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A BRIDGE BETWEEN THE BIG-BANG AND BIOLOGY? PUNCTUATED EQUILIBRIUM IN THE REALM OF THE GALAXIES AND IN THE EVOLUTION OF SPECIES ON EARTH

(astrophysics/paleontology/evolution/complex avalanche phenomena)

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We show that the Hubbe Deep Field Survey displays power law behavior in space and in time. We then check that the spatial power law behavior is consistent with self-organized critical behavior in the Universe at the largest structures. We also check and show that this SOC behavior is analogous to the one displayed by the Evolution/Extinction of species on Earth throughout its History.

I. INTRODUCTION

By considering the characteristics of various models for the description of living systems, Dyson [1] concludes that *they share the following properties,* (1) *they metabolize,* (2) they reproduce, (3a) they are symbiotic and/or (3b) they are parasitic. These properties involve different physical mechanisms which can be described on the basis of Non-equilibrium Statistical Mechanics for (1), Quantum Mechanics for (2), while properties (3a) and (3b) are understood on the basis of what is currently known as the theory of Complex Adaptive Systems. To be somewnat more specific, Non-equilibrium Statistical Mechanics comes in through noisy reaction-diffusion systems, Quantum Mechanics through transitions between vacua and the theory Complex Adaptive Systems enters through the property that these systems have to model situations where, due to their dynamics, many-component systems adapt to the environment in which they are inserted.

Systems with the above properties fall whithin what is beginning to be known in the literature as Self-Organized Critical (SOC) and, although living systems have many of their properties, it is today a matter of hot debate whether they *actually* belong to this class of systems or not. But independently of this, what is known is that both the micro-evolution and the macro-evolution of living forms on Earth display the type of behavior implied by SOC-systems. In a few words (to be expanded upon below) this means that the fossil record of our planet has the property that *both* its space and time correlations display power law behavior, including the presence of relatively long periods of «equilibrium» (stasis) «punctuated», ended, by sudden bursts of activity. This behavior is known in the Paleontological literature as «Punctuated Equilibrium», and reflects the existence of rare events in a background of common, less intense events, all of which share a common physical origin.

We will show in this paper that recent data on very distant galaxies obtained by the Hubble Space Telescope, and collected under the name of the Hubble Deep Field (HDF) survey, display precisely the same kind of behavior as the Fossil Record on Earth. More precisely, we will show that there are signs in the HDF data that as took place with the evolution of species in the Fossil Record, the evolution of *the largest scale structures in the* Universe have also undergone evolution by «Punctuated Equilibrium».

II. PUNCTUATED EQUILIBRIUM IN EVOLUTION

In the early seventies it was noticed by Elredge and Gould [2] that morphological changes in species seemed to take place by sudden changes in their morphologies over very short time periods and after long periods of no, or very little, change. They produced a theory to account for this, and they called it the *Theory of Punctuated Equilibrium in Evolution.*

This type of behavior in a species was noticed, for example, in the trilobite species *Phacops rana milleri,* Figure 1, a species that had been present in Earth for hundred of millions of years and in which the fossil record showed that changes in, e.g. the number of columns of its eyes, went from 18 to 15 in a matter of 10^3 to 10^4 years, a veritably sudden change in view of the long time the species had been alive on the planet. Other species such as *Poecilozonites Bermudensis,* an extinct snail species from Bermuda (which is an isolated ecosystem) showed similar behavior. Elredge and Gould then postulated that this mode of evolution through «punctuated equilibrium» was universal and ought to be shared by most species. Today we know that this conjecture seems to hold for a huge variety of species and to-

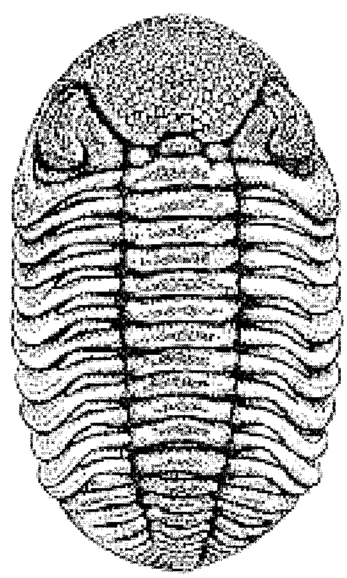

Fig. 1. The trilobites *Phacops rana milleri*. This species changed from 18 to 15 eye columns in about 10,000 years; its presence on Earth has been shown to have been of hundreds of millions of years.

day, many paleontologists spouse the point of view that most species evolve in this fashion.

A typical manifestation of how this takes place at the species level is shown in Fig. 2, where the mean thoracic width for the antarctic radiolarian *Pseudocubus vema* is shown as a function of fossil age or, equivalently, depth of the stratum where the fossil was found. It is clearly appreciated how the thoracic width increased as a function of time: it was about 90 microns for samples 4.33 Myr and older and about 135 microns for samples whose age was typically 2.43 Myr. Furthermore, as can be appreciated in the figure, the change from about 90 microns to about 110 microns took place in a relatively short time-span, as it happenned again for the change from 110 to about 120 microns. This evolutionary pattern of equilibrium followed by sudden change is what characterizes «punctuated equilibrium» behavior, and has been beautifully summarized by Elredge and Gould saying that *«anatomical change in evolution ... happens not throughout the bulk of a species history ... rather at those rare events when a new reproductively isolated species buds off»*.

This «punctuated equilibrium» behavior at the species level also takes place in Macroevolution, i.e., in the collective evolution of all species living on the Earth at a given time. Figure 3 displays the percentage of the total population of species that went extinct as a function of time, and it can be seen here that the time series describing the extinction data is highly irregular, that is, there are some great sudden extinctions (the peaks) while most of the time, the data indicates, the system was in periods of stasis (shown by the valleys and troughs in the figure). It can be seem from the data in this figure that if one plots the number of geological stages N_g vs. the percent of extinctions, *s*, one finds, Figure 4, that it is very well fit by a power law with exponent –2.0, i.e.,

$$N_g\,(s)\ \alpha\ s^{-2.0} \tag{1}$$

which is in itself some form of power law for the temporal behavior of the system.

In fact, a careful and exhaustive analysis of the fossil record pertaining to the history of Life on Earth shows that the data has the following properties (a) it contains periods of stasis, (b) epochs of punctuation, (c) it encodes power law behavior. The existence of (a) and (b) together imply the presence of intermittance and also the presence of some *apparently* non-local (actually ocurring at a global scale) effects. These two properties when taken together with (c) lead one into a scenario of avalanches and self-organized criticality, and brings evolution into that class of phenomena. Avalanches in this context correspond to the actual extinctions (punctuations) and the system self-organizes into a *critical* state whose signature is the existence of power law be-

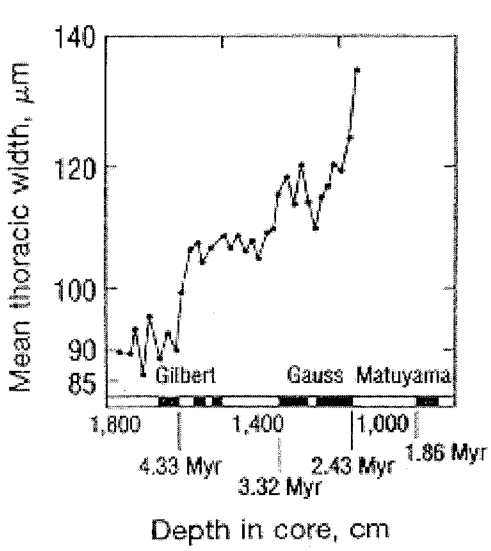

Fig. 2. The evolutionary history of *Pseudocubus Vema*.

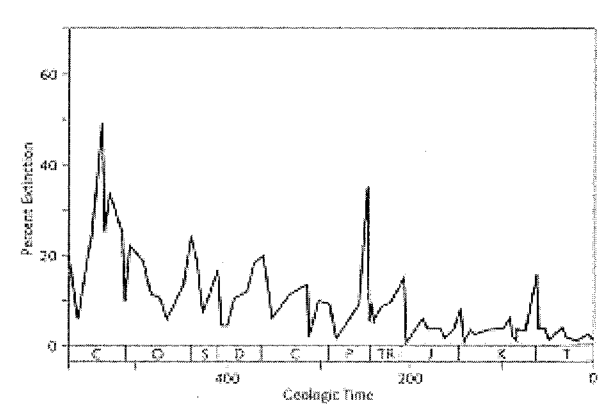

Fig. 3. Extinctions in the Evolution of Species on Earth.

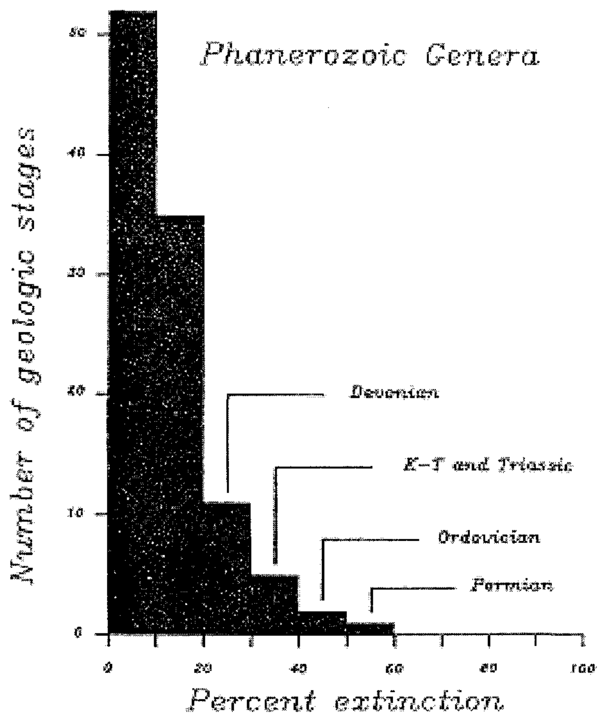

Fig. 4. 10 years in the library.

havior, where large events are rare, while small events are more probable and both are related by a power law.

III. A QUICK TOUR OF SELF-ORGANIZED CRITICALITY AND AVALANCHES

In order to better appreciate what we will discuss about the large scale structure of the Universe, we now give a quick tour of self-organized criticality and avalanches. Let us imagine an hour-glass with the grains of sand falling on the lower half of the glass; as they fall on the heap of sand, they stick on top of each other and pile up, forming a small hill whose slope remains approximately constant. The mechanism due to which the slope of the pile remains constant is by means of avalanches: as the sand falls on the pile, it makes an avalanche which carries away many of the grains of sand in sudden bursts (the avalanches), while giving the system a chance to again start the same process of mound formation with a constant slope. Without getting into the details of why the grains of sand stick and fall collectively, giving rise to avalanches, let us just point out the following features (a) the number of avalanches as a function of their size follows a power law,

$$N(s) \propto s^{-\tau} \tag{2}$$

where s is the avalanches size, $N(s)$ the number of avalanches of size s that take place as we run the experiment for a long time and τ is called the avalanche exponent; (b) the avalanche process displays stasis and punctuation (as described above) with a «first return probability», $P_{First}(t)$, and an «all return probability», $P_{All}(t)$, both of which are power laws in time with exponents τ_{First} and τ_{All}, i.e.,

$$P_{First}(t) \propto t^{-\tau_{First}} \tag{3}$$

$$P_{All}(t) \propto t^{-\tau_{All}} \tag{4}$$

Finally, (c), there are numerous power laws characterized by exponents which are related by scaling relations such as, for example,

$$\tau_{First} + \tau_{All} = 2 \tag{5}$$

In any case, the main features of this avalanche system, or for that matter of any other, are that the system is away from equilibrium (the grains keep falling), lives in a critical state characterized by long range correlations but short range forces, there is scale invariance (hence the name «Critical»), there are multiple scales involved and, finally, the dynamics «automatically» chooses the critical state. Because of all the above, the system must involve (a) non-equilibrium physics, (b) some form of fluctuations and (c) must be in a scaling regime.

All the above properties have been shown, by comparison of theoretical predictions with results of numerical simulations, to be embodied in two main classes of models, which in fact are very closely related: Reggeon Field Theory (RFT) and Directed Percolation Depinning (DPD). These models are respectively described by the equations

$$\frac{\partial \phi}{\partial t} = \nu \nabla^2 \phi + m^2 \phi + g\phi^2 + \eta(\vec{x}, t; \phi) \tag{6}$$

$$\frac{\partial \phi}{\partial t} = \nu \nabla^2 \phi + \frac{1}{2} \lambda (\nabla \phi)^2 + F + \eta(\vec{x}, t; \phi) \tag{7}$$

where ν, m^2, g and λ are coupling constants, F is a constant and η is a random (noise) source that in principle may also depend on the field $\phi(\vec{x}, t)$. This field represents a space-time dependent function which describes some density or potential; in the case of avalanches in grains of sand, it can be related to the columnar number density of grains. As mentioned above, the avalanche-size probability distribution and the all-return probability distribution, for example, satisfy a power law, viz,

$$P_{Aval} \propto s^{-\tau_{Aval}} \tag{8}$$

or

$$P_{All} \propto s^{-\tau_{All}} \tag{9}$$

and where the exponents can be calculated from the field theory in the case of RFT and determined by numerical simulation for DPD.

The fact that there is an underlying dynamics leads to scaling relations between the exponents. Some of these relations are due to general invariances of the equations and other relations are directly a consequence of the way the system approaches equilibrium. In general, these scaling relations can be viewed as predictions of avalanche theory for different classes of phenomena; two such predictions are the following: (a) a prediction that the avalanches form a Levy flight and (b) that the exponents for the probability for backward avalanches and the all-return probabilities are related. In fact, these two predictions appear in the phenomenology as the following scaling relations

$$\tau_{Backwards} = 3 - \tau_{Aval} \quad (10)$$

and the fractal dimension of the Levy fligth π_{Levy} is related to the avalanche *size* exponent D via

$$\pi_{Levy} = 1 + D(2 - \tau_{Aval}) \quad (11)$$

$$\tau_{All} = d/D; \ \tau_{First} + \tau_{All} = 2. \quad (12)$$

It is important to mention that the two forms of SOC in the respective incarnations as an RFT or a DPD phenomena can be traced to the scaling behavior of an underlying non-relativistic hydrodynamics in regimes where velocity and acceleration are parallel. This of course opens the door to the study of SOC in the Universe, since the processes underlying structure formation at the largest scales are precisely a consequence of non-relativistic hydrodynamics.

Finally, we mention that application of SOC to the known fossil record, and to extinctions in particular, leads to *some* success in the understanding of the data. For example, it is predicted that the number of geological stages N for which there is a certain level of extinction, a, follows a power law $N \propto a^{-\tau_{soc}}$, with the exponent $\tau_{soc} = 1.3 \pm 0.2$, and where the exponent is to be compared with an observed value of 2.0. This figure, although not great, is a good start, since at least the prediction that the number of extinctions follows a power law is non-trivial, as it is also non-trivial that the value of the exponent is of the correct order of magnitude.

IV. LOOKING FOR SIGNS OF PUNCTUATED EQUILIBRIUM IN THE REALM OF GALAXIES

When we look at the night sky with a powerful instrument such as the Hubbe Space Telescope, or any of the large aperture telescopes, we are looking at the Universe and seeing it as it was millions of years ago. This is so because we are exploring the Universe through the red-shifted light coming from distant galaxies. In fact, the larger the instrument aperture the higher the probability that we will see very red-shifted and faint objects, whose light, as detected on Earth, was emitted very early in the History of the Universe.

Let us imagine that we restrict our attention to a small patch of the sky. As we do this, we simultaneously receive light coming from closer and more distant galaxies which happen to be located inside the pencil beam of light that we are stydying. The closer objects are less red-shifted and therefore older or, according to the cosmological principle, we are seeing them at a more evolved stage in their evolution than the further objects which are at higher redshift and have had less time to evolve when they emitted the light we receive *today* on Earth. This is very similar to what happens in paleontology, where, on average, the deeper one digs the older is the sediment that one encounters and hence the fossils it contains. In a very direct way, depth of a sediment and red-shift are equivalent, in the sense that in one case one probes age in the fossil record and evolution of life on Earth and in the other one is probing age of galaxies and, for a range of red-shifts, one probes evolution of galaxies and large scale structure in the Universe.

Early in 1996 the HST was pointed at a very narrow, and assumed to be almost empty, region of sky. It was kept at focus for ten consecutive days in an area near the handle of the Big Dipper. The result of this survey is known as the Hubble Deep Field Survey or HDF Survey, and the observational results are very interesting on several counts: many new galaxies were found, their associations are unexpected, their colors are indicative of very early formation and they show very clear indication of early dynamical evolution. Here we will focus on just one aspect of the data gathered in the HST, namely the distribution of the number of galaxies as a function of red-shift.

The data is shown in the Figures 5 and 6. This data is equivalent to a "drill-sample" in paleontology, in that it represents how the abundance of galaxies has changed with the evolution of the Universe, and shows how galaxies have been created at different epochs and how the evolution rate seems to be erratic (in some sense) or random. In particular it shows very clearly that the number of galaxies as a function of red-shift is a non-uniform function. What can be said about this?

In order to gather some intuition to guide our analysis we perform on this data the same transformations and analysis done on the data on the fossil record. The results are shown in Figures 6 and 7. In particular we find that to very good accuracy the number of redshift bins, N, containing a given percent s of the total number of galaxies follows a power law,

$$N \propto s^{-1.27} \quad (13)$$

with an $R^2_{Adjusted} = 0.96$ for the fit. This result is similar to the one we discussed above for what takes place in the evolution of Phanerozoic Genera, where the number of geologic stages in which extinctions have taken place as a function of the percent of extinction also follows a power law (but with a different exponent)

$$N \propto s^{-2.0}, \quad (14)$$

as we have already discussed. The result obtained for the HDF data is shown in a double-log plot in Figure 7; in the

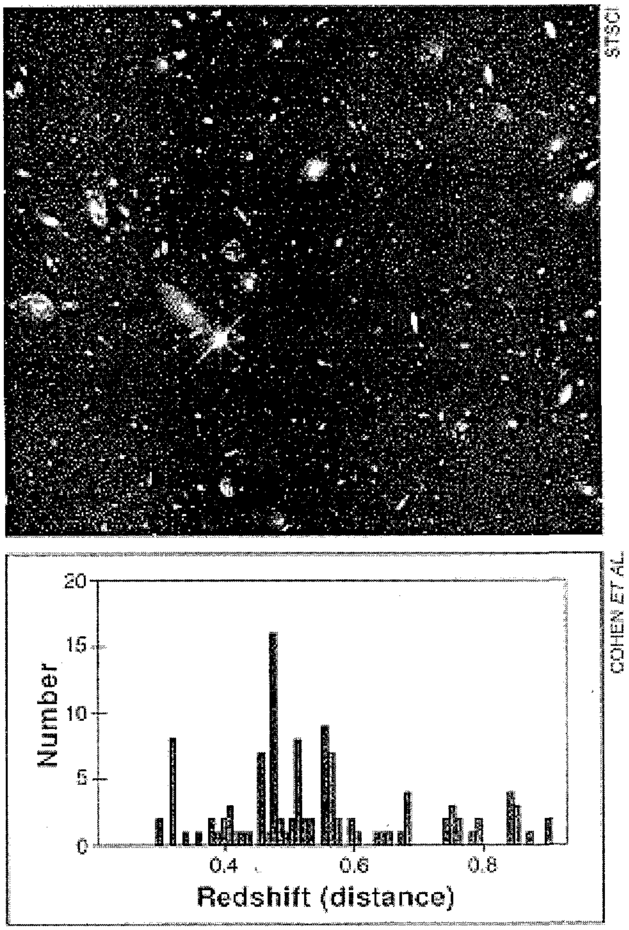

Fig. 5. The HDF and the number-distance. histogram.

inset we have also plotted the residues for the fit, which are clearly randomly scattered and thus gives a visual verification of the goodness of fit.

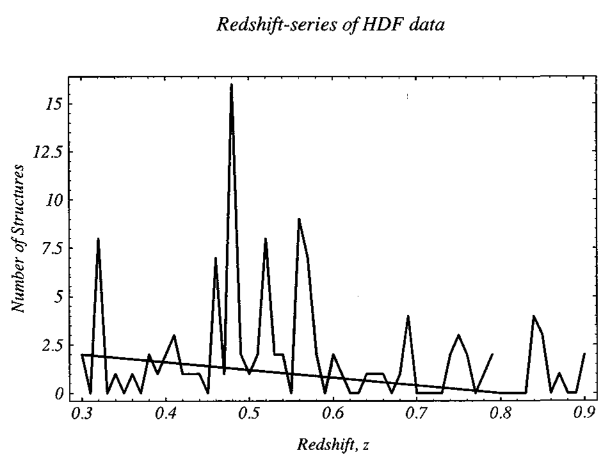

Fig. 6. What does this remind your eye?

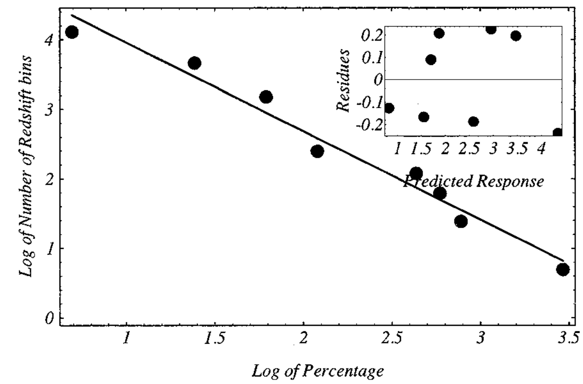

Fig. 7. Power-law fit and residues for the HDF data. This is a log-log plot, and the straight line has equation $y = 5.23 - 1.27x$; the adjusted R^2 of the fit is 0.96.

From the HDF data we can also plot the cumulative activity in the sample as a function of time. As one can inmediately see from the original data, the cumulative activity follows a Devil's Staircase when plotted as a function of time. This is displayed in Figure 8.

We can now also compute two important time-related probabilities. The "First-Return Probability" $P_{First}(t)$ and the "All-Return Probability" $P_{All}(t)$. These are defined as follows: $P_{First}(t)$ is the probability that if an event has taken place within a given spatial location at time t_0, another event will take place again at the same location for the first time at time $t_0 + t$. The all return probability, $P_{All}(t)$ is defined as the probability that events will occur at time $t_0 + t$ in the same region of space. There is no preconceived reason as to why these two probabilities should follow a power law; they could, for example, describe a Poissonian process; but for self-organized critical systems they are power laws of their arguments. Again this can be rigourously shown to be related to the punctuated equilibrium attributes of a SOC many-body system. In fact, for a many-body system to display

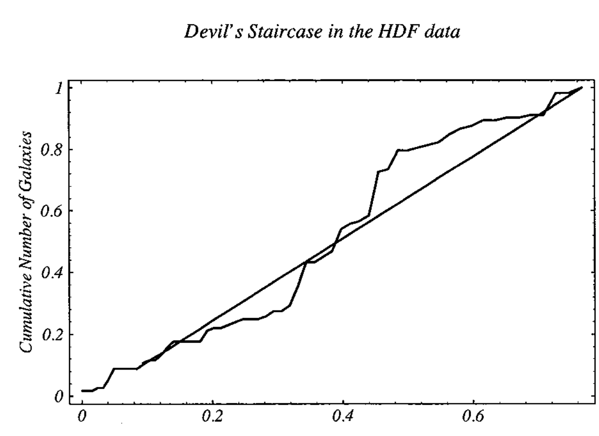

Fig. 8. Devil's staircase in the HDF. Reduced times and times derived from the measured redshift for a flat FRW back-ground.

SOC, it is a necessary and sufficient condition that the system shows power-law behavior in both the spatial and time domain probabilities; in particular the two-point spatial correlation function must follow a power law and the two time-related probabilities just defined must also have power law behaviors.

For the HDF data one finds that both $P_{First}(t)$ and $P_{All}(t)$ show indications of power law behaviors. An analysis of the data gives that

$$P_{First}(t) \propto t^{-1.7}, \tag{15}$$

and

$$P_{All} \propto t^{-0.9}, \tag{16}$$

with a goodness of fit of $R^2 = 0.94$.

From this simple fit to the time series we are then led to one conclusion and three questions. We conclude that there is power law behavior in time, and we ask the following questions: (i) what happens for spatial behavior? (ii) do spatial and time behaviors go together as required by SOC? and (iii) are there any predictions? We now will seek answers for each of the above three questions.

A. Power law behavior in the spatial correlation

It is known from hundreds of independent observations (Table I) that the probability that a multi-component structure of size l exists in the Universe goes as

$$P(l) \propto l^{-2.21}. \tag{17}$$

By a multicomponent structure one understands objects containing smaller components which are held together by gravitation and such that they form a single, collective and coherent structure. For example open star clusters, globular star clusters, galaxies, clusters of galaxies and the whole Universe they all fall into this category. And they are related by the above power law for their spatial extent. This, of course, is an indication that the objects share a common origin (gravitatonial collapse and binding) and is a hallmark for the criticality of this system. Because of the power law behavior, it also adds the needed ingredient for SOC nature of the Universe from the largest to the shorter length scales, provided the objects are multicomponent. But we still cannot claim a full SOC behavior, because in order for this to actually be true we need to check that the predictions of SOC are fulfilled. In particular, we must check if the scaling relations of SOC are respected, and to what extent.

First of all, we point out that by an elementary argument based on probability theory, it can be shown that the probability in equation (17) is equivalent to the following,

$$\langle \delta\rho(r+x)\,\delta\rho(x)\rangle \propto r^{-\pi_{Phen}}, \tag{18}$$

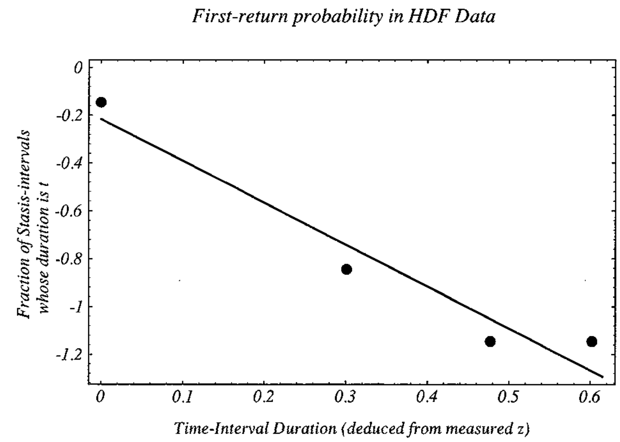

Fig. 9. Power-law fit and residues for First Return Probability. Times derived from the measured redshift for a flat FRW background. This is a log-log plot, cf. main text for fit data.

where $\delta\rho(r)$ is the density contrast at comoving separation r and $\pi_{Phen} = 1.58$. This value has to be compared with an observed value of $\pi_{Obs} = 1.65 \pm 0.15$, and we see that the agreement is well within the observational error band and very good. The probability argument that we have just mentioned goes as follows: the probability (17) can be transformed from length into mass using the relationship $m \propto \rho l^3$, and from there we infer that the observed number of structures with a mass greater than a value m is

$$N_{Obs}(\geq m) \propto m^{-2.21/3} = m^{-0.74} = m^{-b} \tag{19}$$

In an avalanche the number of elements (equivalent to "total number of grains of sand") with mass m is

$$N_{Aval}^{Obs} = \frac{\partial N_{Obs}(\geq m)}{\partial m} \propto m^{-b-1} = m^{-\tau_{Aval}^{Obs}} \tag{20}$$

and we see that if we include the errors in the determination of the power law in equation (17)

$$\tau_{Aval}^{Obs} = 1.74 \pm 0.05 \tag{21}$$

A standard argument used in cosmology and based in the so-called Press-Schechter formula, which assumes that density fluctuations are gaussian, allows one to relate $N(\geq m)$ with the exponent in the power spectrum of density perturbations n, or equivalently, the exponent in the two-point correlation function for density perturbations, γ. In fact, if the two-point correlation function $\xi(r) = \langle \delta\rho(r+x)\,\delta\rho(x)\rangle$ scales as

$$\xi(r) \propto r^{-\gamma} \tag{22}$$

then

$$N_{Cosm}(\geq m) \propto m^{-1+\frac{1}{6}\gamma} \tag{23}$$

and equating (19) with (23), we have

$$b = 1 - \frac{1}{6}\gamma \tag{24}$$

This quantity γ is what we have called before π_{Phen} and, for $b = 0.74 = \frac{2.21}{3}$, as follows from the avalanche interpretation, we get that

$$\gamma = 6 \times \left(1 - \frac{2.21}{3}\right) = 1.58. \tag{25}$$

This is a *prediction* of the phenomenology associated with avalanches, although it does not involve the full apparatus of SOC. To test for this one needs to go further and investigate such connection. This comes from the hydrodynamics associated with the evolution of large scale structure in the Universe. It can be shown that the equations of hydrodynamics in an expanding background for the case of large clouds of matter in gravitational interaction are mathematically equivalent to the equations of Directed Percolation Depinning. These equations have been extensively studied in the literature and shown to display both avalanche behavior and SOC. More particulary, from computer simulations it has been established that the avalanche exponent τ_{Aval}^{DPD} is

$$\tau_{Aval}^{DPD} = 1.70 \pm 0.05 \tag{26}$$

which is to be compared with the value we have obtained from the observational law relating the various multicomponent objects in the Universe,

$$\tau_{Aval}^{DPD} = 1.74 \pm 0.05. \tag{27}$$

These two exponents coincide within less than 3%, and we take them as a clear indication of the existence of avalanche behavior in the larger scales of the Universe.

Since (1) the mathematical description of the evolution of large scale structure in the Universe and DPD are identical, and (2) the subset of predictions concerning avalanche behavior and spatial correlation are in such good agreement, one feels now justified to take a step ahead and test for SOC. If there is SOC in the Universe, then one should be able to check the predictions of SOC in the observational data.

B. Checking the predictions of SOC

The first prediction of SOC that we will analyze is that the clusters of «grains of sand» which partake in avalanches arrange themselves into a Levy flight; this Levy flight has a characteristic exponent and it coincides from its statistical definition in terms of number of objects per unit volume with what we have called π_{Phen}.

It has been known from many years of astronomical observations that the largest structures in the Universe form Levy flights, and that their exponent is around 1.6; in particular, and as we have already discussed for galaxies, this exponent is known to be 1.65 ± 0.15. We conclude then, that this first prediction of SOC applied to large scale in the Universe is a success: the objects arrange themselves in Levy flights *and* the value of the exponent is very well predicted.

C. More SOC predictions and time-behavior

There are three more predictions that derive from SOC, one refers to spatial distribution, and the other two are related to time-behavior. The last prediction related to spatial behavior is the exponent for «backward» avalanches, and is given as calculated from the scaling relations of SOC in 3 space and one time dimension by

$$\tau_b^{DPD} = 1.263, \tag{28}$$

which must be understood as the predicted value. The value measured from the HDF data gives $\tau_b^{Data} = 1.274 \pm 0.090$, which again shows remarkable agreement between the predicted and observed values.

We now discuss the behavior in time. SOC predicts the existence of power law behavior in time for both first return and all return probabilities. The HDF data bears these two non-trivial characteristics, *but* the exponents measured and predicted do NOT agree very well.

A power law fit to the HDF data transformed from redshift data to time series data gives the following result:

$$\tau_{All}^{HDF} = 0.893 \pm 0.093 \tag{29}$$

to be compared with the value predicted by DPD

$$\tau_{All}^{DPD} = 1.28 \pm 0.3. \tag{30}$$

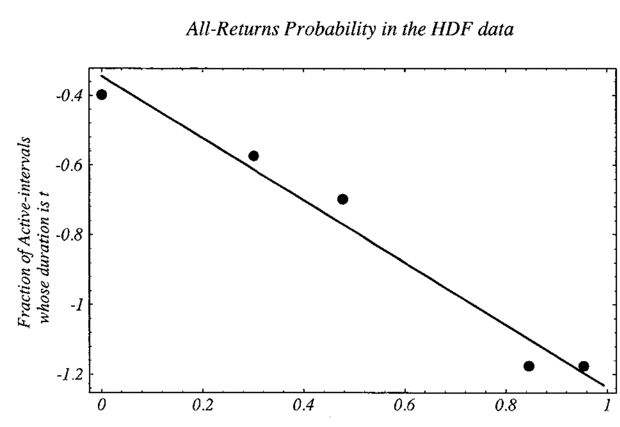

Fig. 10. Power-law fit and residues for All Return Probability. Times derived from the measured redshift for a flat FRW background. This is a log-log plot, cf. main text for fit data.

Object Type	*Class*	*Radius (cm)*	*Mass (g)*
Open Cluster	MC	3 _ 10^{19}	5 _ 10^{35}
Globular Cluster	MC	1.5 _ 10^{20}	1.2 _ 10^{39}
Elliptical Galaxy	MC	(1.5 – 3) _ 10^{23}	2 _ (10^{43} – 10^{45})
Spiral Galaxy	MC	(6 – 15) _ 10^{22}	2 _ (10^{44} – 10^{45})
Group of Galaxies	MC	3 _ 10^{24}	4 _ 10^{46}
Cluster of Galaxies	MC	1.2 _ 10^{25}	2 _ 10^{48}
Universe	MC	$10^{28}/h$	7.5 _ 10^{55} Ω/h

Table I. Characteristic longitudinal sizes and masses for typical celestial objects made up at least tens of stellar objects. Data taken from Padmanabhan (1992). See main text for details.

For the First Return probability, we get

$$\tau^{DPD}_{First} = 1.75 \pm 0.3 \qquad (31)$$

and the calculated value is

$$\tau^{DPD}_{First} = 0.7165 \pm 0.2965. \qquad (32)$$

The agreement between the exponents is *not* good at all, but at least it is important that the data follows a power law. It should be pointed out, however, that these time data are sensitive to the cosmological model used to describe the evolution of matter. The amount of dark-matter present in the model or whether the Universe is assumed to be open, closed or flat has important implications in the redshift-to-time-translation and affects the values of the exponents. The values inferred from the HDF survey data that we have presented here were calculated using a flat Universe. Because of this, it is not clear, nor easy, to conclude that the exponents are not well predicted by SOC: however SOC predicts the existence of power laws in time and, this the data bears.

V. CONCLUSIONS

We have analyzed the Hubble Deep Field data and have found that it shares some key features with the fossil record for the Evolution of Species on Earth. In particular, (1) it displays power law behavior in space and the (scarce) time-data admits a *fair* representation as power laws as well; (2) there are clear signs of punctuation and stasis; (3) the various scaling exponents are related by the same relations as they are in Self-Organized Criticality; (4) there are predictions for Backward Avalanches and for Levy flight distribution of the large scale structures which are well born by observations; (5) one can *interpret* the multistellar structures as gravity-driven avalanches which have occurred during the evolution of the Universe; (6) finally, because of the above, the evolution of large scale structure in the Universe is *analogous* to the evolution of Life on Earth, and seems to proceed by *Punctuated Equilibrium.*

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