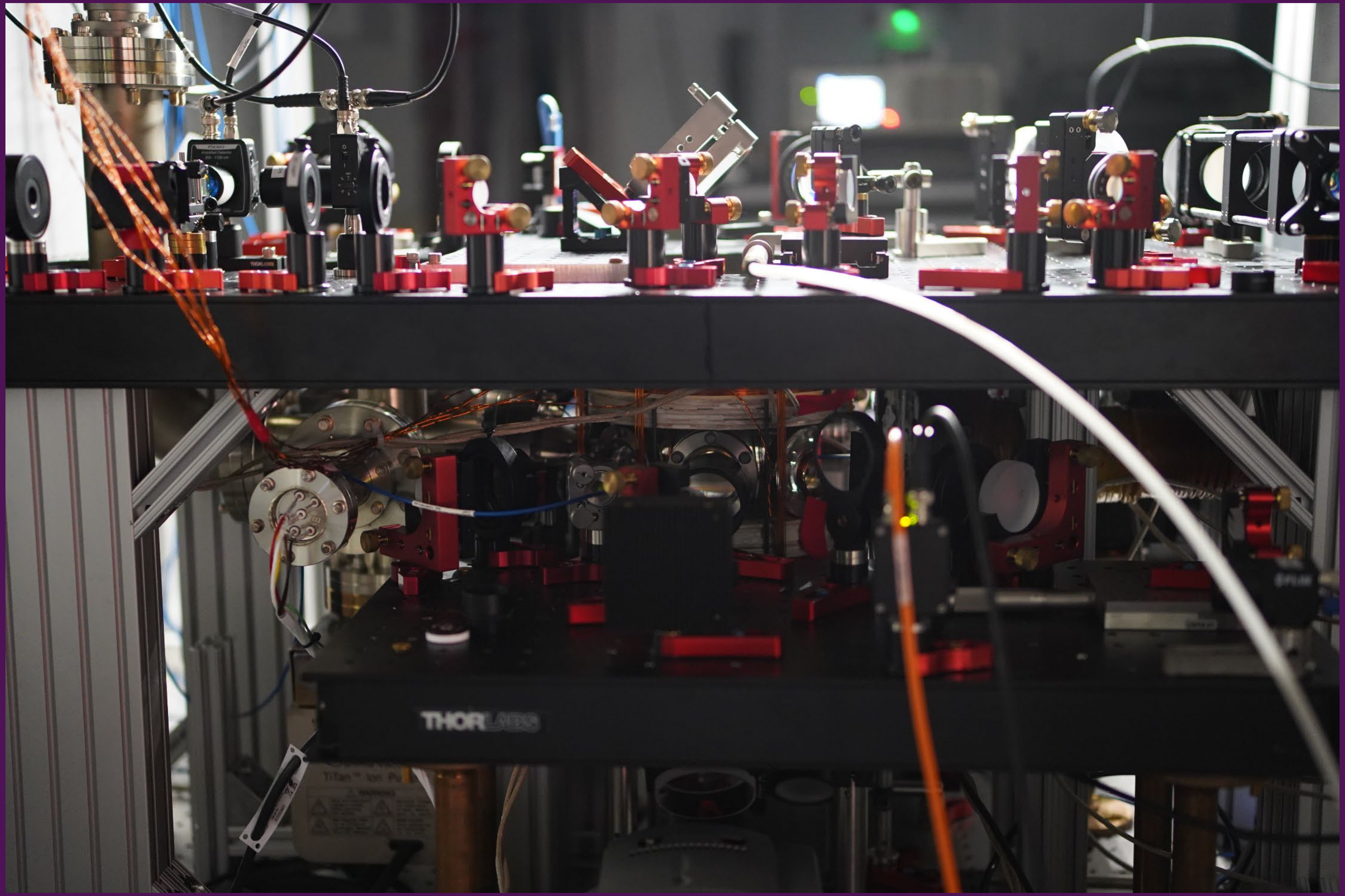
Optical Design is Interesting

09/24/2023 Chinese Journal Club

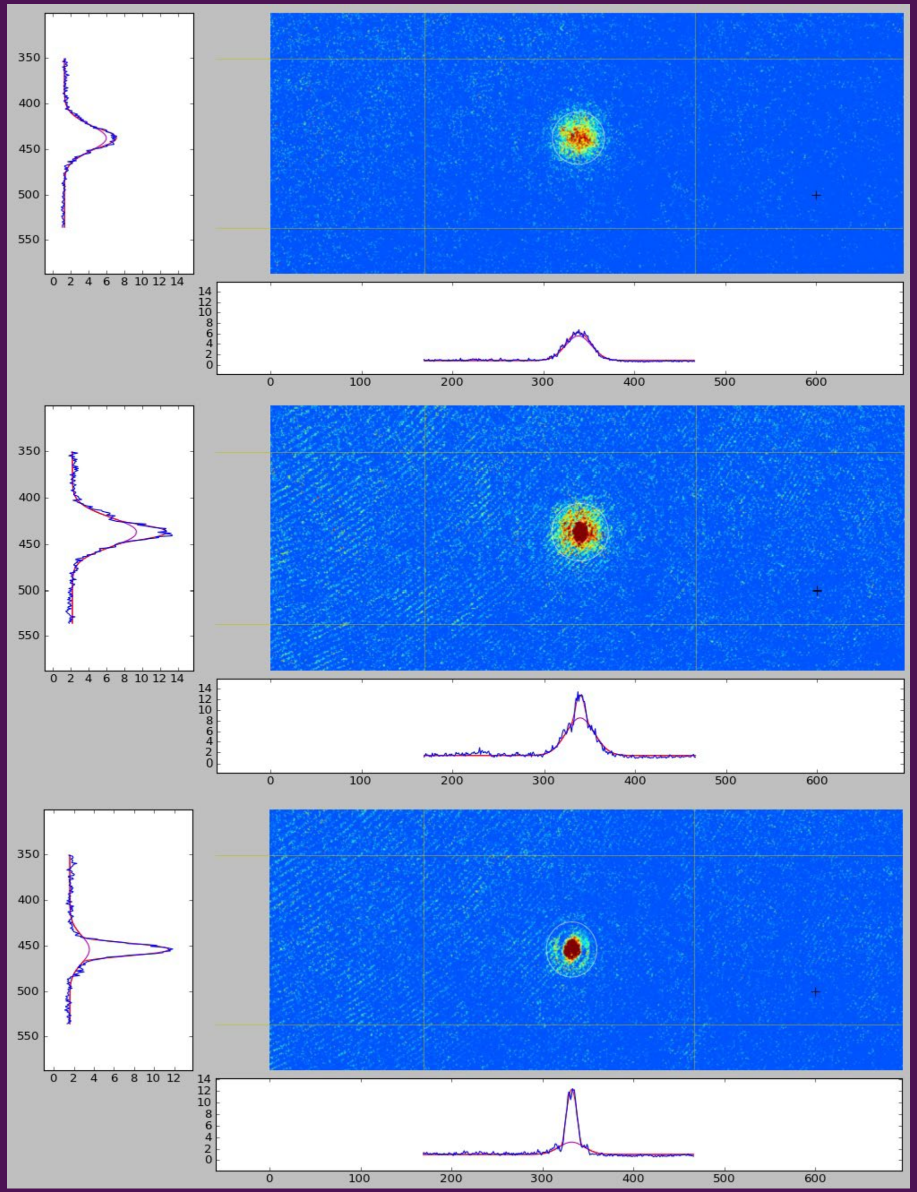
Content

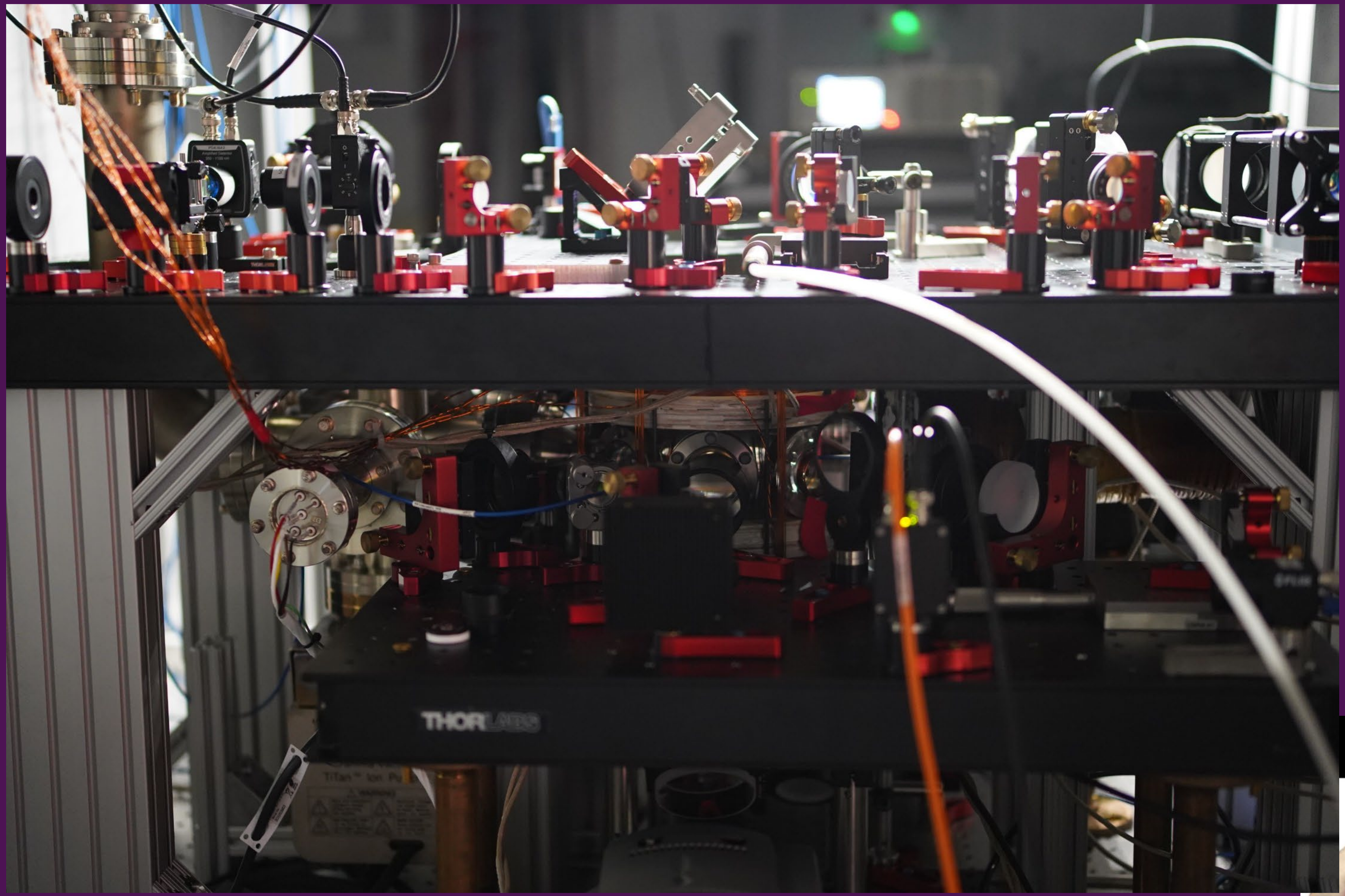
- I. Imaging as an overview
- II. Cold atom imaging with scientific cameras
- III. Other cameras



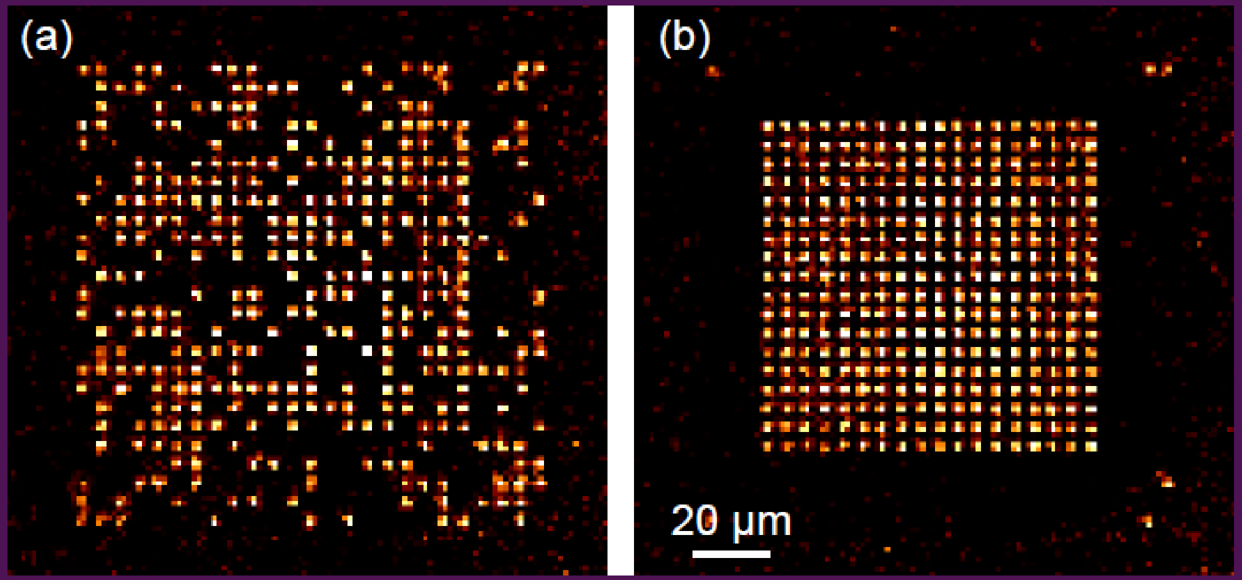
Overview

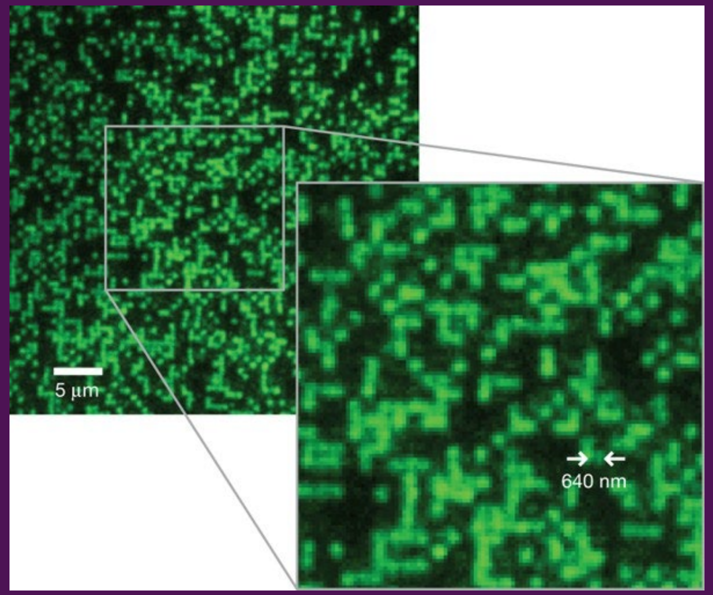
WE HAVE:





WE WANT:





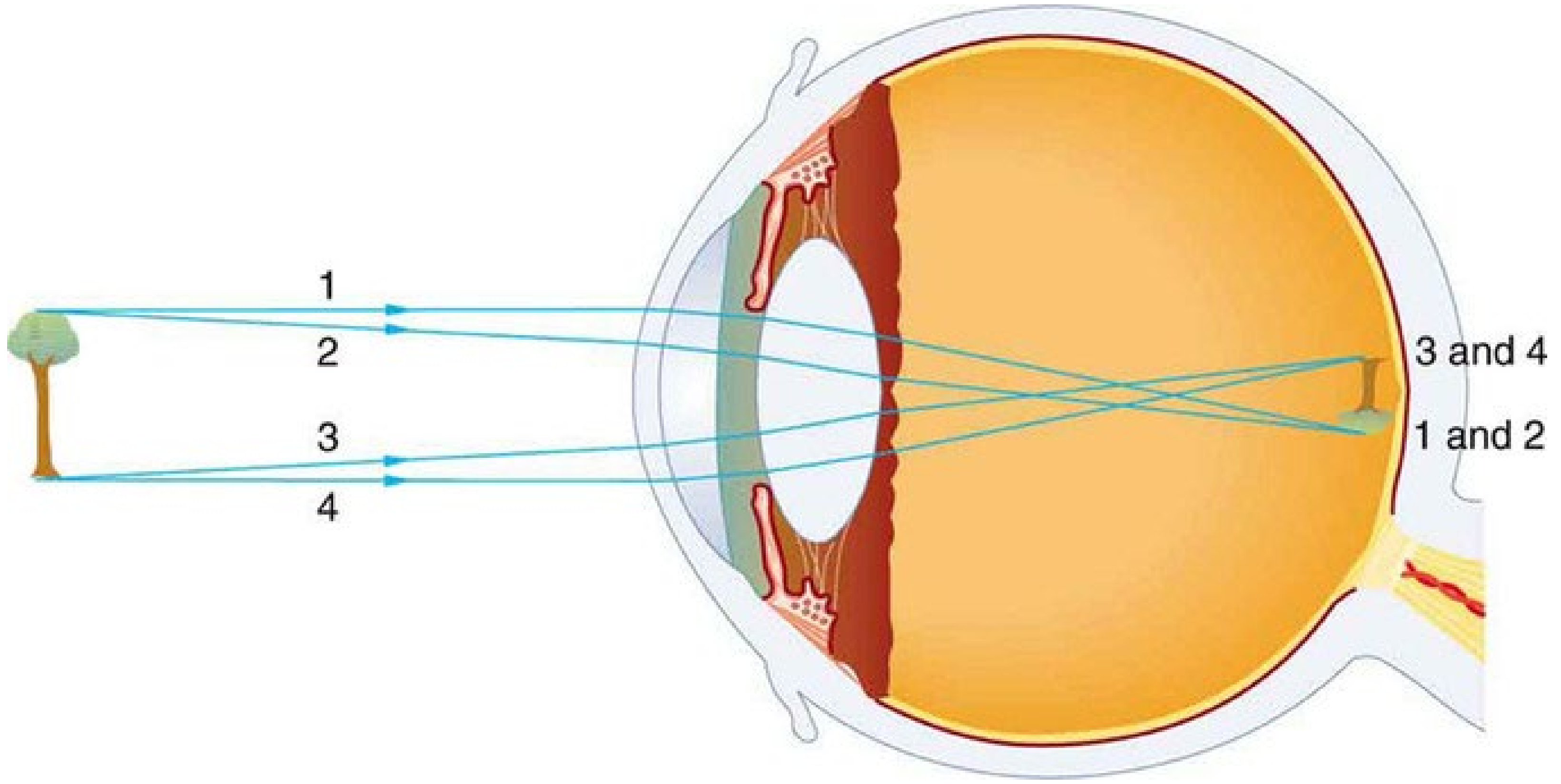
WE GET:

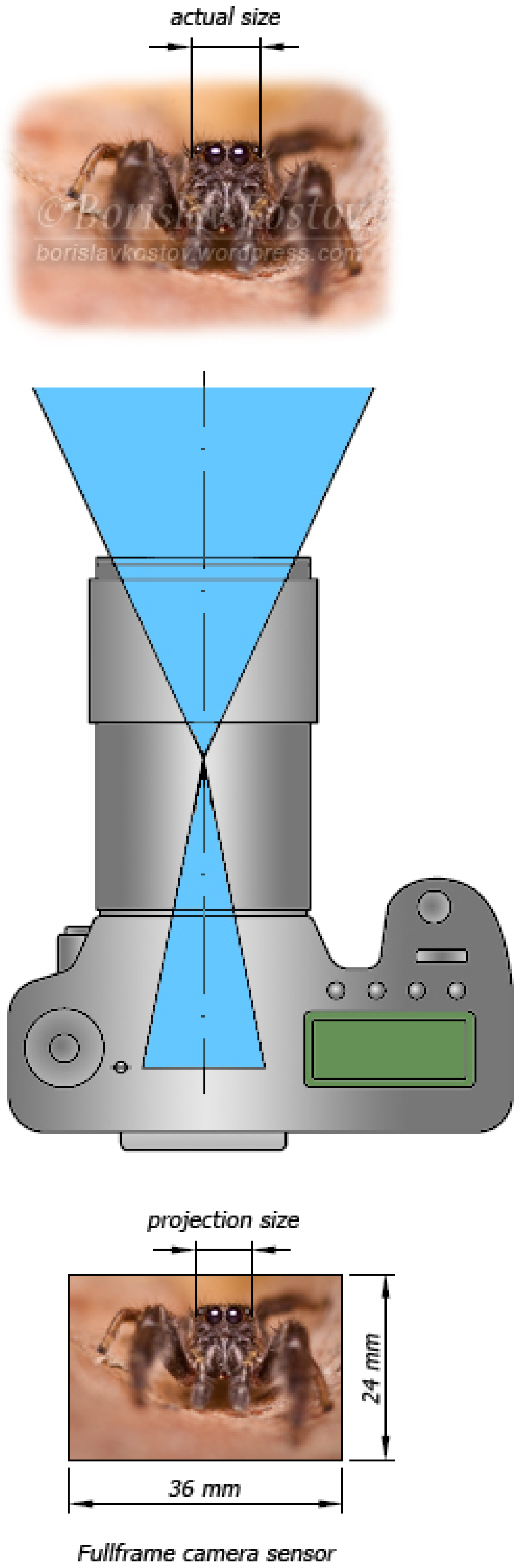
Overview – Ideal Lens

Simplest model:

Two requirements for an imaging system—

1. One ideal lens
2. One sensor: CMOS, CCD
3. Potentially color filter

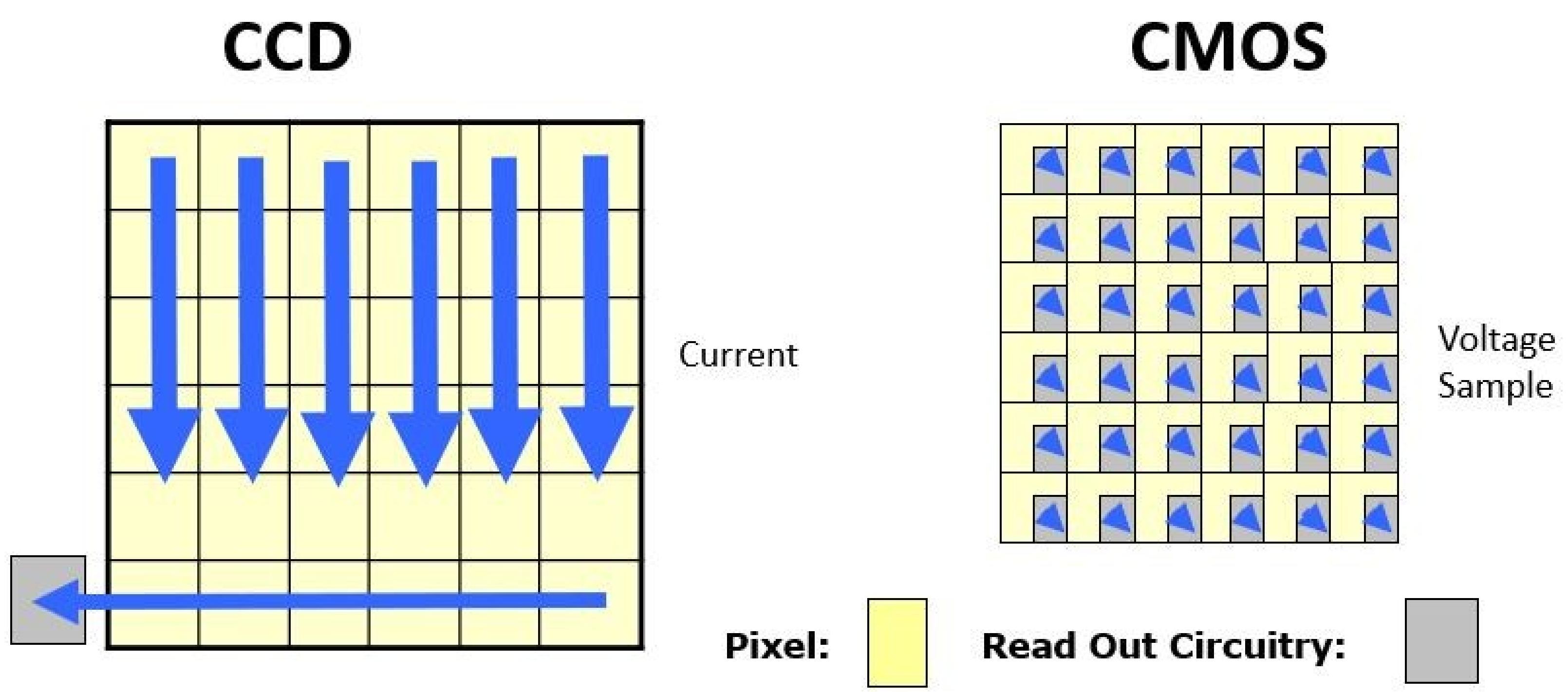




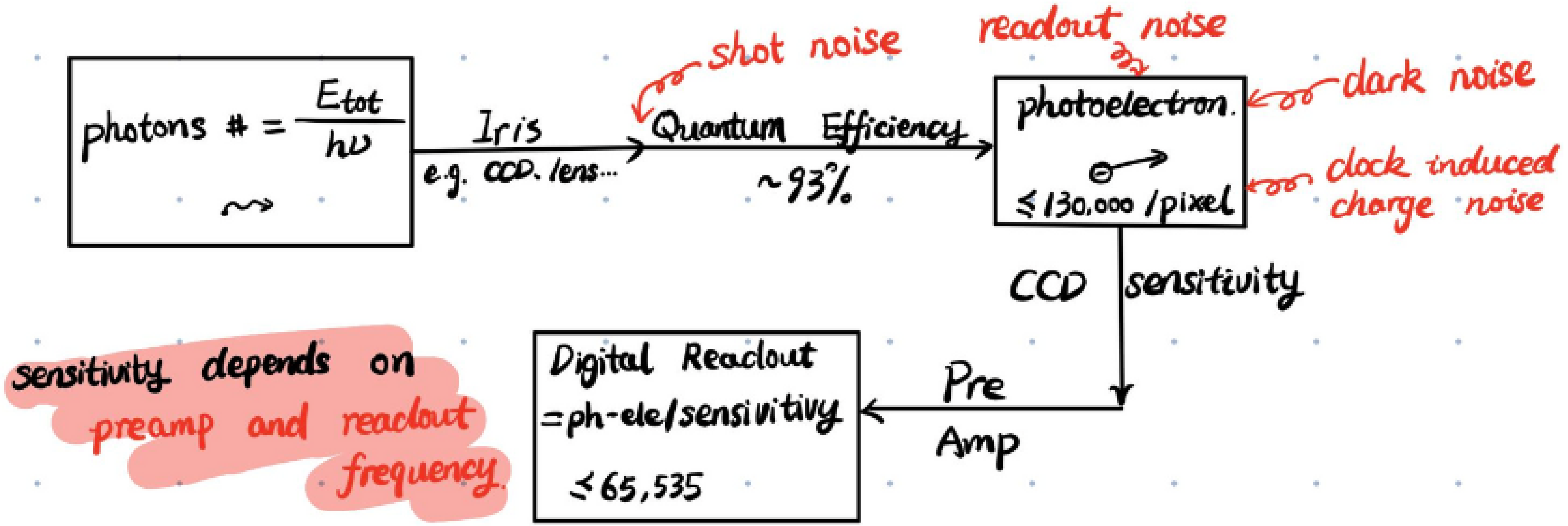
$$\text{Magnification} = \frac{\text{projection size}}{\text{actual size}}$$

Overview -- Sensor

- CCD and CMOS (relatively easy to understand)



- CCD: high failure rate, low readout rate, older technology
  However lower dark noise (astrophysics), EM gain (optical tweezer), scam
- Pixel size: 2 – 15 um



01

Cold Atom Imaging

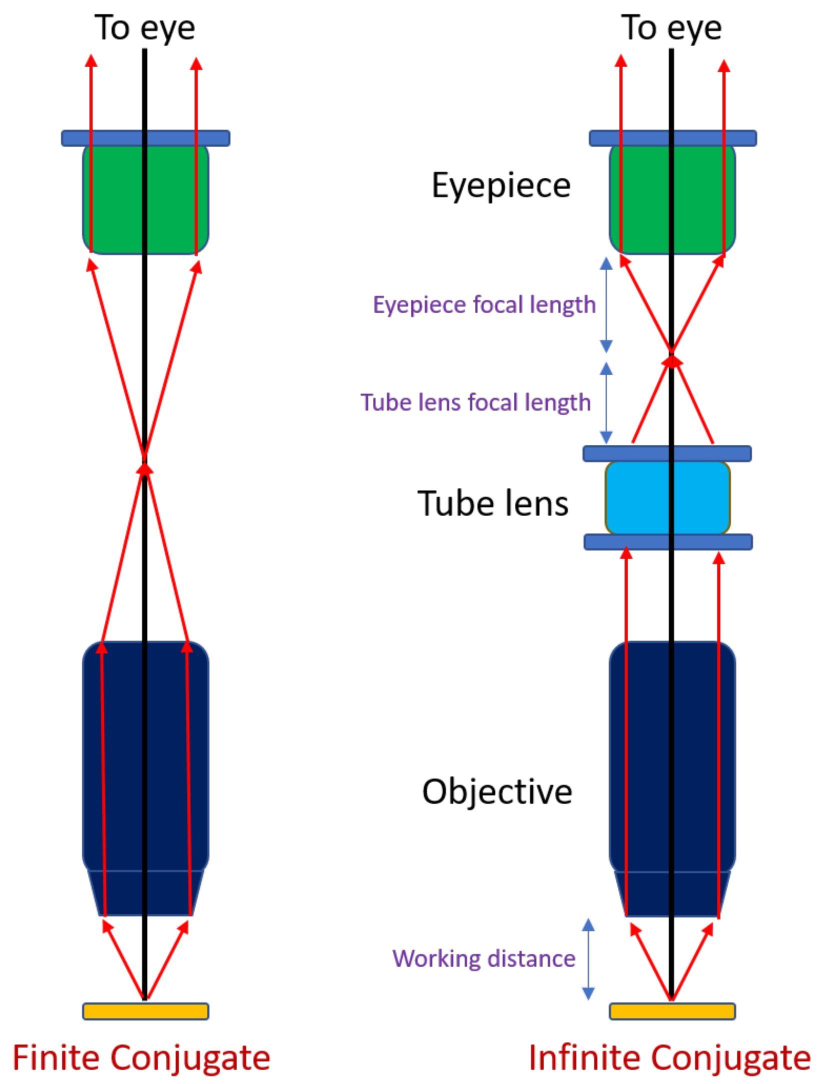
II. Cold atom imaging

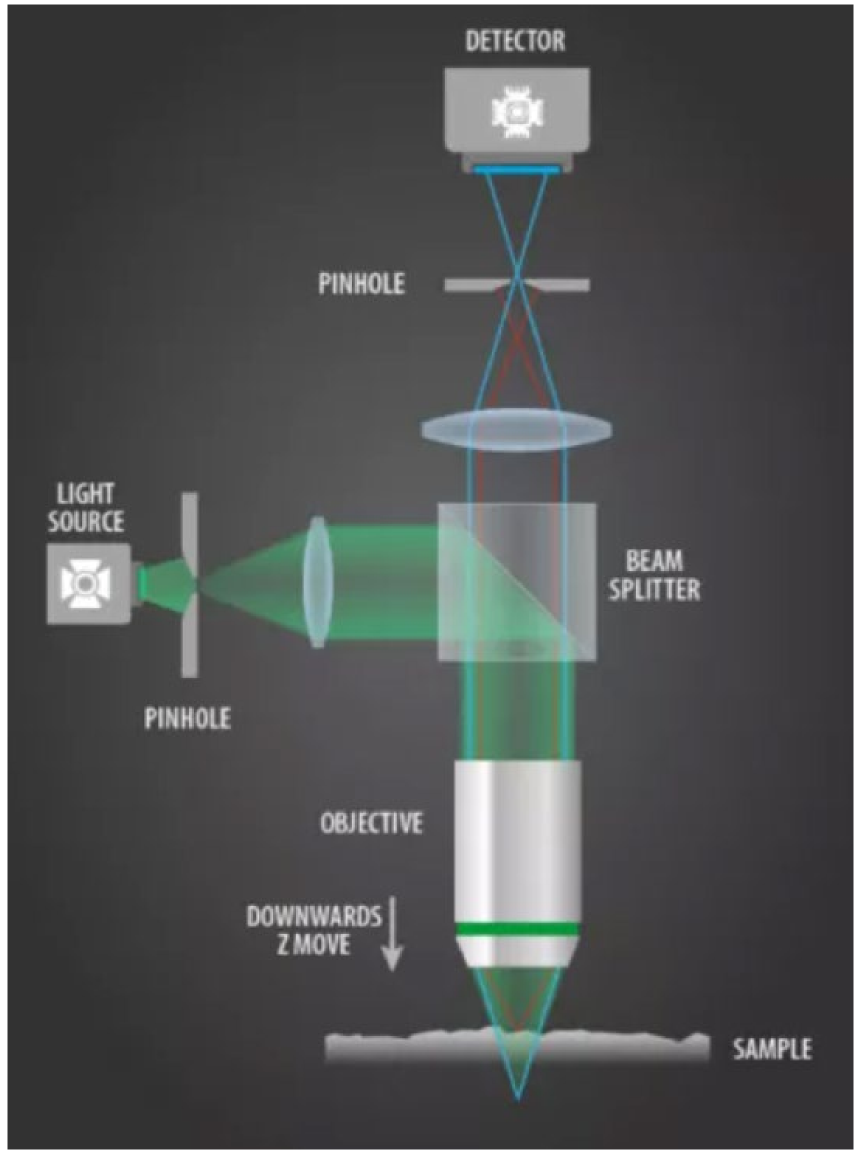
We do not care:

large field of view, chromatic shift, money

We do care about:

low sensor noise, diffraction-limited at foci, long working distance, projecting light

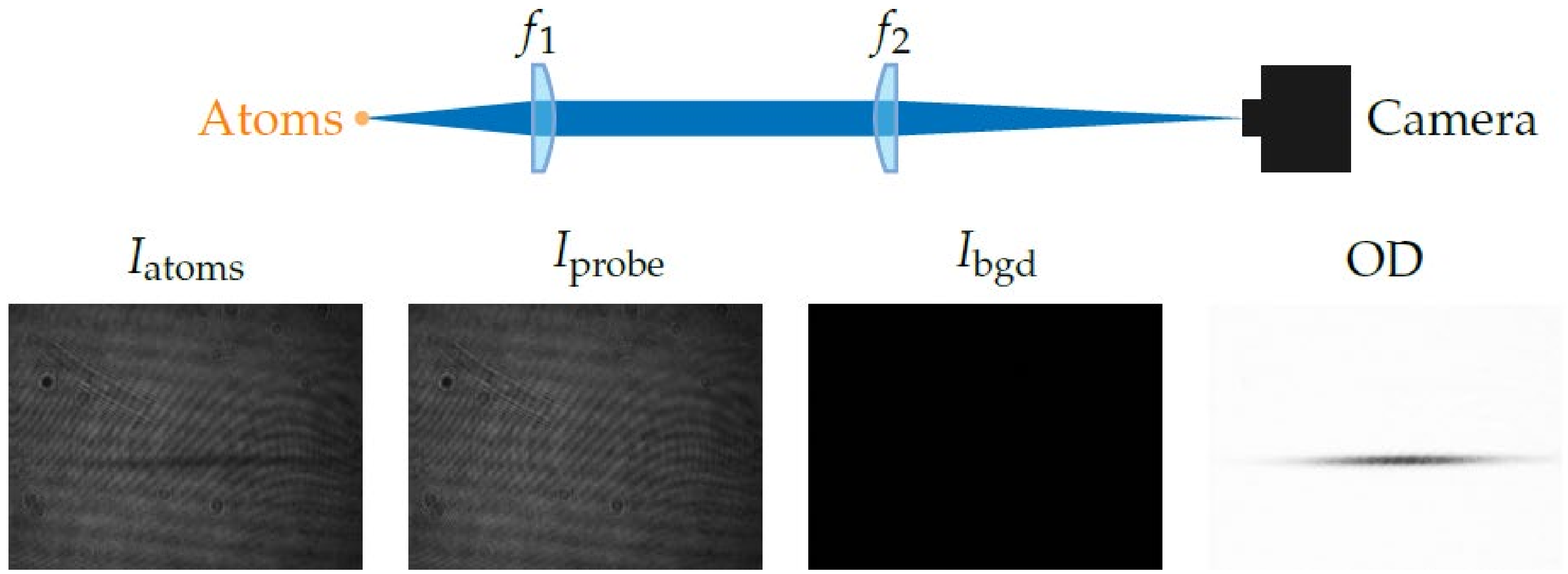




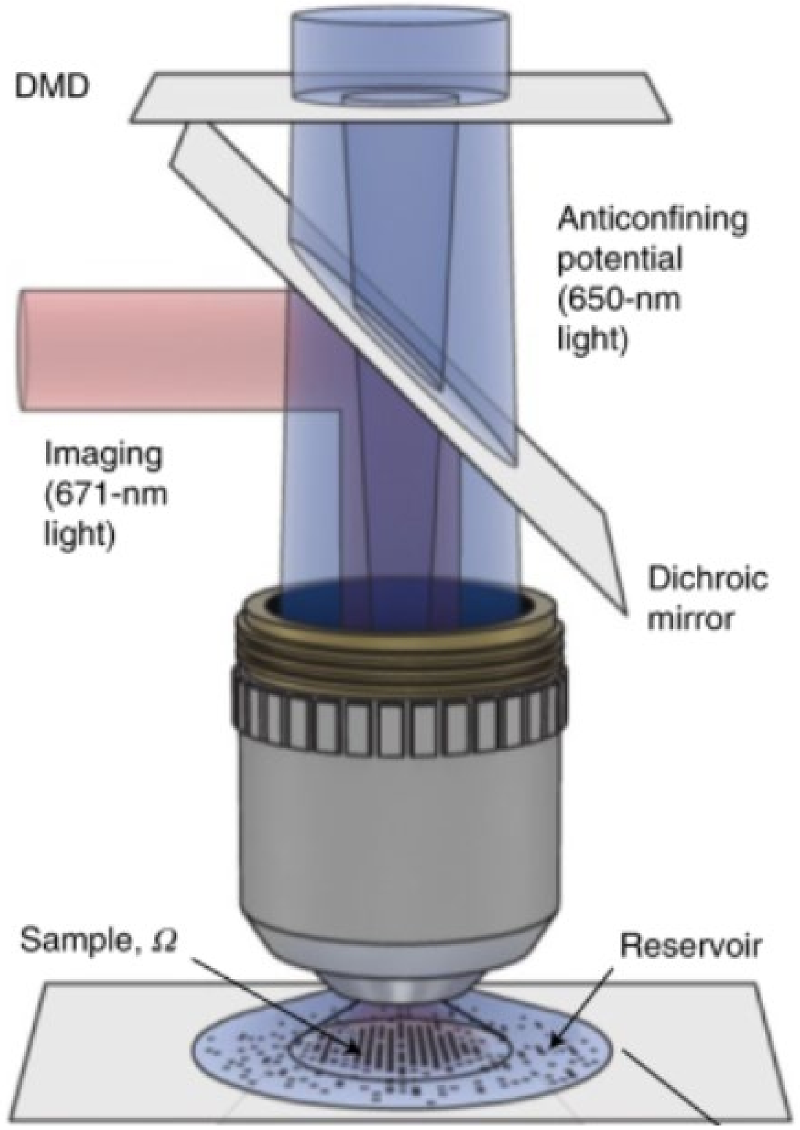
Two ways of imaging

Absorption Imaging

$$I(x,y) = I_0(x,y)\exp\left(-\int \mathrm{d}z\, n(x,y,z)\,\sigma(\delta)\right)$$



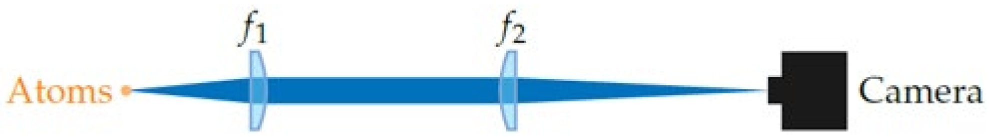
Fluorescence Imaging

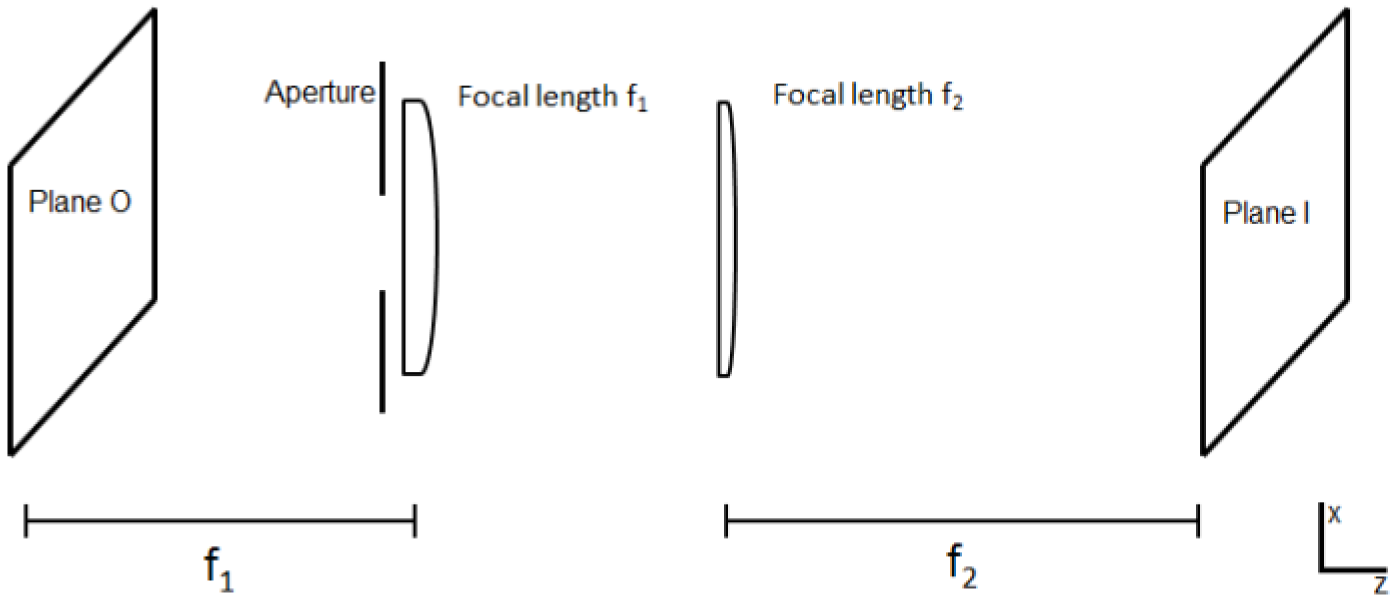


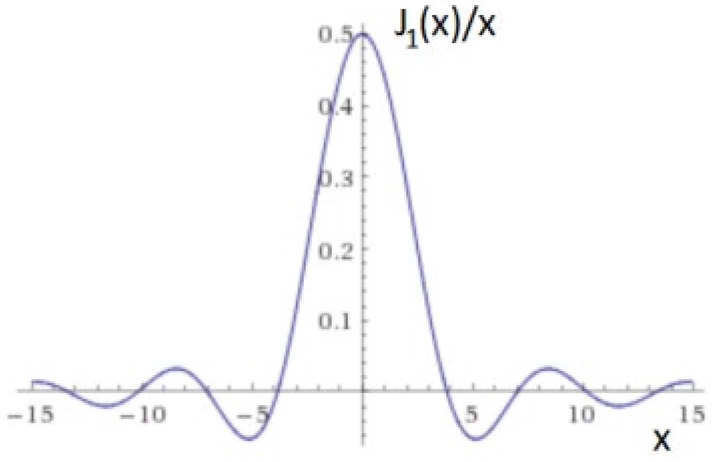
[1] Davide Dreon, PhD thesis
[2] https://greiner.physics.harvard.edu/

Microscope Review

First, focus on foci. A simple derivation at a reasonable f#.







$$u_2(x, y, f_1) = \frac{p(x, y)}{f_1} \qquad u_3(x, y, z) = \frac{p(x, y)}{f_1} \exp\left((ik/2f_2)(x^2 + y^2)\right)$$

$$u(x, y) = \frac{i}{\lambda d} \exp(-ikd) \int\int u_0(x_0, y_0) \exp\left((-ik/2z)((x - x_0)^2 + (y - y_0)^2)\right) dx_0 dy_0$$

$$u_I(x, y) = u_I(0, 0) \frac{2J_1(\pi D \rho / \lambda f_2)}{\pi D \rho / \lambda f_2}, \rho^2 = x^2 + y^2$$

$$\rho_s = 0.61 \lambda f_2 / f_1 NA$$

[1] Vinay Venkatesh Ramasesh, master thesis

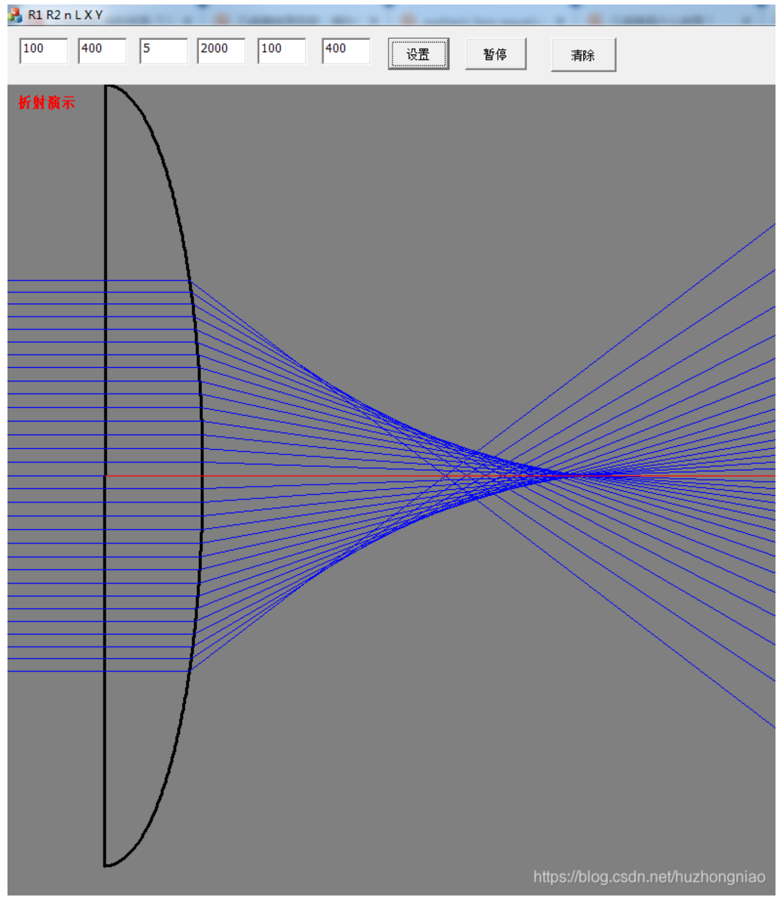
Choose a lens

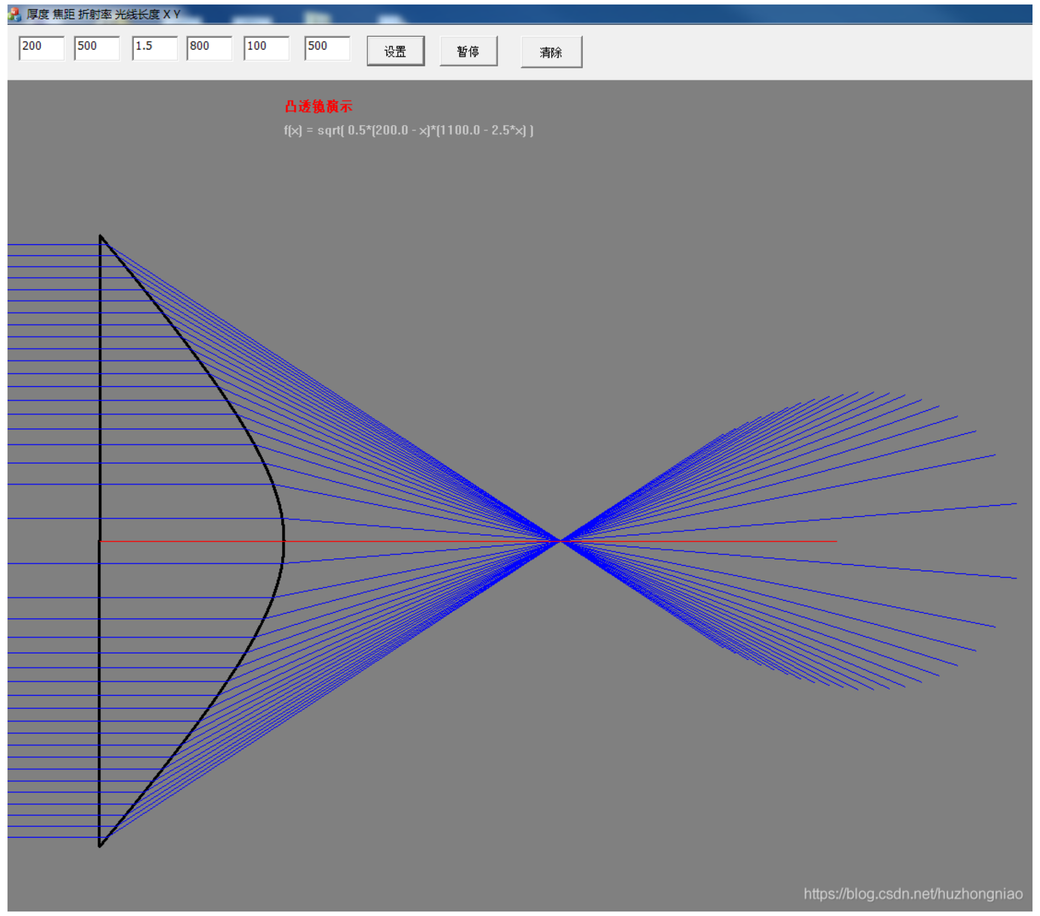
Numerical Aperture $NA = n * \sin(\theta)$, fiber is 0.12

Empirically, for quantum optics labs:

Need to care about everything: Designed wavelength, possible glass plate, aberration from other optics, FOV, DOF

NA<0.03	NA<0.05	0.05<NA<0.2	0.2<NA<0.6	NA>0.6
Spherical < $100	Achromatic $200	Aspheric singlet $ 600 – 1,000	Customized objective In vacuum aspheric lens $ 5,000 – 20,000	Objective with special design



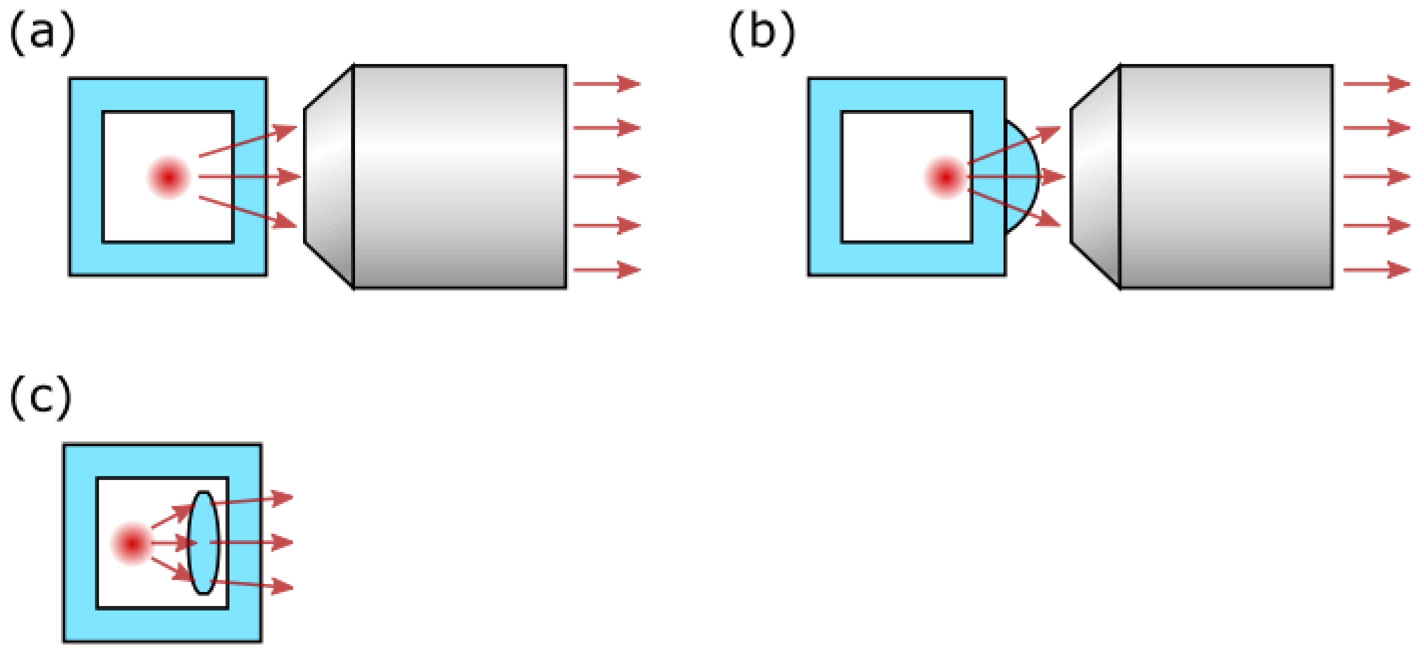


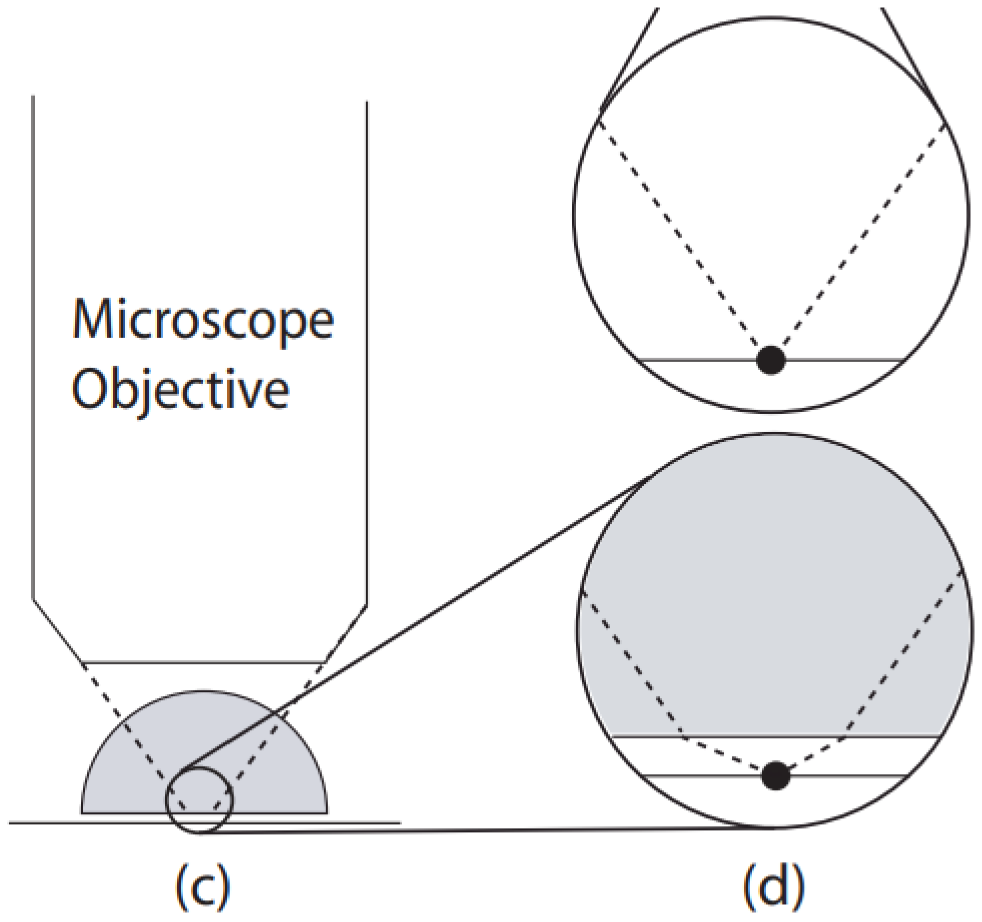
Note: for input fiber coupler, specialized fiber collimator is also better!

[1] https://blog.csdn.net/huzhongniao/article/details/96142503

Case Study

0.05<NA<0.2	0.2<NA<0.6	NA>0.6 site-resolved
Guangcan Guo Dypole	Pfau Chin lab (a) Fletcher (a) Antoine, Vladan (c) KK Ni (a) Doyle	Greiner (b) Bakr (b) Bloch Ketterle (a) Zhensheng Takahashi

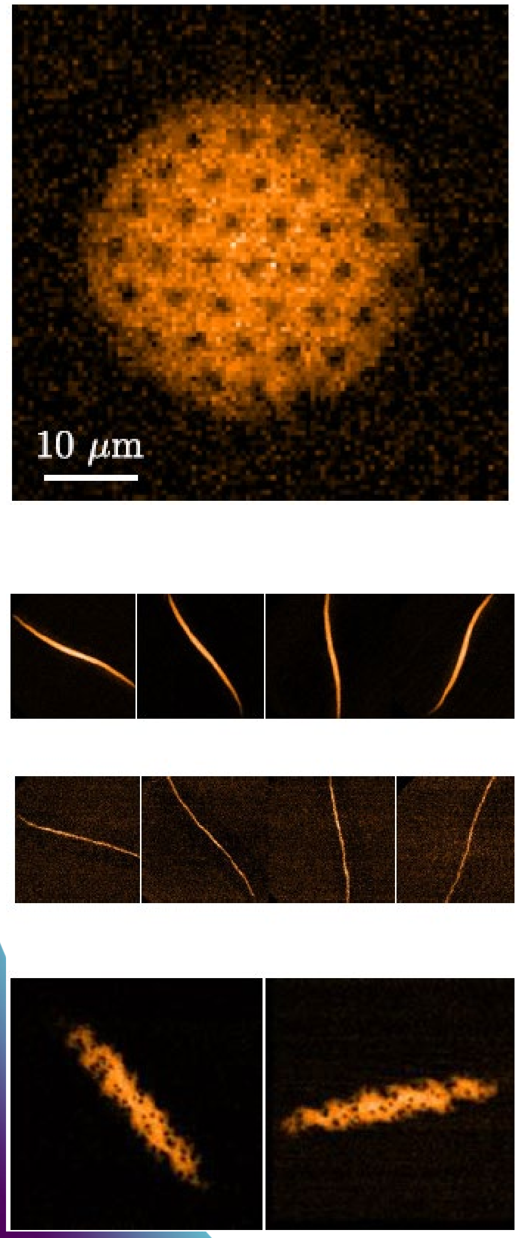




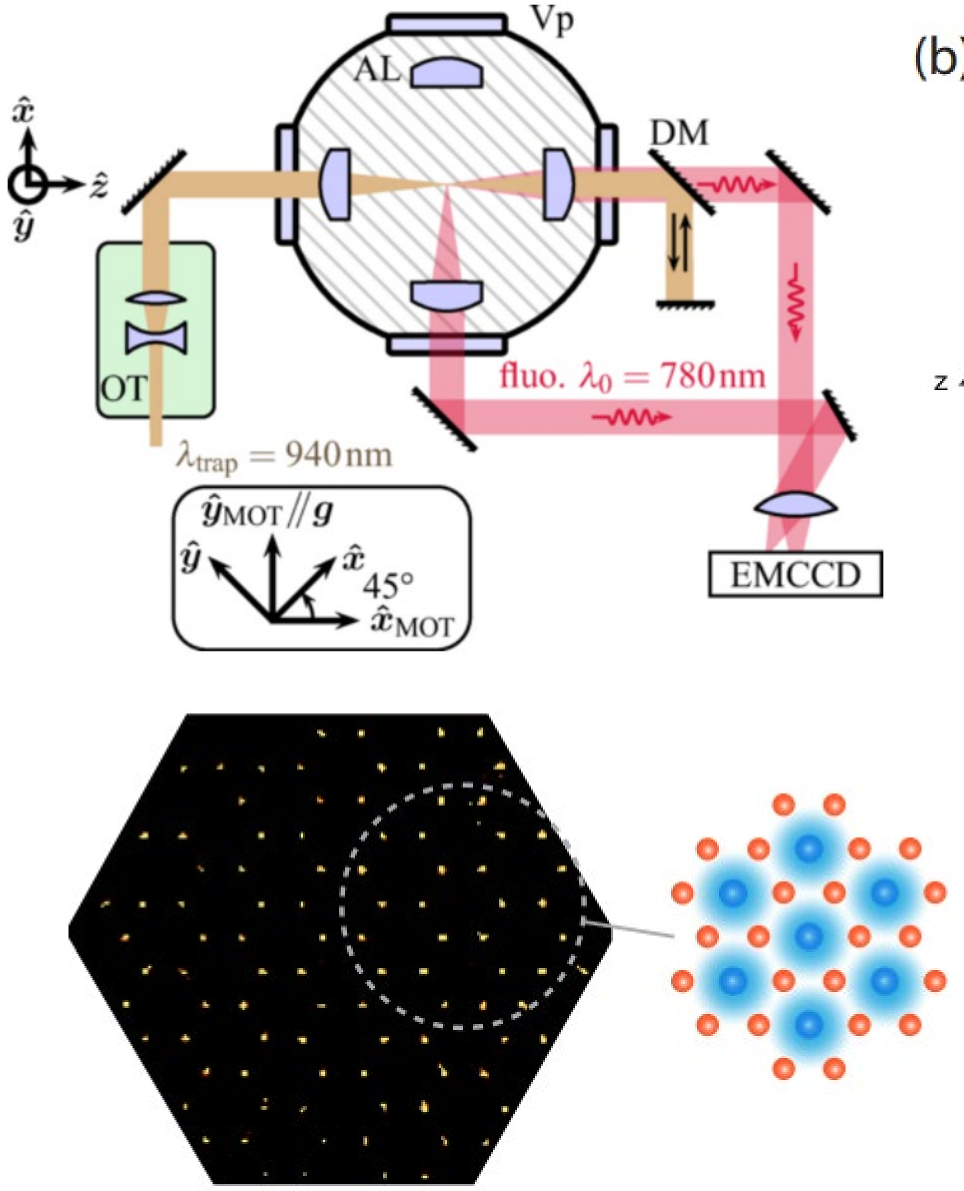
[1] arXiv:2306.05404 [2] Vinay Venkatesh Ramasesh, master thesis

Midrange NA

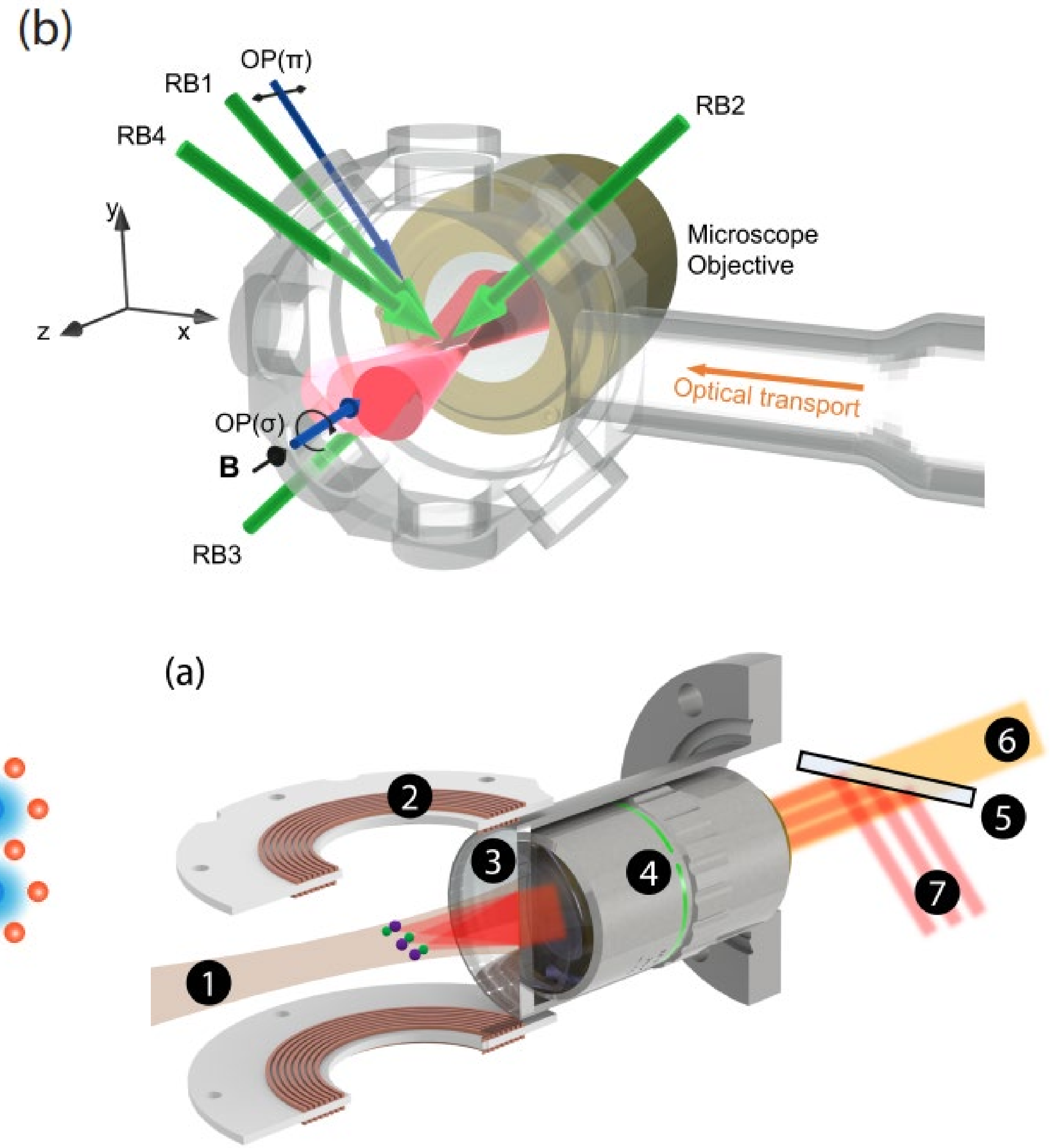
Fletcher



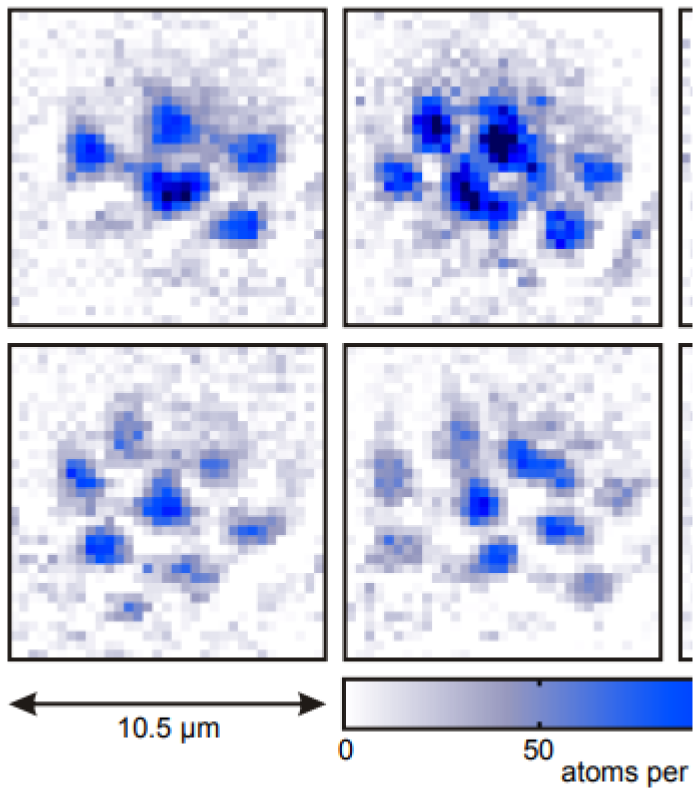
Antoine



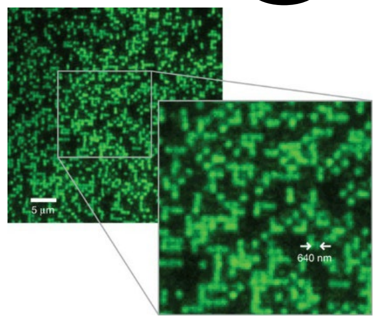
KK Ni/ Doyle



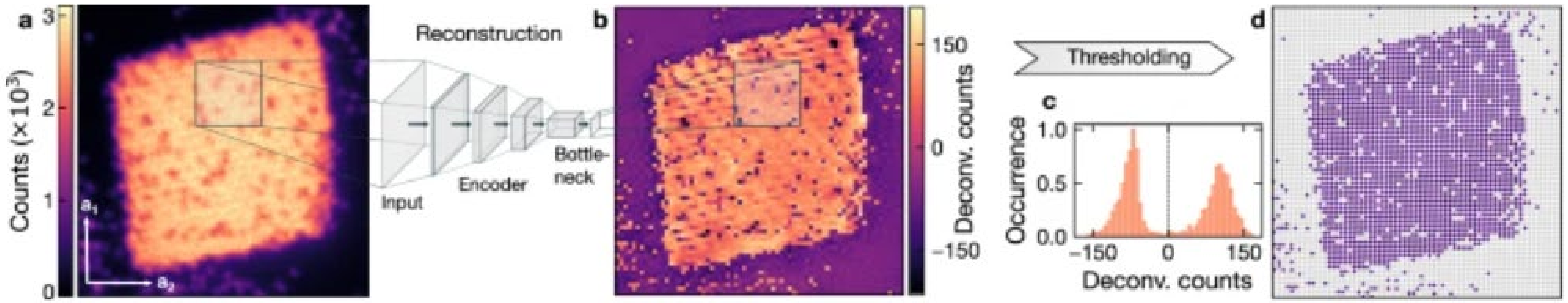
Pfau



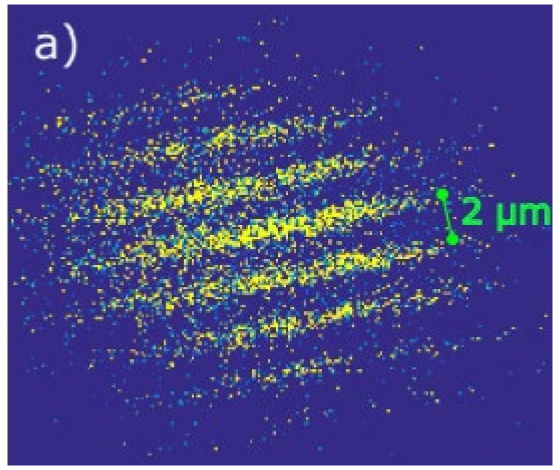
Huge NA



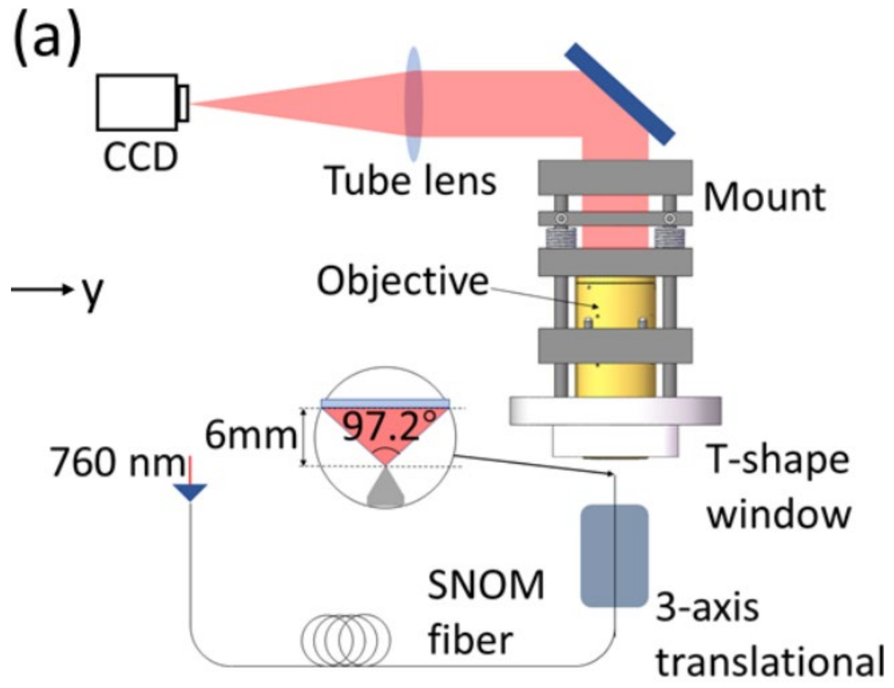
Monika

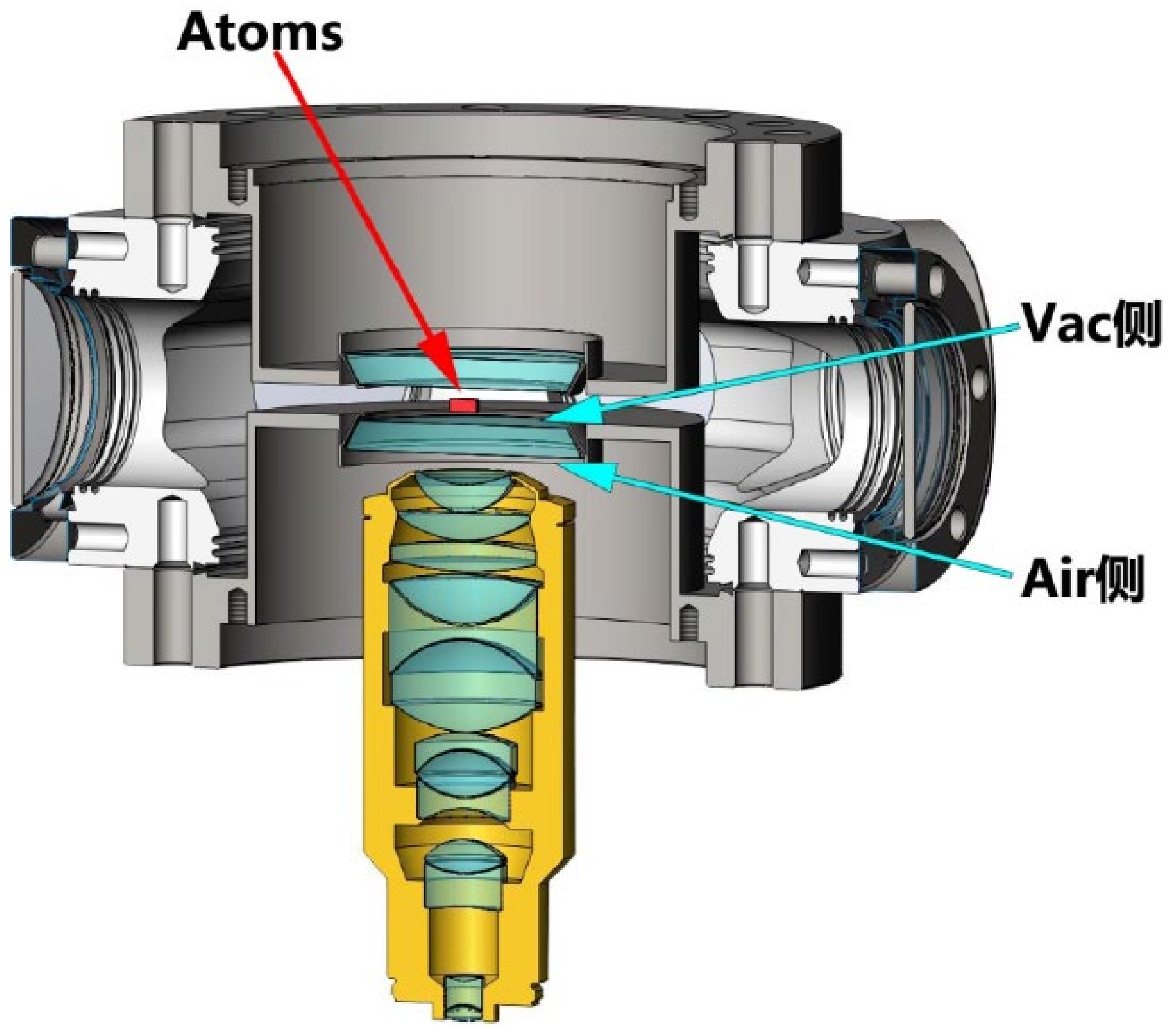


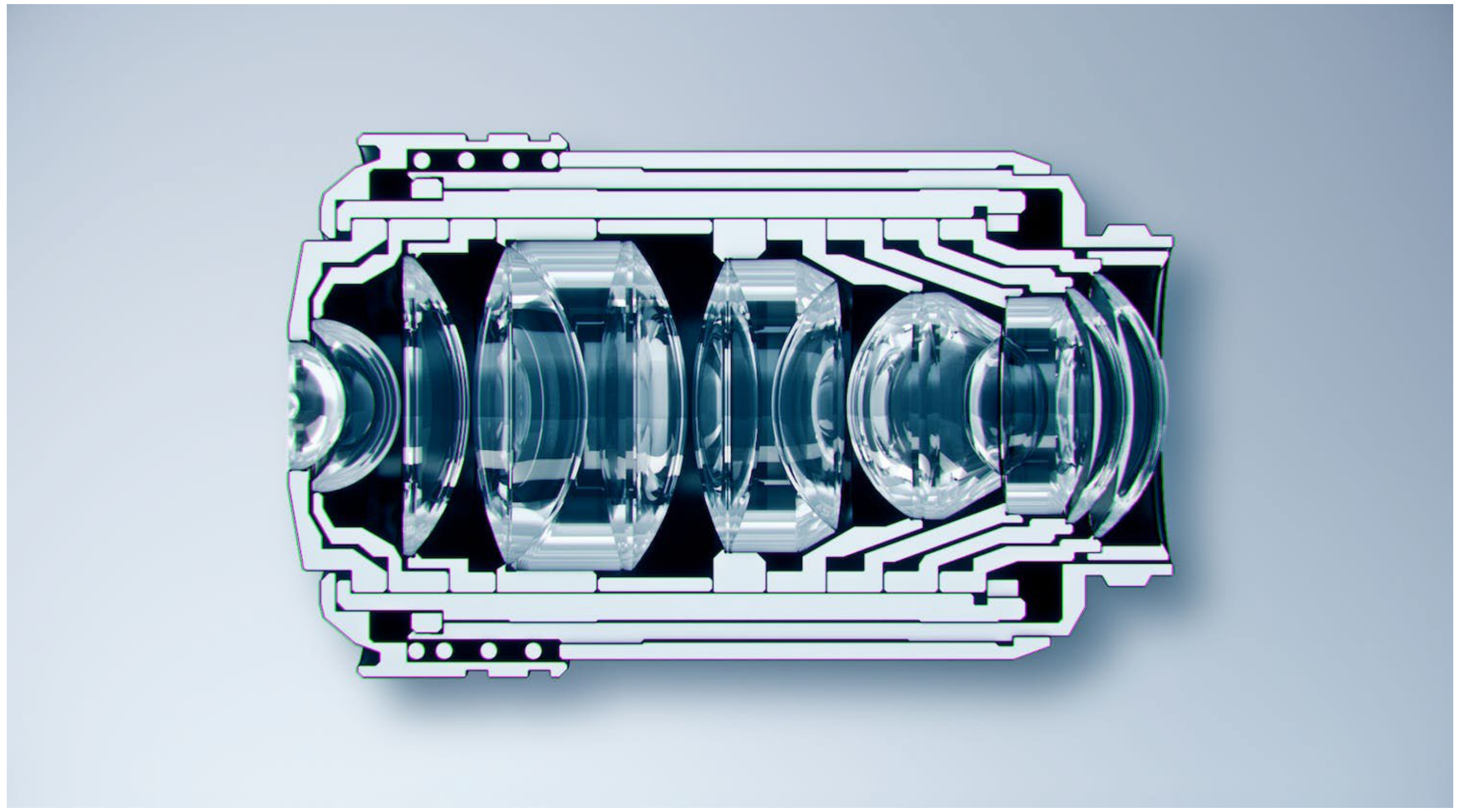
Emil Kirilov



Ketterle

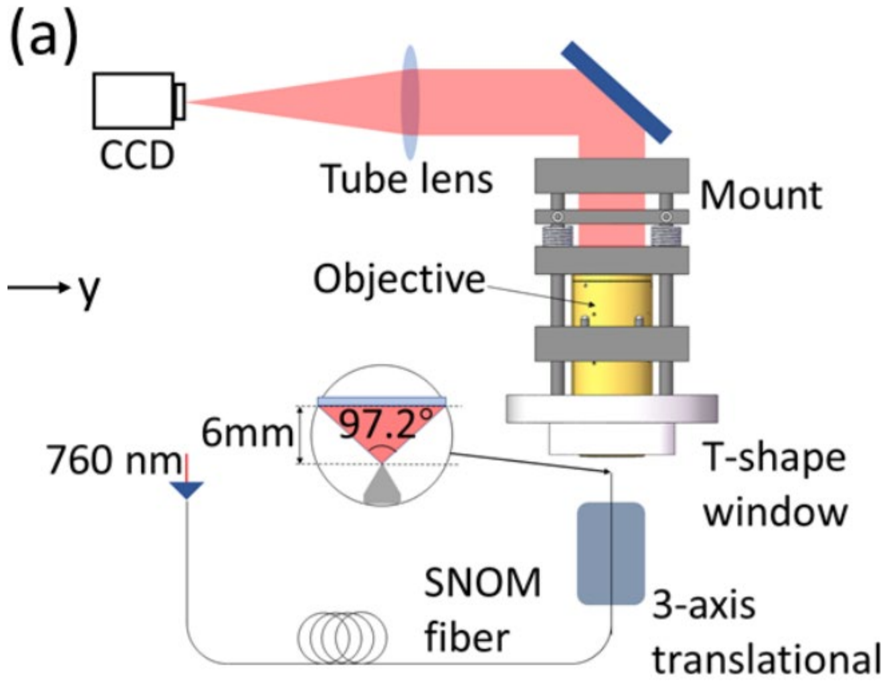


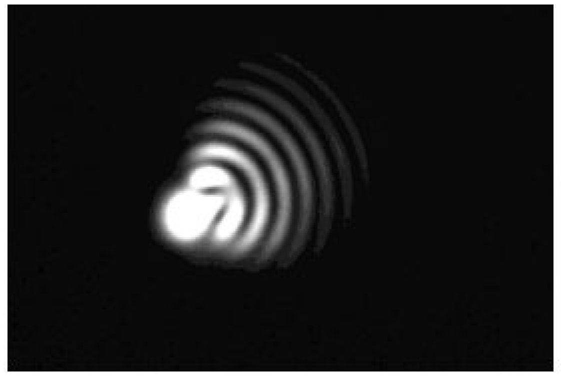




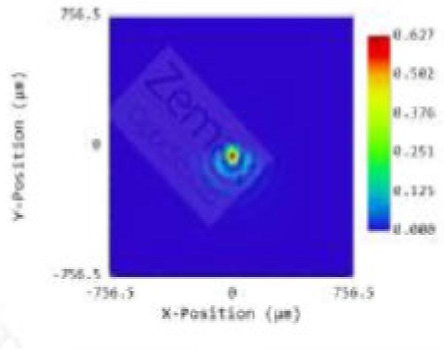
[1] Loïc Anderegg, PhD thesis [2] Qian Xie, PhD thesis

When you have large NA…





(a) Image



(b) Simulation

1. Tilt/ decenter of any kind

0.05◦ tilt between the bucket window and the microscope.

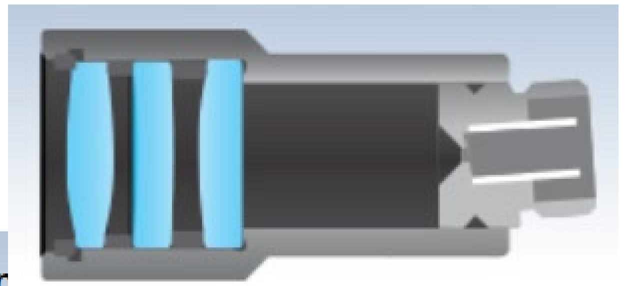
[1] Tian, Ye, et al. "Quantum gas microscope assisted with T-shape vacuum viewports." Optics Express 30.20 (2022): 36912-36920.

When you have large NA...

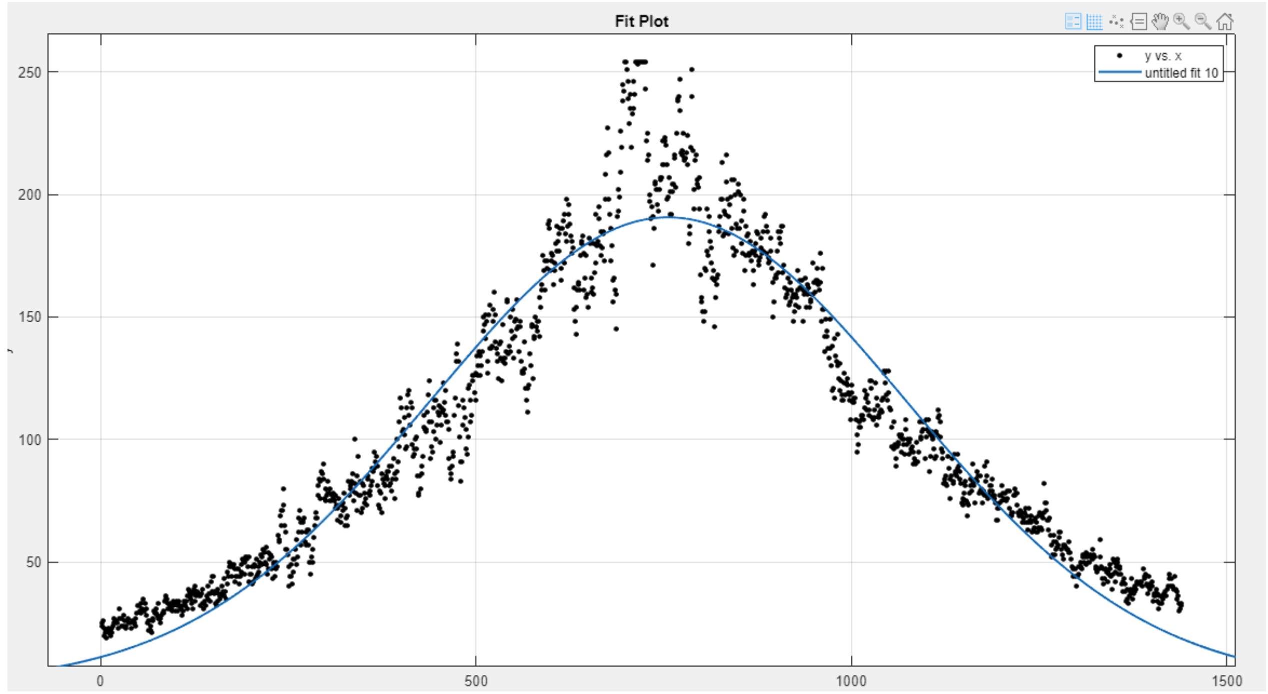
2. Imperfect Gaussian Input

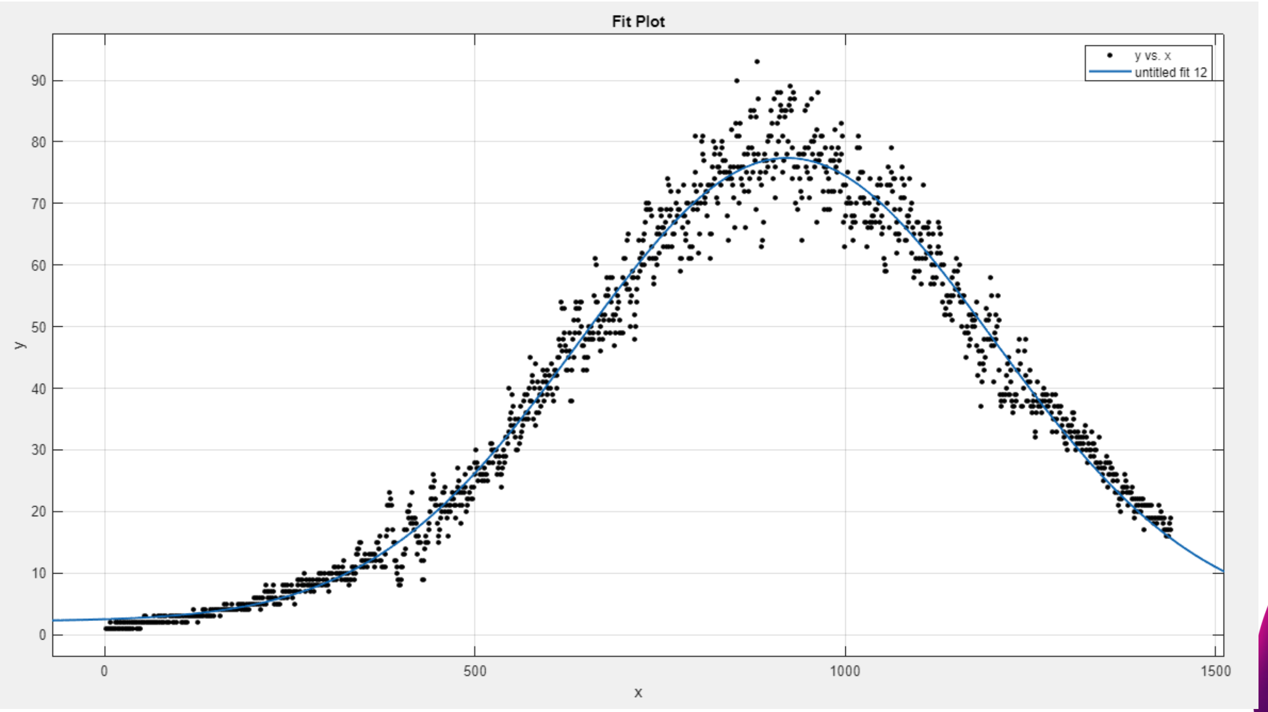
三合透镜光纤准直器/耦合器

- Triplet Lens Design Provides Nearly Gaussian Outp
- Low Wavefront Error: λ/8 (Peak-to-Valley, Typical)
- FC/PC and FC/APC Receptacles Available
- Available with Focal Lengths Near 6 mm, 12 mm, 18 mm, or 2



Our Triplet Collimators Use
an Air-Spaced Design





[1] Tian, Ye, et al. "Quantum gas microscope assisted with T-shape vacuum viewports." Optics Express 30.20 (2022): 36912-36920.

When you have large NA…

3. Mechanical bent or acousto effect

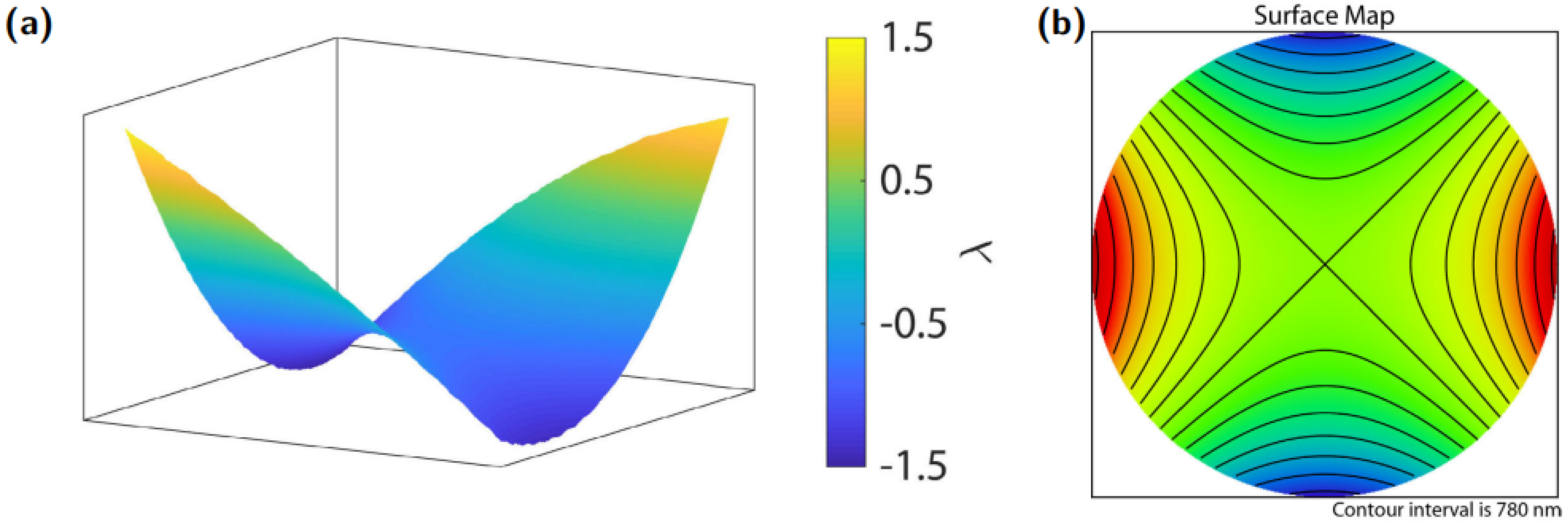
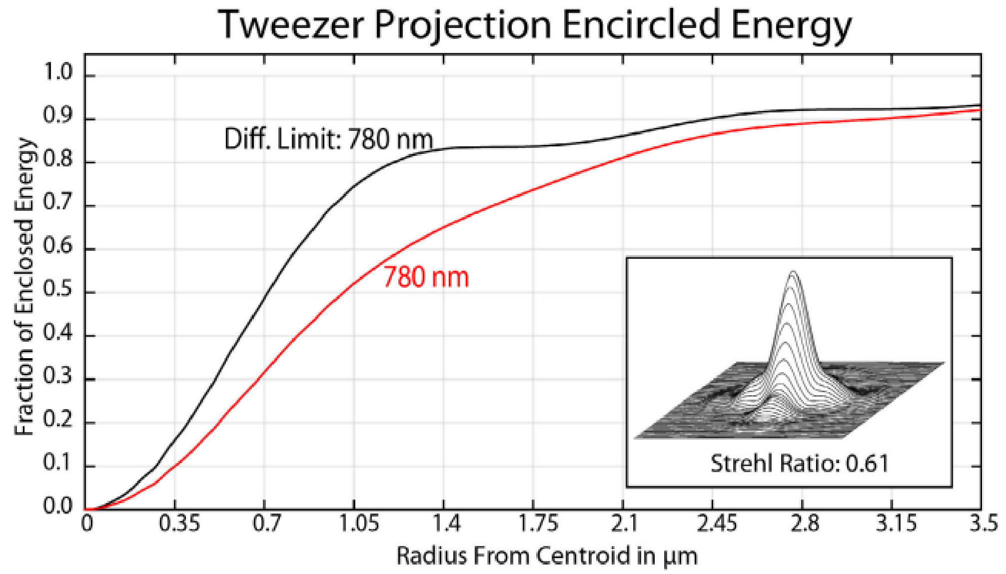
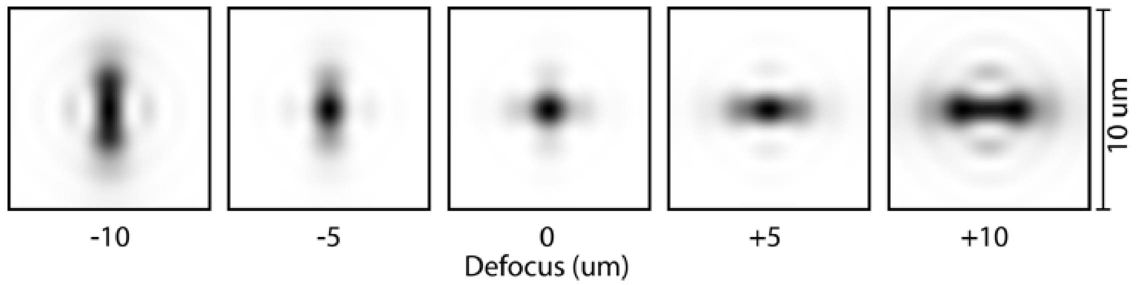


Figure 7.2.7: (a) Measured ISI window curvature over an 8x8 mm region. (b) Surface used in ray tracing simulation, matching the curvature measured.

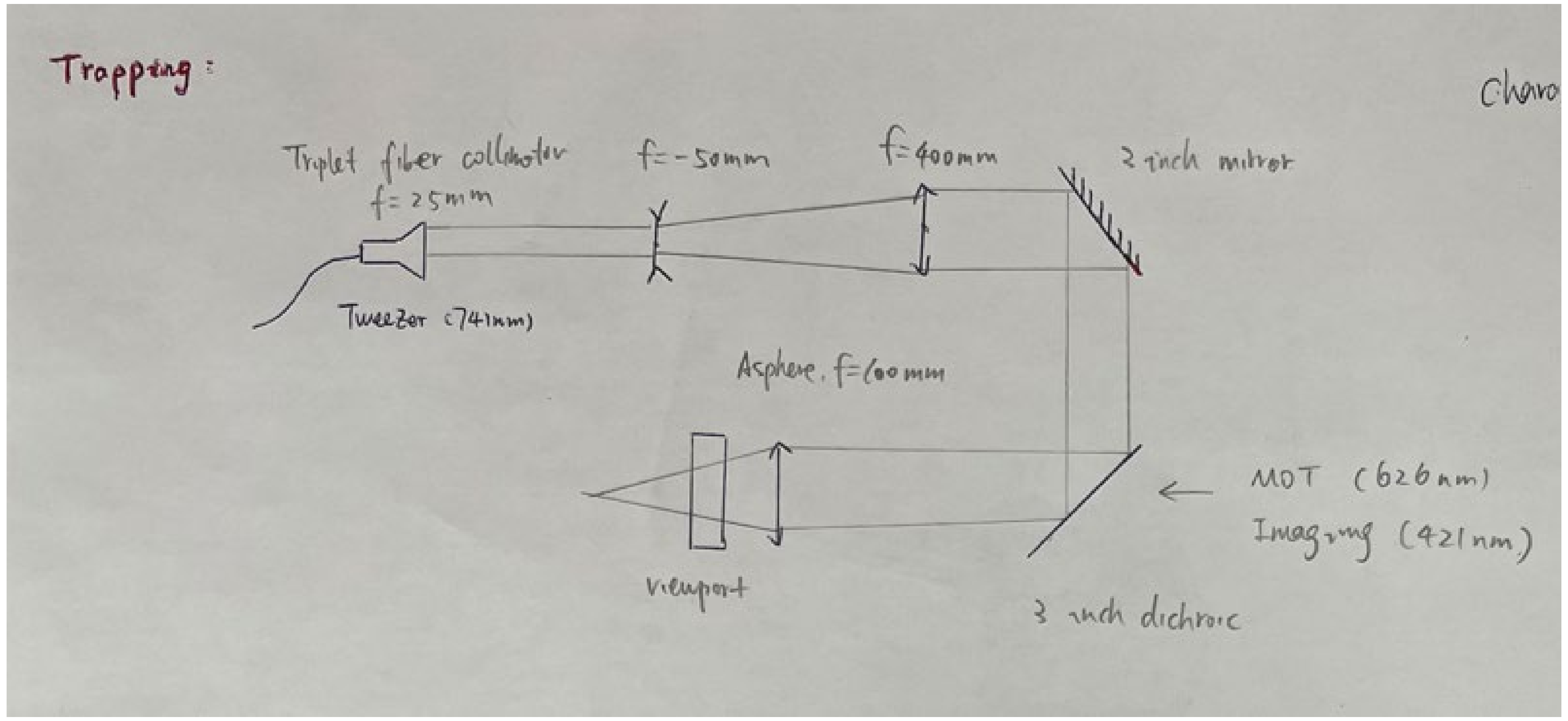


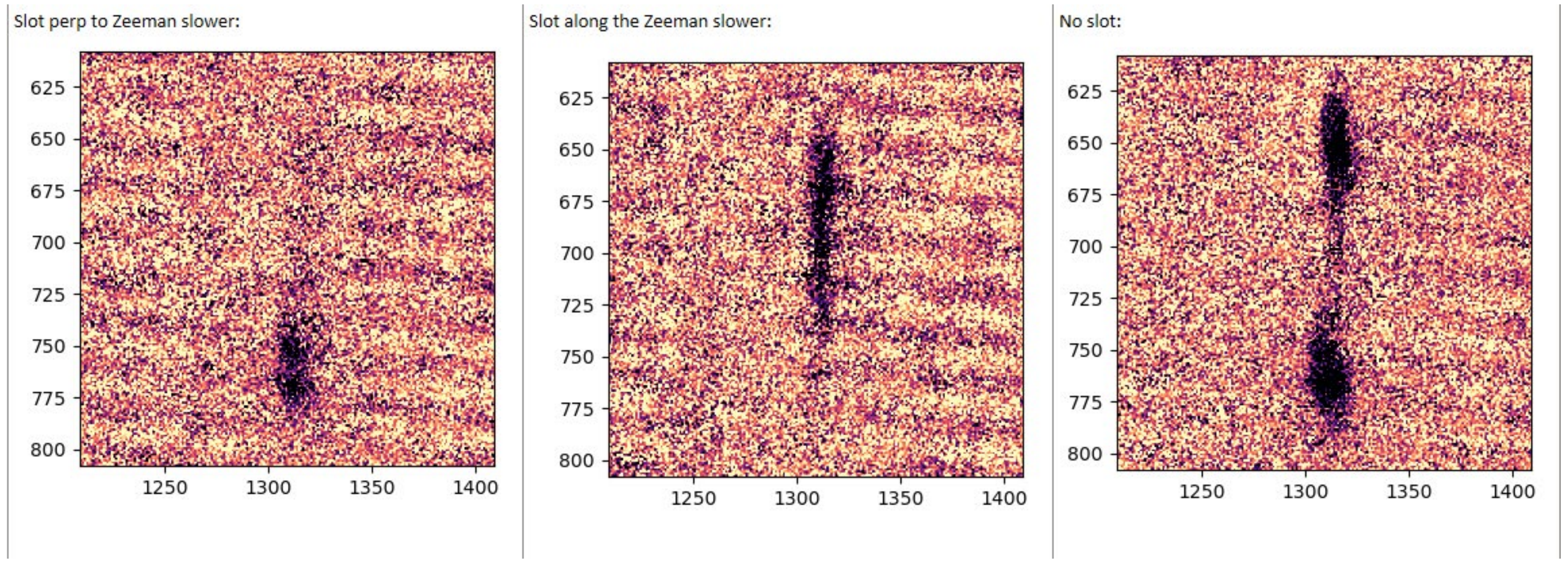


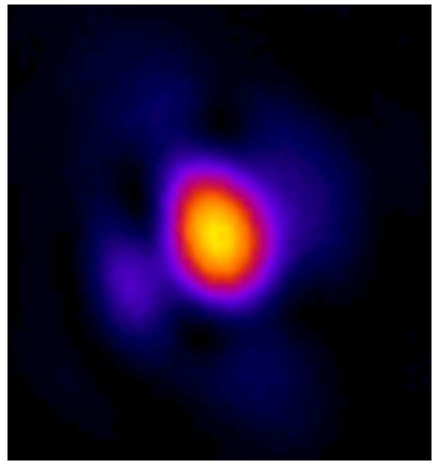
[1] Loïc Anderegg, PhD thesis

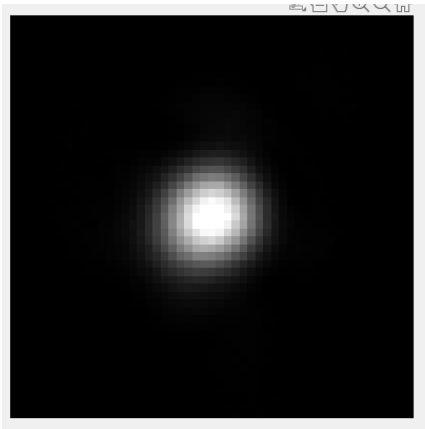
When you have large NA…

3. Mechanical bent at Dypole









[1] Yu-kun Lu, lunch talk
[2] Lee Liu, PhD thesis
[3] Jessie Zhang, PhD thesis

When you have large NA…

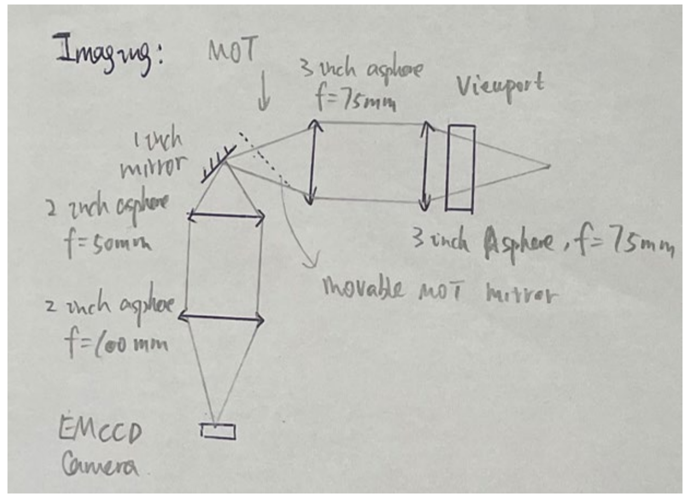
4. Your object – (merit of alkali, imaging while cooling)

Lens Data | 1: Layout | 2: Spot Diagram | 3: Geometric Encircled Energy

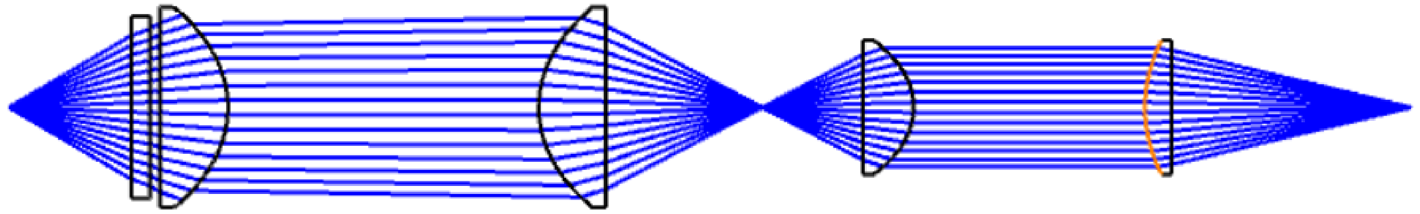
Update: Editors Only

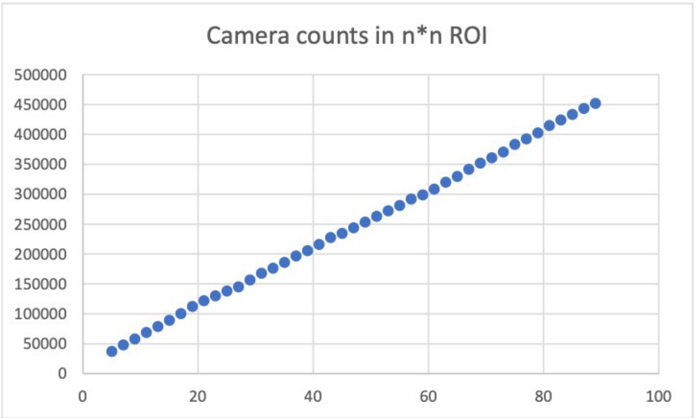
Surface 10 Properties | Configuration

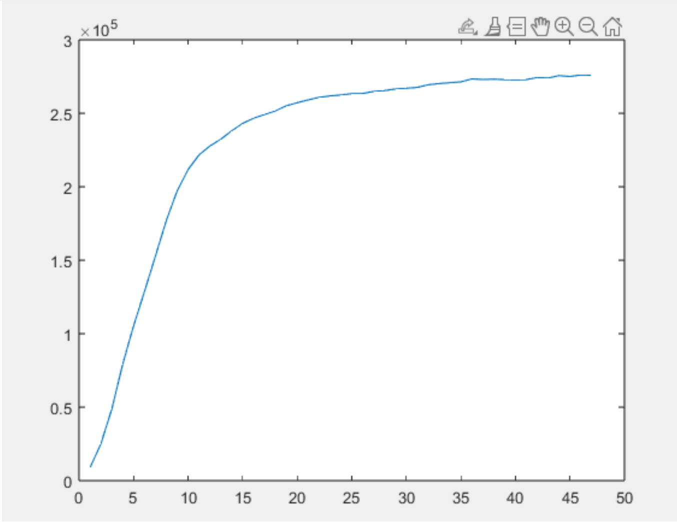
#	Surface Type		Comment	Radius	Thickness		Material	Coating	Clear Semi-Dia		Chip Zone	Mec
0	OBJECT	Standard		Infini…	46.000				0.000		0.000	
1	(aper)	Standard	viewpo…	Infini…	7.000		F_SILI…		34.000	U	0.000	
2	(aper)	Standard		Infini…	4.000				34.000	U	0.000	
3	STOP (aper)	Standard	22705	Infini…	25.400		N-BK7		33.750	U	3.750	
4	(aper)	Even Asphere		-38.760	117.000			EO_VIS0_5…	33.750	U	3.750	
5	(aper)	Even Asphere		38.760	25.400		N-BK7	EO_VIS0_5…	33.750	U	3.750	
6	(aper)	Standard		Infini…	58.800				33.750	U	3.750	
7		Standard		Infini…	37.780				0.034		0.000	
8	(aper)	Standard		Infini…	19.200		C79-80		25.000	U	0.000	
9	(aper)	Even Asphere		-23.804	87.000				25.000	U	0.000	
10	(aper)	Even Asphere	AL5010…	51.120	10.000		N-BK7		25.000	U	0.000	
11	(aper)	Standard		Infini…	90.153	V			25.000	U	0.000	
12	IMAGE	Standard		Infini…	-				0.065		0.000	

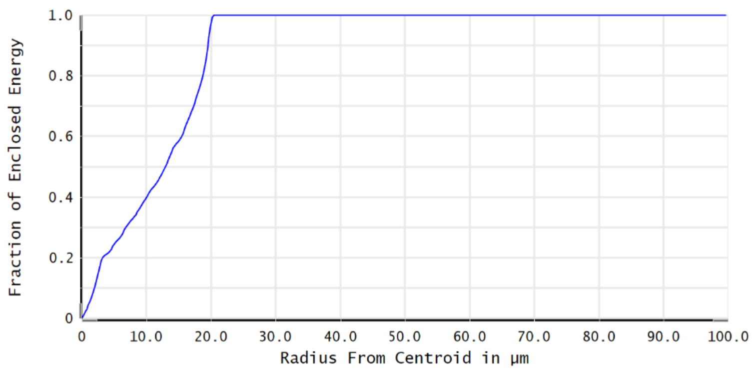


Simulate in Zemax and choose your favorite aspheric lens online (Note: Zemax cannot simulate lens scratch, polish)





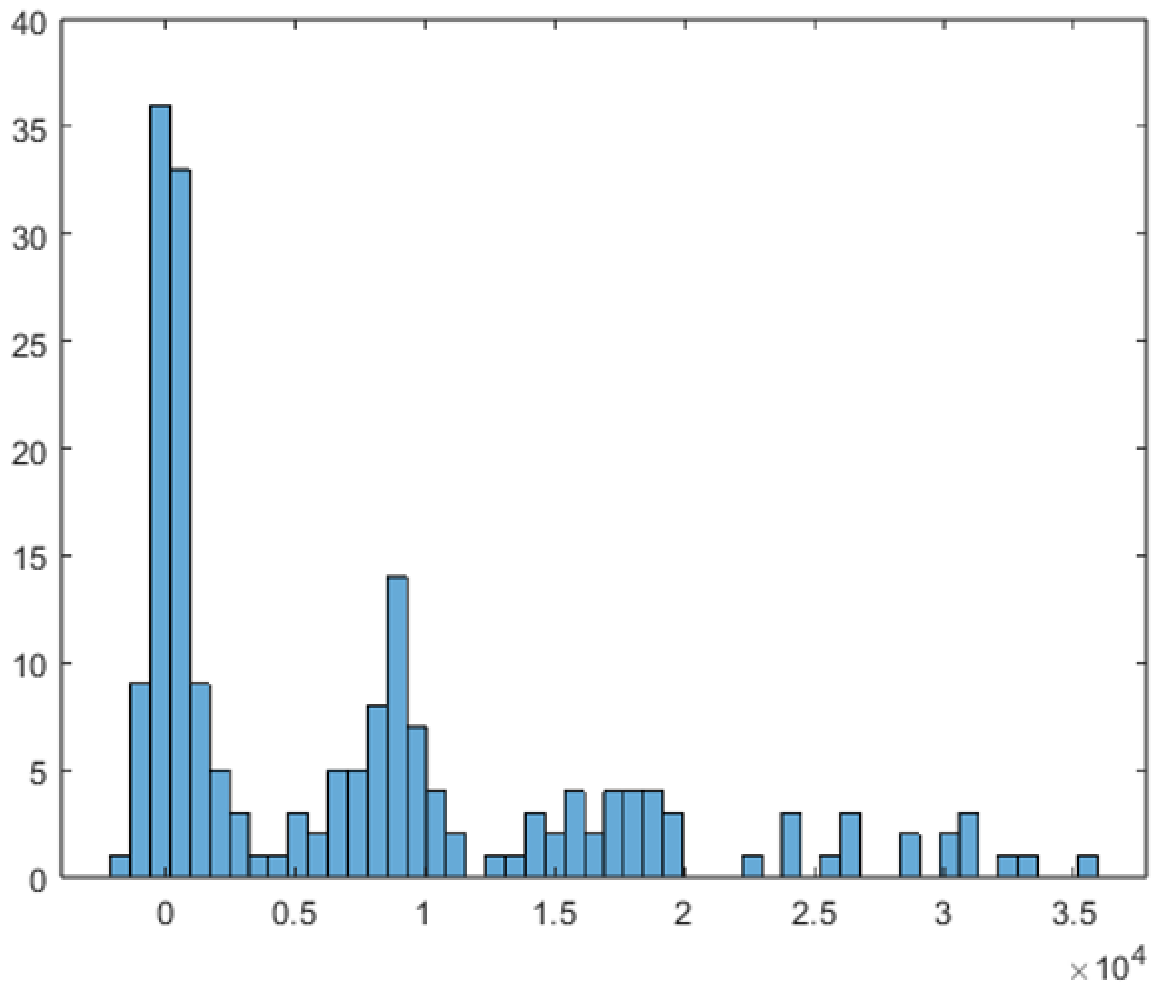


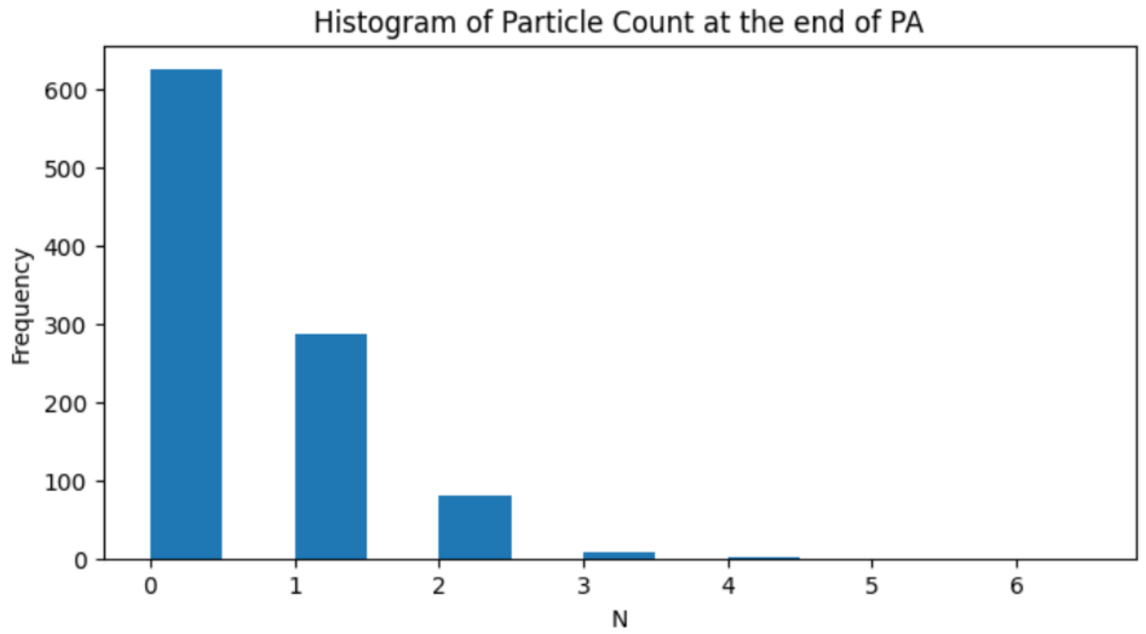


[1] Bergschneider, Andrea, et al. "Spin-resolved single-atom imaging of Li 6 in free space." Physical Review A 97.6 (2018): 063613
[2] Yu-kun Lu, lunch talk

Current Position

Success free space imaging, but no parity-projection

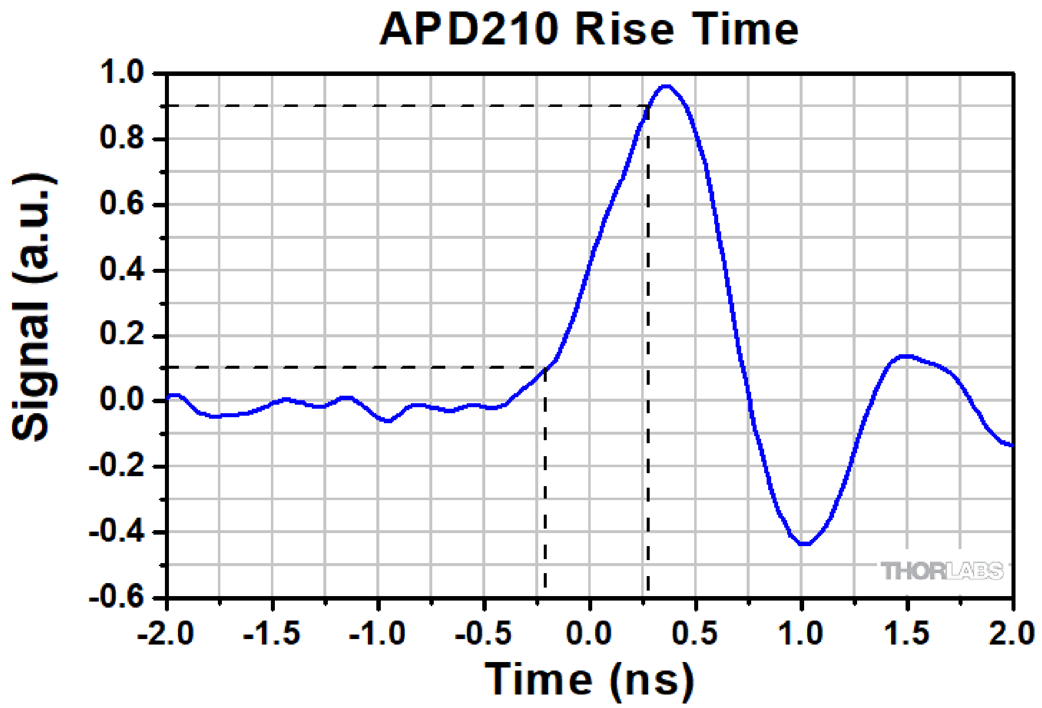




[1] Fuhrmanek, A., et al. "Light-assisted collisions between a few cold atoms in a microscopic dipole trap." Physical Review A 85.6 (2012): 062708.

APD/ PMT – time resolved

H16721-40
Hamamatsu



Disadvantage:

1. One pixel
2. Low quantum efficiency

Advantage:

1. Time resolved signal, photon correlation
2. Efficient in single photon detection, larger pixel!

Summary of Reference

From CUA:

[1] Loïc Anderegg, PhD thesis
[2] Jessie Zhang, PhD thesis
[3] Lee Liu, PhD thesis
[4] Theses from Fermi 2

From Institut d'Optique:

[5] Antoine PRA, PRL
[6] JQI Special Seminar 10/19/2016 - Optical Design - Yvan Sortais, Youtube

Possibly future:

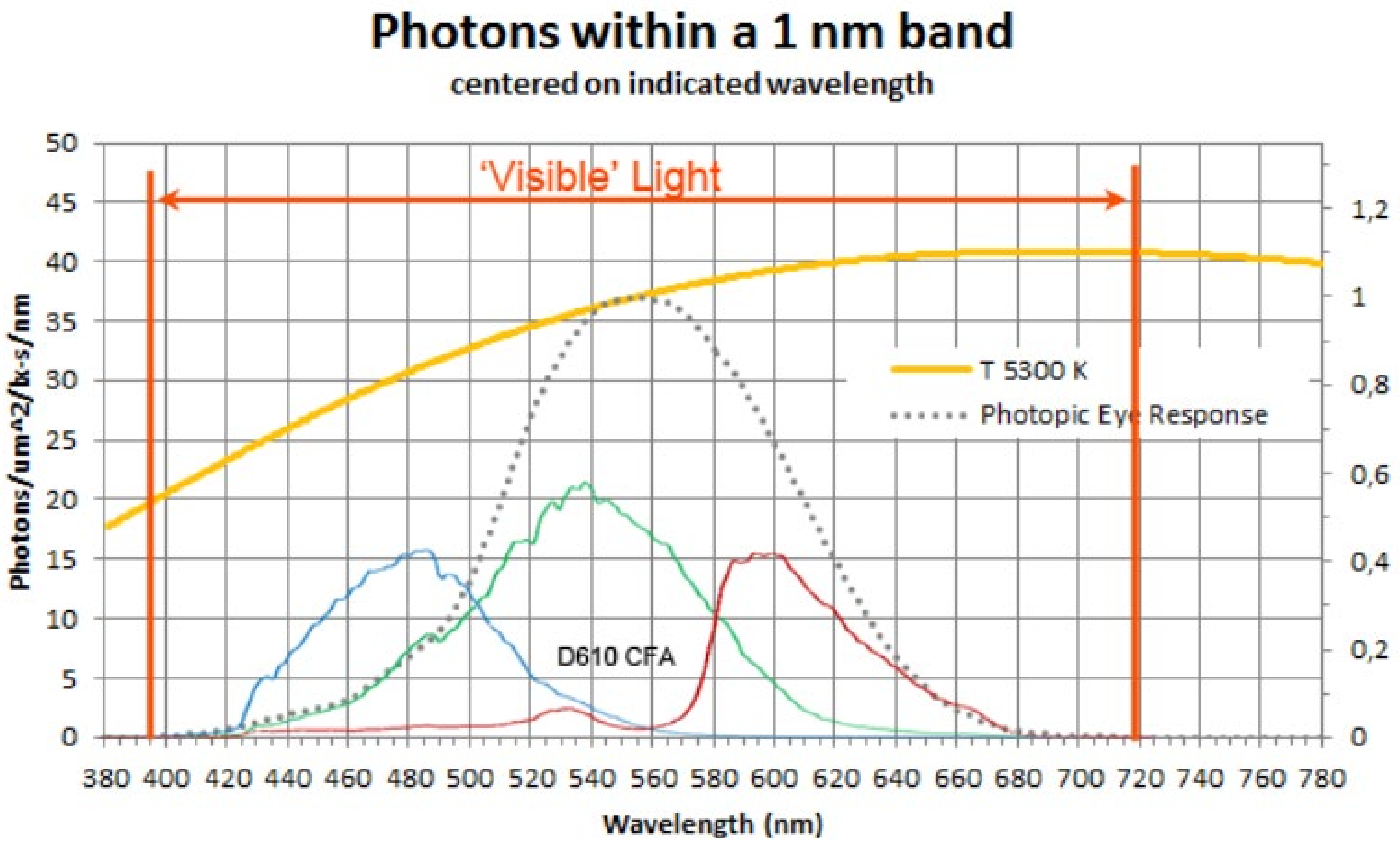
[7] Impertro, Alexander, et al. "An unsupervised deep learning algorithm for single-site reconstruction in quantum gas microscopes." Communications Physics 6.1 (2023): 166.
[8] Anich, Gregor, Rudolf Grimm, and Emil Kirilov. "Comprehensive Characterization of a State-of-the-Art Apparatus for Cold Electromagnetic Dysprosium Dipoles." arXiv preprint arXiv:2304.12844 (2023).
[9] Sohmen, Maximilian, et al. "A ship-in-a-bottle quantum gas microscope for magnetic mixtures." arXiv preprint arXiv:2306.05404 (2023).

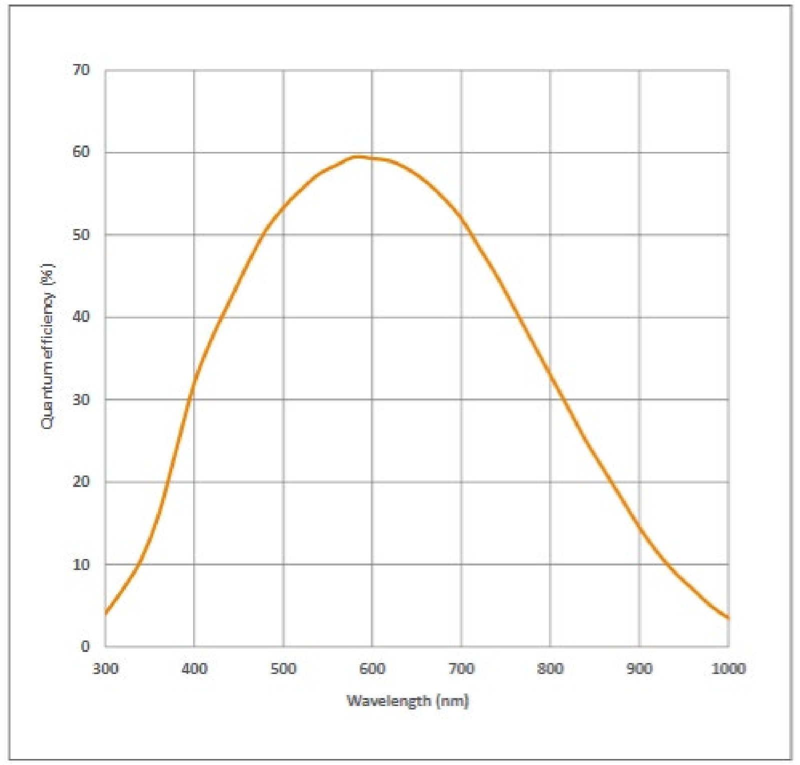
03

Other Cameras

Mirrorless Camera-- sensor

vs



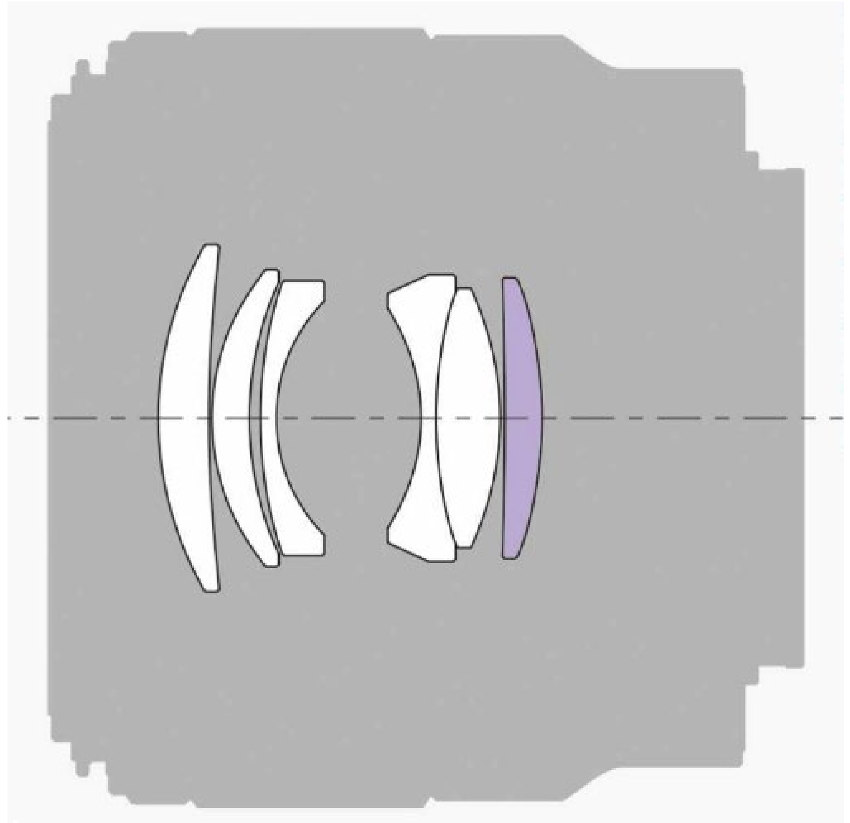


Camera sensor:

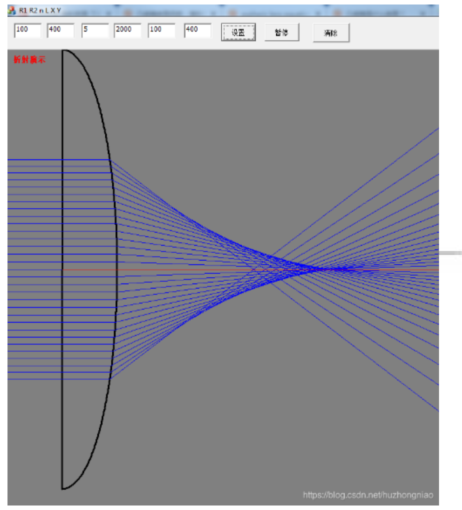
1. Much larger
2. Color Filter
3. Hotter
4. More noisy

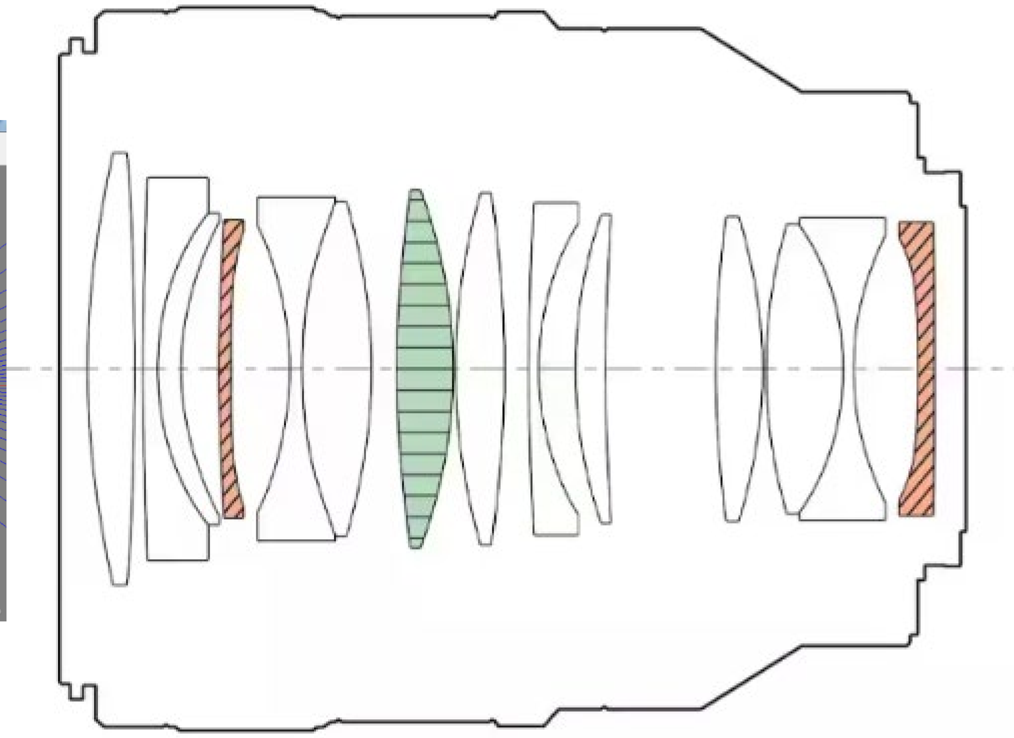
[1] https://www.strollswithmydog.com/effective-quantum-efficiency-of-sensor/

Mirrorless Camera-- Lens



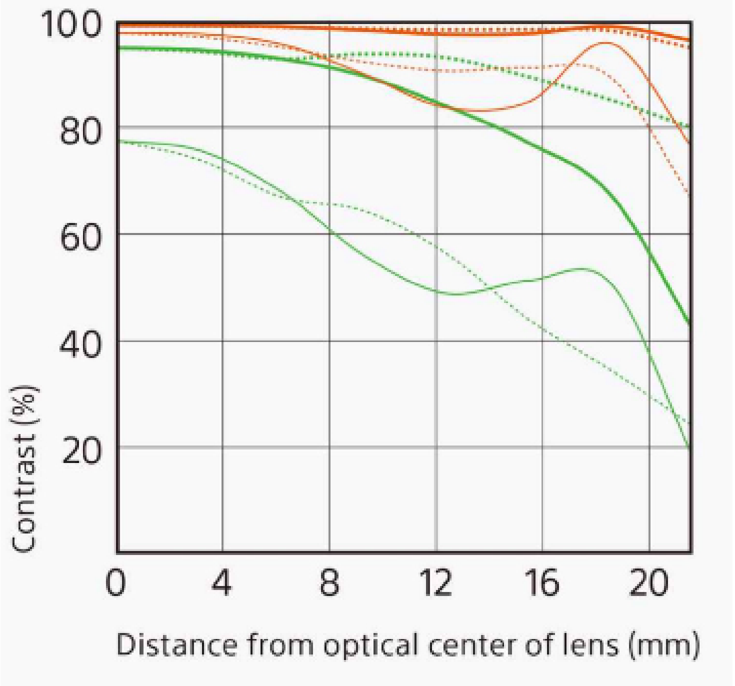
Sony FE 50mm F1.8

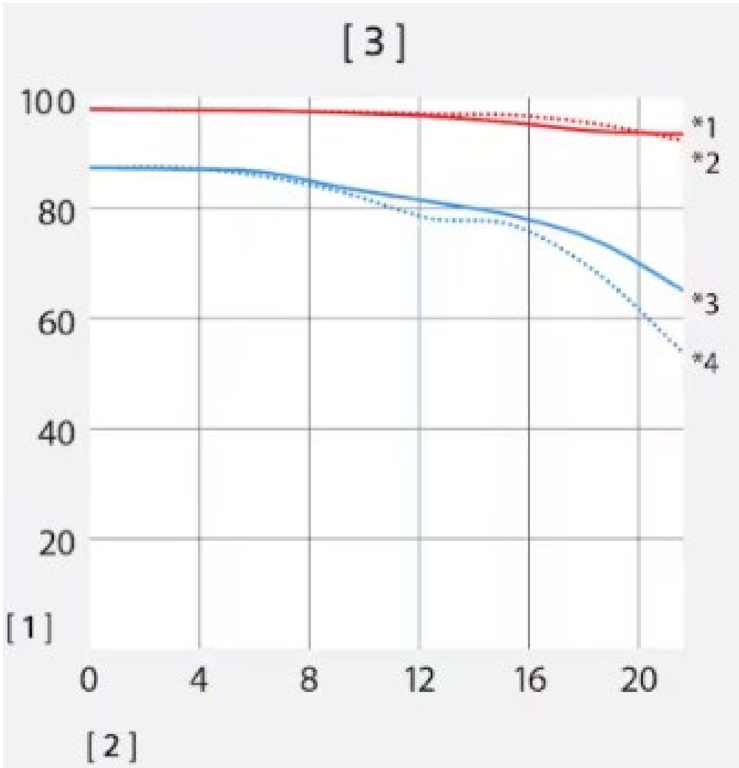




Two important parameters:

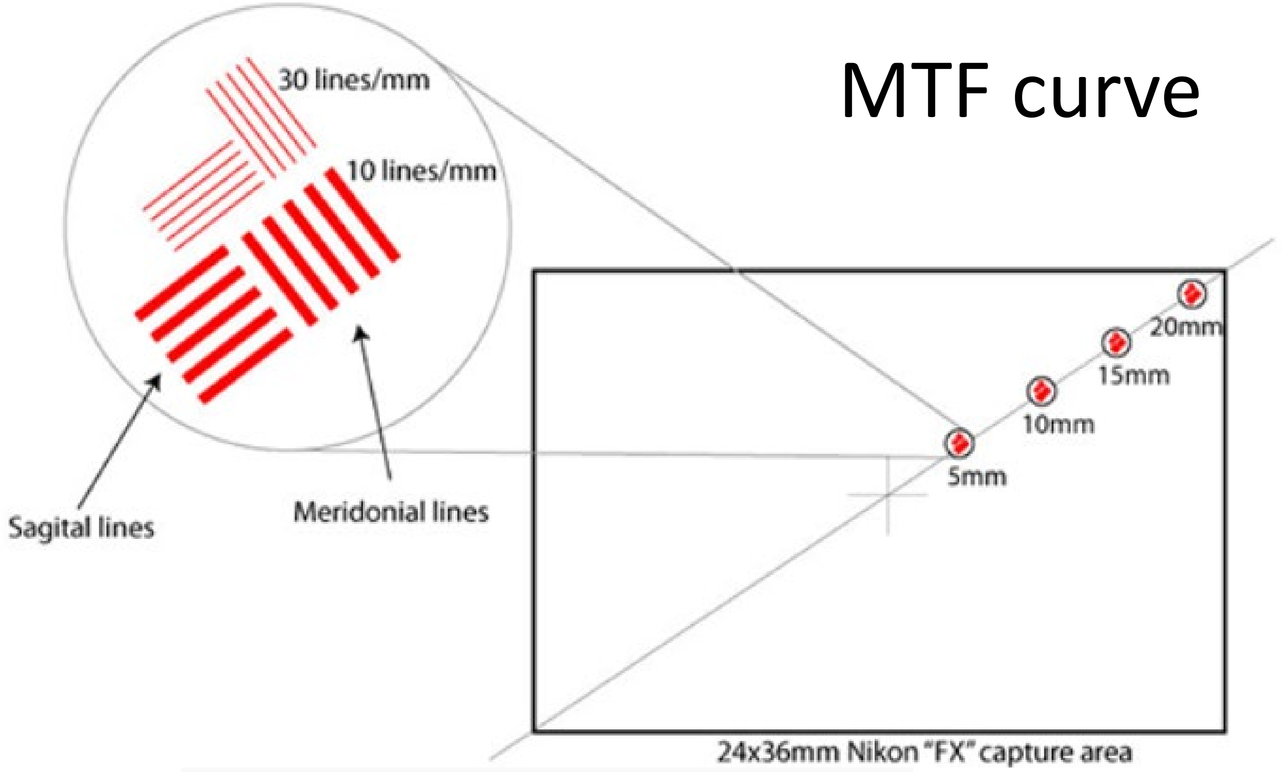
1. F#
2. Effective focal length f

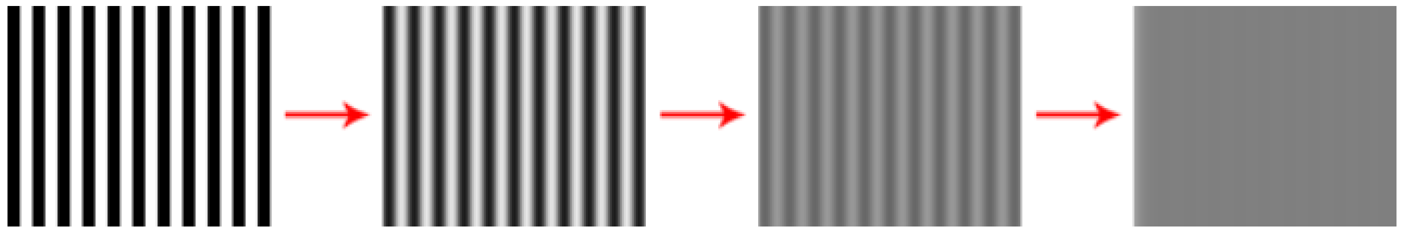


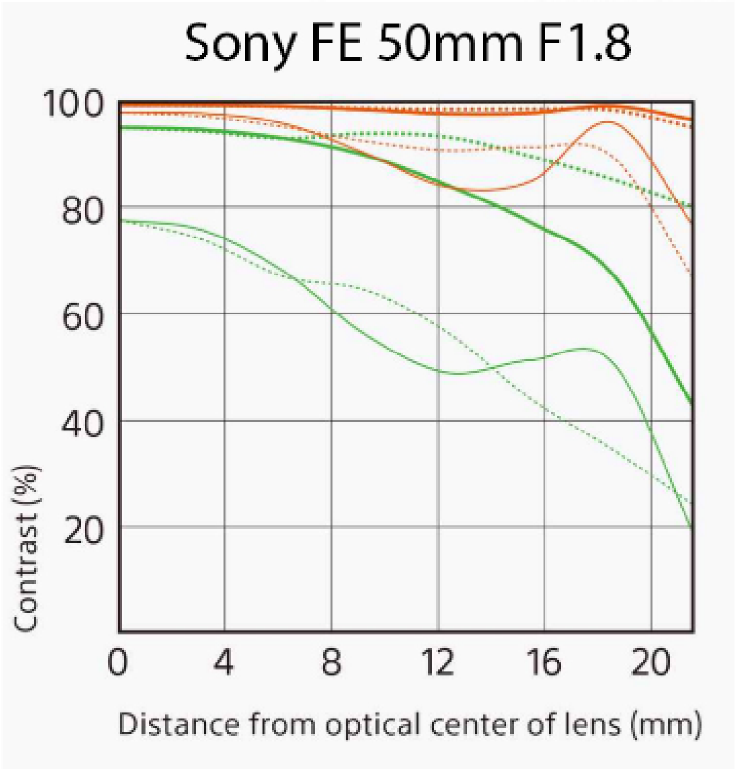


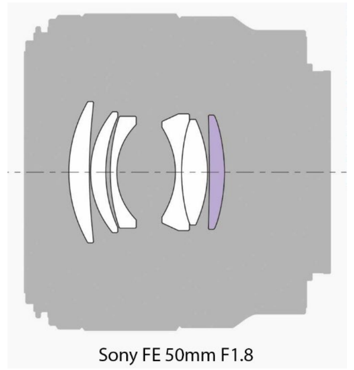
Lens evaluation

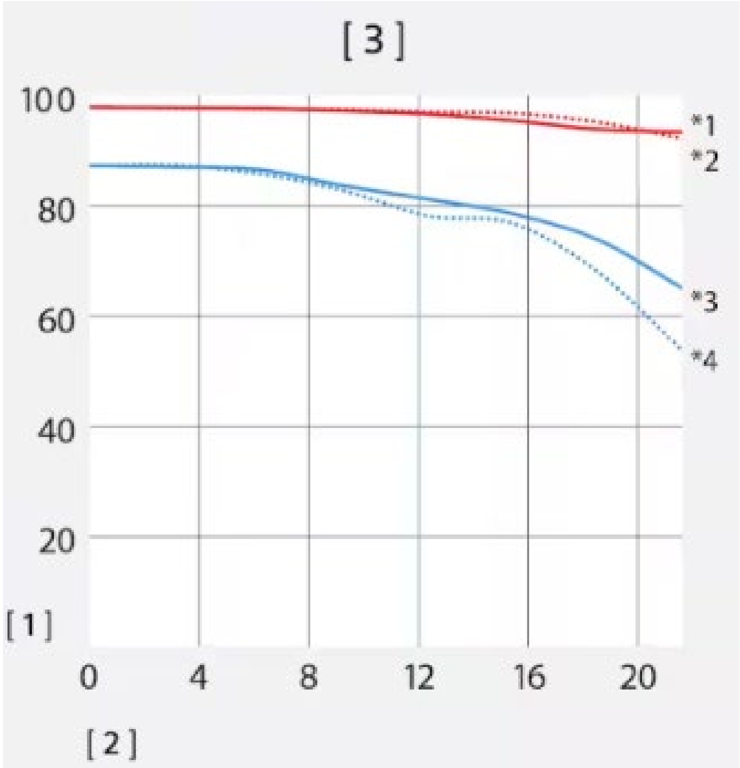
MTF curve

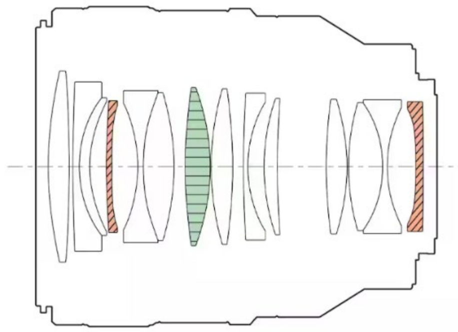












[1] https://photographylife.com/how-to-read-mtf-charts

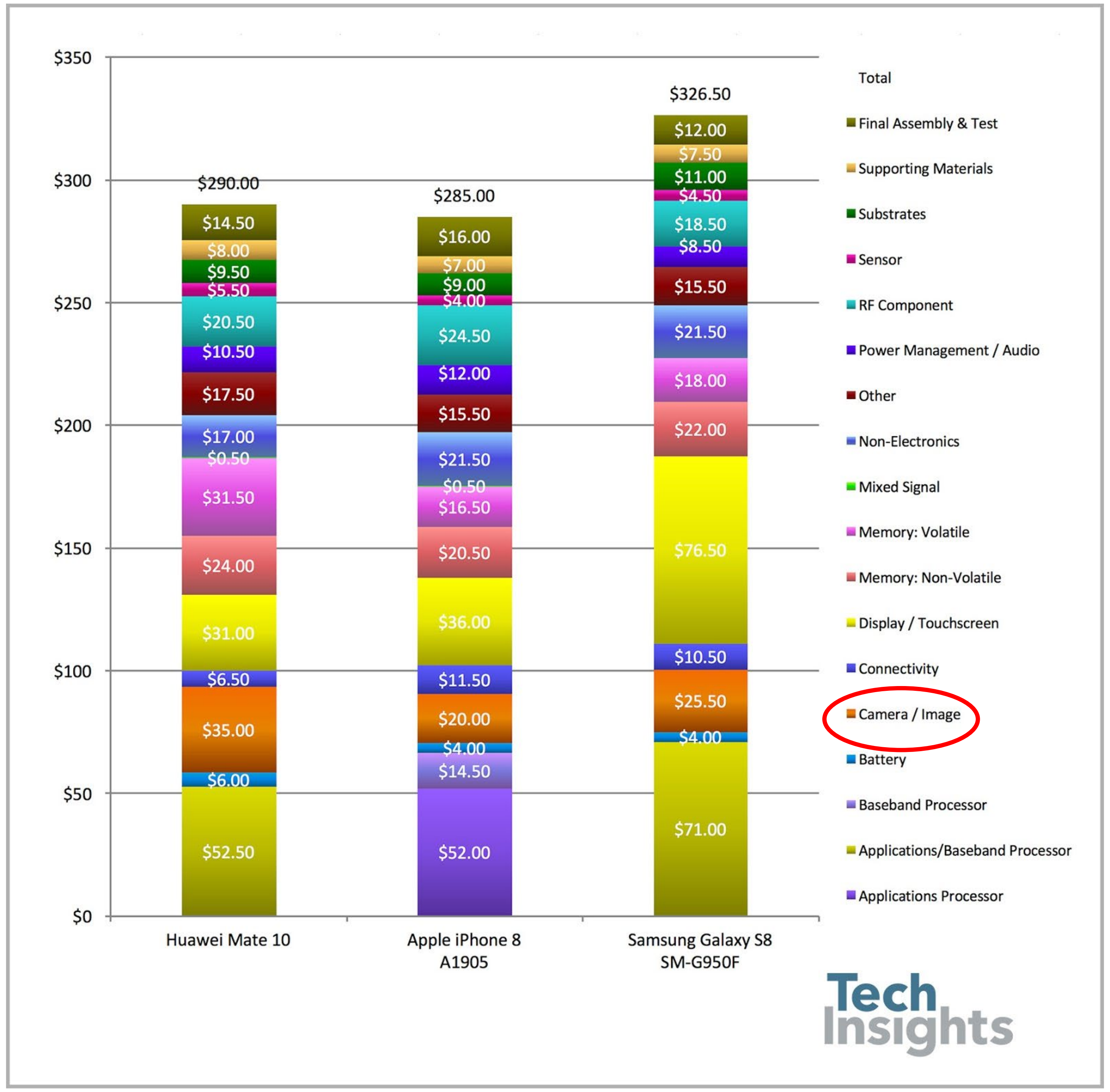
Camera evaluation

1. Aberration
2. Auto focus
3. Focus track
4. Compact
5. Cost

……

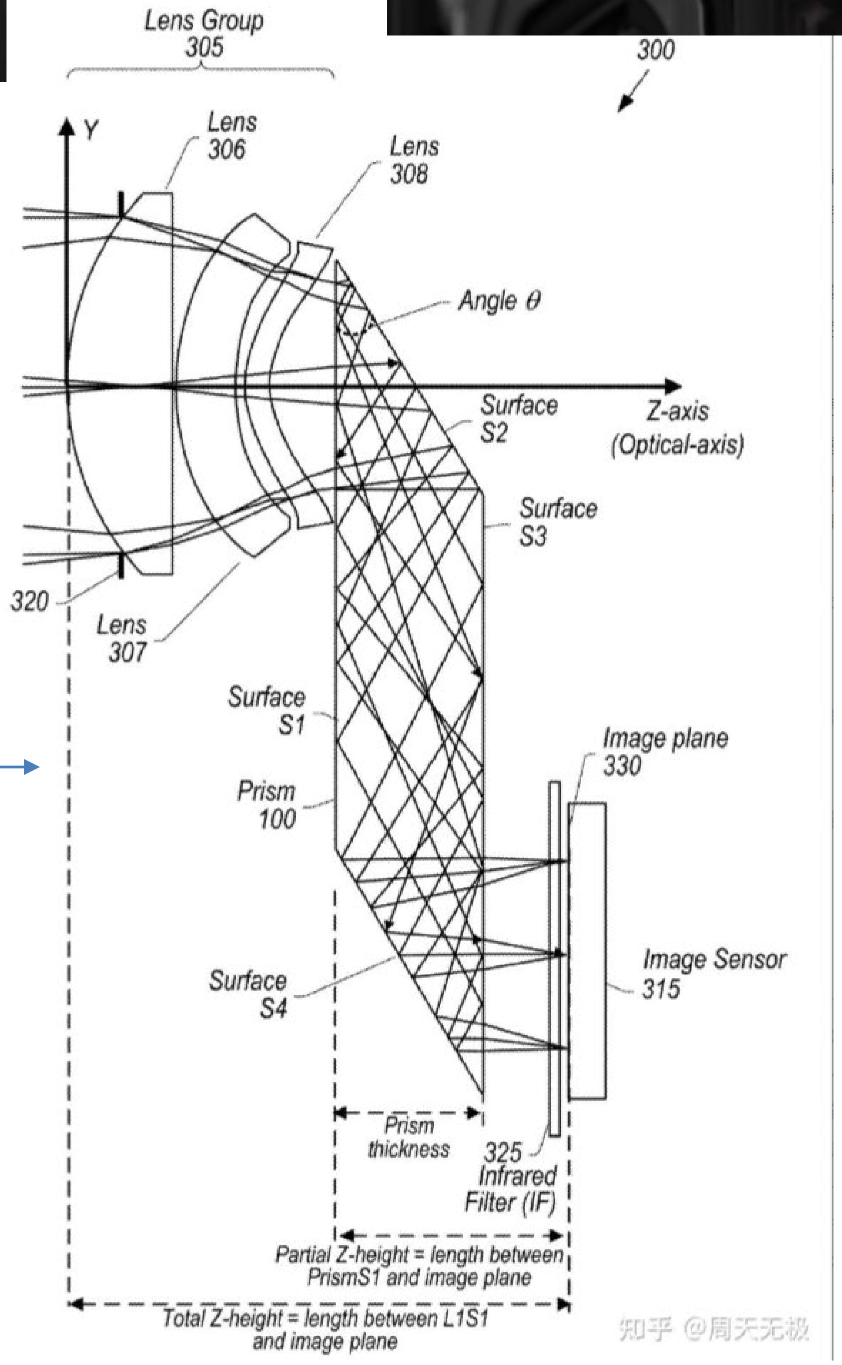
Phone camera

Phone Camera



Price

Compact



[1] http://image-sensors-world.blogspot.com/2017/11/smartphone-camera-cost-comparison.html?m=1
[2] https://www.sony-semicon.com/cn/products/is/mobile/

Phone Camera

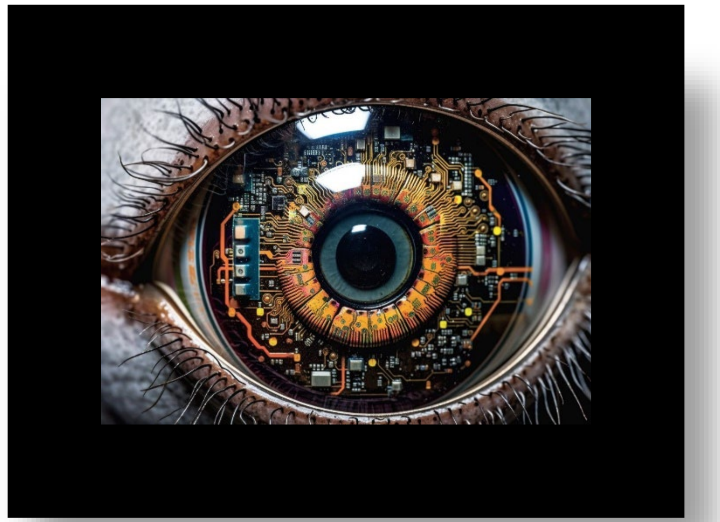
Optical Zoom
/Digital Zoom

Refocus/
Readjust aperture

Anti-shake

Human Eye

An ultimate video camera?



Advantage

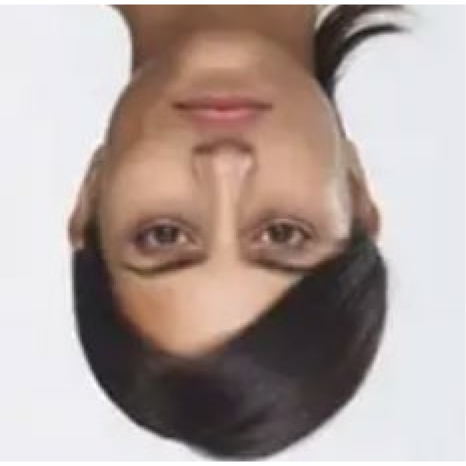
1. Easy to control the angle
2. High dynamical range
3. Easy to carry

Disadvantage

1. Fixed effective focal length
2. Optimized for center
3. Deceptive
4. Short lived

Future of Technology

mimic human eyes and make deceptive photos (jpg does this!)
And more…



[1] https://cgjennings.ca/articles/jpeg-compression/

- Thanks!