21.IndexOfRefraction

Monday, November 11, 2019 7:50 AM

Index of refraction techniques:
- Caustics
- Shadowgraphy
- Schlieren
- Background-oriented schlieren (BOS)

How it works:

http://www.npr.org/2014/04/09/300563606/what-does-sound-look-like
Michael Hargather, New Mexico Tech

speed of light

$$\eta = \frac{C_{VACUUM}}{C_{MEDIUM}}$$ eetah

n = index of refraction

Light is deflected towards more dense medium

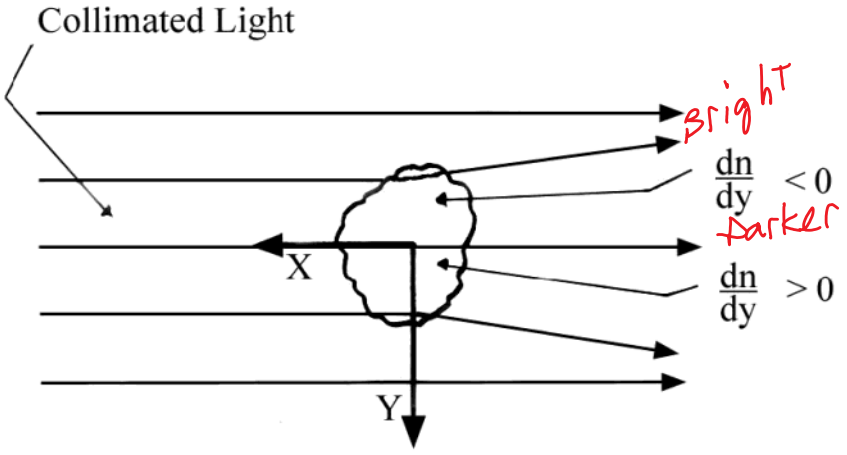


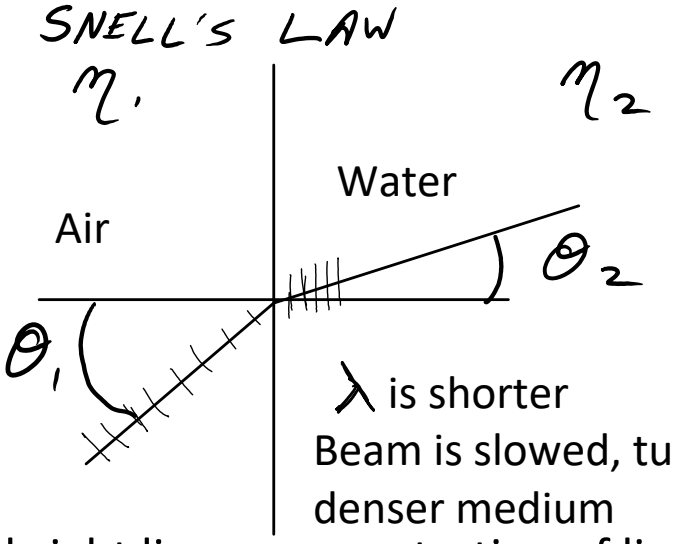
Figure 1. Disturbance in Collimated Beam

Shadowgraphy:

constructive and destructive interference from disturbed parallel light

$$\frac{1}{\eta}\frac{\partial \eta}{\partial y} = \frac{\partial^2 y}{\partial x^2}$$

curve of disturbed line = $y(x)$

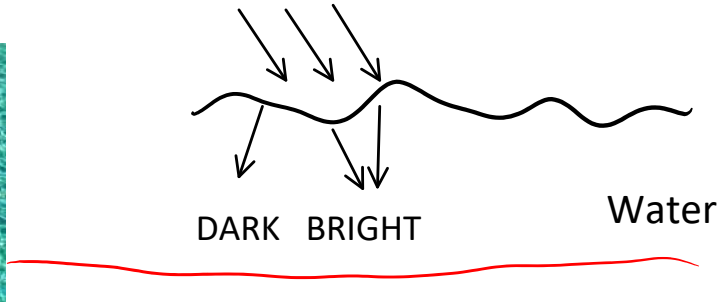


λ is shorter

Beam is slowed, turns into, i.e towards the denser medium

Caustic = bright lines; concentration of light.

Commonly seen in swimming pools



http://www.shutterstock.com/video/clip-3174052-stock-footage-dappled-pool-water-ripple-background-swimming-pool-water-abstract-background-with-seamless-loop.html

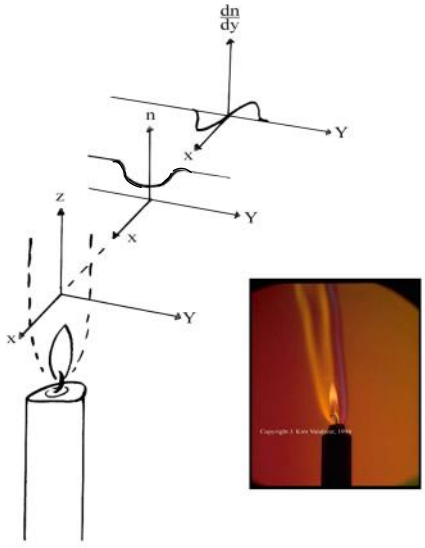


Figure 2. The Refractive Index Gradient Above a Candle

http://web.mit.edu/Edgerton/www/schlieren5.html

schlieren is just a German noun, not somebody's name.

Shadowgraphy:

constructive and destructive interference from disturbed parallel light

schlieren:

Selectively remove constructive or destructive interference from disturbed parallel light.
Higher contrast, controlled sensitivity to gradient directions

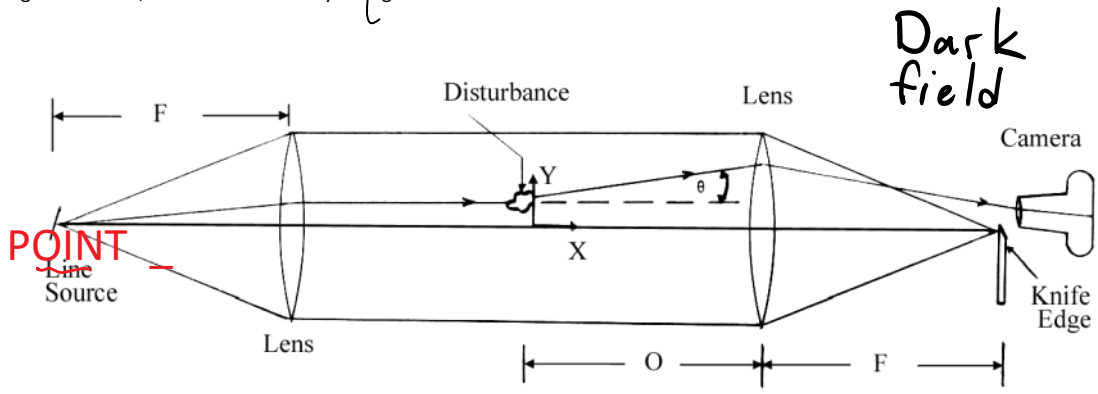
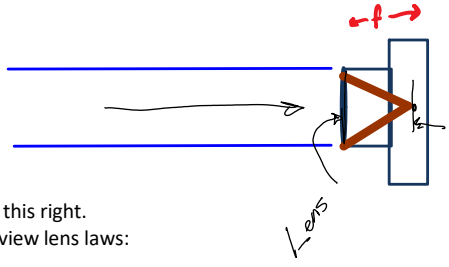


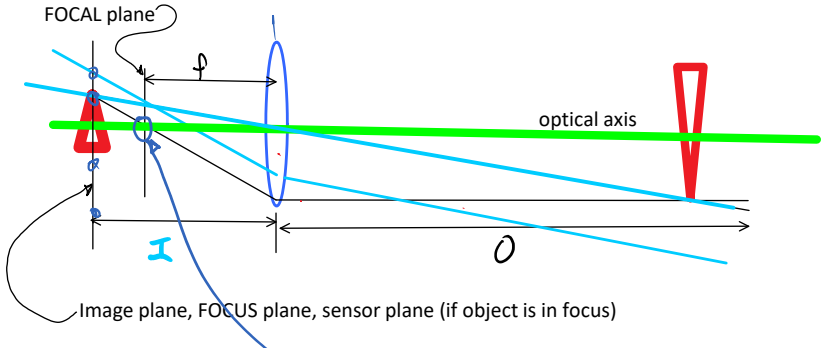
Figure 3. Schlieren System with a Small Disturbance

Minute paper: What would camera or your eyes see looking straight at parallel light, with the camera lens focused at infinity?
Hint: what light sources do you know that emit parallel light? What do they look like?
Hint 2: what does the lens law say about light entering parallel to the optical axis?

Stars: the light is parallel, and they look like points of light in a dark field.



1/2 got this right.
Let's review lens laws:



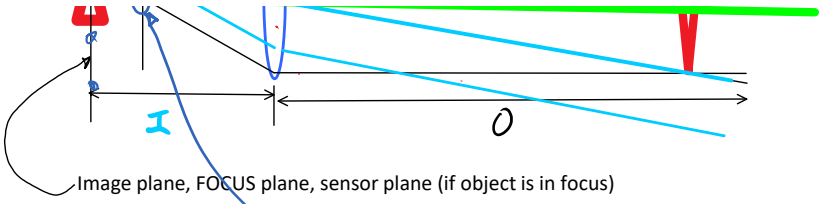


Image plane, FOCUS plane, sensor plane (if object is in focus)

Lens Laws

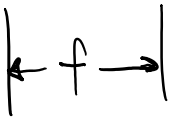
1) light through center of lens is undeflected
2) light parallel to axis goes through focal *point* ≠ focus point
3) all light entering lens at a given direction ends up at the same point in the *focal* plane (**not** *focus* plane)

Focus equation

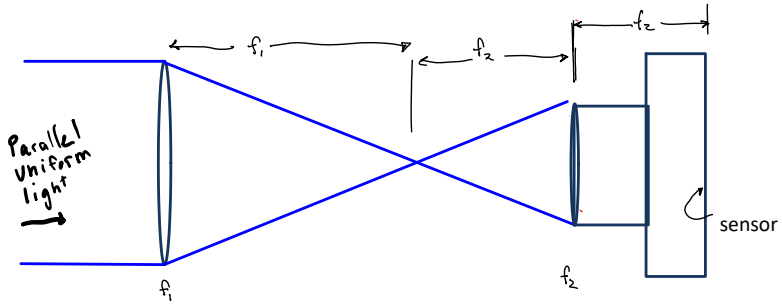
$$\frac{1}{f} = \frac{1}{O} + \frac{1}{I}$$

f = focal length
O = dist. Lens → object
I = dist. Lens → image (sensor)

Minute paper, groups: 1) Where is lens relative to sensor when focus is at infinity?

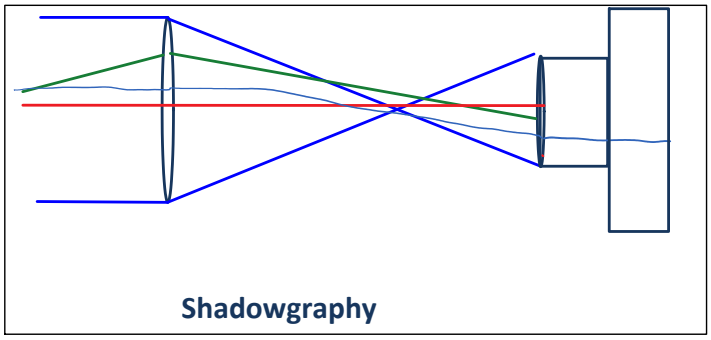


Back to schlieren and shadowgraphy: What does the camera see in this case? No disturbance, no knife edge

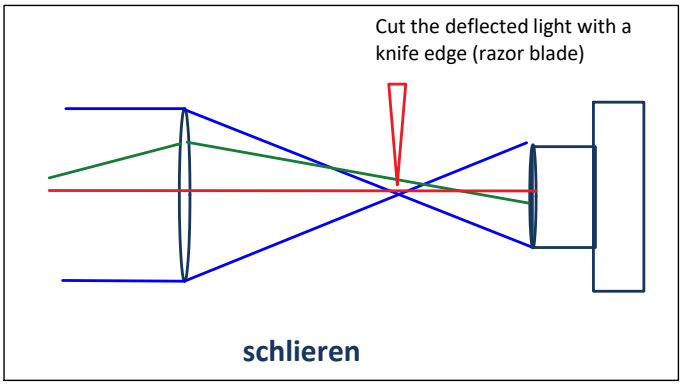


Camera lens+body

Now, deflect some of those light rays. Would add light in some areas, reduce it on others.



Shadowgraphy



schlieren

Bright field

By Foucault, 1859

schlieren: German noun, Not a name

Shadowgraph Equation

Shadowgraph, sensitive to 2nd derivative of η

$$\frac{\Delta I}{I} = l \int_{z_1}^{z_2} \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \right) (\ln \eta)\, dz$$

Relative light intensity at exit. Light propagates in Z direction

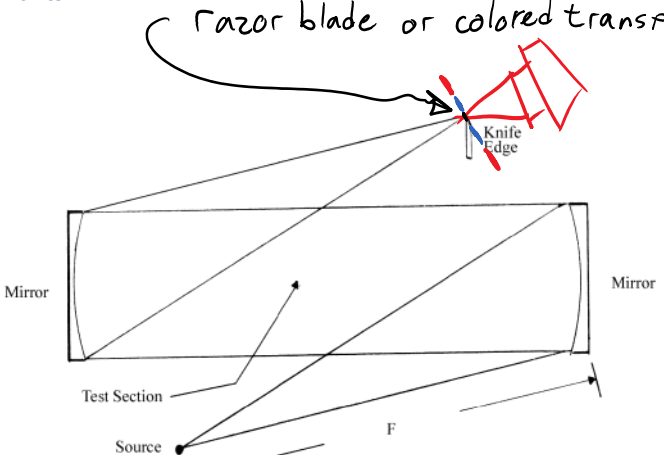
Integrated along line of sight. Drawback for looking at 3-d phenomena

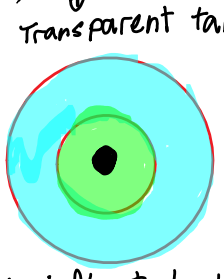
Ref:

1. Wolgang Merzkirch, *Flow Visualization, Second Edition*, 2nd ed. (Academic Press, 1987).

Similar math for schlieren, is sensitive to first derivative; to gradients in temperature.
Has higher contrast, visibility; deflected light is not adding to or confusing light field.

Variants:





Undeflected = blocked by black
Slightly deflected = green
Very deflected = blue

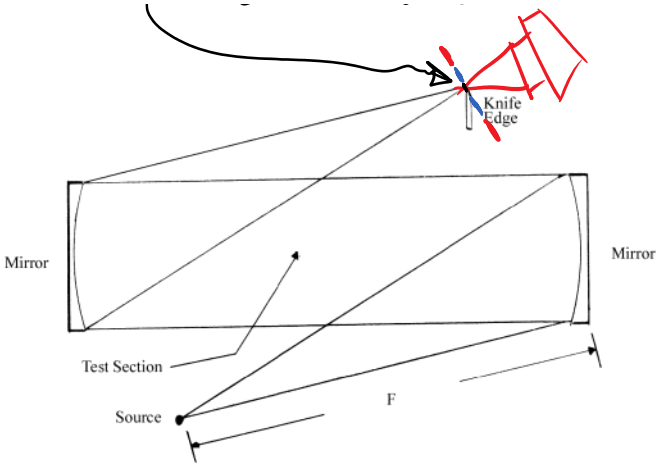
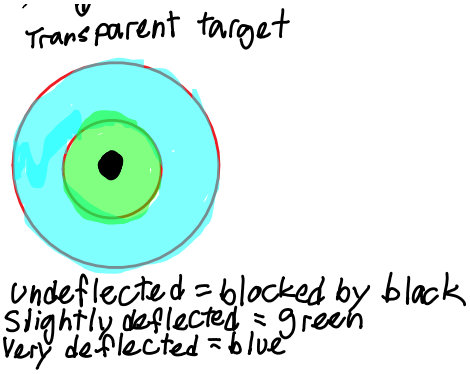
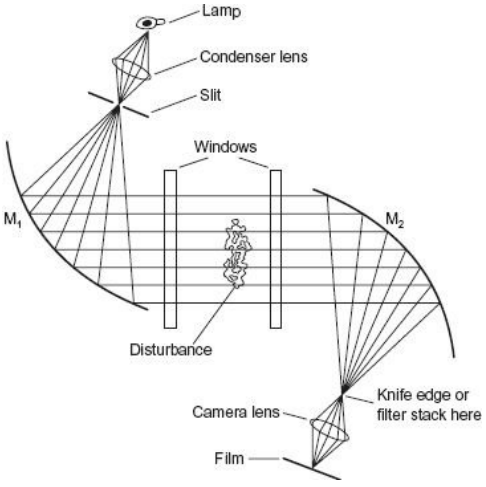


Figure 7. Mirror System

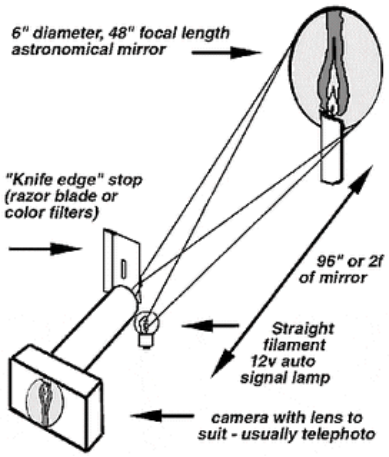


Z fold with mirrors; saves space, cost. Want space between mirrors to be 3 x f

Either spherical or parabolic mirrors work.

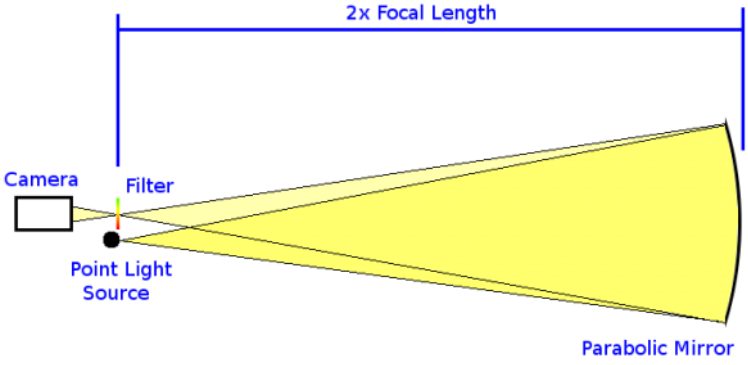


Pasted from <http://2.bp.blogspot.com/_JUESvkRXuK0/SQZ0JdkMBAI/AAAAAAAABPk/OGvKULVzNJ4/s320/schlieren.gif>

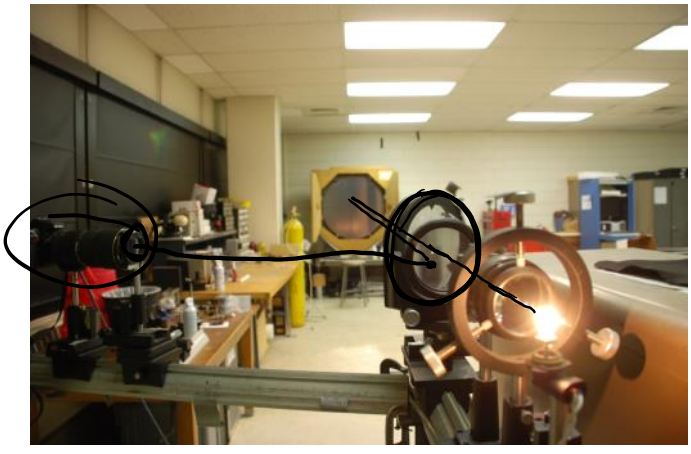


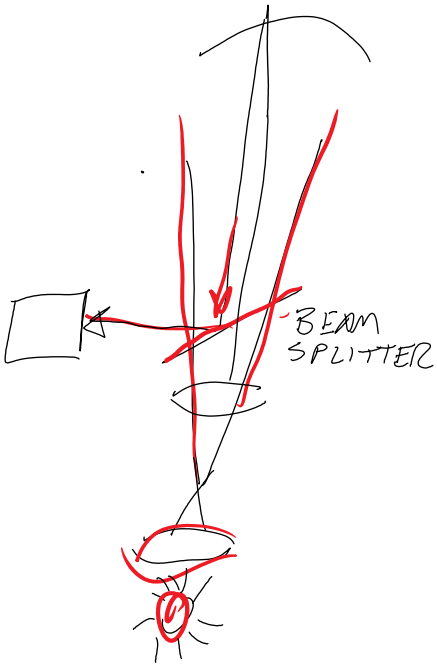
Single mirror system

Pasted from <http://www.ian.org/Schlieren/SchlierenDiagram.png>



https://m.youtube.com/watch?v=BPwdlEgLn5Q Smarter Every Day; high speed video of shock waves from bullets





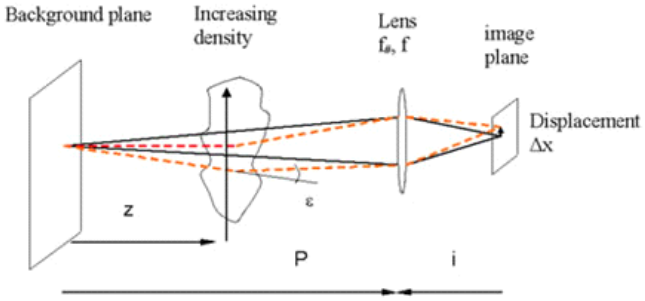
Gas Dynamics lab at Penn State University
Prof. Gary Settles, author of

Schlieren & Shadowgraph Techniques, Corrected. (Springer, 2001).

<file://C:\Users\hertzber\Documents\01CLASSES\FlowVis\MiscImages\Settles\SchlierenVisit\DSC_0324.AVI> My visit in March 2011

BOS = Background Oriented Schlieren

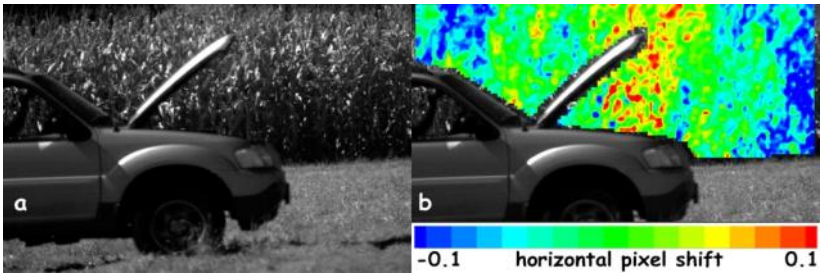
Uses patterned background instead of mirror, any random lighting. View of background will be distorted by η field. Take two images and do cross correlation, like PIV.



http://www.dlr.de/as/en/desktopdefault.aspx/tabid-183/251_read-2726/

http://www.mne.psu.edu/psgdl/Res-Optical.html
The thermal plume generated from a hot truck engine is visualized against a background of corn. The (a) original image is compared to one recorded 7 ms later to determine the (b) horizontal pixel shift. The contour plot of horizontal pixel shift in a BOS image is optically equivalent to a vertical knife -edge cutoff in traditional schlieren.

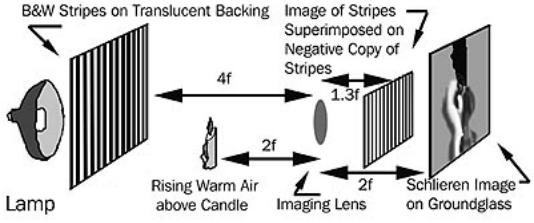
Pasted from <http://www.mne.psu.edu/psgdl/Res-Optical.html>



Hargather, Michael, and Gary S. Settles. "BACKGROUND-ORIENTED SCHLIEREN VISUALIZATI ON OF HEATING AND VENTILATION FLOWS: HVAC-BOS. Paper 266." In *ISFV14 - 14th International Symposium on Flow Visualization*, 1–8. EXCO Daegu, Korea, 2010.
Hargather, Michael John, and Gary S. Settles. "Natural-background-oriented Schlieren Imaging." *Experiments in Fluids* 48, no. 1 (January 1, 2010): 59–68. doi:10.1007/s00348-009-0709-3.

Focusing schlieren

http://people.rit.edu/andpph/text-schlieren-focus.html



https://www.youtube.com/watch?v=DYx2xLLrUyg ice cube in a fishtank, by Spectabit:
http://www.spectabit.com/index.php/product-types

Now, an even simpler method, using an encoded light field:

Light Field Background Oriented Schlieren Photography (LFBOS)

http://www.cs.ubc.ca/nest/imager/tr/2011/LFBOS/

Klemkowsky, Jenna N., Timothy W. Fahringer, Christopher J. Clifford, Brett F. Bathel, and Brian S. Thurow. "Plenoptic Background Oriented Schlieren Imaging." *Measurement Science and Technology* 28,

no. 9 (2017): 095404. https://doi.org/10.1088/1361-6501/aa7f3d.
In Zotero library.

We have two sets of 4" diameter mirrors; would love to see 3D stereoscopic schlieren.