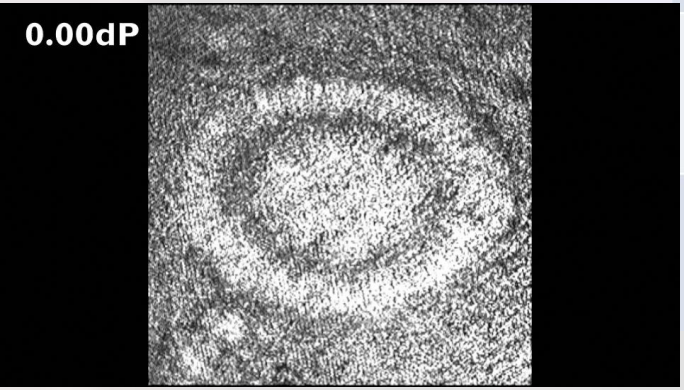
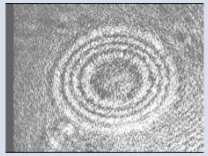
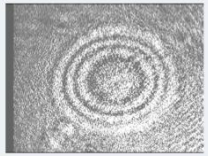
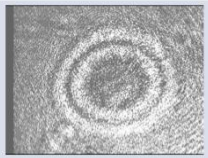
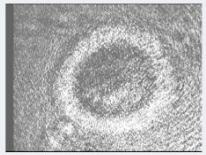
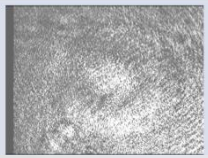
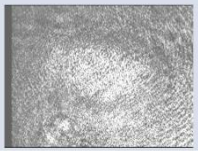
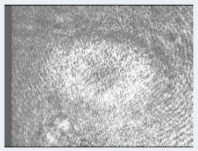
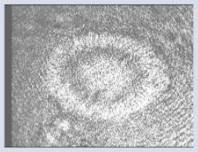
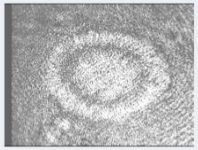
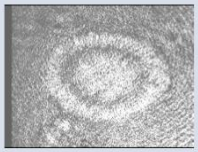


Lens Vector LV Driver Demo V3.5 suite

1 – 0.00dP
2 – 0.25dP
3 – 0.50dP
4 – 0.75dP
.
.
.
44 – 10.75dP



Interferogram	Fringe Count	Nominal lens power [dP]	Measured power [dP]
	5	10.75	5.4
	4	8.75	4.3
	3	6.50	3.2
	2	4.50	2.2
	1	1.75	1.0

Interferogram	Fringe Count	Nominal lens power [dP]	Measured power [dP]
	0-1(?)	1.50	0-0.75 (?)
	1	1.00	-1(?)
	2	0.75	-2.2
	2+	0.50	-2.3 (?)
	2+	0.00	-2.2 (?)

LVAF interferograms and measured optical power

AWARE2 + LVAF exploded lens setup

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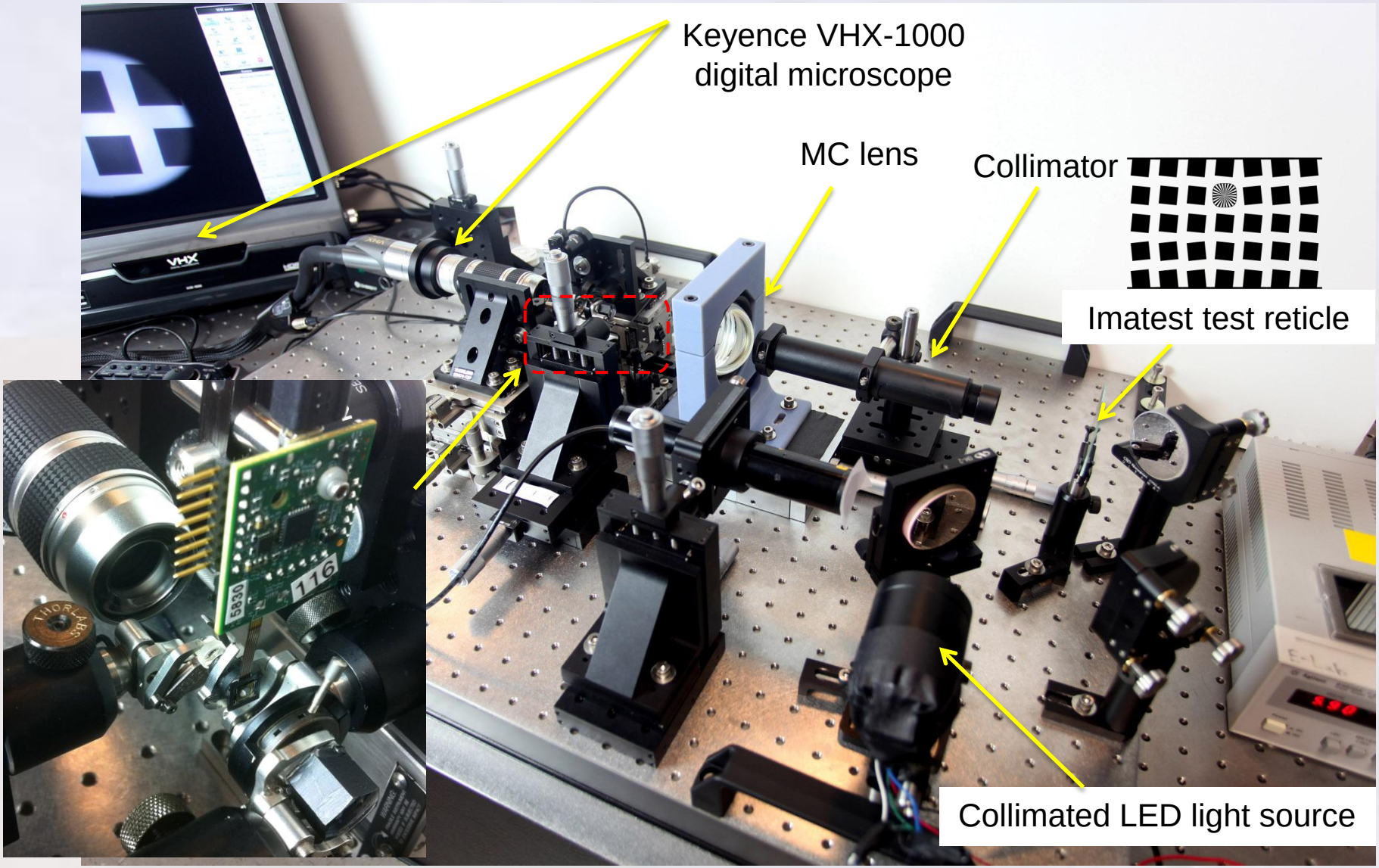
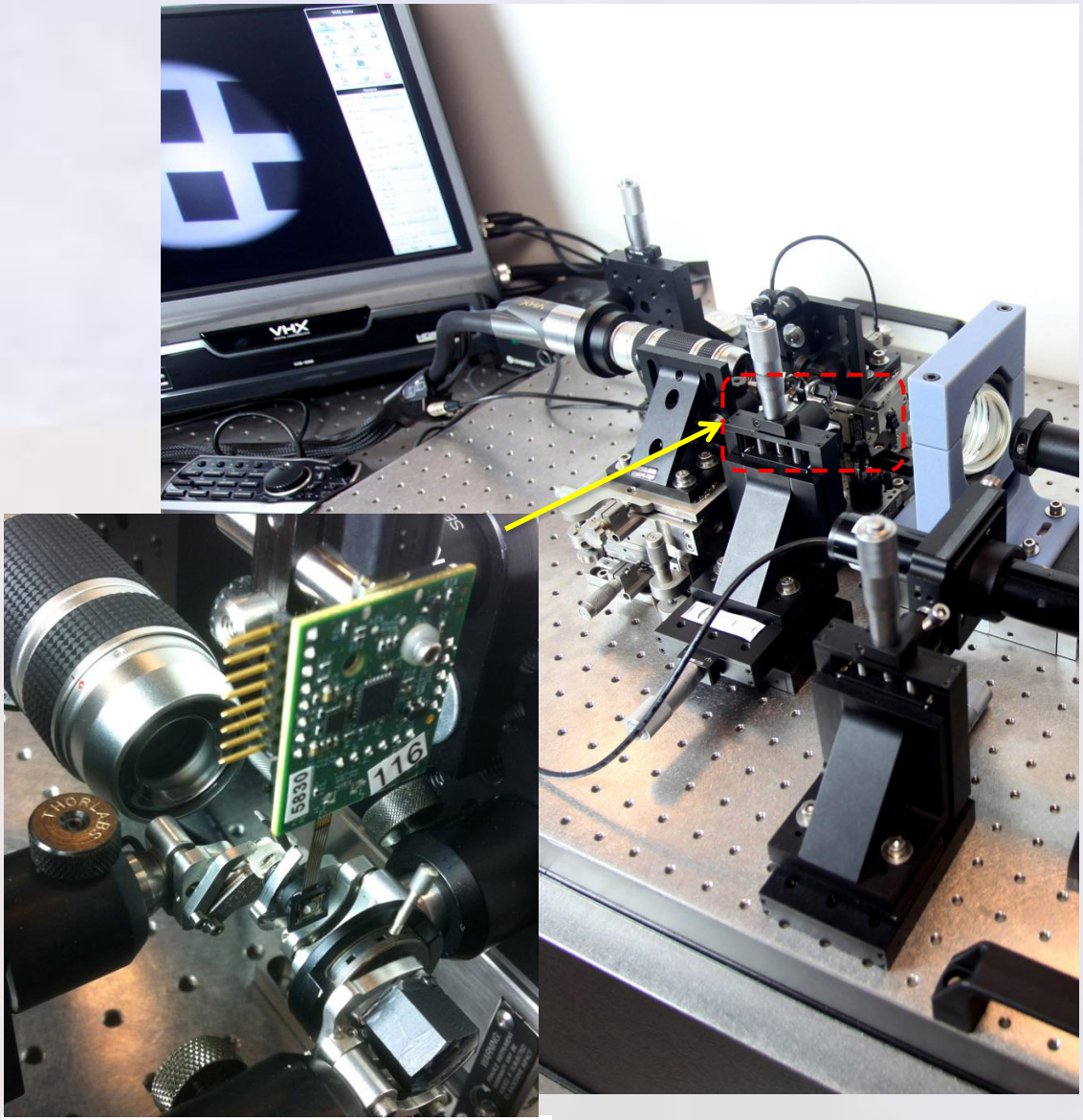


Exploded MC0 lens system

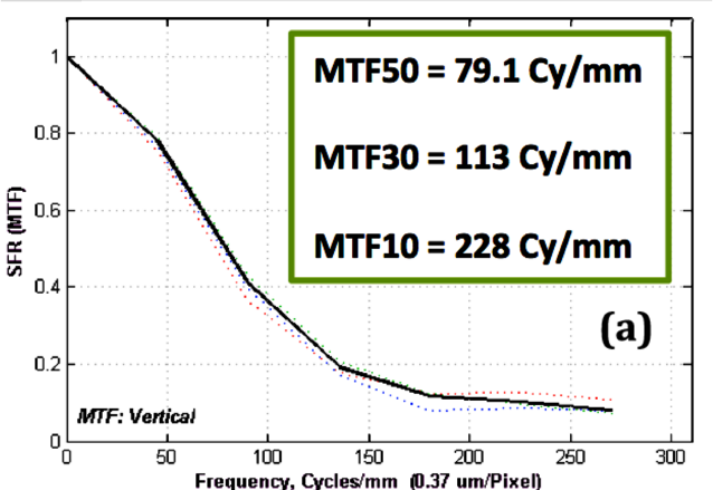
Results obtained by Imatest Master 3.6

AWARE2 + LVAF exploded lens setup

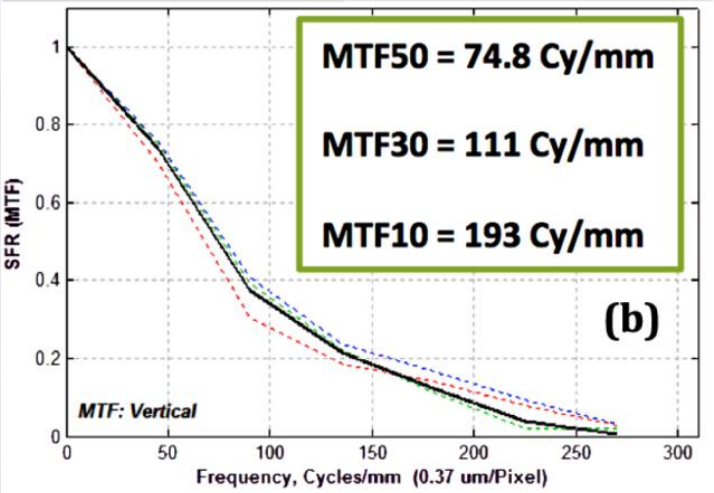
UCSD Photonics



Exploded MC0 lens system



Object at ∞ / without LVAF

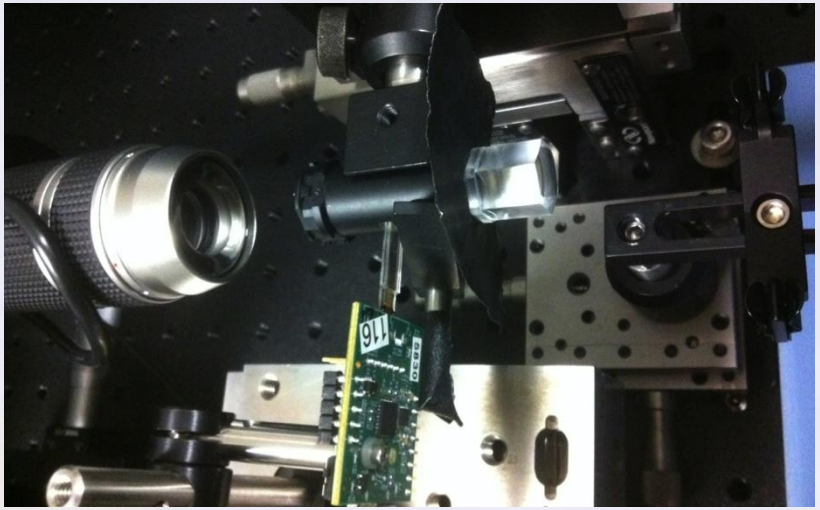


Object at ∞ / with LVAF at 0dP

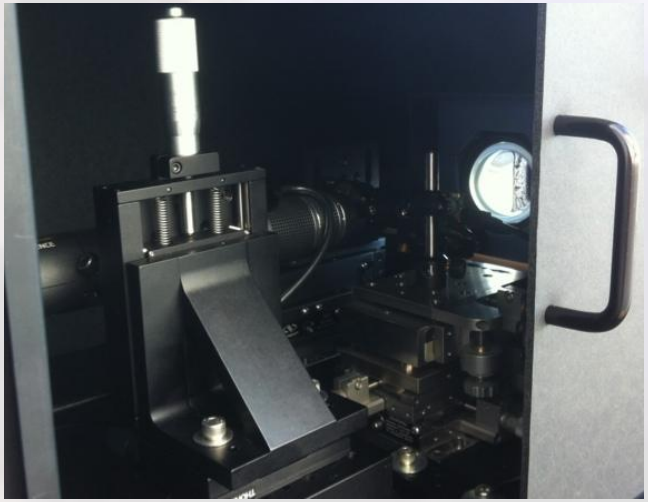
Results obtained by Imatest Master 3.6

AWARE2 + LVAF modified mobile setup

UCSD Photonics



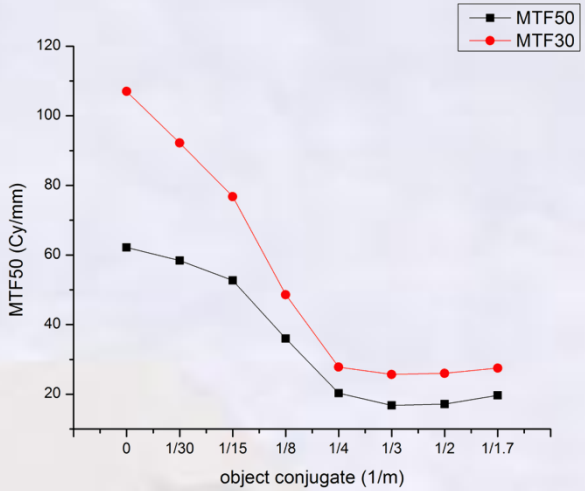
MC0 slotted lens barrel



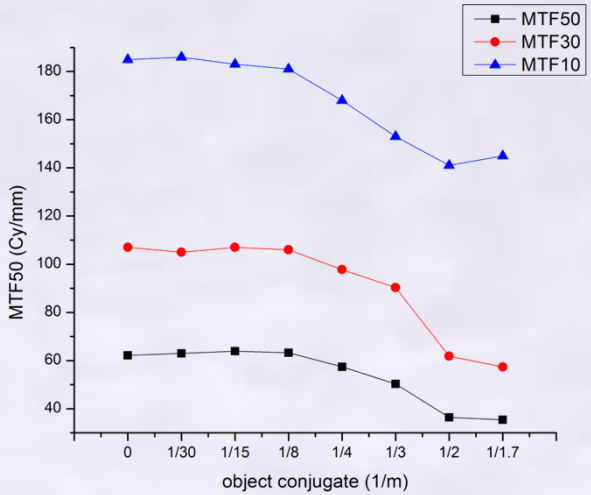
AWARE2 + LVAF setup indoors results

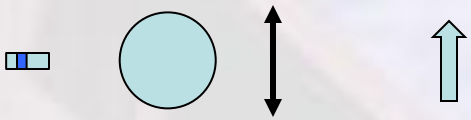
UCSD Photonics

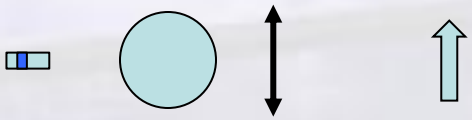
MTF falloff with object distance decrease (LVAF focused to infinity)

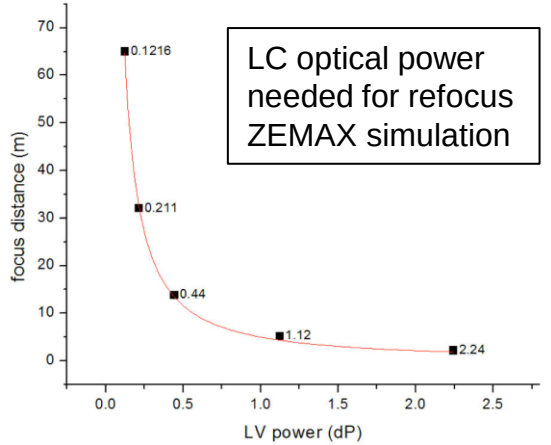


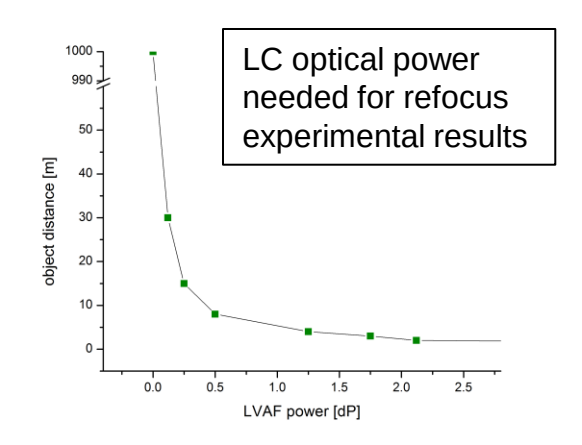
MTF value change when LC refocusing (LVAF at best focus)











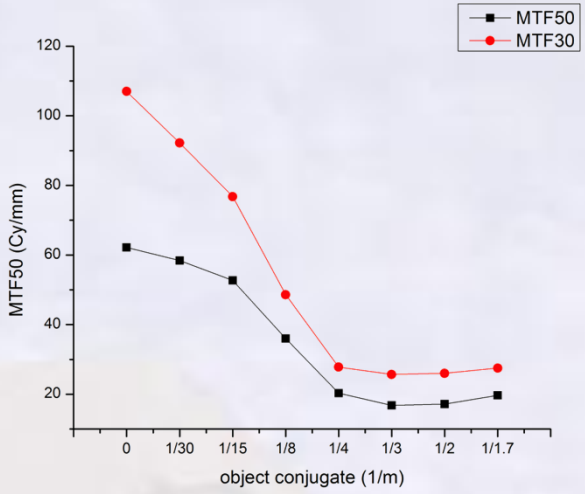
Object distance	Measured lens power [dP]	MTF50 [Cy/mm] MTF30 [Cy/mm]
Infinity (no LVAF)	-	83.8 121
Infinity	1.13	62.2 107
30m	1.25 (+0.12)	63 105
15m	1.38 (+0.25)	63.9 107
8m	1.63 (+0.50)	63.3 106
4m	2.38 (+1.25)	57.4 97.8
3m	2.88 (+1.75)	50.3 90.3
2m	3.25 (+2.12)	36.4 61.8
1.7m	4.63 (+3.50)	35.4 57.4

MTF performance data of refocused system for different object distances

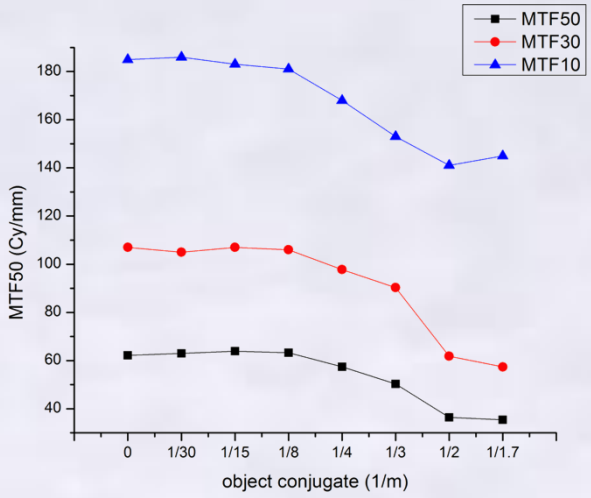
AWARE2 + LVAF setup indoors results

UCSD Photonics

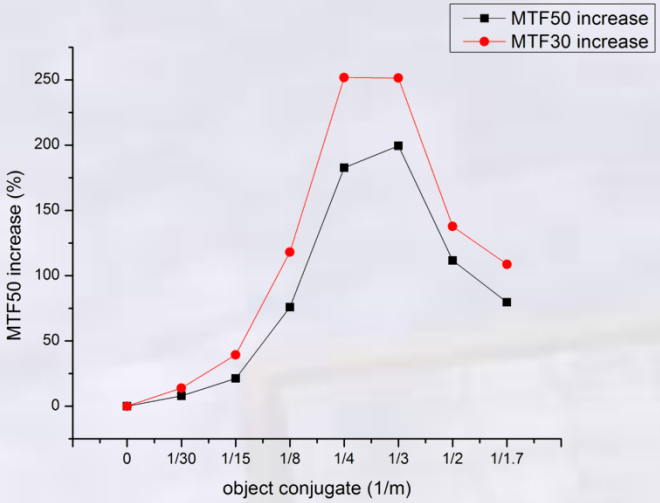
MTF falloff with object distance decrease (LVAF focused to infinity)



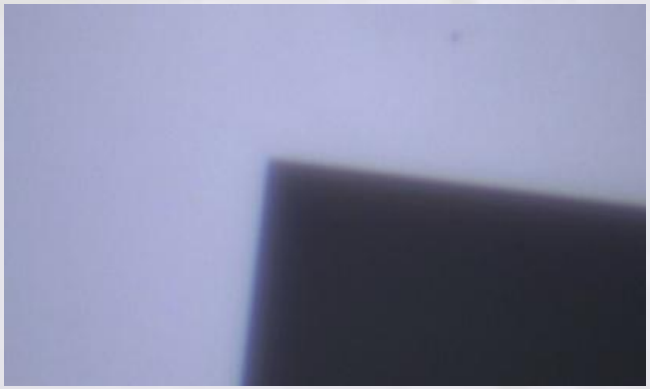
MTF value change when LC refocusing (LVAF at best focus)



MTF percent increase with LVAF refocusing



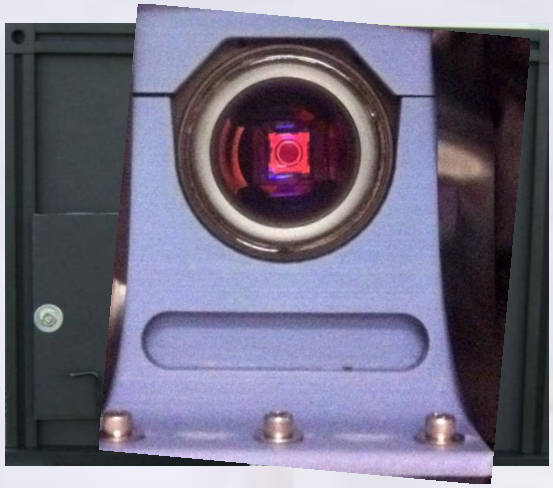
Object @ ≈3m (lens 1.13dP)
NOT FOCUSED

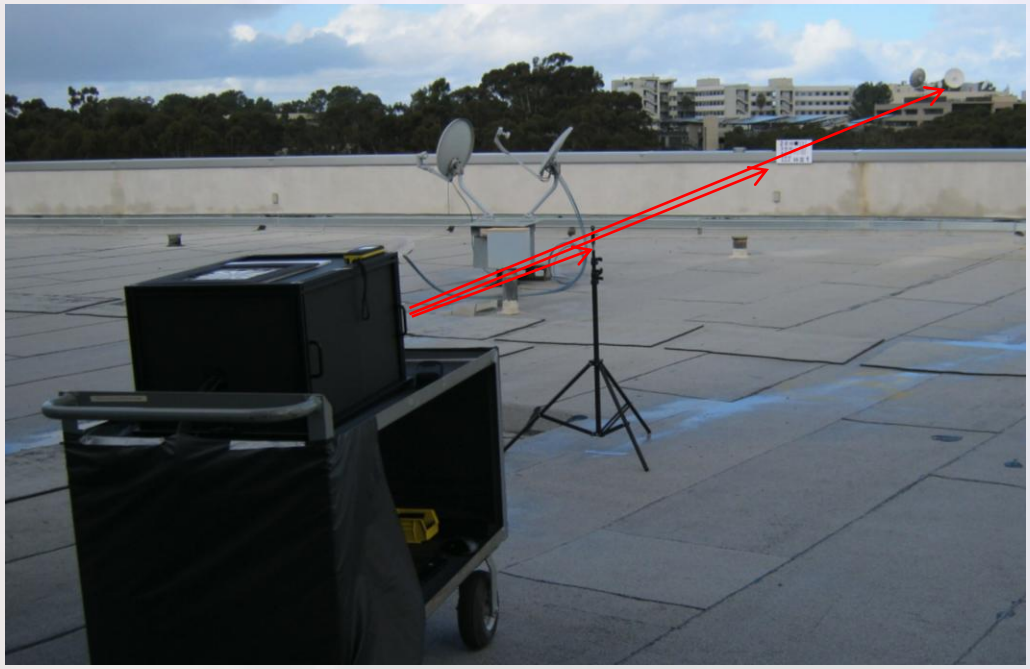


Object @ ≈3m (lens 2.88dP (+ 1.75dP)
FOCUSED

AWARE2 + LVAF modified mobile setup

UCSD Photonics





Top of the CALIT2 building, Jacobs School of Engineering, UCSD.

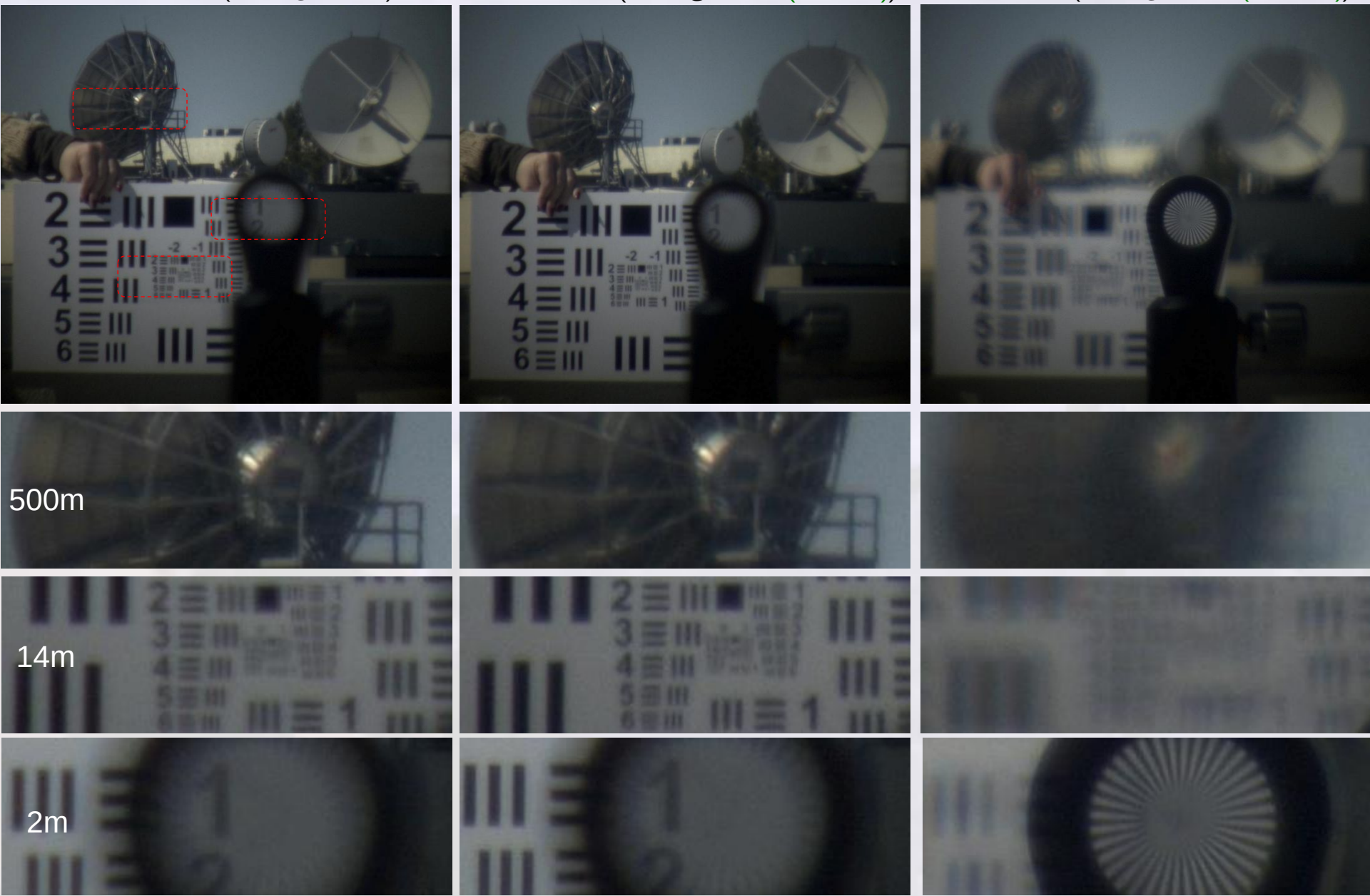
AWARE2 + LVAF setup outdoors results

UCSD Photonics

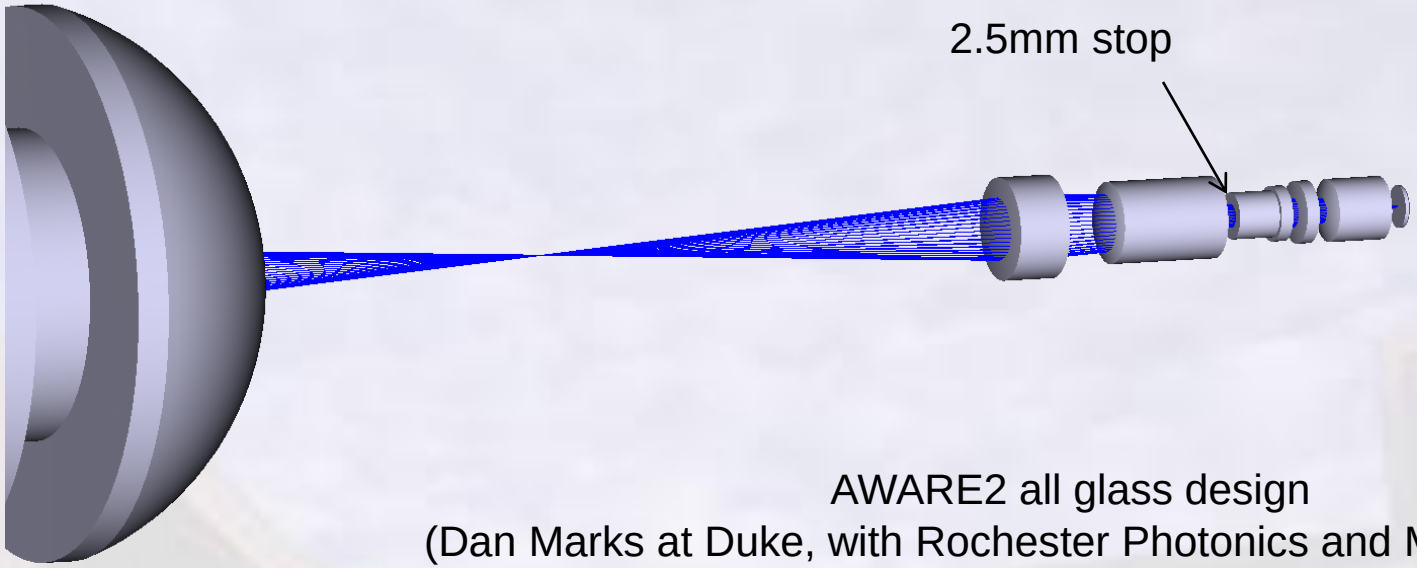
Focus at 500m (LVAF @1.13dP)

Focus at 14m (LVAF @1.38dP (+0.25dP))

Focus at 2m (LVAF @3.38dP (+2.25dP))

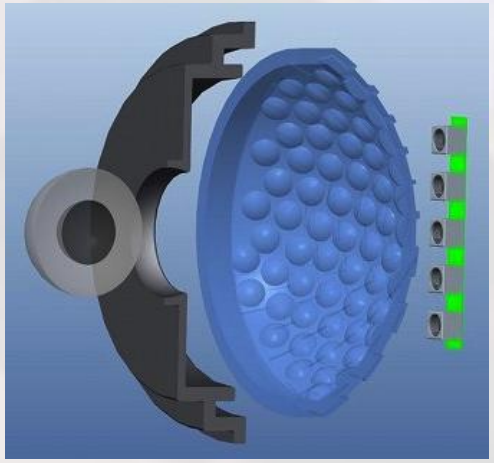


Next steps



Smaller AWARE2 secondary optics aperture

AWARE2 all glass design
(Dan Marks at Duke, with Rochester Photonics and Moondog Optics)



Smaller MMC+WLC integrated systems

Conclusions

- Liquid crystal tunable lens are a viable option for focus of monocentric multiscale imagers.

- Monocentric imagers integrating WLC with LC focusing is an attractive future research direction

This work was done in collaboration with the AWARE research team, lead by David Brady of Duke University, including Dan Marks, Jungsang Kim, Ron Stack, and many others, and supported by DARPA MTO through contract HR0011-10C-0073.