able energy, comparable to a supernova output, is easily enough to power cosmologically visible bursts, and the coalescence of one pair per galaxy per 10^8 years is enough to explain the observed burst rate. In our own Galaxy there are at least two cases where pulsars are spiralling into neutron-star companions, and coalescence is the inevitable endpoint.

But coalescing neutron stars would release their energy mostly in the form of neutrinos (as does a supernova). Piran's idea is that the outburst is dense enough for neutrino pairs to generate electron–positron pairs that produce γ-photons. But the difficulty then is in preventing the resulting fireball from becoming optically thick, and creating everything from radio waves up. Paczynski suggested that a neutron star being swallowed by a black hole might create a cleaner event.

The good news is that GRO collected two more bursts during the meeting, and is still finding one a day. The isotropy and V/V_{max} measurements must get better, and the quality of the spectra being taken is such that cyclotron lines will either be seen or will, with some certainty, be proved not to exist. In the meantime, as one participant said, it's time to "shut up and think". □

David Lindley is Associate Editor of Nature.

FLUID DYNAMICS

Forging the missing link

John D. S. Jones

IMAGINE a busy bar full of people smoking cigars and blowing smoke rings. Each ring is a cylinder of smoke swirling around its central axis and curled back on itself to form a closed loop. Clearly the development of a single smoke ring is a complicated phenomenon, but what happens when two collide? The internal motion within each smoke ring will significantly affect the final collision and it is difficult to predict the final outcome. For example, could two or more smoke rings eventually become linked? This is effectively the question H. Aref and I. Zawadzki answer on page 50 of this issue in their computer simulations of colliding vortex rings.

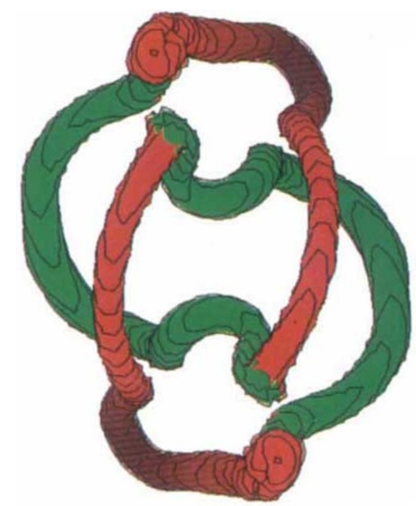
We are in the realm of fluid dynamics, that is, the study of the way fluids (or gases) flow. The vorticity of a fluid flow is a measure of the amount of local rotation in the flow. In two dimensions, there is vorticity when, for example, there is a fixed point in the plane around which nearby points tend to rotate. A specific example is flow in which all the points circulate around a single, fixed point in closed orbits. Another is when the points of the plane spiral into a central, fixed point (here, of course, there are no closed orbits).

In three dimensions, the simplest example of vorticity is simple rotational or spiral flow in a plane which may be moving along the third dimension. A vortex tube is, as with the smoke ring, given by starting with such a flow with vorticity in a cylindrical tube, for example simple rotational or spiral flow, deforming the tube by twisting and even knotting it. Finally, combine the internal flow in the tube with some time evolution of the tube itself. It is not difficult to imagine situations in which vortex tubes occur, for example in tornadoes and water flowing out of a bath.

A vortex ring occurs when the two ends of the vortex tube join up. The geometry and topology of vortex tubes and vortex rings are part of the domain of topological fluid dynamics. Aref and Zawadzki are interested in the dynamics and interactions of vortex rings, that is the way vortex rings evolve and what happens after they collide. Of course the mechanism would be simple if we were dealing with rings that contain no fluid — as the rings collide, one passes through the other and we achieve a state with linked rings. The question is really whether this can be done with the fluid swirling around inside the tubular rings and what happens to the fluid in this process.

This brings us to an important point — the viscosity of a fluid, which is a measure of the tendency of individual particles in the fluid to stick together, or, to put it another way, the internal friction in the fluid. If the fluid is perfect — has no viscosity — unlinked vortex rings cannot become linked. This observation goes back to Lord Kelvin and was instrumental in his 'vortex theory of atoms', developed in collaboration with P. G. Tait. The use of knots and links led Tait to attempt to classify knots in increasing order of complexity (P. G. Tait, *Scientific Papers I*, Cambridge University Press, 1898) and even though the vortex theory of atoms turned out to be misconceived, the catalogue of knots Tait produced and several of the conjectures he was led to are still important in the thriving modern theory of knots.

The equations governing the motion of fluids, the Euler equations for perfect fluids and the Navier–Stokes equations for viscous fluids, are complicated nonlinear equations and it is really quite impractical to attempt to solve them analytically in terms of closed formulas.



Mix and match: two linked vortex rings, from one of Aref and Zawadzki's simulations. The colours identify the original rings.

However, there is an extensive literature on numerical, computational solutions to these equations. Using these methods, Aref and Zawadski produce their examples of flows in which unlinked vortex rings collide and end up linked. The best way to get a feel for the mechanisms involved in these interactions is to look at the pictures of the flows Aref and Zawadski give in their paper. Two intriguing features emerge. First, the authors find it easier to run the simulations backwards, starting with linked rings, to find initial conditions that lead to linking. Second, in the process of linking, the two rings lose their initial identity and become hybrids of one another (see figure).

Vortex tubes and vortex rings occur in many examples of fluid flows: for example, an aircraft taking off creates a vortex tube at the trailing edge of its wing. It is clear that the study of their evolution and interactions will be of some importance in both the qualitative and quantitative understanding of flows.

It is interesting that although these vortex interactions are essentially geometrical phenomena, it requires massive computing power to construct the simulations. Indeed, geometry is one of the few areas of mathematics that have been genuinely influenced by the use of computers.

Three questions arise. First, is it possible to describe this phenomenon of vortex rings colliding and linking in purely geometrical terms? Second, is it possible to characterize some good set of initial states that lead to linking? Lastly, can this be done experimentally — perhaps with smoke rings? □

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