bePOM
Belgian Photonics Online Meetup

Nanostructured Infrared Vortex Phase Masks for Stellar Coronagraphy

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LIÈGE université

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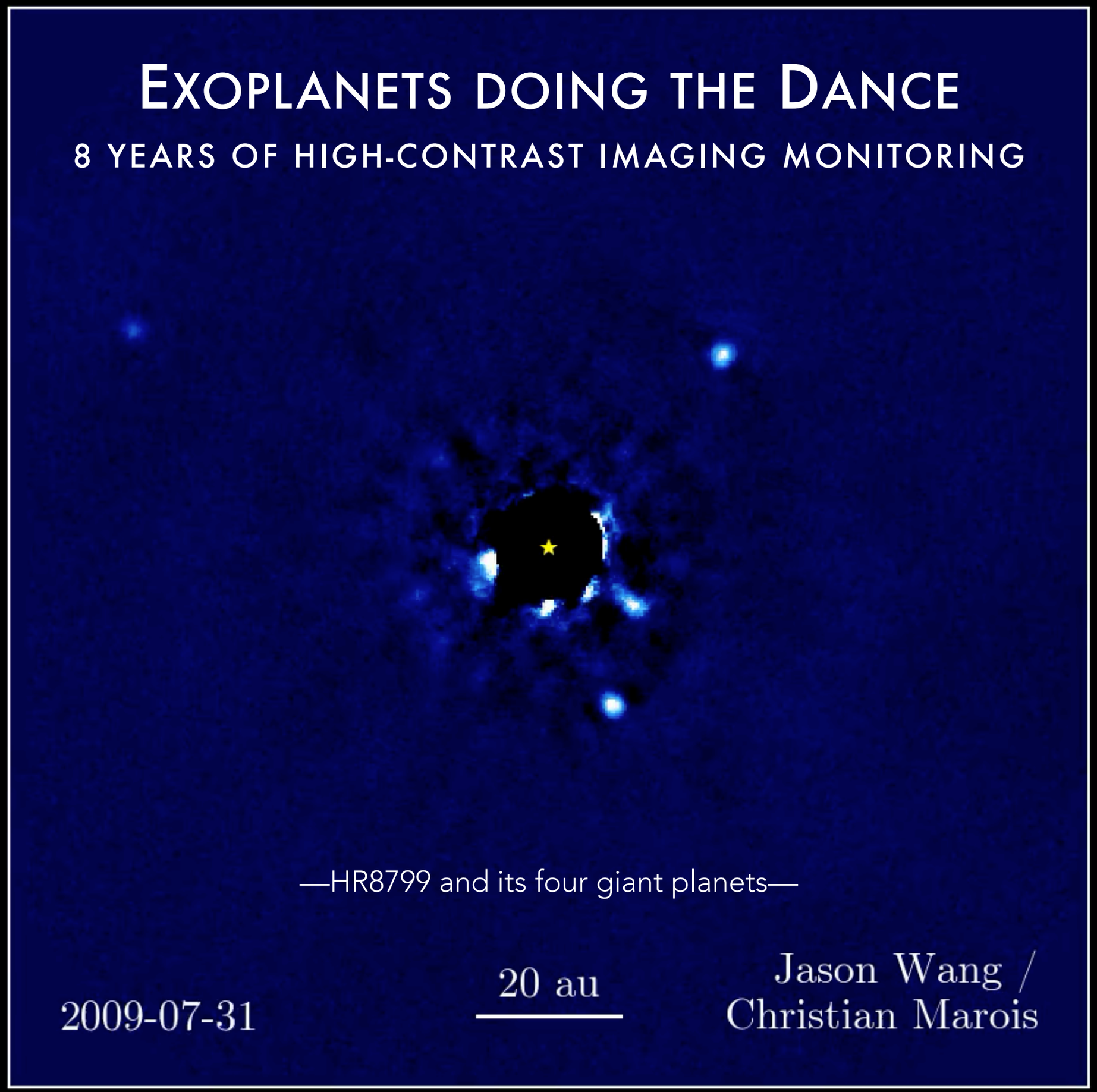
Disclaimer

- No Optics Institute @ ULiège
- Research shown here carried out at Space sciences, Technologies, and Astrophysics Research (STAR) Institute
- Not an overview of ULiège photonics activities, also carried out at
  - CSL (Centre Spatial de Liège): design, metrology, diffractive optics, solar cells, nano-structures, sensing, etching, etc
  - CESAM (Complex and Entangled Systems from Atoms to Materials): quantum optics, nano-materials, etc
  - probably others…

Exoplanets doing the Dance

8 years of high-contrast imaging monitoring



—HR8799 and its four giant planets—

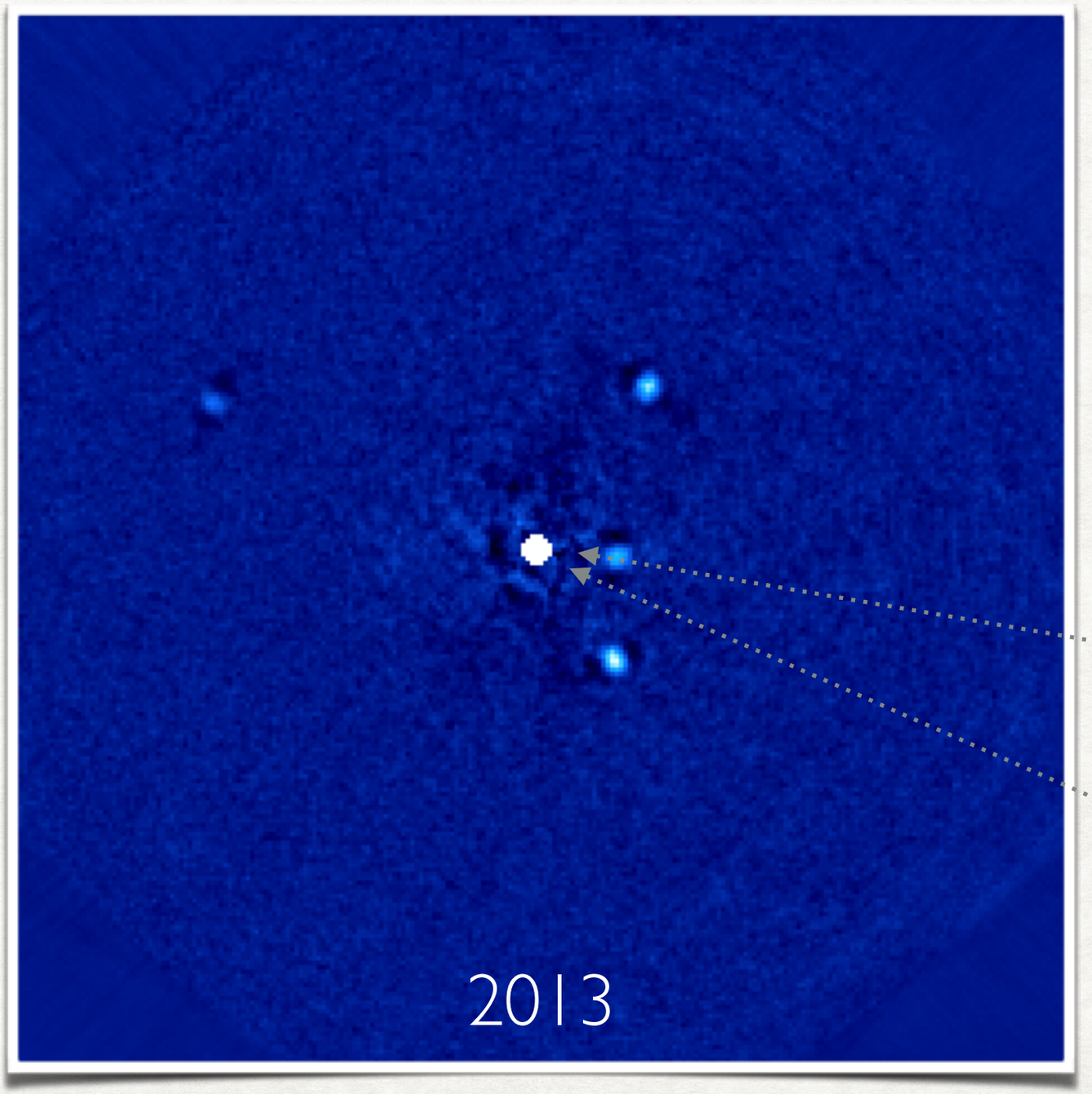
EXOPLANET IMAGING CHALLENGES

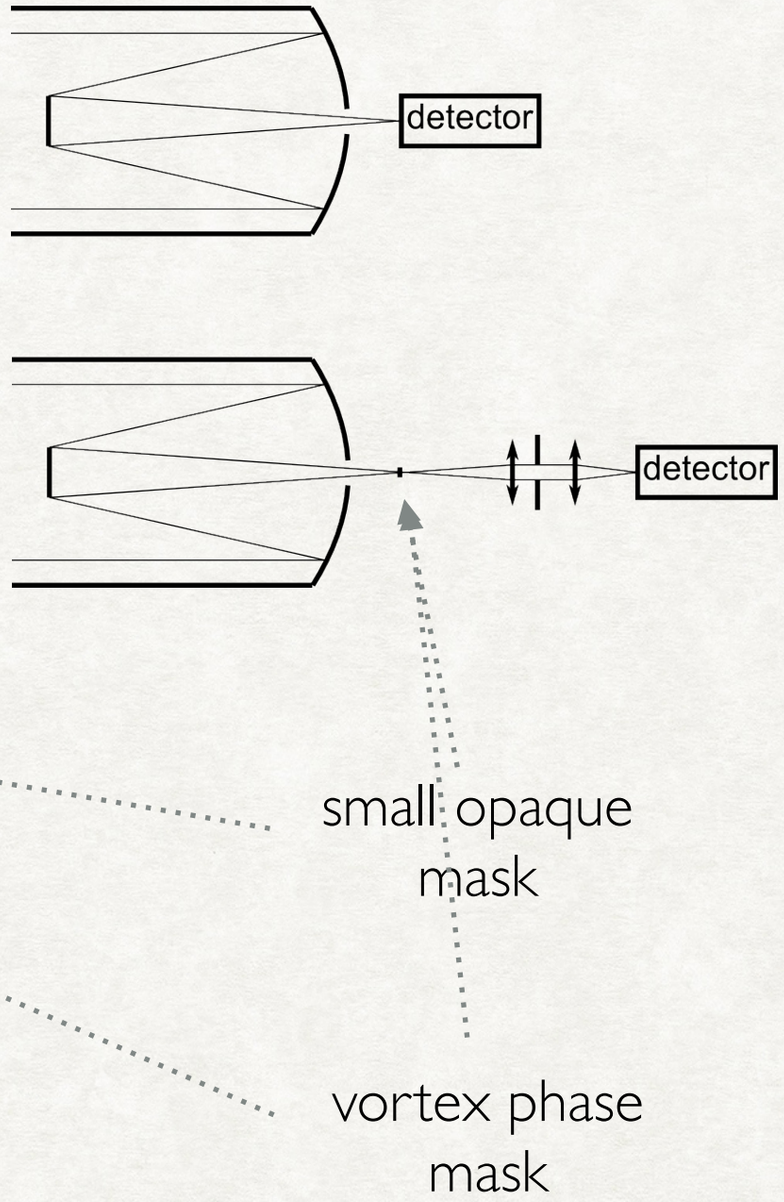
The star never turns off —> need specialized instruments to access

HIGH CONTRAST (from 1,000 to 10,000,000,000)

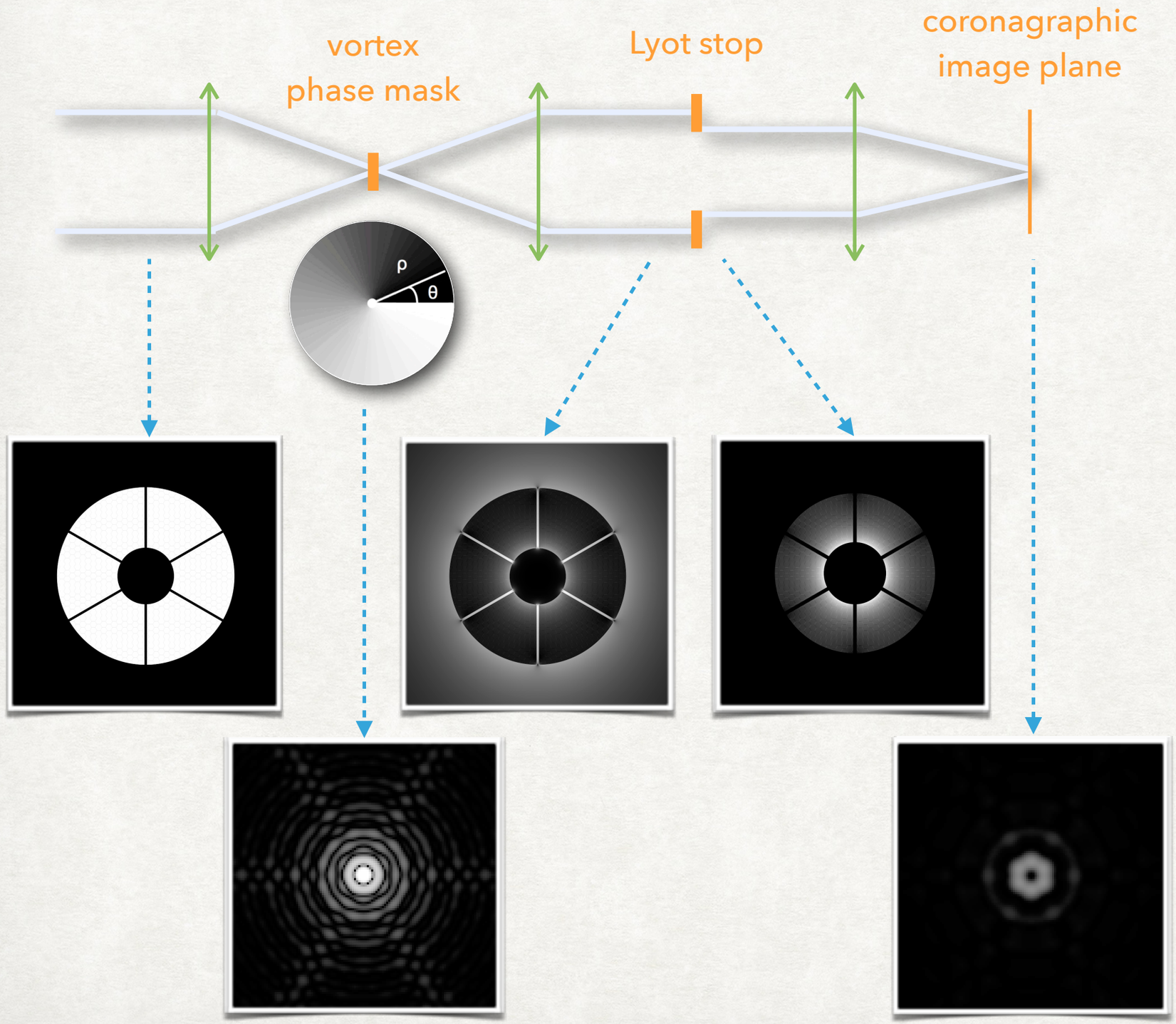
at **SMALL ANGULAR SEPARATION** (below 1 arcsec)

STELLAR CORONAGRAPHY

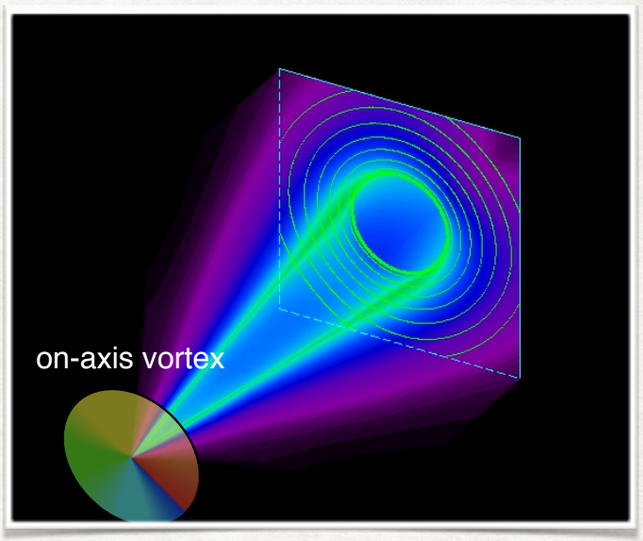


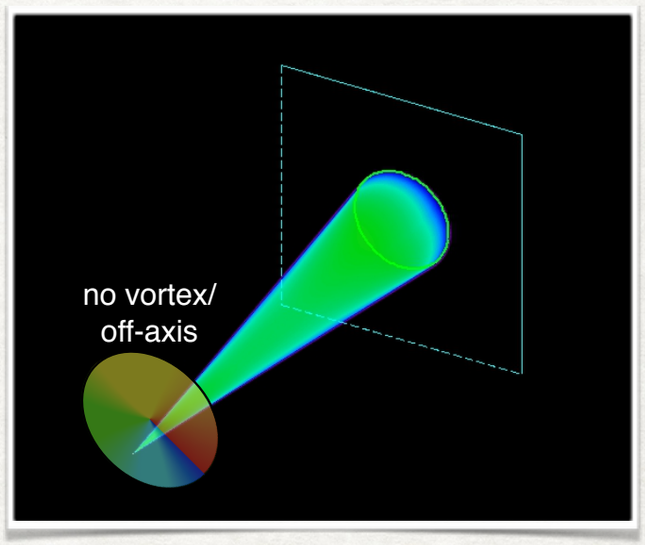


VORTEX CORONAGRAPH



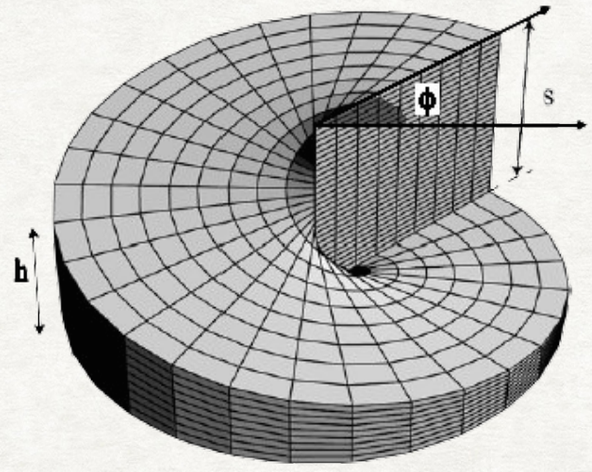
perfect on-axis cancellation
for a circular aperture



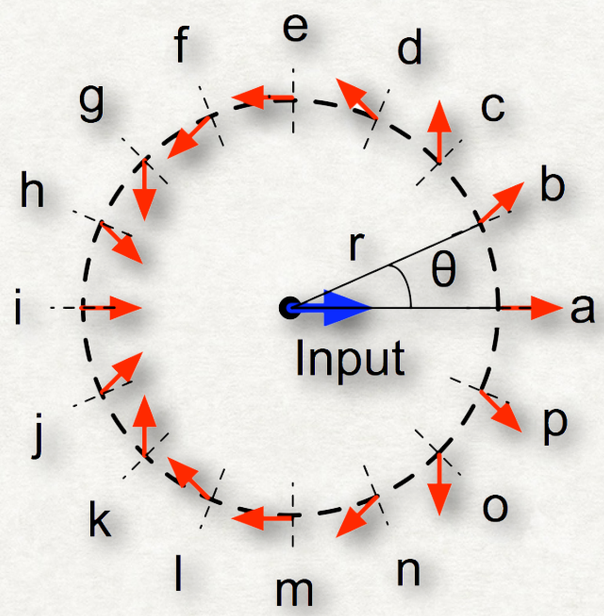


The vortex phase mask

- Scalar vortex
  - helical piece of glass

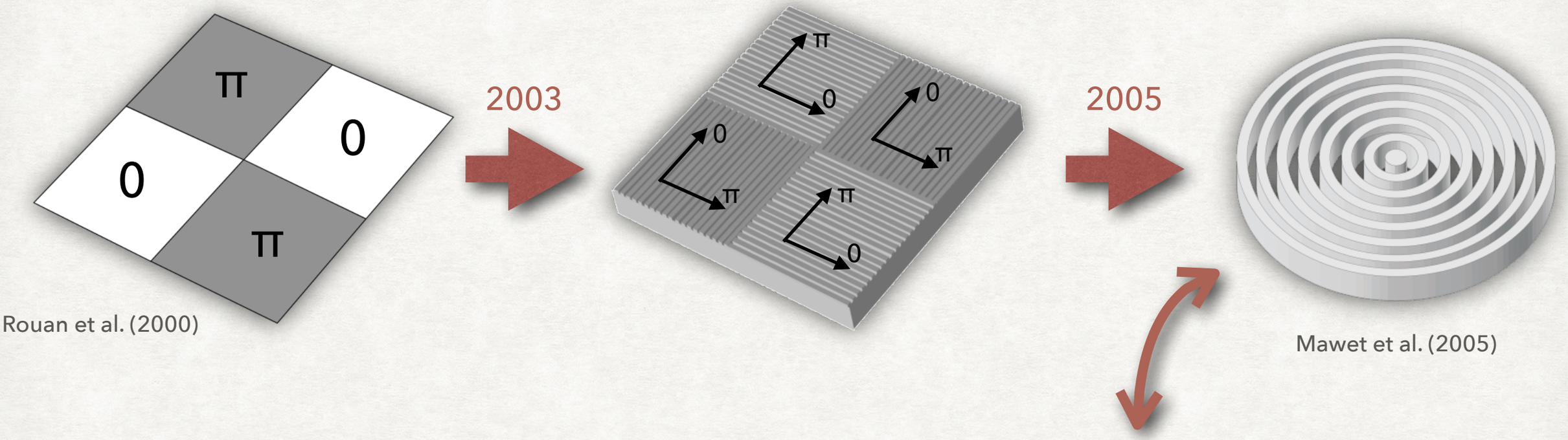


- Vector vortex = spatially variant half wave plate
  - liquid crystal polymers
  - subwavelength gratings
  - photonic crystals



Genesis of the Annular Groove Phase Mask

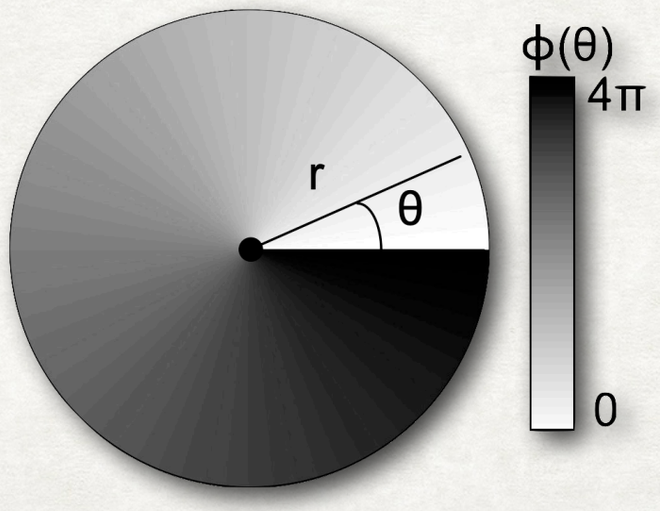
- 4-quadrant PM → sub-wavelength grating → annular groove PM



Rouan et al. (2000)

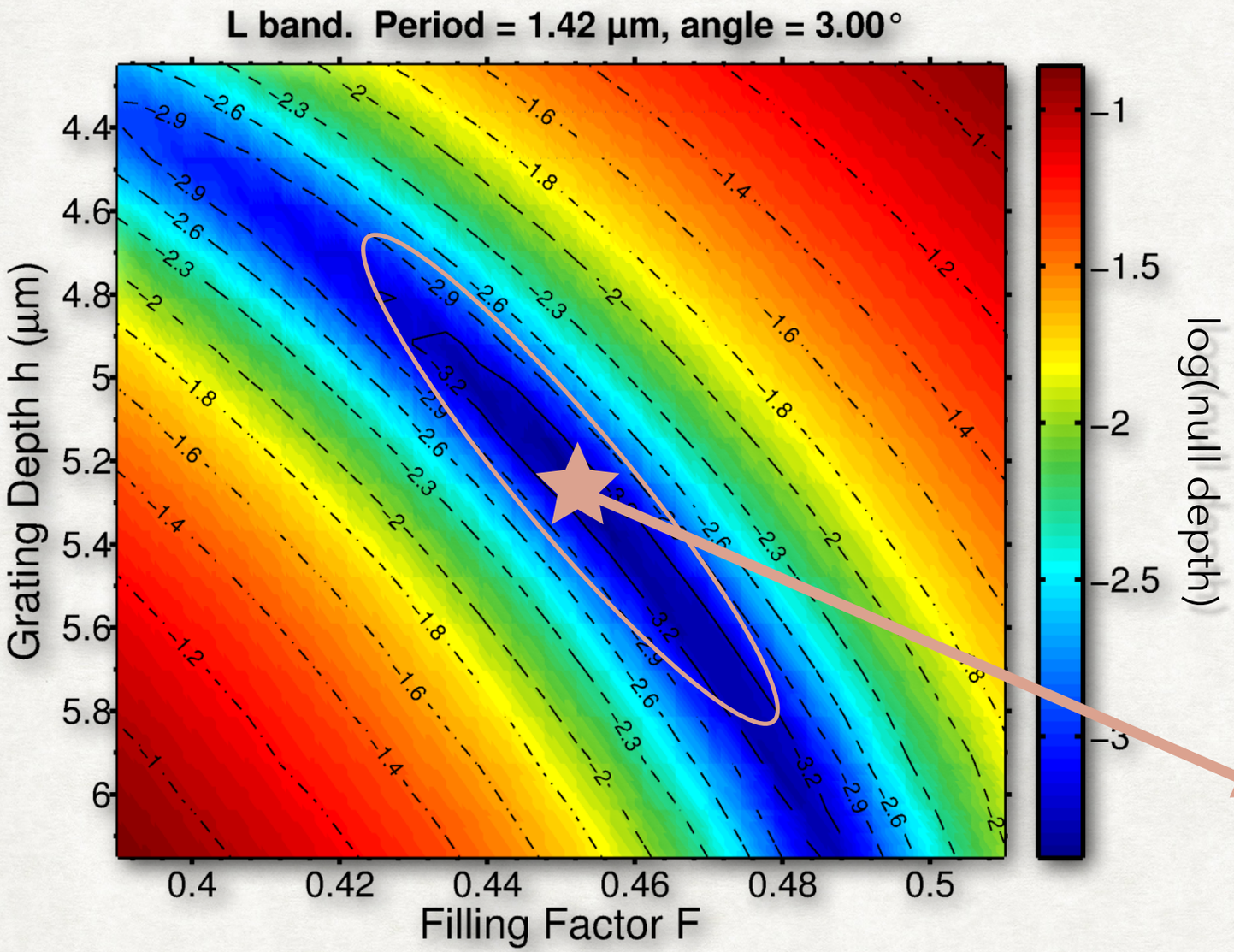
Mawet et al. (2005)

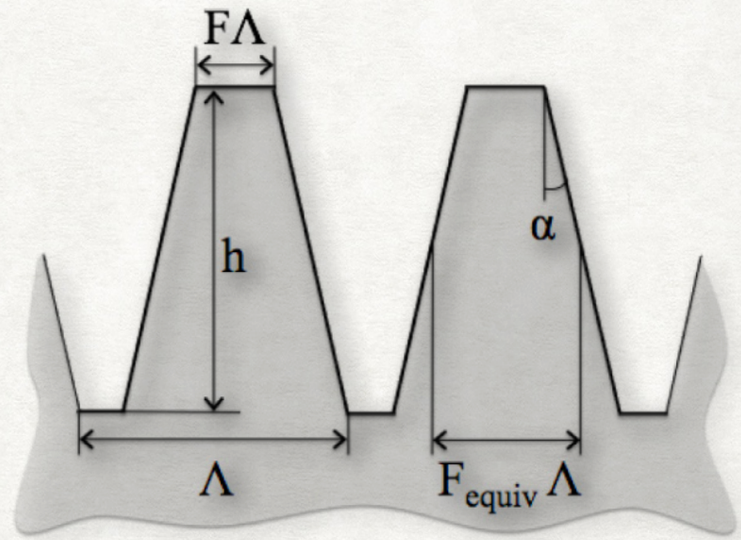
- Advantages:
  - clear 360° discovery space
  - achromaticity

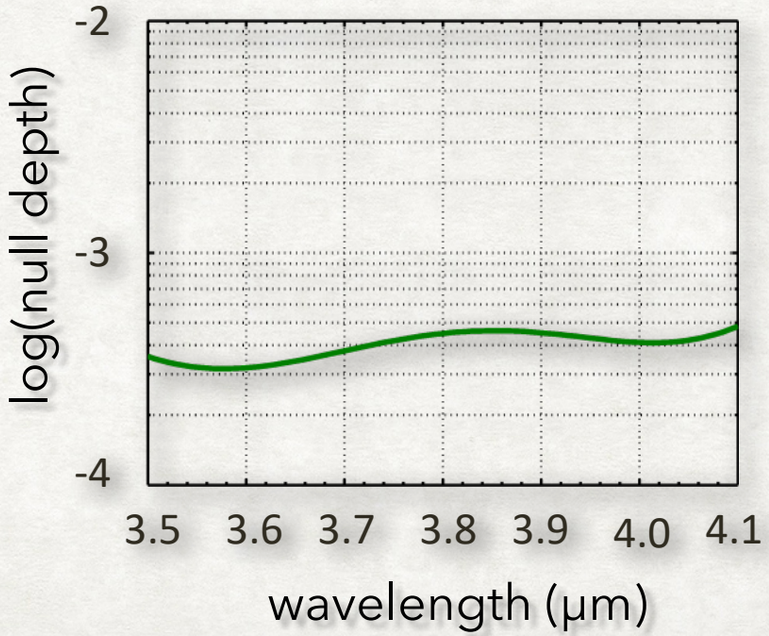


GRATING DESIGN/OPTIMIZATION

Rigorous Coupled Wave Analysis





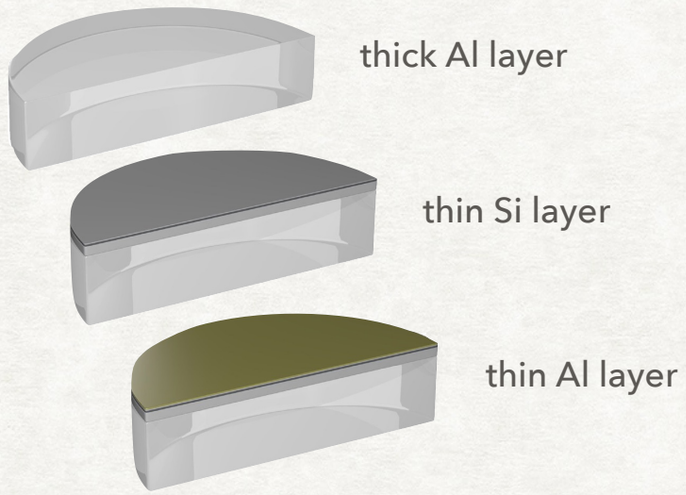


Delacroix et al. (2013)

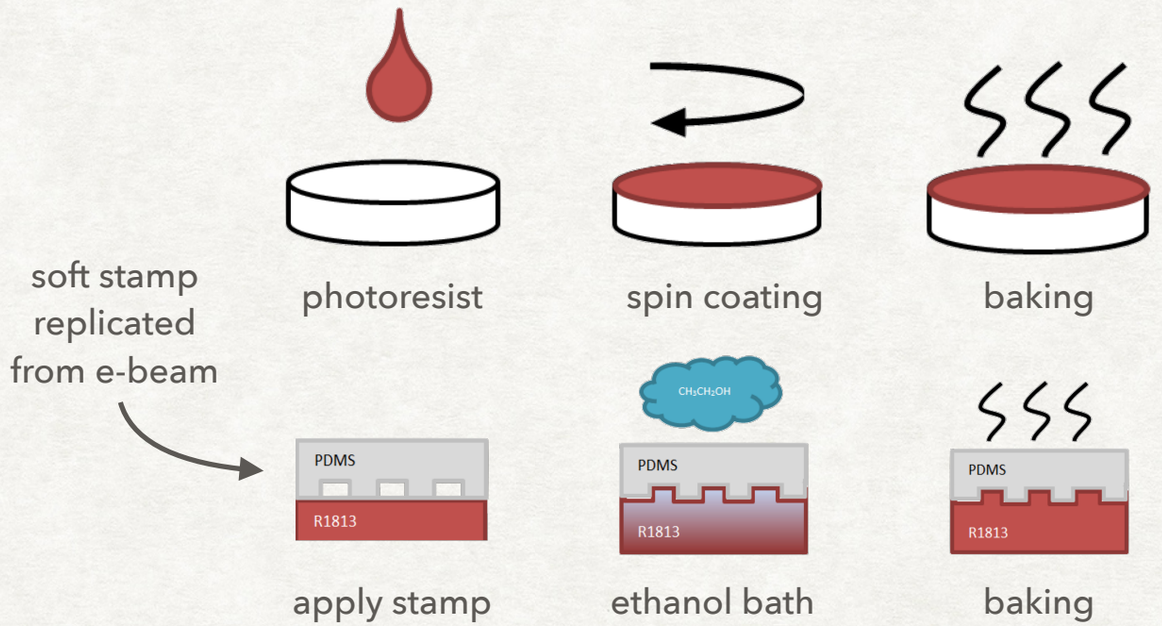
Manufacturing diamond AGPM @ Uppsala

Diamond = ultra broadband transparency + many other convenient properties

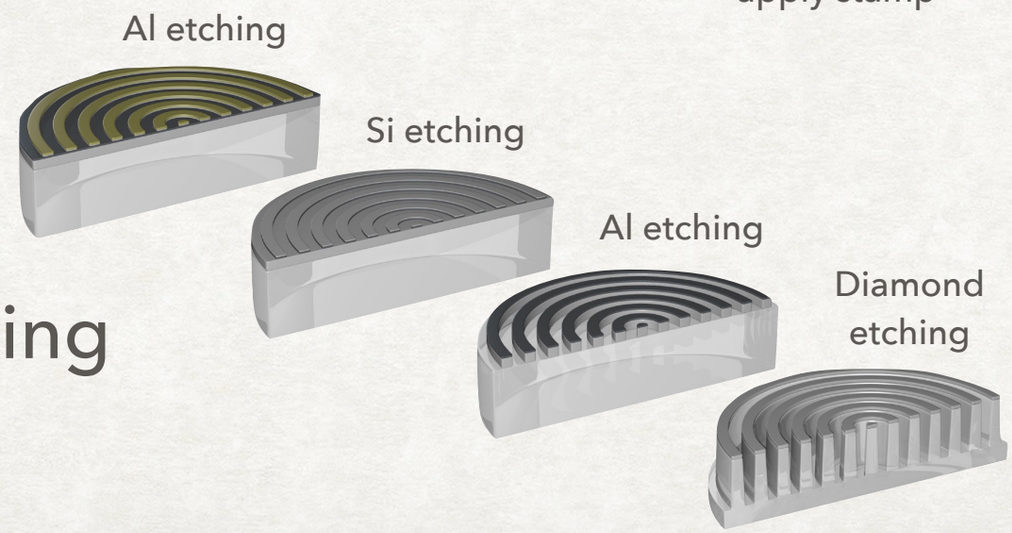
1. diamond coated with Al and Si layers (sputtering)

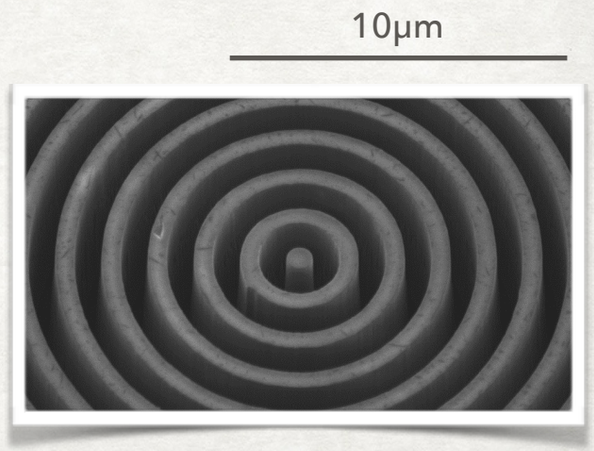


2. e-beam pattern transferred with solvent-assisted moulding



3. reactive ion etching

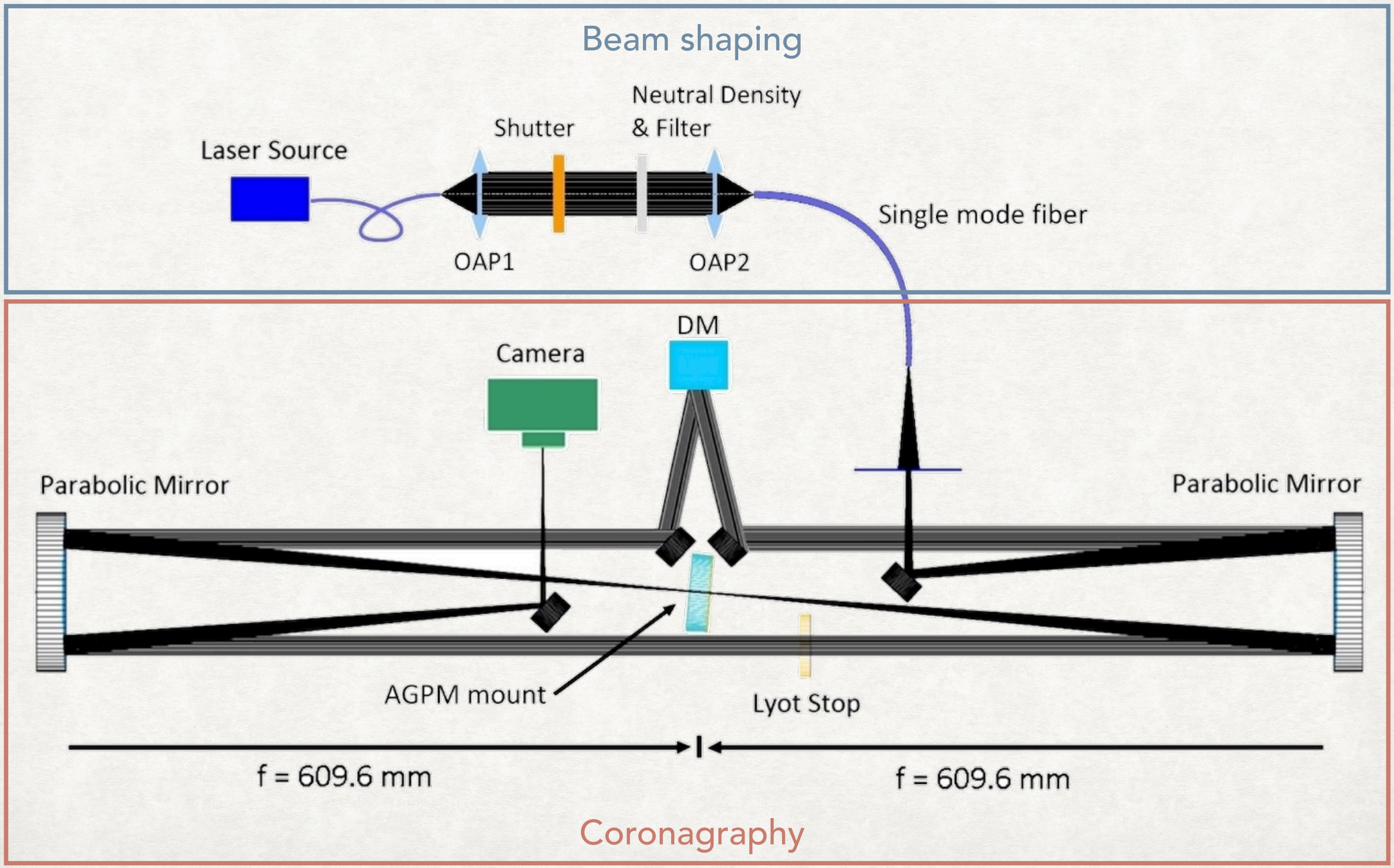




Vargas Catalan et al. (2016)

MWIR/LWIR TESTING ON VODCA BENCH

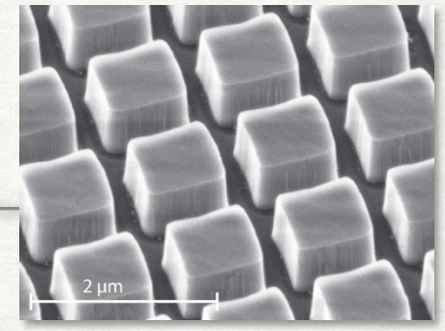
« Vortex Optical Demonstrator for Coronagraphic Applications »

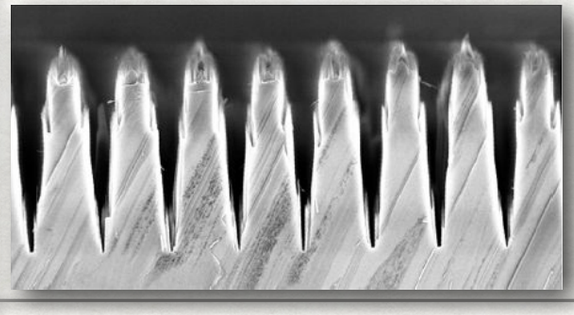


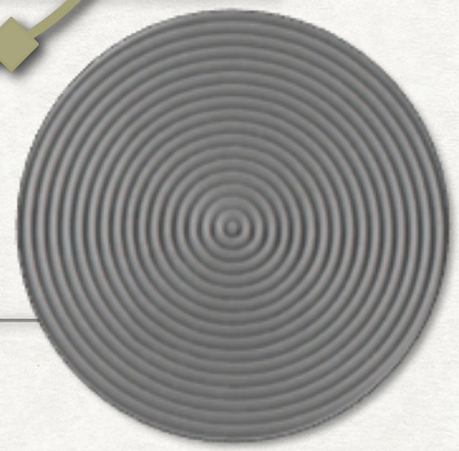
Jolivet et al. (2019)

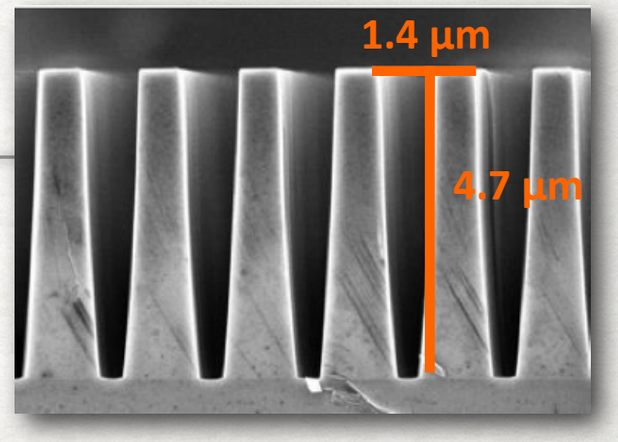
A FEW YEARS TO GET IT RIGHT…

Anti-reflective grating
on the back side



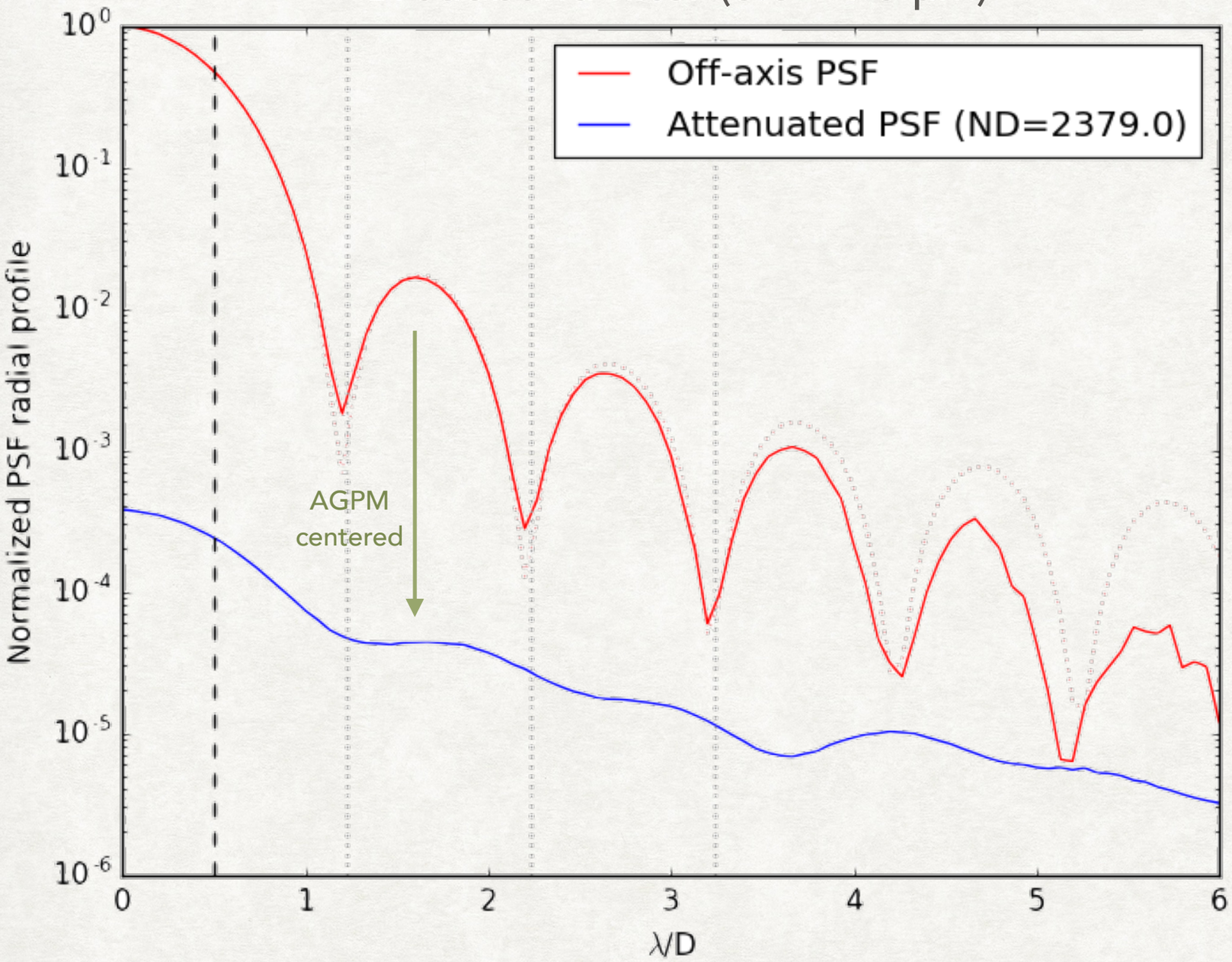


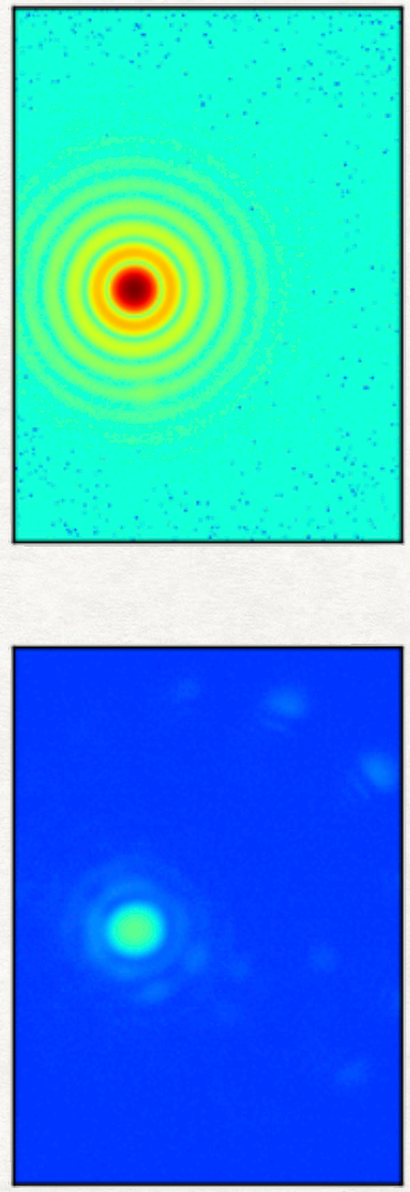


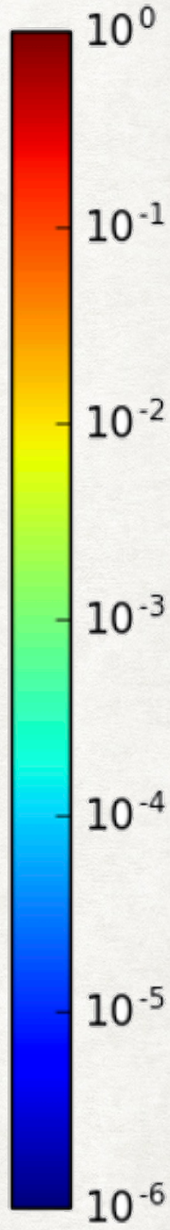


CURRENT STATE-OF-THE-ART

Broadband filter (3.5 - 4.0 µm)



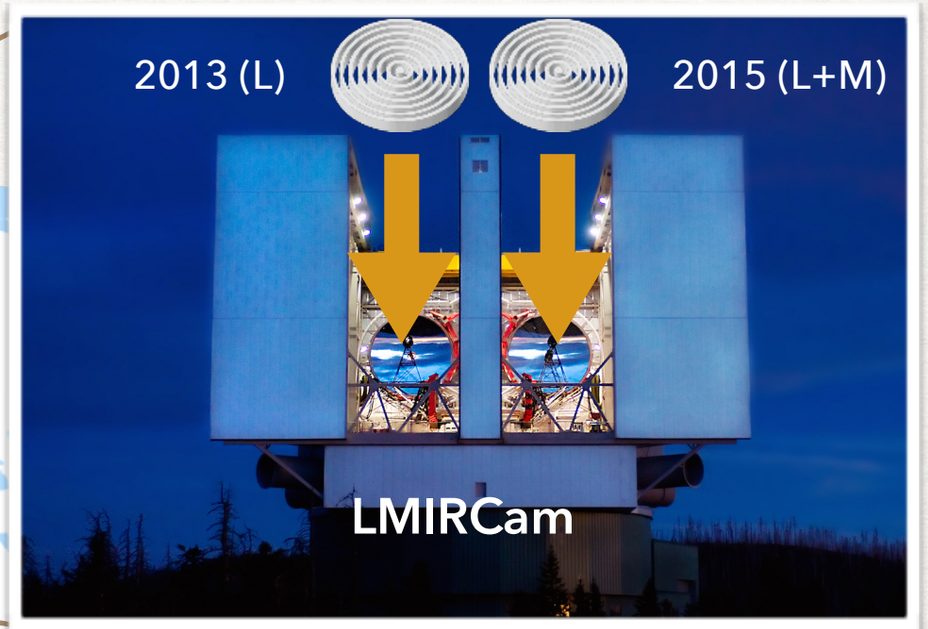




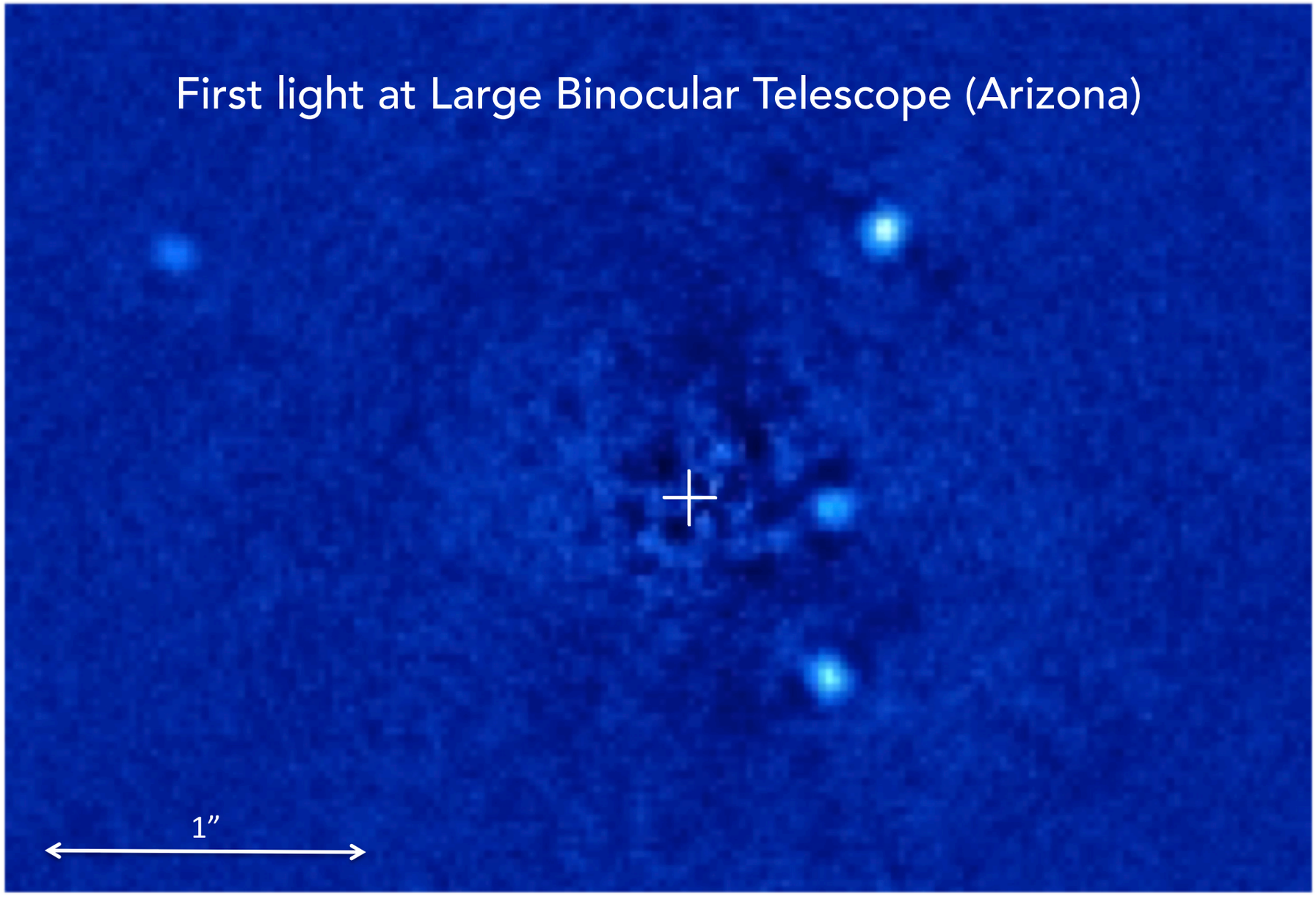
10+ SCIENCE-GRADE AGPMS NOW PRODUCED, RANGING FROM 2 TO 13 µm

Jolivet et al. (2019)

NEXT STEP: CONQUER THE WORLD



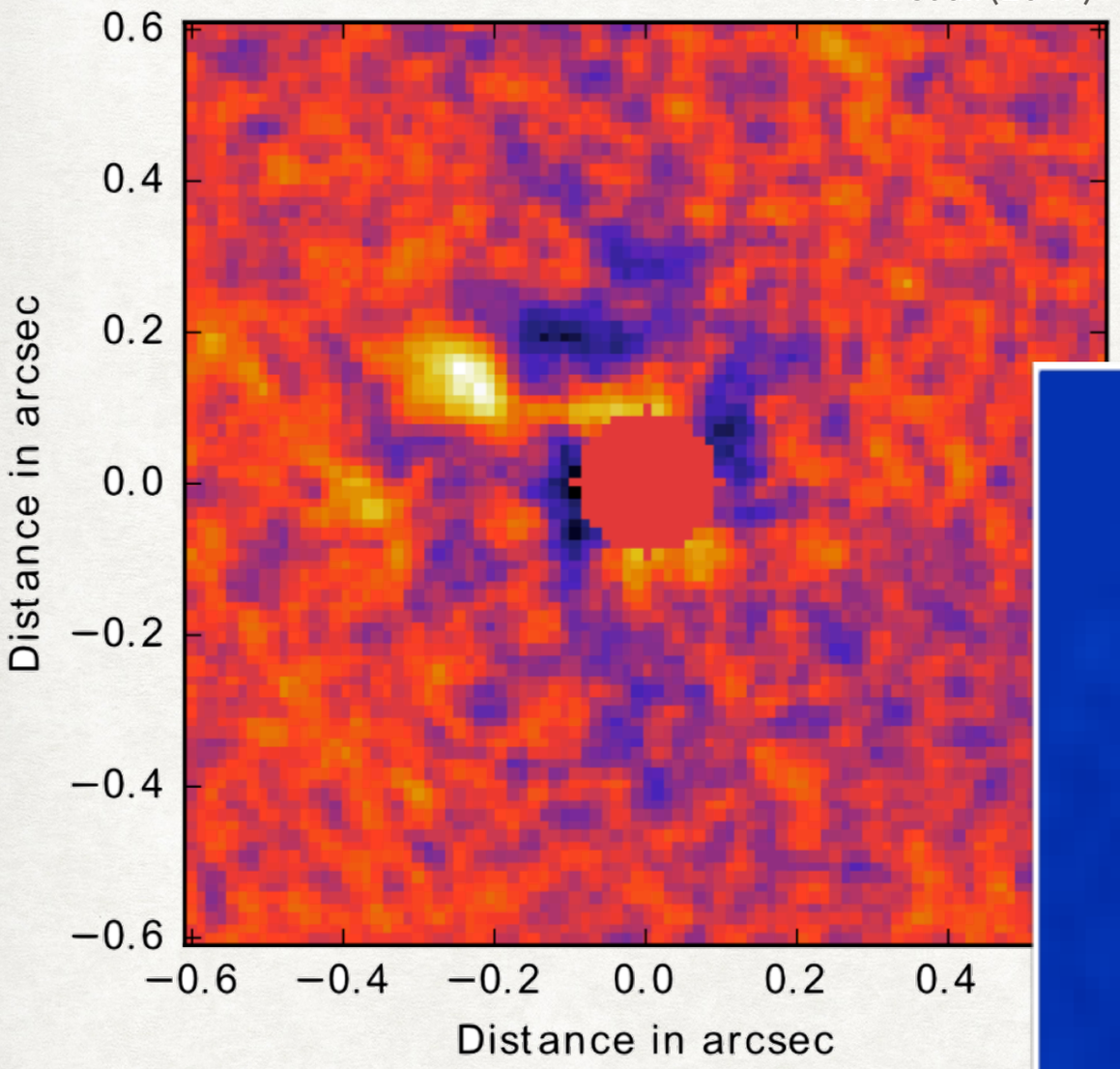
THE VORTEX WORKS!



Defrère et al. (2014)

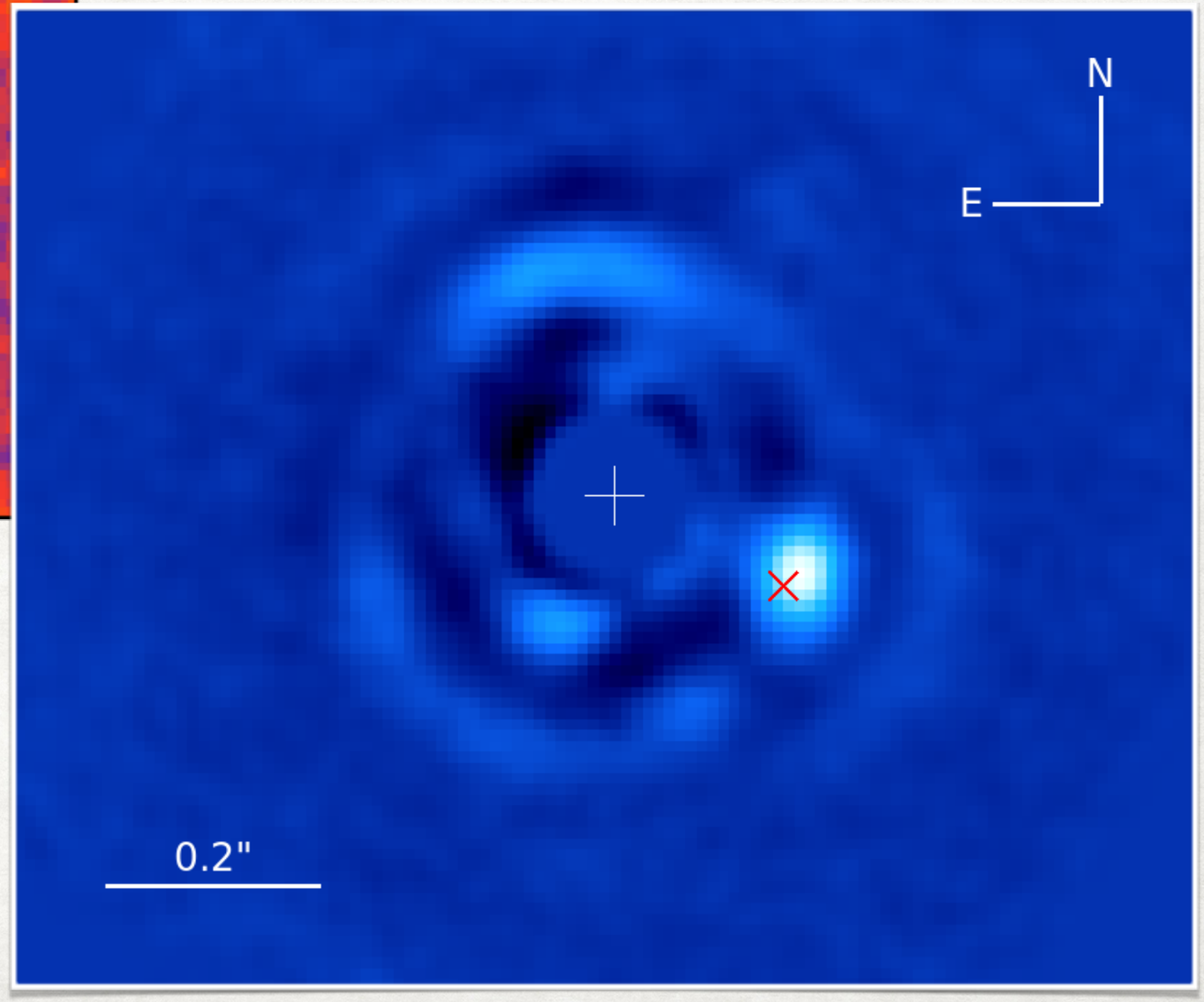
Detection of close companions

Milli et al. (2017)



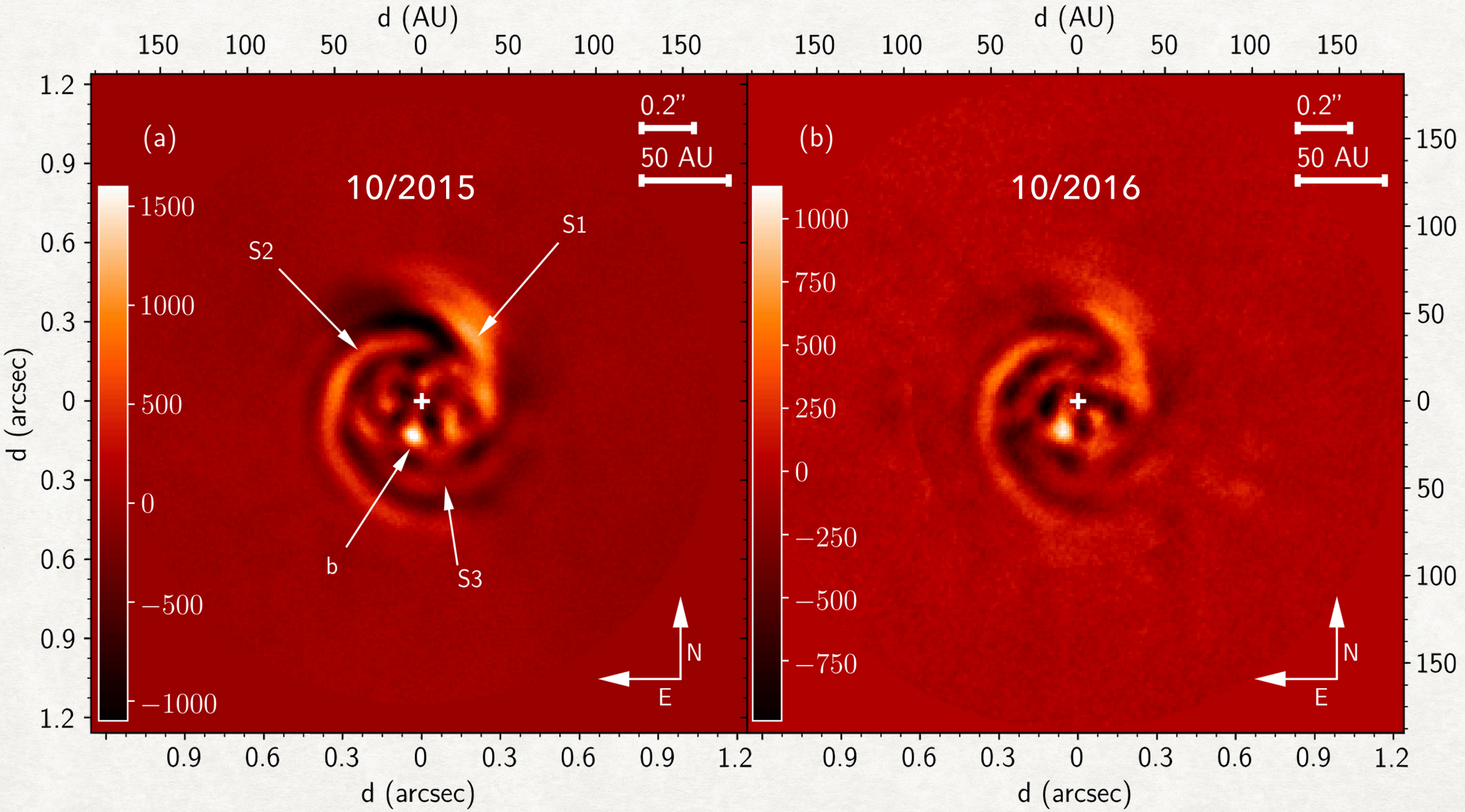
VLT/NACO: confirmation of a close brown dwarf companion around HD 206893

Serabyn et al. (2017)



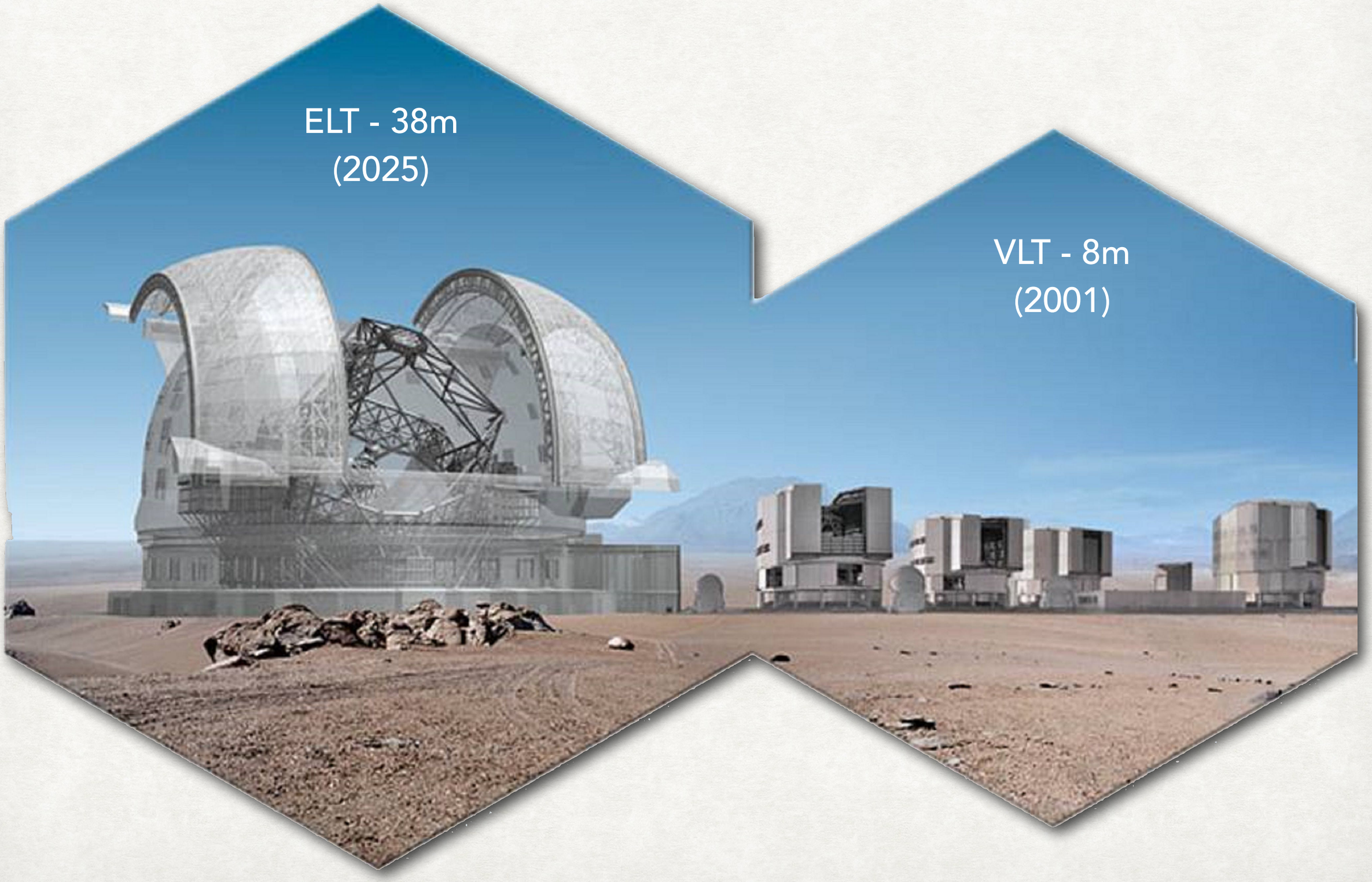
Keck/NIRC2: first image of the brown dwarf companion around HIP 79124

SEARCH FOR PROTO-PLANETS IN YOUNG DISKS



Reggiani et al. (2018)

Next destination: Extremely Large Telescope



BELGIUM CONTRIBUTING TO ELT/METIS

1:1 scale model

METIS PI

NOVA

Max-Planck-Institut für Astronomie Heidelberg
Max Planck Institute for Astronomy Heidelberg

KU LEUVEN

LIÈGE université

DE LA RECHERCHE À L'INDUSTRIE
cea

UKRI Science and Technology Facilities Council

centra
multidisciplinary centre for astrophysics

UNIVERSITY OF MICHIGAN

A*

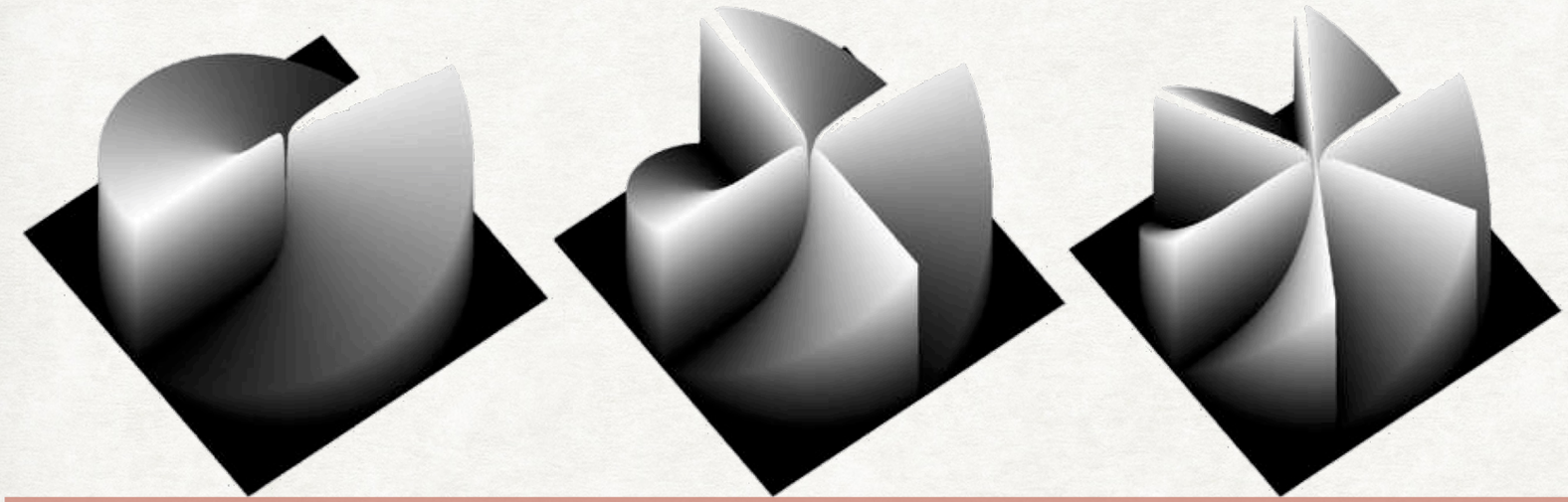
ESO

Universität zu Köln

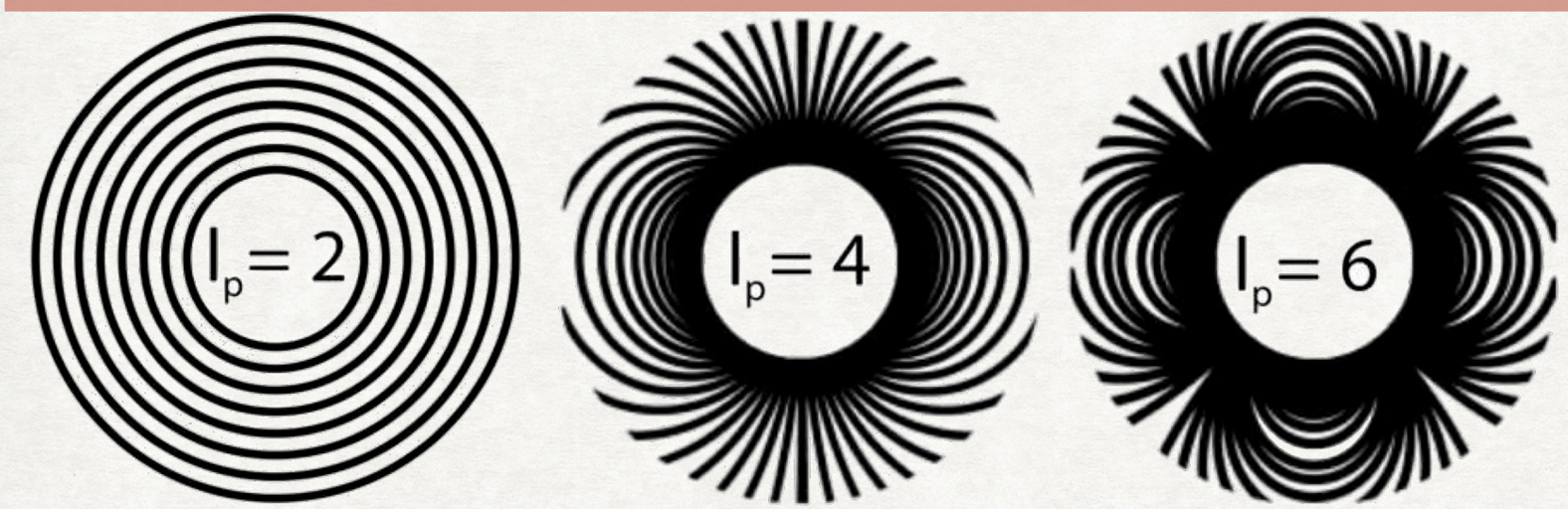
ETH zürich

ASIAA

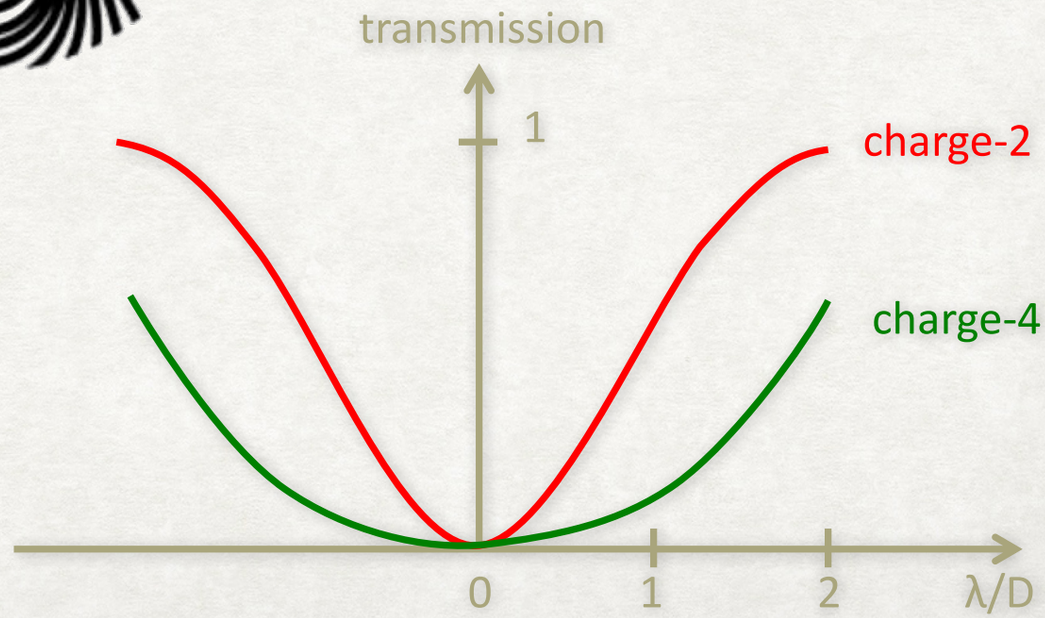
THE ELT'S NEW NEEDS



topological charge

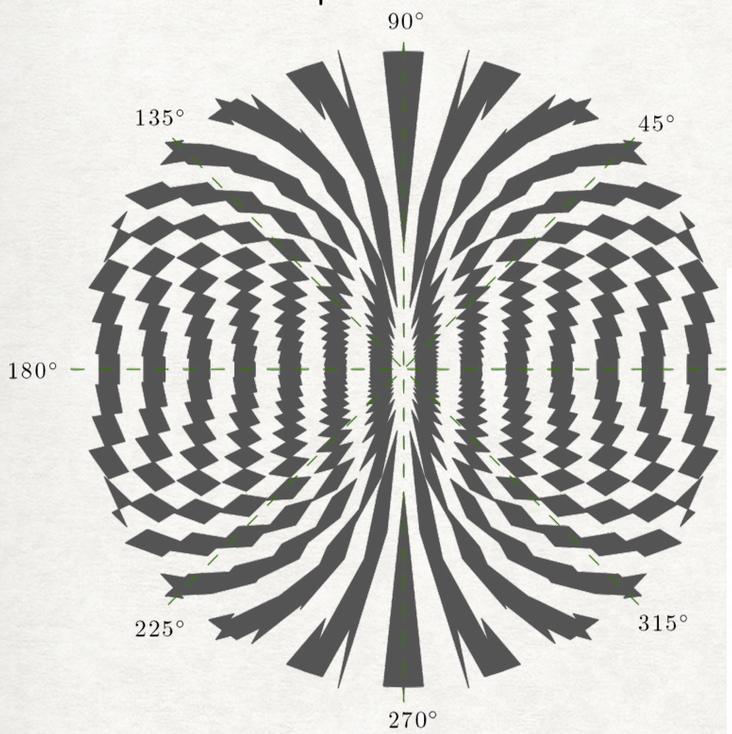


Period not constant, breaking ZOG condition —> need to discretize the pattern

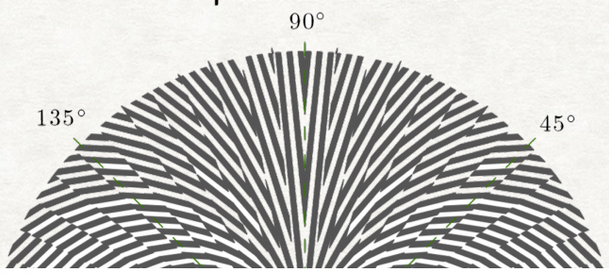


Charge-4 designs

15 periods on x-axis

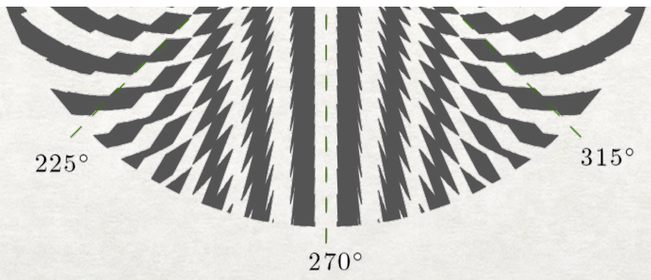


60 periods on x-axis

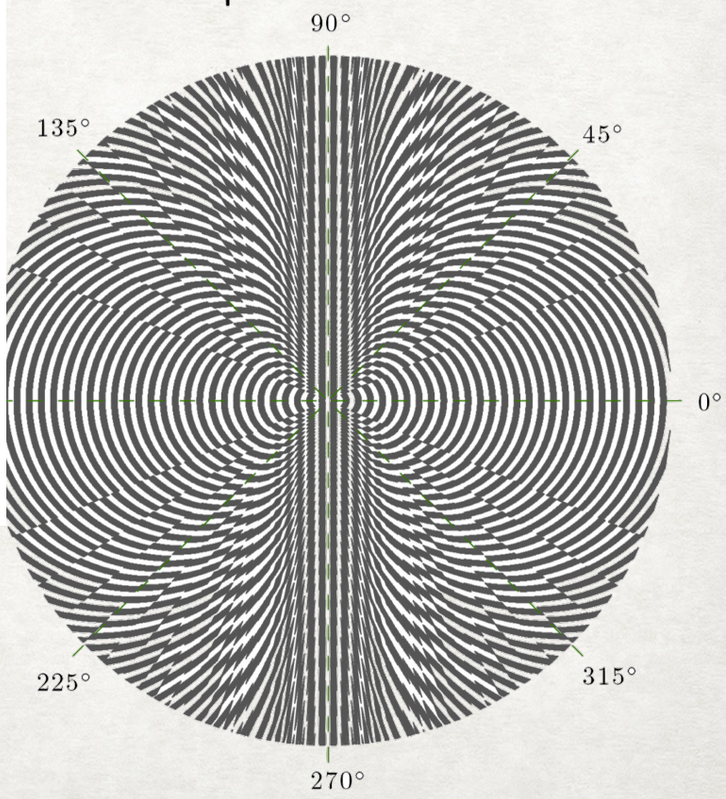


n with straight lines

Construction with curved



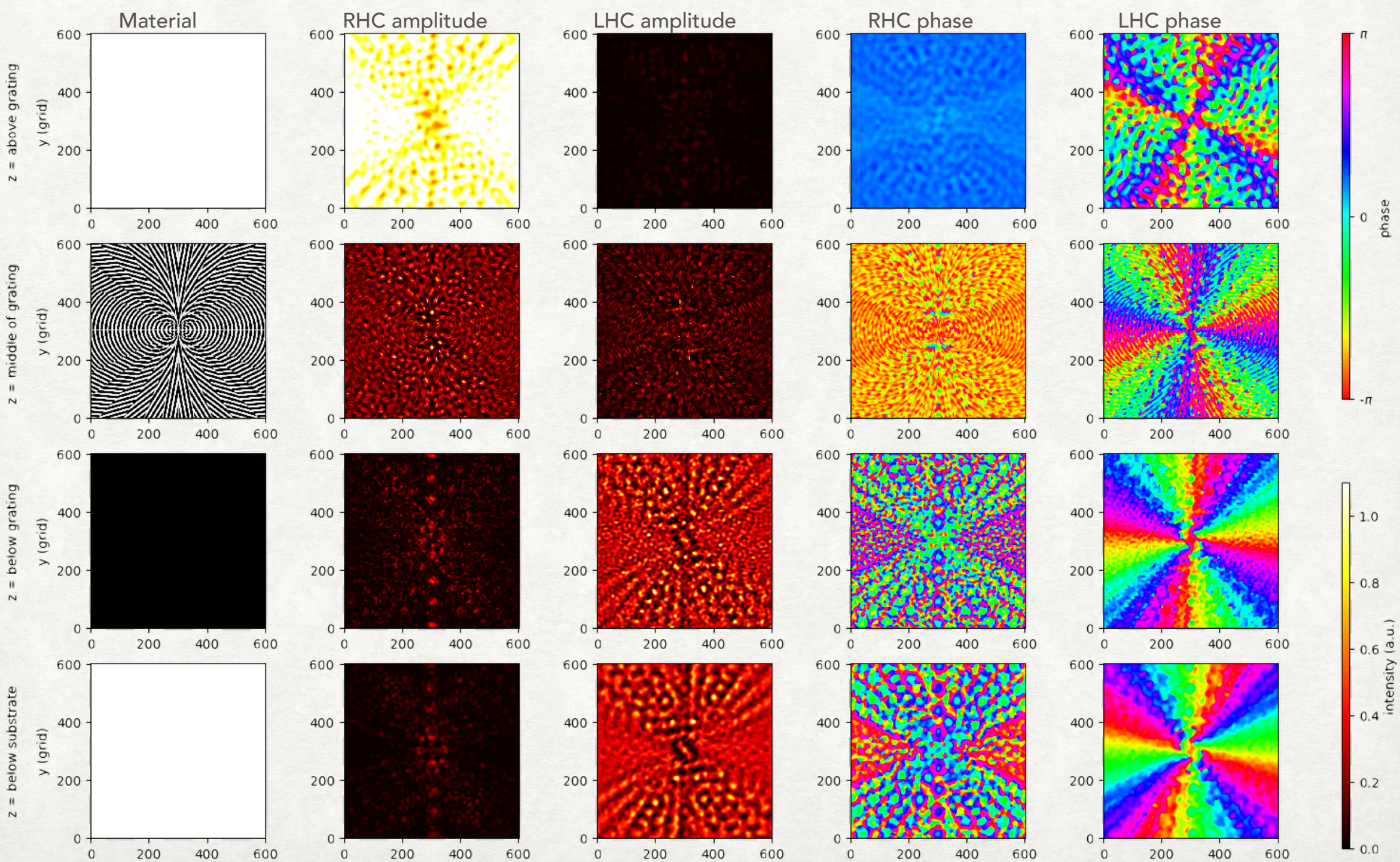
60 periods on x-axis



Delacroix et al. (2014)

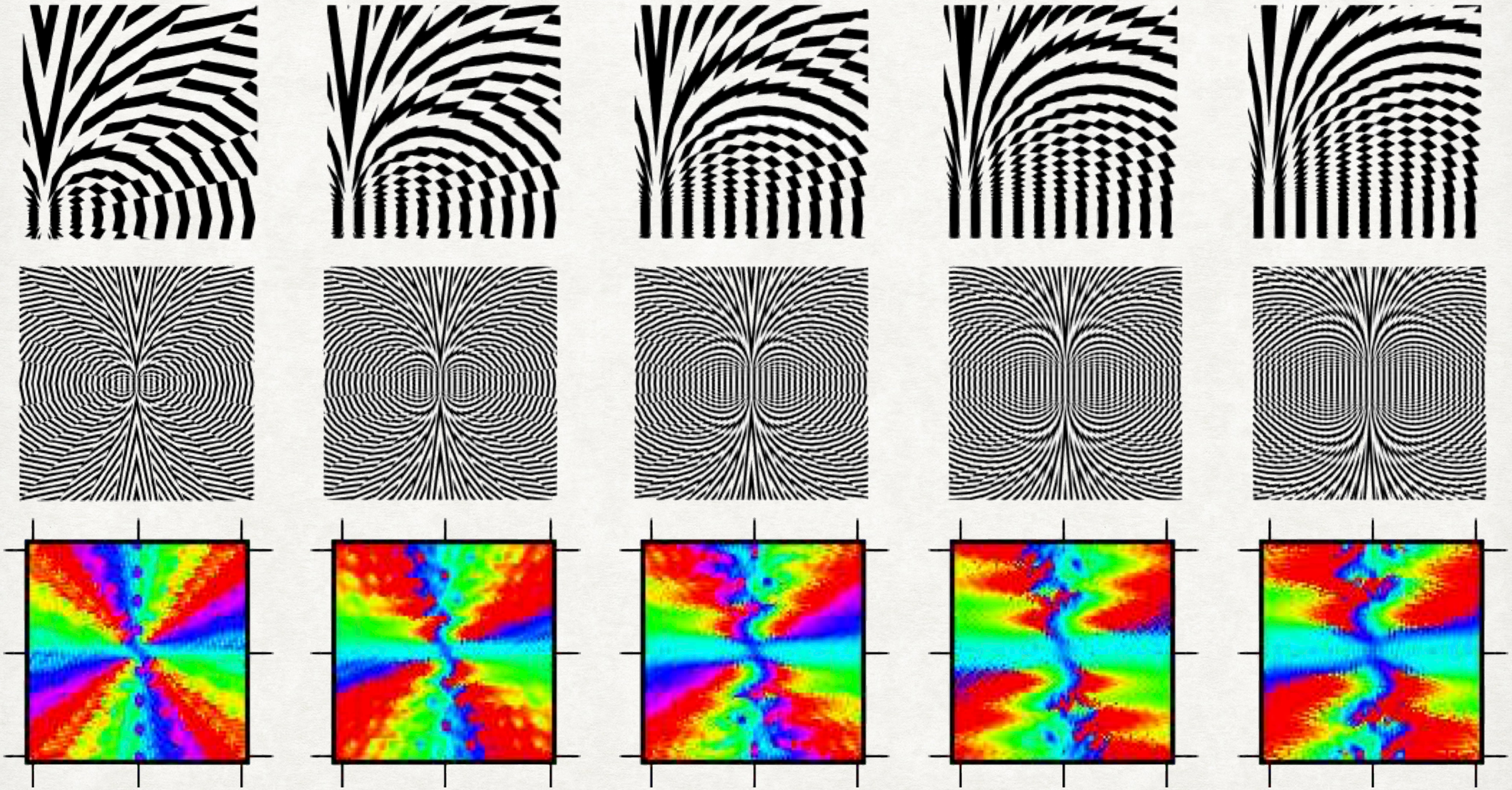
GRATING OPTIMIZATION: FDTD SIMULATIONS

MEEP simulations of charge-4 vortex (L. König, work in progress)



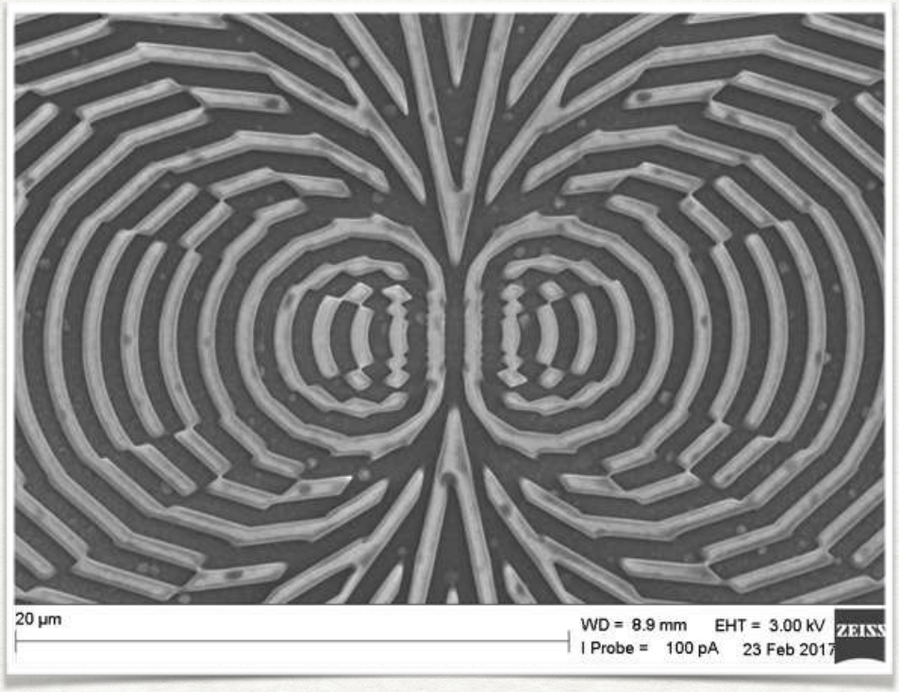
Trying various designs...

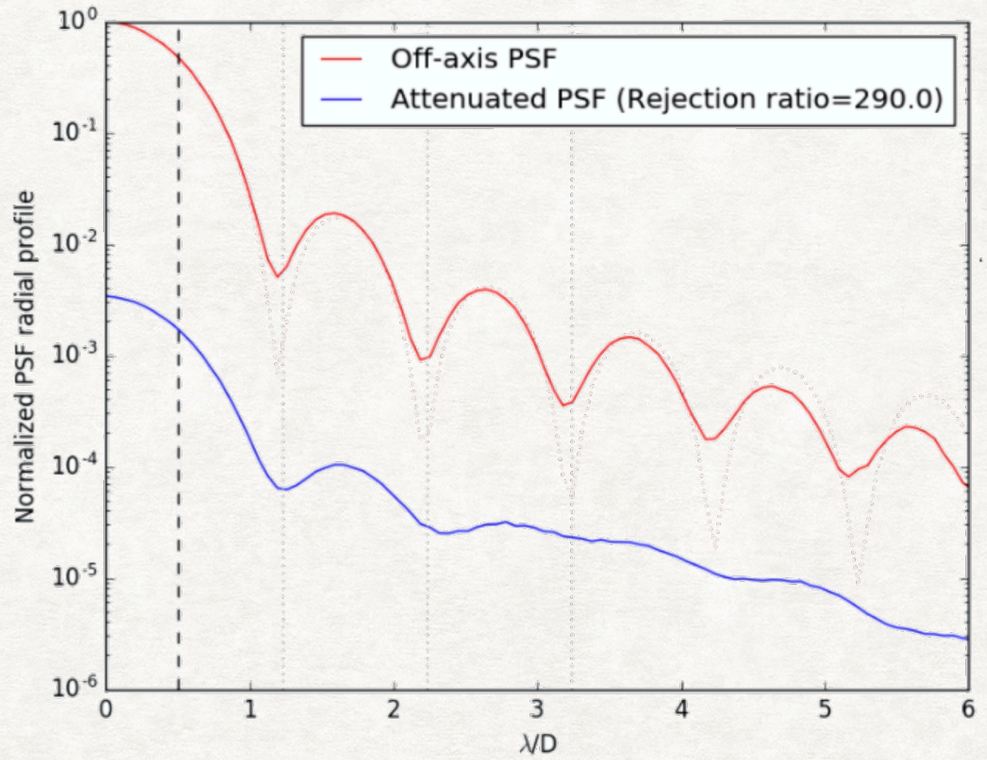
N=8 N=12 N=16 N=20 N=24



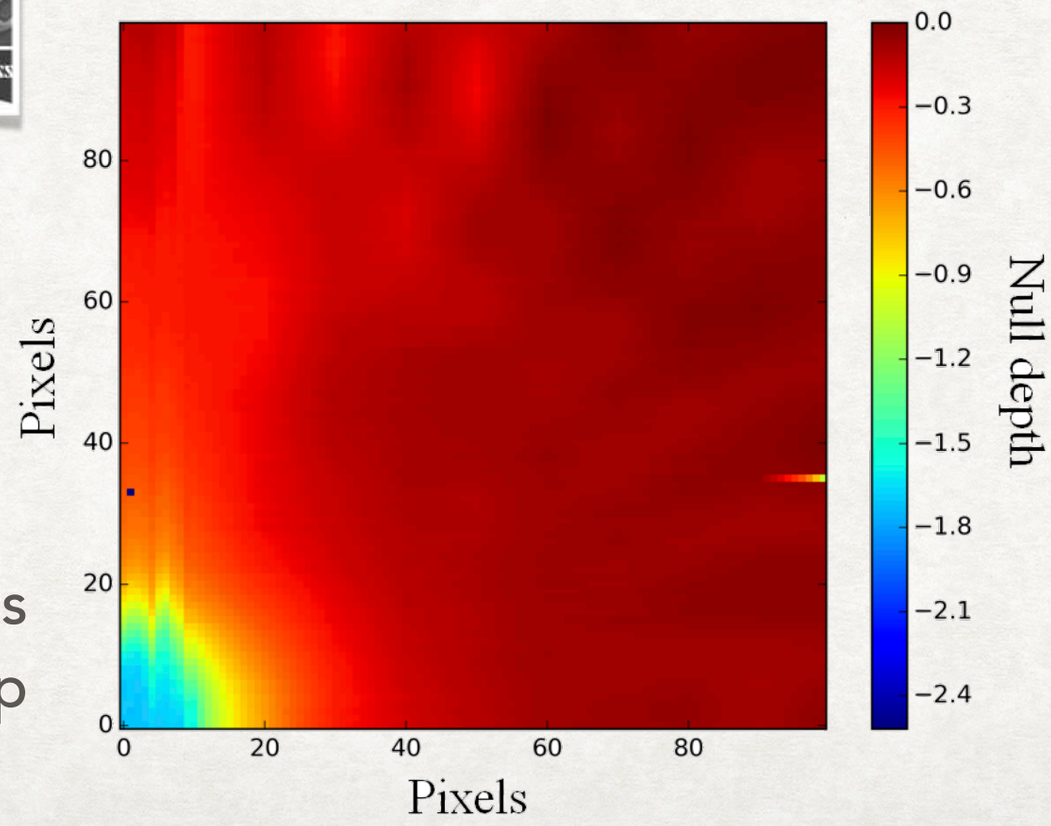
First Charge-4 components: done!

First manufactured charge-4 mask





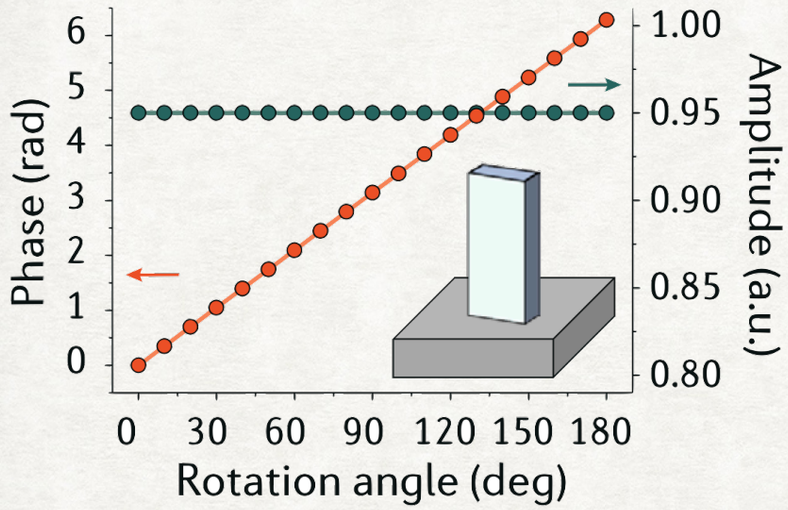
Transitions between sectors shows up in 2D null depth map



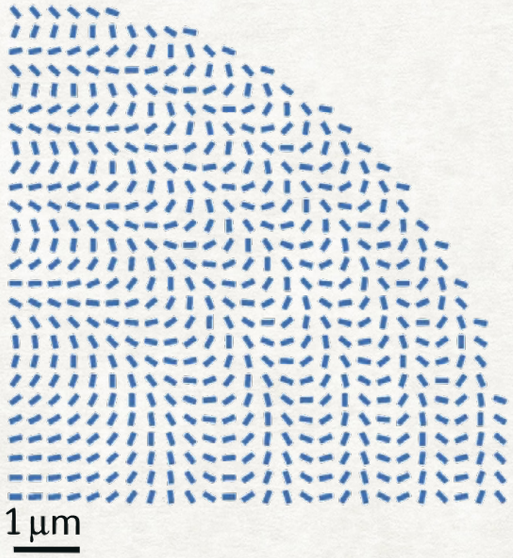
Next step: going full metasurface

Challenges: broadband, high throughput

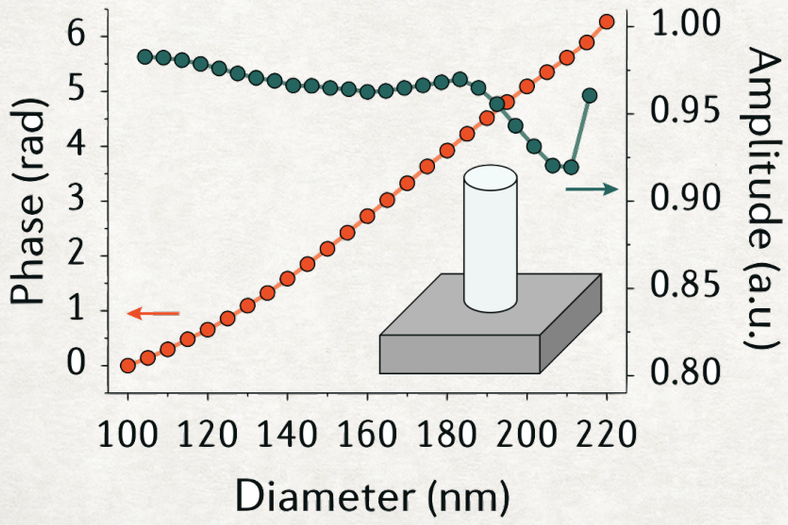
Nanofin



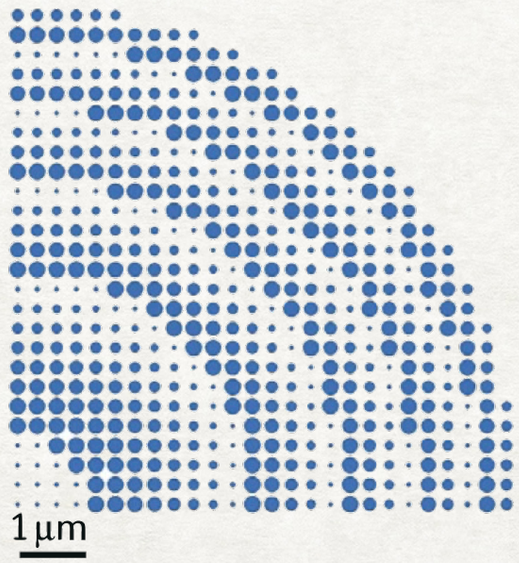
Nanofin metalens



Nanopillar

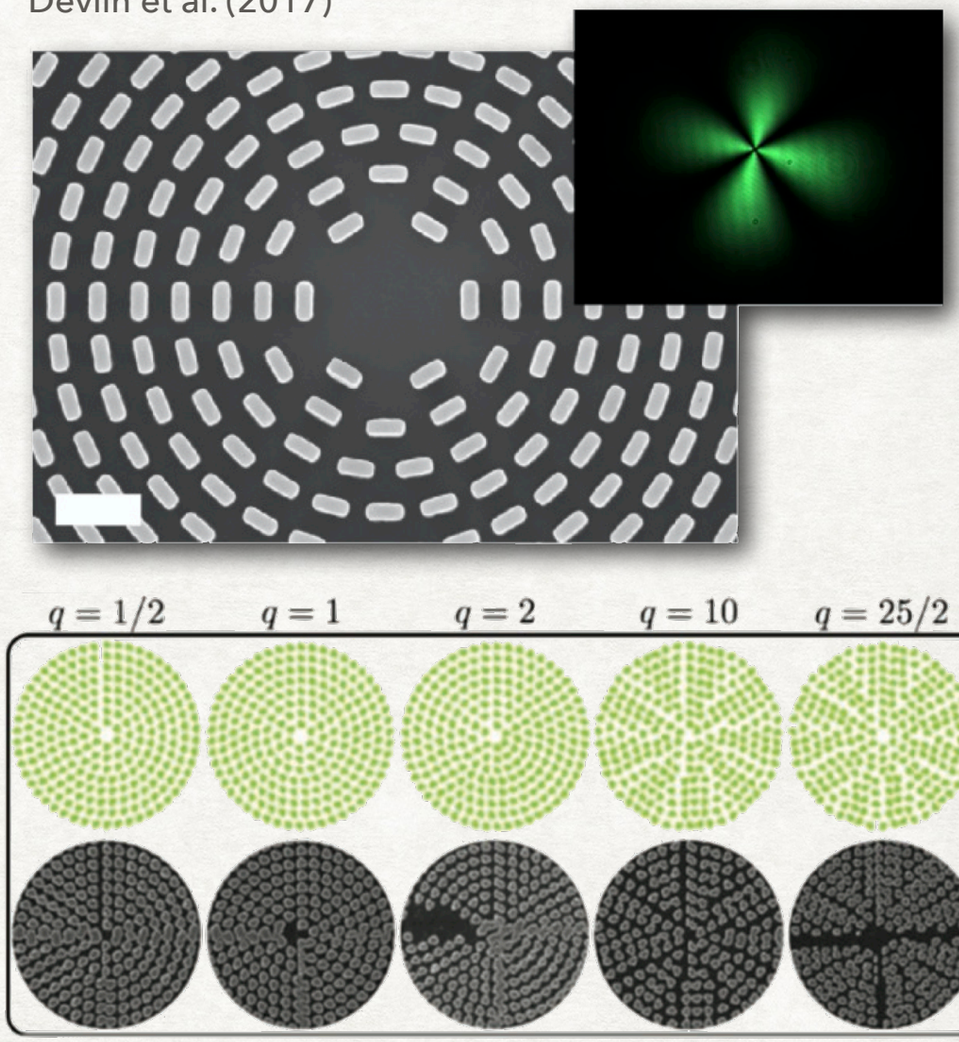


Nanopillar metalens

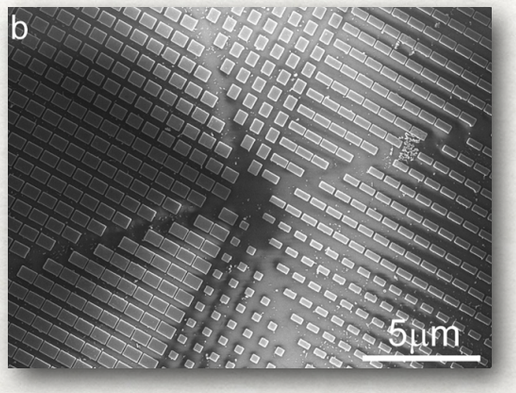


Chen, Zhu & Capasso (2020)

Devlin et al. (2017)



Hsiao et al. (2017)



Shalaev et al. (2015)

On our way towards imaging other Earths