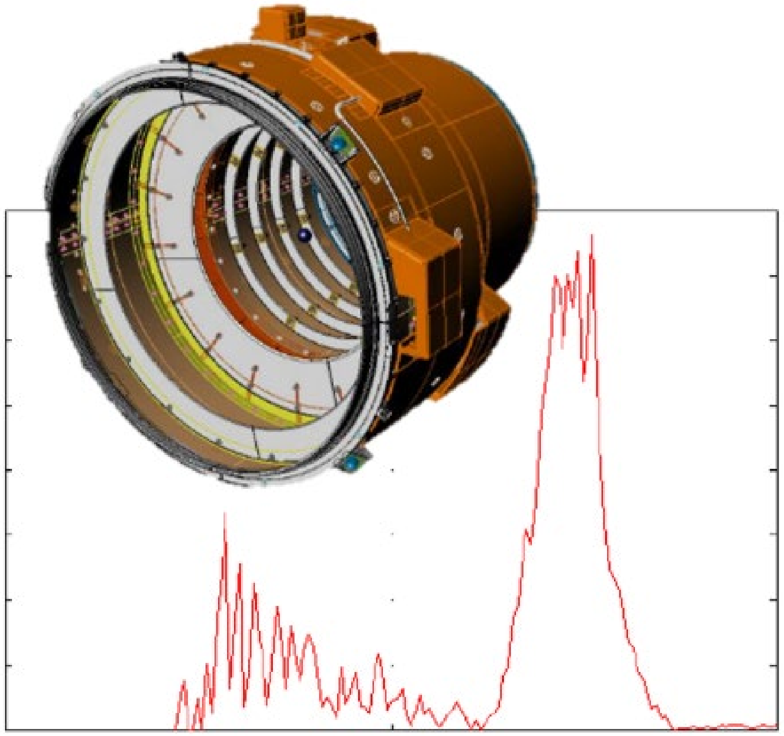


Eleonoor Bosch
Senior R&D Engineer

07.10.2024

SLOTT
FINAL PRESENTATION

TABLE OF CONTENTS

SLOTT CONSORTIUM

EXPERTISE AND RESPONSIBILITIES

CSEM

- Smart mechanisms and scientific instrumentation for space
- Lidar for space

- Project leadership and quality management
- Sub-system manufacture and preliminary test

Thales Alenia Space (a Thales / Leonardo company)

- Straylight performance characterization and simulation, optics and electronics systems, satellite and space technology

- System requirements definition,
- Straylight simulation

LUSOSPACE

- Optoelectronics hardware equipment for space, optical communications, OGSE, AOCS, Laser systems

- Manufacturing and alignment of illumination module

CSL

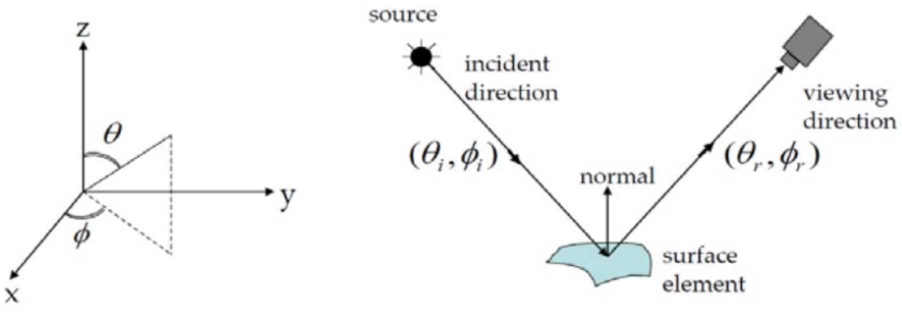
- Straylight characterization with ultrafast time-of-flight imaging
- Optical system test in cleanroom and vacuum

- System performance verification
- Test with representative baffle model

STRAYLIGHT BACKGROUND AND PROJECT OBJECTIVES

STRAYLIGHT

- Sources
  - Rogue paths
  - Ghosts
  - Diffraction
  - Scattering
    - At optical surfaces
    - At structural surface

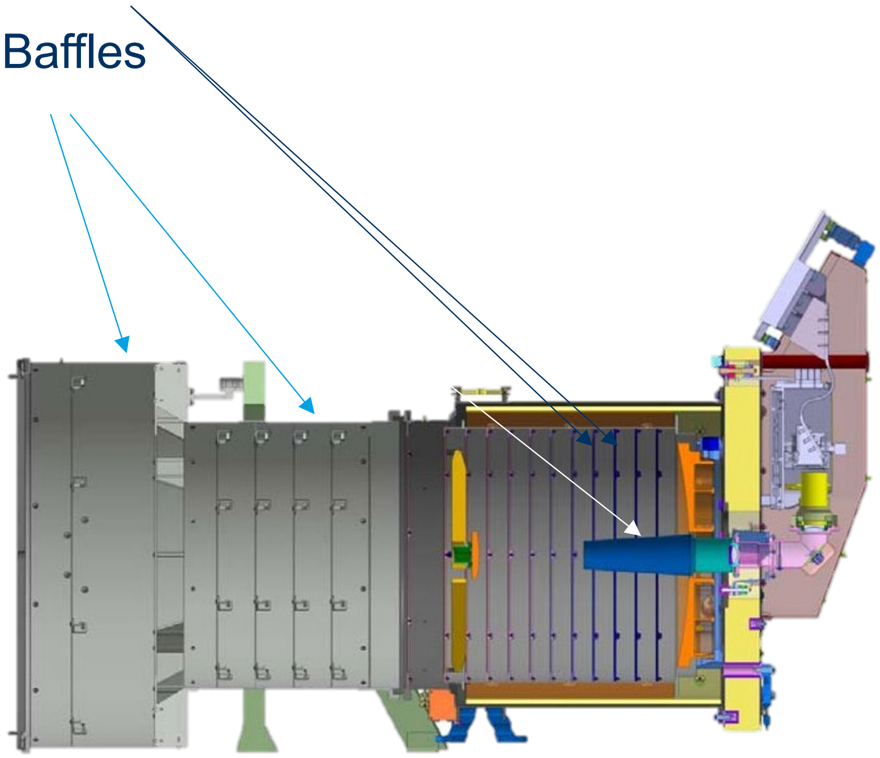


$E^{surface}(\theta_i, \phi_i)$ Irradiance at Surface in direction (θ_i, ϕ_i)

$L^{surface}(\theta_r, \phi_r)$ Radiance of Surface in direction (θ_r, ϕ_r)

$$\text{BRDF} : f(\theta_i, \phi_i; \theta_r, \phi_r) = \frac{L^{surface}(\theta_r, \phi_r)}{E^{surface}(\theta_i, \phi_i)}$$

- Optical design
  - Vanes
  - Baffles



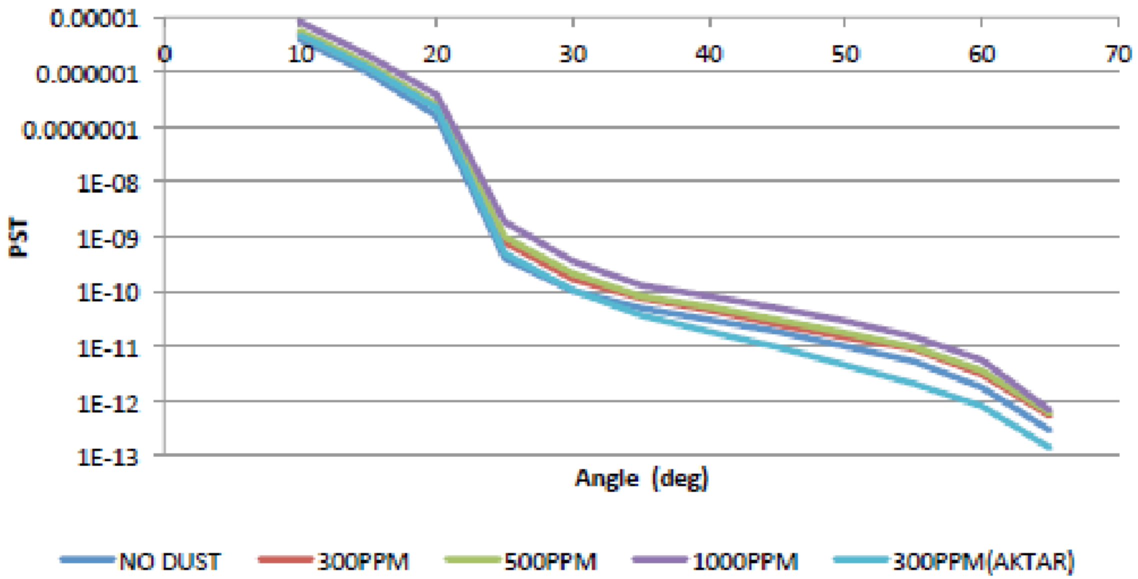
CHEOPS telescope

csem

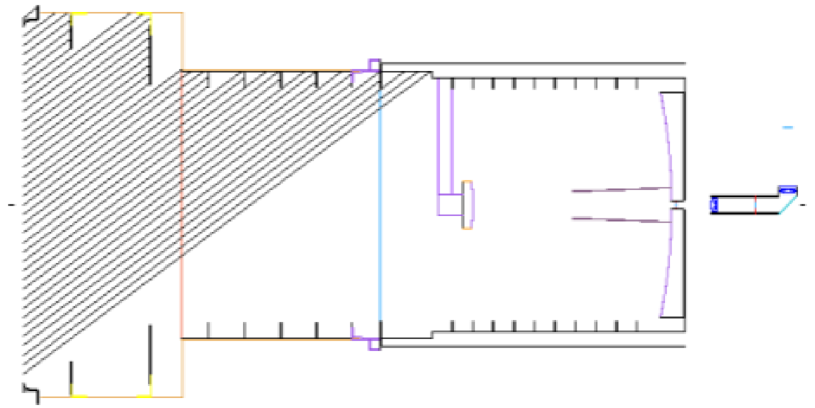
POINT SOURCE TRANSMITTANCE

- Irradiance ratio: focal plane / entrance aperture
  - Focal plane = continuous surface
  - Extremely large dynamic range (e.g. 12 orders of magnitude)

- Simulation softwares
  - ASAP, FRED, TracePro, LightTools
  - Limitations
    - ➢ Estimations of BRDF
    - ➢ Modelling precision (i.e. unexpected defects)
    - ➢ Processing resources & time consumption

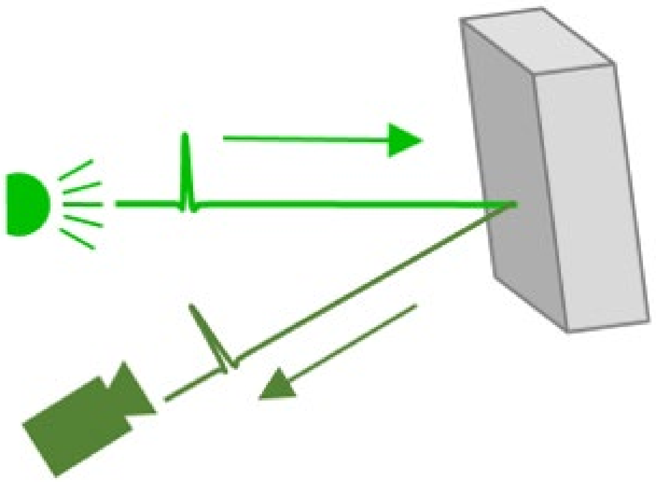


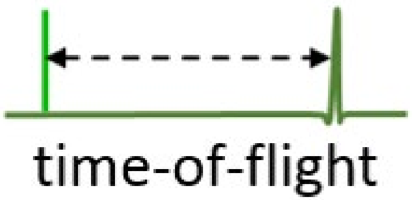
Beck, T. et al. *CHEOPS – Status summary of the instrument development*, SPIE Space Telescopes and Instrumentation 2016, Vol 9904 (2016)



SLOTT – Technical Note 1A, modelled CHEOPS illumination at 35°

DIRECT TIME-OF-FLIGHT LIDAR





Time of flight principle:

1. A pulse travels from its source
2. Some light scatters off a target
3. Some incident light generates a signal at the detector

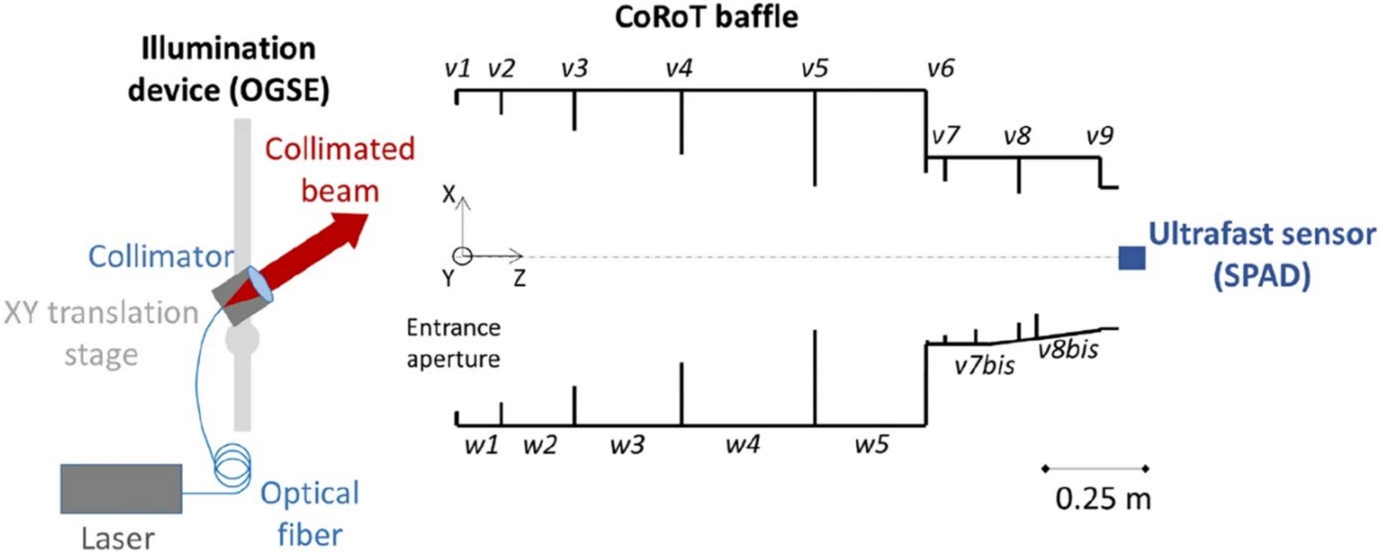
Advantages

- The ability to **time resolve detected straylight sources**
- Highly sensitive detectors
  Sufficient measurement dynamic range (10^{-13}).
- The acquisition time up to a few hours
- Flexible system design
  Can optimize for sensitivity, focal plane resolution or bandwidth

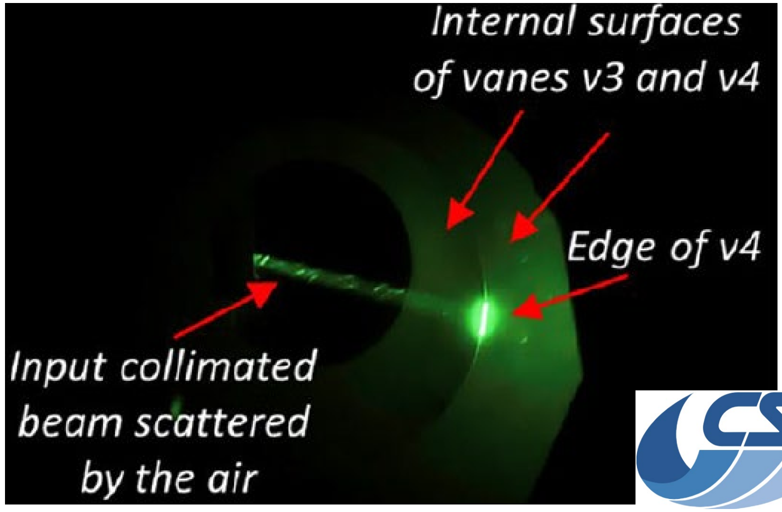
In straylight characterization:
Detected light with different times of flight took different paths to the detector

TIME-OF-FLIGHT STRAYLIGHT CHARACTERIZATION

- Demonstrated at CSL
  - High dynamic range (10^{-11})
  - Detector impulse response FWHM 124ps
    - ➢ Depth resolution 37.68mm
  - Differentiation of intrinsic baffle straylight from external sources
    - Air scattering vs defects



Sketch of the experimental setup.



Clermont, L., Blain, P., Khaddour, W. *et al.* Unlocking stray light mysteries in the CoRot baffle with the time-of-flight method.
Sci Rep **14**, 6171 (2024). https://doi.org/10.1038/s41598-024-56310-z

PROJECT OBJECTIVE

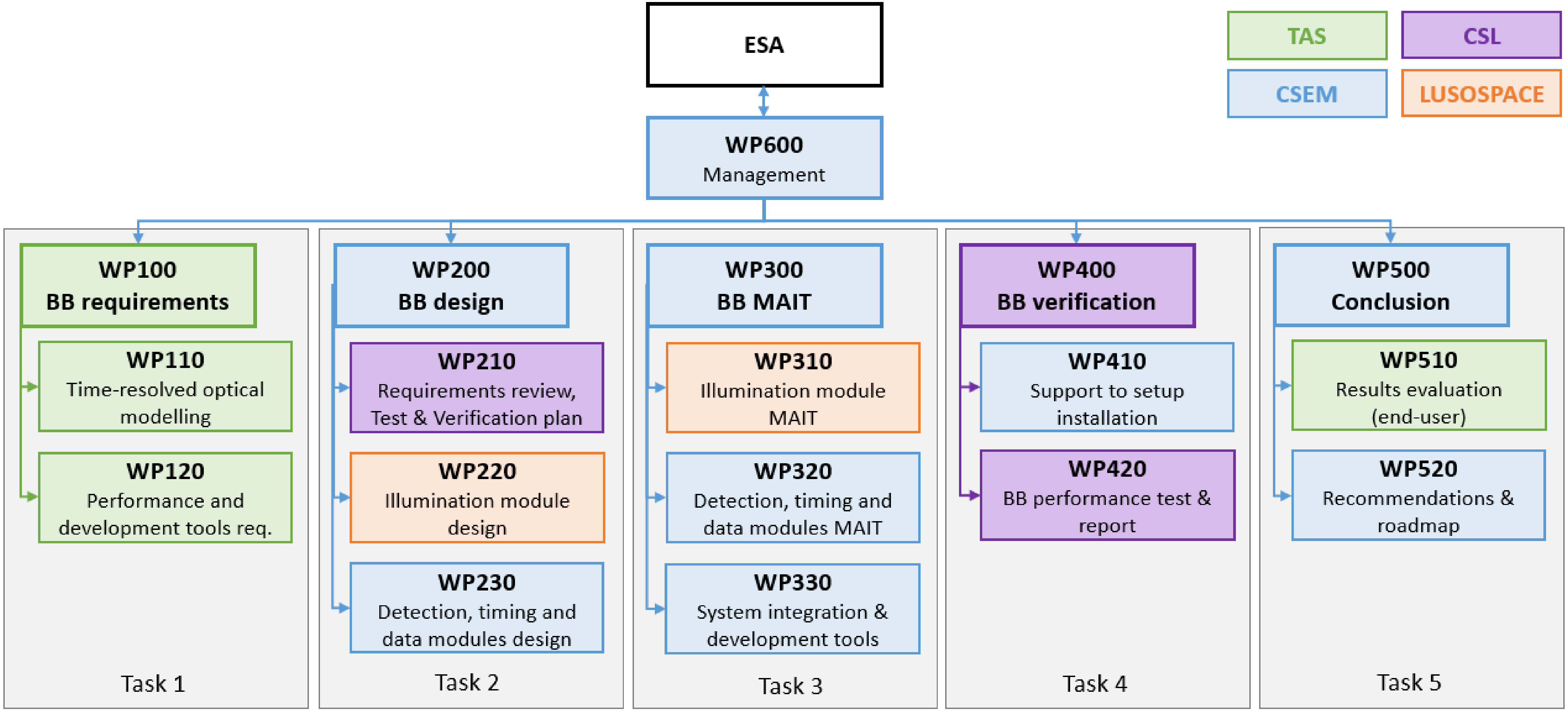
Design, manufacture and test a functional OGSE verification breadboard

- Capable of detecting straylight paths
  - **Based on incidence angle** (classical PST)
  - **With high resolution in time and space**.
- Portable
- For baffle apertures up to 1m

The performance of the manufactured breadboard was verified using a representative test object – a model of the CHEOPS main baffle.

PROJECT ORGANIZATION

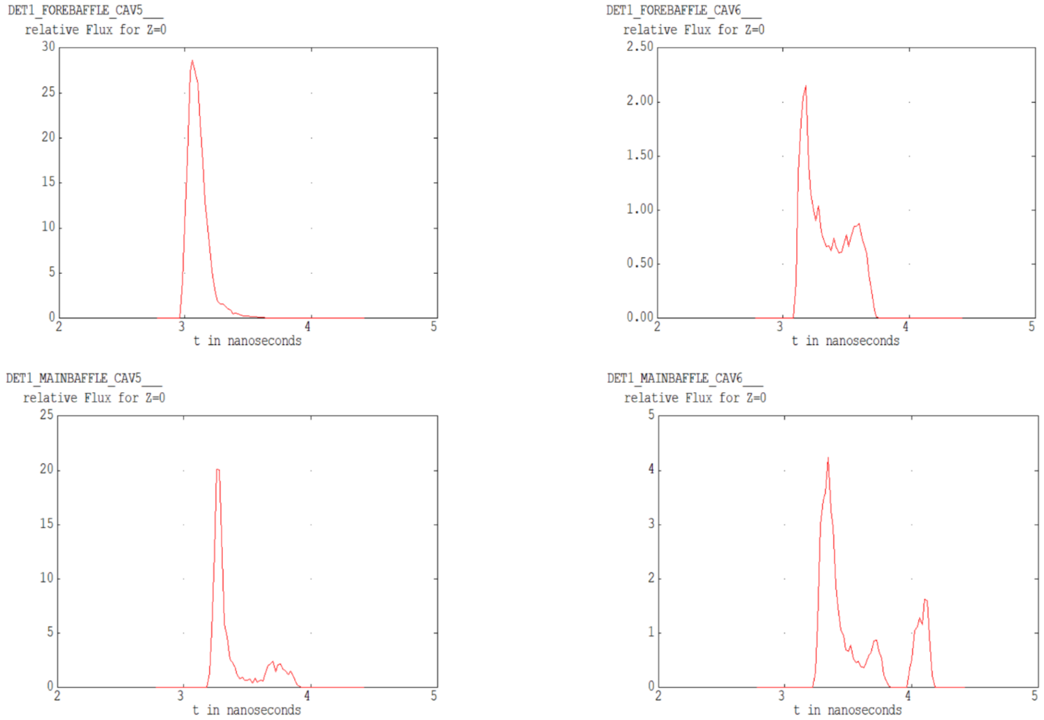
WORK PACKAGES AND RESPONSIBILITY BREAKDOWN



SLOTT RESULTS AND ACCOMPLISHMENTS

OPTICAL SIMULATION AND REQUIREMENTS DEFINITION

- Time of flight simulation considering several optical configurations
- Definition of system requirements for
  - LISA telescope baffle
  - CHEOPS fore and main baffle



Key project decision

Validate time-of-flight straylight characterization with CHEOPS

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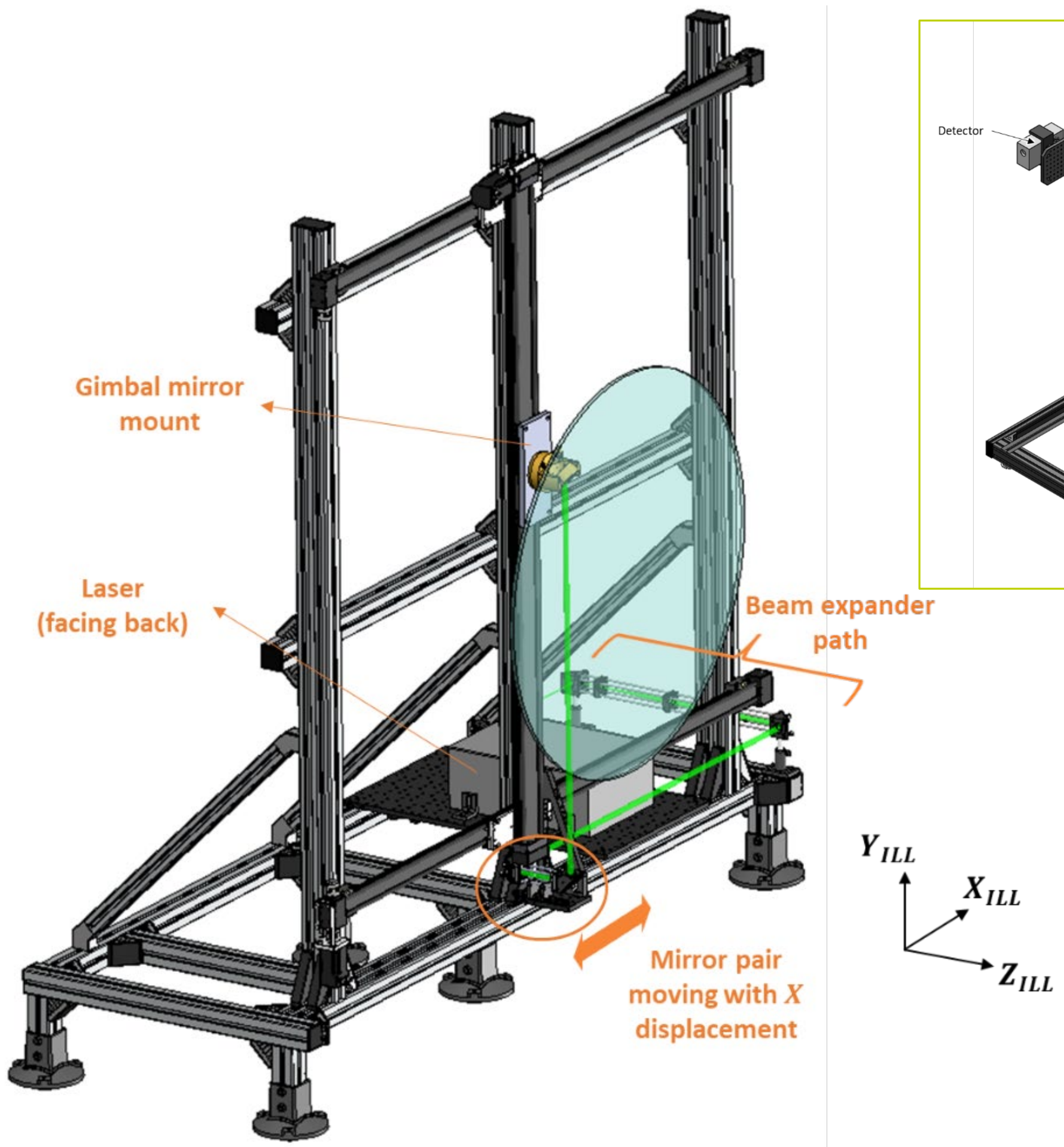
MAIN DESIGN REQUIREMENTS

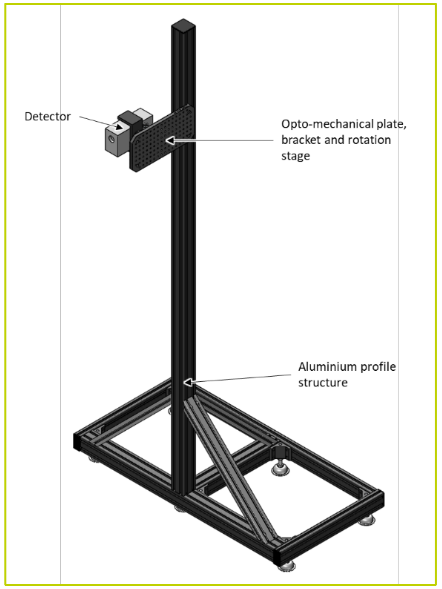
Range resolution	≤10mm
Dynamic Range	10^{-13}
Off-axis elevation angles	from 0° to 90°
Azimuth angles	from 0° to 180
Maximum baffle aperture	1m
Spatial scanning resolution	10mm

Portable

Automated aperture scan + optical path length calculation

DETAILED SYSTEM DESIGN





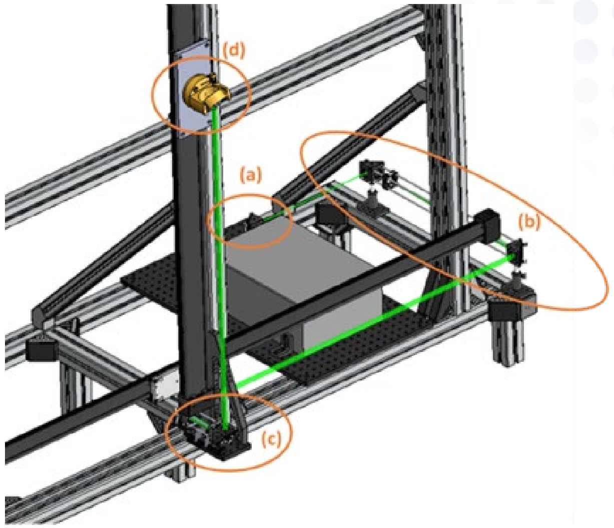
- Illumination module
  - Laser selection
  - Beam expander
  - Gimbal mirror
- Detector module
  - Detector selection
  - Mounting configuration
- Timing system
  - Reverse start-stop mechanism
  - TCSPC selection

OGSE MANUFACTURING

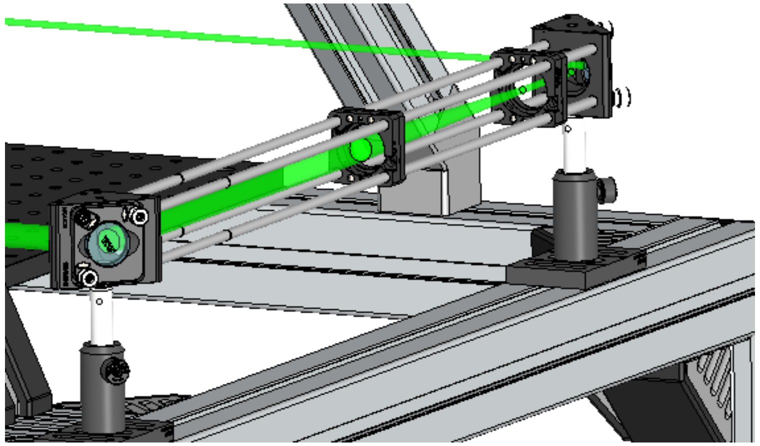
- Illumination module assembly and alignment
  - Gantry system installation
  - Optical path setup and alignment
  - Gimbal attachment
- Detector module assembly
- Electrical connections and communication systems
- Software implementation
  - Timing system
  - User interface
  - Optical path length calculation

Gantry attachment

Fold mirrors

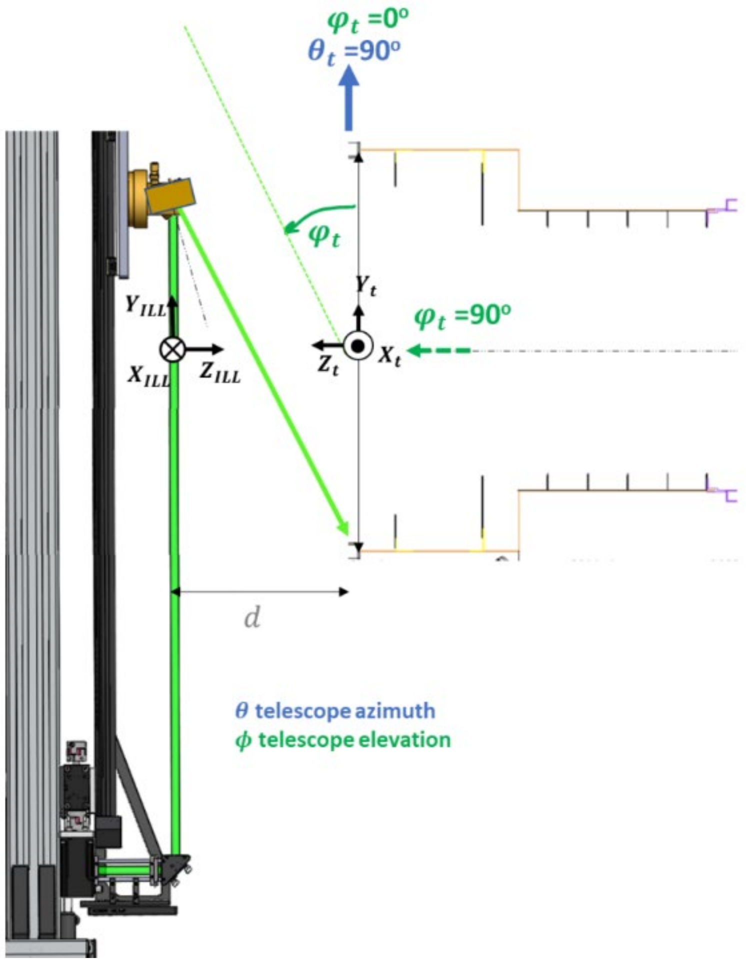


Beam expander



ILLUMINATION MODULE ALIGNMENT

- Coordinate frame definition
- Alignment from laser exit, through beam expander path, into gimbal mirror and telescope aperture
- Optical path length calculation



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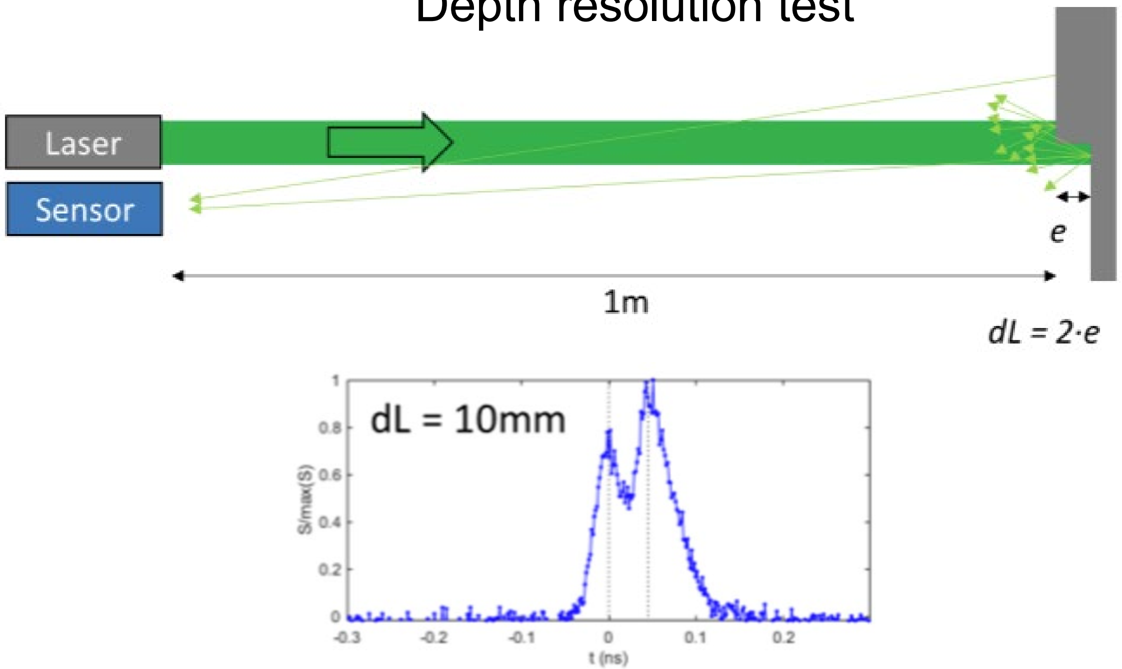
OGSE PERFORMANCE EVALUATION

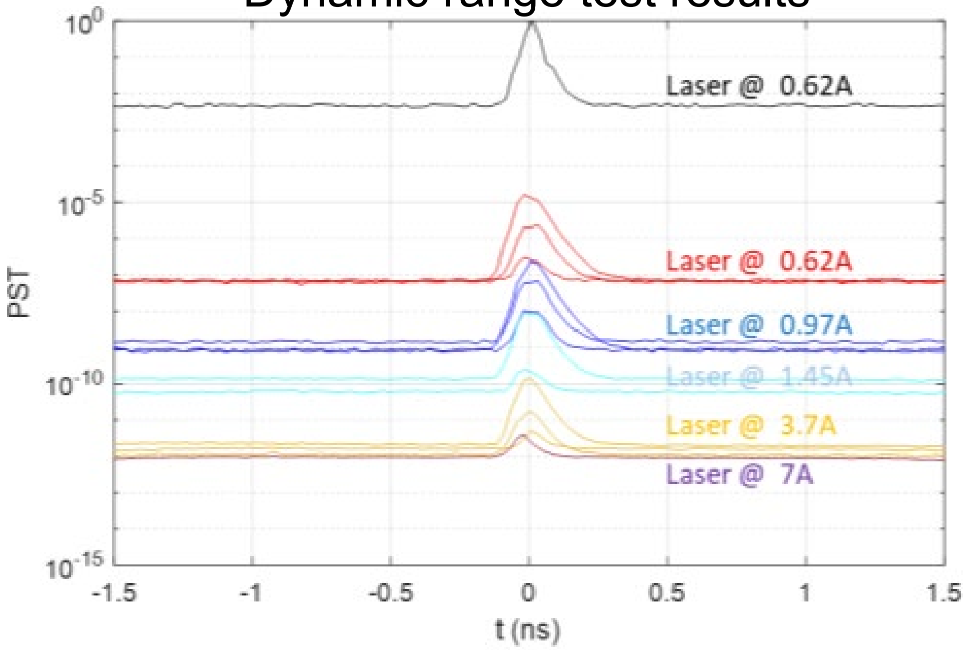
- Time correlation verification
- Detector impulse response
- Depth resolution (right)
- Path length verification

Depth resolution test

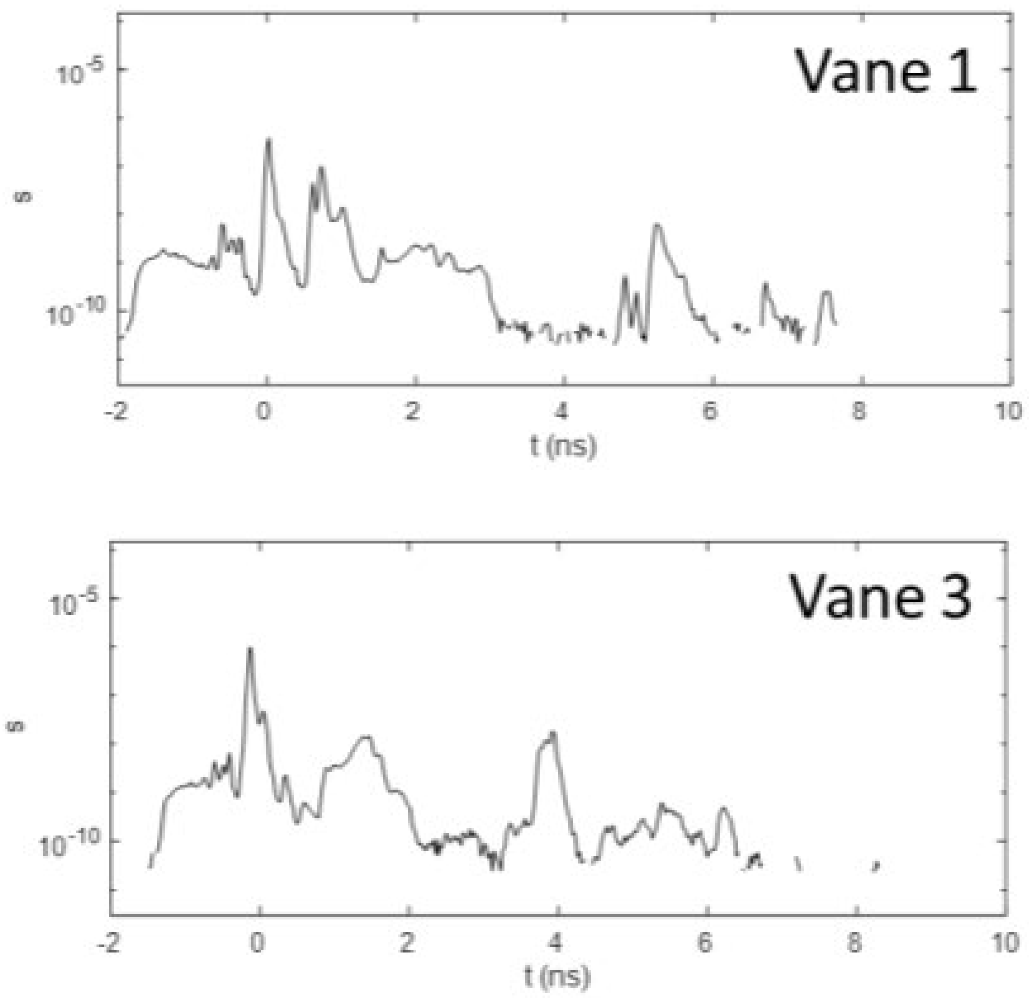


- Dynamic range (left)

Dynamic range test results



CHEOPS BAFFLE TEST



- Full system alignment with test object
- Nine test locations
  - 7 baffle vanes
  - 2 walls
- About 1.1m maximum expected path length for straylight (~3.7ns)

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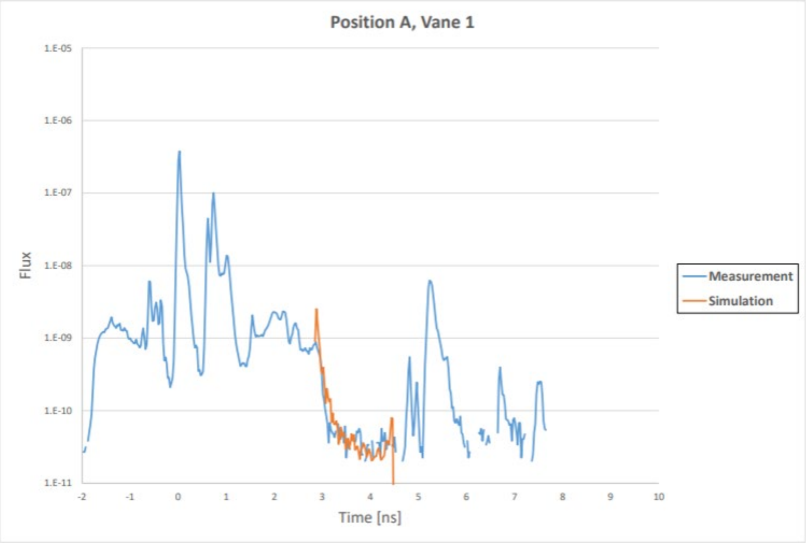
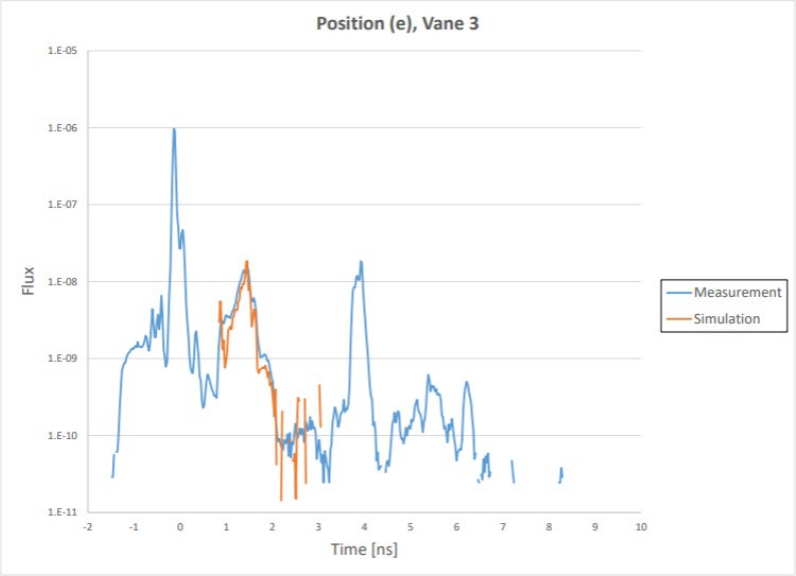
PERFORMANCE EVALUATION





- Simulation based on tested illumination positions
- High dynamic range -> long simulation time
- Overall good correlation
  - Test object is a model, and not stored in clean environment
  - Measurement noise

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OPPORTUNITIES FOR IMPROVEMENT

- Cleanliness testing
  - ➢ Optimization for use in clean room
- Vignetting at extremes of gimbal angle
  - ➢ Larger mirror
- Depth precision, wavelength and detector resolution
  - ➢ Use of super-conducting single photon detector (SSPD)
    - 17.8ps impulse response
    - Compatible with 1064nm light → LISA telescope
    - Liquid helium cooled
    - 48 pixels

CONCLUSION

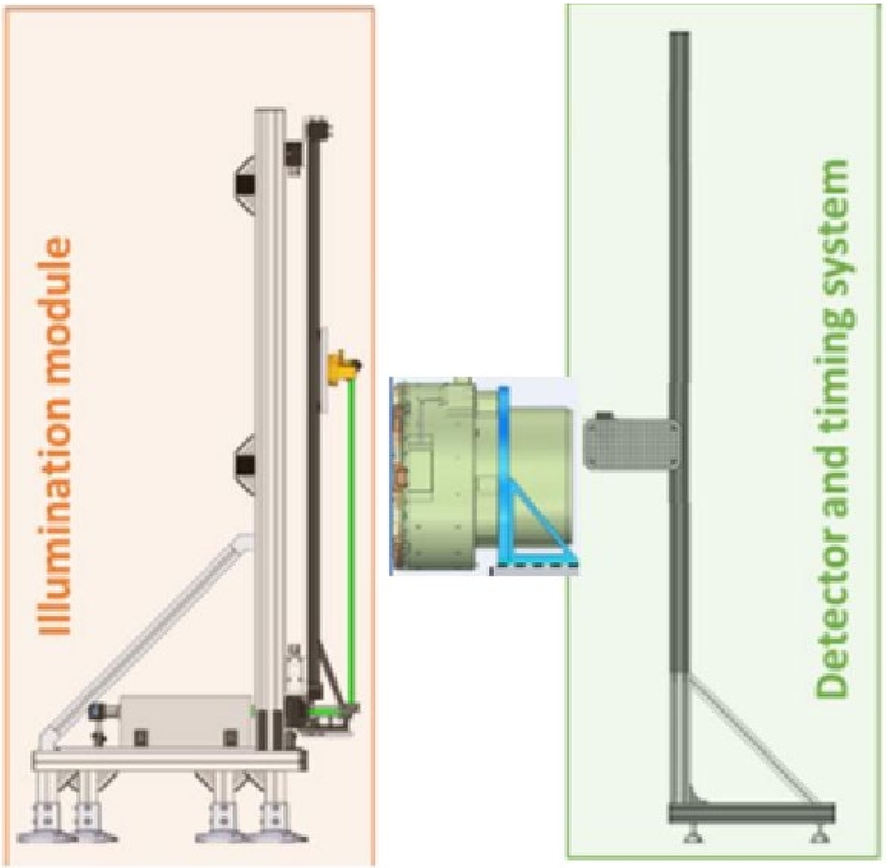
SLOTT PROJECT CONCLUSION

Successful validation of time-of-flight straylight detection scheme using a green laser and single pixel SPAD

- High dynamic range (10^{-13})
- High depth precision (10mm)
- Portable

Ready for upgrade to

- Cleanroom compatibility
- Longer wavelength



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FACING THE CHALLENGES OF OUR TIME