Anomalous Transport Phenomena of Active Particles in Porous Media

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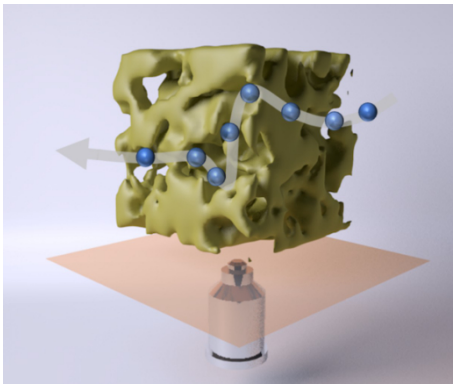
Active particles capable of harvesting ambient energy to generate autonomous motion are emerging as promising agents for targeted transport in drug delivery and environmental remediation. Although extensive studies have examined their behaviors near interfaces or in quasi-two-dimensional settings, systematic understanding of their motion within complex confined spaces—such as three-dimensional porous media—remains limited. To address this challenge, we developed a three-dimensional single-particle tracking platform to directly visualize the trajectories of active particles in heterogeneous porous structures. The measurements reveal an enhancement in transport efficiency exceeding an order of magnitude compared with passive Brownian particles. Combined experimental, simulation, and theoretical analyses further elucidate confinement-induced mechanisms arising from altered chemical microenvironments, distinctive hydrodynamic effects of active propulsion, and the influence of local energy landscapes. These findings demonstrate the capability of 3D single-particle tracking to resolve transport processes in confined environments and provide a mechanistic foundation for the rational design and efficient deployment of active particles in practical applications.

Keywords:
Active particle, particle tracking, nano/micromotors, transport, porous media, confinement



3D single-particle tracking of active particles in porous media

References:

Wu, H.; Greydanus, B.; Schwartz, D. K., Mechanisms of transport enhancement for self-propelled nanoswimmers in a porous matrix. *Natl. Acad. Sci. U.S.A.* 2021, 118 (27). Greydanus, B.; Saleheen, M.;Wu, H.; Heyden, A.; Medlin, J.W., Probing surface-adsorbate interactions through active particle dynamics. *Colloid Interface Sci.* 2022, 614, 425-435 Shi, A.;Wu, H.; Schwartz, D. K. Nanomotor-Enhanced Transport of Passive Brownian Particles in Porous Media. *Sci. Adv* . 2023, eadj220