Recent development of methods based on structured illumination for combustion studies

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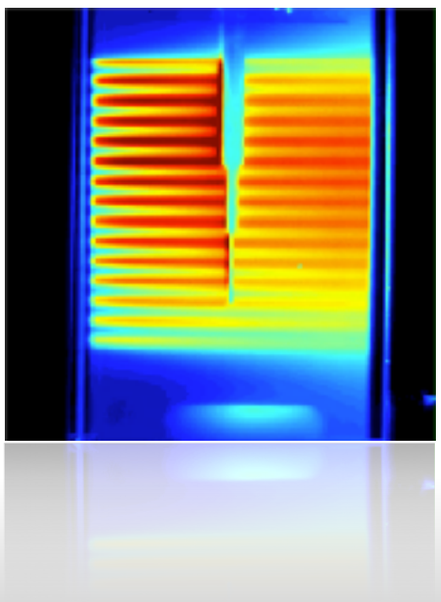
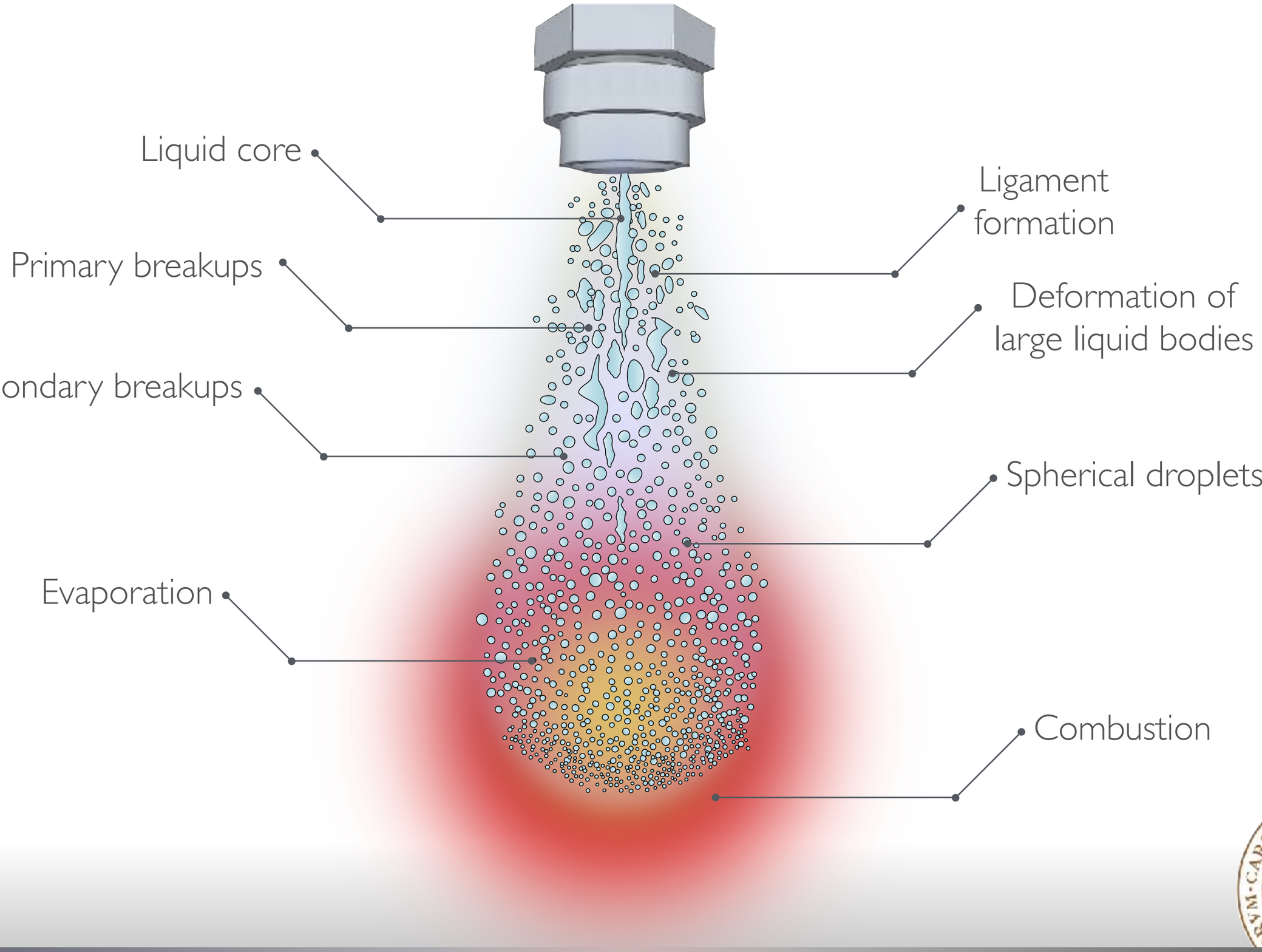
Structured Illumination

Main concept and planar configuration (SLIPI)



Liquid sprays



Structured Laser Illumination Planar Imaging

1 Laser sheet

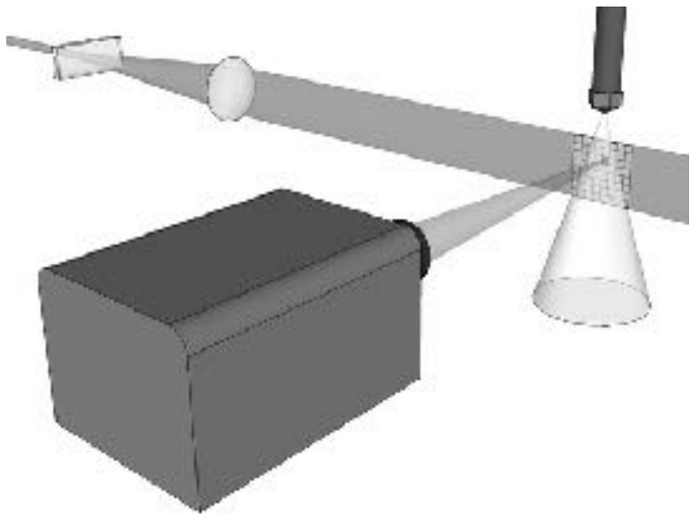
Illuminate sample with a thin sheet of light

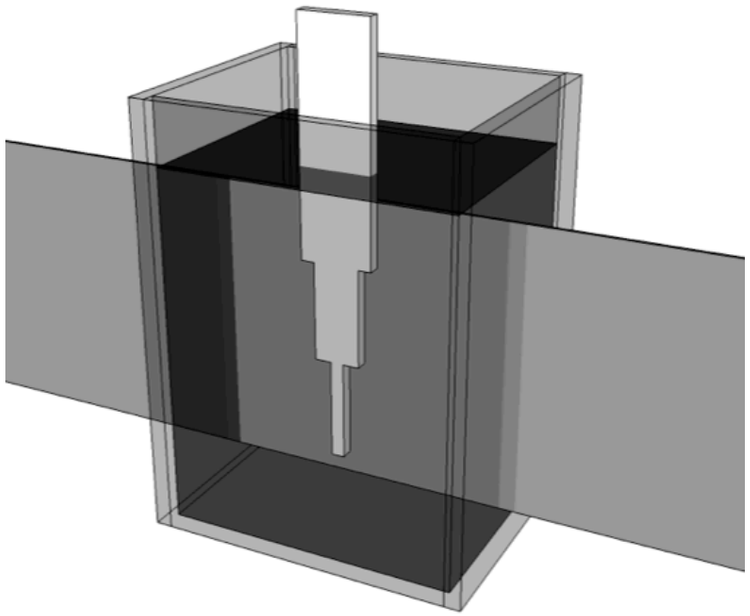
2 Sample

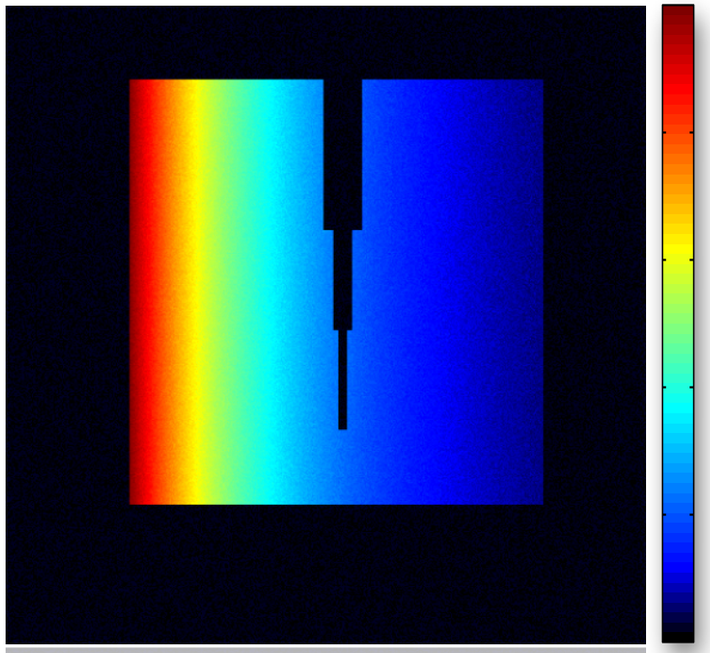
Homogeneous scattering sample with an obstacle

3 Expected

Expect only light where the laser cross



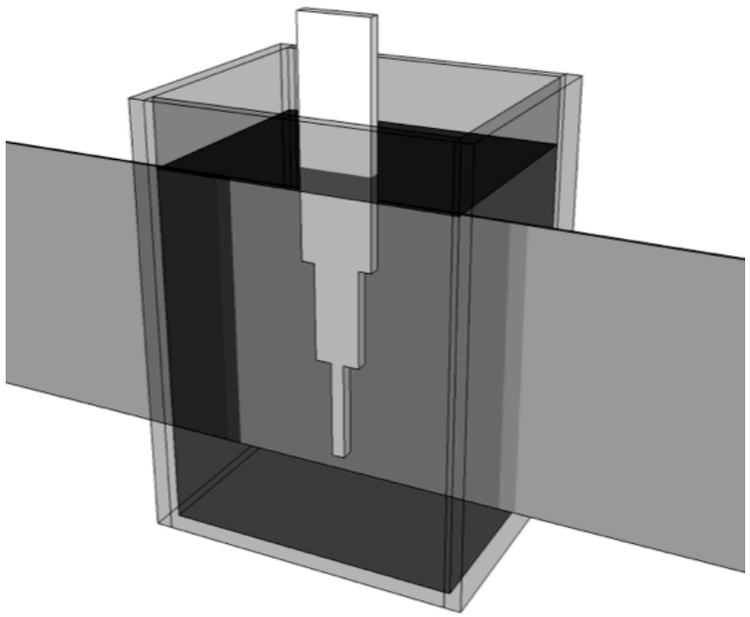




Structured Laser Illumination Planar Imaging

2 Sample

Homogeneous scattering sample with an obstacle



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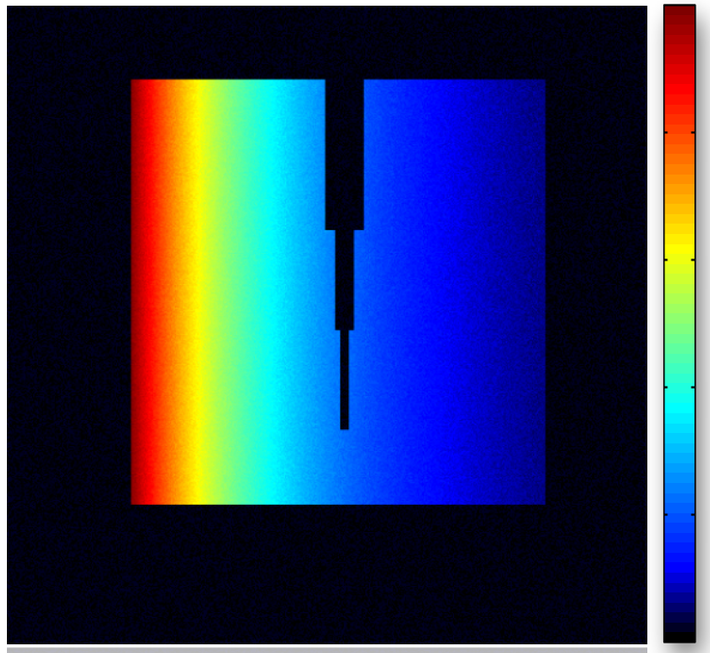
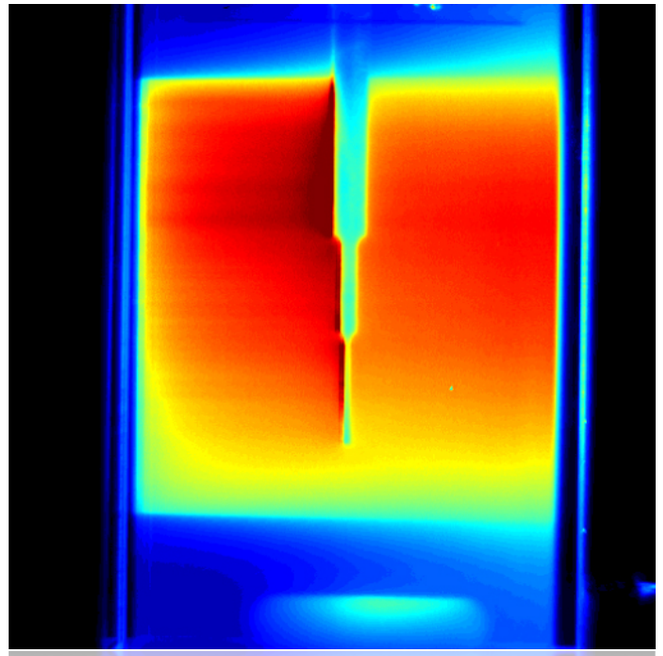
Expect only light where the laser cross



4 Reality

Result with a "normal" laser sheet



Structured Laser Illumination Planar Imaging

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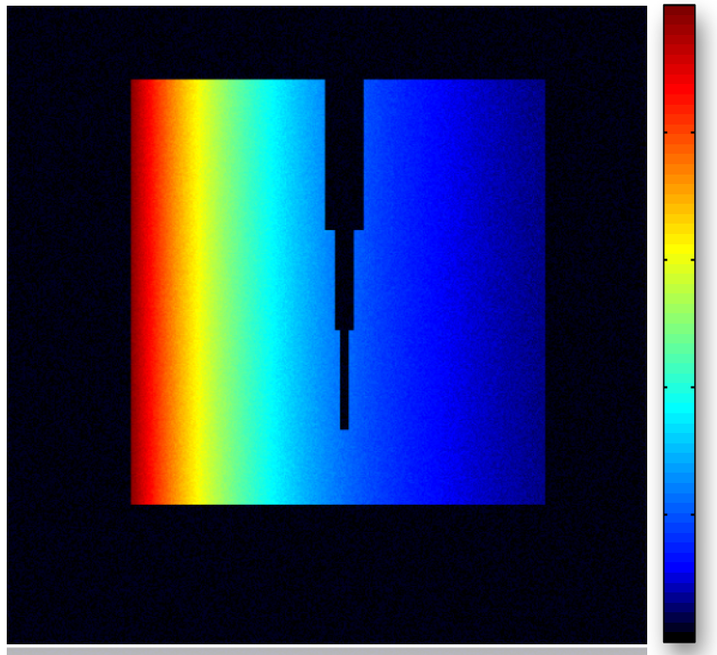

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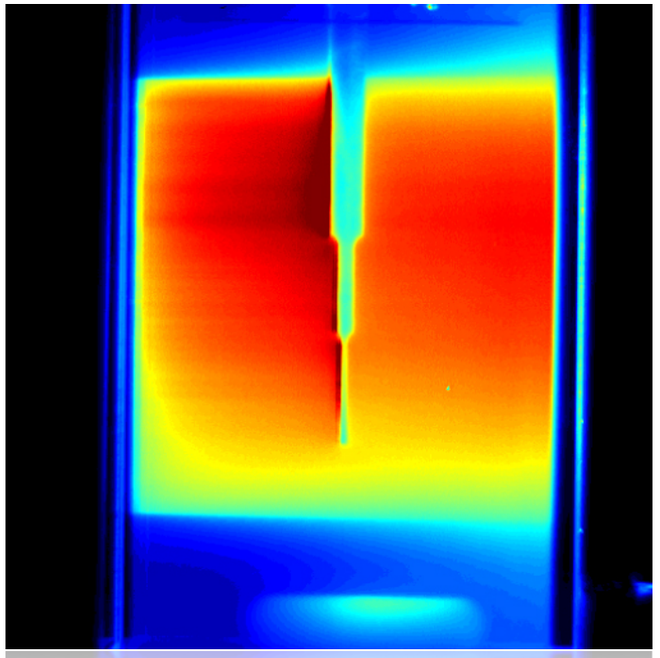
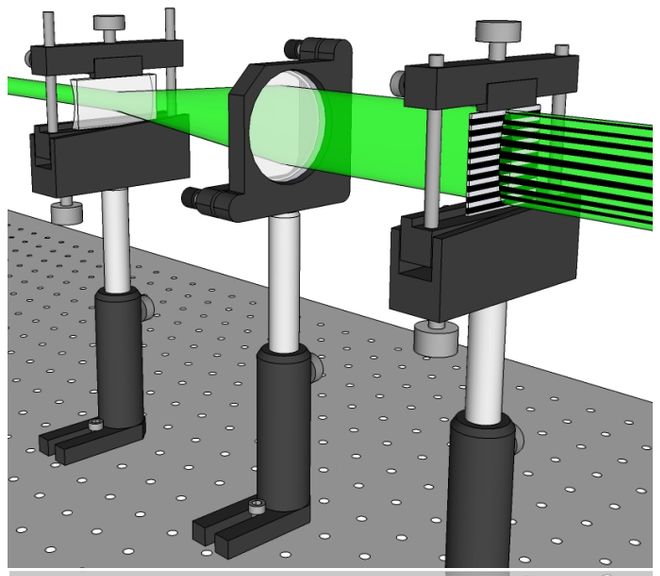


5 New setup

Guide light through a grid pattern



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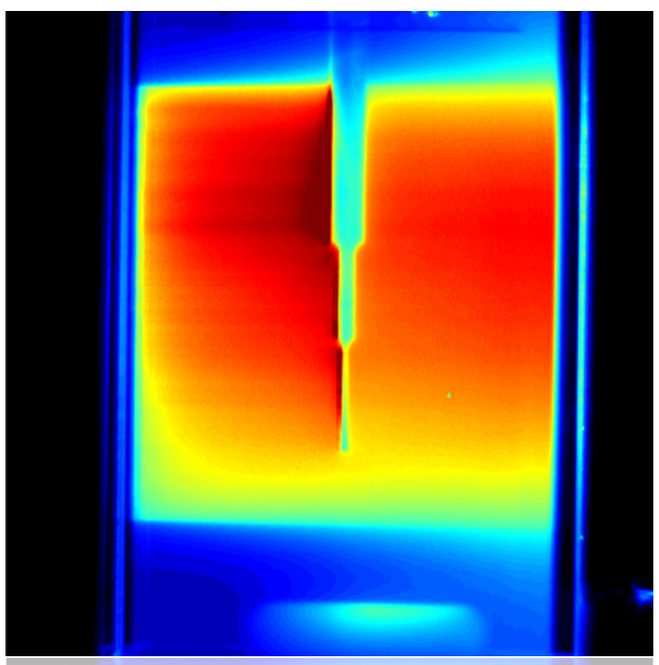

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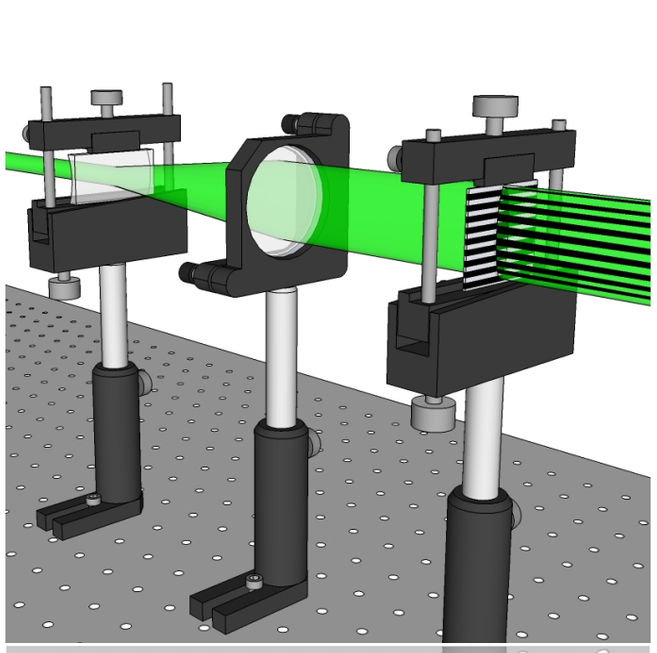
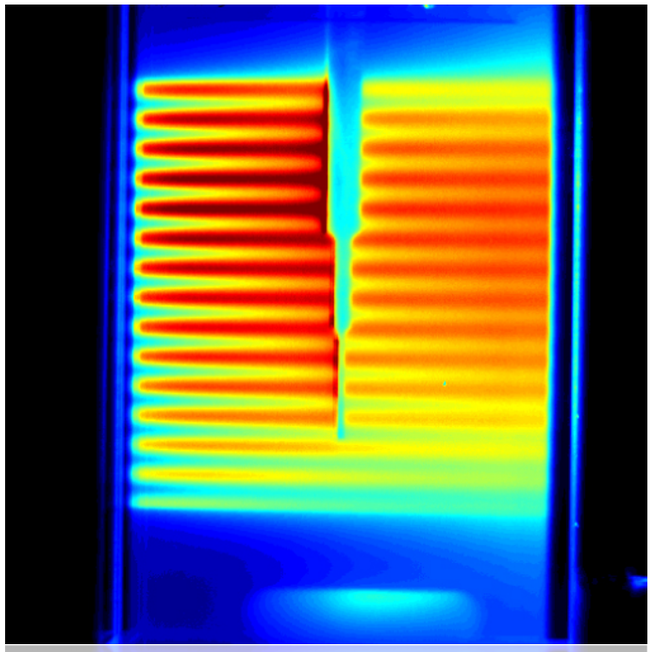


6 Structured laser sheet

Result with a structured laser sheet



Structured Laser Illumination Planar Imaging

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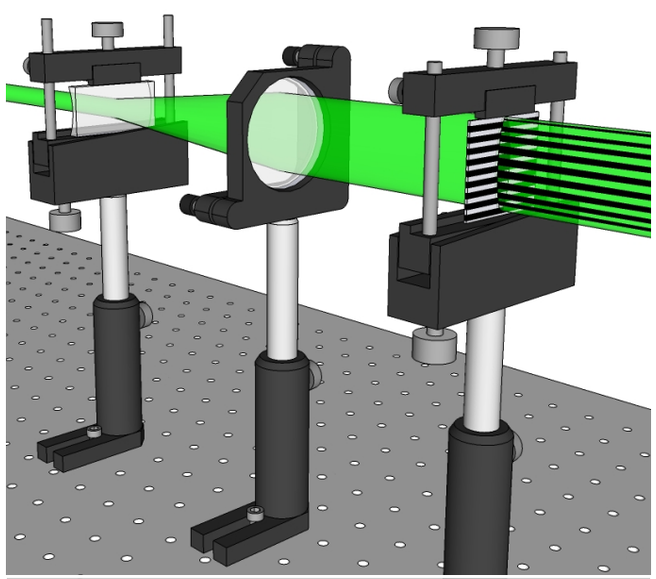

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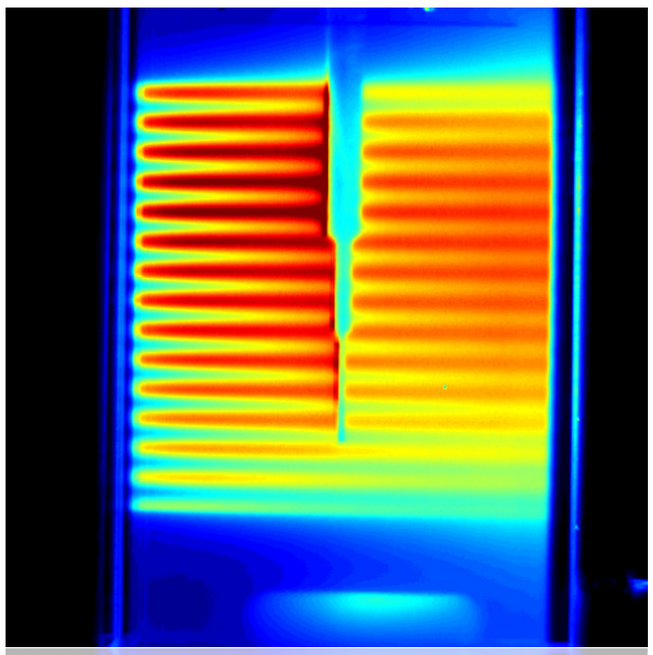
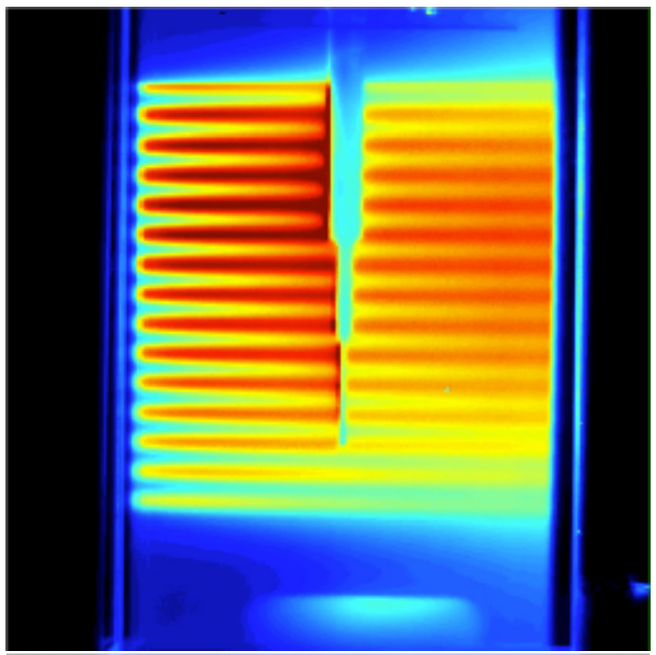


7 Motivation

Separate single and multiple scattering



Structured Laser Illumination Planar Imaging

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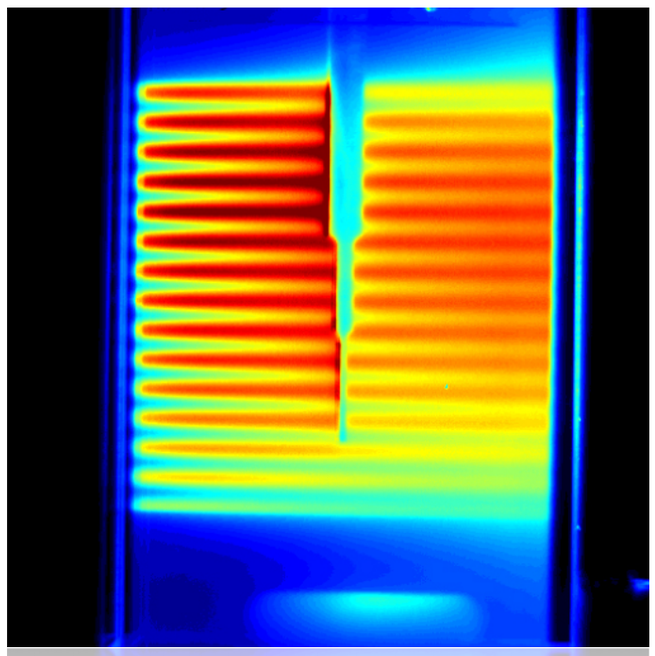

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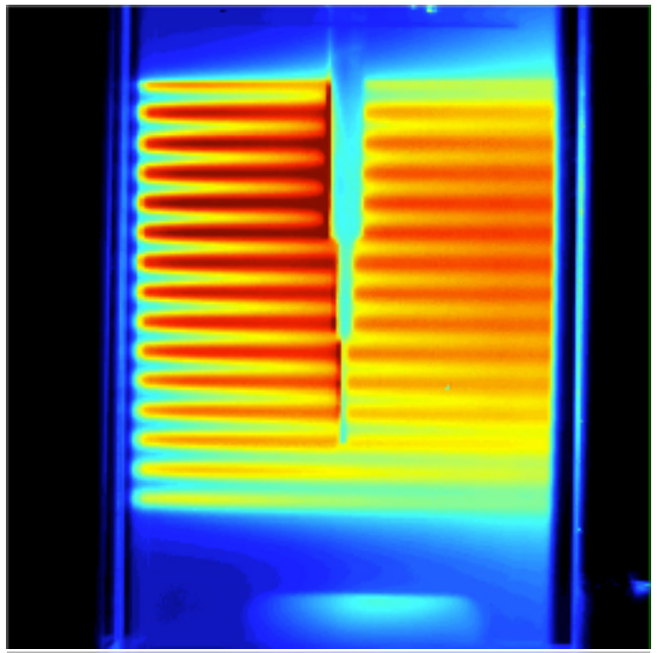
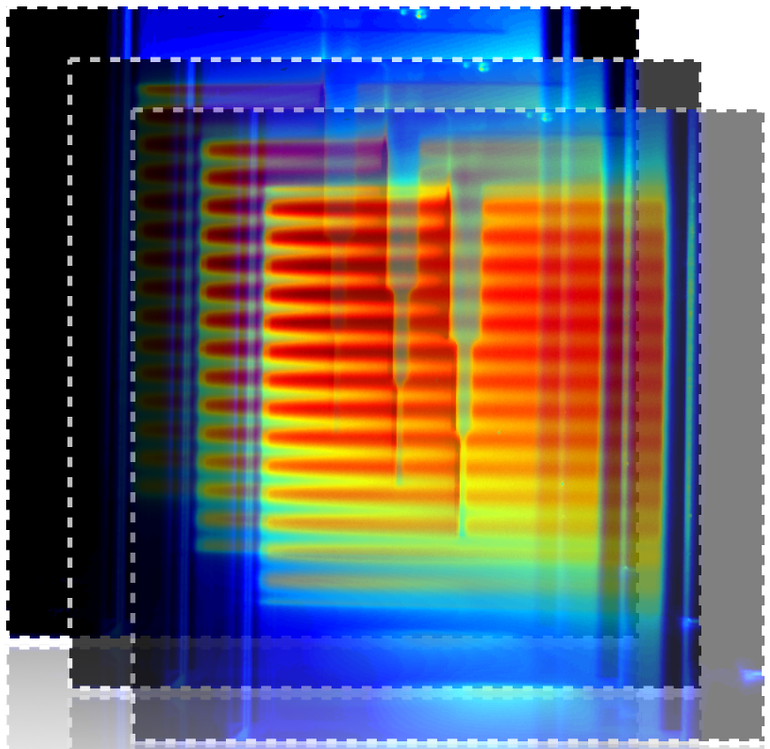


8 Subimages

Modulation shifted 120 degrees (in space)



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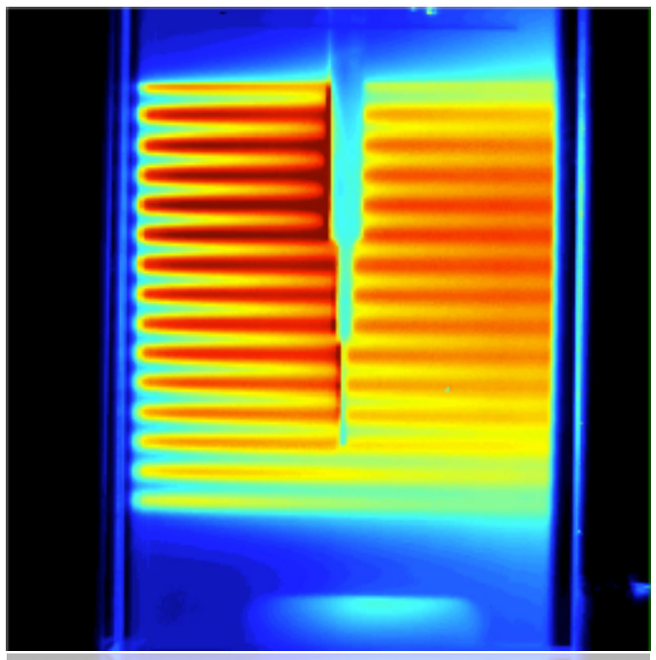

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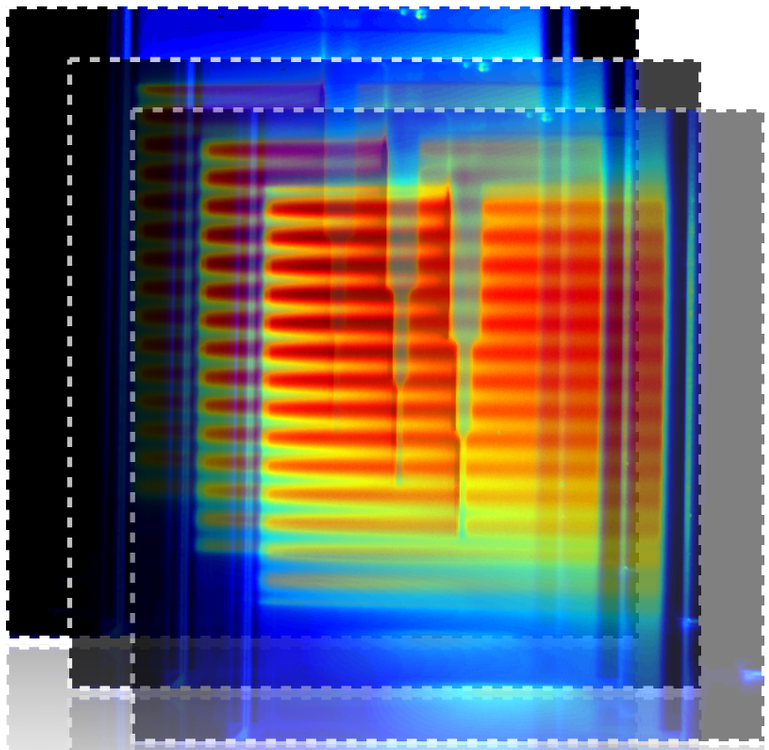
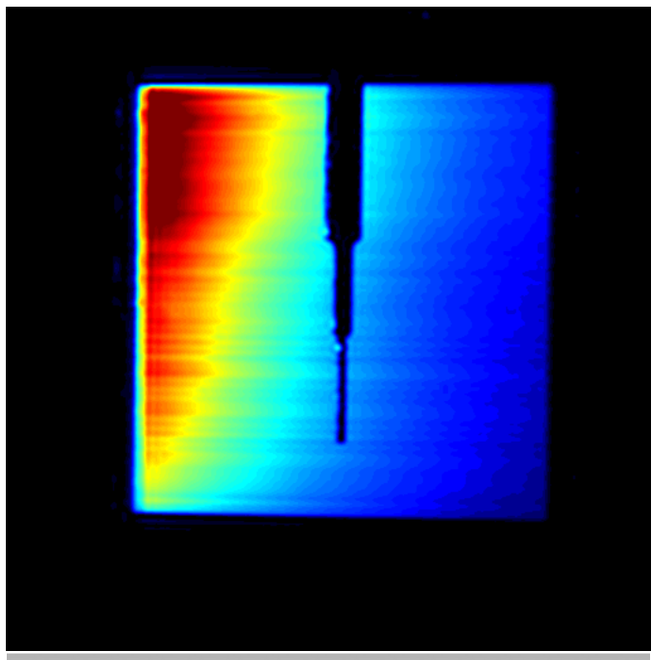


9 SLIPI image

Calculate RMS on a pixel level



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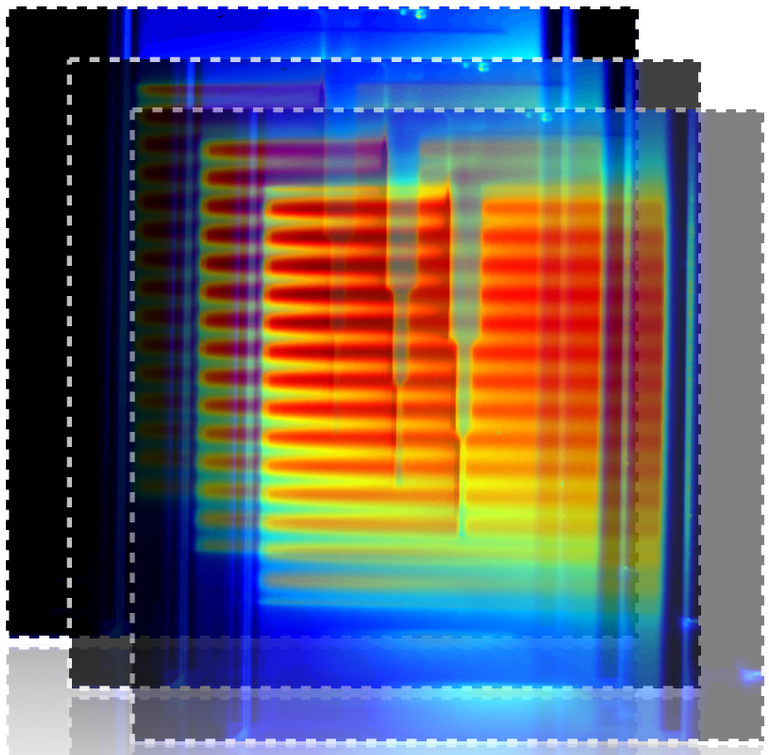

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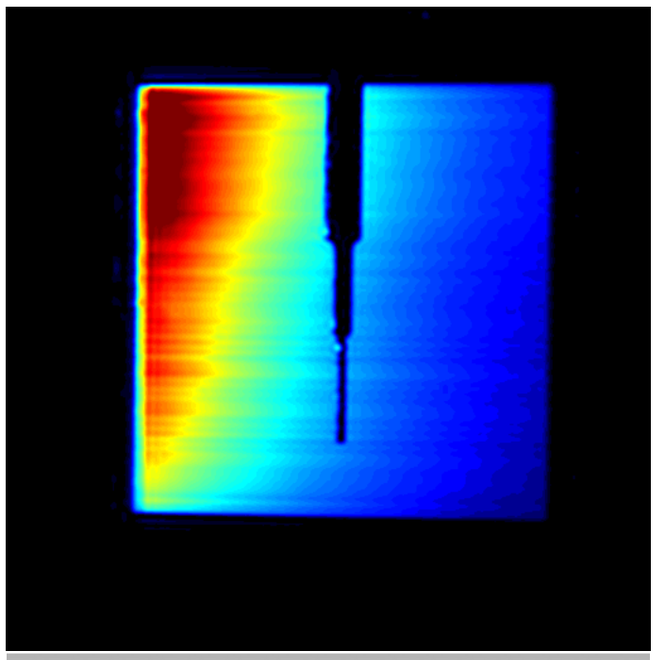
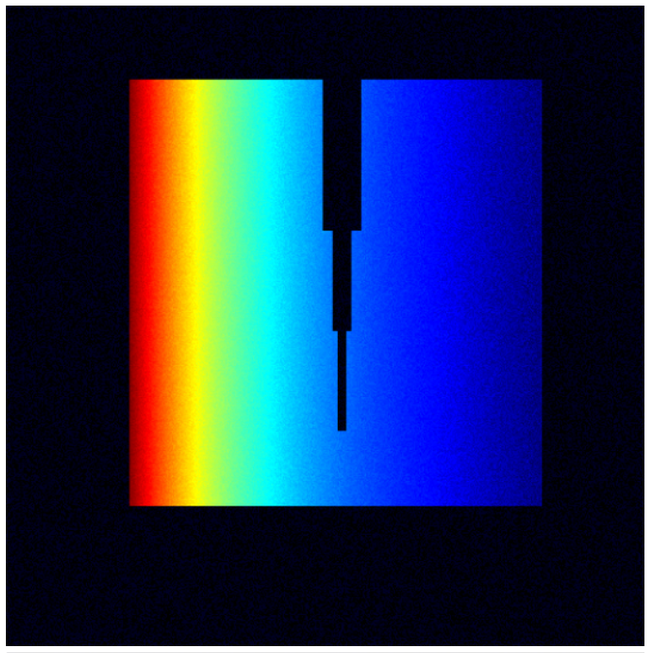


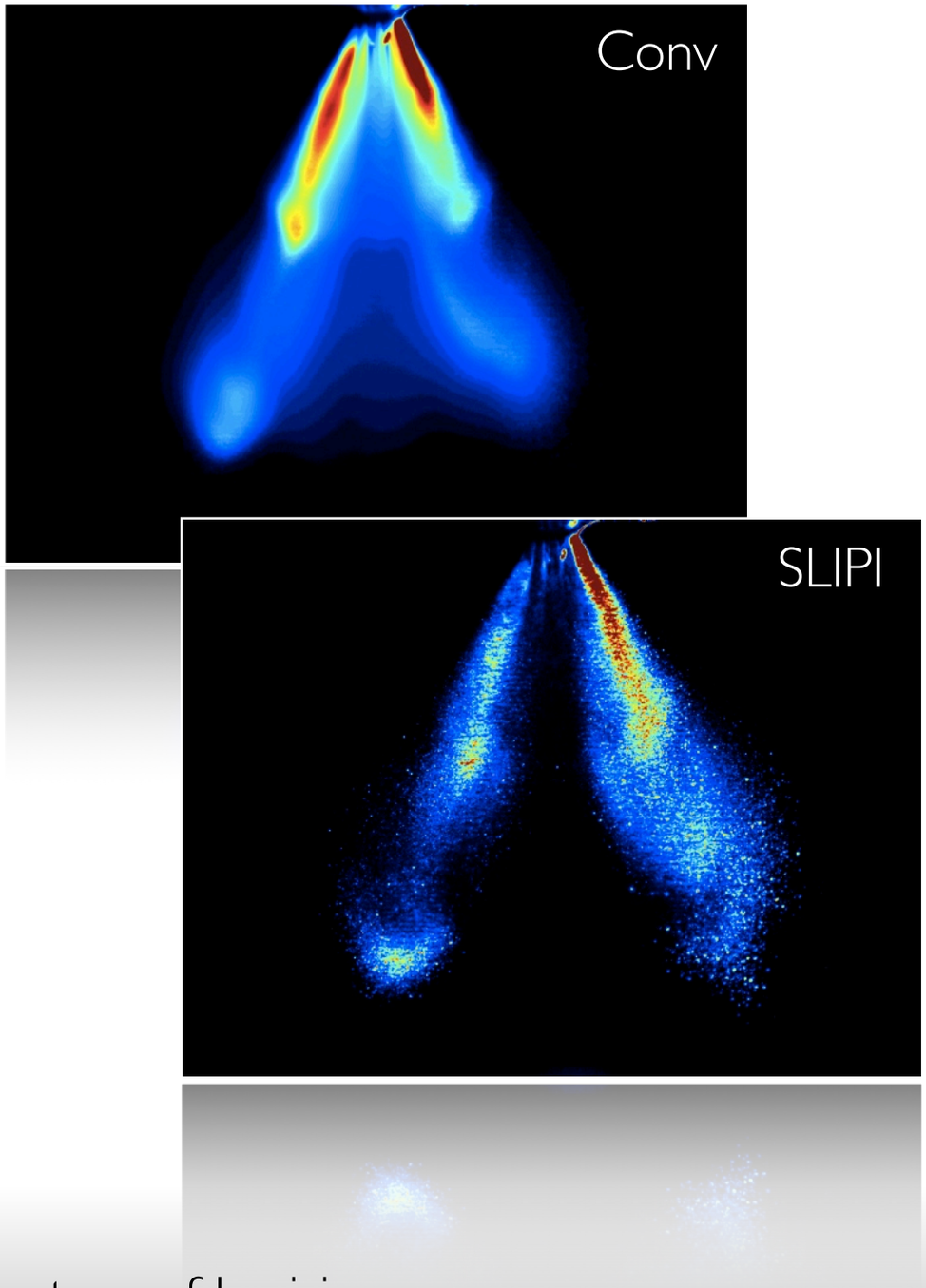
10 In theory

Fairly good agreement

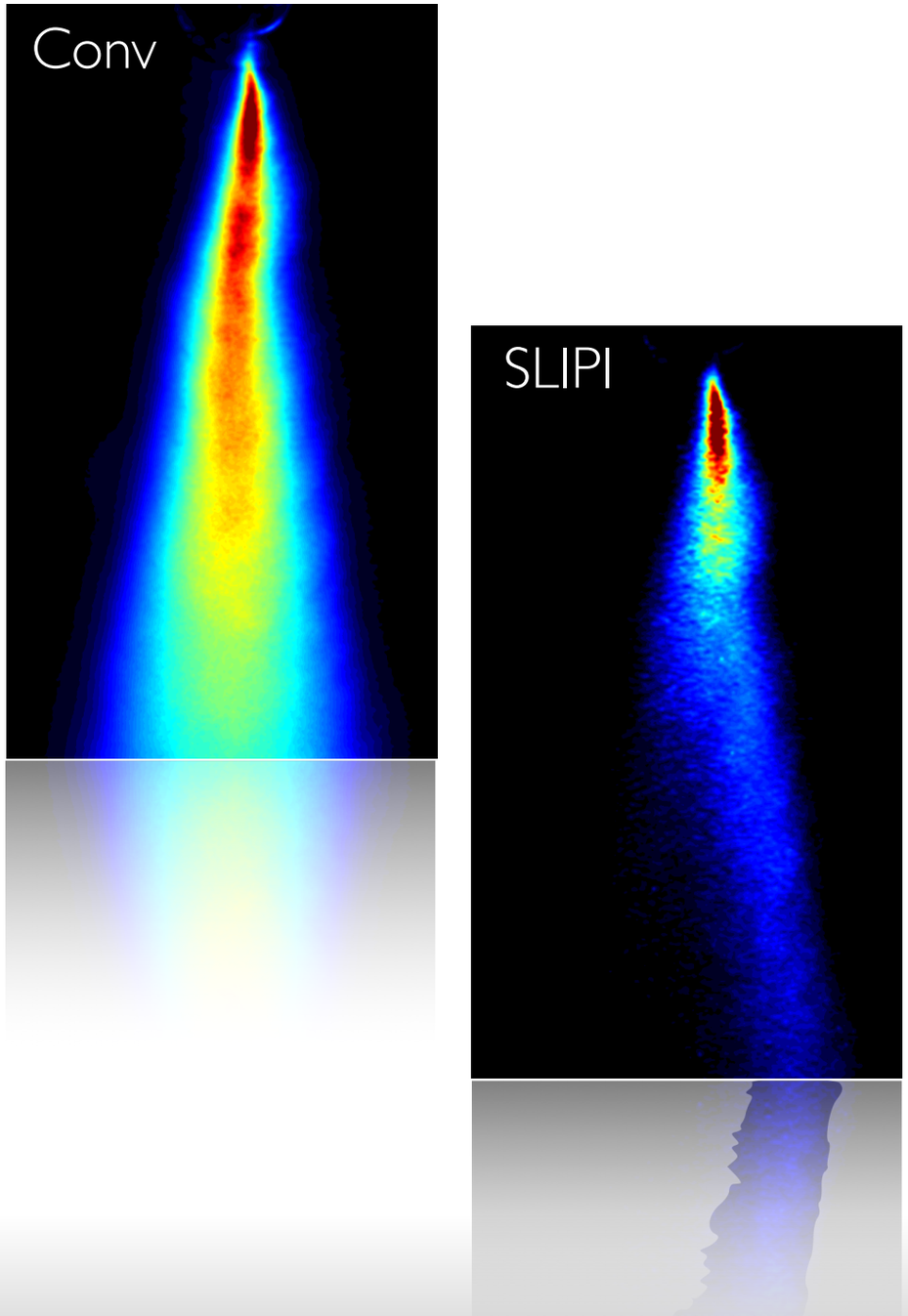


SLIPI results (average imaging)

GDI spray



Diesel spray



Courtesy of Lavision

SLIPI results (average imaging)

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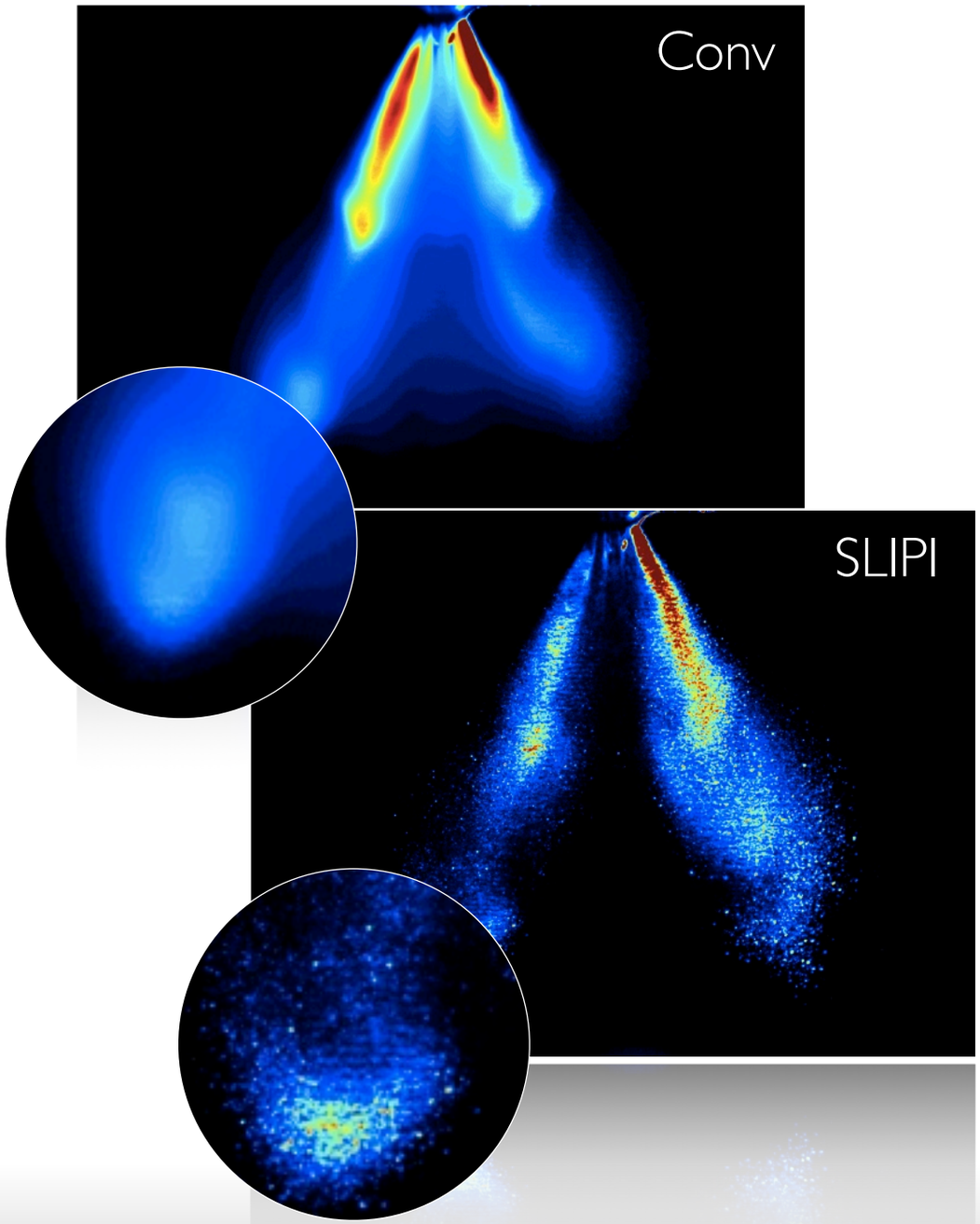

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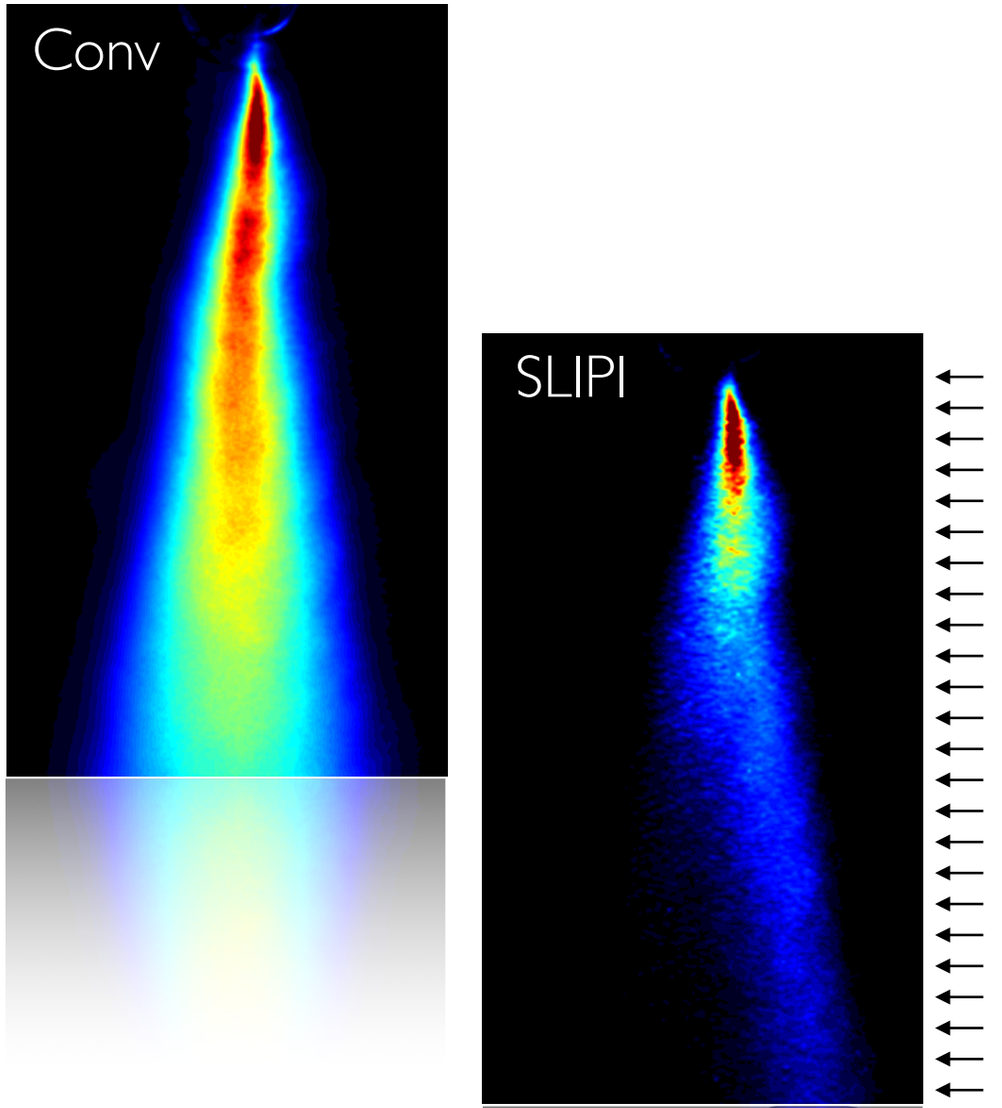

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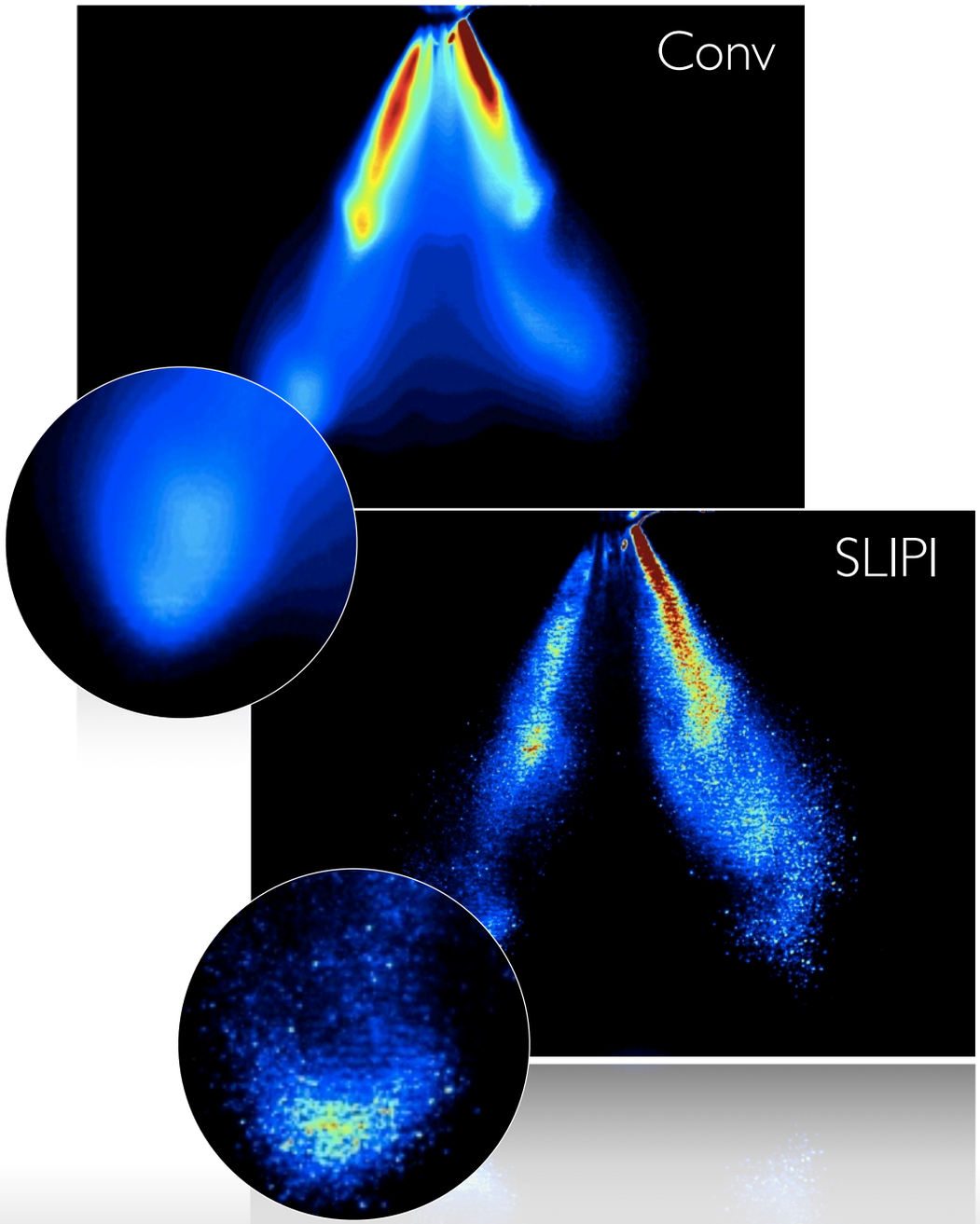

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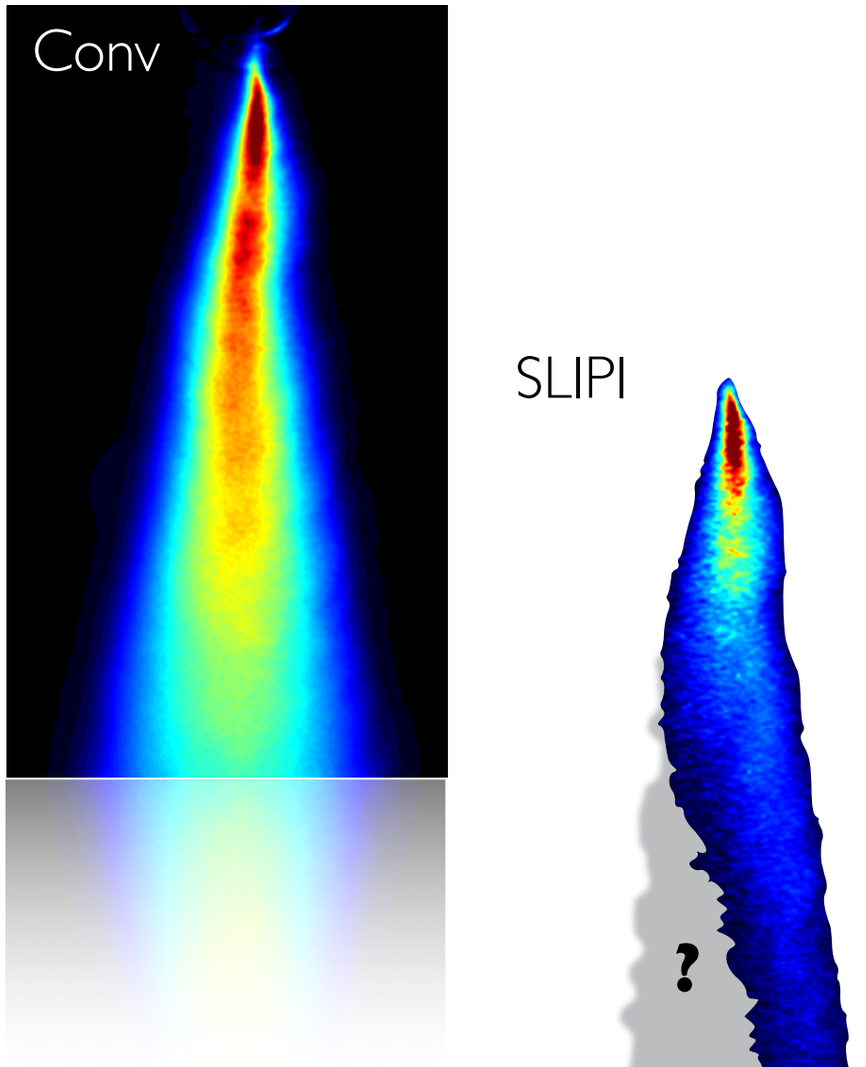
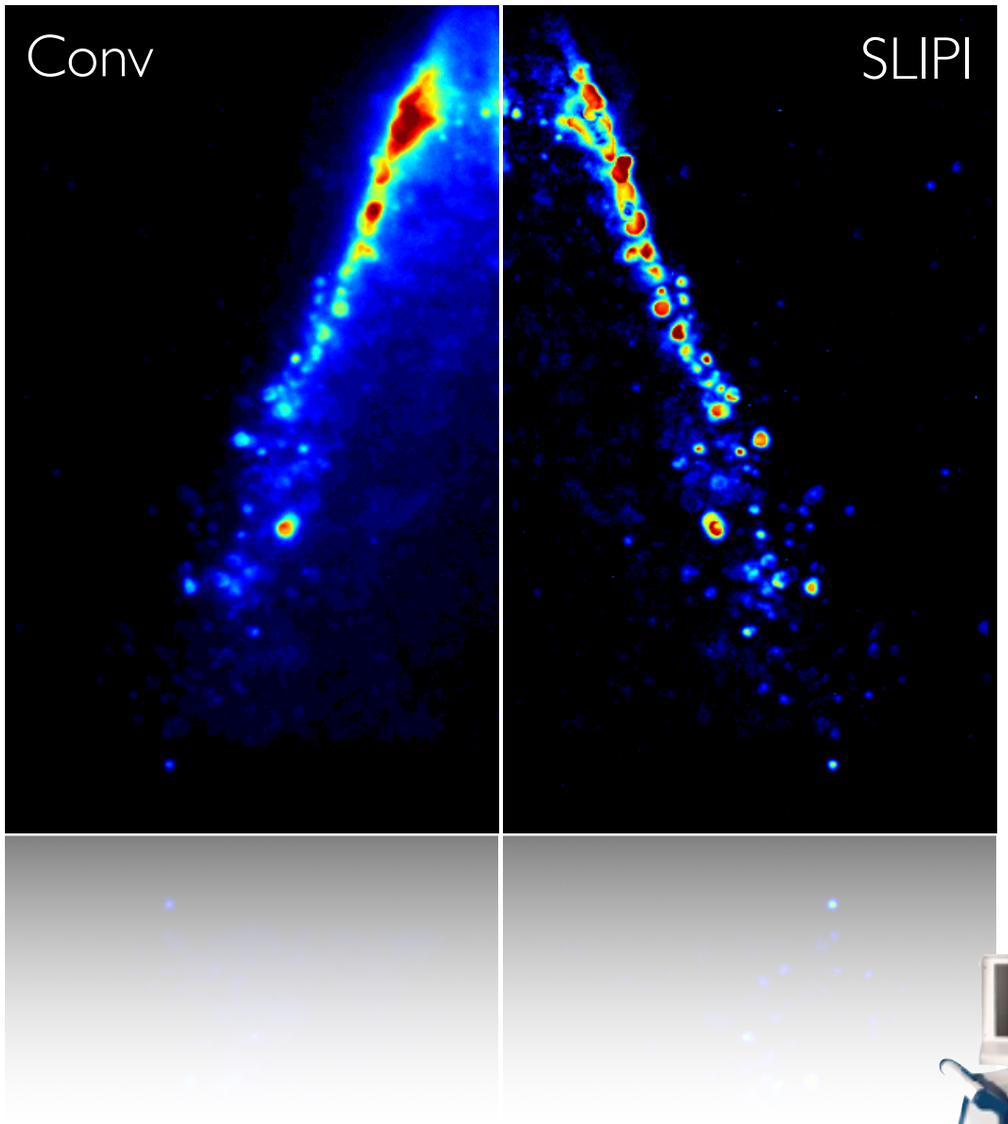
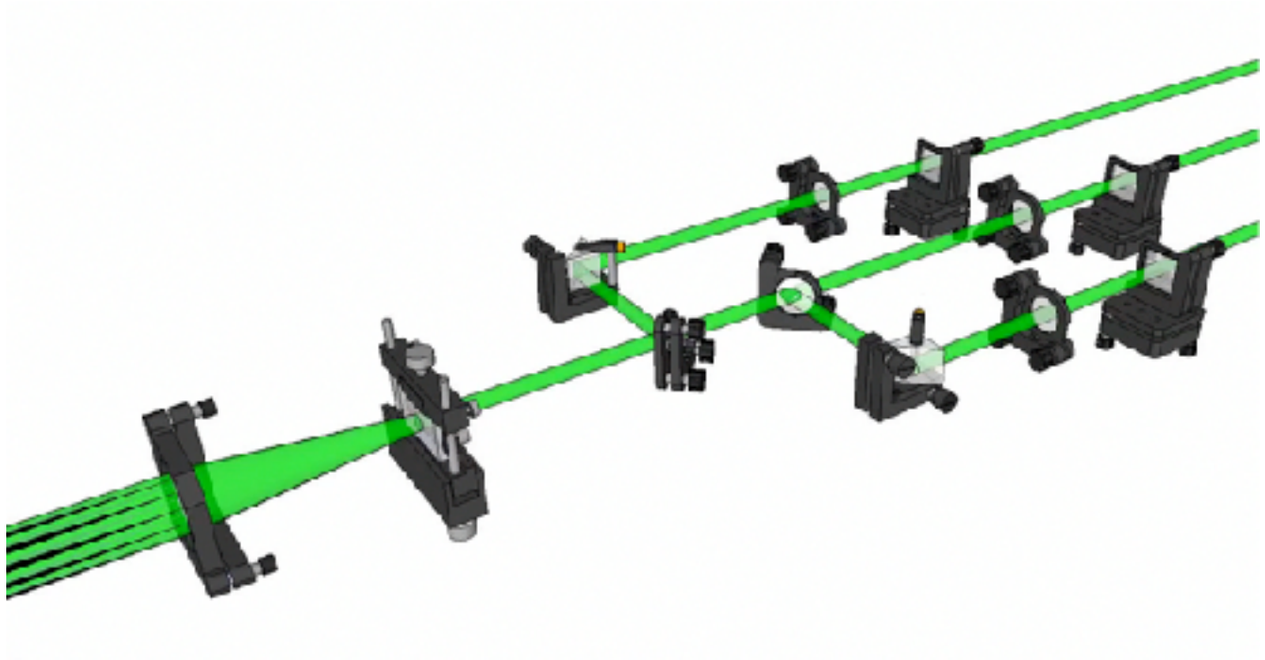


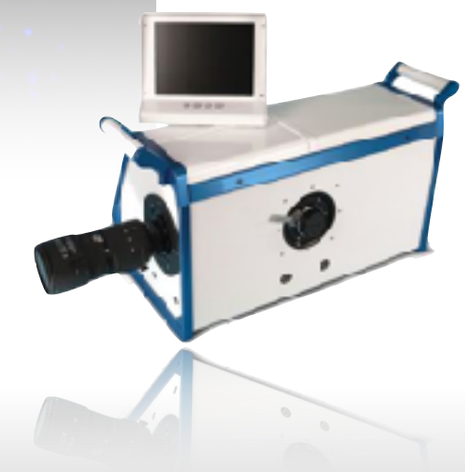
Courtesy of Lavision

"Instantaneous" SLIPI (3 phases)

Hollow-cone spray





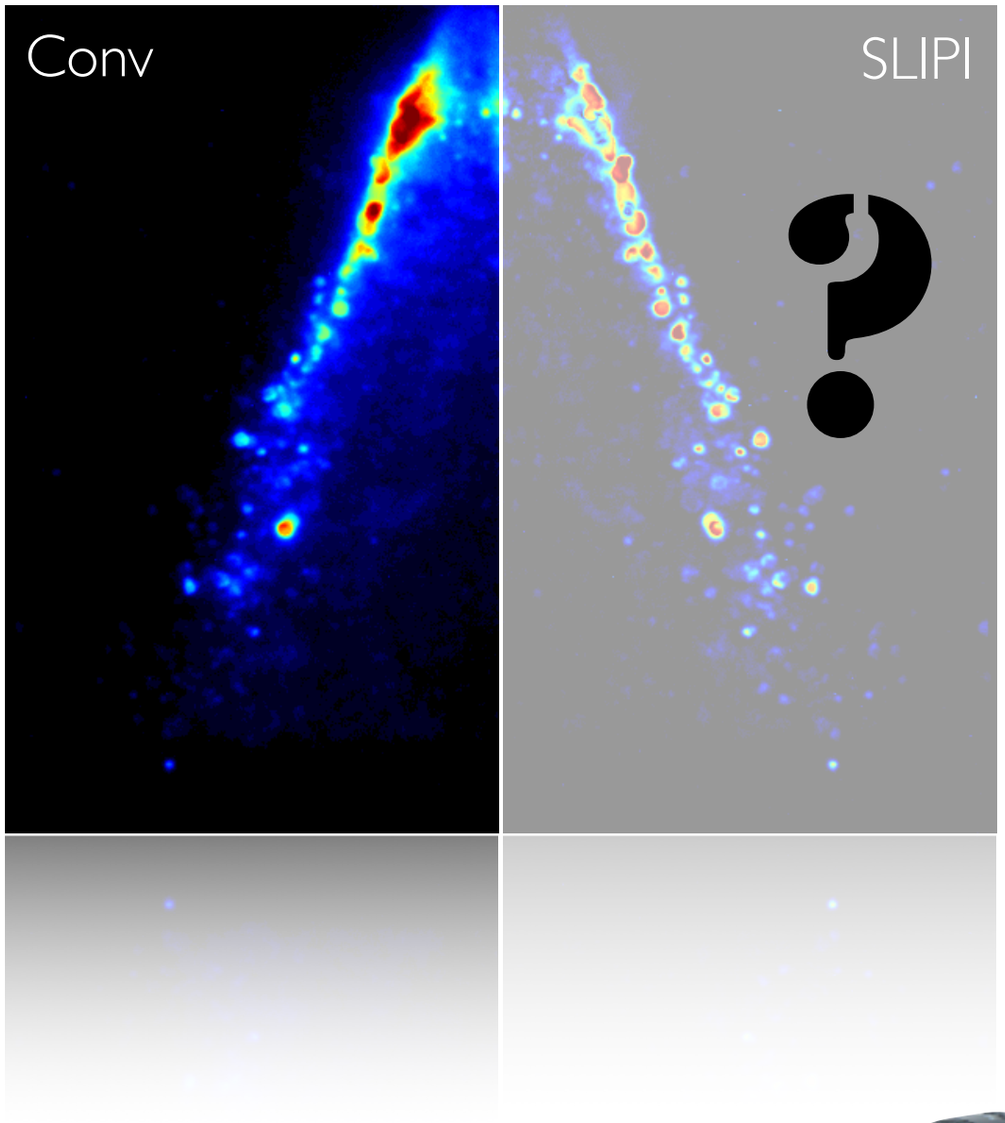


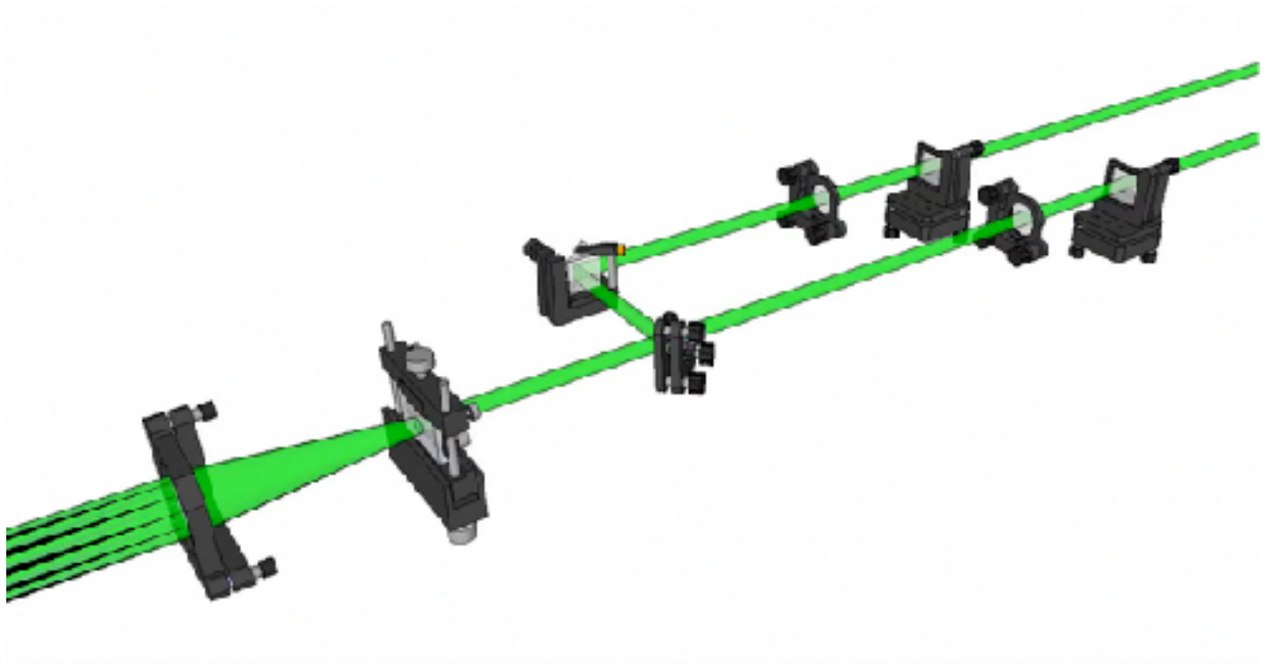
Setup

1. 3 high-power pulsed lasers
2. 3 ICCDs
3. ~90% energy loss
4. Complicated setup

"Instantaneous" SLIPI (2 phases)

Hollow-cone spray



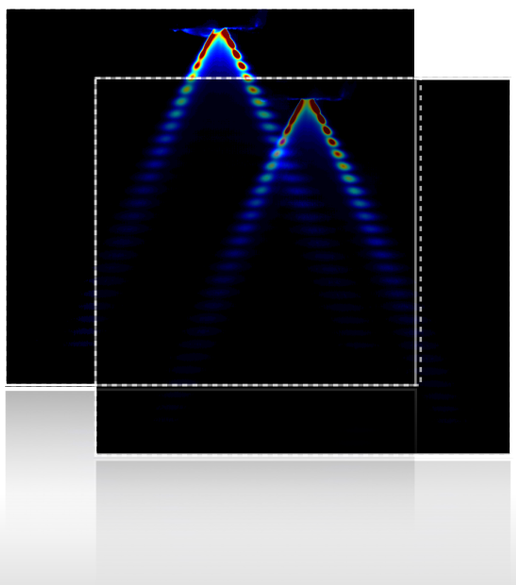


Setup

1. 1 double-pulsed laser
2. 1 double-frame sCMOS
3. ~50% energy loss
4. Reduced complexity

Two-phase SLIPI

SLIPI with only 2 subimages



SLIPI

1 Subimage

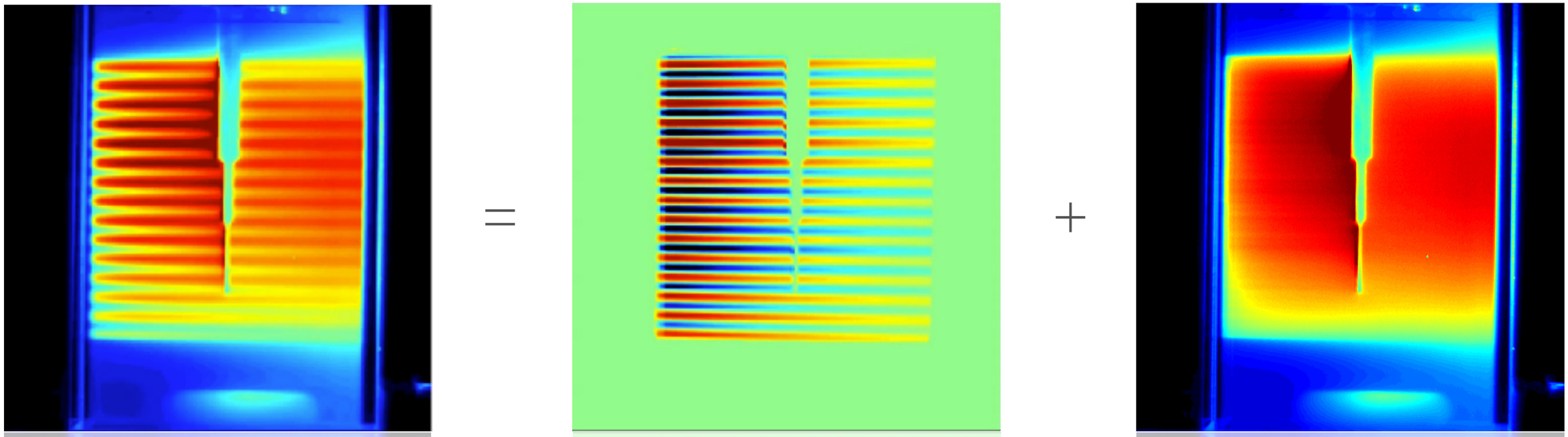
Composed of two parts

2 Modulated part

Information only from laser sheet: <u>unique</u>

3 Offset part

Both signal and noise: <u>identical</u>



SLIPI

2 Modulated part

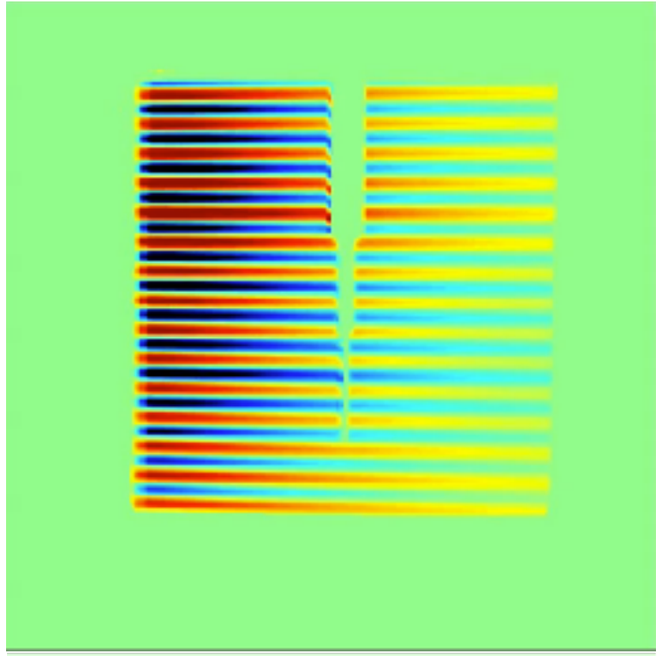
Information only from laser sheet: unique

3 Offset part

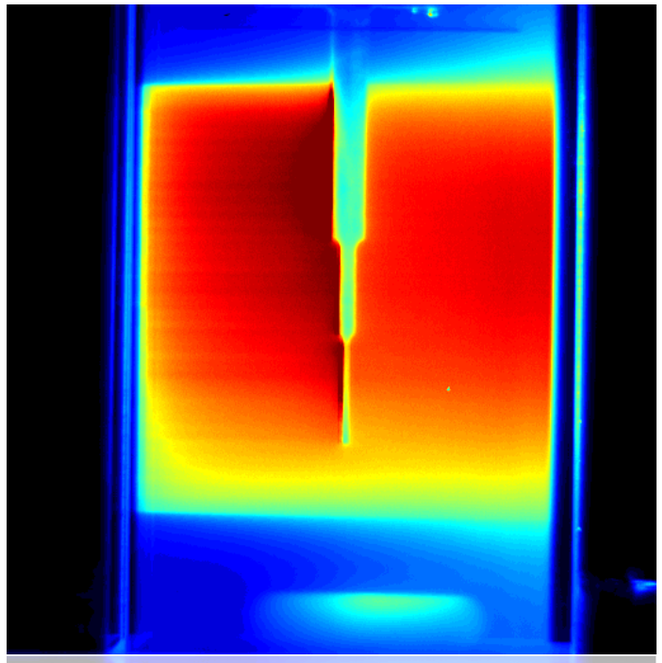
Both signal and noise: identical

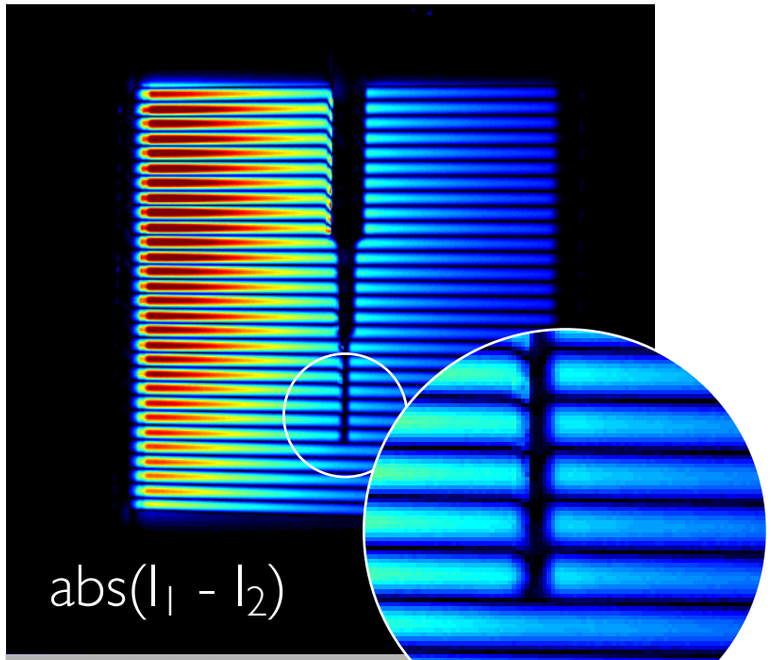
4 Two subimages?

Sufficient to suppress offset part



+

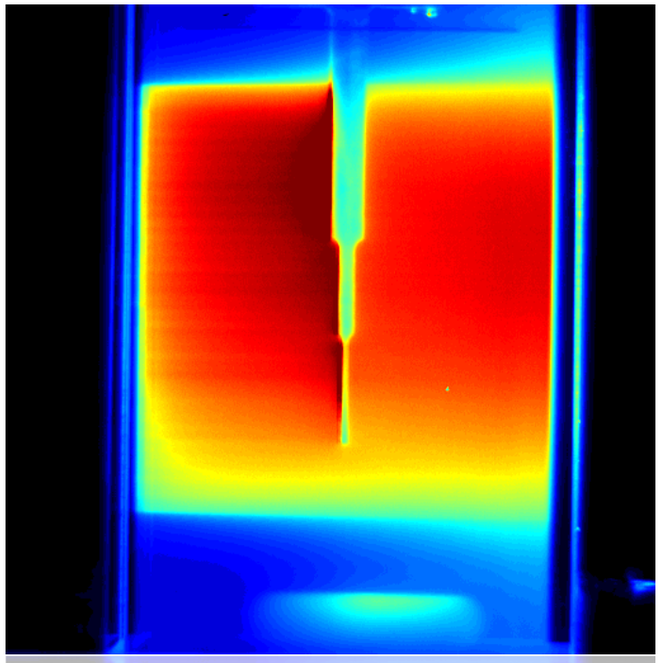




SLIPI

3 Offset part

Both signal and noise: identical



4 Two subimages?

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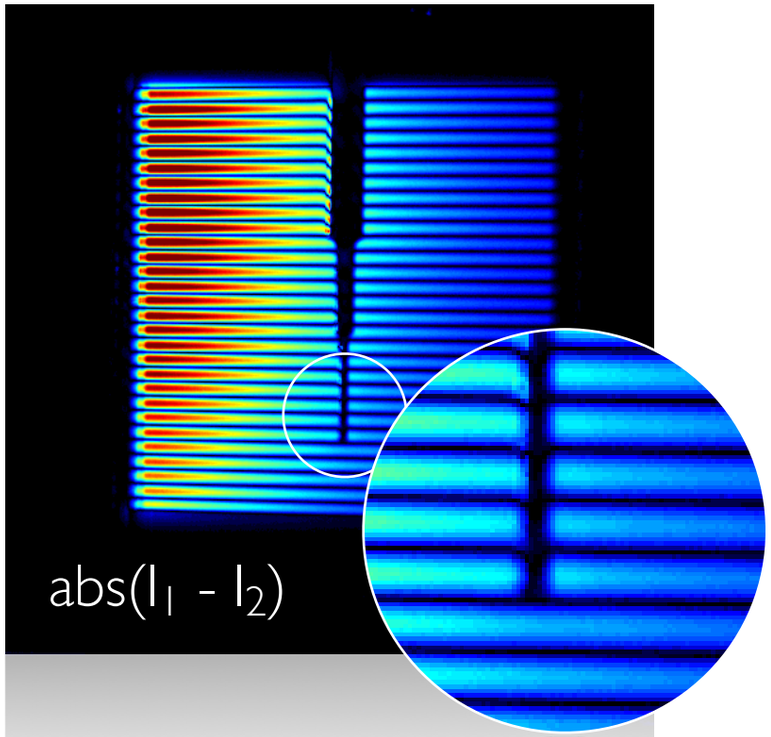
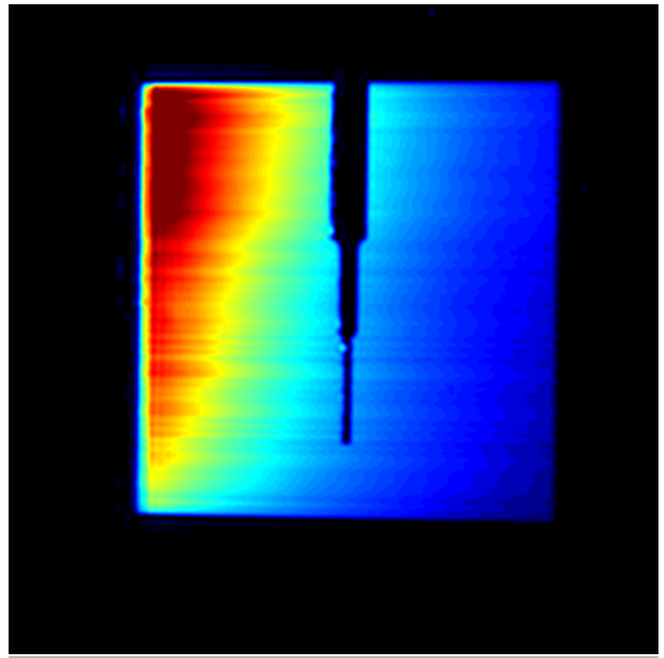


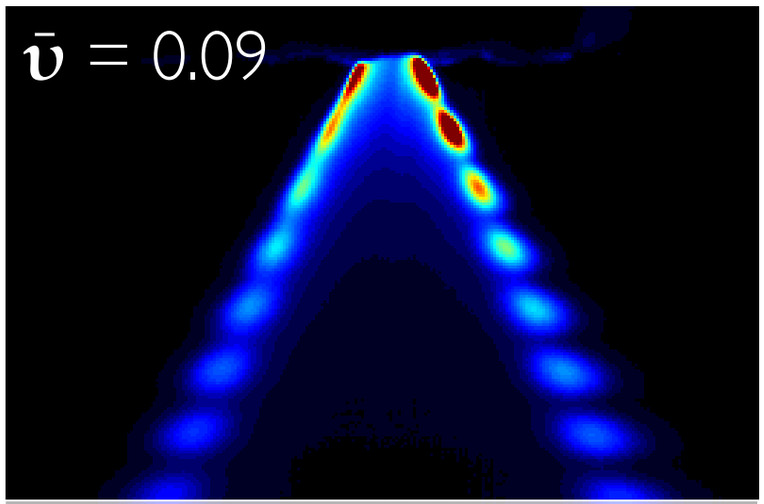
5 Three subimages!

Needed to avoid residuals

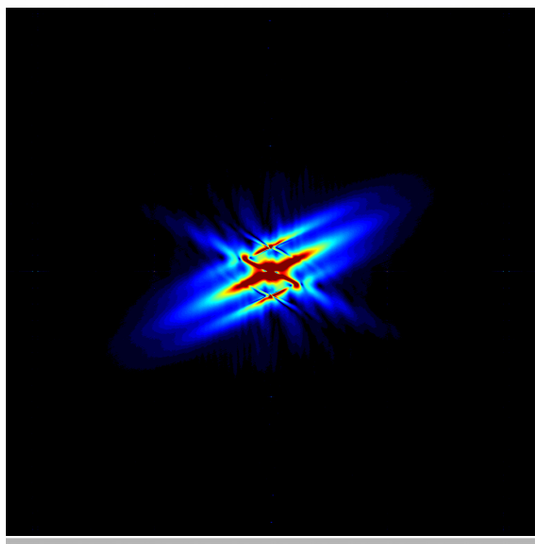


Loophole feasible?

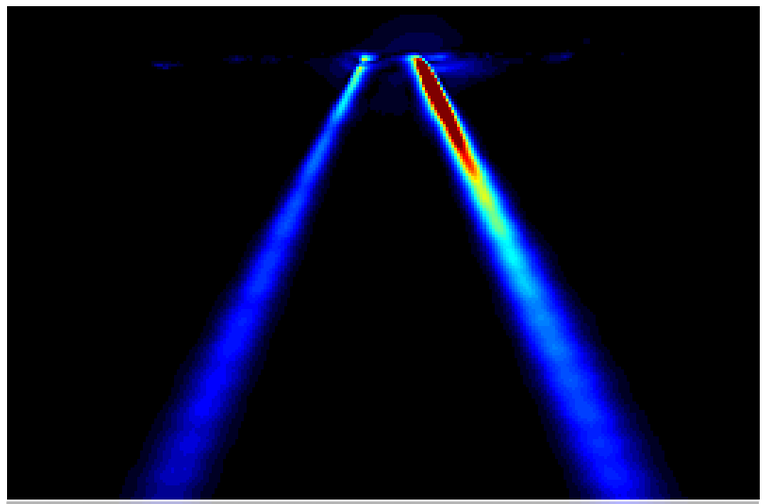
Subimage



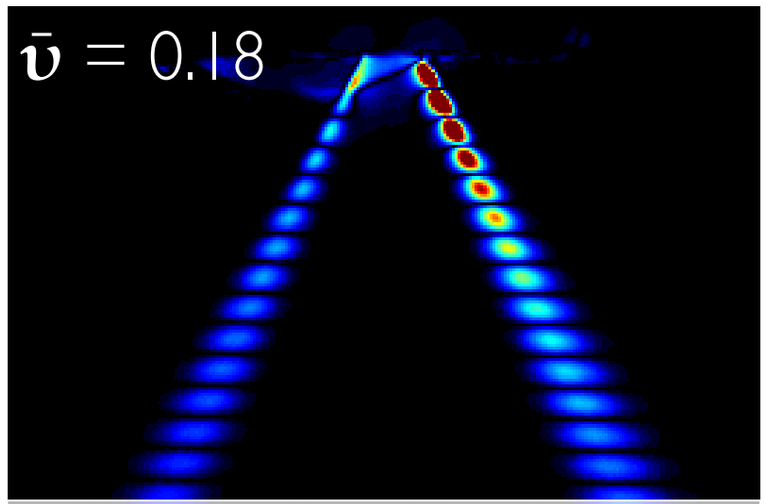
Fourier transform



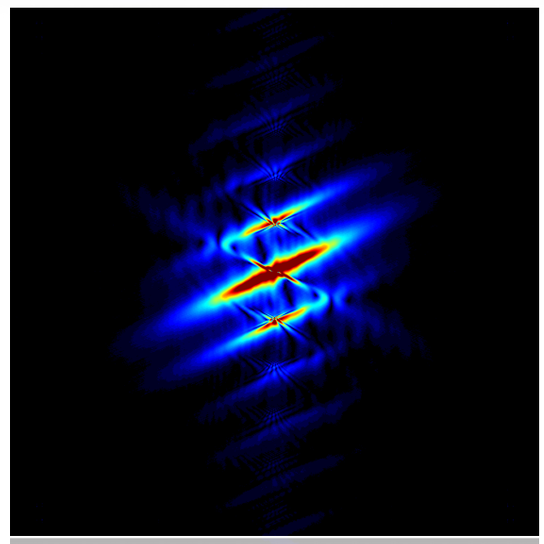
3P-SLIPI



2P-SLIPI

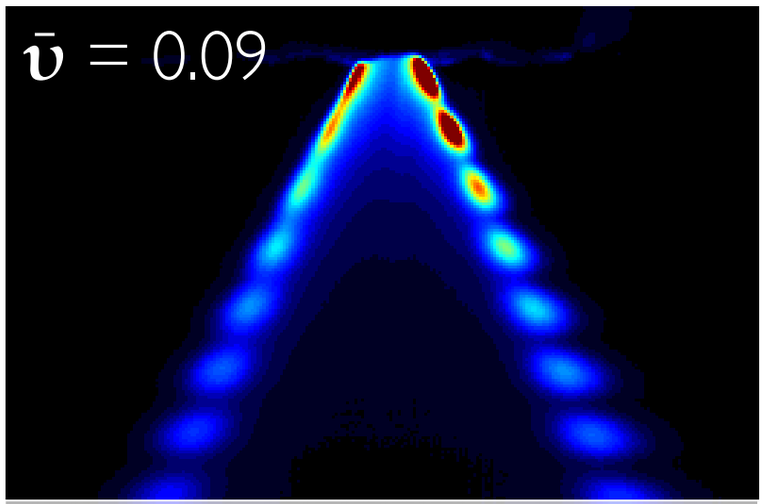


Fourier transform

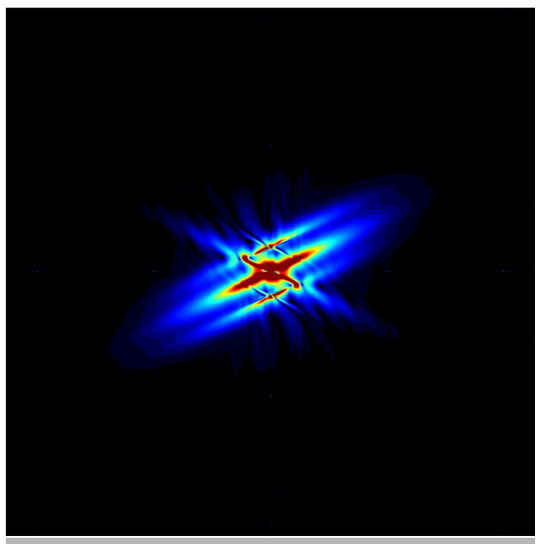


Loophole feasible?

Subimage



Fourier transform



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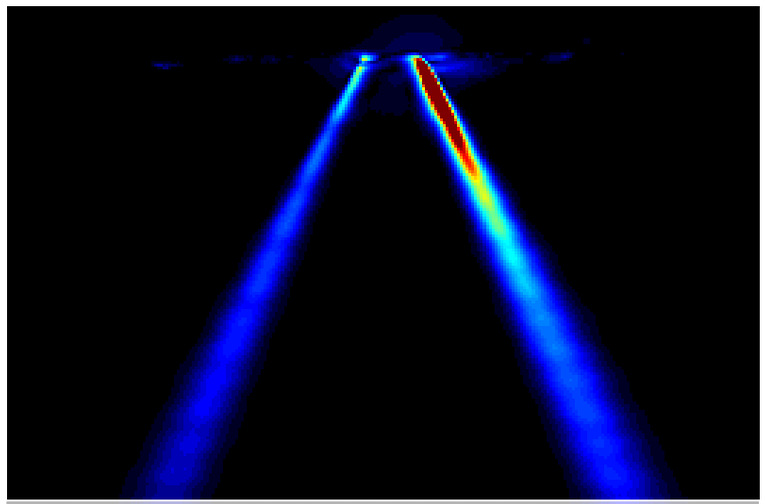

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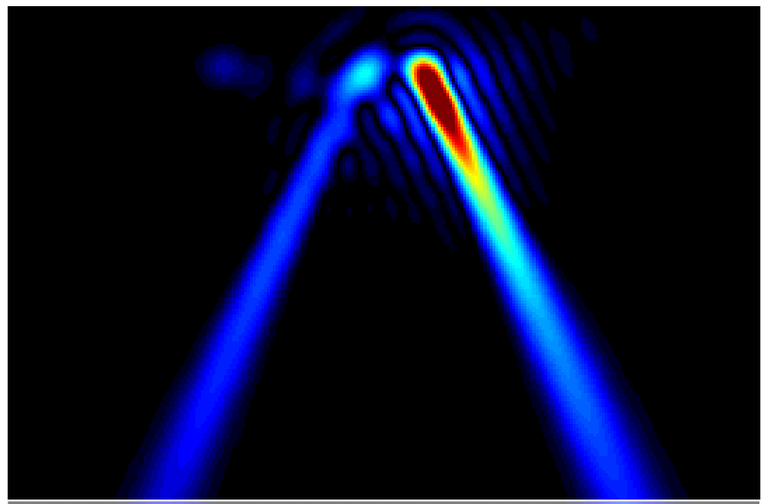
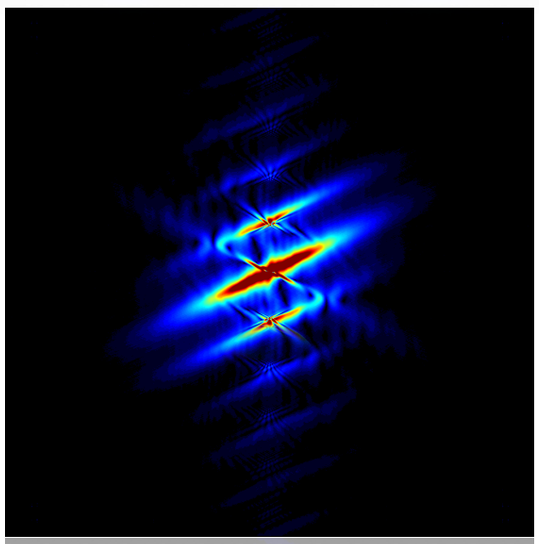
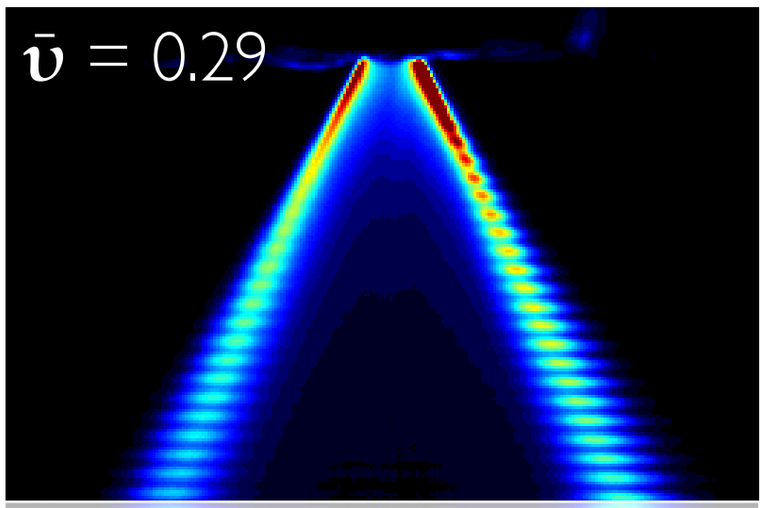


Inverse Fourier transform

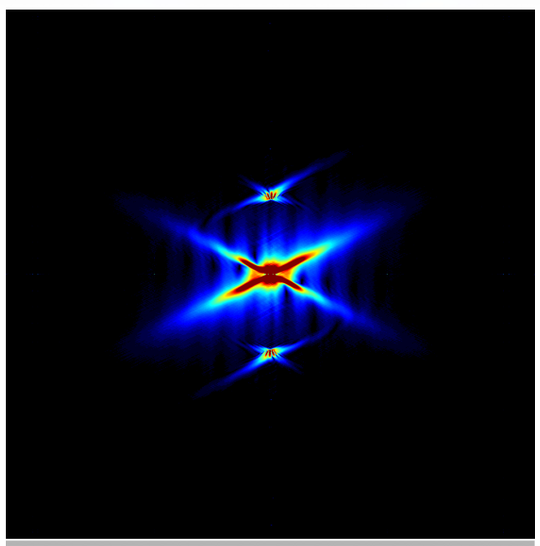


Loophole feasible?

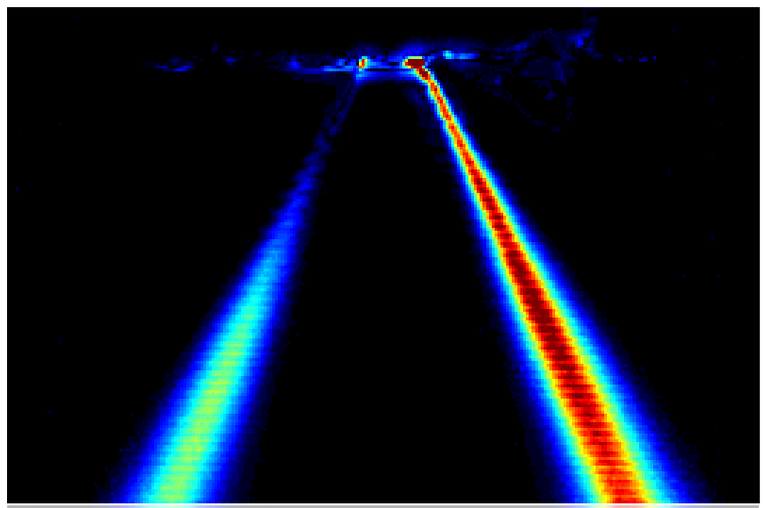
Subimage



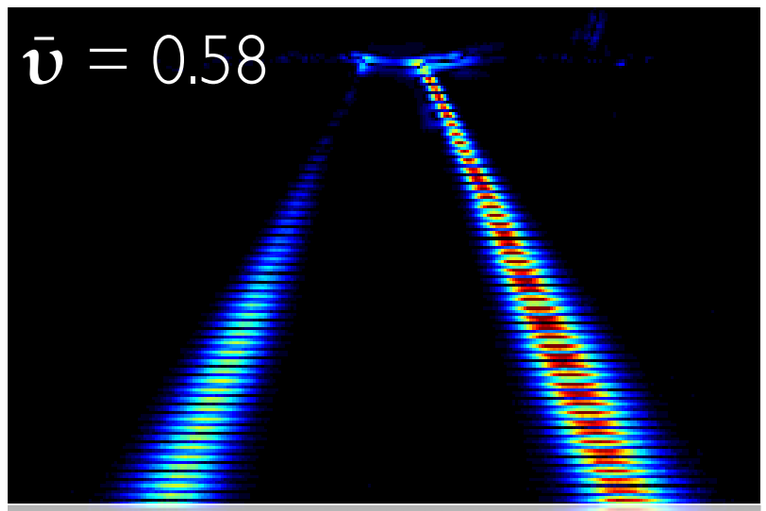
Fourier transform



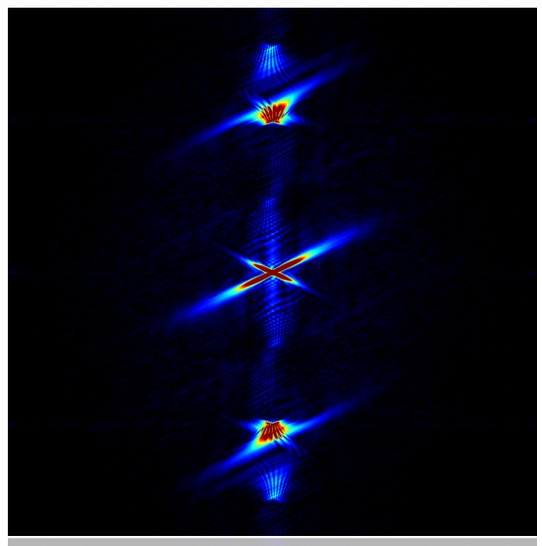
3P-SLIPI



2P-SLIPI

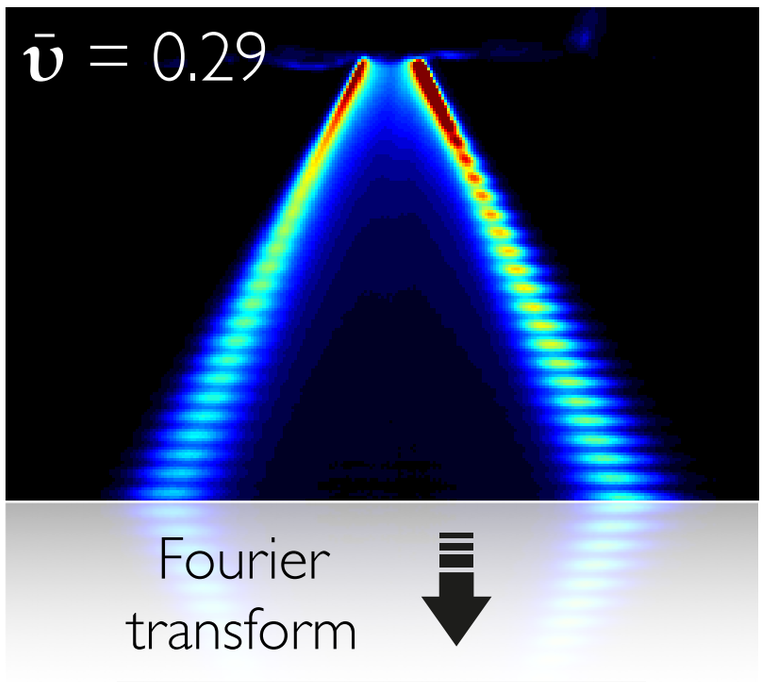


Fourier transform

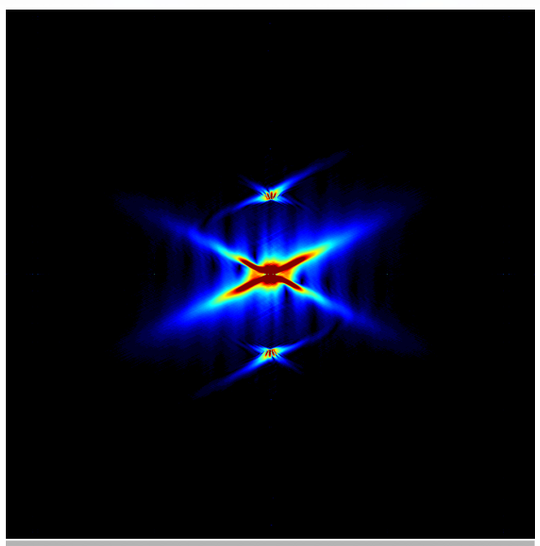


Loophole feasible?

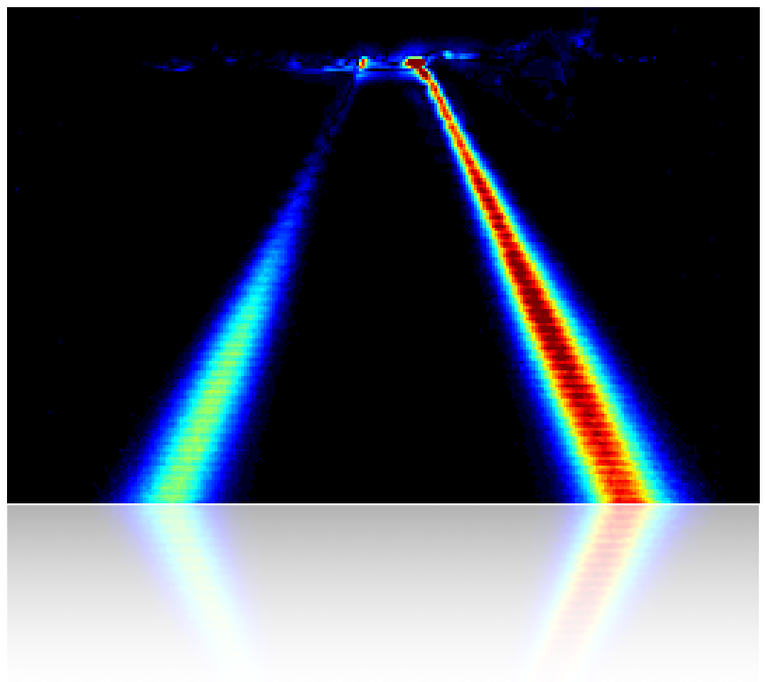
Subimage



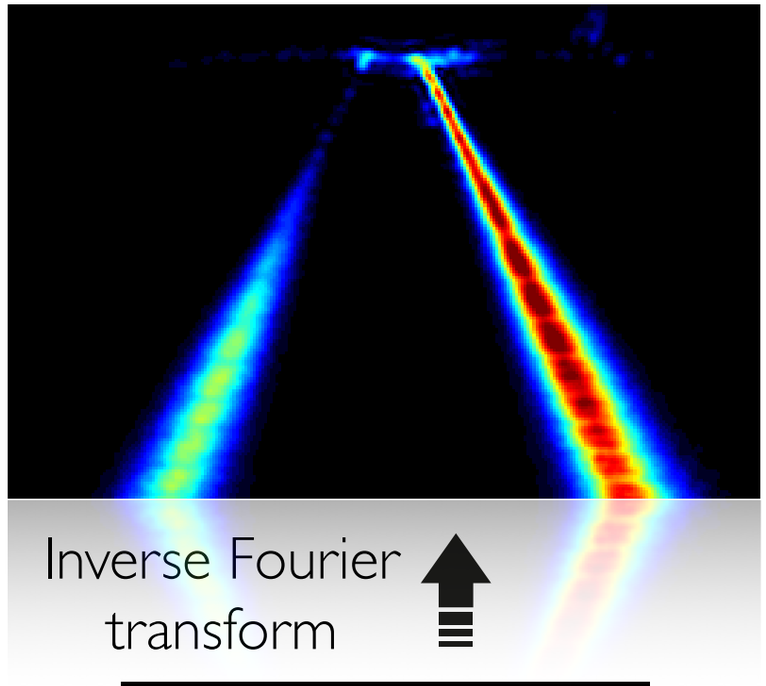
Fourier transform



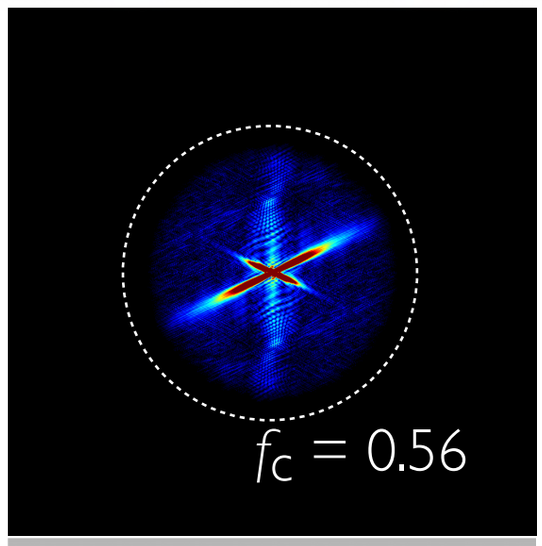
3P-SLIPI



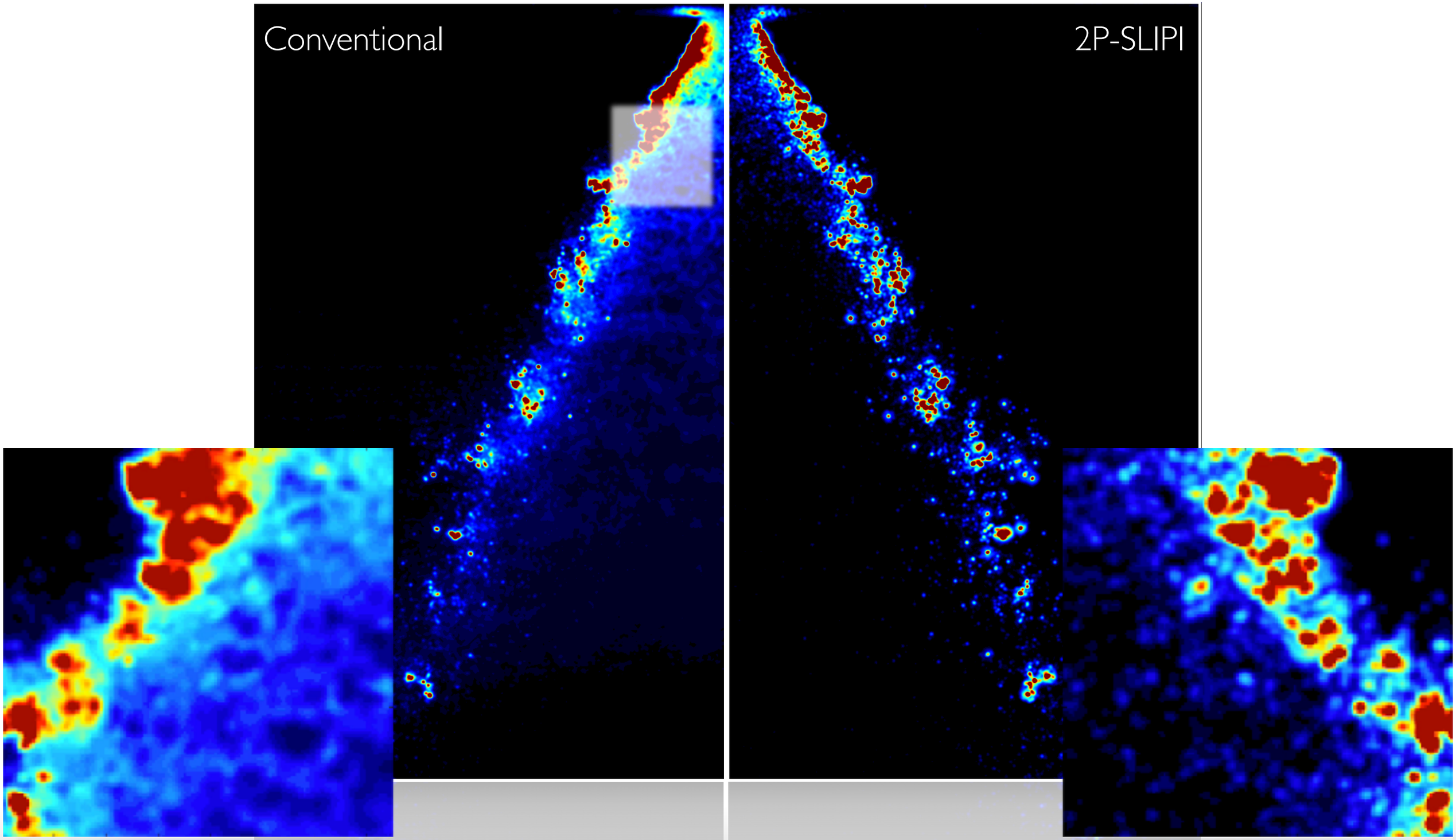
2P-SLIPI



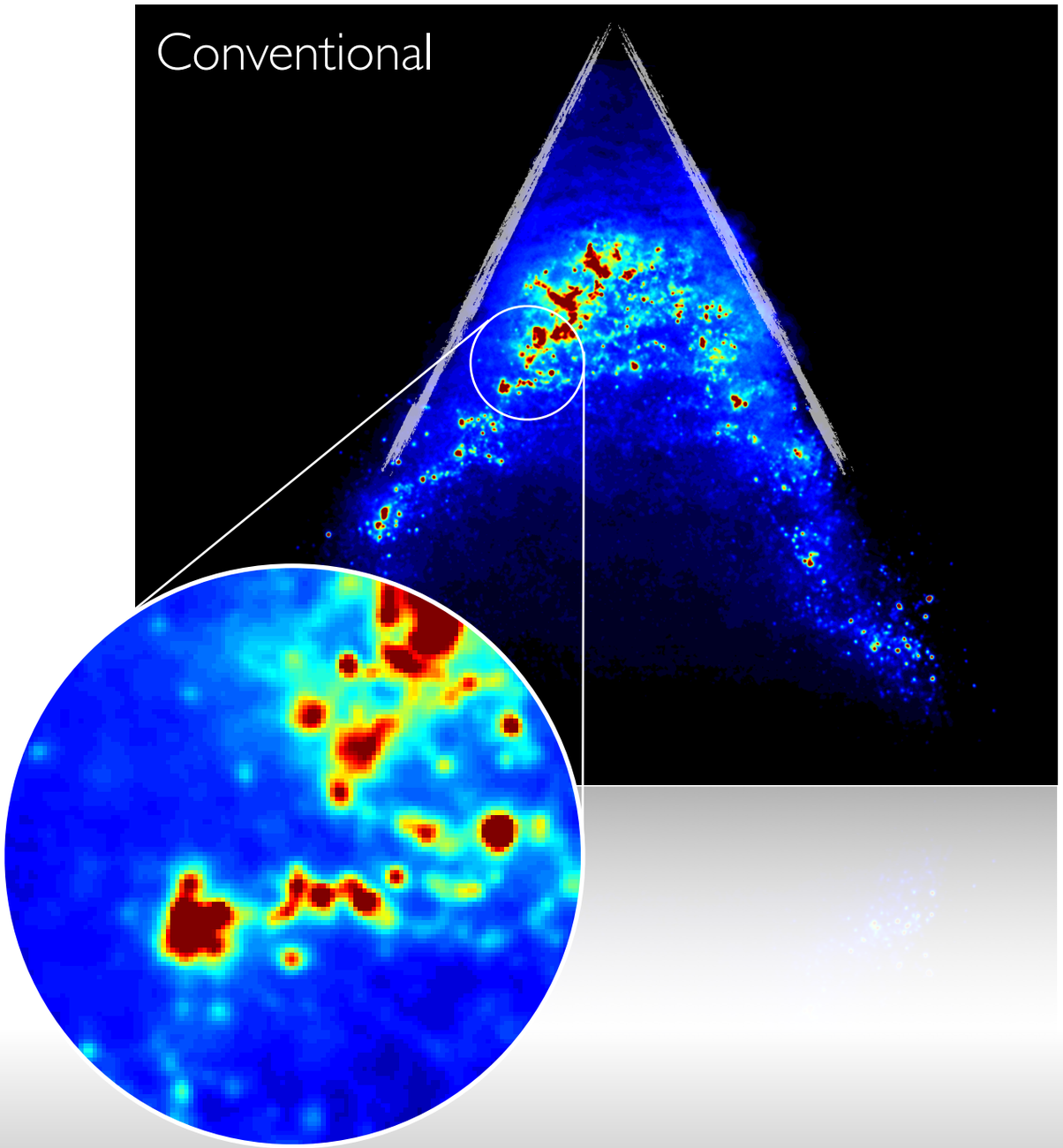
Inverse Fourier transform

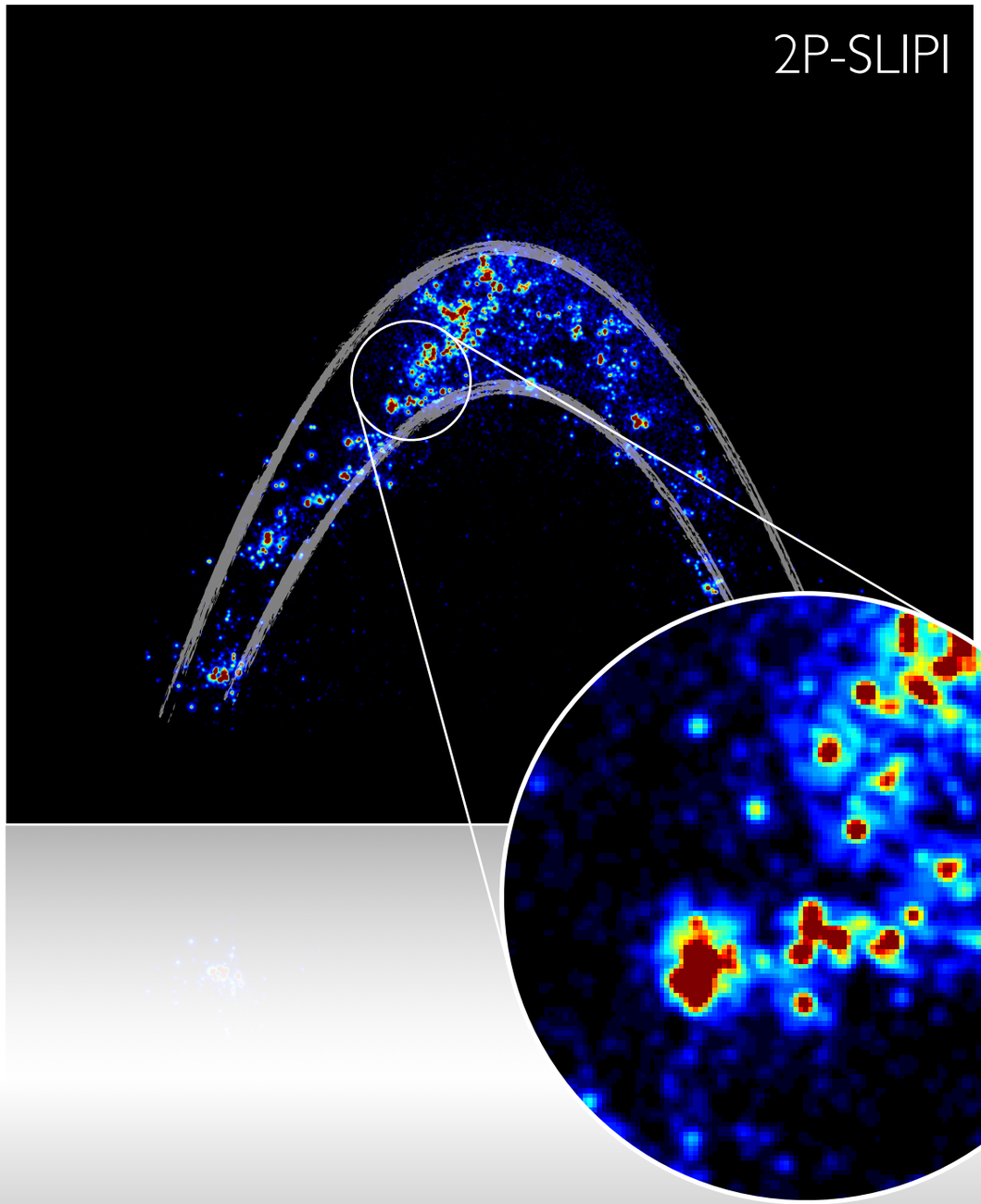


Results (instantaneous)



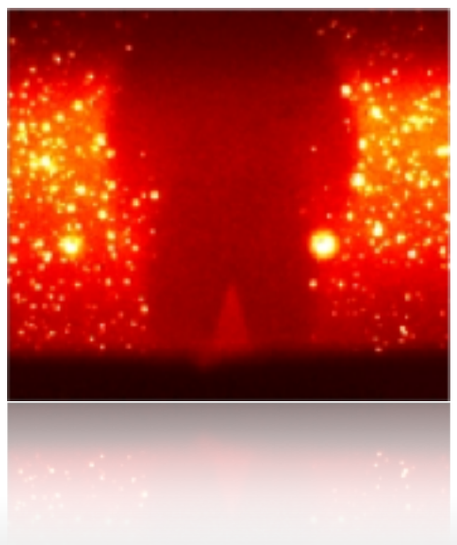
Results (instantaneous)





Rayleigh thermometry

Remove stray light using SLIPI



Rayleigh scattering

1 Elastic scattering

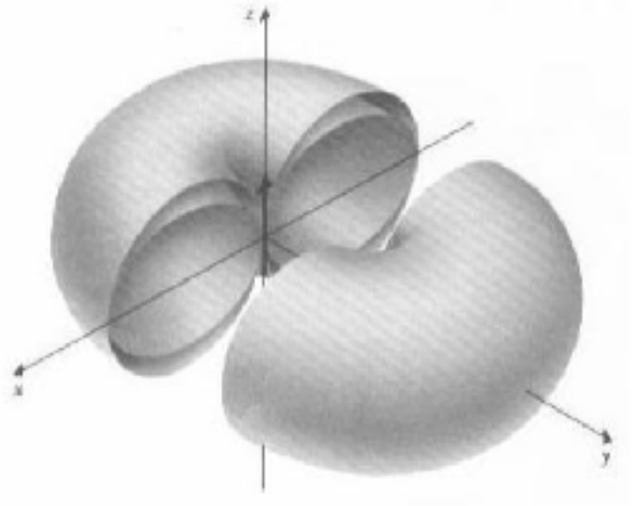
Scattering upon molecules

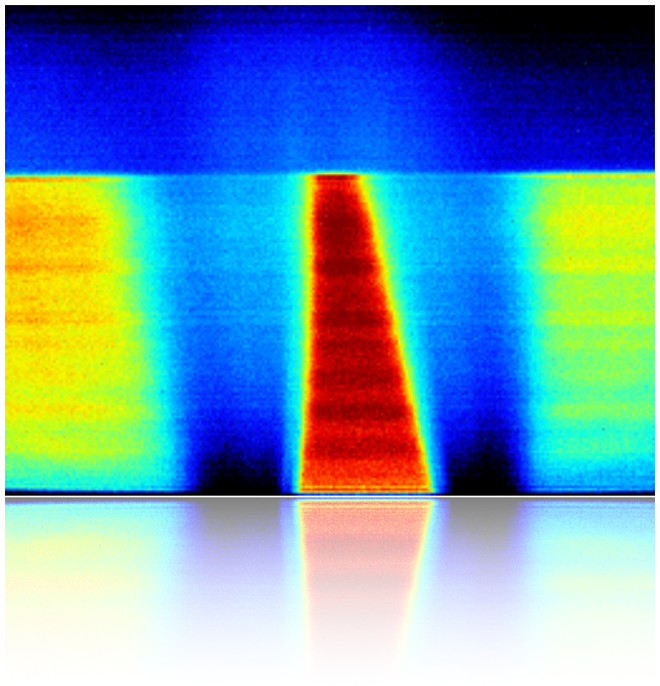
2 Temp. dependent

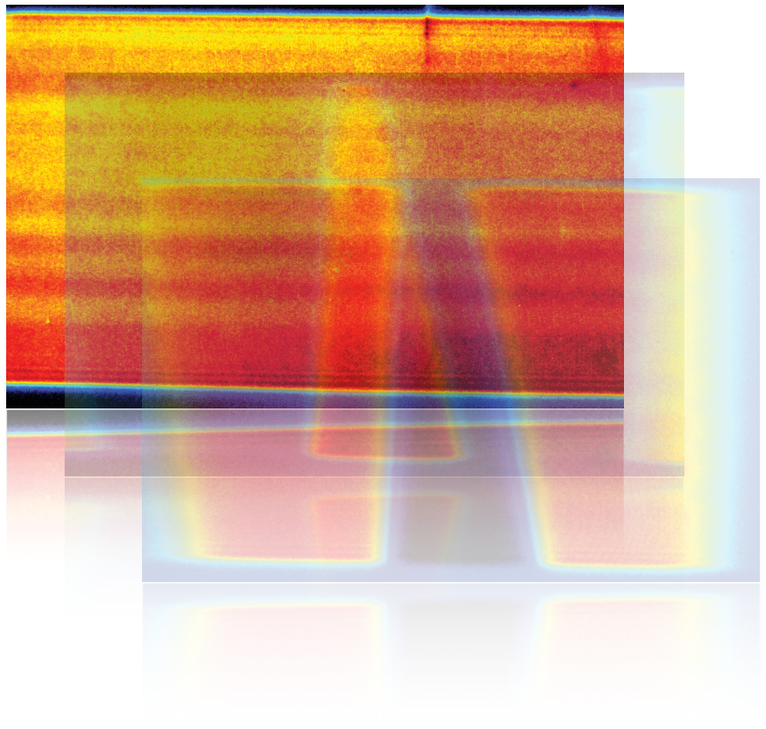
Scattered light intensity scales with T^{-1}

3 Evaluation

Reference + flame measurement



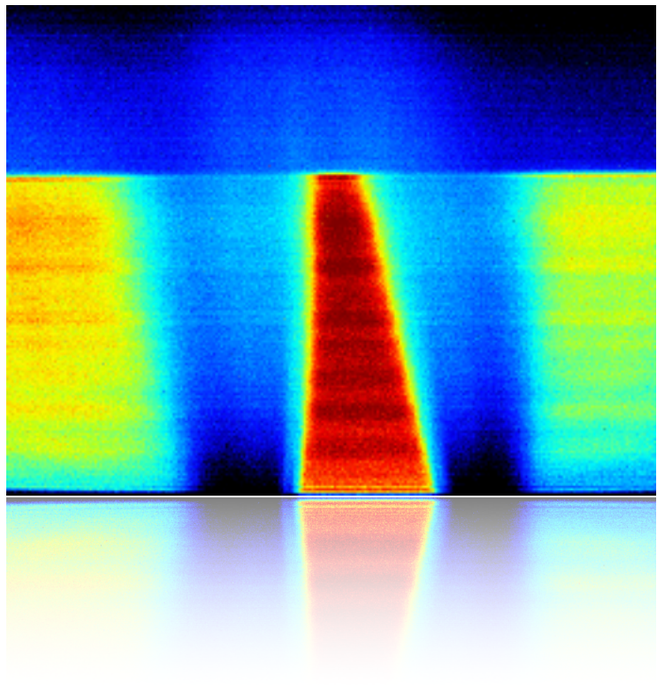




Rayleigh scattering

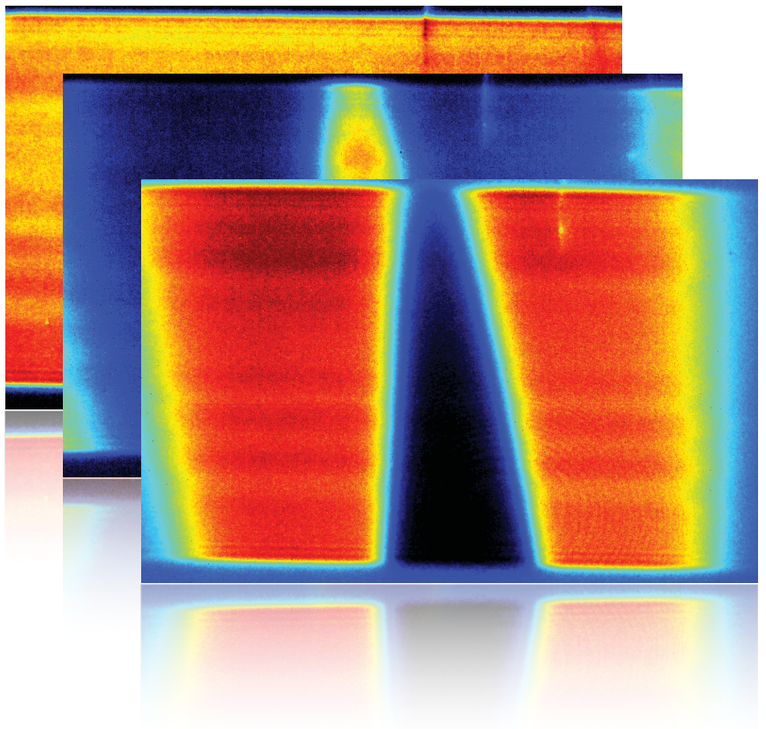
2 Temp. dependent

Scattered light intensity scales with T^{-1}



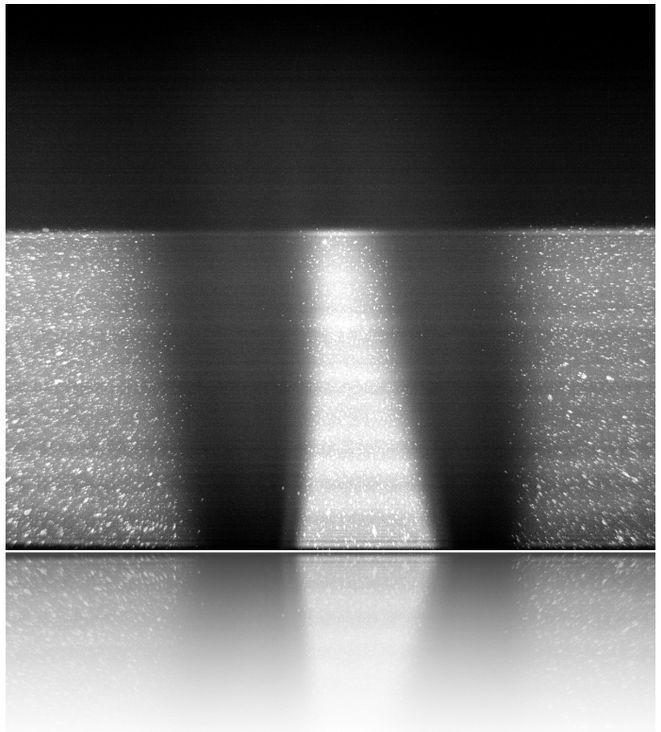
3 Evaluation

Reference + flame measurement



4 Interference

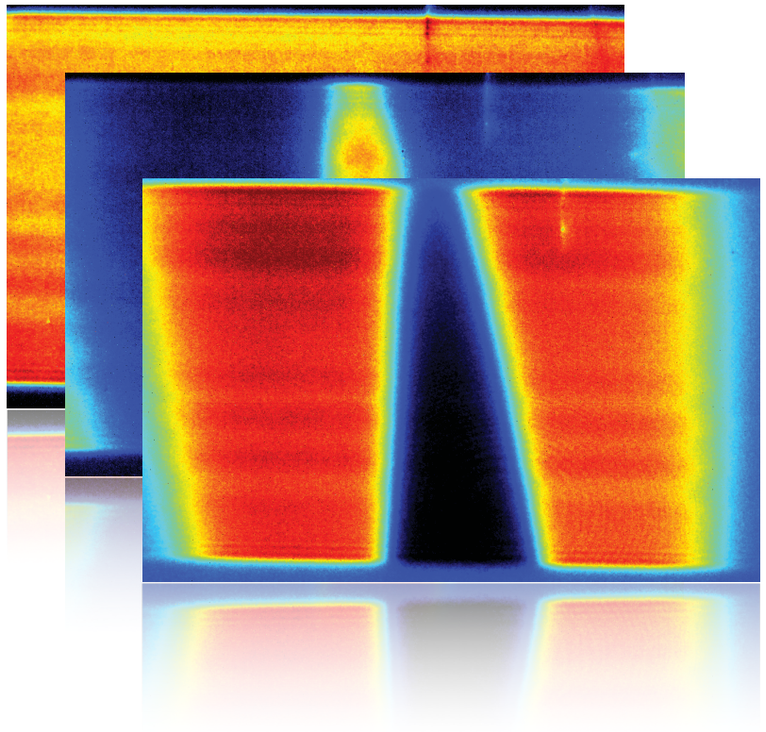
Unwanted signal from sample region



Rayleigh scattering

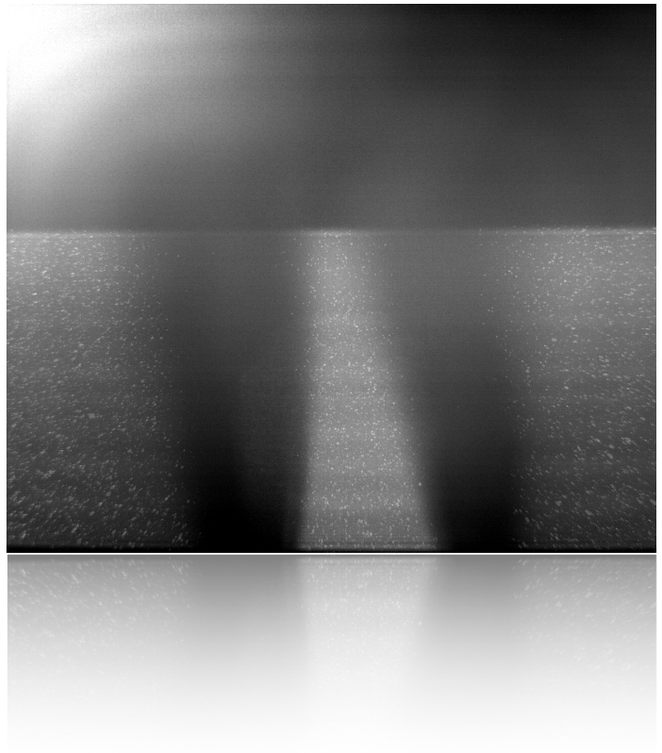
3 Evaluation

Reference + flame measurement



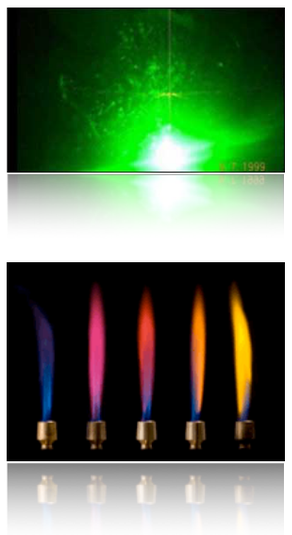
4 Interference

Unwanted signal from sample region

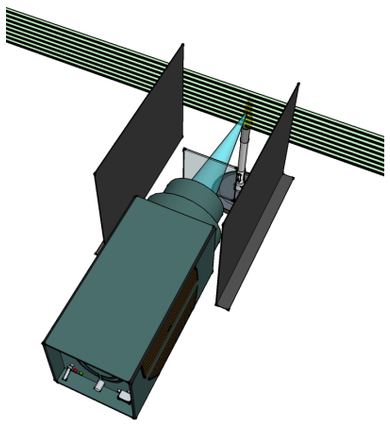


5 Stray light

Interfering signal, difficult to avoid

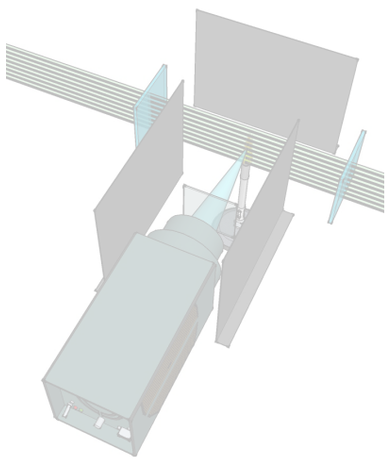


Modulated Rayleigh scattering thermometry



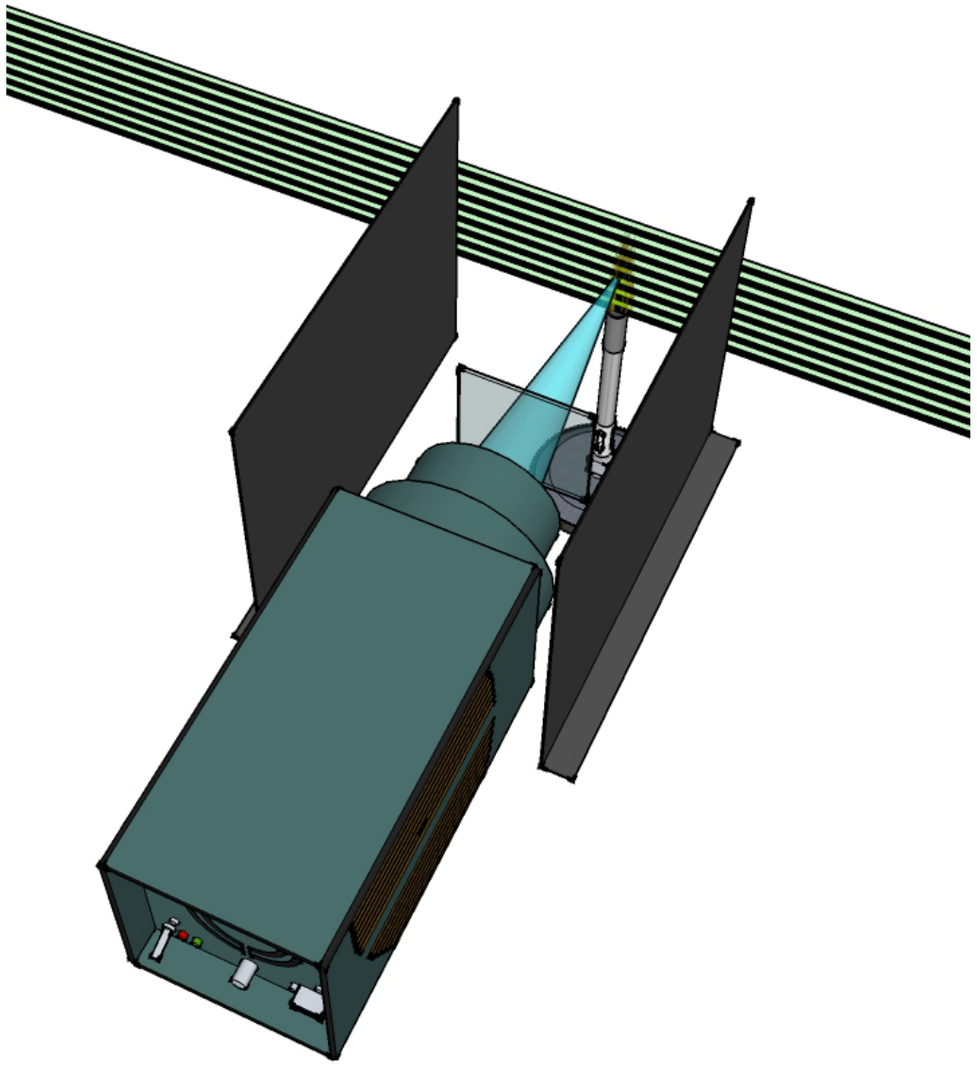
Case 0

Complete shielding

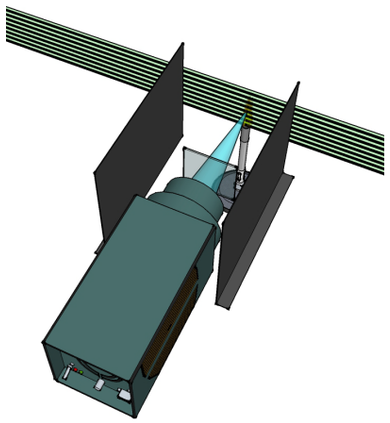


Case 1

High amount of stray light

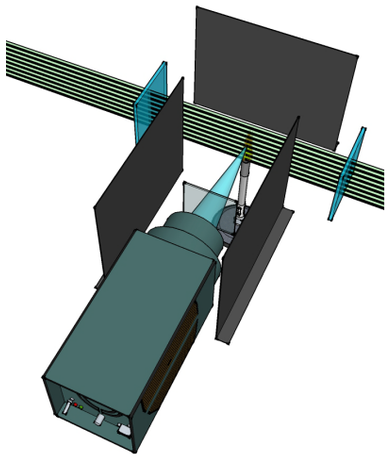


Experimental setup



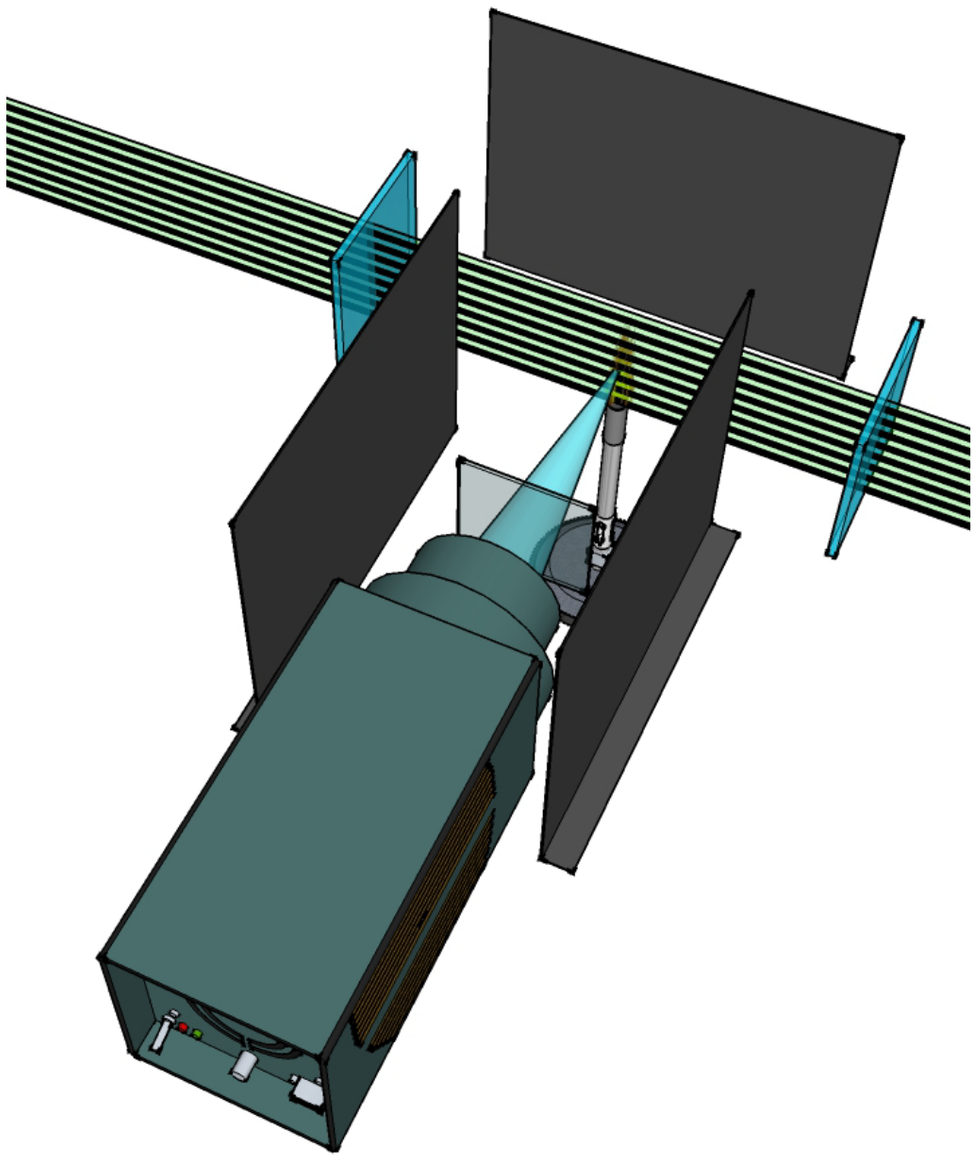
Case 0

Complete shielding



Case 1

High amount of stray light



Results

1 Case 0

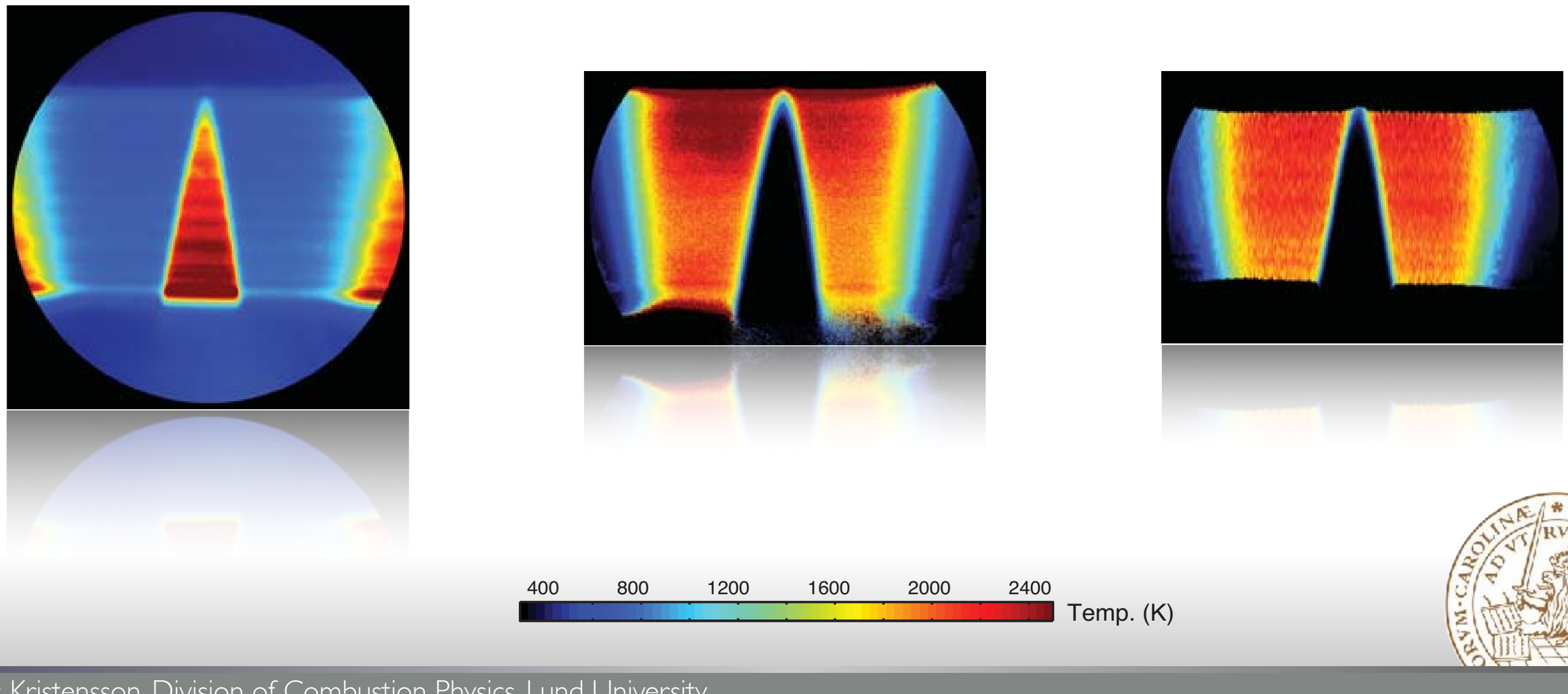
Complete shielding

2 Conv

2D temperature map

3 SLIPI

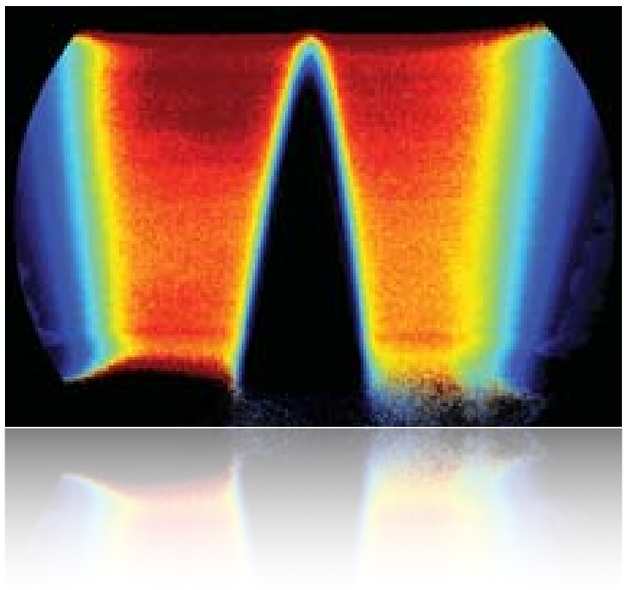
Slightly different field-of-view



Results

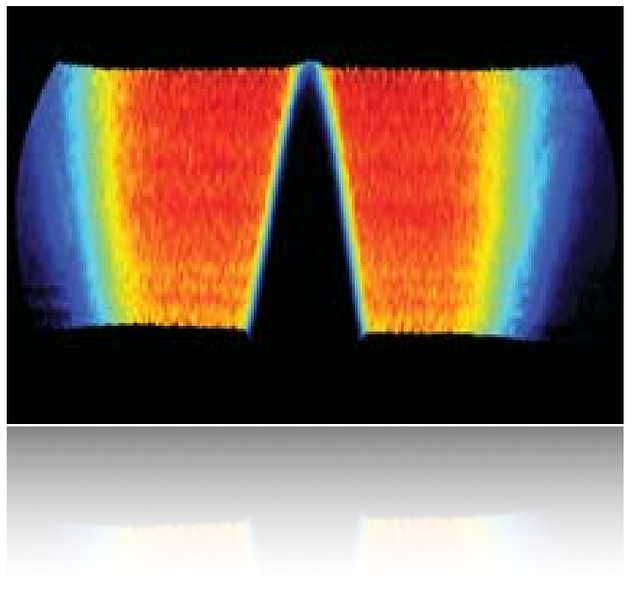
2 Conv

2D temperature map



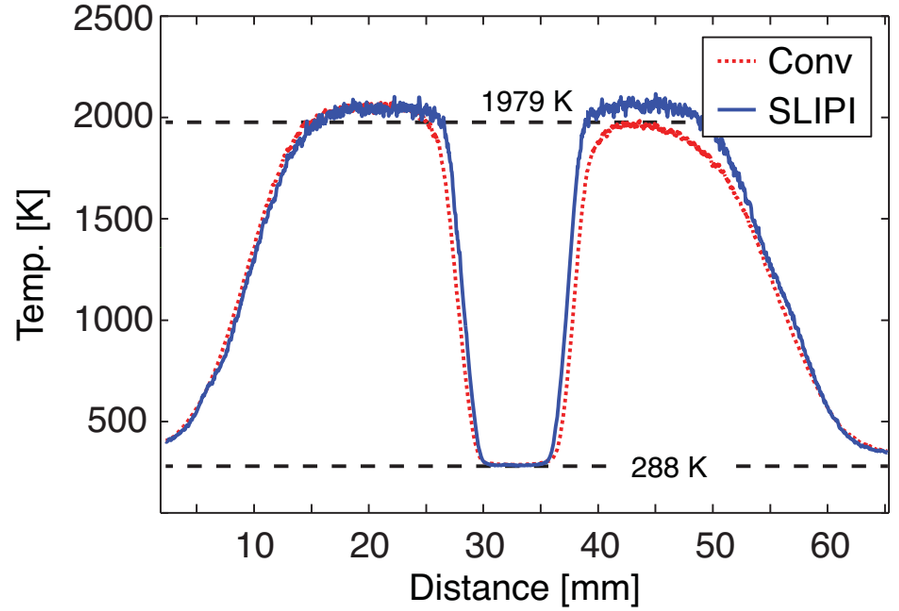
3 SLIPI

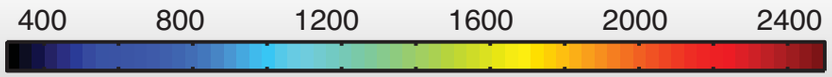
Slightly different field-of-view



4 Comparison

Cross-section view





Results

1 Case 1

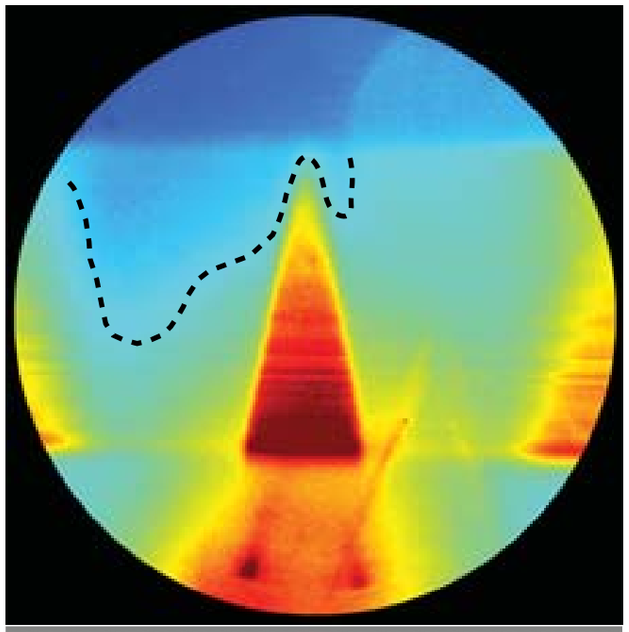
High amount of stray light

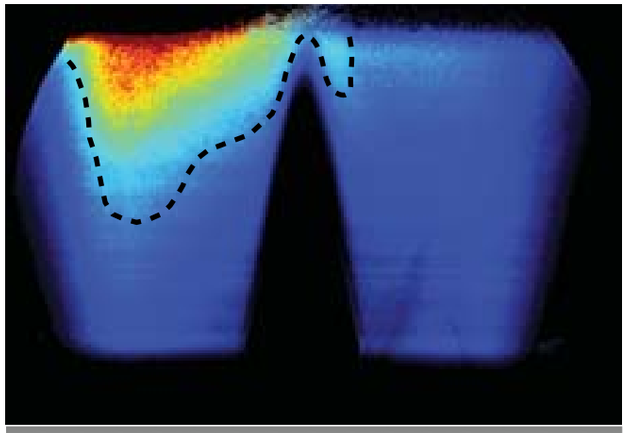
2 Conv

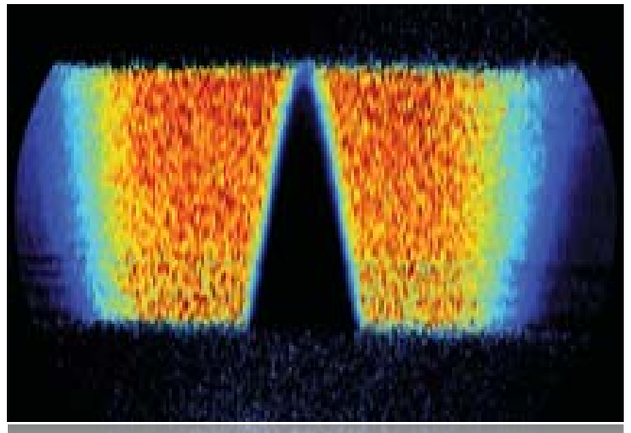
Spatial variations and asymmetric structures

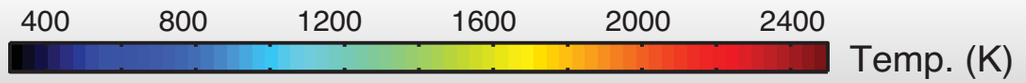
3 SLIPI

Symmetry and absolute T preserved









Results

2 Conv

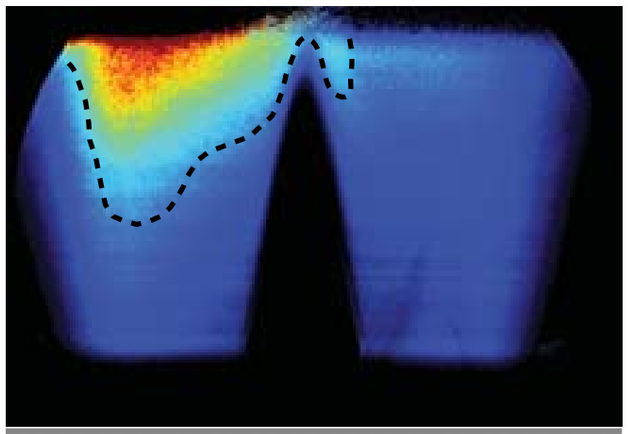
Spatial variations and asymmetric structures

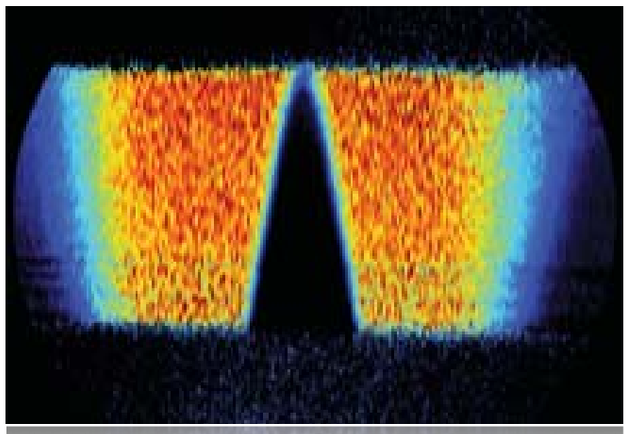
3 SLIPI

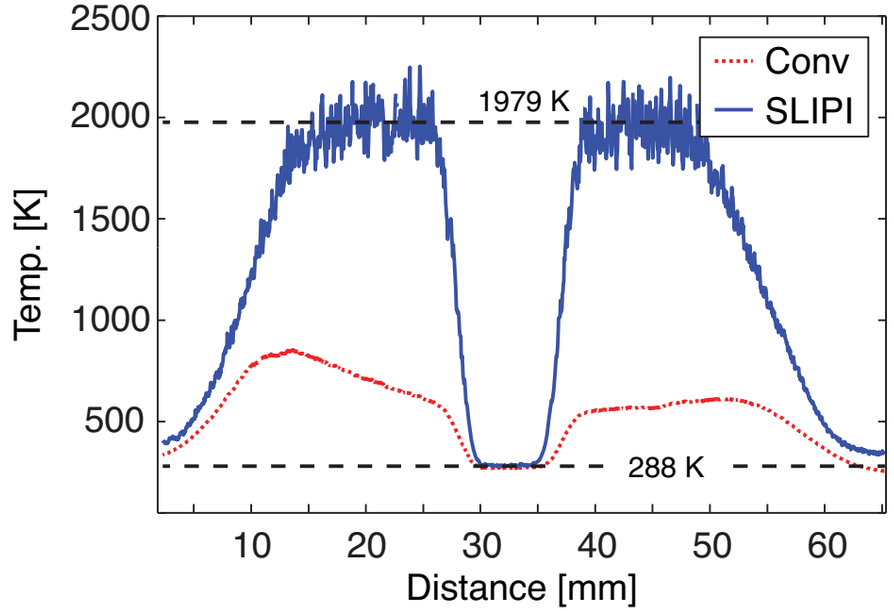
Symmetry and absolute T preserved

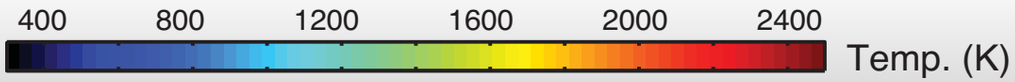
4 Comparison

Cross-section view



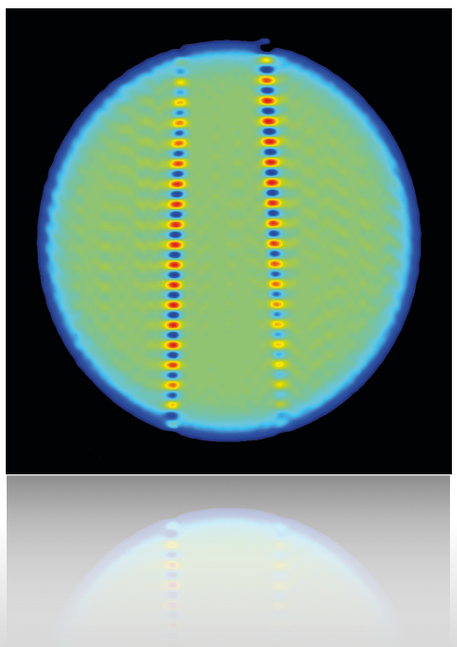




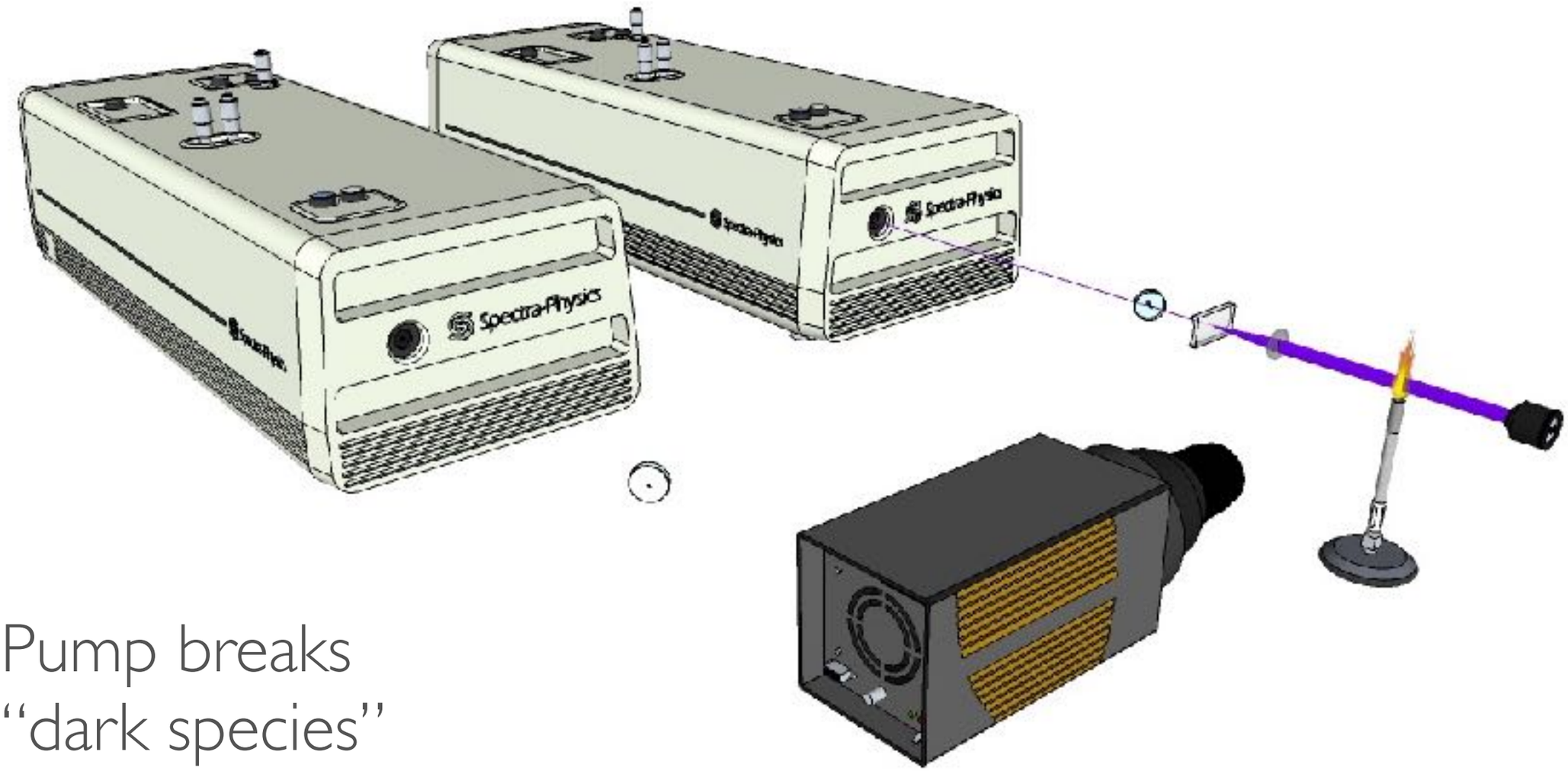


Photofragmentation LIF

Intensity modulation in pump-probe experiments

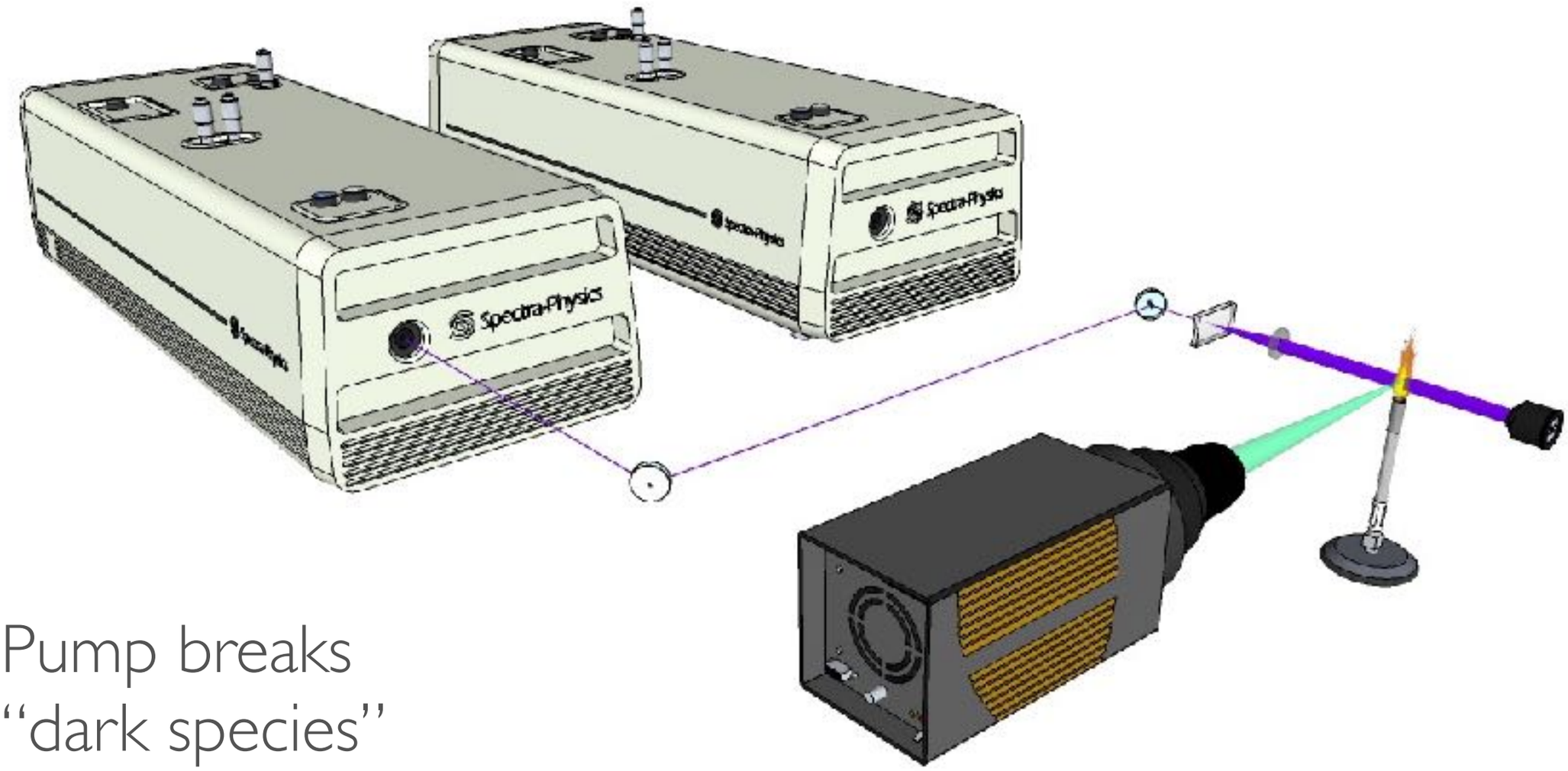


Pump probe experiments



1. Pump breaks “dark species”
2. Probe photofragments
3. Poor selectivity

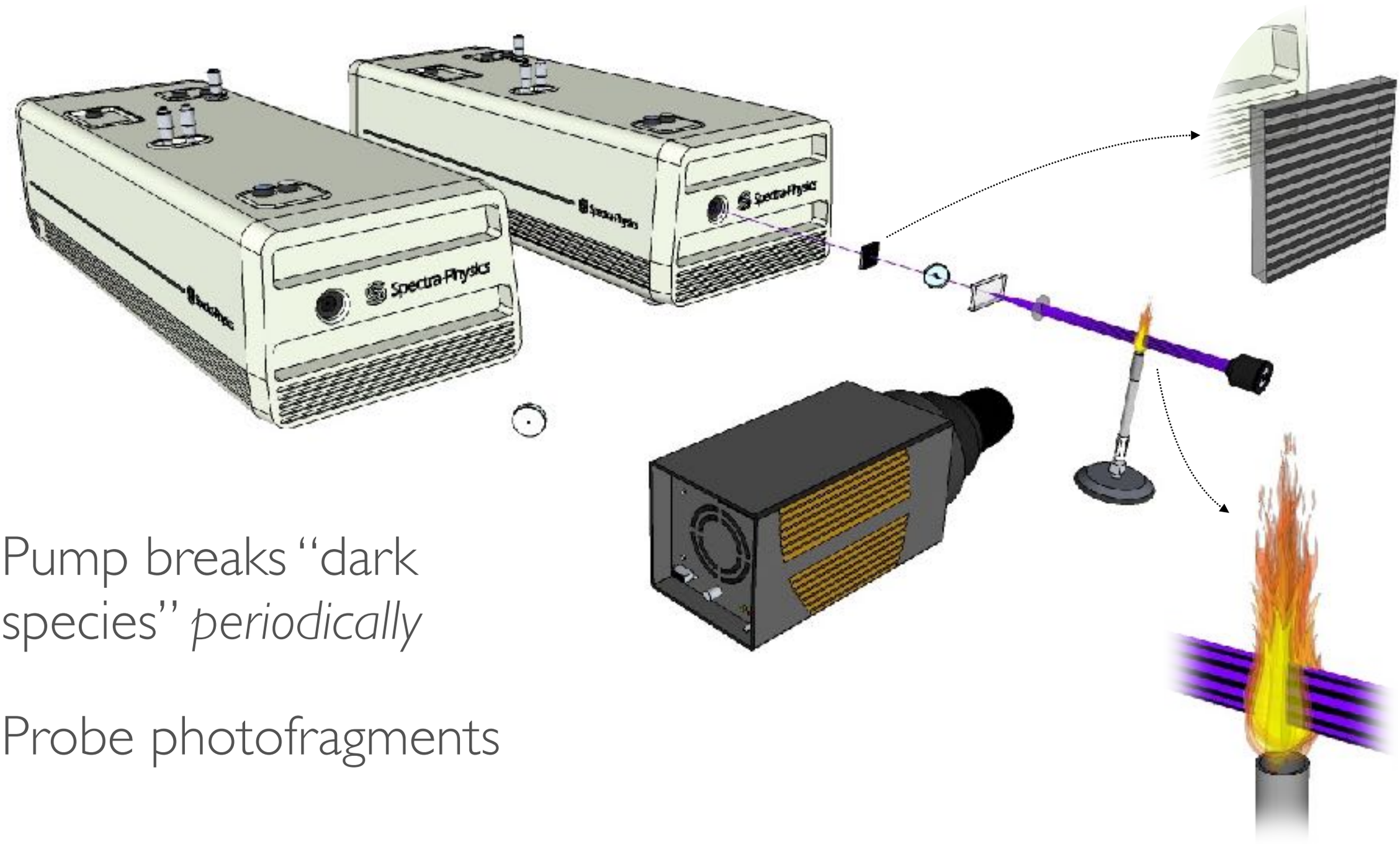
Pump probe experiments



1. Pump breaks "dark species"
2. Probe photofragments
3. Poor selectivity

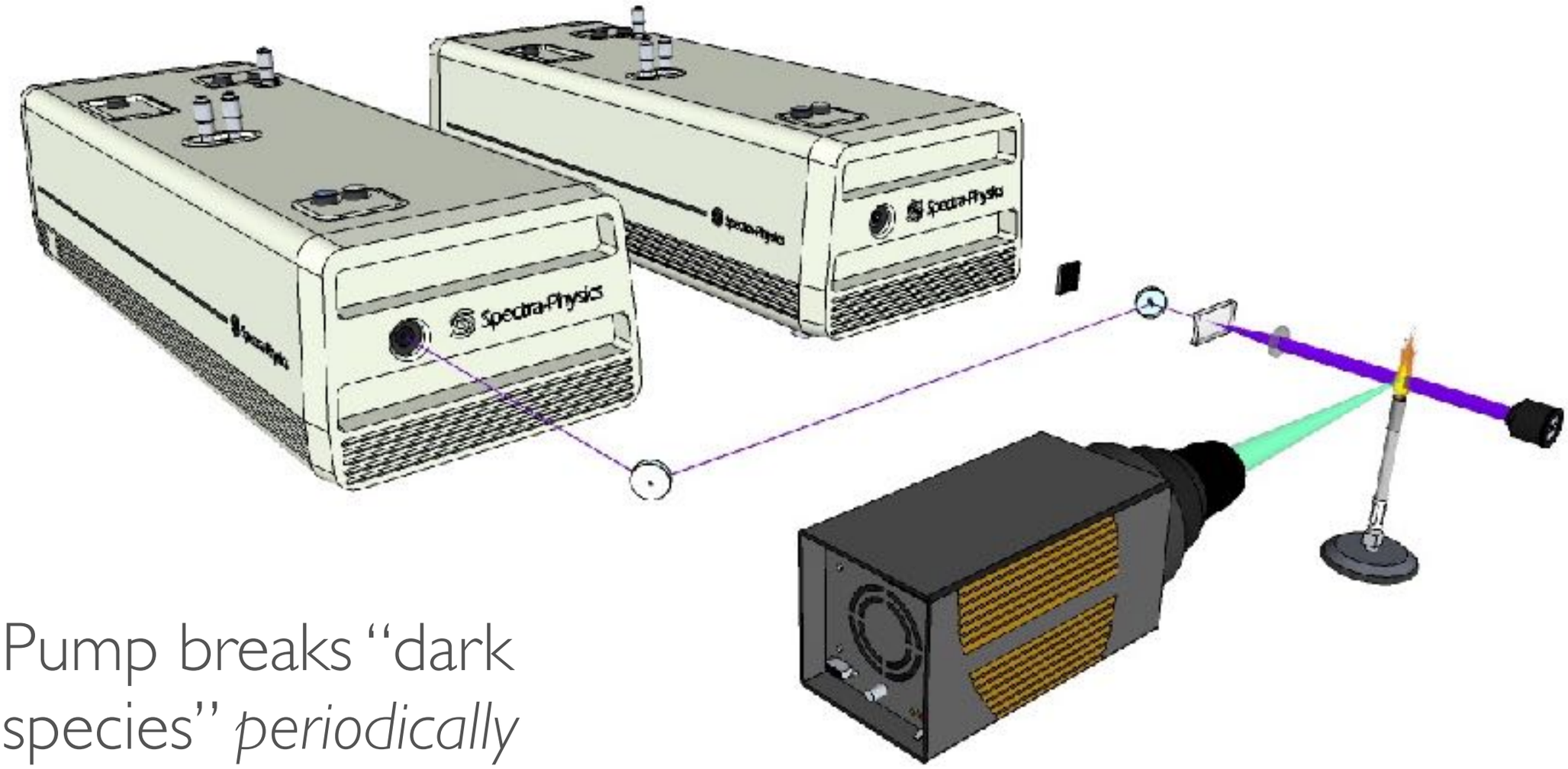
$$H_2O_2 \longrightarrow 2\,OH$$

Modulated pump probe experiments



1. Pump breaks "dark species" *periodically*
2. Probe photofragments
3. Improved selectivity

Modulated pump probe experiments



1. Pump breaks "dark species" *periodically*
2. Probe photofragments
3. Improved selectivity

Intensity-modulated photofragmentation

1 Natural OH

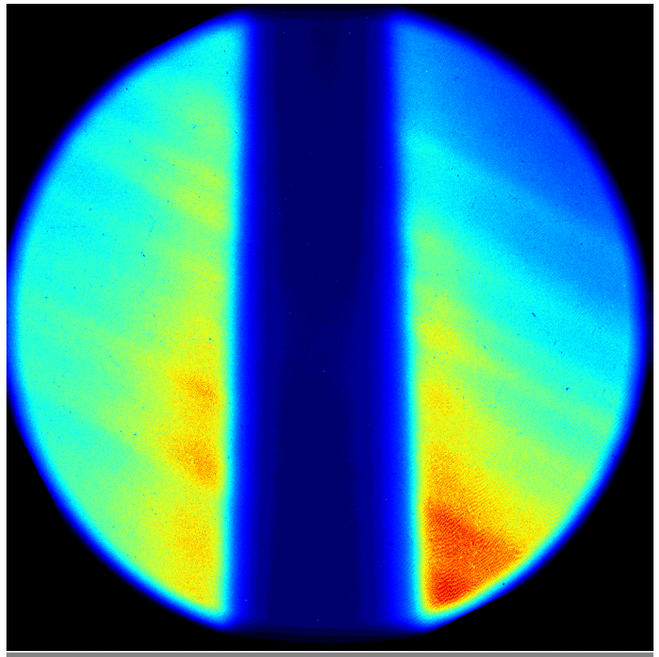
PLIF of naturally present OH

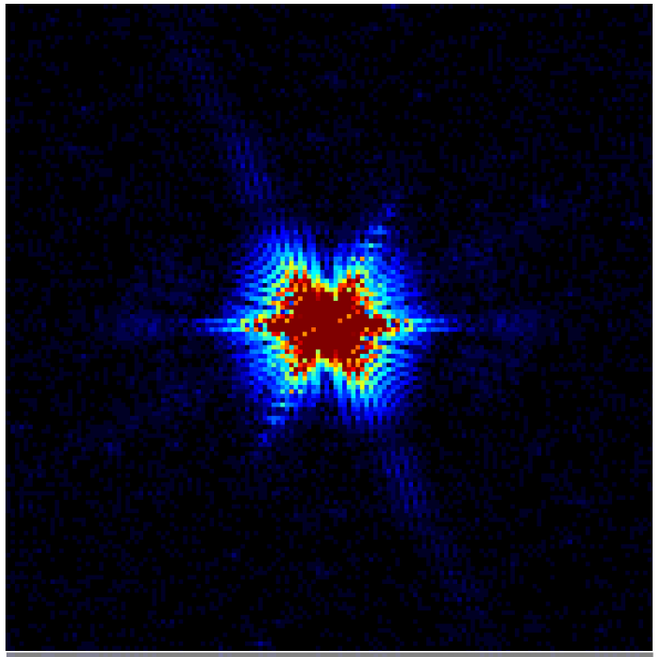
2 Fourier transform

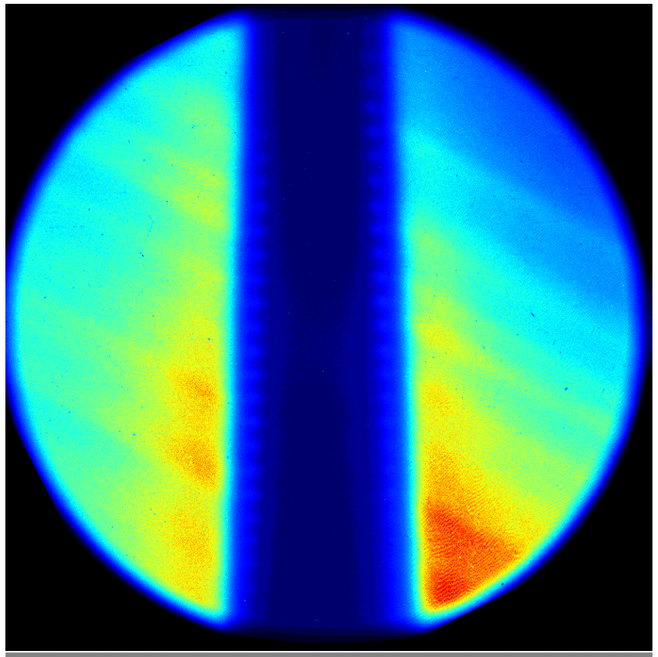
Low spatial frequencies only

3 Modulated pump beam

Photofragments created periodically







Intensity-modulated photofragmentation

2 Fourier transform

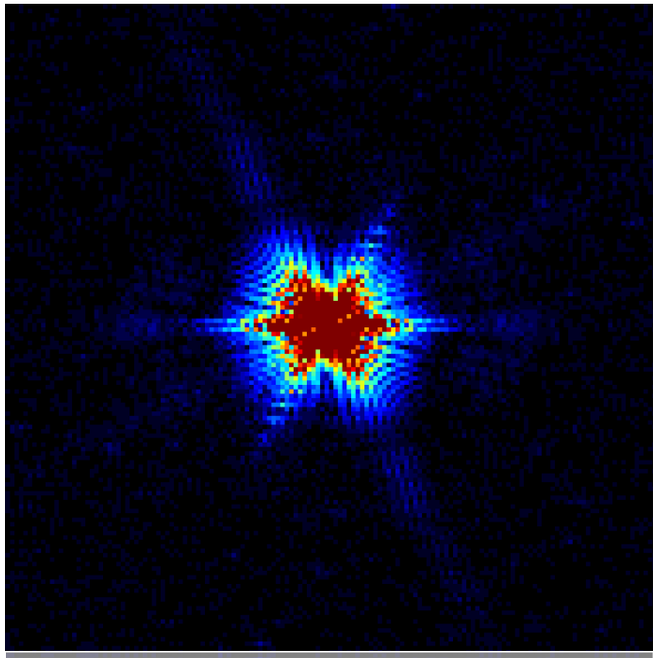
Low spatial frequencies only

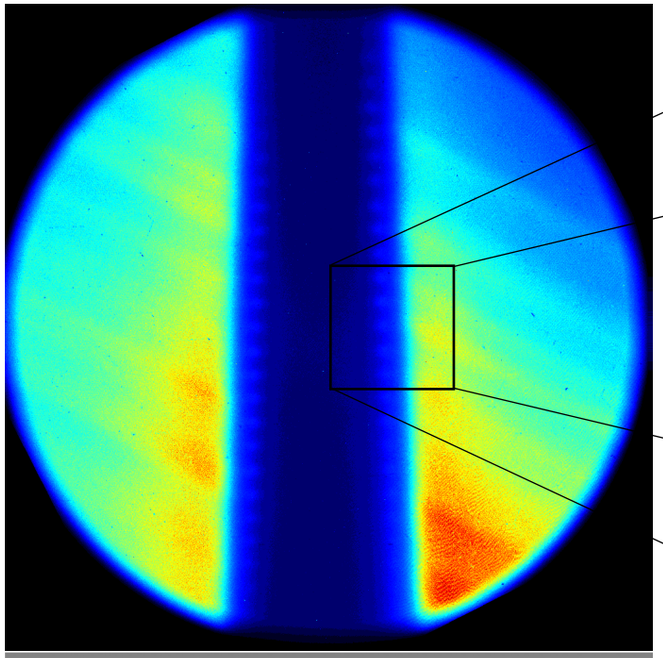
3 Modulated pump beam

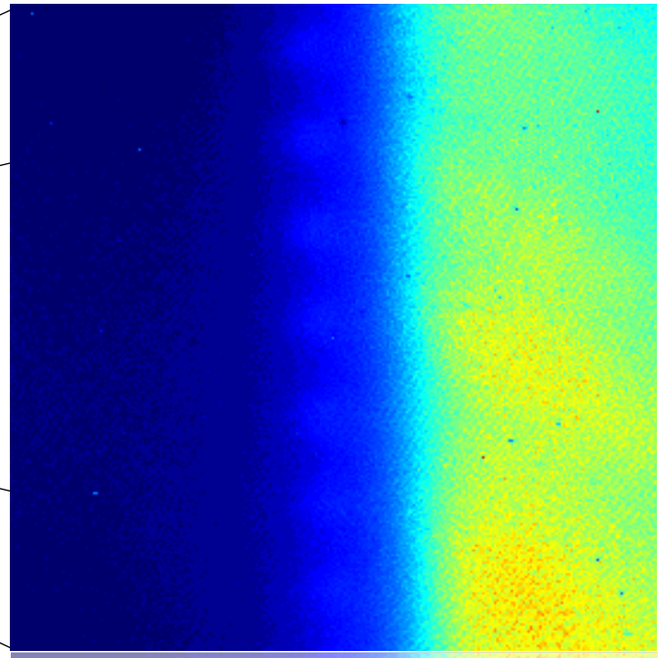
Photofragments created periodically

4 Magnified view

Modulation barely visible







Intensity-modulated photofragmentation

3 Modulated pump beam

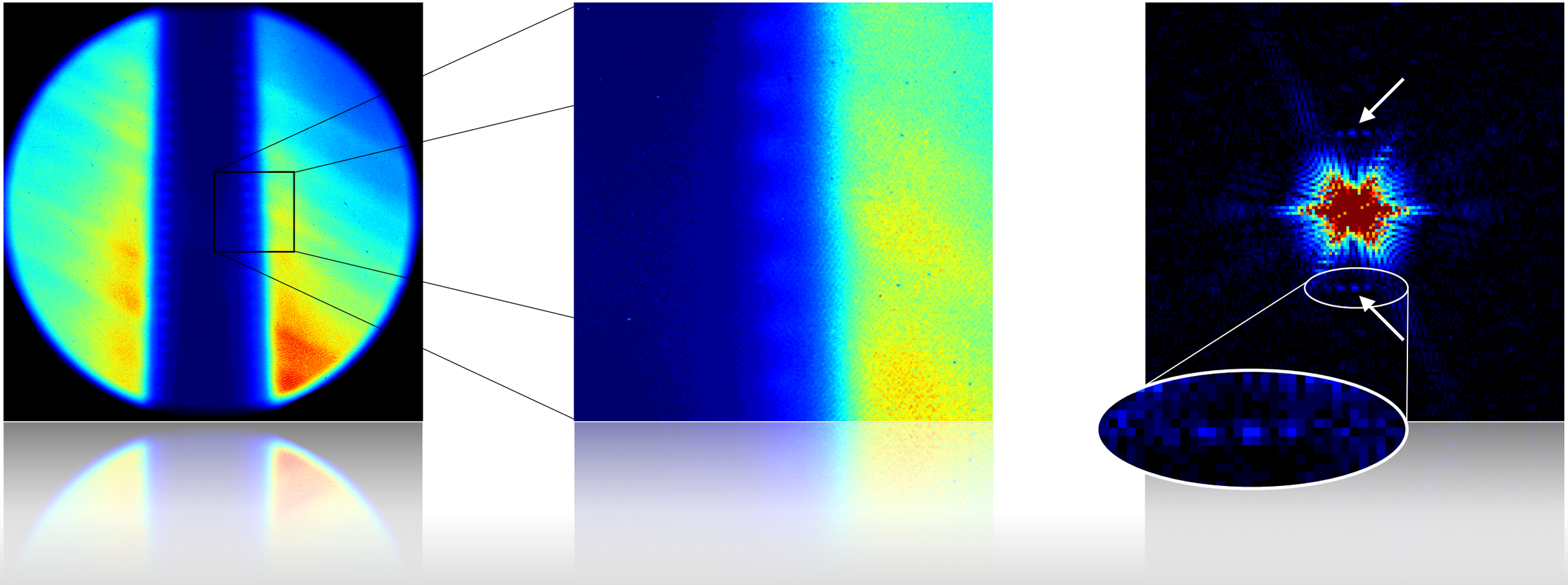
Photofragments created periodically

4 Magnified view

Modulation barely visible

5 Fourier transform

Modulation peak noticeable



Intensity-modulated photofragmentation

4 Magnified view

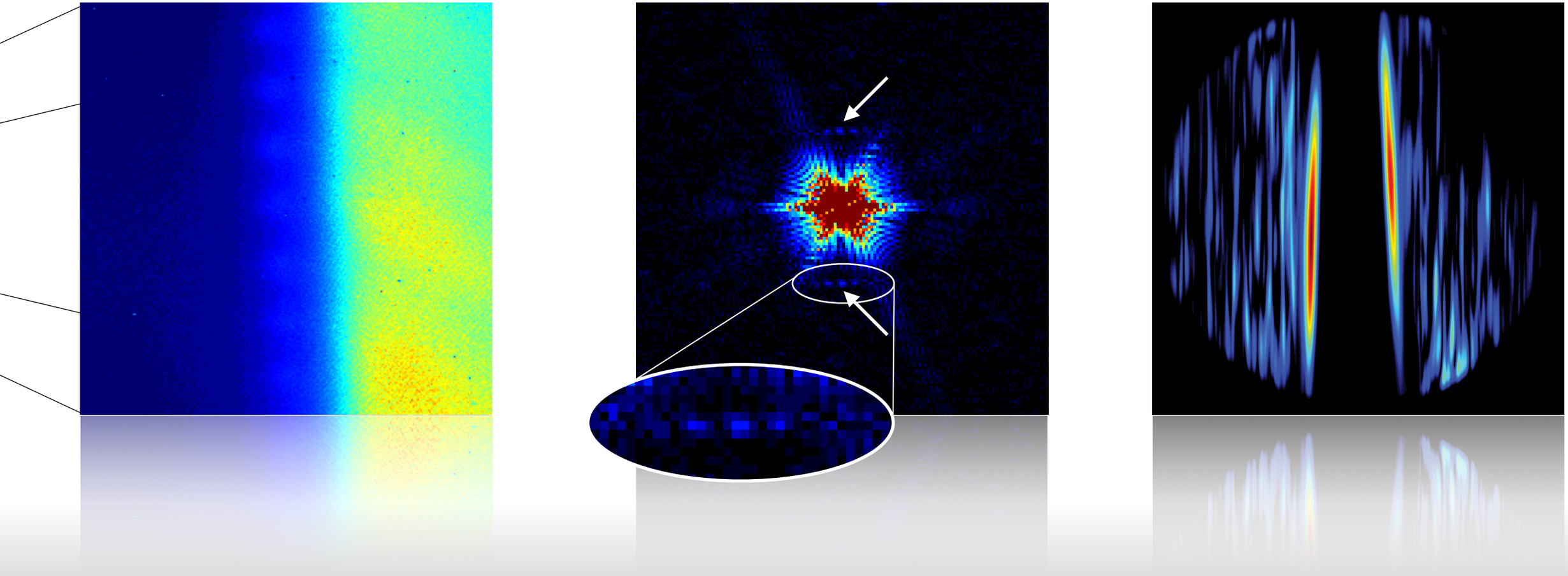
Modulation barely visible

5 Fourier transform

Modulation peak noticeable

6 SI result

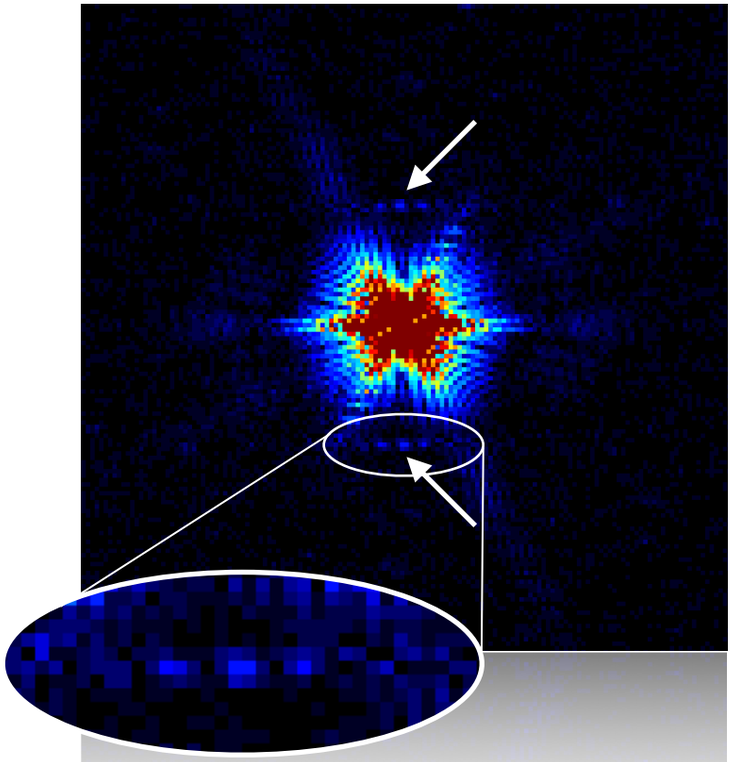
Photofragments distribution extracted



Intensity-modulated photofragmentation

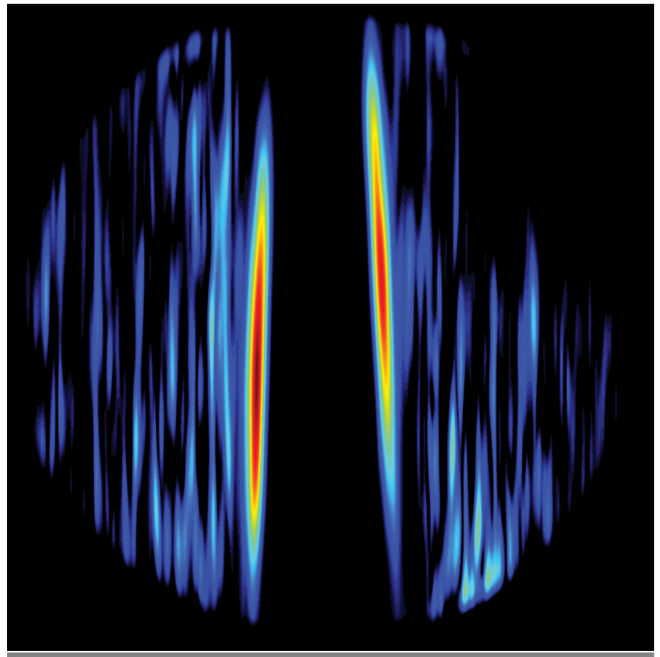
5 Fourier transform

Modulation peak noticeable



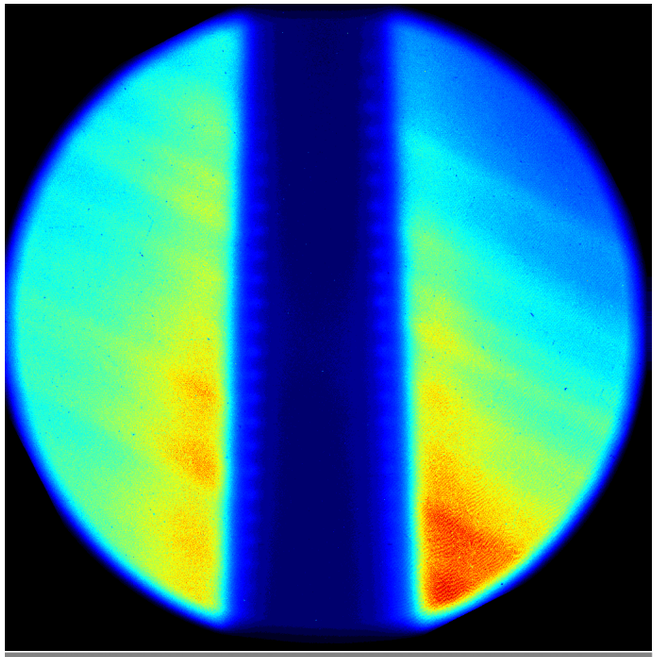
6 SI result

Photofragments distribution extracted



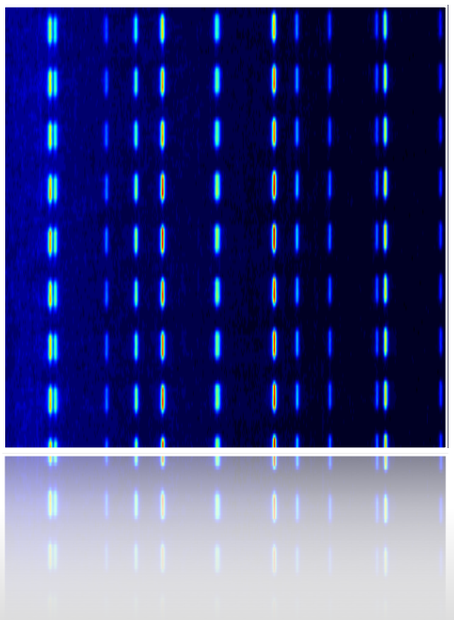
7 Original view

View with probe pulse

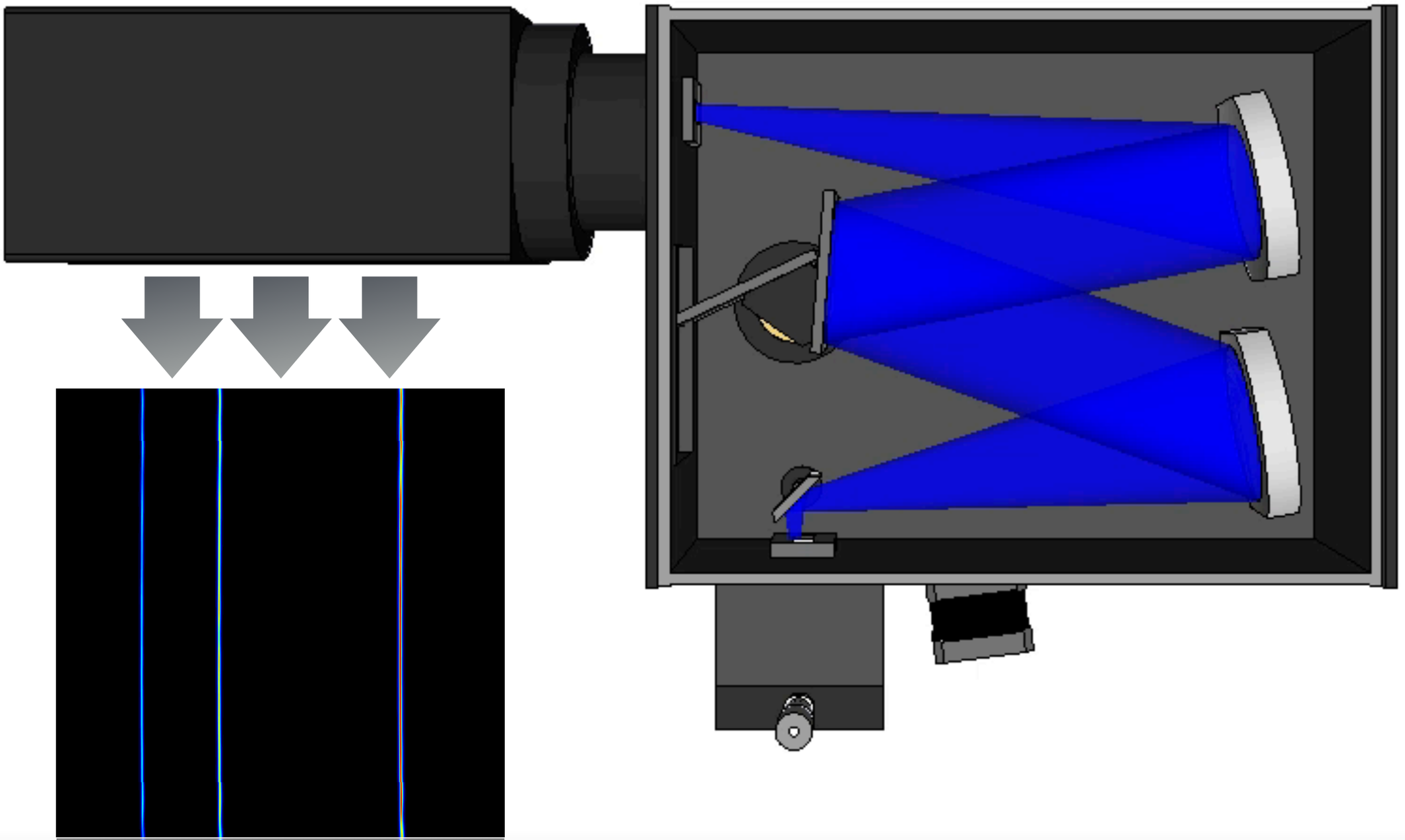


Periodic Shadowing

Intensity modulation in spectroscopy

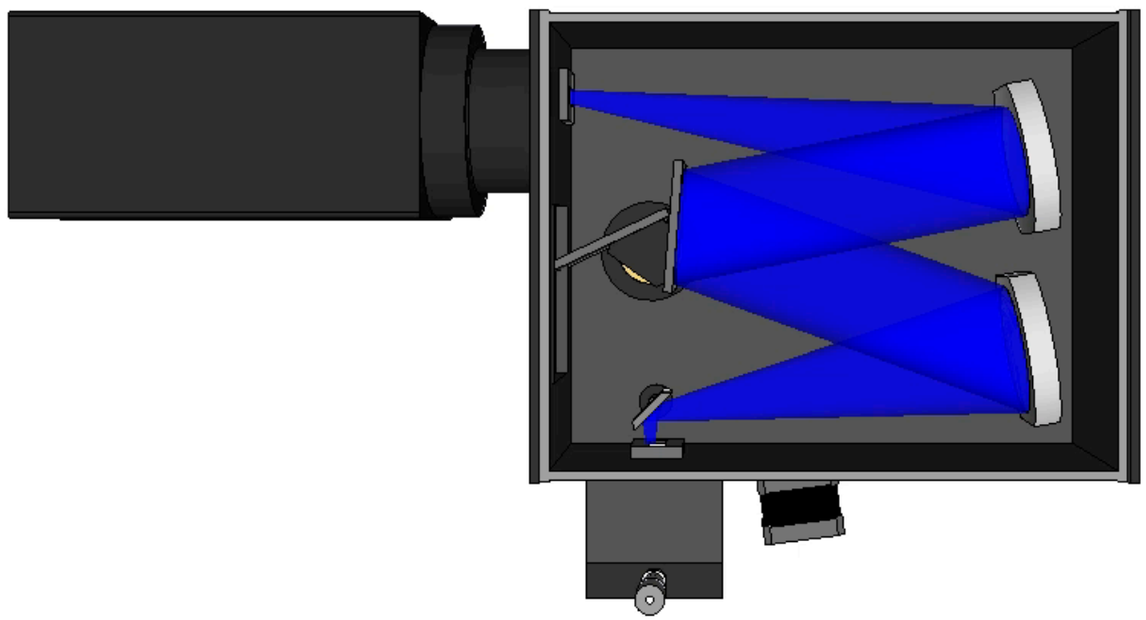


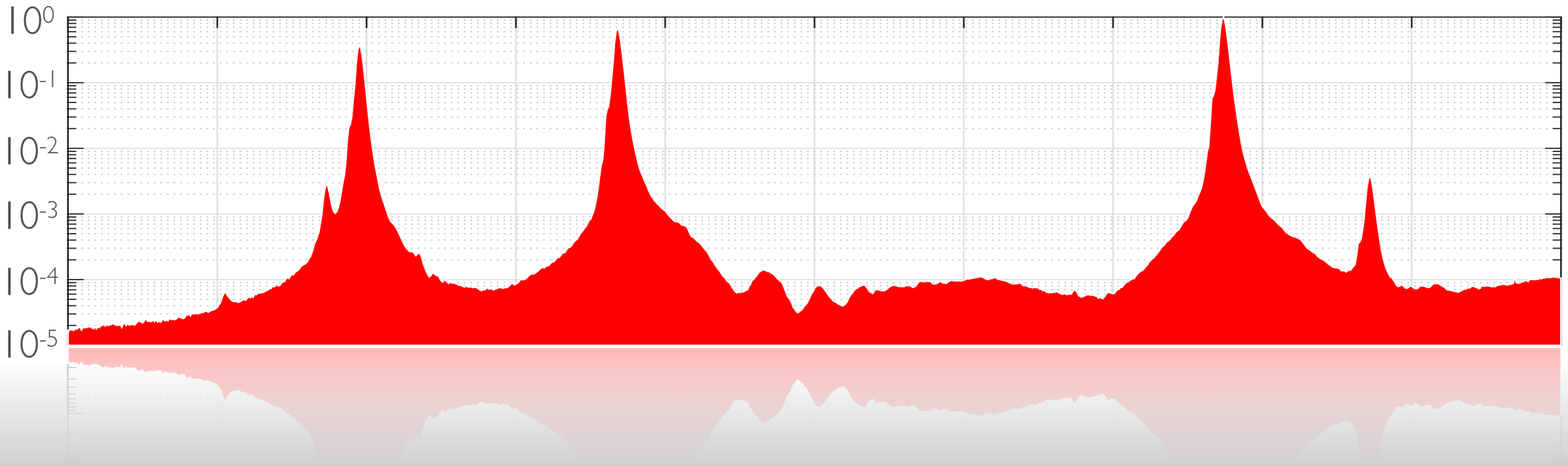
Spectrometer



Spectrometer

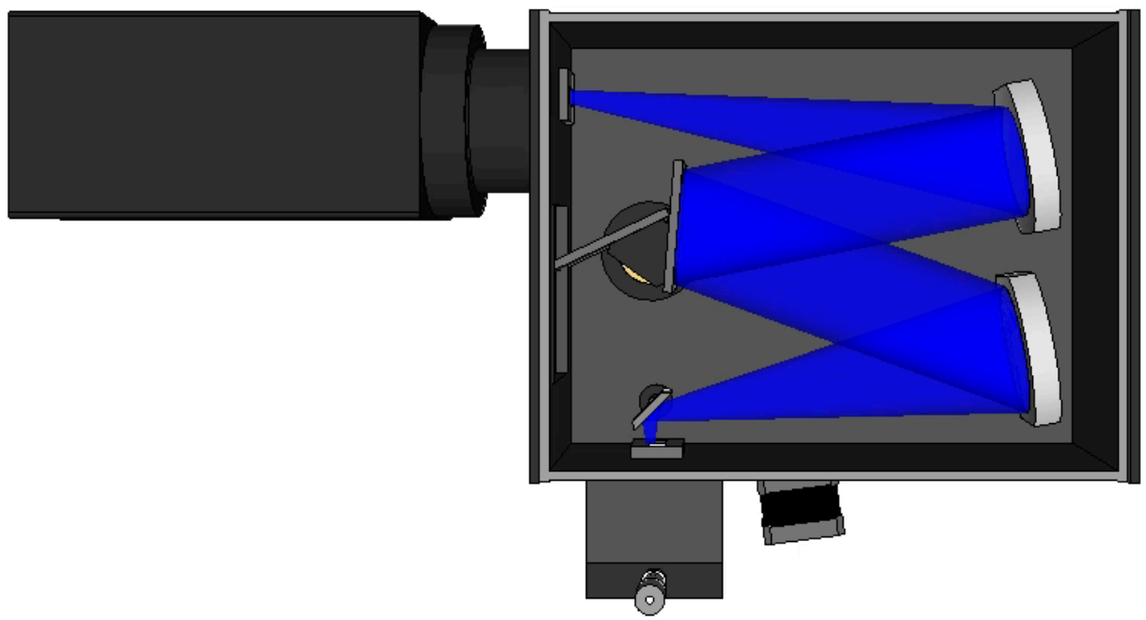
1. Imaging
2. Dynamic range
3. Stray light / backgrounds

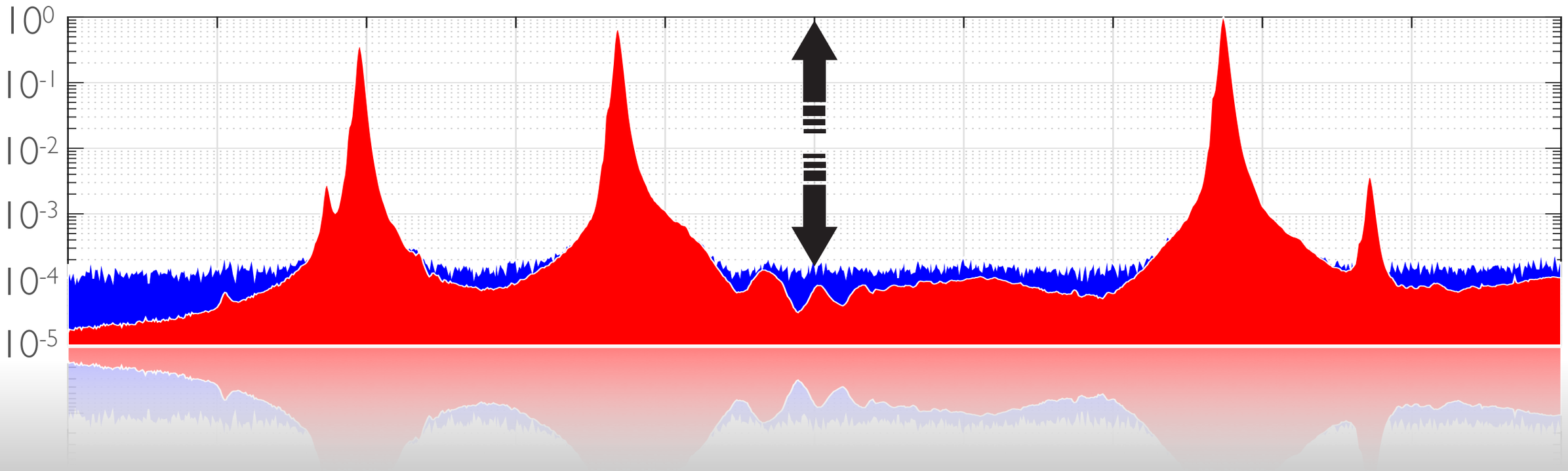




Spectrometer

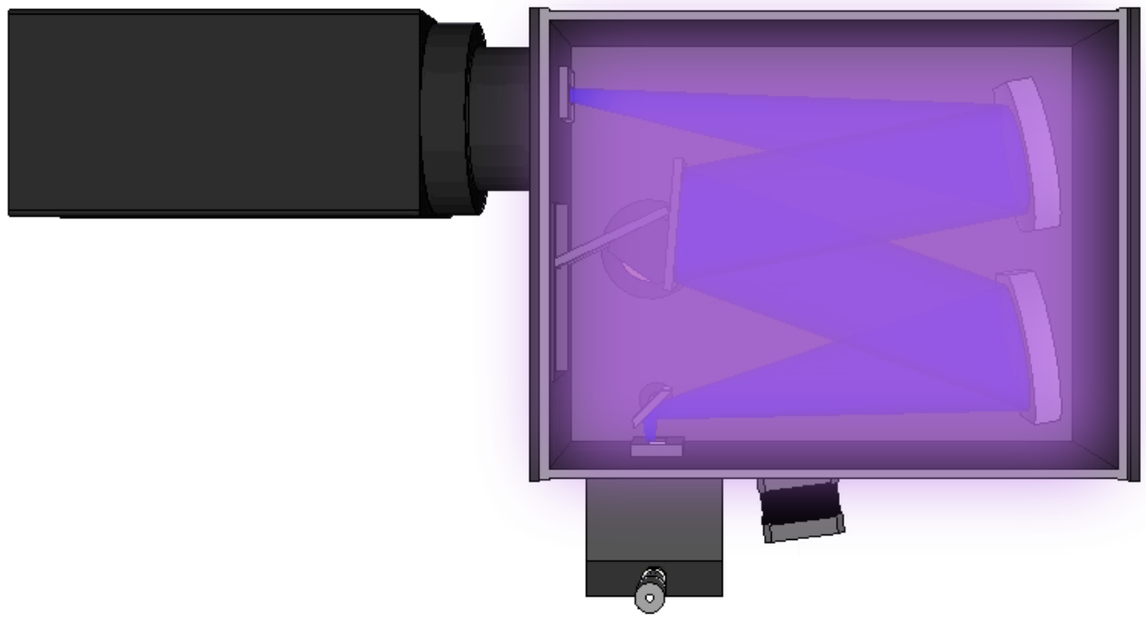
1. Imaging
2. Dynamic range
3. Stray light / backgrounds

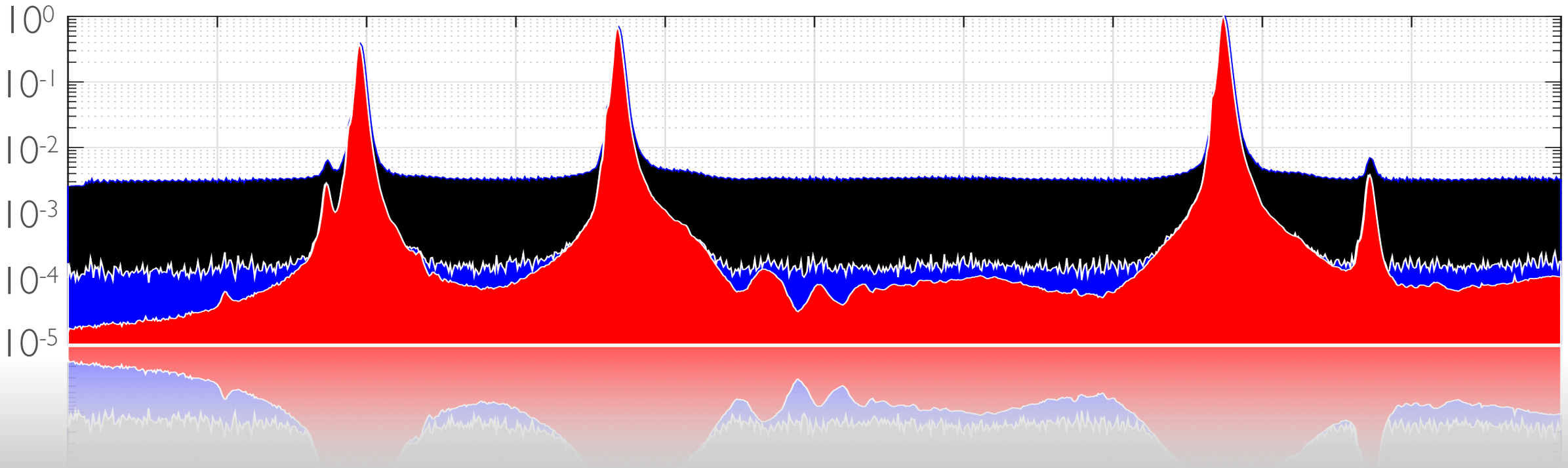




Spectrometer

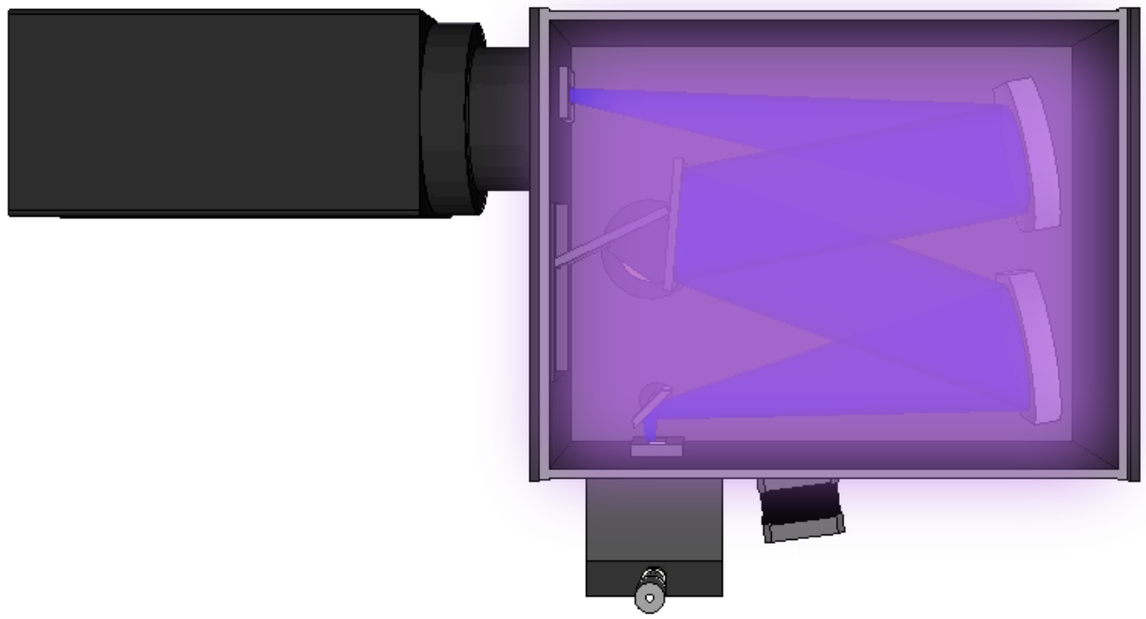
1. Imaging
2. Dynamic range
3. Stray light / backgrounds

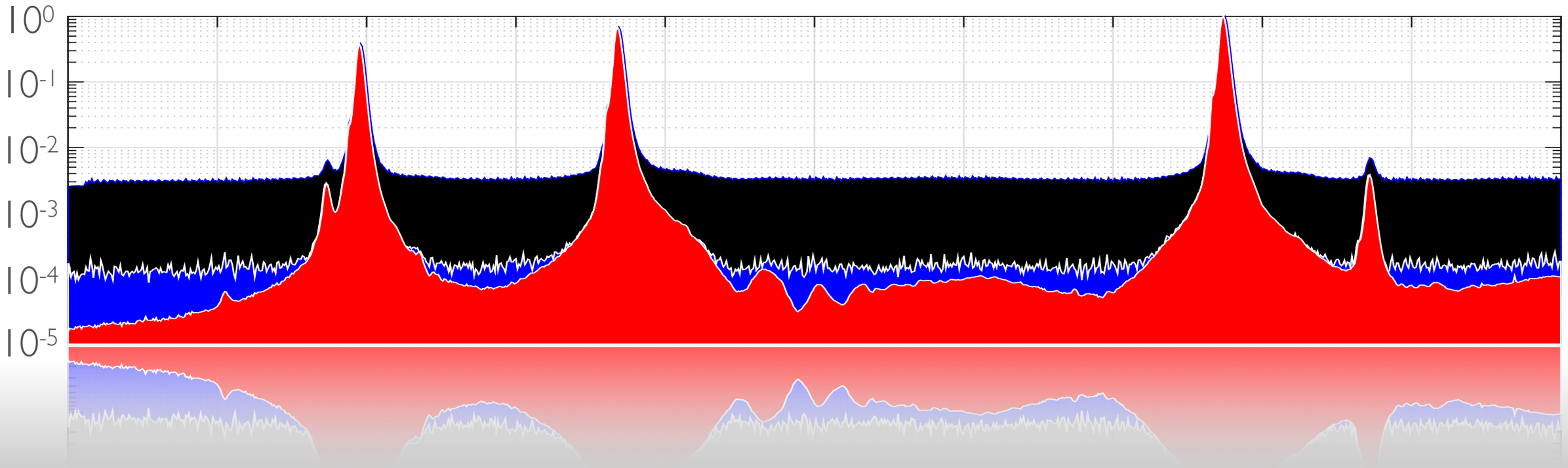




Spectrometer

1. Imaging
2. Dynamic range
3. Stray light / backgrounds

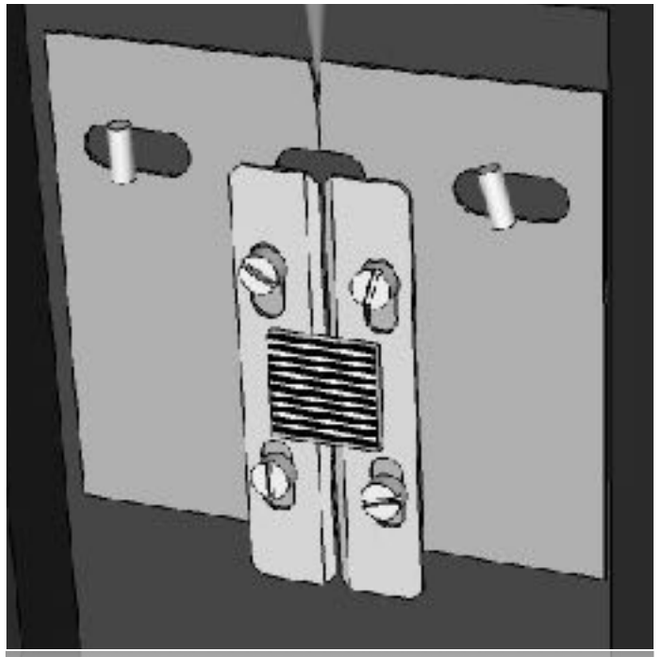




Periodic Shadowing

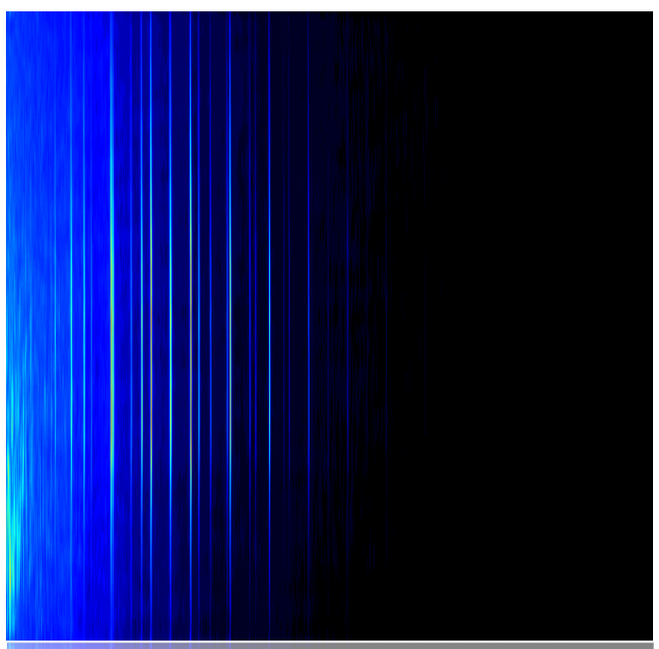
1 Ronchi grating

Mount a Ronchi grating
at the entrance slit



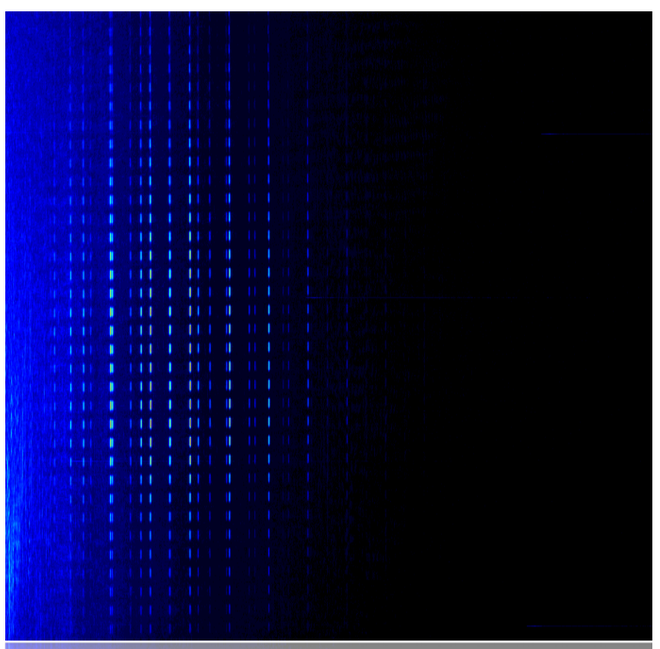
2 Conventional spectrum

CARS 2D spectrum
(with extra stray light)



3 Modulated spectrum

Spectral lines modulated
in space



Periodic Shadowing

2 Conventional spectrum

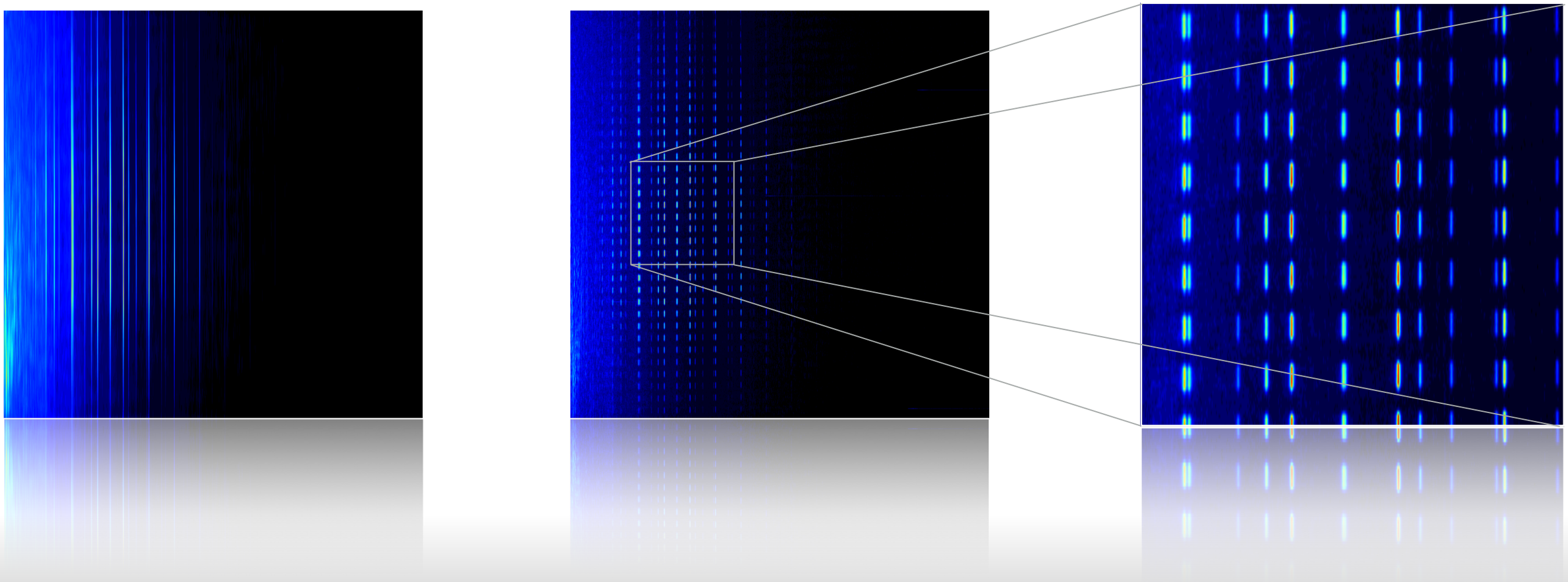
CARS 2D spectrum
(with extra stray light)

3 Modulated spectrum

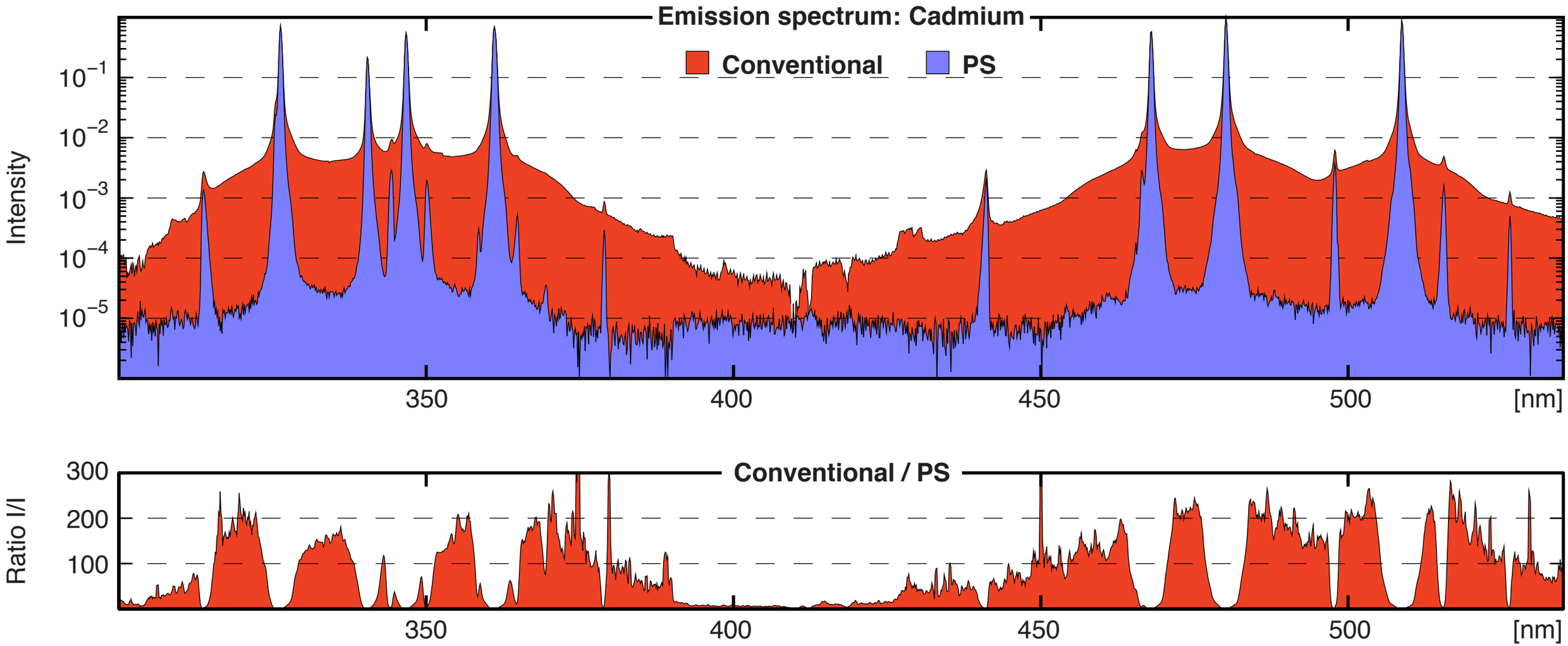
Spectral lines modulated
in space

4 Magnified view

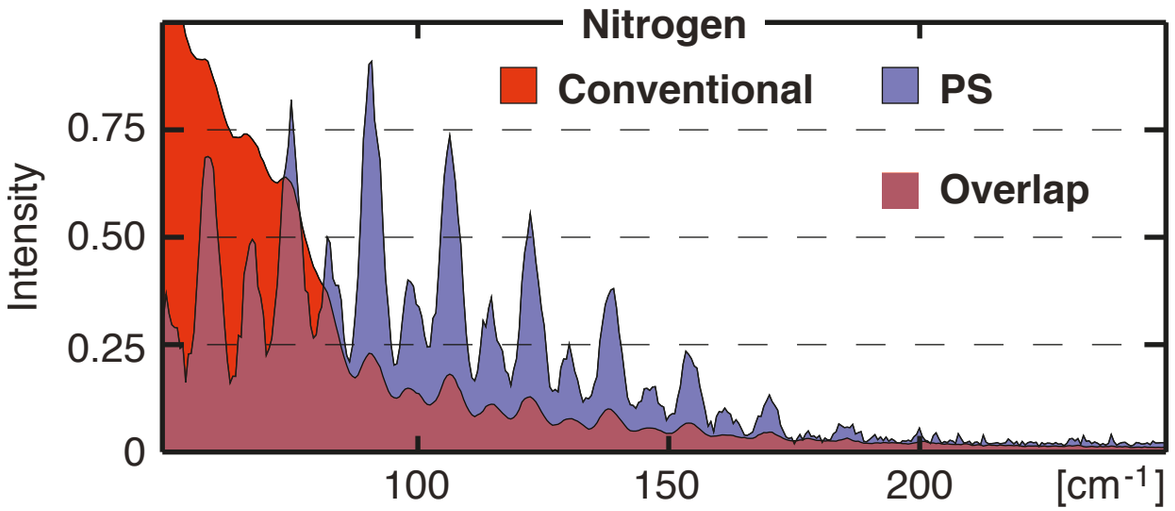
Superimposed square
pattern

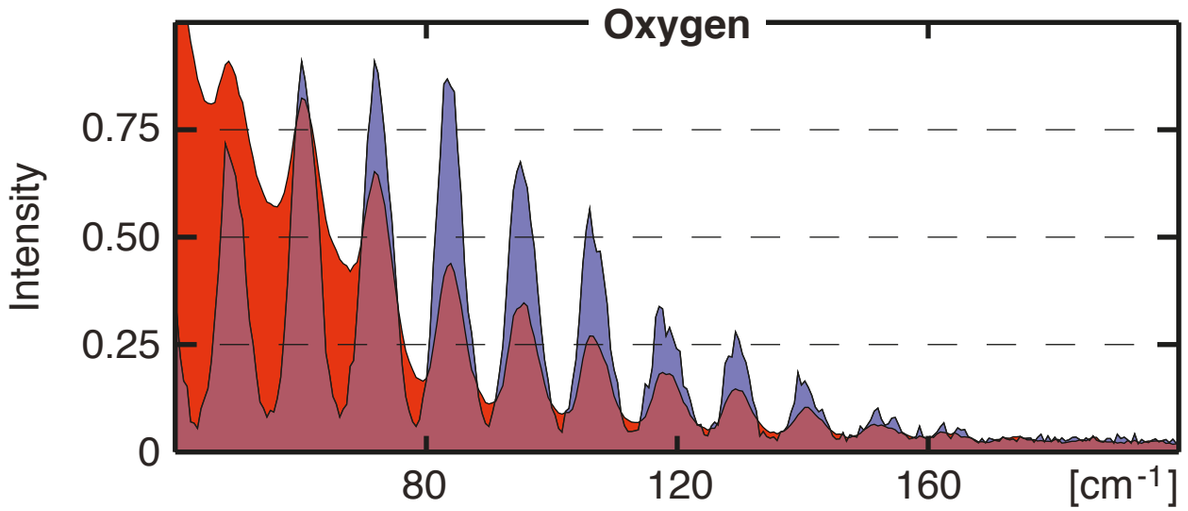


Emission spectrum

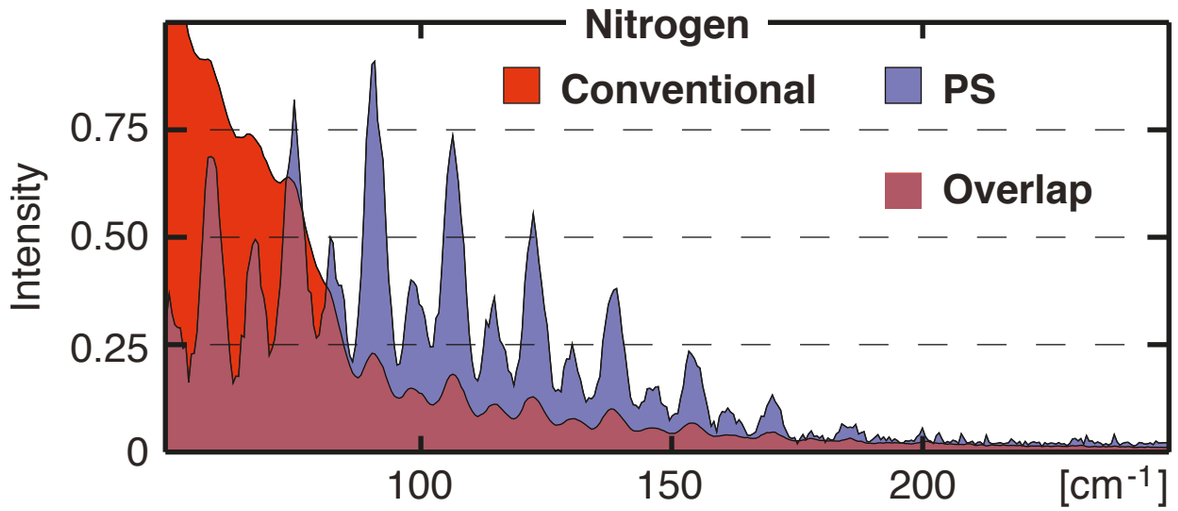


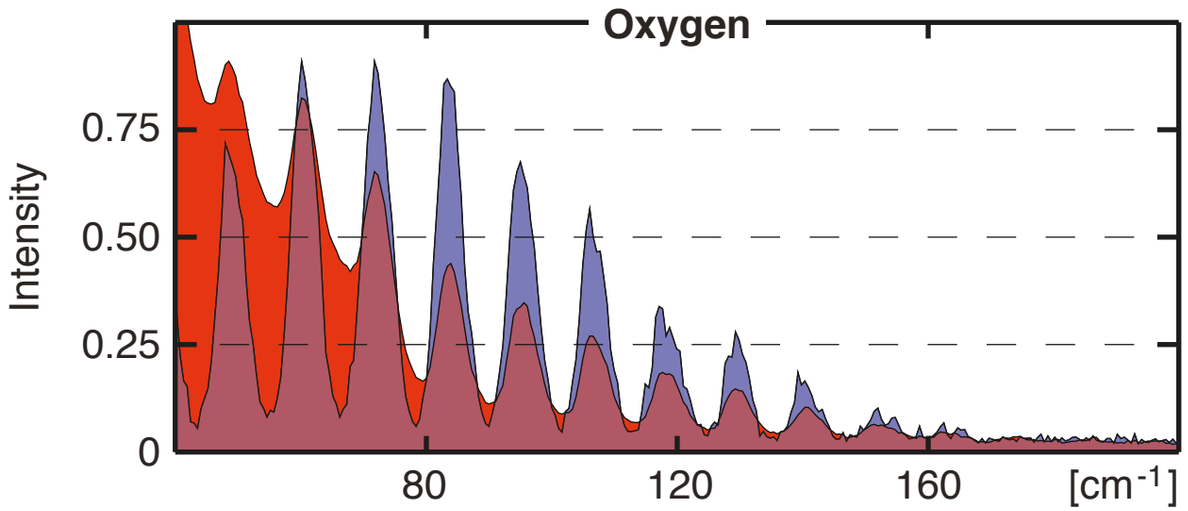
Laser-induced Raman spectroscopy

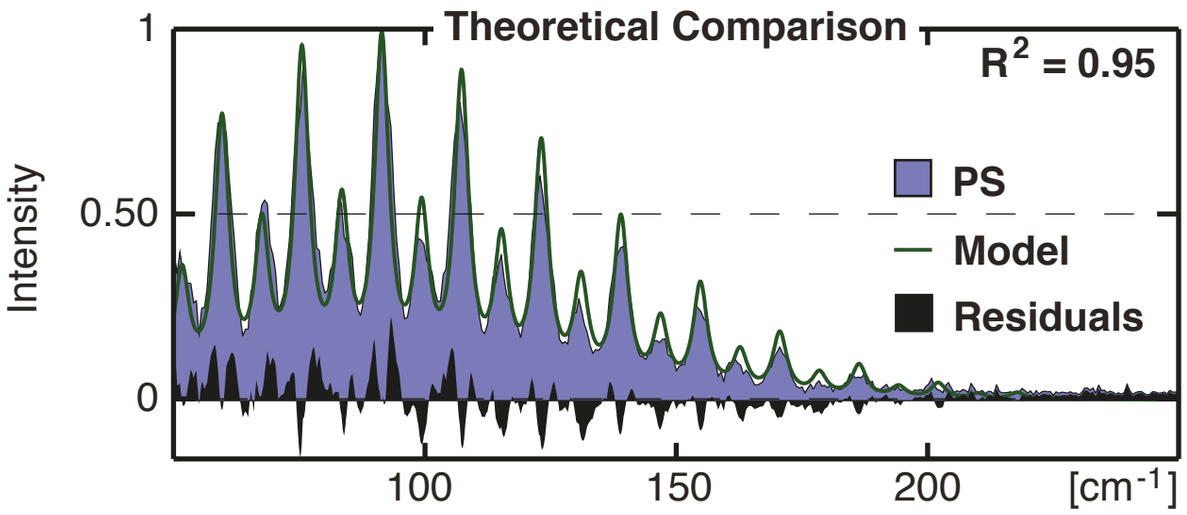


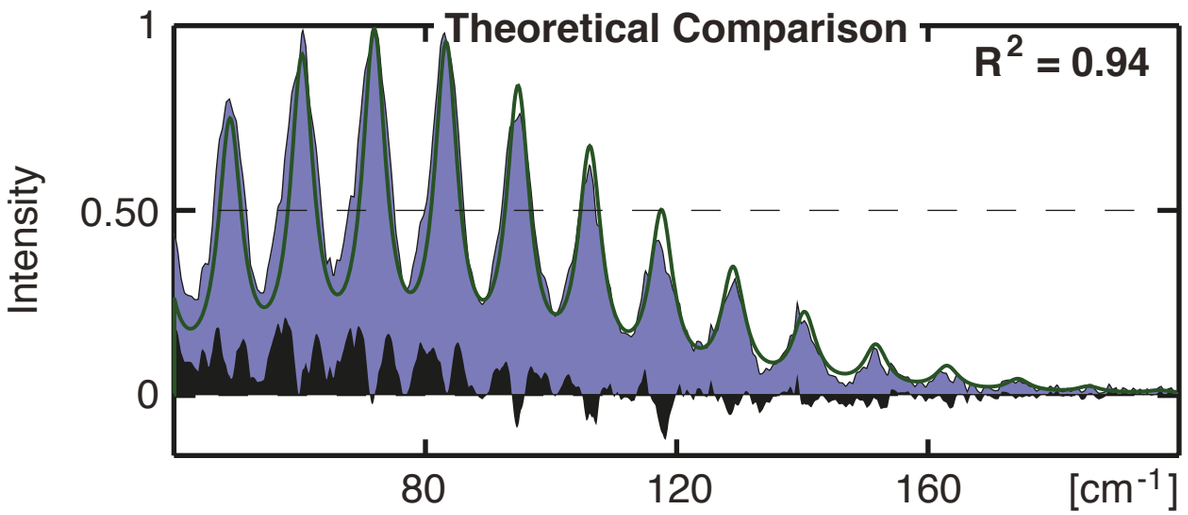


Laser-induced Raman spectroscopy









Summary

SLIPI
- Planar version of SI
- Three subimages
- Full resolution

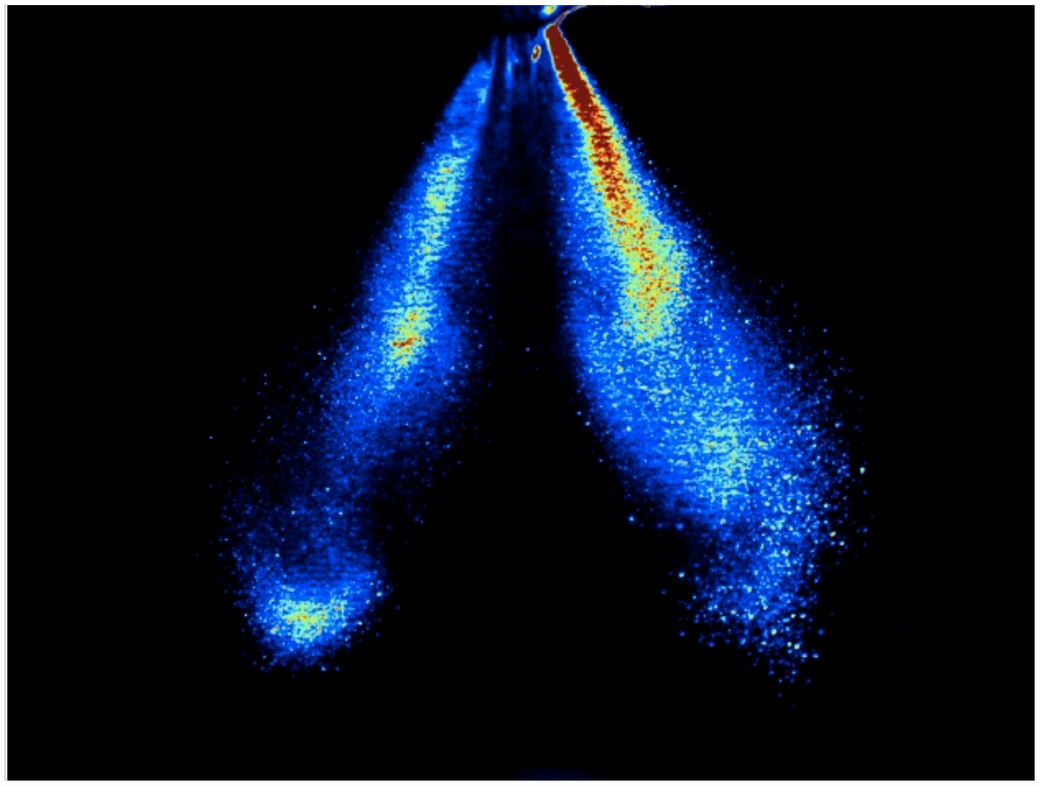
2P
- Two subimages
- Nearly full resolution
- Fast recording

Rayleigh
- SI removes stray light
- Maintain stable temperature readings

Pump/Probe
- Modulated pump beam
- Select only modulated part

PS
- SI + spectroscopy
- Address stray light problem

Thank you for your attention!



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