UNIVERSITY OF KENTUCKY

Out-of-focus point spread functions

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Canon Hack Development Kit (CHDK)

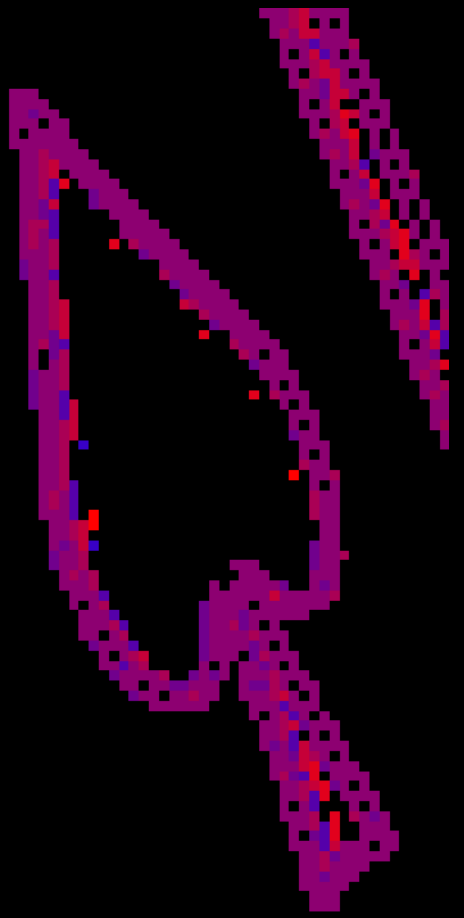
Enables running arbitrary C code in a Canon PowerShot with full access to camera

Spring 2009, EE499

- Jennifer Danhauer, Joe Lanford, Ross Levine project to capture a depthmap inside a Canon PowerShot using depth-from-focus
- CHDK scripting so a single press captures a sequence with different focus distances
- CHDK processing modified with custom C code to measure blur & combine images
- Blur measurement was fairly state-of-the-art

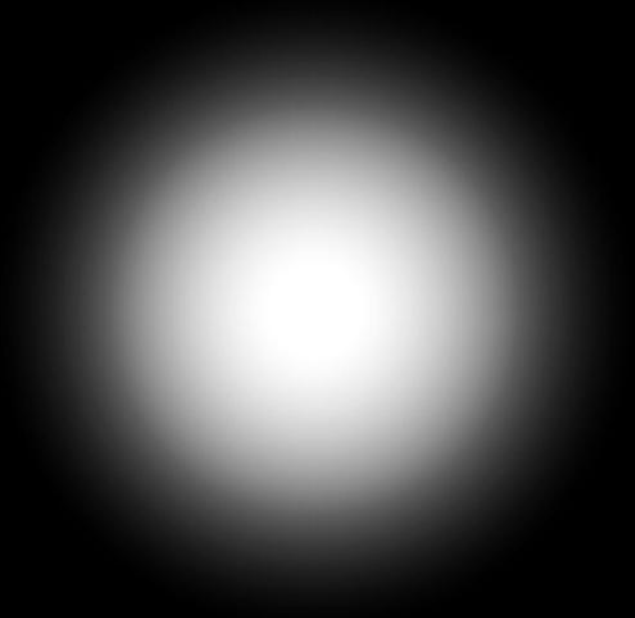
How Good Is The Depthmap?

- Accurate depths at edges
- No depth in featureless fields
- Wrong depths near edges!
- Wrong by a lot
- Wrong both directions
- Seems to “echo” edges...



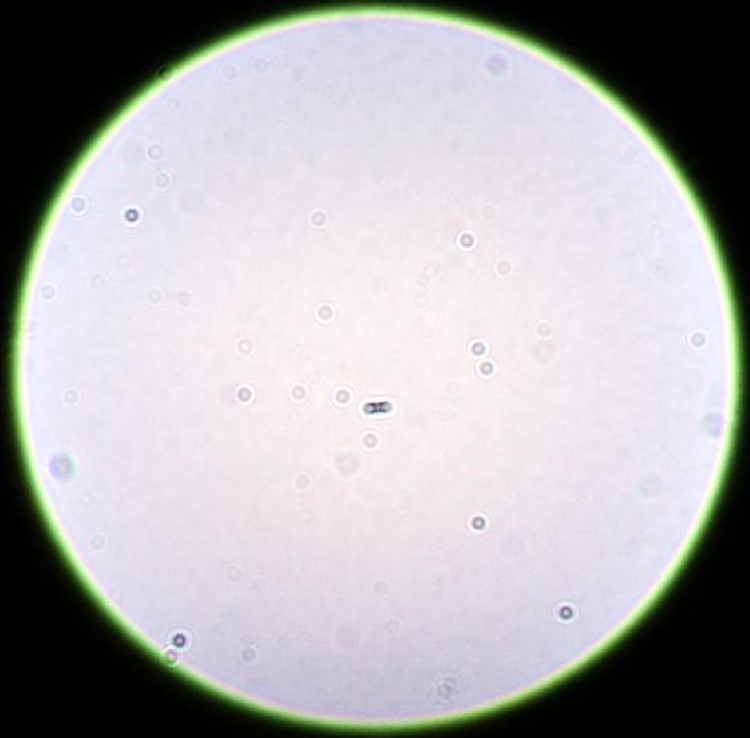
What Went Wrong?

- Most image processing algorithms model out-of-focus (OOF) as Gaussian blur:



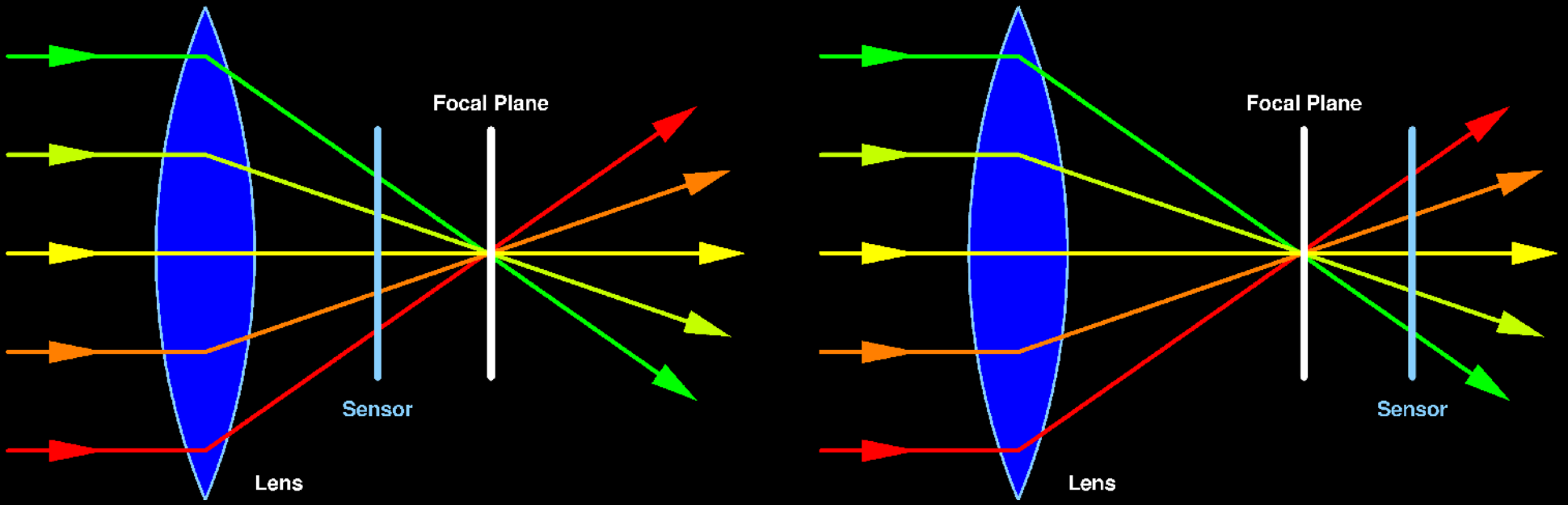
Out-Of-Focus Isn't Blurry!

- OOF point spread function (PSF) typically has a sharp edge!



Why The Sharp Edge?

The lens aperture **occuldes** rays:



PSFs, In Focus Or Not

- PSF describes the response of an imaging system to a point source (impulse response); it is the spatial domain representation of the modulation transfer function (MTF)
- Image is the sum of the **non-occulded parts** of the PSFs of all points of light in the scene
- What do OOF PSFs of real lenses look like?

Measuring OOF PSF

- Work in stable, dark, unobstructed, area
- Place point light source at 10m
  (often can use a white LED penlight)
- Manual focus to 1m, 2m, or 3m
- Expose to *show detail inside* OOF PSF

I've collected & measured **over 125 lenses**

Which Lenses? Fixed+Zoom

F (mm)	F/1	F/1.4	F/2	F/2.8	F/4	F/5.6	F/11
20				1	5+5	+3	1
24			1	4	1+1		
28				5	1+5		
40			4	2	2+5		
60	2	6	16	1	1+4	+3	
135		2	2	9+1	9+7	3+9	
250					3+7	+2	2
500					1	1+2	5

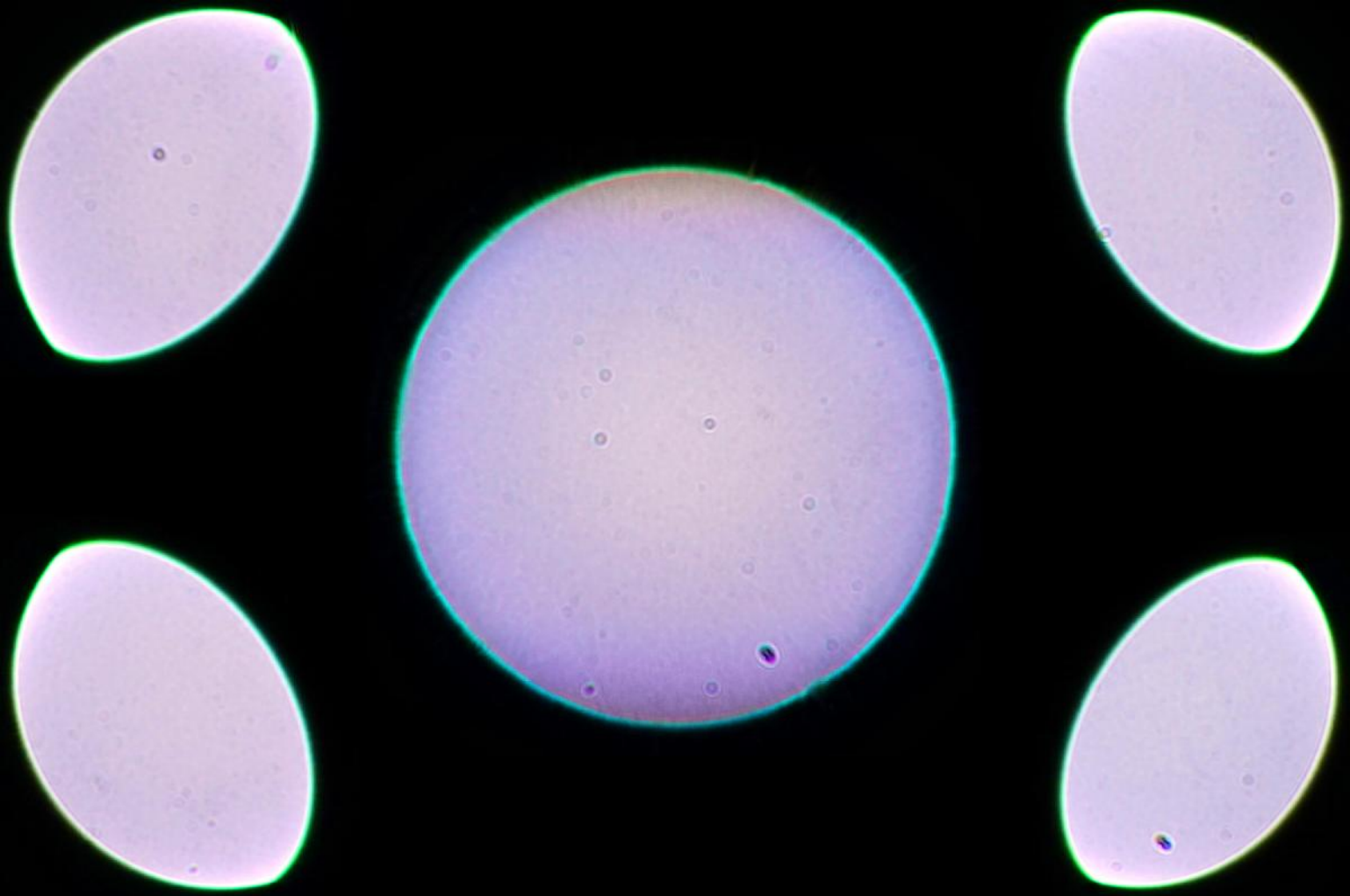
Why Bother?

- Justifies LBA to spouse ;-)
- OOF PSF is easy to measure
- OOF PSF is **not the same** for all lenses:
  - Diagnose inherent & acquired lens defects
  - Forensic applications
  - Recovery of depth & stereo capture
  - Predict & shape bokeh

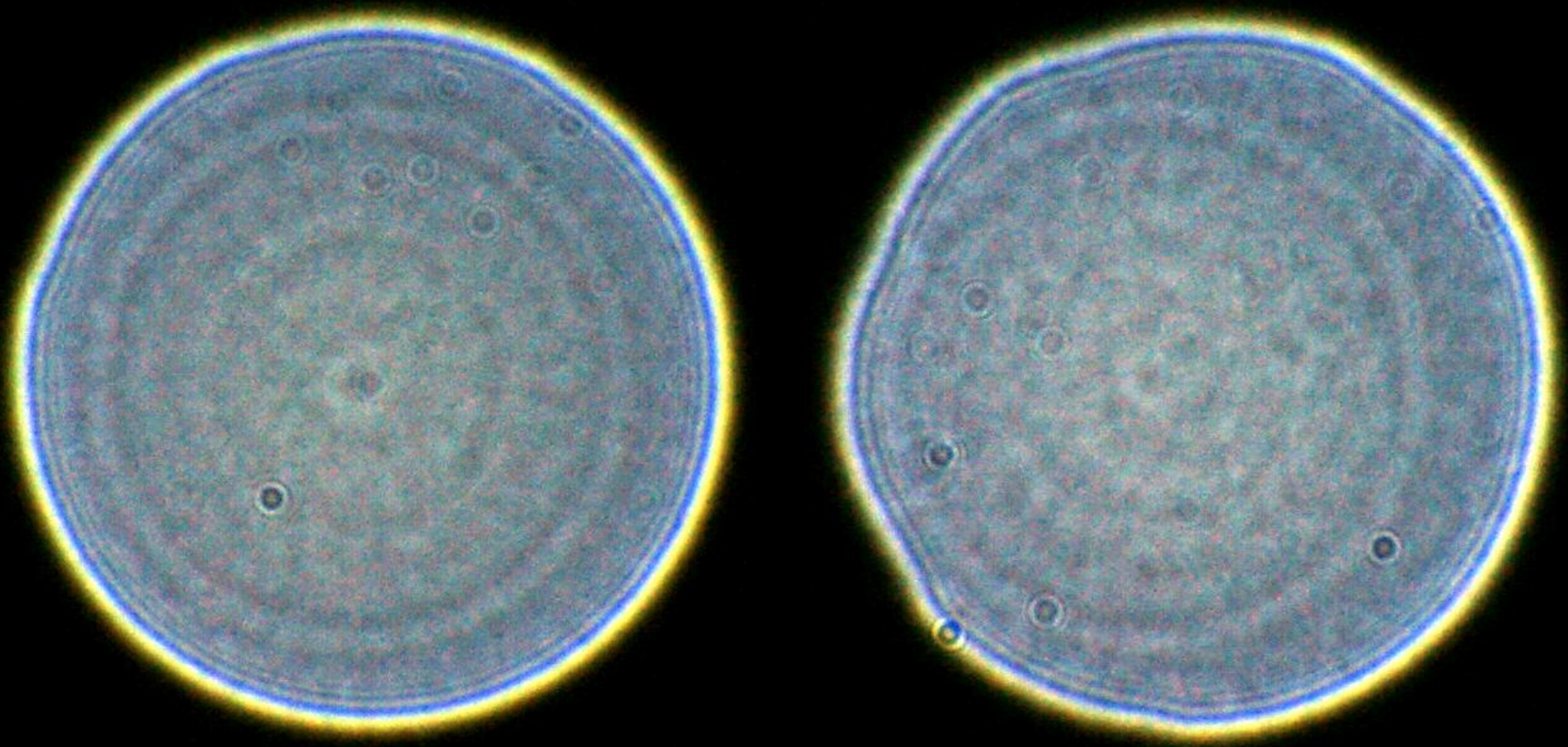
Diagnostic Use

- Ever buy a used lens?
- Two classes of lens defects:
  - Inherent from design or manufacture
  - Acquired from use, storage, and age

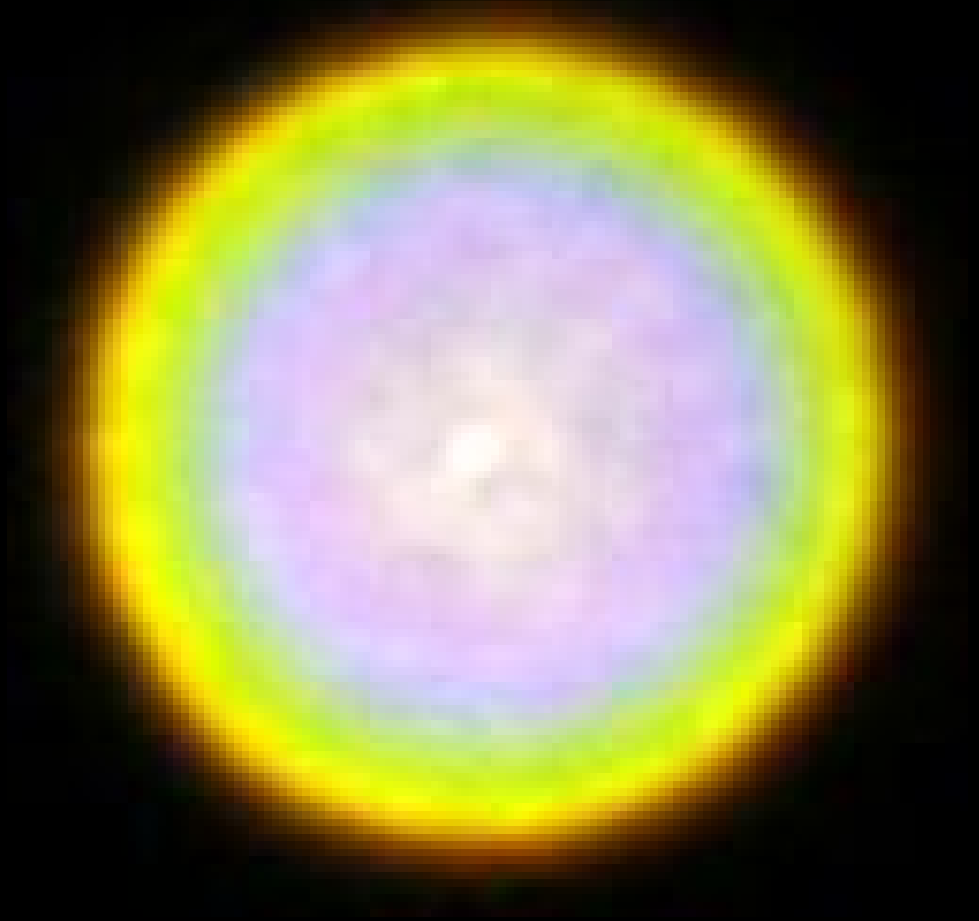
Vignetting



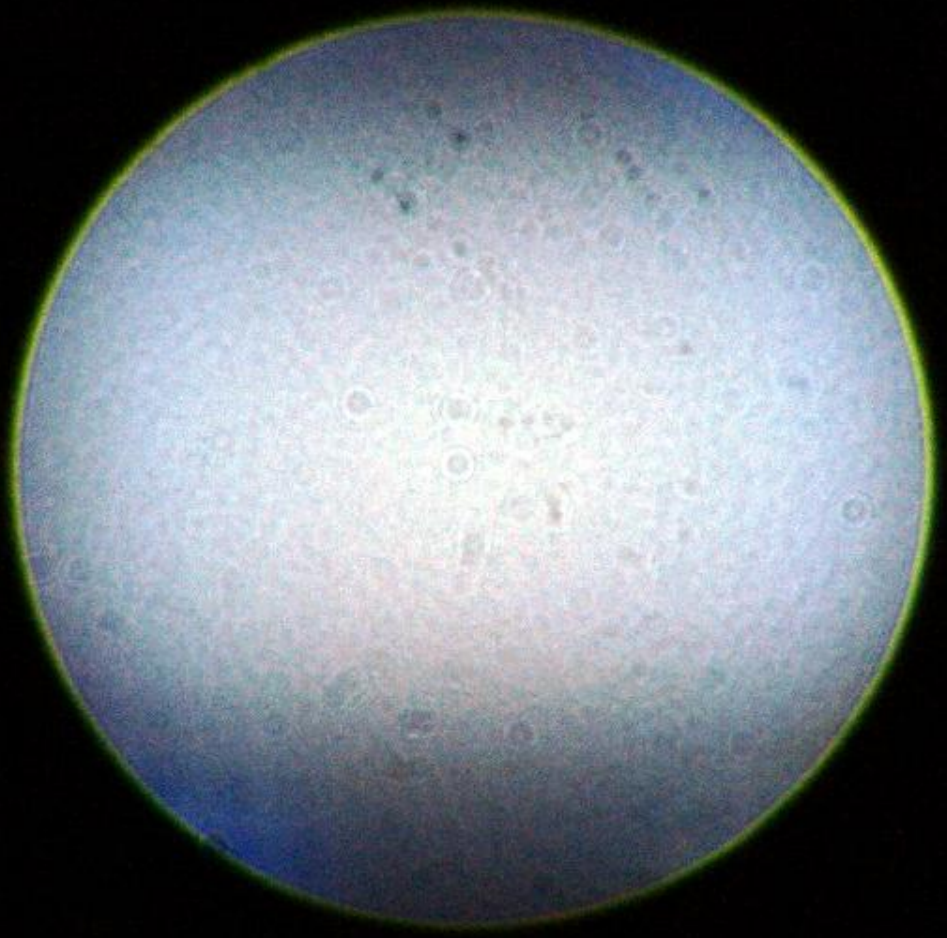
Decentering



Axial Chromatic Aberration

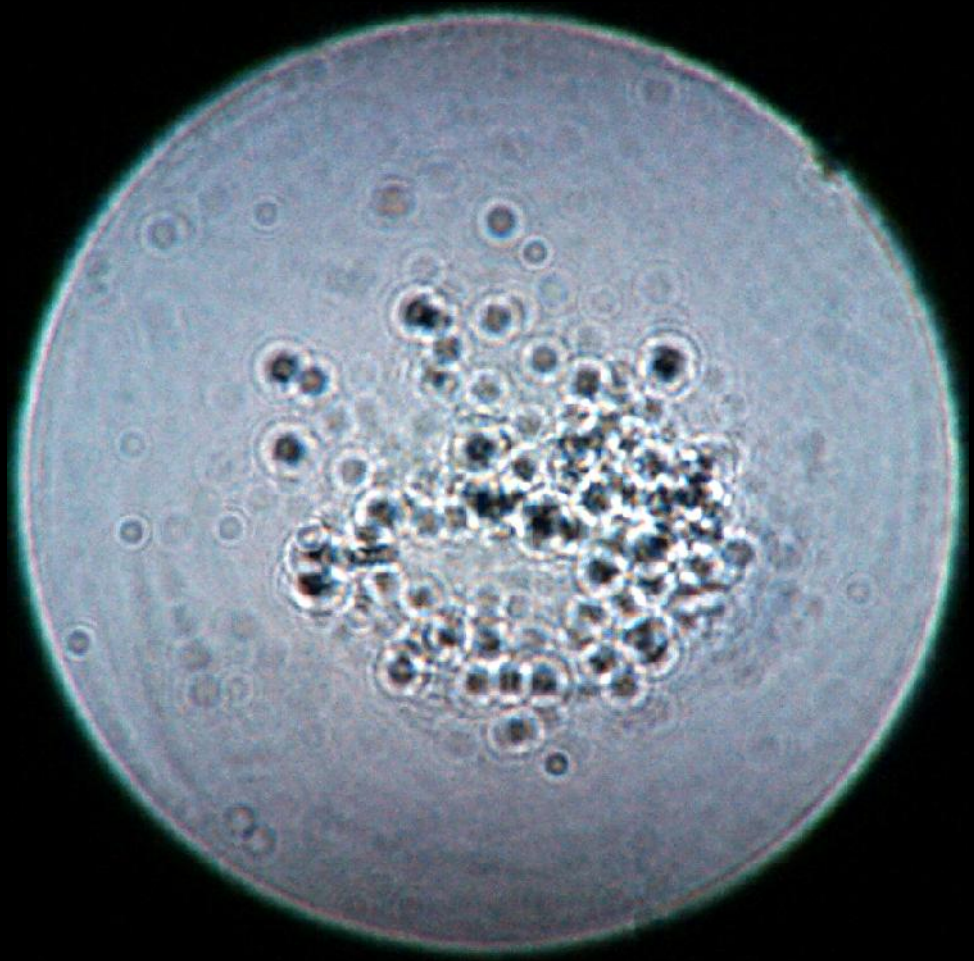


Undercorrected / Overcorrected Spherical Aberration

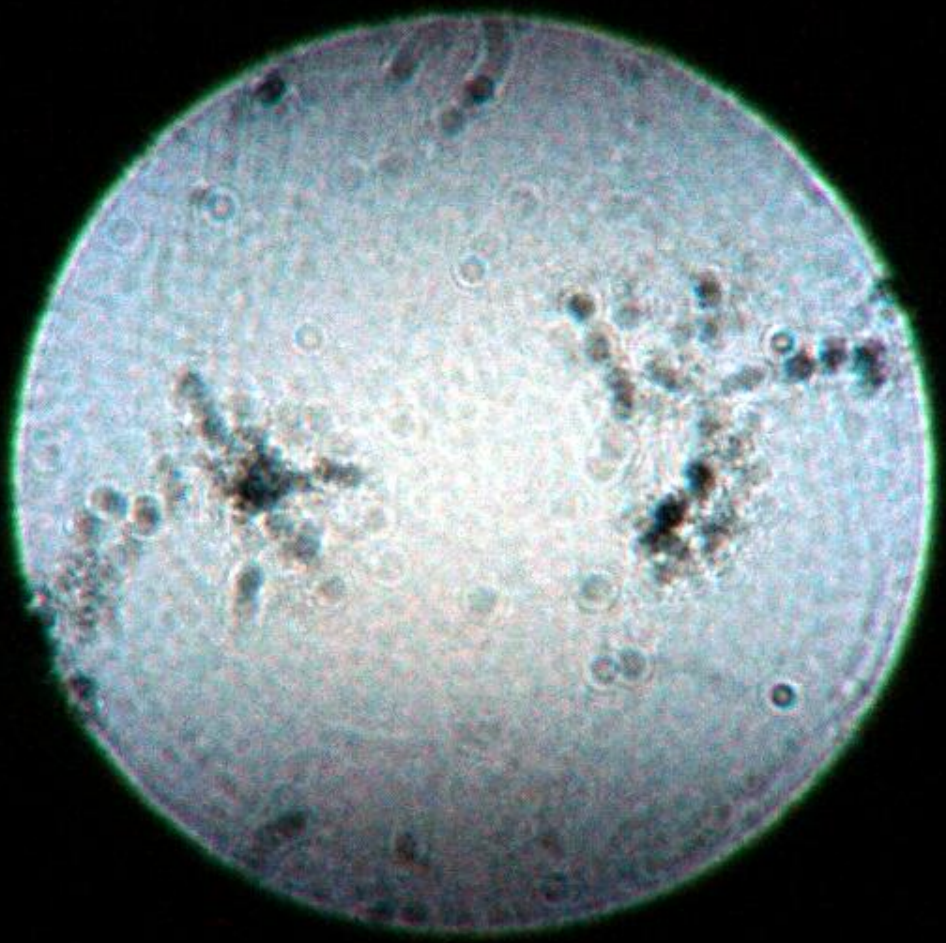


Dust & Dirt

Oily Fingerprint



Fungus Infection



Nicked Element

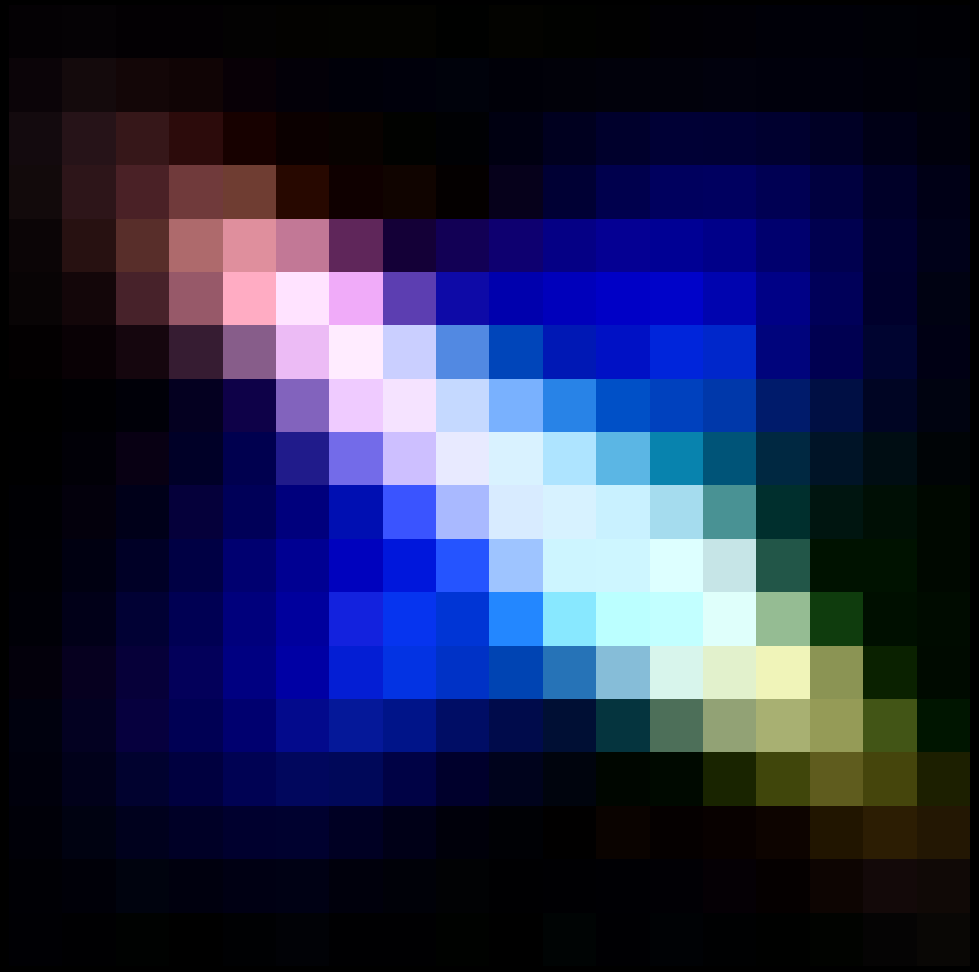
Element Separation

Forensic Use

- Identify faked images
- Make more credible fakes
  (e.g., for computer-generated movie effects)
- Identify the lens used:
  - Determine most likely **type** of lens
  - Distinguish between similar lenses
  - Acquired defects are “lens fingerprints”

Compact Camera Lens

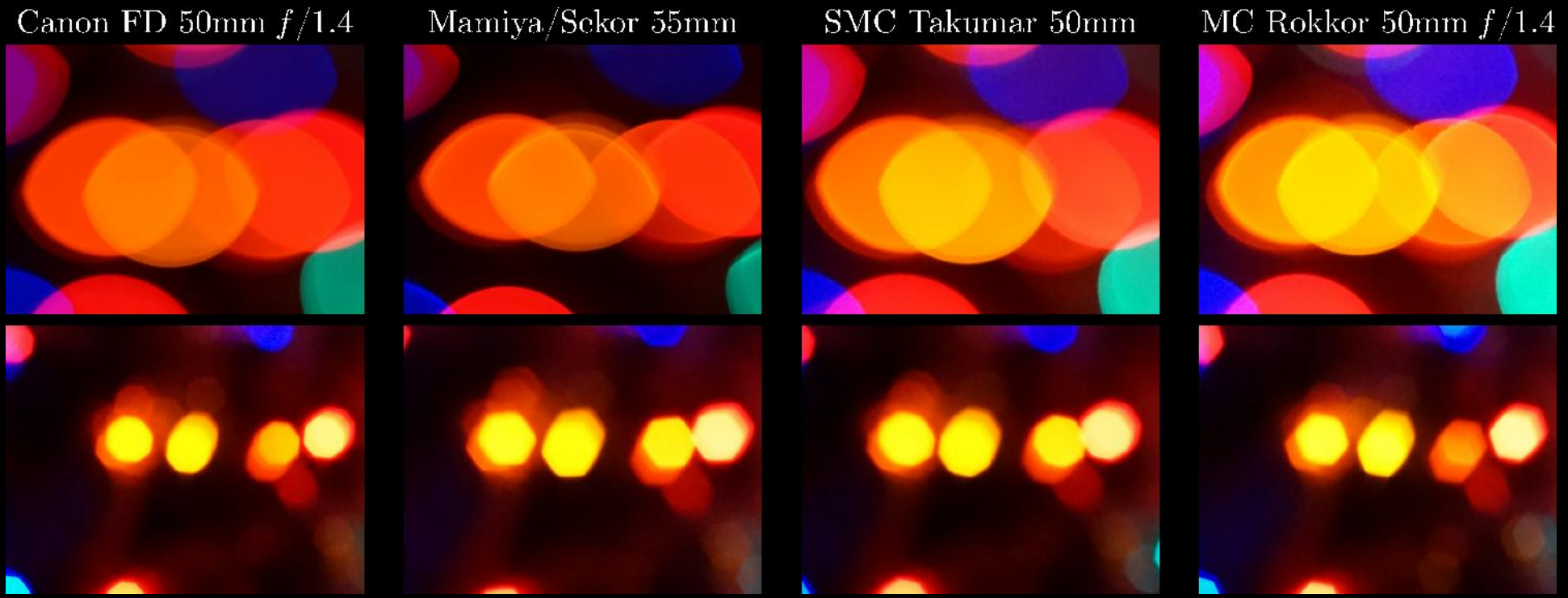
Ultrawide Zoom (corner)



Conventional Telephoto

Mirror Lens

Distinguishing Similar Lenses



- Four very similar lenses, @ *f*/1.4 and *f*/5.6
- Vignetting, blade count/shape/rotation...

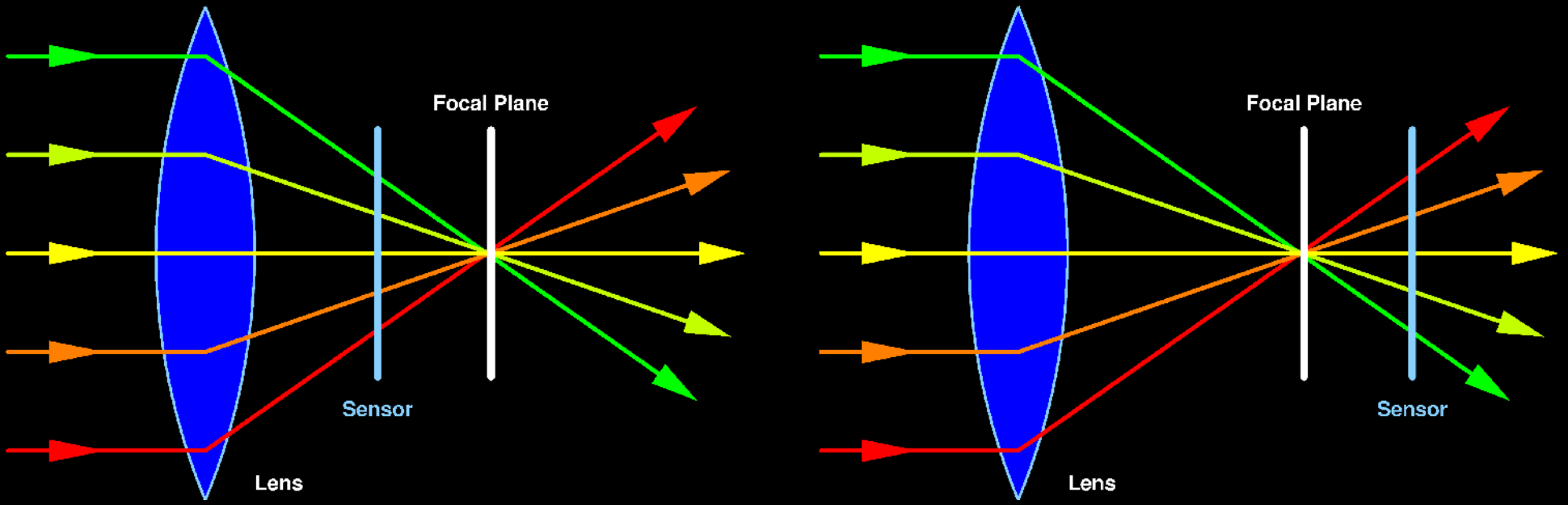
Recovery Of Depth

- Recognize OOF PSF pattern – not "blur"
- The **signed** diameter of the OOF PSF is:

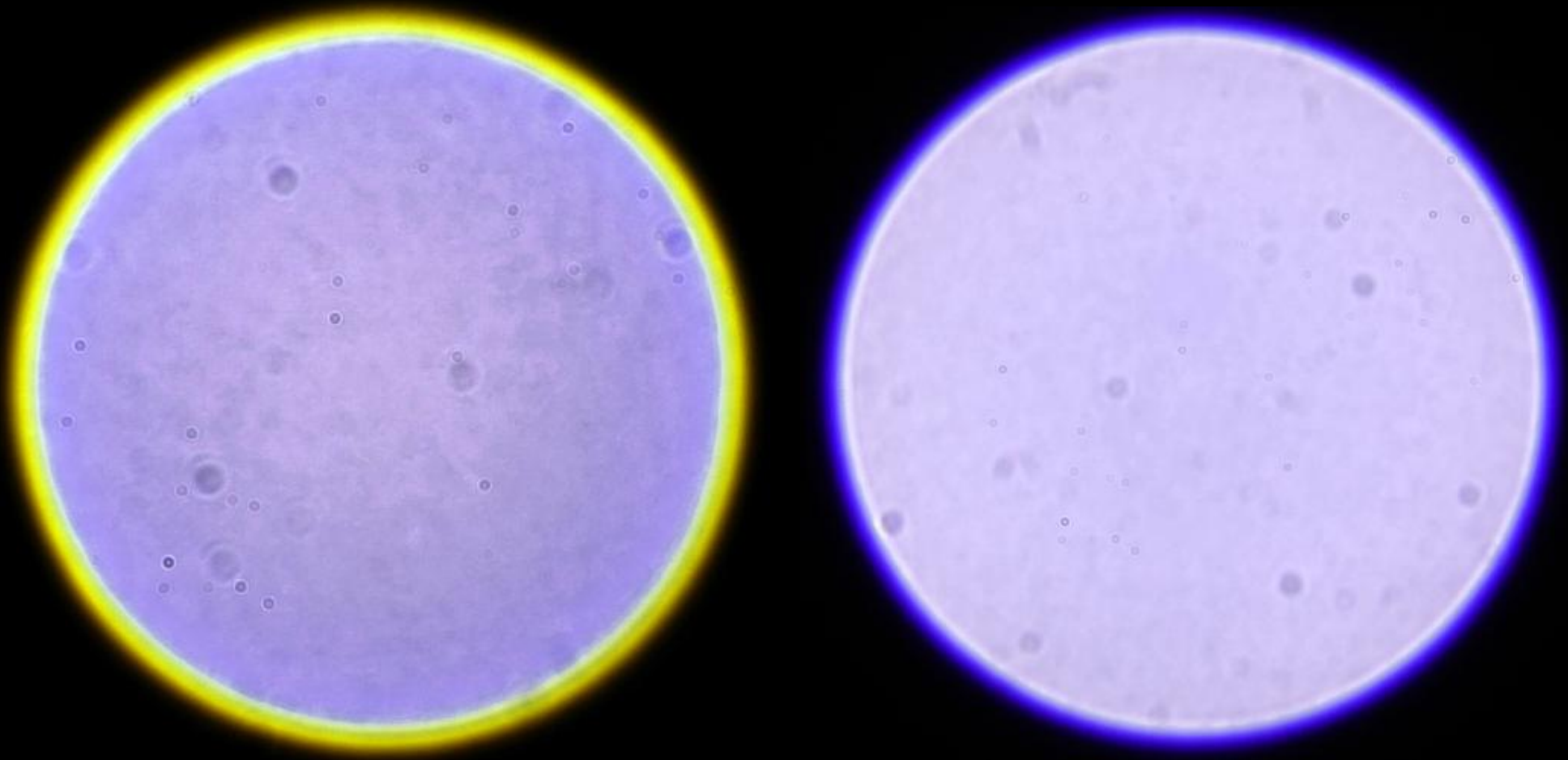
$$Const_1 - (Const_2 / ObjectDistance)$$

- How can we distinguish before/after focus?
  - Stuff in front can occlude stuff behind
  - OOF PSF is "turned inside out"

Before Or After Focus Point?

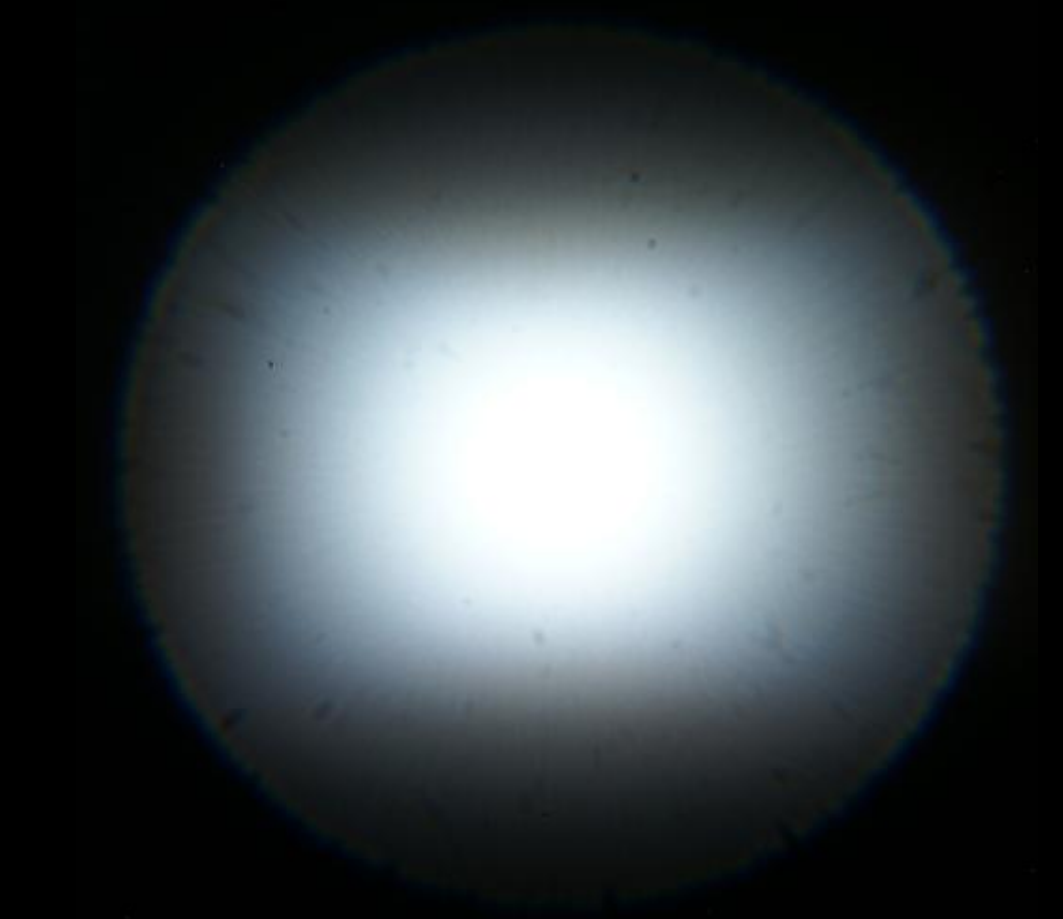


Axial CA After / Before Focus



Axial CA in a photo

Extreme Undercorrected SA, After / Before Focus



Extreme Undercorrected SA in a photo

Depth And Multiple Views

- Multiple viewpoints in OOF PSF can be computationally extracted
- Phase detect autofocus (PDAF) suggests direction & amount to change focus in one reading – so can OOF PSF recognition
- Light field can be extracted (similar to coded aperture or plenoptic)
- Stereo pairs can be extracted

Bokeh

- The properties of OOF regions of images
- Not about quantity or size of OOF things, hence often considered a “magical” property
- Good bokeh look smooth, bad don't
- Worst is nisen bokeh double line artifacts

Both Good & Bad Bokeh Here

OOF PSFs Make The Bokeh

- Bright center ⇒ good bokeh
- Bright outer ring ⇒ nisen bokeh
- Vignette + field curvature ⇒ “swirly” bokeh
- Axial CA ⇒ “bokeh CA”
- Can shape (apodize) OOF PSF to improve

Conclusion

- Out-of-focus really isn't blurry:
  measuring OOF PSFs is easy & worthwhile
- The OOF PSF tells you a lot about a lens...
  and about the scene (e.g., depth & stereo)
- Understanding & manipulating OOF PSF can enable things you couldn't do otherwise
- Lots of algorithms to develop...
- I guess Hank isn't going to show us all 125+ of his lenses....

Want To Know More?

Watch our research WWW site: