Distributed fiber dosimetry solution with ultra-low loss pure-silica core optical fiber

Luca Weninger, Adriana Morana, Aziz Boukenter, Youcef Ouerdane, Emmanuel Marin and Sylvain Girard

RADOPT 2023

UNIVERSITÉ JEAN MONNET SAINT-ÉTIENNE

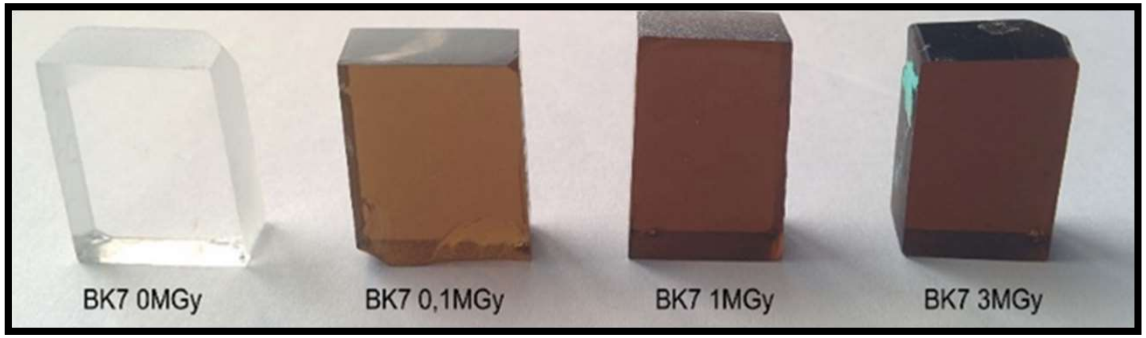
Radiation-induced Attenuation

Main classification of optical fibers (OFs): Dopants.

Two directions to engineer the fibers

- Radiation hard OFs (PSC, F)
- Radiation sensitive OFs (Ge, Al, P)

All doses are expressed in Gy(SiO_2)



Courtesy of T. Allanche

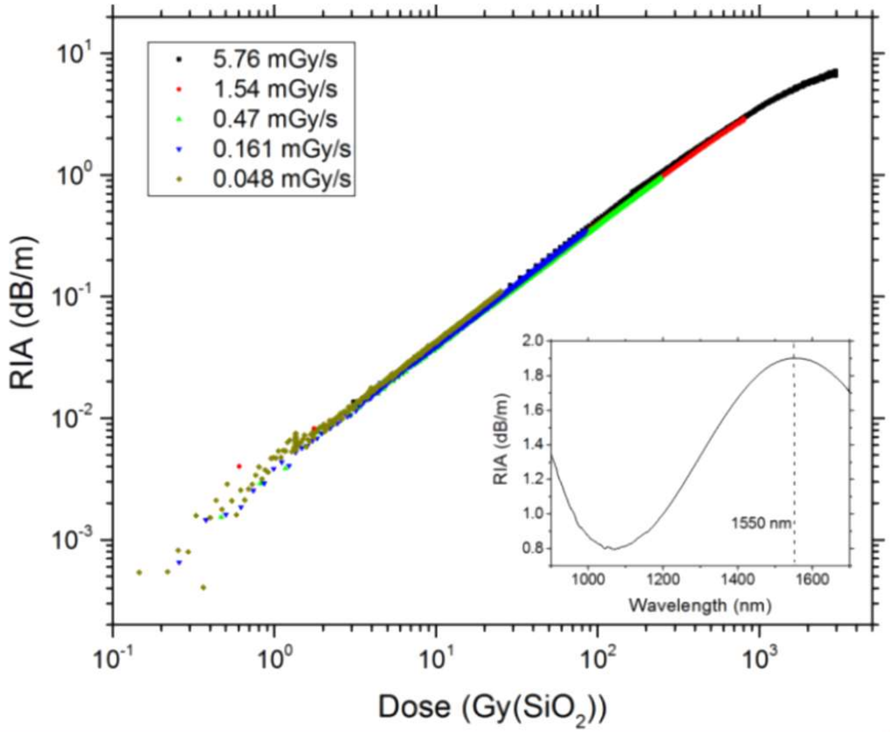
RAD NEXT
UNIVERSITÉ JEAN MONNET SAINT-ÉTIENNE

RIA dosimeters: P-doped fiber

The golden standard today for RIA-based dosimetry is the P-doped fiber.

It is:

- Monotonic with dose.
- Linear with dose. (< 1 kGy)
- Very sensitive to dose (~ 4 dB km^{-1} Gy^{-1})
- Dose rate independent.
- Temperature independent.
- Doesn't recover after irradiation.



D. Di Francesca et al., Journal of Lightwave Technology 37(18) 4643-4649, 2019

RAD NEXT

UNIVERSITÉ JEAN MONNET SAINT-ÉTIENNE

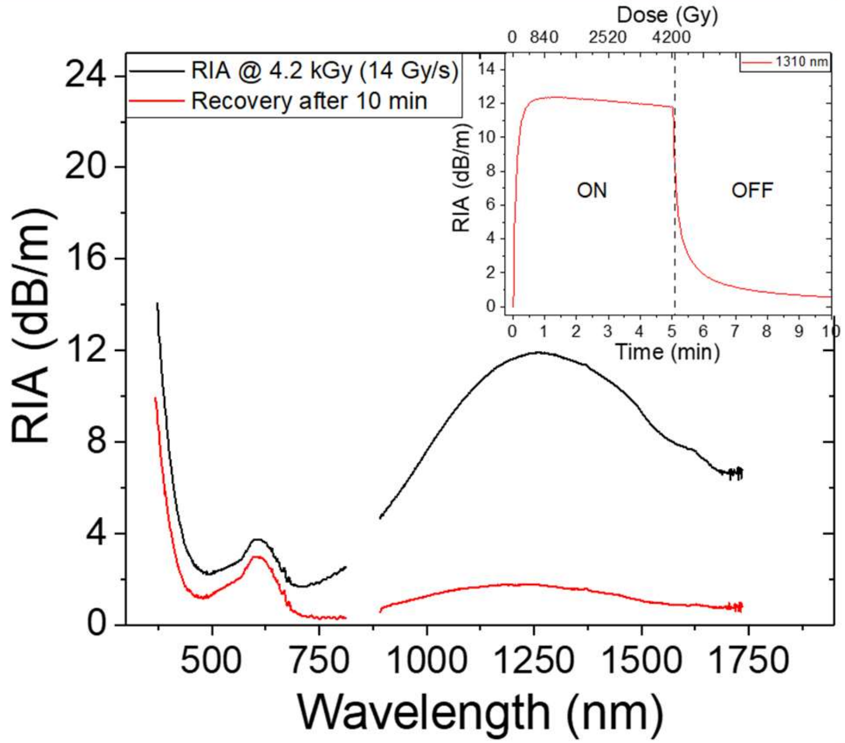
Fiber under test: Spectral RIA

Ultra-low loss pure-silica core fiber.

Contrary to other PSC OFs, it is very sensitive to radiation.

Presented as a poster at RADECS23:

Radiation Detection with Radiosensitive Pure-Silica Core Ultra-Low Loss Optical Fiber.
L. Weninger et al.



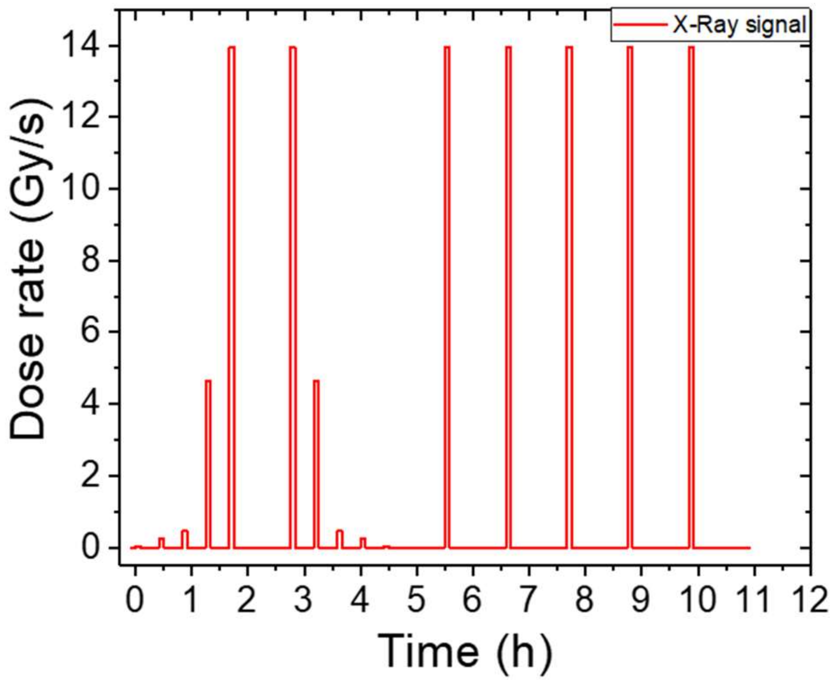
RIA kinetics at 1310 nm

This fiber proved to be very sensitive to dose rate, instead of dose.

Two contributions are clearly visible:

- Permanent losses (observable between irradiation runs, growing with dose)
- Transient losses (only present during irradiation, decreasing with dose)

So we decided to pre-irradiate the fiber to stabilize the defects.



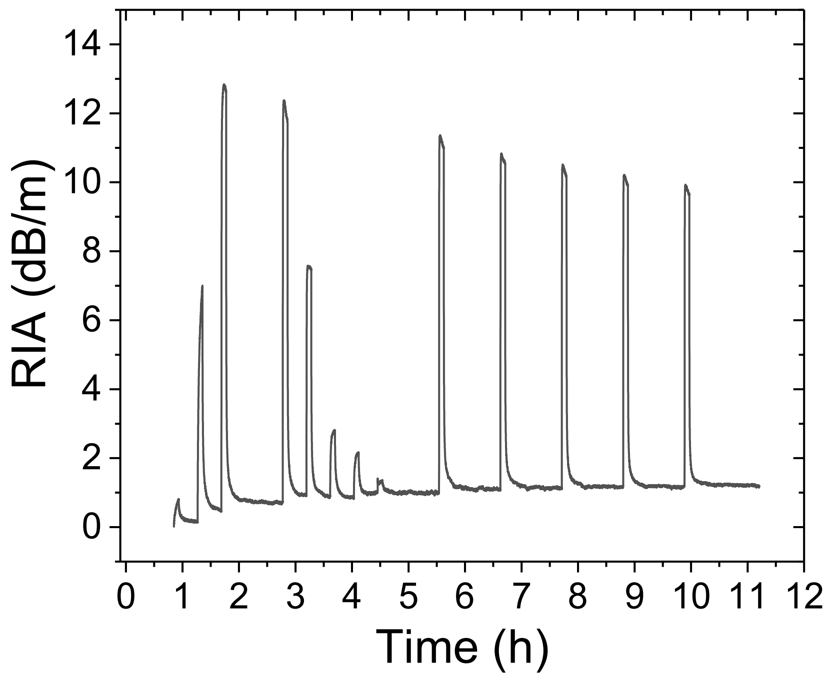
RIA kinetics at 1310 nm

This fiber proved to be very sensitive to dose rate, instead of dose.

Two contributions are clearly visible:

- Permanent losses (observable between irradiation runs, growing with dose)
- Transient losses (only present during irradiation, decreasing with dose)

So we decided to pre-irradiate the fiber to stabilize the defects.

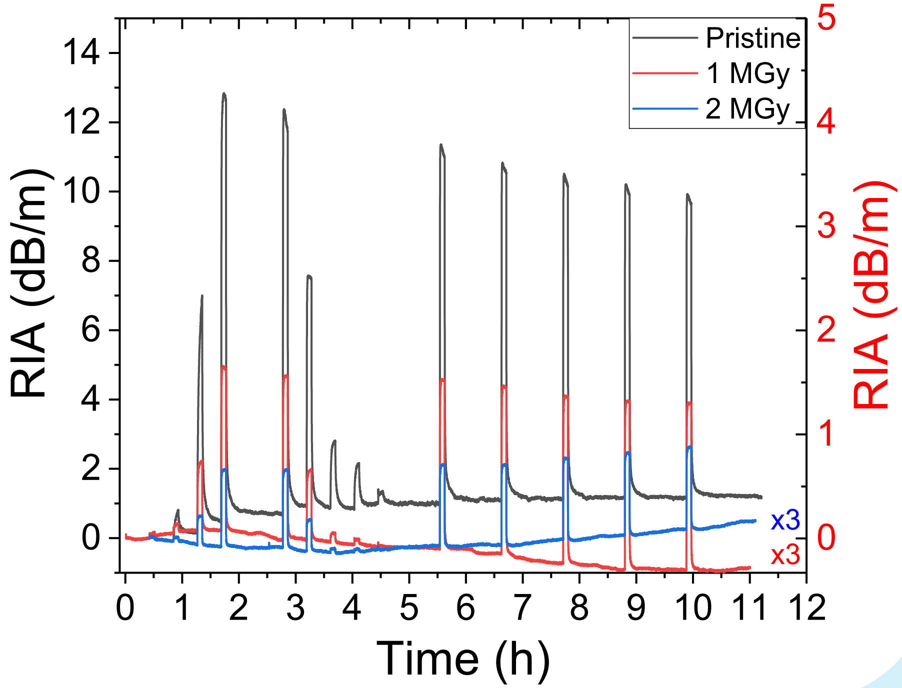


RIA kinetics after pre-irradiation

Improved stability of a pre-irradiated fiber.

Lowered sensitivity -> can be compensated with a longer fiber.

Better ON-OFF behavior, improved time characteristic.

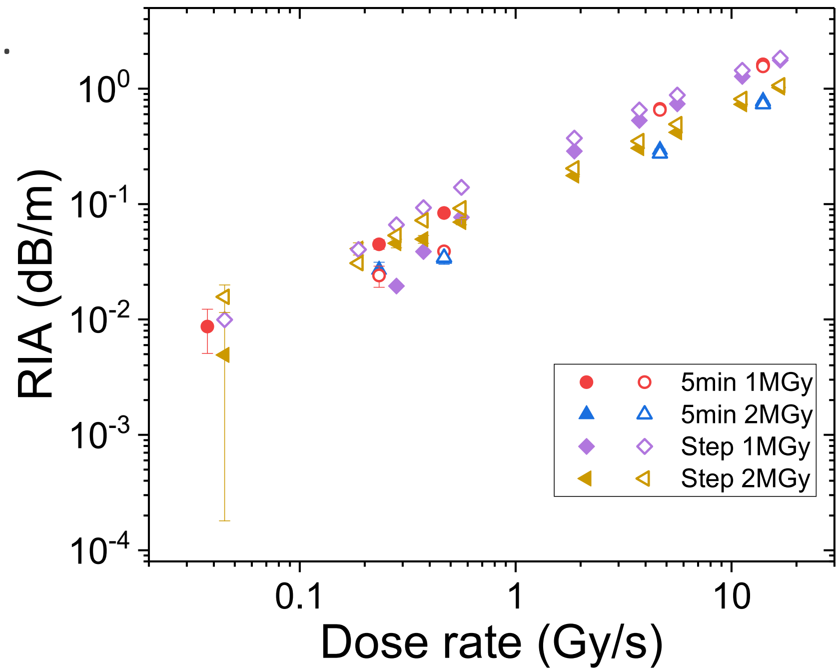


Pre-irradiated fiber: RIA vs Dose rate

The big result of our RADECS poster was the RIA vs dose rate linearity after pre-irradiation.

This was observed both for intermittent and continuous irradiation runs at different dose rates.

The obvious next step was to implement this fiber in an actual dosimeter!



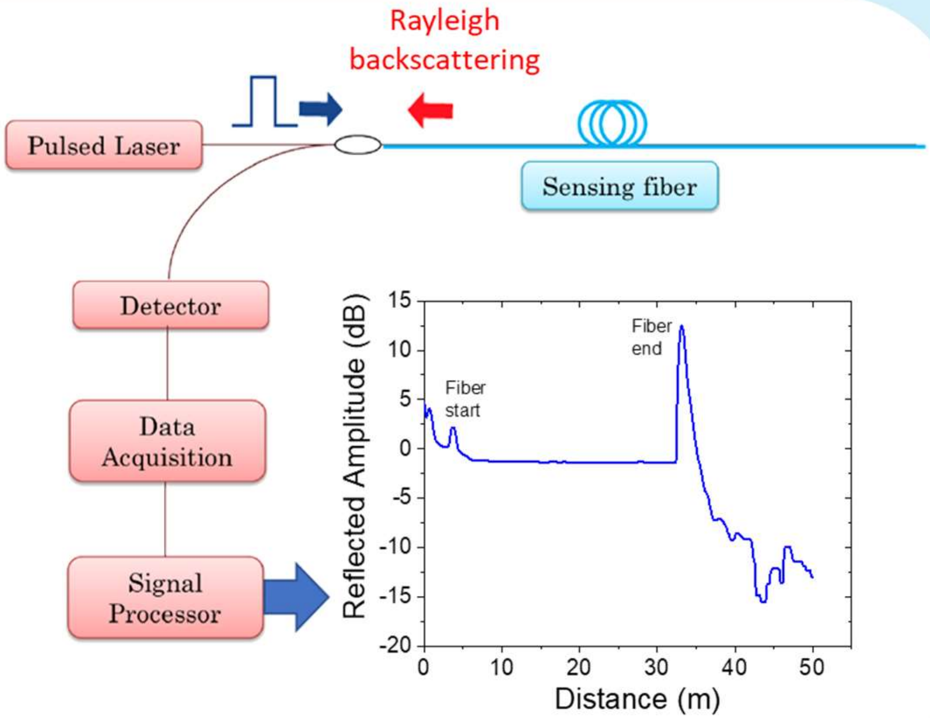
Optical Time Domain Reflectometry

ToF technique based on Rayleigh scattering.

Single-ended sensor.

Typical pulse width ~10 ns.

This corresponds to a spatial resolution around 1 m.



RAD NEXT

UNIVERSITÉ JEAN MONNET SAINT-ÉTIENNE

Setup: Irradiated sample

OTDR

Pigtail (5m) → SF1 (5m) → EF1 (2m) → SF2 (5m) → EF1 (2m) → SF3 (5m) → EF1 (2m) → SF4 (5m)

SF = Shielded part of the fiber

EF = Exposed part of the fiber

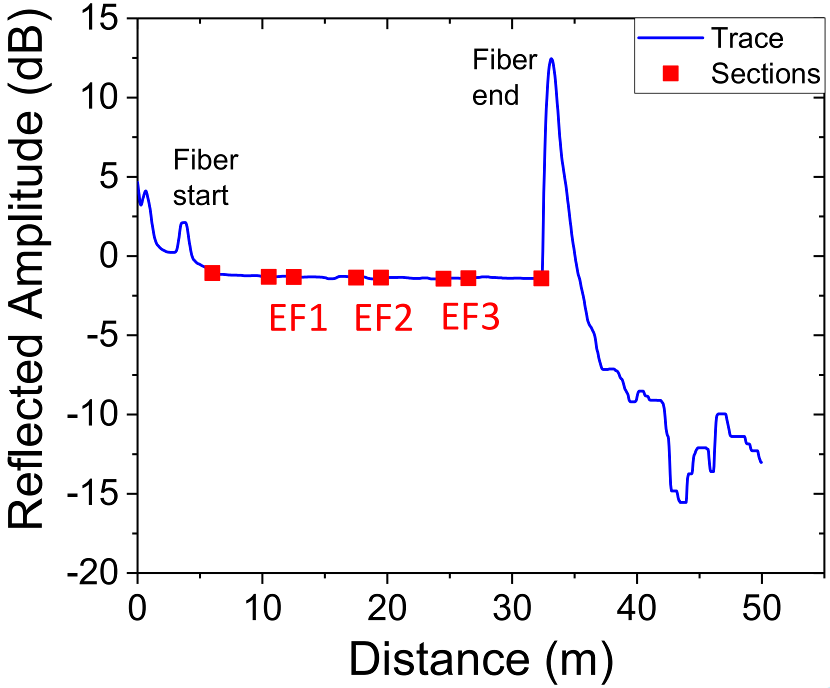
Investigated dose rate range:

From 45 mGy/s to 16.8 Gy/s

Complete OTDR trace

We can recognize the 5m pigtail at the beginning of the fiber.

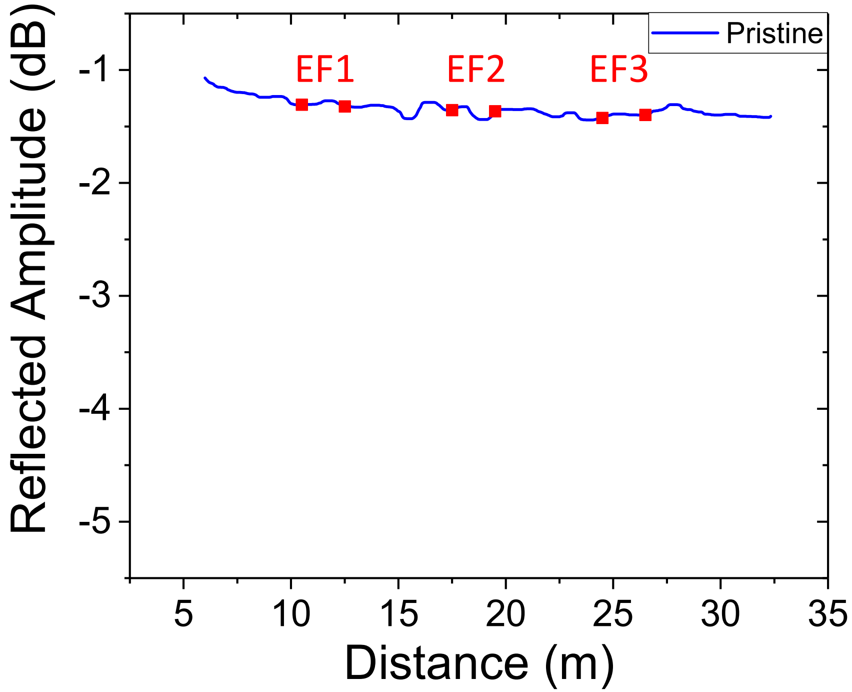
And the big reflection peak related to the interface at the end of the fiber, after 31m.



OTDR trace: FUT only

We can then observe only the fiber under test.

The slope of the trace will give us a measure of the linear losses of the fiber in dB/m.



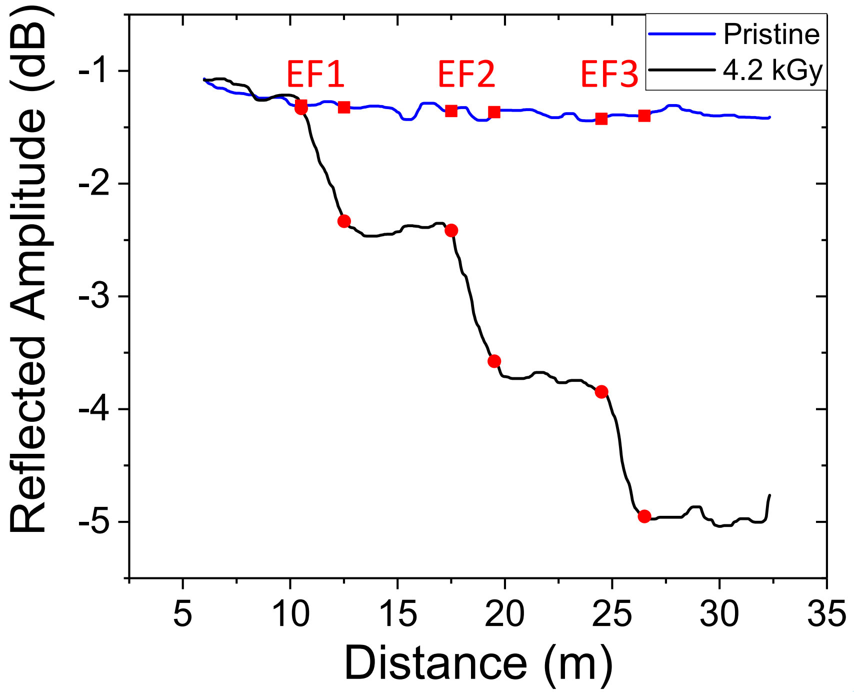
OTDR trace: FUT only

We can then observe only the fiber under test.

The slope of the trace will give us a measure of the linear losses of the fiber in dB/m.

We can see that only the slope of the exposed part of the fiber change.

We then evaluate the slope in these areas to measure the RIA.

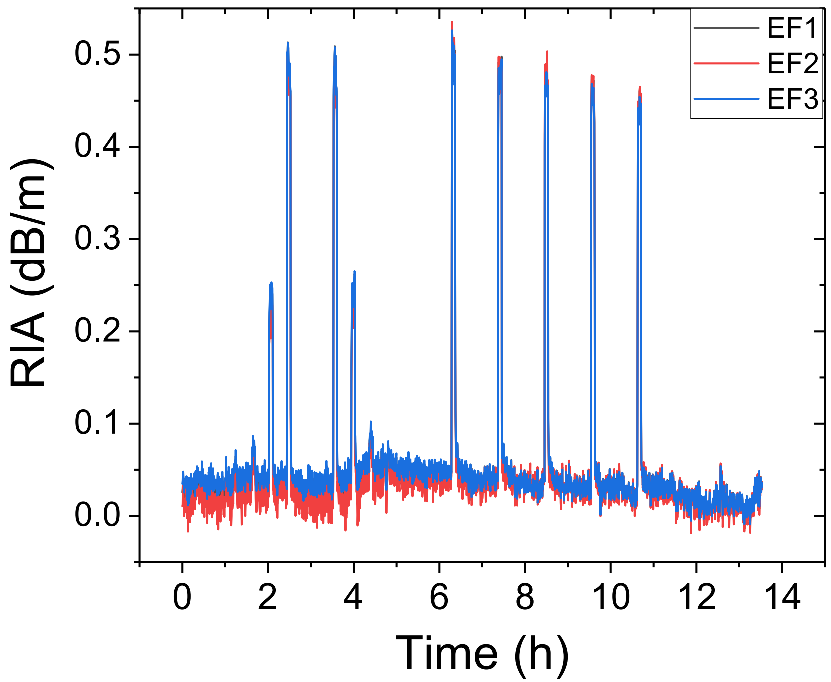


Results: RIA over time after 235 kGy

No visible change between the three exposed parts of the fibers.

We are able to spatially recognize the X-ray irradiations.

The source of these fluctuations is probably the short length used for the exposed fiber, (2m) which is comparable with the resolution of the OTDR.

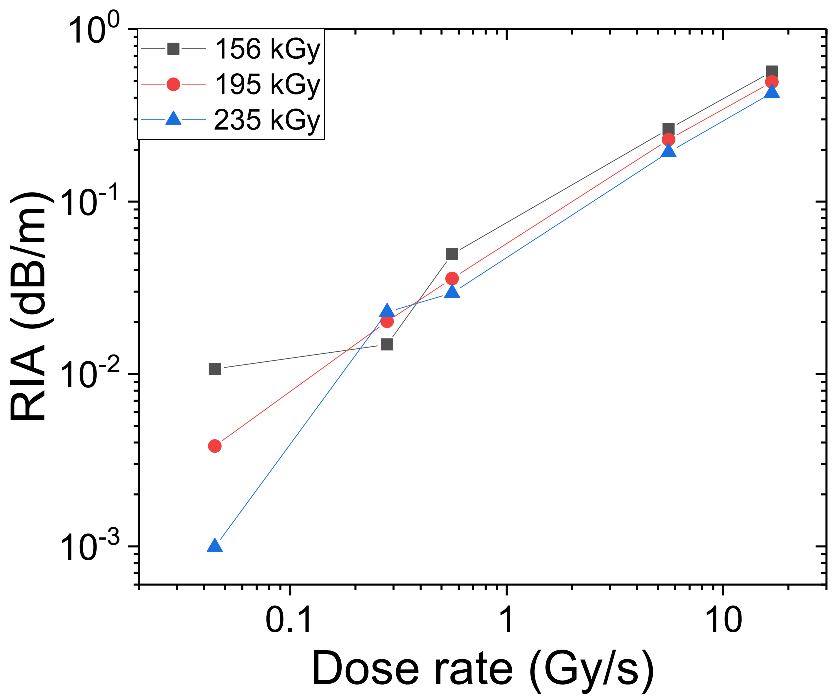


Results: RIA vs dose rate

The overall response is less sensitive than the spectral setup -> Photobleaching.

Increasing the pre-irradiation dose decreases the sensitivity of the fiber.

Pre irradiation (kGy)	Slope (dB m-1 Gy-1 s)	Slope error (dB m-1 Gy-1 s)	Linear regression R-squared
156	0.0352	± 0.0022	0.98126
195	0.0306	± 0.0018	0.98236
235	0.0263	± 0.0015	0.98402



Conclusions

We demonstrated the feasibility of **single-ended spatially-distributed dose rate monitoring**.

The **RIA vs dose rate linearity** is preserved in this setup. A systematic study of different pre-irradiation doses applied to this setup is needed.

About the fiber itself, **temperature** testing and more extensive photobleaching testing will be mandatory for an eventual deployment.

We are currently investigating this fiber with OFDRs to achieve even higher spatial resolution.

UNIVERSITÉ JEAN MONNET SAINT-ÉTIENNE

Thank you for your attention!

LUCA WENINGER

RADOPT 2023

UNIVERSITÉ JEAN MONNET SAINT-ÉTIENNE

Extras

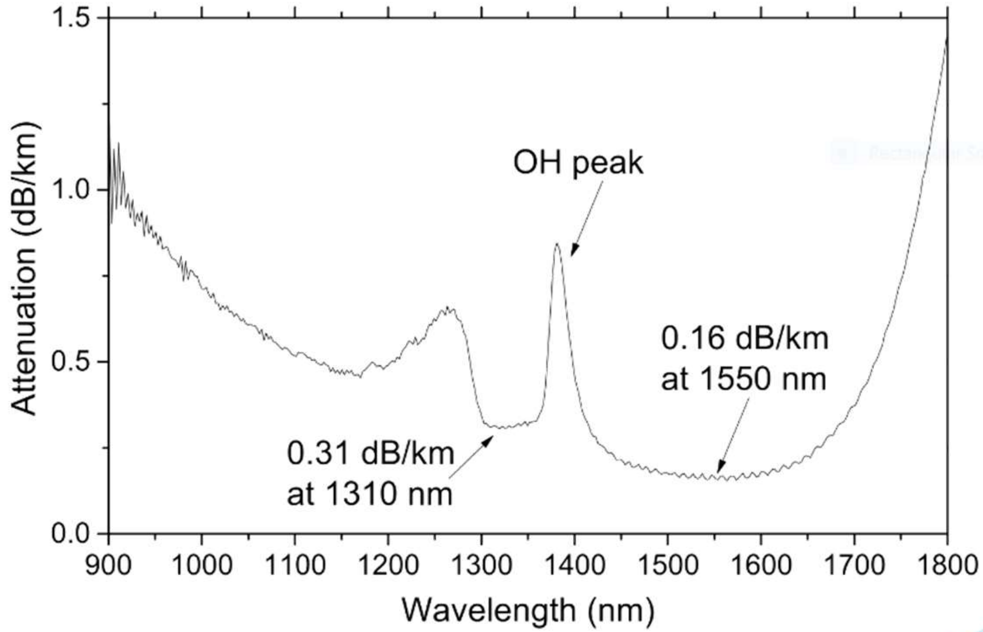
Outline

1. RIA basics (just darkening of the glass)
2. Spectral RIA vascade -> 1310 nm
3. RIA kinetics Vascade ->
   1. + Pre-irr effect
4. RIA vs DR Vascade (linearity)
5. OTDR explanation
6. Sample + setup: VascadeBizarre
7. Results:
   1. Trace
   2. RIA

Fiber under test: ULL-PSCF

Ultra-low loss pure-silica core fiber (ULL-PSCF)

This one is very radiation sensitive



Conclusions