Coronagraph fabrication technologies: liquid crystals

M Kenworthy // Leiden Observatory

2018 April 11 // KISS JPL/MPIA Workshop

LEOPARD

C Keller

V Radhakrishnan

Maaike van Kooten

Emiel Por

David Doelman

Mike Wilby

Sebastiaan Haffert

Stephanie Heikamp

Steven Bos

M Kenworthy

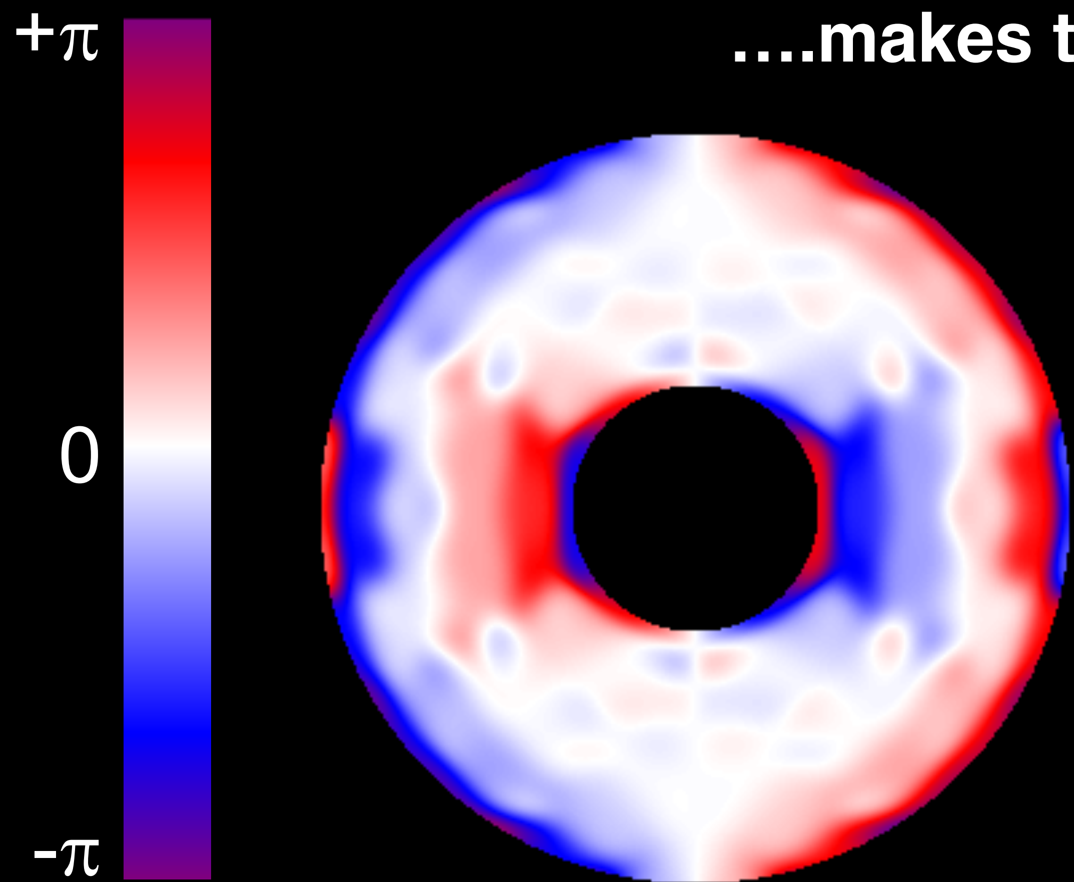
N Doelman

F Snik

R Stuik

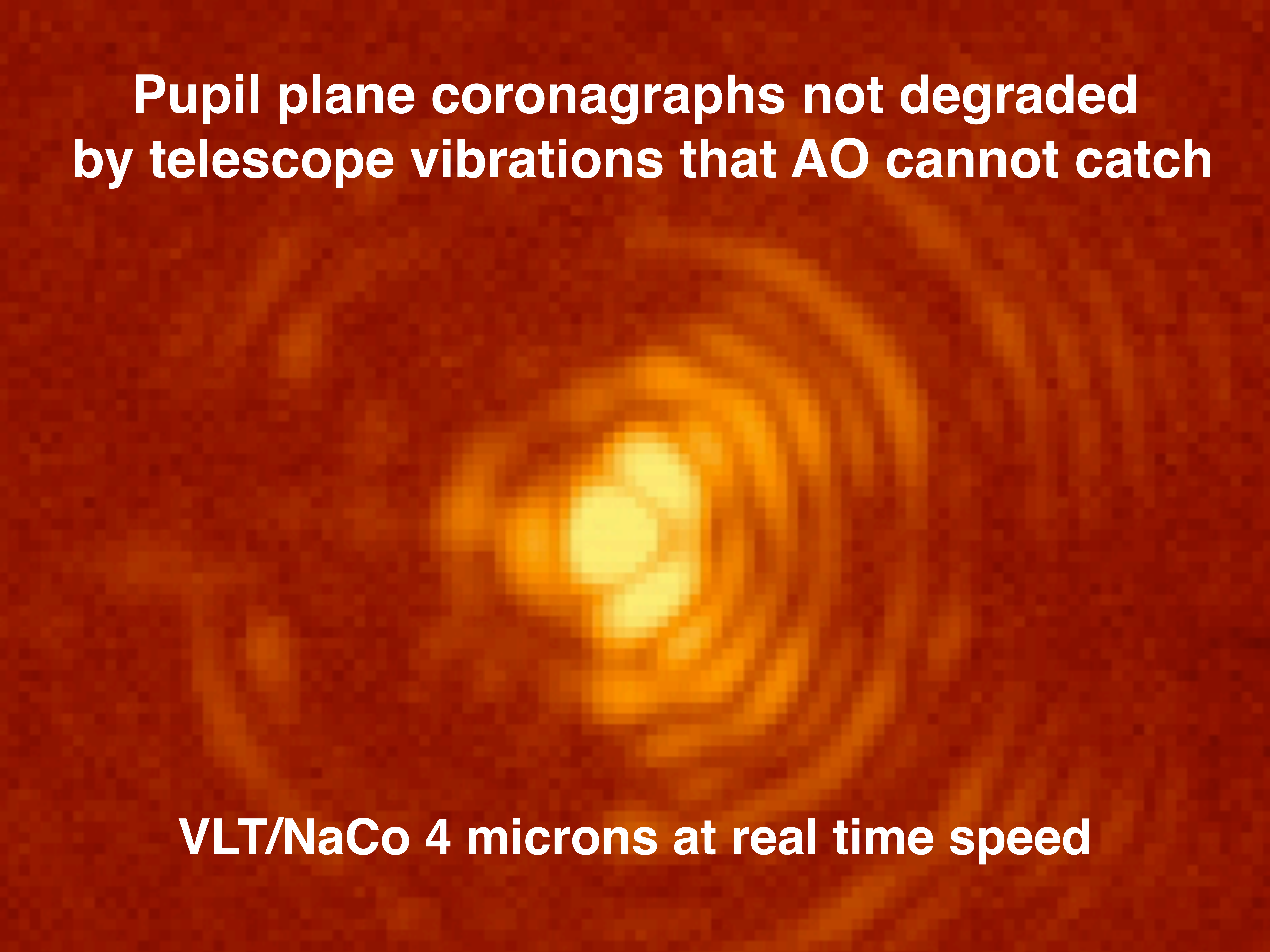
Apodizing Phase Plate (APP)

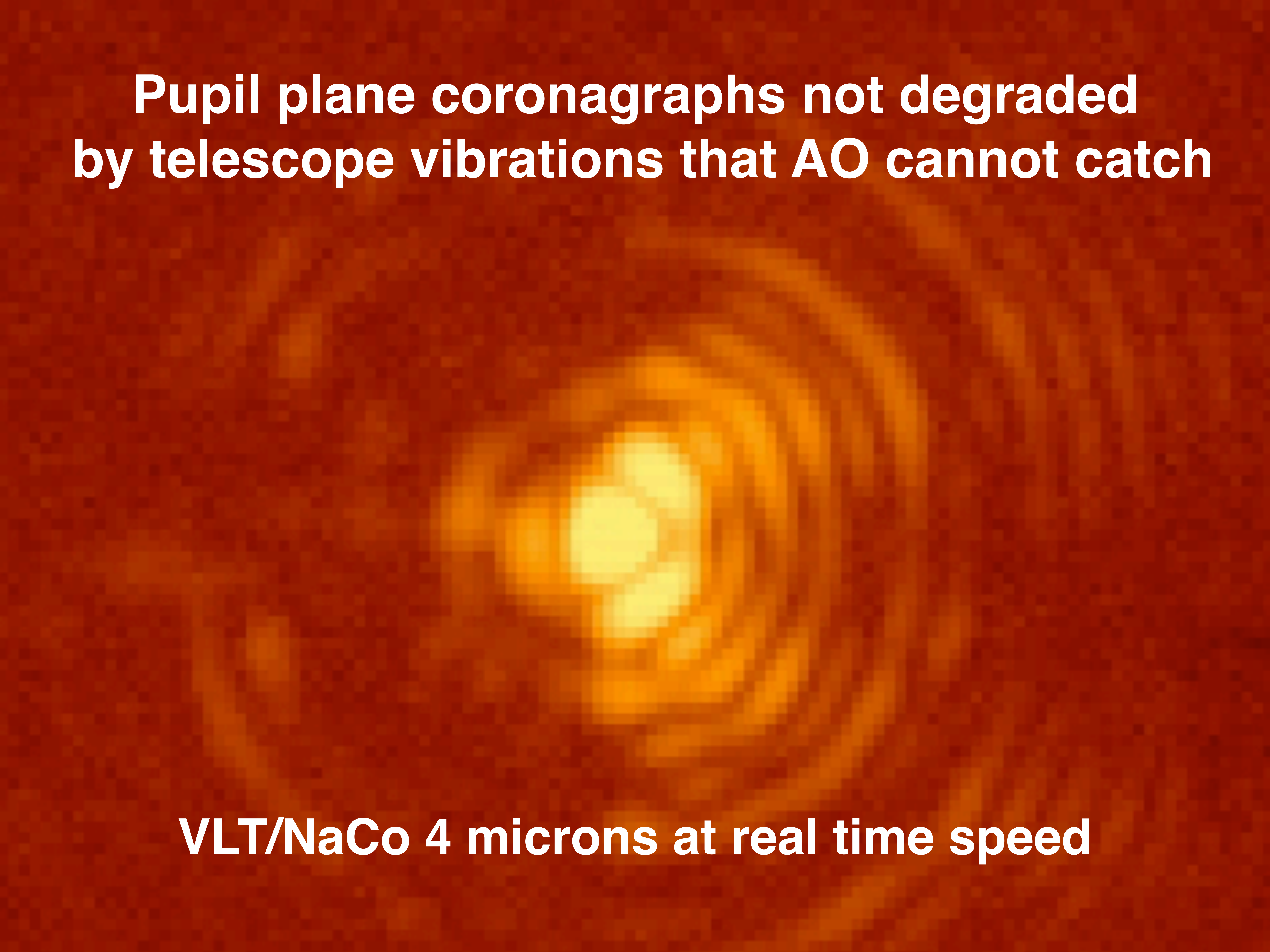
Adding this phase on your telescope pupil…..



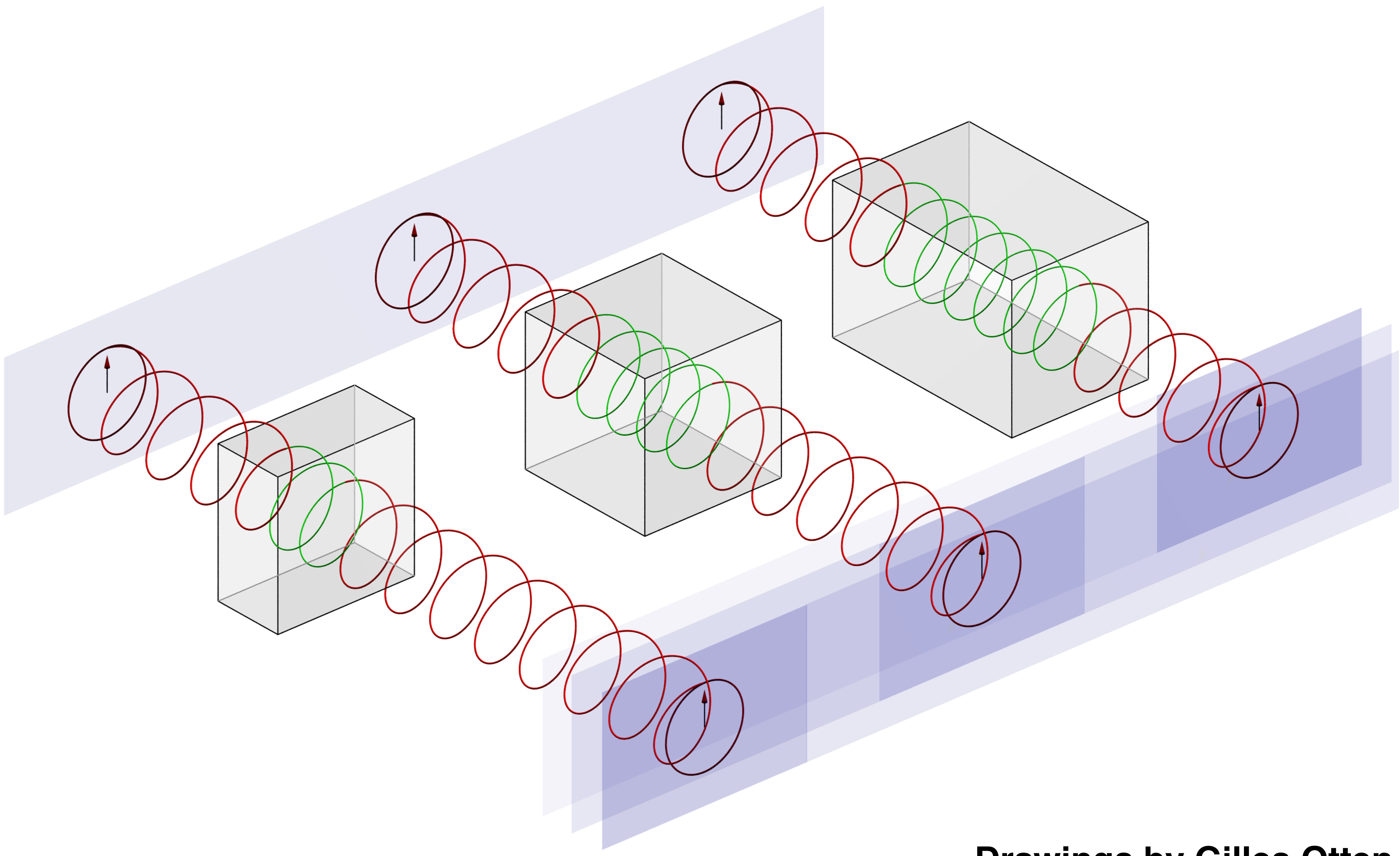
….makes this PSF for all objects in your focal plane

- **Chromatic**
- **Impossible to make complex patterns**
- **Only 180 degree search space**


Pupil plane coronagraphs not degraded
by telescope vibrations that AO cannot catch
VLT/NaCo 4 microns at real time speed

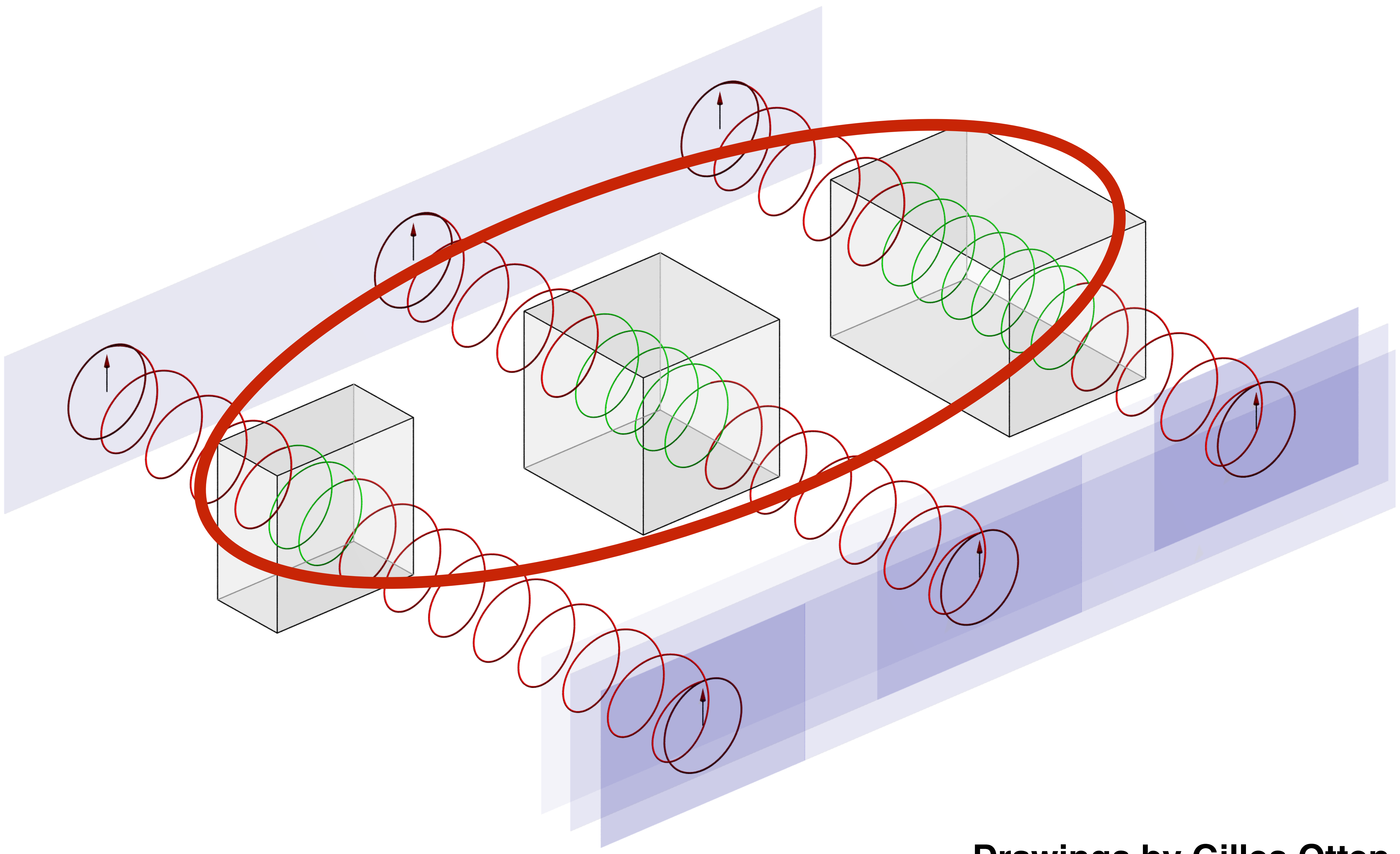

Pupil plane coronagraphs not degraded
by telescope vibrations that AO cannot catch
VLT/NaCo 4 microns at real time speed

Classical Phase



Drawings by Gilles Otten

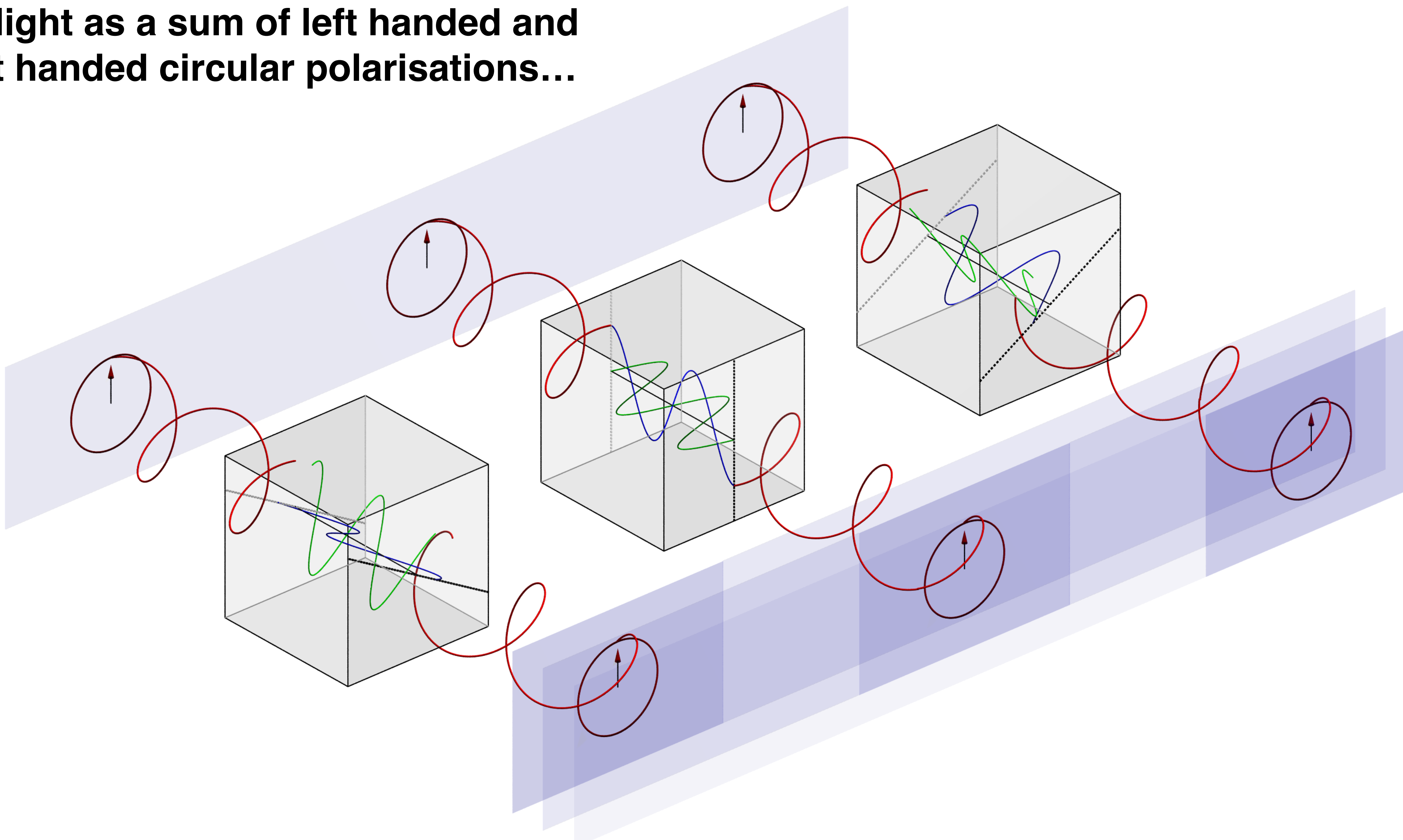
Classical Phase



Drawings by Gilles Otten

Geometric Phase

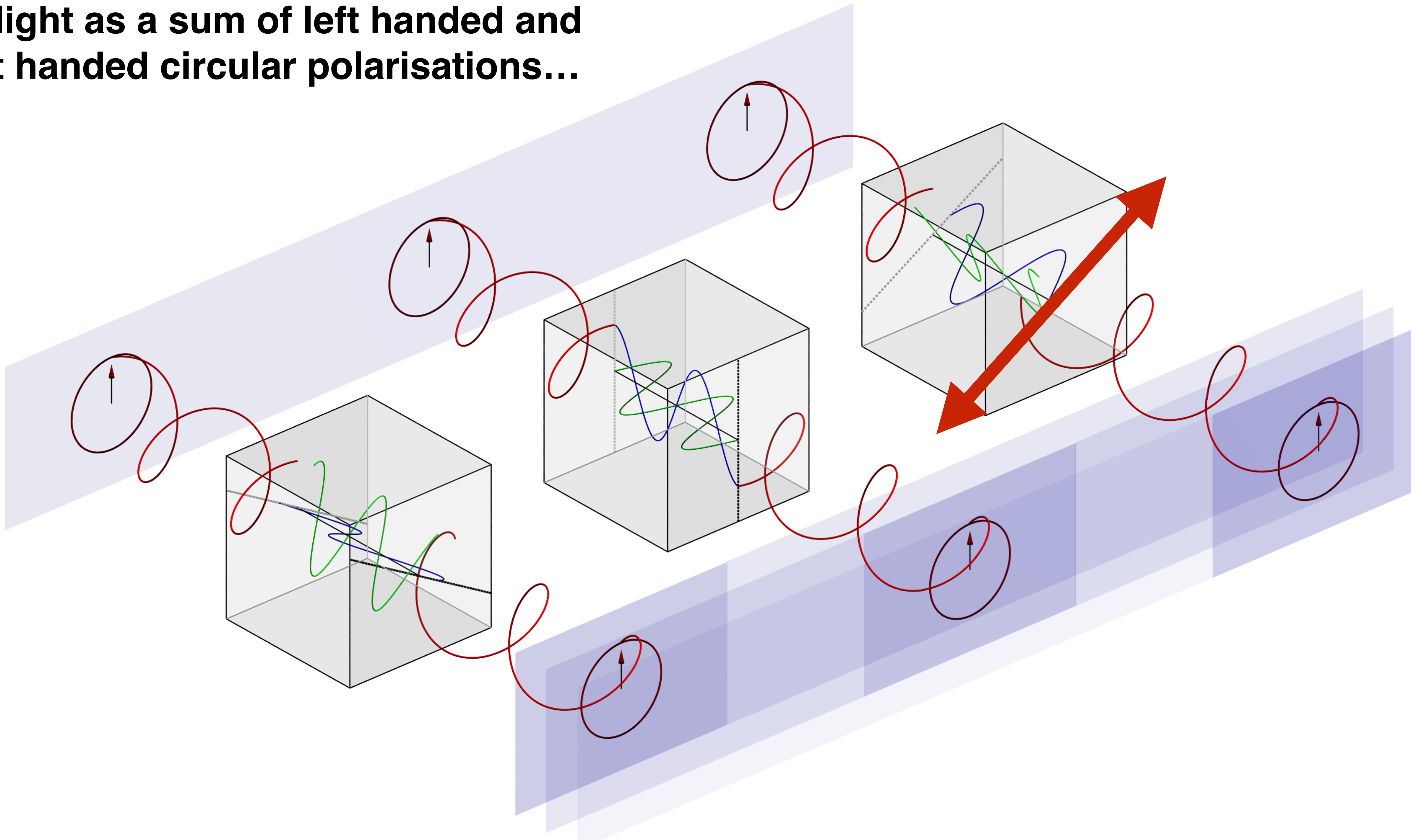
Starlight as a sum of left handed and right handed circular polarisations…



Drawings by Gilles Otten

Geometric Phase

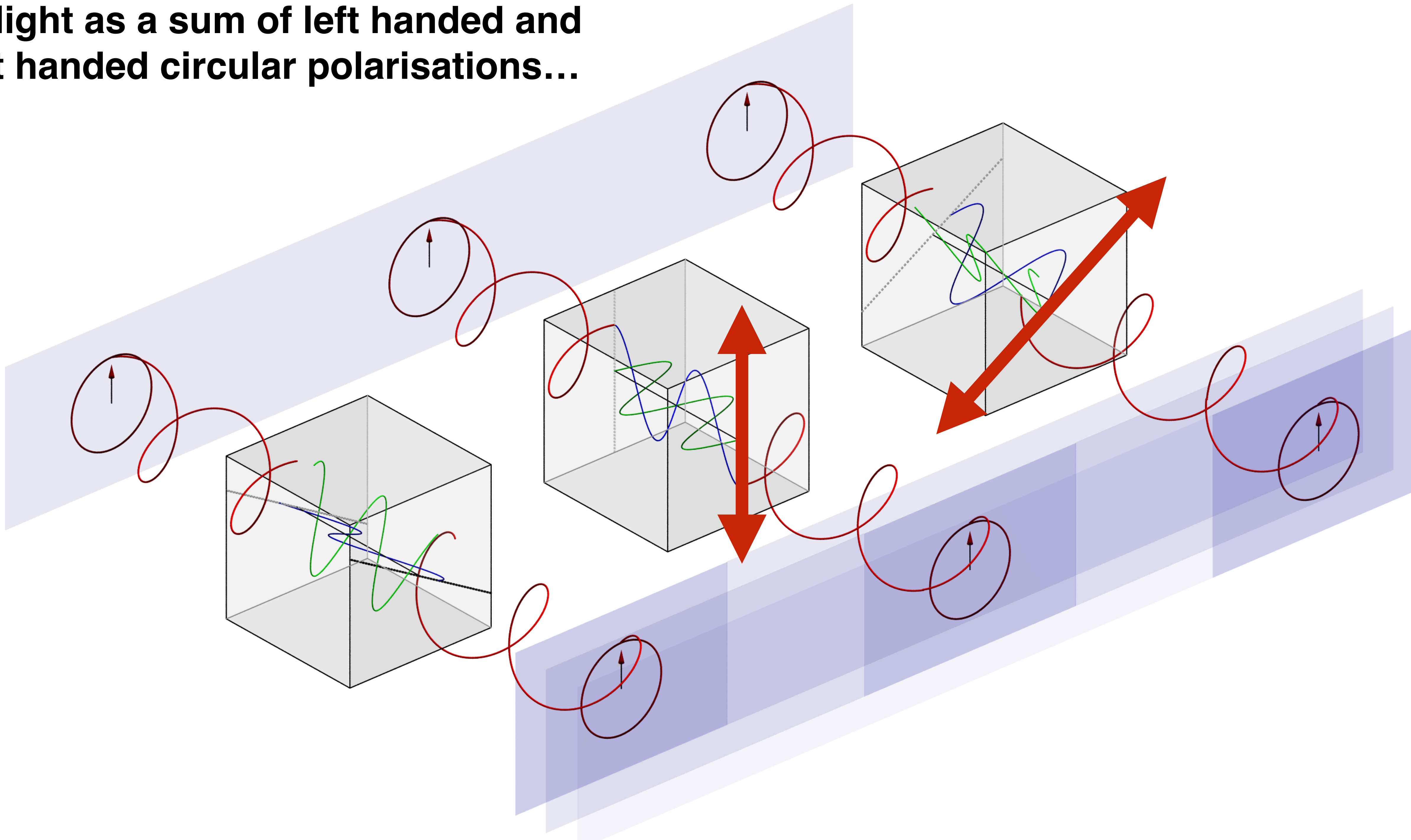
Starlight as a sum of left handed and right handed circular polarisations…



Drawings by Gilles Otten

Geometric Phase

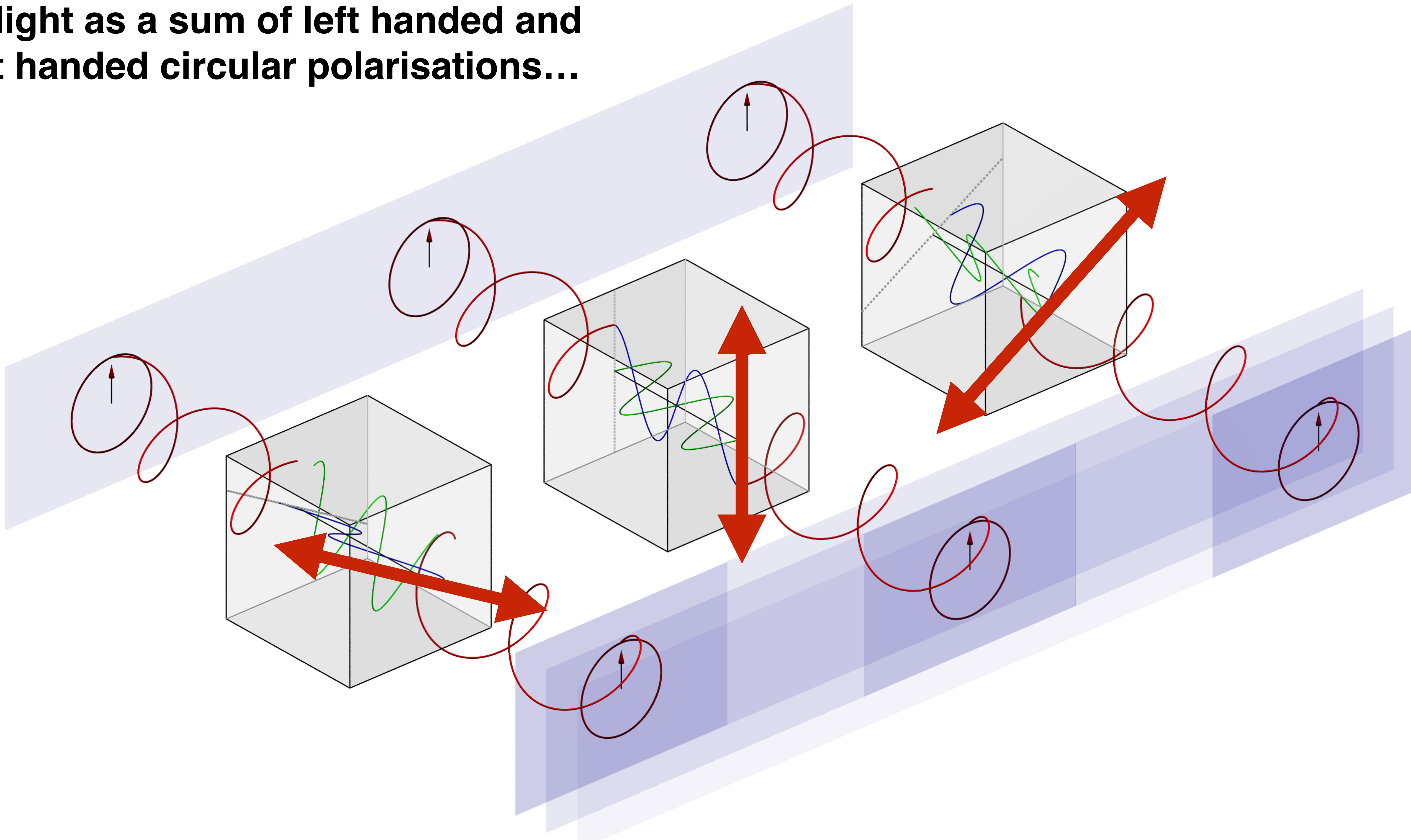
Starlight as a sum of left handed and right handed circular polarisations…



Drawings by Gilles Otten

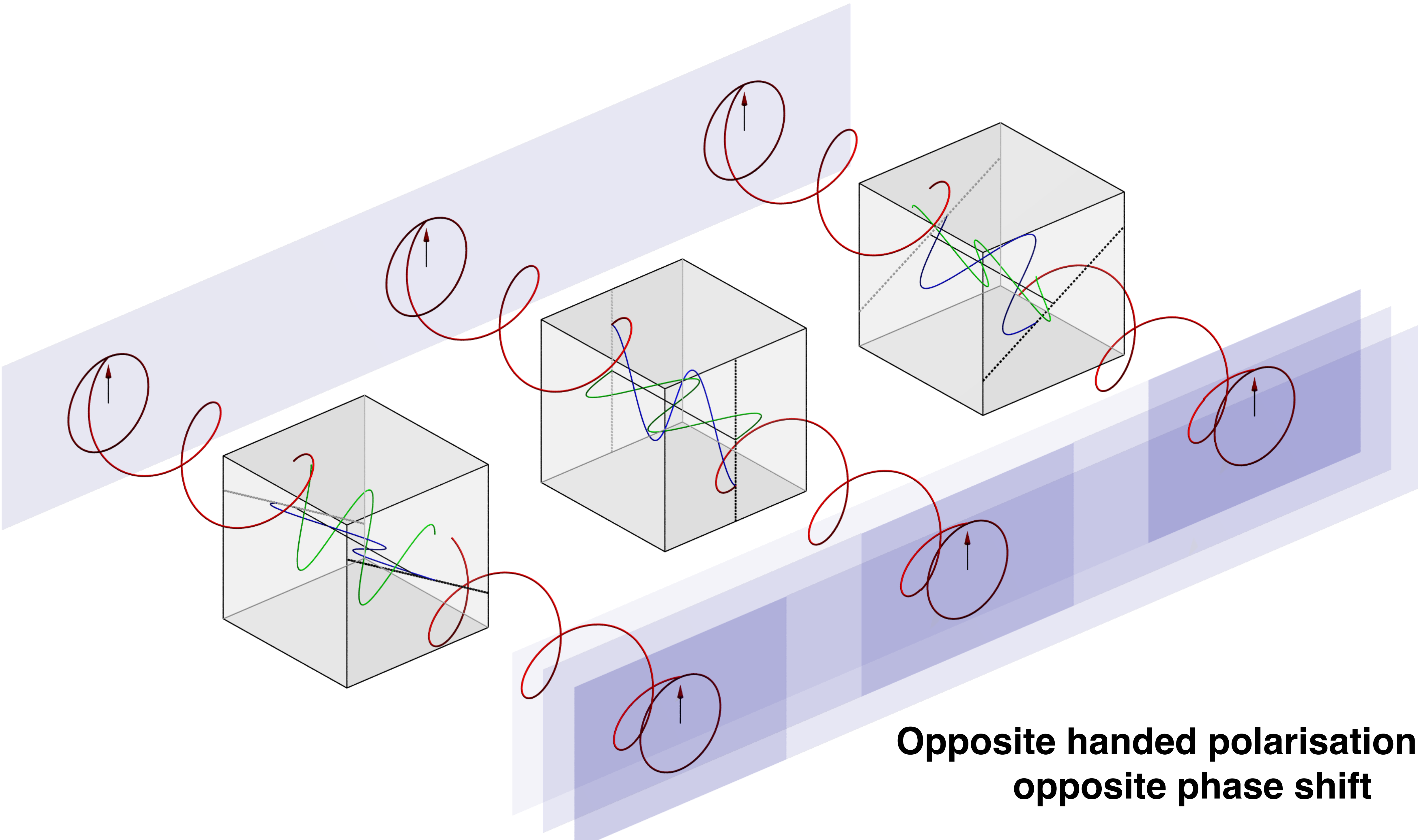
Geometric Phase

Starlight as a sum of left handed and right handed circular polarisations…



Drawings by Gilles Otten

Geometric Phase

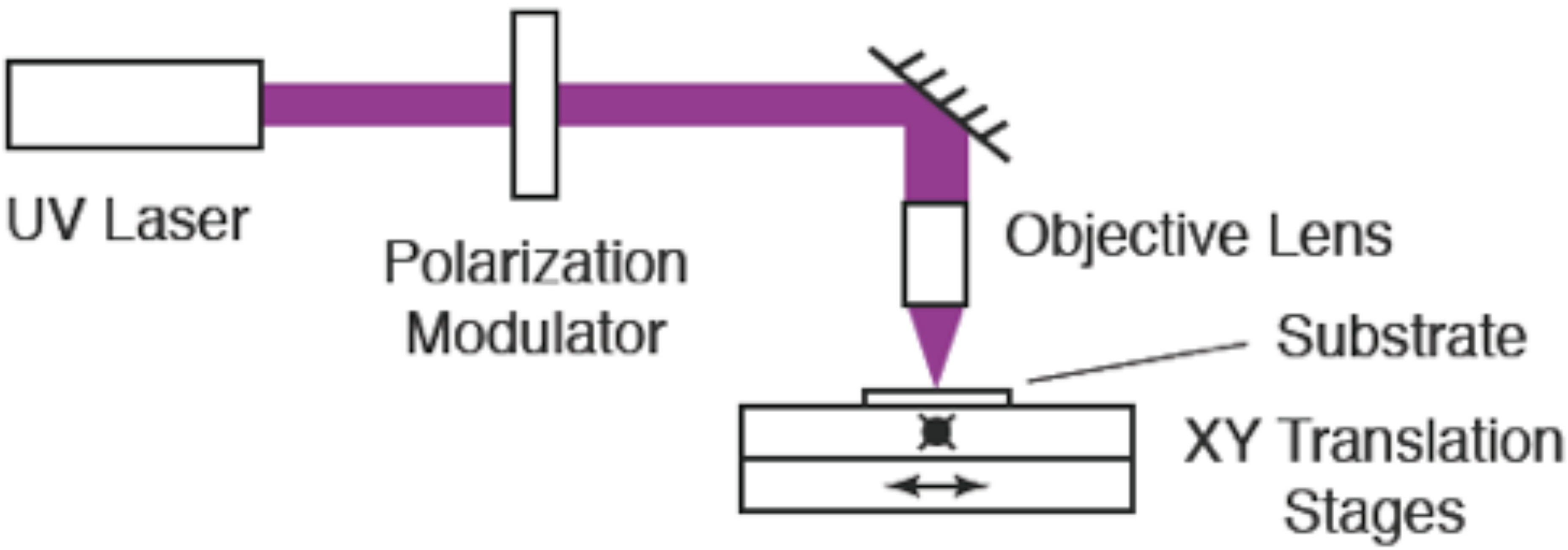


Opposite handed polarisation has opposite phase shift

Drawings by Gilles Otten

Enabling freeform phase patterns

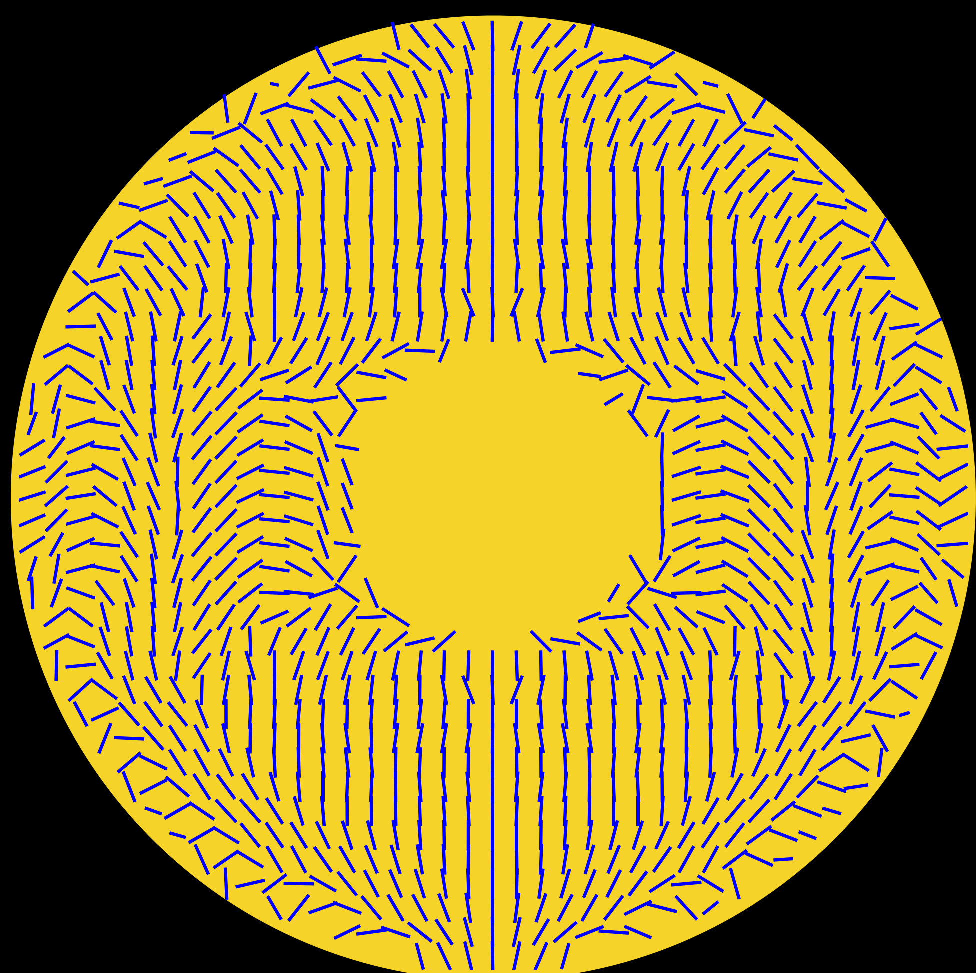
Typically 1 micron accuracy over >50mm optics

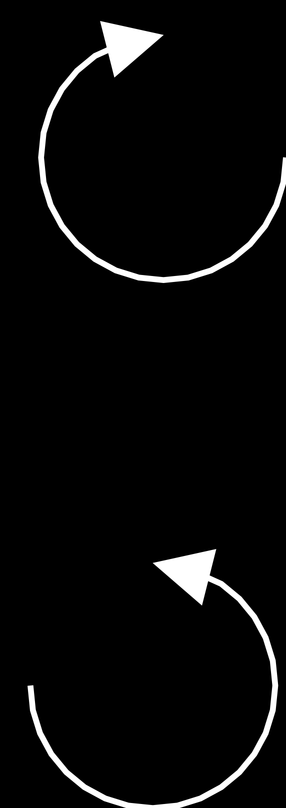


Miskiewicz & Escuti (2014)

Vector APP coronagraph

Orientation of fast axis encodes the phase shift





- Inherently achromatic
- Liquid crystal allows complex pa
- Two PSFs

Geometric phase using self-aligning birefringent polymers

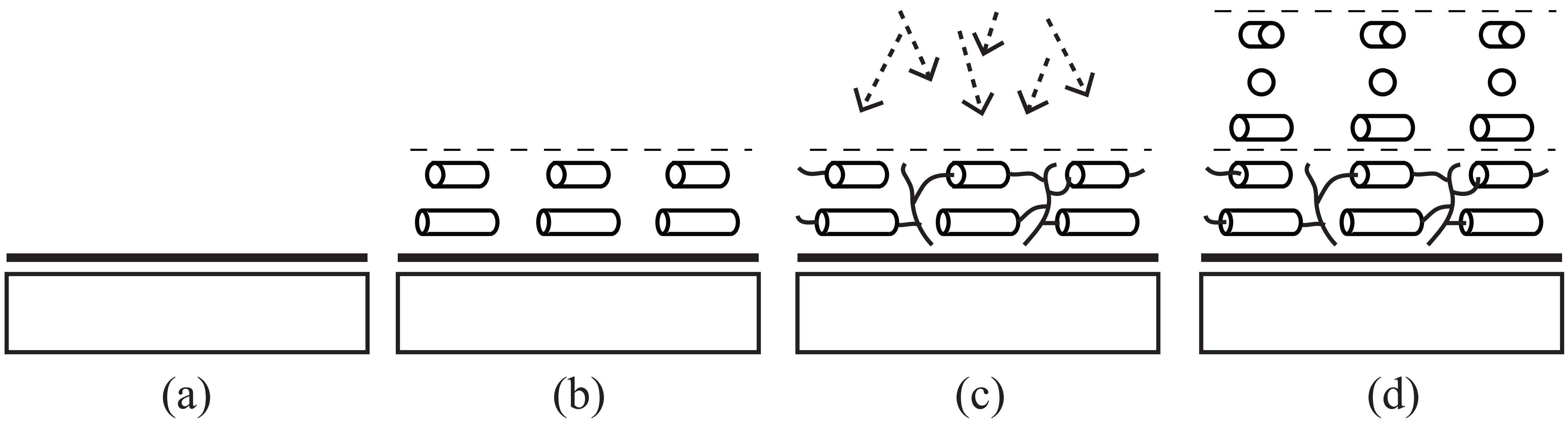
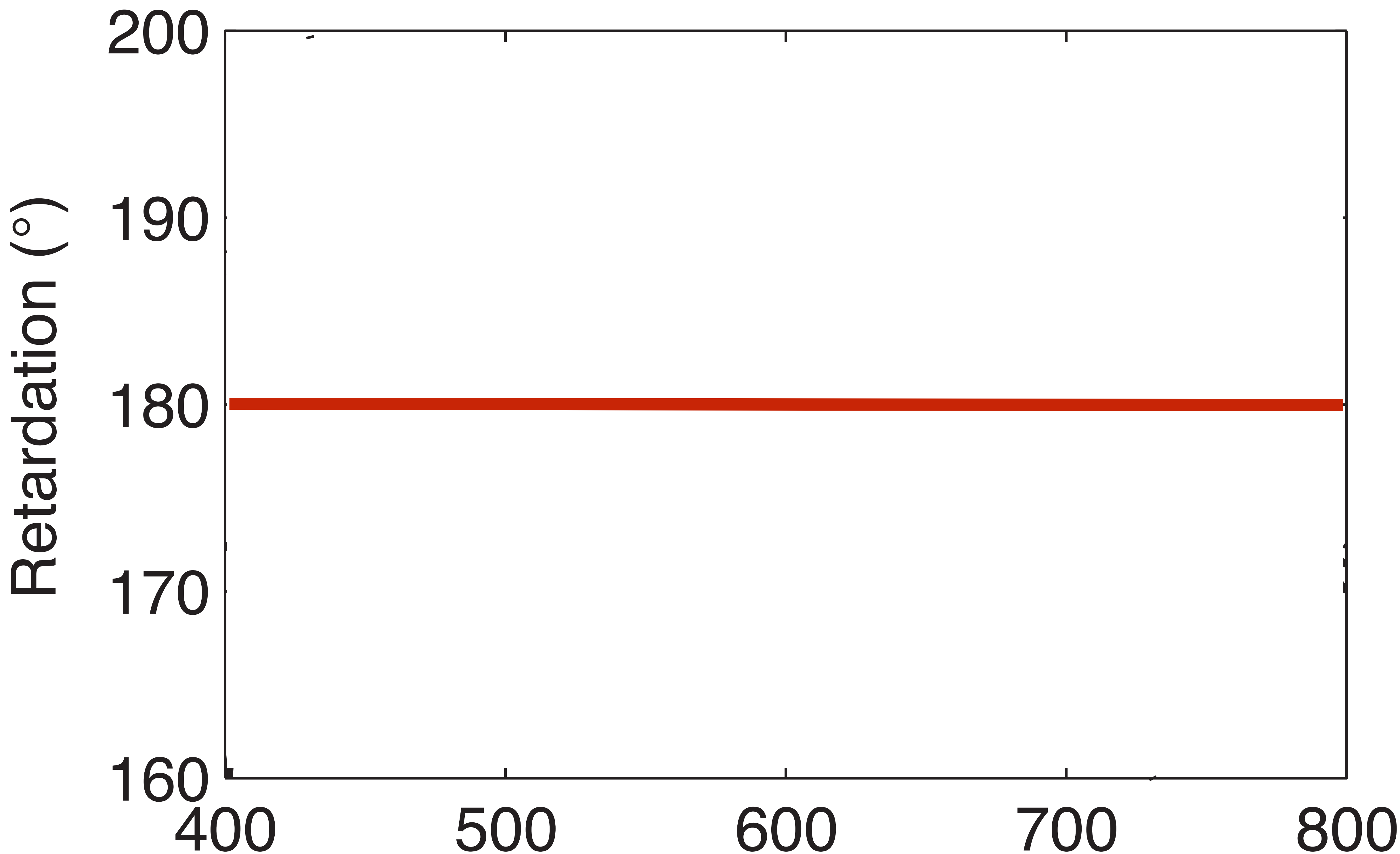


Fig. 8. The MTR fabrication procedure resulting in a monolithic broadband element, on a single substrate and alignment layer: (a) alignment layer processing; (b) LCP coating ($m = 1$); (c) LCP photo-polymerization; and (d) repeat LCP coating and curing for ($m \geq 2$).

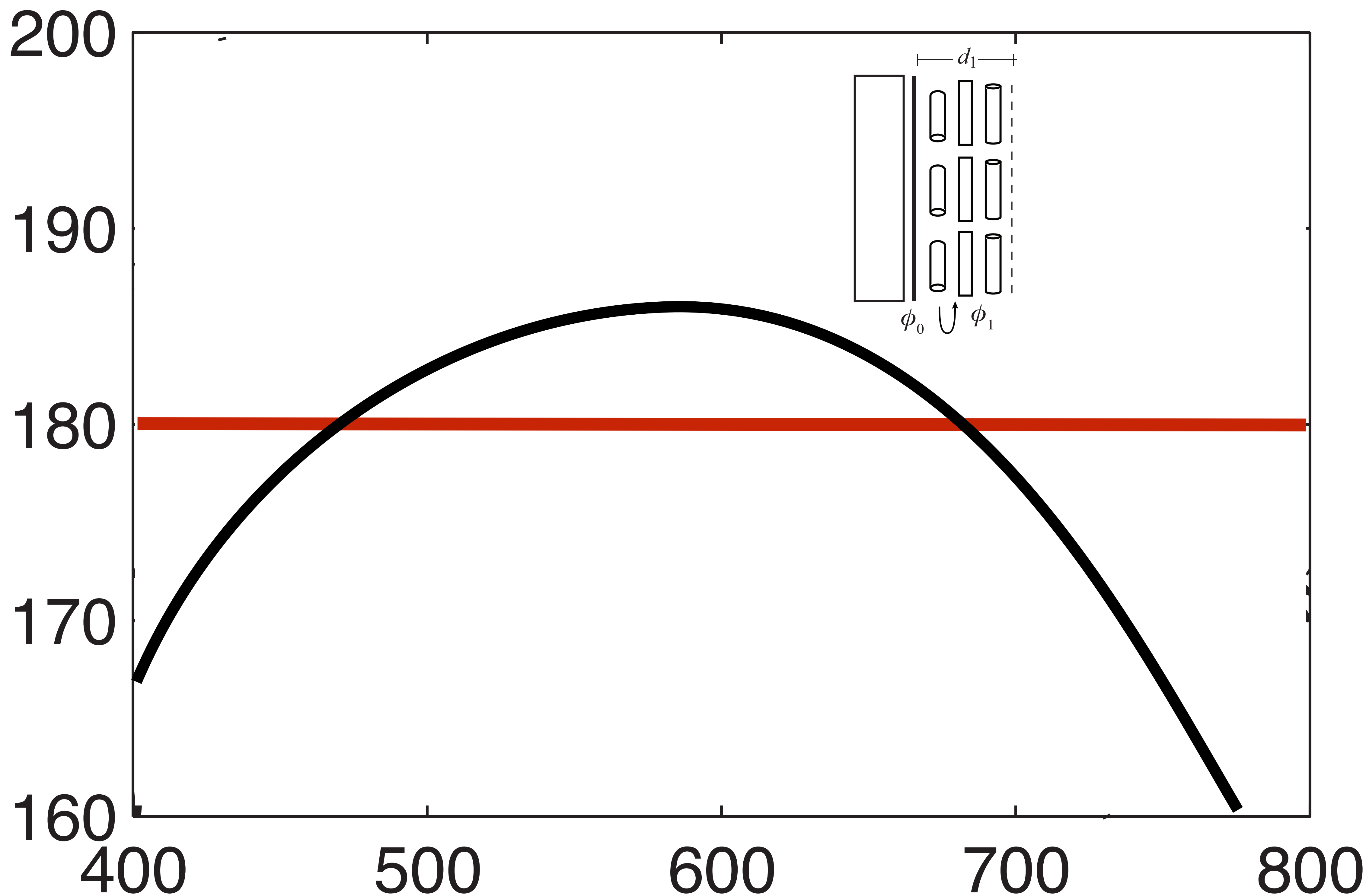
Komanduri+ (2012) Optics Express 21 1 404

Broadband with additional layers



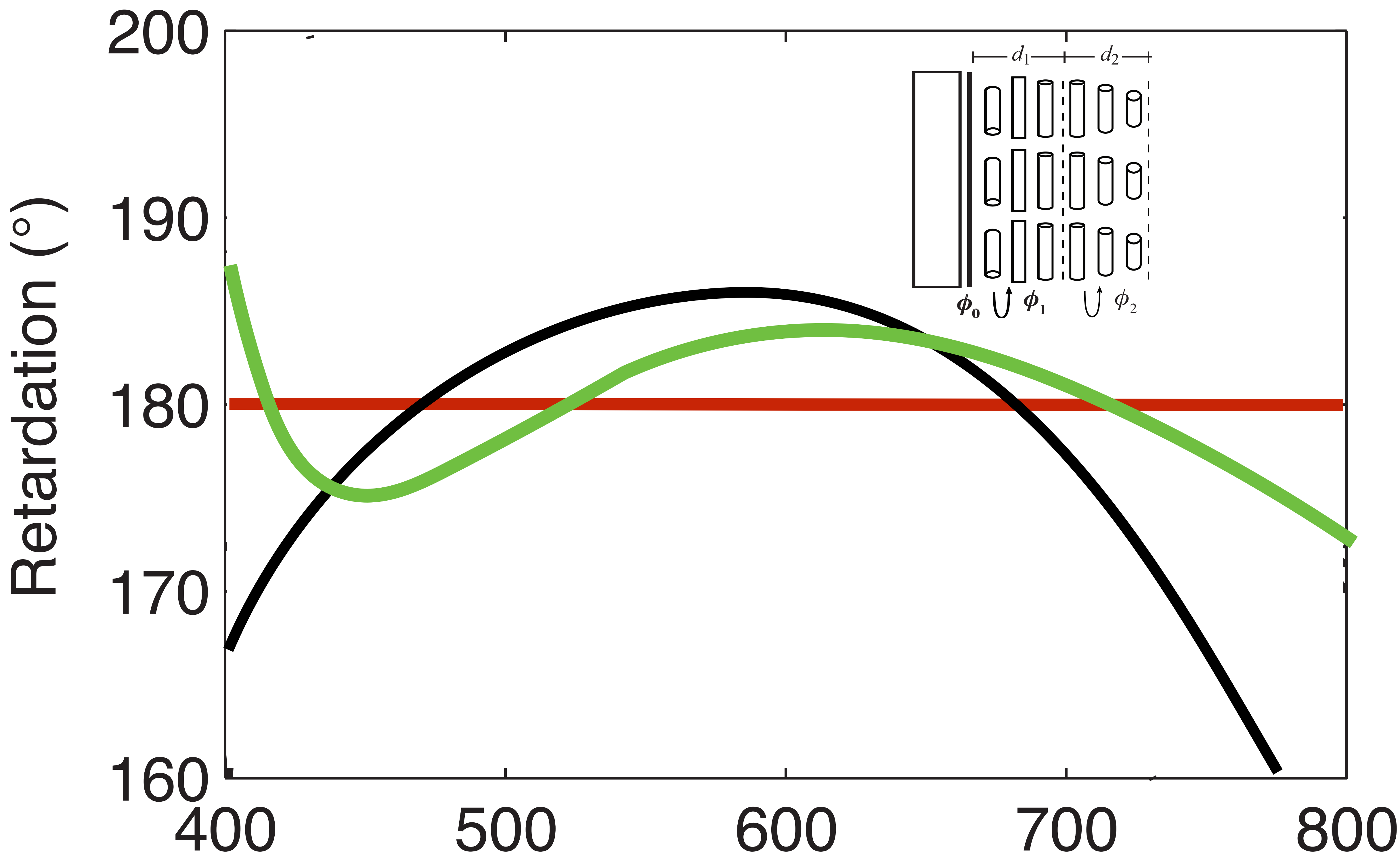
Komanduri+ (2012) Optics Express 21 1 404

Broadband with additional layers



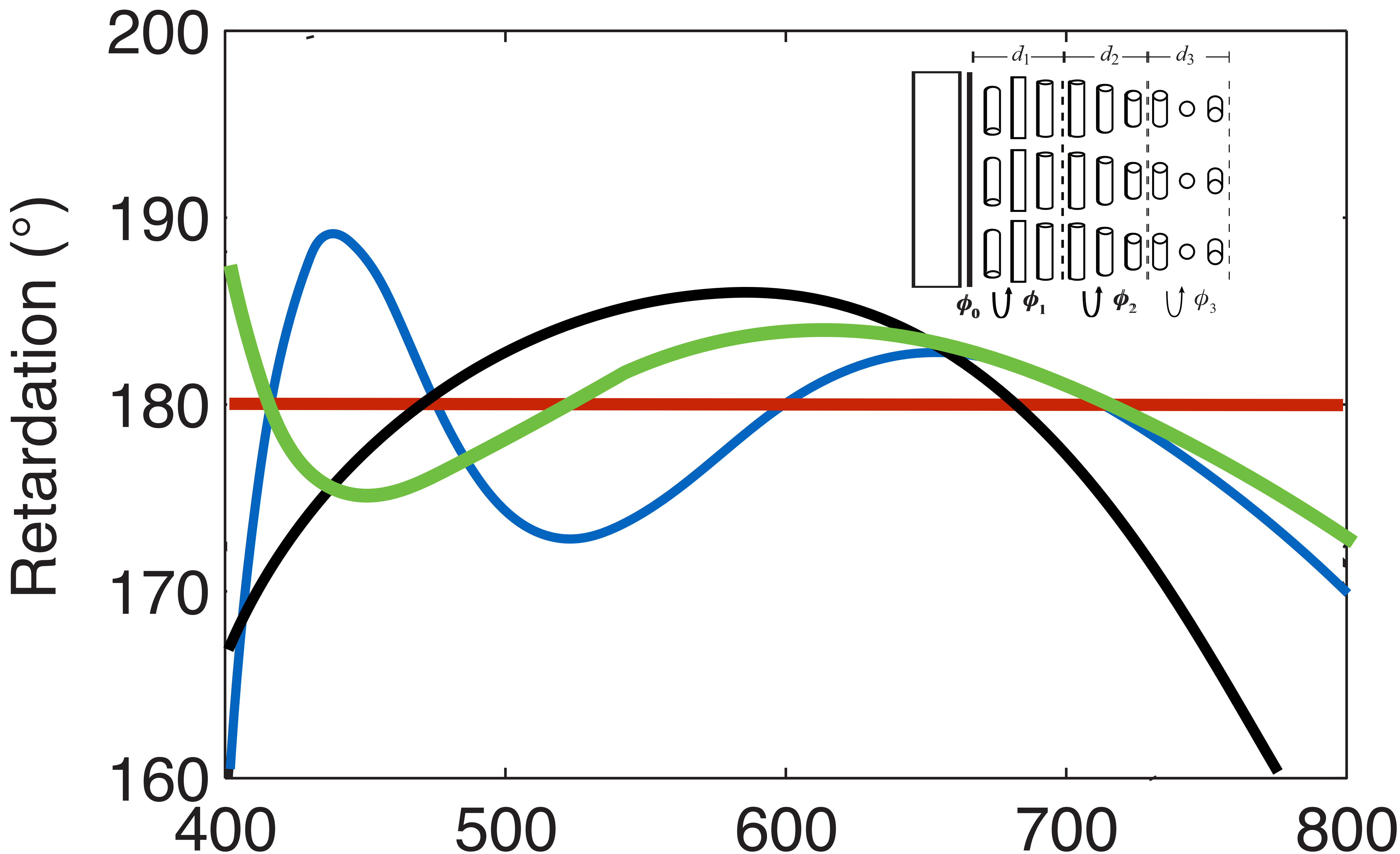
Komanduri+ (2012) Optics Express 21 1 404

Broadband with additional layers



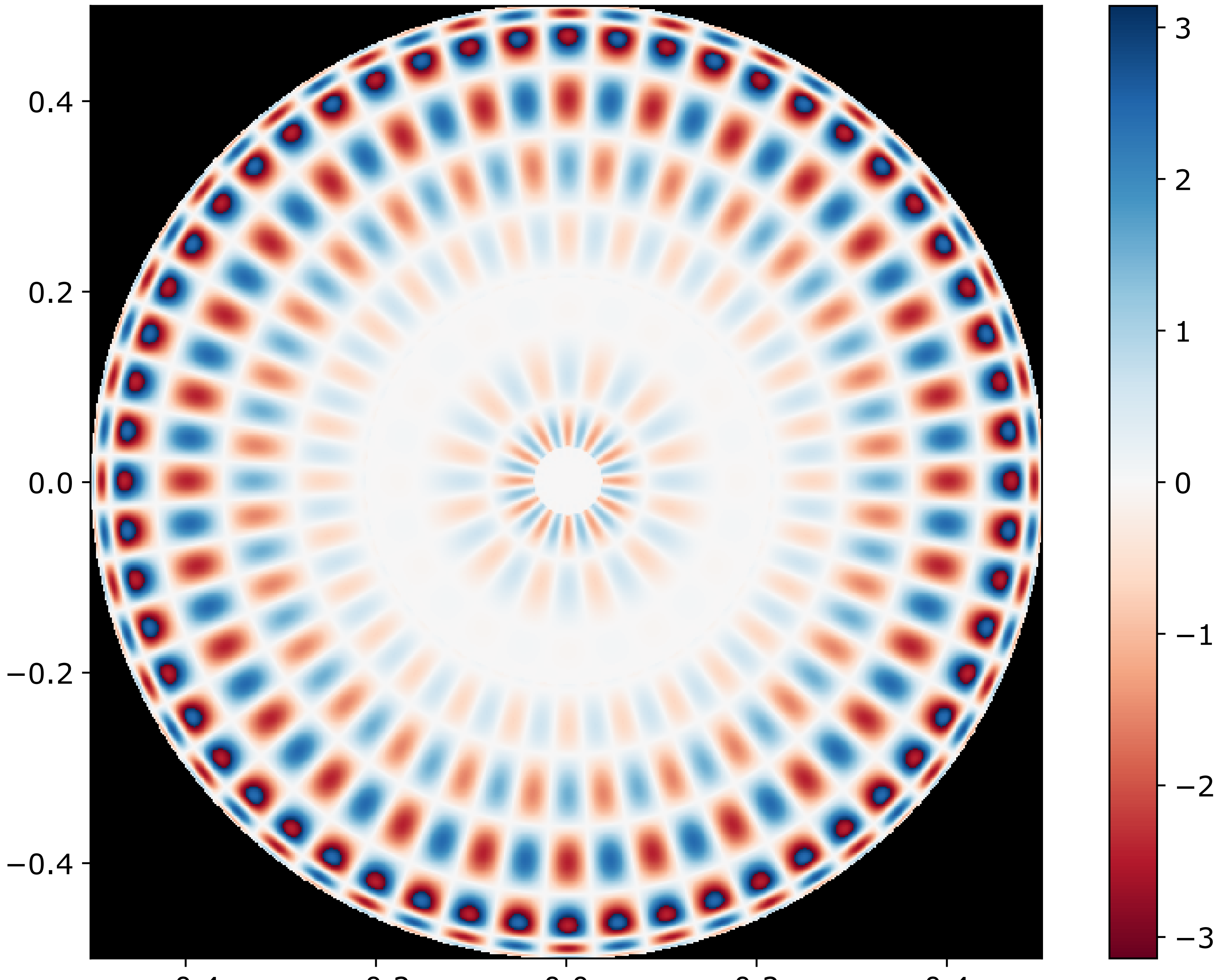
Komanduri+ (2012) Optics Express 21 1 404

Broadband with additional layers

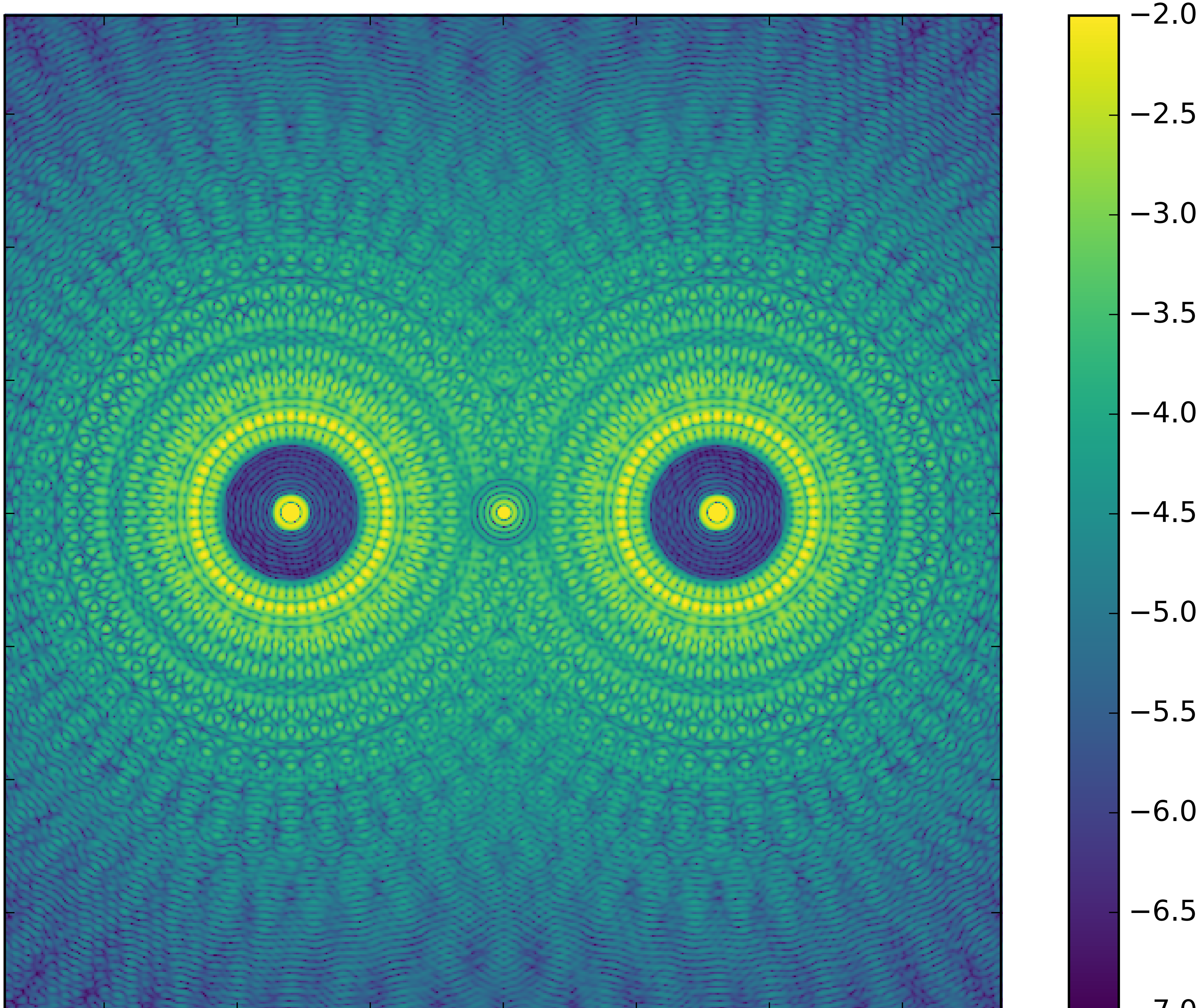


Komanduri+ (2012) Optics Express 21 1 404

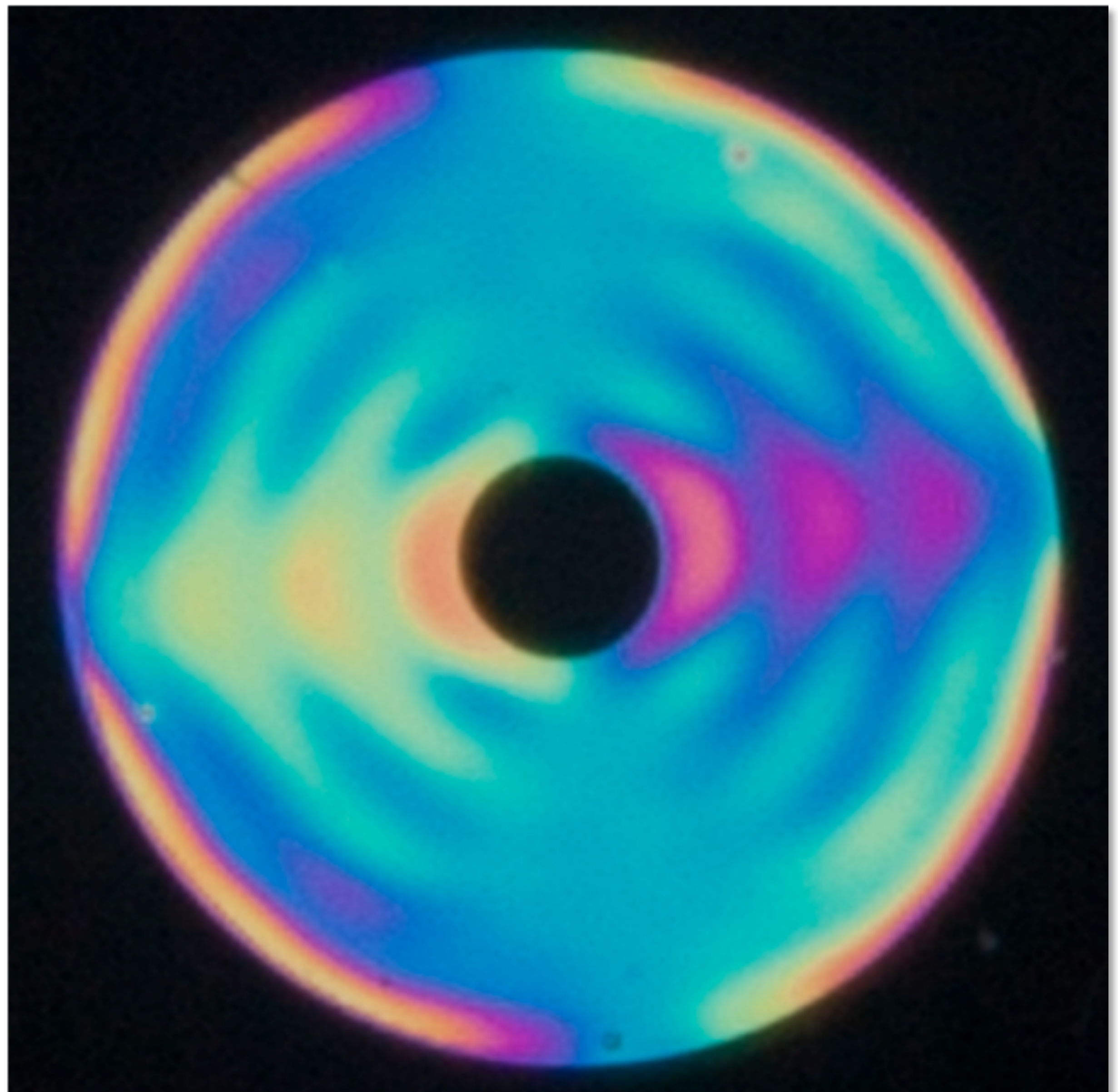
Opens up a new parameter space for coronagraph designs



360 degree APPs

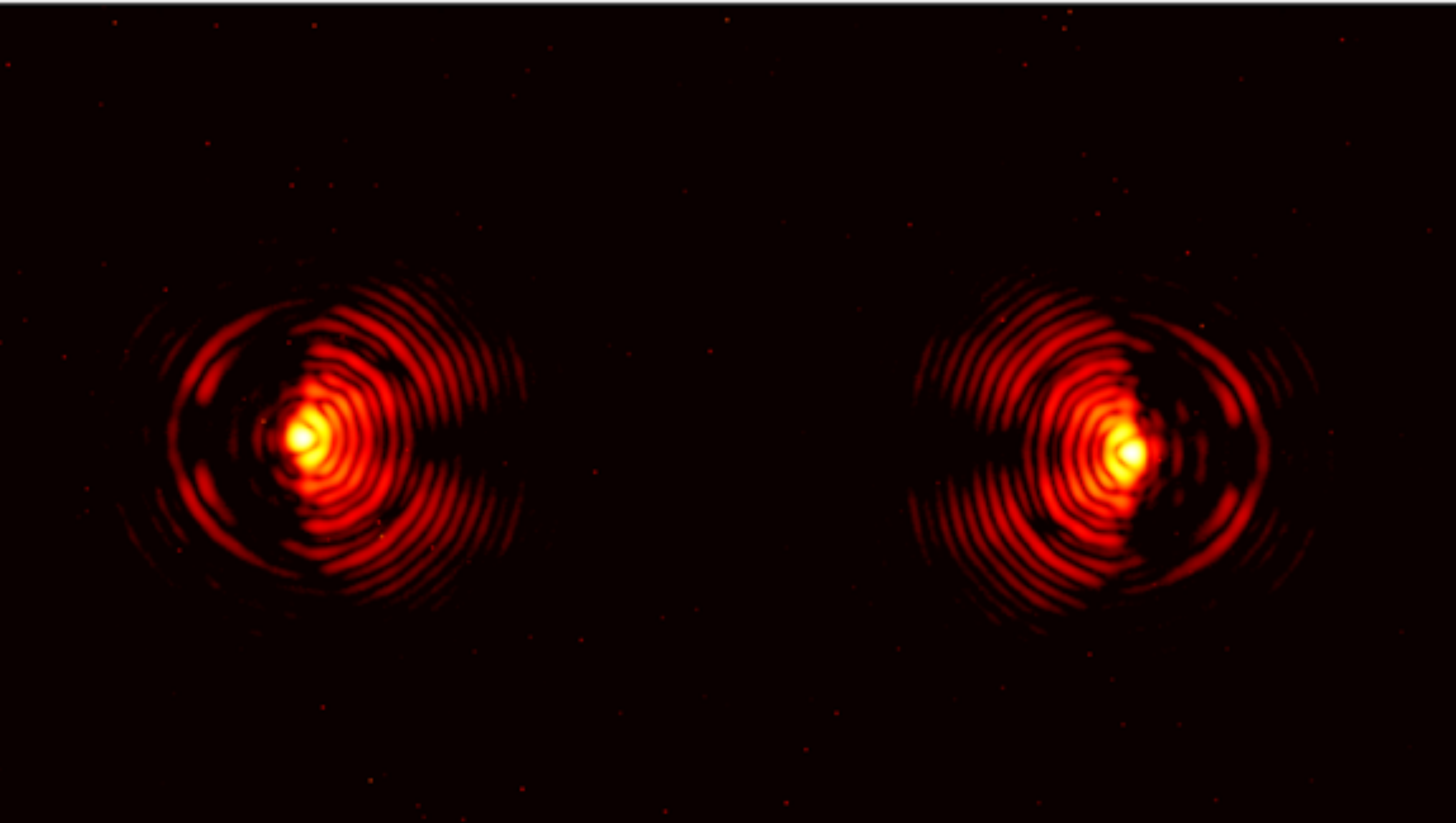


Prototype vAPP tested at optical wavelengths in Leiden

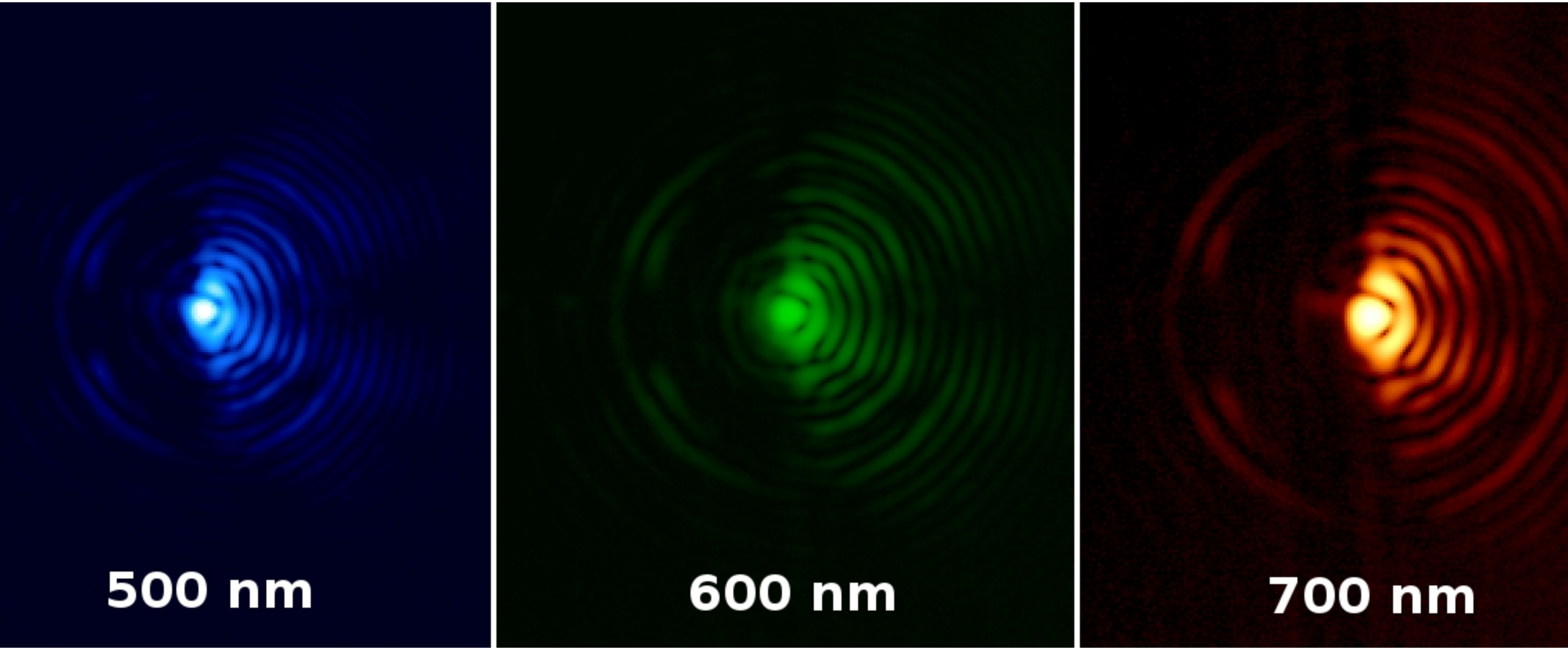


Otten+ (2014) SPIE 91511

Left-hand and right-hand circular polarizations have opposite phases

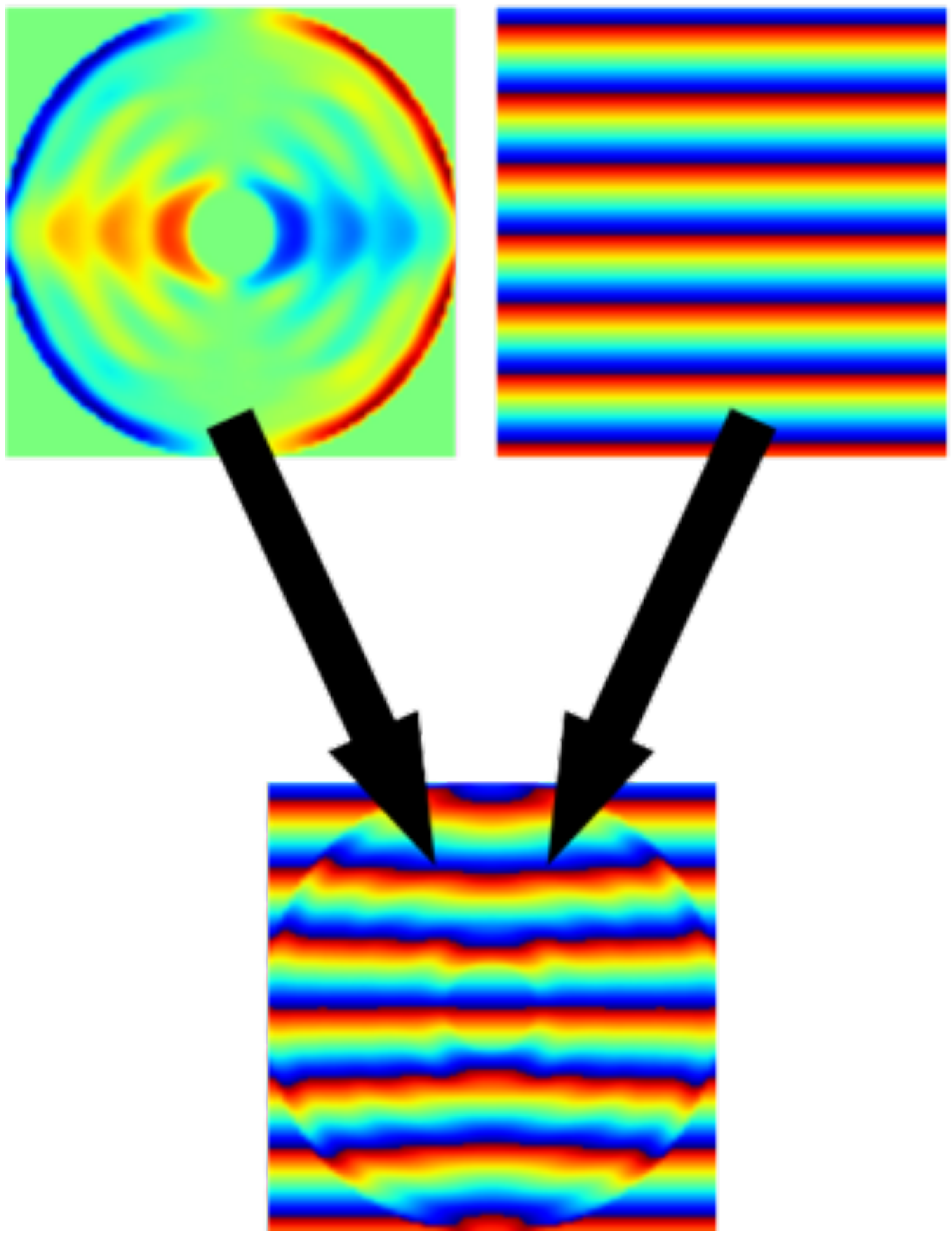


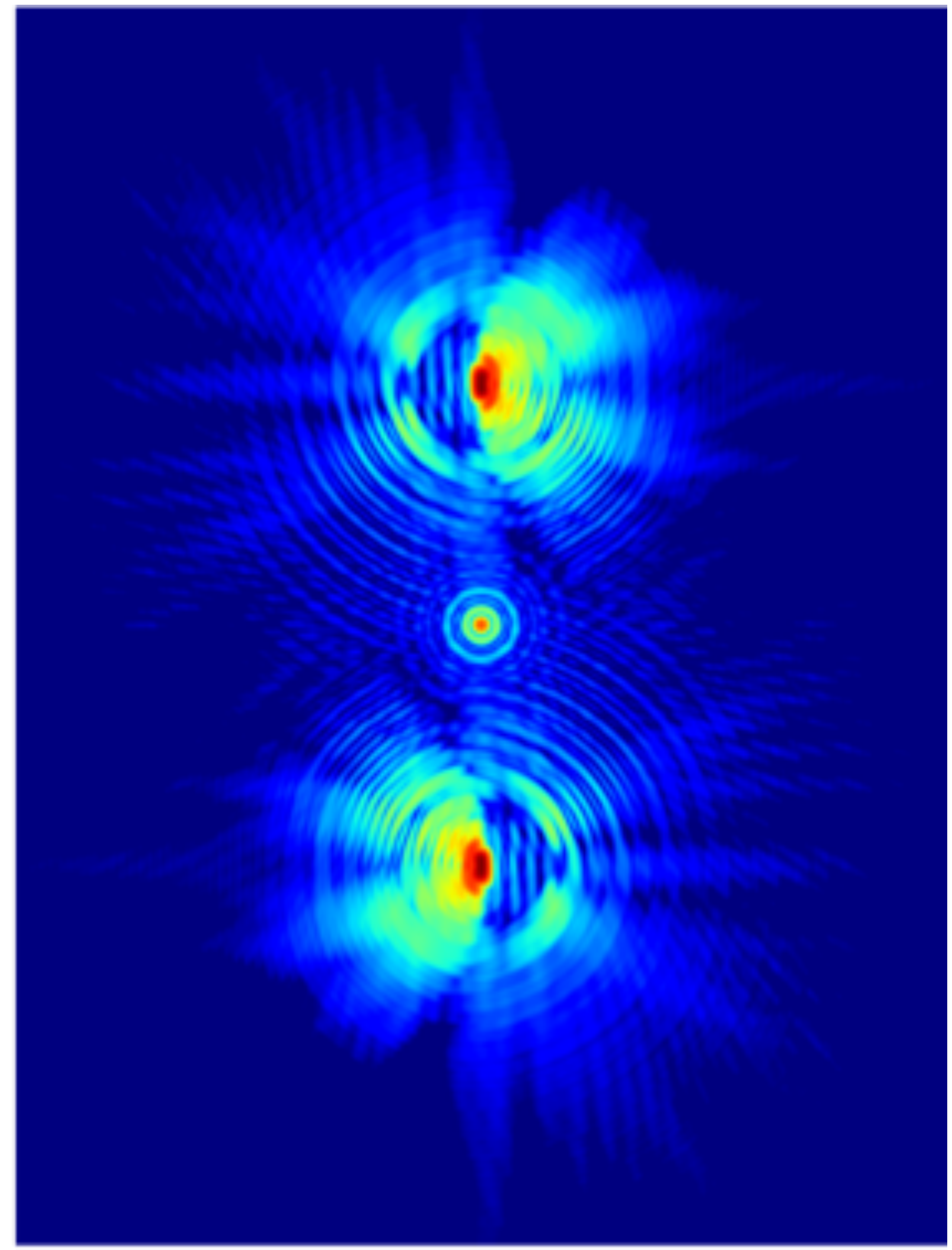
Broadband wavelength works



…but "leakage term" remains

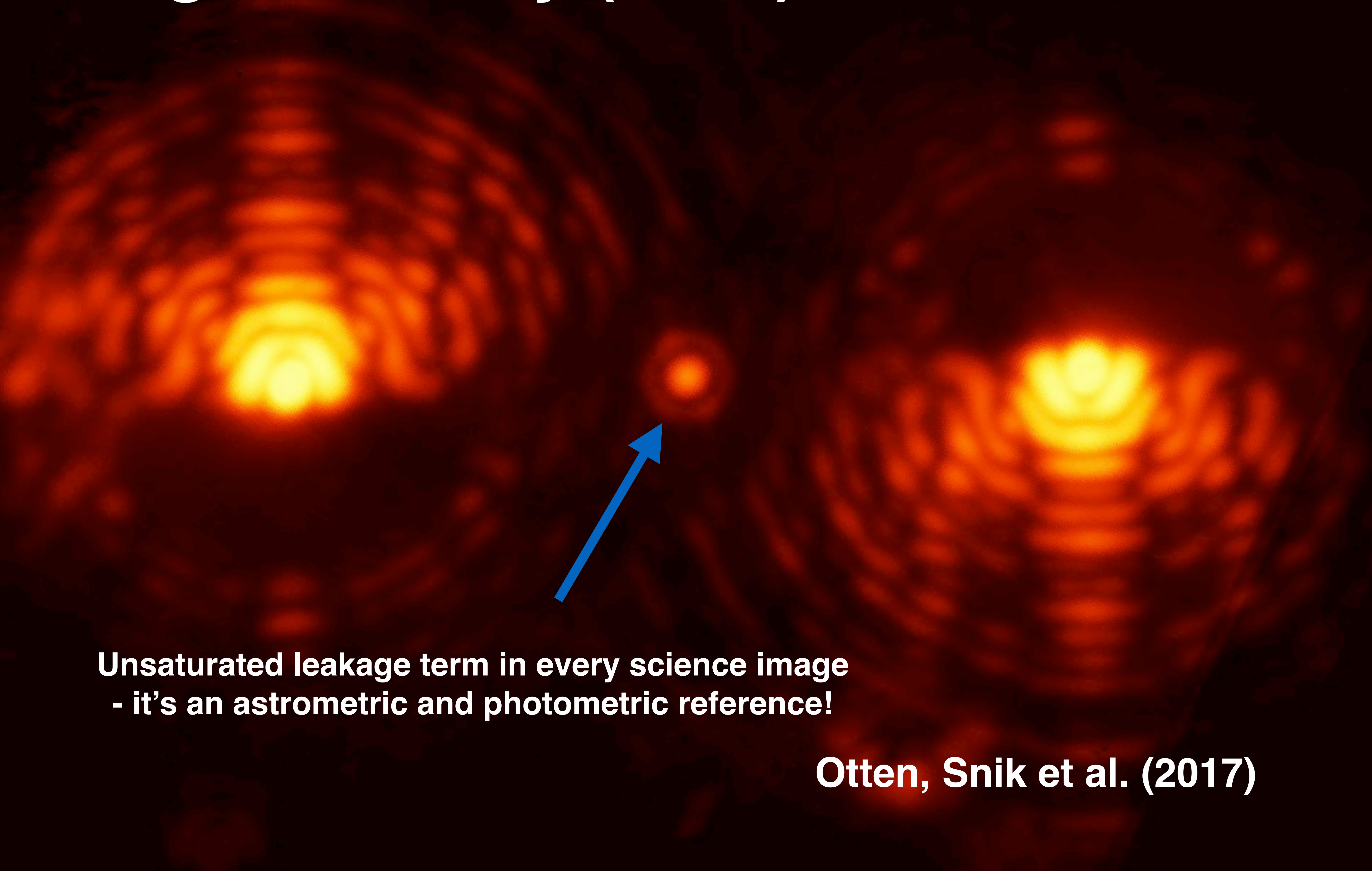
Solved with:
Grating vector APP (gvAPP)





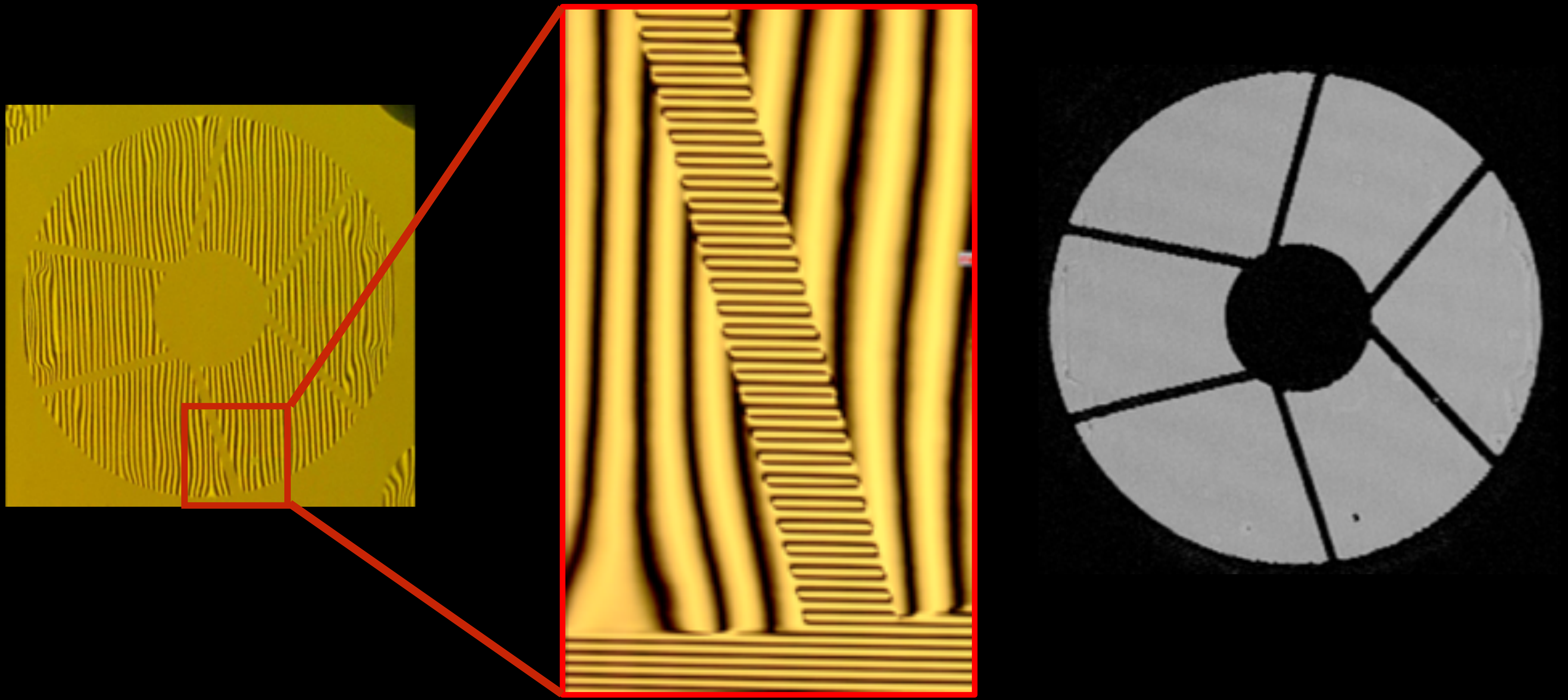
Otten, Snik et al. 2014 SPIE

MagAO on-sky (2015) at 3.9 microns

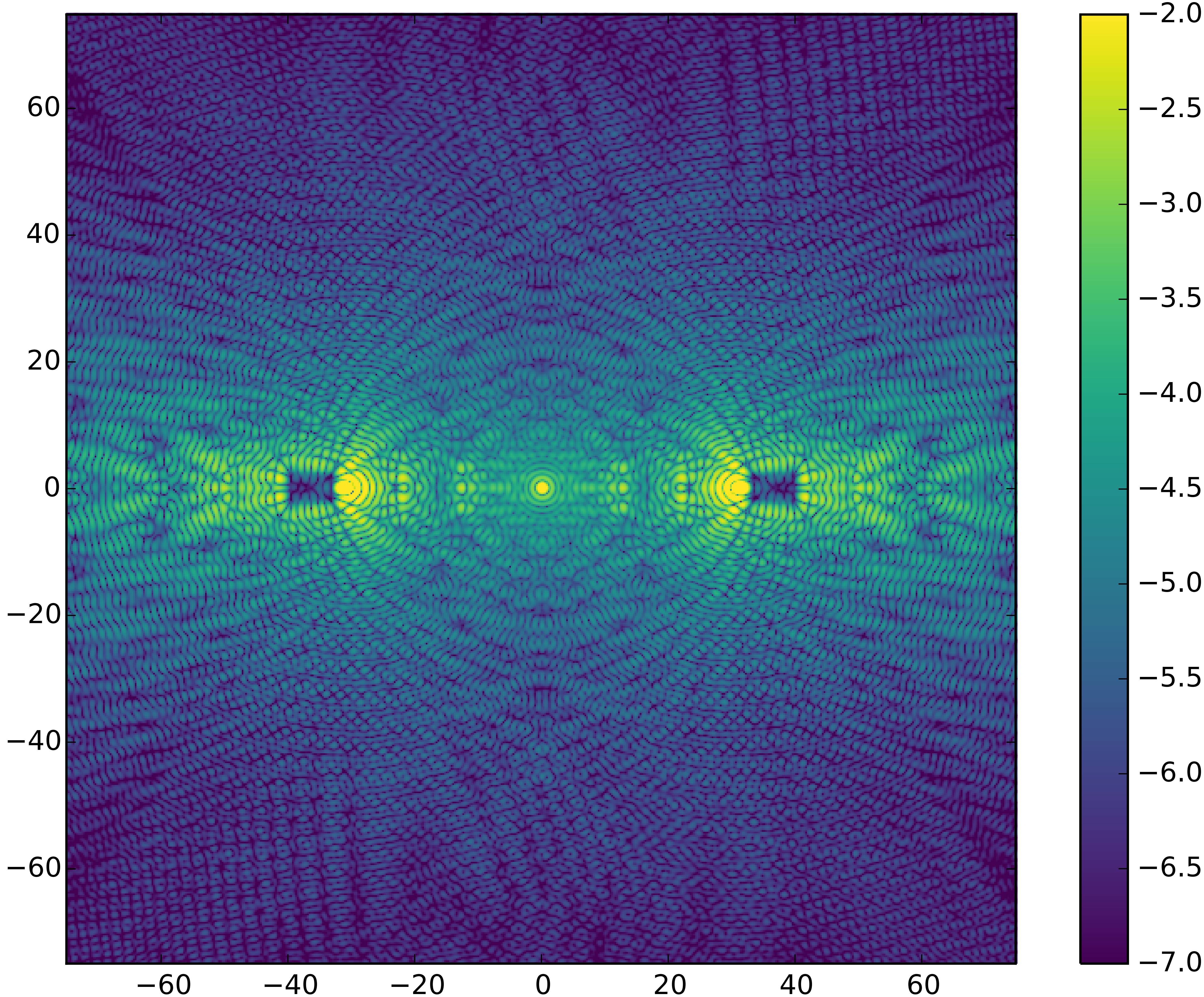


Otten, Snik et al. (2017)

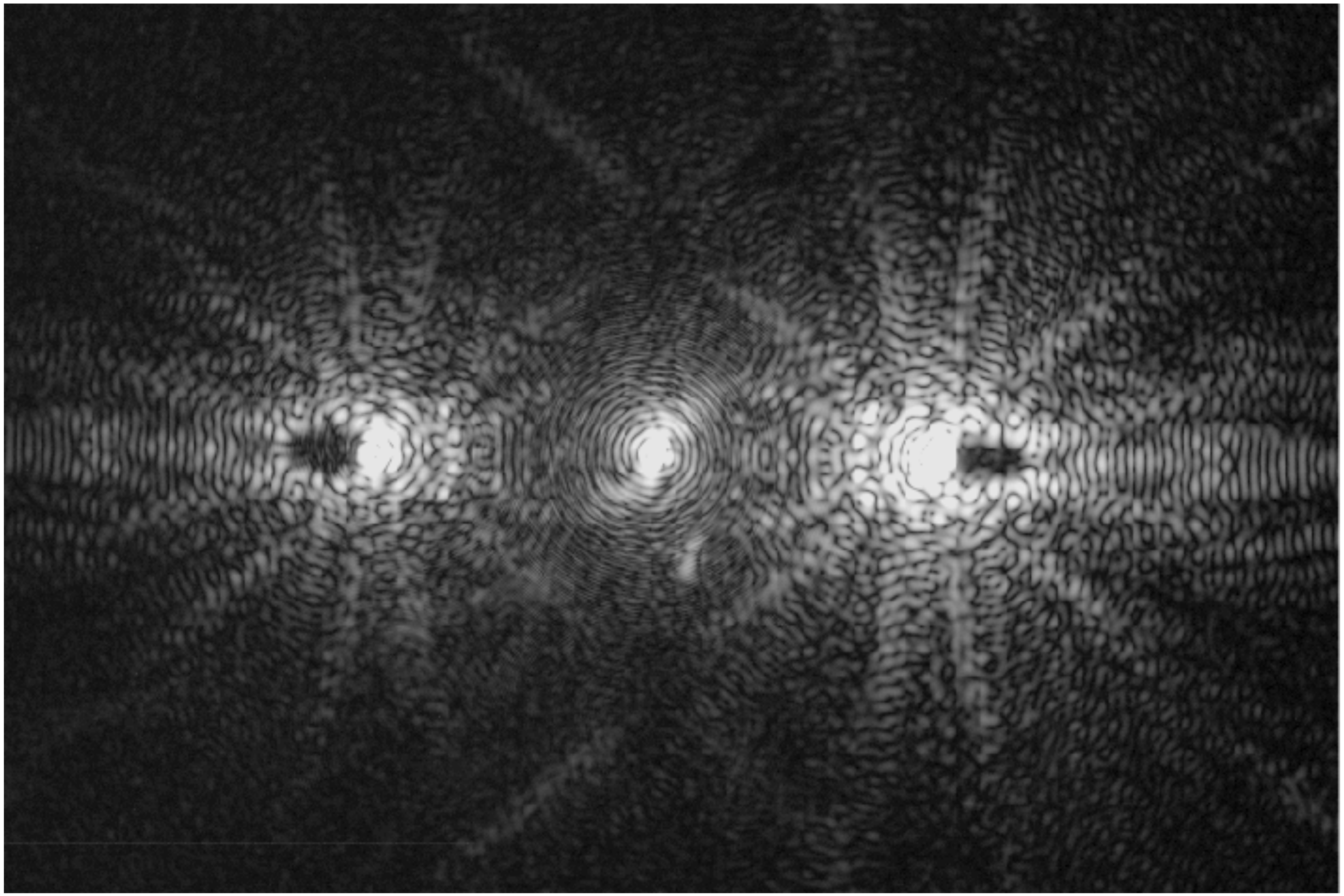
Grating aperture mask



Doelman+ (2017) SPIE

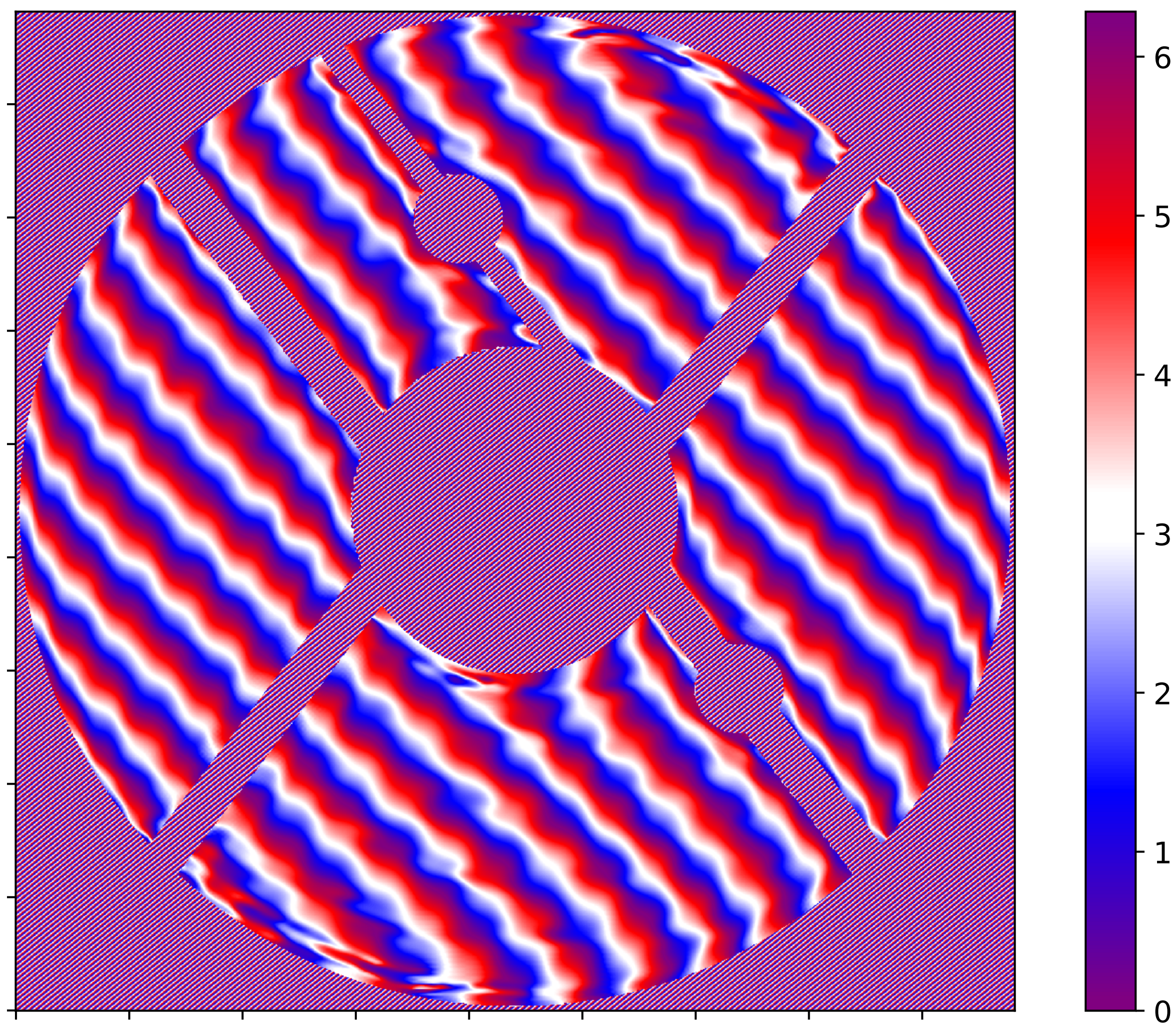

60
40
20
0
−20
−40
−60
−60
−40
−20
0
20
40
60
−2.0
−2.5
−3.0
−3.5
−4.0
−4.5
−5.0
−5.5
−6.0
−6.5
−7.0

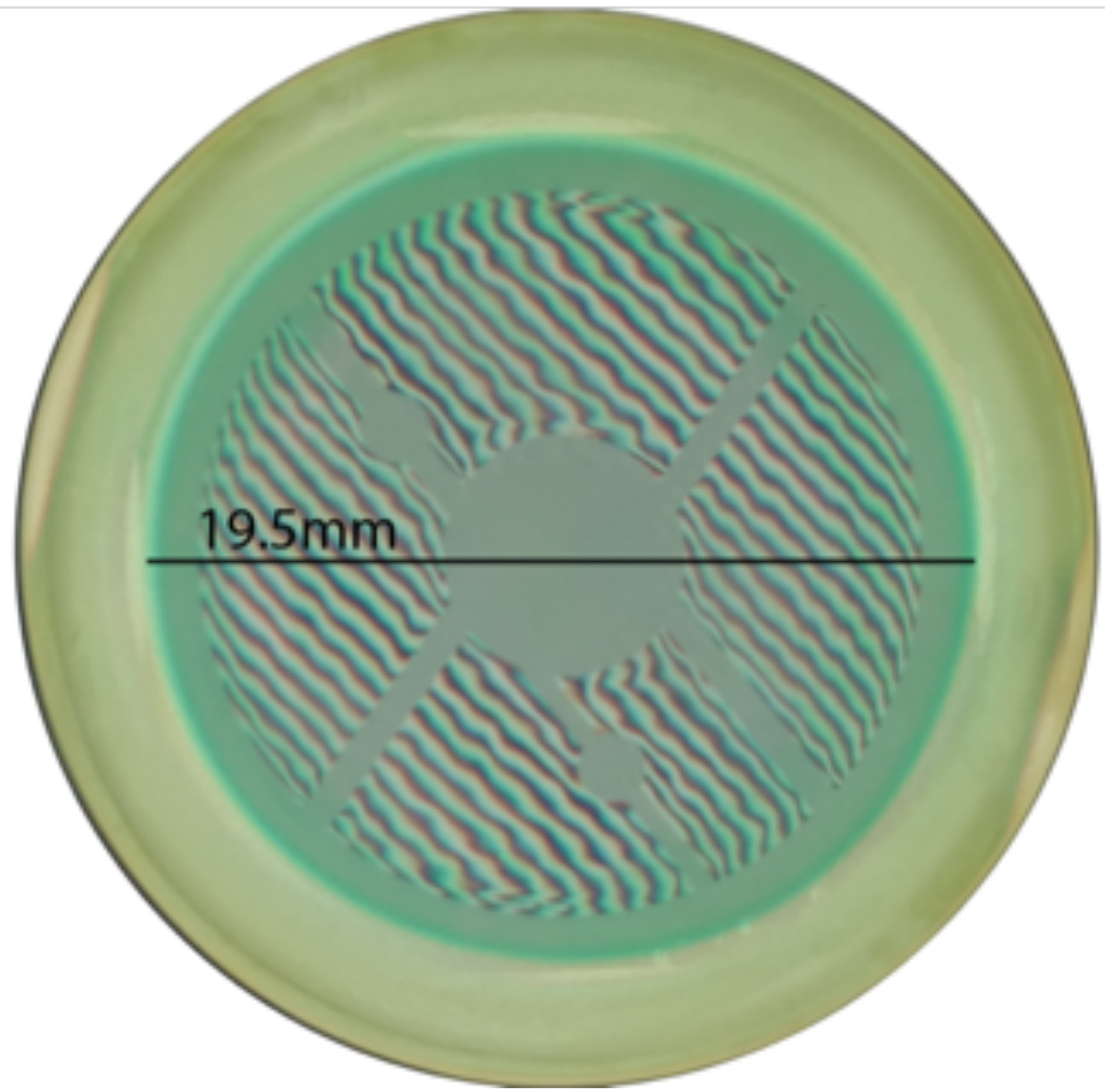
Lab measured PSF (monday!)



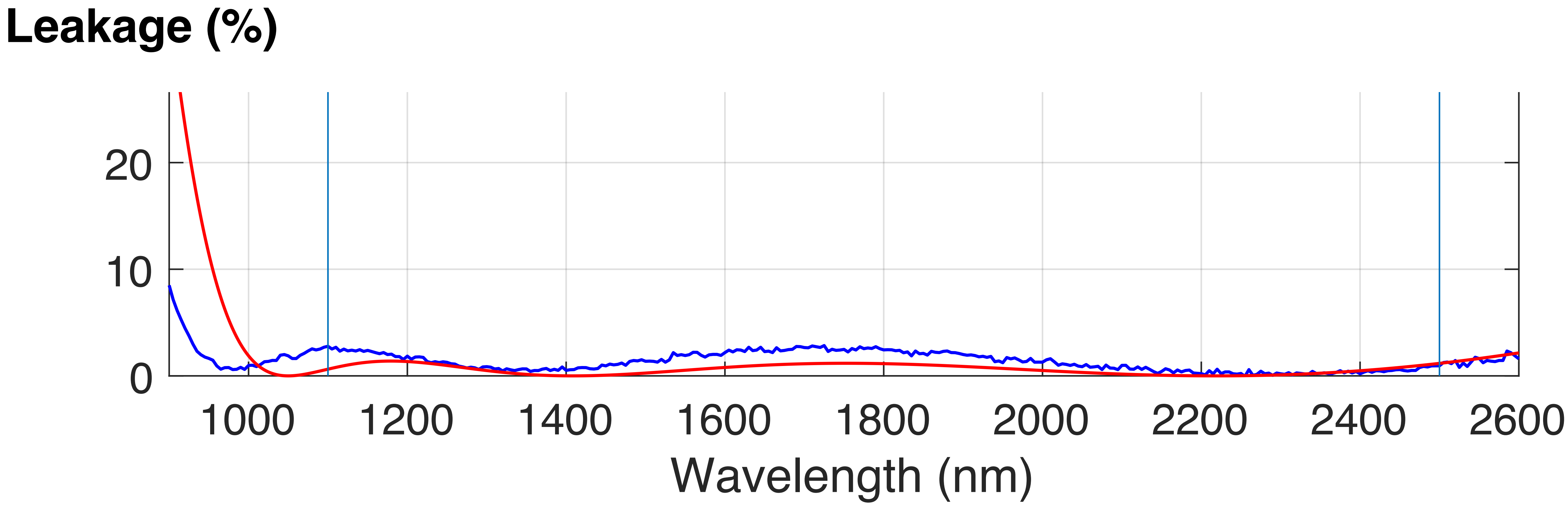
Courtesy Emiel Por

Subaru/SCExAO/CHARIS gvAPP

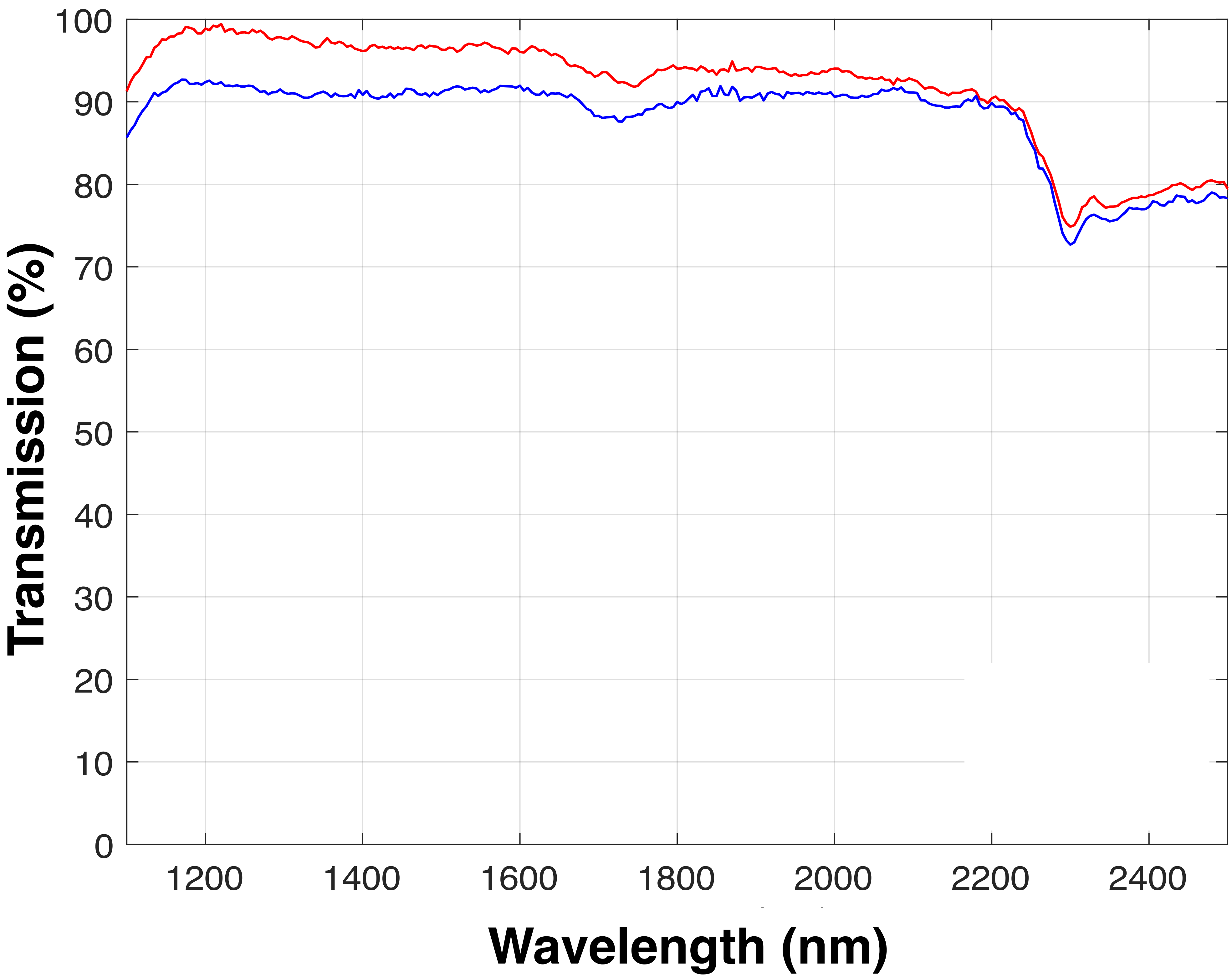




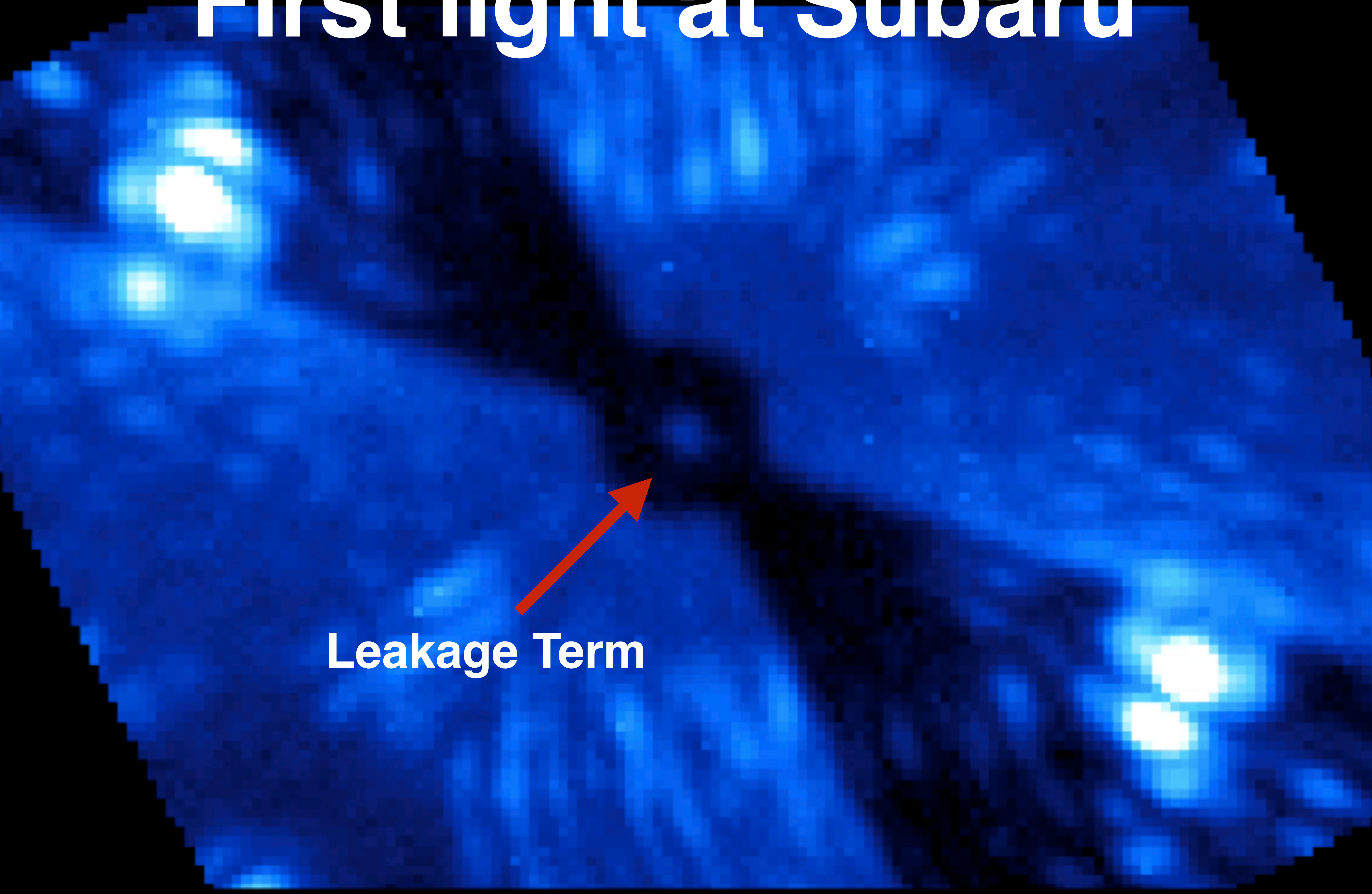
SCExAO Leakage term <5%

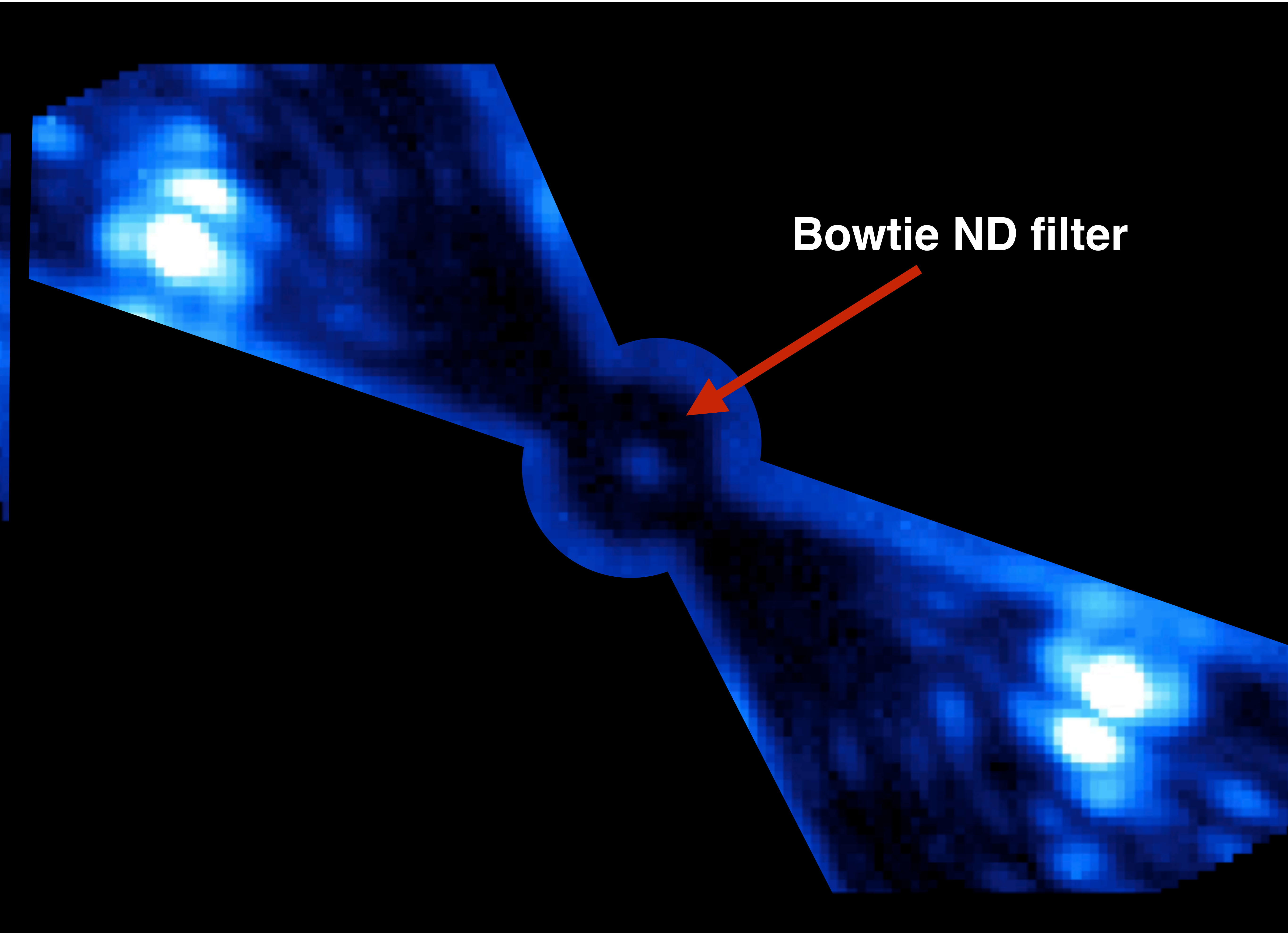


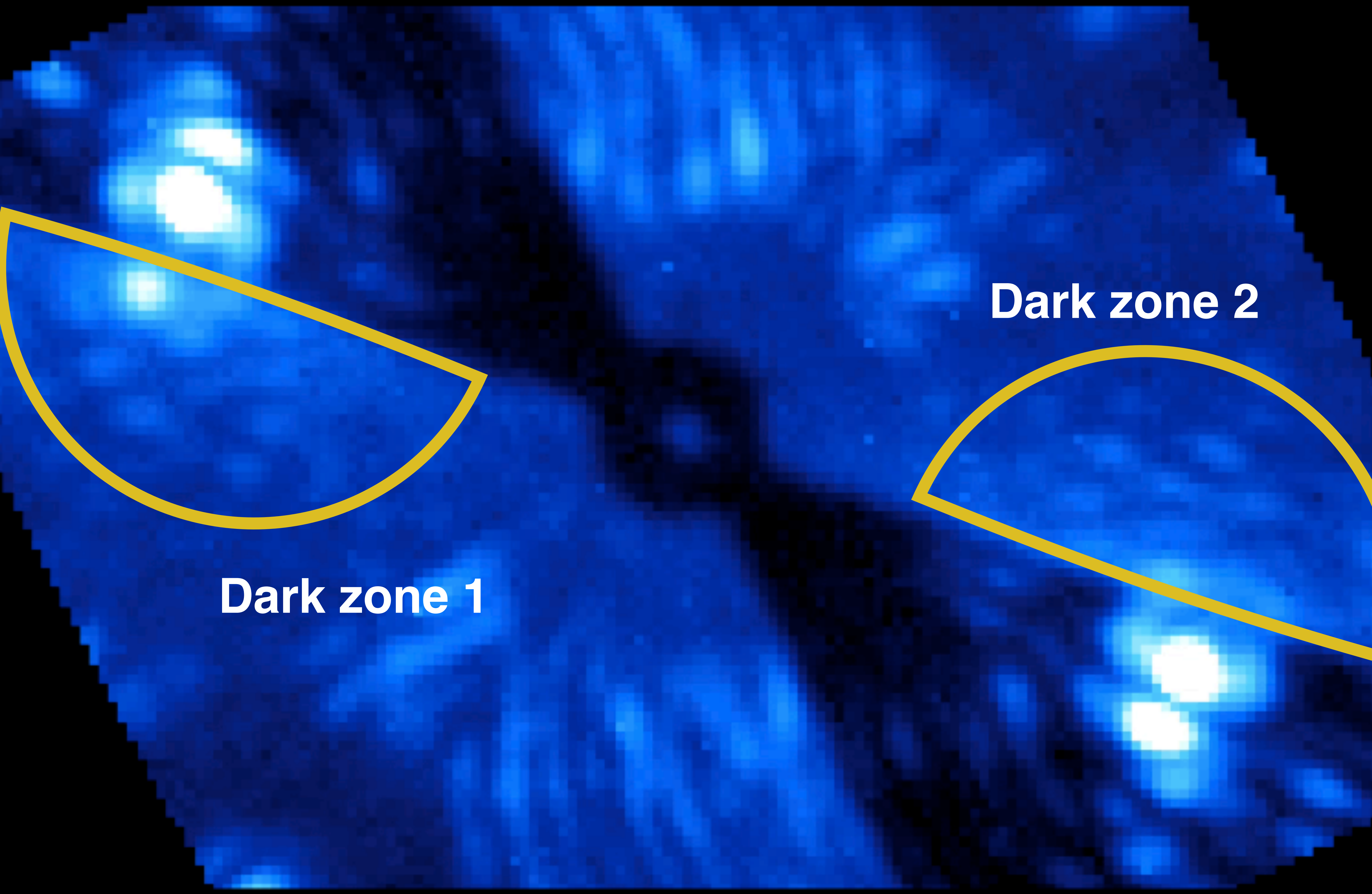
SCExAO gvAPP Transmission

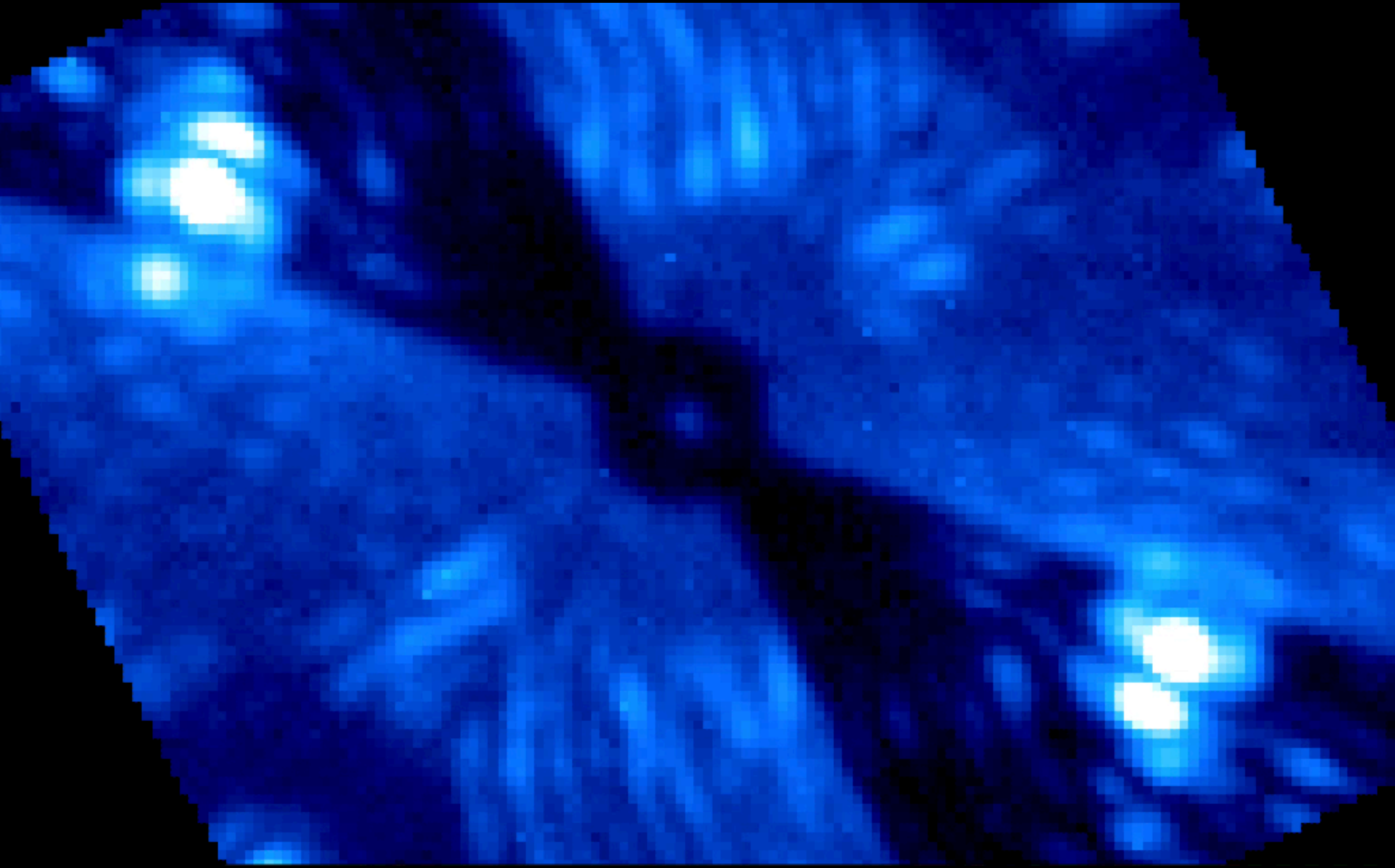


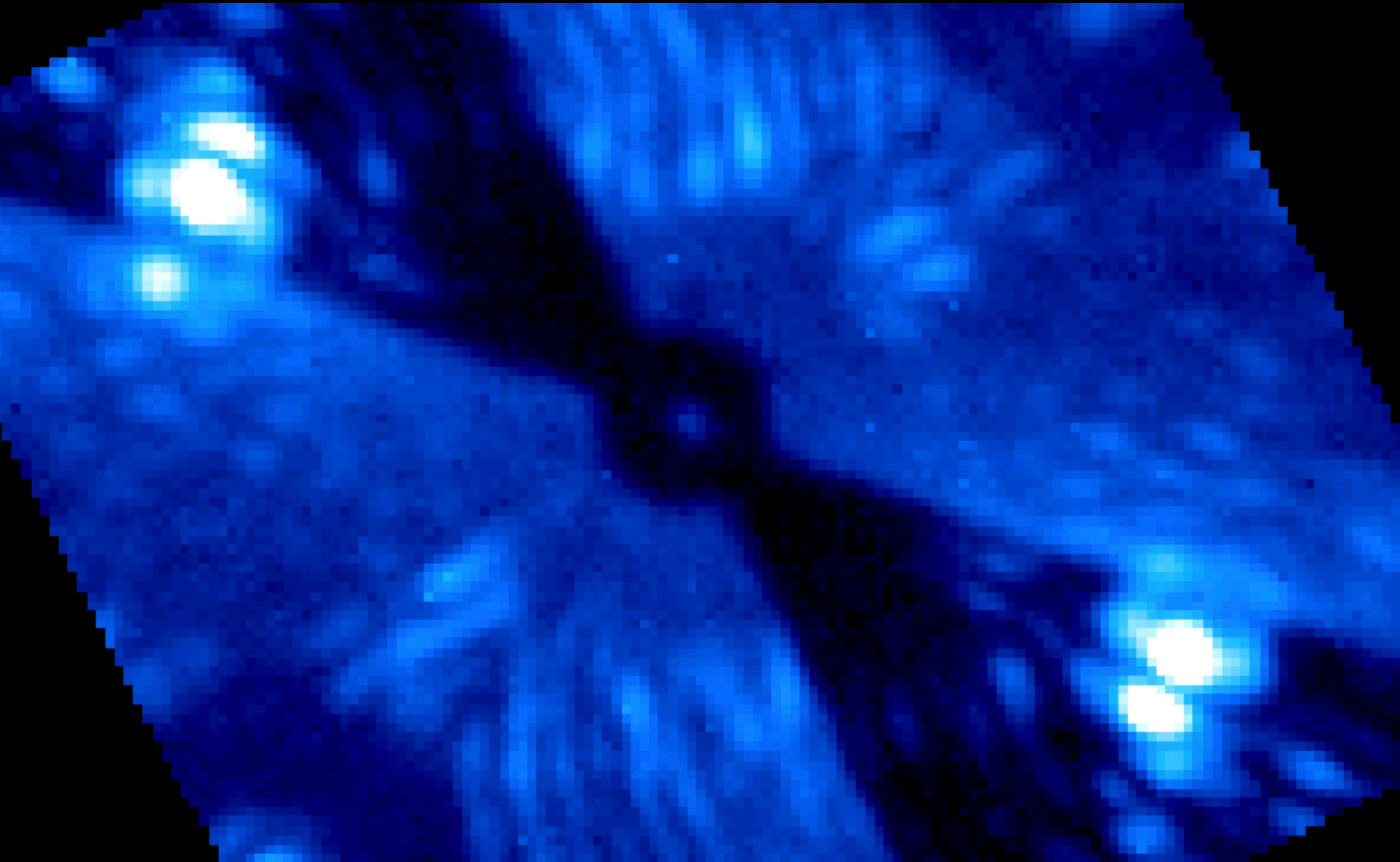
First light at Subaru




Bowtie ND filter


Dark zone 2
Dark zone 1

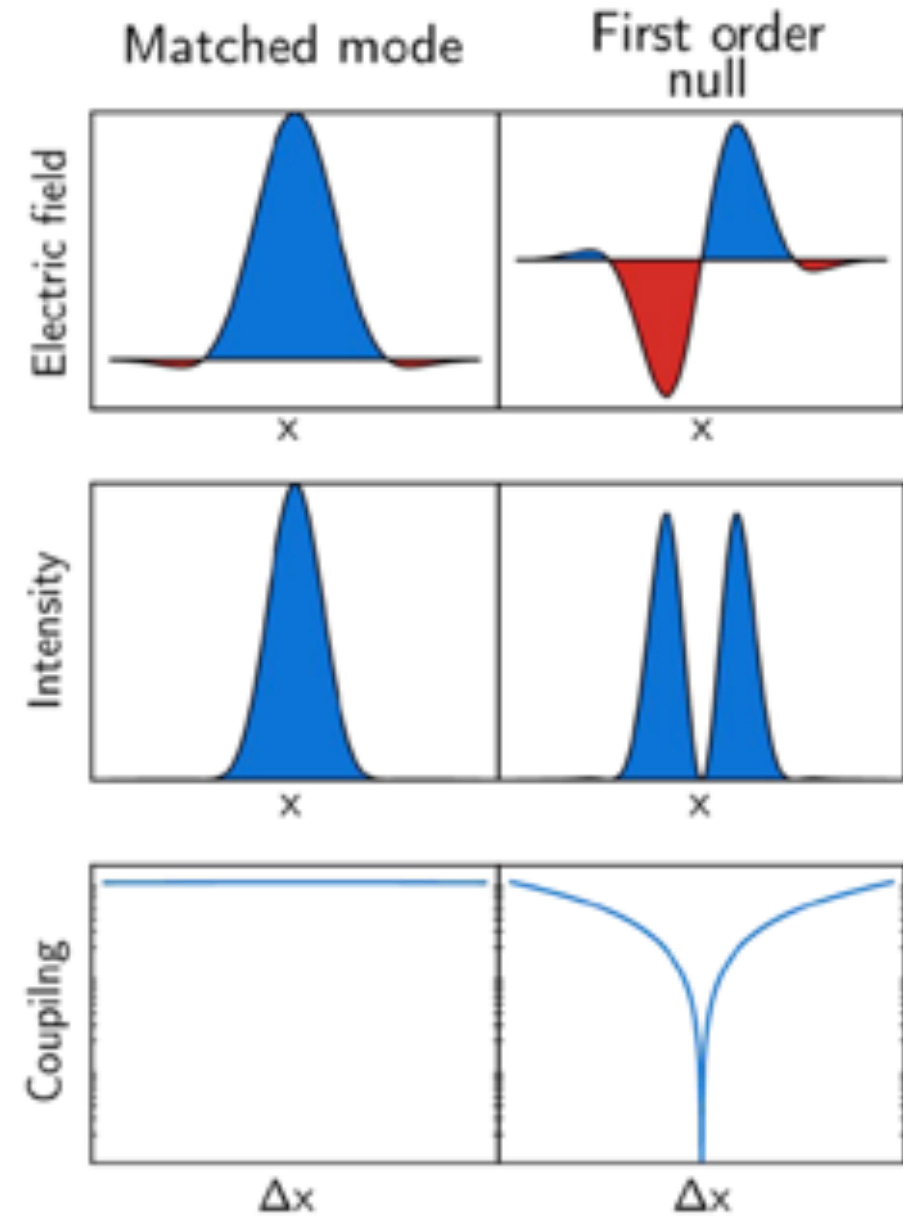




Single-mode Complex Amplitude Refinement coronagraph (SCAR)

Theory: Por and Haffert (2018) 1803.10691
Laboratory measurements: Haffert+ (2018) 1803.10693

Builds on idea of single-mode fiber as a rejection filter for starlight (Mawet+ 2017 ApJ) by shaping PSF with custom APP coronagraph

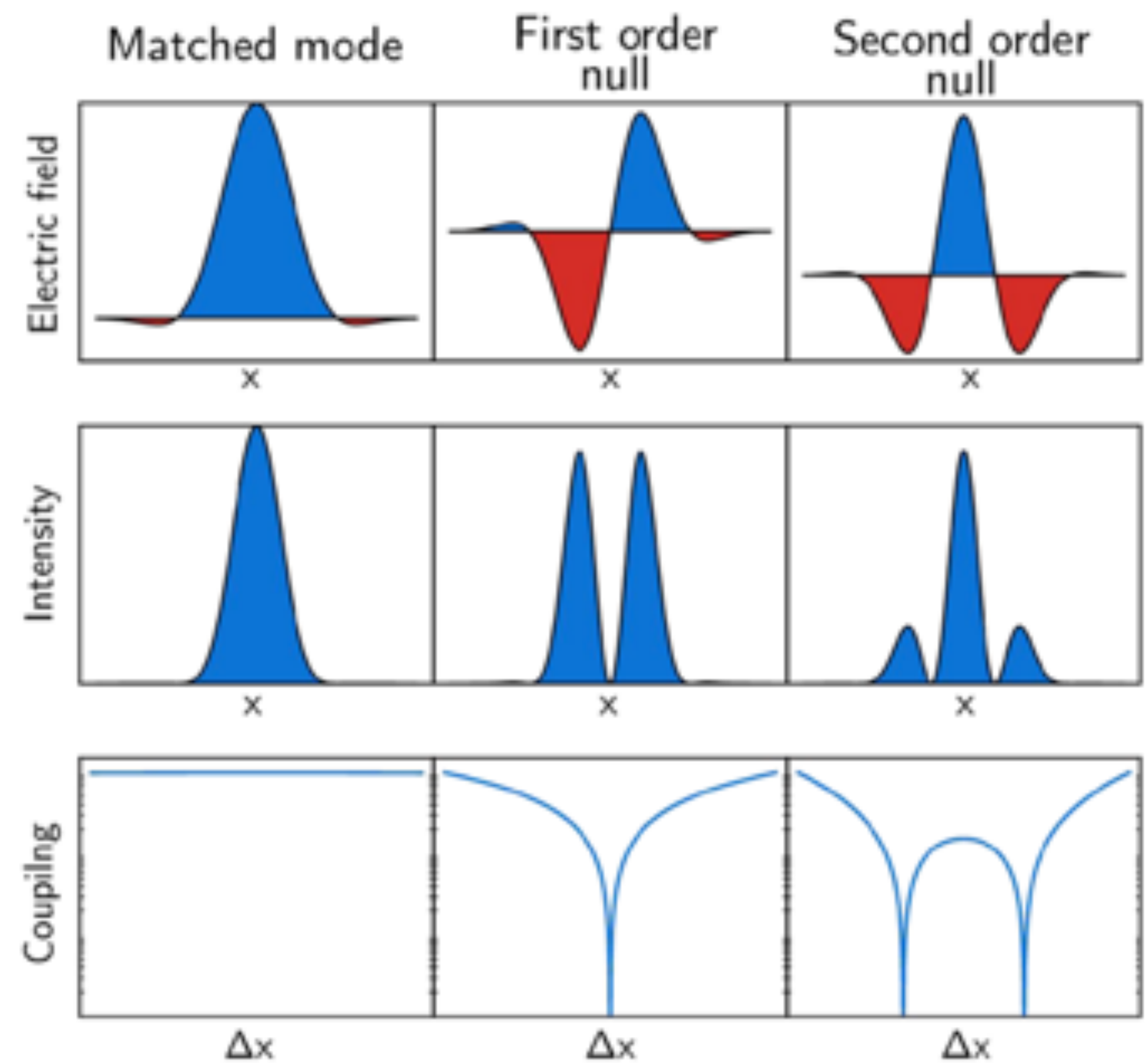


Single-mode Complex Amplitude Refinement coronagraph (SCAR)

Theory: Por and Haffert (2018) 1803.10691
Laboratory measurements: Haffert+ (2018) 1803.10693

Builds on idea of single-mode fiber as a rejection filter for starlight (Mawet+ 2017 ApJ) by shaping PSF with custom APP coronagraph

Putting SECOND order null across fibre face makes it BROADBAND



APP reimages star onto lenslet array with single mode fibres

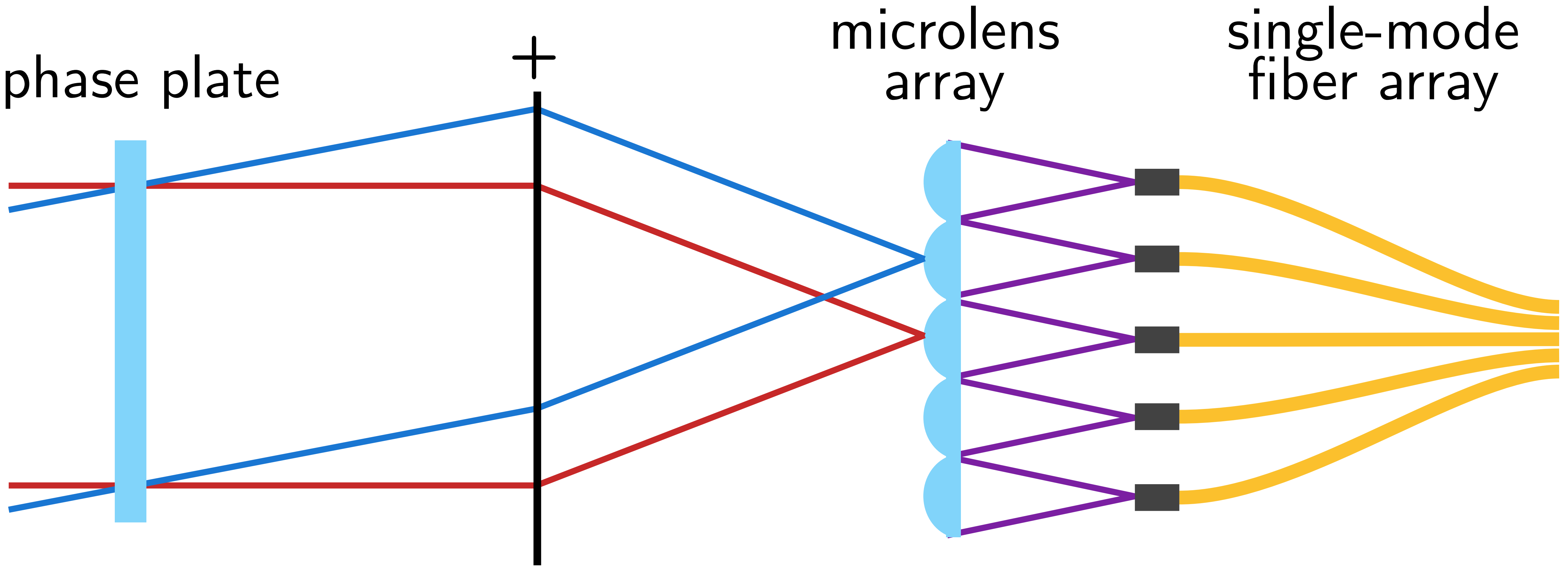
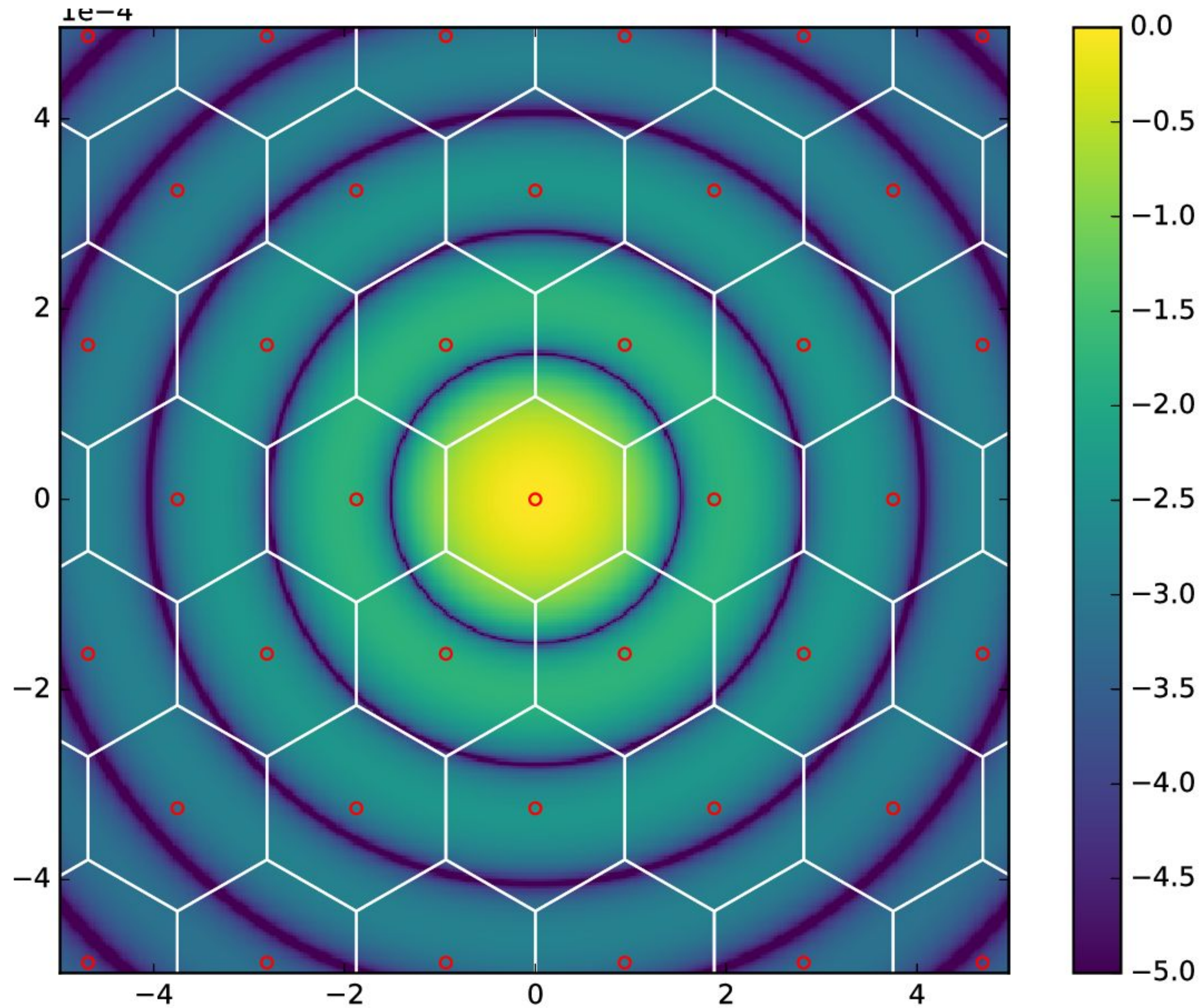
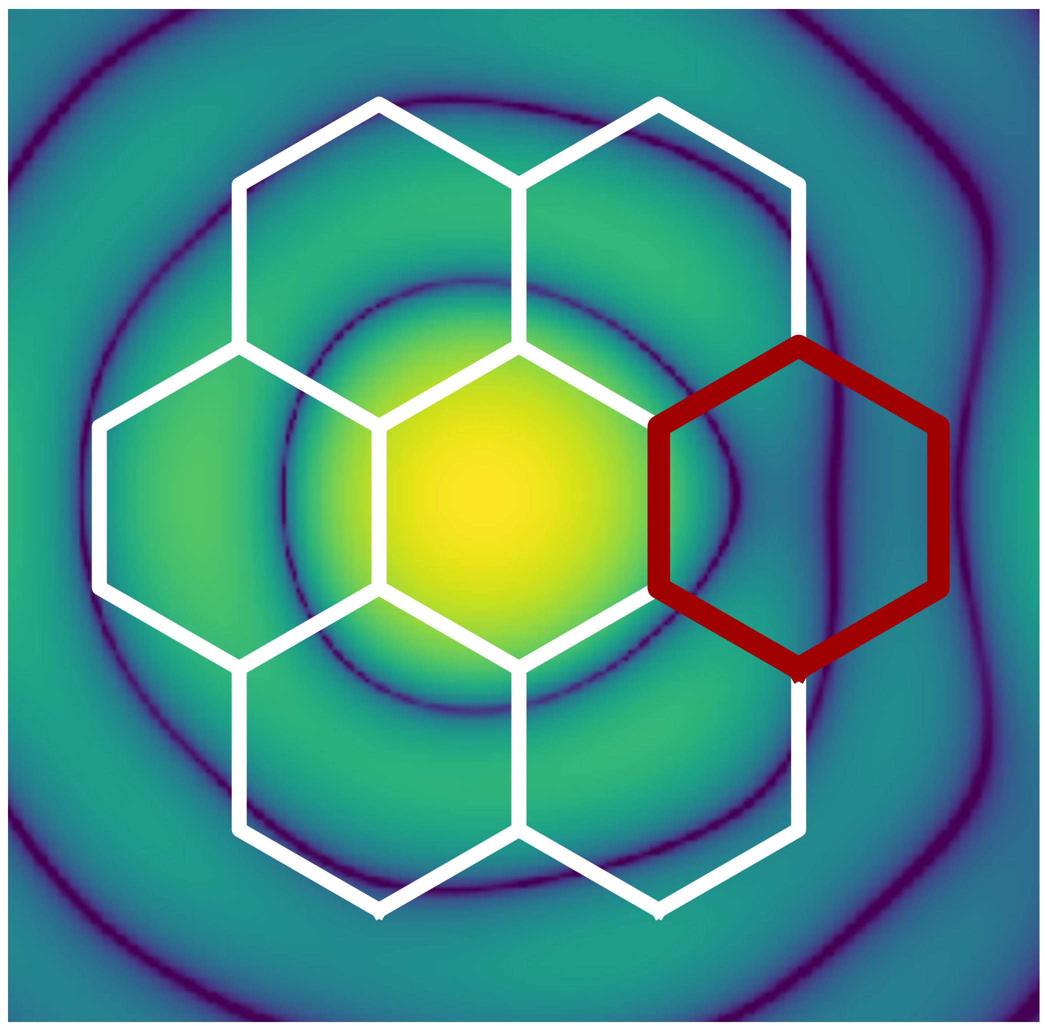


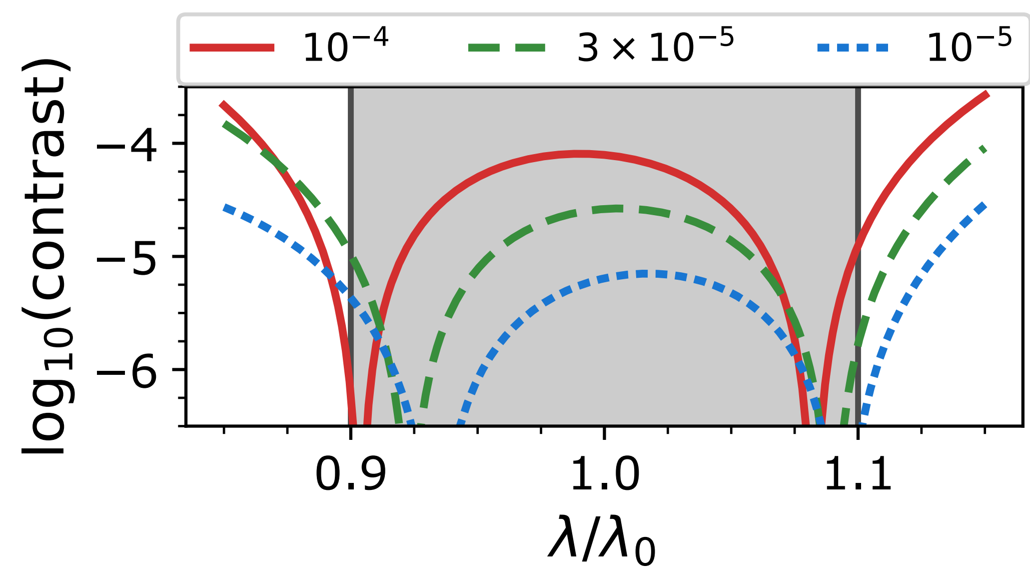
Image of star on hex lenslets



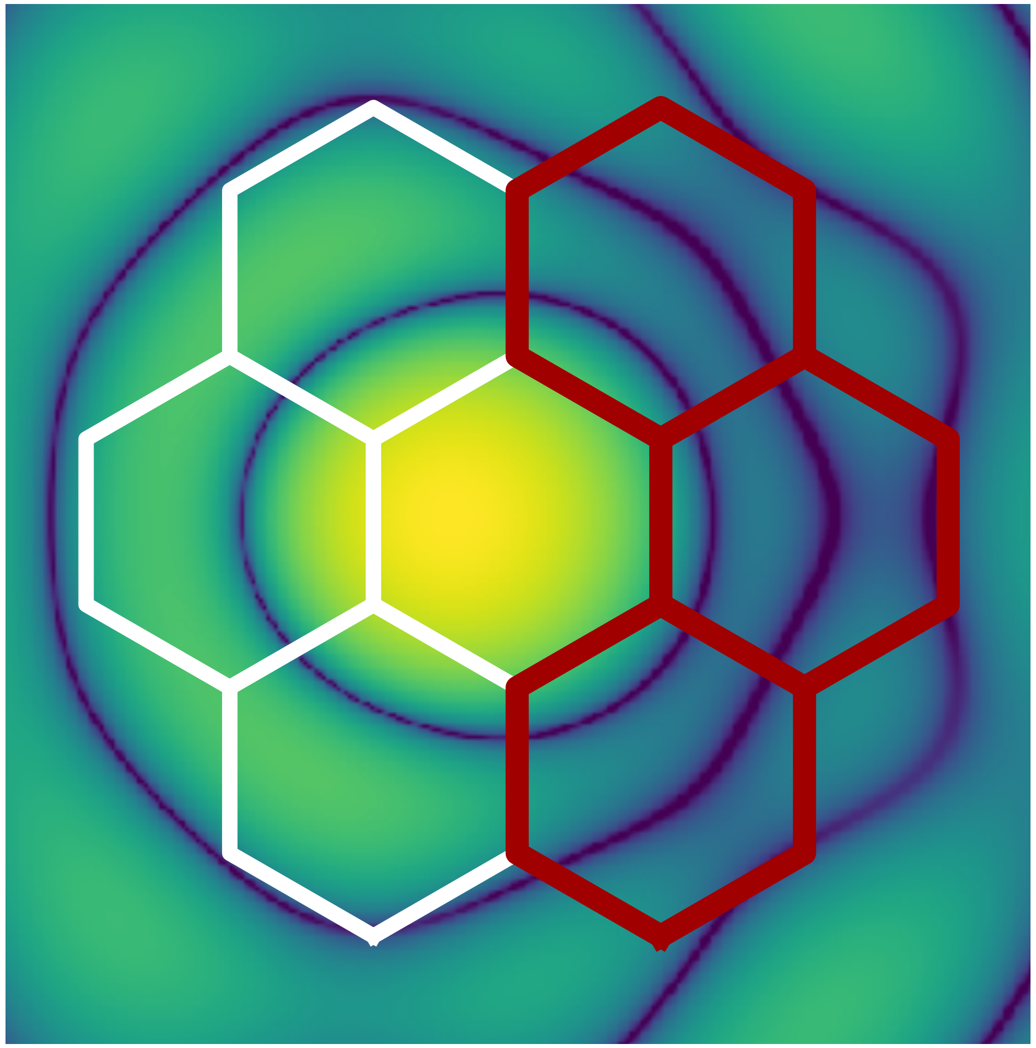
APP squeezes two nulls across one lens….



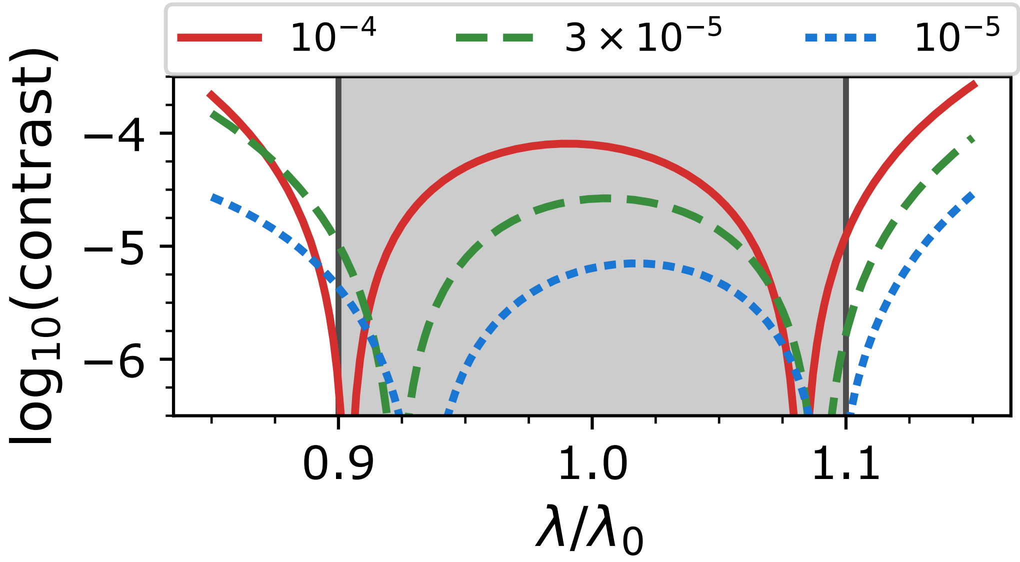
T=98%



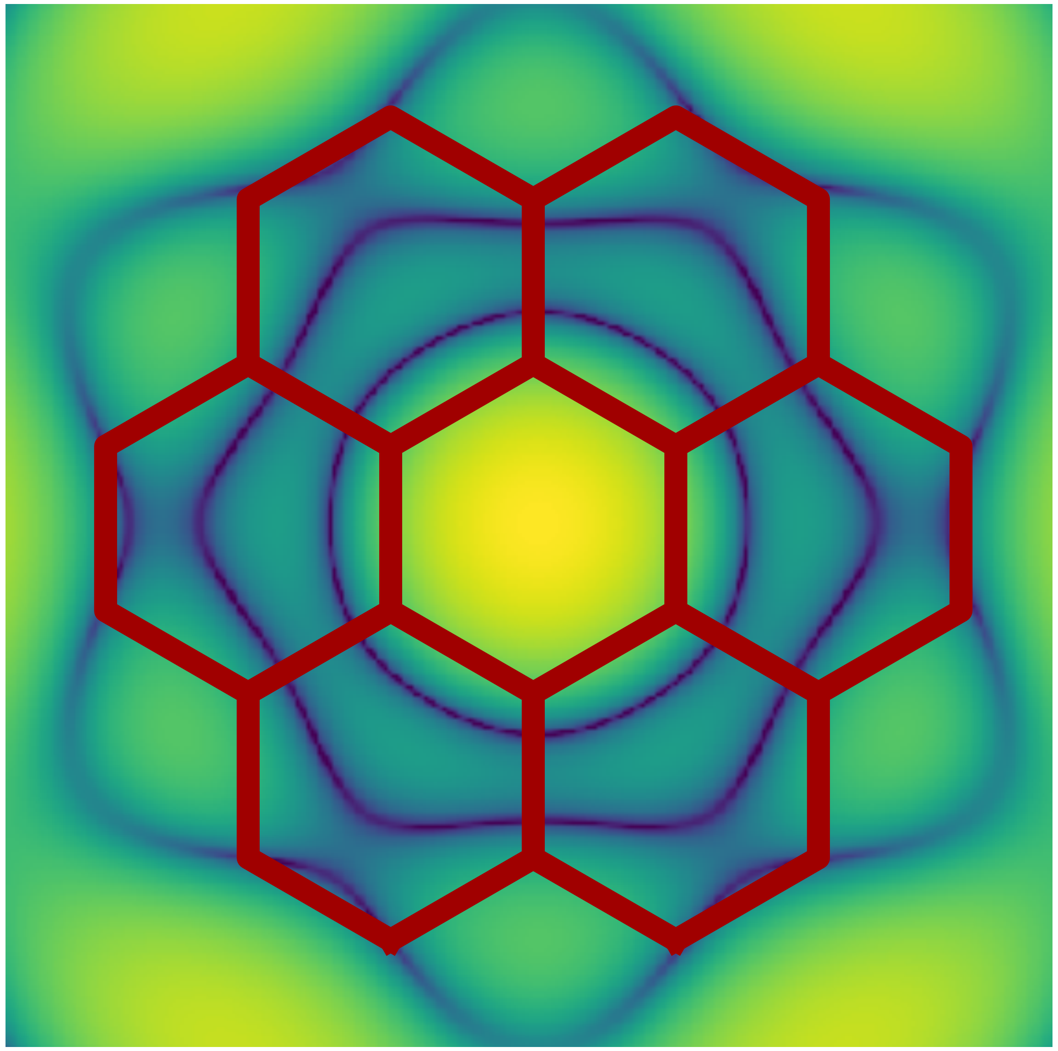
APP squeezes two nulls across three lenses….



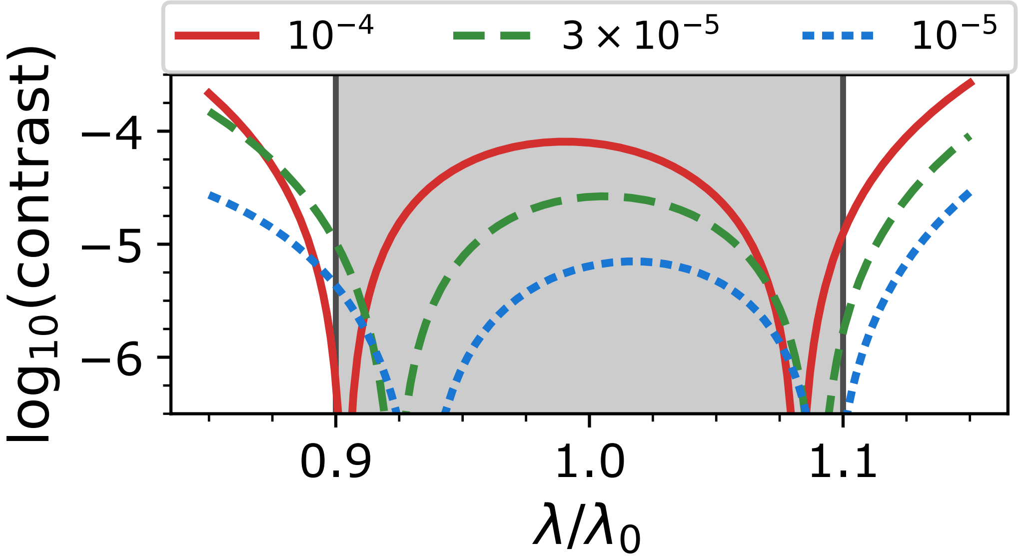
T=94%



APP squeezes two nulls across six lenses….

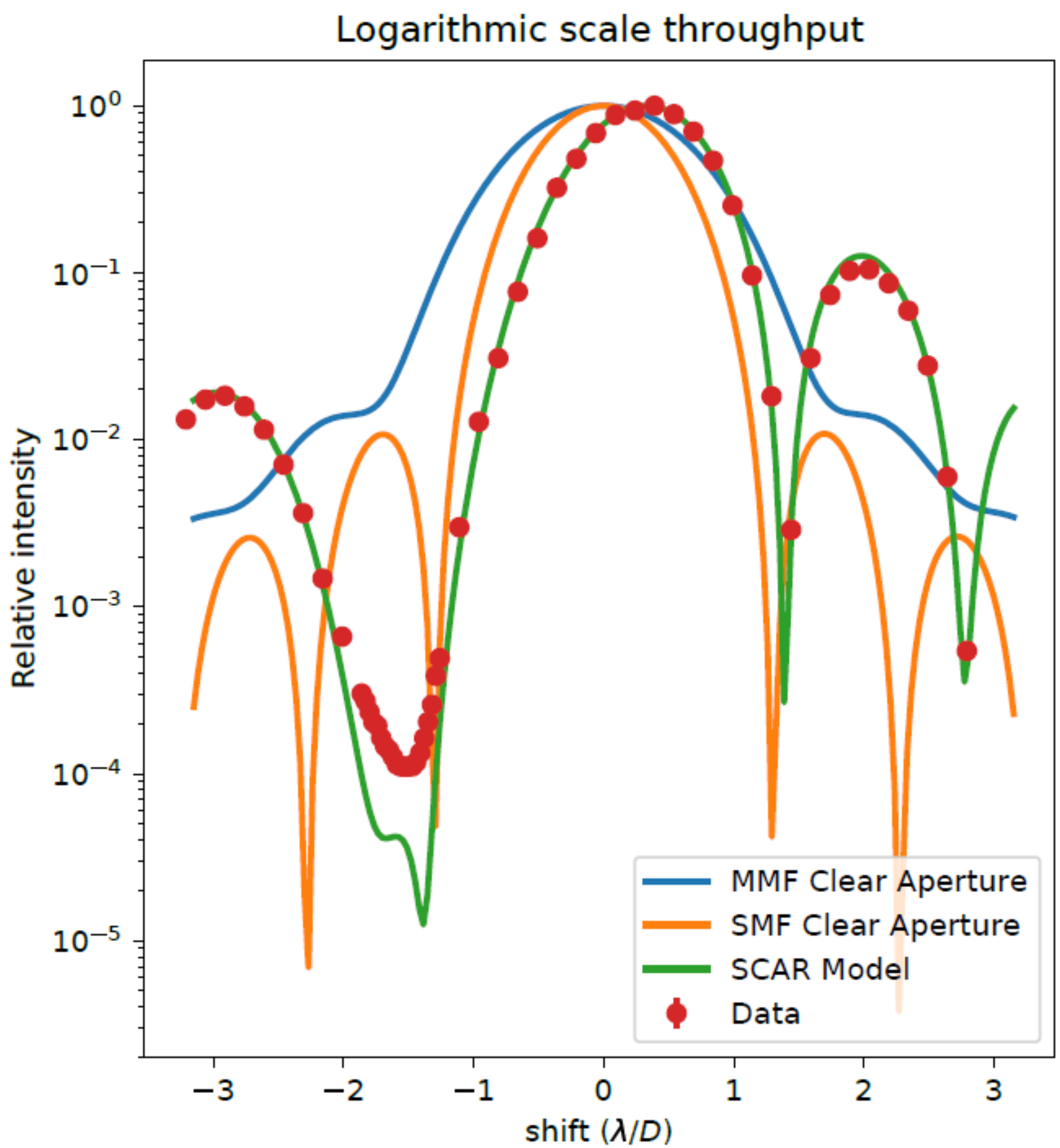


T=63%

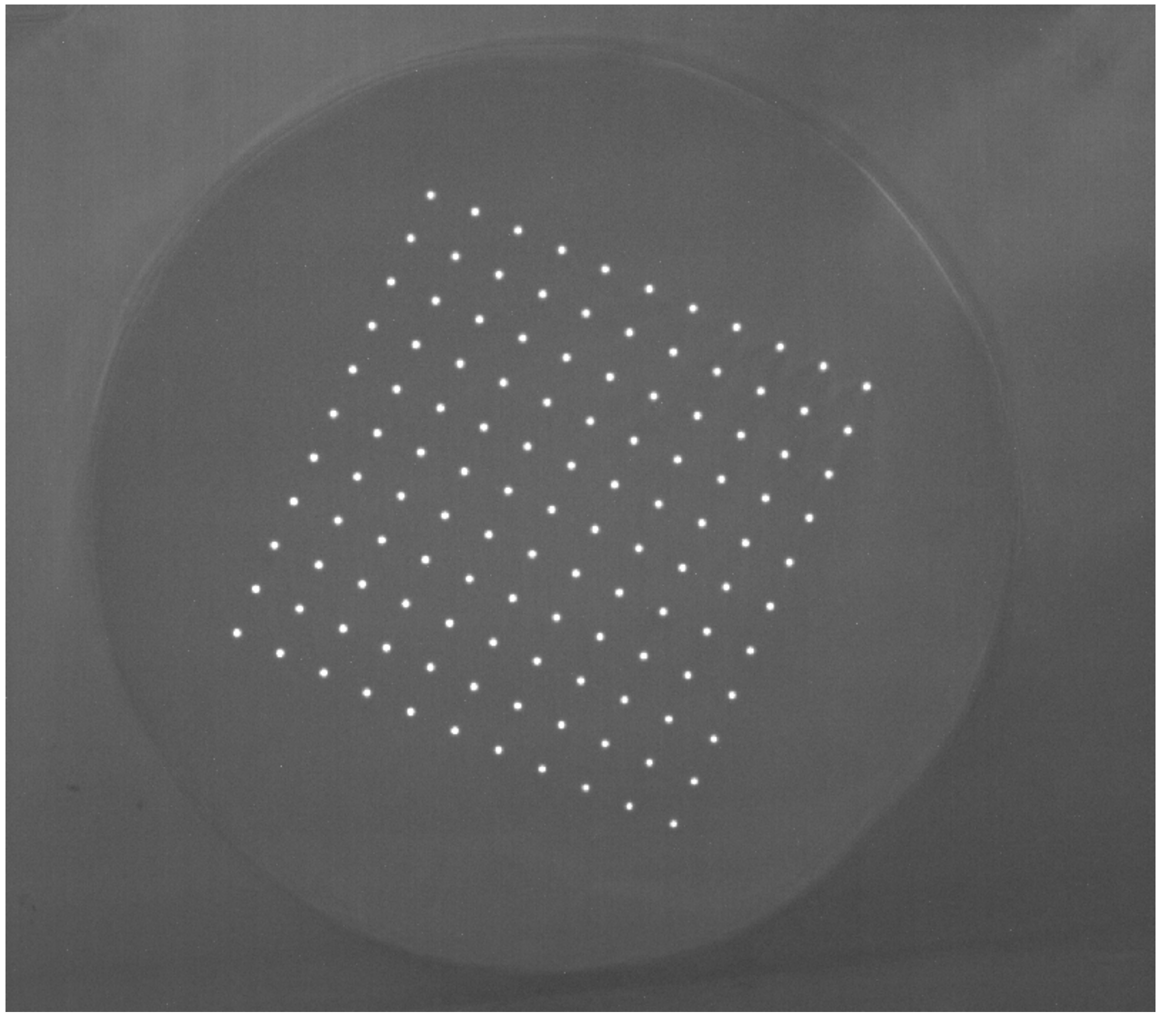


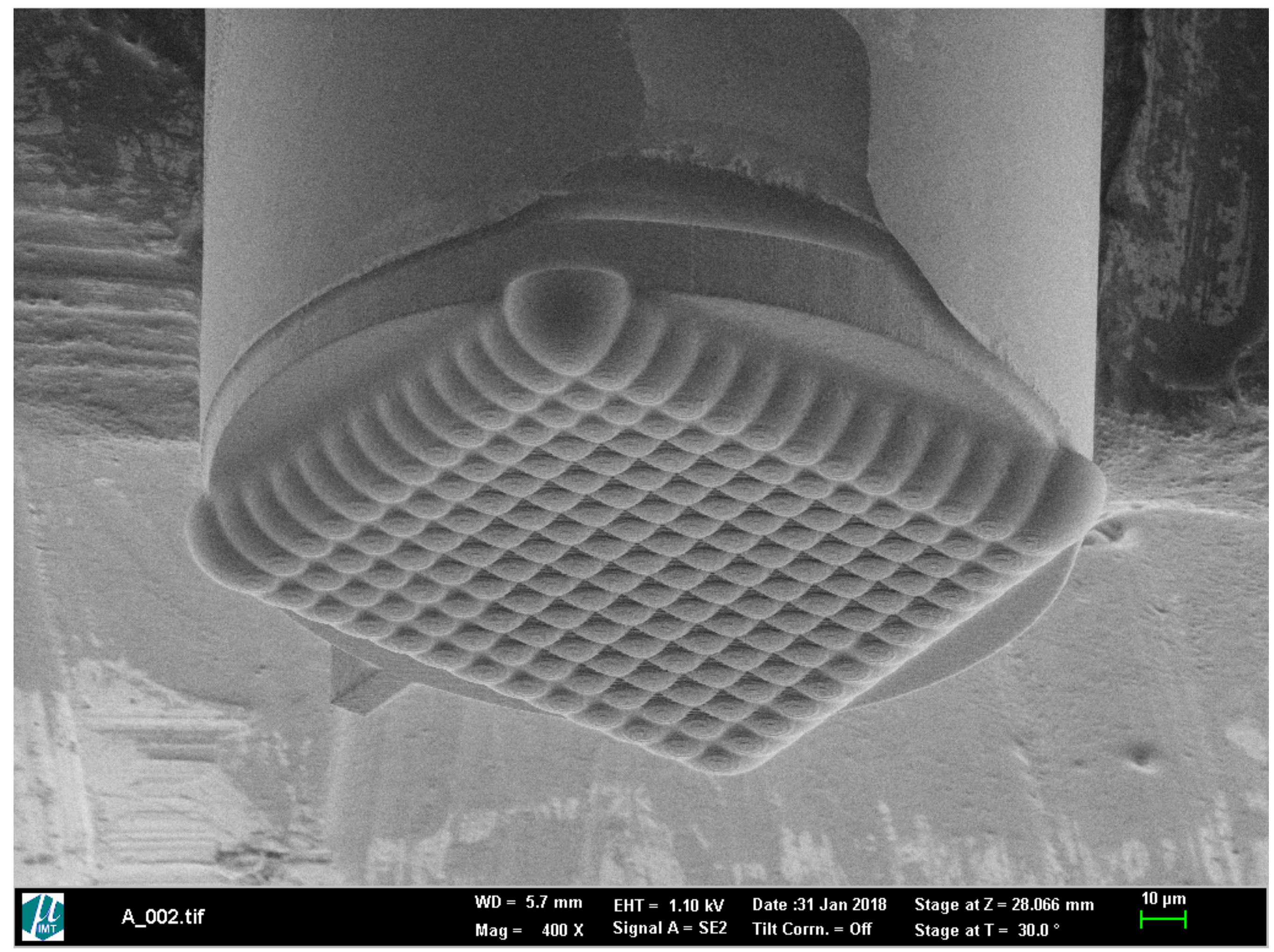
Robust to 0.1 lambda/D tip tilt error!

SCAR APP tested in the lab



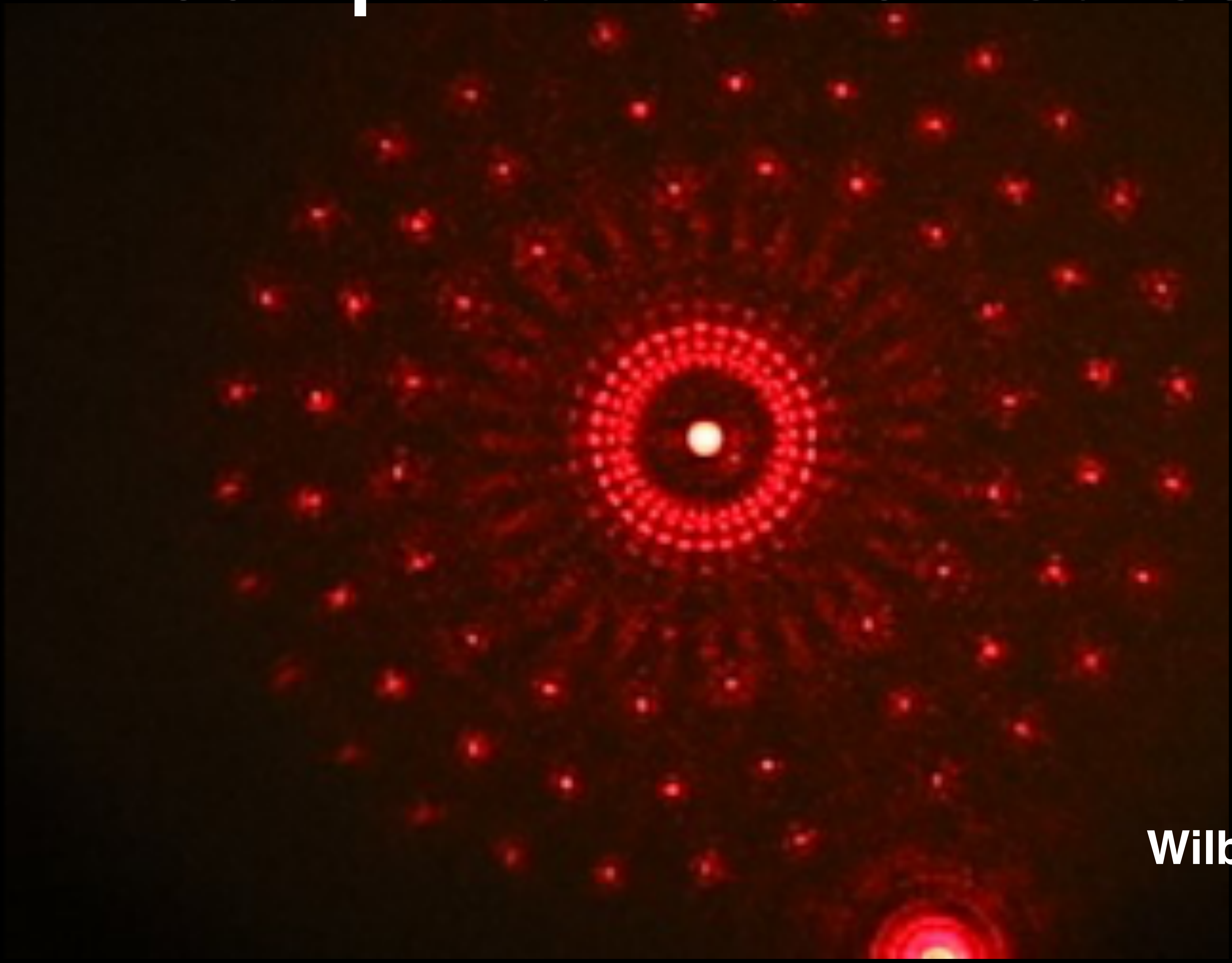
…and multi-fibre SCAR on the way





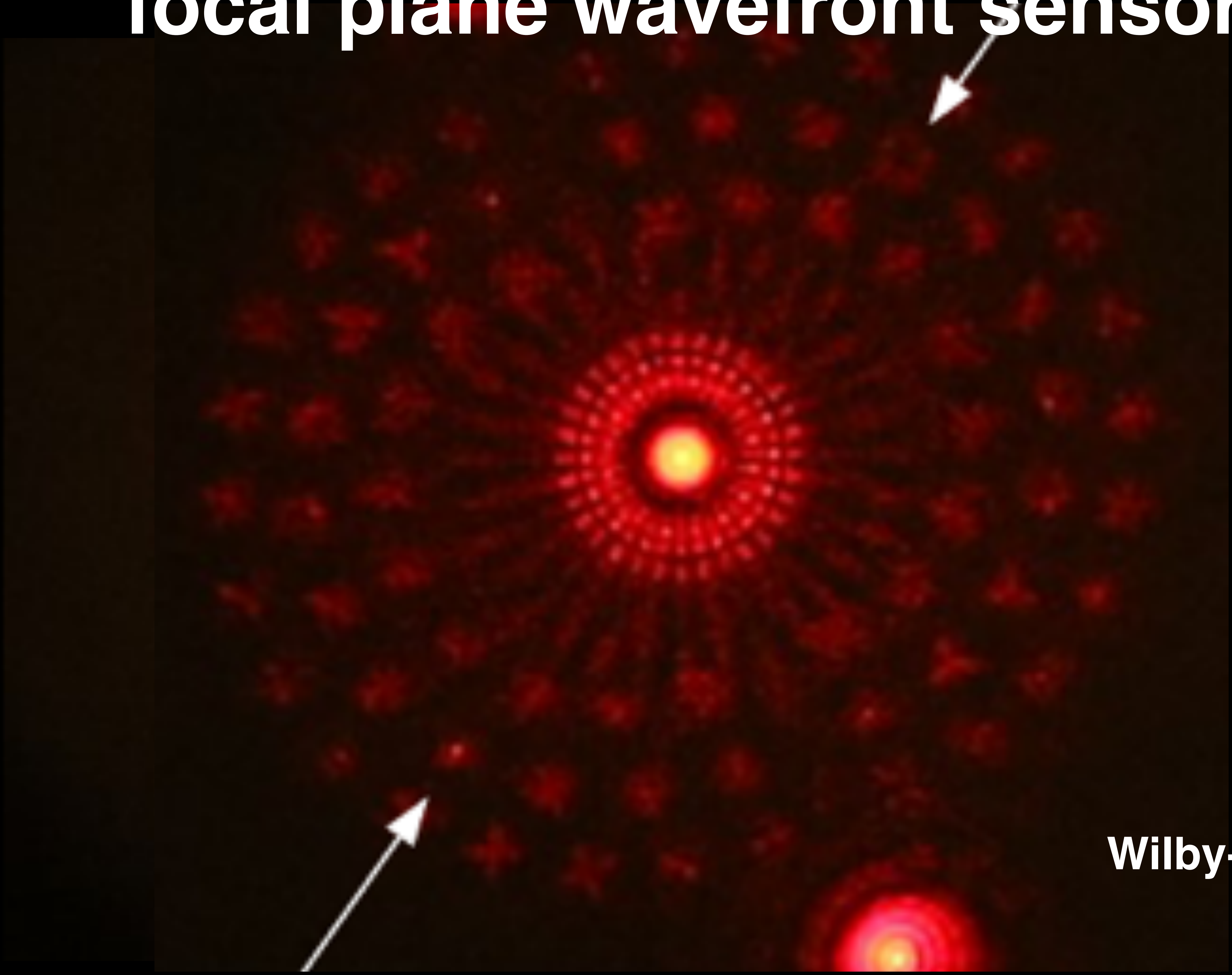
courtesy: Sebastiaan Haffert

Adding holograms to make focal plane wavefront sensors



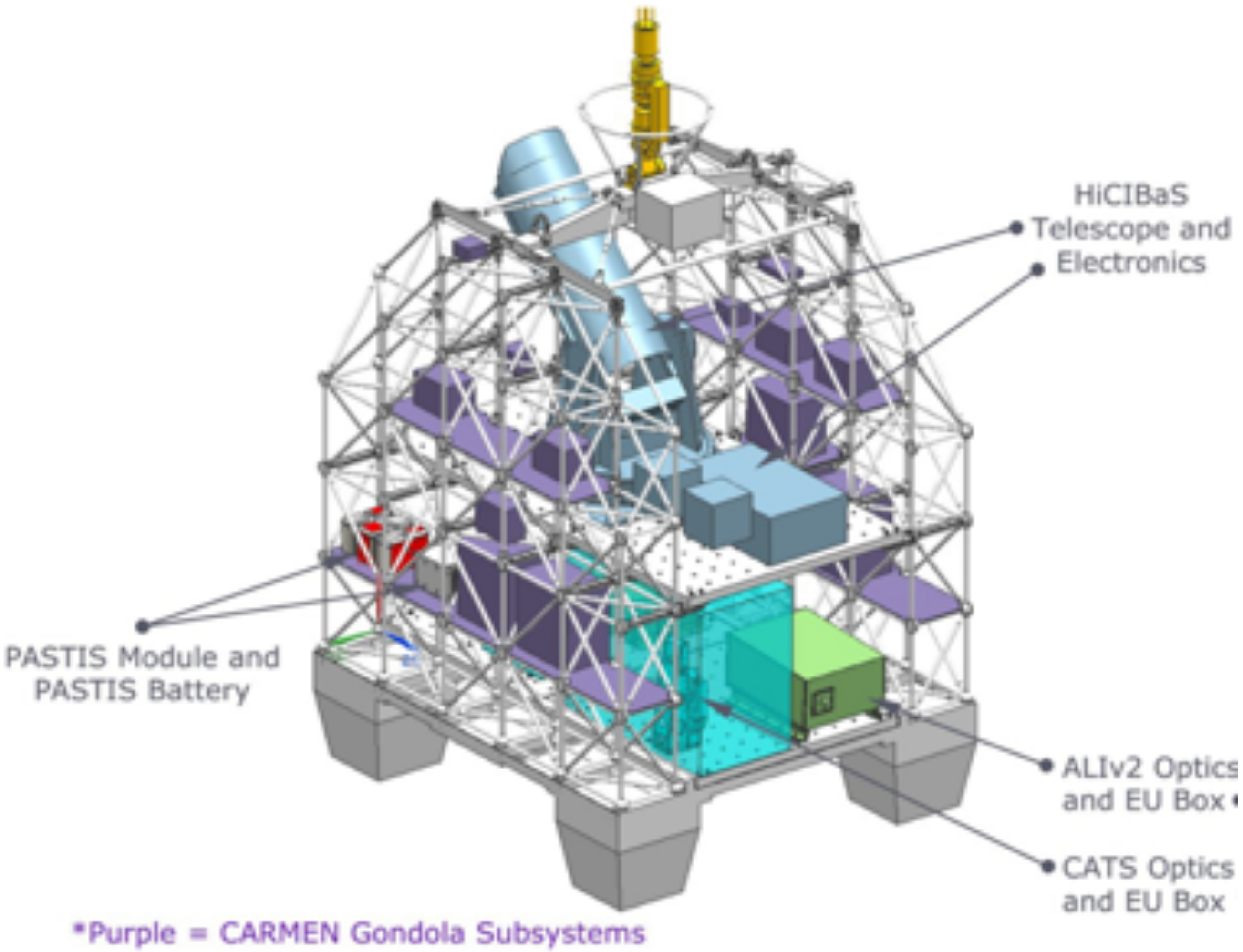
Wilby+ 2007

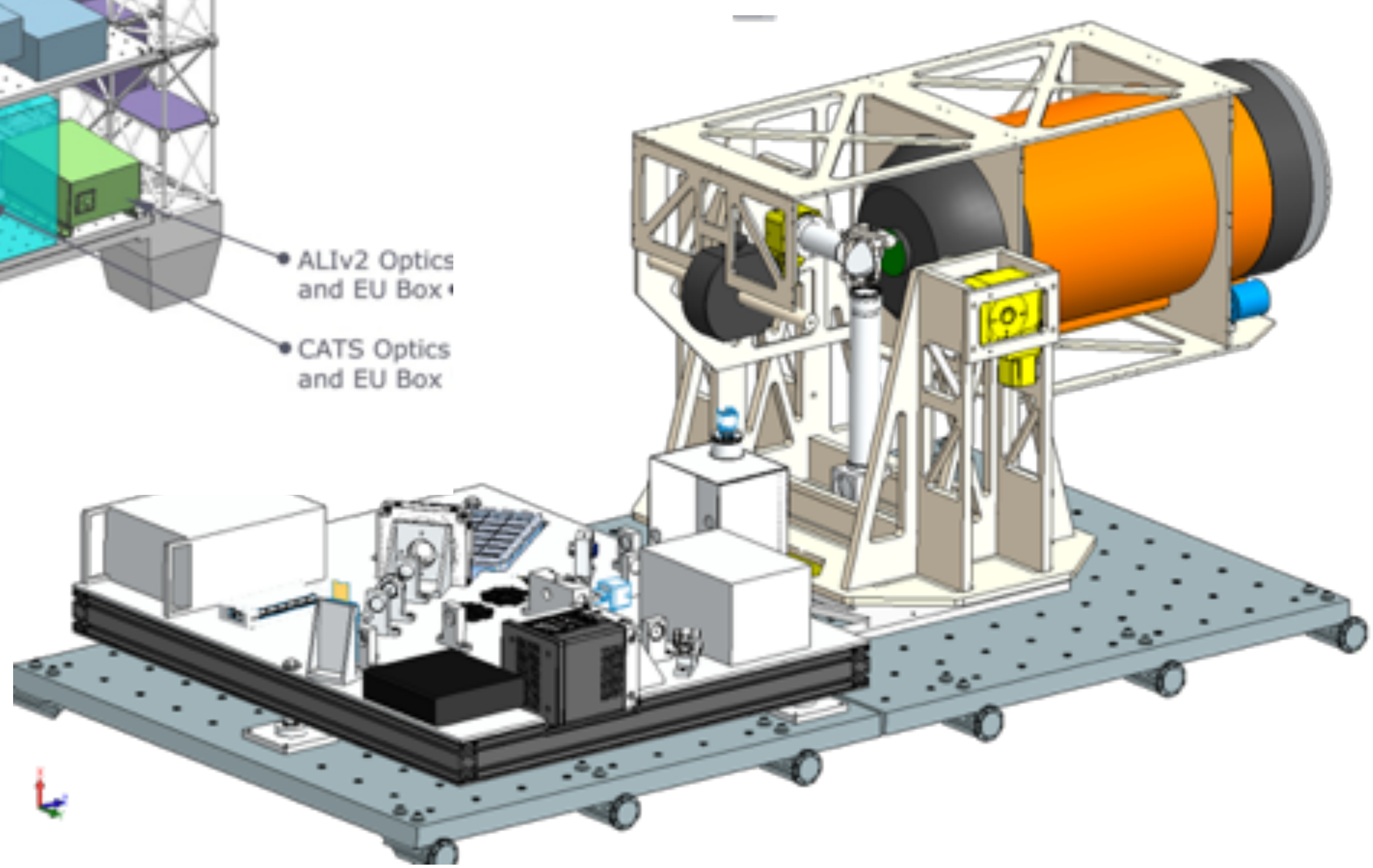
Adding holograms to make focal plane wavefront sensors



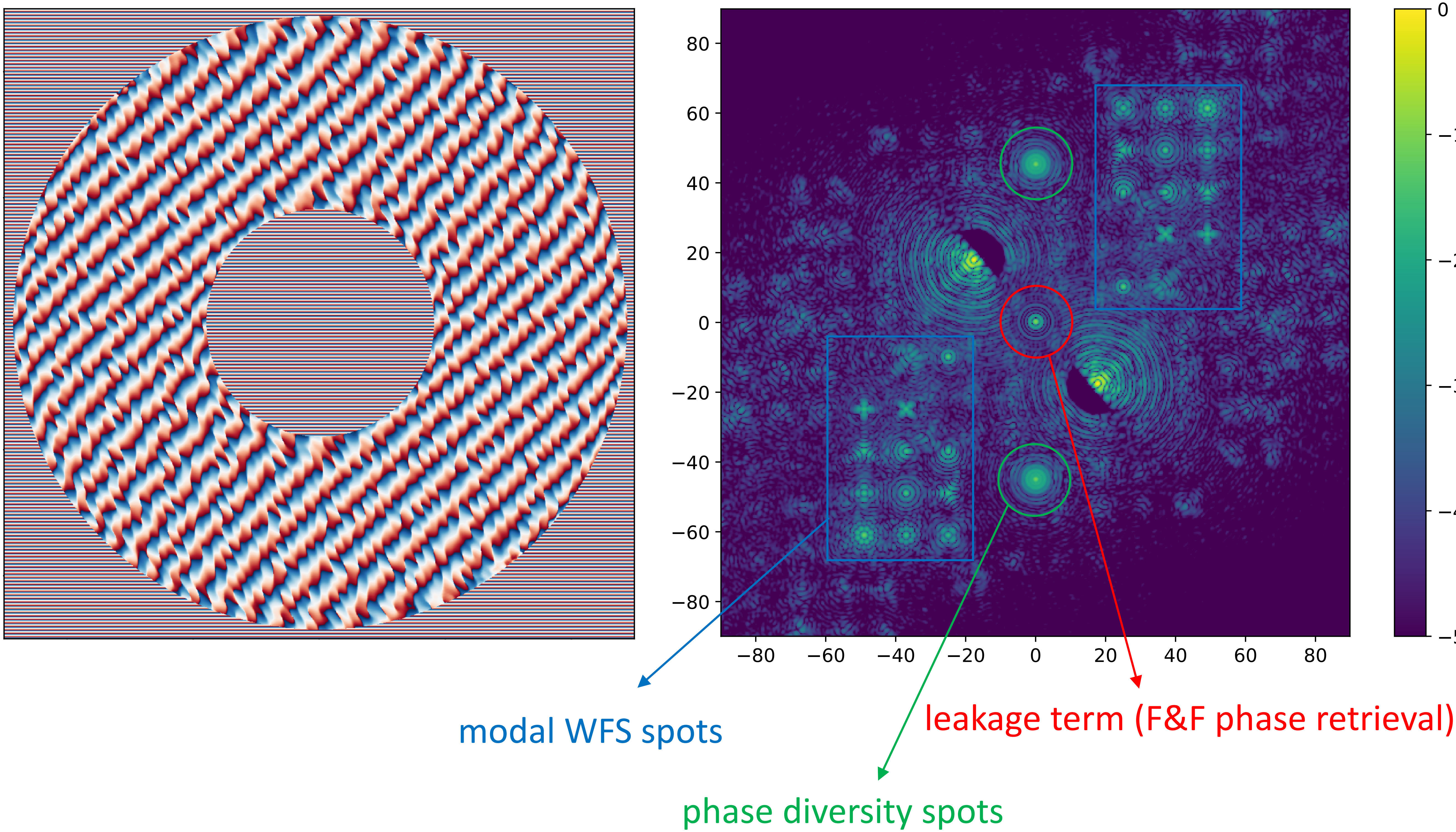
Wilby+ 2007

gvAPP+WFS for balloon experiment HiCiBaS in Aug 2018

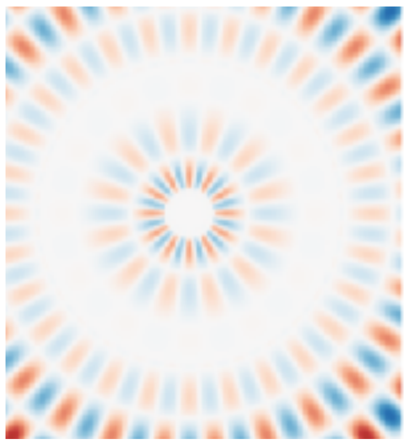


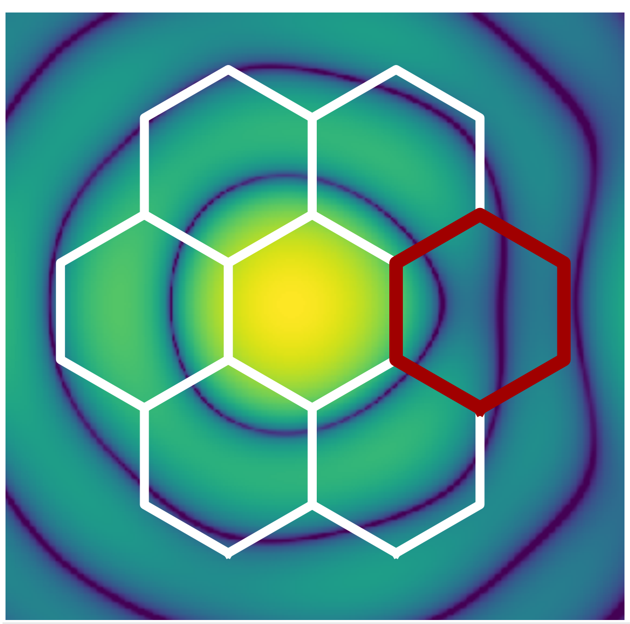


vAPP for **HiCIBaS**



Conclusions





- Complex broadband phase patterns are now possible
- Rich diversity of designs realisable
- Combining coronagraphs and wavefront sensing in one optic
- Pushing up the TRL

LEOPARD