Optical simulations and characterization for Einstein Telescope

ET Workshop

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Summary / plan

1.Short presentation of ET/ Problematics related to 3rd gen detector

2. Specificity of ET

What are the physical problematic specific to ET
What is the situation, what are the tools that we have
What are the need and priorities

3.Virgo development (simulations and characterisation that can be transposed to ET)

Simulation and characterization expertise for second gen detector
Importance of Characterization/simulation
States of art, what are the current expertise and what can be transpose to ET

Optical simulations: A historical French activity

Analytical models of thermal aberrations in massive mirrors heated by high power laser beams

Patrice Hello and Jean-Yves Vinet

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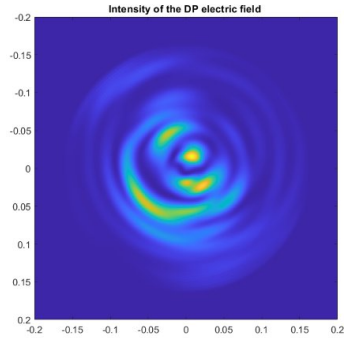
EINSTEIN TELESCOPE

The ET Baseline Detector Layout

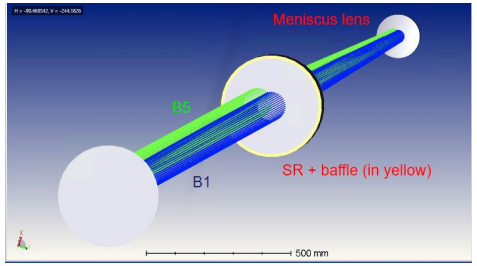
ET-0482A-25

- Long expertise in developing and running optical (and thermal) simulations
- Part of it, started here at the LAL with Jean-Yves Vinet and Patrice Hello
- Strong involvement in the design of Initial Virgo, then Advanced Virgo still continuing today...
- For ET: coordination of the optical design, now available in the TDR

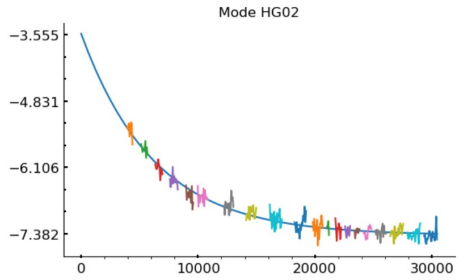
Expertise scattered across various labs



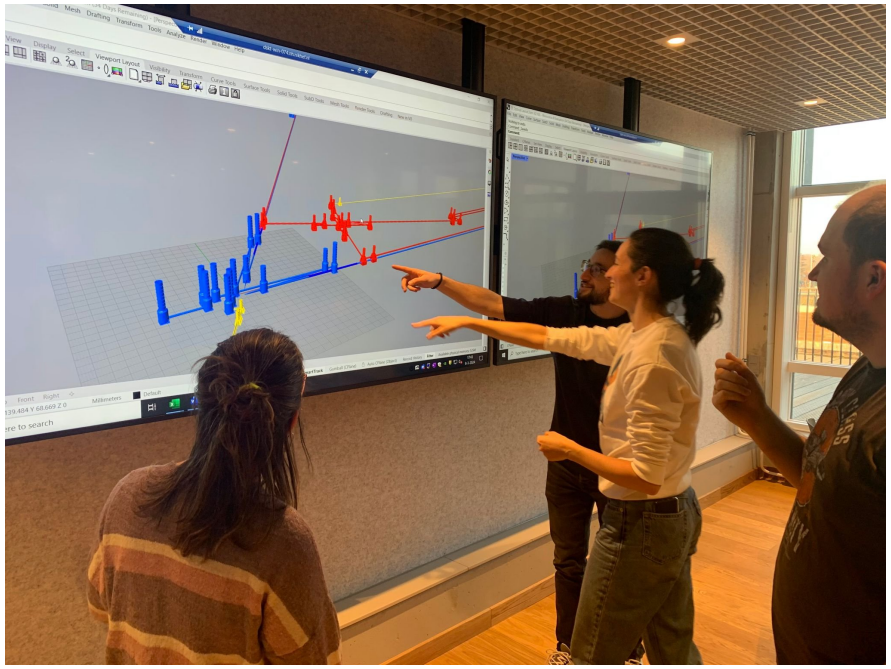
- Core optical design: Artemis, LAPP, LMA, L2IT, APC
- Laser, injection : Artemis
- Detection, telescopes : APC, L2IT, LAPP
- Squeezing simulations : APC, IJCLab, LAPP
- Straylight simulations : Institut Fresnel, LAPP, APC, L2IT, Artemis



And numerous contributions for the commissioning and the optical characterisation which also require simulations



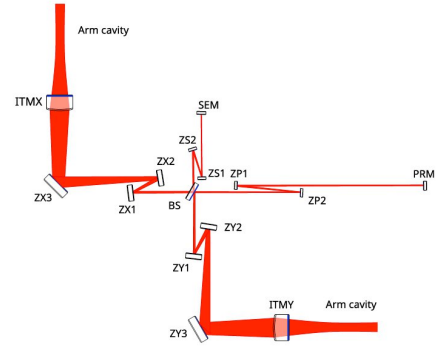
Einstein Telescope: Problematic related to third generations detectors



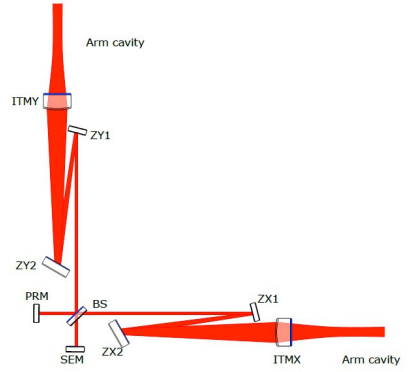
- Starting with a blank page (a good point and a bad point). Several issues have to be studied/considered:
  - Very strong constraint on optical losses to avoid squeezing degradation
  - Thermal effect compensation will be critical for ET-HF *(robust design, derive error signals)*
  - Detuned SR cavity for ET-LF
  - Problematic related to cryogenics in ET-LF
  - ET-LH and ET-HF sharing the same arm cavity tunnel
- We have much better simulation tools and expertise now!

States of art for the ET development

- So far only a rudimentary optical layout has been designed (optics RoC and distances)
- Need to check the tolerance, mirror specifications, derive control signals, thermal effects (**see next slide**)
- Work mainly done within the Interferometer Division (wiki, Git)



ET-HF, L



ET-LF, L

A long task list to tackle to progress on the design

- Lacking dedicated human resource

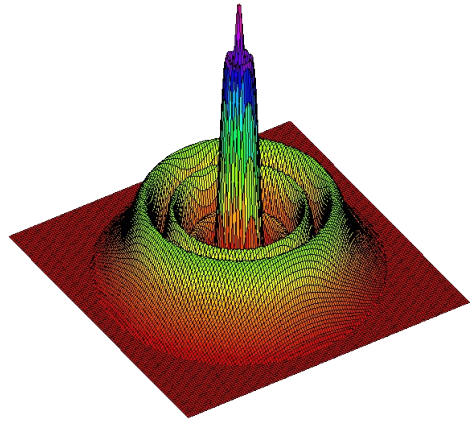
3.2.6	PRC and SRC design: Gouy phase and sensitivity to HOMs	Optical Layout design
3.2.7	PRC and SRC design: impact on longitudinal optical spring	
3.2.8	Error signals generation: Balanced Homodyne Detection	Control control strategy. Time domain simulation necessary
3.2.9	Error signals generation: Schnupp asymmetry	
3.2.10	Error signals generation: RF frequency choice and optical beats needed for controlling the auxiliary DOFs	
3.2.11	Error signals generation: where do we need probes	
3.2.12	Error signals generation: power reaching photodiodes, constraints on signals SNR	
3.2.13	Signal Recycling cavity: effect of the tuning on noise couplings, transfer functions and error signals	SRC tuning and effect on the itf. Requirments estimation
3.2.14	Signal Recycling cavity: coupling to DARM and requirements on control	
3.2.15	Lock acquisition: arm finesse requirements to cope with dynamical effects	Optical parameter requierement for the lock : Preparation of commissionnig
3.2.16	Lock acquisition: ALS / subcarrier lock / variable finesse / frequency comb	

Small amount of example in a very long to do list

Simulations packages available

- ET benefits from all the development made for second generation interferometers:
  - Modal expansion code: Finesse
  - FFT codes: OSCAR, DarkF
  - Noise budget: PyGWINC
  - Optical design and tolerancing : Zemax

Finesse 3



- Missing also some tools:
  - simulations including non uniform birefringence maps
  - 3D Gaussian simulations
  - a robust code of time domain simulations

Essential expertise in optical characterisation

complementary to optical simulations, how to transpose the current expertise to 3rd generation detector ?

	2nd Generation	3nd Generation
Ex-situ measurement	Measurement on witness samples (thermal noise) Ex-situ optical characterization of test masses at LMA.	What are the possibilities for 3rd generation ? Which precision in surface polishing/characterization is necessary ? New benches for the characterisation cryogenic temperatures ?
In-situ measurement	Important contribution of the French community to the optical characterization	Identify the needs for ET, what will be the critical parameters ? How to characterize/evaluate them when the detector will be operating ? We have time to plan, do we need new sensors such as phase camera ?

Example of optical characterization implemented in the finesse Virgo model

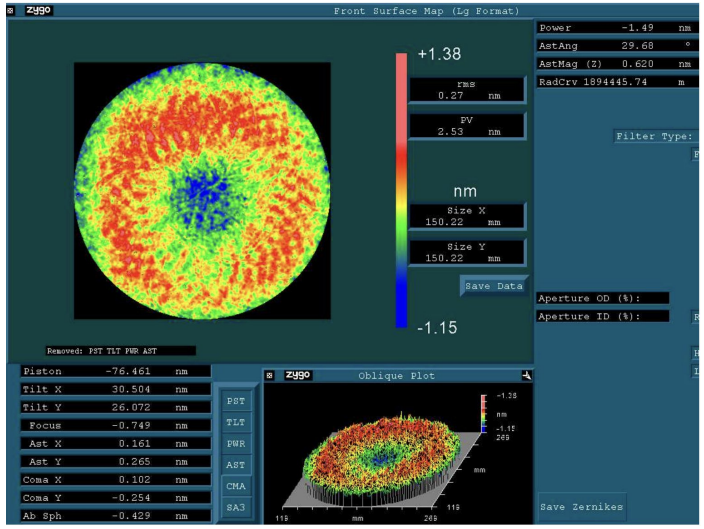
```
# North input mirror. The AR-surface is not wedged, thus the AR-reflectivity
# is set as a reflectivity. NI and NIAR relectvity [IM04, VIR-0544A-14]
# NI Loss set to match measured roundtrip loss of 61 +- 5 ppm [Loggbook 38601]
# TODO get value for NIAR loss, or set a default
# Measured thickness. Ref?
# NI Rc -1424.6, measured cold IFO NI RoC [VIR-0544A-14]
# NIAR Rc -1420, design NI AR RoC [TDR, table 2.6]
```

ex-situ measurement (LMA)

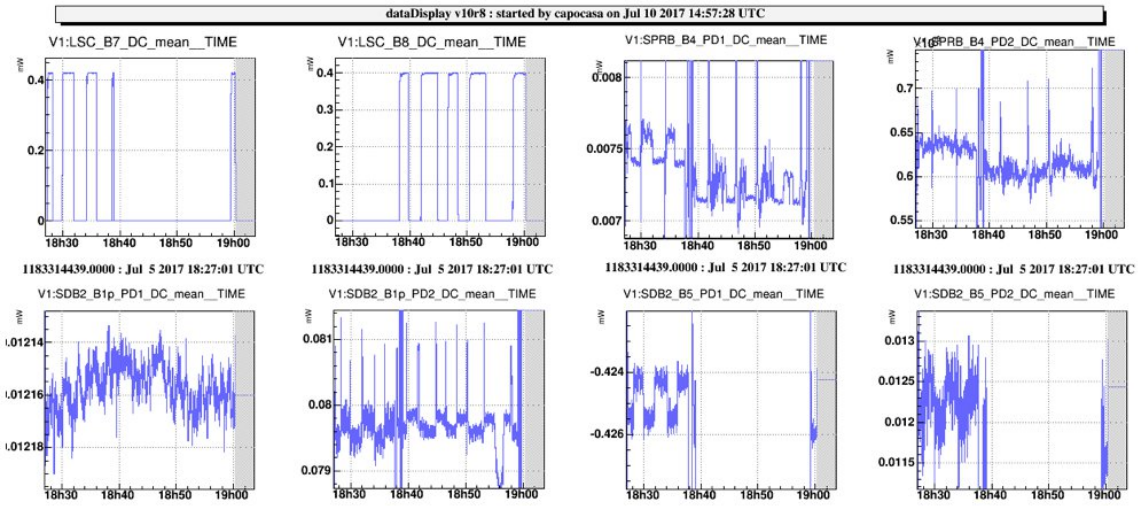
in-situ measurement (APC)

ex-situ measurement (LMA)

Characterization of the test mass surface (VIR-0544A-14)

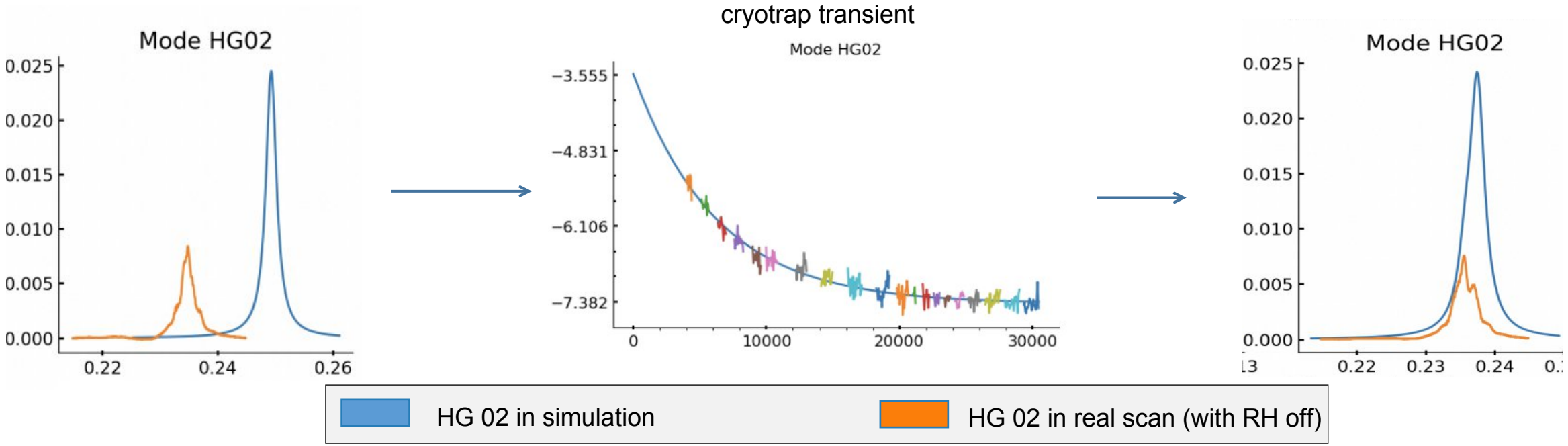


Round-trip loss measurement (Logbook 38601)



Another example that could be reproduced in ET

Plots from VIR-0104A-26



- Thermal effects affecting the Gouy-phase of the Fabry-Perot cavities
  - Measurement of the cryotrap thermal transient
  - Measurement of the ring heater thermal transient

→ Similar studies could be reproduced in ET. This implies preliminary studies to understand what are the dominant effects to consider.

Conclusion and perspective

- Development of simulation is essential for the preparation of ET
  - Improvement of existing tools
  - Development of new software in order to cover the missing simulation solutions

- Precise method of measurement in order to characterize the detector will be necessary
  - To improve the precision of the simulation tools used to assist the commissioning.
  - Development of precise method of characterization needs a lots of effort during the preparation of the detector in order to understand the dominant effects.

- In summary characterization needs simulations to be precise but simulations need characterization to match detector properties. To solve the paradox we need:
  - Experience form previous detector development (LIGO, Virgo, KAGRA).
  - Preliminary elaboration of the design and the study of the physics of 3rd generation detector.

Il y a du travail pour tout le monde - There is work for everyone