

VORTEX

Taking extrasolar planet imaging to a new level with vector vortex coronagraphy: the VORTEX project

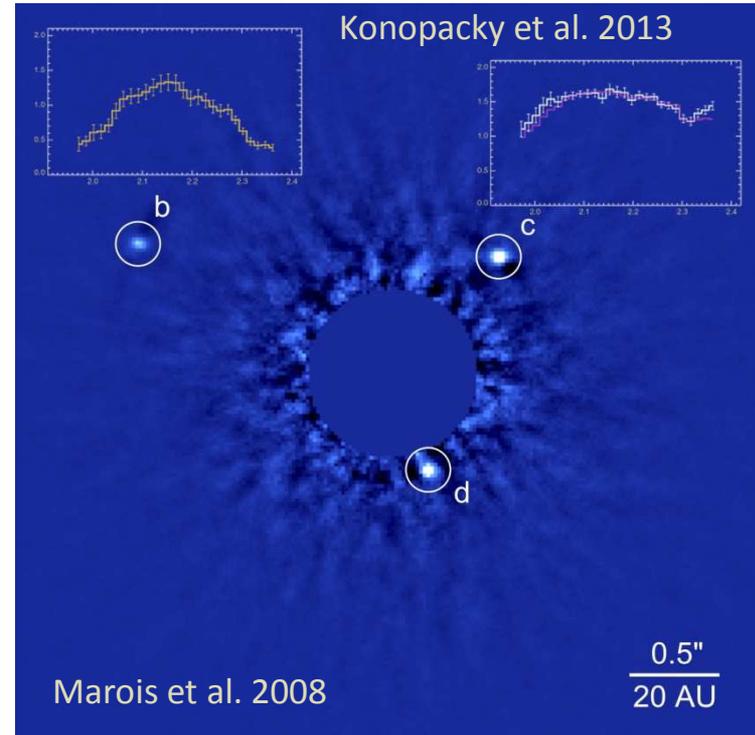
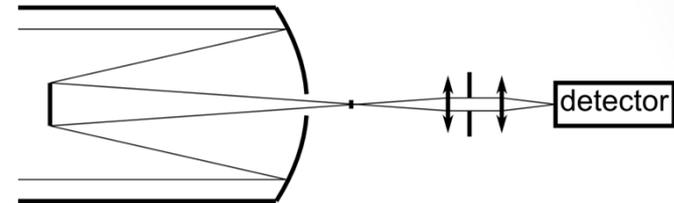
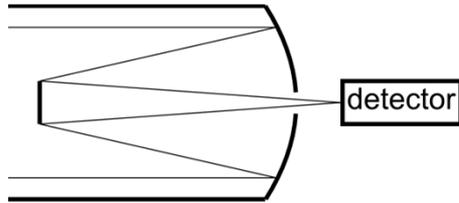
Olivier Absil

FNRS Research Associate

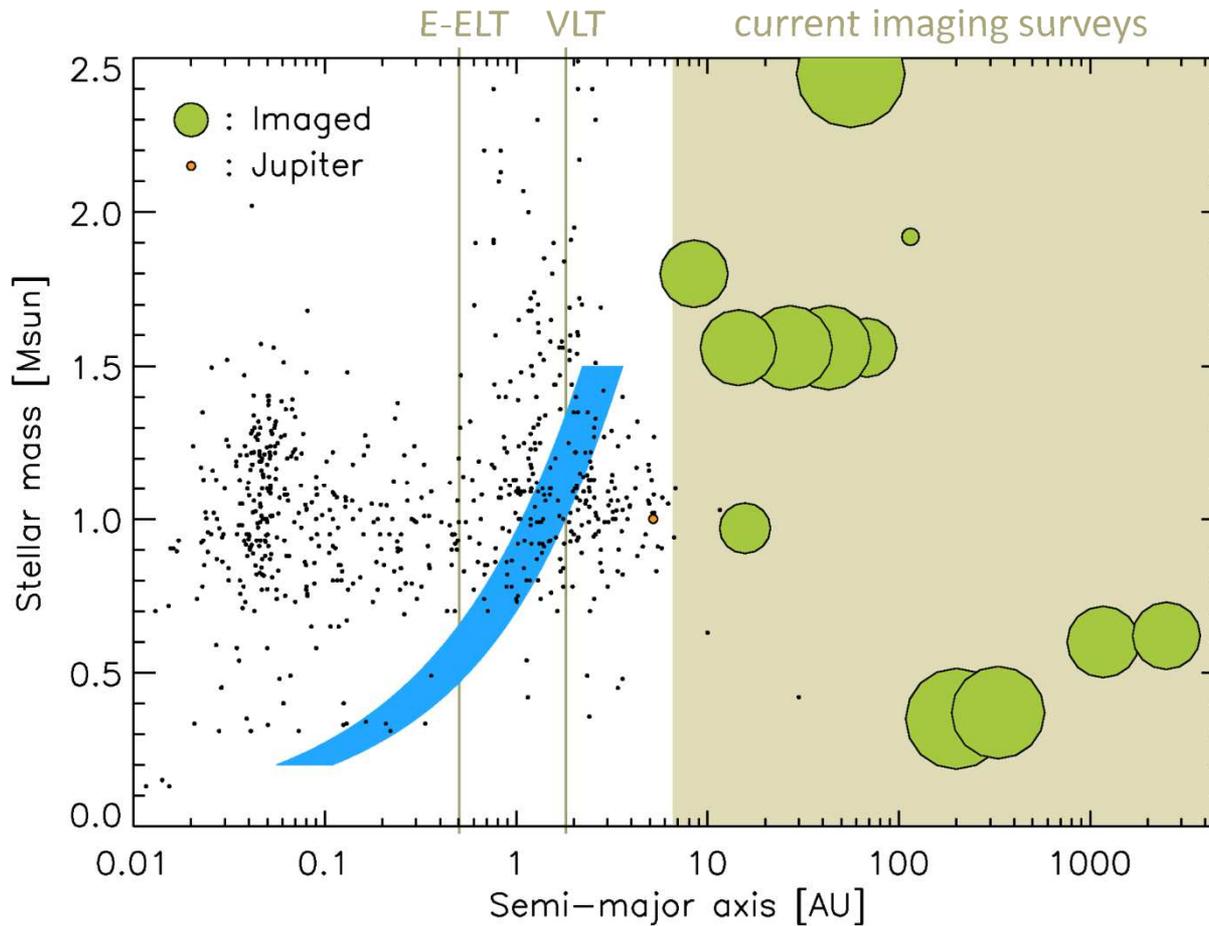
Université de Liège



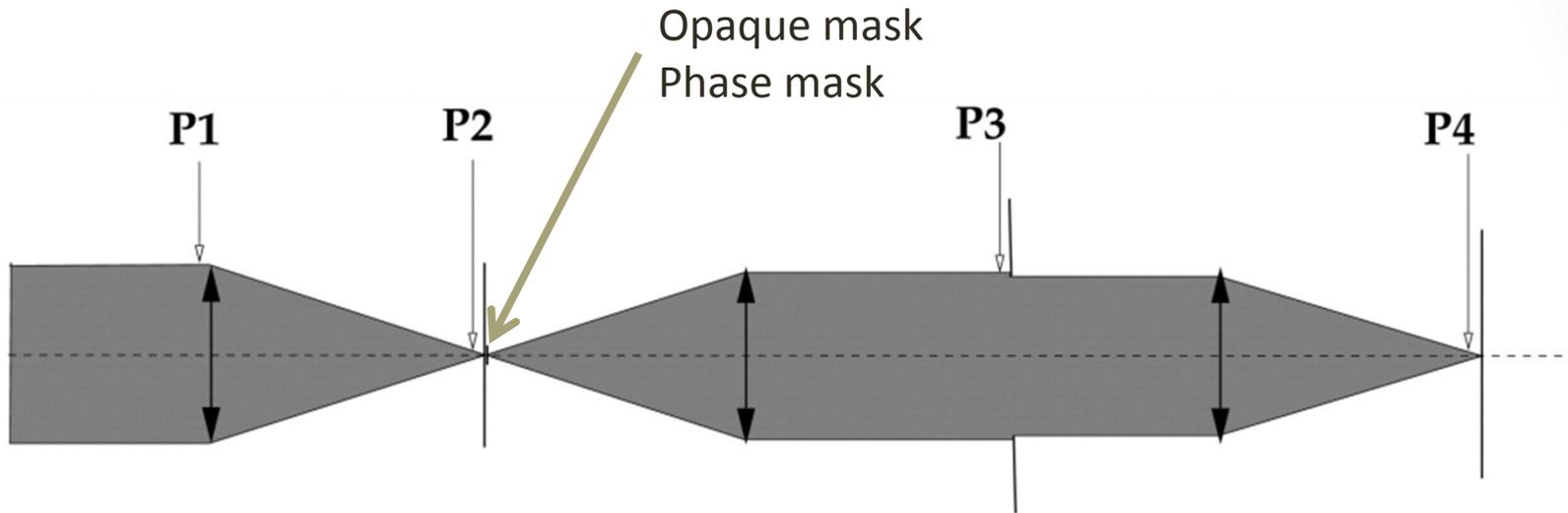
Let there be (no) light!



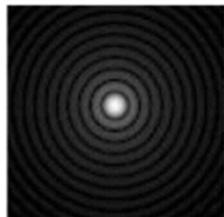
Which planets?



Coronagraphy

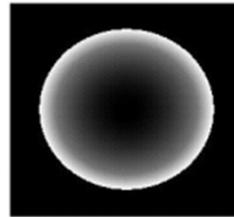


P1

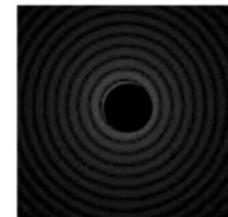


P2

Lyot
coronagraph



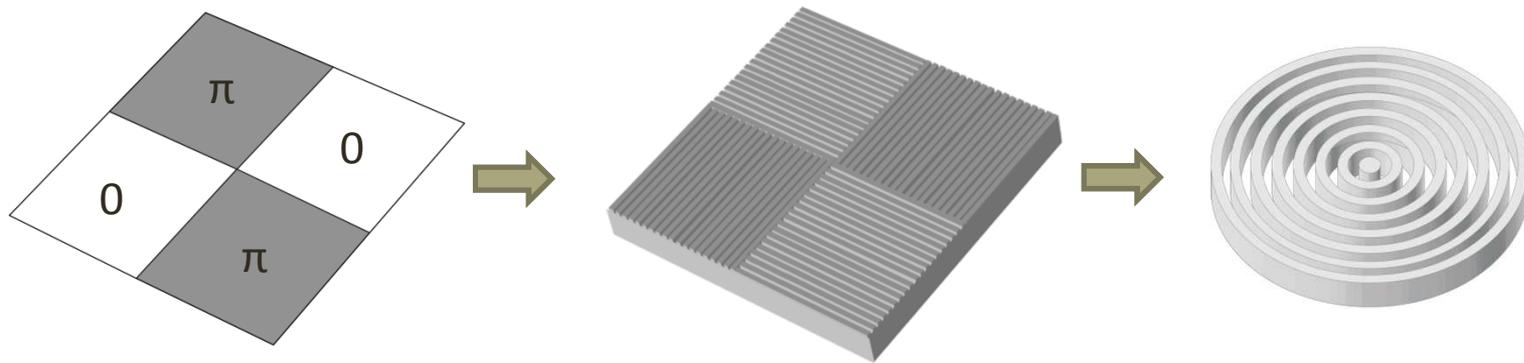
P3



P4

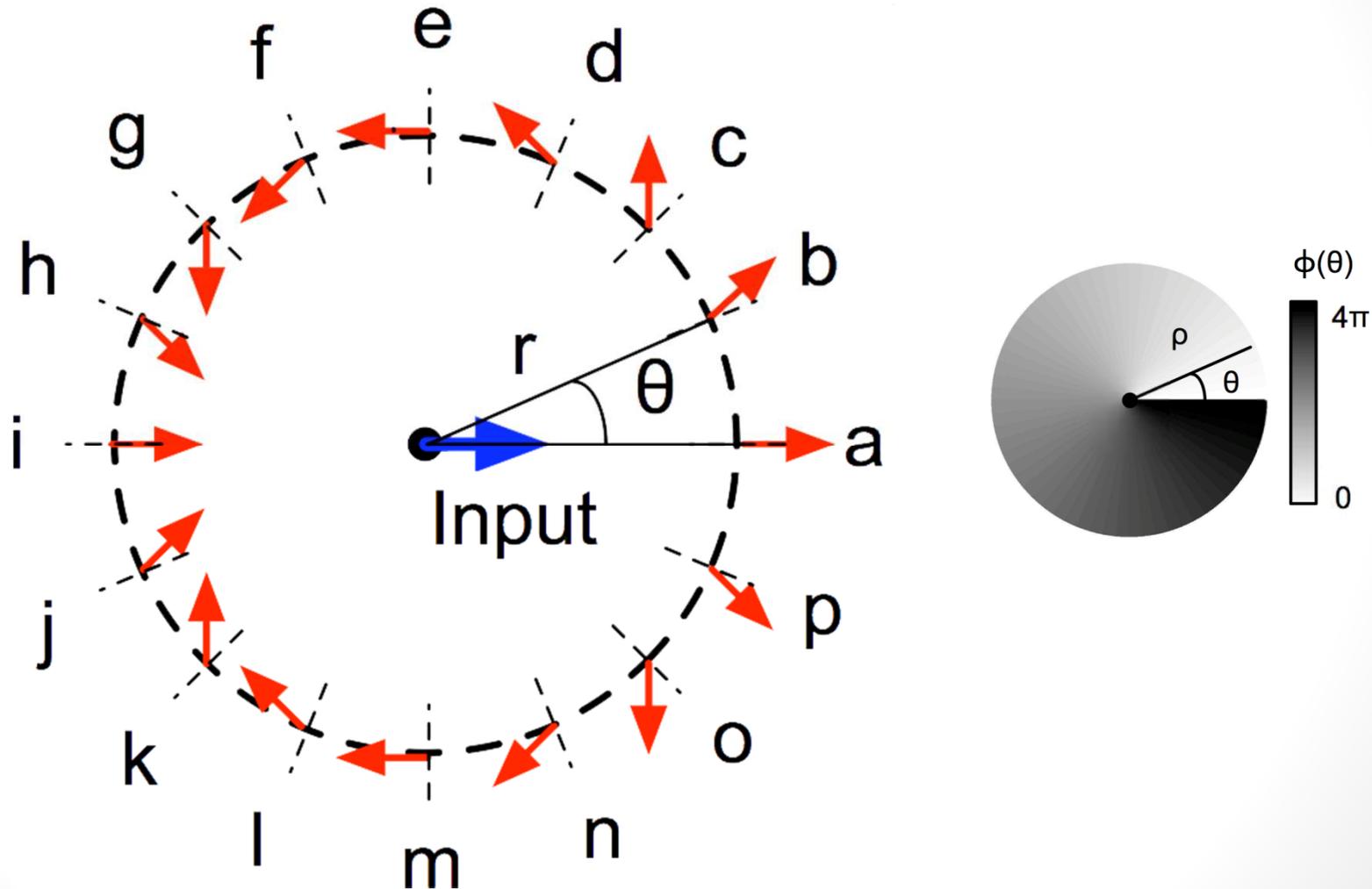
The birth of a concept

- 1997: phase mask (PM) for on-axis light cancellation
- Four Quadrant PM \rightarrow ZOG FQPM \rightarrow Annular Groove PM



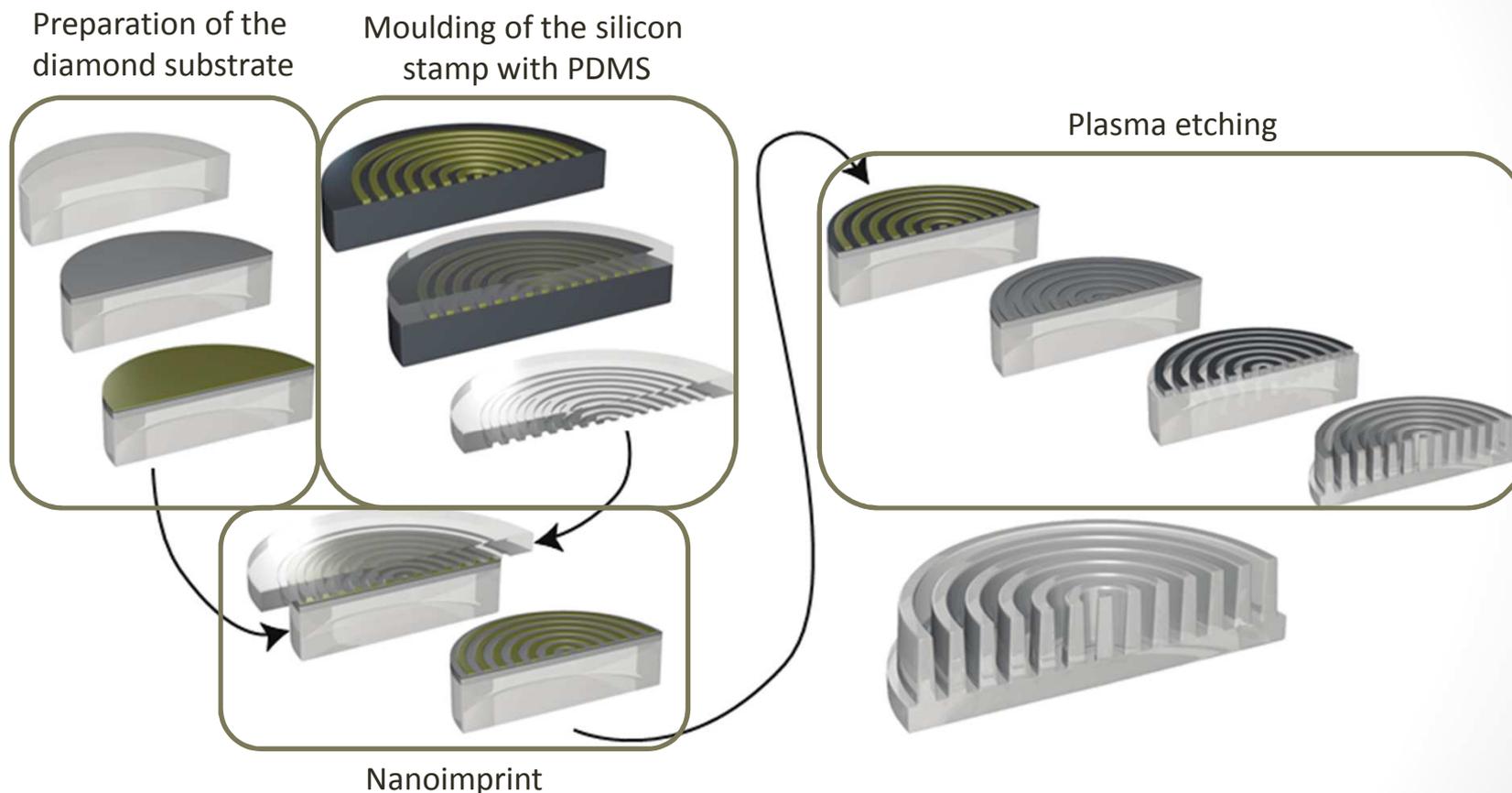
- Advantages of the “AGPM” (first vortex coronagraph)
 - Inner working angle $\approx 1 \lambda/D$
 - Clear 360° discovery space
 - Achromatic thanks to ZOG design
 - Easy to implement

The AGPM, an optical vortex



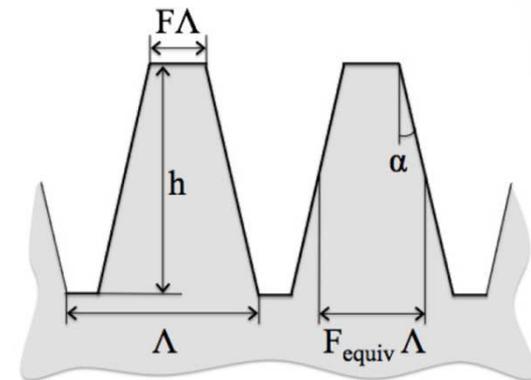
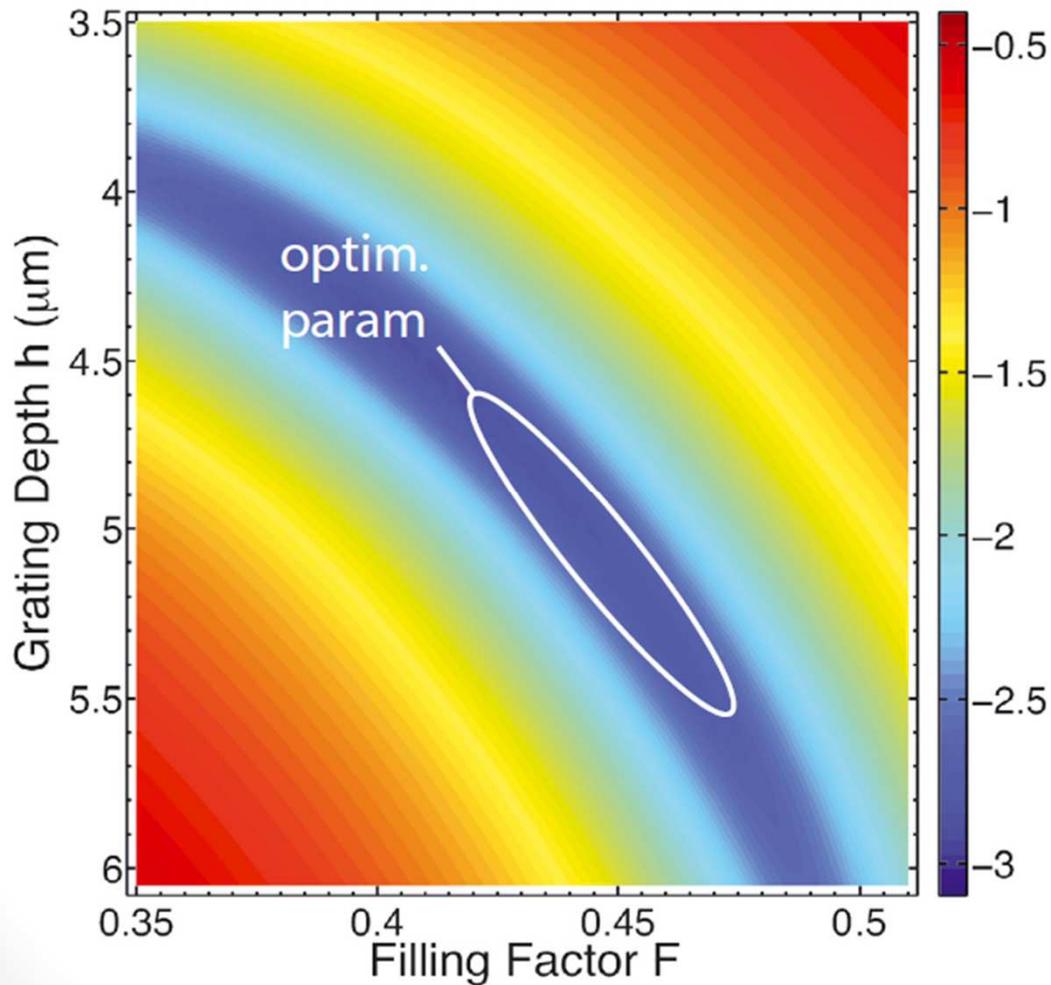


Manufacturing process

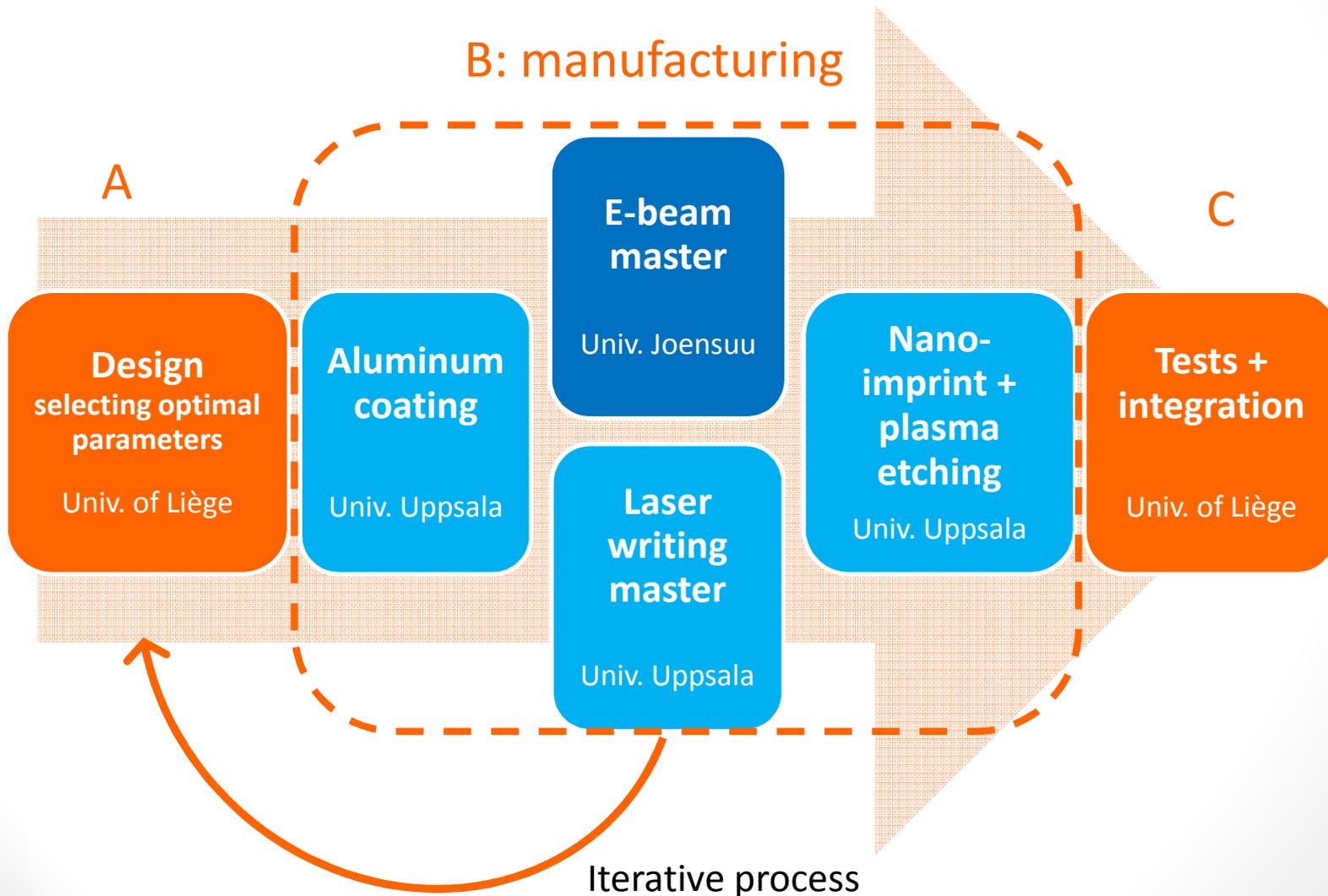


Diamond: optical / IR transmission, mechanical / thermal properties

Grating design/optimization

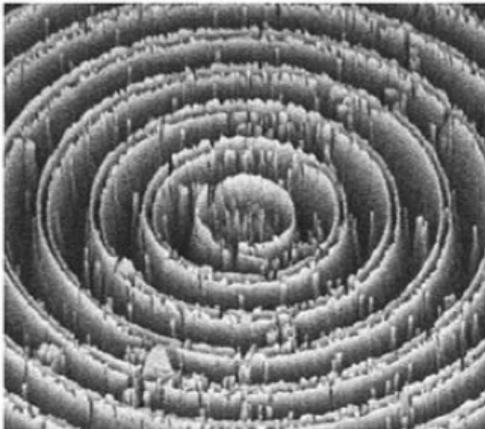


A long, iterative process

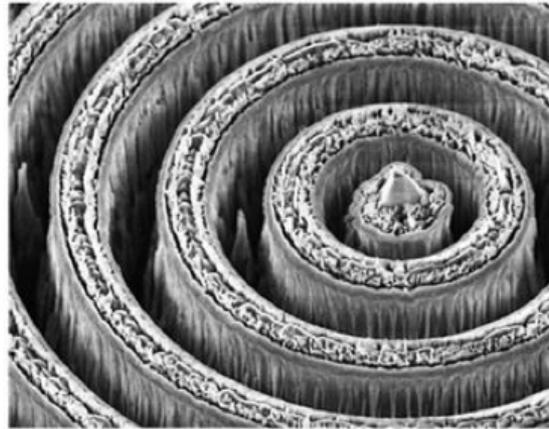


1st step: N-band AGPMs ($\lambda=10\mu\text{m}$)

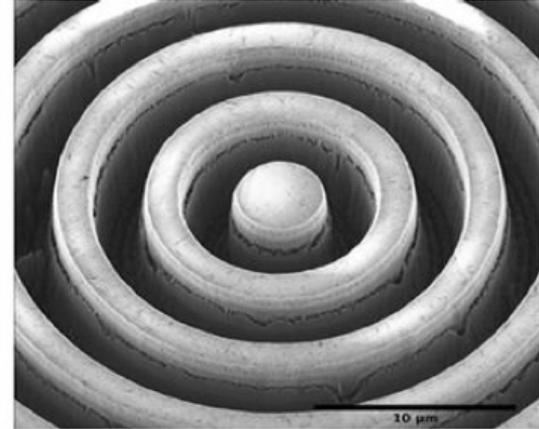
November 2009



October 2010



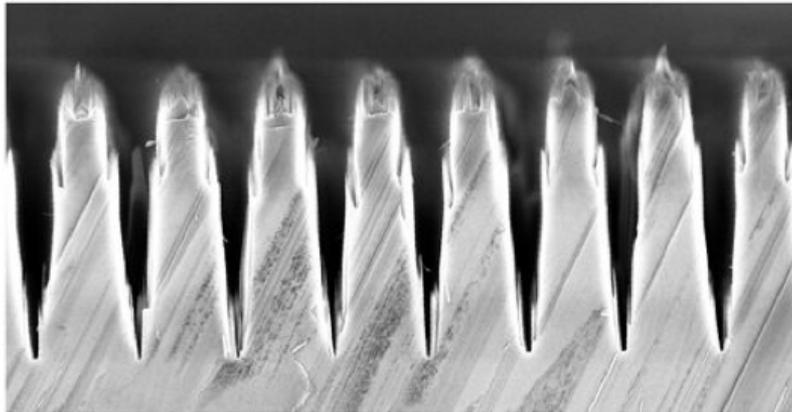
February 2012



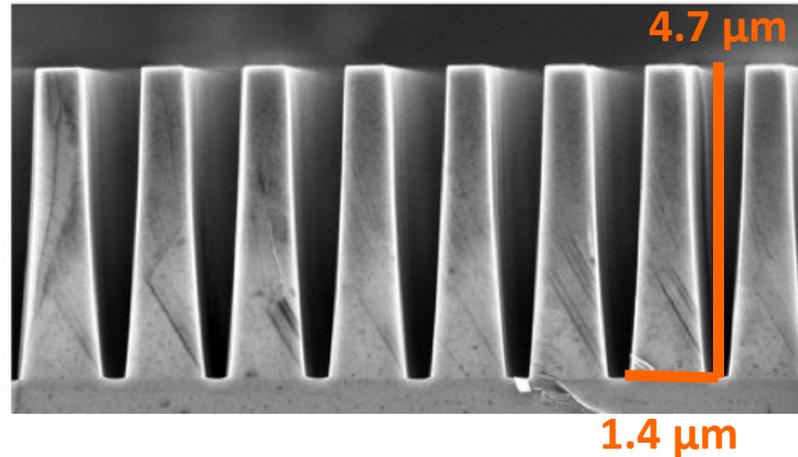
- ☺ Perfect profile of the central annular grooves
- ☺ Improved roughness → reduced scattering
- ☹ N band: - IR background too high
- no test-bench available

2nd step: L-band AGPMs ($\lambda=4\mu\text{m}$)

December 2010



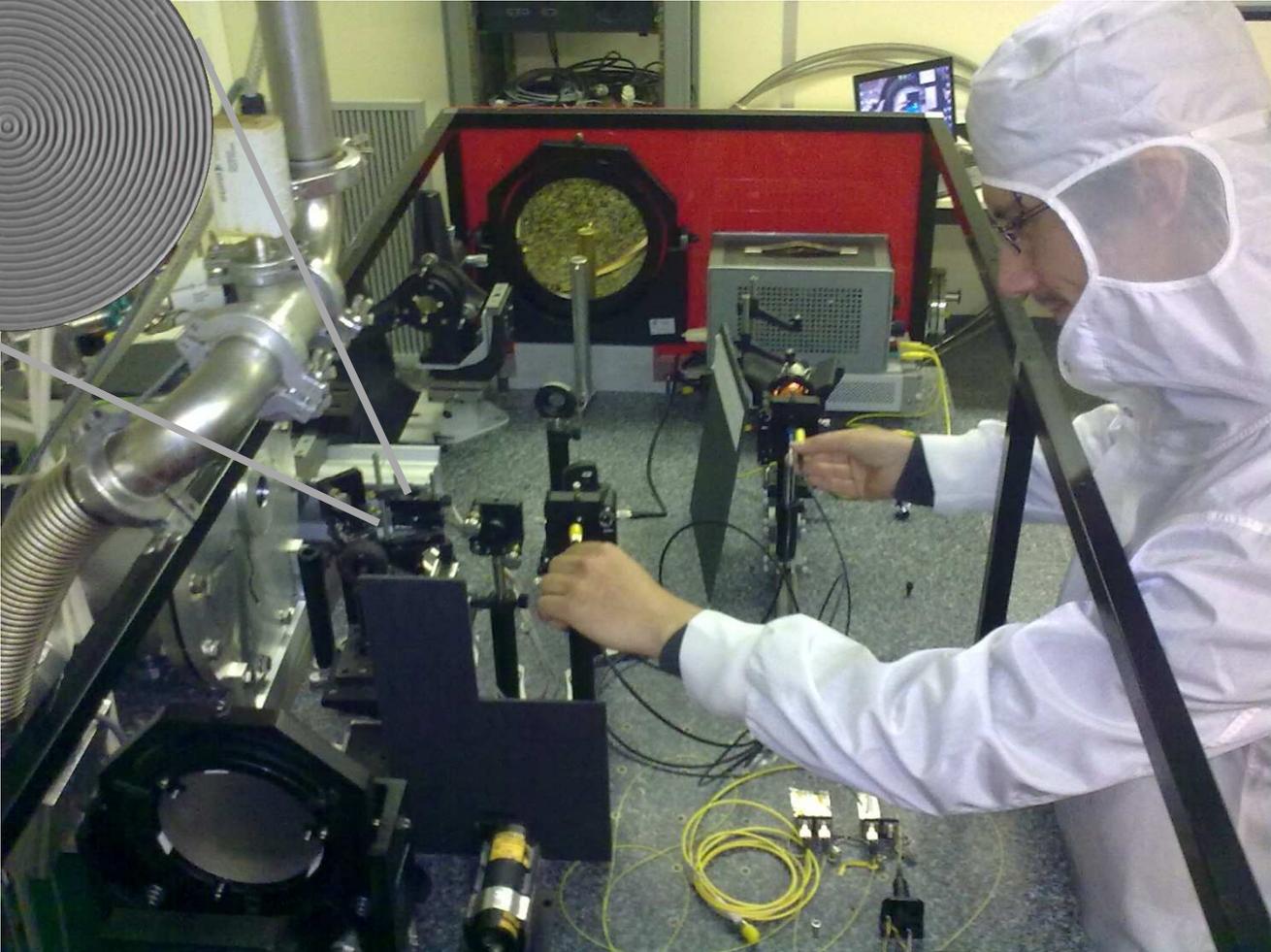
September 2012



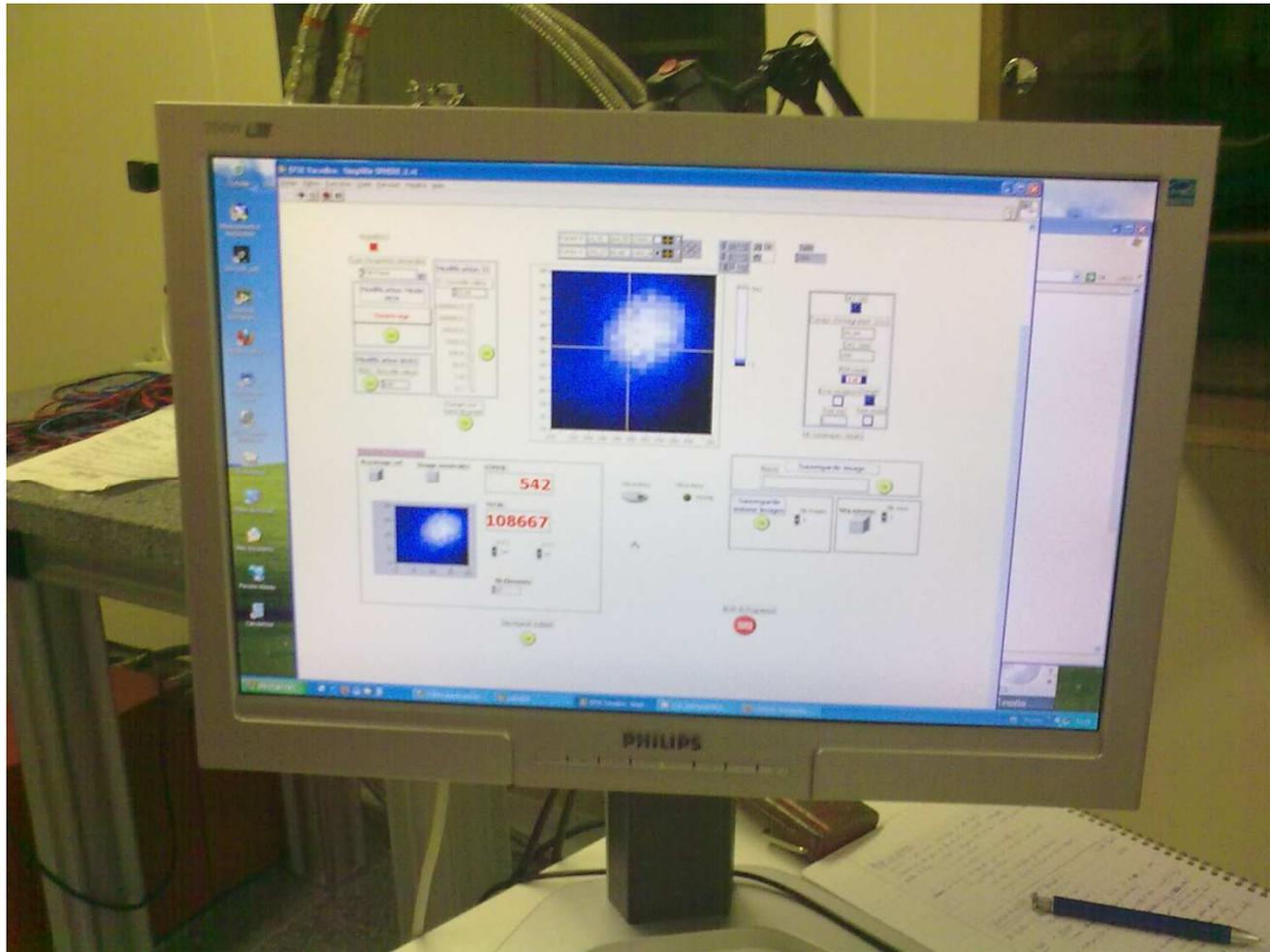
- ☺ Close to optimal design
- ☺ Testbench available in Paris-Meudon

Setting up the bench

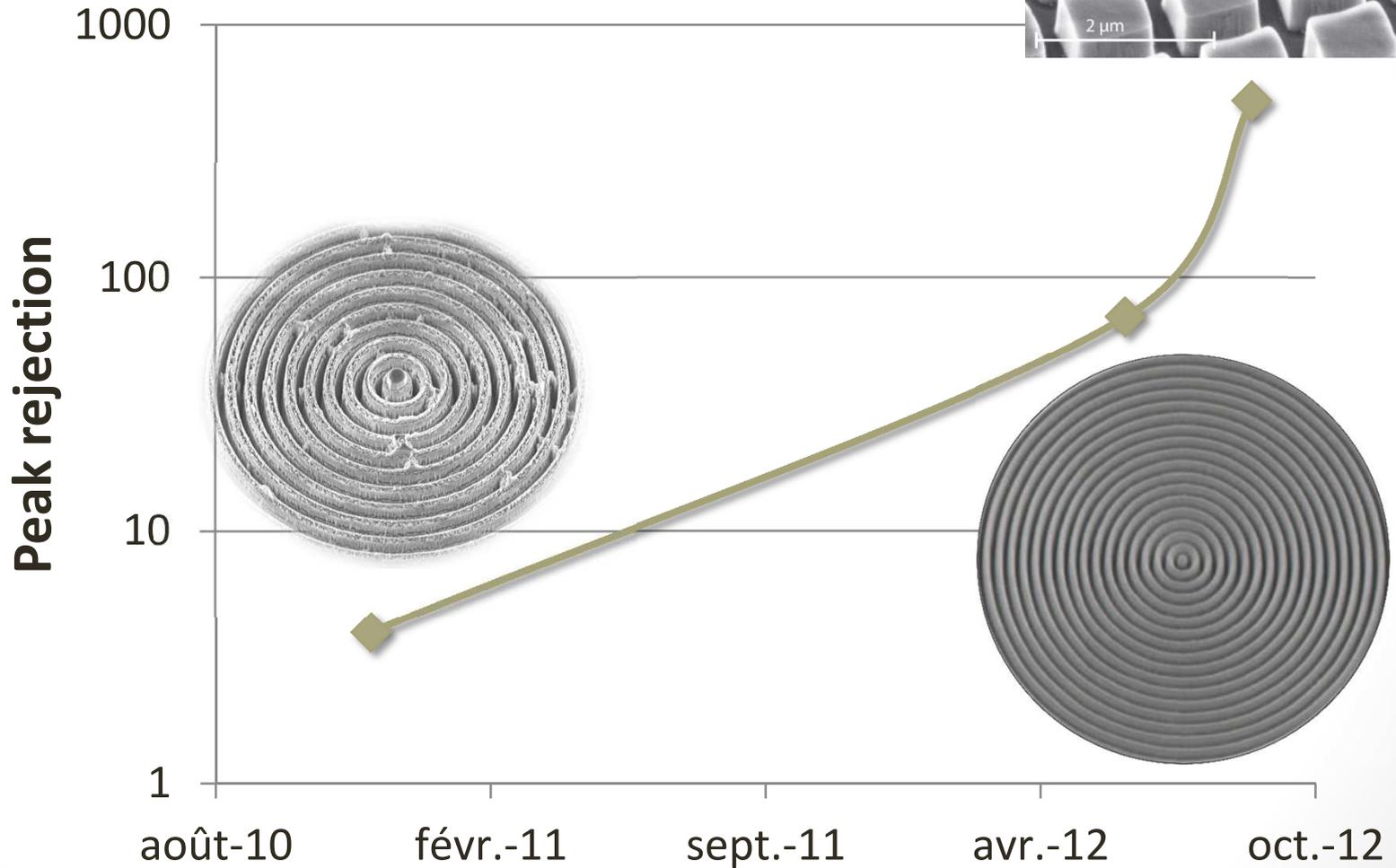
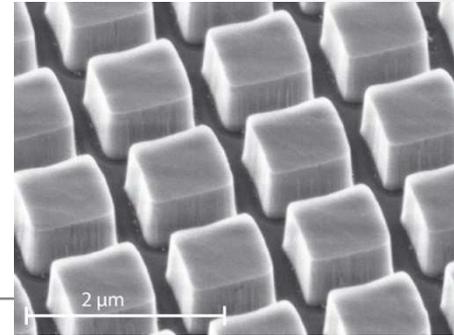
“Yacadire” @ Paris-Meudon



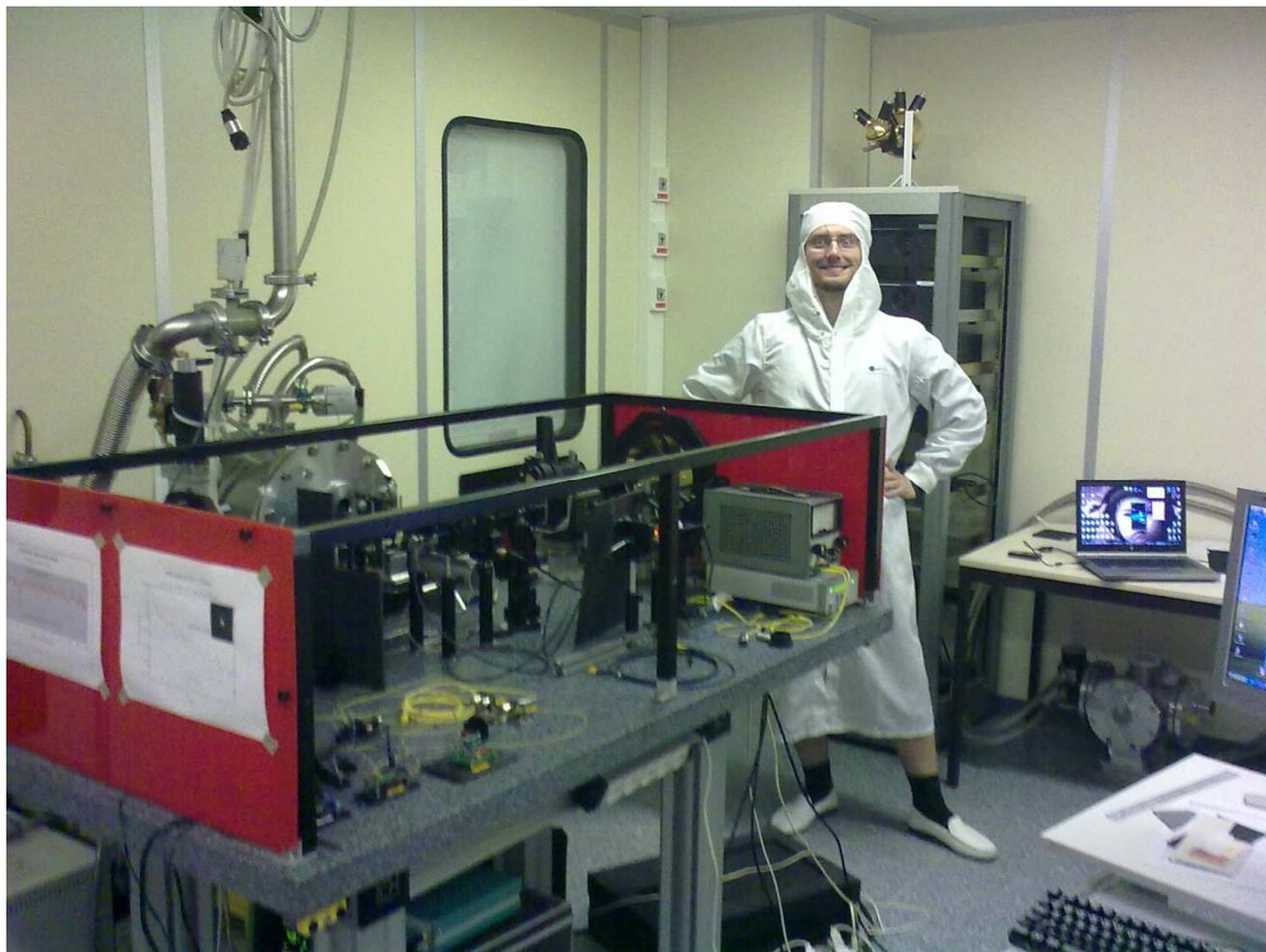
Anguish...



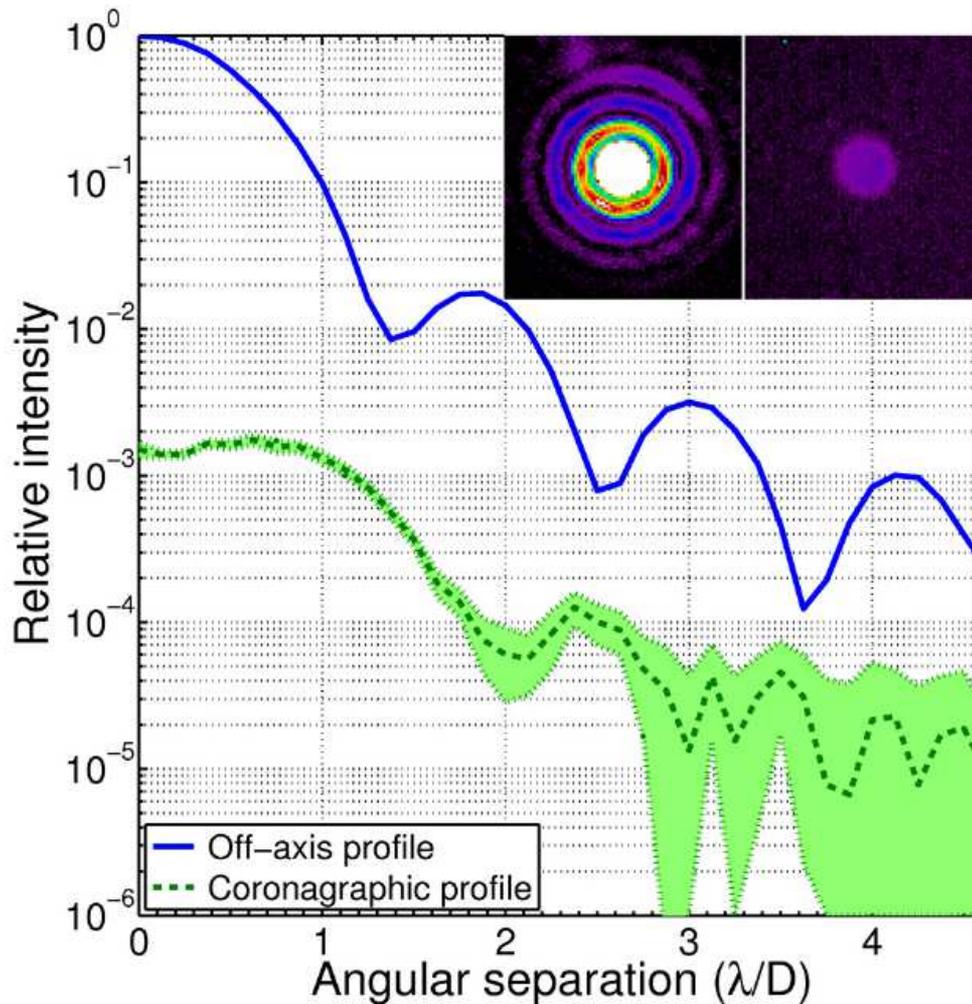
Getting closer...



Bliss!



Outstanding performance

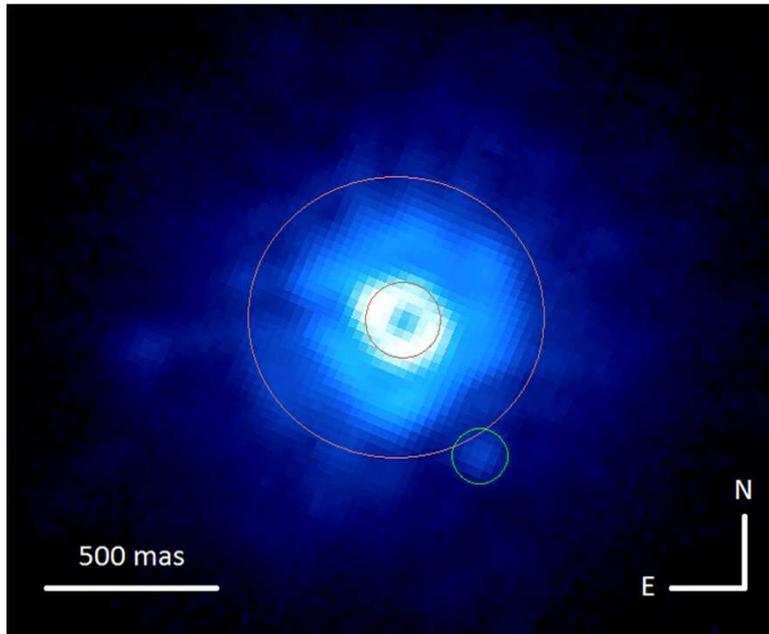


Installation at VLT

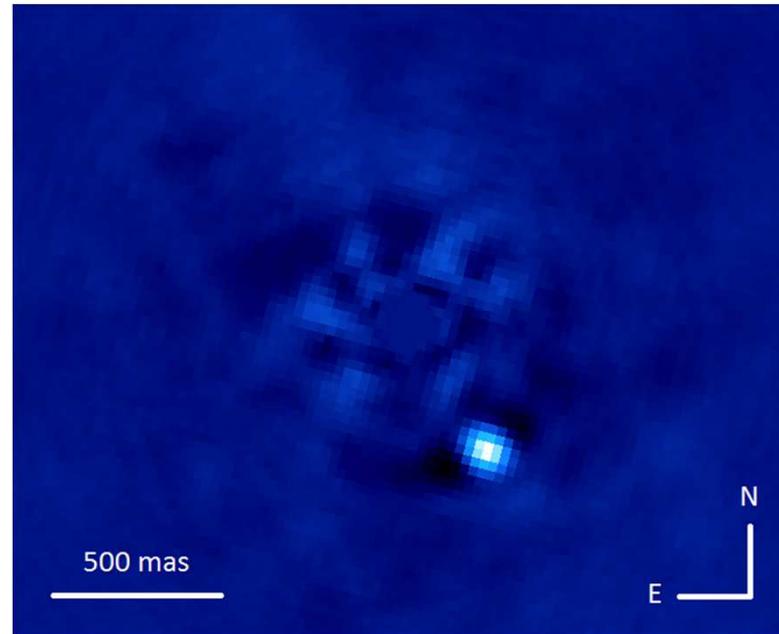


NACO: science demonstration

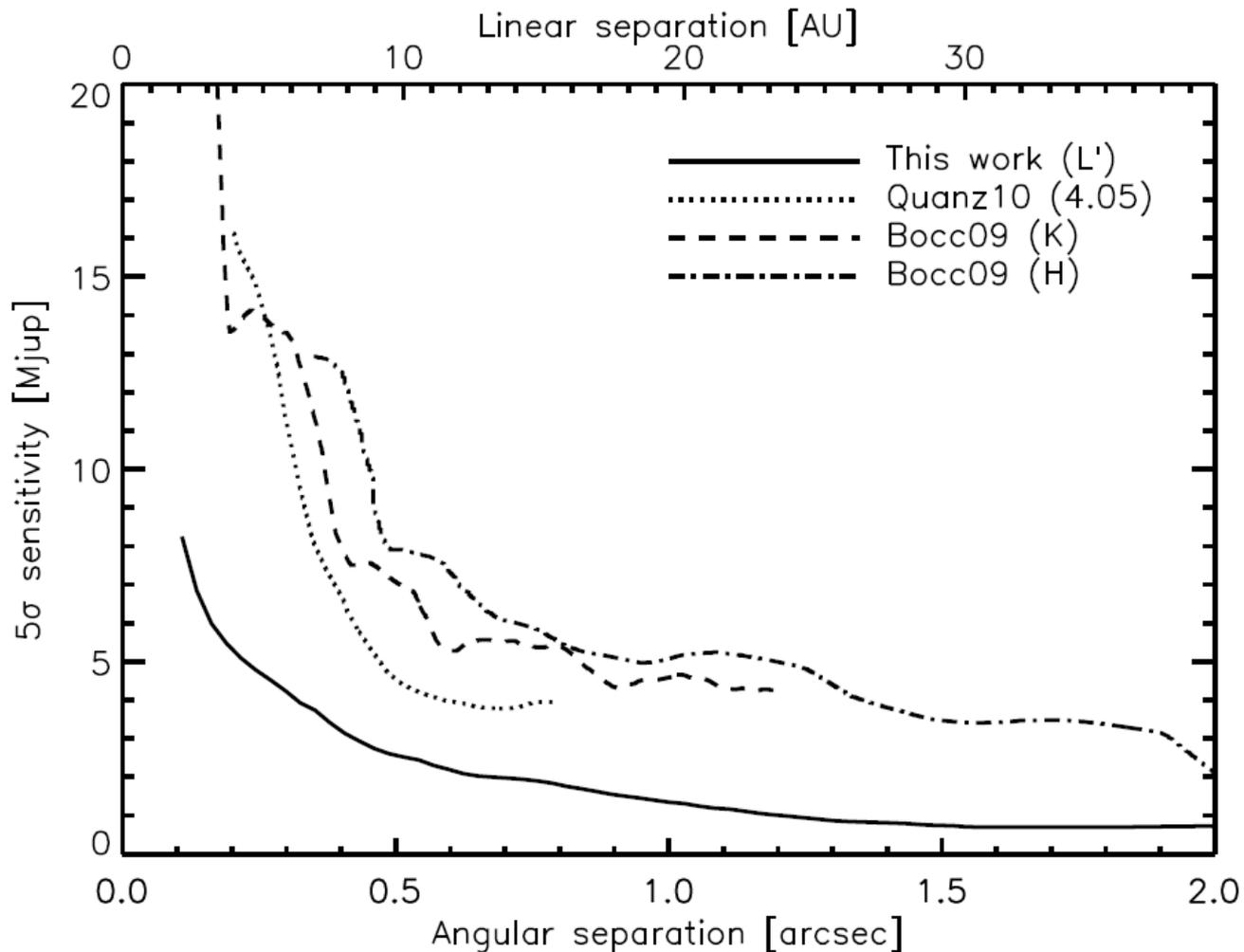
Raw image



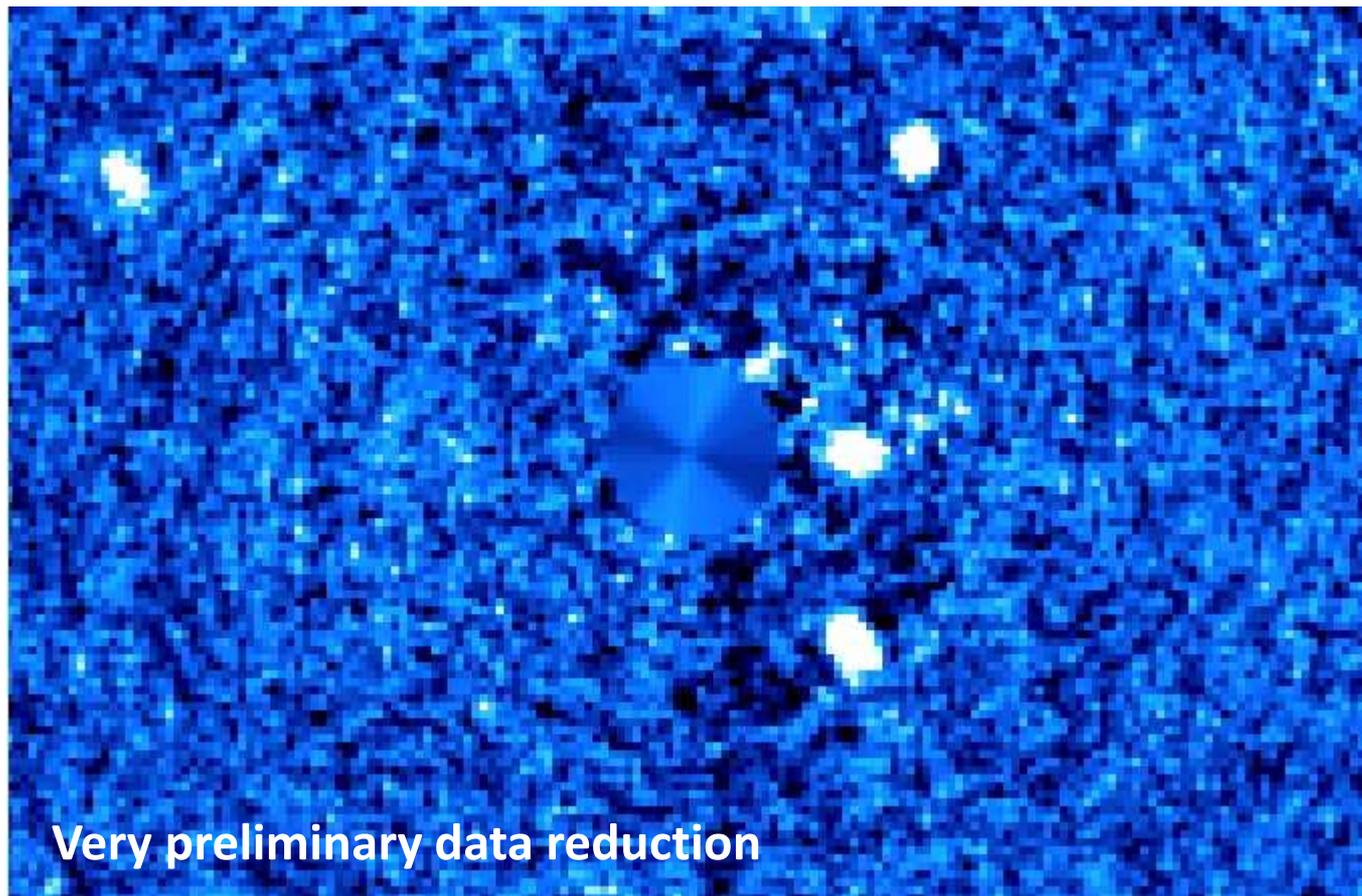
Post-processed image



NACO: sensitivity to planets



October 21st: first light at LBT





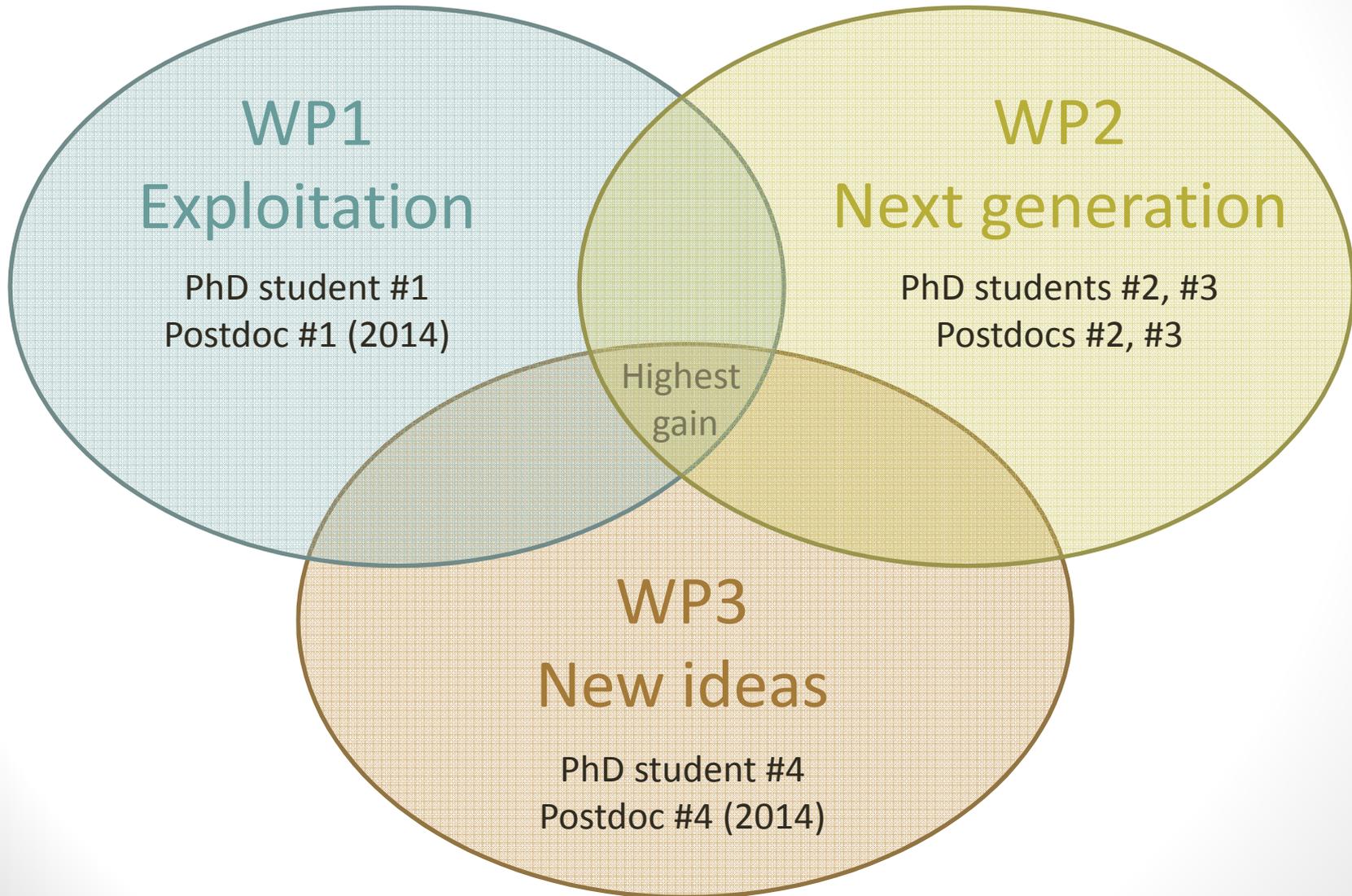
Action de Recherche Concertée (ARC, ULg)
European Research Council Starting Grant (ERC StG)

THE VORTEX PROJECT

The VORTEX project

- **WP1: Exploitation of 1st generation AGPMs**
 - Install, test and optimize AGPMs on world-class telescopes
 - Perform the observations / analyze the data
- **WP2: Development of 2nd generation AGPMs**
 - Better L- and N-band AGPMs
 - Shorter wavelengths (K, H, ... down to $\lambda=1\mu\text{m}$?)
 - Beyond topological charge = 2
- **WP3: Test and validation of new ideas**
 - Exploitation of photon orbital angular momentum (OAM)
 - Post-vortex speckle cancellation techniques
 - Optimal apodization

VORTEX project strategy



The VORTEX team

- **Université de Liège**

- *Coordinator:* O. Absil
- *Academic:* J. Surdej, S. Habraken, M. van Droogenbroeck
- *Postdocs:* 3 (1 hired)
- *PhD students:* 3 (all hired)

- **Uppsala Universitet**

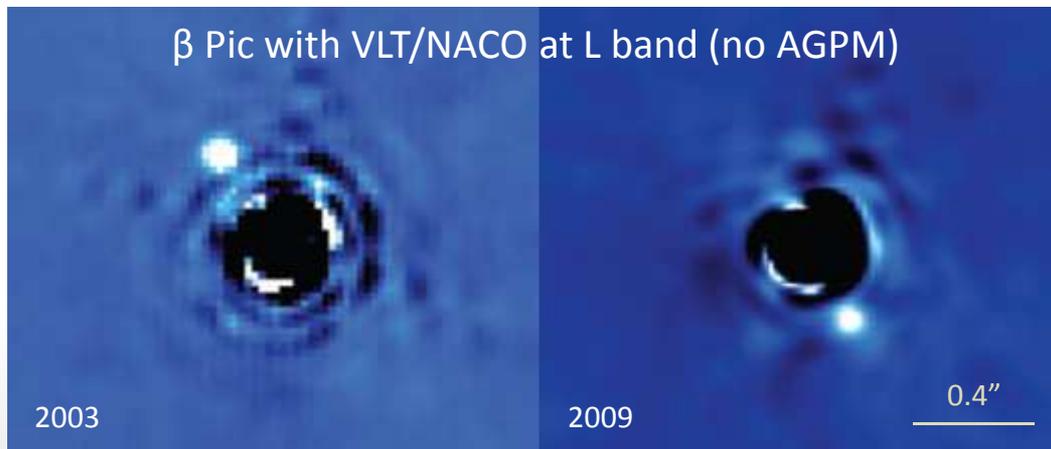
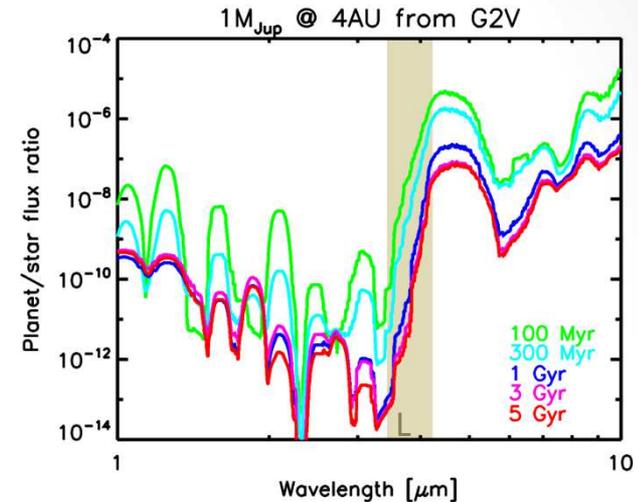
- *Academic:* M. Karlsson
- *Postdoc:* 1 (hired)
- *PhD student:* 1 (hired)

- **Collaborators**

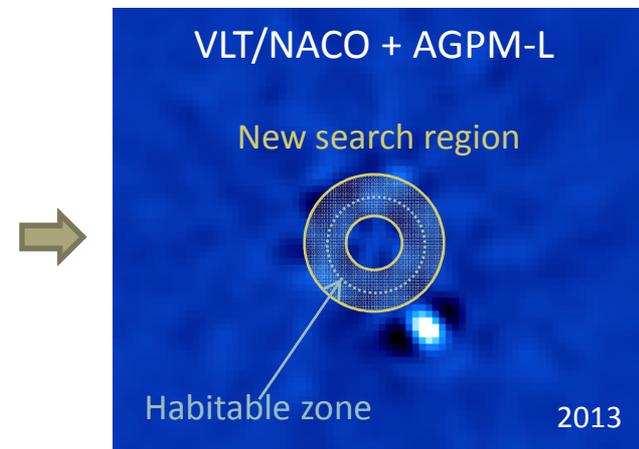
- D. Mawet (ESO), D. Defrère (Arizona), P.A. Absil (Louvain)

WP1: exploitation

- L-band = sweet spot for planet imaging
- Access to new parameter space → surveys
- Complementary to near-IR imagers → characterization



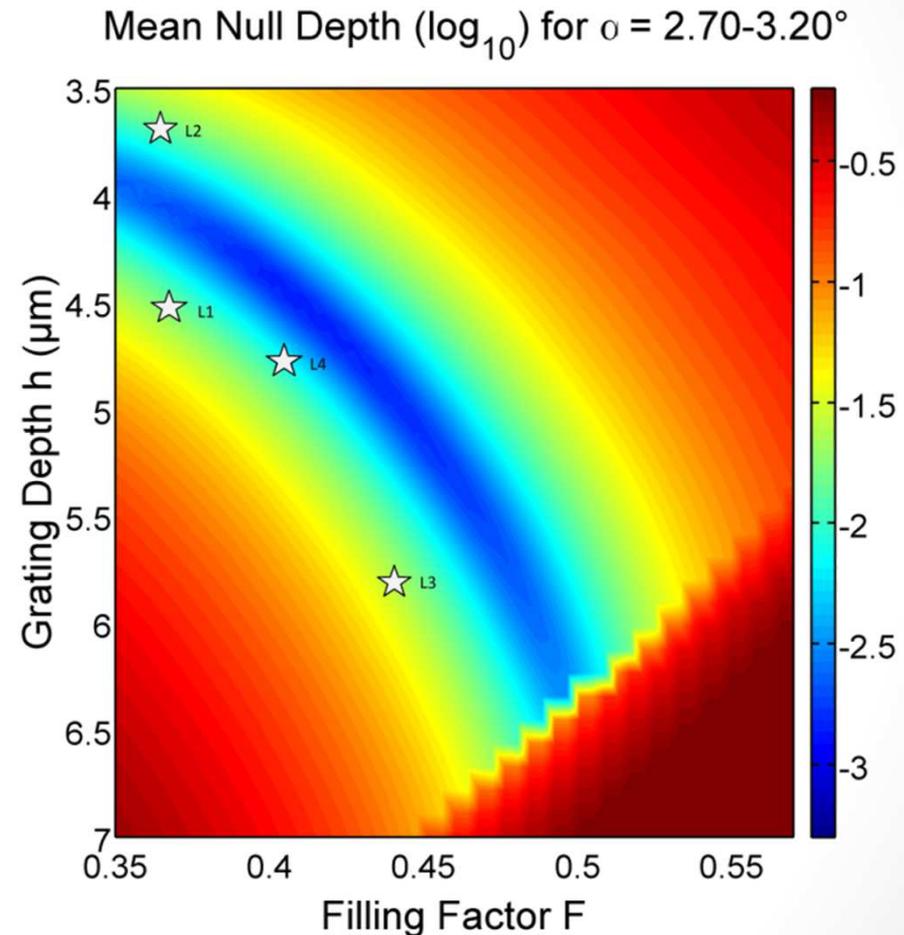
Lagrange et al. 2010 (discovery paper)



Absil et al. (in press)

WP2: mid-infrared AGPMs

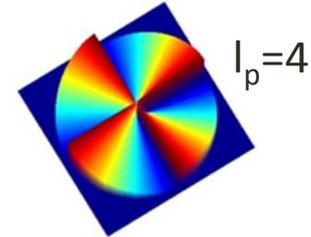
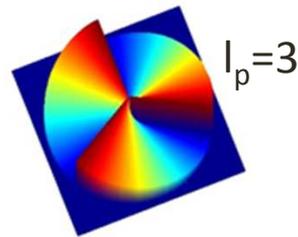
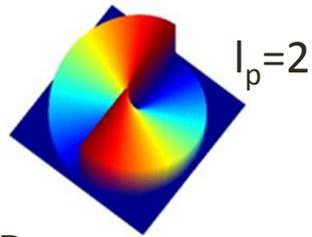
- Improvement of the grating parameters
- Improved anti-reflective solutions
- Goal: EELT/METIS
 - $R > 1000$ over full L, M and N bands



WP2: shorter wavelengths

- Goal: cover near-infrared window (1 – 2.5 μm)
 - More a technology challenge than a design issue
- Goal 1: installation on VLT/SPHERE by 2016
- Goal 2: prepare for E-ELT
 - 1st light infrared camera (MICADO)
 - Dedicated high contrast imaging camera (PCS)
 - May require higher topological charges
- Goal 3: space applications

WP2: High topological charges

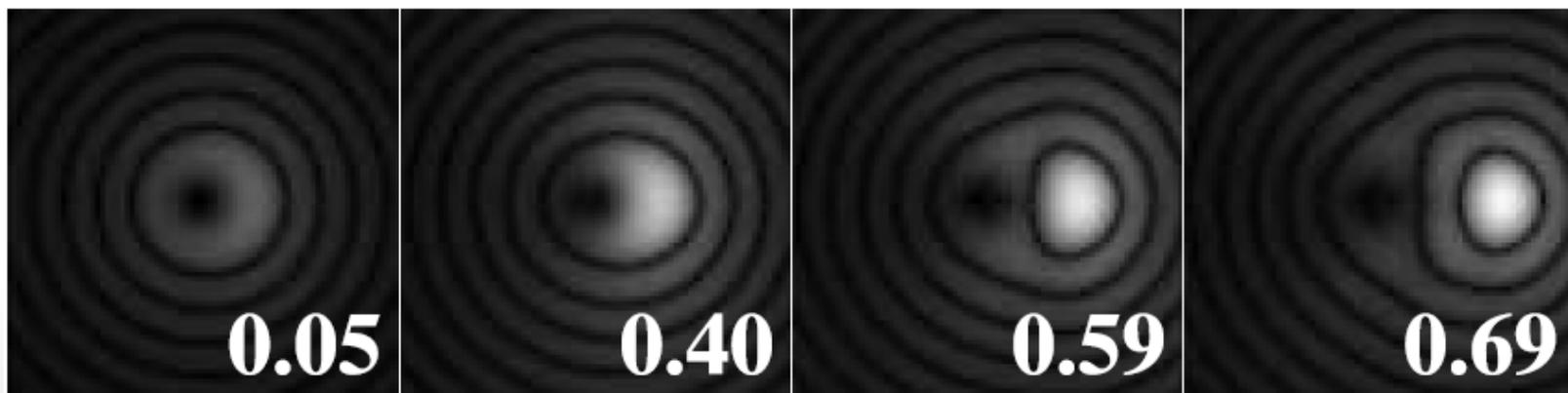
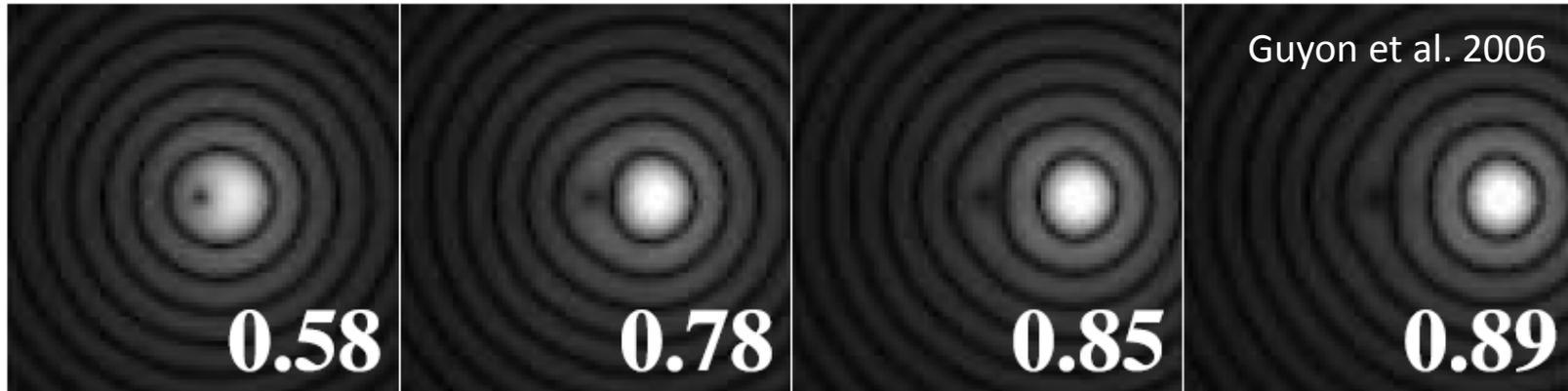


$1\lambda/D$

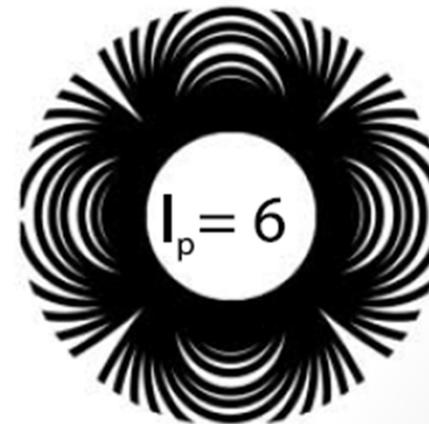
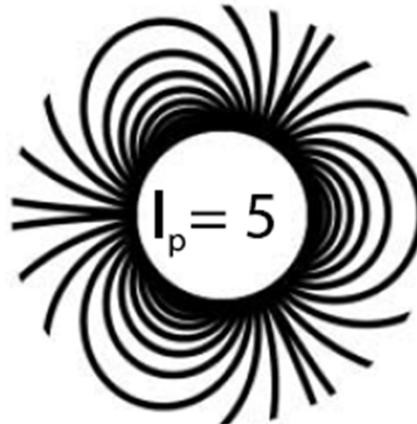
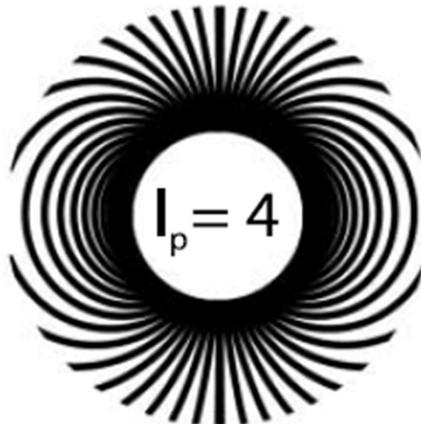
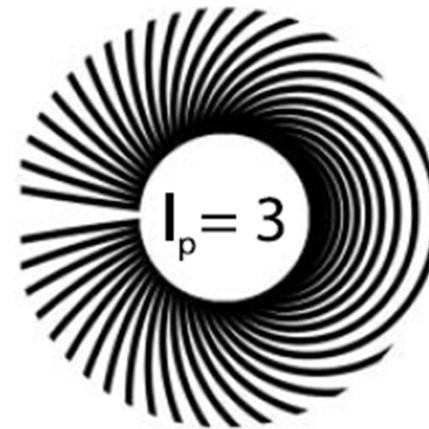
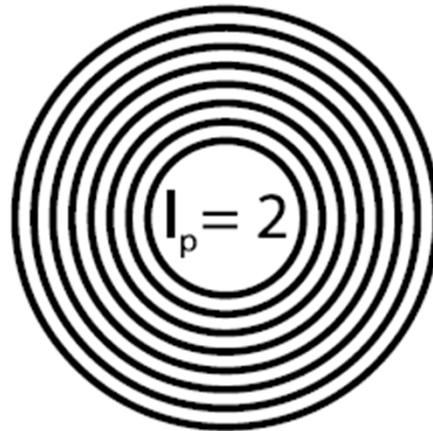
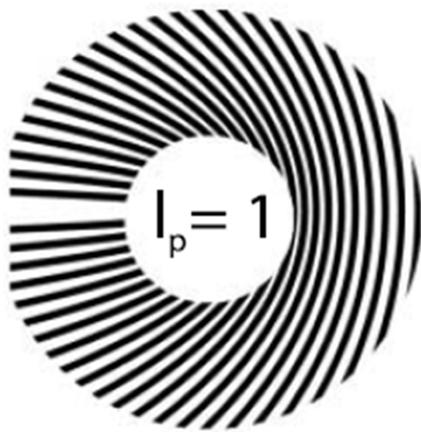
$2\lambda/D$

$3\lambda/D$

$4\lambda/D$



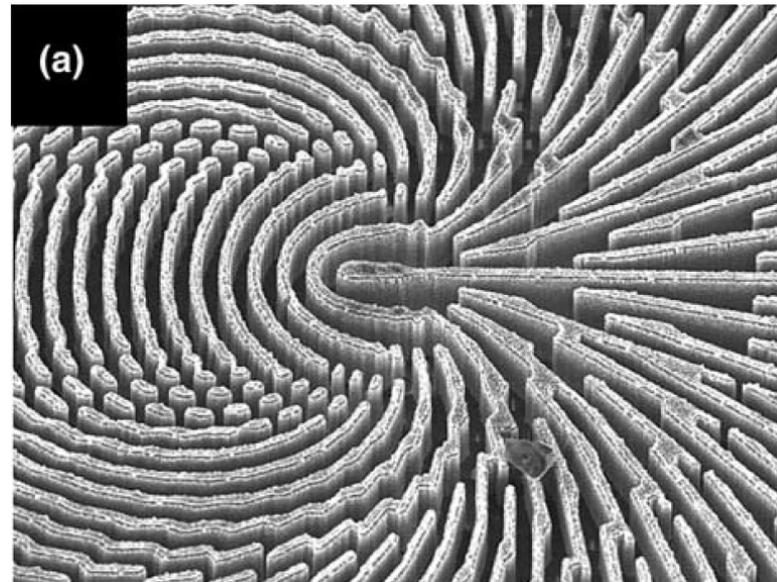
“AGPMs” with various l_p



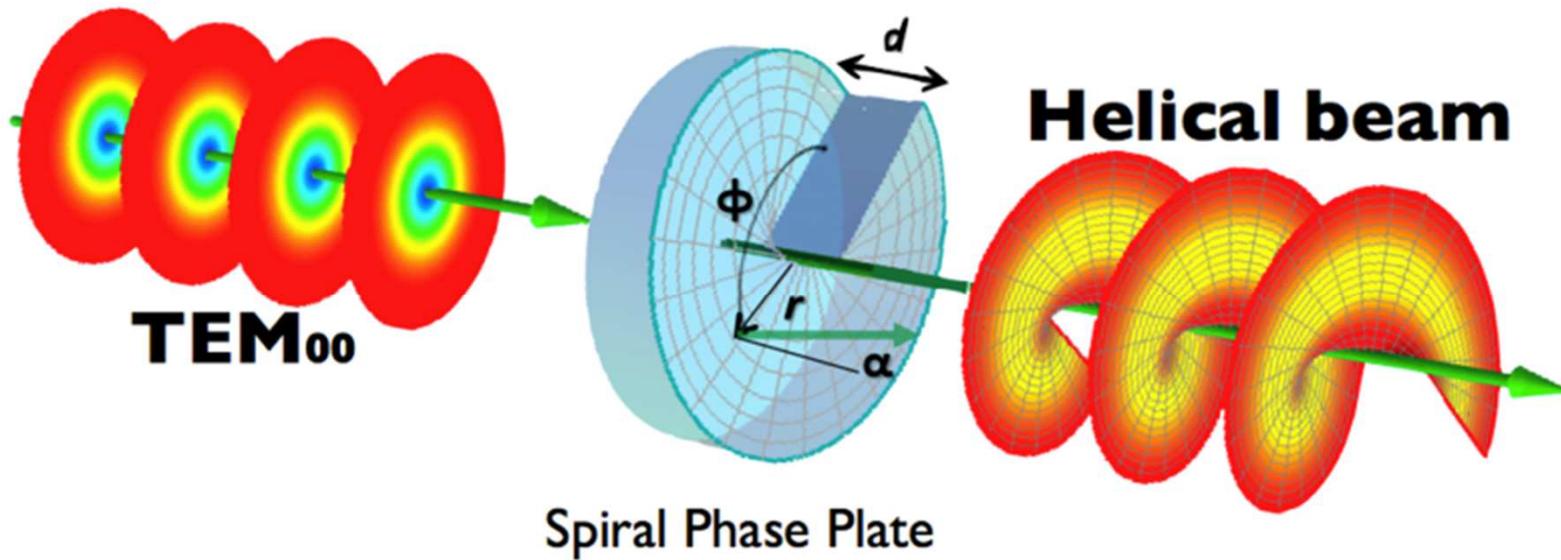
New challenges

- Discretization of the grating seems mandatory
 - Require new 2D modeling tools
- Pioneered by Technion (Israel) for mid-IR applications
 - Adaptation to diamond not straightforward

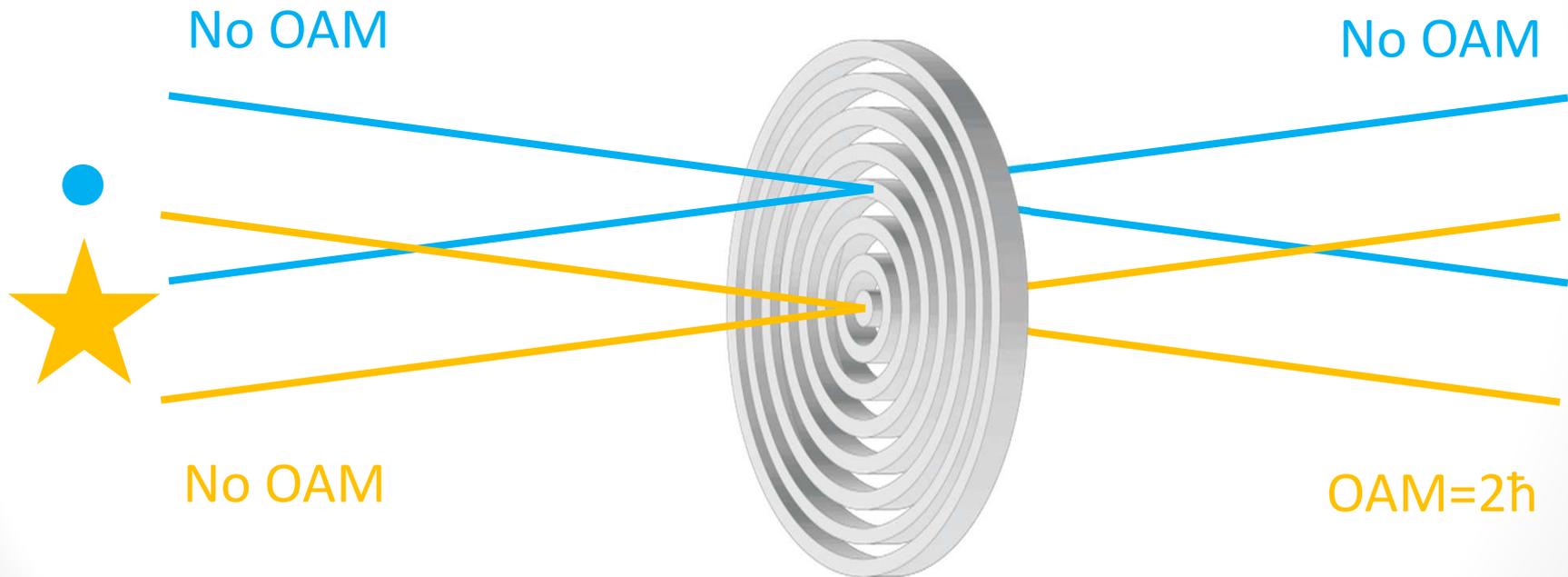
Niv et al. 2006



WP3: Orbital angular momentum

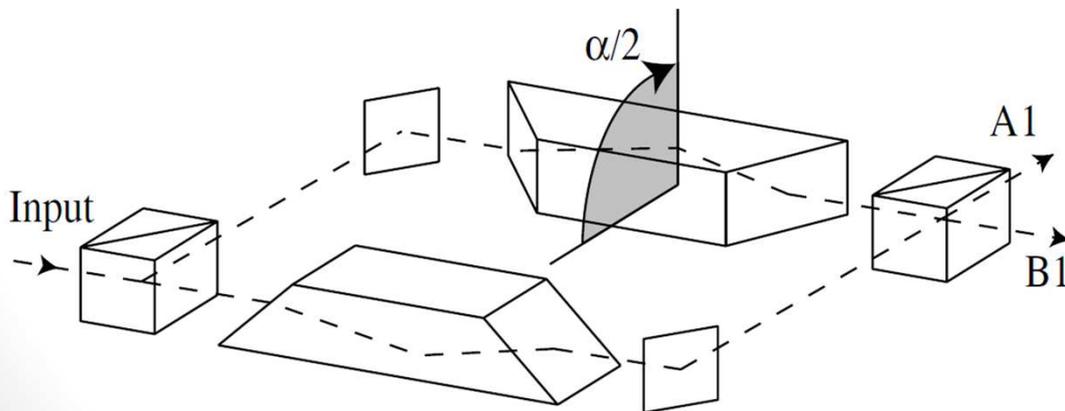


AGPM in convergent beam?



Photon sorting based on OAM

- Beam rotation \rightarrow phase shift
- Separate OAMs with constructive and destructive interferences
 - Isolate planetary signal!



l	$\exp(il\phi)$	$\exp(il(\phi+\pi))$	$\Delta\psi$
0			0
1			π
2			0
3			π
4			0

Long-term goal

