Prospects with the Crossed Cube Nuller

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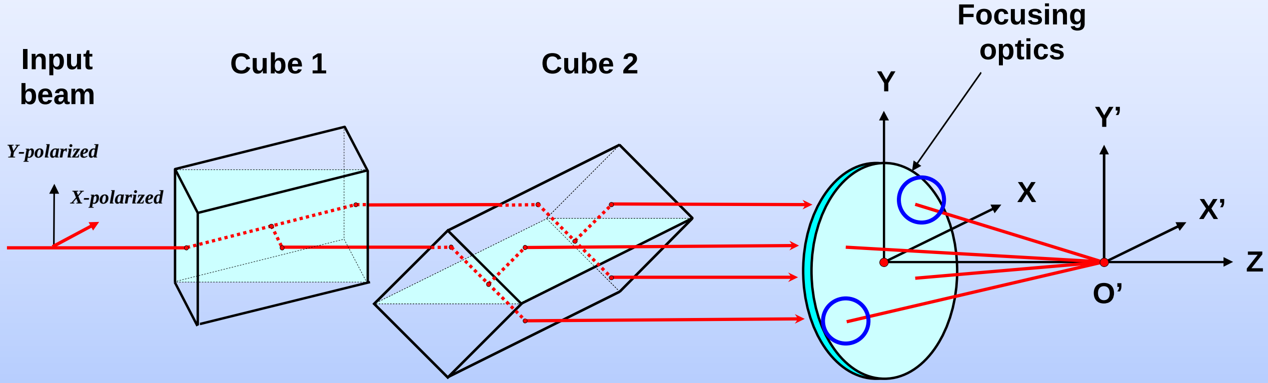
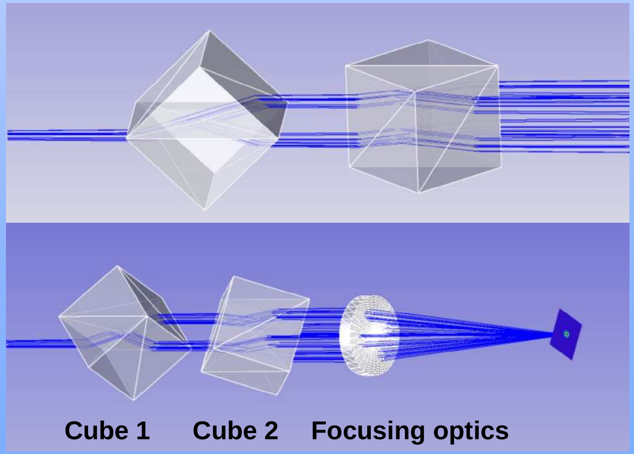
Plan of presentation

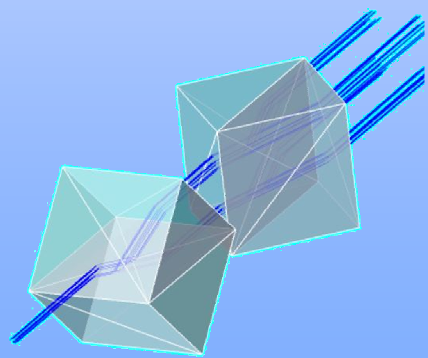
- General view of the Crossed-Cubes Nuller
- Design
- Cubes polarization model
- Use as a nulling combiner
- Preliminary manufacturing requirements
- Experiment and test results
- Discussion / Main advantages
- Integration into a Fully achromatic nulling interferometer (FANI)
  - Principle
  - Simulated fringe patterns
  - Potential SNR gain
- Conclusion

General view of the Crossed-Cubes Nuller (CCN)

- Two “crossed” beamsplitter cubes generate four parallel beams, recombined axially. Only two of them are used to create a “null” at the focal plane centre
- It is independent of wavelength, **chromatic flux unbalance** and polarization orientation







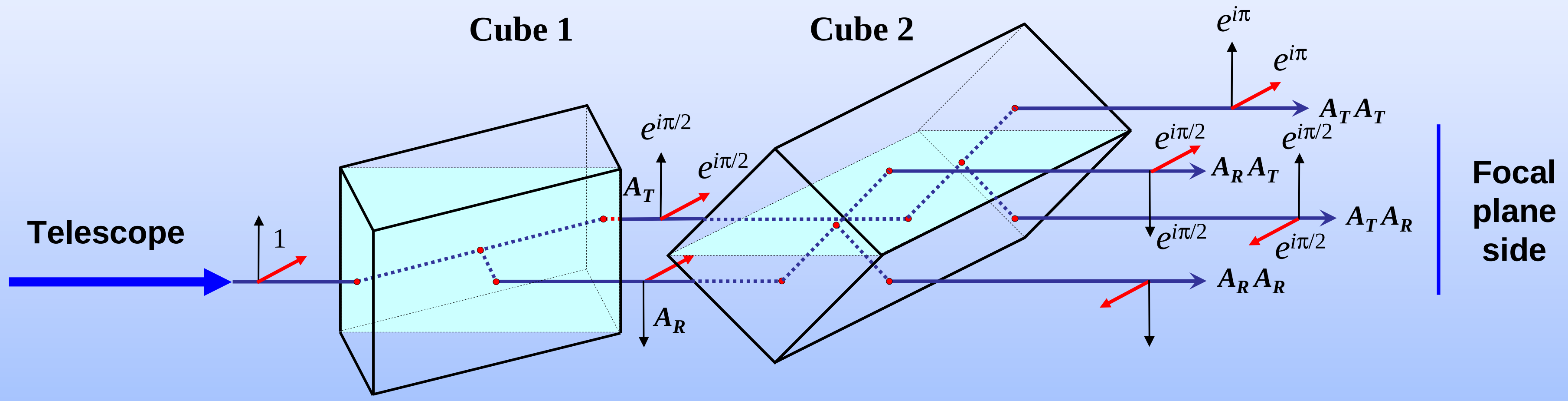
Principle

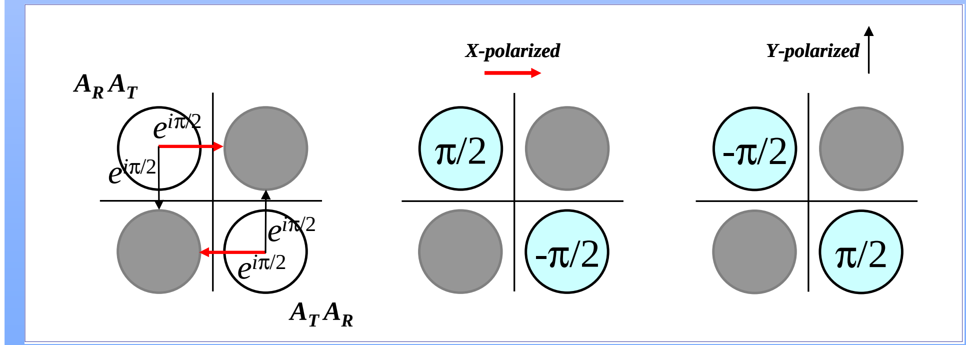
- Both cubes have their semi-reflective (SR) planes perpendicular one to the other
- The input beams propagates parallel to both cubes SR layers
- It is spitted into four parallel beams, being recombined axially
- A null is created at the focal plane centre between the two diagonal, intensity symmetric outputs
- It is independent wavelength, **chromatic flux unbalance** and polarization orientation
- When used in reverse sense, this is actually an Achromatic phase shifter (APS)

- "Cheapest nuller in the world: Crossed beamsplitter cubes," Proceedings of the SPIE vol. 9146, n°914604 (2014)
- "Experimental demonstration of a crossed cubes nuller for coronagraphy and interferometry," Proceedings of the SPIE vol. 9907, n°99072H (2016)

Cubes polarization model

- Shown in coronagraph mode (interferometric mode is in reverse sense)
- Only the two diagonal symmetric ports are usable for nulling





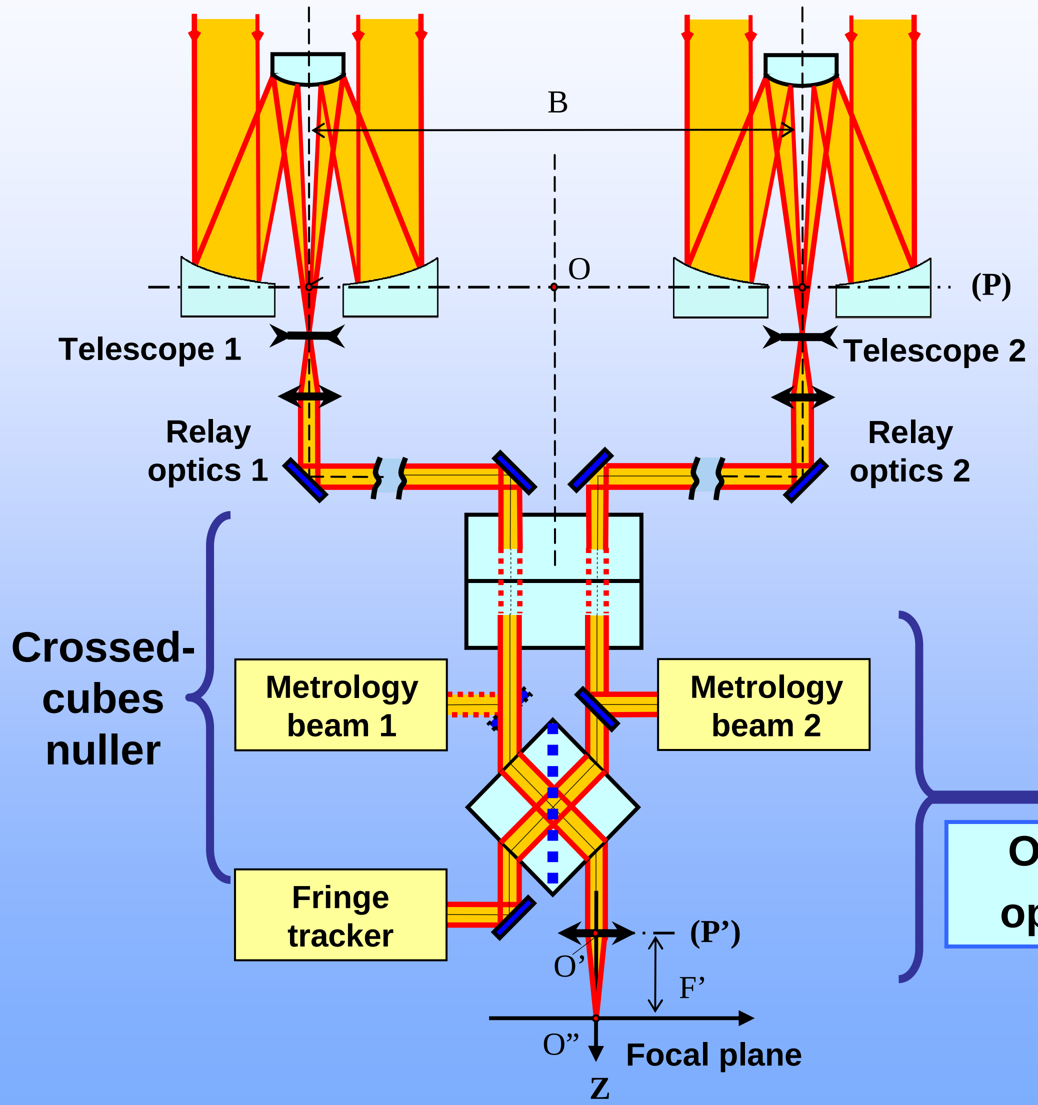
Modified Mach-Zehnder (MMZ) :

$$N = T_{C1}(\lambda)T_{C2}(\lambda) - R_{C1}(\lambda)R_{C2}(\lambda)$$

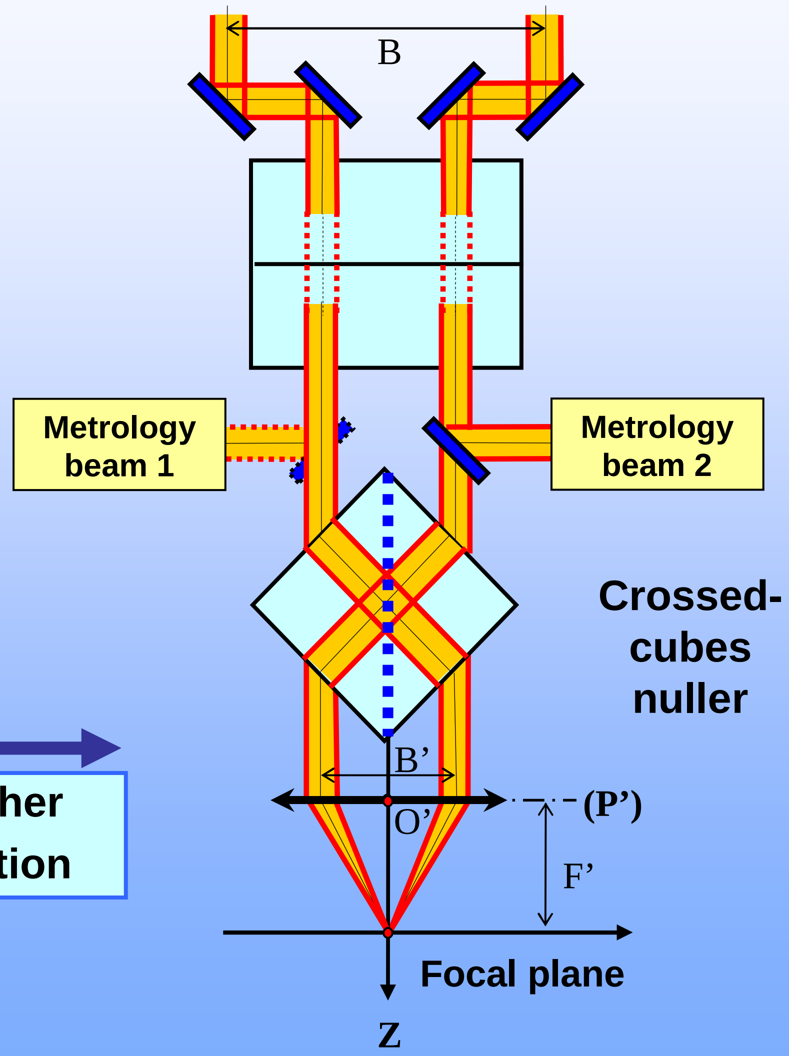
CCN :

$$N = R_{C1}(\lambda)T_{C2}(\lambda) - T_{C1}(\lambda)R_{C2}(\lambda)$$

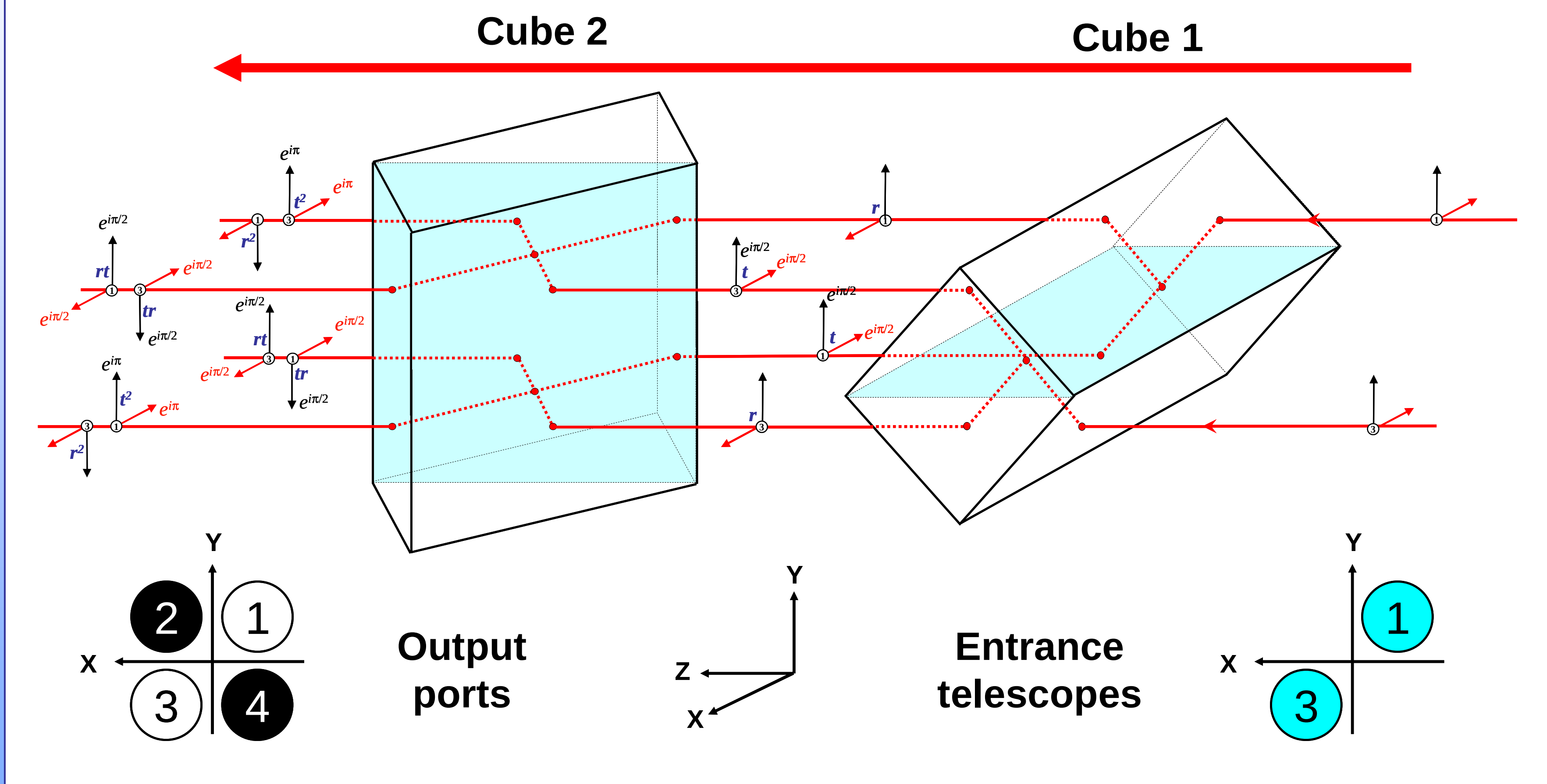
Use as a nulling combiner



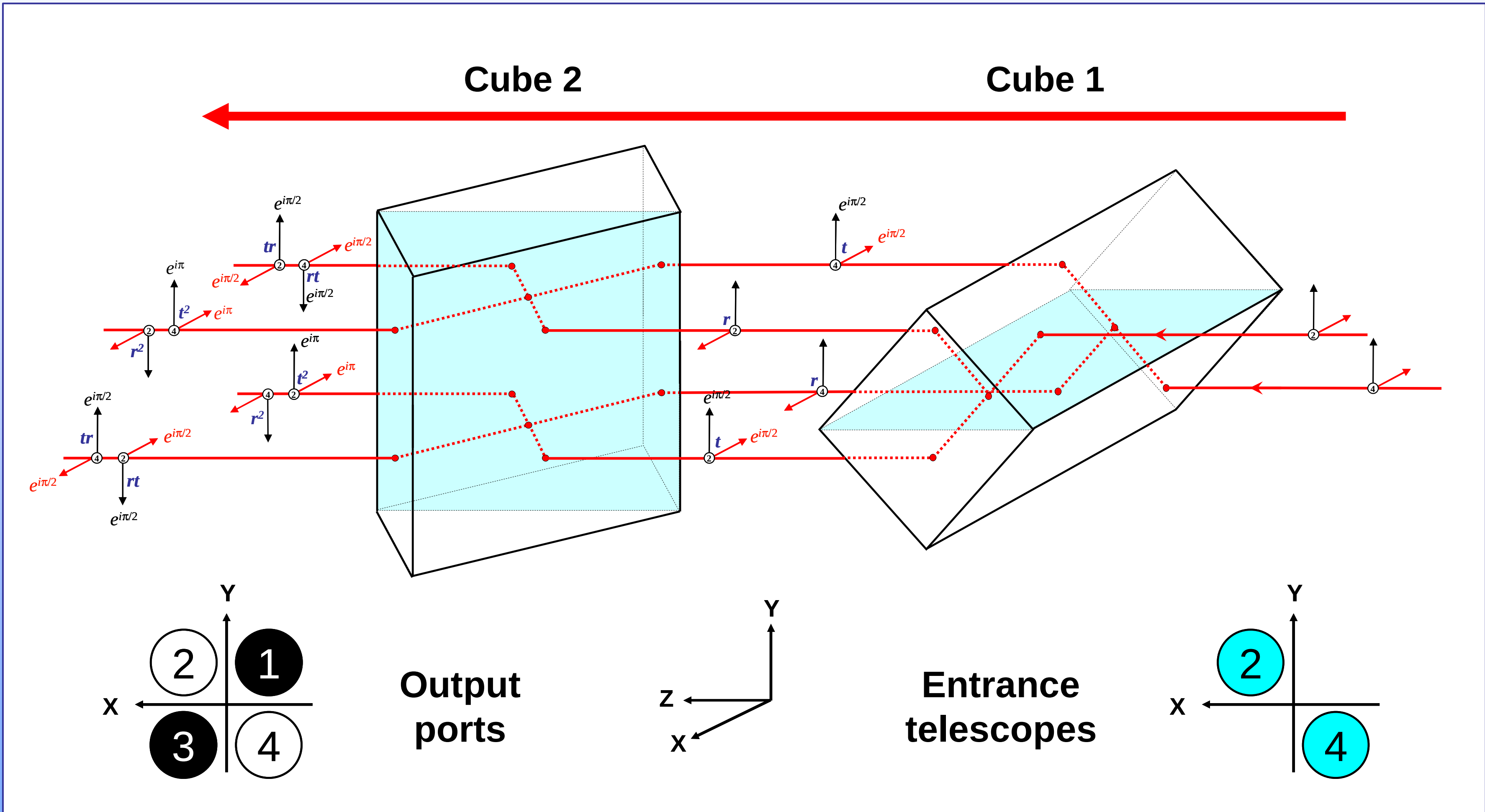
Other option



Use as a nulling combiner – polarization model



Use as a nulling combiner – polarization model



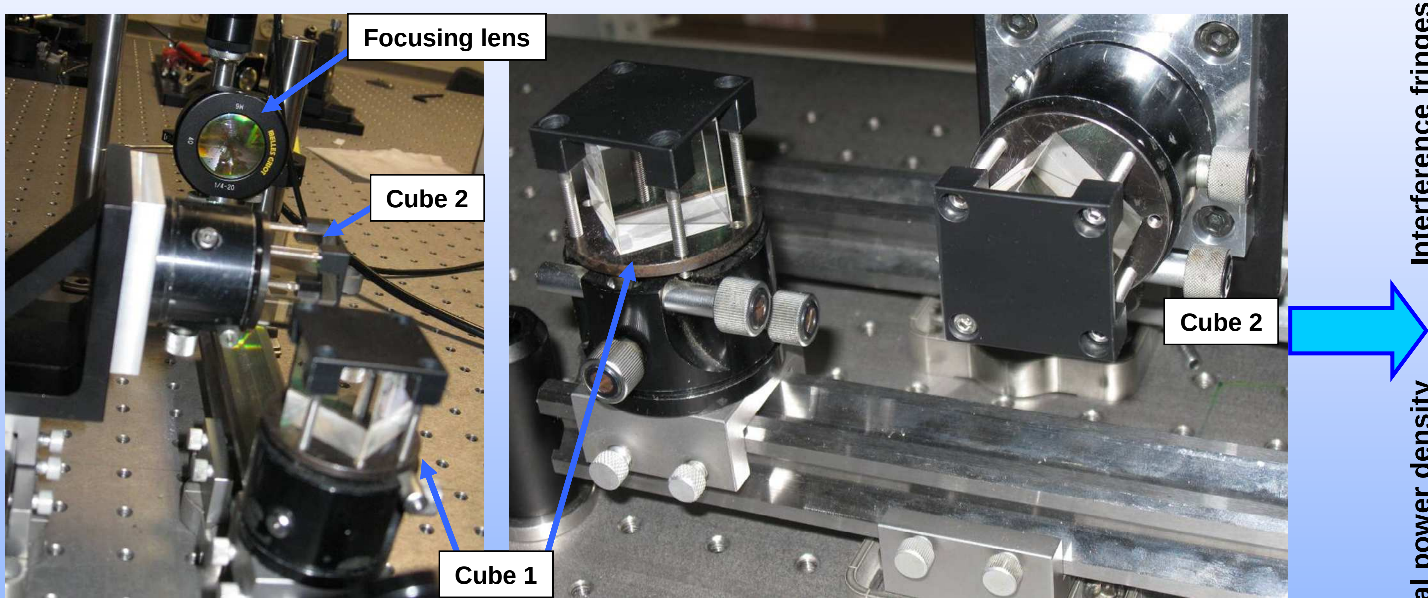
Preliminary manufacturing requirements

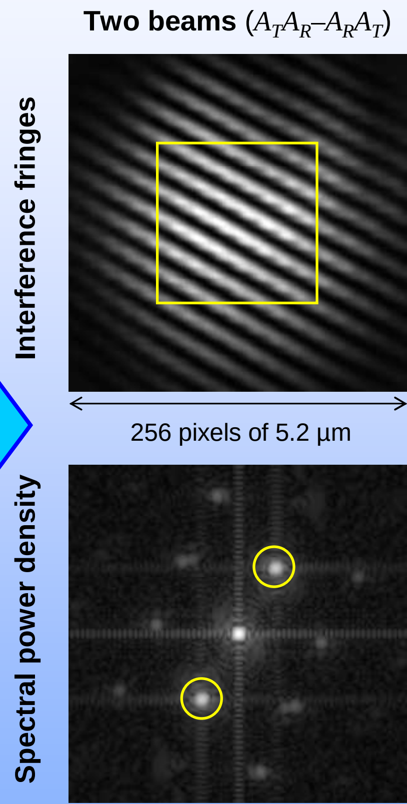
- If OPDs are compensated for by optical delay lines, there remains one tight specification: Flux balance < 0.1 %

PARAMETER	REQUIRED VALUE	EQUIVALENT NULLING RATE	REMARKS
Operating wavelength	λ = 10 µm		Depending on science requirements
Spectral range	8-12 µm		Depending on science requirements
Semi-reflective layer (SR)			
Transmission factor	50 ± 0.1 %		On full spectral band
Reflection factor	50 ± 0.1 %		On full spectral band
Flux mismatch	< 0.1 %	1.0E-06	On full spectral band
Anti-reflective coating (AR)	Standard		λ/4 AR coating
Geometrical parameters			
Cube hypotenuse	75.5 ± 0.1 mm		Case of ZnSe material
Transmitted pathlength in glass	21.4 ± 0.1 mm		Case of ZnSe material
Reflected pathlength in glass	21.4 ± 0.1 mm		Case of ZnSe material
Pathlength difference in glass	< 0.005 µm	9.8E-06	Only applicable to coronagraph
Angular errors	< 3 arcmin	7.6E-07	For both SR/AR faces, including pyramid
Wavefront error	< λ/4 PTV	0.0E+00	For both transmitted and reflected beams, on each sub-pupil
	Total Null (RMS sum)	4.6E-06	

Experiment and test results

- At Institut de Planétologie et d'Astrophysique de Grenoble (June 2016)





First fringes

N ≈ **1.8 10^{-3}**

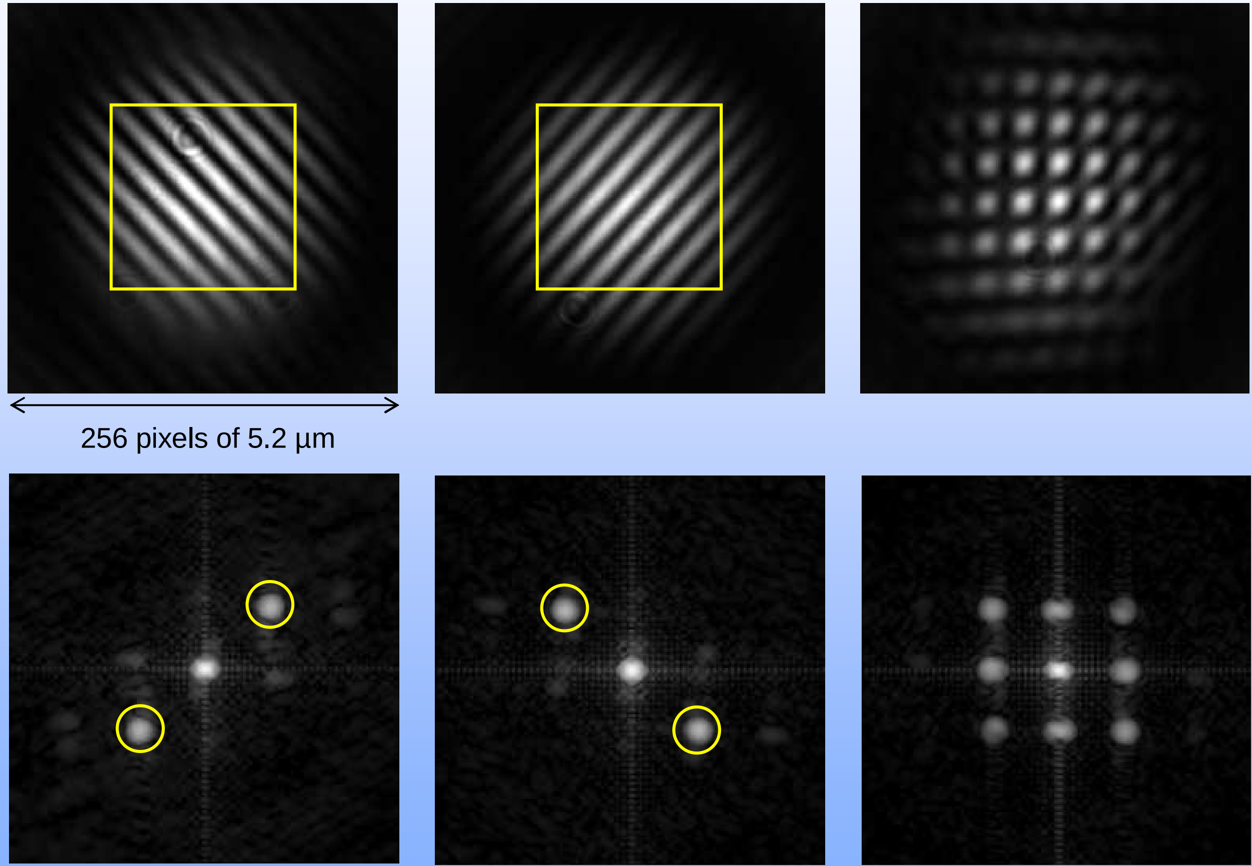
- At Laboratoire Lagrange (Observatoire de la Côte d'Azur): New tests in preparation

Experiment and test results

Two beams ($A_T A_R - A_R A_T$) | Two beams ($A_T A_T - A_R A_R$) | Four beams

Interference fringes

Spectral power density



256 pixels of 5.2 µm

Destructive and symmetric (balanced)	Constructive and not symmetric
N ≈ 1.8 10^{-3}	N ≈ 2.2 10^{-3}

Unlike Mach-Zehnder interferometer !

Discussion / Main advantages

- Simple, compact, low mass and volume
- Reasonable manufacturing tolerances
- Potentially not expensive
- High throughput, close to maximum
- Good candidate for future space missions characterizing extra-solar planets atmospheres

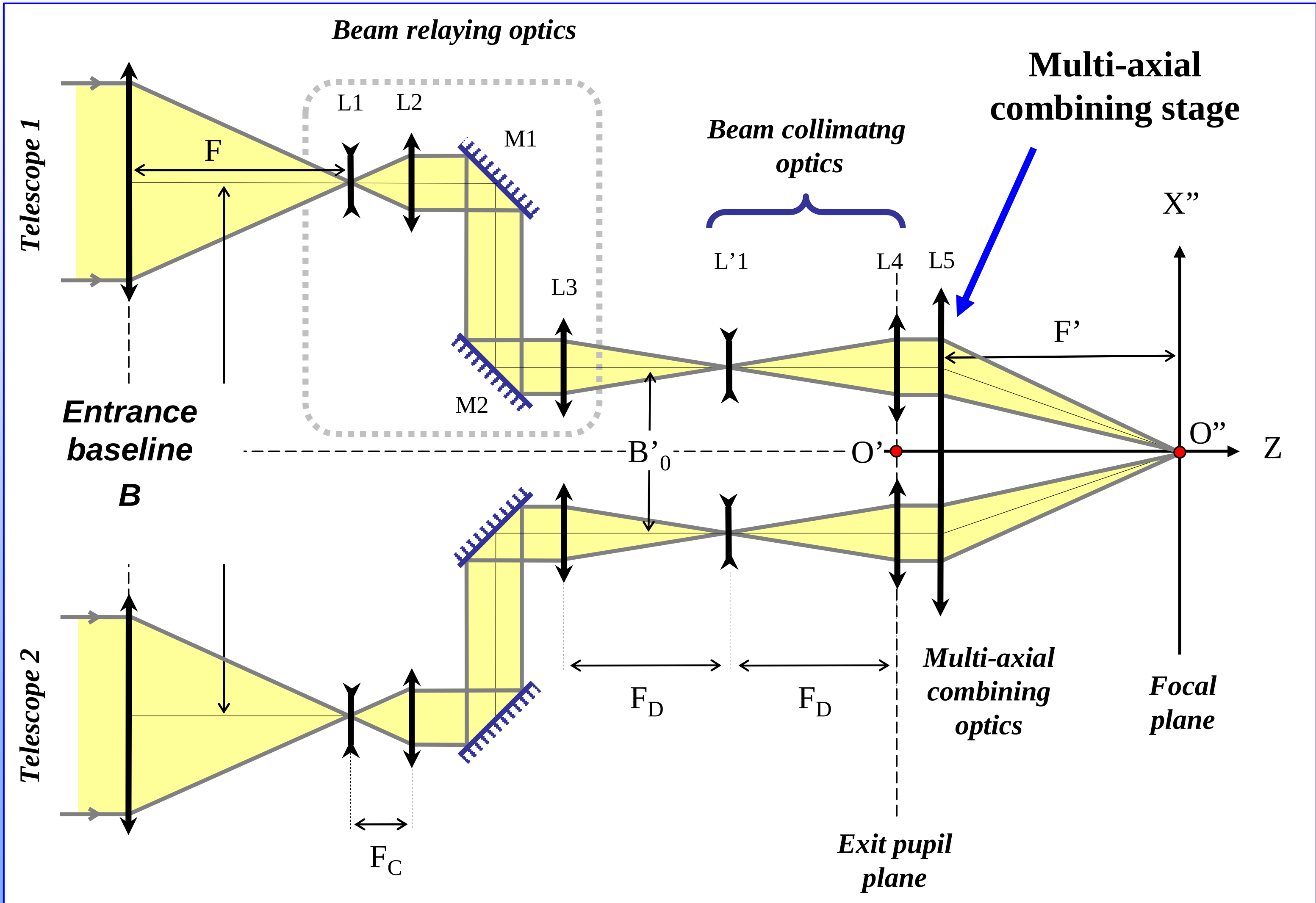
  – Can also be implemented into a nulling coronagraph telescope

The Crossed Cube Nuller could also be integrated into a

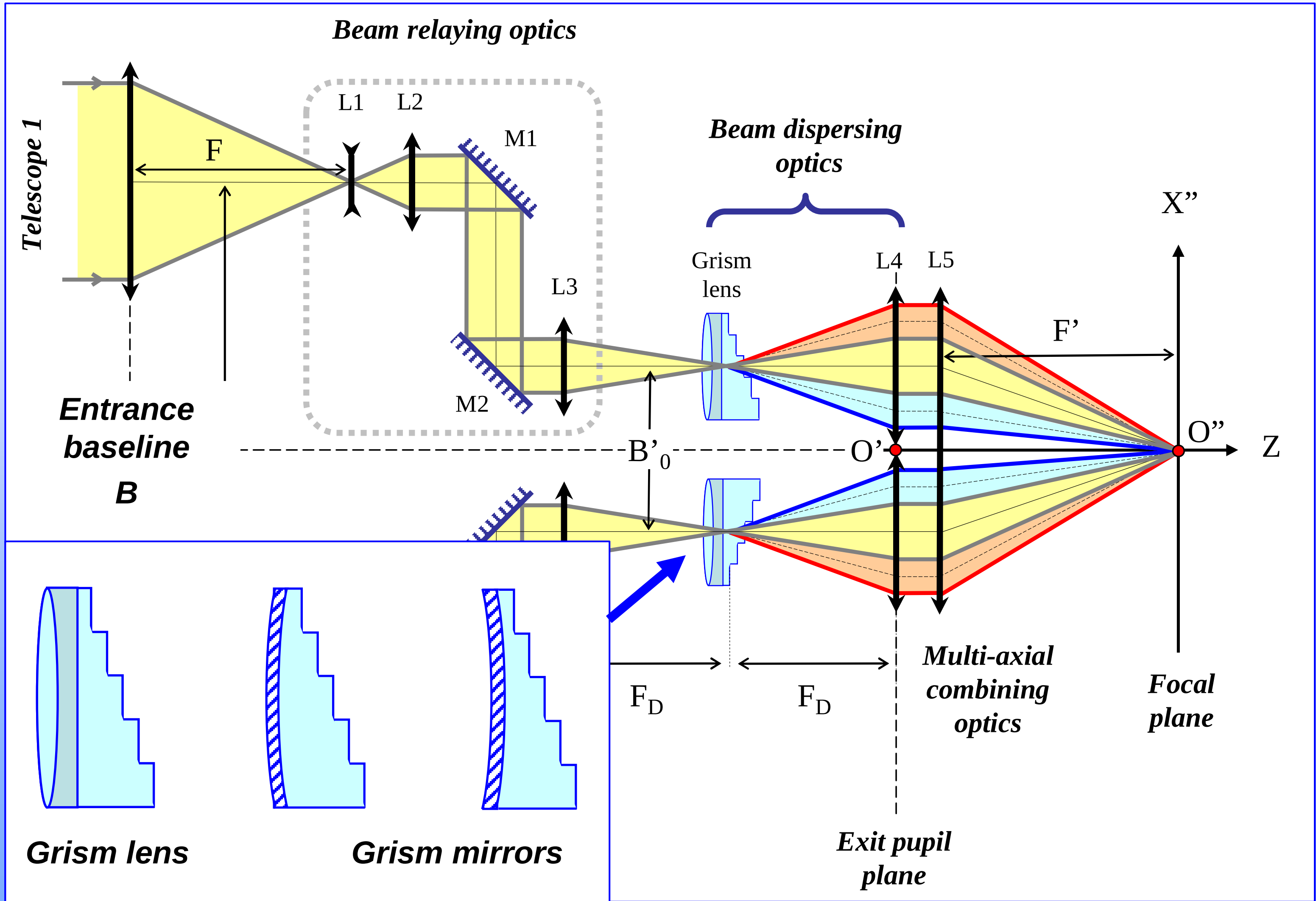
Fully achromatic nulling interferometer (FANI) for high SNR exoplanet characterization

Proceedings of the SPIE vol. 9605, n°960512 (2015)

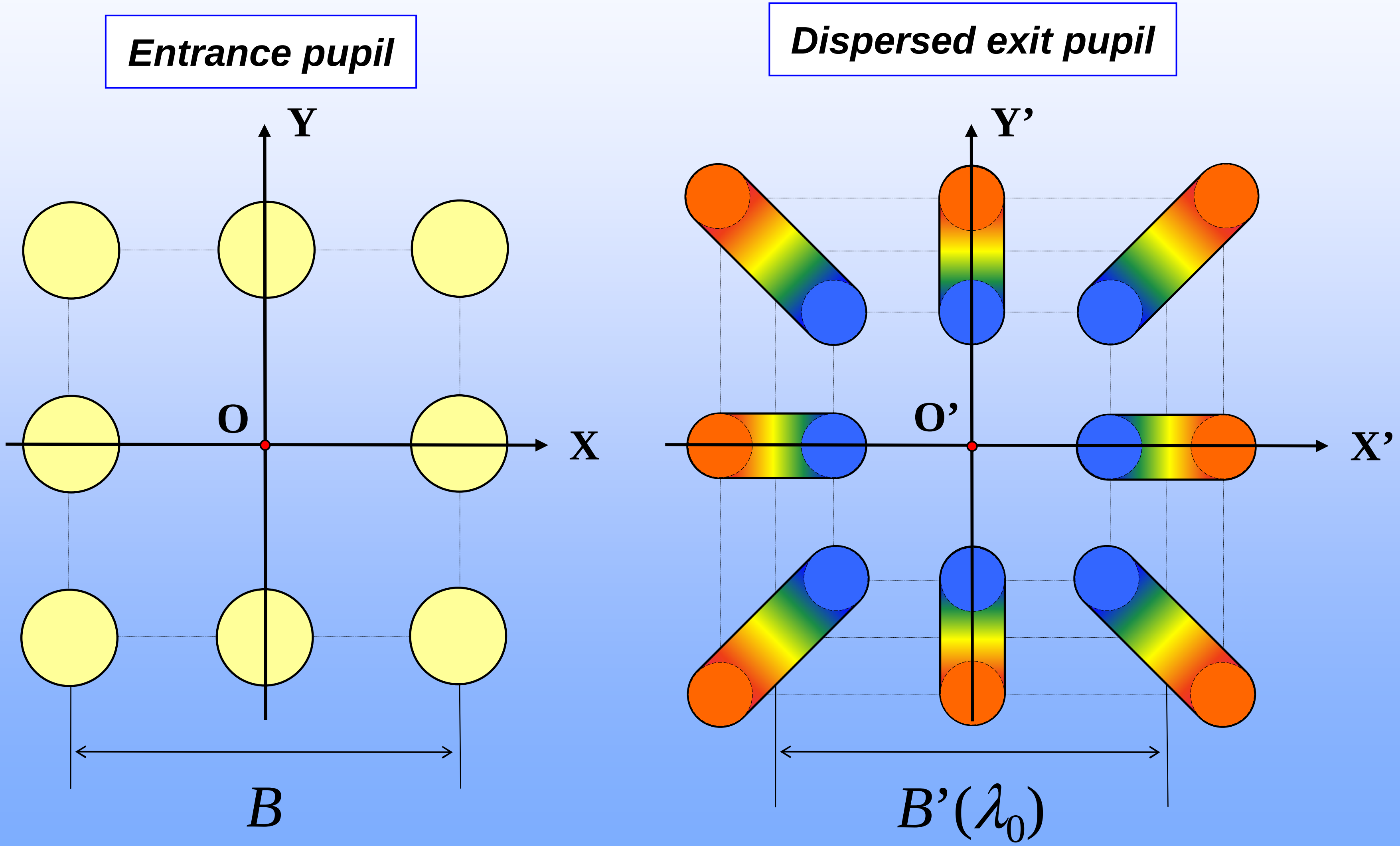
Classical interferometer



Fully achromatic nulling interferometer



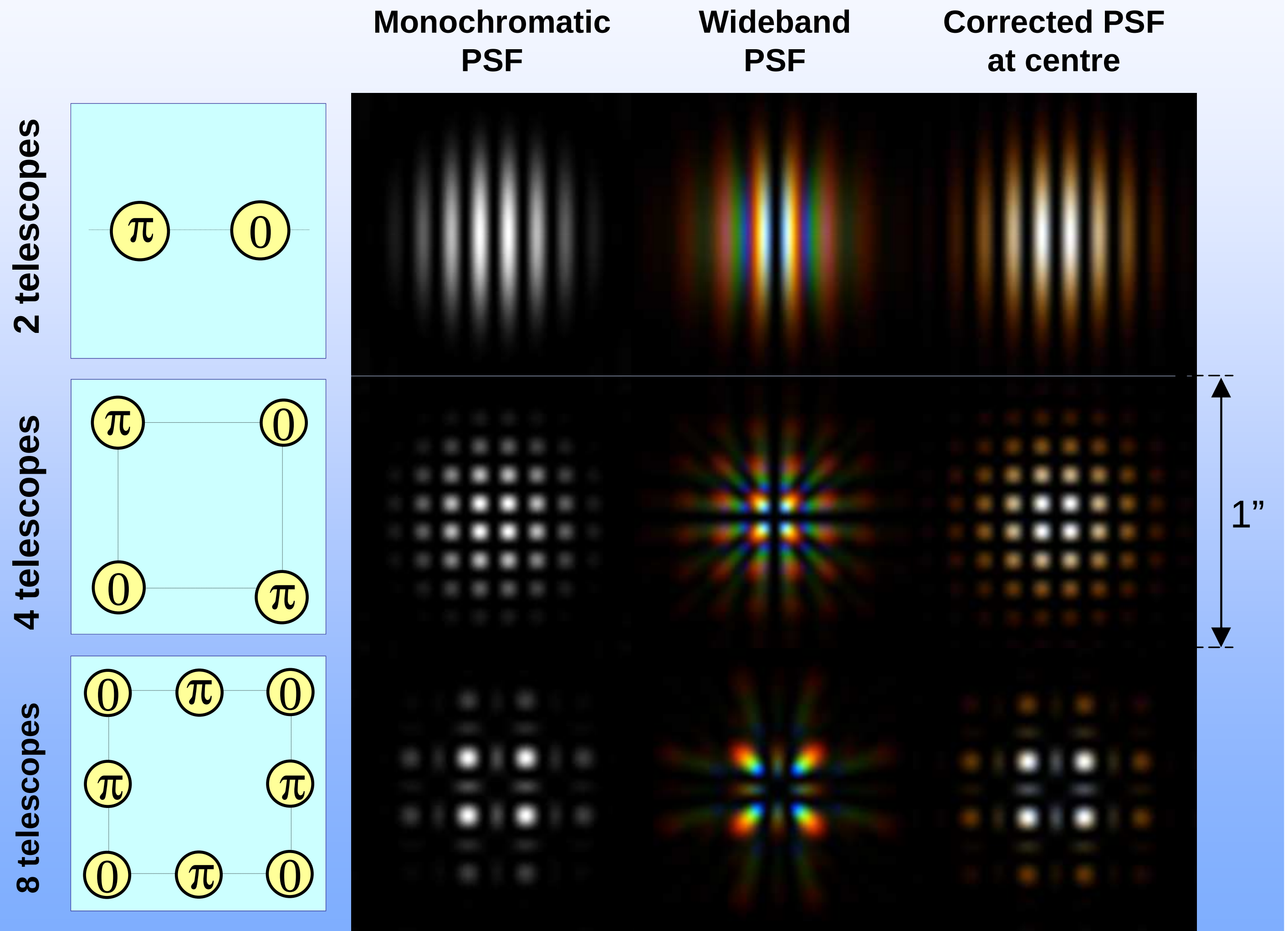
Fully achromatic nulling interferometer



Simulated fringe patterns (Fizeau interferometer)

Specifications

- Spectral range
  7-14 µm
- Entrance baseline
  B = 20 m
- Telescope diameter
  D = 5 m
- Compression factor
  m = 1/500
- Dispersive material
  ZnSe
- Fizeau interferometer
  at λ = 10.5 µm



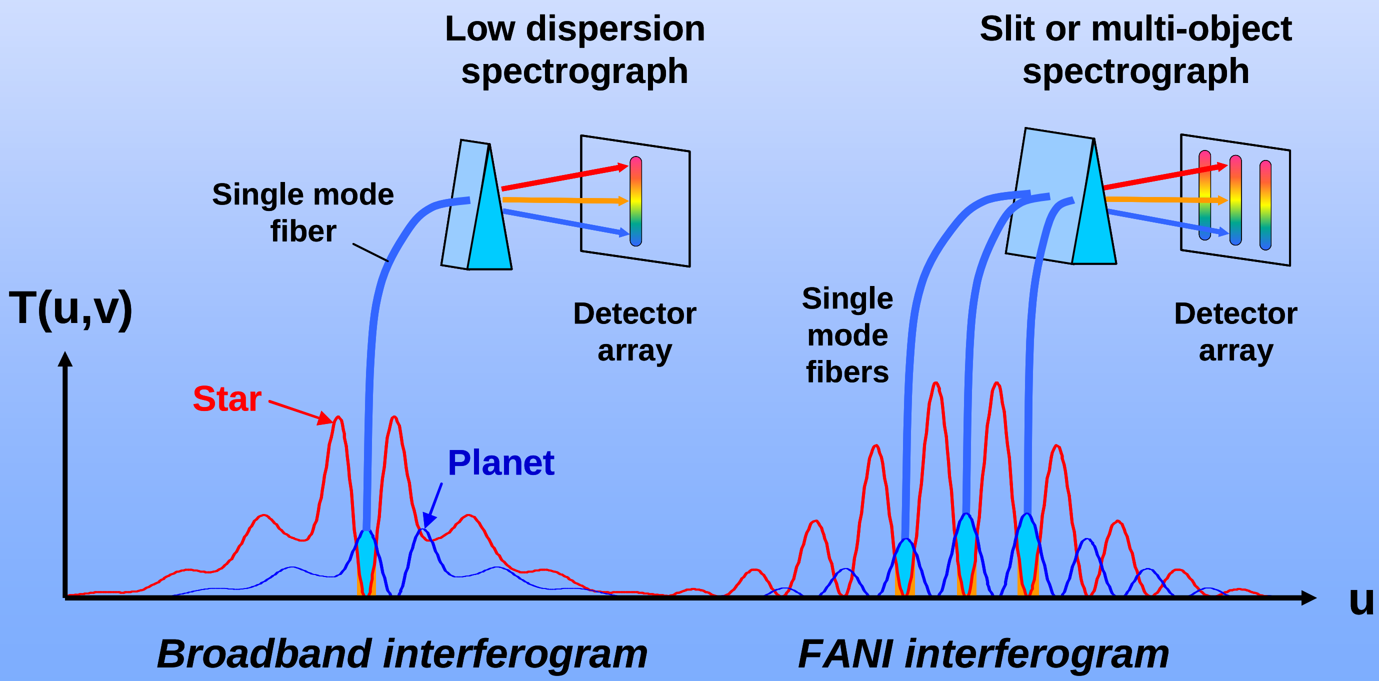
Also covered in the original paper

- Mathematical analysis
- Dimensioning the dispersive element
- Preliminary optical design
- Preliminary tolerancing (no critical alignment)

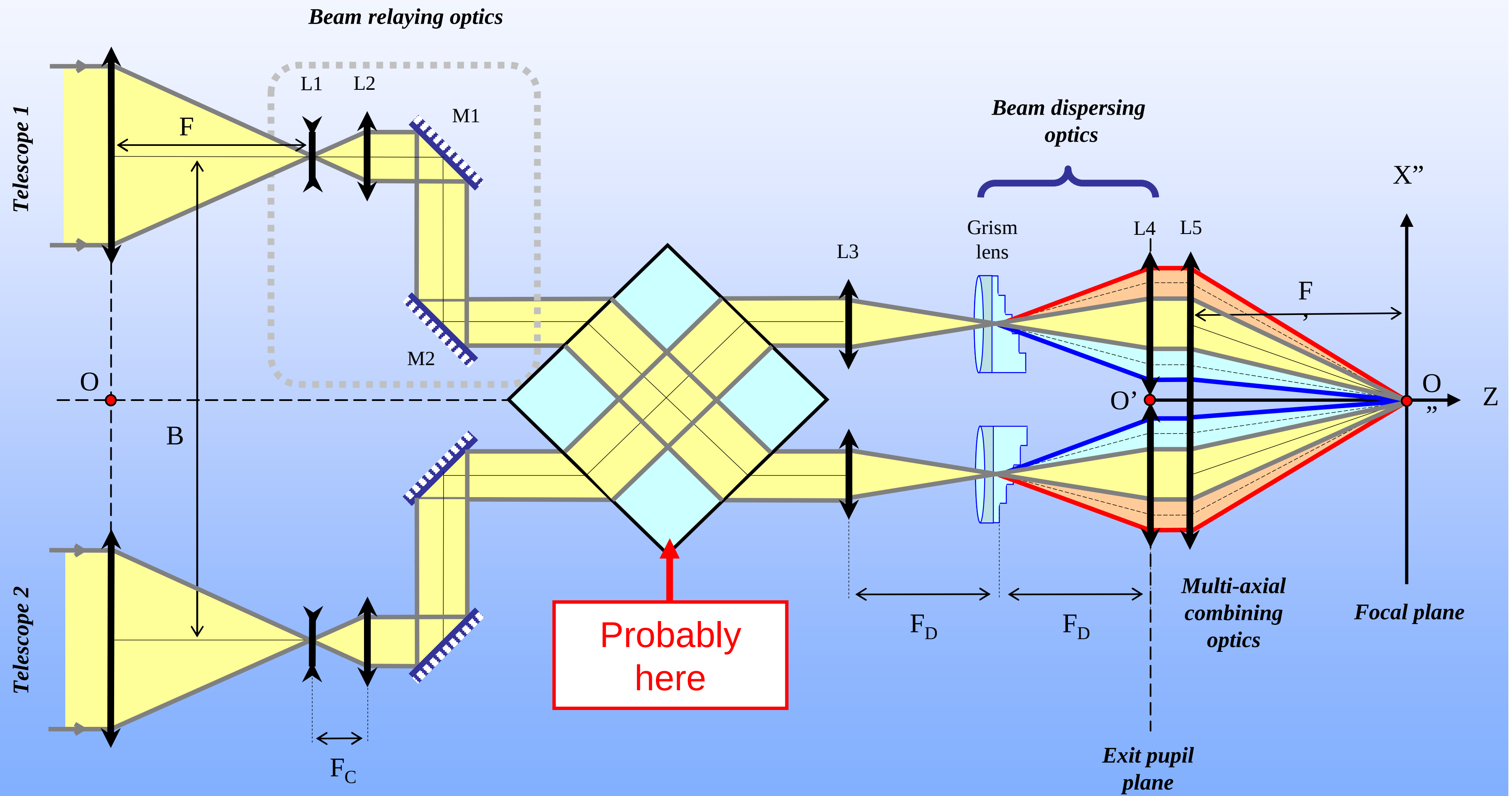
Geometrical parameter	Tolerance
Grism mirror translation along Z-axis	≤ 0.1 mm
Grism mirror decenter (along X' and Y' axes)	≤ 1 mm
Grism mirror tilt around X'-axis	≤ 5 degs.
Grism mirror tilt around Y'-axis	≤ 1 deg.
Grism mirror roll angle(around Z-axis)	≤ 5 degs.
Grism thickness at centre	≤ 0.1 mm
Grism angle α	≤ 1 deg.

Potential SNR gain

- Planet detection possible on ***all*** bright fringes → Higher Signal
- If used as a imaging stellar interferometer, SNR gain $\approx\sqrt{n}$ for read noise
- **But**:
  - No quantitative study has been done so far
  - May not be useful for all types of spectrographs (IFS ?)

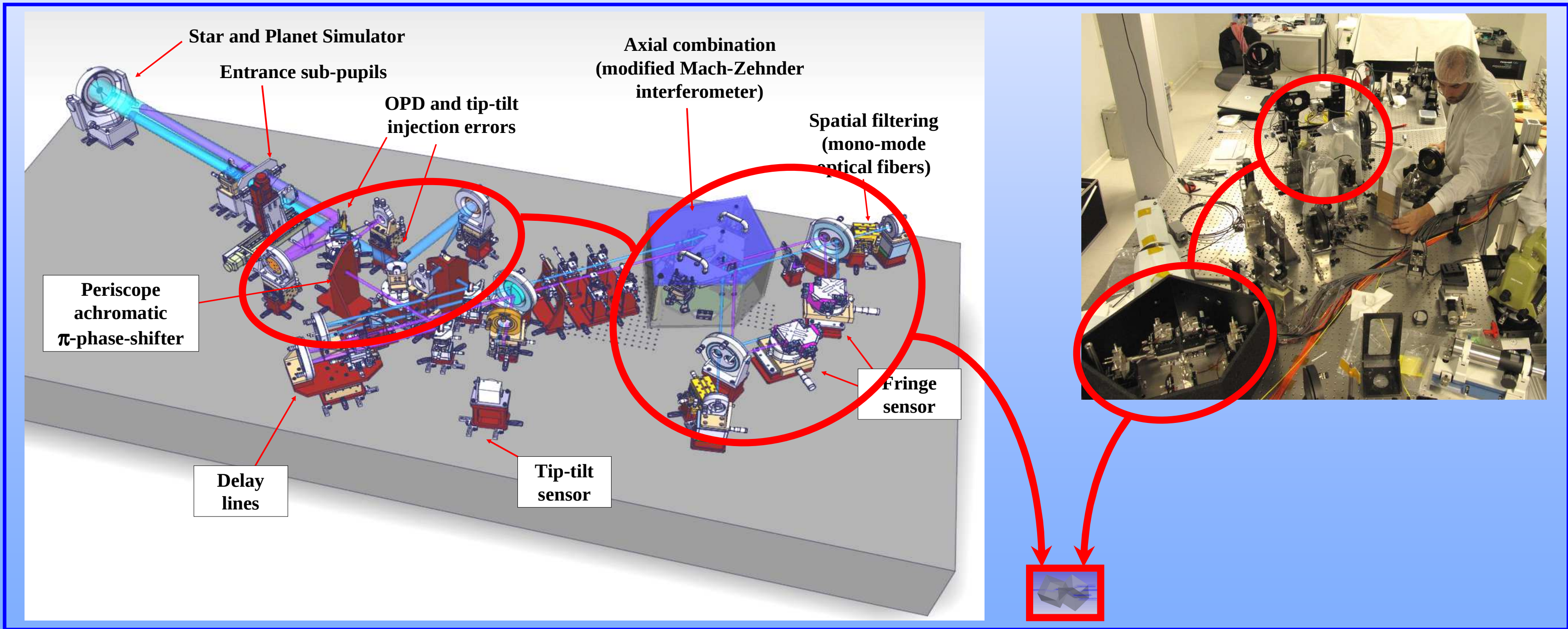


Where should we put the CCN ?



Conclusion

- CCN could have been used to build “**PERSEE interferometer in a nutshell**”
- Quick and dirty experiment in coronagraph configuration shows extinction below 1/256 bits
  - Next step: Measurements with higher dynamic range (Lagrange)
  - Demonstration in interferometer configuration (reverse) remains to be done



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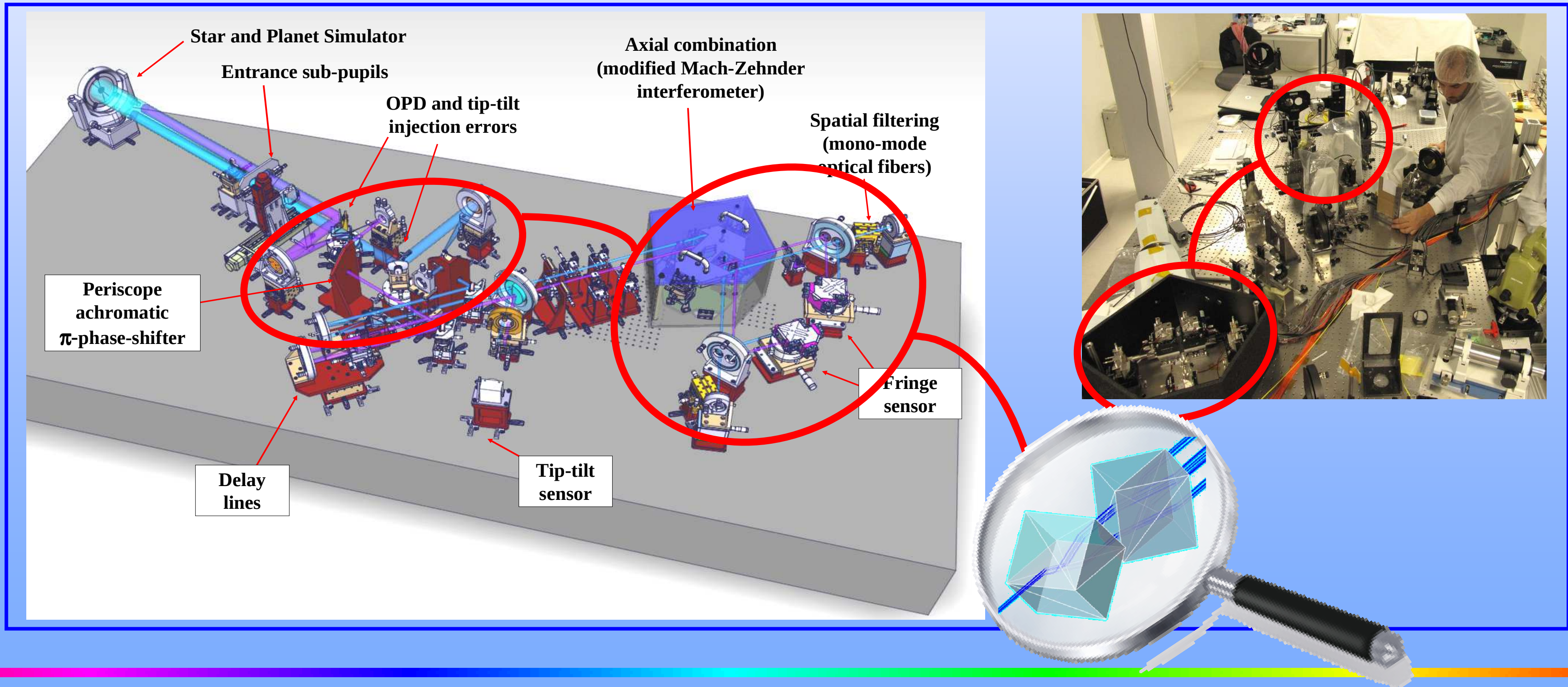

Questions ?