Achromatic multi-four quadrant phase mask : laboratory demonstration

Raphaël Galicher

Pierre Baudoz, Jacques Baudrand

Lyot conference

October 2010

Outline

Monochromatic FQPM

Multi-FQPM principle

Performance in full pupil

Performance with obscuration

Conclusions

Outline

Monochromatic FQPM

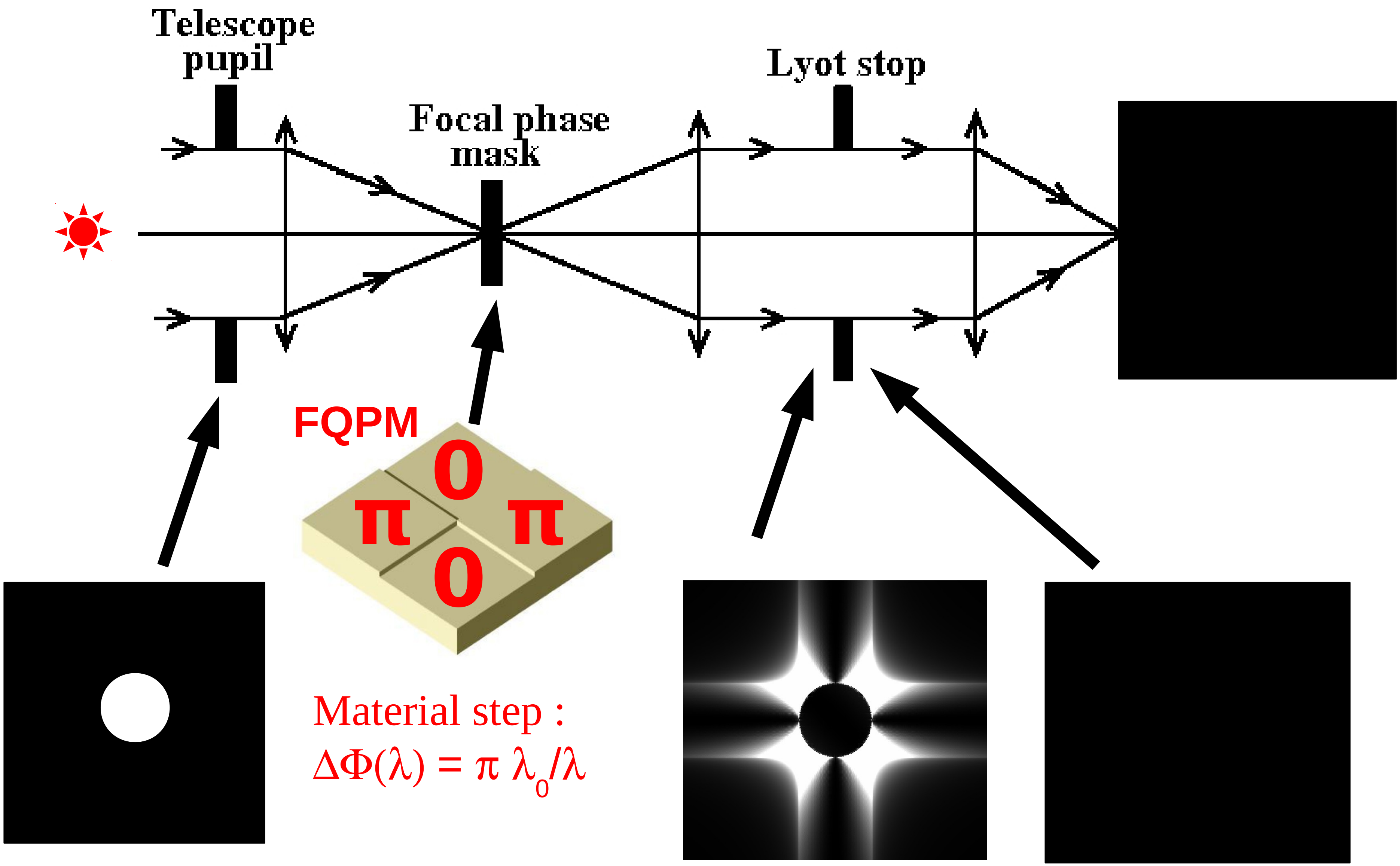
Multi-FQPM principle

Performance in full pupil

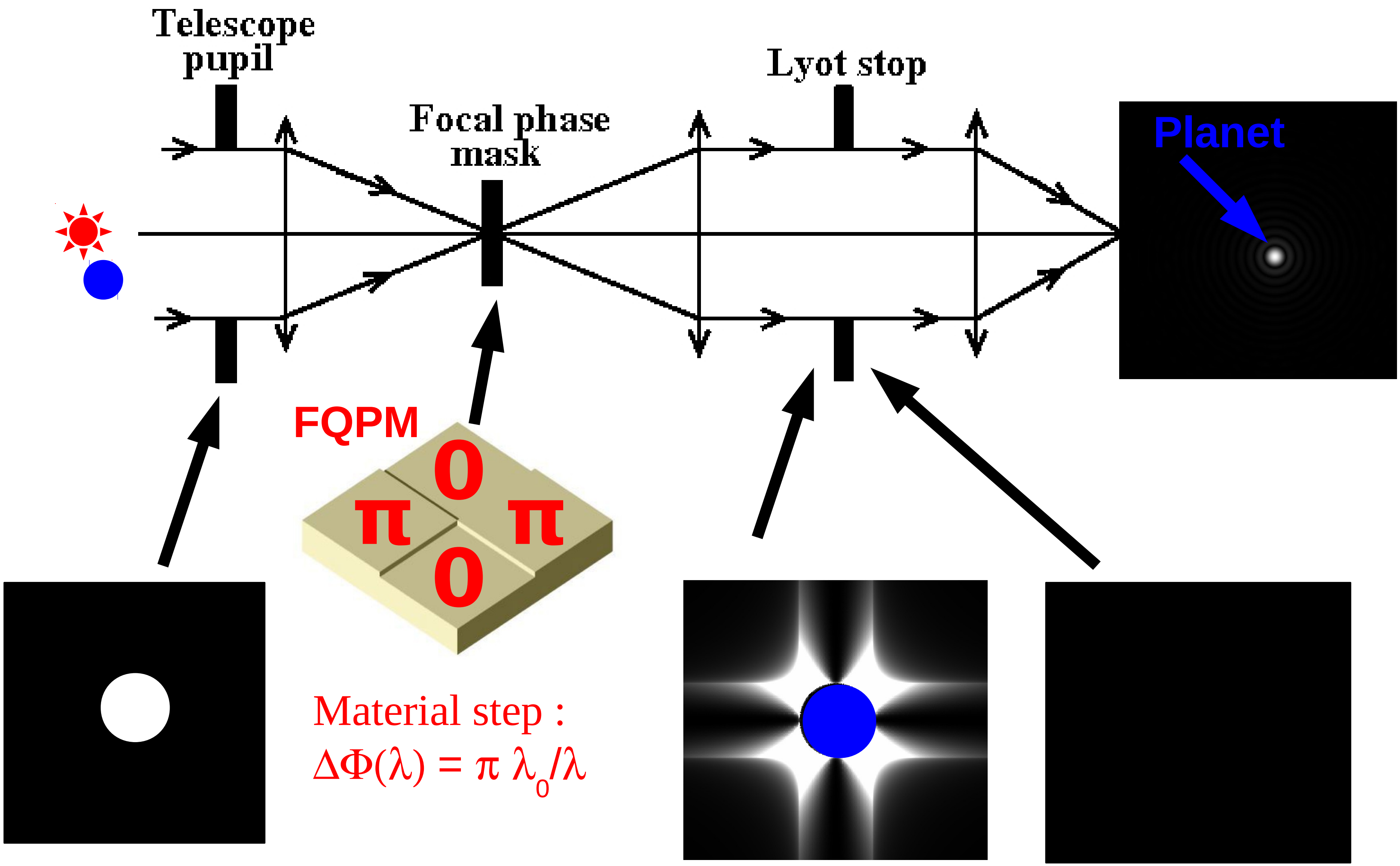
Performance with obscuration

Conclusions

Monochromatic four quadrant phase mask

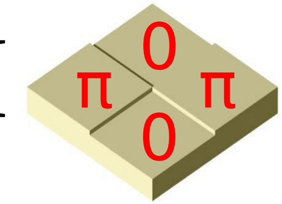


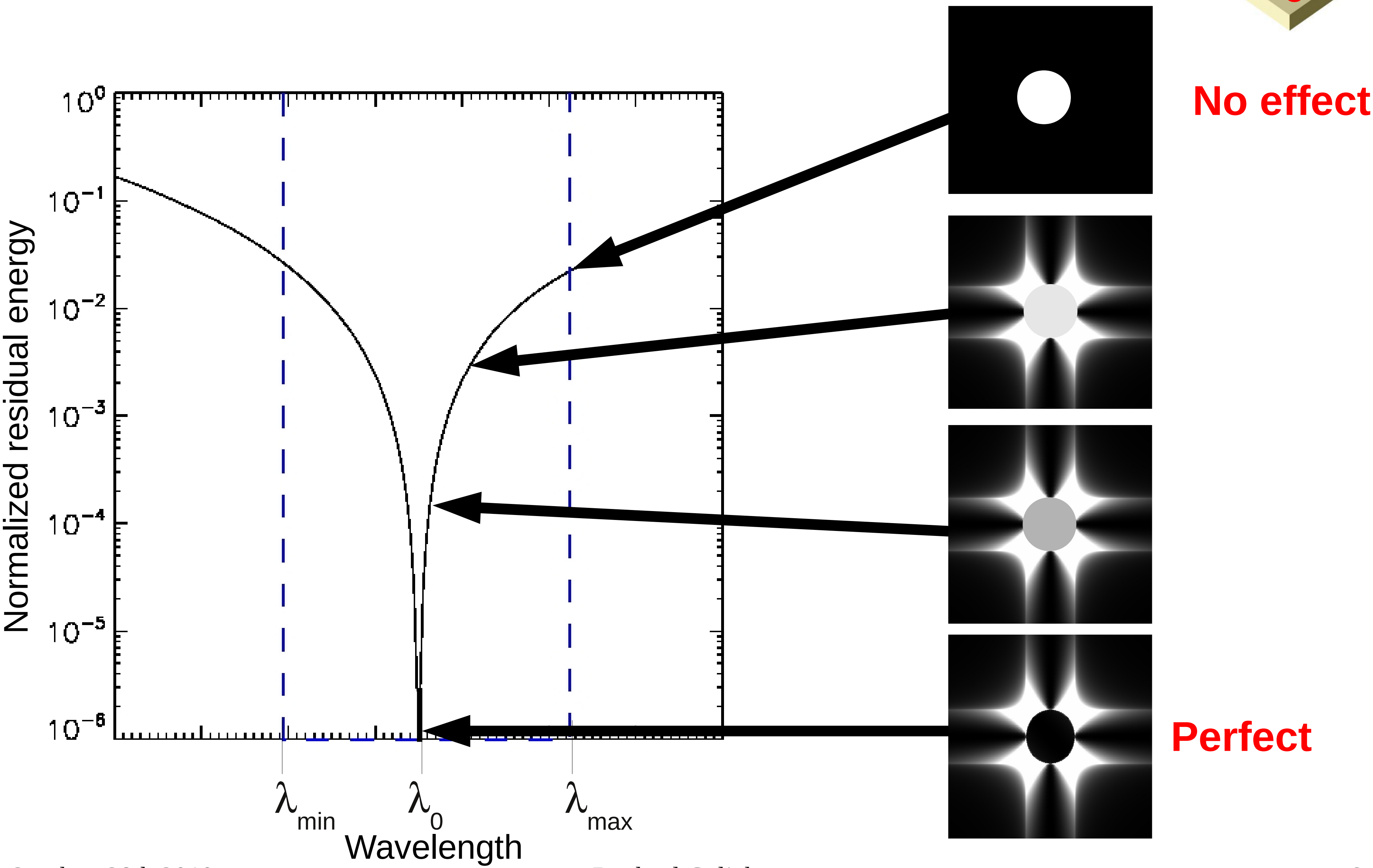
Monochromatic four quadrant phase mask



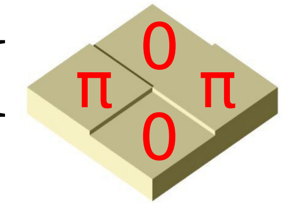
Material step :
$\Delta\Phi(\lambda) = \pi \lambda_0/\lambda$

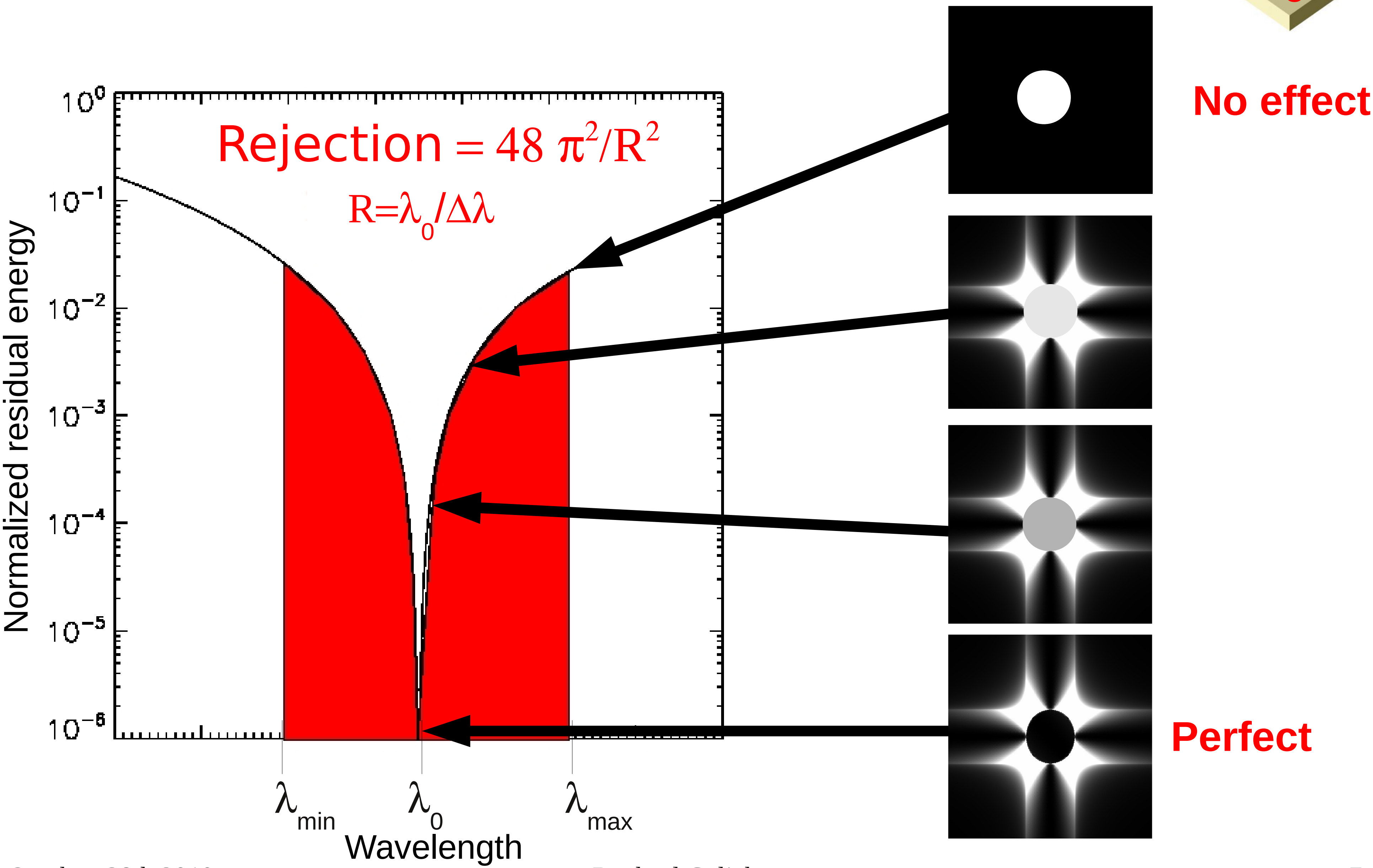
Single monochromatic FQPM



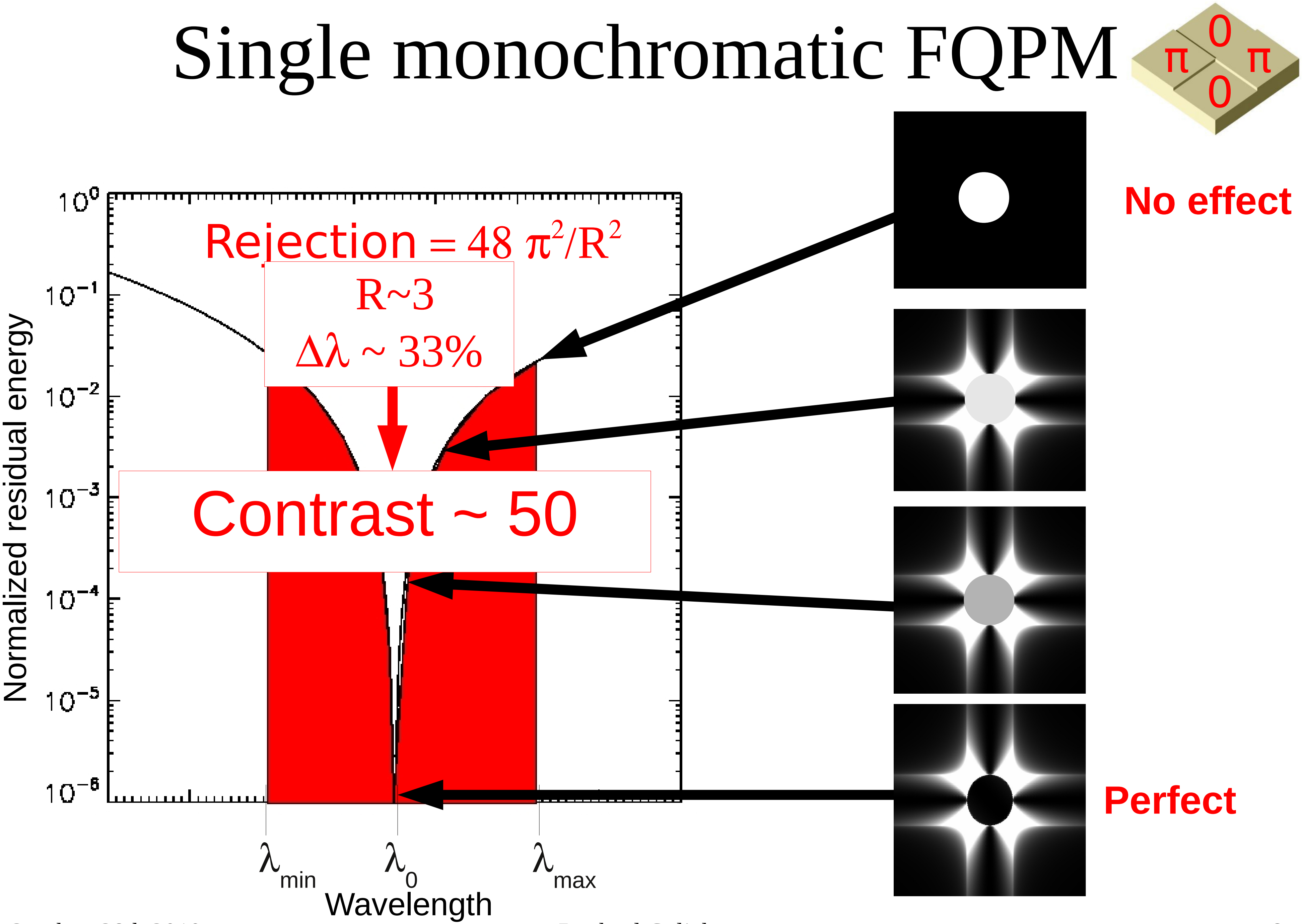


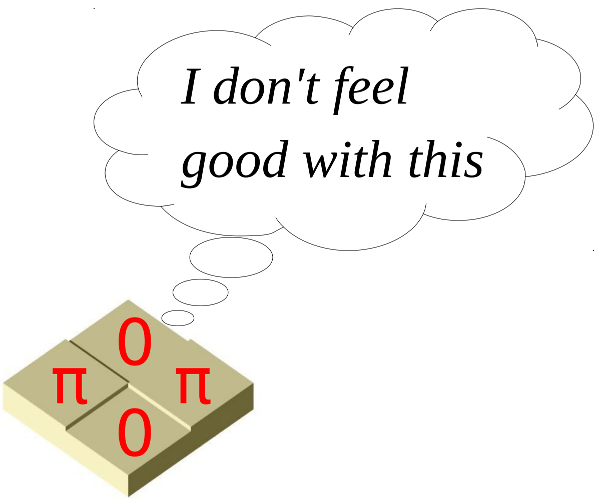
Single monochromatic FQPM

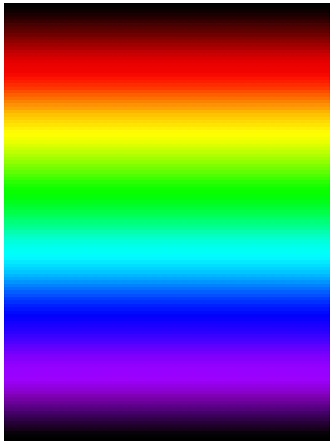




Single monochromatic FQPM




I don't feel
good with this
0
π
π
0

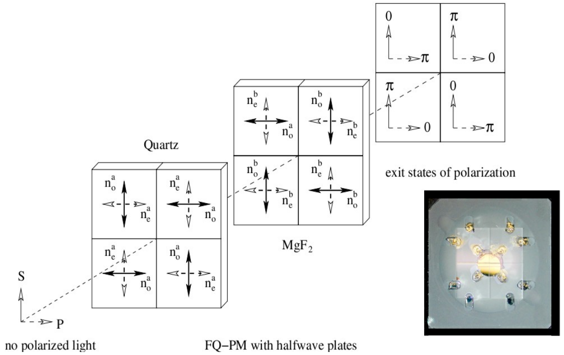


FQPM achromatization

•Halfwave plates

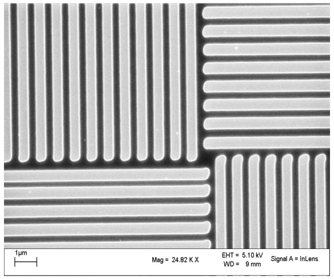
Mawet et al. 2006

Boccaletti et al. 2008



• Sub-lambda grattings

Mawet et al. 2005, 2006



• Mach-Zender interferometer

Carlotti et al. 2008

• Multi-stage four quadrant phase mask → MFQPM

B*audoz et al. 2008*

Outline

Monochromatic FQPM

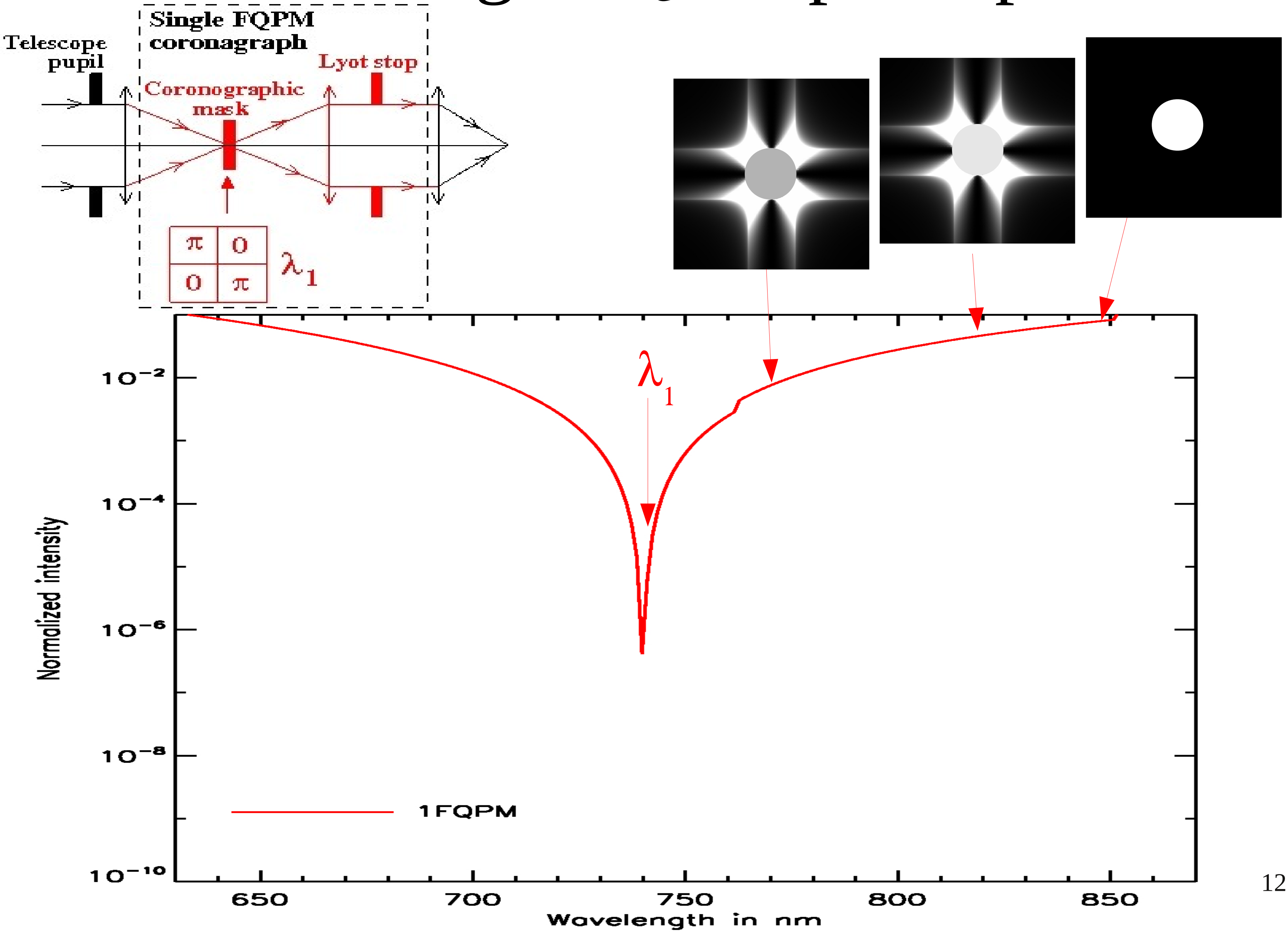
Multi-FQPM principle

Performance in full pupil

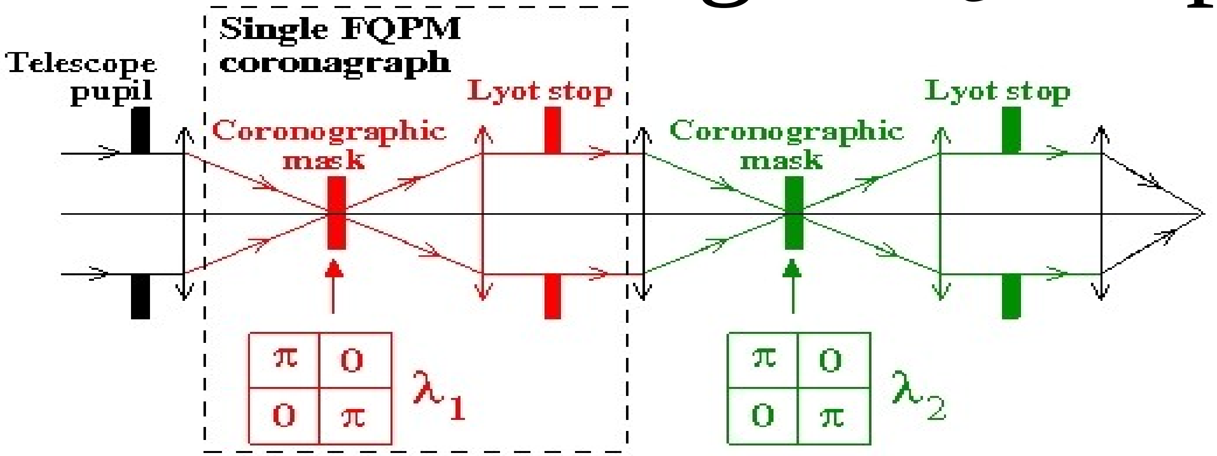
Performance with obscuration

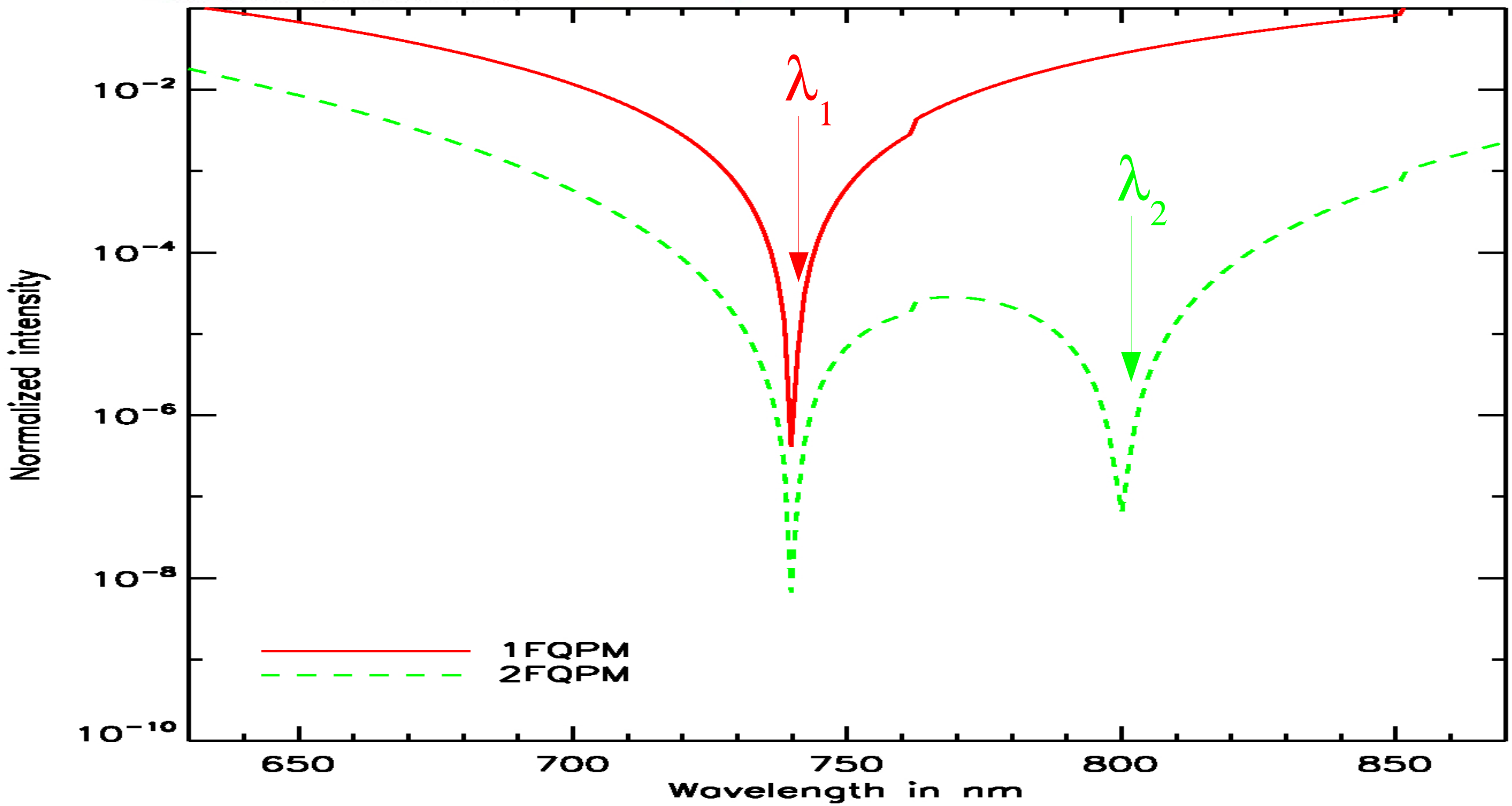
Conclusions

Multi-stage FQPM principle

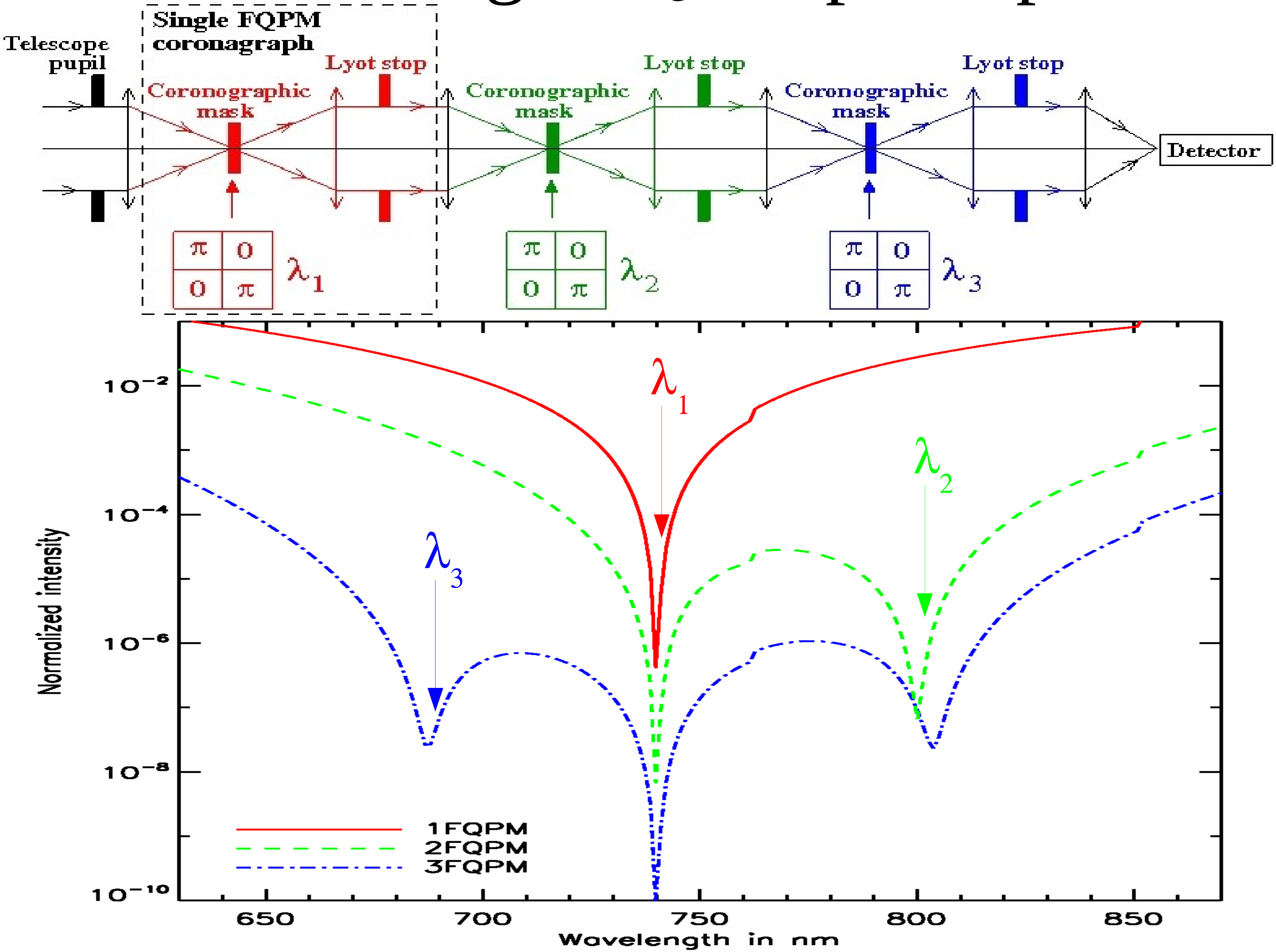


Multi-stage FQPM principle

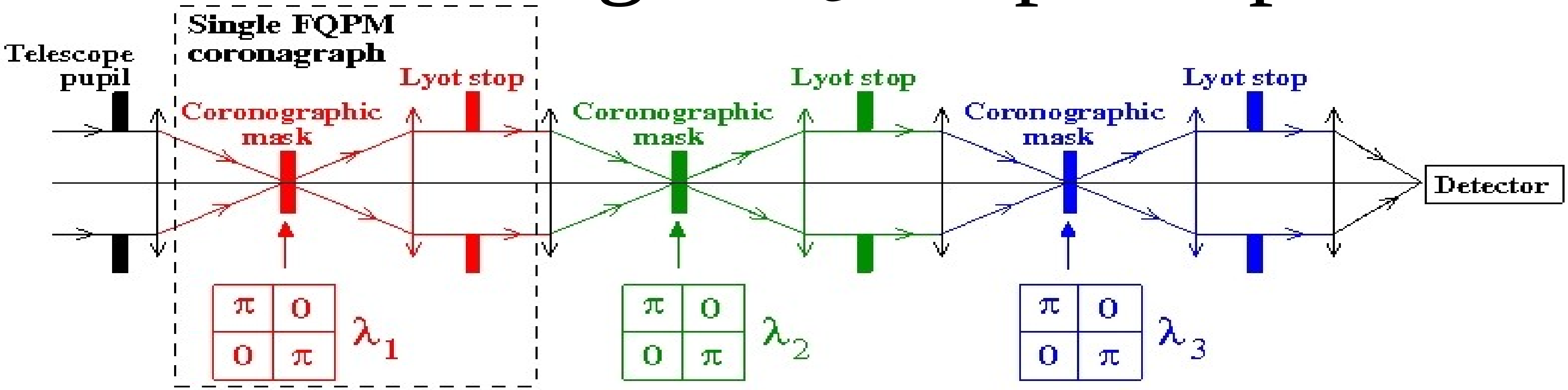


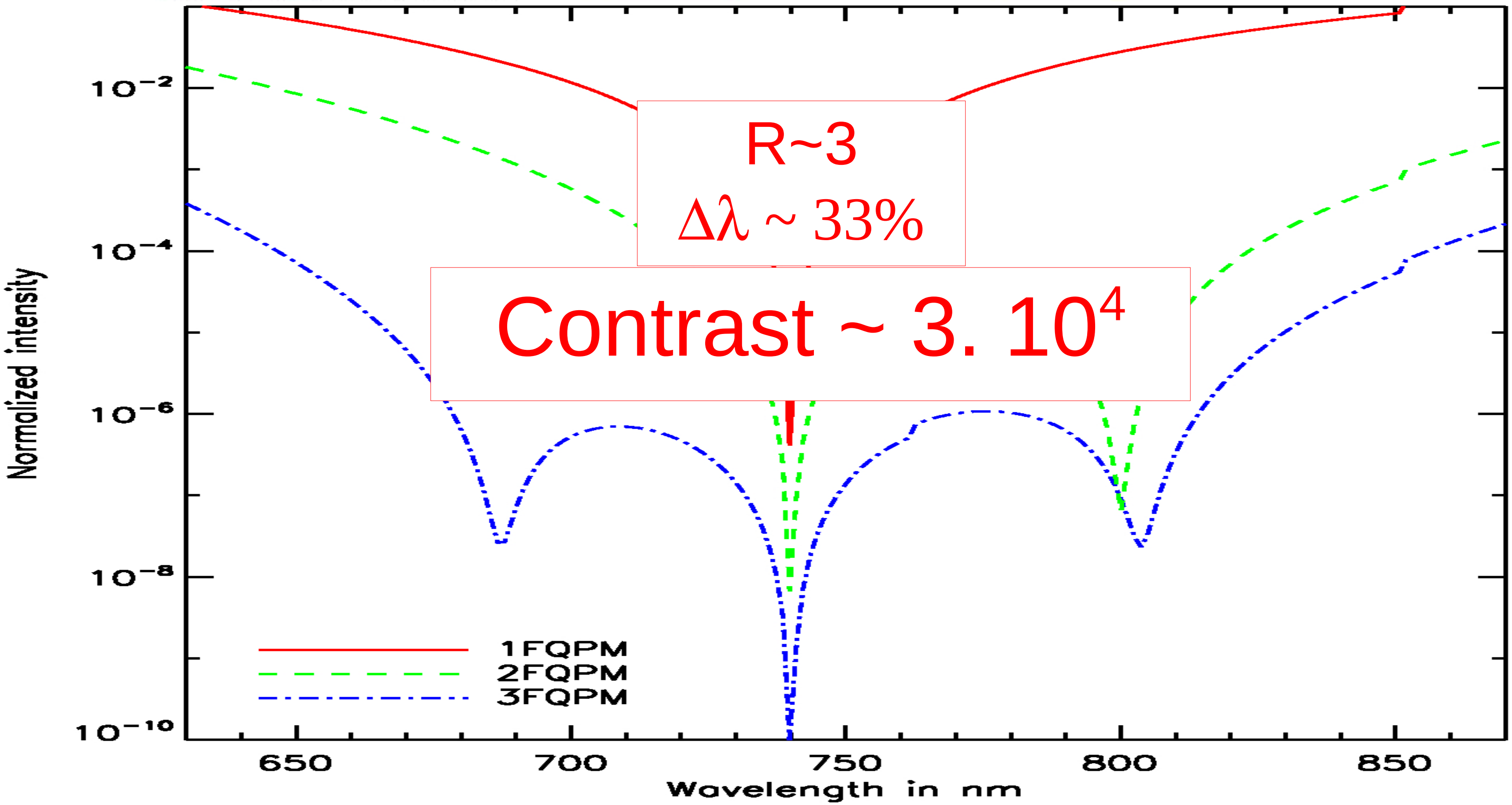


Multi-stage FQPM principle



Multi-stage FQPM principle





Outline

Monochromatic FQPM

Multi-FQPM principle

Performance in full pupil

Performance with obscuration

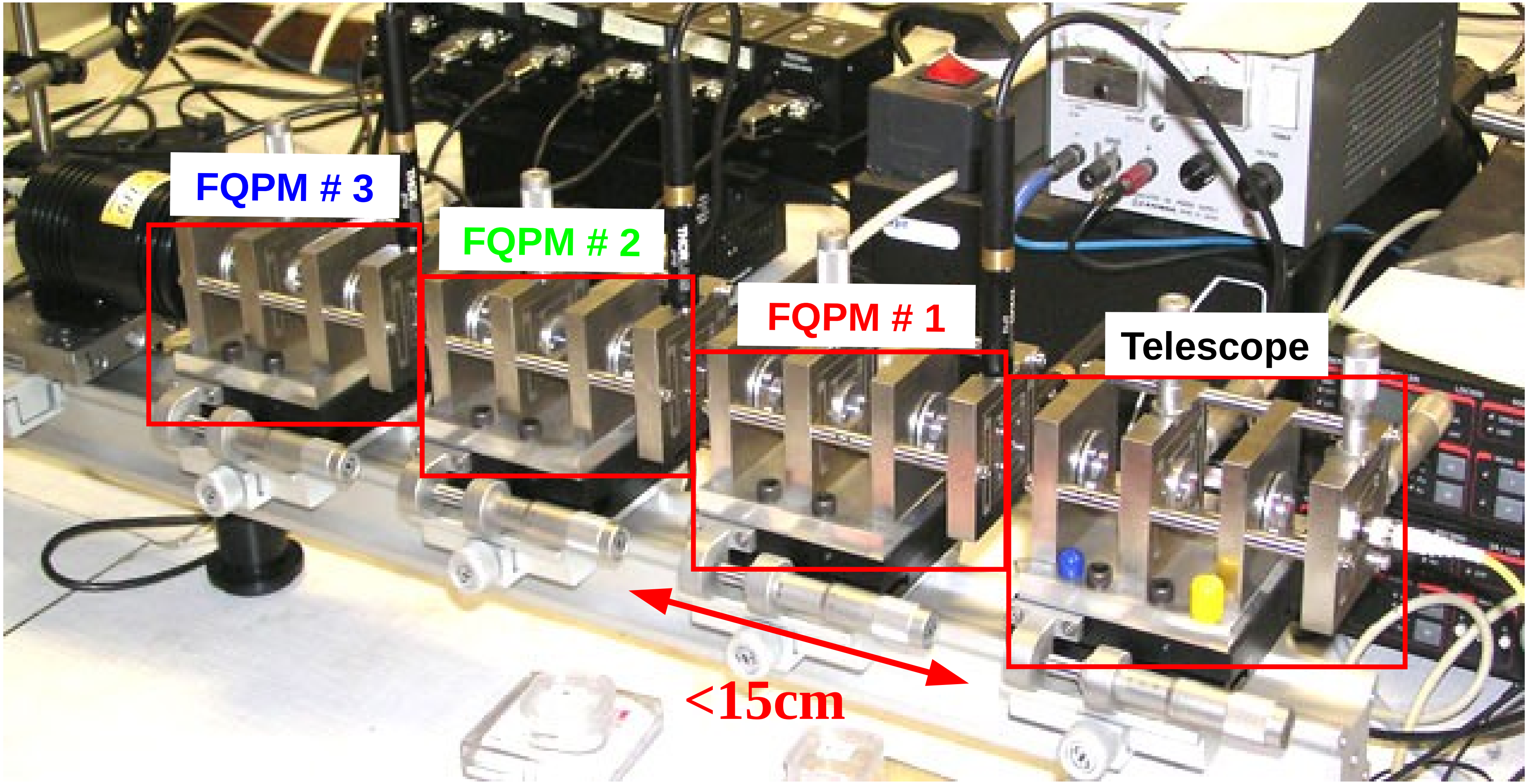
Conclusions

MFQPM prototype

630nm to 870nm ($\Delta\lambda$=240nm, 32% bandwidth)

Aperture : F/D = 40

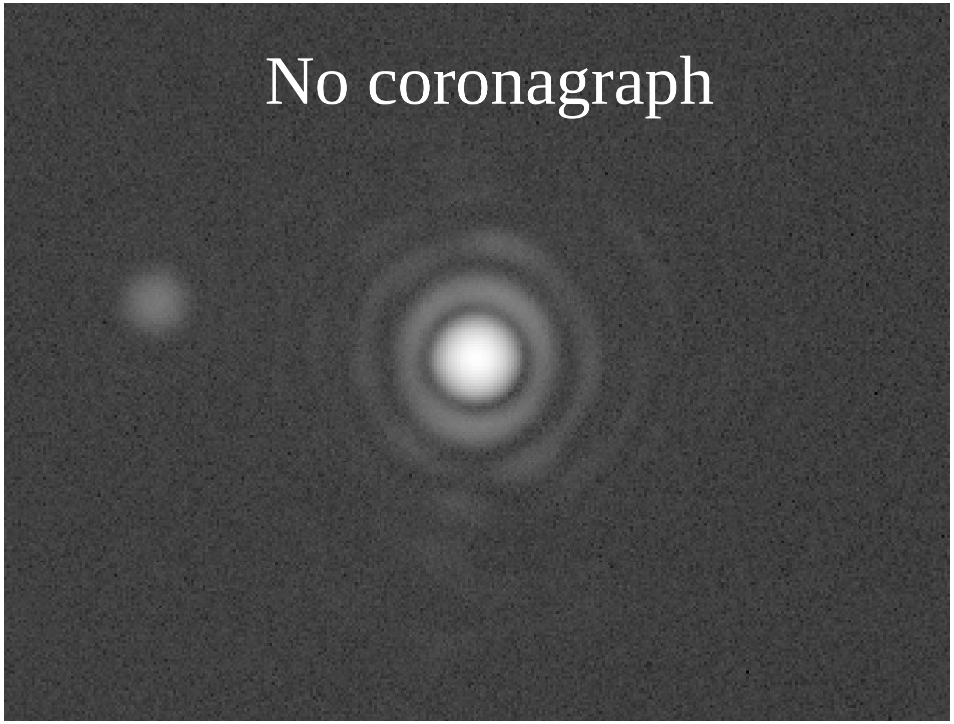
λ_3=800nm λ_2=690nm λ_1=740nm

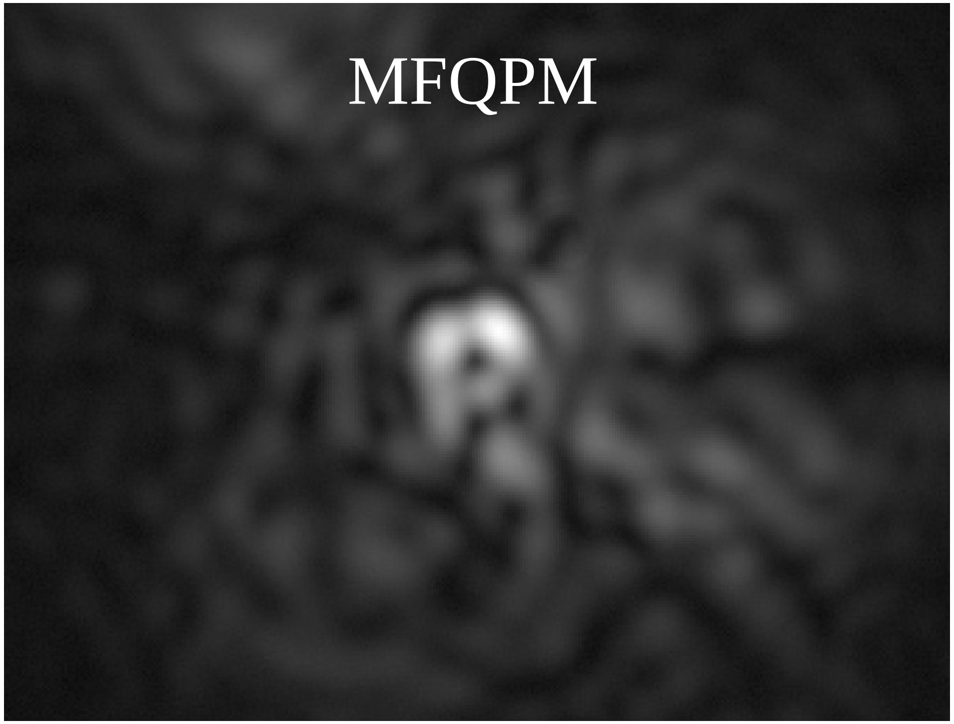


Full pupil R=3 : images

- 630 to 870nm → Δλ=32%
- Aperture F/D=40
- Throughput = 72%

Total energy rejection ~ 2000
→ limited by speckles (no calibration)



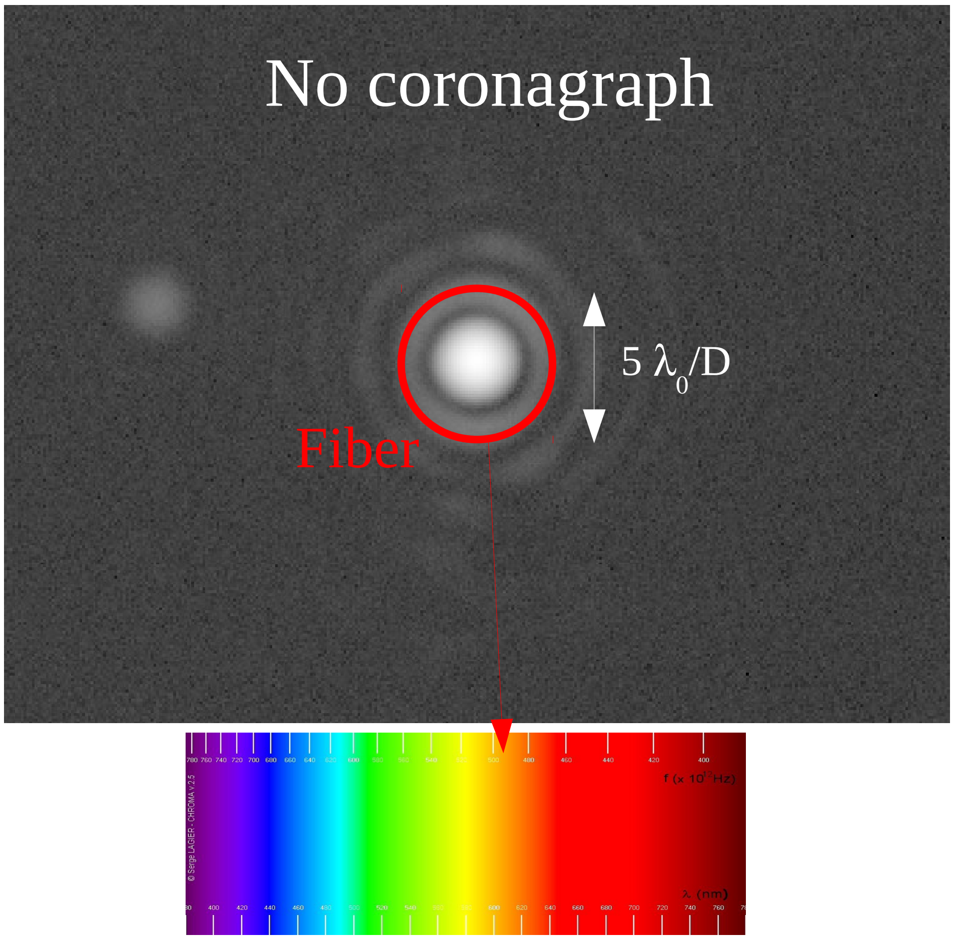


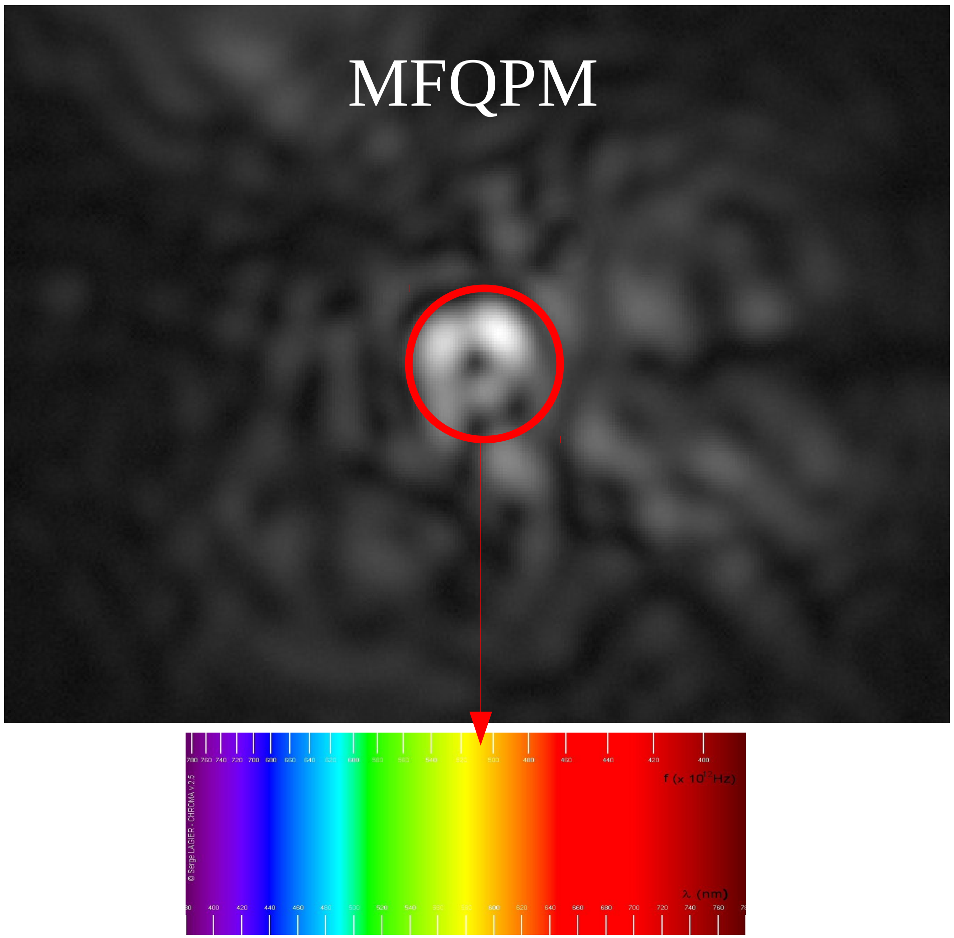
Different scales

Full pupil R=3 : images

- 630 to 870nm → $\Delta\lambda$=32%
- Aperture F/D=40
- Throughput = 72%

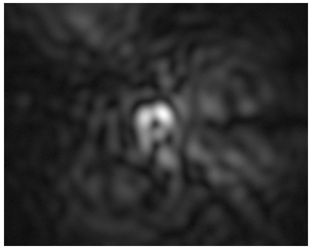
Total energy rejection ~ 2000
→ limited by speckles (no calibration)





Full pupil R=3 : spectra

- Throughput = 72%
- Aperture : F/D=40
- Fiber of $5\lambda_0/D$ diameter put on-axis



Improvements :

- Flatness of spectra

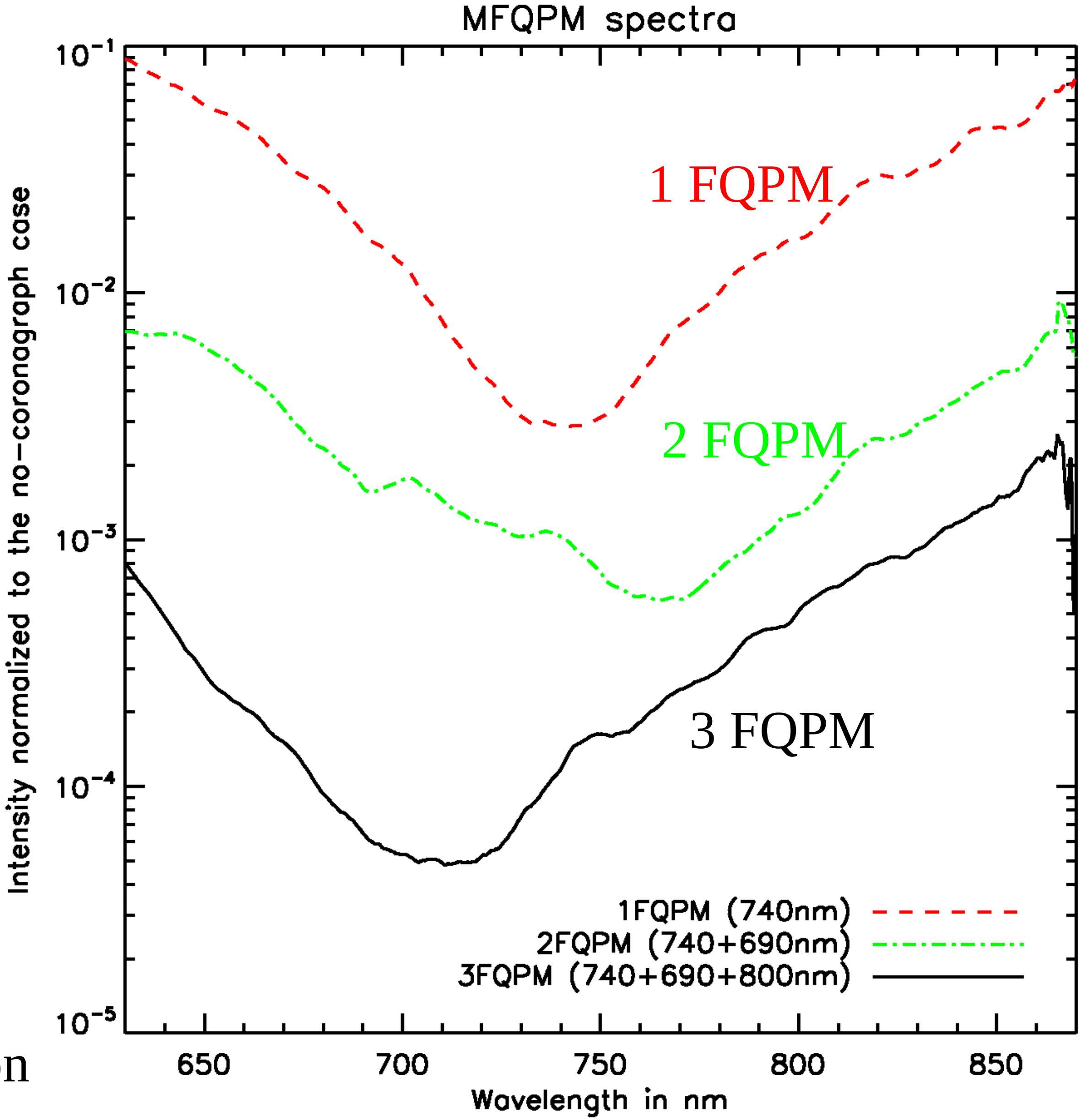
→ focal masks centering

- Contrast

→ speckle limitation

→ better optics

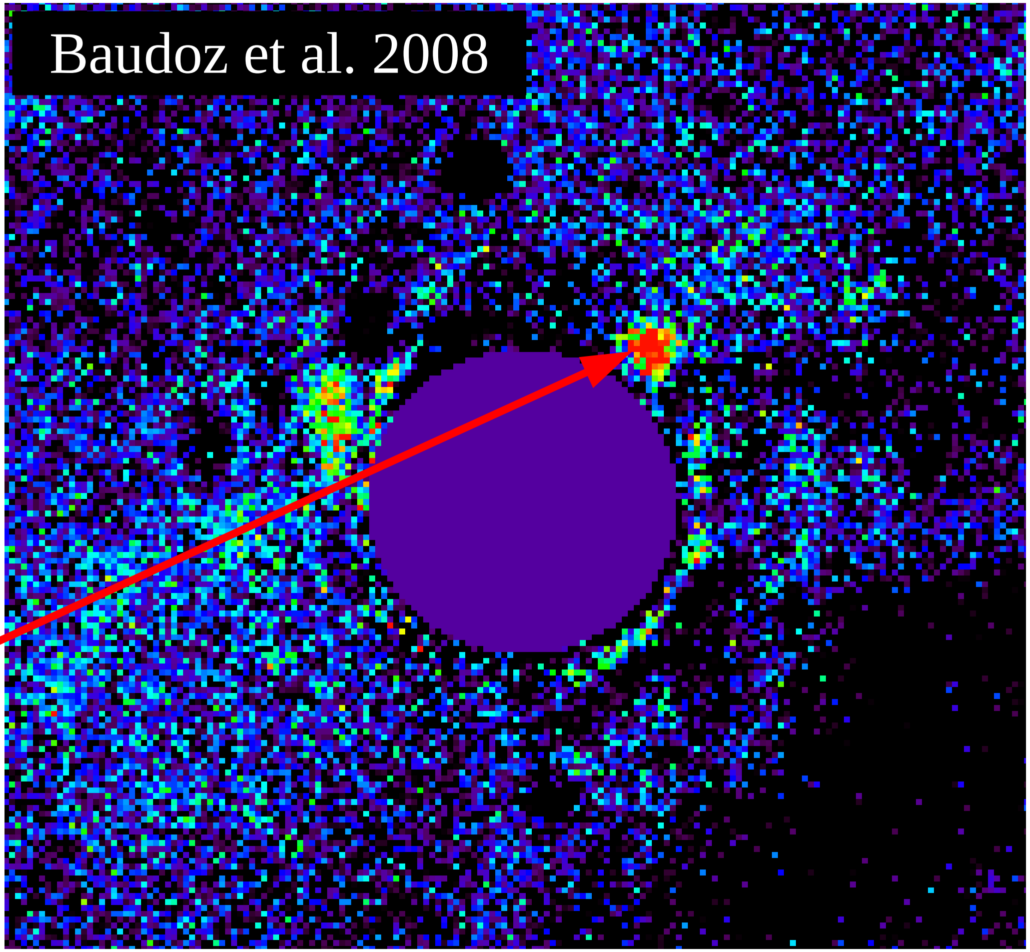
→ active correction/calibration



Full pupil R=4.8

- Throughput = 56%
- Aperture : F/D=250-300
- Differential imaging
  (factor 10 on raw contrast)

Contrast 1.5 10^8
at $4.5\lambda_0/D$
SNR=4.5



Outline

Monochromatic FQPM

Multi-FQPM principle

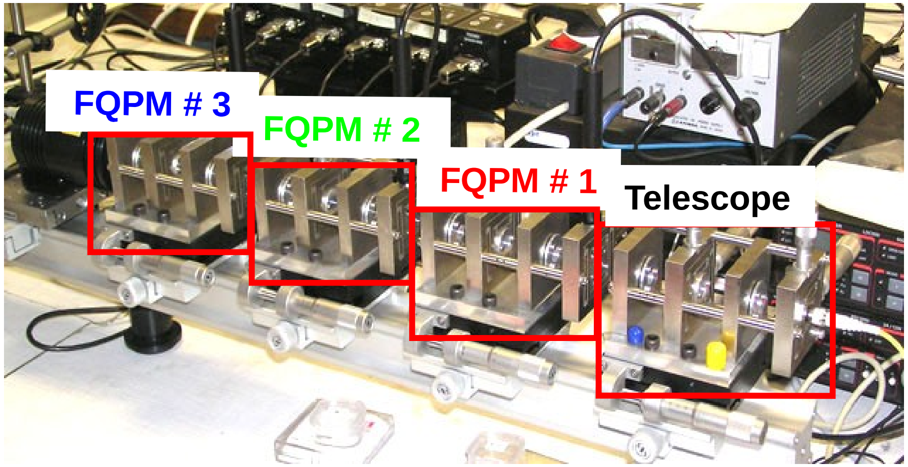
Performance in full pupil

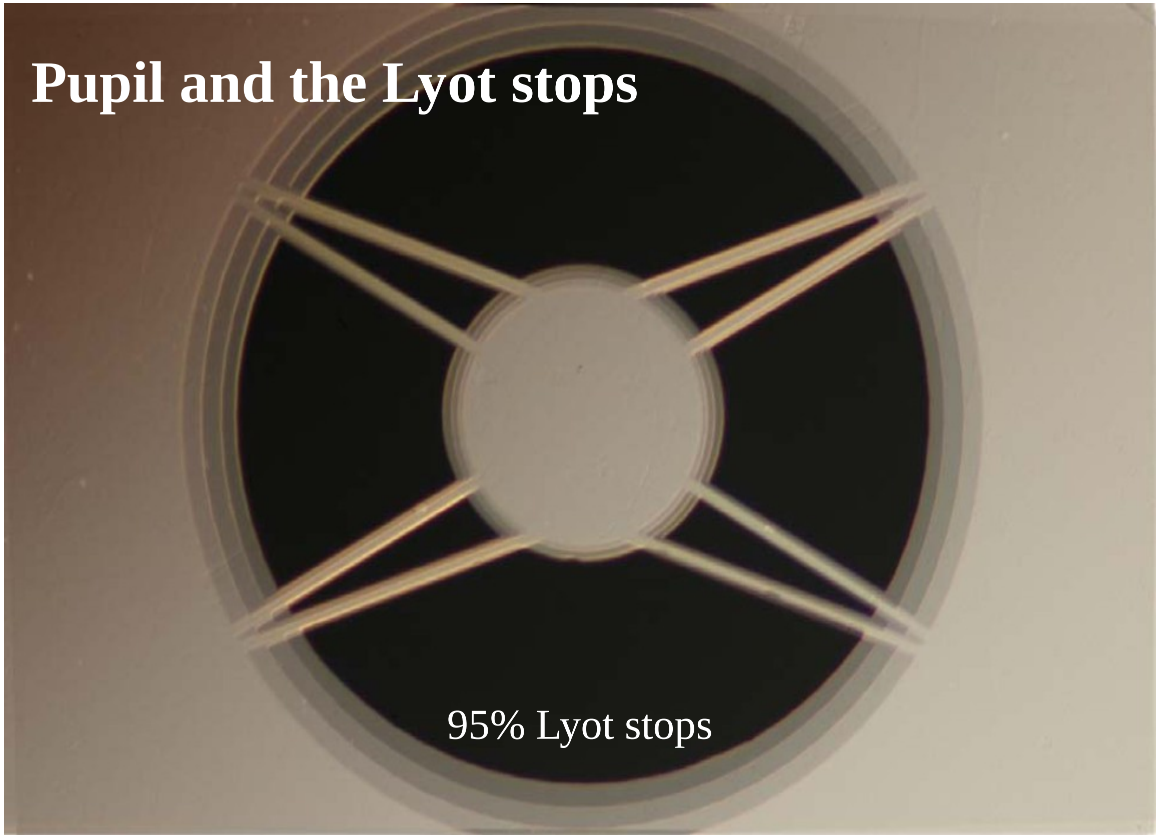
Performance with obscuration

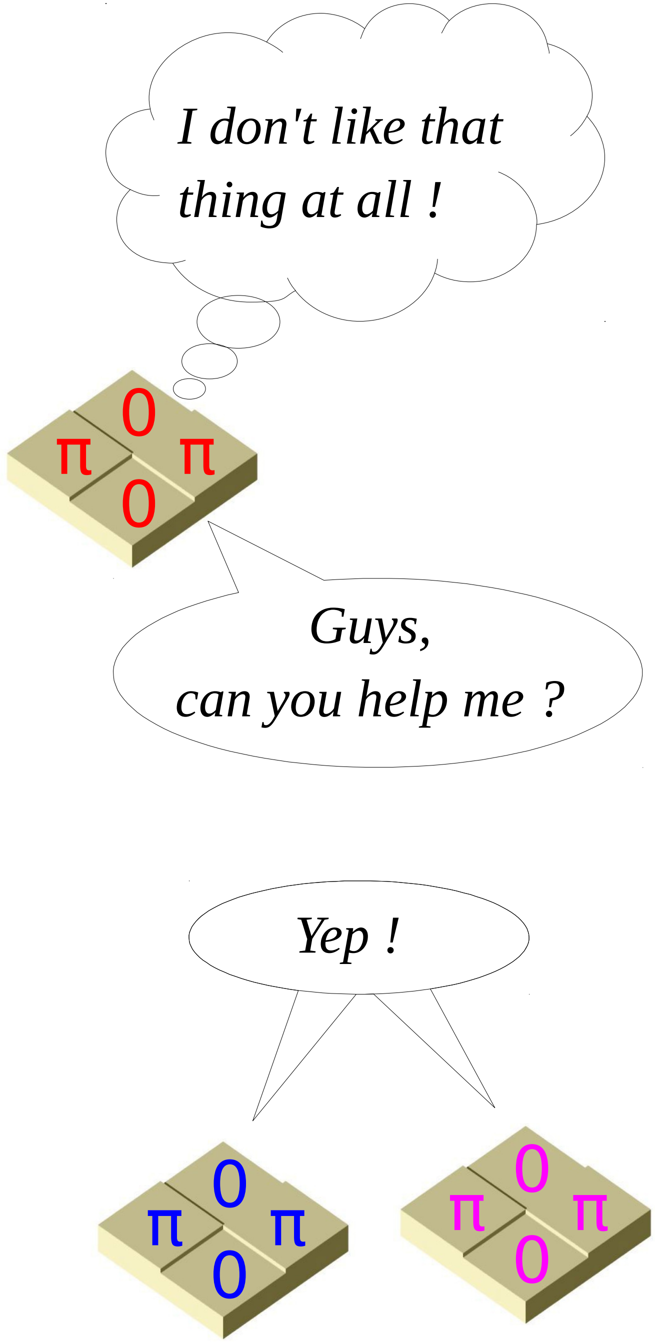
Conclusions

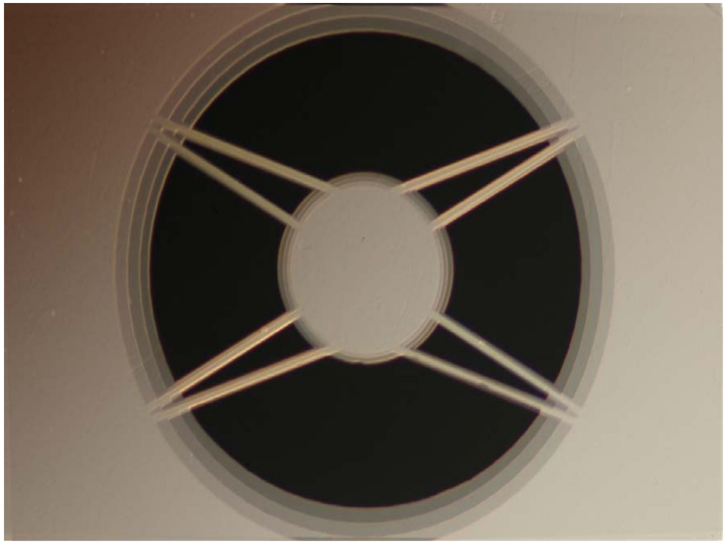
Obstructed pupil R=3

- 630 to 870nm → $\Delta\lambda$=32%
- Aperture : F/D=40
- E-ELT pupil
- Throughput = 86%





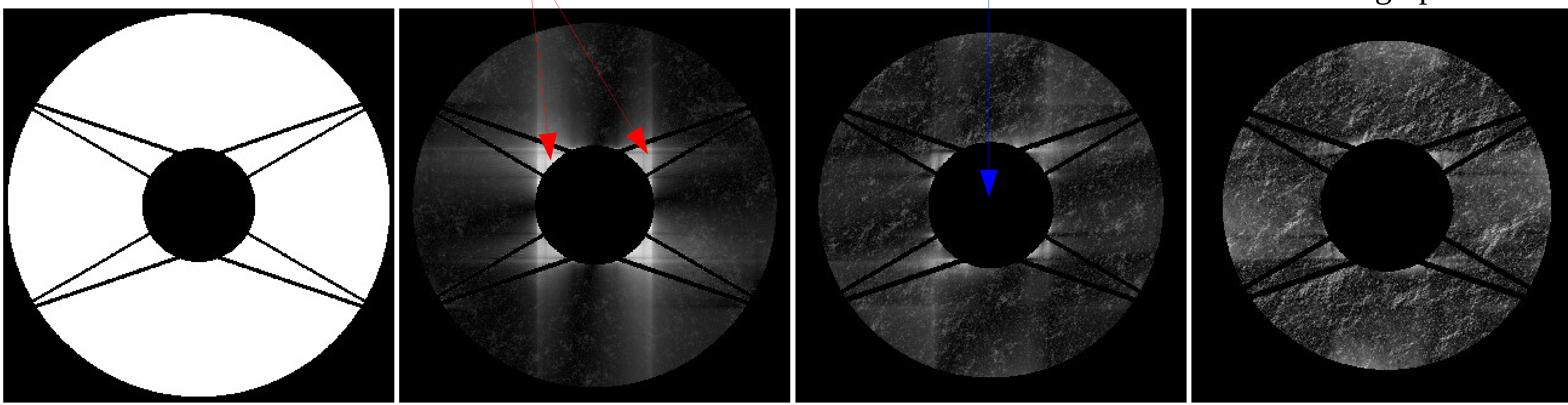

I don't like that thing at all !
π 0 π 0
Guys,
can you help me ?
Yep !
π 0 π 0
π 0 π 0



Obstructed pupil R=3 : pupil images

Central obstruction effects Leaks are stopped

Throughtput = 86%



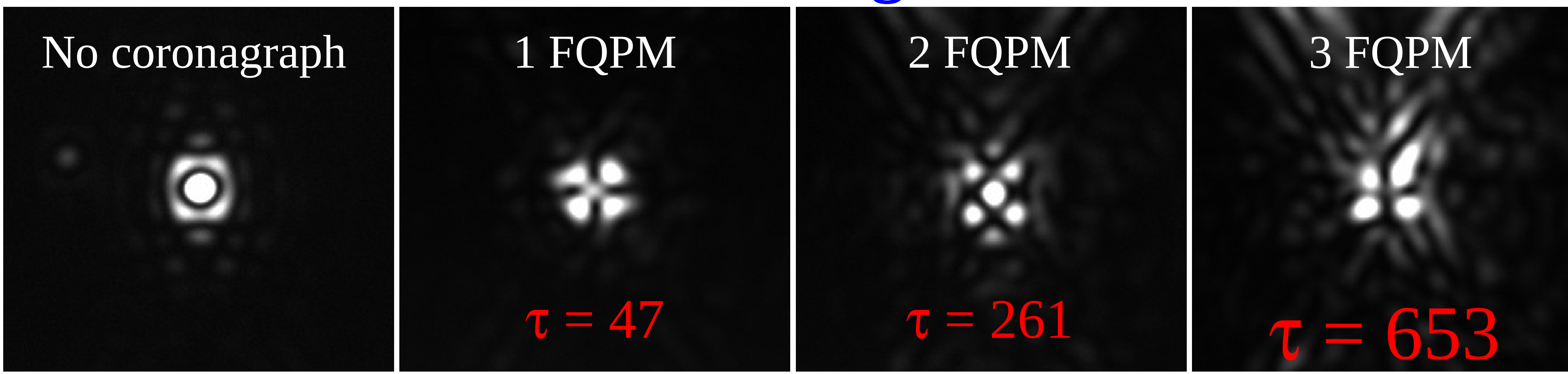
No coronagraph | 1st Lyot stop | 2nd Lyot stop | 3rd Lyot stop

Obstructed pupil R=3 : images

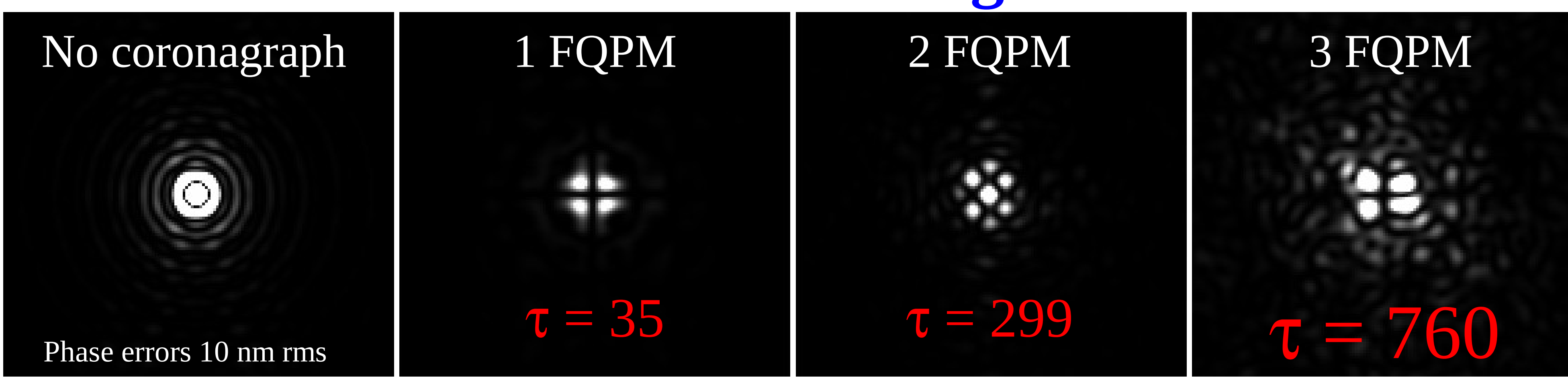
630 to 870nm → $\Delta\lambda$=32% **Throughput = 86%** No speckle calibration

τ = total rejection

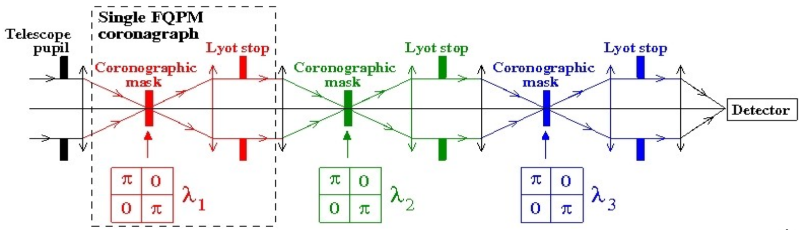
Lab images

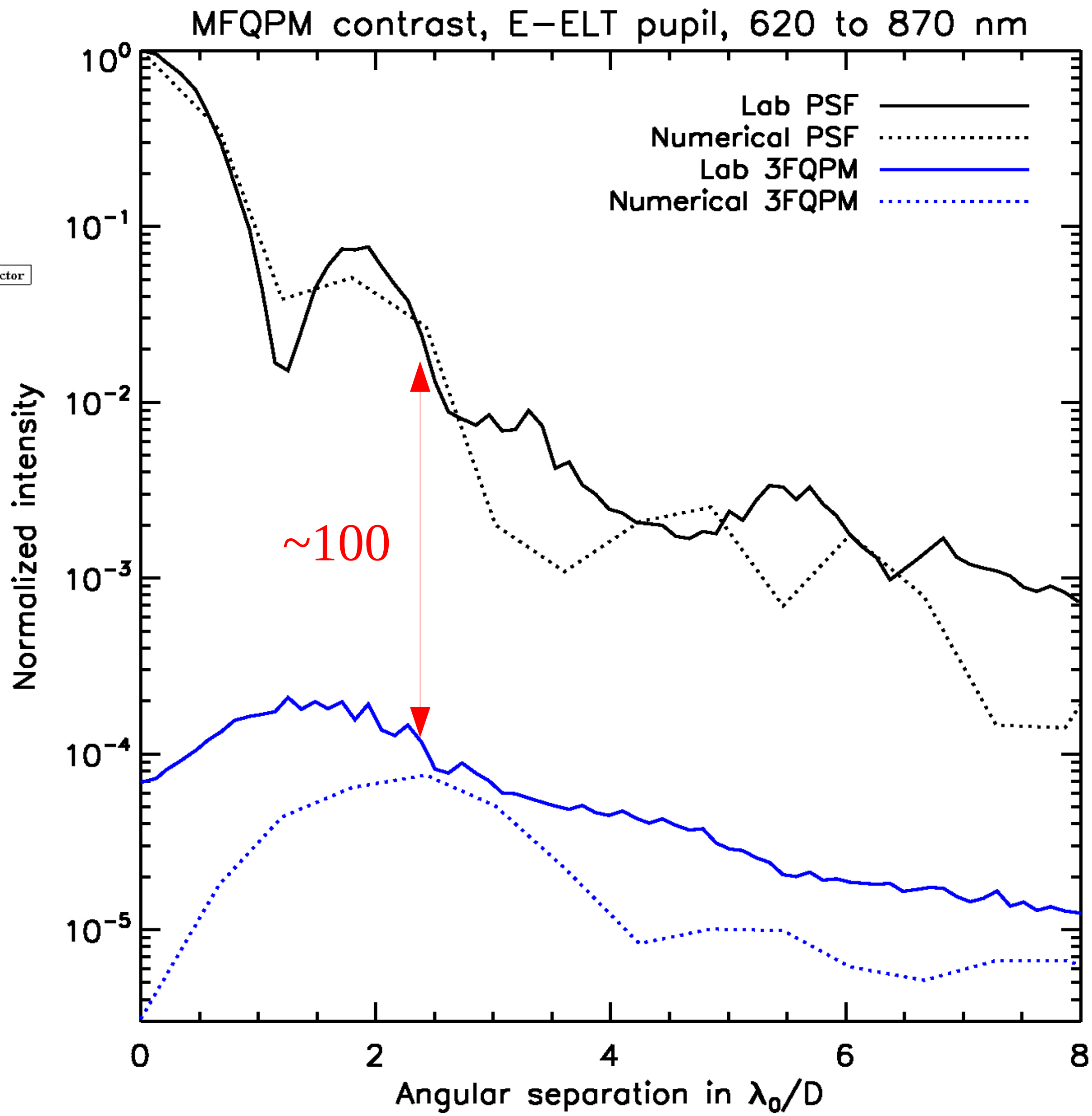


Numerical images



Obstructed pupil R=3 : images



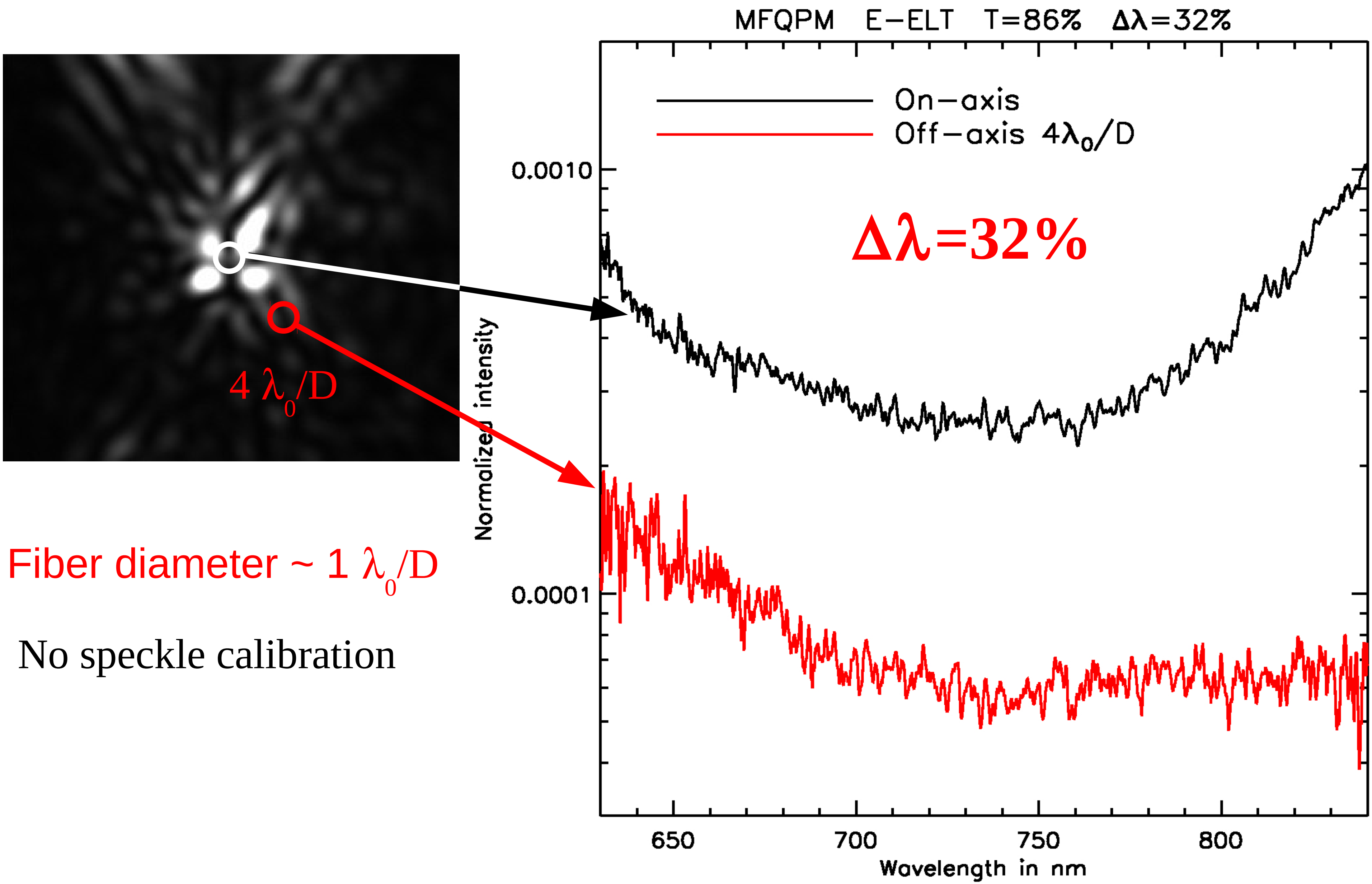


630 to 870nm → $\Delta\lambda$=32%

Throughput = 86%

No speckle calibration

Obstructed pupil R=3 : spectra



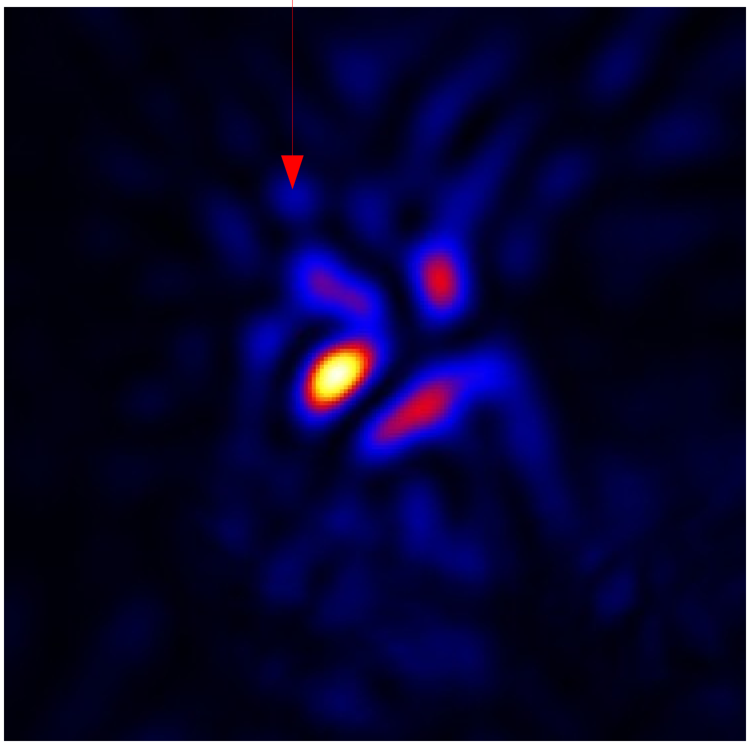
Fiber diameter ~ 1 λ_0/D

No speckle calibration

Obstructed pupil R=3 : lab planet

630 to 870nm → $\Delta\lambda$=32% E-ELT pupil Throughput = 86%

Lab planet : 1.5 10^{-4} at 3.47 λ_0/D



13 λ_0/D

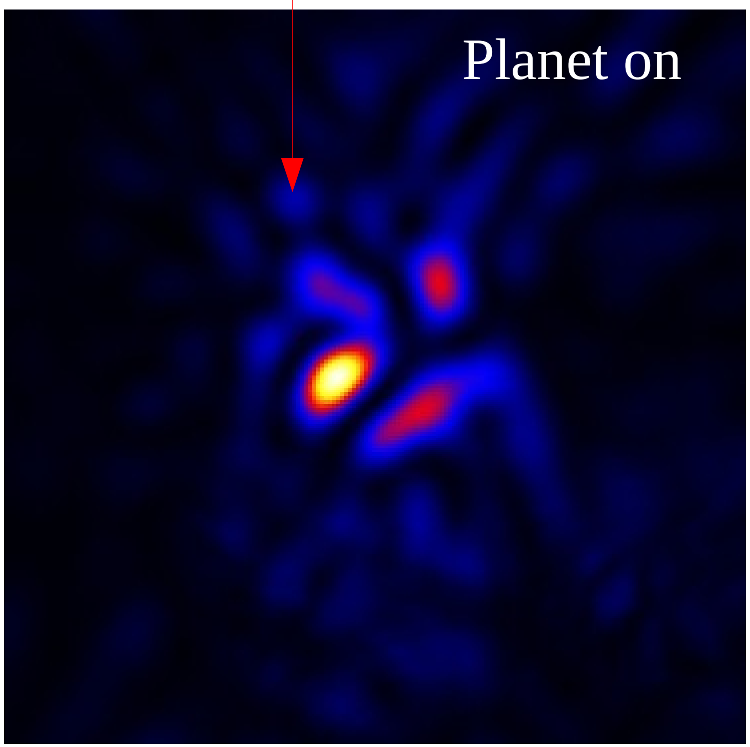
Detected with SNR=2

No speckle calibration

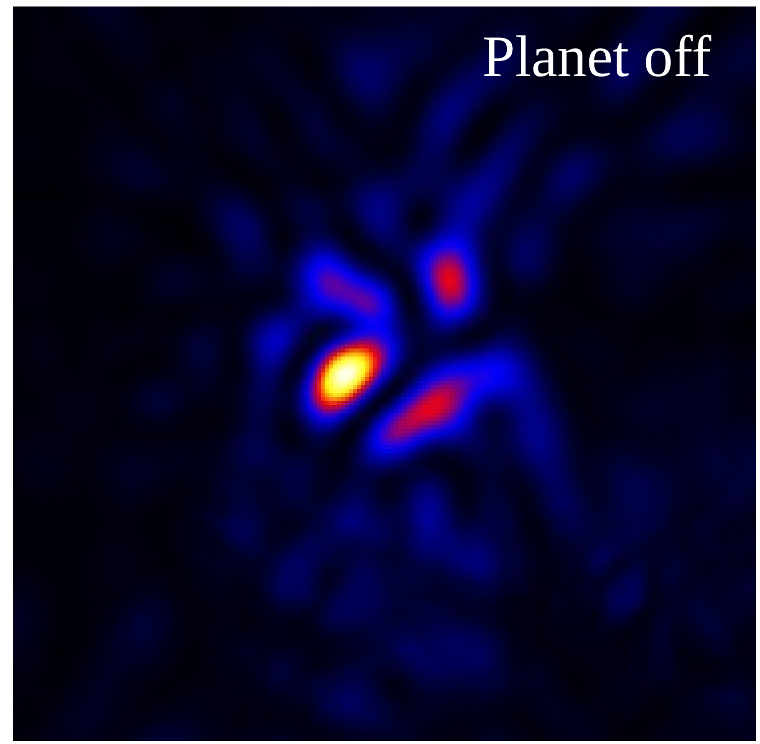
Obstructed pupil R=3 : lab planet

630 to 870nm → $\Delta\lambda$=32% E-ELT pupil Throughput = 86%

Lab planet : 1.5 10^{-4} at 3.47 λ_0/D



13 λ_0/D

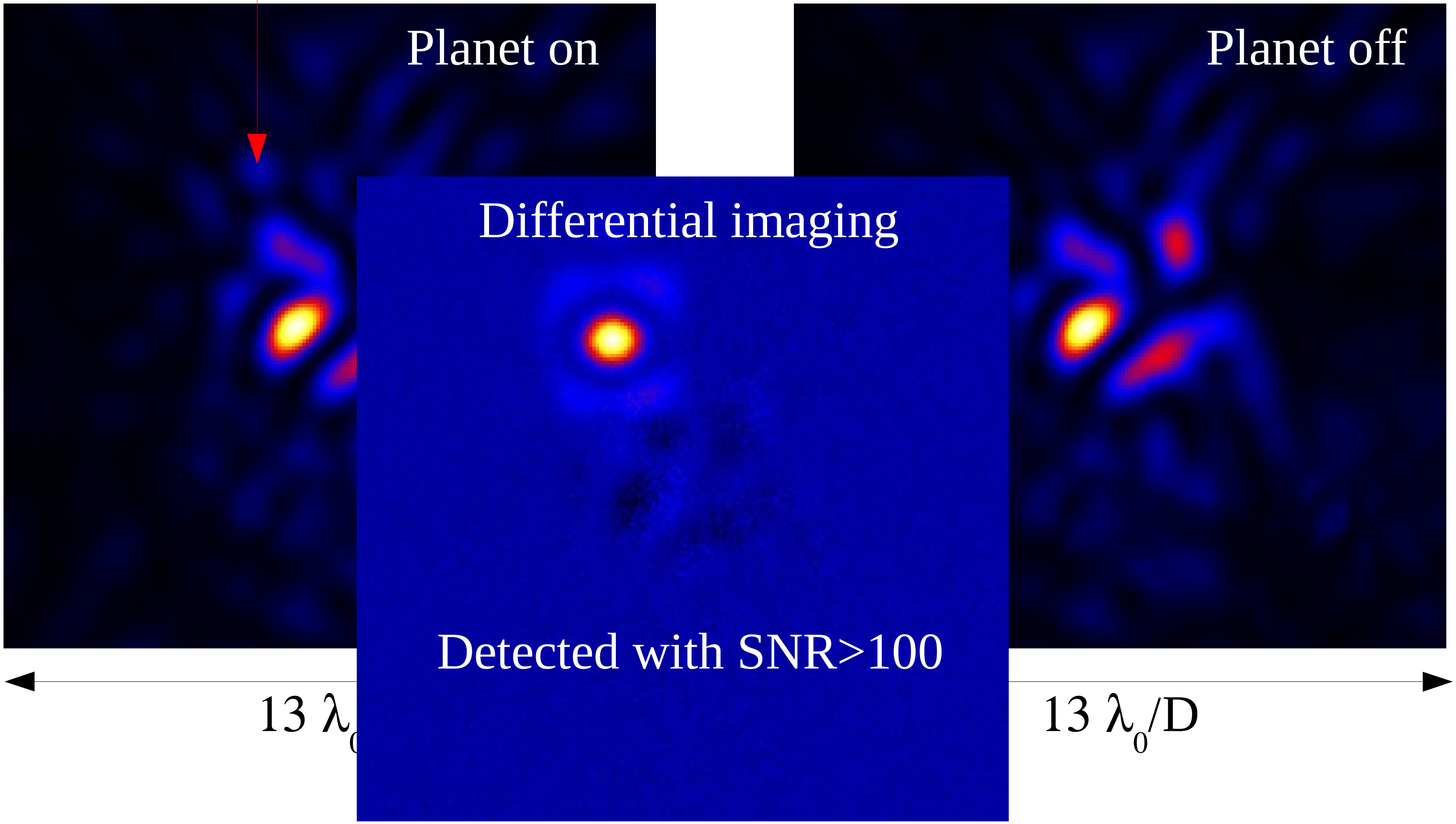


13 λ_0/D

Obstructed pupil R=3 : lab planet

630 to 870nm → $\Delta\lambda$=32% E-ELT pupil Throughput = 86%

Lab planet : 1.5 10^{-4} at 3.47 λ_0/D



Outline

Monochromatic FQPM

Multi-FQPM principle

Performance in full pupil

Performance with obscuration

Conclusions

Conclusions

- MFQPM very easy to build (works at every λ) already specified for space (JWST)

- Full pupil, F/40, 32% bandwidth, T=72% 2000 total energy rejection

  Full pupil, F/250, 20% bandwidth, T=56% 10^8 contrast at 4.5 λ_0/D

- **Obstructed pupil (E-ELT), F/40, 32% bandwidth, T=86%**

  650 total energy rejection

  1.5 10^{-4} lab planet at 3.5 λ_0/D detection

Ongoing works :

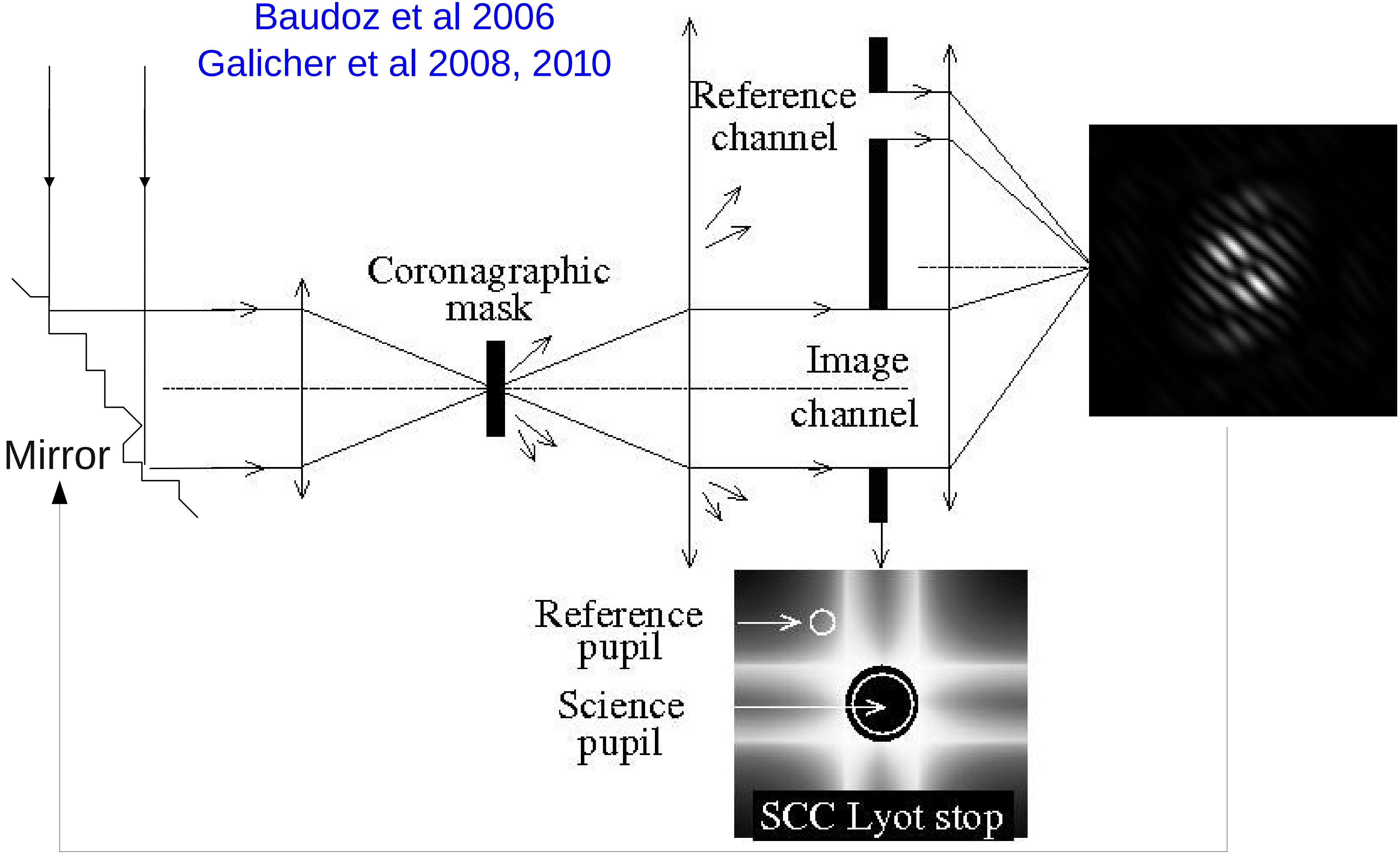
- New prototype with less optic aberrations → flatten spectra
- Association with a speckle calibrator/killer (Self-coherent camera)

See Marion Mas talk tomorrow

Thanks

Self-coherent camera + four quadrant phase mask coronagraph

Baudoz et al 2006
Galicher et al 2008, 2010



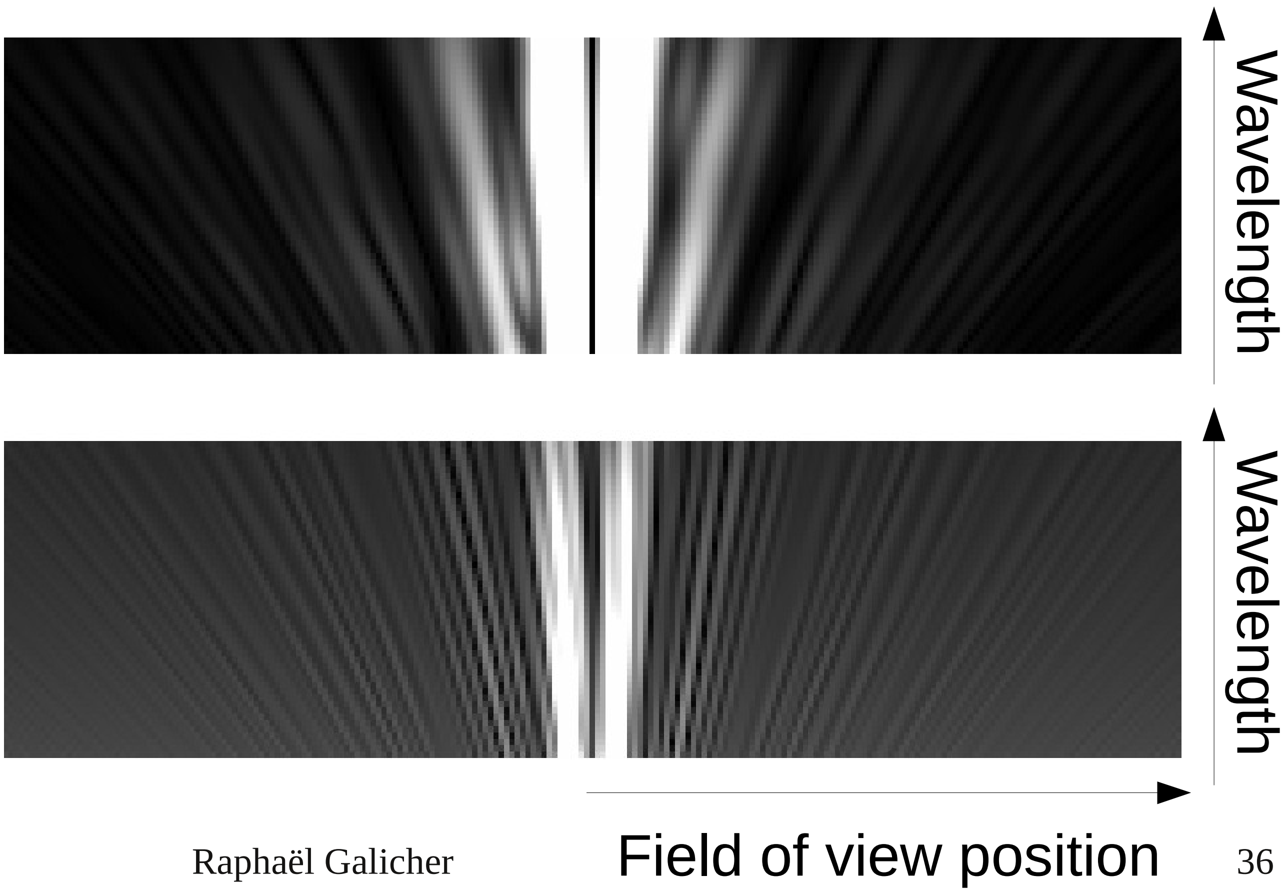
Integral Field Spectrometer

+ Self-coherent camera

Aberrations = function of λ (Fresnel propagation)

Spectral deconvolution strongly limited

One solution : SCC-IFS



MFQPM prototype