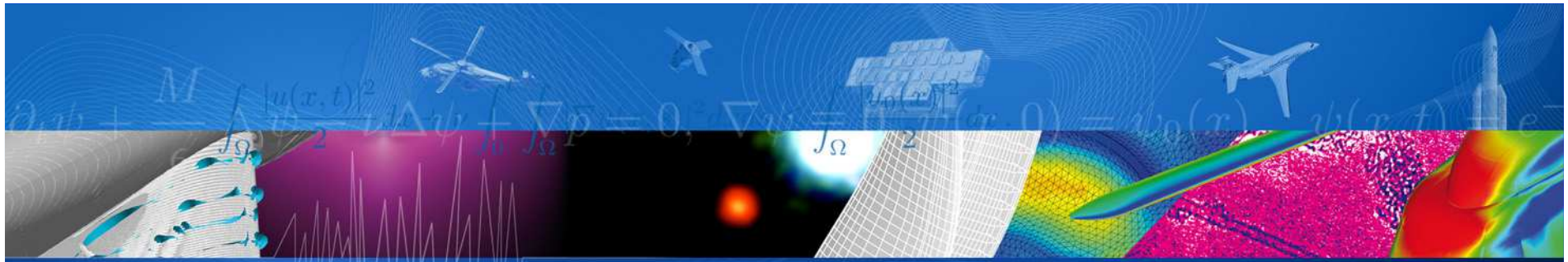

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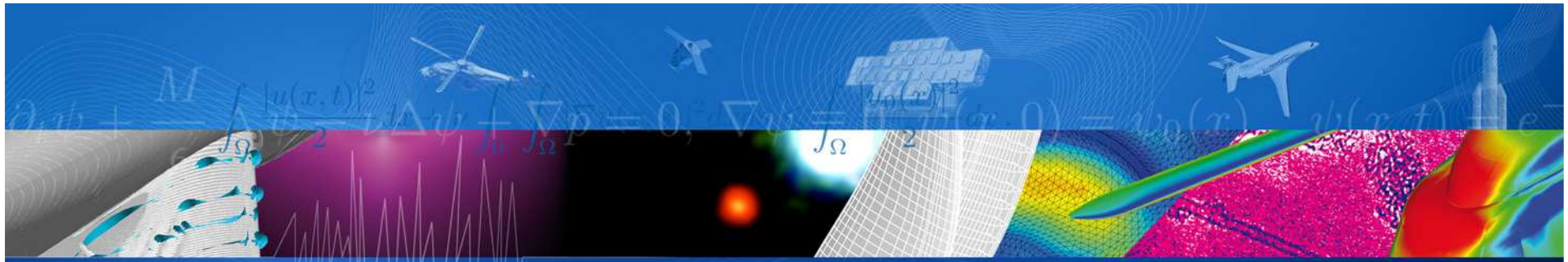

Worshop: Missing Data in Physics **11-12 May 2015 Nice (France)**

Impact of the twangs on the GRACE data recovery

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ONERA, The French Aerospace Lab

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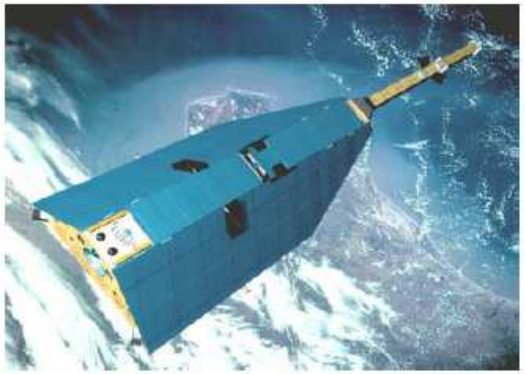
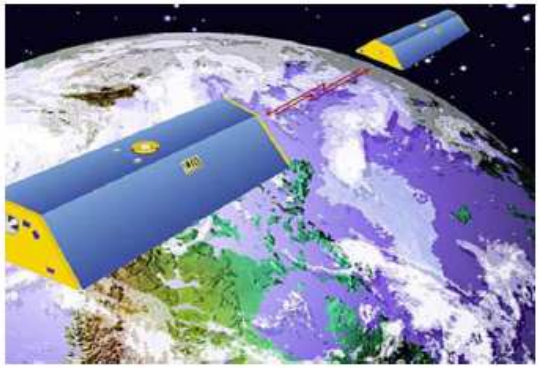
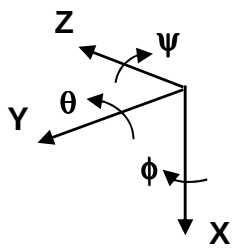
Acceleration disturbance on board Earth Gravity Field satellite missions

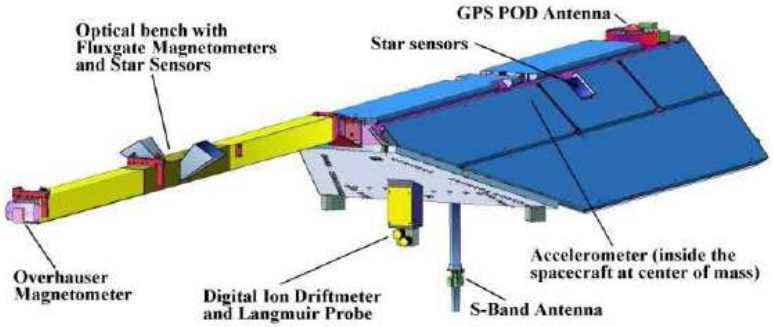
- Twang = sudden spike followed by an oscillating decay

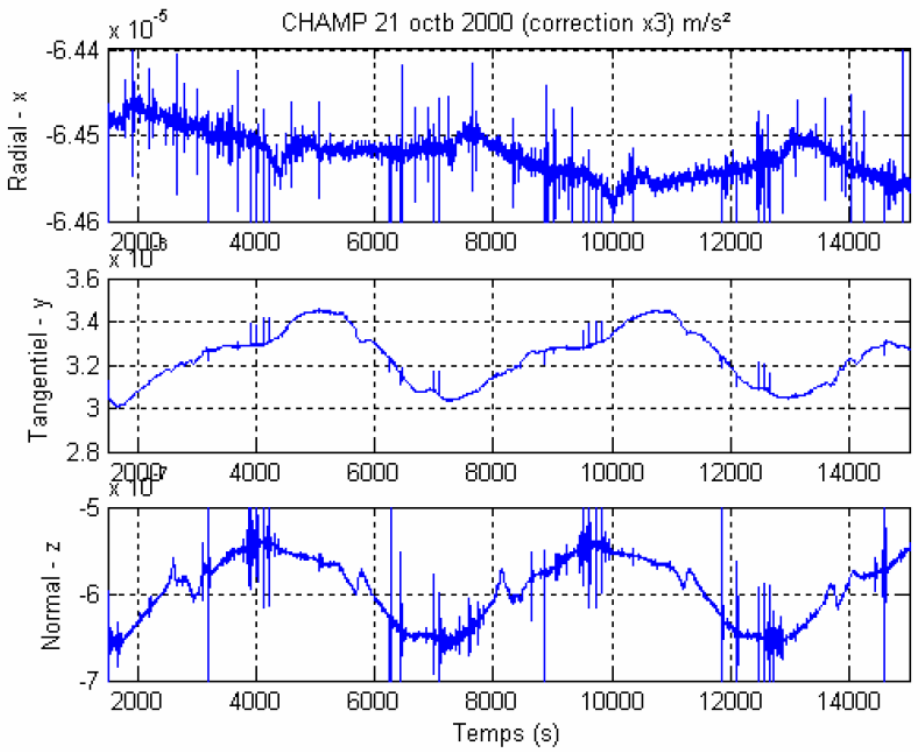
- During last decade 3 Earth gravity field missions with ultra-sensitive electrostatic accelerometers on-board

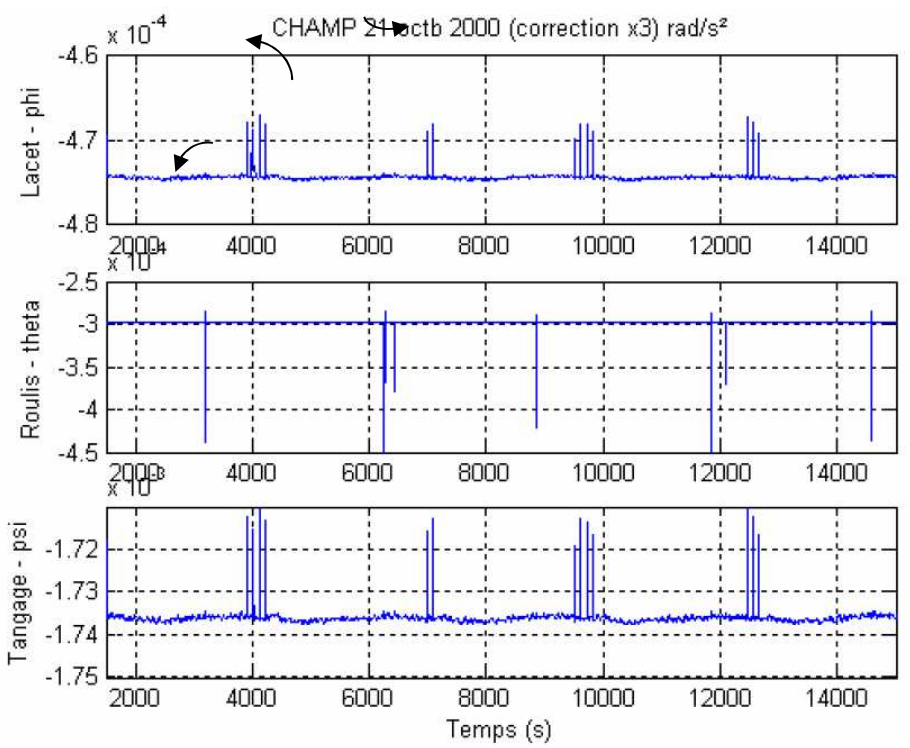
CHAMP	GRACE	GOCE
		
July 2000 - sept 2010	march 2002 - (2017 ?)	march 2009 – nov 2013
1 accelerometer	2 × 1 accelerometer	EGG = 6 accelerometers
10^{-9} $ms^{-2}/Hz^{1/2}$	10^{-10} $ms^{-2}/Hz^{1/2}$	2×10^{-12} $ms^{-2}/Hz^{1/2}$

CHAMP Mission

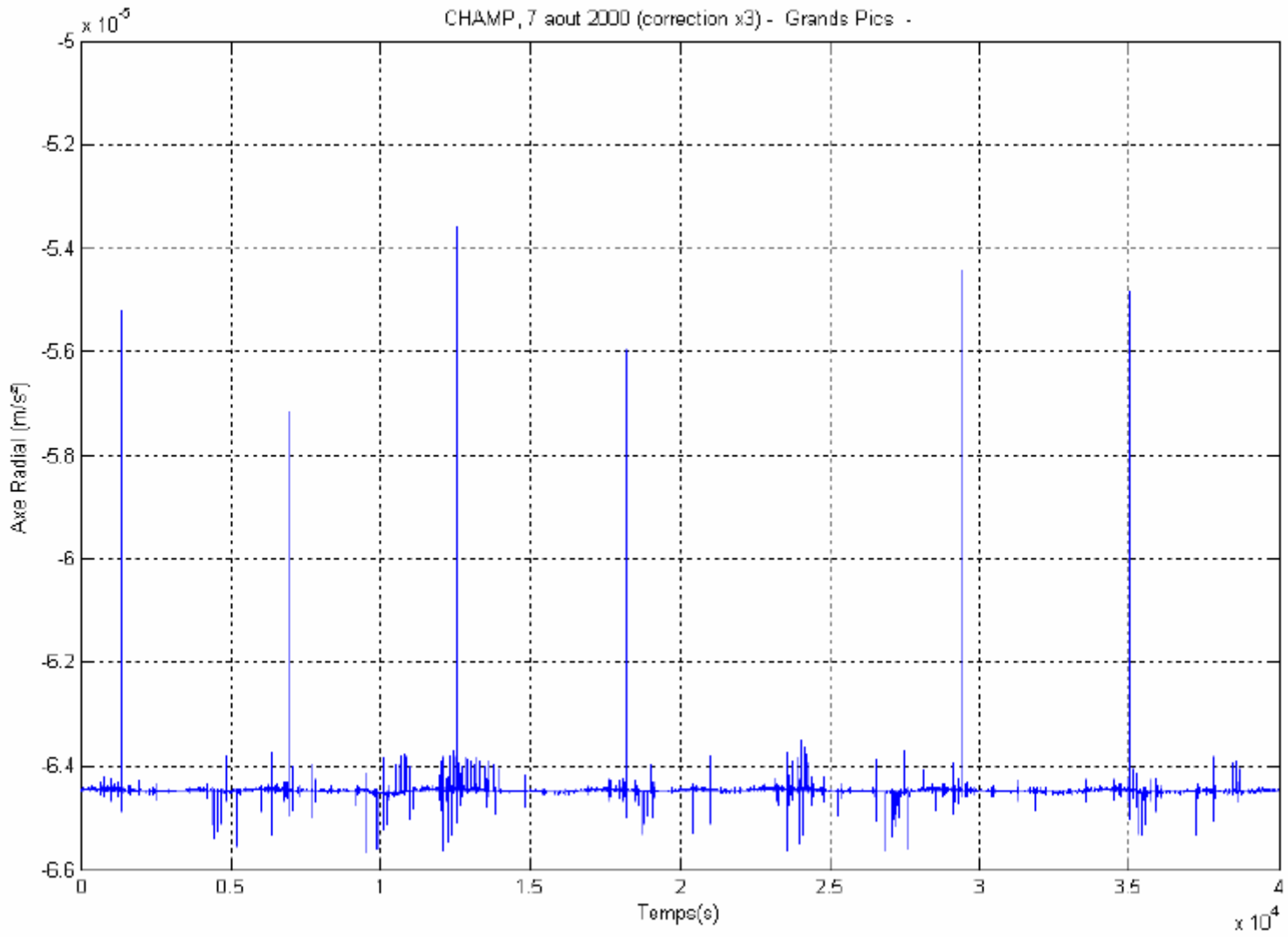








CHAMP Mission : Large spikes induced by Sun/Penumbra transitions



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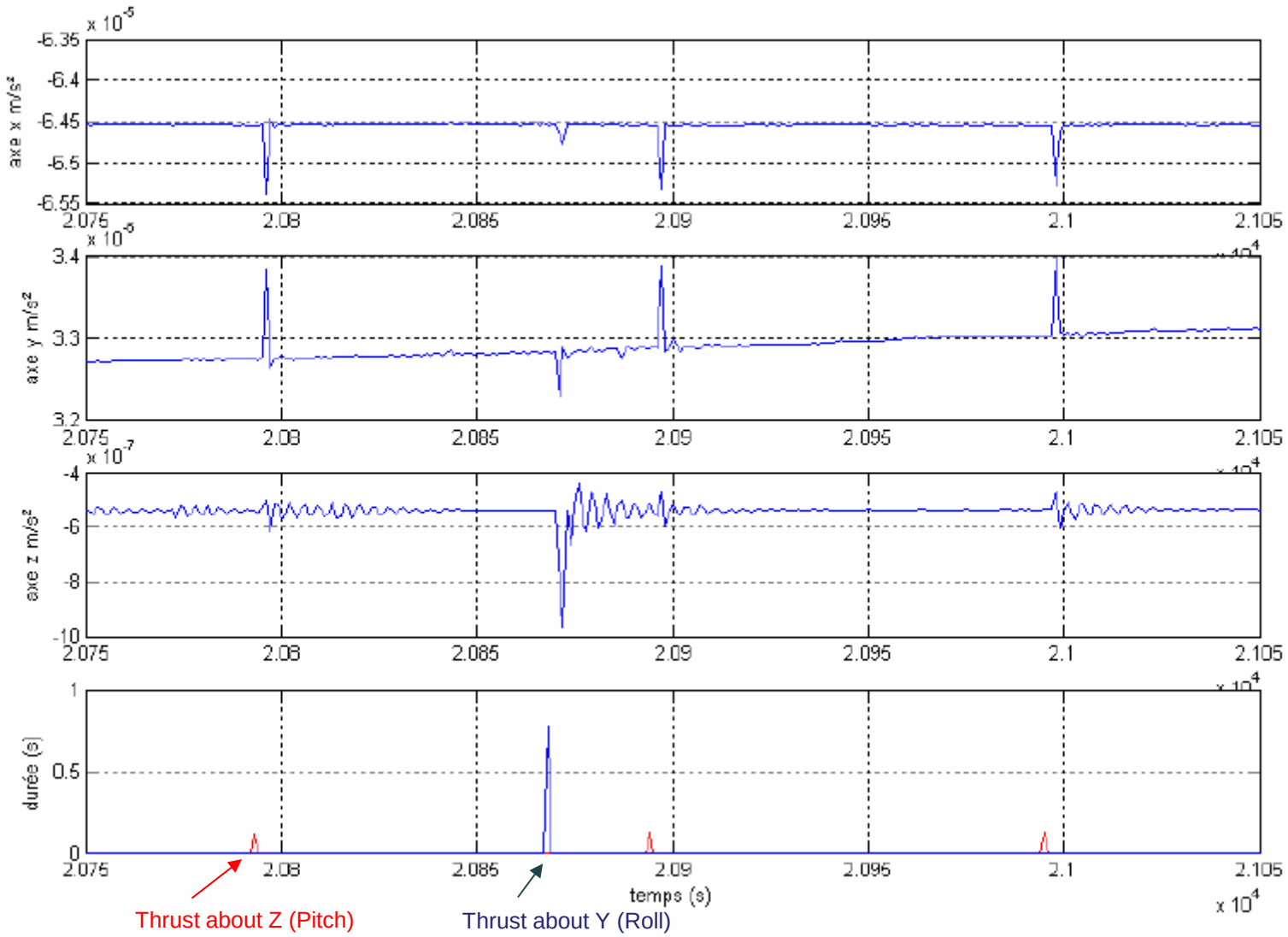
CHAMP Mission : Thruster activation spikes along linear acceleration axes



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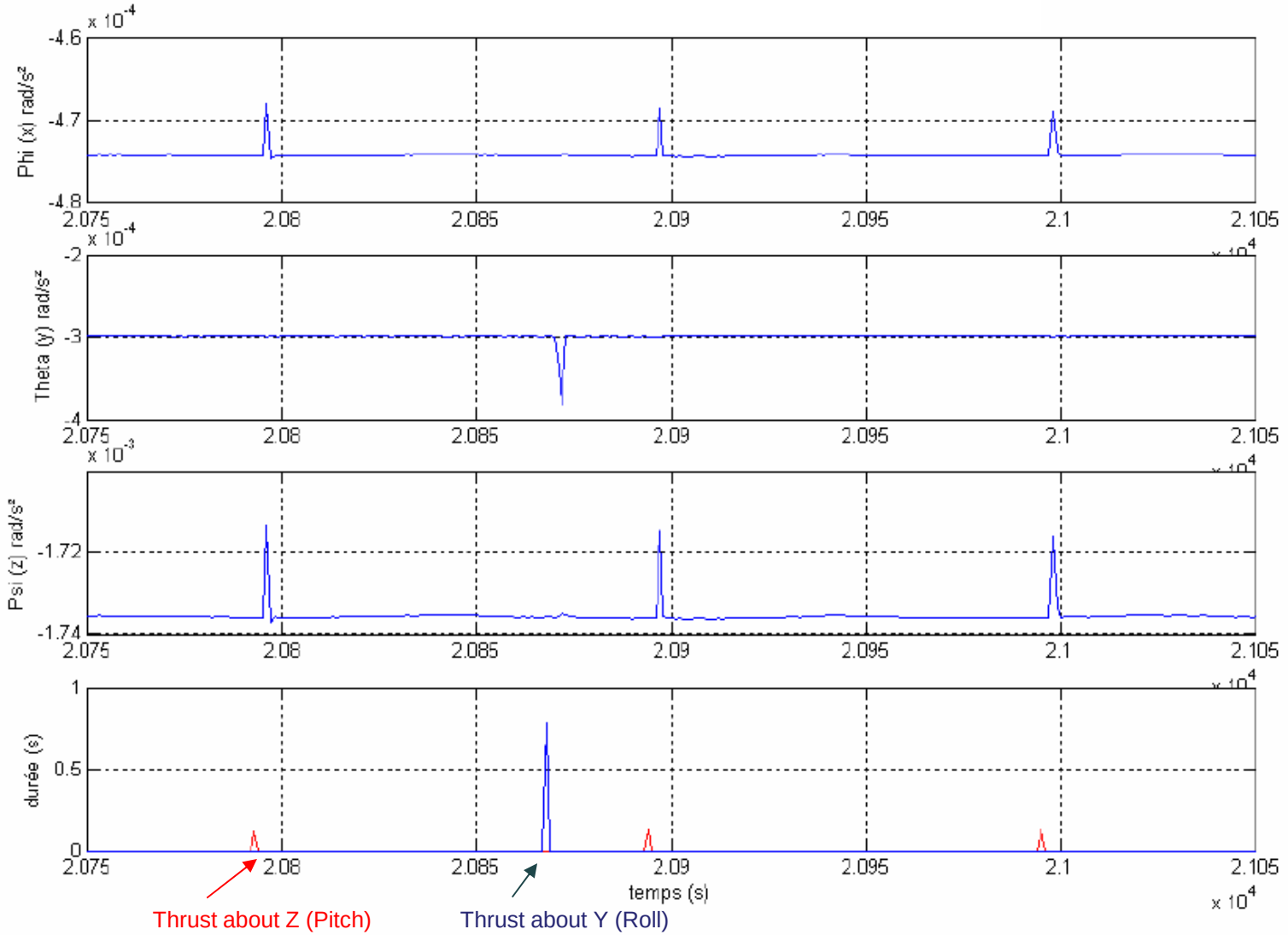
CHAMP Mission : Thruster activation spikes along angular acceleration axes



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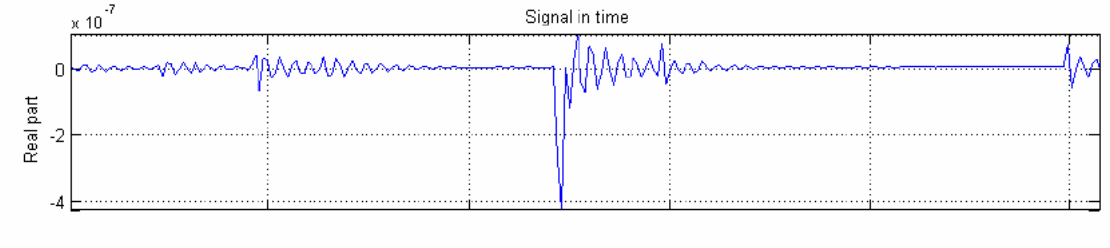
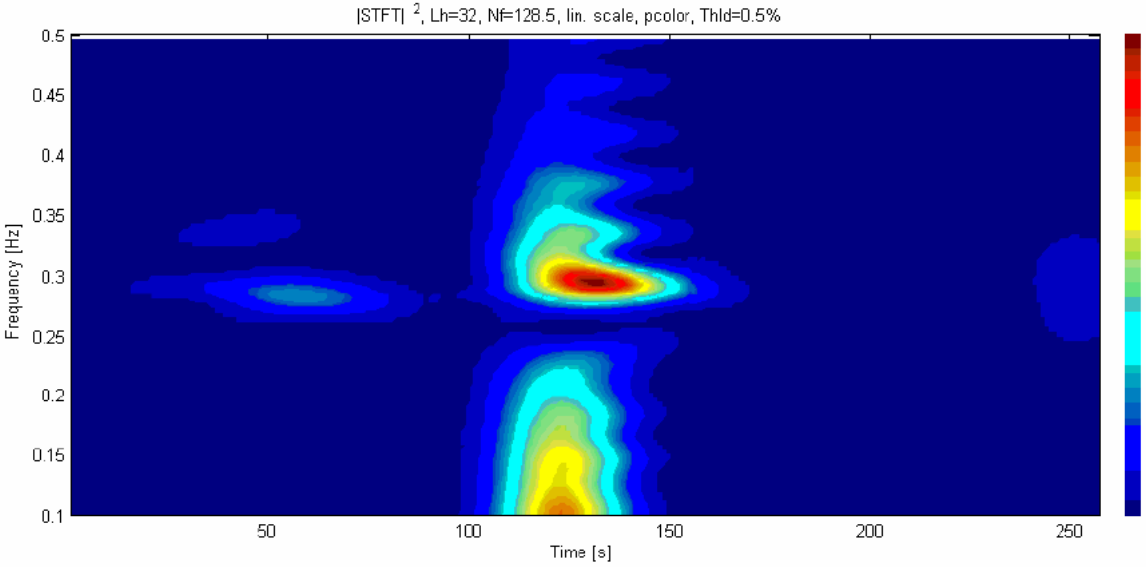
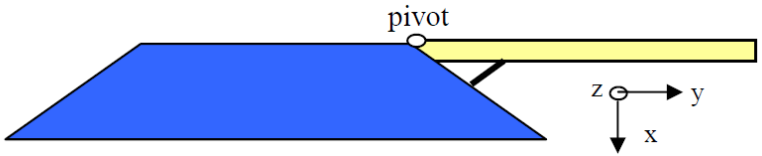
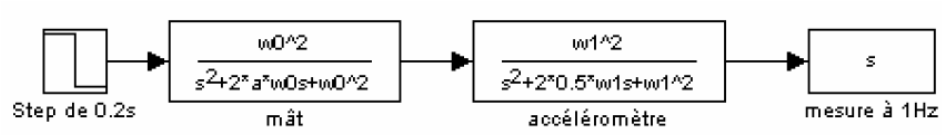
CHAMP Mission : Boom excitation twangs induced by thrusters









Measured oscillations

Frequency : 0,27 Hz

Damping : τ = 8 s with a = 9×10^{-8} ms^{-2}

Boom

Frequency : 27 Hz

Mass 20 kg

Damping : ζ = 0,01 with a = 4×10^{-7} ms^{-2}

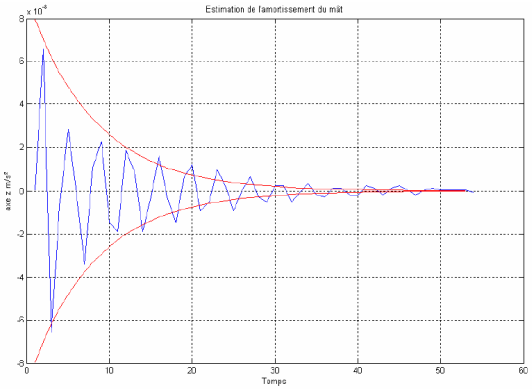
→ h = 2,5 kg/s

Accelerometer

Frequency : 1Hz

Damping : ζ = 0,5

Aliasing between 1Hz acc. rate and 2,7Hz boom oscillation → signal osc. at 0,27Hz



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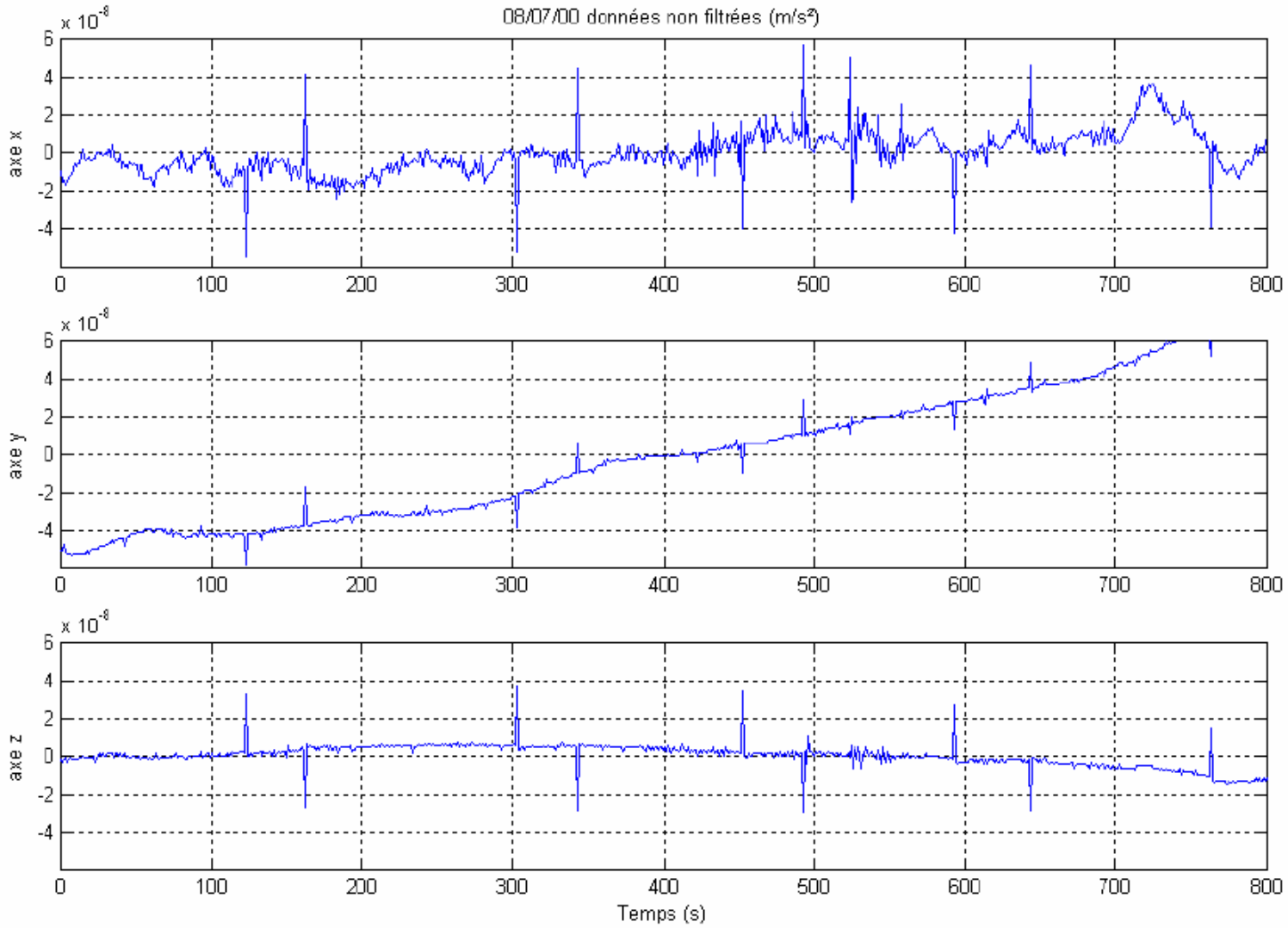
CHAMP Mission : Spikes induced by heaters activation at 10 Hz multiples



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CHAMP Mission data: Detection and filtering of spikes and twangs

- Mean filtering method

Compute the mean m0 and the standard deviation σ on a limited moving window
Detect the points out of the [m0-3σ, m0+3σ] range
Replace these points by m0
→ Very fast filtering but not very efficient, especially in case of multiple spikes in the chosen window

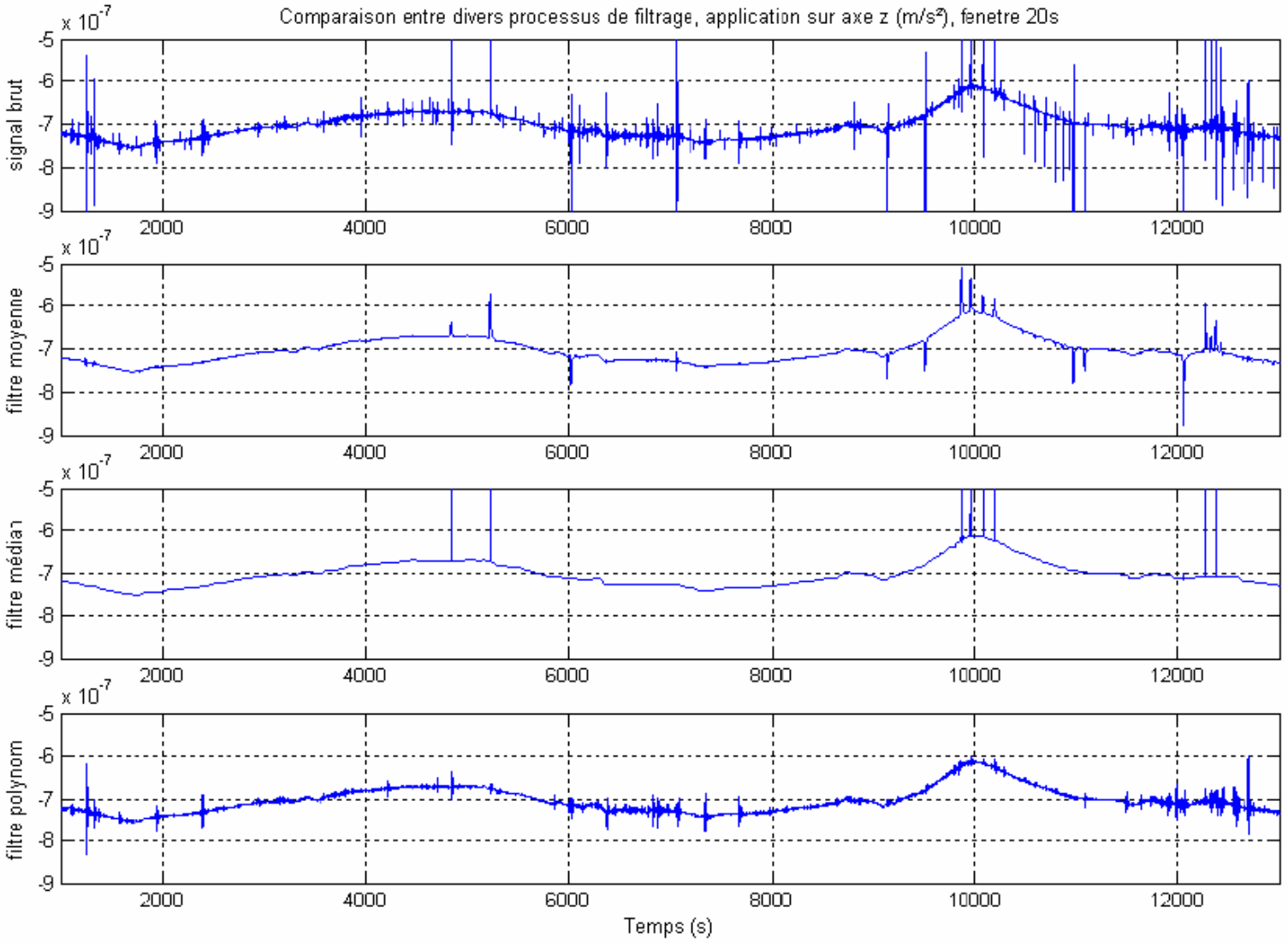
- Median filtering method

Same principle for the detection but the point value is replaced by the median value of the window instead of the mean
→ Need a narrow window and a steady signal

- Polynomial filtering method

In a moving window, the 3rd degree polynomial function fitting the signal is computed by a least squares method. The corresponding standard deviation σ is used for the selection with a 3 σ criteria between the data in the window and the values taken by the polynomial function.
The selected points are removed and the polynomial function is computed a second time in order to provide a better correction,
An overlap (50%) of the moving window is arbitrary chosen.

CHAMP Mission data: Comparison between the filtering methods



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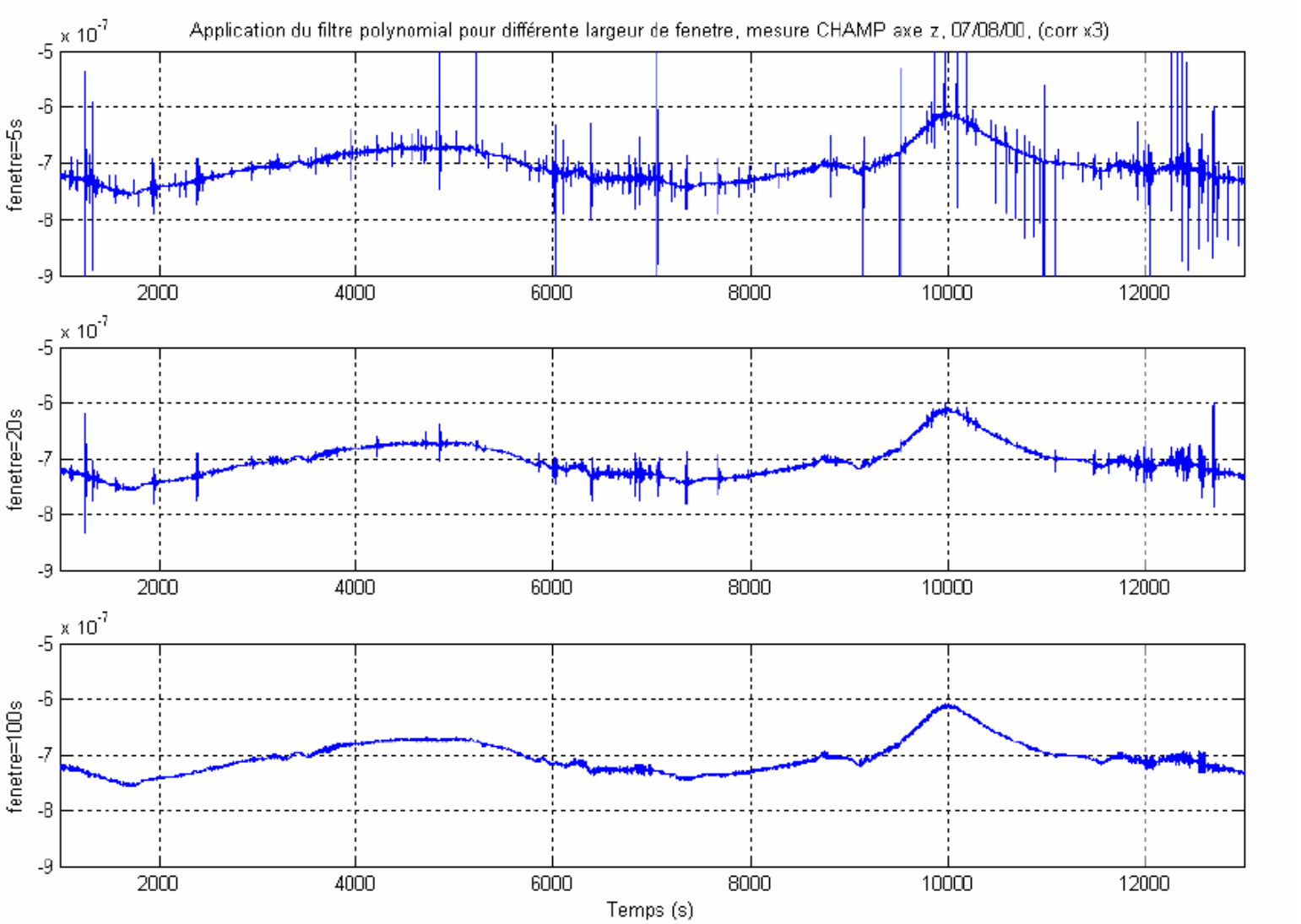
CHAMP Mission data : Polynomial method, impact of the window width



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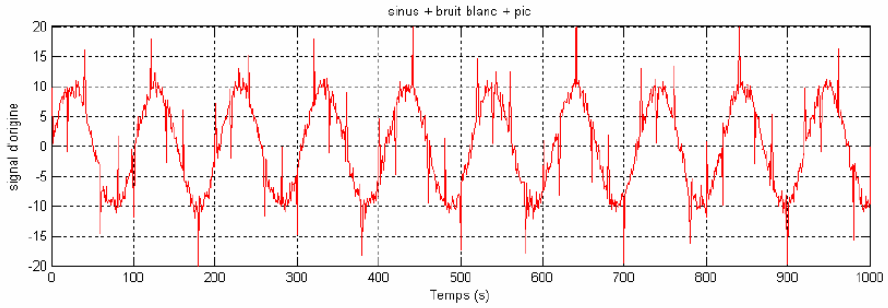
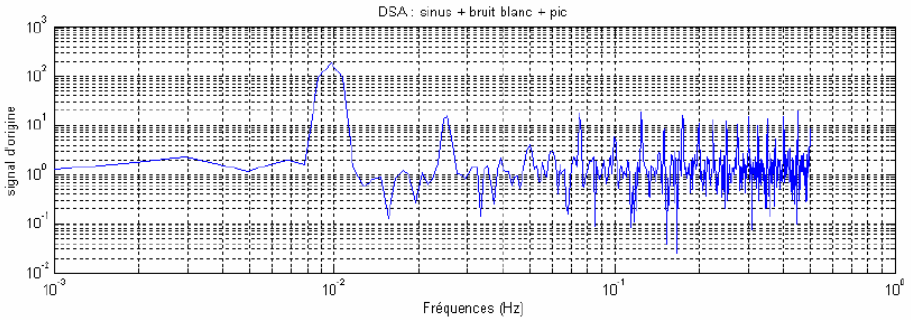
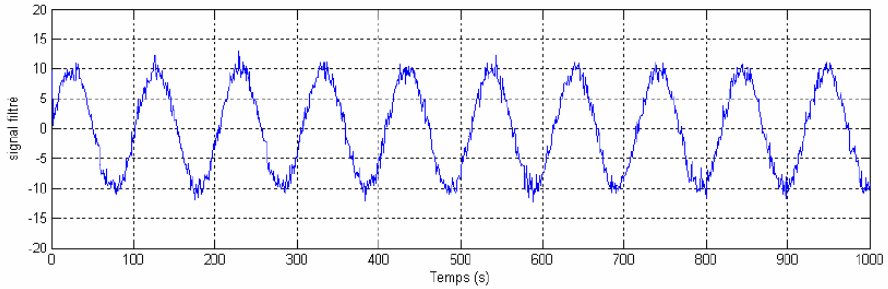
CHAMP Mission data : Polynomial method, impact on the noise

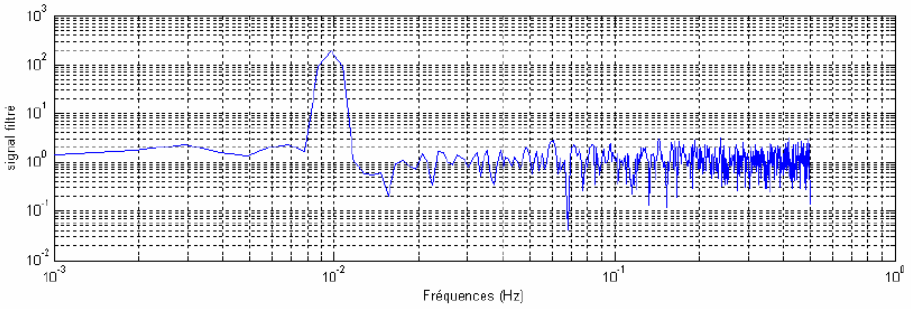
Test of the polynomial method on a signal composed of:

- sine at 0,01Hz, magnitude 5
- white noise, σ = 1
- heater spikes, magnitude + or - 10







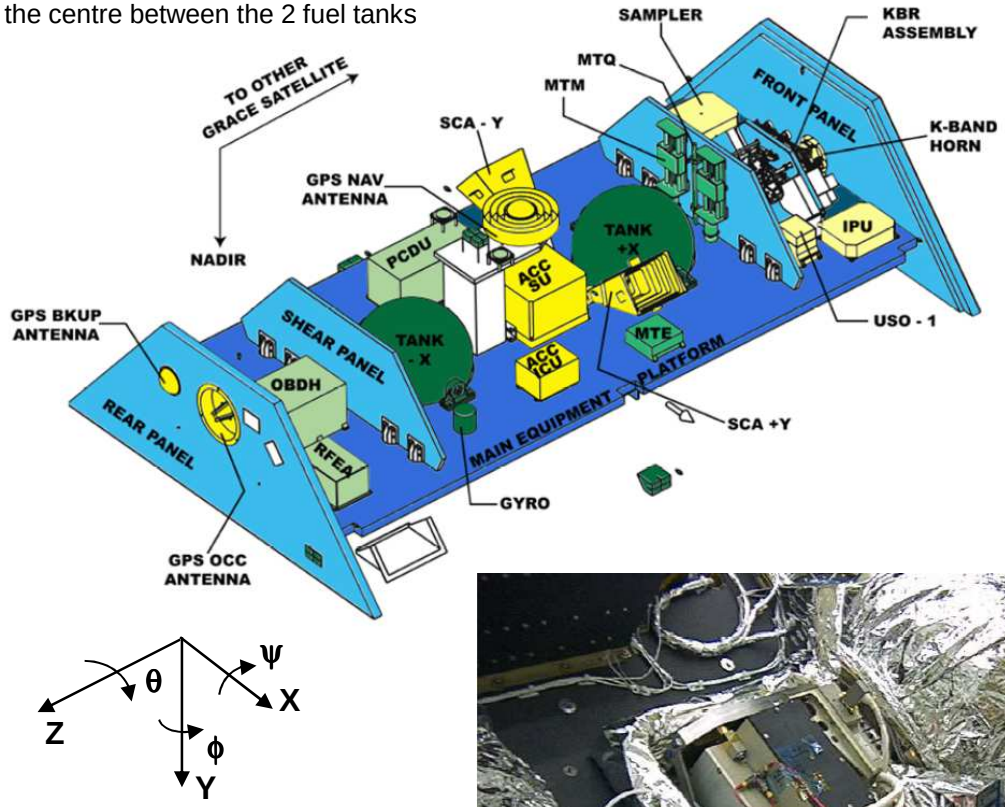


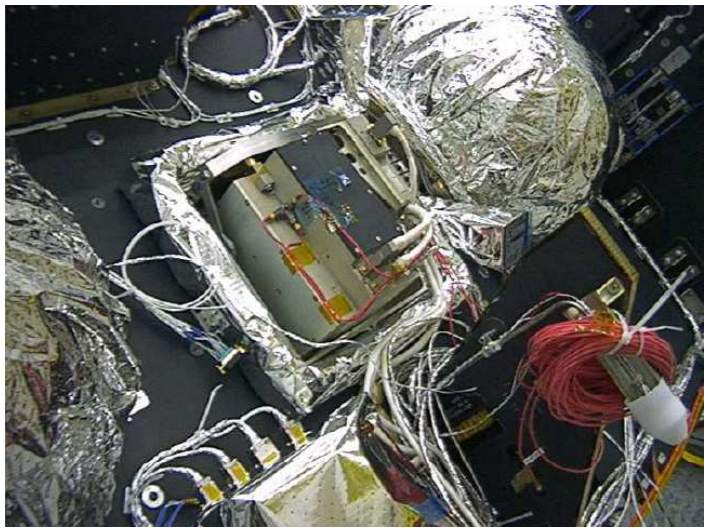
Window : 40 s

The heater spikes are removed and the signal and the noise are preserved

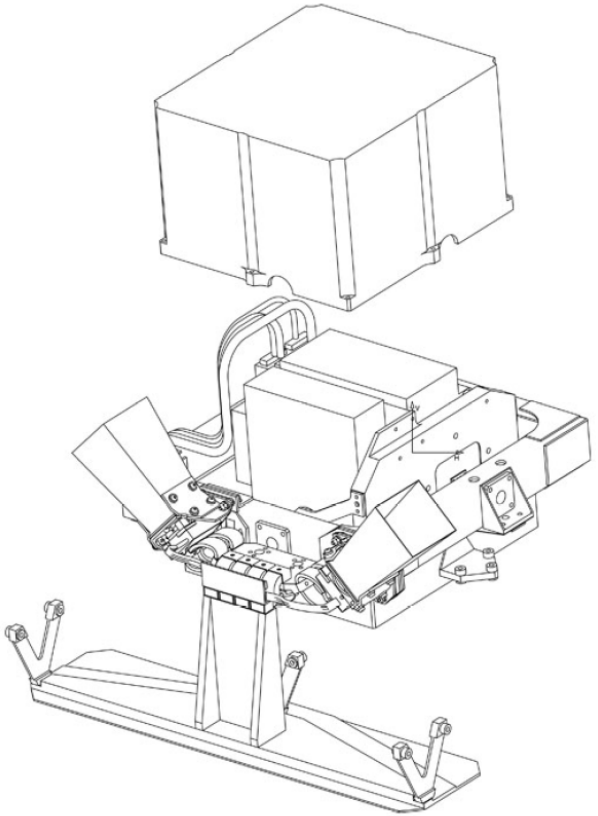
GRACE Mission : Accelerometer configuration inside the satellite

GRACE satellite layout with the accelerometer at the centre between the 2 fuel tanks



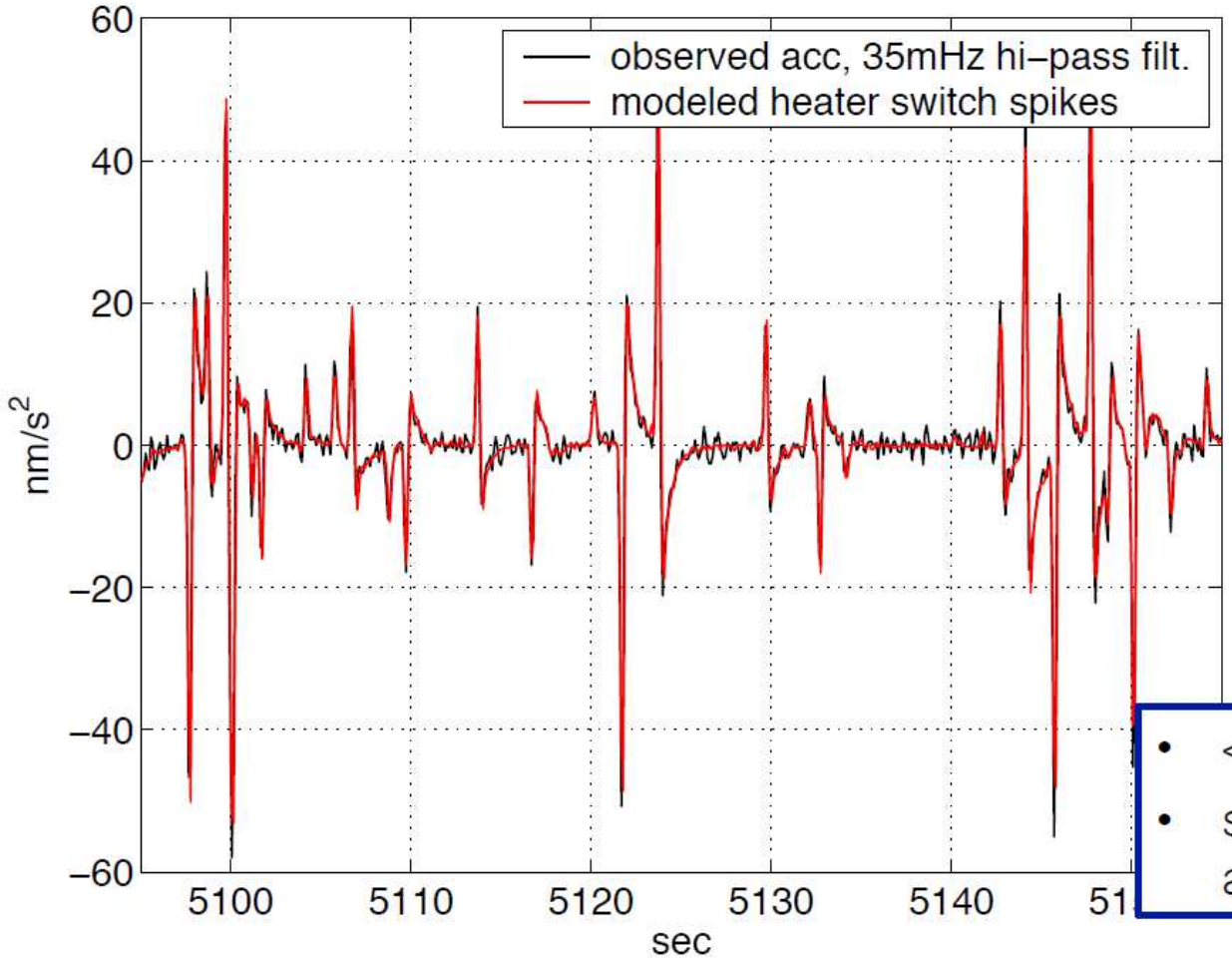


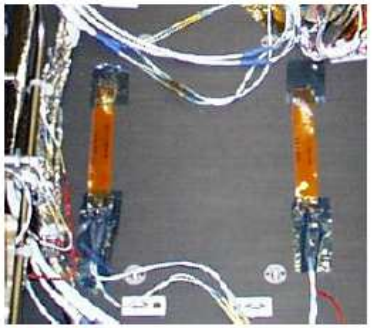
Acceletometer installed in the GRACE satellite with its baseplate toward the upper left corner (© ASD)



Accelerometer Sensor Unit mounted on the support frame with the star camera baffles

GRACE Mission : Heater switch spikes

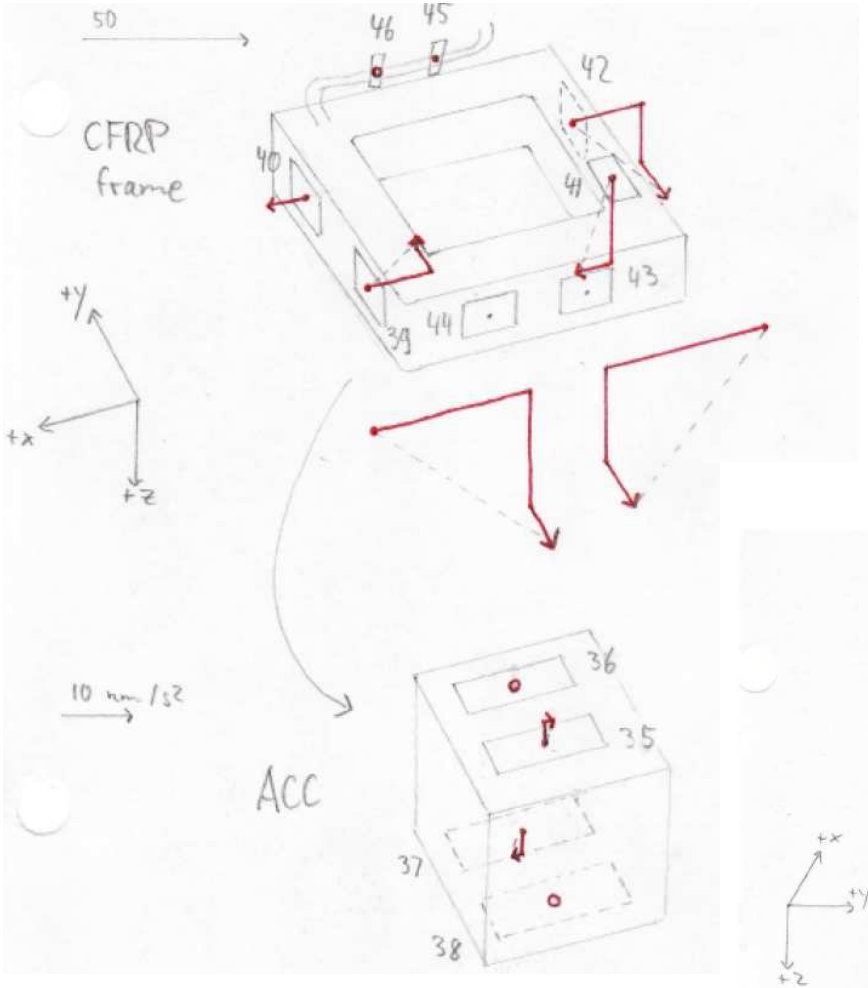




GRACE heater foils

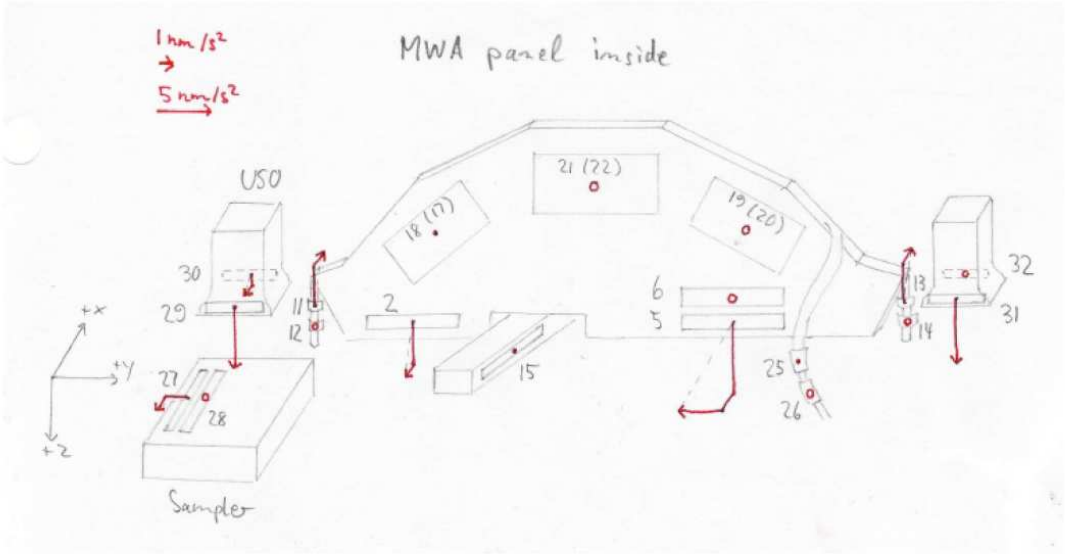
- < 0.5 sec duration
- symmetry due to *on* and *off* switches

GRACE Mission heater configuration



Specific direction and magnitude for each heater element observed from 3 axes accelerometer

Around Micro Wave Assembly



Around Accelerometer

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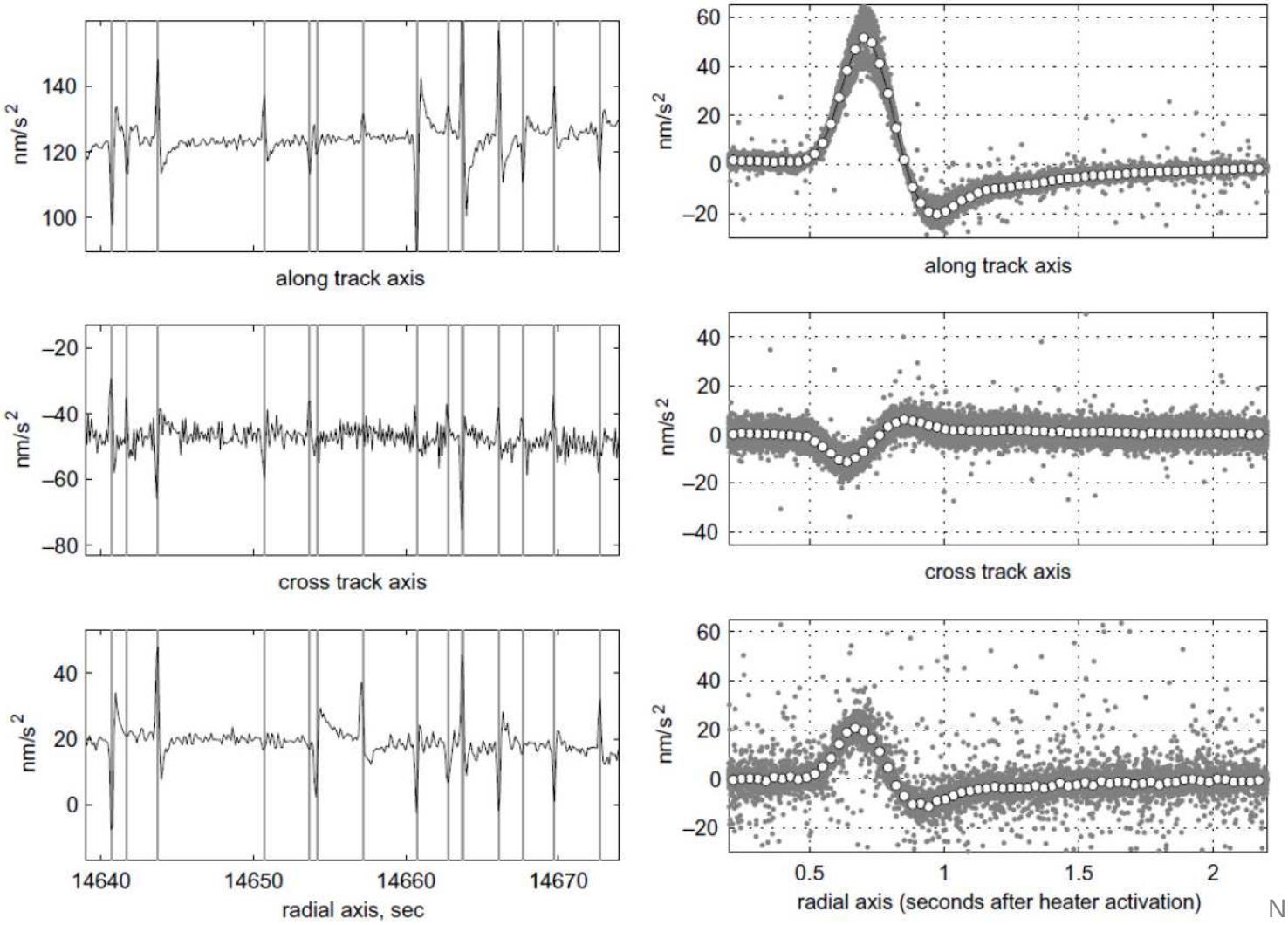
GRACE Mission : Heater signature

Superimposition of 1414 activations events of heater TUUA0113 on GRACE-A



N. Peterseim

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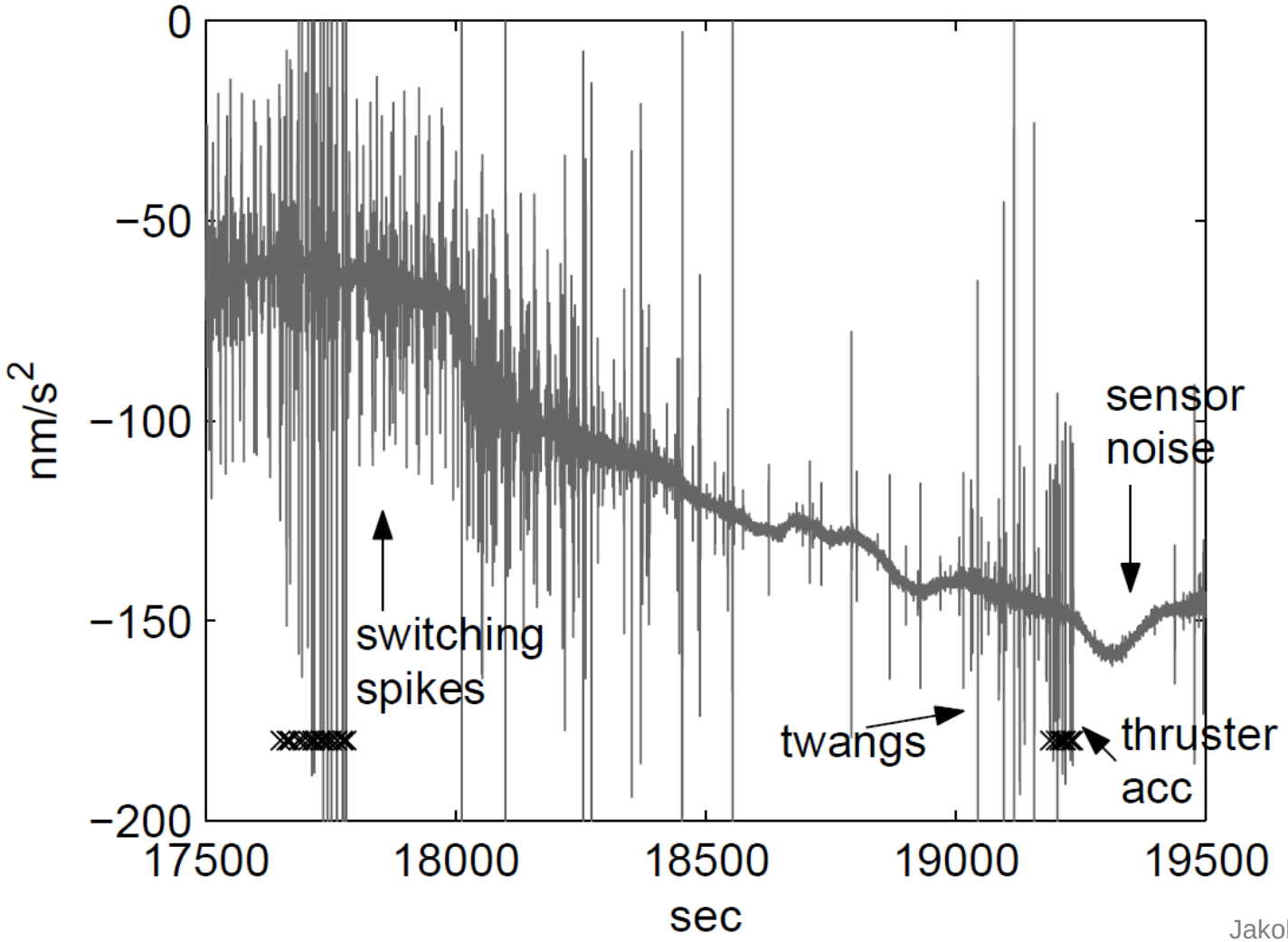
GRACE Mission : heater free period

Along track acceleration – GRACE B on 2004/12/09

All heaters switched off at 18240 sec

Thruster activation marked X



Jakob Flury

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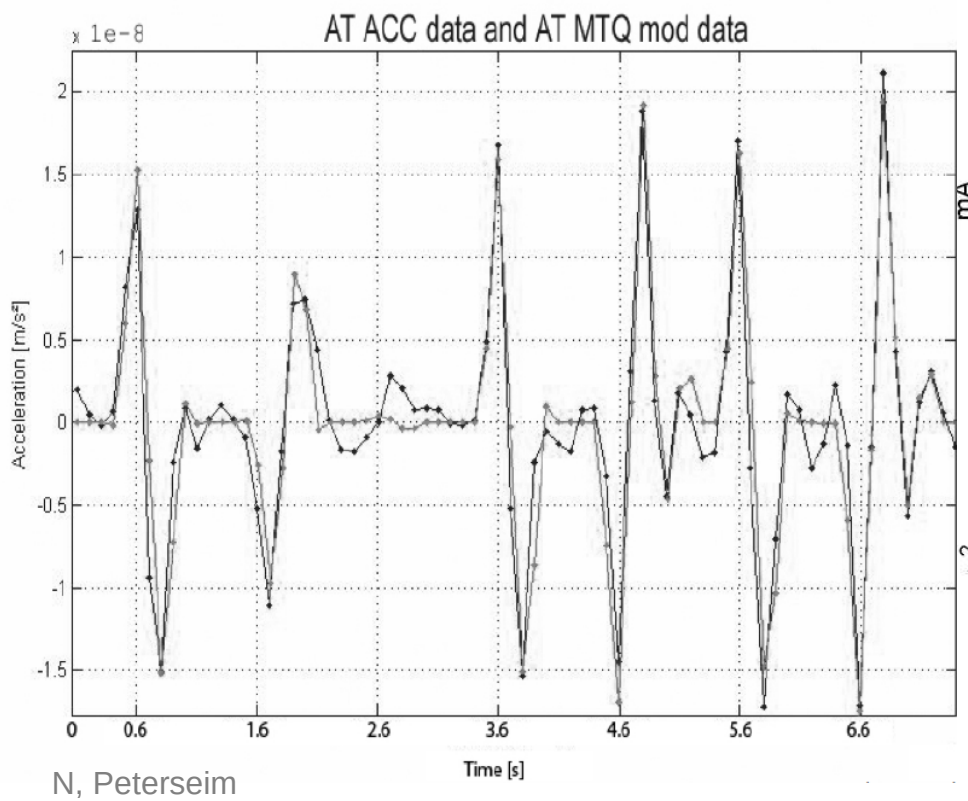
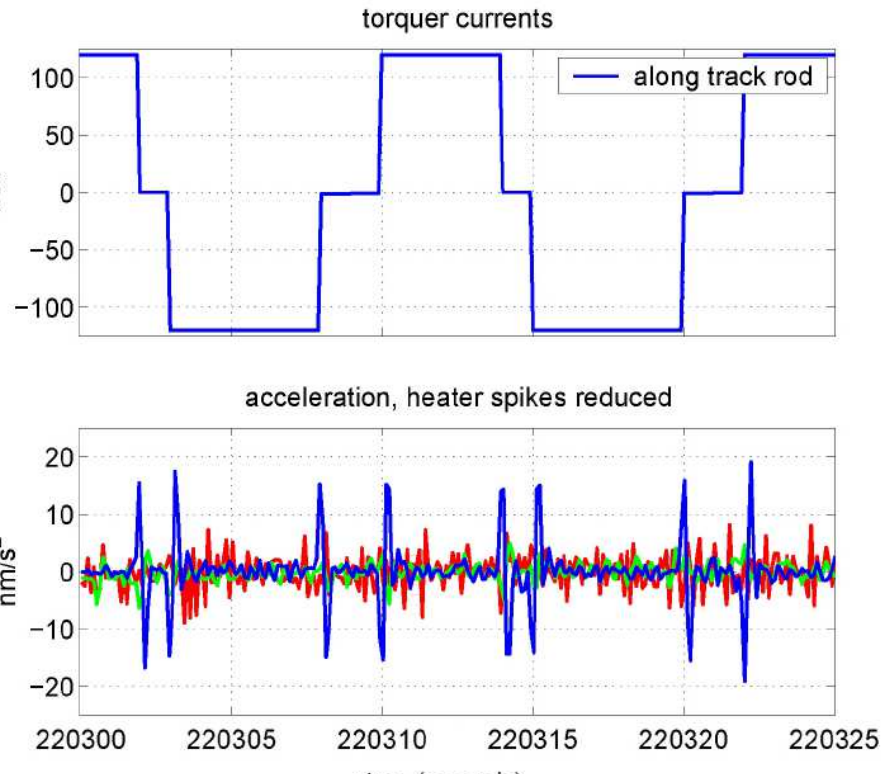
GRACE Mission : Spike correlated with Magneto Torquer current variation

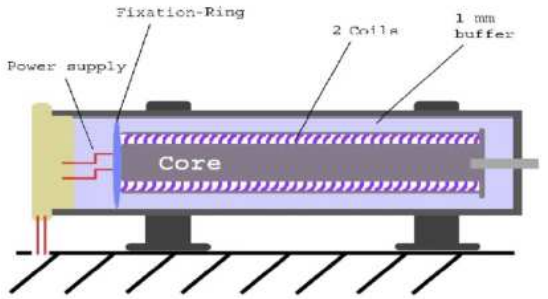




N, Peterseim

Duration < 0,5 s – Simultaneous with fast current changes

ZARM Magneto Torquer



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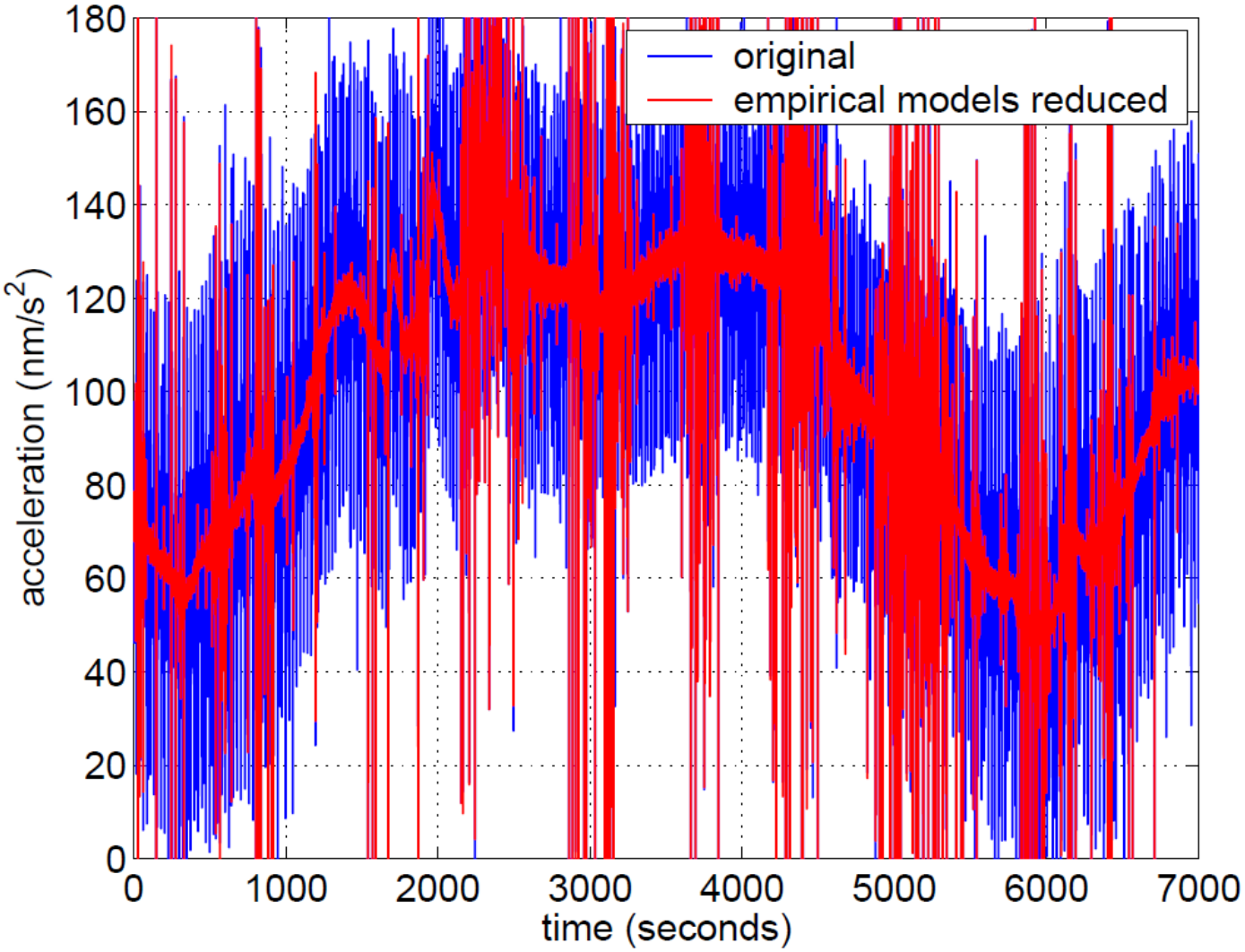
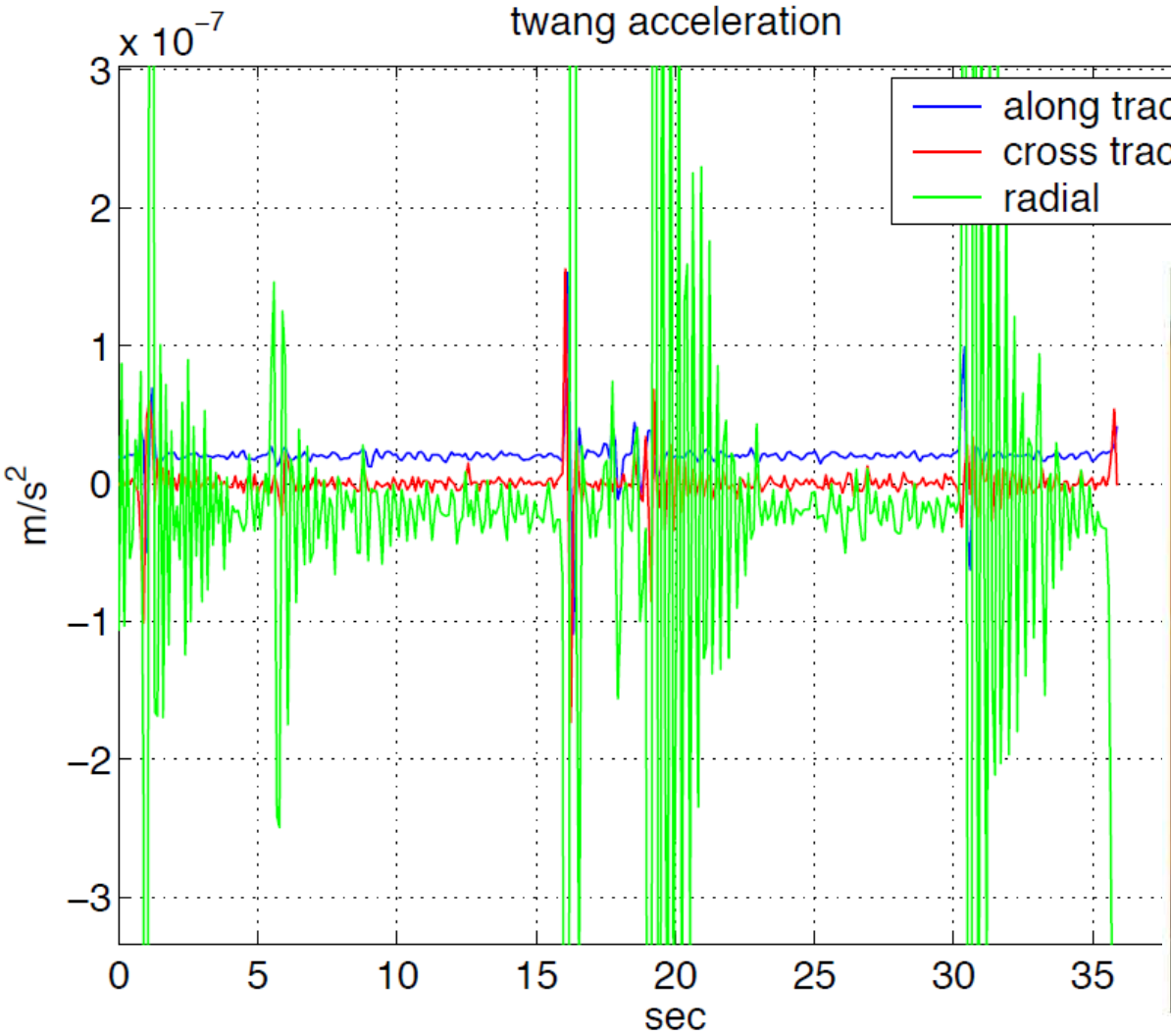
GRACE Mission : Modeling and reduction



After reduction of heater and magnetic perturbations, the twangs remain

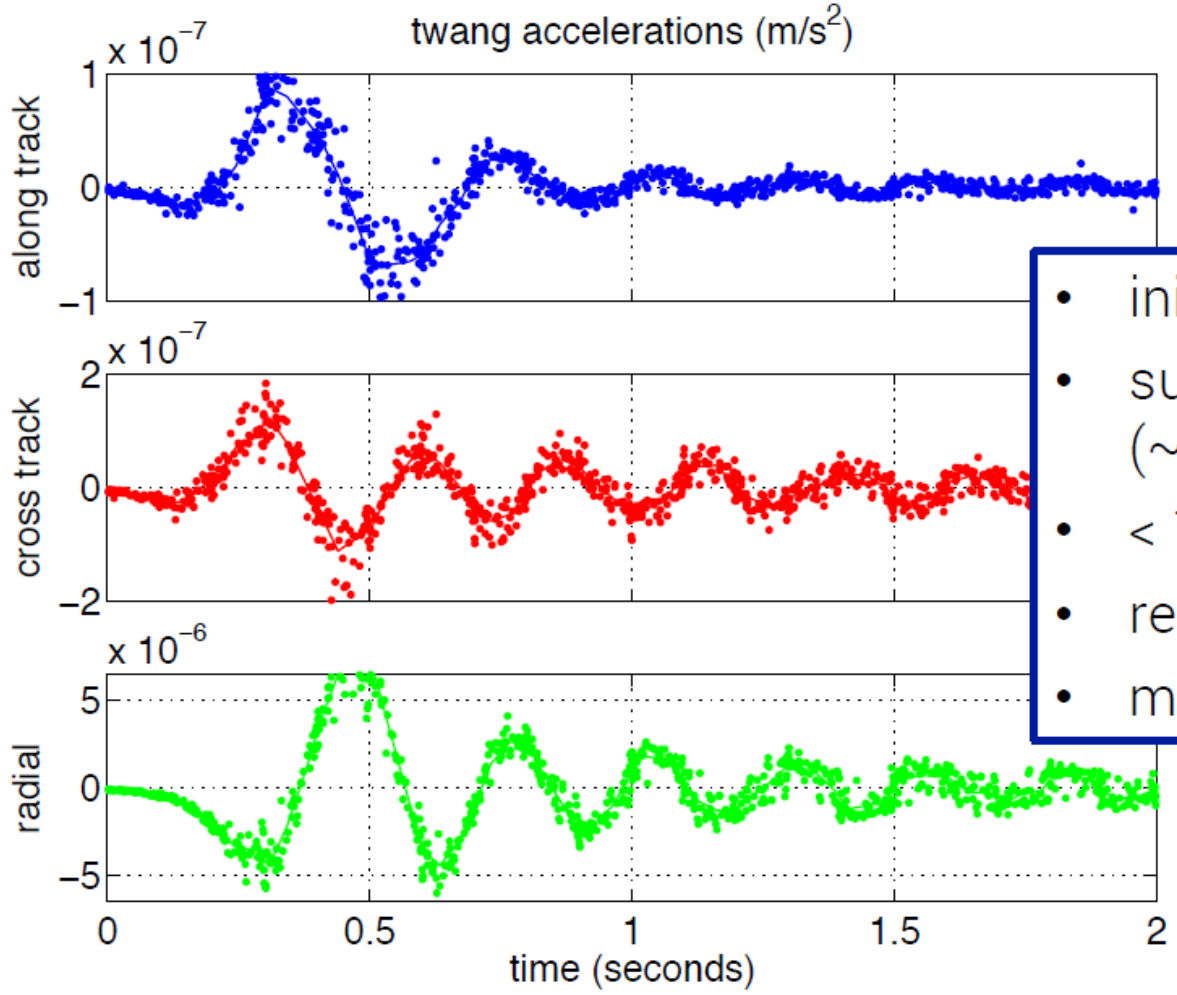
GRACE Mission : Twangs along the radial direction



Radial insulation of GRACE satellite excitated in Nadir illumination

Jakob Flury

GRACE Mission : twang characteristics



- initial spike
- subsequent oscillation (~0.2 sec period)
- < 10 sec duration
- regular shape
- many sub-species

Jakob Flury

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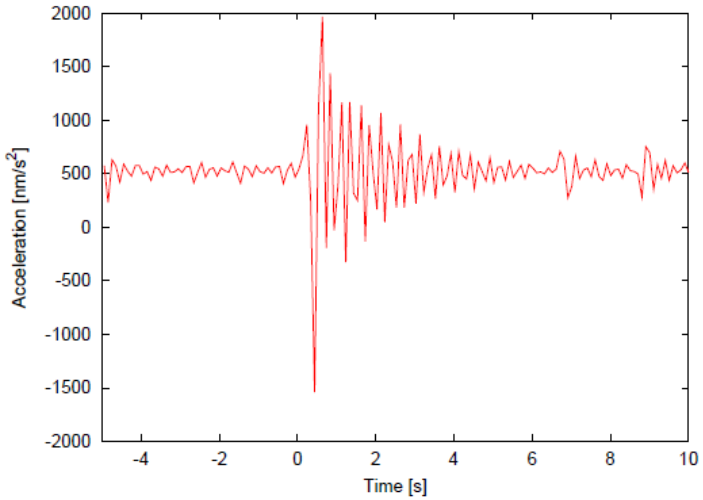
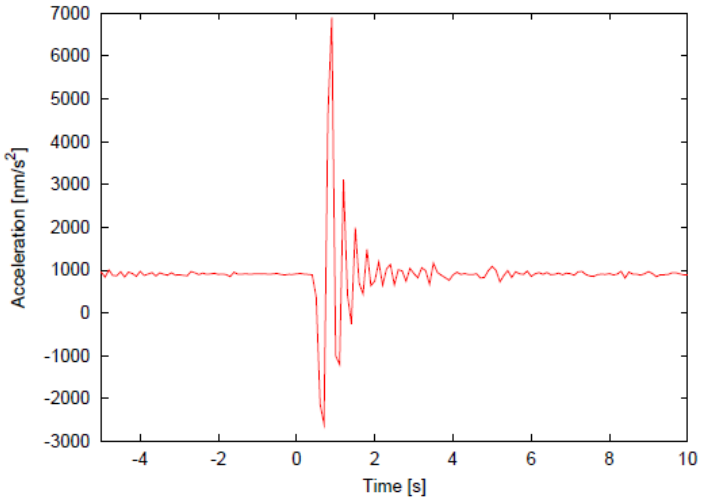
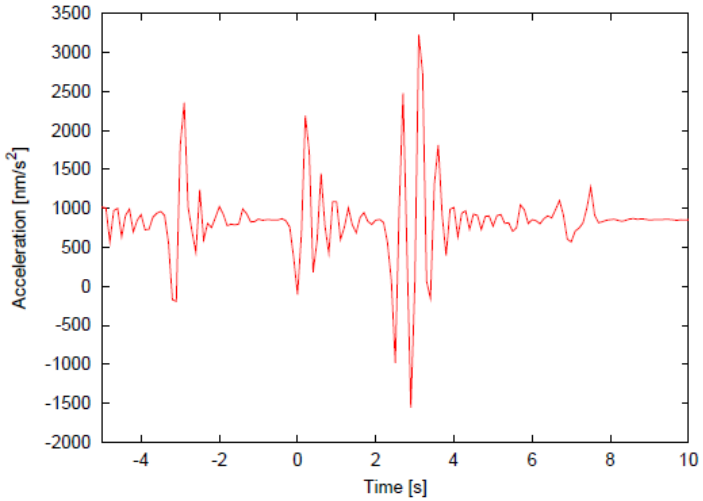
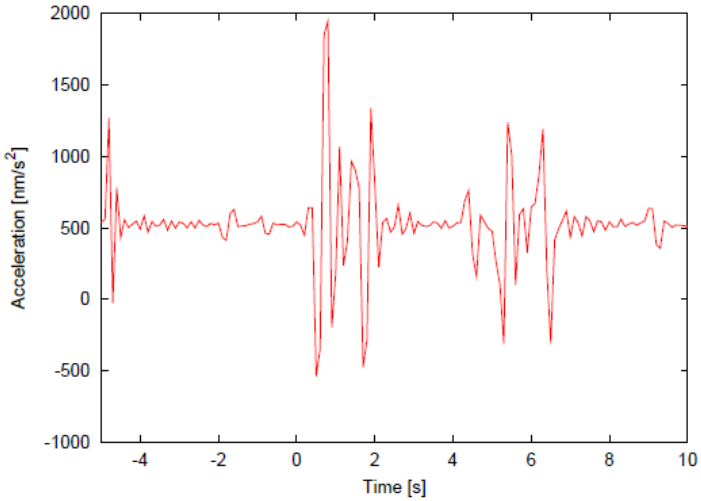
GRACE Mission : Variety of identified twangs









Danya Hudson

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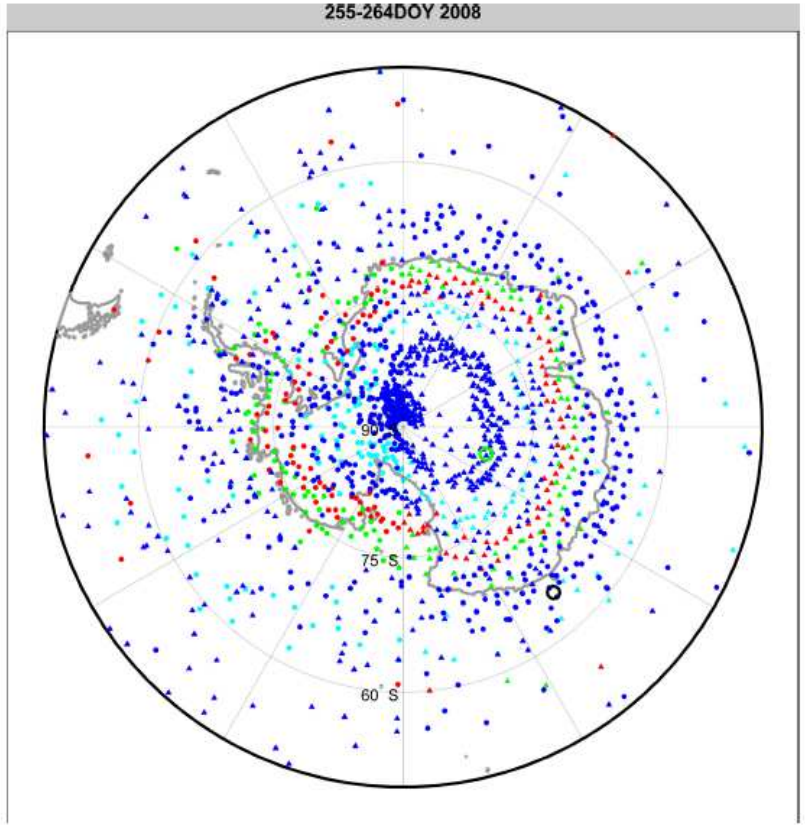
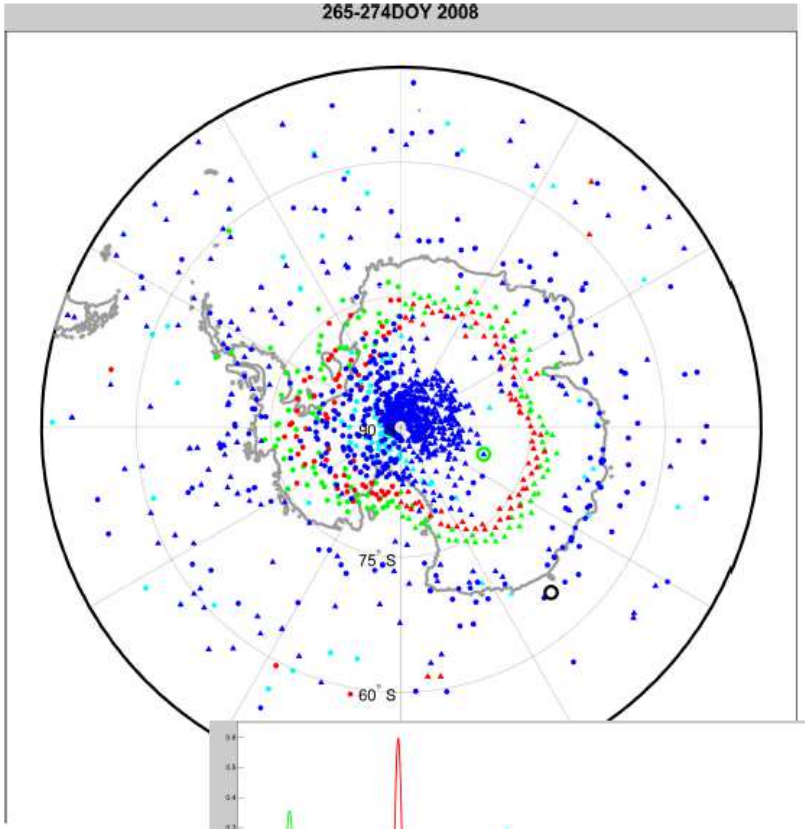
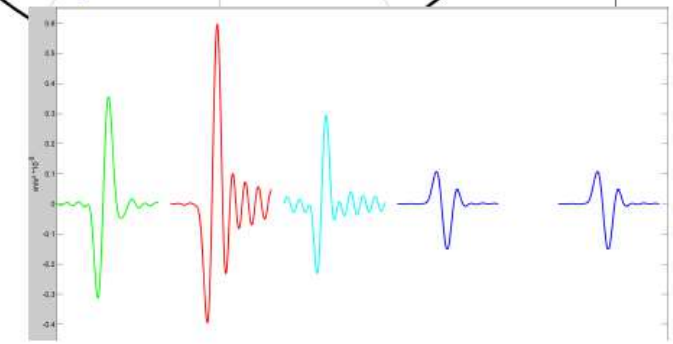
CHAMP Mission : twang distribution around South Pole



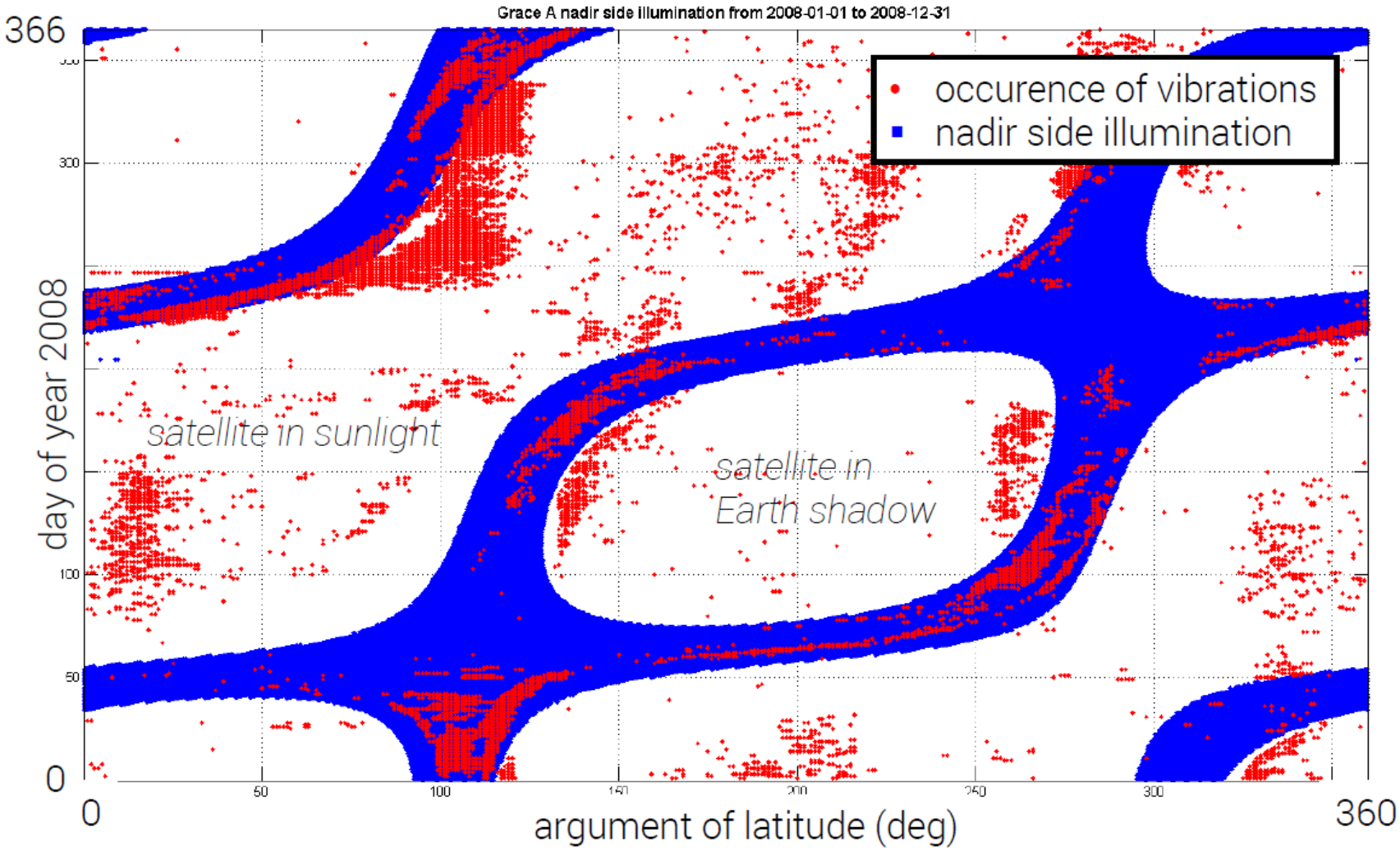




- polar circles of variable shape for some sub-species

Jakob Flury

CHAMP Mission : twang distribution wrt nadir side illumination



Jakob Flury

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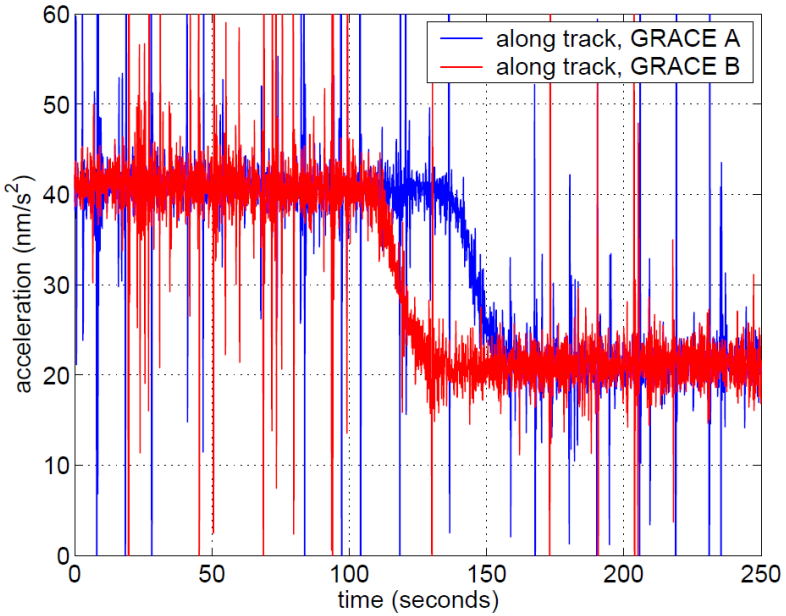
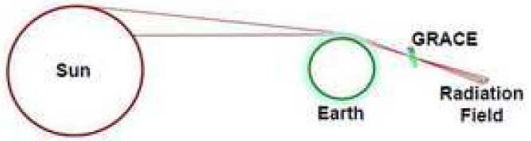
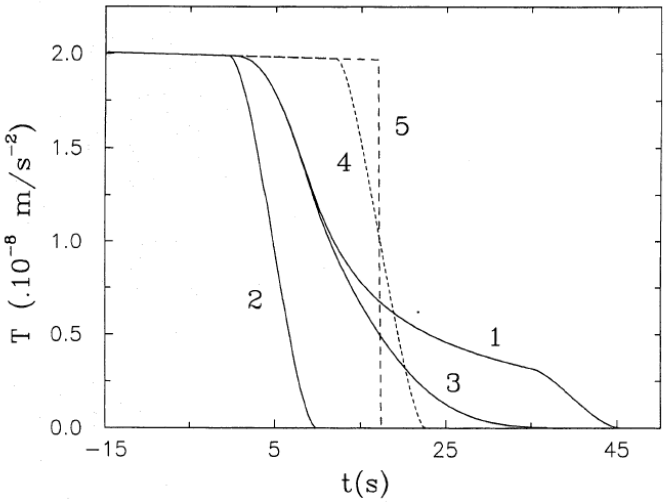
GRACE Mission : Penumbra transition





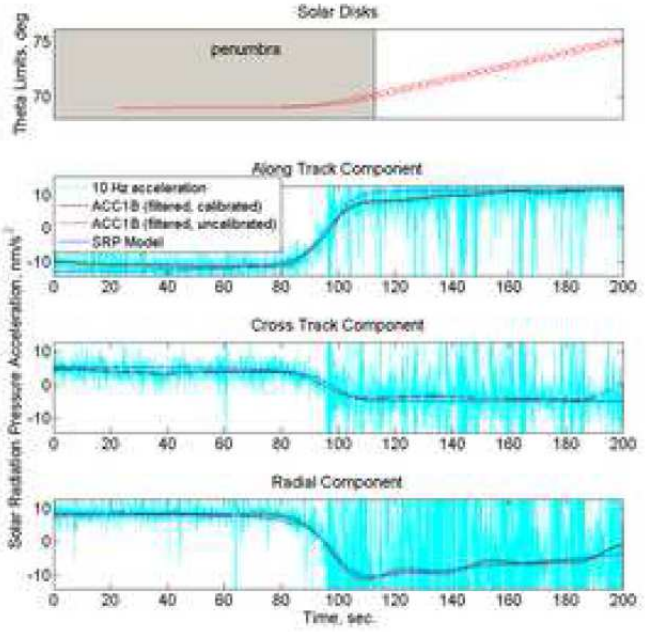
Solar radiation pressure acceleration during shadow exit, GRACE-B on 2008/01/02



Solar radiation pressure perturbation for low orbit satellite (MACEK)

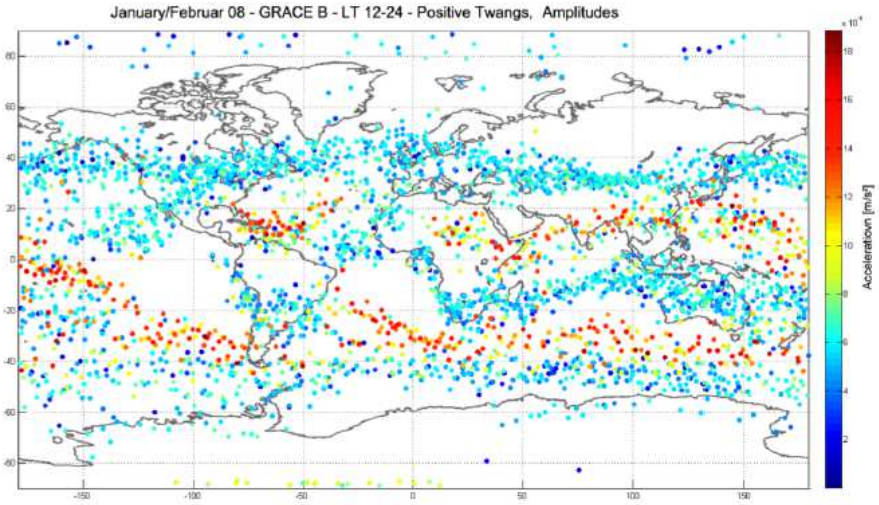
1- refraction only
2- altitude correction case
3- constant absorption model
4- atmosphereless Earth
5- step approximation

D, Vakrouhlicky, P. Farinelle & F. Mignard
Asstron. Astrophys. 280, 295-312 (1993)

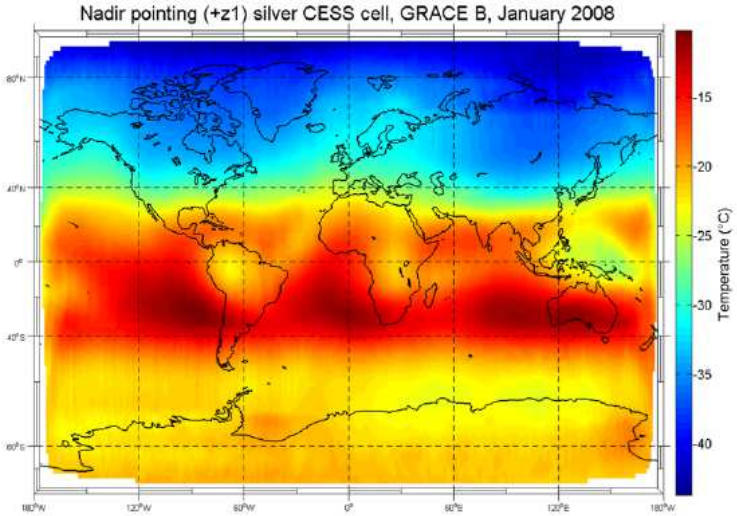


GRACE Mission : Twang distribution wrt Earth albedo

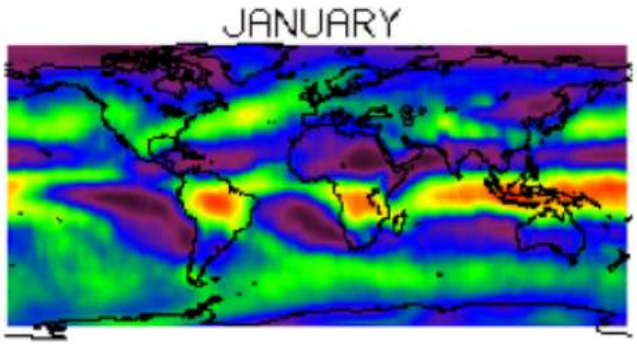
twang distribution, Jan/Feb 2008



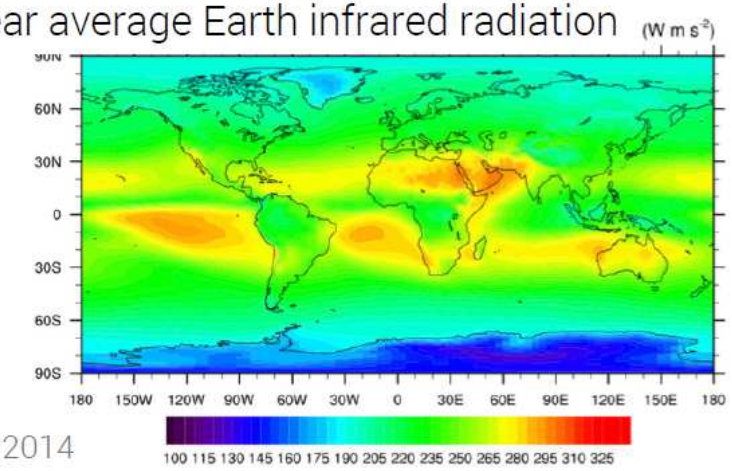
nadir side temperature, Jan 2008



average cloud cover



multi-year average Earth infrared radiation



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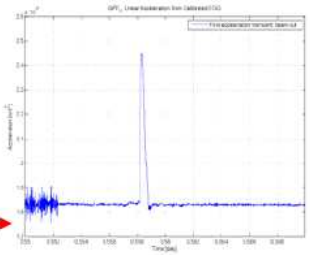
GOCE Mission : Beam-out like and clank-like events

ThalesAlenia Space
A Thales / Finmeccanica Company

Action status from IFTR1 – analysis of clanks

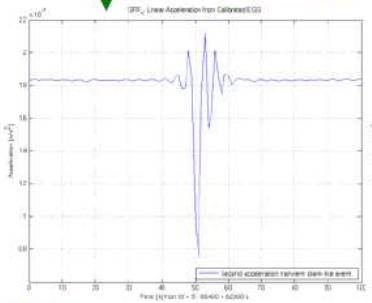


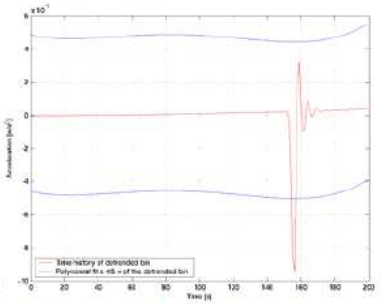
Statistical analysis on clanks

Spikes identified by using science output:

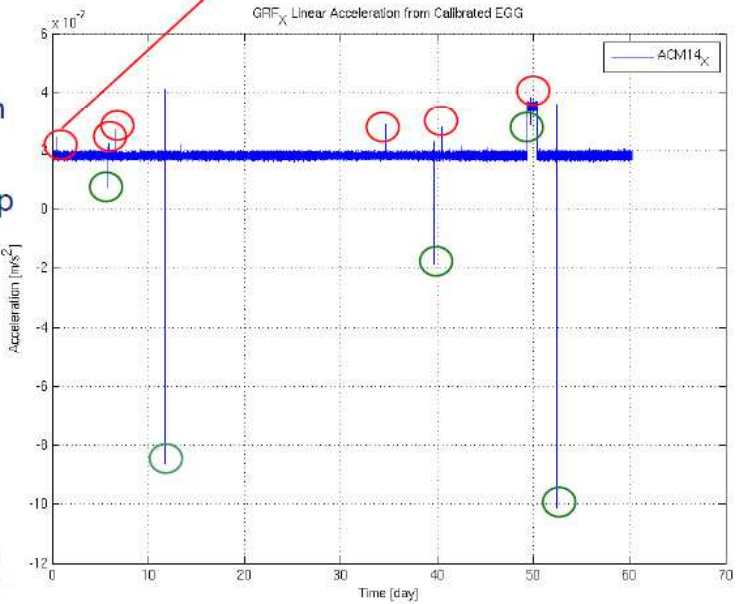
- 5 clank-like events (green circles)
- 6 beam-out like events (red circles), taking into account also the IPA commanded bias

- 1st transient is a beam-out like event
- 2nd transient is a clank-like event, with p-p amplitude $1.3 \cdot 10^{-7}$ m/s^2
- last event (clank-like) with largest p-p amplitude $1.4 \cdot 10^{-6}$ m/s^2





Clank model used in Annex C1 of GO-RP-AI-0037 I3



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ESTEC, 23 March 2010

THALES

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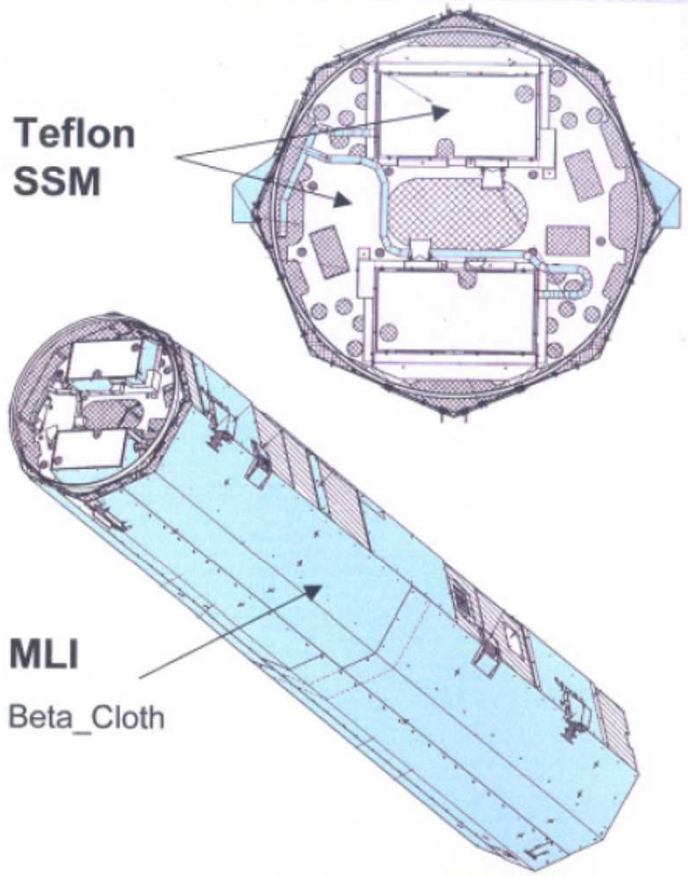
GOCE Mission : Thermal control of the satellite

4.4.2 TCS Characteristics #1

EADS ASTRIUM



- Satellite Body insulated by 30-layered MLI. Beta-cloth as outermost layer
- Test showed that this surface is micro-vibration free
- Radiator surfaces coated by Teflon SSM foil, ITO coated
- OSRs used for radiators oriented in RAM direction

Page 14 GOCE System CDR - Platform Overview – CDR_PL_pres.ppt

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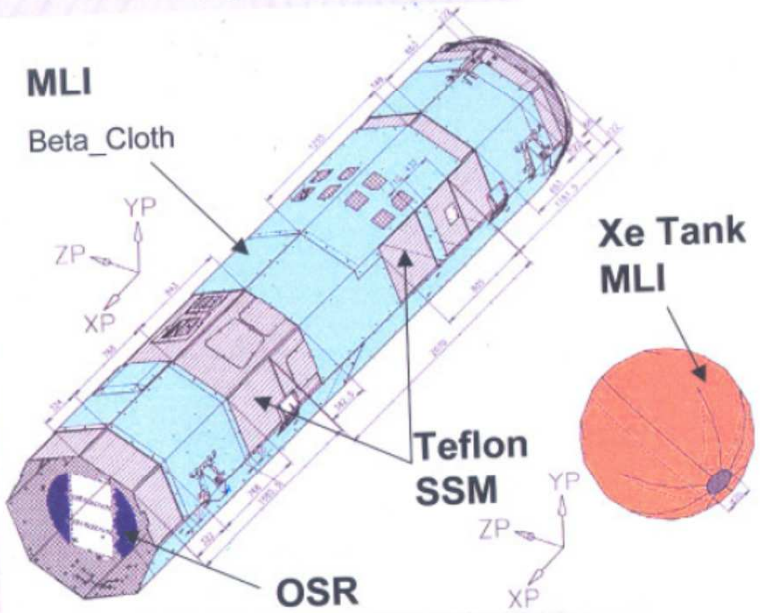
GOCE Mission : Thermal control of the satellite

EADS ASTRIUM

4.4.2 TCS Characteristics #2

- Electrical heater system for heating of:
  - Xenon tank and pipework
  - Unit temperature control
  - EGG I/F heaters; high stability and small gradients
  - S/A wings
- Heater Control Concept:
  - 48 nominal/ 48 redundant heater lines.
  - Majority voted temperature sensors
  - 128 thermistors and 64 PT1000



Page 15 GOCE System CDR - Platform Overview – CDR_PL_pres.ppt

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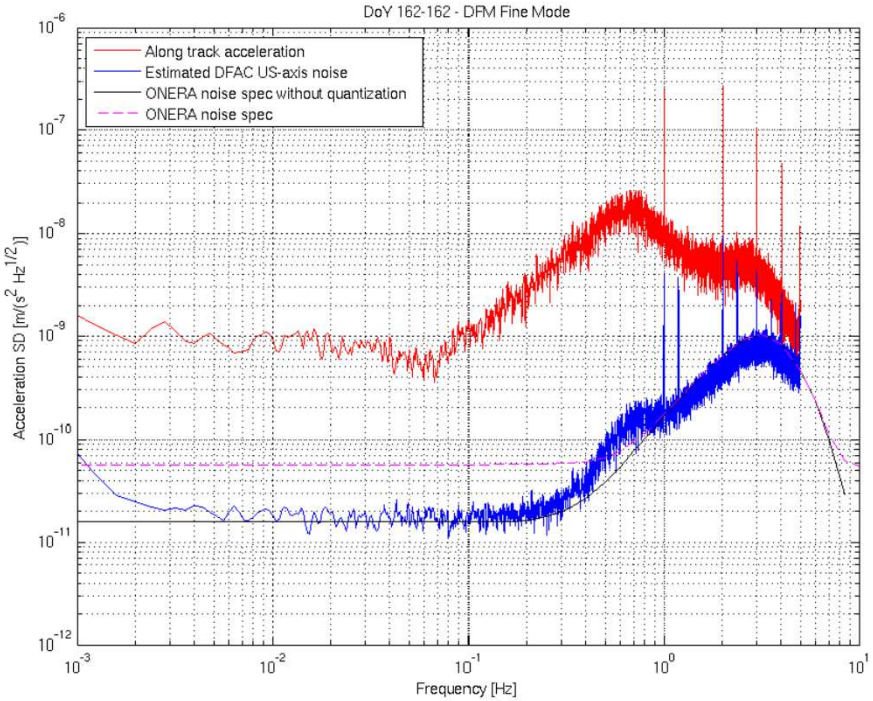
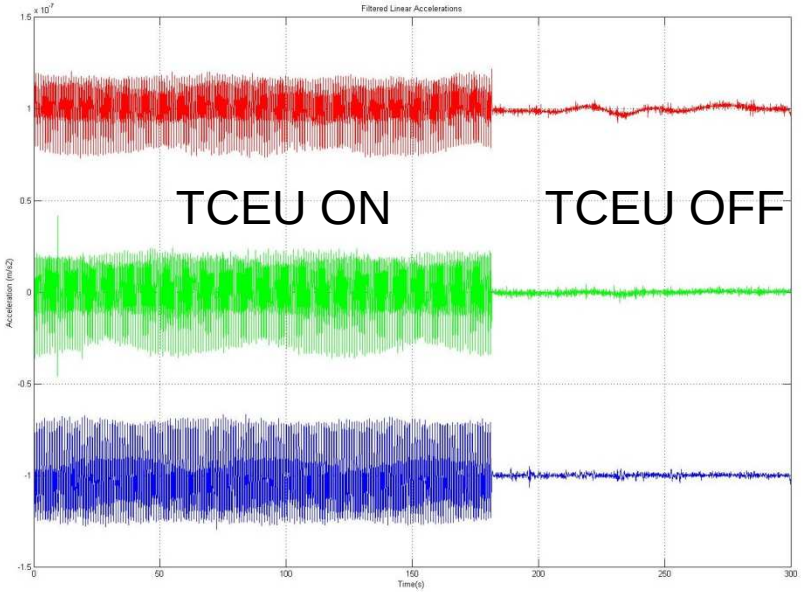
GOCE Mission : Spectral lines at 1 Hz in DFAC

Spectral lines in DFAC outputs
@ ~1 Hz and multiples



Due to thermal control regulator
Heaters on/off with duty cycle
based on period of 0.9984 s (1.0016 Hz)



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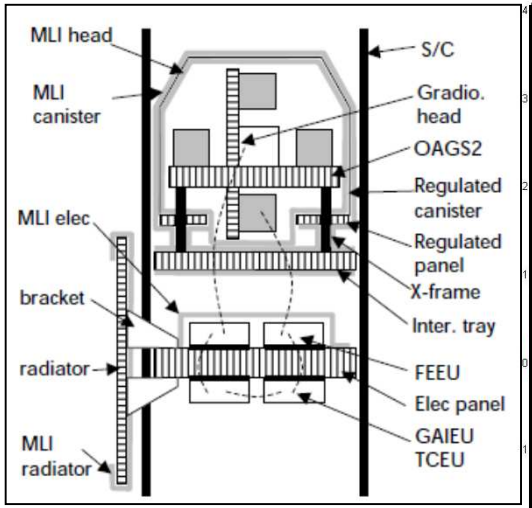
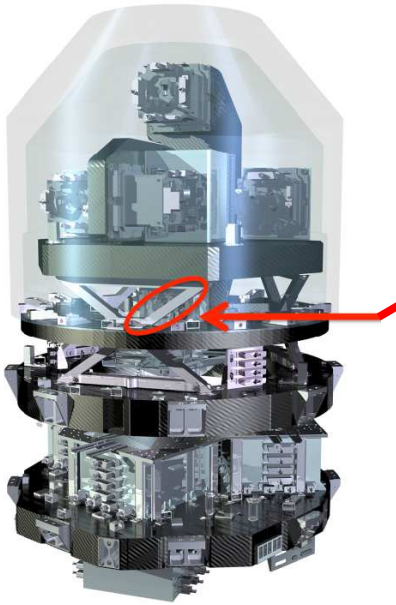
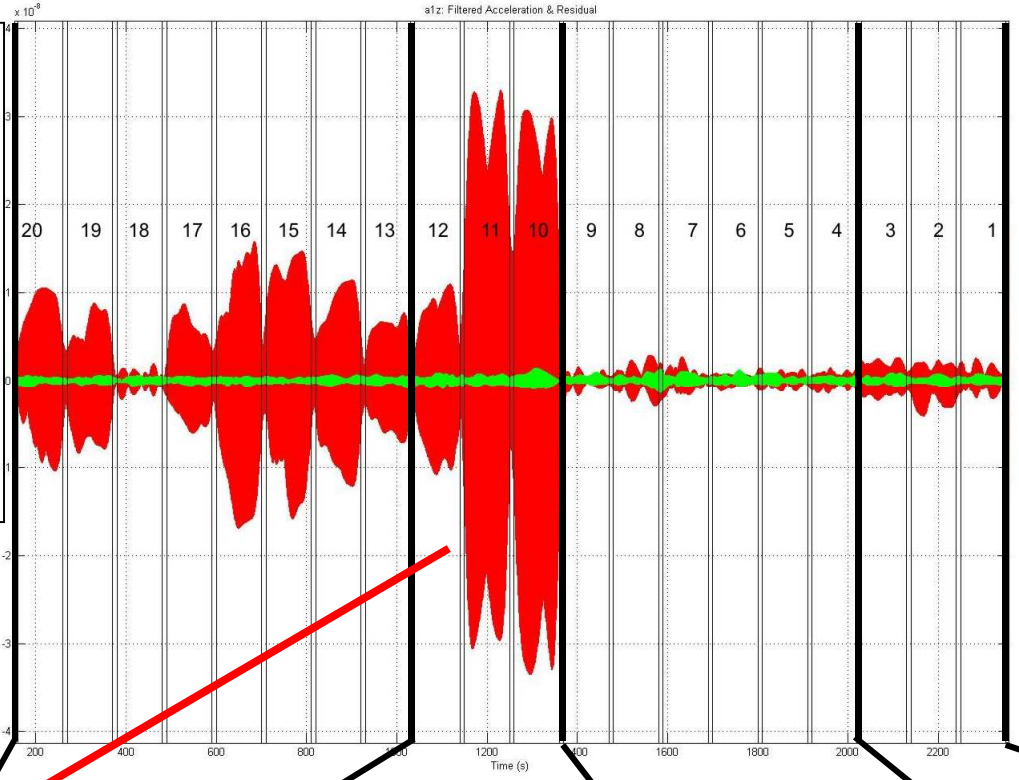
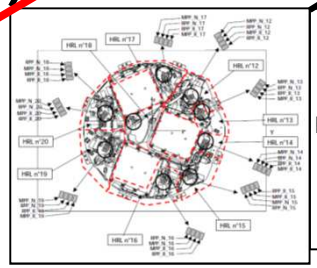
GOCE Mission : Effect of thermal lines on accelerometer outputs



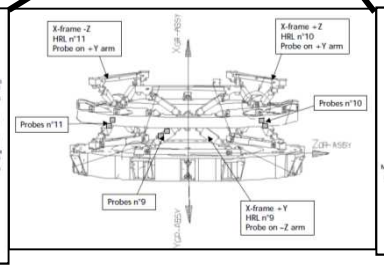




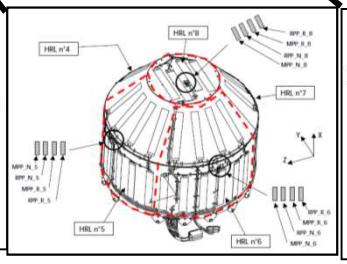
Acceleration
filtered with
comb filter
@ 1.0016 Hz
@ 2.0032 Hz
@ 3.0048 Hz
@ 4.0064 Hz
+
Residuals



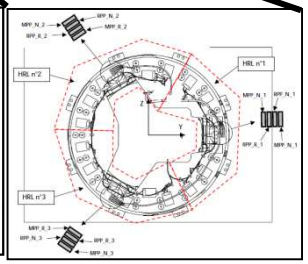
FEEU



X-Frames



Regulated canister



Regulated plateform

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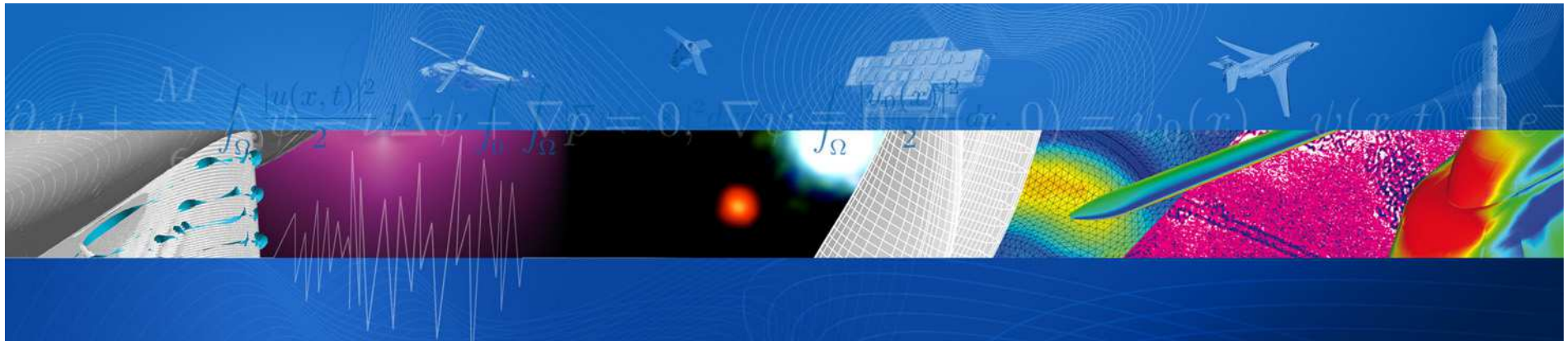

Thank you for your attention

Aknowledgment & references

- **Danya Hudson,** Master of Science in Engineering - The University of Texas at Austin - December 2003
- **Gregory Pradels,** PHD Thesis – UMPC – October 2003
- **Jakob Flury,** Institut für Erdmessung (IfE) - Leibniz Universität Hannover
- **Nadja Peterseim,** Dr.-Ing. Thesis - TU München – March 2014

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