universität innsbruck

Department of
Theoretical Physics

# Theory Colloquium

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"Collective Learning of Smart Active Matter"

**Abstract**

Active matter has emerged as a new central field within statistical physics. A defining characteristic of active matter is its capacity to harness energy to facilitate self propulsion. Usual active matter, however, remains inherently 'dead', lacking the capability to process information, evolve and to adapt to its environment beyond predetermined policies. This limitation has recently fueled growing interest in the concept of smart matter—active systems endowed with learning and responsive capabilities (1,2).

In this talk, I will present a new statistical physics framework for smart matter, where agents dynamically tune their interaction parameters—or policy—to maximize a reward function, thereby steering the system toward a desired collective state. Learning occurs in a decentralized manner: agents not only adapt individually but also share their acquired policies with neighbors. By embedding the learning process into a kinetic theory framework through a reward-dependent interaction rule, we derive hydrodynamic equations that describe the evolution of policy fields. These equations allow for an analytical characterization of collective learning in smart agent systems (3).

We apply this framework to spatially heterogeneous environments, where agents must continually adapt to maintain high rewards amid evolving conditions. Inspired by robotic experiments, using theory and agent-based simulations, we explore a phenomenon we term teaching-induced aggregation, in which collective learning enables agents to optimize their proximity to an external light source.
Altogether, our approach offers a foundational analytical perspective on the behavior and design of smart, evolving matter.

REFERENCES
(1) C. Kaspar et al., "The rise of intelligent matter", Nature 594, 345
(2021) .
(2) H. Levine and D. I. Goldman, "Physics of smart active matter:
integrating active matter and control to gain insights into living systems", Soft Matter 19, 4204 (2023) .
(3) G. Jung, M. Ozawa and E. Bertin, "Kinetic theory of decentralized learning for smart active matter", Physical Review Letters 134, 248302 (2025).

**Wednesday | 14.01.2026 | 5:00pm**

**SR 1 | ICT building**