Direct exoplanet imaging with small-angle \textsc{vortex} coronagraphs

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Which planets?
The birth of a concept

- FQPM → sub-wavelength gratings → Annular Groove PM

- Advantages of the AGPM
  - Inner working angle ≈ 1 λ/D
  - Clear 360° discovery space
  - Achromatic (SG design)
  - Easy to implement

Pathways to habitable planets II, July 2015, Bern
Grating design/optimization

L band. Period = 1.42 μm, angle = 3.00°
Etching on synthetic diamond

• Inductively coupled plasma etching
  o N band (grating period = 4.6 µm)
  o L band (grating period = 1.4 µm)

• Parameters close to optimal ... need to test!
Setting up the bench

“Yacadire” @ Paris-Meudon
High performance

L band

Peak rejection


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Installation at VLT, LBT, and Keck
Installation at VLT, LBT, and Keck

Don’t break a priceless device
Scientific exploitation

Skemer et al. 2014

- $1600\,\text{K}$ (Beta Pic b)
- $1000\,\text{K}$ (HR 8799 cde)
- $700\,\text{K}$ (max T for cold-start)
- $400\,\text{K}$ (max T at 5 Gyr)
- $130\,\text{K}$ (Jupiter)
NACO: science demonstration

Raw image of β Pic

Post-processed image

Peak rejection ~ 50:1

Absil et al. 2013

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Sensitivity to inner planets

Absil et al. 2013 & Mawet et al. 2014

β Pic b

New discovery space
The $\beta$ Pic disk at L band

- Warped, inner component
  - Disk detected down to 10 AU (0.4")
- Spine offset and bowed (anisotropic scattering)

Milli et al. 2014
VISIR: science demonstration

HD139063, NB-4QPM1 10.65\,um

Normalized PSF radial profile

- Off-axis PSF
- Attenuated PSF, $R=21.2$; seeing=0.72\arcsec

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First light with LBT/LMIRCam

Peak rejection ~35:1 (far from optimal)

Defrère et al. 2014
First light with LBT/LMIRCam

Defrère et al. 2014
First light with Keck/NIRC2

~50:1 peak starlight rejection, limited by AO correction, and Keck pupil obscuration
Prospects

• Extension to shorter wavelengths (first K-band components recently etched)

• Extension to higher topological charges (trade some IWA for better resilience to pointing jitter)

• Combine the vortex with pupil-plane apodization (phase and/or amplitude)

• M-dwarf survey

• Protoplanets in transition disks

• Characterize new planets found by SPHERE and GPI
Charge-4 vortices for ELTs

Charge-4 vortex

transmission

charge-2

charge-4

off-axis angle

a) Construction with straight lines
15 periods on x-axis 60 periods on x-axis

b) Construction with curved lines
15 periods on x-axis 60 periods on x-axis

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