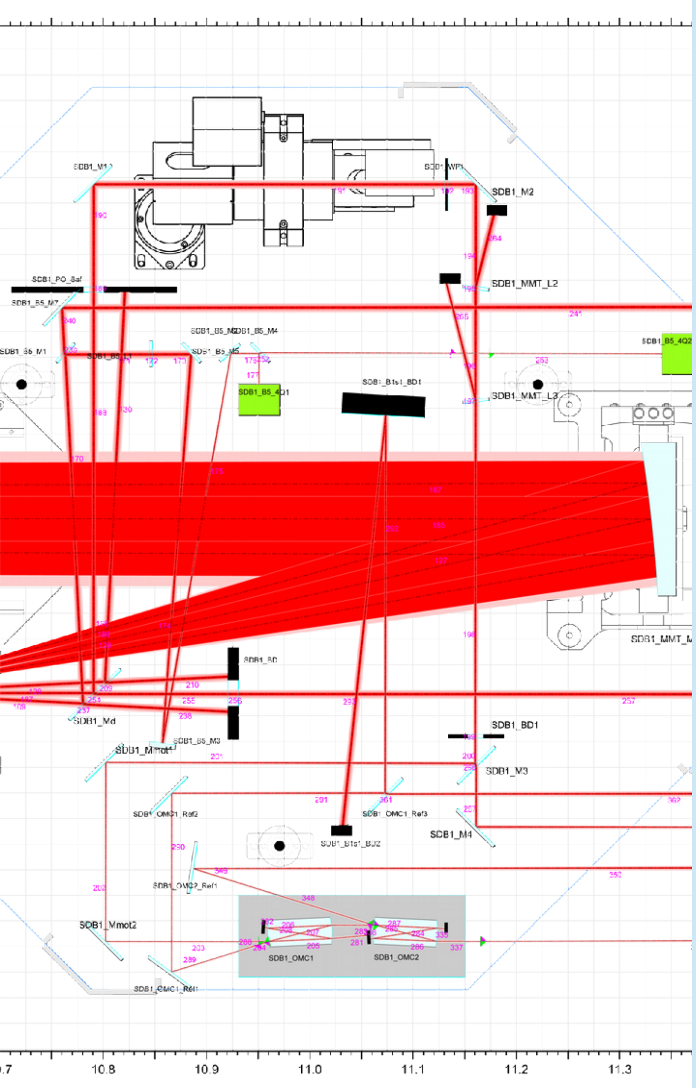
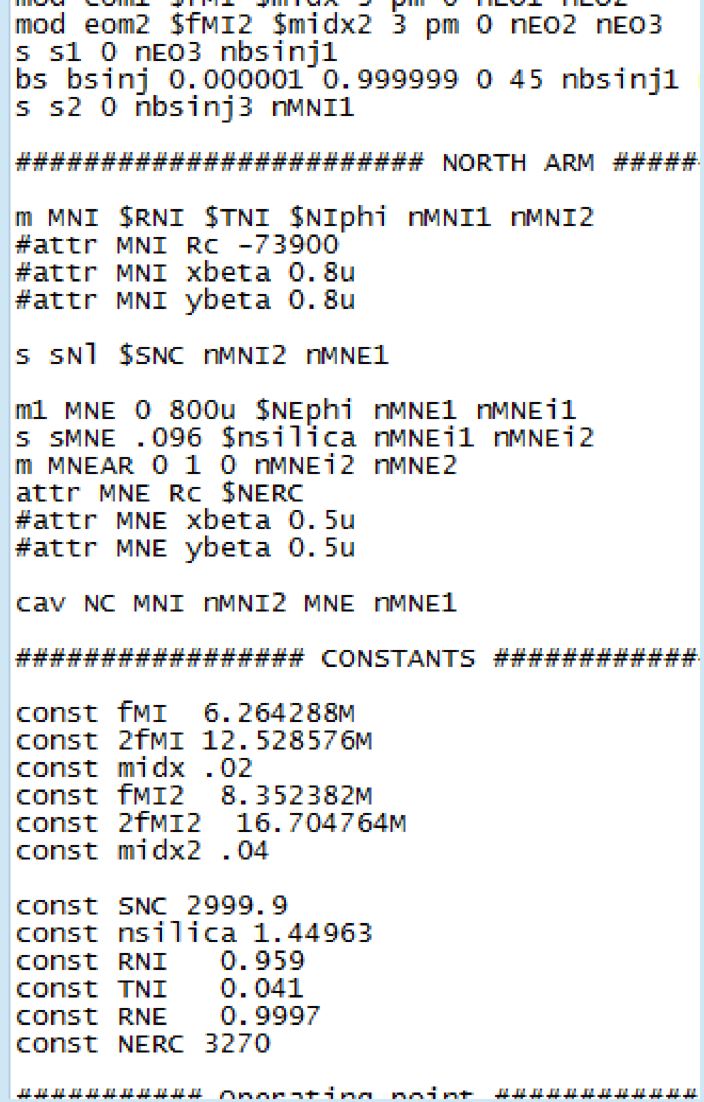
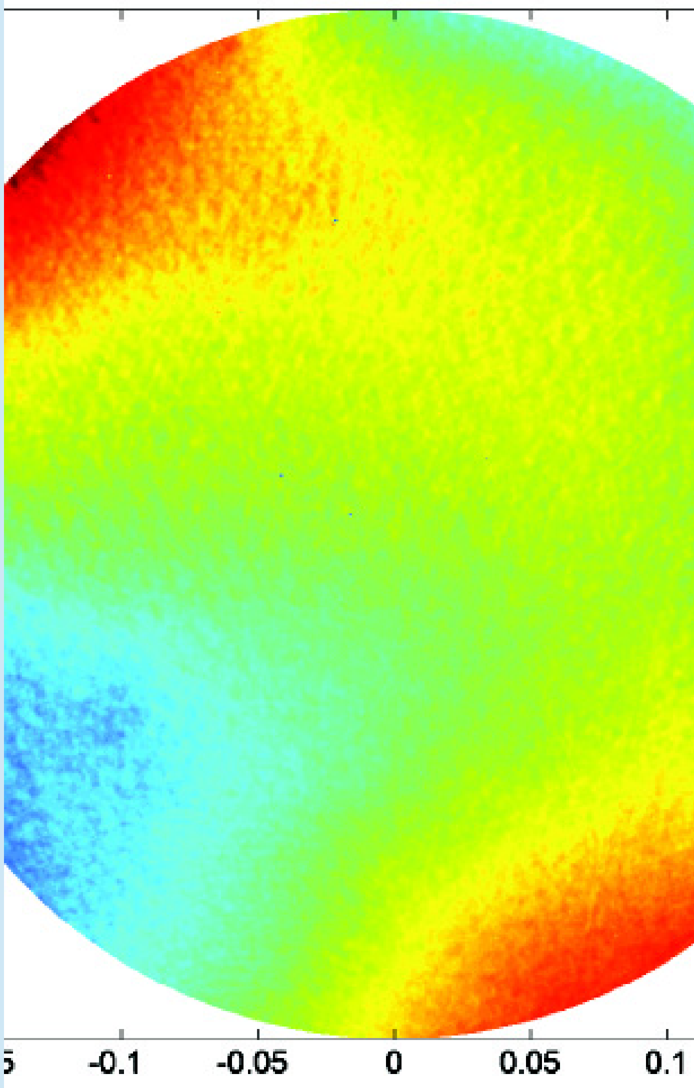





# Simulation session: an introduction

Jerome Degallaix

GWADW 2014

# The (simulation) program

What we have now and how we use it...

What should we expect next...

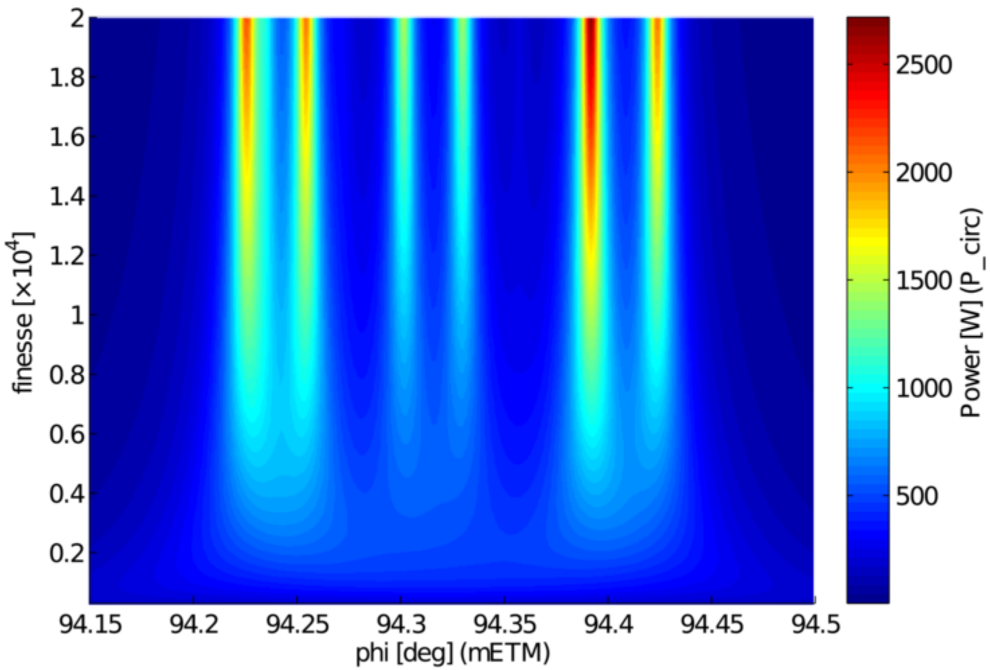
# I

What simulations can do for you:

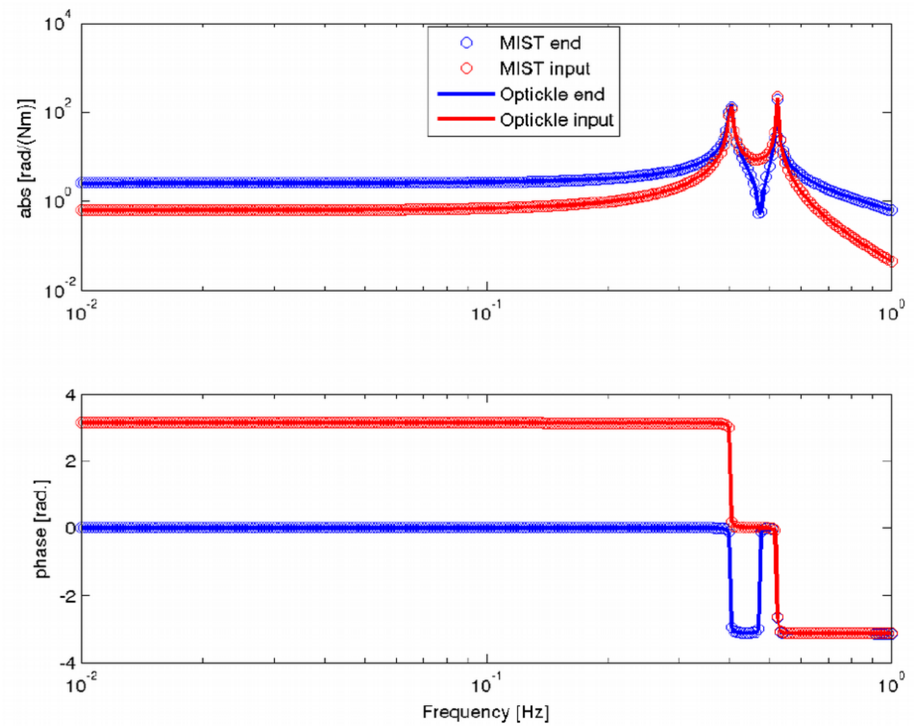
- design
- anticipate issues
- commissioning

# Modal simulations (frequency domain)

## *Finesse, MIST , Optickle*




*LG33 degeneracy*

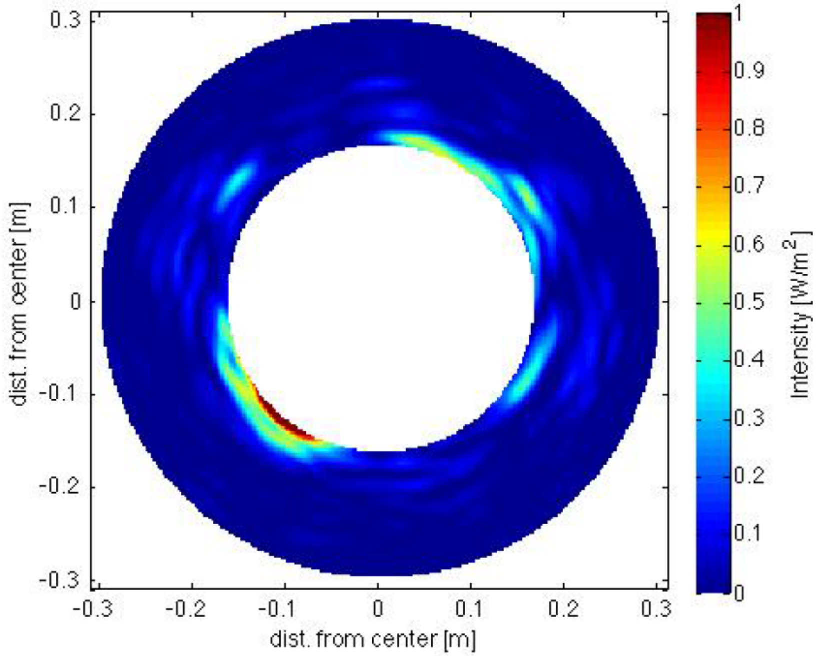



*Angular Siddle-Sigg instabilities*

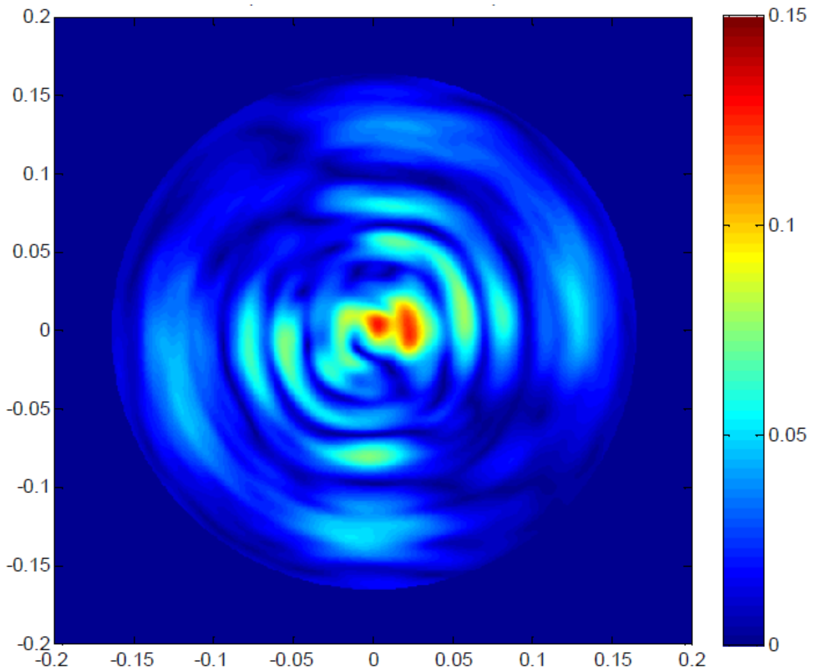
- Steady state interferometer
- Calculate optical transfer function, shot noise level
- Fast and flexible

# FFT simulations

*DarkF, FOG, OSCAR, SIS*




*Light on the arm cavity baffle*

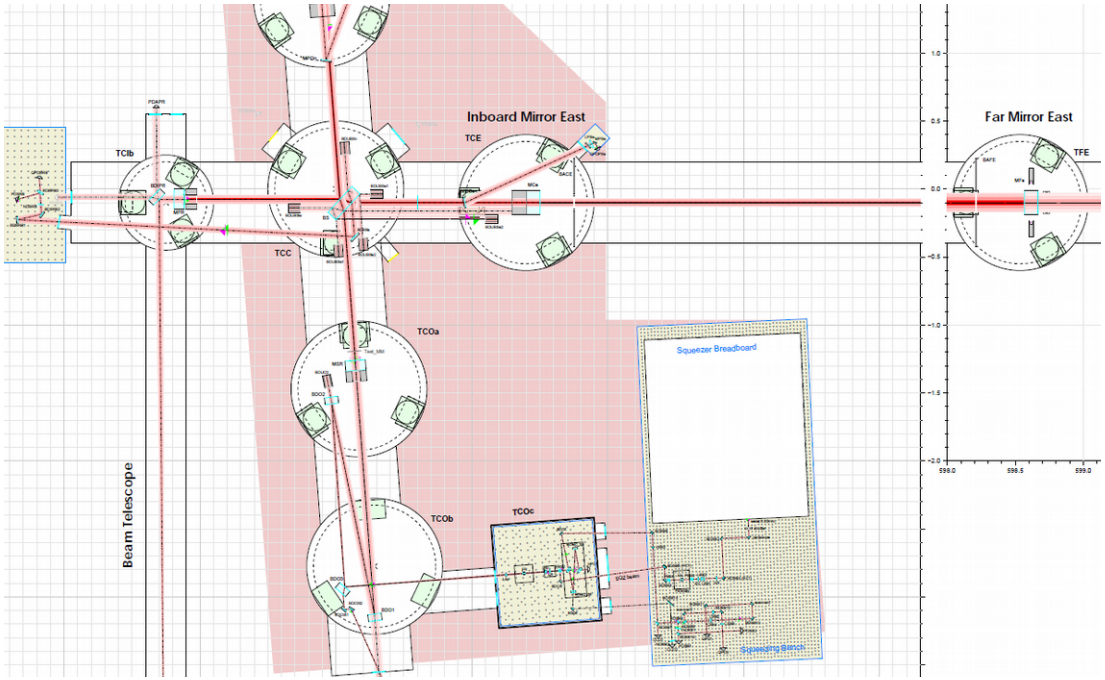



*Dark port image*

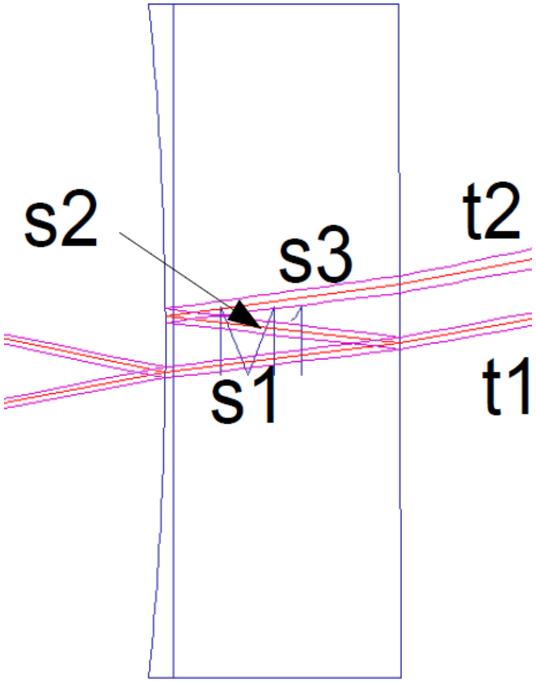
- Calculate steady state fields with realistic mirrors
- Arbitrary beam shape / distortion
- Can handle large beam angle (up to the degree)

# Visual display of the interferometer

*optocad, gtrace, (Zemax)*




*GEO-HF layout*

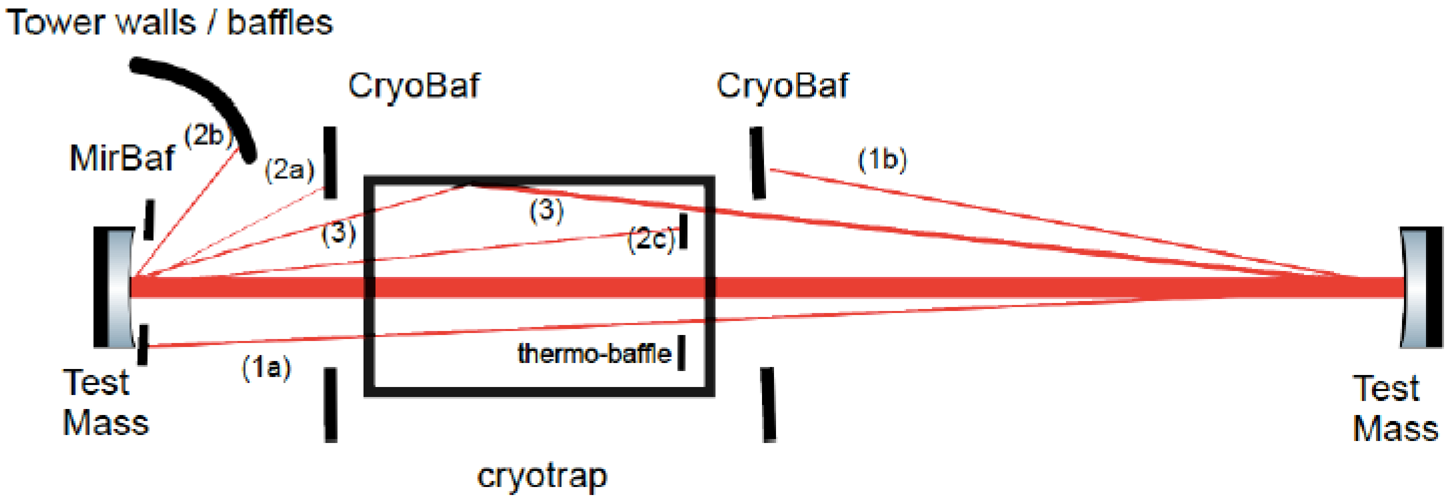



*Gtrace example*

- Physical representation of the interferometer
- Can handle arbitrary tilted beam
- Very useful to check available space

# Keep in mind...

- Different simulation techniques have some overlap (but some codes are more optimised for certain simulations)
- Possibility to mix codes for custom simulations
  Example for the light scattering simulations

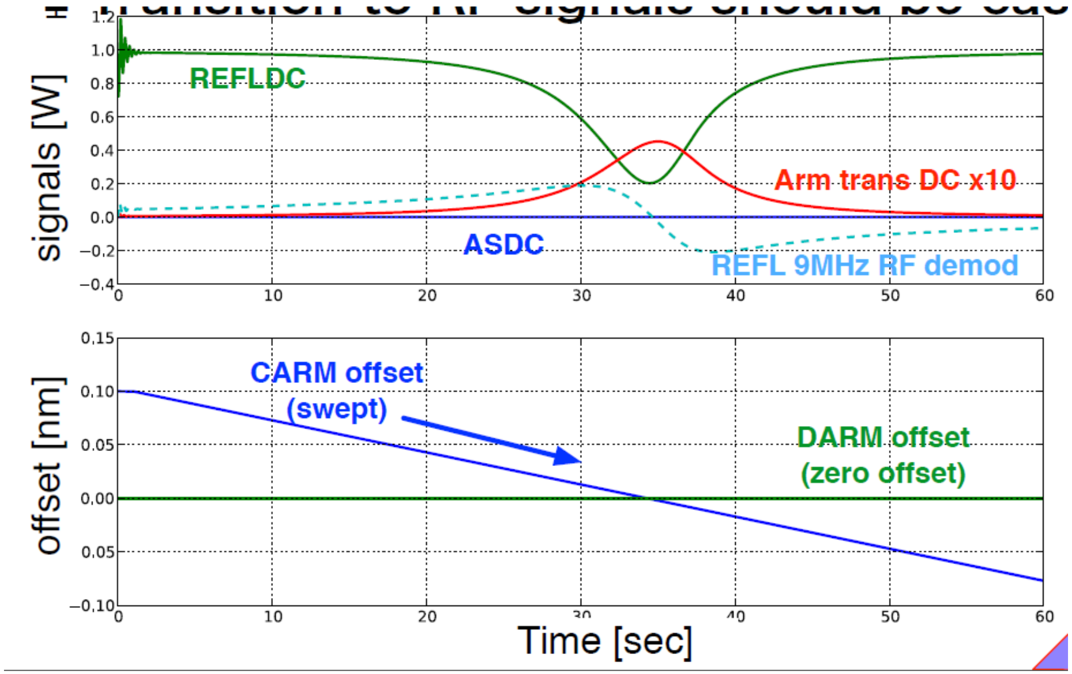



  FFT code + modal expansion code + analytical model are necessary

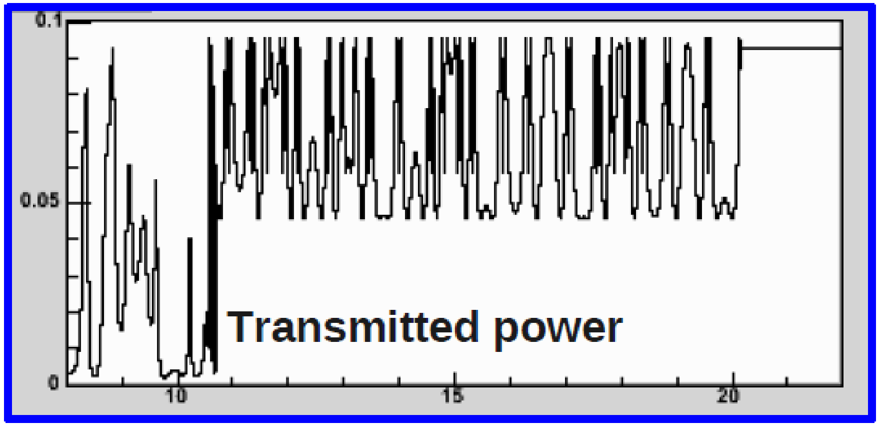
- Talk: Mitigation of scattering light noise in KAGRA (T. Akutsu)

# Time domain simulations

## *E2E, Siesta*




*Crossing the resonance*

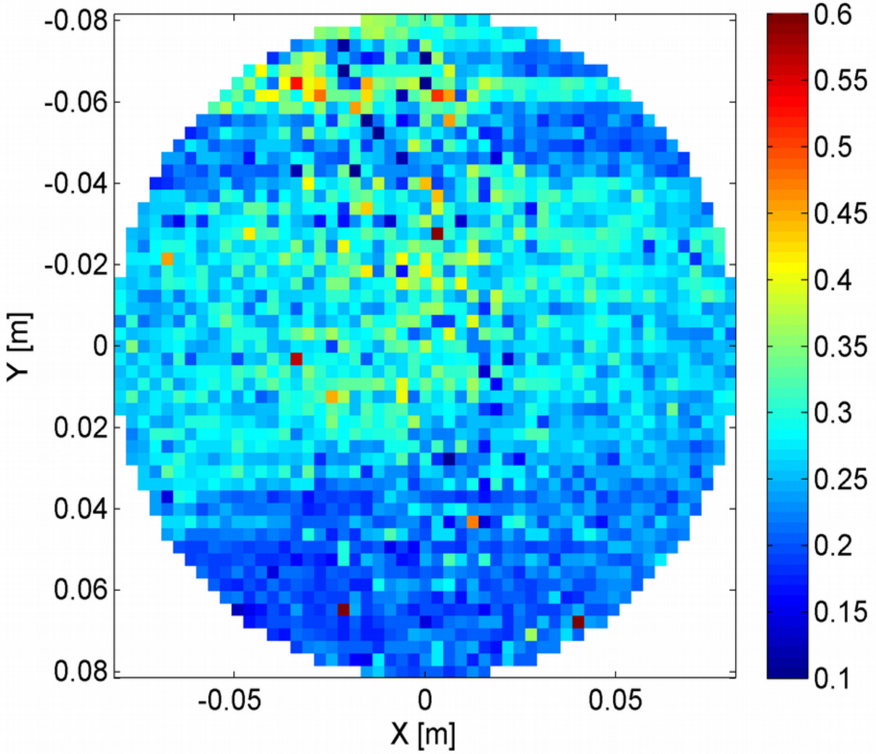



*CALVA simulation*

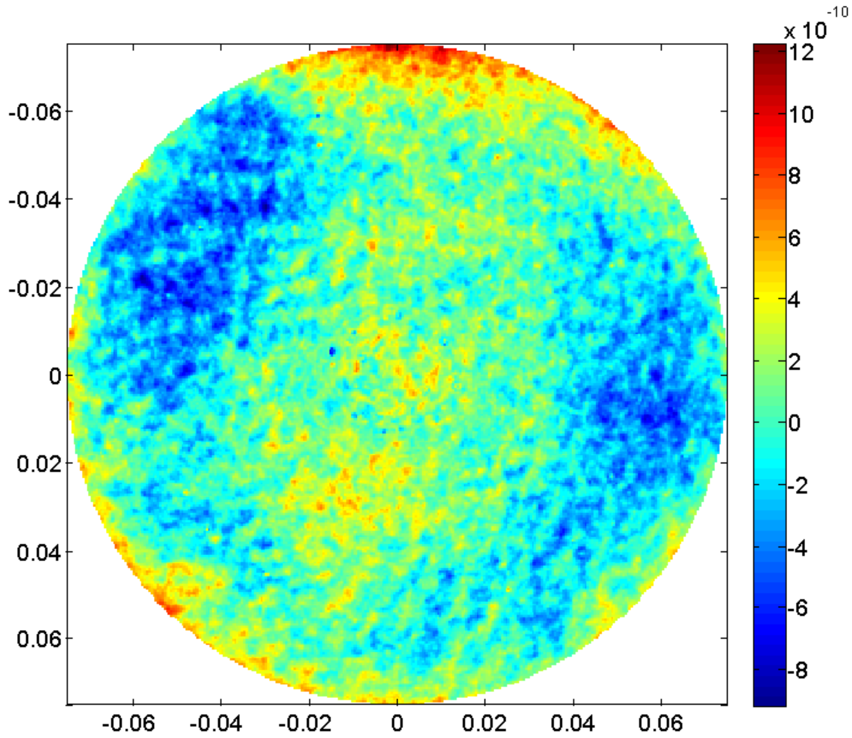
- A world on its own
- Essential for lock acquisition
- Poster: Simulation study for aLIGO lock acquisition (K. Izumi)

# Predict the performance...

... before you install the optics. Caracterisation is essential




*Absorption map*

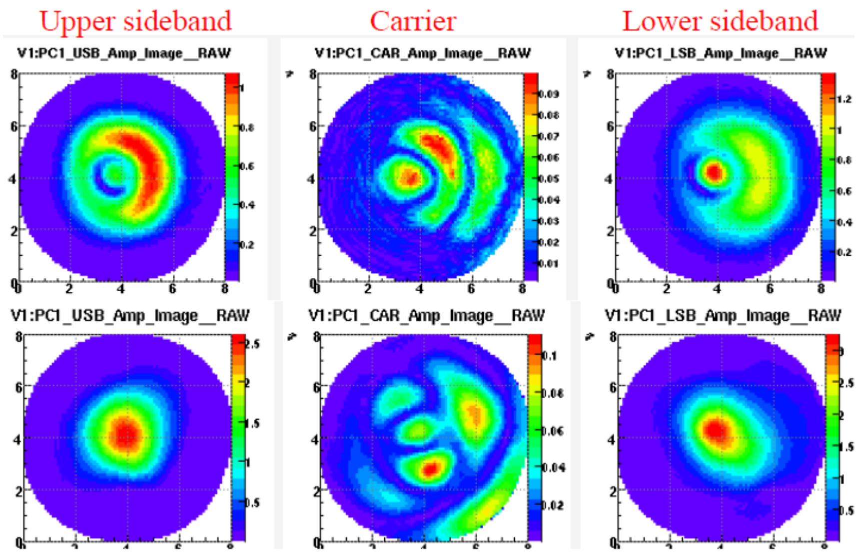



*Surface map after coating*

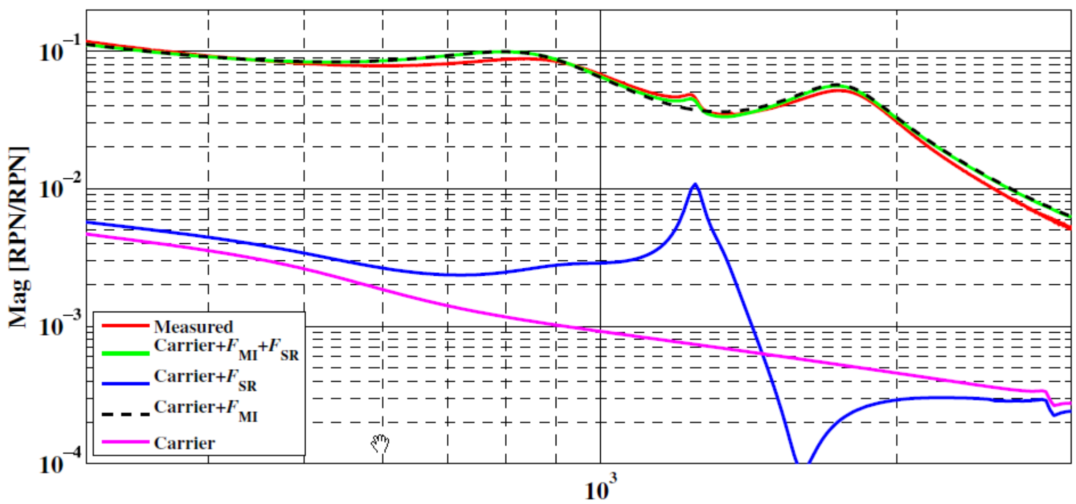
- Estimate the TCS correction
- Calculate loss, mode matching, asymmetry, noise coupling

# Commissioning

## Understand what you see with your interferometer




*TCS tuning with the phase camera*




*Sidebands transfer function*

- Extensive optical caracterisation (length, finesse)
- Get the right operating point!
- Talk: ALIGO commissioning (K. Kokeyama)
- Talk: Noise budgeting for advanced detectors (C. Wipf)

# II

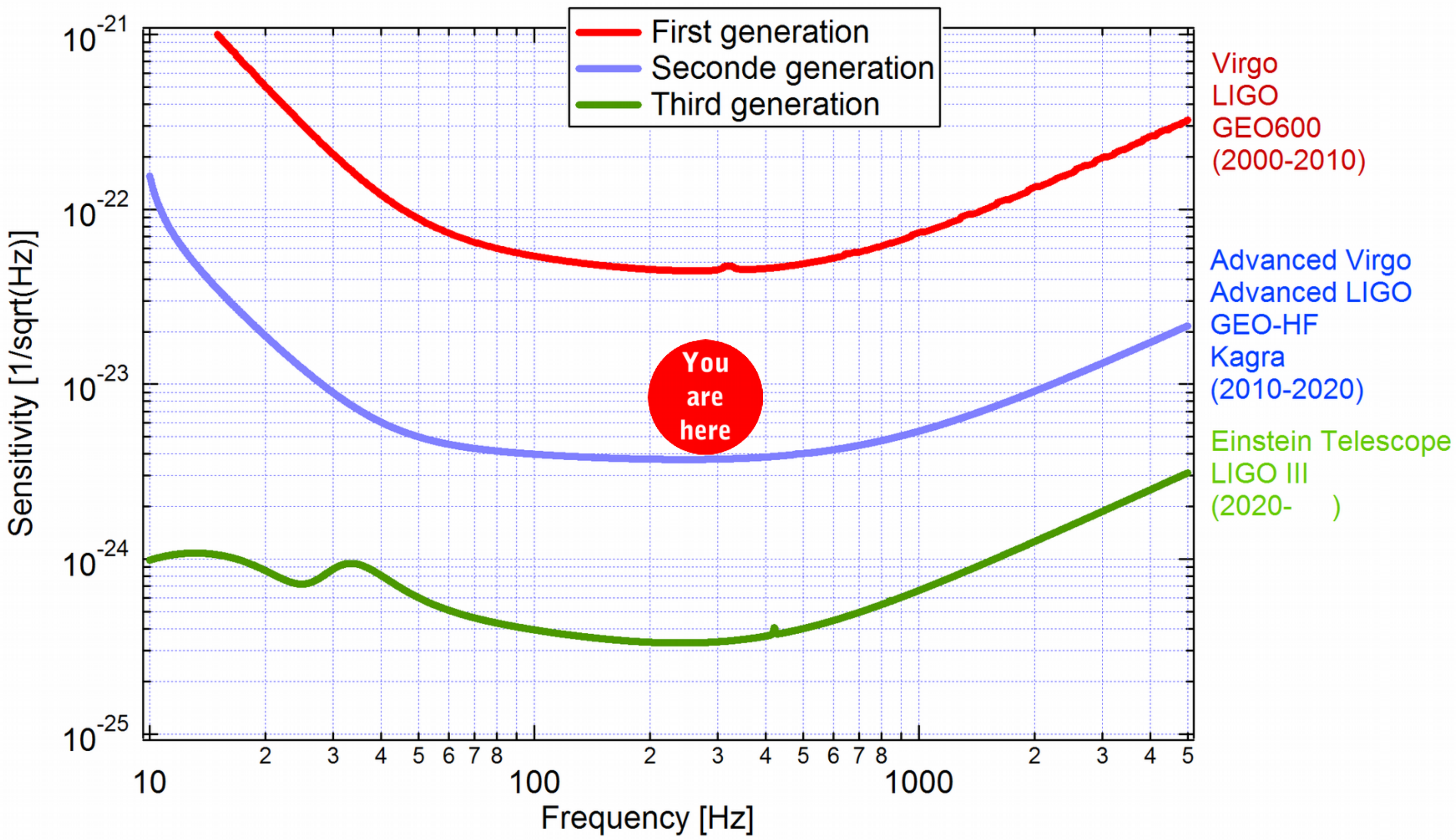
So we have all ?
(and so why I am sitting in this room ?)

# ||

No!
New challenges and tools ahead!

# Why do I need updated tools ?

New generation of interferometer needs a new generation of simulation packages

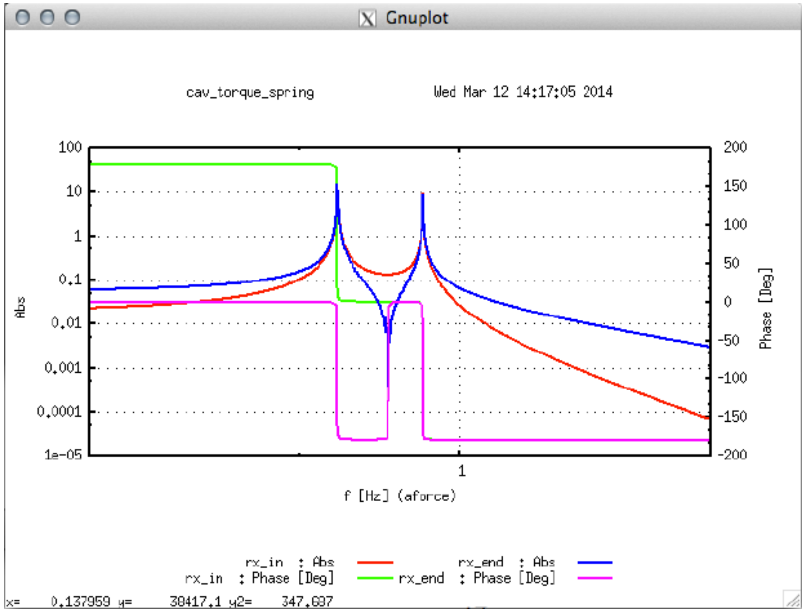



- New limiting new sources of noise to simulate

# Simulating quantum noise

Be able to simulate correctly shot noise AND radiation pressure noise. A long implementation:

- Theoretical framework (80's)
- Plane wave analytical case for 2nd generation (00's)
- Complex system – PI (00's)
- Realistic beam shape, arbitrary configuration (now)

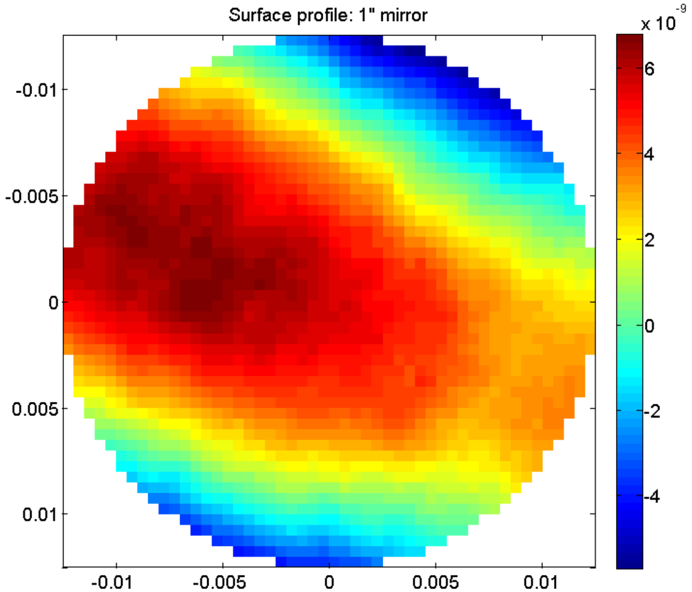



*Angular radiation pressure effects*

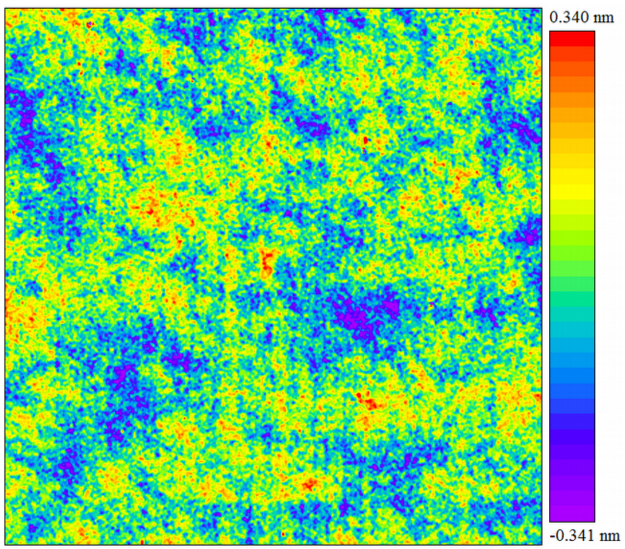
- Talk: MIST update (G. Vajente)
- Talk: Implementation of radition pressure in Finesse (D. Brown)

# And adding some squeeze light

- Loss on the squeezing path very critical
- Research effort to design low loss filtering cavity




*Map of a 1” mirror*

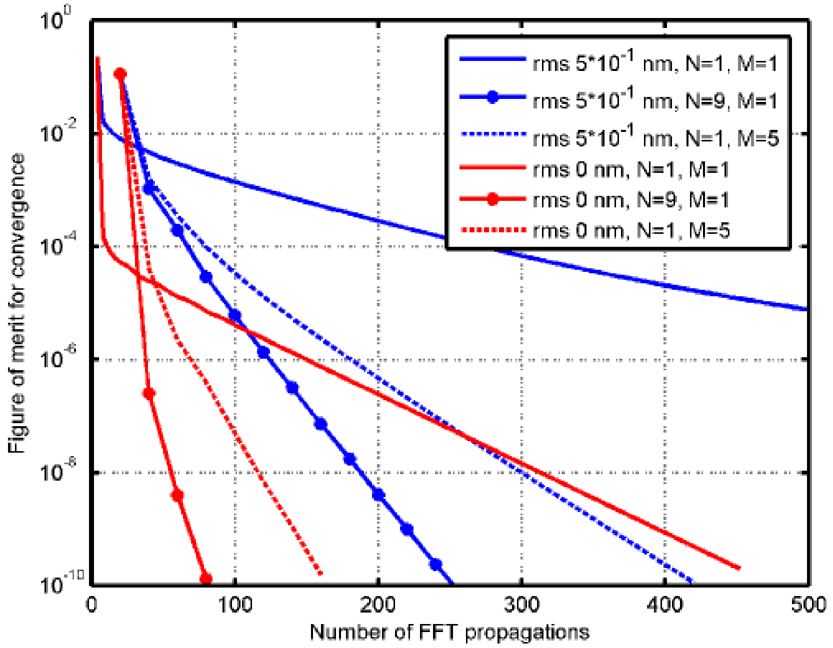


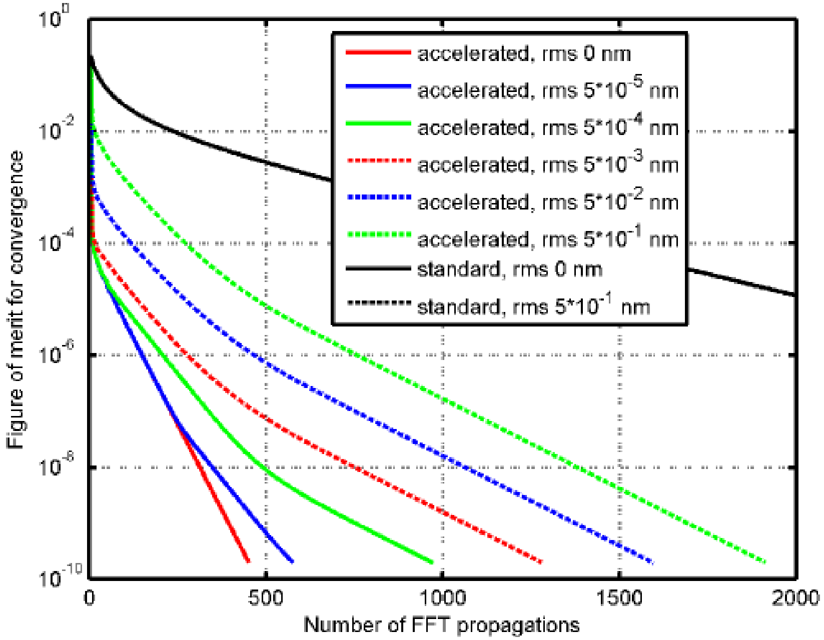

*High spatial frequency ($1mm^2$)*

- How the presence of higher order modes may degrade the squeezing ?
- Talk: Simulation of quantum scattering effect (J. Harms)

# Progress on FFT codes

## Same principle but new motors, new architectures



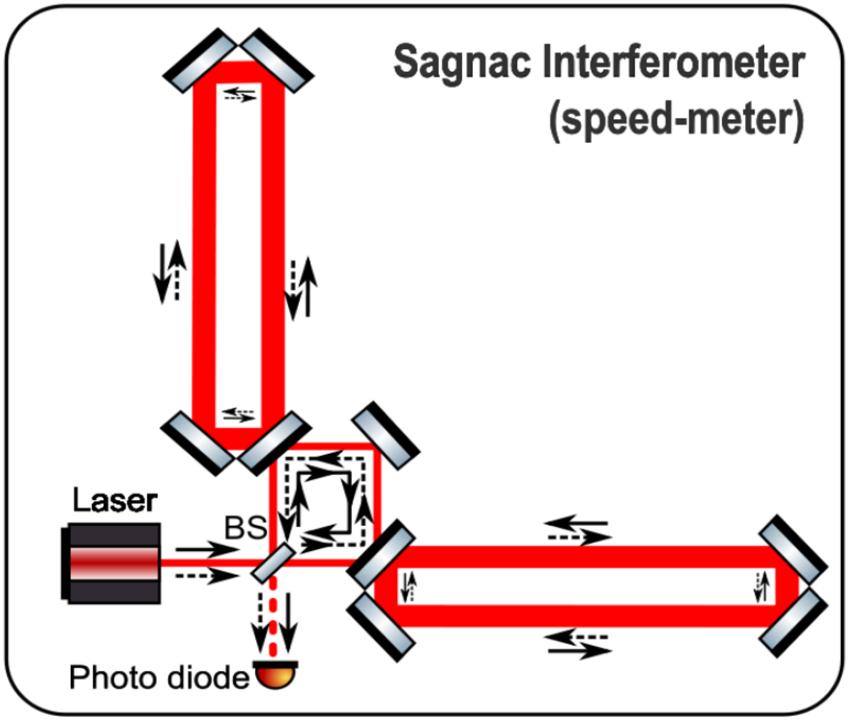




*Testing new approach to accelerate computation time*

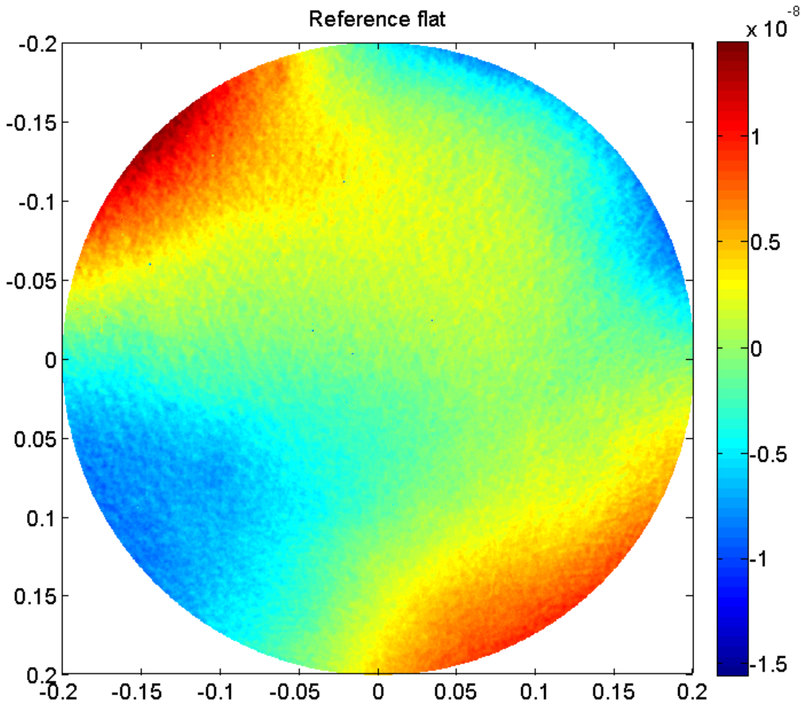
- More advanced algorithm in development
- More flexible (complex configuration) and faster
- Poster: FFT to understand ALIGO performances (K. Yamamoto)

# New input for simulations

## Implementing new ideas, new data




*Not your usual Michelson*




*Surface map over 400mm diameter*

- Looking for measurement data for 3rd generation interferometer
- ~~Talk: Simulation challenges for the Sagnac interferometer (S. Hild)~~

# Conclusion

- Simulation follows theoretical development
- Very active fields
  - Always new systems to simulate
  - With evolving technology (language, algo, GPU)
- Don't be afraid to combine/hack simulations to take the best of them

**Simulations** (Convenors: Hiroaki Yamamoto and Jerome Degallaix)

8:30 Jerome Degallaix (LMA) "Introduction"
8:50 discussion
8:55 Gabriele Vajente (Caltech) "MIST update"
9:15 discussion
9:20 Daniel Brown (Birmingham) "Implementation of radition pressure in Finesse"
9:40 discussion
9:45 Christopher Wipf (MIT) "Noise budgeting for advanced detectors"
10:05 discussion
10:10 BREAK
10:40 Tomotada Akutsu (NAOJ) "Mitigation of scattering light noise in KAGRA"
11:00 discussion
11:05 Jan Harms (Firenze) "Simulation of quantum scattering effect"
11:25 discussion
11:30 Stefan Hild (Glasgow) "Simulation challenges for the Sagnac interferometer"
11:50 discussion
11:55 Keiko Kokeyama (LSU) "Preliminary lessons from the ALIGO commissioning"
12:15 discussion

# Sources and credit

**Title slide photos**

- left: Optocad drawing of the injection bench (VIR-0048B-12)
- middle: Finesse script (Virgo+ North arm)
- right: 18” diameter mirror map

**Slide 4**

- http://www.gwoptics.org/finesse/examples/aligo_lg33.php
- Introduction to optical simulation with MIST, VIR-0382A-13

**Slide 5**

- AdV - Stray Light Control: Impact of the coating ripples on the cryotrap baffles, VIR-0137A-13
- Arm cavity simulations with the current Advanced LIGO mirror maps, G1301032

**Slide 6**

- Optocad drawing of GEO-HF (R. Schilling)
- Right plot from the gtrace presentation at the Commissioning Workshop Jan 2013 (Y. Aso)

**Slide 7**

- AdV - Stray Light Control: Requirements for wide-angle scattering in the arm cavity (VIR-0055A-13)

**Slide 8**

- Time Domain Simulation for the Lock Acquisition Study of aLIGO – K. Izumi – GWADW 13
- Calva update – VIR-0238A-11

# Sources and credit

**Slide 9**

- Absorption map from LMA
- Advanced LIGO ITM12, central part

**Slide 10**

- Using the phase camera in advanced interferometers – GWADW 2013
- Arm Measurement and simulation of laser power noise in GEO 600 CQG 25 (2008) 035003

**Slide 14**

- FINESSE: Radiation pressure effects and a quantum kat – LVC - Nice

**Slide 15**

- 1” mirror map measured at LMA
- High spatial frequency map on a small mirror, also measured at LMA

**Slide 16**

- Accelerated convergence method for the FFT simulation of coupled cavities – JOSA A

**Slide 17**

- Proof-of–Principle Experiment for a Sagnac Speedmeter – LVC 2013
- Map of a large optic over a diameter of 400 mm