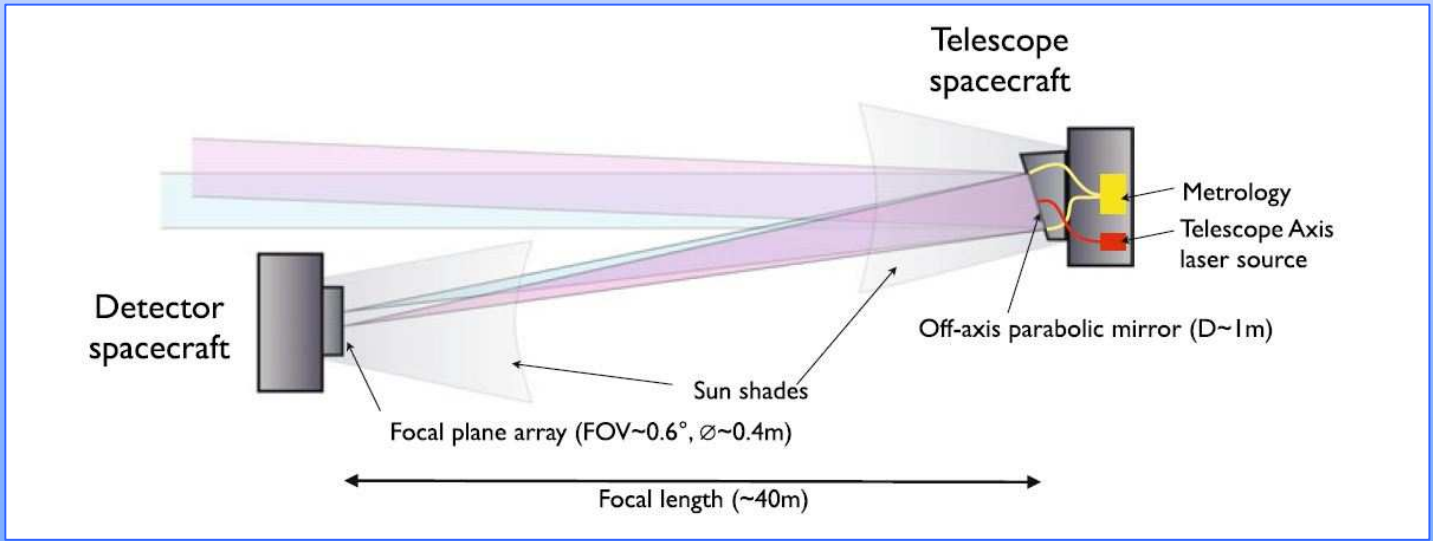
NEAT breadboard system analysis and performance models

François Hénault, Antoine Crouzier, Fabien Malbet, Pierre Kern, Guillermo Martin, Philippe Feautrier, Eric Staedler, Sylvain Lafrasse, Alain Delboulbé, Jean-Michel Le Duigou, Christophe Cara, Alain Léger

a Institut de Planétologie et d'Astrophysique de Grenoble, Université Joseph Fourier, CNRS
B.P. 53, 38041 Grenoble – France
b Centre National d'Etudes Spatiales, 18 Avenue Edouard Belin, 31401 Toulouse – France
c Laboratoire AIM, UMR 7158, CEA-IRFU/CNRS-INSU/Université Paris Diderot,
CEA Saclay, Bât 709, 91191 Gif-sur-Yvette Cedex, France
d Institut d'Astrophysique Spatiale (IAS), UMR 8617, Université Paris Sud/CNRS-INSU,
Bât. 120-121, 91405 Orsay – France

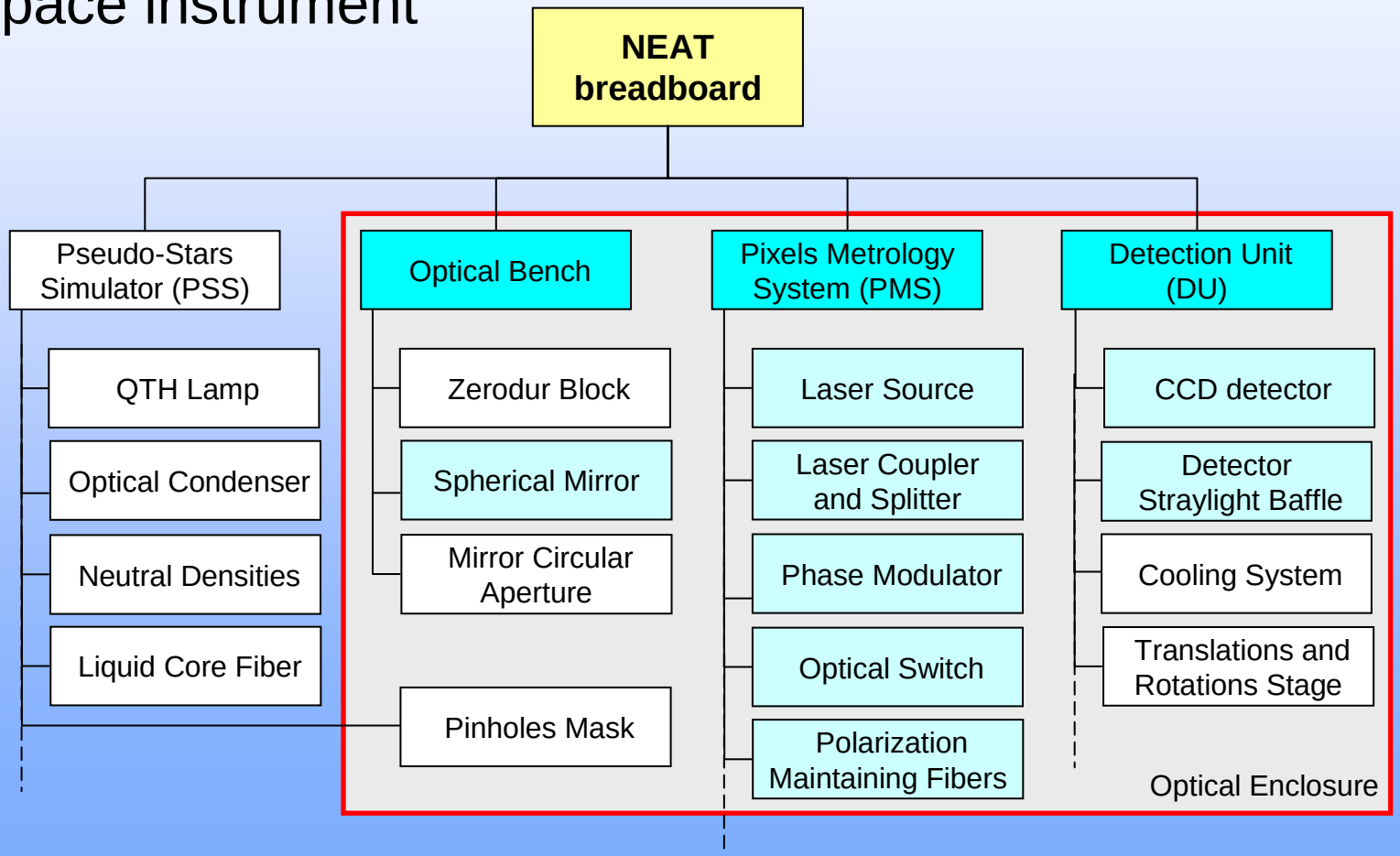
NEAT space instrument

- Detection of Earth-like extra-solar planets around nearby stars
- Two free-flying vessels, one for the single-mirror telescope, the other for the focal plane array
- **Relative** star positions to be measured within 1 micro-arcsec, corresponding to **$5\ 10^{-6}$** pixels !!
- IPAG, CNES, CEA and IAS decided to develop a test bench for demonstrating the feasibility of the extremely ambitious performance

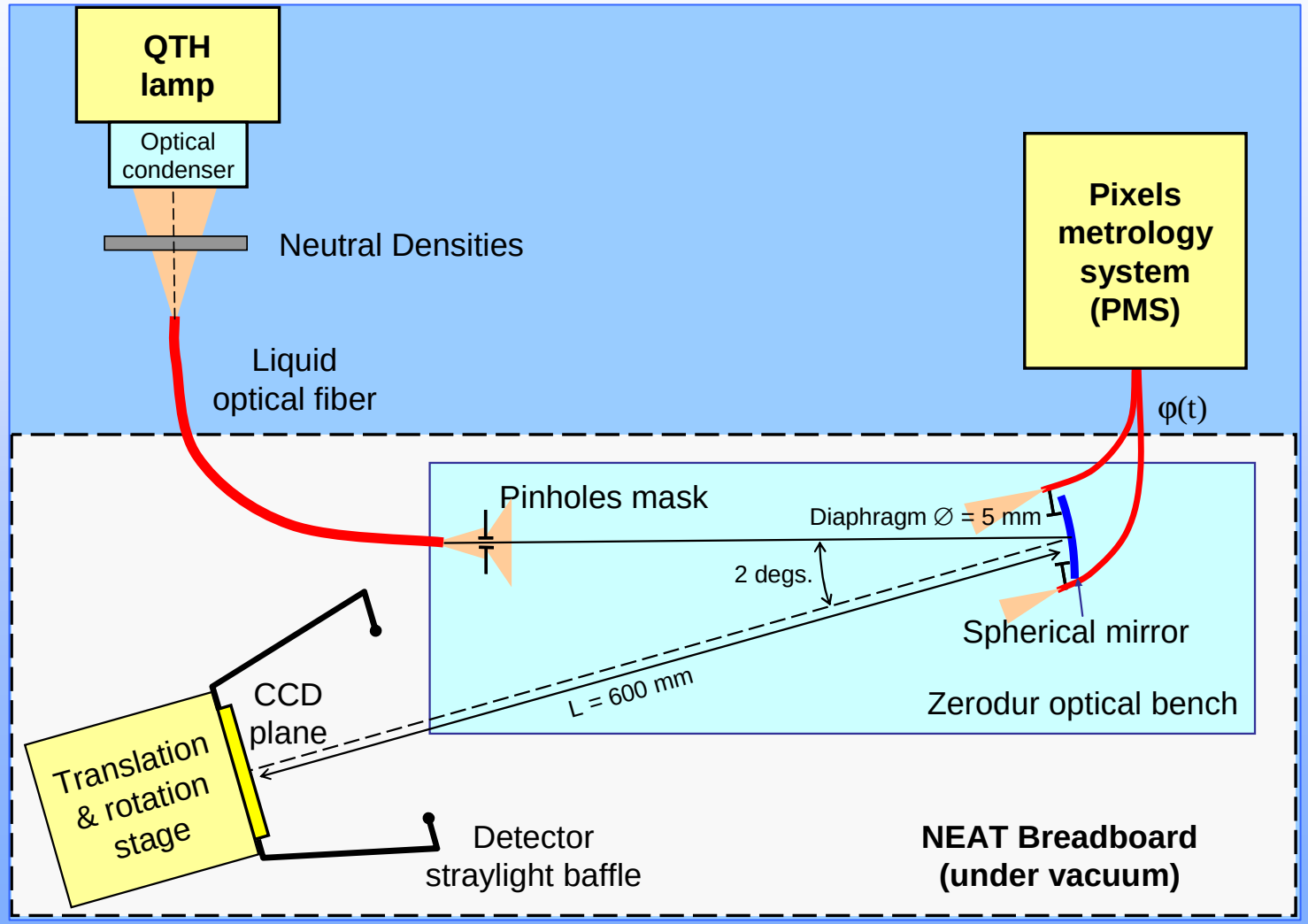


Test bench product tree

- Designed to simulate the most demanding functions of the space instrument

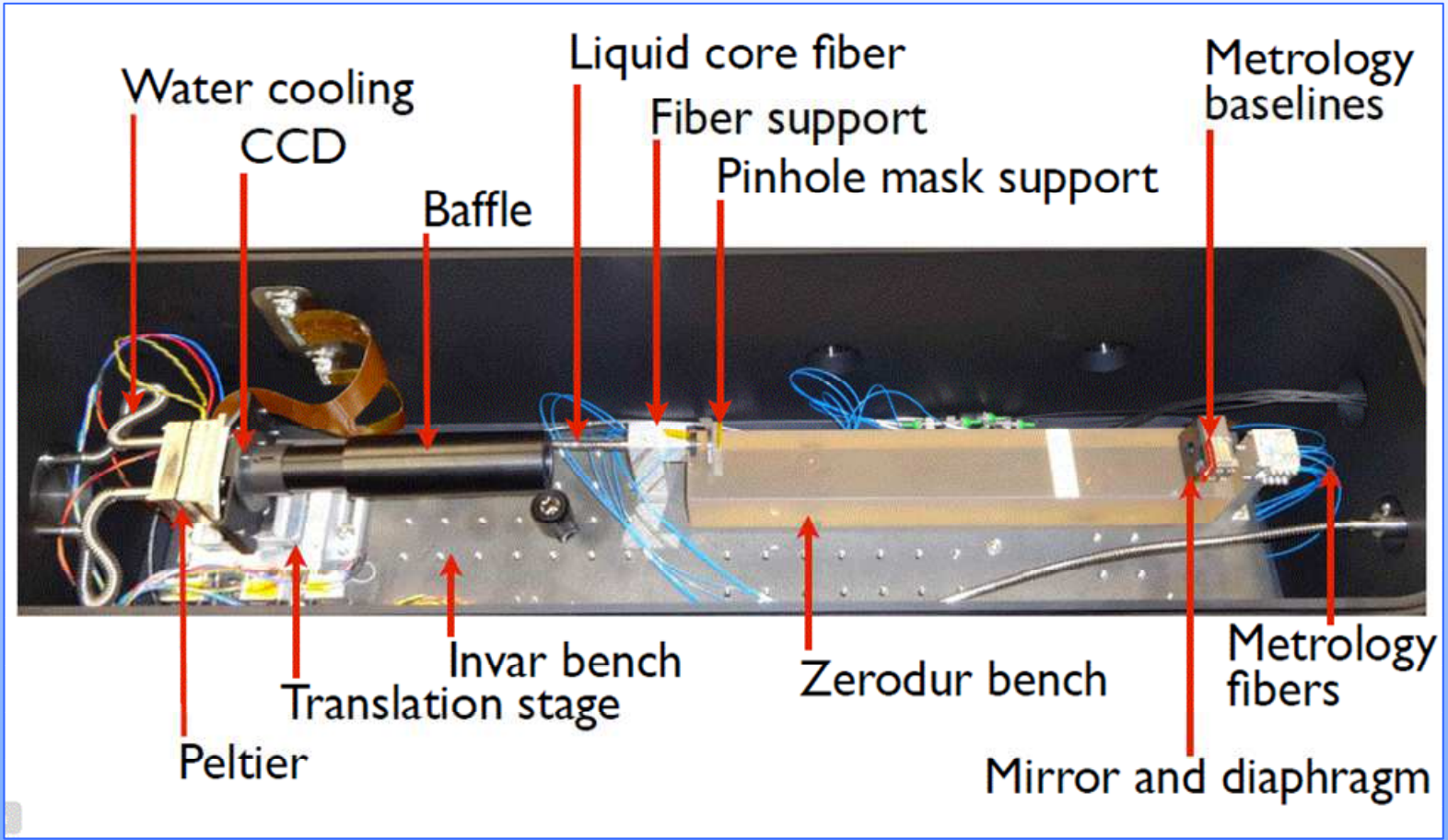


Test bench - Schematic representation



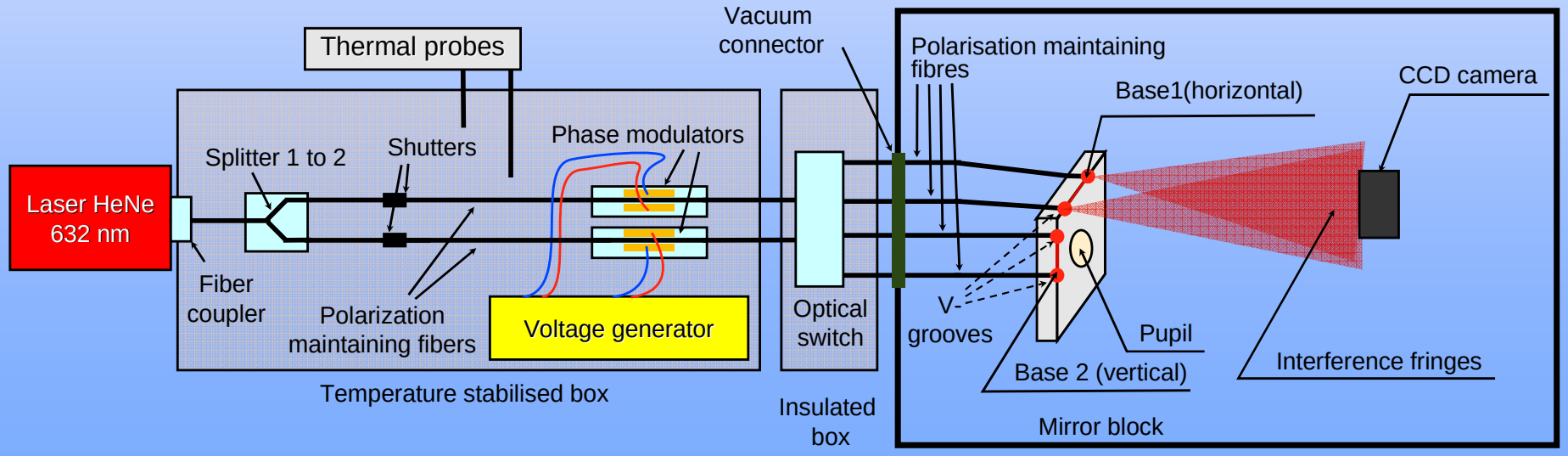
Test bench – General view

- Inside vacuum enclosure :

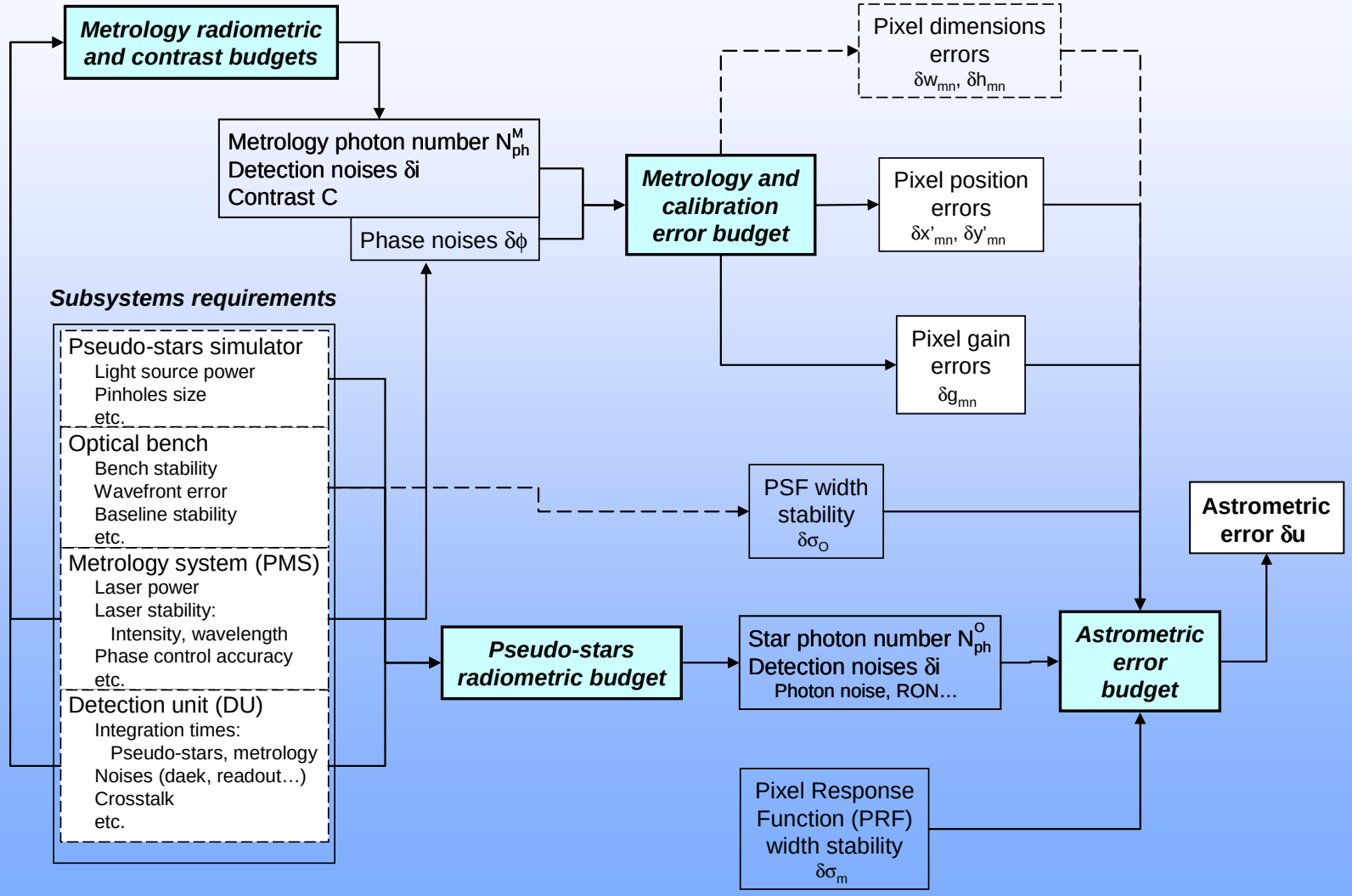


Pixels metrology system (PMS)

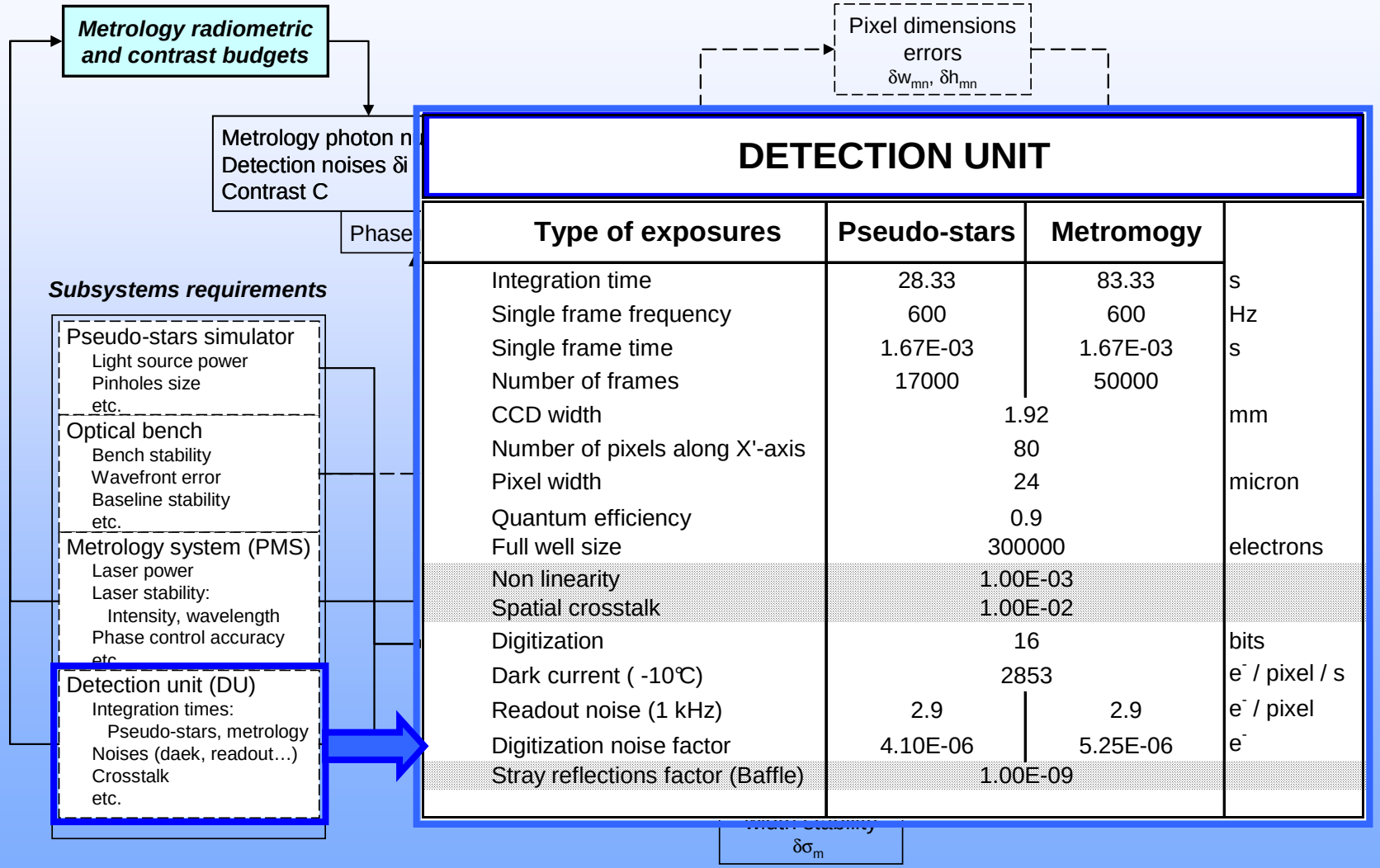
- Heart of the instrument, generates set of Young's fringes with temporal phase modulation, sweeping each individual pixel
- Allows to measure their gains g_{mn} and centroid location errors $(\delta x'_{mn}, \delta y'_{mn})$
- 6 different horizontal and vertical baselines thanks to an optical switch and 8 polarizing maintaining fibers



Analytical performance model - Architecture



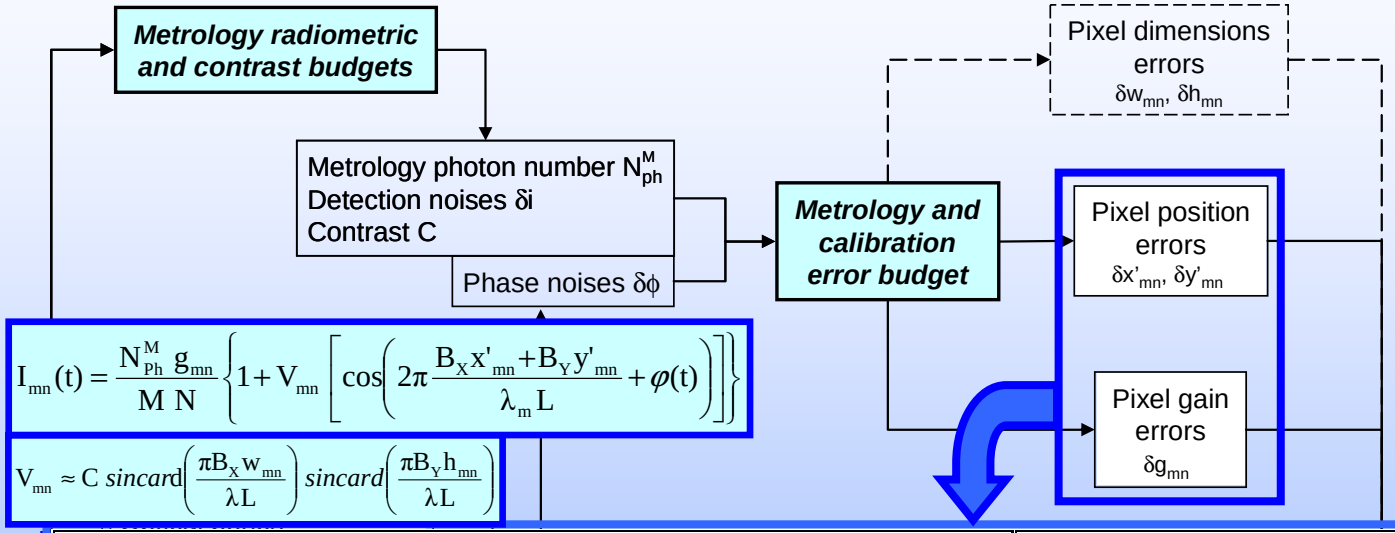
Subsystems requirements



DETECTION UNIT

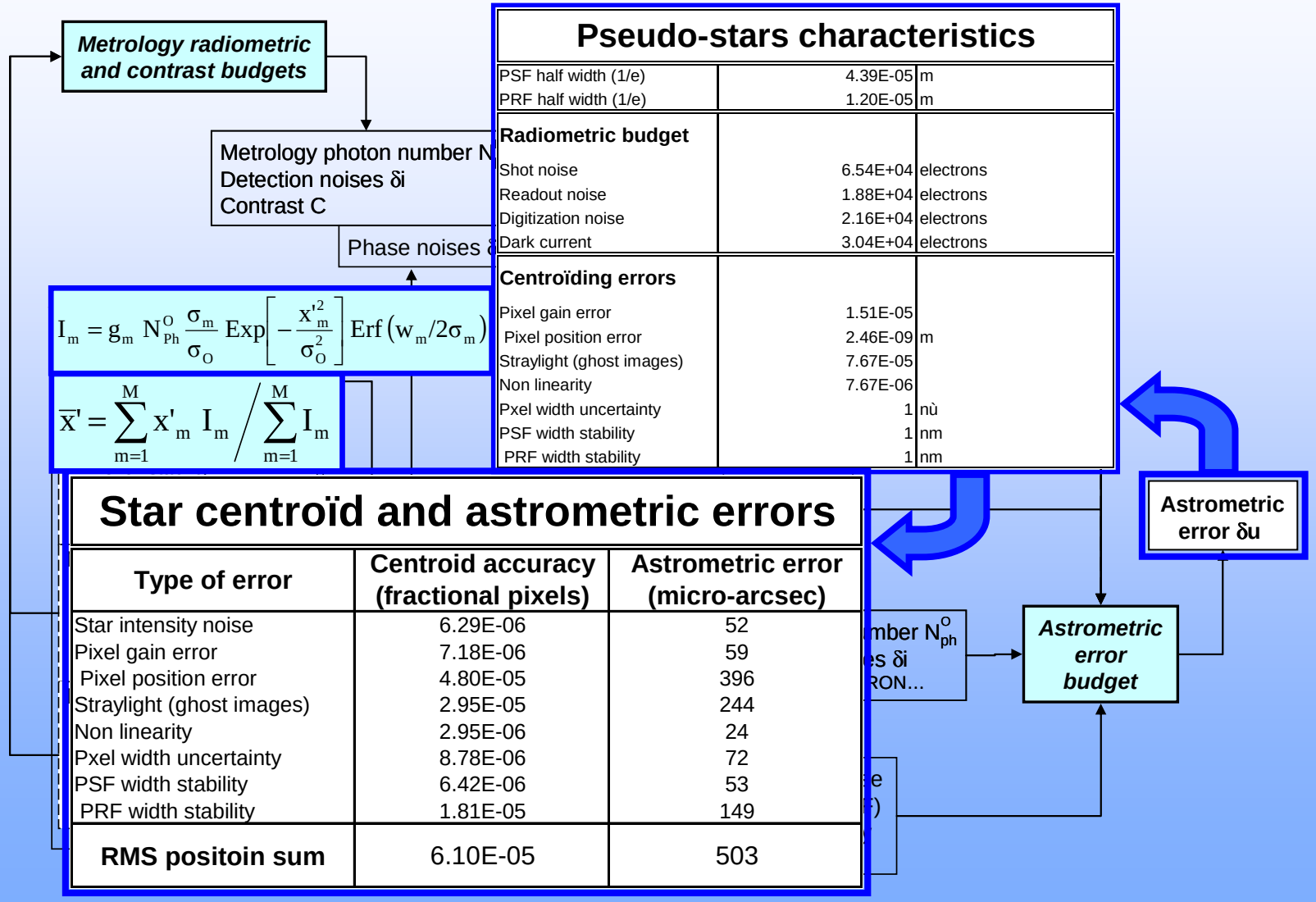
Type of exposures	Pseudo-stars	Metromogy	
Integration time	28.33	83.33	s
Single frame frequency	600	600	Hz
Single frame time	1.67E-03	1.67E-03	s
Number of frames	17000	50000	
CCD width	1.92		mm
Number of pixels along X'-axis	80		
Pixel width	24		micron
Quantum efficiency	0.9		
Full well size	300000		electrons
Non linearity	1.00E-03		
Spatial crosstalk	1.00E-02		
Digitization	16		bits
Dark current (-10℃)	2853		e^- / pixel / s
Readout noise (1 kHz)	2.9	2.9	e^- / pixel
Digitization noise factor	4.10E-06	5.25E-06	e^-
Stray reflections factor (Baffle)	1.00E-09		

Metrology error budgets

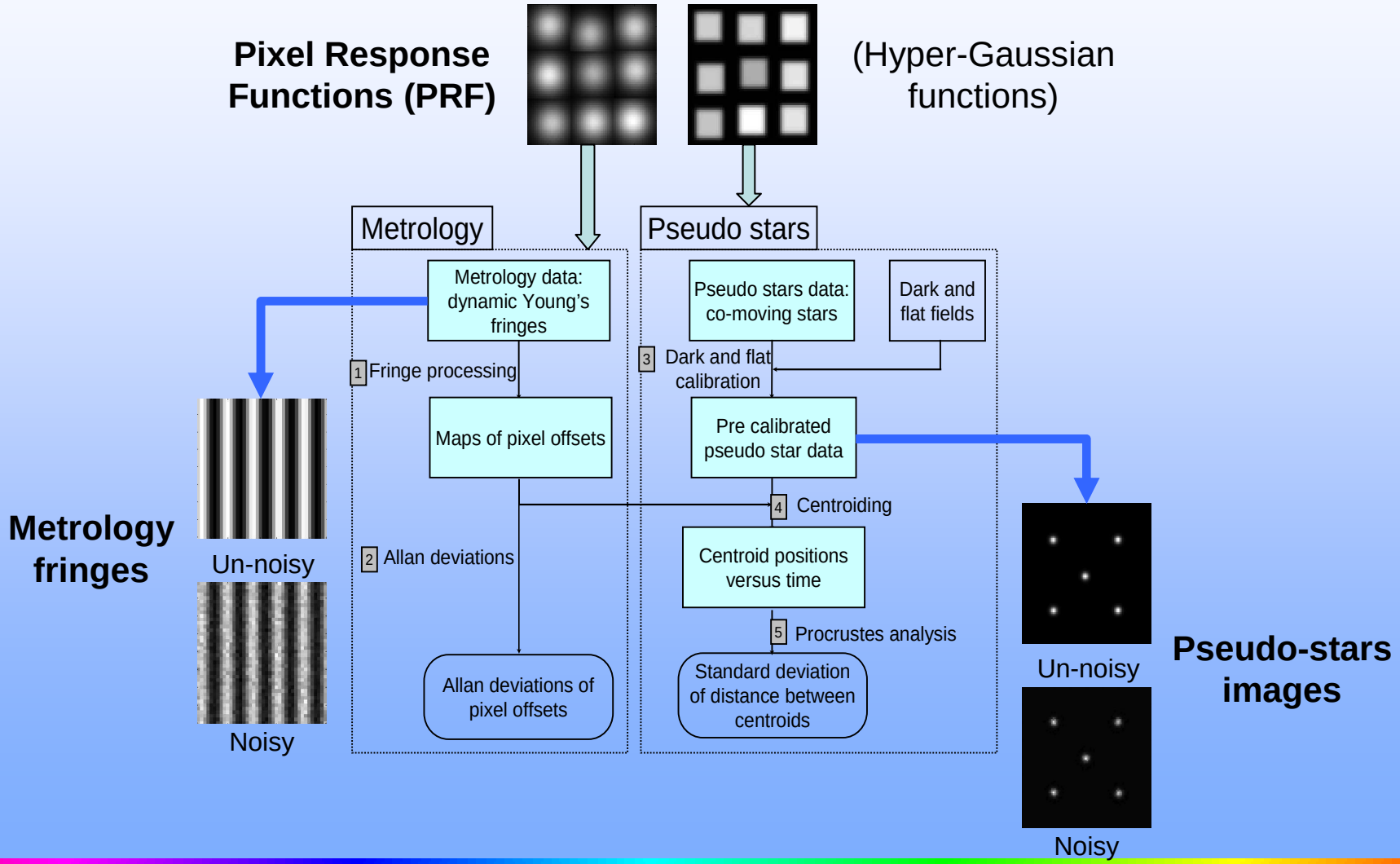


Phase and intensity Noises					Calibration Errors	
Subsystem	**Name**	**Value**	**Unit**	**Type of noise**	**Pixel gain**	**Pixel osition (fraction of pixels)**
Laser source	Wavelength stability	1.00E-05	δλ/λ	Phase noise δϕ	1.75E-18	1.00E-07
Fibered system	Phase control accuracy	1.00E-05	radians	Phase noise δϕ	9.21E-16	5.28E-05
Fibered system	Intensity drift	0.00E+00		Intensity noise δi	0.00E+00	0.00E+00
Fibered system	Intensity noise	2.24E-05		Intensity noise δi	1.01E-05	5.88E-05
Fibered system	Straylight (parasitic interferograms)	2.24E-05		Intensity noise δi	1.01E-05	5.88E-05
Fibered system	Baseline stability	0.00015	micron	Phase noise δϕ	8.73E-21	5.00E-10
Optical bench	Bench stability (Z-axis)	0.6	micron	Phase noise δϕ	1.75E-19	1.00E-08
Detection unit	Metrology non linearity	0.00E+00		Intensity noise δi	0.00E+00	0.00E+00
Detection unit	Shot noise	1.10E+05	photons	Intensity noise δi	4.09E-06	2.39E-05
Detection unit	Readout noise	2.94	e^- / pixel	Intensity noise δi	7.77E-07	4.08E-06
Detection unit	Digitization noise	6.36E+04	e^-	Intensity noise δi	2.63E-06	1.38E-05
Detection unit	Dark current	2853	e^- / pixel / s	Intensity noise δi	1.26E-06	6.61E-06
				RMS Sum	1.51E-05	1.03E-04

Star position error budget

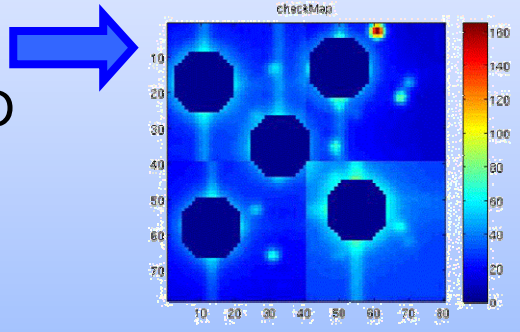


Numerical performance model



Comparing models with experimental results

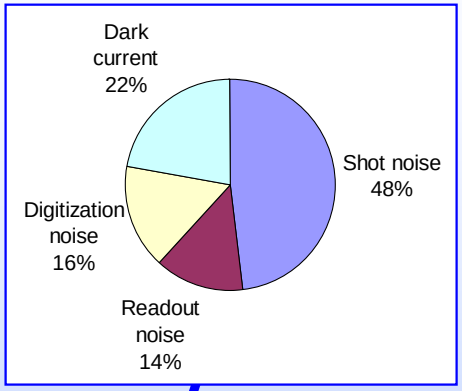
- Both models in global agreement
- Unexpected critical error items appearing on the test bench :
  - **Parasitic interferograms** in laser metrology chain → New camera baffle under design, concentrating optics at a later stage
  - Pseudo-stars **ghost images** of electronic origin
    → Modify electronic circuits or use another CCD



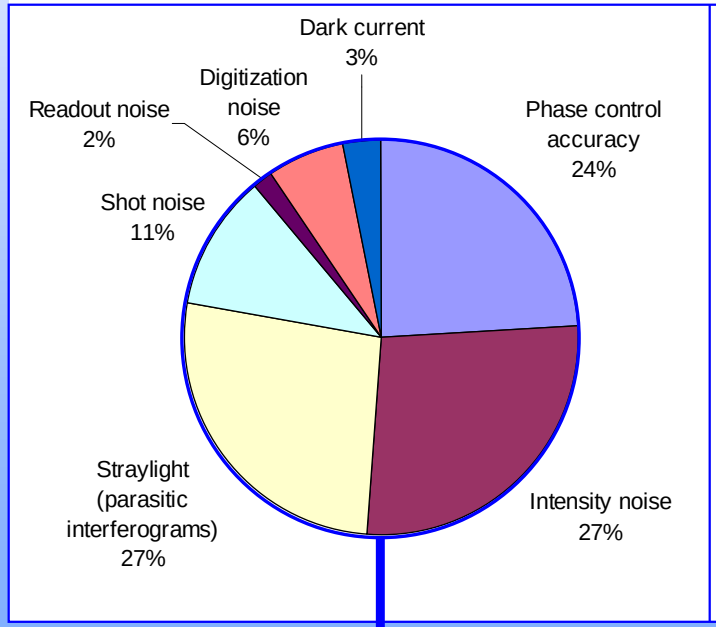
- Error items not so critical as expected :
  - Pseudo-stars photon noise
  - Metrology laser wavelength stability
  - Zerodur and Invar bench thermal stability
- Other errors to be investigated :
  - Laser intensity fluctuations
  - Fringes phase fitting accuracy
  - PRF width instability

Breadboard performance status

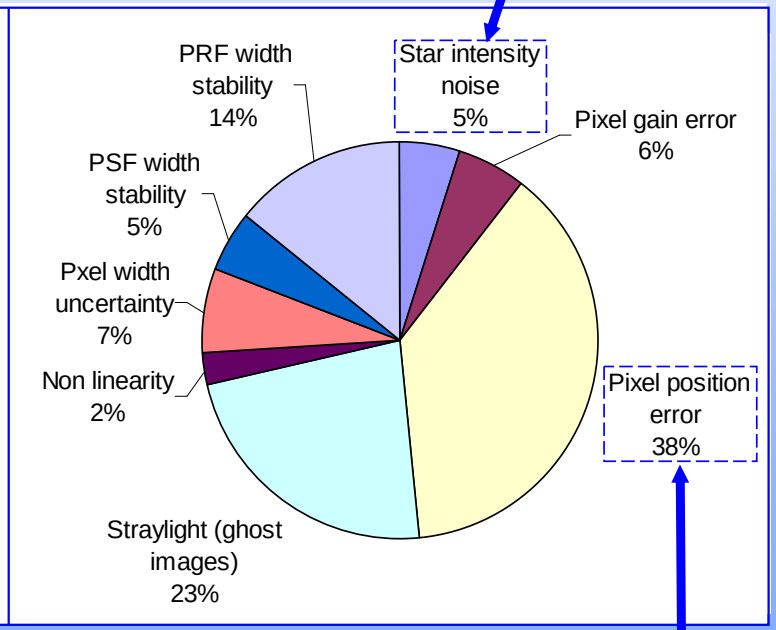
Performance	Required	Estimated
	(fractions of pixel)	
Pixel position error	5.00E-06	1.03E-04
Star position error	5.00E-06	6.10E-05



Pixel position error



Star position error



Conclusion

- The NEAT performance models were very helpful to identify the dominant error sources of the breadboard:
- Most of errors are well understood (shot noise, detector noise)
- Some ones deserving further investigations: parasitic interferograms in metrology beam, pseudo-stars ghost images (electronic crosstalk)

  → In way to be eliminated
- NEAT space instrument will probably be postponed after year 2020, but its test bench will be pursued for high precision characterization of detectors ***in situ***
- Future developments:
  - New detector arrays funded by CNES
  - Evolutions of the metrology and astrometric performance models:
    - Detector defocus and tilt stability effects
    - More realistic PSF and PRF shape
    - Influence of opto-mechanical errors on PSF width stability
    - Ghosts and parasitic interferograms issues