The VORTEX team

- ***U. Liège***: O. Absil, J. Surdej, S. Habraken, M. Van Droogenbroeck, D. Defrère, C. Delacroix, G. Orban de Xivry, M. Reggiani, O. Wertz, B. Carlomagno, V. Christiaens, C. Gomez Gonzalez, A. Jolivet
- ***U. Uppsala***: M. Karlsson, P. Forsberg, P. Piron, E. Vargas Catalan
- ***Caltech/JPL***: D. Mawet, E. Serabyn, K. Matthews, G. Ruane, AJ Riggs, E. Choquet, M. Bottom, H. Ngo, R. Jensen-Clem
- ***Obs. Paris***: E. Huby, P. Baudoz
- + collaborators at *ESO* (J. Girard, J. Milli, M. Kasper, H.-U. Käufl), *CEA Saclay* (E. Pantin), *U. Leiden* (M. Kenworthy, F. Snik), *Keck* (B. Femenia, P. Wizinowich), *U. Arizona* (P. Hinz)

OLIVIER ABSIL

FIVE YEARS OF HARVEST WITH THE VORTEX CORONAGRAPH

OUTLINE

history and technology development

commissioning & on-sky performance

scientific results

image processing with machine learning

future projects

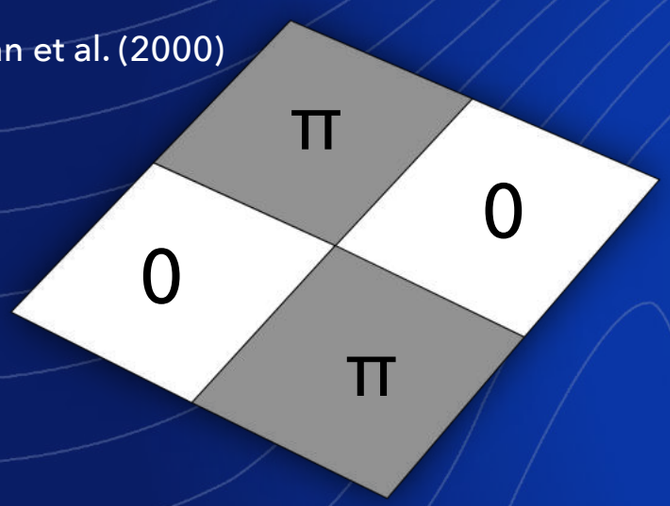
VORTEX

HISTORY AND TECHNOLOGY DEVELOPMENT

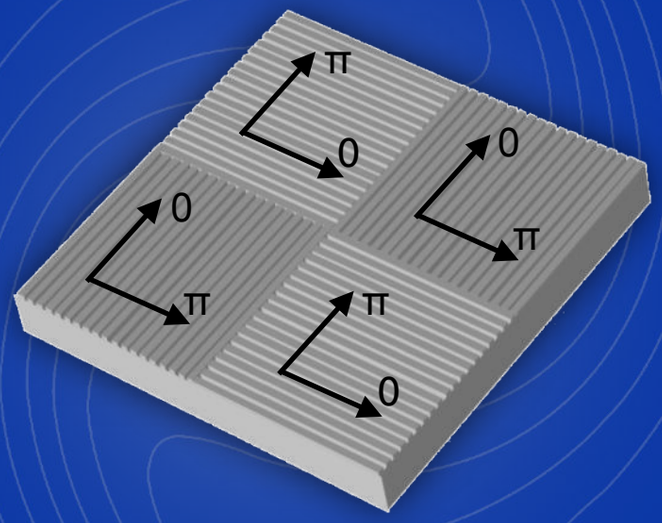
THE BIRTH OF A CONCEPT

- FQPM → sub-wavelength grating → annular groove phase mask

Rouan et al. (2000)



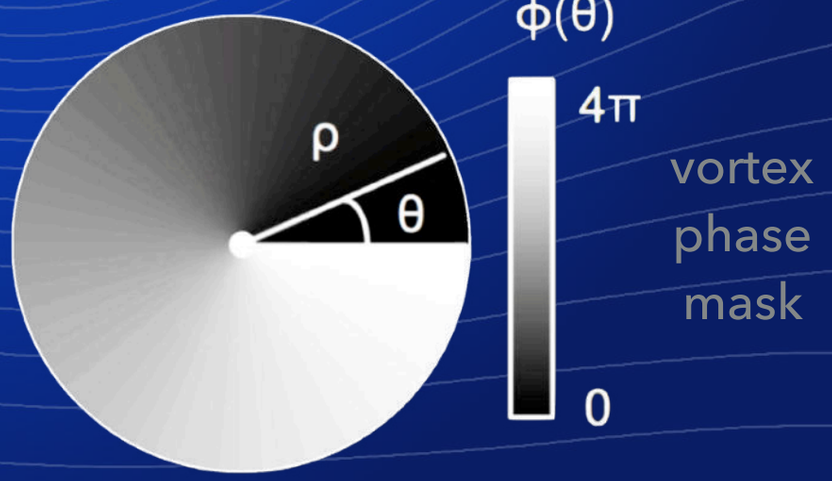
2003



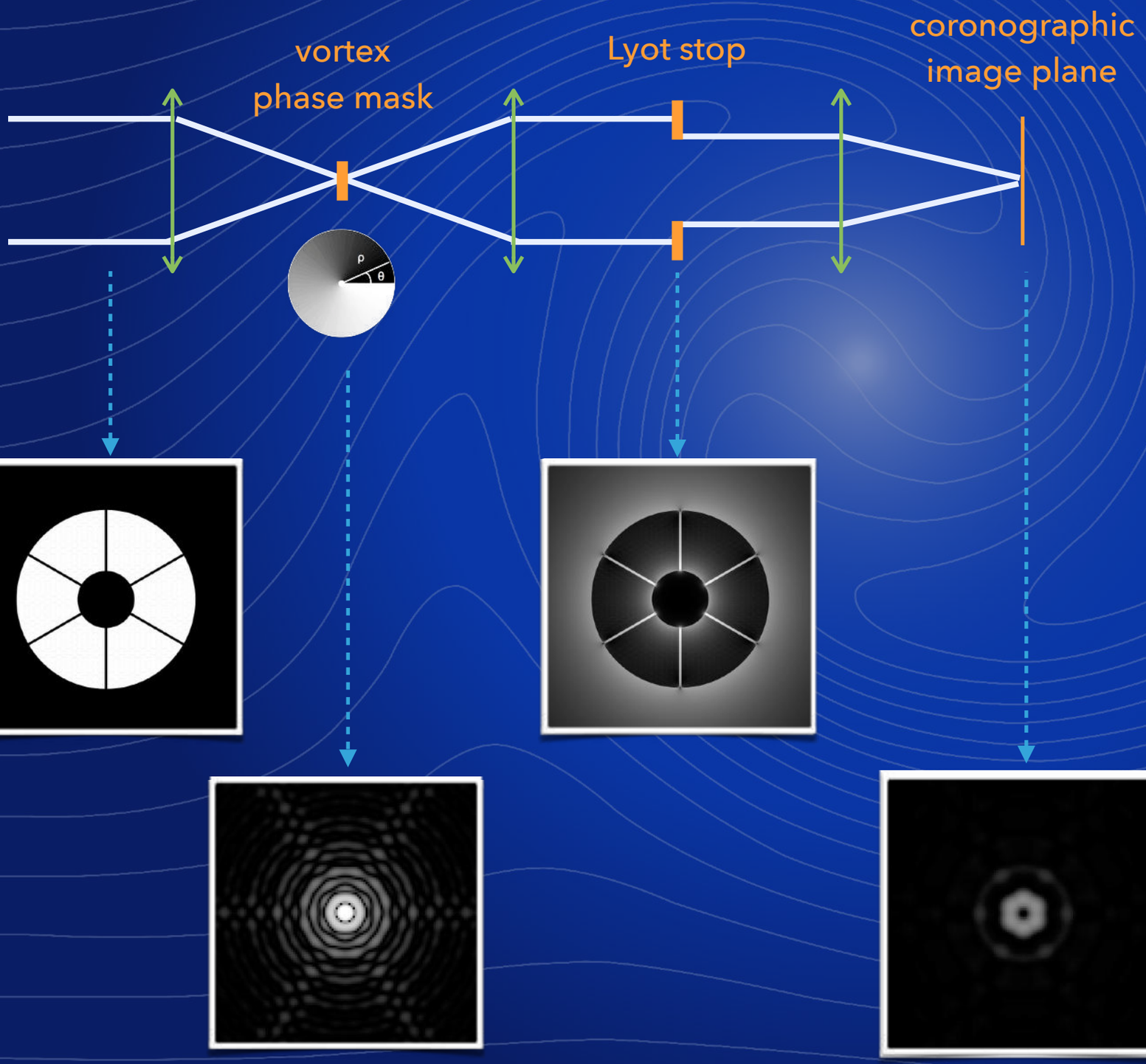
2005

Mawet et al. (2005)

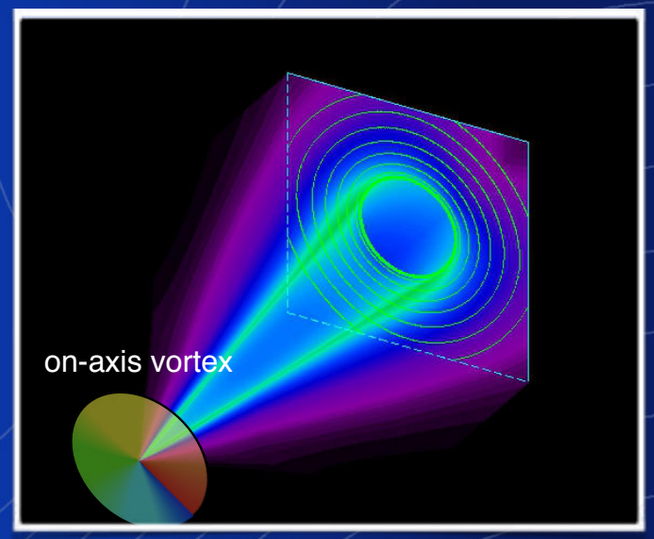
- advantages:
  - ✳ inner working angle
  - ✳ clear 360° discovery space
  - ✳ achromaticity

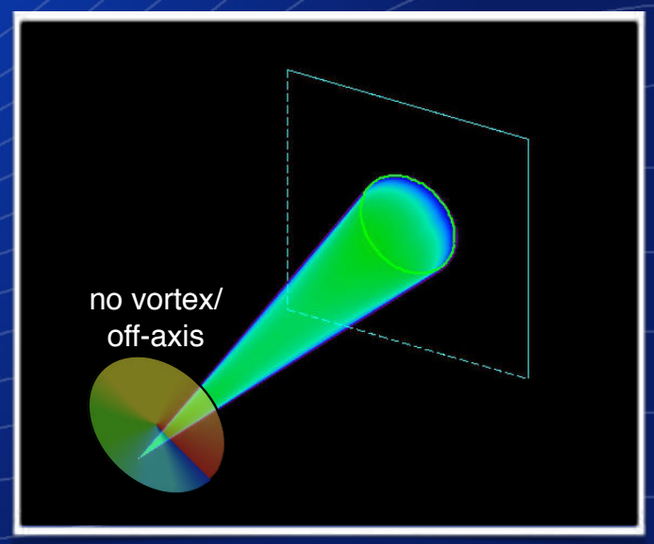


THE VORTEX CORONAGRAPH IN A NUTSHELL



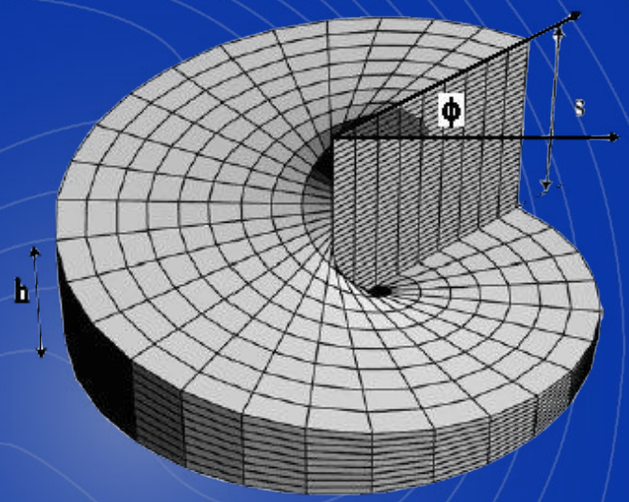
perfect on-axis cancellation
for a circular aperture

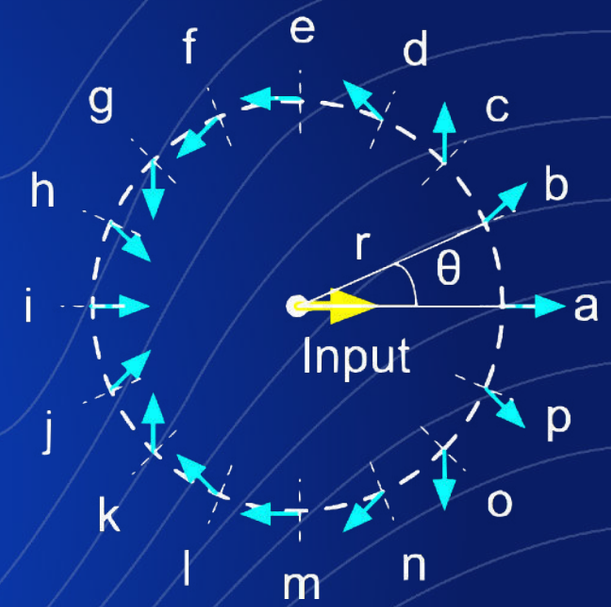




IMPLEMENTATIONS OF THE VORTEX PHASE MASK

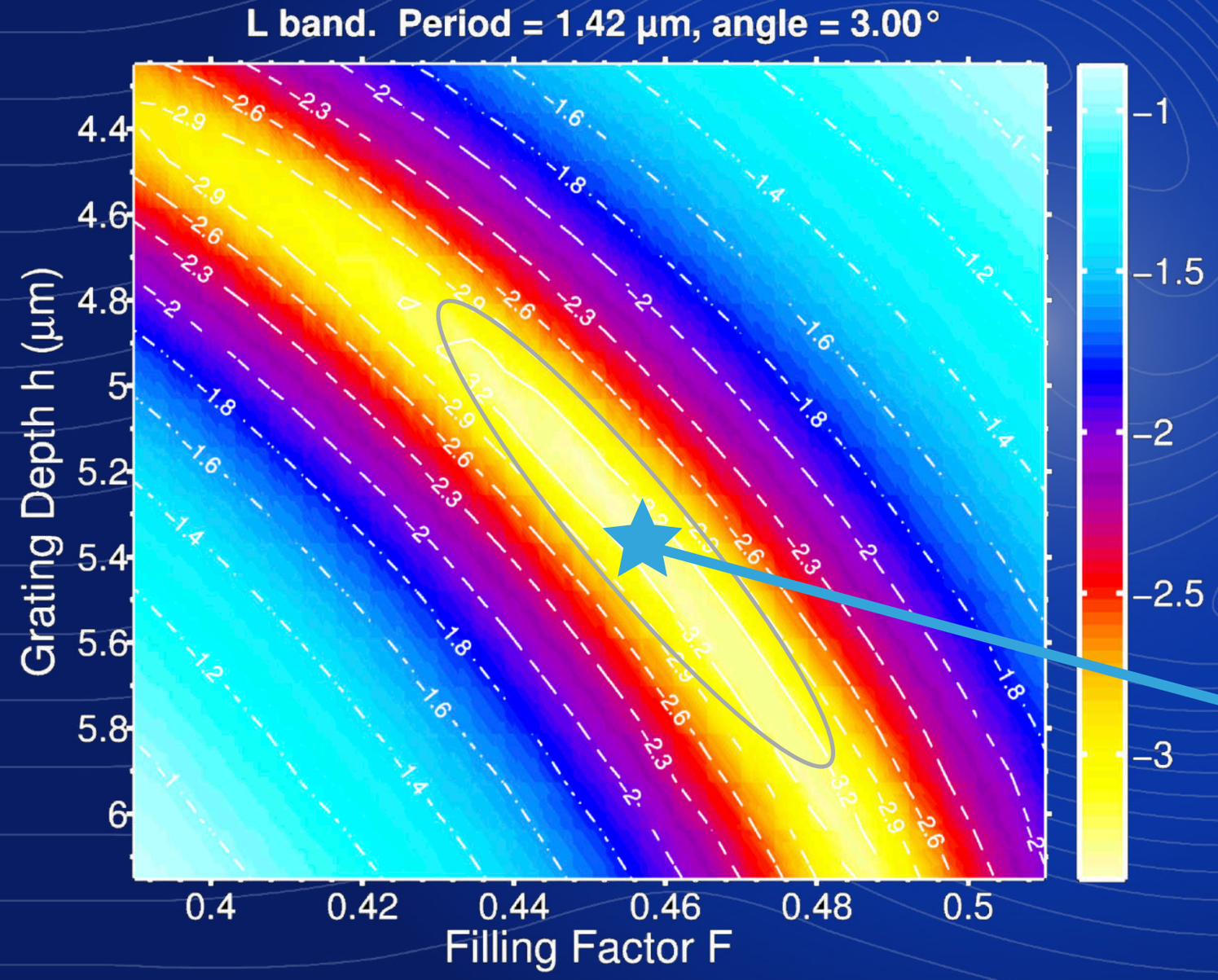
- scalar vortex
  - helical piece of glass
- vector vortex
  - liquid crystal polymers
  - subwavelength gratings
  - photonic crystals

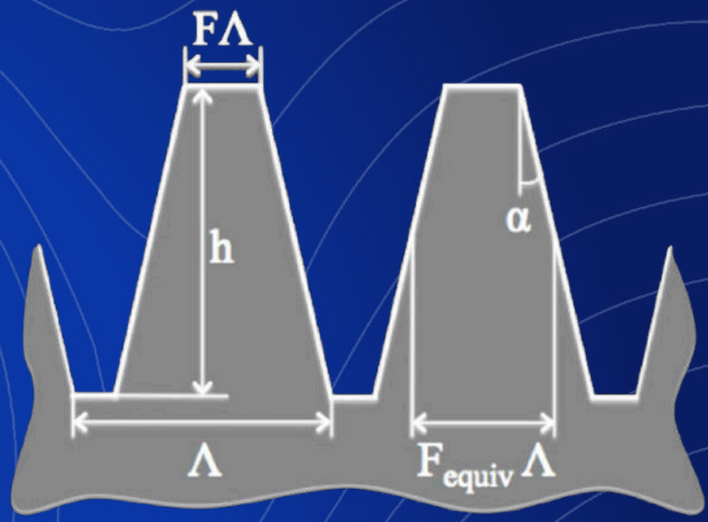


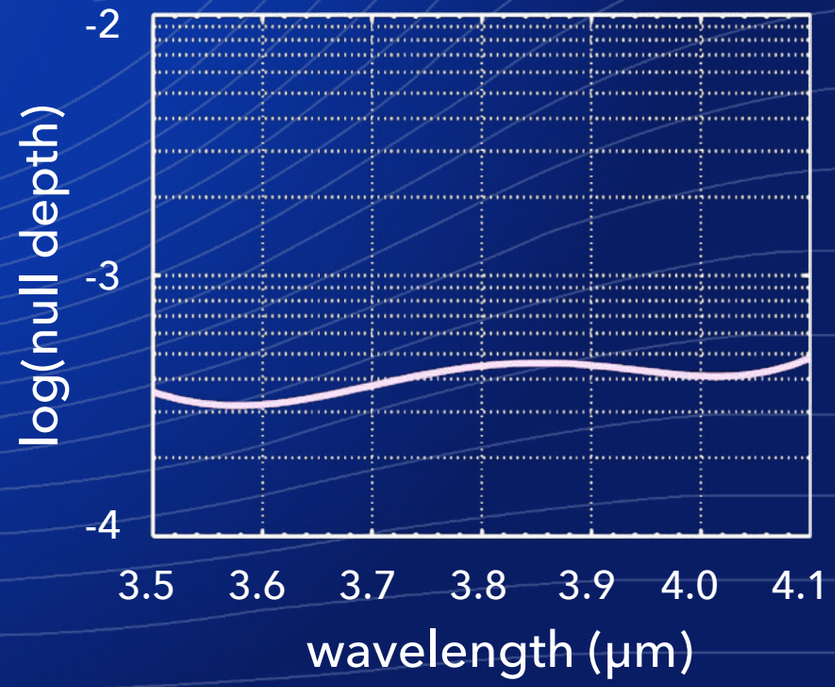


Annular Groove Phase Mask

OPTIMIZING THE GRATING DESIGN





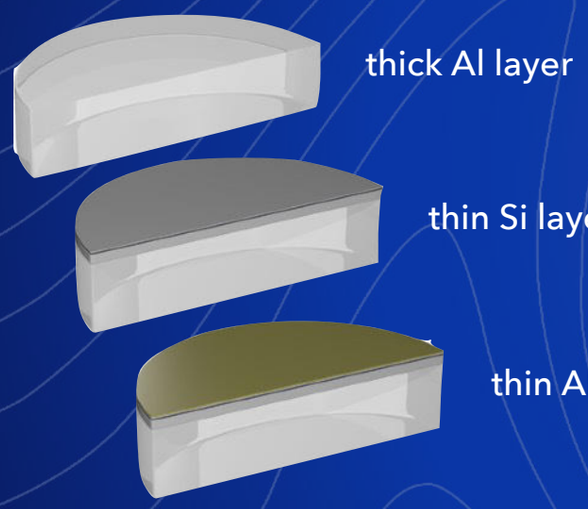


Delacroix et al. (2013)

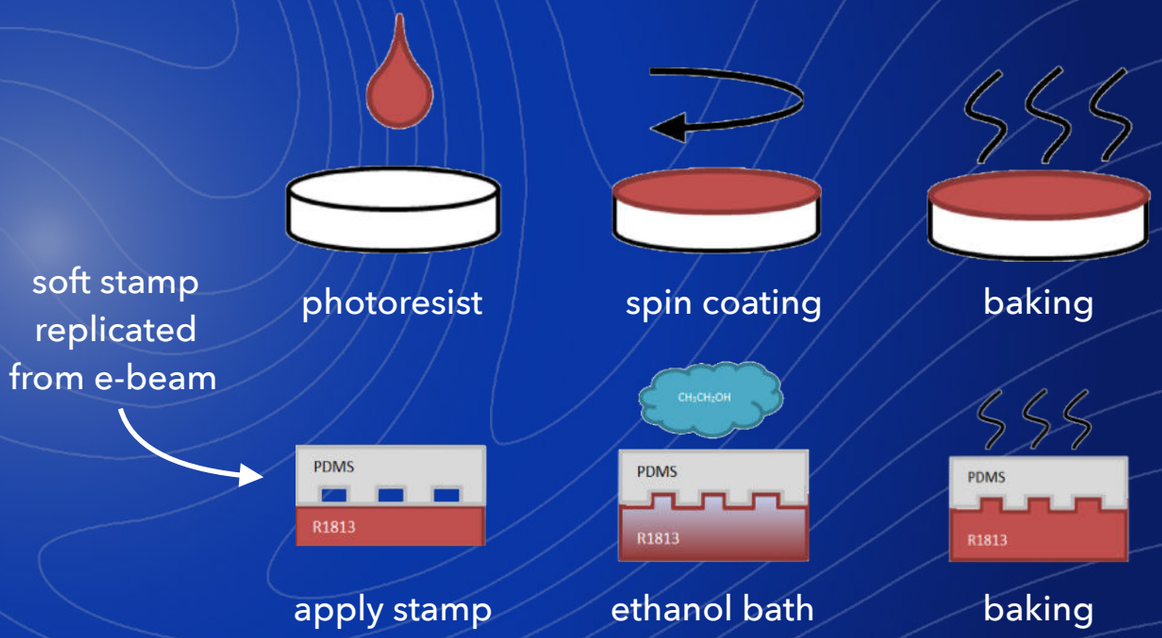
MANUFACTURING DIAMOND AGPM @ UPPSALA

Vargas Catalan et al. (2016)

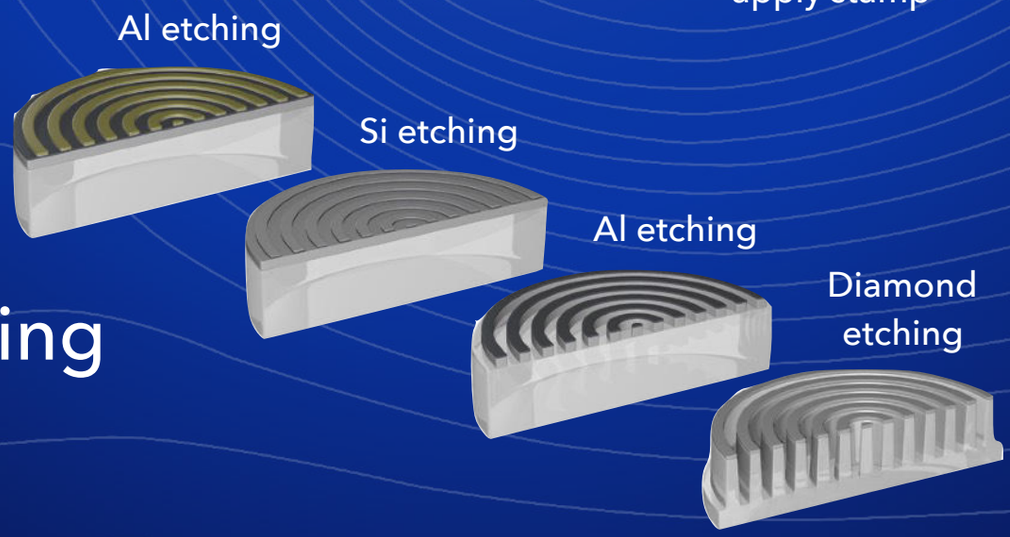
1. diamond coated with Al and Si layers (sputtering)



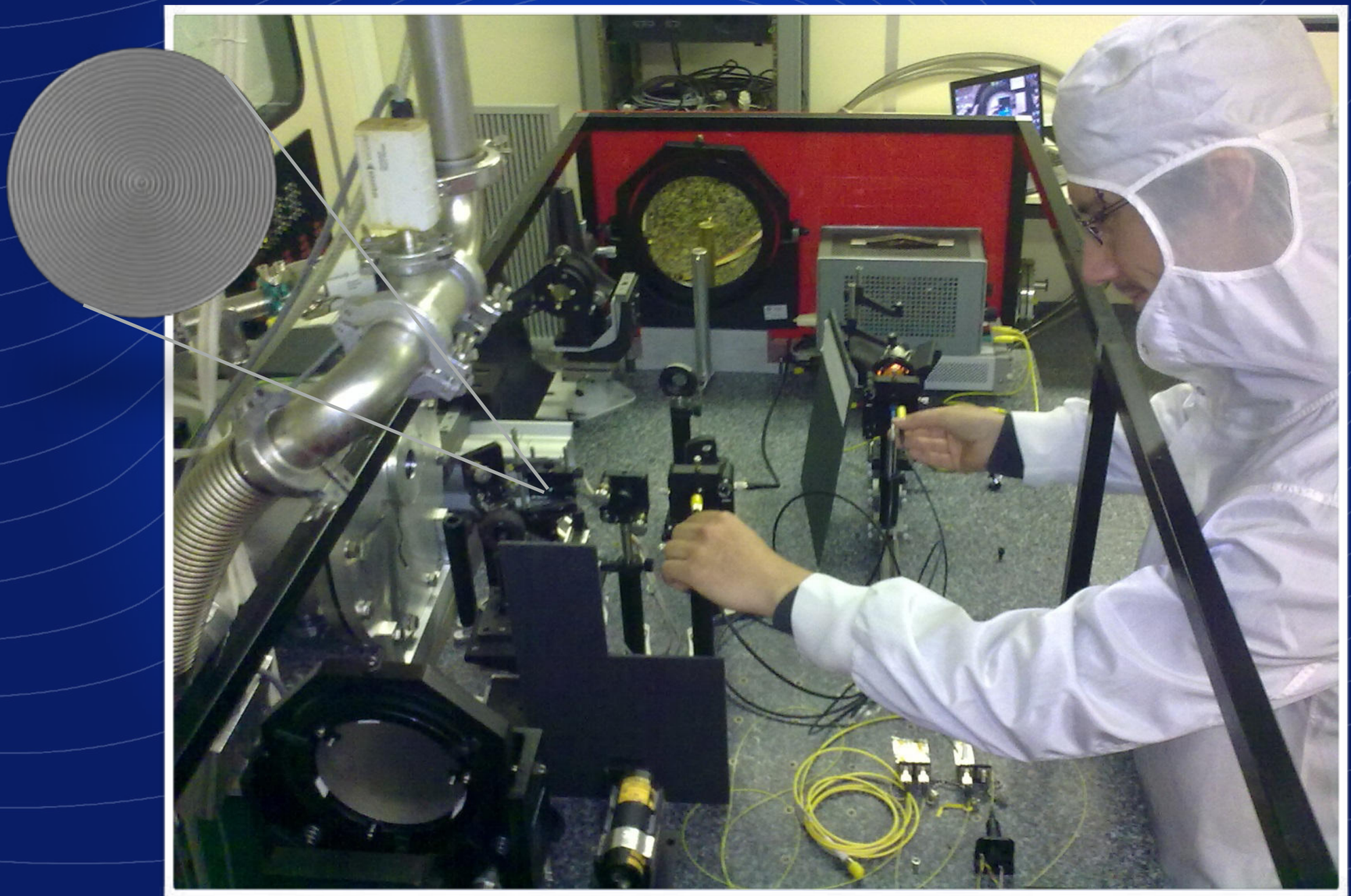
2. e-beam pattern transferred with solvent-assisted moulding



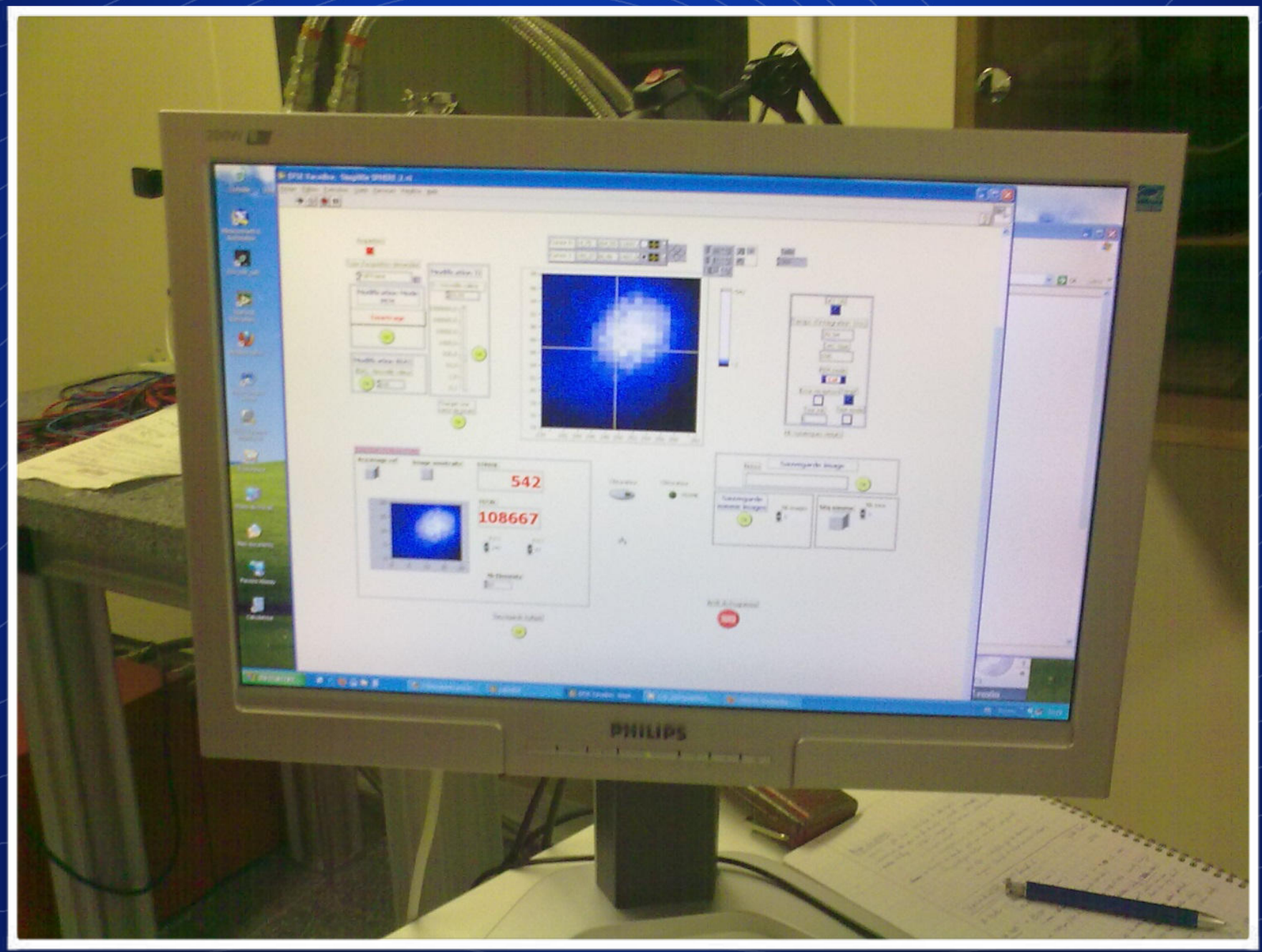
3. reactive ion etching



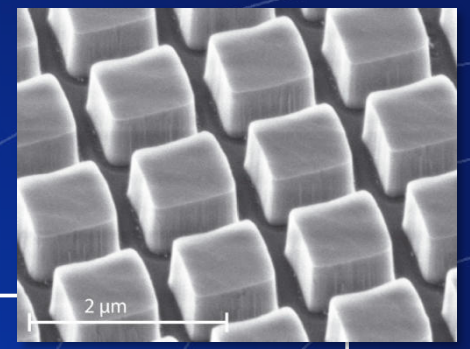
SETTING UP THE « YACADIRE » BENCH @ MEUDON

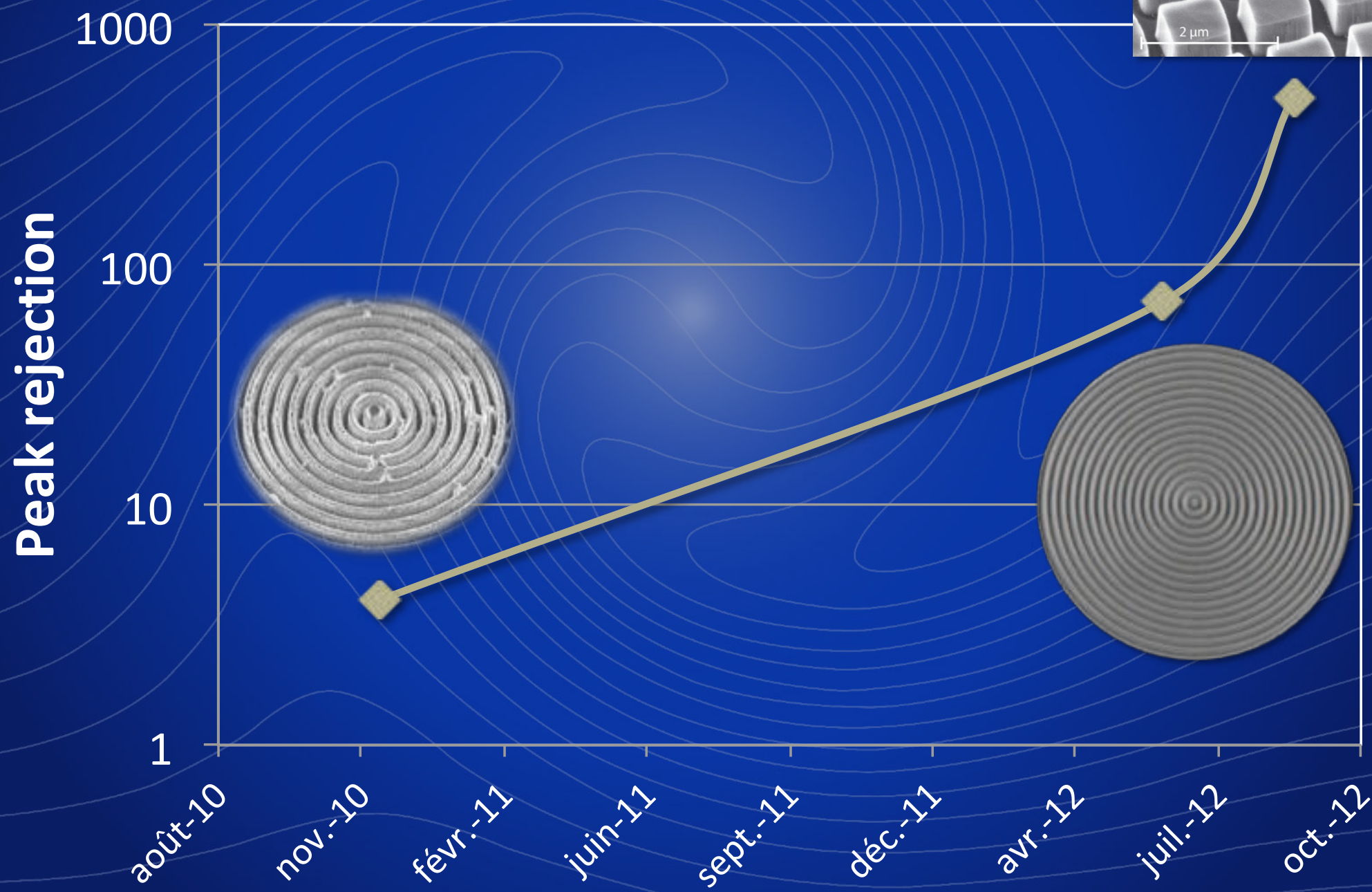


ANGUISH...

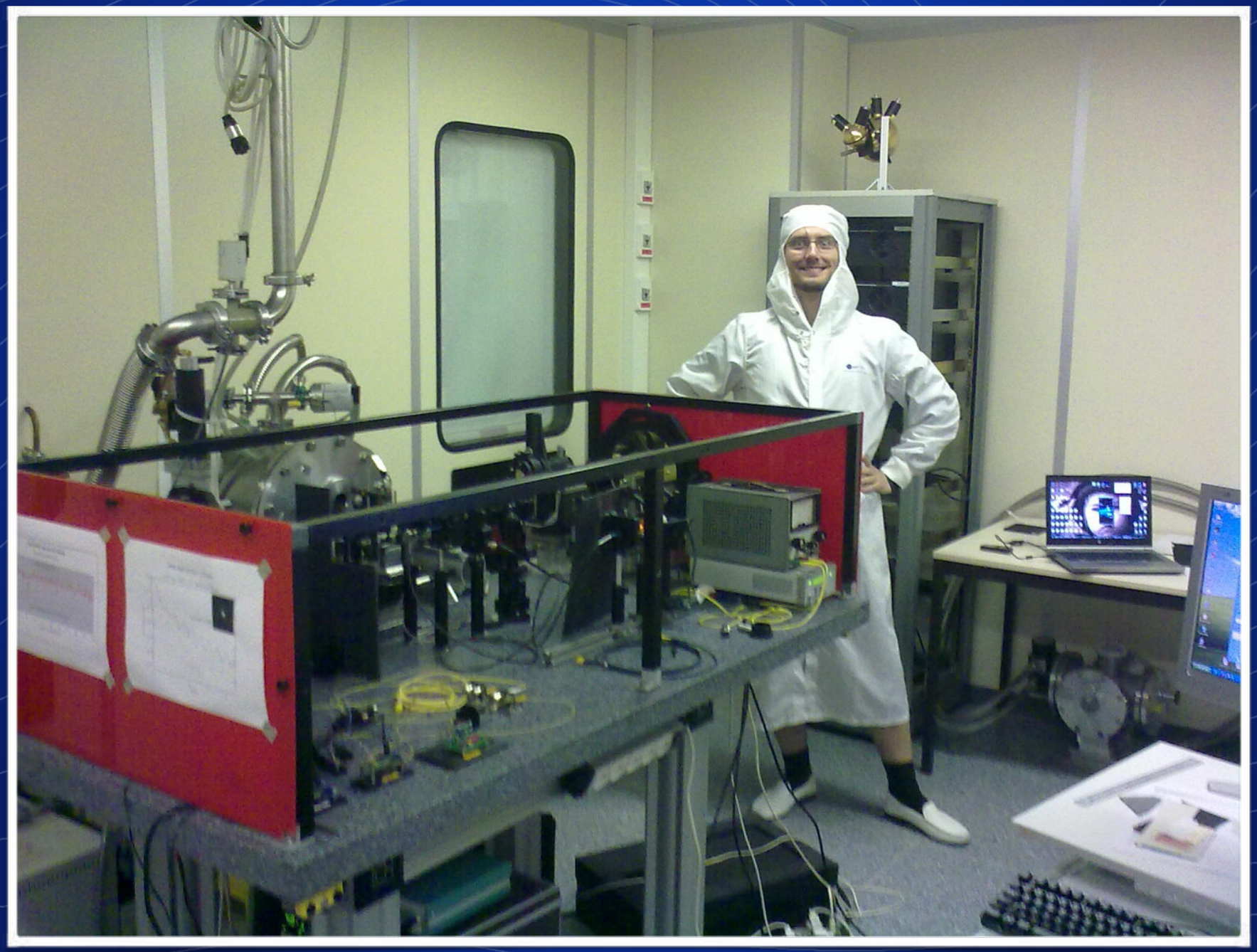


AFTER SOME TUNING…



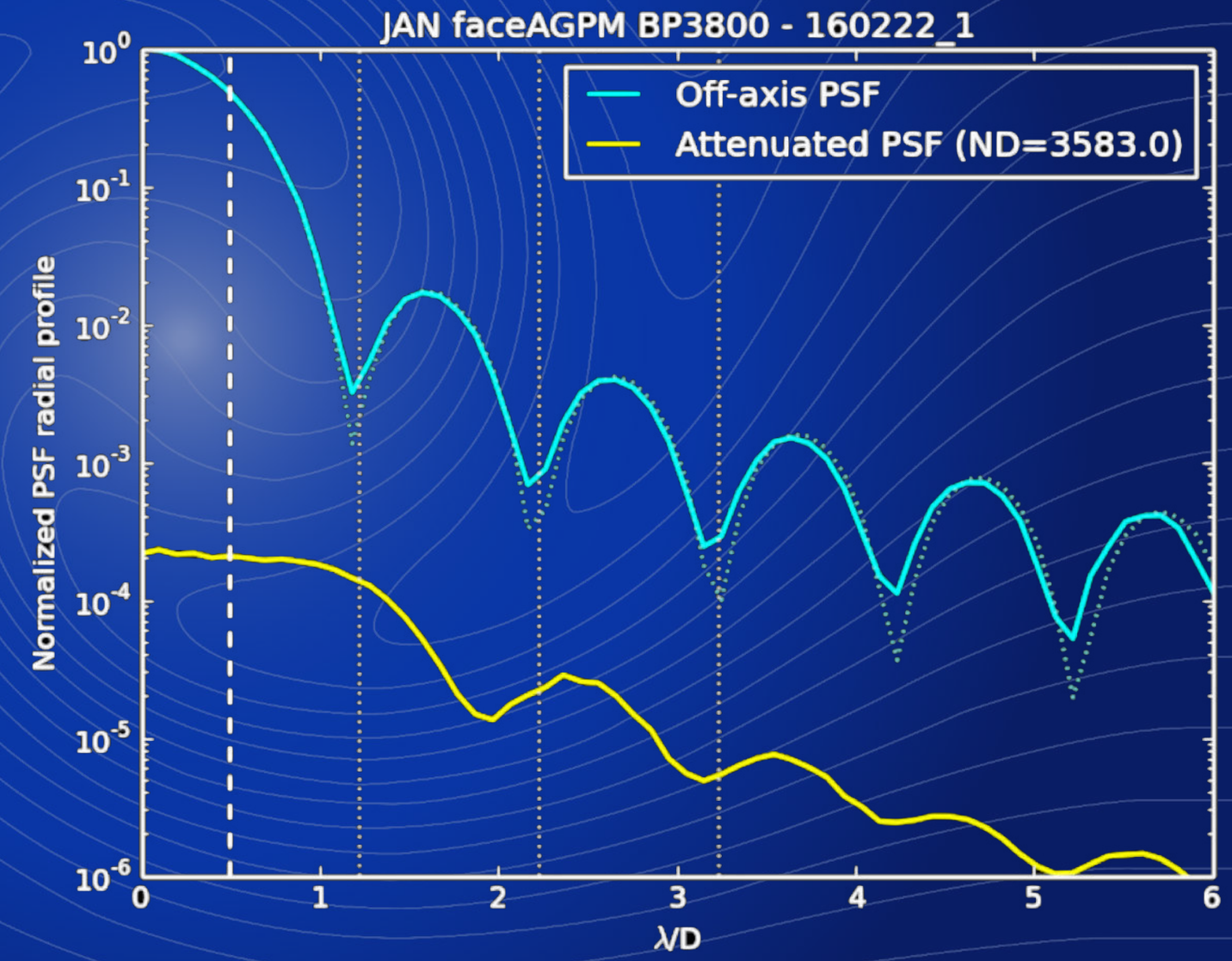


BLISS!



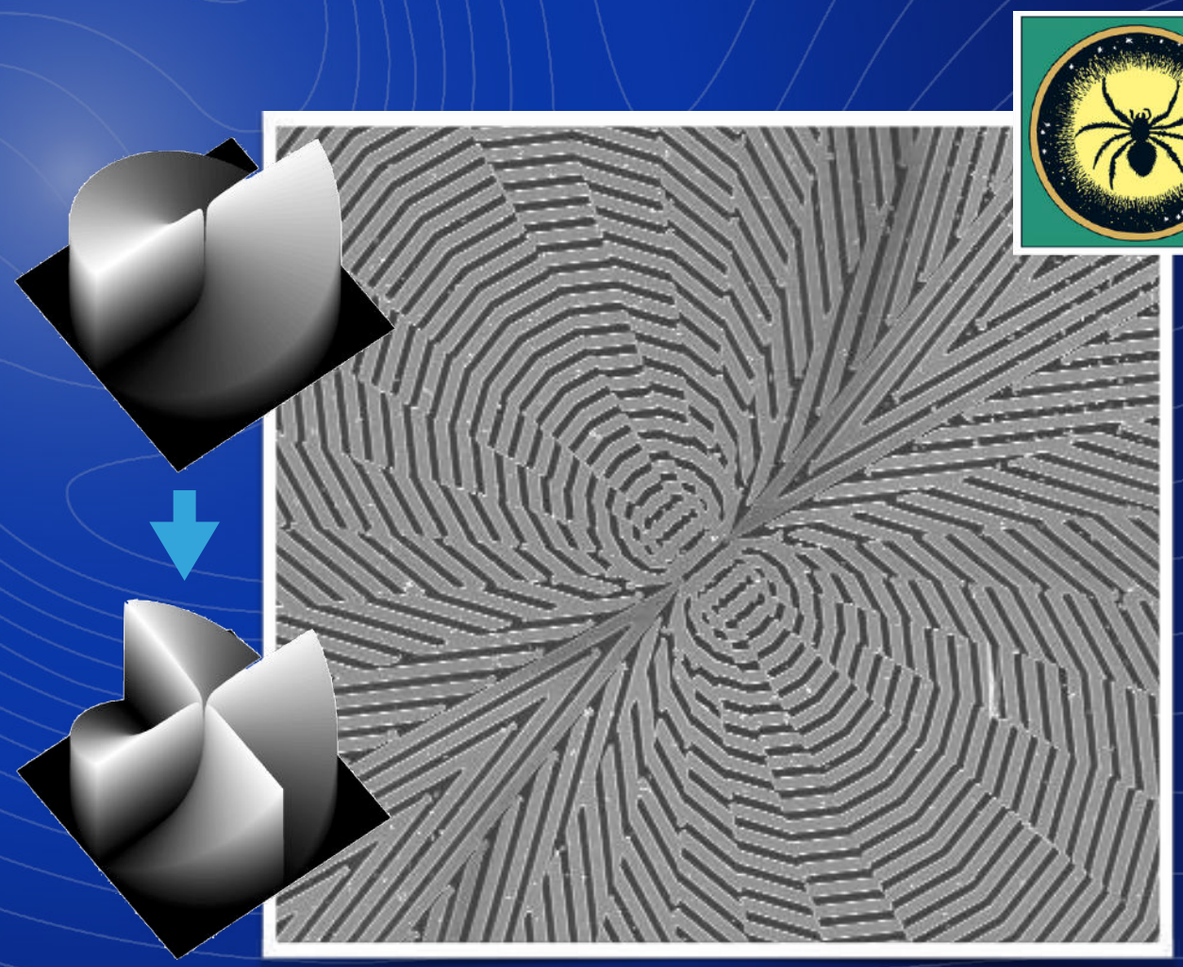
BEST PERFORMANCE IN THE LAB – 2017 UPDATE

- dedicated test bench (VODCA) now available at ULiège
- 10+ science-grade L-band AGPMs etched & tested
- broadband rejection up to 1500 : 1



EXTENDING THE CONCEPT

- AGPM first developed for thermal infrared (L, M, N bands)
  - excellent performance on ~30% bandwidth
- manufacturing tests for H-K bands promising, but more work needed
- now exploring higher topological charges
  - less sensitive to tip-tilt, at the expense of larger IWA



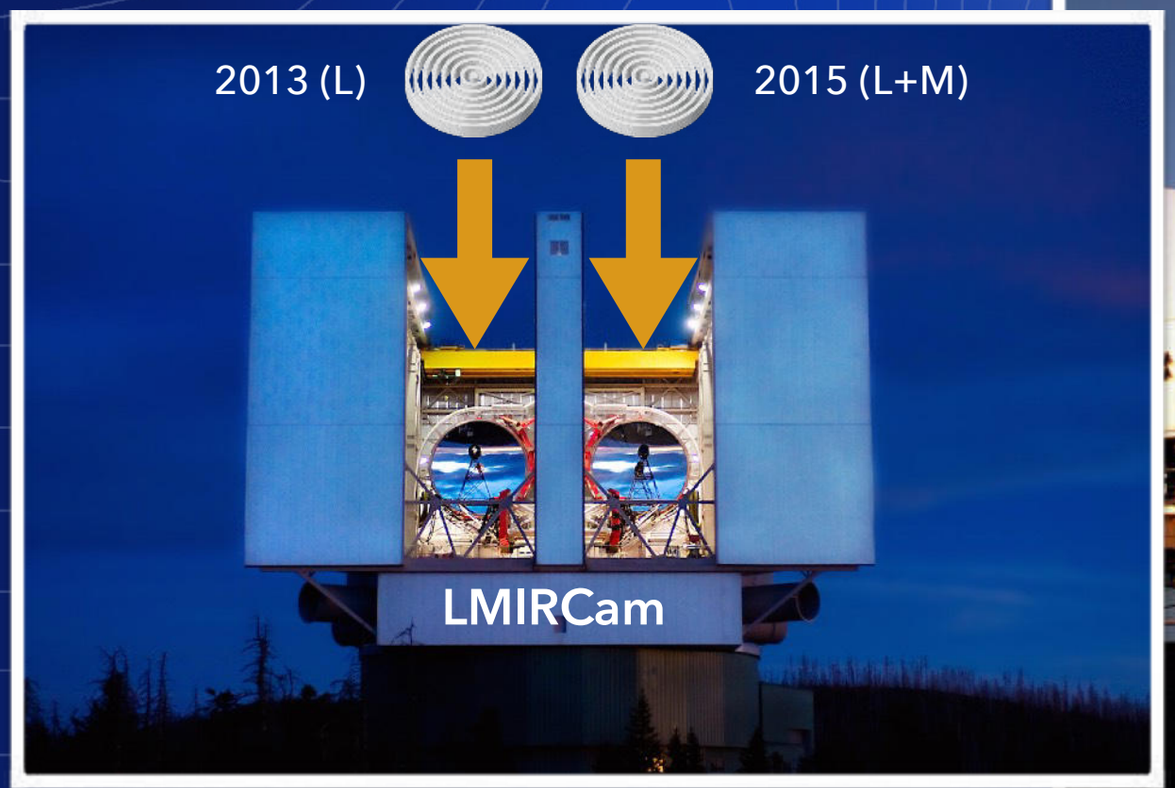
charge-4 vortex, work in progress

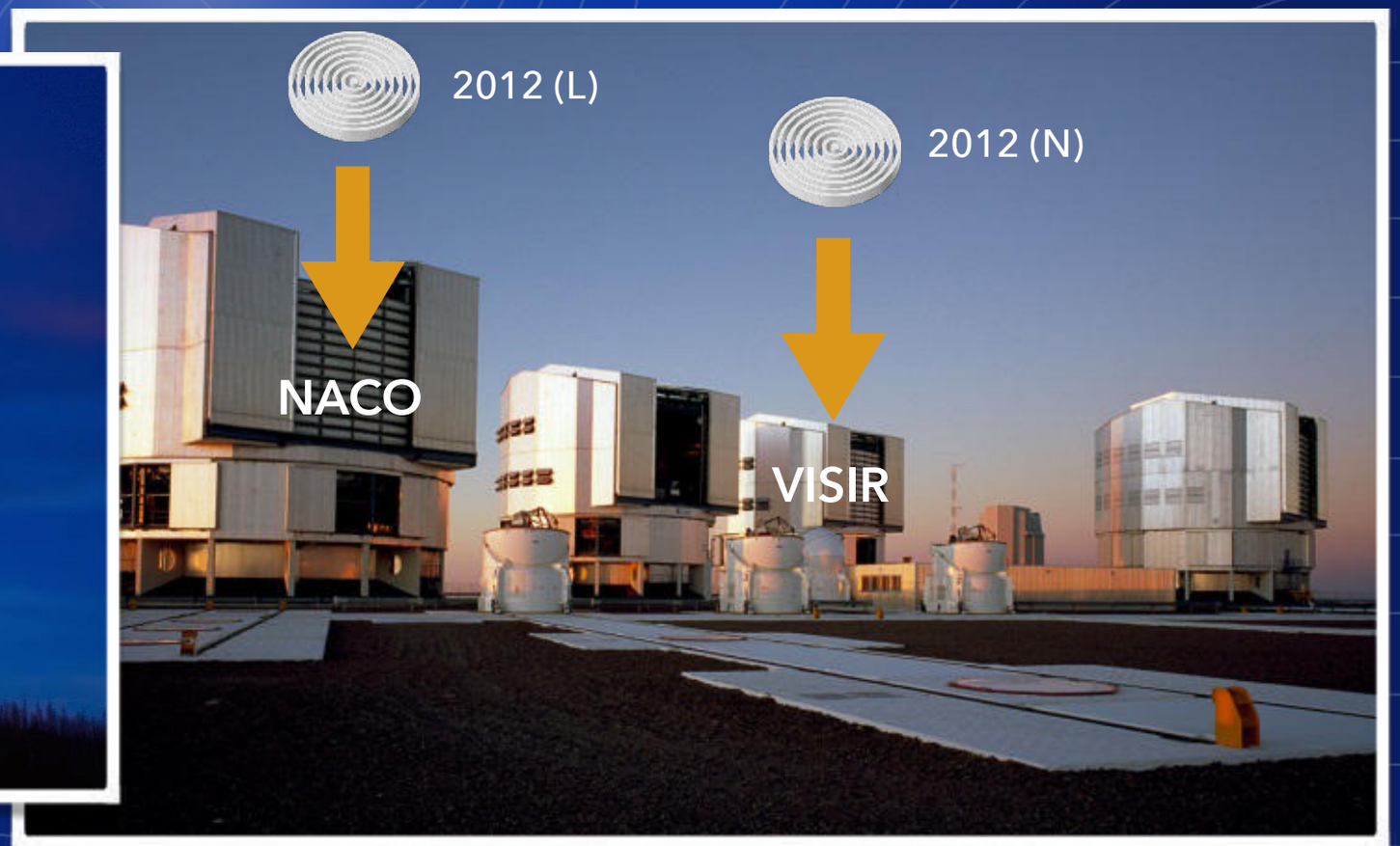
VORTEX

COMMISSIONING & ON-SKY PERFORMANCE

INSTALLATION AND COMMISSIONING

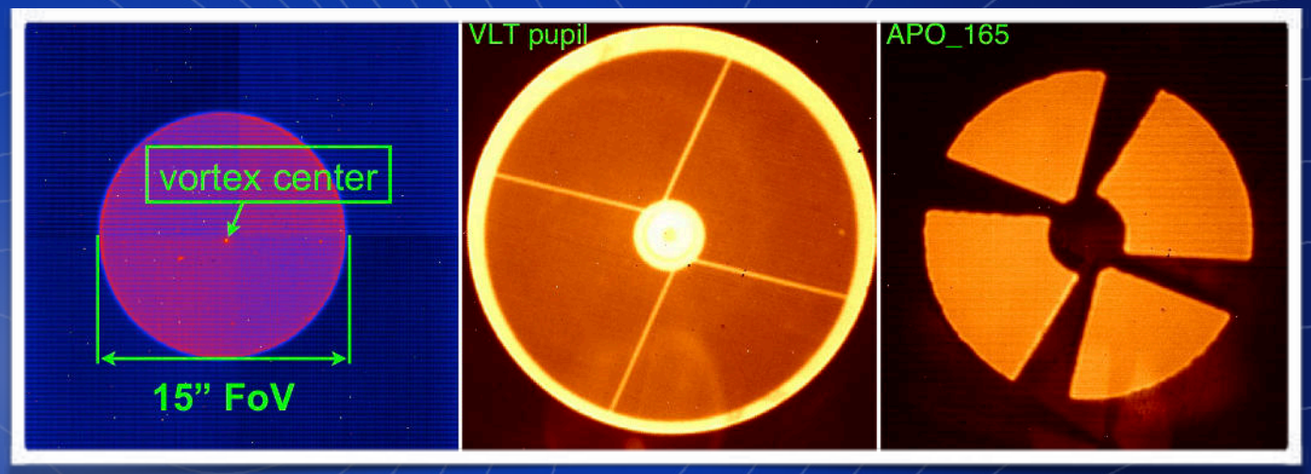
- piggyback on existing coronagraphic IR cameras
- very short commissioning phase (1-2 nights)



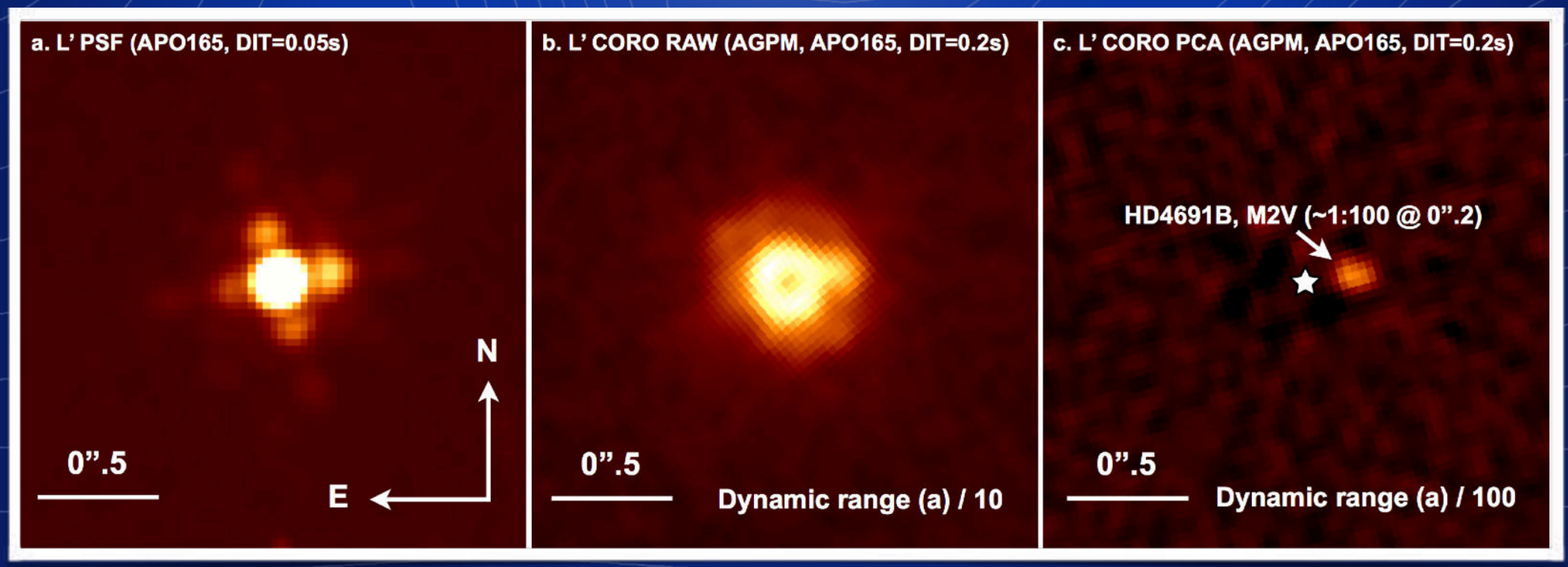


AGPM FIRST LIGHT @ NACO (DEC 2012)

- worked out of the box with available Lyot stops
- serendipitous discovery of M2V at 2λ/D from F0V

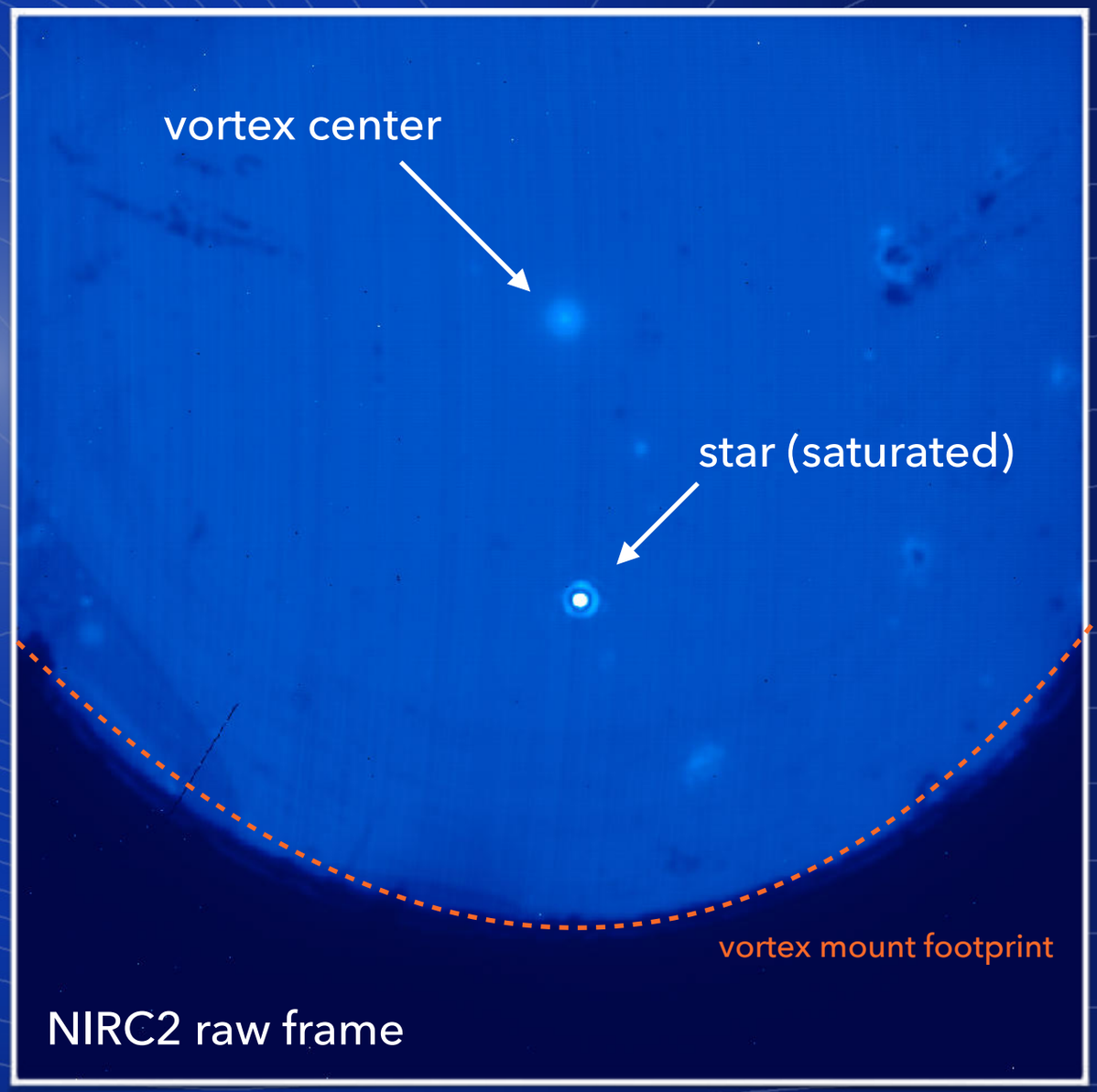


Mawet et al. (2013)



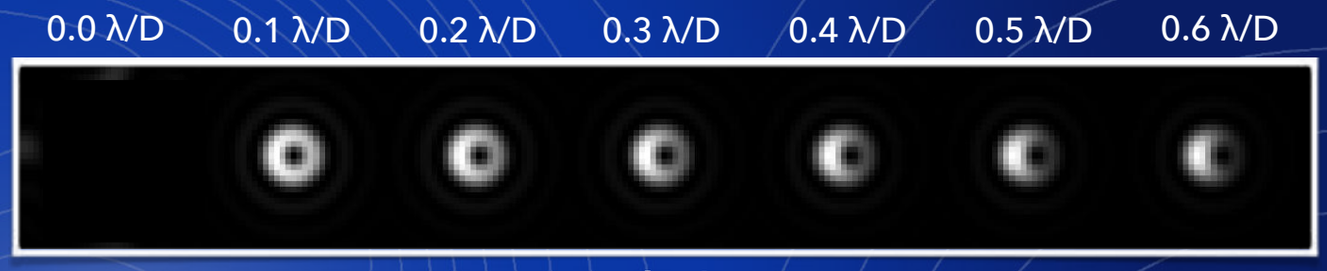
ON-SKY OPERATIONS: THE VORTEX GLOWS!

- thermal emission outside pupil partly diffracted inside pupil by vortex
- seen in all instruments (vortex upstream cold stop)
- removed by background subtraction
- useful for centering

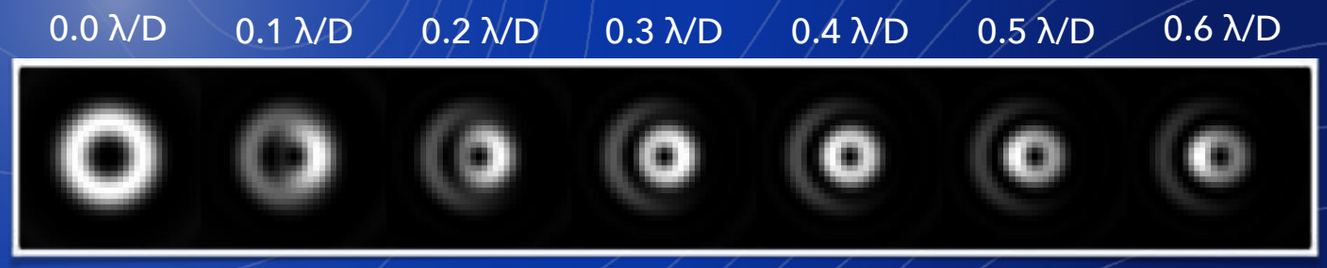


ON-SKY OPERATIONS: ACQUISITION & CENTERING

- pointing errors create asymmetric « donut »
- central obstruction changes the expected behavior of the donut
- need modeling to infer pointing error from image (QACITS algorithm)
- can be used to control pointing at low frequency



w/o central obstruction

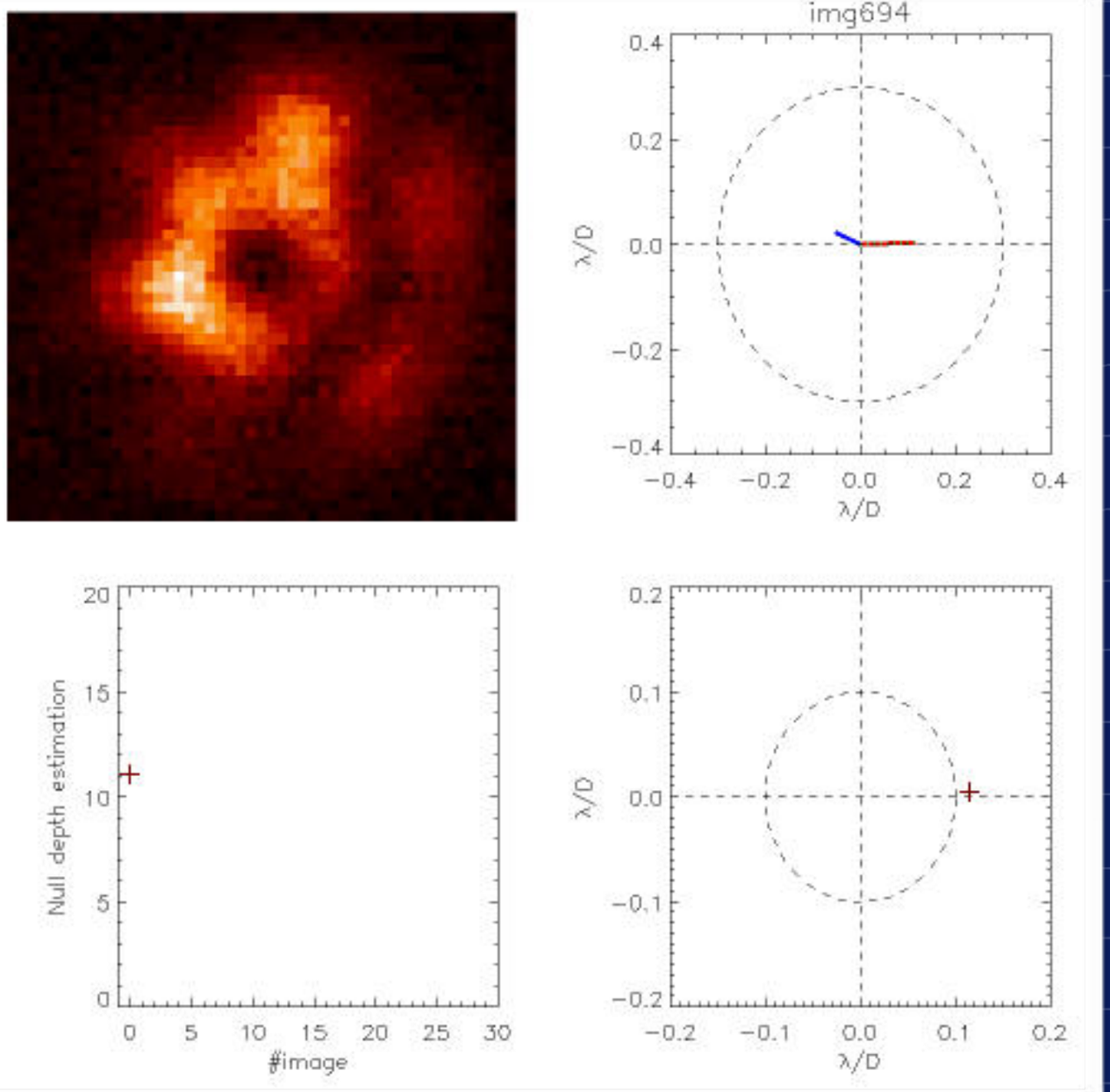


w/ central obstruction

Huby et al. 2015

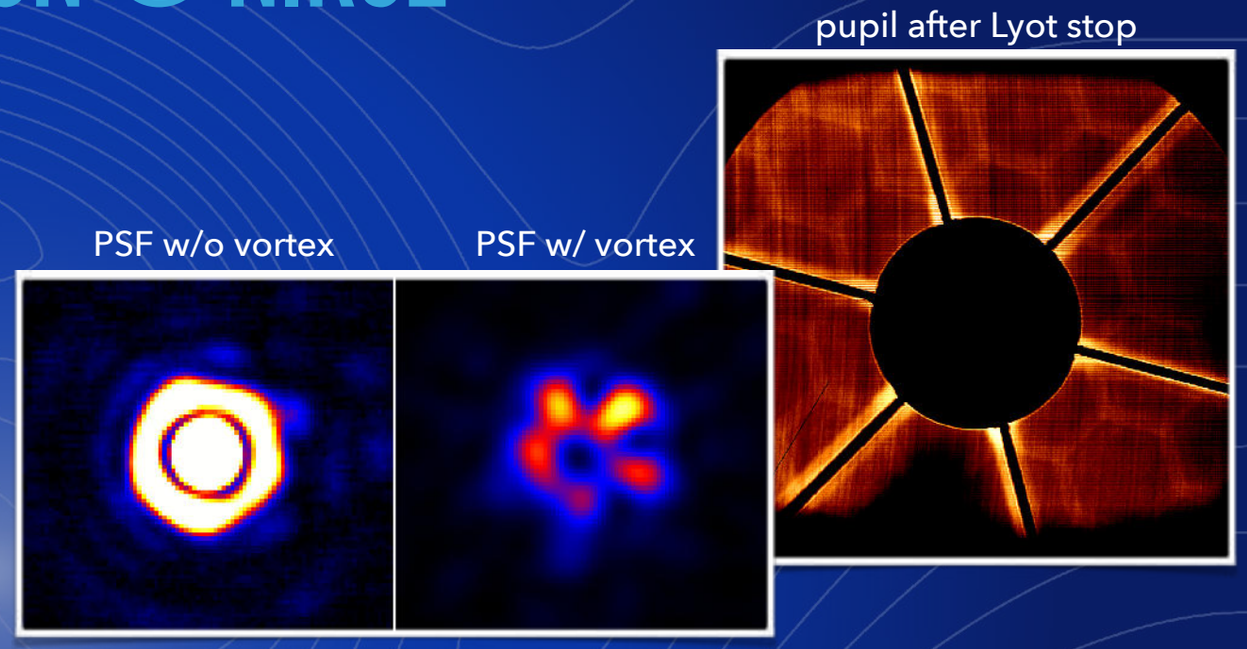
CLOSED-LOOP CENTERING CONTROL

- fully automated vortex operations with QACITS validated on NIRC2
  - ✳ includes acquisition & calibration
- ensures consistant centering and data quality
- rms jitter ~ 0.02 λ/D (@ 0.03 Hz)

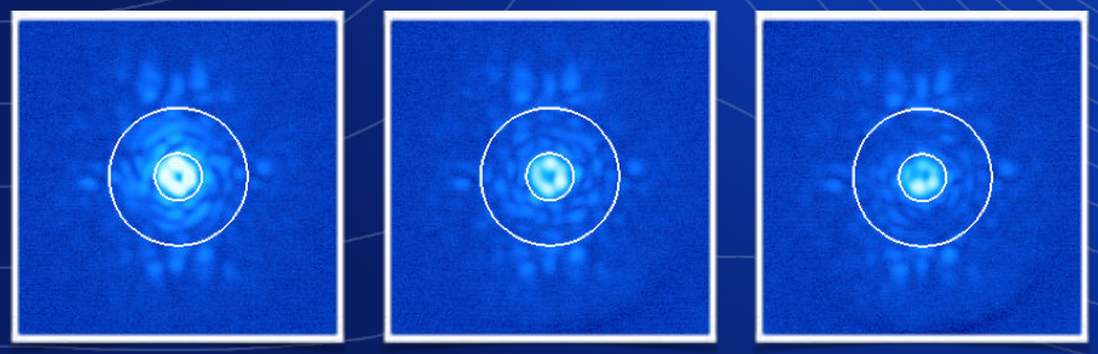


ON-SKY STARLIGHT CANCELLATION @ NIRC2

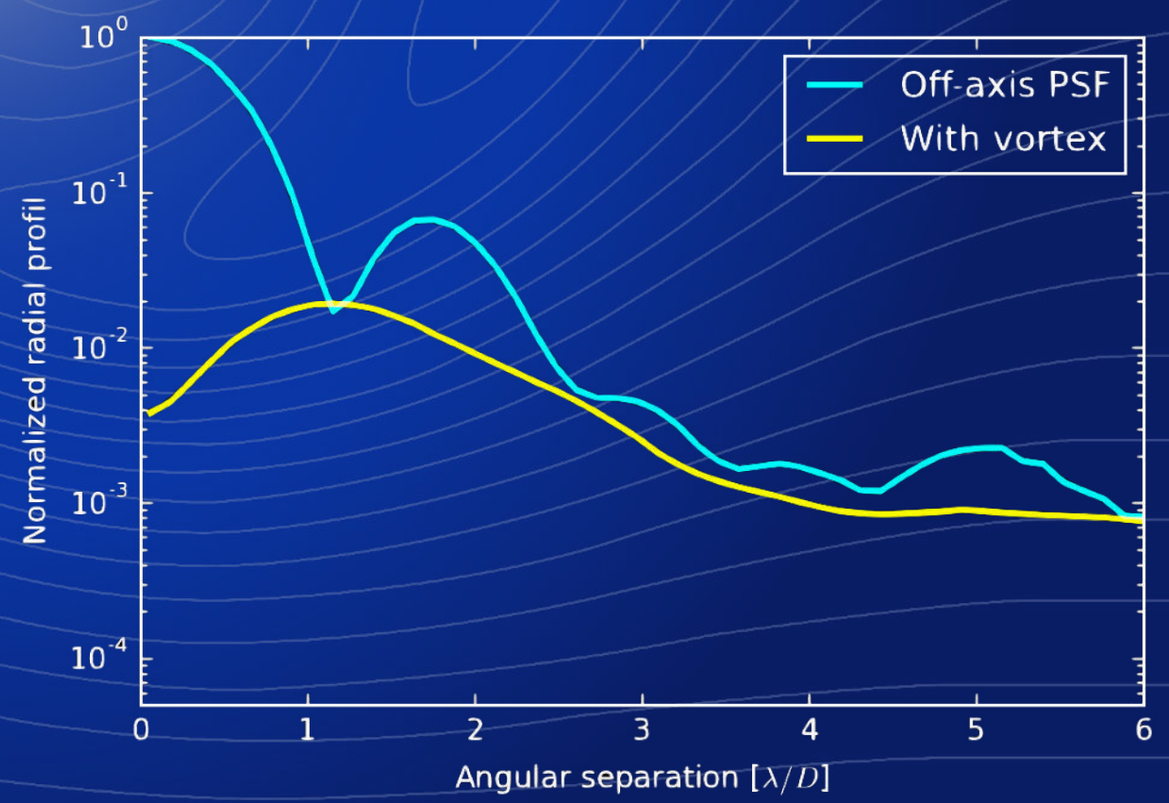
- on-sky extinction limited by
  - pupil geometry / Lyot stop
  - AO residuals
  - non-common path aberrations



- daytime speckle nulling helps reduce NCPA … but NIRC2 upgrade needed!

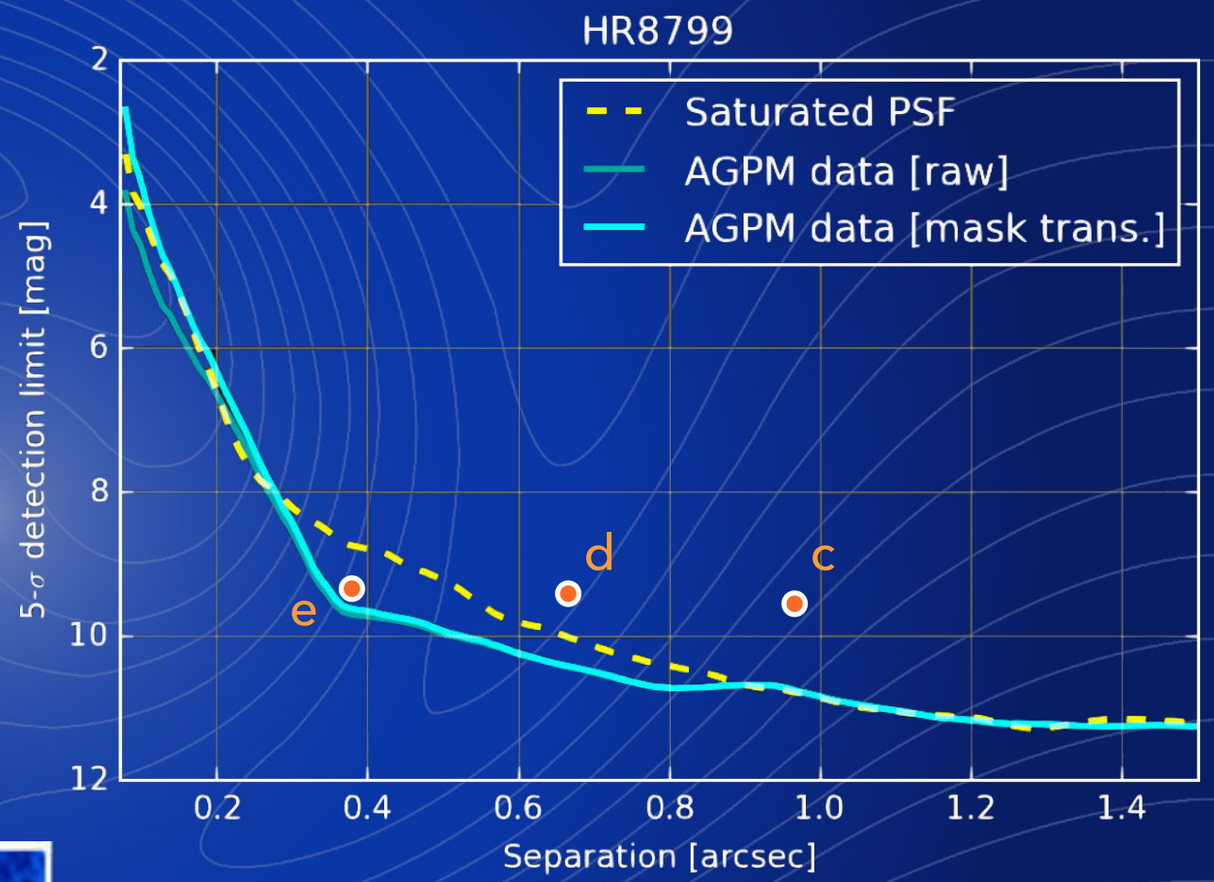


Bottom et al. (in prep)

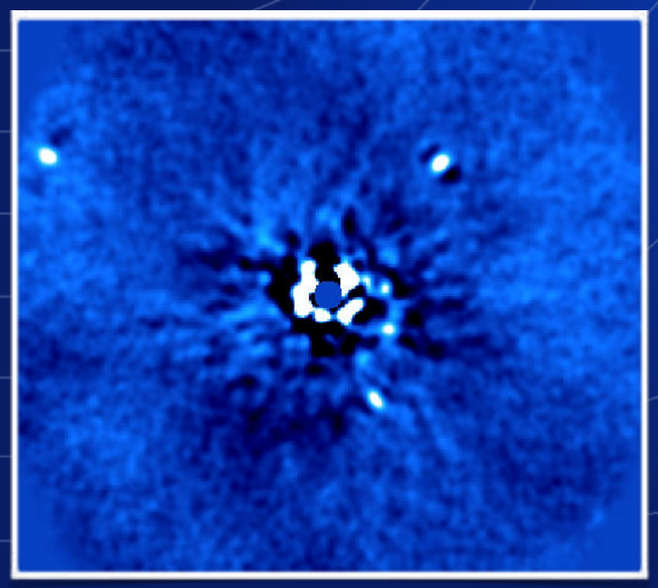


IMPROVEMENT IN DETECTION LIMITS @ NIRC2

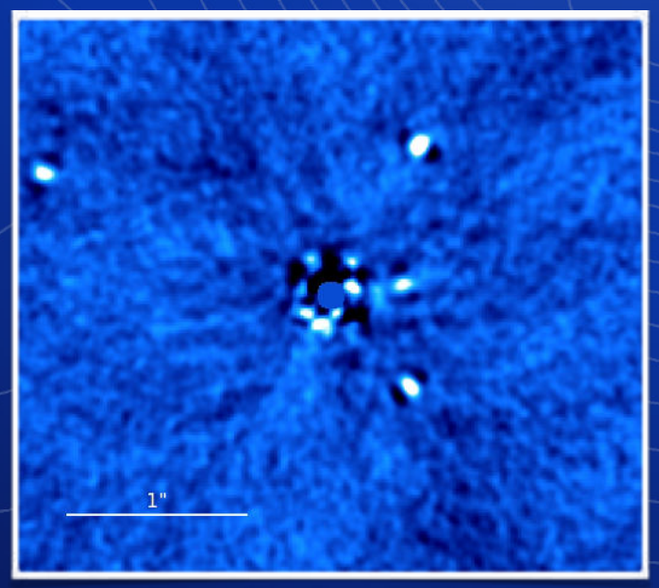
- obvious gain in 3–10 λ/D region (0.25" – 0.8")
- vortex reduces throughput @ 1-2 λ/D



saturated imaging



vortex imaging



comparison based on two HR8799 data sets with similar integration time and parallactic angle rotation, processed using a standard PCA-ADI algorithm

VORTEX PERFORMANCE ON VARIOUS INSTRUMENTS