

# Harnessing Collective Phenomena in Hybrid Nanocomposites for Bright and Fast Scintillation

Xiaohe Zhou<sup>1</sup>, Hiba H. Karakkal<sup>1</sup>, Saptarshi Chakraborty<sup>1</sup>, Francesco Bruni<sup>1,2</sup>, Matteo L. Zaffalon<sup>1,2</sup>, Andrea Fratelli<sup>1,3</sup>, Chengen Wang<sup>1</sup>, Leonardo Poletti<sup>4</sup>, Mengda He<sup>5</sup>, Roberto Lorenzi<sup>1</sup>, Francesca Rossi<sup>4</sup>, Liang Li<sup>6</sup>, Francesco Meinardi<sup>1</sup>, Luca Gironi<sup>2,7</sup> and Sergio Brovelli<sup>\*1,2</sup>

<sup>1</sup> *Dipartimento di Scienza dei Materiali, Università degli Studi di Milano-Bicocca, 20125, Milano, Italy*

<sup>2</sup> *INFN - Sezione di Milano - Bicocca, 20125 Milano, Italy*

<sup>3</sup> *Nanochemistry, Istituto Italiano di Tecnologia, 16163, Genova, Italy*

<sup>4</sup> *IMEM-CNR, Parco Area delle Scienze 37/A - 43124 Parma, Italy*

<sup>5</sup> *School of Environmental Science, Shanghai Jiao Tong University, Shanghai 200240, China*

<sup>6</sup> *Macao Institute of Materials Science and Engineering (MIMSE), Macau University of Science and Technology, Taipa 999078, Macao, China*

<sup>7</sup> *Dipartimento di Fisica, Università degli Studi di Milano-Bicocca, Piazza della Scienza, 20125 Milan, Italy*

\* Corresponding author email: [sergio.brovelli-unimib.it](mailto:sergio.brovelli-unimib.it)

The need to overcome the performance and scalability limitations of current ionizing radiation detectors has stimulated a search for innovative material platforms as next generation scintillators. Hybrid nanocomposites provide a versatile platform to decouple ionizing energy absorption from radiative emission, enabling the independent optimization of stopping power and optical timing to meet increasingly complex detection requirements. However, maximizing their potential requires precise control over electronic and optical interactions at the nanoscale. In this work, we demonstrate that by engineering the spatial arrangement and local environment of emitters, we can activate collective phenomena that optimizes scintillation dynamics through two complementary strategies:

**Self-Sensitization via secondary electrons:** By encapsulating CsPbBr<sub>3</sub> nanocrystals (NCs) within mesoporous SiO<sub>2</sub> nanospheres (MSNs), we engineer dense domains that mimic the inter-emitter spacing of organic scintillators [1]. This architecture exploits the high stopping power of high-Z NCs while efficiently harvesting the secondary electron shower. Experimental results demonstrate a 40-fold increase in radioluminescence (RL) yield compared to standard colloidal suspensions, accompanied by an ultrafast emission component arising from multiexcitons; **Synergistic Plasmonic Coupling and High-Z Sensitization:** We further push the scintillation timing performance by engineering the local density of optical states (LDOS) using nanophotonic particles as optical antennas in a high-Z-sensitized nanocomposite. Ultrafast spectroscopic analysis confirms that the resulting optical coupling remains active under ionizing excitation.

Our results establish a design framework for "metasolid" scintillators, in which high-Z sensitization, self-sensitization and plasmonic enhancement act cooperatively to overcome fundamental efficiency–timing trade-offs. The presented concept provides a versatile route toward ultrafast, lightweight, and scalable scintillators for fast-timing detection and imaging applications.

1. X. Zhou, M.L. Zaffalon, E. Mazzola, et al., “Harnessing Self-Sensitized Scintillation by Supramolecular Engineering of CsPbBr<sub>3</sub> Nanocrystals in Dense Mesoporous Template Nanospheres,” *Adv. Mater.*, 38, e13469 (2026).