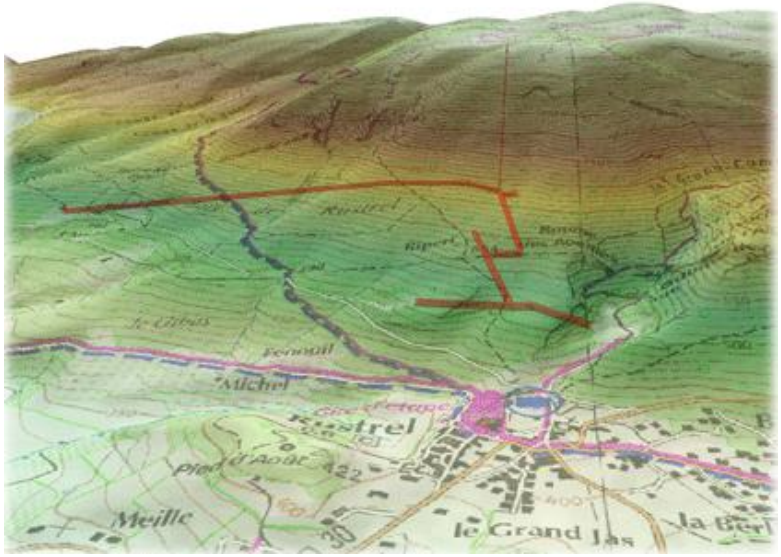
Characterisation of magnetic field fluctuations at different locations within the Laboratoire Souterrain à Bas Bruit

Aim: **Compare data from the [SQUID]^2 magnetometer (in the Capsule), with that measured by a portable SQUID magnetometer (in other locations)**

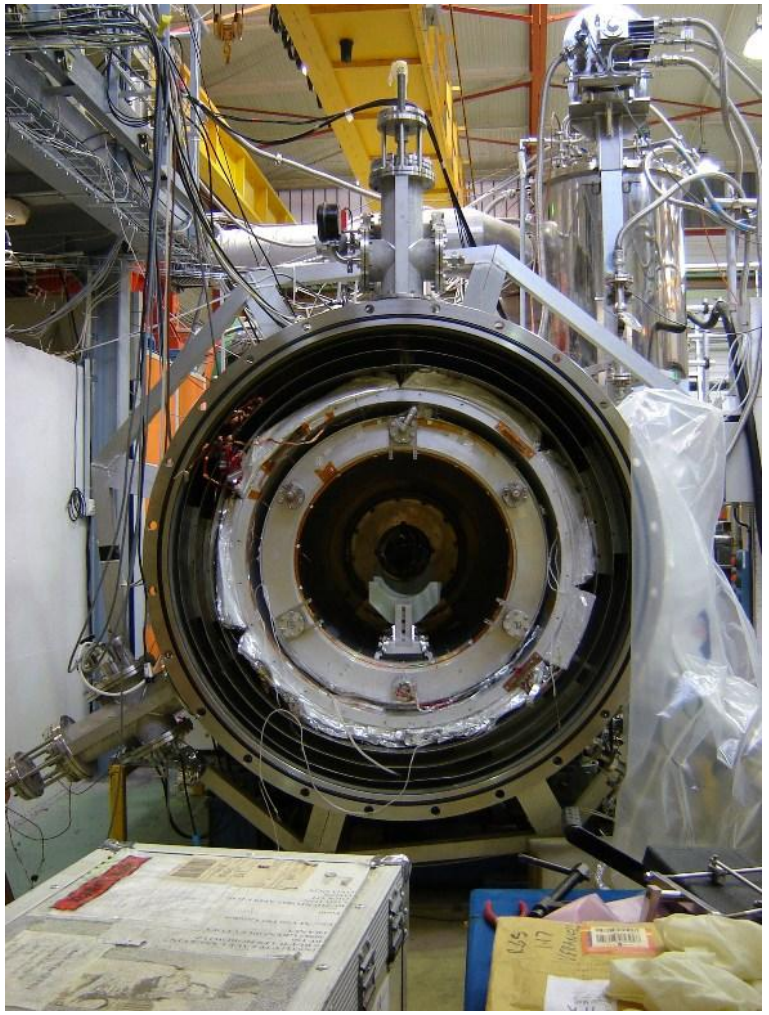


V. Andrieux, C. Clarke, S. Henry, H. Kraus, A. Lynch, V. Mikhailik, M. McCann, P. Febvre, S. Gaffet, E. Pozzo di Borgo, C. Sudre, G. Waysand, D. Boyer, A. Cavaillou, M. Auguste

Sam Henry, University of Oxford

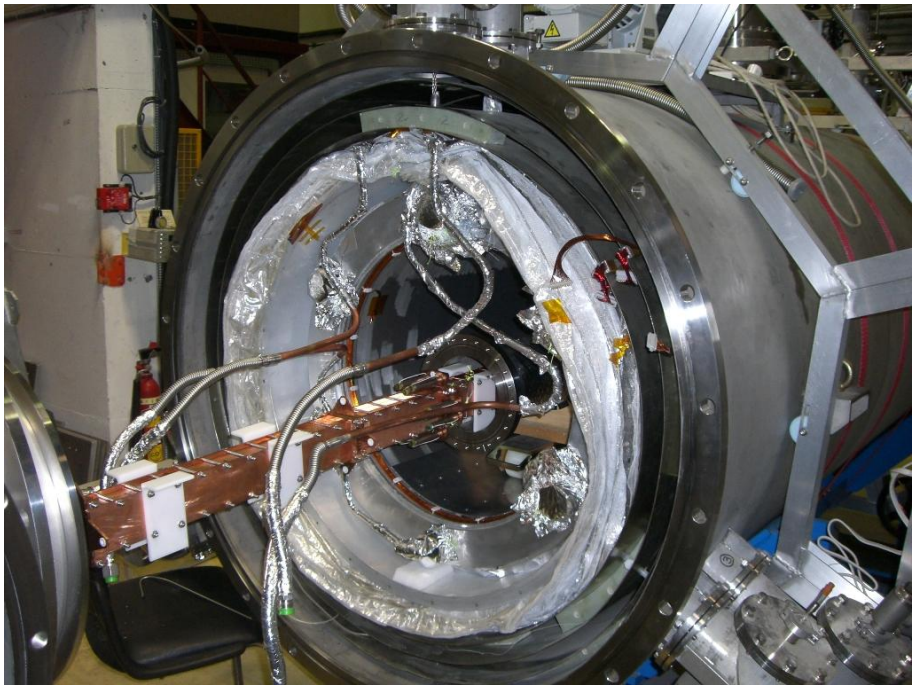
cryoEDM search for the electric dipole moment of the neutron

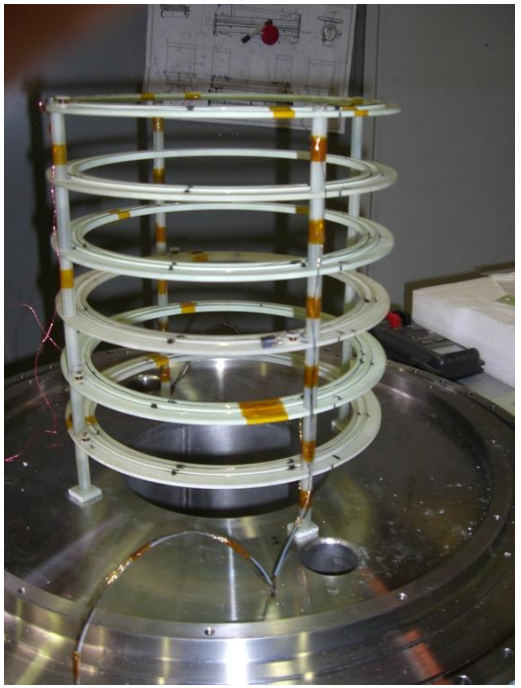
- Non accelerator particle physics experiment
- Location ILL, Grenoble
- **Aim:** measure neutron EDM to 10^{-28}e·cm
- T violation
- **How?** Measure neutron spin precession frequency in +/– electric field
- Magnetic field drift can give false positive signal



cryoEDM SQUID magnetometer

- Track drift in the magnetic field of ≤0.1pT over 100-1000s
- Extrapolate magnetic field in neutron cell from multiple pick-up loop measurements → 12-channel system
- SQUID sensors ~2m from pick-up loops
- High EMI environment





Small SQUID magnetometer used by Oxford group at LSBB

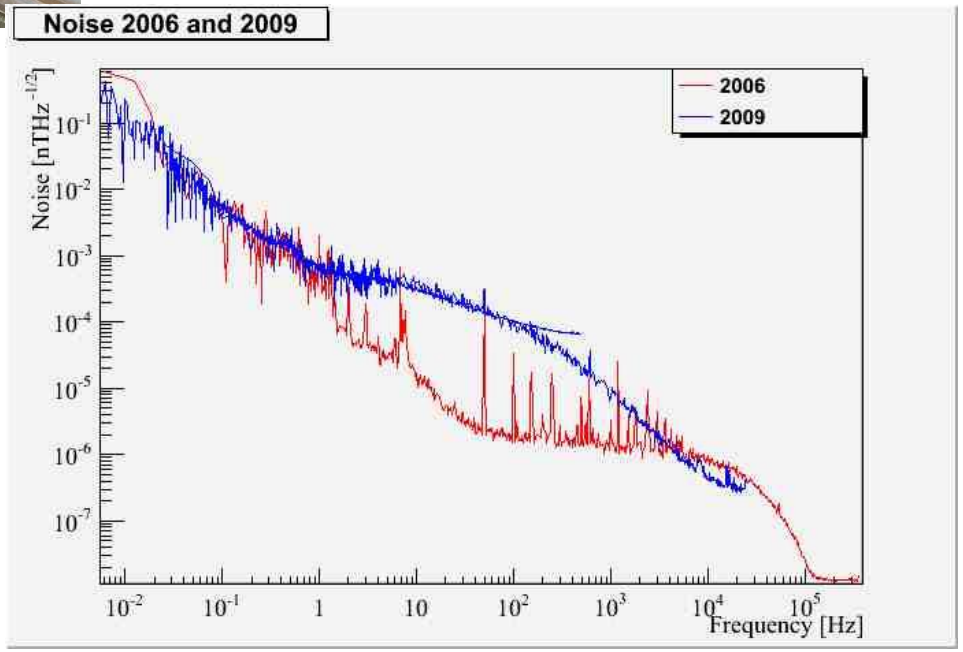
- 3-axis SQUID magnetometer

Operate in helium dewar

No magnetic shielding

Noise higher than expected above 1Hz

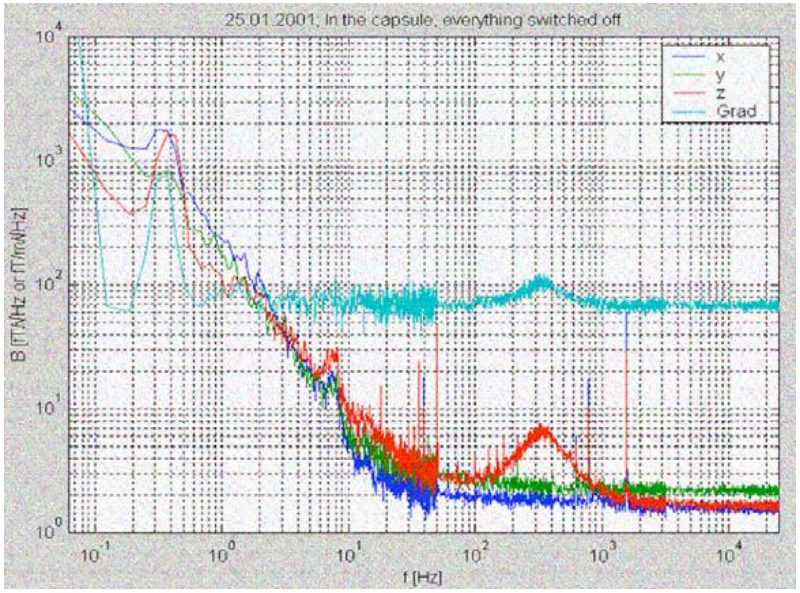
Intrinsic SQUID noise higher than expected



[SQUID]^2 magnetometer

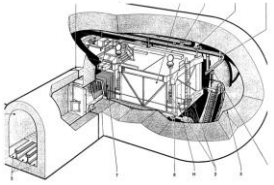
see talk by Elizabeth Pozzo di Borgo for full details

- SQUID with Shielding QUalified for Ionosphere Detection
- 3-axis SQUID magnetometer permanently installed in LSBB capsule
- Study seismo-ionosphere coupling
- LSBB Capsule magnetic noise <2fTHz$^{-1/2}$ above 10Hz



Seismo-ionosphere detection by underground SQUID in low-noise environment in LSBB-Rustrel, France, G. Waysand et al. Eur. Phys. J. Appl. Phys. 47, 12705 (2009) DOI: 10.1051/epjap:2008186

Overview of LSBB



Outside-capsule

Capsule

500m underground

Galerie-Anti-Souffle

200m underground

Galerie-Gaz-Brules

70m underground

Outside

PM 1390
PM 1380
PM 1331
PM 1550
PM 1616
PM 1100
PM 920
MGS (Elv./Depth 546.0 / 344.5 m)
PM 990
RAS VES
(Elv./Depth 549.7 m / 517.8 m)
(Elv./Depth 1062.7 m / 4.8 m)
Shielded capsule
SQUID' magnetometer
Escape gallery
PM 471 à 538
PM 273
PM 288
PM 1256
PM 1205
Gallery C
PM 1141
PM 1081
EGS (Elv./Depth 541.8 / 27.7 m)
Escape shaft
(Elv./Depth 535.4 m / 273.1 m) GAS
PM 977
Antiblast gallery
PM 688-700
Gallery C
PM 470
N
0 100 200 m
PM 358
Services
Gallery B1
Gallery A
Exit West
GGB
(Elv./Depth 536.8 m / 19.7 m)
Entry

LSBB
FRACTURATION & GALLERIES
(S.E.R.E.B study)

- Fracture network visible from surface
- Kilometric main faults
- Secondary decametric faults
- Fracture network observed from galleries
- Main faults with dammaged zone thickness ranging 20 to 40 m
- Secondary faults with damaged zone thickness ranging 5 to 10 m
- PM 238 : Labelled reference point 238 m
- N.B. *Fractures smaller than the ones referenced above are not displayed*

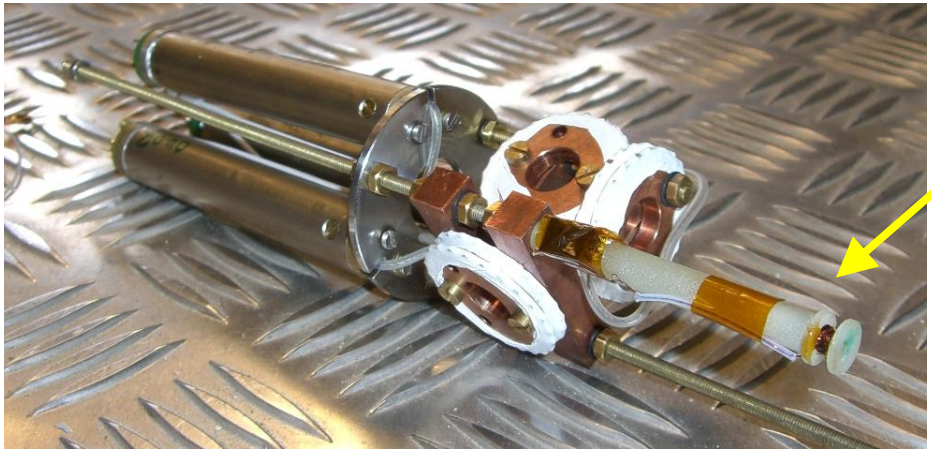
1. Galerie A -P.M 0 à 220 - Service -
2. Galerie B1 (Exit Ouest) -
3. Servitude - Galerie C - P.M. 220 à 700 ended by antiblast gallery
4. Gallery C - P.M. 700 à 1400 -
4A. Shielded capsule
4B. Galerie C - P.M. 1400 à 1580 - Cellule Galerie de Secours P.M. 1520 à 1760 -
5. Escape gallery P.M. 1000 à 1520 -
6. Escape gallery P.M. 0 à 1000 -
- Seismic array
- Magnetometer

Measurements taken

Location	Start date	Duration [hours]
Capsule	25 September	17.3
Galerie Anti-Souffle	26 September	3.4 – disrupted (by thunderstorm?)
	27 September	5.7
Galerie Gaz Brûles	27 September	14.8
Outside capsule	29 September	14.4
Outdoors	30 September	15.1

SQUIDs very unstable due to high frequency noise

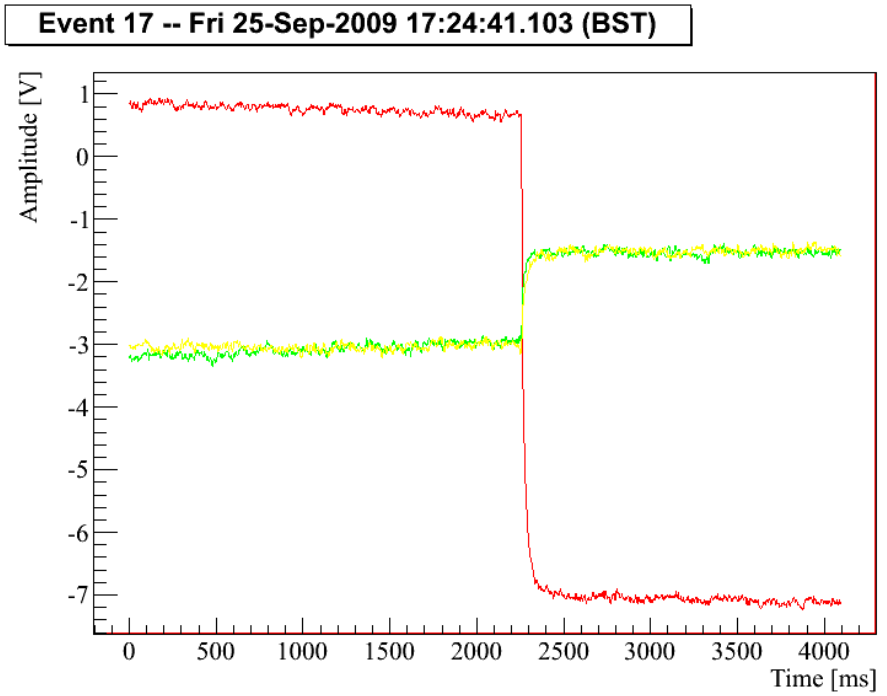
Calibration



200-300 turn calibration coil

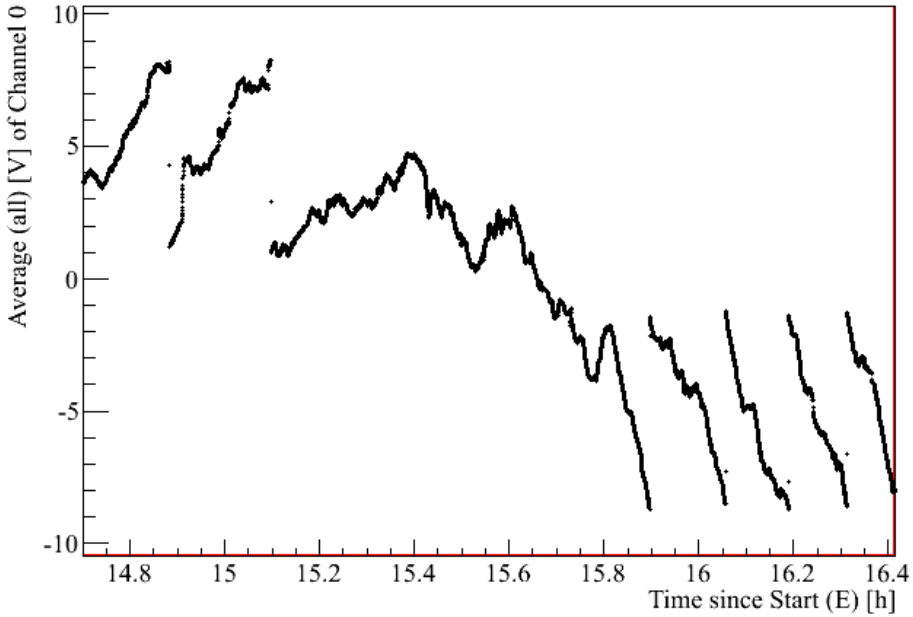
- Apply current step to coil
- Model calibration coil as magnetic dipole to calculate average field through each loop
- Note in cryoEDM experiment absolute calibration will come from neutron precession frequency

Calibration signal recorded by 3 SQUIDS

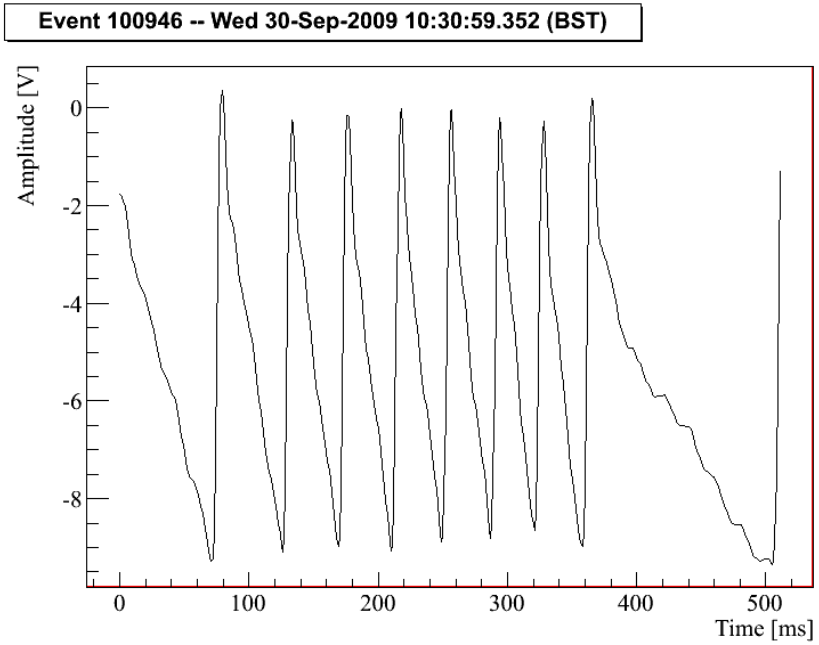


SQUID reset correction

- DAQ range ±10V
- When output approached limit, SQUID resets – output jumps by $n\Phi_0$
- Software correction possible provided dB/dt < slew rate



↑ **Correction possible**



←**Correction not possible**

SQUID reset correction

- Determine magnitude of resets

  SQUID 0 (Z)

  $\pm 3\Phi_0 = \pm 7.56V$

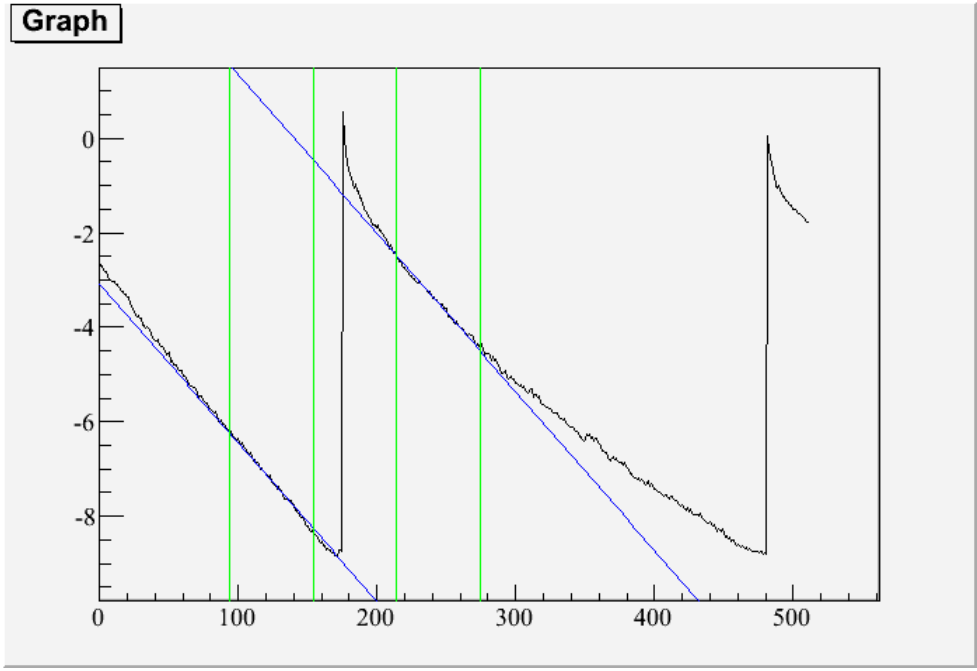
  SQUID 1 (NS)

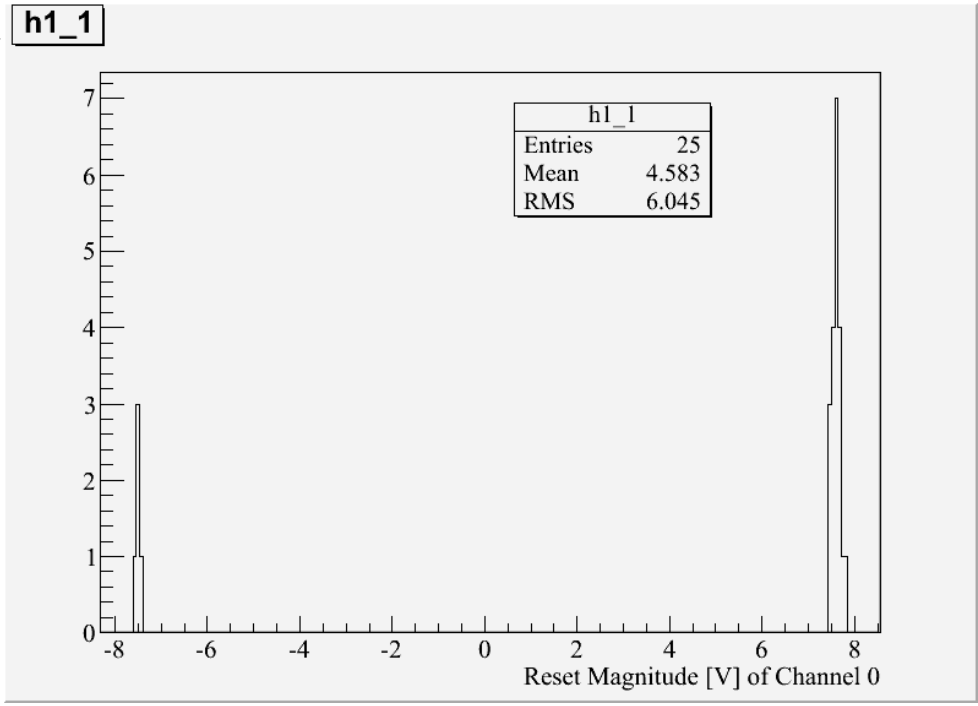
  $\pm 2\Phi_0 = \pm 5.56V$

  SQUID 2 (EW)

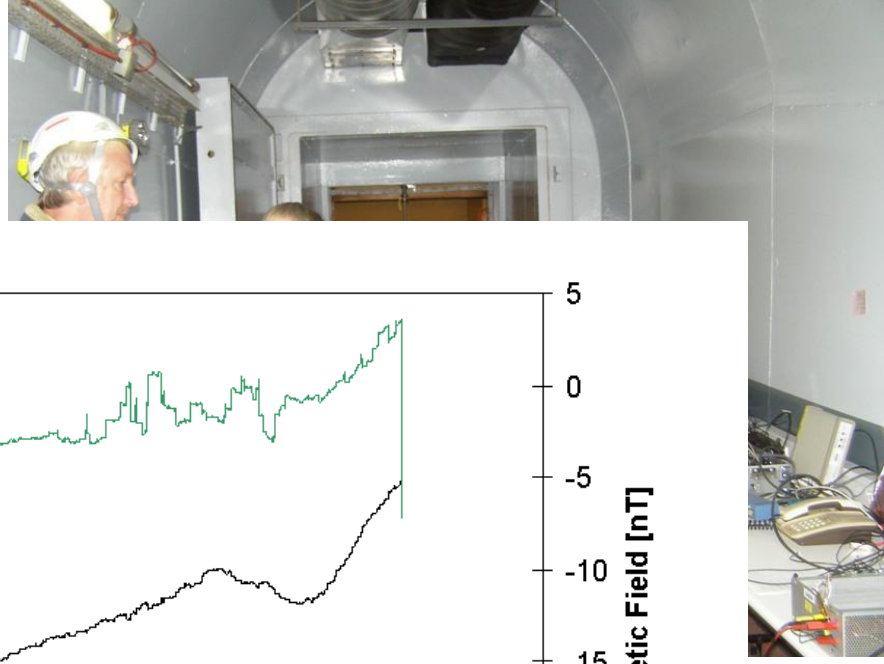
  $-2\Phi_0 = -5.48V$

  $+3\Phi_0 = +8.27V$



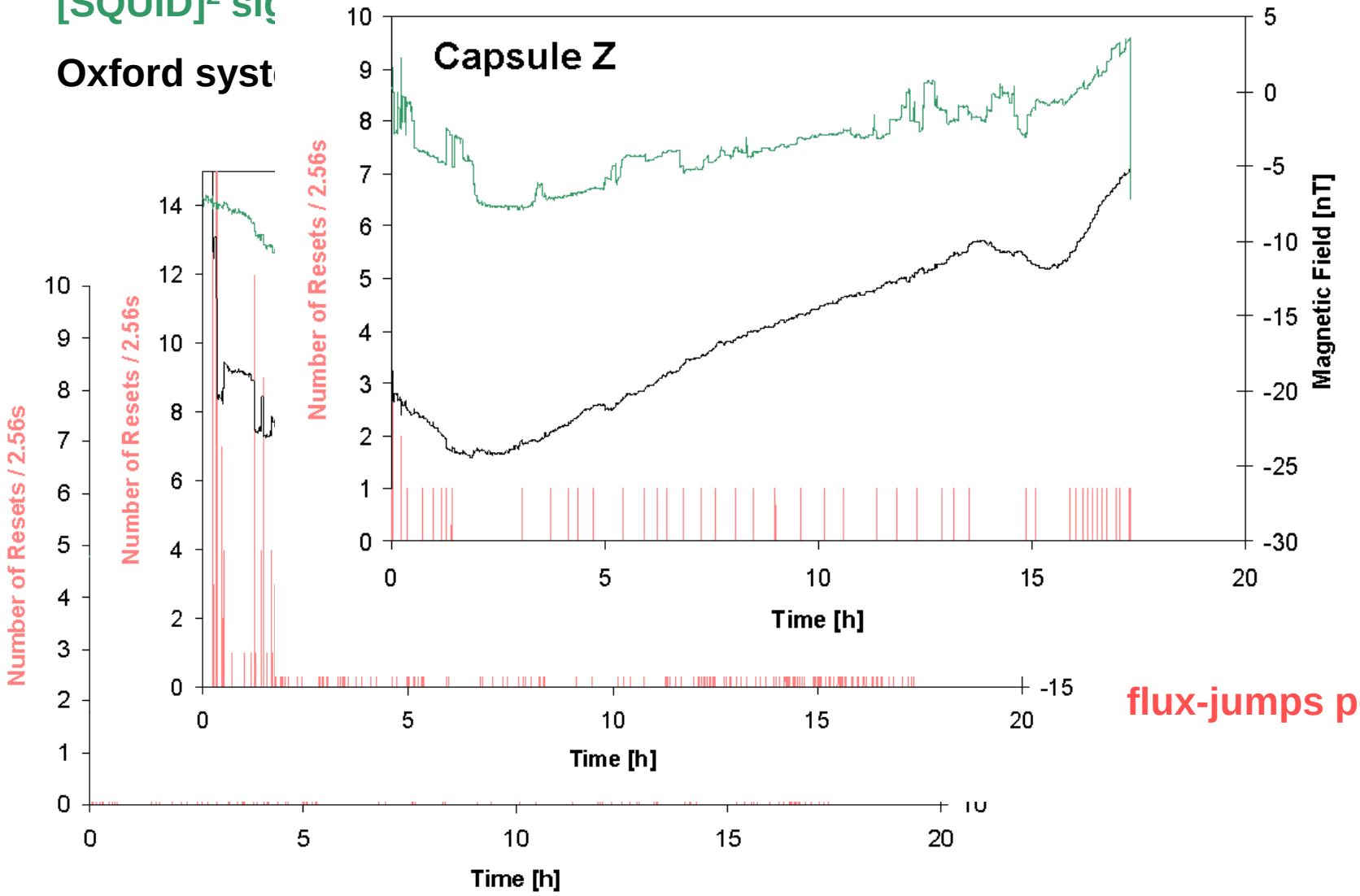


Results: Capsule



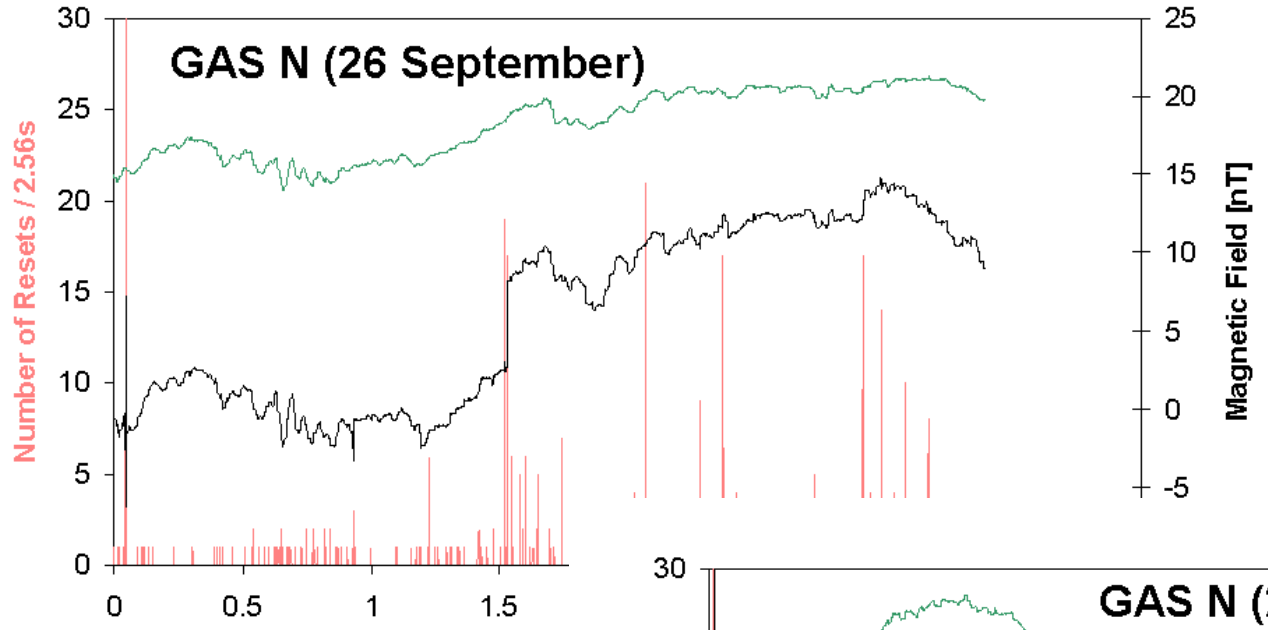
[SQUID]² sig

Oxford syst



ts /
flux-jumps per 2.56s

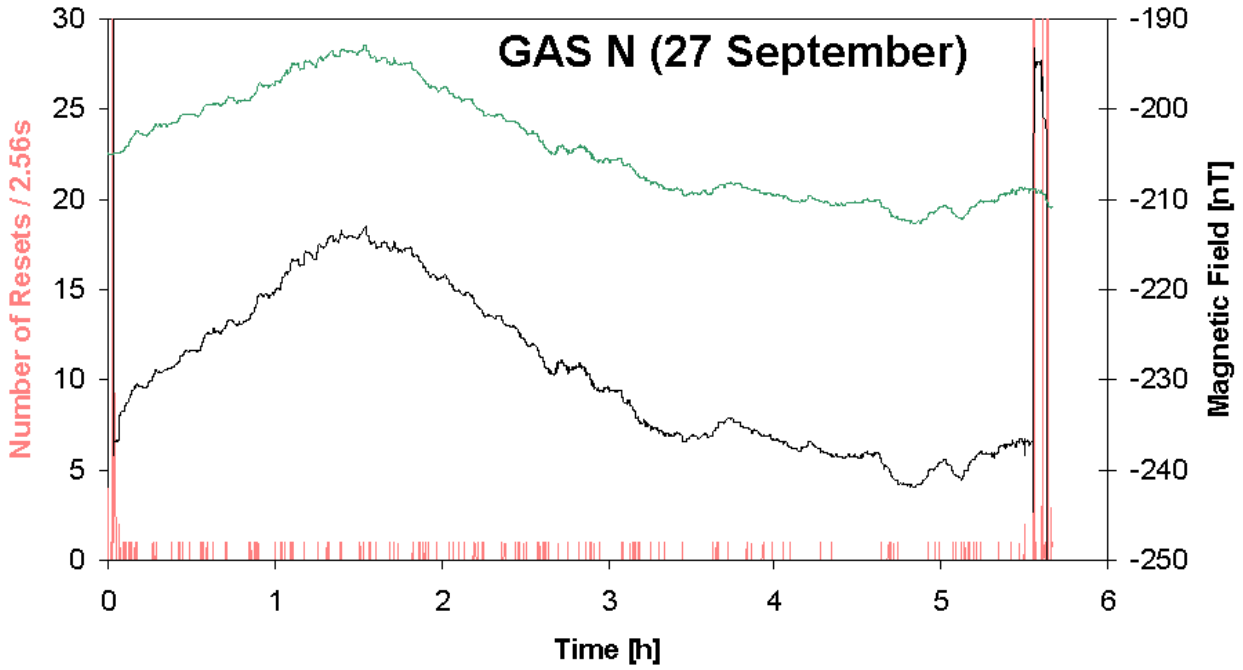
Results: Galerie Anti-Souffle



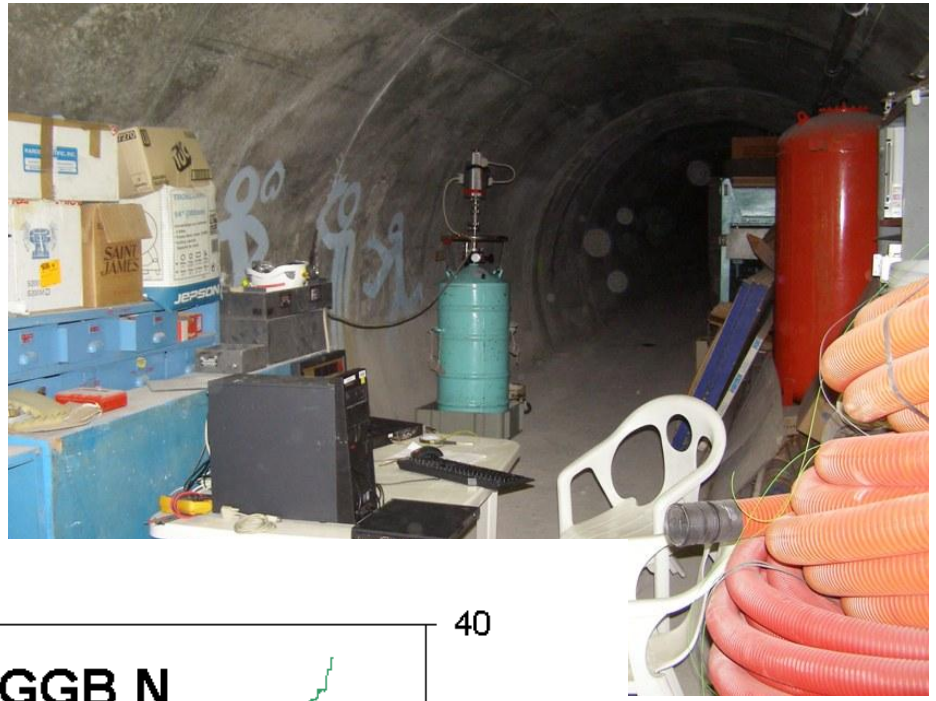
26 September

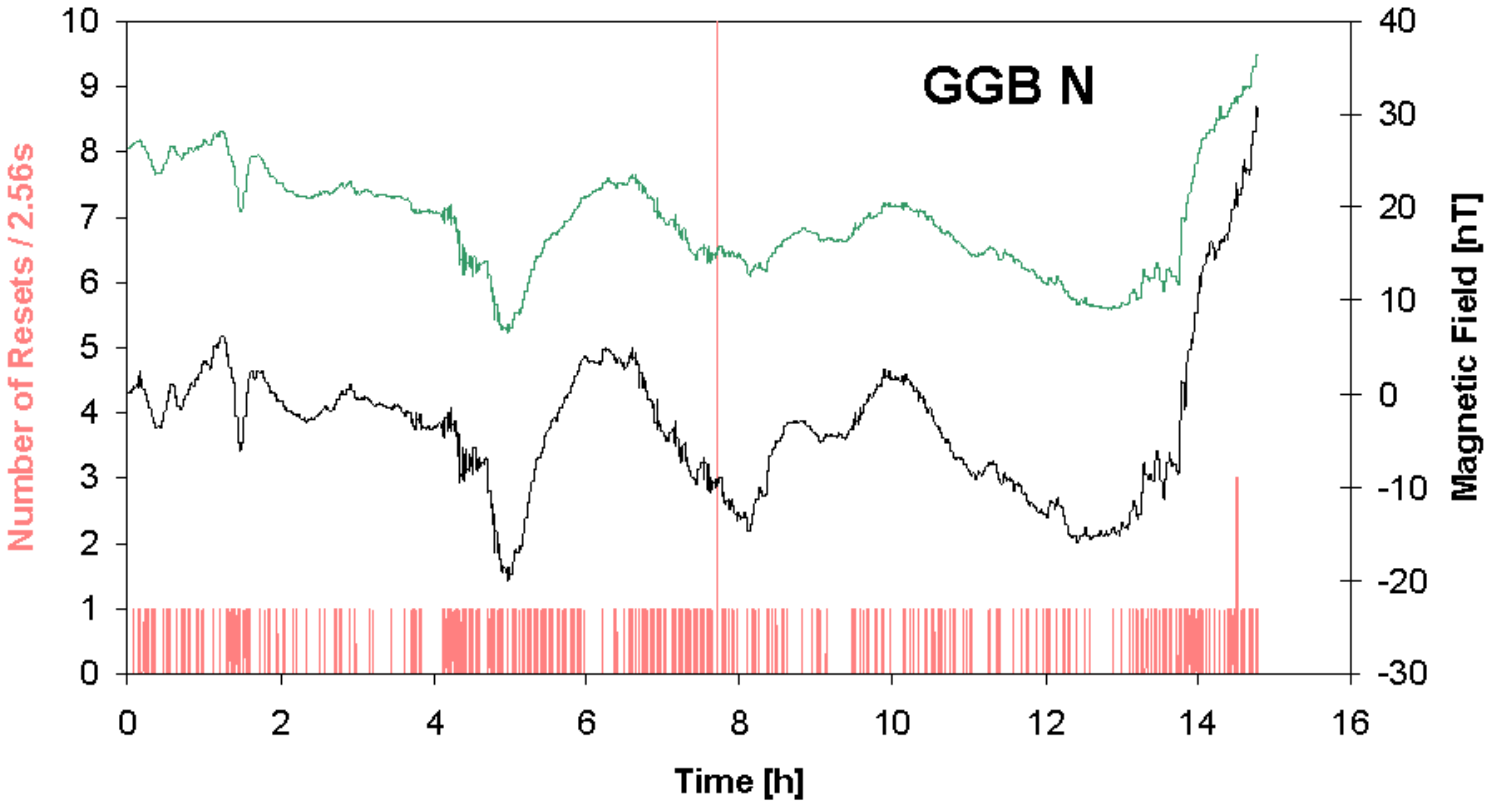
Thunderstorm

DAQ stopped by power glitch

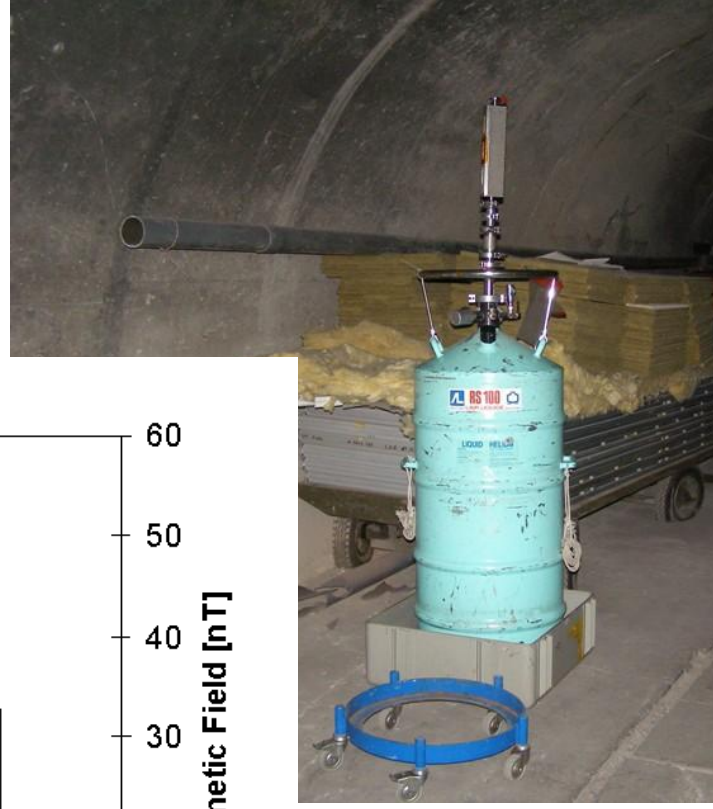


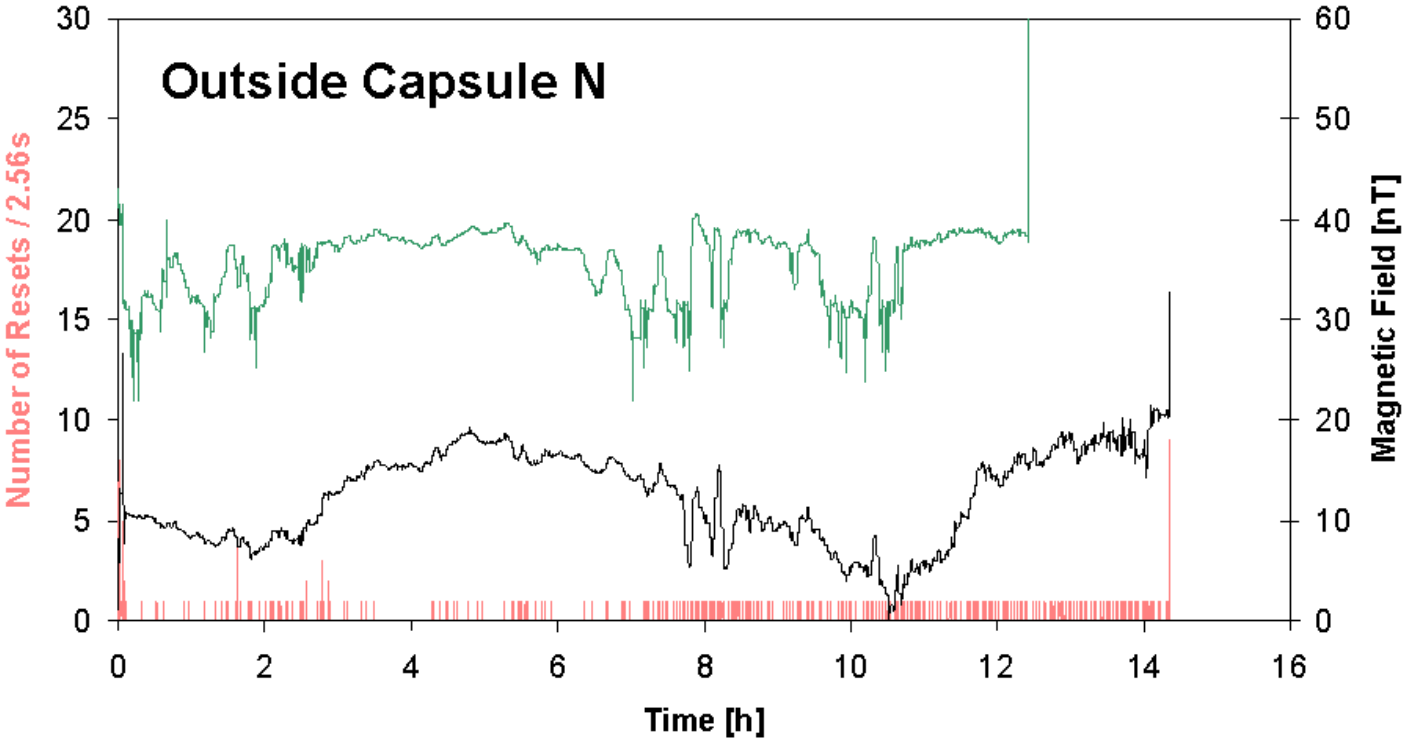
Results:
Galerie Gaz-Brûles



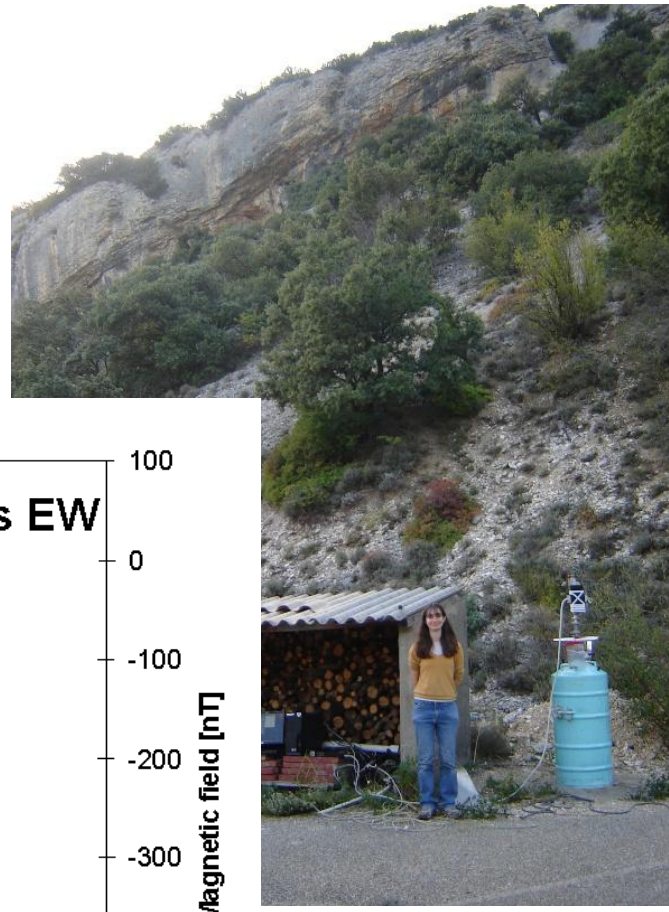


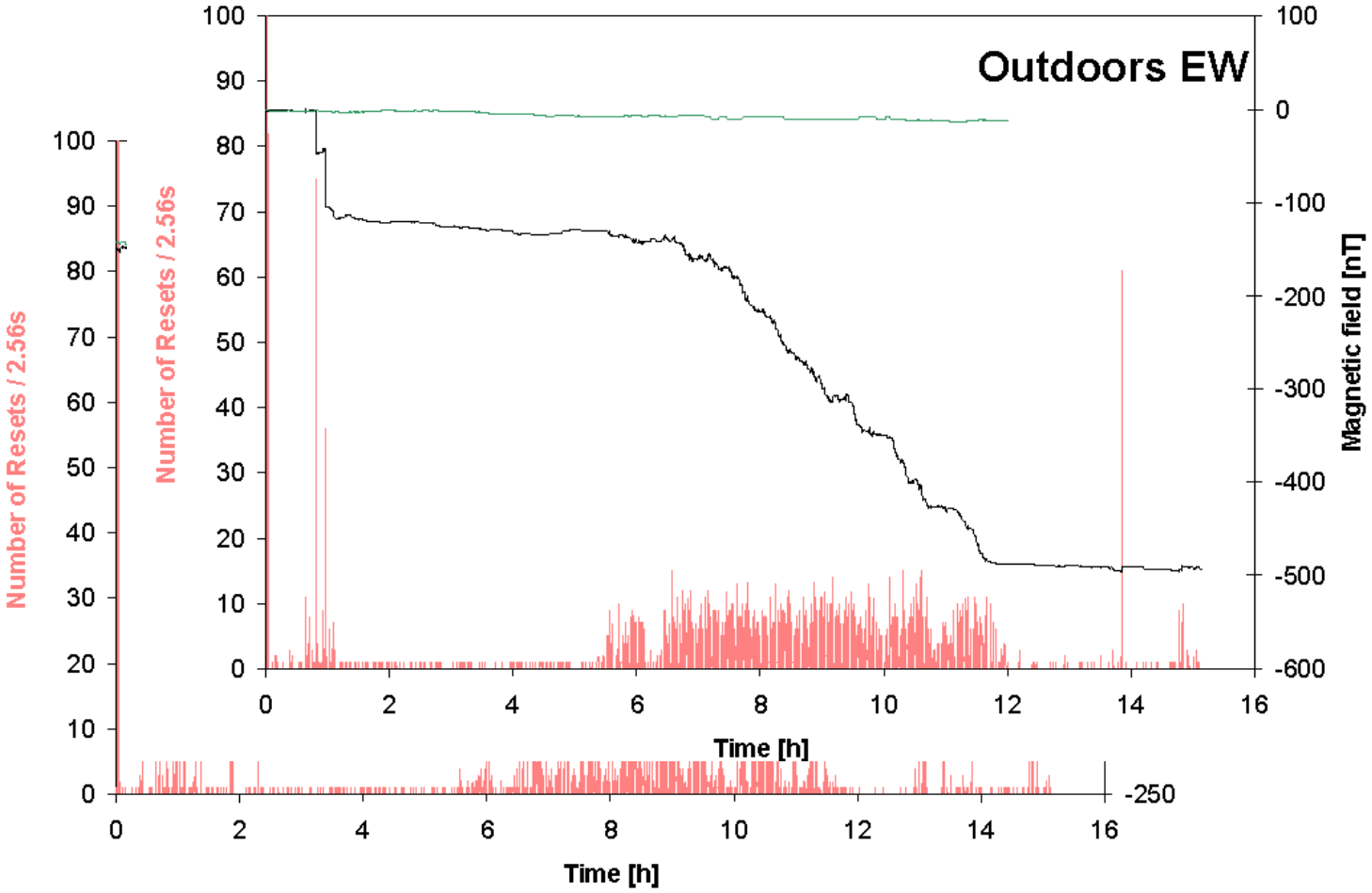
Results:
Outside Capsule





Results: Outdoors





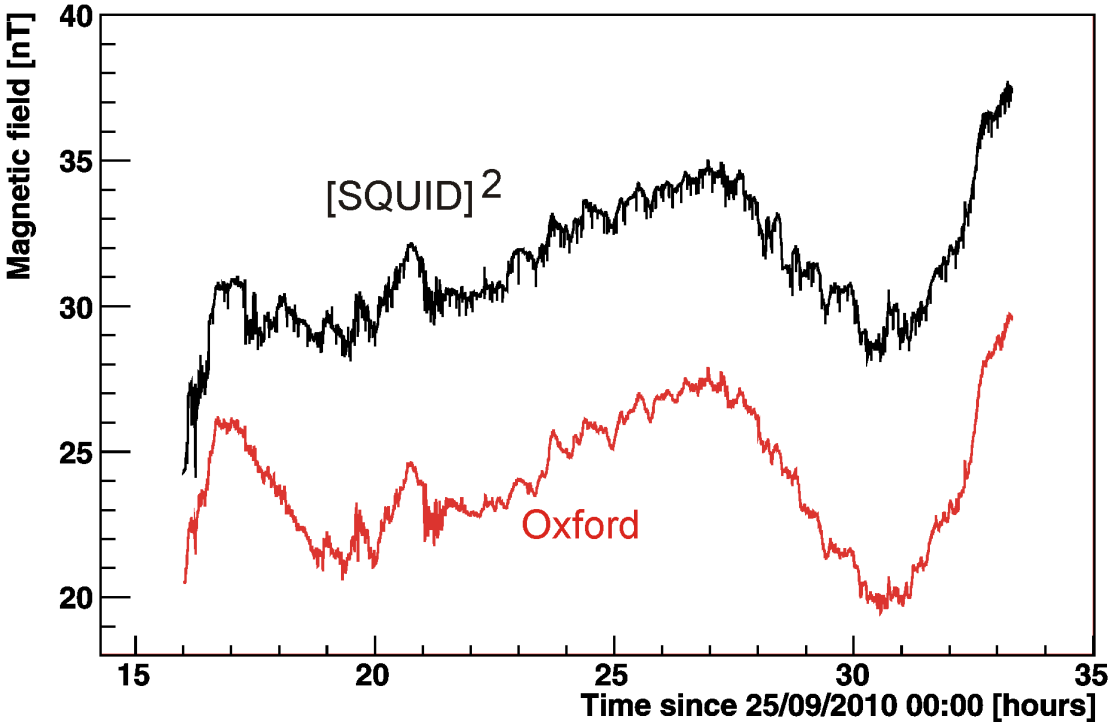
[SQUID]^2 – Oxford comparison

- Scale Oxford data to fit [SQUID]2 signal

$$B'_{ox} = \alpha B_{ox} + \beta$$ calculate α, β to minimise $$\sum \left(B'_{ox} - B_{[SQUID]^2} \right)^2$$

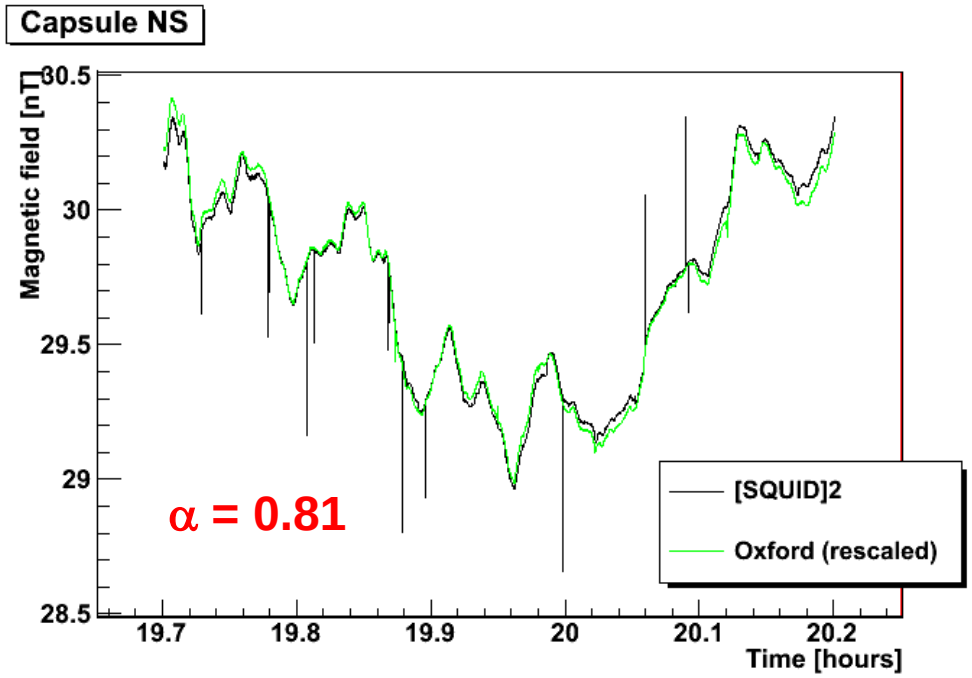
If the [SQUID]^2 and Oxford systems measure the same field when in the Capsule, then

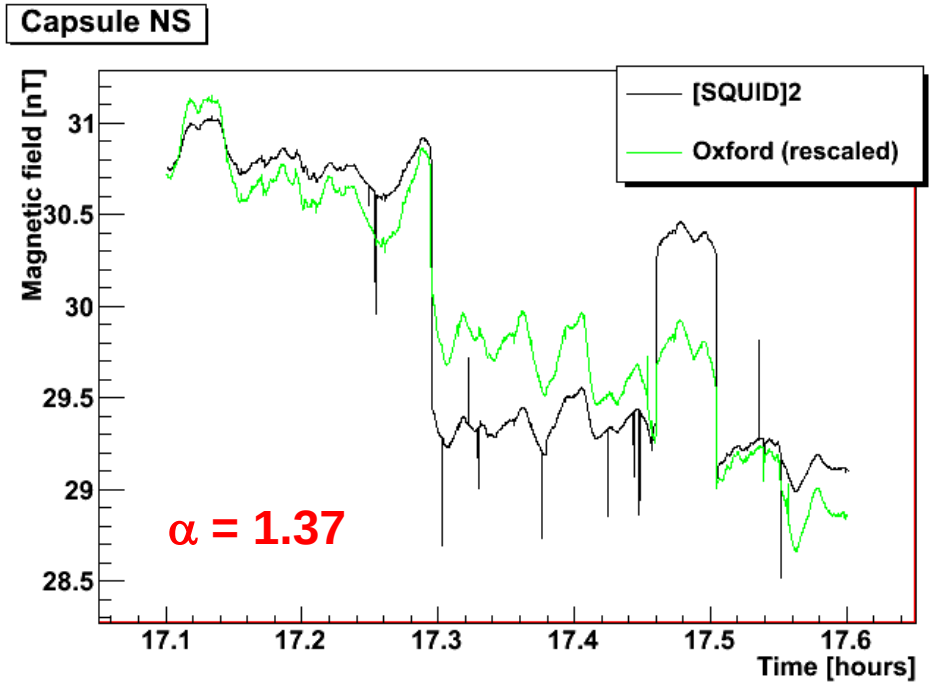
$$\frac{\alpha_{capsule}}{\alpha_{Anti-Souffle}} = \frac{\left\langle B_{Anti-Souffle} \right\rangle}{\left\langle B_{capsule} \right\rangle}$$



[SQUID]² – Oxford comparison

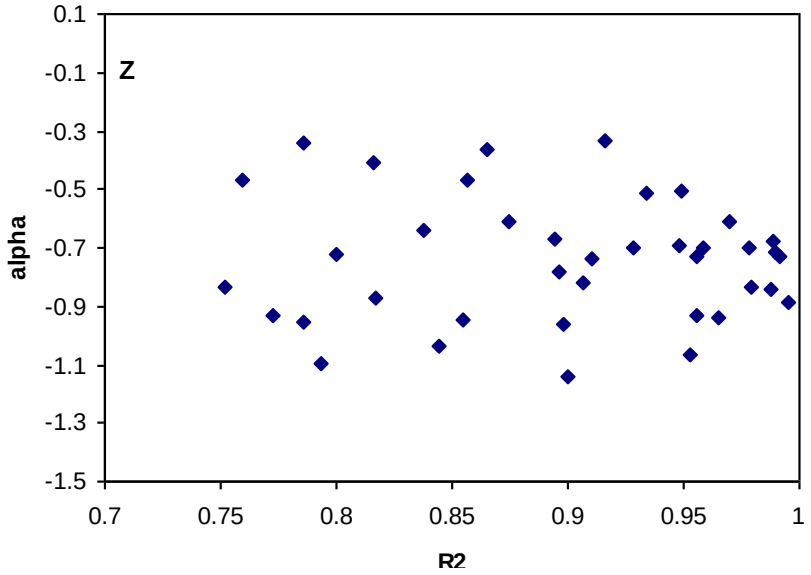
- Problem – flux jumps
- We can only do an accurate comparison for periods without any resets

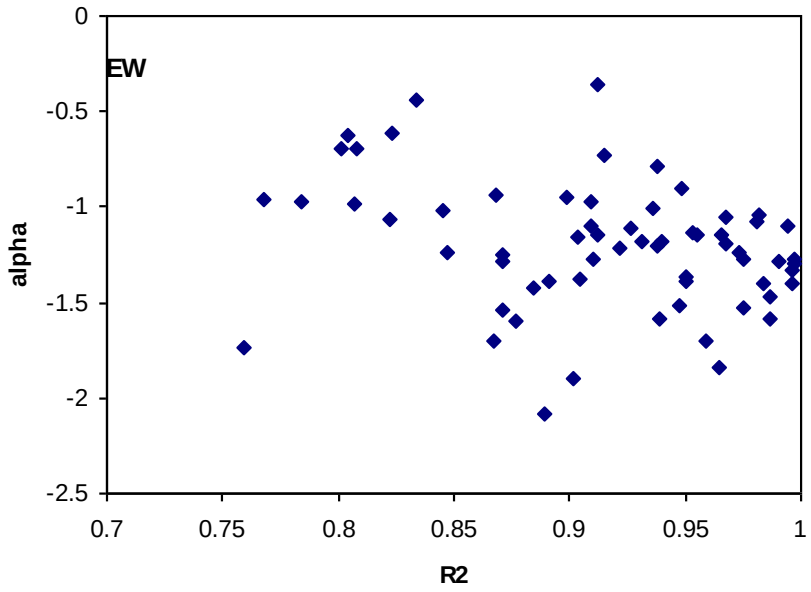


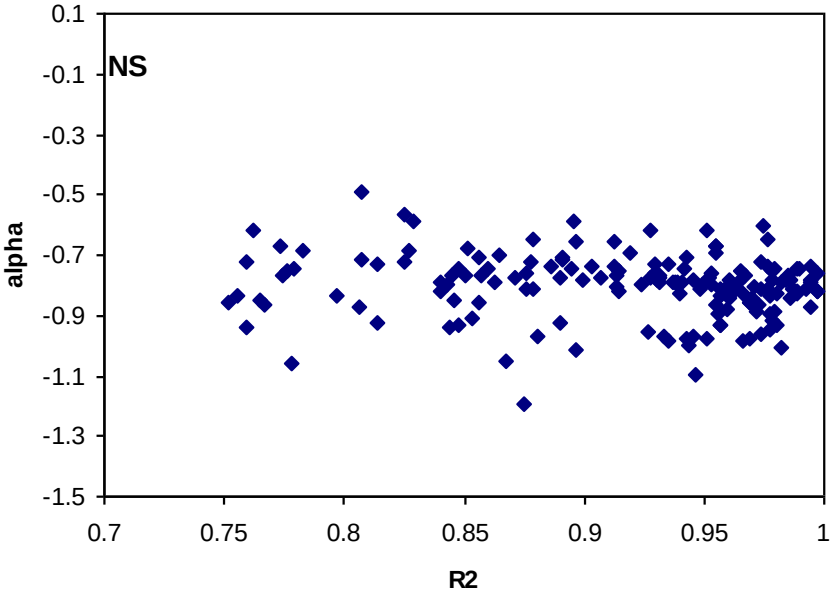


[SQUID]^2 – Oxford comparison

- Better fit $\rightarrow$ more consistent value for α
- Take α values only from samples with $R^2 \geq 0.97$







Preliminary results

If both magnetometers measure same signal in Capsule, then deviation from 1 is due to calibration inaccuracy

- [SQUID]^2 system always in Capsule
- Oxford system in remote location
- α = scaling factor [SQUID]^2 : Oxford

Location	α		
	Z	NS	EW
CAP	0.769	0.811	1.308
GAS	0.563	0.671	0.881
GGB	0.560	0.611	0.985

$\rightarrow$ Magnitude of field fluctuations in Capsule relative to Galerie Anti-Souffle and Galerie Gaz-Brûles

$$\frac{\alpha_{capsule}}{\alpha_{Anti-Souffle}} = \frac{\langle B_{Anti-Souffle} \rangle}{\langle B_{capsule} \rangle}$$

Location	Z	NS	EW
GAS	73%	83%	67%
GGB	73%	75%	75%

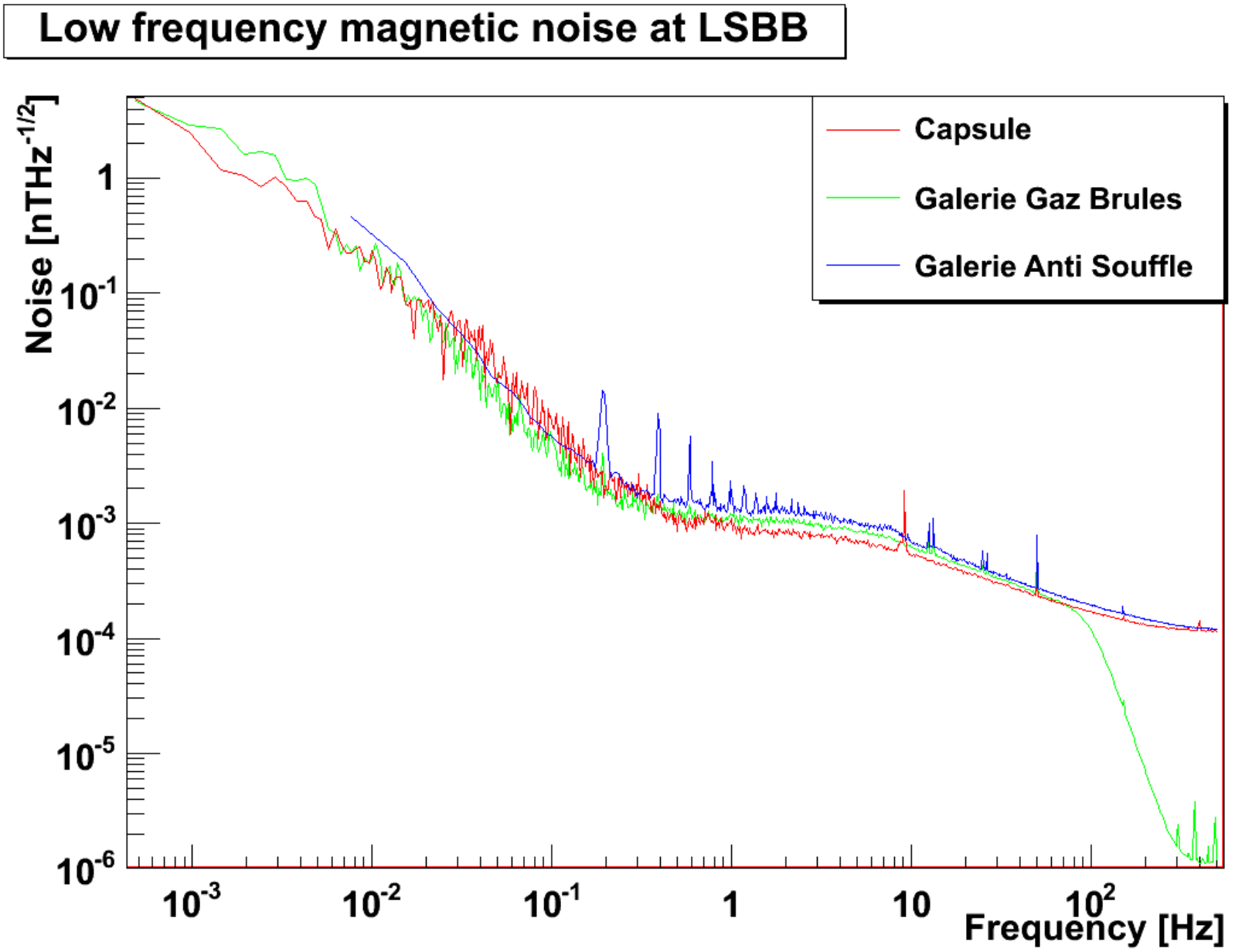
PRELIMINARY

Are these figures accurate?

- This analysis assumes:
  - No local magnetic field sources
  - Field is homogeneous within capsule
  - “Shielding factor” does not change with frequency
  - No sample selection bias when analysing data
  - Negligible pick-up of orthogonal field components

- To assess the significance of these, we need to
  - Take measurements at multiple locations within capsule
  - Analyse frequency spectrum of data
    - Limited by maximum period between resets/flux-jumps

Frequency domain analysis



Conclusions

- LSBB is an ideal environment for testing precision magnetometry
- Noise in Galerie Anti-Souffle (GAS) and Galerie Gaz-Brûles (GGB) is comparable to that in Capsule
- Prelimary time domain analysis suggest magnitude of magnetic field fluctuations in capsule is ~74% that in GAS/GAB.
- Further analysis necessary