Cosmic Vortices

E.A. Spiegel

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Rapidly rotating cosmic bodies with turbulent atmospheres display vortices, as we may see when they are close by or infer when they are not. I would be tempted to say that all cosmic bodies do this except that the sun, for some reason, does not seem to be fitting in. So please allow me in this abstract to consider that a magnetic flux tube is an acceptable surrogate for a vortex tube. The reason for including the sun is that it is also a rotating body with a turbulent atmosphere. We do not know why those flux tubes form any more than we understand the formation of vortices, so I do feel justified in including them both under the same rubric. I'll discuss this intriguing dichotomy in the full talk when I report some calculations by Annalisa Bracco (Georgia Tech).

Turbulence in the sun is driven by convection in the outer third of the solar radius and it is generally accepted that there is dynamo action in the zone of convection and perhaps below. The resulting magnetic flux tubes that protrude from the solar surface inhibit the convection and so reduce the heat flux locally. The result of that is the formation of relatively cool spots in the solar surface. Though these sunspots look dark in solar photographs, they are not cold at all but appear that way because the exposure times for those photographs are adjusted to show the sun well. Sunspots are plenty hot and their magnetic activity produces energetic phenomena resulting (it is thought) from magnetic reconnection.

Energetic activity is also seen around the hottest stars and it has been suggested that this is also caused by starspots. I do not know whether those spots are the sites of vortices or magnetic flux tubes or some combination of these but, in either case, such coherent structures would produce interesting fluid phenomena in the hot stars and around (the so-called) accretion disks as well. Here, the driving process is not the kind of convection that occurs in the sun, which is predominantly made of hydrogen. As one goes inwards from the solar surface (T=6000K), the increase in temperature is accompanied by an increase in the degree of ionization leading to an increase of specific heat (hence a decrease of the |adiabatic temperature gradient|) as well as an increase of the opacity of the material (whence an increase in the actual |temperature gradient|). The resulting Rayleigh number is astronomical in both senses.

In the very hot stars, hydrogen and helium (the two most abundant elements) are ionized everywhere and conventional convection is not expected. Yet the spectroscopic evidence indicates that the outer layers of those stars are in disordered supersonic motion. I interpret these motions as the result of the rising and bursting of photon bubbles in the hottest stellar atmospheres. The picture I shall present relies in part on an analogy between the atmospheres of those hottest stars and fluidized beds. The radiation flowing from those stars exerts a levitating force on the matter as does the outflowing fluid in a fluidized bed. Vigorous bubbling in the atmospheres of the hottest stars can take on the role of turbulence in the vortex formation process. Moreover, hot stars rotate rapidly.

Though stars tend to lose mass and, with it, angular momentum as they age, hot stars cannot last long and are all young. Hence they do rotate rapidly, unlike the sun whose initial angular velocity has been reduced by a factor of thirty. The hot stars may then be expected to produce vortices and, in support of this claim, I shall indicate some laboratory analogues — rotating bubbling fluids. Of course, since the material is fully ionized in hot stars, there ought to be dynamos in them and we may expect flux tubes to form as well. Such coherent objects, whether vortices or flux tubes, will produce starspots and have a pronounced influence on the distribution of the outgoing radiation. We may expect them to play an important role in various stellar processes such as mass outflow. We should also become aware through such thoughts of the problems posed by vortices in conducting fluids.

Finally, I will speak of vortices in the disks that form when material is accreted by a central gravitating object that may be a newly forming star or a compact object such as a black hole. Such accretion disks form because there generally will be a net angular momentum of the inflowing gas. In order for the inflow to reach the central object, the incoming gas must get rid of its angular momentum. And that process will be slow unless it is aided by fluid processes that are currently being much discussed in astrophysics. It is believed that the energy powering the emission of radiation from quasars comes from the gravitational energy of inflow which somehow goes into turbulence and is dissipated into heat in the disks. If there is turbulence, for whatever reason, these rotating objects may form vortices. This notion was at first unpopular because it was felt (by some) that the strong Keplerian shears in accretion disks would destroy vortices. But numerical evidence suggests that anticyclonic vortices can shield themselves from the destructive influence of shear. Such vortices suck in the dust from the ambient disks and so may aid in the agglomeration leading to the formation of larger, protoplanetary objects. In the case of hot disks, such as may surround the black holes in the hearts of quasars, vortices may well play a role in angular momentum transport. Moreover ... but my time is up.