Seeing the Invisible with Schlieren Imaging

Amrita Mazumdar

September 2011

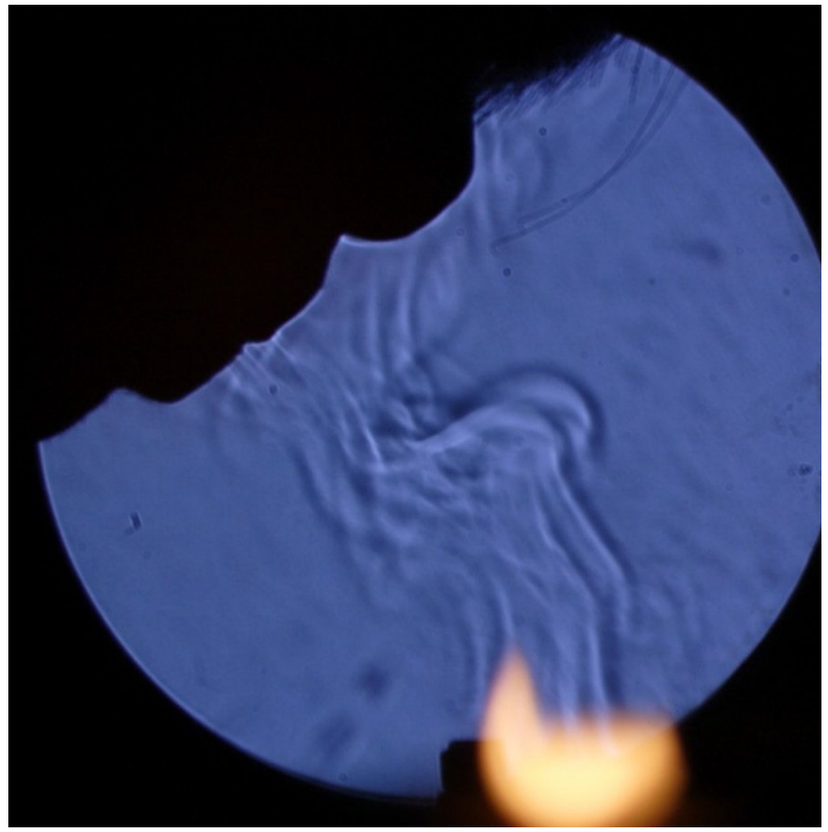
Four Questions

What is schliere?

Where do we see it?

How do we see it?

Why would we want to see schliere?



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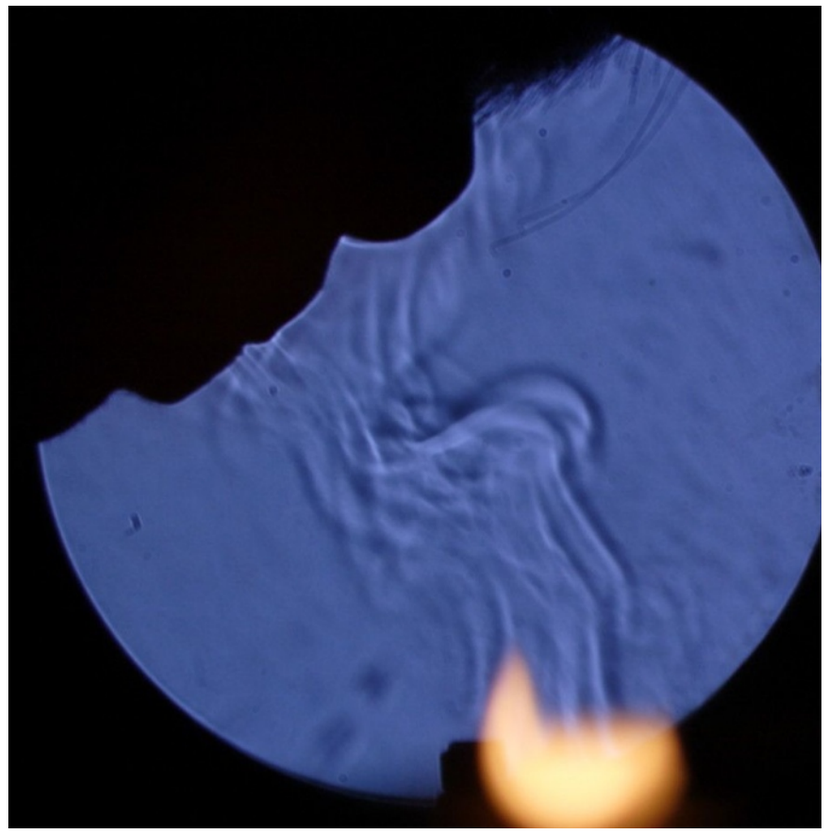

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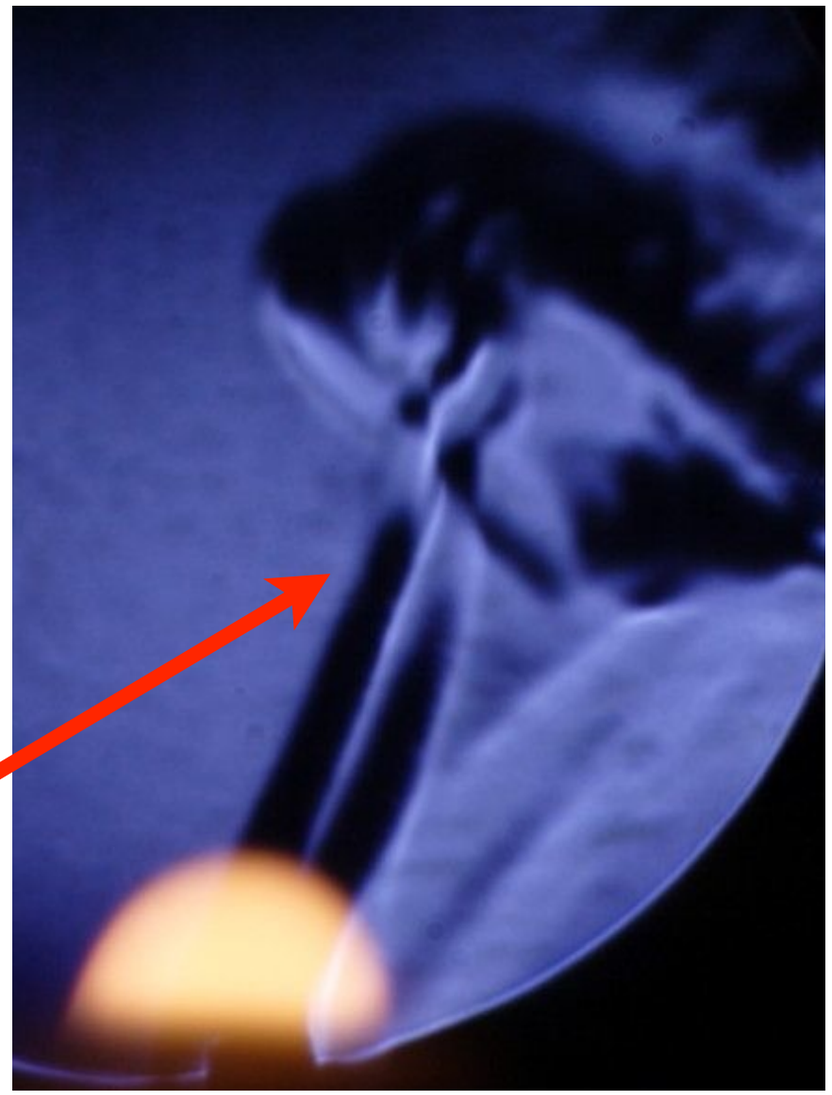
Why would we want to see schliere?

Schliere



this is a *schliere*

- Literally, *schliere* means a streak or striation, from German

- Originally used to describe inhomogeneities in glass

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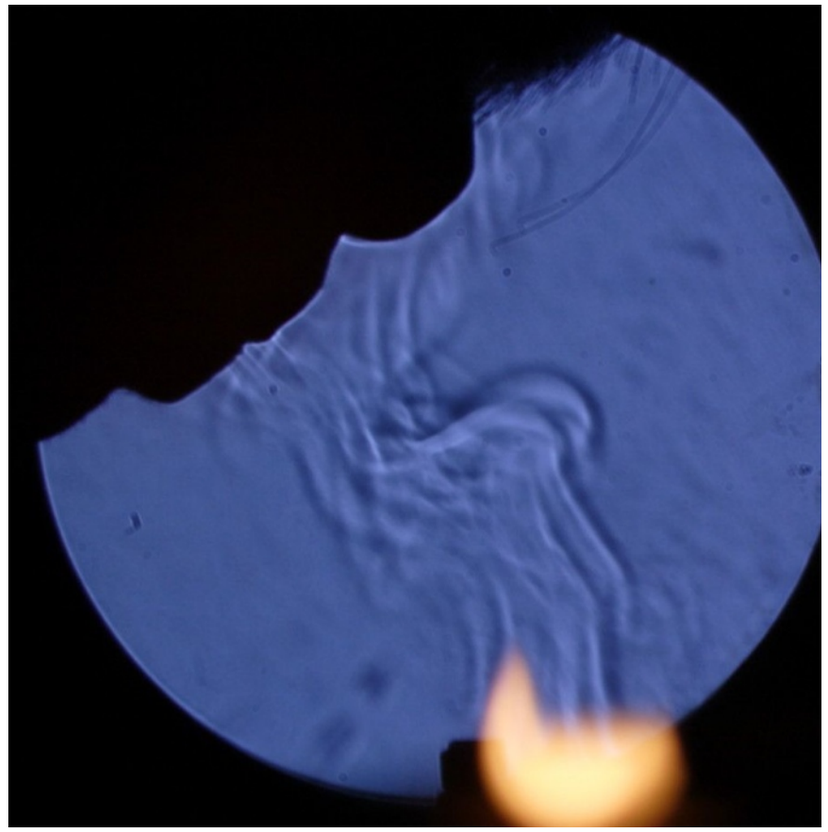
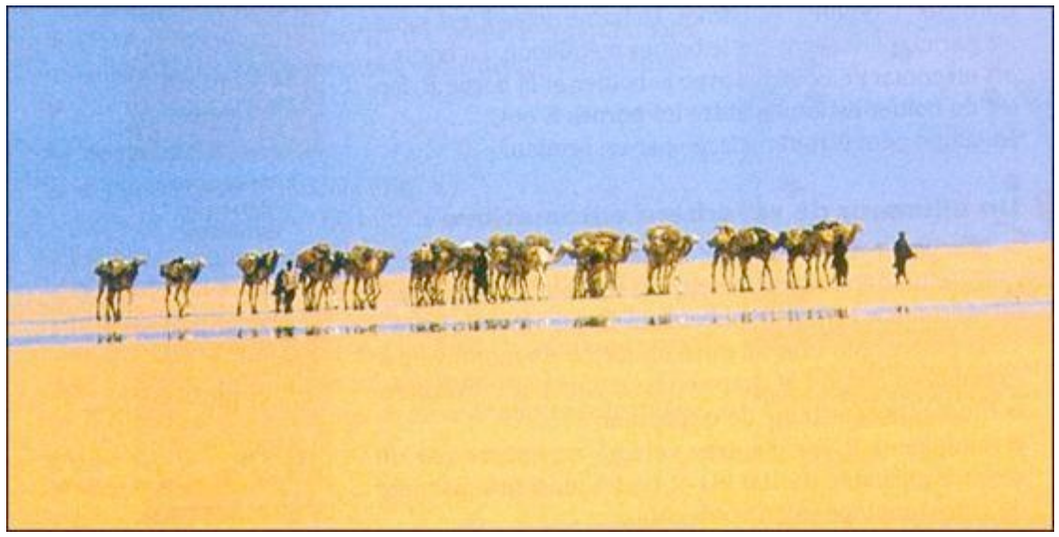


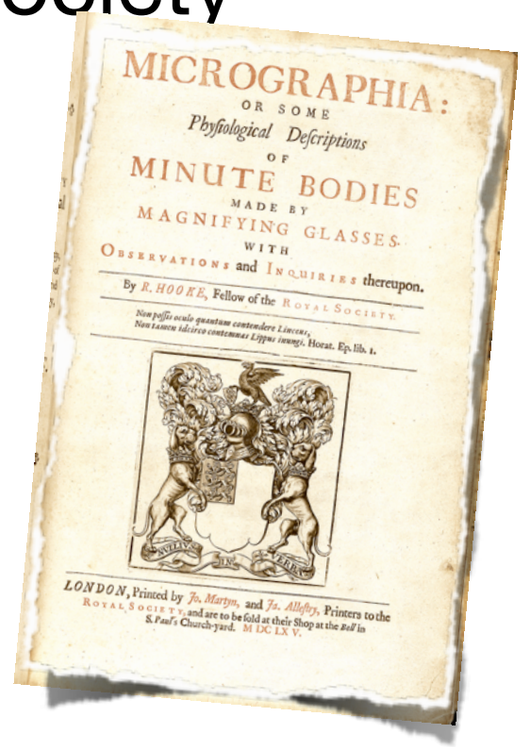
Found in the Wild



- Mirages are a form of schliere
- Where there’s smoke...
- Scratches or distortions inside glass panes

First Sightings

- **Robert Hooke**, in *Micrographia* and before the Royal Society


MICROGRAPHIA:
OR SOME
Physiological Descriptions
OF
MINUTE BODIES
MADE BY
MAGNIFYING GLASSES.
WITH
OBSERVATIONS and INQUIRIES thereupon.
By R. HOOKE, Fellow of the ROYAL SOCIETY.
Non possit oculo quantum contendere Lynceus,
Non tamen idcirco contemnas Lippus inungi. Horat. Ep. lib. 1.
LONDON, Printed by Jo. Martyn, and Ja. Allestry, Printers to the ROYAL SOCIETY, and are to be sold at their Shop at the Bell in S. Paul's Church-yard. M DC LX V.

- **Christiaan Huygens**, as an aspect of his optical analysis techniques

- **August Toepler** first officially published the technique

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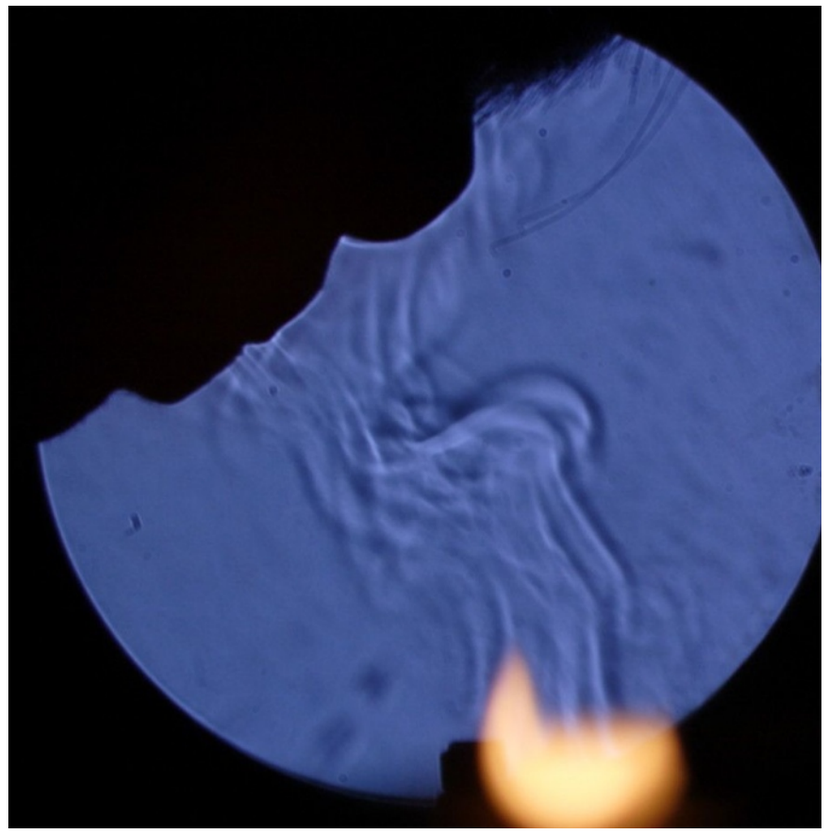
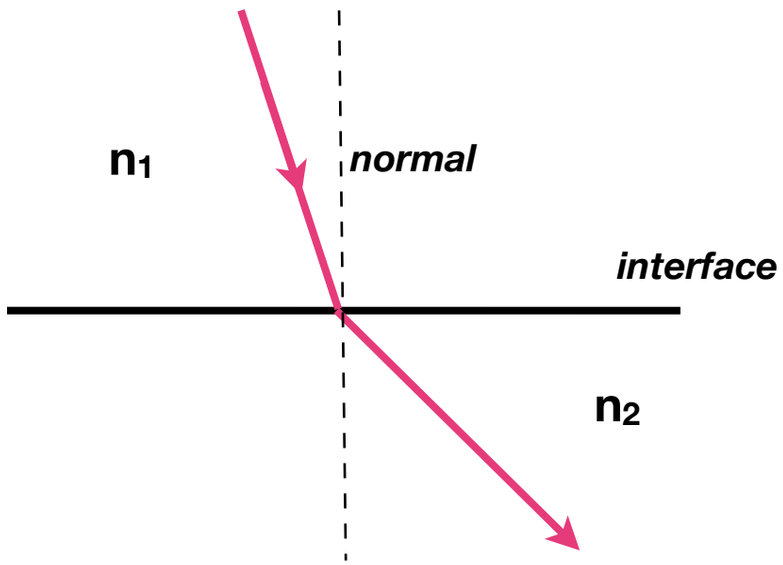
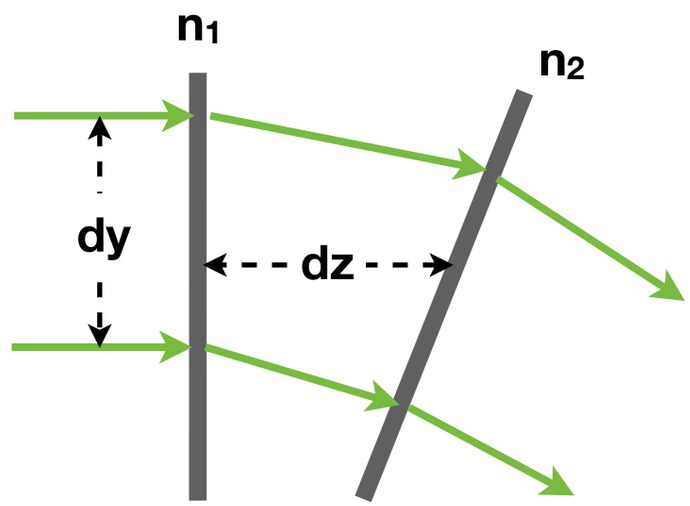


Optical Theory

Snell's Law

$$n = \frac{c}{v}$$



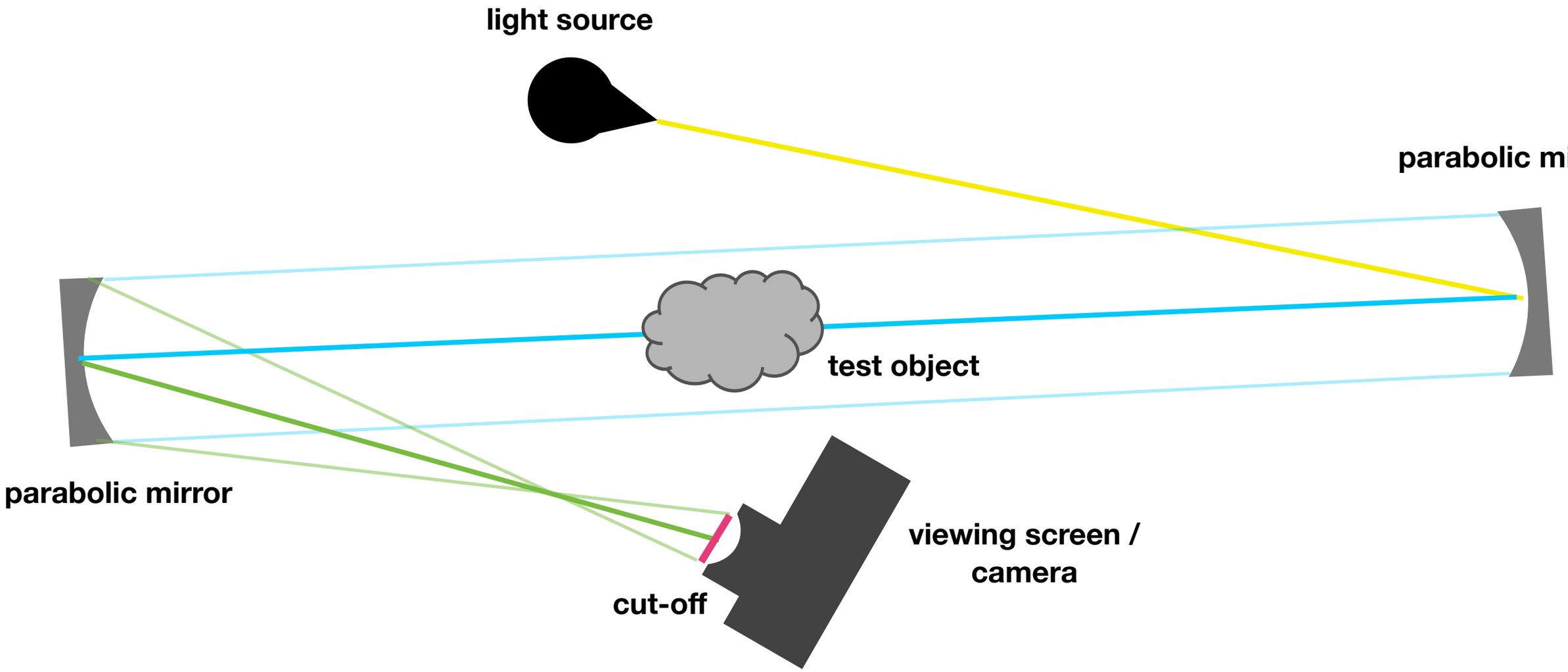


$$\frac{\partial^2 y}{\partial z^2} = \frac{1}{n}\frac{\partial n}{\partial y}$$

Curvature of refracted light ray as related to the refractive gradient (Settles, 2006)

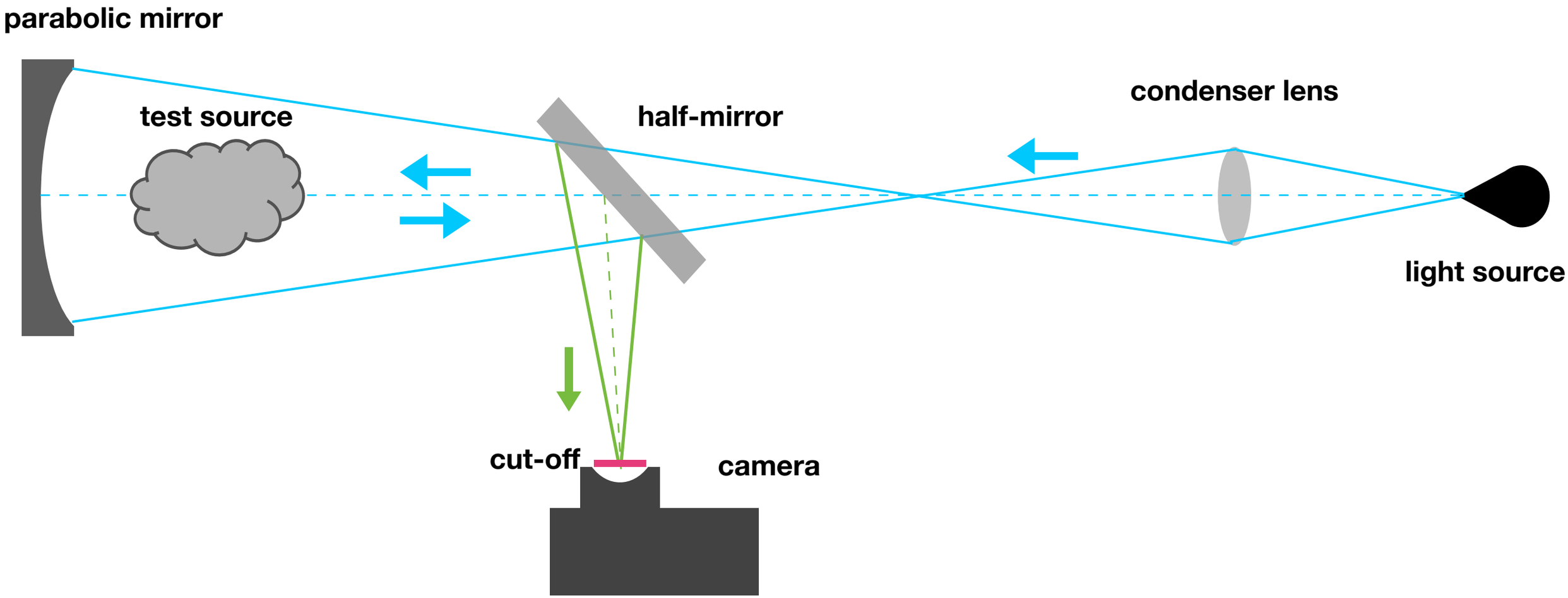
A Basic System

two-mirror incident system

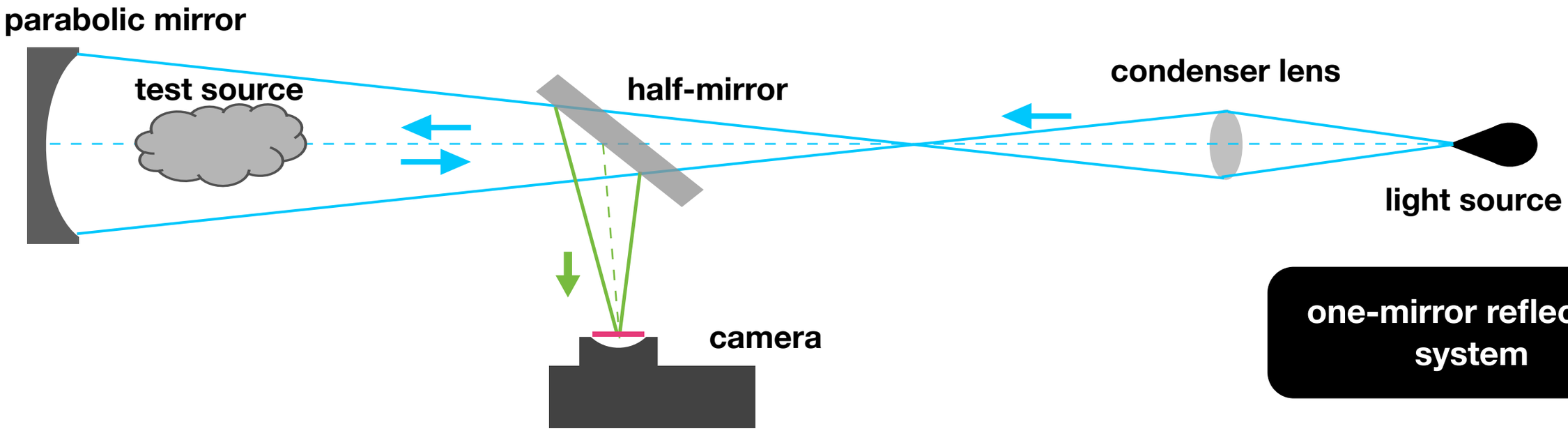


Implemented Design

one-mirror reflection system

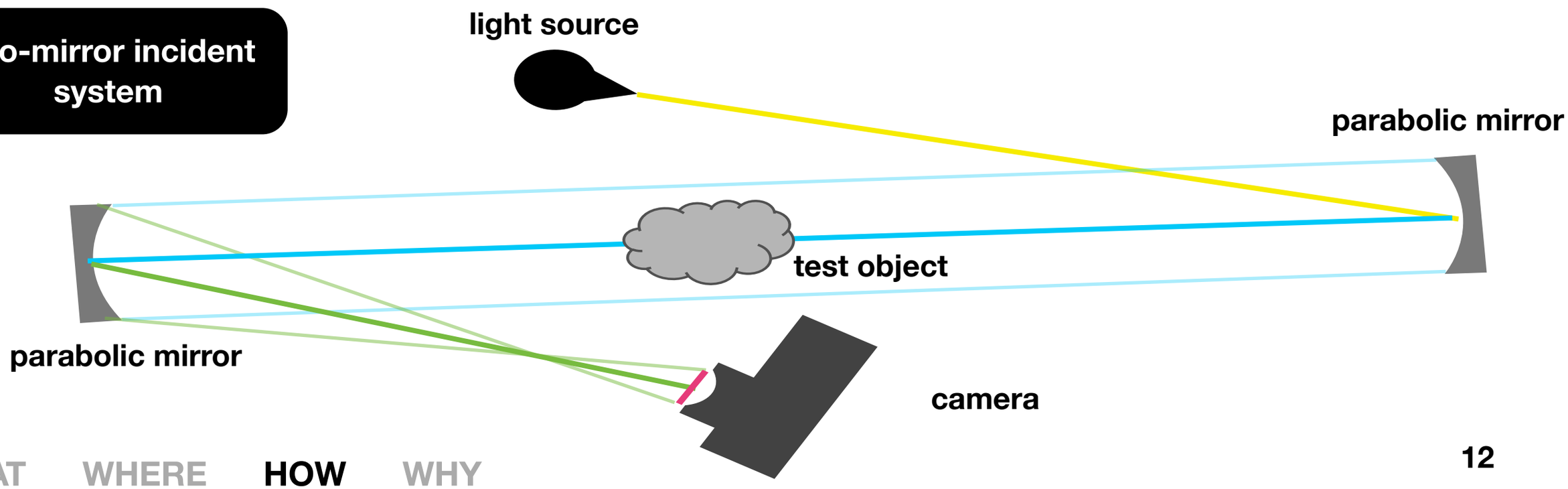


Design Comparisons

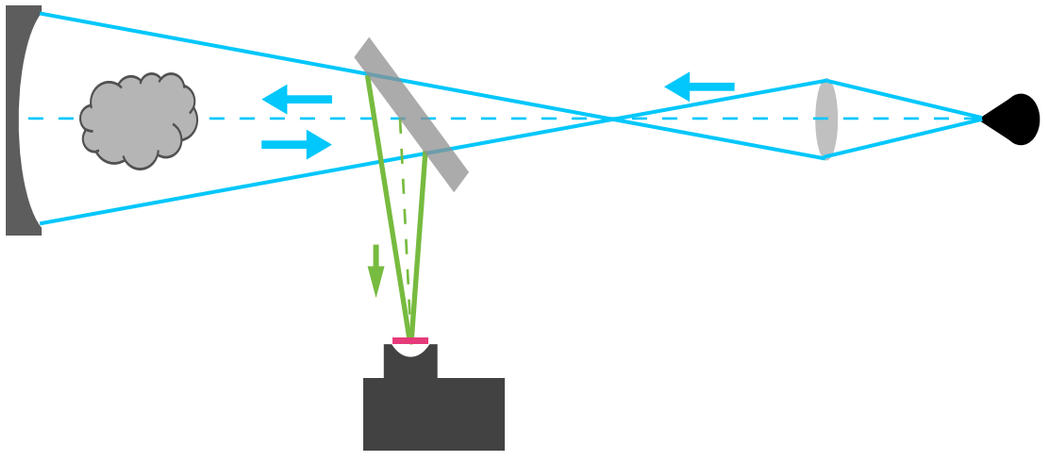


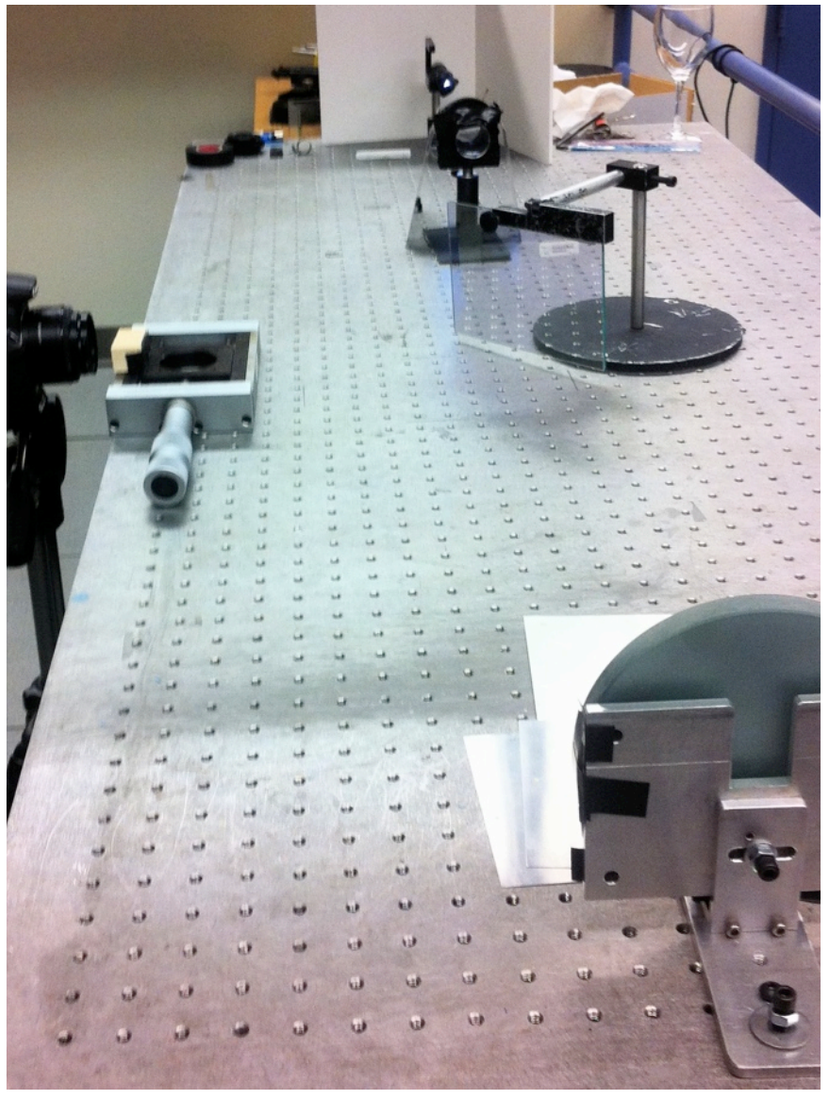
one-mirror reflection system

two-mirror incident system



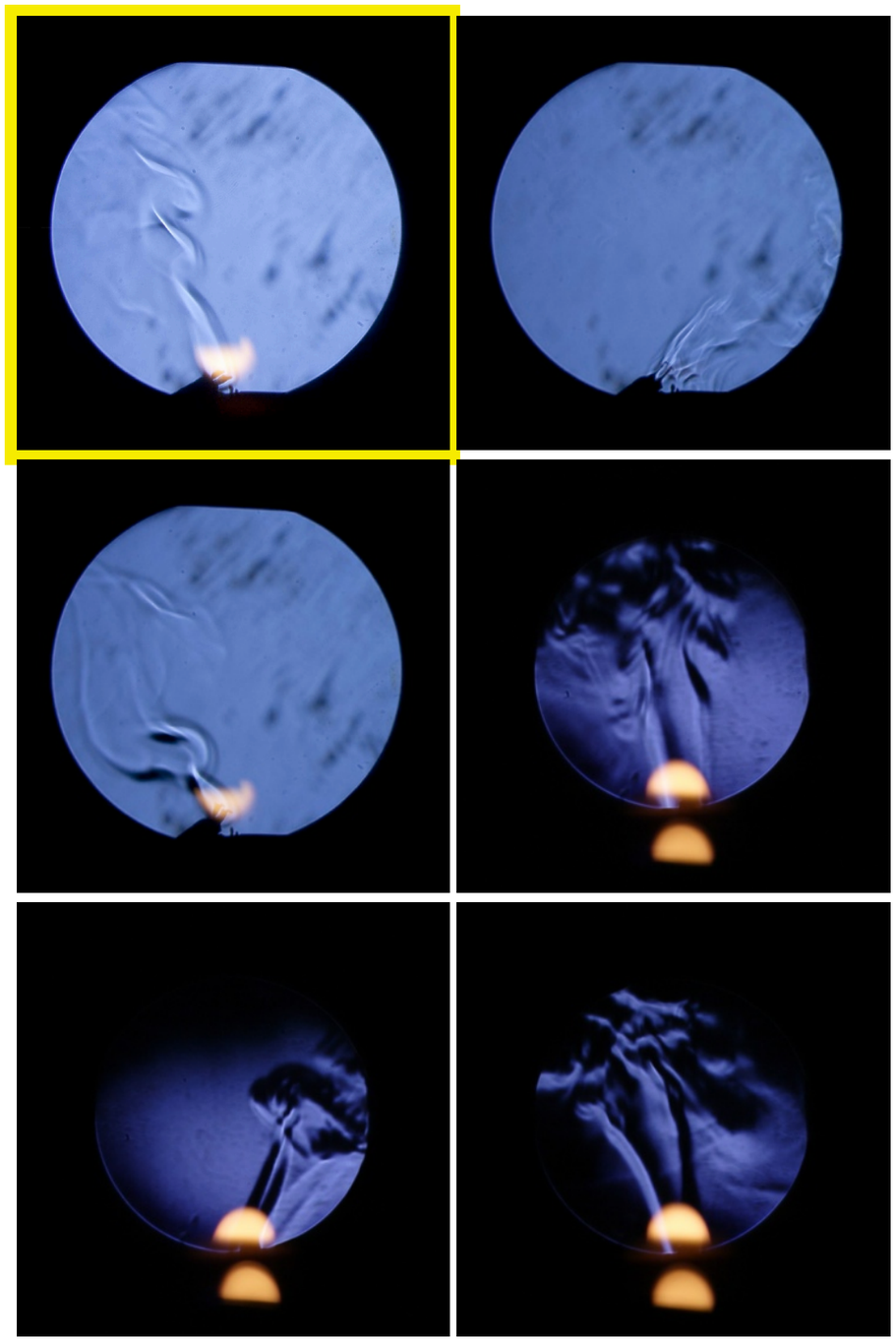
Implementation

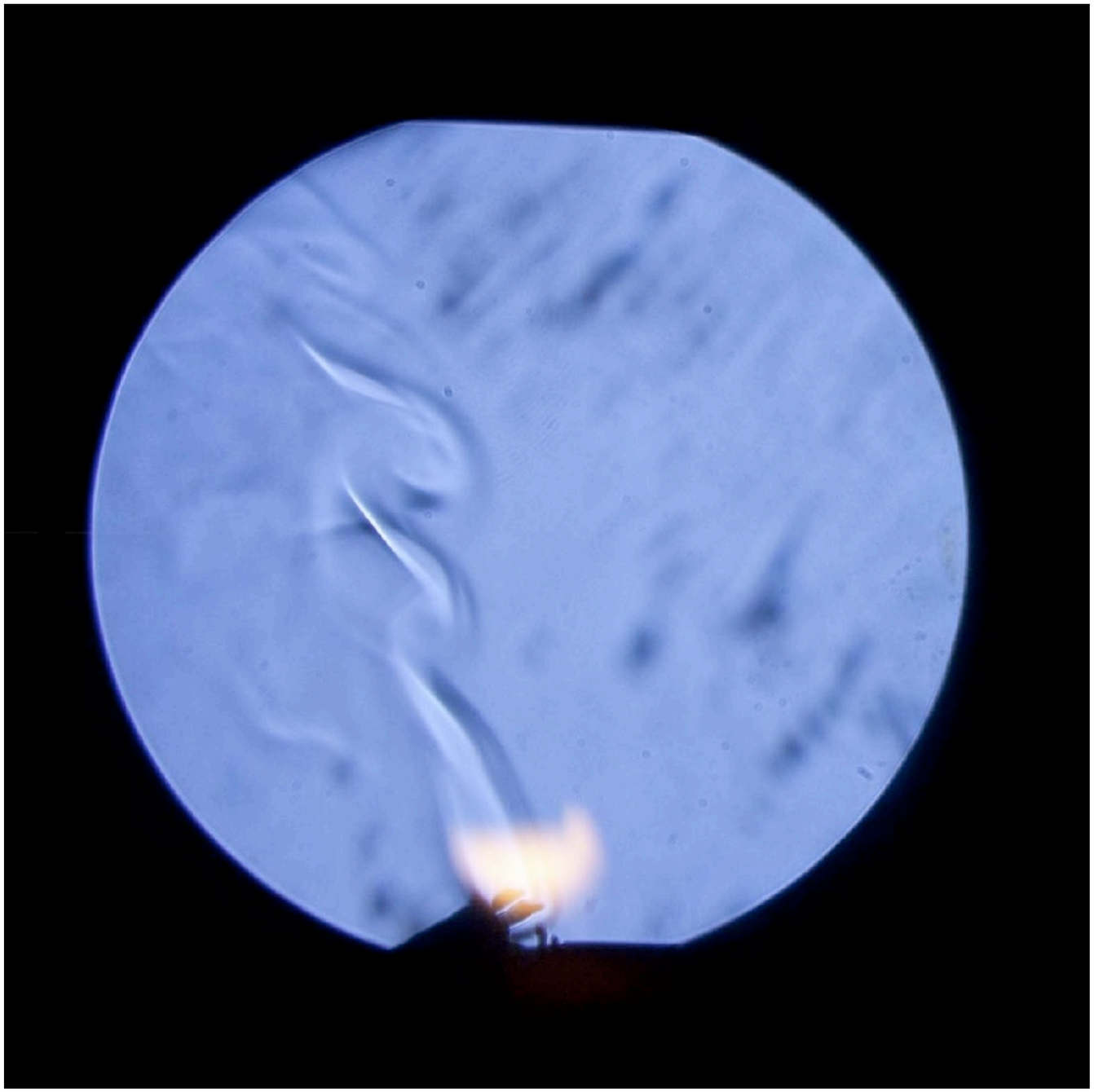




- Constructed using lab parts and a surplus telescope mirror
- One-mirror incident system

Captured Images





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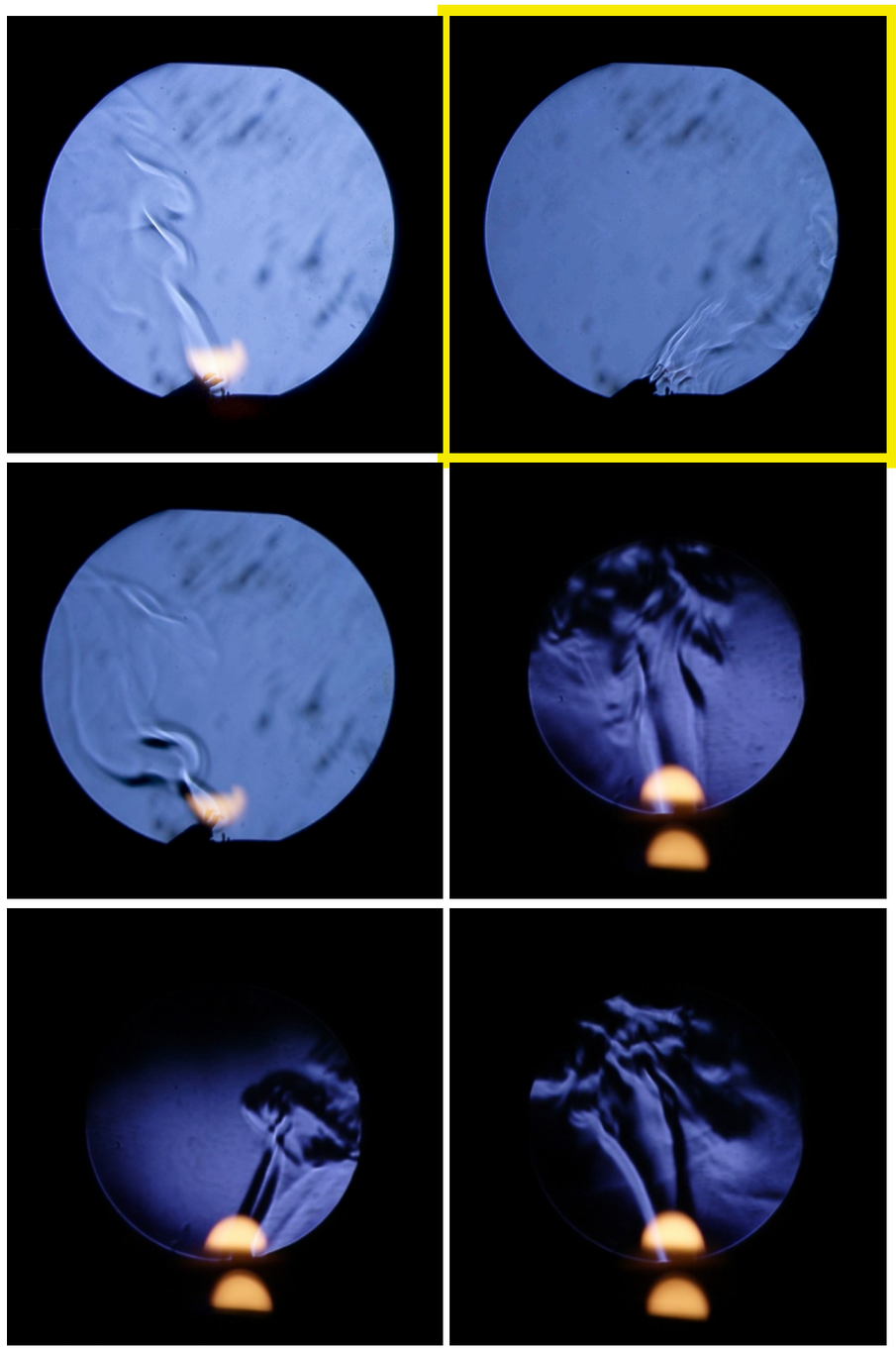

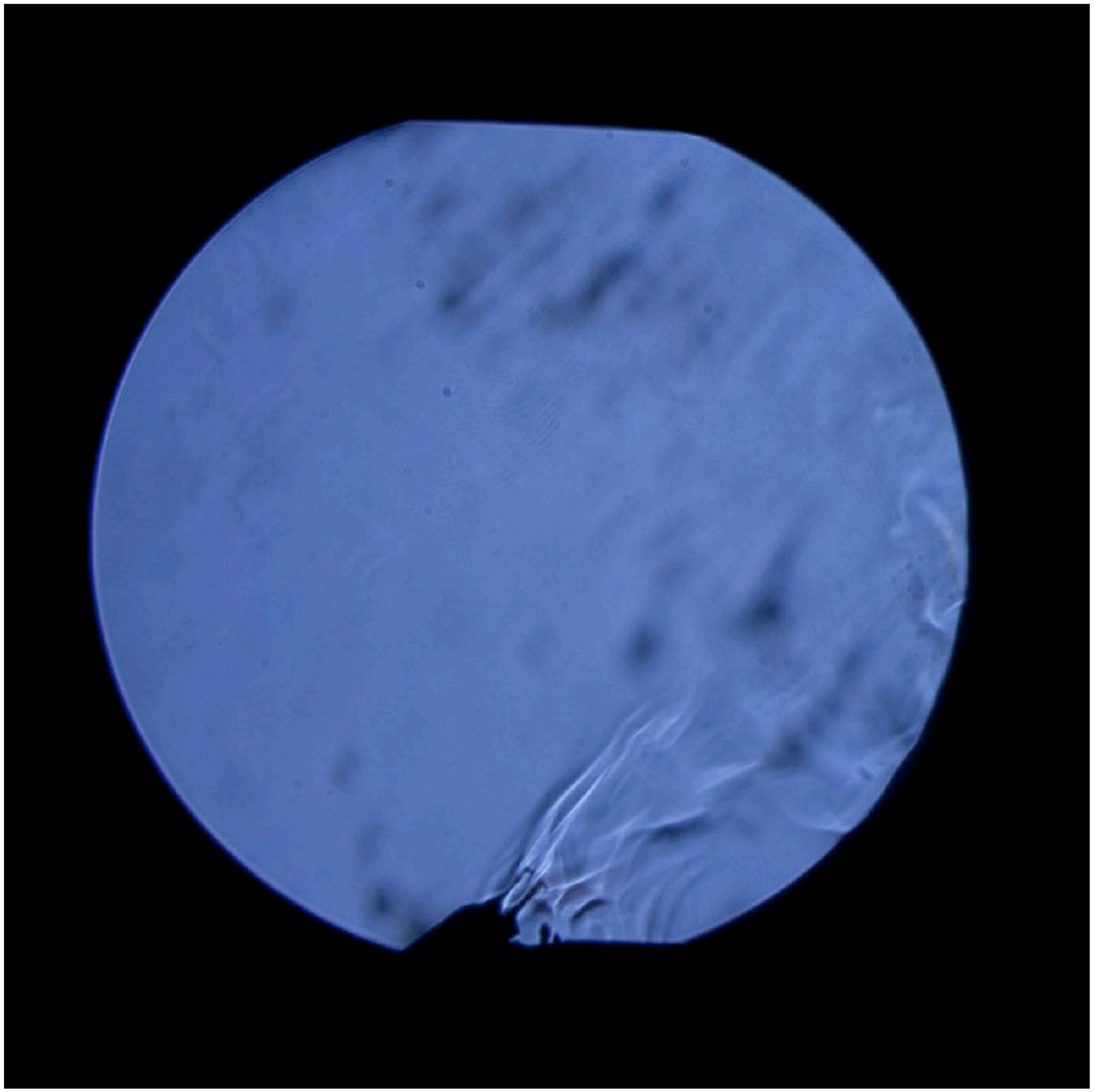

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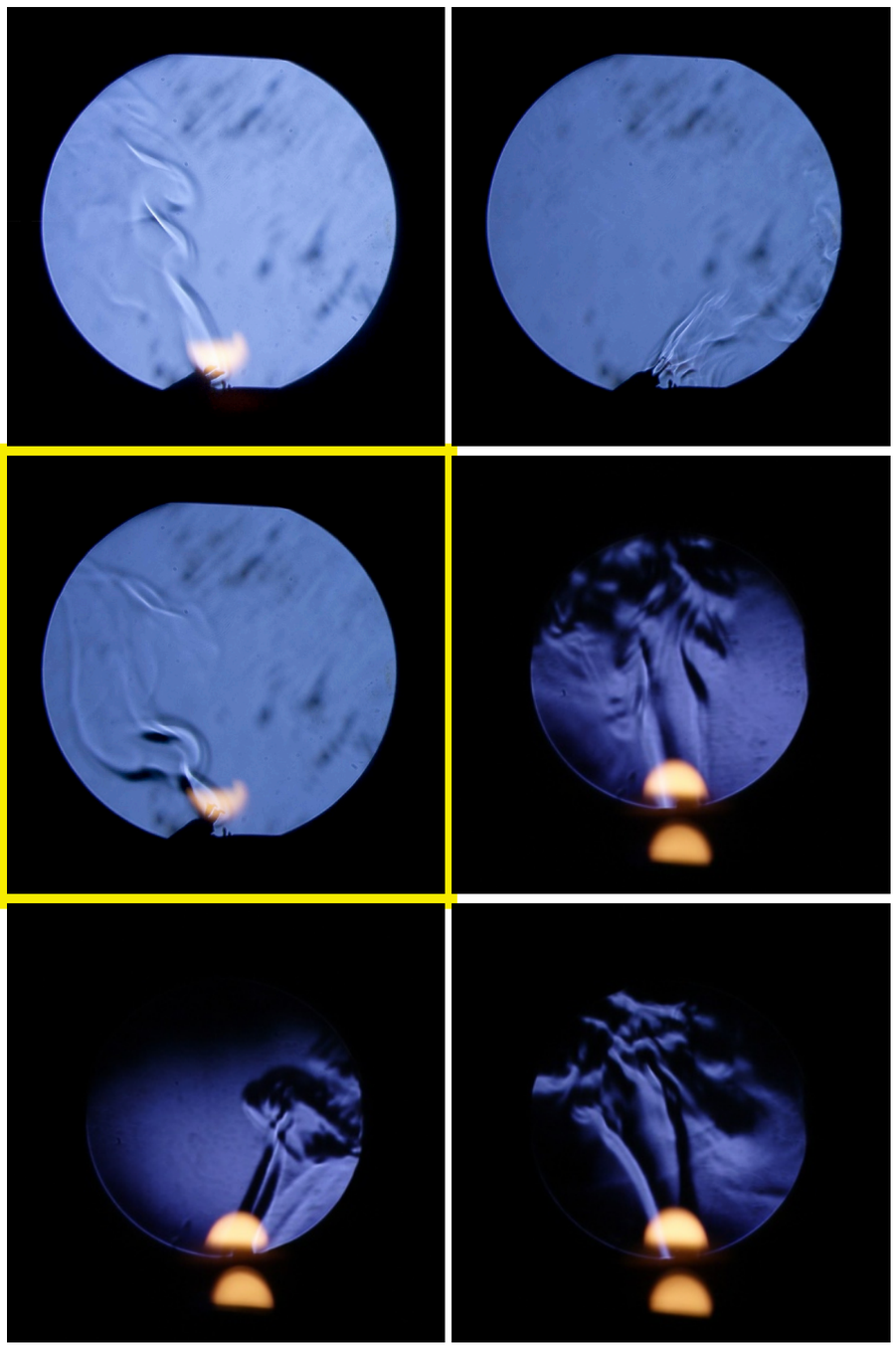

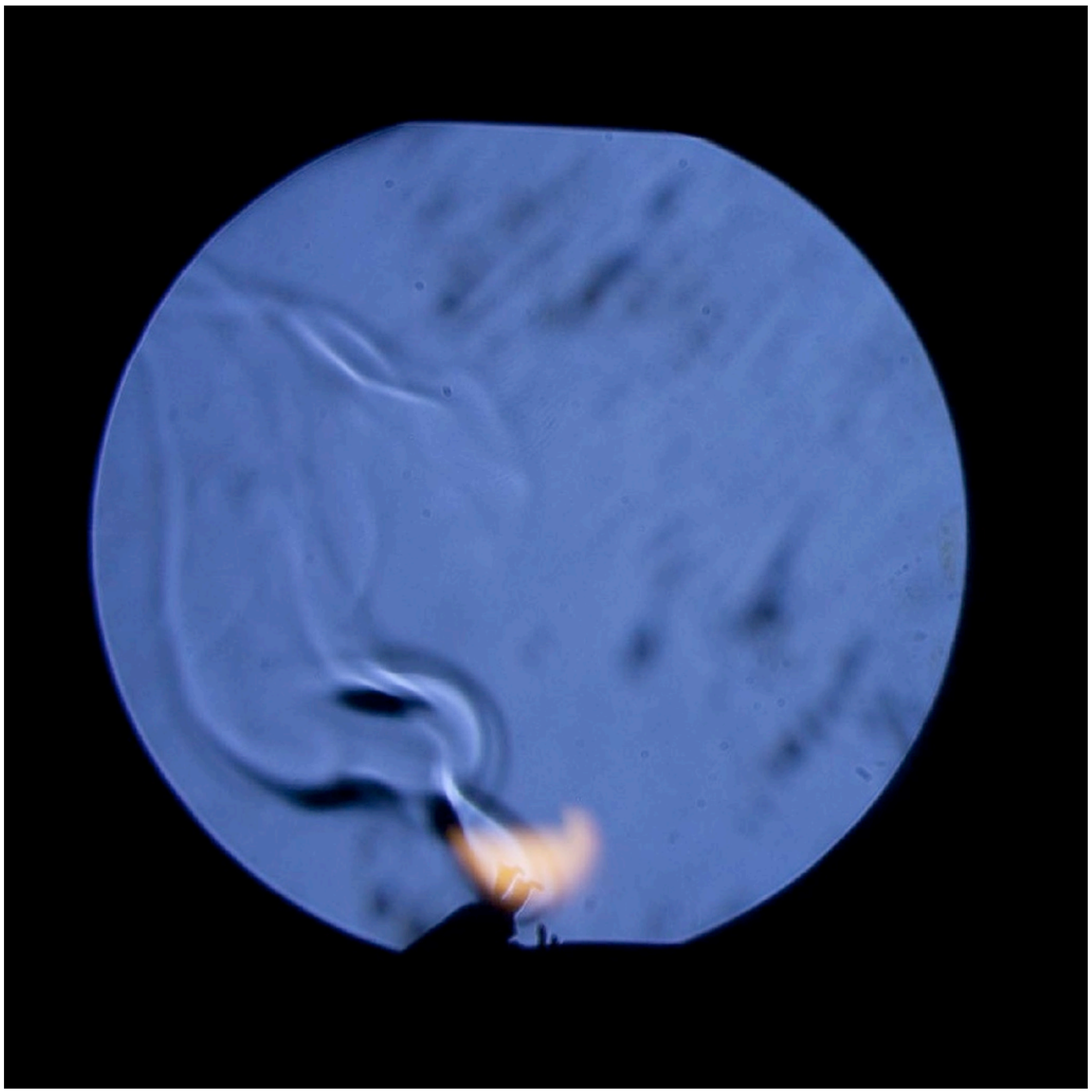

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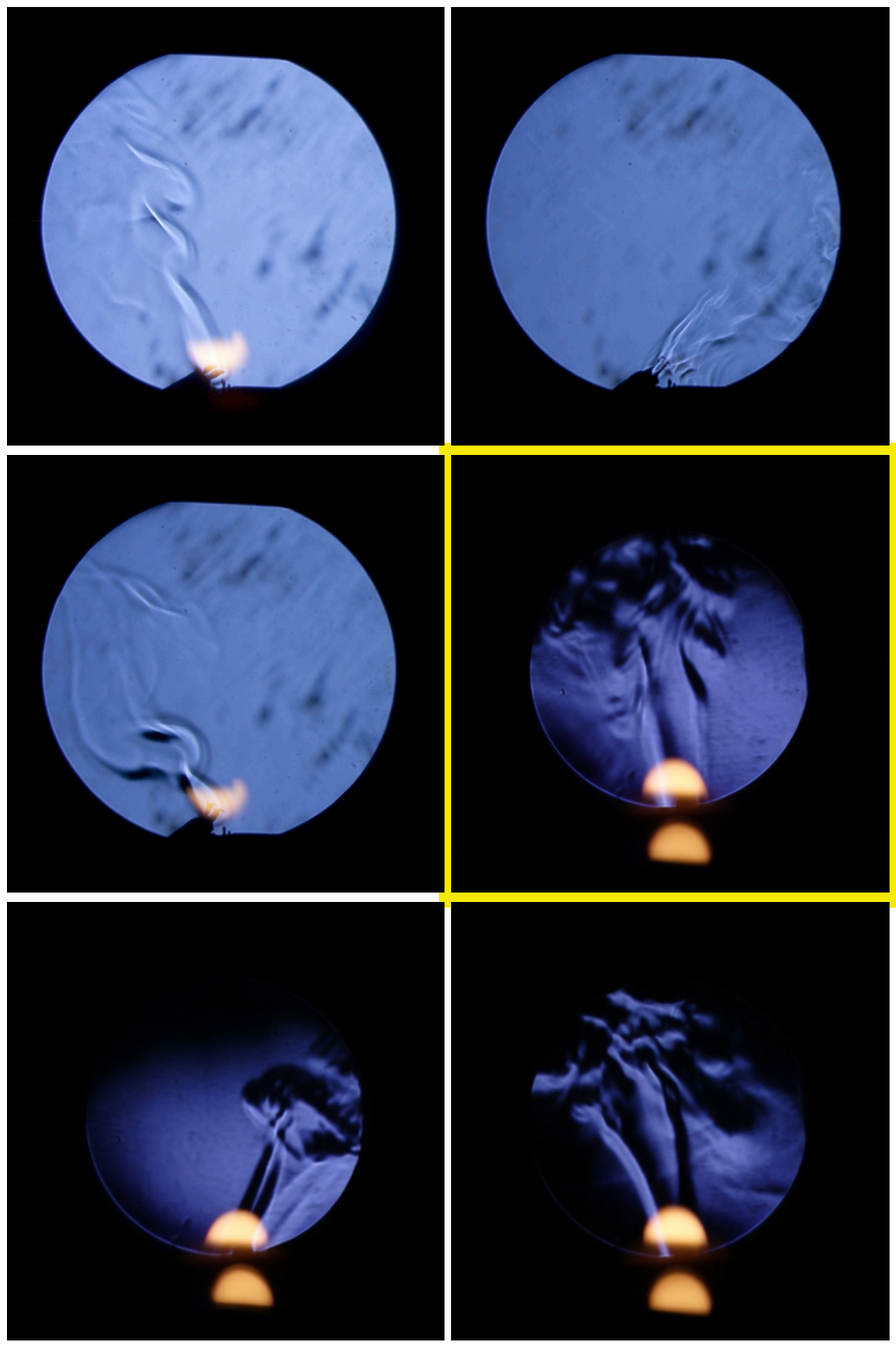

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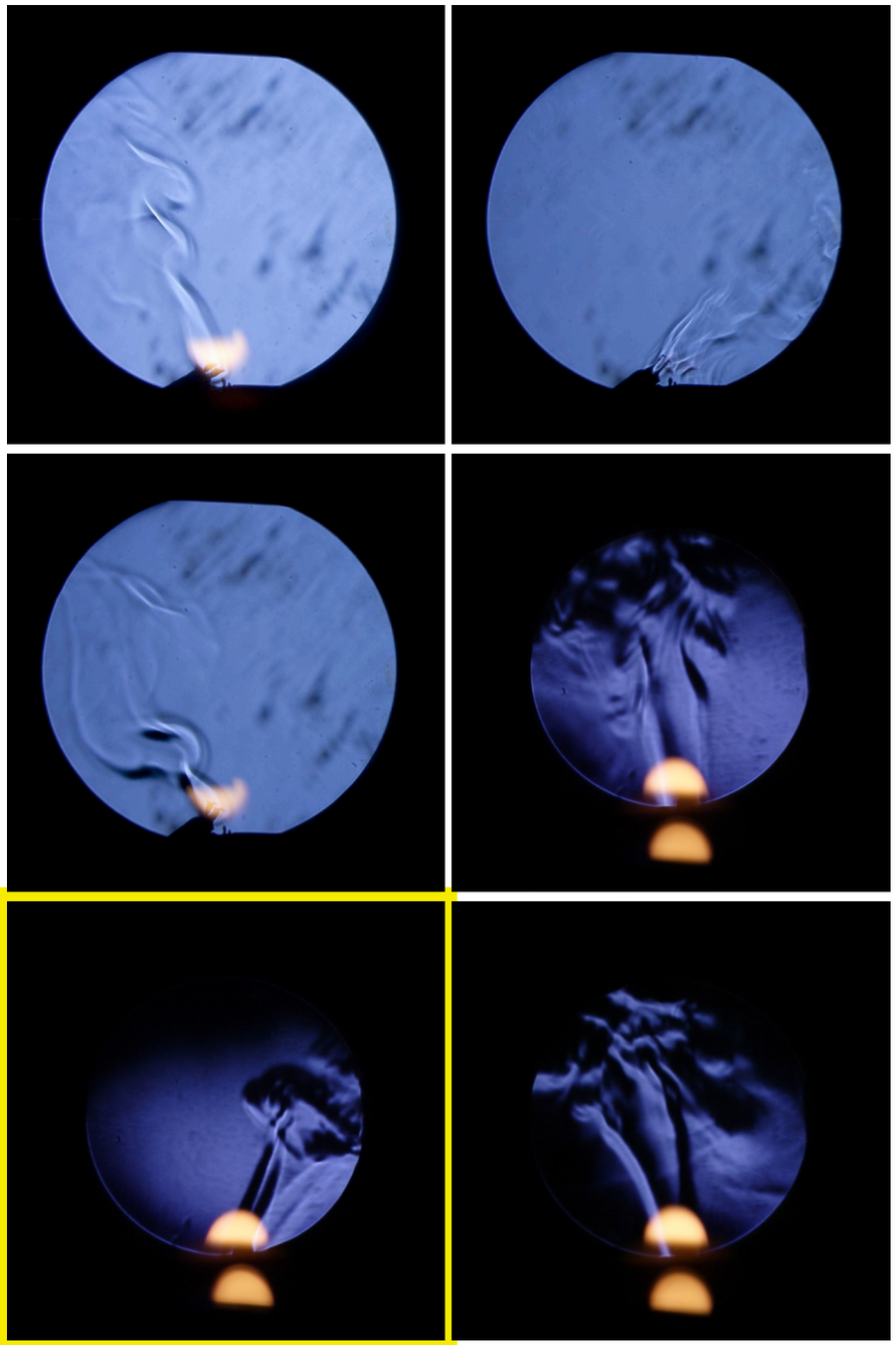

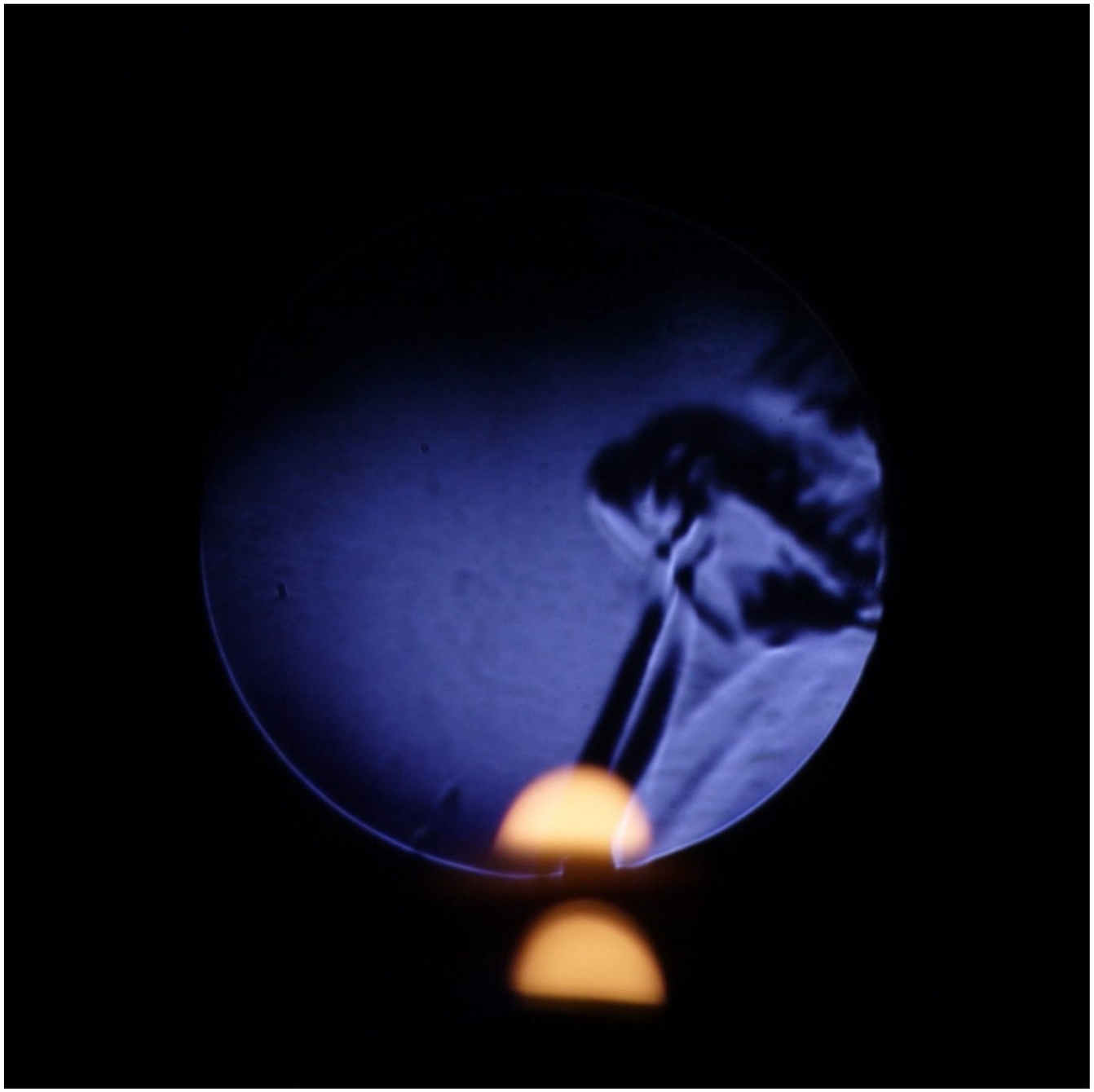

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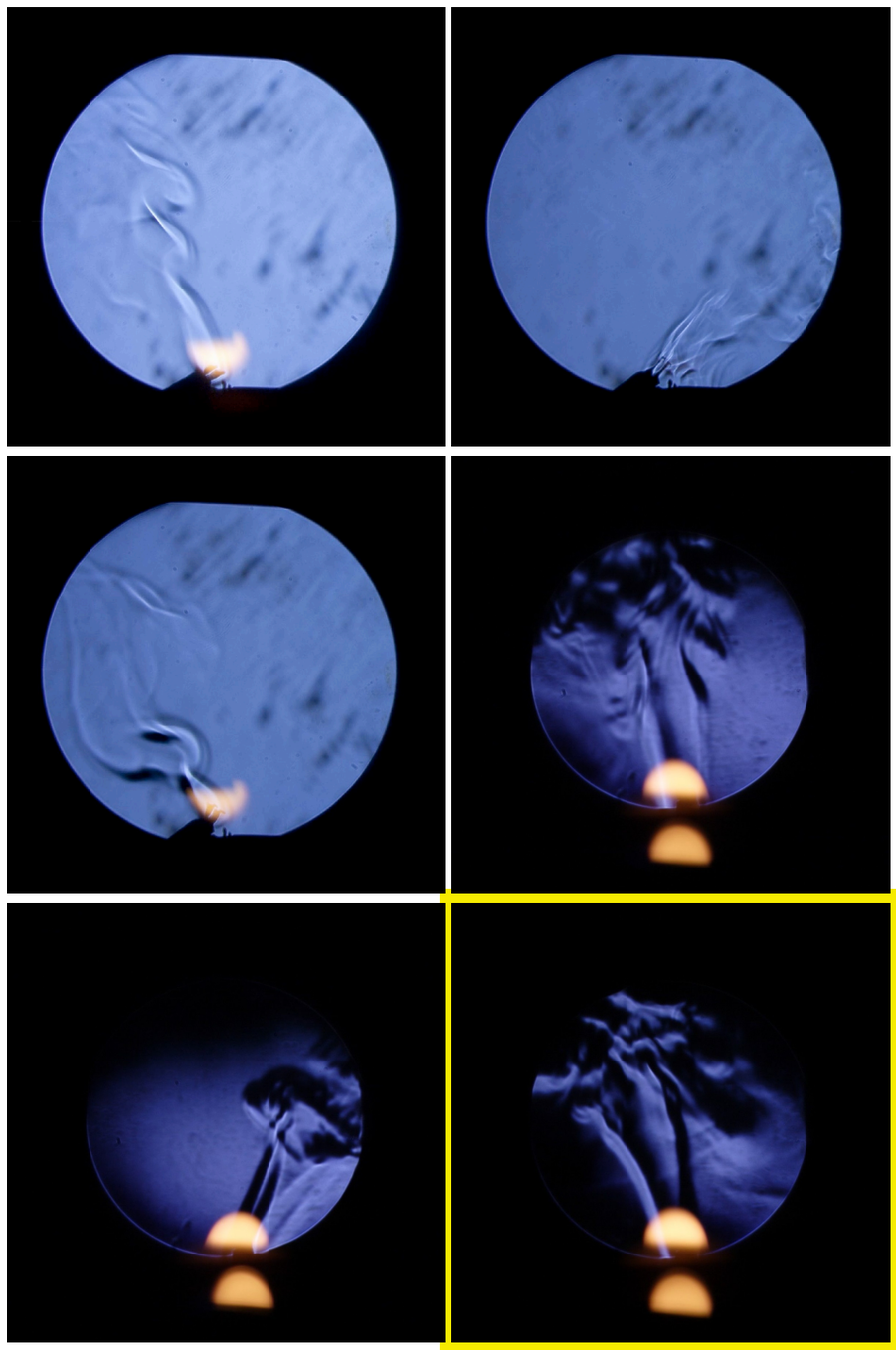

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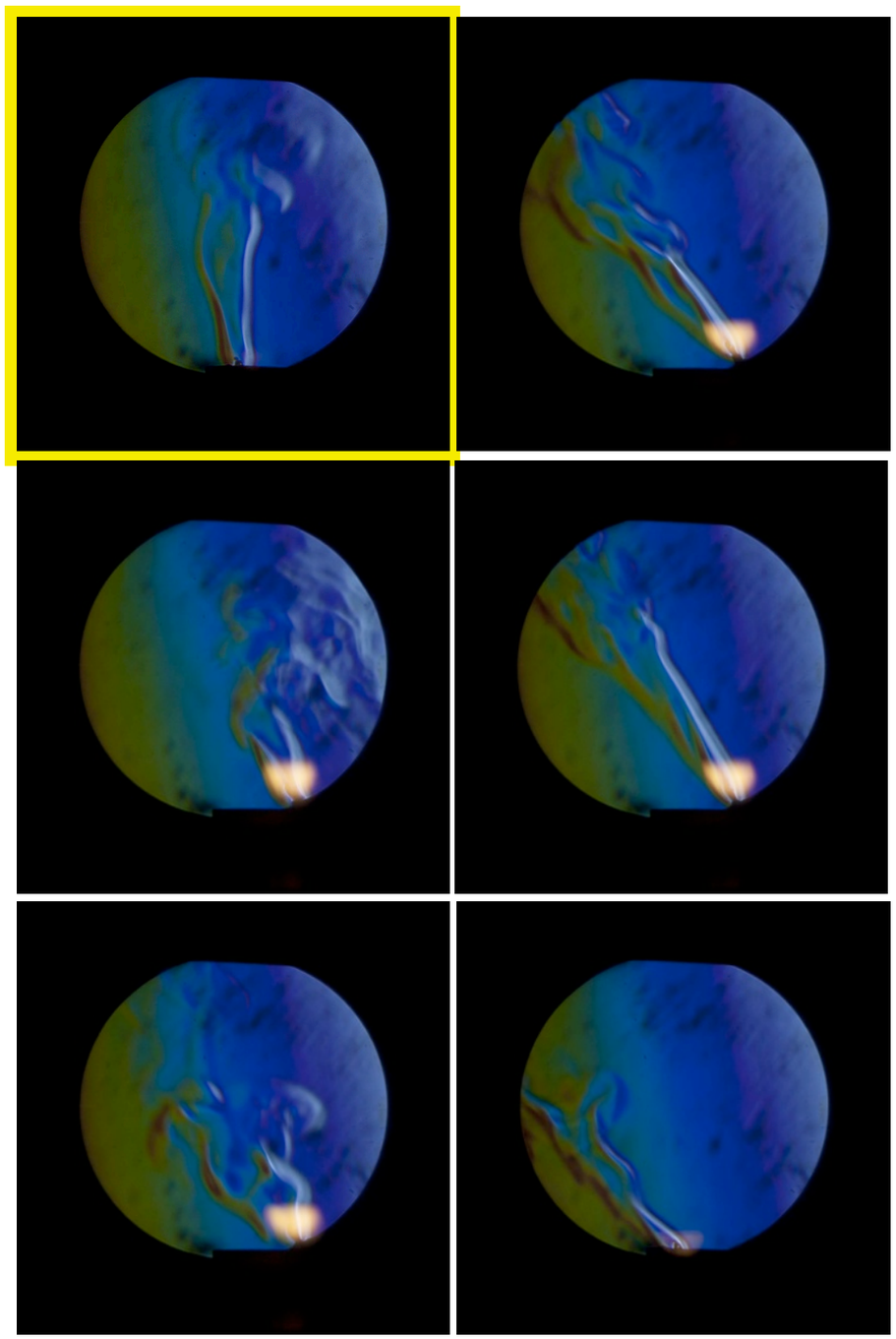

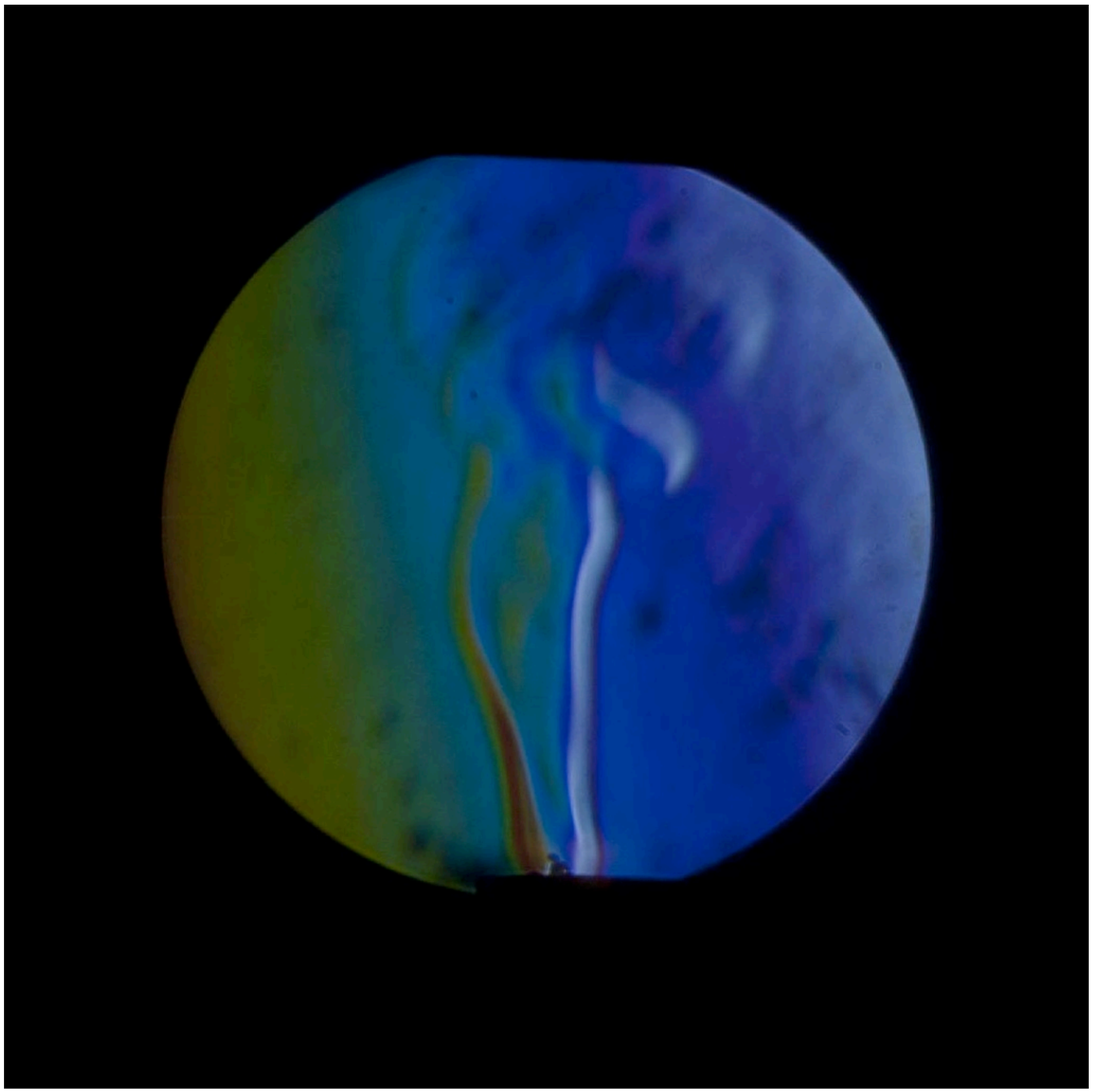

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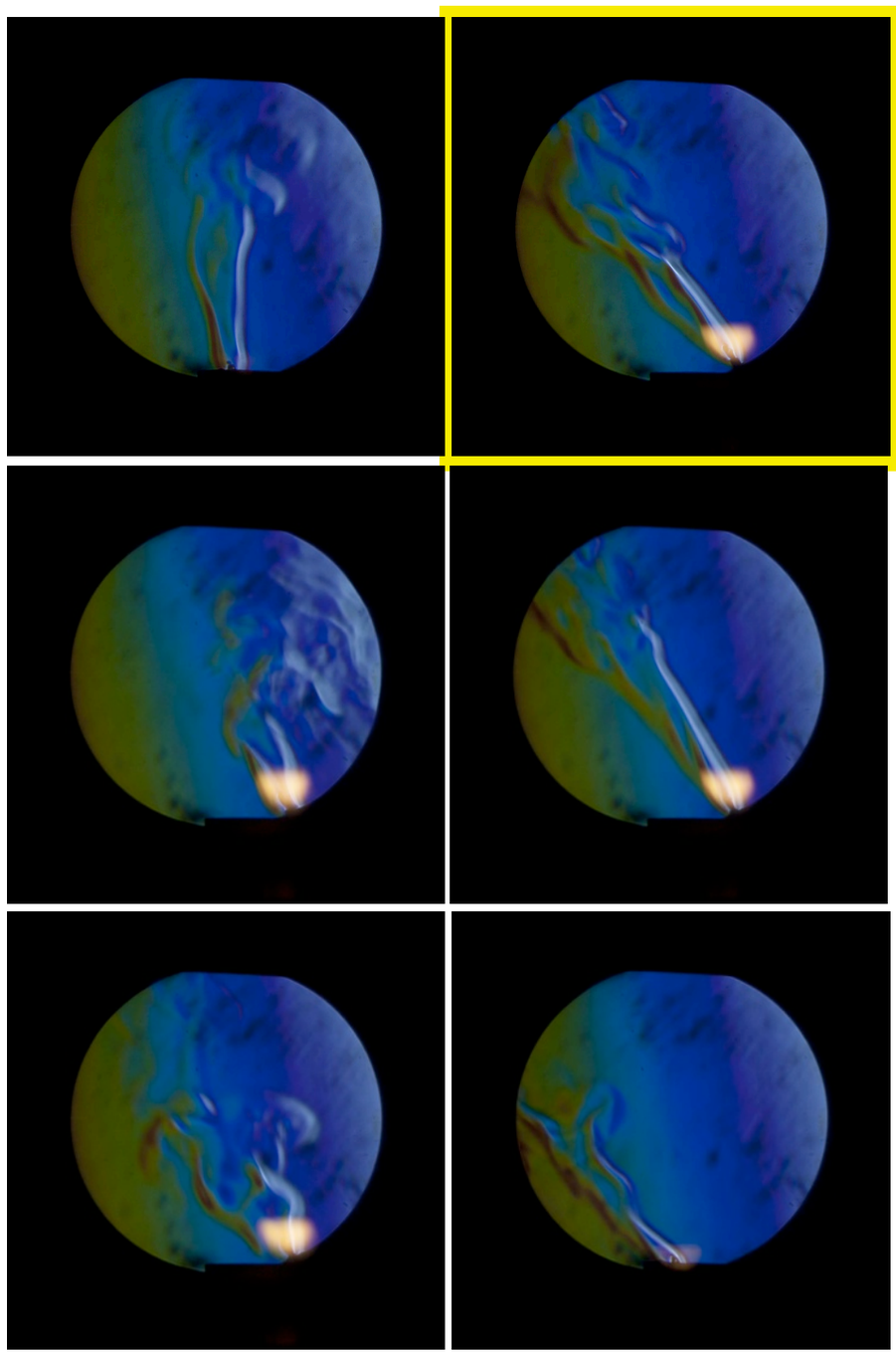

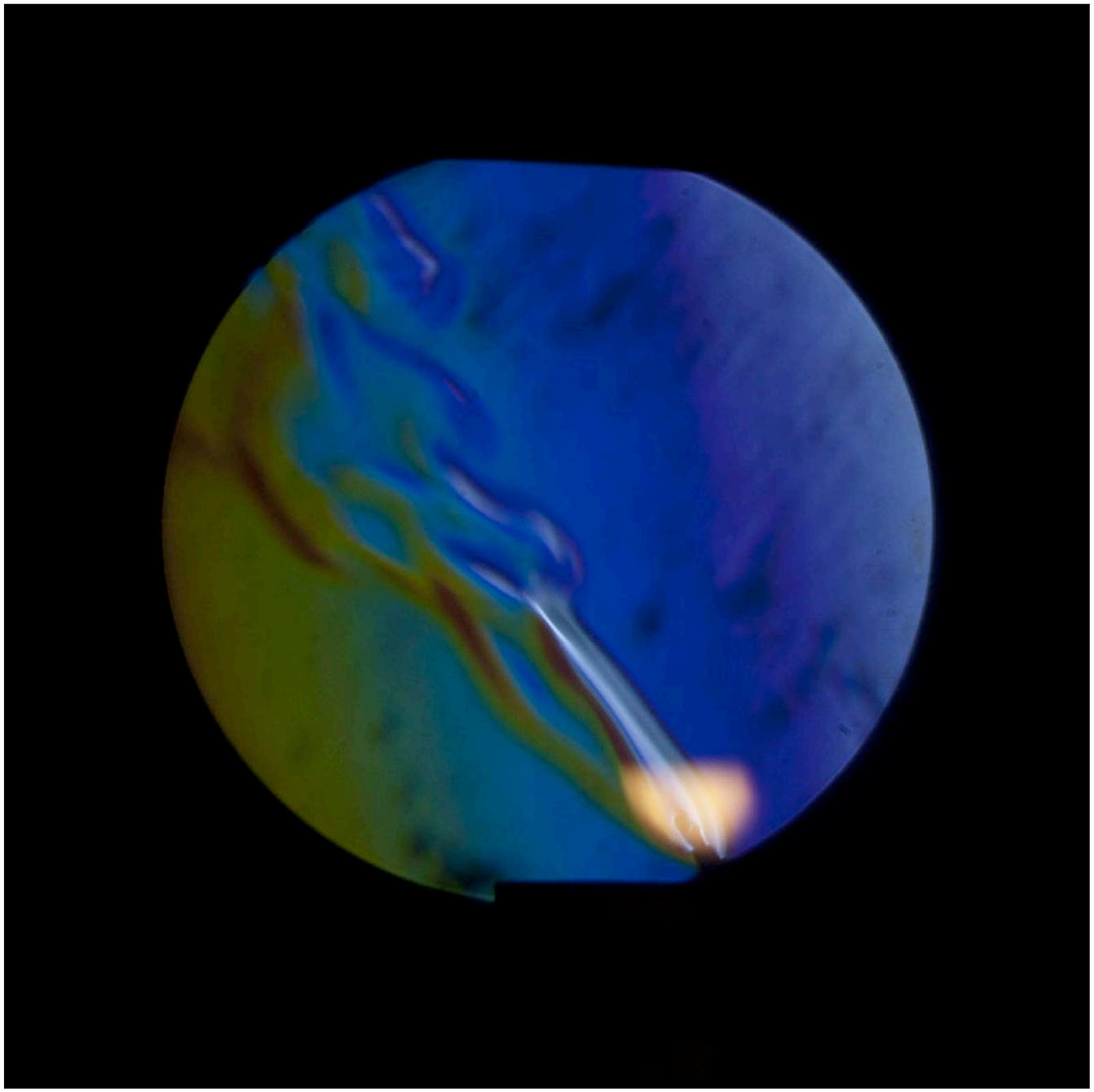

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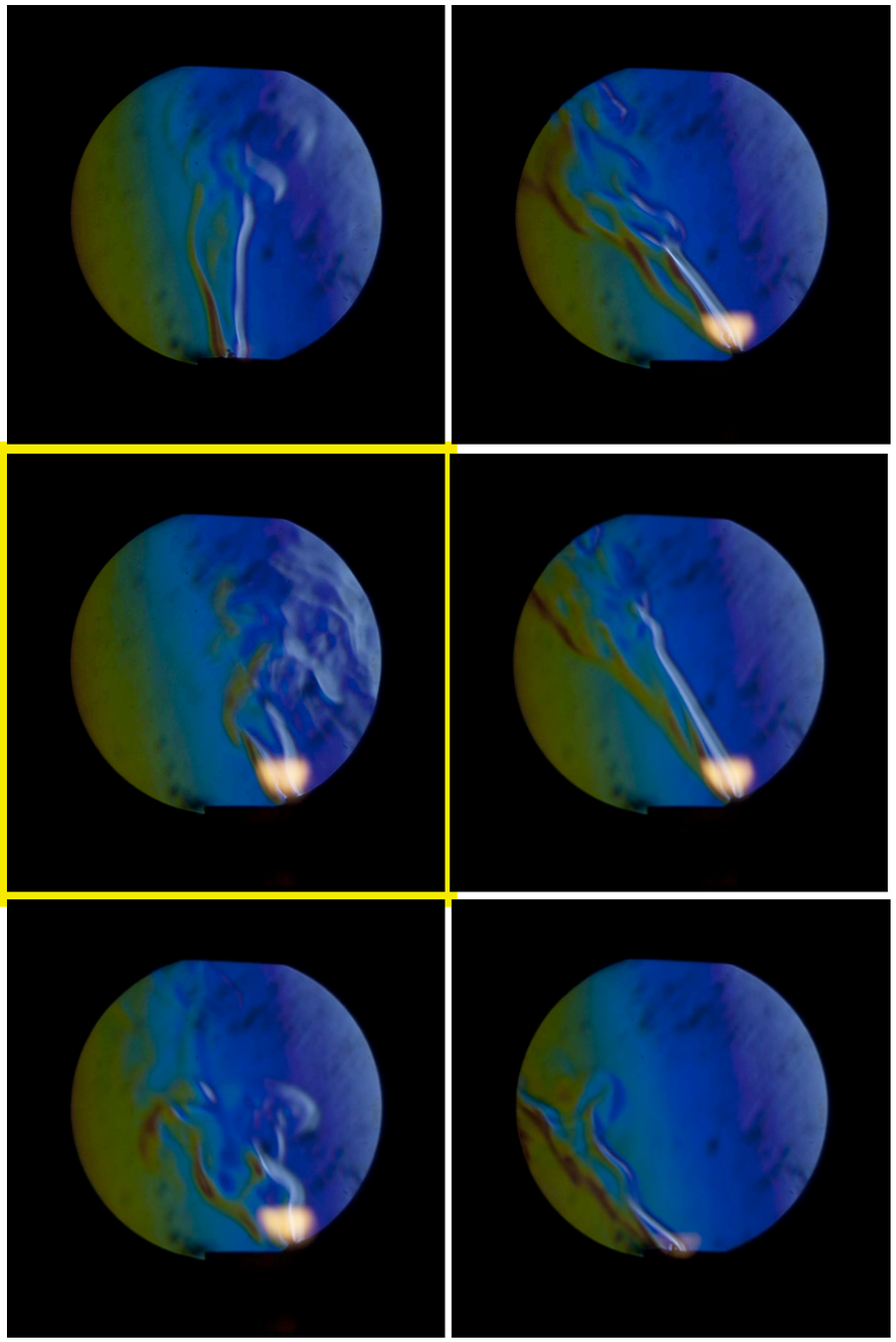

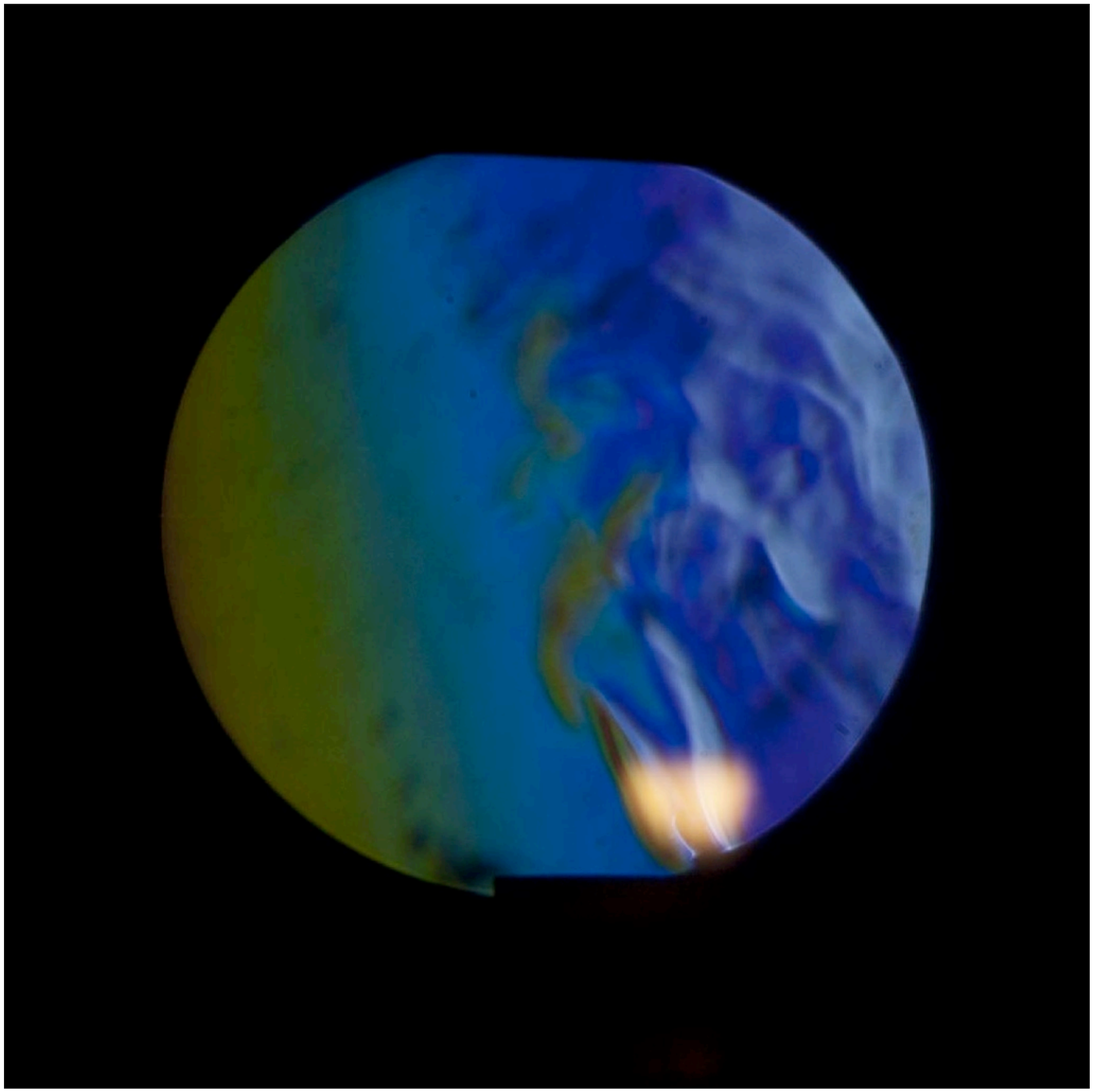

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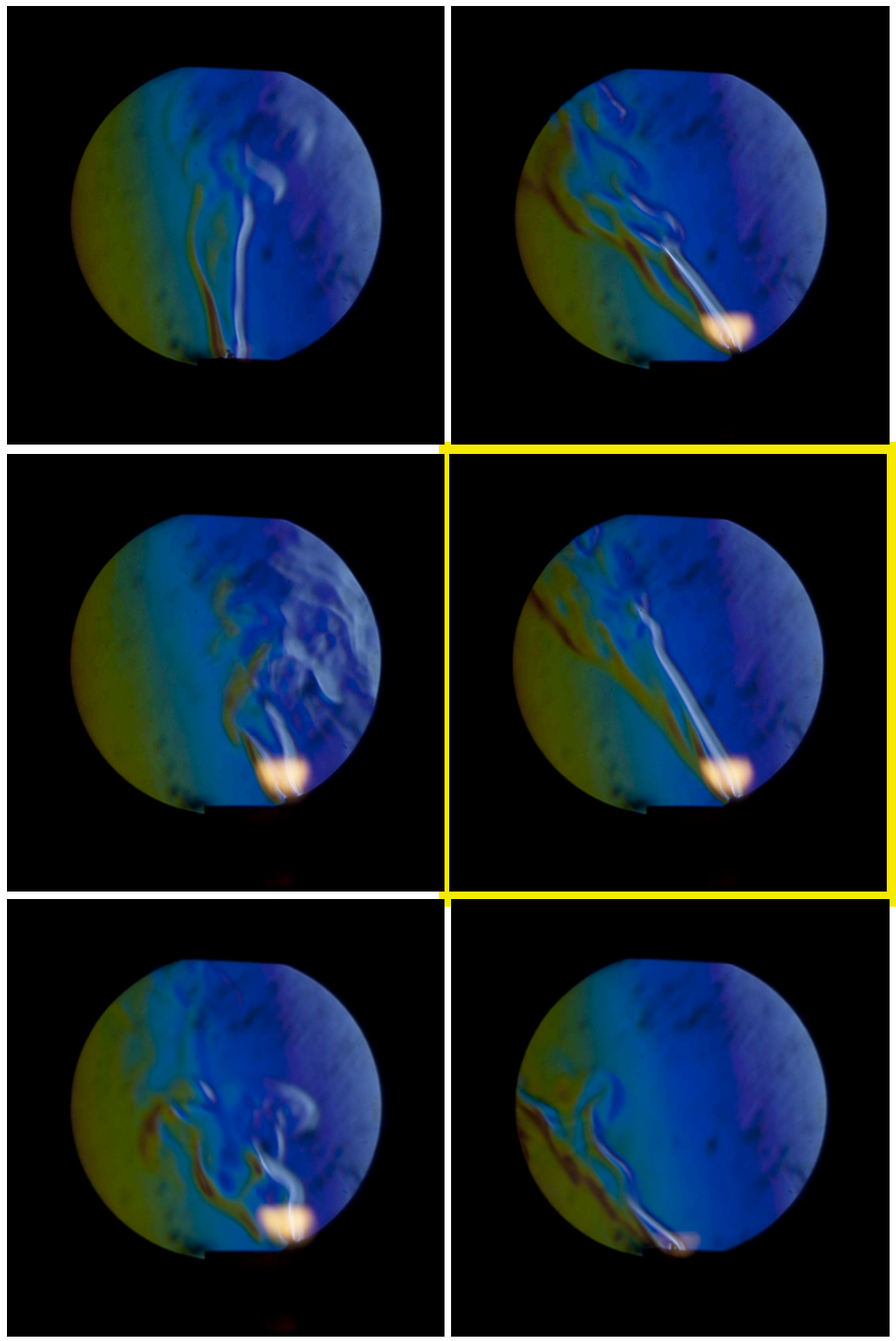

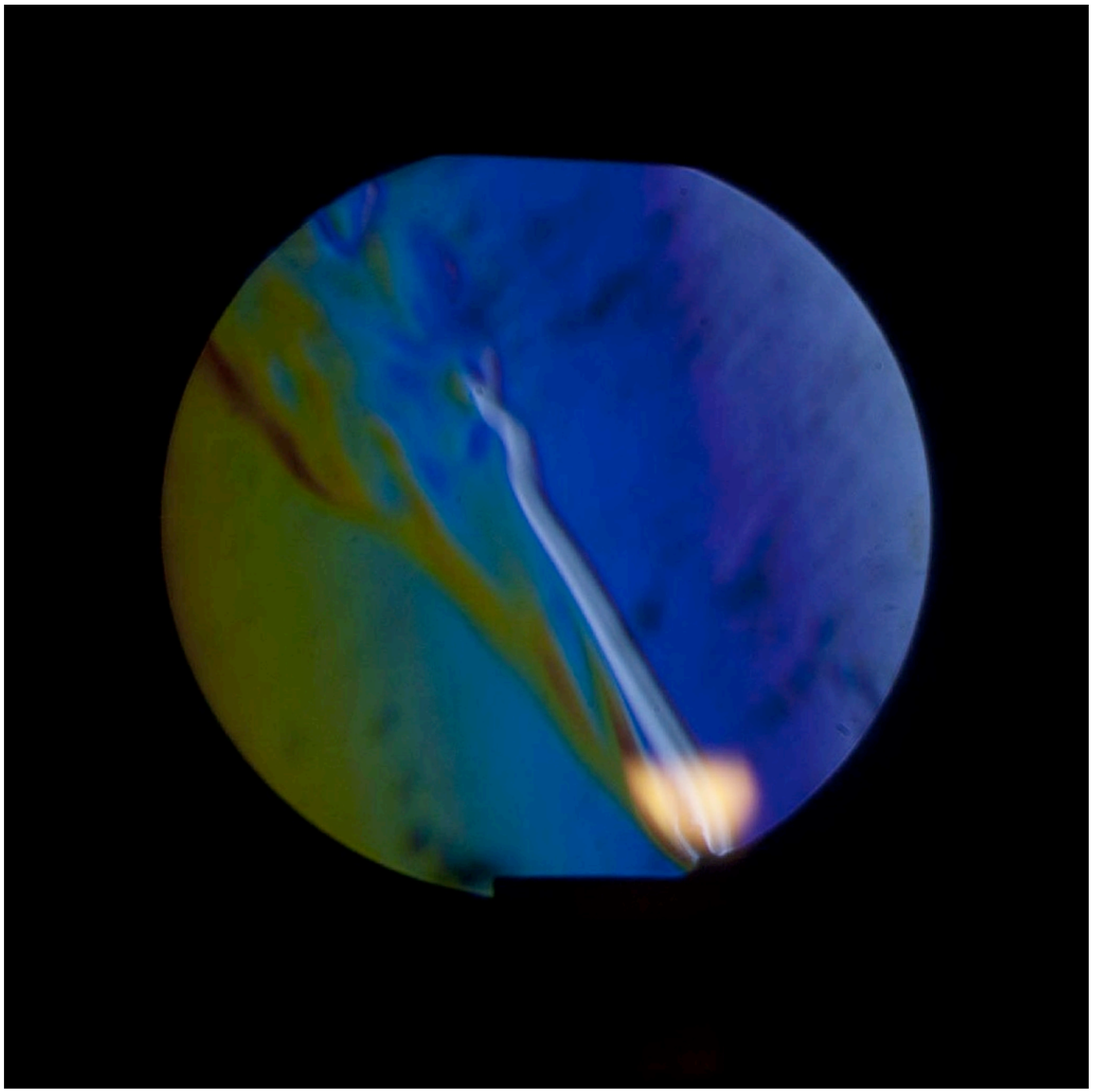

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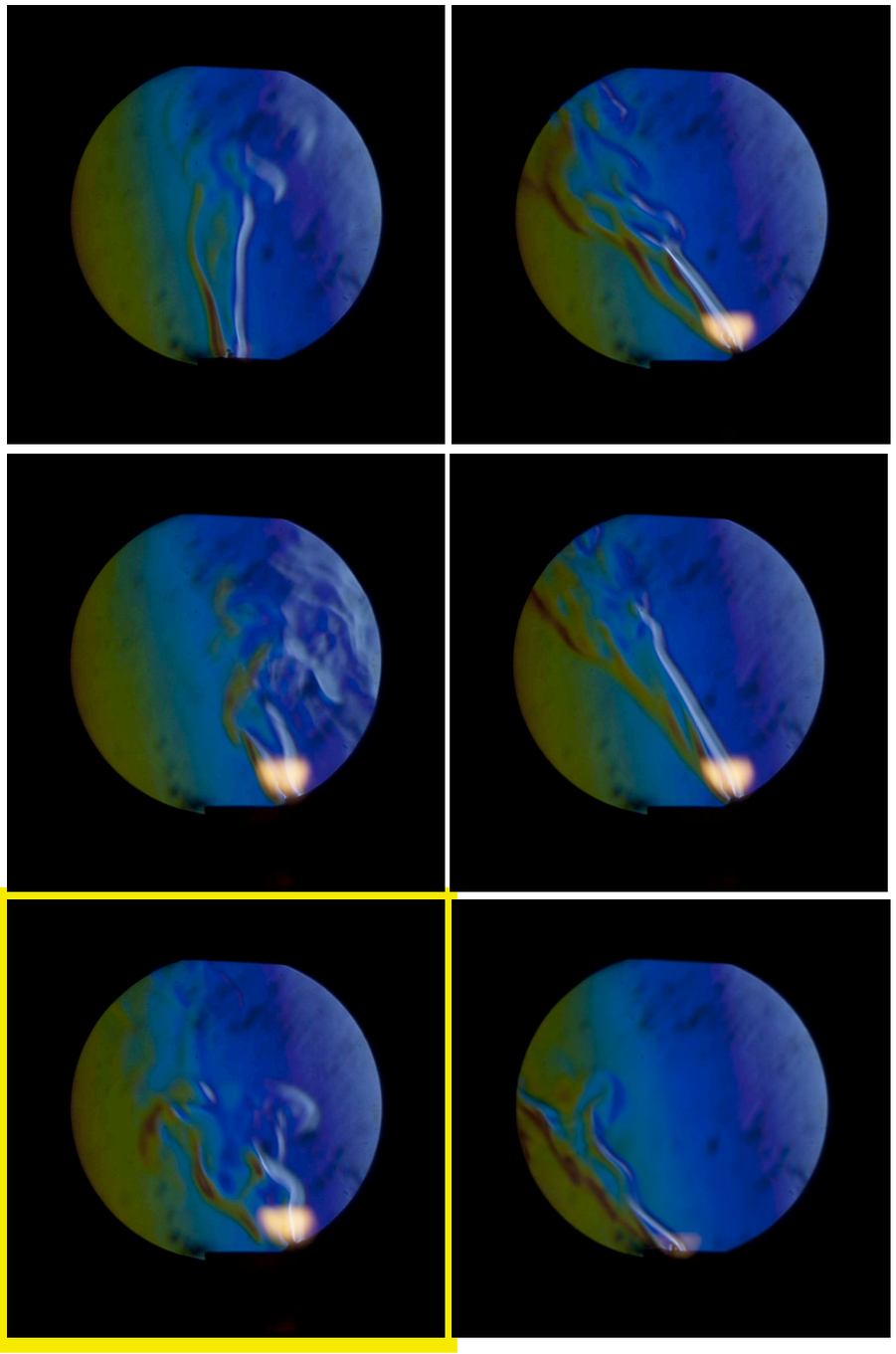

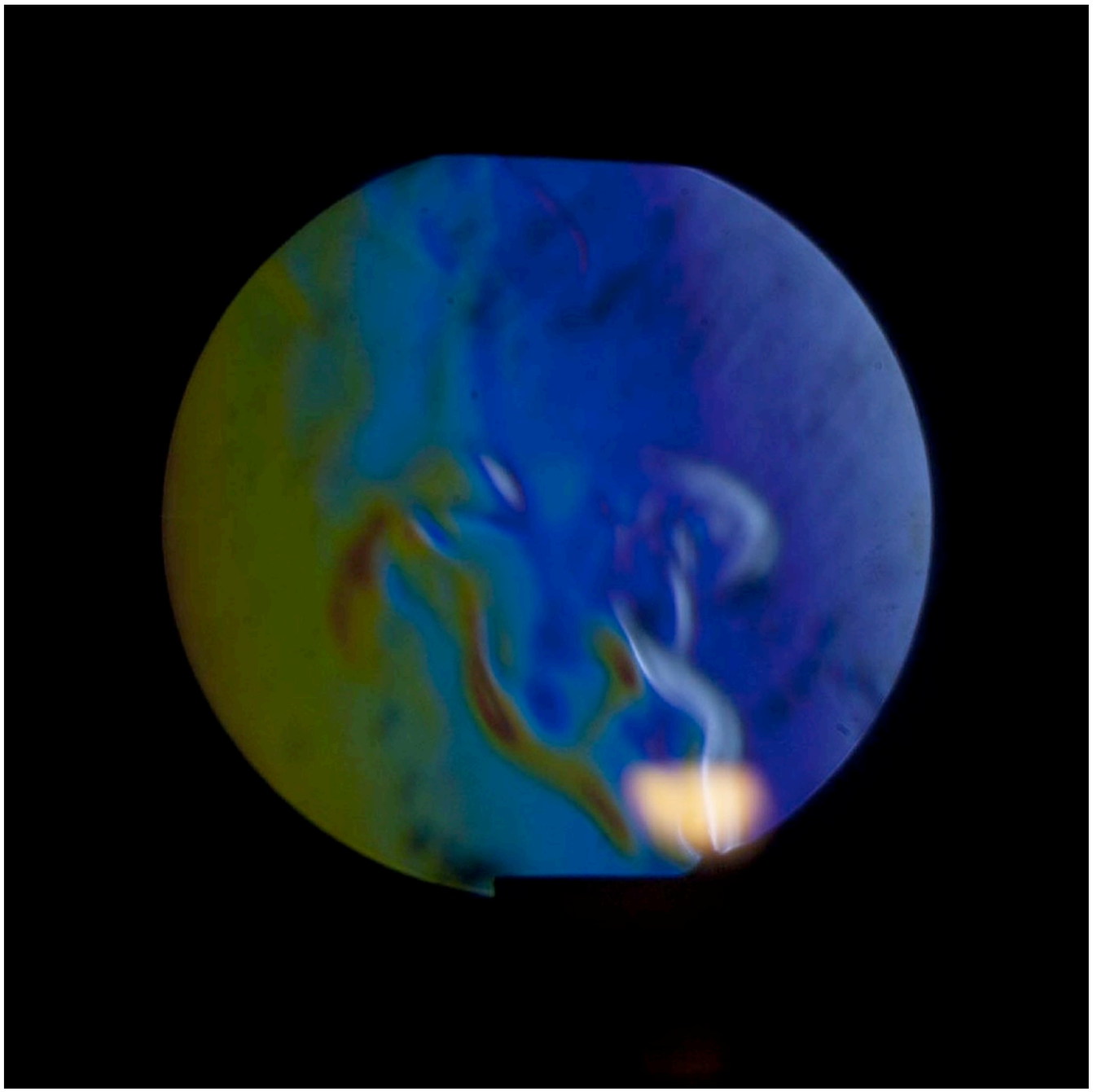

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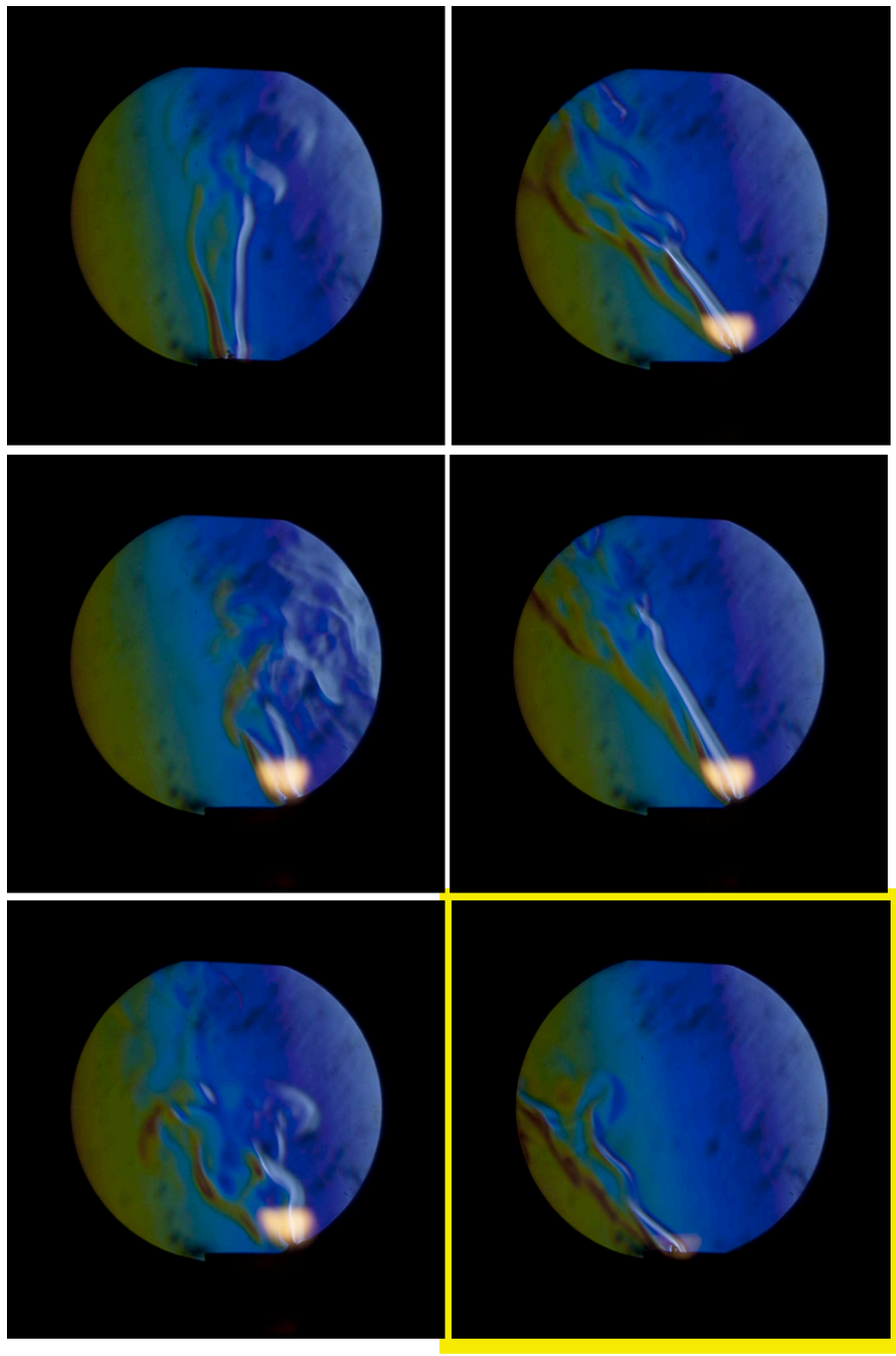
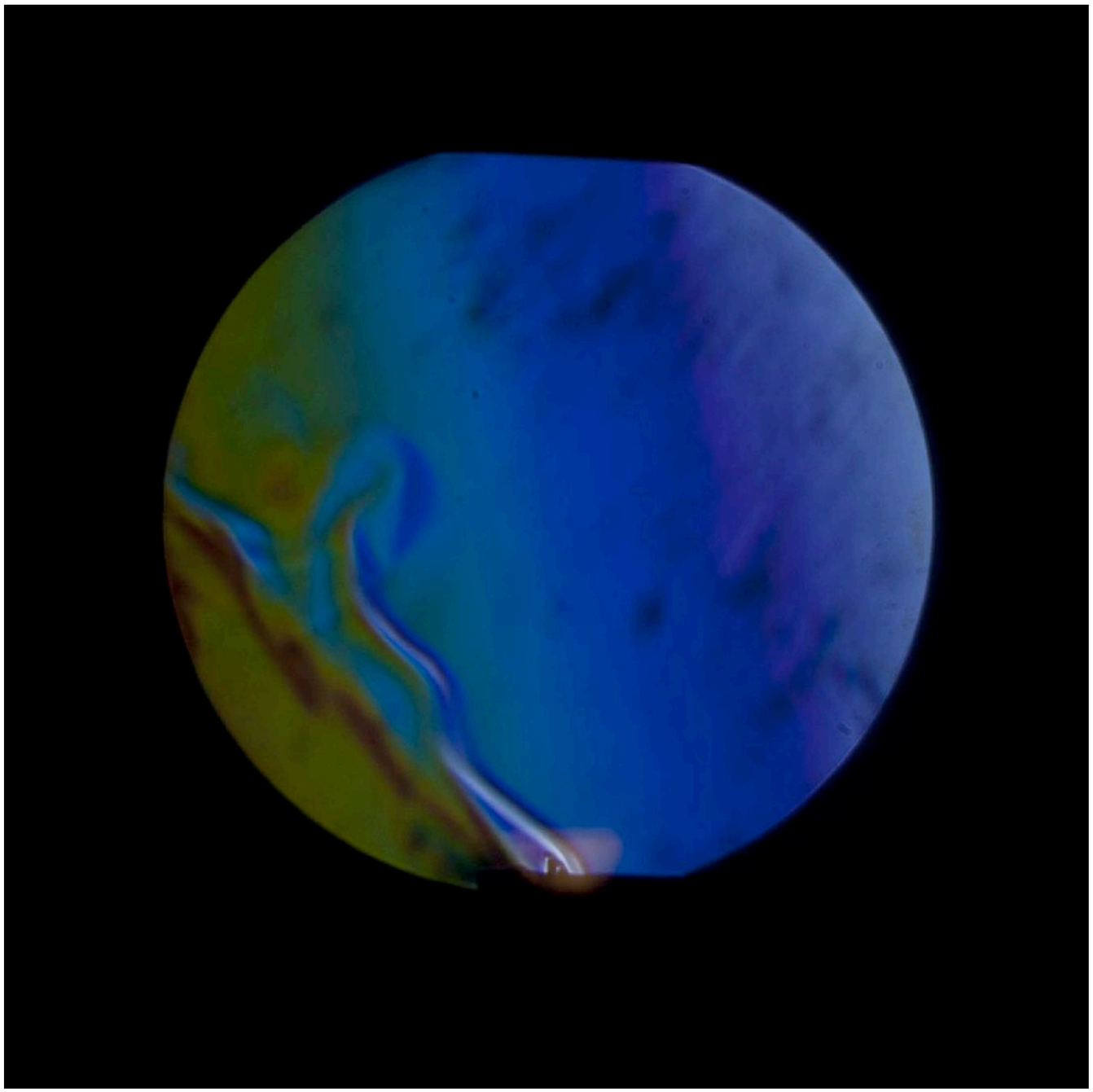
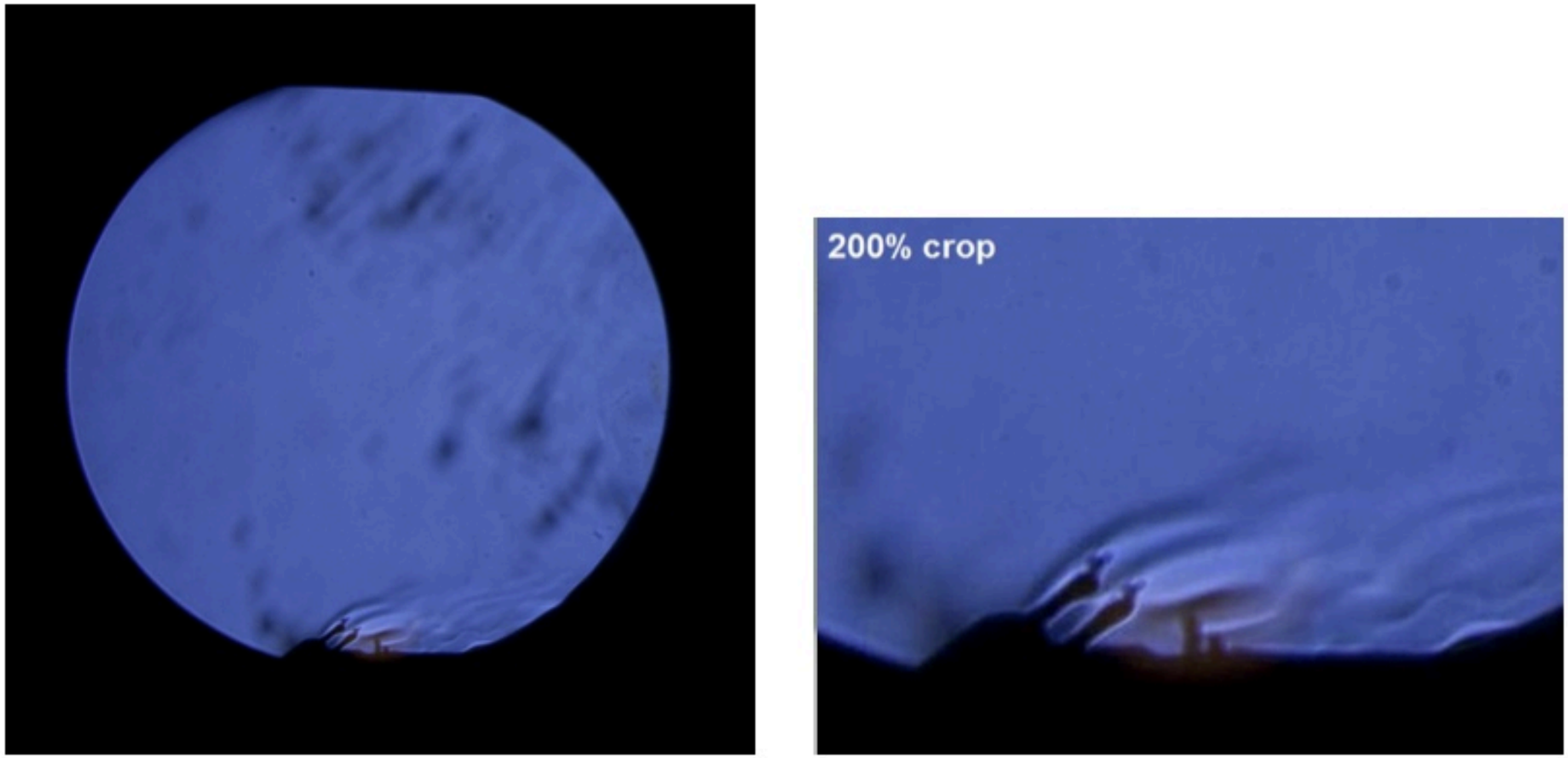




Limitations



200% crop of duplicate schliere in set-up

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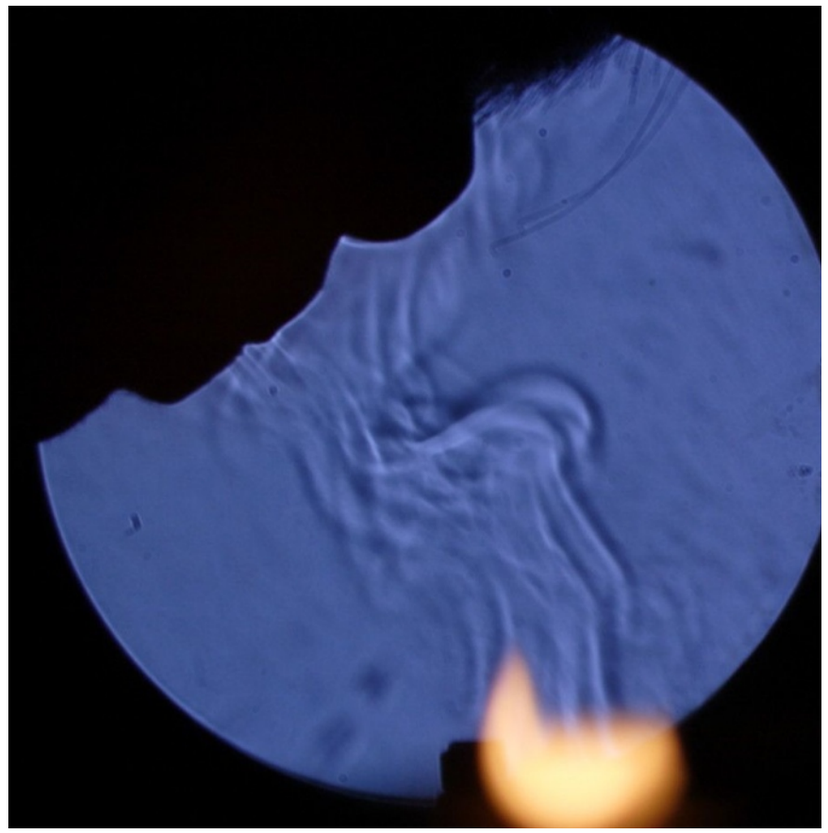


Why would we want to see schliere?

Modern Advances

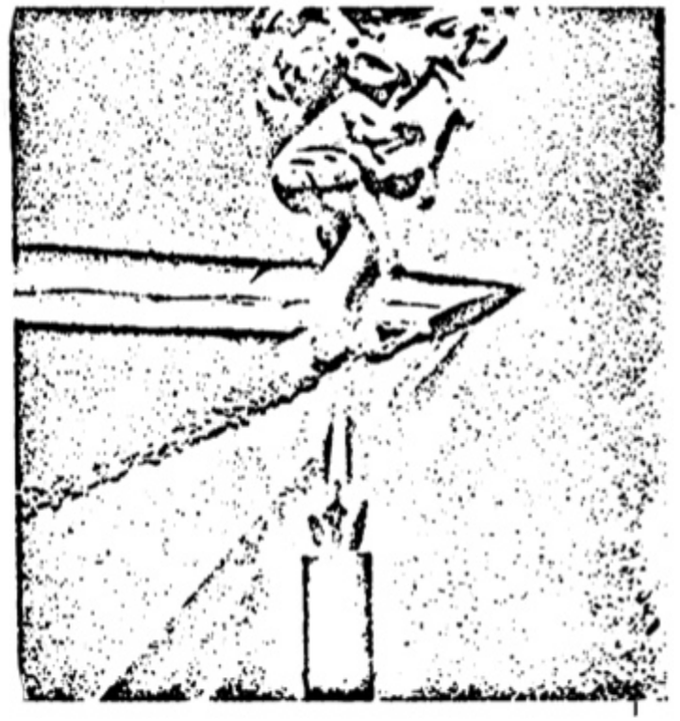


Figure 17. A Candle Flame and a Flying Projectile as Objects in the Toepler Arrangement.

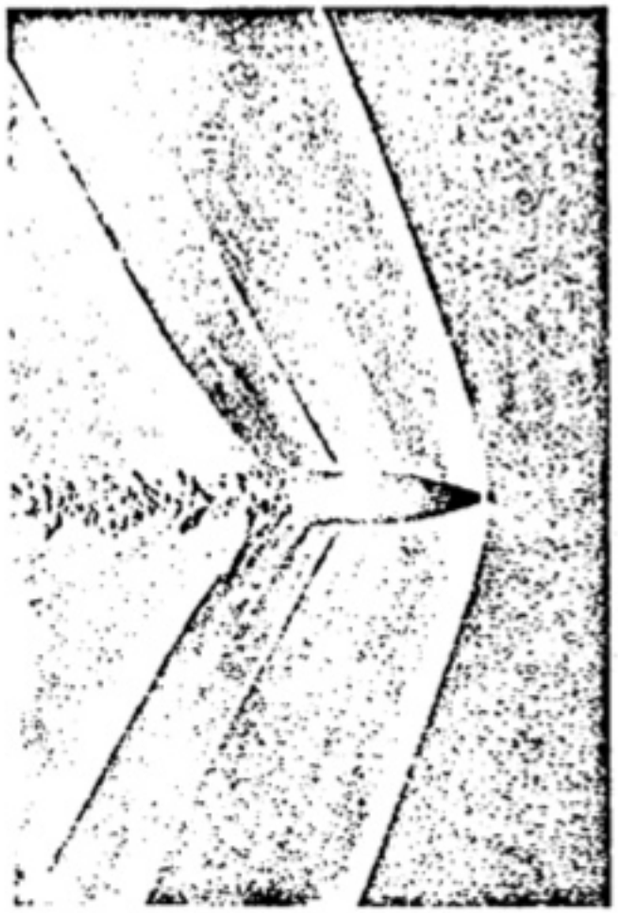


Figure 82. A S-Bullet Flying at 375 m/sec.

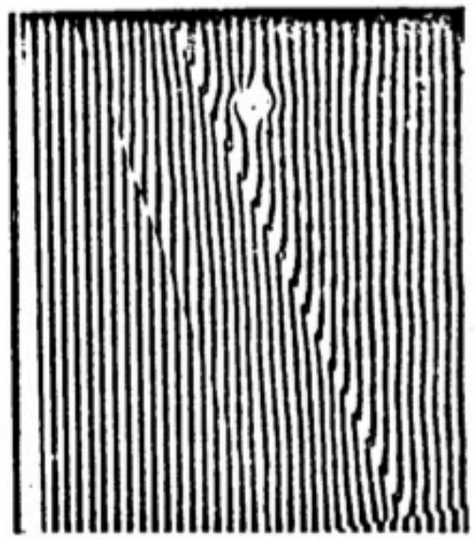


Figure 5a.

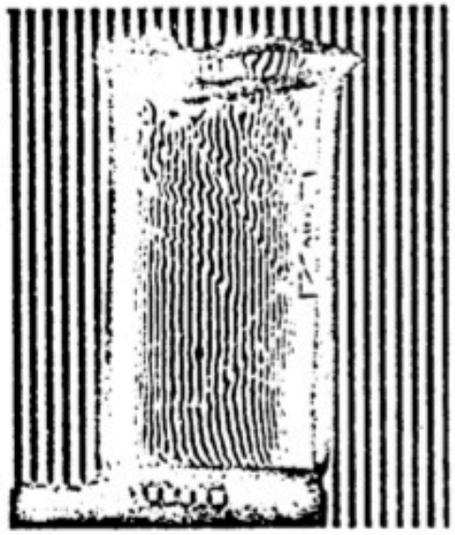


Figure 5b.

Figures 5a and b. Photographs With Schlieren Process Number 2: a, Plate Glass; b, Water Glass.

Schardin, 1942

Modern Advances

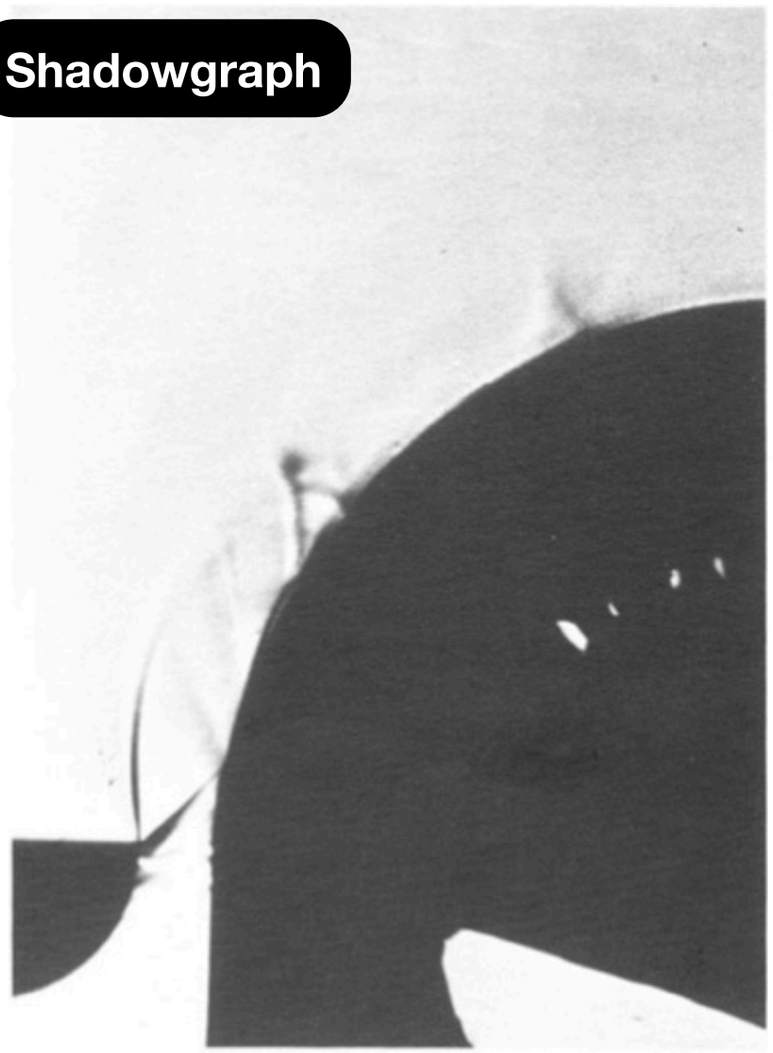
Settles et.al., 2004

What do we want to see next?

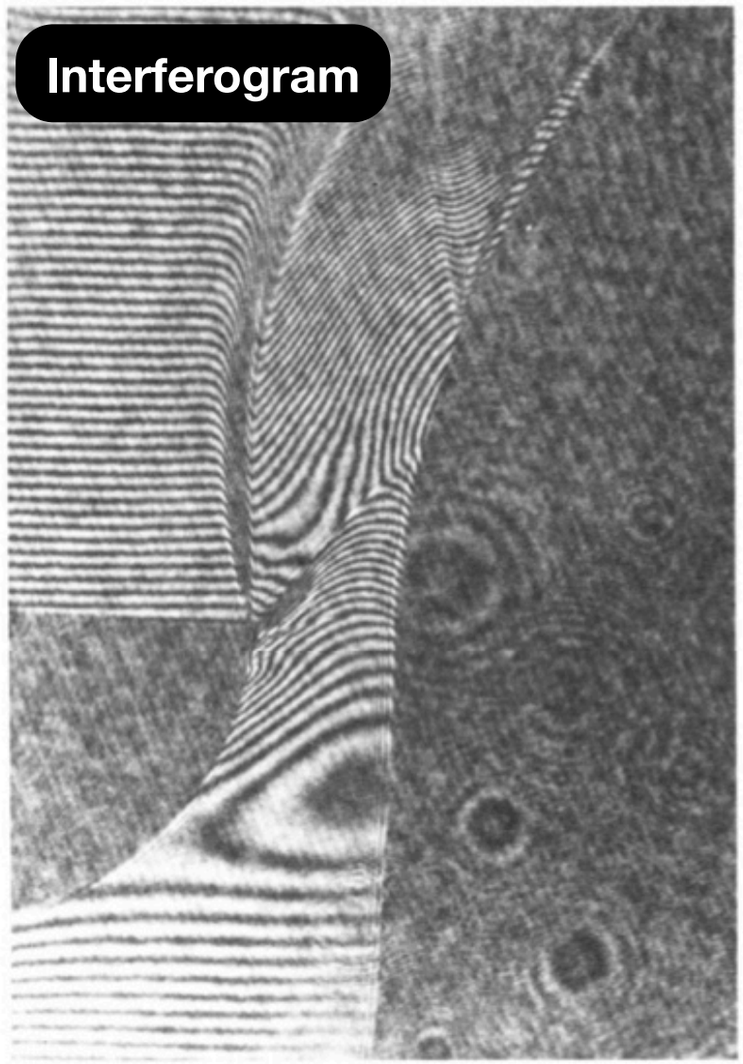
Shadowgraphy & Interferometry

Schlieren

Shadowgraph

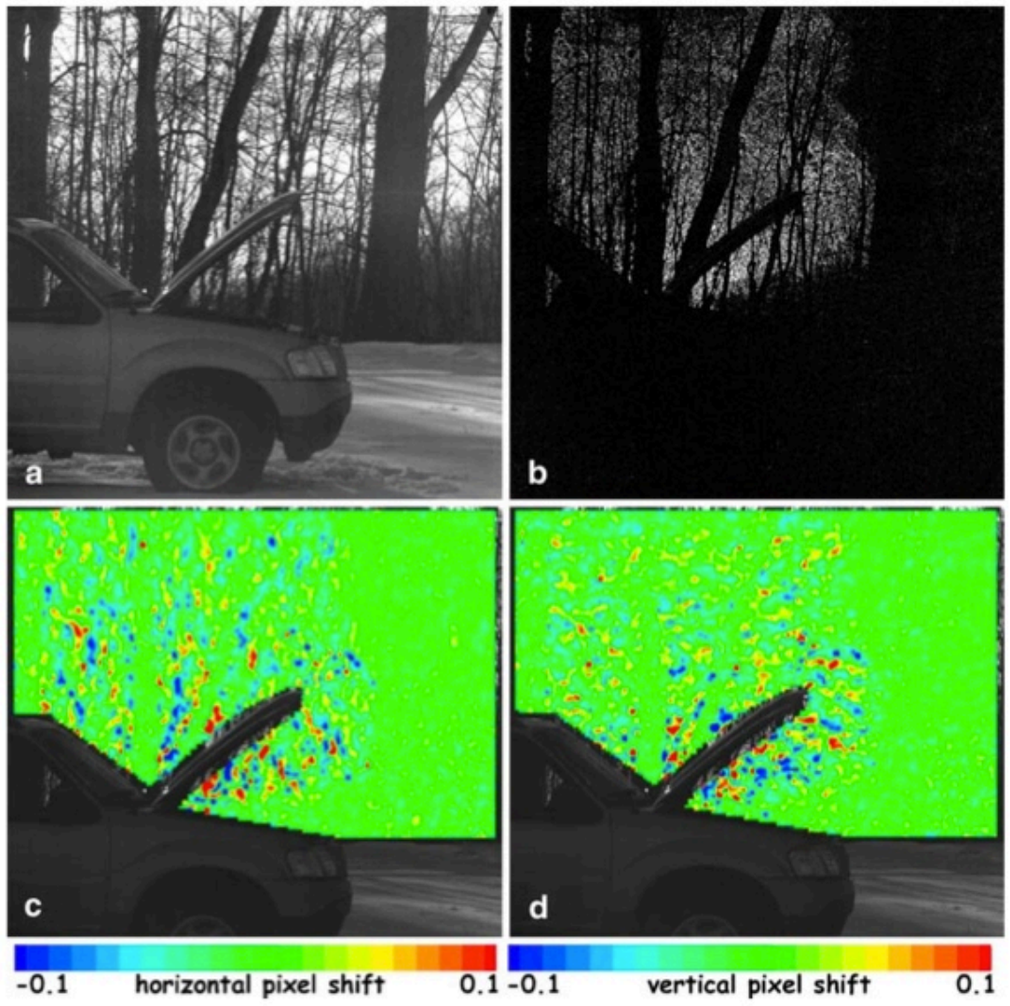


Interferogram

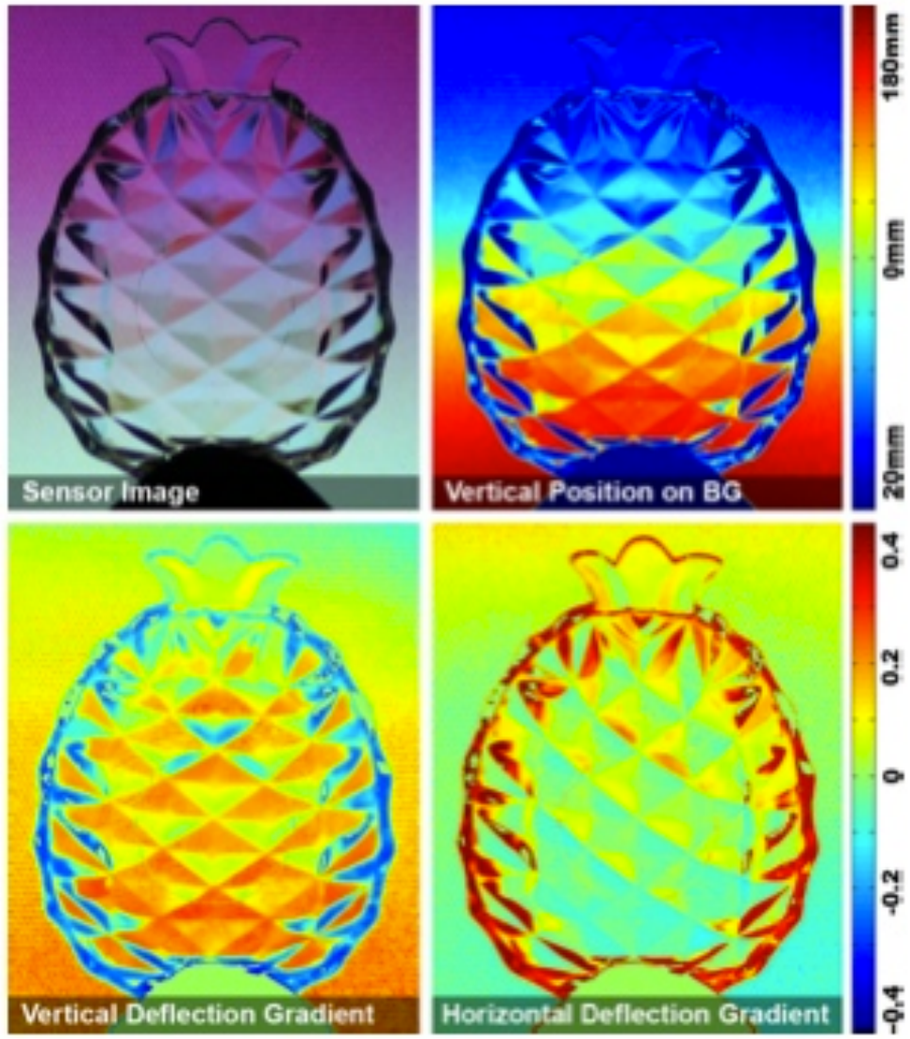


Gilchrist et. al., 1989

Background Oriented Schlieren



Natural BOS system
Settles et al, 2009



Light field BOS system
Heidrich et al, 2011

Resolution Improvements

- **Spatial Resolution**
- **Dynamic Range**
- **Noise**

Acknowledgements

Dr. Nayar

Changyin Zhou

Everyone at the CAVE lab

Any Questions?