lisa pathfinder

Disentangling the magnetic force noise contribution in LISA Pathfinder

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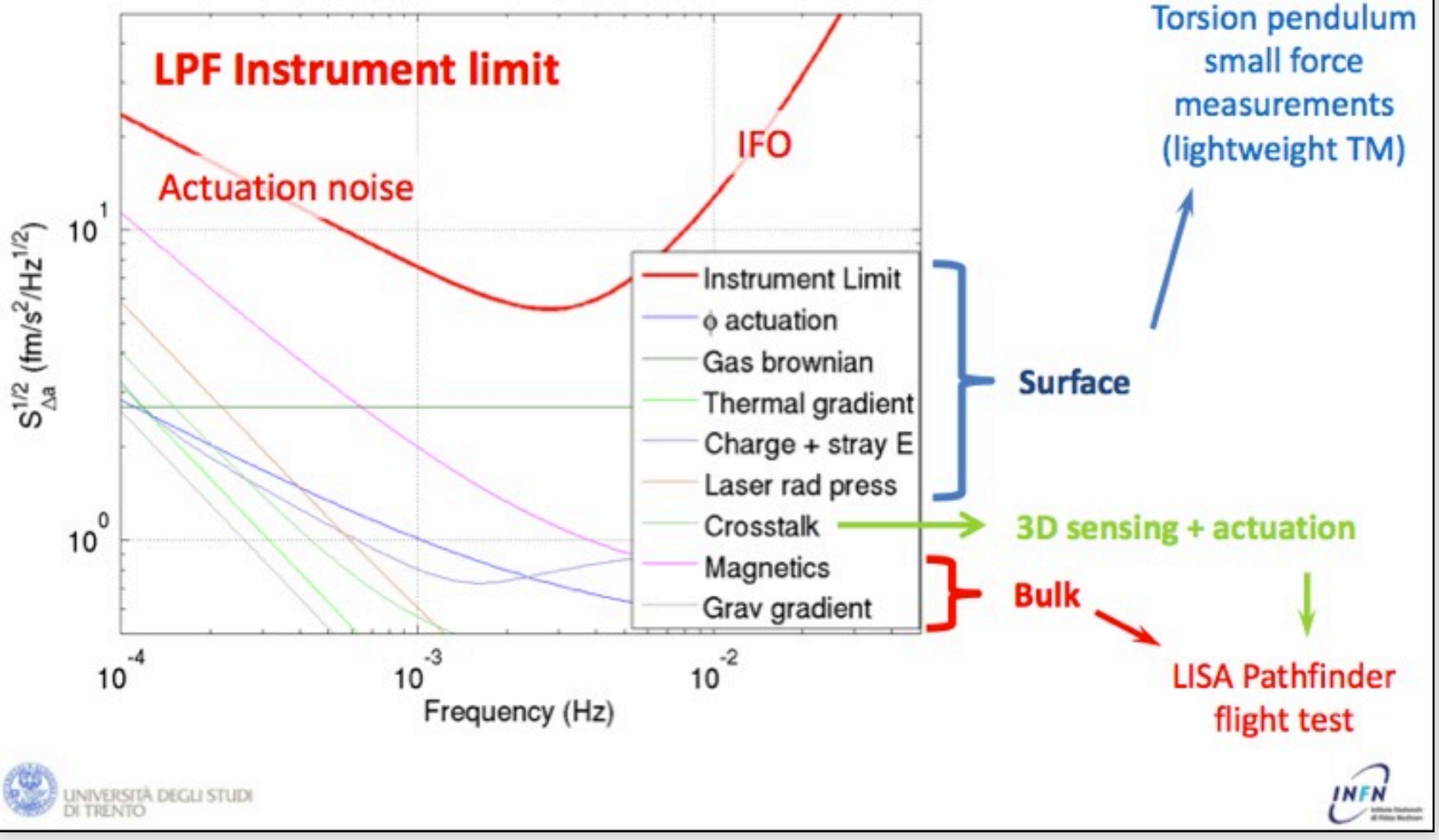
CSIC
Consejo Superior de Investigaciones Científicas

IEEC

Motivation

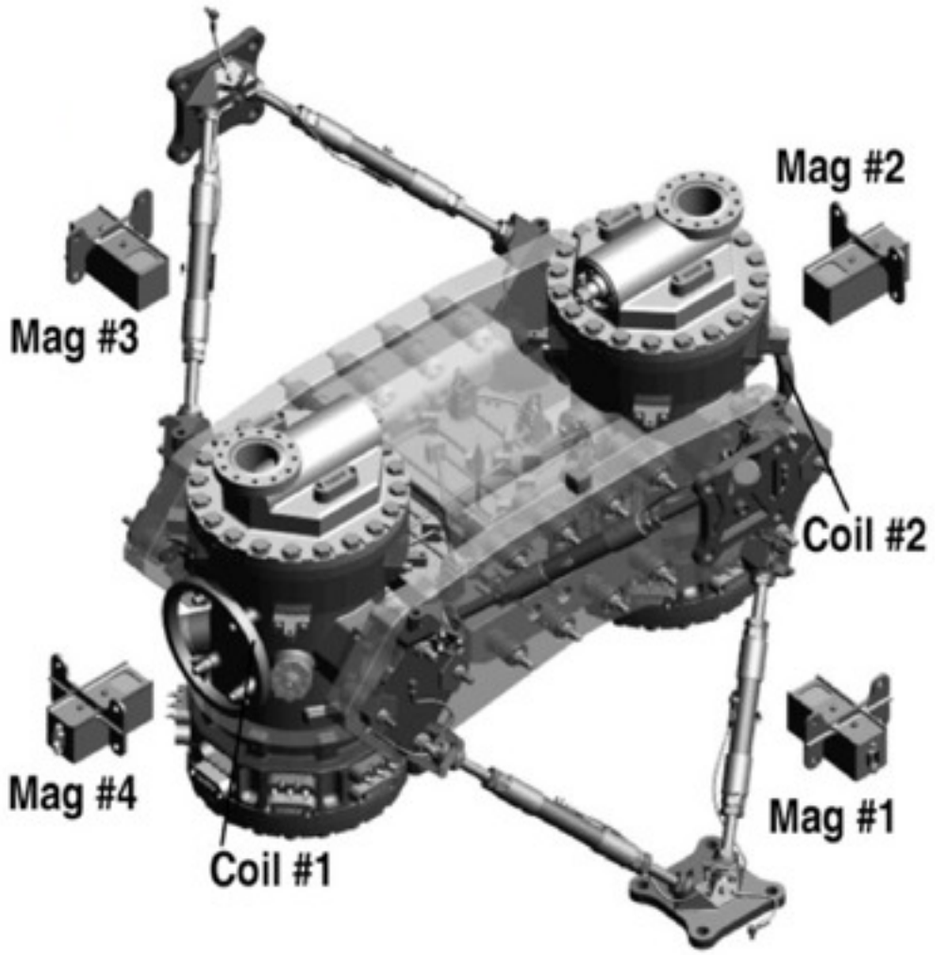
How low can we go?

LPF as a measurement of acceleration noise for eLISA



Magnetic Diagnostics in LPF

- Magnetic diagnostics in LPF:
  - 4 Fluxgate magnetometers
  - 2 Coils



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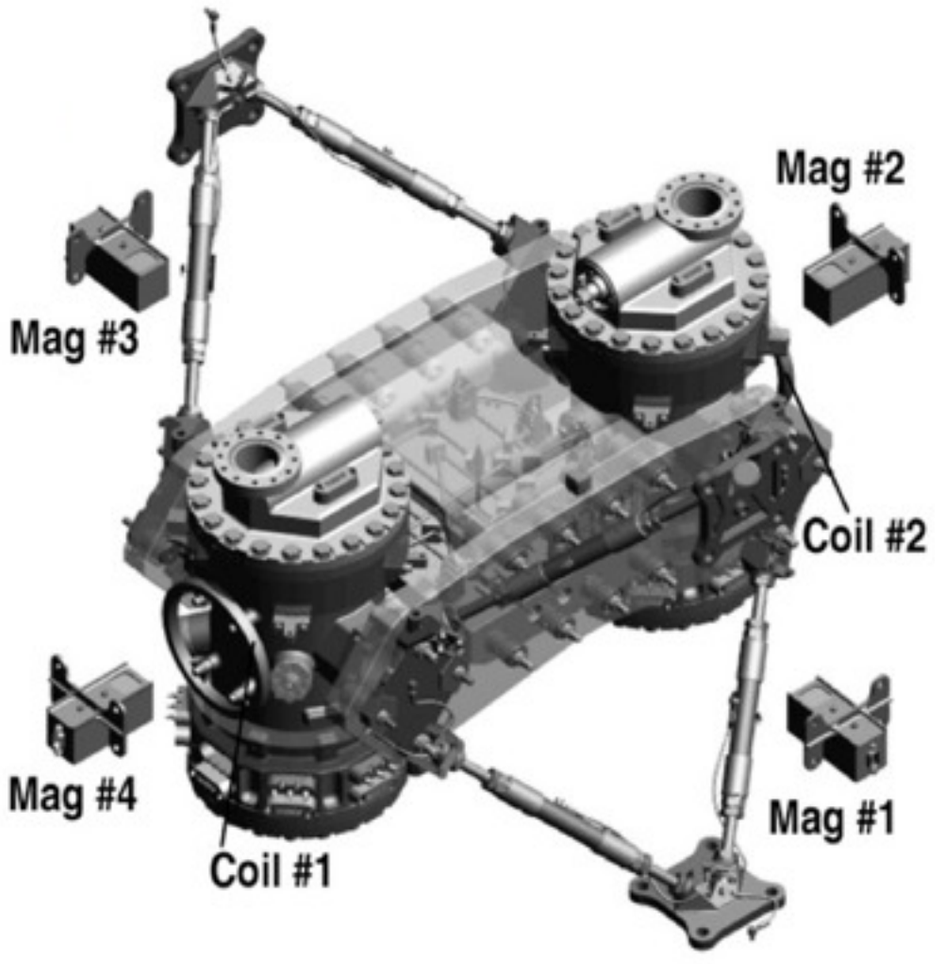
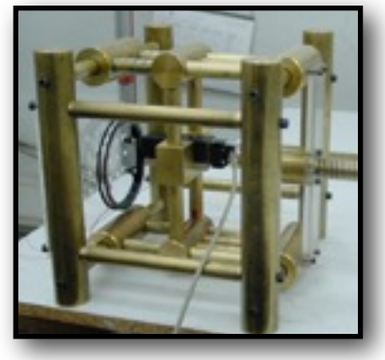


(1) Estimation test mass magnetic parameters

- Injected signals
- Estimation force noise contribution



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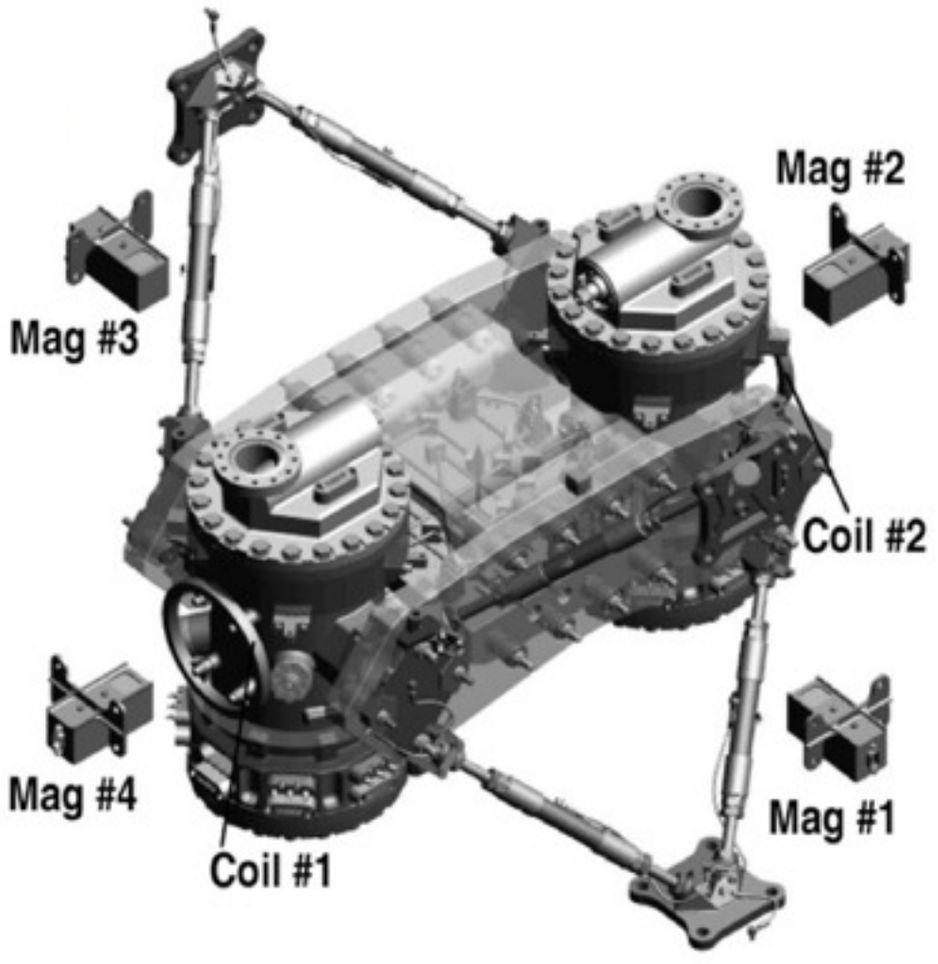

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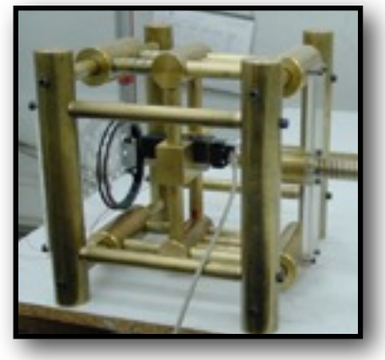
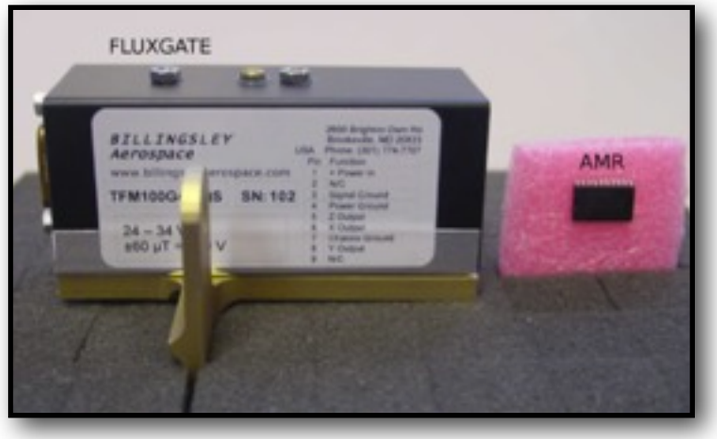


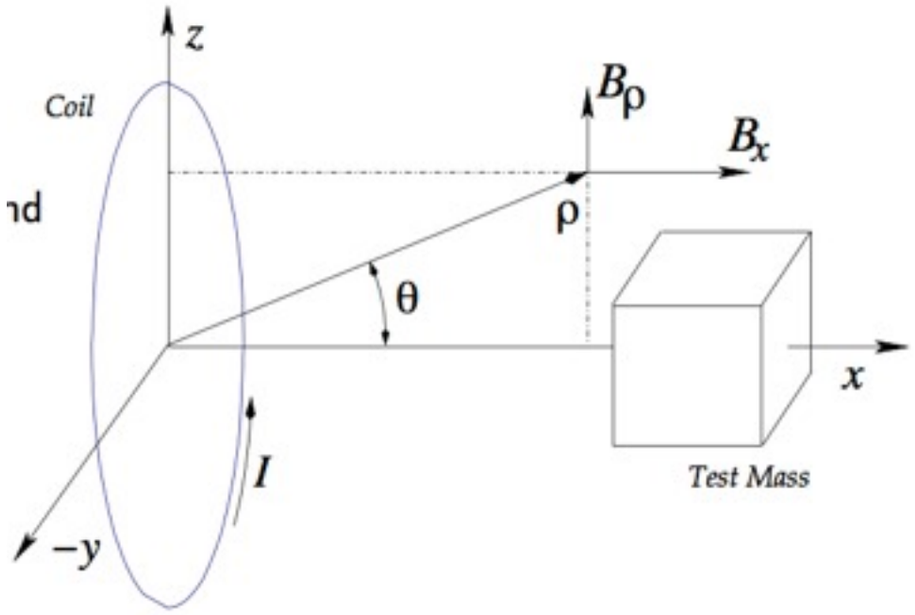
(2) Magnetic field interpolation

- Characterisation of magnetic env.
- Contribution of mag. sources



Magnetic analysis #1: coils experiment

- Coils attached to ISH to apply a force/torque on the TM
- The response must allow a precise characterization of the the moment and susceptibility of the TMs



$$
\begin{aligned}
F_x &= \chi_0 f_{DC} + M_x f_{x_{1\omega 0}} + \chi_0 f_{x_{2\omega 0}} + \chi_e f''_{x_{2\omega 0}} \\
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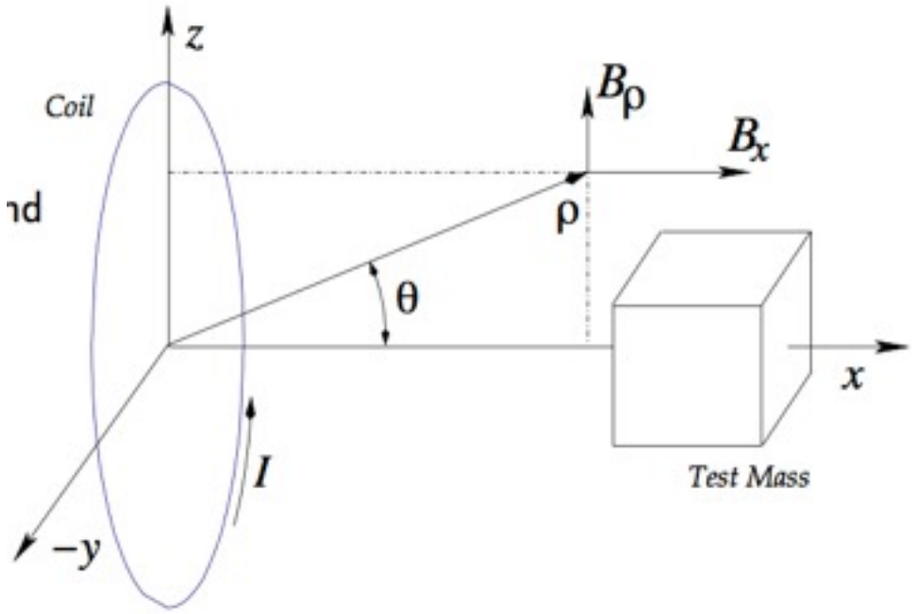

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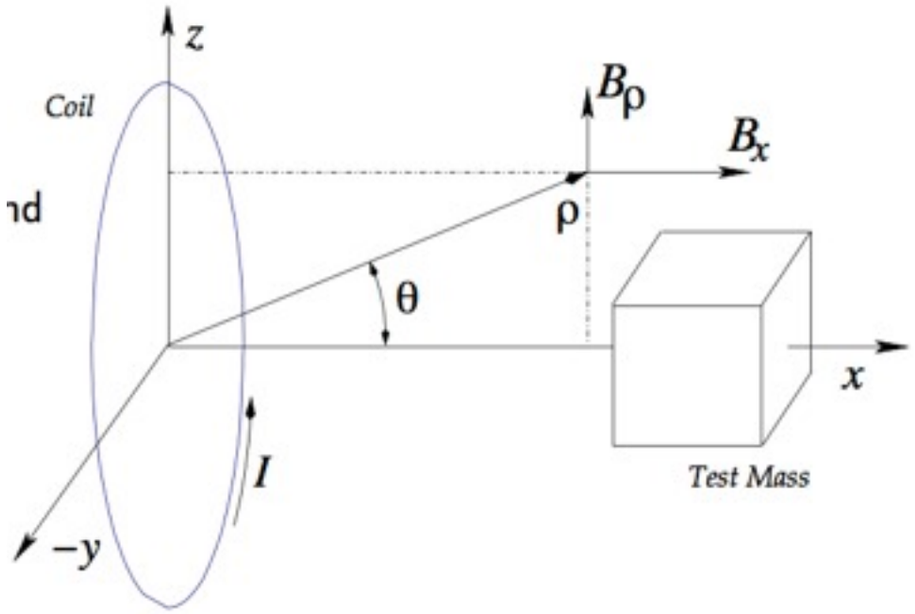

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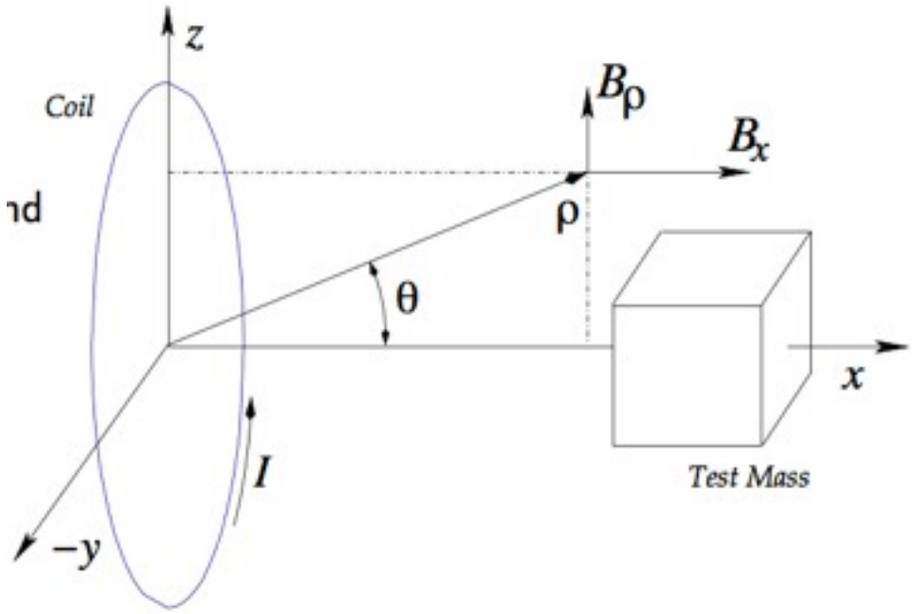

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\begin{aligned}
f_{DC} &= \frac{V}{2\,\mu_0} \langle B \cdot \nabla B_{0,x} \rangle \\
f_{x_{1\omega 0}} &= V \left\langle \frac{\partial B_{0,x}}{\partial x} \right\rangle \sin \omega_0 t \\
f_{x_{2\omega 0}} &= \frac{V}{2\,\mu_0} \langle B \cdot \nabla B_{0,x} \rangle V \cos 2\,\omega_0 t \\
f''_{x_{2\omega 0}} &= \frac{V}{2\,\mu_0} \langle B \cdot \nabla B_{0,x} \rangle V \cos(2\,\omega_0 t - \pi/2) \\
n_{y1\omega_0} &= \left\langle B_{0,x} + z \frac{\partial B_{0,x}}{\partial z} - x \frac{\partial B_{0,z}}{\partial z} \right\rangle \sin \omega_0 t \\
n_{y1\omega_0} &= \left\langle -B_{0,x} + x \frac{\partial B_{0,y}}{\partial y} - y \frac{\partial B_{0,x}}{\partial y} \right\rangle \sin \omega_0
\end{aligned}
$$

STOC Simulation #4

- STOC Simulations are exercises to train the team for LPF operations
  - different DA teams/sites
  - mission-like schedule
  - telecommand/telemetry as in operations

- STOC end-to-end Simulation #4 (16-23 Nov 2013) included magnetic characterisation

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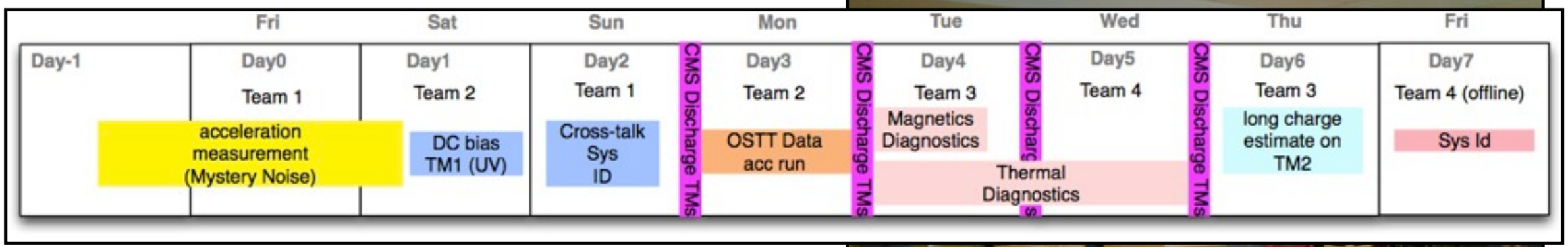

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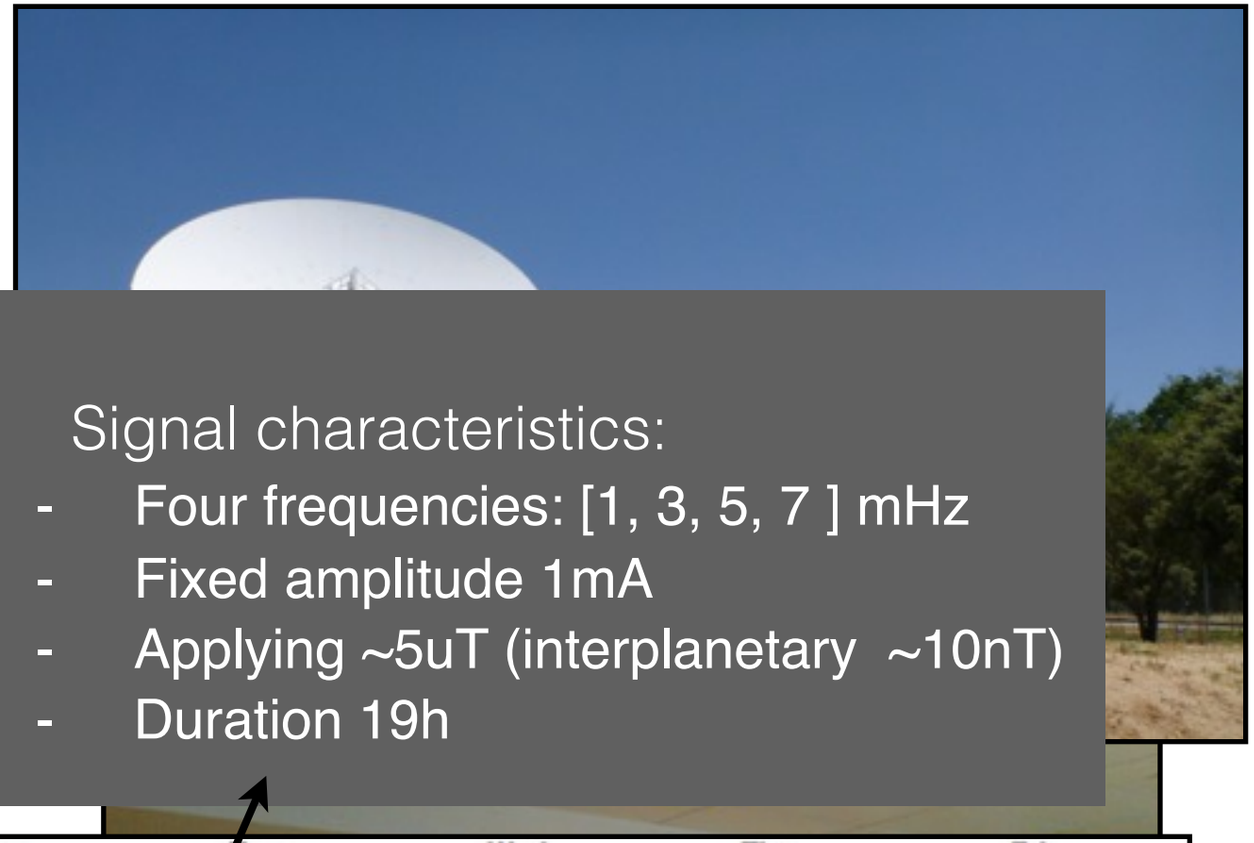
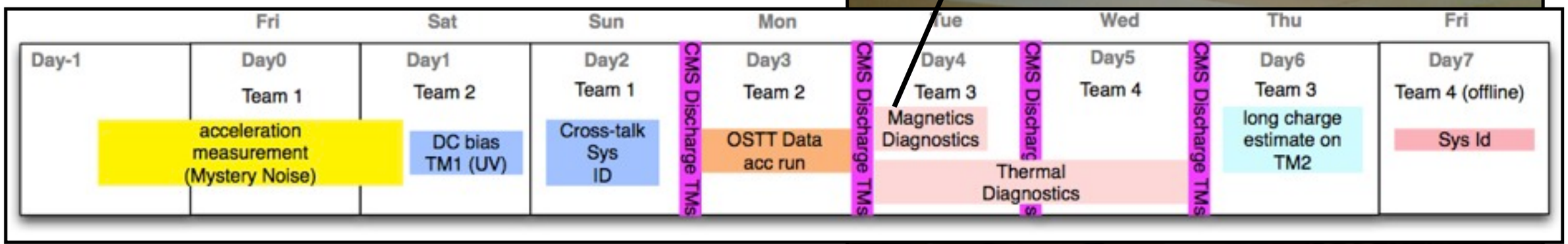
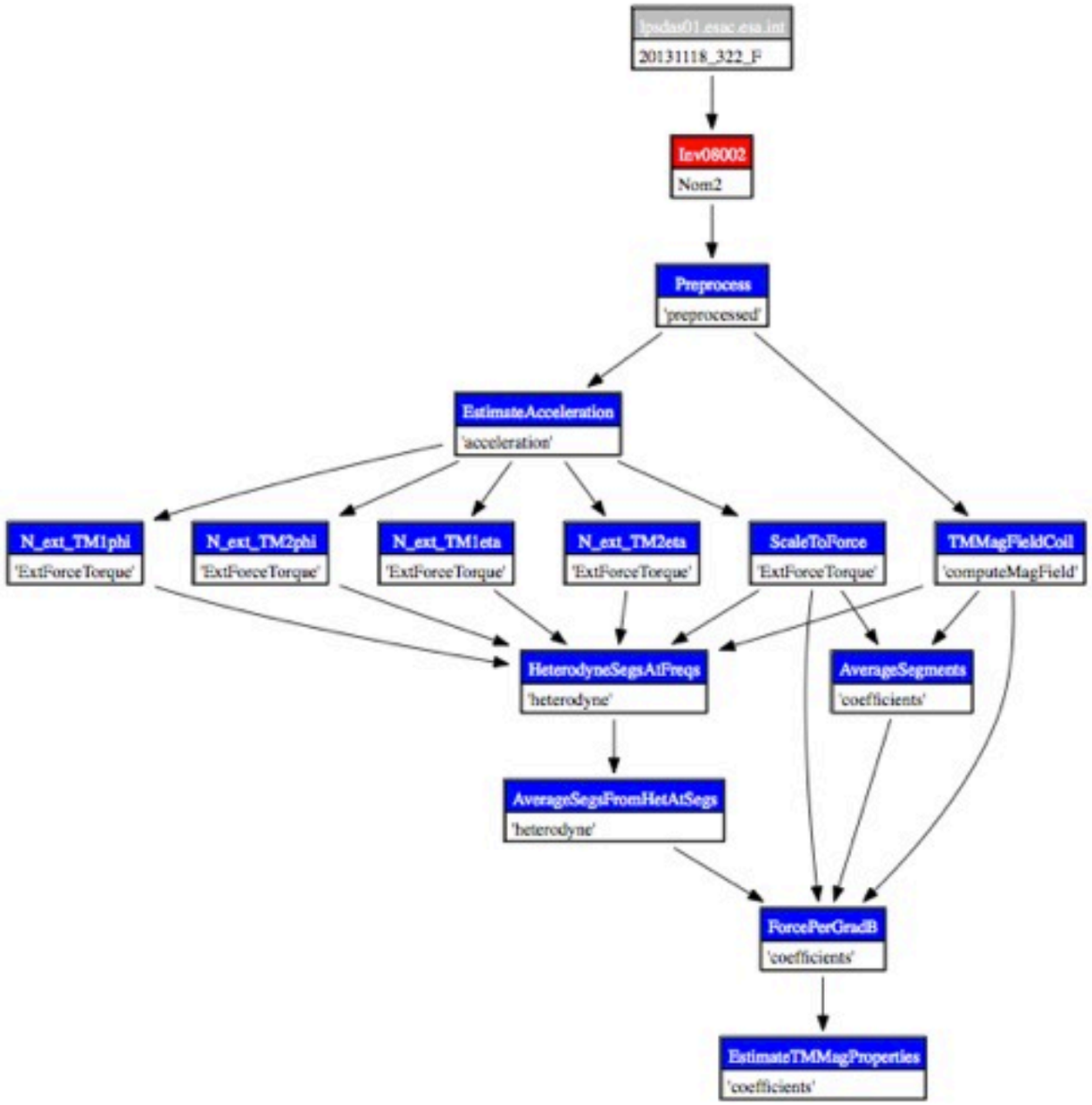


Signal characteristics:
- Four frequencies: [1, 3, 5, 7] mHz
- Fixed amplitude 1mA
- Applying ~5uT (interplanetary ~10nT)
- Duration 19h



Magnetic analysis pipeline



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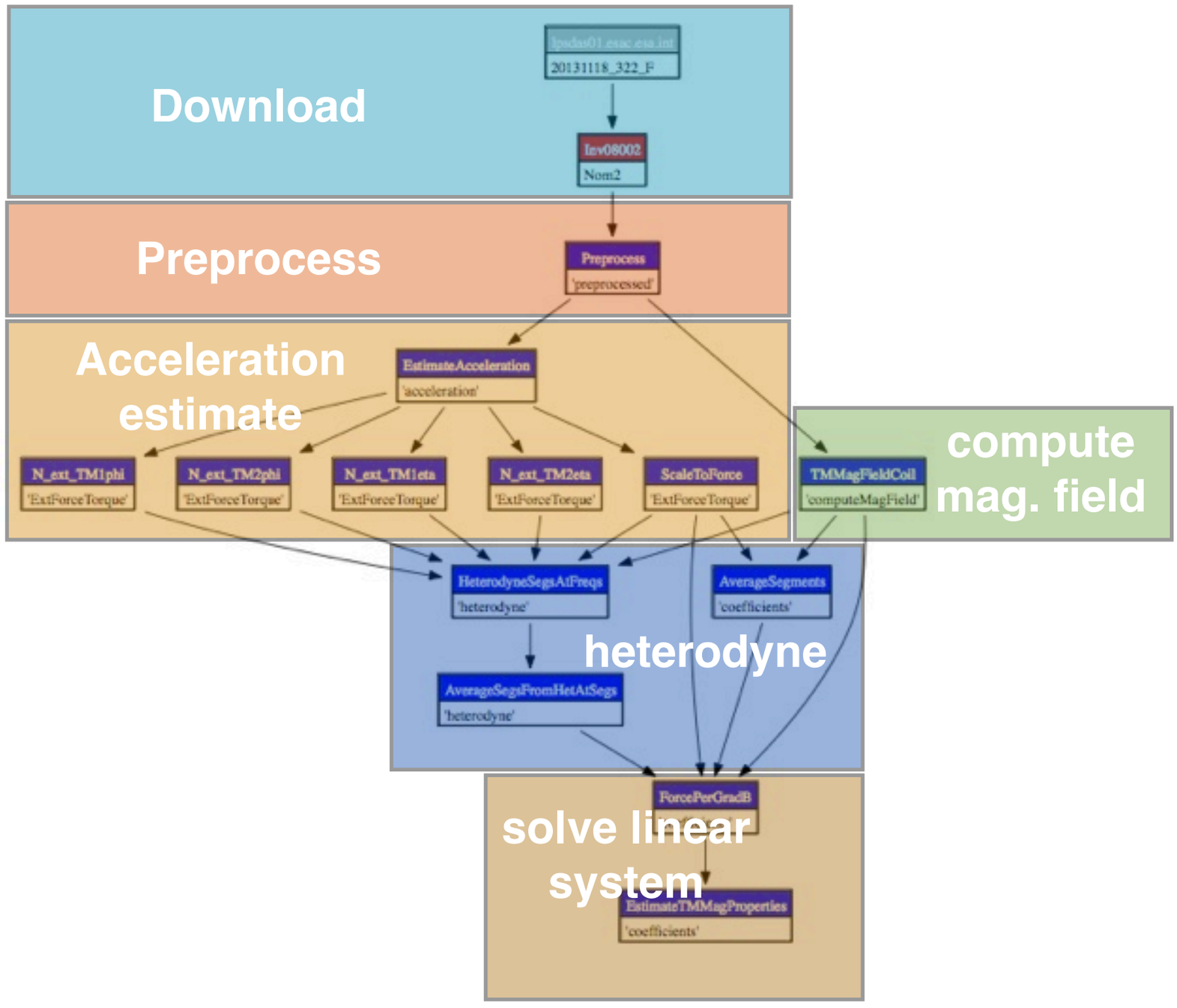
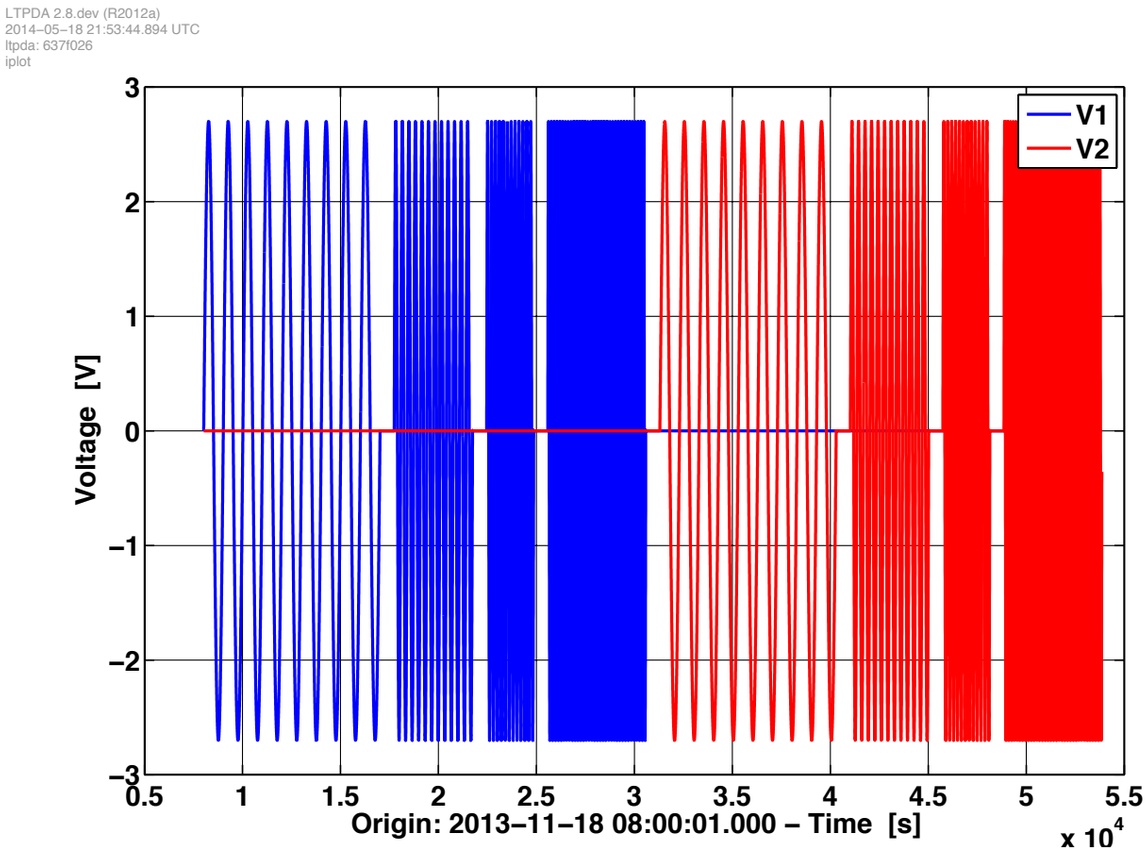
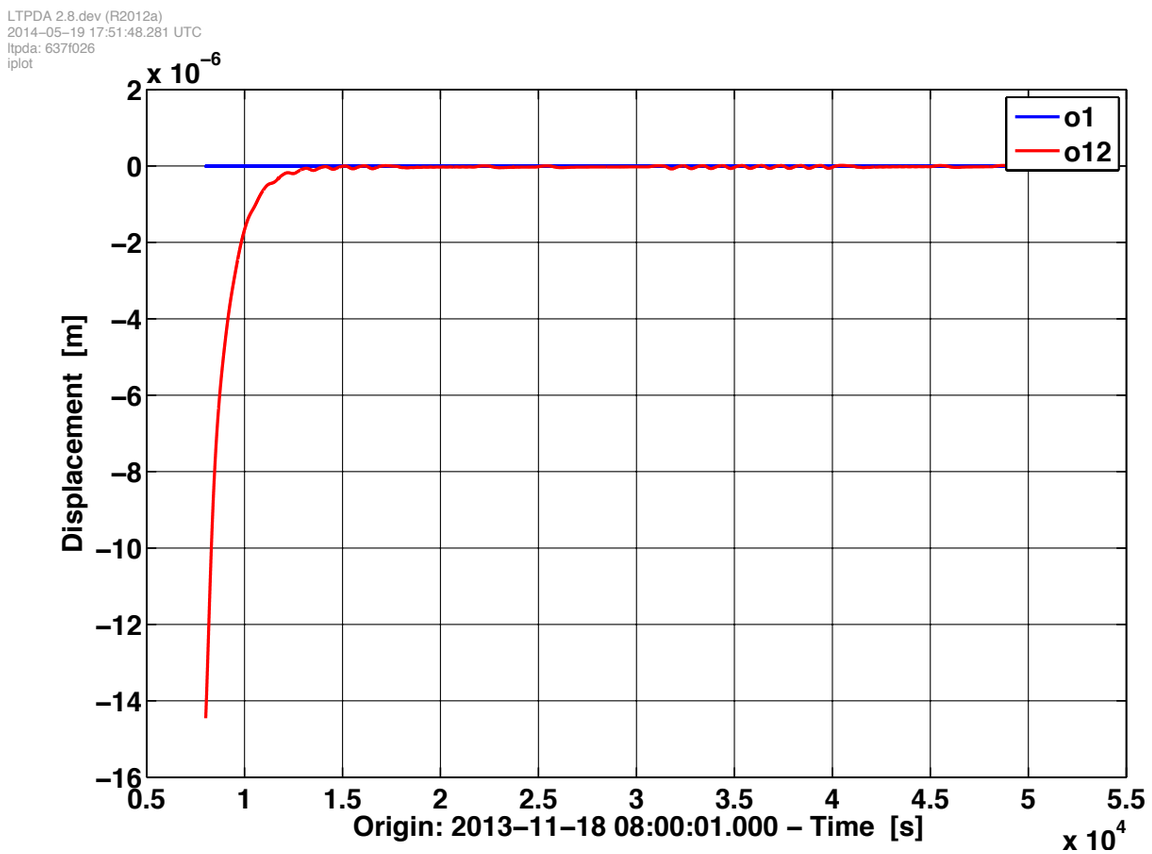


Analysis pipeline - displacement

- Analysis based on telemetry parameters
  - applied voltage on coils, TM displacement
  - magnetic experiment too close to CMS discharge (planning error)





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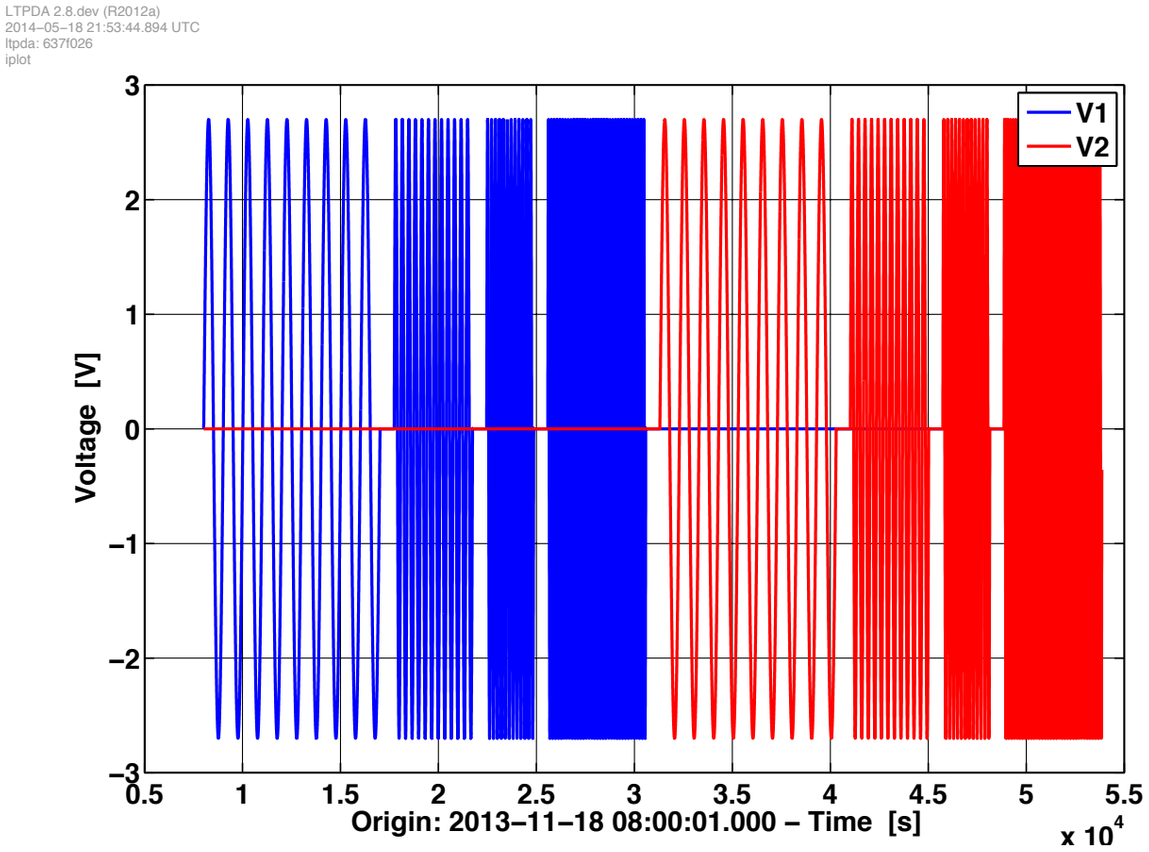
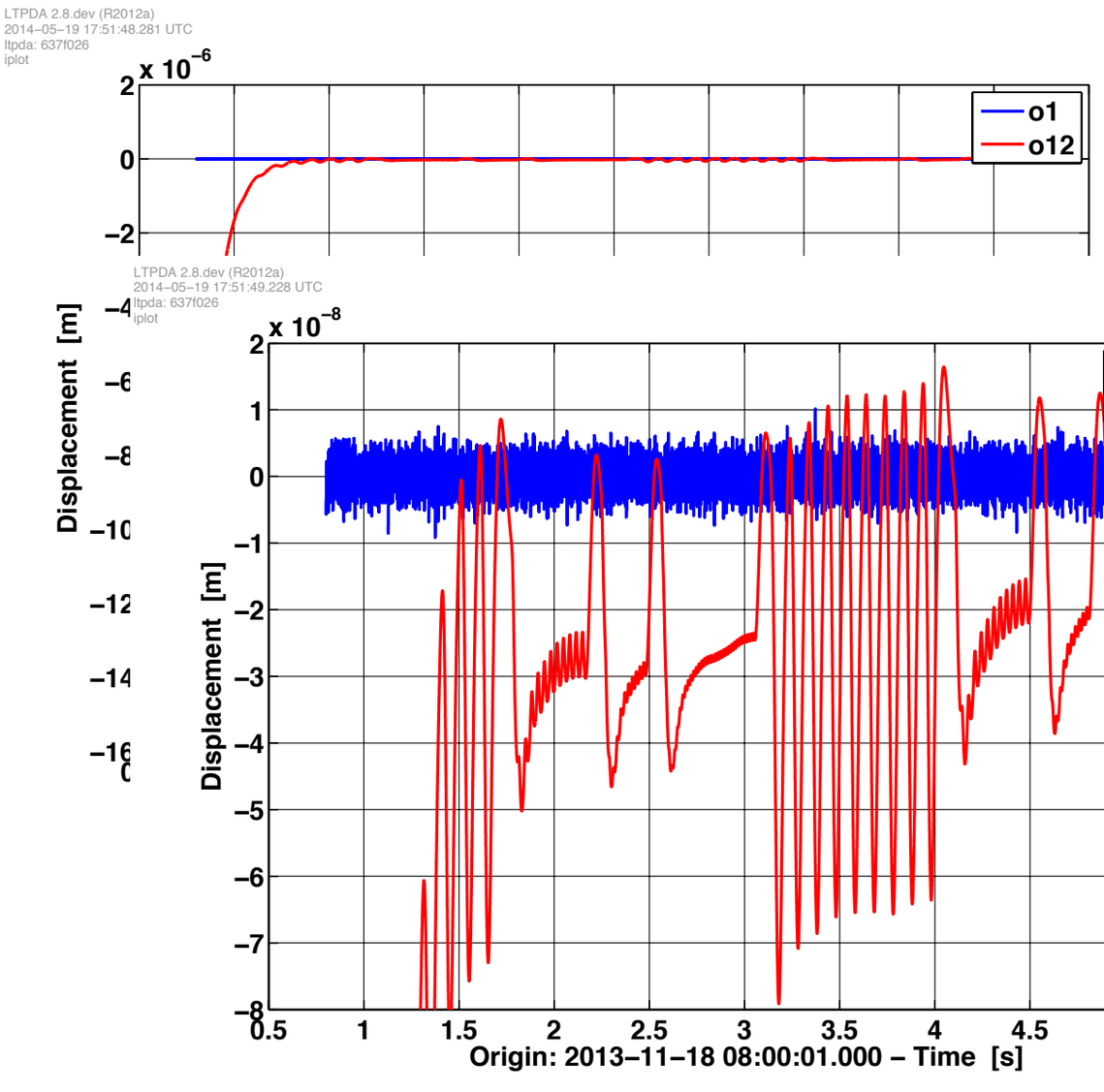
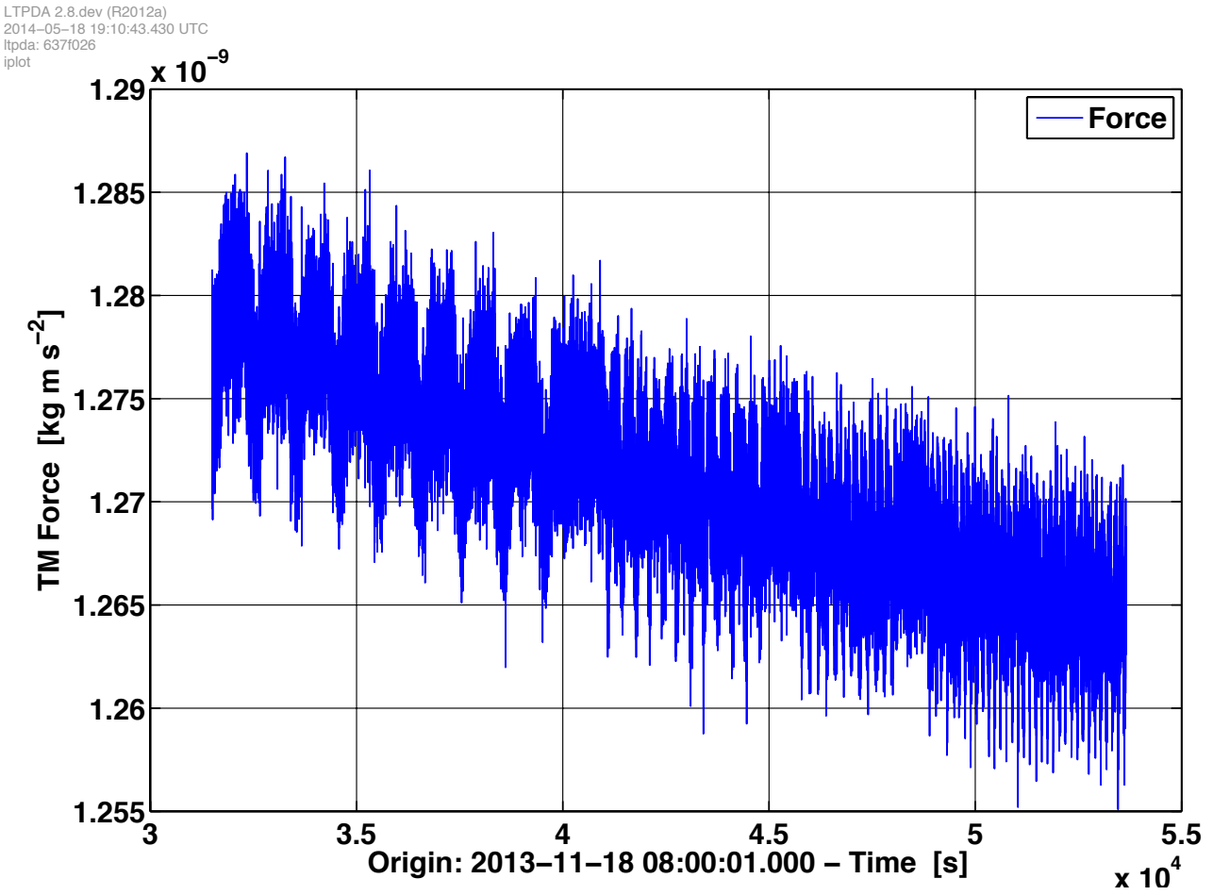
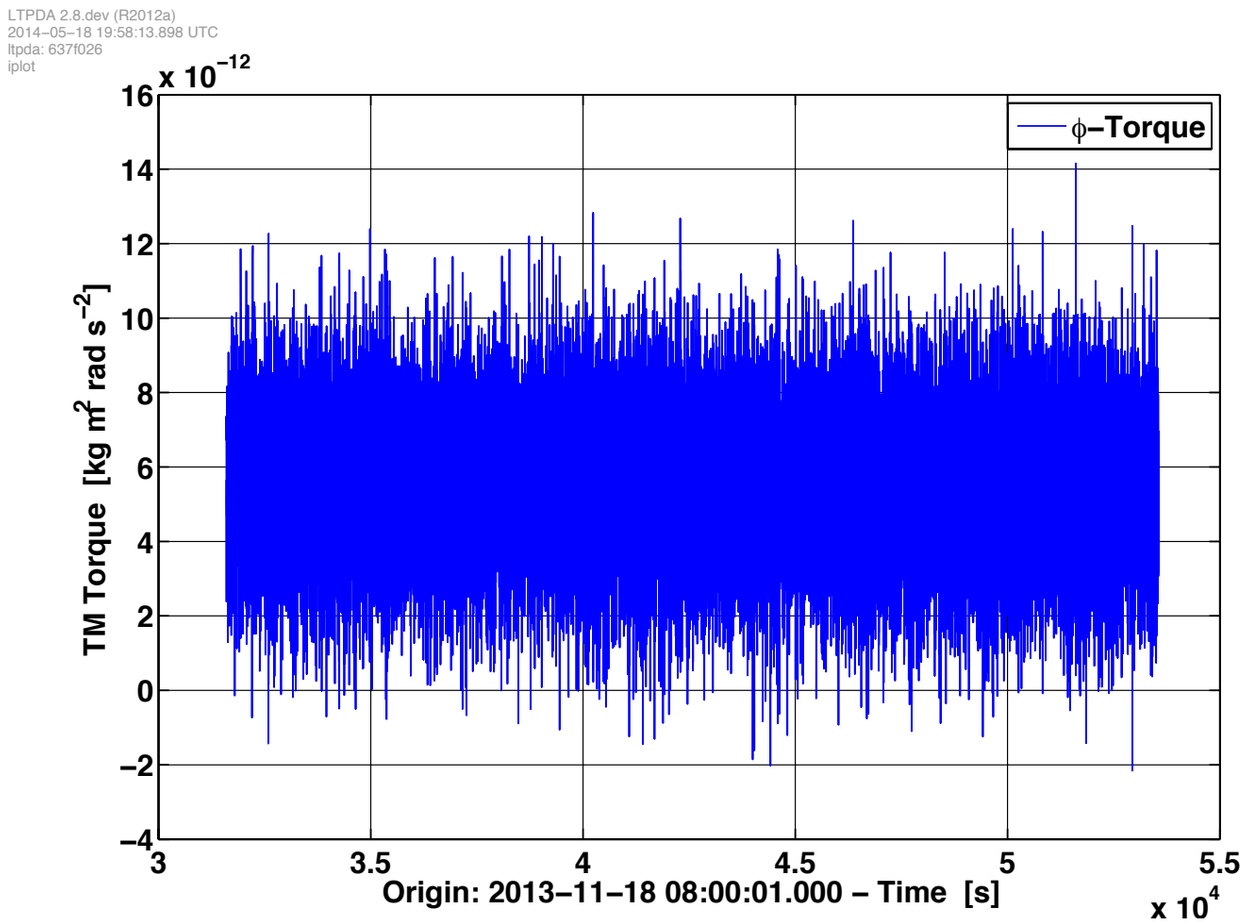




Analysis pipeline - force and torque

- Translation into force and torques
  - requires system parameters (assumed to be known)





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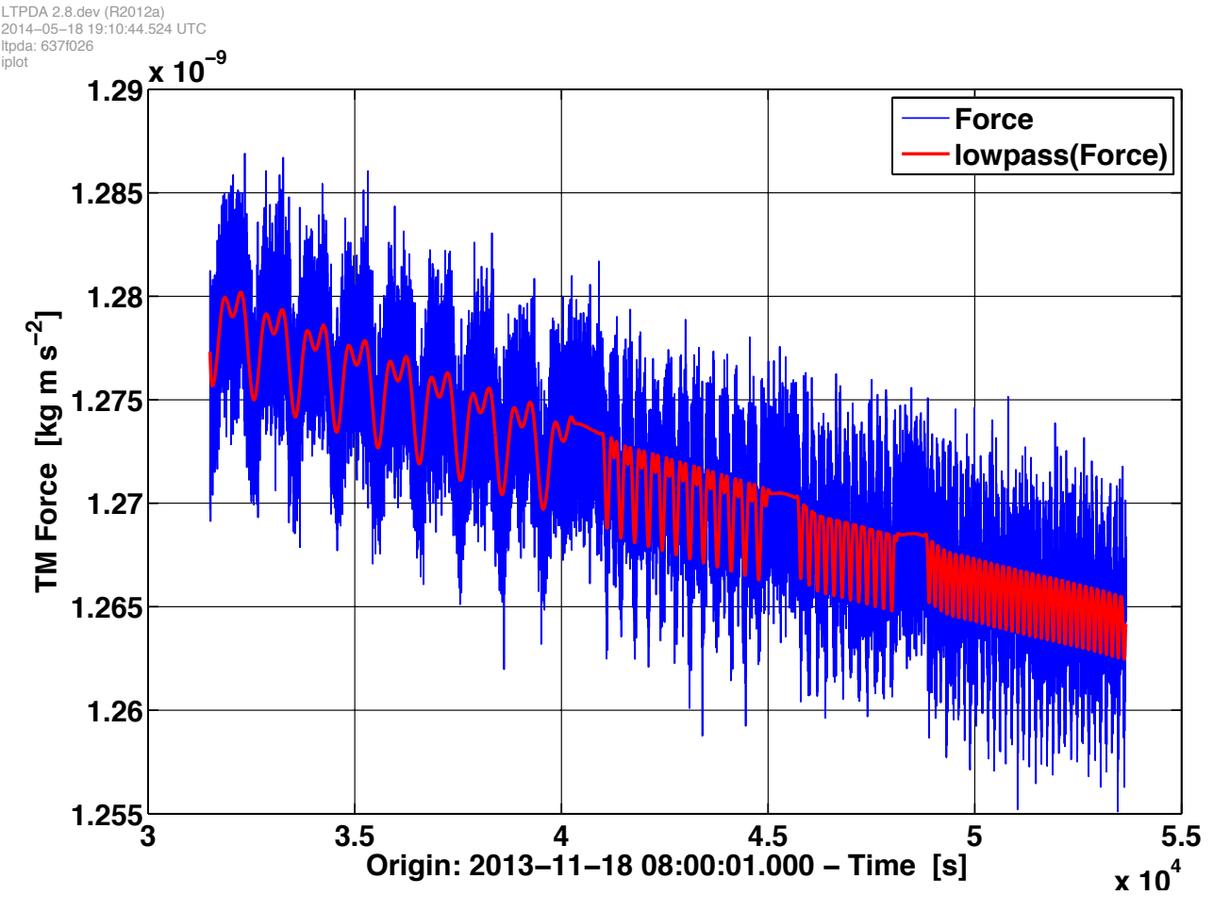
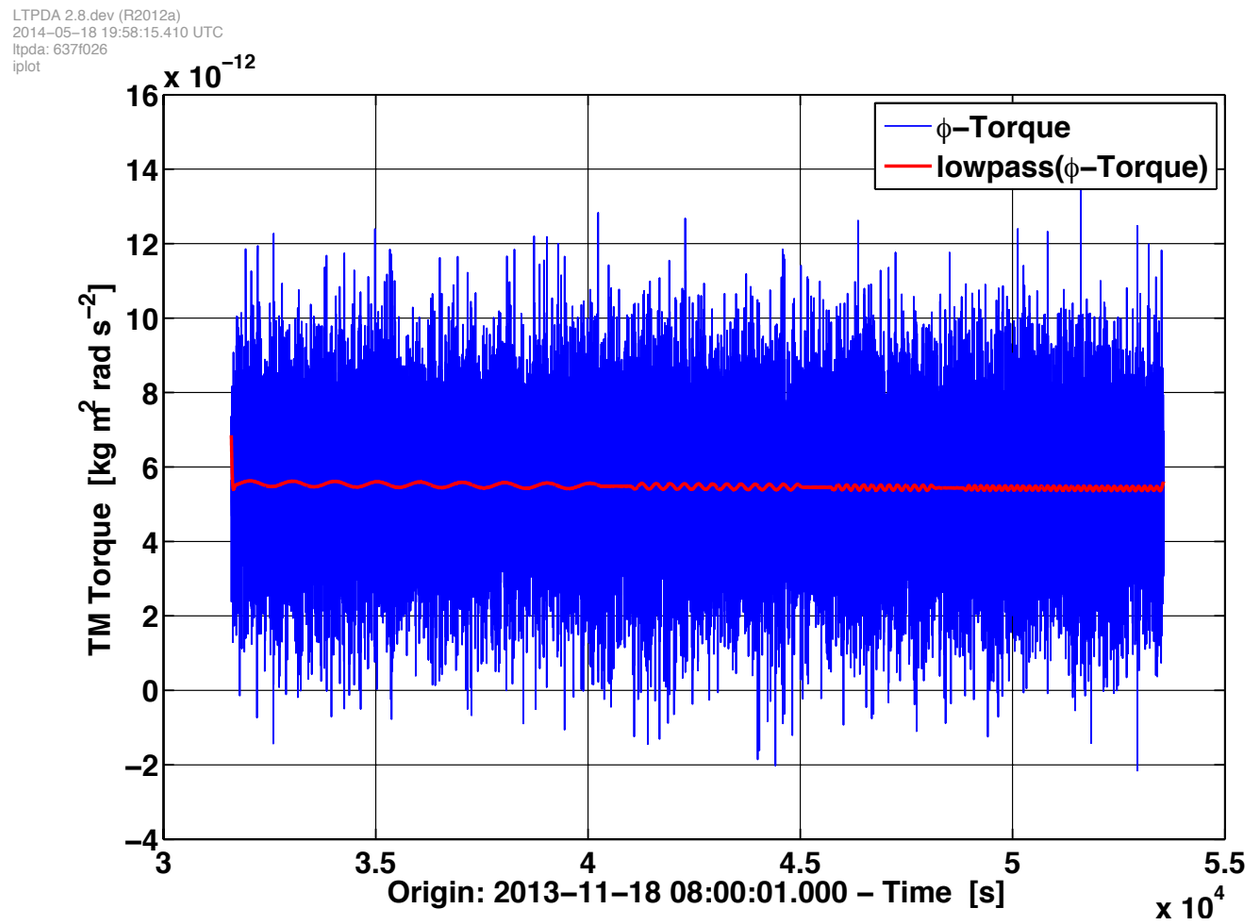
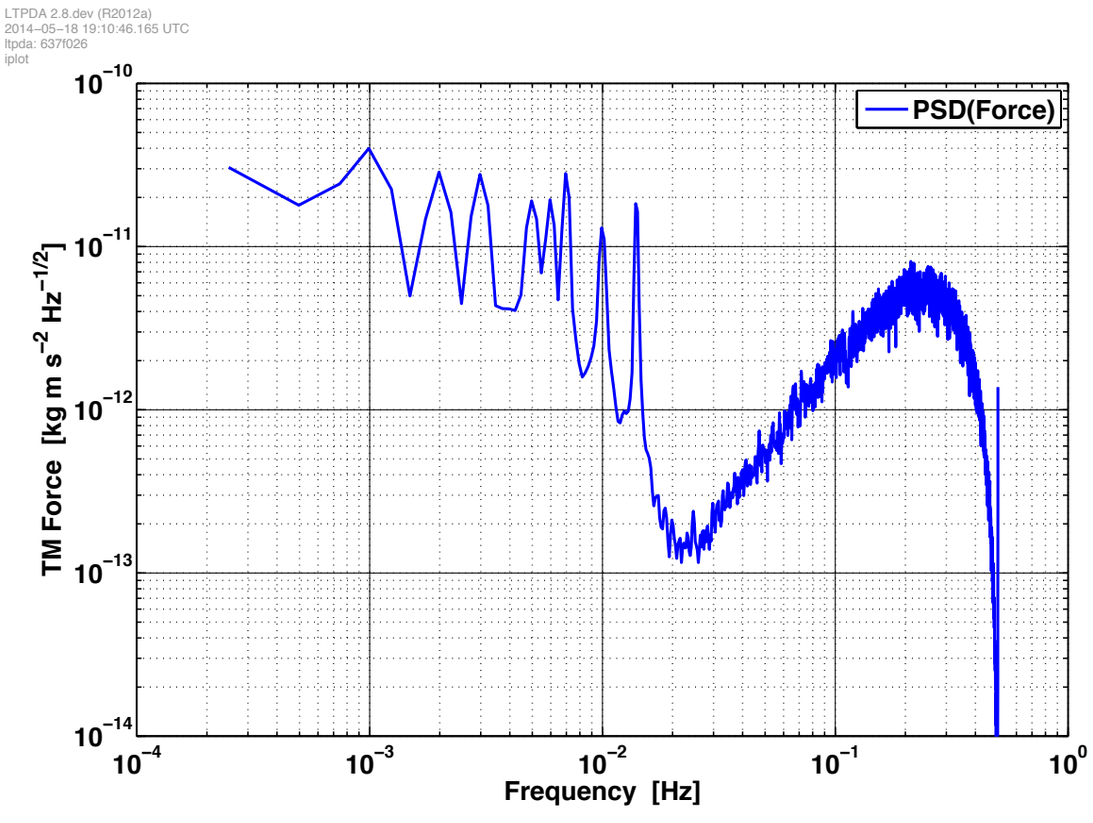
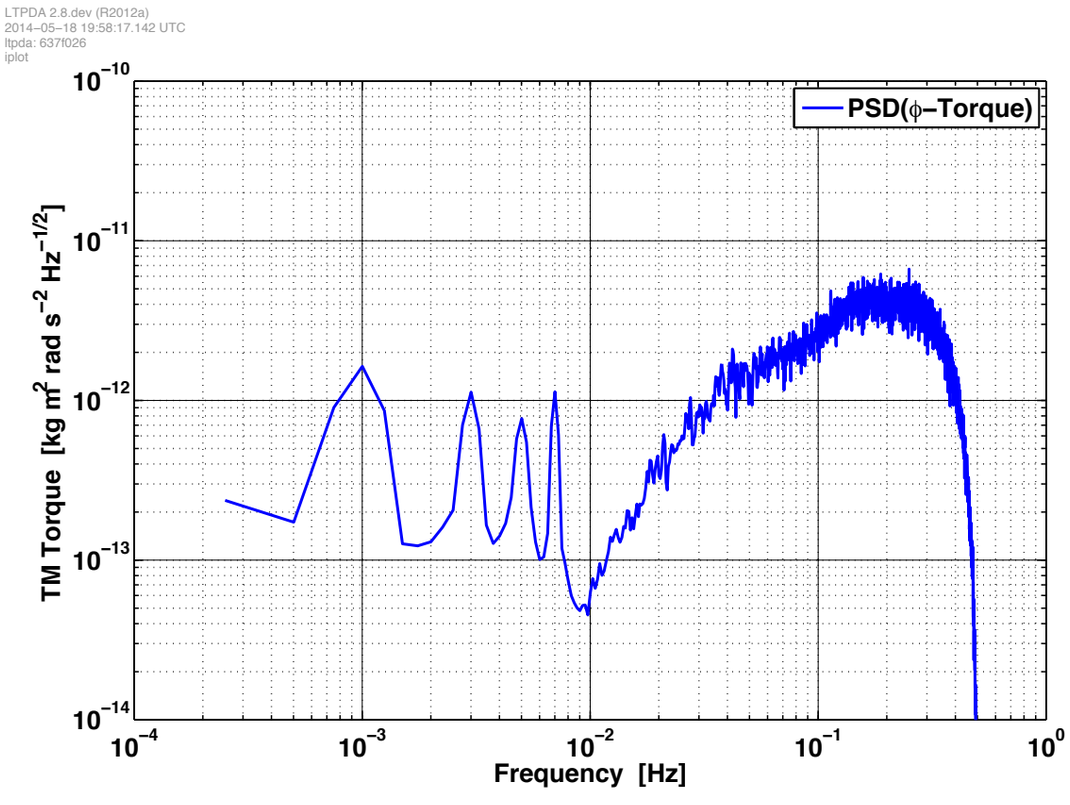




Analysis pipeline - force and torque

- Translation into force and torques. Spectra:
  - Force contribution at f_0 and $2xf_0$
  - Torque contribution at f_0
  - High frequency IFO noise

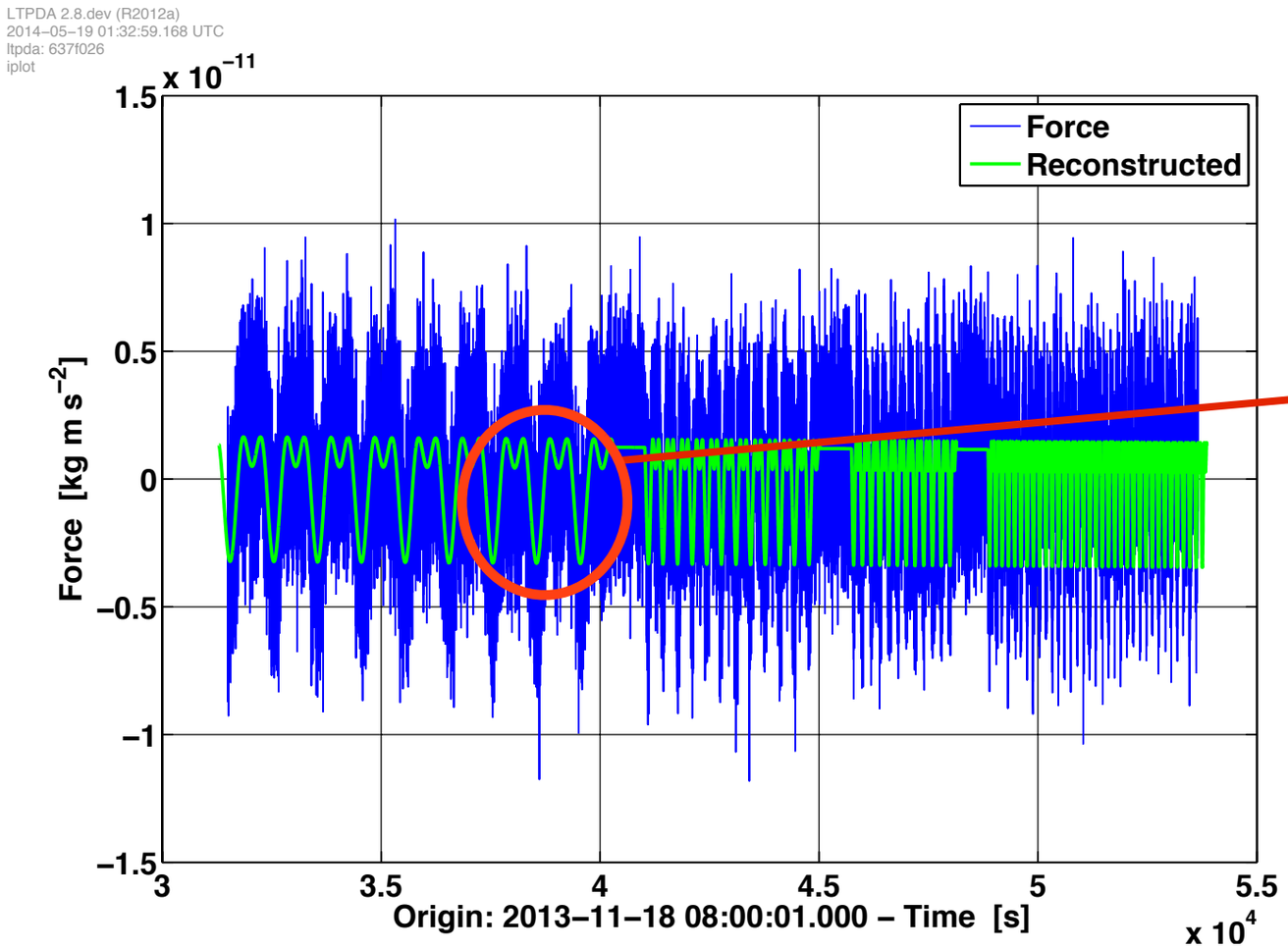


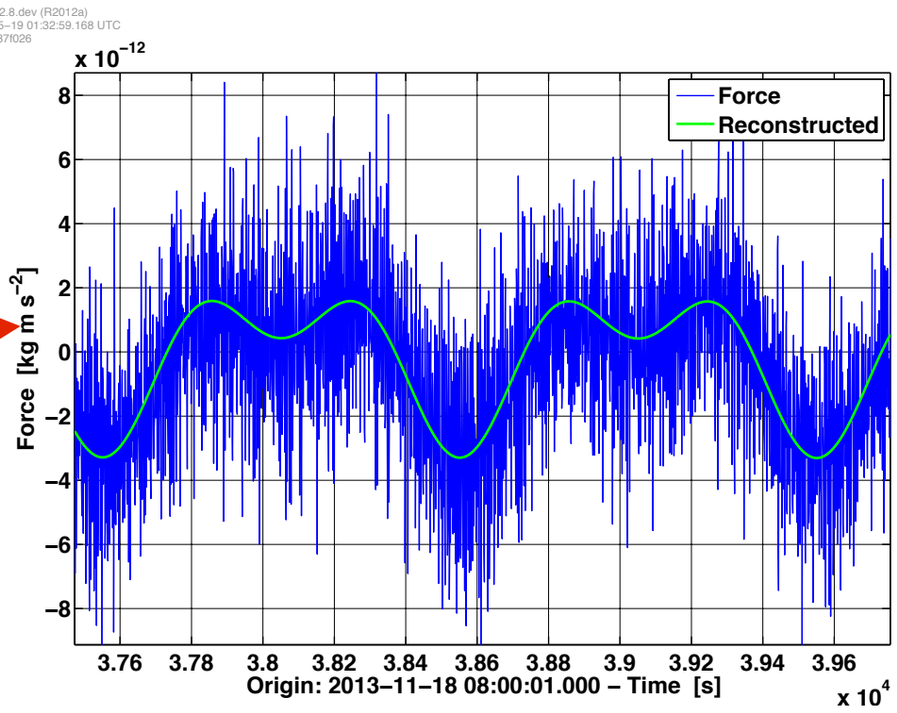


Analysis pipeline - parameters

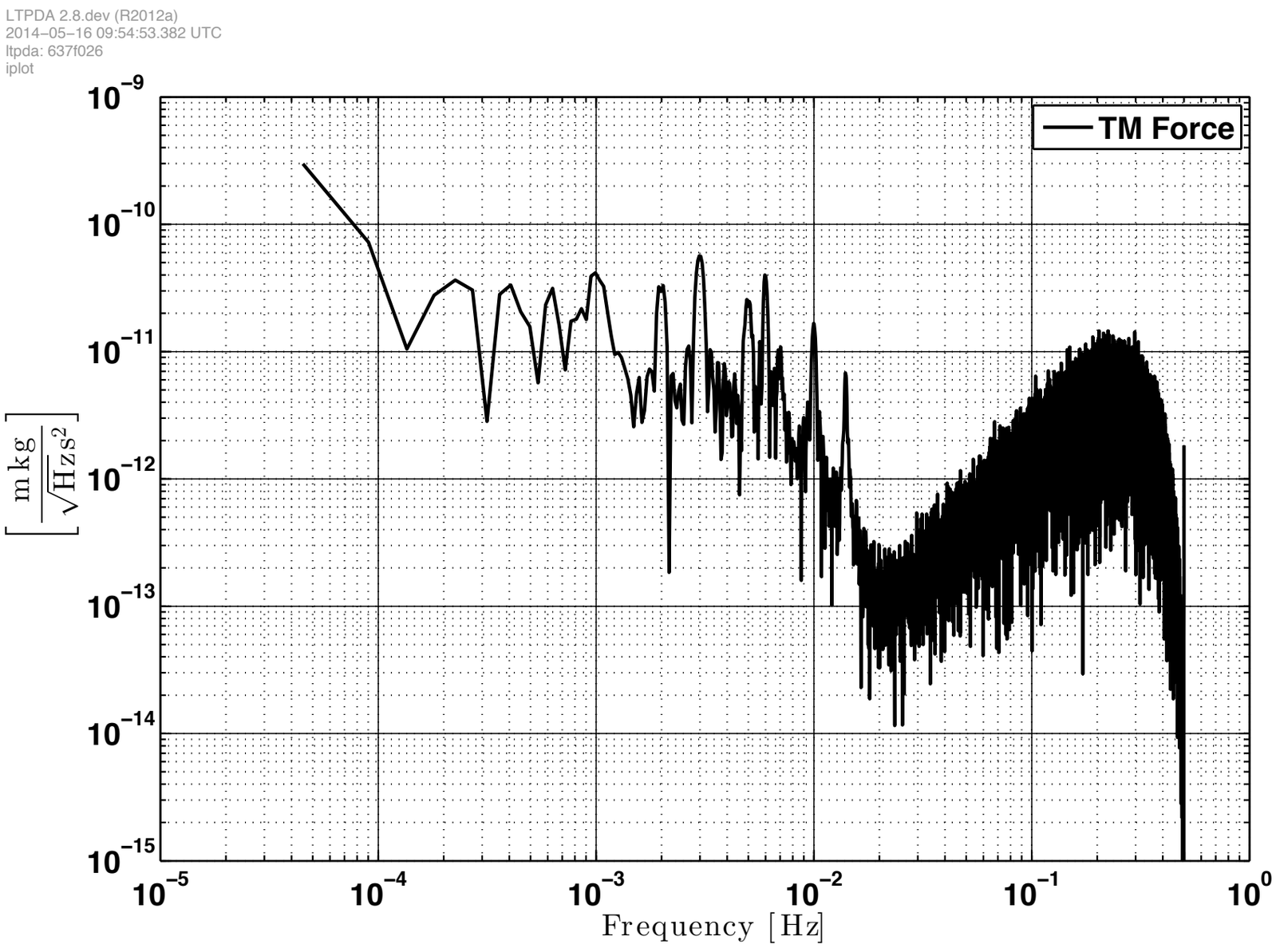
- To determine the parameters:
  - heterodyne at the injected frequency to get the coupling coefficients
  - solve the linear system

Parameter	Value
χ_0	$(5.81 \pm 0.09) \times 10^{-5}$
M_x	$(1.18 \pm 0.01) \times 10^{-4}$ A m^{-1}
M_y	$(1.29 \pm 0.02) \times 10^{-4}$ A m^{-1}
M_z	$(1.40 \pm 0.03) \times 10^{-4}$ A m^{-1}





Analysis pipeline - reconstructed force



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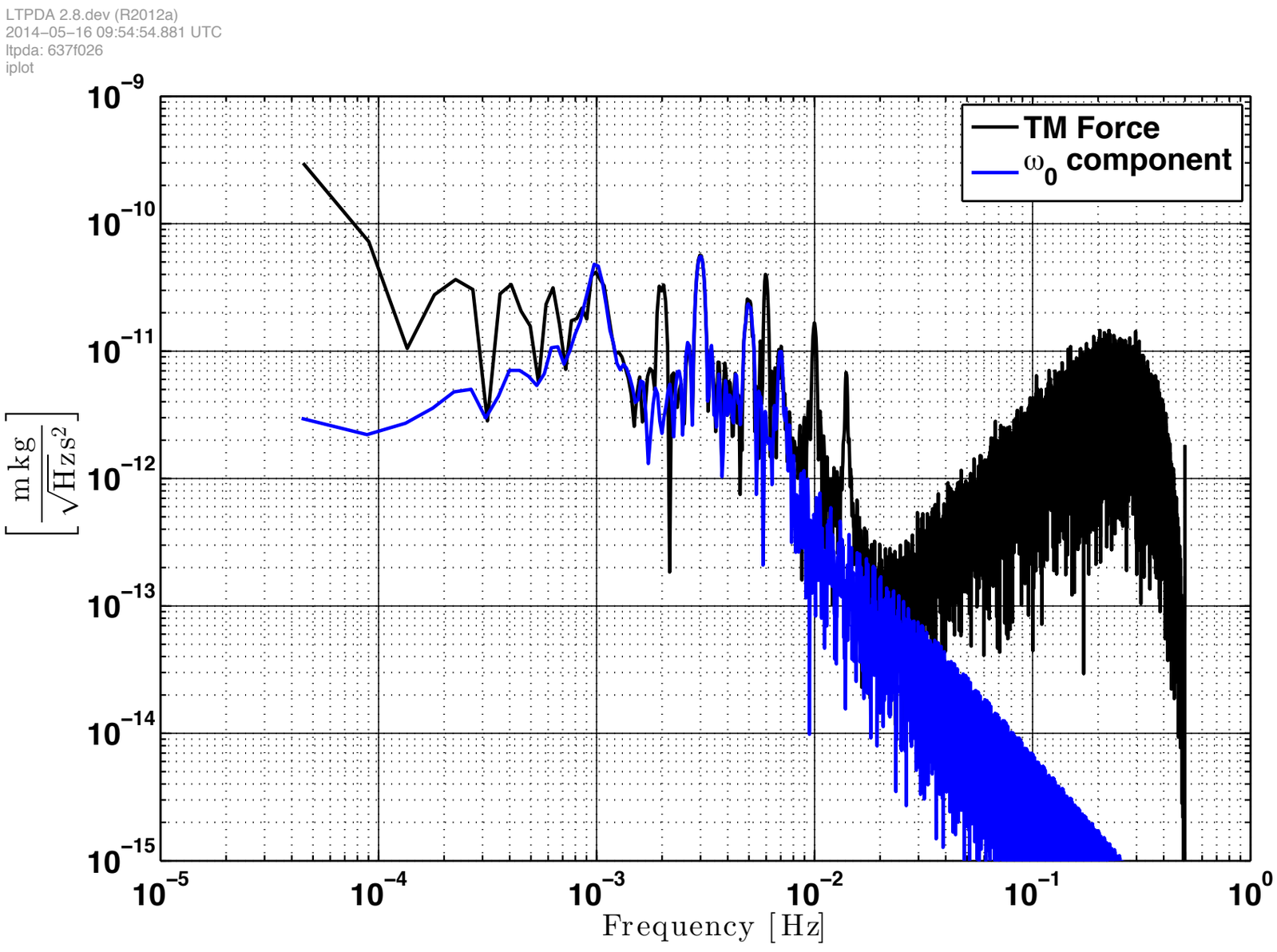

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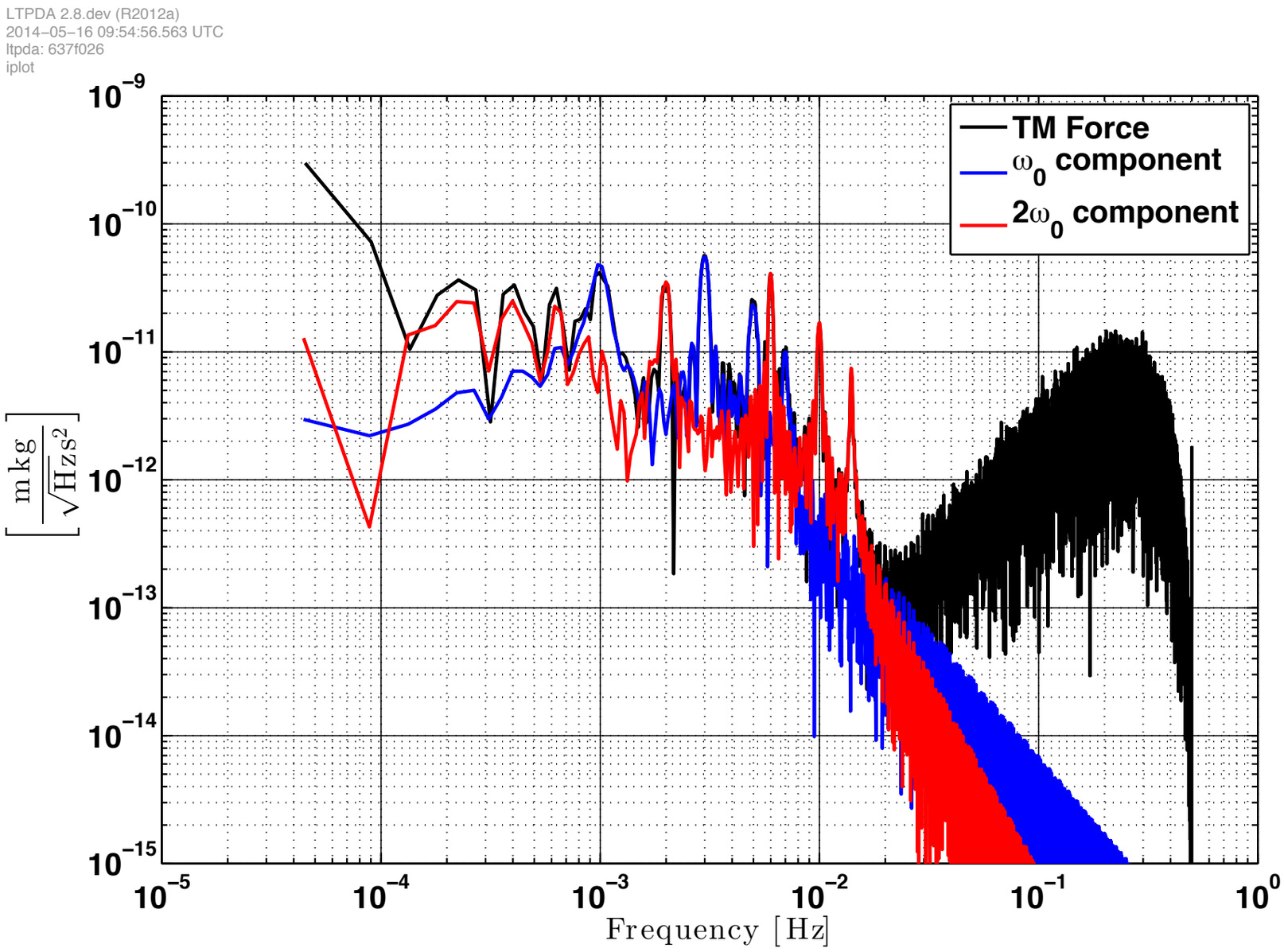

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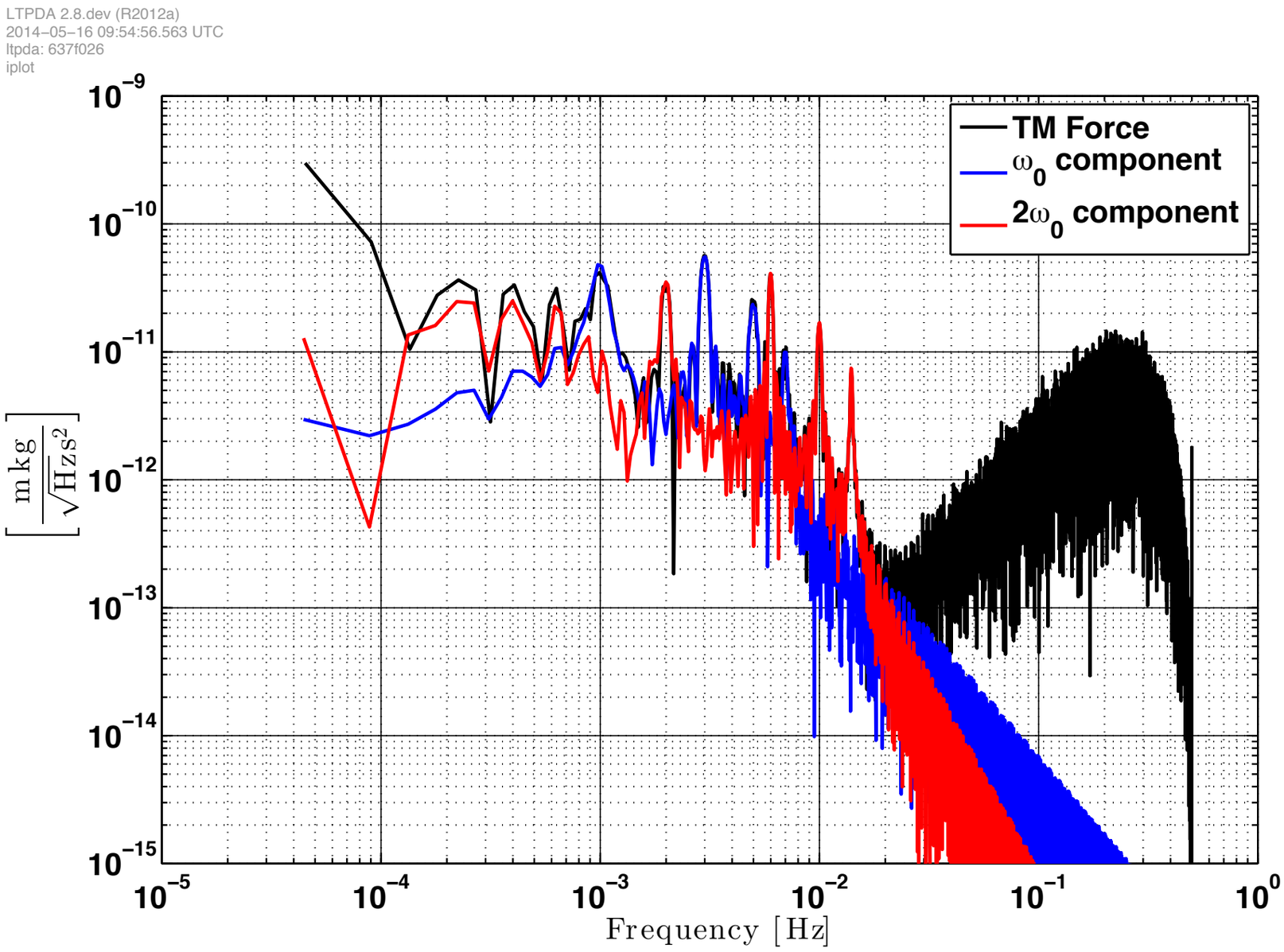


Last step in the pipeline is noise projection (requires magnetic field)

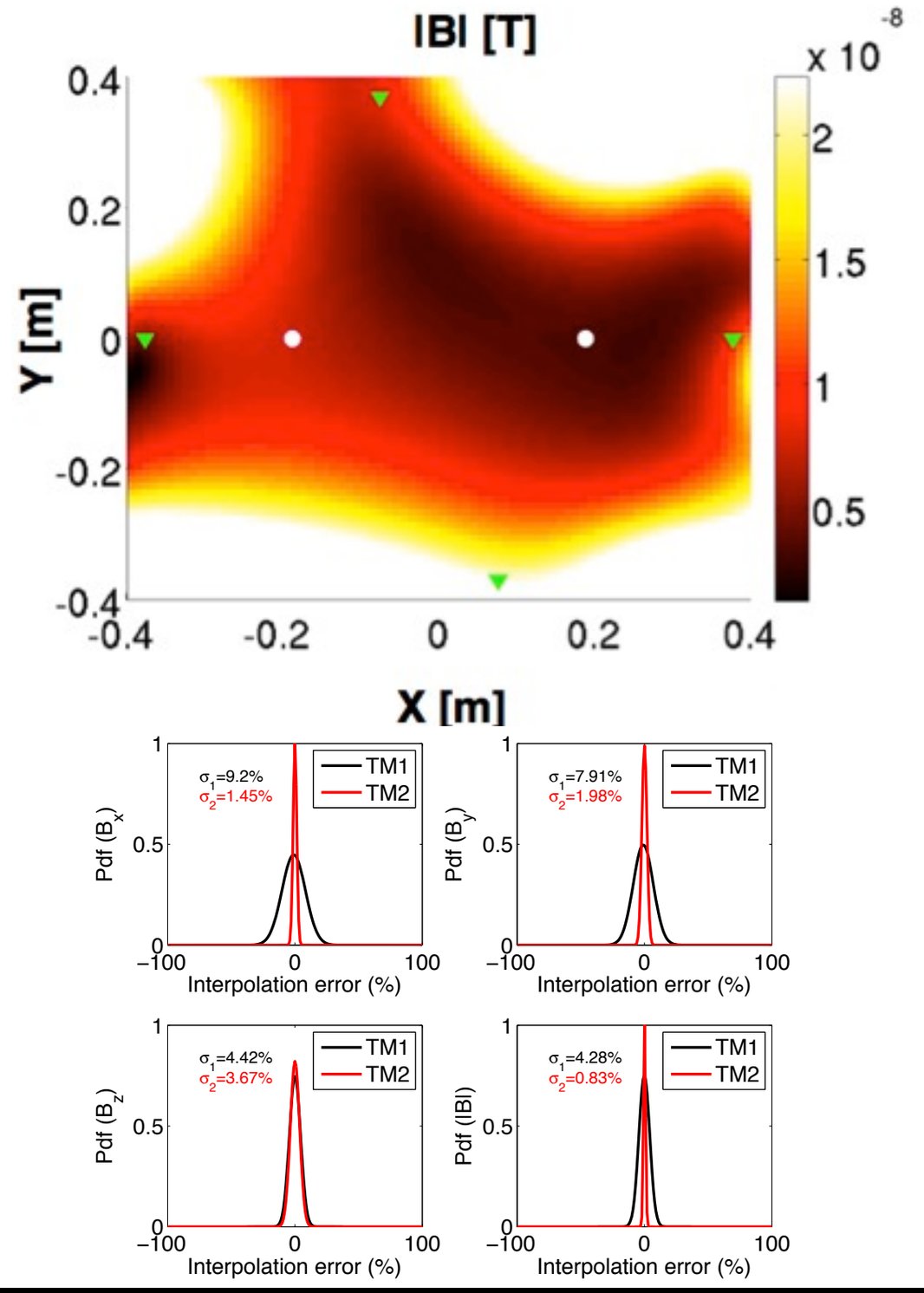
Magnetic analysis #2: magnetic field extrapolation

- Magnetometers are fluxgate, so magnetically active
  - can't be near the TMs

- Magnetic field needs to be interpolated to TM position
  - ~ 30 magnetic active units surrounding the TMs create a complex mag. environment

- Neural networks found to solve the problem
  - need to be 'trained', so relying on previous knowledge

M Diaz-Aguilo, A Lobo, E Garcia-Berro.
Exp. Astronomy 30 2011



Exploring the LPF magnetic map

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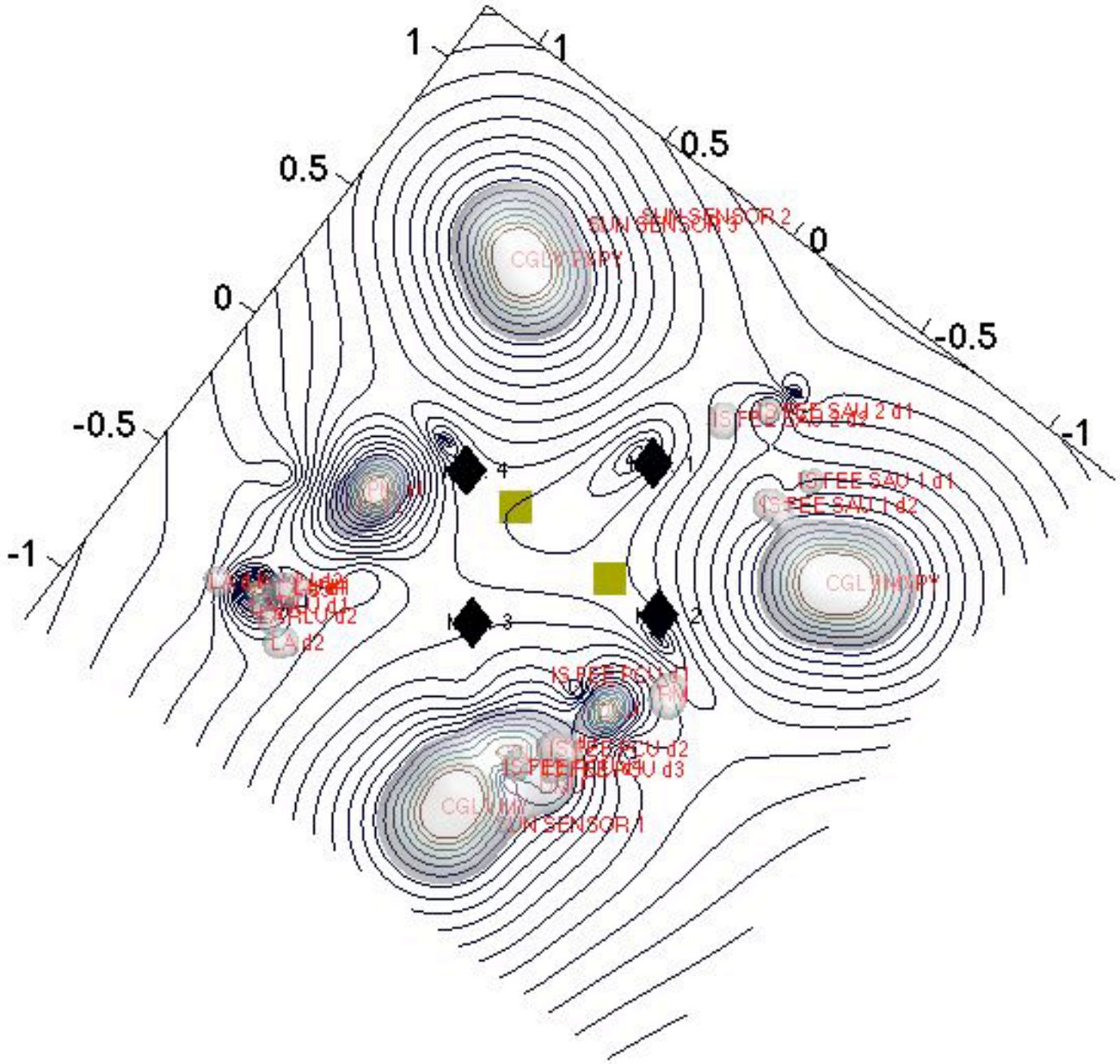

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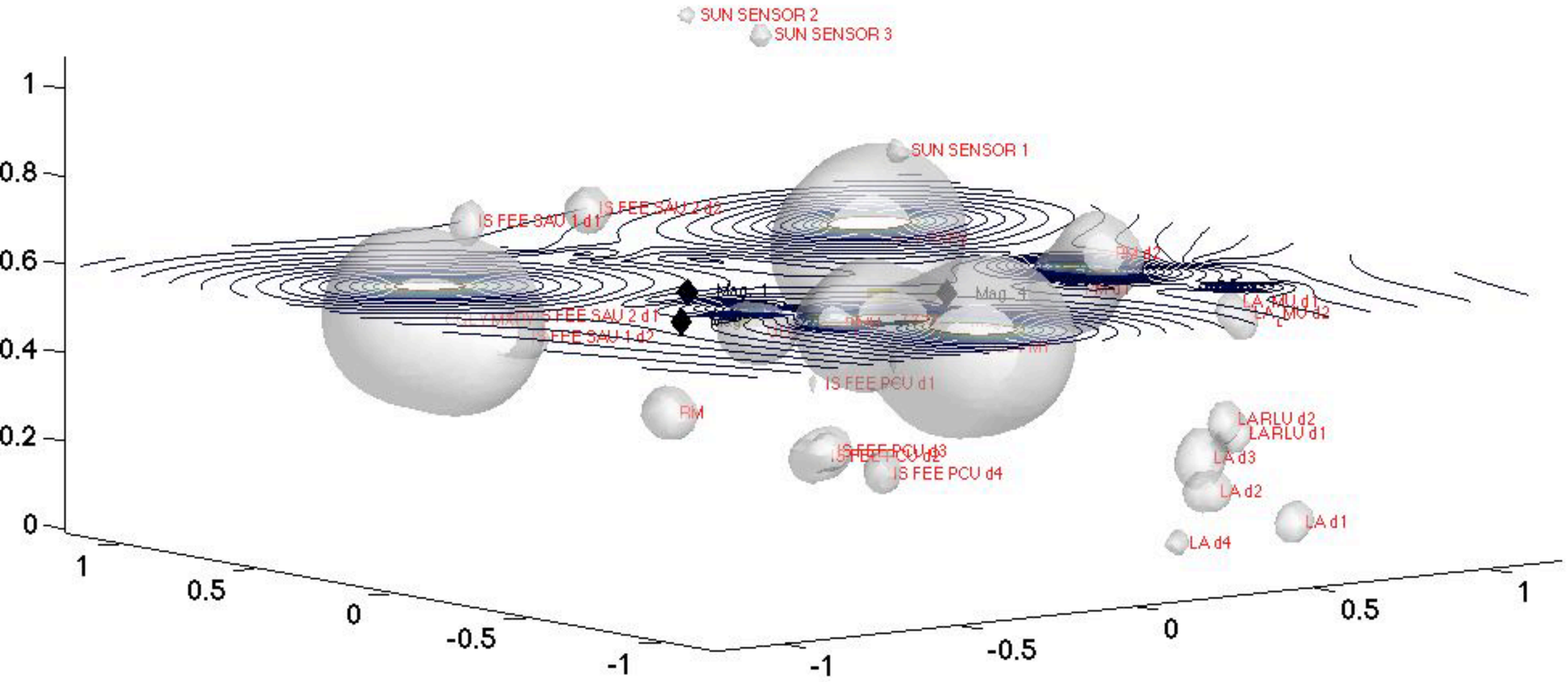

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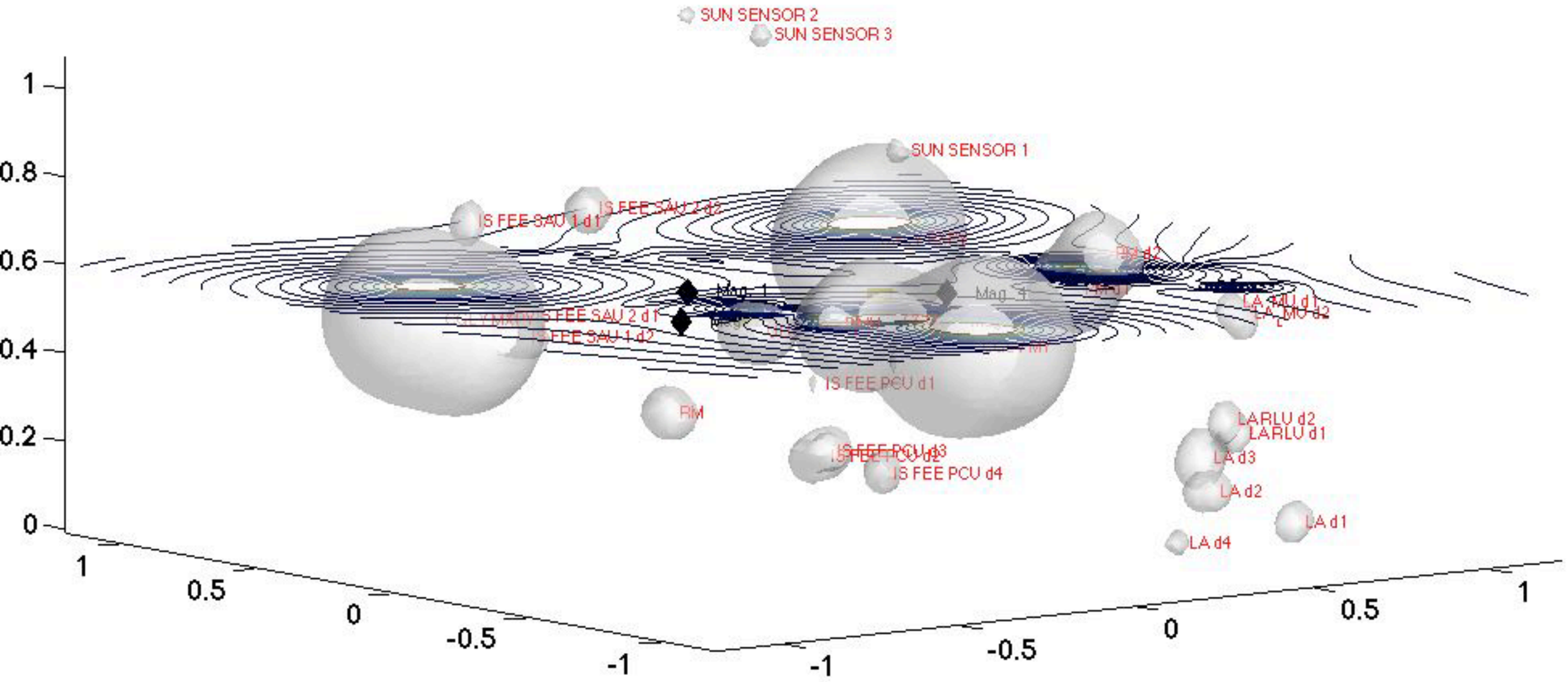
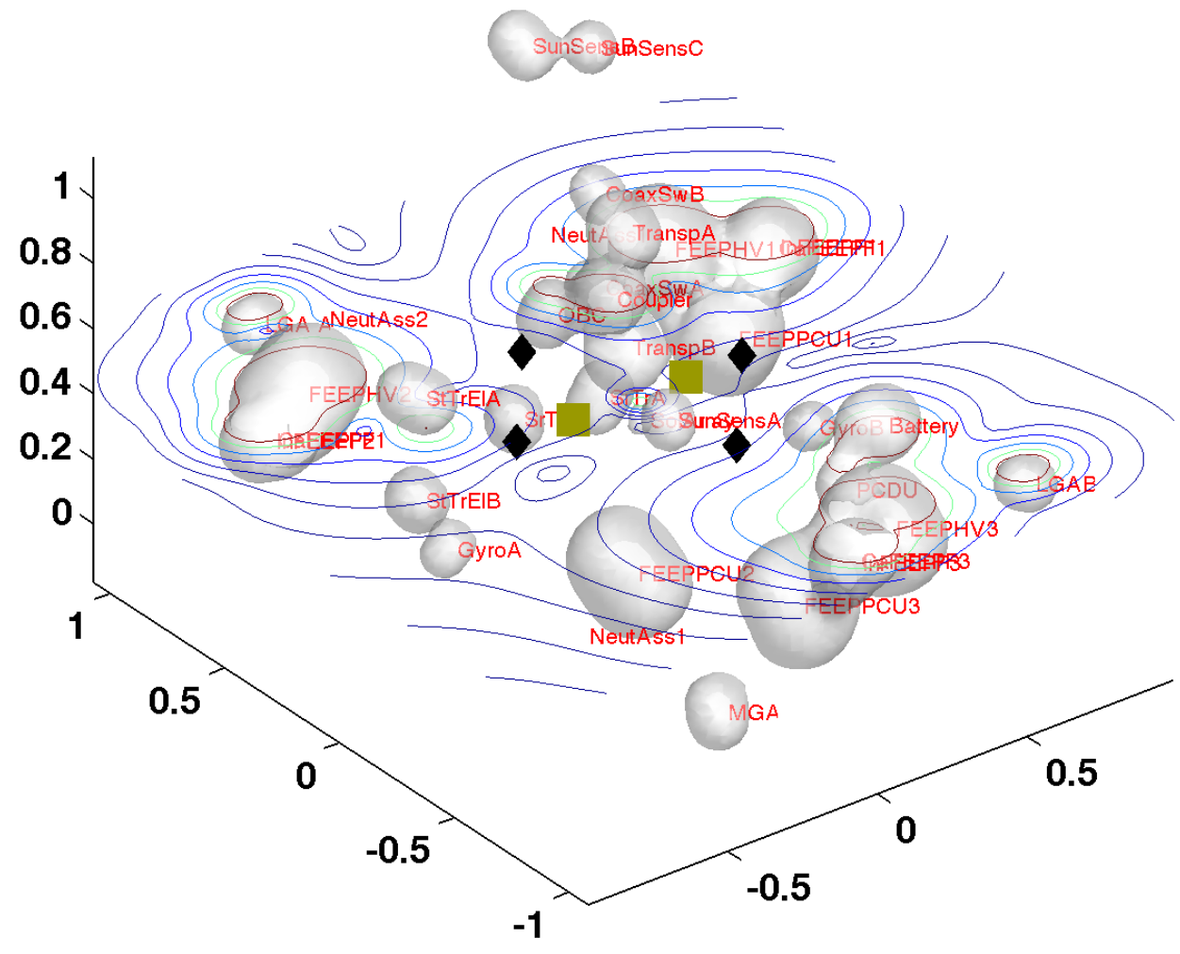


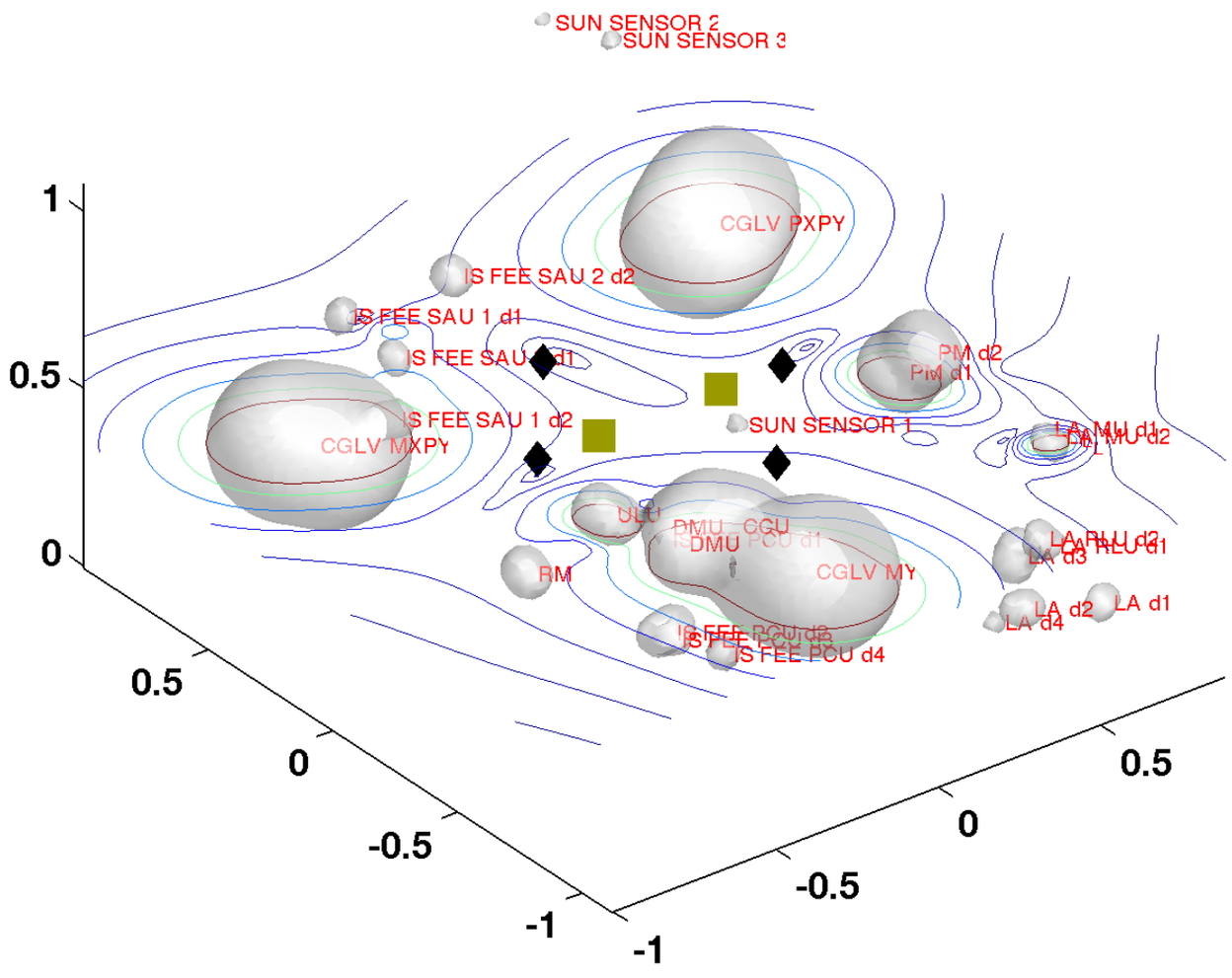
FEEP to Cold Gas thrusters

FEEPs



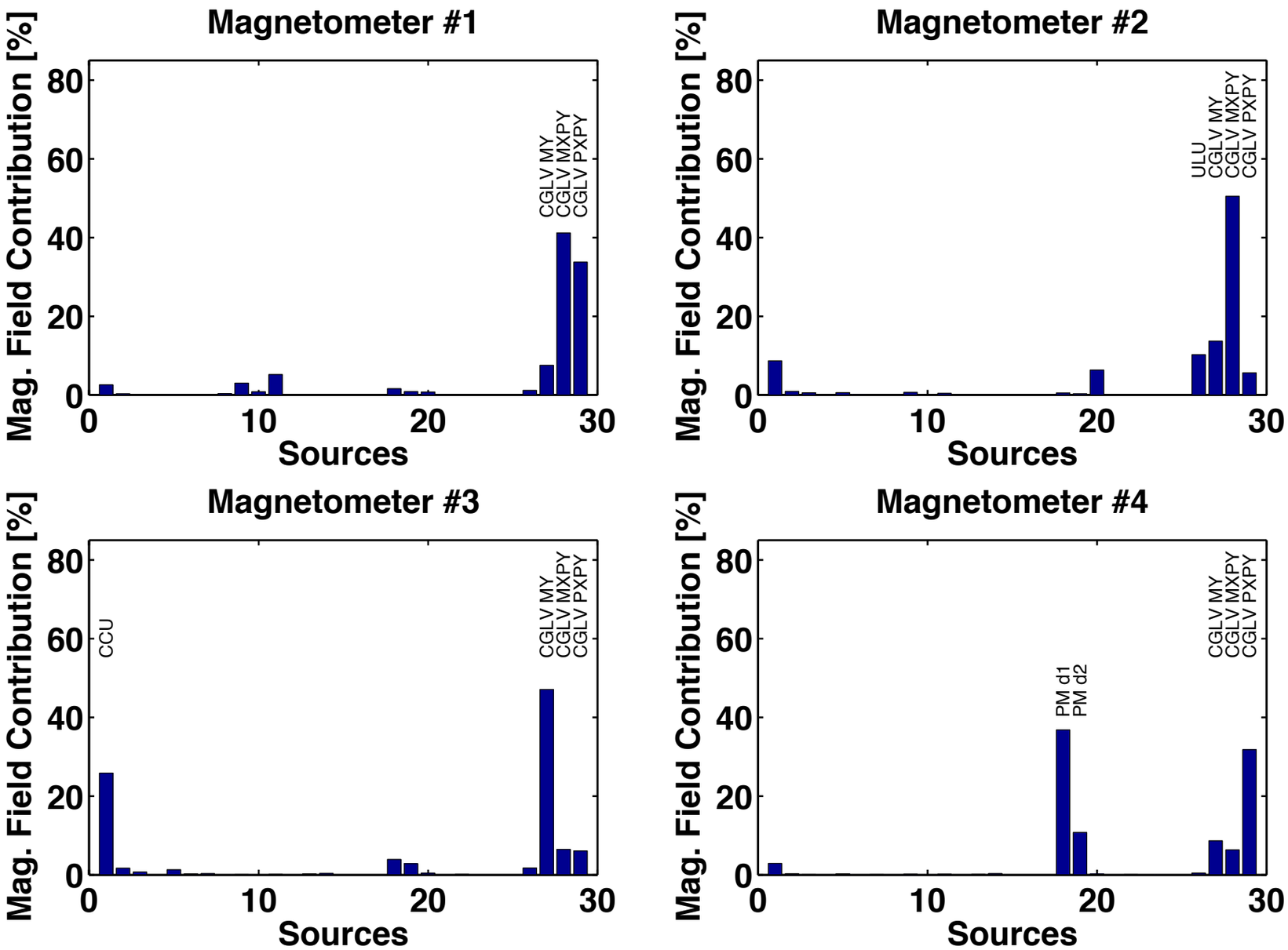
Cold Gas

(measured sources)

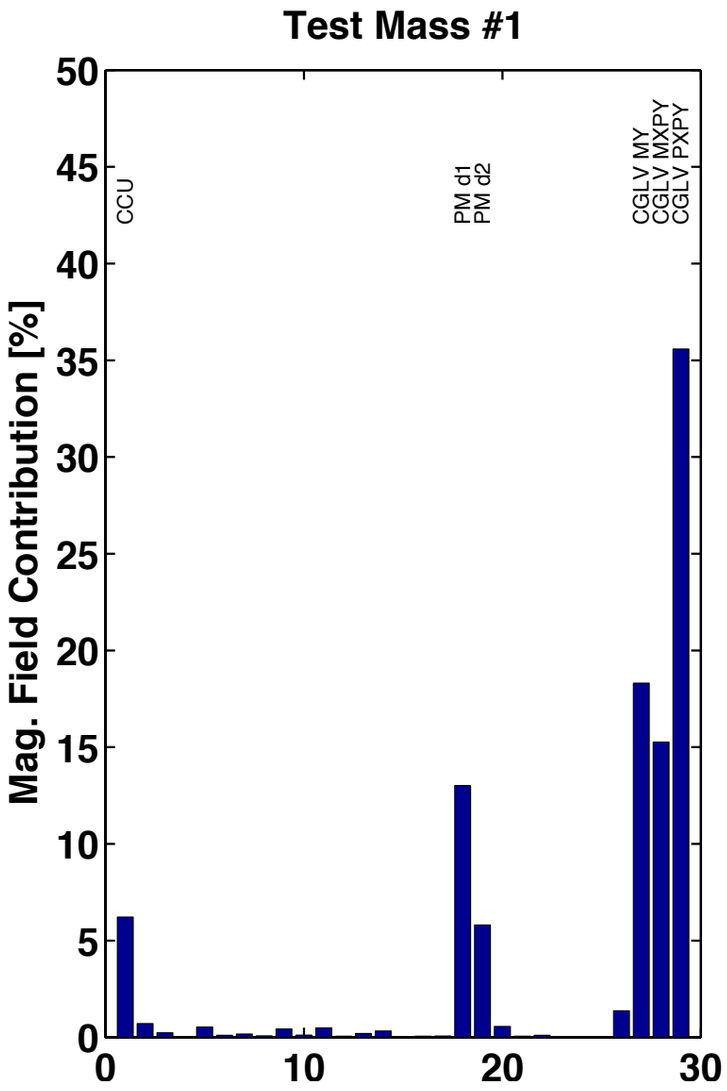


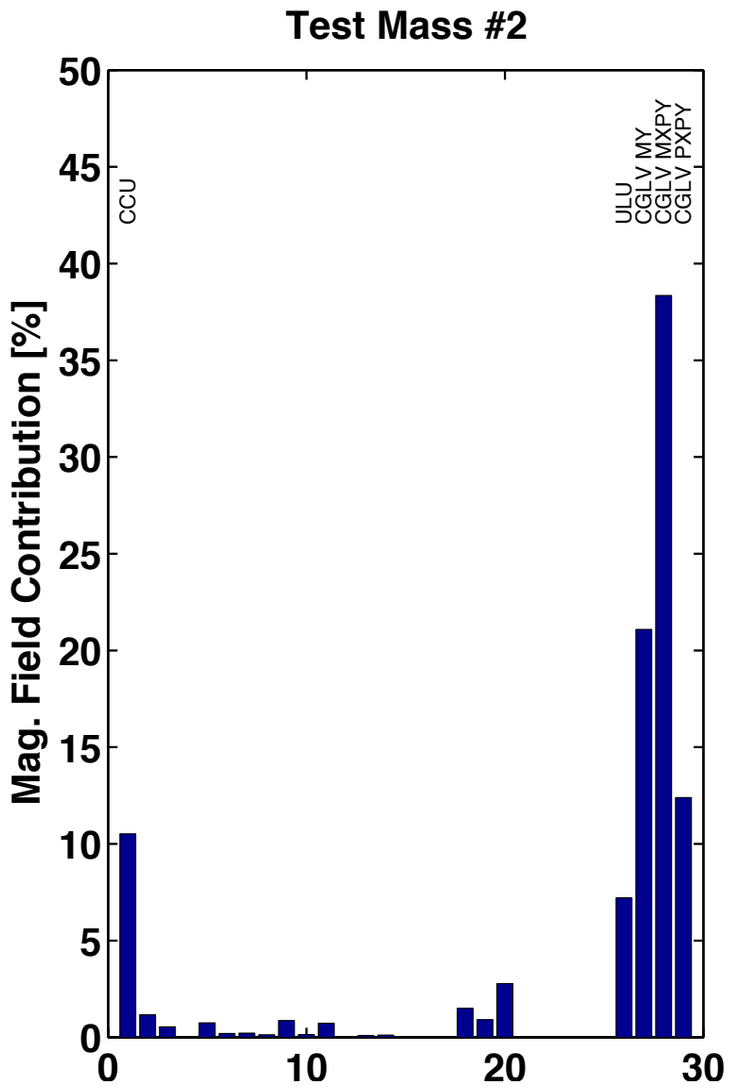
Sources contribution - magnetometers

- Nominal contribution of sources to mag. measurement
  - Dominated by cold gas latch valves (CGLV)



Sources contribution - test masses

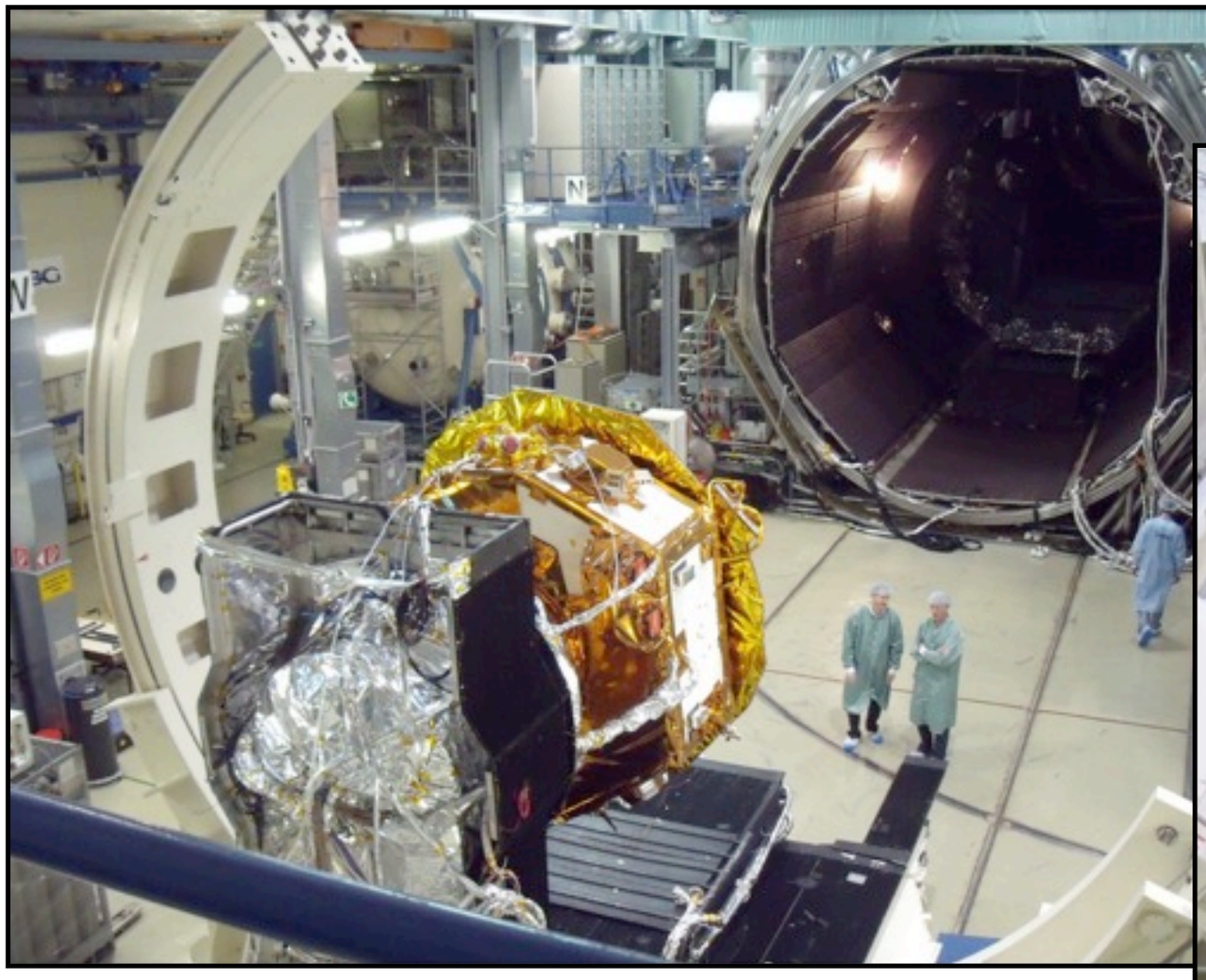


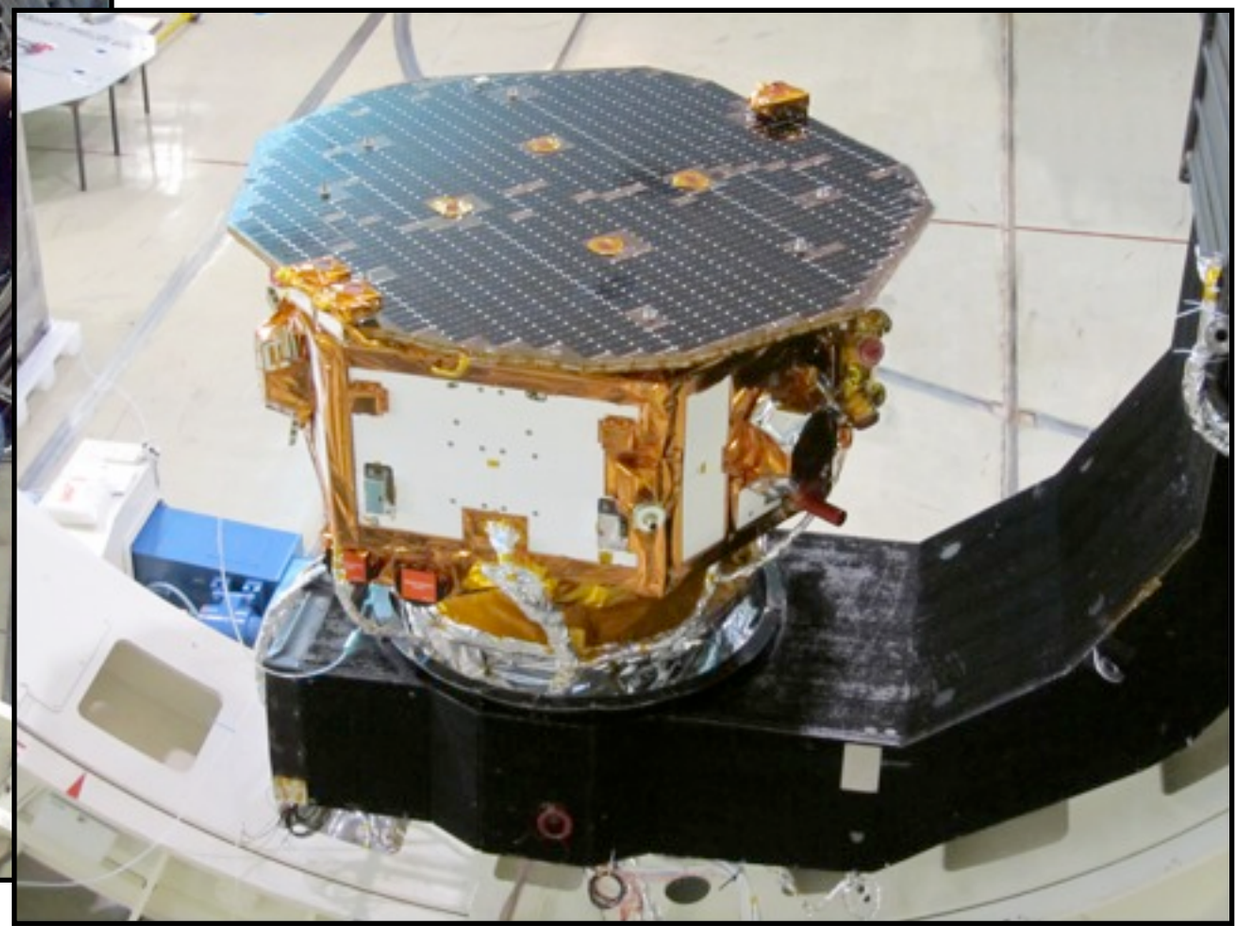


- TM contribution dominated by Cold Gas LV (~70%)
- Cold Gas Thrusters (and other units) are actively tested during operations
- Could we turn the problem into a source detection/subtraction ?

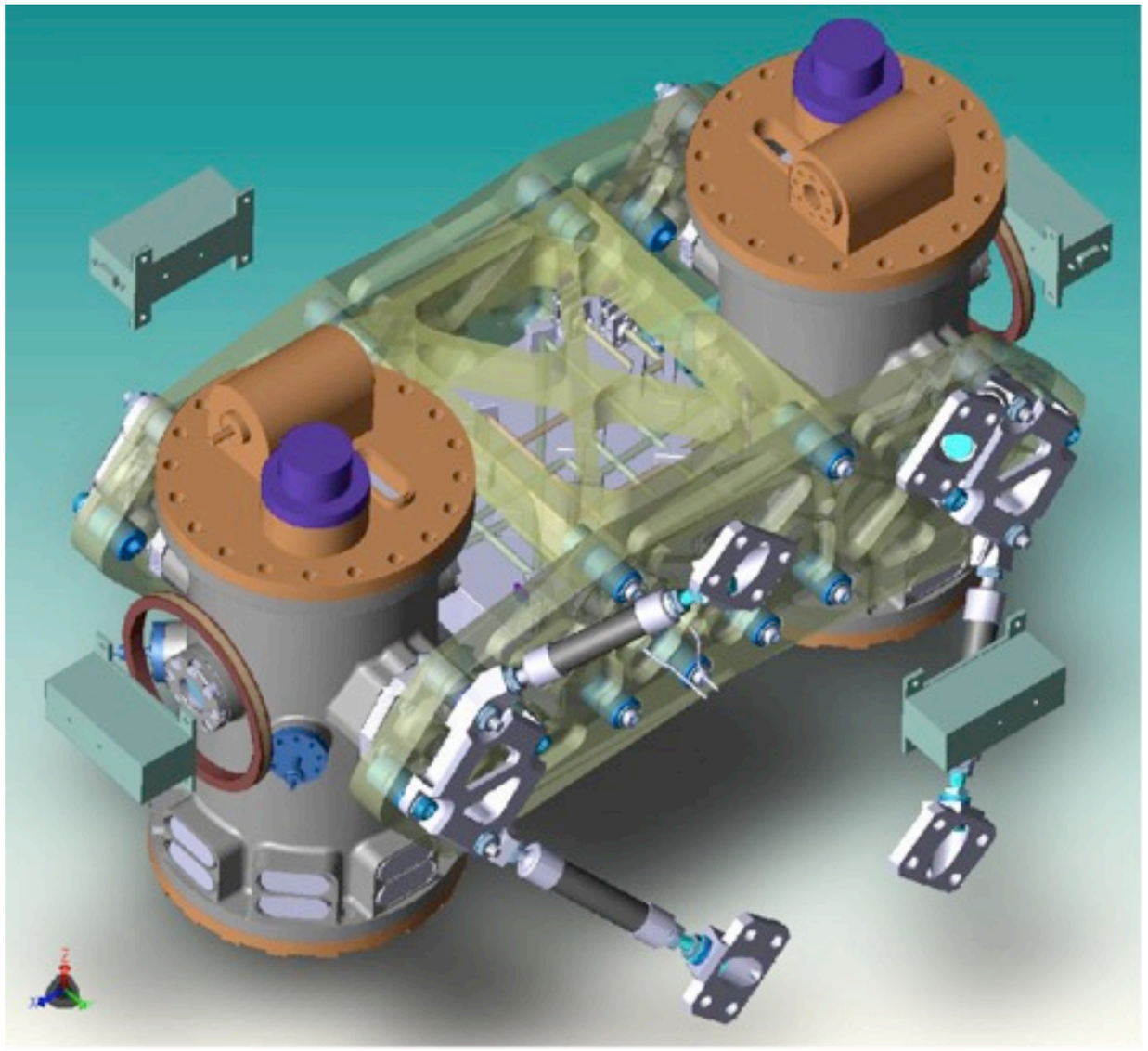
Magnetic sources location exercise

- The LPF spacecraft went through a Thermal Balance/Thermal Vacuum test (Oct 2011)
  - including magnetometers in the payload





OSTT campaign real data



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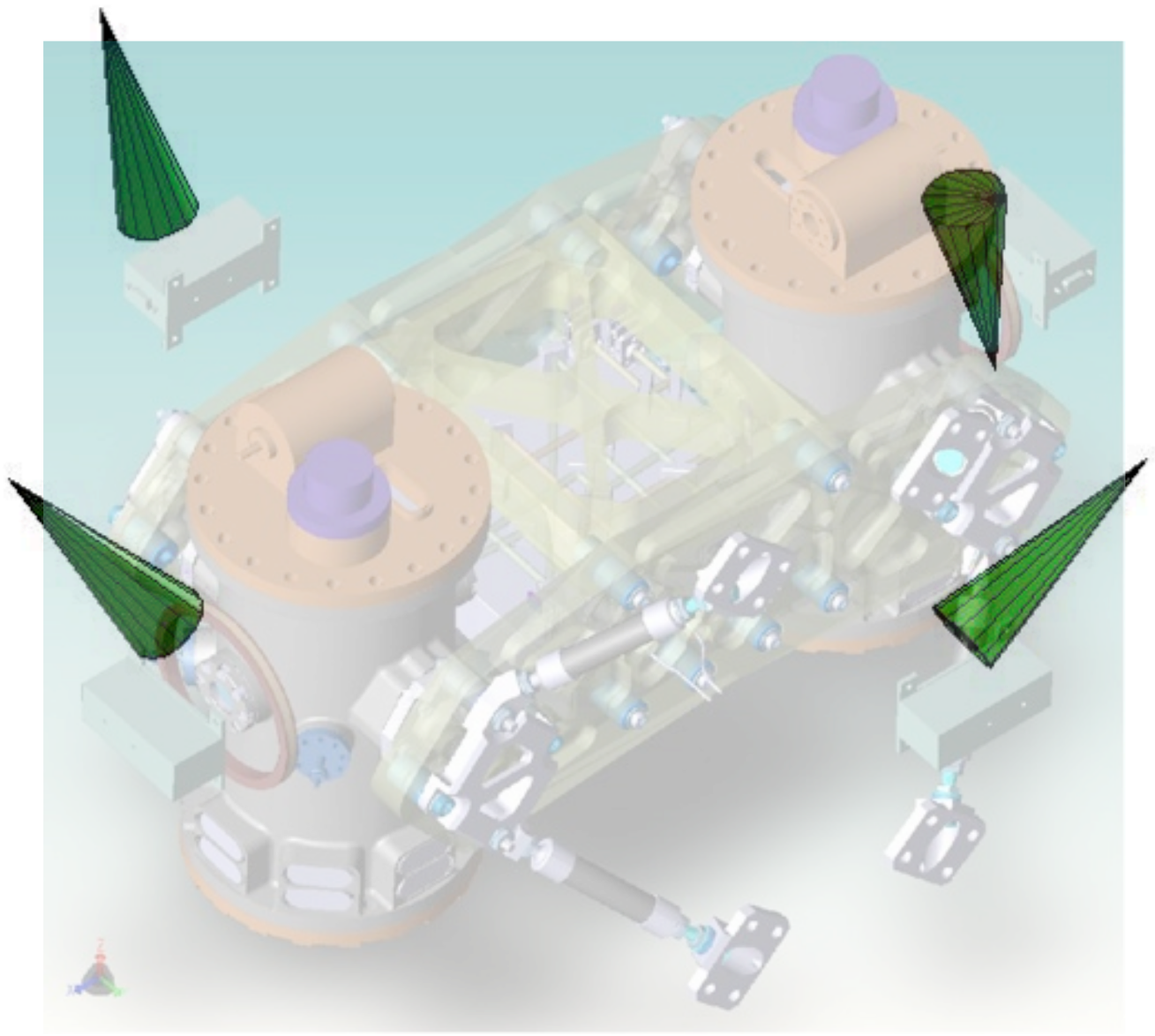
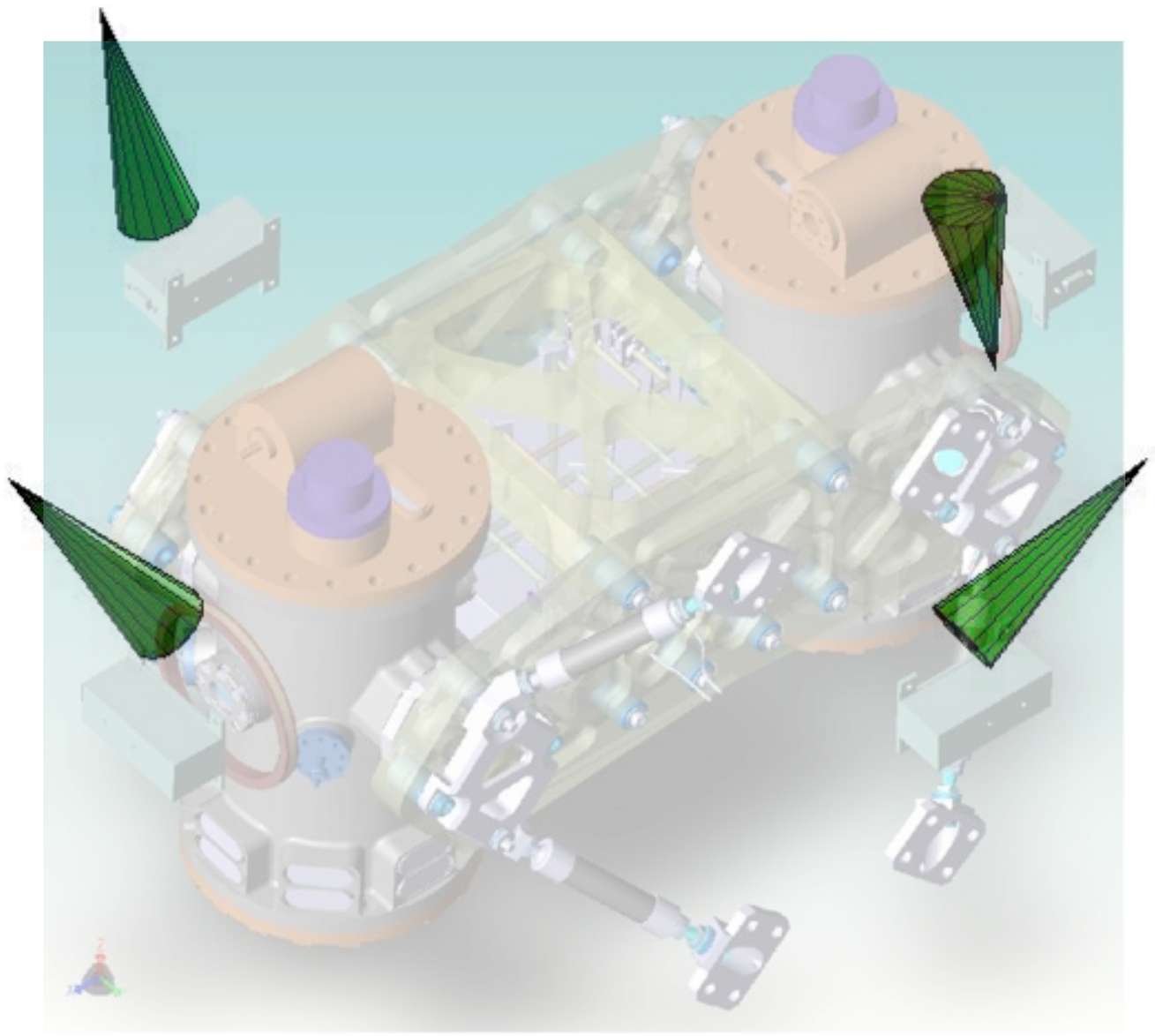


OSTT campaign real data



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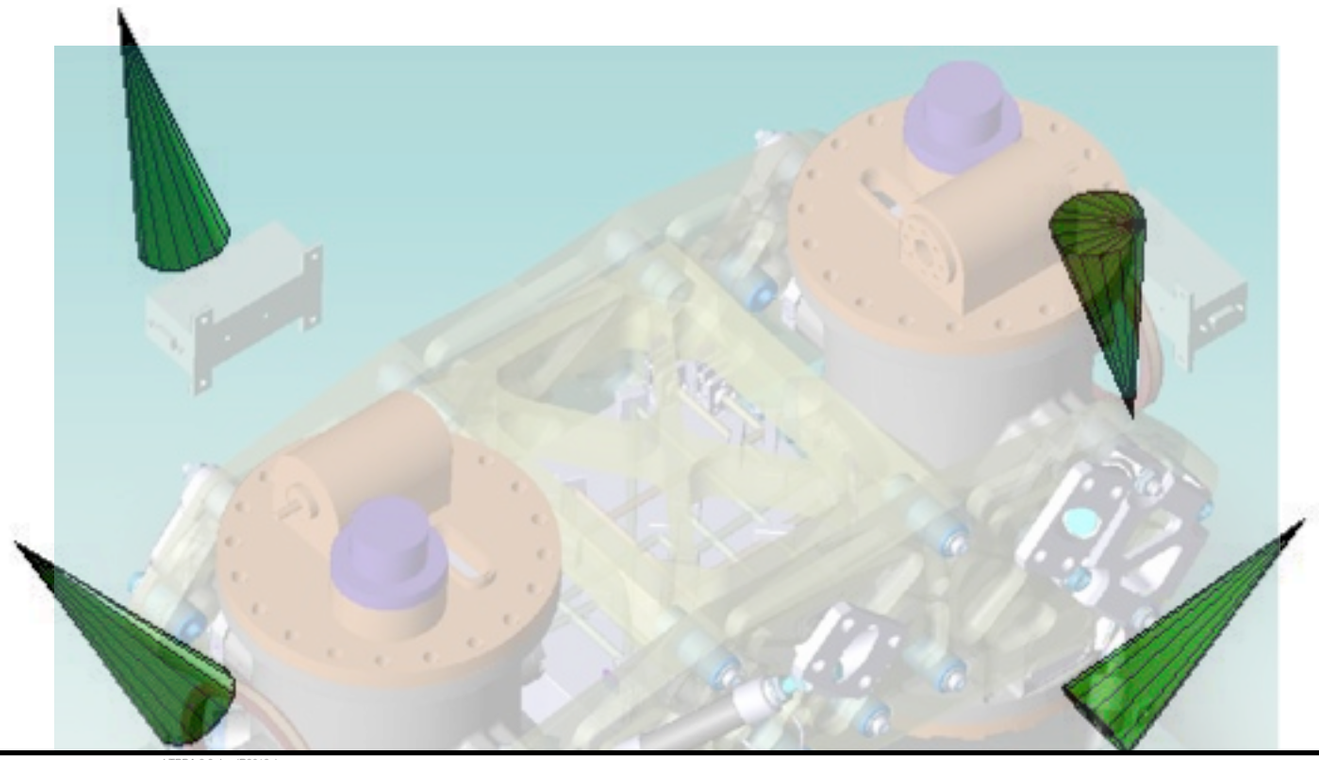

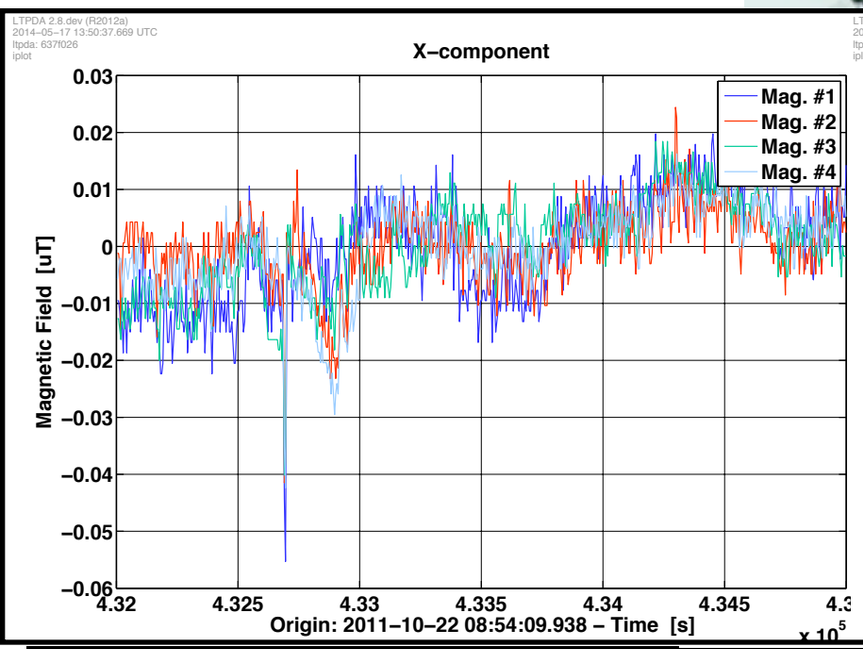

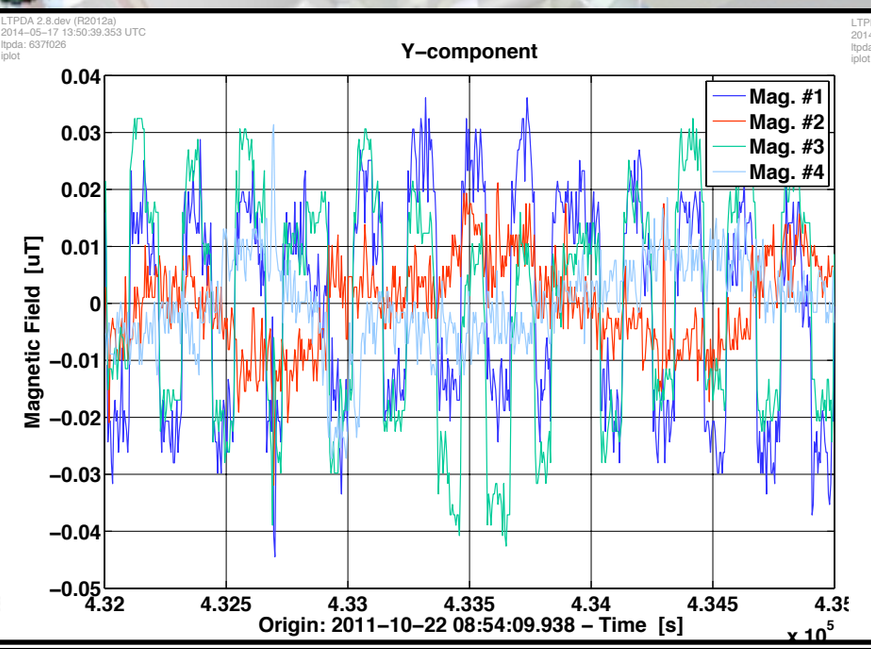

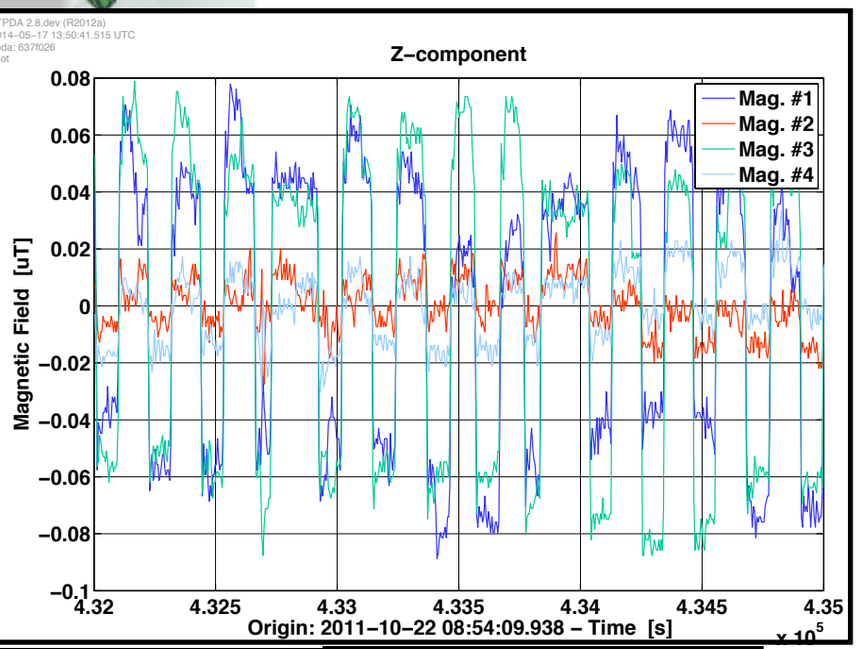

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Schmidt, R.O, IEEE Vol. AP 34 (March 1986)

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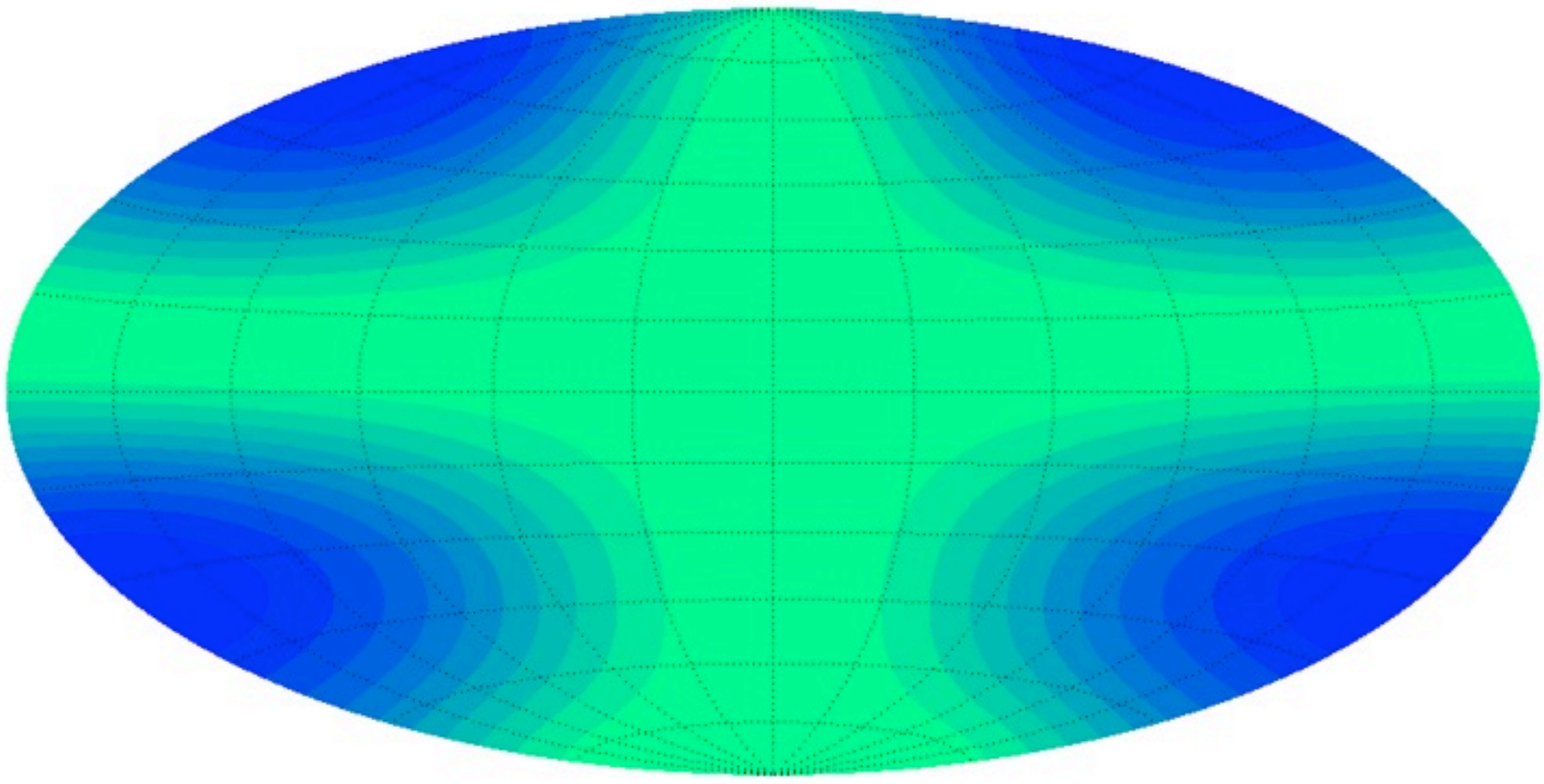
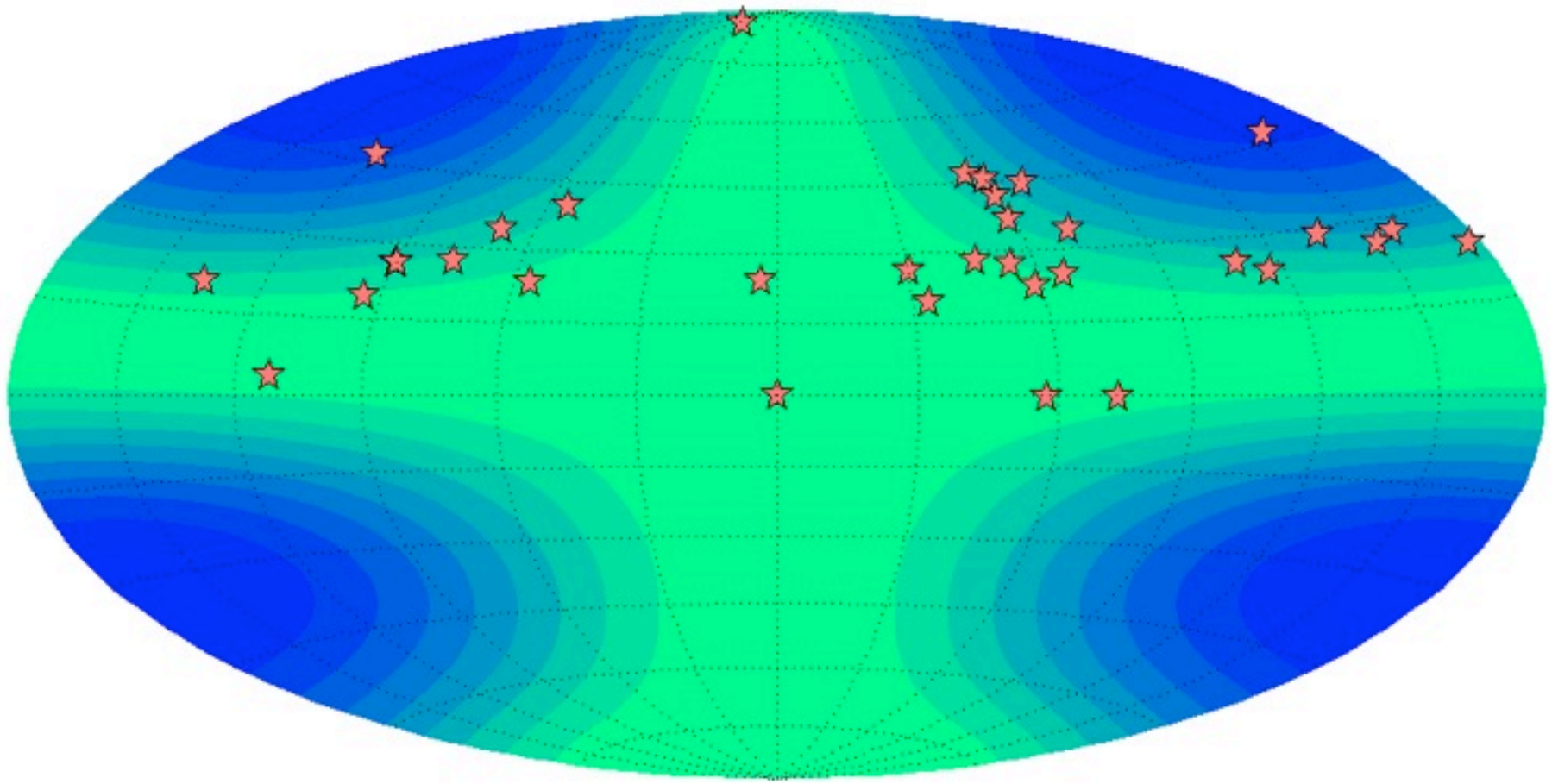
Music algorithm:

$$(1)\,\hat{R} = \mathbf{X}\,\mathbf{X}^{\mathbf{H}} = \hat{\mathbf{U}}\hat{\mathbf{\Lambda}}\hat{\mathbf{U}} \longrightarrow (2)\,\mathbf{U} = [\mathbf{U_s}, \mathbf{U_n}] \longrightarrow (3)\; S(\theta,\phi) = \frac{1}{\left|\hat{U}_n^H\, A(\theta,\phi)\right|^2}$$

Magnetic MUSIC - real data



Magnetic MUSIC - real data



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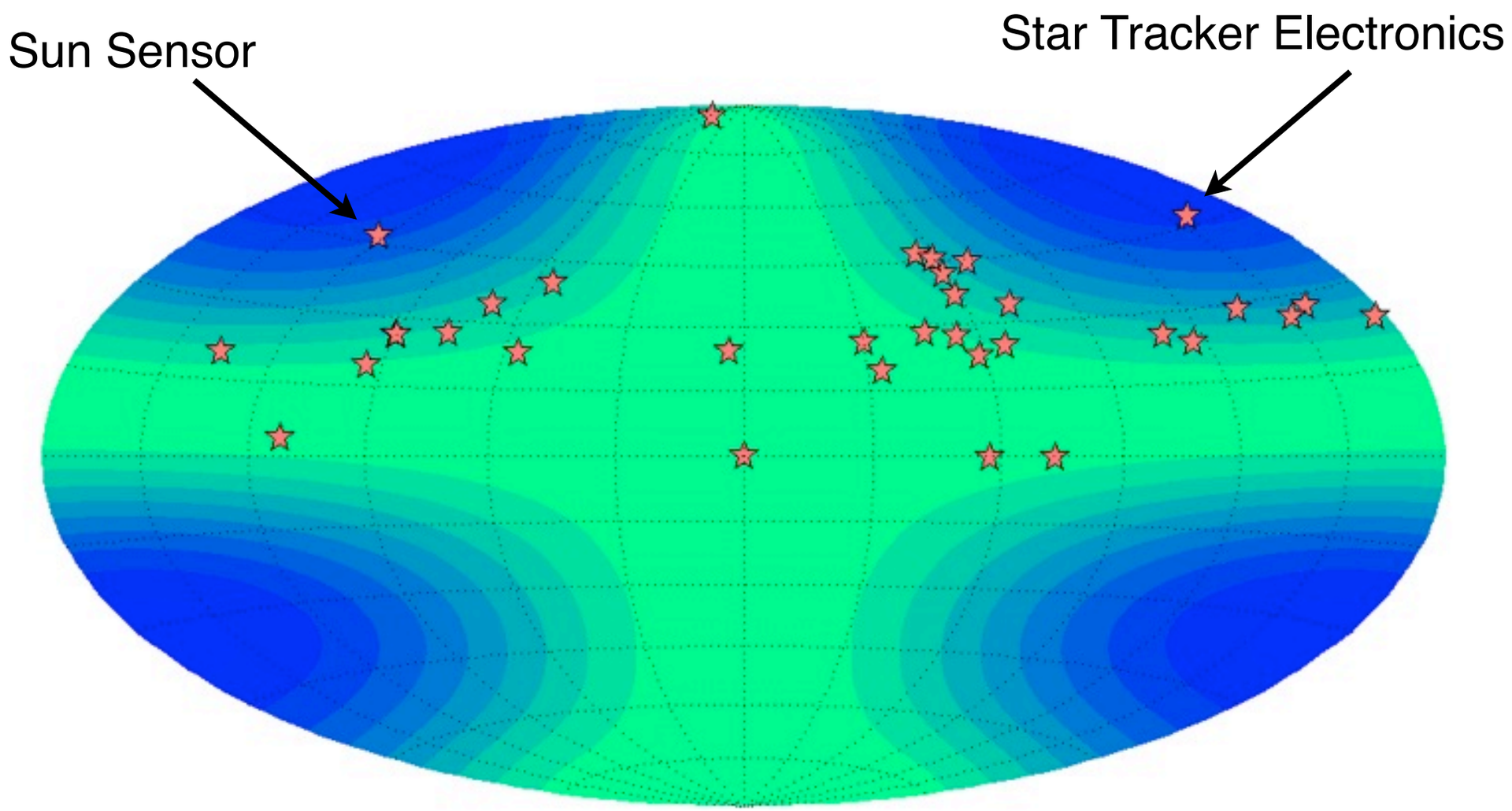

Conclusions

- Force noise due to magnetic coupling of the test mass is the main contribution coming from direct forces at low frequency

- We have developed a data analysis pipeline for the in-flight experiments with coils. Tested in STOC Simulation

- Magnetic field needs to be interpolated to the TM position. Work to improve better understand the structure and main contributors of the magnetic field

- We are developing tools to help locate magnetic sources introducing a magnetic signal in the system

Thank you