LABORATOIRE HUBERT CURIEN
UMR • CNRS • 5516 • SAINT-ETIENNE

labH6
A joint research lab between iXblue and UJM
https://photonics.ixblue.com/labcom/labh6

SYMPOSIUM 2019 • ISROS SOCIETY • TOULOUSE

Recent progresses on fiber-based technologies for radiation-rich environments

Sylvain Girard
sylvain.girard@univ-st-etienne.fr ; Phone: +33 477 915 812

UNIVERSITÉ JEAN MONNET SAINT-ÉTIENNE

Membre de UNIVERSITÉ DE LYON

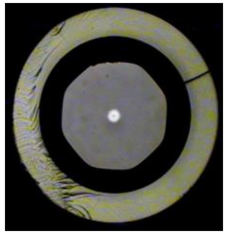
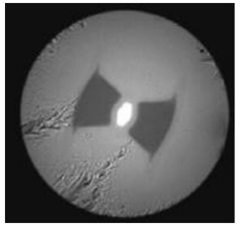
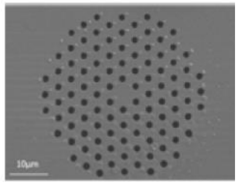
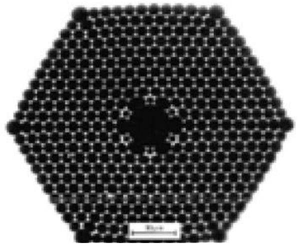
Outline

Introduction

- **Part 1:** Basic mechanisms of radiation effects on optical fibers
- **Part 2:** Recent Advances on radiation hardened optical fibers
- **Part 3:** Recent Advances on radiation hardened fiber-based sensors
- **Part 4:** Recent Advances on fiber-based dosimetry

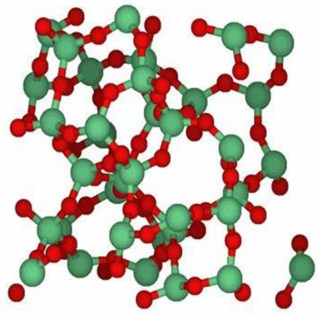
Conclusions

Fiber technology is still an active research domain ➔ new fibers, new functionalities appear driven by Telecom and sensing markets

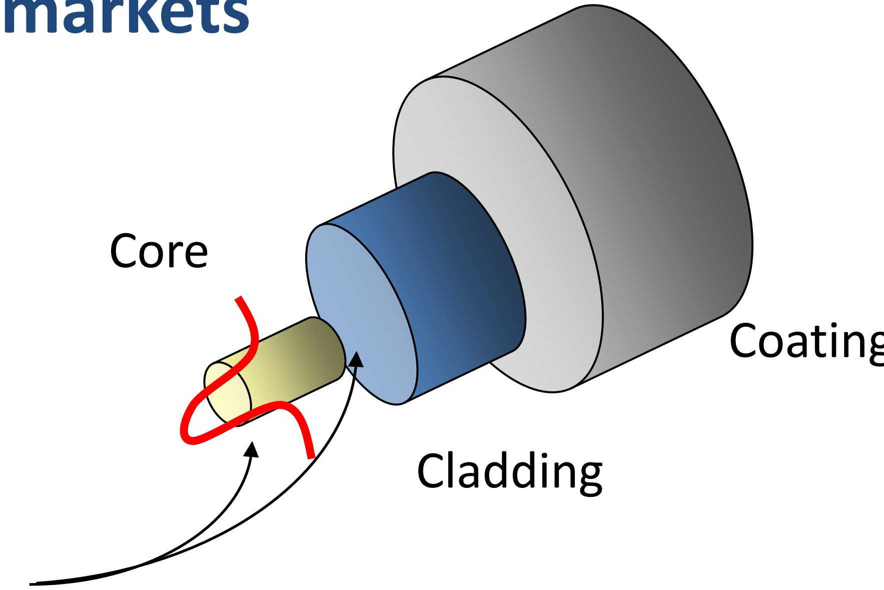





- Telecom-grade optical fibers : **Single-mode** or **Multimode**
- Polarization-maintaining optical fibers
- Rare-earth doped optical fibers
- Microstructured optical fibers
- Hollow core optical fibers
- Plastic optical fibers

- *Few modes optical fibers*
- *Multicore optical fibers*
- *Polarising optical fibers*
- *IR-optical fibers (sapphire)*

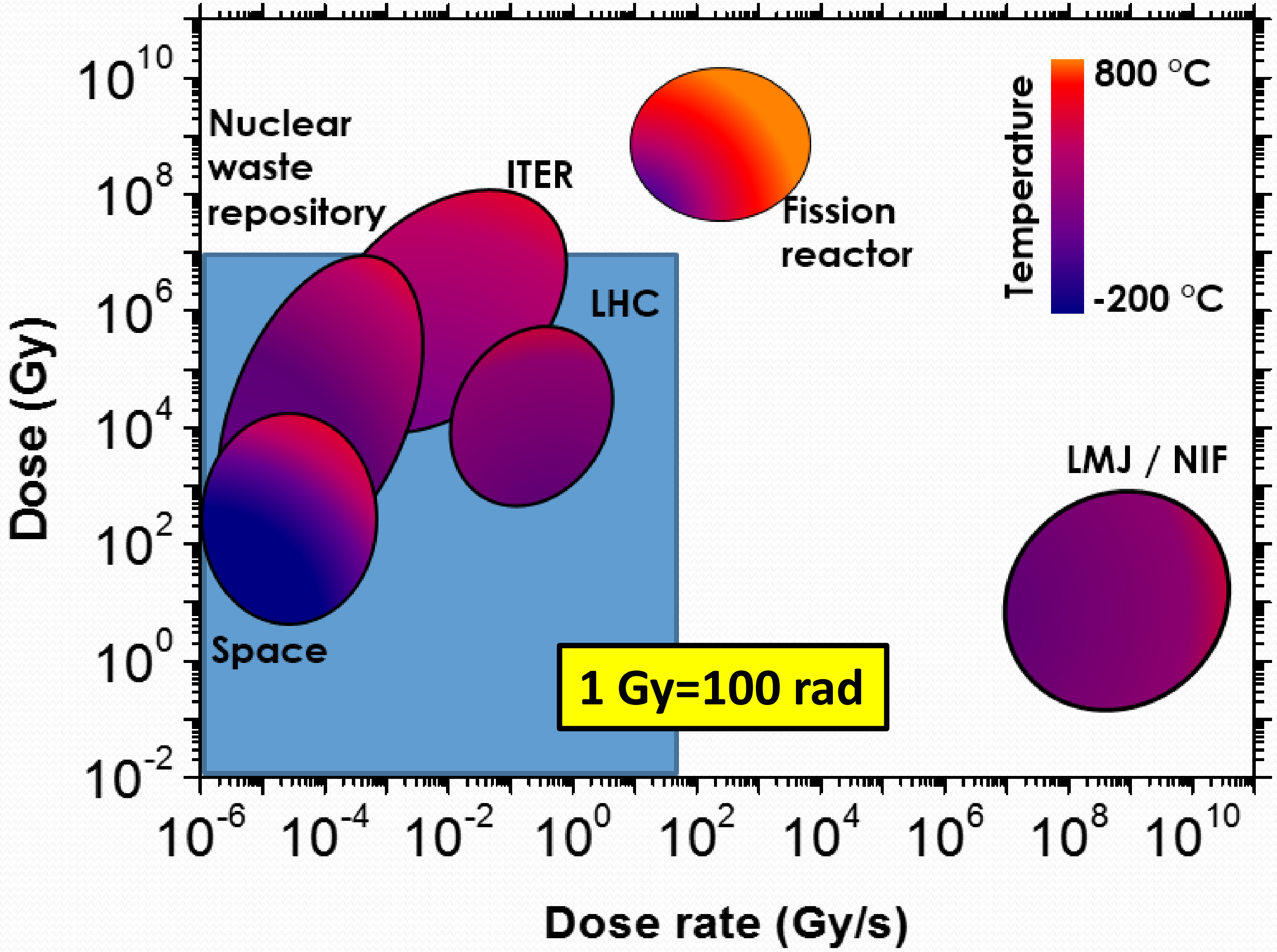


Amorphous silica (SiO_2)



In this talk, we focus on silica-based optical fibers for which the light guiding is ensured by Total Internal Reflection (TIR)

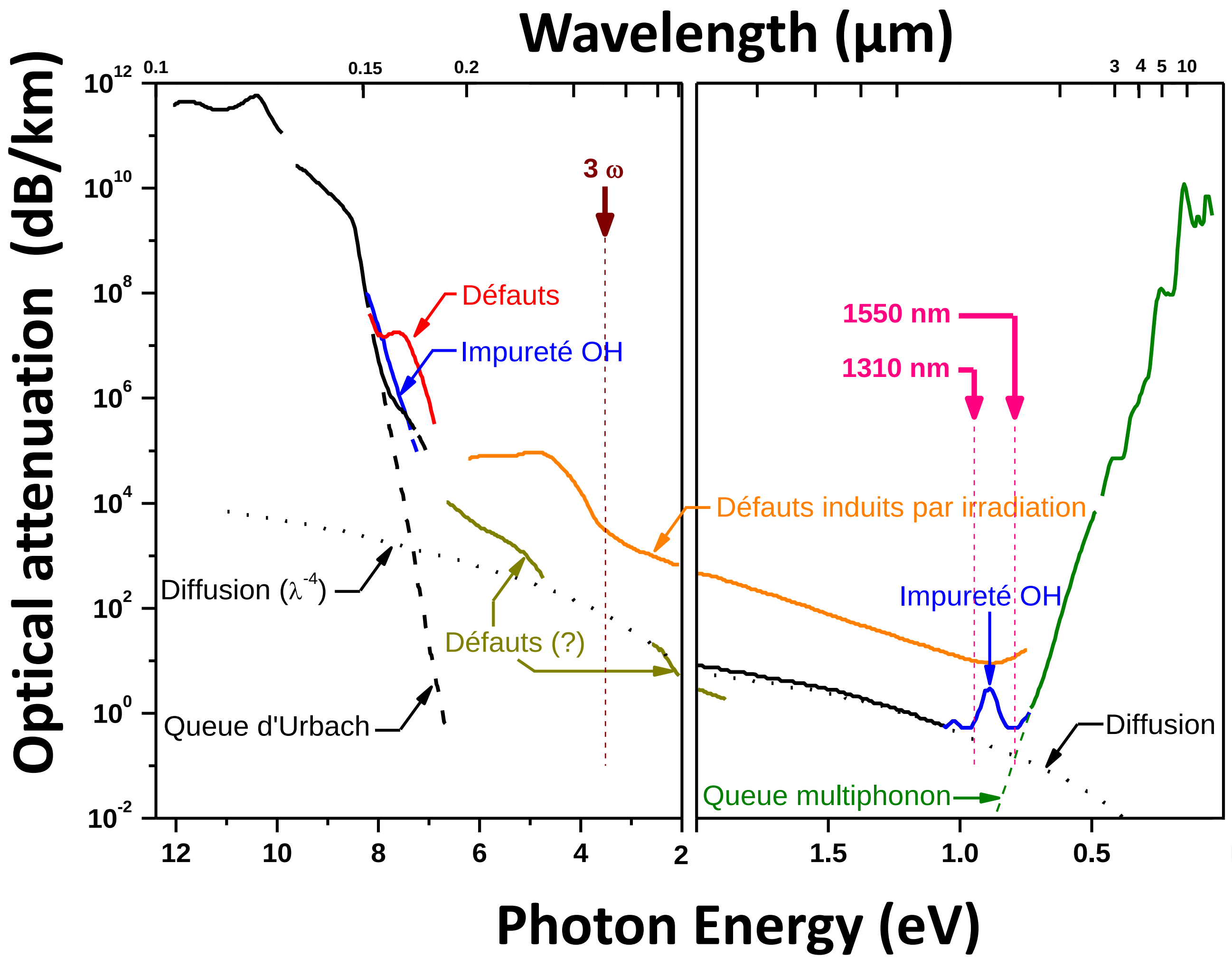
Optical fibers present key advantages for a variety of applications in harsh environments



1. Electromagnetic immunity
2. High bandwidth/ multiplexing capability
3. Low attenuation
4. Low weight and volume
5. High temperature resistance

- ❑ Data Transfert
- ❑ Diagnostics
- ❑ Point or distributed sensors
  - ✓ Temperature, Strain, Liquid level, radiations….

Silica-based optical fibers can be designed for light transmission from the ultraviolet to the IR part of spectrum (250 – 2µm)



- ✓ **Data links:** Telecom wavelengths
- ✓ **Diagnostics:** UV - visible
- ✓ **Fiber lasers:** visible - IR
- ✓ **Fiber amplifiers:** IR
- ✓ **Sensing:** visible - IR

The whole UV to IR domain is of interest for application in harsh environments

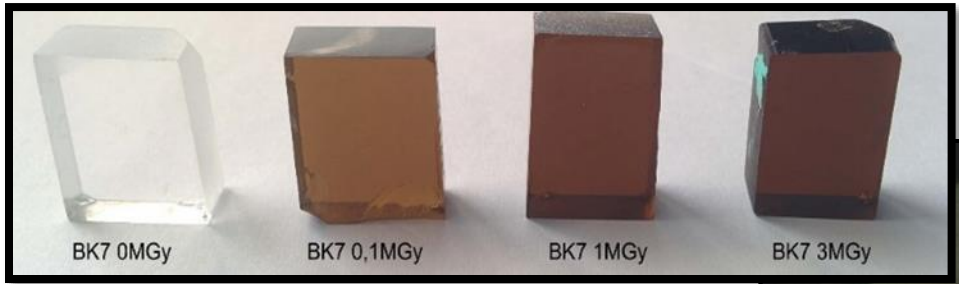
Part 1: Basic Mechanisms of Radiation Effects on Optical Fibers

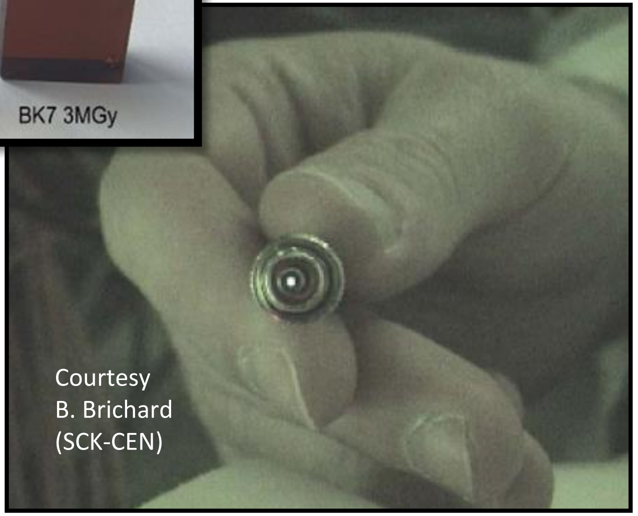
Review paper (2013) : S. Girard, J. Kuhnhenn, A. Gusarov, B. Brichard, M. Van Uffelen, Y. Ouerdane, A. Boukenter, and C. Marcandella, "***Radiation Effects on Silica-based Optical Fibers: Recent Advances and Future Challenges***", IEEE TNS, vol.60 (3) 2015 - 2036, 2013

Review paper (2018): S. Girard, A. Morana, A. Ladaci, T. Robin, L. Mescia, et al., "***Recent advances in radiation-hardened fiber-based technologies for space applications***", Journal of Optics, vol. 20, issue 9, article number # 093001, 2018.

Review paper (2019) : S. Girard, A. Alessi, N. Richard, L. Martin-Samos, V. De Michele, L. Giacomazzi, S. Agnello, D. Francesca, A. Morana, B. Winkler, I. Reghioua, P. Paillet, M. Cannas, T. Robin, A. Boukenter, Y. Ouerdane, **"Overview of radiation induced point defects in silica-based optical fibers"**, Reviews in Physics, vol. 4, 100032 (2019)

Three degradation mechanisms at macroscopic scale have been identified under irradiation

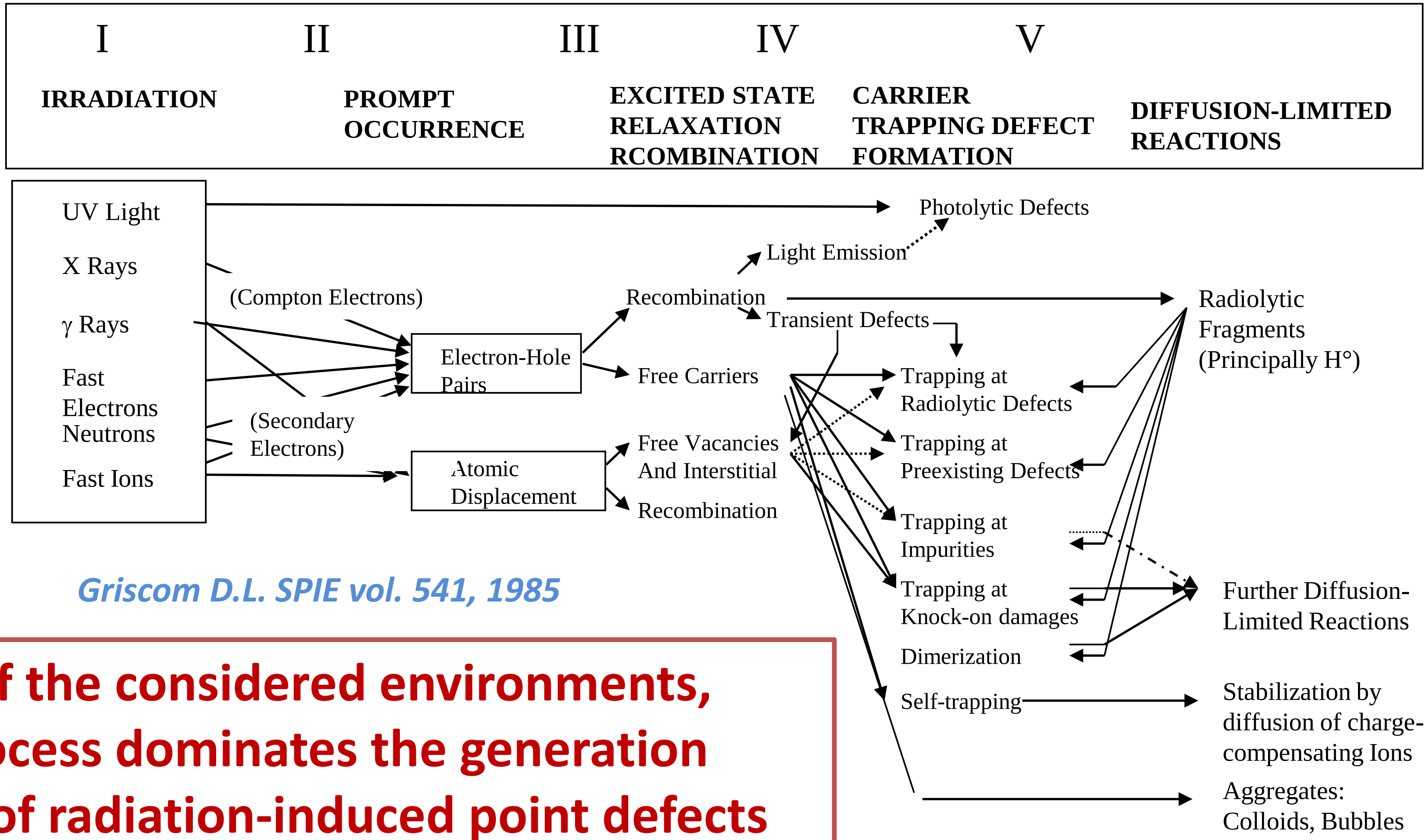




1. **Radiation-Induced Attenuation (RIA)**
2. **Radiation-Induced Emission (RIE)**
3. **Compaction**

➢ **The relative contributions of these 3 mechanisms depend on the <u>radiation environment</u>, on the <u>targeted application</u> and <u>on the fiber properties</u>**

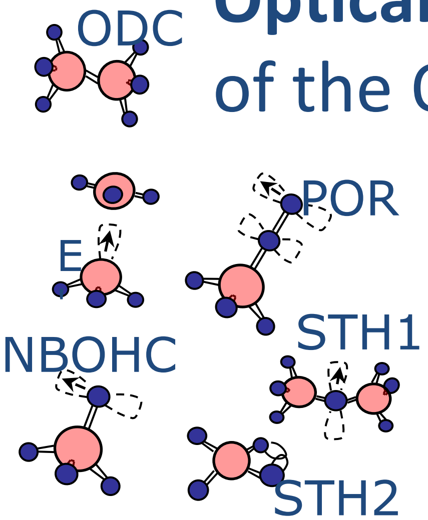
Radiation-induced mechanisms occurring at the microscopic scale in amorphous SiO_2 have been identified…and are a bit complex



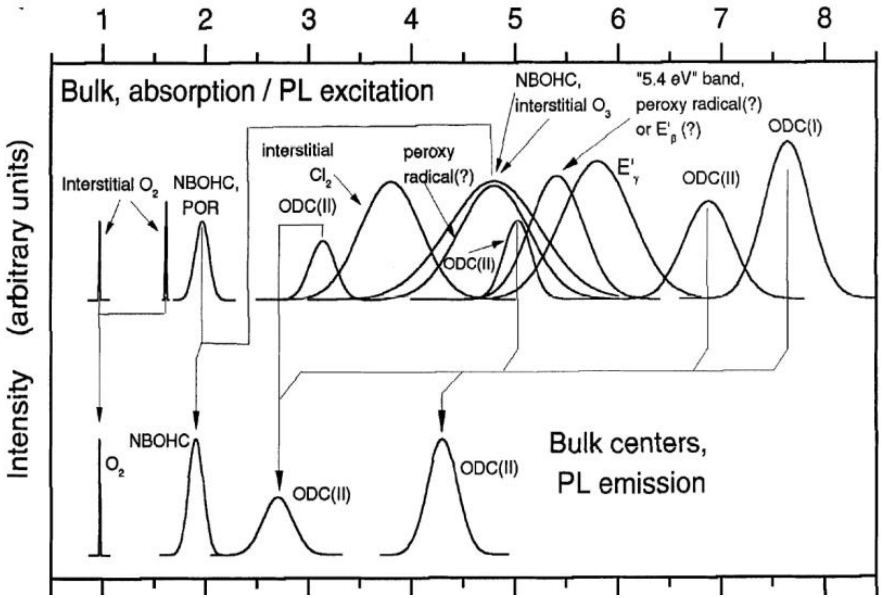
Griscom D.L. SPIE vol. 541, 1985

⇨ For most of the considered environments, ionization process dominates the generation mechanisms of radiation-induced point defects

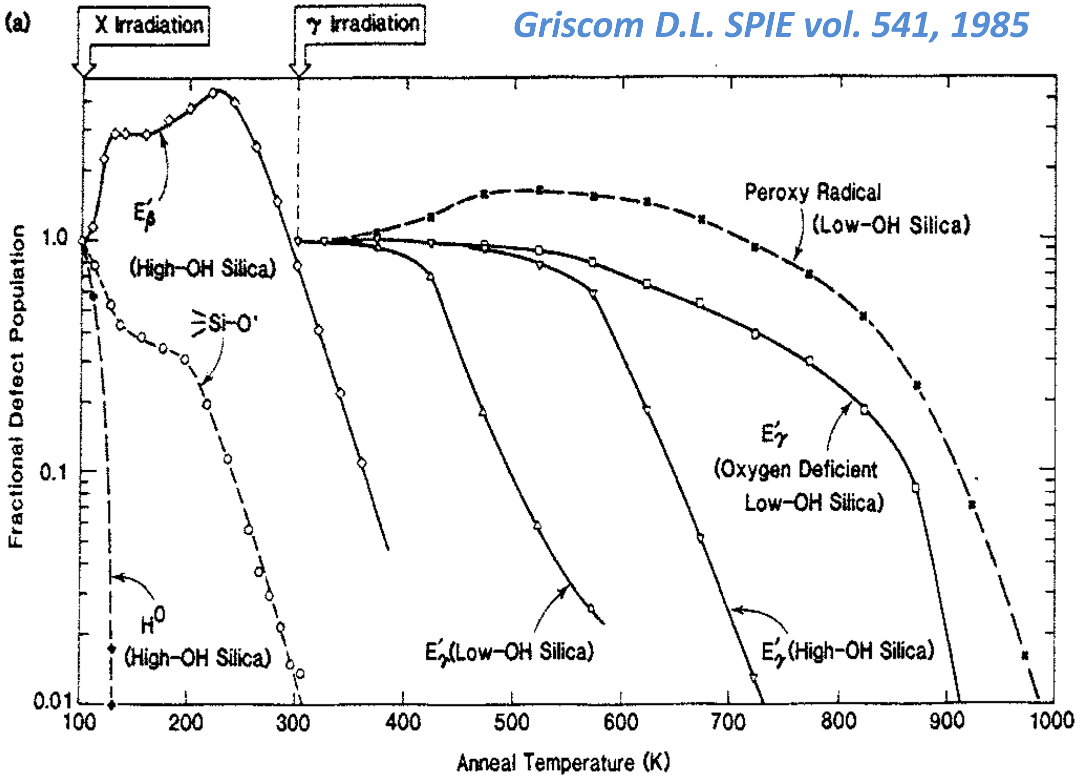
Optical and energy properties of these point defects explain the complexity of the OF radiation-response



L. Skuja; NATO Book Chapter, 2000

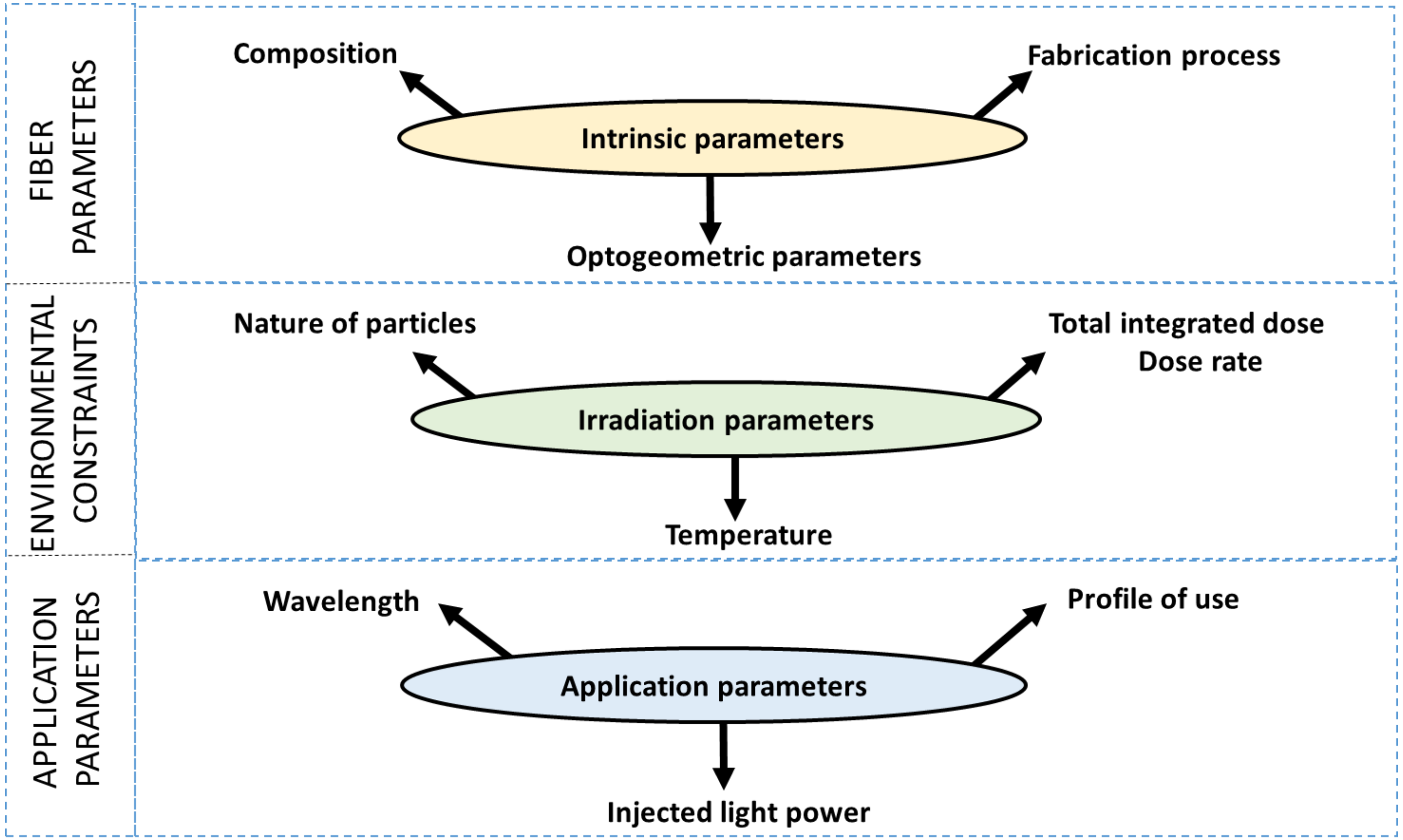


Griscom D.L. SPIE vol. 541, 1985



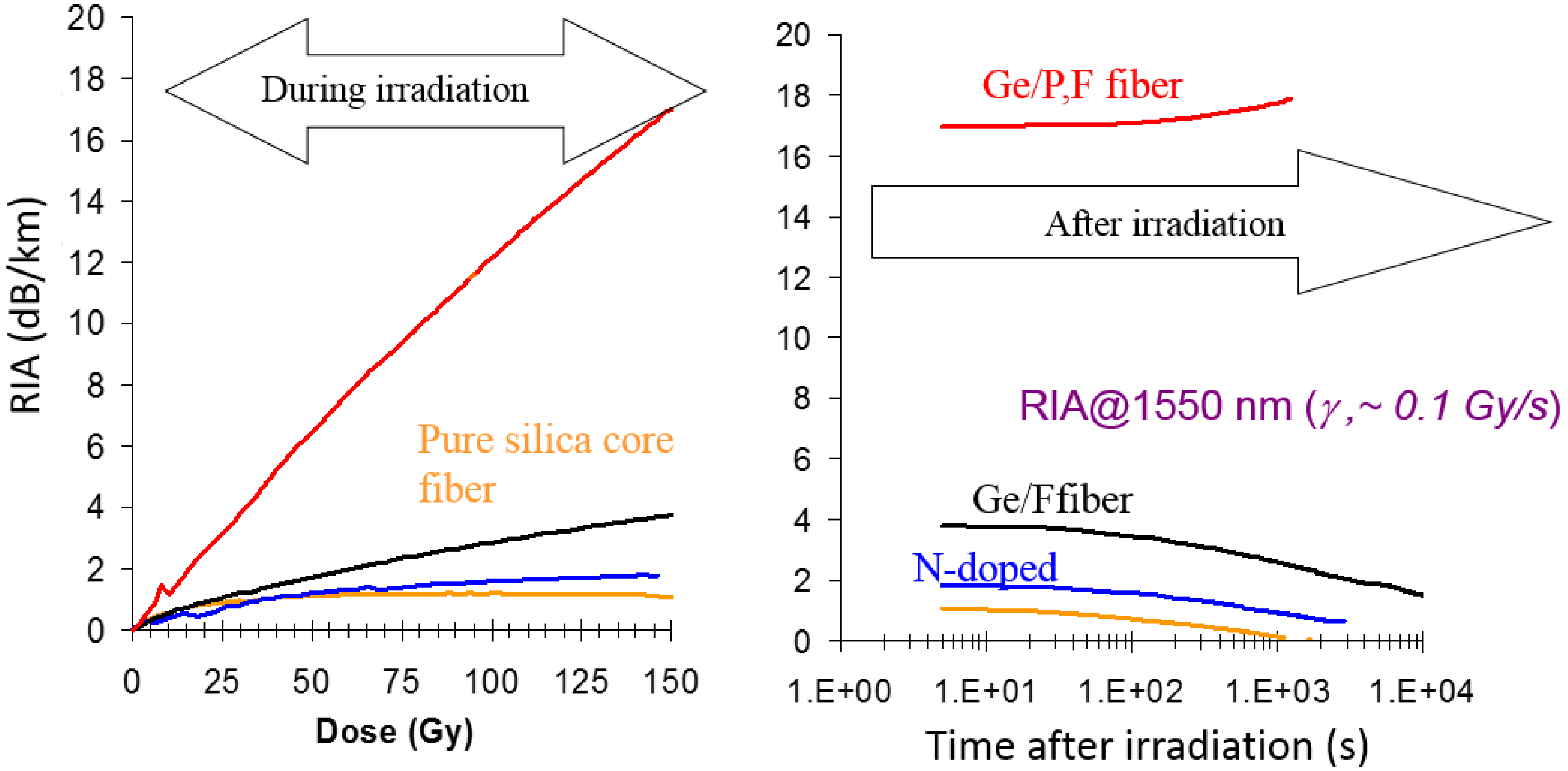
- ❑ Each parameter affecting the stability, generation efficiency or optical properties of these point defects will affect the OF radiation response ➔ **Too complex to be yet predictable!**

Numerous parameters, intrinsic or extrinsic, influence the OF radiation response



- These parameters affect the **RIA** levels & kinetics that generally define the **OF vulnerability, or the OF dosimeter performances**

Ex1: Fiber sensitivity strongly depends on the fiber composition: core dopants, process parameters are less impacting

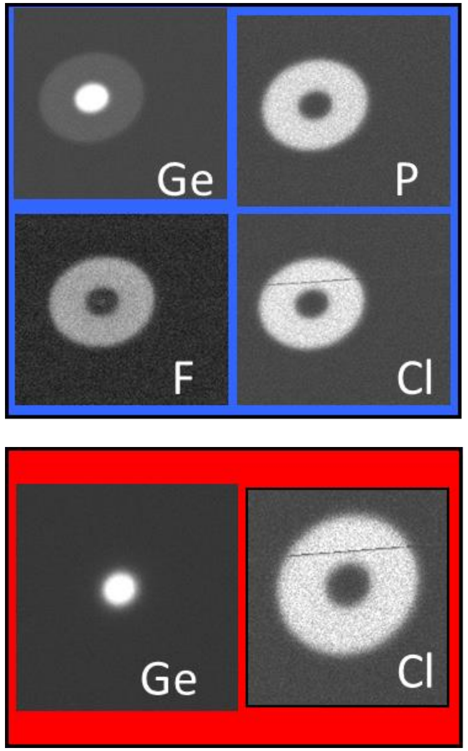


S. Girard et al., NIMB 215: 187-195, 2004 S. Girard et al., JLT 22(8): 1915-1922, 2004.

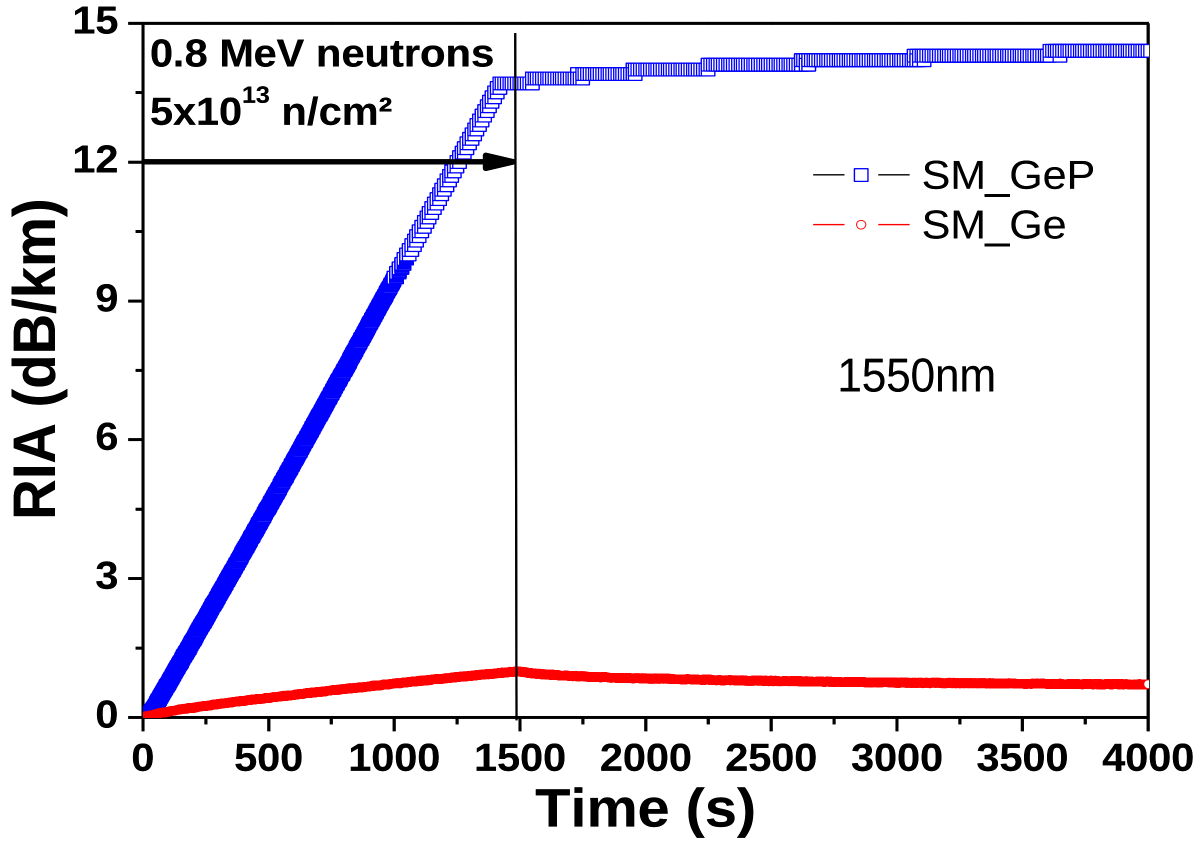
➡ **<u>No ideal composition exists</u>, fiber relative RIA levels depend on the radiation environments, fiber profile of use…**

Ex2: Fiber sensitivity strongly depends on the fiber composition: cladding dopants, stœchiometry, impurities, …

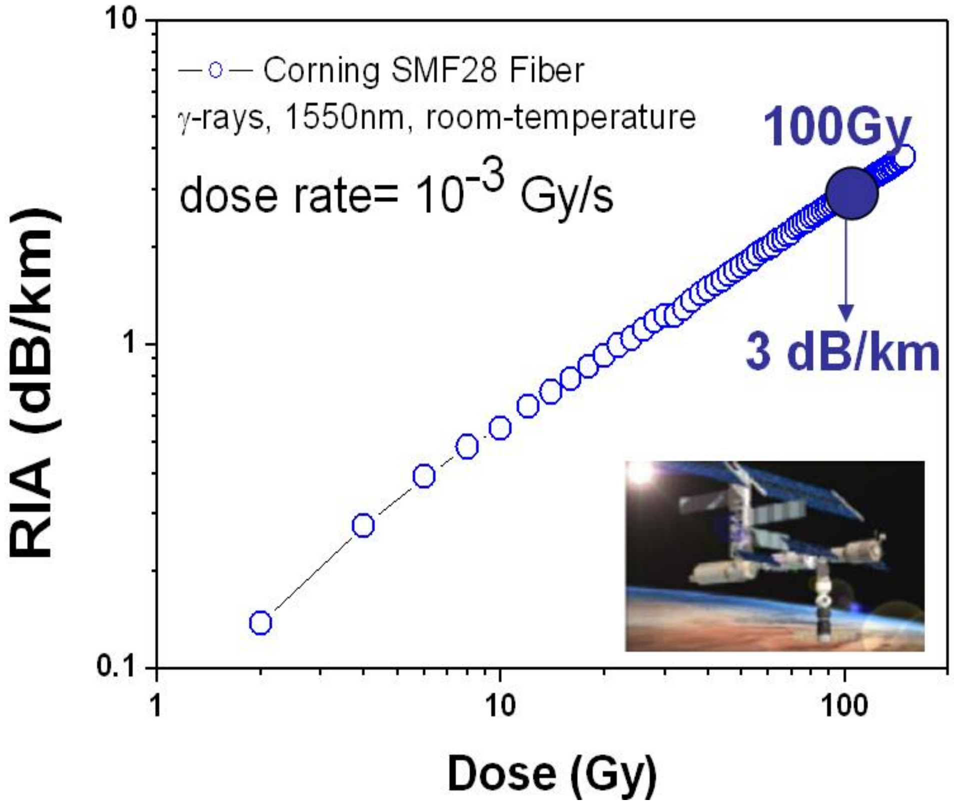
- A **slight** change in composition **strongly** changes the nature, concentration and stability of induced defects

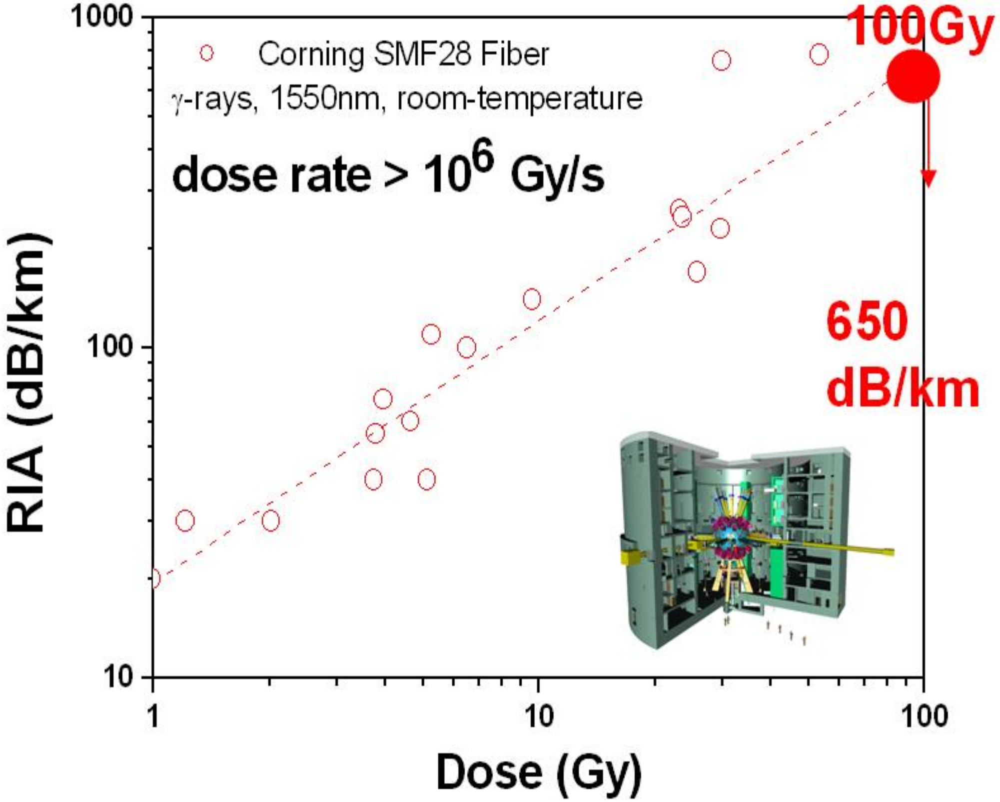


2 Telecom SMF ➔ same reference and different cladding compositions



Ex3: Fiber vulnerability: RIA growth kinetic depends on the harsh environment: *dose, dose rate, T, irradiation duration,…*

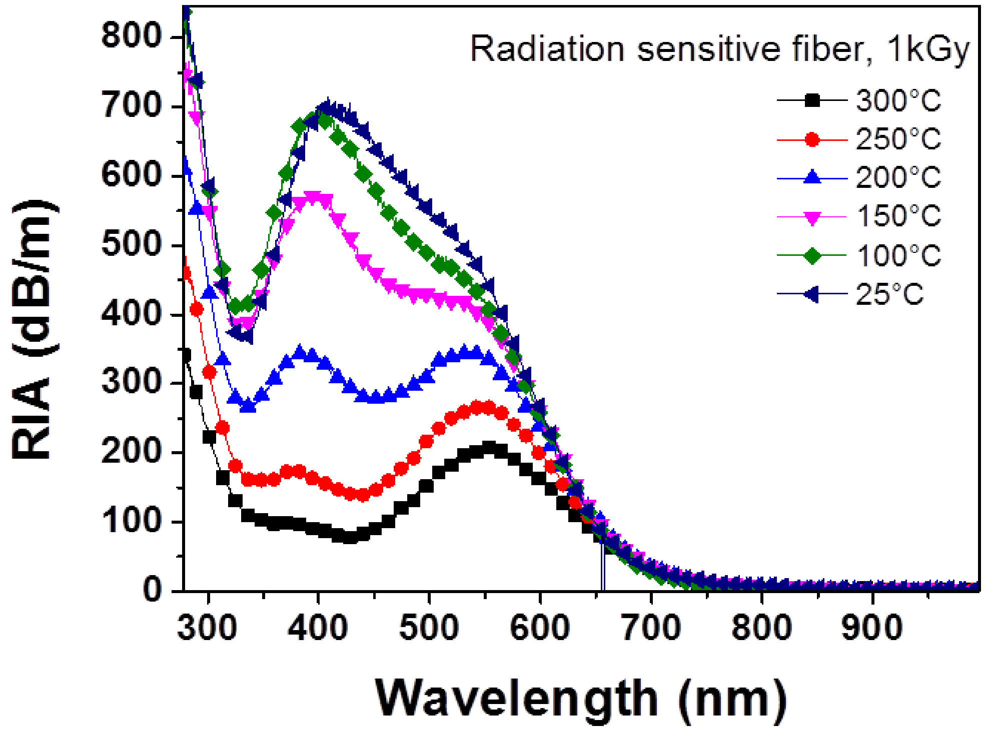


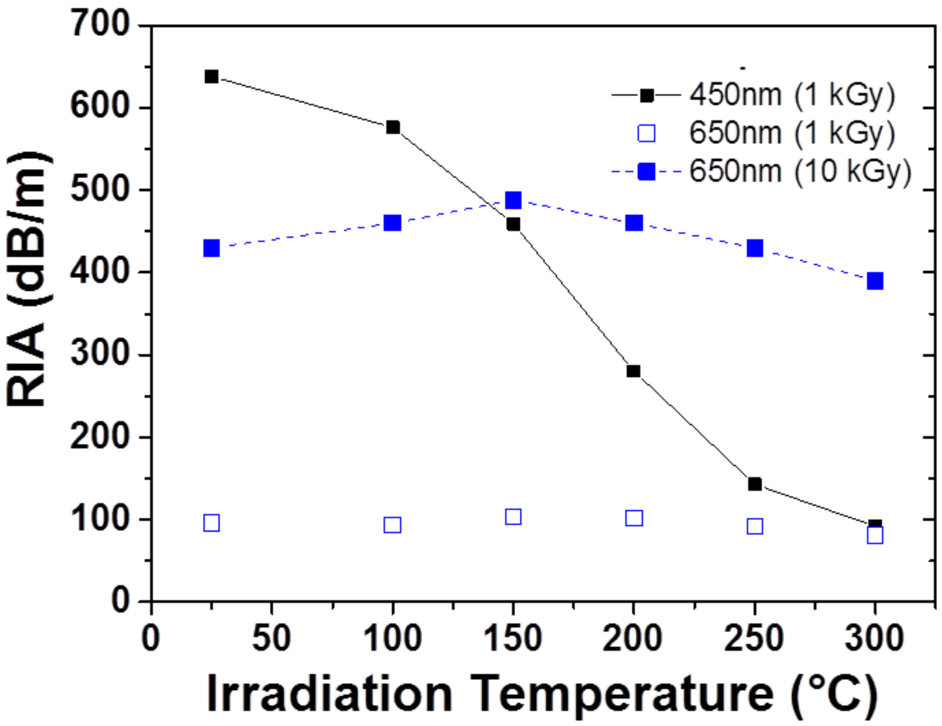


⇨ Vulnerability strongly depends on the harsh environment associated with the application ➔ **what means Rad Hard or Rad-Sens Fibers?**

Ex4: Fiber vulnerability: RIA levels and kinetics depends on the temperature of irradiation

S. Girard, et al., IEEE TNS, 60(6), pp. 4305 - 4313, 2013.





- ➢ **Temperature parameter has been too poorly and badly studied (R+T instead R&T) ➔ work in progress in the framework of the CERTYF project**

Part 2: Recent Advances on Radiation Hardened Optical Fibers

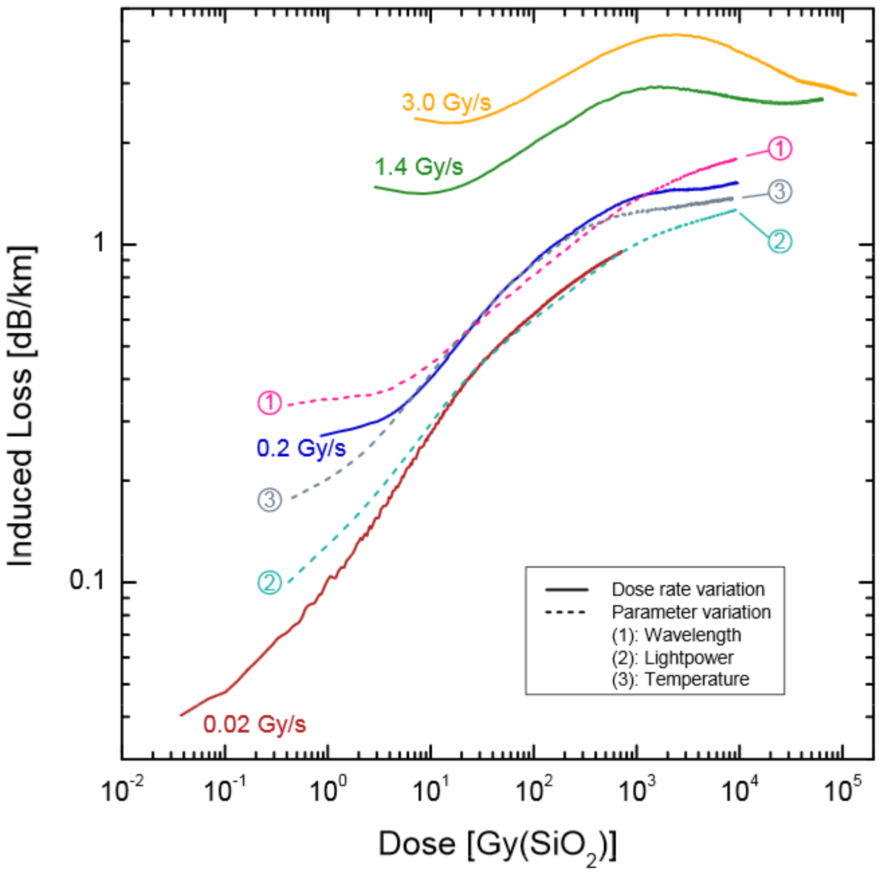
Review paper (2013) : S. Girard, J. Kuhnhenn, A. Gusarov, B. Brichard, M. Van Uffelen, Y. Ouerdane, A. Boukenter, and C. Marcandella, "***Radiation Effects on Silica-based Optical Fibers: Recent Advances and Future Challenges***", IEEE TNS, vol.60 (3) 2015 - 2036, 2013

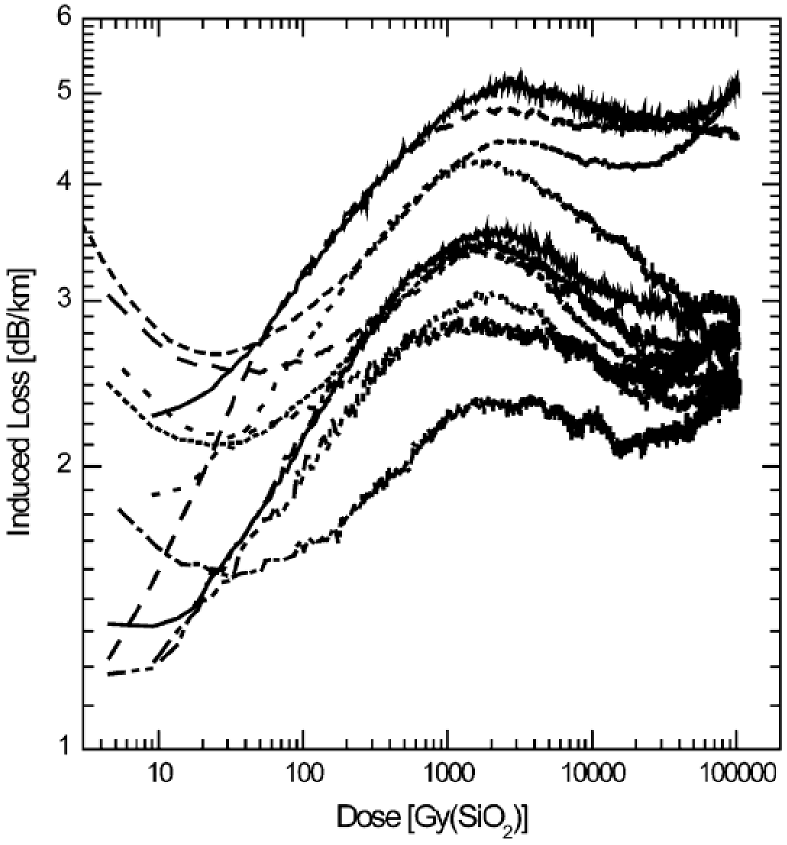
Review paper (2018): S. Girard, A. Morana, A. Ladaci, T. Robin, L. Mescia, et al., "***Recent advances in radiation-hardened fiber-based technologies for space applications***", Journal of Optics, vol. 20, issue 9, article number # 093001, 2018.

CERN LHC: identification of a radiation hardened SMF @1310nm

(steady state, 100 kGy dose level)

Fraunhofer INT Institut Naturwissenschaftlich-Technische Trendanalysen





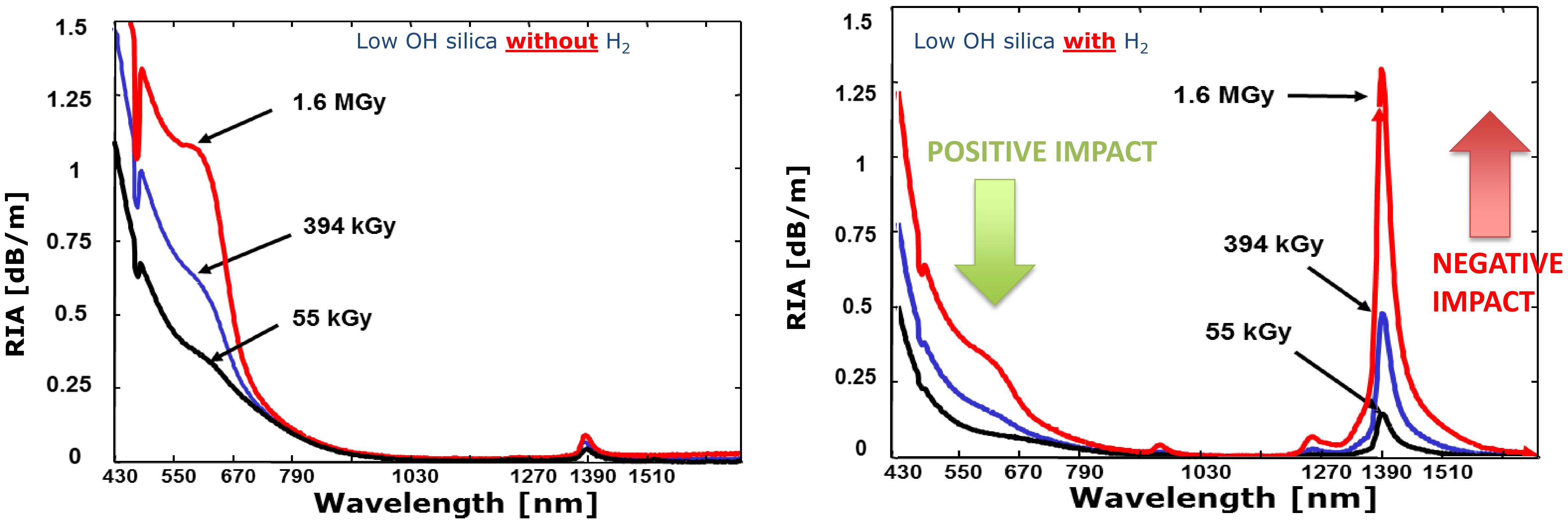
- **F-doped fiber + ?**
- Very complex radiation response
- Strongly dependent on irradiation conditions

T. Wijnands, *et al.*, JLT 29, 3393-3400 (2011)
T. Wijnands, *et al.*, IEEE TNS. 55, 2216-2222 (2008)

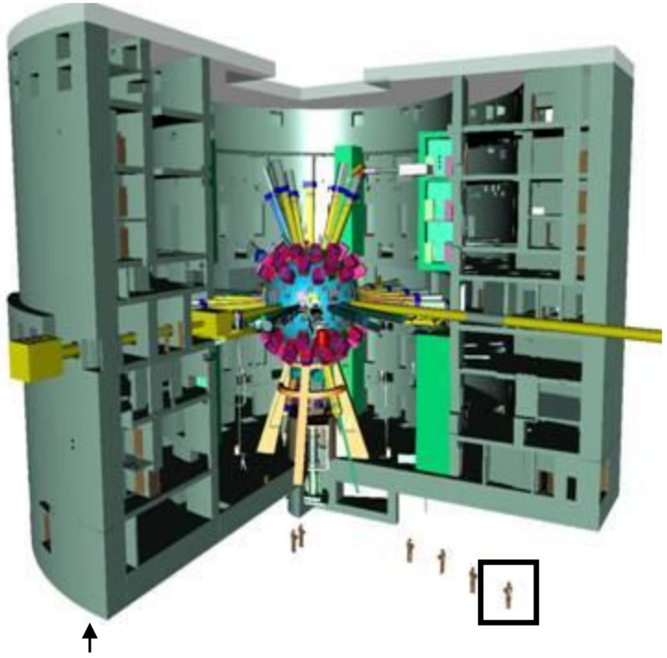
ITER diagnostics: RIA mitigation techniques can be applied to reduce the fiber sensitivity for given application and radiation environment

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

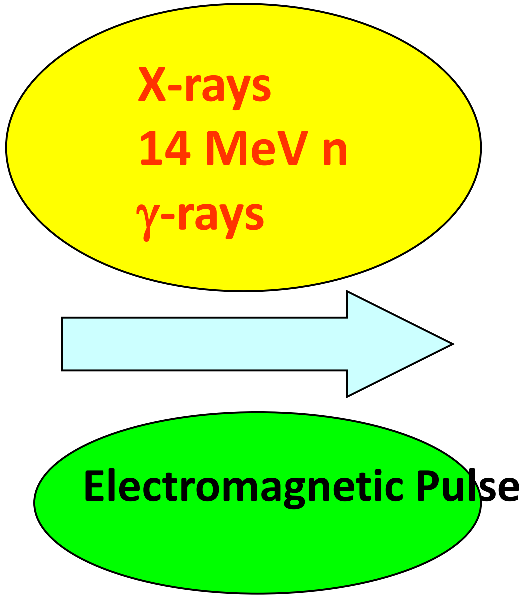
- For some applications, loading of the fiber with H_2, (D_2 or O_2) can reduce the RIA wavelengths: difficult to predict too!

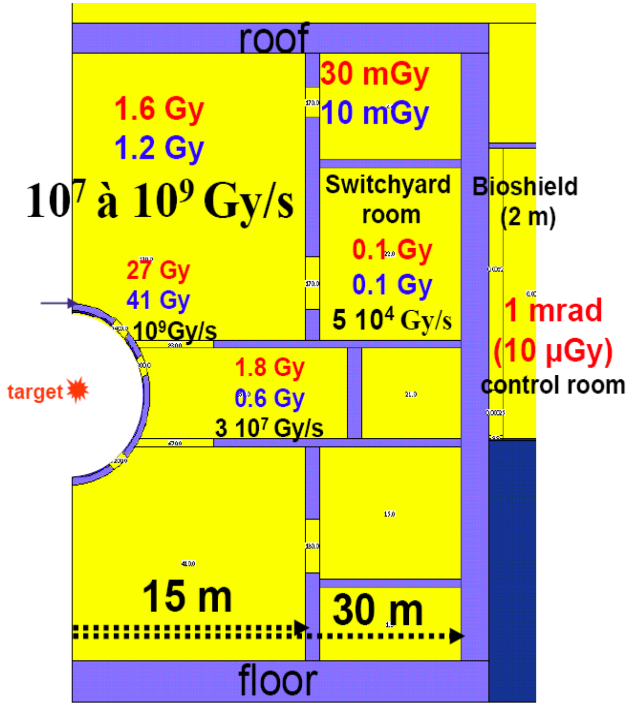


LMJ control command: All the equipments located inside the E.H. have to be radiation-tolerant to the LMJ mixed environment



2m thick outer wall to protect outside workers and adjacent buildings

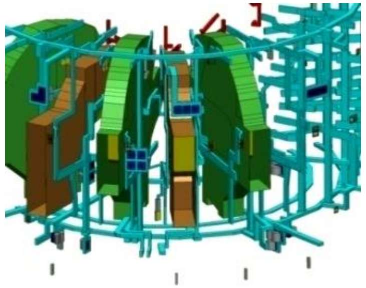




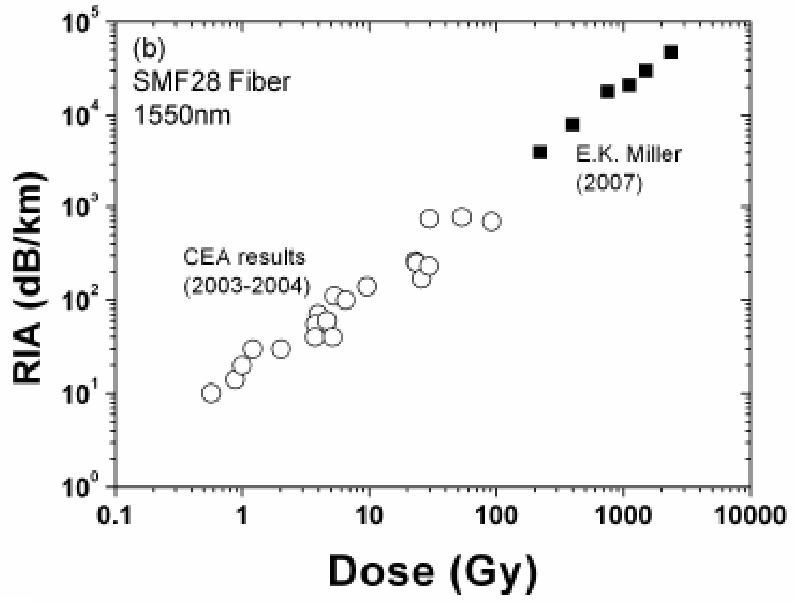
Monte Carlo Simulation of dose and dose rate levels

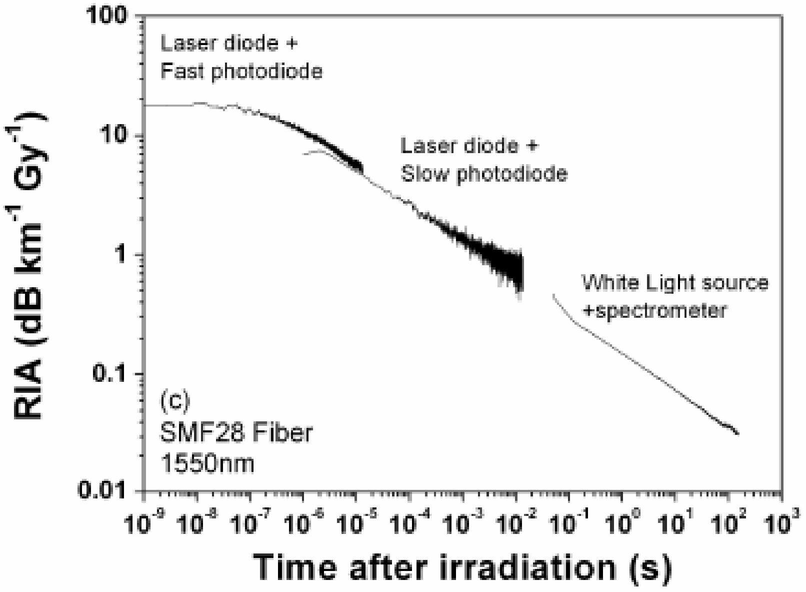
- ❑ Characterize, reduce the component vulnerability (EMP and **radiations**): electronics (CCD, transistor, memory,...), optics (**fiber optics, glasses**), CMOS image sensors (ISAE-CEA-LabHC)

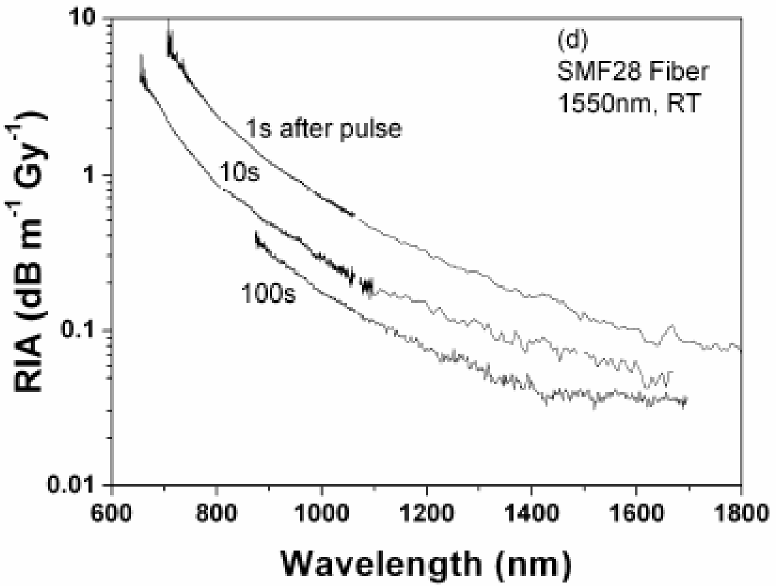
LMJ control command: COTS fibers have been selected and systems adapted to the transient irradiation constraints



- **Control-command links** mainly operate at Telecom wavelengths, before and after the LMJ shots
  - Evaluation of the vulnerability of COTS components
  - Guidelines for the LMJ design engineers

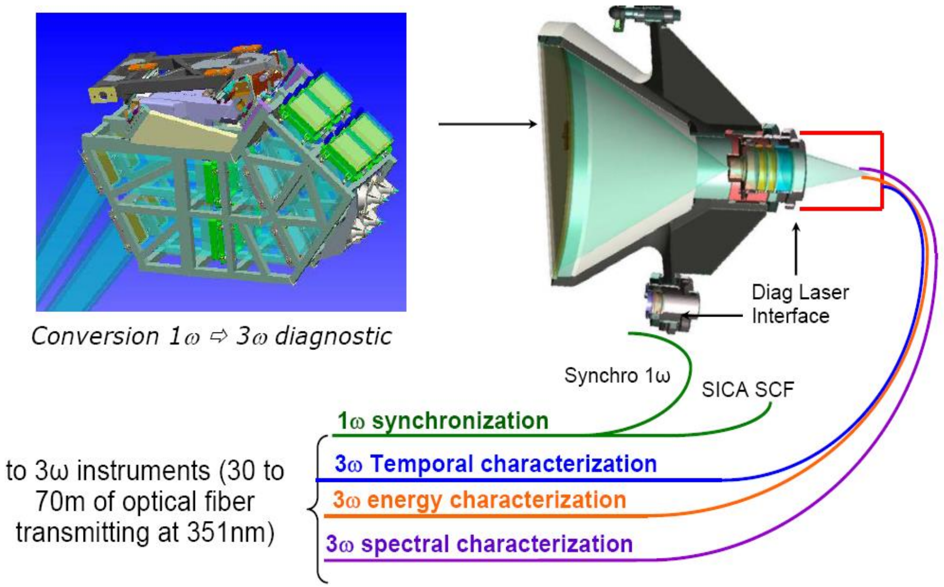






S. Girard *et al.*, IEEE TNS **52**, 1497, 2005
S. Girard *et al.*, IEEE TNS **52**, 2683, 2005
S. Girard *et al.*, IEEE TNS **53**,1756, 2006.

LMJ: Vulnerability of a large panel of optical fibers has to be characterized to the LMJ harsh environment: prototype fibers



- **Laser diagnostics:** operate **during** the shot, mainly at 3ω.
- **Plasma diagnostics:** operate **during** the shots, from 1ω to 3ω.

- **Biggest challenge:** time-resolved diagnostics (time resolution < 1ns) in the ultraviolet part of the spectrum
  - RIA is larger for shorter times, shorter wavelengths
  - No comparable studies in literature

- **R&D development concluded**
  - A commercial product has the required characteristics for the diagnostics @ 3ω and is radiation-hardened

iXblue

Space: Rare-earth (RE) doped fibers are very radiation sensitive and mainly explain the amplifier gain degradation under irradiation

LOW Power (Er-doped, <1W)	HIGH Power (Er/Yb, > 1W)	VHP (Er/Yb), >10W

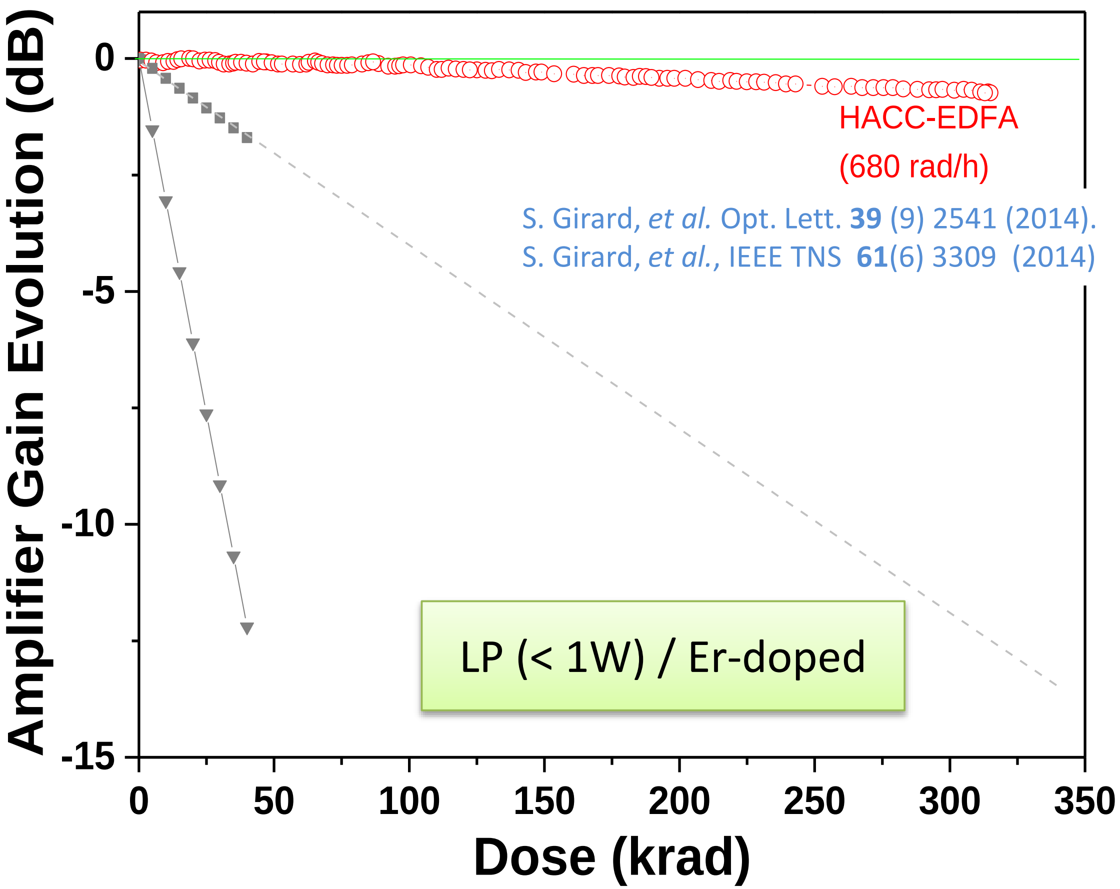
State-of-the-art in 2012

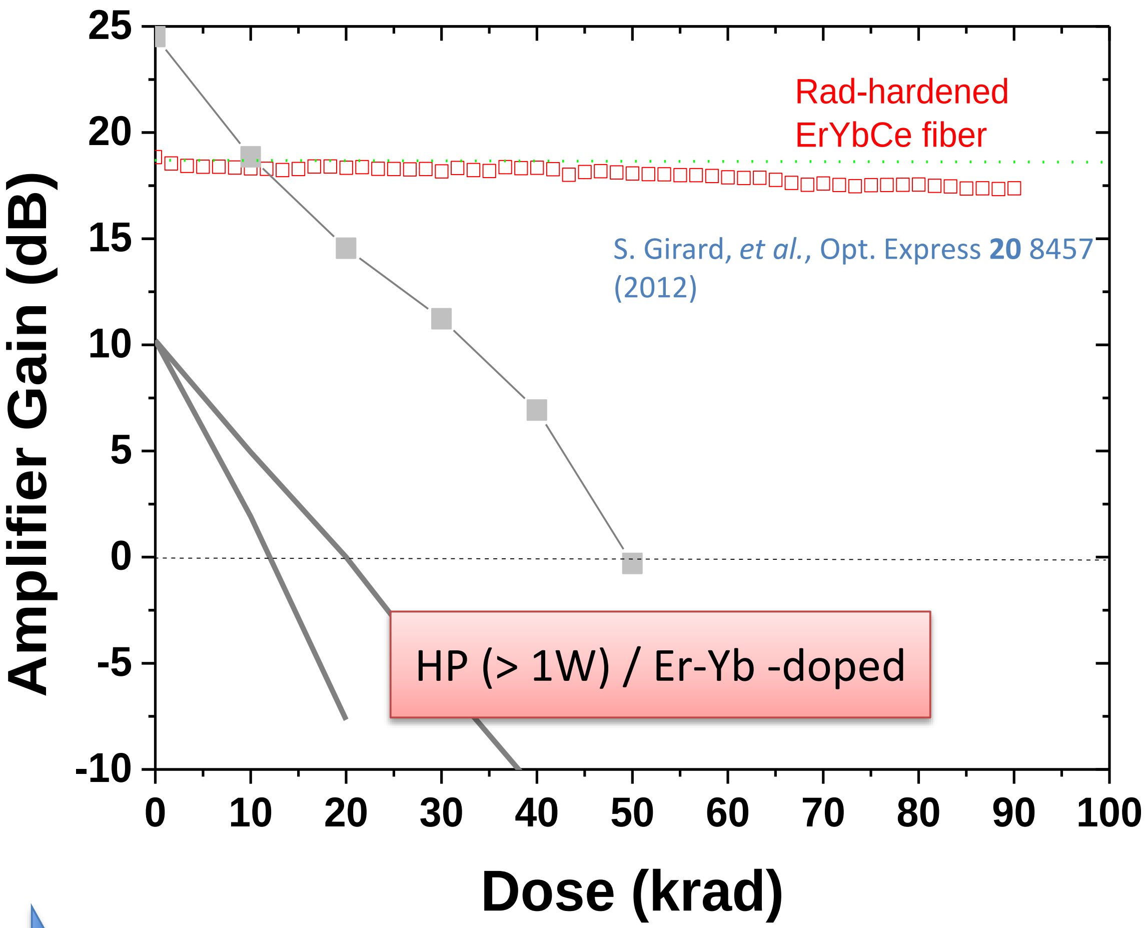
- **Origin of RIA:** Their host matrix is mainly responsible of RIA at the pump and signal wavelengths that causes the amplifier degradation

- **Different techniques have been used to improve their responses with some limitations:**
  - **Nanodeposition to avoid Al in Er-doped fibers:** J. Thomas et al., Opt. Express 20 2435 (2012)
    - Affects the amplifier properties: gain, gain flatness…
  - **H_2 or D_2 Loading:** K. Zotov et al, Phot. Techn. Lett. 20(17) 1476 (2008).
    - Affects the amplifier gain, difficulty to maintain gas into the fiber

State-of-the-art in 2016

Radiation-hardened Er and Er/Yb-doped fibers exist today even for the most challenging missions





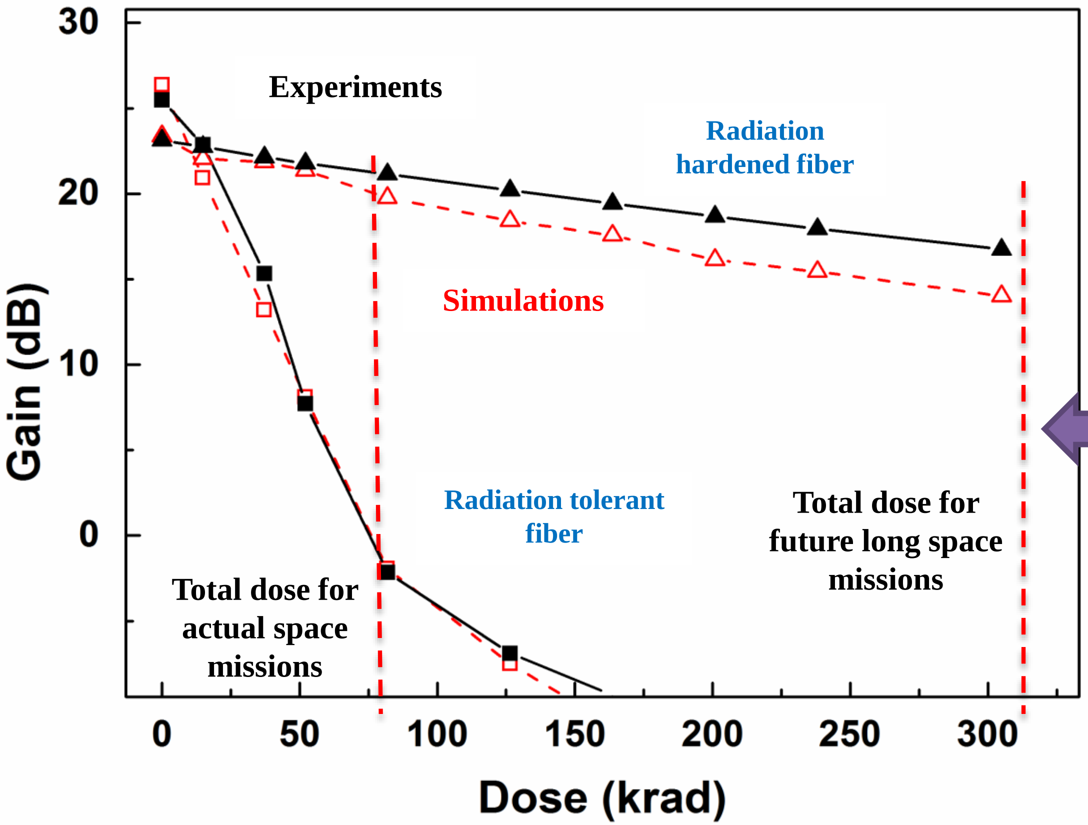
- Er rad hard fibers are commercially available
- Er-Yb rad hard fibers commercially available

LABORATOIRE HUBERT CURIEN
UMR • CNRS • 5516 • SAINT-ETIENNE

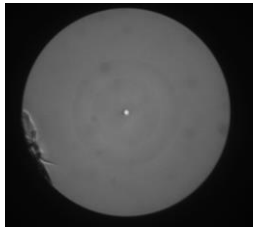
iXblue

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

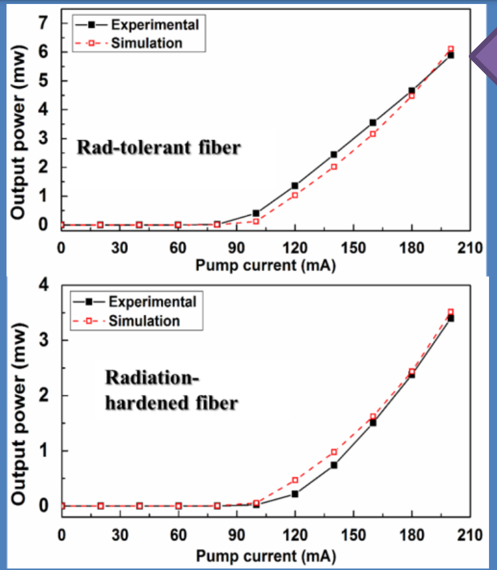
2016-2018: Building simulation tools for prediction of radiation and temperature effects on EDFA and EYDFA



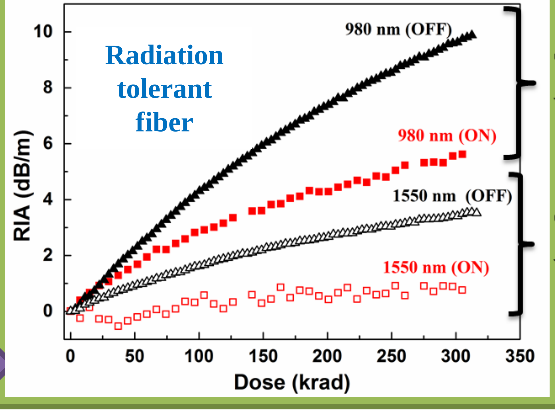
Fiber properties (geometry, spectroscopic properties,…)



State-of-the-art REDFA Codes



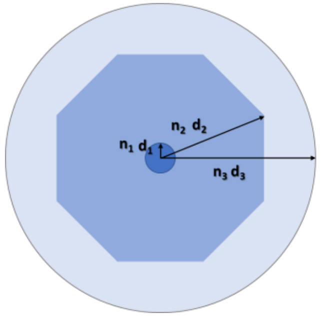
Radiation Effects

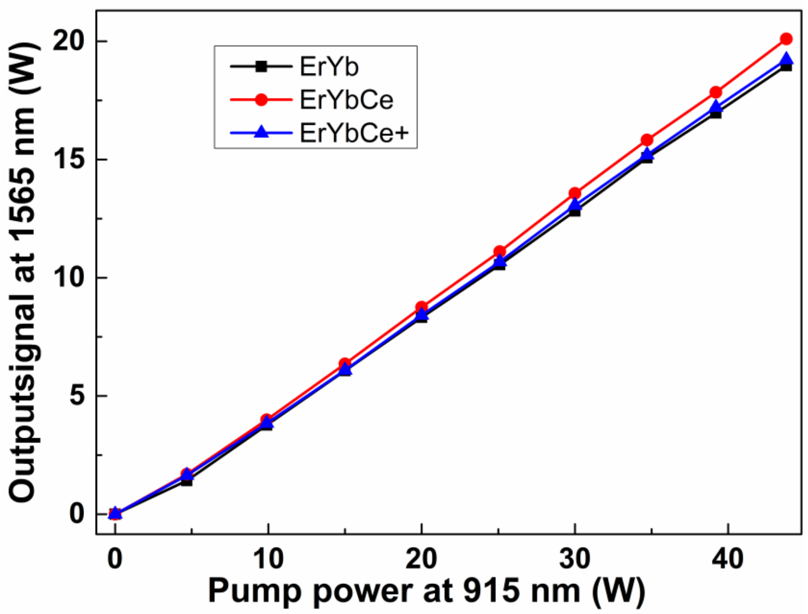


Since 2018: towards very high power (20W) for free space optical communications through simulation/experiments optimization

VHP (Er/Yb), >10W

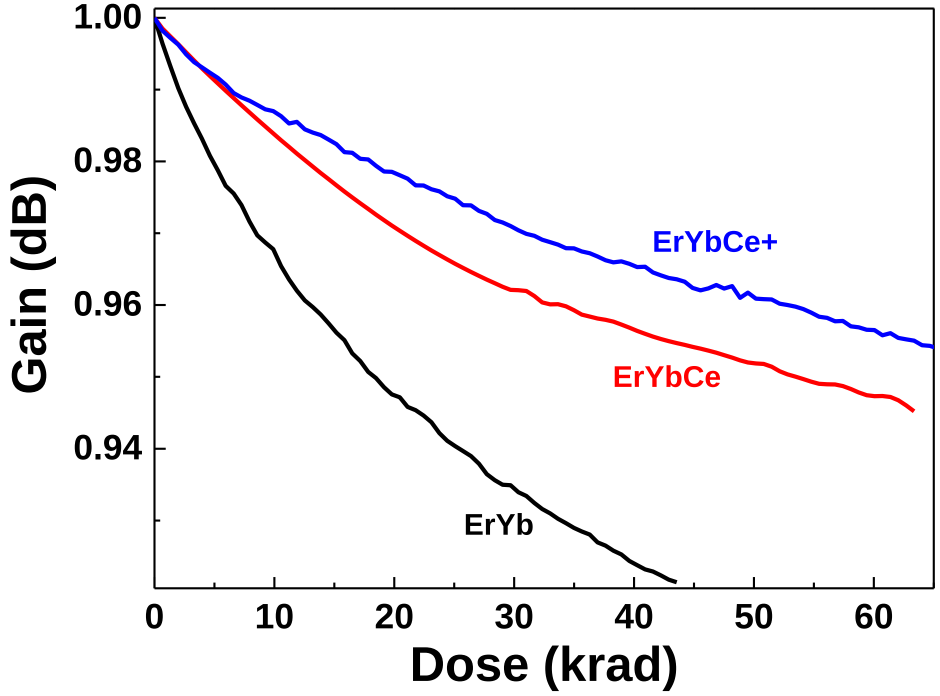
A. Ladaci, et al., Optics Letters, vol.43, issue 13, pp.3049-3052, 2018.





It is possible to achieve a signal power of about 20 W using 12 µm optical fibers

The radiation resistance of such HP amplifiers was never been investigated in literature



LABORATOIRE HUBERT CURIEN

UMR • CNRS • 5516 • SAINT-ETIENNE

iXblue

cnes

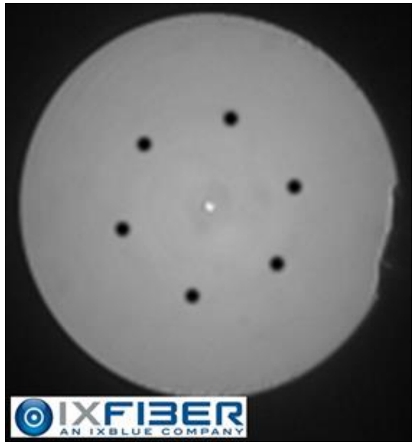
CENTRE NATIONAL D'ÉTUDES SPATIALES

COTS Radiation tolerant or hardened optical fibers are now available for some applications/environments

- Radiation Hard Optical Fibers exist today for most of IR applications at MGy dose

- More efforts are in progress to have a **full product** (coating, cable, connectors,…) **qualified for harsh environments**

- **CHALLENGES:**
  - ✓ Fibers for **UV-visible operation for fusion/ fission**
  - ✓ New fiber generations (PCF, HACC, metal-coated,…)
  - ✓ Fiber amplifiers and fiber-based lasers



➡ **Today, functionalization of OF is targeted in order that in addition to data transfer, fibers can be used to monitor environmental parameters**

Part 3: Recent Advances on radiation hardened fiber-based sensors

Review paper (2017): Delepine-Lesoille, S.; S. Girard.; Landolt, M.; Bertrand, J.; Planes, I.; Boukenter, A.; Marin, E.; Humbert, G.; Leparmentier, S.; Auguste, J.-L.; Ouerdane, Y. ***"France's State of the Art Distributed Optical Fibre Sensors Qualified for the Monitoring of the French Underground Repository for High Level and Intermediate Level Long Lived Radioactive Wastes".*** Sensors 2017, 17, 1377.

Review paper (2018): S. Girard, A. Morana, A. Ladaci, T. Robin, L. Mescia, et al., "***Recent advances in radiation-hardened fiber-based technologies for space applications***", Journal of Optics, vol. 20, issue 9, article number # 093001, 2018.

The vulnerability and hardening studies of OFS technologies is under progress

- Fiber Bragg Gratings (strain, temperature, ….)

DISCRETE SENSING (temperature, strain)

- Raman (T)
- Brillouin (T, strain,…)
- Rayleigh (T, strain, …)

DISTRIBUTED SENSING (temperature, strain, liquid level, pressure,..)

- Dosimetry
  - RIA (*active, distributed*)
  - TL (*passive*)
  - RIL, OSL (*active punctual*)

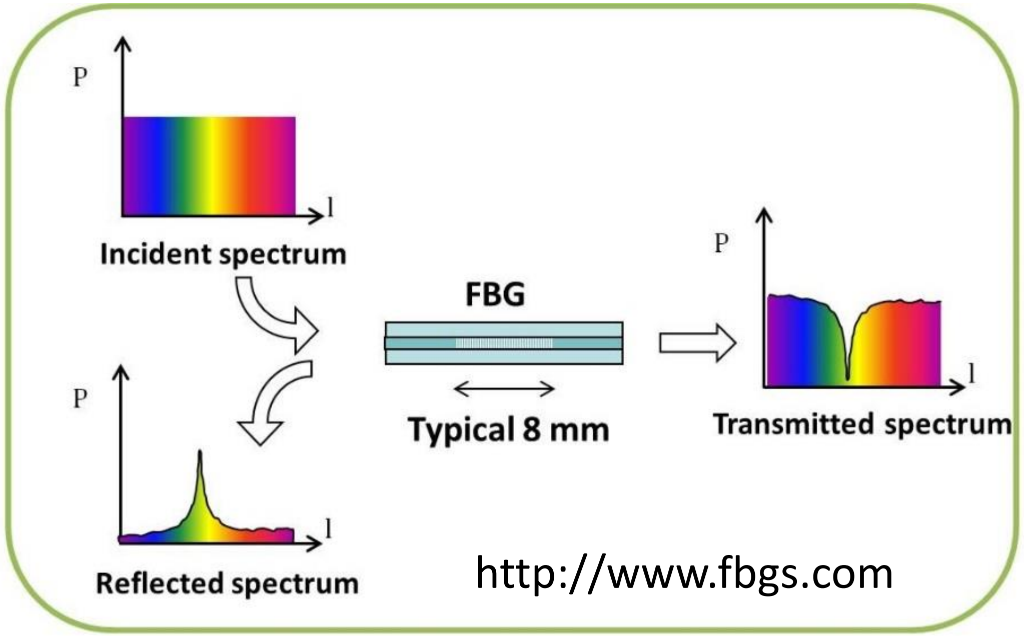
PUNCTUAL, ONLINE, OFFLINE SENSING

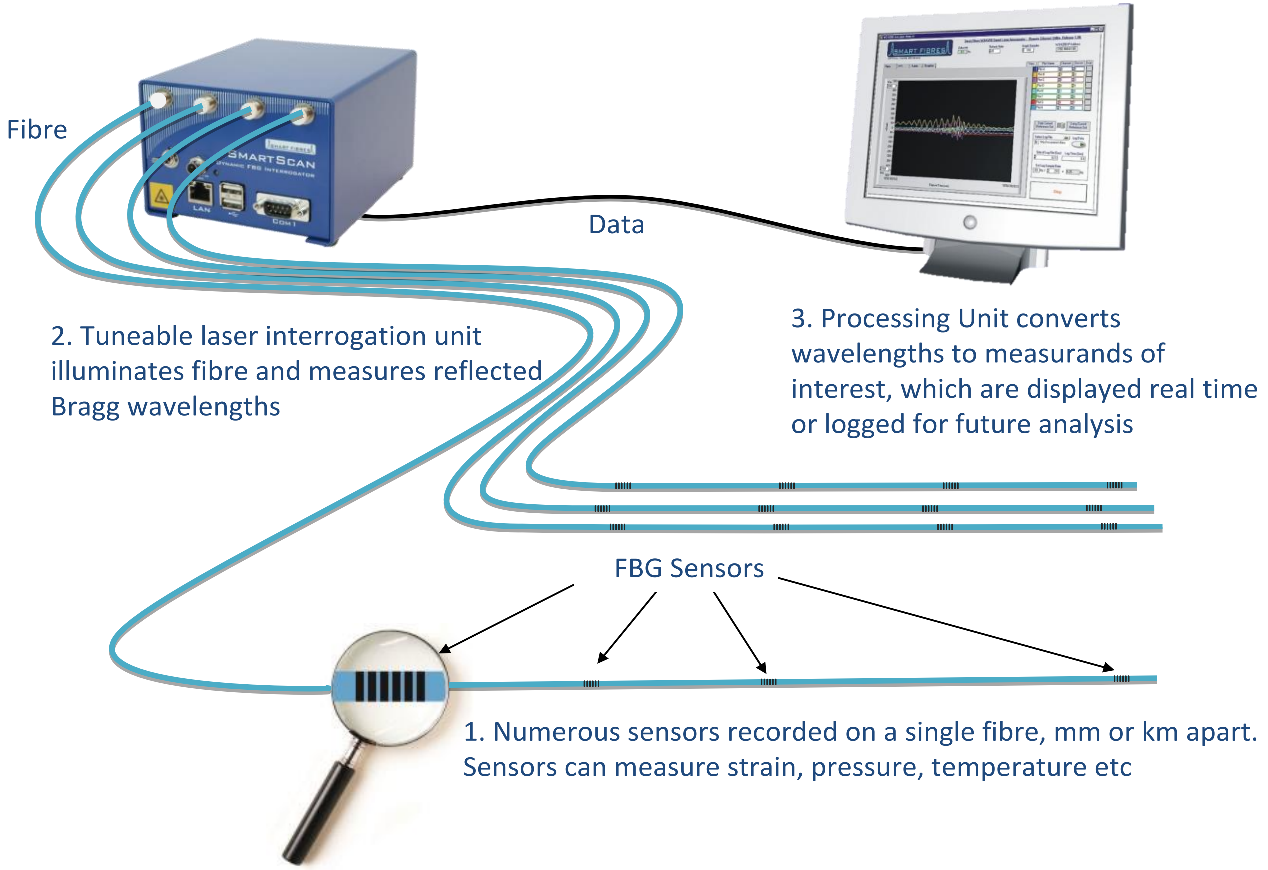
FBG Temperature & Strain Sensing in Nuclear Industry

AREVA

Advantages:

- Small size (Ø~100µm), Light weight
- Resistance to electromagnetic interference
- No need of electrical power at the sensing point
- Quick response (<1s), Multiplexing



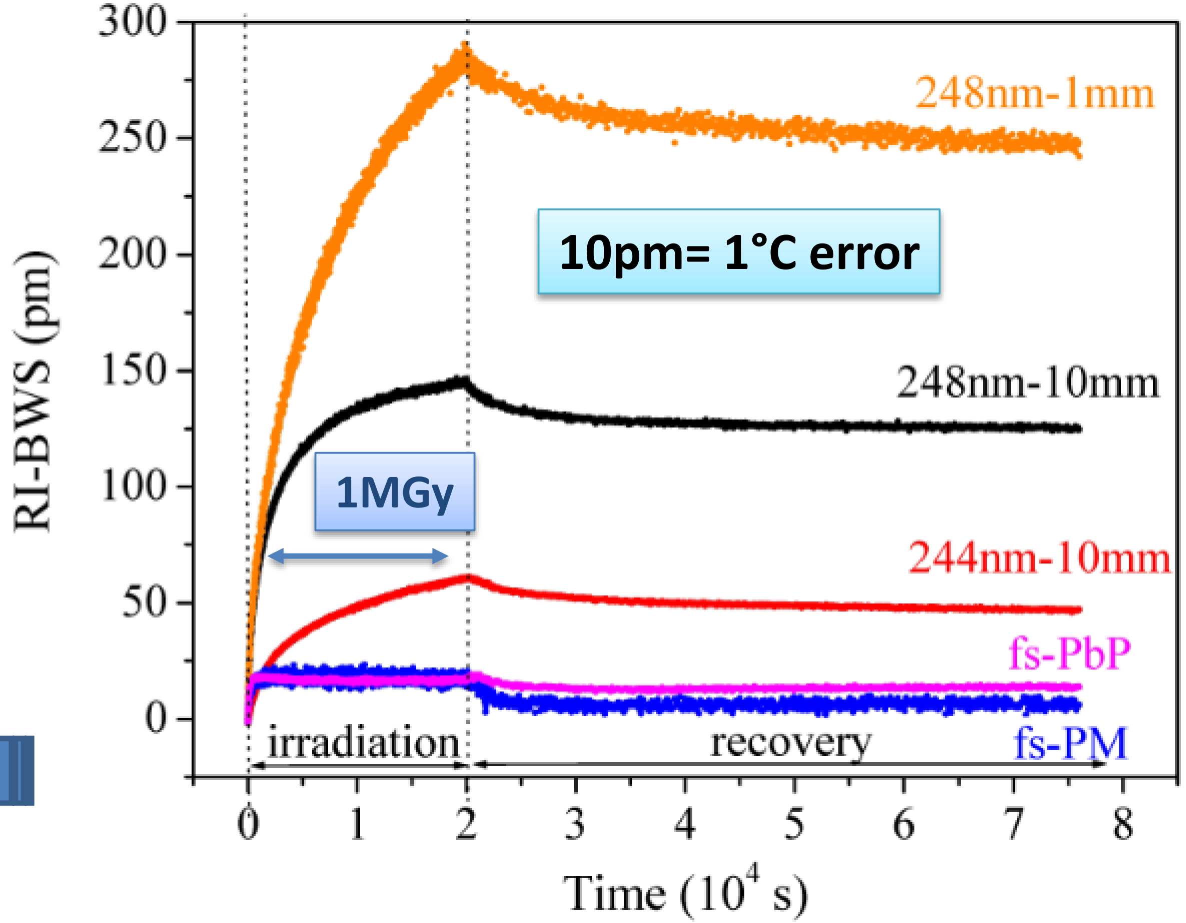


Radiation effects on FBG properties

A. Gusarov et al., IEEE TNS, 60, 2037(2013)

- Degradation of OF ➔ RIA
- Influence on the FBG properties:
  - **Amplitude:** possible FBG erasing under irradiation ➔ loss of OFSfunctionality
  - **Bragg Wavelength Shift:** error on T measurements ➔ OFS performance degradation

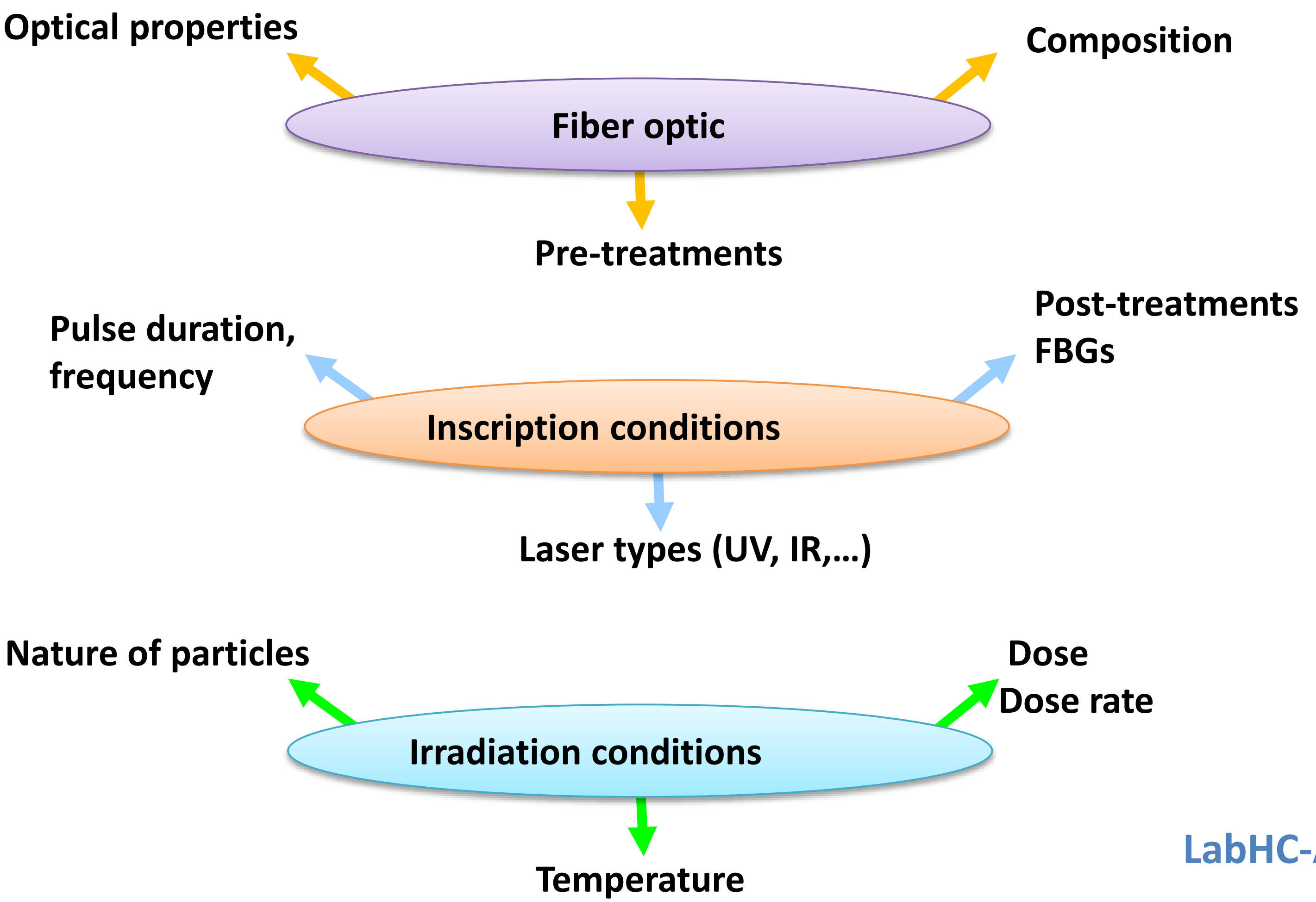
What is the best FBG technology for MGy dose levels (nuclear industry)?



A. Morana et al., Opt Express, 23(7), 8663 (2015)

Parameters impacting the FBG response

AREVA



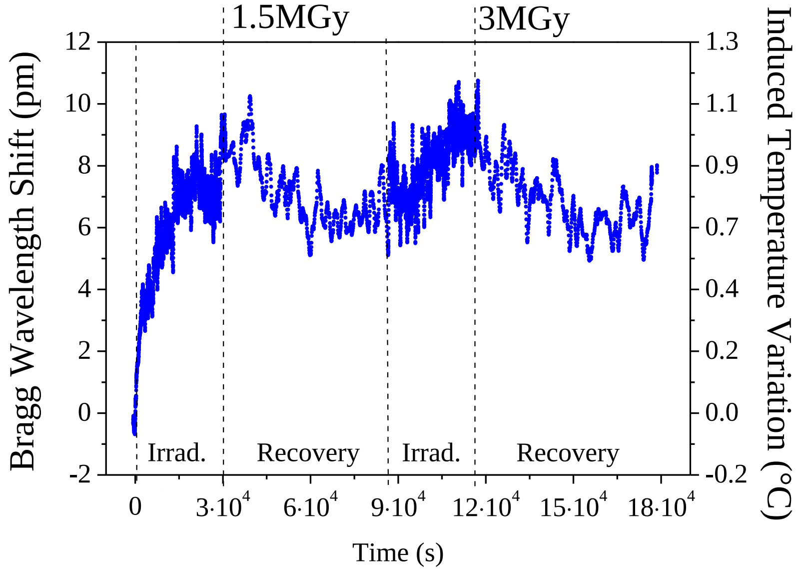
LabHC-AREVA patent (Dec. 2013)

➡ **We identified a procedure to develop RH FBGs for high T operation (up to 350°C)**

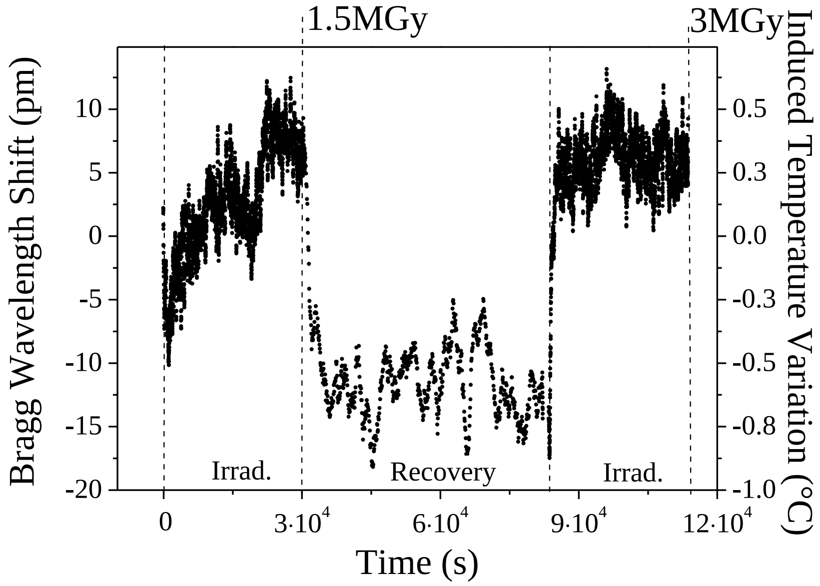
RH-FBGs are made with *fs* lasers following the patented procedure into RH-OF

A. Morana, et al. Opt. Letters 39 (18) 5313, 2014

ROOM TEMPERATURE (~25°C)



HIGH-T (~230°C)



➡ These RH FBGs also present the best response to high-T (300°C) and high fast neutron fluence up to 3×10^{19}n/cm² (collaboration with CEA DEN/DRT)

eit Knowledge & Innovation Community
KIC InnoEnergy

HOBAN

LabHC - *AREVA – FINT– iXBlue – SmartFibres*

Development of hard optical fiber Bragg grating sensors (2015 -2017)

The vulnerability and hardening studies of OFS technologies is under progress

- Fiber Bragg Gratings (strain, temperature, ….)

DISCRETE SENSING
(temperature, strain)

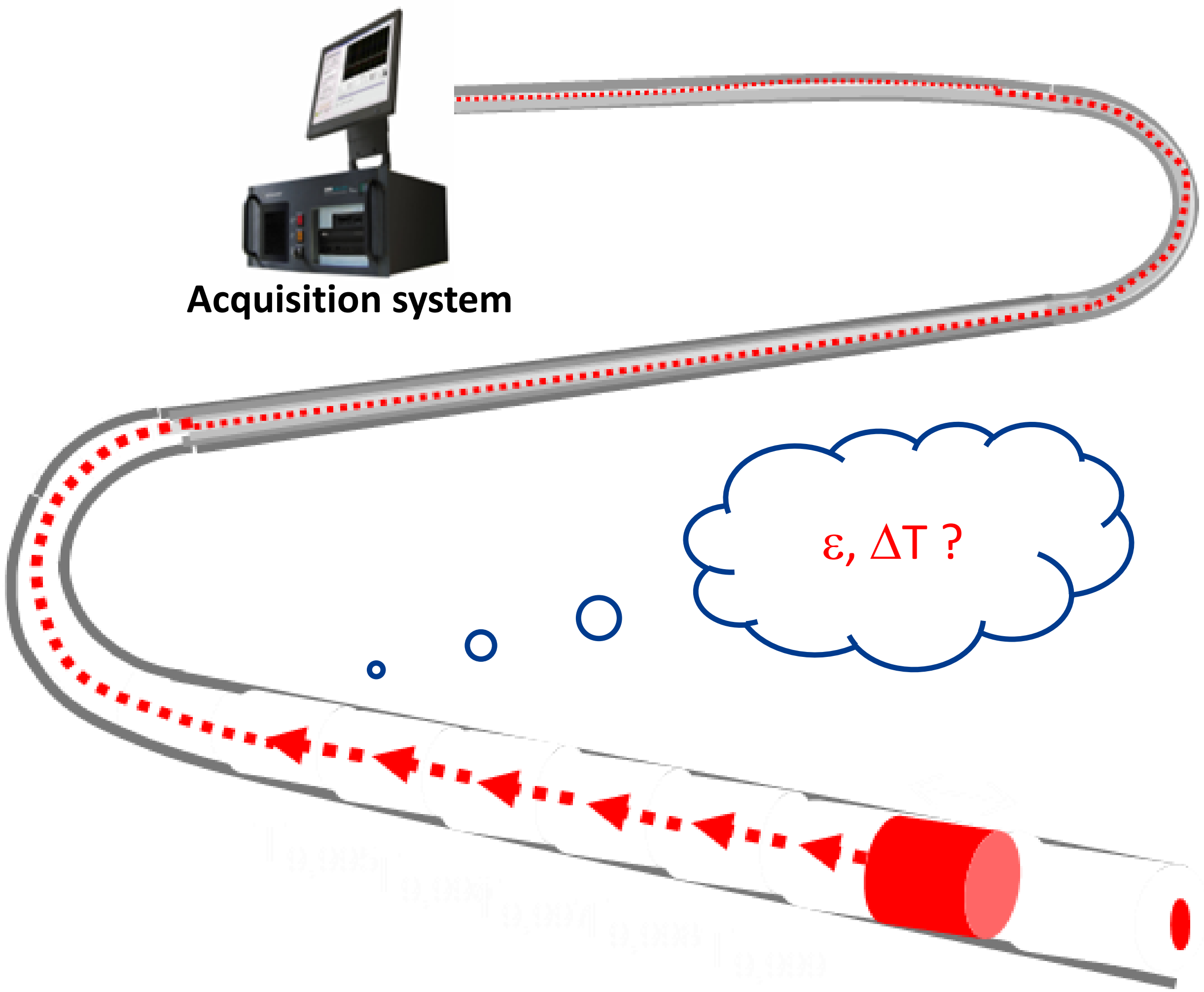
- Raman (T)
- Brillouin (T, strain,…)
- Rayleigh (T, strain, …)

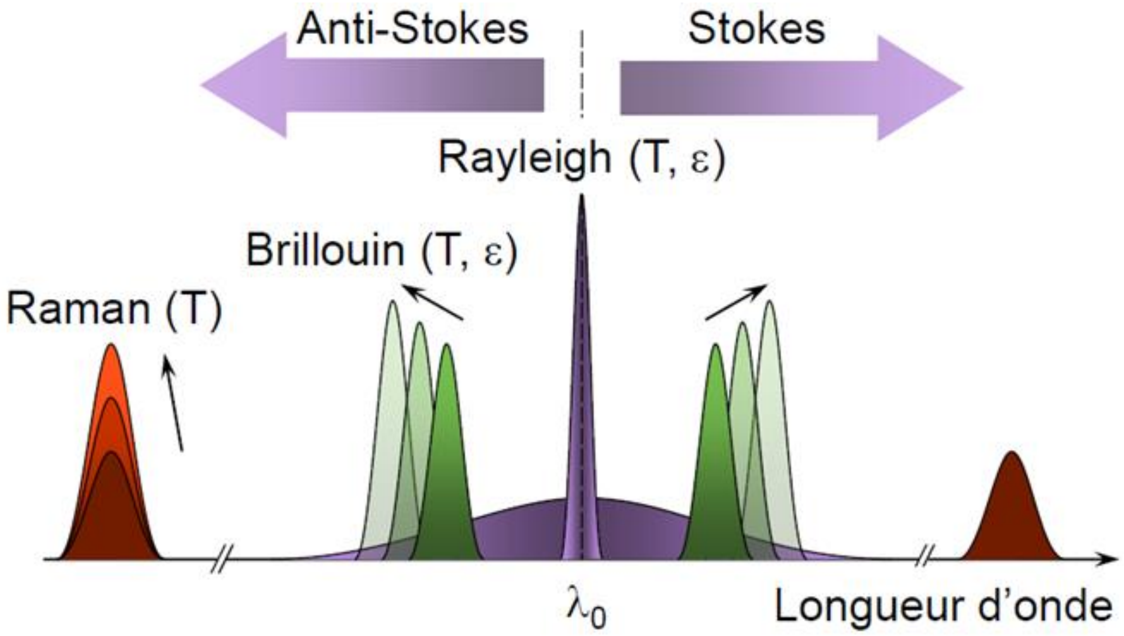
DISTRIBUTED SENSING
(temperature, strain, liquid level, pressure,..)

- Dosimetry
  - RIA (*active, distributed*)
  - TL (*passive*)
  - RIL, OSL (*active punctual*)

PUNCTUAL, ONLINE, OFFLINE SENSING

Distributed sensing based on backscattered light into OFs

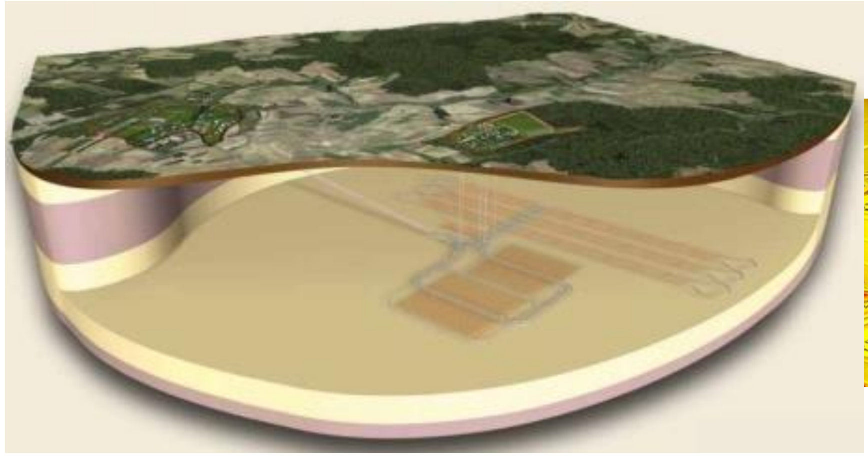


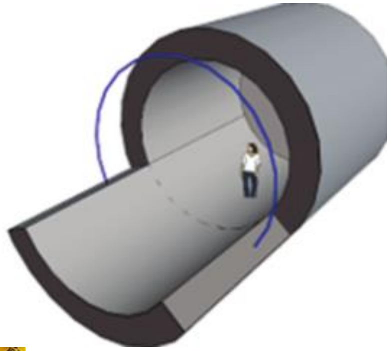


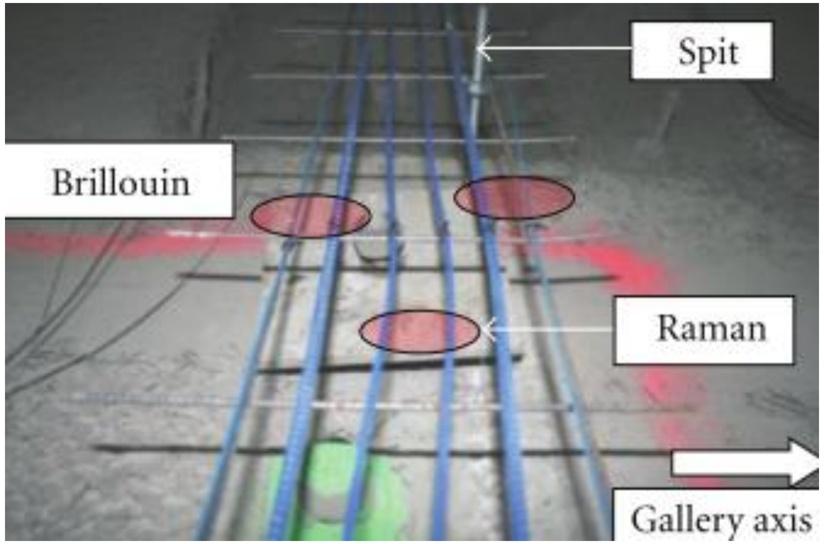
PhD thesis Xavier Phéron
PhD thesis Serena Rizzolo
PhD thesis Chiara Cangialosi
PhD thesis Isabelle Planes

ANDRA needs for radioactive waste storage

- Temperature and strain monitoring will be implemented in the envisioned French geological repository for high- and intermediate-level long-lived nuclear wastes.







Review: S. Delepine-Lesoille, et al. *Sensors* 2017, 17, 1377.

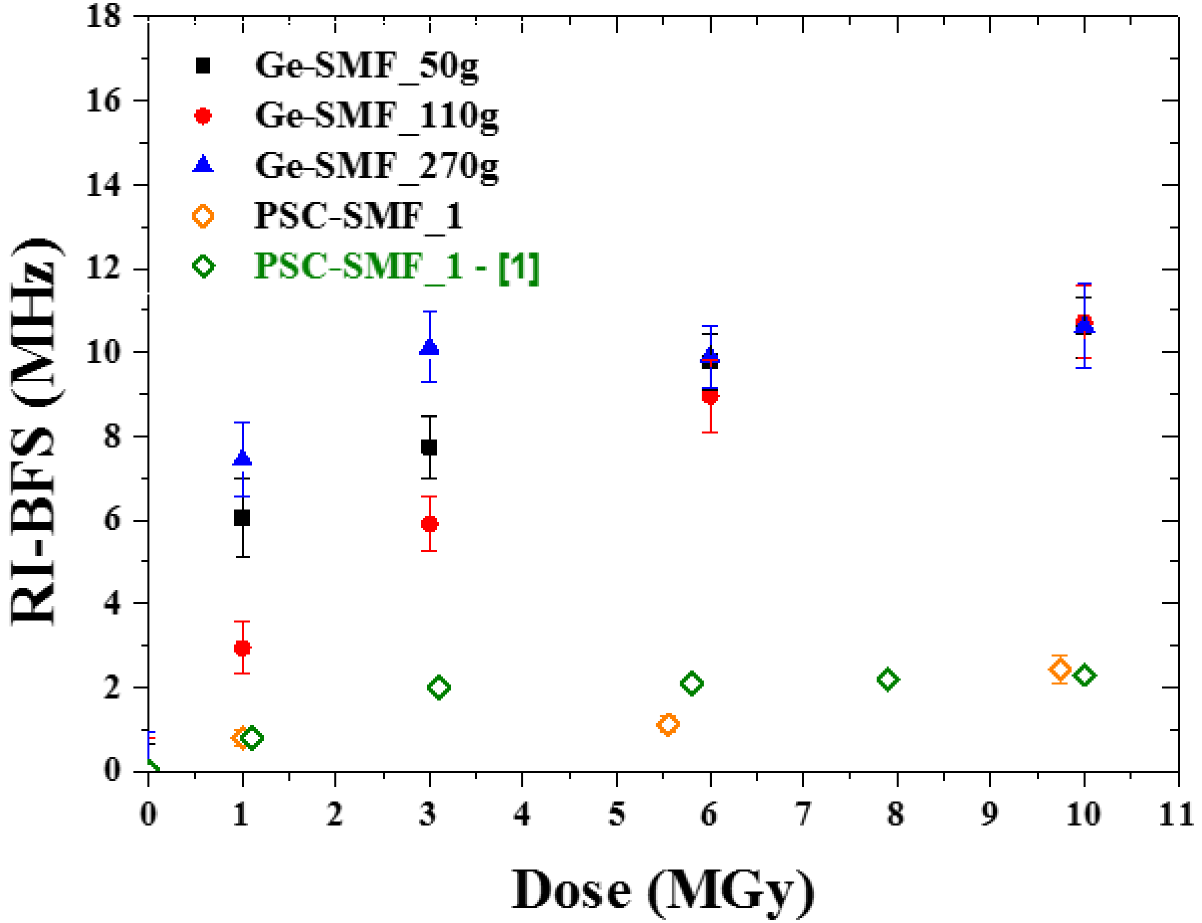
➡ Investigations of **<u>Gamma radiation and hydrogen release</u>** effects on **Raman** and **Brillouin** sensors to provide T, strain discrimination using a 2 fiber cable

Brillouin-based distributed temperature measurements is possible at MGy dose levels

- Radiations affect Brillouin sensors by different ways:
  - **RIA** limits the possible distance range
  - Radiation shifts the BFS ➔ direct error on the T or strain measurement

By using best optical fibers, it is possible to limit the error below 1-2°C at MGy dose over hundredths of meters

C. Cangialosi, PhD Thesis, 2016

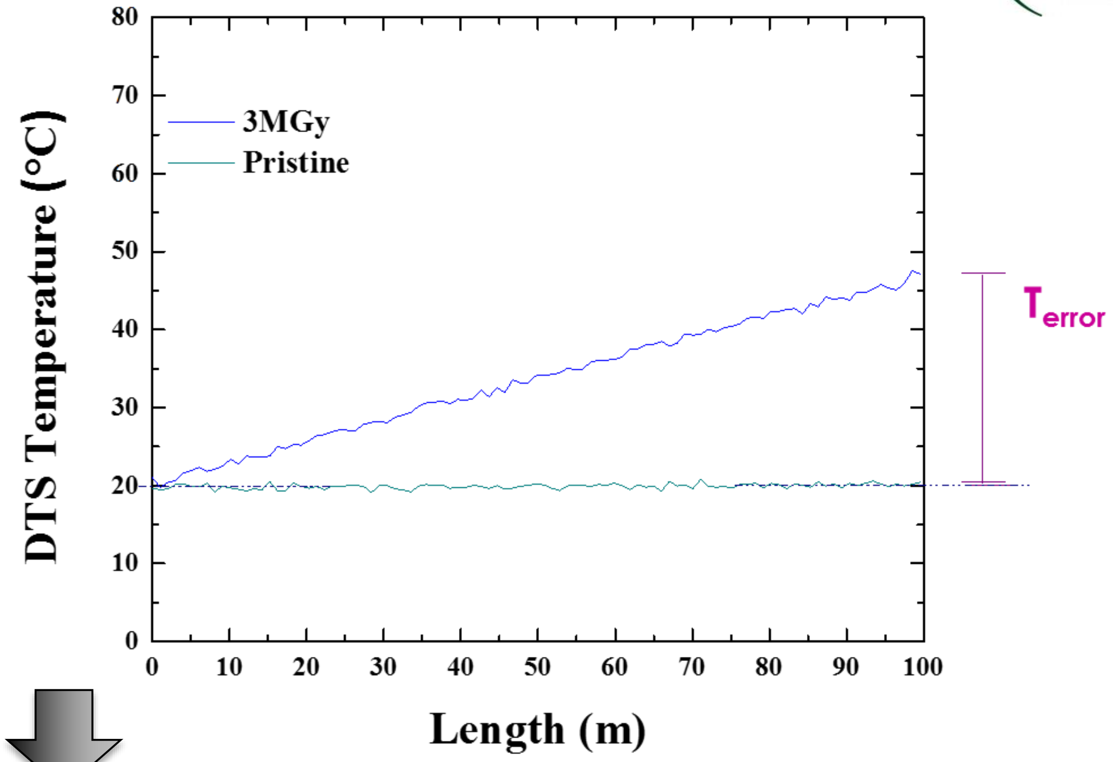


Review: S. Delepine-Lesoille, et al. *Sensors* 2017, 17, 1377.

Raman-based distributed temperature (RDTS) measurements are not possible with single-ended (SE) commercial sensors

C. Cangialosi, PhD Thesis, 2016

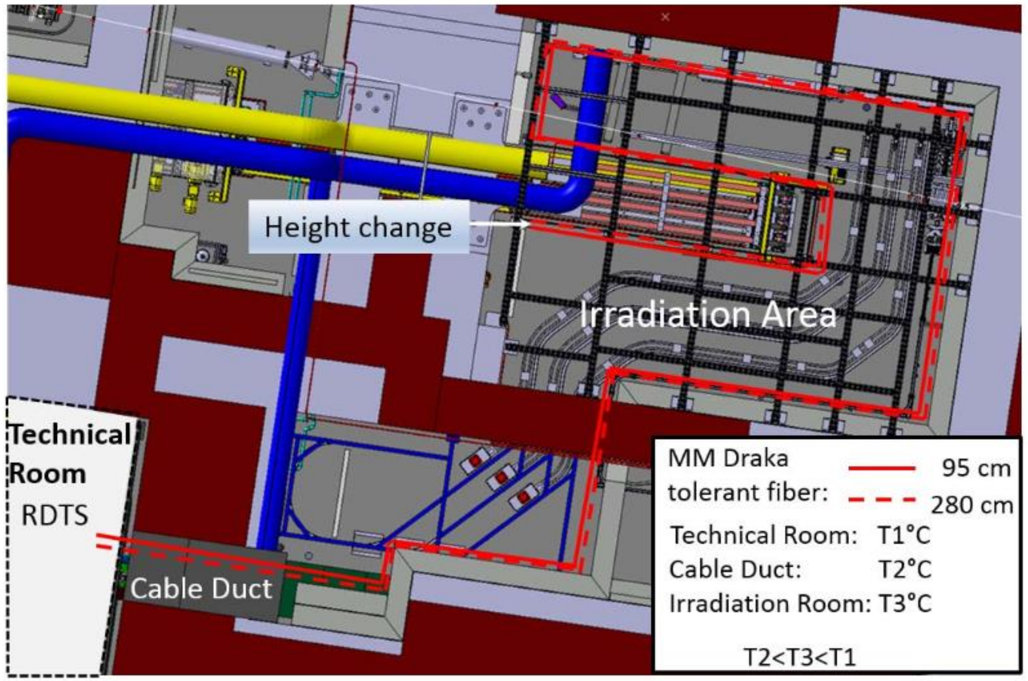
- Radiations affect Raman sensors by different ways:
  - RIA limits the possible distance range (x2 in the case of double-ended)
  - Radiation can affect the S/AS ratio ➔ direct error on the T measurement due to ΔRIA

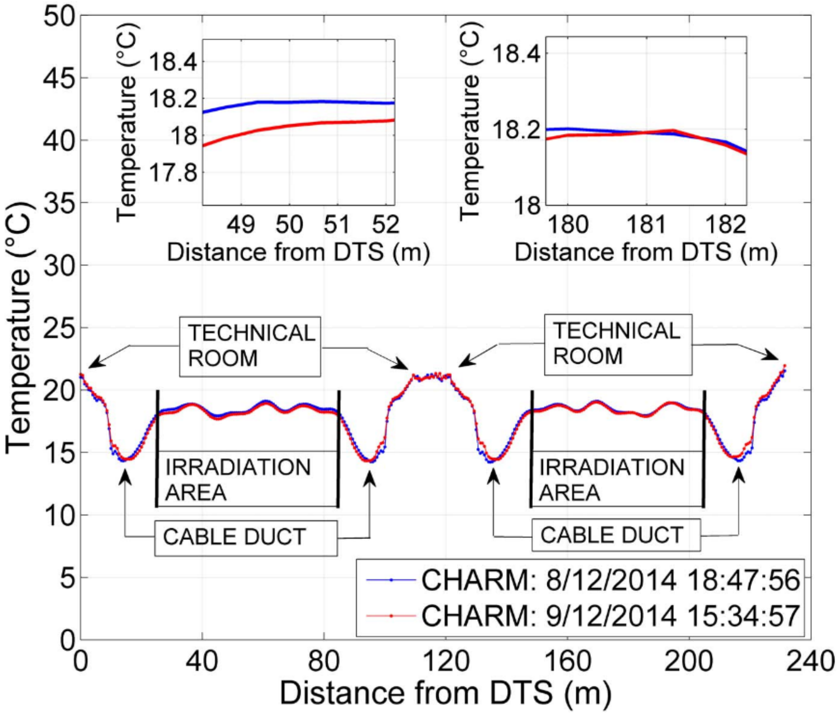


Hardening is not possible by components ➔ the architecture of the sensors must be adapted

Raman-based distributed temperature (RDTS) measurements are possible with double-ended (DE) commercial sensors

I. Toccafondo, PhD thesis, 2015
I. Toccafondo, IEEE Photonics Technology Letters, 27 (20) 2182-2185, 2015

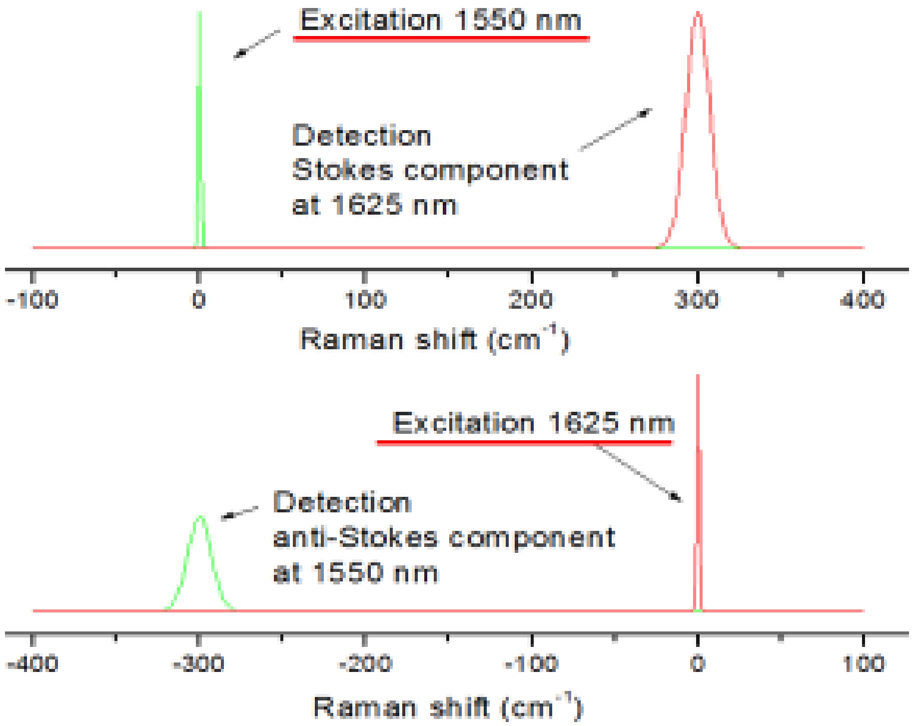


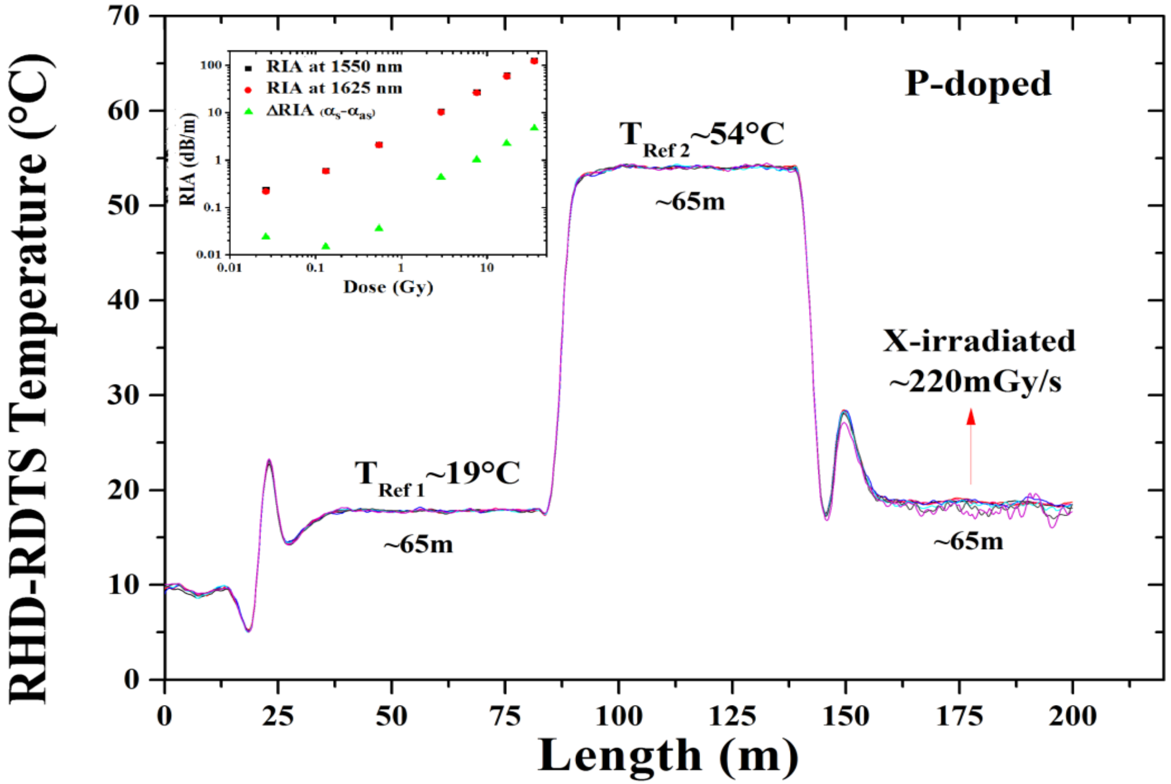


➡ **Solve ΔRIA issues, up to ×2 RIA issues**

A Hardening-by-System approach allows us to perform Raman measurements at high doses

Di Francesca et *al.*, *IEEE TNS, accepted, 2016.*





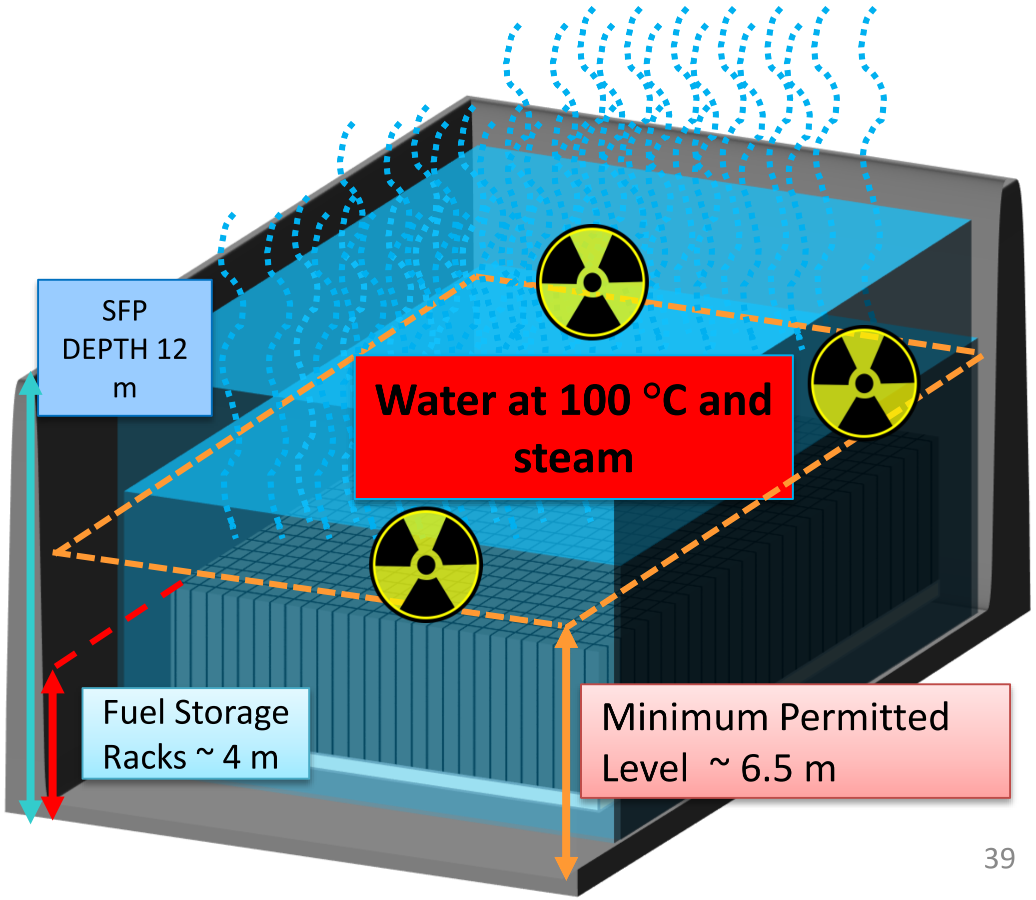
This new SE-RDTS architecture limits both RIA and ΔRIA issues

Rayleigh-based OFS: Fukushima-Daichii accident: a break point in the nuclear safety rules

AREVA

NEED: Development of a distributed **TEMPERATURE** and **WATER LEVEL** sensor for **STORAGE FUEL POOLS**

	Operating Conditions
Temperature	10 - 60 °C
Humidity	0 - 95%
Pression	86 -106 kPa
Radiation	1 MGy in 40 years

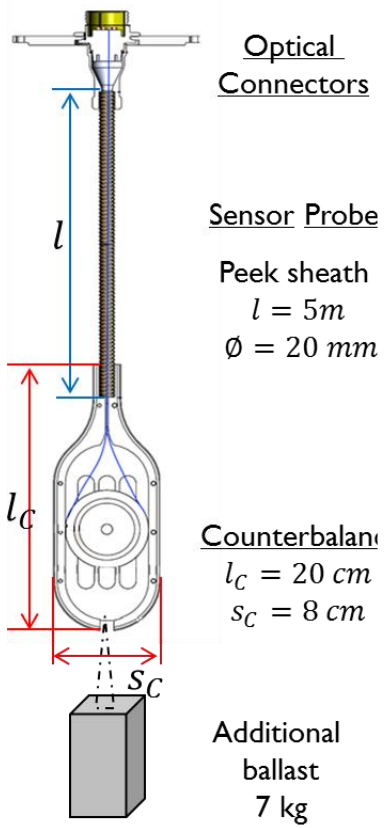


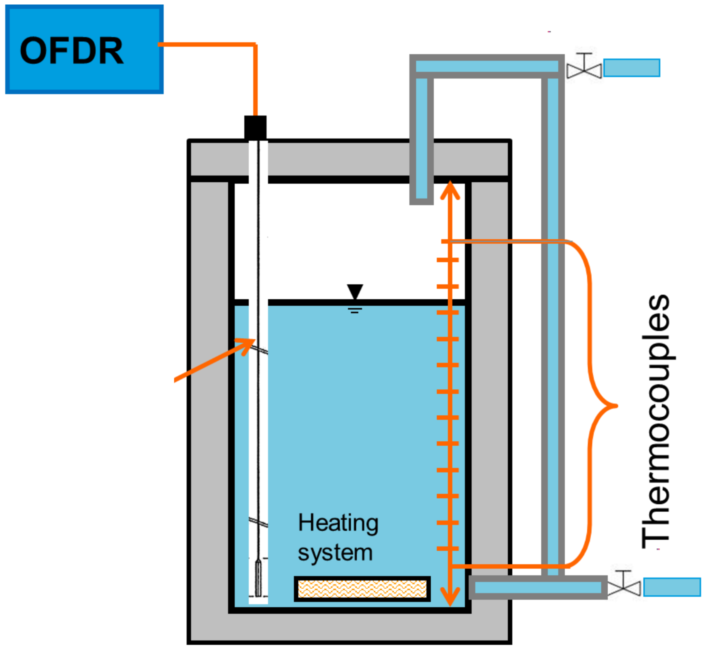
CHALLENGE: Ability to withstand to ACCIDENTAL CONDITIONS

OFDR reflectometry is a very promising technique with a high spatial resolution (100µm over 70m for LUNA OBR4600)

- ❑ Limited knowledge about radiation effects on this technology (*Alexey Faustov, PhD* <100kGy TID)
- ❑ Rayleigh scattering is not affected by irradiation, at least up to 10MGy
- ❑ **Only RIA limits the fiber sensing range**

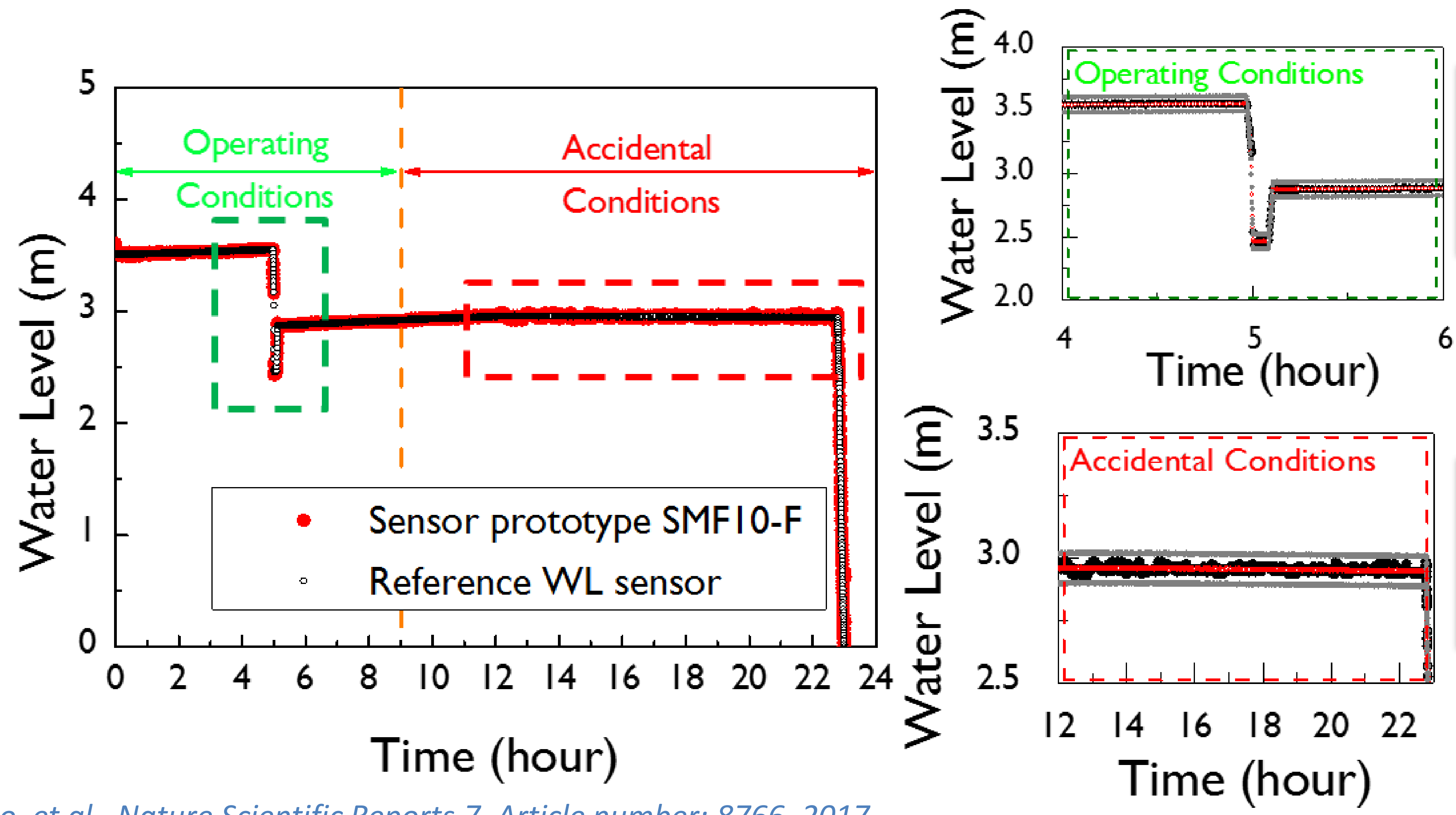
➡ **Very recent results demonstrated the potential of this technique for monitoring T, strain in nuclear facilities**





S. Rizzolo, et al., Optics Express, vol.23 (15), 18998 , 2015.
S. Rizzolo, et al., Optics Letters, 2015 ; S. Rizzolo et al., IEEE TNS, 2015.
AREVA – LabHC, 2015 patents

Water level is well detected with a F-doped OF with polyimide coating



Incertitude on WL: 1 cm

Incertitude on WL: 3 cm

S. Rizzolo, et al., Nature Scientific Reports 7, Article number: 8766, 2017.

Part 4: Recent Advances on fiber-based dosimetry

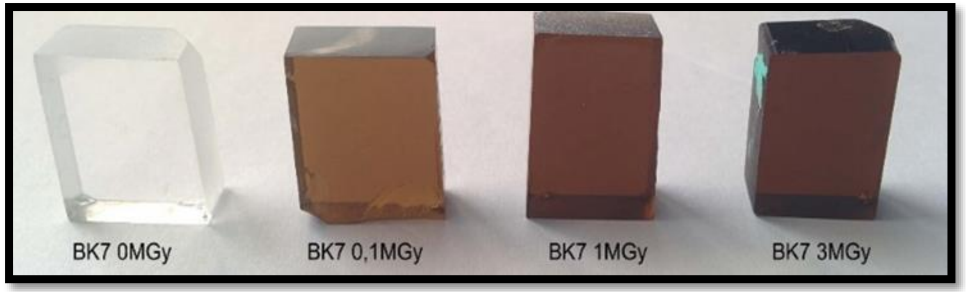
1. RIA based dosimeters
2. RIL based dosimeters
3. TL based dosimetry (no time!)

Part 4: Recent Advances on fiber-based dosimetry
1. RIA based dosimetry

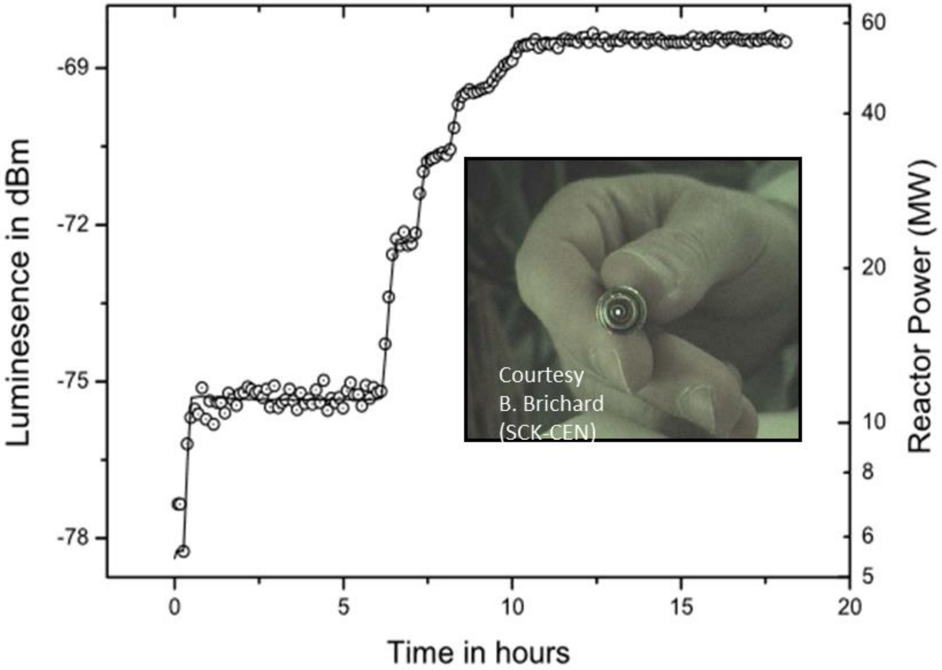
LABORATOIRE HUBERT CURIEN
UMR • CNRS • 5516 • SAINT-ETIENNE
labH6
Membre de Université de Lyon

Different technologies of fiber-based dosimeters

- ❑ Based on **radiation-induced attenuation (RIA)**
  - ✓ **Active** or **passive** dosimetry is possible
  - ✓ **Point** or **distributed** dosimetry is possible
  - ✓ **Discriminative dosimetry** should be possible



- ❑ Based on **radiation-induced luminescence (RIL)** and **optically-stimulated luminescence (OSL)**
  - ✓ Active (RIL) or passive (OSL) dosimetry is possible
  - ✓ Point dosimetry, distributed dosimetry should be possible
  - ✓ Discriminative dosimetry should be possible

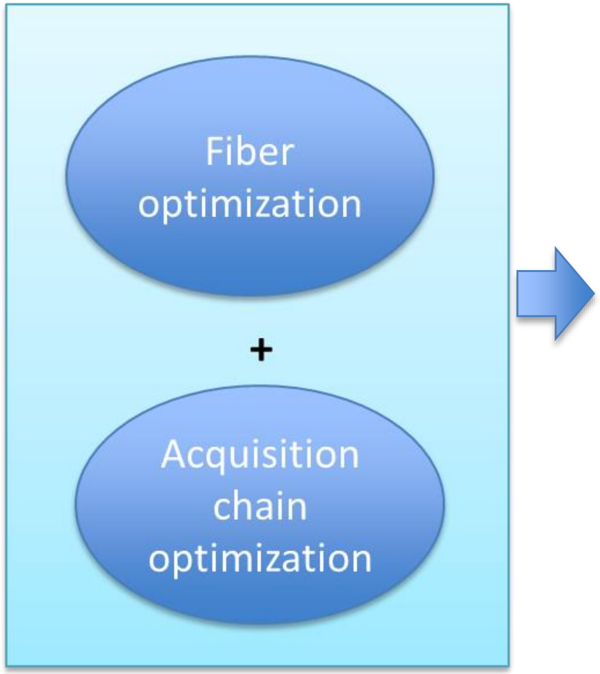


Brichard et al., Meas. Sci. Technol., 2007

- ❑ Dosimetry based on **Thermoluminescence (TL)**
  - ✓ Passive dosimetry, point dosimetry- ONLY
  - ✓ Discriminative dosimetry should be possible

What defines a highly performant RIA-based dosimeter? (1/2)

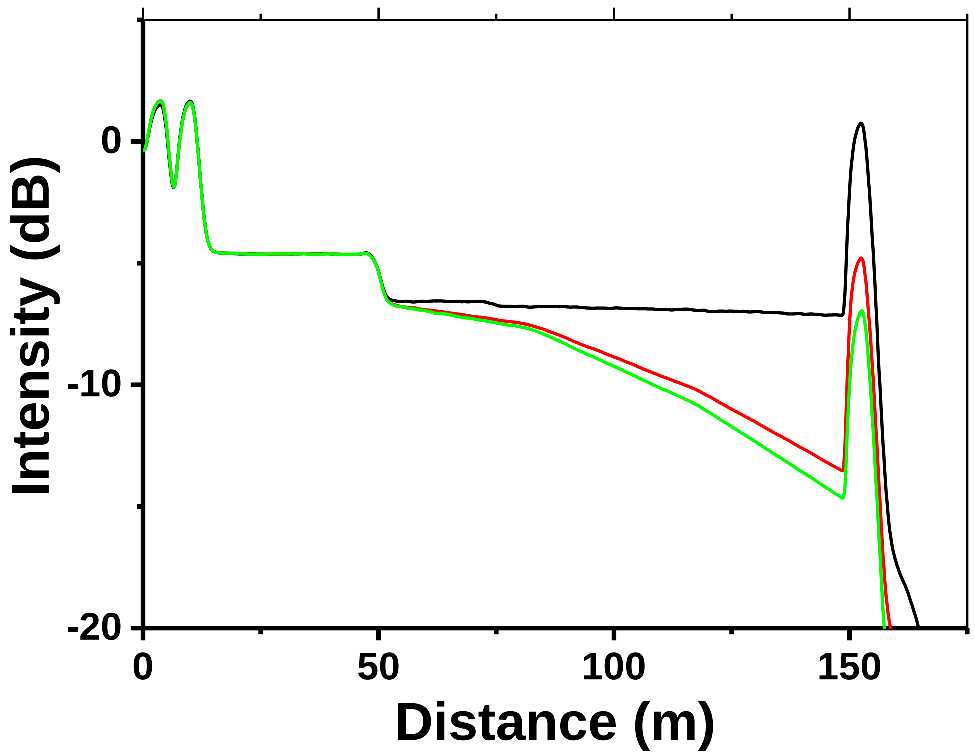
- **A radiation sensitive optical fibers with good sensing characteristics**
  - ✓ Radiation sensitivity (expressed in dB km^{-1} Gy^{-1})
  - ✓ "Linear" RIA increase with dose
  - ✓ Dose rate independence
  - ✓ Temperature independence
  - ✓ Absence of recovery (possibility to reset)
  - ✓ Compatibility with interrogation tools (source & detectors)



Dedicated dosimetry system for a given environment

What defines a highly performant RIA-based dosimeter? (2/2)

- **Dosimeter Performances Criteria**
  - ✓ **Spatial resolution:** point sensor or distributed sensor (cm to m resolution)
  - ✓ **Sensing distance** (point sensor to km range)
  - ✓ **Detection threshold** (min dose)
  - ✓ **Operating dose range** (min – max dose)

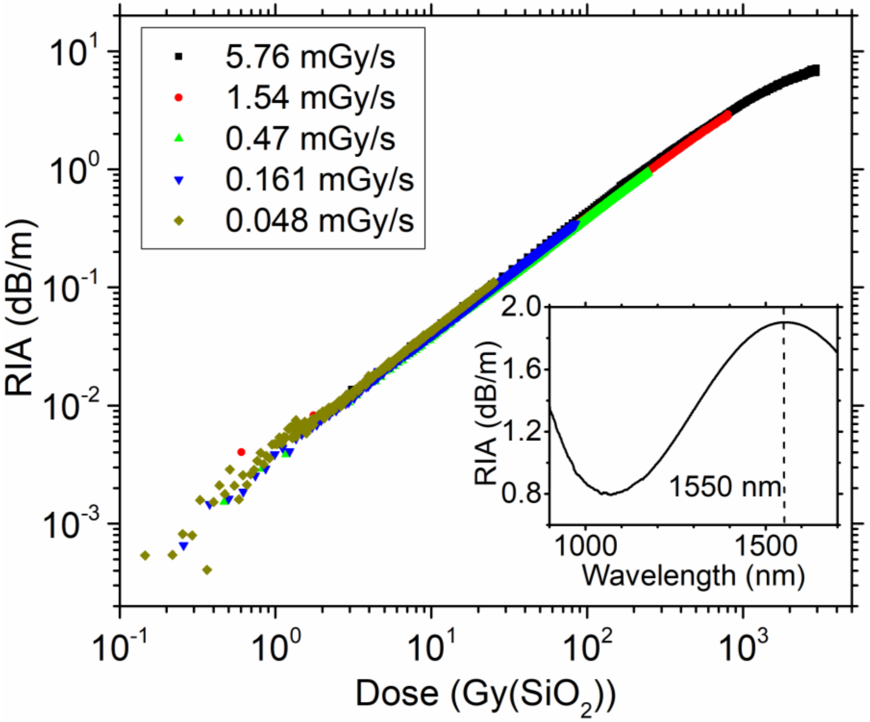


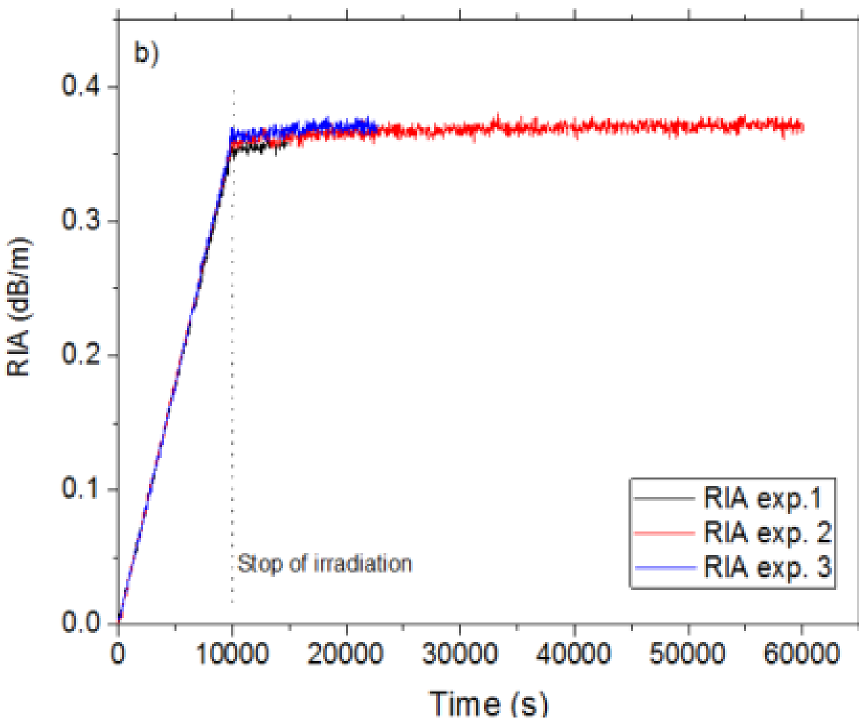
Depending on the interrogator architecture, various sensing configurations are possible

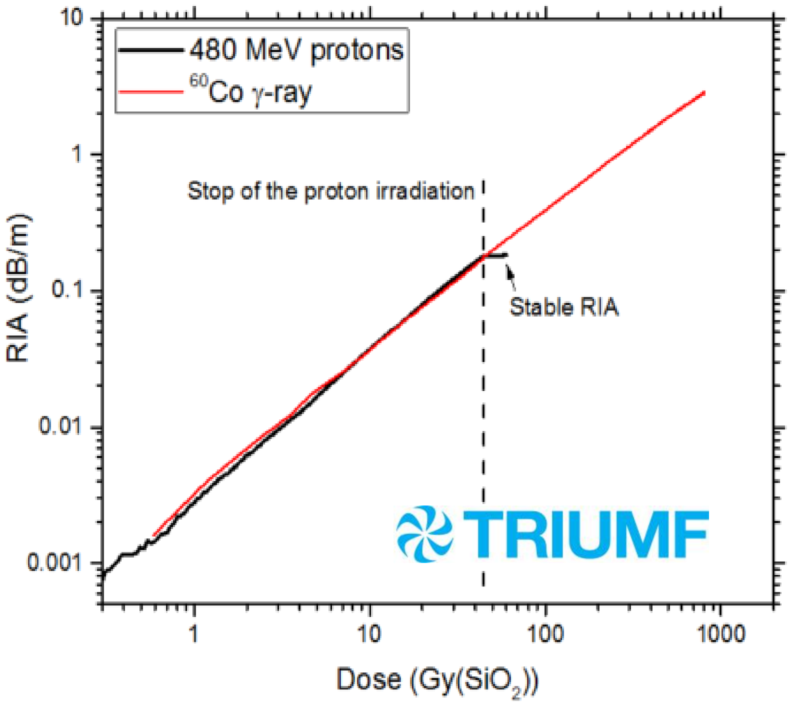
Which optical fiber for RIA-based dosimetry?

- Radiation sensitive optical fibers are identified such as the P-doped fibers
  - ✓ 4 dB km^{-1} Gy^{-1} **@1550nm (Third Telecom windows)**, Compatibility with interrogation tools (source & detectors)
  - ✓ "Linear" RIA increase with dose (up to 500Gy); dose rate independence, Temperature independence
  - ✓ Absence of recovery (possibility to reset)

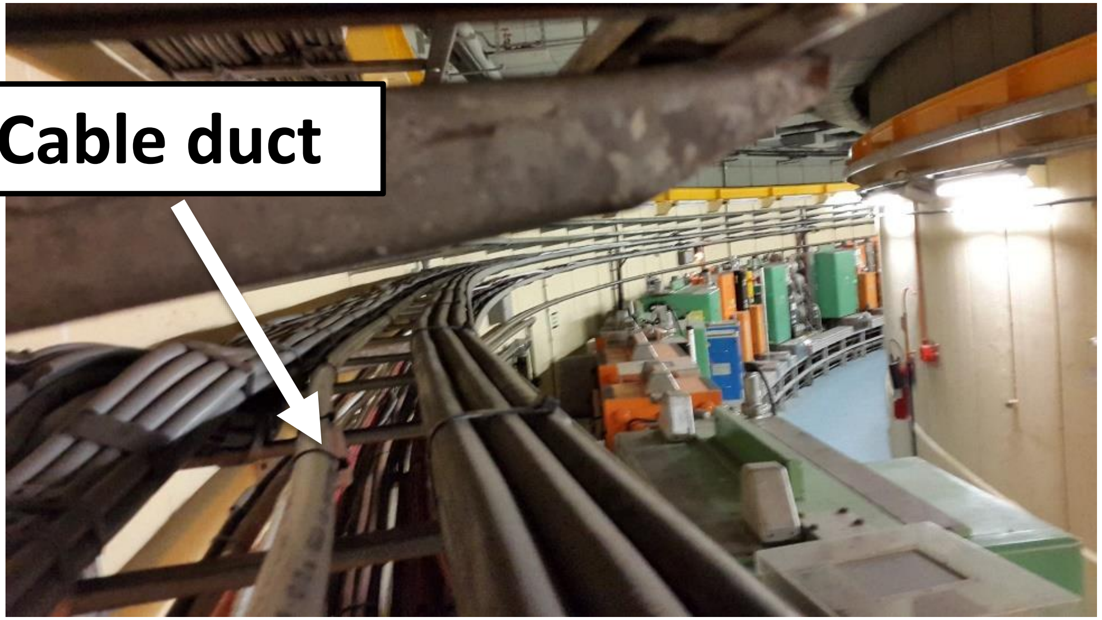
D. Di Francesca et al., JLT, 37(18) 4643-4649 (2019)

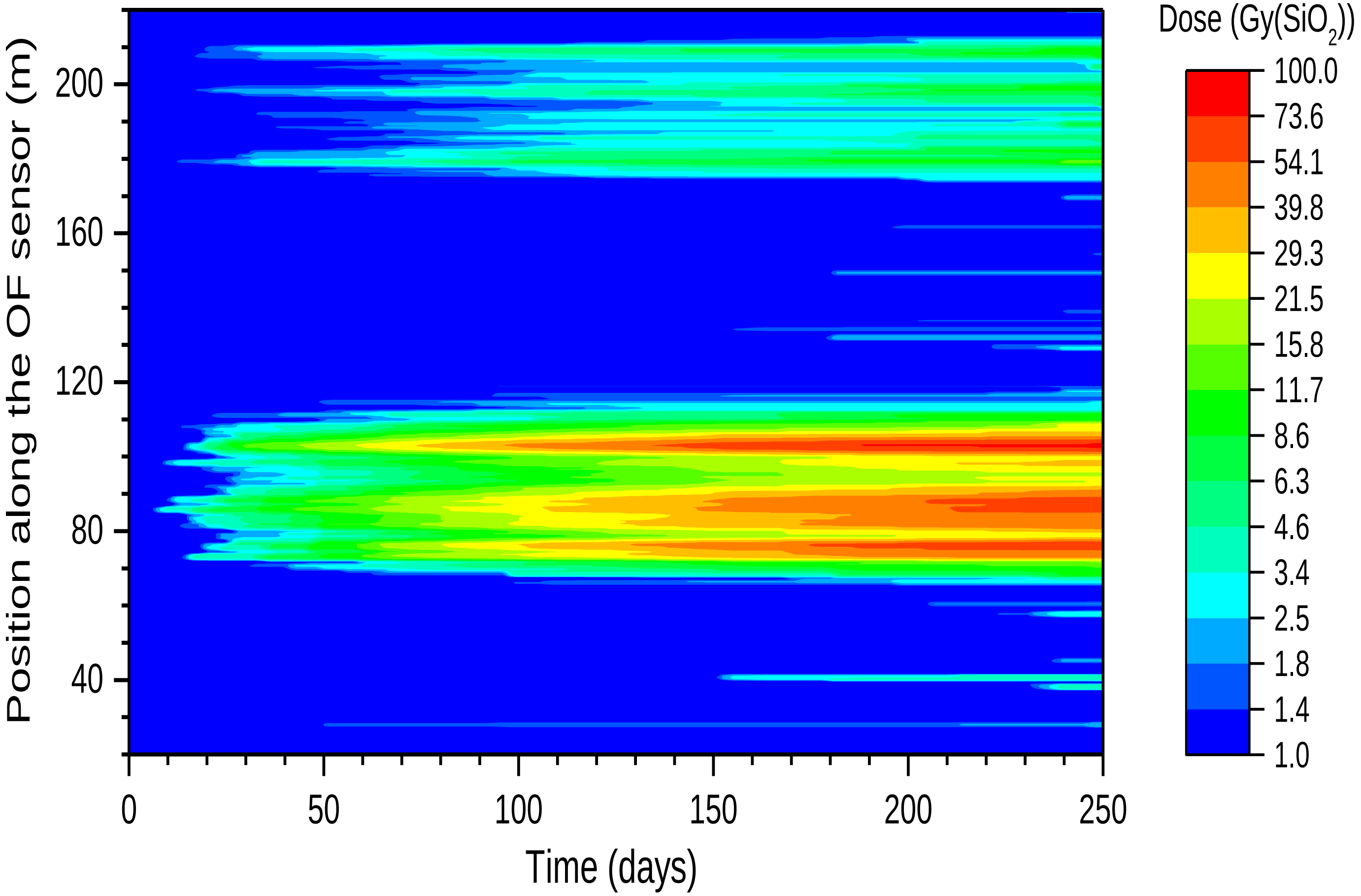






Towards the on-site application: dose mapping at the PSB during 2017





➔ The **Distributed Optical Fiber Radiation Sensor (DOFRS)** is currently deployed within all CERN accelerators and parts of the LHC by the R2E group

D. Di Francesca et al., IEEE TNS 65 (2018) 1639 / G. Li Vecchi, IPAC 2018

Part 4: Recent Advances on fiber-based dosimetry
2. RIL based dosimetry

PhLAM
Physique des Lasers Atomes et Molécules

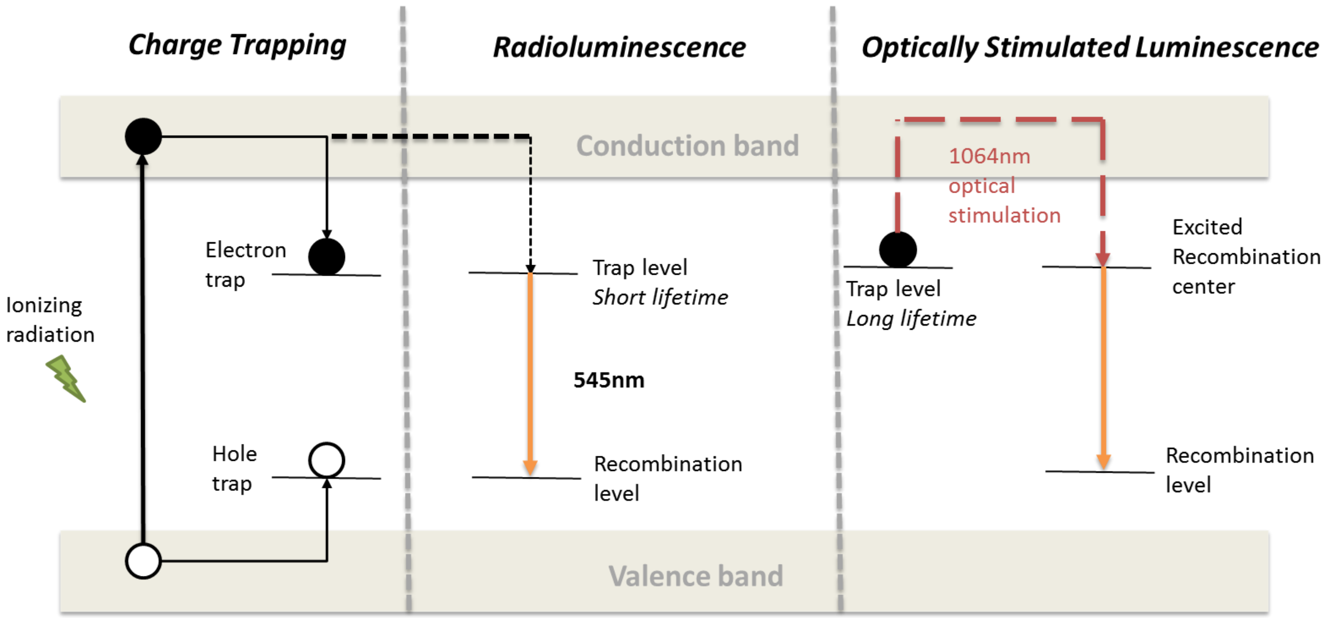
TRIUMF

DE LA RECHERCHE À L'INDUSTRIE
cea
Direction des Applications Militaires

CERN

cnes

Identification of optical fibers exhibiting **RadioLuminescence (RL)** during irradiation or **Optically Stimulated Luminescence (OSL)** post-irradiation



❑ Scintillating optical fibers (Φ few mm)

* High QE, RIL
* Low TID resistance

❑ New sol-gel materials

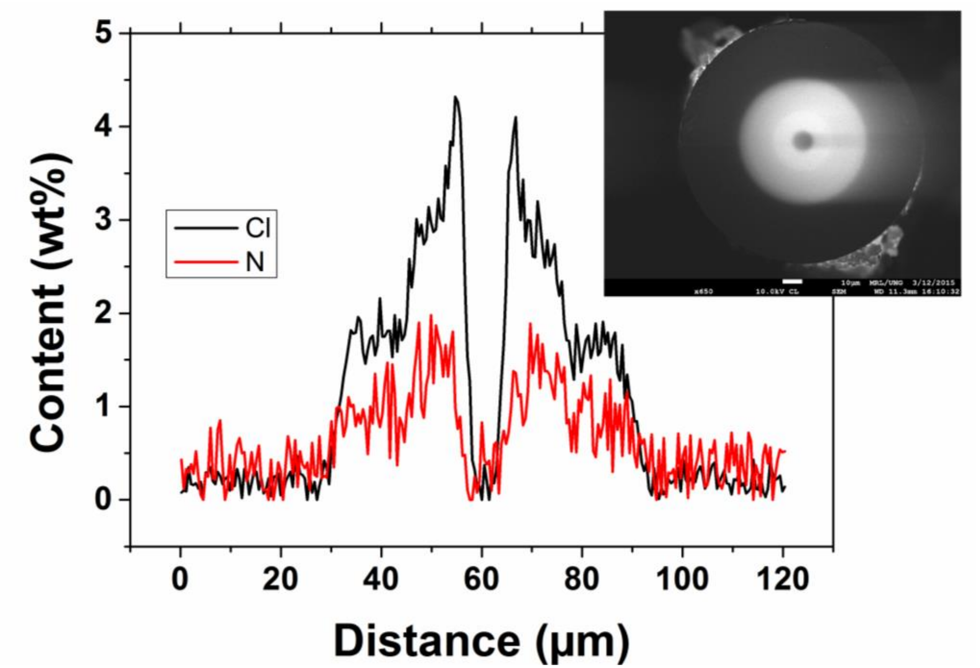
* Cu-doped, Ce-doped, CuCe-doped
* Gd-doped

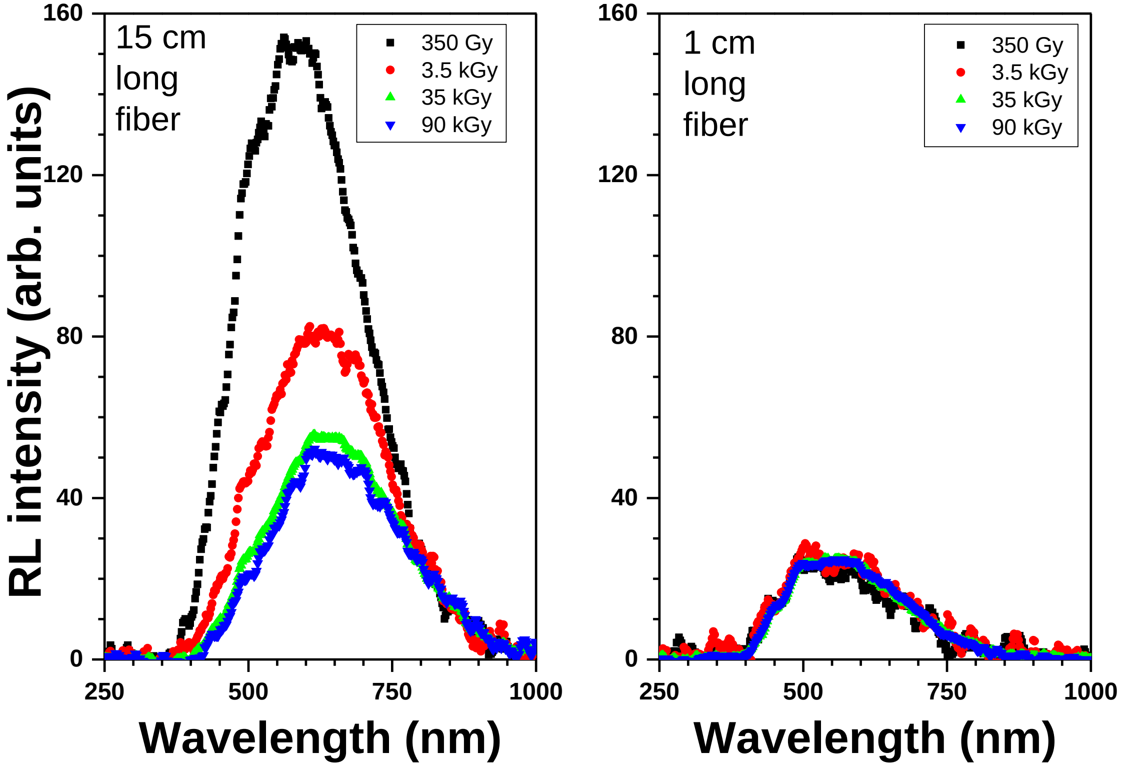
❑ New optical fibers

* N-doped

Focus on the potential of a small size (Φ 250µm, 50µm core) **radiation-hard (RIA)** multimode fiber ➔ **NITROGEN-DOPED / HIGHLY-SPATIALLY RESOLVED DOSIMETRY**

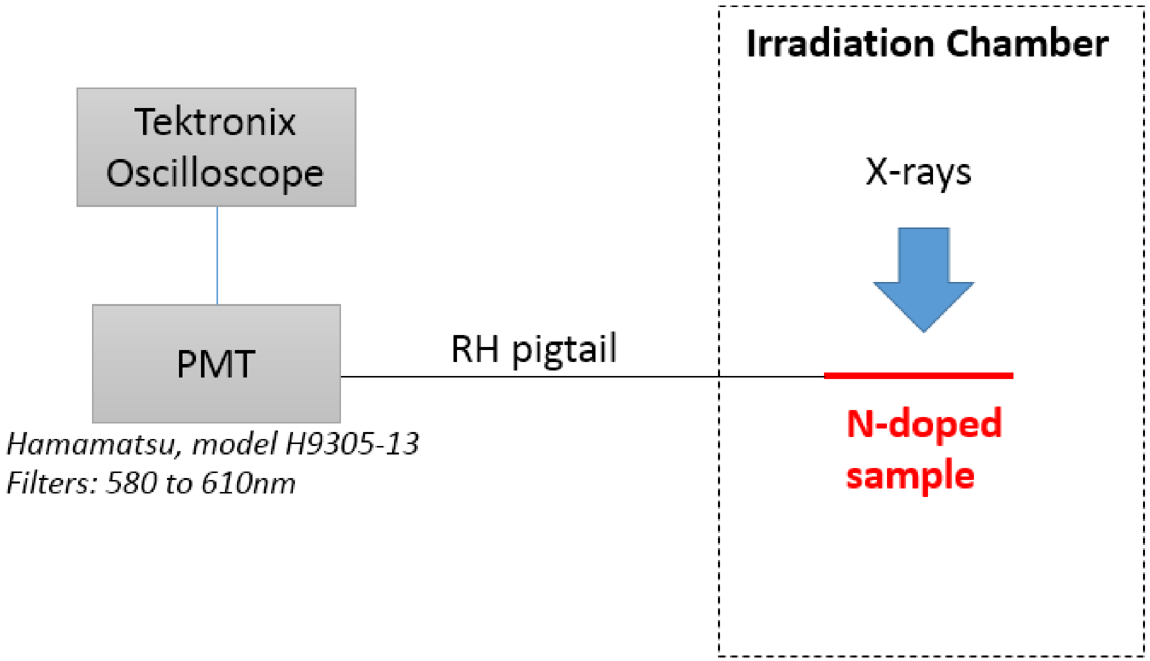
Tested Optical Fiber: Under X-rays (50 Gy/s), the fiber presents a strong Radioluminescence (RL) peaking around 625nm

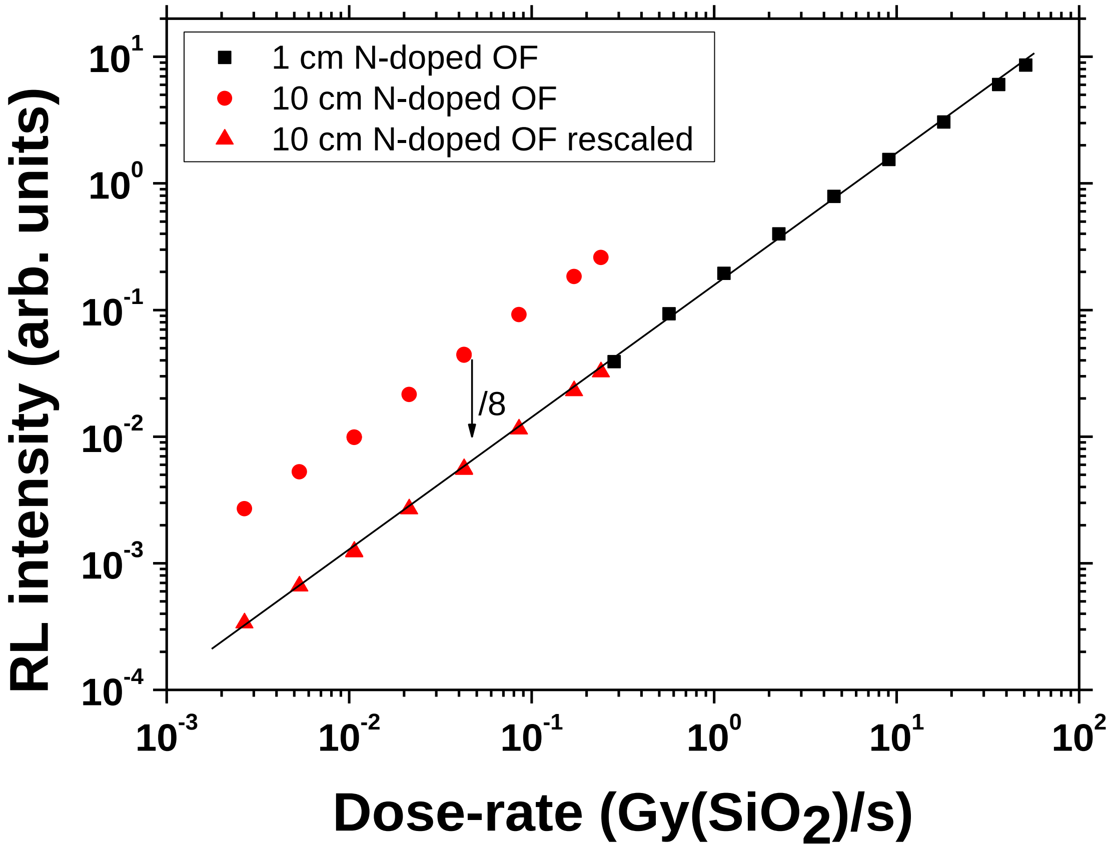




At **HIGH** Dose rate/ TID ➔ Short lengths of fibers have to be used to reduce RIA issues.
At **LOW** Dose rate/TID ➔ Fiber length can be optimized to increase the RL level

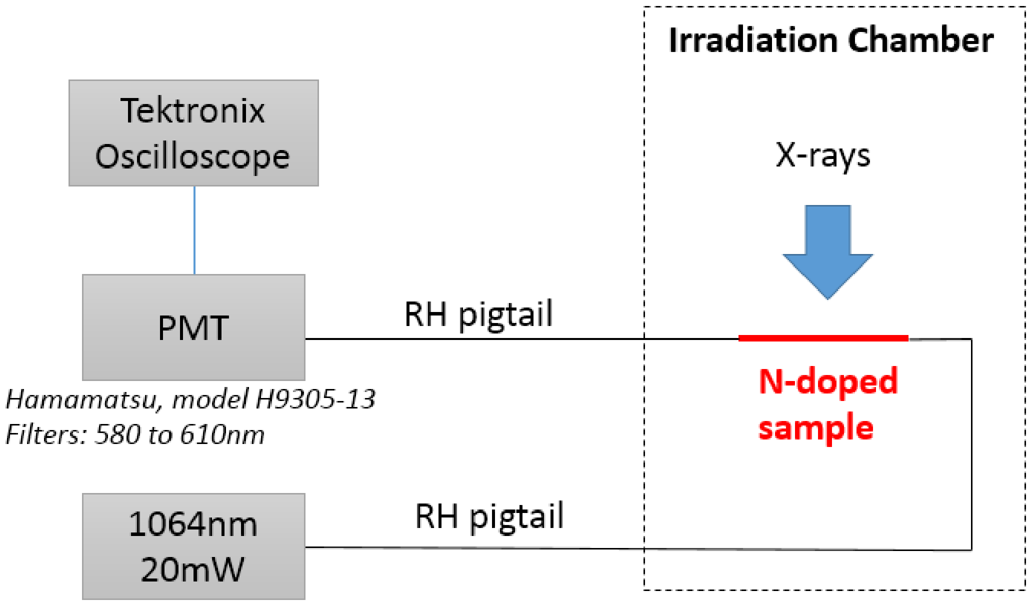
Tested Optical Fiber: RL of the N-doper fiber linearly depends on the dose rate at least from **1mGy/s (100mrad/s) to 50 Gy/s (5krad/s)**

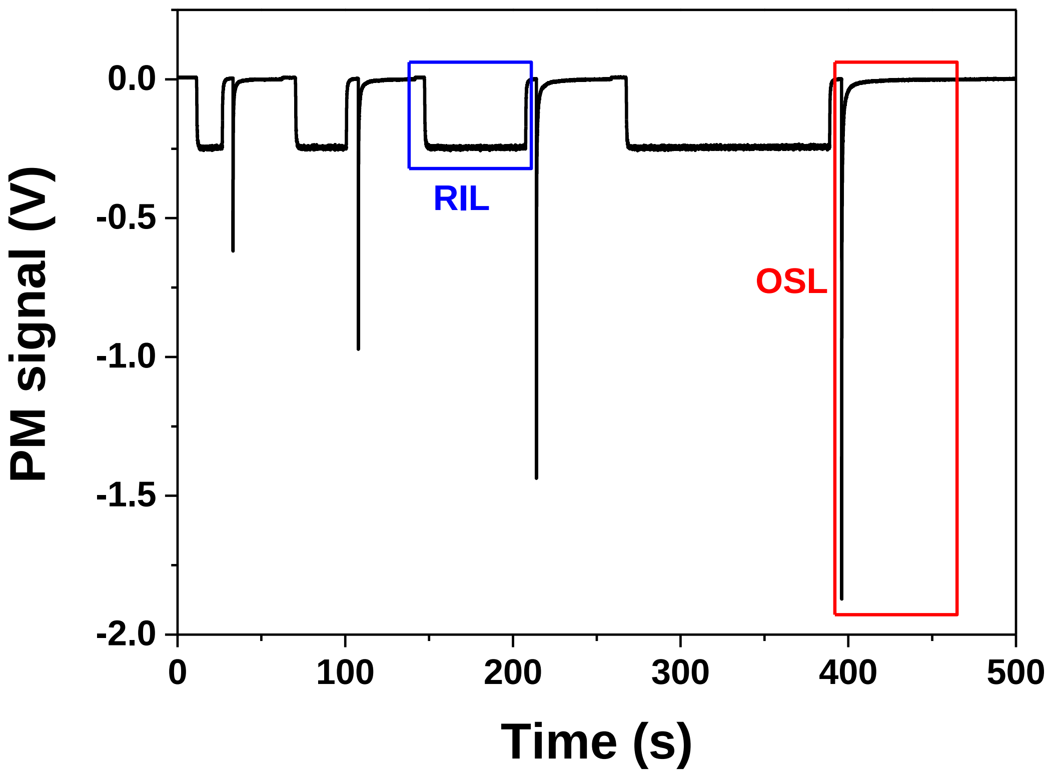




In absence of Cerenkov, RL measurements provide the time evolution **(with millisecond resolution)** of dose rate and then of the dose (if the irradiation duration is known)

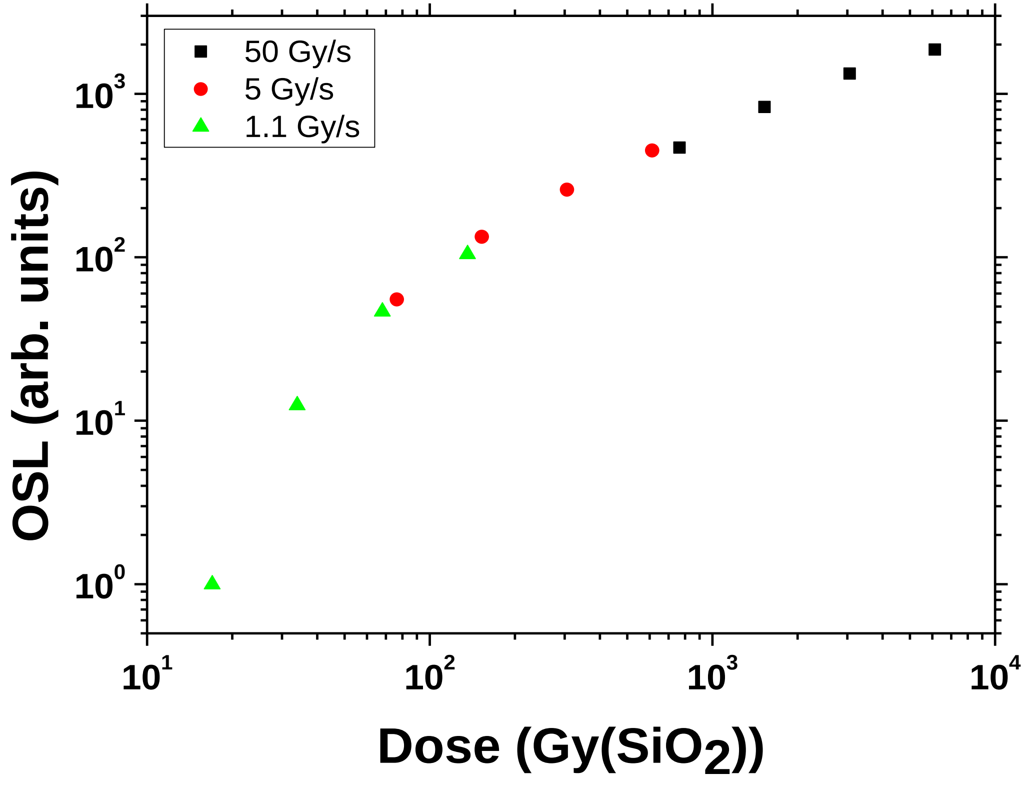
Tested Optical Fiber: the N-doped fiber presents an OSL signal under 1064nm excitation





By integrating the OSL signal after irradiation, its dose dependence of the OSL can be reconstructed and the fiber being calibrated if the OSL is dose rate independent

Tested Optical Fiber: the OSL signal under 1064nm excitation can be used to monitor the TID after the end of the irradiation

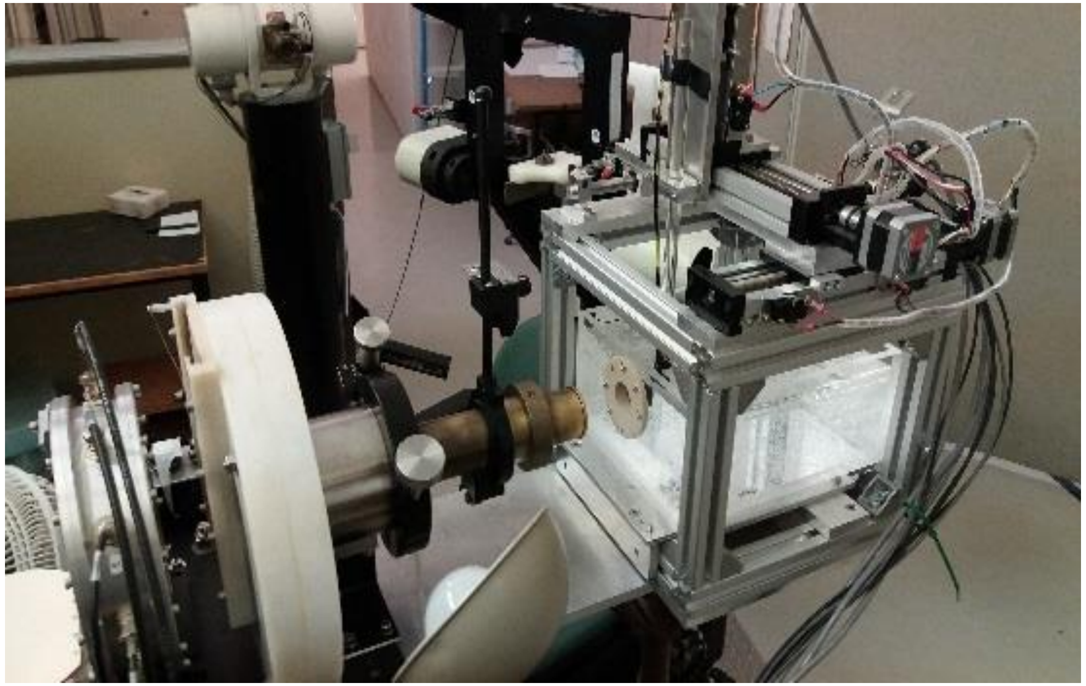


- ❑ **OSL appears as dose rate independent**
  - * 1 – 50 Gy/s dose rate
- ❑ **OSL monotonically grows with dose**
  - * 1 – 10kGy dose range

In presence of Cerenkov, RL measurements provide the time evolutions **(with millisecond resolution)** of dose rate and a precise measure of the dose can be achieved by OSL measurements

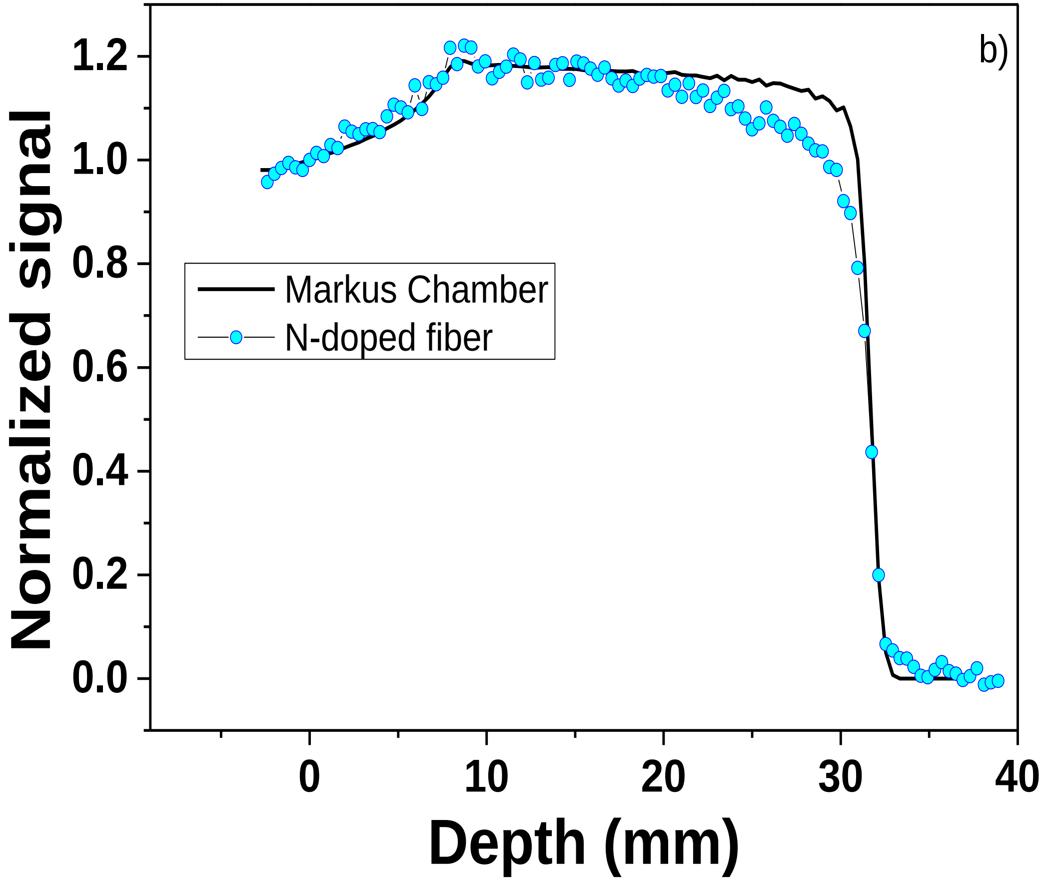
Proton tests: Potential of the N-doped fiber for proton-therapy beam monitoring is investigated in collaboration with TRIUMF

- Some of the investigated fibers (N-doped; Gd sol-gel doped) present better dosimetry characteristics than COTS scintillating fibers



S. Girard et al., IEEE TNS**66** 306 (2019)

C. Hoehr et al., Nature Scientific Reports vol.9, 16376 (2019)



Conclusions

- Optical fibers and fiber sensors are quickly integrated in facilities encountering radiations for data transfer and sensing

- Future challenges concern the **functionalization of these fibers** to monitor parameters such as temperature (eg. fire detection), strain, pressure, liquid level, vibrations, radiations….

- Overcoming these future challenges will be possible through a **coupled simulation/experiments approach** to identify & predict the basic mechanisms describing the radiation effects on dielectrics

- The fundamental knowledge can bring new insights about the nature of point defects and how to control them to tune the fiber response for new applications in harsh environments

Acknowledgements

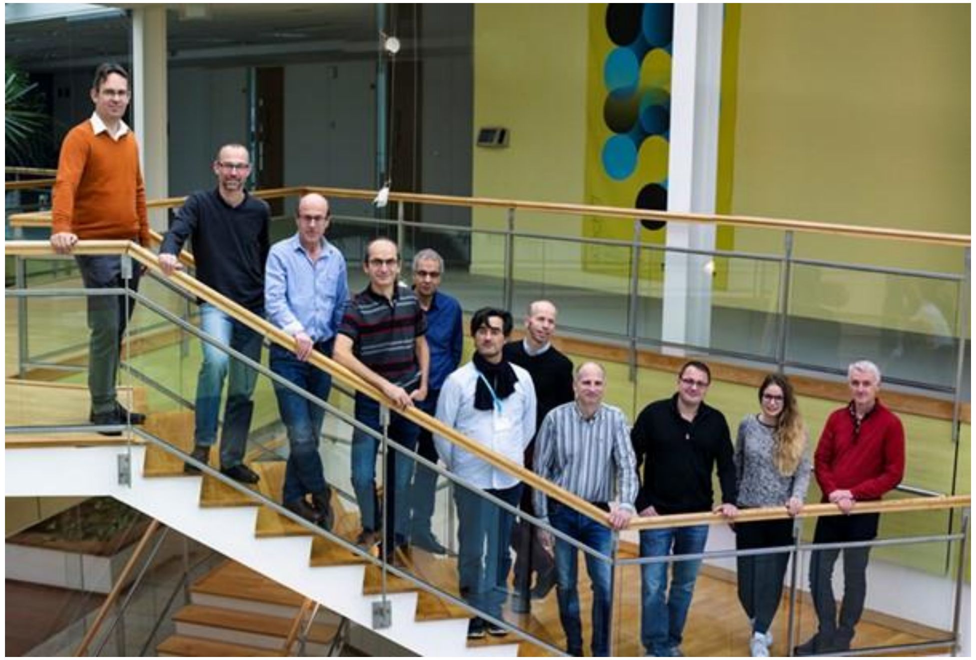
Thanks to our partners !

labH6

A joint research lab between iXblue and UJM

https://photonics.ixblue.com/labcom/labh6

MOPERE team June 2018



LabH6 meeting, Lannion, Dec. 2018

Thanks for your attention

LABORATOIRE HUBERT CURIEN

UMR • CNRS • 5516 • SAINT-ETIENNE

iXblue

UNIVERSITÉ JEAN MONNET SAINT-ÉTIENNE

Membre de UNIVERSITÉ DE LYON