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SELF-ORGANIZED CRITICALITY IN DAILY INCIDENCE OF ACUTE MYOCARDIAL INFRACTION

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Abstract

Continuous periodogram power spectral analysis of daily incidence of acute myocardial infarction (AMI) reported at a leading hospital for cardiology in Pune, India, for the two-year period June 1992 to May 1994 show that the power spectra follow the universal and unique inverse power law form of the statistical normal distribution. Inverse power law form for power spectra of space-time fluctuations are ubiquitous to dynamical systems in nature and have been identified as signatures of self-organized criticality. The unique quantification for self-organized criticality presented in this paper is shown to be intrinsic to quantumlike mechanics governing fluctuation (space-time) patterns in dynamical systems.

Running Title : *Self-Organized Criticality and Acute Myocardial Infarction*

1. INTRODUCTION

The daily incidence of acute myocardial infarction (AMI) during the two-year period June 1992 to May 1994 was obtained from admission records of a premier Institute of cardiology at Pune, India. Continuous periodogram power spectral analysis of the data show a broadband spectrum with embedded dominant wavebands, the bandwidth increasing with period length. Broadband spectra for fluctuations are ubiquitous to dynamical systems in nature[1-4], such as atmospheric flows, stock market price fluctuations, population growth, spread of infectious diseases, etc. The broadband power spectra exhibit inverse power law f^{-B} where f is the frequency and B the exponent. Inverse power law form for power spectra imply long-range (space-time) correlations. Long-range spatiotemporal correlations are ubiquitous to dynamical systems in nature and are identified as signatures of self-organized criticality[5]. The physics of self-organized criticality is not yet identified. Atmospheric flows exhibit self-organized criticality manifested as the selfsimilar fractal geometry to the spatial pattern concomitant with inverse power law form for spectra of temporal fluctuations, documented and discussed in detail by Lovejoy and his group[6-7] . A recently developed cell dynamical system model for atmospheric flows predicts the observed self-organized criticality as intrinsic to quantumlike mechanics governing flow dynamics[8-19] . The model predicts the universal inverse power law form of the statistical normal distribution for the power spectrum of fluctuations thereby providing universal quantification for self-organized criticality. The model is based on the concept that cumulative summation (integration) of small scale fluctuations give rise to large scale perturbations generating a hierarchical network, the generation mechanism being dependent only on the intensity of fluctuations and independent of the detailed mechanisms governing the fluctuations. The model is therefore a general systems theory[20-21] applicable to all dynamical systems in nature. The model concepts are applied to show that daily incidence of AMI, probably triggered by stress-free and stressful activity cycle corresponding respectively to sleep-wake diurnal (night to day) activity rhythm self-organizes to form a broadband spectrum for temporal fluctuations, with universal inverse power law form of the statistical normal distribution. Daily incidence of AMI exhibits self-organized criticality with model predicted unique quantification in terms of the statistical normal distribution. Quantumlike mechanical laws may therefore govern fluctuation pattern of AMI incidence.

2. MODEL CONCEPTS

In summary[8-19] , the model is based on Townsend's[22] concept originally proposed for growth of large eddy structures visualized as envelopes enclosing internal small scale eddy circulations in atmospheric flows. A hierarchical eddy continuum is generated by successive cumulative integration of internal small scale fluctuations, the eddy growth process being dependent only on the intensity and length/time scale of fluctuations and independent of details of mechanisms generating the fluctuations. Large scale fluctuations of intensity $\mathbf{W}^2$ and length scale $\mathbf{R}$ result from integration of enclosed small scale fluctuations of intensity $\mathbf{w_*}^2$ and length scale $\mathbf{r}$ given by the relation

$$W^2 = \frac{2}{\pi}\frac{r}{R} w_*^2 \qquad (1)$$

The fluctuations self-organize to form a hierarchical eddy continuum. Since the intensity $\mathbf{W}^2$ at any large scale is the cumulative integration of enclosed small scale eddies of intensities $\mathbf{w_*}^2$, the eddy energy spectrum follows the statistical normal distribution. The square of the eddy amplitude represent the probability. Such a result that additive amplitudes of eddies, when squared, represent probabilities is observed in subatomic dynamics of quantum systems. The growth of fluctuation pattern therefore follows quantumlike mechanical laws. The above visualization for growth of large scale structures from small scale fluctuations result in the following model predictions.

1) The successive values of amplitude **W** and length scale **R** follow the Fibonacci mathematical series.

2) The growth of fluctuation pattern follows an overall logarithmic spiral trajectory $OR_1R_2R_3R_4R_5$ with the quasiperiodic *Penrose* tiling pattern for the internal structure(Fig. 1). The amplitudes of fluctuations for successive growth stages follow the logarithmic relationship.

$$W = \frac{w_*}{k} \ln Z \tag{2}$$

where **Z** is the scale ratio equal to **R/r** and **k** is the steady state fractional volume dilution of large eddy by turbulent eddy fluctuations.

3.) The logarithmic spiral can be resolved as an eddy continuum with embedded dominant wavebands $R_oOR_1, R_1OR_2, R_2OR_3$, etc. ,the peak periodicities P_n being given by

$$P_n = \tau^n(2+\tau)T \tag{3}$$

where τ is the *golden mean* equal to $(1+\sqrt{5})/2$ (≈ 1.618) and **T** is the diurnal trigger such as the sleep - wake/night - day cycle associated with stress-free and stressful activity rhythms.

4.) The angular turning $d\theta$ for successive stages in growth of the logarithmic spiral trajectory is given fro Eq.(1) as

$$d\theta = \frac{r}{R} \tag{4}$$

The phase angle θ at any stage of growth is therefore proportional to the variance from Eq.(1)

$$\theta \propto W^2 \tag{5}$$

The phase spectrum will therefore represent the variance spectrum.

The successive growth stages of the logarithmic spiral trajectory may therefore be visualized, particularly in traditional power spectrum analysis, as a continuum of eddies with progressive increase in phase.

The association between phase angle, variance and length scale as obtained above at Eqs.4 and 5 are intrinsic to the microscopic dynamic of quantum systems and has been identified as *Berry's phase* [23-28].

5) The root mean square (r.m.s.) amplitude of fluctuations **W** and w_* (Eq.2) represent the standard deviation and also the mean, since each level represents the mean for next stage of eddy growth. The standard deviation of the fluctuations is therefore represented by **log Z** where **Z** is the scale ratio representing the ratio of frequencies(or periods or wavelengths).

6) The conventional power spectrum plotted as cumulative percentage contribution to total variance versus the frequency (or period or wavelength)on log-log scale will now represent the

cumulative percentage probability on log scale versus the standard deviation on linear scale since earlier (Eq.1) it was shown that variance, i.e. W^2 distribution corresponding to **log Z** represents probability densities and also that **log Z** represents the standard deviation of the fluctuations (Eq.2).

Following traditional concepts in statistics, a normalized standard deviation **t** for **log Z** distribution can be defined as

$$t = \frac{\log L}{\log T_{50}} - 1 \quad (5)$$

where **L** is the period in years and T_{50} the period up to which the cumulative percentage contribution to total variance is equal to *50*. **Log** T_{50} will correspond to the mean value for the variance W^2 distribution which was shown to follow normal distribution (Eq.1).

The power spectrum when plotted as cumulative percentage contribution to total variance versus **log Z** expressed in terms of the normalized standard deviation **t** (Eq.5) will represent the statistical normal distribution.

The above model concepts are dependent on the amplitude **W** of fluctuations of length (or time) scale **R** alone and totally independent of the detailed mechanisms underlying the fluctuations. The model predicts that temporal (or spatial) fluctuations of dynamical systems in general self -organize to form the universal inverse power law form of the statistical normal distribution (Eqs 1 - 6).

3. DATA AND ANALYSIS

The daily incidence of acute myocardial infarction (AMI) for the two year period June 1992 to May 1994, was obtained from admission records of a premier Institute for Cardiology at Pune, India. The power spectrum of AMI incidence (daily) was computed by an elementary but very powerful method of analysis developed by Jenkinson[29] which provides a quasi-continuous form of the classical periodogram allowing systematic allocation of the total variance and degrees of freedom of the data series to logarithmically spaced elements of the frequency ranges (*0.5*, *0*). The peridogram was constructed for a fixed set of *10000(m)* periodicities which increase geometrically as $L_m = 2 \exp (Cm)$ where $C = .001$ and $m = 0, 1, 2, ...m$. The data series Y_t for the N data points were used. The periodogram estimates the set of $A_m \cos (2\pi\nu_m t - \phi_m)$ where A_m, ν_m and ϕ_m denote respectively the amplitude, frequency and phase angle for the m^{th} periodicity. The cumulative percentage contribution to total variance was computed starting from the high frequency side of the spectrum. The period T_{50} at which *50%* contribution to total variance occurs is taken as reference and the normalized standard deviation t_m values are computed as (Eq.6).

$$t_m = (\log L_m / \log t_{50}) - 1 \quad (7)$$

The corresponding phase spectrum was computed as the cumulative percentage contribution to total rotation, i.e. normalized with respect to total rotation. The variance spectrum, phase spectrum and the statistical normal distribution plotted respectively as cumulative percentage contribution to total variance, cumulative percentage contribution to total rotation and cumulative percentage probability are shown in Fig. 2.

It is seen that variance and phase spectra follow each other closely and also the statistical normal distribution. The "goodness of fit" of variance spectrum and phase spectrum to statistical normal distribution is within 95% level of significance as determined by the standard statistical chi-square test[30].

The dominant wavebands identified as those for which normalized variance is greater than or equal to *1.0* are shown in Fig. 3a plotted in the conventional manner, i.e. normalized variance versus logarithm of period in days. Fig. 3b shows the cumulative percentage contribution to total variance and cumulative normalized phase for each dominant waveband. The peak periodicities corresponding to each dominant waveband is listed in Table 1.

4. DISCUSSION AND CONCLUSIONS

A general systems theory for self-organization of fluctuations gives following model predictions. Space-time integration of small-scale fluctuations give rise to an overall logarithmic spiral trajectory with the quasiperiodic *Penrose* tiling pattern for the internal structure. The logarithmic spiral trajectory can also be resolved as an hierarchical eddy continuum with progressive increase in phase. The eddy continuum has embedded in it dominant wavebands, the bandwidth increasing with period length. The dominant peak periodicities are functions of the golden mean and the primary triggering cycle of stress - free and stressful activity cycle associated with sleep - wake (night to day) rhythm. Since cumulative integration of enclosed small scale fluctuations results in large scale fluctuations, the eddy energy spectrum follows inverse power law form of statistical normal distribution according to *Central Limit Theorem*. The square of the eddy amplitude or, the variance represents the probabilities. Such a result that additive amplitudes of eddies, when squared, represent probability densities is observed in the subatomic dynamics of quantum systems such as the electron or photon. The dynamics of fluctuation pattern formation therefore follows quantumlike mechanical laws.

Continuous periodogram power spectral analysis of daily incidence of acute myocardial infarction for the two-year period June 1992 to May 1994, reported at an Institute for Cardiology in Pune, India show that the following dynamical characteristics of AMI variability are consistent with model predictions summarized above.

(1) The spectrum is broadband with embedded dominant wavebands, the bandwidth increasing with period length (Fig. 3).

(2) The dominant peak periodicities (Table 1) closely correspond to model predicted values (Eq. 3) *2.24*, *3.62*, *5.85*, *9.47*, *15.33*, *24.80*, *40.13*, *64.92* corresponding respectively to **n** values ranging from *-1 to 6*.

(3) The spectrum follows the universal power law form of statistical normal distribution (Fig.2) which signifies (a) quantumlike mechanics for the dynamics of AMI incidence (b) long-range temporal correlations, or fractal structure to temporal fluctuations, namely self-organized criticality [5].

(4) The phase spectrum closely follows the variance spectrum, for the total spectrum and also within each dominant waveband (Figs. 2 - 3). The close association between phase, variance and period length is a feature intrinsic to quantum systems and identified as "*Berry's phase*"[23-28].

Self-organized criticality, namely long-range spatiotemporal correlations exhibited by dynamical systems in nature, is a signature of quantumlike mechanics governing the dynamics of space-time pattern evolution. Universal spectrum of AMI day to day variability implies prediction of total pattern of fluctuations.

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Table 1
Dominant peak periodicities (days)

2 -3 days								
2.006	2.022	2.030	2.042	2.055	2.067	2.082	**2.090**	2.122
2.128	2.151	2.158	2.186	2.199	2.217	2.228	2.246	2.280
2.301	**2.326**	2.352	2.373	2.411	2.440	2.448	2.460	2.477
2.517	2.548	2.565	2.578	2.623	2.636	2.649	2.660	2.673
2.689	2.735	2.757	2.785	2.810	2.824	2.838	2.901	2.933
2.963								
3 - 4 days								
3.035	3.065	3.081	**3.146**	3.181	3.197	3.213	3.248	3.274
3.307	3.357	3.418	3.439	3.484	3.544	3.576	3.604	3.688
3.714	3.785	3.866	3.916	3.964	3.991			
4 - 6 days								
4.101	4.175	4.209	4.268	4.394	4.514	4.550	4.596	4.670
4.880	5.044	5.079	5.151	5.208	**5.388**	**5.535**	5.636	5.687
5.750	5.972							
6 - 12 days								
6.099	6.450	6.574	6.694	7.023	7.251	7.442	7.669	**8.441**
8.569	8.856	8.990	9.135	9.357	9.499	9.652	**9.916**	10.383
10.763	11.895							
12 - 20 days								
12.124	14.256	15.598	16.186	16.763	17.657	**18.712**	19.436	
20 - 30 days								
23.598	29.969							
30 - 50 days								
32.367	39.931							
50 - 80 days								
64.531*								
120 - 200 days								
162.739								
200 - 300 days								
245.709								

*Periodicities significant at or less than 5% level are given in **bold** letters.*

Legend

Figure 1. The quasiperiodic *Penrose* tiling pattern

Figure 2. Variance and phase spectra.The statistical normal distribution is also shown in the Figure.

Figure 3a. The power spectrum plotted as normalized variance versus period (days) for dominant wavebands(normalized variance >= 1.0).

Figure 3b. cumulative percentage contribution to total variance versus cumulative normalized phase for each dominant waveband, demonstrating *Berry's phase*.

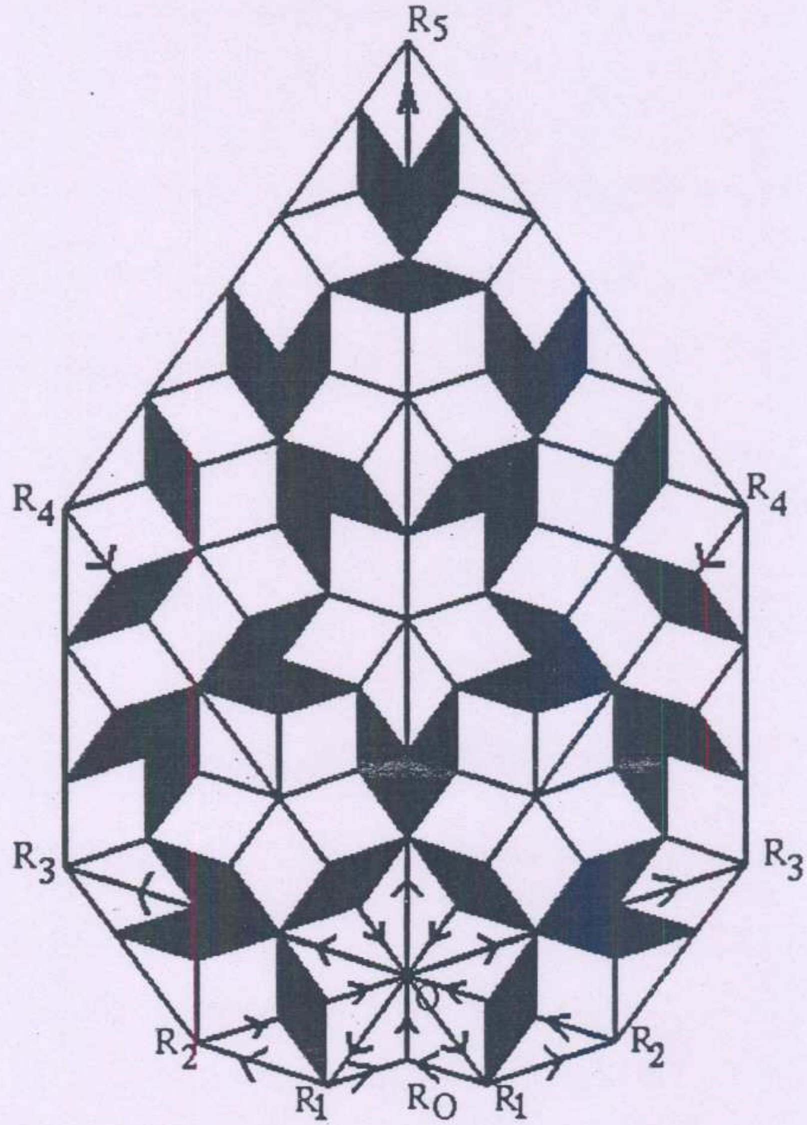

Figure 1

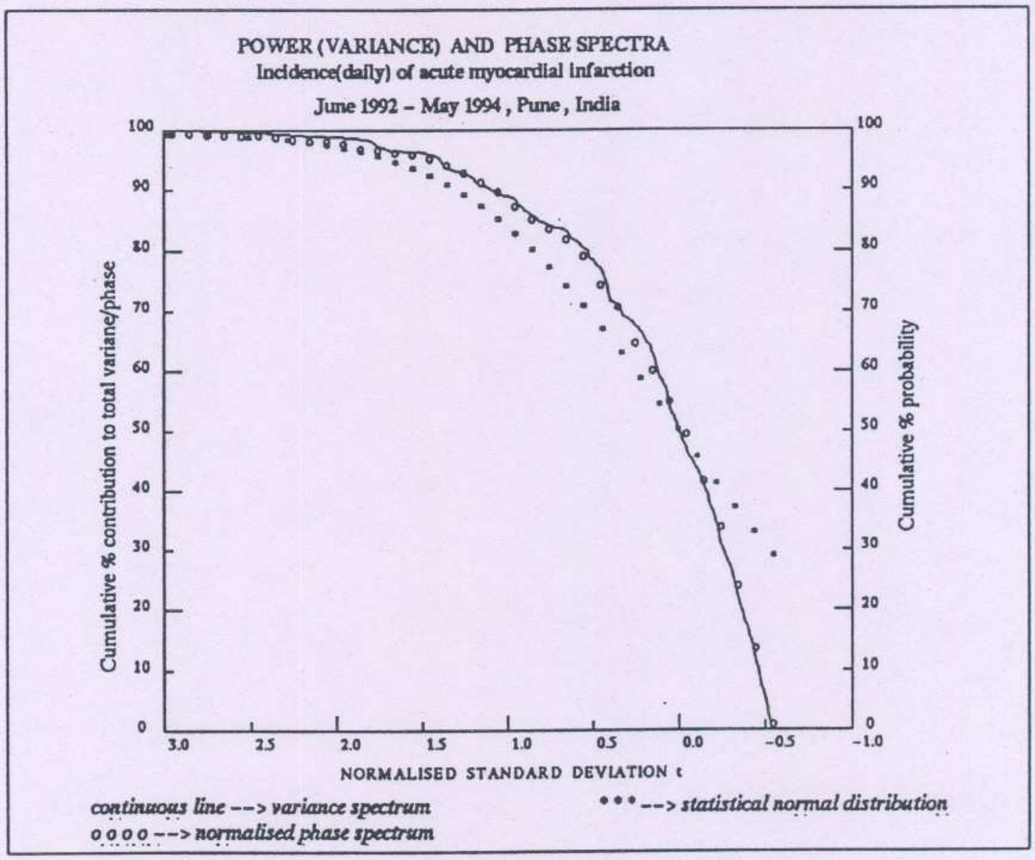
POWER (VARIANCE) AND PHASE SPECTRA
Incidence(daily) of acute myocardial infarction
June 1992 – May 1994, Pune, India
Cumulative % contribution to total variane/phase
Cumulative % probability
100
90
80
70
60
50
40
30
20
10
0
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
NORMALISED STANDARD DEVIATION t
continuous line --> variance spectrum
o o o o --> normalised phase spectrum
* * * --> statistical normal distribution

Figure 2

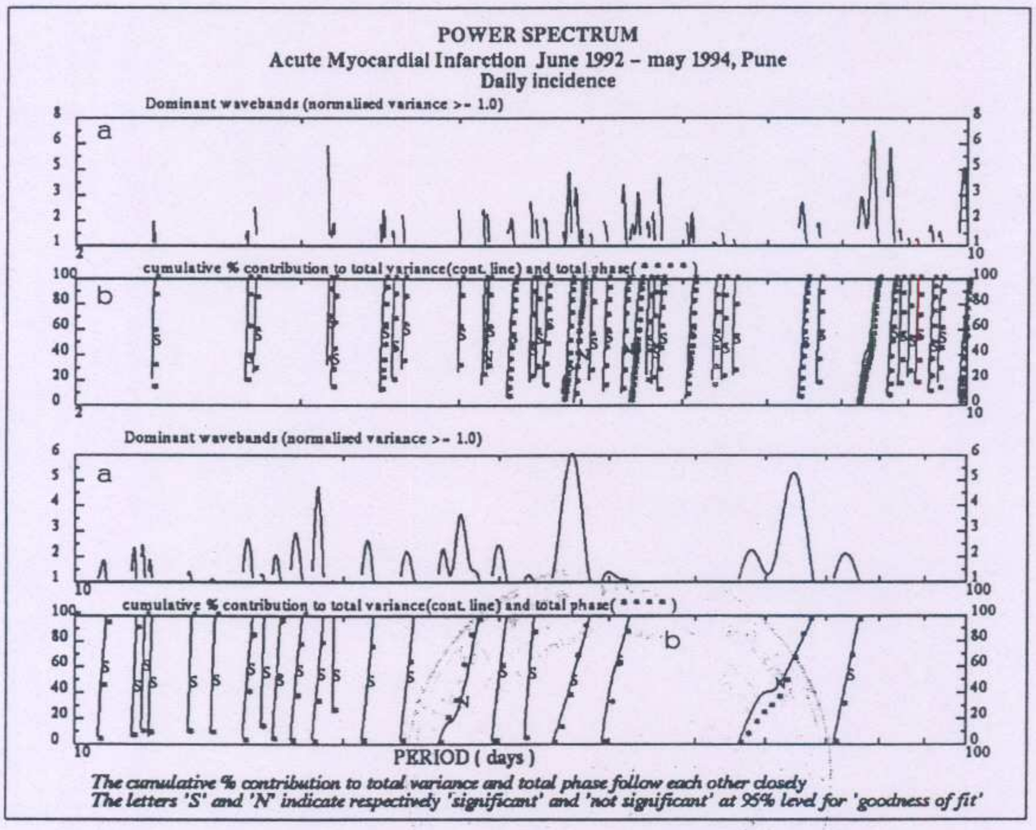
POWER SPECTRUM
Acute Myocardial Infarction June 1992 – may 1994, Pune
Daily incidence
Dominant wavebands (normalised variance >= 1.0)
cumulative % contribution to total variance(cont. line) and total phase(* * * *)
Dominant wavebands (normalised variance >= 1.0)
cumulative % contribution to total variance(cont. line) and total phase(* * * *)
PERIOD (days)
The cumulative % contribution to total variance and total phase follow each other closely
The letters 'S' and 'N' indicate respectively 'significant' and 'not significant' at 95% level for 'goodness of fit'

Figure 3