# Swimming Modes of Self-Assembled Magnetic Micropropeller

C. Calero[1, 2], J. M. García-Torres[1, 2, 3], F. Sagués[2, 3], I. Pagonabarraga[1, 4, 5], P. Tierno[1, 2, 4]
*1. Departament de Física de la Materia Condensada, U. Barcelona, 08028 Barcelona, Spain*
*2. Institut de Nanociencia i Nanotecnologia, U. Barcelona, Barcelona, Spain*
*3. Departament de Ciència de Materials Química Física, U. Barcelona, 08028 Barcelona, Spain*
*4. Universitat de Barcelona Institute of Complex Systems, U. Barcelona, Barcelona, Spain*
*5. CECAM, Centre Europeen de Calcul Atomique et Moleculaire, École Polytechnique Fédérale de Lausanne, Batochime, Avenue Forel 2, 1015 Lausanne, Switzerland*
*Presenting Author's e-mail address: ccalero@ffn.ub.es*

Controlling the motion of micro and nano propellers is of great interest and the focus of intense research due to their potential applications as efficient drug-delivery vectors, non-invasive microsurgery devices, or chemical biodetectors. A variety of strategies have been devised to design microswimmers and direct their trajectories at low Reynolds numbers, where these systems operate. Here, we propose the use of self-assembled magnetic aggregates as micropropellers and theoretically investigate the different swimming modes that can be induced by their actuation with time-dependent magnetic fields. In particular, we focus on a hybrid system composed of a ferromagnetic nanorod and a paramagnetic spherical microparticle which self-assemble due to their mutual dipolar attraction. We discuss two different actuation strategies which generate locomotion. We show that the application of in-plane linearly oscillating magnetic fields results in the rotation of the ferromagnetic rod, which governs the motion of the swimmer. We demonstrate that the direction of the rod's rotation (and, thus, of propulsion of the microswimmer) can be selected by balancing gravity, magnetic and hydrodynamic interactions [1] (see Fig.1). We also investigate the locomotion of the self-assembled propeller under an in-plane field of constant magnitude which oscillates about a given direction. The basic locomotion mechanism is discussed and leading-order analytical expressions are obtained for the velocity and efficiency of the propeller under small fields, which are tested against computer simulations.

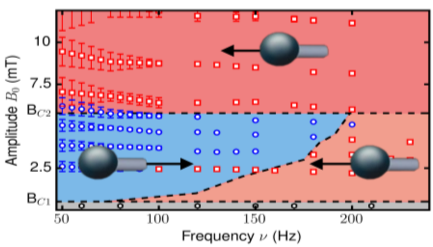


Fig. 1: *Bidirectional locomotion of the self-assembled swimmer.*

## References

1. J. M. Torres-Garcia, C. Calero, Nature Comm. **9** 1663 (2018).