Of Changing Visions and Burning Bushes

While recently reading Arthur Koestler's book *The Sleepwalkers* (Arkana Press, 1959), which outlines a history of humankind's changing vision of the universe, I came across a curious passage concerning Tycho Brahe's "New Star," the supernova of 1572. With Brahe's impassioned determination to find a realistic model of the universe through measurements of unprecedented accuracy, and Johannes Kepler poised to place the Sun at a focus of elliptical planetary orbits, this new star was the first serious nail in the coffin for Aristotle's cosmology.

Changes in the universe were previously believed to occur in the sublunary sphere, the sphere containing the Moon's orbit. By Brahe's measurements, the supernova showed no detectable parallax; thus it lay outside that sphere. Hence the "sphere of the fixed stars," the domain of Aristotle's god, was subject to change and thus imperfect.

For me at least, Koestler's text struck a loud, resounding chord with some events at the beginning of the third millennium AD:

> All Europe was agog, both with the cosmological and astrological significance of the event [the supernova]. The German painter George Busch, for instance, explained that it was really a comet condensed from the rising vapours of human sins, which had been set afire by the wrath of God. It created a kind of poisonous dust (rather like the fall-out from a Hydrogen bomb) which was drifting down on people's heads and caused all sorts of evil, such as "bad weather, pestilence and Frenchmen." (page 293)

It is often said that history repeats itself. I wonder if, this past fall, we should have turned our clocks back 1 hour and 433 years, in the hope of witnessing another era of scientific enlightenment, but this time without the birth pains of an inquisition.

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Possible Gaps in ITER's Foundations

In news items about controlled fusion research (see, for example, Physics Today, August 2005, page 26), it has become commonplace to dwell on the political and financial aspects but to act as if the important scientific questions have been answered and only engineering details remain. However, there are scientific gaps in the conceptual foundations of ITER, the proposed international prototype fusion energy reactor—or any other magnetic confinement device—that are worth further consideration from the whole physics community.

The most awkward gap is the lack of a manageable mathematical framework for calculating the state of the plasma in a confinement device in a way that relates the calculation globally and convincingly to what actually happens in the machine. This becomes apparent when theoretical claims are set alongside the experiments being contemplated. For half a century, the textbook theoretical starting point for such a global calculation has been the use of ideal magnetohydrodynamics to provide a zeroth-order description of the state of the confined plasma. "Ideal" MHD here means a fluid-mechanical formulation from which the dissipative terms (viscous and resistive) have been dropped. Much more elaborate and less restrictive descriptions are often used to identify instabilities that might make the confined plasma less tractable than the initial ideal MHD equilibria would suggest. In such perturbative instability or "turbulent transport" calculations, which sometimes claim to include microscopic turbulence, dissipative terms are often reintroduced, despite their omission from the calculated ideal MHD configuration that is being "perturbed."

This perspective, which slides freely back and forth between ideal and non-ideal descriptions, is not supportable in fluid mechanics, nor is there reason to expect it to be in plasma physics.[1] In both cases the introduction of the dissipative terms changes the mathematical character of the steady states that can be sustained and made to satisfy boundary conditions. One cannot generally get close to a non-ideal steady state with an ideal one, nor can one treat the stability of a non-ideal steady state with anything like the systematic mathematics that the ideal case permits. This awkwardness is not the subject of debate; rather, it is simply ignored. So is the fact that the extent of MHD turbulence is often best predicted by dimensionless numbers, such as Reynolds or Hartmann numbers, that have dissipation coefficients in their denominators and diverge as these coefficients approach zero.

It follows that in any project as ambitious as ITER (or for that matter, the Joint European Tokamak or the Tokamak Fusion Test Reactor, or other similar devices), what one is doing is carrying out experiments—mostly just trying things—with theory largely having a decorative role, or at best providing suggestions for something to try next. Such a secondary role for theory is not necessarily fatal. Many important discoveries have been made in the absence of a proper theoretical framework to predict them. But two points should be noted here. First, the conceptual gap between the theory and device building does not need to be as great as it becomes when discussions of it are essentially not taking place. And second, all the consensus, all the money, publicity, and sophisticated organization in the world will not necessarily satisfy the "aim to get 10 times more power out than goes in," as the August Physics Today item reports. That is still just wishful thinking.

Reference

1. See, for example, L. P. J. Kamp, D. C. Montgomery, *J. Plasma Phys.* **70**, 113 (2004); *Phys. Plasmas* **10**, 157 (2003).

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