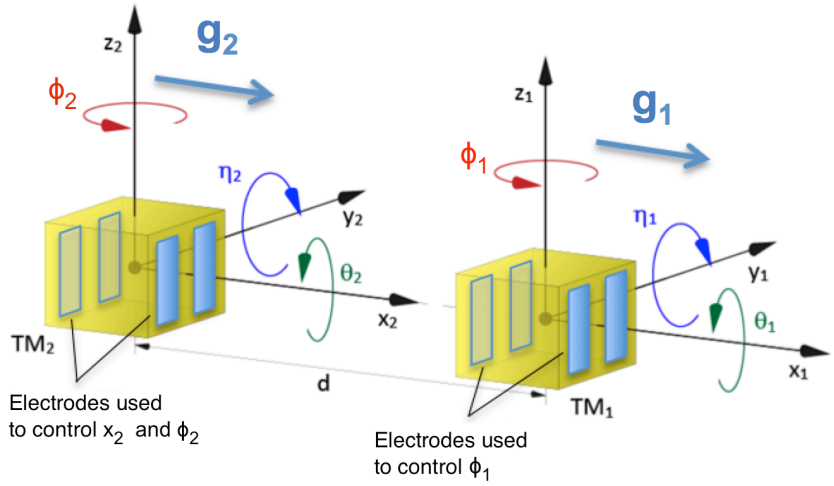
The free-fall mode experiment on LPF: first results

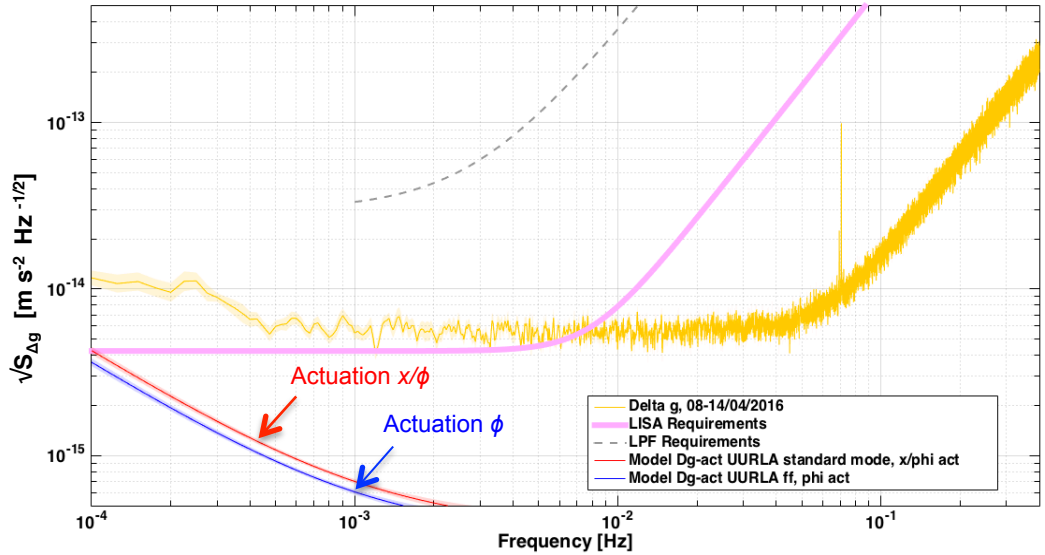
Roberta Giusteri on behalf of the LPF collaboration
University of Trento and INFN-TIFPA

LISA Symposium XI, 5 - 9 September 2016

LPF and actuation control

- LPF as an accelerometer
- Down-scaled version of one LISA arm
- TM1 “drag free” (geodesic reference)
- TM2 continuously controlled along *x*





[M Armano *et al.* PRL **116** 231101 (2016)]

$$F \propto V_{act}^2 \quad \Rightarrow \quad \delta(F) \propto 2\,F\,\frac{\delta V_{act}}{V_{act}}$$

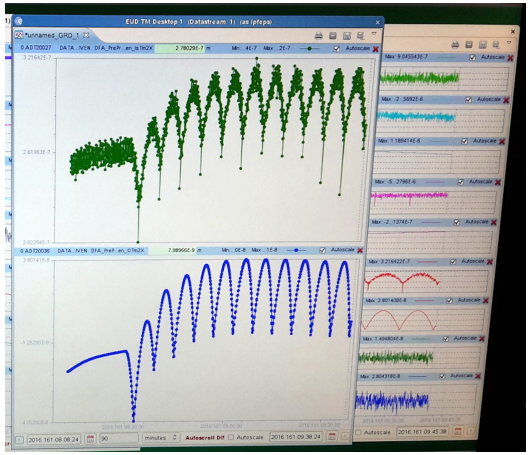
$$\Rightarrow \quad S_{\Delta g}^{1/2} \propto 2\,\Delta g_{DC}\; S_{\delta V_{act}/V_{act}}^{1/2}$$

$$S_{\delta V_{act}/V_{act}}^{1/2} \simeq 5\ ppm/\sqrt{Hz}$$

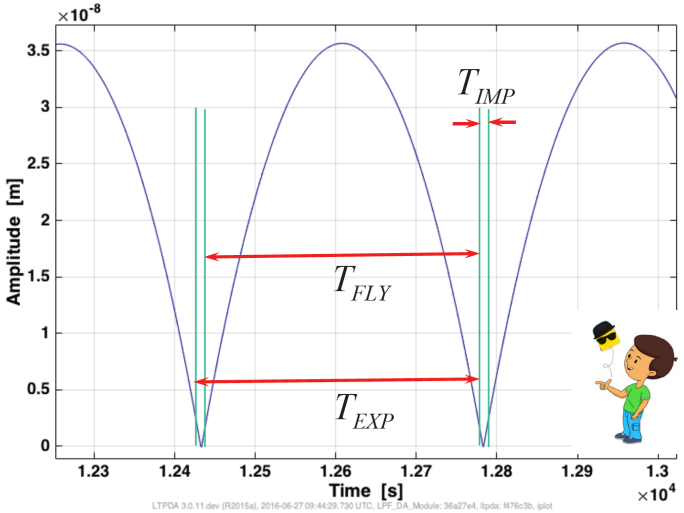
Actuation along *x* not present in LISA

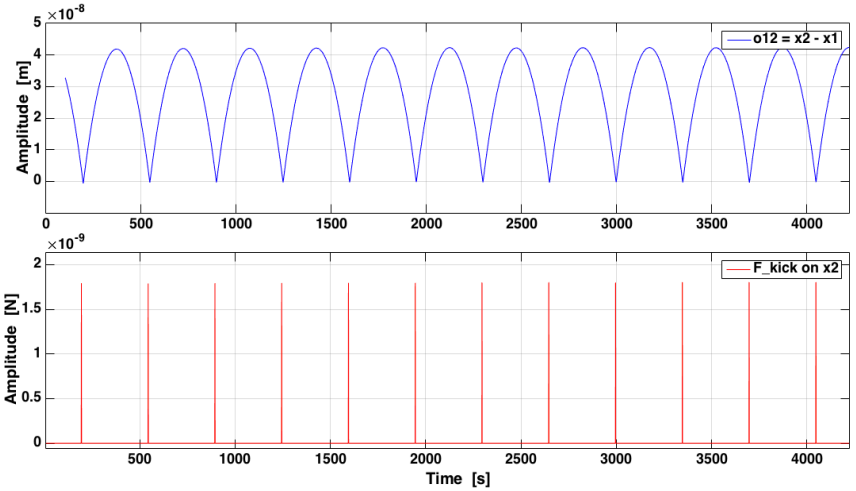
Free Fall experiment

- Proposed to subtract the actuation noise on TM2
- Actuation limited to short impulses
- Repeated stretches of parabolic flights



T_{fly} = 349.2 s
T_{imp} = 1 s
T_{exp} = 350.2 s
$f_{exp} \approx$ 2.85 mHz



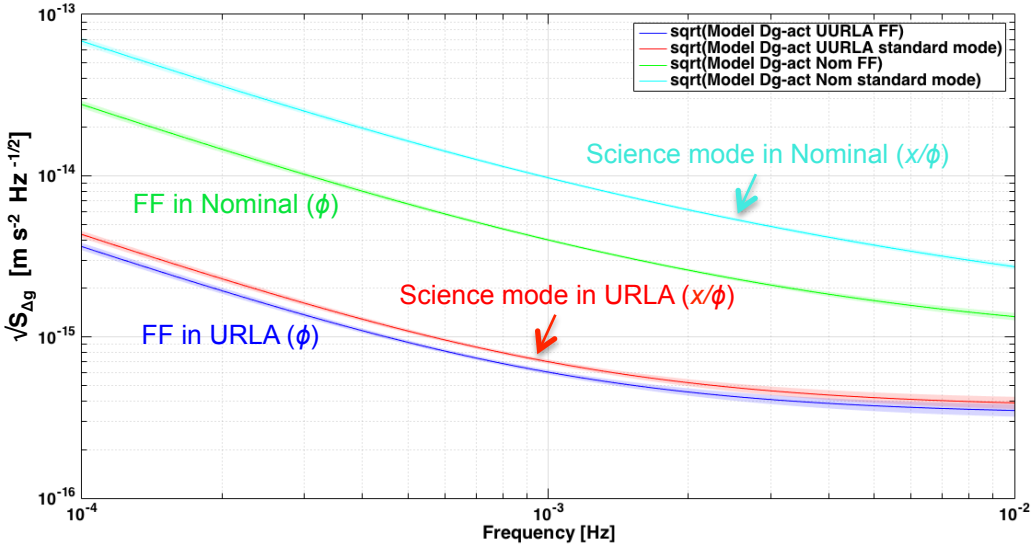


- ➢ No dependence on the actuator calibration
- ➢ Acceleration noise in "actuation-free" condition: characterization for LISA

FF mode vs standard science mode

Predicted actuation noise in different authority configurations →

Nominal:	$F_{max\ x2}$	= 2200 pN
	$N_{max\ \phi 2}$	= 10.4 pN m
URLA:	$F_{max\ x2}$	= 50 pN
	$N_{max\ \phi 2}$	= 1 pN m



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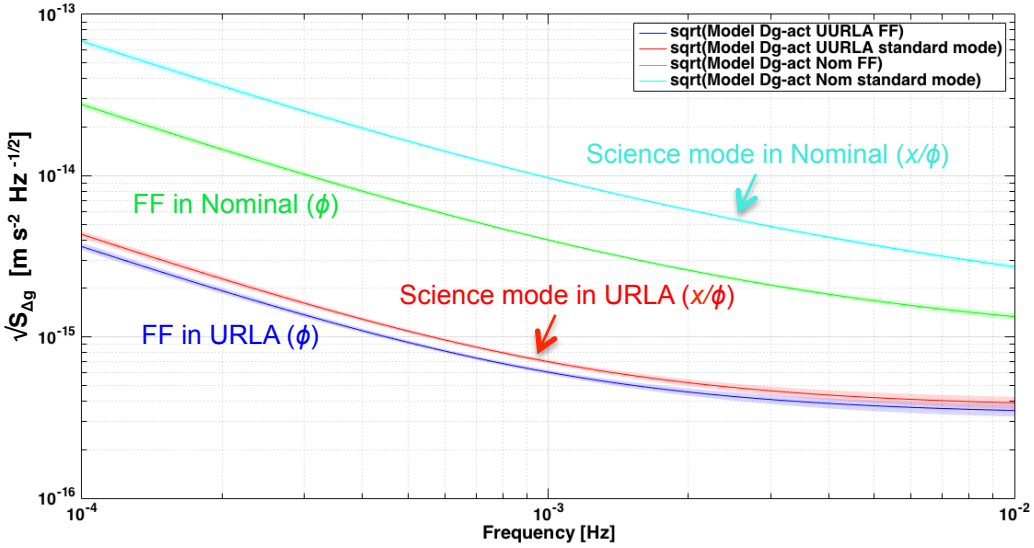
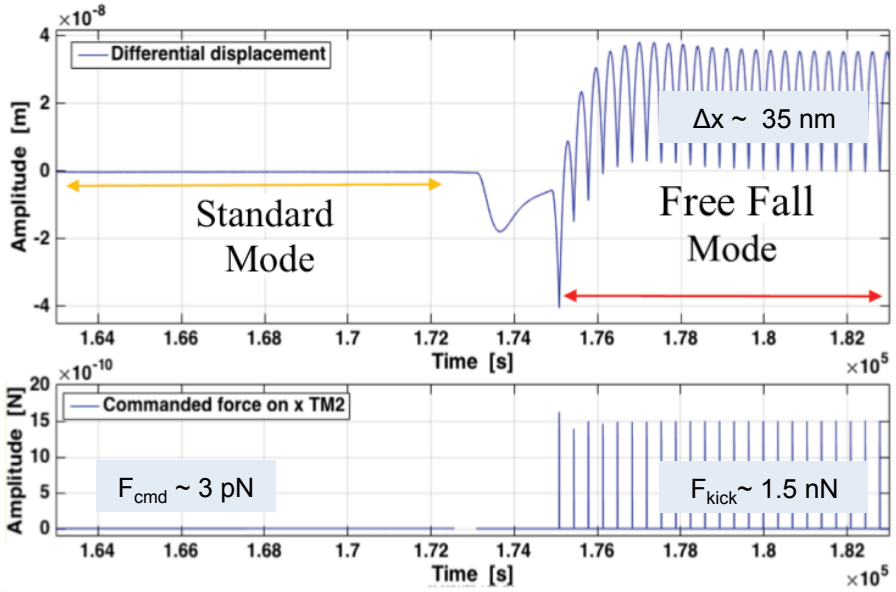
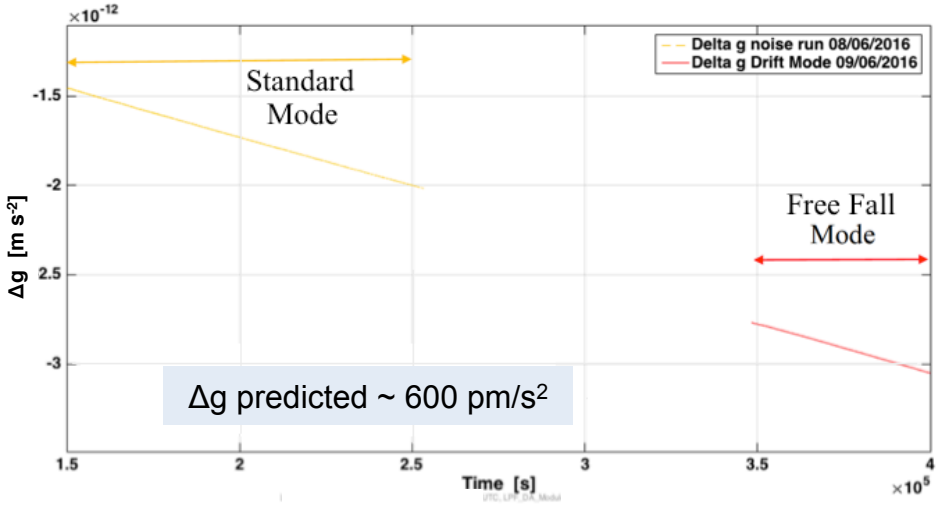






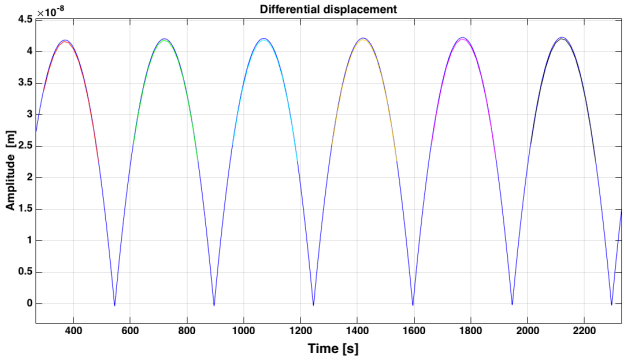
Experiment calibration

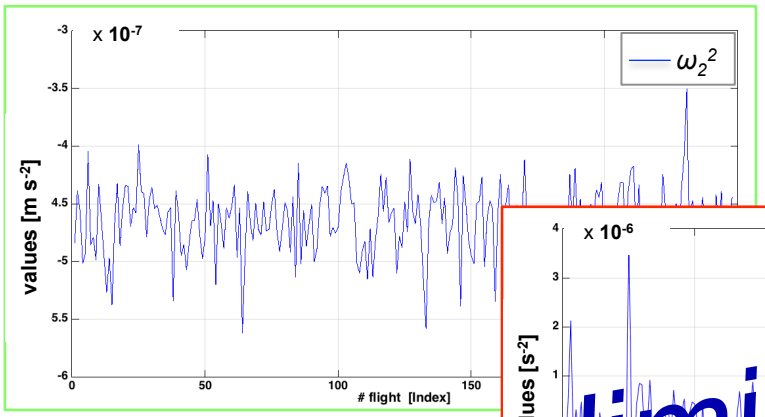
Equation of motion to fit:

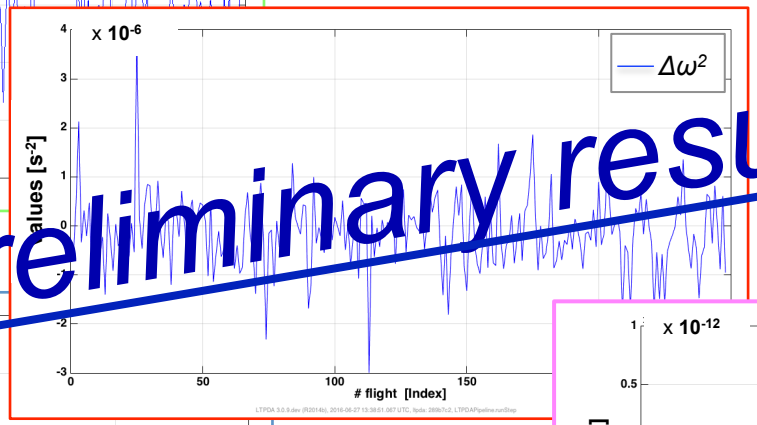
$$\Delta\ddot{x} = -\omega_2^2 \Delta x - \Delta\omega^2 (x_1 - x_{SC}) + \Delta g + \dot{g}_0 \cdot t$$

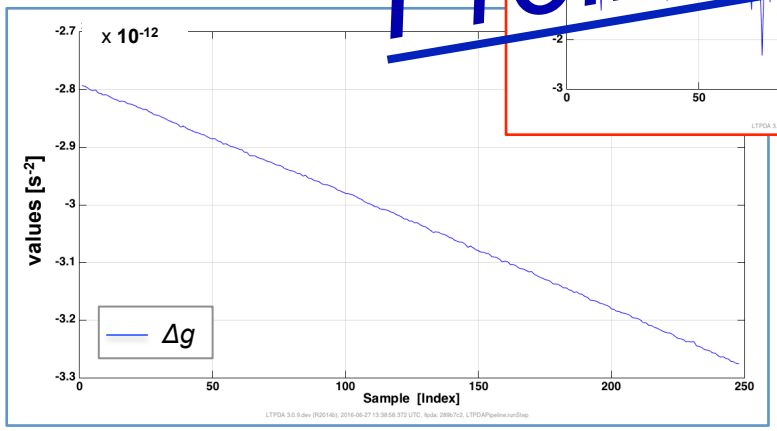
Filtering and decimation:

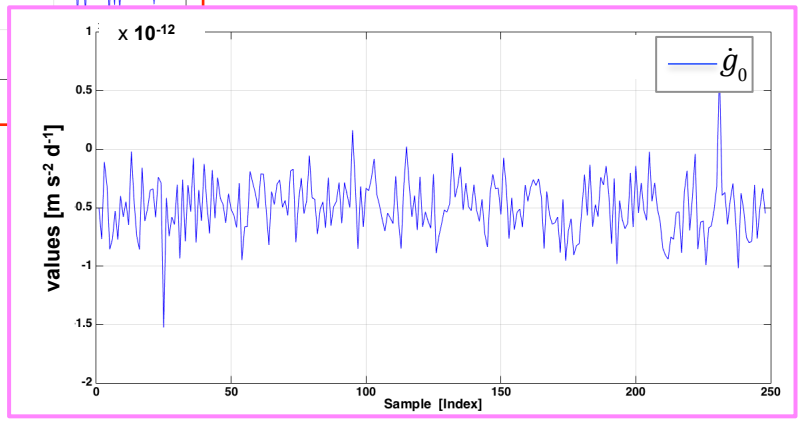
T_{samp} ~ 17 s
f_{samp} ~ 57 mHz
n_{fit} = 14











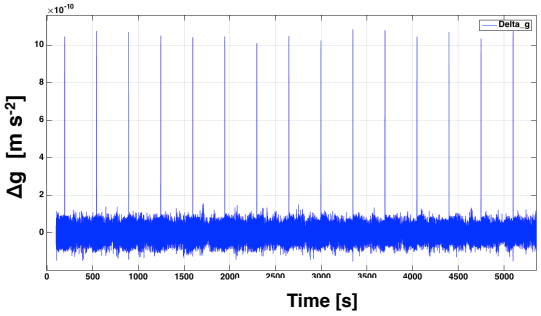
Parameter	Mean value	Error
ω_2^2 [10^{-7} s^{-2}]	- 4.661	0.019
$\Delta\omega^2$ [10^{-7} s^{-2}]	- 1.289	0.461
Δg [pm s^{-2}]	- 3.031	0.009
$\dot{g}_0$ [pm s^{-2} d^{-1}]	- 0.493	0.016

[FF on June 10th in URLA authority]

Preliminary results

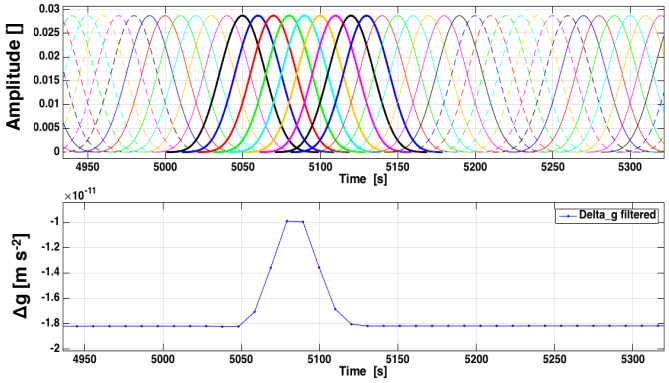
Data analysis challenge

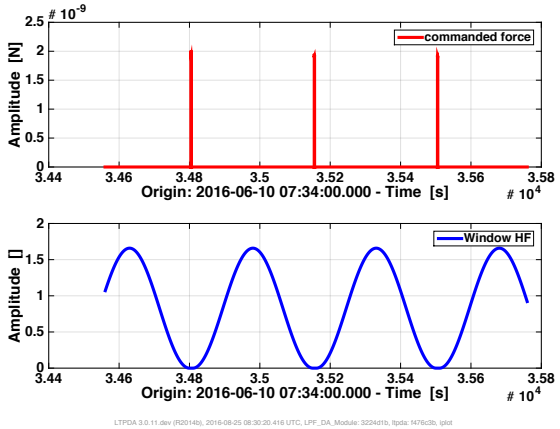
Kicks: high-noise configuration
analysis of “actuation-free motion” → gaps in data

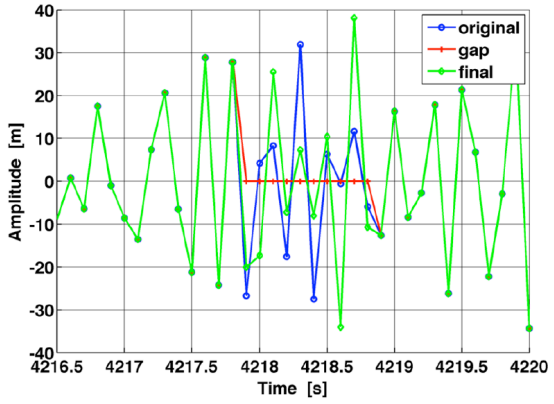


Analysis techniques:

Blackmann-Harris low pass filtering	Windowing technique	Constraint-Gaussian Gap Patching
low pass filtering + downsampling and set kicks to zero	masking the gaps with spectral windows	filling the gaps with artificial data







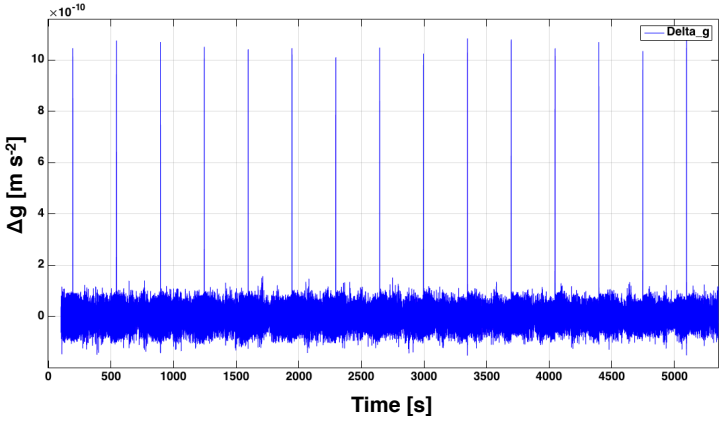
[Poster: G. Russano “LISA Pathfinder Free Fall Mode”, A18]

BH low pass approach

lisa pathfinder

Δg estimation at 10Hz

$$\Delta g(t) = \Delta\ddot{x} + \Delta\omega^2(x_1 - x_{SC}) + \omega_2^2 \Delta x - \dot{g}_0 \cdot t$$



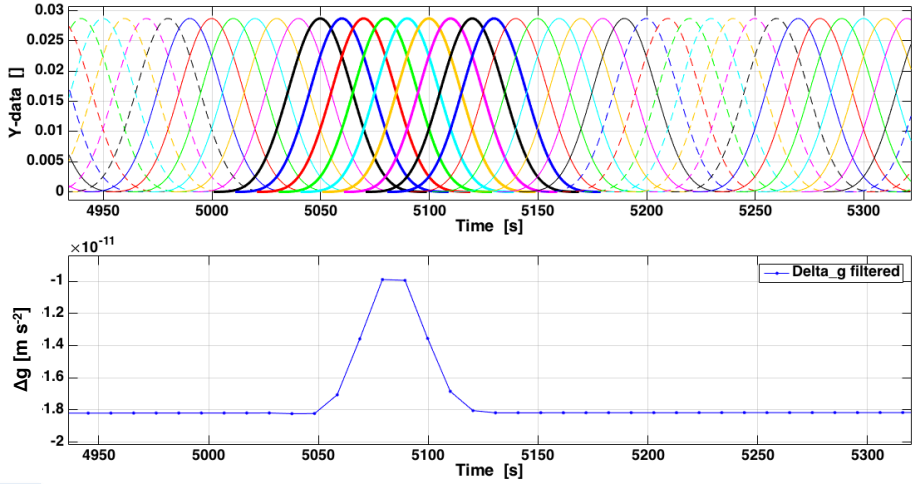
BH low-pass filter

- n_{tot} per T_{exp} , n_{keep} per T_{fly}
- $T_{samp} = T_{exp} / n_{tot}$
- BH window, $T_{win} = T_{fly} - 2 \cdot margin - (n_{keep} - 1) \cdot T_{samp}$
- filtering and downsampling

Set to zero
$n_{gap} = n_{tot} - n_{keep}$

Evaluate the spectrum

PSD correction for n_{tot}/n_{keep} and BH transfer function



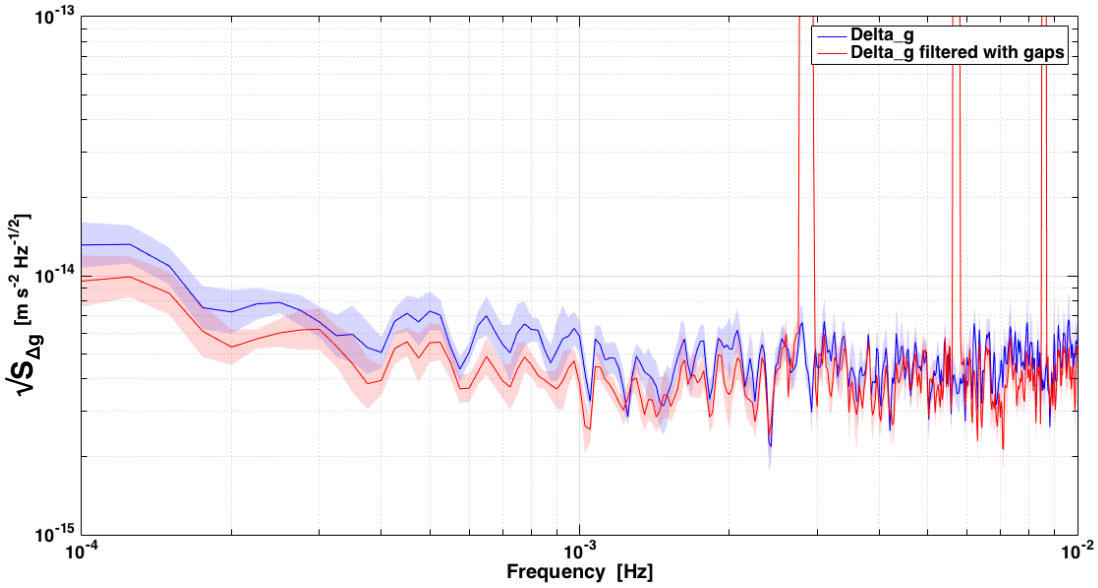
Configuration:

n_{tot}	34
n_{keep}	25
n_{gap}	9
T_{samp} [s]	10.3
f_{samp} [mHz]	97
margin [s]	2
T_{win} [s]	98

Calibration of BH technique

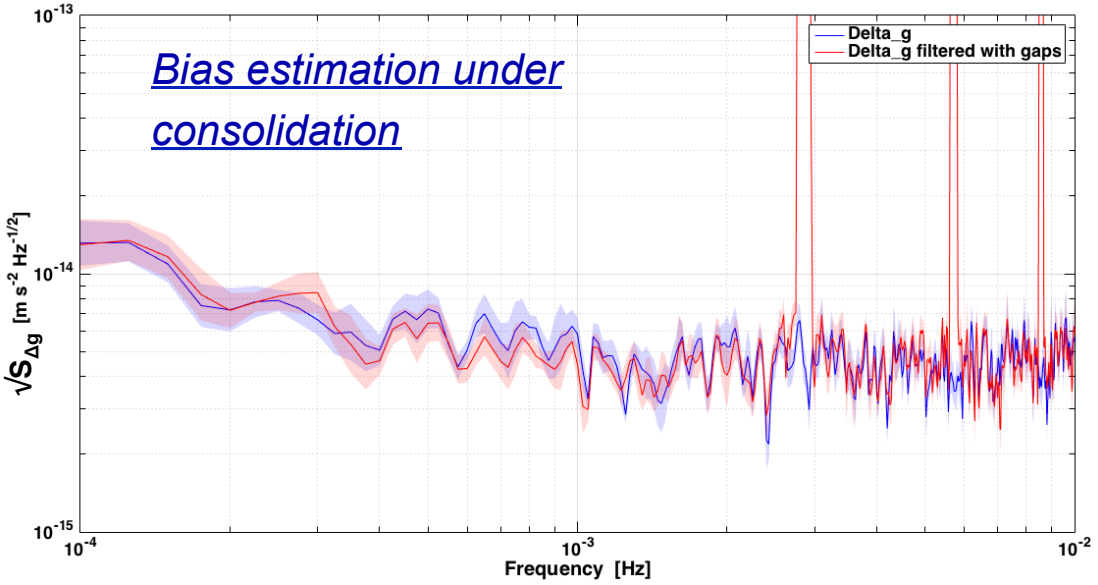
Investigation into the **potential BIAS** introduced by the BH technique:

1. Science measurement (URLA, May 16-18)
2. Apply BH filtering method
3. Insert artificial gaps
4. Estimate the spectrum
5. Correction for filter transfer function



Bias estimation necessary to correct the spectrum accurately.

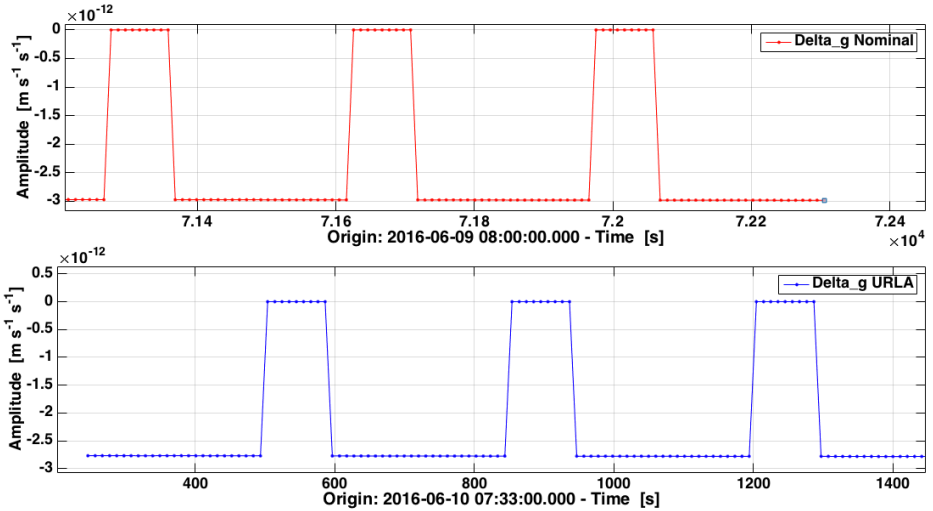
Correction related to n_{tot}/n_{keep}
(work in progress)



First results applying BH method

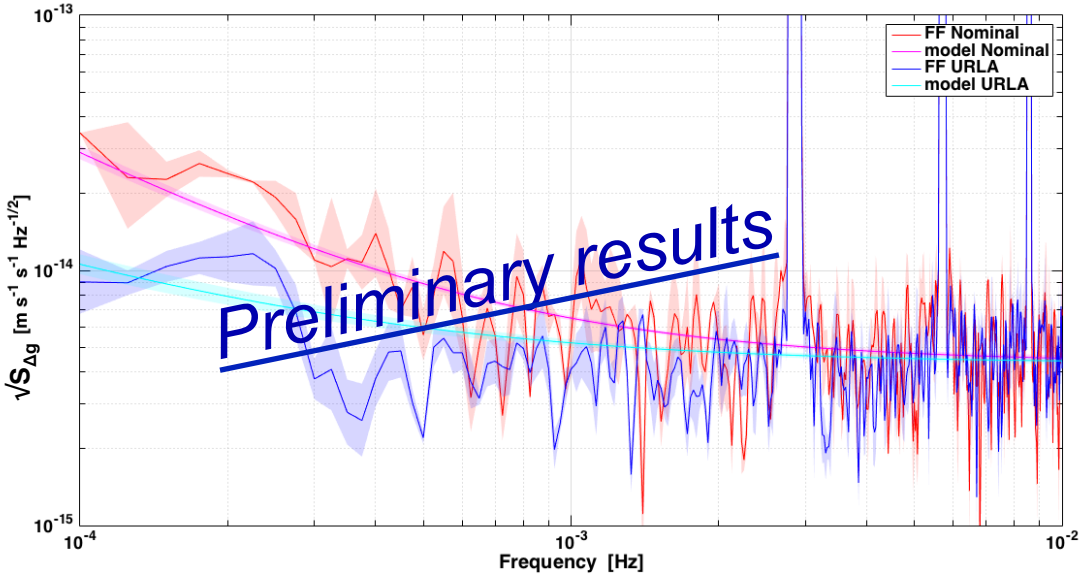
FF Nominal x/ϕ authority on TM2, 1 day
(F_{max} = 2200 pN , N_{max} = 10.4 pN m):

Parameter	Mean value	Error
ω_2^2 [10^{-7} s^{-2}]	- 7.116	0.029
$\Delta\omega^2$ [10^{-7} s^{-2}]	- 1.715	0.403
Δg [pm s^{-2}]	- 2.500	0.007
$\dot{g}_0$ [pm s^{-2} d^{-1}]	- 0.400	0.021



FF URLA x/ϕ authority on TM2, 1 day
(F_{max} = 50 pN, N_{max} = 1 pN m):

Parameter	Mean value	Error
ω_2^2 [10^{-7} s^{-2}]	- 4.586	0.019
$\Delta\omega^2$ [10^{-7} s^{-2}]	- 1.271	0.407
Δg [pm s^{-2}]	- 3.029	0.009
$\dot{g}_0$ [pm s^{-2} d^{-1}]	- 0.493	0.016

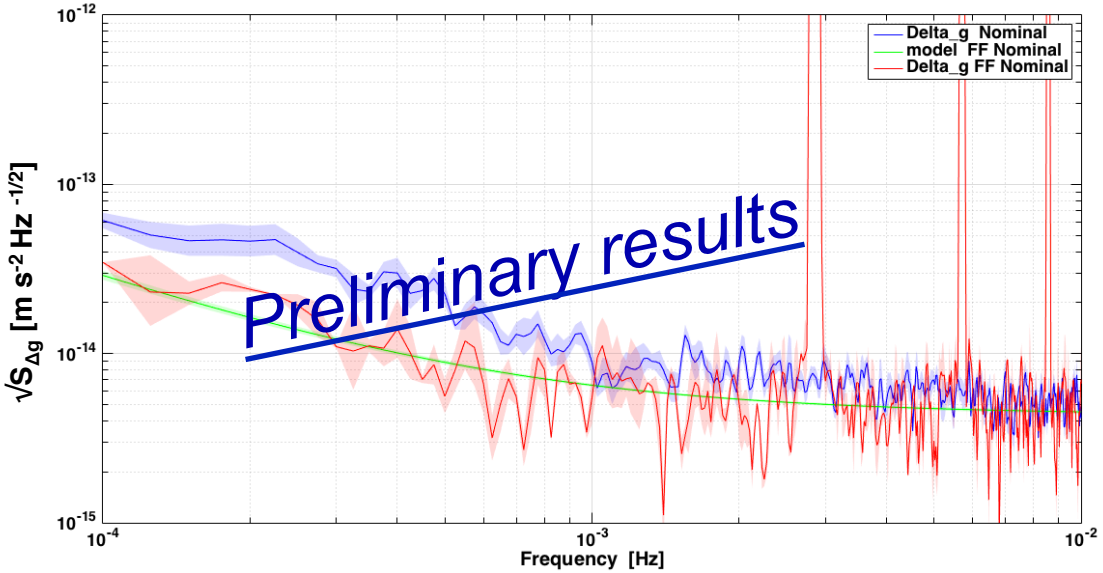


Comparison with standard mode

Nominal authority:

Science mode: May 19-21

Free Fall: June 9th



URLA authority:

Science mode: May 16-18

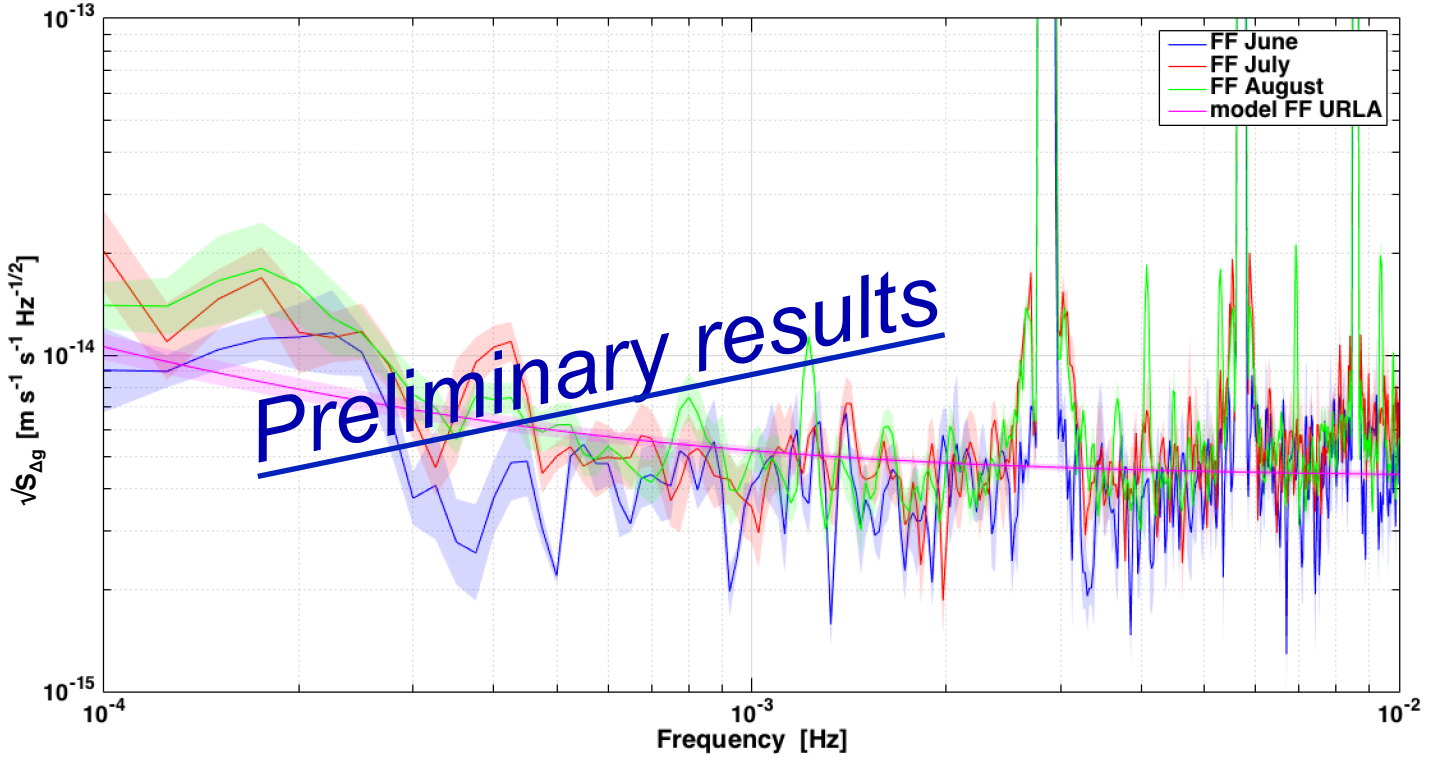
Free Fall: June 10th

Comparison among all FF runs

URLA authority,
BH technique applied

Averaged spectral values in [0.1, 0.4] mHz band

FF run	√S [fm s^{-2} Hz$^{-1/2}$]
June run (1 d)	9.464 ± 0.473
July run (1.5 d)	15.302 ± 1.750
August run (3 d)	12.384 ± 1.159



Conclusions and perspectives

- **Free-fall mode control** achieved and maintained
- All analysis techniques have extracted spectra
- Free Fall results consistent with **actuation models** predicted
- Free Fall results consistent with **long science measurements (URLA)**

Future work:

- Analysis **consolidation** of the two last FF experiments
- Correction for **BIAS** introduced by each method
- **New Free Fall experiment** in same conditions of the first one (and longer)
- **New design Free Fall experiment with kicks also on ϕ_2**

Perspectives:

- Free Fall implementation → closer to **LISA performance**
- Spectral estimation in presence of gaps

Thank you