LIGO-G010163-00-D

Notes on the simulation programs "FFT-code" and "Melody"

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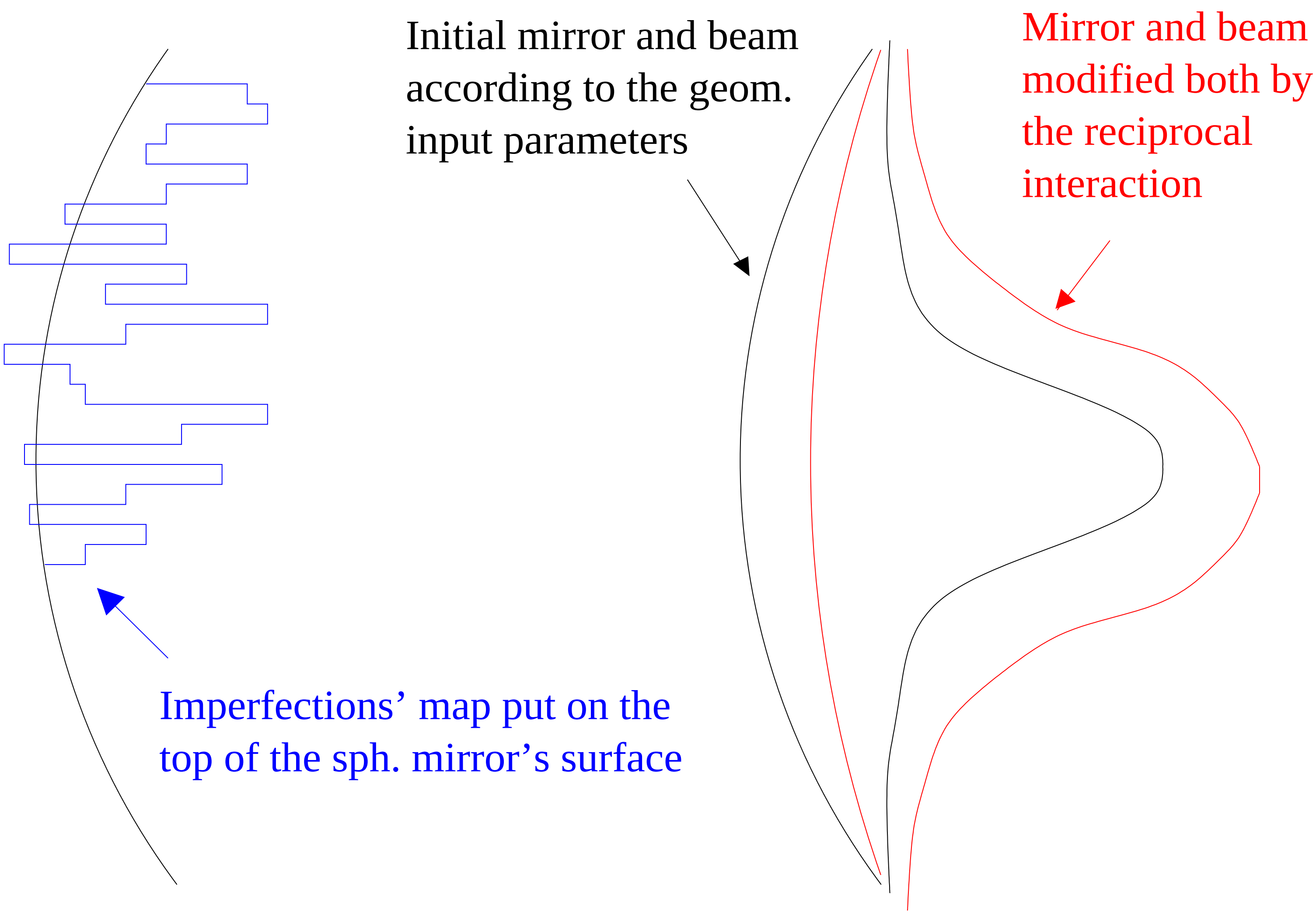
1. **Purposes** the two codes have been written for and
   main differencies between

   - the informations they need as input and
   - the results they can give as output

   with a view to address different kinds of perturbation that can limit the sensitivity of gravitational wave interferometers.

2. The aim is at a validation of the two that might establish a certain degree of confidence in their numerical results for those sets of perturbations that are hard to study analytically.

The working principle of the two codes

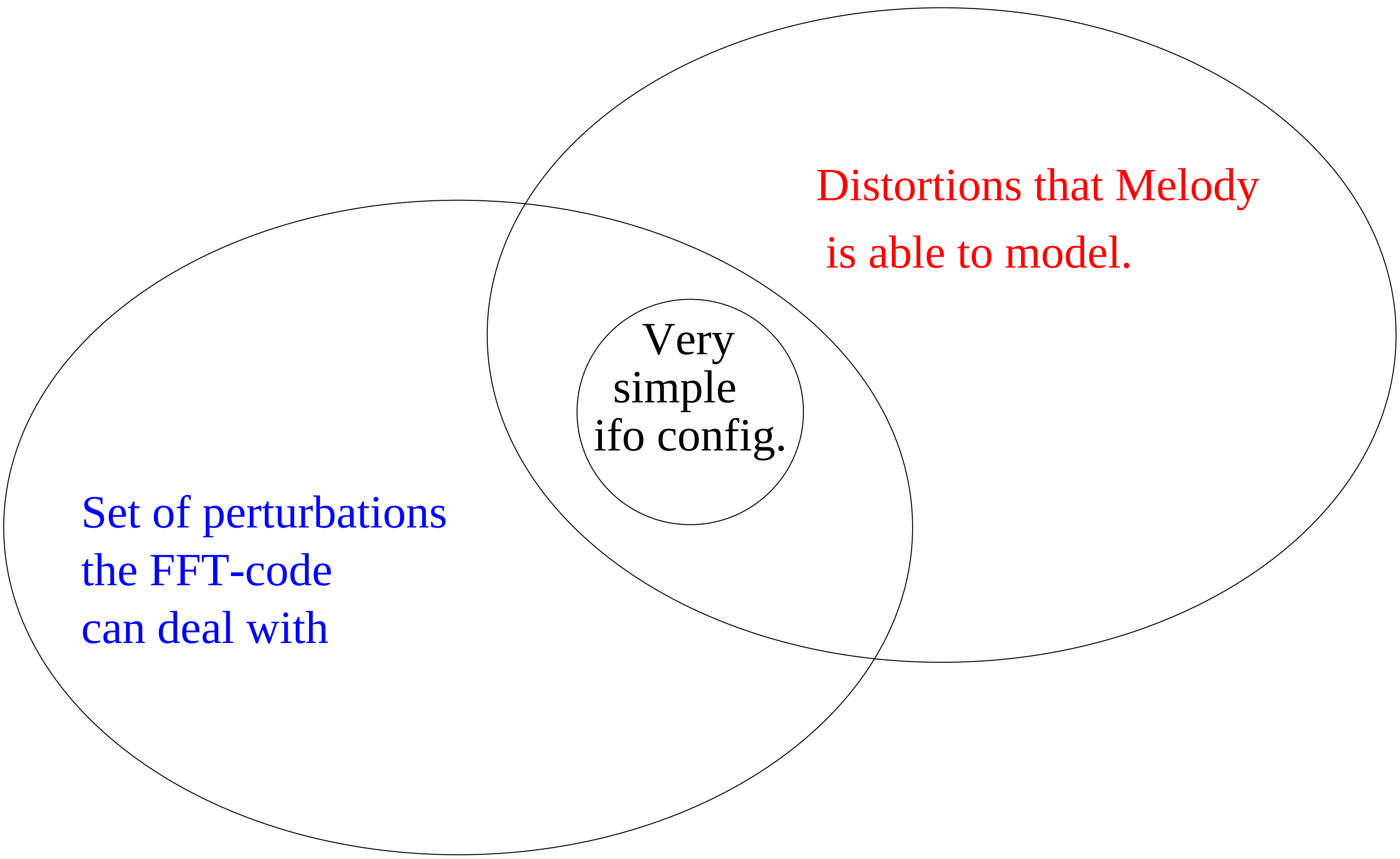


FFT-code: P. Hello, J. Y. Vinet, B. Bochner, Y. Hefetz, T. Phung, R. Jenet

Melody: Ray Beausoleil

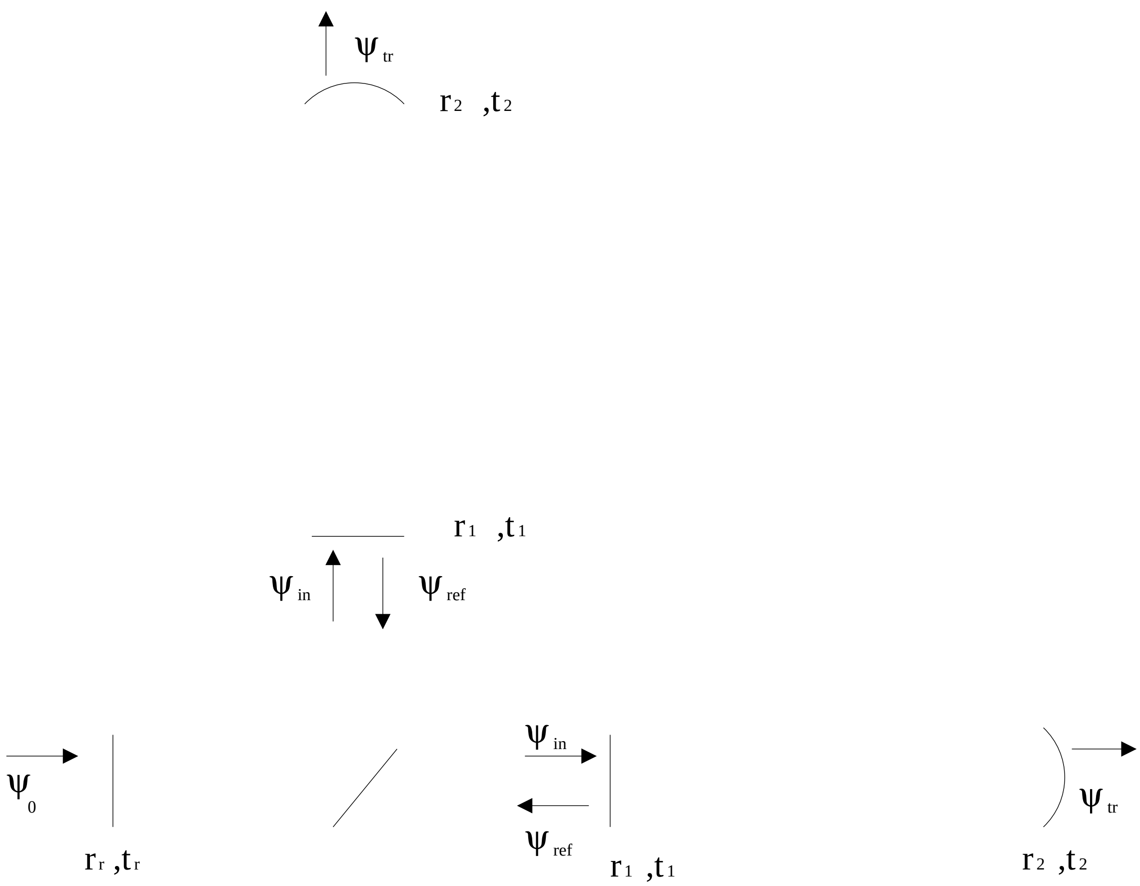
From the user's point of view

Input parameter	FFT input file	Melody input files
Mirrors' shape	dimensions, r.o.c., maps	dimensions, r.o.c.
Optics constants	R_{ref}, $R_{A.R.}$, T, L	R_{ref}, T, L_{ref}, $L_{A.R.}$, L_{bulk}
Laser	carrier and modul. freq.	carrier and modul. freq.
Beam's geometry	spot size and r.o.c.	Max $m+n$ for TEMmn
Materials	refractive index	all the properties



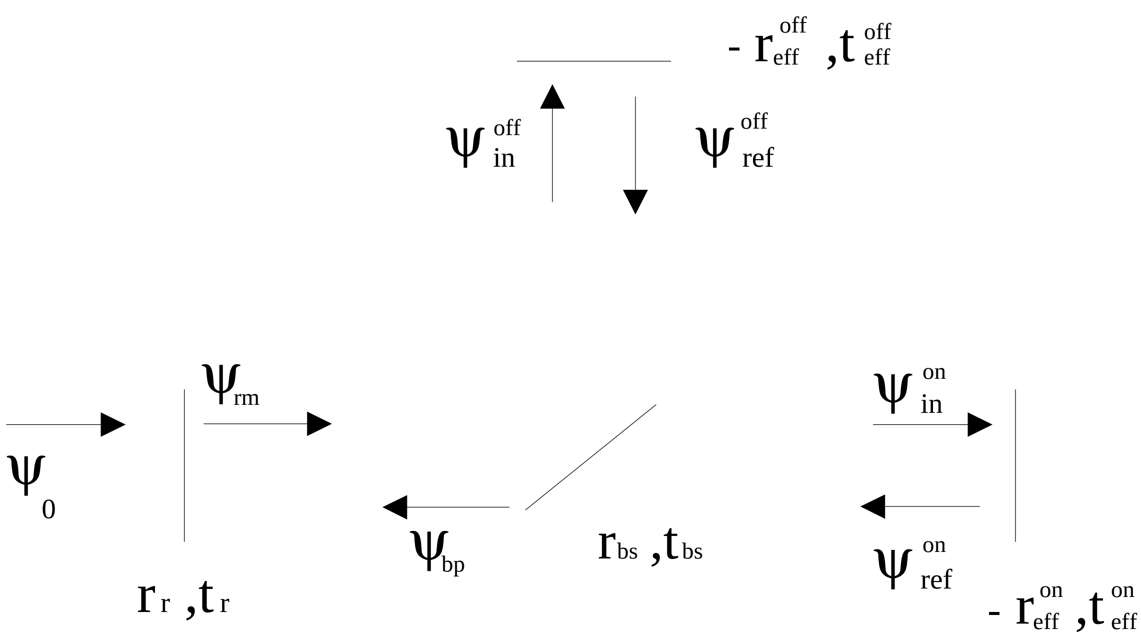
Basic informations	FFT summary file	Melody summary file
Lengths	optimized values	optimized values
Beam amplitude	prop. through mirrors	distorted (as mirrors)
Round-trip phases	arms, rec. cav.	arms, rec. cav.
Final Power	b.s. ports, arms, refl., RM	b.s. ports, arms, refl.
Decomposition	TEM00, TEM01, TEM10	TEMmn $m+n<N$

The "ideal" interferometer



Gains values	FFT-code	Melody	Analytical
Power by rec. mirror	65.6943		65.7331
On-line arm cav.	4288.09	4283.92	4290.62
Off-line arm cav.	4288.09	4283.92	4290.62
B.S. bright port	64.6979	64.6826	64.7365

No recycling, one arm is resonating, the other is completely lossy



Gains values	FFT-code	Melody	Analytical
Power by rec. mirror	1.00695		1.00693
On-line arm cav.	65.722	65.729	65.729
Off-line arm cav.	0.5035	0.5035	0.5035
B.S. bright port	0.2493	0.2494	0.2465
B.S. dark port	0.2464	0.2465	0.2494

Improvements went on with more demanding tests

With no perturbation:
agreement between numerical and analytical results

One resonating cavity:
the two simulation programs give the same results

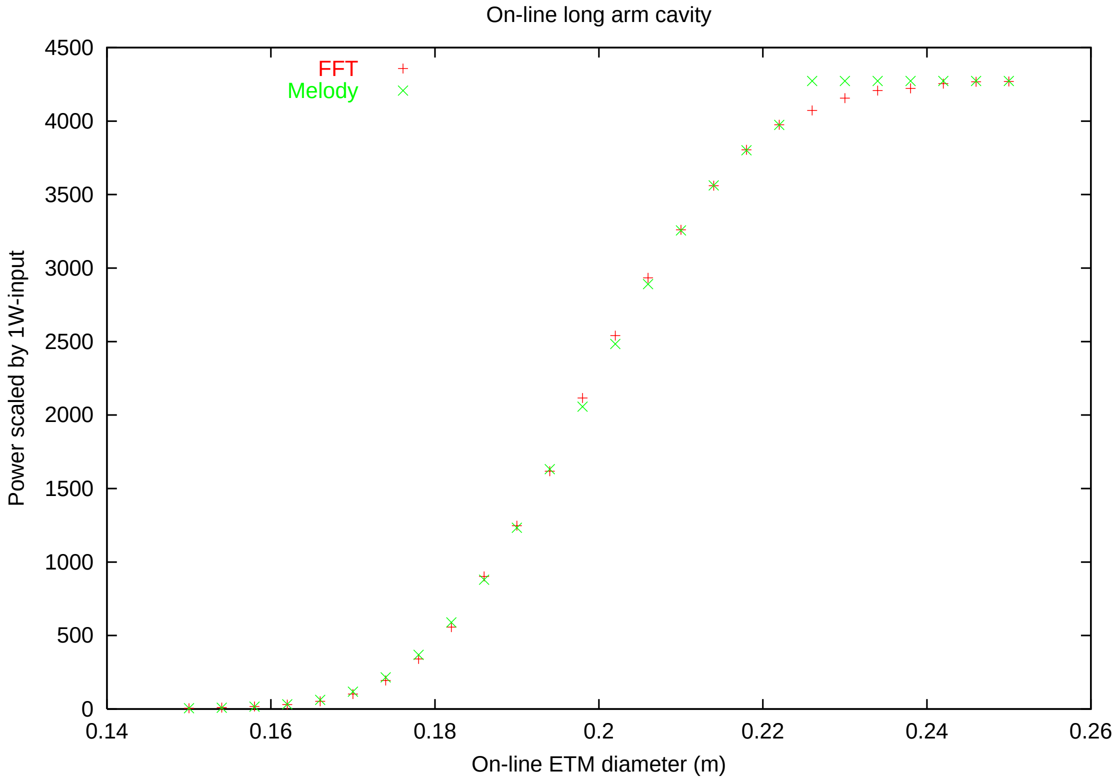
ETM on-line mirror's diameter:

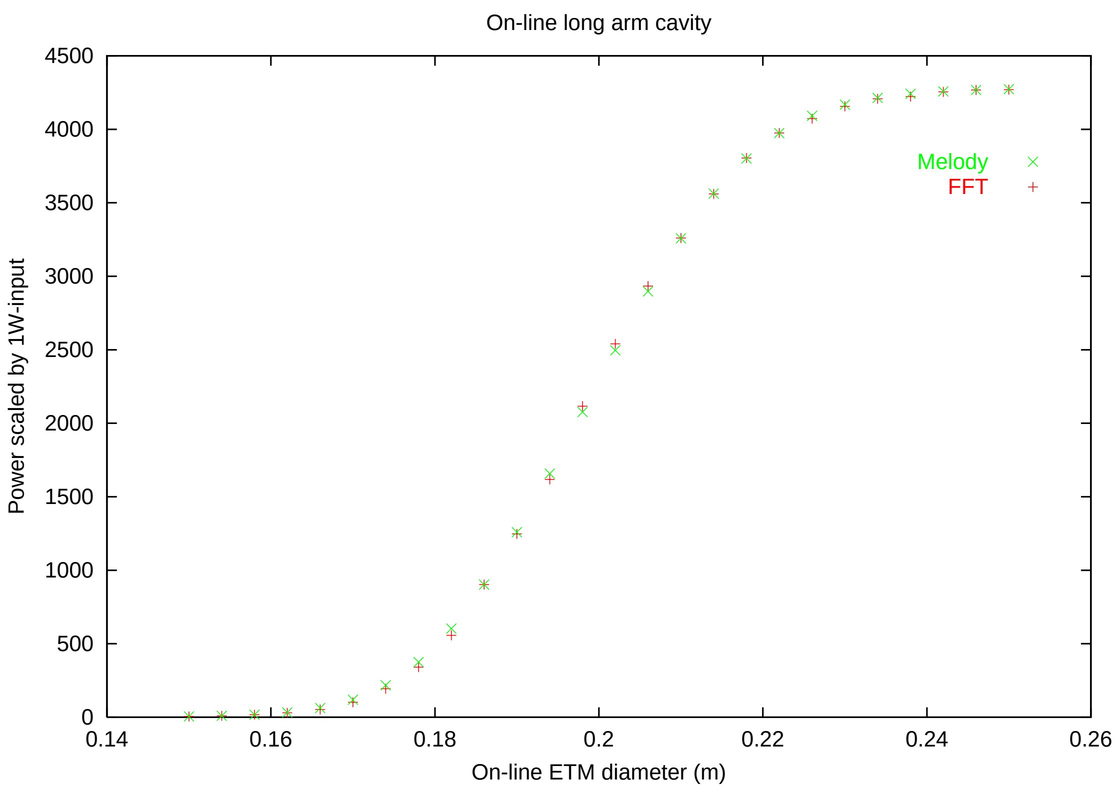
- problems for small perturbations
  that are not solved by including more higher order modes
  for sensing diffraction losses
- the optimization acted by the pseudolocker is even
  too good since all the gains stay near their maxima

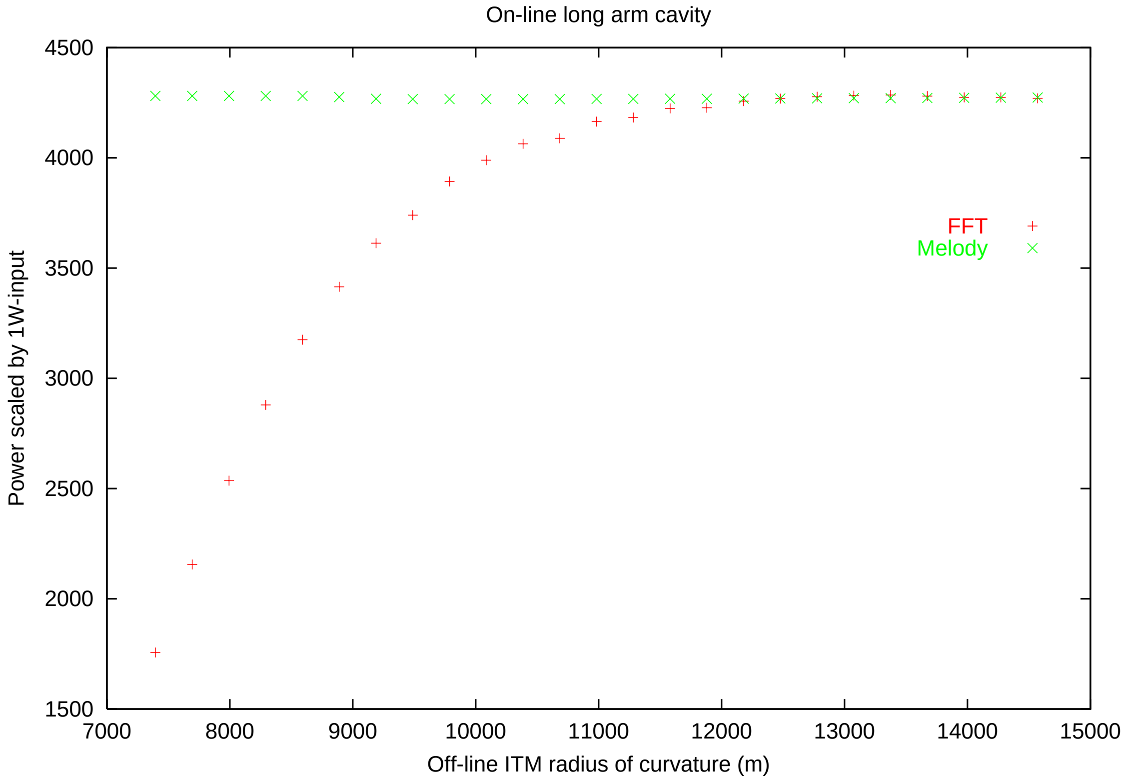
ITM off-line mirror's R.O.C.:

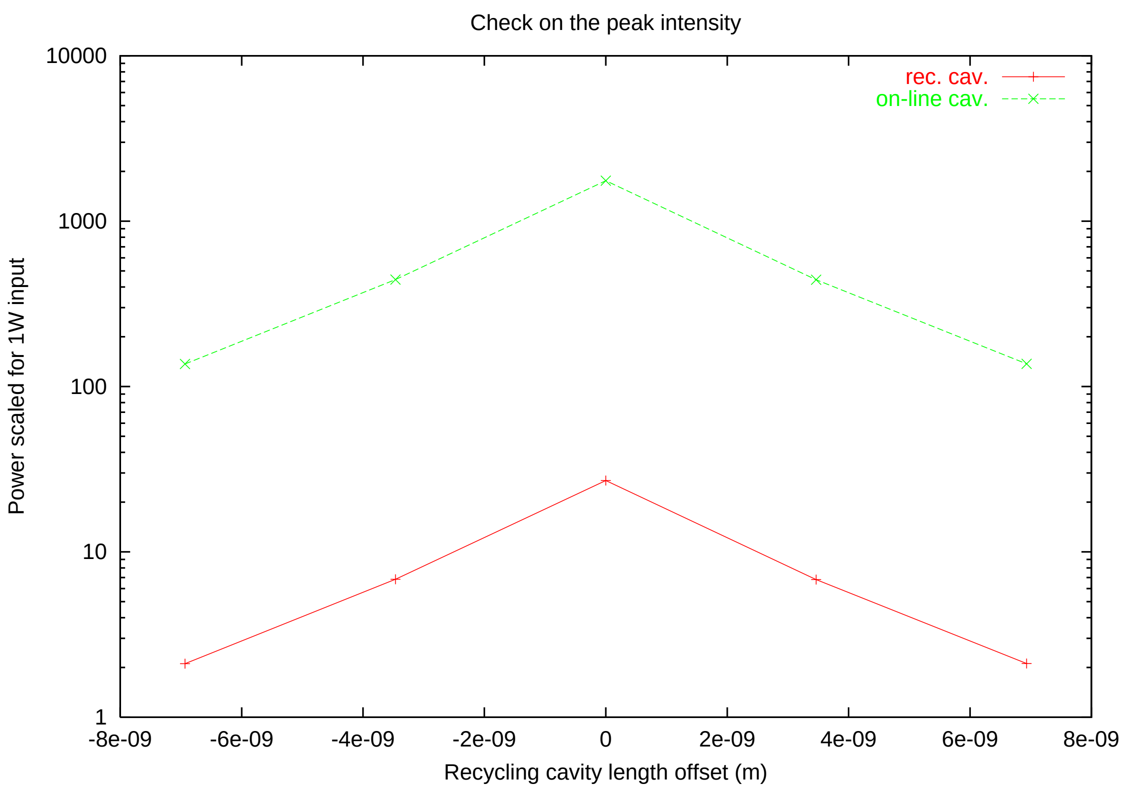
- starting with the perturbed or unperturbed field gives
  different results at the end of the iterations
- if the pseudolocker is disabled the curves
  of the built up powers versus the perturbation are flat

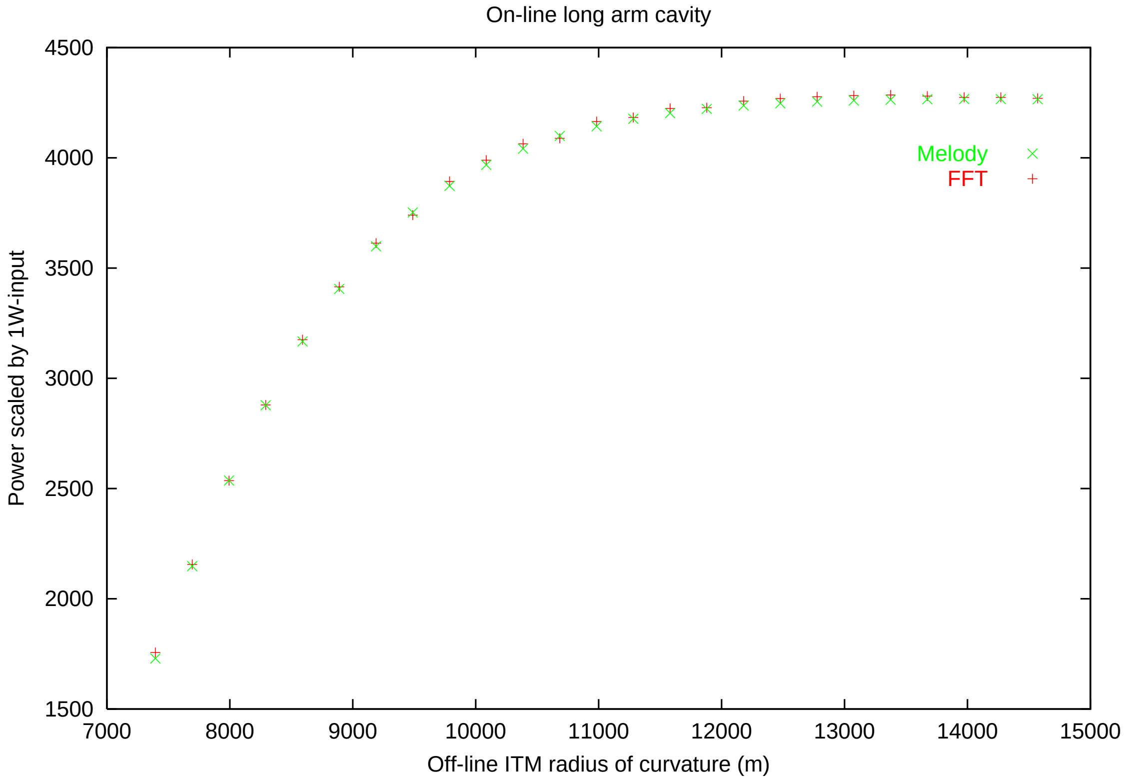
Many tests have been done to understand the causes of such inconsistencies and,after many upgrades gradually introduced by **Ray Beausoleil**, Melody can now deal with the examined perturbations, giving results that are in good agreement with the FFT-code data. **Moreover its speed has improved of a factor 100-1000 because of the new routines**.

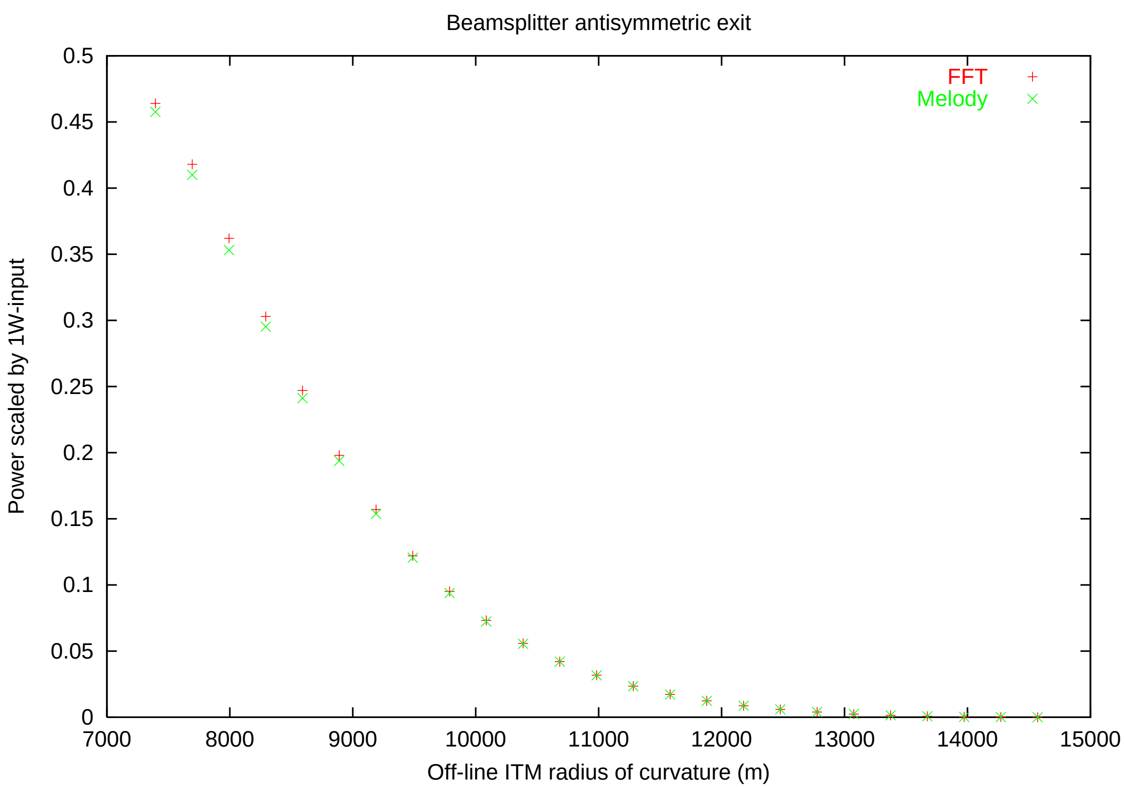

On-line long arm cavity
FFT
Melody
Power scaled by 1W-input
On-line ETM diameter (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0.14
0.16
0.18
0.2
0.22
0.24
0.26


On-line long arm cavity
Melody
FFT
Power scaled by 1W-input
On-line ETM diameter (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0.14
0.16
0.18
0.2
0.22
0.24
0.26


On-line long arm cavity
4500
4000
3500
3000
2500
2000
1500
7000
8000
9000
10000
11000
12000
13000
14000
15000
Power scaled by 1W-input
Off-line ITM radius of curvature (m)
FFT
Melody


Check on the peak intensity
10000
1000
100
10
1
-8e-09
-6e-09
-4e-09
-2e-09
0
2e-09
4e-09
6e-09
8e-09
Power scaled for 1W input
Recycling cavity length offset (m)
rec. cav.
on-line cav.


On-line long arm cavity
Melody
FFT
Power scaled by 1W-input
Off-line ITM radius of curvature (m)
4500
4000
3500
3000
2500
2000
1500
7000
8000
9000
10000
11000
12000
13000
14000
15000


Beamsplitter antisymmetric exit
FFT
Melody
Power scaled by 1W-input
Off-line ITM radius of curvature (m)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
7000
8000
9000
10000
11000
12000
13000
14000
15000

Preliminary conclusions

- Agreement within few percents even for severe perturbations.

- Stable results for bases of $TEMmn$ with $Max[n+m] \geq 4$.
  The field inside the interferometer is represented by a linear combination of $(Max[n+m]+1)(Max[n+m]+2)/2$ components

- Though the FFT-code doesn't allow the mirrors' shape to be dynamically changed, this validation takes also into account the perspective of the thermal effects, since the procedure that has been settled for the cold geometrical distortions has shown to be effective also for the non-linear perturbations that depend on the laser power, by gradually increasing the light intensity and evaluating the the small modifications at each step by using the results of the previous step.

- Next studies will focus on some issues related to the recycling cavity and the sidebands in order to investigate possible models for explaining observed data.