Generalised optical differentiation with patterned Liquid-Crystals

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WaveFront Sensing in the VLT/ELT era II
Tuesday 3rd October 2017

Generali… diffe… …terned … crystals

GODWFS

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Generali… diffe… …terned … Crystals

GODWFS

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Generali… diffe… …ctrned … crystals

g-ODWFS

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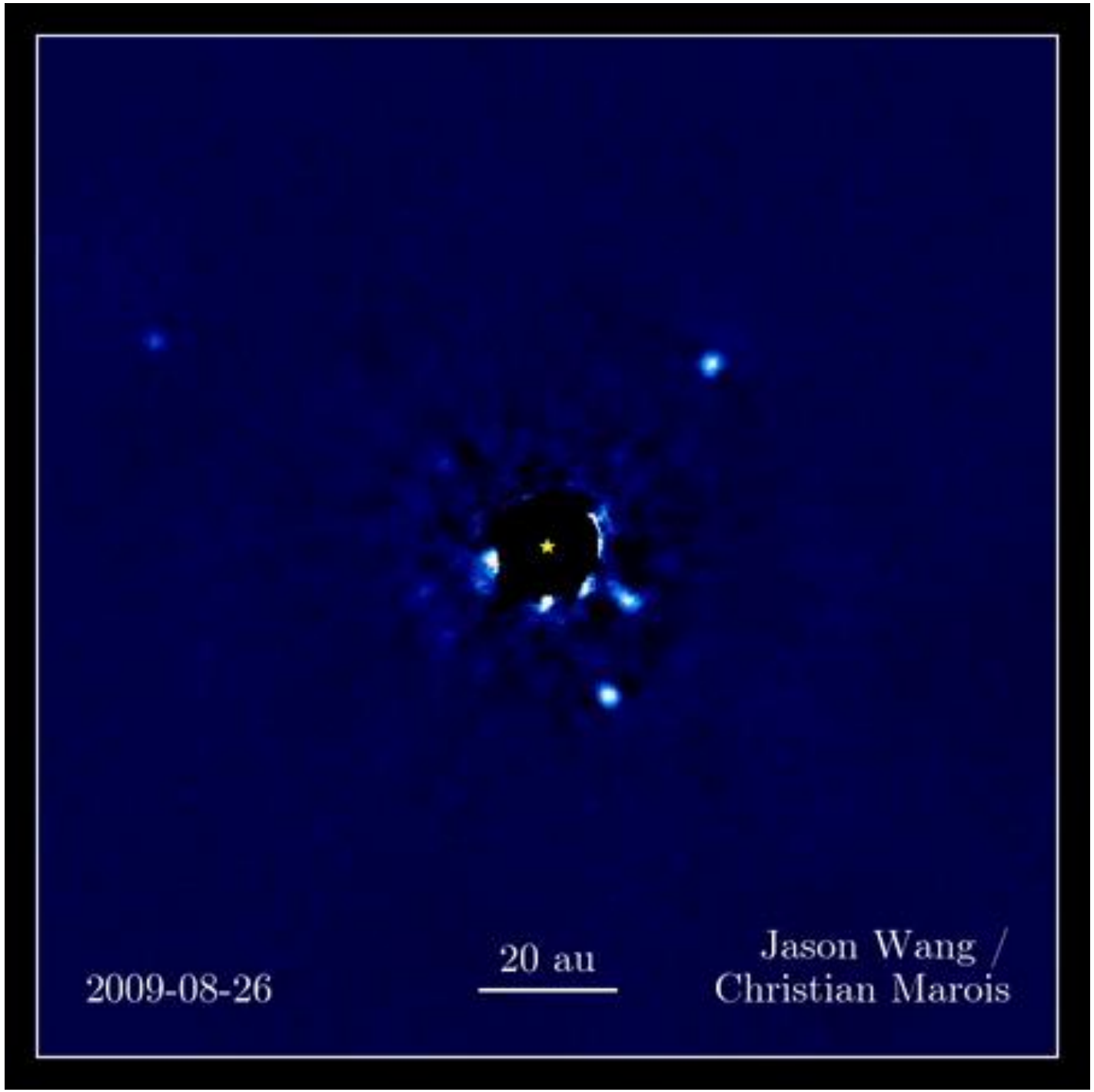
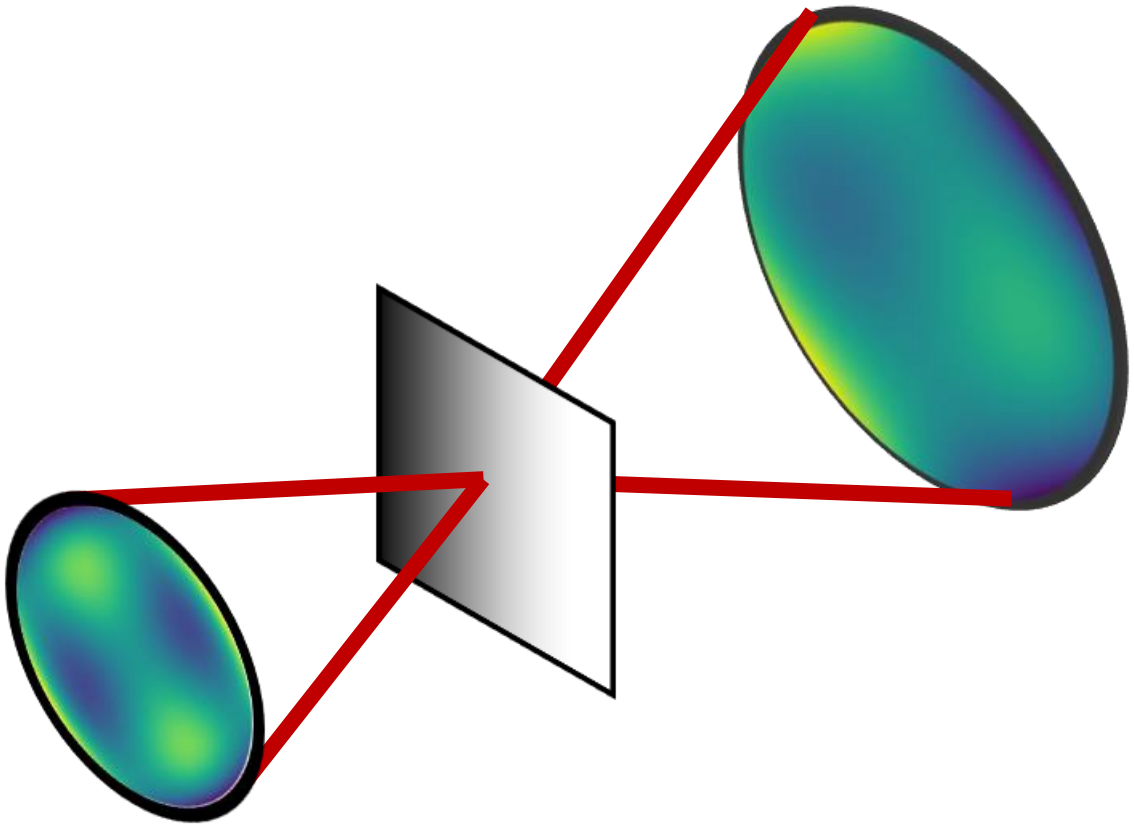

2009-08-26
20 au
Jason Wang /
Christian Marois

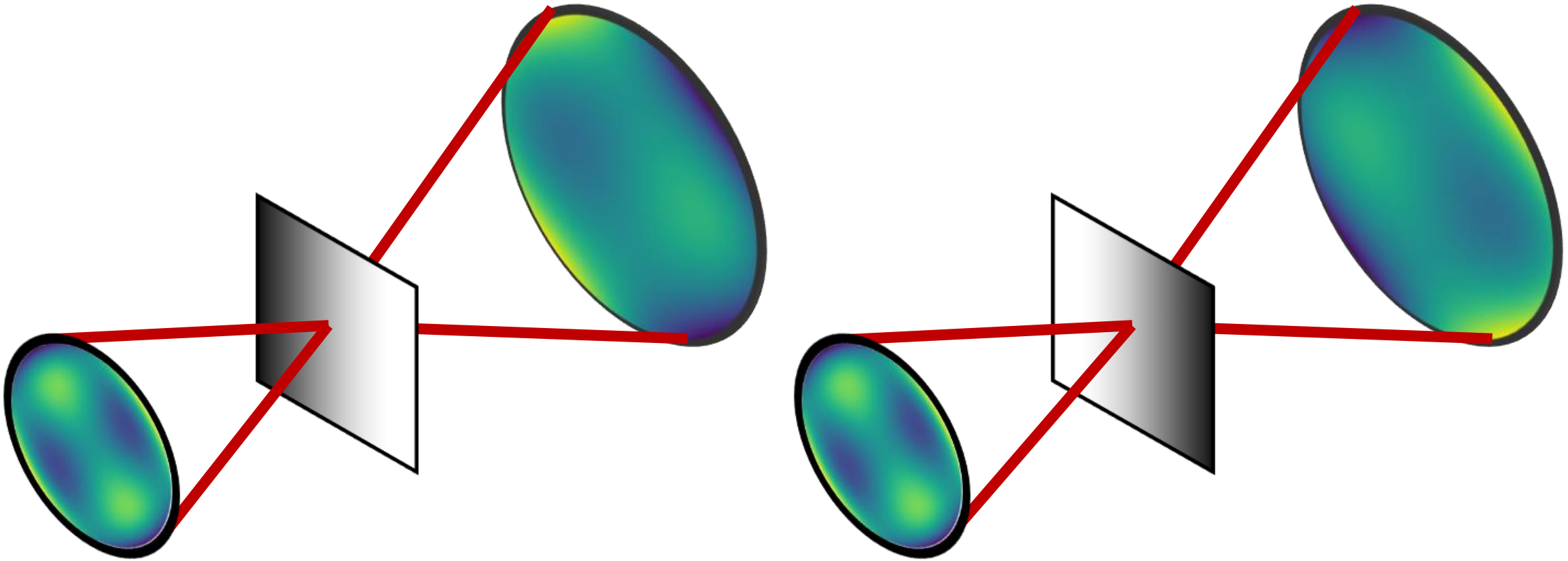
Introduction

- We want high sensitivity for accurate wavefront correction
- We want large dynamic range for the large range of seeing conditions.
- Wavefront sensors usually have a linear trade-off between dynamic range and sensitivity.
- Choose which one you want, or not. The g-ODWFS can help you!

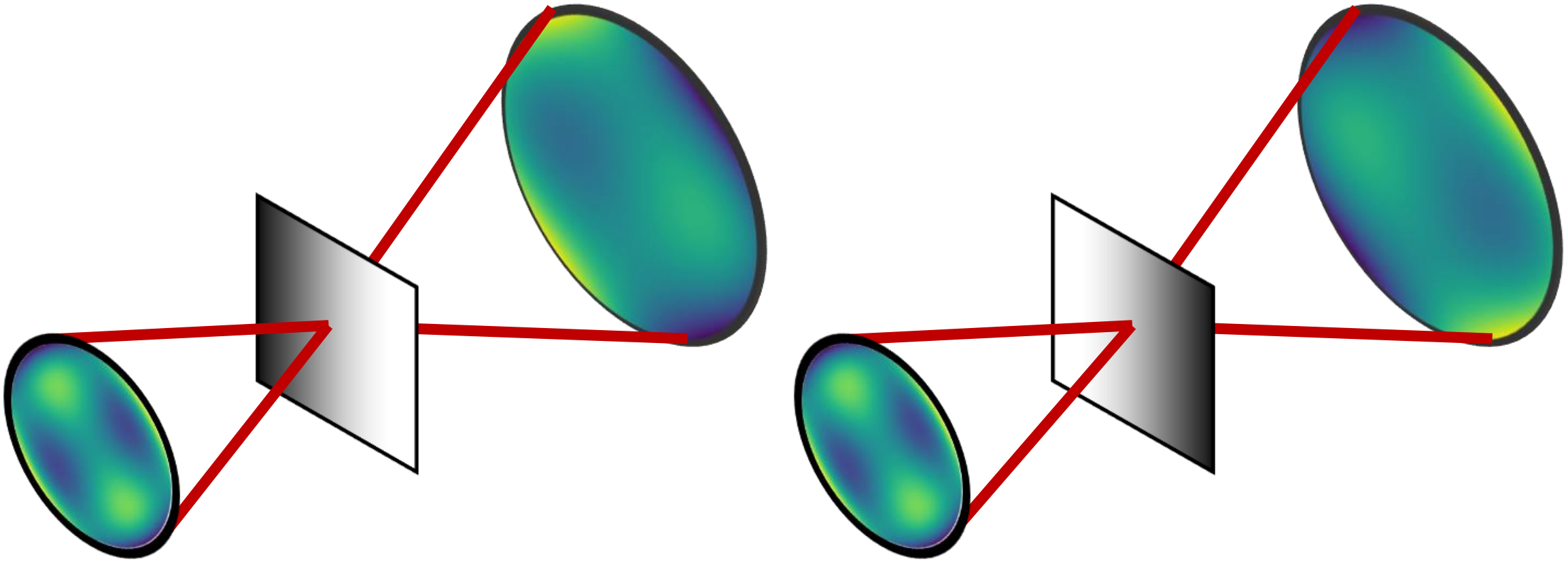
Optical differentiation wavefront sensor



Optical differentiation wavefront sensor

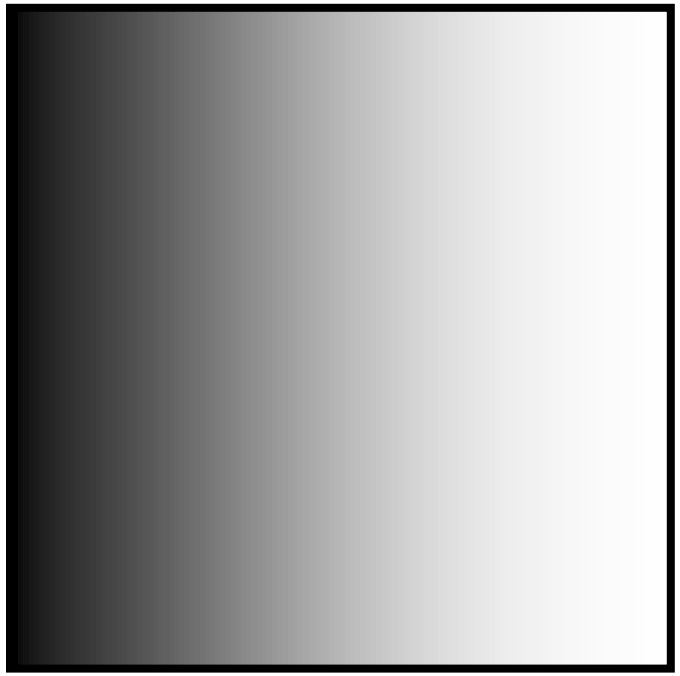


Optical differentiation wavefront sensor

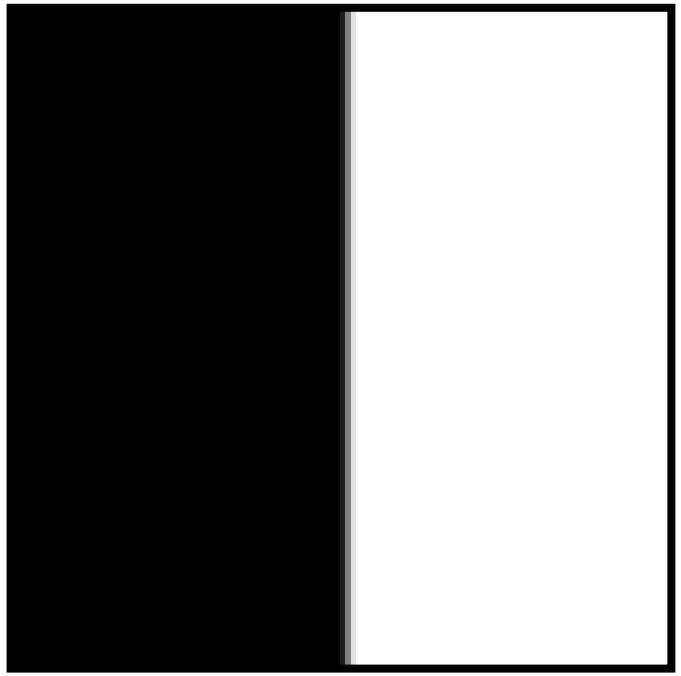


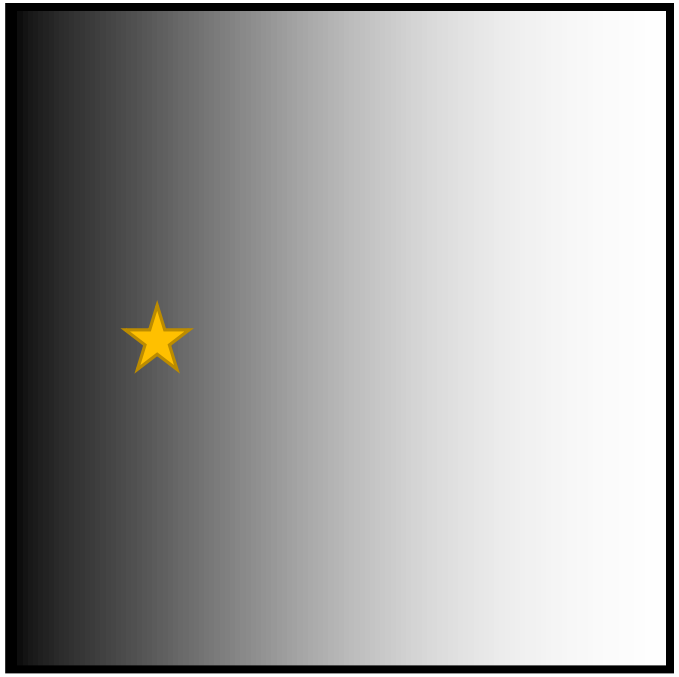
$$\frac{I_1 - I_2}{I_1 + I_2} \propto \frac{dW}{dx}$$

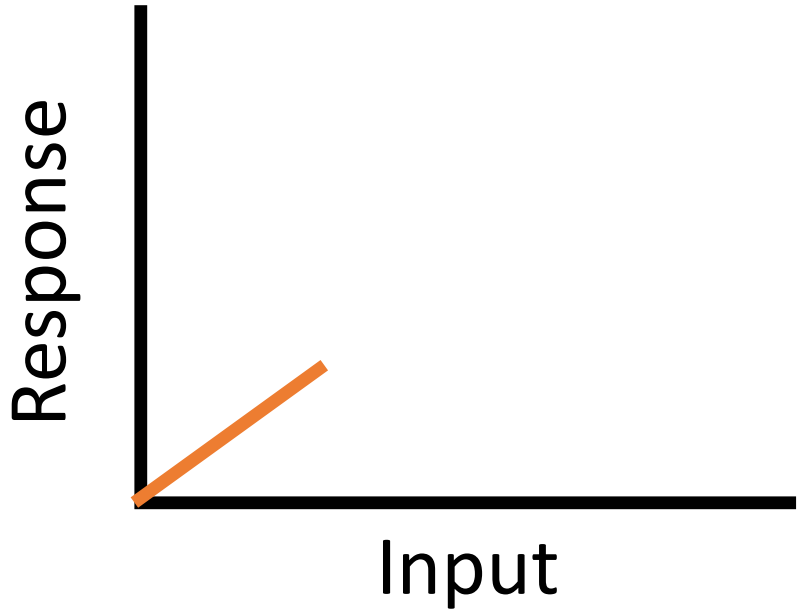
Optical Differentiation

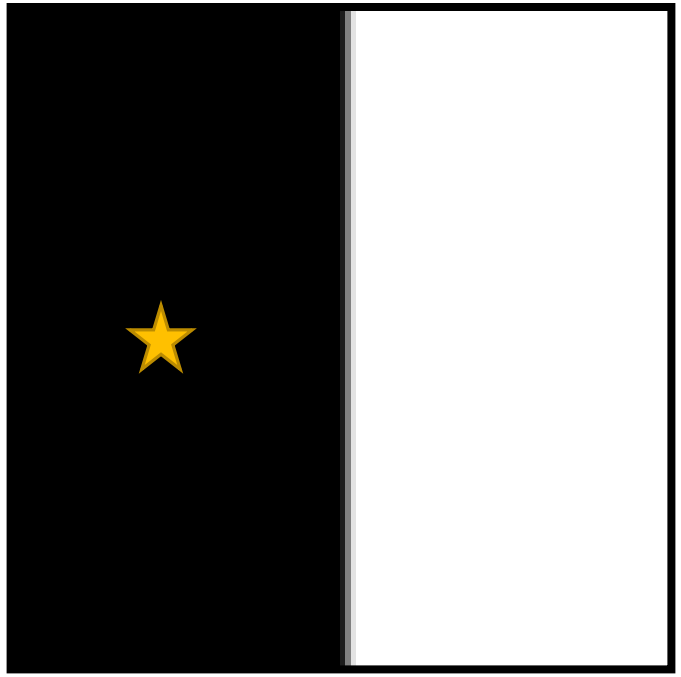


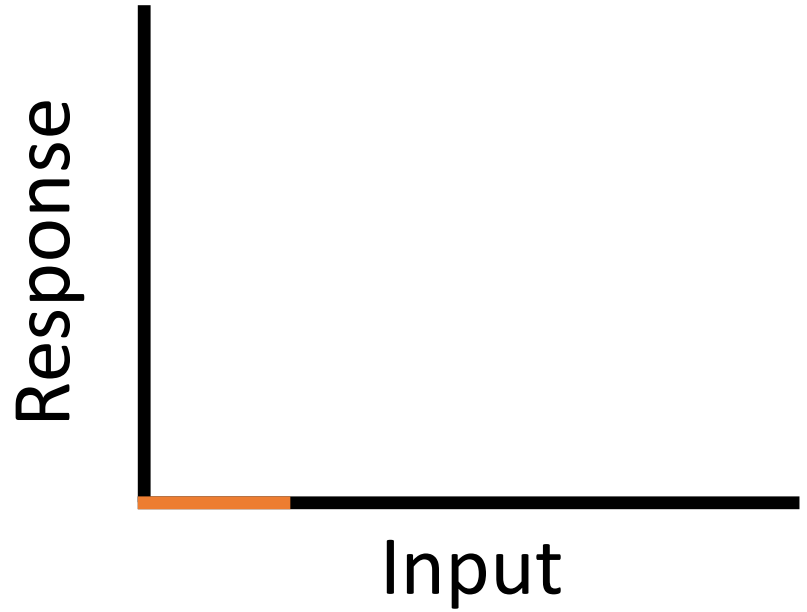
Foucault knife-edge test

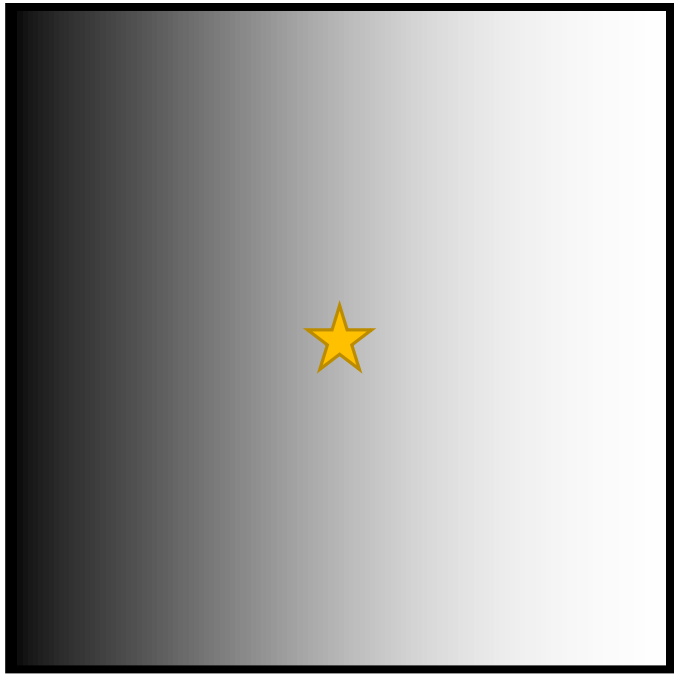


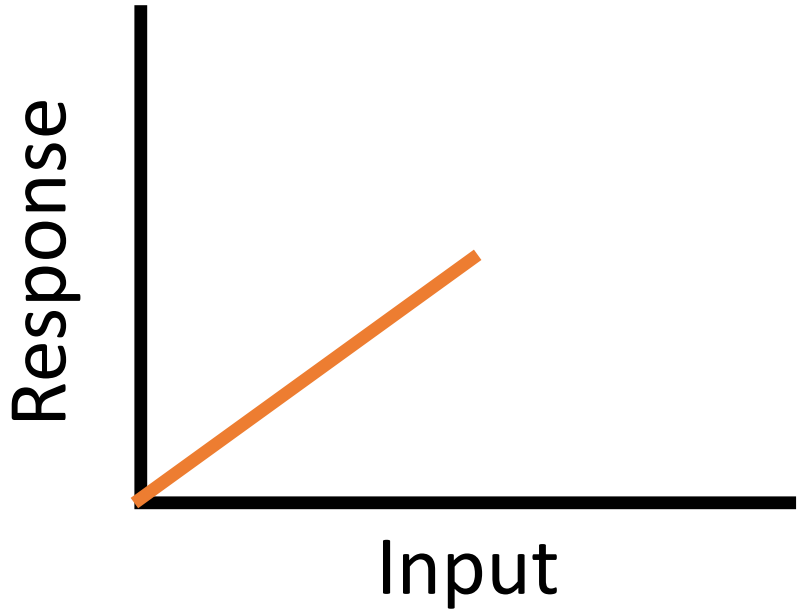


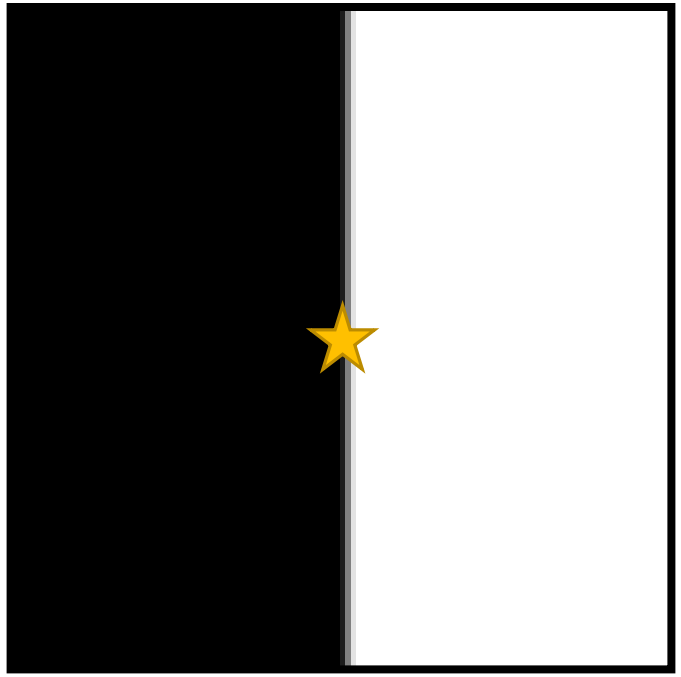

Response
Input

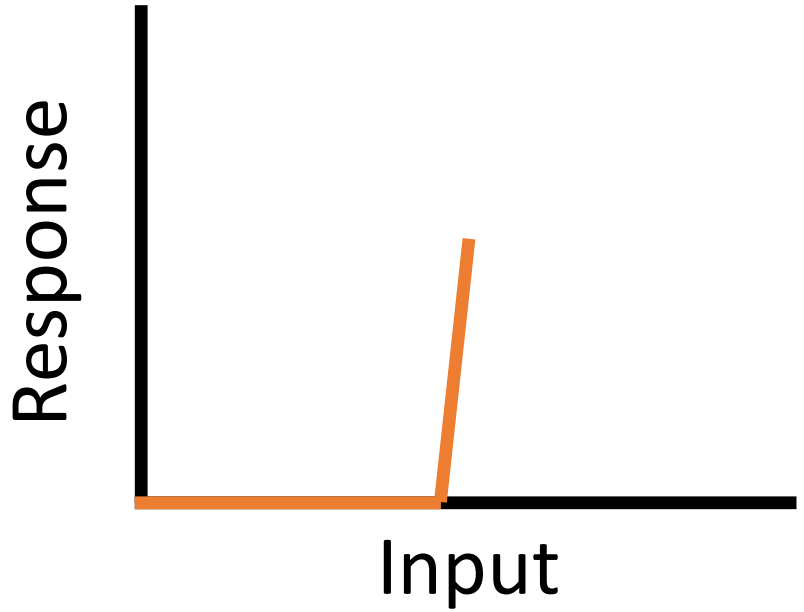


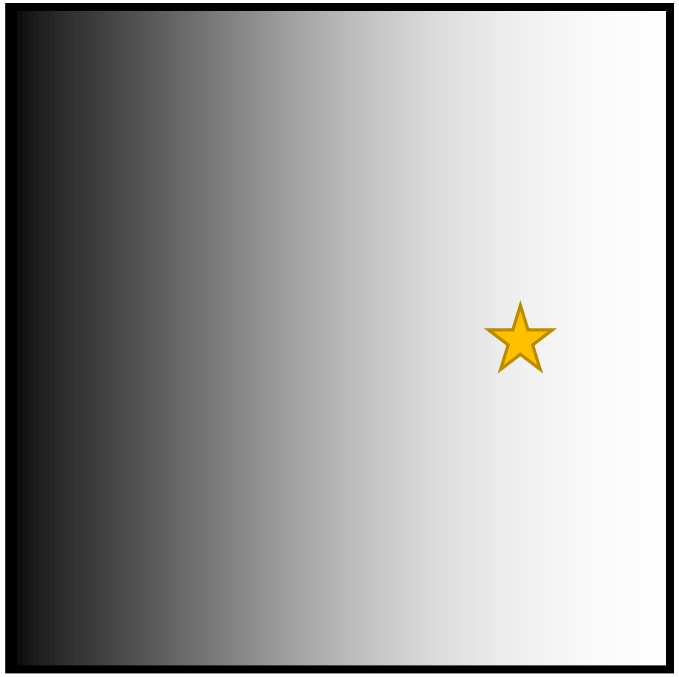

Response
Input

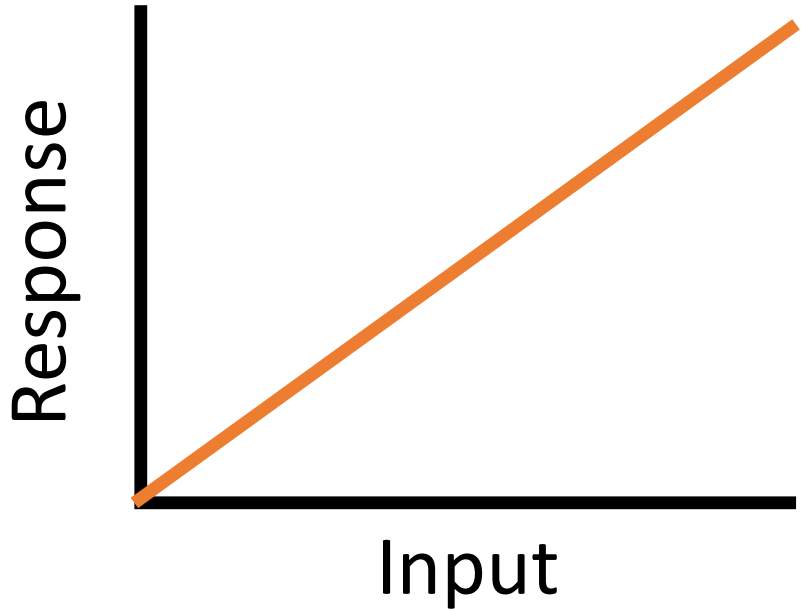


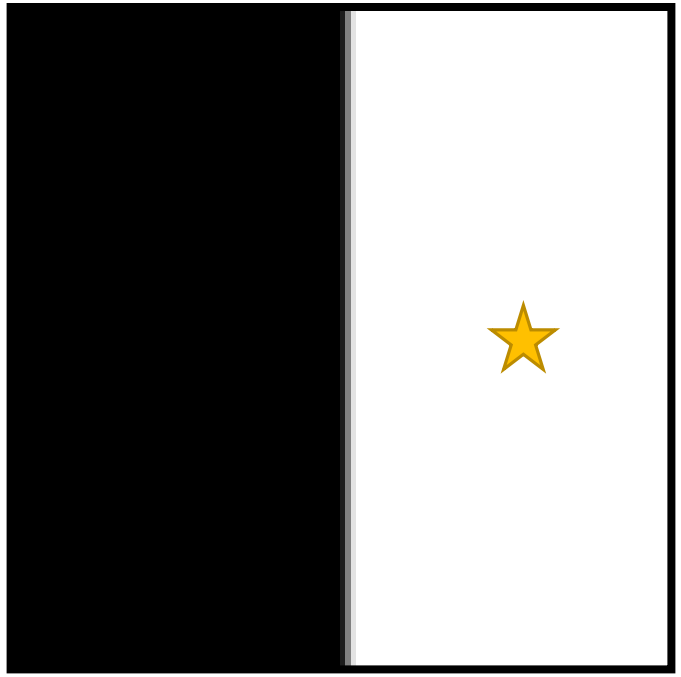

Response
Input

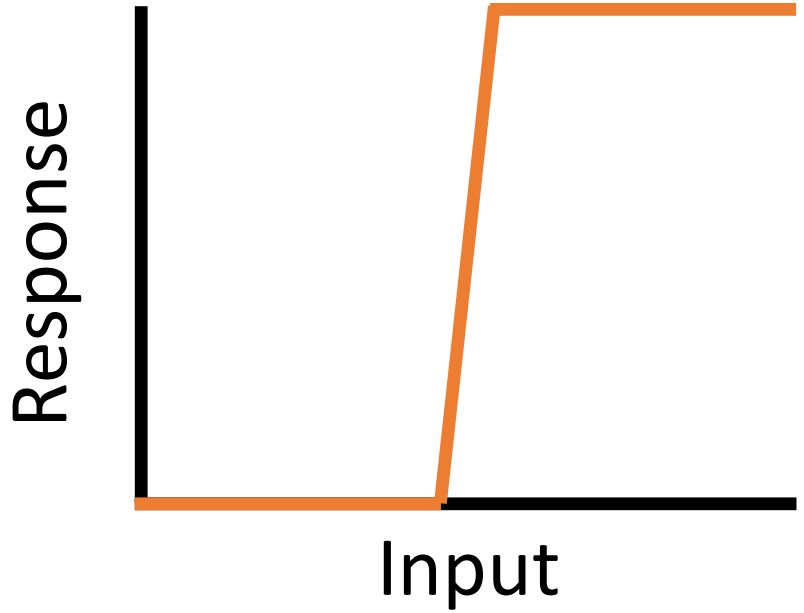



Response
Input

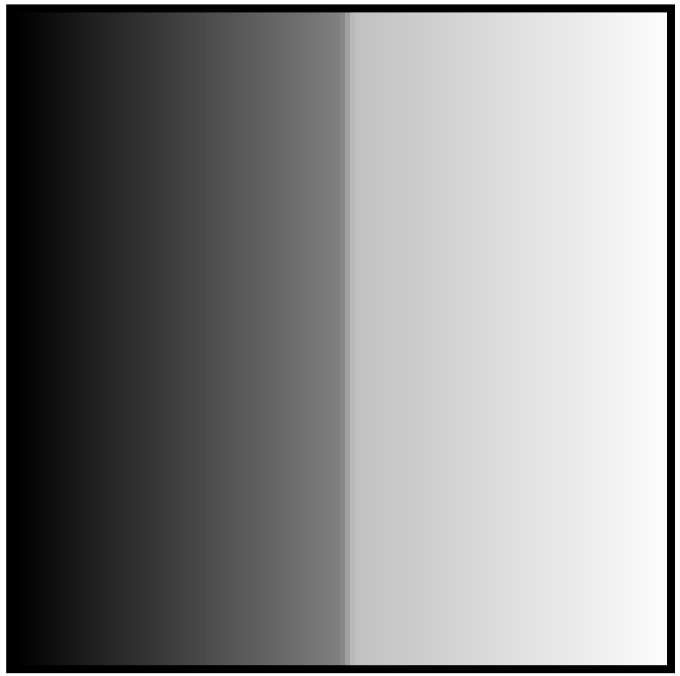



Response
Input

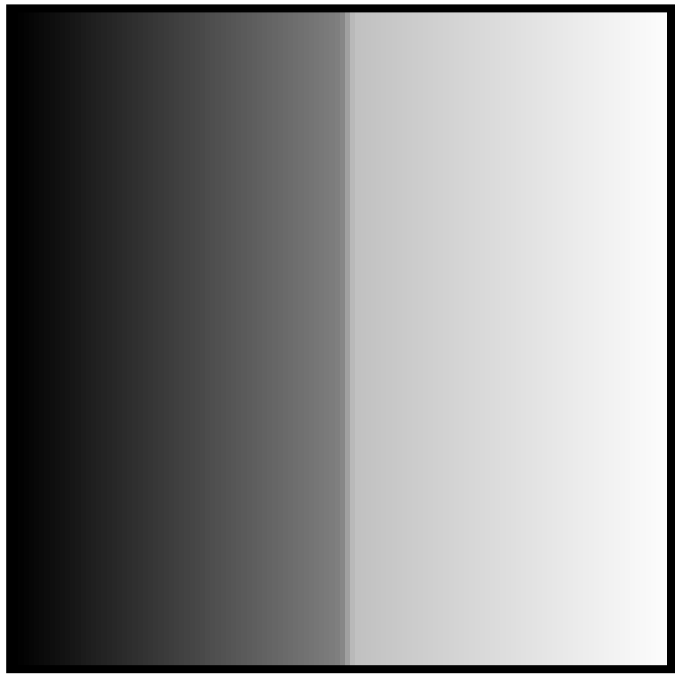


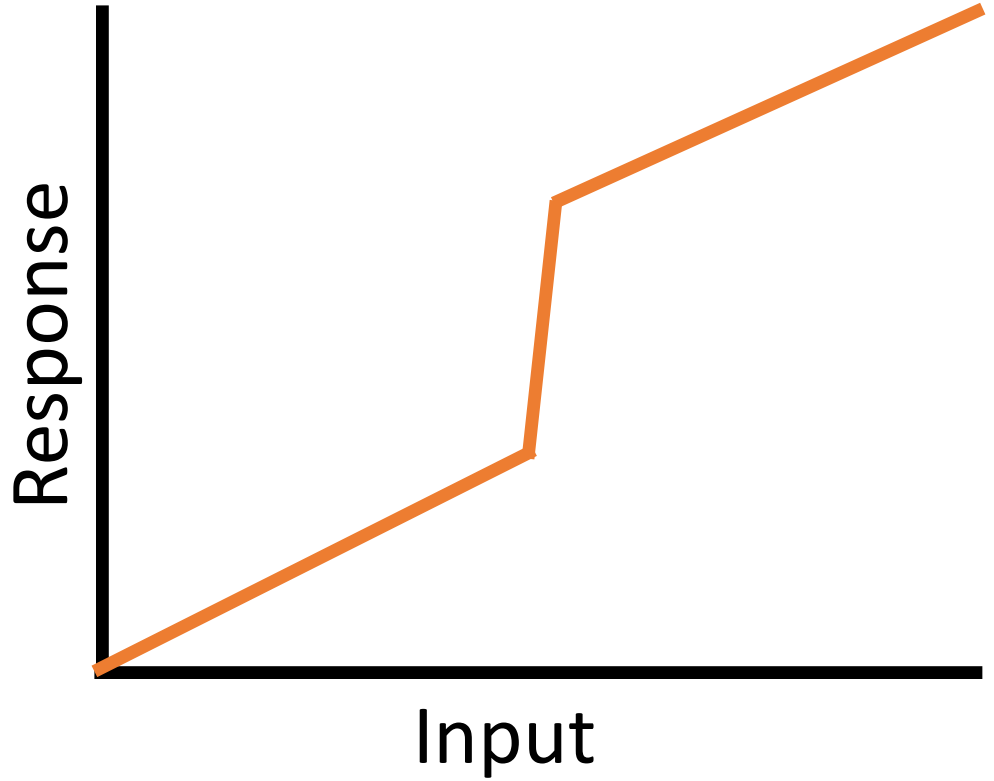

Response
Input

Hybrid amplitude mask



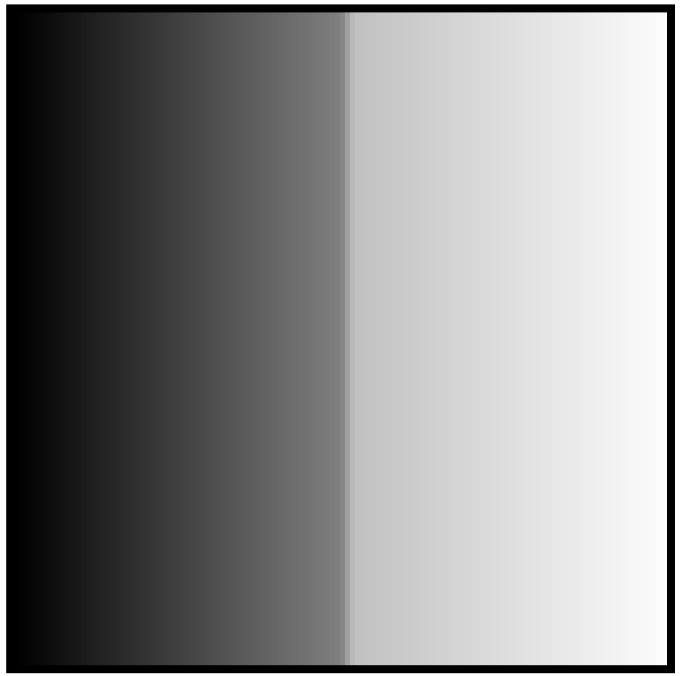
Hybrid amplitude mask

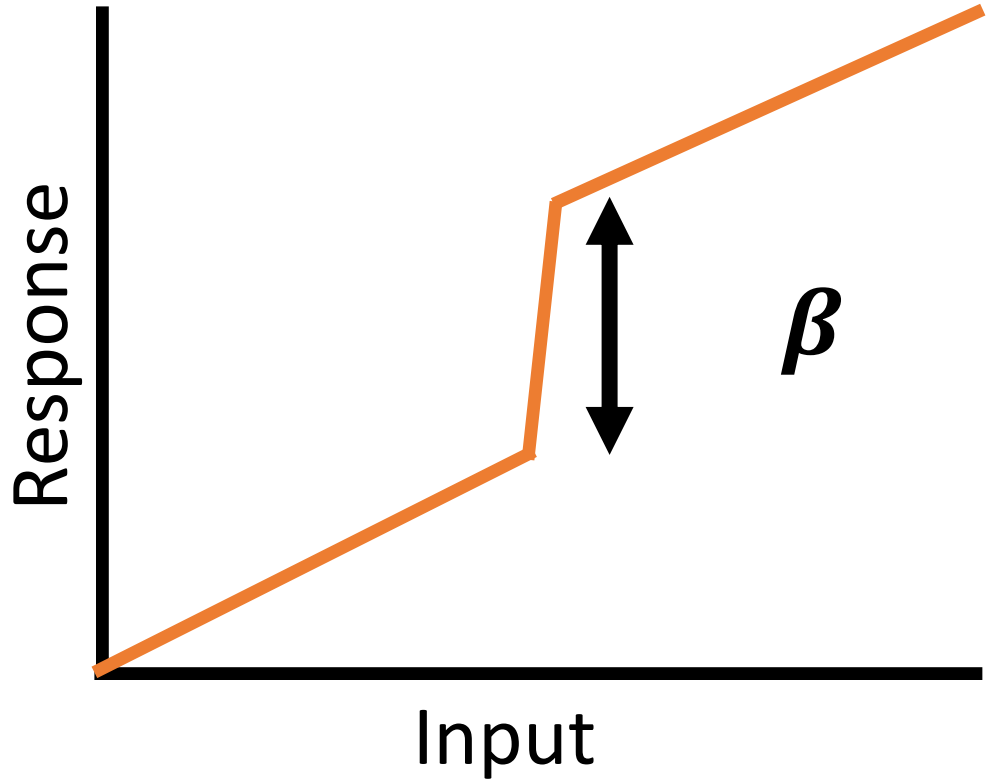




Generalised optical differentiation wavefront sensor. Haffert 2016

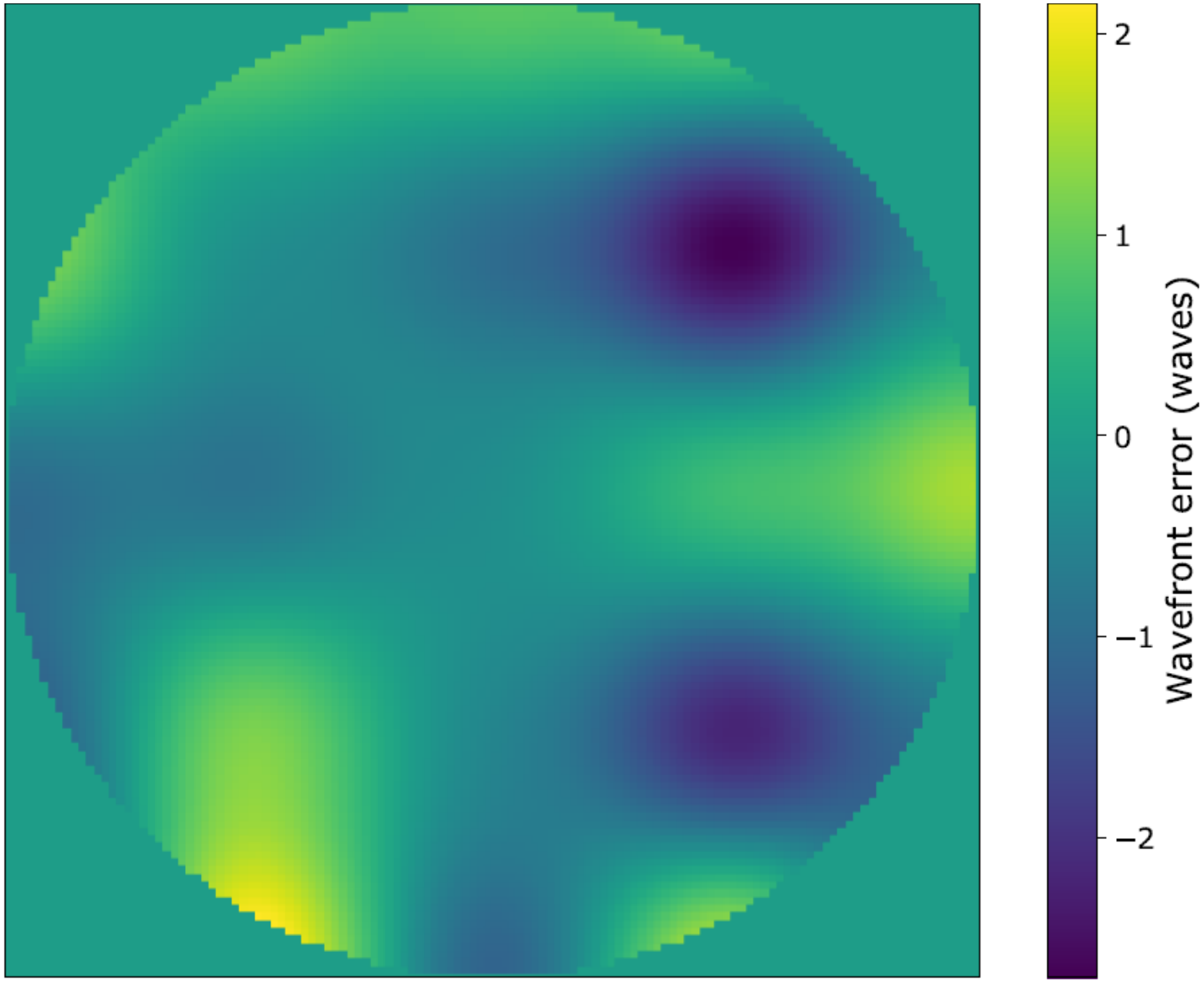
Hybrid amplitude mask

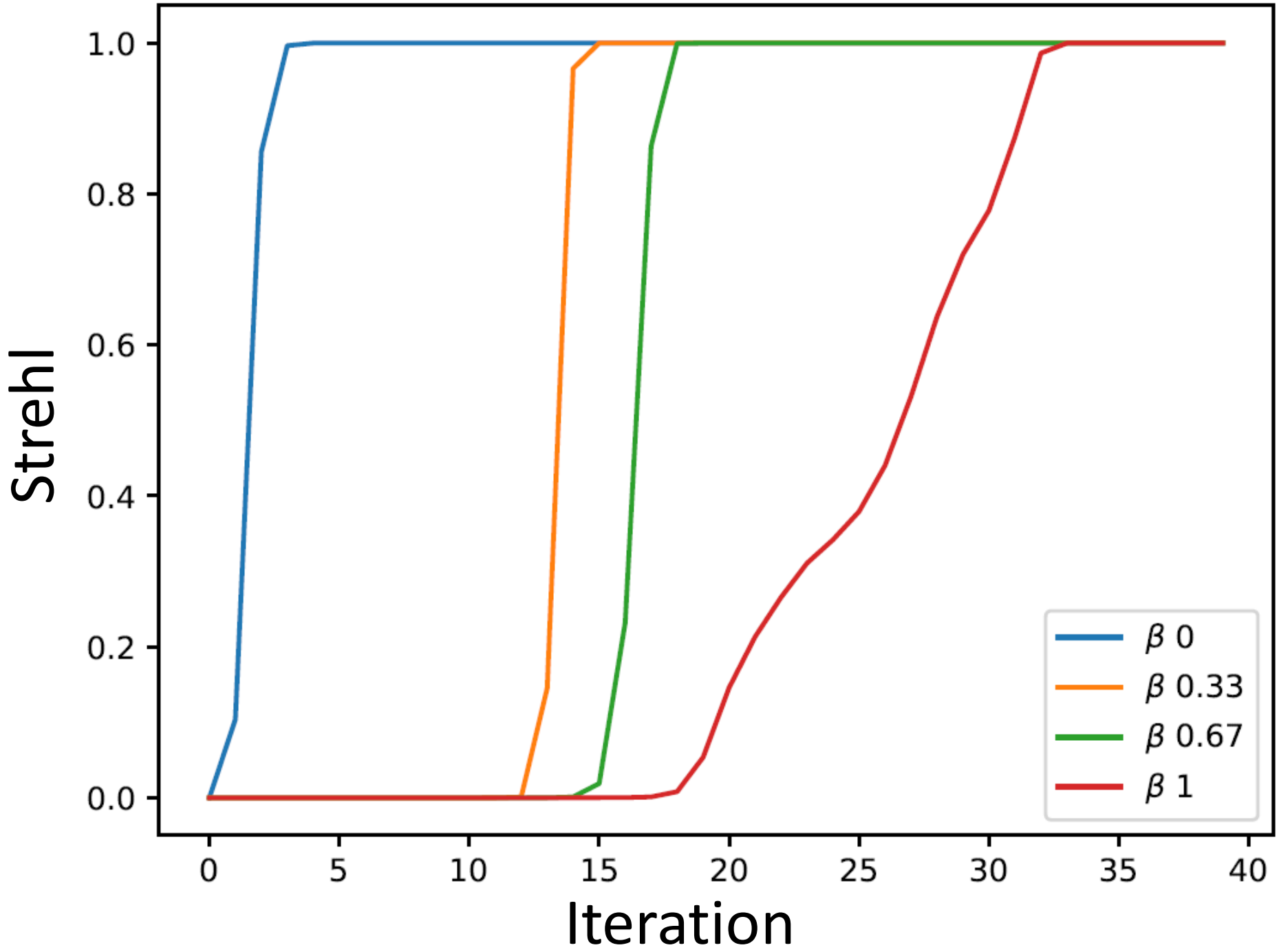


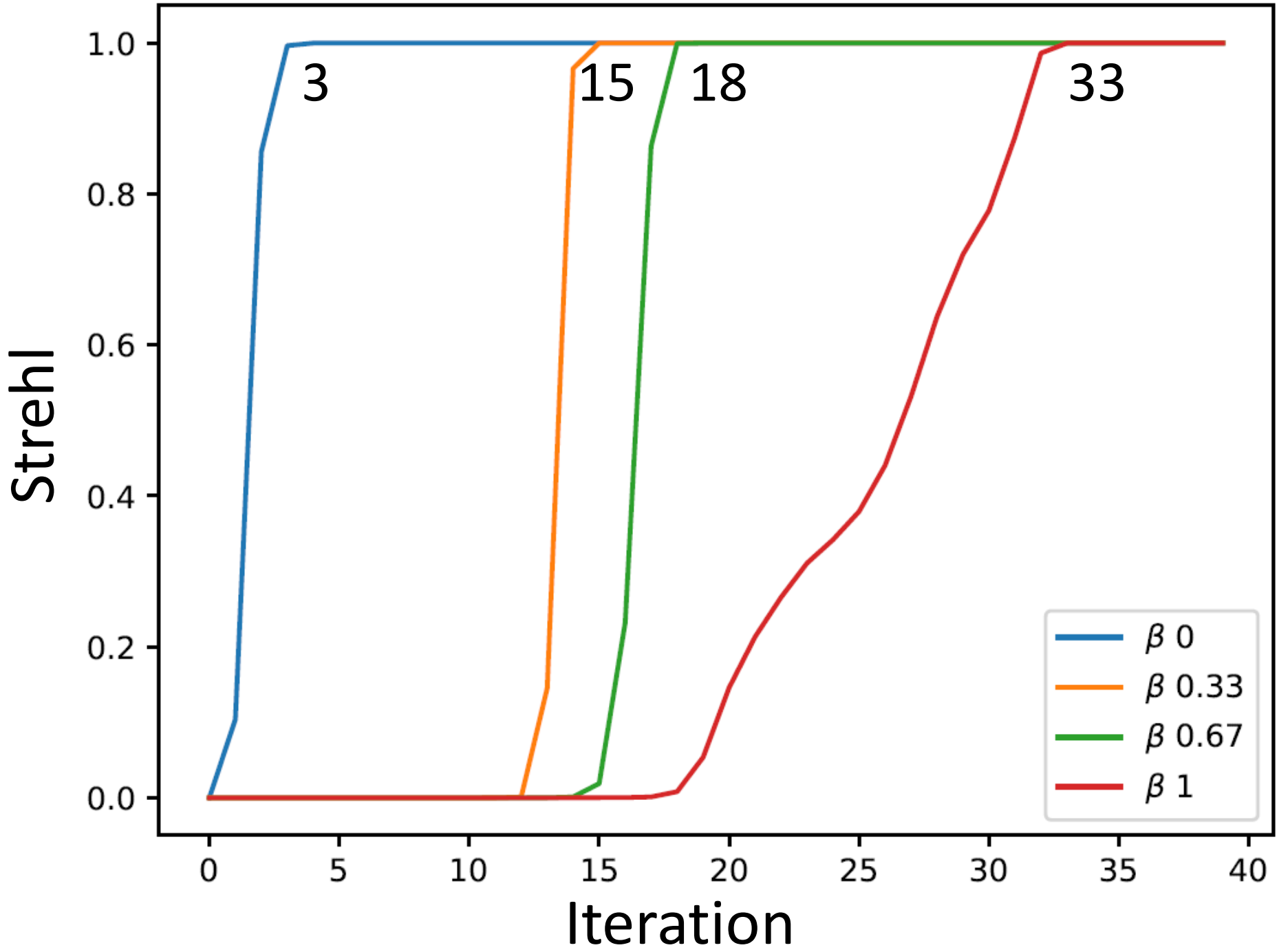


Generalised optical differentiation wavefront sensor. Haffert 2016

RMS wavefront error 0.81 waves



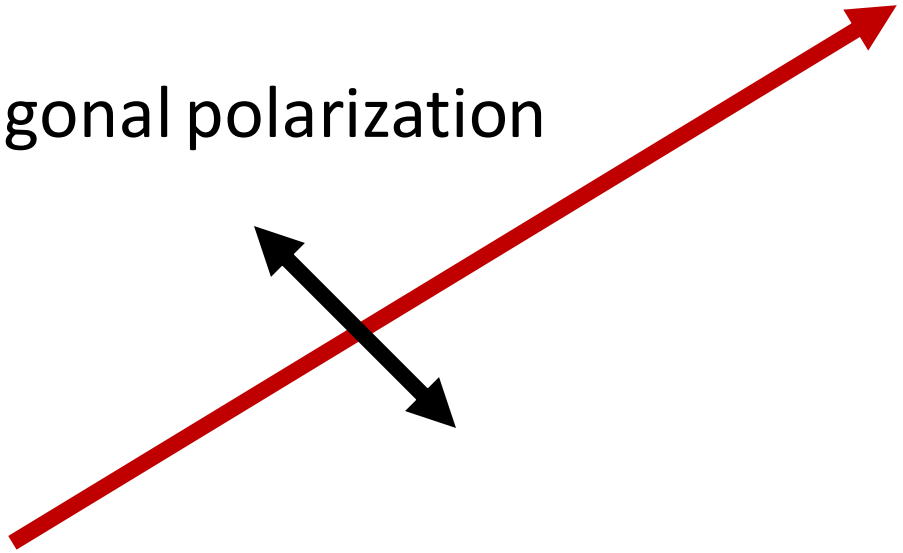

Strehl
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
Iteration
β 0
β 0.33
β 0.67
β 1


Strehl
Iteration
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
3
15
18
33
β 0
β 0.33
β 0.67
β 1

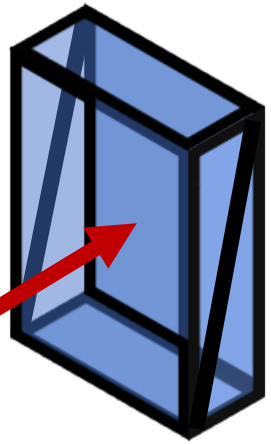
Amplitude filters

- Amplitude filters are easy to make.
- Not photon conserving.
- You only measure 1 filter so it’s sensitive to exact shape of amplitude profile.

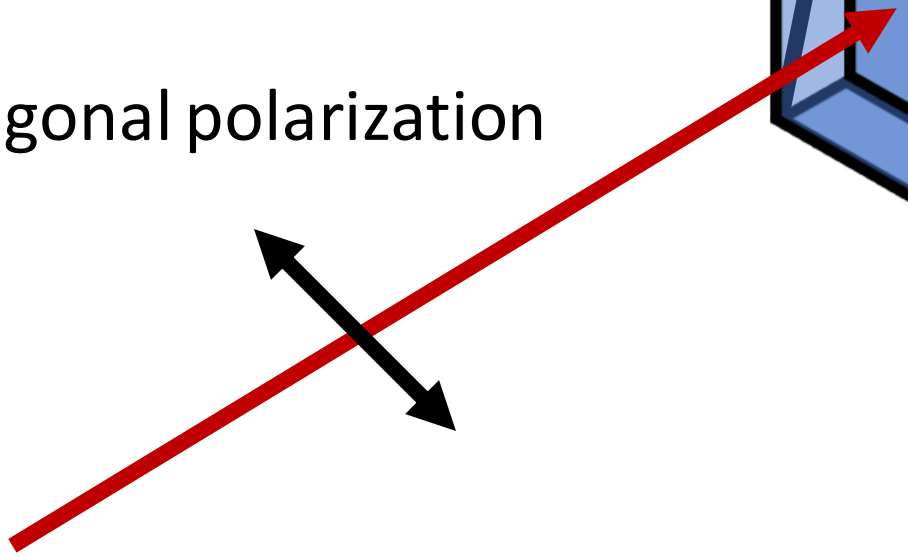
Diagonal polarization

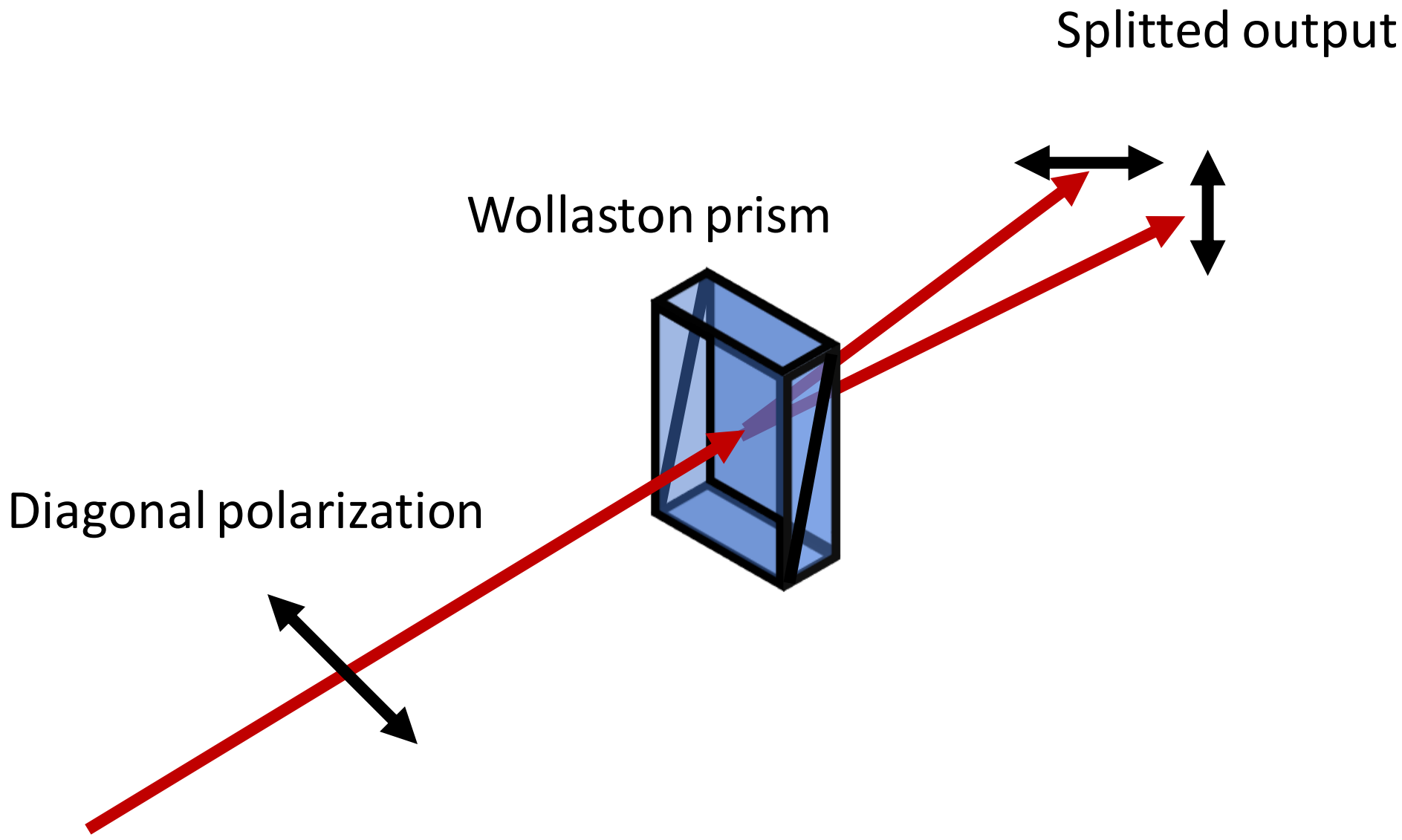


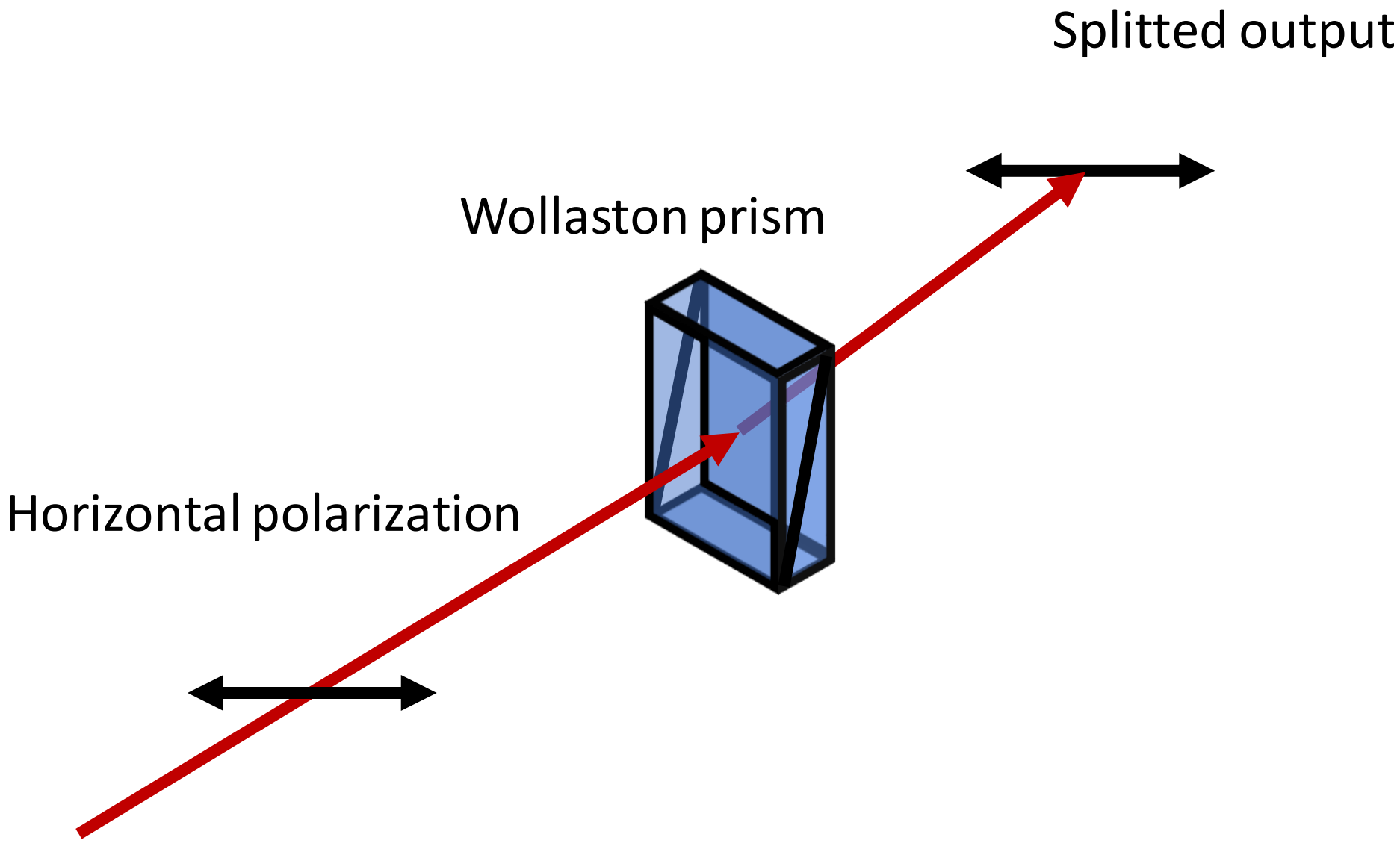
Wollaston prism

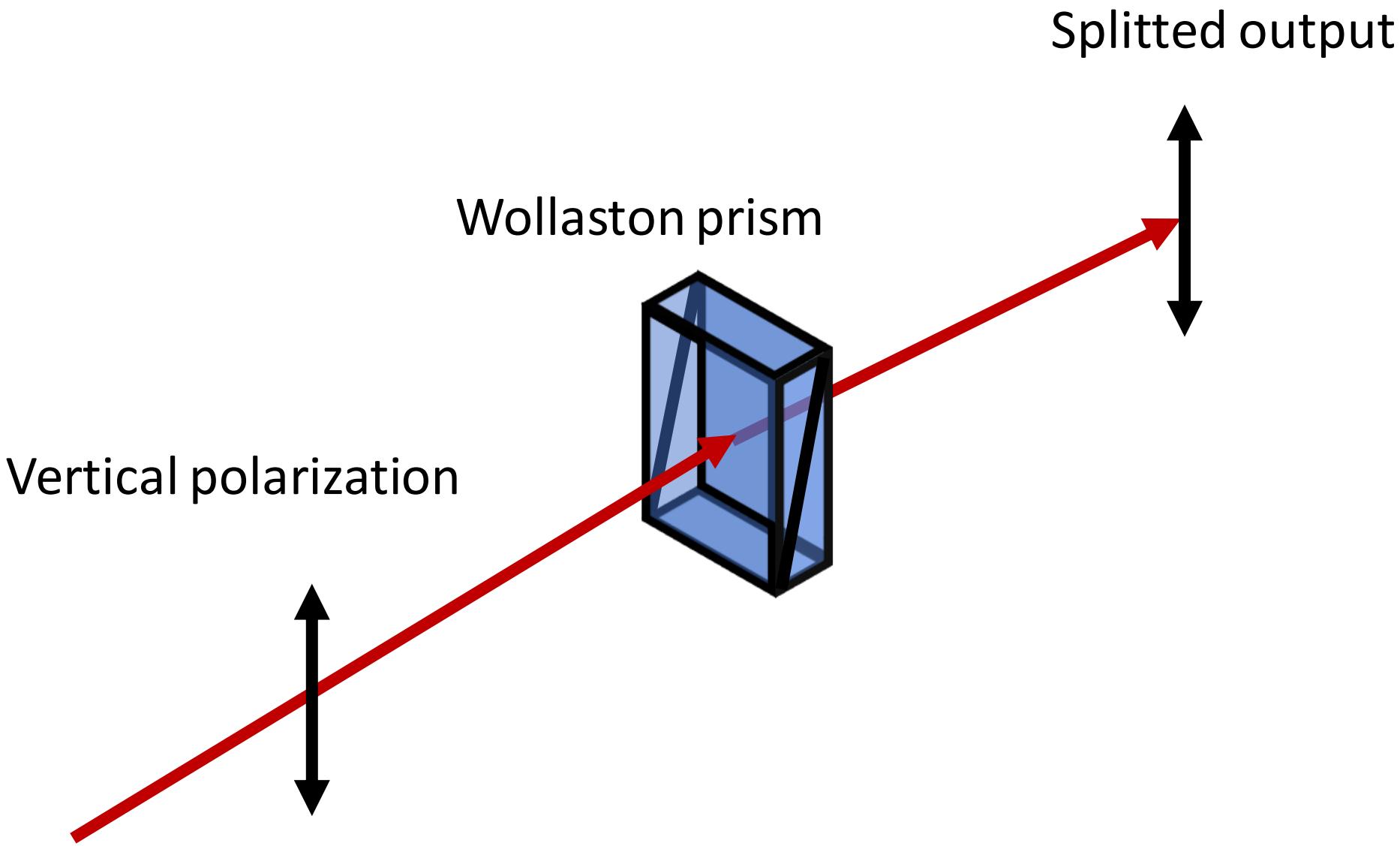


Diagonal polarization

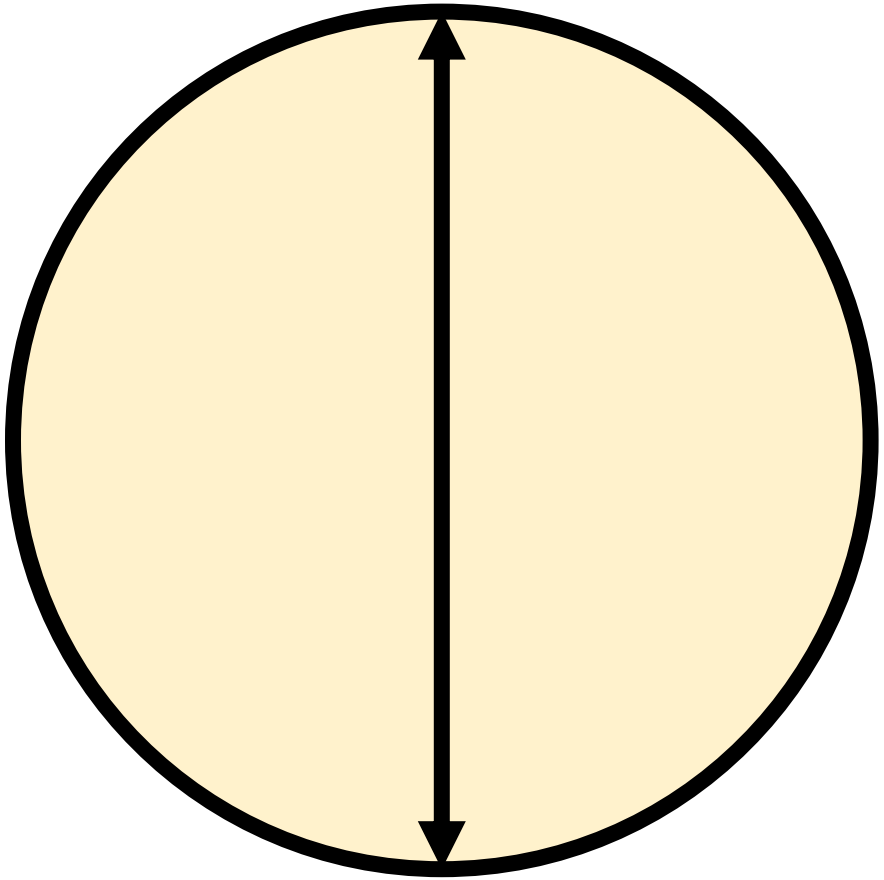



Splitted output
Wollaston prism
Diagonal polarization

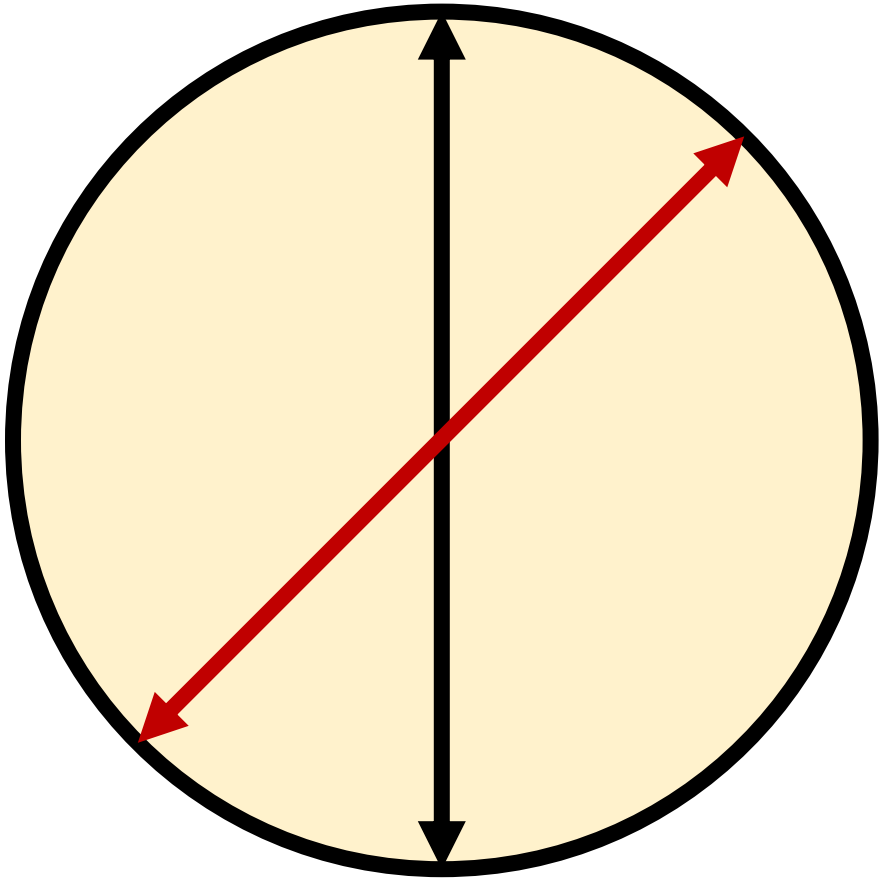

Splitted output
Wollaston prism
Horizontal polarization


Splitted output
Wollaston prism
Vertical polarization

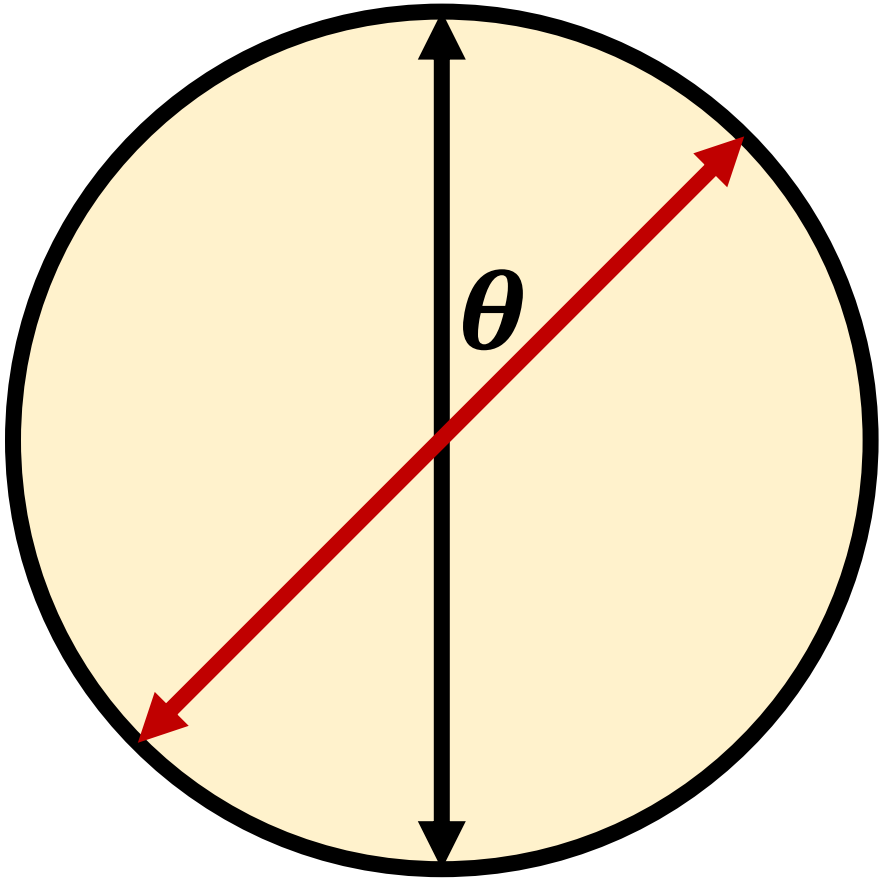
Half wave plate



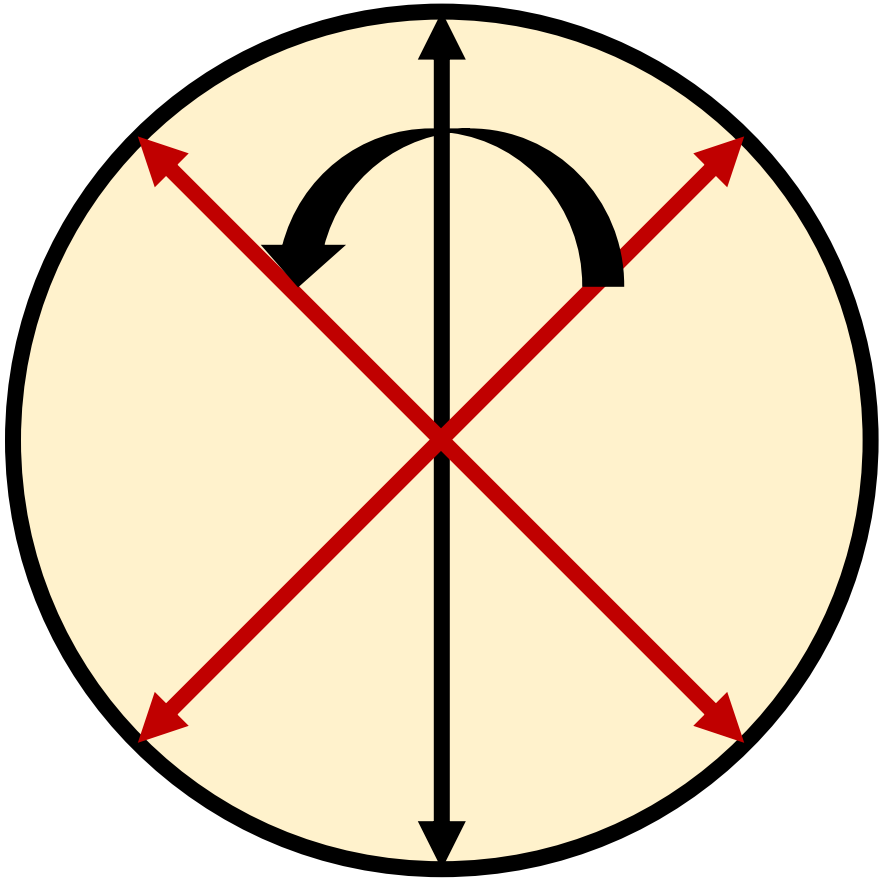
Input polarization

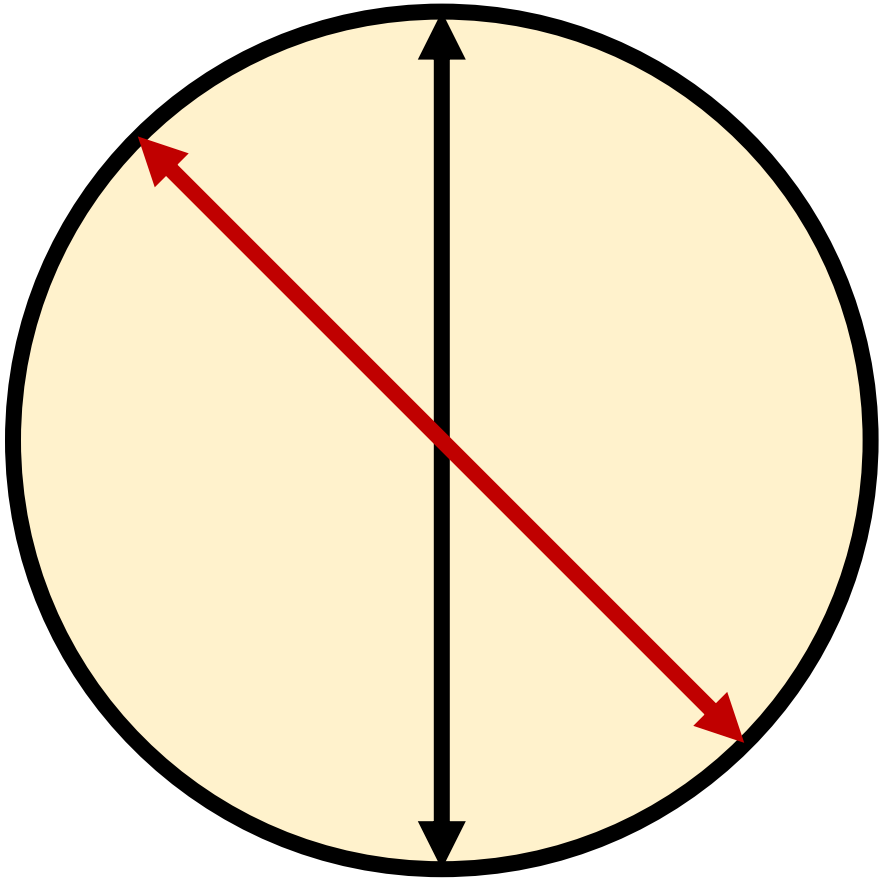


Angle with fast axis

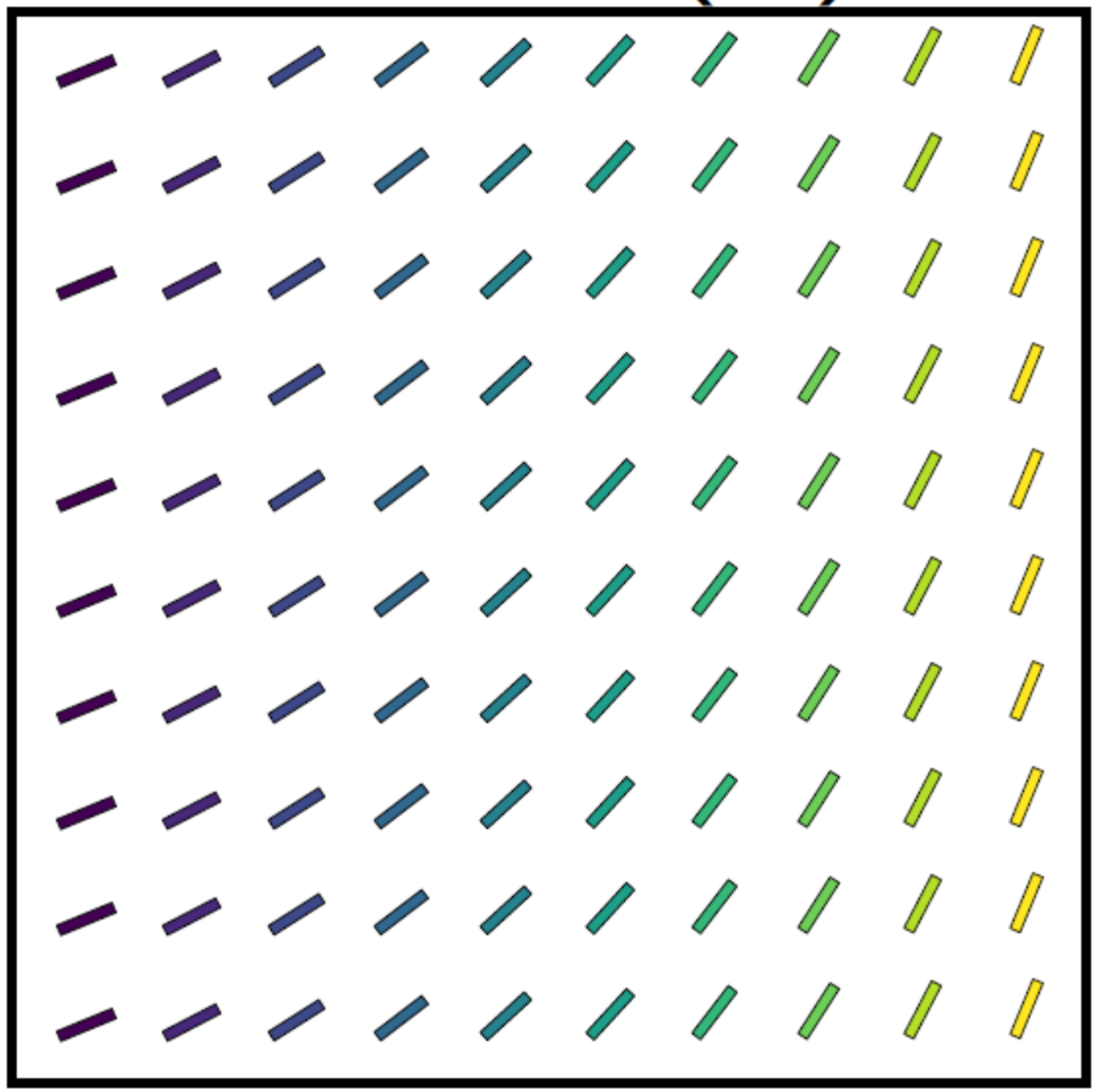


Rotates by twice the angle

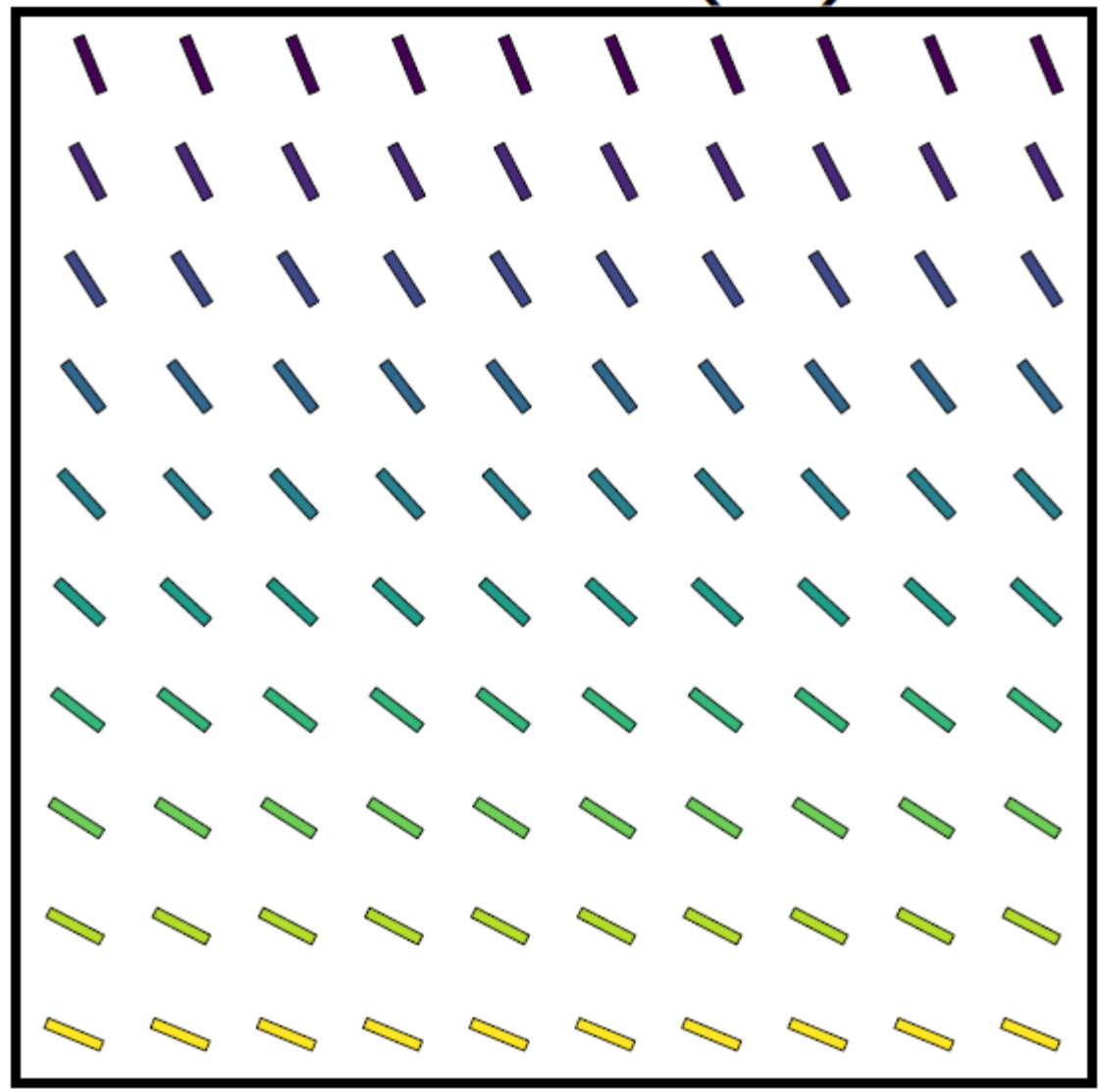




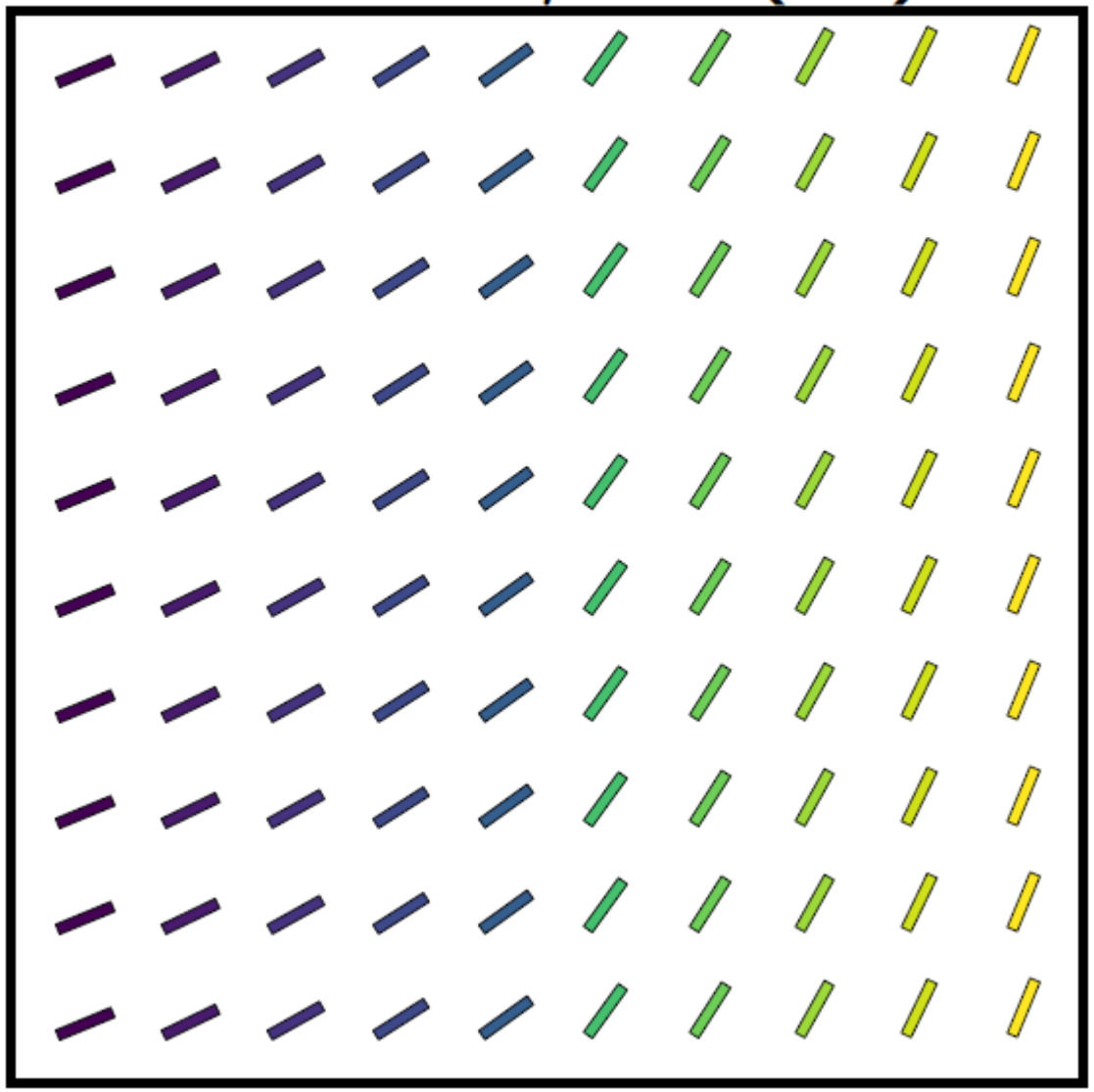
$\beta = 0\ (x)$



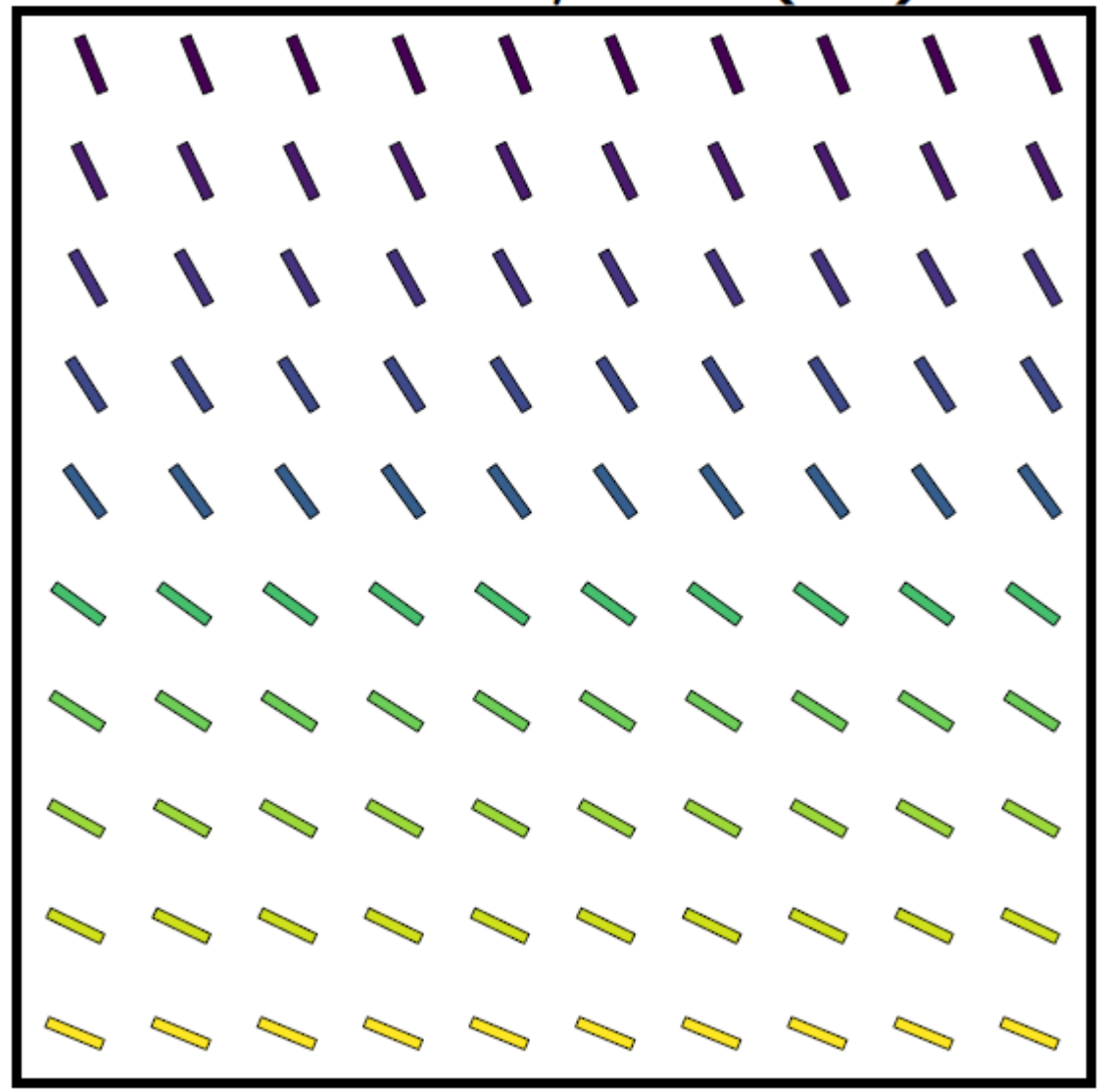
$\beta = 0\ (y)$

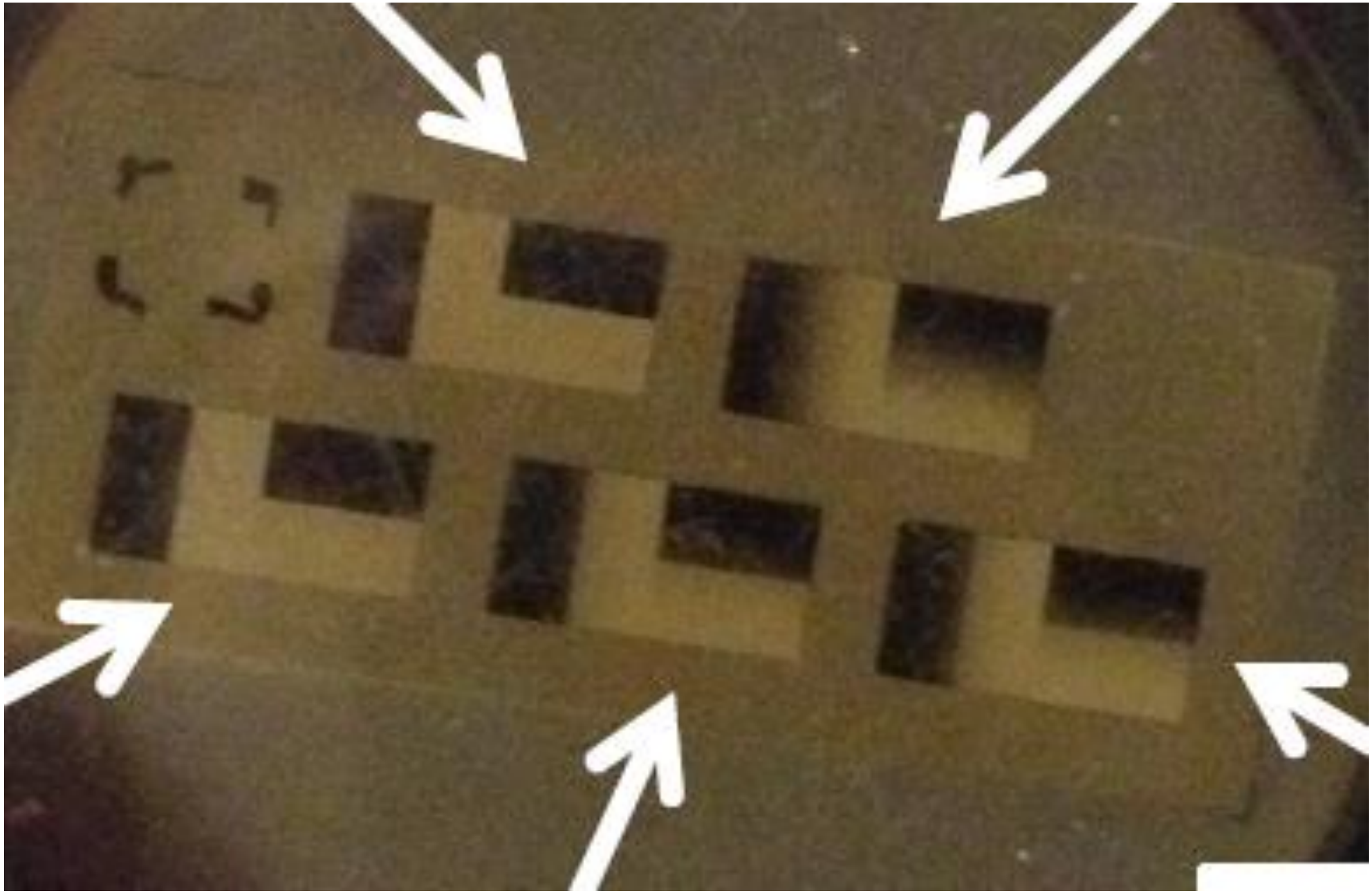


$\beta = 1/3\ (x)$



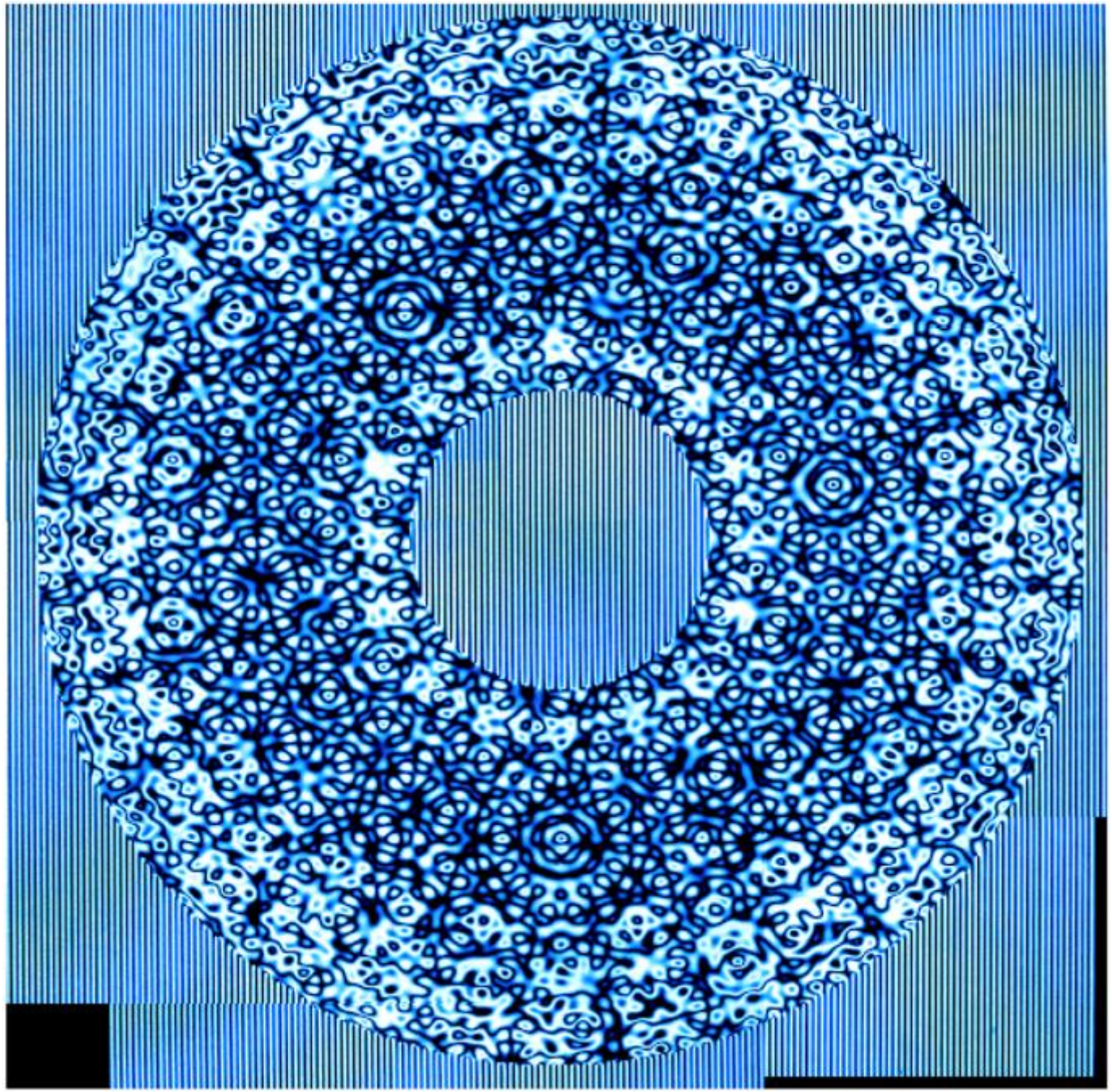
$\beta = 1/3\ (y)$



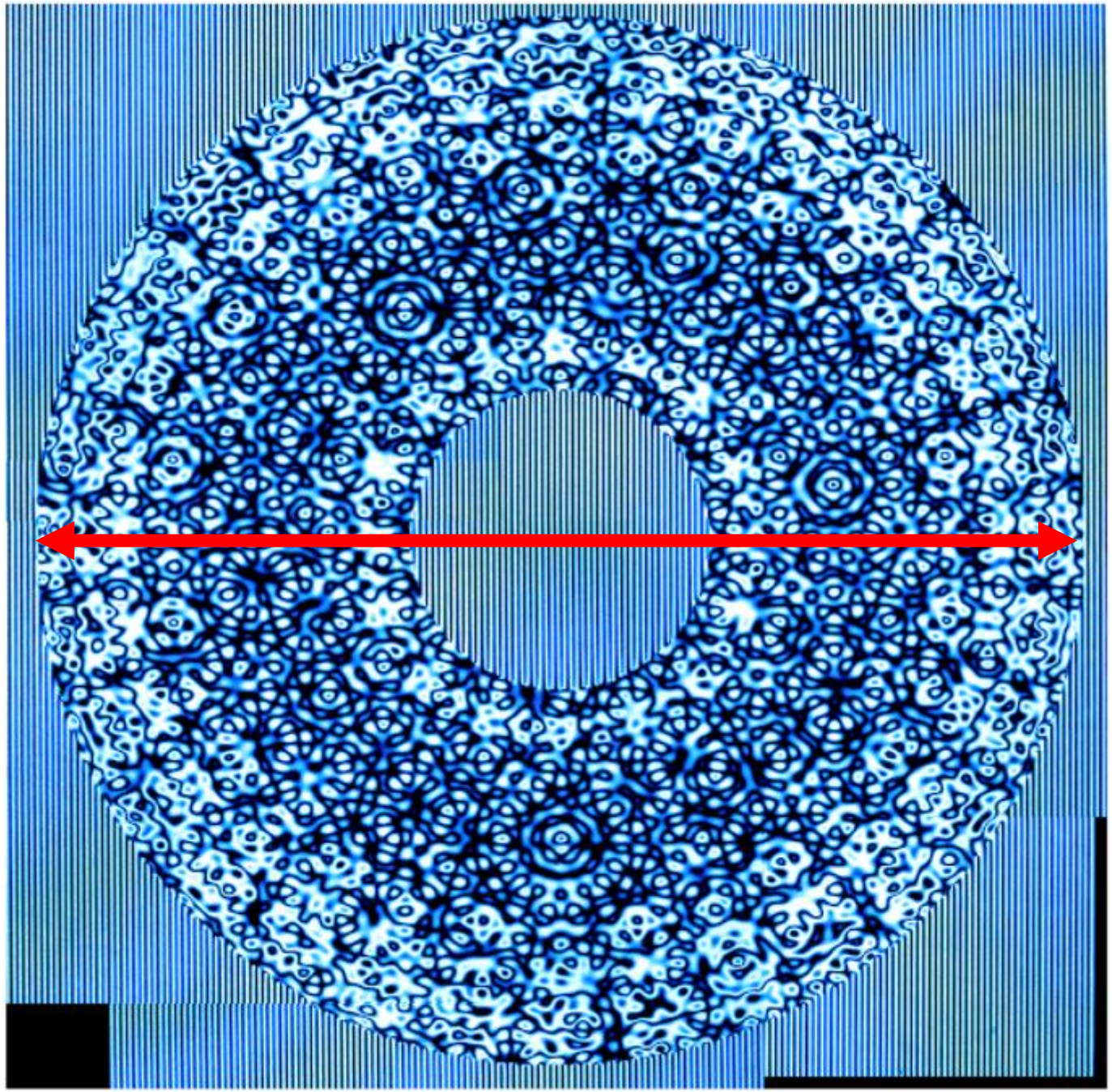


Direct write of patterned liquid crystals

- 1 um pixels size, discontinuities are much smaller.
- Up to 2 inch plates.
- Can be made achromatic over 100% percent bandwidth
- Have been used in cryotostatic environments (LBT, MagAO)



Doelman & Wilby



4.5 mm

Doelman & Wilby

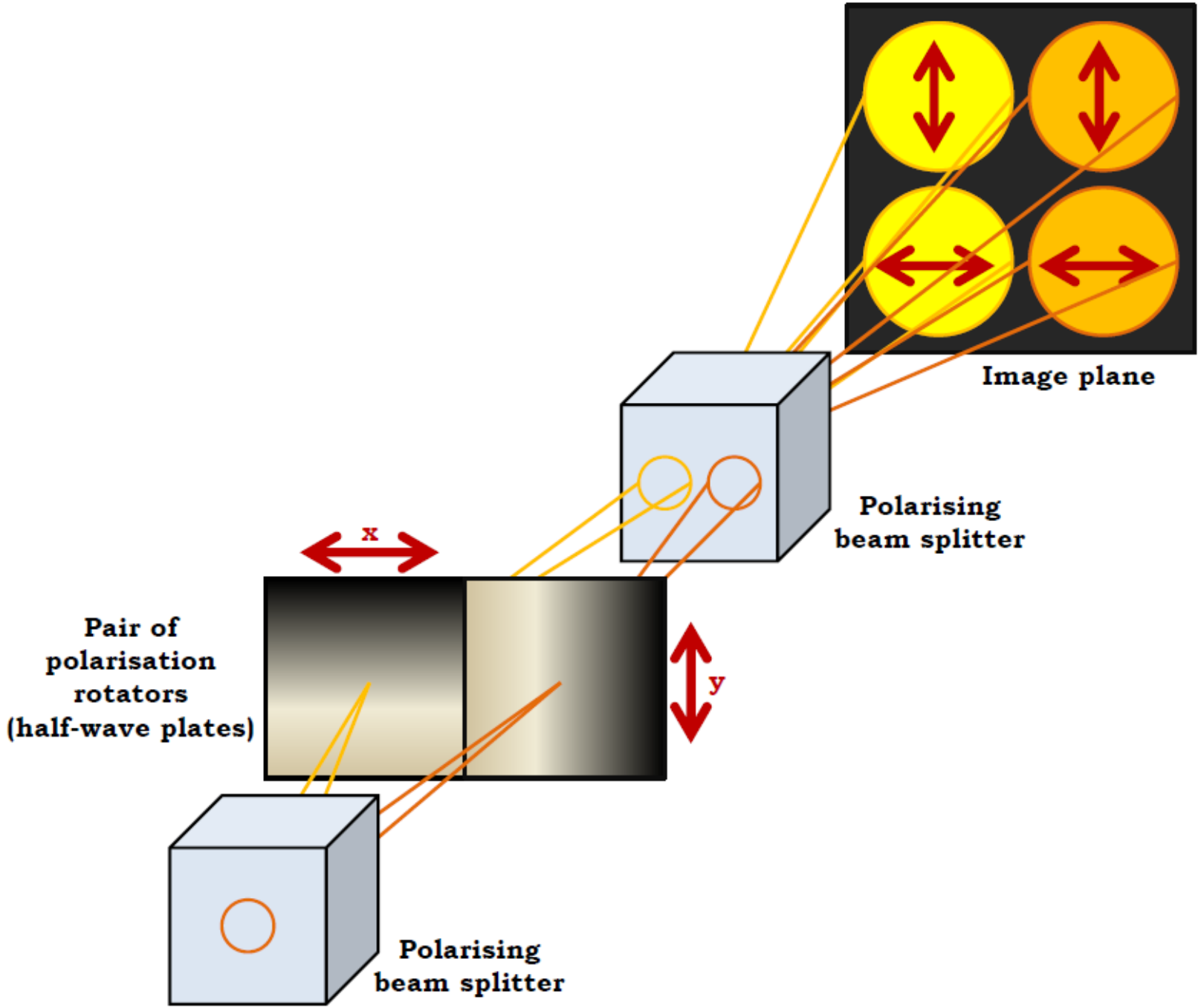
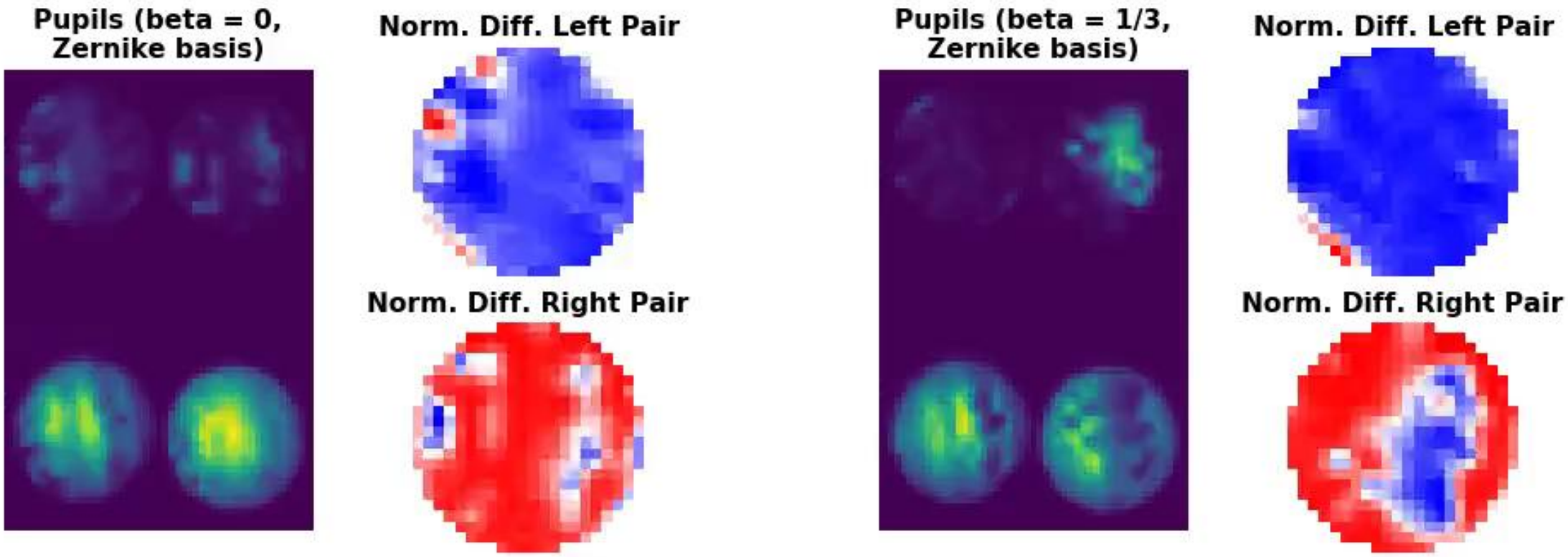
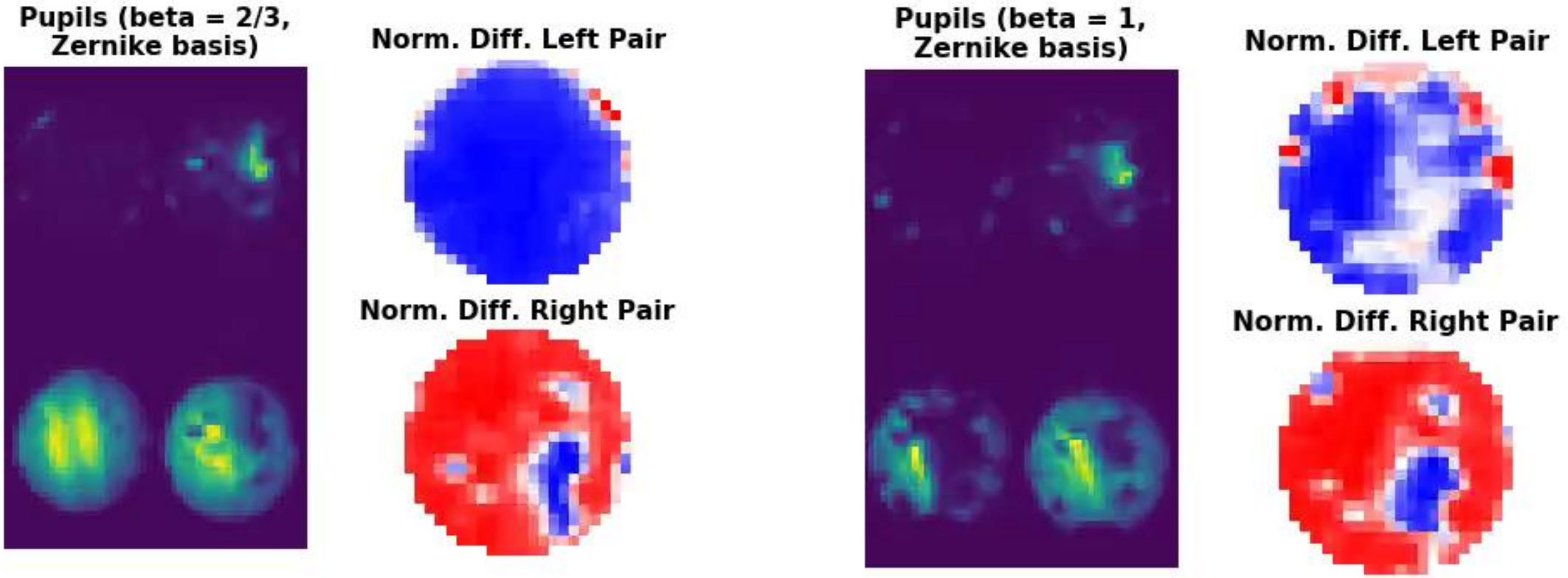


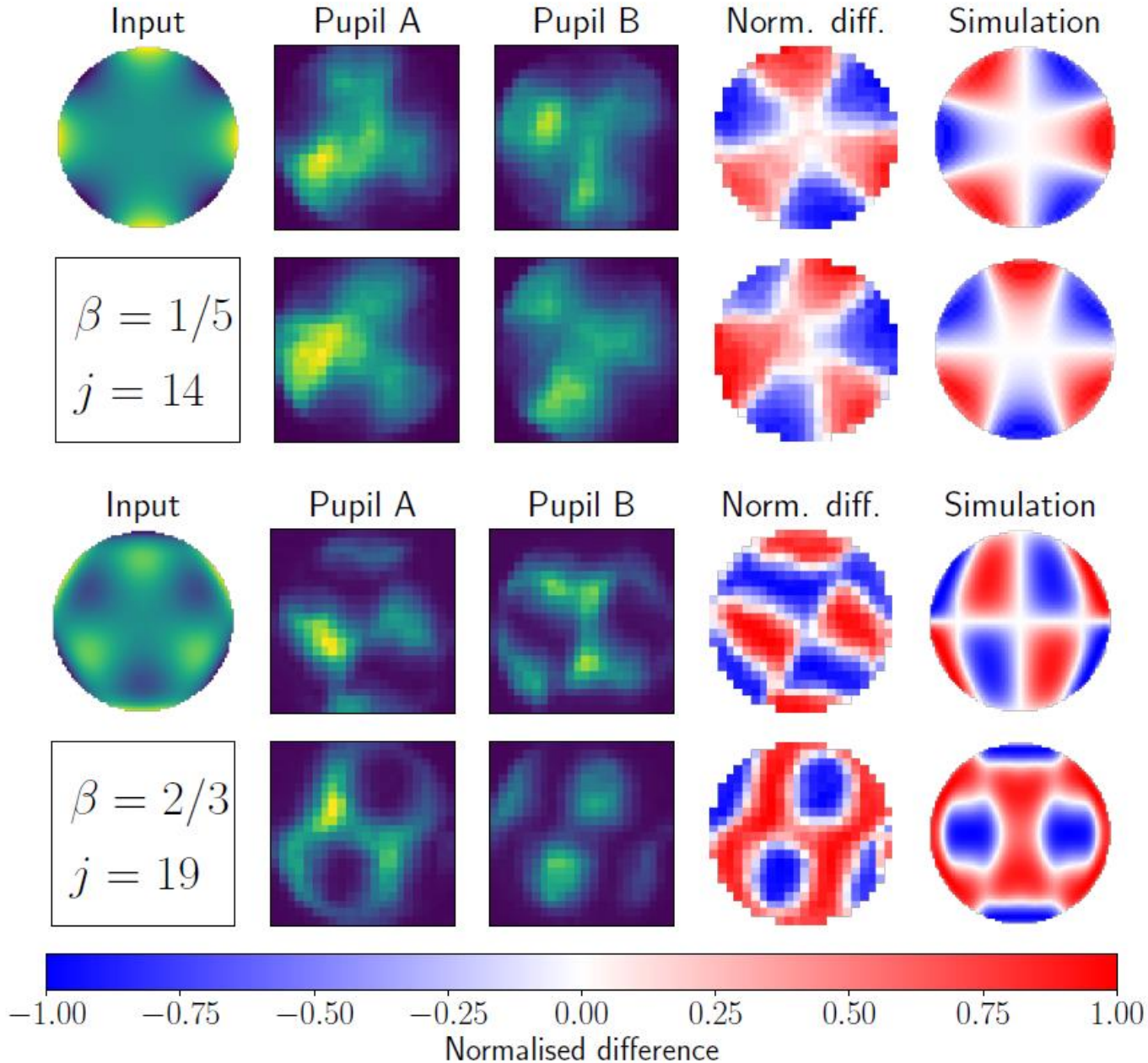
Image plane
Polarising
beam splitter
x
Pair of
polarisation
rotators
(half-wave plates)
y
Polarising
beam splitter

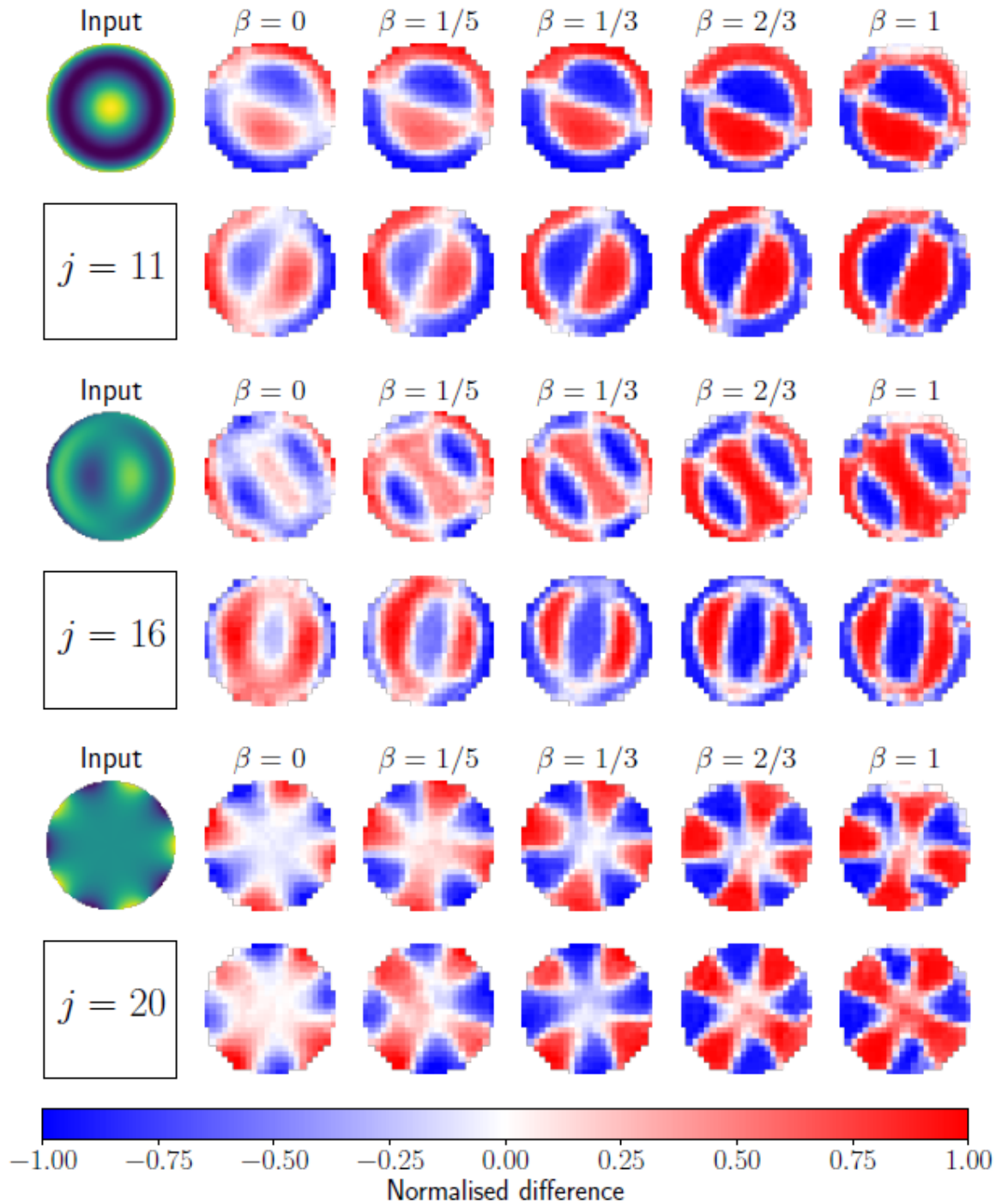
Different wavefront sensor responses

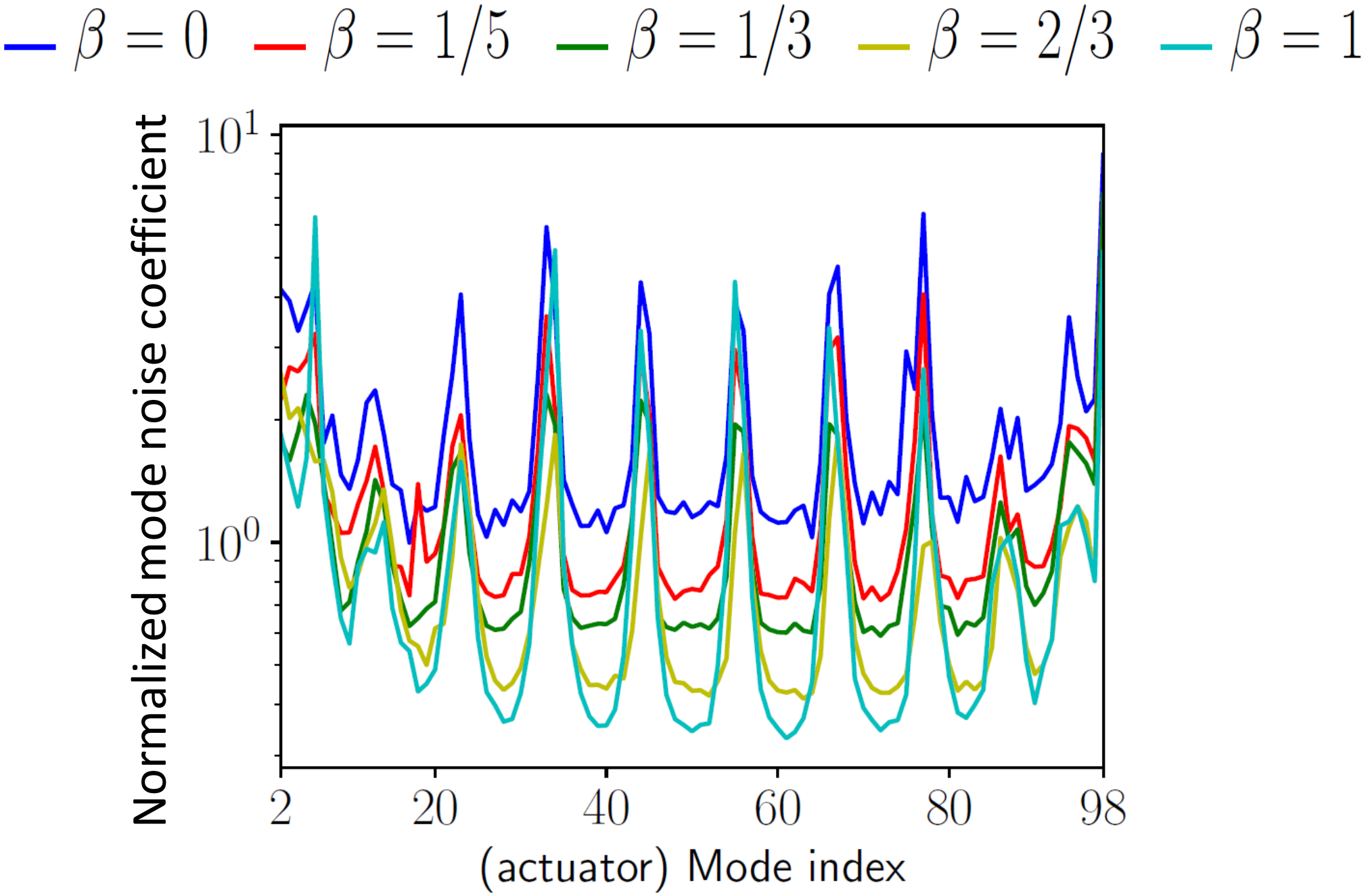


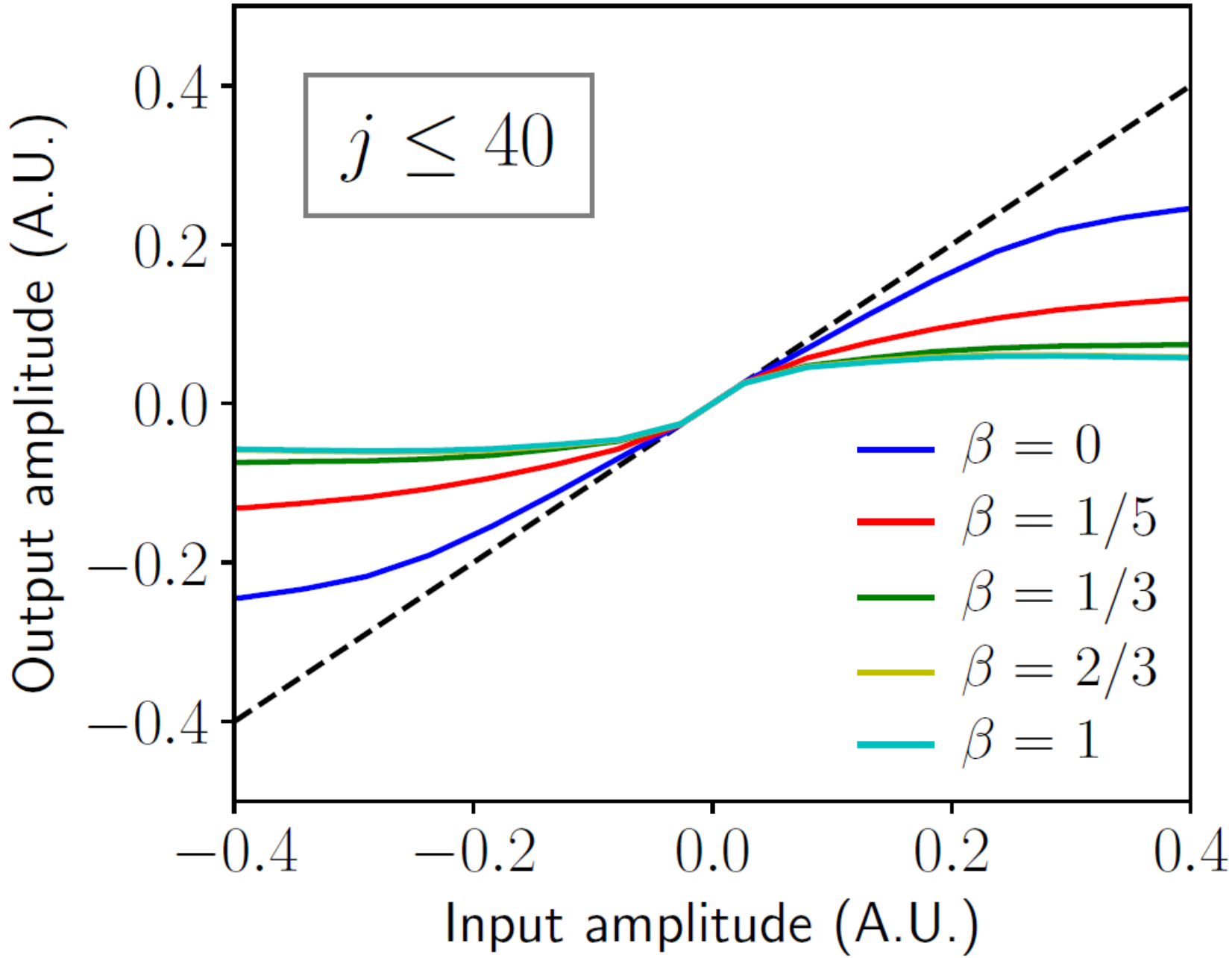
Different wavefront sensor responses




Input
Pupil A
Pupil B
Norm. diff.
Simulation
$\beta = 1/5$
$j = 14$
Input
Pupil A
Pupil B
Norm. diff.
Simulation
$\beta = 2/3$
$j = 19$
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
Normalised difference


Input
$\beta = 0$
$\beta = 1/5$
$\beta = 1/3$
$\beta = 2/3$
$\beta = 1$
$j = 11$
Input
$\beta = 0$
$\beta = 1/5$
$\beta = 1/3$
$\beta = 2/3$
$\beta = 1$
$j = 16$
Input
$\beta = 0$
$\beta = 1/5$
$\beta = 1/3$
$\beta = 2/3$
$\beta = 1$
$j = 20$
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
Normalised difference


$\beta = 0$
$\beta = 1/5$
$\beta = 1/3$
$\beta = 2/3$
$\beta = 1$
Normalized mode noise coefficient
10^1
10^0
2
20
40
60
80
98
(actuator) Mode index


$j \leq 40$
0.4
0.2
0.0
−0.2
−0.4
Output amplitude (A.U.)
−0.4
−0.2
0.0
0.2
0.4
Input amplitude (A.U.)
$\beta = 0$
$\beta = 1/5$
$\beta = 1/3$
$\beta = 2/3$
$\beta = 1$

The Leiden EXoplanet Instrument (LEXI)

- High contrast imaging + high resolution spectroscopy instrument.
- Visitor instrument for the William Herschel Telescope at La Palma.
- R&D instrument to test new HCI techniques on-sky.

Conclusion

- New sensitive and high-dynamic range wavefront sensor.
  - Finally we can decouple sensitivity and dynamic range!
- Simulated, tested and verified to work in lab.
- Will go on-sky in December 2017 on the WHT at La Palma.