*Workshop R&D Virgo, Institut Fresnel, Marseille, 4-6 mars 2024*

# Caractérisation composants
## Lumière diffusée, bruit thermique

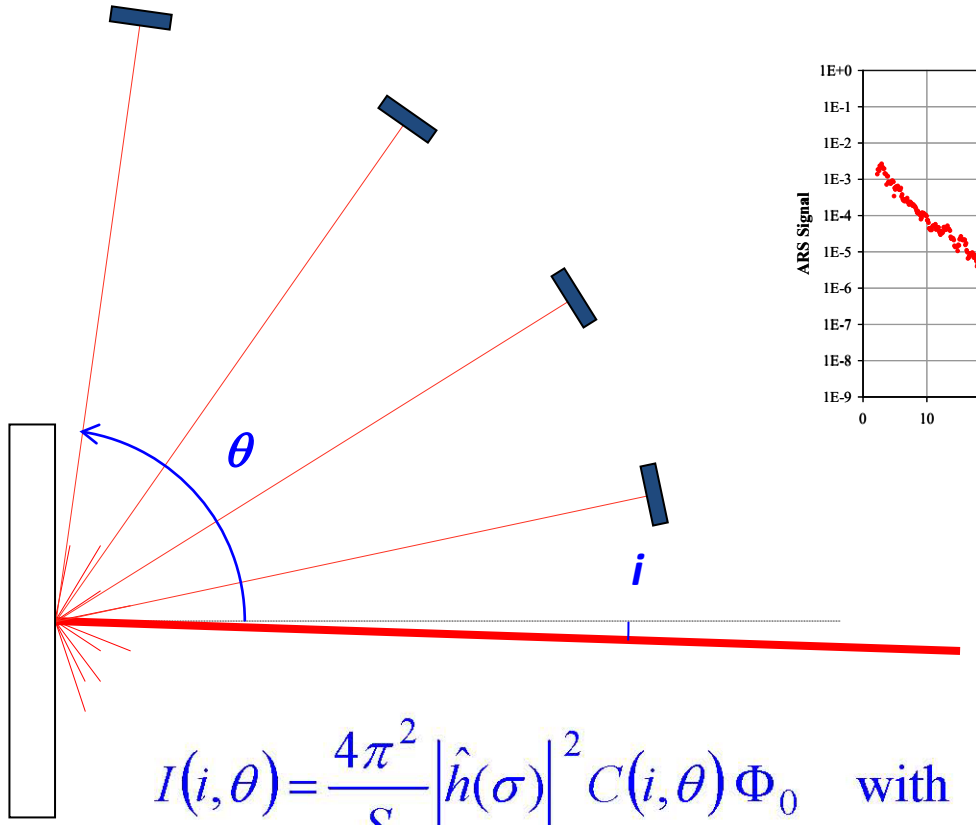
*Michel LEQUIME and Myriam ZERRAD*

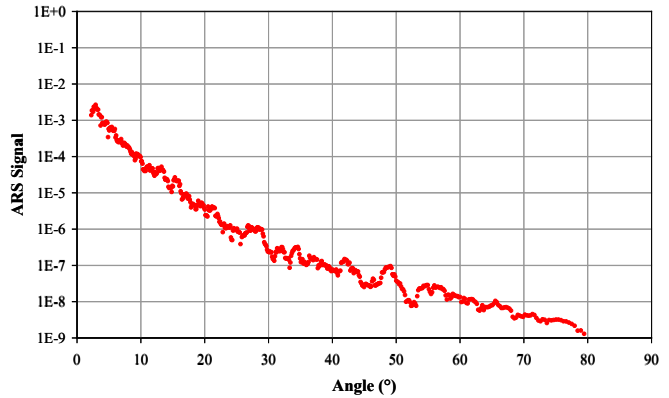
# Outline

- **3 key R&D topics**
  - Develop an improved version of ***SPARSE*** capable of detecting the presence of ***point defects*** on the surface of a ***large diameter substrate***, coated or uncoated, and determining the contribution of these defects to scattering loss budget.
  - Develop an improved version of ***BARRITON*** capable of detecting the axial position and strength of retroreflection and/or ***backscatter sources*** along the optical axis of a ***large instrument***.
  - Development of a compact and ***adjustment free*** interferometric instrument for the measurement of the ***thermal noise*** of an optical interference coating (***GRAVITERM***).

# SPARSE – Point Defects

- **BRDF measurement - Standard configuration**

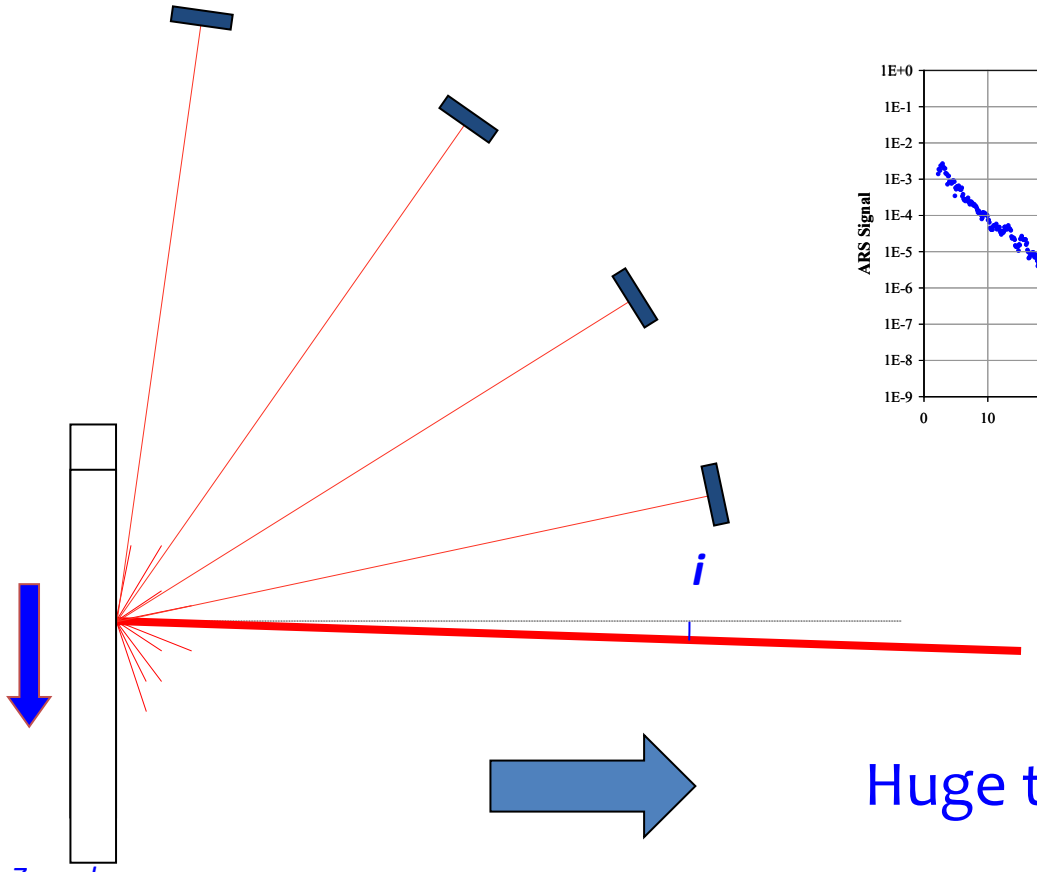


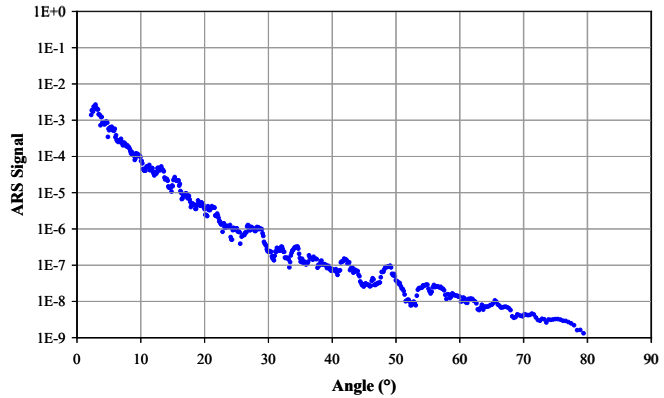




$$I(i,\theta) = \frac{4\pi^2}{S}\left|\hat{h}(\sigma)\right|^2 C(i,\theta)\,\Phi_0 \quad \text{with} \quad \sigma = \frac{2\pi}{\lambda}(\sin\theta - \sin i)$$

# SPARSE – Point Defects

- **BRDF measurement - Spatial sample scan configuration**

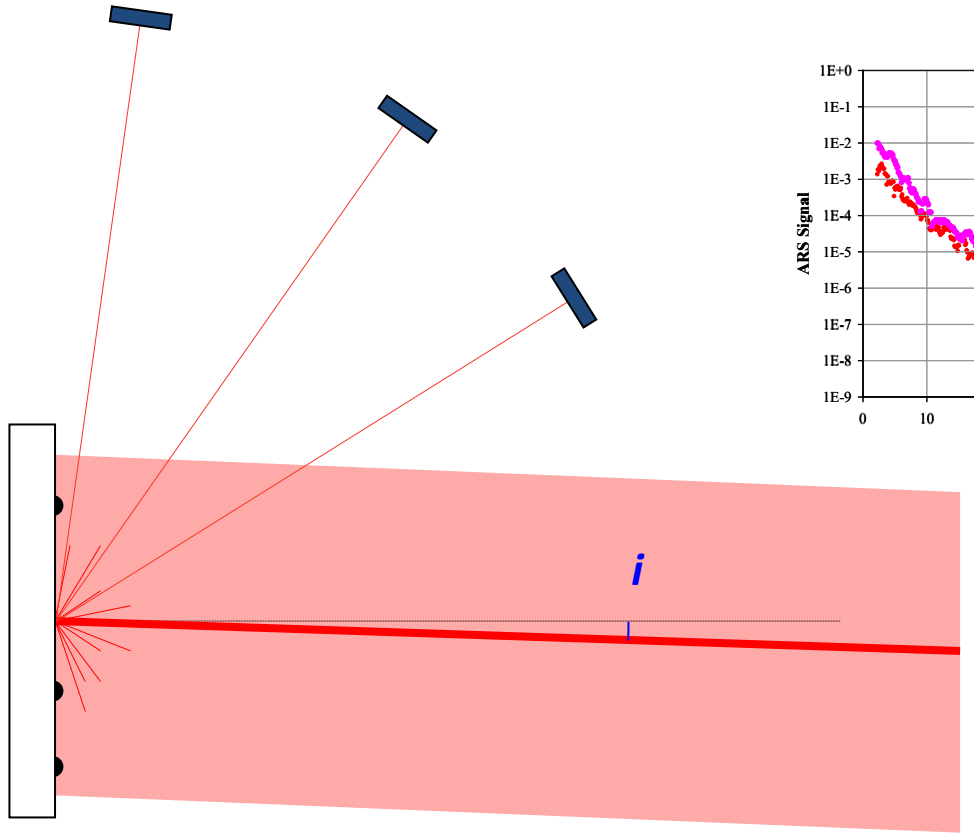


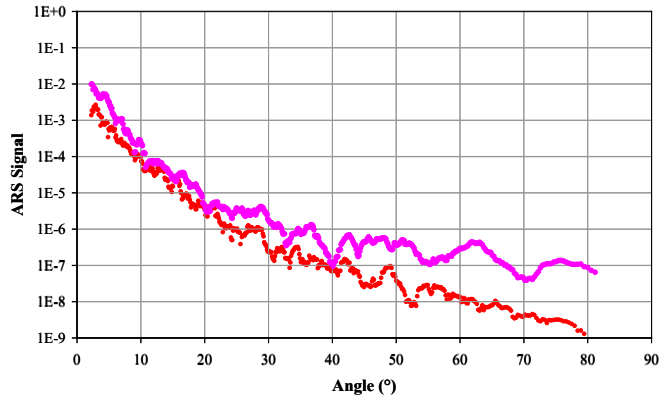




Huge time required for acquisition

# SPARSE – Point Defects

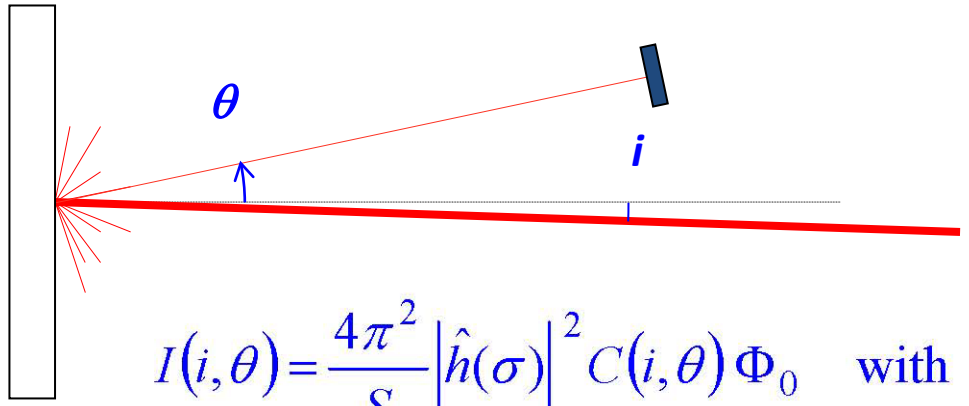
- **BRDF measurement - Extended beam configuration**



# SPARSE – Point Defects

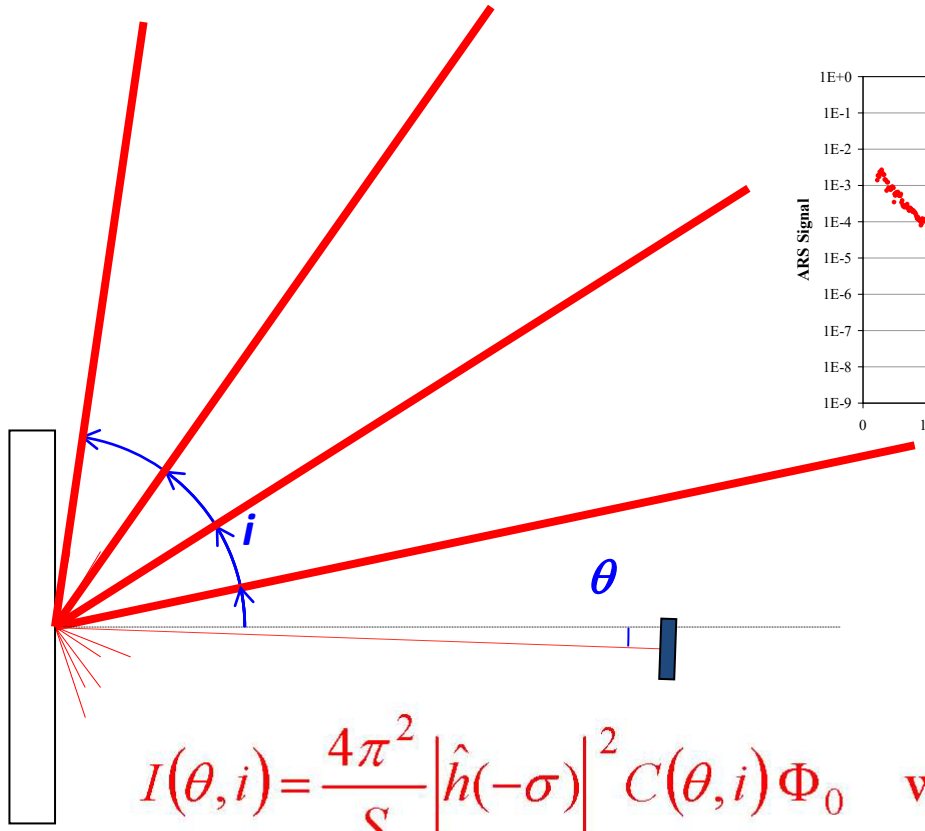
- **BRDF measurement – Standard configuration**

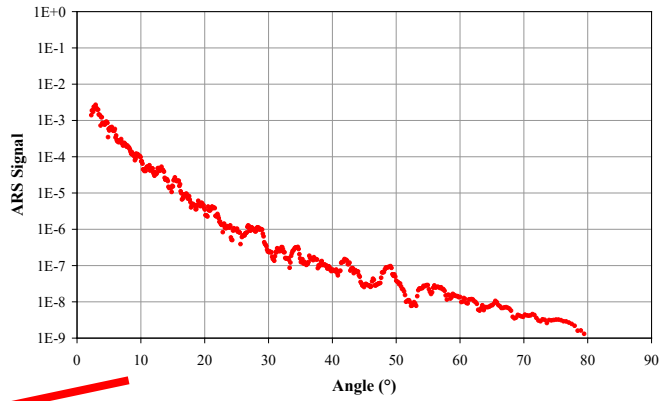



$$I(i,\theta) = \frac{4\pi^2}{S}\left|\hat{h}(\sigma)\right|^2 C(i,\theta)\,\Phi_0 \quad \text{with} \quad \sigma = \frac{2\pi}{\lambda}(\sin\theta - \sin i)$$

# SPARSE – Point defects

- **BRDF measurement - Reverse configuration**

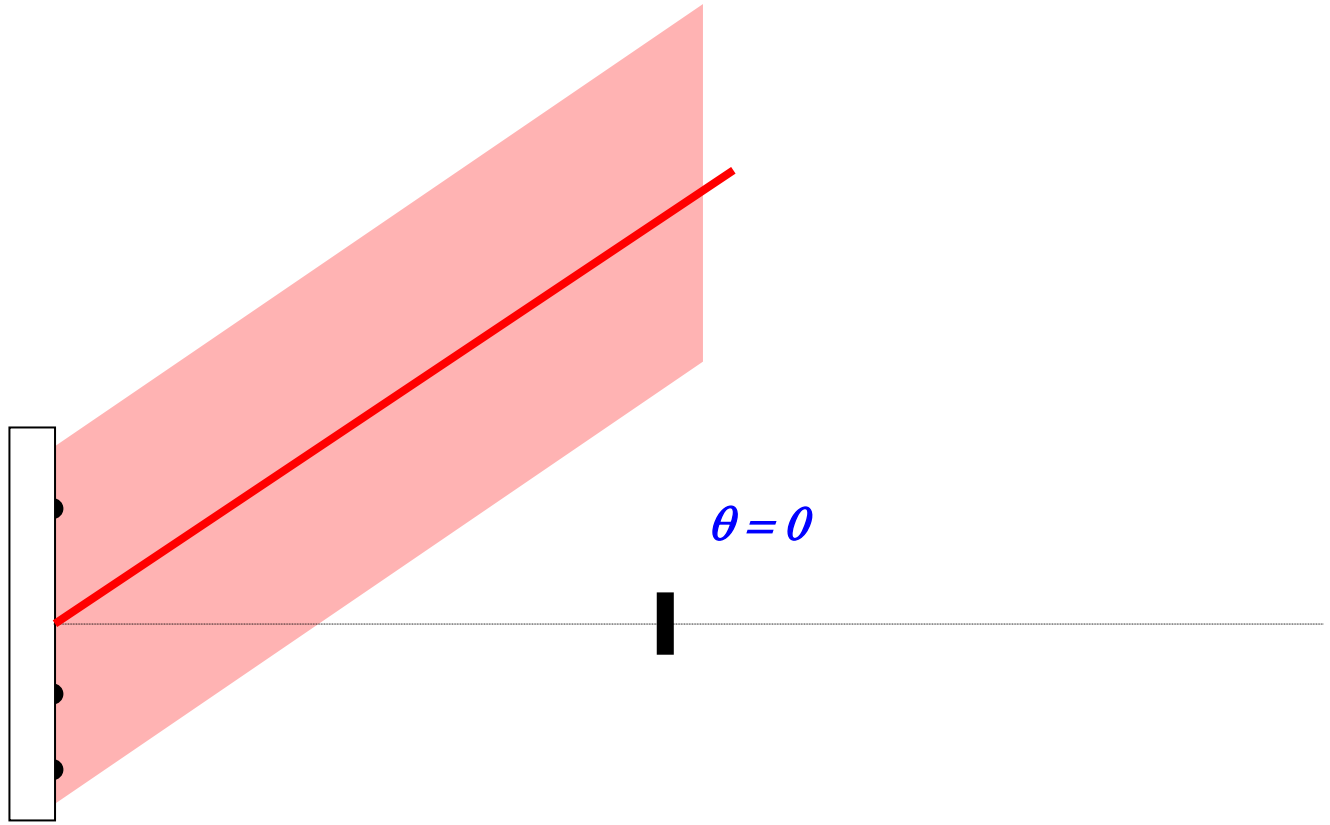



$$I(\theta,i)=\frac{4\pi^2}{S}\left|\hat{h}(-\sigma)\right|^2 C(\theta,i)\,\Phi_0 \quad \text{with} \quad \sigma=\frac{2\pi}{\lambda}(\sin\theta-\sin i)$$

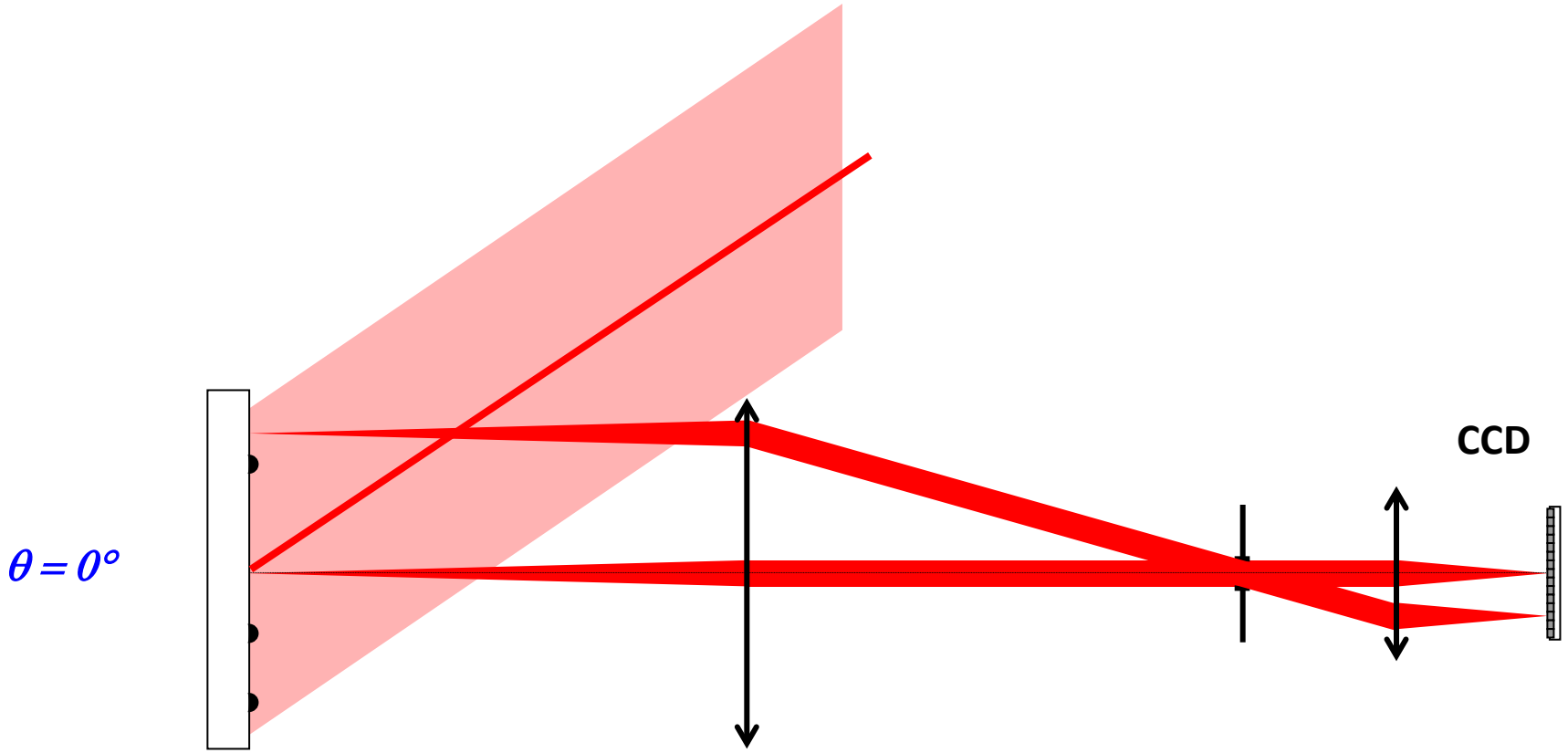
# SPARSE – Point Defects

- **BRDF measurement - Reverse configuration with extended beam**



# SPARSE – Point Defects

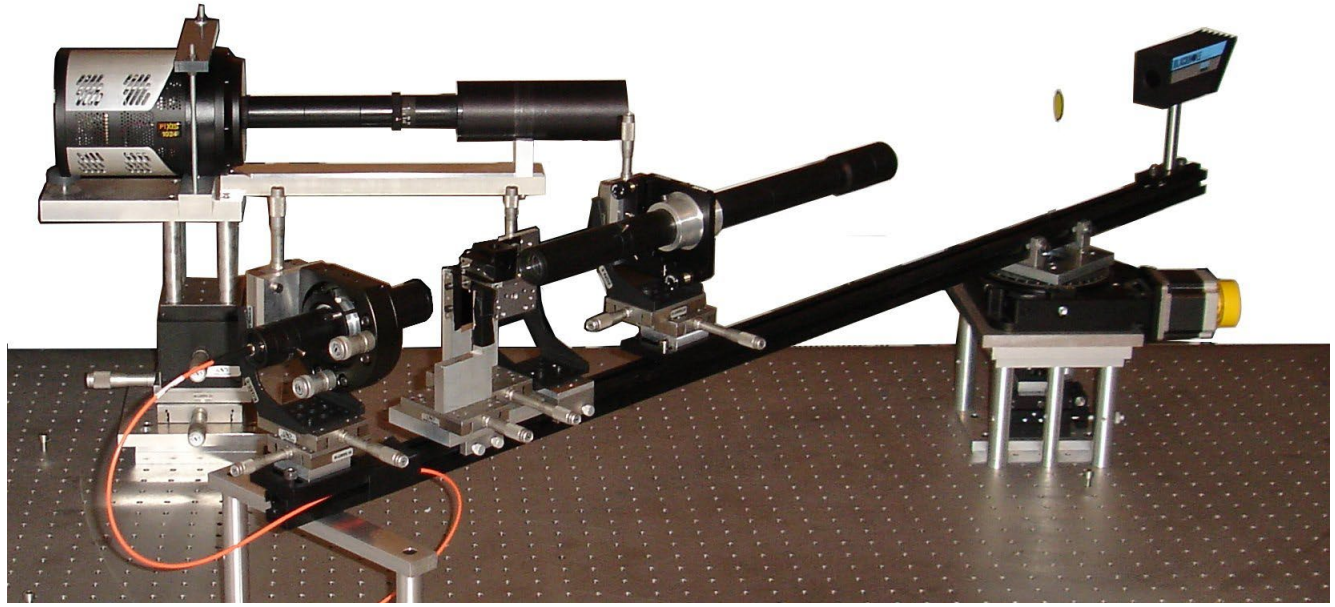
- **BRDF measurement - Reverse configuration with extended beam and photodetector array**




Telecentric objective

# SPARSE – Point defects

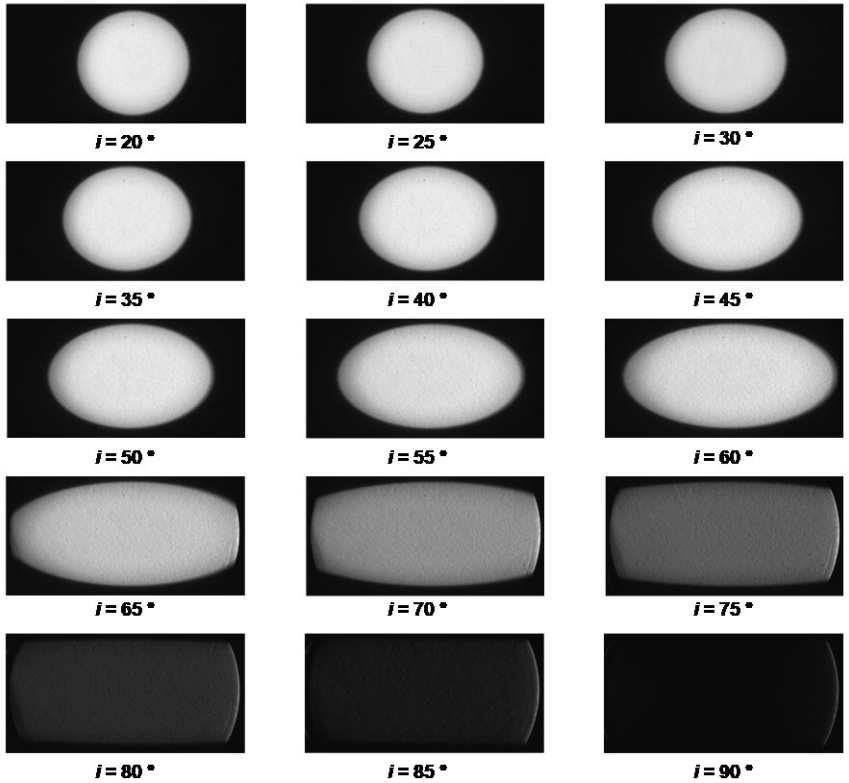
- **Reverse configuration with extended beam and photodetector array**



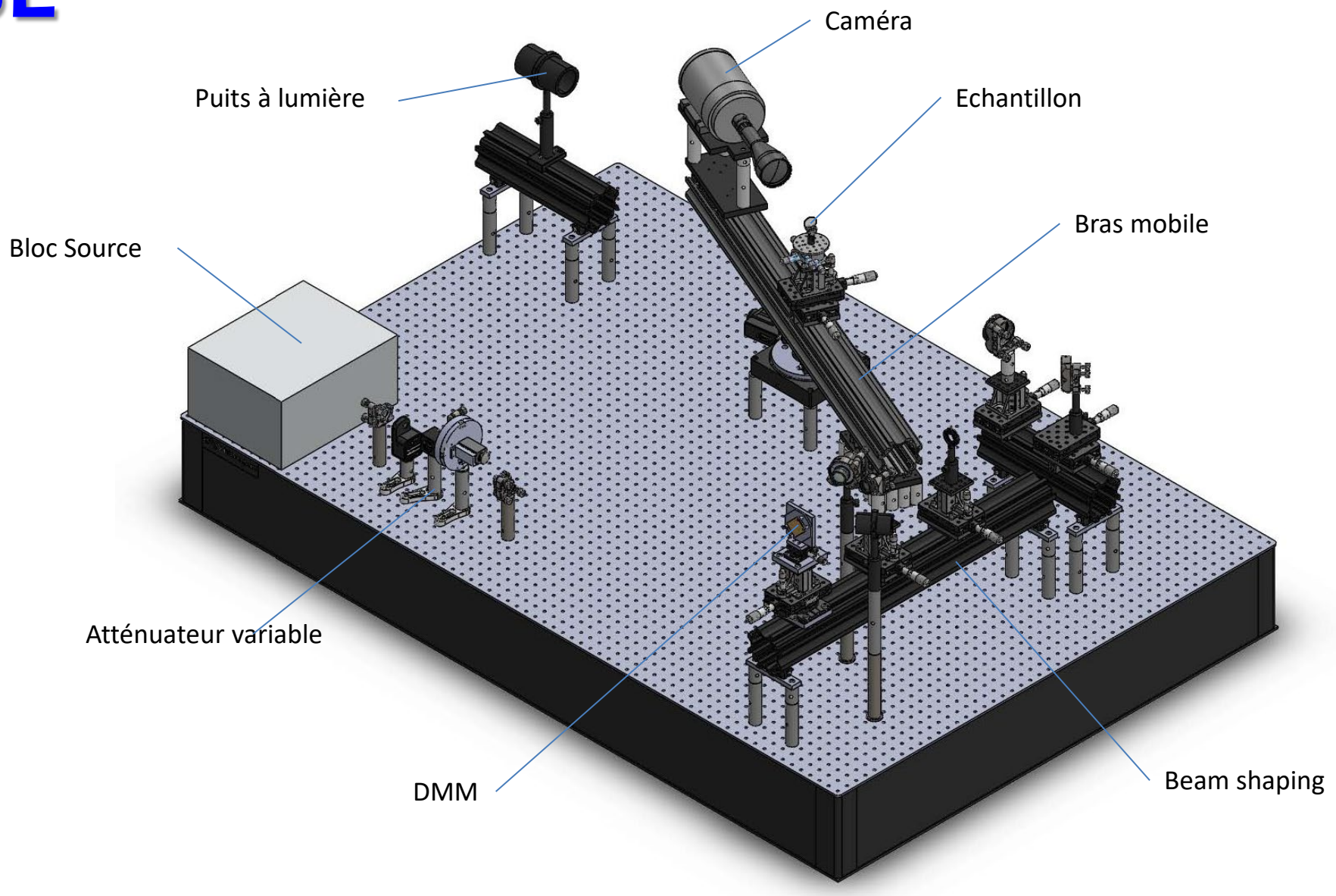
M. Lequime, M. Zerrad, C. Deumié, and C. Amra, "A goniometric light scattering instrument with high-resolution imaging," Opt. Commun. **282**, 1265-1273 (2009)

# SPARSE – Point Defects

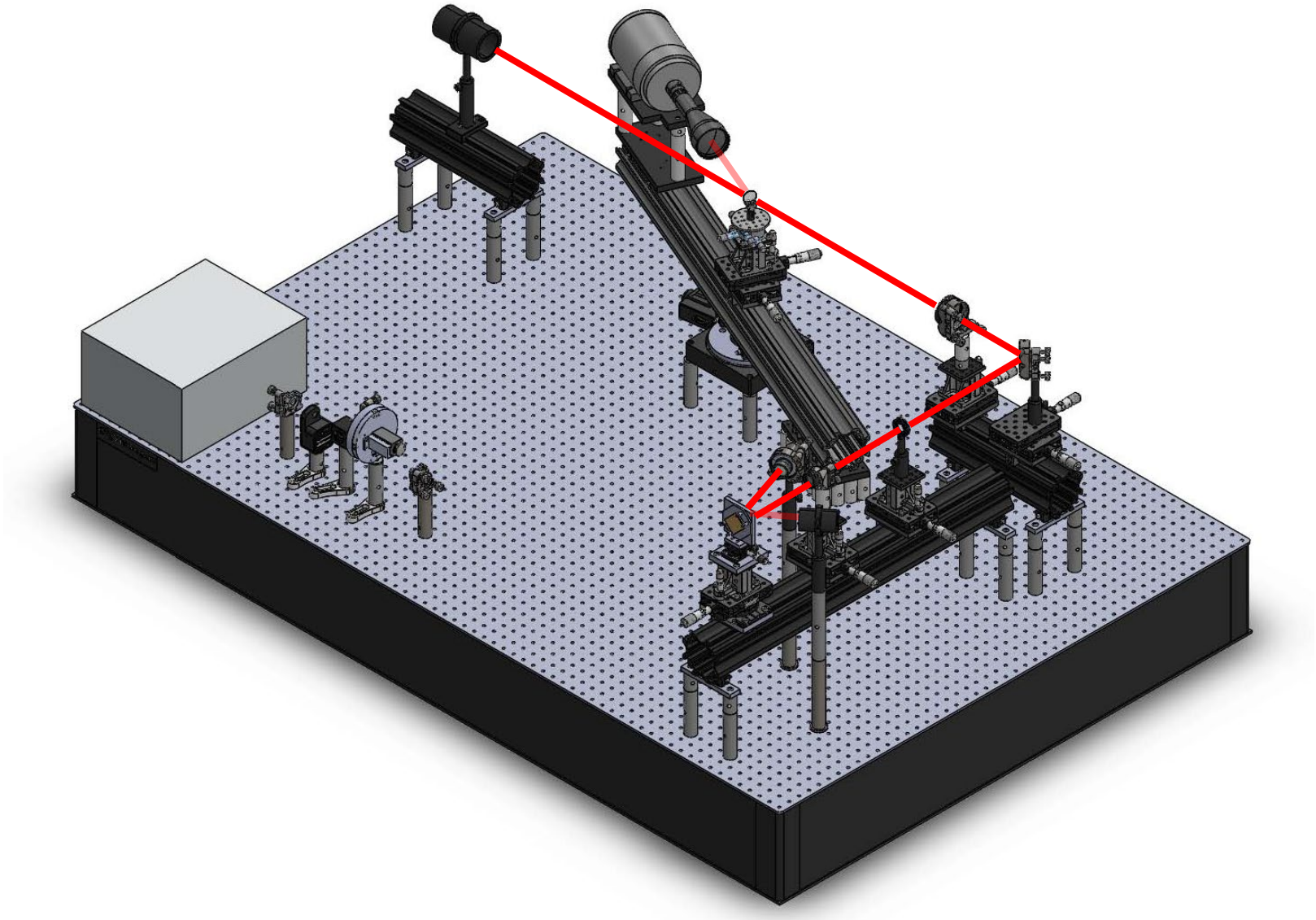
- **Problem: continuous distortion of the illuminated area**



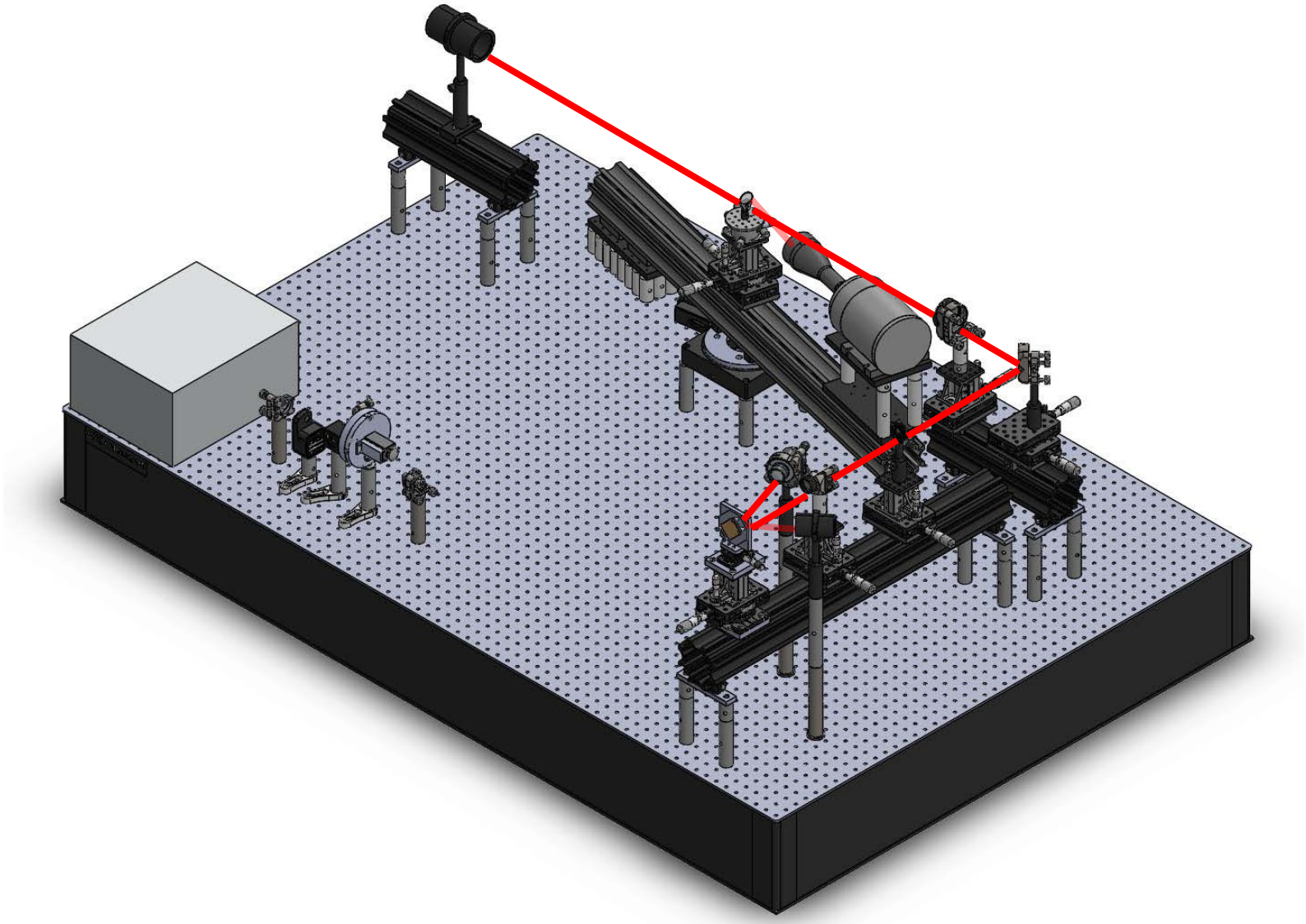
# SPARSE


Caméra
Puits à lumière
Echantillon
Bras mobile
Bloc Source
Atténuateur variable
DMM
Beam shaping

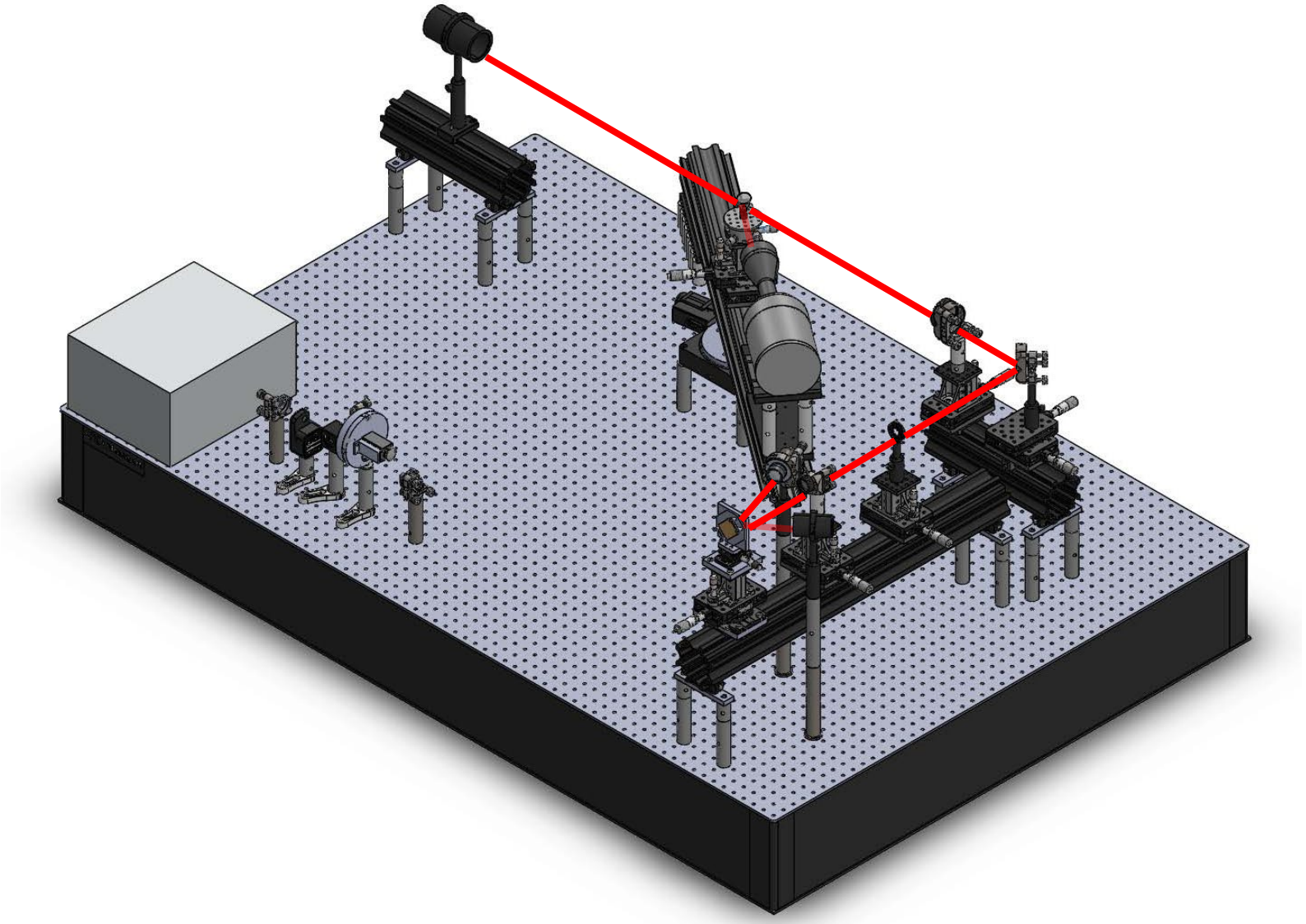
# SPARSE



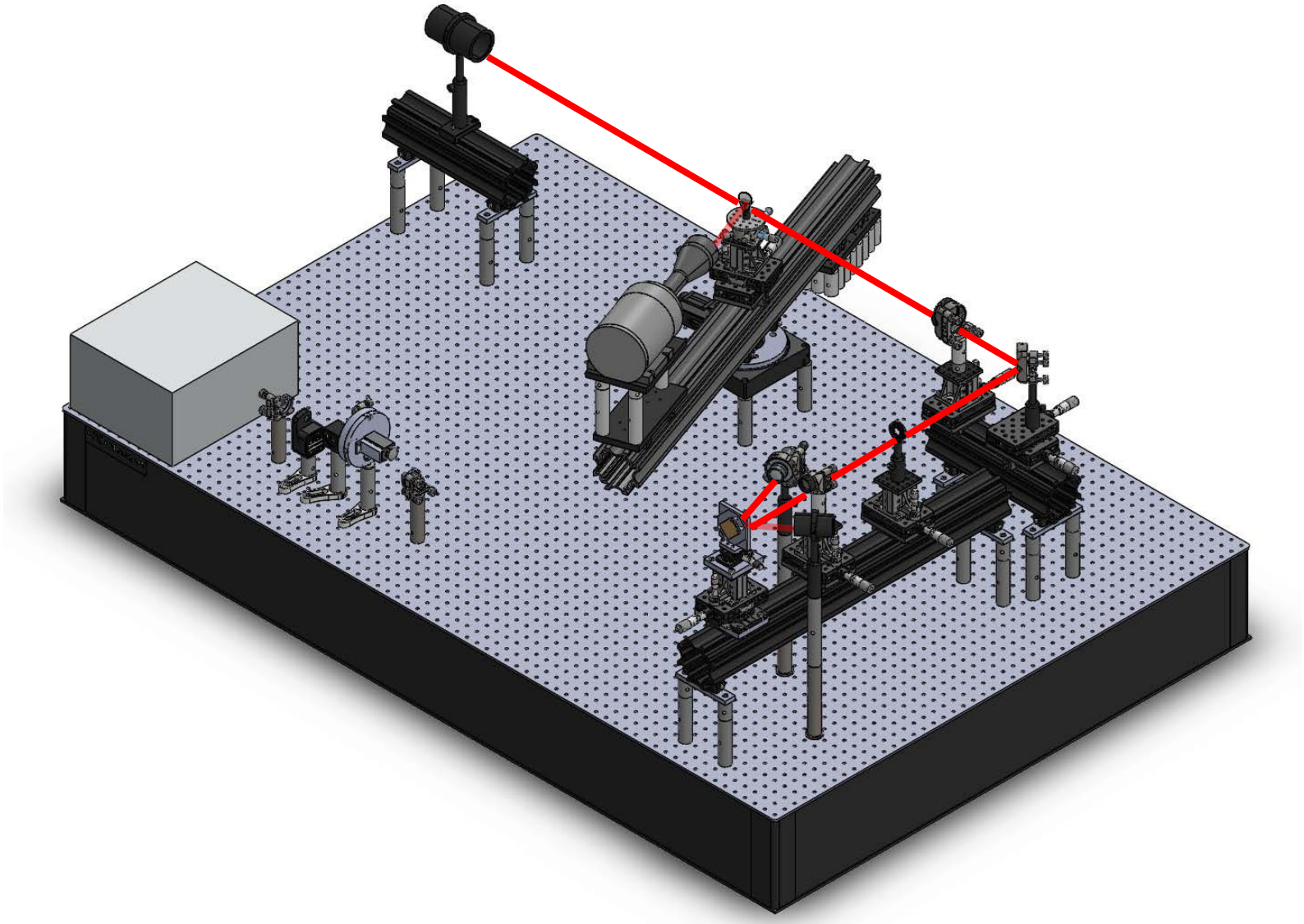
# SPARSE



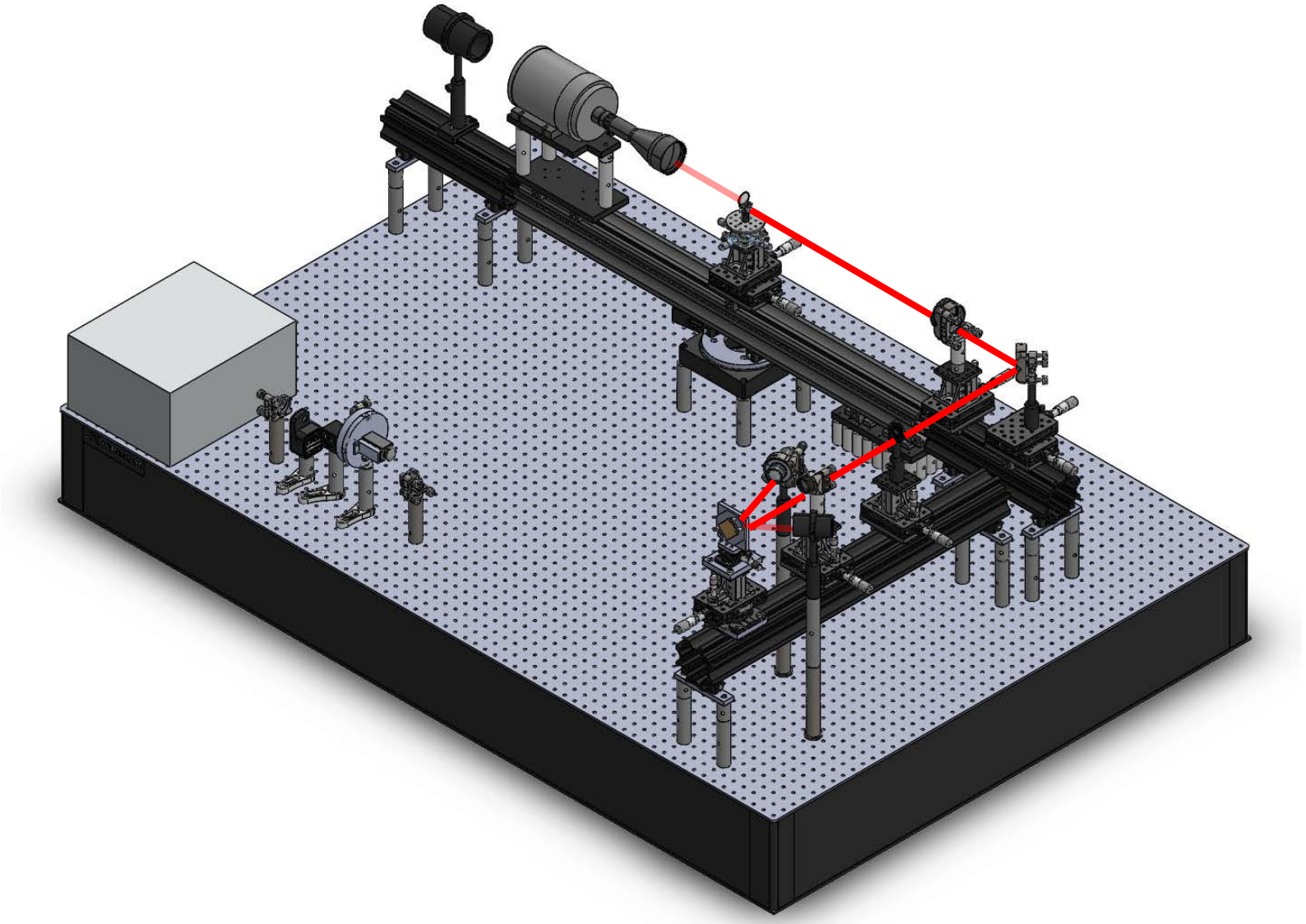
# SPARSE



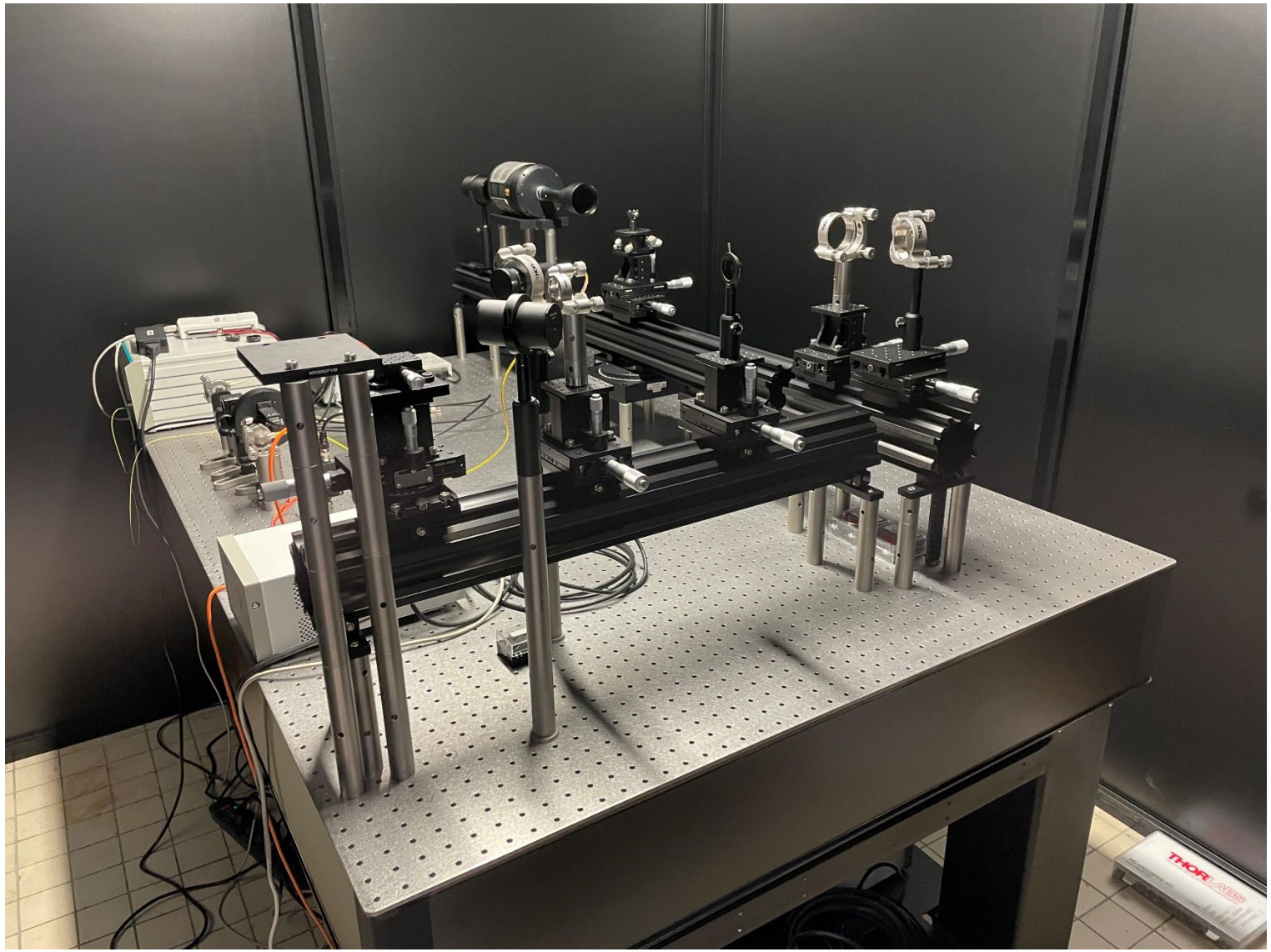
# SPARSE



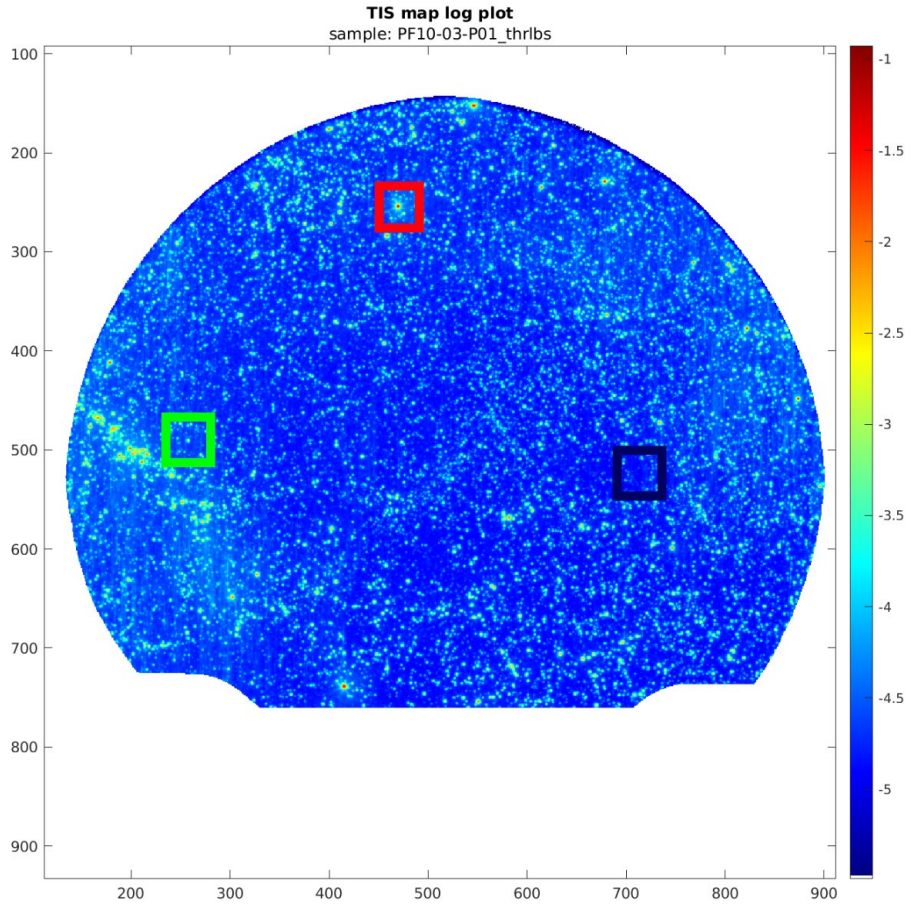
# SPARSE

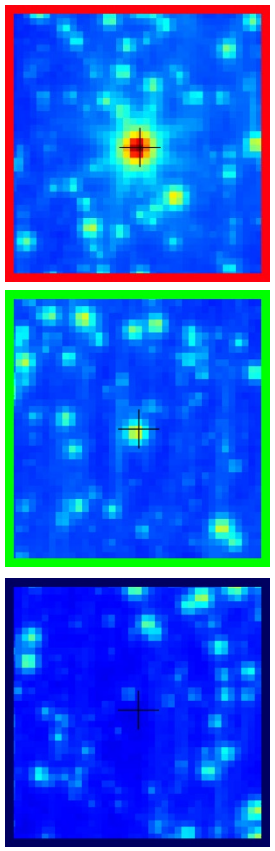


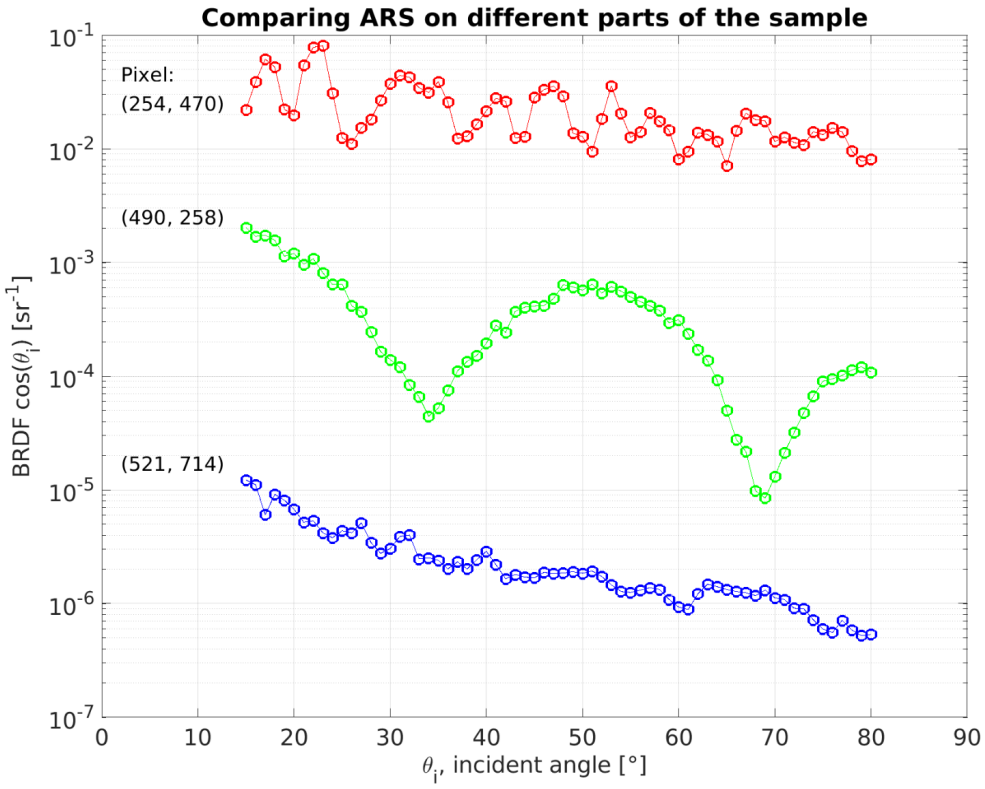
# SPARSE



# SPARSE – Point Defects



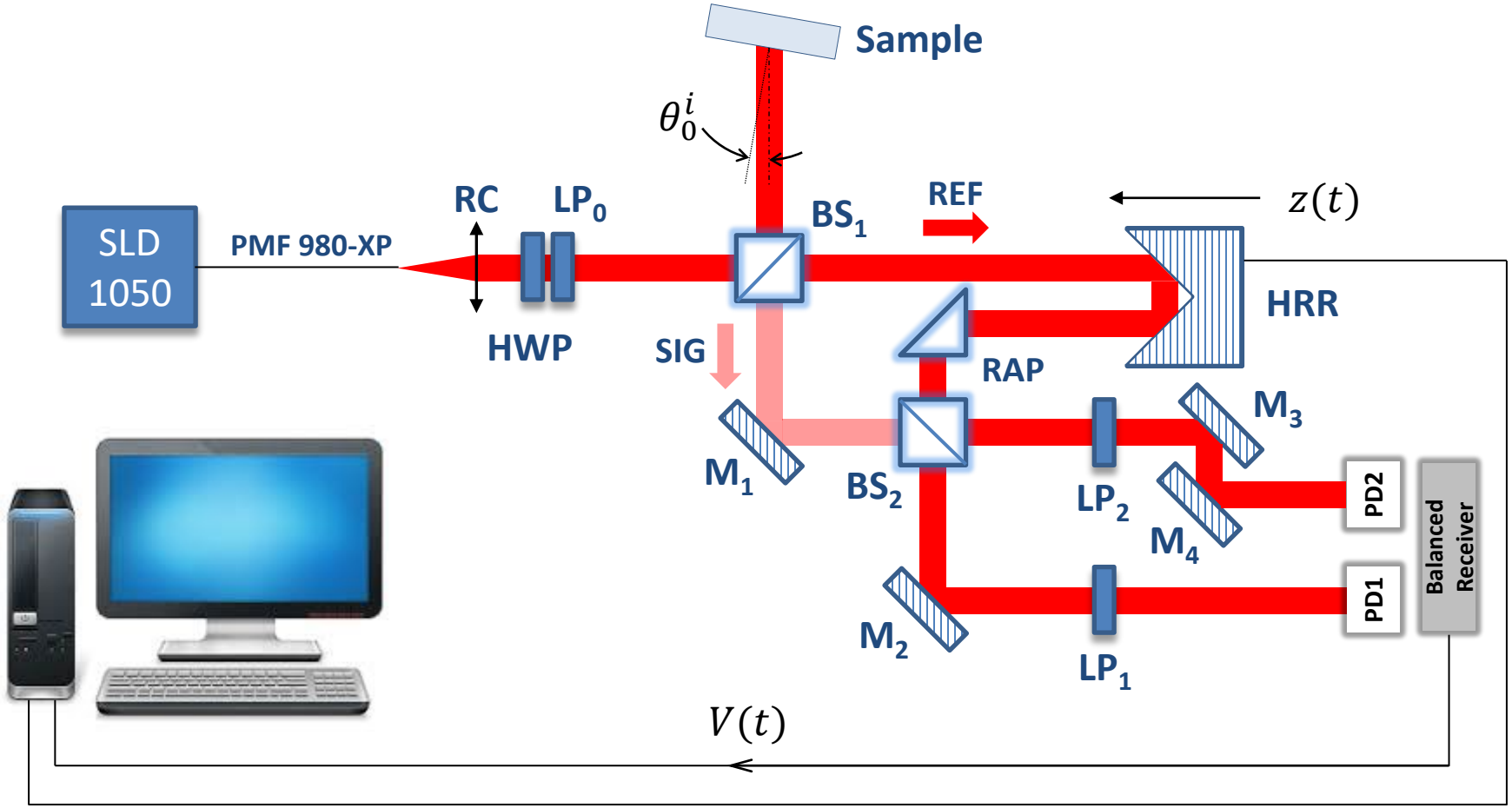





# SPARSE – Point Defects

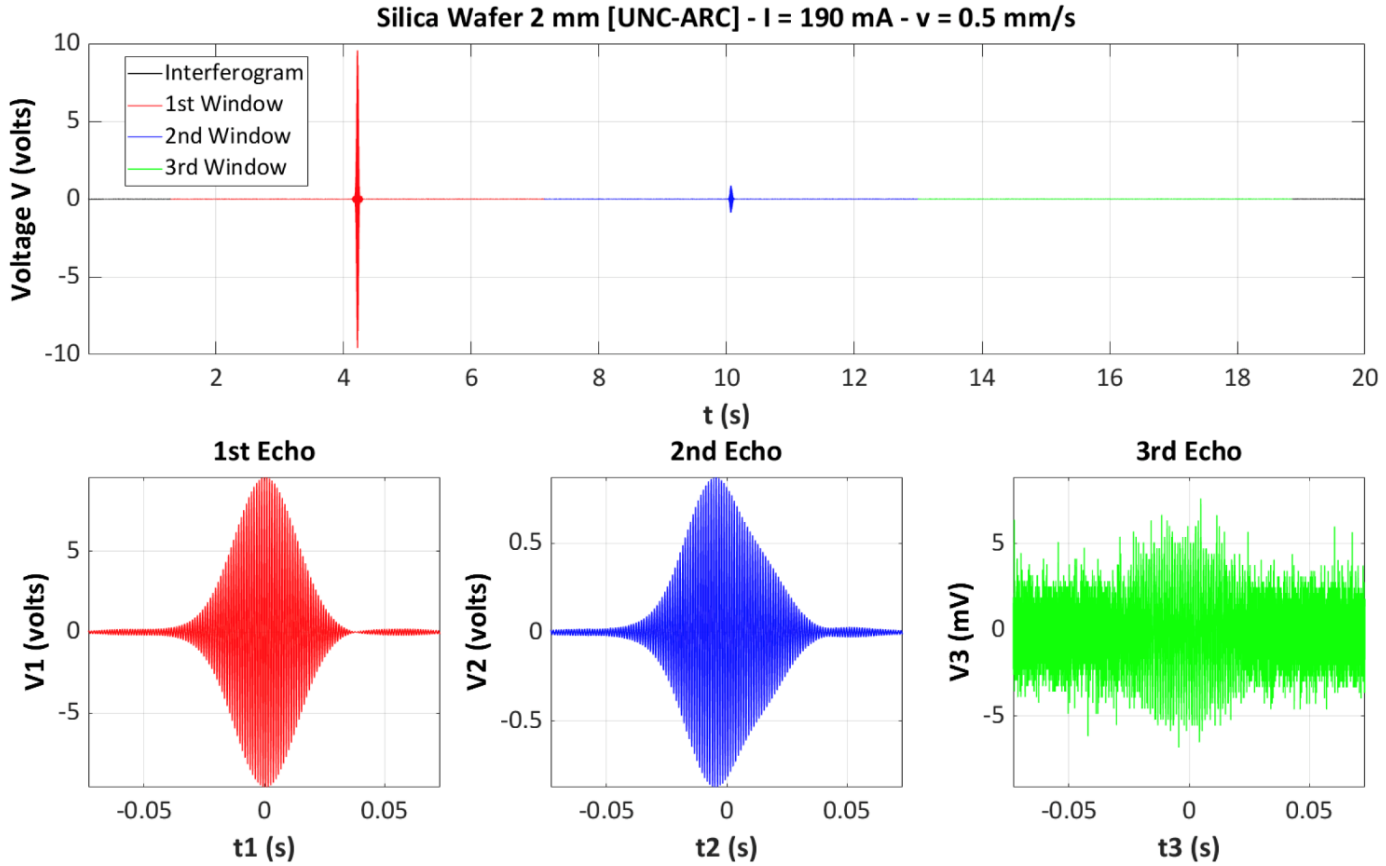
- **Major planned improvements**
  - *CCD camera with 2048 x 2048 pixels of 13 µm x 13 µm (4 million BRDF recorded in parallel)*
  - *Low magnification telecentric objective (0.25X) with large pupil diameter (100 mm)*
  - *High power light source (supercontinuum laser with wide bandwidth tunable filter)*
  - *2-axis motorized sample holder to increase spatial field of view (400 mm x 400 mm, stitching)*

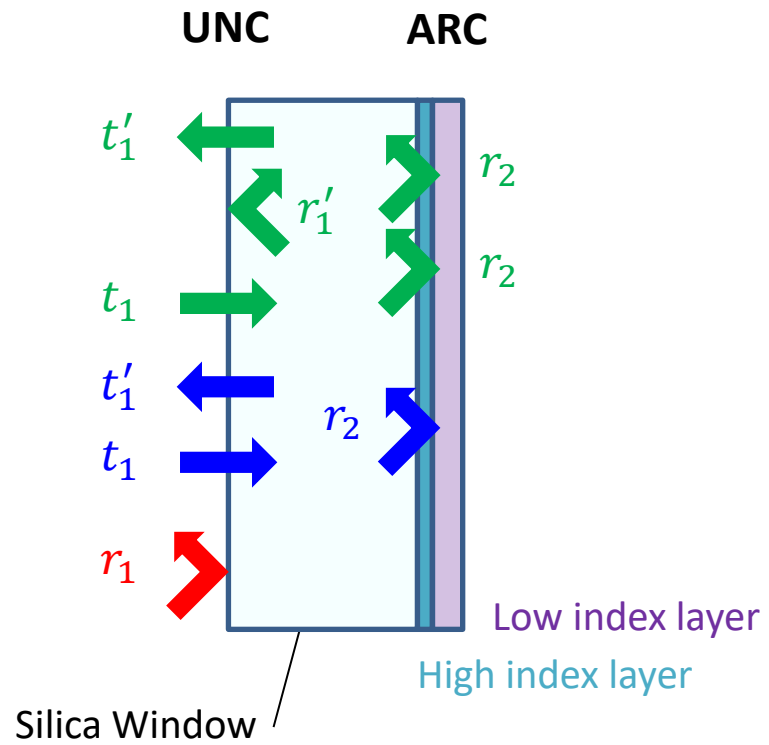
# BARRITON – Retroreflection and Backscattering




M. Lequime, I. Khan, M. Zerrad, and C. Amra, "Low coherence interferometric detection of the spectral dependence of the reflection coefficient of an anti-reflective coated interface," Opt. Express **31**, 8748-8774 (2023)

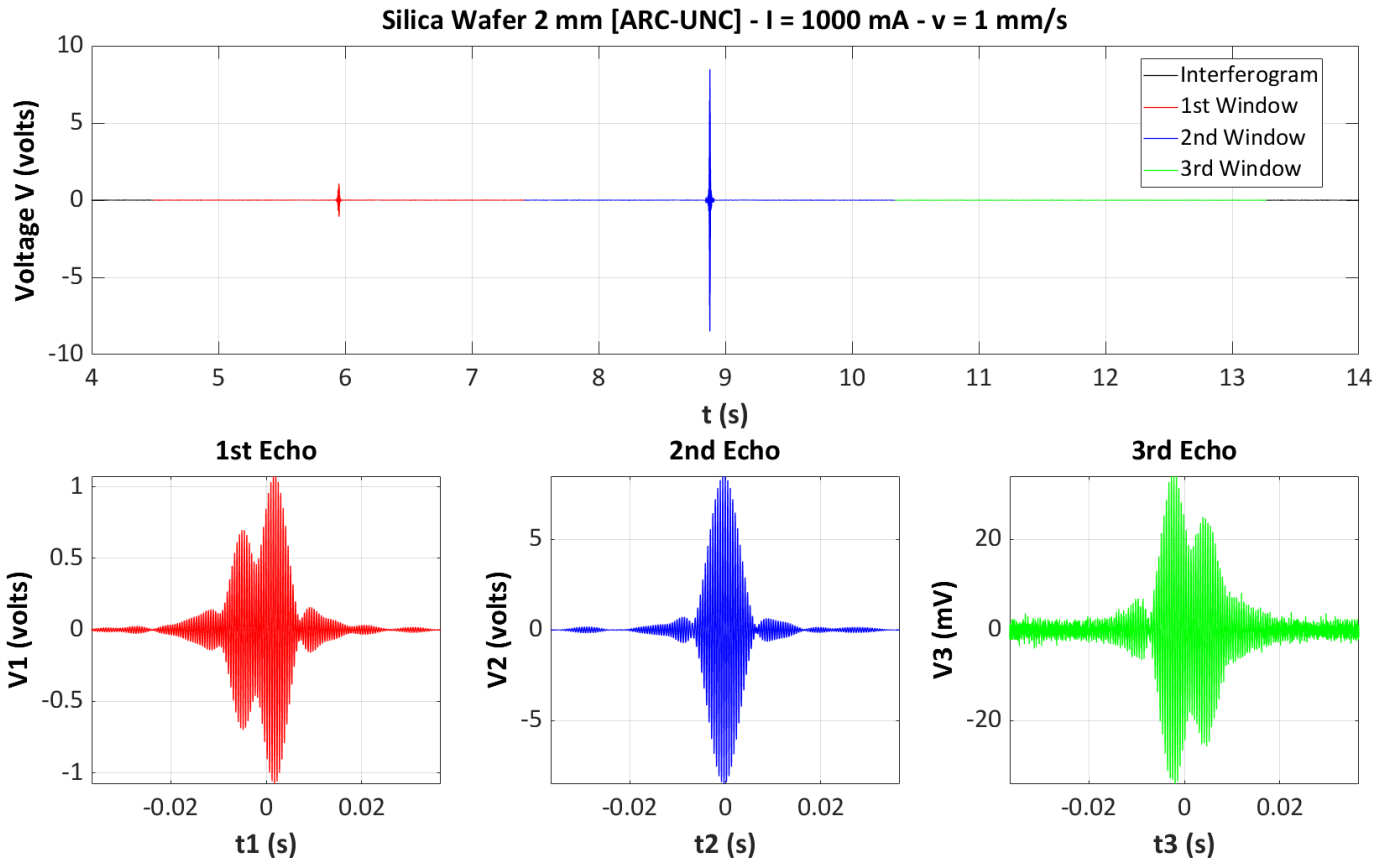
# BARRITON - Retroreflection

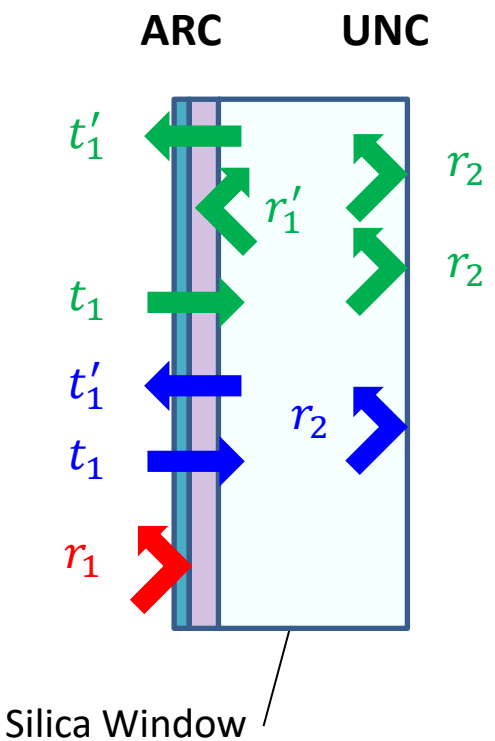



M. Lequime, I. Khan, M. Zerrad, and C. Amra, "Low coherence interferometric detection of the spectral dependence of the reflection coefficient of an anti-reflective coated interface," Opt. Express **31**, 8748-8774 (2023)

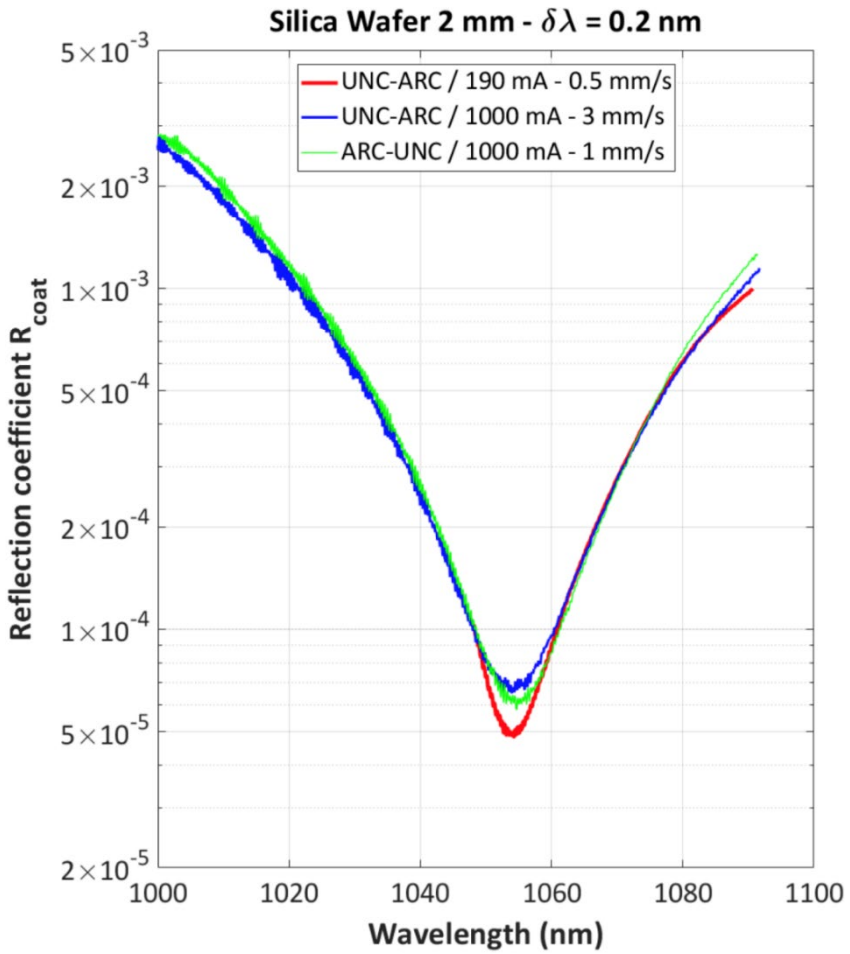
# BARRITON - Retroreflection



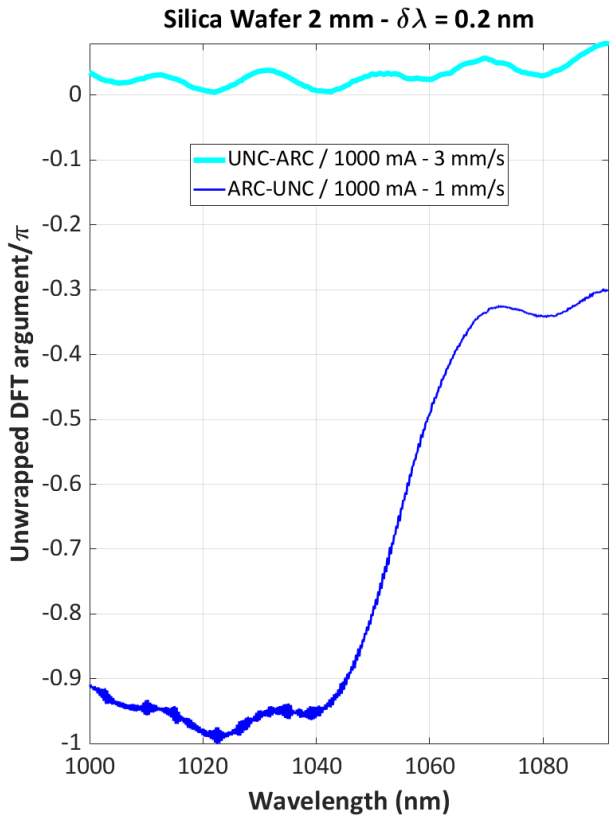

M. Lequime, I. Khan, M. Zerrad, and C. Amra, "Low coherence interferometric detection of the spectral dependence of the reflection coefficient of an anti-reflective coated interface," Opt. Express **31**, 8748-8774 (2023)

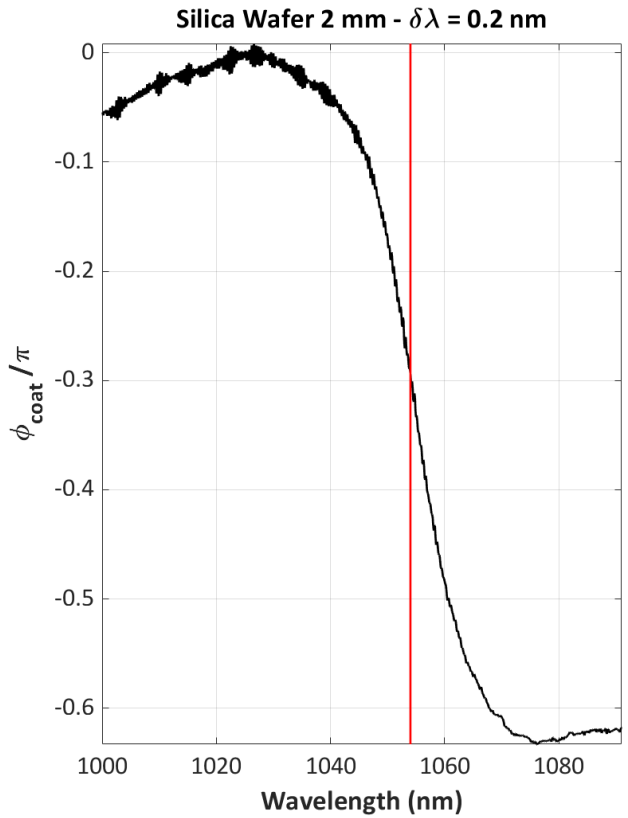
# BARRITON - Retroreflection




M. Lequime, I. Khan, M. Zerrad, and C. Amra, "Low coherence interferometric detection of the spectral dependence of the reflection coefficient of an anti-reflective coated interface," Opt. Express **31**, 8748-8774 (2023)

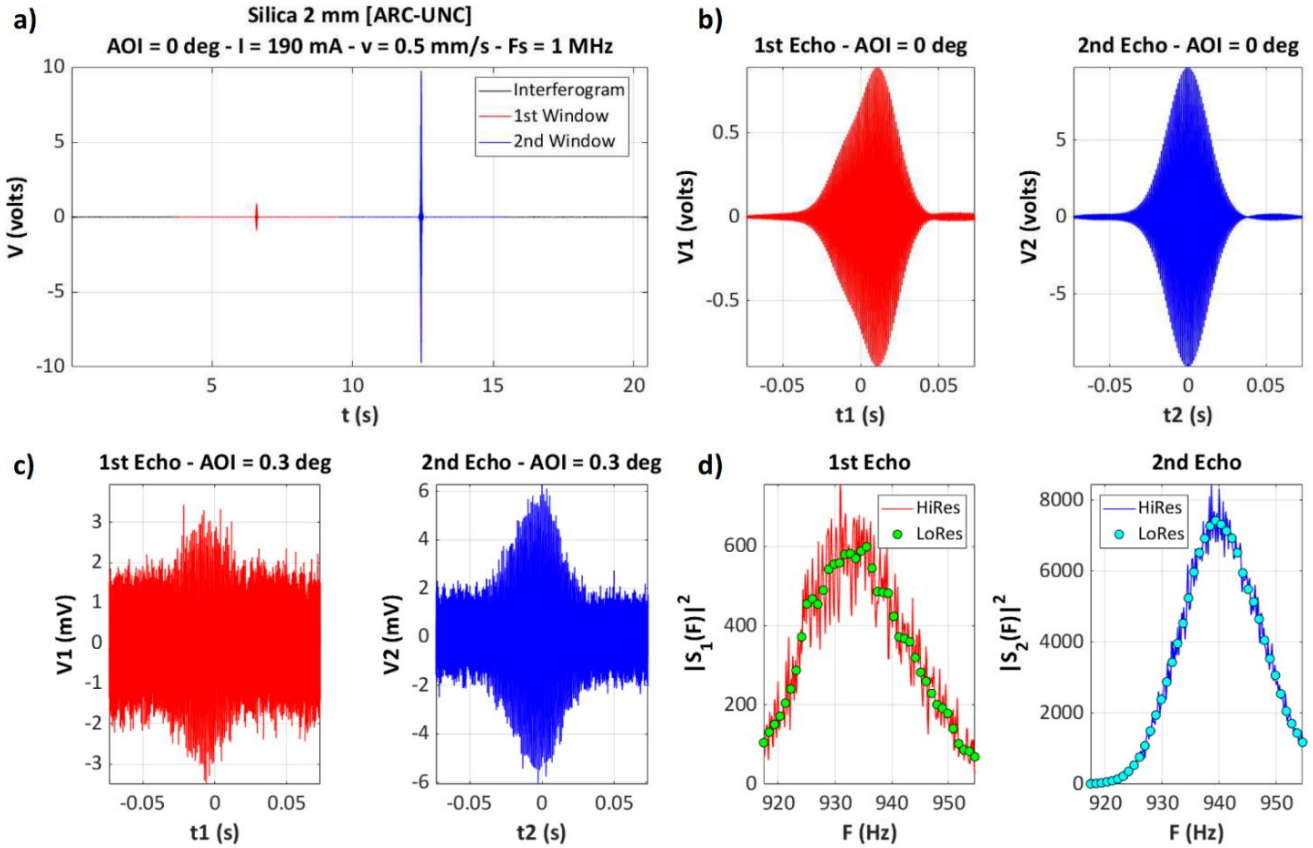
# BARRITON - Retroreflection

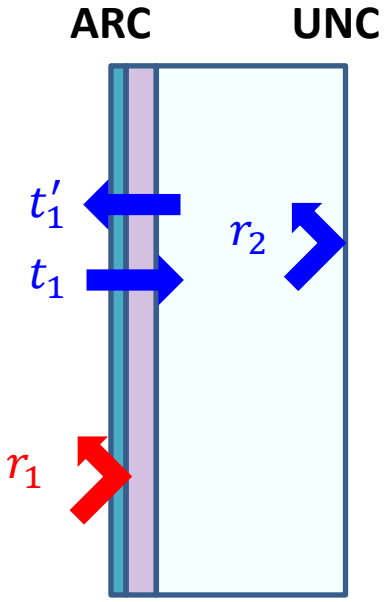



M. Lequime, I. Khan, M. Zerrad, and C. Amra, "Low coherence interferometric detection of the spectral dependence of the reflection coefficient of an anti-reflective coated interface," Opt. Express **31**, 8748-8774 (2023)

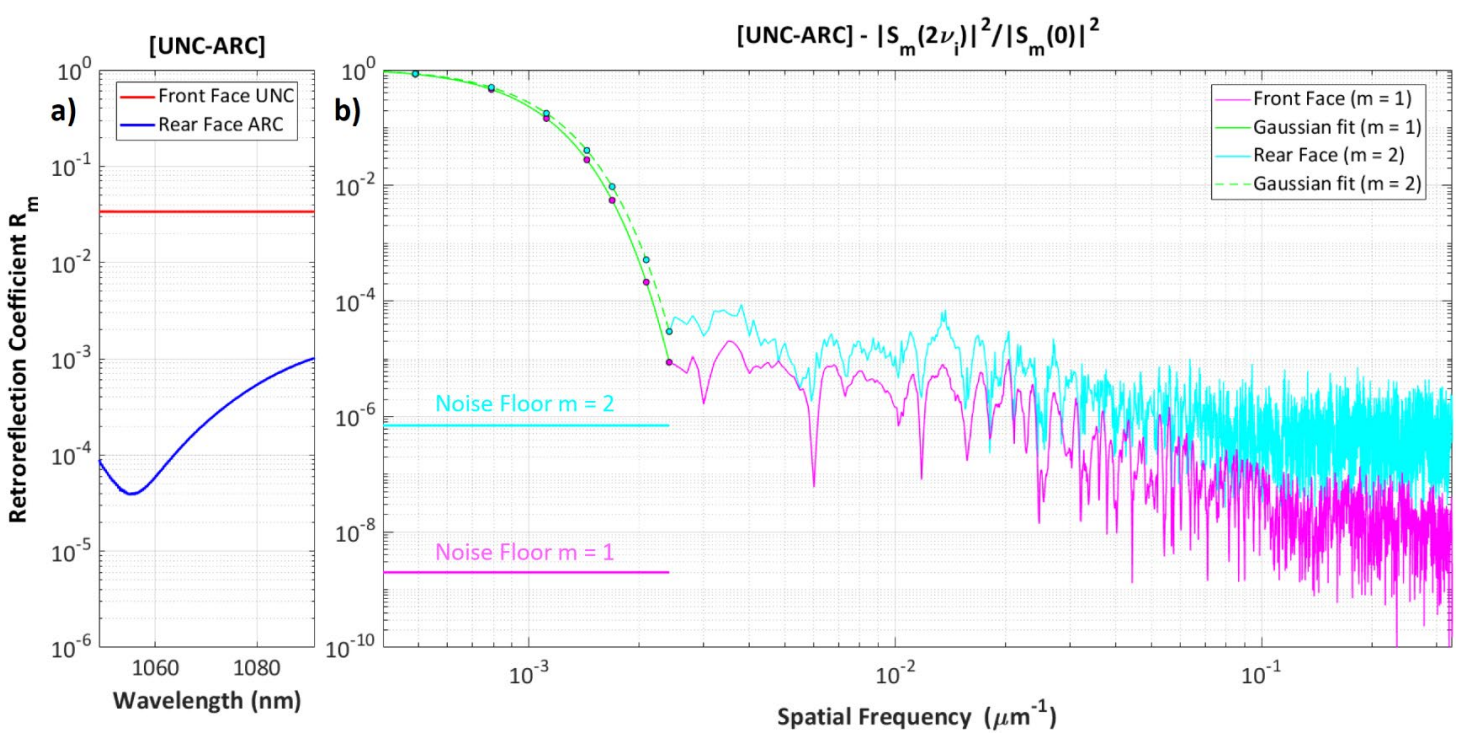
# BARRITON – Retroreflection and Backscattering

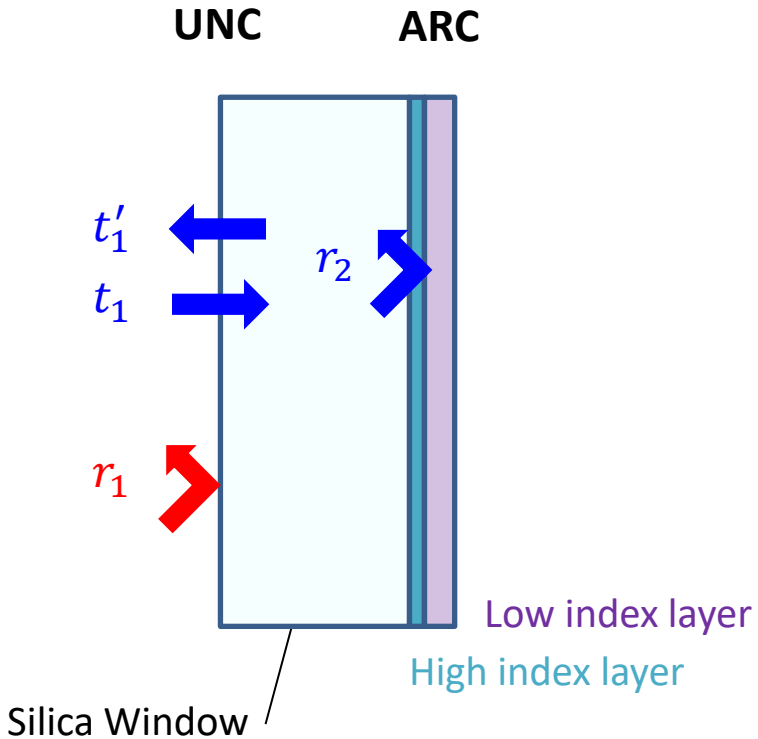



M. Lequime, I. Khan, A. Bolliand, M. Zerrad, and C. Amra, "Low-coherence interferometric measurement of the spatial frequency dependence of the light field backscattered by optical interfaces," Appl. Phys. Lett. **122**, 191103 (2023)

# BARRITON – Retroreflection and Backscattering




M. Lequime, I. Khan, A. Bolliand, M. Zerrad, and C. Amra, "Low-coherence interferometric measurement of the spatial frequency dependence of the light field backscattered by optical interfaces," Appl. Phys. Lett. **122**, 191103 (2023)

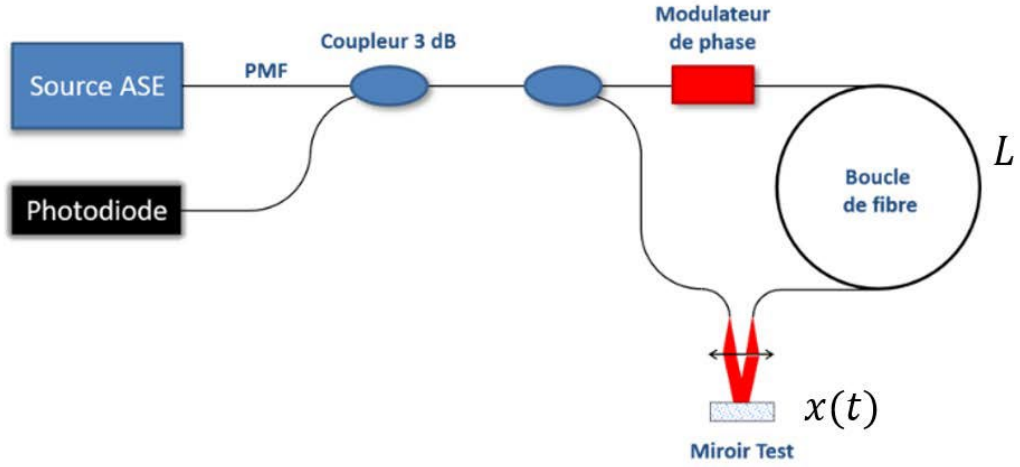
# BARRITON – Retroreflection and Backscattering sources

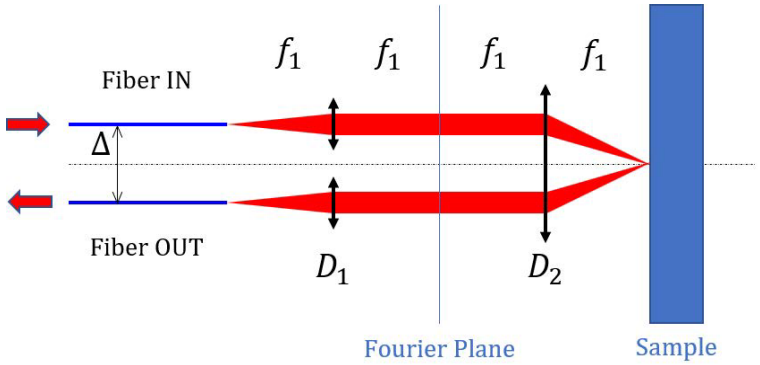
- **Major planned improvements**
  - *Extension of the OPD range (100 mm → several meters)*
  - *Source coherence function cleanup (purchase of high quality components with high efficiency antireflective coatings)*
  - *Increase of the ASE source power*
  - *Use of an optical circulator operating in TE and TM polarization*

# GRAVITERM – Thermal noise

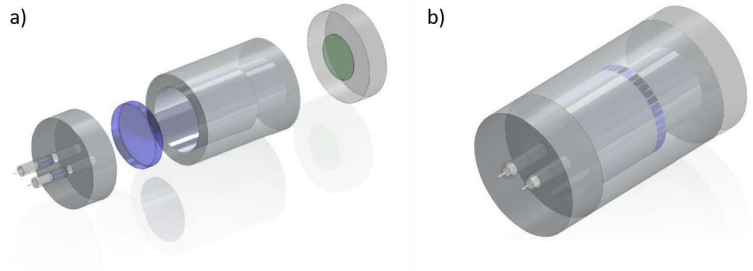
- **Use of a cyclic interferometer to record mirror thermal noise for gravitational wave detectors**
  - ***Main advantage: Suppression of the influence of all reciprocal effects***
- **Key requirements**
  - ***Direct measurement***
  - ***Differential configuration (MIT setup spatially differential, here temporally differential)***
  - ***Adjustment free***

# GRAVITERM – Thermal noise




$$\sigma_x = \frac{\lambda_0}{2\pi^2 f \tau}\sqrt{\frac{e}{2SP_e}} \qquad \tau = \frac{nL}{c}$$




P. Rouquette, “L'interférométrie cyclique pour accéder au bruit thermique des miroirs pour les détecteurs d’ondes gravitationnelles” (2024)

# Conclusion

- **3 key R&D topics**
  - *Develop an improved version of SPARSE capable of detecting the presence of point defects on the surface of a large diameter substrate, coated or uncoated, and determining the contribution of these defects to scattering loss budget.*
  - *Develop an improved version of BARRITON capable of detecting the axial position and strength of retroreflection and/or backscatter sources along the optical axis of a large instrument.*
  - *Development of a compact and adjustment free interferometric instrument for the measurement of the thermal noise of an optical interference coating (GRAVITERM).*