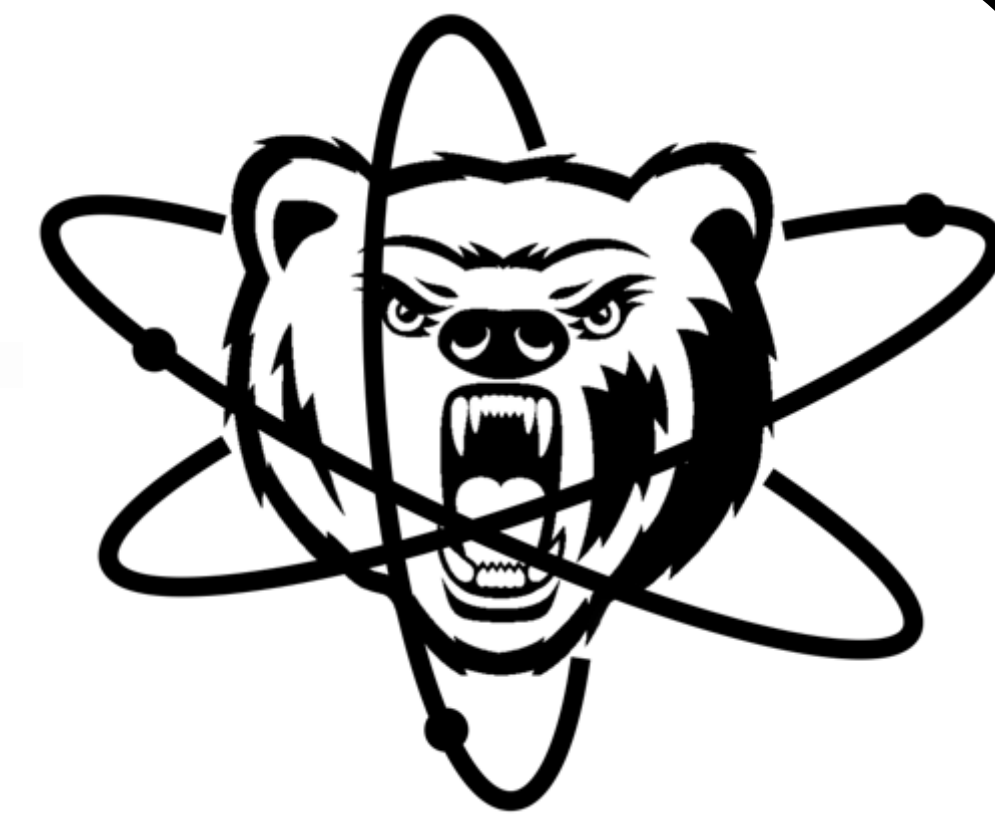


# Color Schlieren Imaging with Monochromatic Sources



Jan L. Chaloupka

Department of Physics & Astronomy, University of Northern Colorado, CO, USA

## Abstract

Color, direction-indicating schlieren images are generated with a two-path system using monochromatic light. Two simultaneous views of physical processes are captured that can be combined into a single, synthesized color composite.

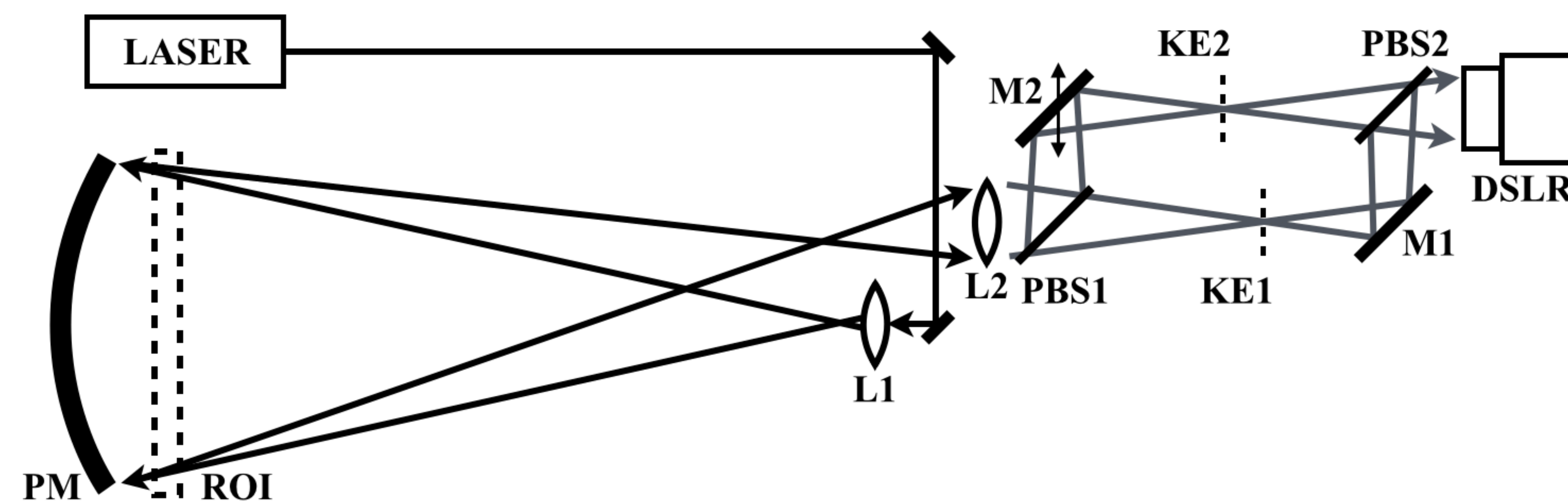
**All things schlieren:** G. S. Settles, *Schlieren and Shadowgraph Techniques* (Springer 2006).

**Other two-view systems:** F. W. Barry and G. M. Edelman, "An improved schlieren apparatus," *J. Aeronaut. Sci.* 15, 364 (1948); R. B. Owen and W. K. Witherow, "Dual laser optical system and method for studying fluid flow," United States Patent #4,391,518 (1983).

**Color schlieren:** G. S. Settles, "A Direction-Indicating Color Schlieren System," *AIAA Journal* 8, 2282-2284 (1970); W. L. Howes, "Rainbow schlieren and its applications," *Applied Optics* 23, 2449-2460 (1984).

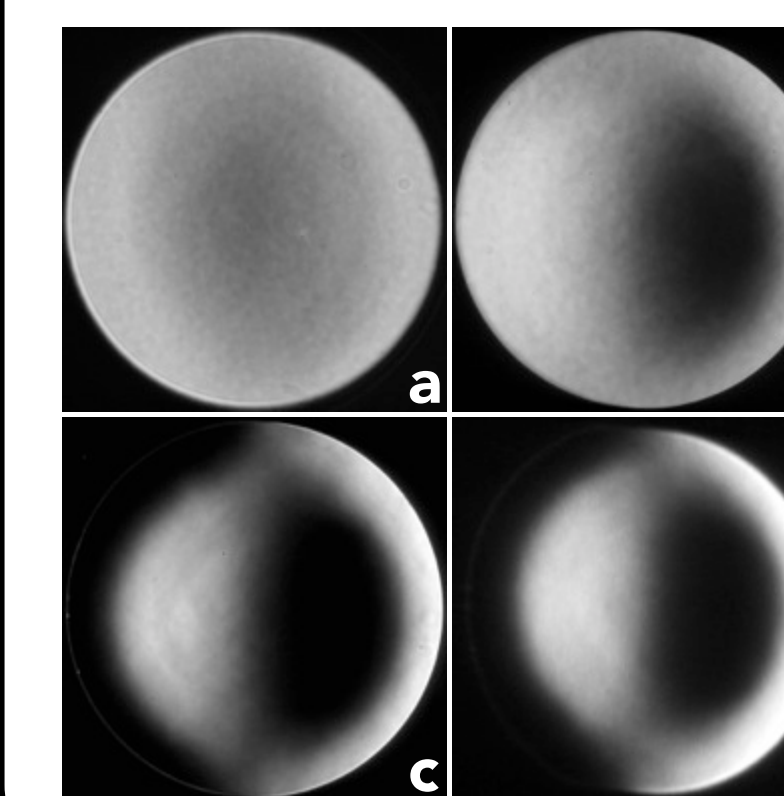
**Our two-view system:** J. L. Chaloupka, M. Woods III, J. Aas, J. Hutchins, and J. D. Thistle, "Color schlieren imaging with a two-path, double knife edge system," *Optics Express* 22, 8041-8046 (2014).

## Double Knife Edge Experimental Arrangement

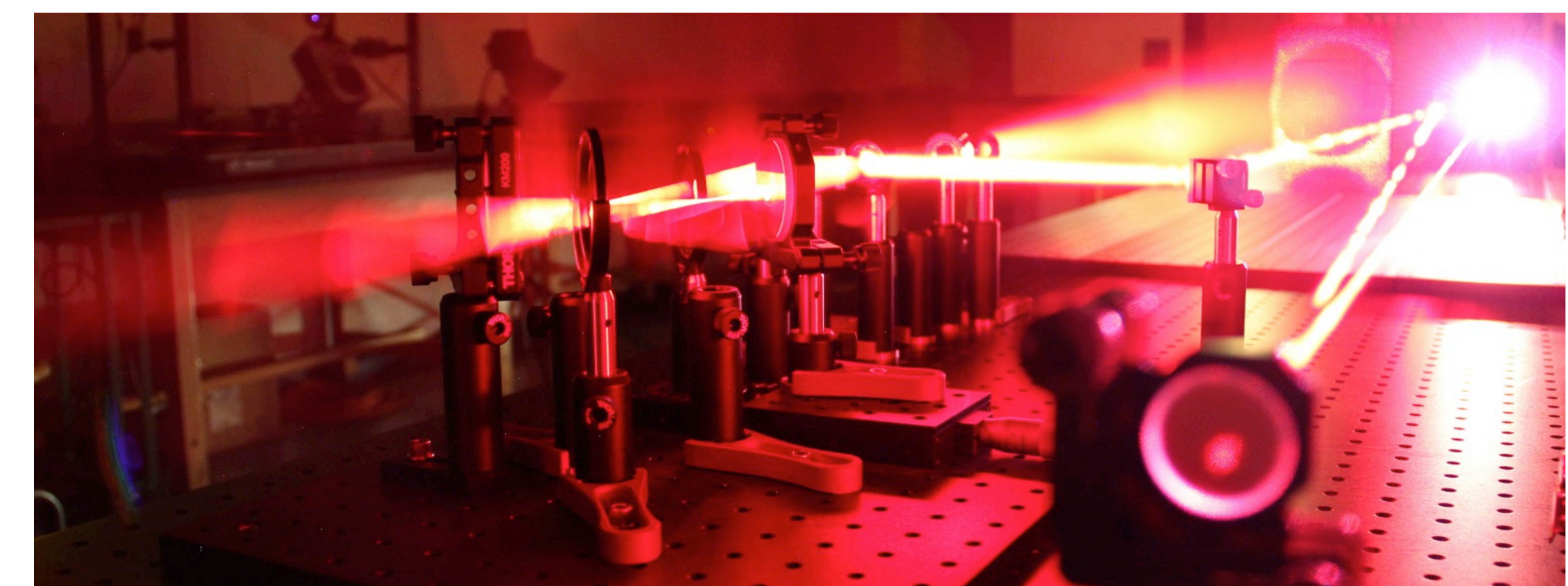


The experimental arrangement utilizing a two-path, double knife edge system: light from a pulsed laser is focused with lens L1 to a point  $2f$  from a 10" f/4.5 astronomical-grade parabolic mirror (PM). After passing through the region of interest (ROI) and reflecting off of the mirror, the converging light comes to an initial focus and is refocused with lens L2. The beam comes to a secondary focus within the Mach-Zehnder arrangement consisting of two pellicle beam splitters (PBS) and two mirrors (M). A knife edge (KE) is placed in each path and the resulting image is viewed with a digital camera (DSLR: Canon 60D, 180mm lens).

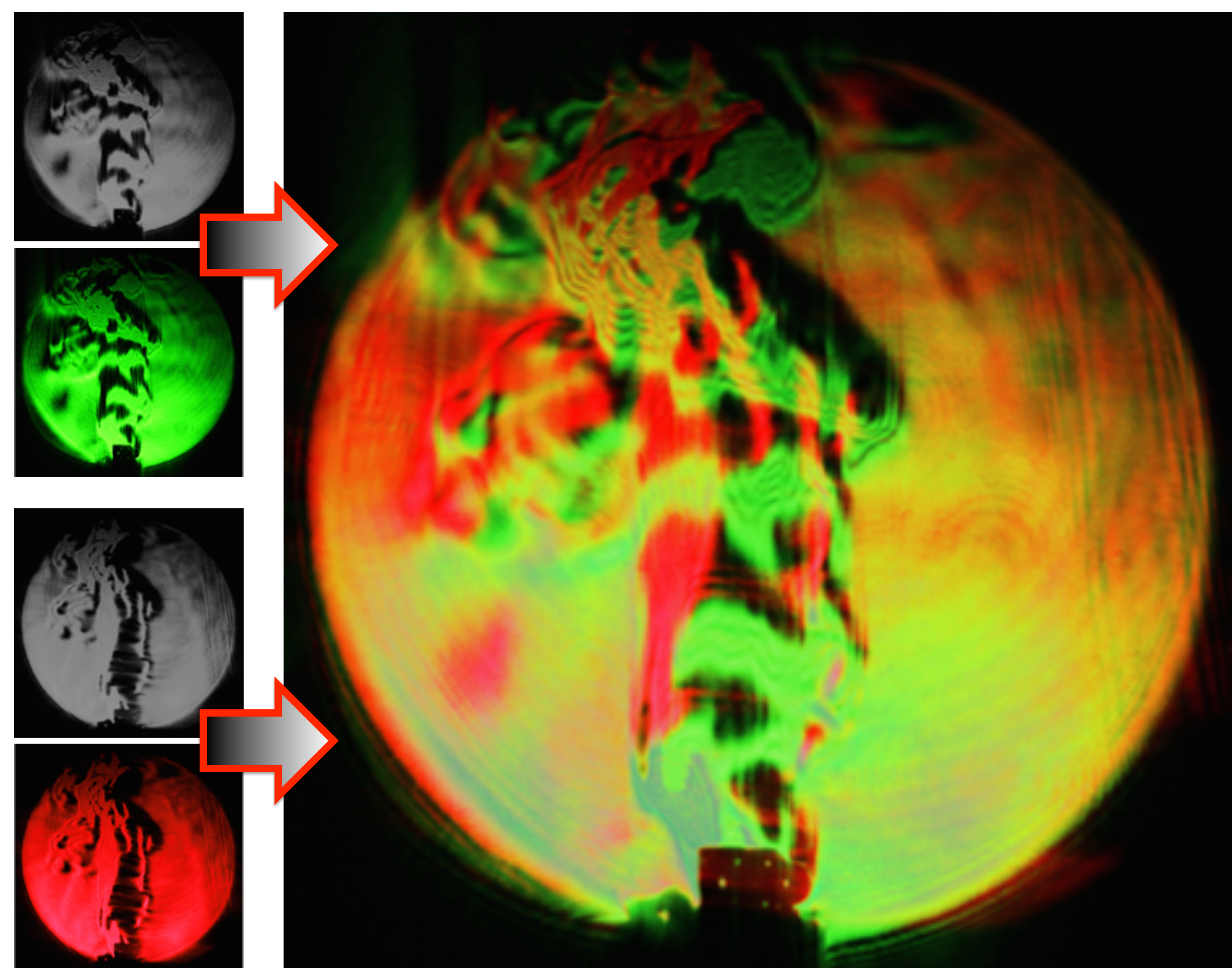
## Aberration Correction



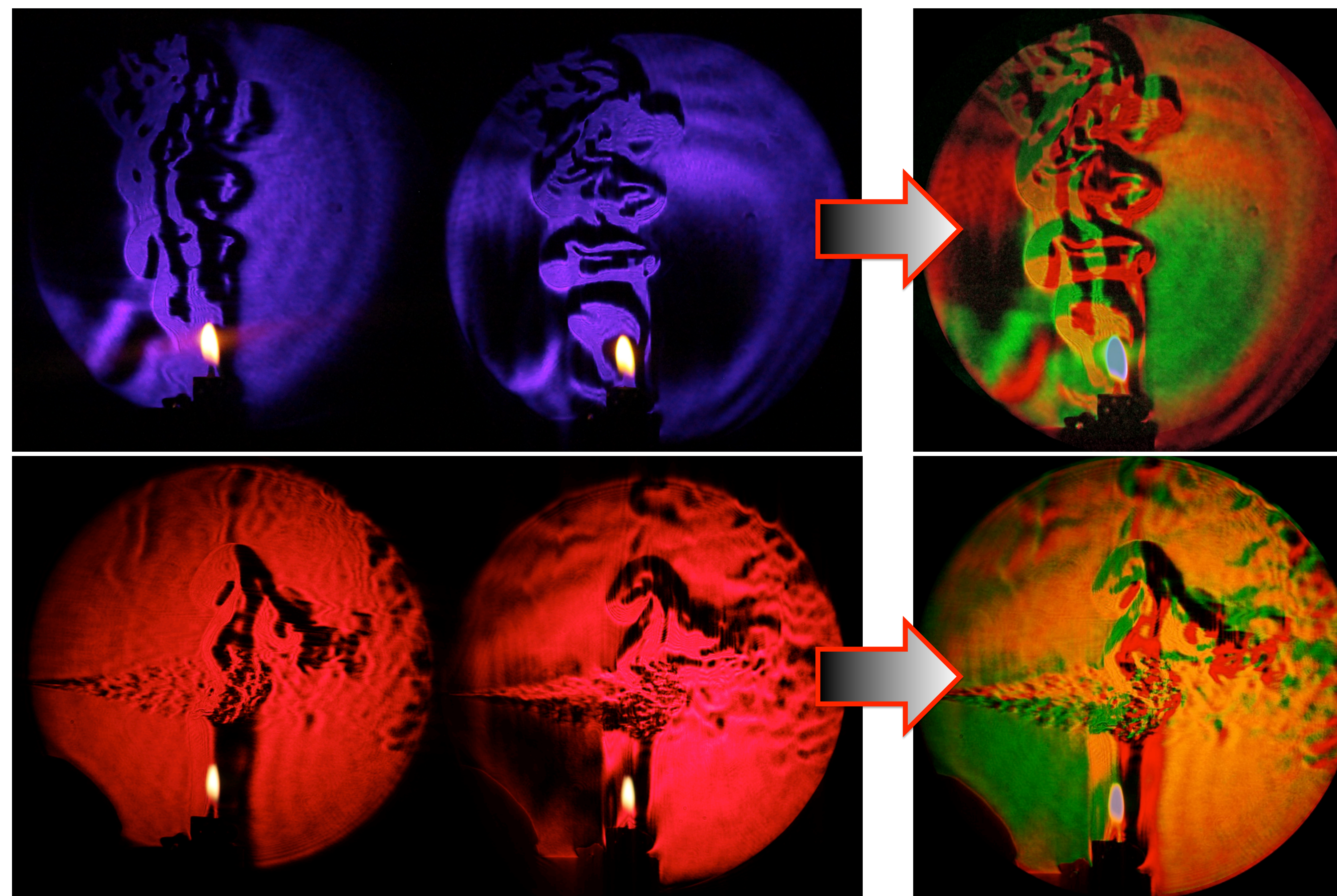
The lens L2 (achromatic  $f=100\text{mm}$ ) refocuses the imaging light to a secondary focus within the two arms of the Mach-Zehnder setup. It also serves a critical role as a spherical aberration corrector. The schlieren field generated with a white LED and knife edge inserted is shown for (a) the optimal L2 position, (b) L2 shifted by 5cm along the beam direction, (c) L2 shifted by 10cm. The schlieren field with no secondary lens and with a knife edge at the primary focus is also shown (d), indicating significant spherical aberration.



## Generating Synthesized Color Images



A CW He-Ne laser is used to view the heat plume generated by a flame. The image from each path is colorized (green and red), and the two images are combined into a synthesized composite using Adobe Photoshop software. The result is a color, direction-indicating image from a monochromatic source. While similar results have been obtained using white-light sources and segmented color filters, this approach, for example, would allow for the generation of color images using ultrafast pulsed sources.



A pulsed blue laser diode ( $\lambda=406\text{nm}$ ) is used to image the heat plume generated by a flame from a lighter. The raw image from the Canon 60D is shown on the left. In the composite image (right), horizontal and vertical flow is easily discernable by color.

A pulsed red laser diode ( $\lambda=635\text{nm}$ ) is used to image aerosol dust flow interacting with the heat plume from a flame. Here, the laser pulse width was set to 20  $\mu\text{s}$ , but this technique could be readily applied to ultrafast pulsed laser systems.