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Cameras
As Computing Systems

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Focus

University of Kentucky
Electrical & Computer Engineering

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What's so tricky about Focus?

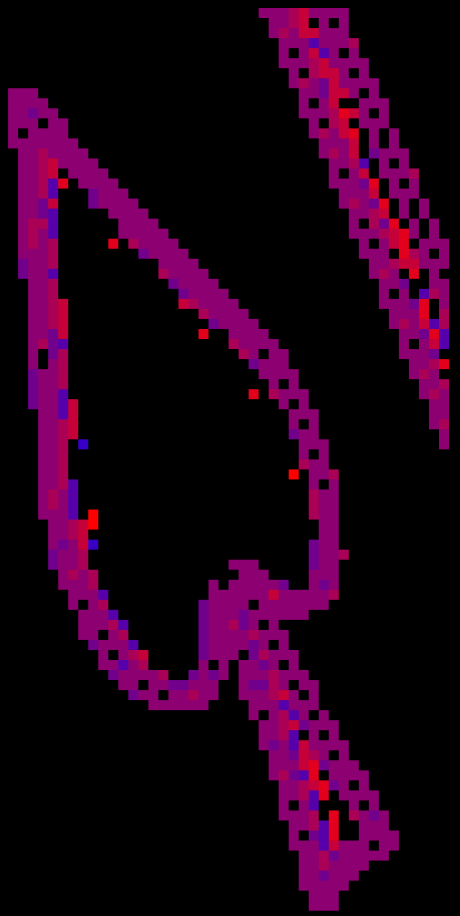
- PD: Phase Detection
- CD: Contrast Detection
- PSF (point spread function) Detection
- Autofocus algorithms
- Focus-priority (vs. shutter priority)
- Trap focus (catch in-focus)
- Focus Peaking
- Focus stacking
- Depth from focus / depth from defocus

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...



Point Spread Function (PSF)

- Describes the response of an imaging system to a point source (impulse response)
- PSF is the spatial domain representation of the modulation transfer function (MTF)
- An image is essentially the sum of the PSFs of all points of light in the scene
- What does a typical out-of-focus (OOF) PSF look like?

Measuring OOF PSF

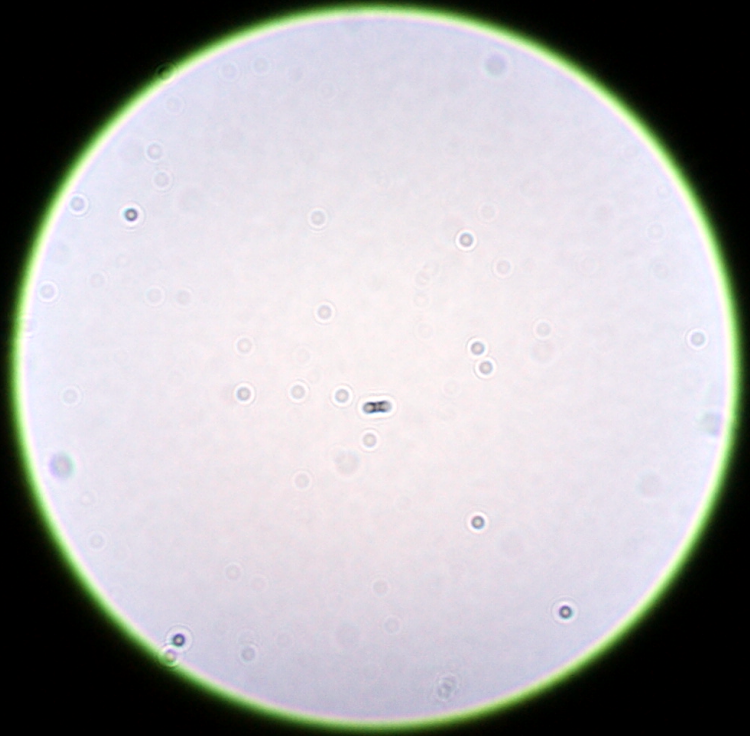
- Work in stable, dark, unobstructed, area
- Place point light source at 10m
  (often can use a white LED penlight)
- Manual focus to 1m, 2m, or 3m
- Expose to *show detail inside* OOF PSF

What Went Wrong?

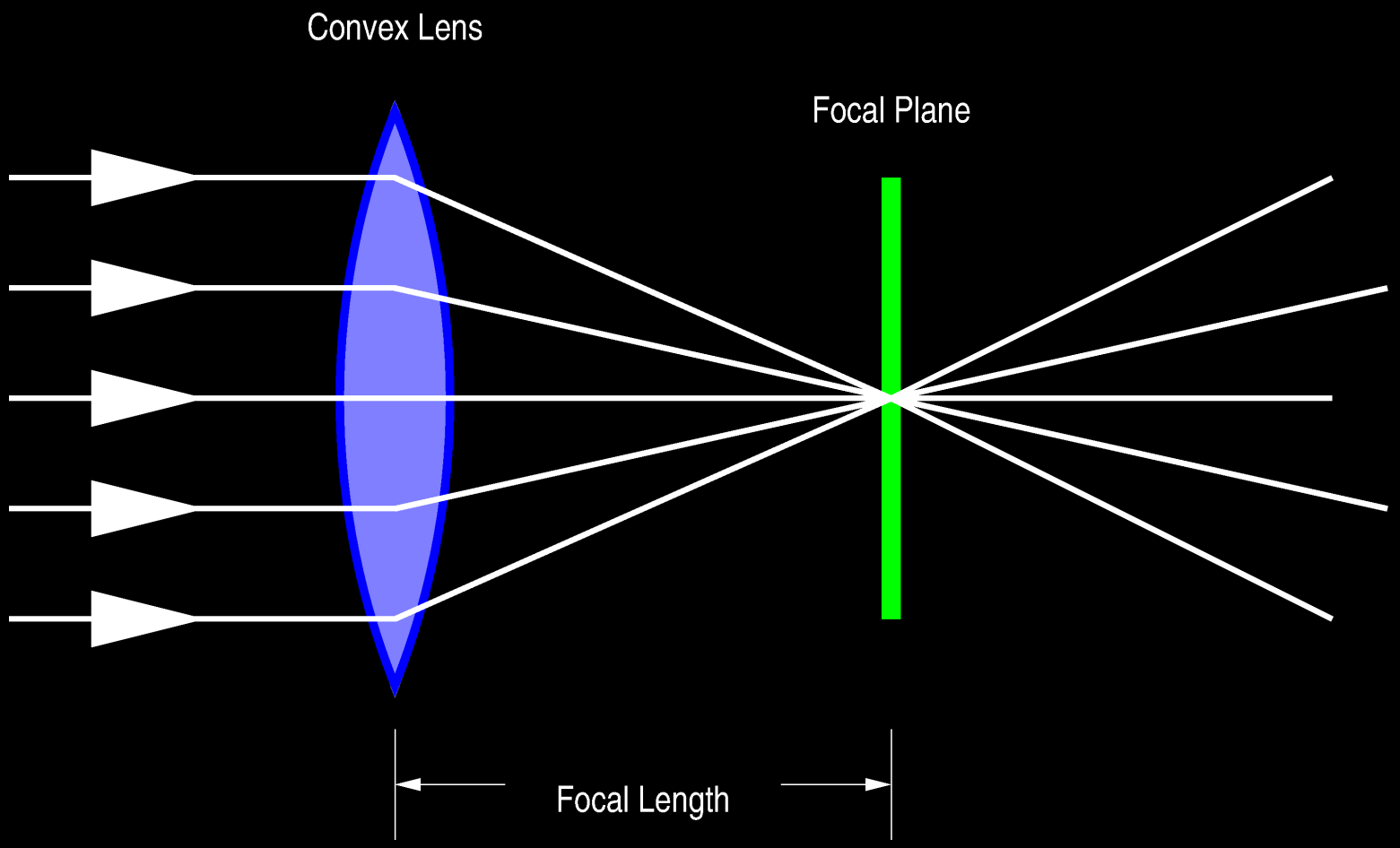
- Most image processing algorithms model OOF PSF as Gaussian blur:

Out-Of-Focus Isn't Blurry!

- OOF PSF typically has a sharp edge!



Why The Sharp Edge?



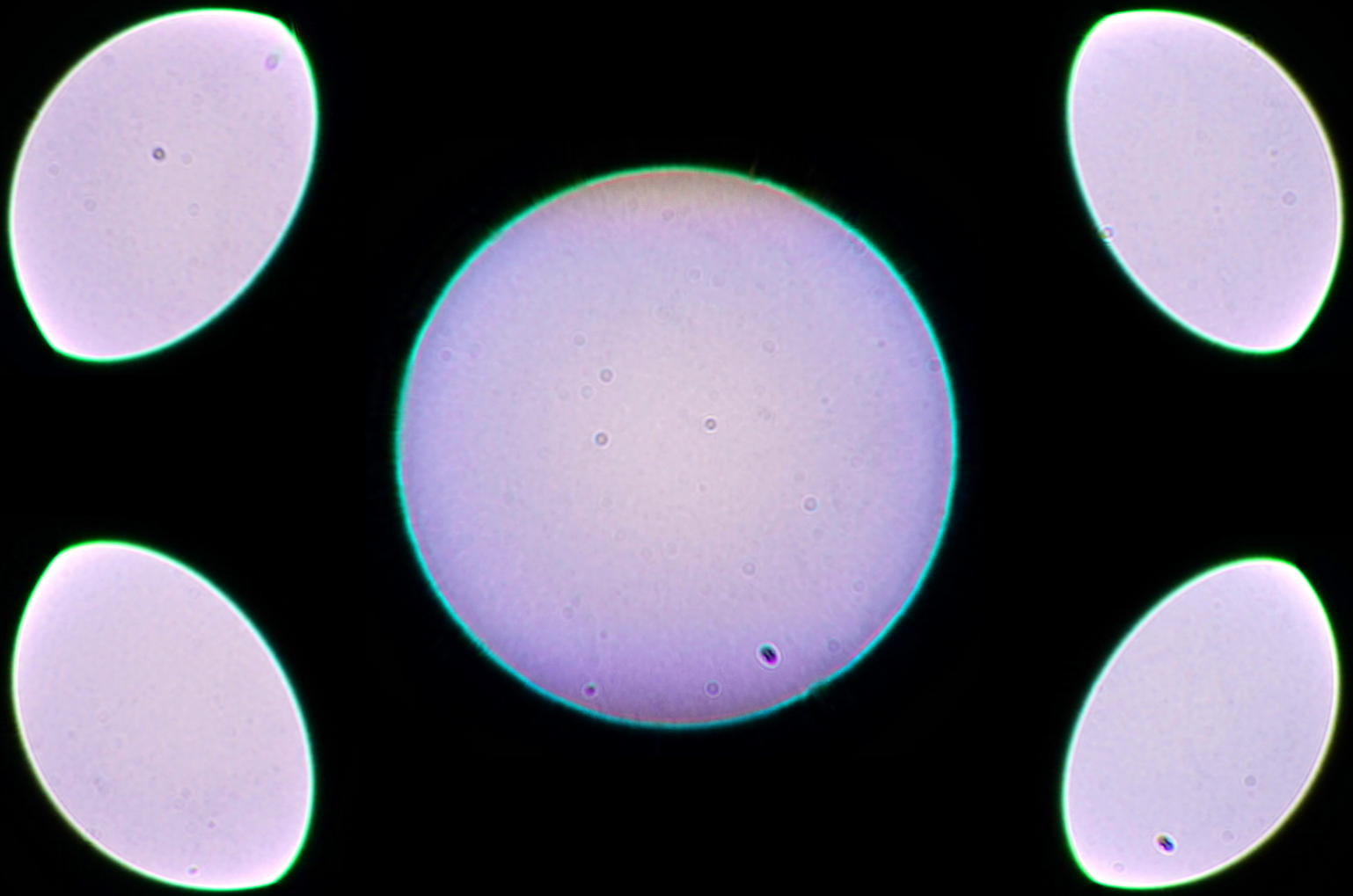
Why Should I Care?

- OOF PSF is easy to measure...
  collected and measured **125+ lenses**
- OOF PSF is **not the same** for all lenses:
  - Diagnose inherent & acquired lens defects
  - Forensic applications
  - Predict & shape bokeh
  - Recovery of depth & stereo capture

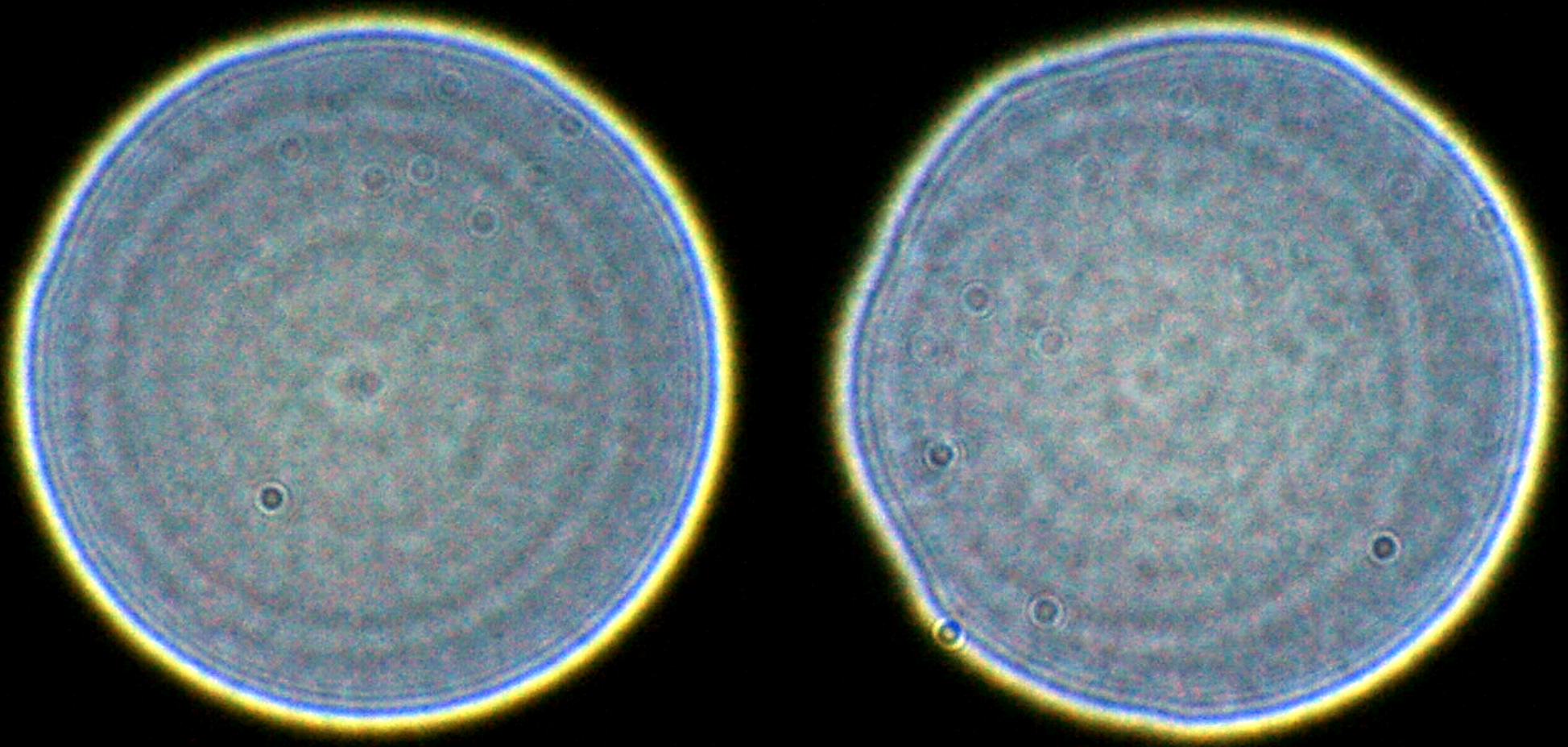
Diagnostic Use

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

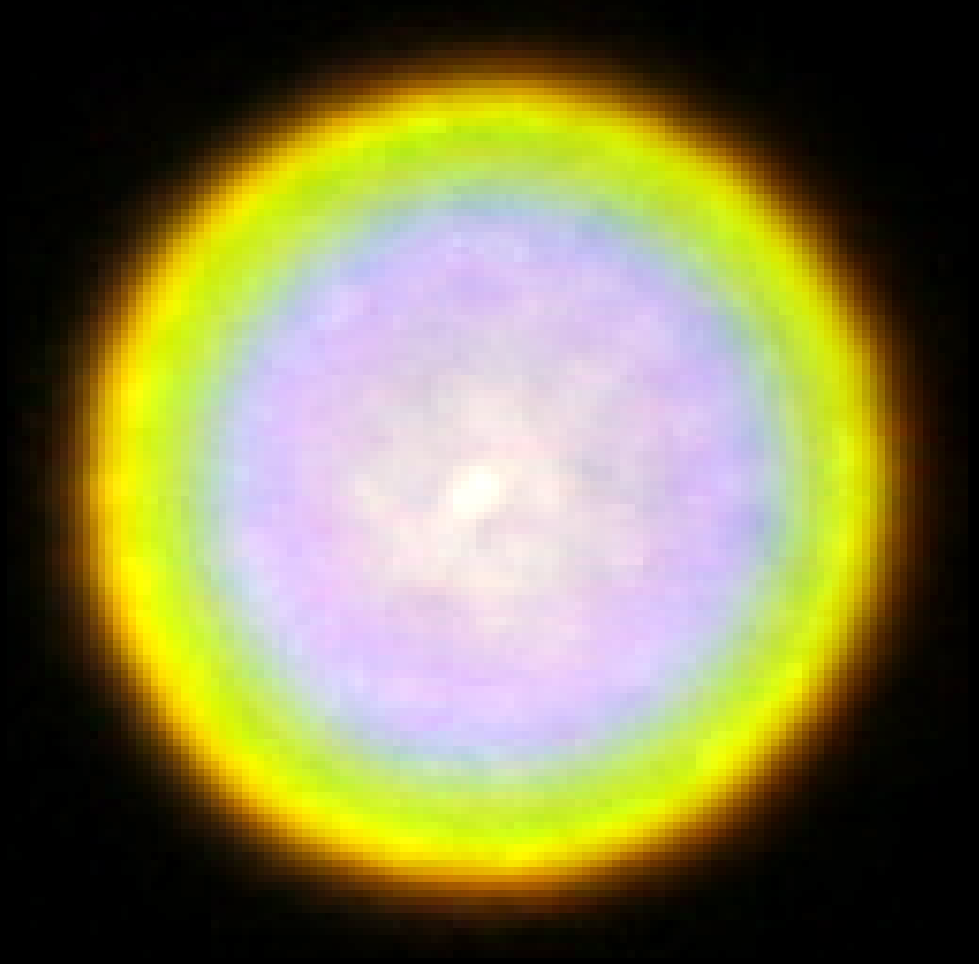
Vignetting



Decentering



Axial Chromatic Aberration



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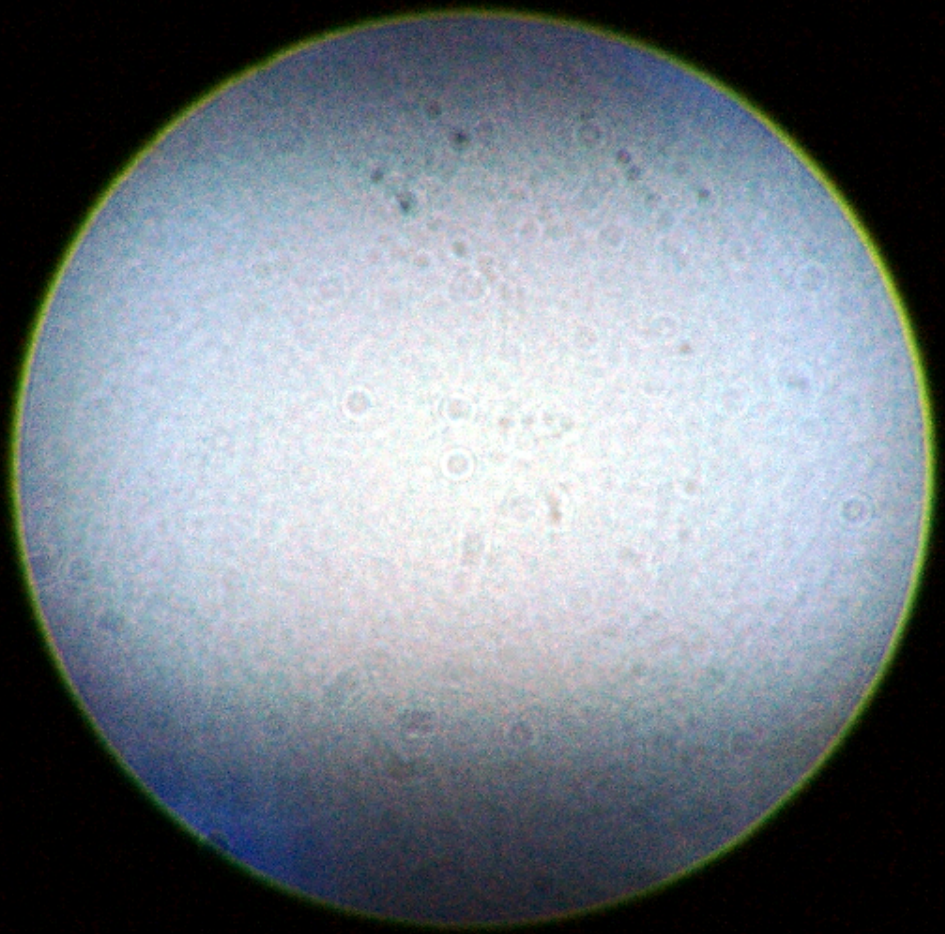
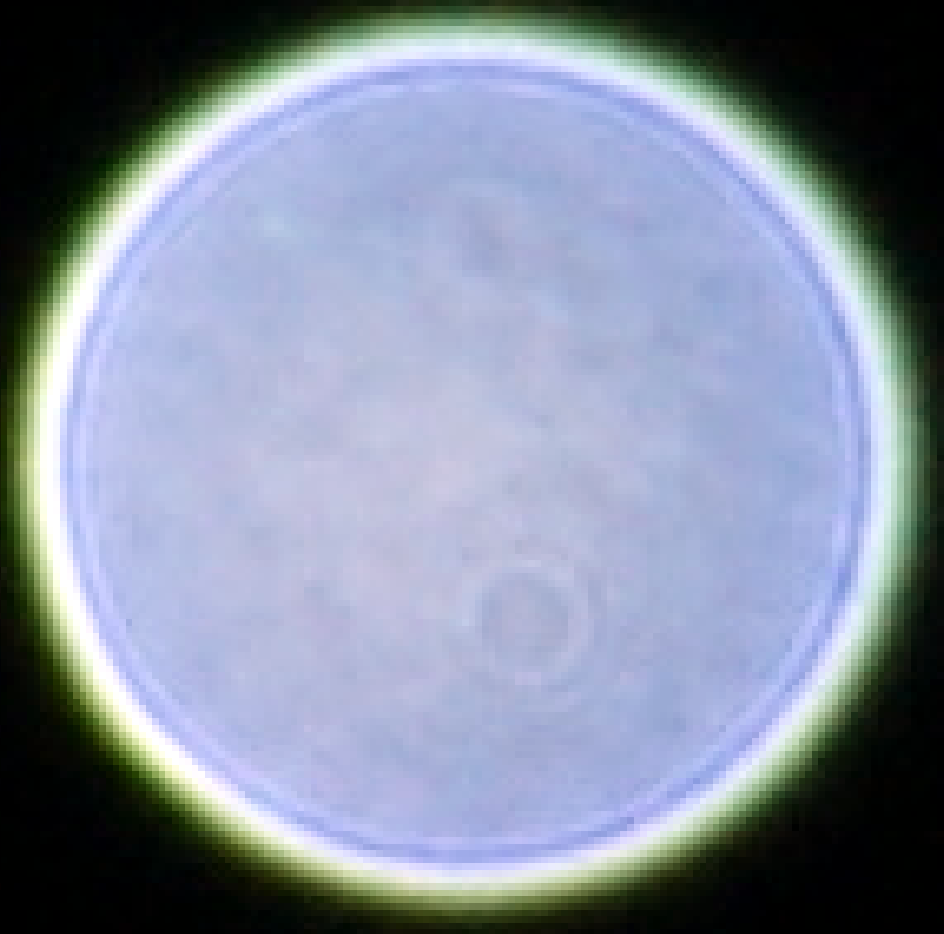
Undercorrected / Overcorrected Spherical Aberration





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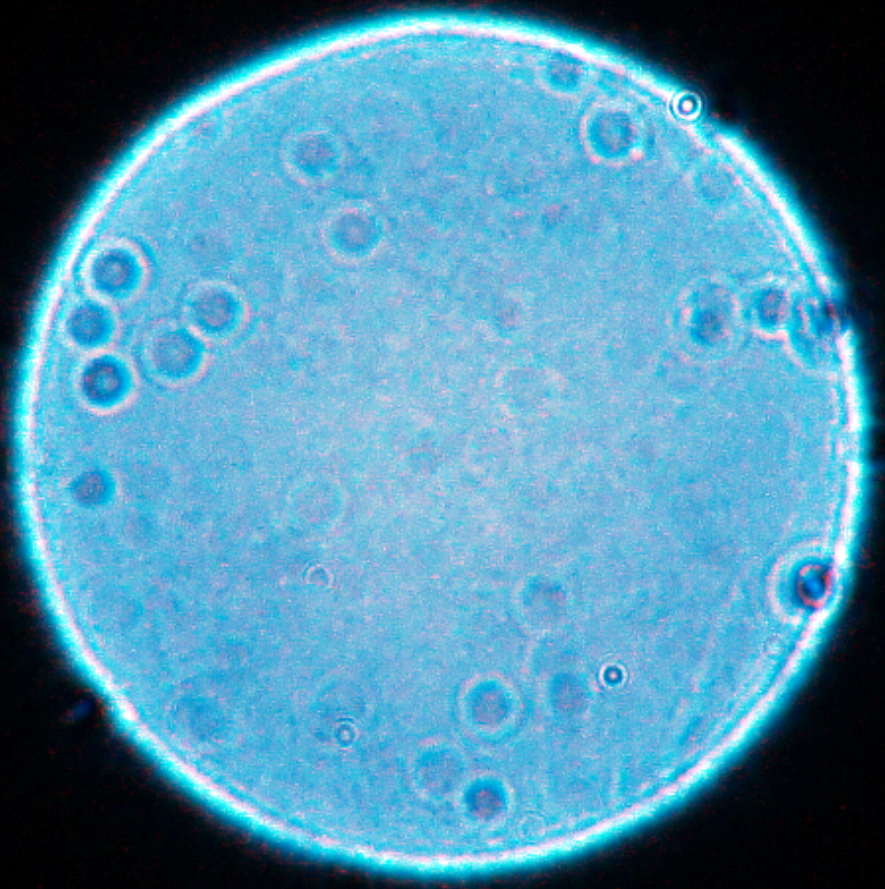
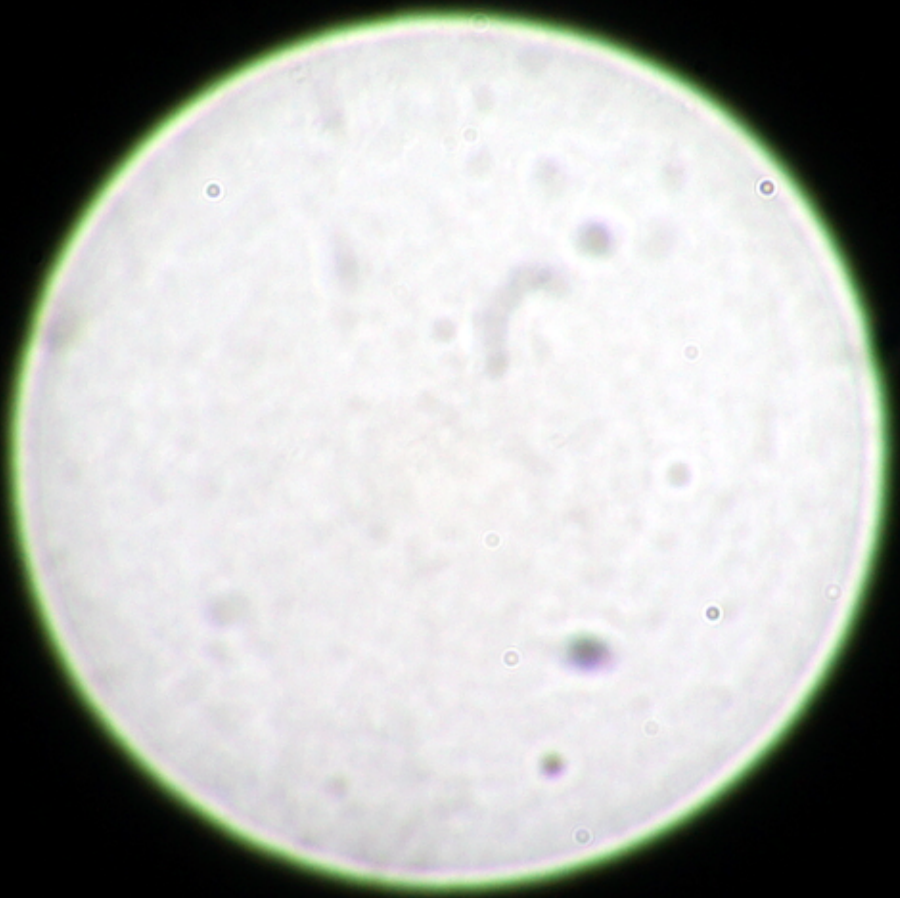
Dust & Dirt





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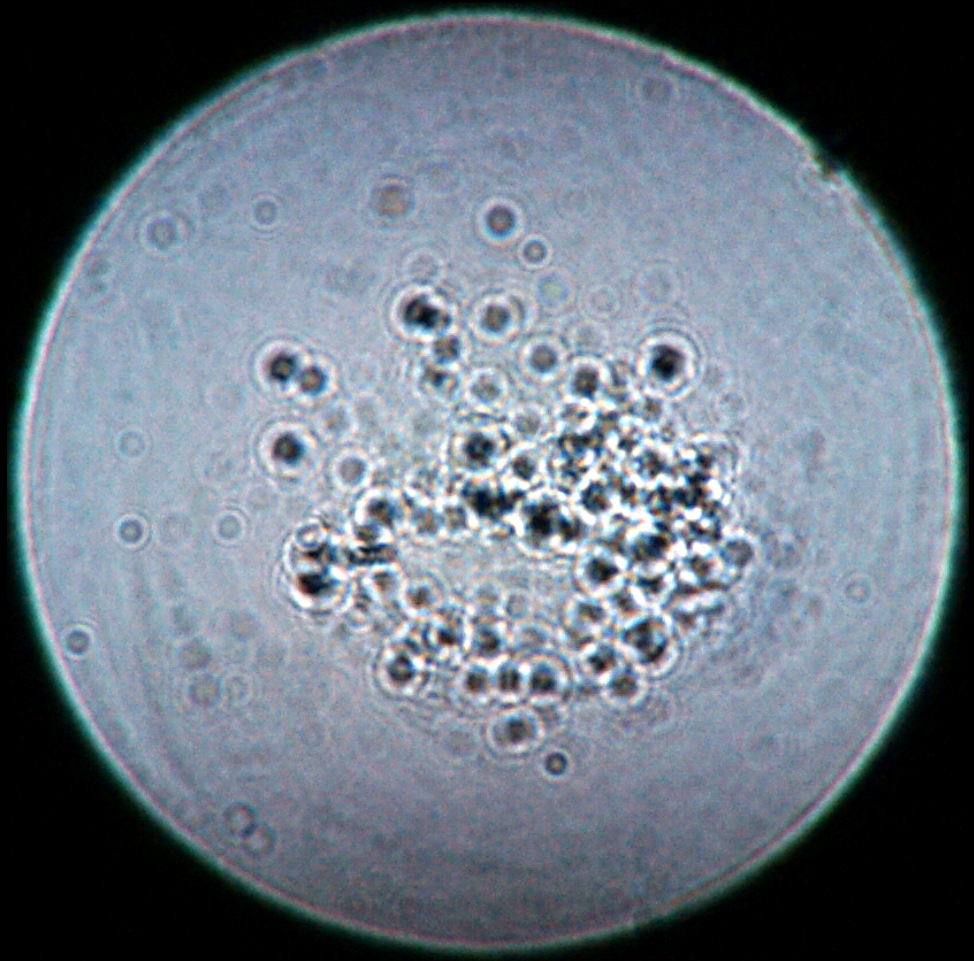
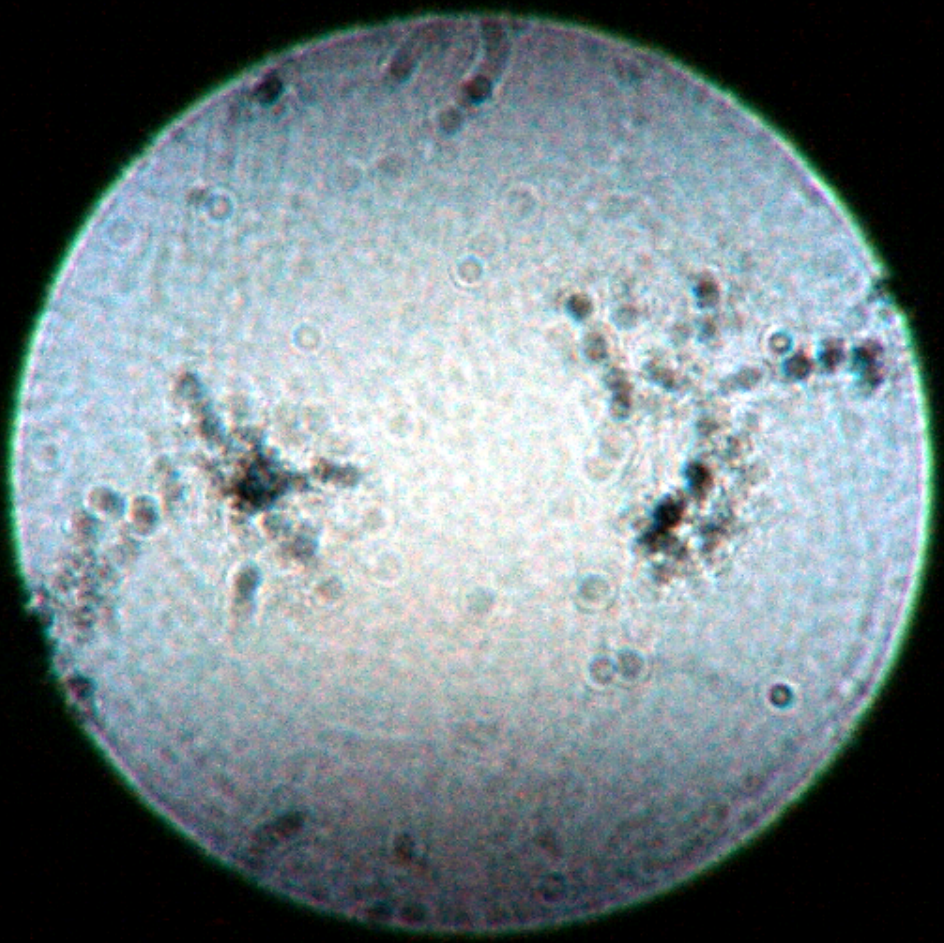
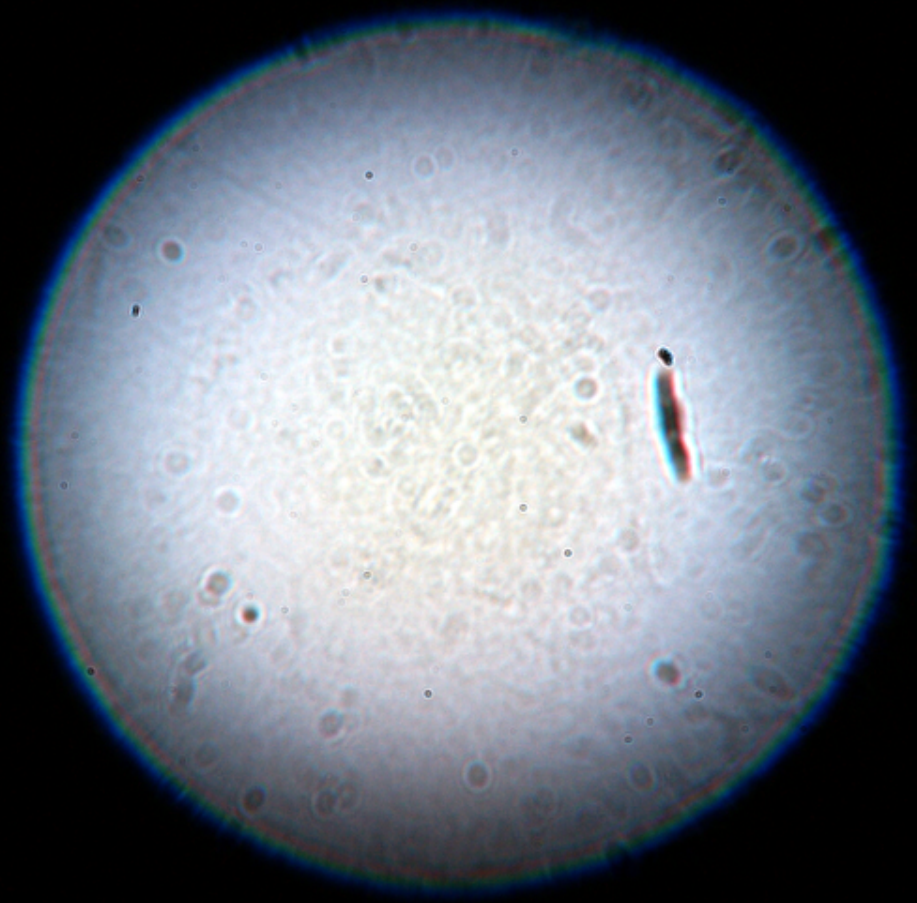
Oily Fingerprint



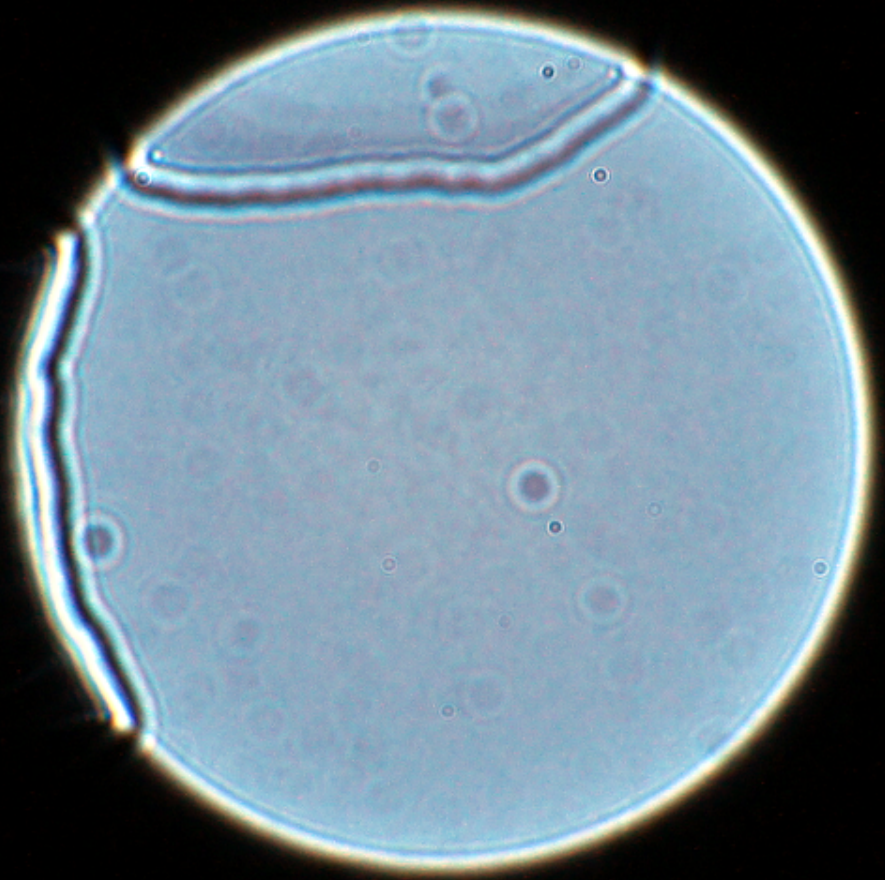
Fungus Infection



Nicked Element



Element Separation

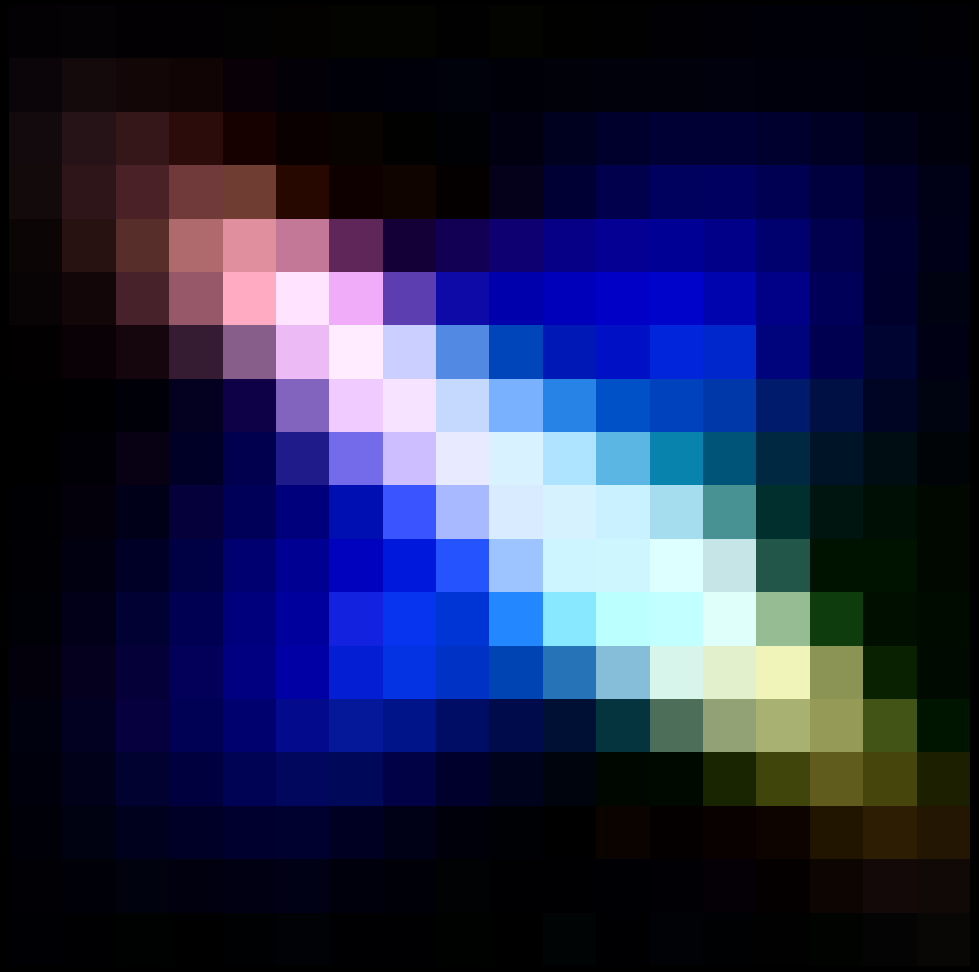


Forensic Use

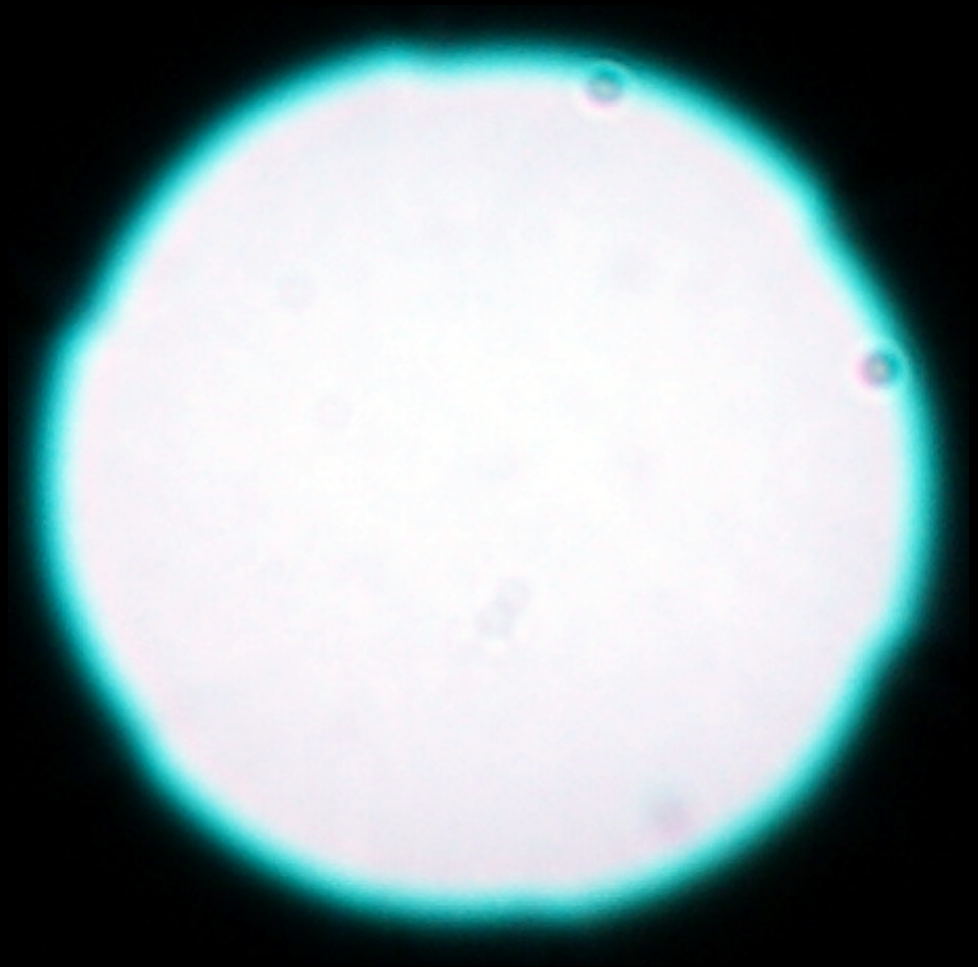
- Identify faked images
- Identify the lens used:
  - Defects as lens fingerprints
  - Distinguish most likely type of lens

Compact Camera Lens

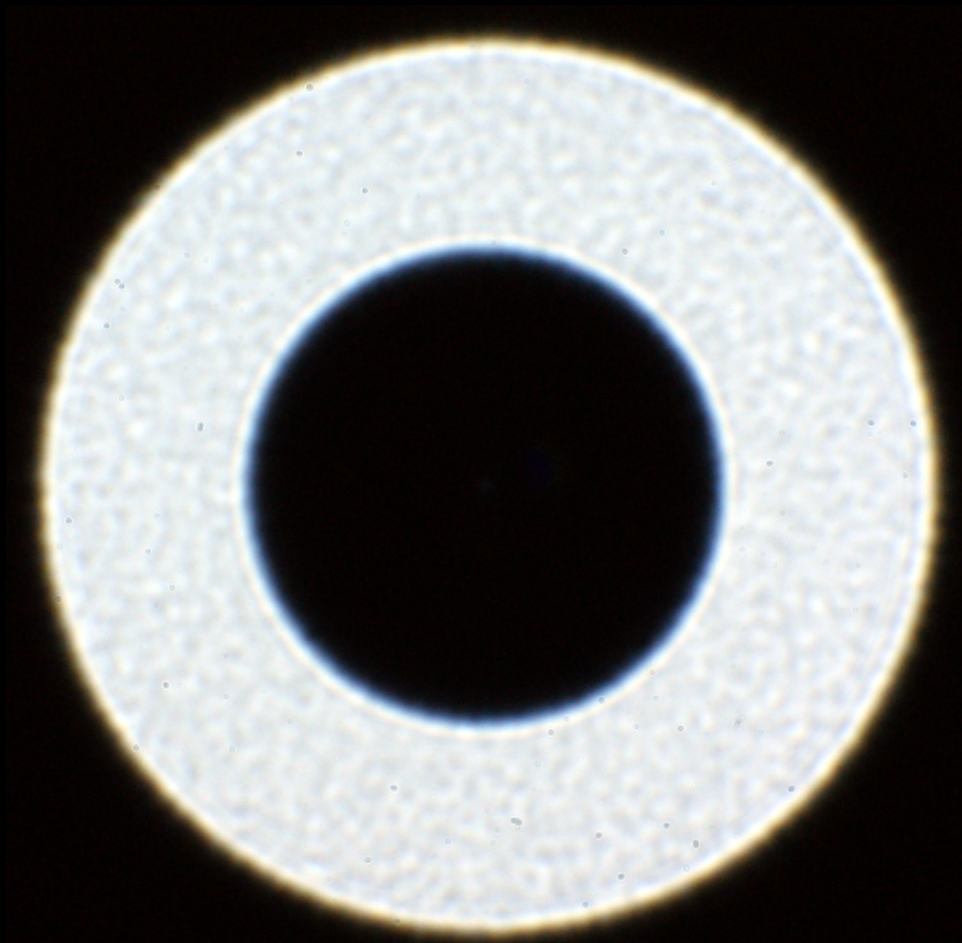
Ultrawide Zoom (corner)



Conventional Telephoto



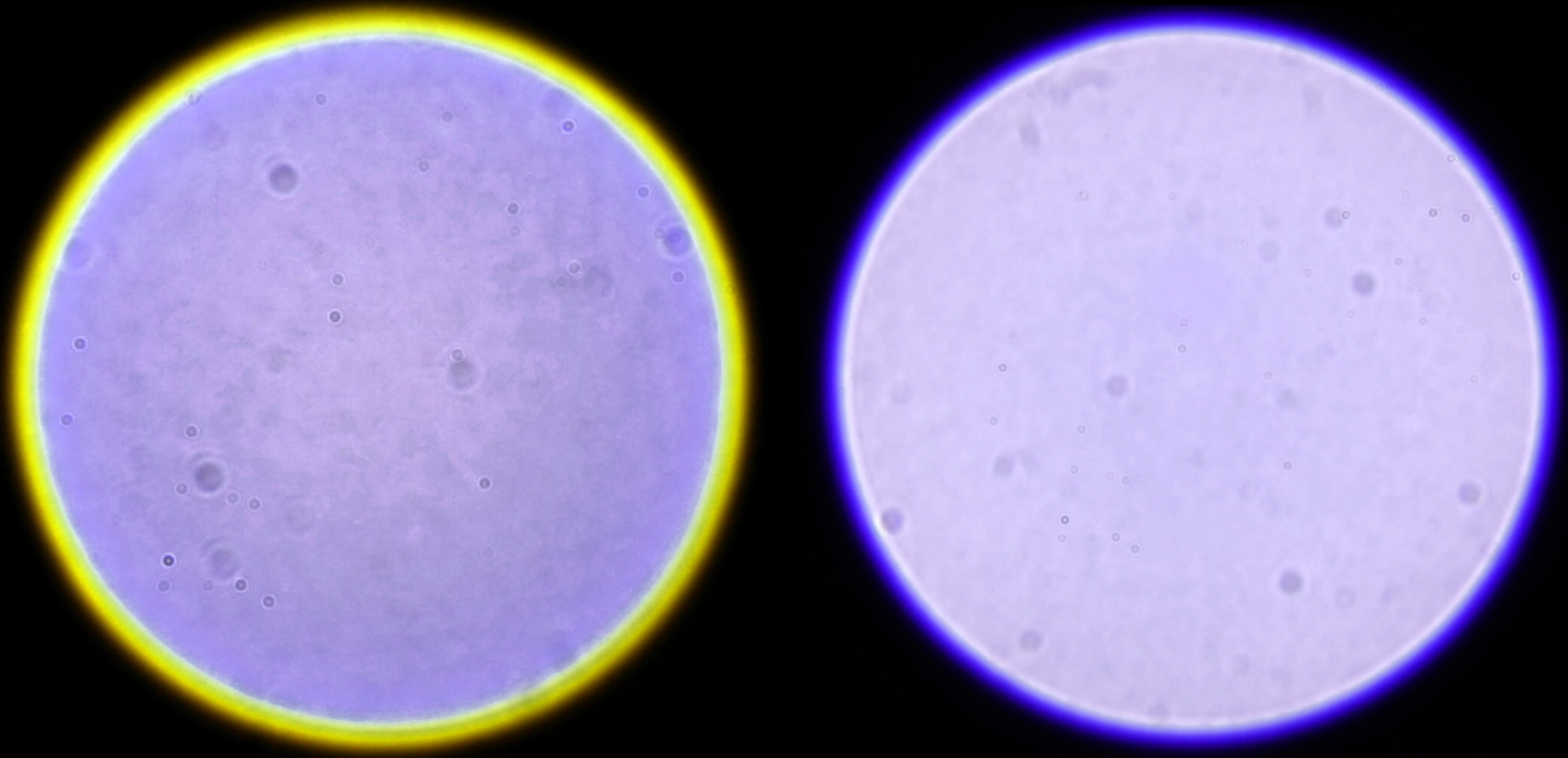
Mirror Lens



Bokeh

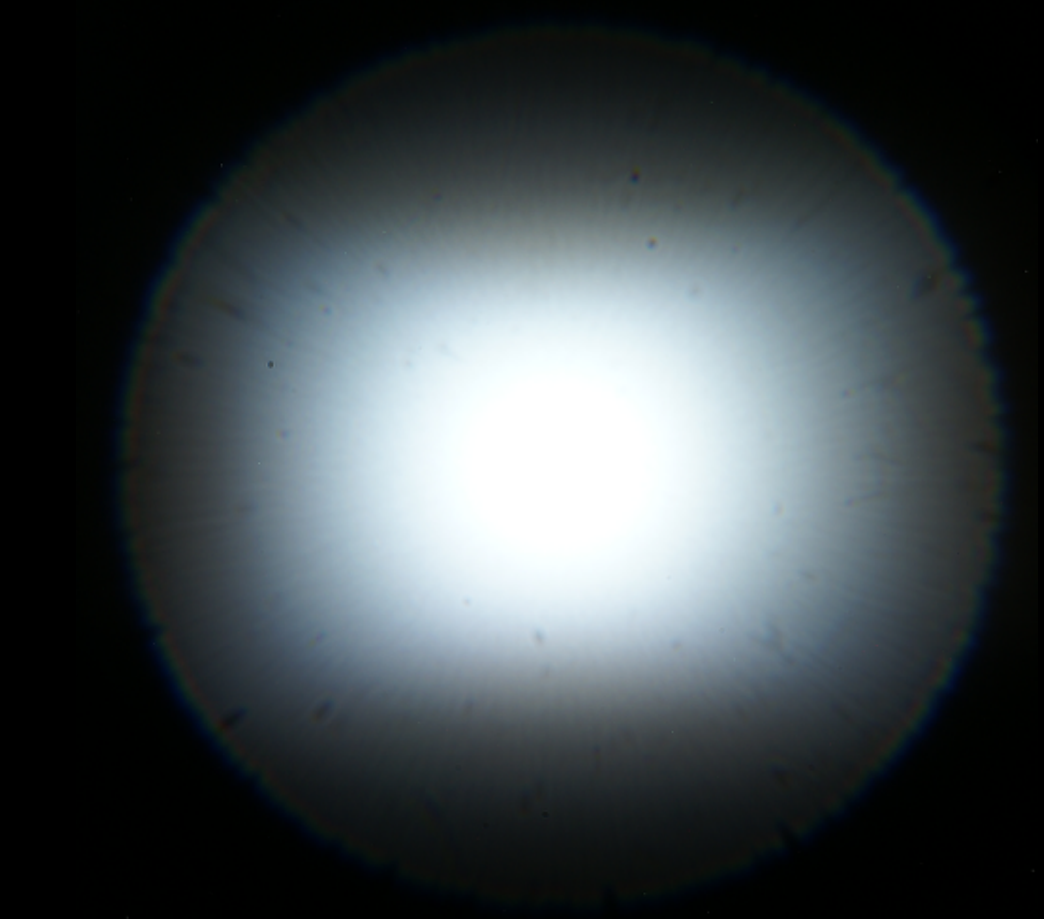
- The properties of OOF regions of images
  - Not about quantity or size of OOF things
  - Good bokeh look smooth, bad don't
  - Worst is nisen bokeh double line artifacts
- OOF PSF define most bokeh properties:
  - Bright center ⇒ good bokeh
  - Bright outer ring ⇒ nisen bokeh
  - Vignette + field curvature ⇒ “swirly” bokeh
  - Axial CA ⇒ “bokeh CA”

Axial CA After / Before Focus



Axial CA in a photo

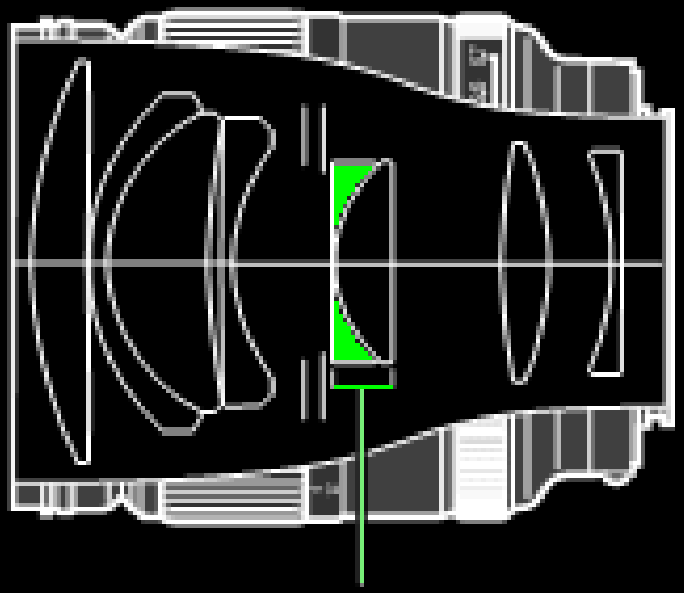
Extreme Undercorrected SA, After / Before Focus



Extreme Undercorrected SA in a photo

Minolta's STF Apodization (Smooth Trans Focus)

- The Sony/Minolta 135mm f/2.8 t/4.5 STF incorporates an apodizing element



Dynamic Apodization

- Minolta Maxxum 7 STF mode (Custom 25-2)
- Multiple exposure with varying aperture

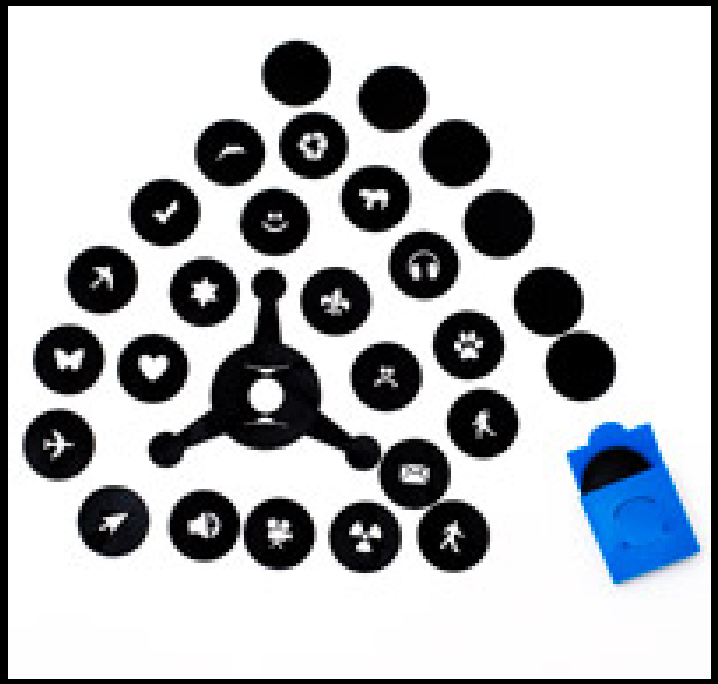
Apertures For Soft Focus

Imagon & Fujinon “Sink Strainer” apertures

(photos from mflenses.com and m42.org)

Apertures For Bokeh Effects

E.g., from `bokehmasterskit.com`

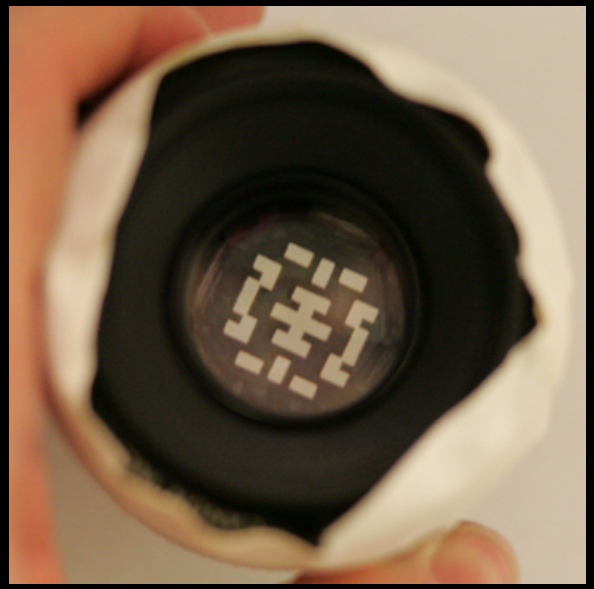


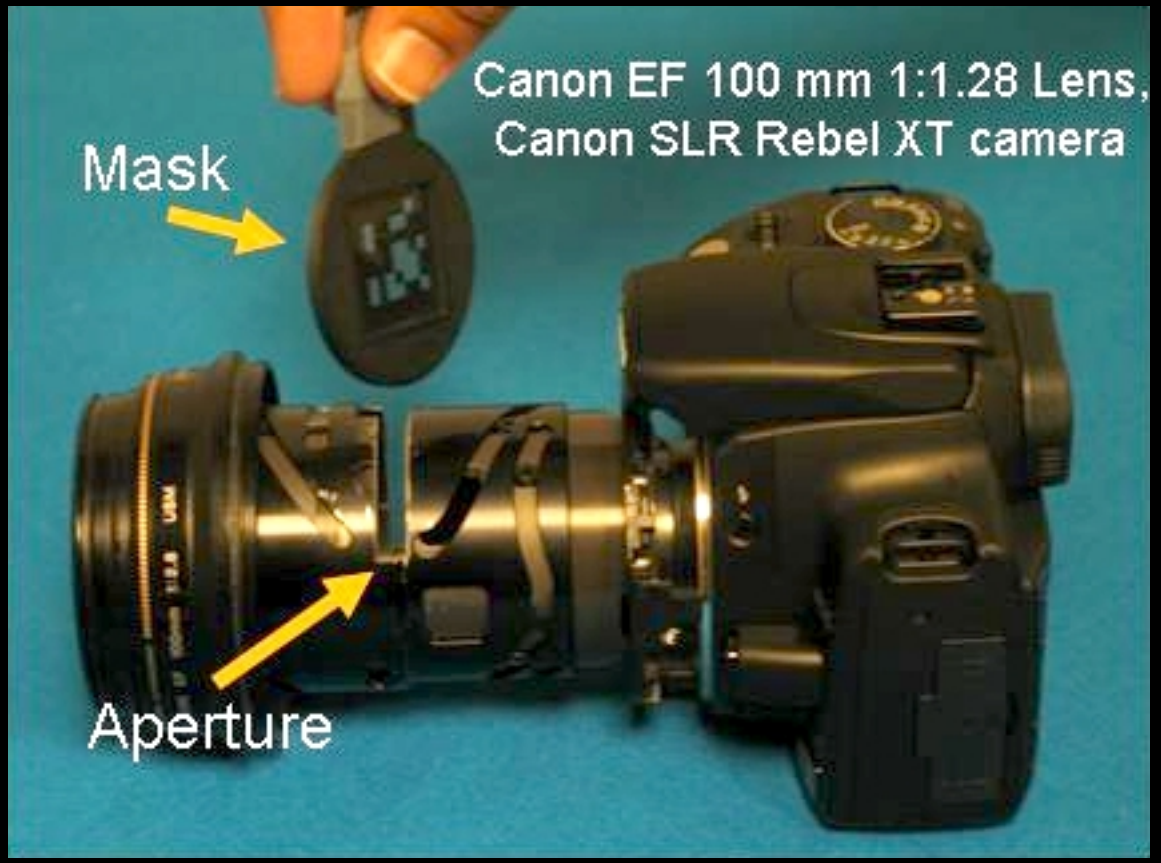
Depth & Stereo Capture

- OOF “blur” is really multiple viewpoints not converging at the film/sensor plane
- Diameter of OOF PSF encodes distance: *Diameter=const1-(const2/ObjectDistance)*
- Sign of *Diameter* encodes before/after focus
- OOF viewpoints encode stereo pair data and can be recovered by computation

Coded Aperture Deconvolution

(images from MIT CSAIL)

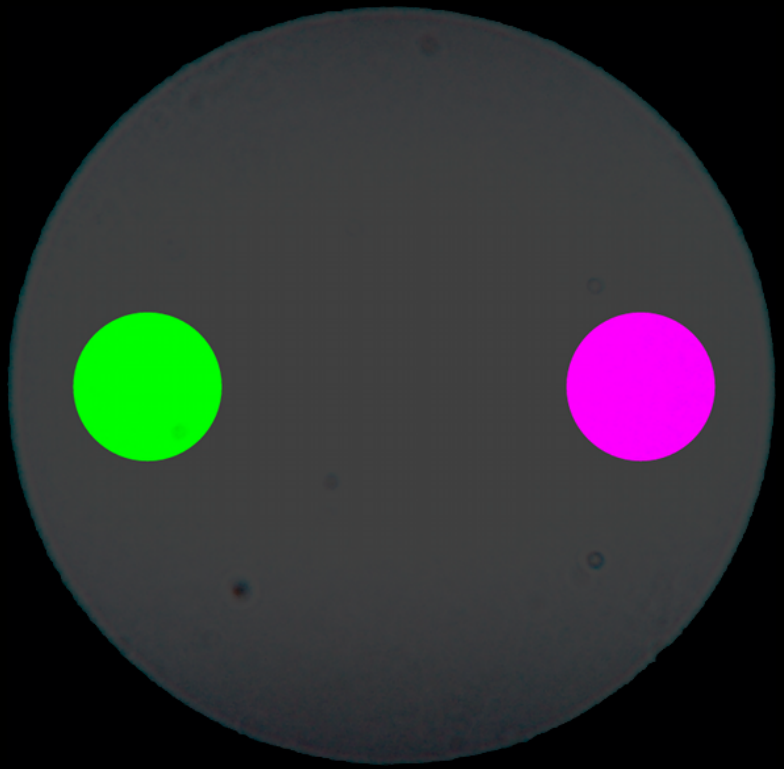


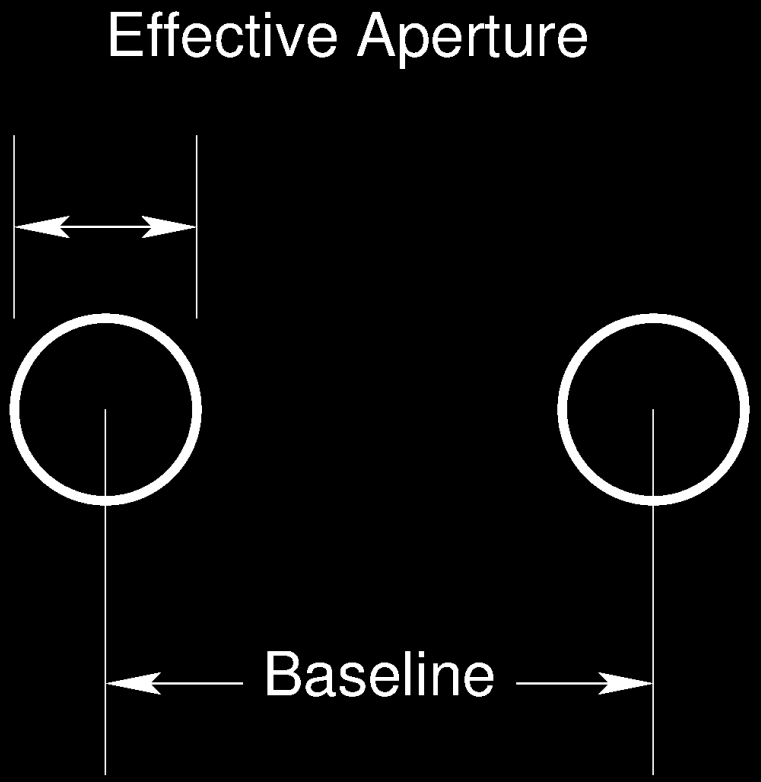


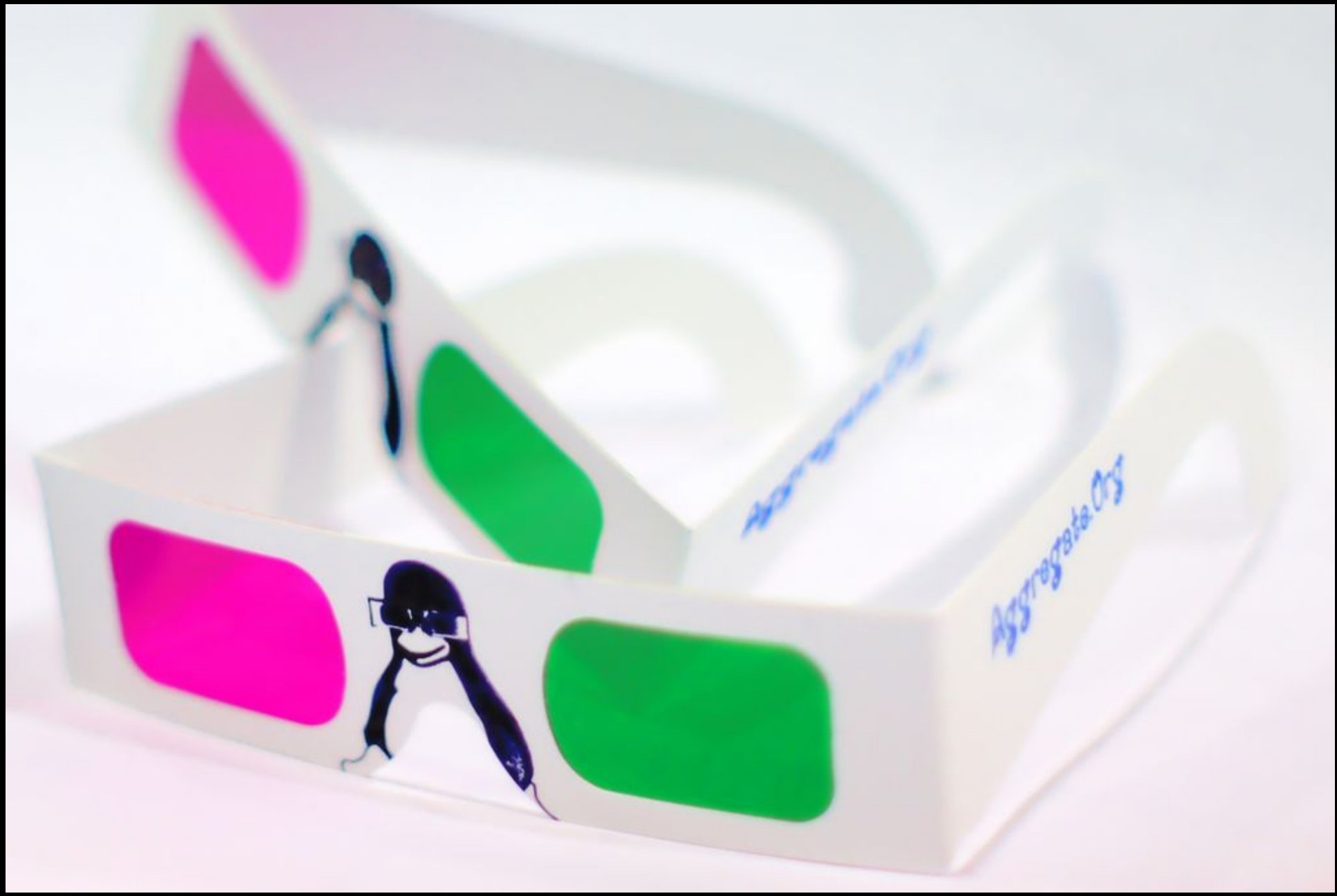
Why Not Color-Code Aperture?

- Color code views through left and right sides of the lens... to directly capture an anaglyph
- Stereo view with glasses (even live view)
- Computationally extracting the views allows:
  - Full color stereo pairs
  - After-the-fact refocus, depth capture, etc.
- Design for reprocessing, e.g., green/magenta Instead of red/cyan

Anaglyph Capture Aperture



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AMD x86-


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1878
1916
1865
UNITED WE STAND - DIVIDED WE FALL
MAIN BUILDING
Opened in 1882 and
known as the Main or
College Building, it

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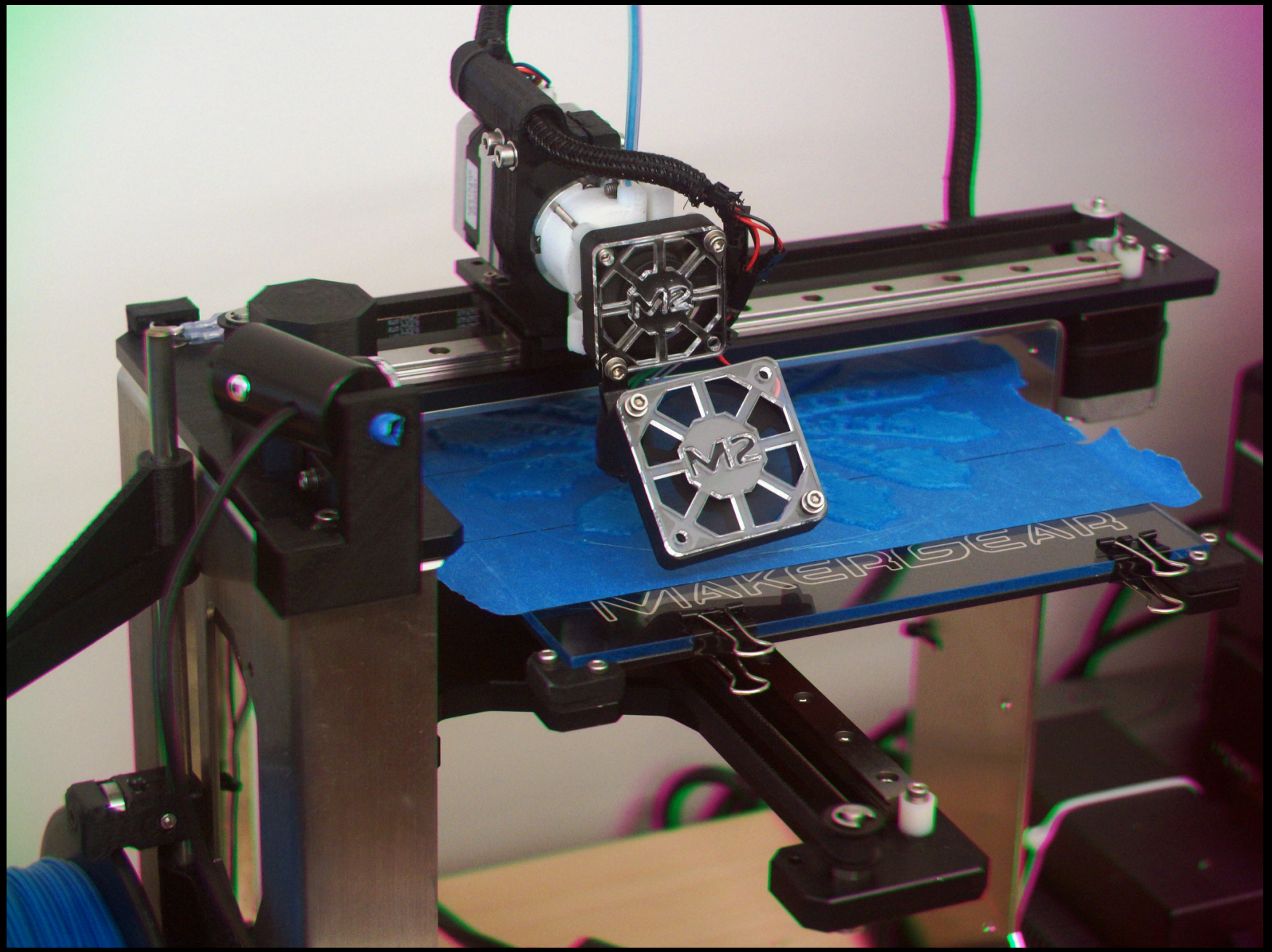
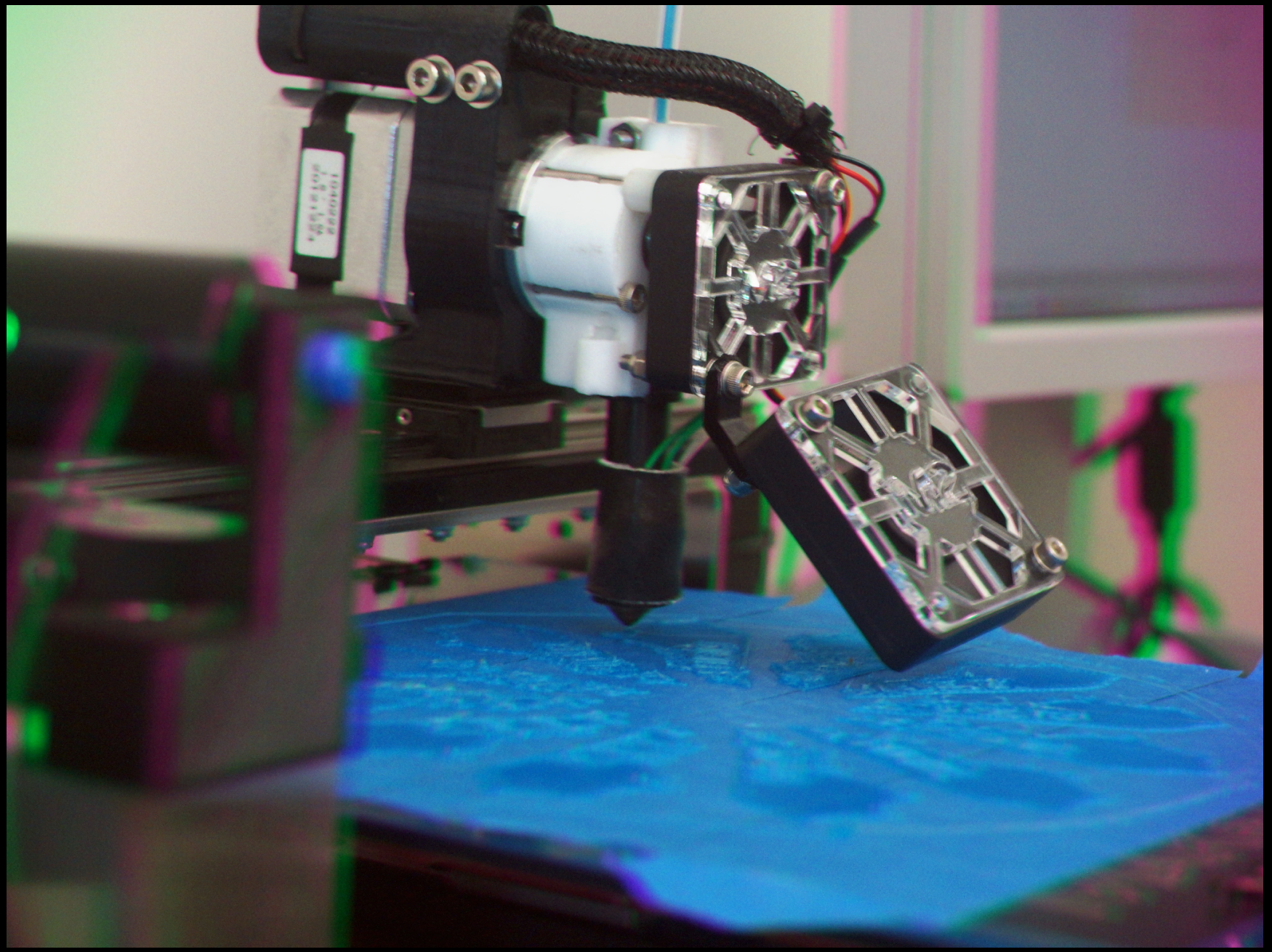

M2
M2
MAKERGEAR




intel
Cluster
Ready

Can We Computationally Create A Full-Color Stereo Pair?

- Theoretically it's impossible...

Red

Green

Blue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MAIN BUILDING
Opened in 1882 and
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Computed Left & Right Views

Computed Left & Right Views

Conclusion

- Out-of-focus really isn't blurry
- 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