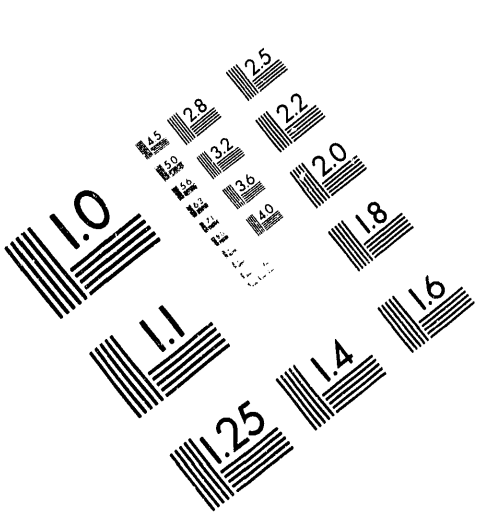

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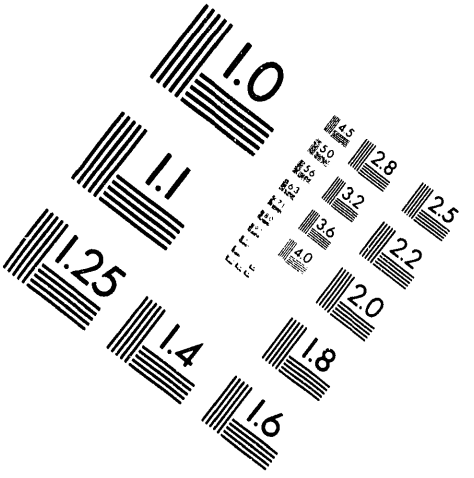

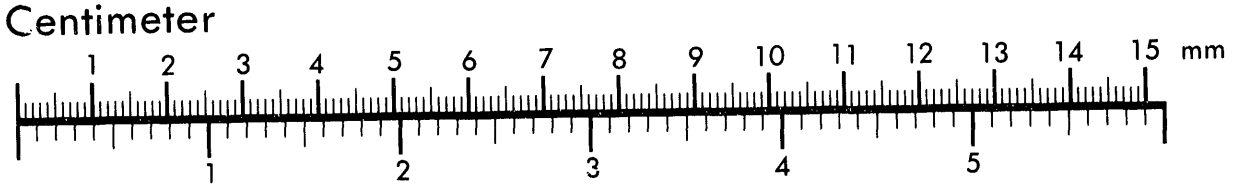

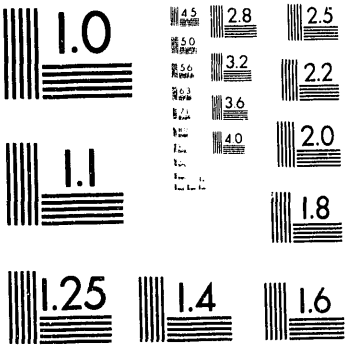

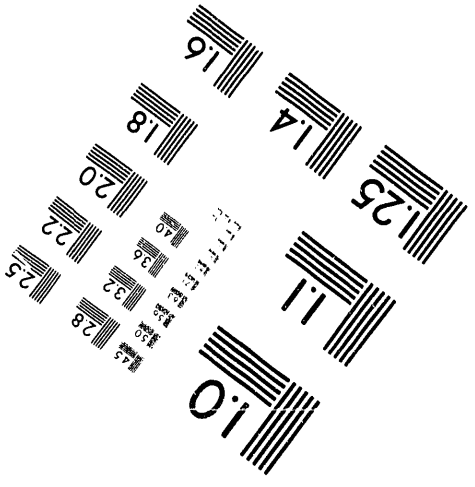

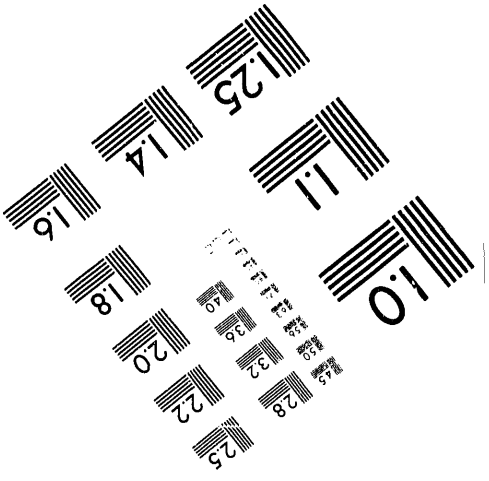

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DoE/ER/13740-11

INVESTIGATIONS OF TRANSITIONS FROM ORDER TO CHAOS IN DYNAMICAL SYSTEMS

Annual Progress Report
March 1993

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Arter Flow and Fast Dynamo

The aim was to study a physically realistic flow and see if it can bring about dynamo action. The Arter flow, a relatively simple time independent flow, arising from Benard convection of a fluid heated from below, was studied computationally as well as analytically. Since the flow is incompressible, the configuration space can be turned into the phase space of a Hamiltonian system. As the Rayleigh number is increased above the critical value, KAM tori form and disintegrate while chaotic regions arise and grow. This flow turned out to be a promising candidate for dynamo action. The results were published in Physics Letters A.[1]

Next a supercomputer analysis was carried out in collaboration with A. Rogalsky at the University of Maryland, on magnetic field generation by this flow. The kinematic fast dynamo generates, from a small seed magnetic field an exponentially increasing magnetic flux over a finite area in a perfectly conducting fluid. Since the magnetic field lines undergo complex stretching, twisting and folding the computational work is very demanding. A new method, the fractal grid approach was developed and applied in this computation.

The computational results show a steady increase of flux over several orders of magnitude. To the best of our knowledge this is the first time a fast dynamo was found in a physical flow. Furthermore in flows studied by others (ABC flow, etc.) the flux oscillates while the amplitude grows, while in our case there is steady growth. This work was presented as an invited paper on Stochastic Processes in Astrophysics meeting and will be published in the Annals of the New York Academy of Sciences.[2]

While the aim of these studies is to gain an understanding of how solar and other astrophysical magnetic fields are generated, the kinematic fast dynamo model has two obvious shortcomings; it ignores finite resistivity as well as the reaction of the magnetic field on the flow. These effects will certainly lead to dynamo saturation. Our next aim is to consider them and establish estimates for the saturation of dynamos.

Chaotic Ion Motion in the Magnetosphere

Satellites monitoring the Earth's magnetosphere have observed magnetic field fluctuations ascribed to externally excited kinetic Alfven waves. It has been suggested that these waves can be responsible for charged particle precipitation observed in the polar region.

At the suggestion to S. P. Kuo of the Polytechnic University we have studied together the question of chaotic ion motion in a magnetic field with a simulated magnetic mirror under the influence of fast Alfven waves. This is a problem in Hamiltonian chaos, that can be reduced by averaging over fast particle gyration to a standard problem with one and a half degrees of freedom. We find significant chaotic motion for relatively small wave amplitudes, which may explain the observed effects. This work was published in Comments of Plasma Physics.[3]

Nonlinear Waves in Two Dimensional Plasmas

Two dimension plasma phenomena are of increasing importance in solid state devices. While linear waves have been extensively studied, large amplitude waves have not been analyzed. It turns out that a fully analytic treatment can be easily carried out by carrying out a Lorentz transformation to the wave frame. We find that as the amplitude is increased the wave shape becomes deformed approaching solitary waves as the amplitude goes to infinity. This work is ready for publication.[4]

Stochastic Webs and Transport Phenomena

We study the Hamiltonian $H(x,y) = \sum_{j=1}^{q} \cos(x \cos(2\pi j/q) + y \sin(2\pi j/q))$, which arises from the stochastic web. The remarkable property of this Hamiltonian is the existence of long trajectories with self similar properties (isolines $H(x,y) = \text{const}$) at a special value of H which is the percolation threshold. This is a continuum percolation problem different from its lattice analog. We determined analytically the fractal properties of such isolines for $q = 5$ and 8 using the projection method from higher dimensional space. With A. Rogalsky from the University of Maryland we showed numerically that the scaling characteristics of stochastic webs and discreet percolation clusters converge as $q \to \infty$, indicating an intriguing connection between the discreet and continuous percolation models.[5]

The more difficult three dimensional percolation problem has also been studied in collaboration with the computer group of the East West Center (U. of Maryland) and a solvable quasiperiodic 3D percolation model has been found, and its scaling characteristics determined.

Chaotic Mixing

Several previous studies on chaotic mixing and mixing windows have been completed with F. Ling from the Polymer Processing Institute at Stevens and some of these results are now published.[6] Some other earlier work has also been published.[7-9]

Publications

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9. F. H. Ling and G. Schmidt, Box Counting Algorithm and Dimensional Analysis of a Pulsar, J. Comp. Phys. 99, 196 (1992).

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