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# FROM FIBERS & COMPONENTS TO SENSING SYSTEMS

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1. Exail – iXblue overview

2. Specialty Optical Fibres

3. Components: modulators, optical hybrid, DFBs

4. From fiber to systems: Fiber based Dosimetry



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# Eca + iXblue = exail
# Stronger together

**1500**

EMPLOYEES

**250+**

MILLIONS EUROS
OF TURNOVER

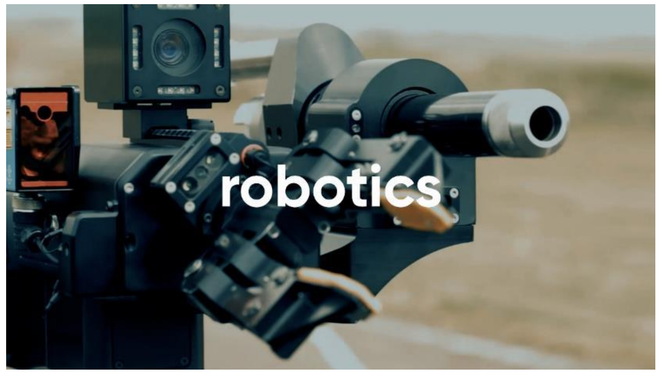
**20+**

% OF TURNOVER
INVESTED IN R&D

**80%**

OF TURNOVER
IN EXPORT

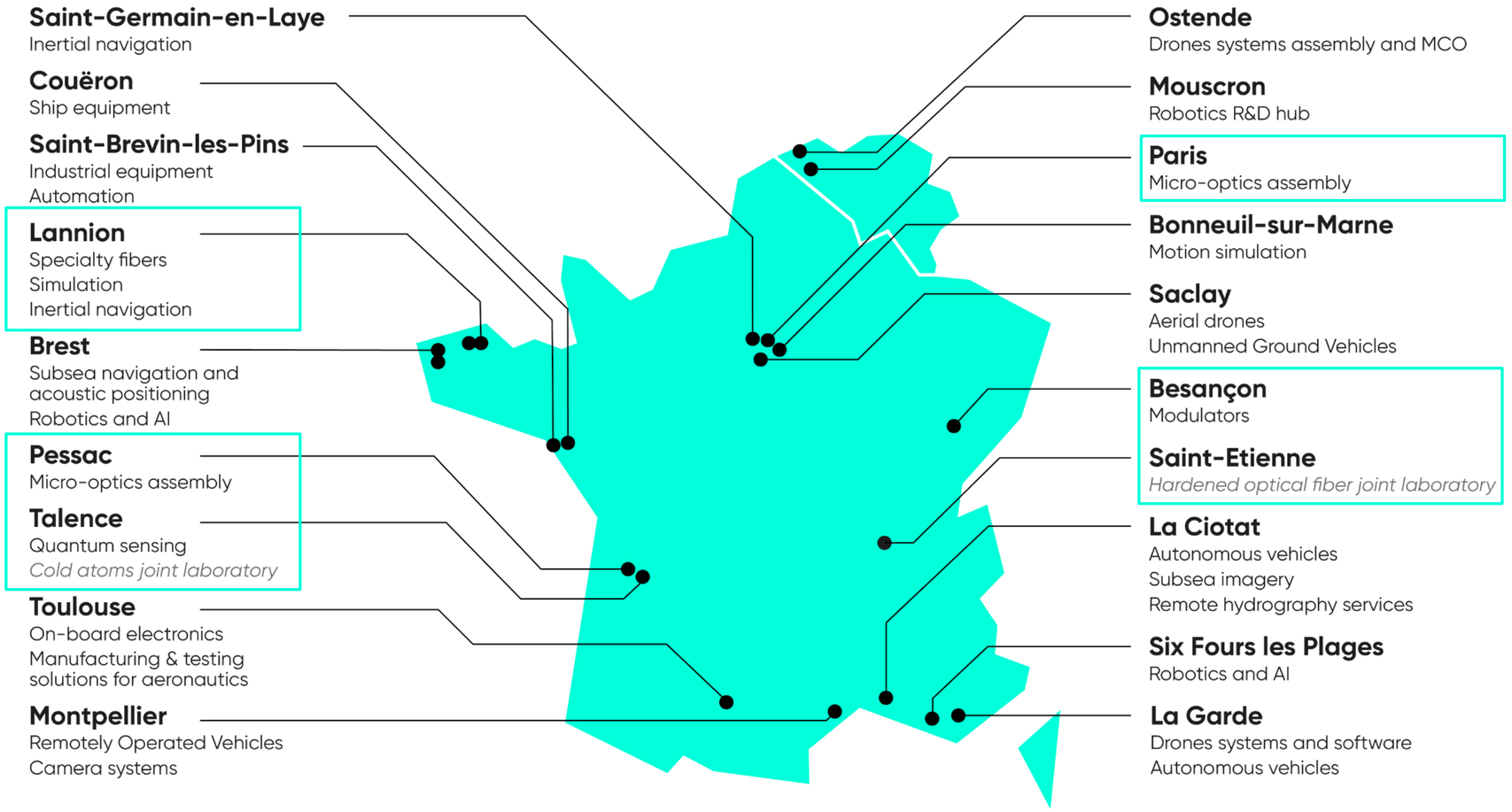
# Cutting-edge technologies







# A unique technological know-how



**Saint-Germain-en-Laye**
Inertial navigation

**Couëron**
Ship equipment

**Saint-Brevin-les-Pins**
Industrial equipment
Automation

**Lannion**
Specialty fibers
Simulation
Inertial navigation

**Brest**
Subsea navigation and acoustic positioning
Robotics and AI

**Pessac**
Micro-optics assembly

**Talence**
Quantum sensing
*Cold atoms joint laboratory*

**Toulouse**
On-board electronics
Manufacturing & testing solutions for aeronautics

**Montpellier**
Remotely Operated Vehicles
Camera systems

**Ostende**
Drones systems assembly and MCO

**Mouscron**
Robotics R&D hub

**Paris**
Micro-optics assembly

**Bonneuil-sur-Marne**
Motion simulation

**Saclay**
Aerial drones
Unmanned Ground Vehicles

**Besançon**
Modulators

**Saint-Etienne**
*Hardened optical fiber joint laboratory*

**La Ciotat**
Autonomous vehicles
Subsea imagery
Remote hydrography services

**Six Fours les Plages**
Robotics and AI

**La Garde**
Drones systems and software
Autonomous vehicles

**21 INDUSTRIAL SITES**

**2 JOINT RESEARCH LABORATORIES**

# The Exail Photonics activities


Specialty Fibers - Lannion Fibers

IXFIBER

Quantum Sensors - Talence

*Instruments and Lasers*

µQUANS

Photonic Solutions - Pessac

*Free space micro-optics assembly*

SYSTEMS

kylia

Photonic Solutions - Paris

*Free space micro-optics assembly*

kylia


*Modulation Solutions - Besançon*

Photline TECHNOLOGIES

**LabCom**
**IOGS/LP2N**
***iXatom***

**LabCom**
**Univ St Etienne**
***LabH6***



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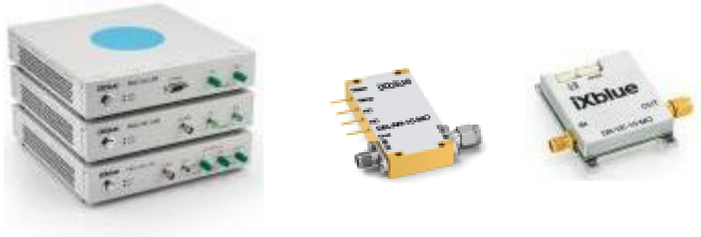
# Photonics and Quantum COTS solutions, from components to instruments

## › Scalable technologies to address a full range of applications

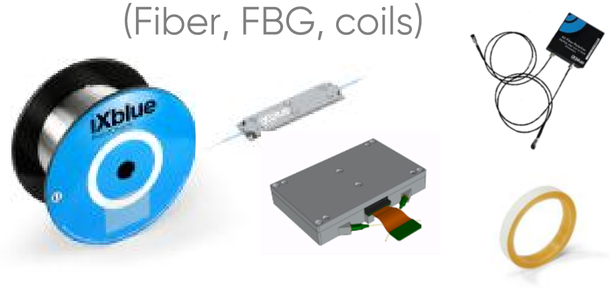
**Components**

$LiNbO_3$ Phase, Amplitude, IQ Modulators (COTS, Space model)

Modulators Matching components (RF Amplifier, Low Noise Electronic)



Fibers and fiber solutions (Fiber, FBG, coils)



**Turn-key devices and systems**

µoptics and passive optics integration

Transmitters, transceivers, laser pilot, coherent regeneration station

Lasers (Narrow-linewidth, high-power) Optical Low Noise & Power amplifiers

**Instruments**

Absolute Quantum Gravimeter

Cold atom frequency metrology

# Examples of high-end sensor solution in Exail

- **Fiber Opic Gyroscope based navigation system for satellite**
- **As far as Lagrange point !**

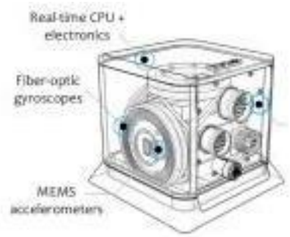
**Components** → **Systems** → **Solutions**

Integrated electro-optical component

PM Optical fiber

FOG

Accelerometer




Inertial Navigation System

Optical Systems for space

- **Absolute Quantum Gravimeter**
- **g with 10-8 m/s2 (1 µGal) accuracy**

**Components** → **Systems** → **Solutions**

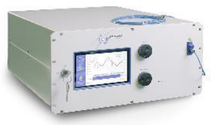
Doped Fiber

Fiber Amplifier

Modulators & PPLN

iMOB

Low noise electronic



Laser

Intelligent Laser System

Gravimeter

# 2. SPECIALTY OPTICAL FIBERS

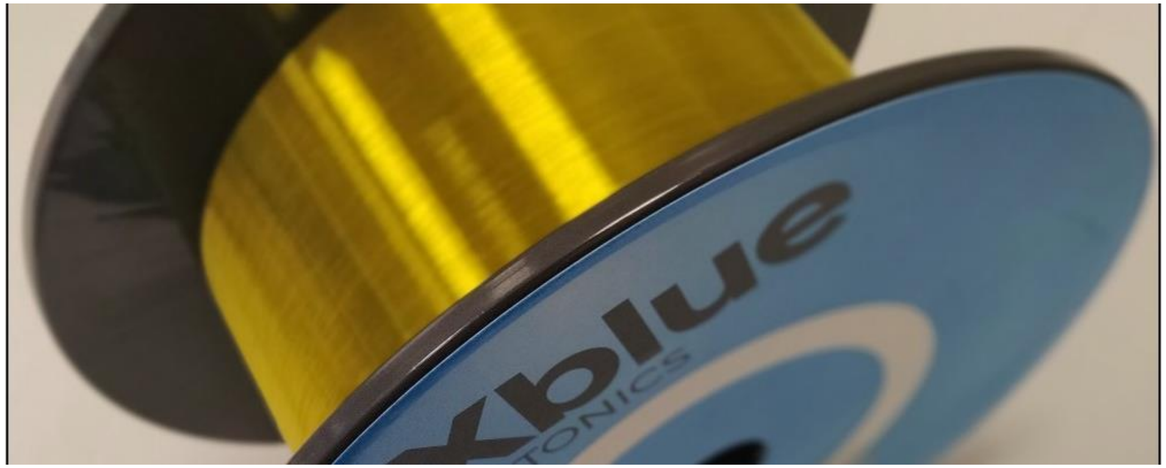
## SENSING MEDIUM

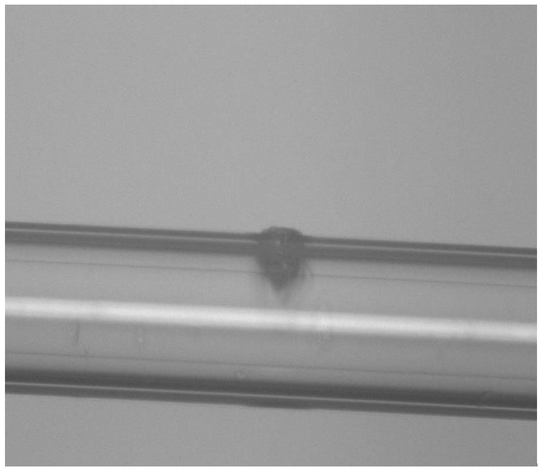
# SM & MM Optical Fibers for Harsh Environment

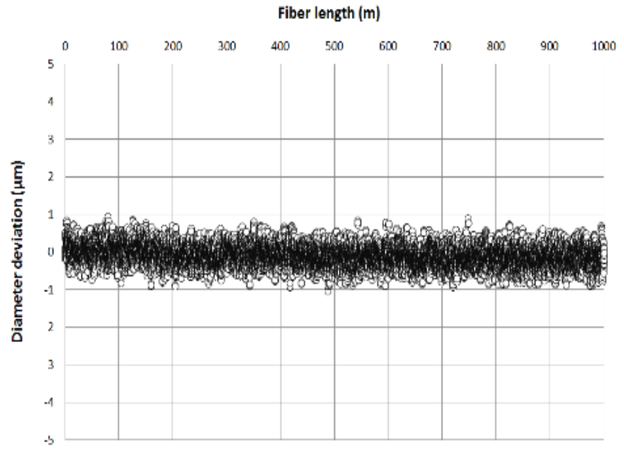
- **From 350 to 2100 nm**
- **From 40 to 650 µm cladding**
- **From 2 to 600 µm core**
- **SM, MMSI, MMGI**

- **High Temperature Acrylate Coating**
  - +150°C long term operation

- **High Quality Polyimide Coating**
  - Ideal for temperature sensing
  - +300°C long term operation
  - Validated also at Cryogenic temperature
  - Low outgasing for space applications
  - Fully qualified for volume production
  - SMF suitable for FBGs femto inscription
    - No coating defect
    - Ex: 2000 FBGs with 10 cm spacing



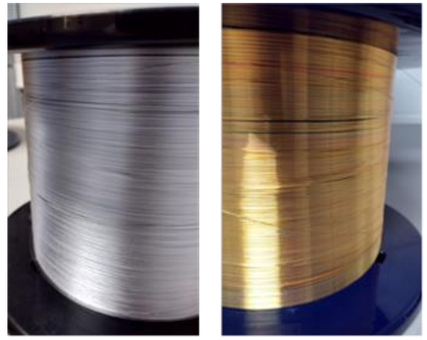



More info in the Application note on polyimide fibers :

# Metallic and Carbone Coatings

- **Coating to match max. temperature range**
- **Aluminum coating suitable for soldering – embedded fiber sensor in metallic pieces**
- **Carbon layer for hydrogen, water bareer**

| Coating | Max. temperature |
|---|---|
| Acrylate (Telecom Type) | 85°C |
| Acrylate High Temperature | 150°C |
| Polyimide | 300°C |
| Aluminum | 400°C |
| Carbon+Coper | 600°C |



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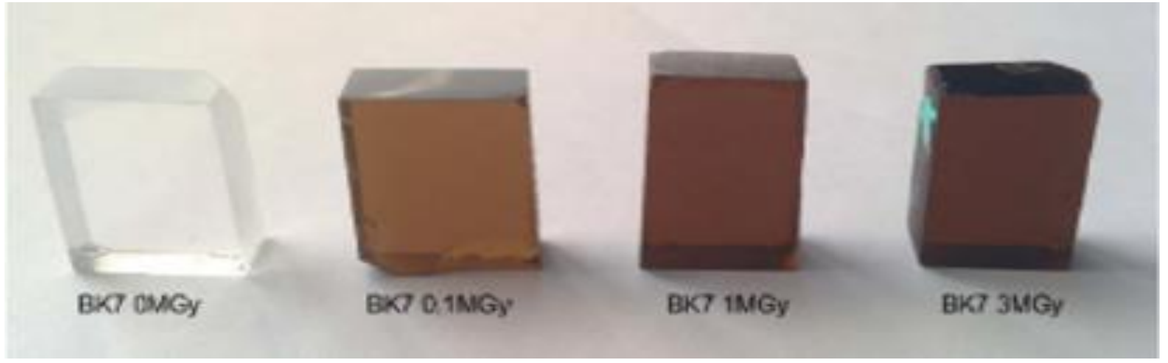
TA TechnicAtome

EDF

# Radiation Hardened fibers

- **25 years experience in rad-hard fibers**
- **labH6 joint-research laboratory with Laboratoire Hubert Currien**
- **Be careful to all parameters:**
  - Debit dose/total dose/ radiation type
  - Temperature
  - Wavelength
  - Coatings



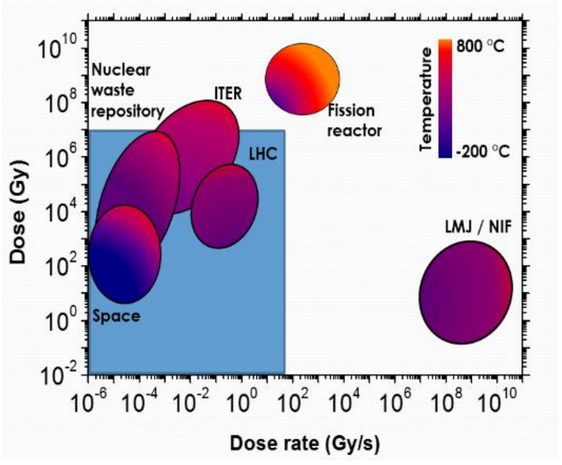
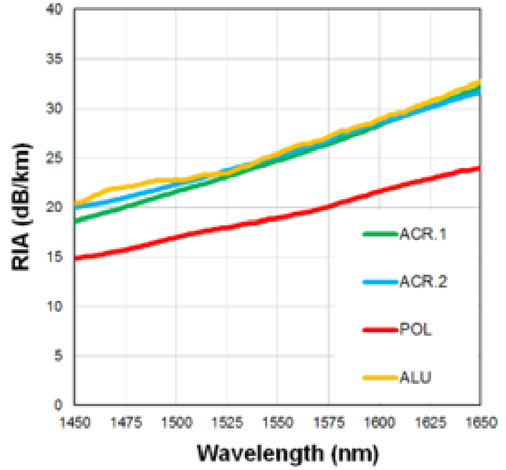
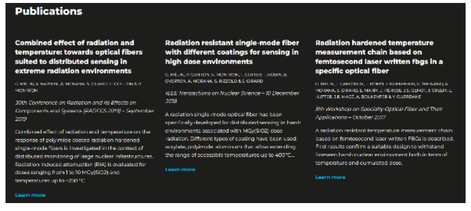




Image from *"Radiation Effects on Silica-Based Optical Fibers: Recent Advances and Future Challenges"*




*Spectral RIA of different samples fiber with various coating with 750 kGY irradiation*

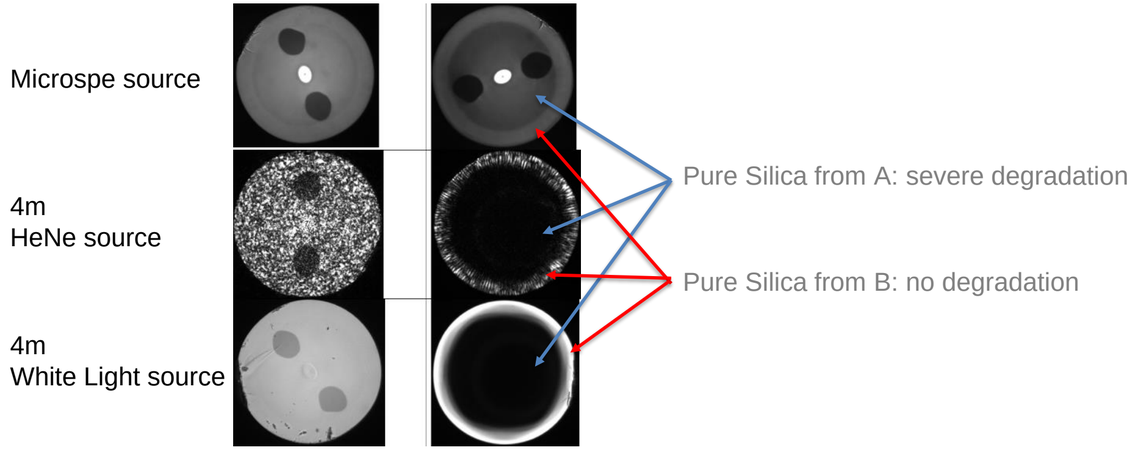
Publications available :



# Radiation Hardened fibers

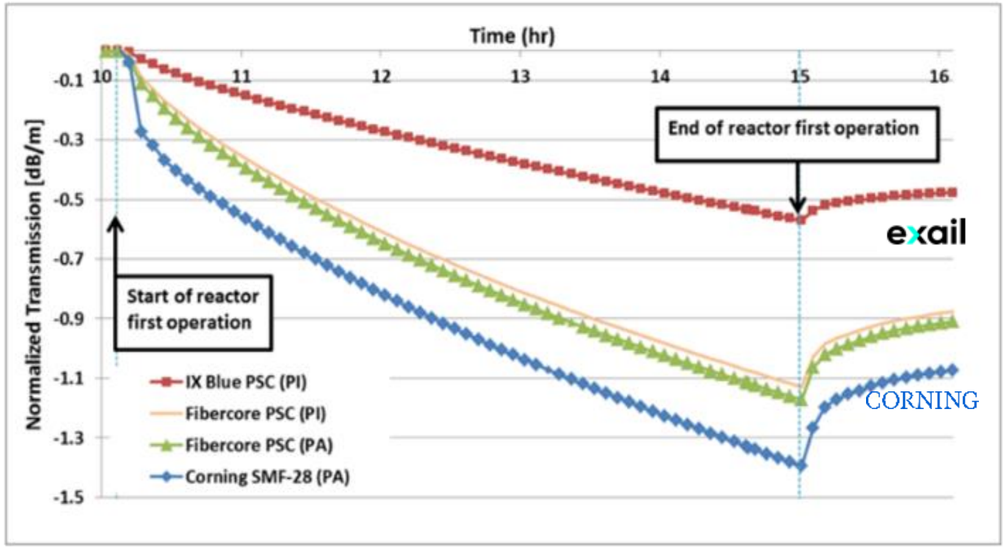
## Pure Silica Core is not enough !

- Measurement in Nuclear reactor
  - Exail: 2x better RIA than competitive PSC fibers
  - RIA : 0,55 dB/m RIA @4MGy @ 1550 nm




## Large choice of standard Rad-Hard fibers

- Three Grades:
  - Radiation Tolerant
  - Rad-hard
  - Super Rad-hard
- From UV to 2µm
- SM & MM




From "*Characterization of radiation hardened fibers in a research grade nuclear reactor*"

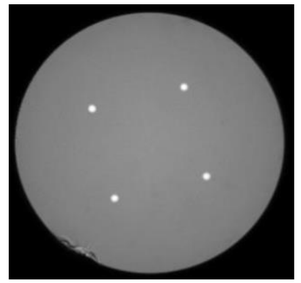
## Custom fibers from prefrom to fibers

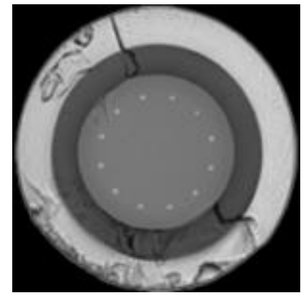
# Multicore and Hollow Core fibers

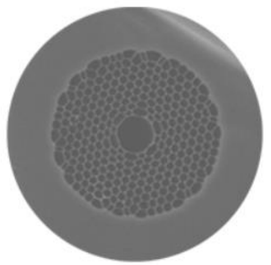
- **Multicore fibers**
  - In-house mastering of the entire doped and passive fiber core manufacturing: form core preform deposition to fiber draw
  - Germanium, Phosphorous but also doped cores
  - All specs could be customized
- **Super custom available through Photonics Bretagne: high number of cores & draw tower FBG inscription.**

- **Air core: Hollow Core & Anti-resonant fibers by Photonics Bretagne**
  - Gas sensing
  - Low latency
  - High power delivery

- **Available from stock:**
  - 2 cores
  - 4  cores, 980 nm to 1550
  - 7 cores, 1550
  - 12 cores







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# 2. COMPONENTS

## IMPROVED DETECTION



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# High contrast pulses for BOTDA
# Lithium Niobate Electro Optic modulators and matching components

## MXER-LAN intensity modulators

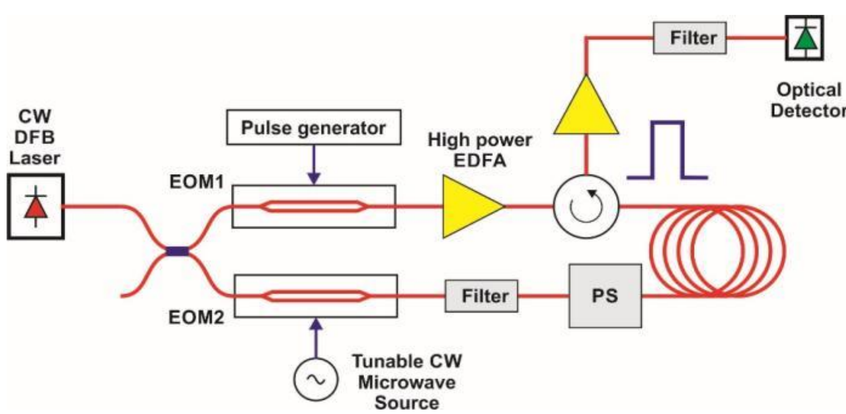
- Based on patented Majic junction
- High extinction ratio, up to 40 dB

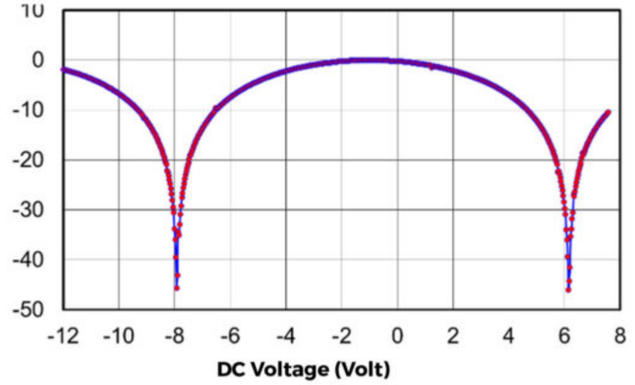
## DR-VE-10-MO drivers

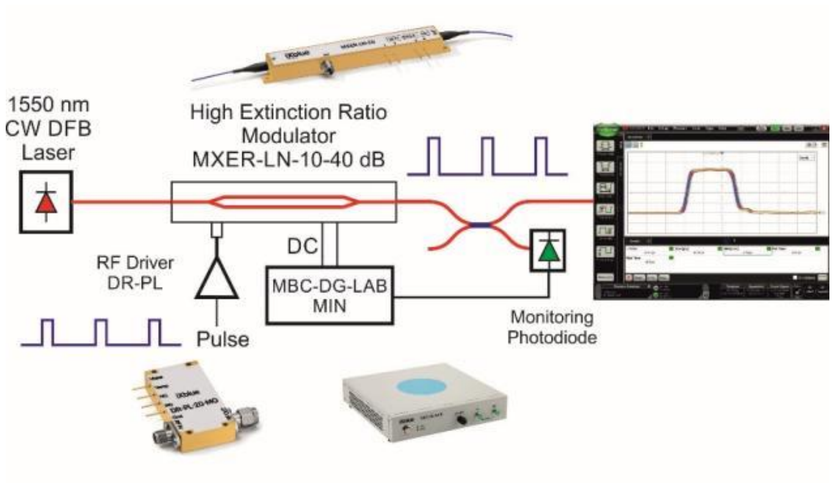
- Generate undistorted optical pulses
- from 70 ps narrow pulse to 300 ns longer pulseing

## Modulator Bias Controler

- To control the drift



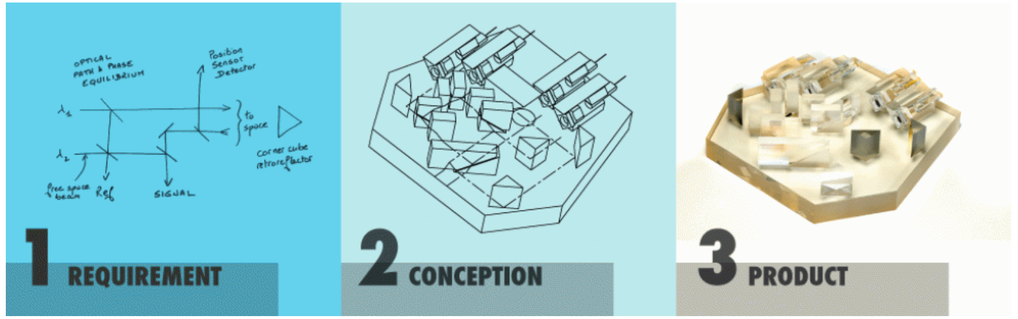

More info in the Application note BOTDA

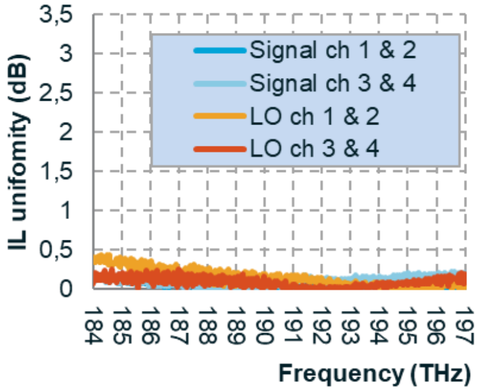
# For improved detection : 90° & 180° Optical Hybrid Integrated Micro-Optical Benches

- Mixing Signal with a Local Oscillator
- Based on polarization
- Adding a 90° phase shift between In-phase outputs and Quadrature outputs
- Enables to recover phase and amplitude of a signal

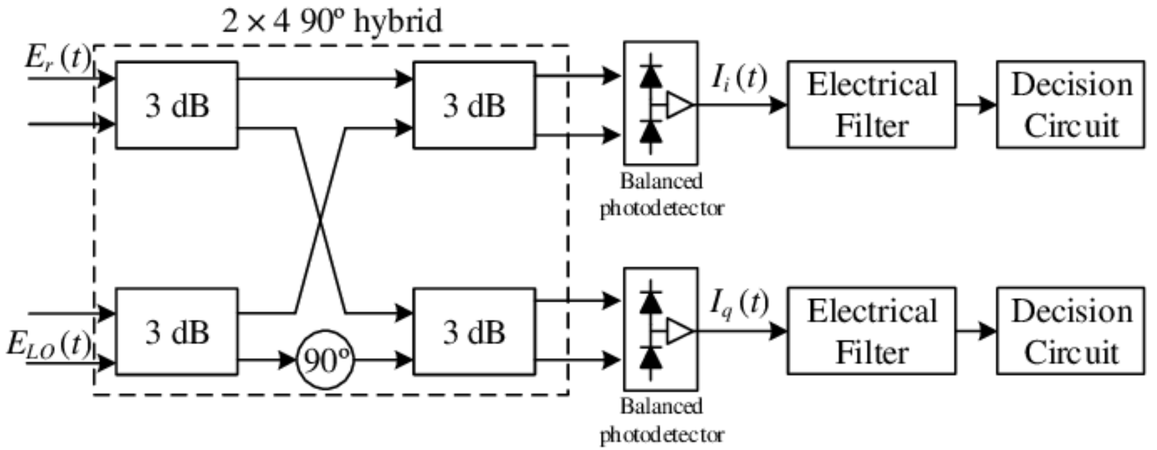
## Applications :

- Metrology (Lidar, Distributed Temperature Sensing) or medical (OCT)
- Coherent detection (QKD generation)
- Optical fiber Telecom systems



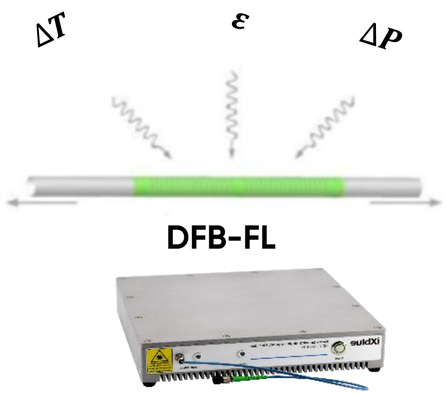



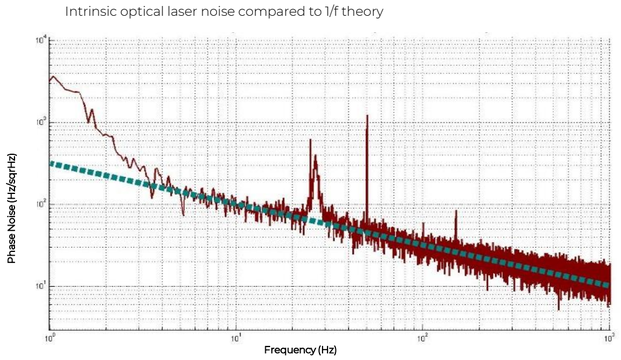




# DFBs- Single Frequency Narrow Linewidth Fiber Laser

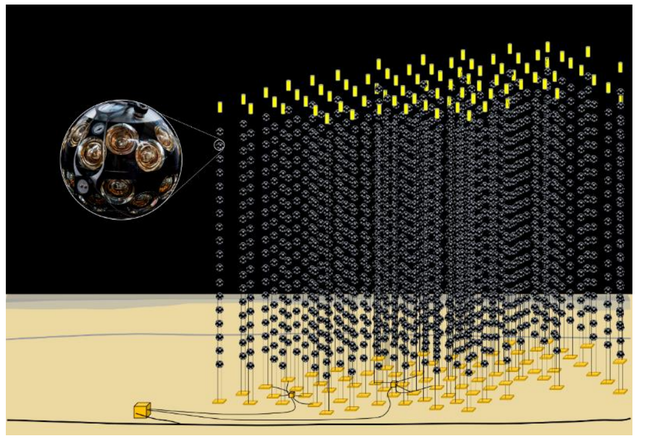
- **Pi-shifted FBG inscribed on active fiber**
- **Nd (0.9 µm) , Yb (1µm), Er or ErYb (1.5µm), Tm (2µm)**
- **Advantages:**
  - Low Phase noise
  - Sub-kHz linewidth
  - Wavelength shift with temperature, strain, pressure.
  - Flexibility, large choice of wavelengths
- **Usage:**
  - Ultra narrow seed source for sensing
  - Bundle with the appropriate package: perfect acoustic sensor / hyddrophone
- **Example: Acoustic neutrino detection: European project KM3NeT (Kilometer Cube Neutrino Telescope)**
  - Acoustic cosmic ray detection in the deep sea
  - Many hydrophones (>1000) are required in a telescope

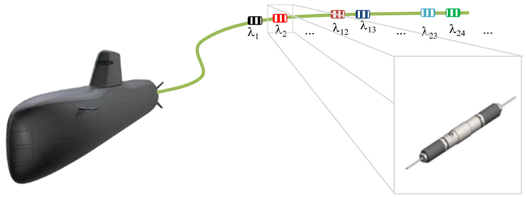




https://www.exail.com/customer-story/telescope-listen-universe/





https://www.km3net.org

# 3. FIBER BASED DOSIMETRY

## FROM FIBER TO SYSTEM



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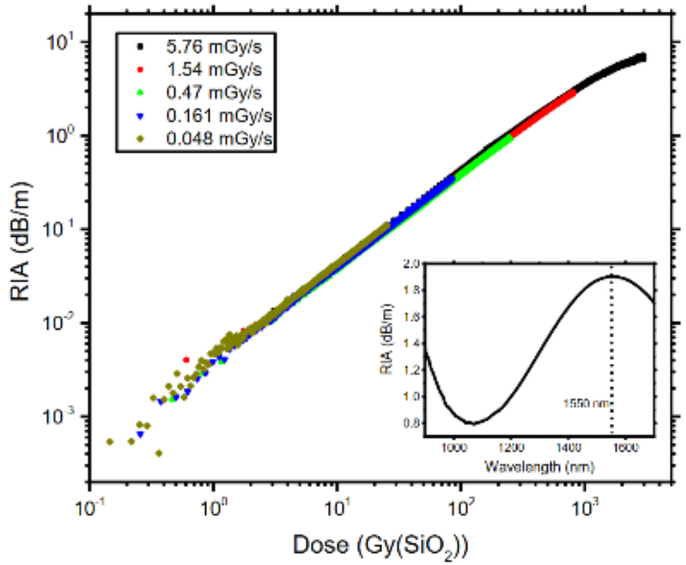
# RAD-SENSE fibers for dosimetry

- **Selected chemical composition to enhance fiber sensitivity to radiation**

- **Advantage of an all-fibered solution**
  - Ability to deport the measurement unit out of irradiated dose
  - Radiation Induced Attenuation (RIA) increases linearly with the cumulated dose, up to moderate dose levels
  - Limited dependence of the RIA to the dose rate and temperature(1)

(1) : "*Infrared radiation Induced attenuation of radiation sensitive optical fibers: influence of temperature and modal propagation*


From "*Qualification and Calibration of Single-Mode Phosphosilicate Optical Fiber for Dosimetry at CERN*"

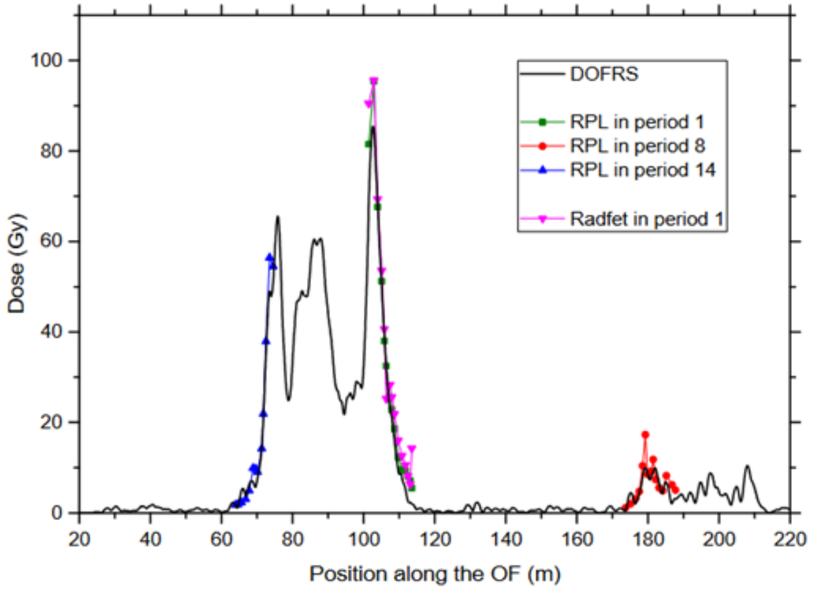
# Point and distributed dosimetry

## Point sensing

- Optical configuration:
  Light source → Rad-Sense fiber → Powermeter
- Single punctual dose measurement
- RIA measured with high resolution (mdB) & dynamic range (>50 dB)

## Distributed sensing

- OTDR based measurment – single ended
- Dose received along the fiber : can replace dozens / hundreds of point sensors
- Spatial resolution ~1 m
- Limited optical budget (~ 15 dB) of the OTDR
- Ex: *already deployed in CERN in the Proton Synchrotron Booster and Proton Synchrotron.*




From "*Dosimetry Mapping of Mixed-Field Radiation Environment Through Combined Distributed Optical Fiber Sensing and FLUKA Simulation*"

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