FINESSE: Quickstart

Charlotte Bond and Daniel Brown

LIGO commissioning workshop- 29/01/2013

```
%% INTERFEROMETER COMPONENTS

l L0 1 0 n1
s s0  1 n1 nbsp1
bs BSP 0.01 0.99 0 45 nbsp1 dump nbsp3 dump

s s01 1 nbsp3 n2

bs BS0 0.5 0.5 59.6 45 n2 n3 n4 n5      # Beam
Splitter

const T_ITM 7e-3 # 7000ppm transmission from ET book
const T_ETM 0E-6 # 6ppm transmission from ET book

s sNin  1           n3 n6
m1 IMN $T_ITM 0 0   n6 n7
s sNarm 10000       n7 n8
m1 EMN $T_ETM 0 180 n8 dump

s sWin  1           n4 n9
m1 IMW $T_ITM 0 0   n9 n10
s sWarm 10000       n10 n11
m1 EMW $T_ETM 0 180 n11 dump
```

```
# Computing the signal for horizontal misalignment
# i.e. a Theta y motion
pd1 Q71 $fMI -10 nQ71
pdtype Q71 y-split
pd1 Q72 $fMI -3 nQ72
pdtype Q72 y-split

# i.e. a The
#pd1 Q71 $fM
#pdtype Q71 y-split
#pd1 Q72 $fMI -3 nQ72
#pdtype Q72 y-split

# Power on one of the quadrants
pd  Q71DC nQ71
scale 0.003 Q71DC

#misalign NE either horizontally (xbeta) or vertically (ybeta)
xaxis MNE xbeta lin -10u 10u 200
#xaxis MNE ybeta lin -10u 10u 200

cav NC MNI nMNI2 MNE nMNE1
maxtem 12

yaxis lin abs
pause
gnuterm x11
```

```
m MNE 0.9999 50u 0 nMNE1 nMNEi1   # primary su
s sMNE .096 1.44963 nMNEi1 nMNEi2 # fused silica
m MNEAR 0 1 0 nMNEi2 nMNE2       # secondary su
attr MNE Rc 3530               # tuned radius of curvat
#attr MNE xbeta -.3u            # some arbritrary mis-

######################### NORTH BENCH ########

# L1 first large lens after NE
s sN1 1.7 nMNE2 nL1
lens L1 1.02 nL1 nL2

# L2 and L3, small lenses after L1
s sN2 .89 nL2 nL3
lens L2 -.2 nL3 nL4
s sN4 .2146 nL4 nL5

s sN5 .365 nL6 nL7

# beam split into 50% going to B7 and 50% going to
bs M71 .5 .5 0 0 nL7 nL8 nB7 dump
s sB7 0.97 nB7 noutB7

# beam split again 50/50, for Q71 and Q72
s sN6 .305 nL8 nL9
bs M72 .5 .5 0 0 nL9 nL10 nL11 dump

# lens L4a and Q71
s sN7 .10 nL10 nL12
lens L4a -.1 nL12 nL13
s sN8 .759 nL13 nQ71

# lens L4b Q72
s sN9 .286 nL11 nL15
lens L4b -.1 nL15 nL16
```

Motivations behind FINESSE…

- Analytic solutions to the optics get complicated!

- Many physical effects at work and we want to model them
  - Features for the near future in FINESSE…
    - Radiation pressure effects
    - Quantum noise

- We want reliable, tested and documented code

- Need a **quick** way to **understand** and **experiment** with optical systems – not something that you leave running for days on end on a supercomputer

FINESSE: Frequency domain INterfErometer Simulation SotfwarE

- Started by Andreas Freise during his PhD
- Used extensively worldwide - http://www.gwoptics.org/finesse/impact.php
- Open sourced in 2012 - http://kvasir.sr.bham.ac.uk/redmine/projects/finesse
- Ten Simple Rules for the Open Development of Scientific Software http://www.ploscompbiol.org/article/info%3Adoi%2F10.1371%2Fjournal.pcbi.1002802

Rule 1: Don't Reinvent the Wheel

Rule 2: Code Well

Rule 3: Be Your Own User

Rule 4: Be Transparent

Rule 5: Be Simple

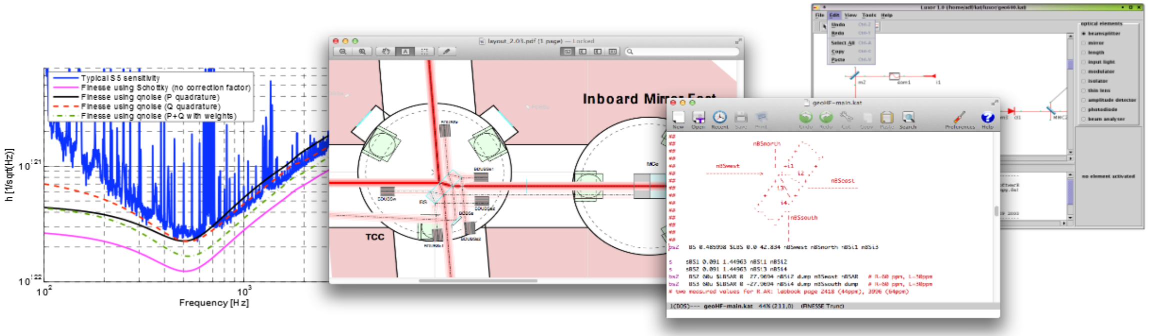
Rule 6: Don't Be a Perfectionist

Rule 7: Nurture and Grow Your Community

Rule 8: Promote Your Project

Rule 9: Find Sponsors

Rule 10: Science Counts


Typical S5 sensitivity
Finesse using Schottky (no correction factor)
Finesse using qnoise (P quadrature)
Finesse using qnoise (Q quadrature)
Finesse using qnoise (P+Q with weights)
h [1/sqrt(Hz)]
10^{-21}
10^{-22}
10^2
10^3
Frequency [Hz]
Inboard Mirror East
TCC

FINESSE: What does it do?

```
%% INTERFEROMETER COMPONENTS

l L0 1 0 n1
s s0  1 n1 nbsp1
bs BSP 0.01 0.99 0 45 nbsp1 dump nbsp3 dump

s s01 1 nbsp3 n2

bs BS0 0.5 0.5 59.6 45 n2 n3 n4 n5         # Beam
Splitter

const T_ITM 7e-3 # 7000ppm transmission from ET book
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s sNin  1           n3 n6
m1 IMN $T_ITM 0 0   n6 n7
s sNarm 10000       n7 n8
m1 EMN $T_ETM 0 180 n8 dump

s sWin  1           n4 n9
m1 IMW $T_ITM 0 0   n9 n10
s sWarm 10000       n10 n11
m1 EMW $T_ETM 0 180 n11 dump
```
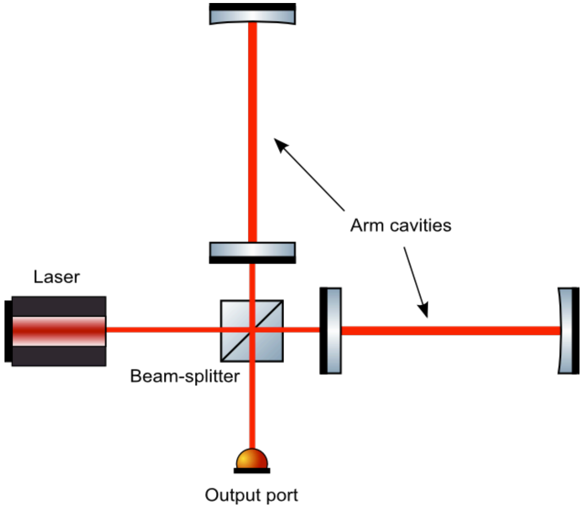
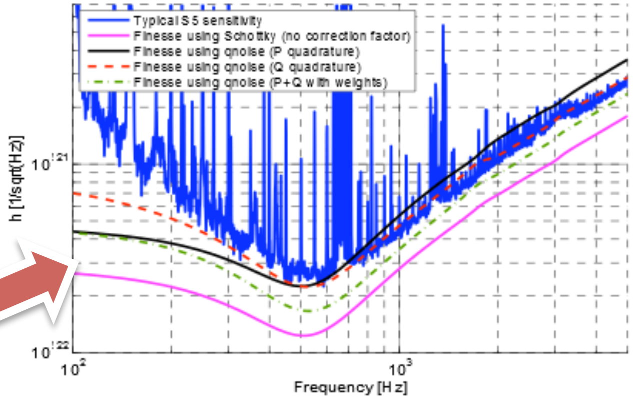
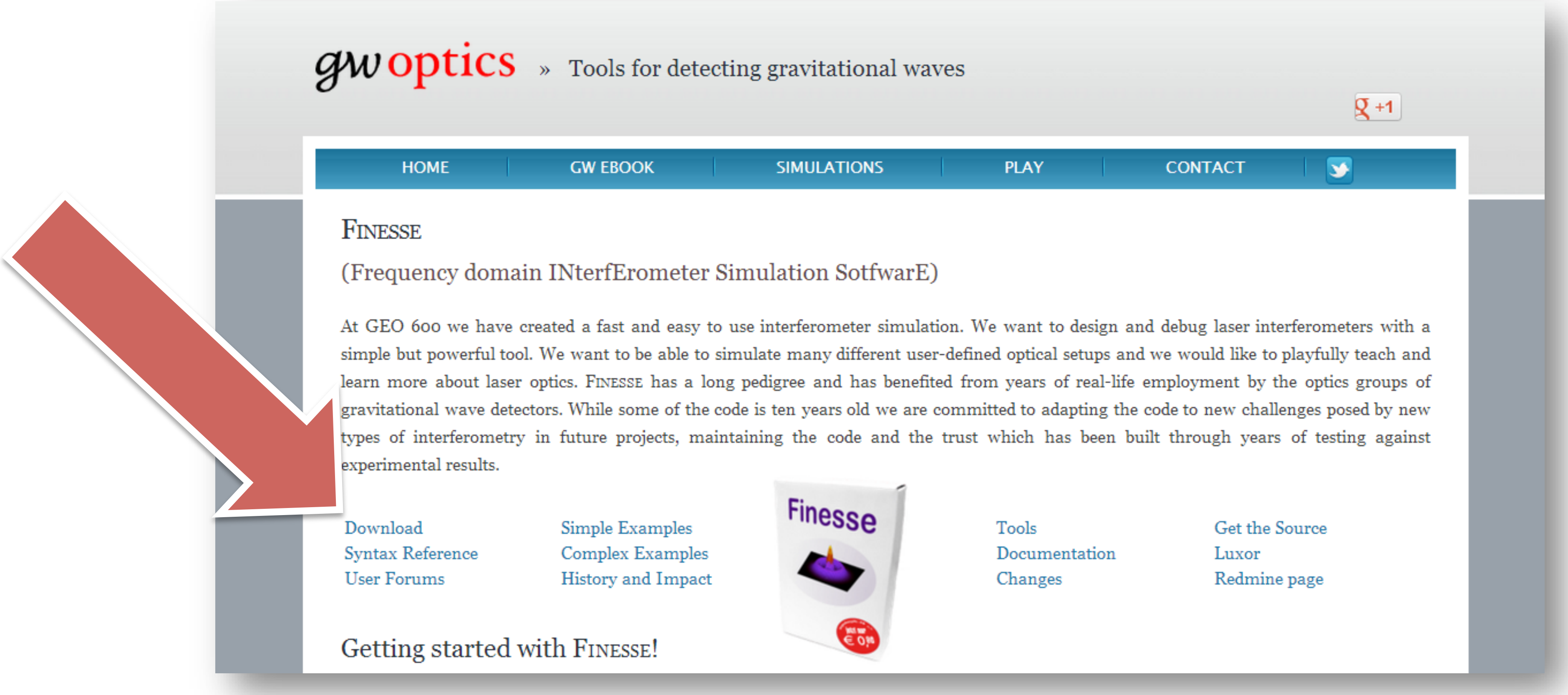





FINESSE: How do I get it?

- Go to www.gwoptics.org/finesse

- Versions available for Windows, Linux and Mac OSX



FINESSE

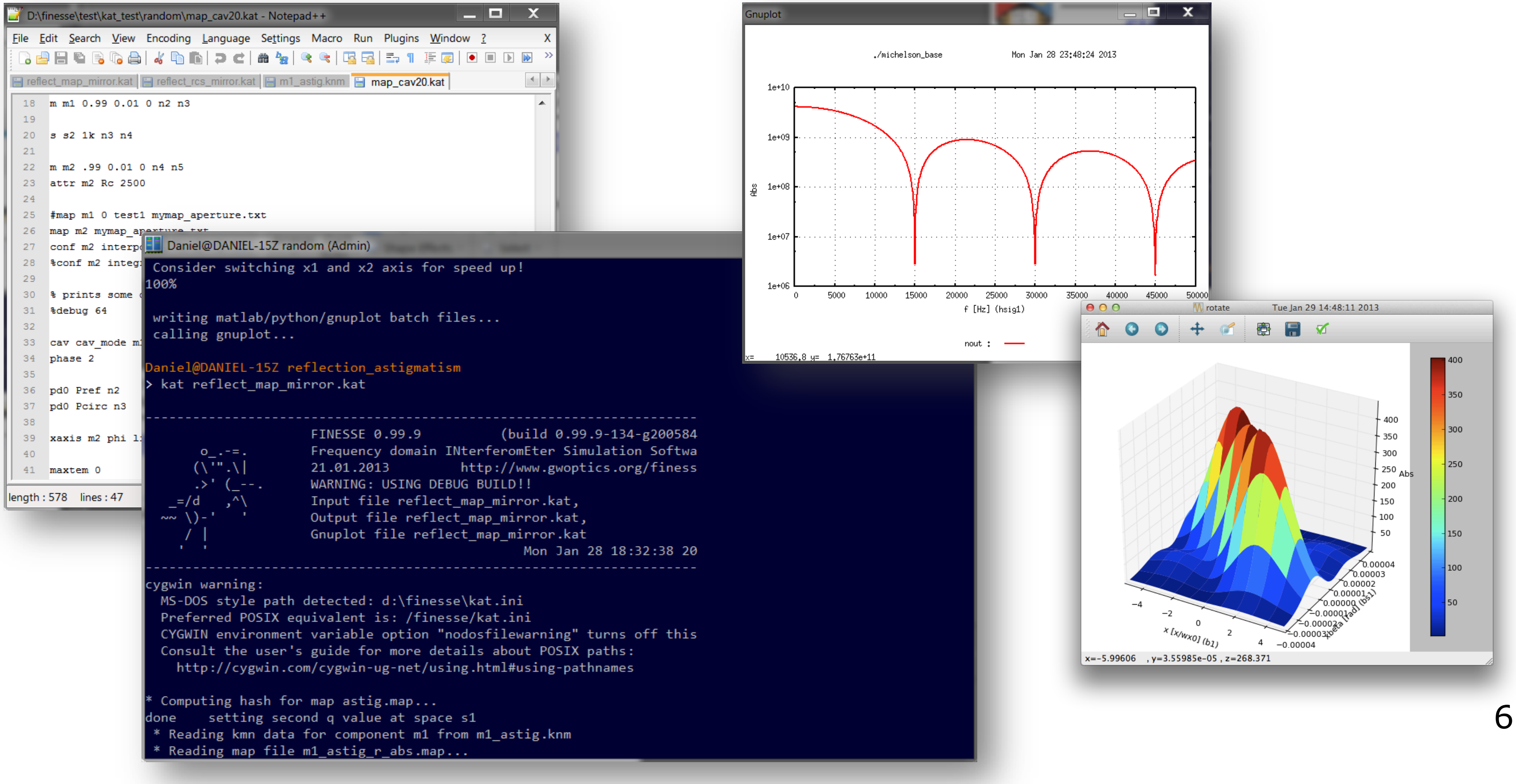
(Frequency domain INterfErometer Simulation SotfwarE)

At GEO 600 we have created a fast and easy to use interferometer simulation. We want to design and debug laser interferometers with a simple but powerful tool. We want to be able to simulate many different user-defined optical setups and we would like to playfully teach and learn more about laser optics. FINESSE has a long pedigree and has benefited from years of real-life employment by the optics groups of gravitational wave detectors. While some of the code is ten years old we are committed to adapting the code to new challenges posed by new types of interferometry in future projects, maintaining the code and the trust which has been built through years of testing against experimental results.

Getting started with FINESSE!

FINESSE: How do I use it?

- Text based scripts with command line interaction
- Produces plots in gnuplot, matlab and python matplotlib



D:\finesse\test\kat_test\random\map_cav20.kat - Notepad++
File Edit Search View Encoding Language Settings Macro Run Plugins Window ?
reflect_map_mirror.kat
reflect_rcs_mirror.kat
m1_astig.knm
map_cav20.kat
length : 578 lines : 47

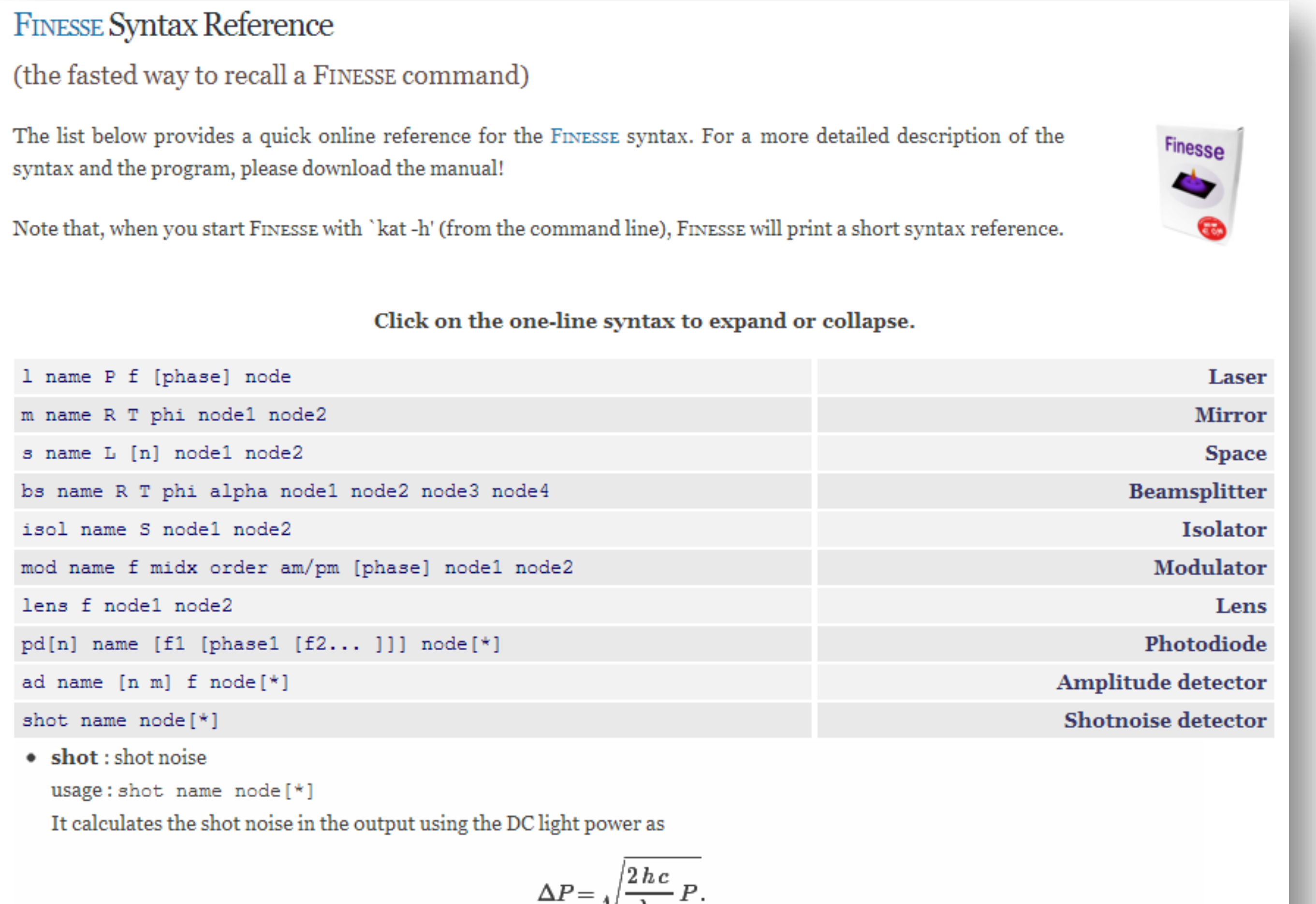
```
m m1 0.99 0.01 0 n2 n3

s s2 1k n3 n4

m m2 .99 0.01 0 n4 n5
attr m2 Rc 2500

#map m1 0 test1 mymap_aperture.txt
map m2 mymap_ap
conf m2 interp
%conf m2 integ

% prints some
%debug 64

cav cav_mode m
phase 2

pd0 Pref n2
pd0 Pcirc n3

xaxis m2 phi l

maxtem 0
```

Daniel@DANIEL-15Z random (Admin)

```
 Consider switching x1 and x2 axis for speed up!
100%

 writing matlab/python/gnuplot batch files...
 calling gnuplot...

Daniel@DANIEL-15Z reflection_astigmatism
> kat reflect_map_mirror.kat

----------------------------------------------------------------------
                     FINESSE 0.99.9          (build 0.99.9-134-g200584
      o_.-=.         Frequency domain INterferomEter Simulation Softwa
     (\'".\|         21.01.2013          http://www.gwoptics.org/finess
     .>' (_--.       WARNING: USING DEBUG BUILD!!
  _=/d    ,^\        Input file reflect_map_mirror.kat,
 ~~ \)-'   '         Output file reflect_map_mirror.kat,
    / |              Gnuplot file reflect_map_mirror.kat
    '  '                                   Mon Jan 28 18:32:38 20
----------------------------------------------------------------------
cygwin warning:
  MS-DOS style path detected: d:\finesse\kat.ini
  Preferred POSIX equivalent is: /finesse/kat.ini
  CYGWIN environment variable option "nodosfilewarning" turns off this
  Consult the user's guide for more details about POSIX paths:
    http://cygwin.com/cygwin-ug-net/using.html#using-pathnames

* Computing hash for map astig.map...
done    setting second q value at space s1
 * Reading kmn data for component m1 from m1_astig.knm
 * Reading map file m1_astig_r_abs.map...
```

FINESSE: How do I use it?

- 180 page manual full of worked examples and useful information
- Script quick reference http://www.gwoptics.org/finesse/reference/
- We also have a forum for questions at kvasir.sr.bham.ac.uk/redmine/projects/finesse



FINESSE Syntax Reference

(the fasted way to recall a FINESSE command)

The list below provides a quick online reference for the FINESSE syntax. For a more detailed description of the syntax and the program, please download the manual!

Note that, when you start FINESSE with `kat -h' (from the command line), FINESSE will print a short syntax reference.

Click on the one-line syntax to expand or collapse.

`l name P f [phase] node`	**Laser**
`m name R T phi node1 node2`	**Mirror**
`s name L [n] node1 node2`	**Space**
`bs name R T phi alpha node1 node2 node3 node4`	**Beamsplitter**
`isol name S node1 node2`	**Isolator**
`mod name f midx order am/pm [phase] node1 node2`	**Modulator**
`lens f node1 node2`	**Lens**
`pd[n] name [f1 [phase1 [f2... ]]] node[*]`	**Photodiode**
`ad name [n m] f node[*]`	**Amplitude detector**
`shot name node[*]`	**Shotnoise detector**

- **shot** : shot noise

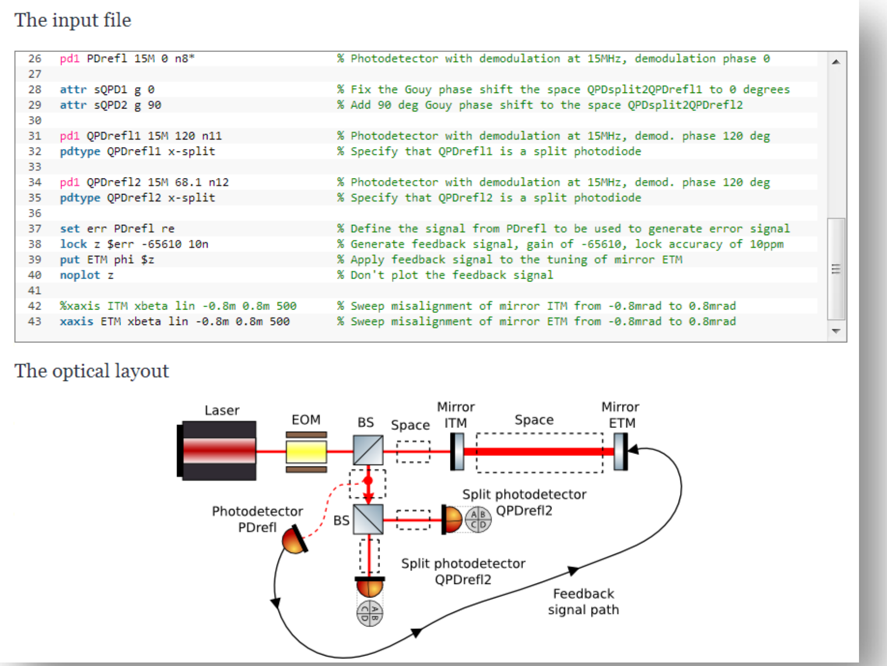
  usage : `shot name node[*]`

  It calculates the shot noise in the output using the DC light power as

$$\Delta P = \sqrt{\frac{2hc}{\lambda} P}.$$

FINESSE: What can I do with it?

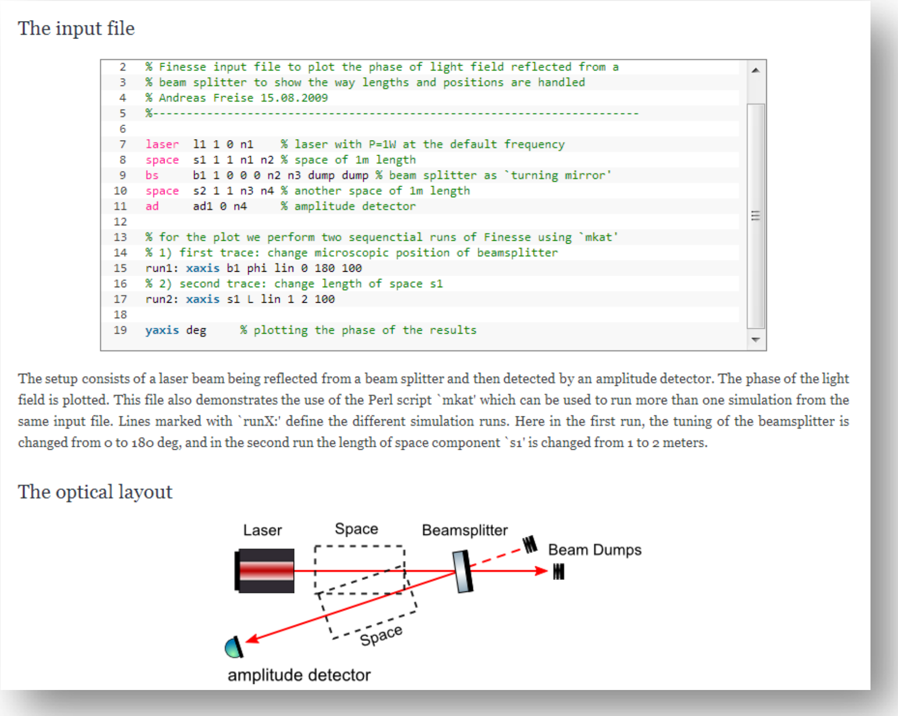
- Example scripts at www.gwoptics.org/finesse/examples
- Can pretty much tune every parameter
- Calculate transfer functions, error signals, alignment matrices, beam deformations, noise couplings…



The input file

```
pd1 PDrefl 15M 0 n8*                    % Photodetector with demodulation at 15MHz, demodulation phase 0

attr sQPD1 g 0                          % Fix the Gouy phase shift the space QPDsplit2QPDrefl1 to 0 degrees
attr sQPD2 g 90                         % Add 90 deg Gouy phase shift to the space QPDsplit2QPDrefl2

pd1 QPDrefl1 15M 120 n11                % Photodetector with demodulation at 15MHz, demod. phase 120 deg
pdtype QPDrefl1 x-split                 % Specify that QPDrefl1 is a split photodiode

pd1 QPDrefl2 15M 68.1 n12               % Photodetector with demodulation at 15MHz, demod. phase 120 deg
pdtype QPDrefl2 x-split                 % Specify that QPDrefl2 is a split photodiode

set err PDrefl re                       % Define the signal from PDrefl to be used to generate error signal
lock z $err -65610 10n                  % Generate feedback signal, gain of -65610, lock accuracy of 10ppm
put ETM phi $z                          % Apply feedback signal to the tuning of mirror ETM
noplot z                                % Don't plot the feedback signal

%xaxis ITM xbeta lin -0.8m 0.8m 500     % Sweep misalignment of mirror ITM from -0.8mrad to 0.8mrad
xaxis ETM xbeta lin -0.8m 0.8m 500      % Sweep misalignment of mirror ETM from -0.8mrad to 0.8mrad
```

The optical layout



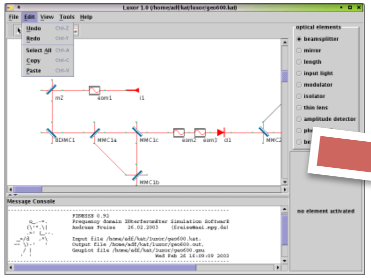
The input file

```
% Finesse input file to plot the phase of light field reflected from a
% beam splitter to show the way lengths and positions are handled
% Andreas Freise 15.08.2009
%----------------------------------------------------------------------

laser  l1 1 0 n1    % laser with P=1W at the default frequency
space  s1 1 1 n1 n2 % space of 1m length
bs     b1 1 0 0 0 n2 n3 dump dump % beam splitter as `turning mirror'
space  s2 1 1 n3 n4 % another space of 1m length
ad     ad1 0 n4     % amplitude detector

% for the plot we perform two sequenctial runs of Finesse using `mkat'
% 1) first trace: change microscopic position of beamsplitter
run1: xaxis b1 phi lin 0 180 100
% 2) second trace: change length of space s1
run2: xaxis s1 L lin 1 2 100

yaxis deg     % plotting the phase of the results
```

The setup consists of a laser beam being reflected from a beam splitter and then detected by an amplitude detector. The phase of the light field is plotted. This file also demonstrates the use of the Perl script `mkat' which can be used to run more than one simulation from the same input file. Lines marked with `runX:' define the different simulation runs. Here in the first run, the tuning of the beamsplitter is changed from 0 to 180 deg, and in the second run the length of space component `s1' is changed from 1 to 2 meters.

The optical layout

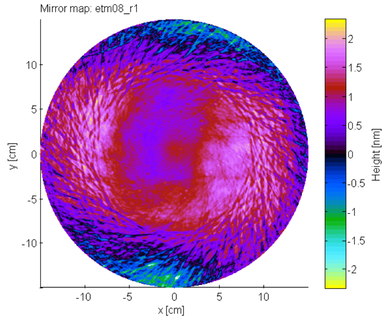
FINESSE: Ecosystem



```
FINESSE 0.92
Frequency domain INterferomEter Simulation SoftwarE
Andreas Freise    26.02.2003    (Freise@aei.mpg.de)

Input file /home/adf/kat/luxor/geo600.kat,
Output file /home/adf/kat/luxor/geo600.out,
Gnuplot file /home/adf/kat/luxor/geo600.gnu
                              Wed Feb 26 16:09:09 2003
```

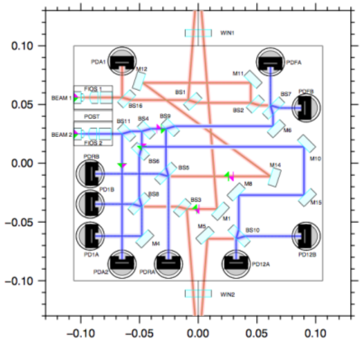
Luxor

www.gwoptics.org/finesse/luxor.php



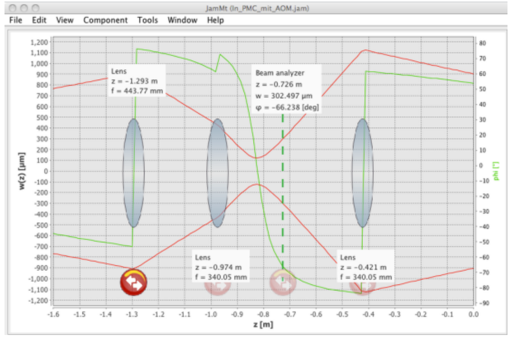
SimTools

www.gwoptics.org/simtools/



OptoCad

http://home.rzg.mpg.de/~ros/



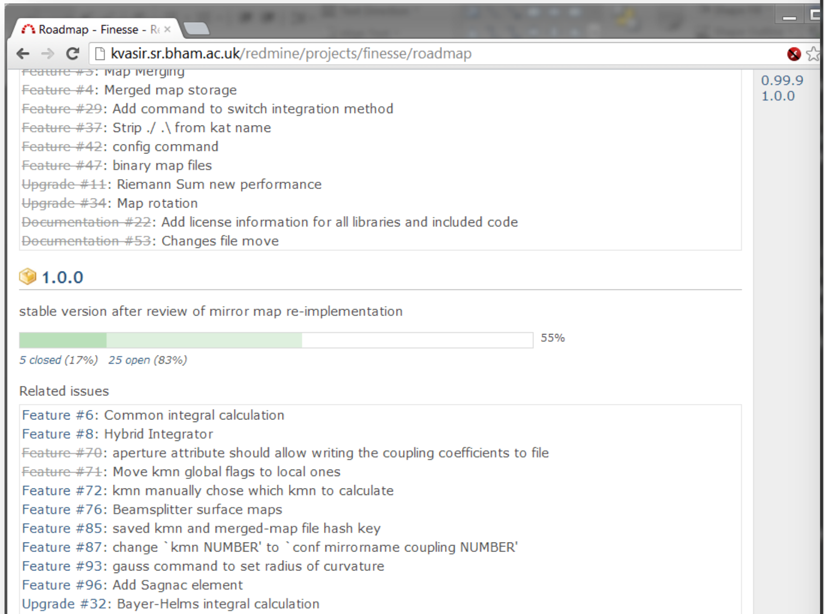
JamMT

http://www.sr.bham.ac.uk/dokuwiki/doku.php?id=geosim:jammt

UNIVERSITY OF BIRMINGHAM

FINESSE: How can I get involved?

- Completely open source -> kvasir.sr.bham.ac.uk/redmine/projects/finesse
- Can browse the code and the very latest updates / fixes / features
- A forum is also available that you can ask questions or suggest features
  - *We like hearing from users!*
- Instructions for download source in wiki



~~Feature #3~~: Map Merging
~~Feature #4~~: Merged map storage
~~Feature #29~~: Add command to switch integration method
~~Feature #37~~: Strip ./ .\ from kat name
~~Feature #42~~: config command
~~Feature #47~~: binary map files
~~Upgrade #11~~: Riemann Sum new performance
~~Upgrade #34~~: Map rotation
~~Documentation #22~~: Add license information for all libraries and included code
~~Documentation #53~~: Changes file move

1.0.0

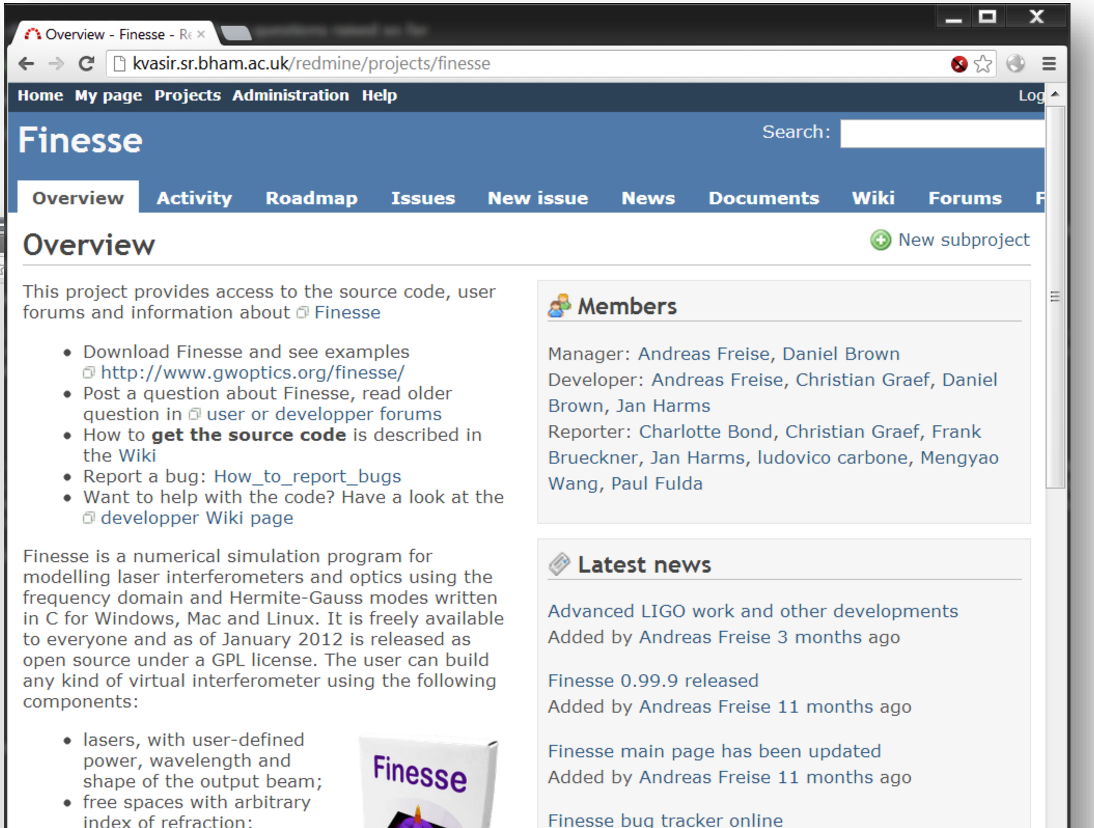
stable version after review of mirror map re-implementation

55%

5 closed (17%)   25 open (83%)

Related issues

Feature #6: Common integral calculation
Feature #8: Hybrid Integrator
~~Feature #70~~: aperture attribute should allow writing the coupling coefficients to file
~~Feature #71~~: Move kmn global flags to local ones
Feature #72: kmn manually chose which kmn to calculate
Feature #76: Beamsplitter surface maps
Feature #85: saved kmn and merged-map file hash key
Feature #87: change `kmn NUMBER' to `conf mirrorname coupling NUMBER'
Feature #93: gauss command to set radius of curvature
Feature #96: Add Sagnac element
Upgrade #32: Bayer-Helms integral calculation



Overview

This project provides access to the source code, user forums and information about Finesse

- Download Finesse and see examples http://www.gwoptics.org/finesse/
- Post a question about Finesse, read older question in user or developper forums
- How to **get the source code** is described in the Wiki
- Report a bug: How_to_report_bugs
- Want to help with the code? Have a look at the developper Wiki page

Finesse is a numerical simulation program for modelling laser interferometers and optics using the frequency domain and Hermite-Gauss modes written in C for Windows, Mac and Linux. It is freely available to everyone and as of January 2012 is released as open source under a GPL license. The user can build any kind of virtual interferometer using the following components:

- lasers, with user-defined power, wavelength and shape of the output beam;
- free spaces with arbitrary index of refraction;

Members

Manager: Andreas Freise, Daniel Brown
Developer: Andreas Freise, Christian Graef, Daniel Brown, Jan Harms
Reporter: Charlotte Bond, Christian Graef, Frank Brueckner, Jan Harms, ludovico carbone, Mengyao Wang, Paul Fulda

Latest news

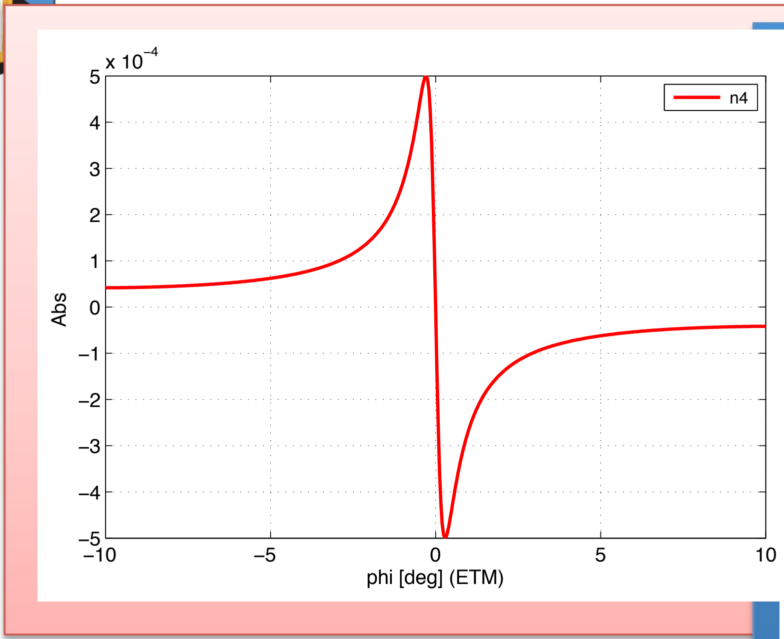
Advanced LIGO work and other developments
Added by Andreas Freise 3 months ago

Finesse 0.99.9 released
Added by Andreas Freise 11 months ago

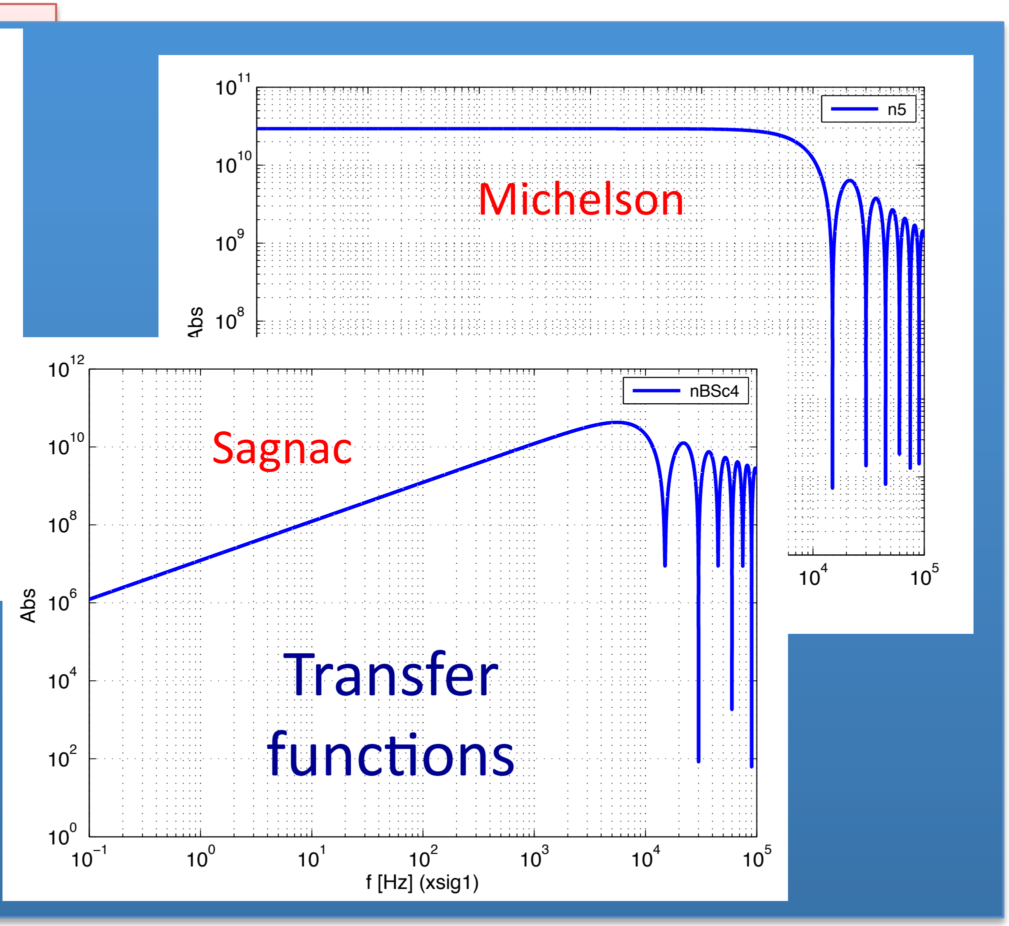
Finesse main page has been updated
Added by Andreas Freise 11 months ago

Finesse bug tracker online

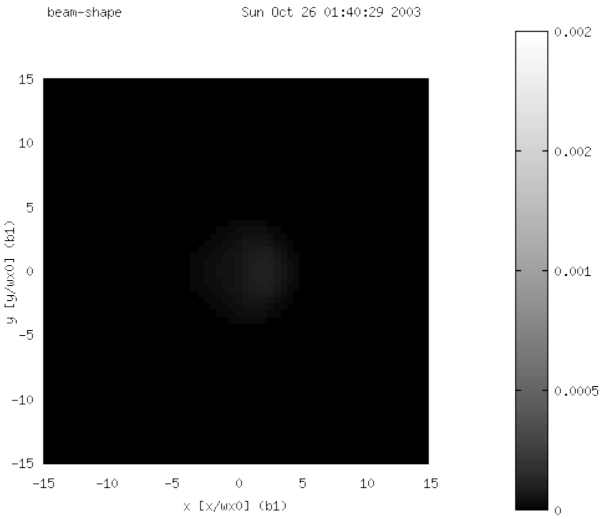
…and now a tutorial on FINESSE



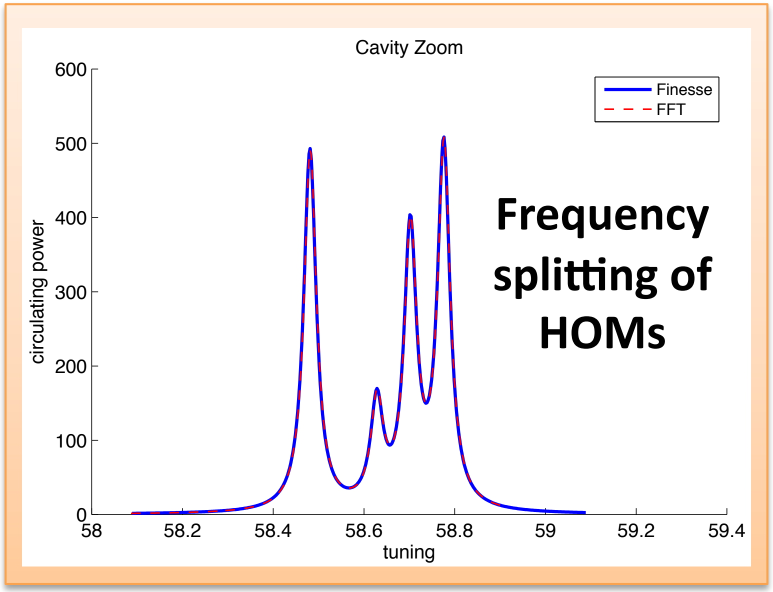
Error signals



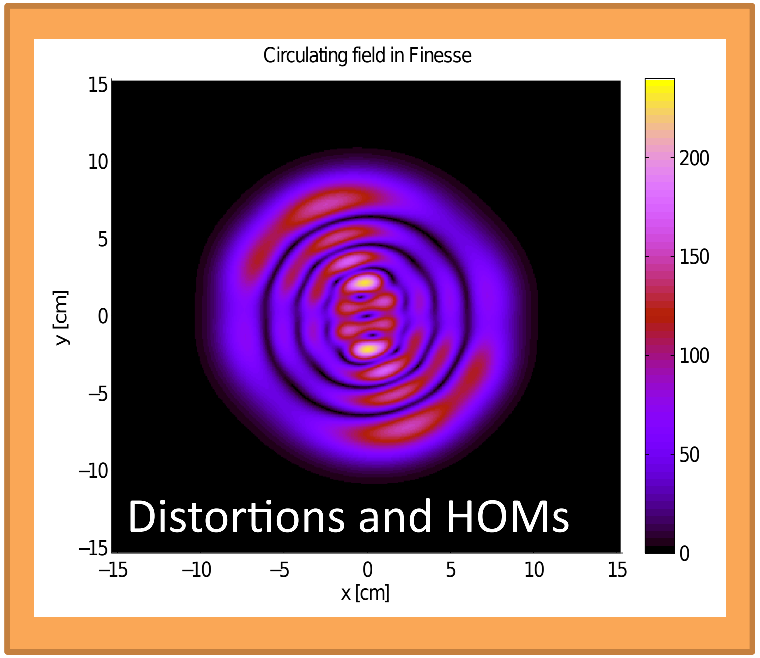
Transfer functions



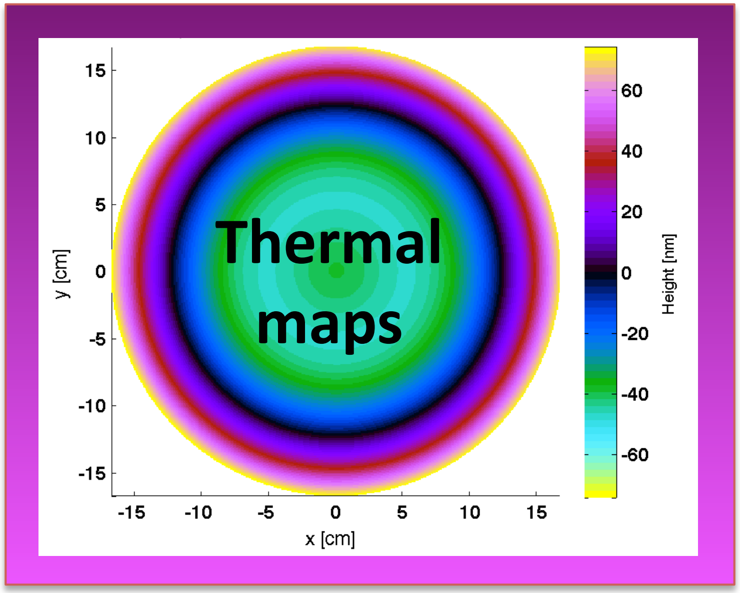
Distortion modeling



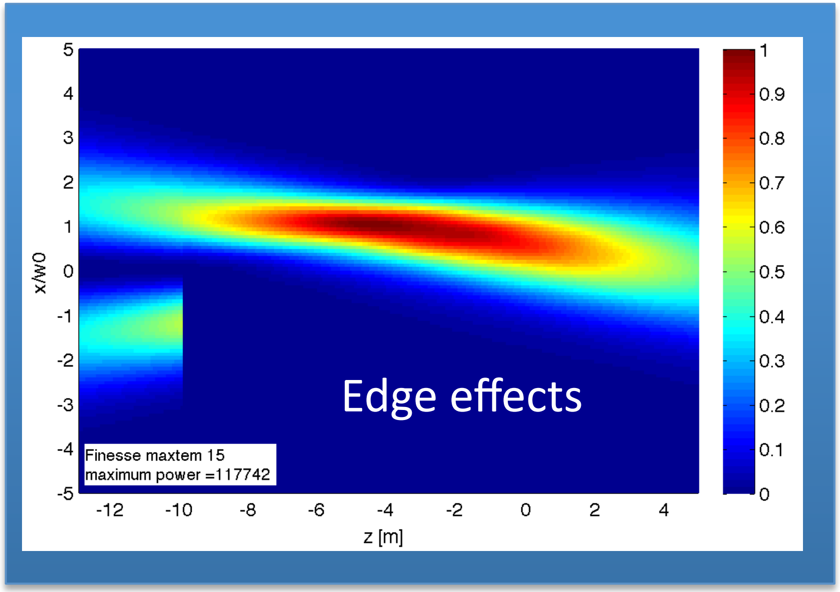
Frequency splitting of HOMs



Distortions and HOMs



Thermal maps



Edge effects

FINESSE: What's the proper reference?

The best way to reference FINESSE (e.g. in a paper) is by citing

A Freise and G Heinzel and H Luck and R Schilling and B Willke and K Danzmann
Frequency-domain interferometer simulation with higher-order spatial modes
Classical and Quantum Gravity, 2004

…and our website http://www.gwoptics.org/finesse

Thanks!

SIMTOOLS!

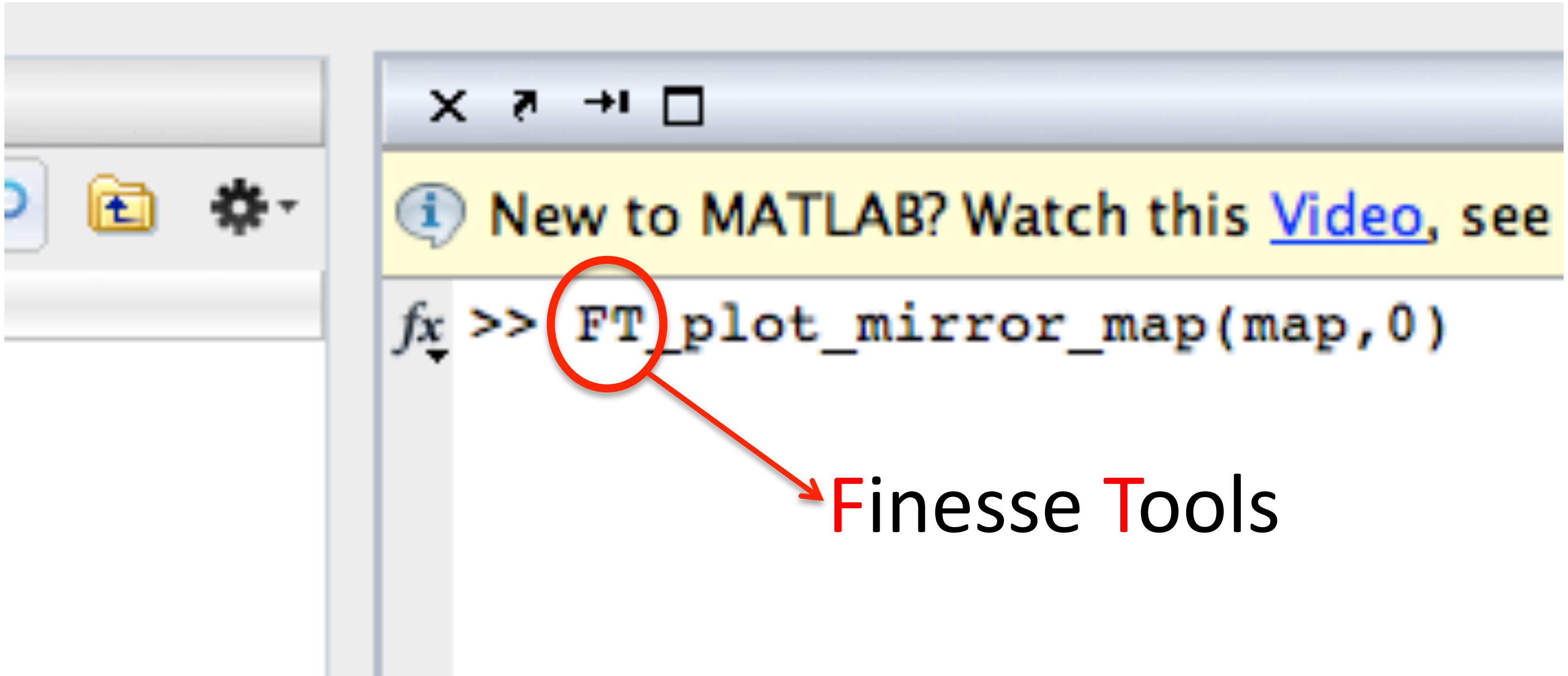
Charlotte Bond, Daniel Brown and Andreas Freise

- FT_function_template
- FT_help
- FT_ABCD_lens
- FT_ABCD_mirror
- FT_ABCD_space
- FT_ABCD_trace_beam
- FT_cavity_ABCD_to_q
- FT_check_cavity_ABCD
- - FT_invert_ABCD
- FT_multiply_ABCDs
- FT_q_ABCD_q
- FT_HermitePoly
- FT_FFT_cavity_scan
- FT_FFT_lens
- FT_FFT_mirror
- FT_FFT_plot_field
- FT_FFT_precompute_roundtrips
- FT_FFT_propagate
- FT_FFT_reorganise_tmp_files
- FT_FFT_required_cavity_roundtrips
- FT_FFT_required_scan_accuracy
- FT_FFT_results_buildup
- FT_FFT_results_cavity_fields
- FT_FFT_scan_range
- FT_hanning_window2D
- FT_init_grid
- FT_tilt_map
- FTE_FFT_premodecleaner
- FTE_FFT_results_premodecleaner
- FT_check_for_kat_binary
- FT_convert_finesse_4D
- FT_create_new_FT
- FT_create_new_kat_run
- FT_init_Finesse
- FT_kat_clean
- FT_make_finesse_video
- FT_min_max

- FT_prepare_kat_filename
- FT_run_kat_simulation
- FT_save_finesse_map
- FT_set_kat_filenames
- FTE_finesse_01
- FTE_finesse_02
- FTE_finesse_03
- FTE_finesse_04
- FTE_finesse_ad_nm
- FTE_finesse_ccd
- FT_add_line_to_block
- FT_comment_block
- FT_comment_lines_in_block
- FT_copy_block
- FT_copy_lines_block_to_block
- FT_create_new_block
- FT_find_element_in_active_block
- FT_find_element_in_all_blocks
- FT_find_element_in_block
- FT_find_text_in_active_block
- FT_find_text_in_all_blocks
- FT_find_text_in_block
- FT_index_of_block
- FT_list_block_names
- FT_print_block
- FT_read_blocks_from_file
- FT_read_kat_constant
- FT_remove_comment_char_in_block
- FT_remove_lines_from_block
- FT_search_string_for_block_commands
- FT_uncomment_block
- FT_uncomment_lines_in_block
- FT_write_blocks_into_file
- FT_write_kat_constant
- FT_read_kat_output_data
- FT_read_kat_output_header
- FT_CON_field

- FT_conv_fields
- FT_gauss_coefficients_to_field
- FT_get_mode_coefficient
- FT_HG_field
- FT_init_gauss_coefficients
- FT_init_gauss_param
- FT_LG_cos_field
- FT_LG_field
- FT_mode_coefficients_to_field
- FT_new_mode_coefficients
- FT_power_in_field
- FT_q_to_Psi
- FT_q_to_Rc
- FT_q_to_w
- FT_q_to_w0z
- FT_q_to_zr
- FT_Rcw_to_w0z
- FT_SG_field
- FT_ulp
- FT_ulp_cos
- FT_un
- FT_unm
- FT_update_gauss_param
- FT_clipping_loss_LG
- FT_fit_beam_size
- FT_fit_GaussBeam
- FT_fit_GaussBeam_intensity
- FT_fit_LG
- FT_fit_LG_cos
- FT_guess_center_LG
- FT_guess_size_LG
- FT_lg2hg
- FT_mode_content
- FT_print_gauss_coefficients
- FT_print_gauss_coefficients_to_file
- FT_print_mode_coefficients
- FT_set_mode_coefficient

- Simtools?
  - Matlab functions and scripts developed for FINESSE.
  - Extensive collection and growing!
  - From simple tools (e.g. calculating gauss parameter) to functions to run FINESSE from Matlab.



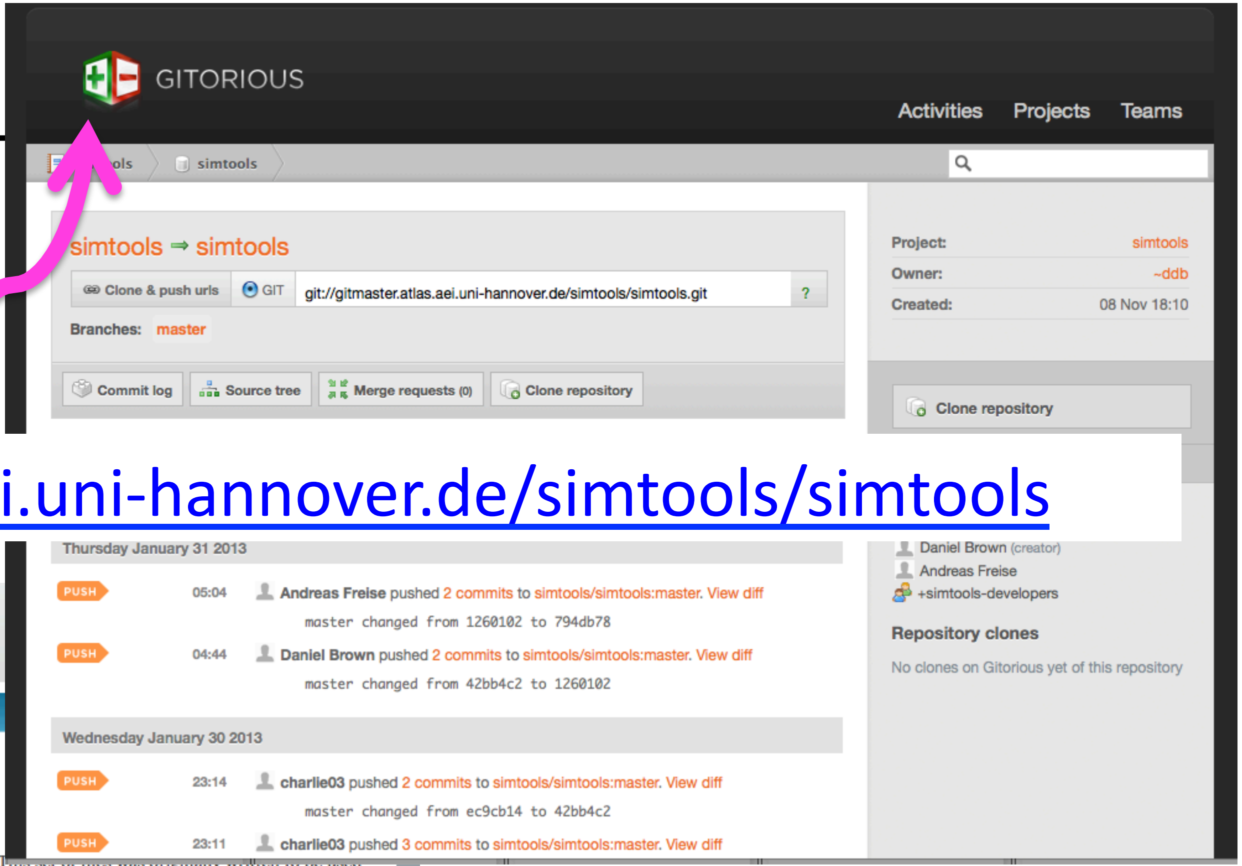
New to MATLAB? Watch this Video, see

```
>> FT_plot_mirror_map(map,0)
```

Finesse Tools

UNIVERSITY OF BIRMINGHAM

Up-to-date version: git repository



GITORIOUS

Activities Projects Teams

ols › simtools

simtools ⇒ simtools

Clone & push urls | GIT | git://gitmaster.atlas.aei.uni-hannover.de/simtools/simtools.git ?

Branches: master

Commit log | Source tree | Merge requests (0) | Clone repository

Project:	simtools
Owner:	~ddb
Created:	08 Nov 18:10

Clone repository

Thursday January 31 2013

PUSH 05:04 Andreas Freise pushed 2 commits to simtools/simtools:master. View diff
master changed from 1260102 to 794db78

PUSH 04:44 Daniel Brown pushed 2 commits to simtools/simtools:master. View diff
master changed from 42bb4c2 to 1260102

Wednesday January 30 2013

PUSH 23:14 charlie03 pushed 2 commits to simtools/simtools:master. View diff
master changed from ec9cb14 to 42bb4c2

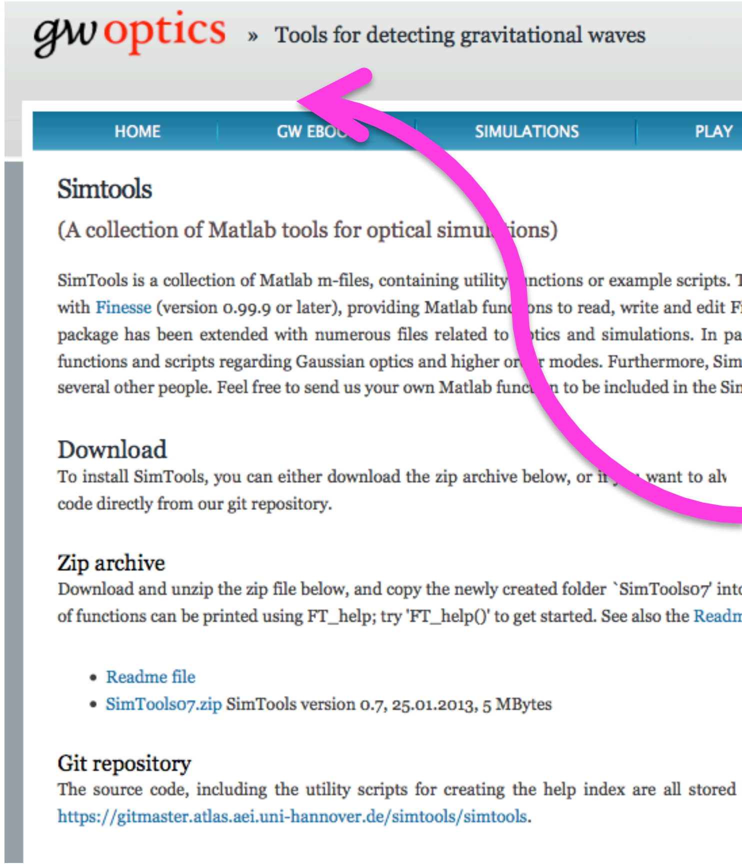
PUSH 23:11 charlie03 pushed 3 commits to simtools/simtools:master. View diff

Daniel Brown (creator)
Andreas Freise
+simtools-developers

Repository clones

No clones on Gitorious yet of this repository

https://gitmaster.atlas.aei.uni-hannover.de/simtools/simtools



gwoptics » Tools for detecting gravitational waves

HOME | GW EBOO | SIMULATIONS | PLAY

Simtools

(A collection of Matlab tools for optical simul ions)

SimTools is a collection of Matlab m-files, containing utility nctions or example scripts. This set of files was originally written to be used with Finesse (version 0.99.9 or later), providing Matlab fun ons to read, write and edit Finesse input files automatically. Since then, this package has been extended with numerous files related to ptics and simulations. In particular, it includes an extensive set of Matlab functions and scripts regarding Gaussian optics and higher or r modes. Furthermore, Simtools includes many contributed functions from several other people. Feel free to send us your own Matlab func n to be included in the Simtools package!

Download

To install SimTools, you can either download the zip archive below, or i want to alw code directly from our git repository.

Zip archive

Download and unzip the zip file below, and copy the newly created folder `SimTools07' into a directory which is in your Matlab path. A list of functions can be printed using FT_help; try 'FT_help()' to get started. See also the Readme file below for a list of the included functions.

- Readme file
- SimTools07.zip SimTools version 0.7, 25.01.2013, 5 MBytes

Git repository

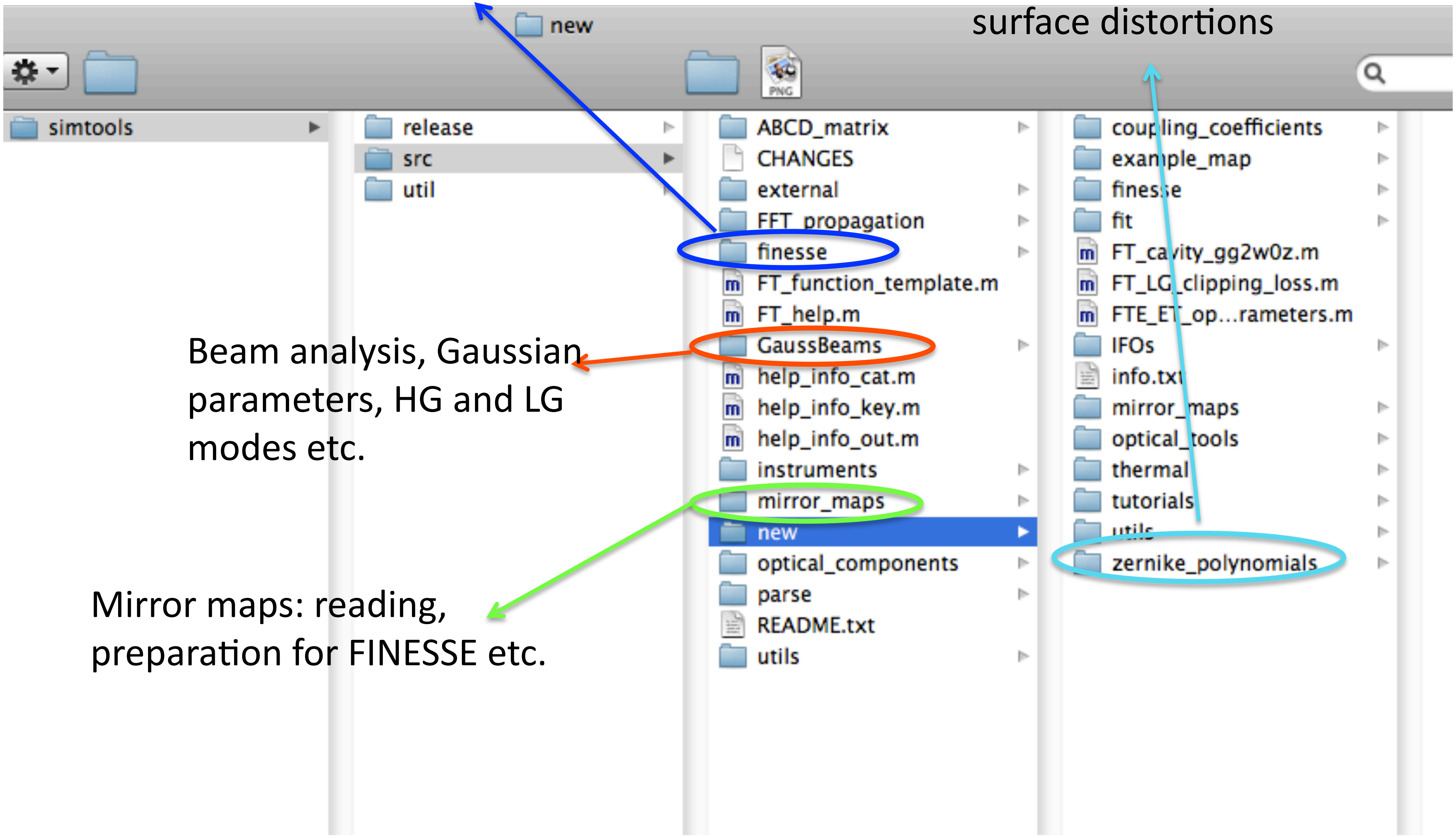
The source code, including the utility scripts for creating the help index are all stored in a git repository, which can be accessed at: https://gitmaster.atlas.aei.uni-hannover.de/simtools/simtools.

http://www.gwoptics.org/simtools/

Current release: Simtools07

Run FINESSE
through Matlab

Analysis of mirror
surface distortions



new

- simtools
  - release
  - src
  - util

- ABCD_matrix
- CHANGES
- external
- FFT_propagation
- finesse
- FT_function_template.m
- FT_help.m
- GaussBeams
- help_info_cat.m
- help_info_key.m
- help_info_out.m
- instruments
- mirror_maps
- new
- optical_components
- parse
- README.txt
- utils

- coupling_coefficients
- example_map
- finesse
- fit
- FT_cavity_gg2w0z.m
- FT_LG_clipping_loss.m
- FTE_ET_op...rameters.m
- IFOs
- info.txt
- mirror_maps
- optical_tools
- thermal
- tutorials
- utils
- zernike_polynomials

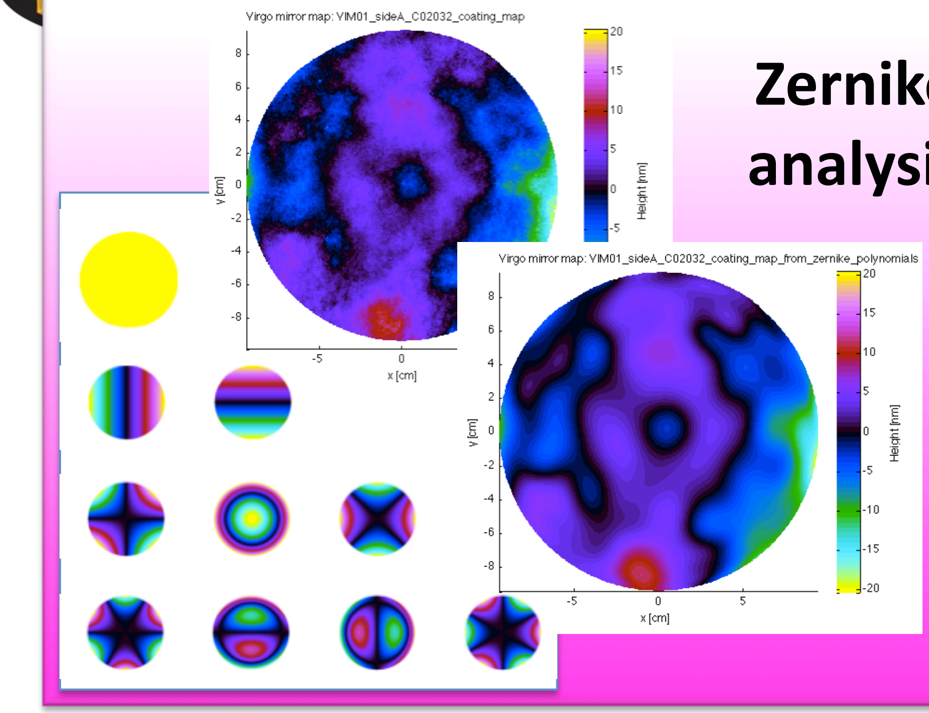
Beam analysis, Gaussian
parameters, HG and LG
modes etc.

Mirror maps: reading,
preparation for FINESSE etc.

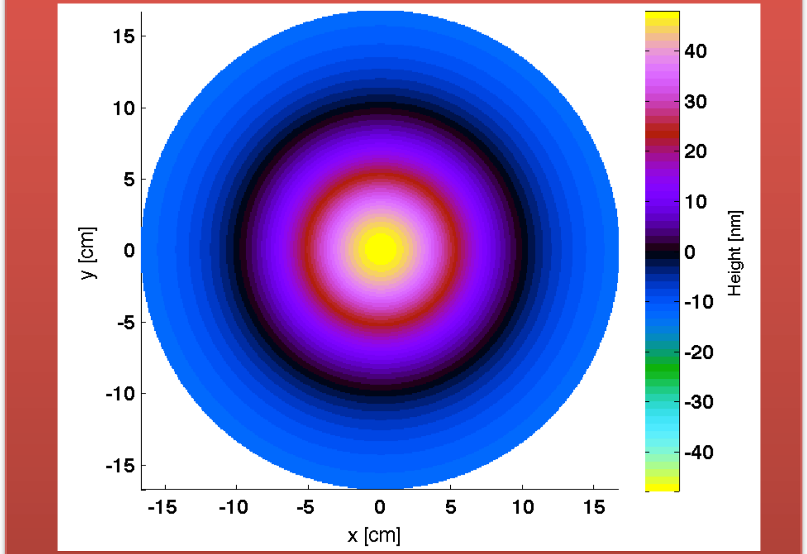
… let’s look at some examples

simtools/src/new/tutorials

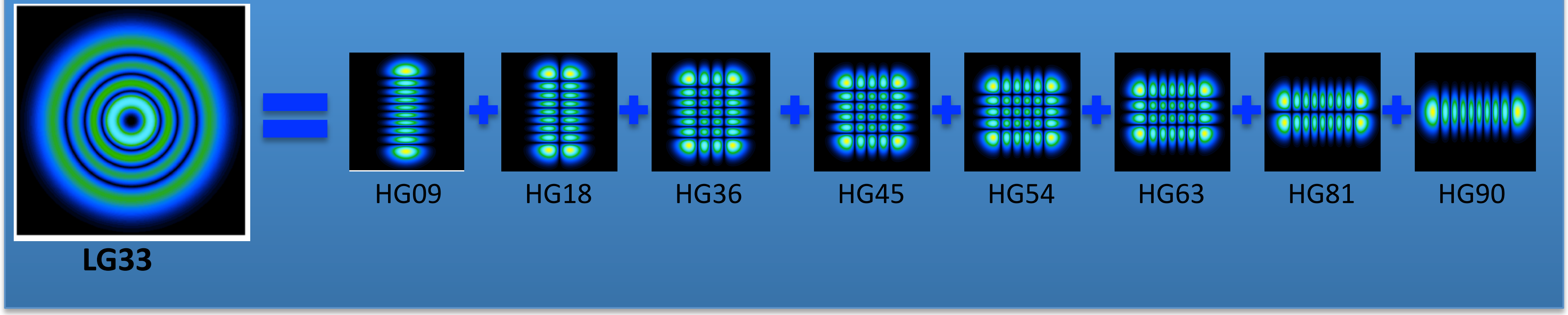
Zernike analysis



Thermal maps



LG modes as sum of HG modes for FINESSE



… get involved and write your own SIMTOOLS!