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# Calibration pour ET

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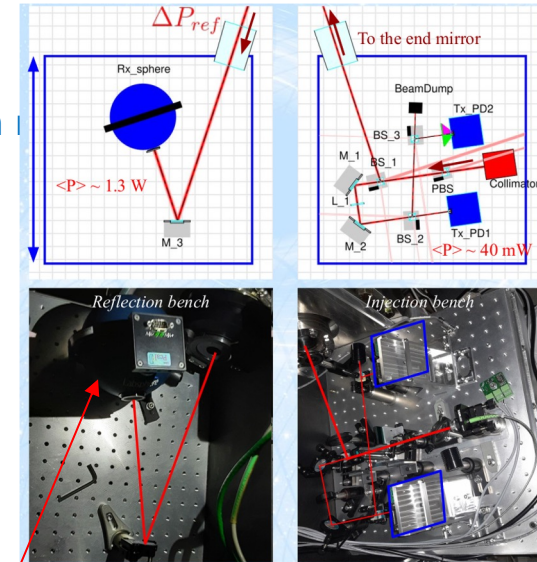
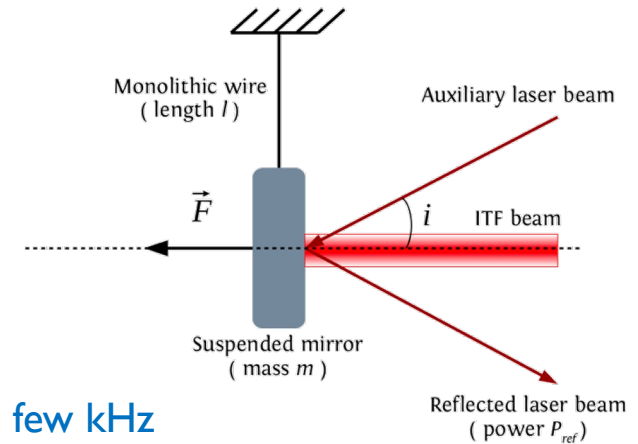
Einstein Telescope France Workshop

# Calibration?

- ▶ Goal: provide calibrated  $h(t)$  strain data
- ▶ Needed accuracy for ET: better than 0.1%
  - Needed for sky localization, Hubble constant, rate measurement, testing GR...
- ▶ Calibration basic:
  - Main techniques need a device to move a mirror by a known amount: PCal and NCal
  - $h(t)$  production is not just to apply a transfer function on the dark fringe signal
    - ▶ But removal of the control signals and some known noises
  - As important: provide the associated uncertainties
- ▶ Not just a single point measurement: stability over frequency and time needed

# Photon Calibrator (PCal)

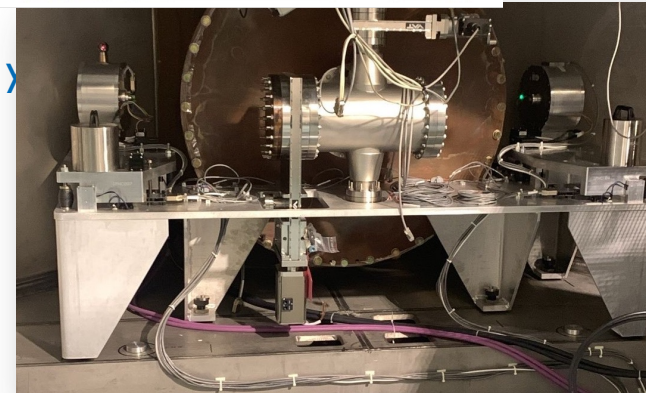
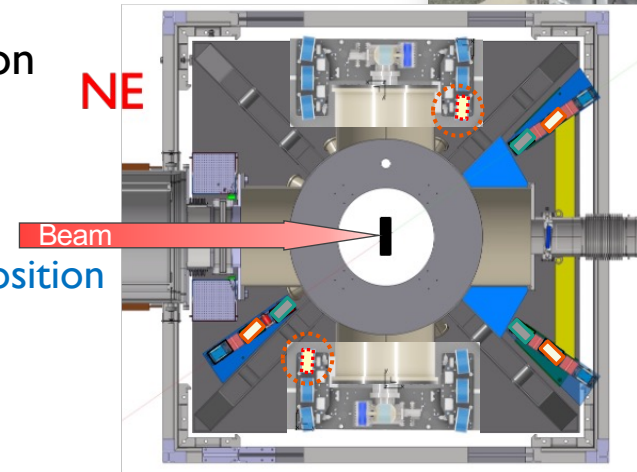
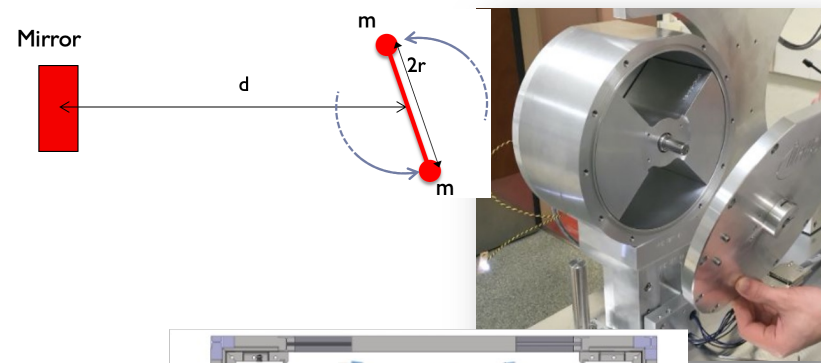
- ▶ Modulate the power of an auxiliary laser beam
- ▶ The main tool for studying the Virgo response
  - Installed at NE and WE during O4
- ▶ Benefits:
  - Versatile system: easy to produce complex waveforms, up to few kHz
  - Simple optical system, but....
- ▶ Challenges
  - Difficult to calibrate the absolute power reflected by the in-vacuum
    - ▶ Parameters of the optics, viewports, polarization...
  - Absolute calibration is based on calorimetry (power-meter),
    - ▶ Difficult to reach sub-percent level
    - ▶ Some discrepancy between national institutes
    - ▶ But intercalibration with LIGO done during O4
  - System stability (environment, alignment, cleanliness, ageing...)
  - Reduction of the laser power noise
  - Mirror mechanical response



NIST-calibrated  
integrating sphere

# Newtonian Calibrator (NCal)

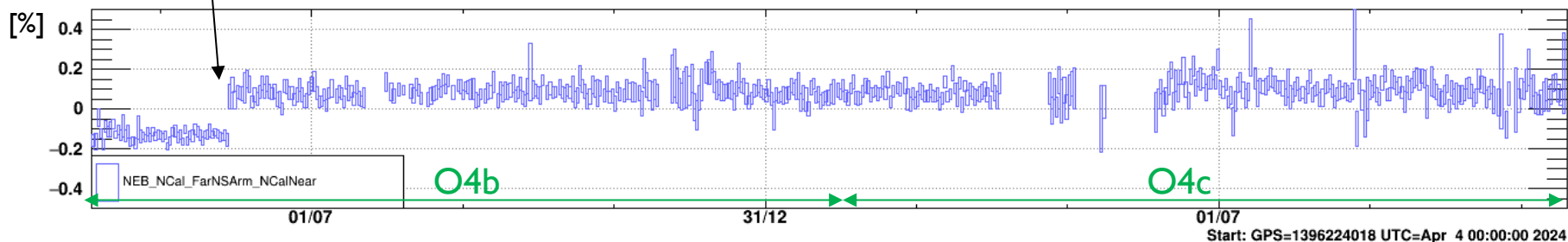
- ▶ Basic model: rotor made of two masses
  - Signal at twice the rotor frequency;  $1/d^4$  effect
- ▶ Provide the absolute reference for Virgo calibration
  - Continuous operation at 36 Hz in  $h(t)$
  - 5 pairs of NCals around NE and WE at O4c end
- ▶ Expected benefits
  - Signal depends mostly on the rotor geometry and position
    - ▶ Mirror mass cancels out
  - No aging effect of the signal
  - Simple interface with the ITF
- ▶ Challenges
  - Able to rotate at (few?) hundred 100 Hz (10k-20k RPM), for  $y$ 
    - ▶ “Without” mechanical vibration or electromagnetic noise
  - Well known rotor geometry, mass and rotor locations



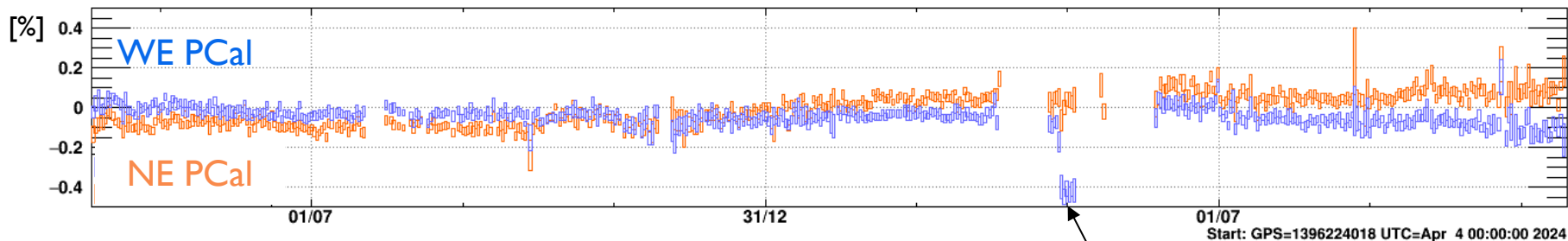
# PCal vs NCal stability over O4b/O4c

Replace Al rotor by PVC  
for the "far" pair

### North End NCal stability (Far/Near NCal - I)



### PCal/NCals stability (PCal/NCal - I)

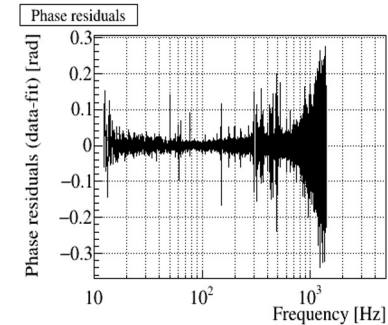
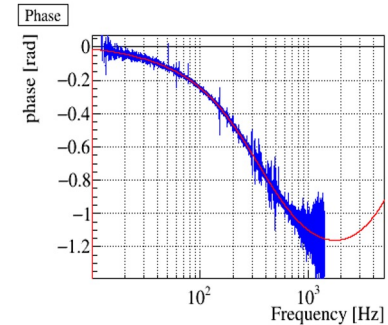
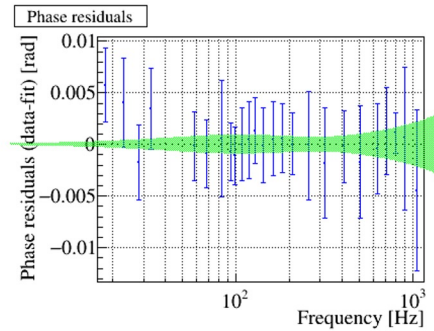
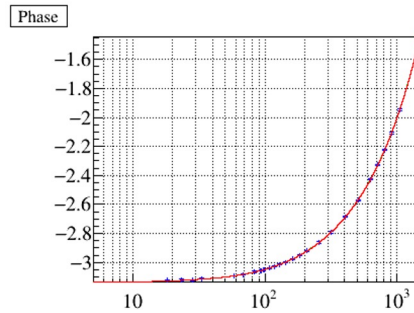
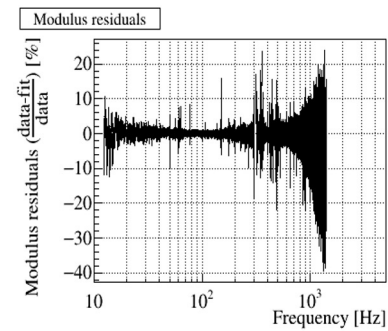
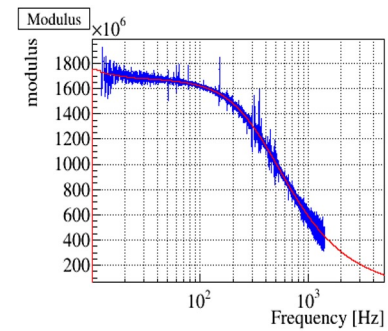
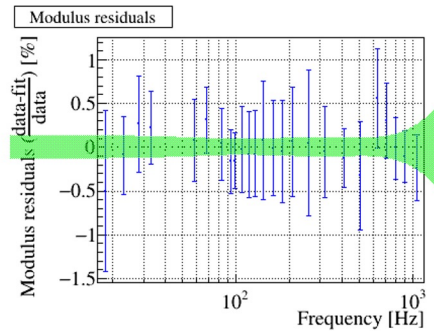
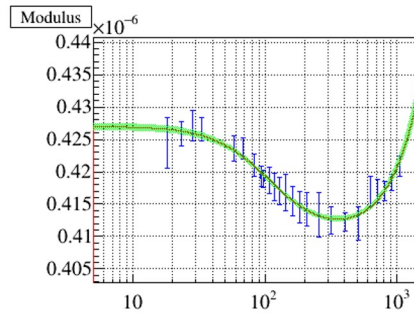


► More drift for the PCals

Beam shifted on WE mirror by 6 mm  
No effect on NCal

# $h(t)$ production

- ▶ Provided online
  - Computed by correcting for the optical response and removing the control signals
    - ▶ + some noises subtraction
- ▶ Require detailed models of the actuators and optical responses



# ET Calibration

- ▶ Virgo vs ET: same interferometer concept → same calibration procedures
  - Just more accurate by an order of magnitude...
- ▶ Preferred solution:
  - PCal for frequency studies with NCal for absolute reference
  - Additional solution(s) for extra redundancy:
    - ▶ Inter-calibration with astrophysical sources
    - ▶ Back scattering light and/or non-linear reconstruction of free Michelson/cavities
- ▶ R&D is require to go further than current Virgo calibration

# Examples of calibration R&D to pursue with Virgo

## ▶ NCal:

- Build new rotors with less vibration to reduce parasitic coupling
- Better understanding of the on-site metrology

## ▶ PCal:

- Develop the two beams setup to better probe the high frequency
- Install the system in (light) vacuum?

## ▶ Astrophysical (relative) calibration:

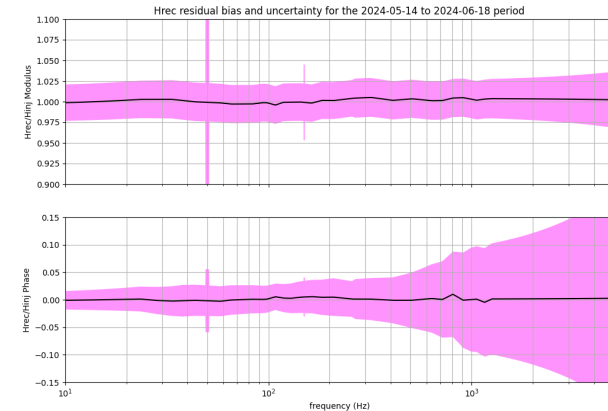
- 3.5% H-L overall relative calibration achieved during O3
- To be extended by frequency band

## ▶ $h(t)$ reconstruction:

- Reduce the latency

## ▶ Calibration “envelope”

- Add correlation between frequencies
- Uncertainties are larger than the accuracy of our calibration devices → reduce them



# Final remarks

- ▶ ET calibration could be fully developed and tested on Virgo
  - Plus interactions during technical design to reserve space and access
- ▶ This is as more about acquiring know how that new technology development
  - Require long term commitment by a few groups
- ▶ French groups (LAPP and IPHC) are leading the Virgo calibration
  - But PhD & postdoc funding is an issue