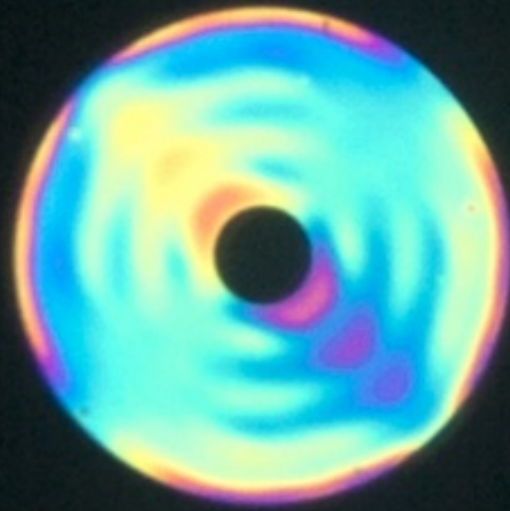


vector Apodizing Phase Plate coronagraph

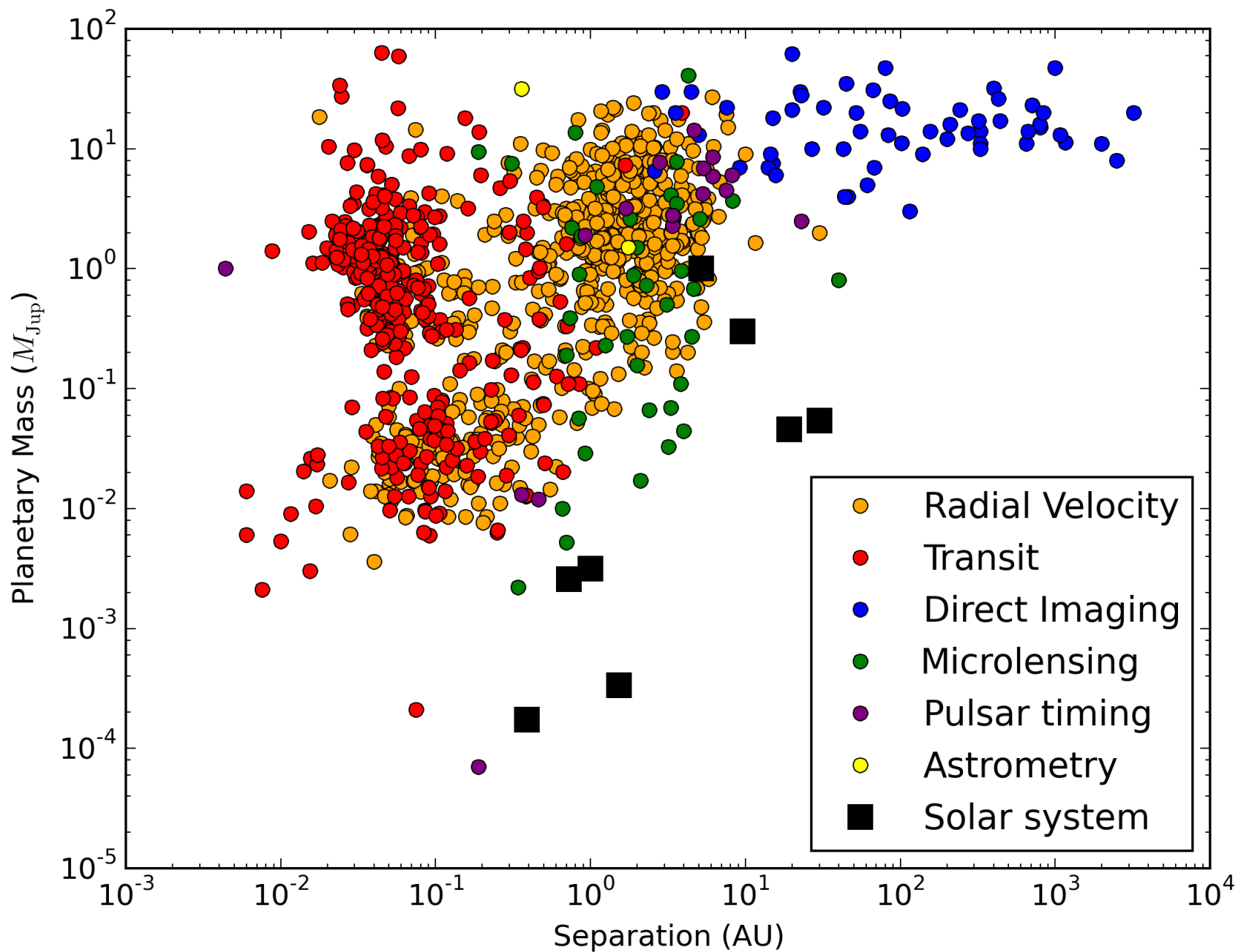


Gilles Otten

Frans Snik, Matthew Kenworthy, Christoph Keller
Leiden Observatory, the Netherlands

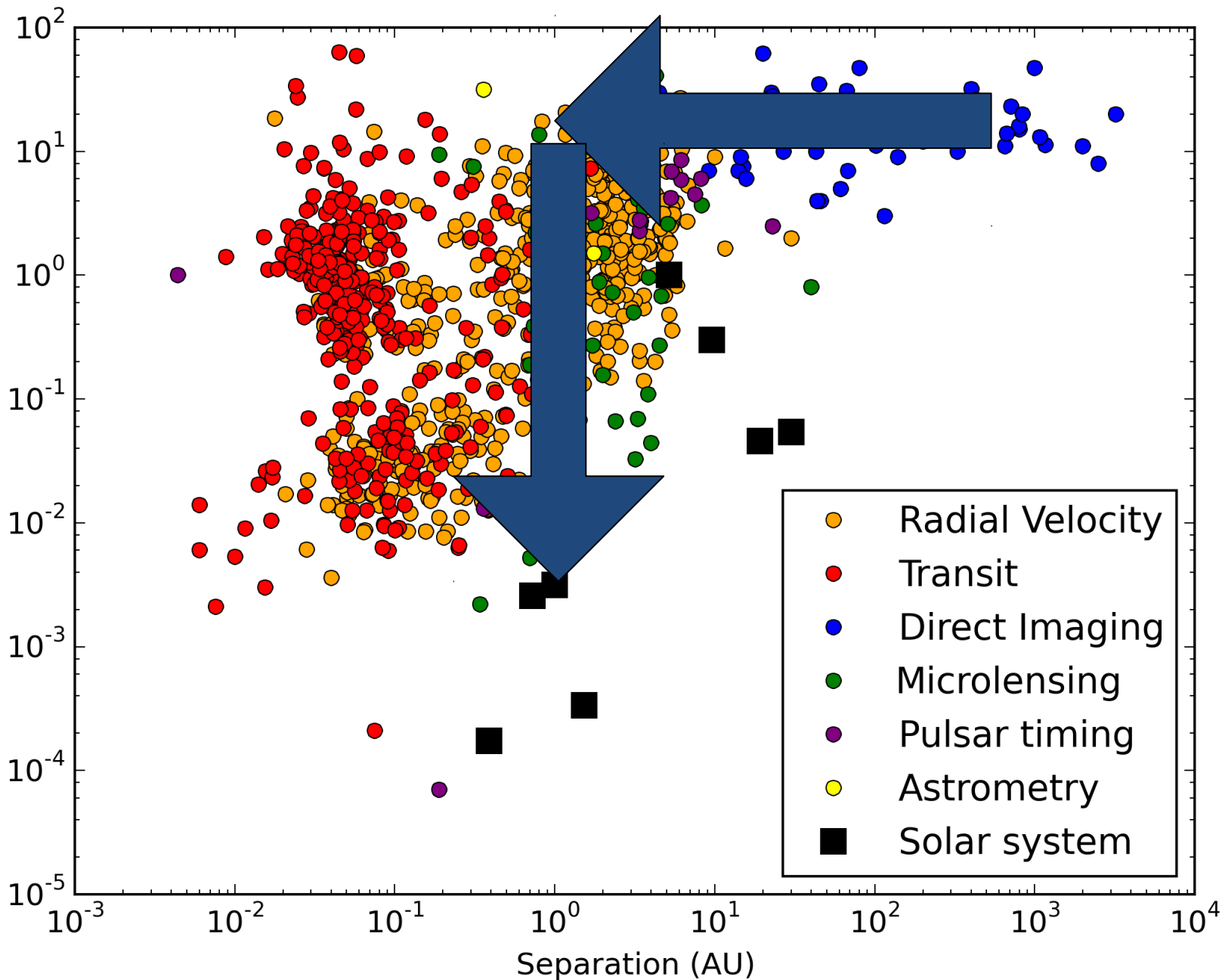
Jared Males, Katie Morzinski, Laird Close, Johanan Codona, Phil Hinz
University of Arizona, USA

Kathryn Hornburg, Leandra Brickson, Matt Miskiewicz, Ravi Komanduri, Michael Escuti
North Carolina State University, USA



<closer to star

<higher contrast



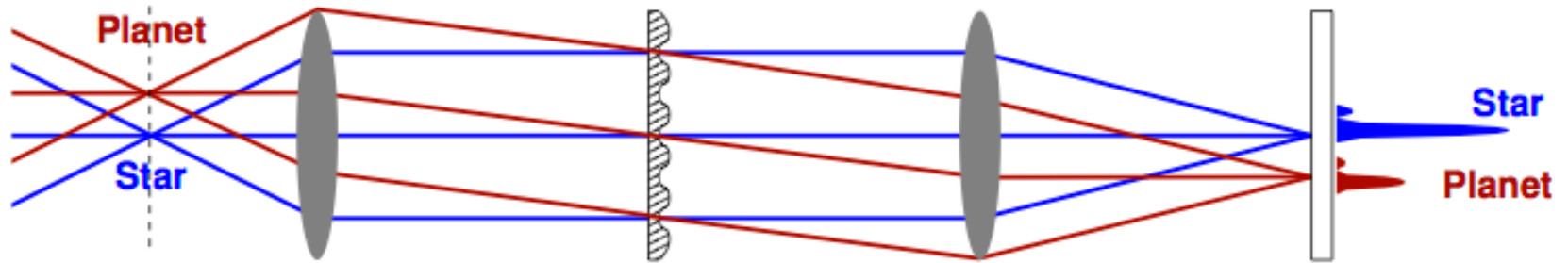
Approach

1. Spatially resolve planets
Large Earth-based telescopes
2. Correction of turbulent atmosphere
Adaptive Optics
3. Separating star and planet light
Starlight subtraction techniques
4. Suppressing residual starlight
Coronagraphs [my PhD thesis]

Pupil-plane coronagraphs

No Focal Plane Mask

Optic



Focal Plane (FP)

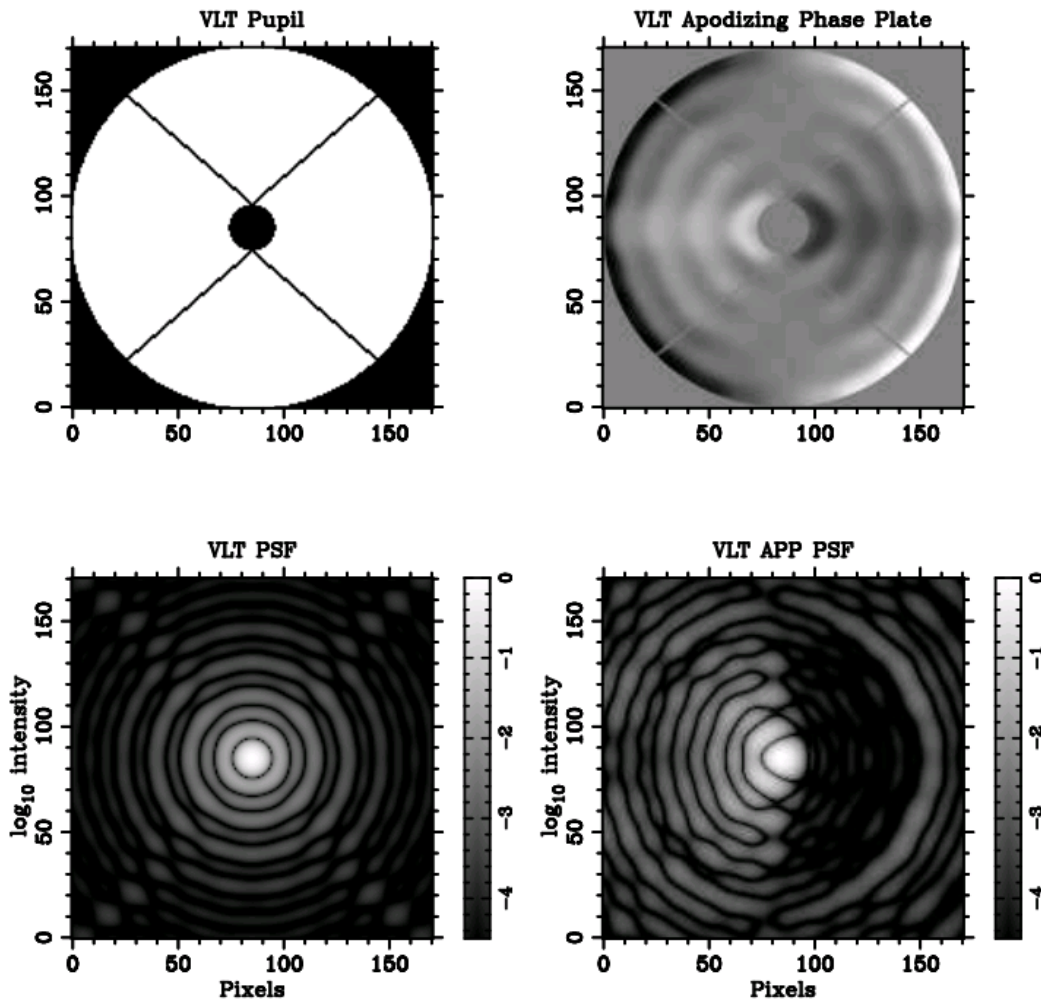
Pupil Plane (PP)

Detector

Matt Kenworthy

- insensitive to tip/tilt errors
- permits nodding for IR background subtraction
- single plane in telescope

Apodizing Phase Plate (APP)



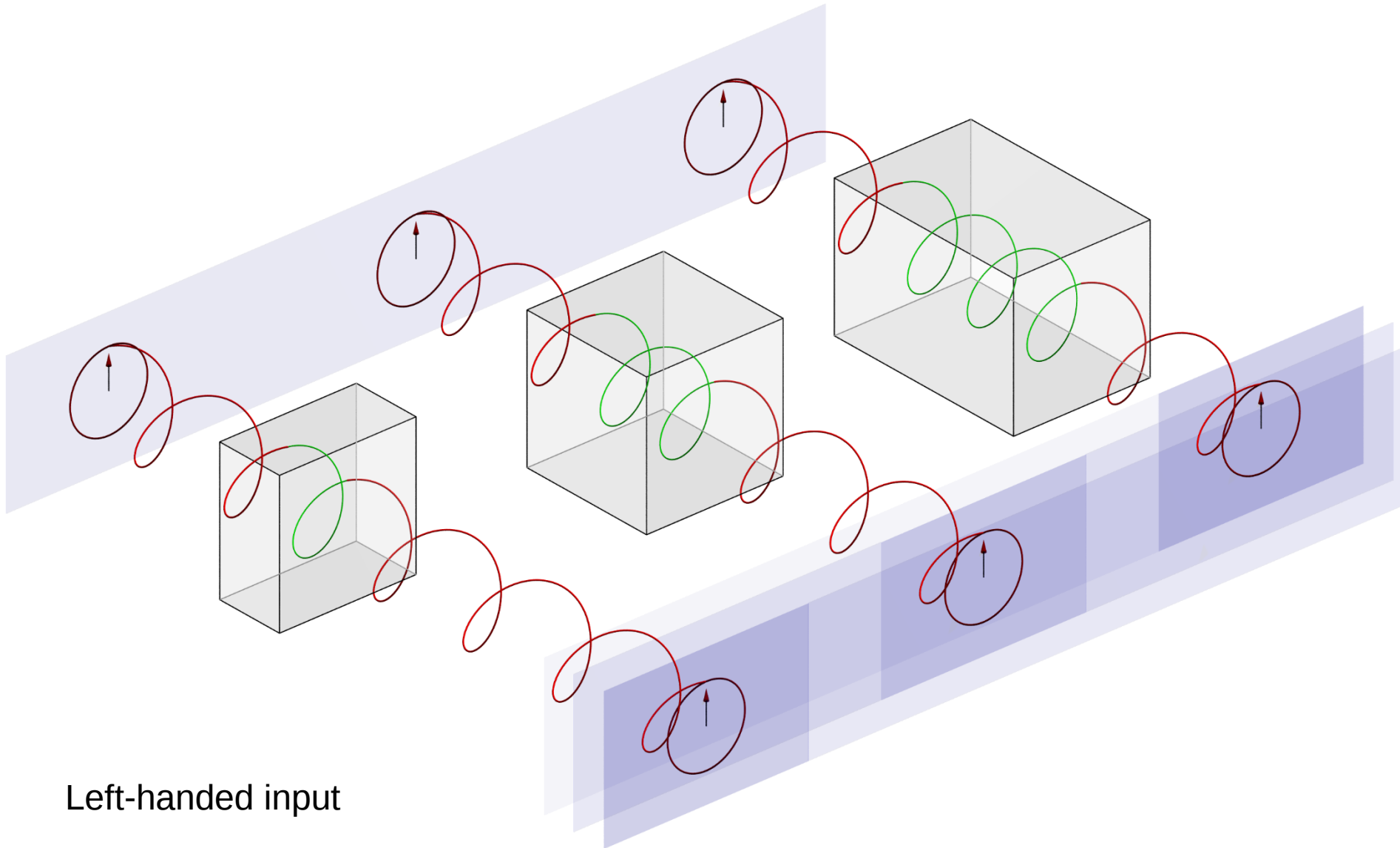
Optic is diamond turned
out of Zinc Selenide

Codona & Angel, (2004)

Codona et al. (2006)

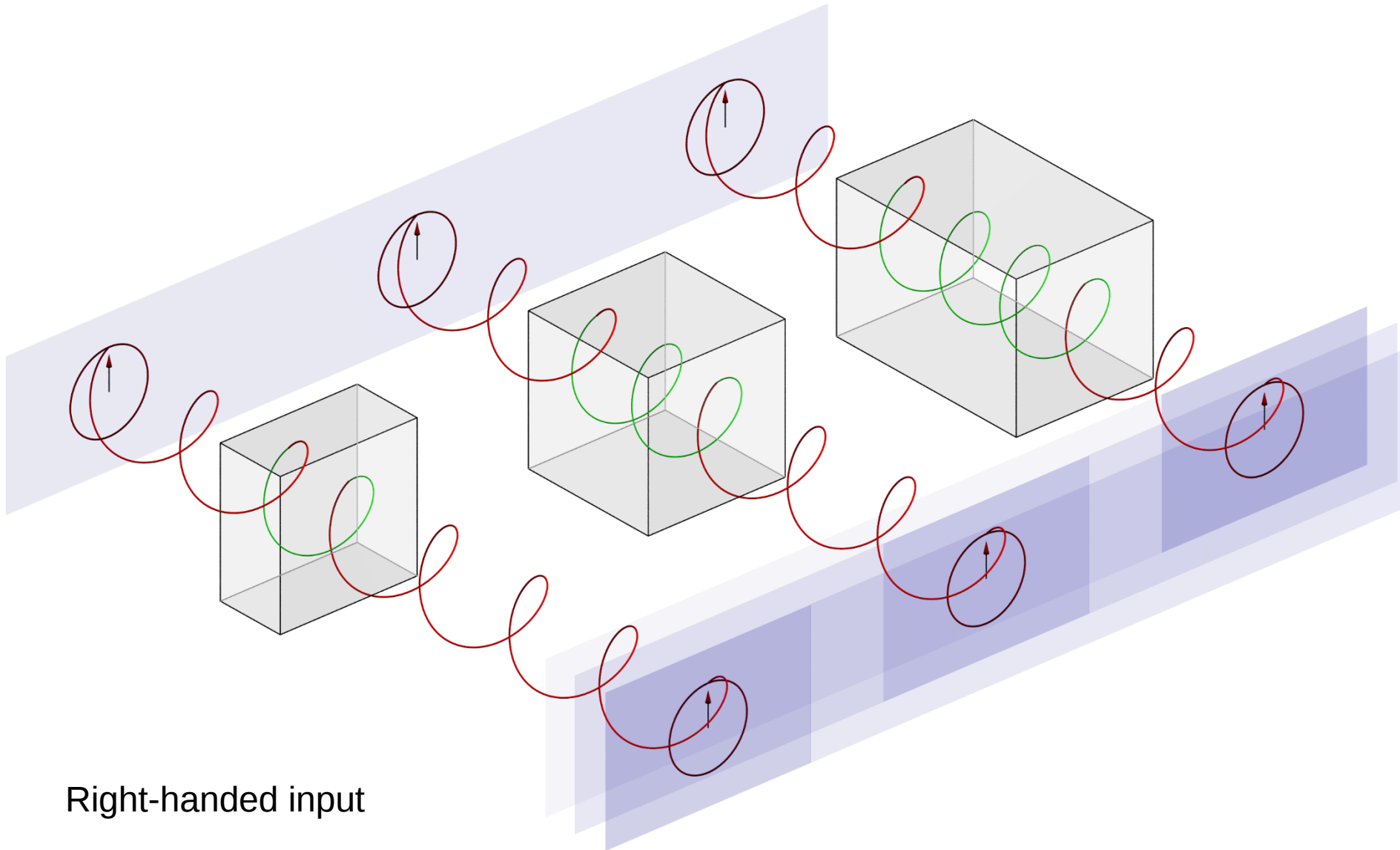
Kenworthy et al. (2007)

Classical Phase

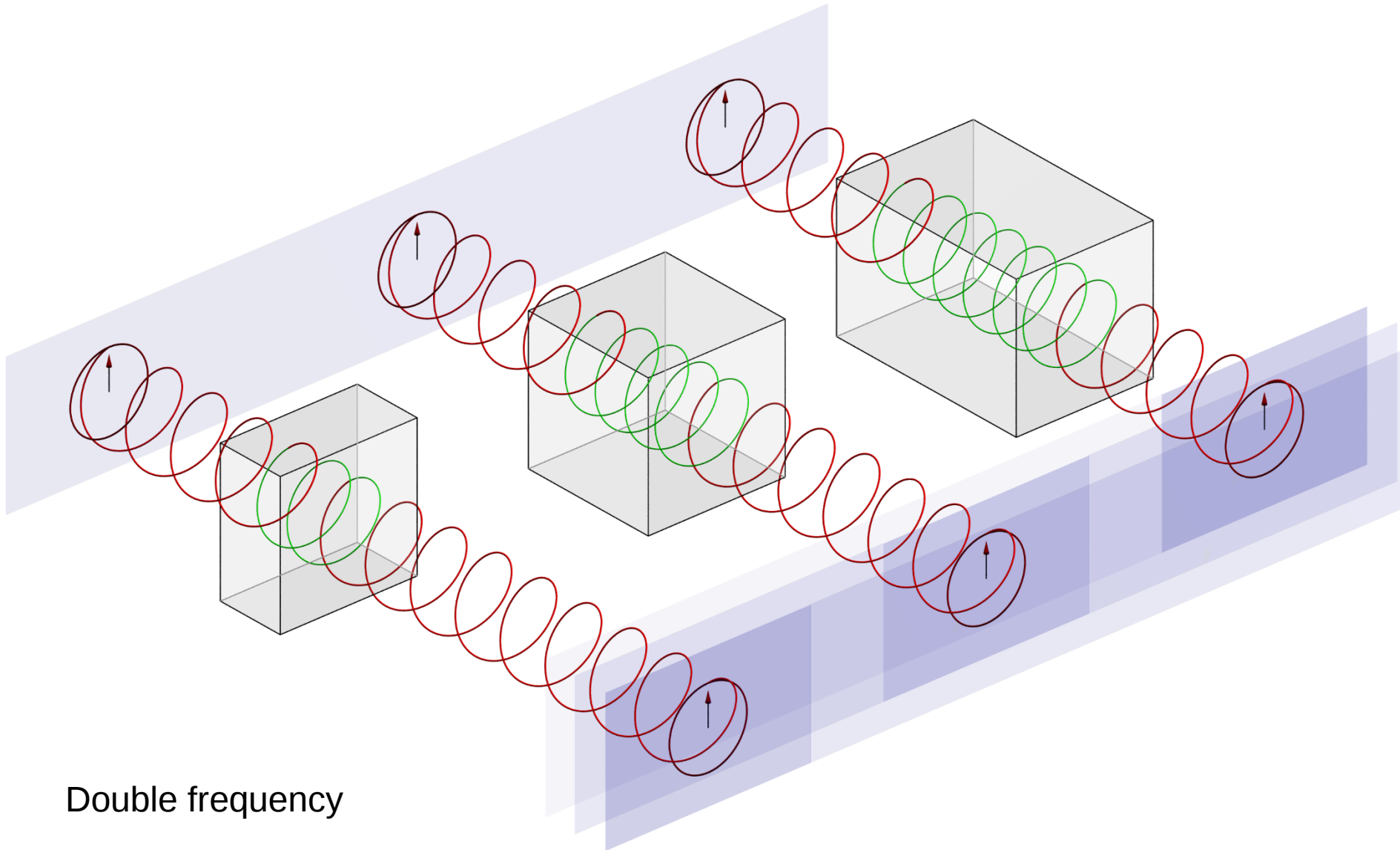


Left-handed input

Classical Phase

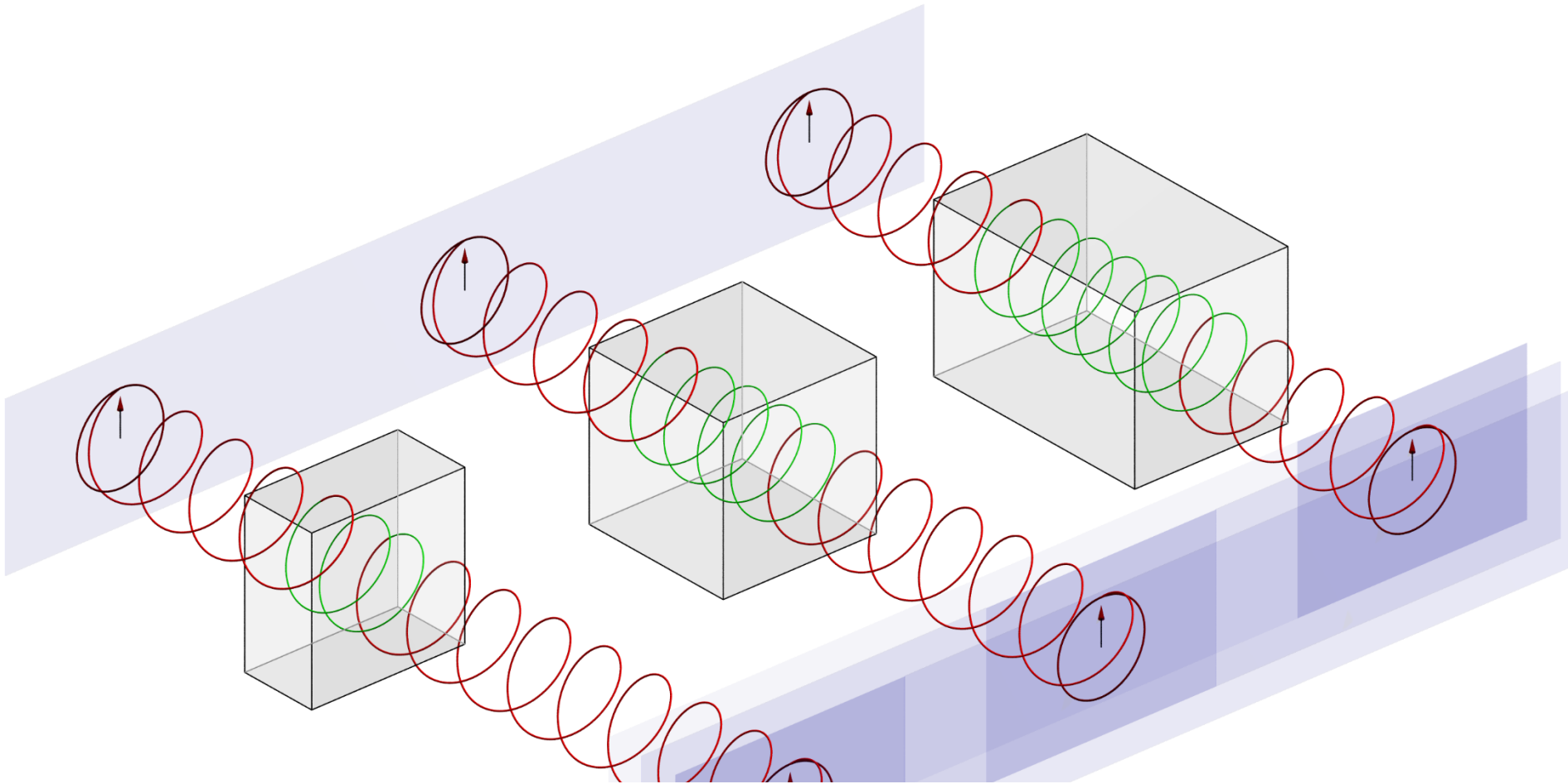


Classical Phase



Double frequency

Classical Phase

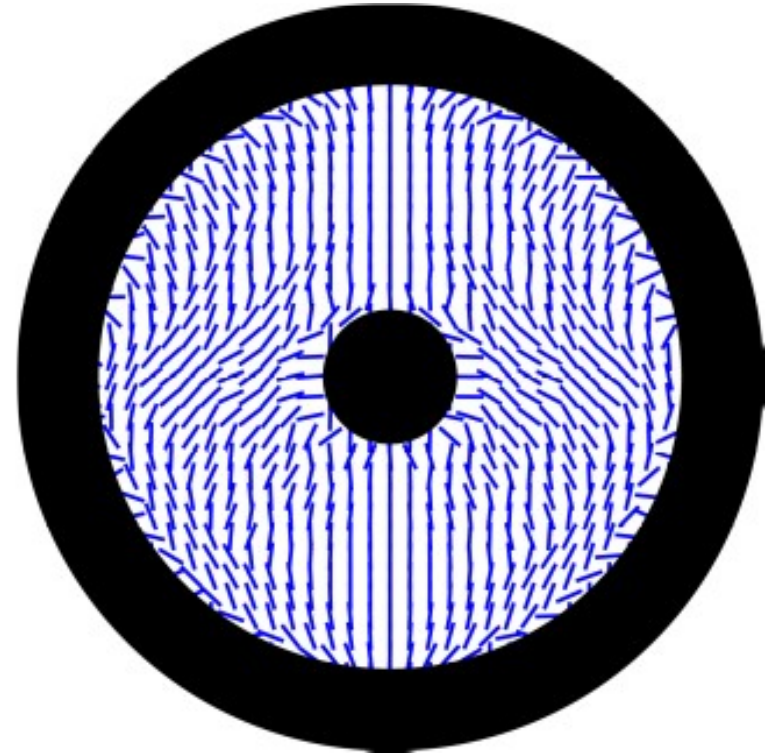
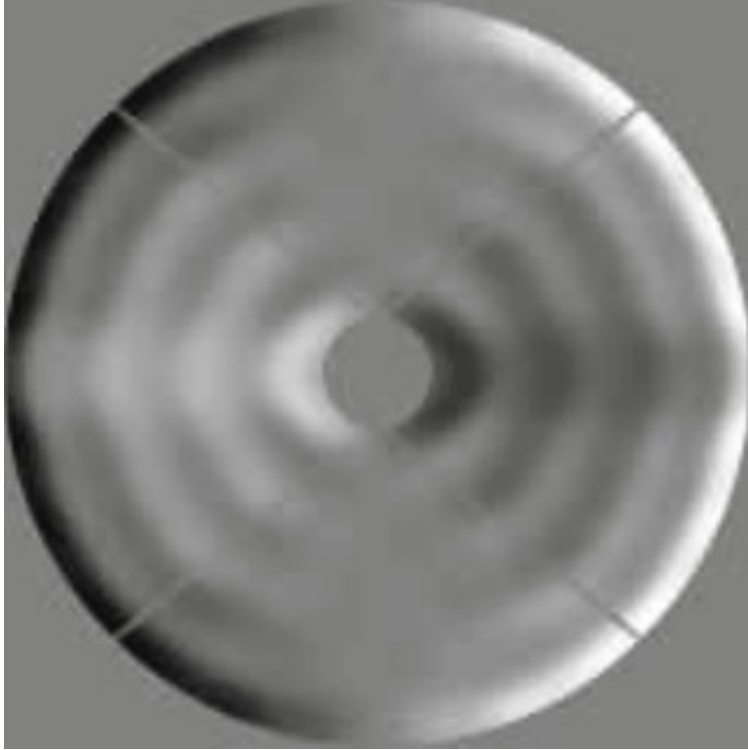


$$\Delta\phi = 2\pi (n - 1)\Delta x / \lambda$$

Pros and Cons of APP

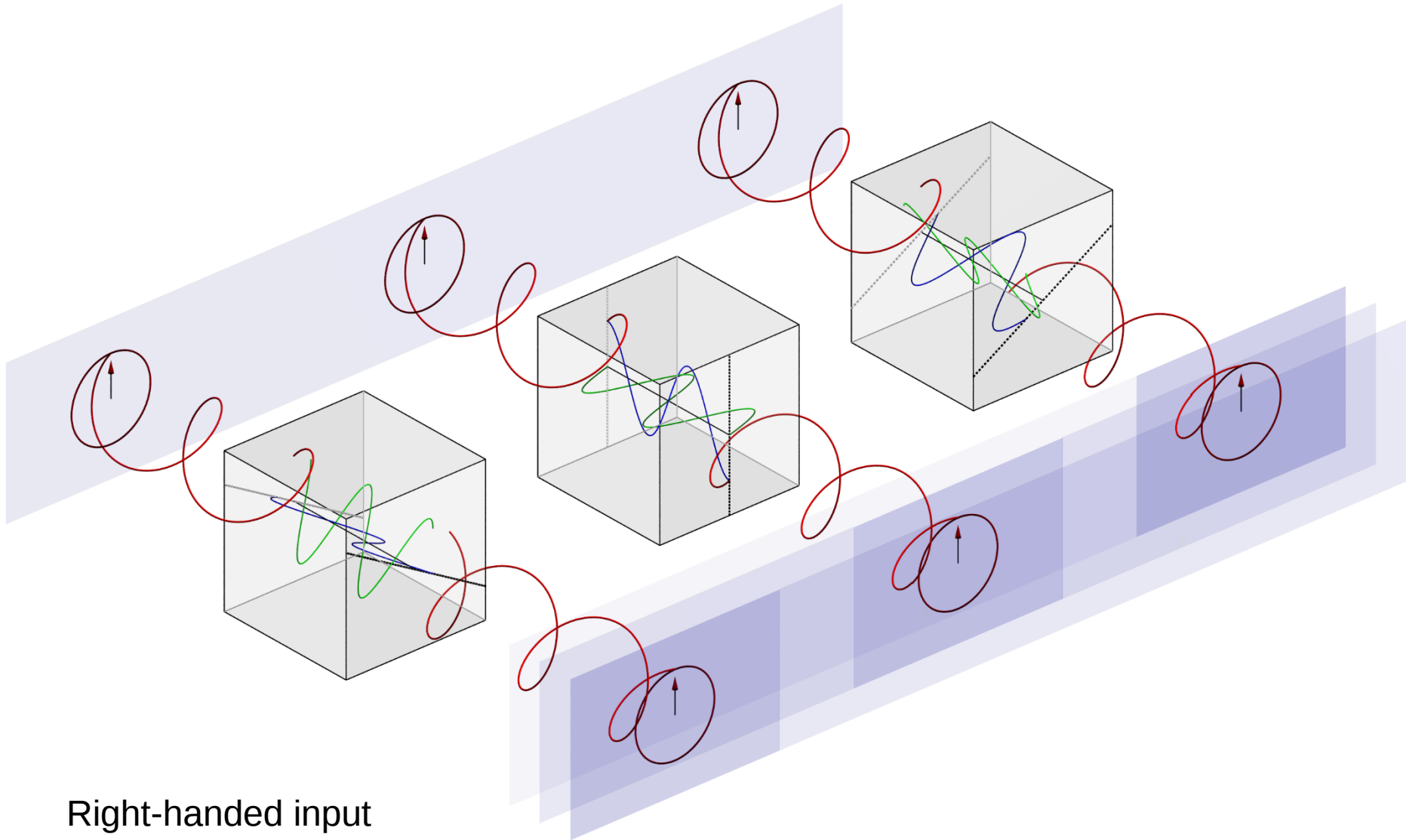
- + Single optic
- + Easy alignment
- + Insensitive to tip-tilt errors
- + Small inner working angle
- + High contrast
- One-sided PSF
- Chromatic
- Extreme phase patterns cannot be manufactured with diamond turning

Classical \Rightarrow Geometric Phase



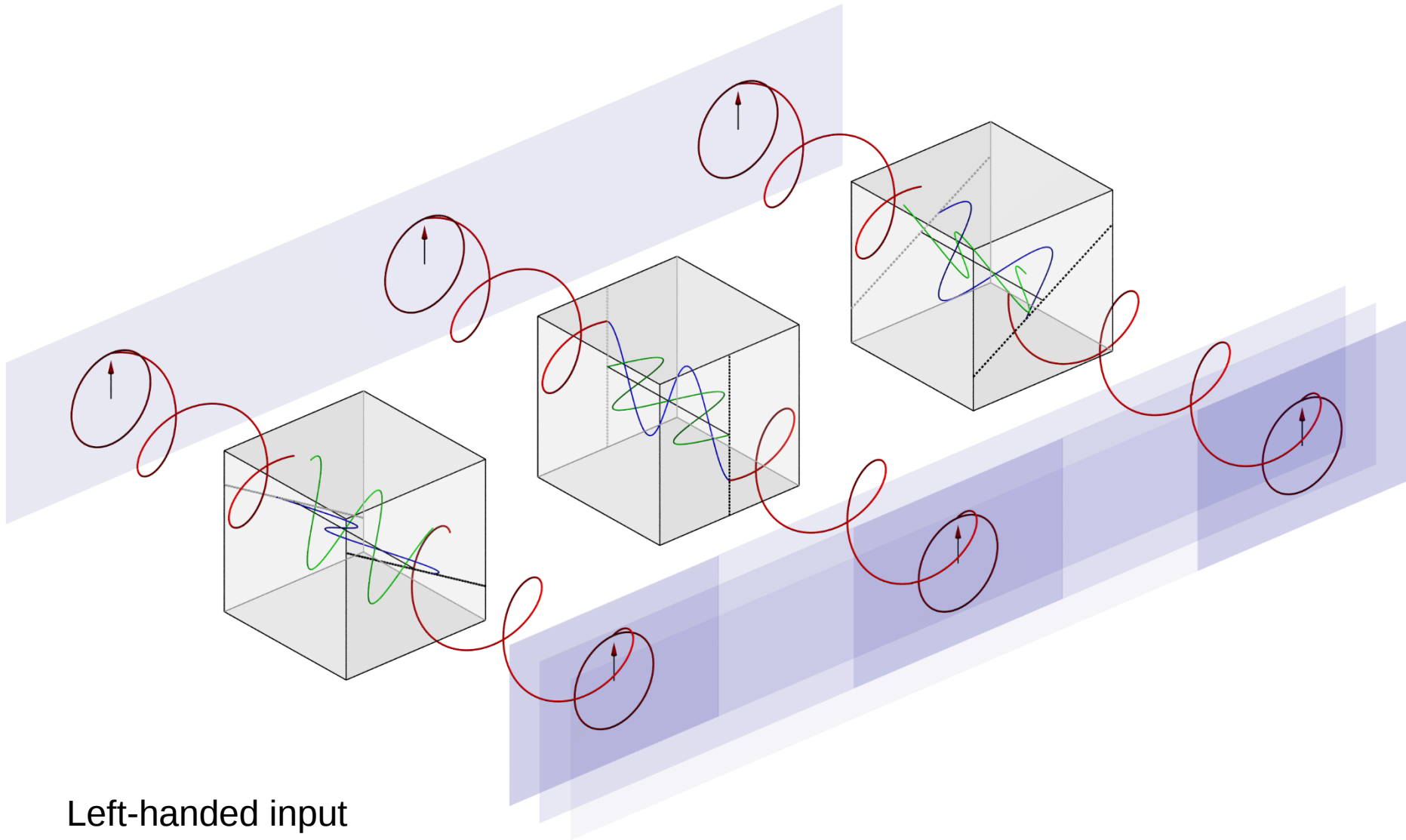
From thickness variations in 'glass' to fast axis orientations in a half-wave retarder

Geometric Phase



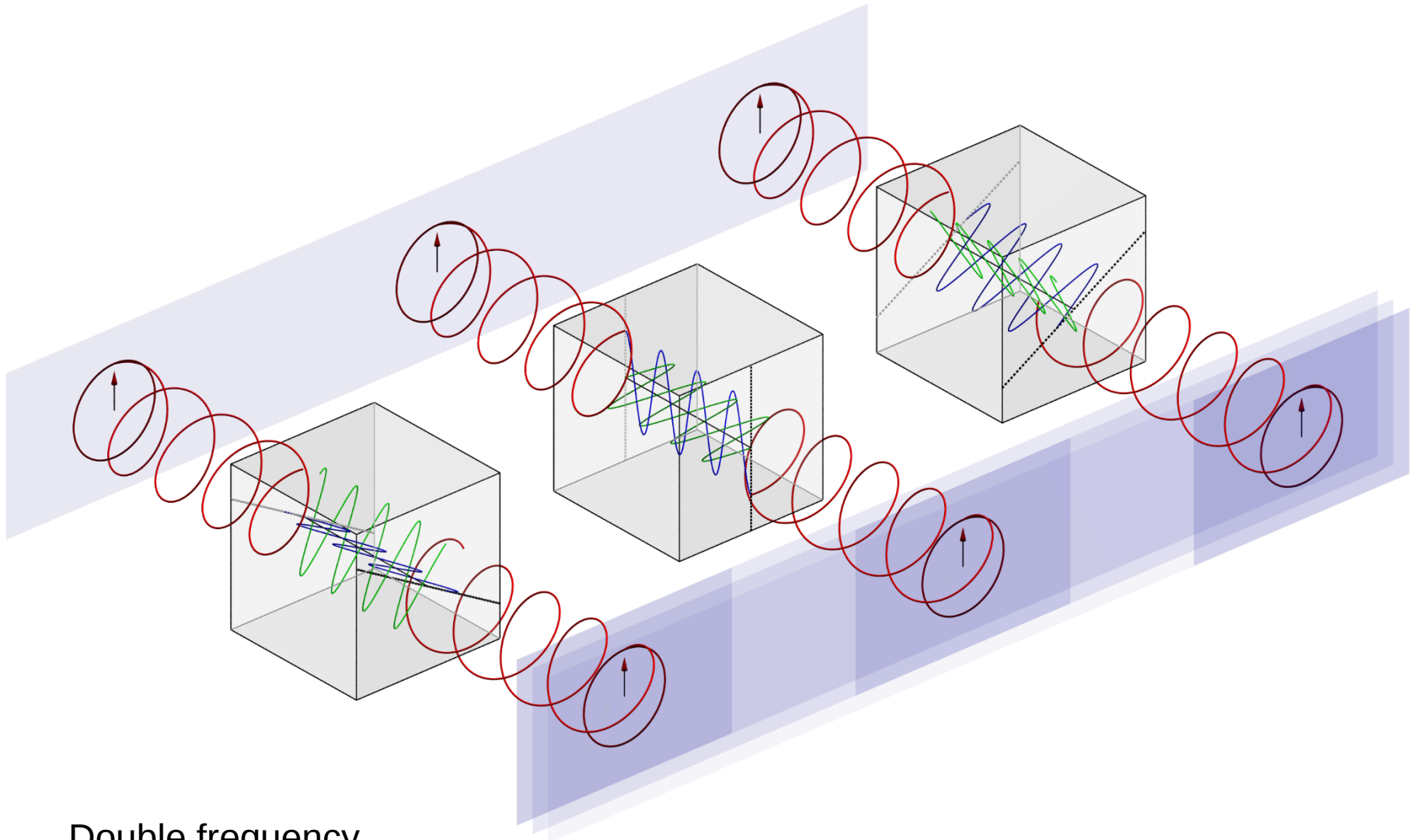
Right-handed input

Geometric Phase



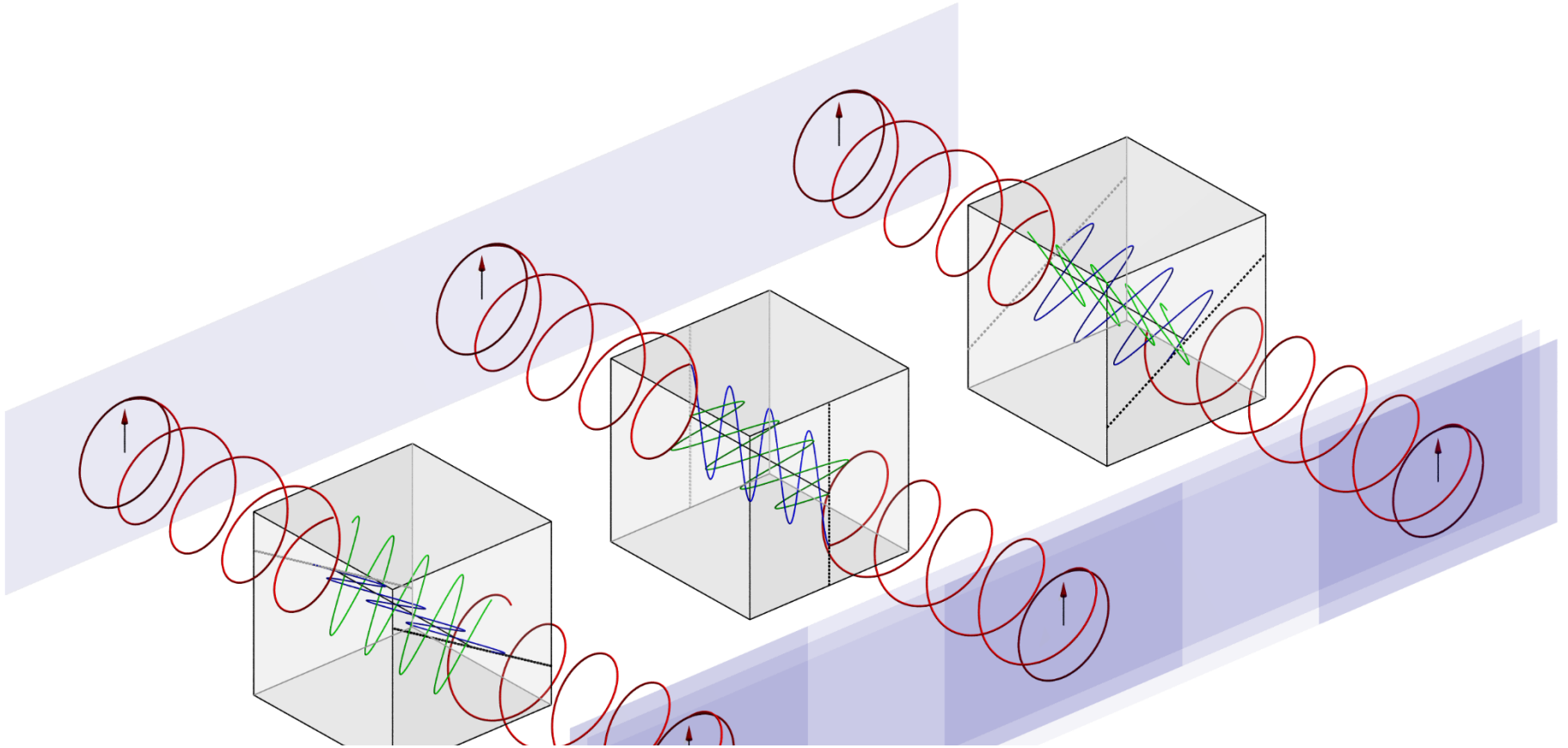
Left-handed input

Geometric Phase



Double frequency

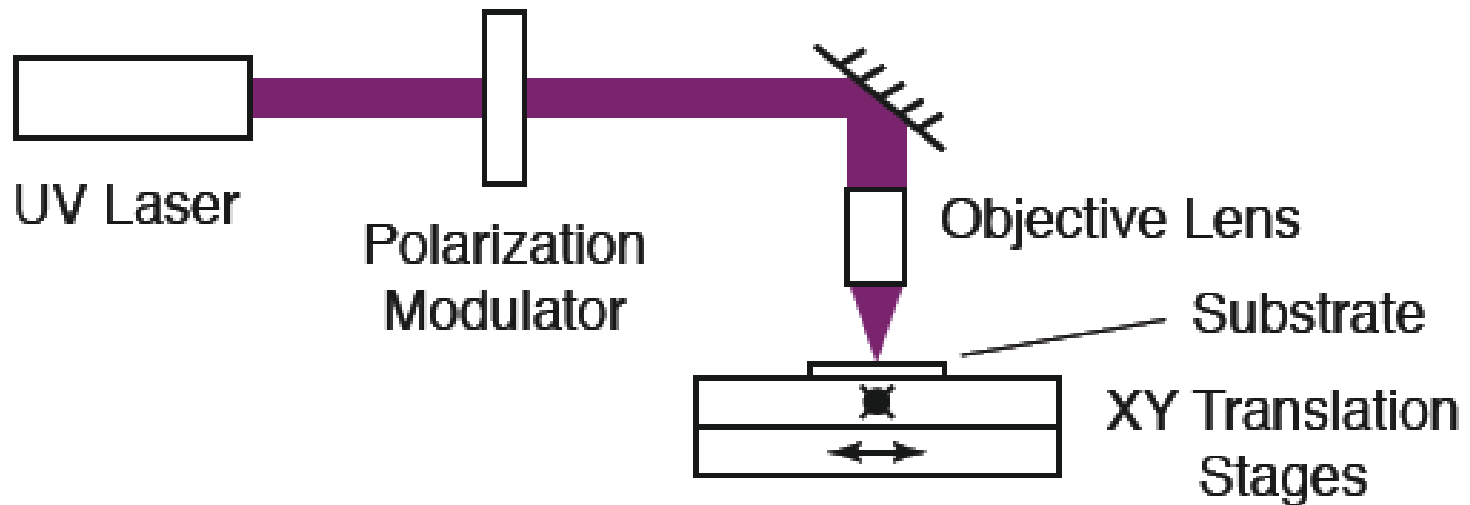
Geometric Phase



$$\Delta\phi = \pm 2 \Delta\theta$$

Liquid crystal manufacturing

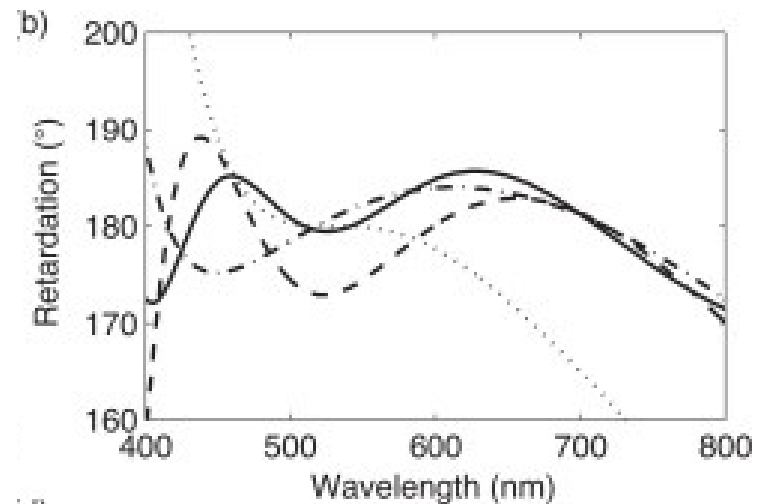
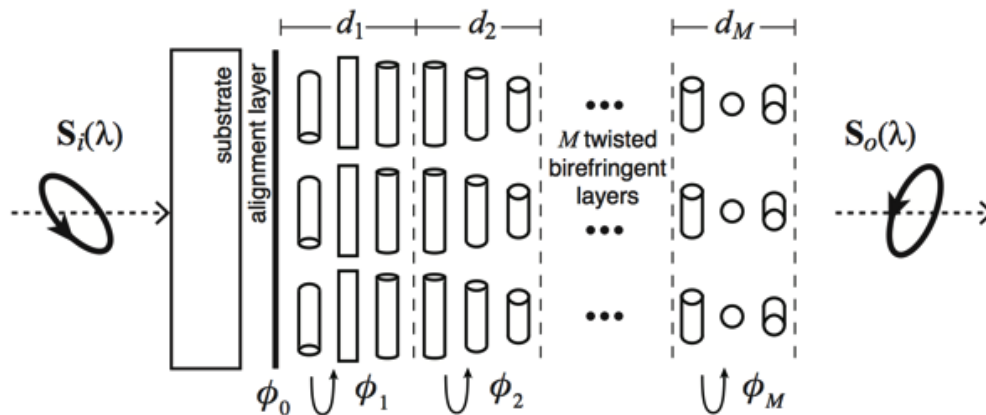
1. any phase pattern thanks to direct-write technique



Miskiewicz & Escuti (2014)

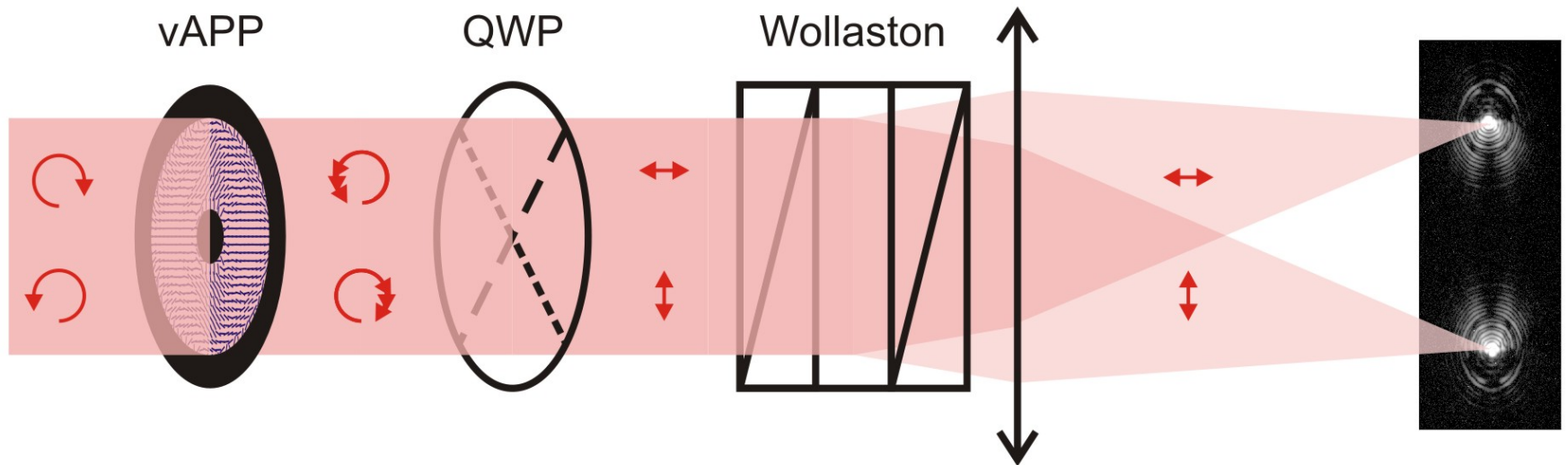
Liquid crystal manufacturing

2. achromatization thanks to self-aligning multi-twist liquid crystal retarder



Komanduri et al. (2013)

vector-APP (vAPP) layout



Snik, Otten et al. (Proc. SPIE 8450, 2012)

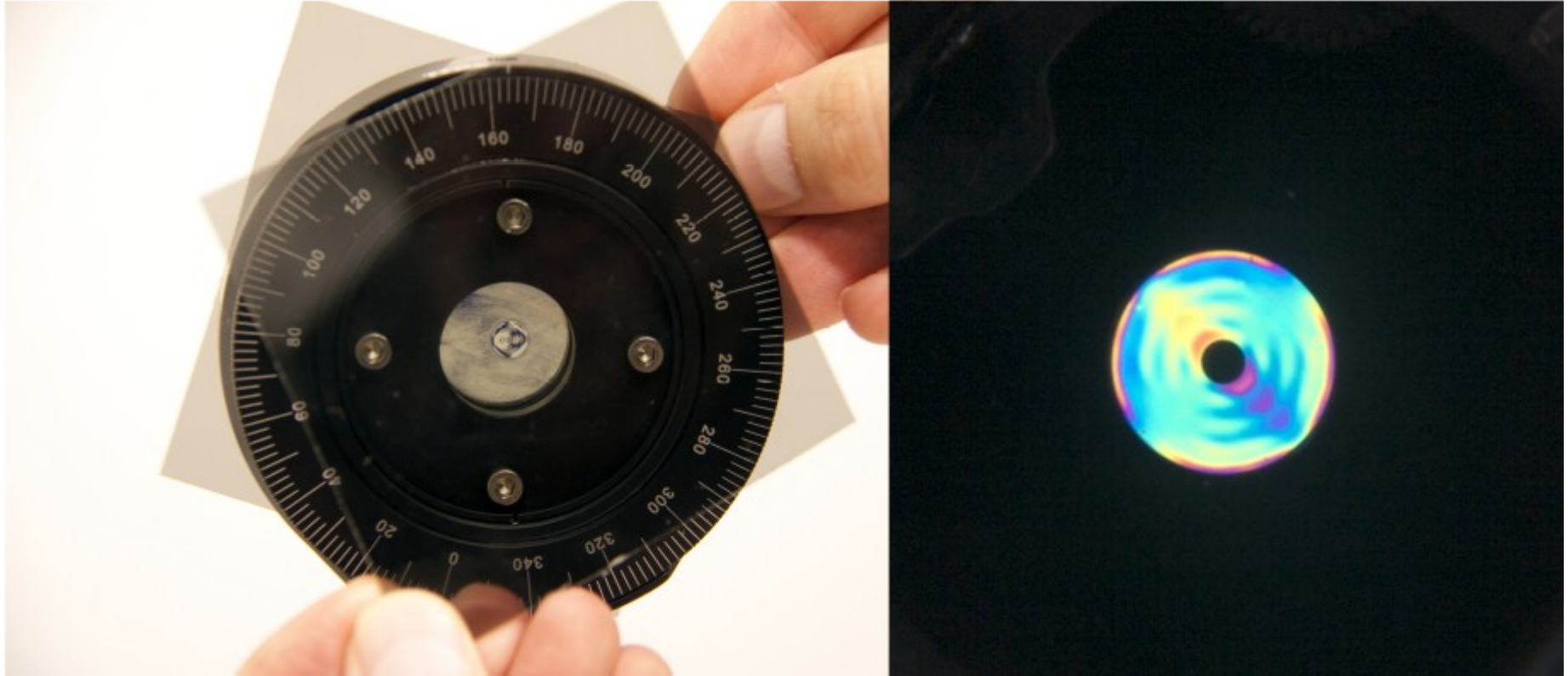
Pros and Cons of APP

- + Single optic
- + Easy alignment
- + Insensitive to tip-tilt errors
- + Small inner working angle
- + Potentially high contrast
- One-sided PSF
- Chromatic
- Extreme phase patterns cannot be manufactured with diamond turning

Pros and Cons of vAPP

- + Single optic
- + Easy alignment
- + Insensitive to tip-tilt errors
- + Small inner working angle
- + Potentially high contrast
- + Full coverage around star
- + Achromatic
- + Extreme phase patterns possible

First broad-band vAPP prototype



Optimized for 500 – 900 nm

*Otten et al, Optics Express, (2014)
Phase design by John Codona*

vAPP prototype



Otten et al, Optics Express, (2014)

vAPP prototype



Otten et al, Optics Express, (2014)

vAPP prototype



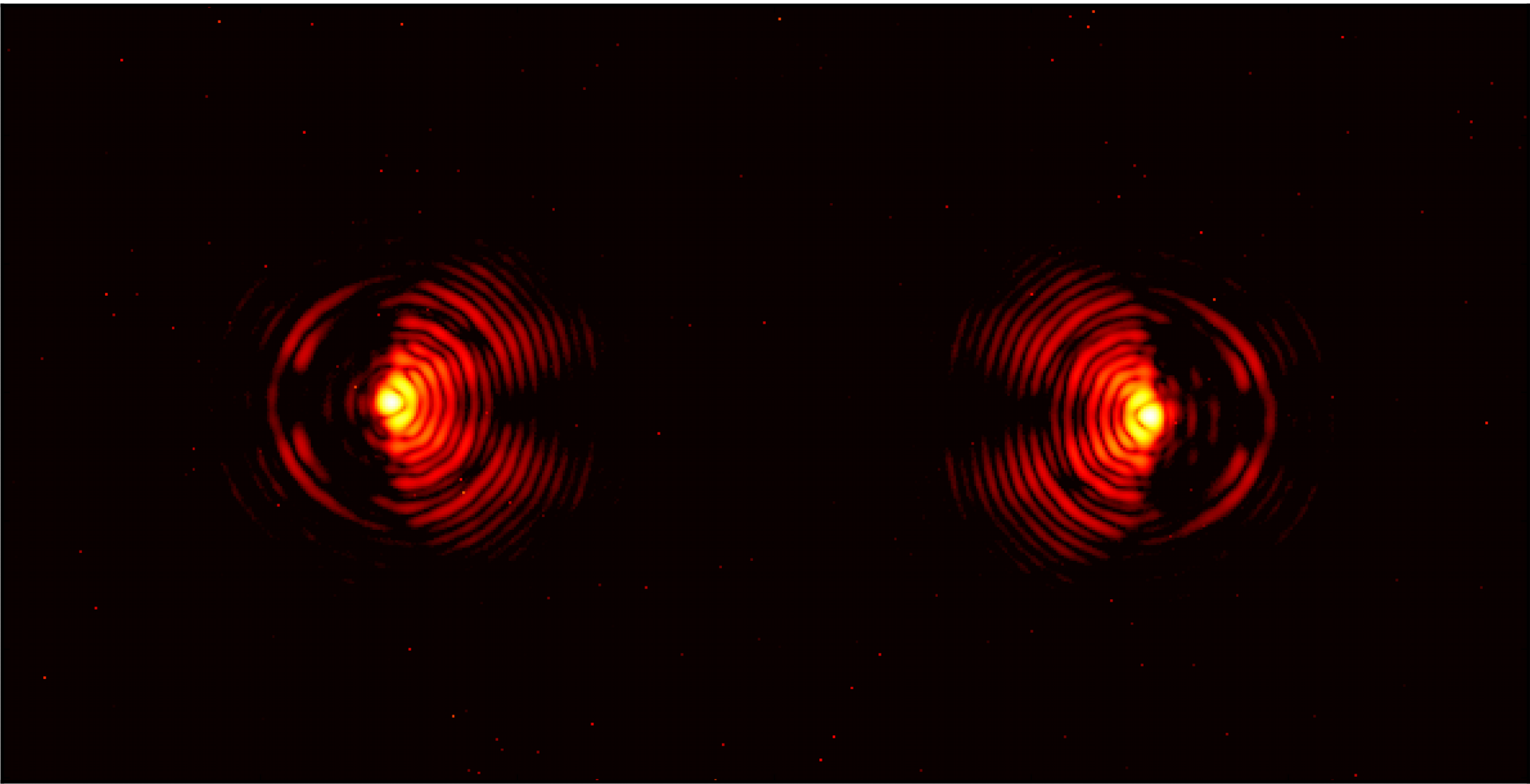
Otten et al, Optics Express, (2014)

vAPP prototype

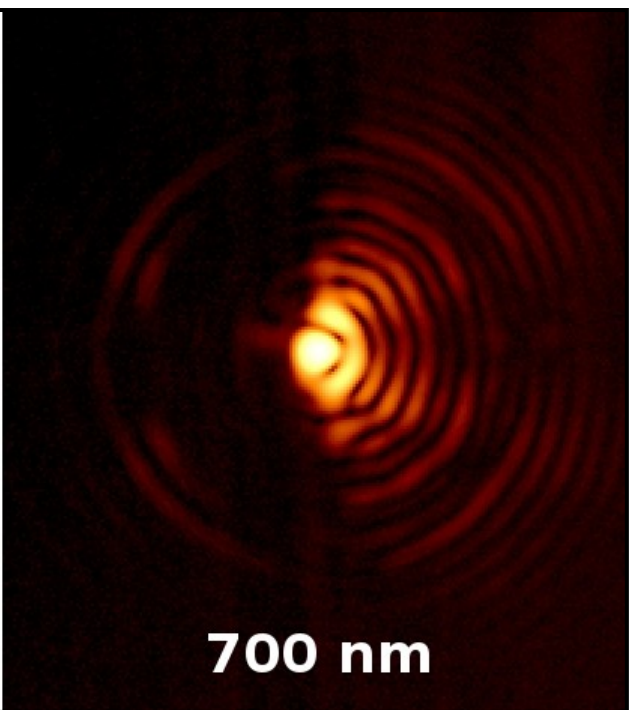
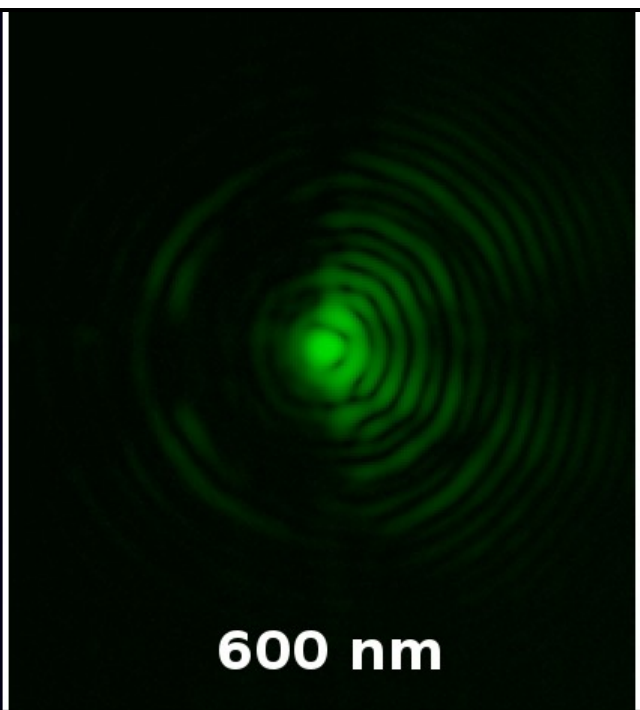
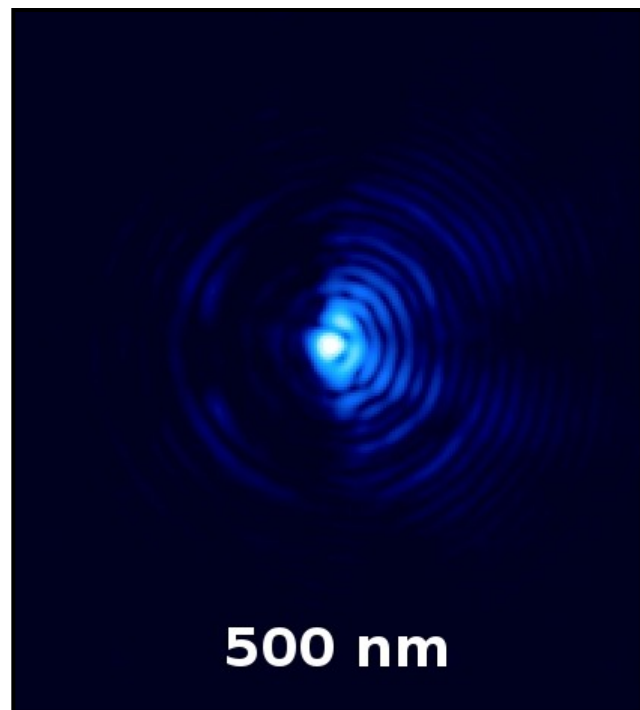


Otten et al, Optics Express, (2014)

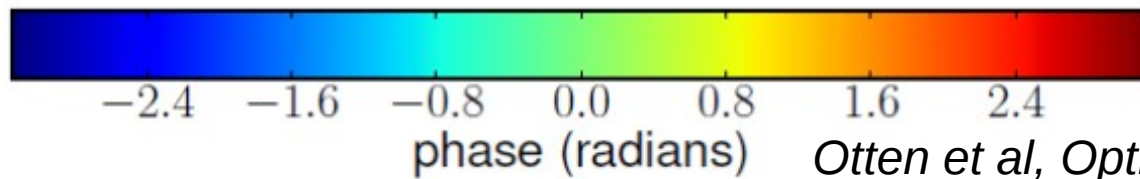
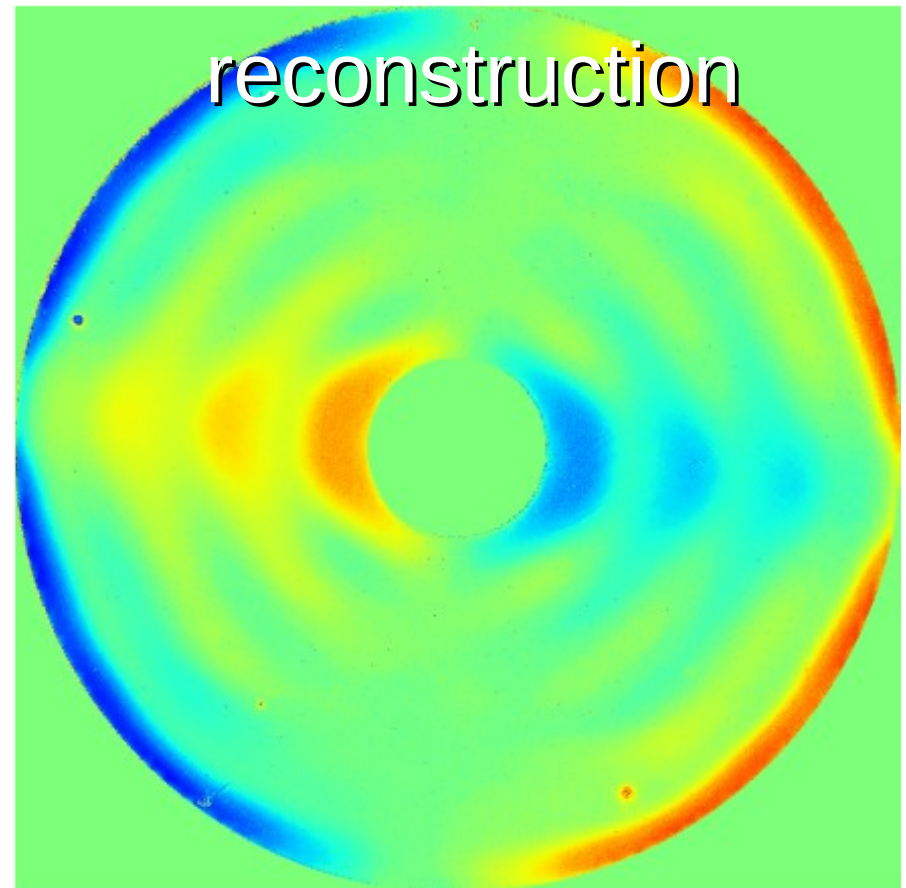
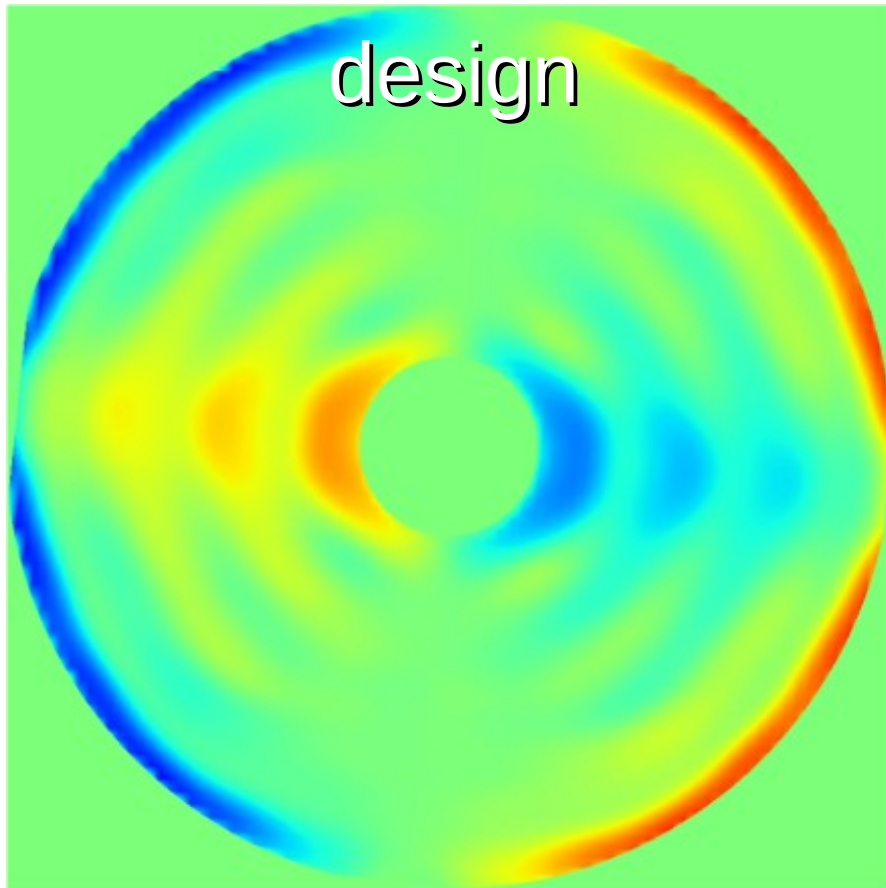
vAPP prototype



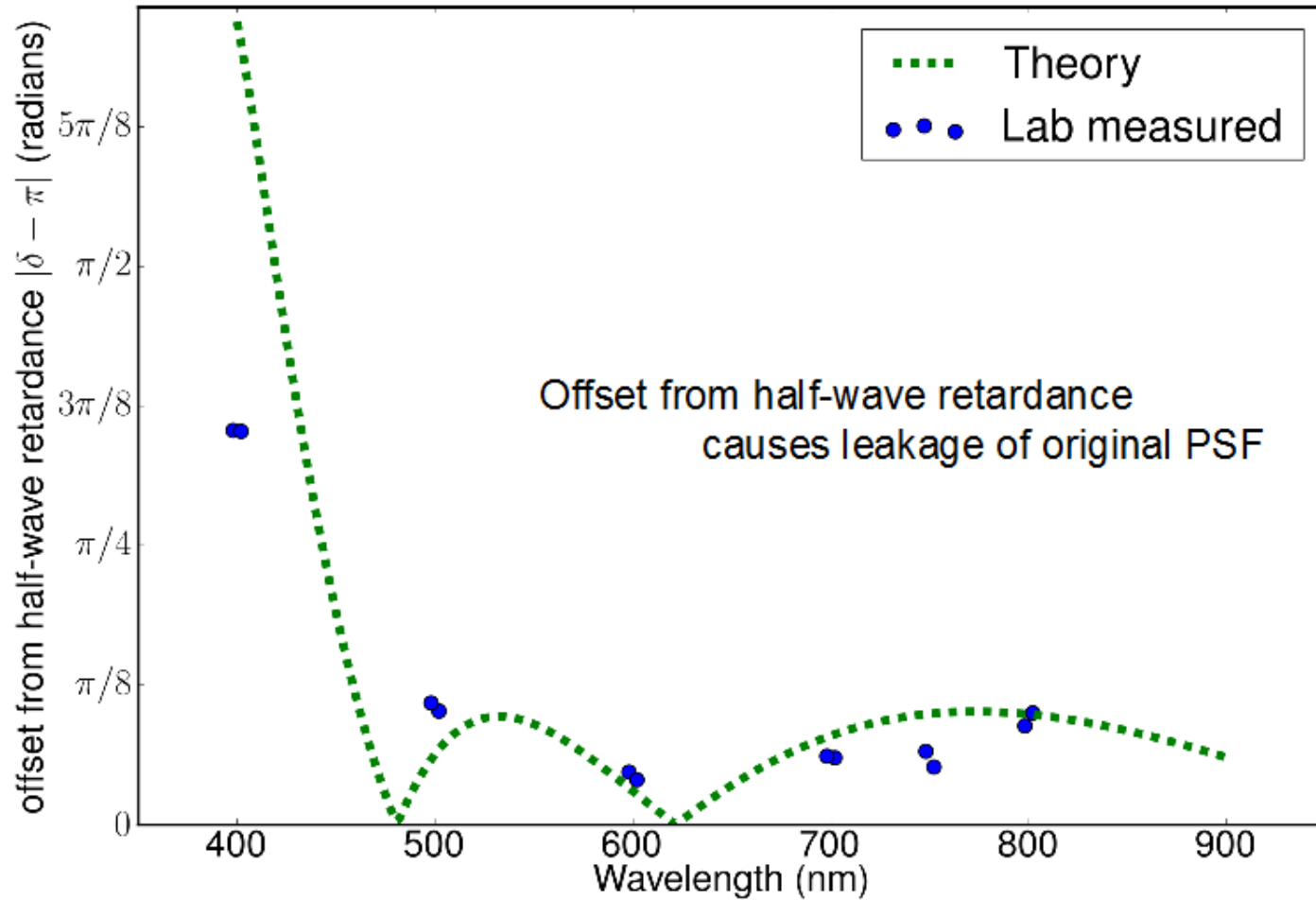
Otten et al, Optics Express, (2014)



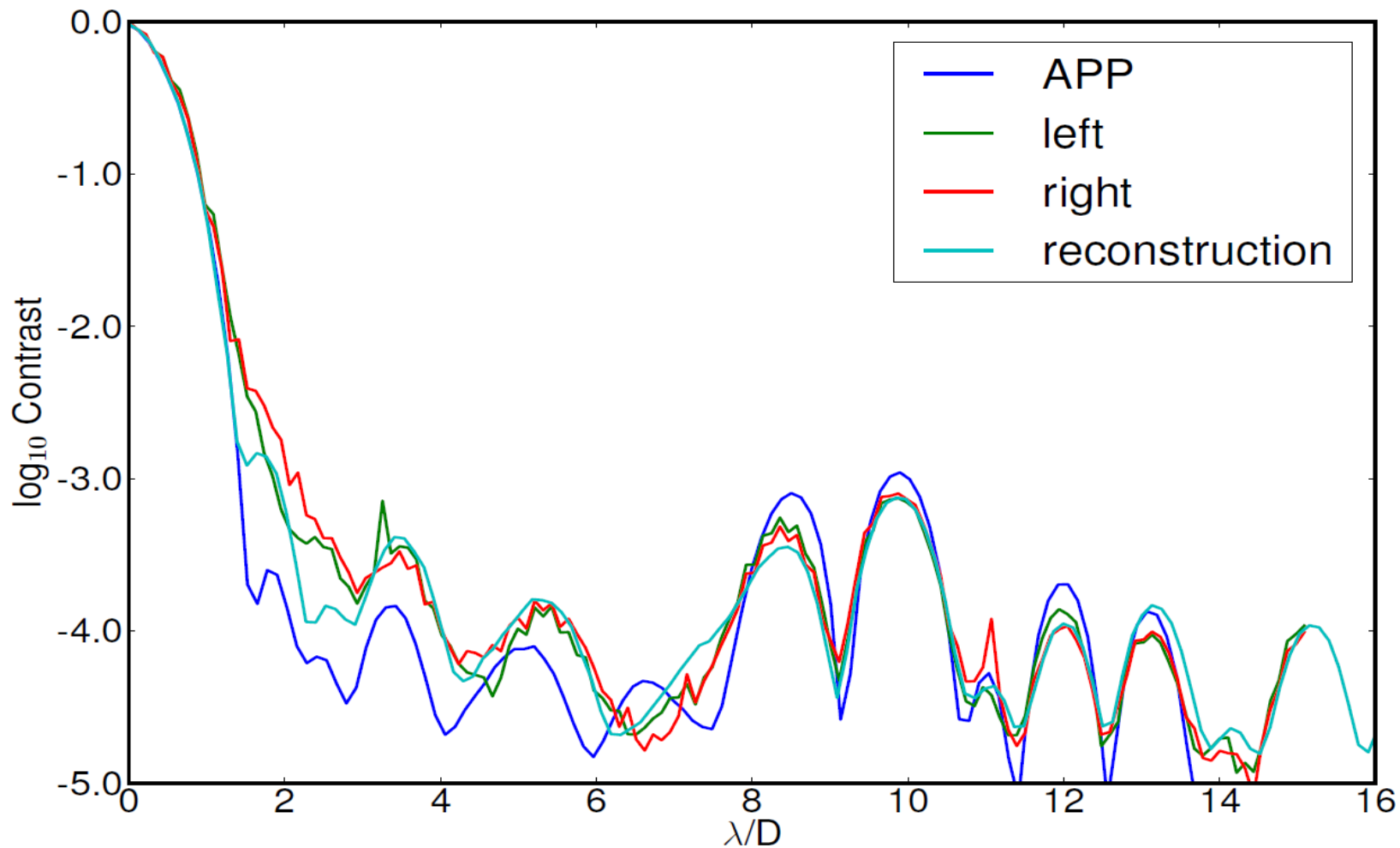
Phase map



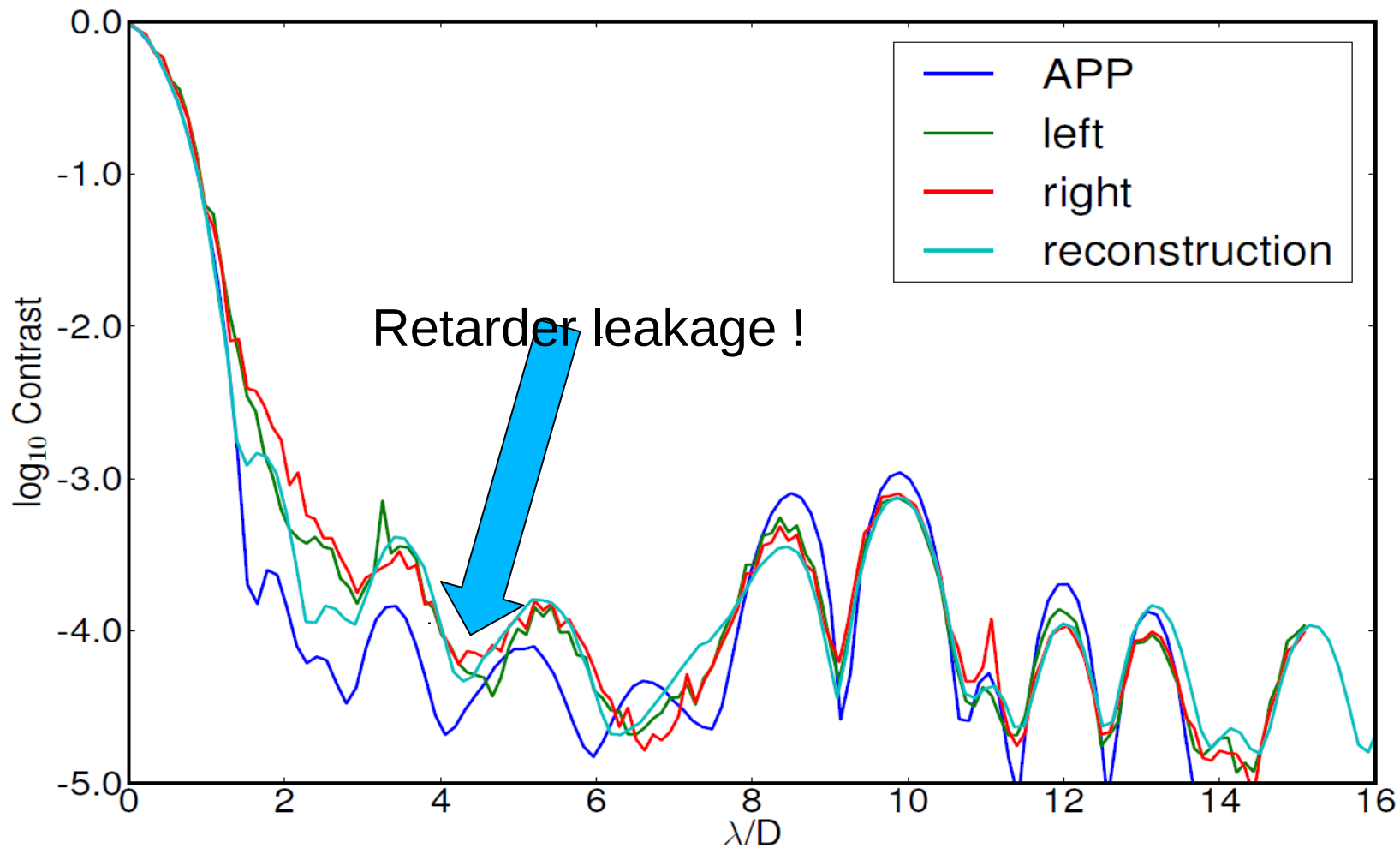
Retardance vs wavelength



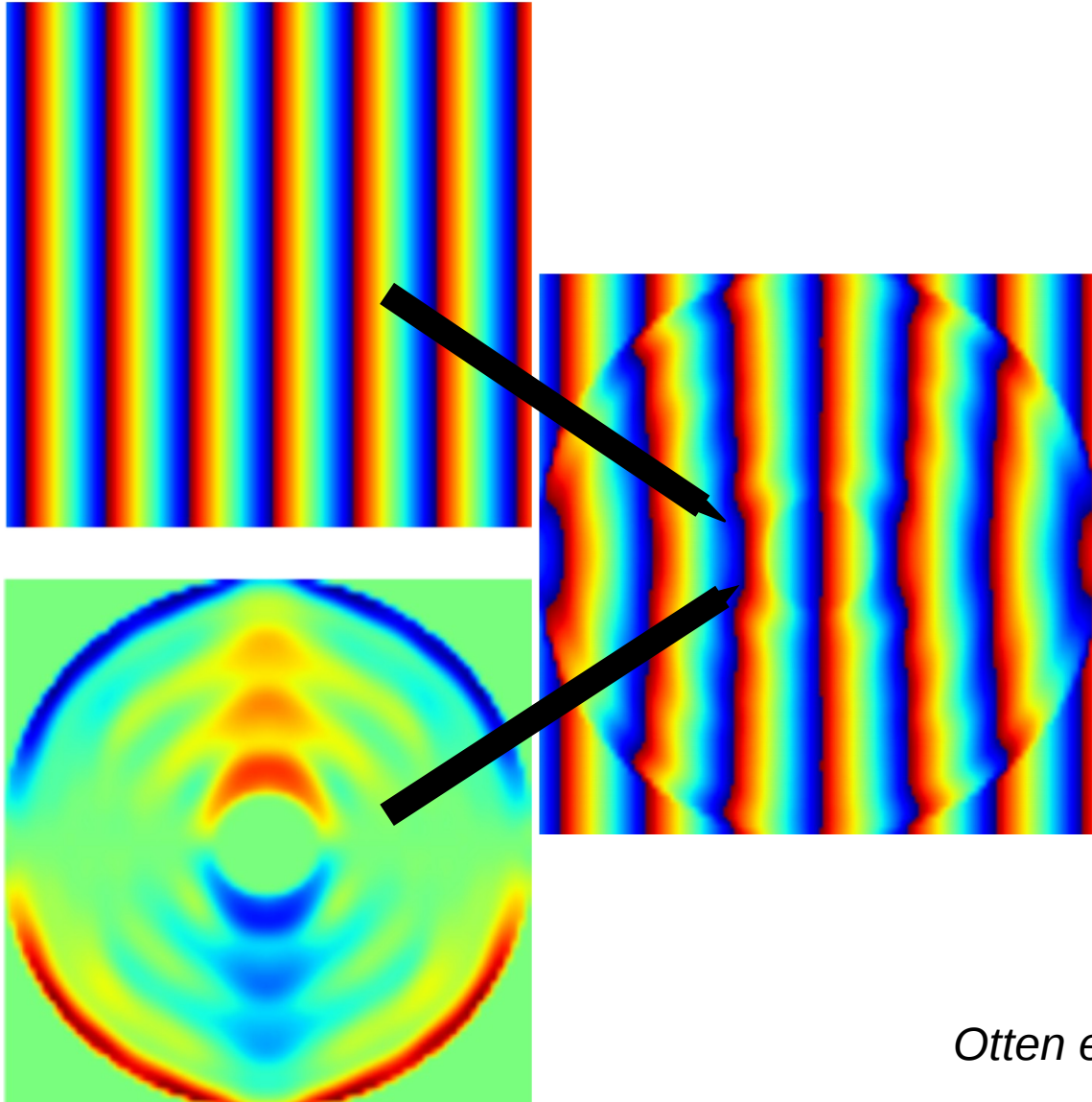
Intensity profile



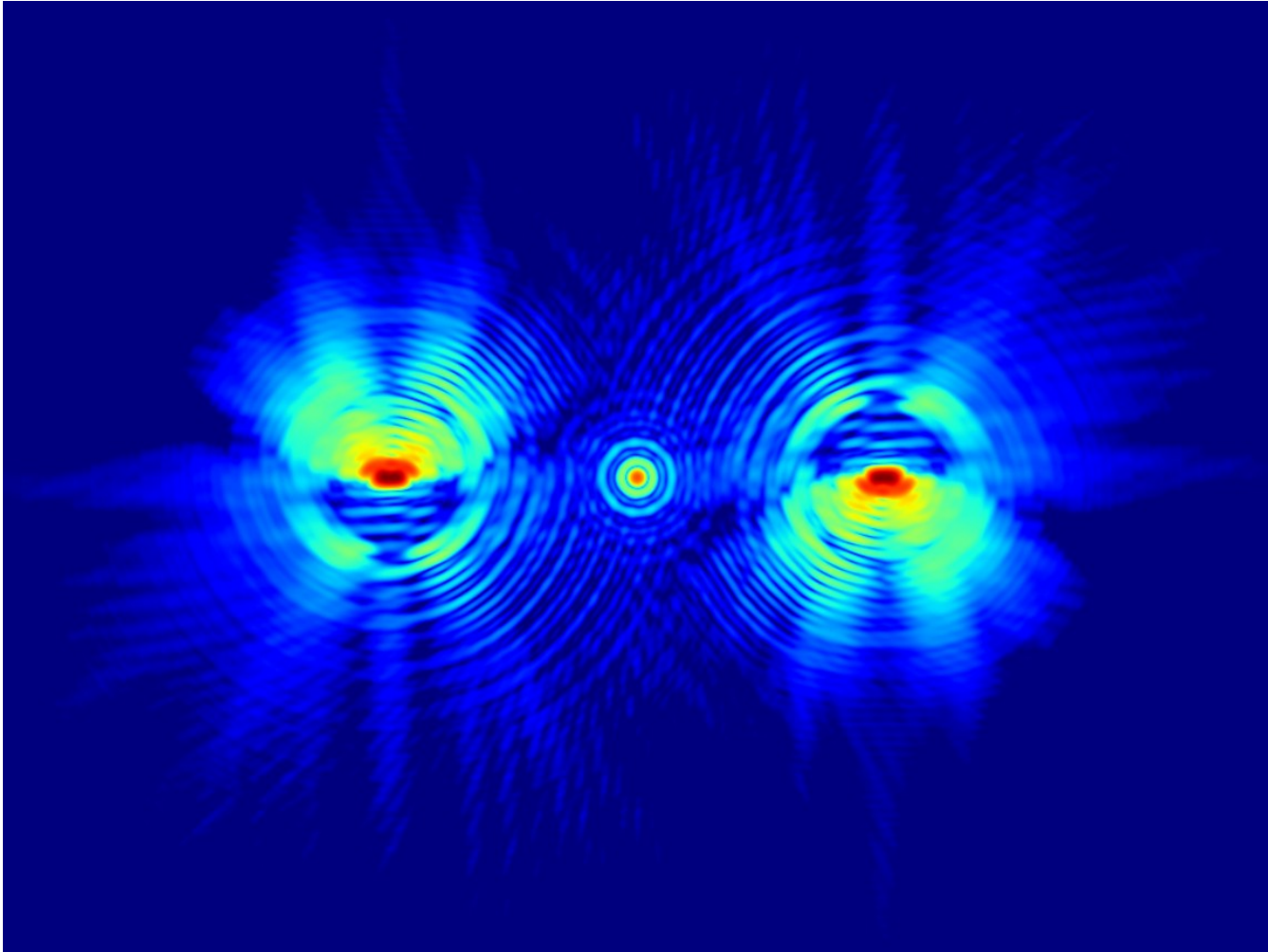
Intensity profile



grating-vAPP (gvAPP)



grating-vAPP (gvAPP)

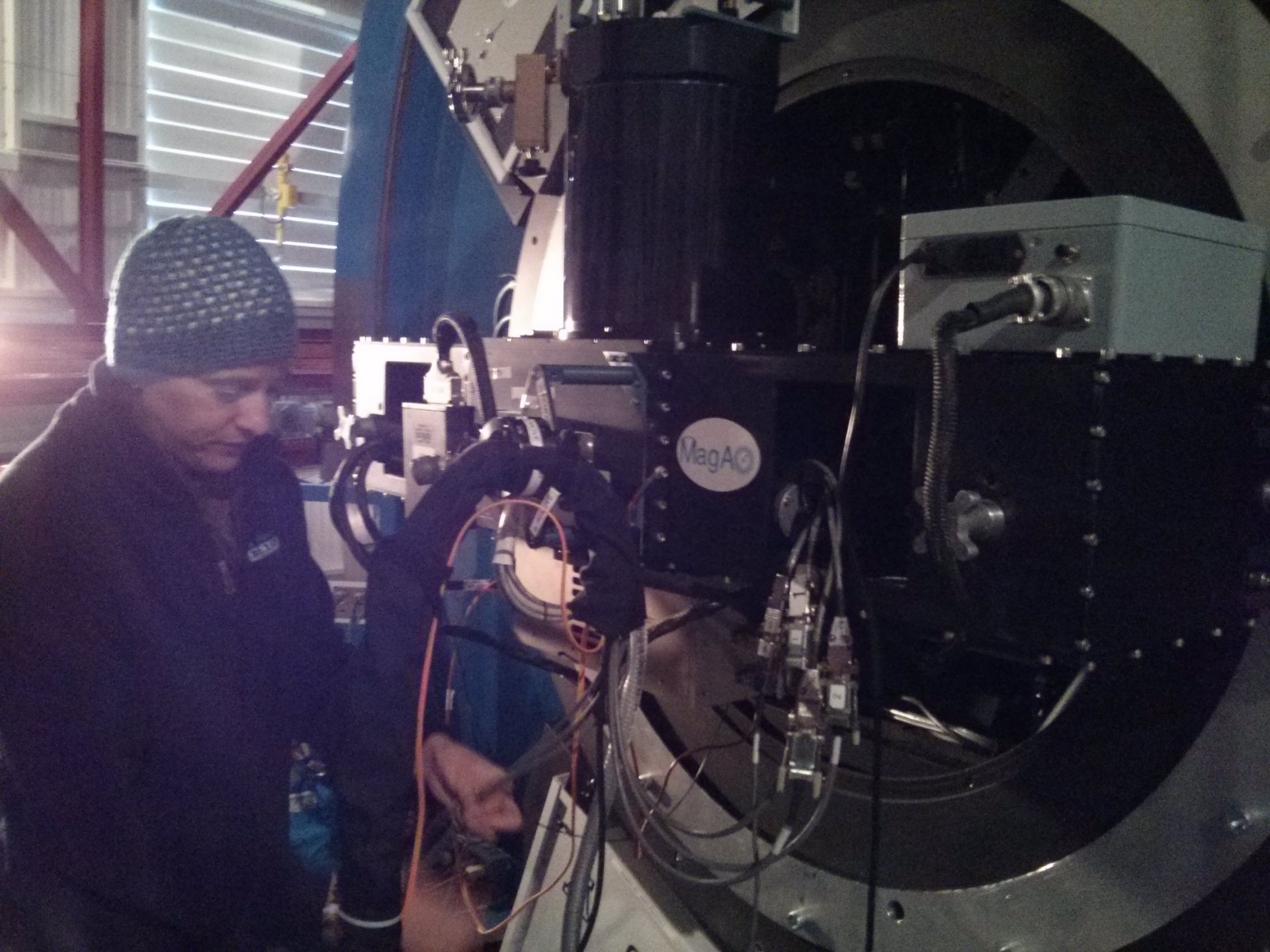


Otten et al, SPIE, 2014

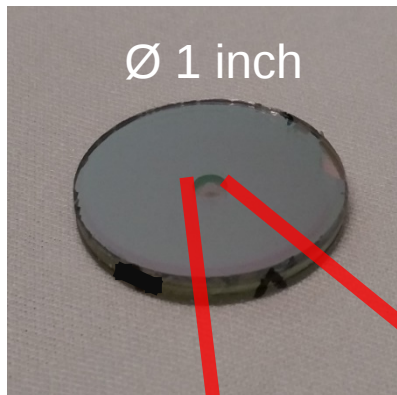
Clay/MagAO



CLAY 6.5 METER TELESCOPE

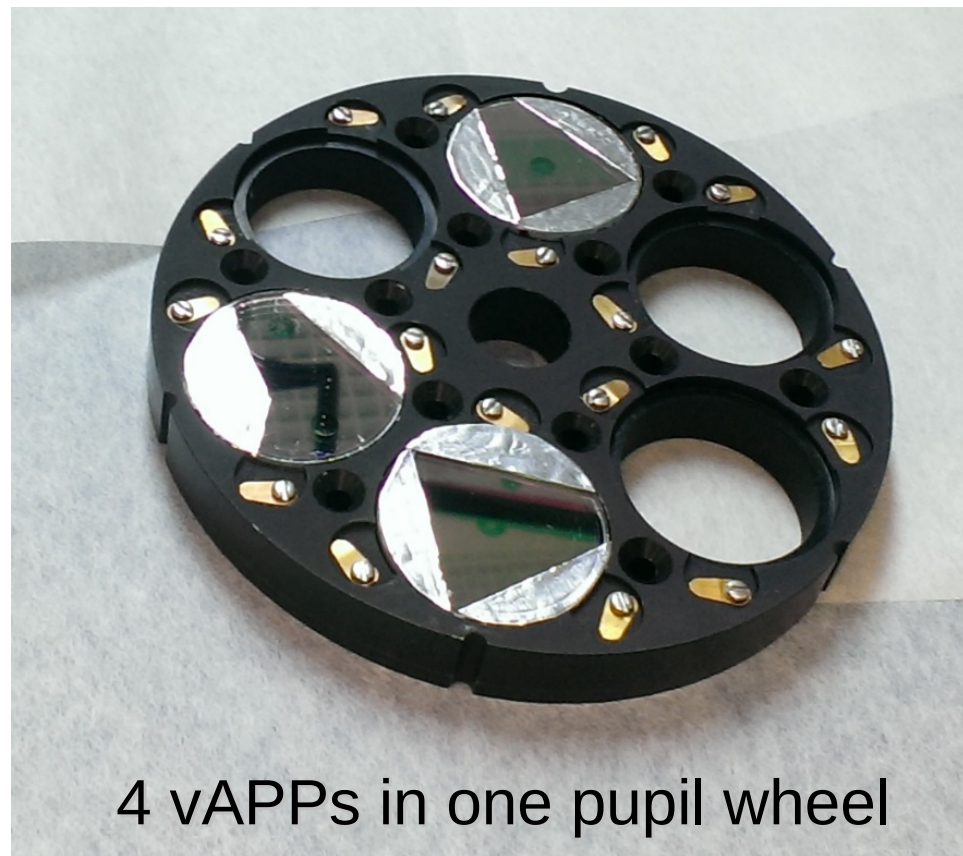
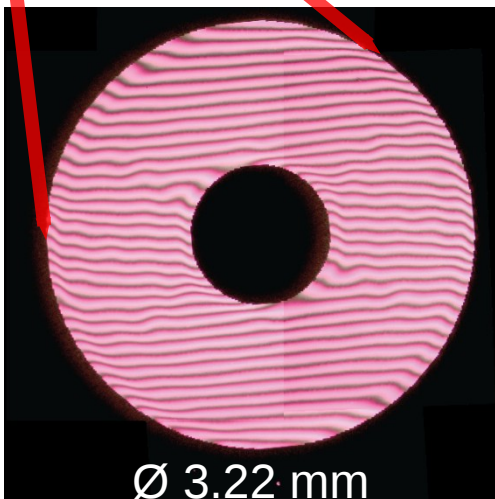


Installation



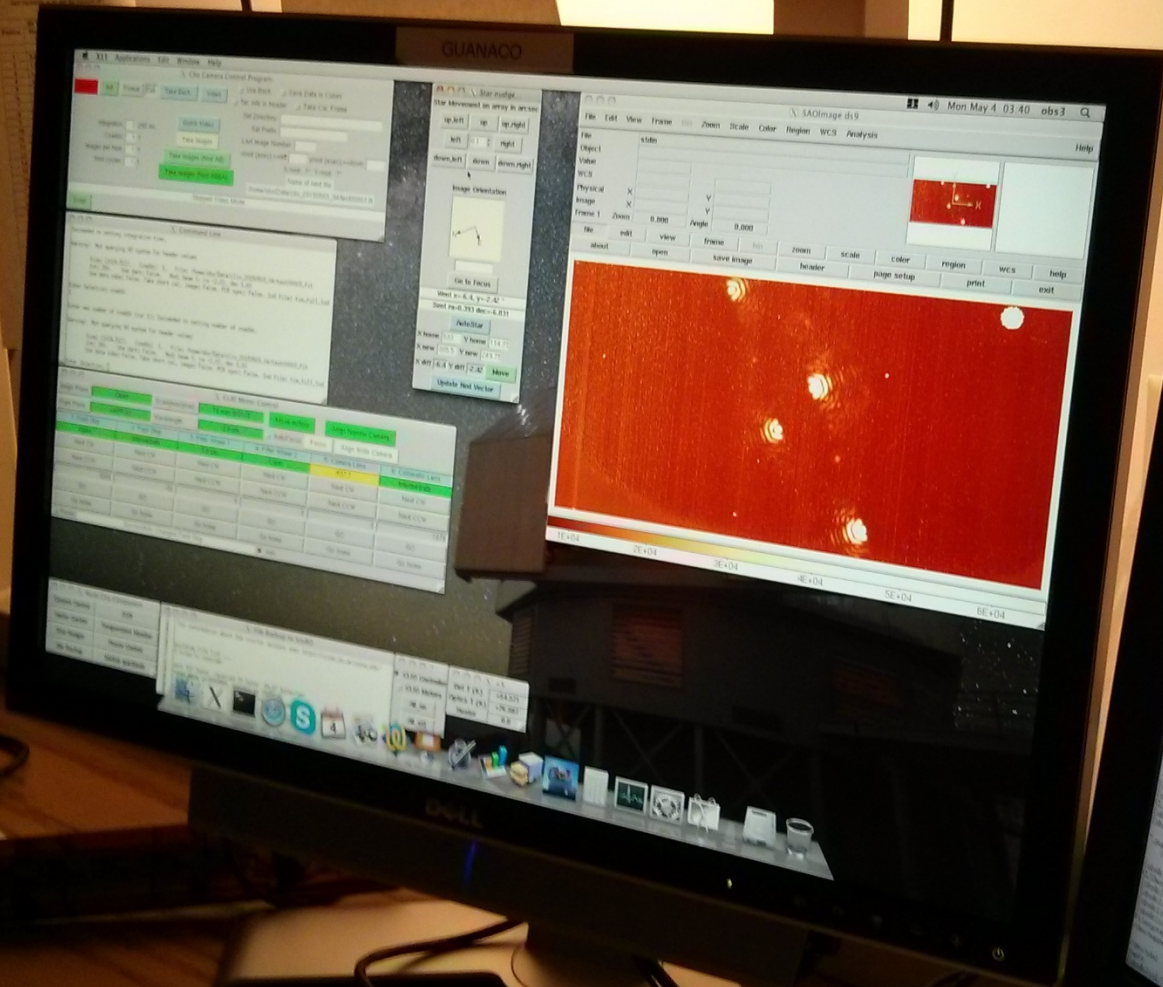
*ImagineOptix &
Geometric-Phase
Photonics Lab NCSU*

*Phase design by
Christoph U. Keller*



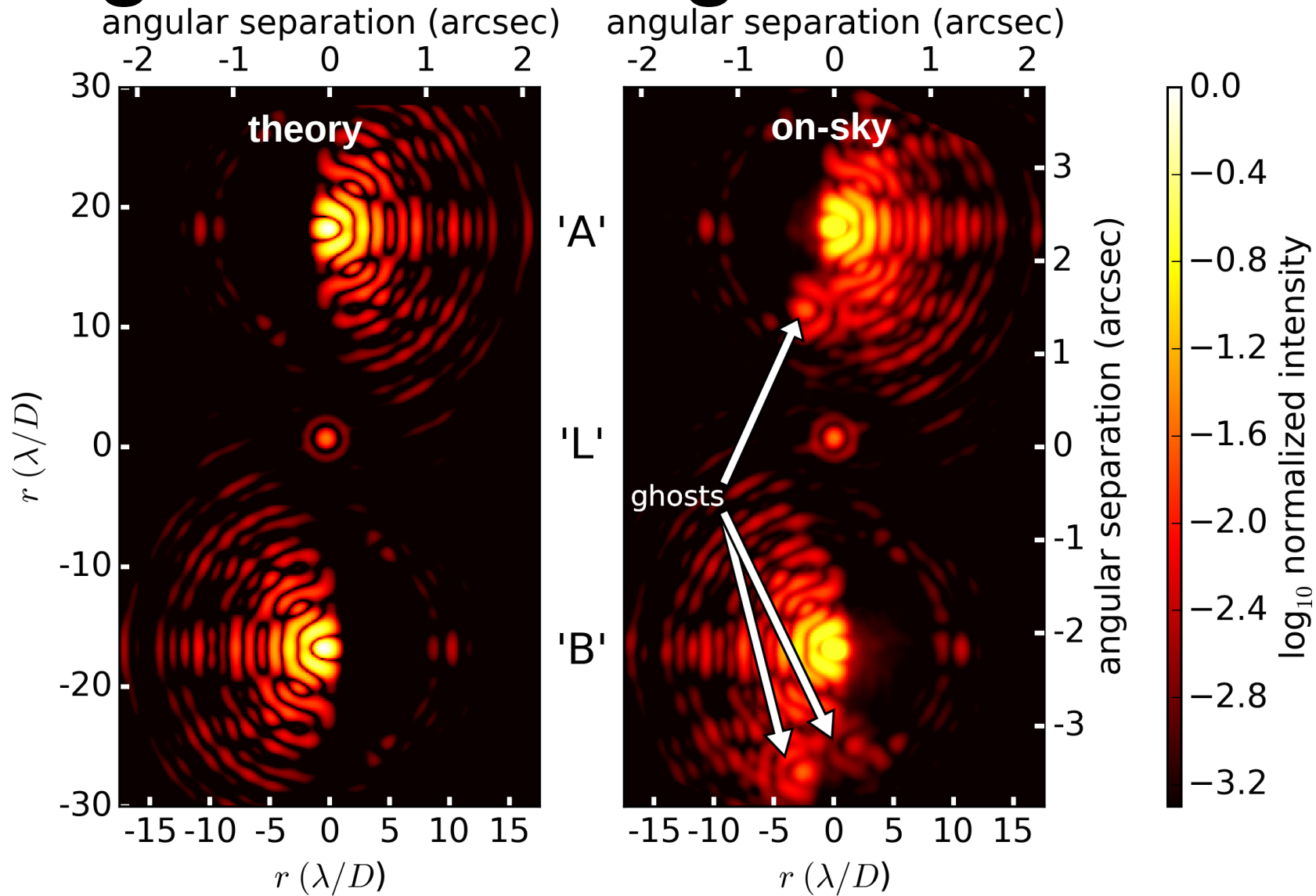
Jared Males

First light at MagAO – May 2015

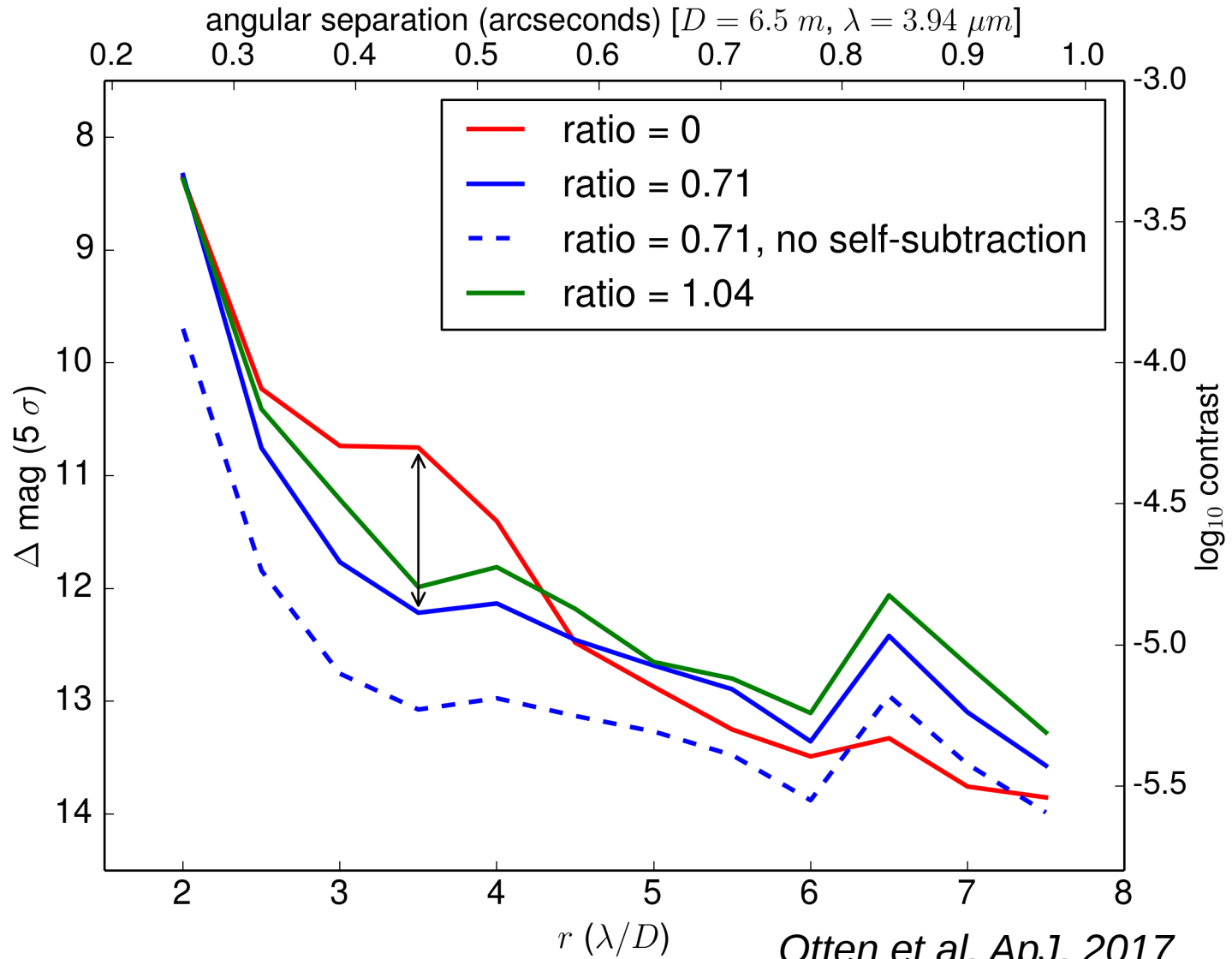


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171 # 201SA
172 pupil.pos add command -label "vAPP A1" -command {definepos 2 2}
173 # 201SA
174 pupil.pos add command -label "vAPP A2" -command {definepos 2 3}
175 pupil.pos add command -label "f/37.7" -command {definepos 2 4}
176 # pupil.pos add command -label "3 hole NRM" -command {definepos 2 5}
177 # 201SA
178 pupil.pos add command -label "vAPP B1 & B2" -command {definepos 2 5}
179 # pupil.pos add command -label "6 hole NRM" -command {definepos 2 6}
180
181 # pupil.pos add command -label "f/21.5" -command {set_pupil 0}
182 # pupil.pos add command -label "M APP" -command {definepos 2 6}
183 # pupil.pos add command -label "L APP" -command {set_pupil 1}
184 # pupil.pos add command -label "f/37.7" -command {set_pupil 2}
185 # pupil.pos add command -label "3 hole NRM" -command {set_pupil 3}
186 # pupil.pos add command -label "6 hole NRM" -command {set_pupil 4}
187
188 label prate -text "$posz" -relief sunken -width 20
189
190 menu selector for magnification
191 menubutton -mag -text "Scale(mus/pixel)" -relief raised -menu .mag.1
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gvAPP on MagAO/Clio2

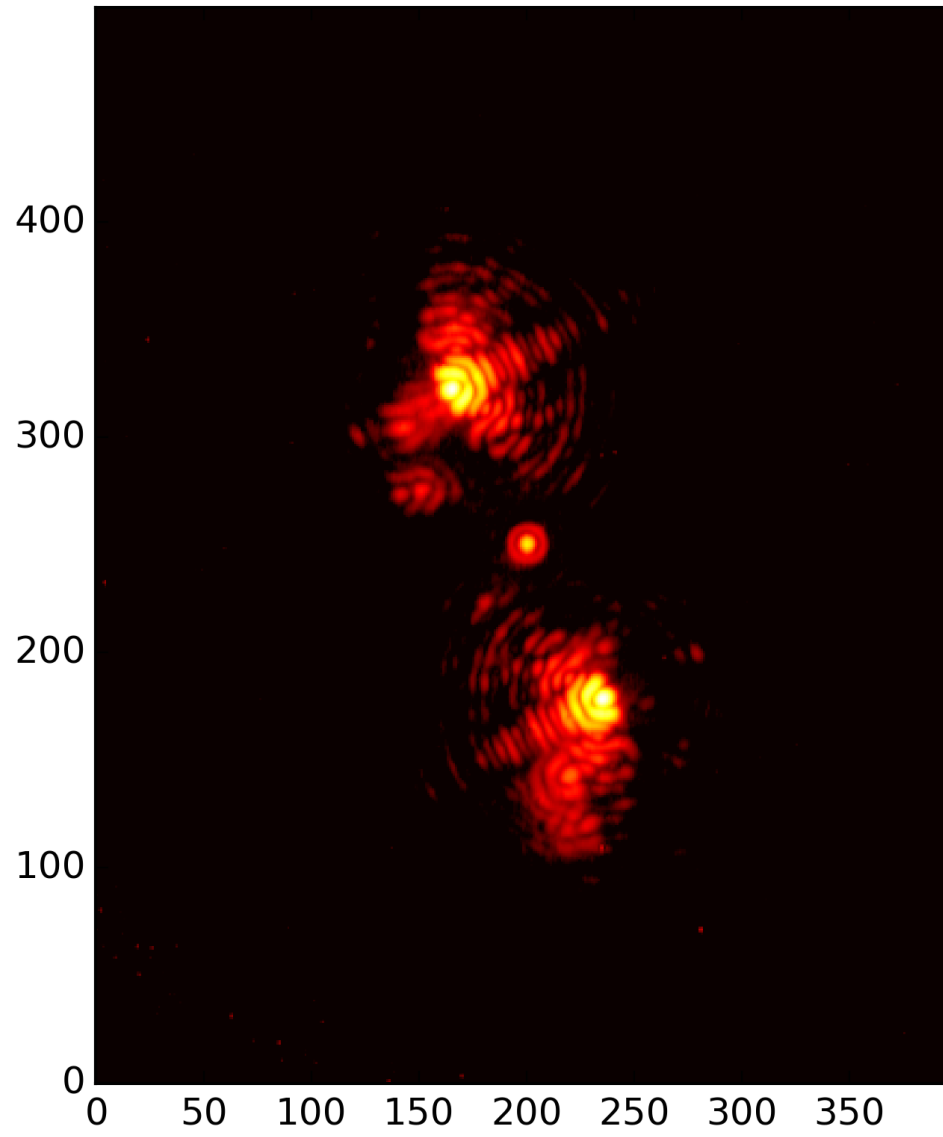


on-sky contrast



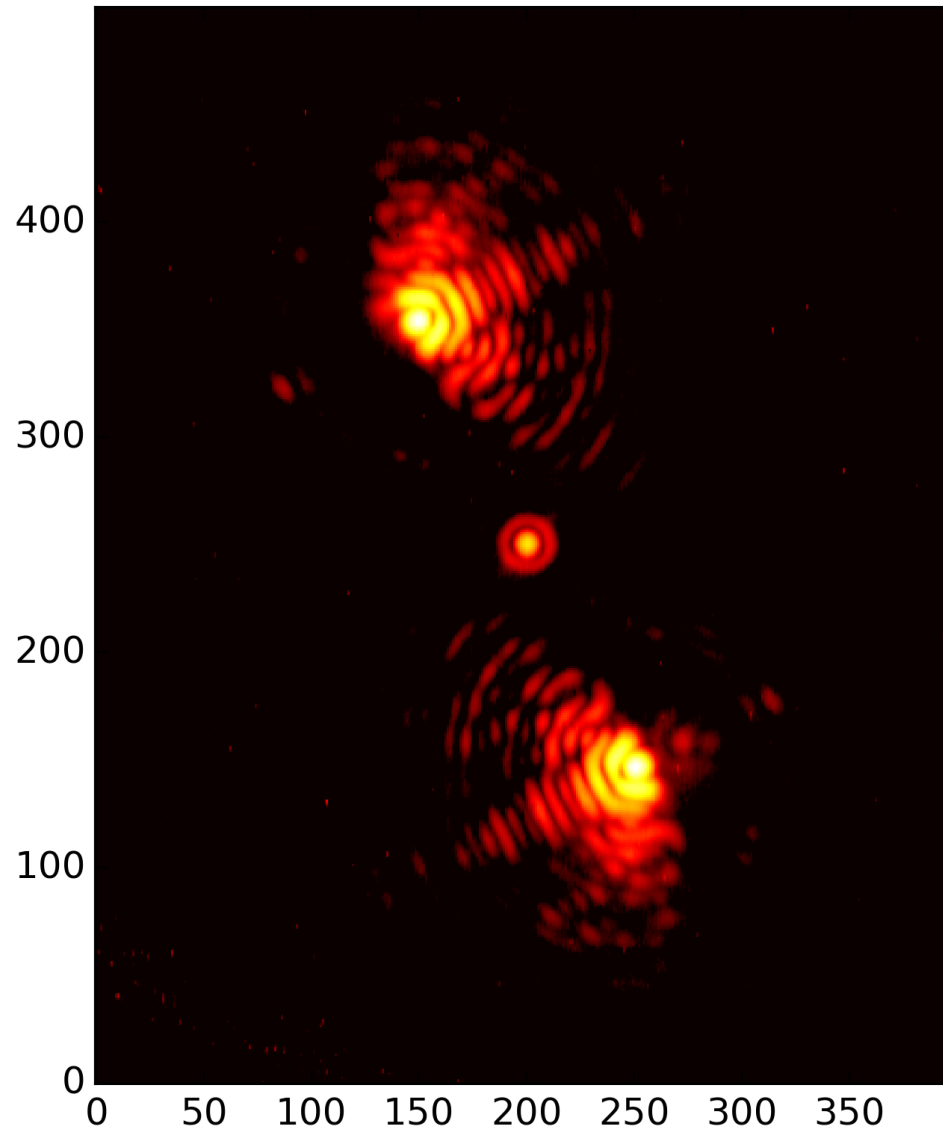
Achromatic behaviour

Br Gamma



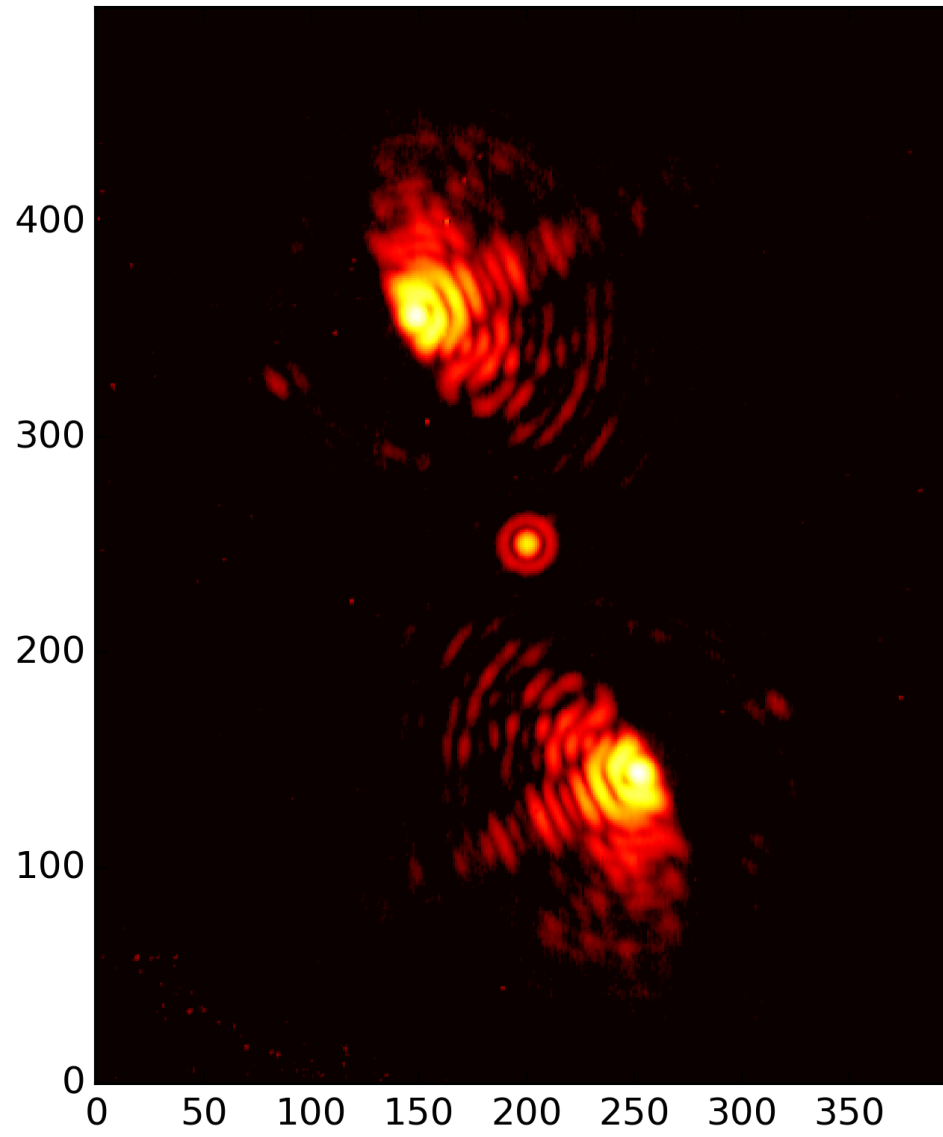
Achromatic behaviour

3.1 micron



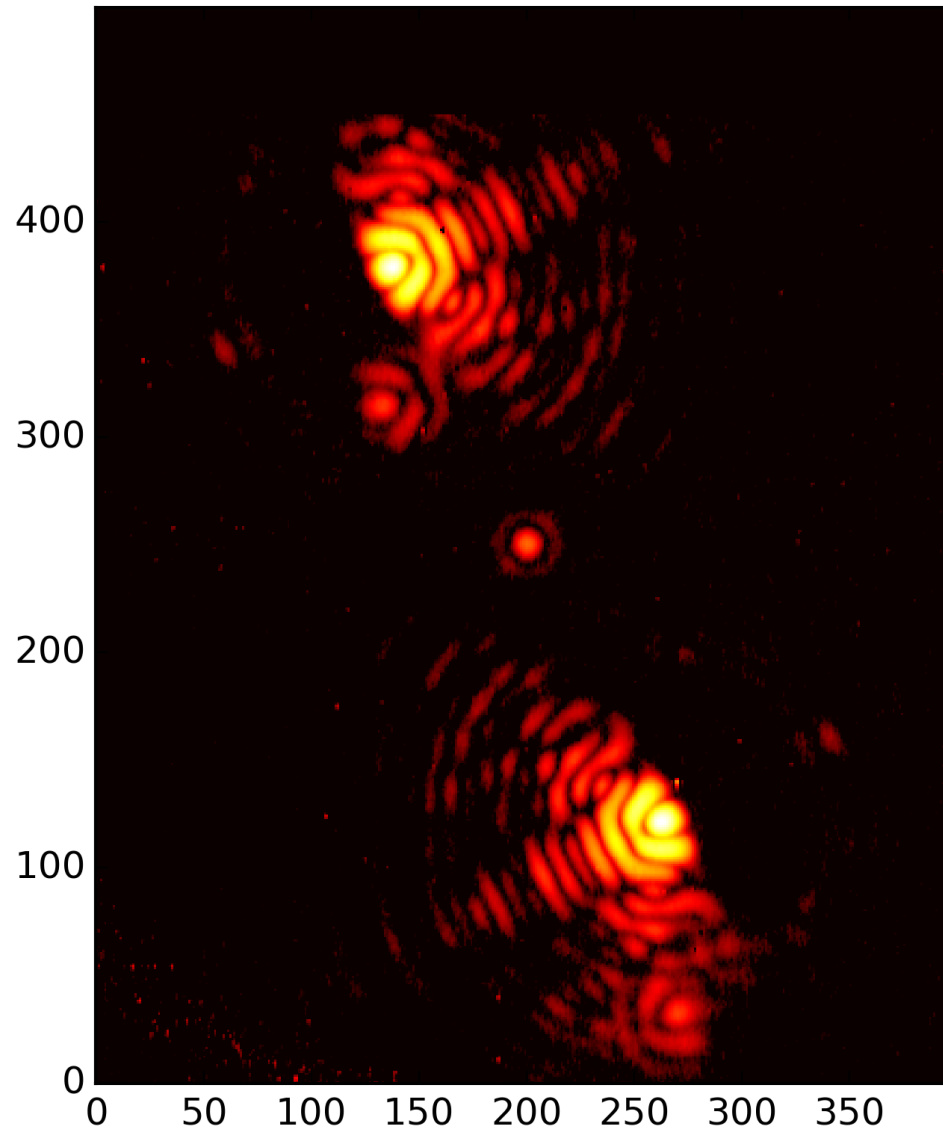
Achromromatic behaviour

3.3 micron



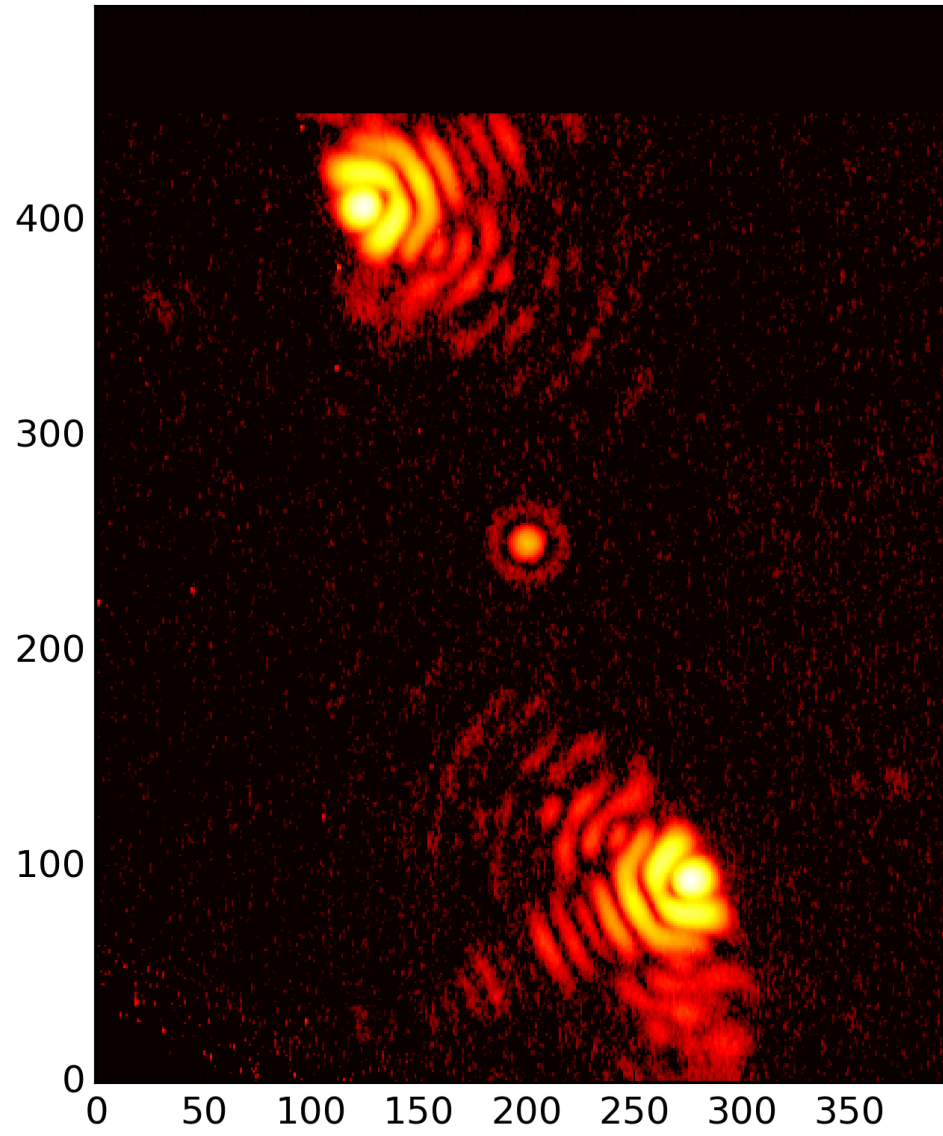
Achromatic behaviour

3.9 micron

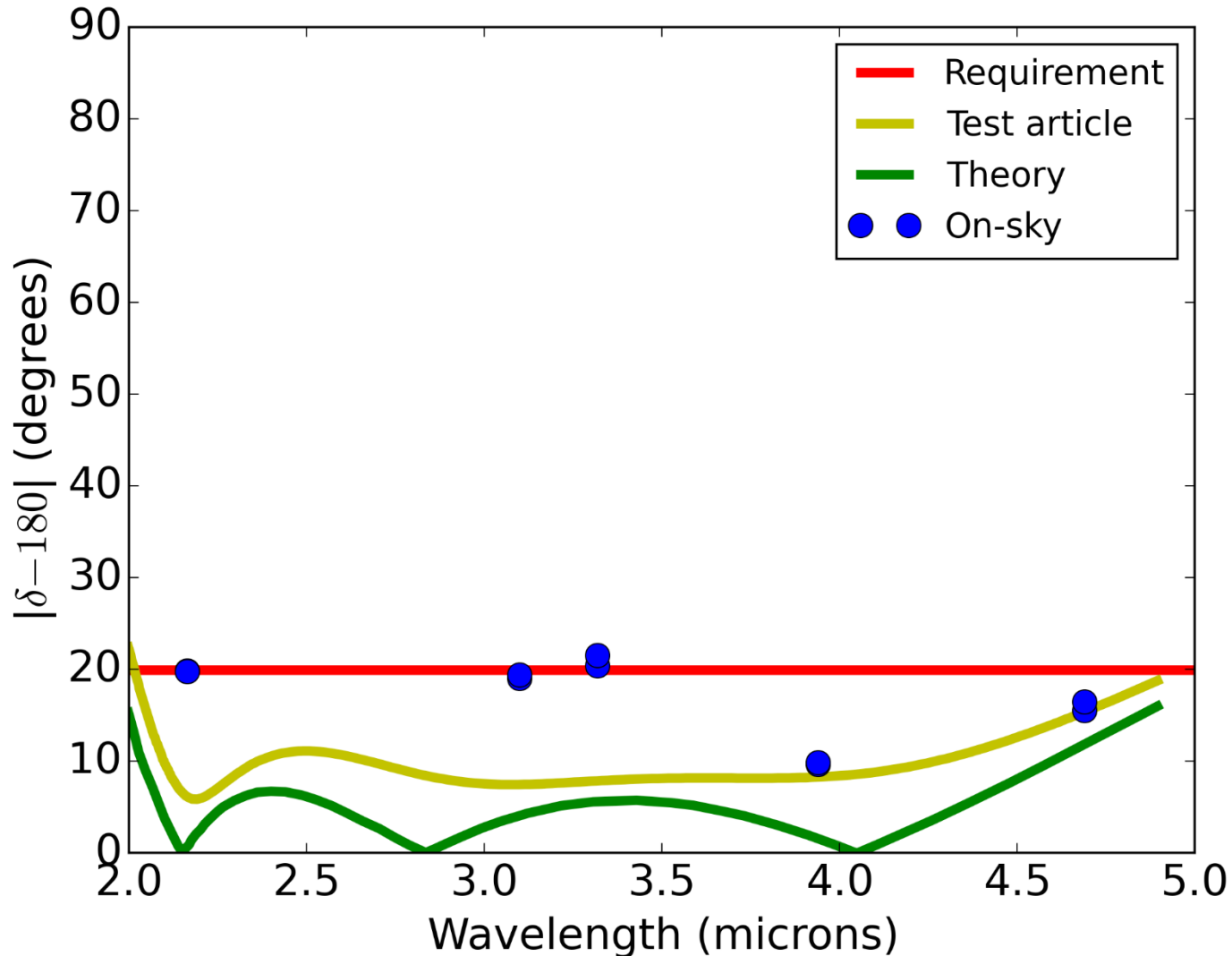


Achromatic behaviour

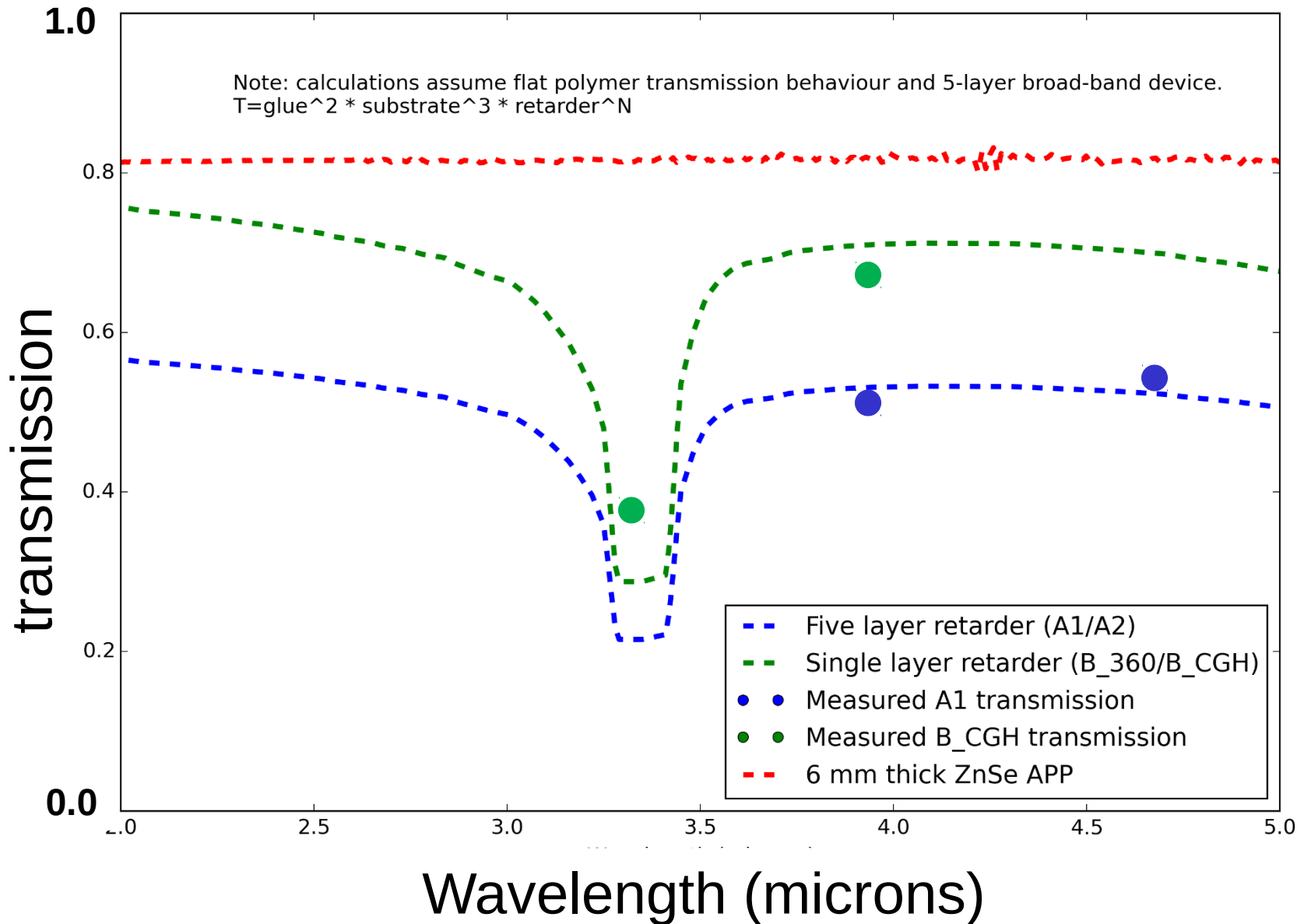
MKO M'



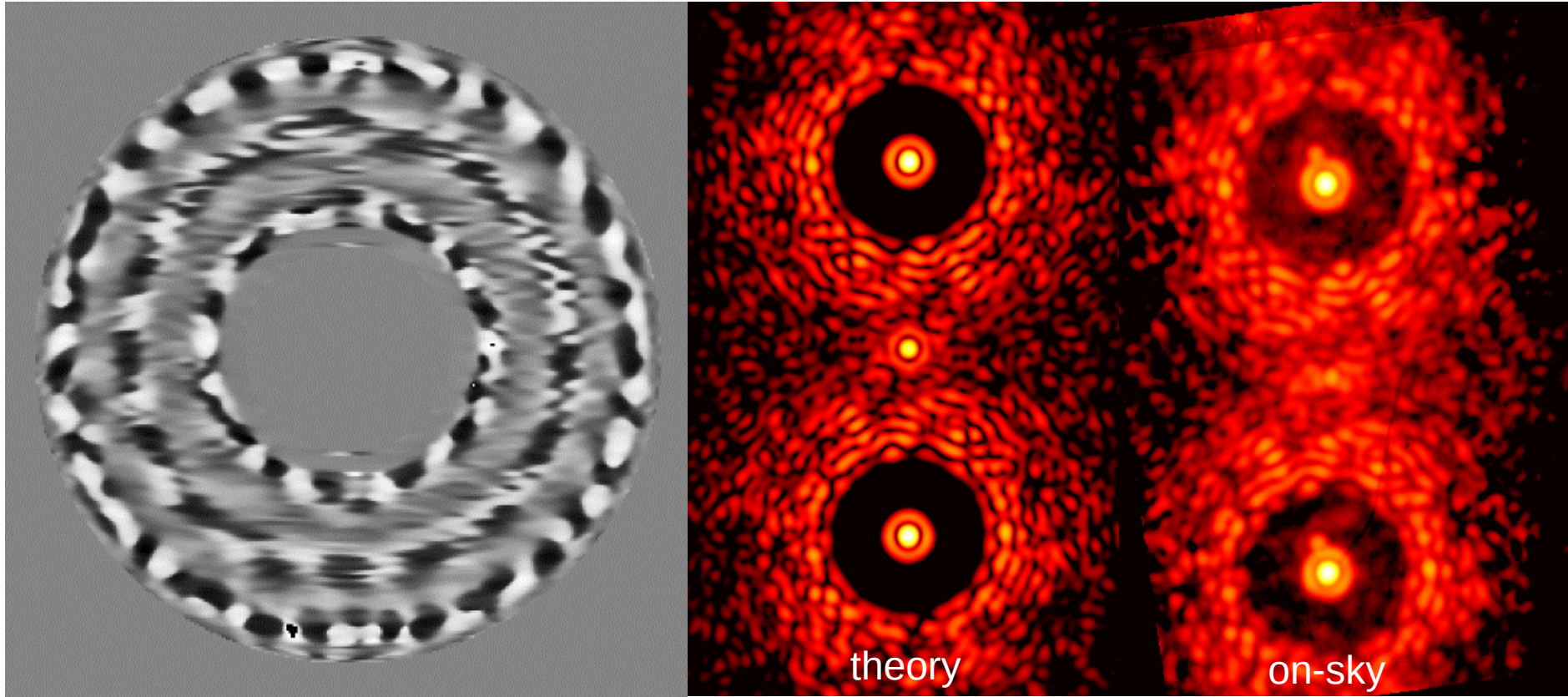
Derived retardance



Throughput



Improved phase designs



Phase pattern: Christoph U. Keller

Many more tricks and latest work with liquid crystal optics in talk by Frans Snik, Friday March 16 @ 11h, Amphi, LAM

