UNIVERSITY OF BIRMINGHAM

Advanced LIGO

# BOSEM Production Status and EUCLID Development

Stuart Aston
University of Birmingham

LSC-Virgo Meeting

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G1000825-v2

# Presentation Overview

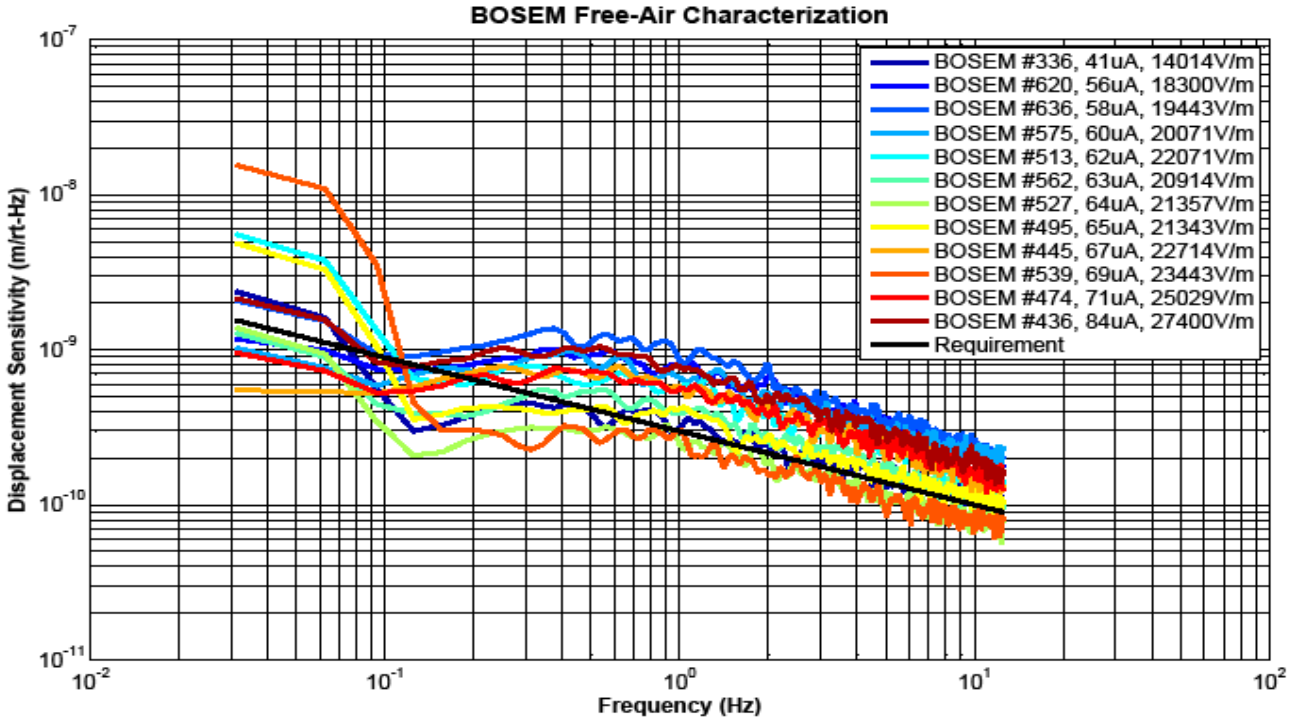
- **BOSEM** *S.Aston, D.Lodhia, N.Lockerbie (University of Strathclyde) and A.Vecchio*
- *Advanced LIGO UK Deliverable*
  - Initial BOSEM Characterisation Results
  - Alternative IRLED Candidate
  - Alternative IRLED Batch-to-Batch Variation
  - IRLED Screening – 1st Batch Results
  - BOSEM Characterisation – 1st Batch Results
  - BOSEM Status & Production Plan

- **Satellite Box & Drive Electronics** *R.Cutler, L.Carbone and A.Vecchio*
- *Advanced LIGO UK Deliverable*
  - Advanced LIGO UK Suspension Electronics (see poster session)

- **EUCLID** *C.Speake, S.Aston, F.Peña Arellano and D. Hoyland*
- *Non Deliverable*
  - Optical Sensor Development
  - Motivation
  - Realisation
  - Fabrication Status
  - Displacement Calibration
  - Tilt Immunity
  - Sensitivity Characterisation

# Initial BOSEM Characterisation Results

- Requirement [1]:-
  - Sensitivity at 1Hz = $3\times10^{-10}$m/√Hz and at 10Hz = $1\times10^{-10}$m/√Hz
  - Operating Range 0.7mm (peak-peak)



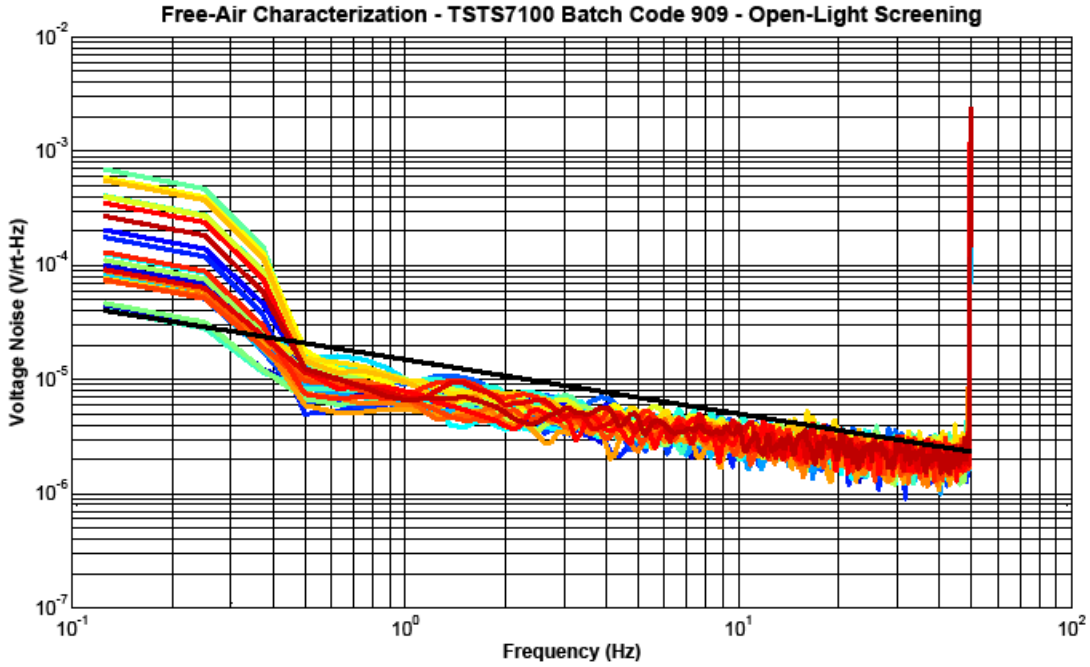

- Results [2] obtained were unexpected & disappointing as only ≈10% of units measured met the sensitivity requirement!

**[1] T040110-01-K, Ken Strain "Input to the OSEM selection review decision".**

**[2] T0900496-v2, Stuart Aston "Advanced LIGO BOSEM Noise Measurements".**

# Alternative IRLED Candidate

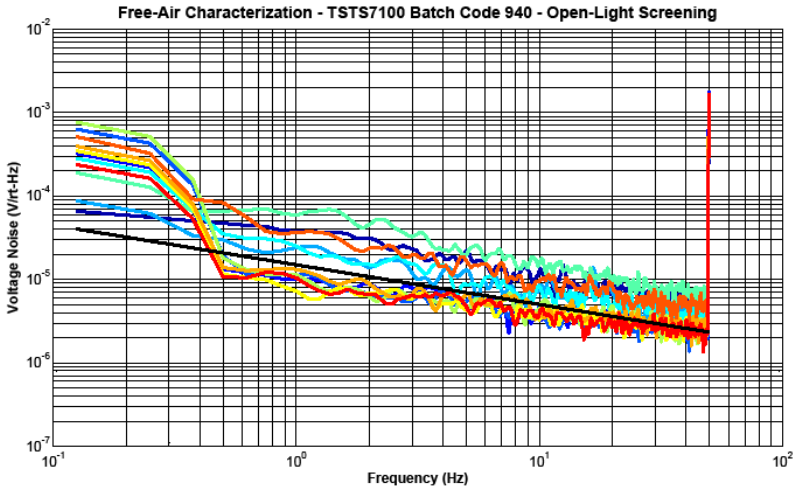
- During testing we identified a promising alternative candidate, Vishay TSTS7100
  - Represents a more recent state-of-the-art device (at similar cost)
  - Opto-mechanical properties of TSTS7100 and OP232 are essentially identical
  - However, pin-outs reversed and TSTS7100 larger forward current capability (250mA)

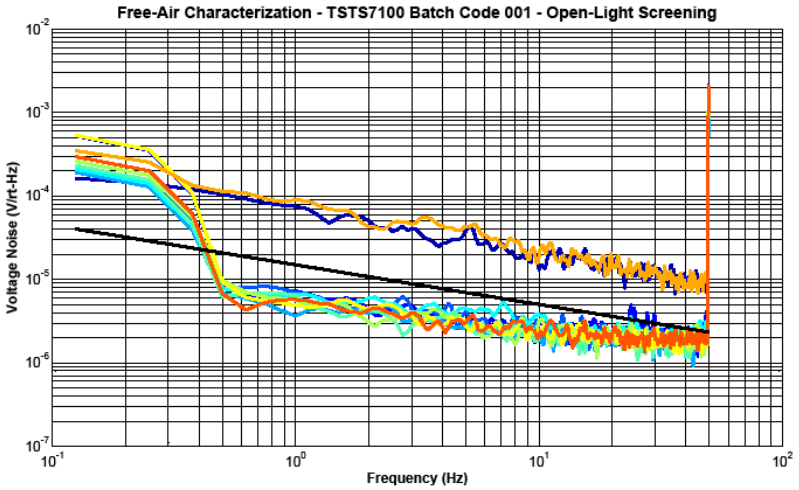



- 1st batch open-light photo-current noise test results (54 units)
  - Black line illustrates estimated requirement
  - This initial batch demonstrated 100% pass rate (not all traces included in plot)

# Alternative IRLED Batch-to-Batch Variation

- However, for subsequent batches received the pass rate fell:-
  - 1st batch (909) 100% pass rate (54 tested)
  - 2nd batch (940) ~50% pass rate (11 tested)
  - 3rd batch (001) ~80% pass rate (10 tested)
  - ⇒ Indication of significant batch-to-batch variation

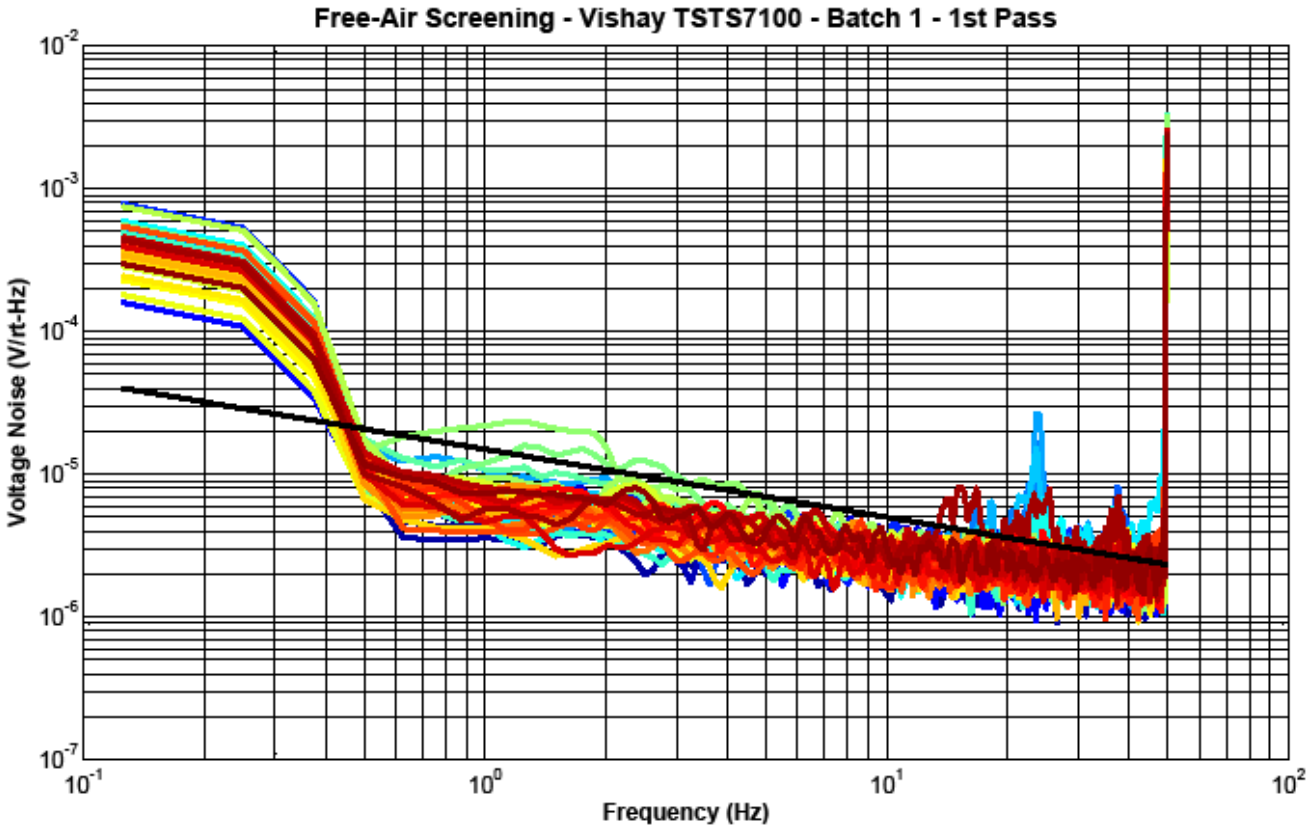



- Therefore, screening of photo-current noise offers the only way forward
- Alternative IRLED offers much higher yield than original OP232 device
- We recommended to aLIGO that we should swap devices:-
  - aLIGO UHV qualification was obtained and MTTF data provided by manufacturer

# IRLED Screening – 1st Batch Results (1)

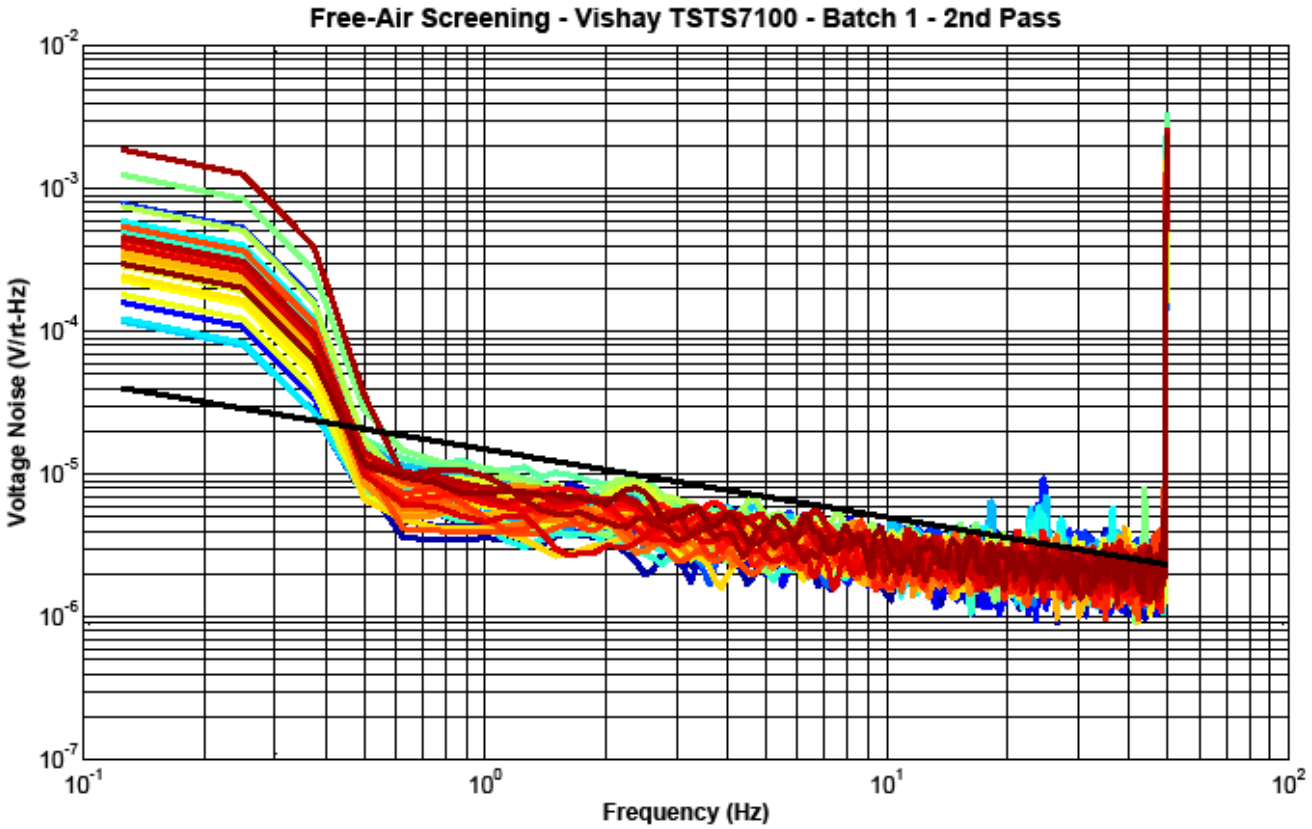
- Vishay IRLED Screening 1st Batch – 1st Pass Results:-




- Screening procedure generated by SMA and undertaken by UoB Technical Staff
- Each batch comprises of 55 units, we are anticipating 60-70% pass rate
- Following on from screening each batch will be burned-in

# IRLED Screening – 1st Batch Results (2)

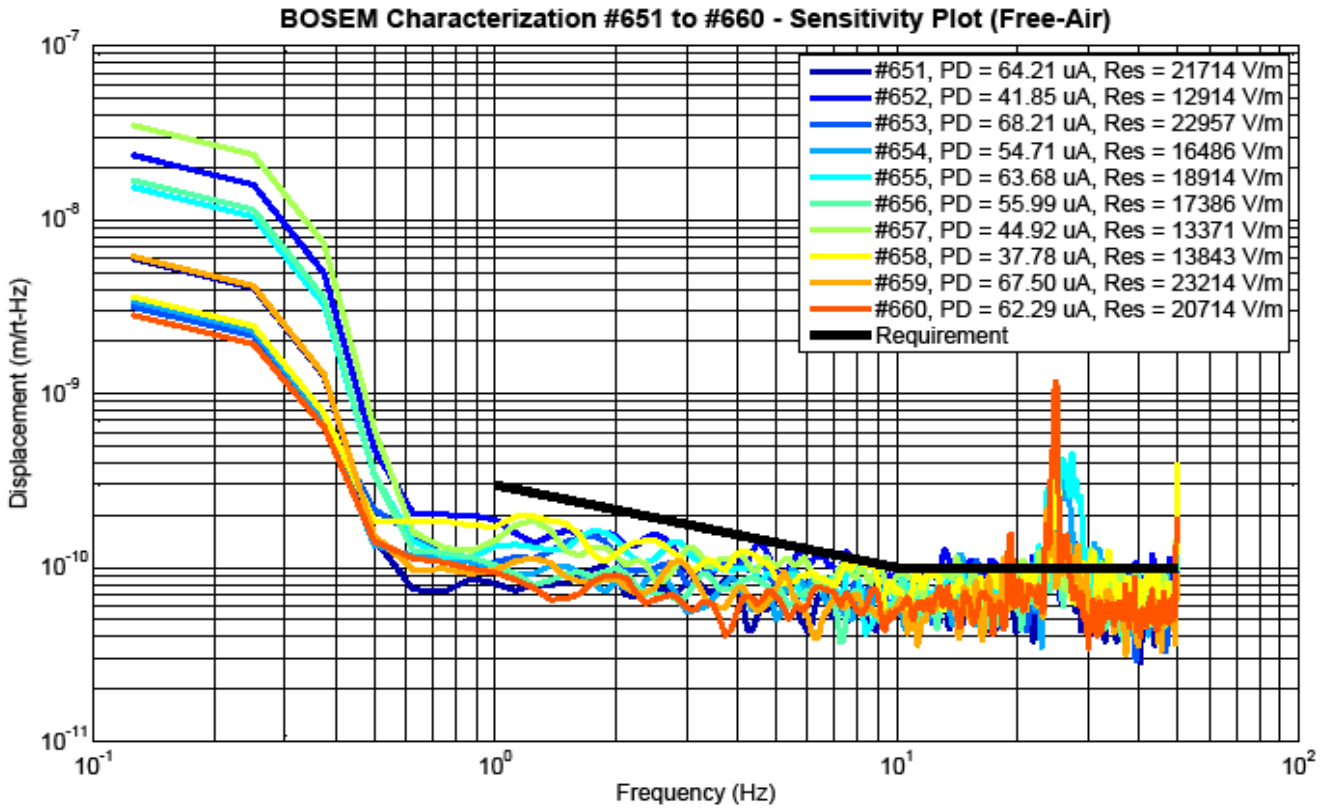
- Vishay IRLED Screening 1st Batch – 2nd Pass Results:-




- SMA analyses traces for each IRLED within batch across requirement band
- Repeat measurements for devices out of specification at other frequencies
- Verification check for repeated, omitted or erroneous measurements

# BOSEM Characterisation – 1st Batch Results

- Assembly of in-process spare BOSEMs (50 units)
  - Incorporating alternative Vishay IRLED (screened, burned-in, cleaned and baked)




  - Complete batch were fully characterised, responsivity and noise measured
  - 50 out of 50 BOSEMs meet the sensitivity requirement (black trace)

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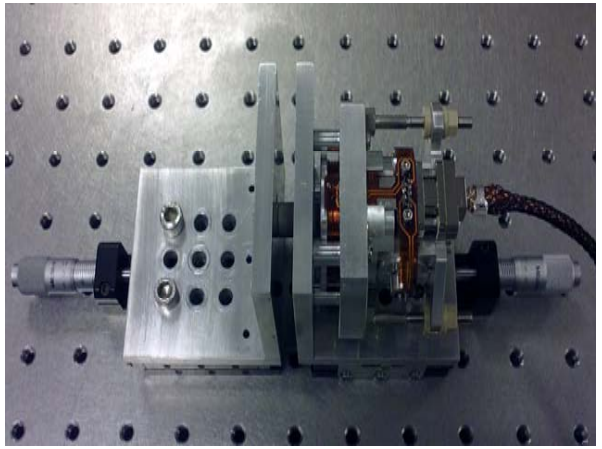
# BOSEM Status & Production Plan

- 103 pre-production units have already been delivered:-
  - NPOSEMs units shipped in December 2007
- 625 production BOSEMs to deliver in total:-
  - 40 shipped for test stands / quad training exercise in April 2010
  - 50 shipped (retro-fitted IRLED and all fully characterised) in August 2010
- 535 remaining to be shipped:-
  - 100% are to be tested during assembly using the Automated Test Equipment
  - 12.5% are to be fully characterised (responsivity and noise measured) s/n #575-#700
- Proposed delivery schedule of shipments of UHV-clean and tested units (with retro-fitted alternative IRLED) to Caltech ≈100 per month [3]

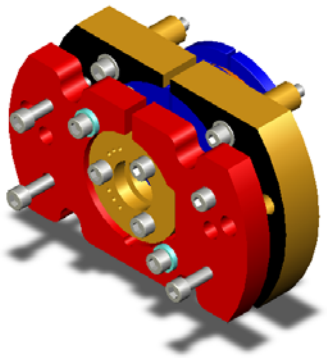
Dedicated clean-room assembly facility


Assembled BOSEMS at ATE station


Lab based full characterisation tests

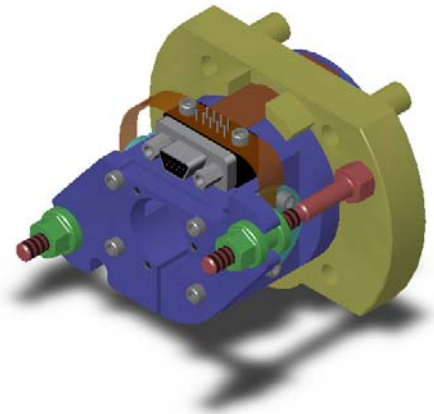
[3] T0900496-v3, Stuart Aston "Advanced LIGO BOSEM Noise Measurements".

# Optical Sensor Development



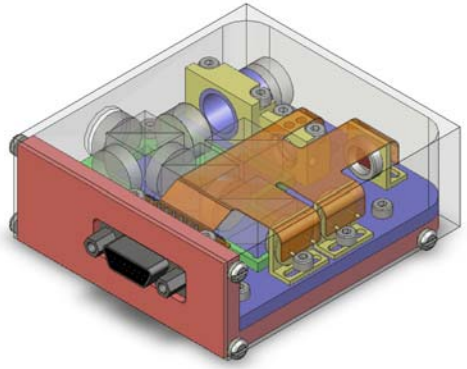
Advanced LIGO

Controls Prototype (Hybrid OSEM)



Advanced LIGO

Noise Prototype &
Production BOSEM

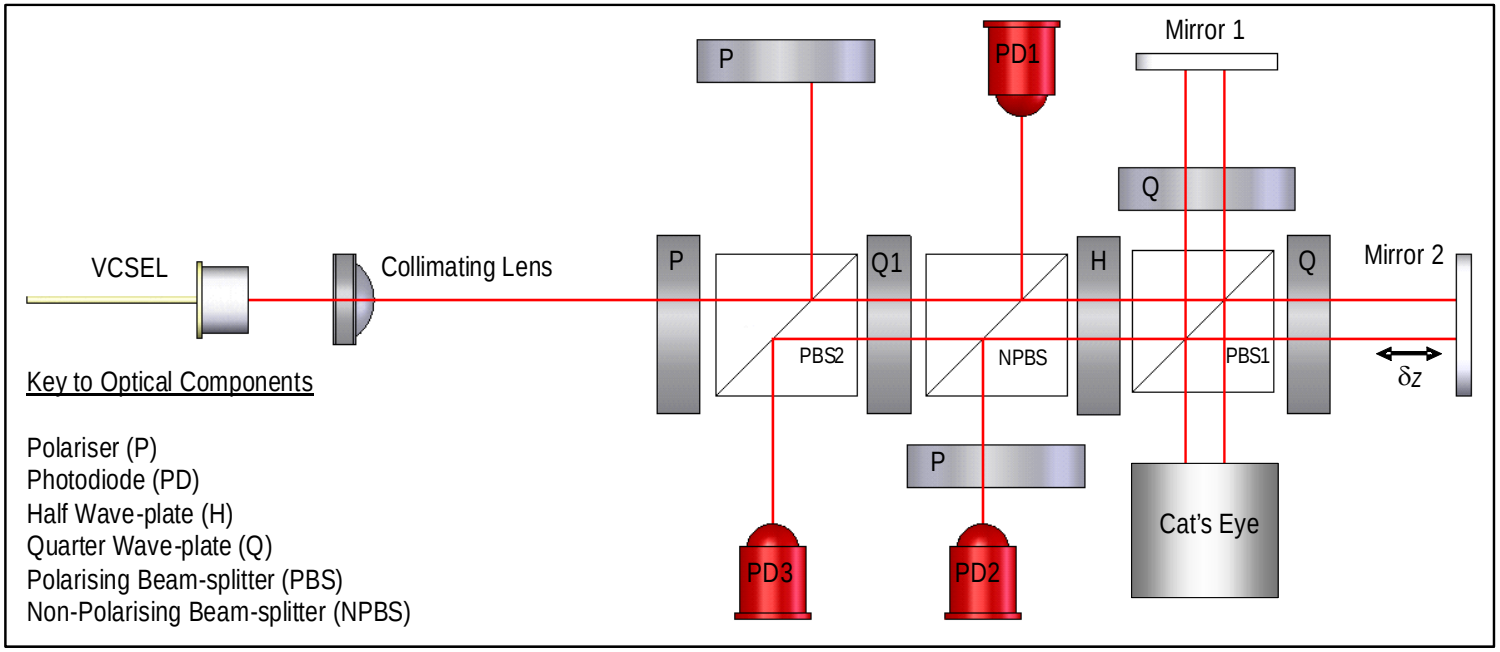


Advanced / Ultra LIGO

Interferometric Sensor (EUCLID)

# EUCLID Motivation

- We believe BOSEMs offer the best sensitivity you can readily achieve with shadow sensor technology
- To ensure good low frequency stability we needed to avoid active parts that can age, thermally expand, generate heat, exhibit hysteresis, e.g. piezos, AOMs, EOMs etc. This naturally led to a Homodyne Interferometer
- Required to be, compact / portable, and robust against misalignment. This has led us to develop a compact interferometric sensor called EUCLID

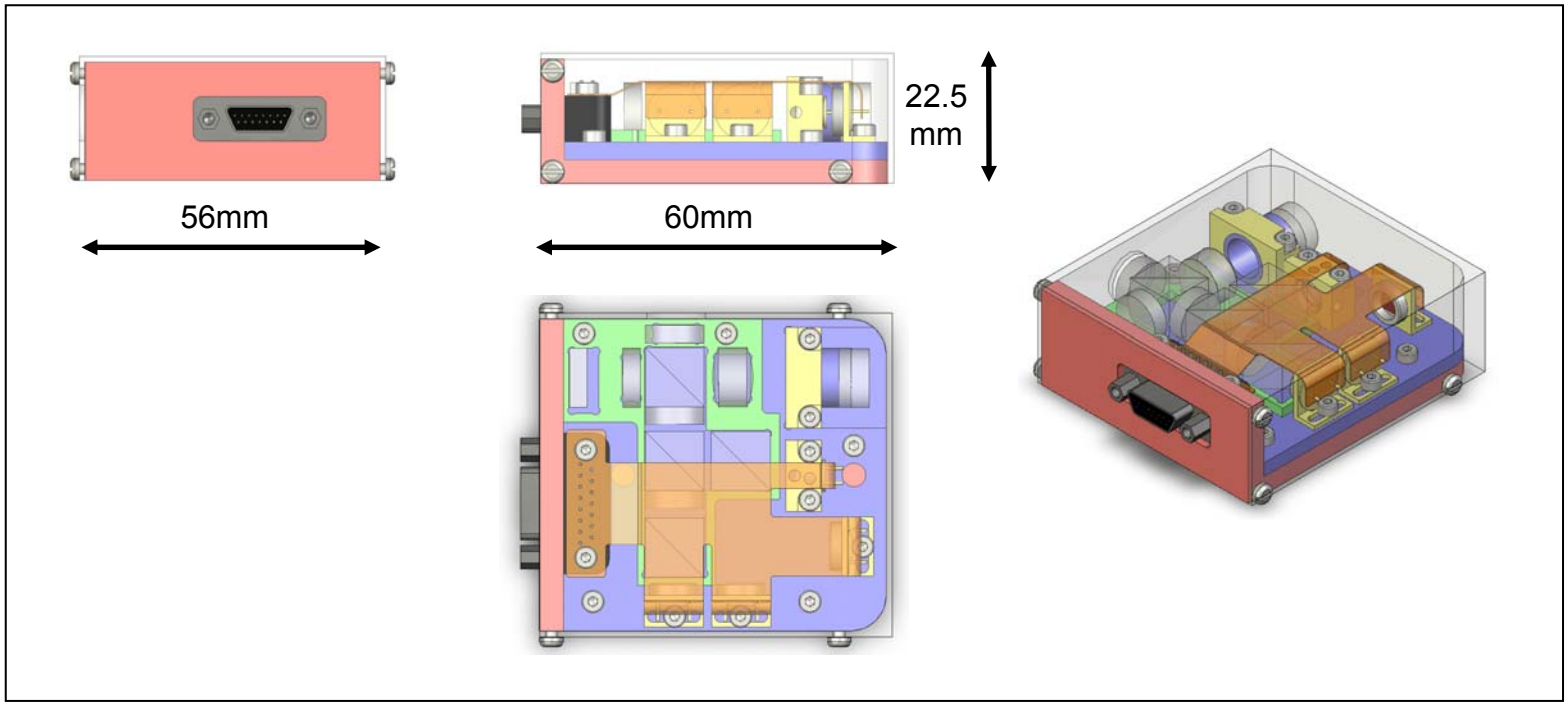



Optical Layout [3]

[3] C. C. Speake and S. M. Aston *"An interferometric sensor for satellite drag-free control".* IOP, Class. Quantum Grav. 22 (2005)

# EUCLID Realisation

- Compact dimensions of 60mm x 56mm x 22.5mm
- Robust against misalignment +/- 1°
- Resolution of up to 1 pm/√Hz over a large working range > 2mm
- Can be constructed to be LIGO UHV compliant
- Incorporates 667nm VCSEL

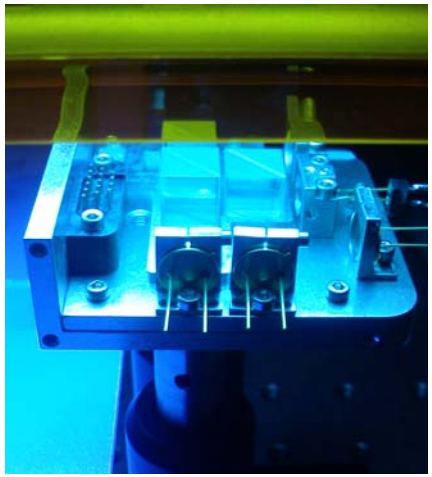



3D CAD Model Engineering Drawing

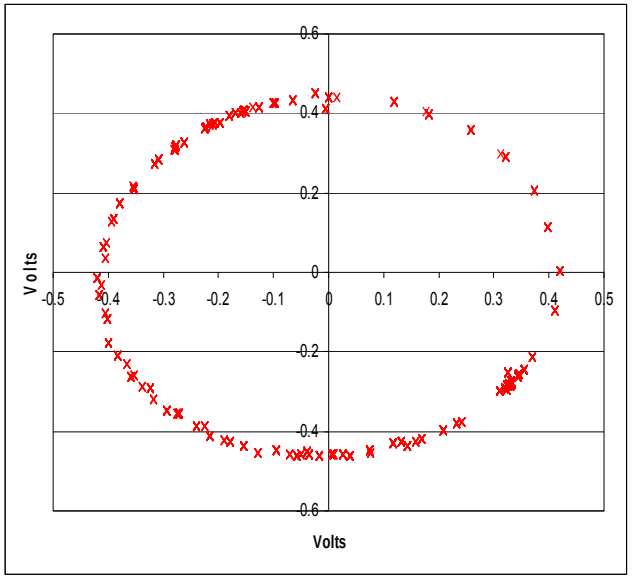
# EUCLID Fabrication Status (1)

- 4 x EUCLID units have been fabricated so far:-
  - 2 for evaluation at MIT (Rich Mittleman)
  - 1 for evaluation by ONERA
  - Initially ‘non’ aLIGO UHV compliant versions using Norland NA063 UV adhesive
  - Provided with electronic support equipment (modified satellite box)
  - 3 x output version (+cos, sin, -cos) to remove DC offset from Lissajous pattern
  - Obtained first-light Lissajous figure in March 09


Modified satellite box



UV curing optical adhesive




First-light fringe visibility

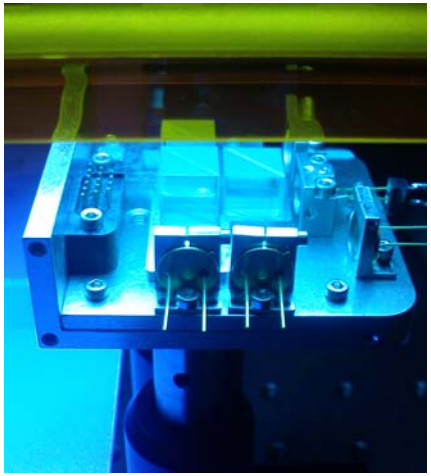
# EUCLID Fabrication Status (2)

- 4 x EUCLID units have been fabricated so far:-
  - 2 being characterised at MIT (by Rich Mittleman *et al*)
  - 1 being characterised at ONERA

  - Initially 'non' aLIGO UHV compliant versions using Norland NA063 UV adhesive
  - **Now with new electronics support equipment (bespoke onboard FPGA)**

  - 3 x output version (+cos, sin, -cos) to remove DC offset from Lissajous pattern
  - **18-bit ADC's and upto 1MHz sampling**
  - **Operational in August 2010**
  - **Very low-noise front end**


New EUCLID Electronics



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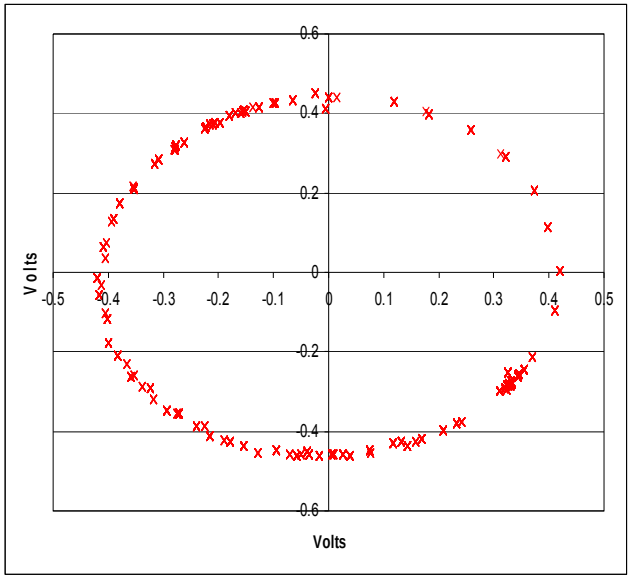
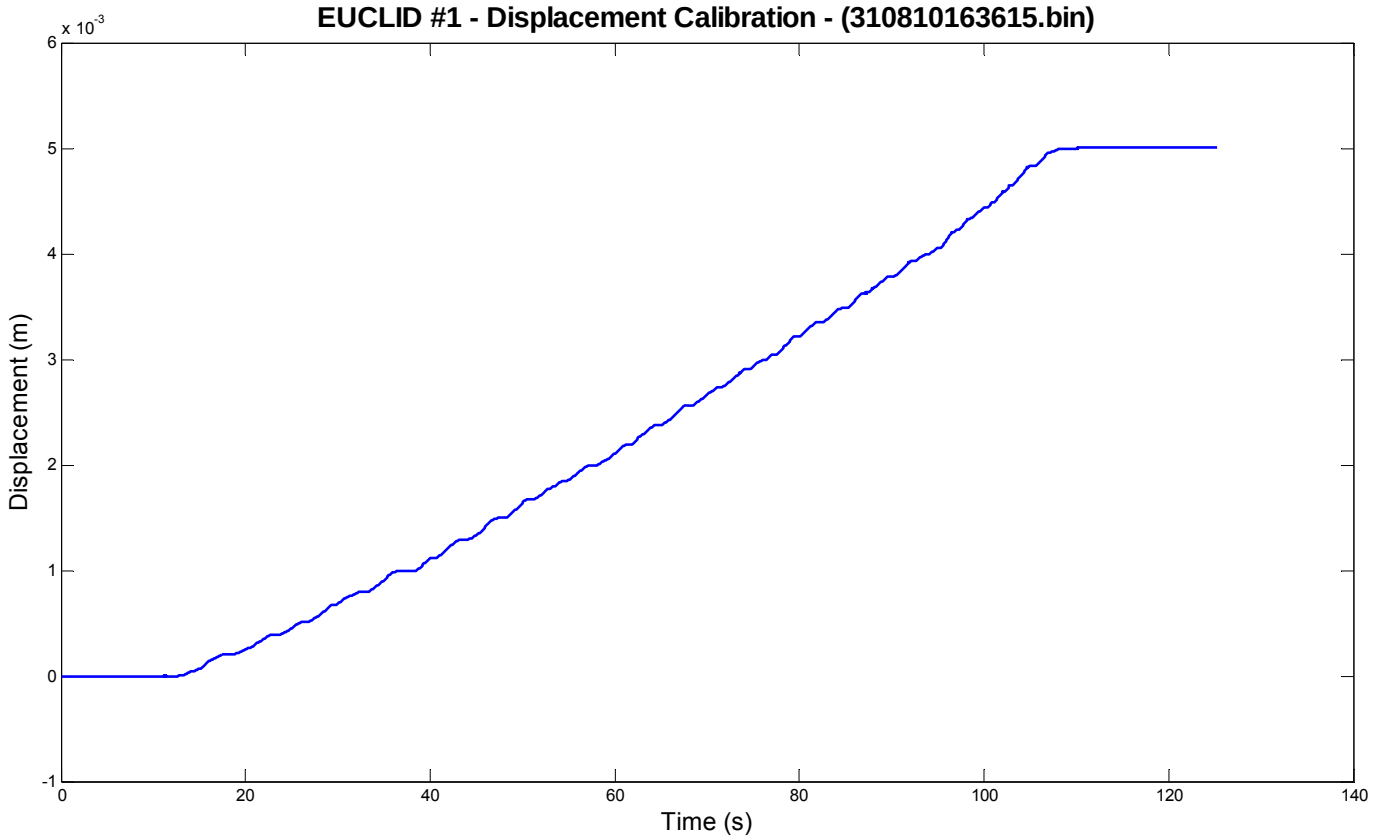



Fringe visibility

# EUCLID Displacement Calibration

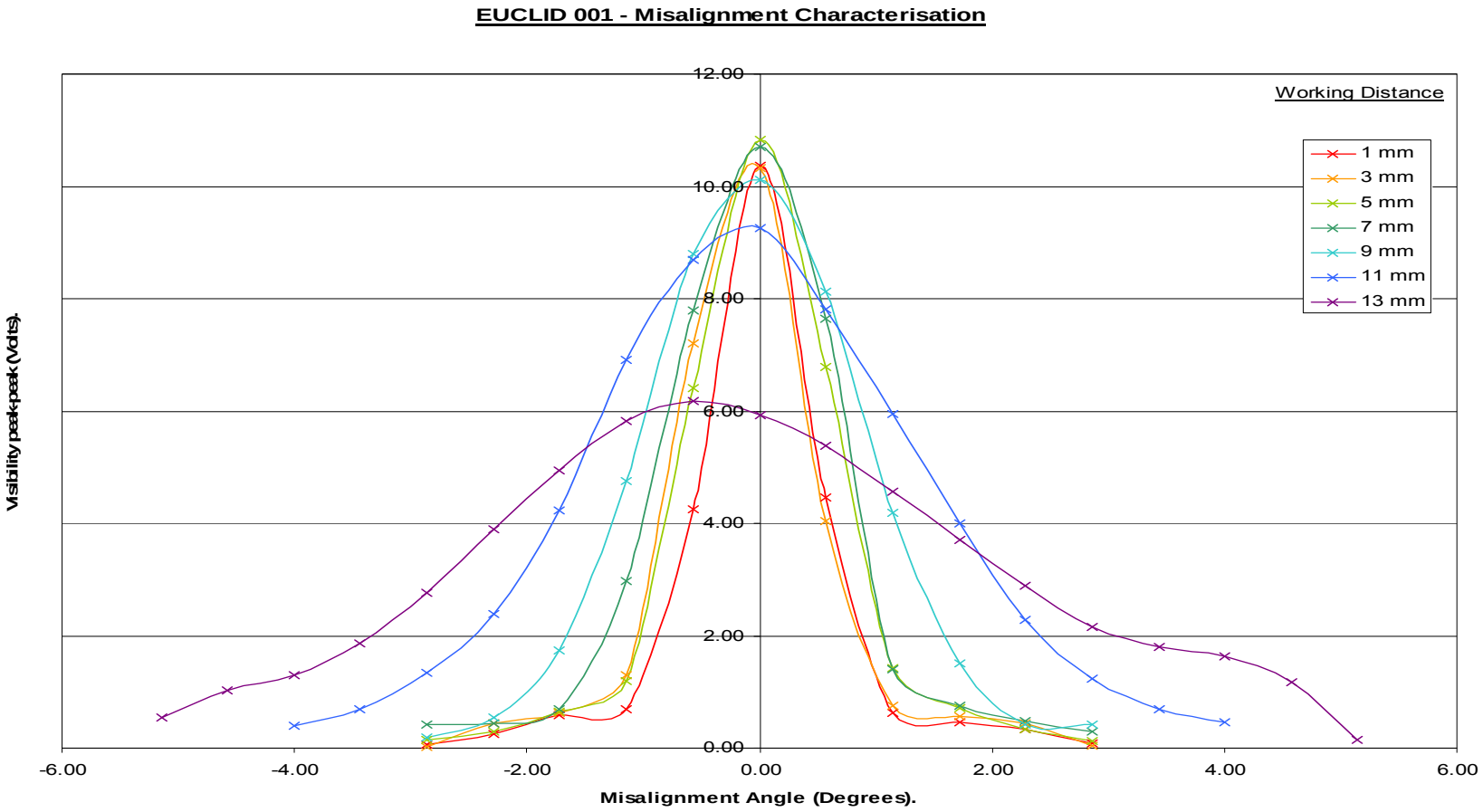
- High sample rates allows us to track fringes continuously (i.e. not missing any):-
  - Fringes can be tracked over 10mm working range with <1% error




  - Plot showing crude calibration measurement over 5mm

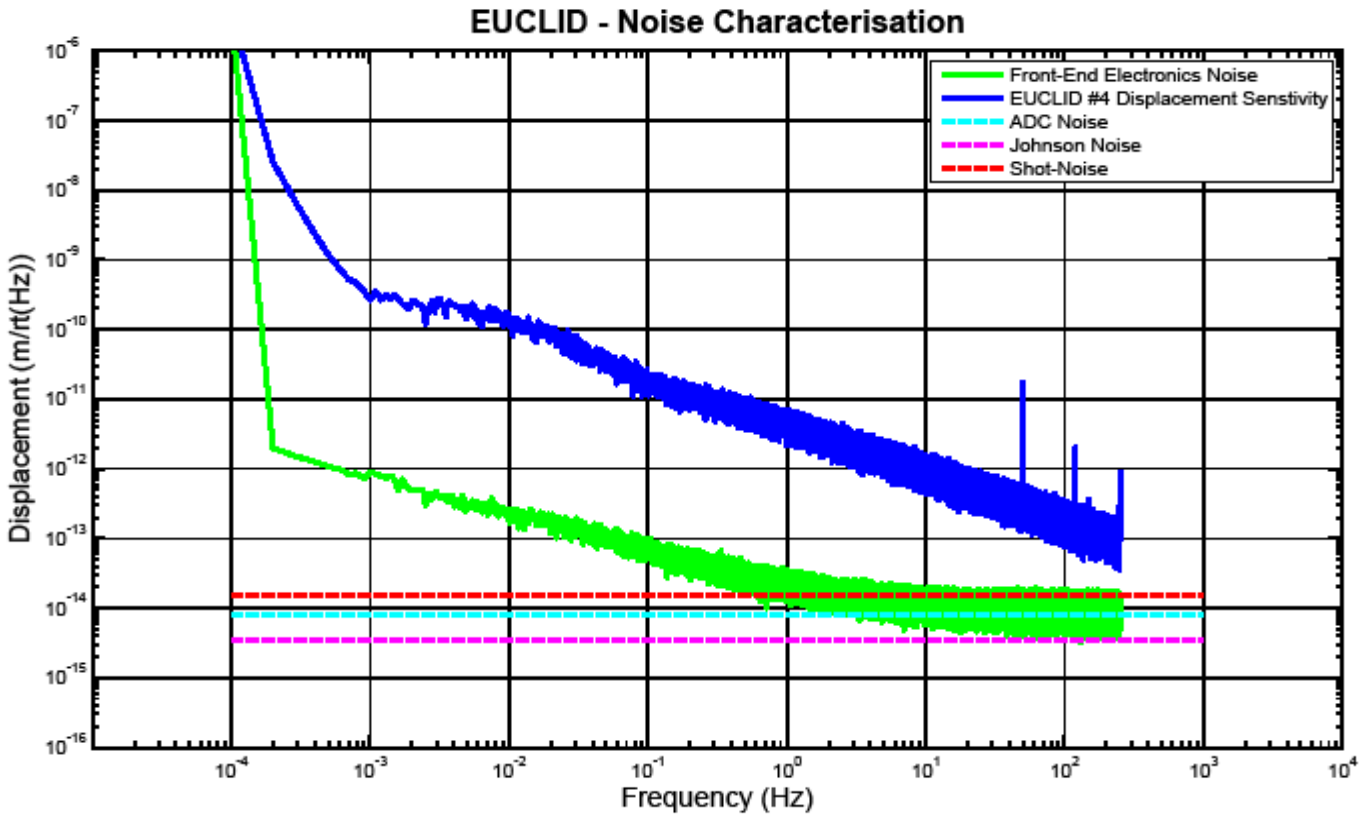
# EUCLID Tilt Immunity

- Misalignment measurements:-
  - Tilt-immunity ≈ ±1 degree
  - Optimal working range ≈ 6 mm



# EUCLID Sensitivity Characterisation

- In Vacuum sensitivity measurements:-




  - Achieve a vacuum level of ≈ 10 milliTor ($10^{-2}$ millibar)
  - Sensitivity at 1Hz ≈ $5\times10^{-12}$m/√Hz and at 10Hz ≈ $1\times10^{-12}$m/√Hz

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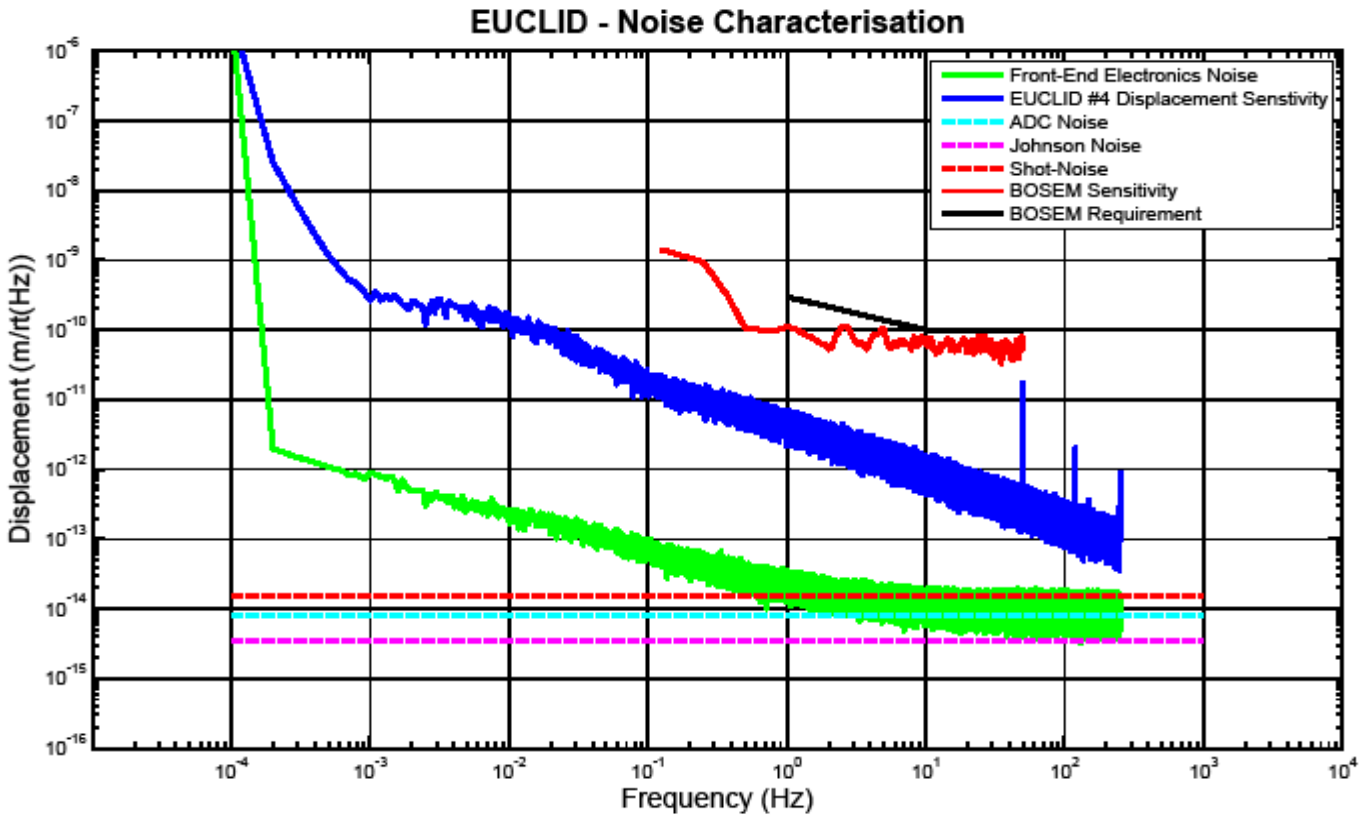


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# Thank you for your attention