

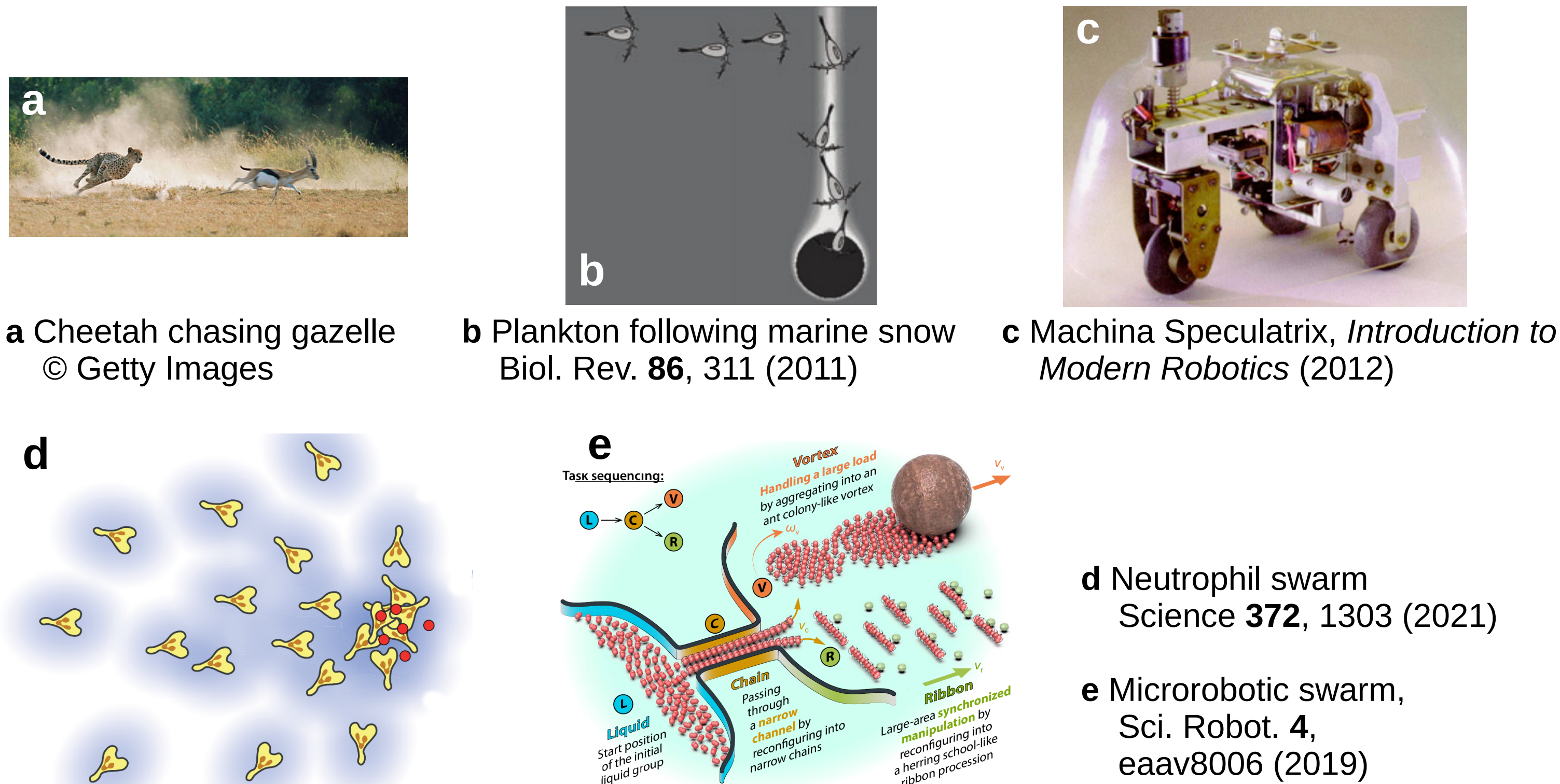
Collective Dynamics of Intelligent Microswimmers

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Intelligent Active Matter

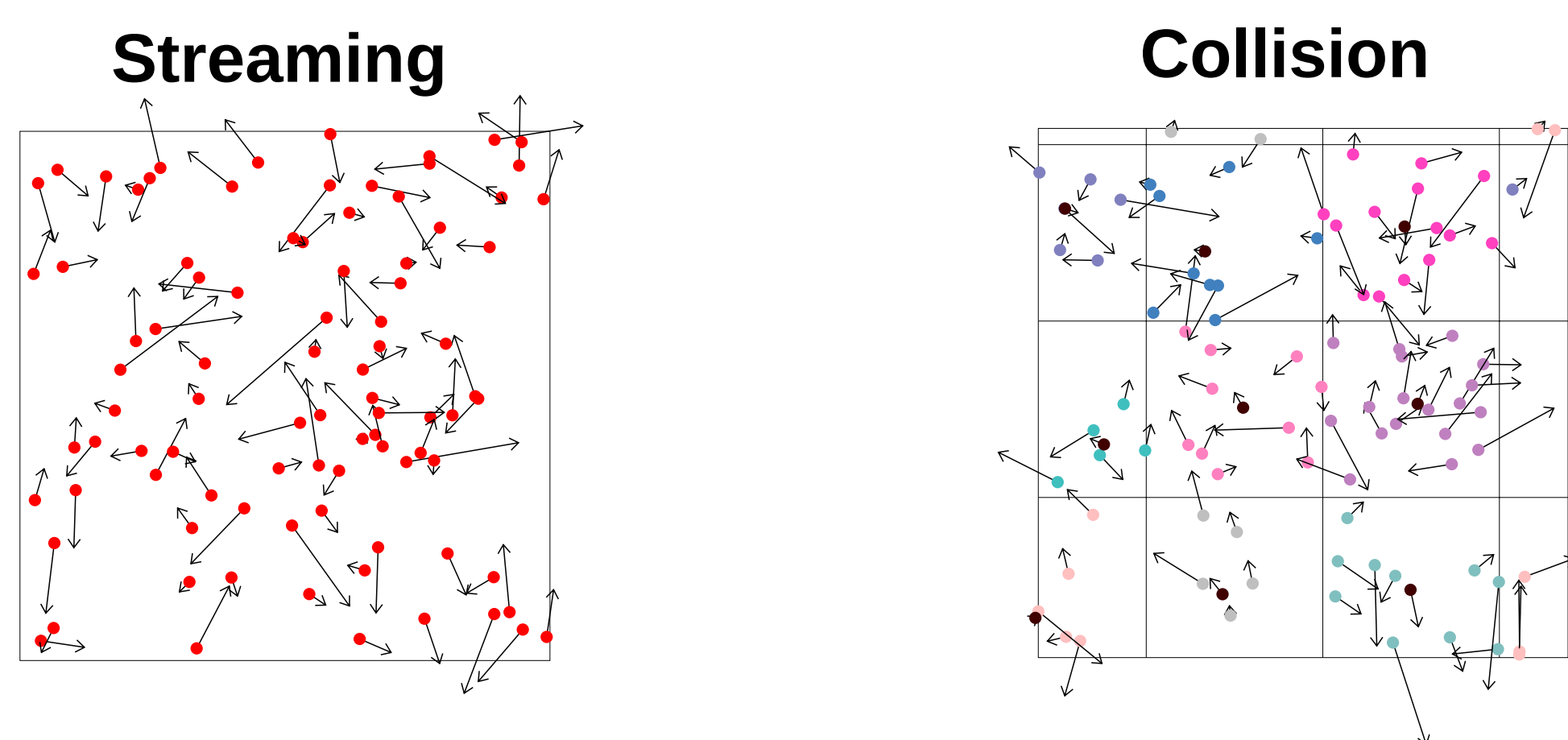


- Sensing environment, information processing, adaptation of motion
- From modeling **cognitive, self-steering, active particles** to investigating their **swarming dynamics**

On microscales: fluid environment

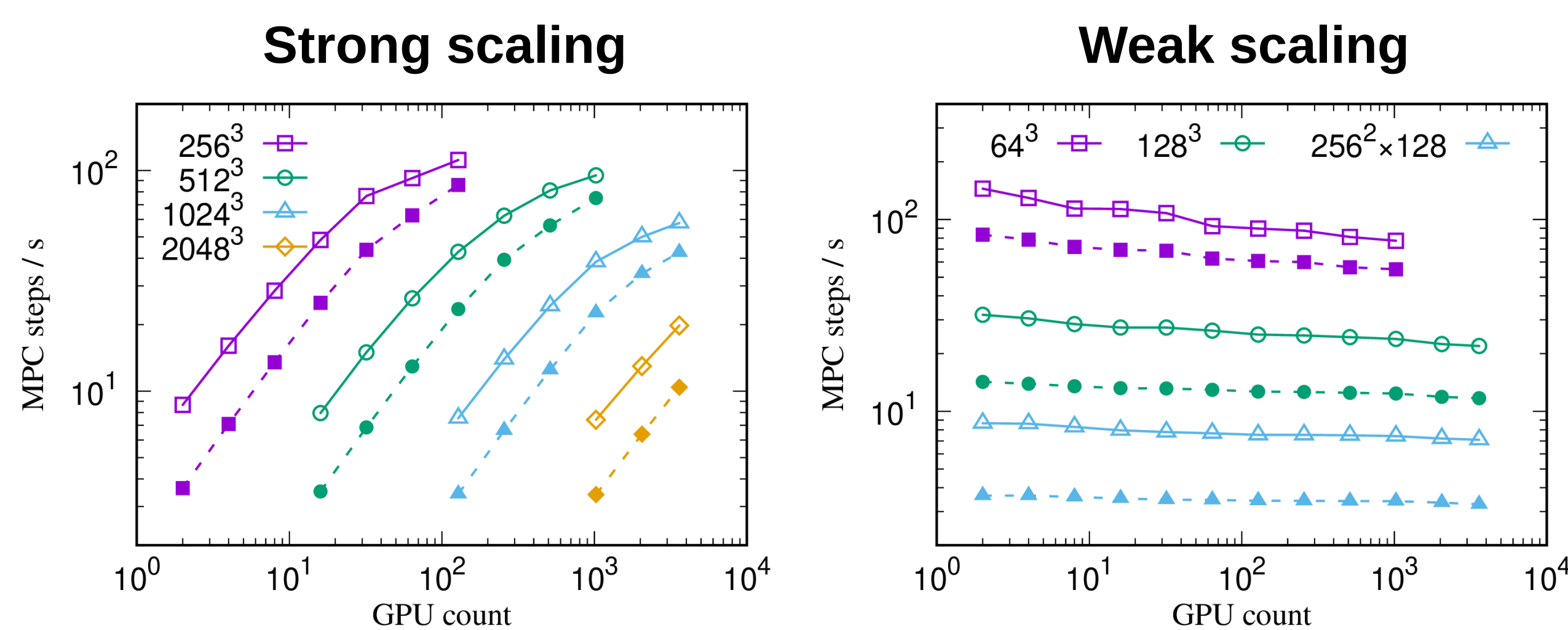
Fluid: Multiparticle Collision Dynamics (MPC)

- Particle-resolved mesoscale hydrodynamic simulation method
- Angular momentum conservation
- Maxwell-Boltzmann thermostat

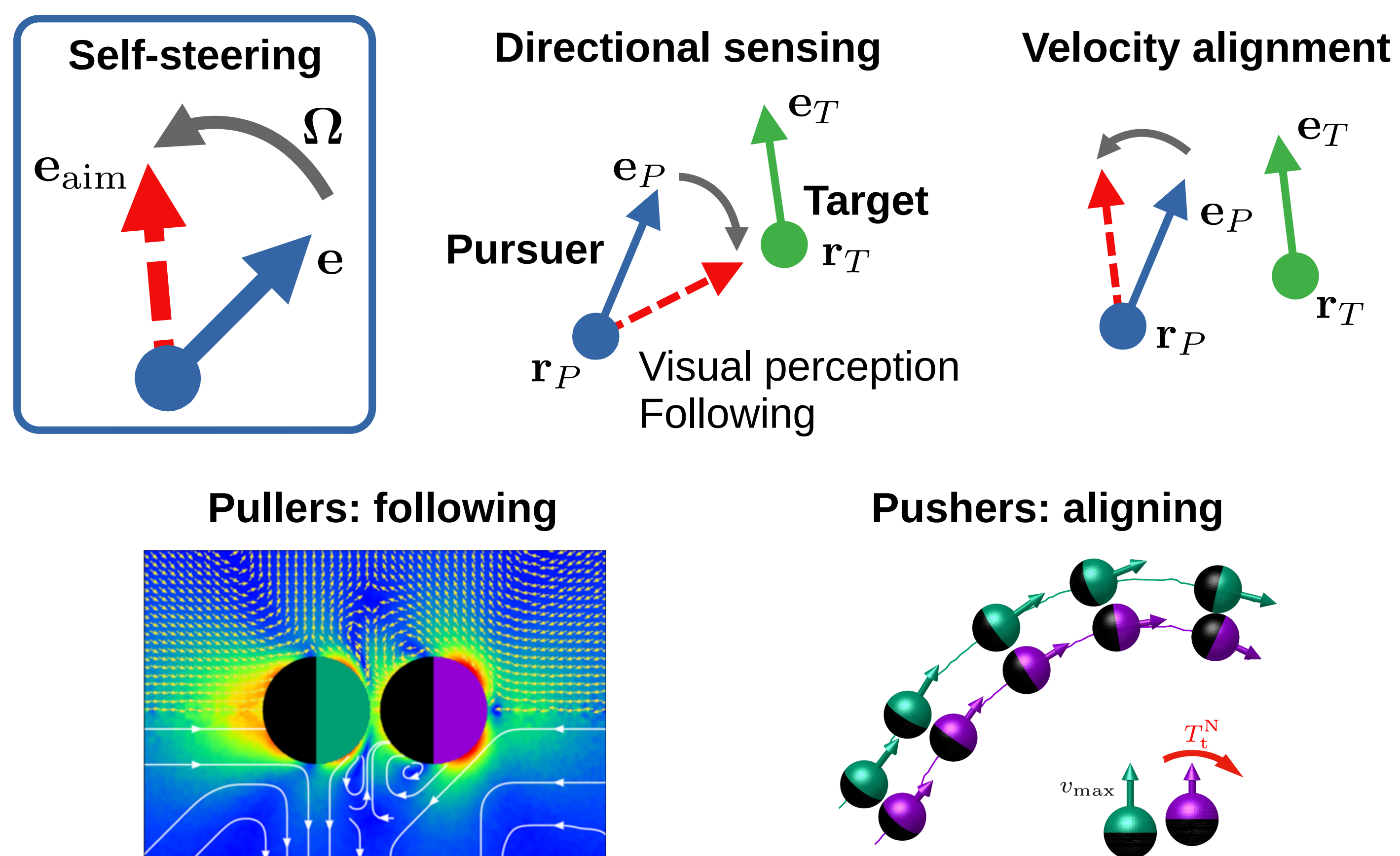


Implementation: HTMPC[1]

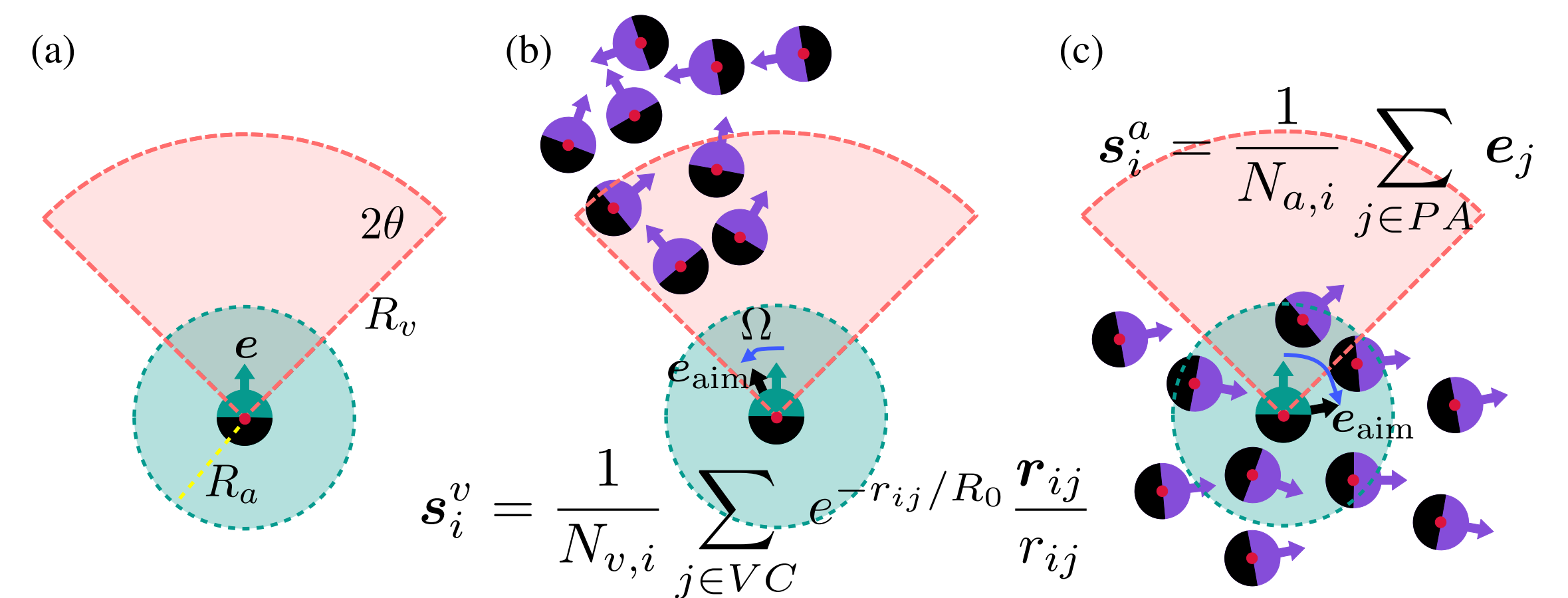
- Plugin-based C++17 template library
- CPU and CUDA-based backends, MPI-based domain decomposition



Intelligent microswimmer: self-steering squirmer[2]

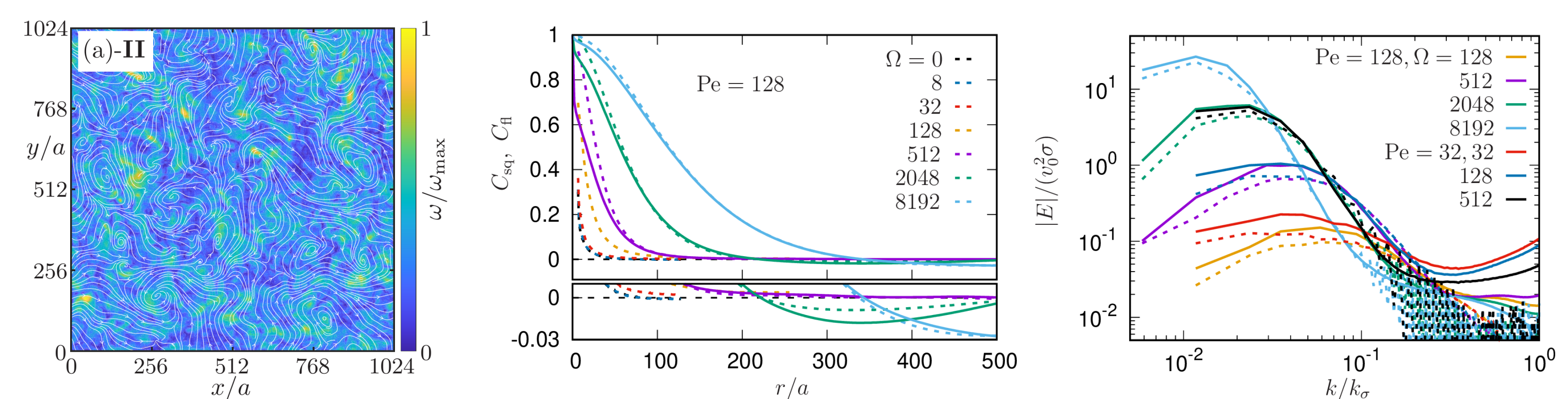


Sensing range and sensing rules



Collective behavior I. Active turbulence[3]

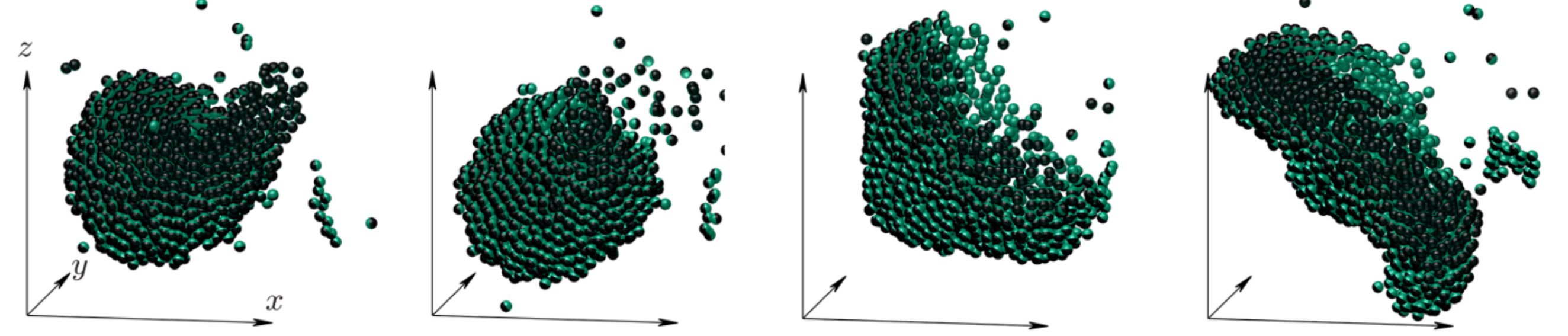
- Aligning pushers: enhanced microswimmer advection



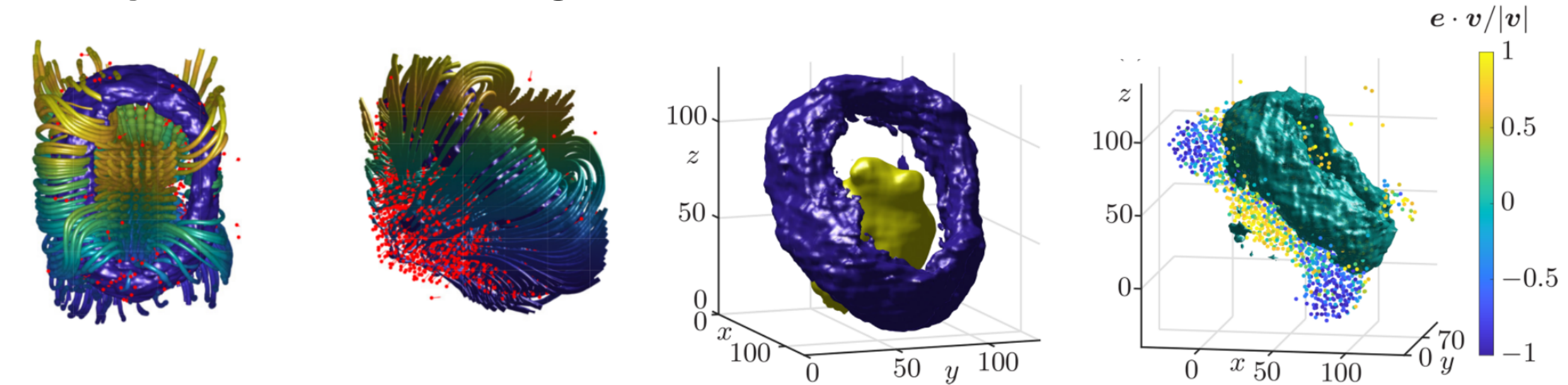
Collective behavior II. Vortex ring[3]

- Aligning pullers: enhanced clustering tendency

Dynamics of a cluster



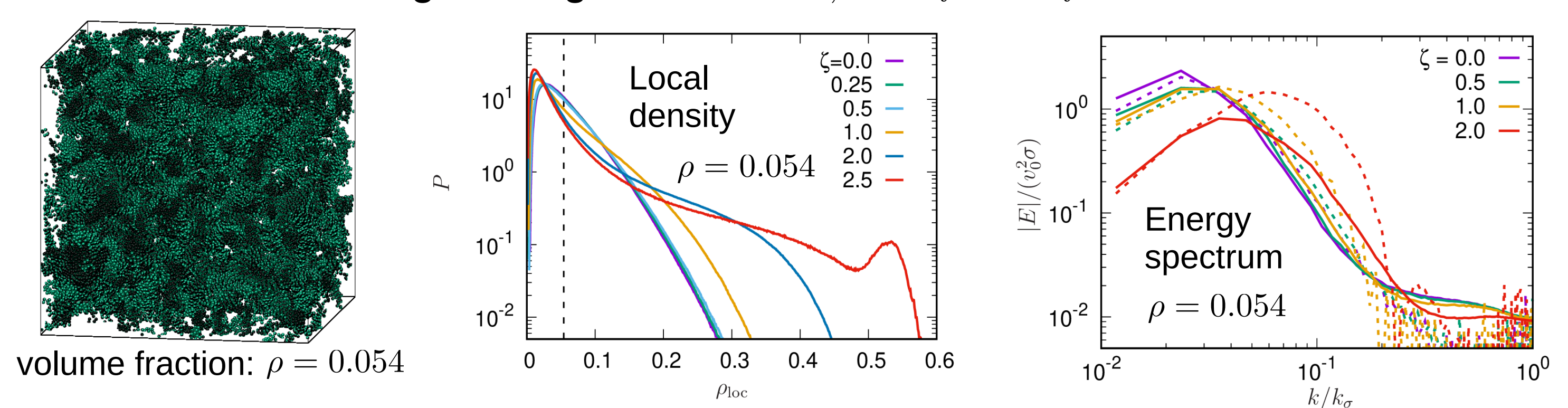
Fluid jet and vortex ring



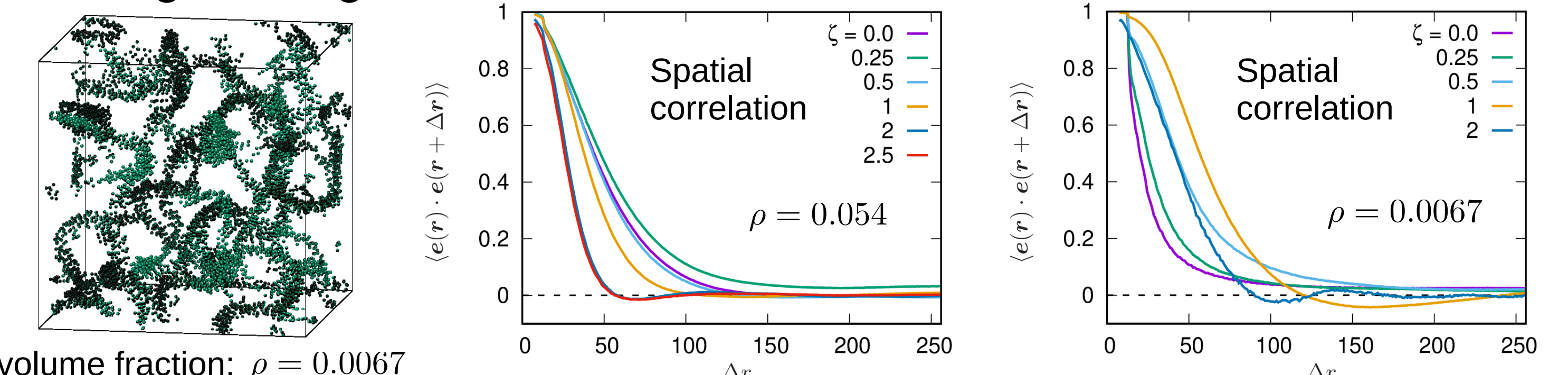
Collective behavior III. Worm-like swarm

- Directional sensing vs. hydrodynamic interactions
- Directional sensing vs. alignment $e_{aim,i} = s_i^a + \zeta s_i^v$

Pushers



milling/swirling



Conclusion

- Rich interplay between self-steering and hydrodynamic interactions
- Fluid may pose challenges for intelligent agents to navigate and maneuver
- Provide guidelines for microbot design

Publications

- [1] Comput. Phys. Commun. **309**, 109494 (2025); <https://go.fzj.de/HTMPC>
- [2] Commun. Phys. **6**, 310 (2023)
- [3] Phys. Rev. Res. **24**, 093039 (2025)