| | |
|---|---|
| Title | Spatio-temporal Chaos in Fluid Systems |
| Author(s) | Sawada, Yasuji |
| Citation | 物性研究 (1992), 58(5): 504-509 |
| Issue Date | 1992-08-20 |
| URL | http://hdl.handle.net/2433/94926 |
| Right | |
| Type | Departmental Bulletin Paper |
| Textversion | publisher |

# Spatio-temporal Chaos in Fluid Systems

Yasuji Sawada

Research Institute of Electrical Communication,
Tohoku University, Sendai 980

Fluid systems are known to undergo series of changes of macroscopic states when they are driven far from equilibrium. A typical example is convection system where fluid is confined among two parallel boundaries and heated from below. As the temperature difference is increased, the system changes from a quiescent state, steady convective structure, oscillatory, chaotic, and so on. The bifurcation route to chaos were pretty much clarified for a system whose horizontal size is comparable to the vertical dimension(1). When the horizontal size is extended one-dimensionally or two-dimensionally, the spatial degree of freedom contributes to increase the effective number of dynamical variables, and the bifurcation sequence of the system becomes more complicated.

It is, therefore, questioned whether the behavior of a spatially extended system can still be efficiently looked at as a deterministic dynamical system, or should it be more effectively treated as a statistical system. The spatio-temporal chaos is a name for the complex behavior of spatially extended systems including fluids taking the former view point. This brief note overviews the recent works on spatio-temporal chaos of fluid systems driven far from equilibrium.

S.Sato et. al.(2) showed that fluids in a one-dimensionally extended rectangular thermal convection cell whose aspect ratio is 15x1 exhibited an inhomogeneity in oscillatory strength and dimension of chaotic attractors when the controll parameter is relatively low. Whether the localization of activity is intrinsic or caused by a boundary effect remained unclarified there. Recently T.Kato et.al.(3) undertook a similar experiment using an annular cell to avoid boundaries. They found that the localization of oscillation strength is intrinsic and related to the deformation of the underlying periodic structure.

At higher control parameter regions, spatio-temporal intermittency, which is a mixed state of laminar and turbulent domains is, generally obserbed . It was predicted, first by K.Kaneko(4) based on numerical simulation of coupled map lattice model and later by H.Chate et.al.(5) based on numerical simulation of a phase equation, that turbulence is achieved in one-dimensional system by spatio-temporal intermittency.

The experimental evidence was provided first by S.Ciliberto et. al.(6) and later by F.Daviaud et.al.(7). They have shown that the spatio-temporal intermittency shows an interesting statistical behavior. It was found that the number of laminar region of a given laminar length is a power of the length and that the exponent behaves similar to the second-order phase transition. The experimental results are partially in accordance with the numerical simulation of the model systems. S.Ciliberto et.al. tried to construct a thermodynamics of spatio-temoral chaos based on these experimental observations(8).

Spatio-temporal chaos has also been studied in two dimensional system. As two-dimensional experimental systems, electro-hydrodynamic convection phenomena of nematic liquid crystals is often used because of the time constant faster than the ordinary thermal convection. The phenomena was introduced into physics community by Kai et.al.(9) as the one which shows variety of interesting pattern formation. The electro-hydrodynamic convection of nematic liquid crystal shows a more complicated bifurcation diagram compared to the thermal convection(10). However, one may simply say that the system undergoes from a quiescent state to a regular parallel role state to a fluctuating parallele role state by choosing a proper experimental parameters. Then, after some complicated states one can reach a two dimensional oscillating lattice state.

Here, two problems may be relevant. One is how to understand deterministically the fluctuation and defects in the parallel roll state. Theoretically, it is shown that the spatially and temporally slow variable just above a bifurcation point can be described by a Ginzburg-Landau type of equation with complex coefficients. Furthermore, for a phenomena in which only phase variation, not phase variation, is relevant, the complex GL equation is reduced to Kuramoto-Shivashinski equation(11). This equation should be useful to describe a phenomena such as fluctuating parallel role of convection structure.

P.Coullet et.al.(12) have made a large scale computer simulation on the GL equation with complex coefficients. Their results showed that as soon as the phase stability condition is broken the amplitude variation occurs and from time to time zero amplitude spots appear and create pairs of defects. It may mean that phase-turbulence without defects may be not stable. Recently H.Chate is carrying out simulation over wider parameter space[13], so the situation will become clearer in near future. A clear result by experimental research is also needed.

The second point is self-organization of a pacemaker which emits target pattern of phasewaves in an oscillating grid lattice state[14]. This phenomena is interesting in two aspects. One is that it is similar to the pacemaker of Belouzov-Zhabotinski system, yet it is intrinsic in the sense that it is created without any spatial inhomogeneity. The second is that the emitted wave is spatially bounded. It was experimentally verified that the convection pattern is spatially expandede in the pacemaker region. Recently H.Sakaguchi[15] and independently F.Daviaud et.al.[16] derived phase equations based on coupled equations of oscillatory field and underlying spatially periodic structure proposed by P.Coullet et.al.[17]. Detailed experimental measurement by M.Sano et.al.[18] verified that the theory well explains experimental results. However, the physical coupling mechanism between the oscillatory field and the underlying convection structure is unknown at present stage.

Spatio-temporal chaos is after all a deterministic view point for complex phenomena. In other words, according to this view point, the complex phenomena is a collection of yet unknown orders. It would be interesting to know how far one can continue this view point to understand turbulence. On the other hand biological system is certainly complex but generally considered to be in a complex ordered state. The research to understand the living state(19) is also considered to be along the same line with the present subject.

## REFERENCE

1) For example, P.Berge, Y.Pomeau and Ch.Vidal, Order within Chaos(wiley, New York, 1987)

2) S.Sato, M.Sano and Y.Sawada, Phys. Rev. A37,1679(1988)

3) T.Kato and Y. Sawada, submitted

4) K.kaneko, Prog. Theor. Phys. 74, 1033(1985)

5) H.Chate and P.Manneville, Phys. Rev. Letters 58, 112(1987)

6) S.Ciliberto and P.Bigazzi, Phys. Rev. Letters 60, 286(1988)

7) F.Daviaud, M.Bonetti and M.Dubois, Phys. Rev. A42, 3388(1990)

8) S.Ciliberto and M.Caponeri, Phys. Rev. Letters 60, 2775(1990)

9) S.Kai and K.Hirakawa, Suppl. Prog. Theor. Phys. No.64, 212(1978)

10) S.Sasa, Prog. Theor. Phys. 83, 824(1990); 84, 1008(1991); S.Nasuno and S.Kai, Europhys. Lett. 14, 779(1991); S.Nasuno, Ph.D thesis(Tohoku Univ. 1989 unpublished)

11) Y.Kuramoto, Chemical Oscillations, Waves, and Turbulence (Springer-Verlag, Berin, Heidelberg, New York, Tokyo, 1984)

12) P.Coullet, L.Gil and j.Lega, Physica D, 37, 91(1989)

13) private communication

14) S.Nasuno, M.Sano and Y.Sawada, J.Phys. Soc. Jpn. 58, 1875(1989); S.Nasuno and Y.sawada, Suppl. Prog. Theor.99 450(1989); M.Sano, K.Sato, S.Nasuno and H.Kokubo, Phys. Rev. A 1992 to appear; M.Sano, K.Sato and B.Janiaud, Pattern Formation in Complex Dissipative System(World Sience, to appear 1992 ed. by S.Kai)

15) H.Sakaguchi, Prog. Theor. phys. 97, 241(1992)

16)F.Daviaud, J.Lega, P.Berge, P.Coullet and M.Dubois, Physica D, 55, 287(1992)

17) P.Coullet and G.Iooss, Phys. Rev. Letters, 64, 866(1990)

18) M.Sano, K.Sato, S.Nasuno and H.Kokubo, Phys. Rev. A, 1992 to appear

19) Y.Sawada, Proc. 4-th Asia Pacific Phys. Conf., 695(World Scientific 1991); Pattern formation in Complex Dissipative Systems(World Science, to appear 1992)