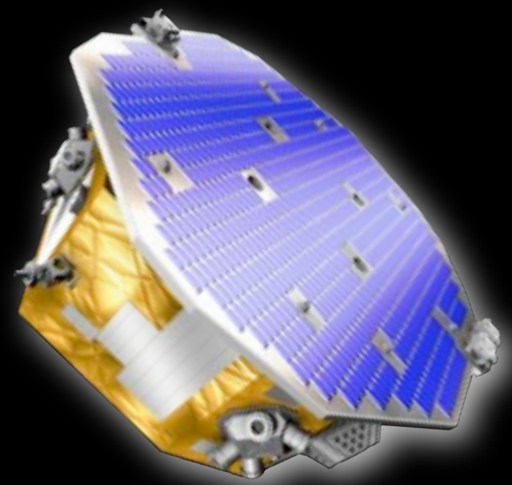

Characterisation of LTP

M Hewitson for the LTP Team

G0900658-v1

Outline

- Physics of LTP
- Data Analysis Tools
- Experiment Master Plan
- Mock Data Challenges

Mission Goals

- Technology demonstration for LISA
- Characterisation of the instrument subsystems
- Noise reduction and noise budget

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Free-falling test-mass at the level of about

$$3 \times 10^{-14}\,\mathrm{m\,s^{-2}}/\sqrt{\mathrm{Hz}}\,@\,1\,\mathrm{mHz}$$

Measurement system

Measurement system

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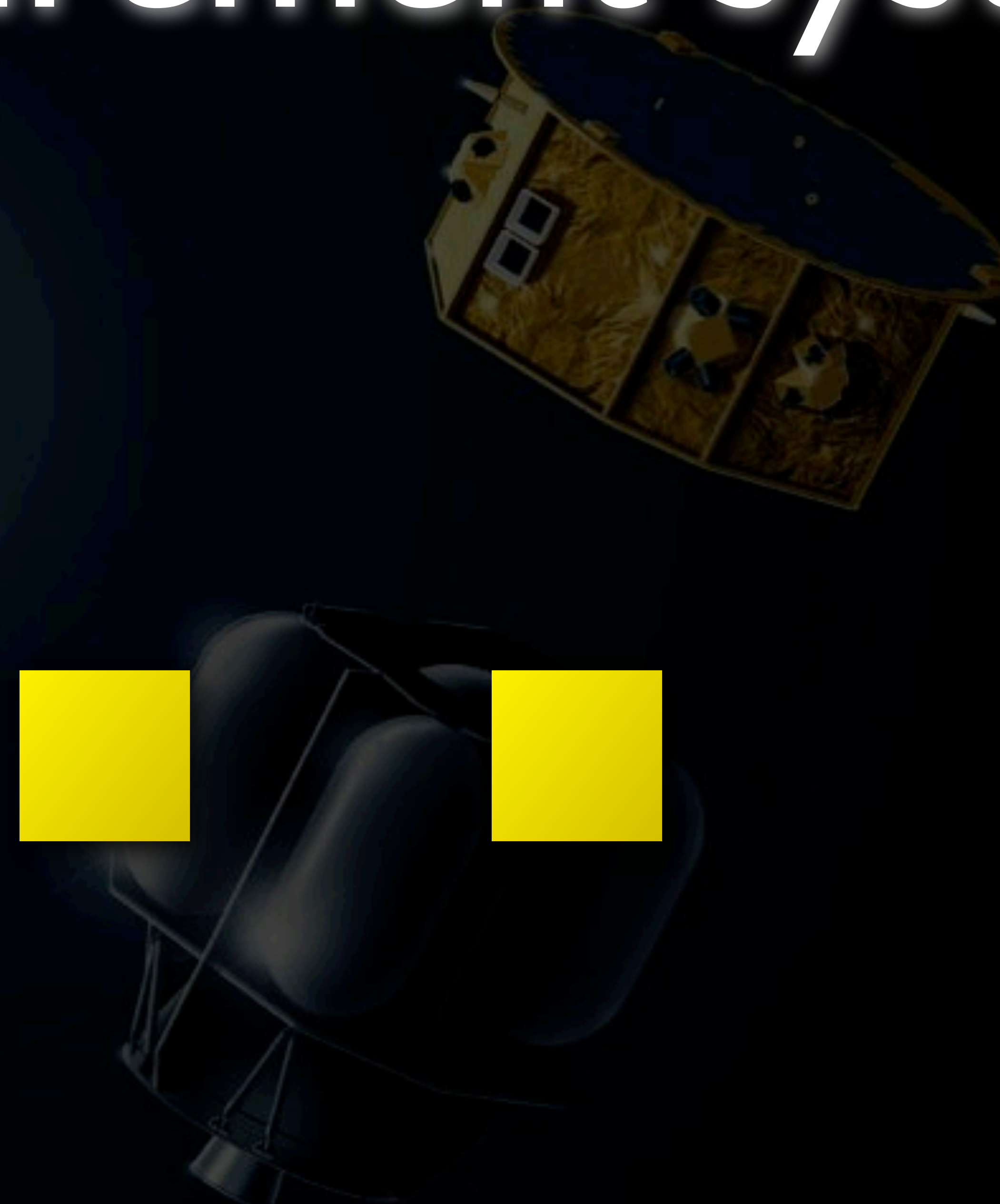

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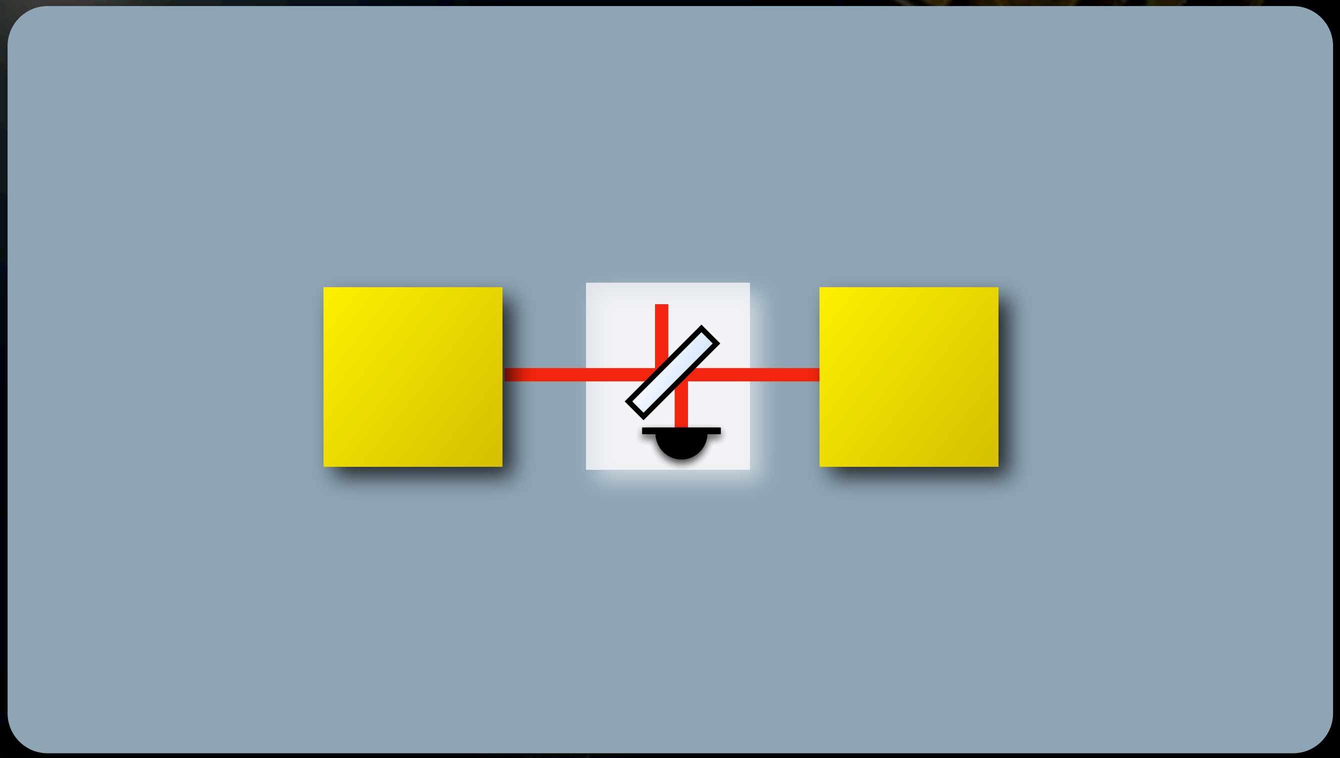

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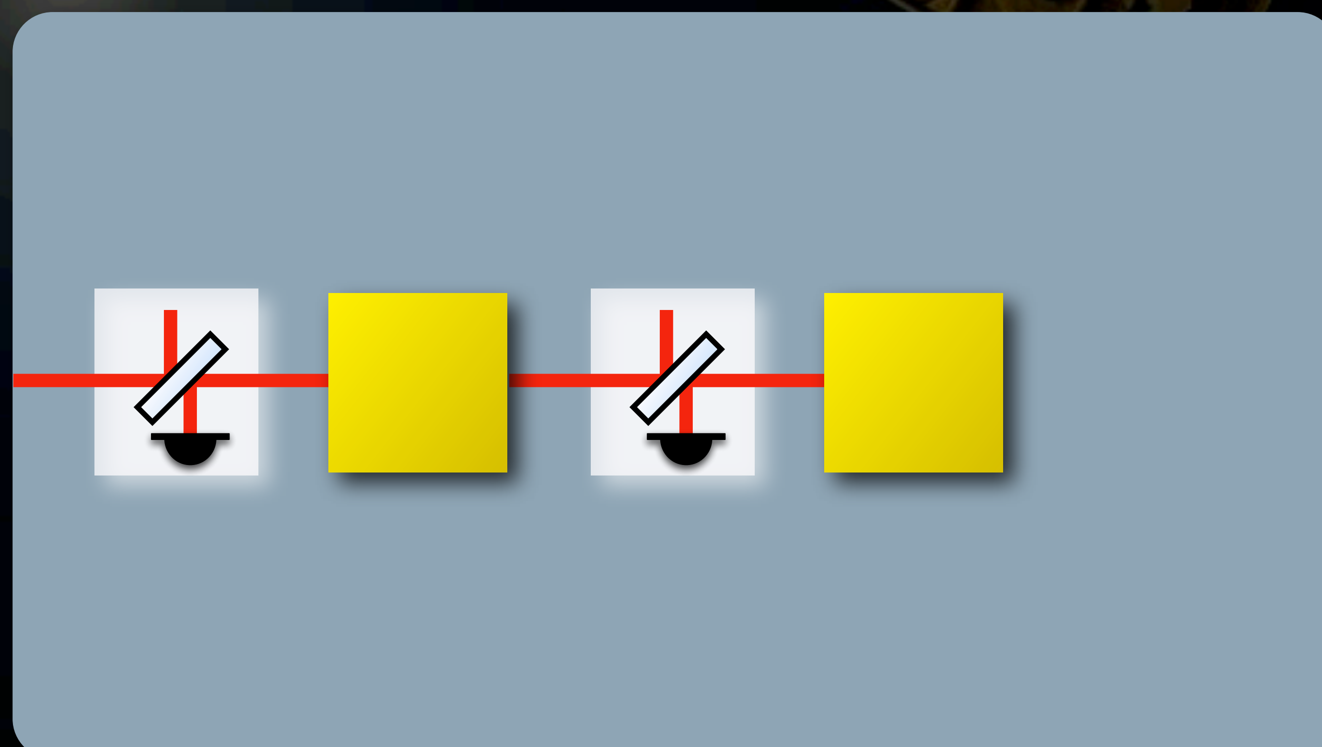

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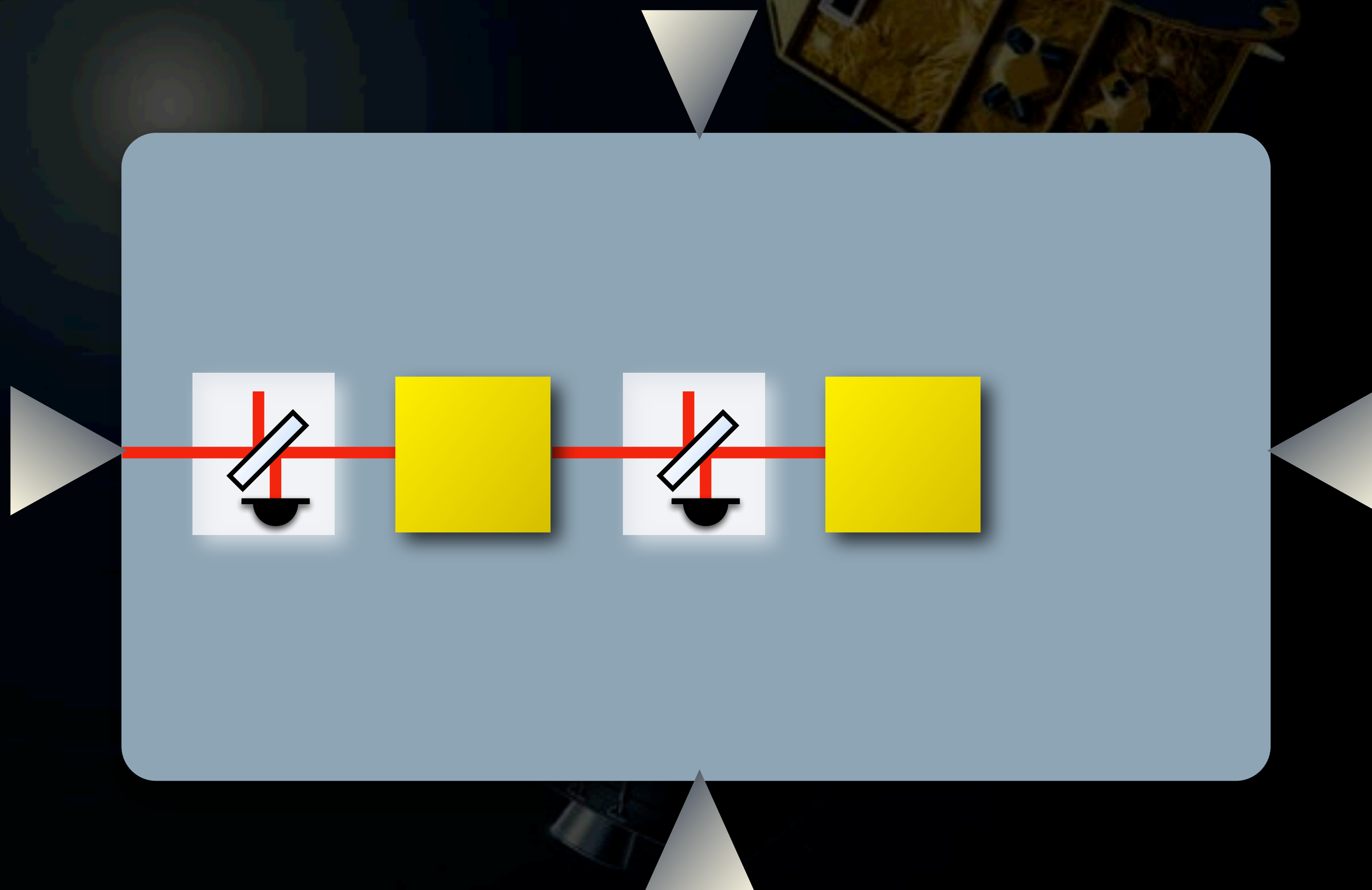

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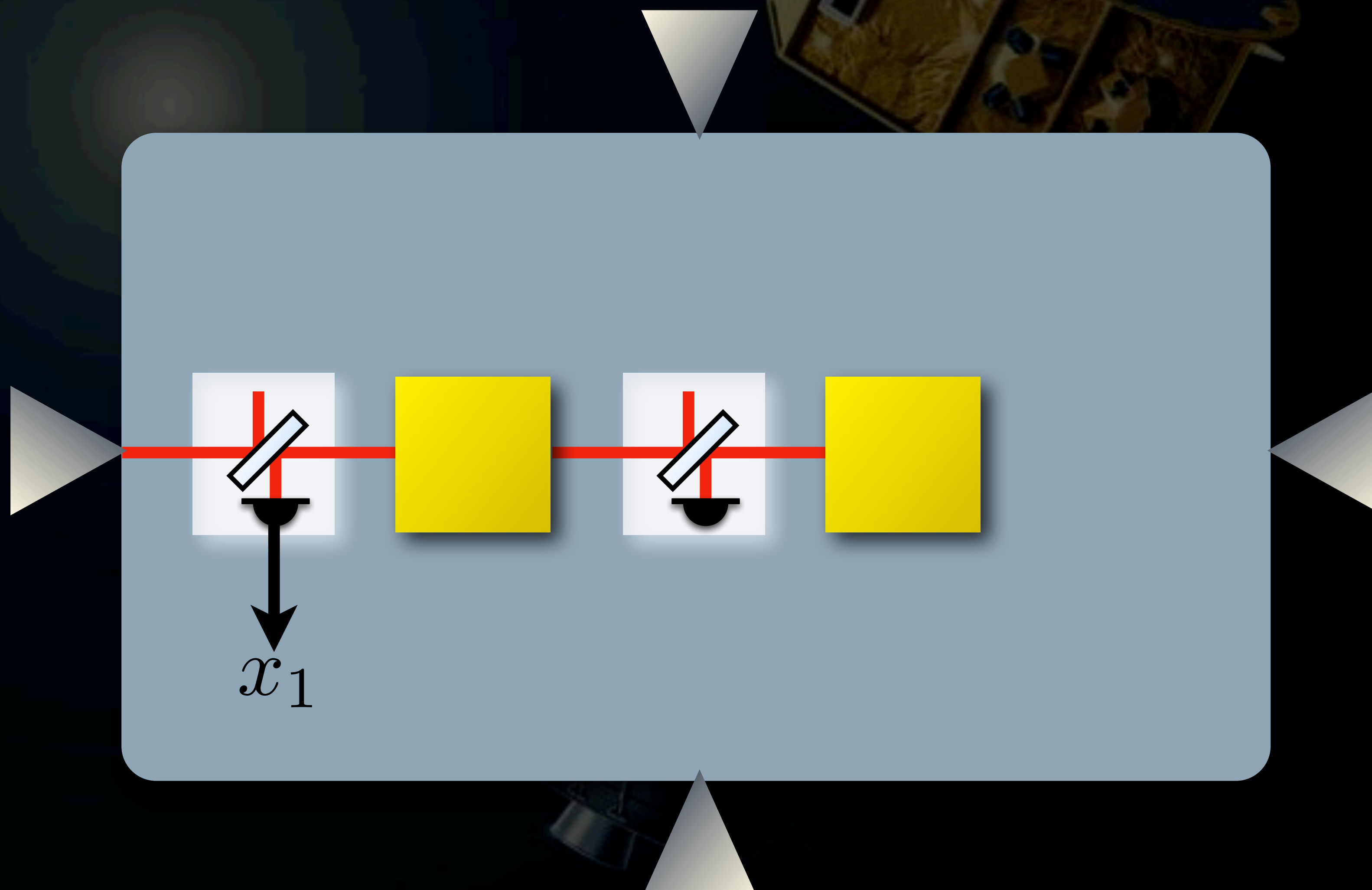

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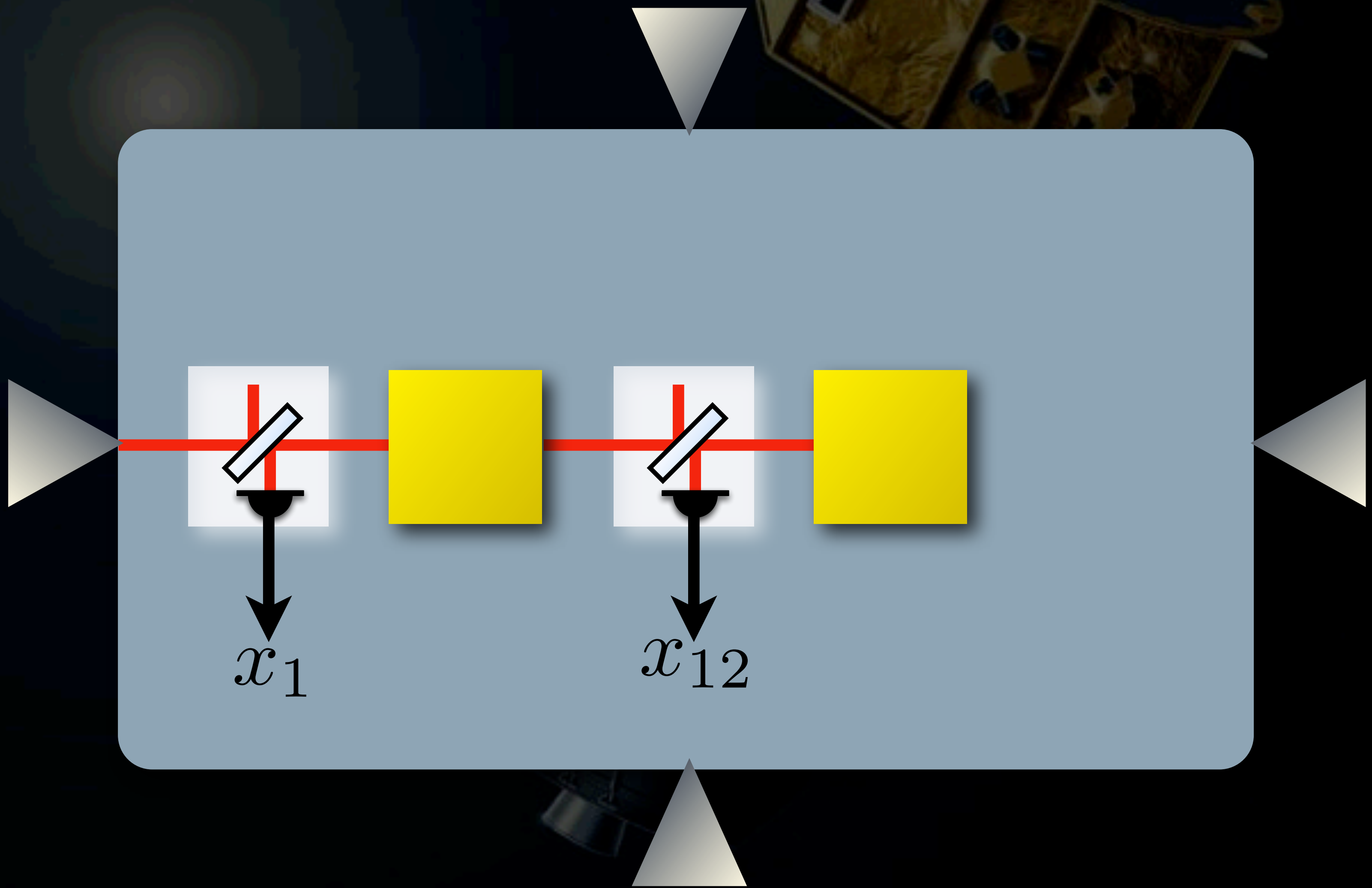
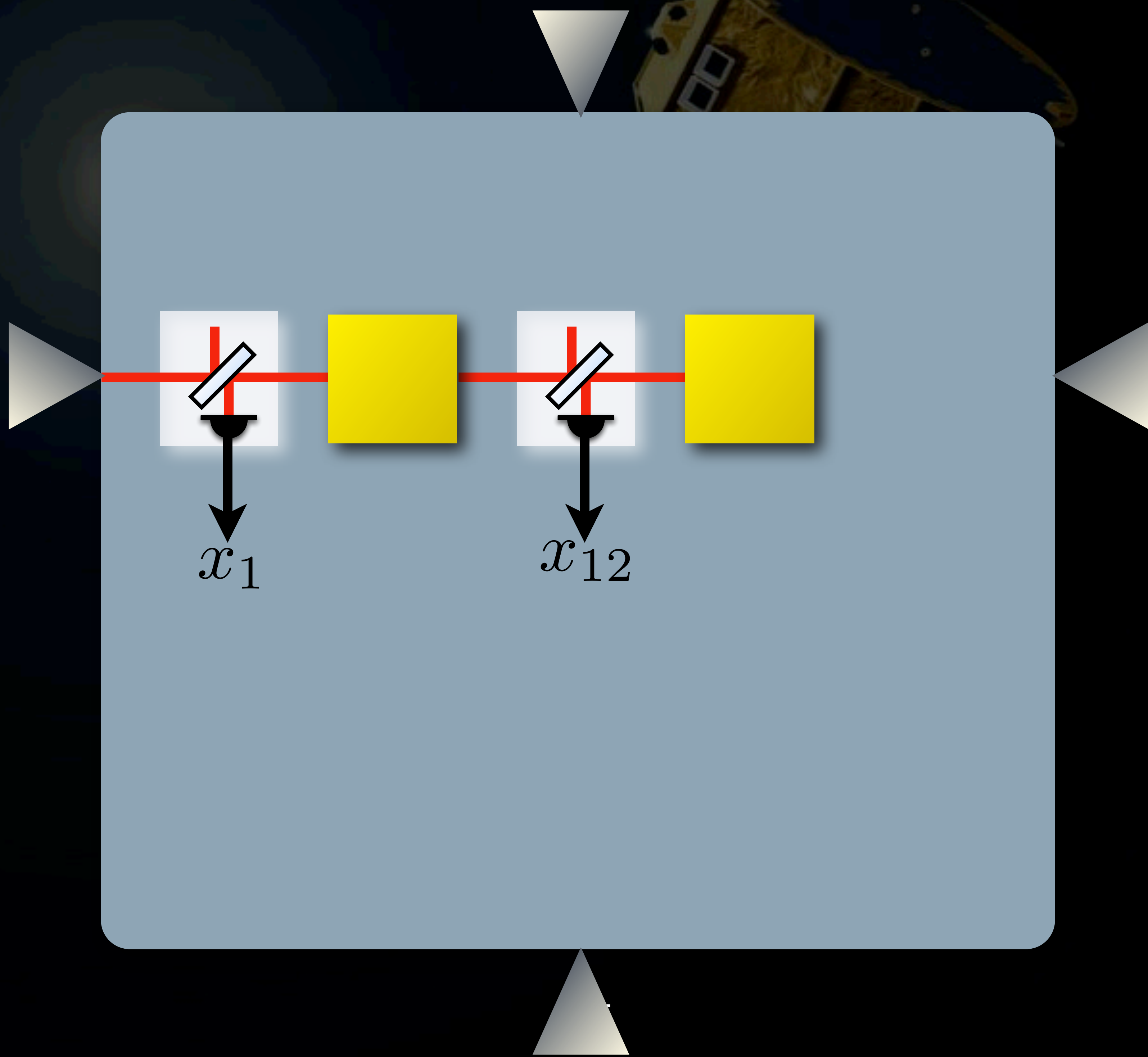


X-axis control



M Hewitson, Characterisation of LTP, GWADW, 2009

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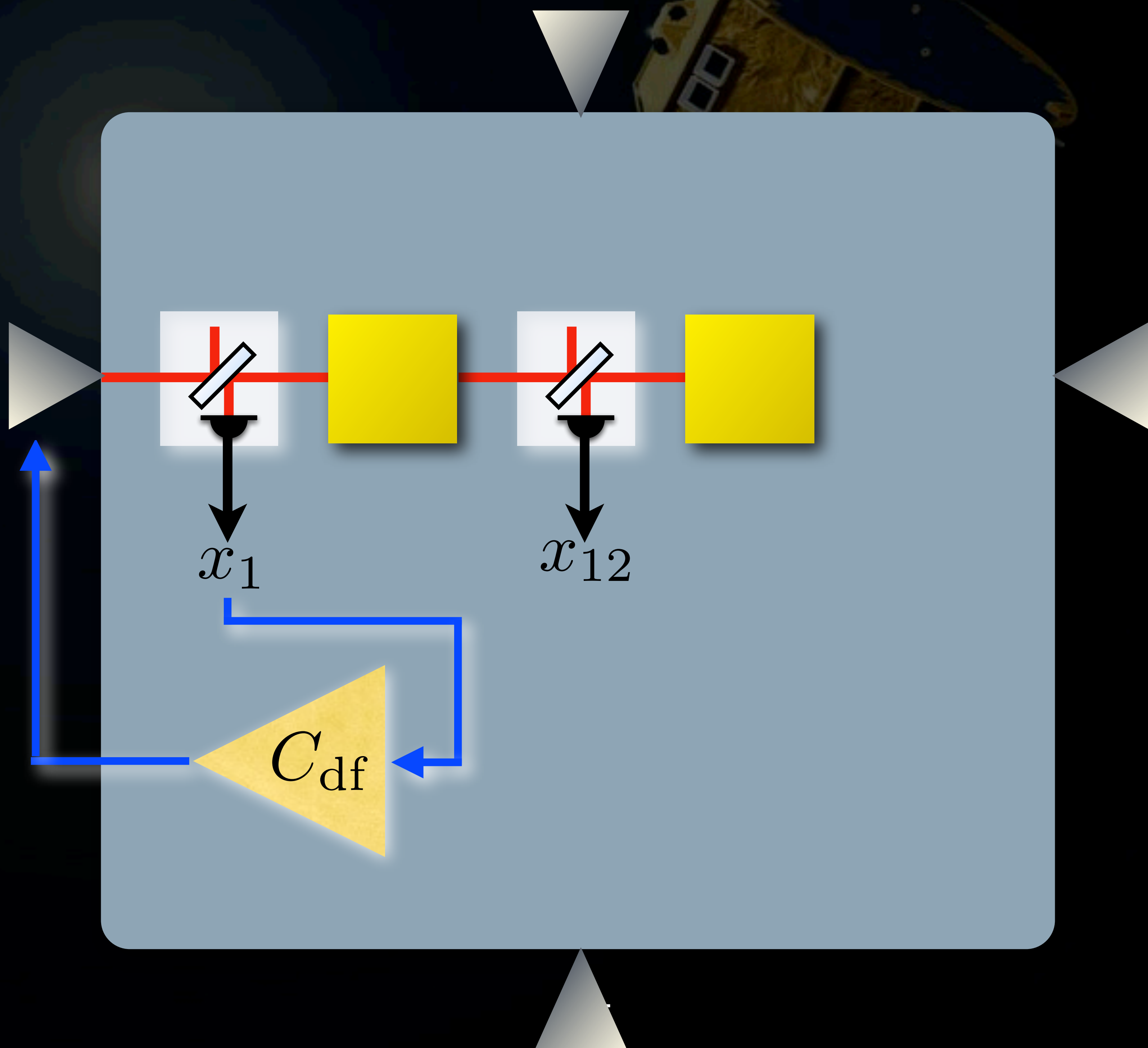

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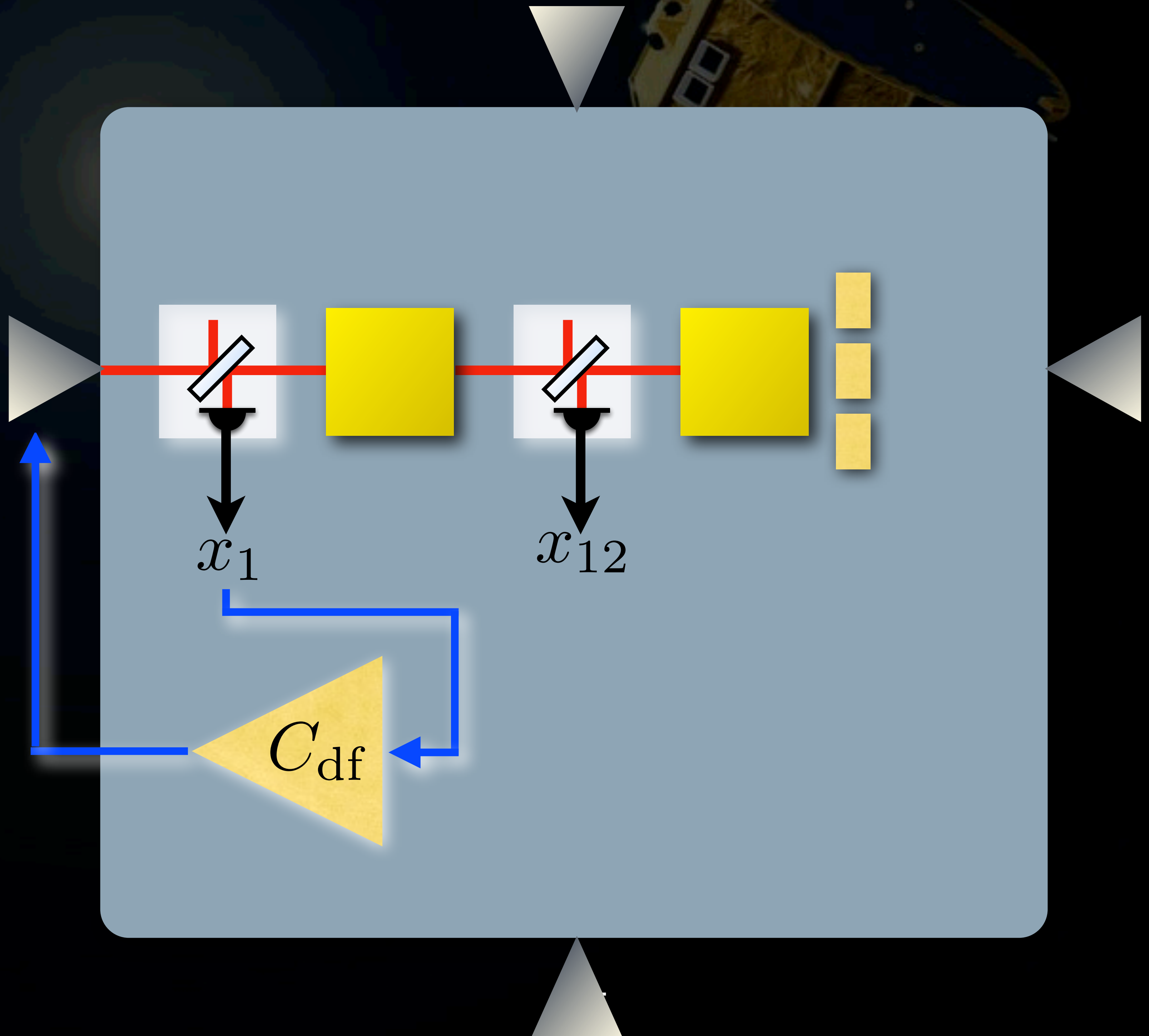

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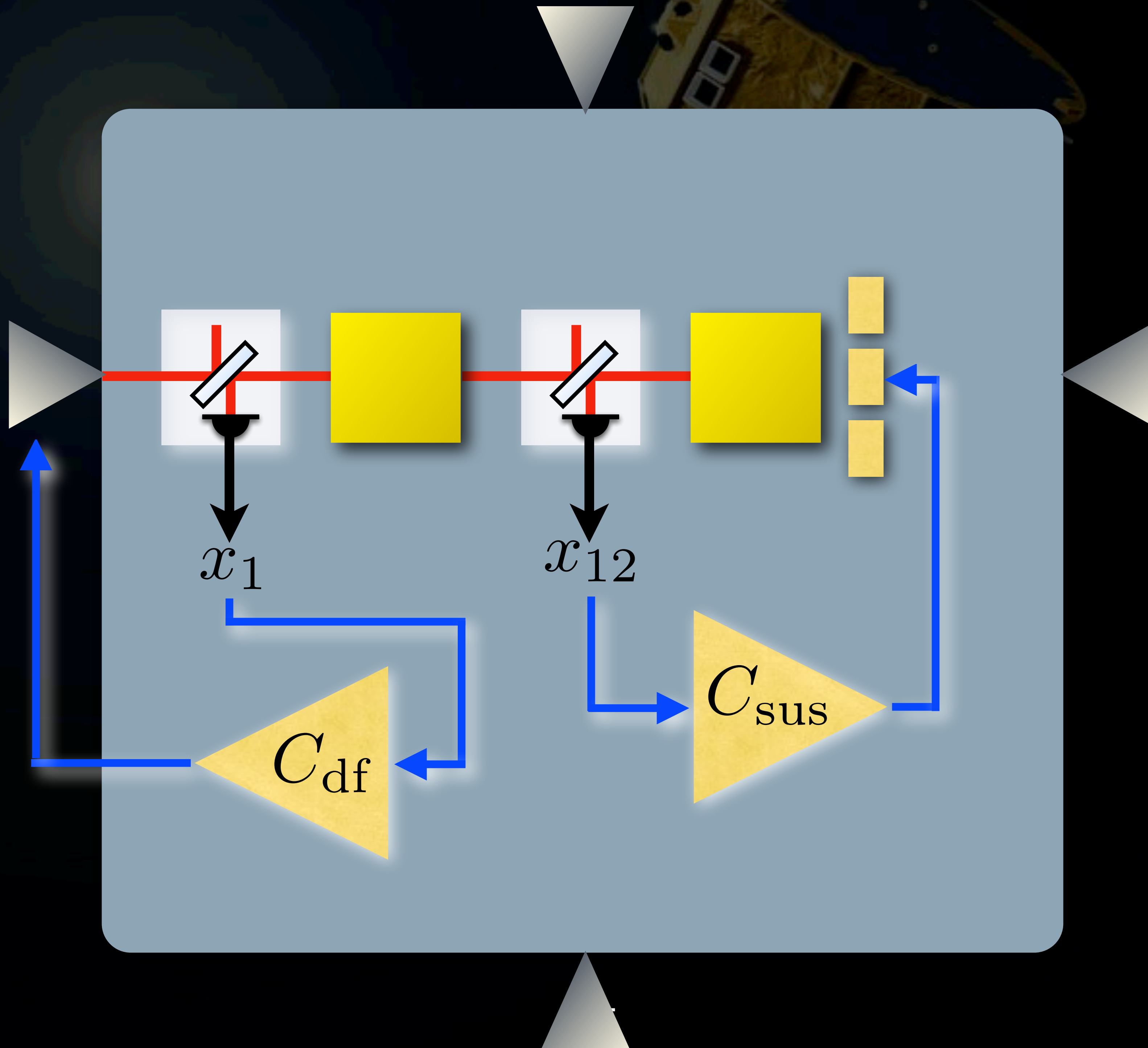
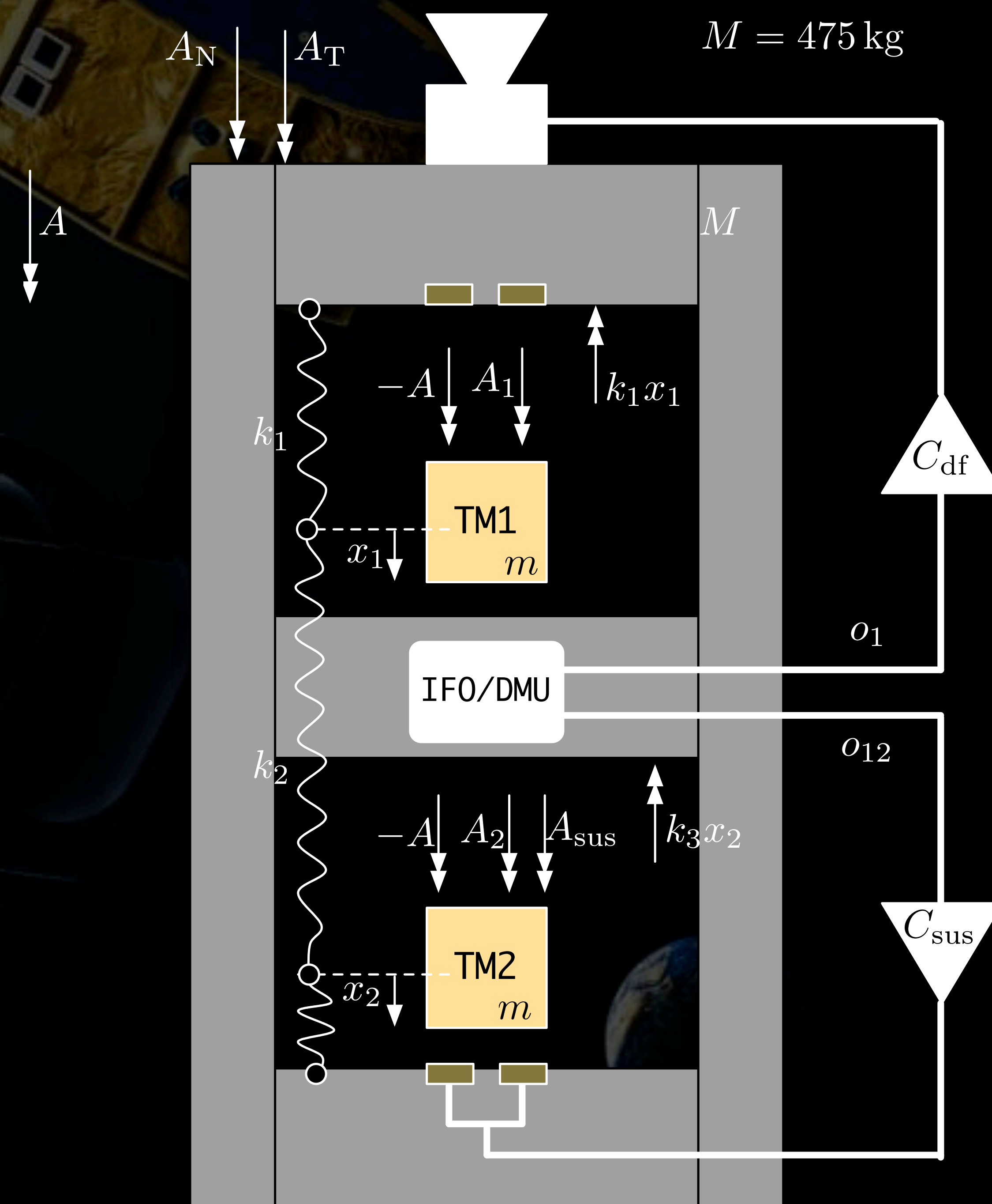


M Hewitson, Characterisation of LTP, GWADW, 2009

Main parameters

$m_1 = m_2 = 1.96\,\mathrm{kg}$

$M = 475\,\mathrm{kg}$



Main parameters

- Spring couplings between SC and TMs (actuation stiffness)

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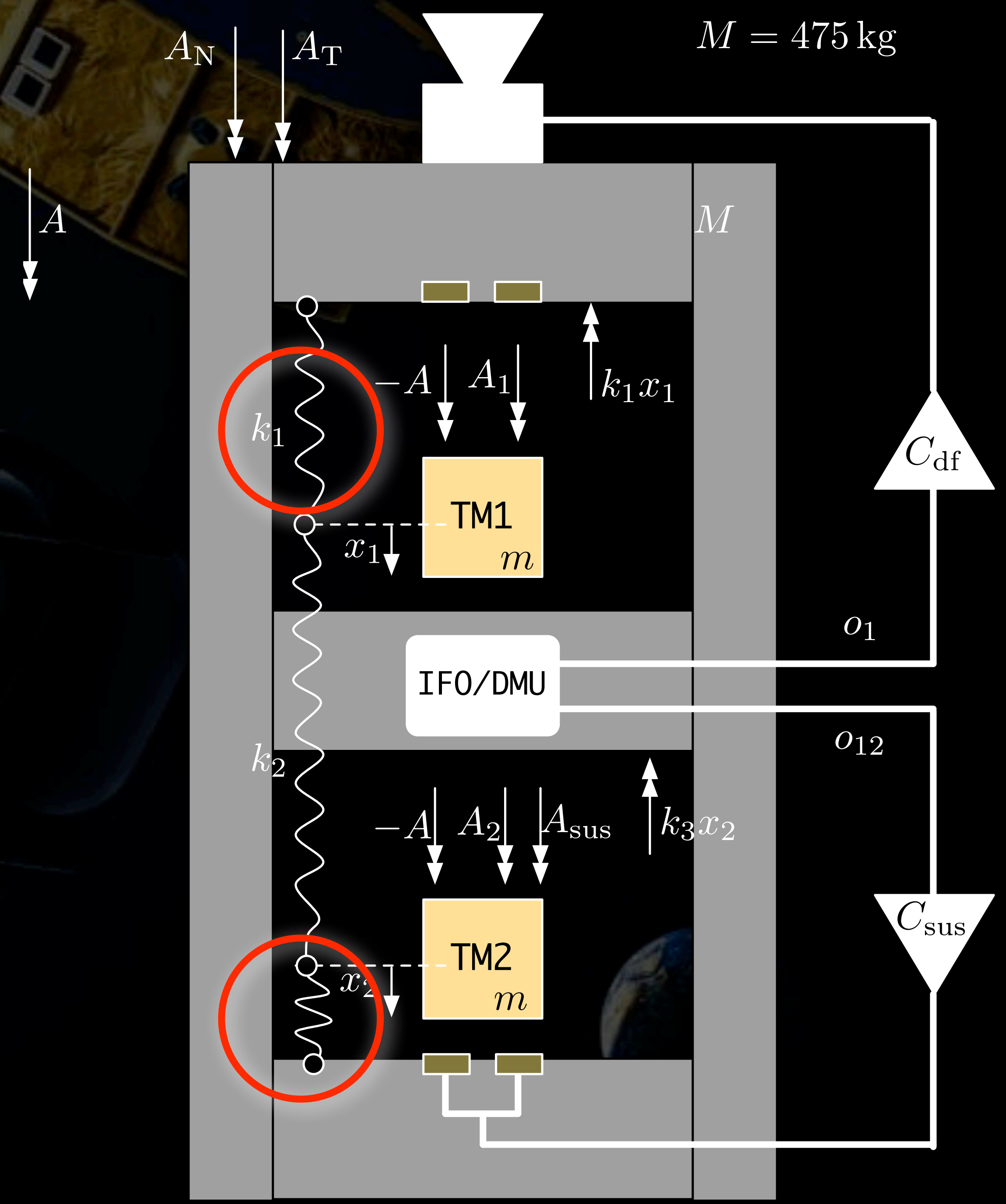

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- Spring couplings between SC and TMs (actuation stiffness)
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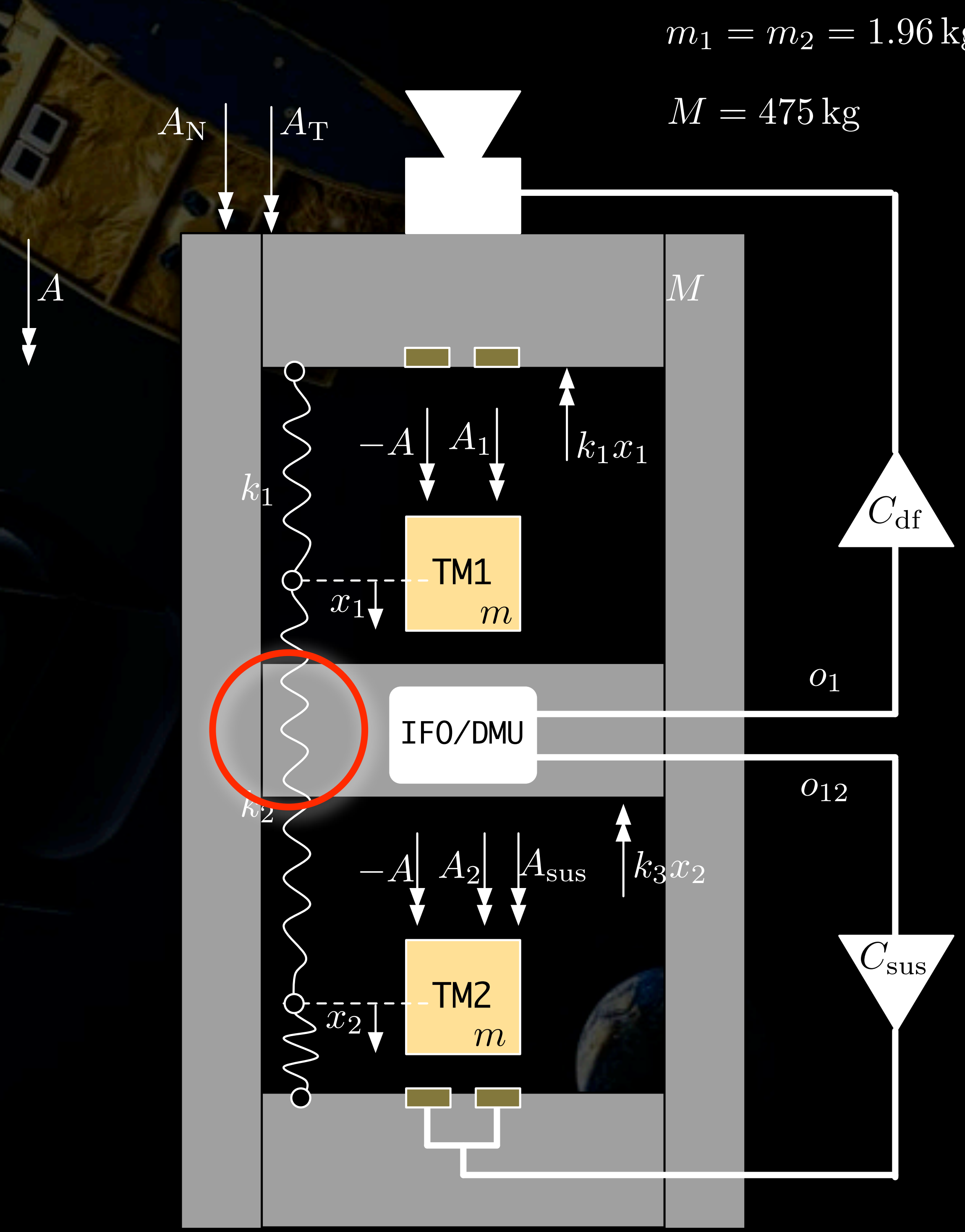

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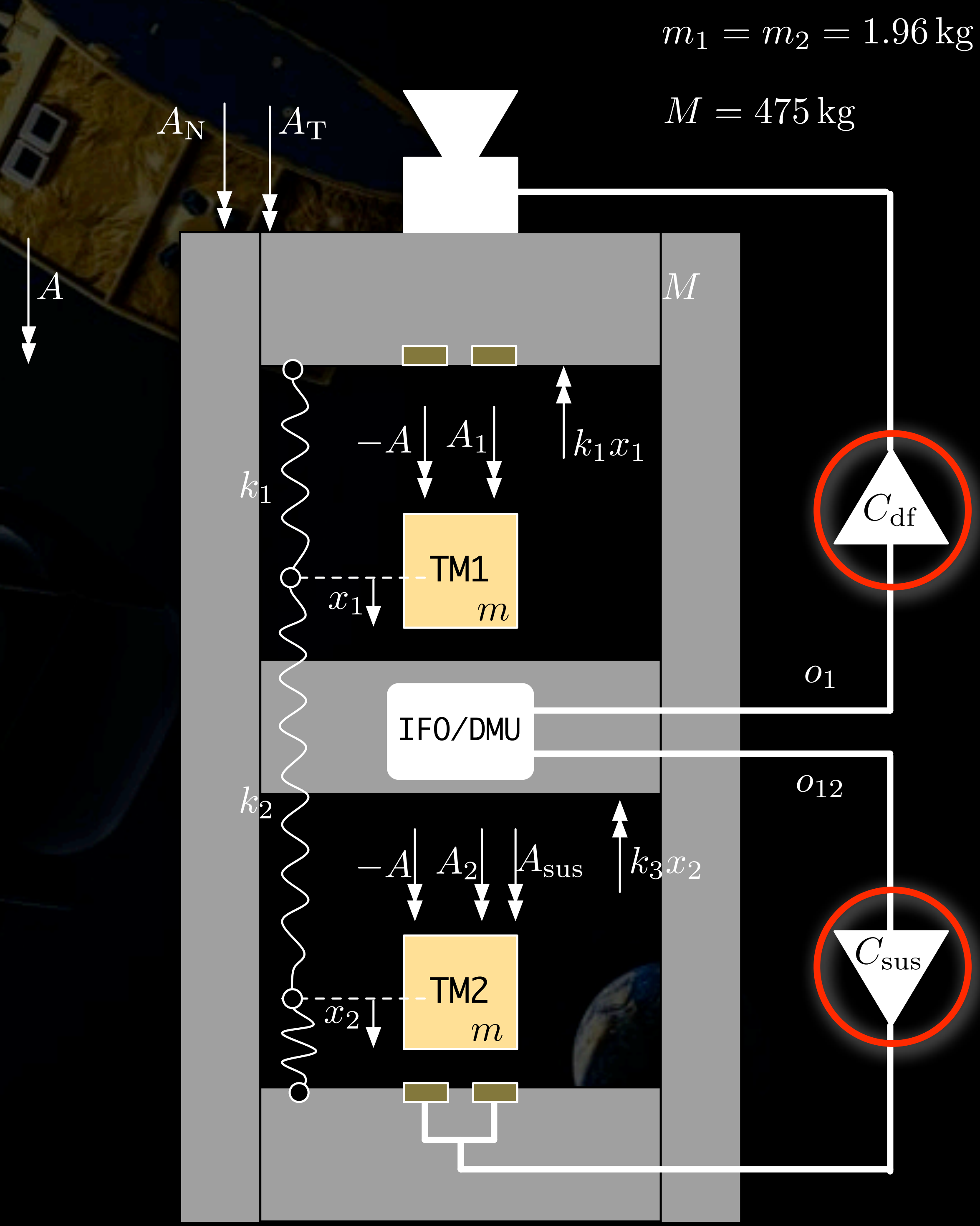

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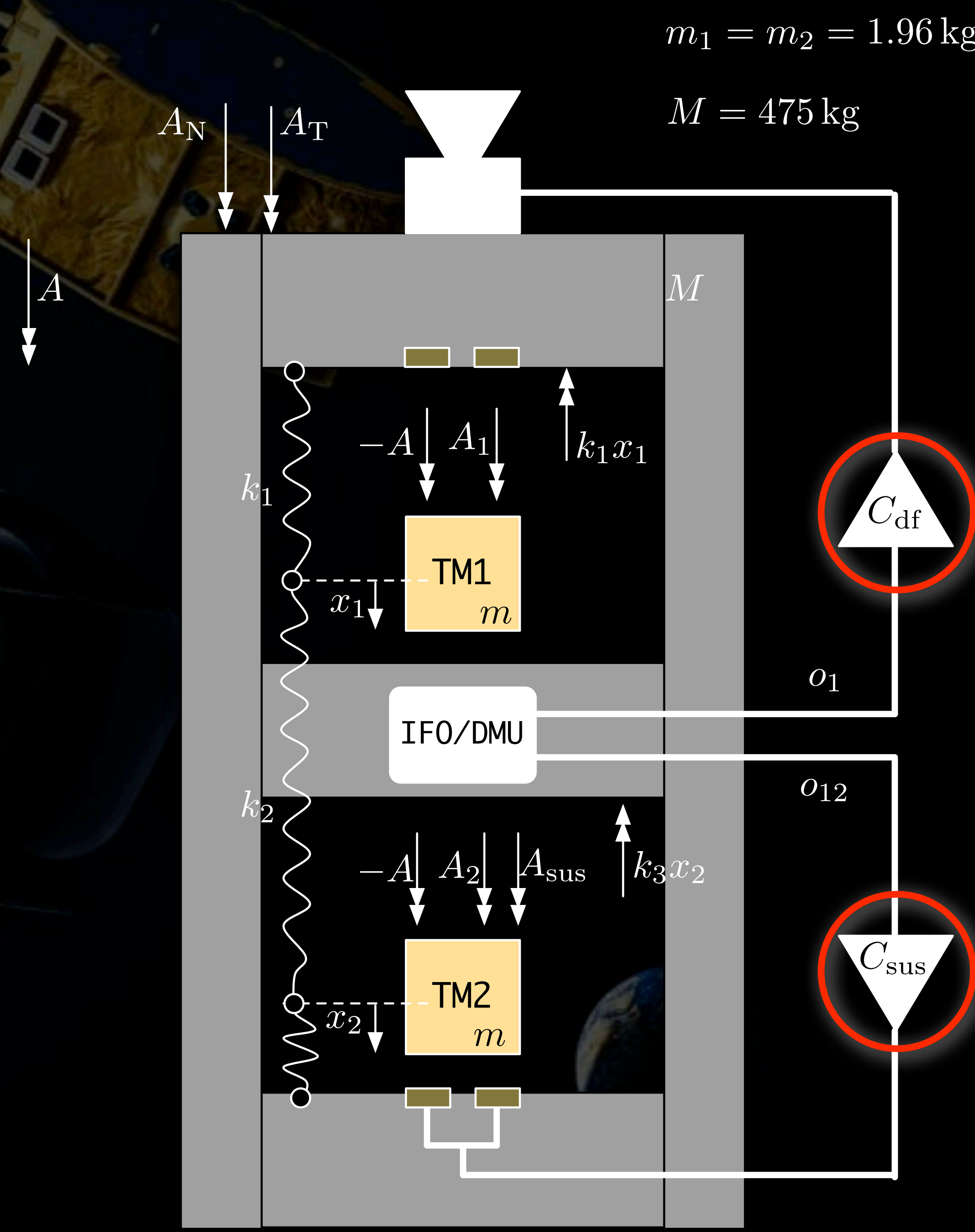
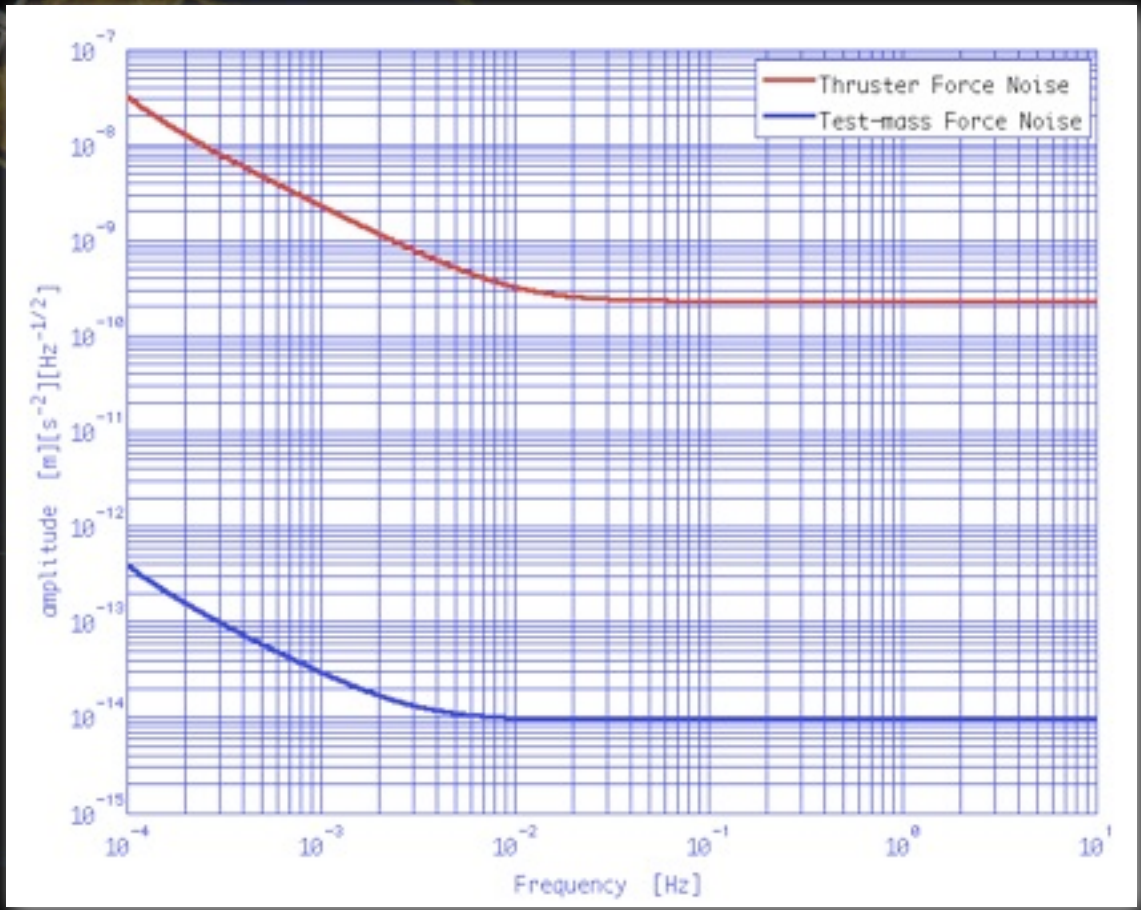
- Cross-couplings (various)



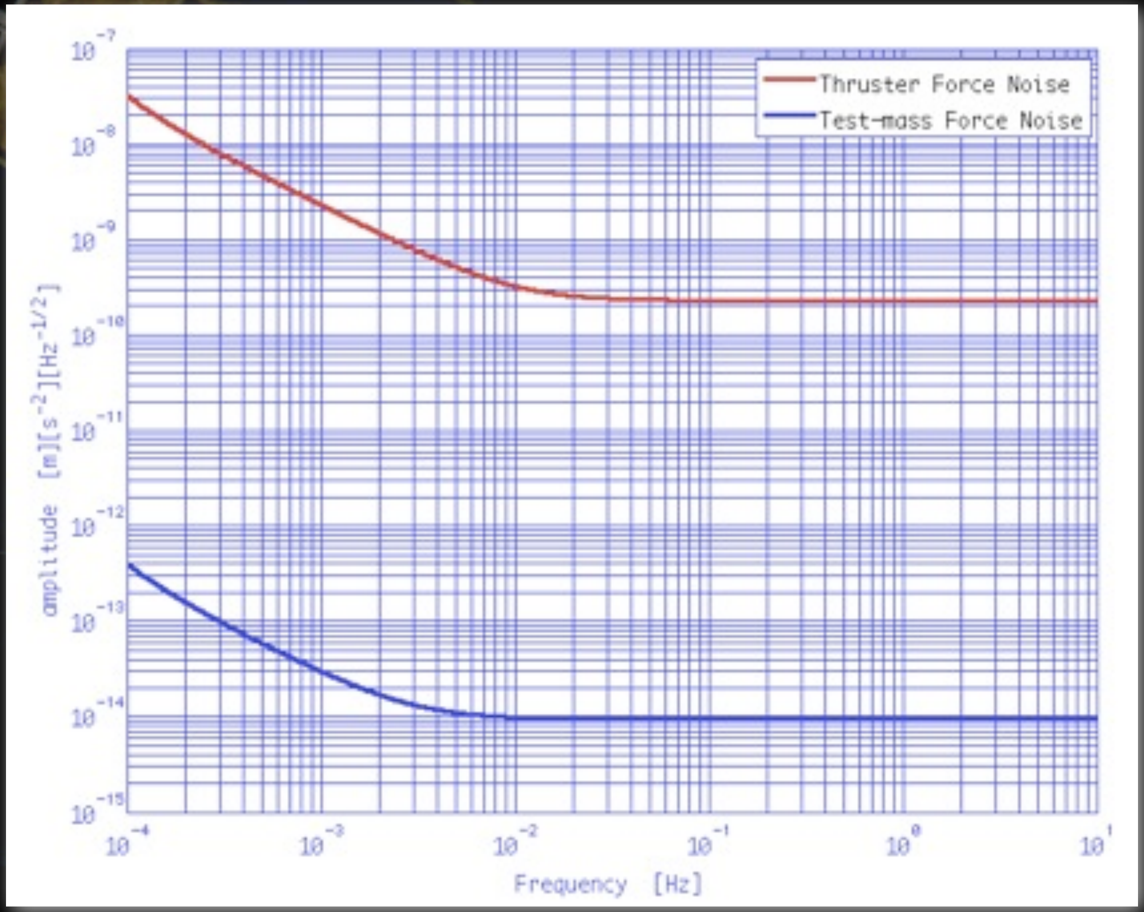
Main noise sources



Main noise sources

Thruster force noise

Force noise of the thrusters couples directly to the TM-SC measurement.
Also couples to TM-TM measurement via differences in the stiffness of each TM to SC.



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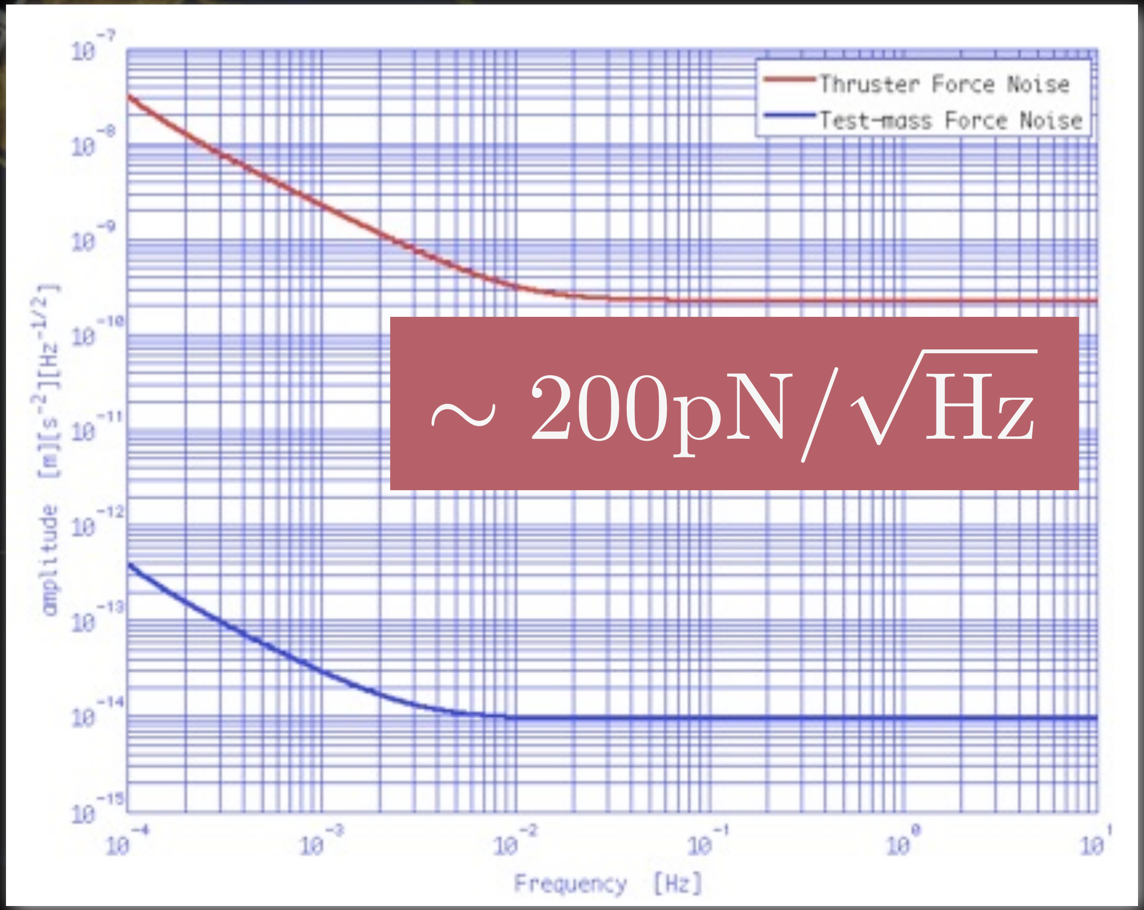

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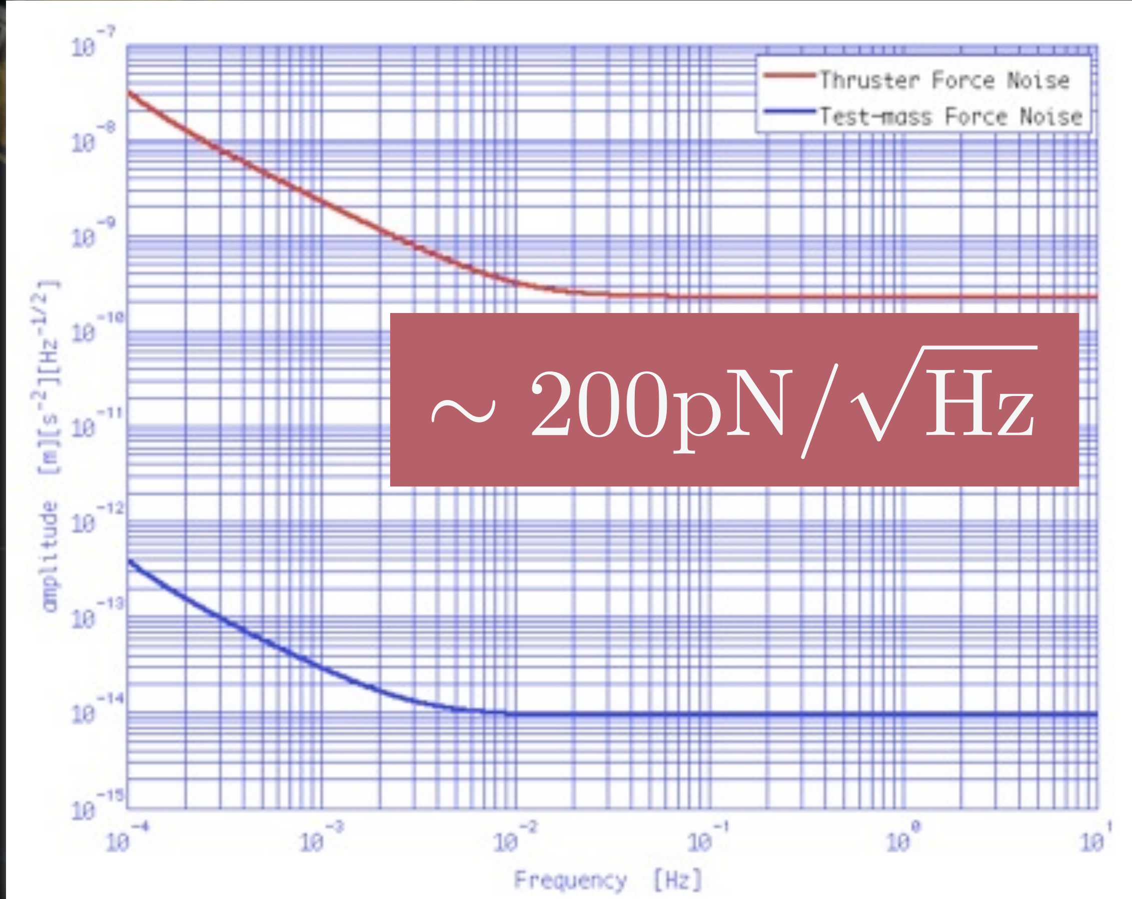

$$\sim 200\mathrm{pN}/\sqrt{\mathrm{Hz}}$$

Residual force noise on TMs

Environment forces acting on test-masses: radiometer, actuation, thermal, charging, magnetic, etc

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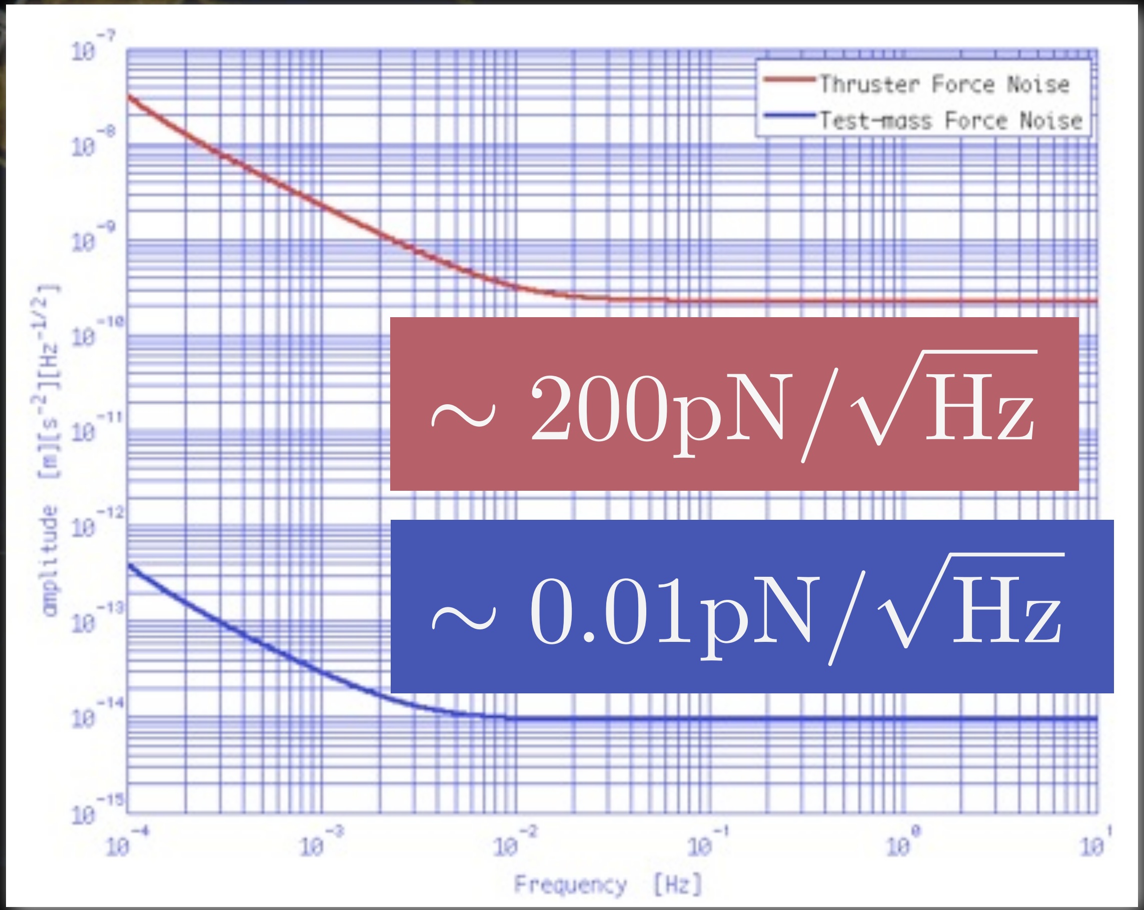

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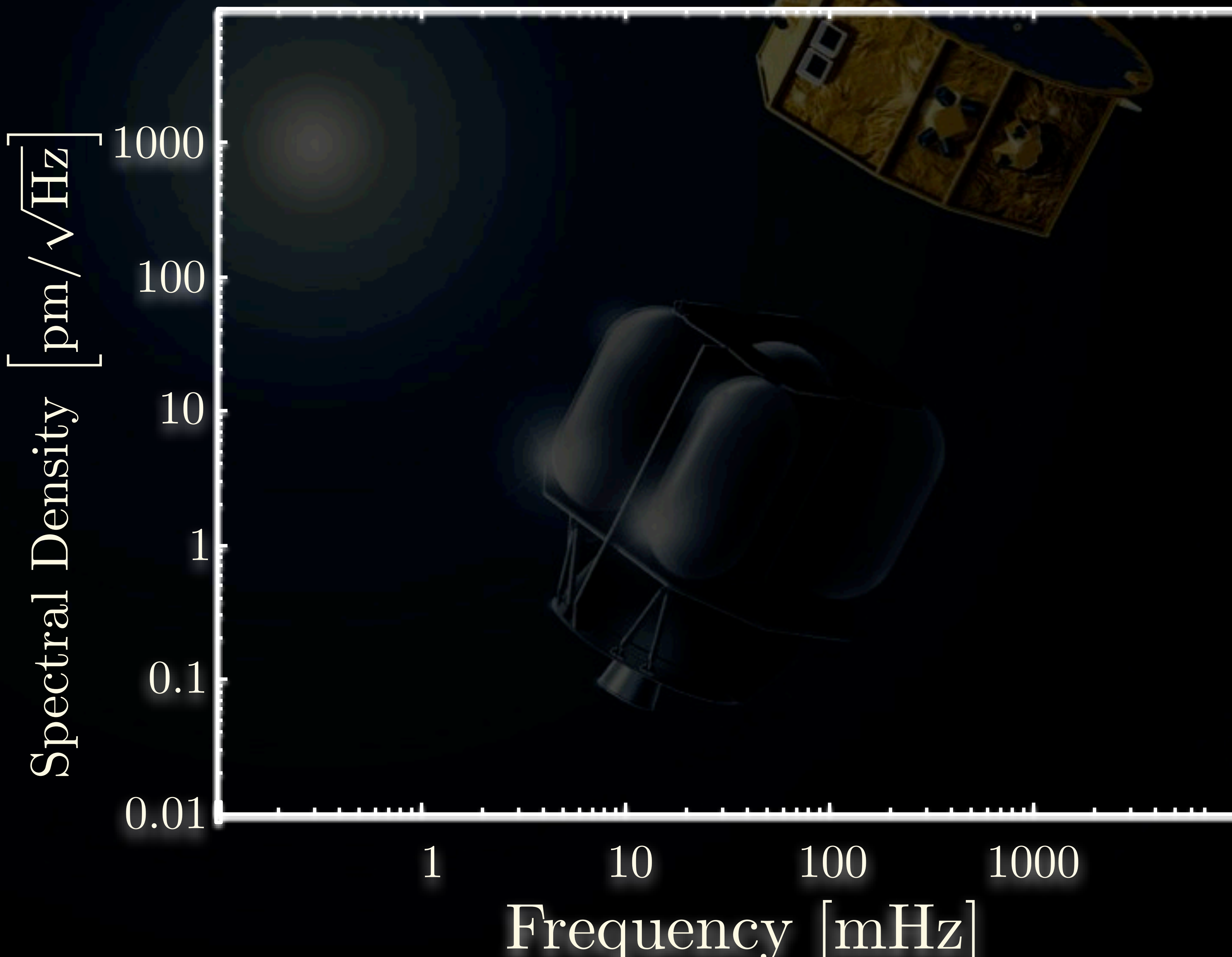
Noise budget - X1



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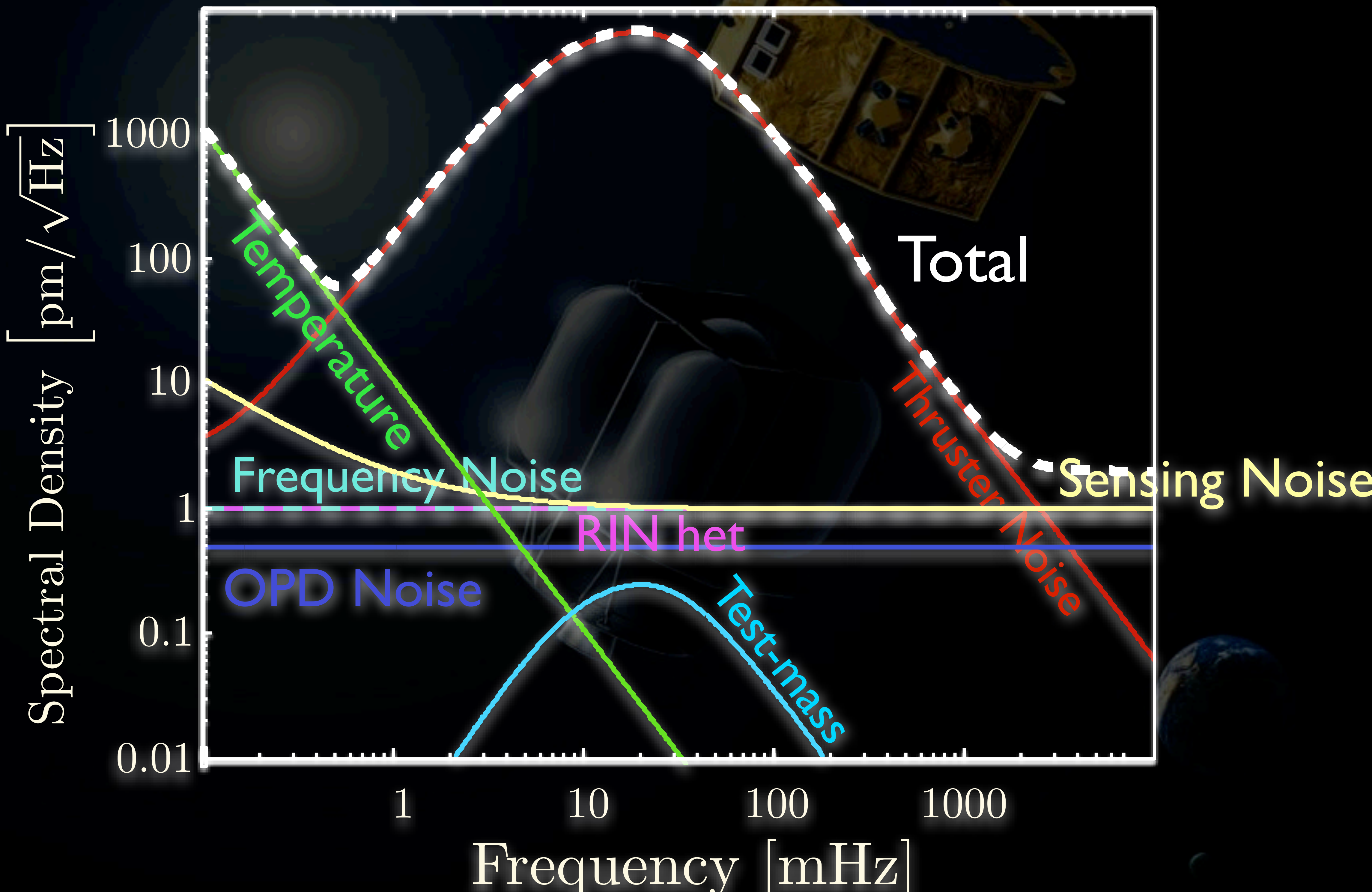

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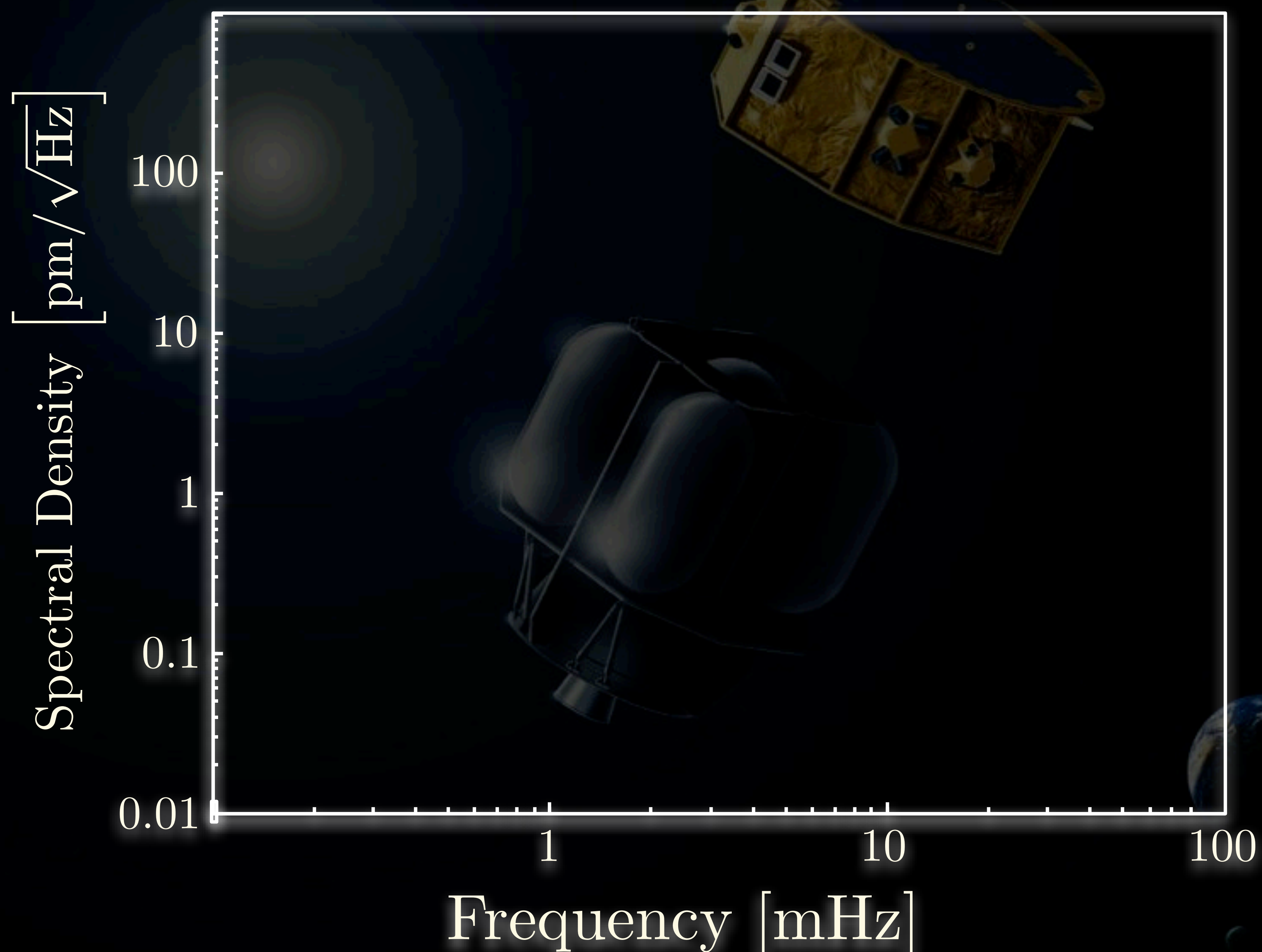
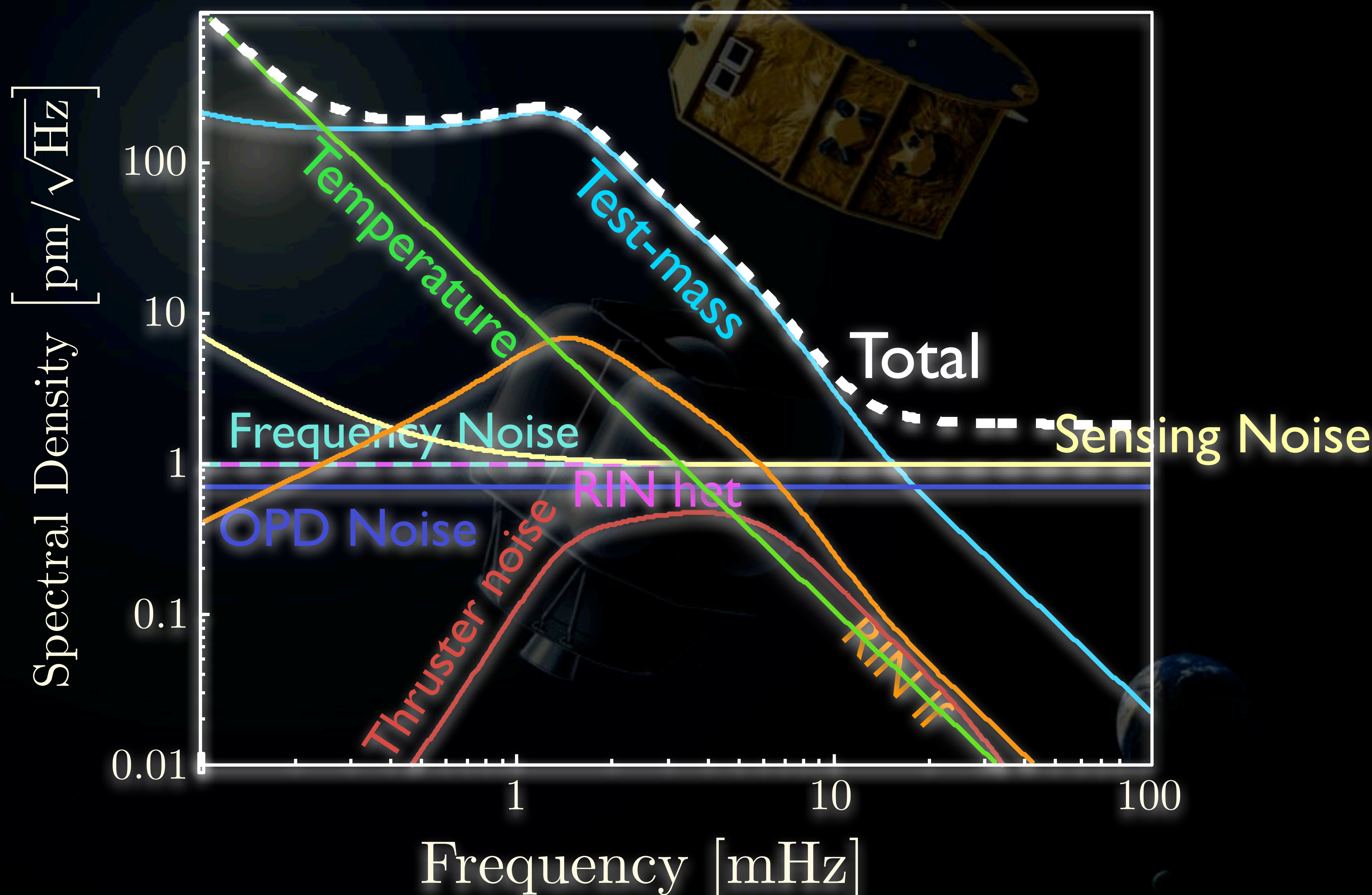
Noise Budget - X12



Noise Budget - X12



9

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Experiment Master Plan

Experiment Master Plan

- Mission will consist of about 90 runs
  - Each run lasts 24H
  - Each run may contain more or less than one investigation
  - Each run will be planned and tested in advance of the mission
  - A run may affect following run configurations
  - Analysis of each run must be carried out promptly to allow the mission time-line to be changed

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  - Analysis of each run must be carried out promptly to allow the mission time-line to be changed
- Designing a run involves
  - defining the experiment and goals
  - defining the state of instrument
  - design the analysis
  - calculate the expected result/sensitivity
  - perform simulations / MDCs

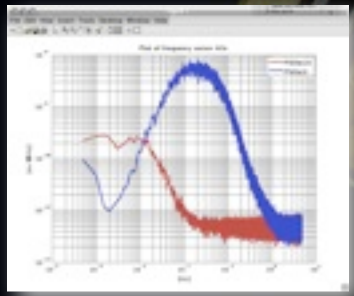
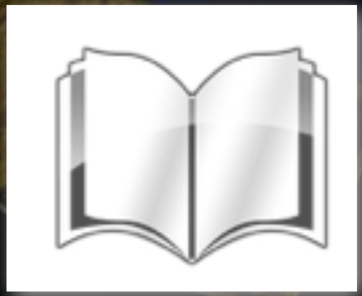
Data Analysis - Requirements

- Analysis is typical of commissioning and characterisation of ground-based detectors (except with limited/no access to the instrument)
- Multiple scientists to analyse data concurrently
  - centralised data access
- Analysis results need to have a long life to carry forward to LISA
  - an analysis result should contain a full processing history
- Mission will generate a large number of 'results'
  - searching for these with meta-data must be possible
- Graphical User Interface
  - avoid the need for 'programming' experts during the mission

Introducing LTPDA

- Object-oriented data analysis toolbox for MATLAB
- Concept of 'Analysis Objects' which track their processing history
- Toolbox contains a large number of 'standard' signal processing algorithms which all work on AOs
- LTPDA Repository for storing AOs
- Client/server system allows access to AOs in repository directly from within MATLAB
- Graphical programming via drag-n-drop pipeline construction

Analysis Objects

- Not results:   

Analysis Objects

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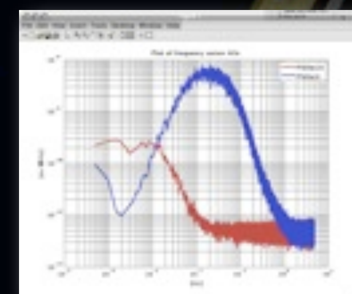

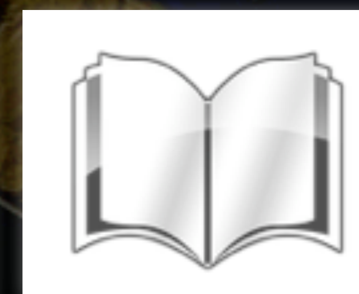

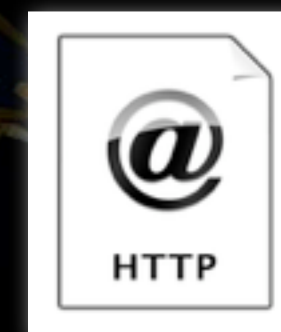

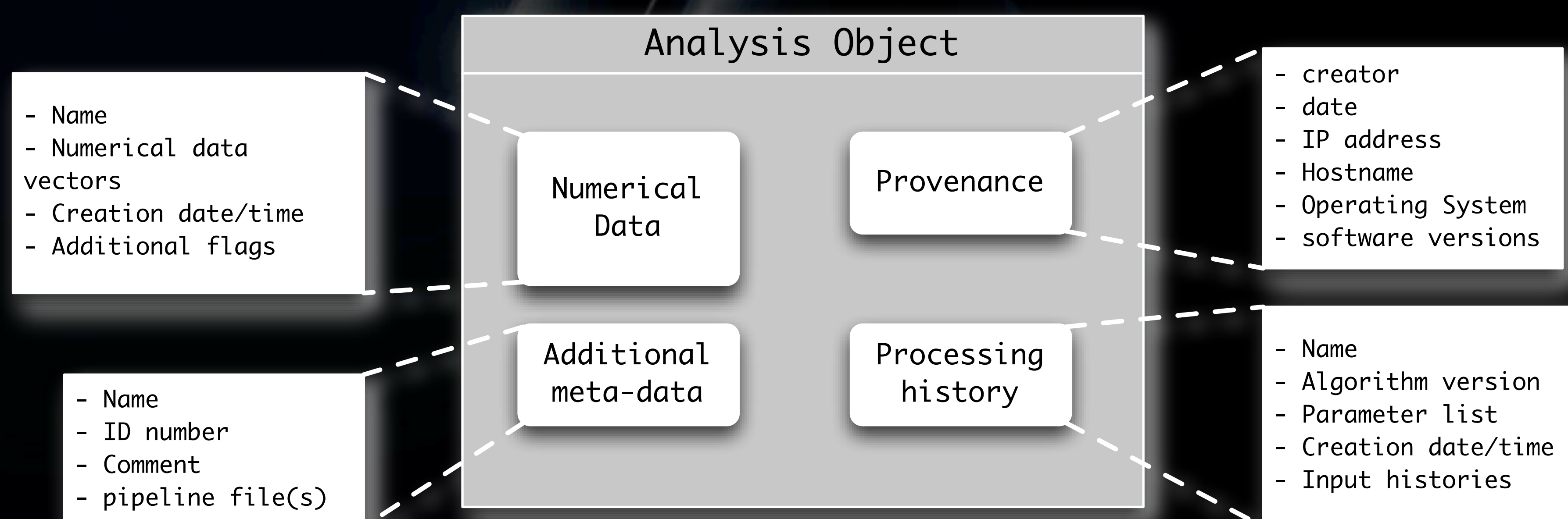

Tracking history

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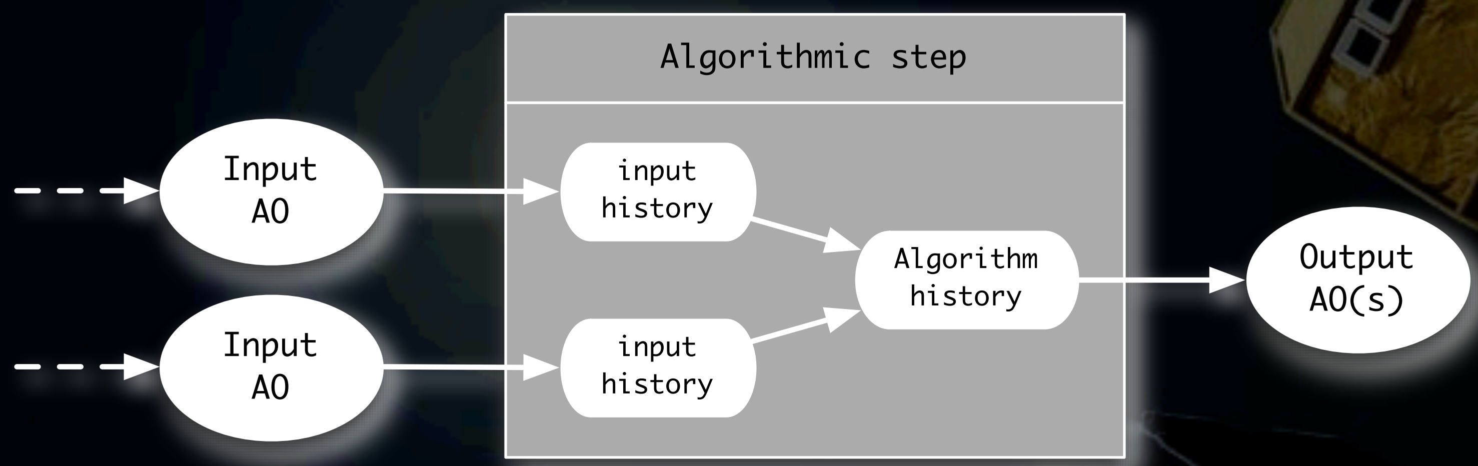
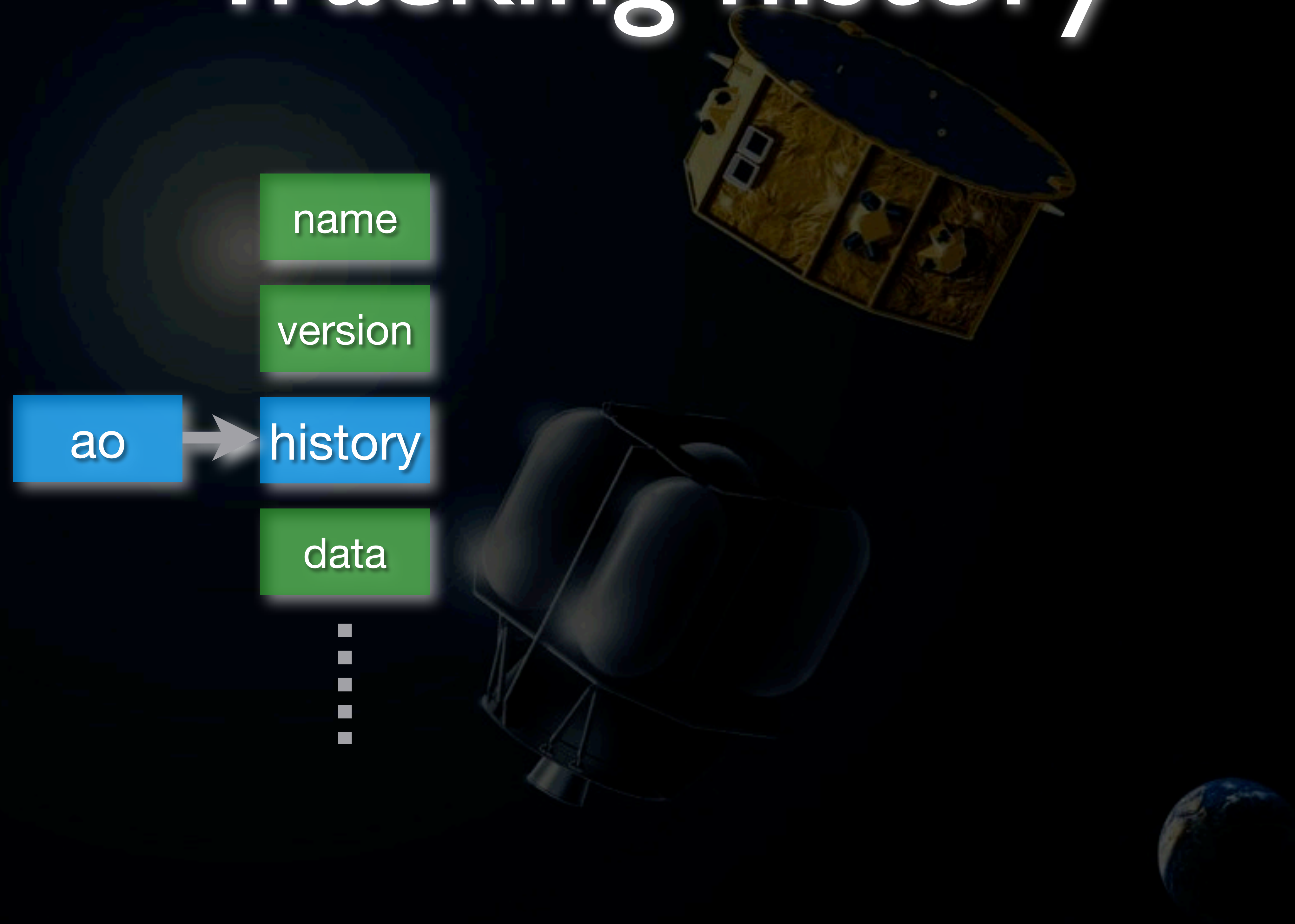


Tracking history

ao

Tracking history



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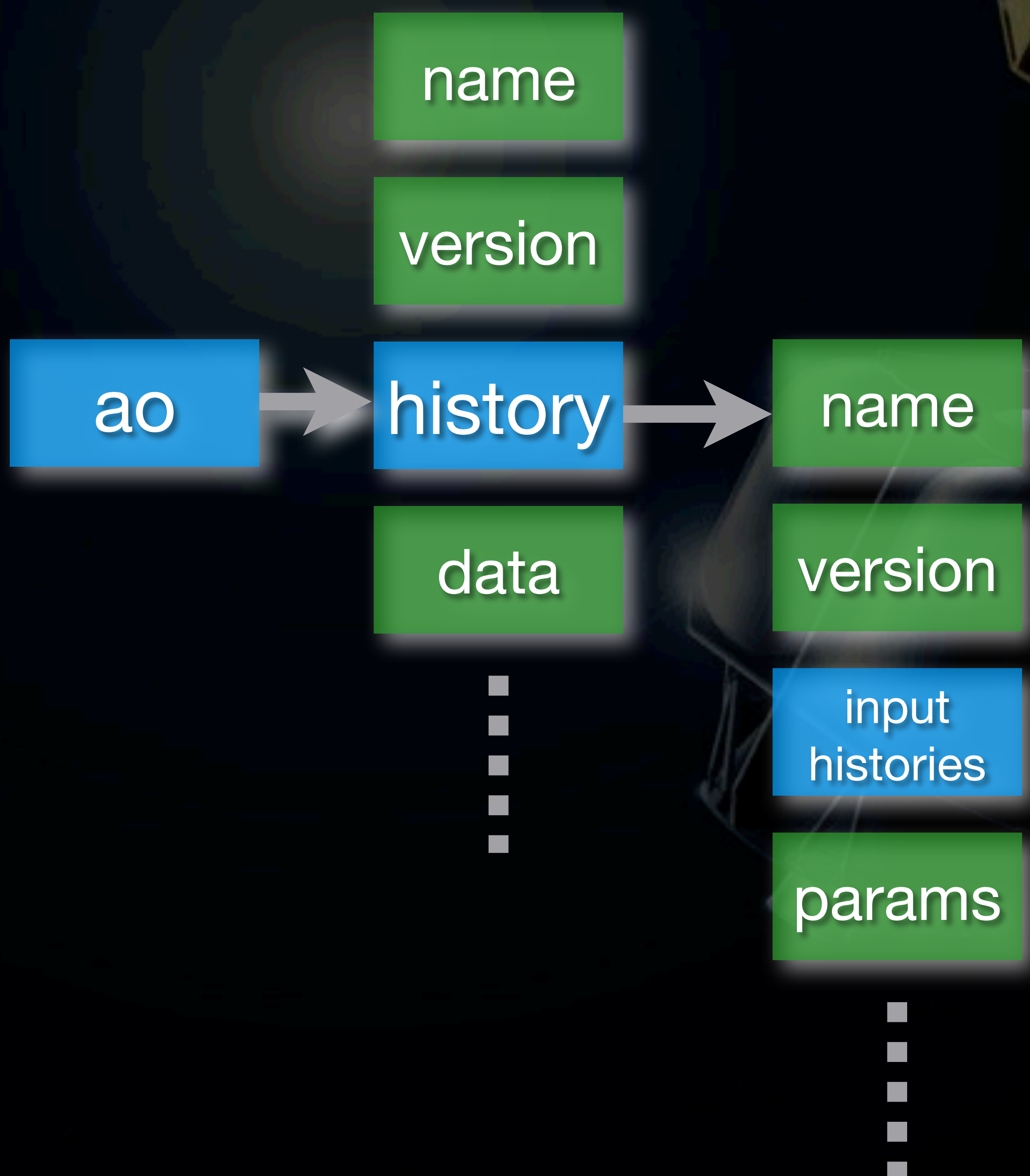

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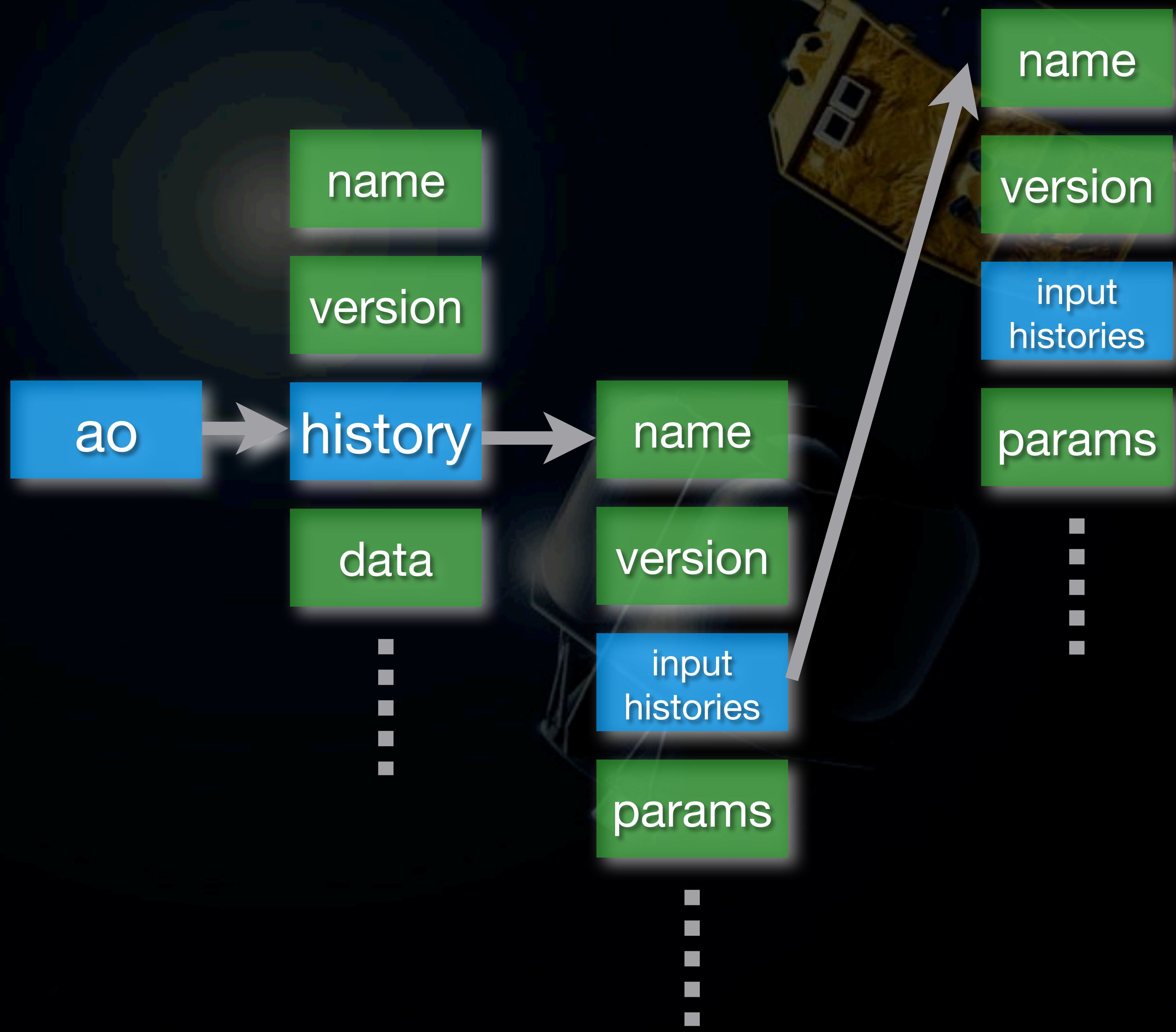

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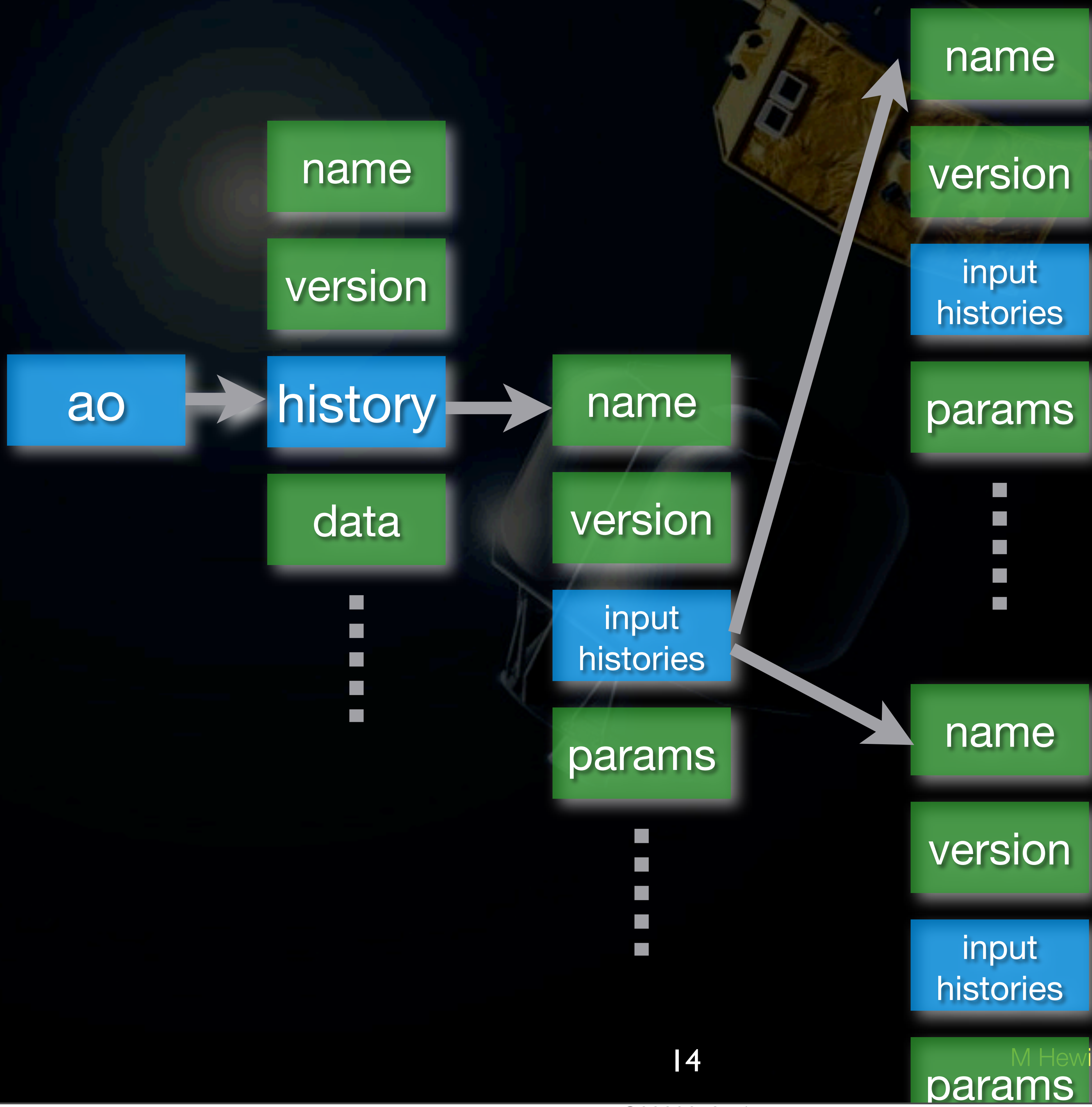

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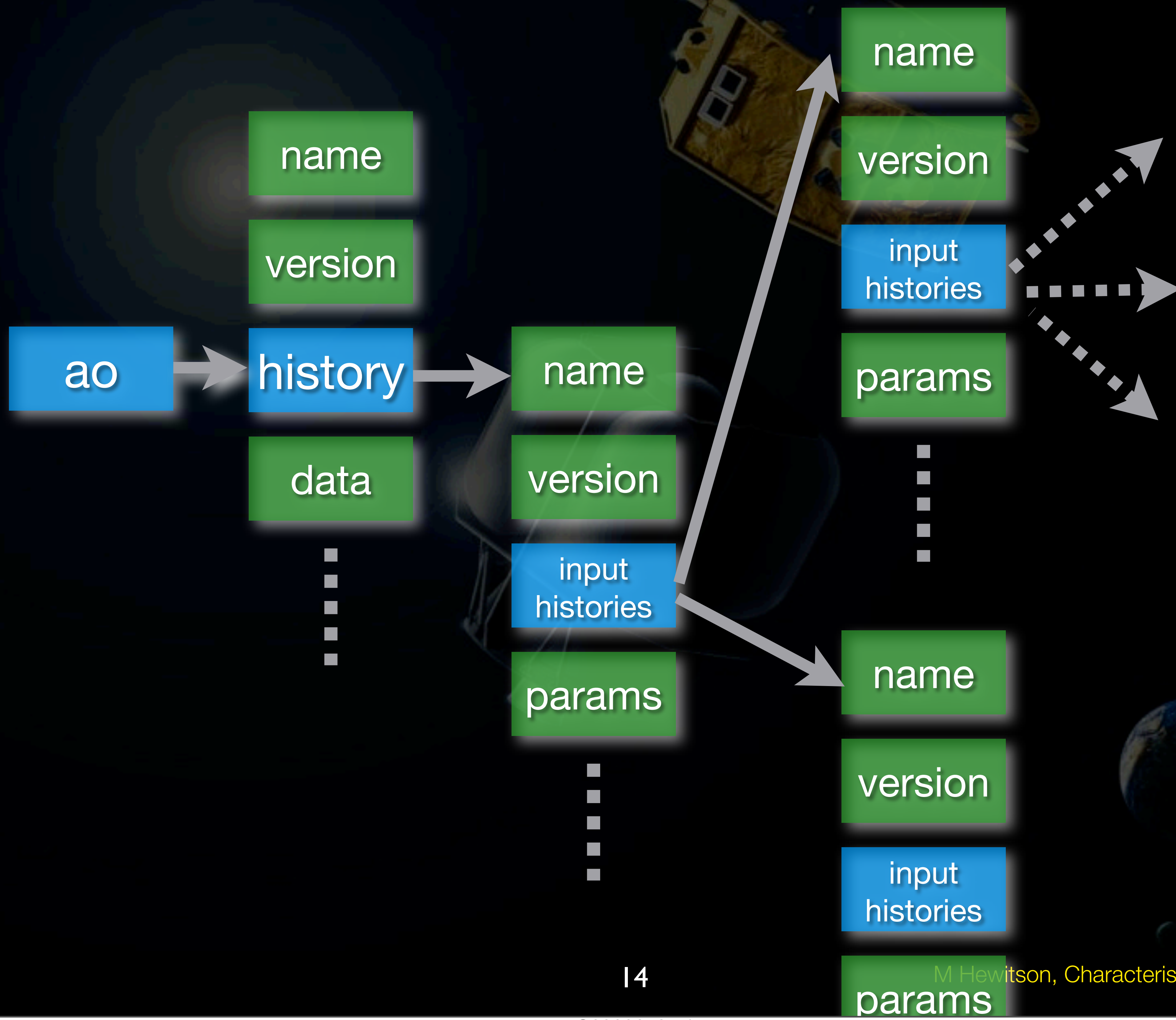

Reliving history

- rebuild objects
- produce block-diagrams from objects
- produce scripts from objects
- view history tree

Reliving history

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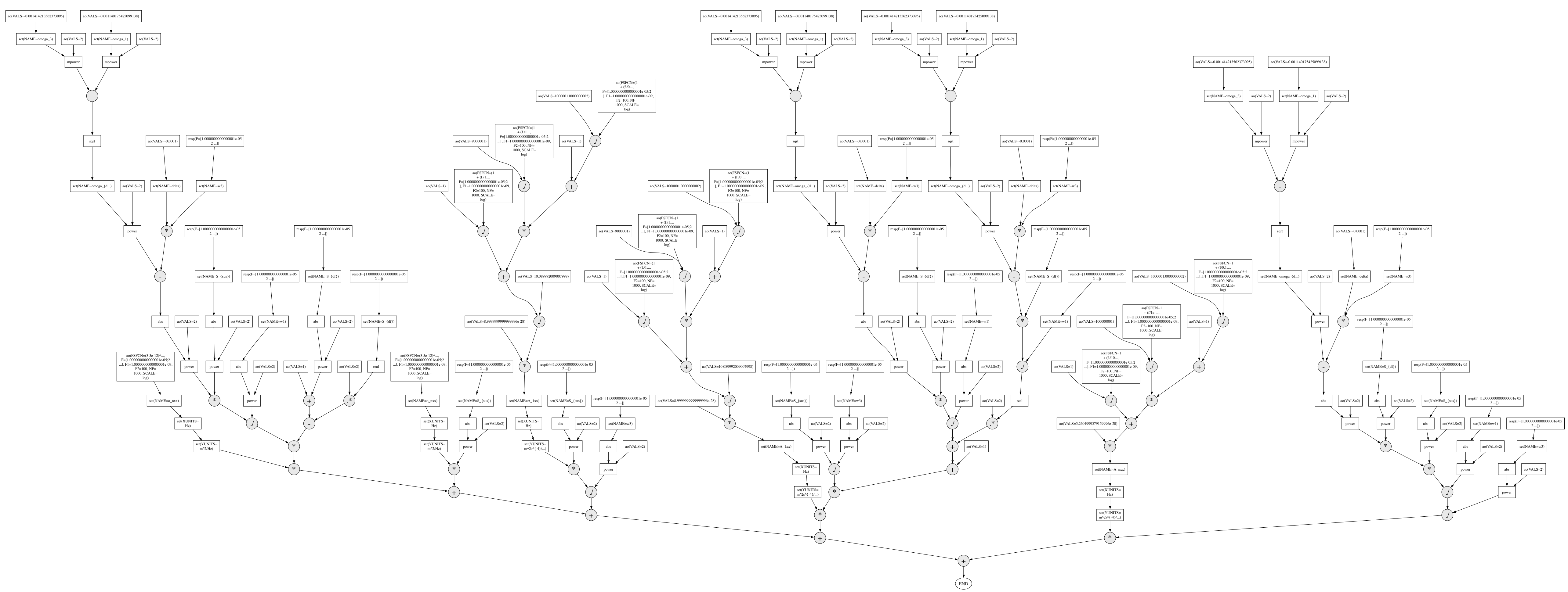
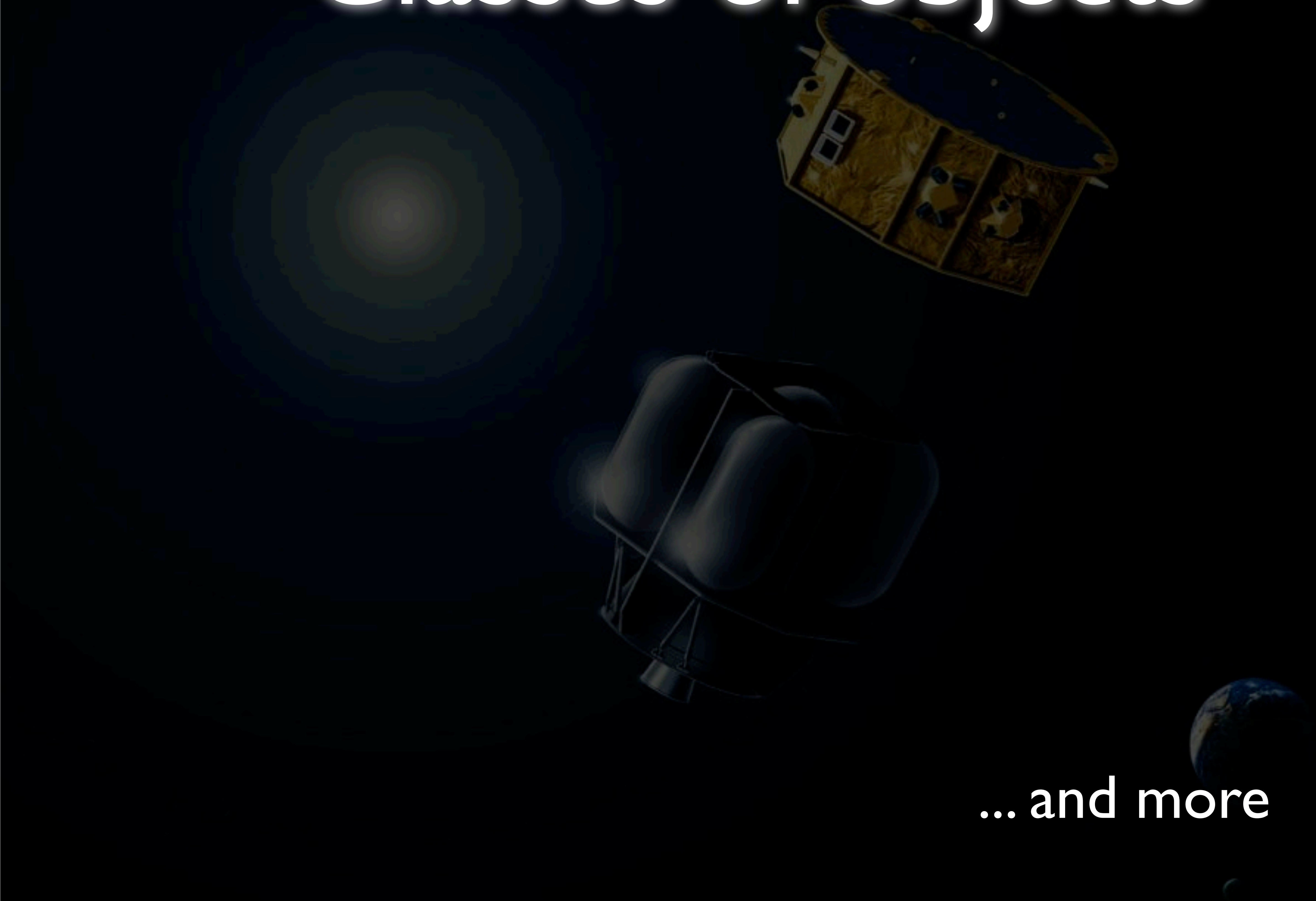
- produce block-diagrams from objects



Classes of objects



... and more

Classes of objects

AO

Objects containing different data series: time-series, frequency-series, x-y data, etc

abs	gapfilling	acos
angle	rebuild	report
resample	asin	rms
heterodyne	sDomainFit	ifft
interp	iplot	corr
lincom	cpsd	curvefit
spectrogram	detrend	downsample
filter	whiten1D	polyfit
zDomainFit	zeropad	psd

ssm

Objects describing state-space systems

pzmodel

Objects describing a pole/zero system

ltpdamodel

Objects which describe parametric models, eg, y=ax+b

miir/mfir

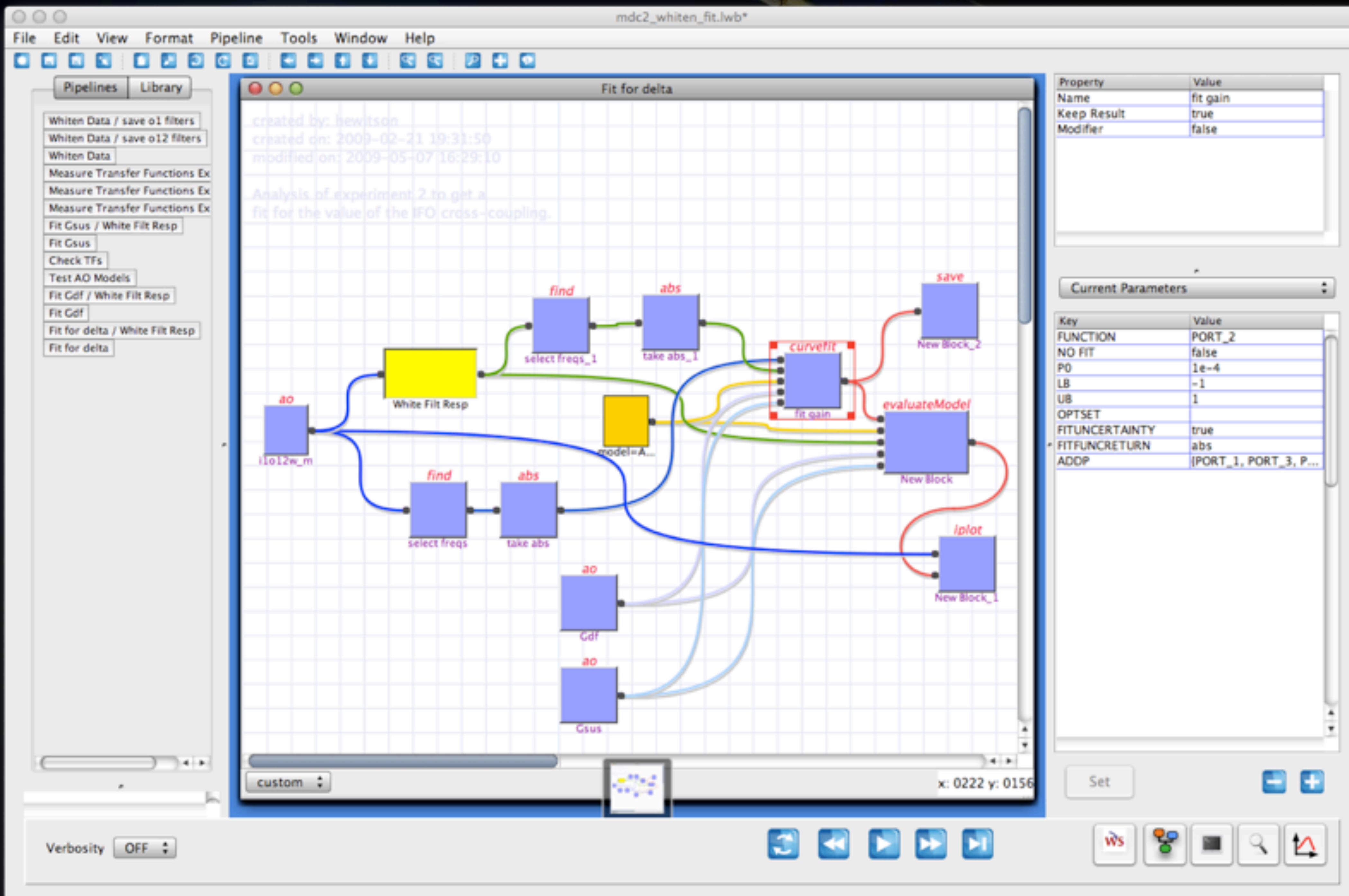
Objects describing an IIR/FIR filters

... and more

Graphical Design

- Use a drag-n-drop based pipeline construction method
- Pipeline just executes underlying LTPDA functions

Graphical Design



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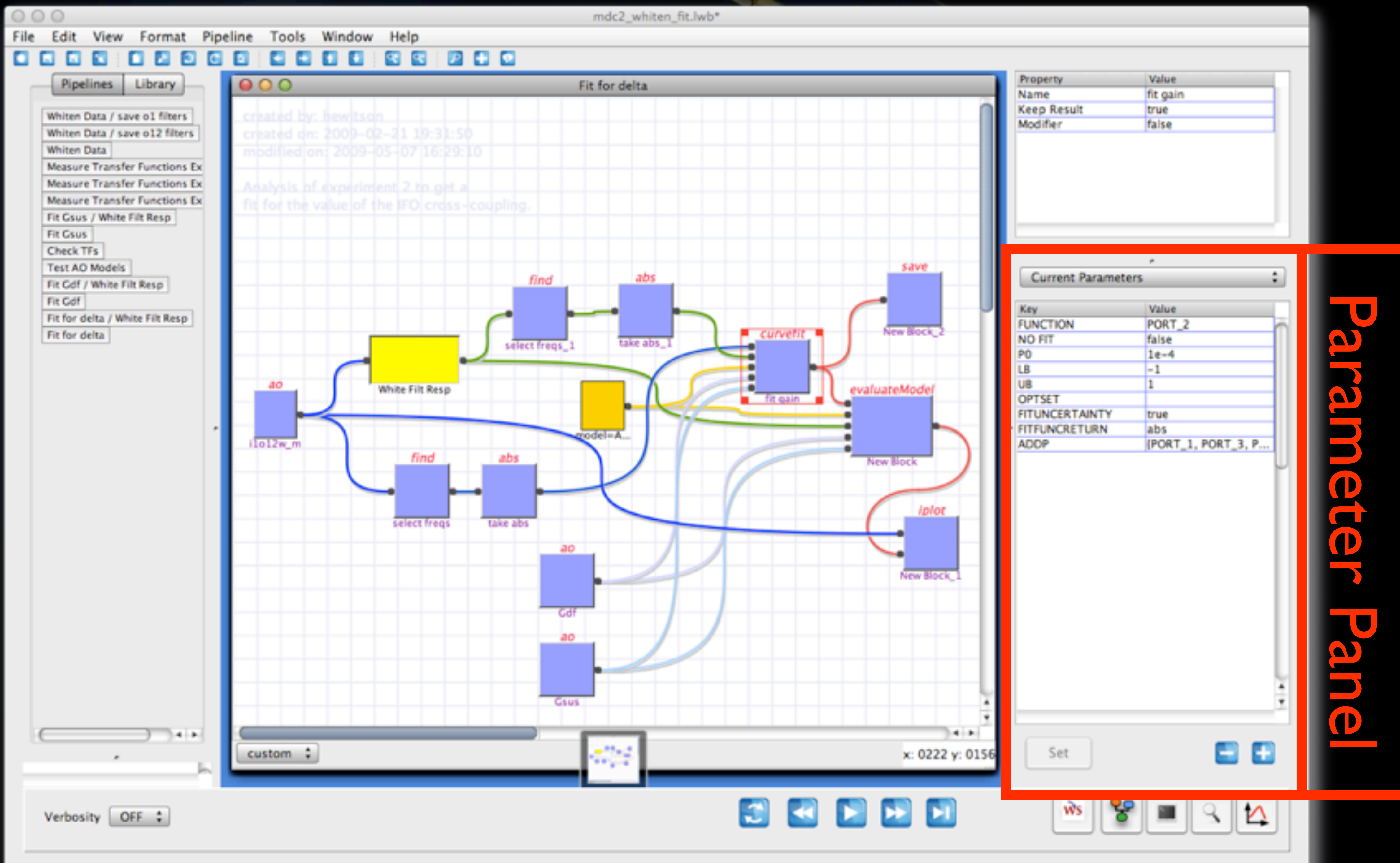

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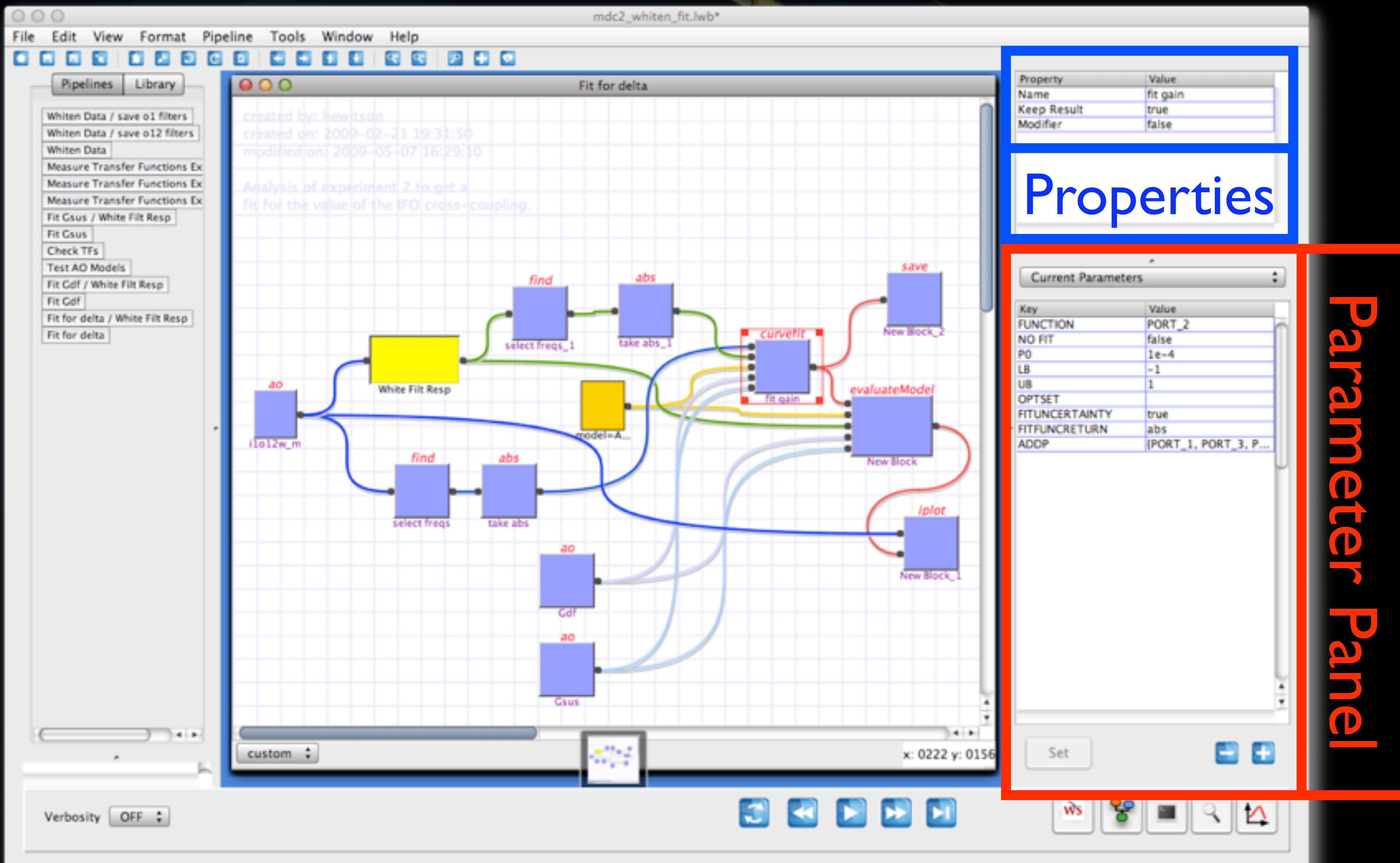

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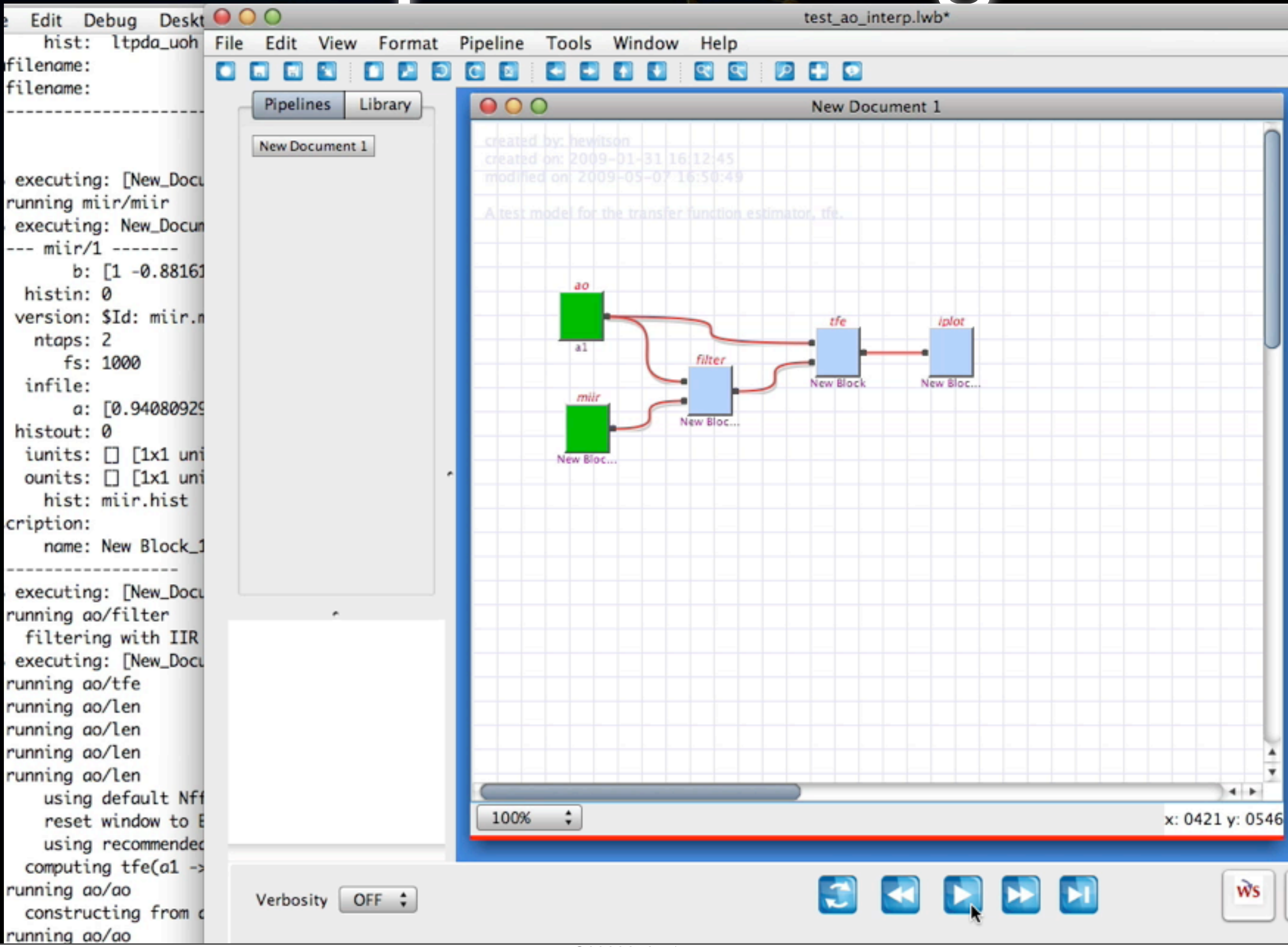

Get it now!

http://www.lisa.aei-hannover.de/ltpda/

Mock Data Challenges

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- We use mock data challenges (MDCs) to

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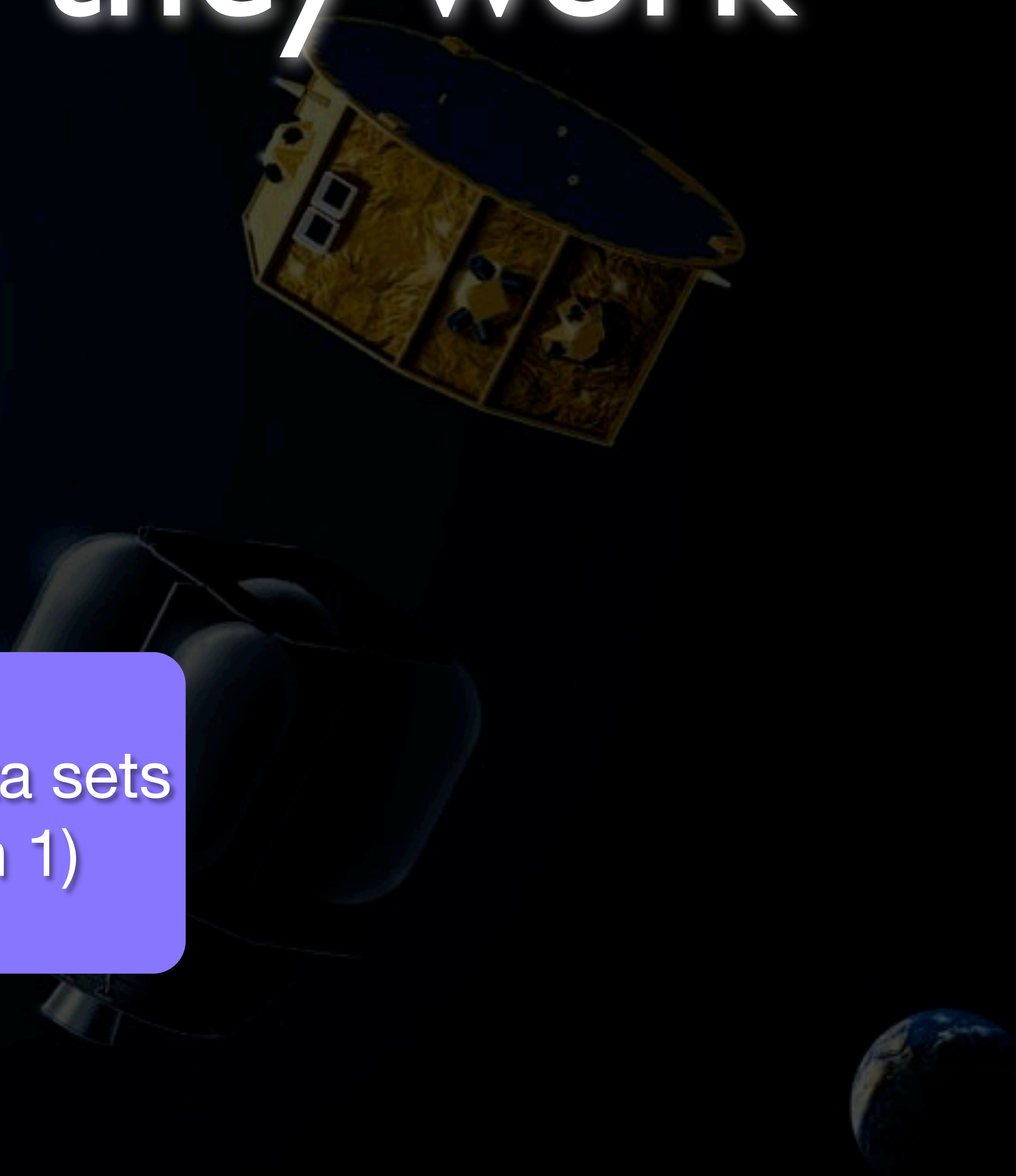
  - train scientists

How they work

1 Define MDC model(s), assumptions, etc

How they work



1 Define MDC model(s), assumptions, etc

2 Produce data sets based on 1)

How they work

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3 Analyse data (based on some details from 1)

How they work

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2 Produce data sets based on 1)

3 Analyse data (based on some details from 1)

4 Compare results to expected

MDC1

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- Simple model of LTP (x-axis dynamics)

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- Simple model of LTP (x-axis dynamics)
- Data generation
  - Model is based on 5 parameters of the system
    - stiffness of two test-masses, gains of two control servos, cross-coupling in IFO from X1 to X12
  - Generate two IFO output time-series

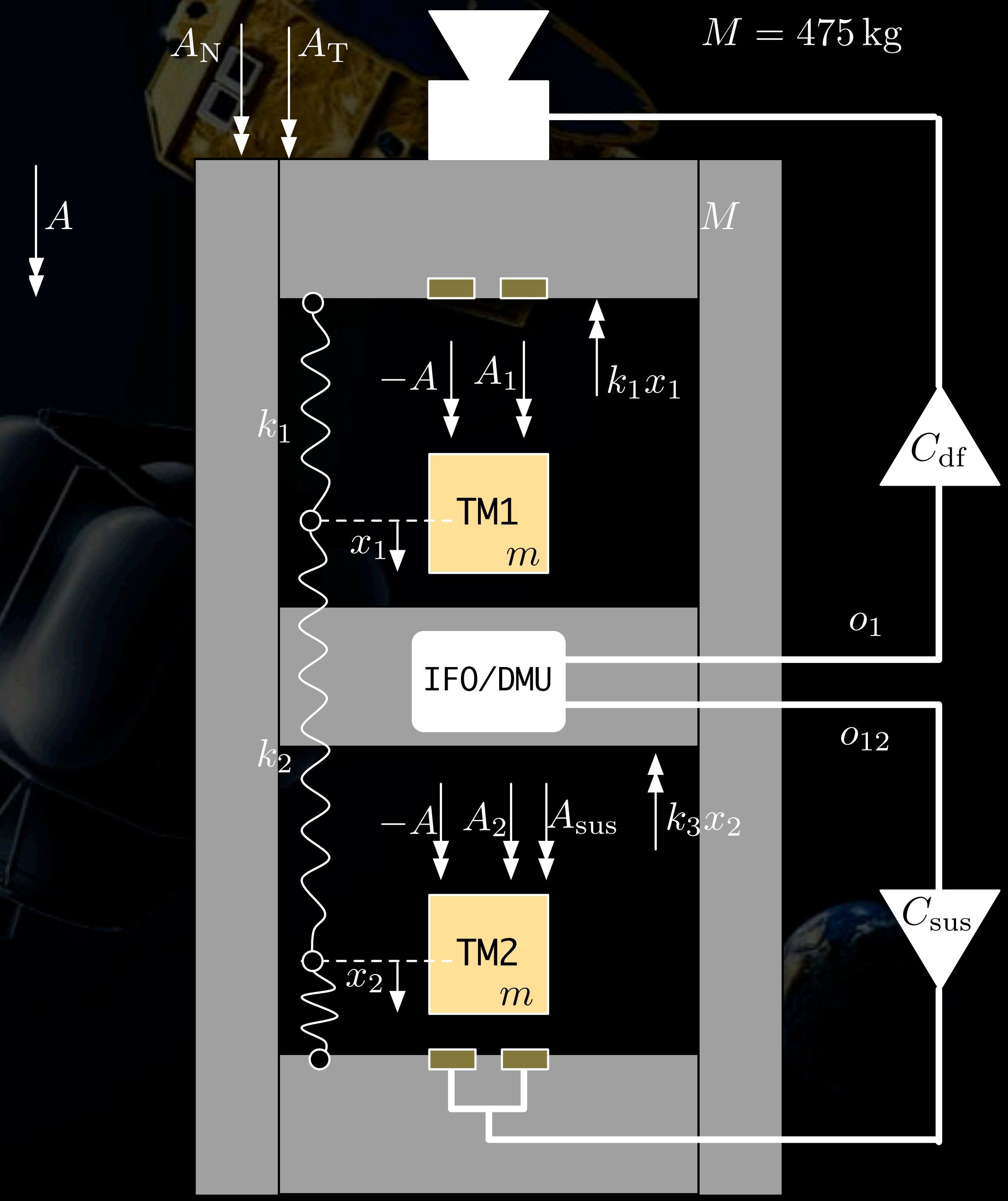
MDC1

- Simple model of LTP (x-axis dynamics)
- Data generation
  - Model is based on 5 parameters of the system
    - stiffness of two test-masses, gains of two control servos, cross-coupling in IFO from X1 to X12
  - Generate two IFO output time-series
- Data analysis
  - convert the two IFO outputs to out-of-loop acceleration
    - convert each to in-loop acceleration
    - account for control forces

The model

$m_1 = m_2 = 1.96\,\mathrm{kg}$

$M = 475\,\mathrm{kg}$



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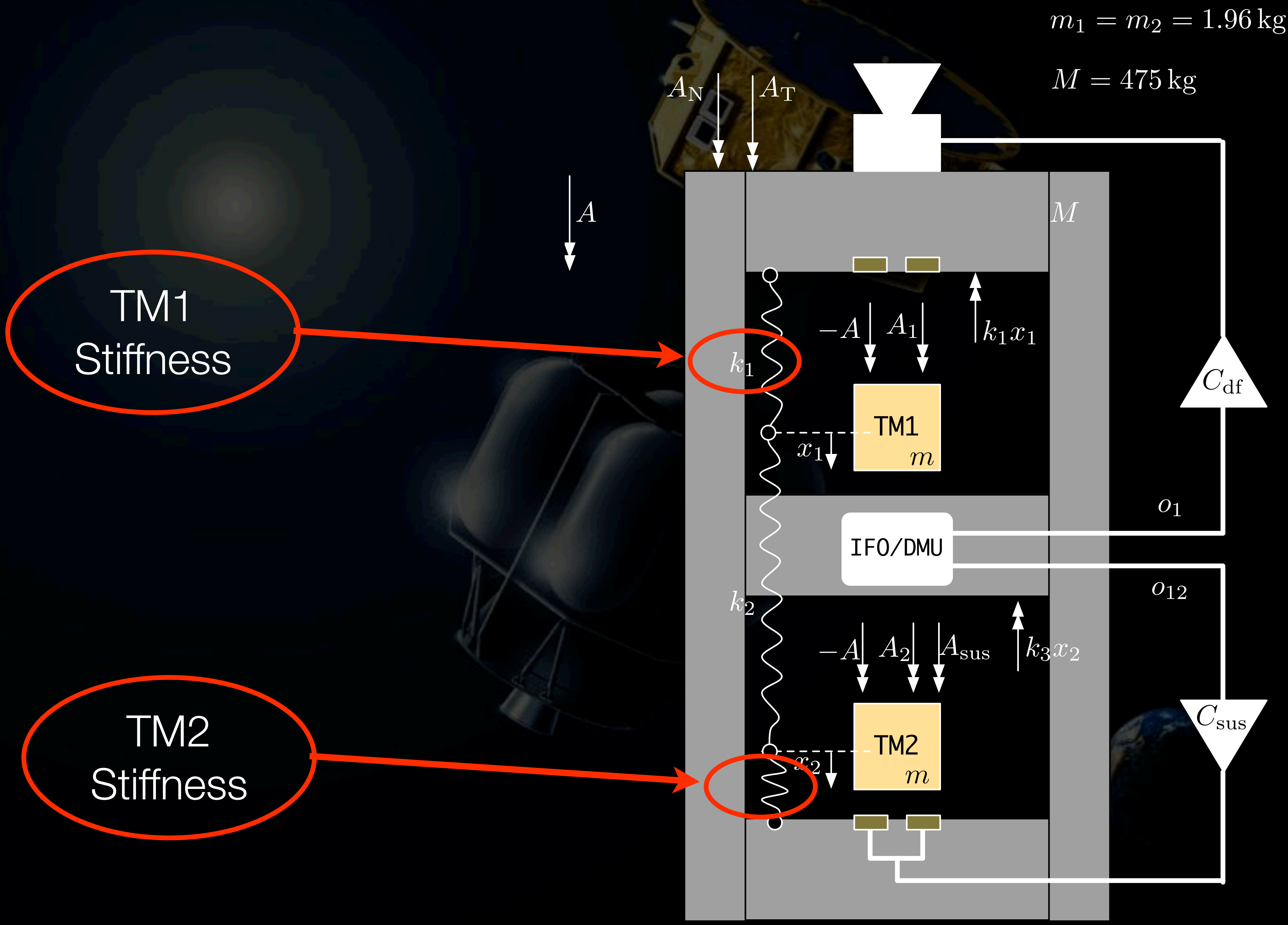

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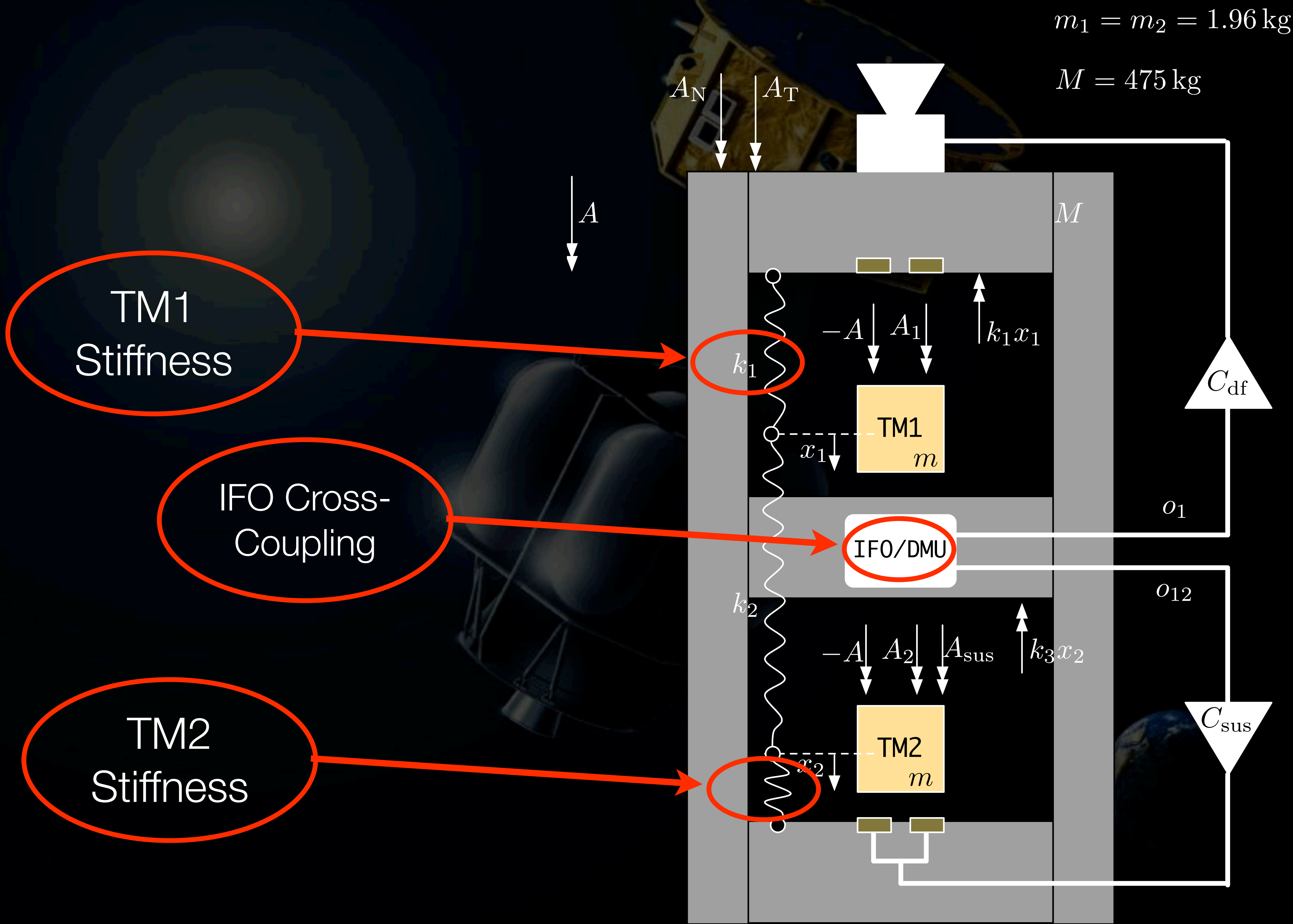
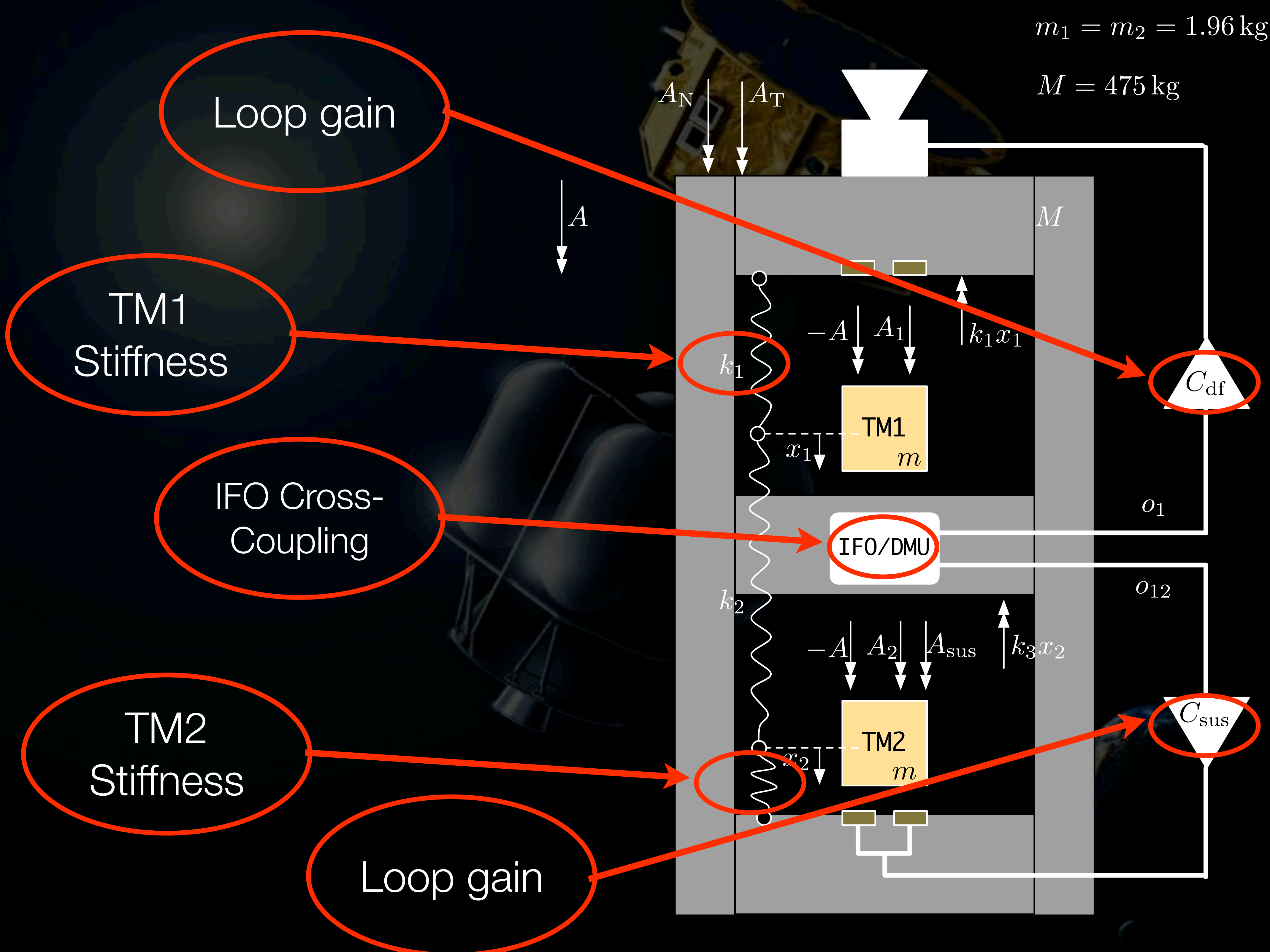


$m_1 = m_2 = 1.96\,\mathrm{kg}$
$M = 475\,\mathrm{kg}$
A_N
A_T
A
M
TM1 Stiffness
k_1
$-A$
A_1
$k_1 x_1$
C_{df}
TM1
x_1
m
IFO Cross-Coupling
o_1
IFO/DMU
o_{12}
k_2
$-A$
A_2
A_{sus}
$k_3 x_2$
C_{sus}
TM2 Stiffness
TM2
x_2
m

The model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Loop gain
TM1 Stiffness
IFO Cross-Coupling
TM2 Stiffness
Loop gain
A_N
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A
M
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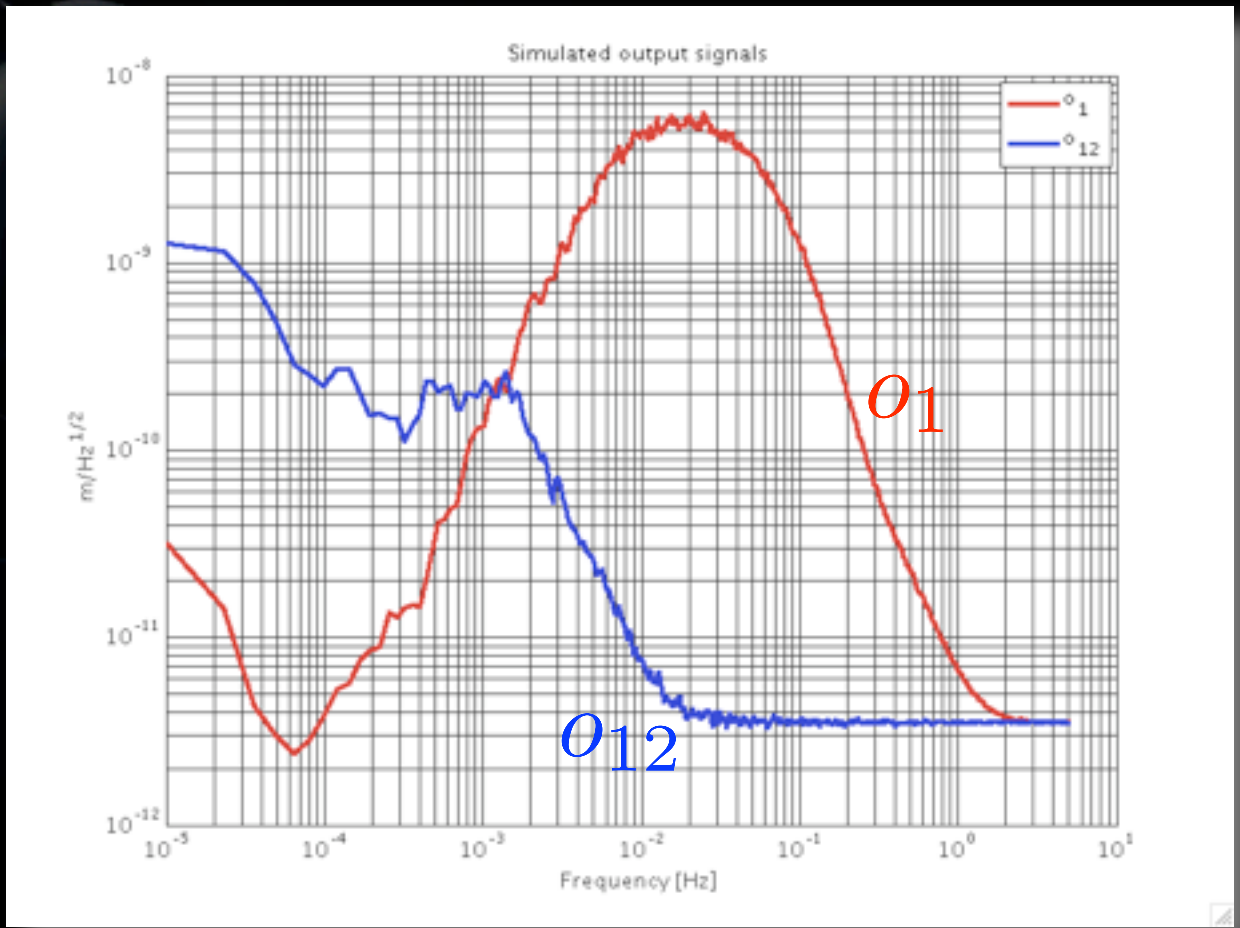
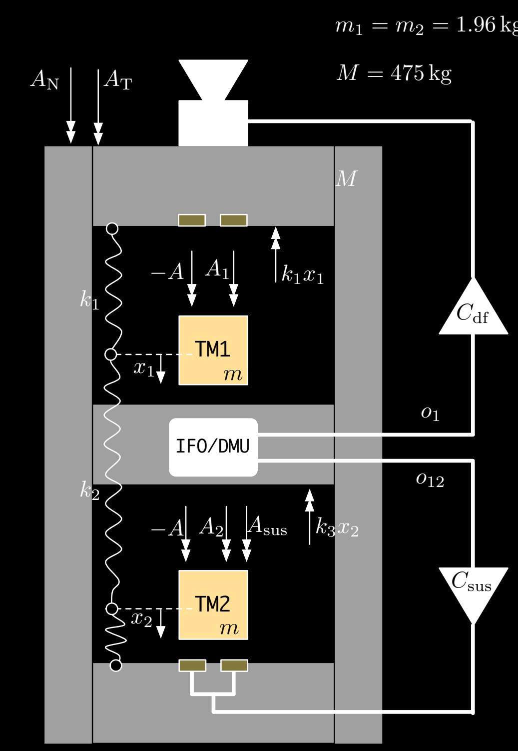
A_1
$k_1 x_1$
k_1
C_{df}
TM1
x_1
m
o_1
IFO/DMU
o_{12}
k_2
$-A$
A_2
A_{sus}
$k_3 x_2$
C_{sus}
TM2
x_2
m

Data generation

- Frequency-domain analytical model of transfer functions
- Fit sets of digital filters to the transfer functions
- Filter white-noise time-series to produce simulated IFO outputs



Control loops



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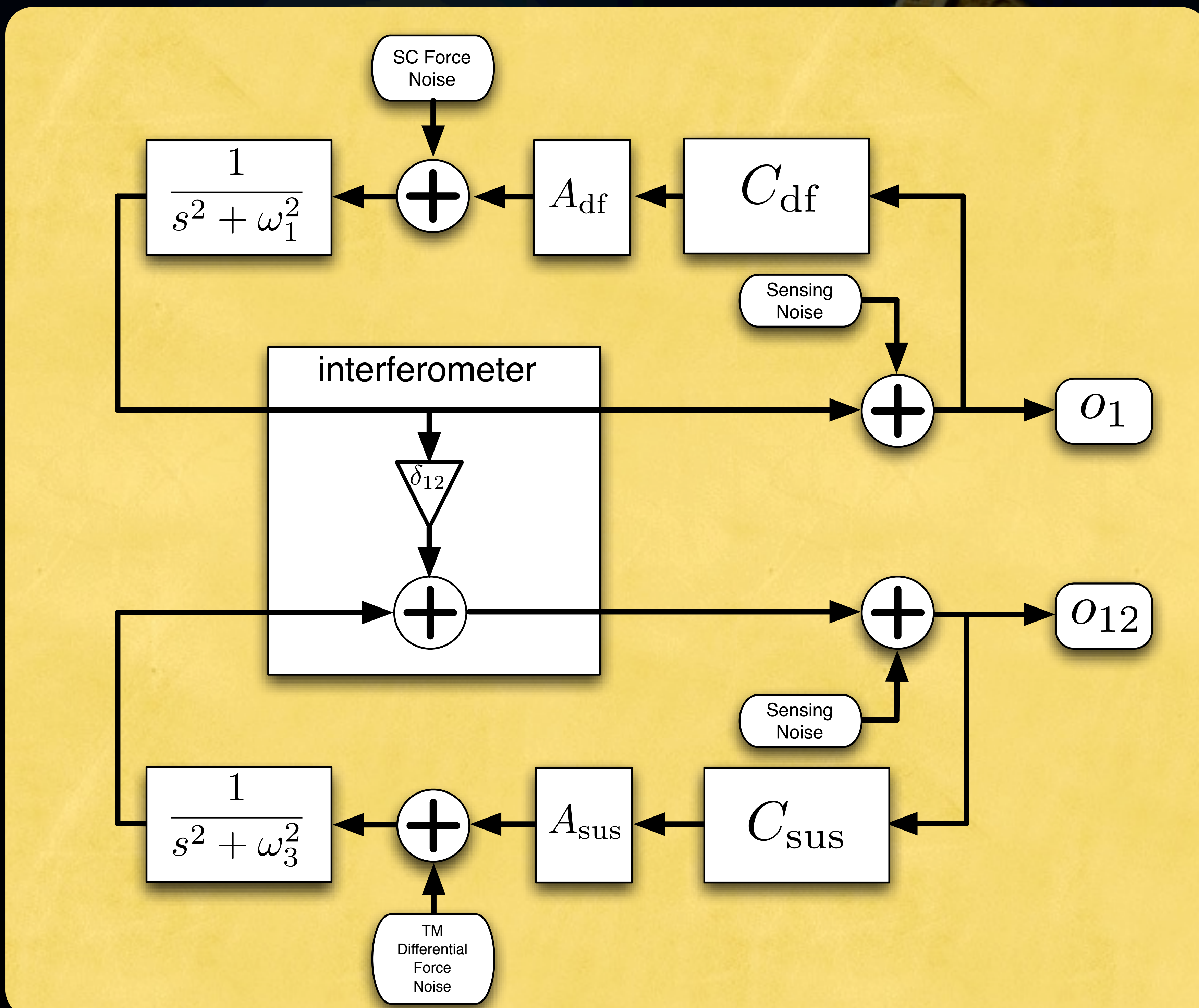
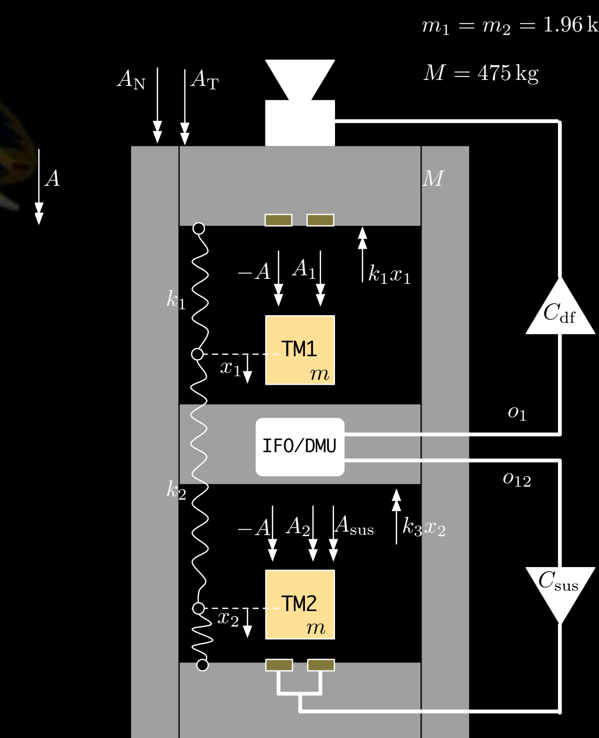
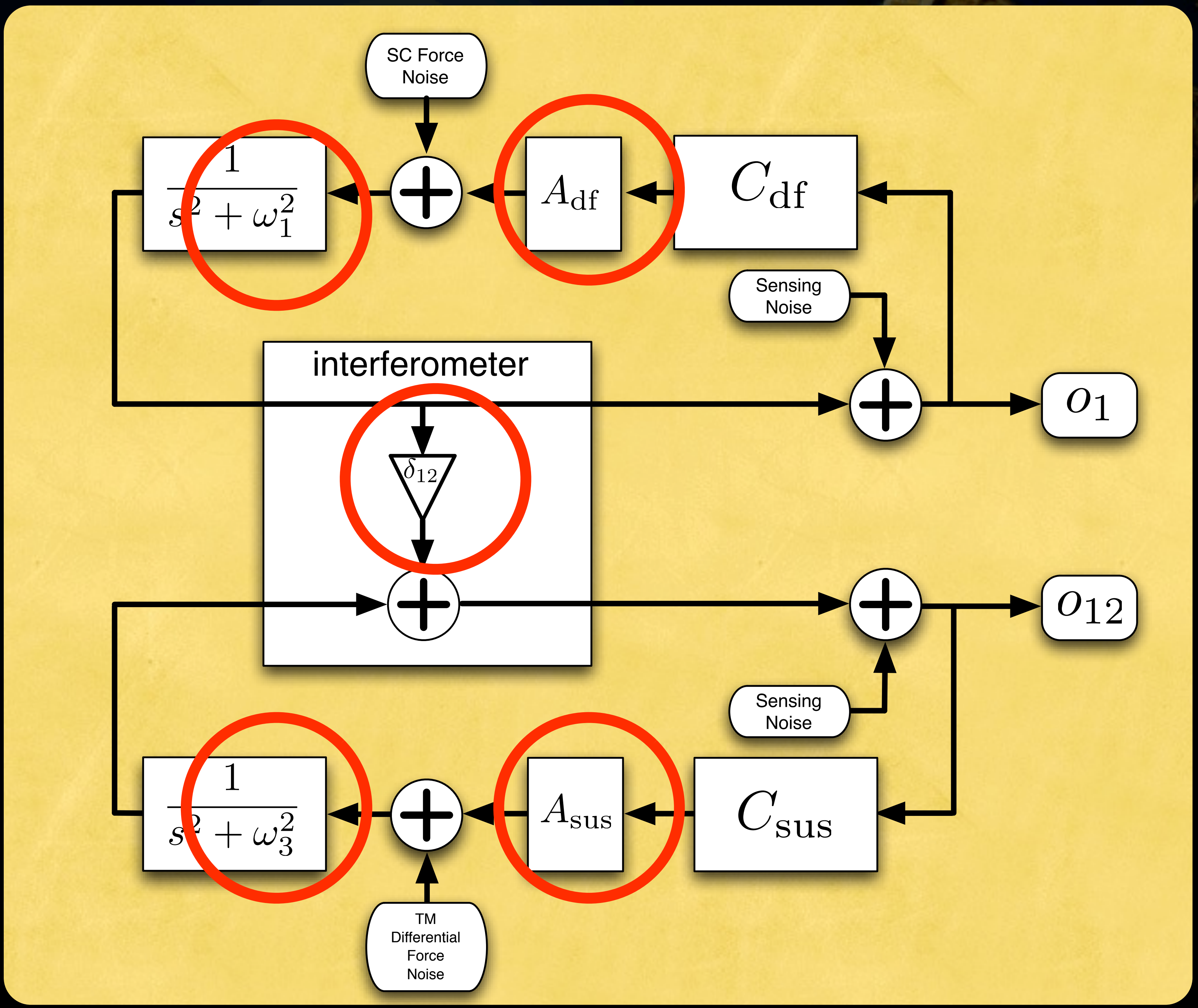
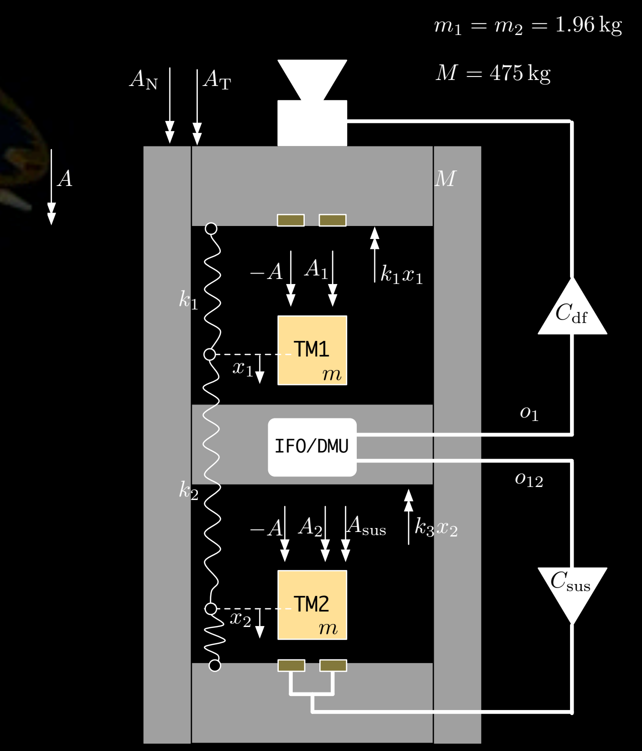




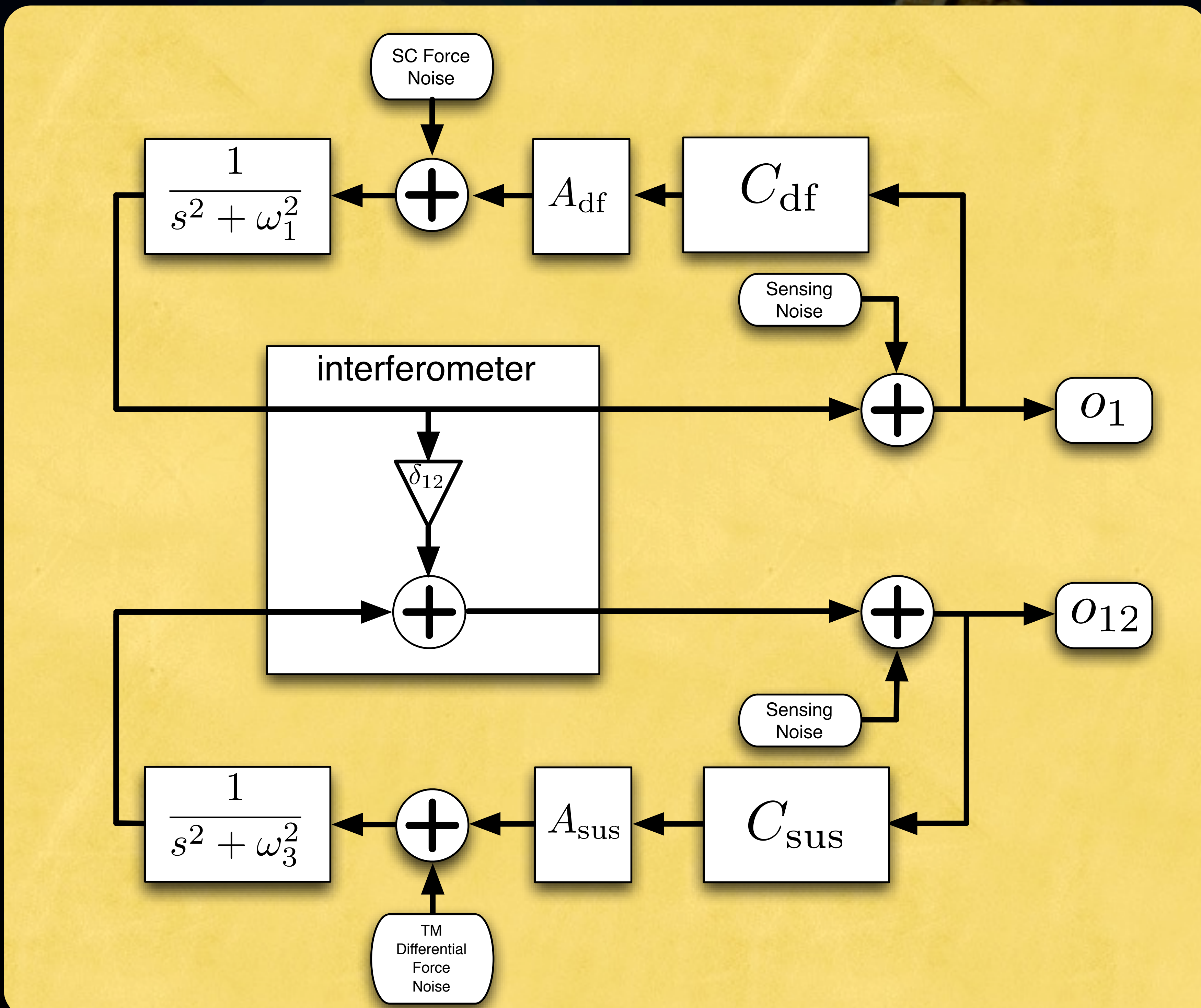
Control loops

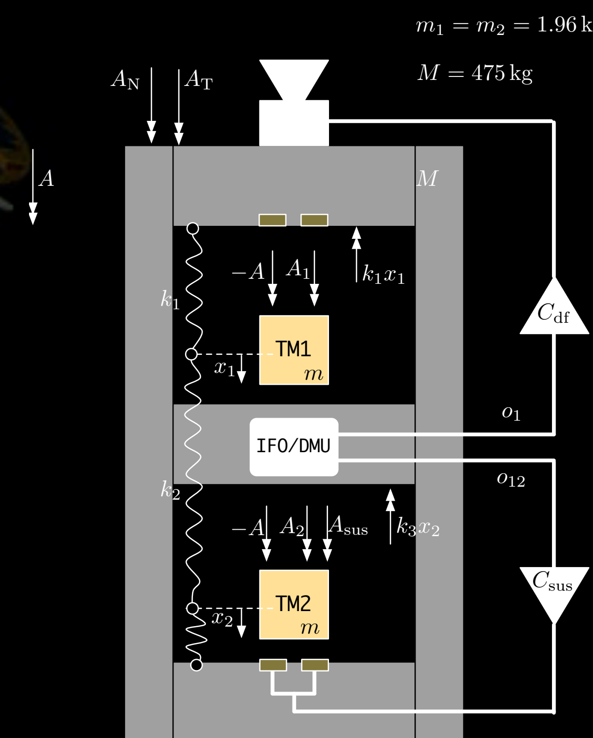




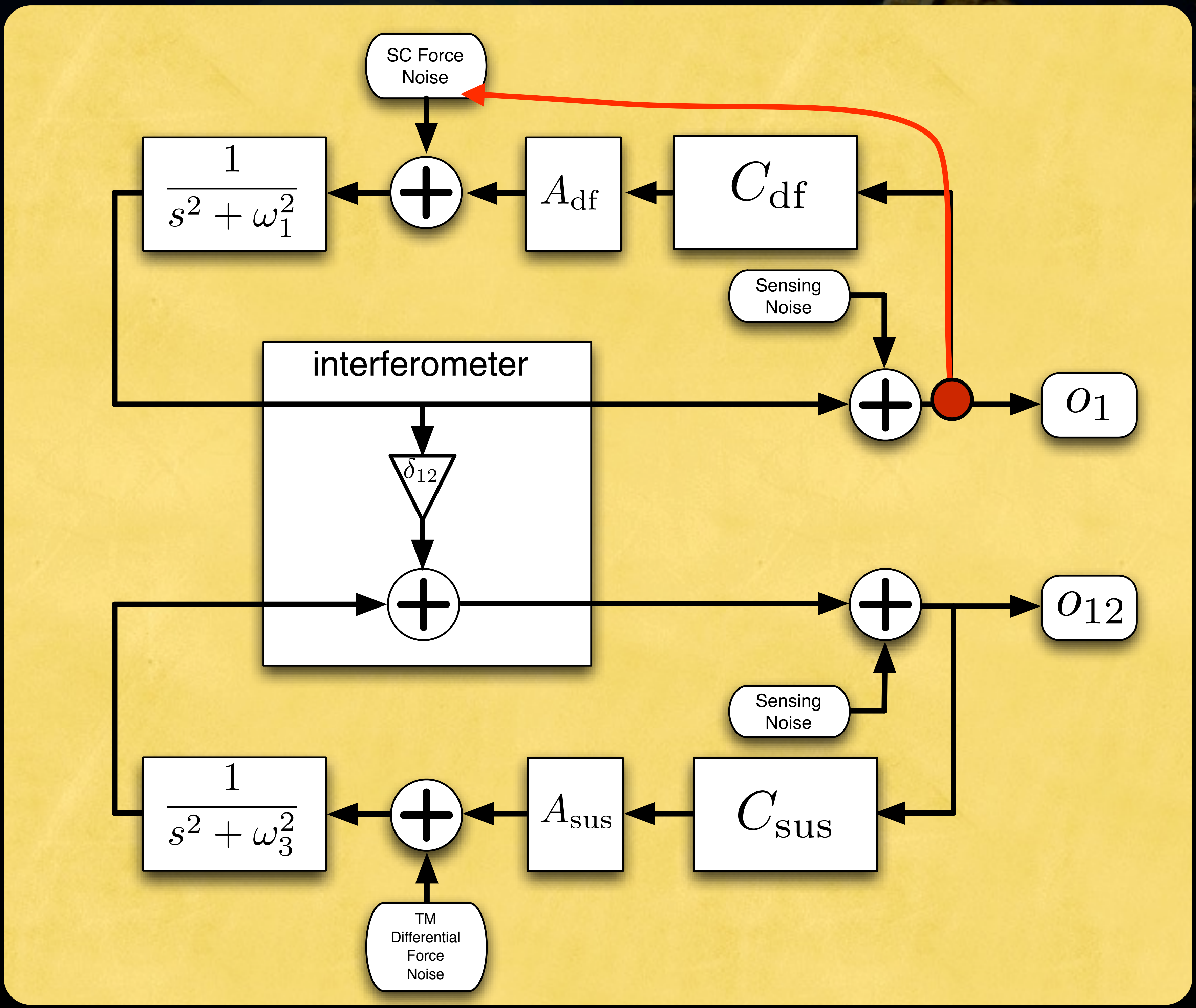
M Hewitson, Characterisation of LTP, GWADW, 2009

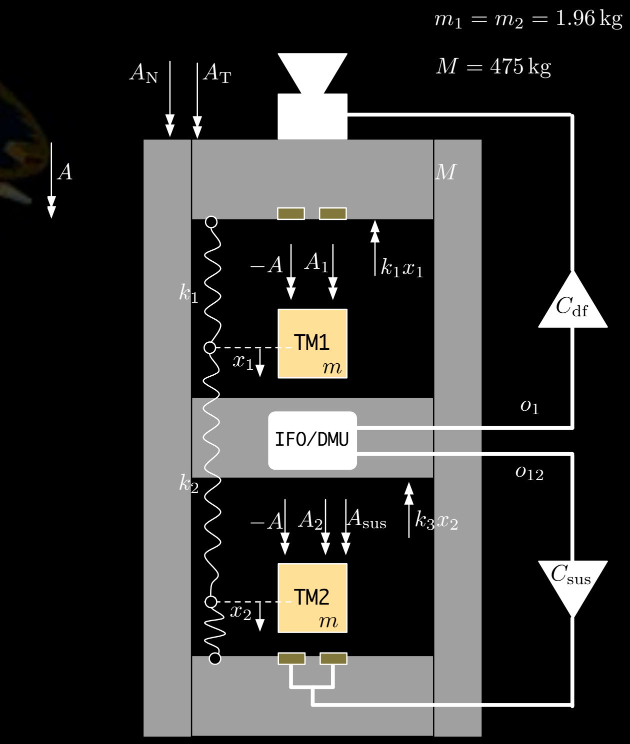
Control loops



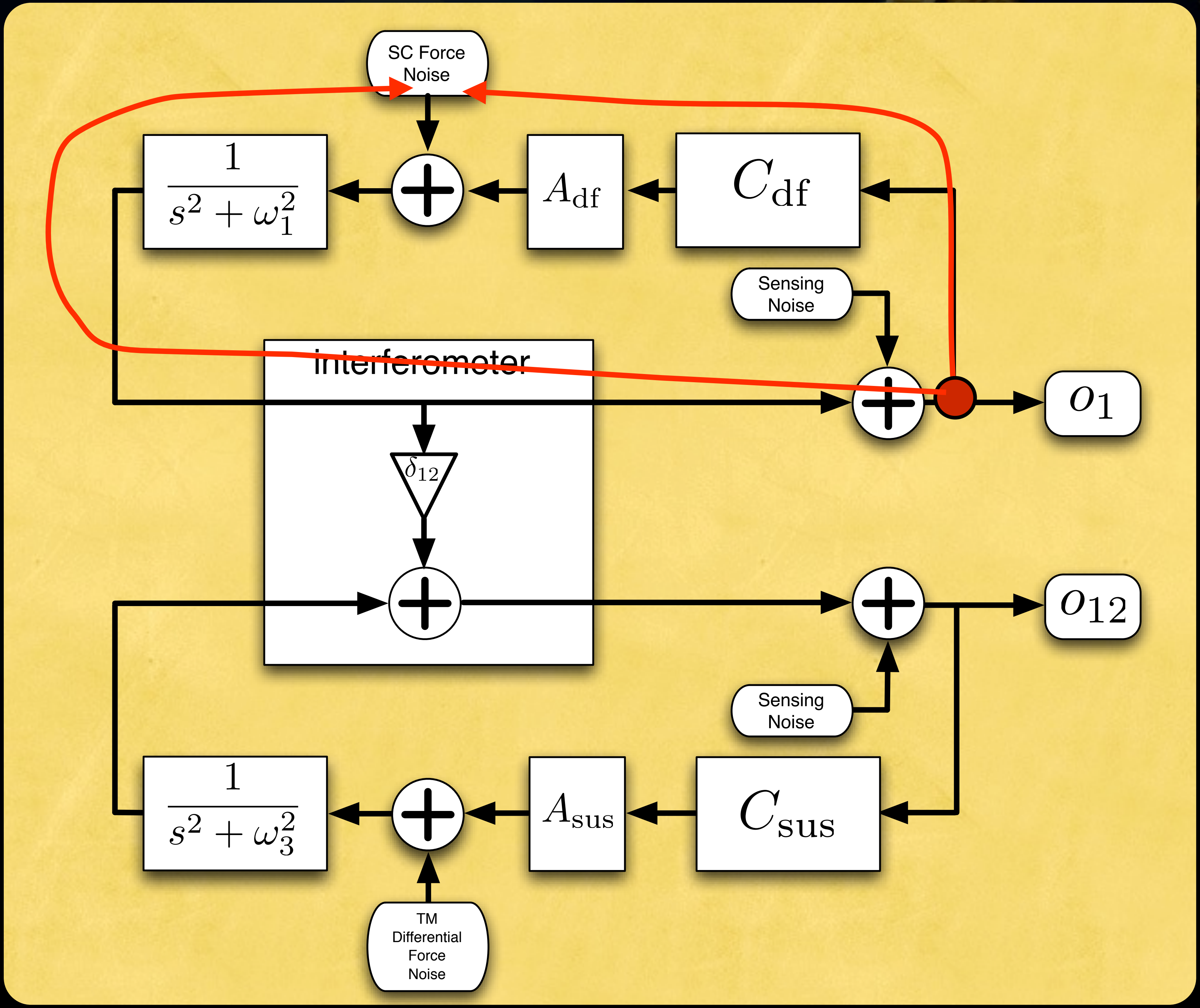


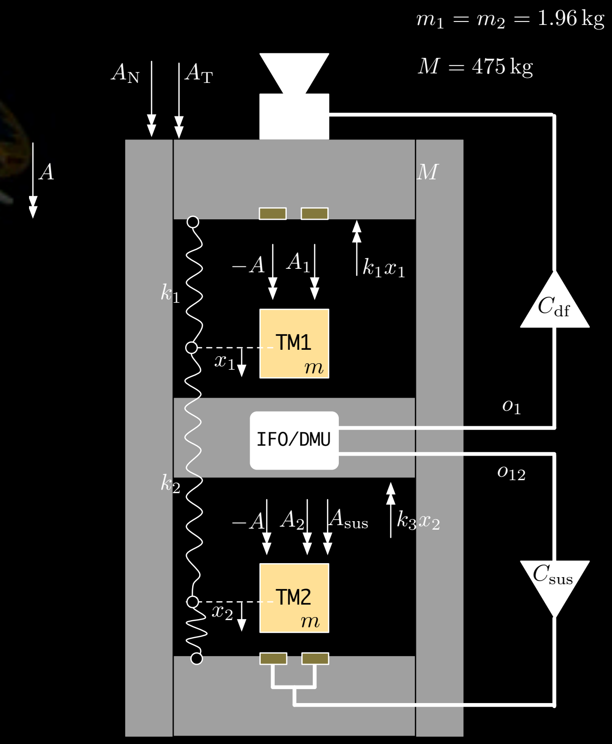
Control loops





Control loops





M Hewitson, Characterisation of LTP, GWADW, 2009

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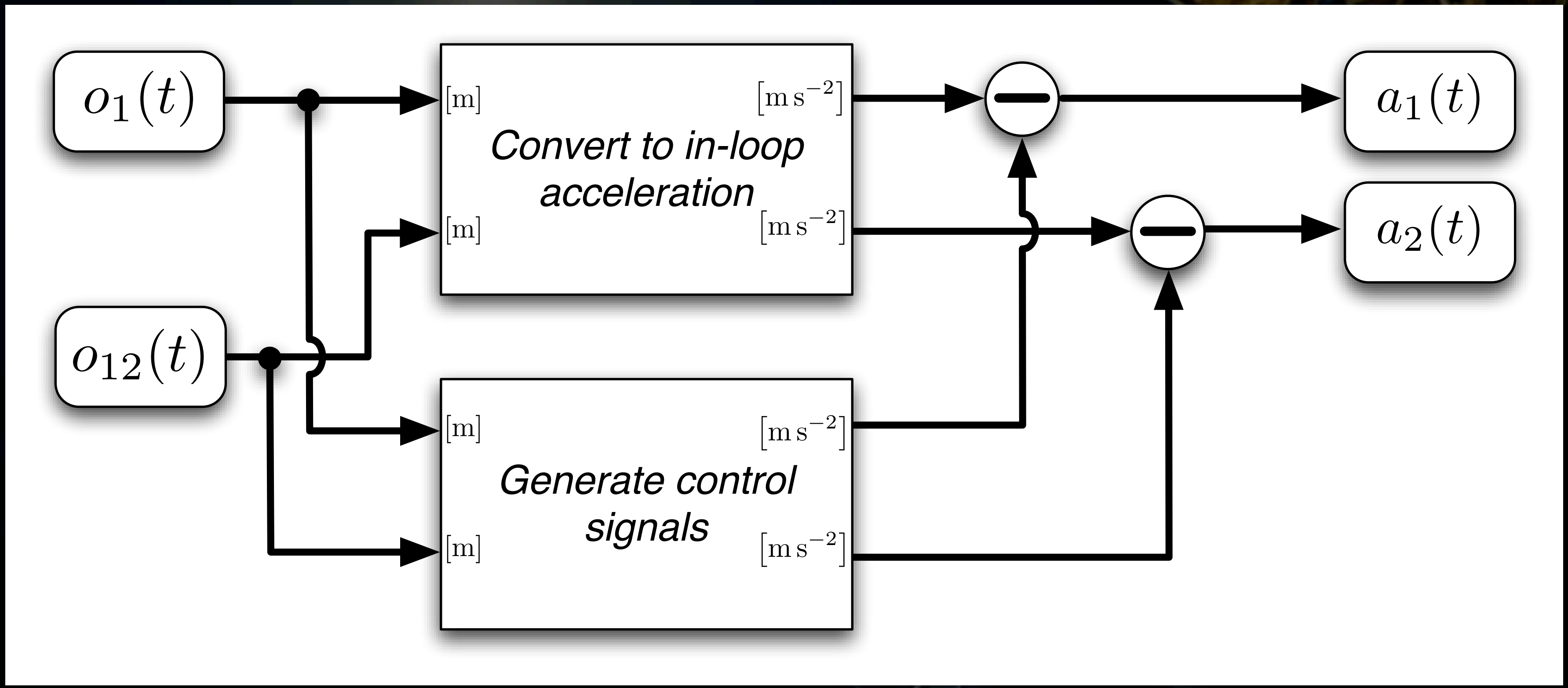
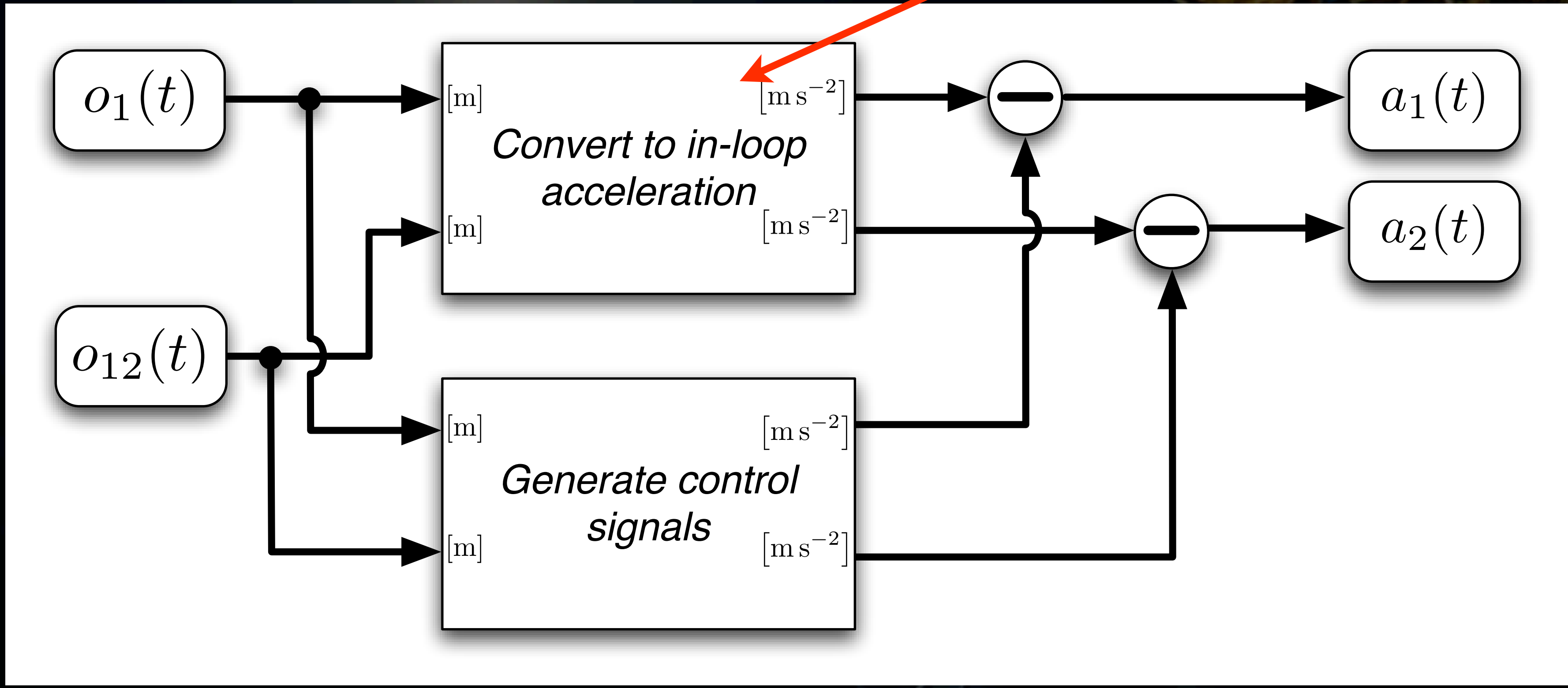
Calibration procedure



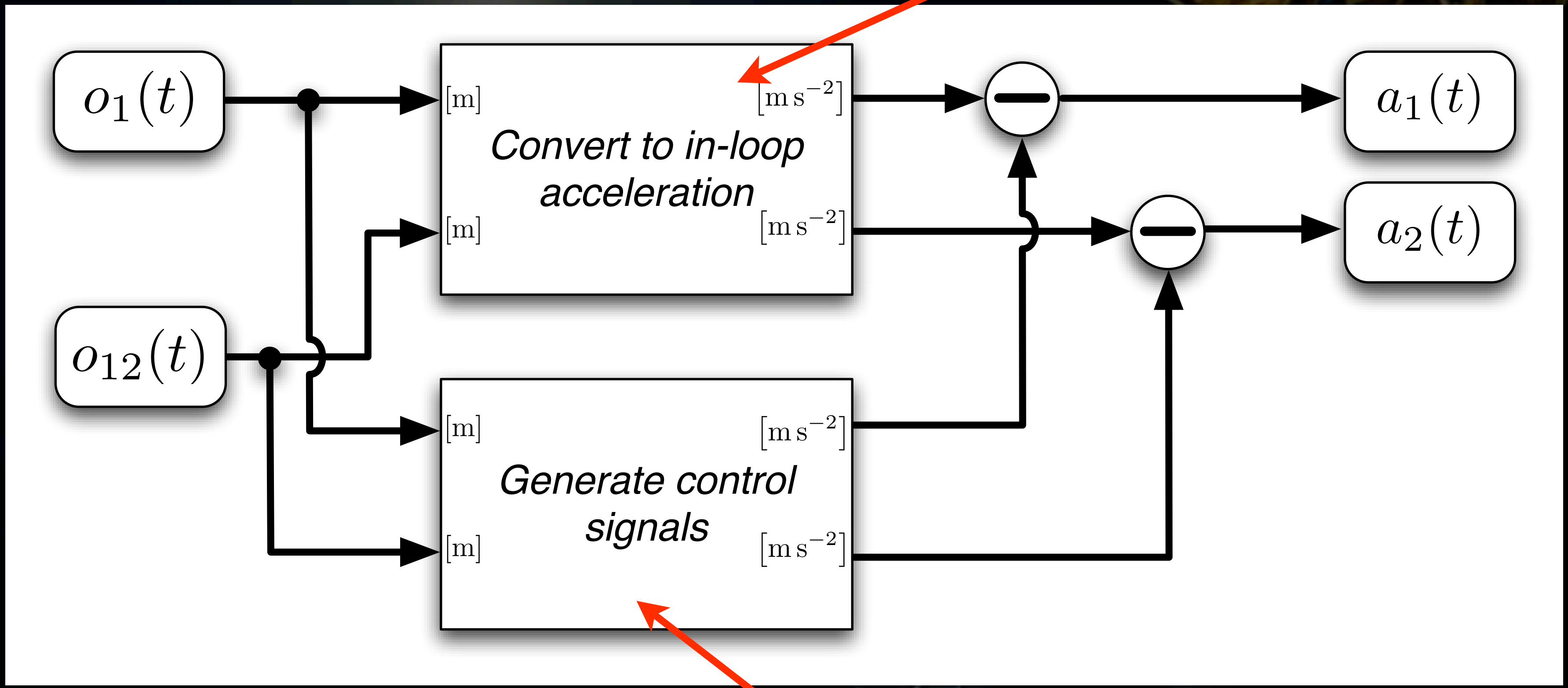
Calibration procedure

Double differentiation



Calibration procedure

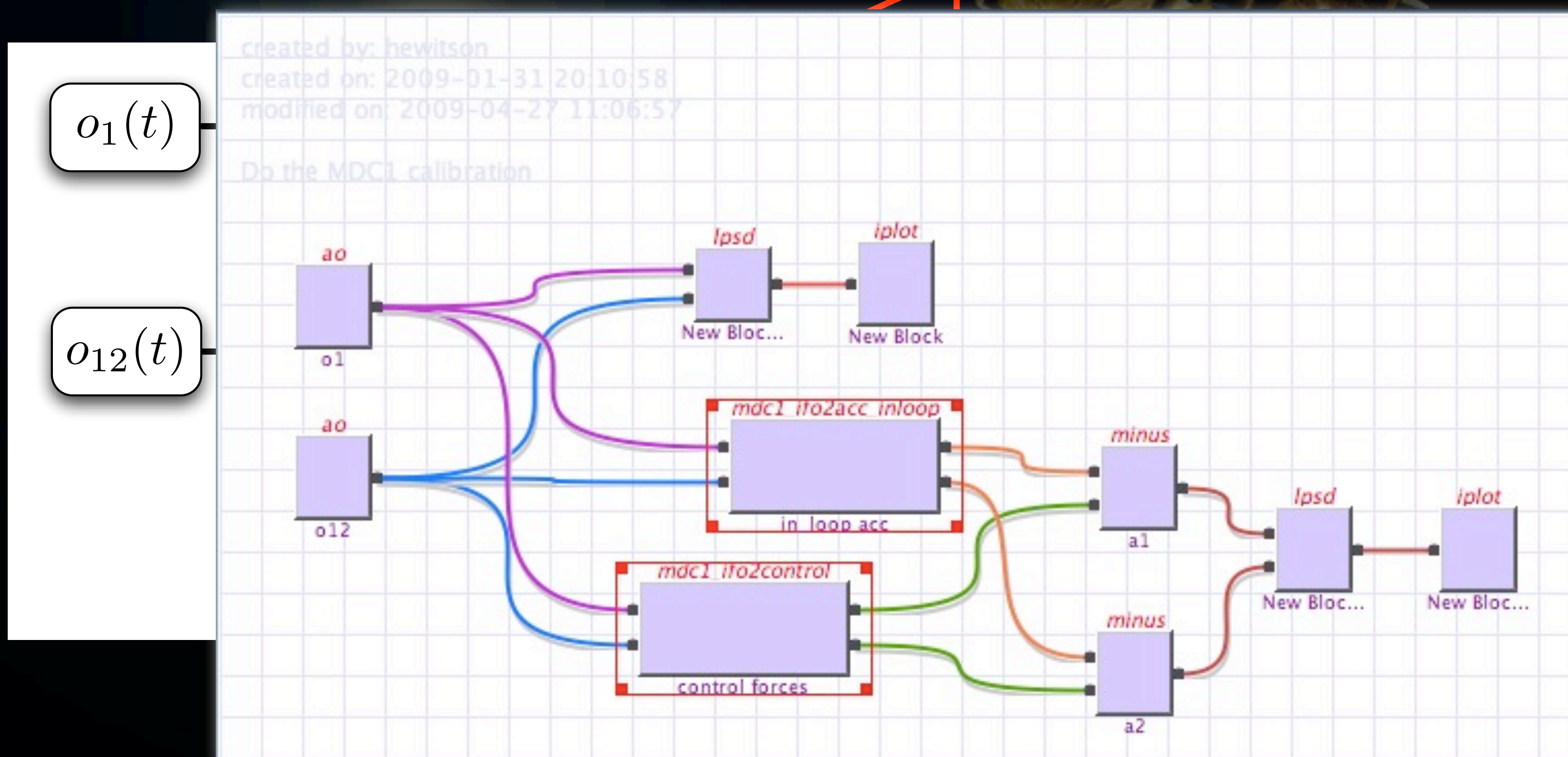
Double differentiation



Filter with controller transfer functions

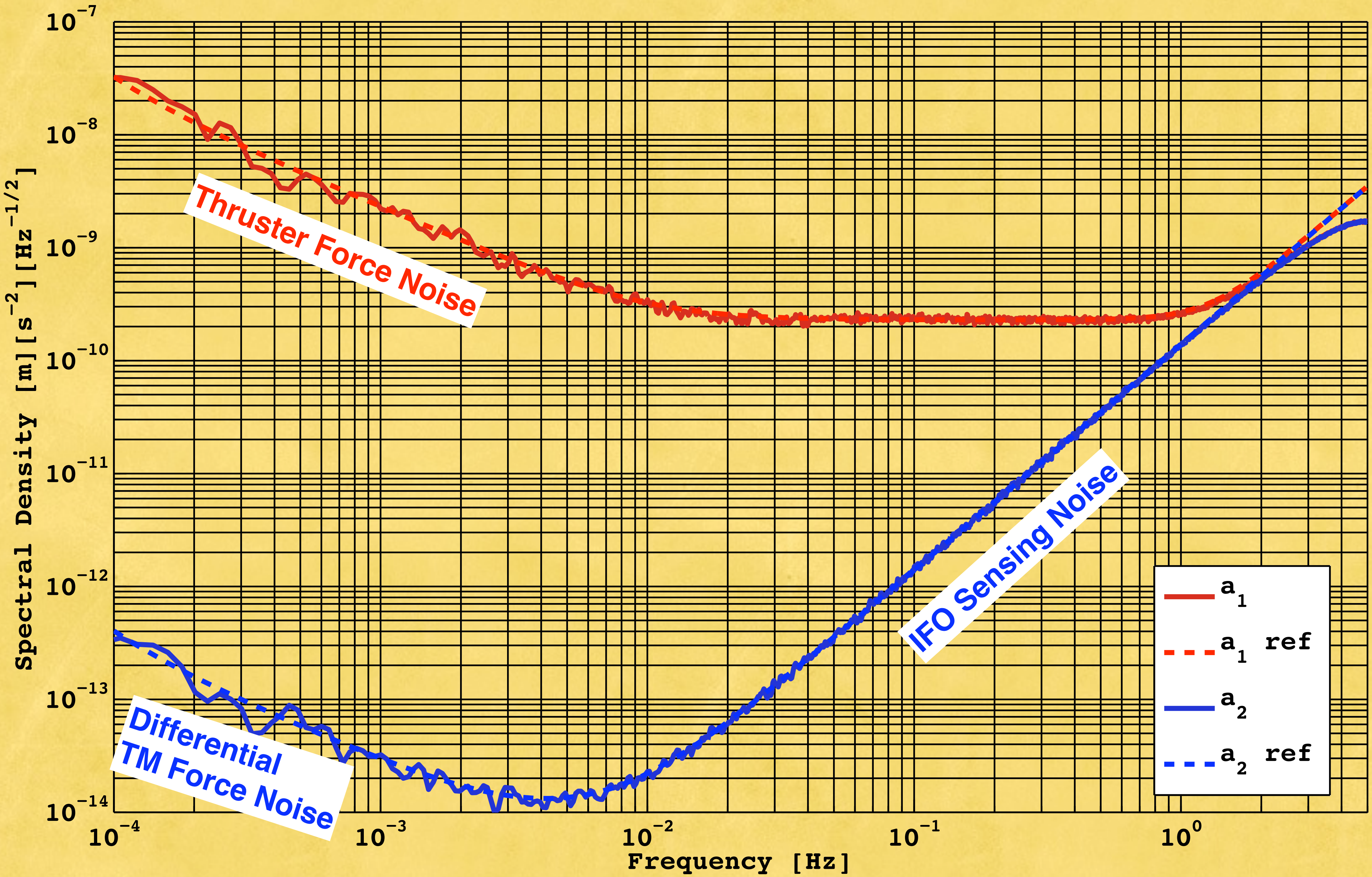
Calibration procedure

Double differentiation



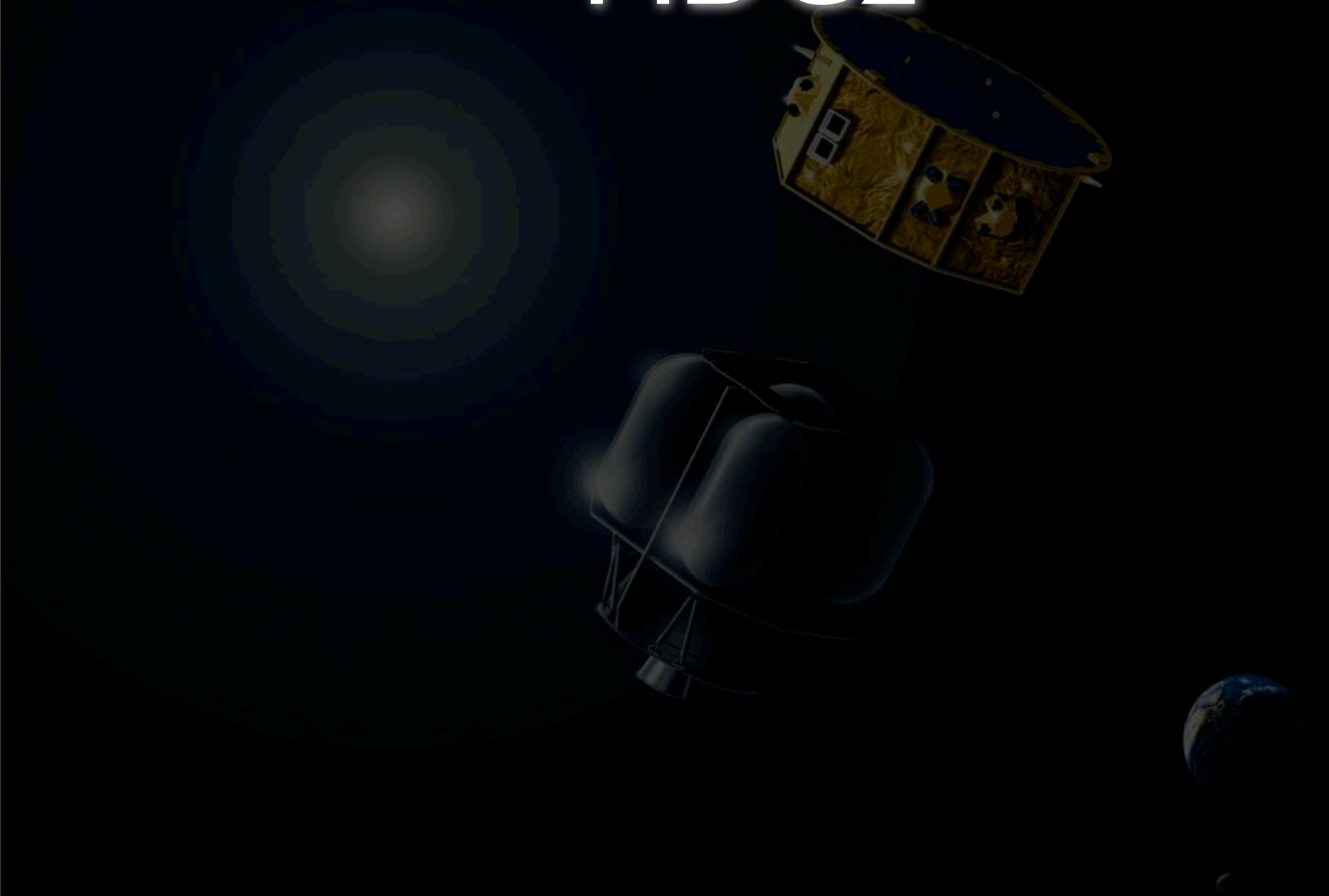
transfer functions

Results

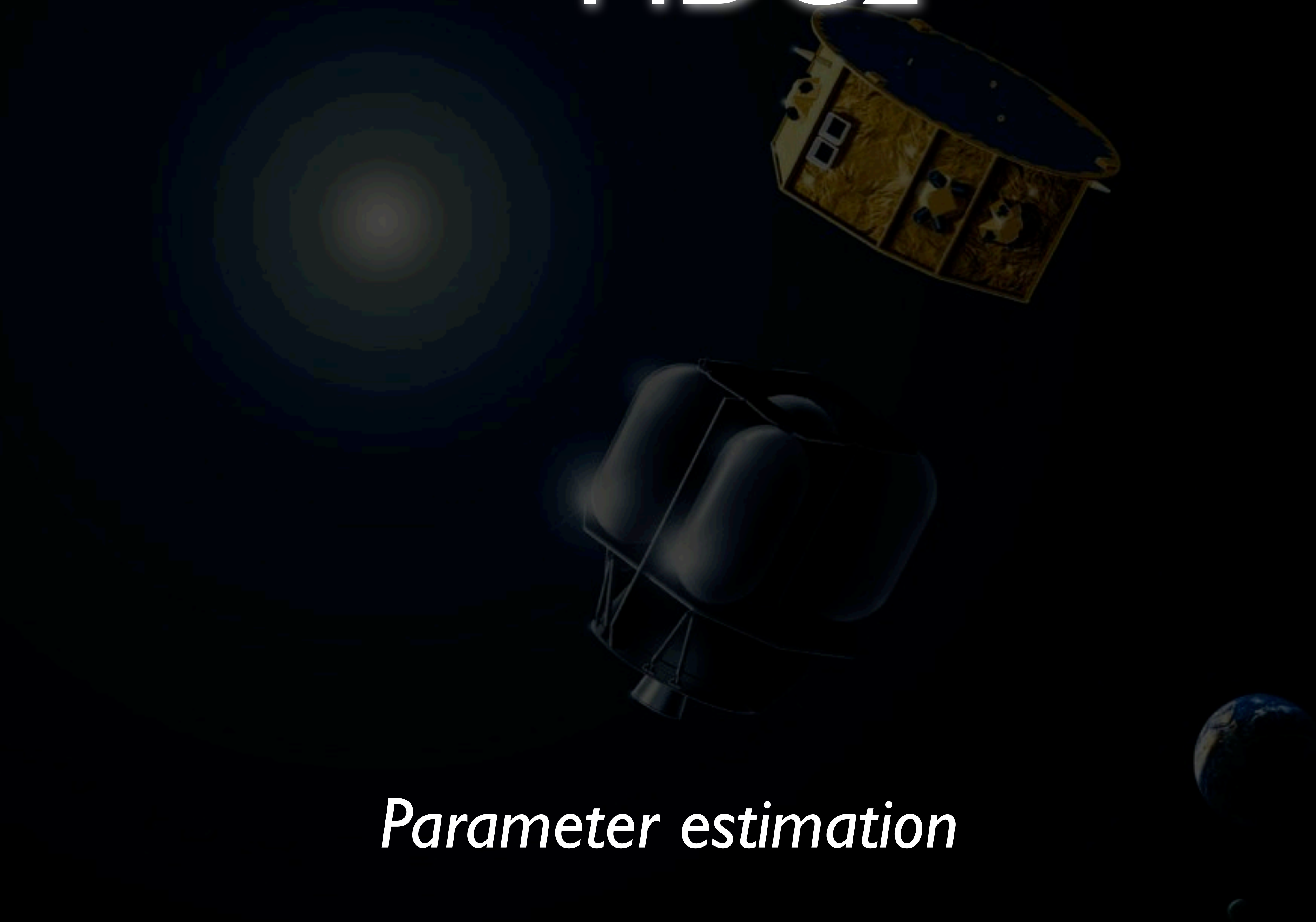


Thruster Force Noise
IFO Sensing Noise
Differential TM Force Noise
a1
a1 ref
a2
a2 ref
Spectral Density [m][s^-2][Hz^-1/2]
Frequency [Hz]

MDC2



MDC2



Parameter estimation

MDC2

- Model same as MDC1

Parameter estimation

MDC2

- Model same as MDC1
- Analysis team does not know exact parameter values for the model

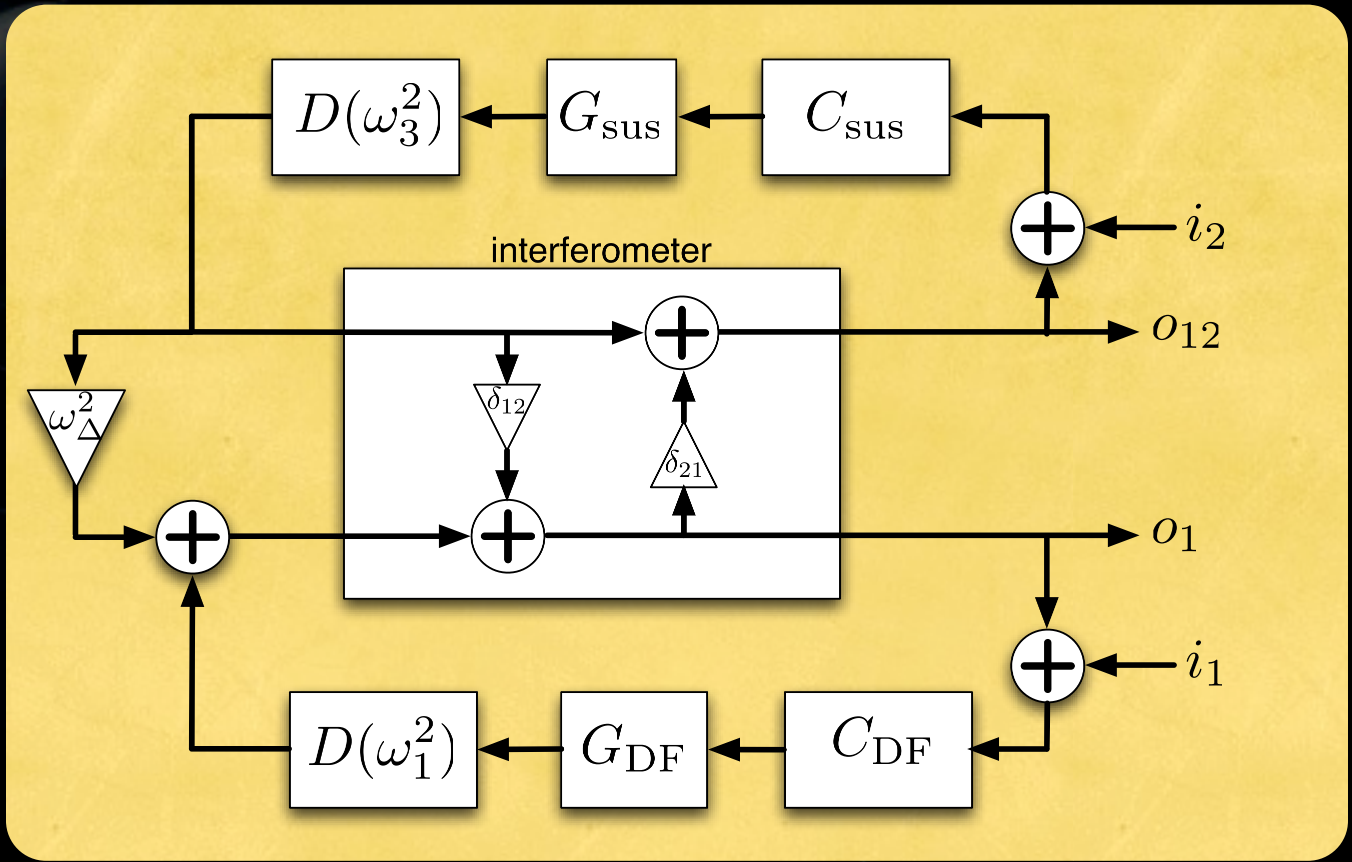
Parameter estimation

MDC2

- Model same as MDC1
- Analysis team does not know exact parameter values for the model
- Instead, they must be determined from a series of experiments where the system is excited

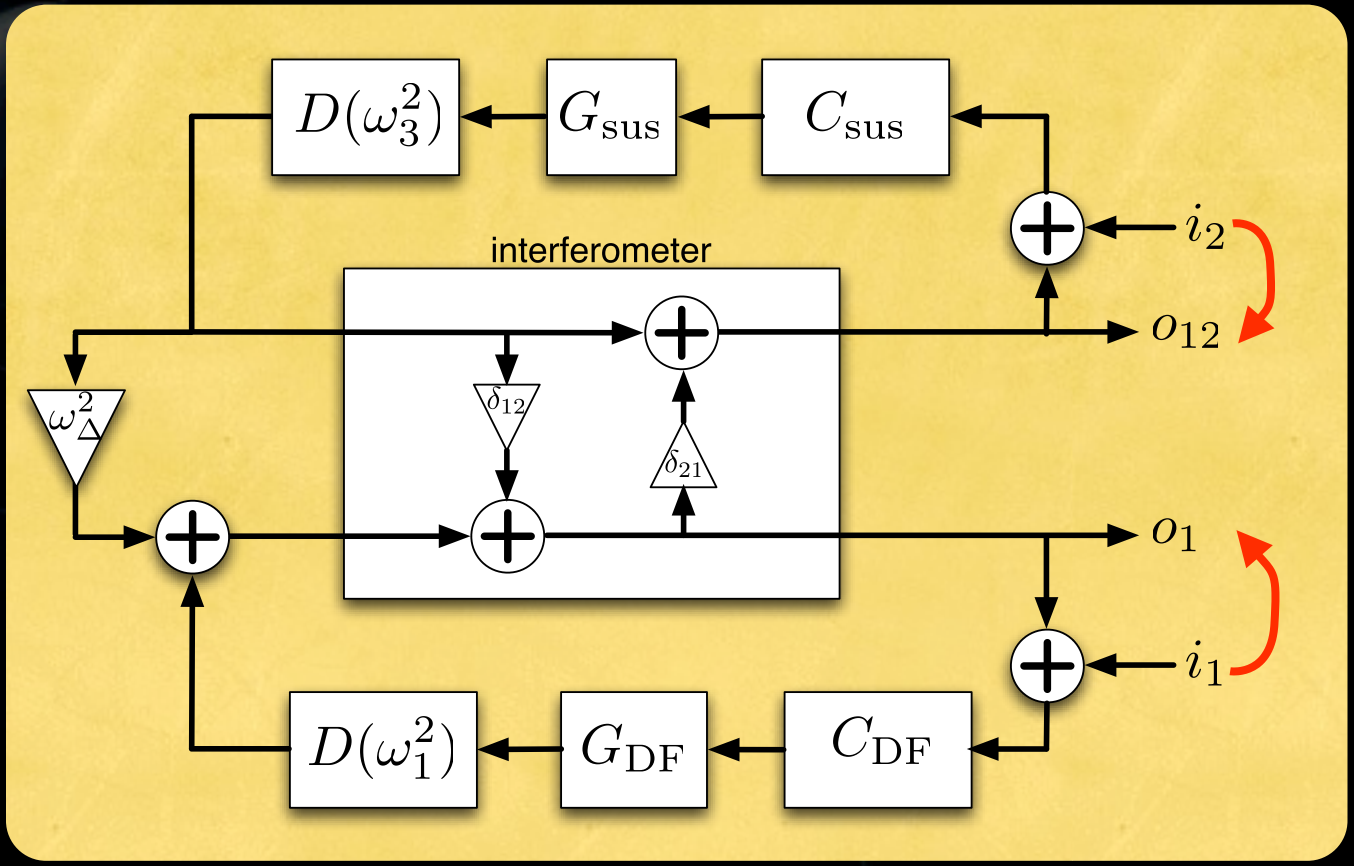
Parameter estimation

The experiments



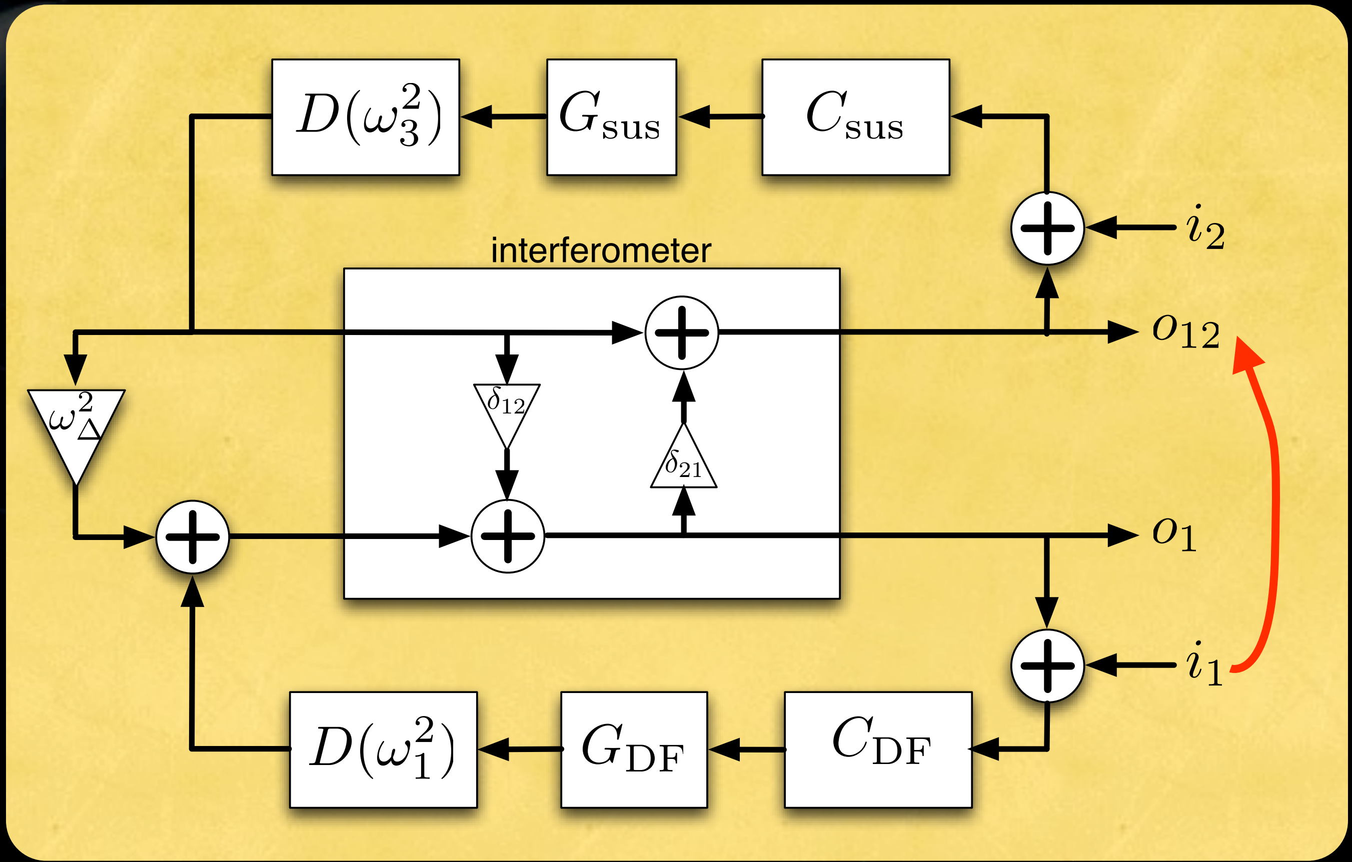
- Experiment 1
  - inject signals into both control loops and measure at the outputs
    - i1->o1 and i12->o12
      - Gdf, Gsus (stiffnesses?)

The experiments



The experiments

- Experiment 1
  - inject signals into both control loops and measure at the outputs
    - i1->o1 and i12->o12
      - Gdf, Gsus (stiffnesses?)
- Experiment 2
  - Match stiffness of two TMs
  - Inject in drag-free loop, measure in X12 loop
    - i1->o12
      - IFO cross-coupling



The experiments

- Experiment 1
  - inject signals into both control loops and measure at the outputs
    - i1->o1 and i12->o12
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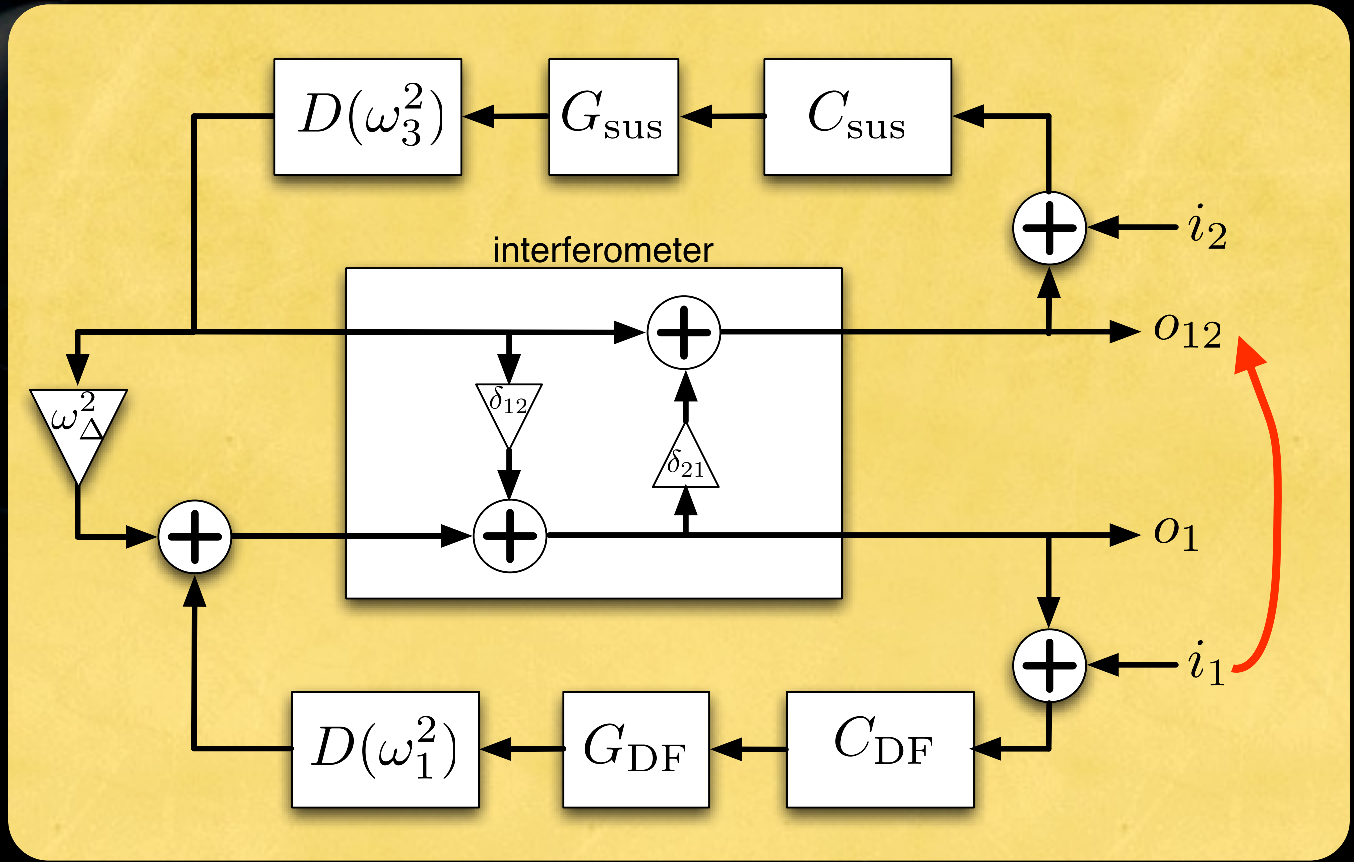
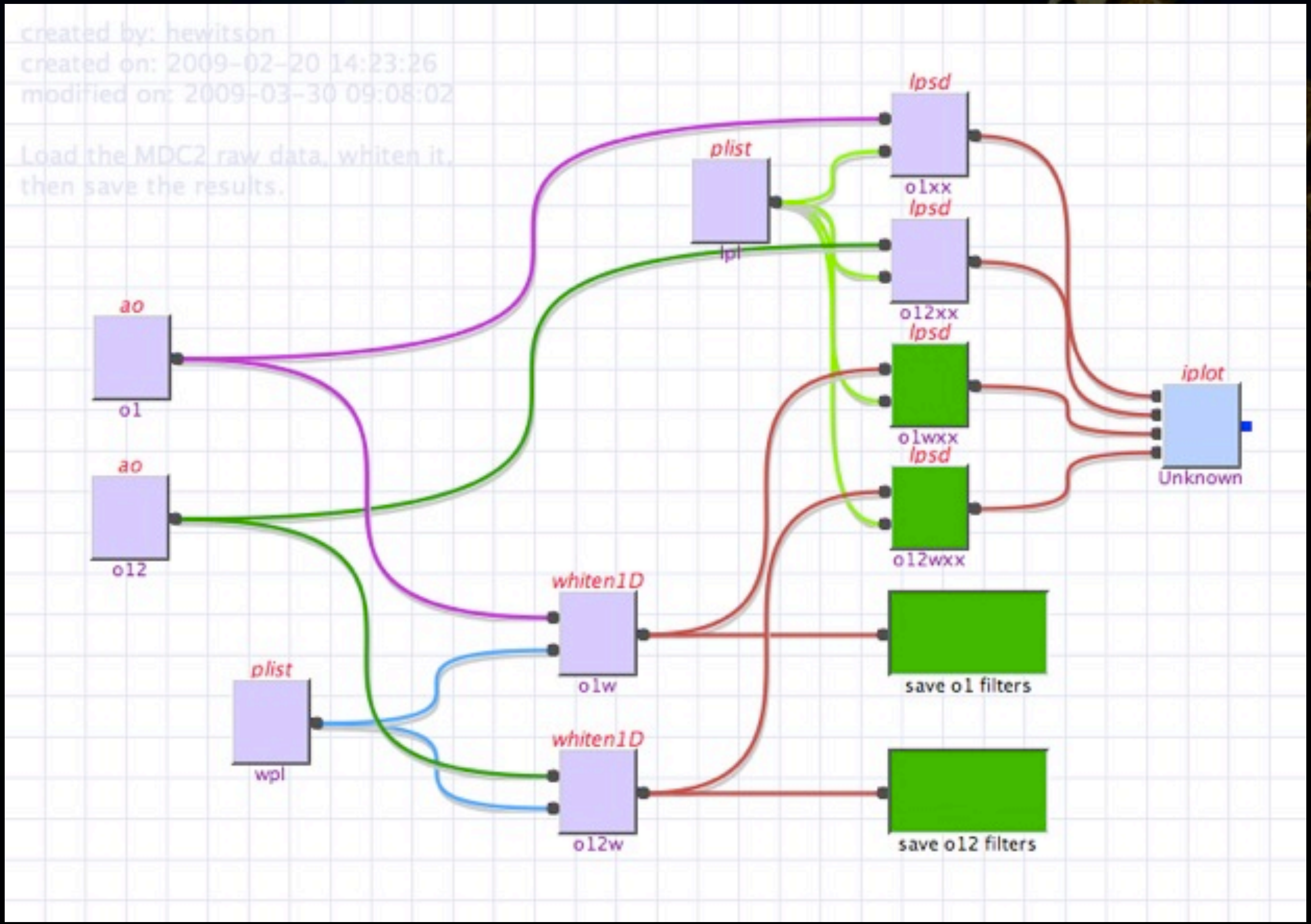
- Experiment 2
  - Match stiffness of two TMs
  - Inject in drag-free loop, measure in X12 loop
    - i1->o12
      - IFO cross-coupling
- Experiment 3
  - Un-matched stiffness
  - Same injection
    - i1->o12
      - difference of stiffness



Experiment 3

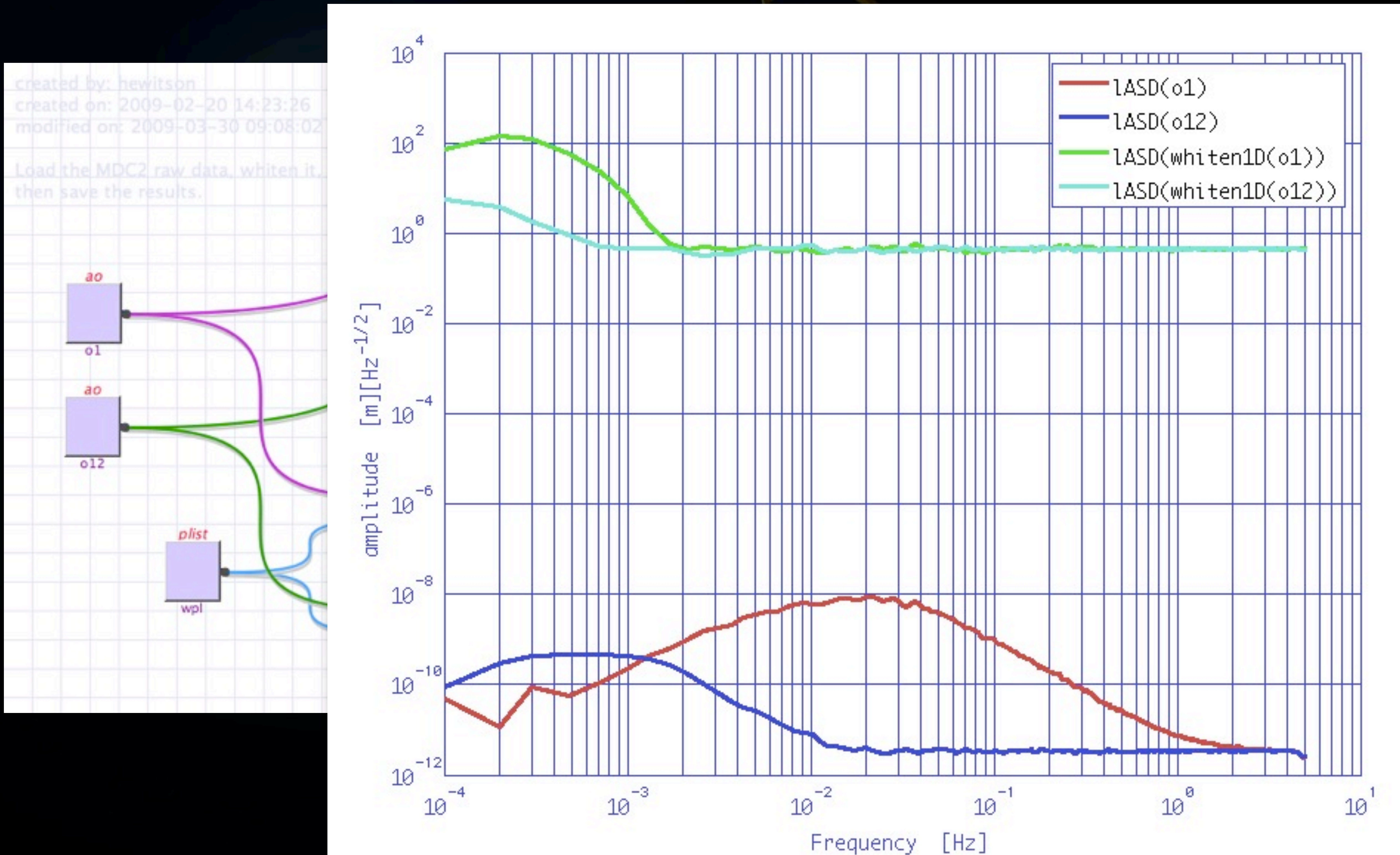
- Whitening data
- Measuring Transfer function
- Building the model to fit
- Fitting the model to the data
- Calibrate to acceleration

Whiten data



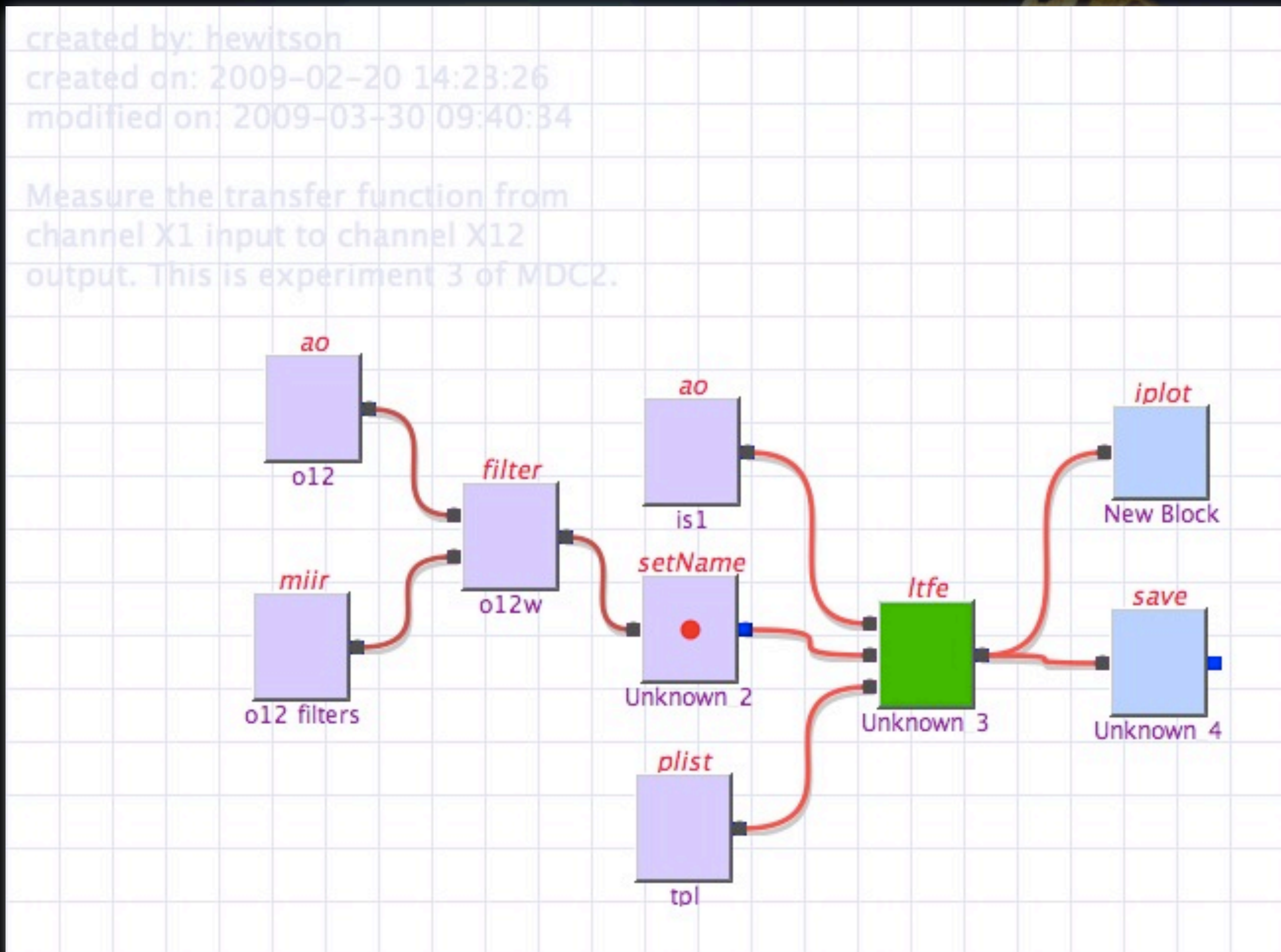
created by: hewitson
created on: 2009-02-20 14:23:26
modified on: 2009-03-30 09:08:02
Load the MDC2 raw data, whiten it, then save the results.
ao
o1
ao
o12
plist
wpl
plist
lpl
whiten1D
o1w
whiten1D
o12w
lpsd
o1xx
lpsd
o12xx
lpsd
o1wxx
lpsd
o12wxx
save o1 filters
save o12 filters
iplot
Unknown

Whiten data

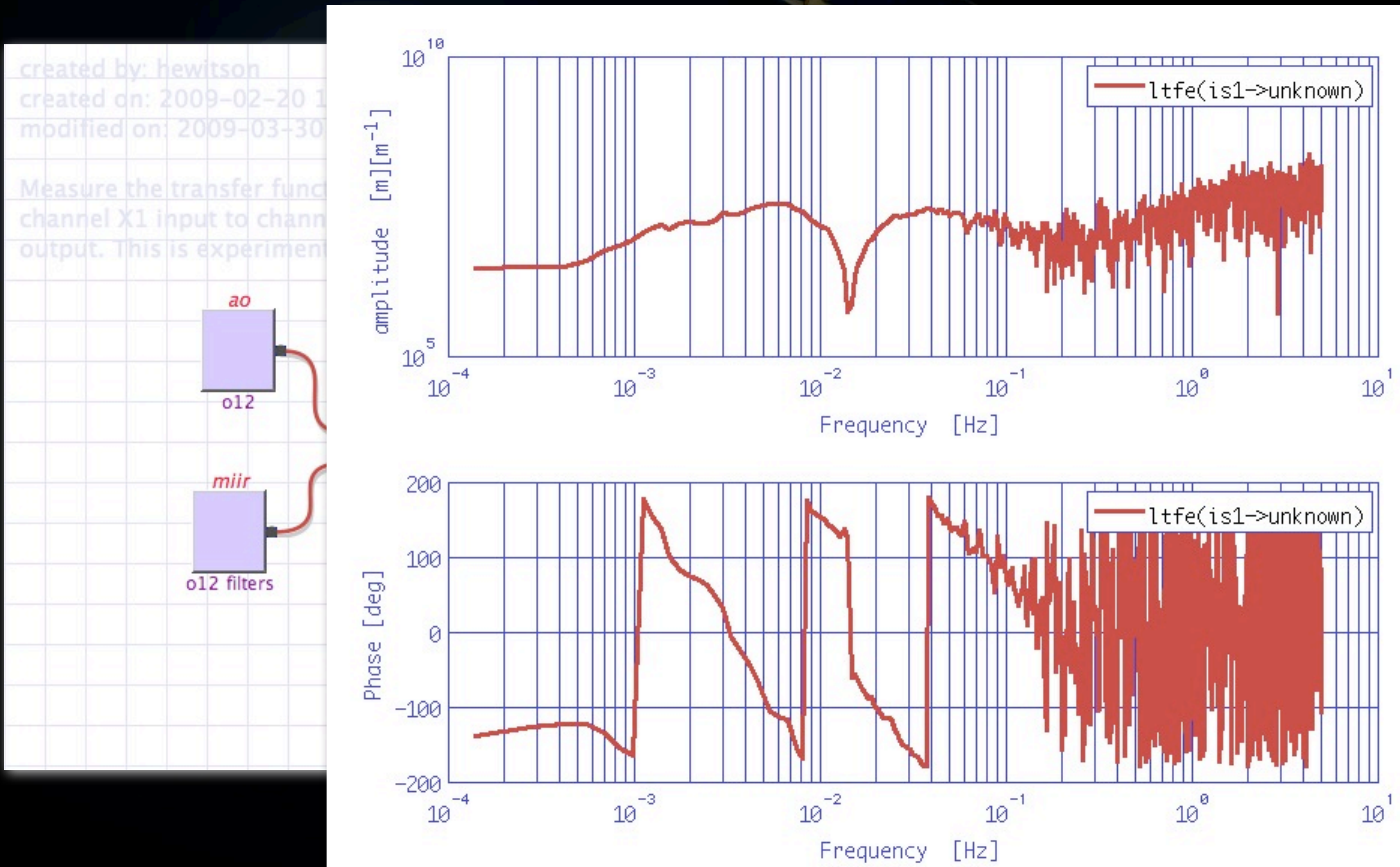


created by: hewitson
created on: 2009-02-20 14:23:26
modified on: 2009-03-30 09:08:02
Load the MDC2 raw data, whiten it,
then save the results.
ao
o1
ao
o12
plist
wpl
lASD(o1)
lASD(o12)
lASD(whiten1D(o1))
lASD(whiten1D(o12))
amplitude [m][Hz^-1/2]
Frequency [Hz]

Measure TF

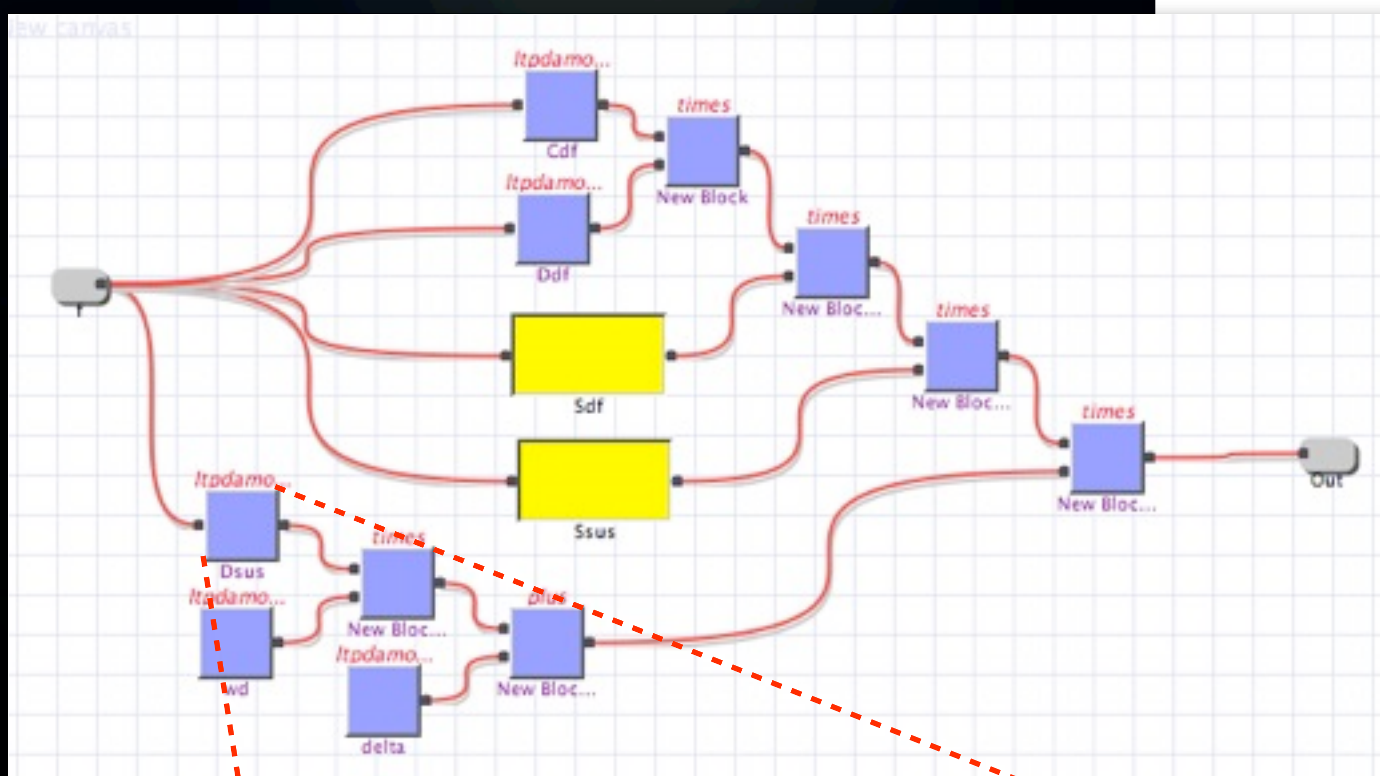

created by: hewitson
created on: 2009-02-20 14:23:26
modified on: 2009-03-30 09:40:34
Measure the transfer function from channel X1 input to channel X12 output. This is experiment 3 of MDC2.
ao
o12
miir
o12 filters
filter
o12w
ao
is1
setName
Unknown 2
plist
tpl
ltfe
Unknown 3
iplot
New Block
save
Unknown 4

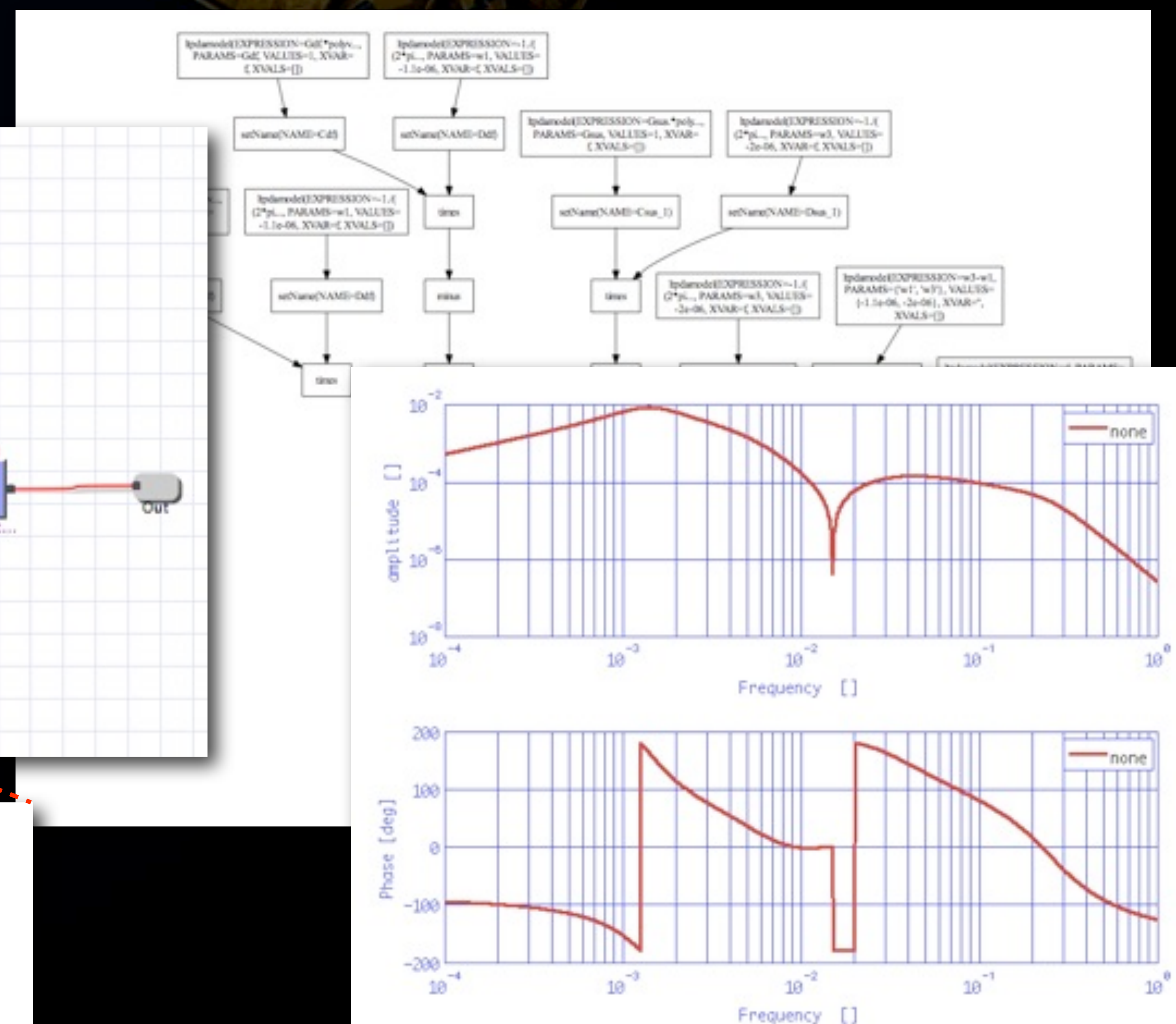
Measure TF


created by: hewitson
created on: 2009-02-20 1
modified on: 2009-03-30
Measure the transfer funct
channel X1 input to chann
output. This is experiment
ao
o12
miir
o12 filters
ltfe(is1->unknown)
amplitude [m][m^-1]
Frequency [Hz]
Phase [deg]

Build the model

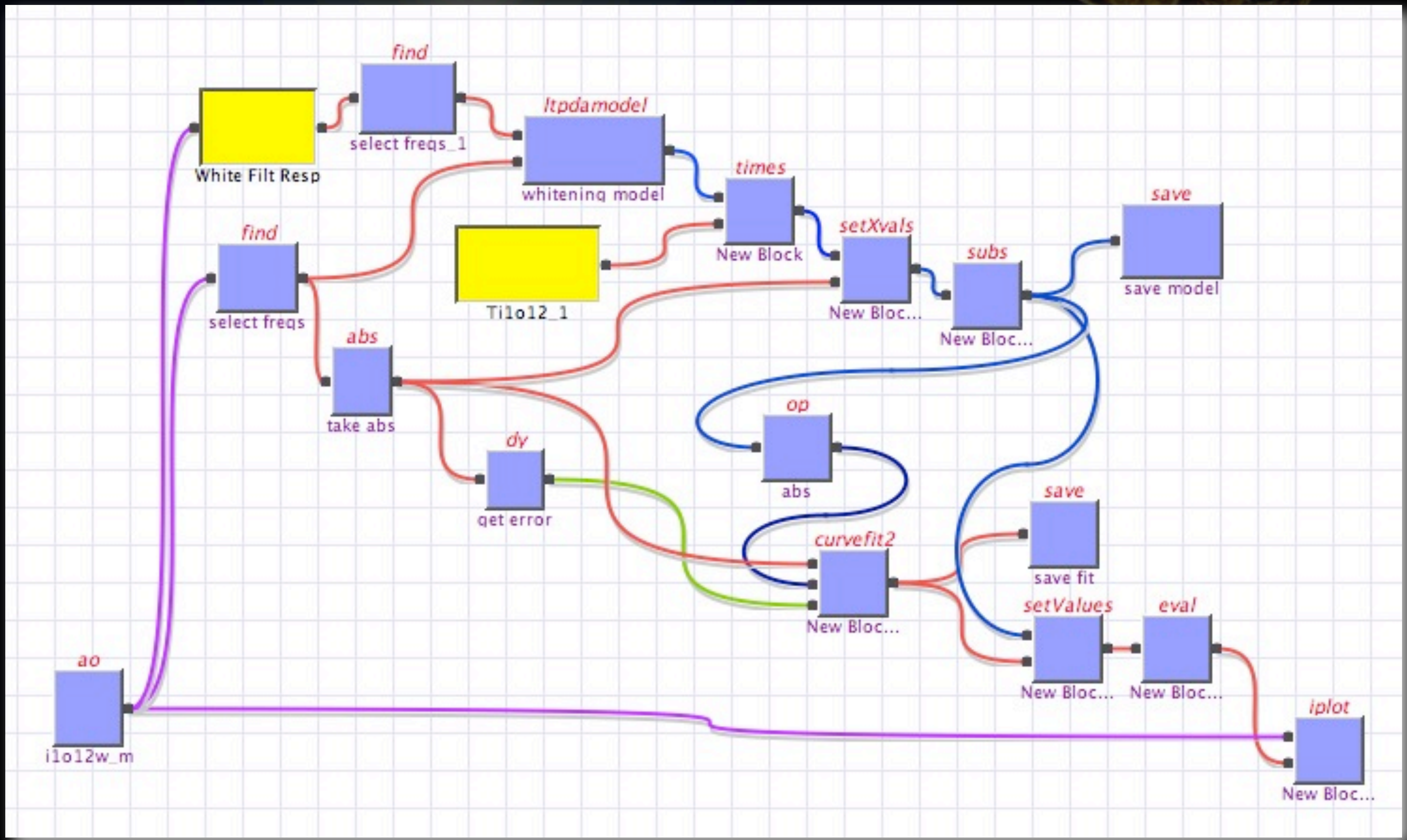
- Model is built with various `ltpdamodel` objects



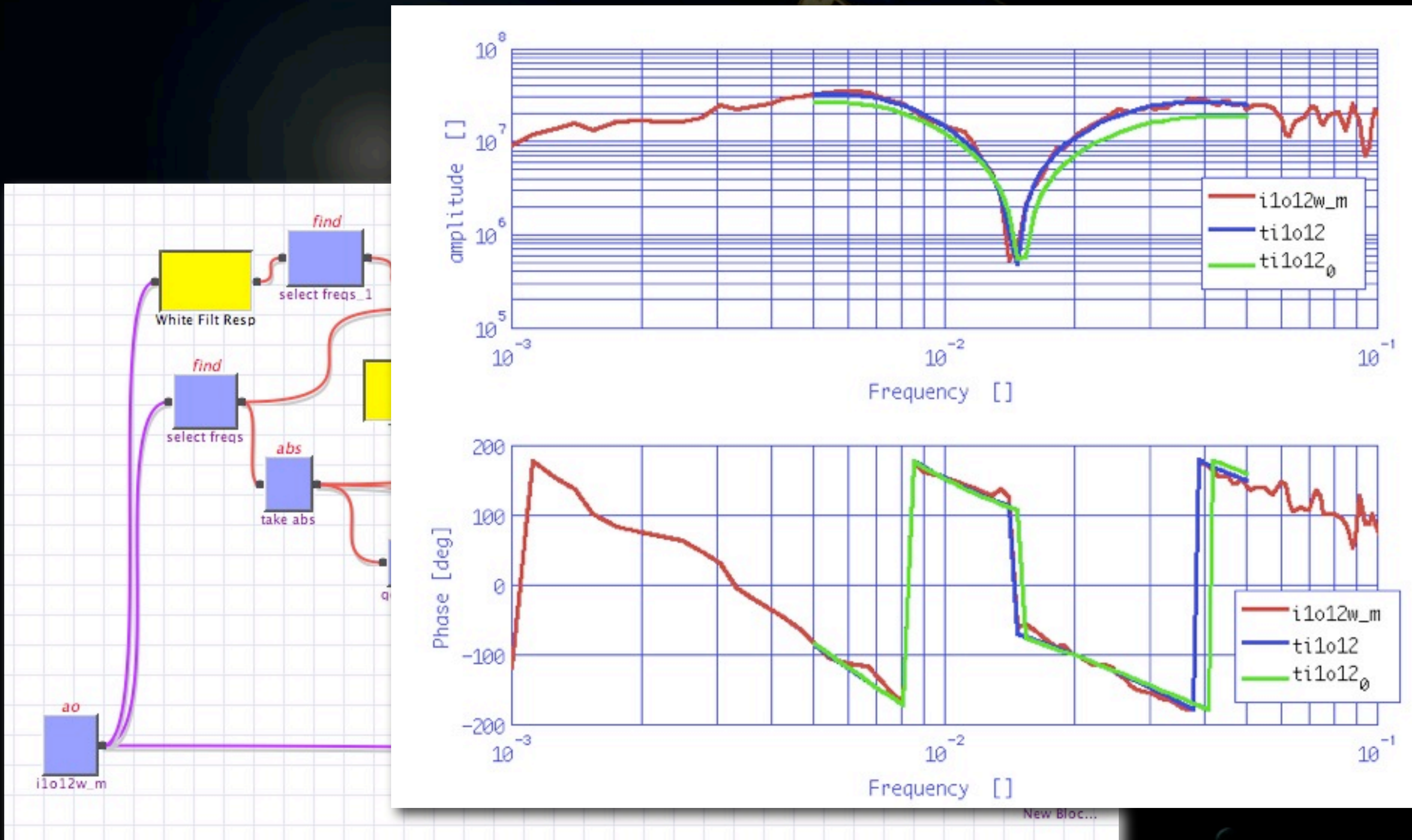



```
---- ltpdamodel 1 ----
  name: Dsus
  expr: -1./((2*pi*1i*f).^2 + w1)
params: {'w1'}
values: {-1.1e-06}
  xvar: f
  xvals: [0.0001 0.000100926219098705 ...]
----------------------
```

Fit model to data



Fit model to data

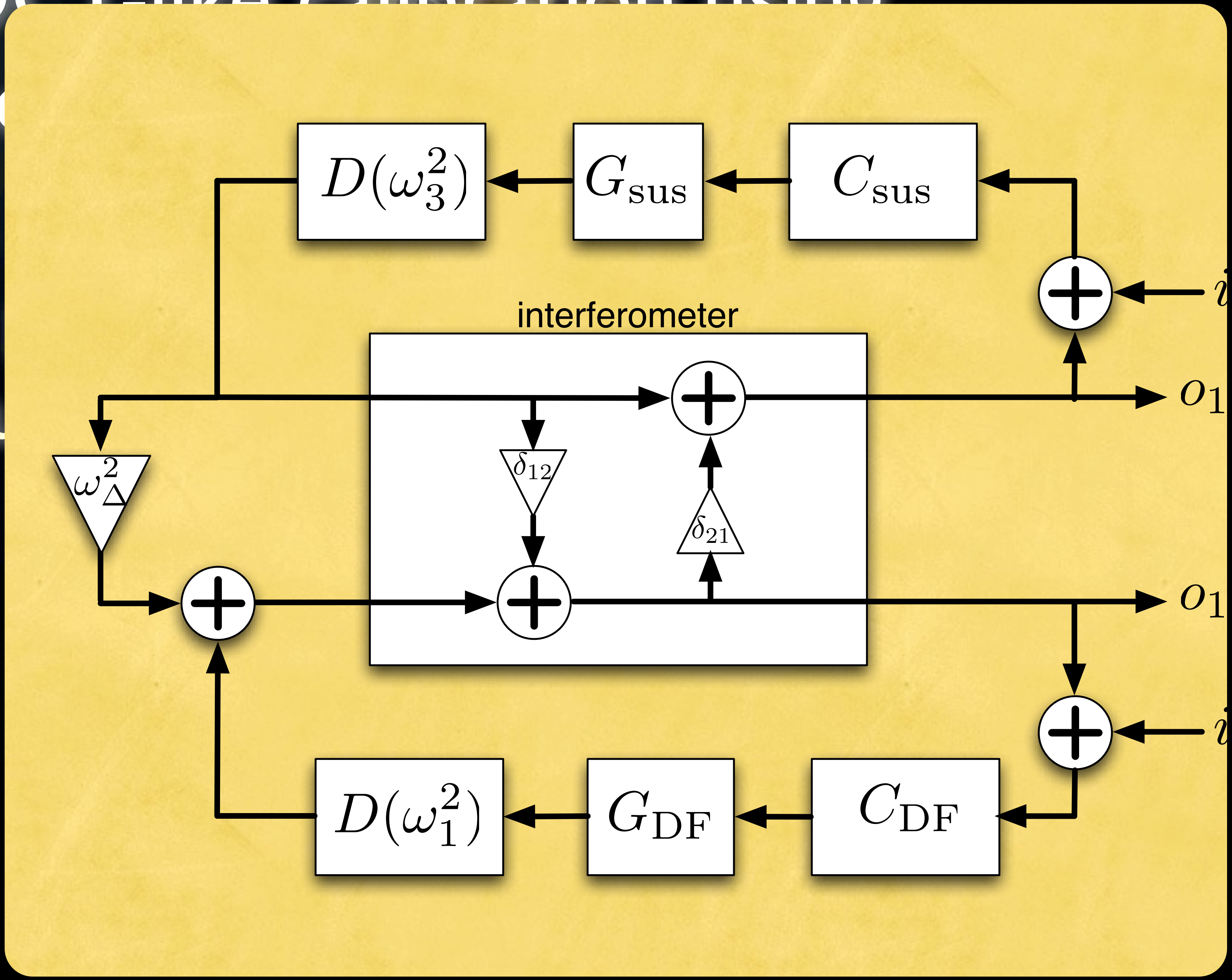


Calibration to acceleration

- Perform MDC1-like calibration using the experiment 3 data
  - for perfect parameter estimation and calibration process the injected signals should subtract!

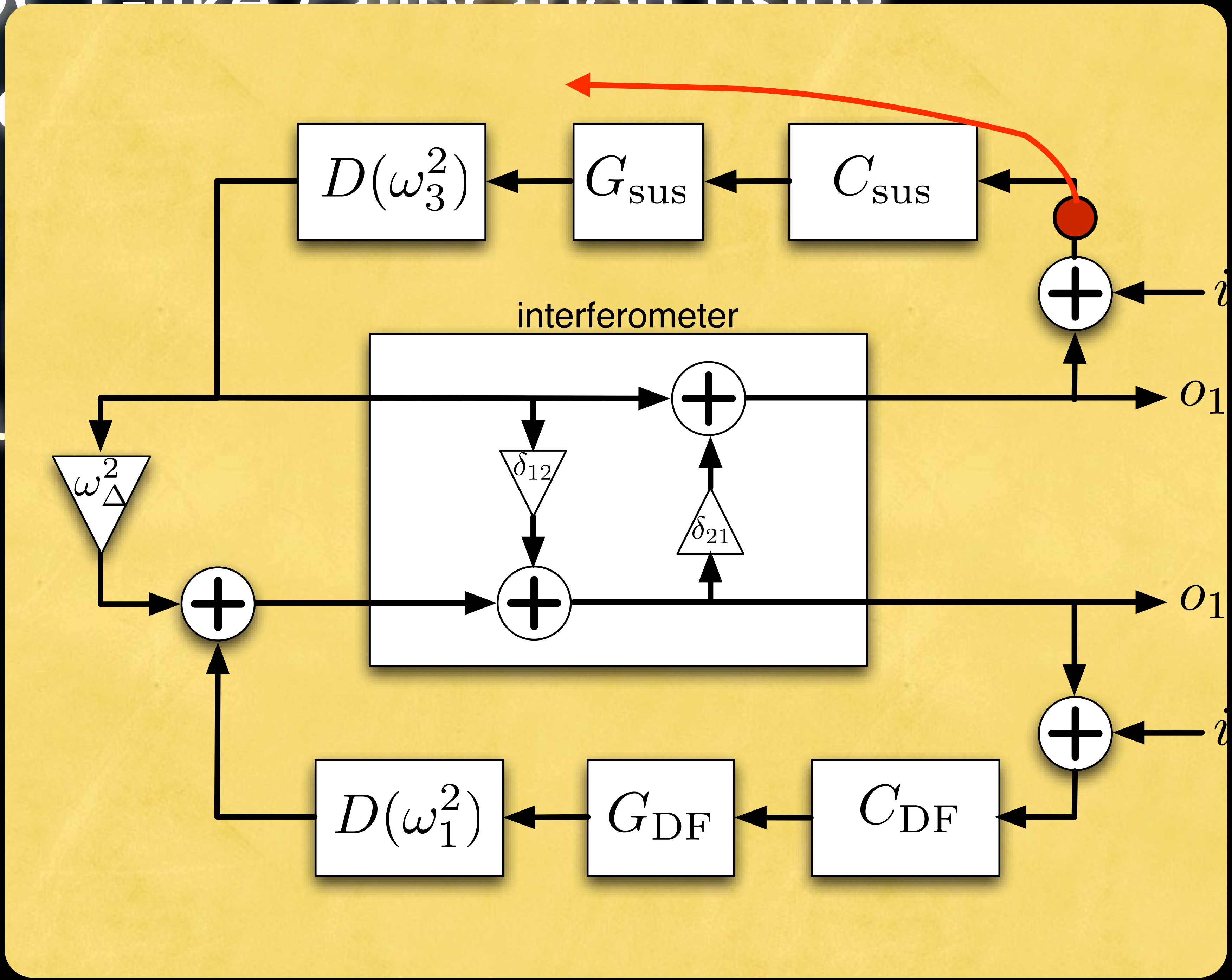
Calibration to acceleration

- Perform MDC1-like calibration using the experim
  - for perfect calibration signals shou



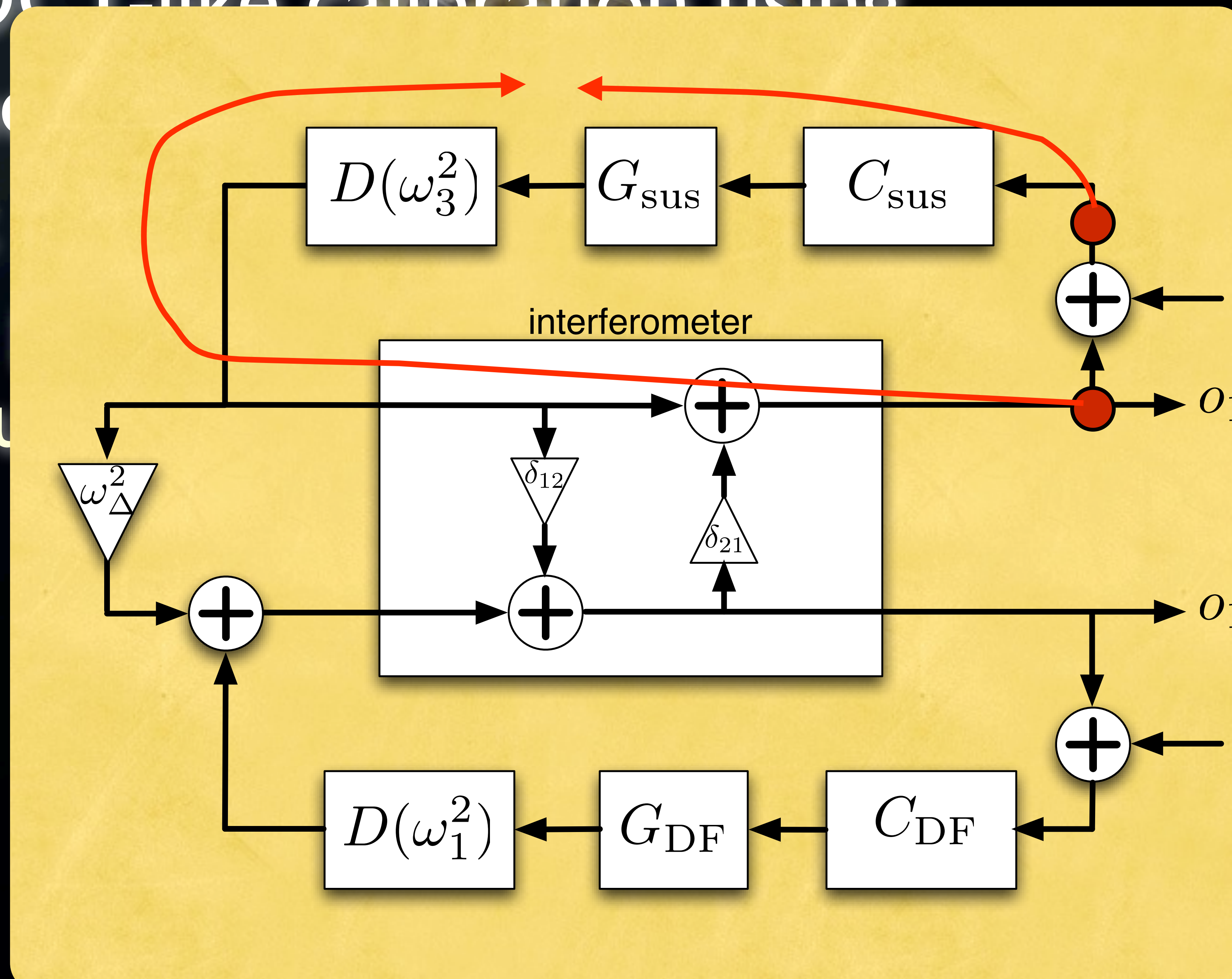
Calibration to acceleration

- Perform MDC I-like calibration using the experim
  - for perfect calibration signals shou



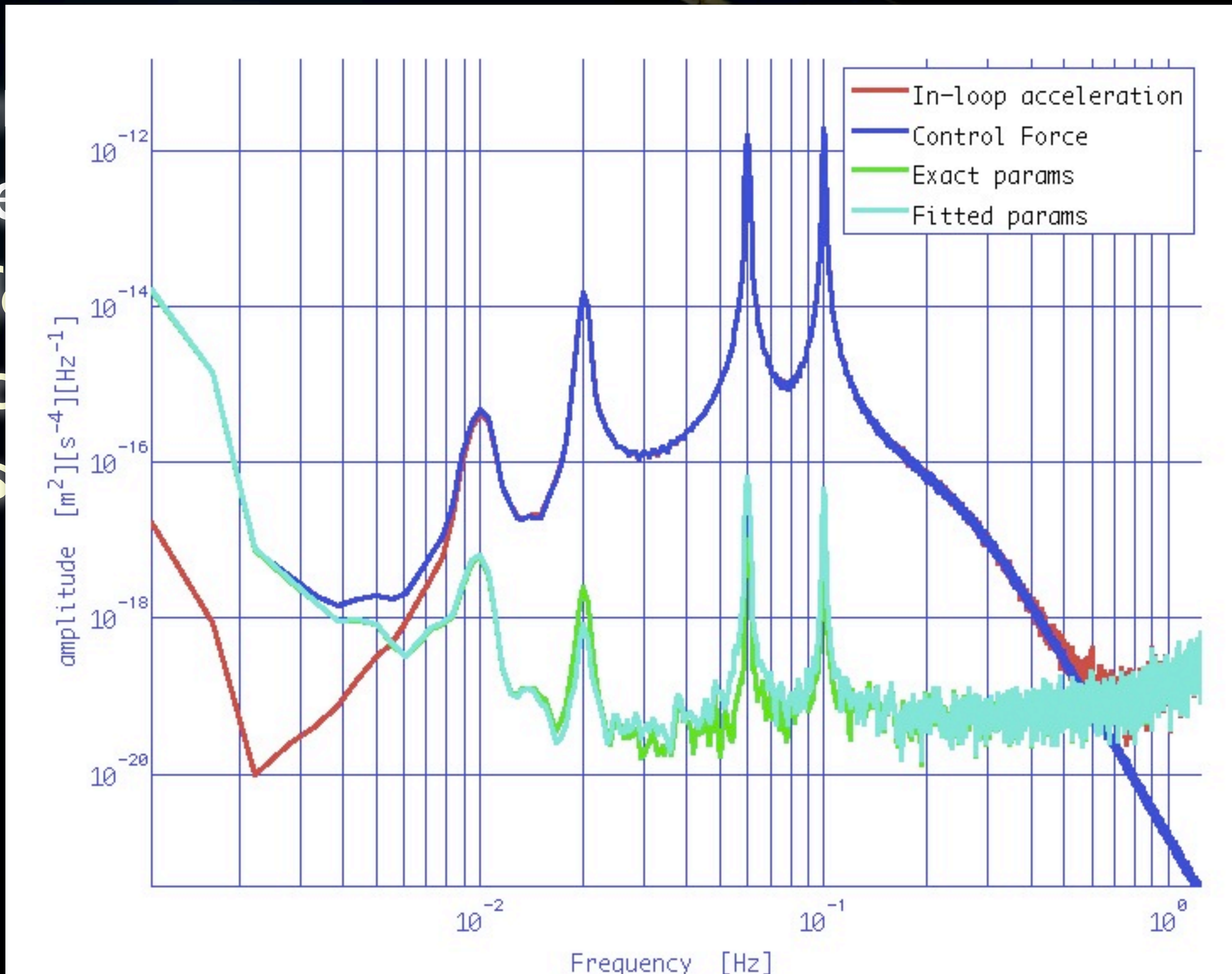
Calibration to acceleration

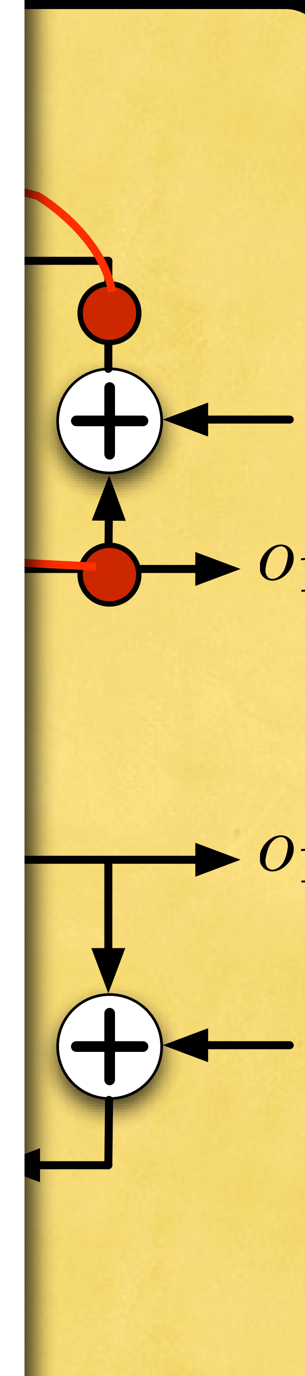
- Perform MDC1-like calibration using
  the experim
  - for perfect
    calibration
    signals shou



Calibration to acceleration

- Pe
  the
  - f
    c
    s

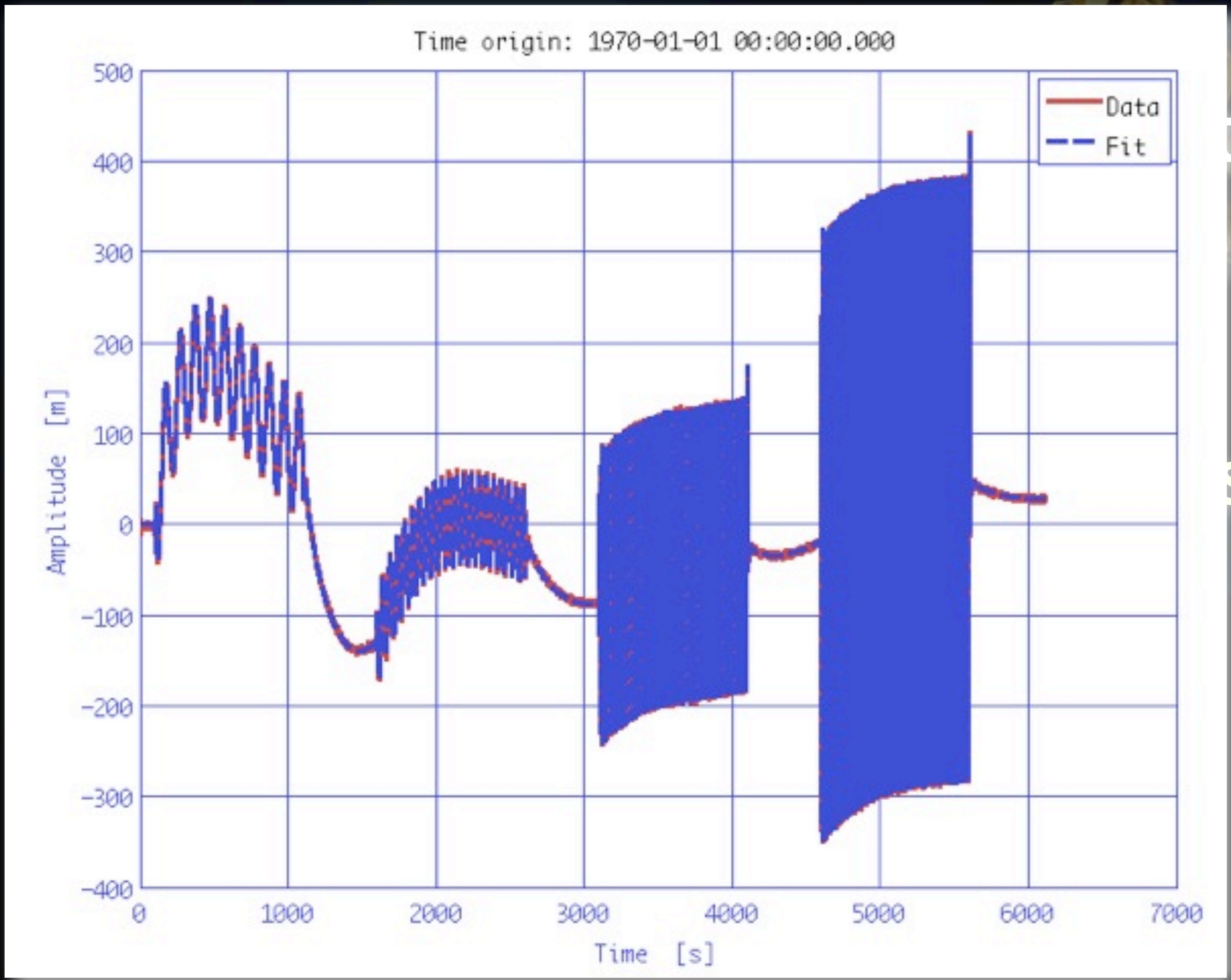




Time-domain fitting

- Try to generate template signals in time-domain and fit these to the measured data
  - use `ltpdamodel` objects with FFT filtering techinique

Time-domain fitting

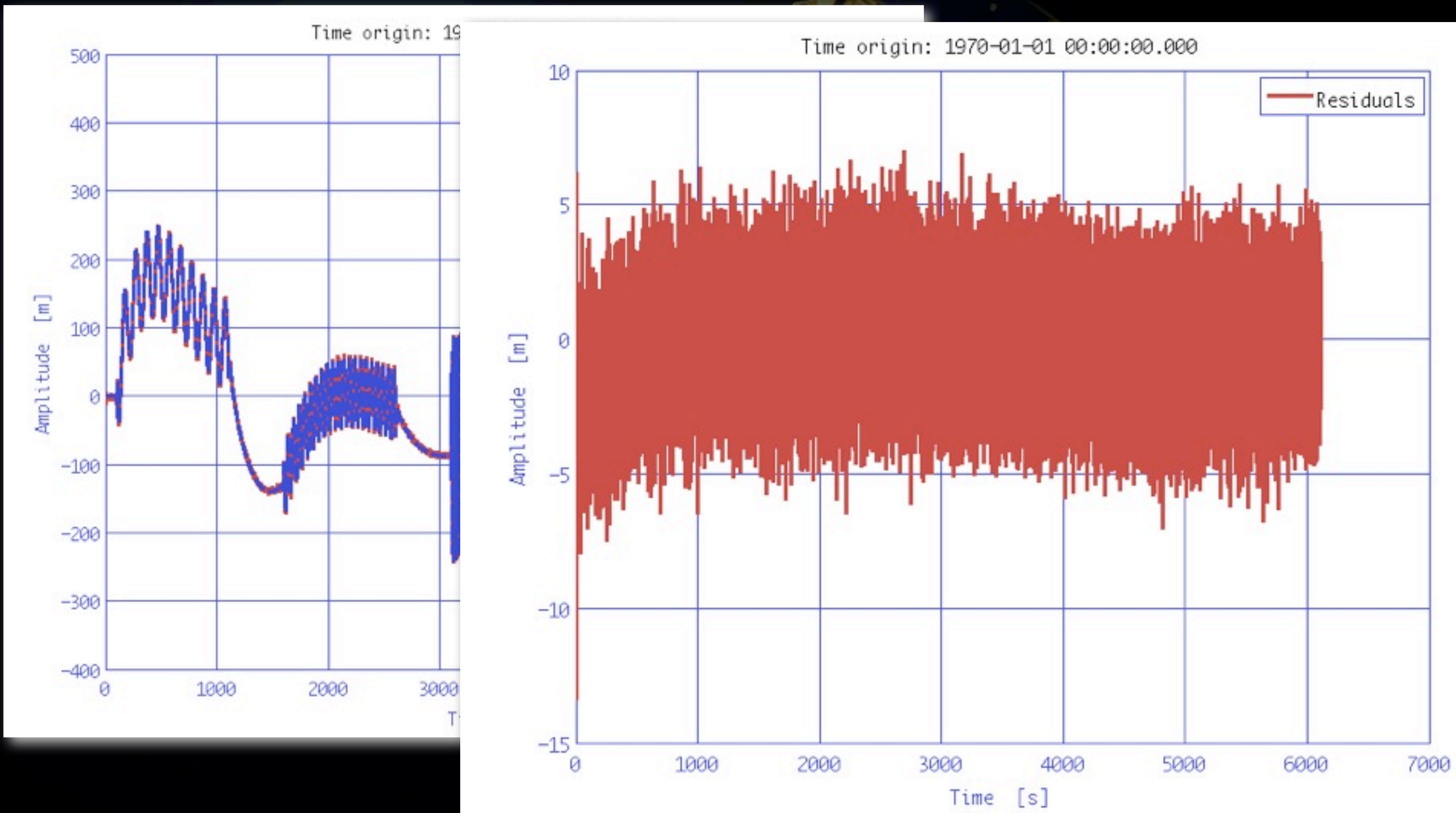


te signals in

se to the

s with FFT

Time-domain fitting



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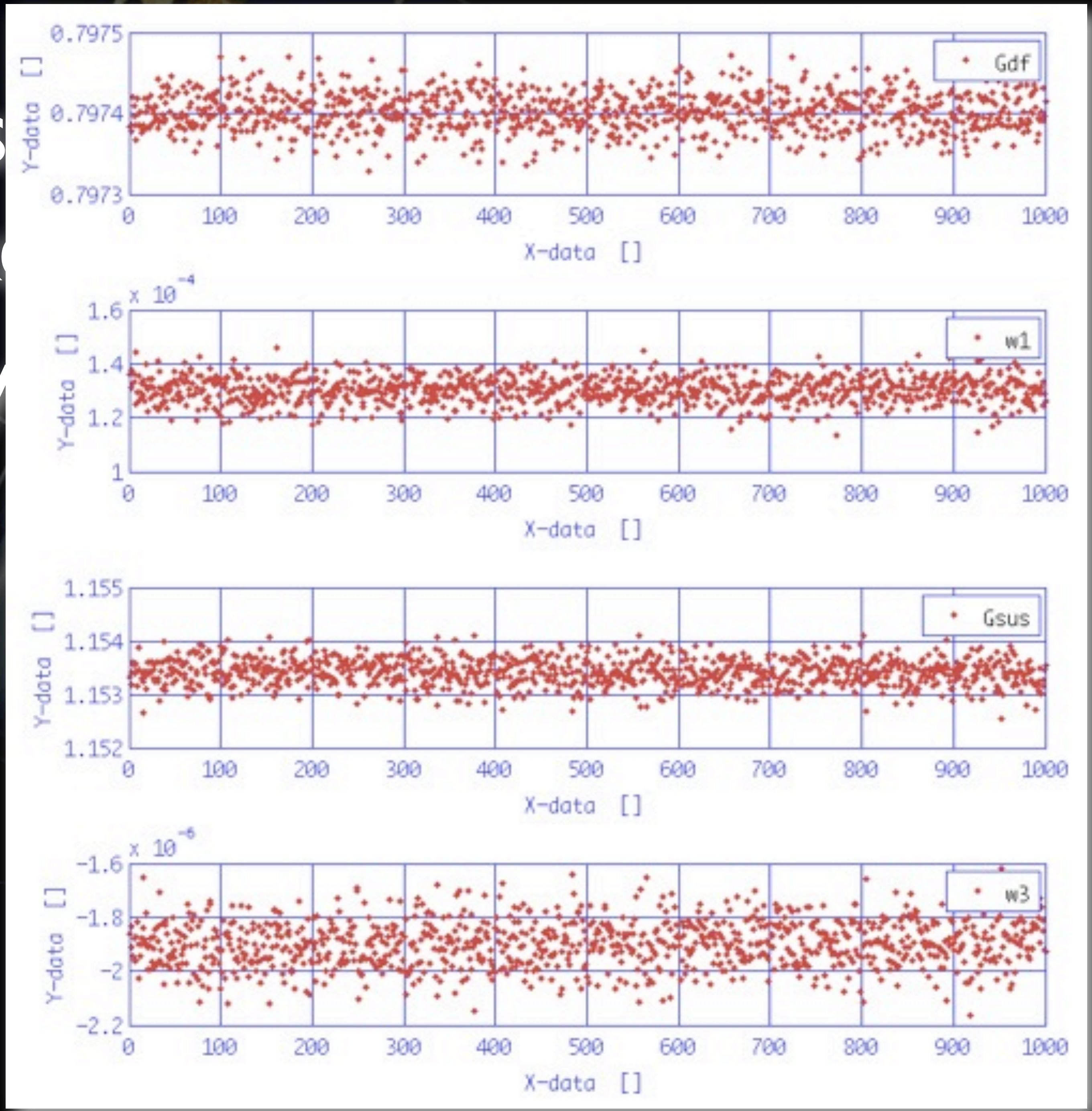
Monte Carlo Analyses

- Do our error estimates on the parameters make sense?
- Are there any systematic errors?

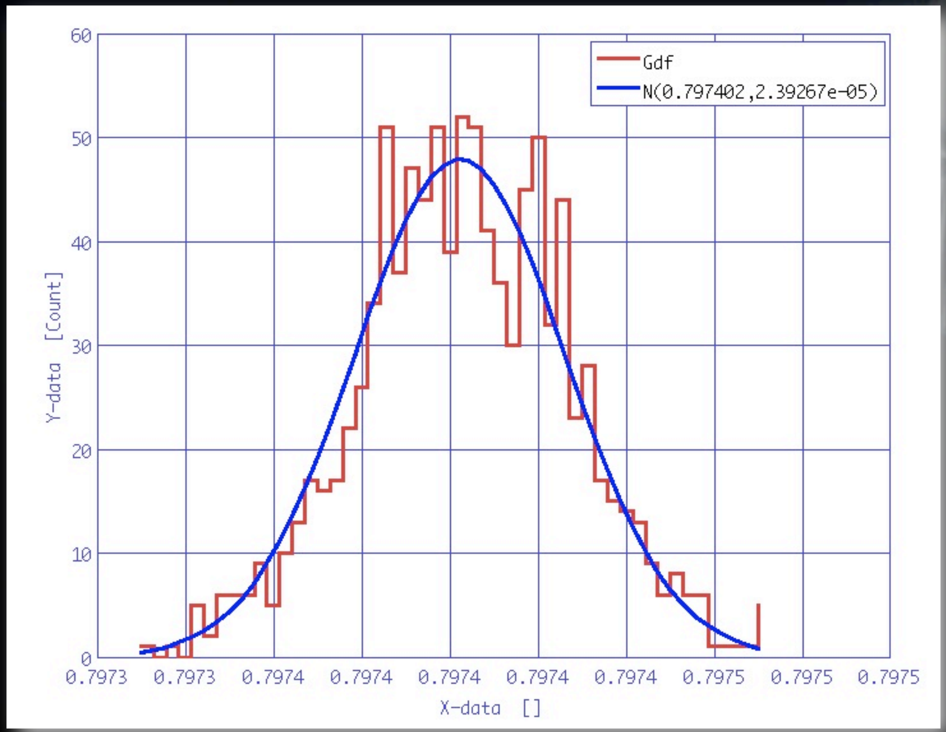
Monte Carlo Analyses

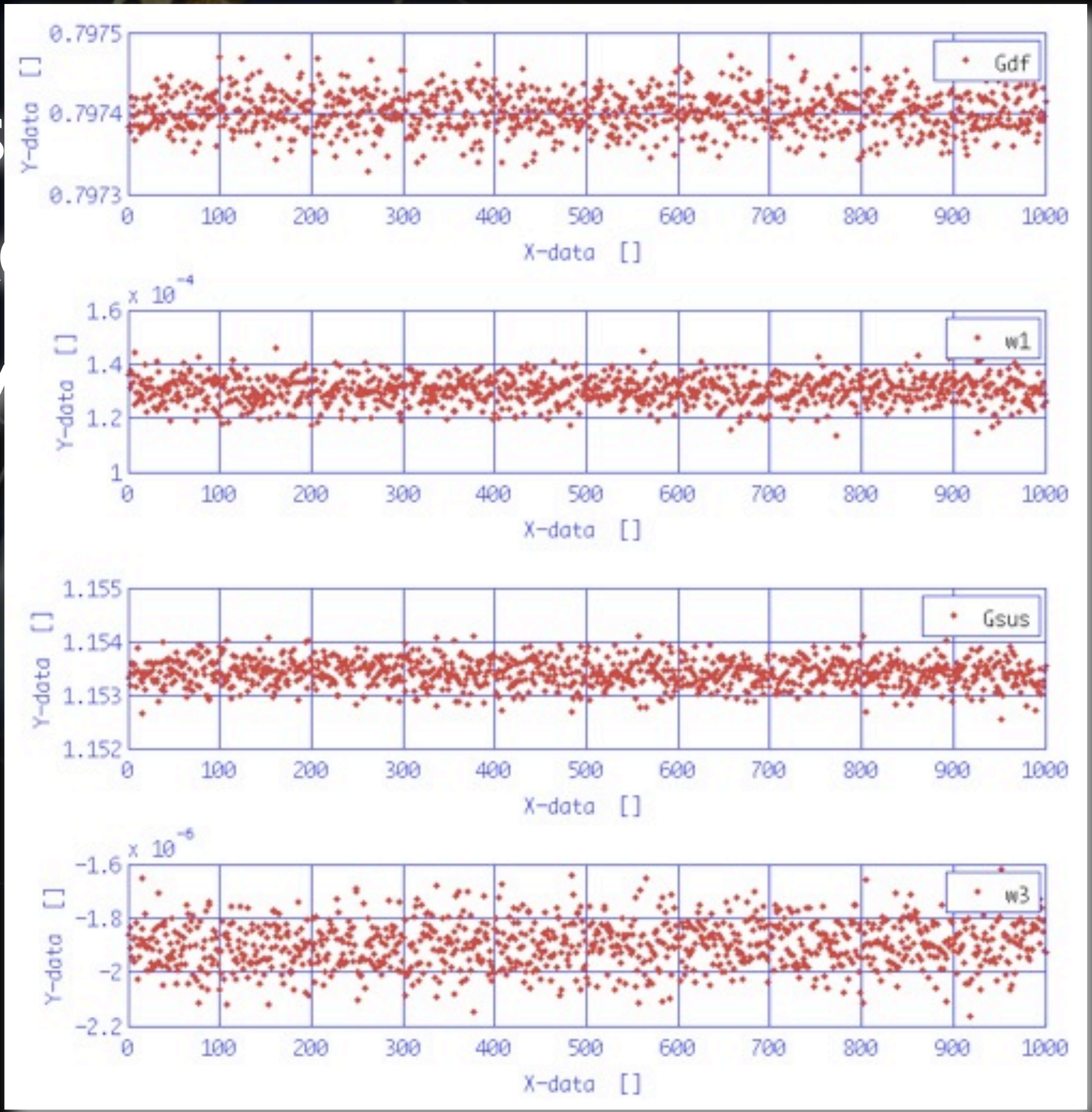
- Do our error es
  parameters mak
- Are there any sy



Monte Carlo Analyses

- Do our error es
  parameters mak
- Are there any sy





Future MDCs

- MDC3
  - aim to demonstrate the proposed system-identification runs for x-axis dynamics
- Further MDCs
  - demonstrate other planned experiments
    - working through technical notes of the EMP