Noise Budgeting for Advanced Detectors

Christopher Wipf, MIT LIGO
for the aLIGO NoiseBudget team

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LIGO-G1400587

Overview

- Motivation:
  control model is essential

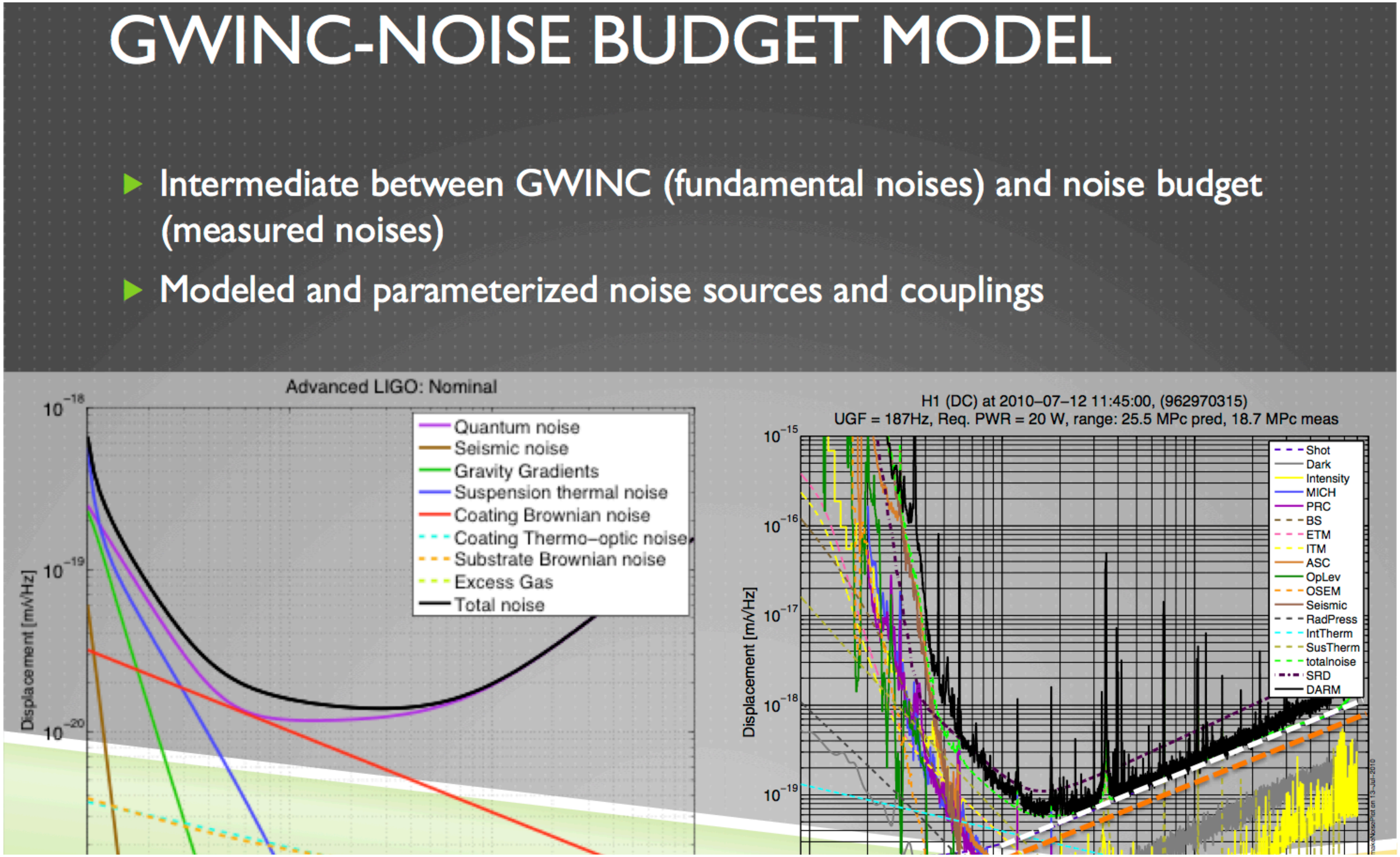
- Implementation:
  new toolbox for Simulink

- Examples:
  ALS and Full aLIGO noise budgets

- Summary

“Problems that we should solve...”

from Matt & Lisa @ GWADW 2013 in Elba

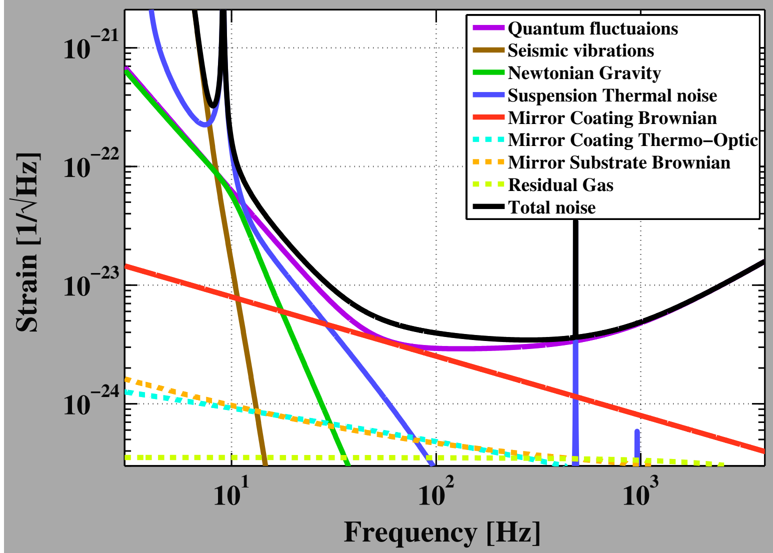


GWINC-NOISE BUDGET MODEL

- Intermediate between GWINC (fundamental noises) and noise budget (measured noises)
- Modeled and parameterized noise sources and couplings

How We Use Noise Budgets

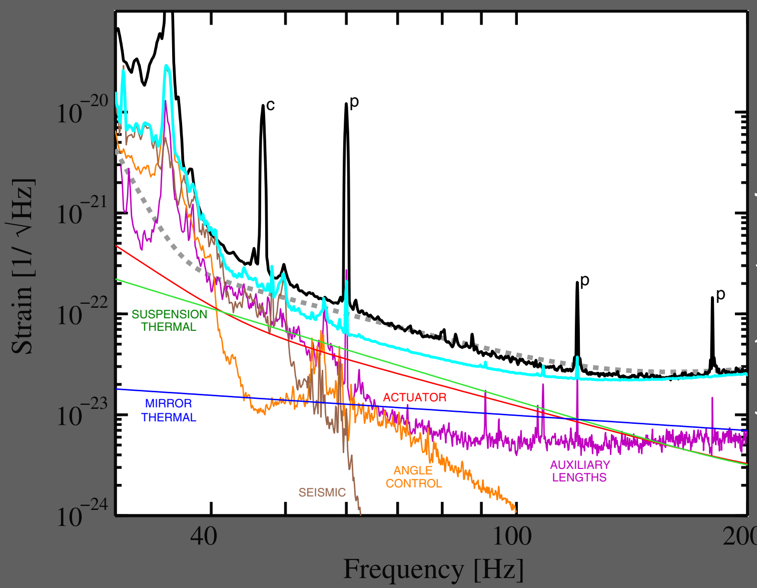
Theoretical Noise Budget



Rev. Mod. Phys. 86, 121 (2014)

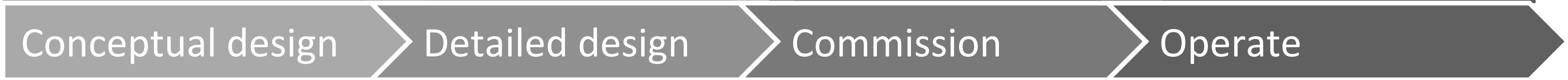
- Flexible modeling to explore the design parameter space
- Deal with fundamental noise limits only
- Establish sensitivity goals

Realistic Noise Budget



Rev. Mod. Phys. 86, 121 (2014)

- Mix of measurements and modeling; design is fixed
- Catalog all relevant noise terms in order to explain the observed noise
- Triage mechanism


Conceptual design

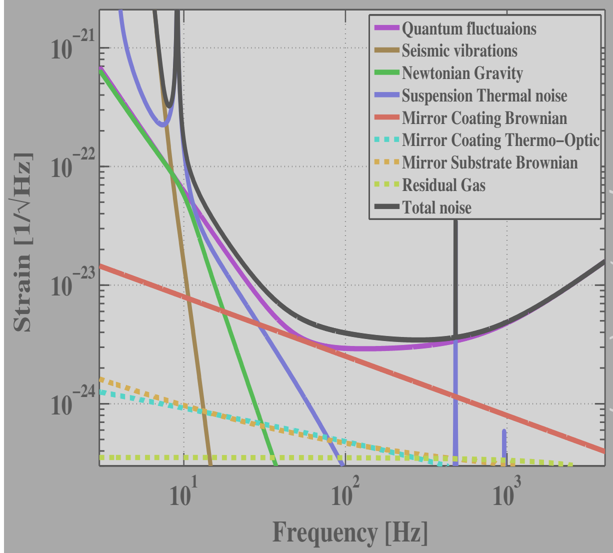
Detailed design

Commission

Operate

How We Use Noise Budgets

Theoretical Noise Budget



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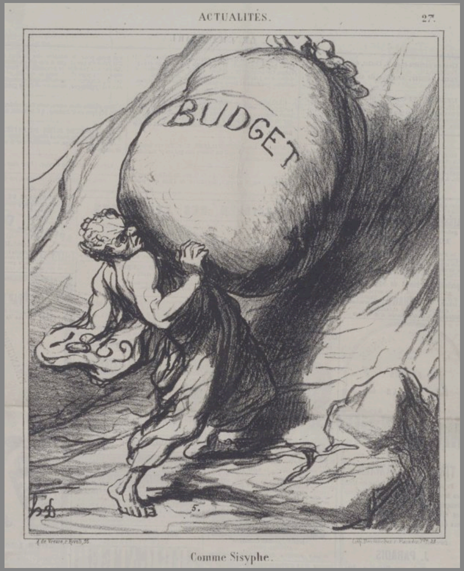
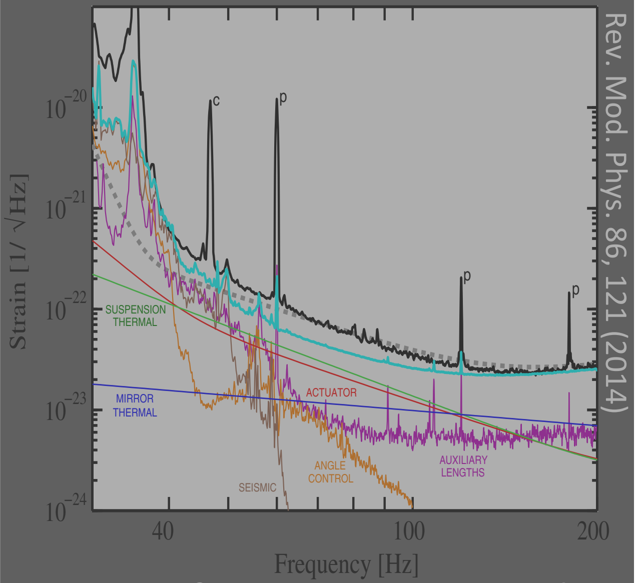
Design-Based Noise Budget



Comme Sisyphe.

- Flexible modeling; design is still a moving target
- Catalog all relevant noises
- Build and combine NBs for subsystems, intermediate configurations

Realistic Noise Budget



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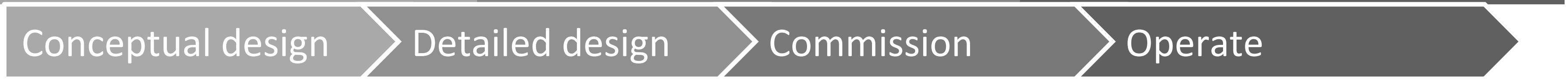

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How We Use Noise Budgets

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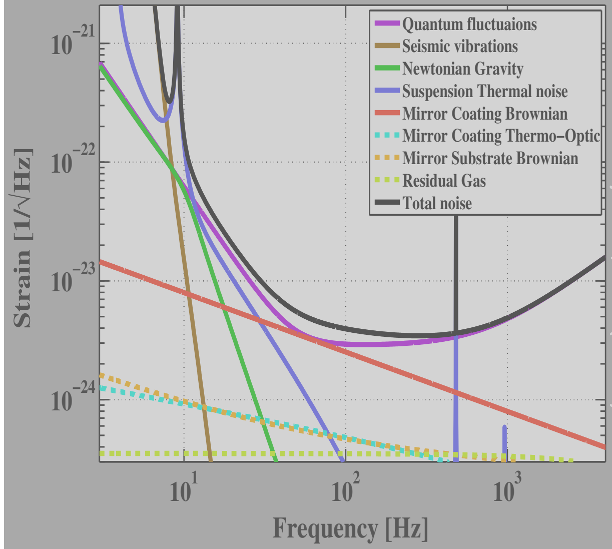

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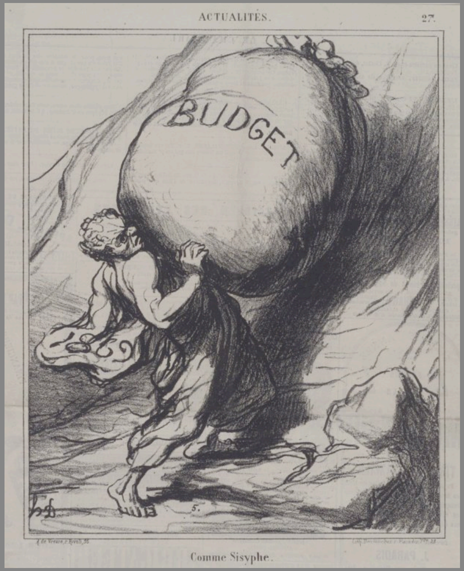

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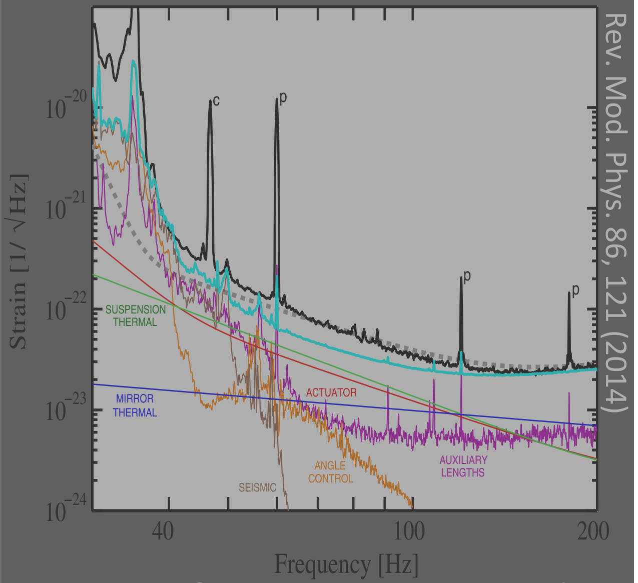
- Build and combine NBs for subsystems, intermediate configurations
- **Ca$h value of each curve…**

Realistic Noise Budget



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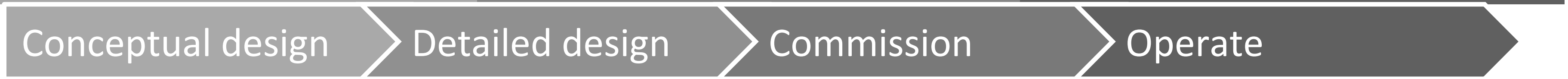
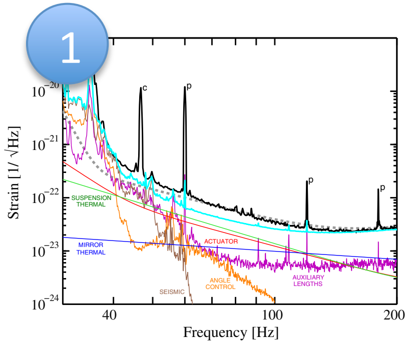


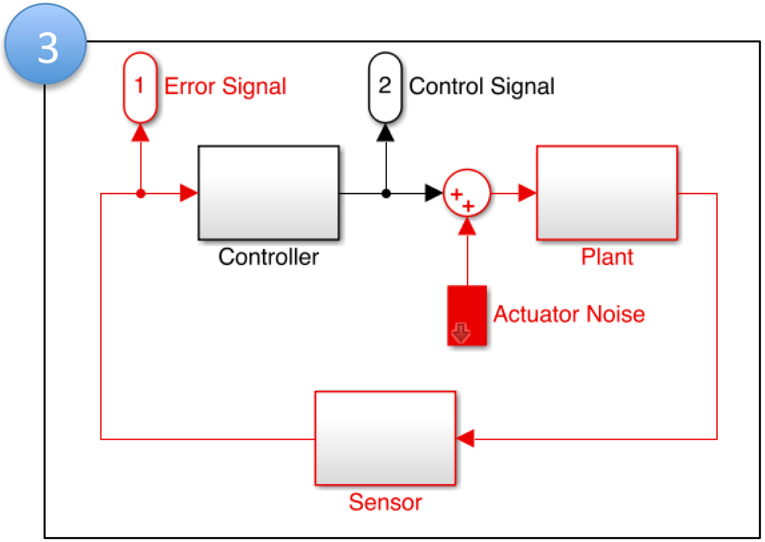
Conceptual design → Detailed design → Commission → Operate

How We Make Noise Budgets



Identify noise curves needed for the NB plot. For each curve do the following:

Make the noise source's spectrum (model or measure)

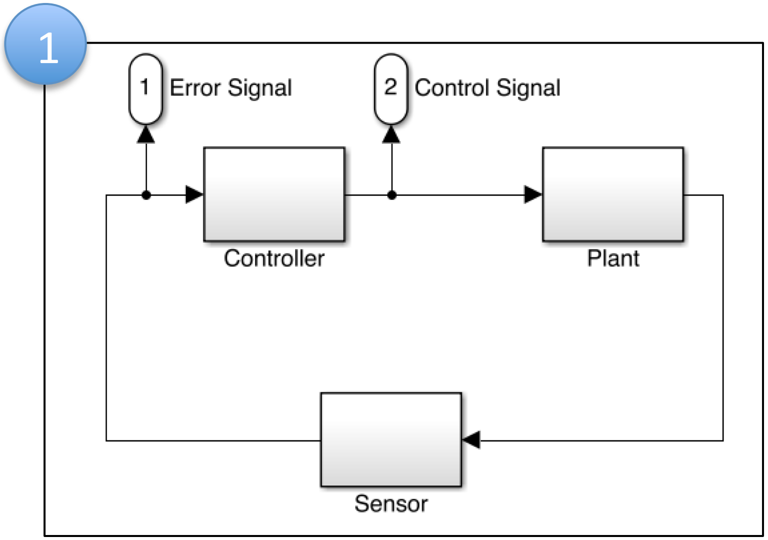


Implement a transfer function to calibrate the noise as a strain (model or measure)

- If you make a simple change to the system, which calibration TFs need to change?
- How do you check consistency vs. a measured open loop gain or other TF?
- How do you reuse all this work for another noise budget or other commissioning task?

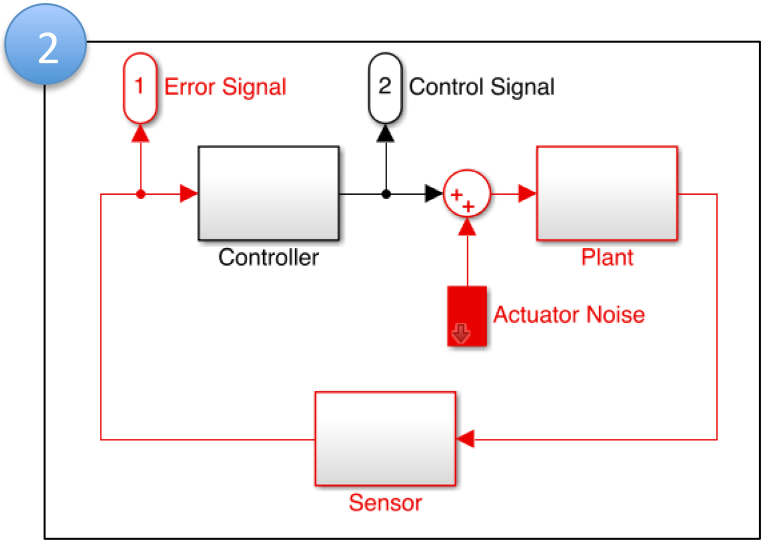
How We Make Noise Budgets

1



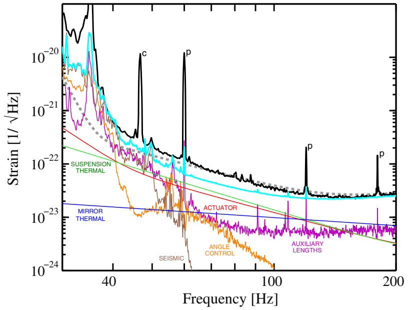
Build a good control model first!

2



Locate each point in the model where noise couples. This determines calibration TFs.

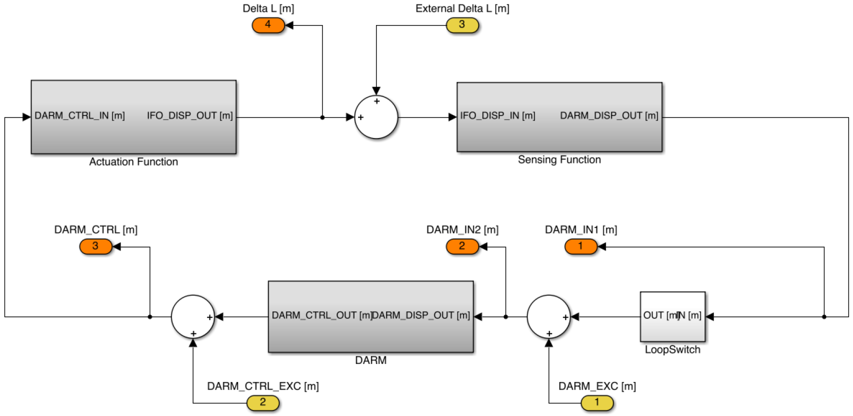
3

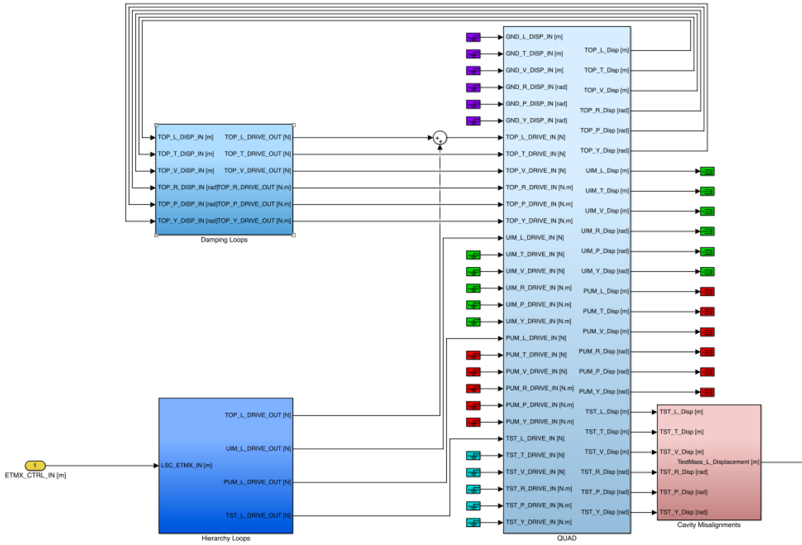


Make spectra and project through the model

Building Control Models in Simulink

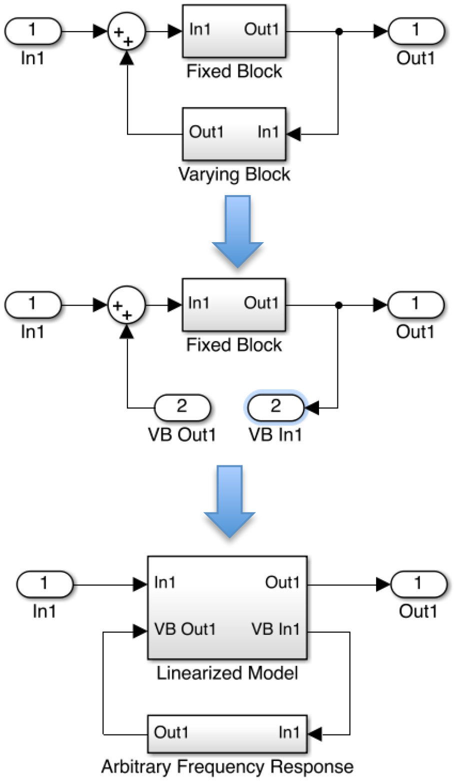
- Easy, flexible graphical editor
- People already use it
- Ecosystem of MATLAB-based simulations (Optickle, GWINC, MIST…)
- Complication: Simulink is a time-domain tool
  - Must fit frequency responses with a time-domain model before using them
  - Obtaining frequency-domain results requires another conversion step (linearize)

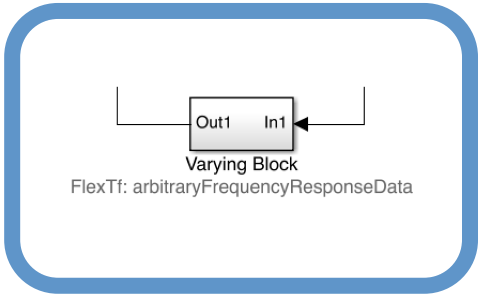




Pluggable Frequency Responses

- Unplug selected blocks from the model
  - This allows you to bypass time-domain fitting and linearization for these blocks
- Linearize the rest of the model as usual
  - Extra I/O ports are added for the bypassed blocks
  - Extreme case: all blocks can be taken out. Then linearizing just returns the connection matrix.
- Get frequency response of the linearized model, and plug in frequency response of the bypassed blocks
- Automatic procedure for Toolbox
  - Use “linFlexTf” linearization routine
  - Blocks commented with “FlexTF” are automatically replaced by your chosen frequency response data

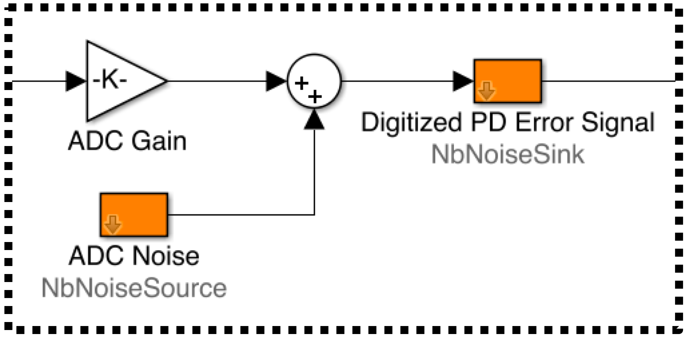




Adding and Calibrating Noise

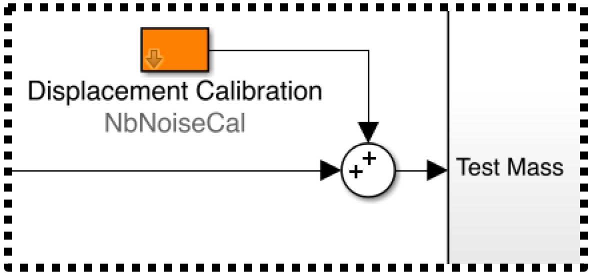
- Dummy blocks label endpoints of the calibration TFs

"Source block" sums in where noise enters



"Sink block" is placed where noise is measured (may be in or out of loop)

"Cal block" sums in where we *wish to know* the noise

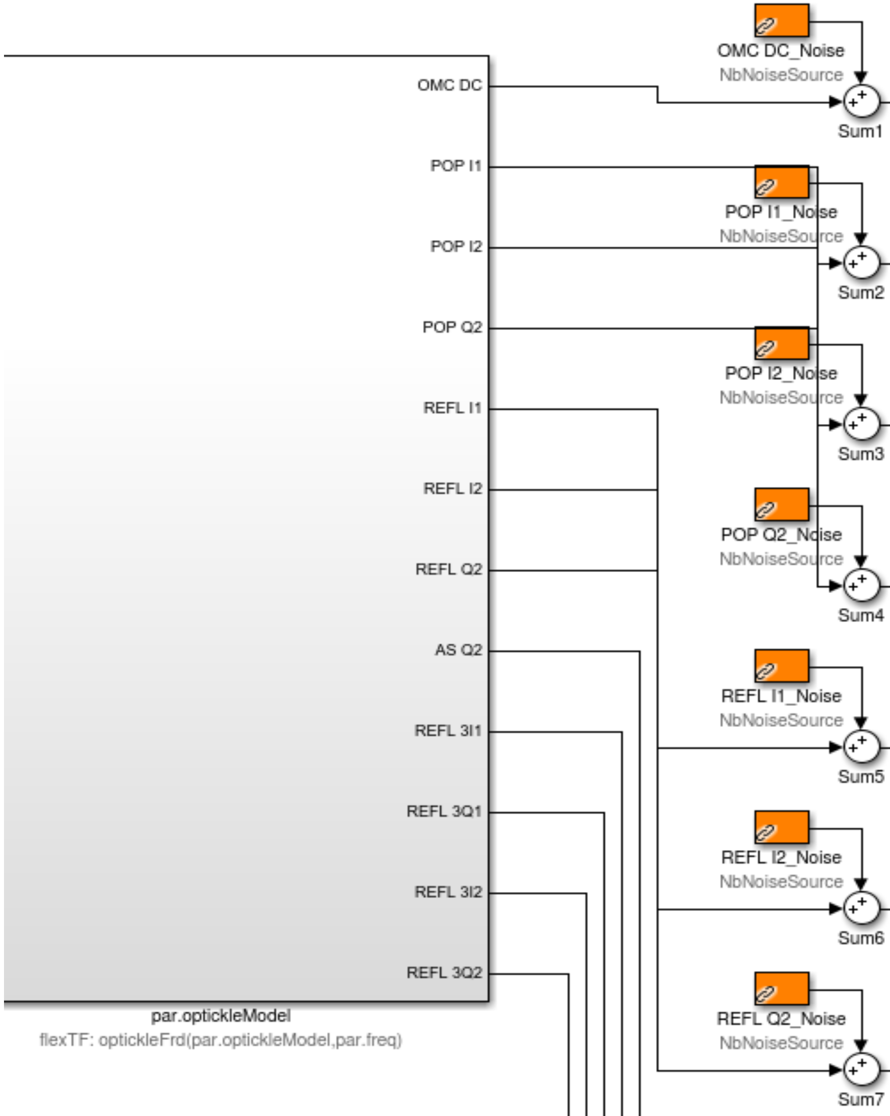


TF from Cal to Sink is needed to convert sensor units to physical units (ADC counts to meters, for instance)

- These blocks have associated parameters for defining noise spectra, units, etc.

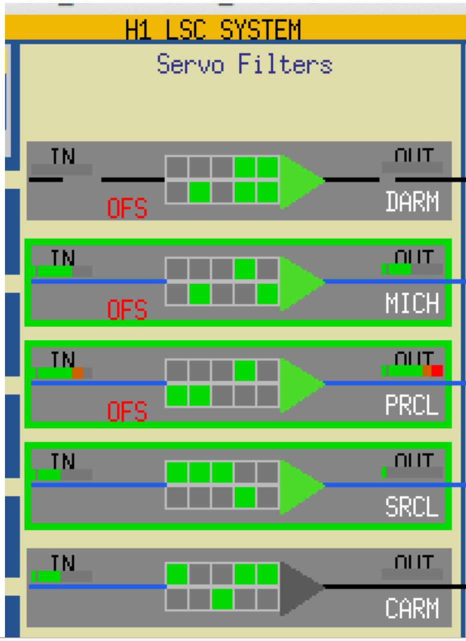
Bridging Optickle and Simulink

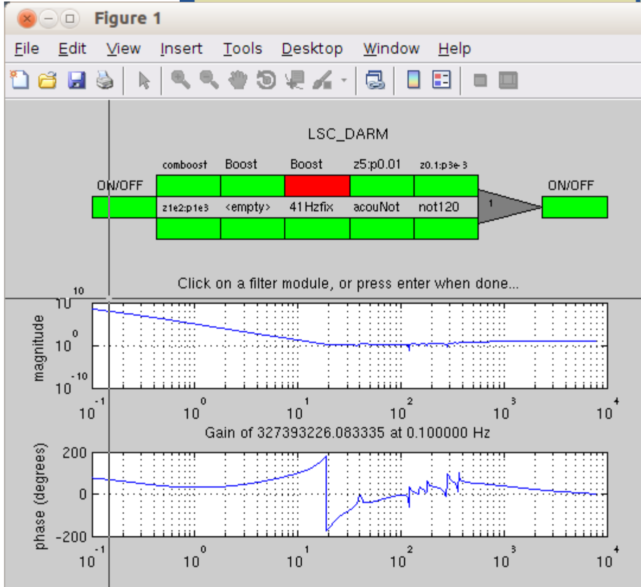
- Contributed by Nicolas Smith-Lefebvre
- Auto-create a block from an Optickle model, for easy copy-pasting into a NoiseBudget model
- Supplies frequency response and quantum noise terms
- Clever caching ensures Optickle runs only when the configuration is changed
- Requires FlexTF linearization (other Simulink functions do NOT work)



Syncing Models and Reality

- Sources and Sinks link to LIGO NDS channels
  - Model automatically grabs time series, makes ASDs, and calibrates them as noise terms
  - Sink block takes out the loop gain to obtain the unsuppressed noise
- “LiveParts” blocks link to EPICS digital control parameters
  - Gains, matrices, and filters automatically configure themselves in the model
  - Retrieves past settings from DAQ and digital filter archive
  - Cool graphical editor for filter states (contributed by Matt Evans)





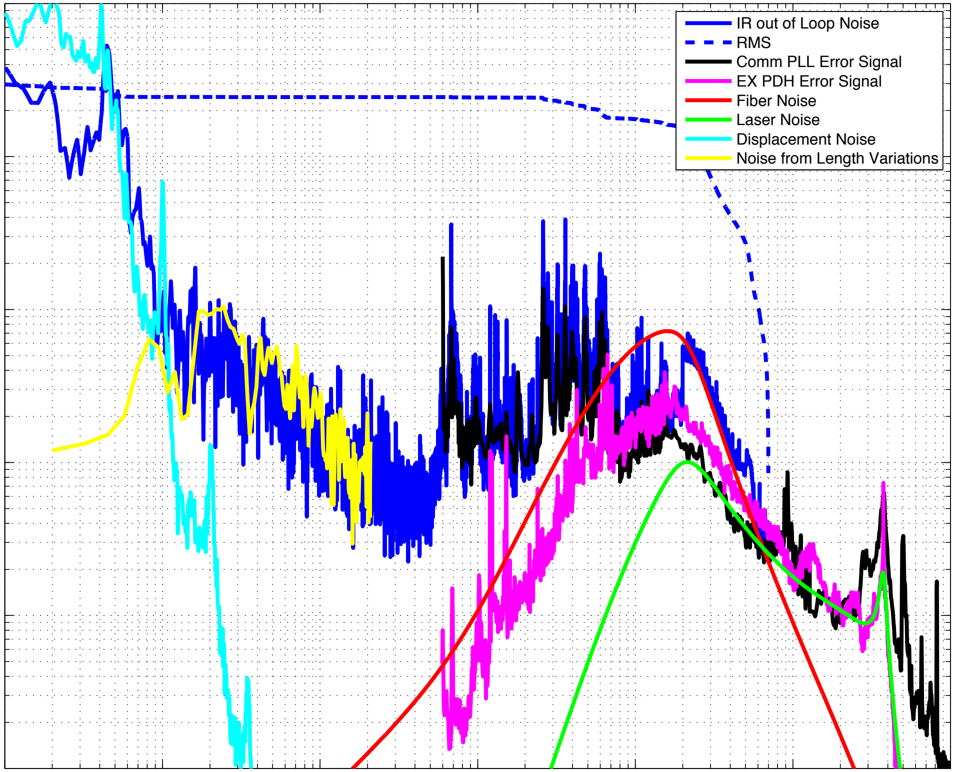
Click on a filter module, or press enter when done...

Gain of 327393226.083335 at 0.100000 Hz

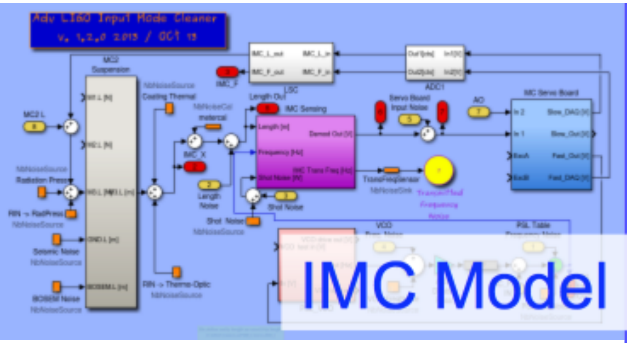
ALS Noise Budget

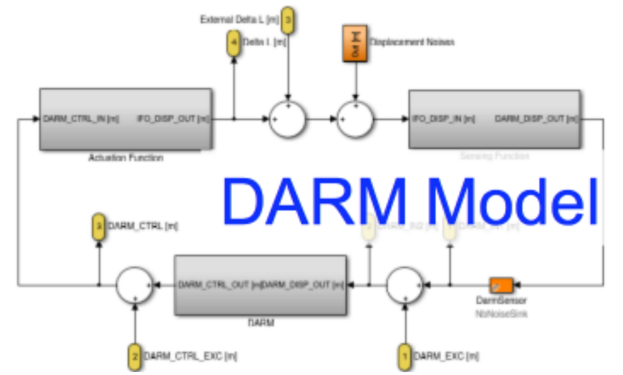
- Easy to cope with major departures from the initial design expectations
  - Green beat note sensor redesigned (wrapped with PLL to improve range)
  - Basic optical parameters shifted (mirror coatings out of spec for green)
- Hard to validate the control model, but no harder than it had to be
  - Found and fixed: broken electronics, inconsistent documentation, our misconceptions
- Heavily used during noise hunting to evaluate speculative noise sources
- Noise requirements were met, limiting noises are known

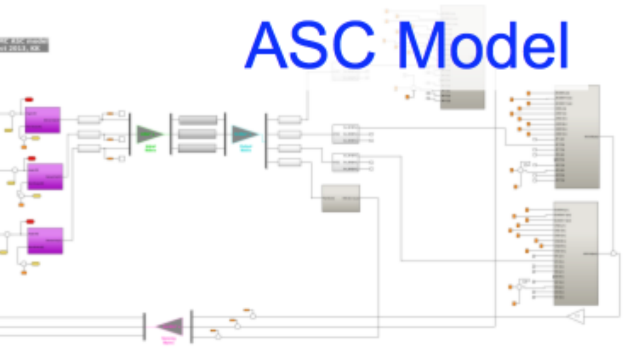
A. Staley et al, paper in preparation (2014)

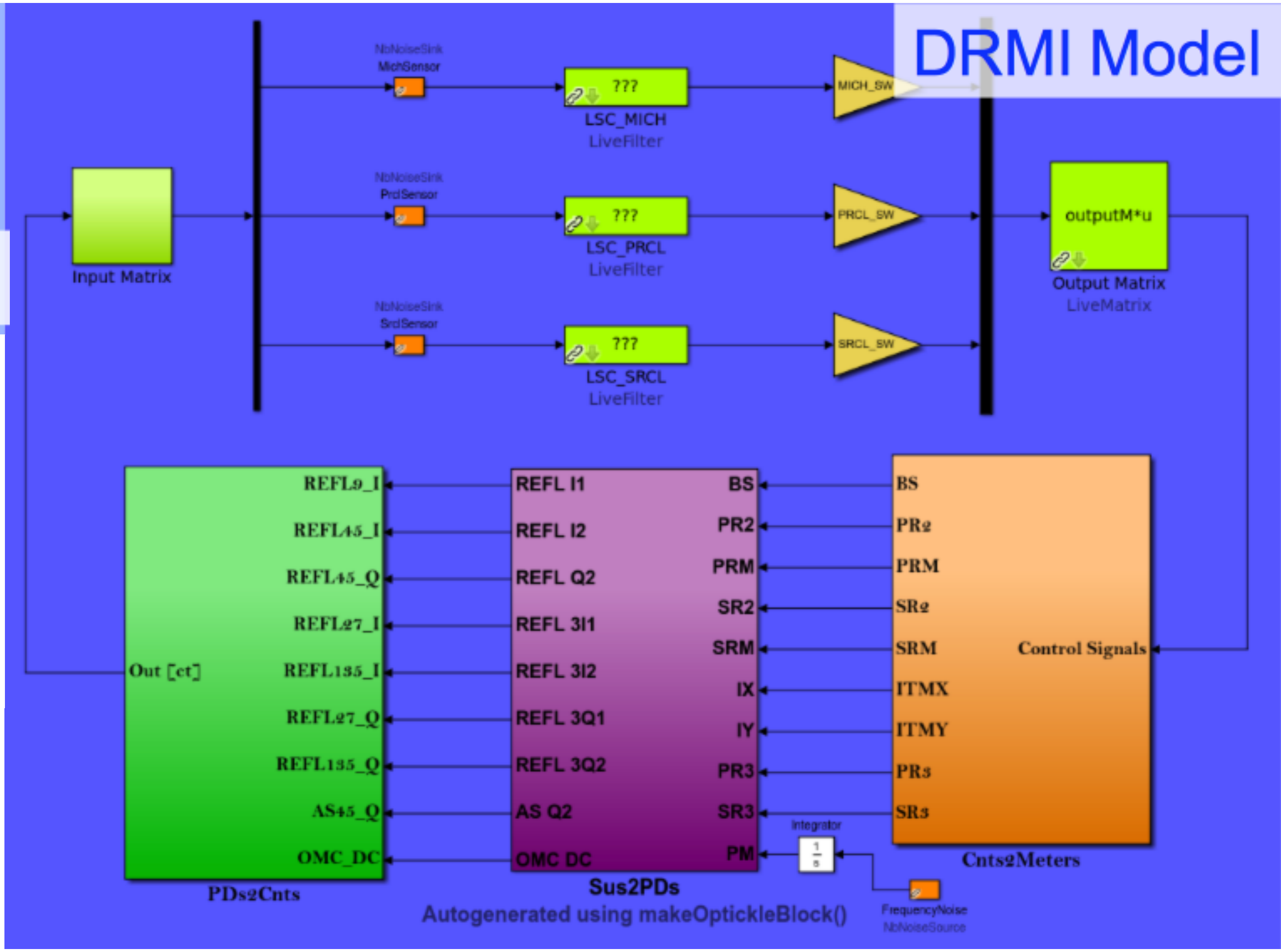


Noise Budgets as Building Blocks





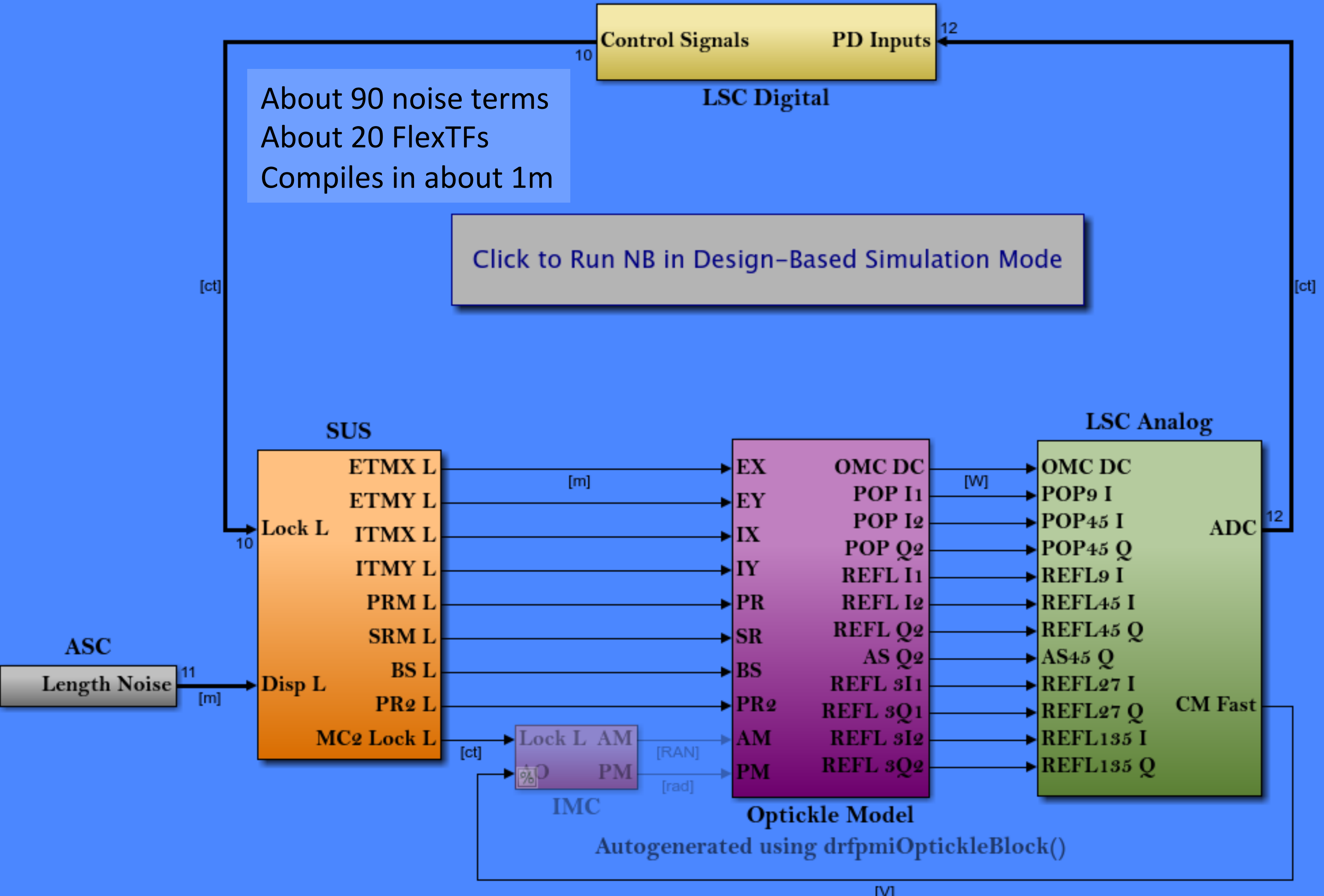




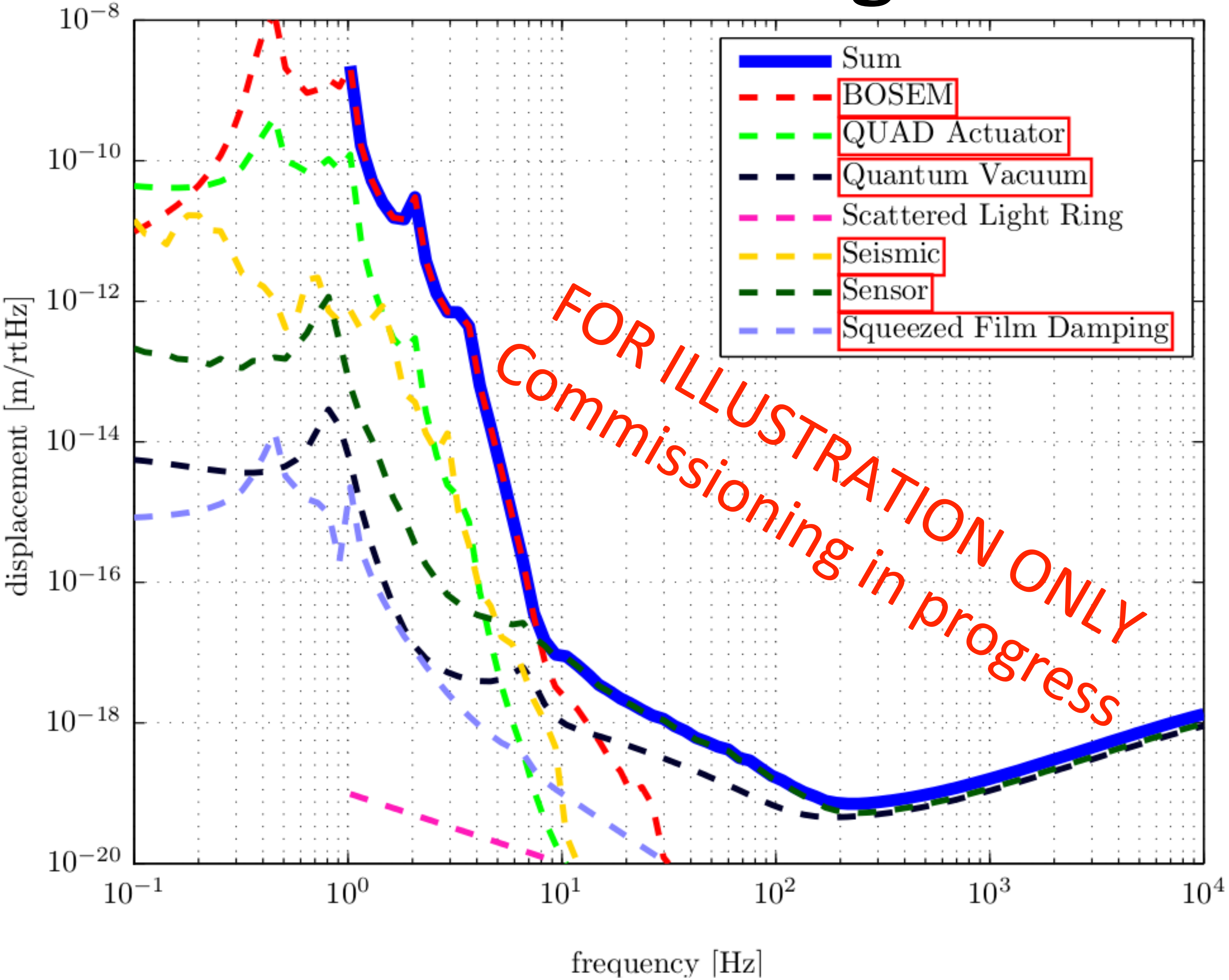
Autogenerated using makeOptickleBlock()

ALIGO NoiseBudget Model

About 90 noise terms
About 20 FlexTFs
Compiles in about 1m



aLIGO Noise Budget



FOR ILLUSTRATION ONLY
Commissioning in progress

Summary

- Control model is the engine of the noise budget, so build it well

- NB modeling toolkit available for Simulink https://svn.ligo.caltech.edu/svn/aligonoisebudget

- Several new NBs have been developed for aLIGO commissioning

- Full aLIGO noise budget assembled, commissioning ongoing (same with the real interferometers!)