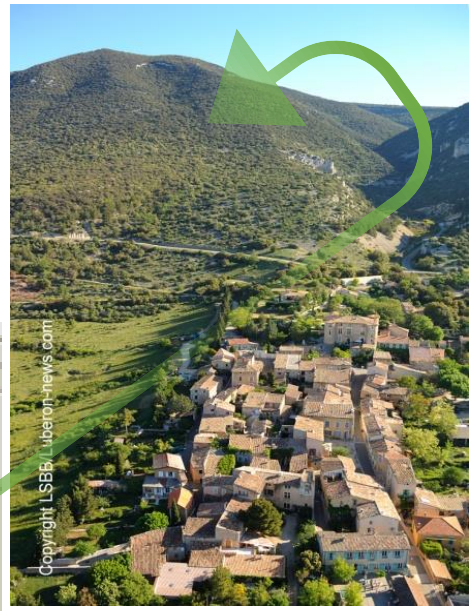
SURFACE & UNDERGROUND BASED LOW BACKGROUND NOISE INTERDISCIPLINARY RESEARCH LABORATORY, RUSTREL

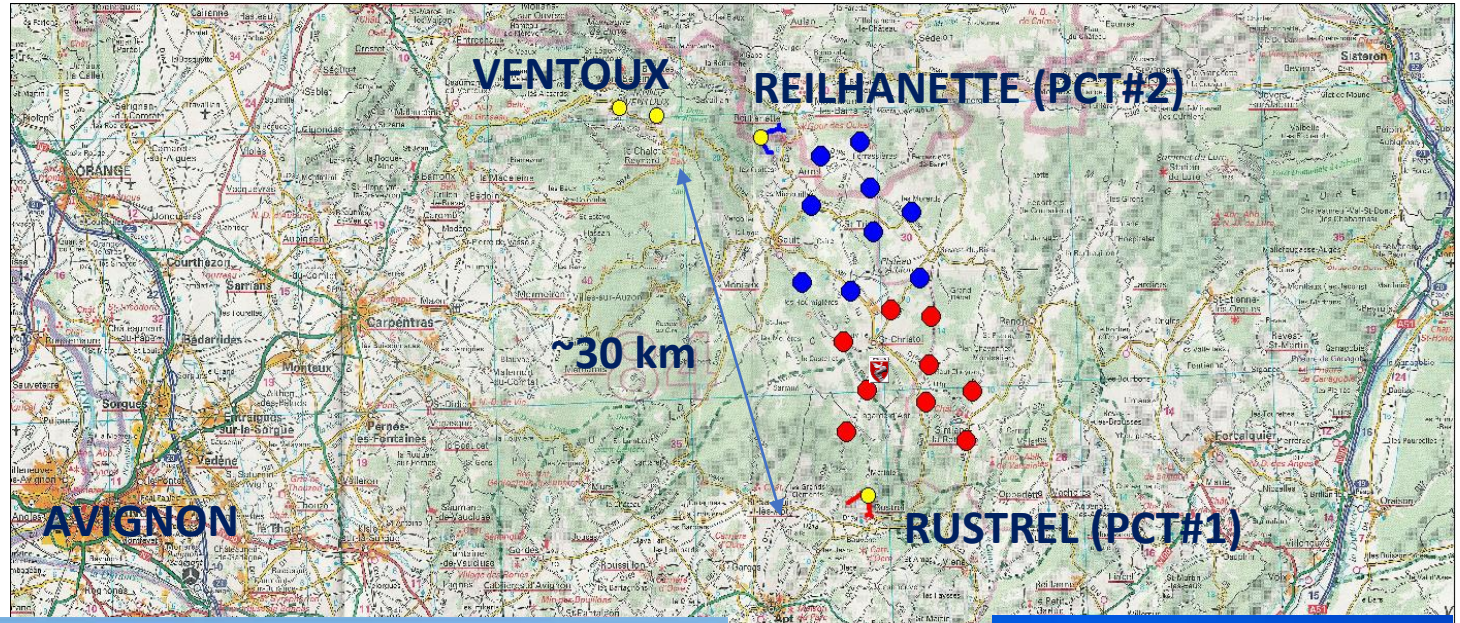
current status of LSBB development and inter-disciplinary activities

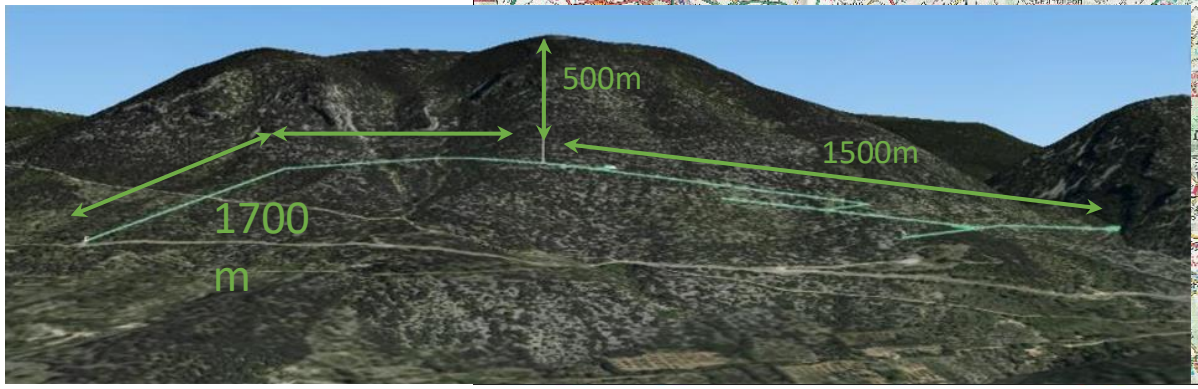
LEGACY FROM HISTORY

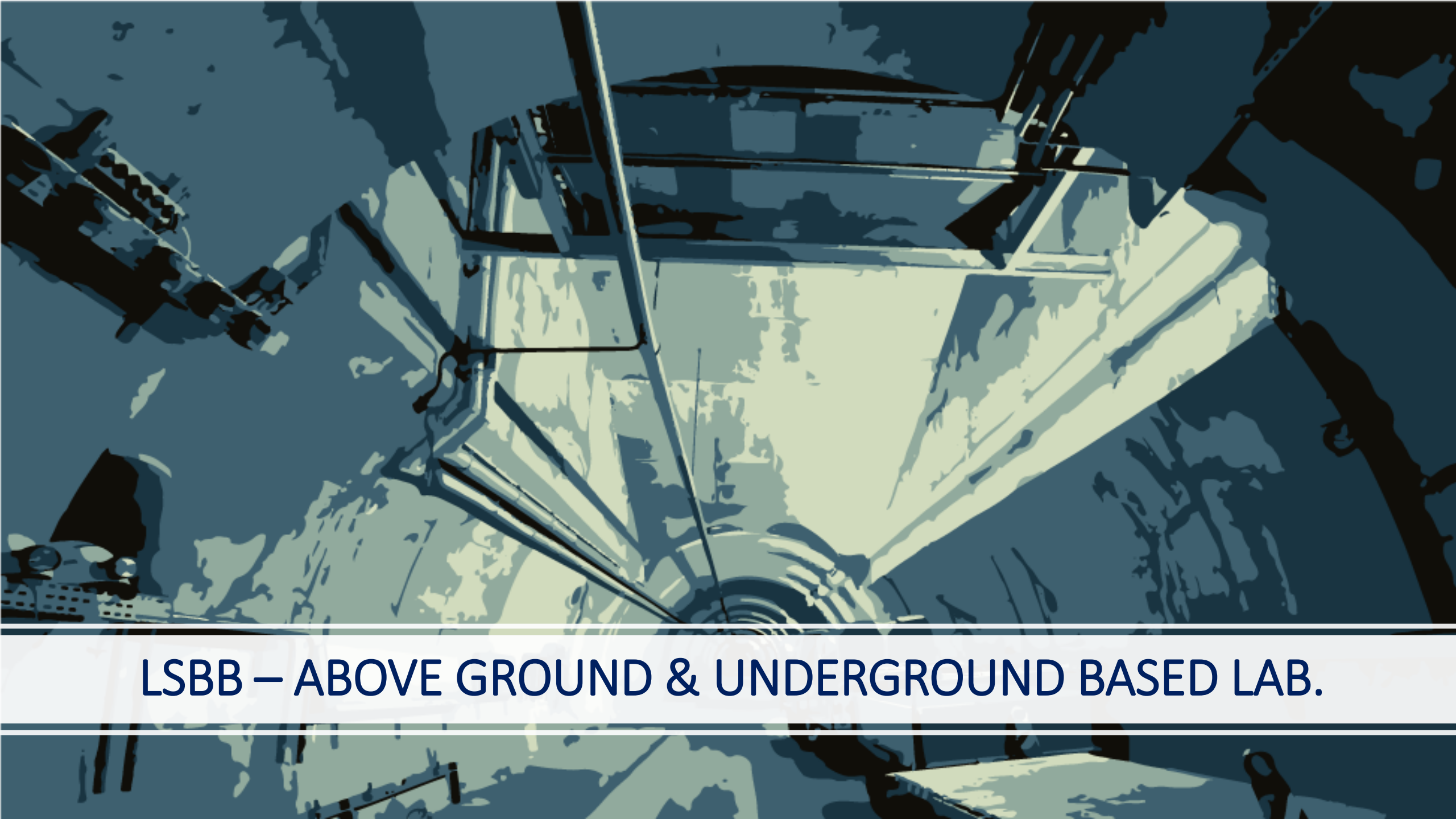
GMS ALBION → LSBB UNDERGROUND RESEARCH LABORATORY (1996)

Reconversion of a Cold War nuclear weapon system toward interdisciplinary research and sustainable development of knowledge









LSBB – ABOVE GROUND & UNDERGROUND BASED LAB.

UNIQUE SYNERGY: LOW NOISE ENVIRONMENT - COLD WAR INFRASTRUCTURE

→ Environment

Low anthropogenic noise within the Regional Natural Park of Luberon
5th largest water resource in the world, 1st in the Mediterranean, fed exclusively by rain
Major seismogenic region in the South of France
Geological analogue of the carbonate platforms of the Middle East

+

→ Infrastructure

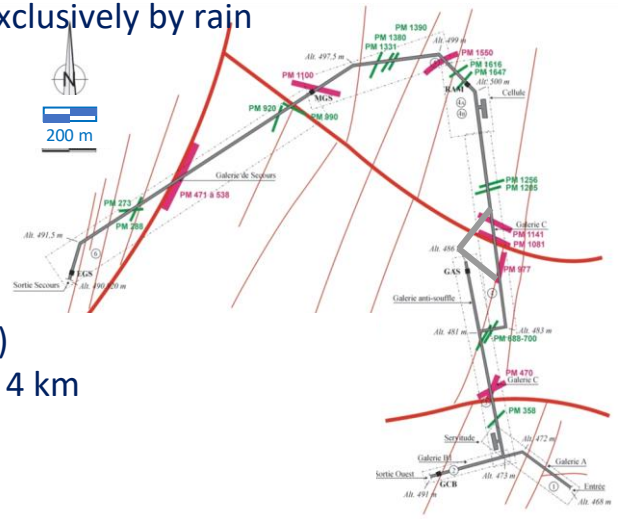
Electromagnetic shielding 28 m × ∅ 8 m capsule at a depth of 518 m
Fully equipped infrastructure on the surface and at depth (E, FO, security)
Surface access in the Regional Natural Park of Luberon and at depth over 4 km
Boreholes from the surface and from depth accessible to experiments

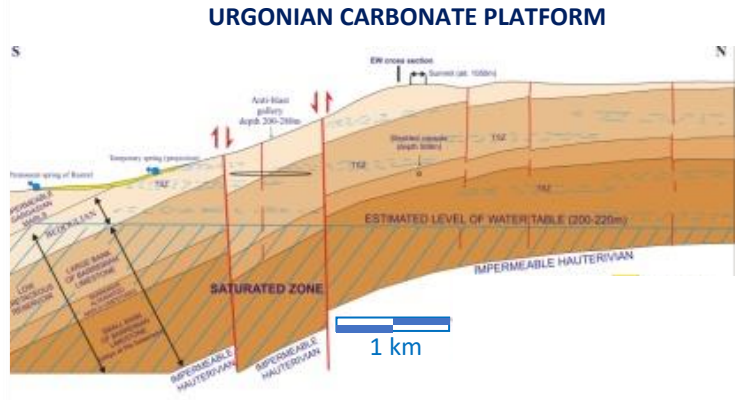
=

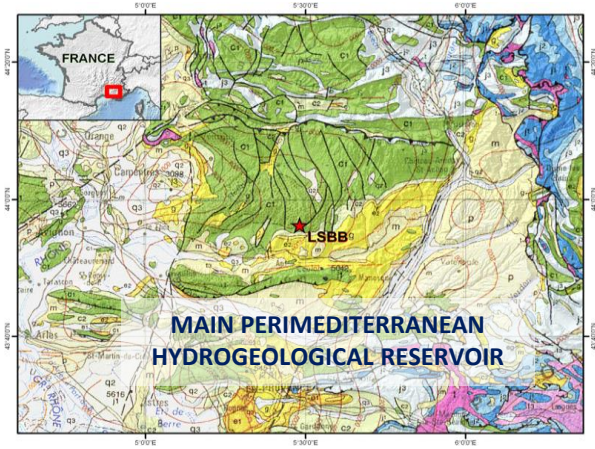
→ A worldwide unique multi-scale Research Infrastructure for ultra-sensitive science

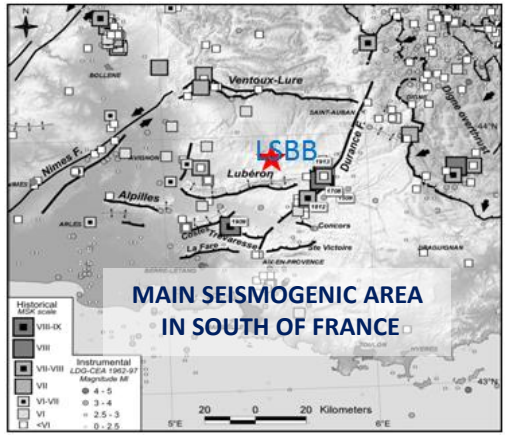
- **Observation of the Earth and the Universe**
- **Accommodation of academic and industrial R&D platforms**
- **Integration of large scientific instruments**
- **Synergy of research transdisciplinary research programs**

Keywords: *Geophysics, geology, physics, astrophysics, biology*
And health, metrology, calibration, characterisation instrumentation, carbonate, porous and fractured reservoirs, groundwater resources resources, water transfers, critical zone, global changes







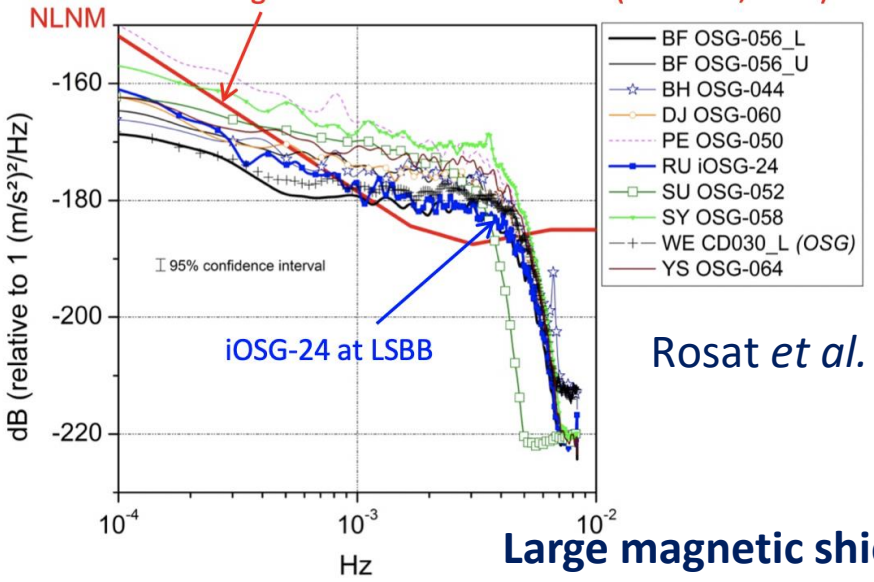


CHARACTERISATION OF THE LSBB LOW NOISE ENVIRONMENT

Superconducting gravimeters

One of the quietest sites in the world

Seismological New Low Noise Model (Peterson, 1993)



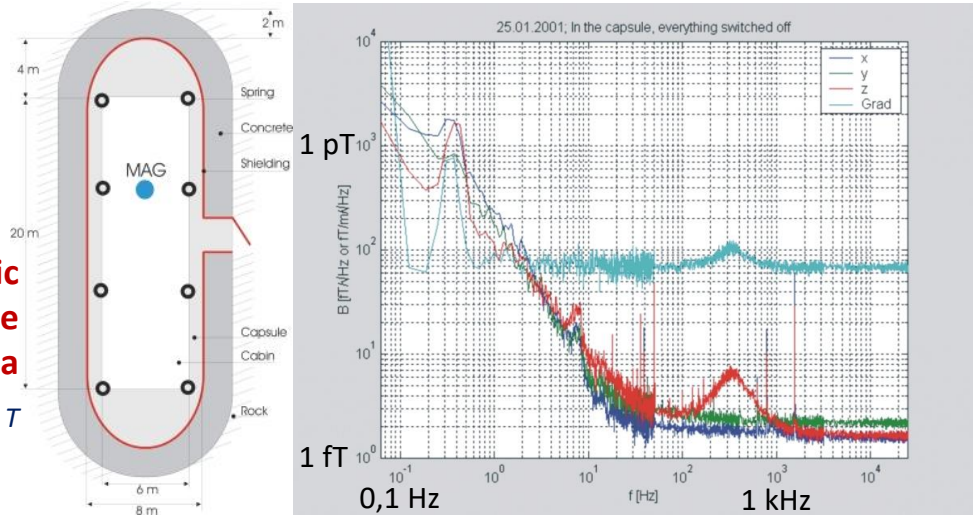
Rosat *et al.* (2018)

Large magnetic shielded room

IPHT Jena (Waysand G., A. Chwala & R. Stolz, 2001)

Magnetic spectra in the shielded area

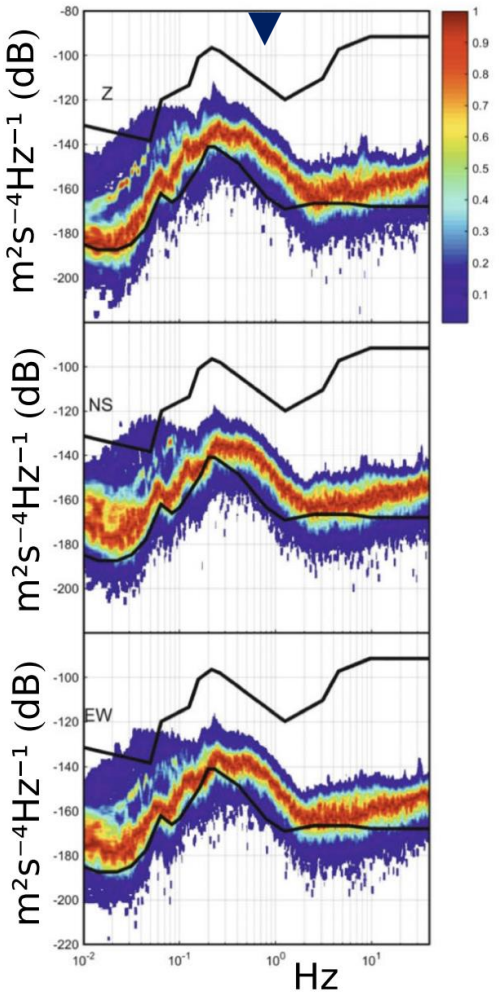
Floor at 2x10⁻¹⁵ T



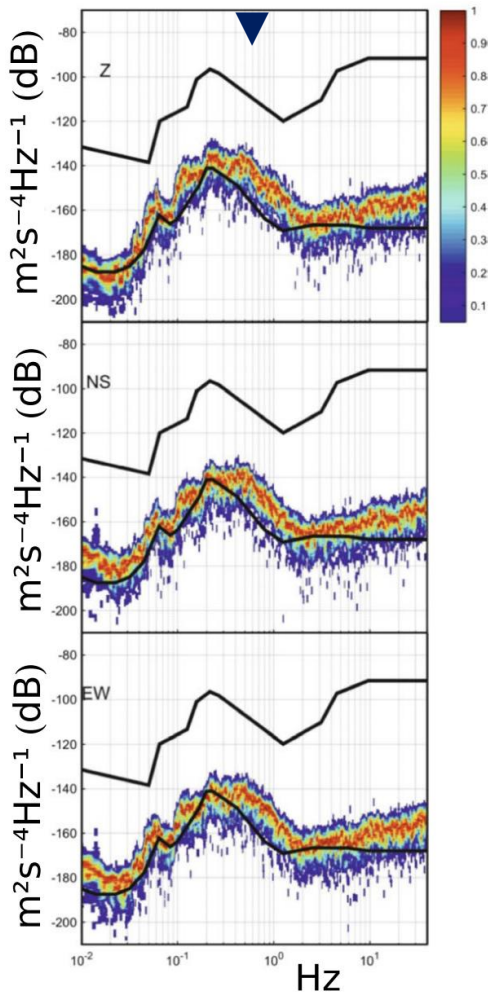
Low-noise properties of the seismic environment

Seismic noise power spectra (high, Z; middle, NS; low, EO) compared to Peterson noise models

Average noise in 2011



Quiet day



AN EVOLUTIVE AND SCALABLE LABORATORY FOR SCIENCE AND TECHNOLOGY

→ **Resources & fluid dynamics in the critical zone**
Karst underground water resource, critical zone, carbonate platform

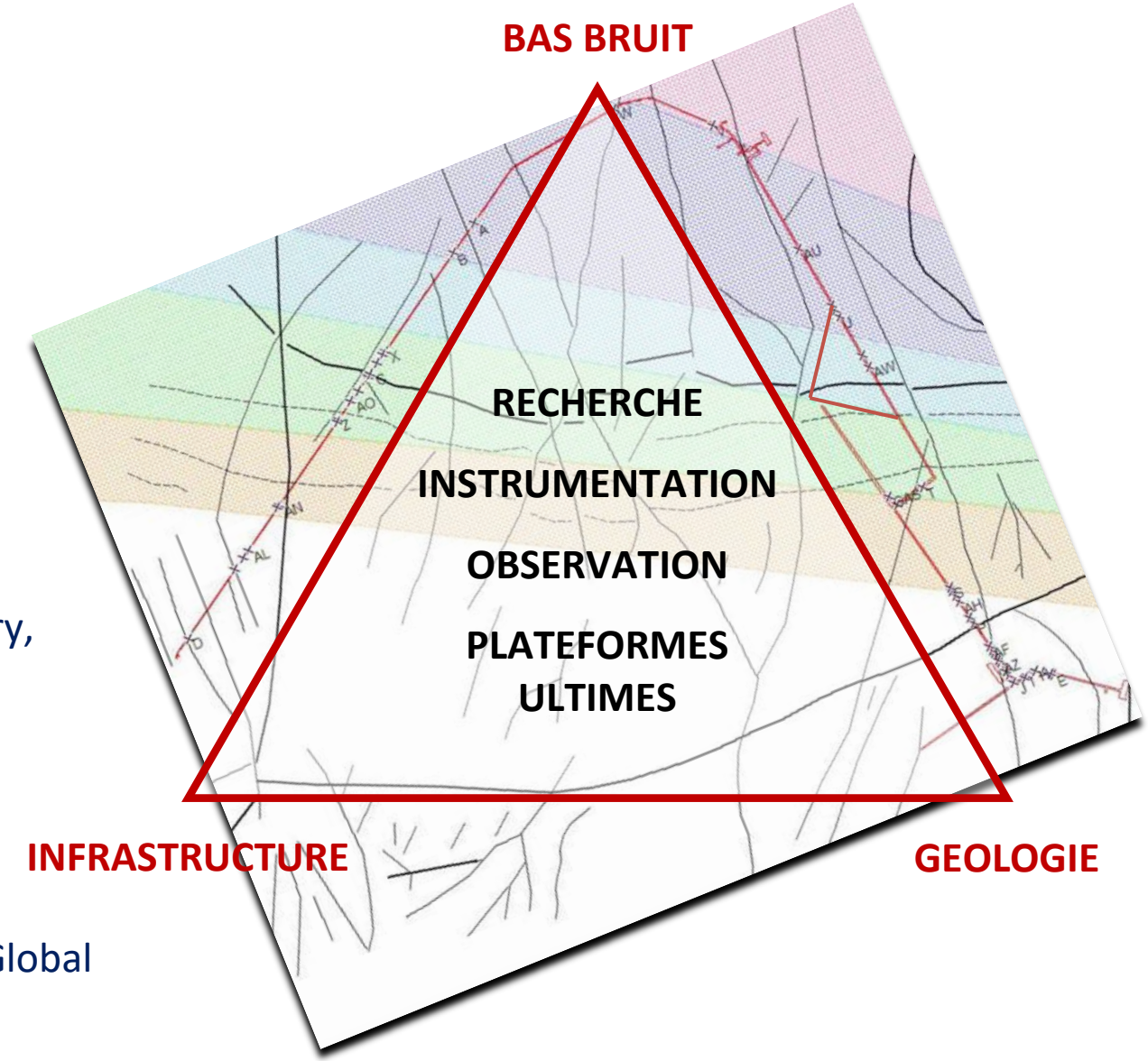
→ **Fluids & medium interactions**
Thermo-hydro-mechanical & poro-elastic processes, geomechanics

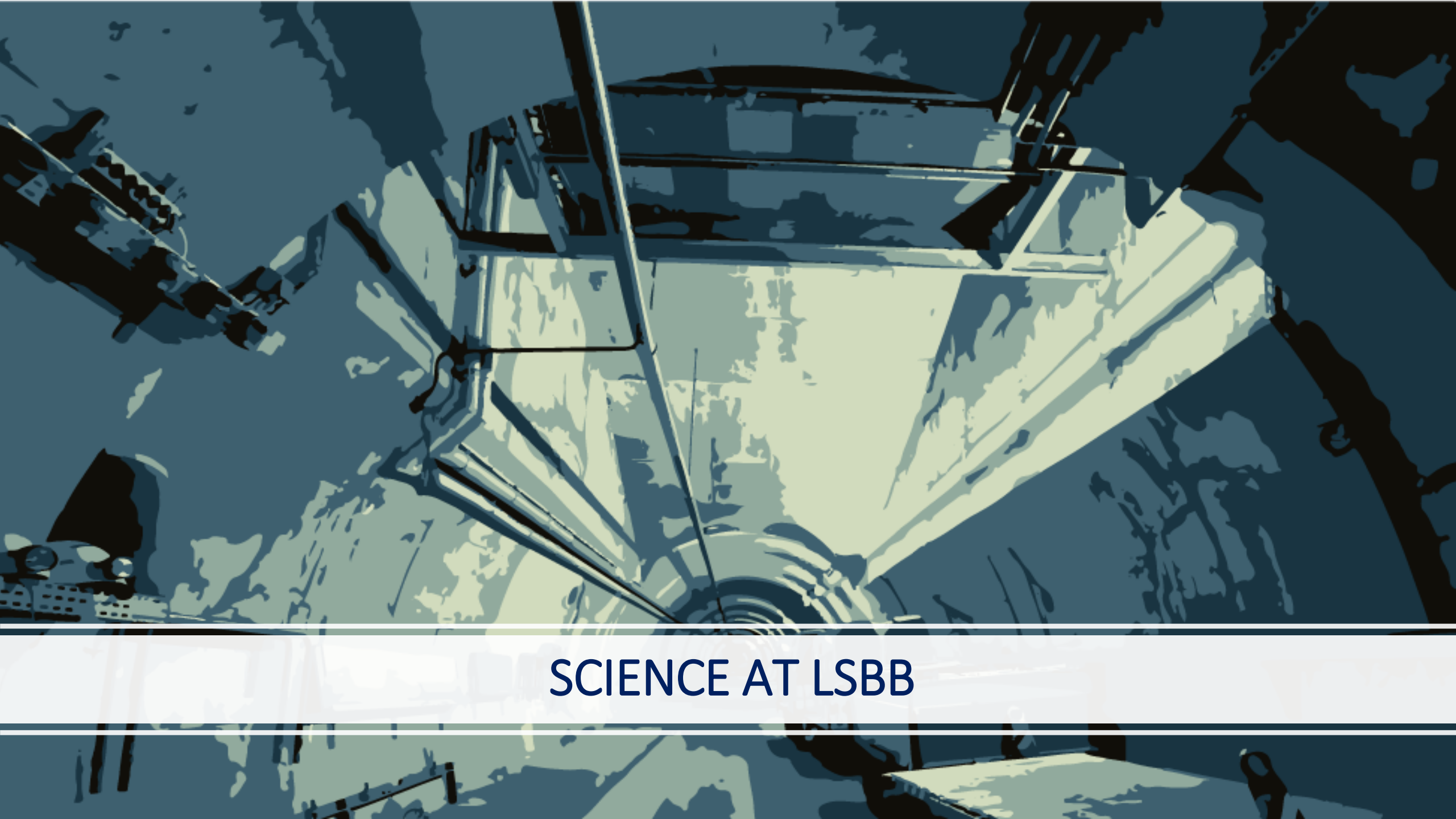
→ **Wave physics & radiative environment**
Seismology, Magnetism, particles Neutrons / Muons

→ **High sensitivity metrology & measures**
Densitometry, Magnetometry, Rotationnal seismometry, Atom interferometry, Optics …

→ **Life**
Biology, Brain imagery

→ **Society & Human Sciences**
Contemporary History *vs* Cold War, anthropisation *vs* Global Changes, water resource vs Global Changes





SCIENCE AT LSBB

ILLUSTRATION OF SCIENTIFIC LINES OF ACTIONS

→ HIGH SENSITIVITY INSTRUMENTS & MEASUREMENT METHODOLOGY

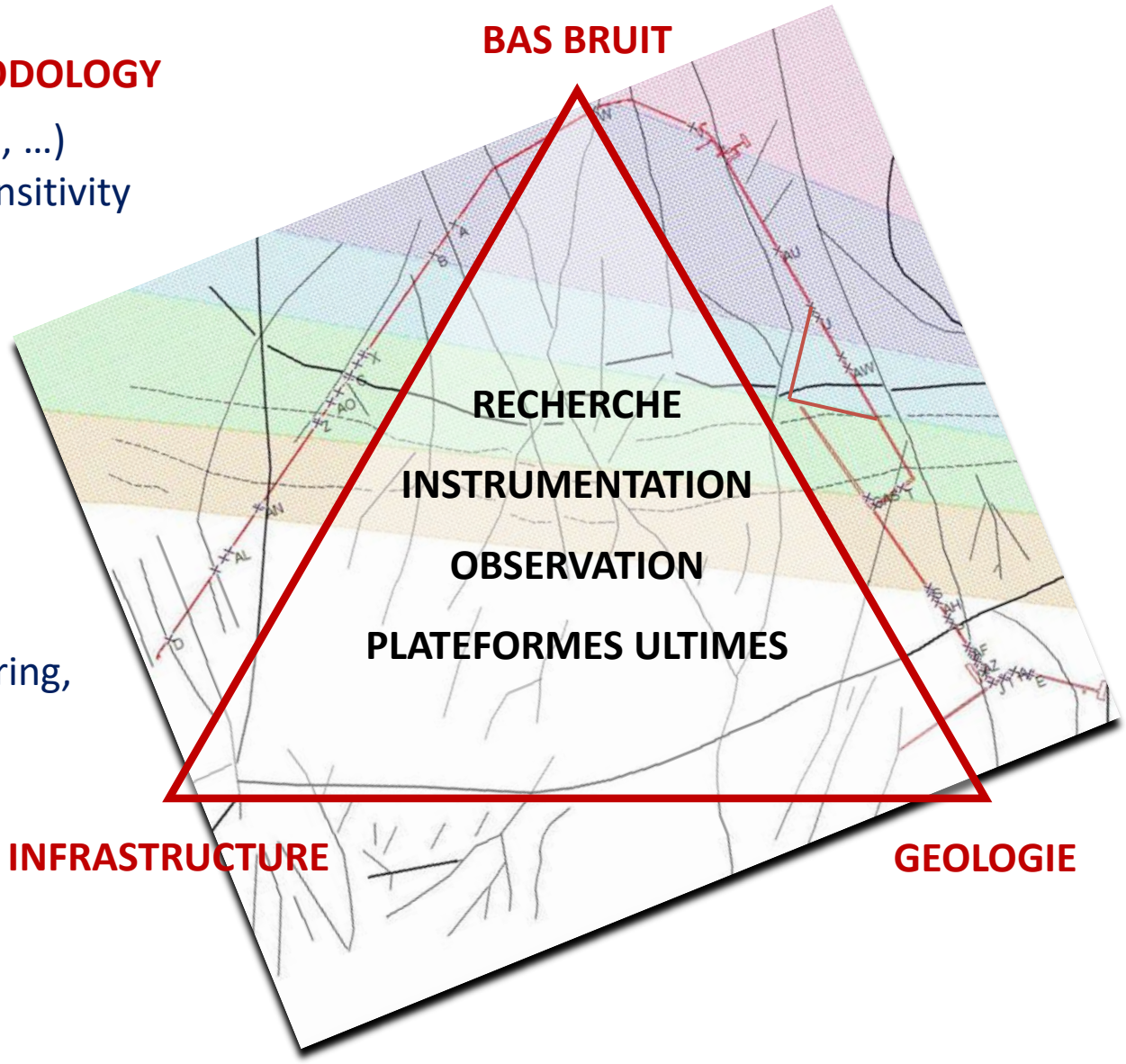
- Instrumentation (AI, Muon Trackers, fiabilité électronique, …)
- Electroencephalography (EEG) at Wide Band and High Sensitivity

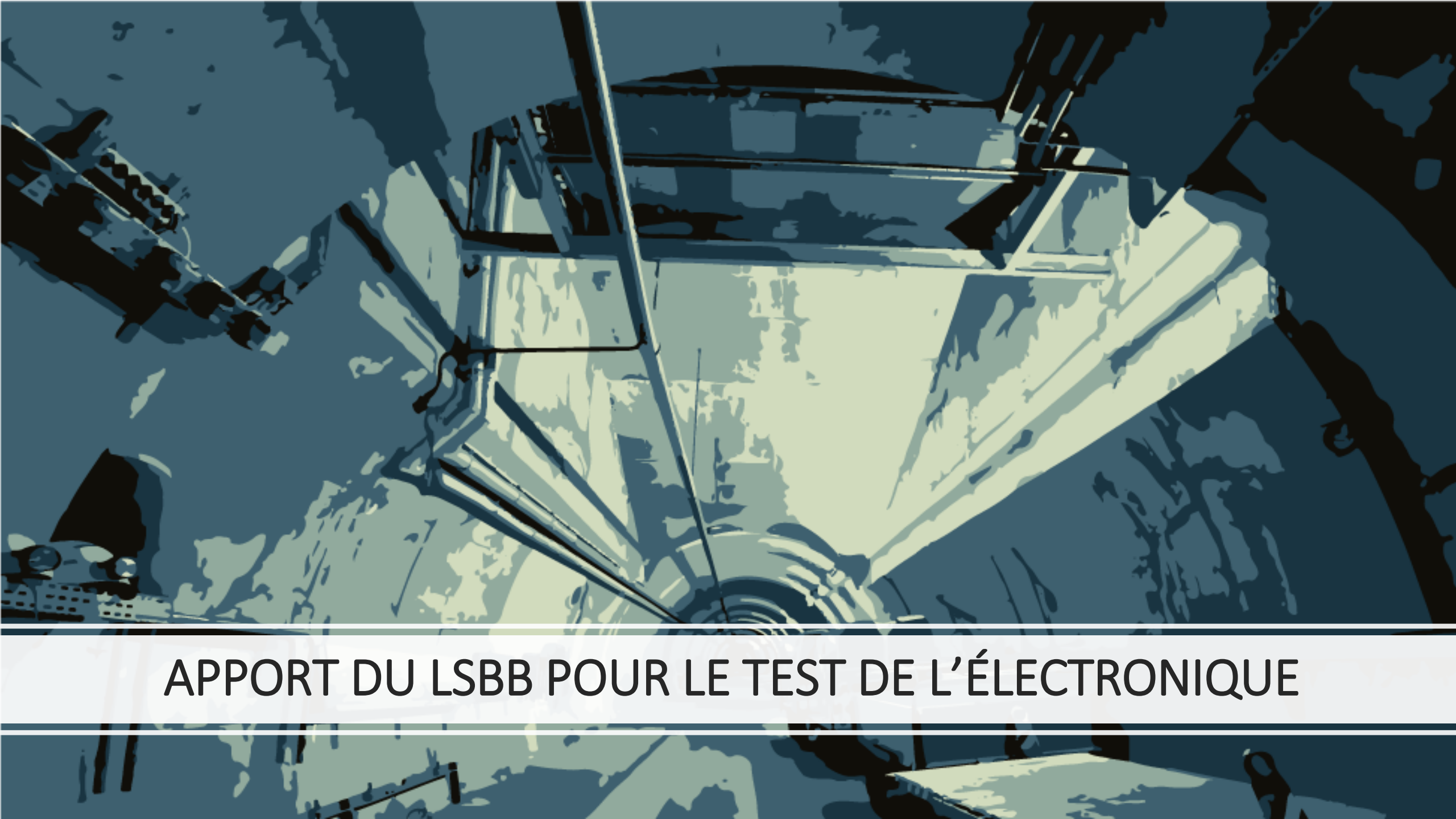
→ OBSERVATIONS & STUDIES

- Multi-physics Observatory (Seismology, Gravimetry, Magnetometry, Hydrogeology, Atmospheric TLE …)
- Observation and Analysis of Geophysical Phenomena (Earth Interior, Surface, Atmosphere)
- Critical Zone Processes, Hydrodynamics of Geological Reservoirs, biosphere
- Couplings and Physics- and Geophysical Processes (Fracturing, Poroelasticity)

→ R&D PLATFORMS & LARGE INSTRUMENTS

- Wave Physics and Rotational Seismology
- AI Measurement of Gravitation
- Ultimate characterization of mirrors





APPORT DU LSBB POUR LE TEST DE L'ÉLECTRONIQUE

BAS BRUIT RADIATIF : LE CAS DE XILINX

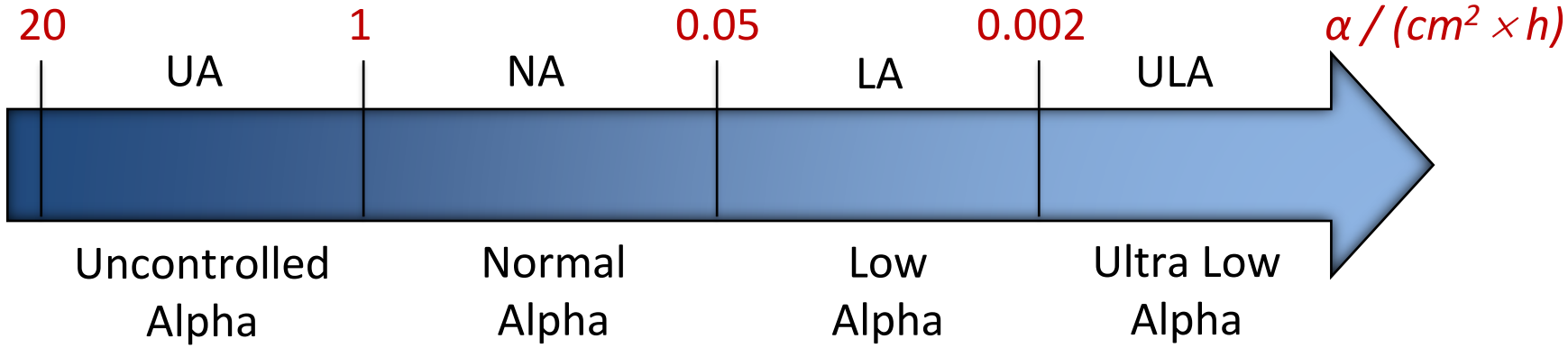
→ CONTAMINATION ALPHA : LE DANGER VENU DE L'INTÉRIEUR

Emetteurs Alpha : 2 sources possibles dans les composants

- Émetteurs naturellement présents: soudures, dopages …
- Émetteurs introduits: nouveaux matériaux, procédés de fabrication

Niveaux d'émissivité

- Le choix dépend du niveau de fiabilité requis
- Ratio coût / fiabilité attendue



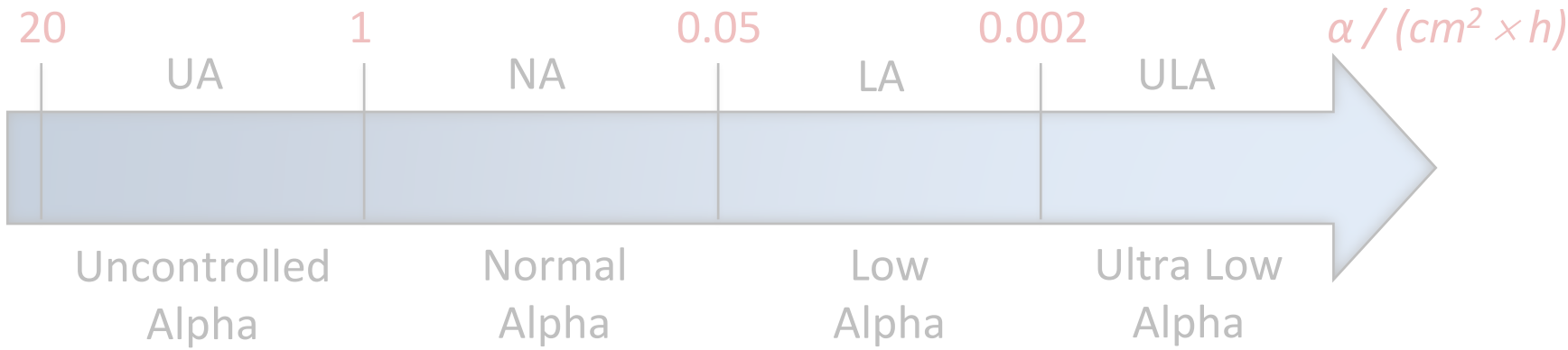
Un vrai problème de fiabilité pour les composants électroniques

En 2002 XILINX rencontre un problème de contamination alpha de plusieurs lots de boitiers flip-chip

BAS BRUIT RADIATIF : LE CAS DE XILINX

→ CONTAMINATION ALPHA : LE DANGER VENU DE L'INTÉRIEUR

→ **XILINX** lance le programme **ROSETTA** associant le **LSBB**



Un vrai problème de fiabilité pour les composants électroniques

En 2002 XILINX rencontre un problème de contamination alpha de plusieurs lots de boitiers flip-chip

PROGRAMME ROSETTA: TEST DE FPGA EN ENVIRONNEMENT NATUREL

→ APPROCHE ALTITUDE SEULE

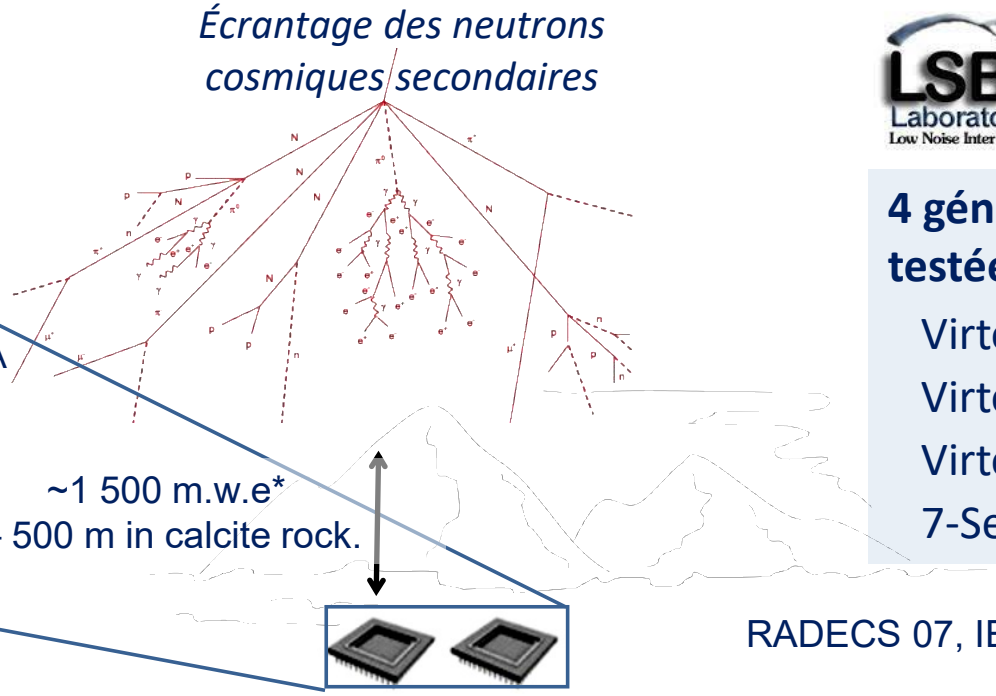
- Taux d'alpha extrait de la corrélation d'**au moins 3 sites en altitude**
- Précision des résultats difficile à évaluer à cause de l'incertitude sur le **facteur d'accélération**

→ APPROCHE DIRECTE LSBB + ALTITUDE

- 1 **site souterrain** bas bruit **comme référence**: le niveau de **contamination alpha** peut être évalué directement
- **1 seul site en altitude** pour obtenir une évaluation en environnement radiatif

Banc de test FPGA Xilinx au LSBB

XILINX®



LSBB
Laboratoire Souterrain à Bas Bruit
Low Noise Inter-Disciplinary Underground Science & Technology

4 générations de FPGA testées au LSBB

Virtex 2 Pro (130nm)
Virtex 5 (65nm)
Virtex 6 (40nm)
7-Series (28nm)

RADECS 07, IEEE TNS 2008, A. Lesea et al.

** Meter Water Equivalent*

BAS BRUIT ELECTRONIQUE : TEST D'UN OSCILLATEUR

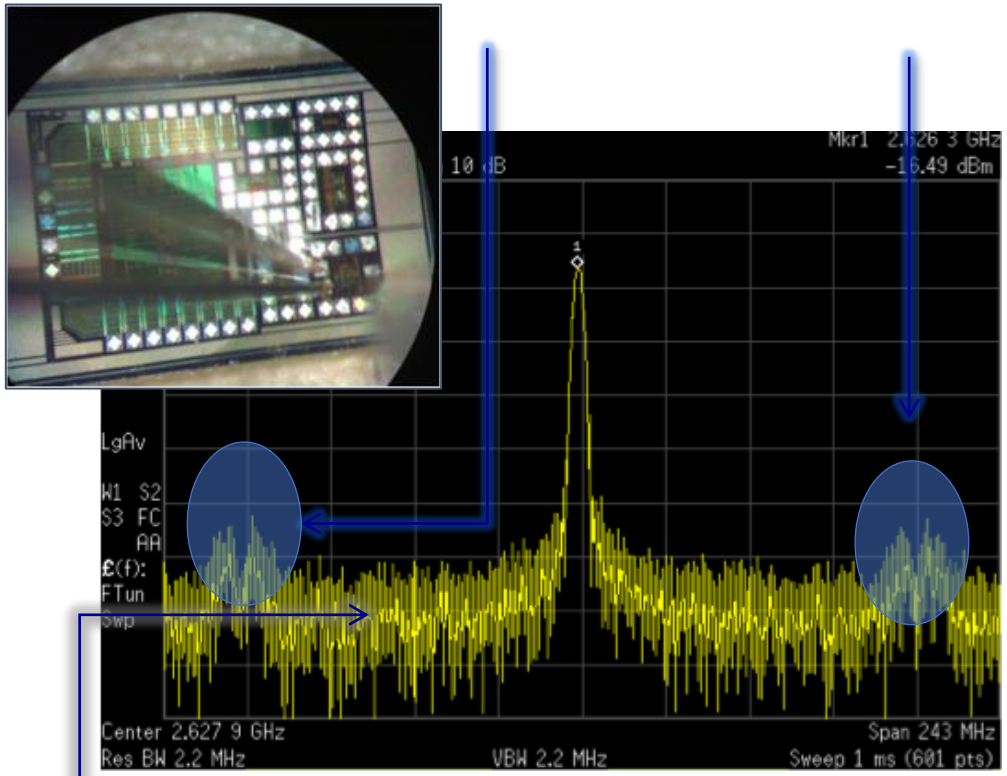
COLLABORATION LSBB – IM2NP

→ **MESURES À L'IM2NP (MARSEILLE)**

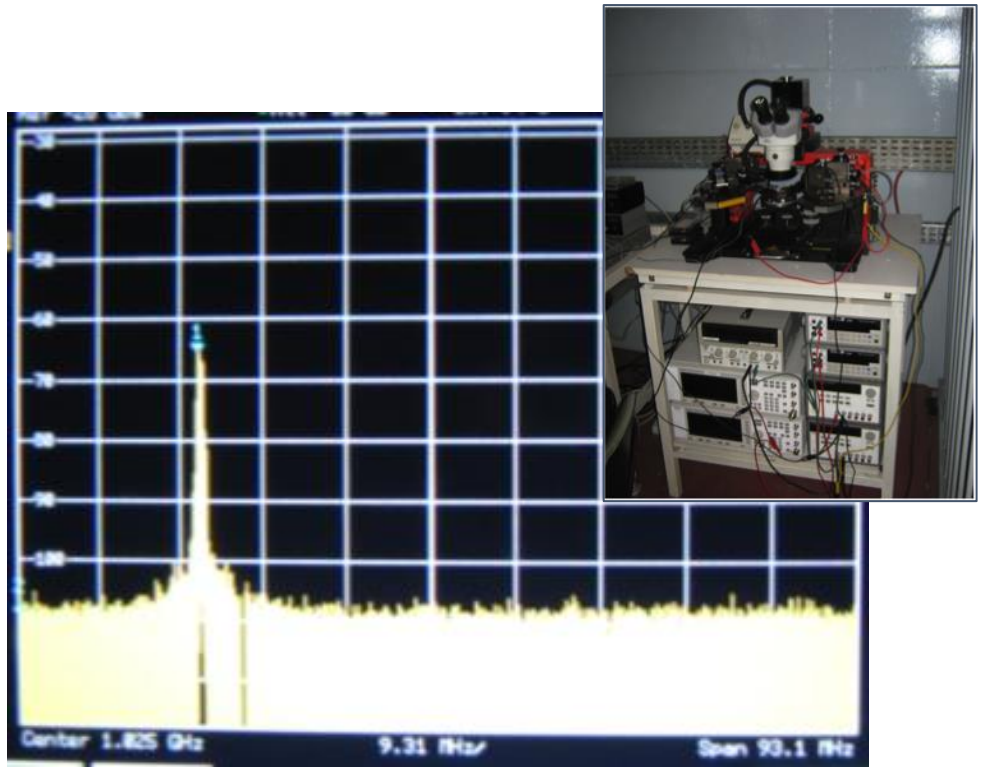
- Bruit parasite correspondant à la fréquence de la bande FM

→ **MESURES AU LSBB (RUSTREL)**

- Meilleur niveau de bruit
- Absence de signal parasite



Niveau de bruit



DES PROJETS ALLIANT DES COMPÉTENCES MULTI-PHYSIQUE ET MULTI-ÉCHELLE

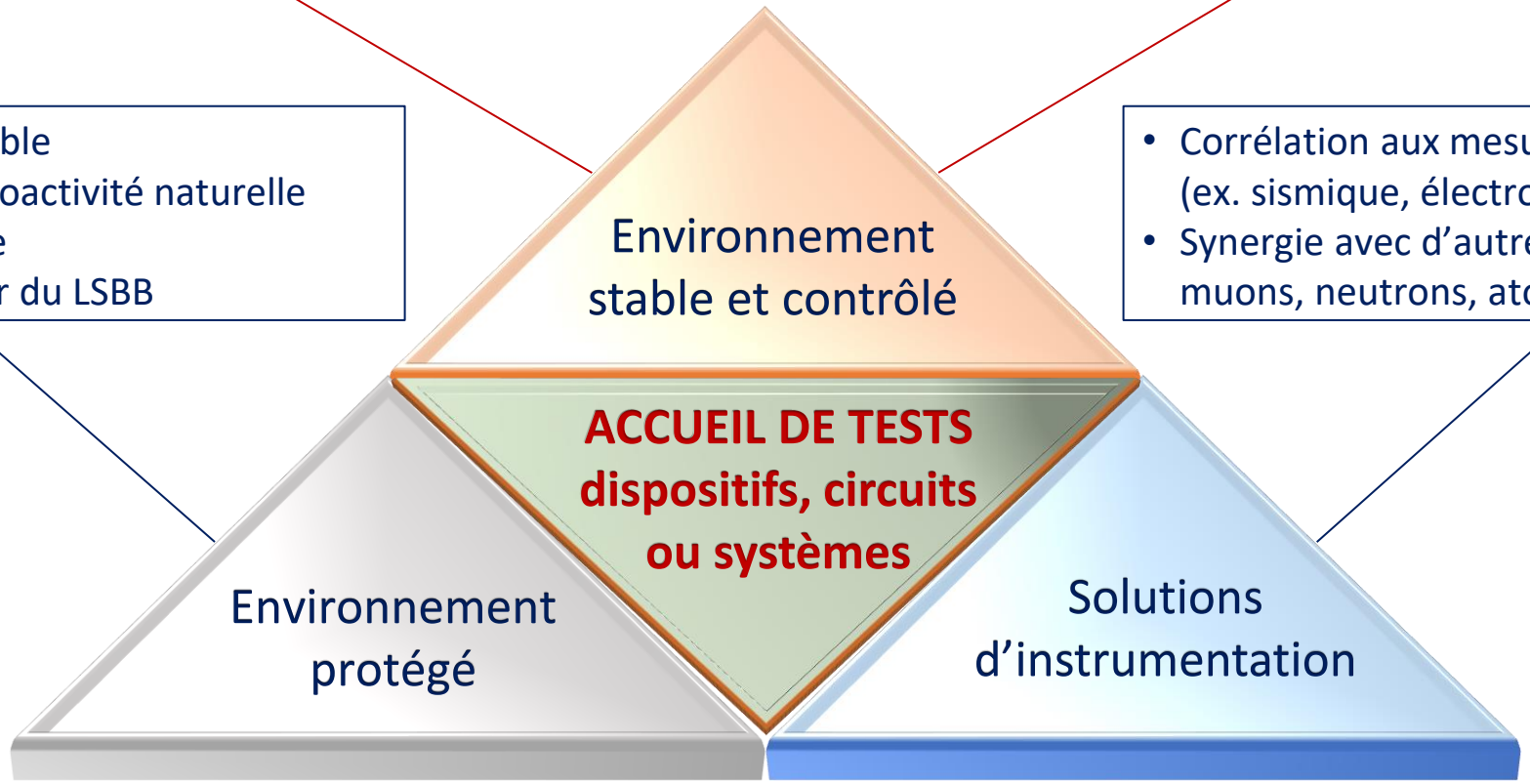
→ UNE APPROCHE COMPLÈTE DU TEST EN ENVIRONNEMENT NATUREL

- **Observation continue 24h/24h**
- **Qualification 24h/24h**

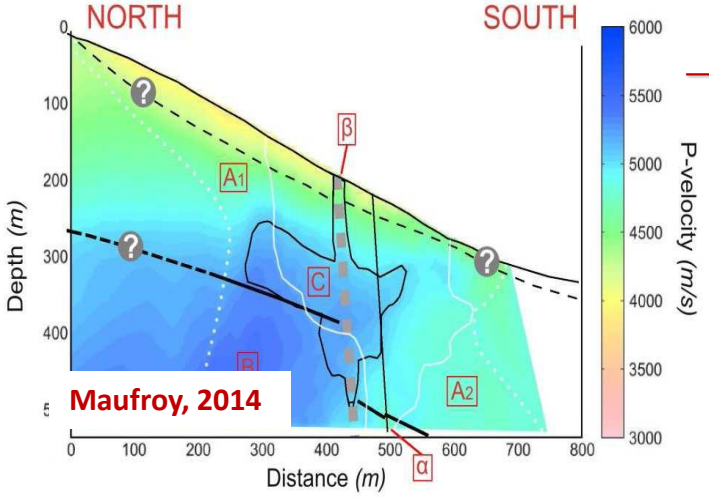
- **Environnement souterrain -500 m et en altitude +1100 m**
- **Environnement équipé, monitoré et sécurisé**

- Bruit EM ambiant très faible
- Roche calcaire basse radioactivité naturelle
- Anthropisation très faible
- Zone blindée EM au cœur du LSBB

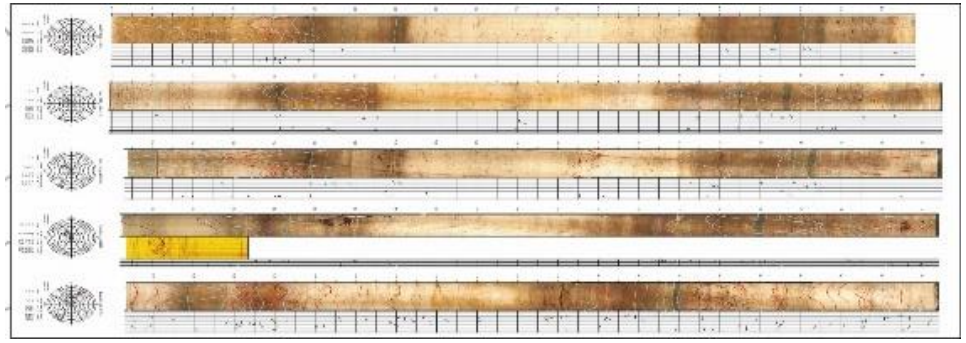
- Corrélation aux mesures environnementales (ex. sismique, électromagnétique …)
- Synergie avec d'autres plateformes R&D (ex. muons, neutrons, atomes froids …)

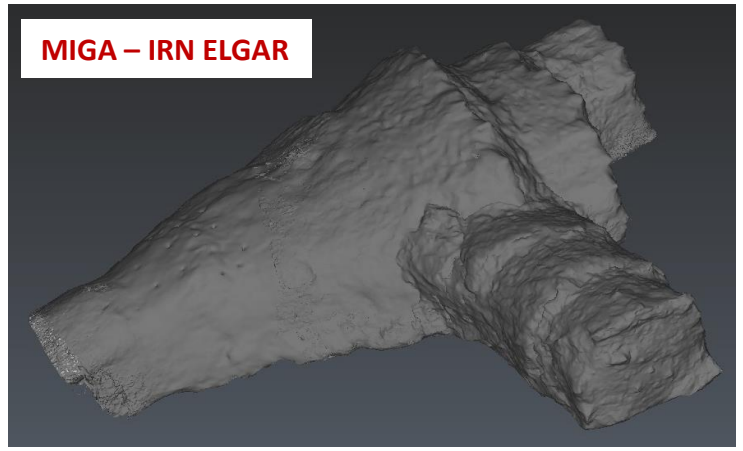


OBSERVATIONS & STUDIES

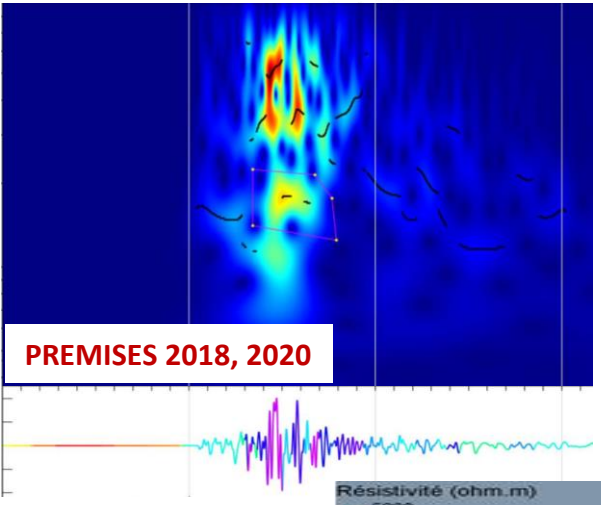


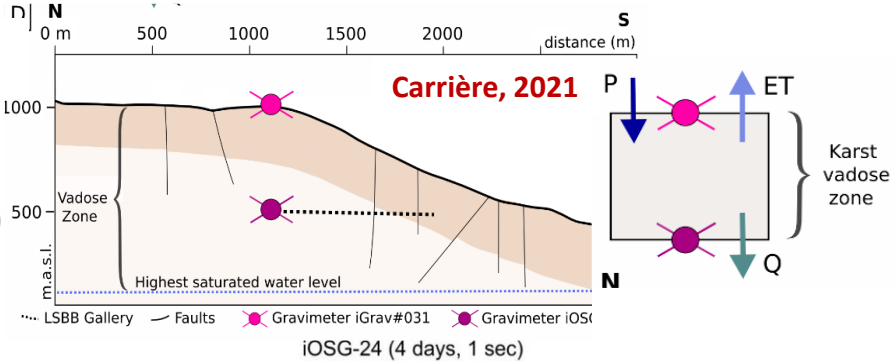
→ RESERVOIR TRANSDISCIPLINARY INVESTIGATION

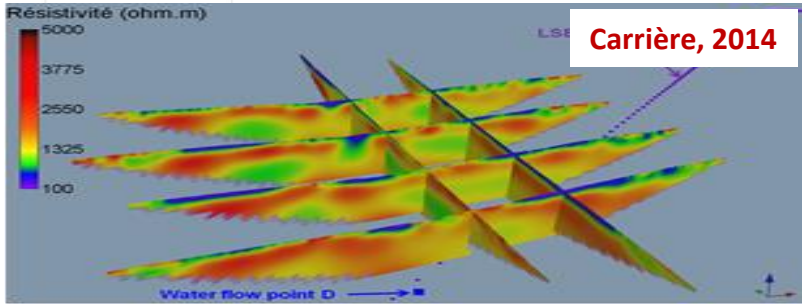


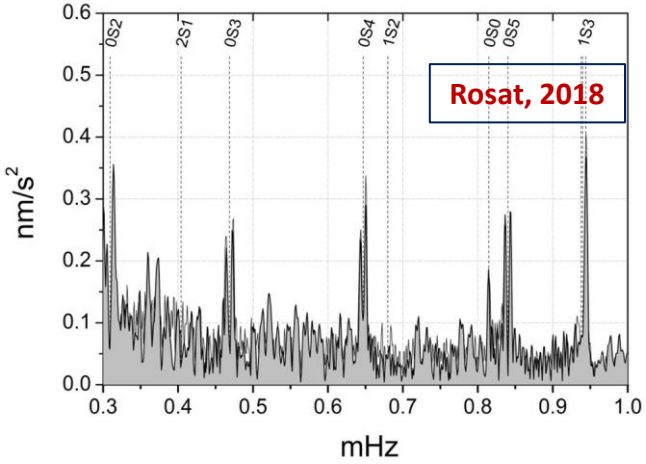


Boreholes & cores (*scale*)
Photogrammetry (*step-by-step tunnel excavation)*)
Seismology, densitometry (*RESIF, INTERIMAGES, TRUST-ME*)
Seismic signature *vs* alteration of the massif (*PREMISES 1&2*)
Gravimetry (*IOSG MIGA/LSBB et CRITEX*)
…





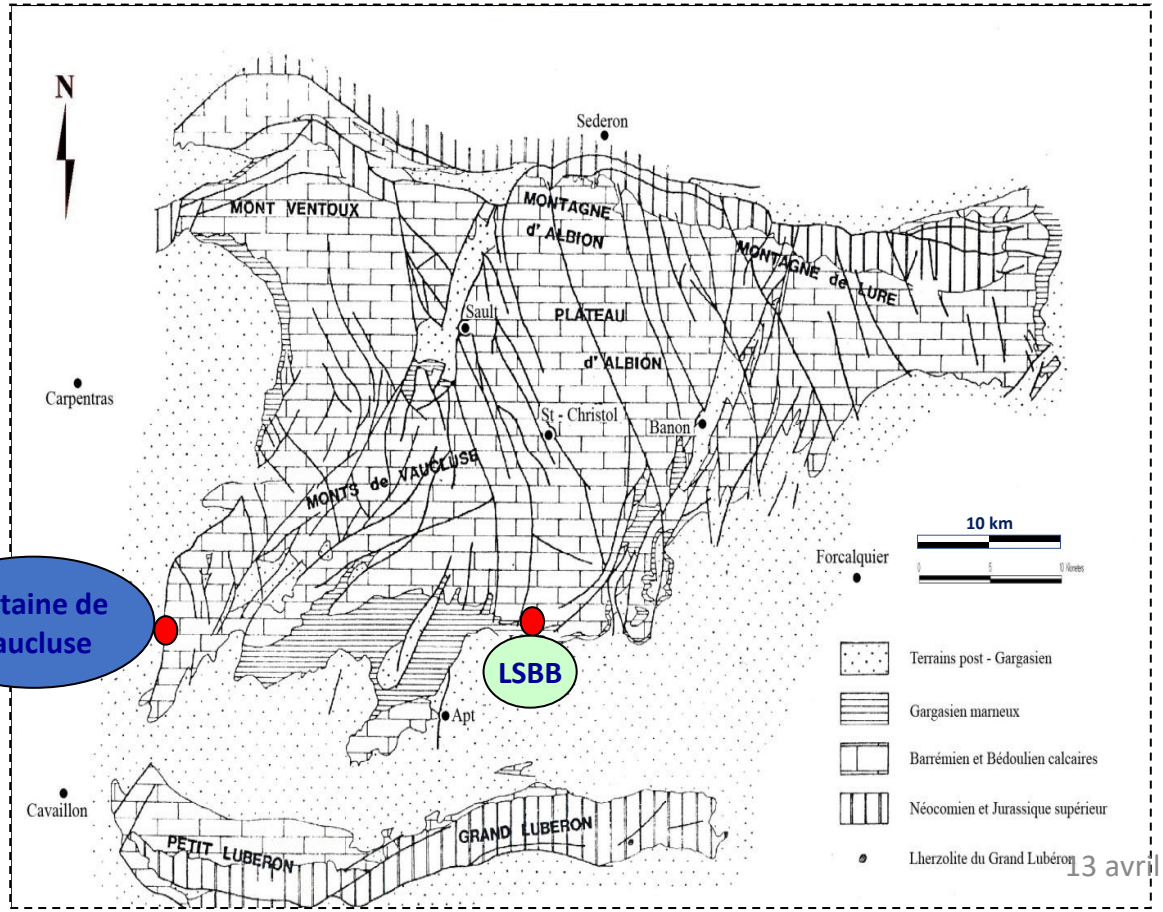


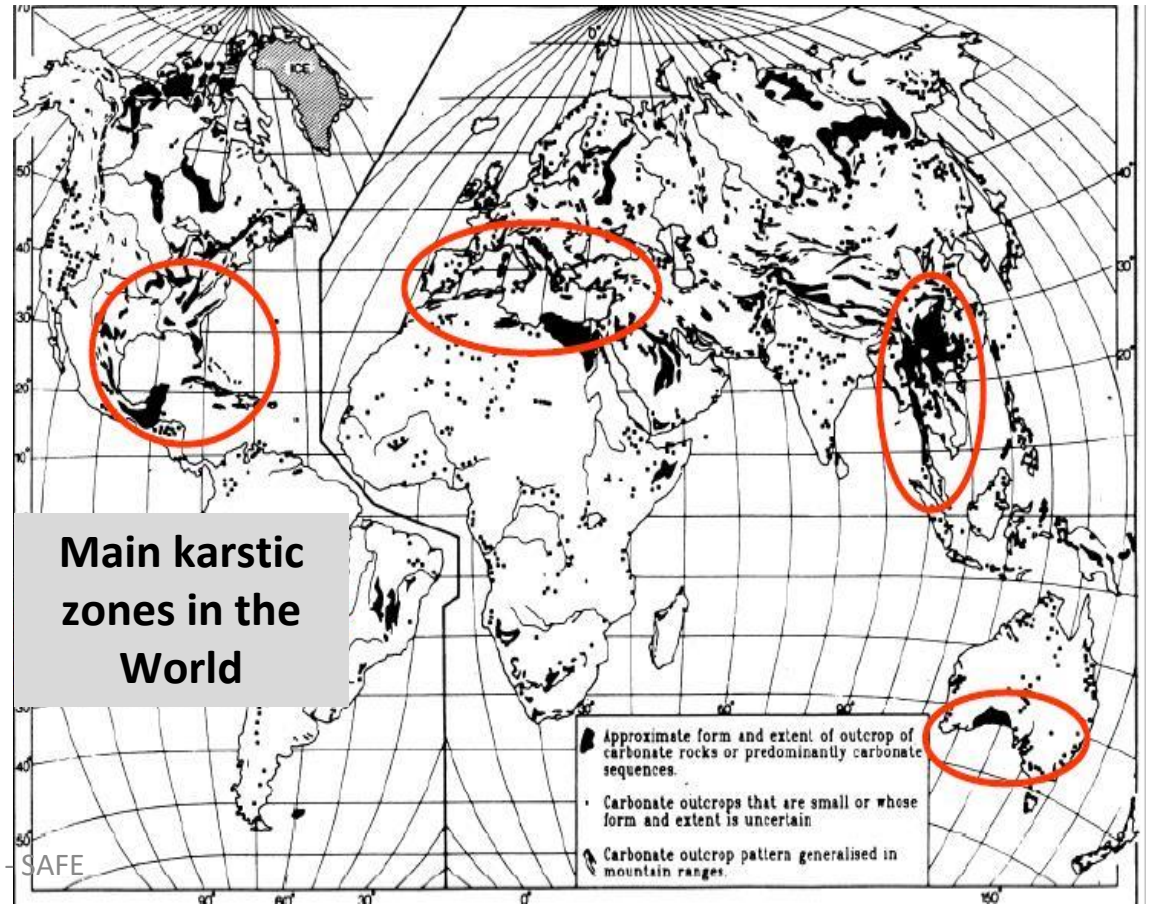


→ WATER RESOURCE & RESERVE IN PERI-MEDITERRANEAN AREA (IR OZCAR, SNO KARST ET H+)

Monitoring of the dynamic of fluid transfer – Télédétection : végétation, déformation, humidité / Ballon stationnaire, satellite, drone

- **150 years of flow measurements** at Fontaine-de-Vaucluse catchment
- **20 years (2002-2022) of hydrochemical simultaneous measurements at both LSBB and Fontaine-de-Vaucluse**
- **Easy and « random » access** to LSBB flows in the unsaturated area of the karstic aquifer and within the saturated zone towards boreholes



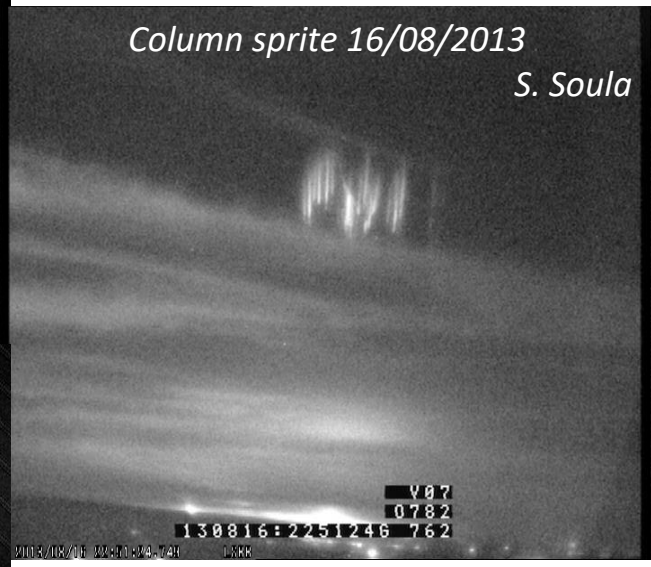


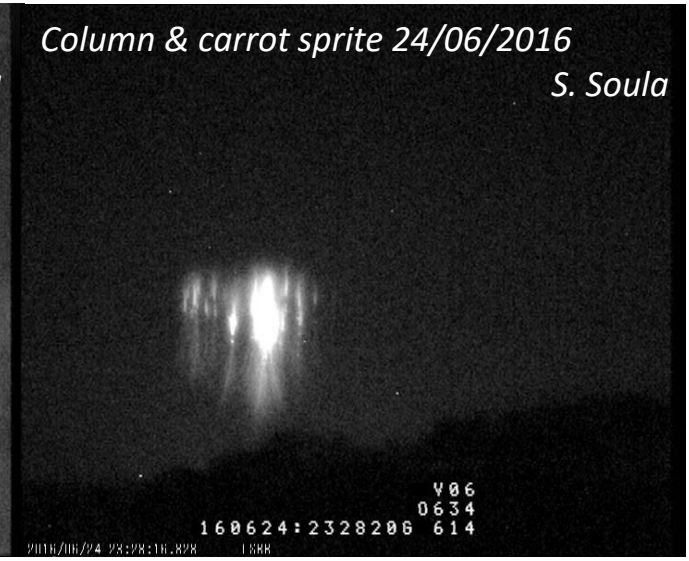
→ ATMOSPHERE PHYSICS - TRANSIENT LUMINOUS EVENTS (TLE)

A European collaboration

OMP (Toulouse, FR), CEA/DASE (Bruyères-le-Châtel, FR), IAP (Prague, CZ), DEEE (Bath, UK), AGH (Cracovie, PL), TUD (Copenhague, DK)

LSBB top



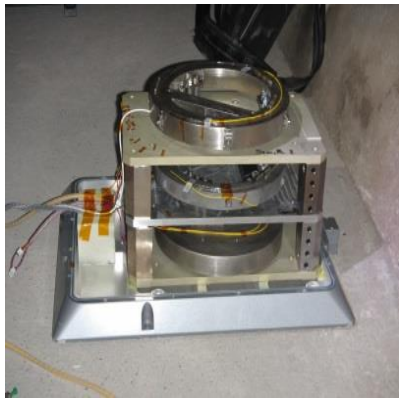


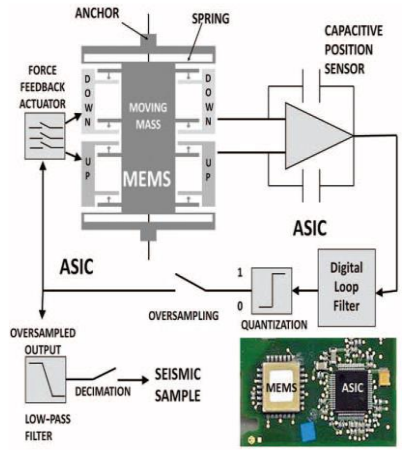
Pizzuti et al., 2021, Kolmašová et al., 2018, *Kašpar et al., 2017; Liu et al., 2016; Soula et al., 2016*

R&D PLATFORMS &
LARGE INSTRUMENTS

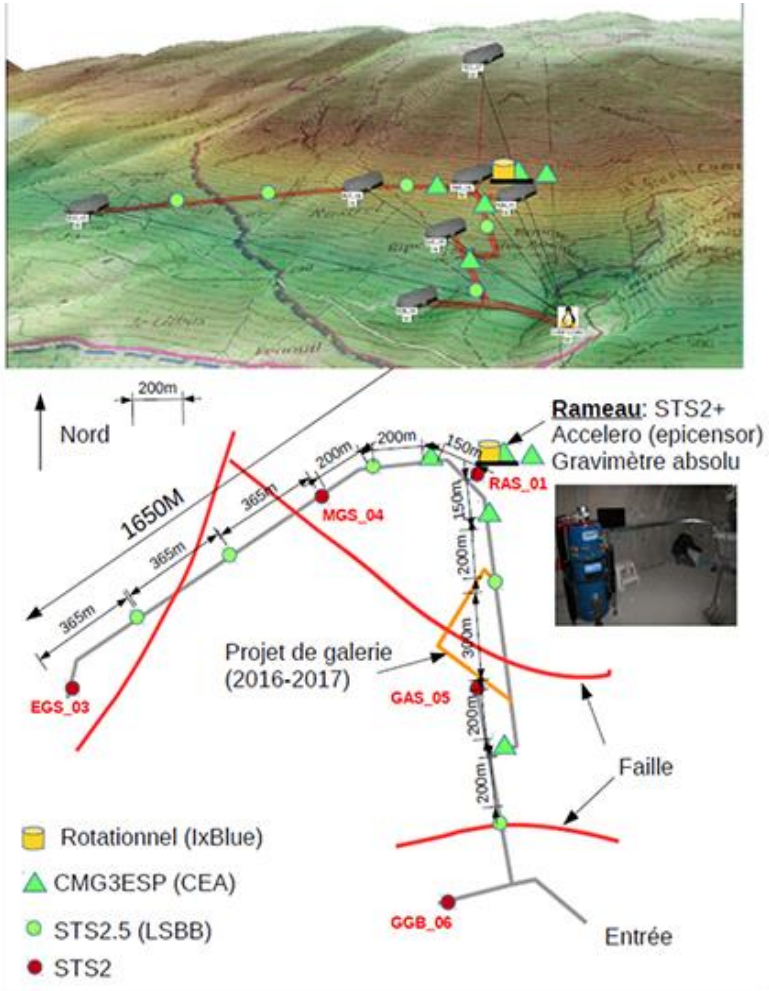
→ ENABLE 3D CONFIGURATION FOR SEISMIC INSTRUMENTATION, ROTATION FIELD MEASUREMENT

Comparison of measurements from an interferometric fiber-optic gyroscope and
the spatial derivation of the seismic rotation field recorded by a dense network of seismometers





Laine & Mougenot, SEG 2014 EGU 2018



Comparison of gravimetric, micro-barometric, velocimetric, accelerometric measurements in a broad frequency band

WINLIGHT : Surface control of mirrors at nanometer level

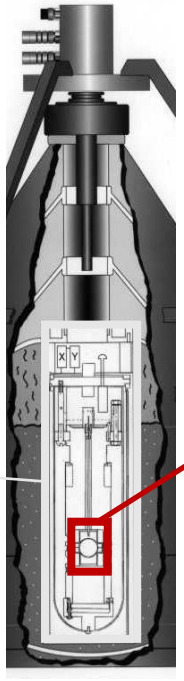
Aménagement du laboratoire de métrologie et de retouche

Développement des process et bancs de métrologie

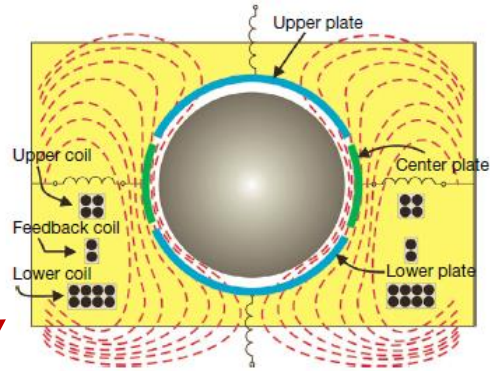
Inauguration 15 novembre 2021

→ SUPERCONDUCTING GRAVIMETRY @ LSBB SINCE 2015

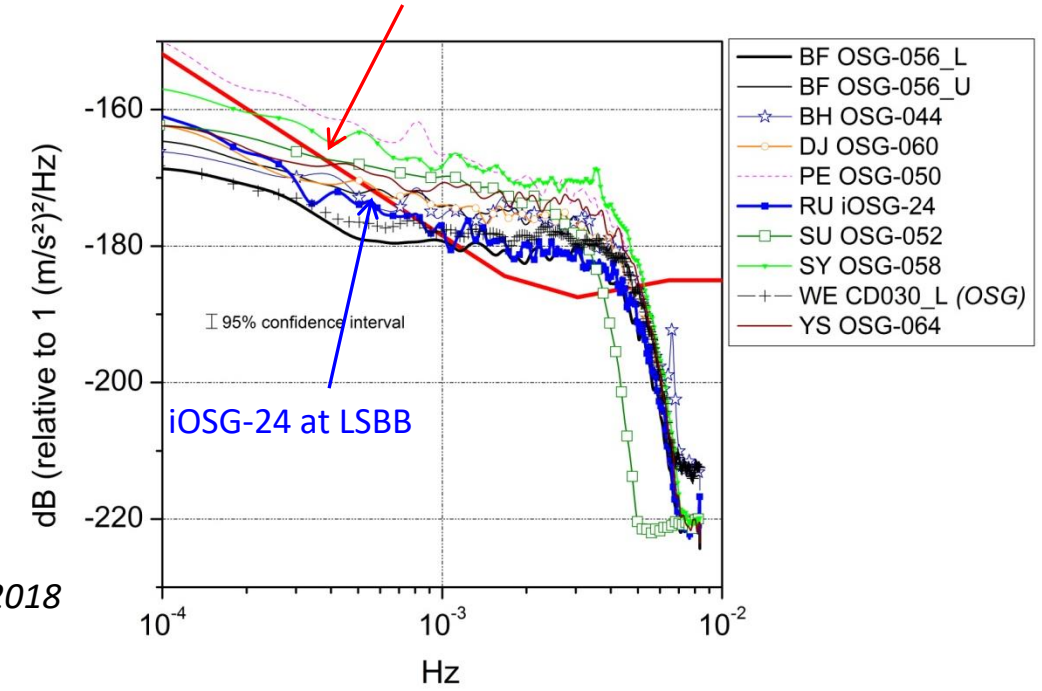
iOSG-24 @ LSBB → **one of the quietest site in the world**



Levitating Superconducting
Nb sphere (4K)

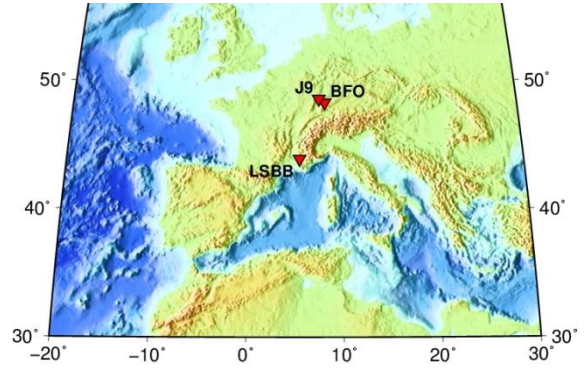


Seismological New Low Noise Model (Peterson, 1993)



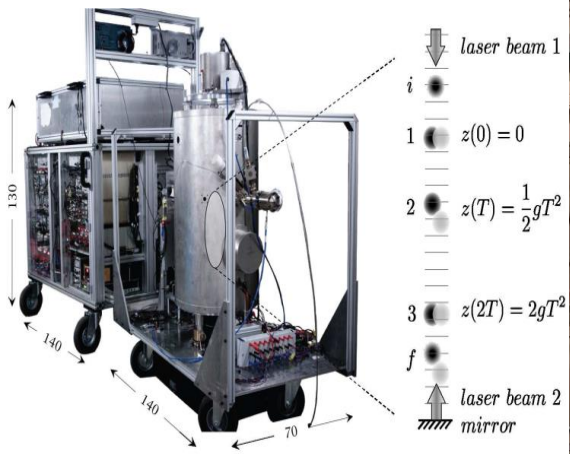
Rosat et al. 2016, 2018

- ✓ Magnetic feedback very low instrumental drift (a few µGal/year, where 1 µGal ~ 10^{-8} m/s²)
- ✓ Very high sensitivity at the nanogal level (~ 10^{-12} g)
- ✓ International node (iOSG-24) and continuous measurement of time-varying gravity: to be used for a consistent and rigorous quality check and intercomparison with the MIGA antenna

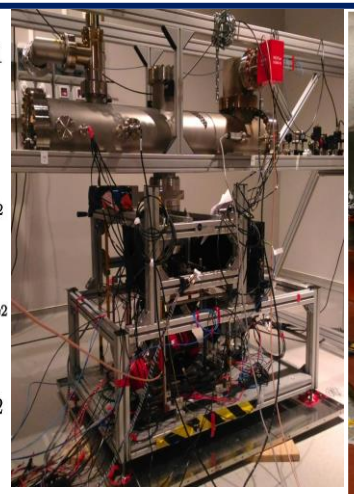


LSBB
Laboratoire Souterrain à Bas Bruit
Low Noise Inter Disciplinary Underground Science & Technology

ATOMIC INTERFEROMETER FOR GRAVITATION GRADIENT INVESTIGATION

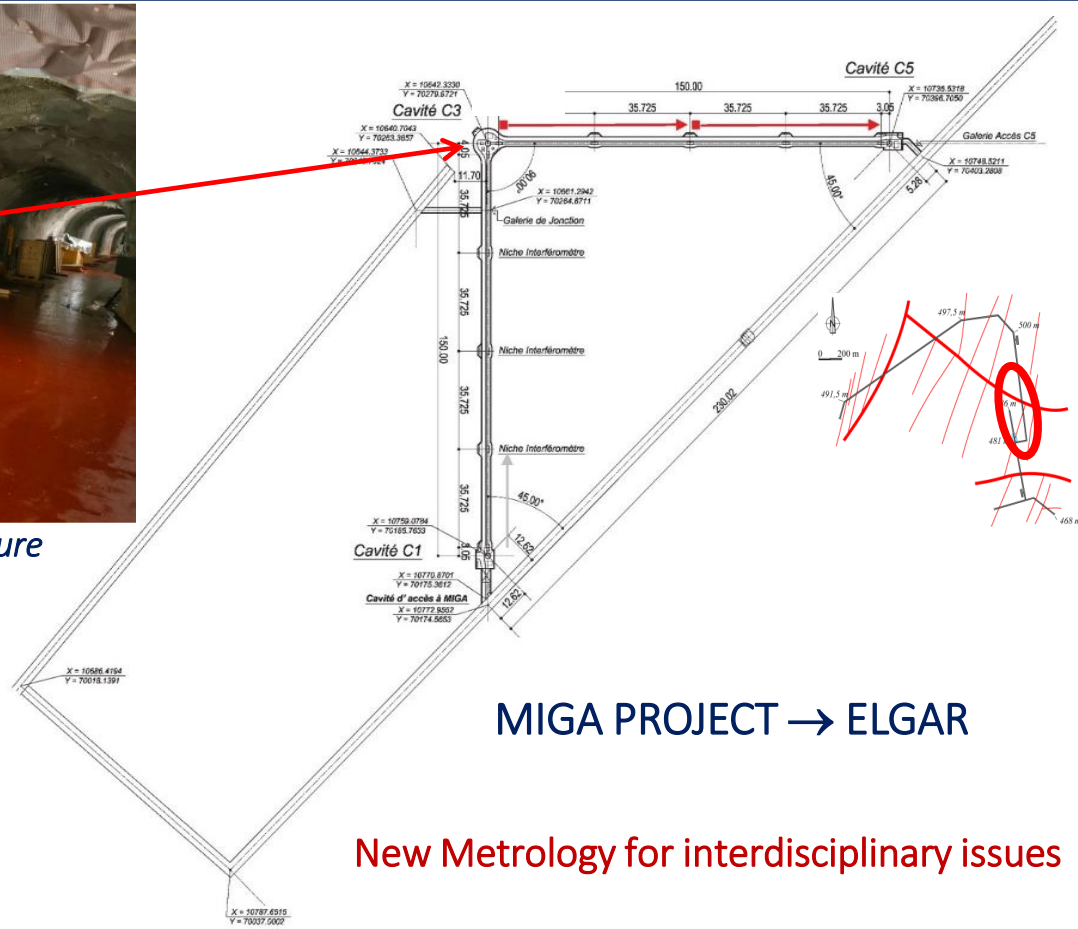


Cold atom gravimetry
(Observatoire de Paris)
Farah et al., Gyr. & Nav. 2014



Cold atom sources
(LP2N, SYRTE 2018)

Underground infrastructure
(LSBB, 2023)



MIGA PROJECT → ELGAR

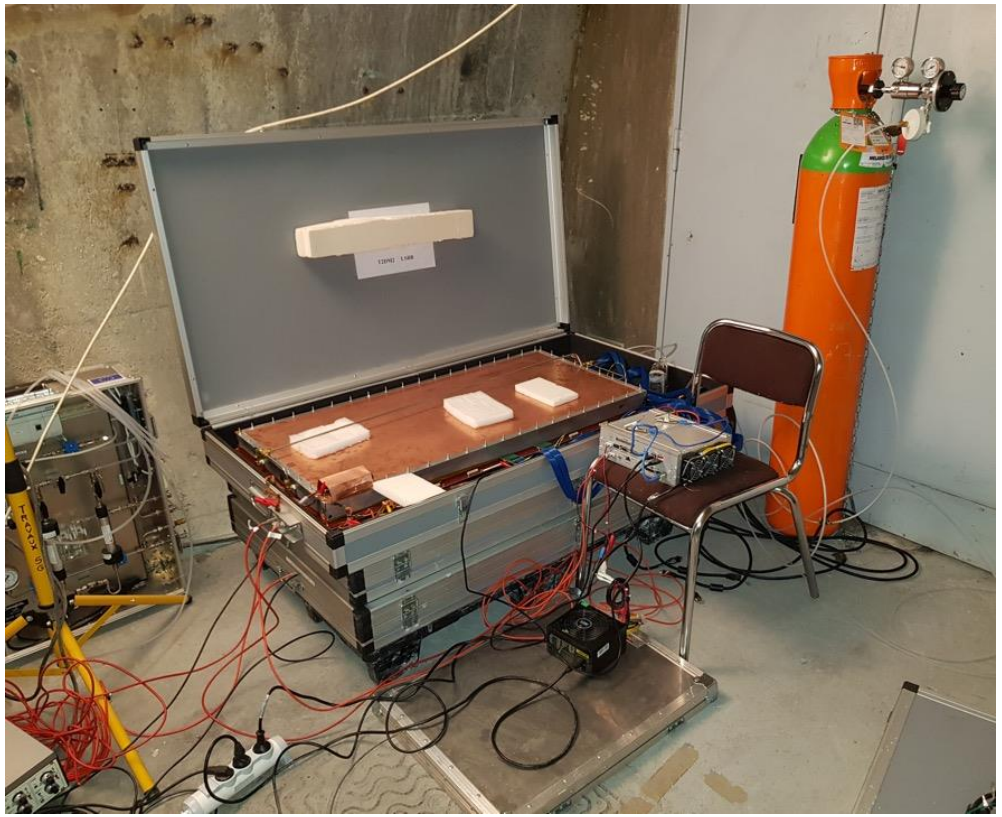
New Metrology for interdisciplinary issues

Prototype and exploration of the environmental conditions for future sub-Hz ground based GW detectors base on Multi-photon Atom Interferometry

- GW in astrophysics
- Very small changes from local to regional gravity field

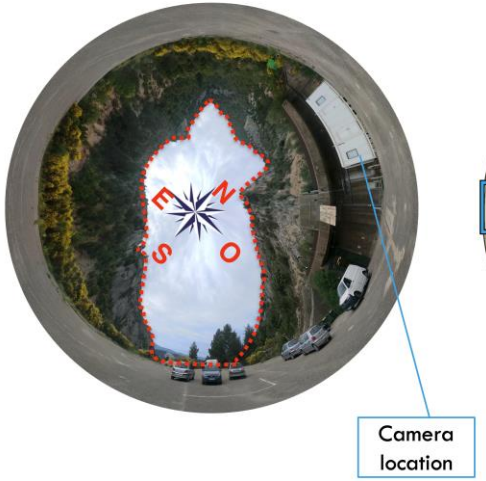
HIGH SENSITIVITY INSTRUMENTS & MEASUREMENT METHODOLOGY

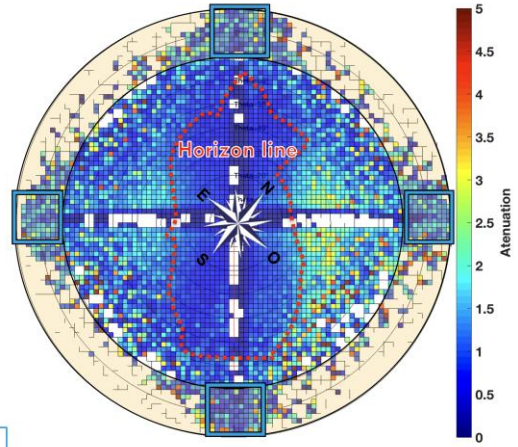
→ INHOUSE MUON TRACKING TECHNOLOGY

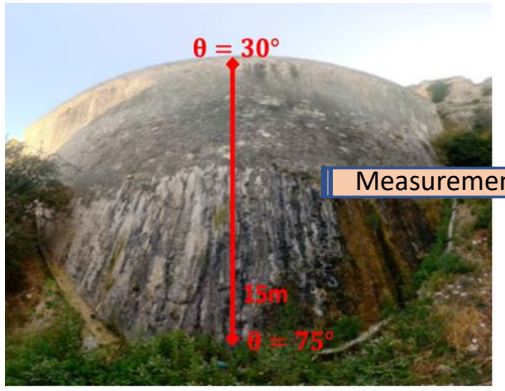


Lázaro Roche et al., 2021

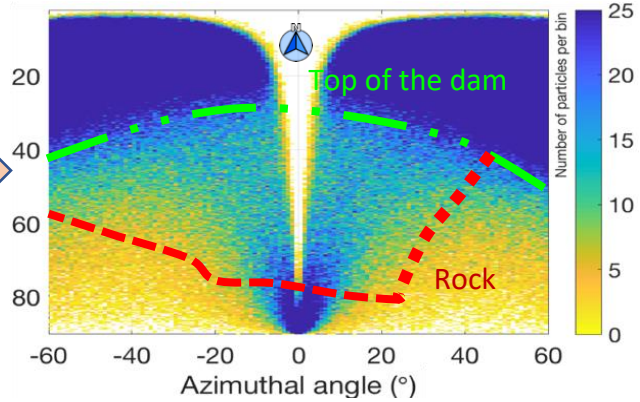
- Patented technology and ongoing valorization
- Network of 20 inhouse, autonomous, detectors
- Permanent setup for groundwater monitoring and mobile muon trackers for large civil structures survey.

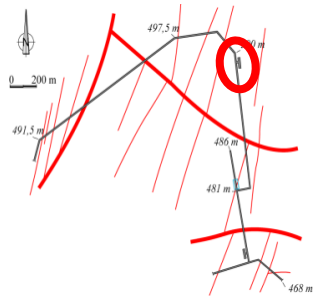






Measurement

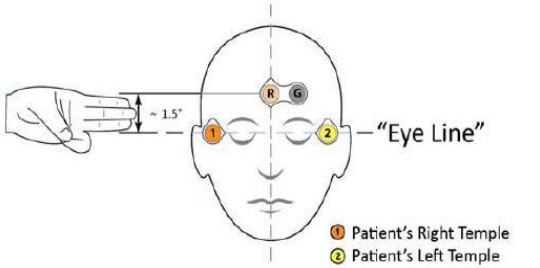




→ IRP MAXWELL BERGER LABORATORY CNRS-LSBB / UBC-Vancouver

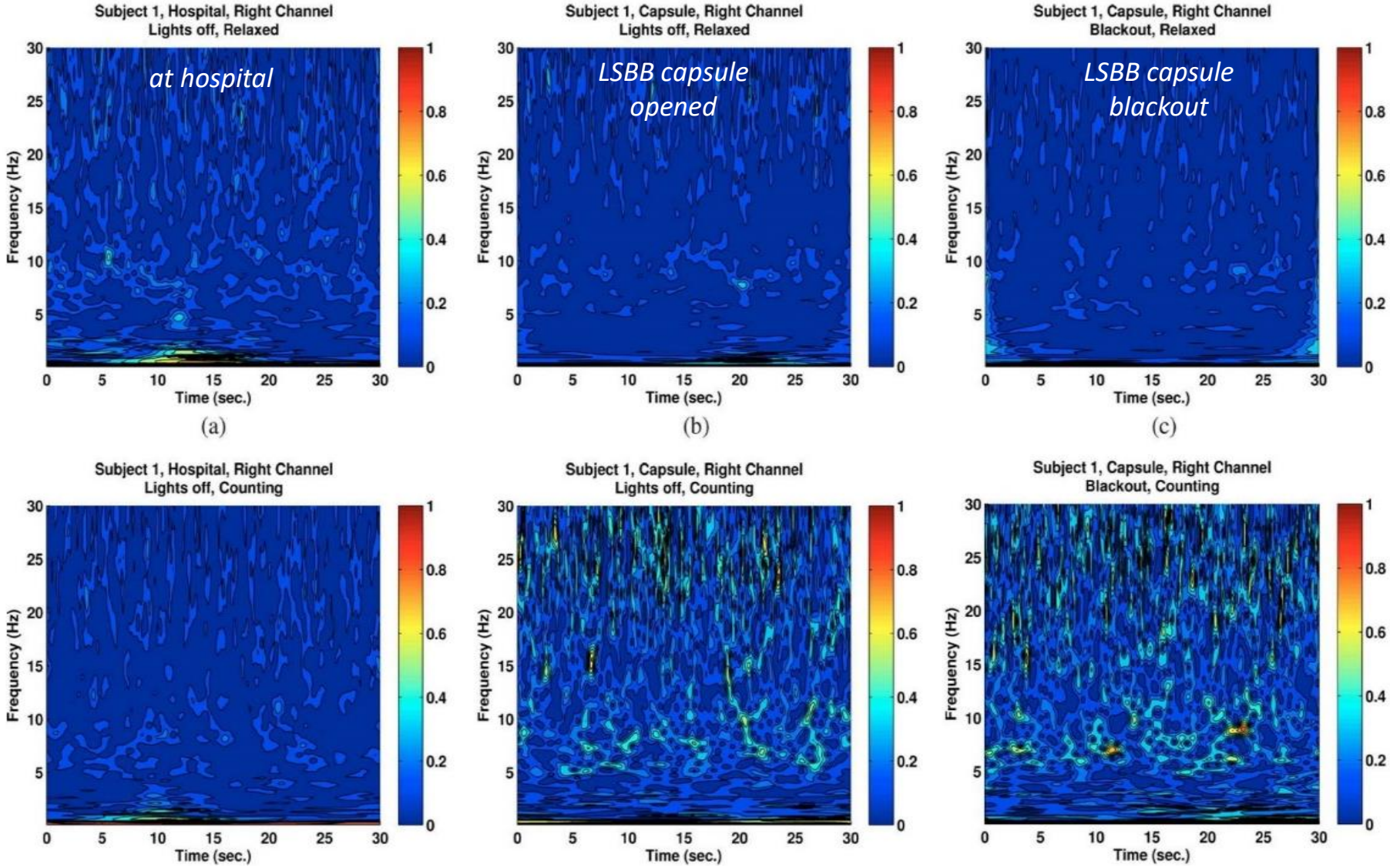
High sensitivity electroencephalography (EEG)

RELAXED SUBJECT



Shahidi Zandi et al., IEEE/TMBE 2011
Hamzei et l., 2016

COUNTING SUBJECT



ACCESS TO LSBB

The LSBB is open to collaborations and to hosting any project that respects the environment and the low background noise

→ **CONTACT MAILS : contact@lsbb.eu & direction@lsbb.eu**

→ **HOW TO DEVELOP AN ACTIVITY AT LSBB ?**

- **COMPLETION OF THE ACTIVITY SHEET** describing the research activity planned (see *lsbb.cnrs.fr → PROPOSE AN EXPERIENCE*)
- **ANALYSIS CRITERIA** by the LSBB direction – Compatibility with the low noise, the environment, the capacity of LSBB and with the forthcoming or already underway experiences
- **FEEDBACK AND ADAPTATION** of the activity where appropriate, discussion of the needs and cost of implementation
- **LEGAL AGREEMENT** with the CNRS including compliance to internal rules of LSBB (safety, low noise, dissemination, if necessary, condition for long-term residence defining the modality of maintenance)
- **PLANNING FOR IMPLEMENTATION** at LSBB including the workload of the engineer team of LSBB

Merci, bonne visite
et à bientôt au LSBB