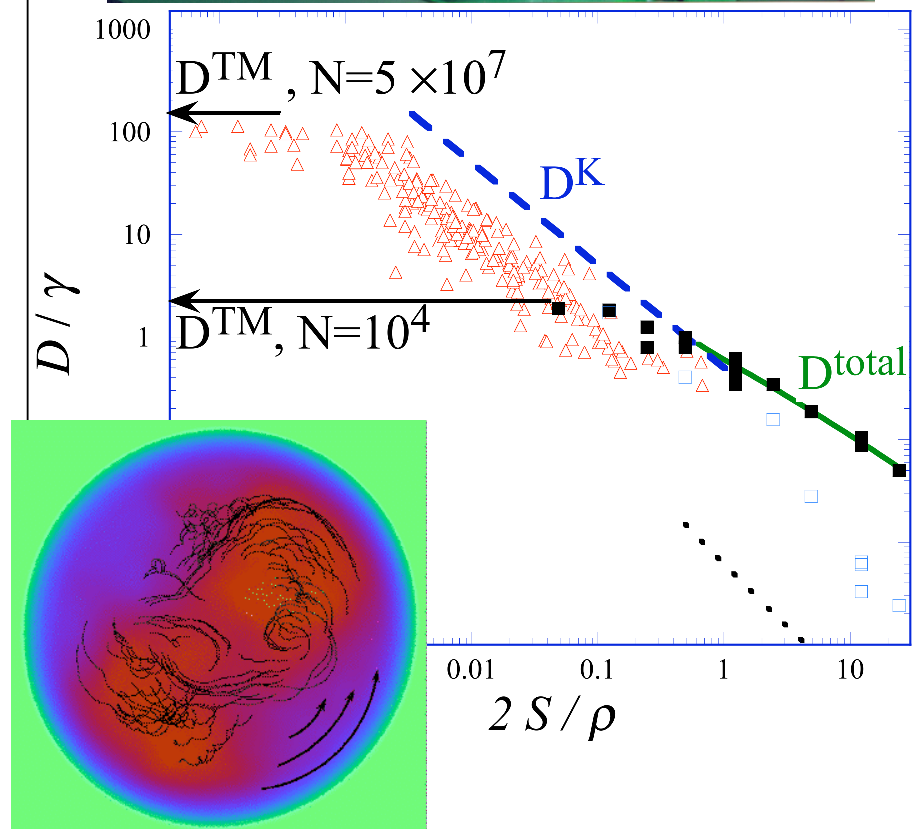
Shear Reduction of 2D Diffusion

T.M. O’Neil, C.F. Driscoll, and D.H. Dubin, UCSD, PHY-9876999



Experiments, theory, and simulation now quantitatively explain how shear in the overall flow velocity can reduce the diffusion of particles and heat in 2-dimensional point vortex gasses. The experiments are performed on a rotating cloud of Magnesium ions held in a cylindrical Penning-Malmberg trap [center]. A sophisticated laser system [top] generates two continuous, tuned beams in the ultraviolet; these heat or cool the cloud and control the shear S, and measure the diffusion rate D of “tagged” ions.

Computer simulations [bottom] also show the random paths of tagged ions due to microscopic and macroscopic fluctuations (colors); here, the overall flow shear (arrows) is controlled. Most importantly, a rigorous statistical analysis now connects all these results, giving the irreducible minimum thermal diffusion for point vortex fluids and magnetized plasmas.

The graph shows experimental data (red diamonds) and simulation results (solid and open squares), compared to theory predictions. Increasing shear decreases the measured diffusion, as expected from the theory. For sufficiently small shear, the diffusion approaches the Taylor MacNamara limit, which depends on the number of charges (5 x 10^7 for experiments, and 10,000 for simulations). Simulations were done for both prograde (solid boxes) and retrograde (open boxes) shear, while experiments have retrograde shear only. Theory works well for retrograde shear; but an estimate based on mobility in a prograde flow (dashed black line) strongly underestimates the observed diffusion.

This may serve as a paradigm for understanding shear reduction of diffusion in more complex turbulent systems.