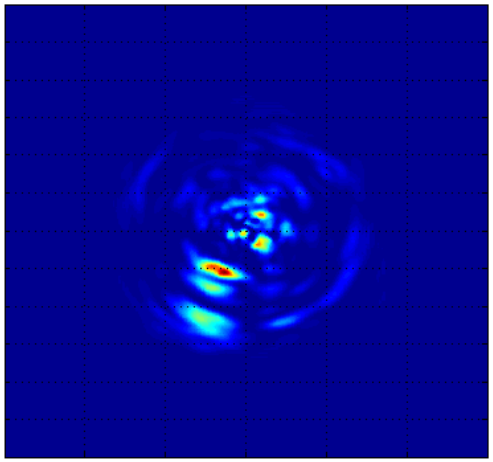
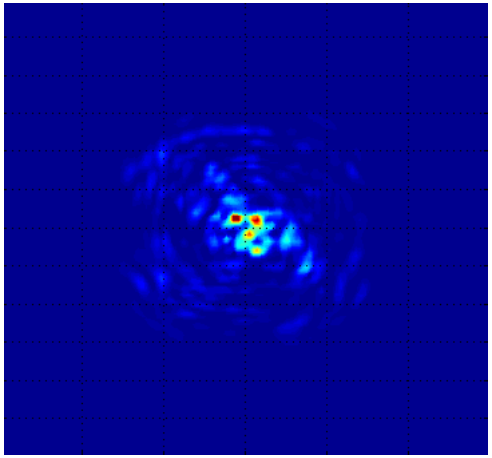
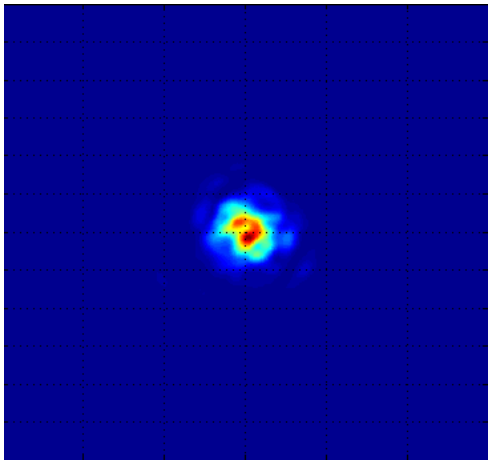
DarkF user's guide

Mikhaël Pichot

ARTEMIS, Observatoire de la Côte d'Azur, Nice, France

Outlines



- **Introduction**
  - Architecture
- **Main knowledge**
  - The simulation parameters
  - The propagation principle
  - Beams and mirrors
- **Mirror and phase maps**
  - Thermal effects
- **Using DarkF**
- **Automatic results given by the simulation**
- **Examples of DarkF use**
- **Summary**
  - More information

Introduction



- DarkF: simulation → diffraction of an arbitrary optical beam.

  (Fortran90 by J.-Y. Vinet, M. Laval, M. Pichot in ARTEMIS)

  (former code developed by JYV and P. Hello in the 90's)

- Uses Fourier Transform to treat paraxial diffraction, and extensively exploits FFT's.

- Beams and mirrors are sampled on a grid (x,y) .

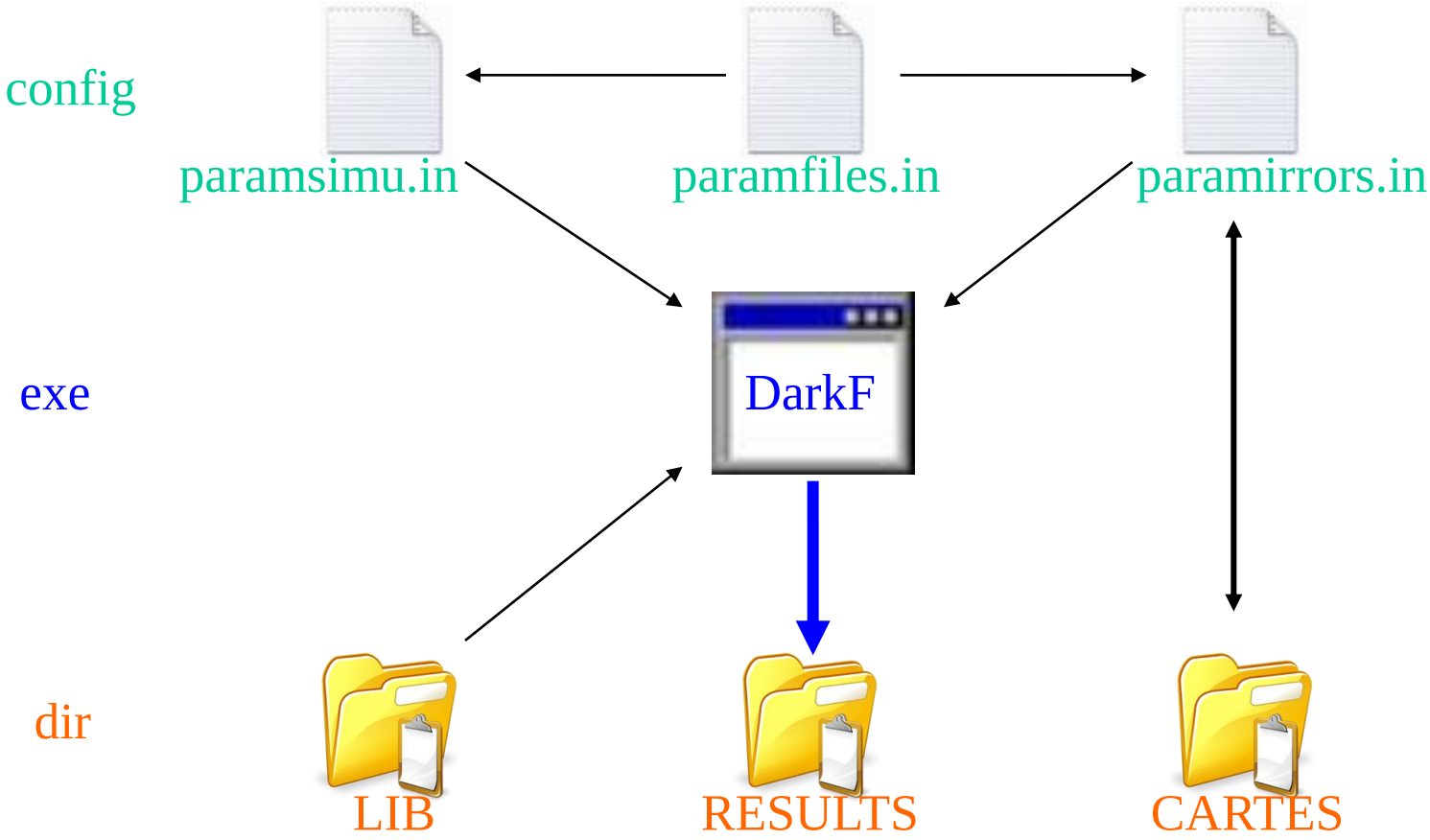
- DarkF resolution depends on the grid size and on the number of points (typically a size of 0.6m (larger than a mirror) with 128*128 points).

- Includes: mirror surface maps, thermal effects (thermal lens and coating deformation) and thermal compensation (TCS).

- Simulates: Simple Fabry Perot cavity to Gravitational Waves Advanced Detectors (for the carrier and for the sidebands).

Introduction
(Architecture)

- DarkF is composed by, 3 parameter files (config), the main program (exe), and 3 directories (dir).



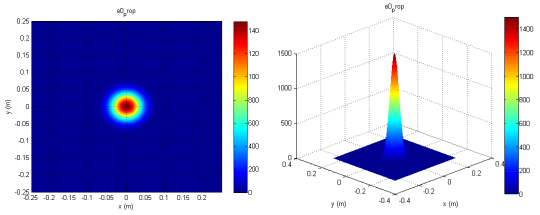
Main knowledge
(The simulation parameters)

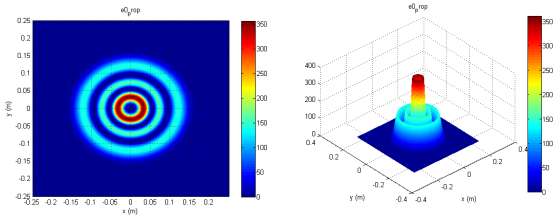


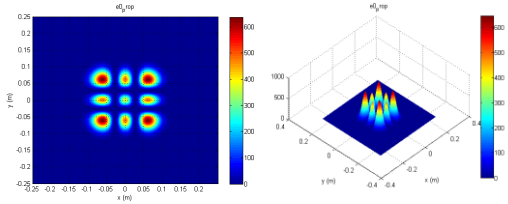
Concerning the three parameter files for DarkF:

❖**paramfiles.in:** This is the parameter file which defines the name of the other parameter files and the result file name.

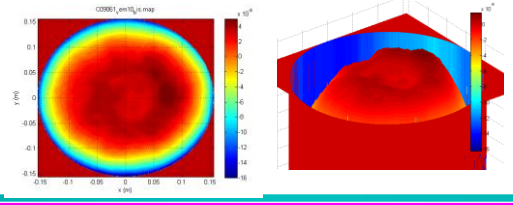
❖**paramsimu.in:** This is the parameter file of the simulation (size of the sampling window, number of points of the window, power of the initial beams, waist, kind of simulation, modulation frequency, interferometer lengths,…).







❖**paramirrors.in:** This file contains all the mirror parameters (transmission, losses, tilt, rotation,…) and the name of the mirror maps (present in the “CARTES” directory).



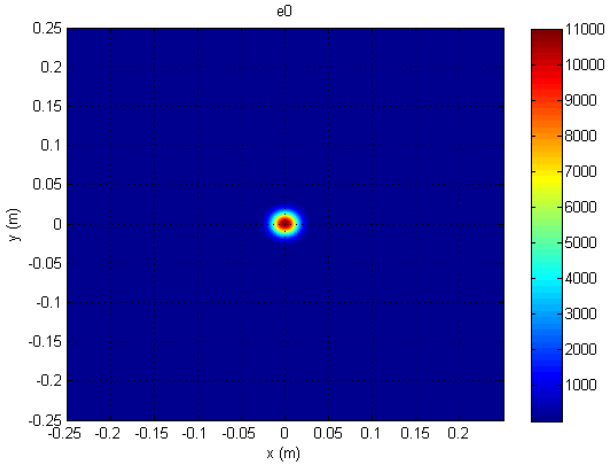
Main knowledge
(Propagation principle)

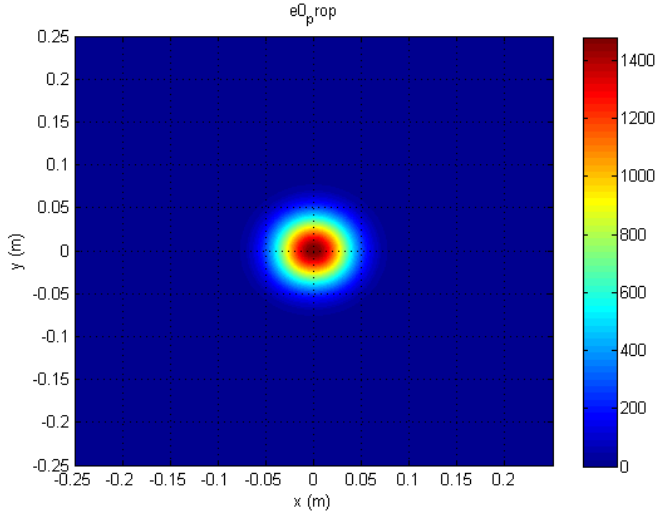
Input laser beam (2cm waist)

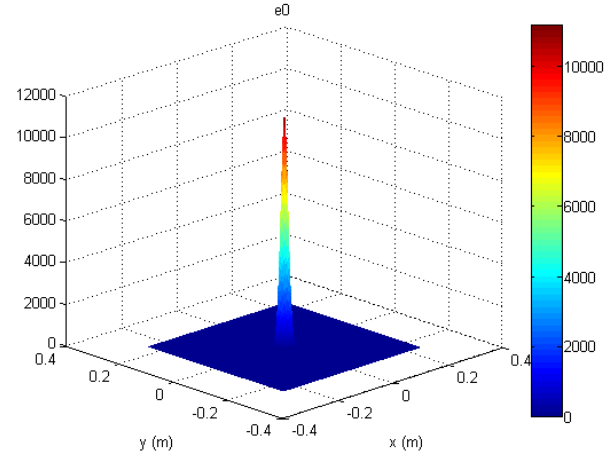
FFT $\times P$ FFT^{-1}

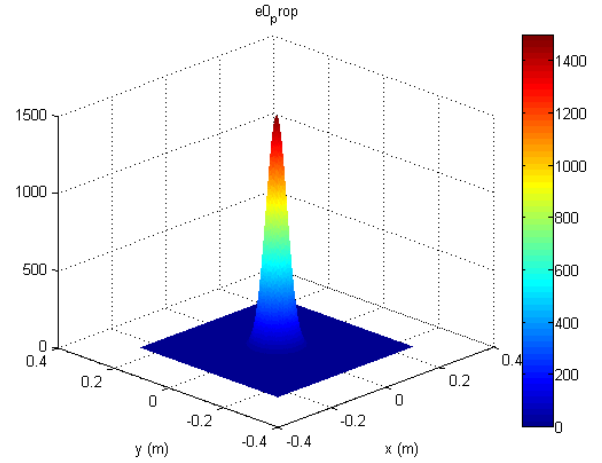
Output beam (~5cm)

3km Propagation





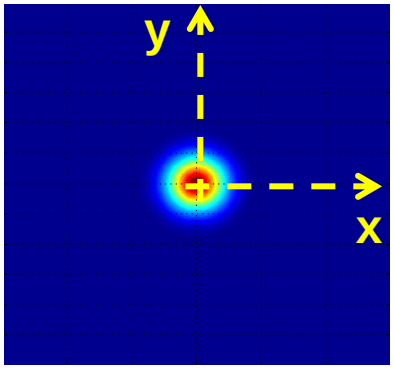


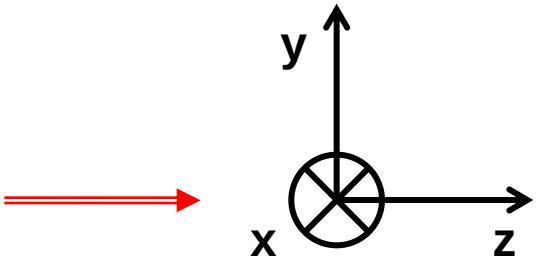


Main knowledge
(Beams and mirrors 1/3)

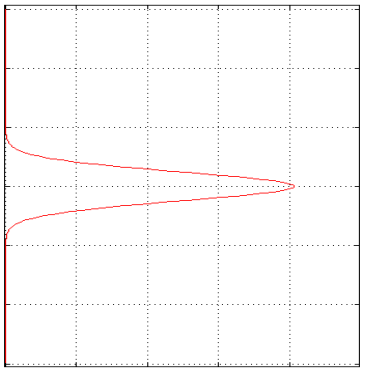


Representation of beams and mirrors :





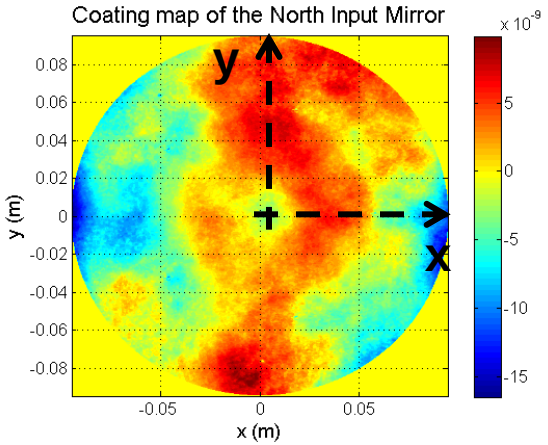
Propagation in z

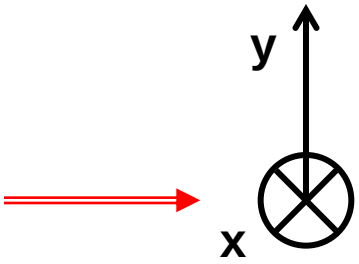


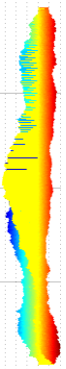


Example of a laser input beam.

Beams are always seen in front view.







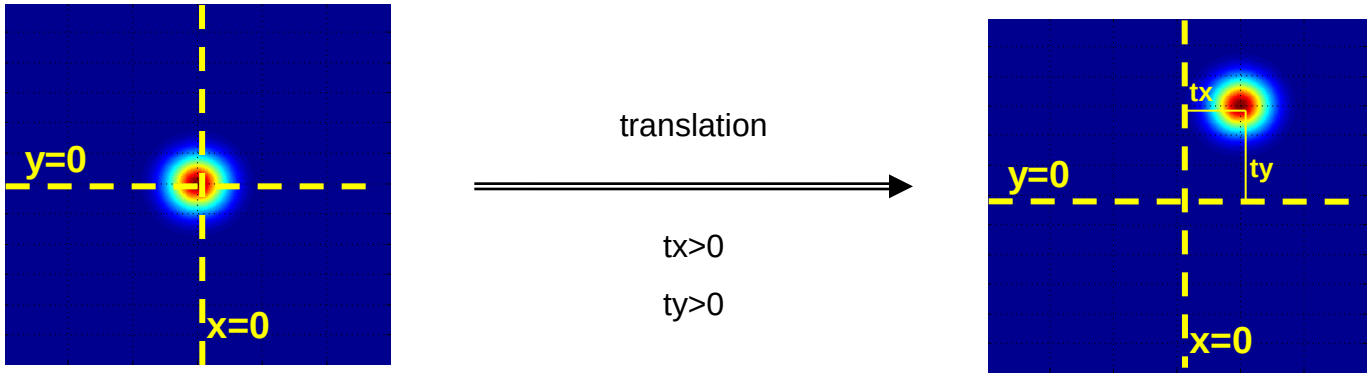


Example of a mirror coating map (without curvature).

Main knowledge
(Beams and mirrors 2/3)



Beam translation:



Mirror translation:

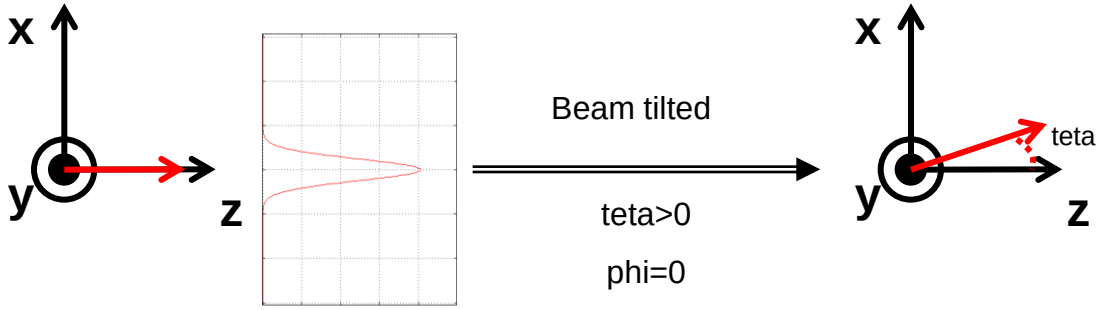
-Same principle as the beam translation.

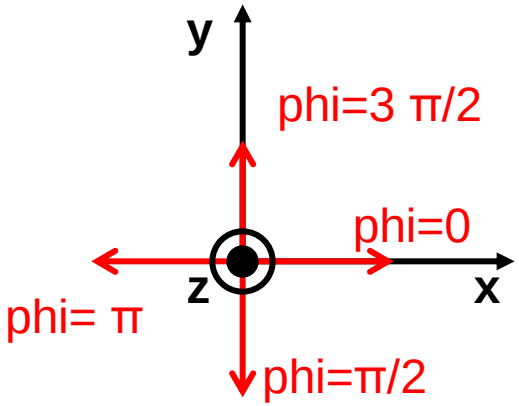
=> In the two cases be careful of the window size, if you want to keep your beam or your mirror inside it.

Main knowledge
(Beams and mirrors 3/3)



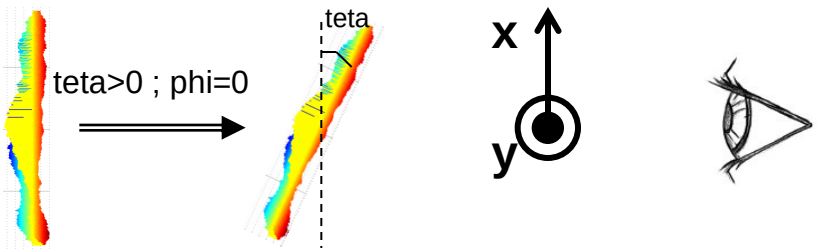
Beam tilt and orientation:

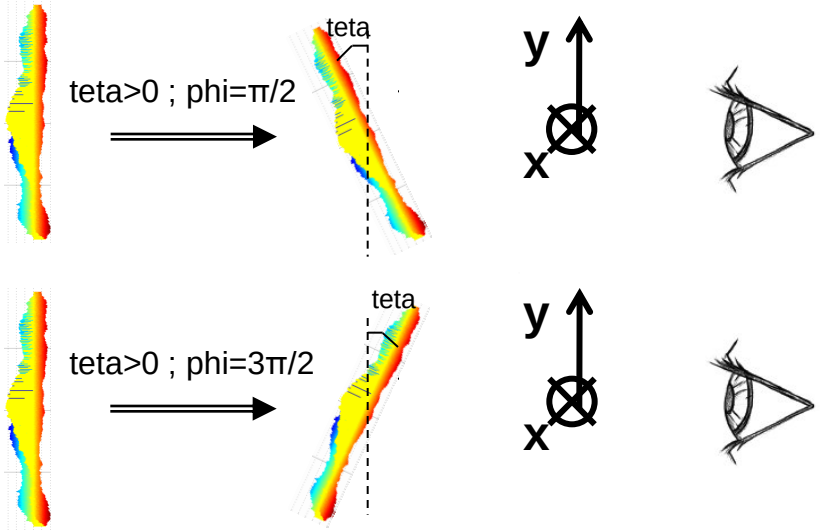




tilt orientation

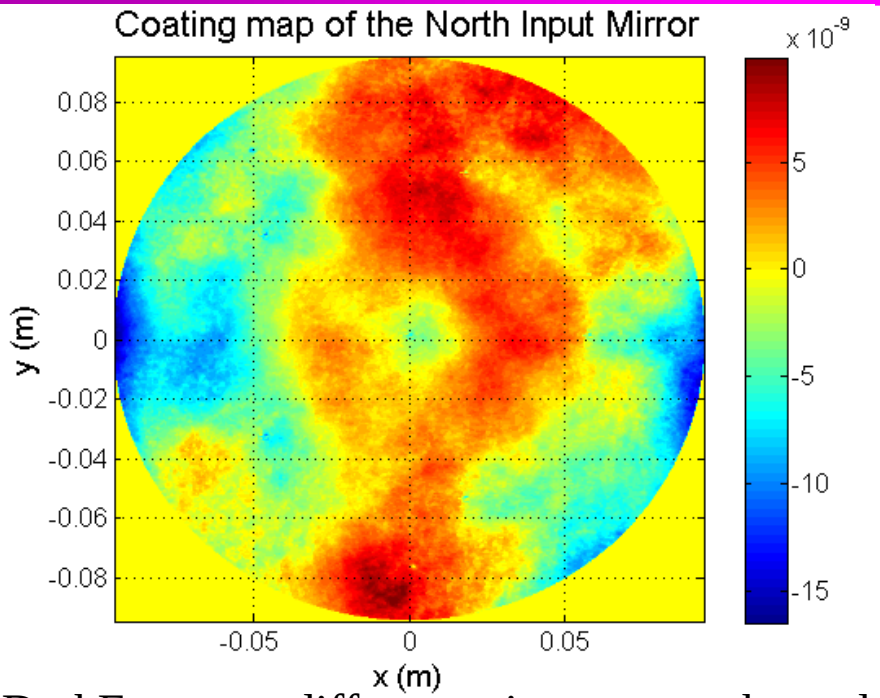
Mirror tilt and orientation:

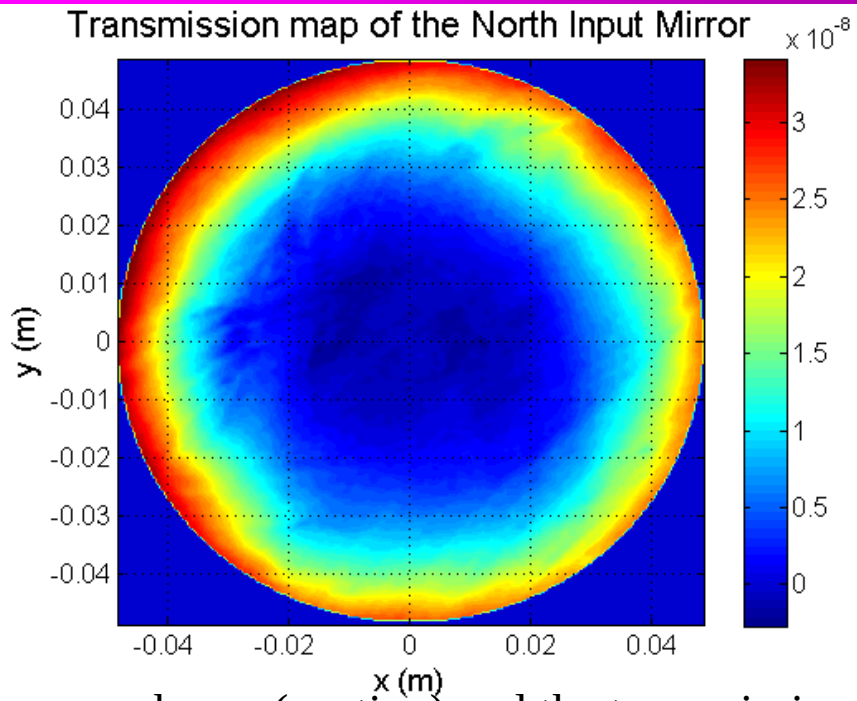




Mirror and Phase maps







DarkF can use different mirror maps: the real mirror roughness (coating) and the transmission phase.

Coating => Residual roughness, is applied on a perfect paraboloid. Consequently it is easy to modify the curvature of these mirrors.

Transmission => Phase shifting through the substrate.

Reflected field = E_{in} x $R.e^{\varphi r(x,y)}$

Transmitted field = E_{in} x $T.e^{\varphi t(x,y)}$

Thermal effects and TCS maps



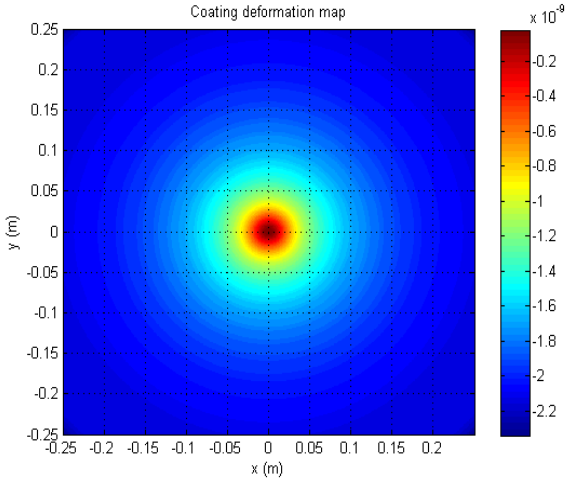
- The thermal effects are added in DarkF, as mirror maps.

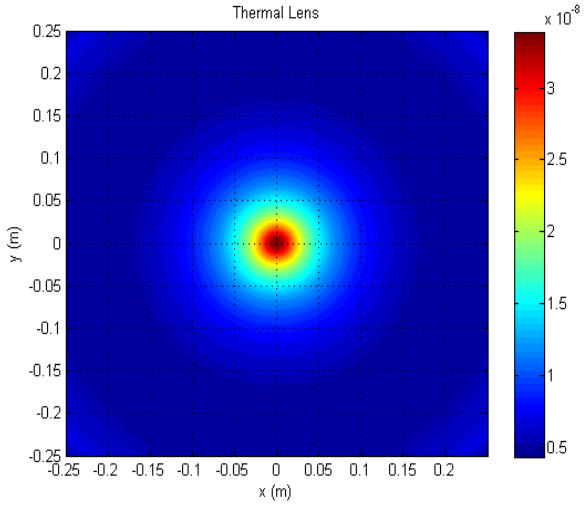
  -We have the Coating deformation (real surface deformation) and the Thermal lens (transmission phase map, due to the changing index in the substrate).

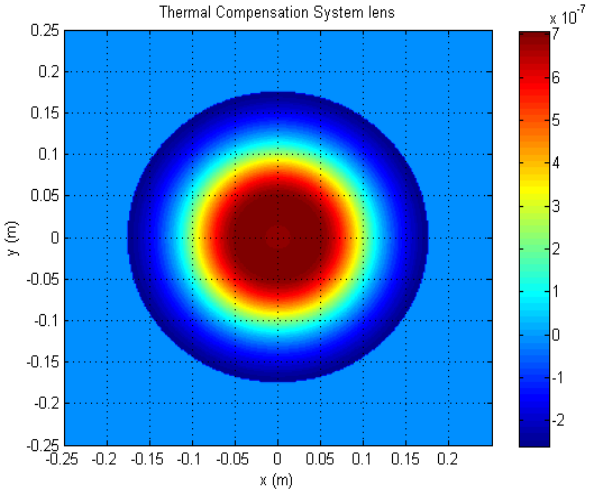
- To correct we can add TCS maps, which only correct the main thermal effect, the thermal lens.

- All these maps are added by superposition to the concerned mirror.

Example of thermal effects and TCS maps:







Using DarkF (1/2)



DarkF is complex but it has been coded to have an automatic version. In addition to this user's guide, a "Readme.txt" has been written for complementary explanations.

DarkF is composed by a main program, 3 parameter files and 3 directories.

The user will have to modify the parameter list and to choose the kinds of simulation.

The "kind of simulation"

One of the DarkF parameters is the "kind of simulation". Six kinds are available.

- **"FP":** Simulate a Fabry Perot cavity, with the input beam parameter, until the steady state is reached (maximized the intra cavity power).
- **"DC":** Simulate a Double cavity, Fabry Perot with a recycling power cavity, with the input beam parameter, until the steady state is reached (maximized the recycling cavity power and the FP cavity power).
- **"CITF":** Simulate the Central Interferometer, with the input beam parameter, until the steady state is reached (maximized the recycling cavity power and minimized the dark fringe power).

Using DarkF (2/2)



- **"Main":** With this parameter, DarkF will simulate the advanced interferometer but only for the carrier (maximized the recycling cavity power, the long arms and minimized the dark fringe power).
- **"Main&ASB":** This second kind will simulate the advanced interferometer for the carrier and the audio sidebands (same procedure as before and optimized the sensitivity by adjusting the long arms).
- **"Main&VSB":** This last kind will simulate the advanced interferometer for the carrier and the video sidebands (maximized the recycling cavity power, the long arms and minimized the dark fringe power for the carrier, and simulated the video sidebands).

Remark: Once a first simulation has been made, you have to possibility to run several other ones, based on the previous simulation (start from the previous state).

Automatic results given by the simulation (in the "RESULTS" directory)

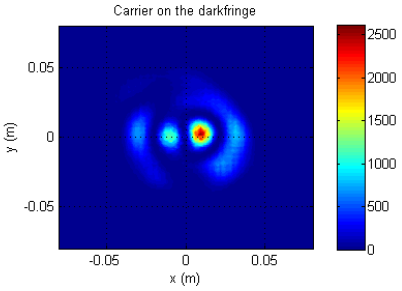


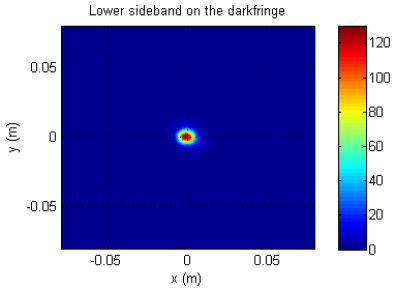
❖**Result files:**

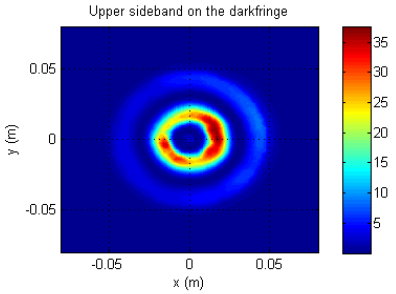
- The configuration
- The parameters
- The results of the simulation (power of the different beams, the losses, the coupling defect, the coupling of the main beams with perfect TEM, the main beam baric center,…)

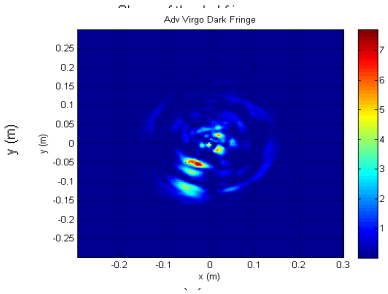
❖**Beam files:** The main beams are in complex form and saved in different files (see "Readme.txt).

Consequently we can plot the beam shape or the phase profile, with a Matlab code.





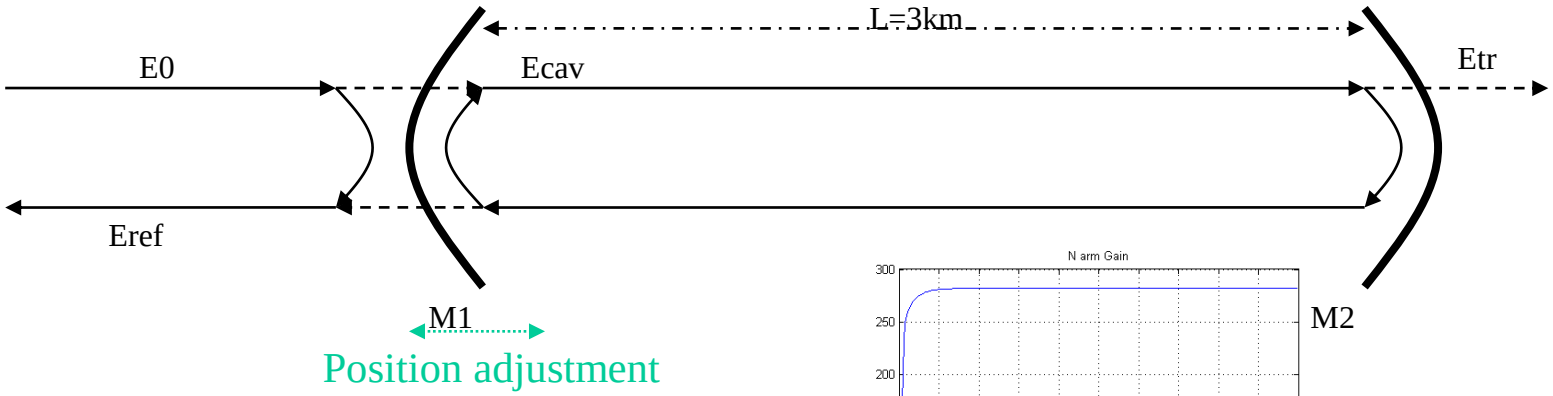




Examples of DarkF use 1/4
(The FP locking system)



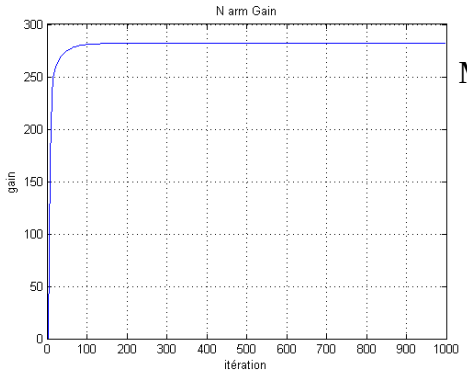
Example with a Fabry-Perot cavity:



Position adjustment

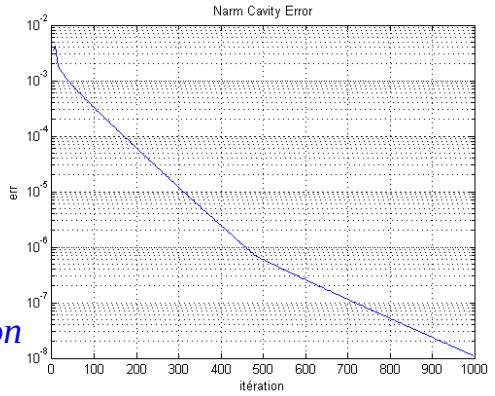
Beams superposition (in phase)

= Energy stored



(Cavity power vs iteration number)

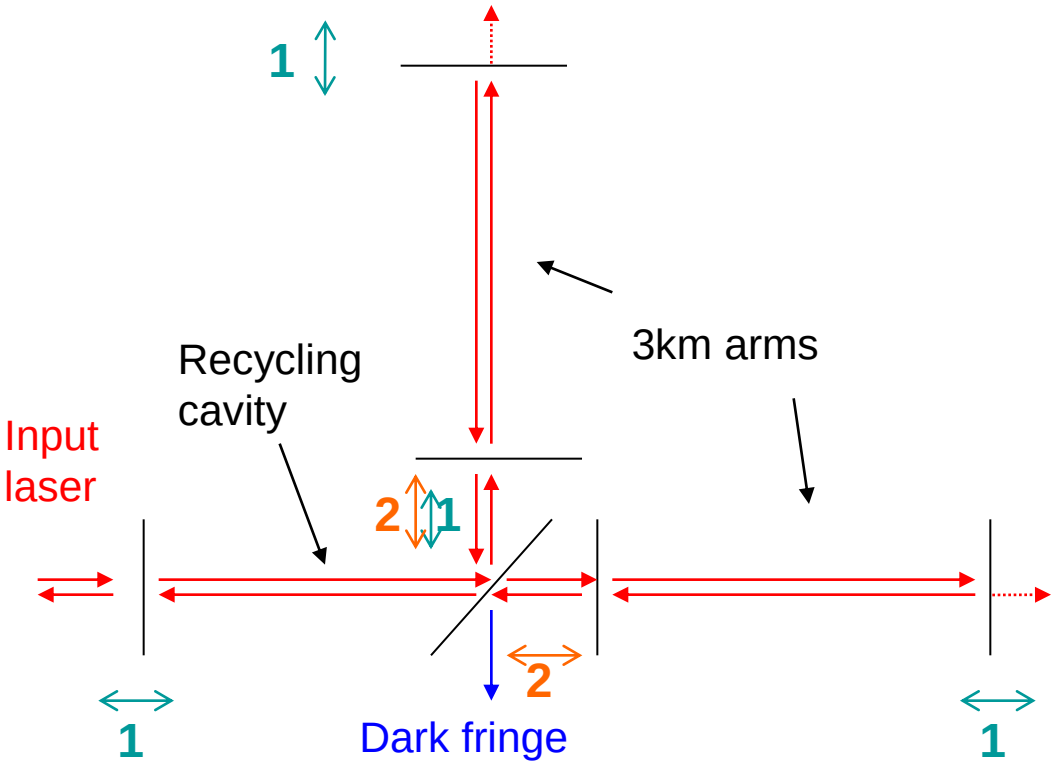
=> The simulation ends when the difference between the beam in the cavity and the same after un round trip, are nearly identical => relative error is minimal.



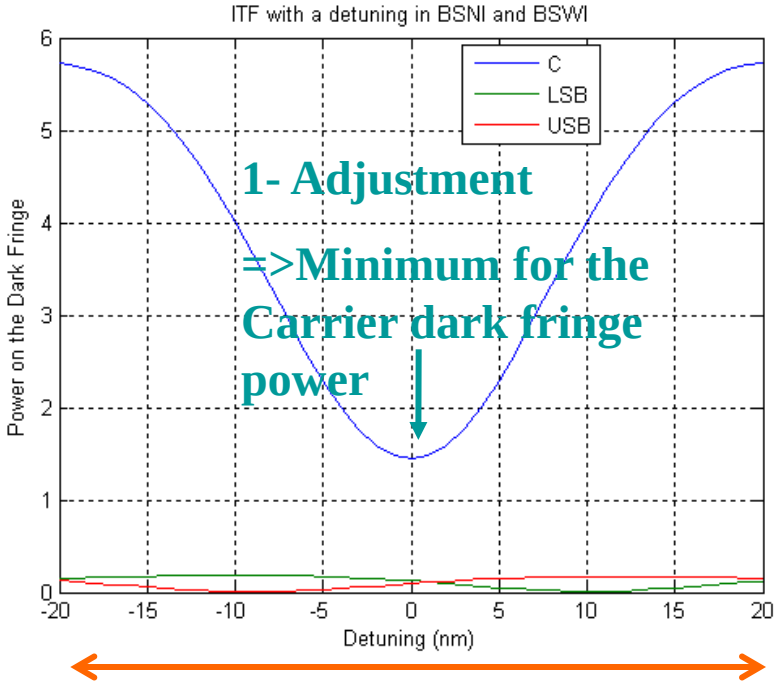
(Cavity error vs iteration number)

Examples of DarkF use 2/4
(Detuning of the Virgo ITF)

- Virgo interferometer scheme.



- Study of the short arms detuning, on the dark fringe powers.



(dark fringe powers vs short arms detuning)

Examples of DarkF use 3/4
(Thermal effects and TCS results)



-Case of FP cavity with recycling.

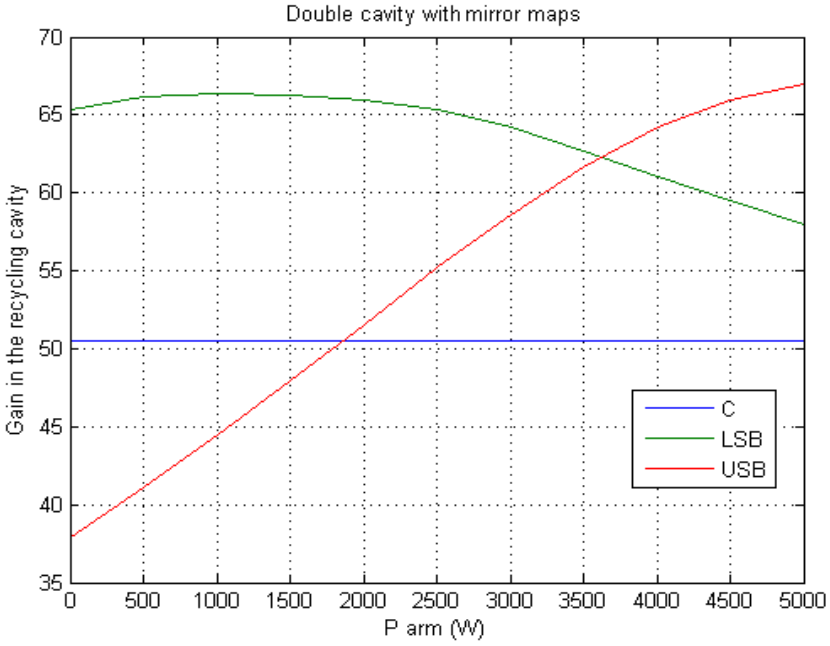
-Heating process (increase of the FP power => change thermal effect maps).

-Effect on the recycling gains in function of the power stored in the long arm.

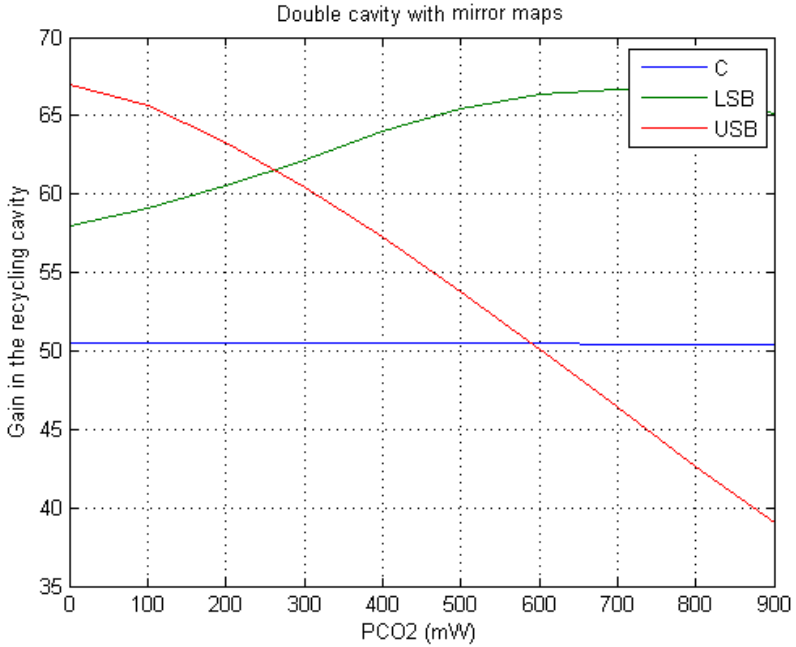
-The double cavity is in hot state.

-We apply the TCS (increase of the CO_2 power => hot state maps + change TCS maps).

=>We can perfectly correct the thermal effects for a double cavity.



(recycling gains vs power stored in the FP cavity)



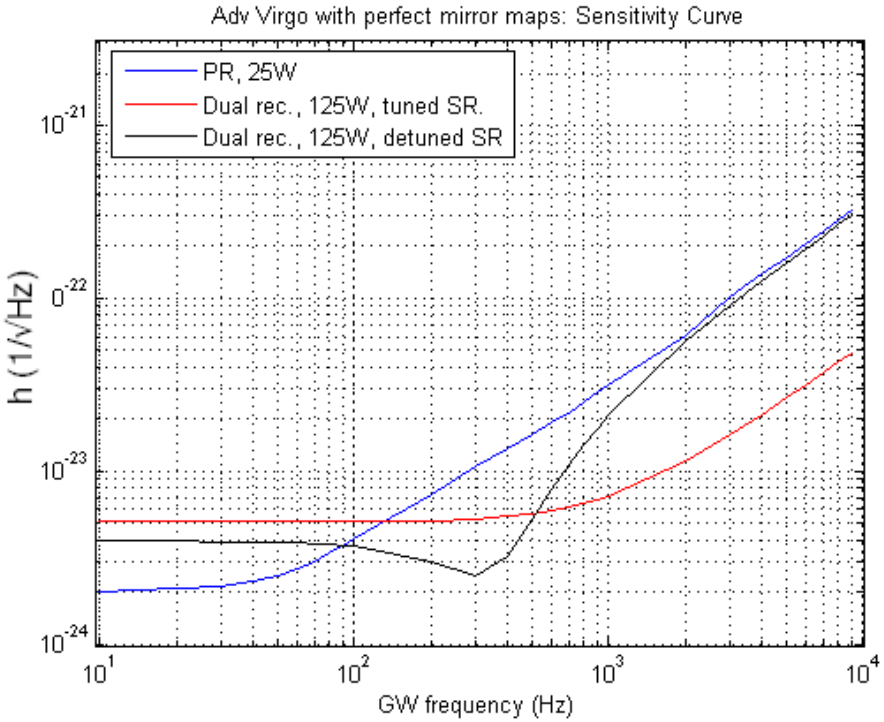
(recycling gains vs power TCS power)

Examples of DarkF use 4/4
(Shot noise limited sensitivity curves)



- Implementation of the Audio Sidebands for the simulation of the interferometer with dual recycling => plot the sensitivity curve.

- The Sensitivity is only limited by the Shot Noise.



(Adv Virgo sensitivity curve)

Summary



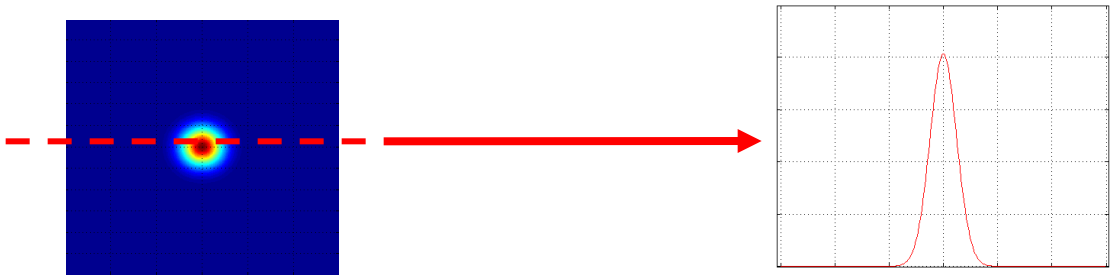
- **DarkF is used for the Optical Characterization (Losses estimation, recycling length, sideband dissymmetry, modulation frequencies, input mode cleaner,…) and its main advantage is the use of FFT (for high order modes) and especially with real mirror maps.**

- **DarkF is now developed enough to be used by all Gravitational Waves Detector collaborations, with simple automatic version and user's guides.**

More information 1/2



- **DarkF can be used in “1D” simulation (128x1 or 1x128) , for even faster simulations:**



- **The current DarkF code uses acceleration method, to calculate the steady state of the interferometer (Ref: "Fast estimation of transverse fields in high-finesse optical cavities", Partha Saha, J. Opt. Soc. Am. / A, Vol 14 N.9 (1997) p.2195-2202).**
- **DarkF is available for Adv Virgo, aLIGO and KAGRA on different OS (Unix, MAC, Windows).**
- **For the aLIGO and KAGRA versions, an adaptive coordinates method is used in the Non Degenerated Recycling Cavities (NDRC), due to the wide diffraction of the beam.**
- **DarkF is compiled with the Fortran compiler “g95” and uses the FFT library “FFTW” (in the “LIB” directory).**

•*Contact: mikhael.pichot@oca.eu*

More information 2/2



• **Abbreviation of the different fields in the interferometer and their positions:**

- **all fields begin with "e": e*******

- **the middle term is the position name:**

0: input laser

Rrec: Reflected recycling

rec: recycling

ref: reflected Michelson

tr1: transmitted through BS to North arm

tr2: transmitted through BS to West arm

Nref: North reflected

Wref: West reflected

N: North arm

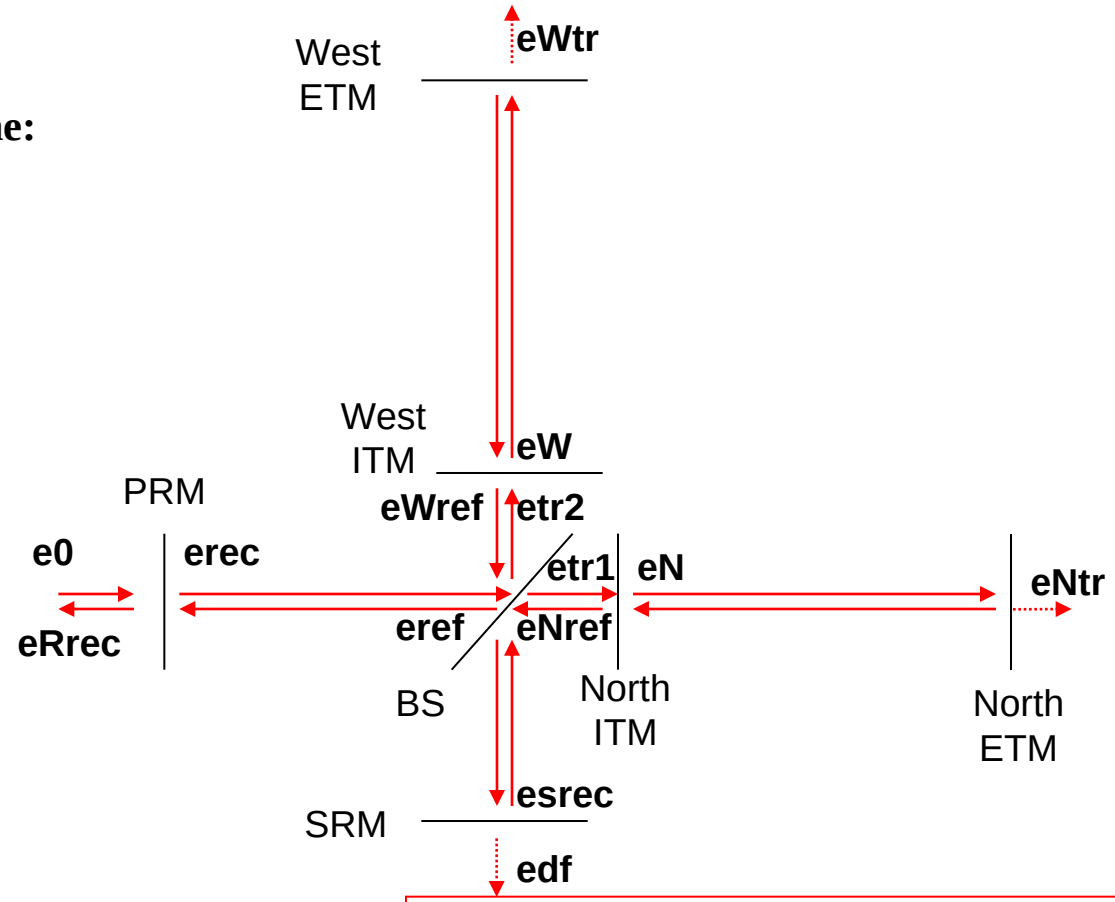
W: West arm

Ntr: North transmitted

Wtr: West transmitted

srec: signal recycling

df: dark fringe



- **the last term is for the beam name (CAR, LSB, USB,…):**

For example **eWrefLSB**, means:

West reflected field for Lower SideBand

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