Next-generation phase-mask coronagraphy for extrasolar planetary system imaging

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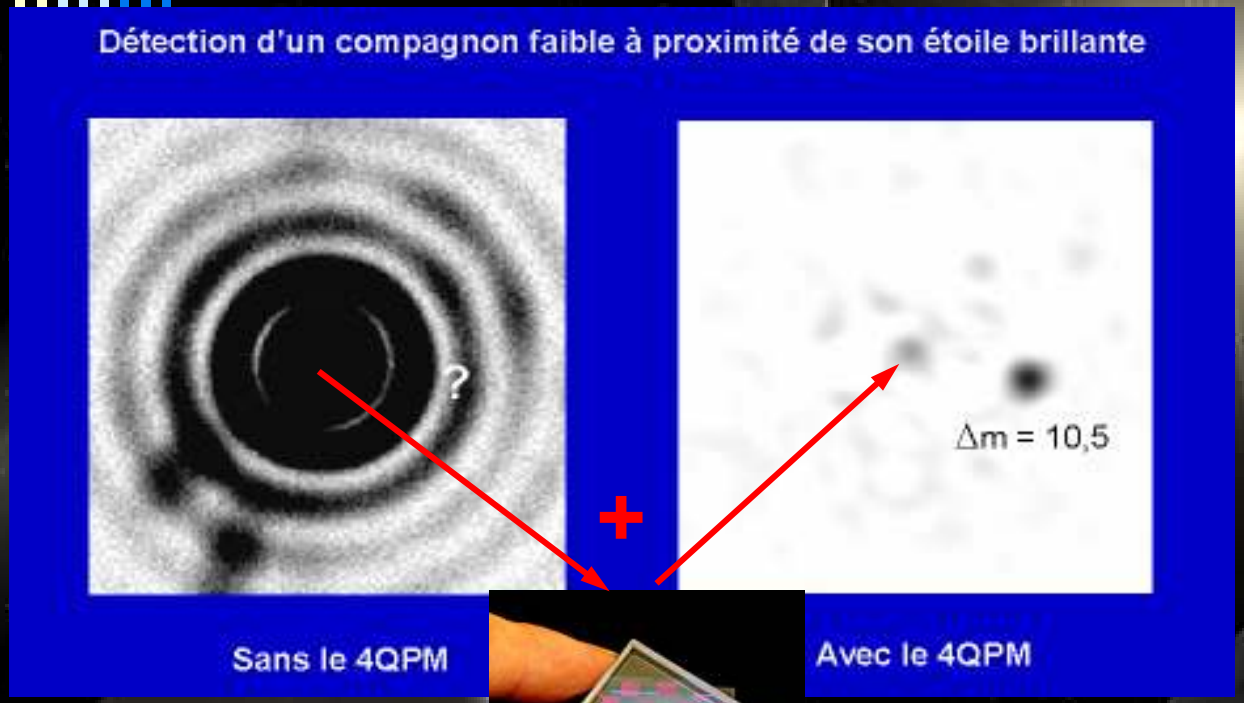
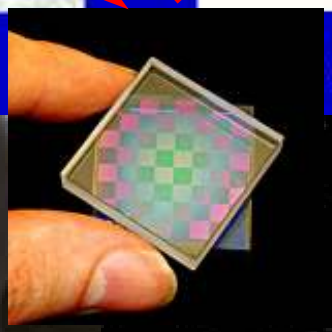
ROB March 2007

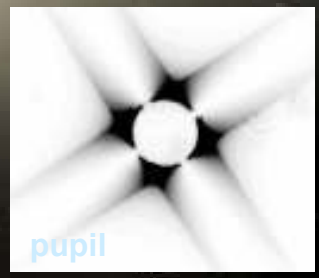
Coronagraphy

- So far, opaque/amplitude masks (Lyot coronagraphs)
  - Mask the star (annoying for companionship analysis)
  - Mask the objects behind it (up to 6 λ/D)
- Phase mask coronagraphs (transparent)
  - FQPM much more efficient but still not perfect
  - Achromatization
  - FQPM discovery space affected by quadrant transitions (loss of 20 % at 5 λ/D)
  - Transitions creates artefacts in extended objects studies

Four Quadrant Phase Mask





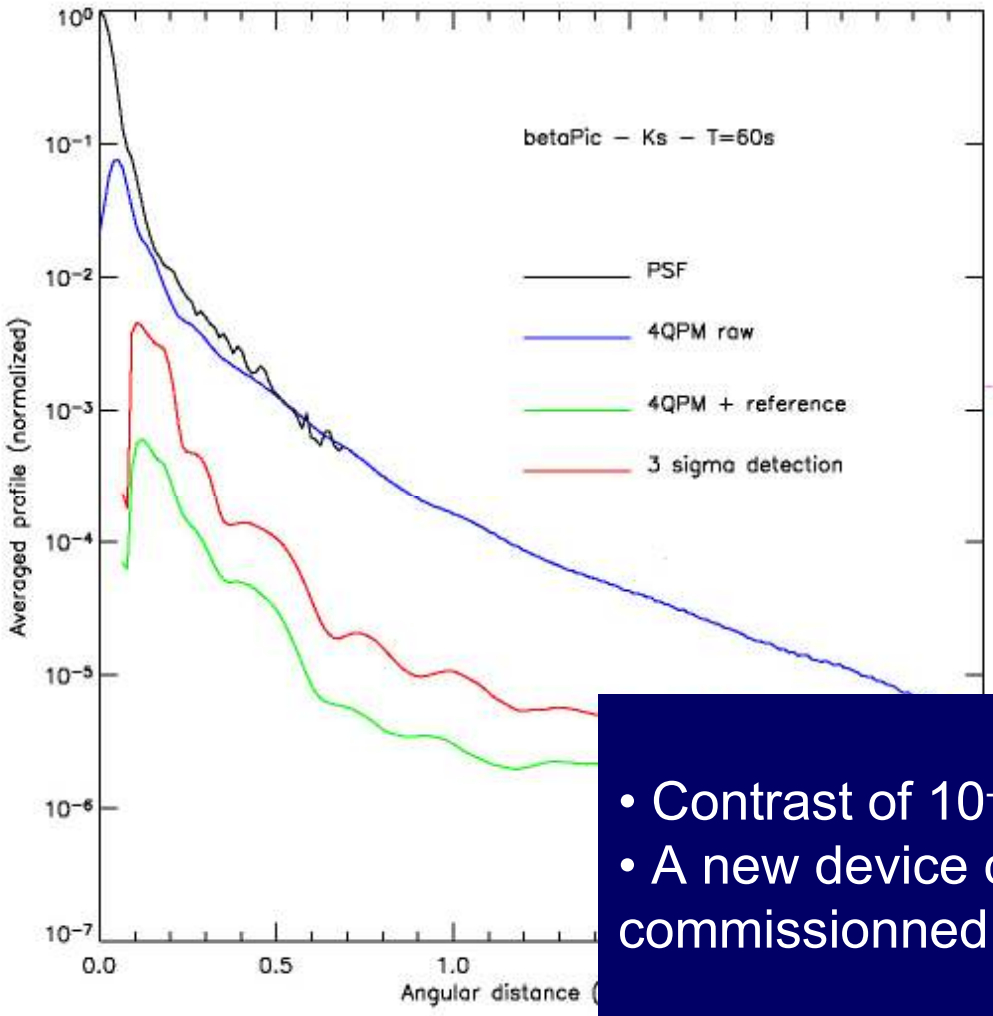


Rouan et al., 2000, PASP ;
Riaud et al., 2001, PASP ; Riaud et al. 2003, PASP

manufactured and characterized for :

- Visible (laboratory R&D)
- Near IR (implemented on NACO/VLT)
- For mid IR (JWST/MIRI project)
- Near IR achromatic version (VLT/SPHERE project)

FQPM @ VLT

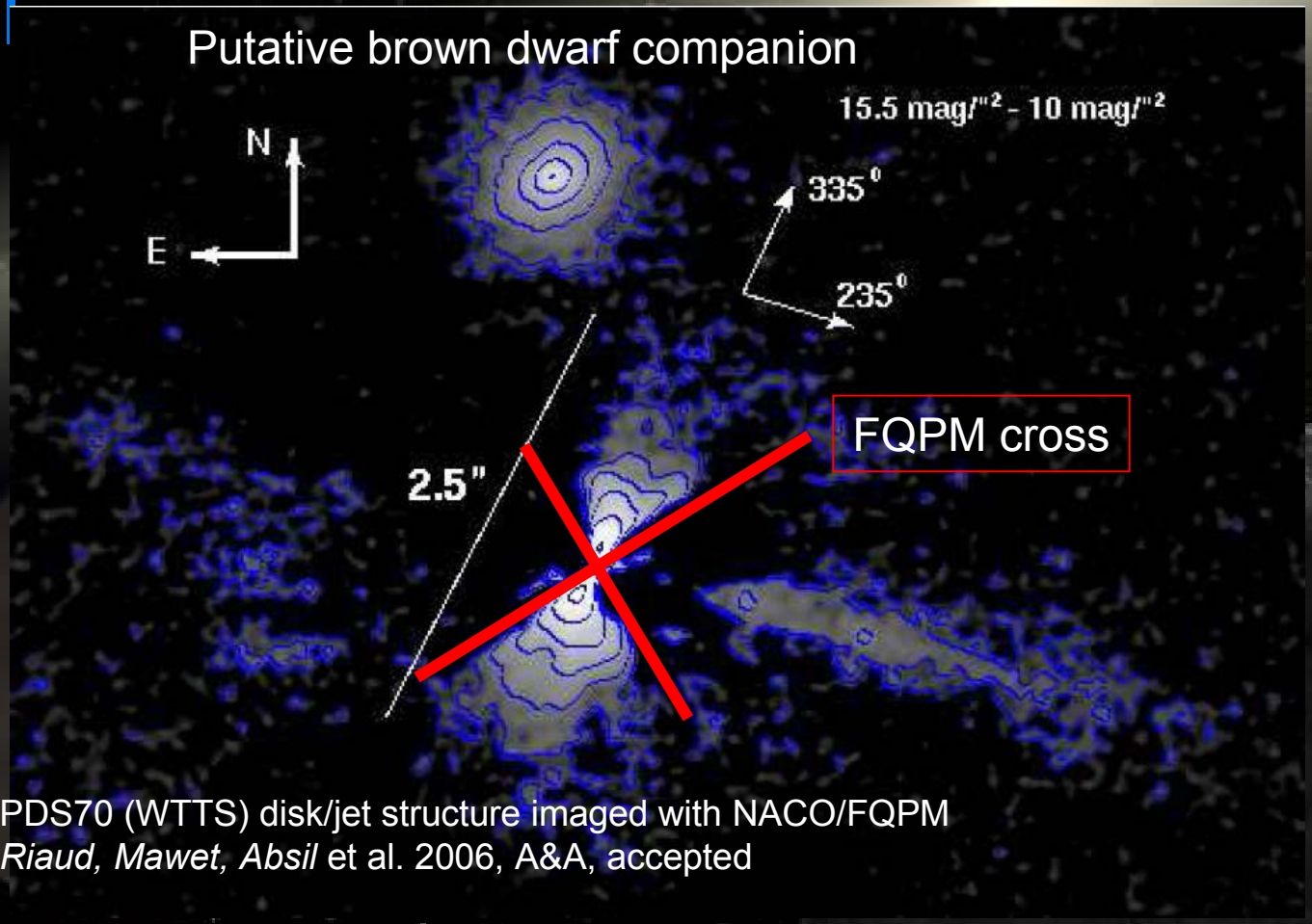


HIP 1306
ρ = 0.128'' - 1.075''
Δm = 1 .6 - 3.5mag
seeing = 0.9''

- Contrast of 10^{-4} @ 0.5 ''
- A new device coupled with differential imaging was commissionned last month

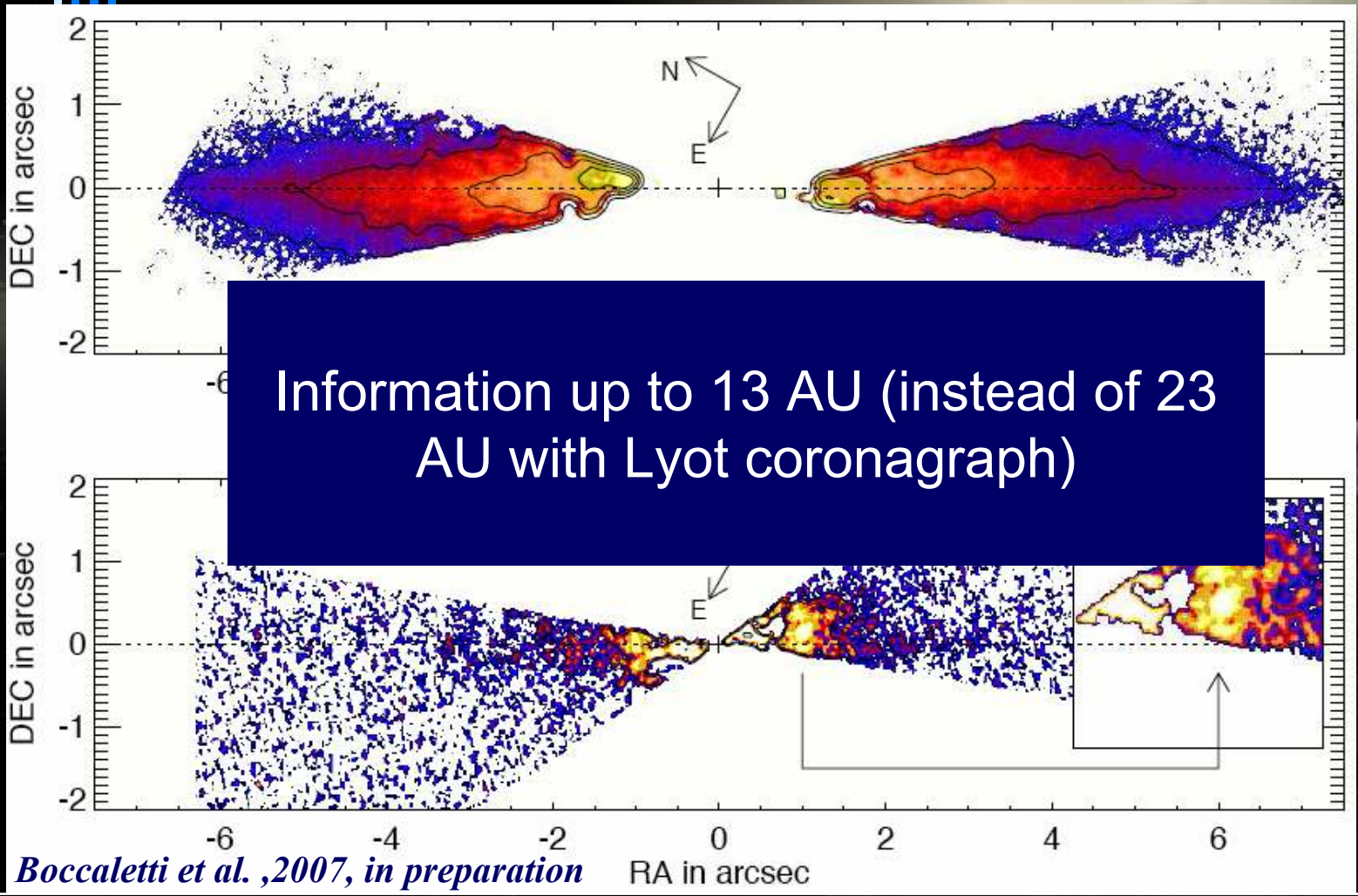
Boccaletti et al. ,2004, PASP ; Boccaletti et al. ,2007, in prepara

NACO / FQPM imaging I



PDS70 (WTTS) disk/jet structure imaged with NACO/FQPM
Riaud, Mawet, Absil et al. 2006, A&A, accepted

NACO / FQPM imaging II



Information up to 13 AU (instead of 23 AU with Lyot coronagraph)

Boccaletti et al. ,2007, in preparation

Achromatic FQPM with halfwave plates: laboratory results

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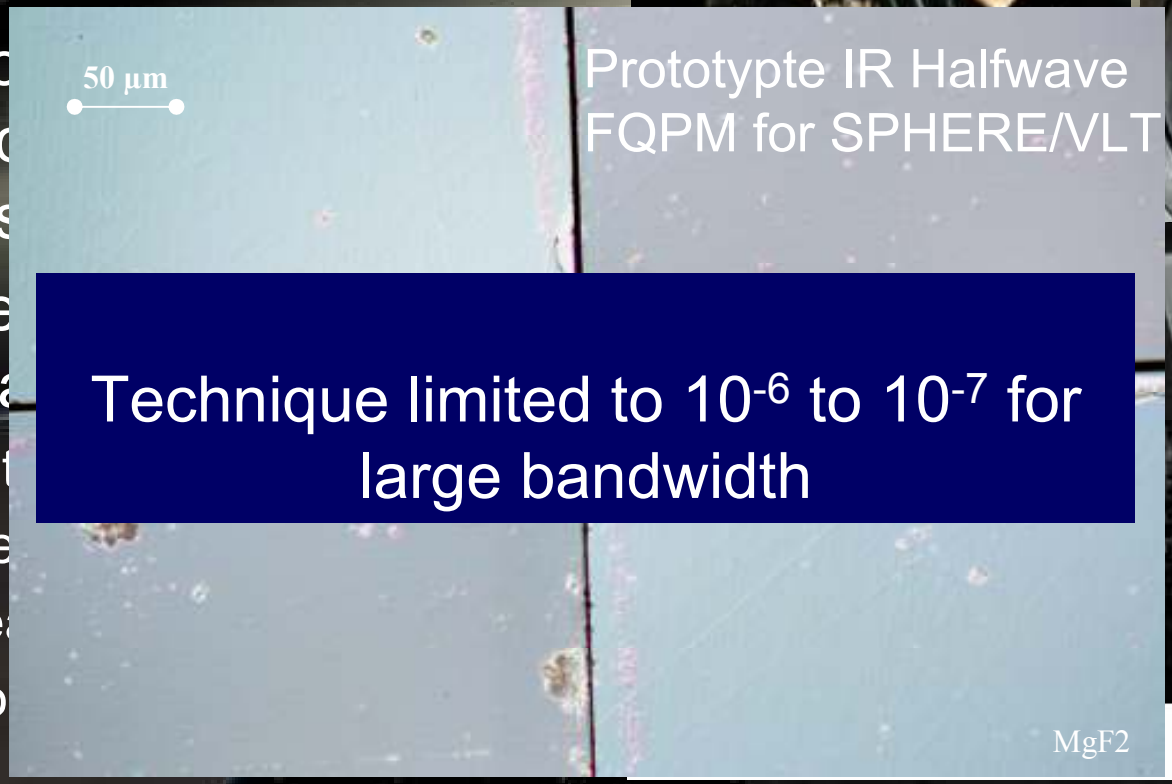
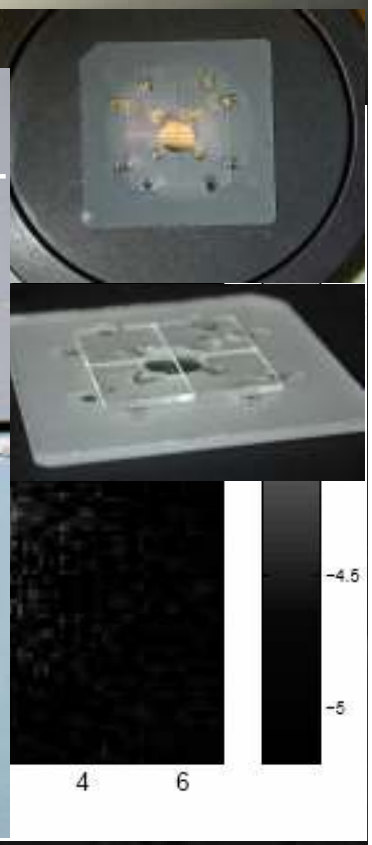


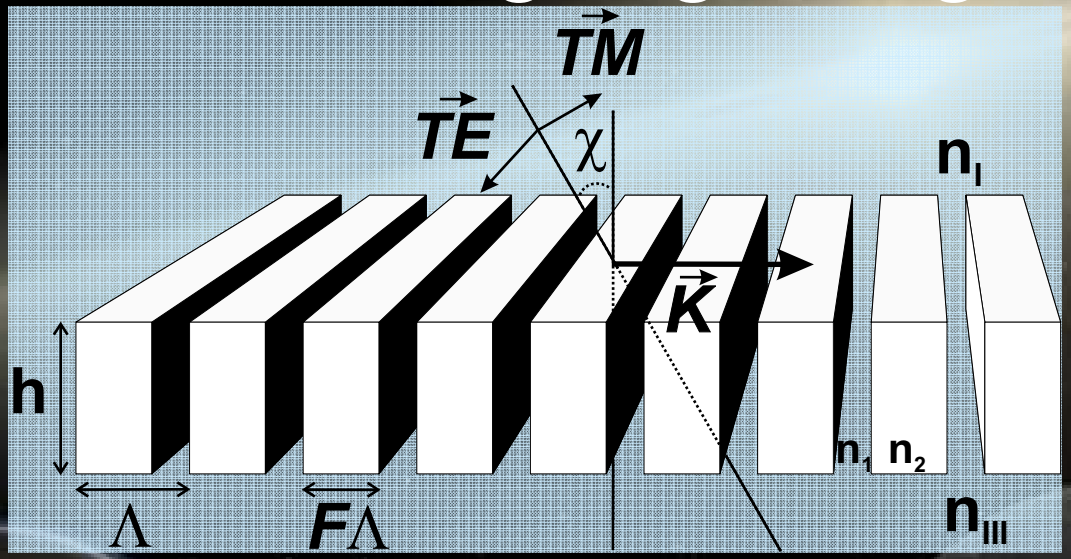
Prototypte IR Halfwave FQPM for SPHERE/VLT

Technique limited to 10^{-6} to 10^{-7} for large bandwidth



Mawet D. et al, A&A 448

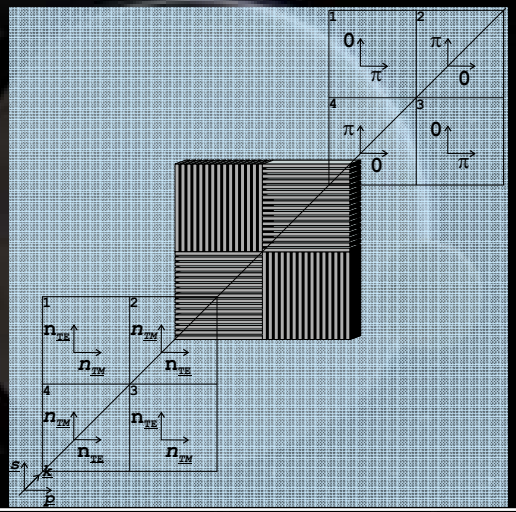
Subwavelength gratings



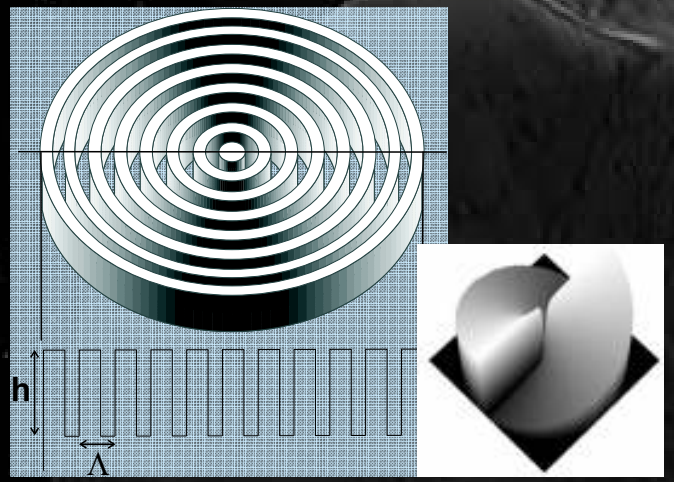
- Subwavelength gratings / Zeroth Order Gratings are artificially birefringent
- The effective indices, associated to the polarization states TE and TM, can be tuned by controlling the geometry at the nanometer scale (period, filling factor)
- The subsequent phase shift can be made quasi- achromatic

Coronagraphic implementation

- 4QZOG: Mawet *et al.* 2005, Appl. Opt. 44, 34, 7313
- An anti-symmetrical implementation of 4 identical ZOGs can mimic the FQPM focal plane phase shift distribution
- Monolithic structure
  (engraved on a unique substrate)



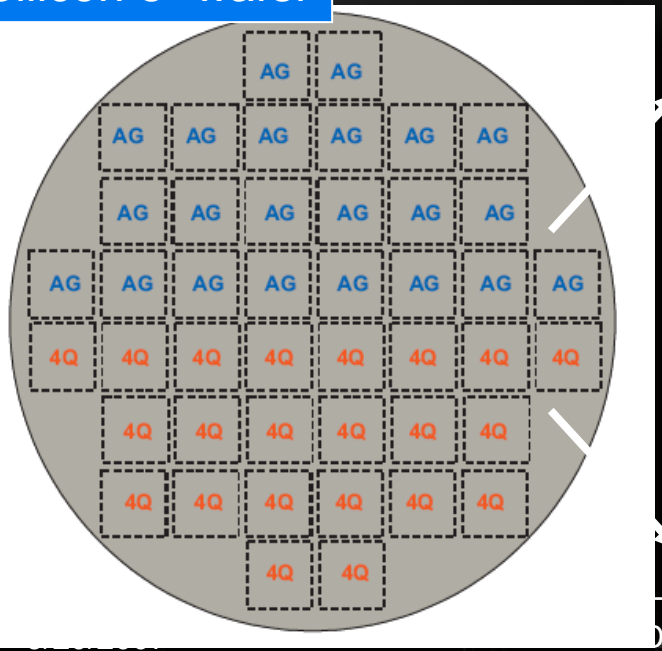
- AGPM (Mawet *et al.* 2005, ApJ 633, 1191)
  Annular Groove Phase Mask Coronagraph
- AGPM creates a second order *Optical Vortex* (= phase singularity)
- Prevent the source attenuation on the quadrant transitions
- Chromatic behavior as good as the 4QZOG (same optimized ZOG)



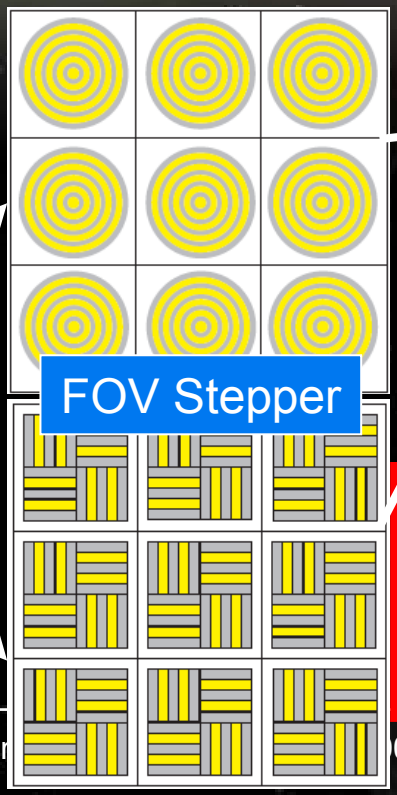
4QZOG & AGPM Prototyping

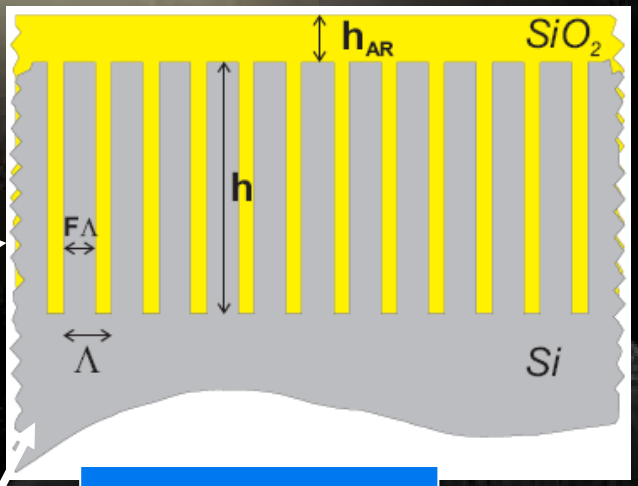
- Collaboration Belgium-France:
  - ULg/LESIA/LAOG/CEA-LETI
  - Micro-electronics Silicon technology

Silicon 8” wafer



FOV Stepper



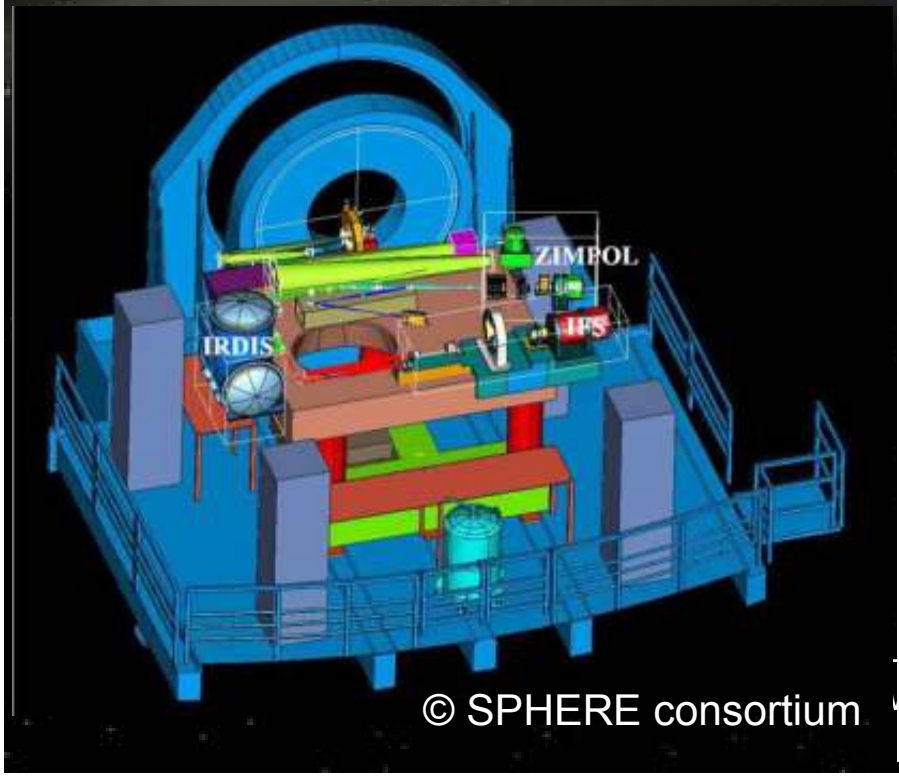


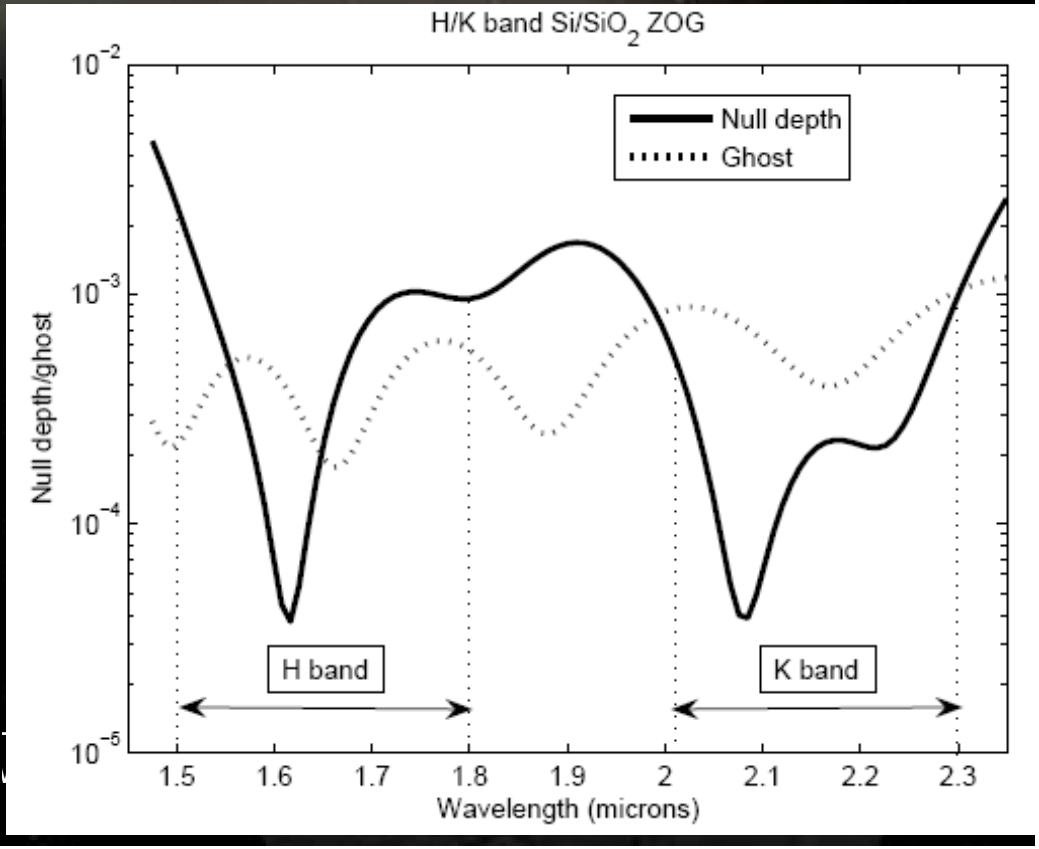
ZOG geometry

Parameters	Value
Grating period Λ	0.402 μm
Grating depth/thickness h	2.1973 μm
Grating filling Factor F	80%
SiO_2 AR layer thickness h_{AR}	280 nm

SPHERE

- *VLT-Planet Finder/SPHERE :*
  - Second generation instrument for the VLT
  - Extreme Adaptive Optics system (41x41 actuators, 90% Strehl at H)
  - Detection and characterization of young hot Jupiter 1-10 M_J
  - 3 instruments + coronagraphs





Conclusion

- Phase-mask coronagraphy provide very small Inner Working Angles and high contrasts ;
- They advantageously replace classical amplitude Lyot coronagraphs ;
- Have already allowed state-of-the-art high contrast imaging Science at the VLT ;
- Subwavelength gratings metamaterial synthesis ability will be used in the near-future to further improve their performance.

Perspectives

- VLT-PF/SPHERE
- Palomar/Keck WCS
  - Extreme AO before time
- Super Earth Explorer-COAST
  - will be proposed to ESA's Cosmic Vision
- TPF-C and precursor missions.