Simulation of a Weak Interaction Induced Chiral Transition in a Prebiotic Medium*

D. Cline Y. Liu H. Wang
University of California Los Angeles
Departments of Physics & Astronomy
405 Hilgard Avenue, Los Angeles, CA 90024-1547

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Abstract

For several decades there has been speculation on the possibility that the weak interactions are responsible for the chiral nature of DNA. We have carried out a detailed simulation of the symmetry breaking transition bifurcation process and have studied the sensitivity to noise at the critical point (one of the major criticisms of the approach). We present the results of this study here and discuss the implications for the possibility that the weak interaction has influenced the development of life on earth or elsewhere.

For more than one century there has been evidence for the chiral nature of life forms on earth. Pasteur was among the first to point this out in 1884 and the universal nature of chiral symmetry breaking in DNA and RNA is now very well established for all life forms. With the discovery in 1956 of parity violation in charged current and Weak Neutral Currents (WNC) in 1973, two universal symmetry breaking processes were uncovered that could have effected the handedness of DNA and RNA (WNC and β decay). The main problem is the extremely small symmetry breaking effects ($\Delta E/\mathrm{kT} \sim 10^{-17}$). There are plausible non-linear mechanisms that could have amplified this small symmetry breaking phase transition up to the full symmetry breaking observed in life forms. However, there is a long standing controversy as to whether these non-linear effects are actually large enough to have the selection of the handedness of life[1, 2, 3, 4, 5].

The WNC that interferes with the electromagnetic field and gives rise to weak distortions of virtually all electromagnetic effects could be one of the candidates that causes symmetry breaking in the bio-system. It could make the broken symmetry of the micro-world translate to the macro-world finally leading protein and both DNA and RNA to display *left-handed* (L) and *right-handed* (R) form, respectively. For organic molecules however, the difference between the ground state energies of the R-

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and L-type is about $\Delta E \sim 10^{-17}$ of the thermal energy at room temperature[6, 7]. The value $g(\Delta E/k_B T \sim 10^{-17})$ characterizes the relative difference in the time to effect the phase transition is given by[2]

$$T_{tr} > \frac{1}{\Gamma N (\Delta E)^2} \tag{1}$$

where Γ is the replication time of the system, N the number of DNA or RNA molecules, and ΔE the chiral symmetry breaking parameter. If we take the total DNA in the current ocean of the earth $N \sim 10^{23}$ and for $\Gamma \sim 1\,\mathrm{hr}^{-1}$ we find that $T_{tr} > 10^7$ years for $\Delta E \sim 10^{-17} k_B T$. This is a plausible period of time for life to have formed on earth, given the reactions concerning the amplification mechanisms to be discussed next.

Modeling this theory we have exploited a bi-stable dynamic system[8, 9, 10, 11]. It can transit to one of two states when the system passes through the transition point in the presence of a small bias (similar to WNC interactions), smaller in magnitude than the rms value of the fluctuations (white Gaussian noise). Such a system can be simply described by a first order stochastic equation (2):

$$\frac{d\alpha}{dt} = -A\alpha^3 + B(\lambda - \lambda_c)\,\alpha + Cg + \epsilon^{1/2} f(t) \tag{2}$$

where α is the amplitude of the symmetry breaking solution, λ the control parameter, g is the interaction or bias *symmetry breaking selector*, λ_c the symmetry breaking transition point, $\epsilon^{1/2}$ is the rms value of fluctuation (noise), and $f(t)$ is the normalized fluctuations (noise).

$$\lambda = \lambda_0 + \gamma t \tag{3}$$

where λ_0 is the initial value of λ, γ the evolution rate, and t the evolution time.

In contract to the gradual build-up of symmetry breaking, we propose another mechanism resulting from the effects of a nearby SN. At first sight this might seem to be an unimportant effect and has been ignored in the past literature on this subject. This subject will be discussed in a future paper. In this paper we present some results which come from the same model which Kondepudi presented in a previous paper[11] but attempt to study some of the weakness of this work.

First, we took a series of calculations with fixed g (< 0 in all calculations) and $\epsilon^{1/2}$, and varied γ to investigate the effect on the transition rate. It is quite clear that for a given ratio $\epsilon^{1/2}/g$, the selectivity depends on the evolution rate γ or the evolution time $T_{tr} \sim 1/\gamma$ (see Fig. 1). Also, we notice that for a different $\epsilon^{1/2}/g$ the selectivity can be the same with different values of γ. The slower the process evolves, the higher the selected probability. If the environment is very noisy the $\epsilon^{1/2}$ is far larger than $|g|$, and the symmetry breaking in the bio-system is reduced.

Second, we examined the effects of varying g (Figs. 2,3) and found the g coupling (mixing) with $\epsilon^{1/2}$ has considerable affect on the system around the transition region. In this area the effect of g seems to be amplified and, thus, gives a bigger contribution to the process at the far regions before and after the transition area, hence, either a bigger g or $\epsilon^{1/2}$ does not make much contribution to the system, the system tends to

be stable. Figs. 2,3 are the results of around 40,000 trajectories and give a $P_- = 88\%$ chance that the process favored by **g** will emerge dominant even though the rms values of the random chiral influences (white Gaussian noise) are 10 times larger. However, such sensitivity can not be realized if the system does not evolve through the critical point. To save CPU time and for easier graphical visualization, we set all parameters larger than those in the bio-system. Future simulations will attempt to explore the much smaller bio-system parameters.

In connecting these to the life forms in nature, two conjectures may be made:

1. Before the organic molecules formed, the WNC effect existed in the universe. The chirality of the organic molecules such as DNA (RNA) and protein were automatically selected, then these selected molecules underwent their reproduction and evolved into modern life on earth. When the evolved molecules became stable their chirality could not be changed independently of how large the noise was.

2. Initially the organic molecules almost displayed an equal chiral form due to the large noise in the environment compared with the WNC effect. However, during some period the noise became relatively smaller and the evolution rate was speeded up, finally leading to the life forms that display the chirality present on earth.

In fact, there are many unclear factors which should be investigated. But the WNC could be a key factor in evolutionary processes.

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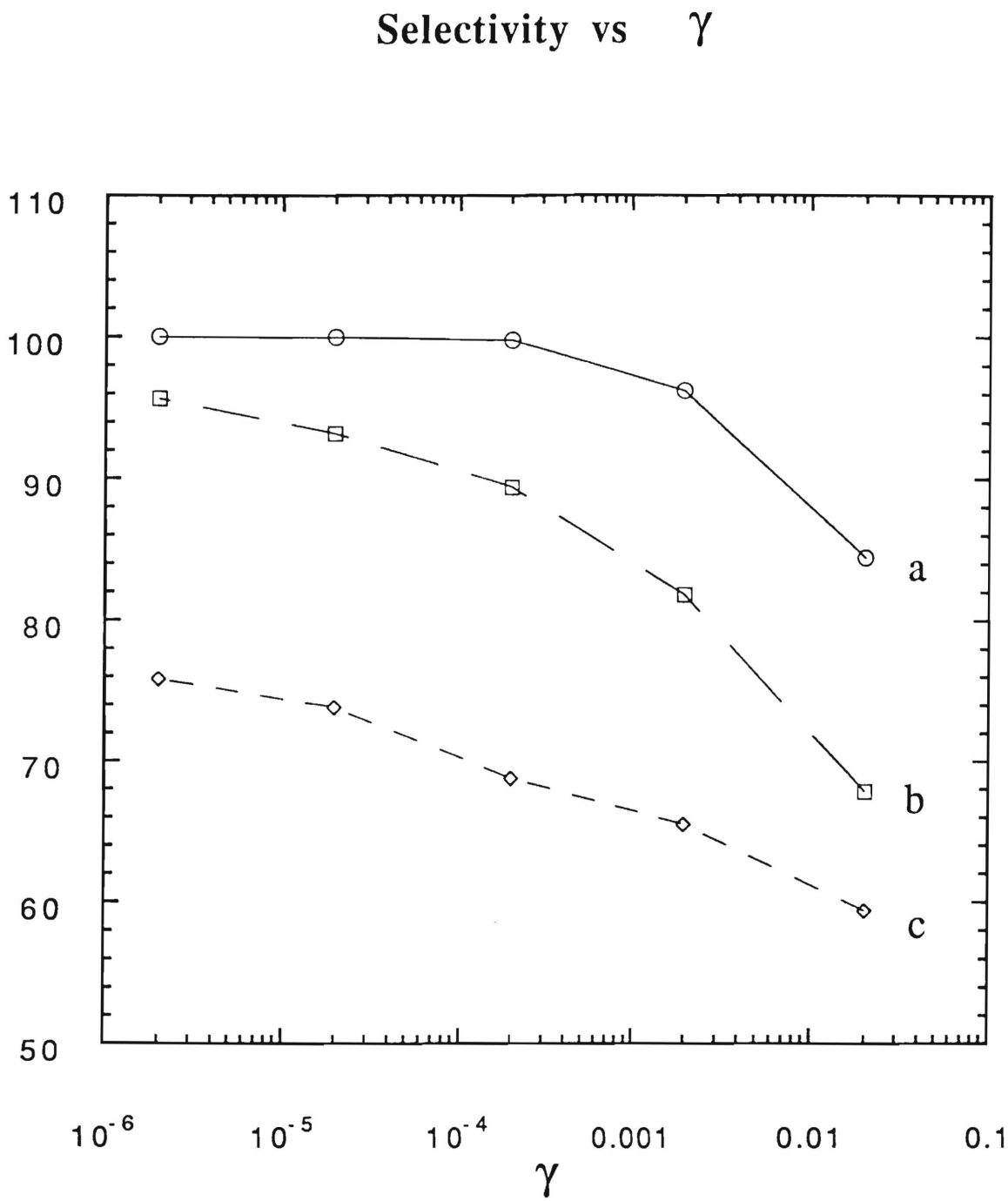

Fig. 1: The selectivity vs. the evolution rate. The three curves, a,b,c, correspond to $\epsilon^{1/2}/g = -5,\ -10$, and -20, where $g < 0$.

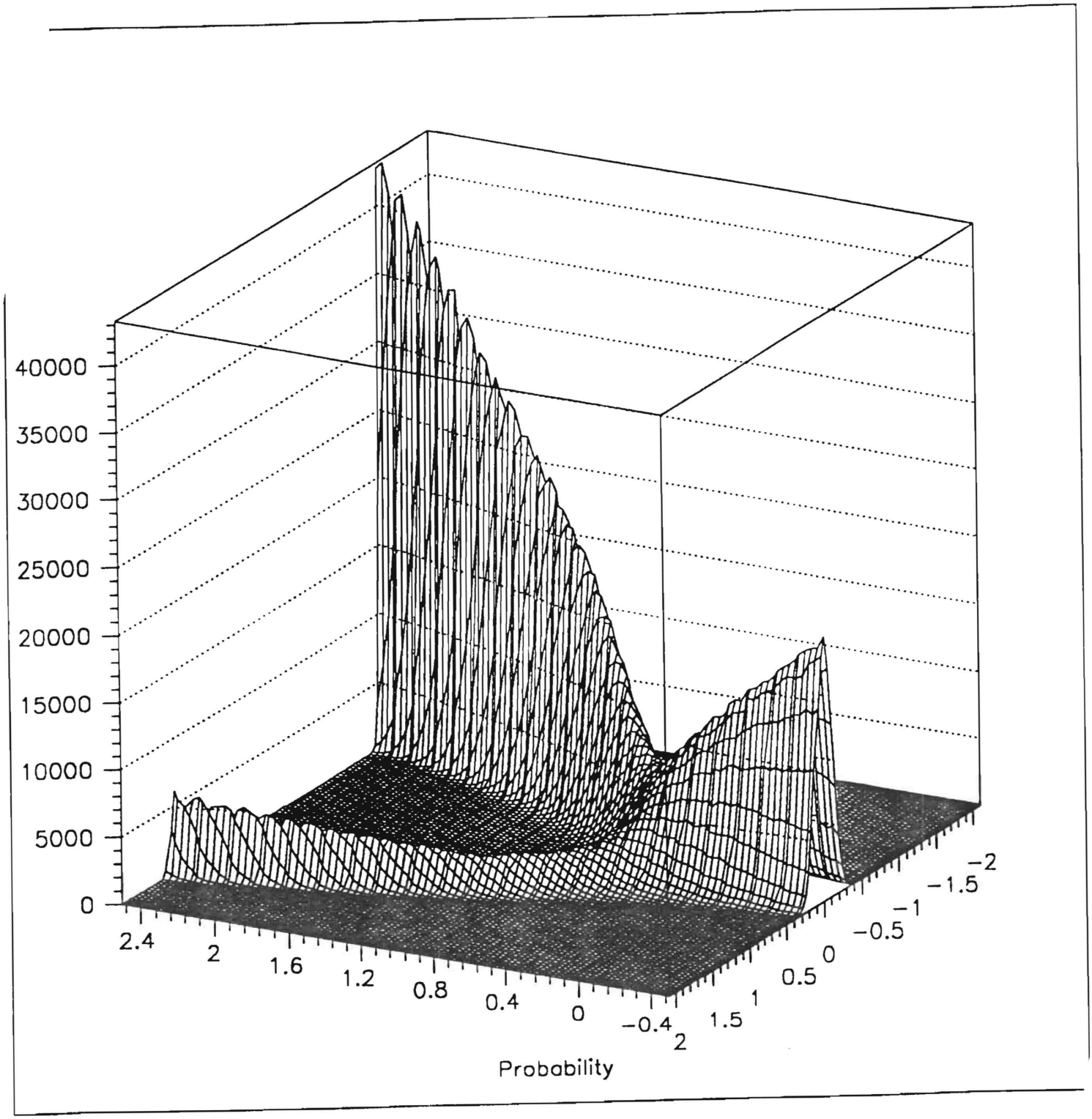

Fig. 2: The results of around 40,000 trajectories giving a $P_- = 88\%$ chance for the process favored by g, where g = 10.015, $\epsilon^{1/2} = 0.15$, and $\epsilon^{1/2}/\mathrm{g} = -10$.

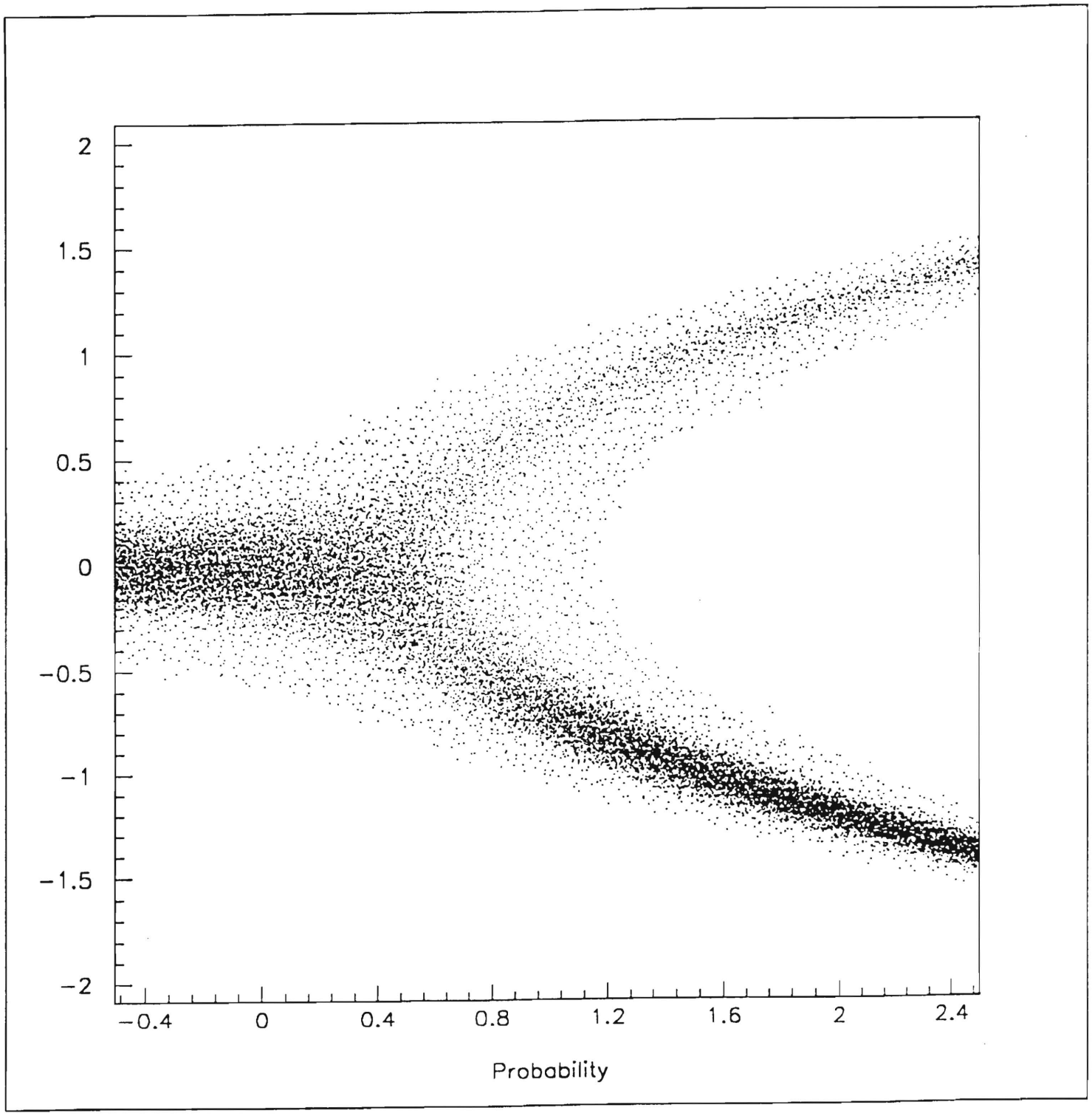

Fig. 3: The projection of Fig. 2.