



**HAL**  
open science

# Numerical Prediction of Incoherent Modulation Instability Dynamics through Deep Learning Approaches

Yassin Boussafa, Lynn Sader, Van Thuy Hoang, Bruno Chaves, Alessandro Tonello, Benjamin Wetzel

► **To cite this version:**

Yassin Boussafa, Lynn Sader, Van Thuy Hoang, Bruno Chaves, Alessandro Tonello, et al.. Numerical Prediction of Incoherent Modulation Instability Dynamics through Deep Learning Approaches. 2023 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC), Jun 2023, Munich (Allemagne), Germany. pp.1-1, 10.1109/CLEO/Europe-EQEC57999.2023.10232332 . hal-04307446

**HAL Id: hal-04307446**

**<https://hal.science/hal-04307446>**

Submitted on 29 Nov 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

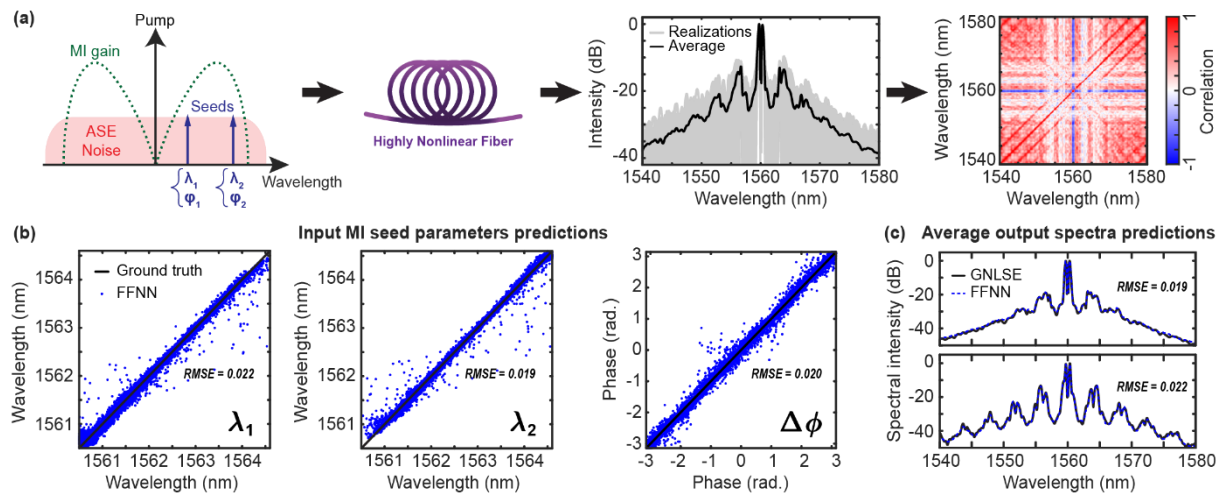
# Numerical Prediction of Incoherent Modulation Instability Dynamics through Deep Learning Approaches

Yassin Boussafa, Lynn Sader, Van Thuy Hoang, Bruno P. Chaves, Alessandro Tonello, Benjamin Wetzel

*XLIM Research institute, CNRS UMR 7252, University of Limoges, Limoges, France*

In nonlinear fiber optics, Modulation Instability (MI) is characterized by the emergence of new spectral components, either seeded from optical signals or appearing spontaneously from noise amplification. MI then constitutes an ideal playground for studying complex and incoherent nonlinear propagation dynamics [1]. In recent years, Artificial Neural Networks (ANN) have been used to characterize nonlinear dynamics and investigate ultrafast optical pulse evolution with remarkable accuracy and precision [2,3]. However, few works focused on incoherent optical propagation, with the identification of precursors and key-parameters responsible for the apparition of specific nonlinear phenomena in noise-driven systems [3-5].

Here, we report on a numerical study based on the generalized Nonlinear Schrödinger Equation (GNLSE) [6] used to model nonlinear fiber propagation where two optical seeds compete with broadband noise to drive incoherent MI broadening dynamics (Fig. 1 a). Specifically, we generate a dataset comprising 200,000 propagation scenarios using different optical seed parameters (wavelength and phase). Each propagation scenario is computed 100 times using random input noise, in order to characterize the fluctuation of the output MI spectrum and retrieve the corresponding spectral correlation map and average spectrum. Using this dataset, we trained Feed-Forward Neural Networks (FFNN) to either retrieve the optical seed parameters at the fiber input or to forecast the shape of the average spectrum with an average accuracy of  $\sim 98\%$ , as shown in Fig. 1 (b) and Fig. 1 (c), respectively.



**Fig. 1** (a) Schematic of the incoherent induced MI broadening dynamics studied numerically. Two weak optical seeds with adjustable parameters  $\lambda_1$ ,  $\lambda_2$ ,  $\phi_1$ ,  $\phi_2$  are randomly selected in each case. The fluctuating output spectra, are computed considering different input noise and used to retrieve the average spectrum and the spectral correlation map. (b) Seed parameters prediction (i.e.  $\lambda_1$ ,  $\lambda_2$  and  $\Delta\phi = \phi_1 - \phi_2$ ) from FFNN training using correlation map measurements. (c) Examples of average output spectra prediction from FFNN training from variable seed parameters.

In this work, we further discuss the potential and limitations of ANN training based on noisy experimental dataset obtained from DFT measurements [7] and study other types of ANN architectures for the retrieval of relevant information on incoherent MI dynamics. We expect this approach to efficiently mitigate experimentally-intensive data acquisition for the study of incoherent nonlinear dynamics beyond MI. We also anticipate this work to provide insight into noise-driven nonlinear conversion processes and its potential to conceal relevant optical information.

## References

- [1] J.M. Dudley, et al. "Instabilities, breathers and rogue waves in optics," *Nat. Photon.* **8**, 755 (2014).
- [2] G. Genty et al., "Machine learning and applications in ultrafast photonics", *Nat. Photonics*, **15**, 1–11, (2020).
- [3] A. Sheveleva et al., "Idealized four-wave mixing dynamics in a nonlinear Schrödinger equation fiber system," *Opt. Lett.* **9**, 656 (2022).
- [4] M. Närhi, et al. "Machine learning analysis of extreme events in optical fibre modulation instability", *Nat. Commun.* **9**, 4923 (2018).
- [5] S. Coulibaly, F. Bessin, M. G. Clerc, and A. Mussot, "Precursors-driven machine learning prediction of chaotic extreme pulses in Kerr resonators," *Chaos Solitons & Fractals* **160**, 112199 (2022).
- [6] J. M. Dudley, G. Genty, and S. Coen, "Supercontinuum generation in photonic crystal fiber," *Rev. Mod. Phys.* **78**, 1135 (2006).
- [7] T. Godin et al., "Recent advances on time-stretch dispersive Fourier transform and its applications," *Adv. Phys. X* **7**, 2067487 (2022).