ADI Programme

Isaac Newton Institute 8/1/24–28/6/2024

“Anti-diffusion” refers to that remarkable class of processes in which particles, fluid elements, etc. tend to migrate up-gradient, contrary to expected diffusive relaxation. “Anti-diffusive” includes what are known as “negative viscosity phenomena”, and refers to similar dynamics, in a broader range of contexts. A particularly dramatic and fascinating anti-diffusion phenomenon is layering or staircase formation, in which turbulent stirring leads to the formation of mixed regions, interspersed by layers of steepened gradients; the latter may be thought of as transport barriers. The phenomena of layering are often said to result from *inhomogeneous mixing*, which should be contrasted to gradient relaxation, the usual outcome of mixing processes. Indeed, layering as the outcome of stirring is quite contrary to intuitive expectations based on homogenization. This programme did indeed study Anti-Diffusion from Sub-Cellular to Astrophysical Scales. Specific phenomena discussed include: biophysical transport and response in micro-vascular flows; flocking of bacteria as an active fluid phenomenon; transport barriers and staircases in confined plasmas; layering in turbulent, stably stratified fluids; atmospheric and oceanic jets and their dynamics; layering due to thermohaline convection and its importance to the polar ice cap; planetary and exoplanetary super-rotation; the dynamics of the Jovian and Saturnian atmospheres, including the origin of their famous bands and jets.

The programme included five workshops: (i) *Layering – a structure formation mechanism in oceans, atmospheres, active fluids and plasmas*, which surveyed the fields of the programme at the outset; (ii) *Layering in Magnetized Plasmas*, held at the University of York, which focused on applications to fusion physics and the implications of Anti-Diffusion for future magnetic confinement devices (this workshop included a Newton Gateway Day); (iii) *Mathematical and Computational Modelling of Anti-Diffusive Phenomena*, which addressed theoretical and computational approaches to problems of layering and anti-diffusion; (iv) *Climate Applications of Layering*, which explored layering in the context of climate physics, including multi-phase flows (‘real world’ questions concerning staircases were discussed extensively); and (v) *Anti-Diffusion in Multiphase* *and Active Flows*, which explored anti-diffusive phenomena such as coarsening and spinodal decomposition, active fluid dynamics, flocking and clustering, and environmental applications of multiphase flows. Taken together, these five workshops and the associated programme constituted the broadest and most comprehensive study of anti-diffusive phenomena ever undertaken.

The Rothschild Lecture, I*nertia, Turbulence and the Concentration Field in Active Fluids*, was given by Professor Sriram Ramaswamy. The Kirk Lecture, *Evading Newton's Third Law and Setting Patterns in Motion,* was presented by Professor M. Cristina Marchetti. The Heilbronn Colloquium (delivered at the University of Bristol) by Professor Anna Frishman, was entitled *Universality of Satellite Formation During Breakup of a Fluid Bridge.* In addition, there were typically 3–5 seminars and working group meetings during most weeks of the programme.

Discussions throughout the programme were extremely wide-ranging, reflecting the broad range of topics covered. However, one thread that ran throughout the programme was the question of whether there is some (small) set of common mechanisms that underlie the wide range of layering phenomena? A few possibilities emerged. One is *bistable mixing* — i.e. from transport processes involving two mixing scales, one of which is emergent, dependent upon gradient and turbulence intensity. Such processes typically exhibit *nonlinear flux-gradient curves*, with at least two stable branches. Another idea is *phase separation*, as in spinodal decomposition phenomena. Here, the mechanism of motility-induced phase separation is of particular interest. A third mechanism for inhomogeneous mixing is *homogenization within non-overlapping cells or phase space islands*. Here also, the interplay between two scales – the island or cell width and the distance between resonances – is critical. If the latter exceeds the former, the mixing is inhomogeneous.